STELLAR PHOTOMETRY FROM ABOVE THE EARTH'S ATMOSPHERE

J. W. Campbell

A Thesis Submitted for the Degree of PhD
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BY

J. W. CAMPBELL B.Sc.

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ABSTRACT

ABSOLUTE STELLAR PHOTOMETRY ABOVE THE EARTH'S ATMOSPHERE

Although relative ground based stellar photometry has been an established investigative technique for many years, there have been very few programmes which have provided absolute stellar fluxes and indeed where such results have been published, they have been derived mainly from spectro-photometric data for a few bright stars. Such measurements are essential for the confirmation of model atmosphere calculations and for those models relating to early type stars, it is essential to extend such observations well into what is known as the vacuum ultraviolet region, i.e. below 3000Å. The measurements are technically very difficult because of the need to use balloon or rocket platforms and when this work was started in 1962, only a very few observations had been conducted by the Naval Research Laboratory in Washington using very simple photometers with no absolute calibration.

Under the auspices of a Senior Research Fellowship (the first in Scotland), held at the Royal Observatory, Edinburgh, the author proposed to the newly formed European Space Research Organisation, a number of stellar investigations aimed at obtaining absolute stellar fluxes in the region 1200Å - 2800Å.

This thesis gives an account of almost a decade spent in developing the techniques of rocket astronomy and absolute calibration in the vacuum ultraviolet. Since no other European groups were engaged in similar studies, it was necessary for the author to essentially begin at the very beginning and a substantial period was spent in designing and testing optical systems which would withstand a typical Skylark Rocket launch. Systems of this type had never been flown before and many hours of vibration testing were necessary to ensure a satisfactory optical and mechanical configuration.

The choice of a suitable ultraviolet detector was not easy and a substantial part of the early laboratory research was aimed at evaluating commercially available detectors and in the end an entirely new range of photo-multipliers was developed as a co-operative

venture between the author and E.M.I. Hayes, Middlesex, resulting in a commercially saleable product. Wavelength isolation techniques were developed and the use of reflective mirror surfaces was successfully pioneered. A complete range of rocket-borne electronic systems was developed including solid state electrometers and high voltage power supplies. The techniques for encapsulating photomultipliers to withstand the rocket environment and the mounting of large optical mirrors were successfully developed and over fifty telescopes constructed and launched.

The problems of calibrating on an absolute basis these rocket borne telescopes of large aperture were investigated and a network of traceable sub-standards was developed which ensured comparison with other (American) data. Highly stable microwave sources were developed and detectors calibrated at several national laboratories. These techniques were eventually used in the calibration of the T.D.I. S2/68 satellite experiment. The problem of integration of the payloads at centres throughout Europe was successfully overcome and the development of range facilities undertaken. Seven fully instrumented Skylarks were proposed and launched with a total of twenty photometers out of fifty-five photometers actually observing the Sky. The remainder having failed to produce any data due to rocket failure.

During the period of the investigation, i.e. (1962-1970) the author obtained the first absolute stellar fluxes above the Earth's atmosphere and the total observations obtained equalled that obtained by all the other U.S. Groups including the satellite results of A. Smith. The results were compared with current model atmosphere calculations and showed that if blanketed models were used, the results would be to within ± 0.25 magnitude in the region 1400Å-2800Å. The results also showed that it was possible to establish an absolute calibration network which was capable of not only permitting inter-comparison between the author's photometers, but also with other rocket groups, a situation that had hitherto been impossible.

These results were the only stellar data to be obtained by any Group within the ESRO rocket programme. No other European results were obtained during that period.

This thesis is dedicated to my late mother whose support and understanding were always present.

J.W.C. 1980

CERTIFICATE

I certify that J.W. Campbell has spent nine terms in research at the University Observatory, St Andrews, that he has fulfilled the conditions of Ordinance No. 16 and that he is qualified to submit the accompanying thesis in application for the degree of Ph.D.

D.W.N. Stibbs

DECLARATION

Except where reference is made to the work of others, the research described in this thesis and the composition of the thesis are my own work. No part of this thesis has previously been submitted in application for a higher degree. I was admitted to the Faculty of Science of the University of St Andrews as a research student under Ordinance No. 61 on the 8th July, 1957.

J.W. Campbell

The author would like to acknowledge the kindness, consideration, and opportunity given to him by the Astronomer Royal for Scotland, Professor H. A. Brück, C.B.E. during the time of a Senior Research Fellowship awarded by the D.S.I.R. at the Royal Observatory Edinburgh. Had it not been for Professor Brück's extreme interest in space astronomy, the research would not have taken place and the first European Stellar observations outside the Earth's atmosphere would not have been obtained.

I am also extremely grateful to Professor D. W. N. Stibbs, Professor of Astronomy of the University of St. Andrews, for his agreeing to continue to supervise my research work, on the retiral of Professor Finlay Freundlich of the same University and to have his continued encouragement and support over a very long period of time.

Finally, the author owes a special debt of gratitude to Naomi Douglas of the Royal Observatory, Edinburgh, who, over many years has endeavoured to ensure that this thesis was actually written and who took so much care and attention in its typing and presentation: to her, I am most grateful and appreciative for her patience and hard work over many months of endeavour.

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CHAPTER 1 INTRODUCTION

ULTRA VIOLET RADIATION FROM STARS.

By applying the physical laws appropriate to a stellar atmosphere, it is possible to construct model stellar atmospheres for a given chemical composition. Such a model describes the variation of temperature, pressure, and opacity with physical depth into the star, and the nature of the emergent radiation. If the predicted radiation matches that observed from a particular star, the temperature, pressure and chemical composition are then known for that star. This not only has a bearing on the structure of the star, but provides information relevant to the origin and the evolution of the star. Fig. 1. shows the spectral distribution for main sequence BO stars based on blanketed and unblanketed models of MORTON (1967) for the wavelength region between 1000Å and 10,000Å. The energy scale is normalised to the energy incident cm^2/sec/unit frequency interval above the atmosphere for stars of visual magnitude V=0. While ground based observations above 3000Å seemed to fit reasonably well these model atmospheres, the bulk of the energy for the hotter stars lies to the shortward of the atmospheric cut-off at 3000Å, and cannot be observed from the ground and observations of such a star's energy distribution in the photographic and visible region give very little information applicable to the hotter stars.

This is shown more clearly in Fig. 2. which represents the far ultraviolet spectral energy distribution for a

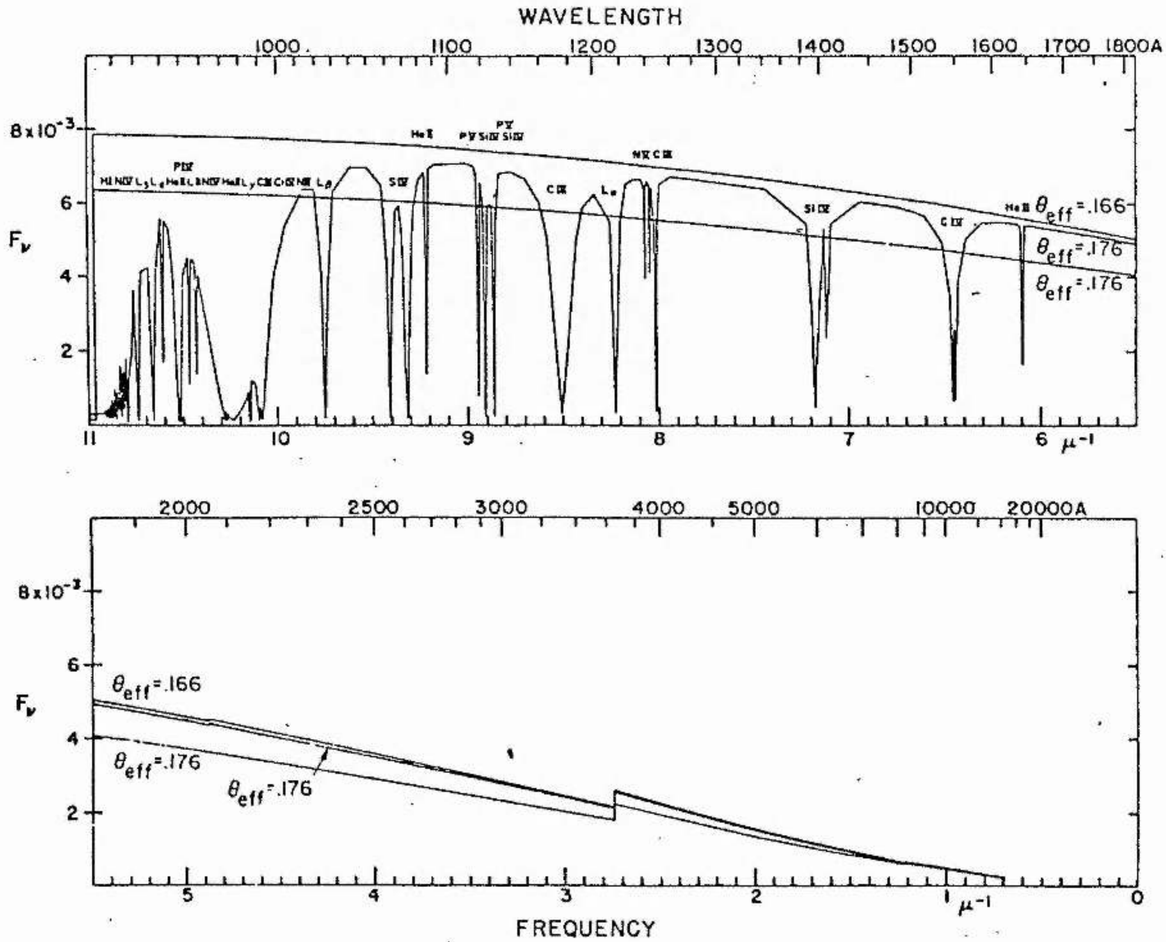


Fig. 1.

THE SPECTRAL ENERGY DISTRIBUTION FROM BO STARS FROM

1000Å - 10,000Å

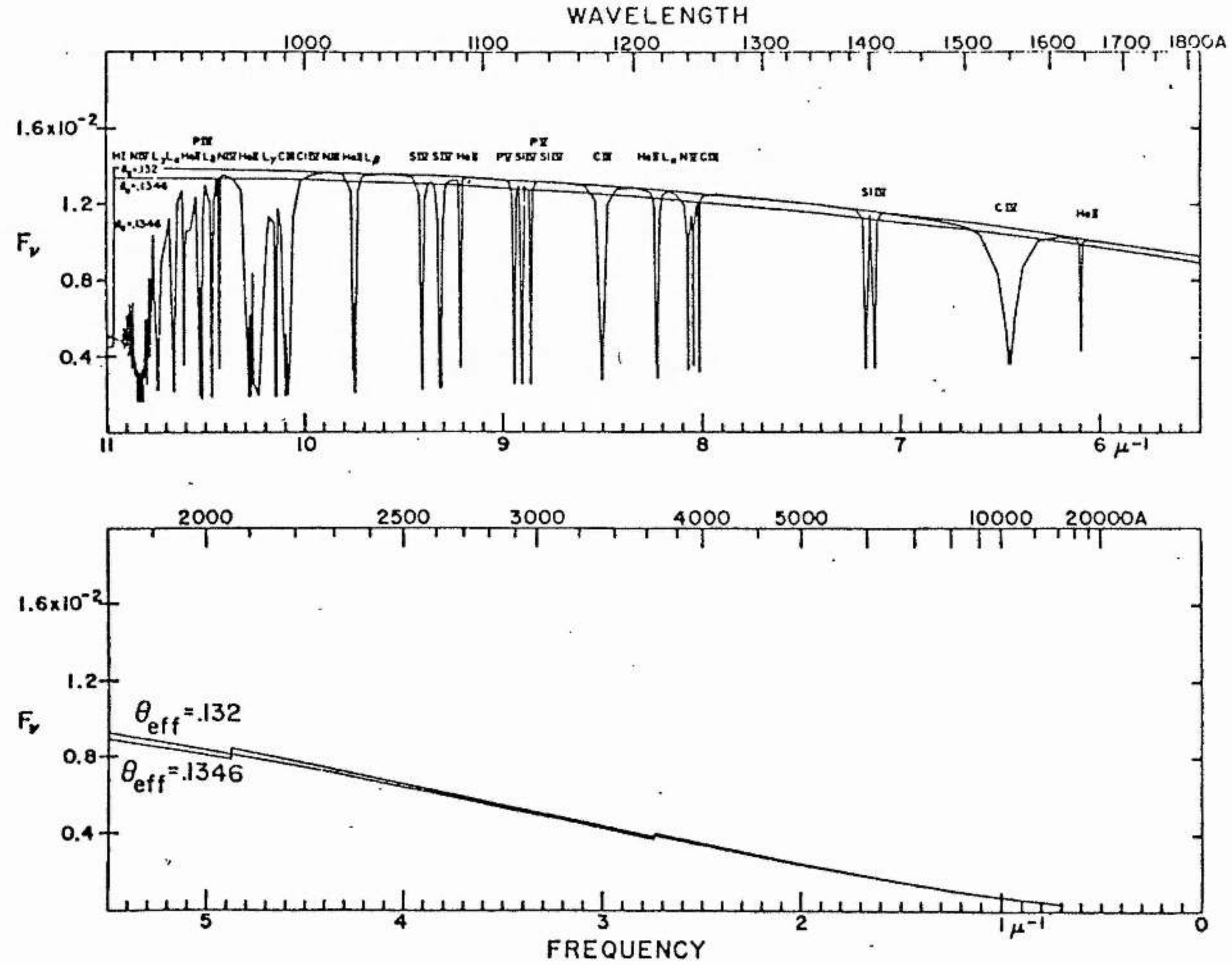


Fig. 2.

SPECTRAL ENERGY DISTRIBUTION FROM O5 STARS FROM 1000Å - 10,000Å main sequence O5 star between 1000Å and 10,000Å based on model atmosphere calculations. The atmospheric cut-off occurs at 3000Å. It is worth noting that the energy in the visible region corresponds to approximately 1000 photons/Å/sec/cm^2 and although the energy per unit frequency interval at the maximum for an O5 star at 1000Å is ten times as great, the number of photons is only twice as large. This also implies that the number of recorded events from an ultraviolet detector is not significantly increased. In the visible region, the agreement is satisfactory even for the hottest stars which radiate only a small part of their energy in this range.

In the development of the stellar models only the continuum opacity is considered, but attempts have been made to correct roughly the temperature distribution for the blanketing effect due to the line absorption. This energy, absorbed by the lines in the continuum and re-emitted at lower frequencies, is of importance in the outer layers of the atmosphere and has the effect of reducing the surface temperature of the star and of increasing the temperature gradient in the outer layer where strong lines are formed.

According to some early work done by GAUSTAD and SPITZER (1961) we should expect a heavy blanketing for a B2 star between 912Å and 1400Å. For longer wavelengths, very few lines have been considered, and it is virtually impossible to predict the blanketing effect in the longer wavelength region which is crowded with faint lines, such as FeII, FeIII, MnII, MnIII, SiIII, etc., and which will probably be in absorption in most of the observed hot stars. In stars of type later than FO, emission lines are to be expected, and these stars will probably be of the solar type. We must also remember that emission lines in the visible region of the spectrum are already observed in some stars of types, O, B, and A, in all the Wolf-Rayet stars and in some peculiar stars. There will probably be more stars with emission lines in the u.v. because the predominant lines of the most abundant atoms or ions lie in this region. In the case of stars too faint to be observed at high resolution, information on their energy distribution can be obtained using wide band photometry. In this so called multi-colour photometry, the colour index depends on the ratio of integrated intensities in two wavelengths of widths λ_1 and λ_2

$$C = 2.5 \log_{10} \frac{I_{\lambda 1}}{I_{\lambda 2}}$$

The difficulty is to tell what part of the colour is due to the continuous spectrum and the absorption or emission lines of the star, and what part comes from the interstellar reddening and the interstellar lines. Such multi-colour photometry has been very successful in the determination of spectral classification, of interstellar reddening and of the age of main sequence stars, which is important in connection with the evolutionary theory.

Borgman (1961) draws attention to the importance of the u.v. in the solution of two problems: on the one hand, of the nature of the interstellar medium, and on the other hand of the slope of the extinction curve in the u.v. which is important in connection with problems of galactic structure, the two problems are of course inter-related. From the observed dependence of extinction upon wavelength we will probably be able to tell what the nature of interstellar particles is; whether there are dielectric, graphite flakes; conglomerations of molecules etc., what their size is and their electrical compositions. From these data it should also be possible to compute a model extinction curve which fits the observations in the u.v. and from which it should be possible to predict accurately, absolute extinctions in the visible and infrared. The slope of the extinction curve can be determined by using wide-band photometry or by determining the ratio of intensities of certain emission lines in the gaseous nebulae. It is clear therefore, that accurate stellar models applicable to the hot early type stars can easily be constructed if the energy of such stars is known beyond 3000Å.

TOUSEY (1961) gives a chart showing the depth of penetration of incident ultraviolet radiation through the atmosphere. With the exception of a small window near 2100Å, the level to which 37% of the incident radiation penetrates is above 30km for all wavelengths shorter than 3000Å. Between 2000Å and 3000Å, the absorption is caused primarily by ozone (O_3), and although the maximum ozone density occurs near 20km, VIGROUX (1960), appreciable amounts extending above 30km effectively block the radiation between 2200Å and 2800Å. Between 1000Å and 2000Å the absorption is produced primarily by molecular oxygen (O_2). Throughout most of this region, 37% of the incident radiation penetrates to a level near 100km. Since the Earth's atmosphere is not transparent in the spectral range in which the maximum of emission of the O and B stars occurs, such maxima can only be observed by means of rockets and satellite vehicles.

PREVIOUS INVESTIGATIONS.

The first observations of astronomical significance obtained in the far ultraviolet, were carried out by TOUSEY of the U.S. Naval Research Laboratory in 1946, using captured German V2 rockets. The rockets were unstabilised and although very simple spectrographs were flown, good solar spectra were obtained to below 2000Å.

In due course the V2 rockets were replaced by the AEROBEE rocket which although having a military origin, was mainly developed for scientific investigations; the rocket, like its predecessor, the V2, was liquid fuelled, spin-stabilised, with a diameter of 15 inches and an overall length of 26 feet. The rocket was capable of lifting a payload of 250 pounds to approximately 200 kilometers.

In 1955, the first ultraviolet observations of stellar sources were obtained by BYRAM et al (1957) of the U.S. Naval Research Observatory who used simple gas gain ionization chambers mounted at the foci of 4 and 6 inch diameter parabolic mirrors, the photometers having fields of view of 20°. The ion chambers were sensitive to relatively narrow wavebands in the far ultraviolet. The data for a number of stars observed in the bands 1290Å-1350Å and 1350Å - 1550Å indicated that the stellar fluxes were three to five times less bright than predicted by the then current stellar atmosphere theory.

Much interest was aroused when bright nebulosities were reported in the direction of SPICA (α VIRGINIS) by KUPPERIAN et al (1958) and a flight by BOGGESS (1960) at the Goddard Space Flight Centre seemed to confirm the existence of such a nebulosity, when he flew a photometer which made fifty-eight consecutive scans of the α VIRGINIS source, showing an angular extent of 9°. However, another photometer flown in 1959 by the N.R.L. Group showed sources of a similar intensity in the ORION region, but with no indication of an angular extent. The matter was partially resolved when FRIEDMAN of the N.R.L. suggested that temperature effects had modified the spectral response of the calcium fluoride optics in the photometers in such a way as to permit the transmission of LYMAN α and that the geo-corona was in fact being observed throughout the whole of the flight.

An identical photometer was flown by BYRAM et al (1963) in April 1963, and the star appeared as a point source. Further observations were obtained by the N.R.L. Group: FRIEDMAN et al (1962); CHUBB et al (1963); BYRAM et al (1964); at (1350Å - 1550Å) and at(1314Å - 1350Å). Additional observations were made in the 2000Å-3000Å range by BOGGESS (1961) and in the Southern Hemisphere for the same wavelength regions, by BOGGESS (1964); GULLEDGE and PACKER (1963) observed stellar sources at 2985Å and 2100Å with respective passbands of 52Å and 160Å.

During this time no European observations had been conducted. However, ALEXANDER et al (1964), using a British Skylark rocket, made a number of stellar observations in the Southern Hemisphere at a wavelength of 1950Å.

A comparison of the absolute ultraviolet fluxes at 1115Å, 1314Å and 1427Å obtained by CHUBB (1965), relative to fluxes at 5560Å obtained from ground based observations, indicated that the absolute fluxes were fainter than expected from the unblanketed models vy factors of 2 to 10. MORTON (1966), showed that part of the discrepancy could be removed by including strong absorption lines which fell within the observed passbands. The discrepancies were further reduced by the newer models which predicted lower ultraviolet fluxes and higher fluxes near 5560Å than the original unblanketed models had predicted.

The results of ALEXANDER et al (1964) indicated that the B stars were only 50 to 33 percent as bright at 1900Å as predicted for the unblanketed models. However, the uncertainty in the absolute calibration of the photometers did not permit an accurate comparison to be made. The results of GULLEDGE and PACKER (1963), at 2120Å, were about 0.75 of those predicted from the unblanketed models.

A number of observations at 2100Å, 2500Å and 2800Å were obtained by BLESS et al (1968) with passbands of the order of 400Å. A comparison of these observations with the fluxes predicted by unblanketed models, agreed to within 0.5 mag.

It seemed, therefore, that some sort of agreement existed between the observational absolute fluxes and those predicted by unblanketed models for the region

2000Å - 3000Å, although no real agreement could be said to exist in the region 1000Å - 2000Å. However, STECHER and MILLIGAN (1962), obtained 50Å resolution spectral scans of seven stars between 1700Å and 4000Å. Their observations showed that at wavelengths greater than 2600Å the general shape of the spectra were in agreement with the predicted spectra, but the spectra appeared to have a maximum between 2400Å and 2300Å and then decreased rapidly to shorter wavelengths.

Two additional flights with the same type of equipment indicated that the absolute observed ultraviolet flux continued to rise beyond 2300Å and the fluxes were in general agreement with the results reported by BLESS et al (1968) at 2100Å and 2500Å. From the results it would seem that as for the earlier N.R.L. results, some instrumental error had produced the spurious observational data.

The importance of taking into account the effects of line blanketing below 1600Å was clearly indicated by the results obtained by SMITH (1967), who flew a photometer on board the American Satellite 1964-83C, and obtained absolute stellar fluxes for 96 stars at a wavelength of 1376Å. When the data were corrected for interstellar reddening and compared with unblanketed models, the observational fluxes were consistently below the predicted values, the fluxes were however, in agreement with MIHALAS-MORTON blanketed models.

Table 1. shows a list of the presently published photometric and spectro-photometric data for the period

TABLE 1

Technical Specification of Previous Rocket-Borne Photometers*

	Boggess, NRL	Chubb, NRL	Alexander, UCL	Boggess, GSFC	Byram, NRL	Bless, SAL	Yamashita, Japan	Carruthers, NRL
Year of launch	1957	1960	1961	1961	1963	1964	1965	1967
Wavelength range	2200 Å 2600 Å	1350–1550 Å 1290–1350 Å	1950 Å	2600 Å 2200 Å 1050–1300 Å	1050–1190 Å 1150–1180 Å	2100 Å 2500 Å 2800 Å	1060–1180 Å 1230–1350 Å	1050–1180 Å 1230–1350 Å
No. of stars	13	50 80	7	6	59	61	6	7
Bandwidth	210 Å 250 Å	— —	400 Å	220 Å	—	300 Å	—	—
Optical system	Refractor reflector	Prime focus reflectors	Honeycomb collimators	Cassegrain optics and spherical mirrors	Spherical mirror	Refractive telescopes	Reflective prime focus	Mechanical collimator
Aperture diameter	60 mm 150 mm	150 mm 100 mm	—	150 mm 150 mm	100 mm	50 mm	90 mm	—
Accuracy of absolute calibration	None stated	Not stated	Absolute calibration not clear	Good agreement with Bless, 1968	Relative photometry ±25%; 50% probability good to factor 2	±25%	Relative to Smith's observation of α-Leonis	±20% corrected by factor 4 at 1150 Å and 1.35 in 1969 at 1270 Å
Field of view	4° × 4°	$2^1/_2$° circular	±1.5°	2° 2°	$2^1/_2$° circular	3° × 3°	10° circular	7°
Filter efficiency	25% transmission (1)	—	Q.E. = 0.1%	17–20% transmission (1)	—	25% transmission	—	—
Mirror reflectance	—	$R^1 = 0.85$	$R^1 = 0.25$	$R^2 = 0.72$	$R^1 = 0.85$		$R^1 = 0.32$	—
Transmission	$T^2 = 0.64$	—	Collimator $T = 64\%$	$T^4 = 0.80$	—	$T^2 = 0.64$	—	—
Q.E. of detector	0.15	0.40	—	0.15	0.40	0.10–0.14	0.23–0.40	0.25–0.40
Efficiency product	0.024	0.34	0.025	0.22	0.34	0.16–0.22	0.08–0.128	0.25
Effective collecting area	0.7 cm^{-2}	60 cm^{-2}	0.01 cm^{-2}	4 cm^{-2}	27 cm^{-2}	0.3 cm^{-2} 0.43 cm^{-2}	1.0 cm^{-2} 1.4 cm^{-2}	2.4 cm^{-2} 4.8 cm^{-2}
Year data published	1958	1963	1964	1964	1965	1968	1968	1968
Reference	3	4	5	6	7	8	9	10

	Campbell, ROE	Campbell, ROE	Campbell, ROE	Campbell, ROE	Stecher, GSFC	Carruthers, NRL	Smith, Johns Hopkins
Year of launch	1967	Nov. 1968	Dec. 1968	1968	1968	1969	Satellite 1964
Wavelength range	2150 Å 2550 Å	2150 Å 2550 Å	2150 Å 2550 Å	1450 Å	912–3000 Å	1030–1180 Å 1230–1350 Å	1050–1650 Å 1297–1650 Å
No. of stars	35	40	40	94	26	27	96
Bandwidth	150 Å 150 Å	250 Å 250 Å	250 Å 250 Å	300 Å	100 Å	—	—
Optical system	Reflective Newtonian telescope	Reflective Newtonian telescope	Reflective Newtonian telescope	Reflective cassegrain	Reflective off-axis convergent beam spectrometer	Reflective prime focus	Reflective Newtonian telescope

1955-1968 and for more detailed treatment of the absolute accuracies and instrumentation details, the reader is referred to a data review by BLESS (1970), and an instrumentation review by CAMPBELL (1972). By 1967, it became obvious that the discrepancies between model atmosphere theory and the observational data, were due in the main to the large errors in absolute calibration and the use of unsophisticated instrumentation and at the end of that year data began to be obtained from highly sophisticated pointing rockets.

The PRINCETON Group MORTON and SPITZER (1966); MORTON (1967), obtained objective grating spectrograms of a number of bright stars in the region 1200Å - 3000Å with a spectral resolution of 1Å and 3Å. Objective grating photo-electric spectra were also obtained in the region 1600Å - 3000Å with a resolution of 10Å by BOGGESS (1968). STECHER (1970) obtained spectra in the region 1200Å - 1400Å with a resolution of 10Å and 5Å. CARRUTHERS (1969), obtained objective grating spectra with an electronographic camera over the range 950Å - 1400Å with two photometers in the respective ranges 1050Å - 1180Å and 1230Å - 1350Å.

CHAPTER II

INSTRUMENTATION

THE SKYLARK ROCKET

The Skylark sounding rocket, unlike its American counterpart the AEROBEE rocket, was developed for purely scientific research. It owed its development to the Royal Society who in 1955 decided to sponsor a programme of upper atmosphere research in conjunction with the International Geophysical Year of 1957/1958. The original specification called for an uncontrolled, fin stabilised vehicle with the capability of lifting a 45Kg. payload to an altitude of 100Km. The project was co-ordinated by the Royal Aircraft Establishment at Farnborough, and the first Skylark was constructed in 1956. In addition, the Rocket Propulsion Establishment at Westcott, was charged with providing a suitable solid fuel propulsion system. The new motor was given the name RAVEN and was the largest solid fuel motor available at that time in the U.K., with a specific impulse of 1780Ns/Kg (at sea level) and a motor burn period of thirty seconds.

A portable, gimbal mounted launch tower of length thirty metres and constructed of BAILEY bridge sections, was designed and built by the Royal Ordinance Factory at WOOLWICH. The launcher was erected at WOOMERA, (Aboriginal name for spear thrower), South Australia, in May 1956 and the first proving Skylark launched in February 1957. After only one additional proving round, the first scientific experiments were flown in July 1957.

In 1960, by the addition of a booster stage (CUCKOO) which burned for four seconds with a thrust of 90kN, it was possible to achieve an increase of 40% to the peak altitude. The dimensions of the RAVEN and CUCKOO motors are shown in figure 1.

PAYLOAD CONFIGURATION

A typical Skylark payload section is constructed using a modular system of magnesium alloy body sections, manacle ring clamped together. In this way, it is possible to construct scientific payloads of widely varying composition, the payload length being dependent on the number and complexity of the experiments to be carried.

In practice the experiments are housed in the forward section of the rocket and there is in addition the possibility of utilising the space under the nose-cone. The housekeeping section of the payload (telemetry and tracking beacons) are generally located in the lower part of the payload in order to facilitate testing without the experimenter's equipment.

In the U.K. configuration of Skylark, an E.M.I. FM/AM telemetry transmitting system operating on 465/MHZ/FM/AM is used with two separate UHF transmitters radiating 2 W.r.f. through simple dipole spike antennae on the side of the rocket. With this system there is available 34 high speed channels at 85 pps and 44 low speed channels at 21 pps.

In the case of ESRO constructed Skylark payloads a

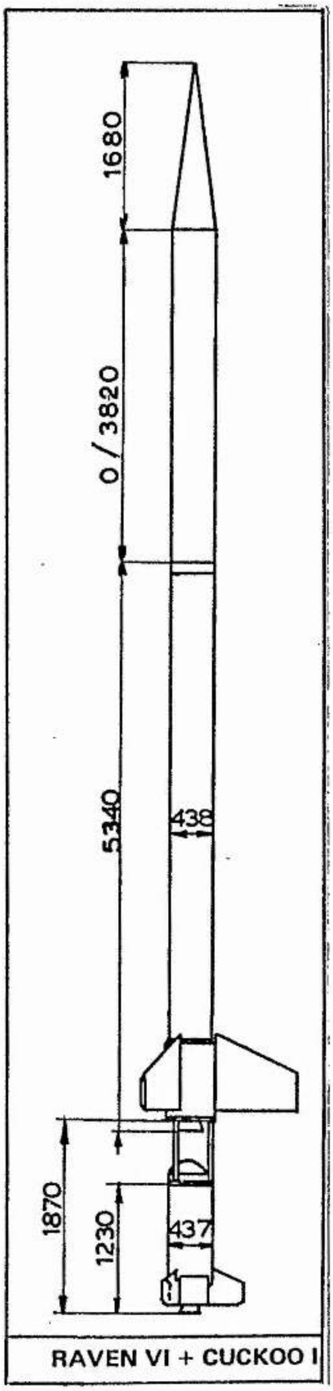


Fig. 1.

PHYSICAL DIMENSIONS OF RAVEN AND CUCKOO MOTORS

245 MHz transmitter is used with a FM/FM system employing up to 18 full bandwidth channels any of which can be multiplexed into a maximum of eighty sub-channels. With this system it was possible to utilise more and wider bandwidths than with the U.K. telemetry system.

An attitude determination system was included in the standard instrumentation package, and Sun or Moon sensors were employed, giving an overall accuracy in attitude determination of $\pm 3^{\circ}$.

PAYLOAD DESIGN

Before considering the type of optical system to be employed in the photometers, it was necessary to decide in which direction the photometers should view the sky. There were two possibilities:

(a) the photometers could be mounted below a jettisonable nose-cone of the rocket and view forward. With such configuration it would then be possible to employ very large aperture systems of up to 35cm in diameter (the inside diameter for the Skylark rocket being 38.6cm.) However, because of the precessional motion of the Skylark rocket, only a small region of the sky would be scanned, although many times.

(b) the photometers could be mounted with their optical axes perpendicular to the roll axis of the rocket and would view the sky through jettisonable hatches cut in the side of the rocket body. The advantages of using such a mounting were that although the maximum instrumental aperture was 23cms. many more experiments could be flown in individual rocket sections, and a more complete sky coverage would also be possible.

In view of the many advantages of method (b), all the photometers were mounted perpendicular to the roll axis of the rocket. Unfortunately, at the time of the investigation, no rocket section with a jettisonable cover was available and it became necessary for the author to become involved in the development of a suitable section. Initially, it was decided to take a standard type VI rocket section, cut a rectangular hole some 10 inches by 9 inches in the side and to strengthen the remaining section by increasing the wall thickness of the rocket section round the aperture. Provision was also made for ejecting the hatch cover by means of pneumatic plungers, activated by high pressure nitrogen. Many tests and modifications were made and the author would like to acknowledge the foresight shown by Mr. Des. Warr of the Royal Aircraft Establishment, Farnborough, who, on his own initiative, developed the section solely at the request of the Royal Observatory, Edinburgh. Such rocket sections have now been flown many times by ESRO and in the U.K. National Programme, and were the main-stay of the stellar programmes although the early work of Mr. Warr has long been forgotten.

OPTICAL SYSTEMS

As it was intended to fly a number of wide aperture photometers on each rocket, the requirements for the optical system was that it should be compact, but with as large a collecting area as possible, and a circular field of view of 2°, although it was felt that the sky background might make it necessary to use a much smaller field. A Cassegrain system seemed an obvious choice and a computer produced spot diagram confirmed that an F/1,22 cm diameter paraboloid used with a 6.4cm diameter hyperbolic secondary of magnification factor 3 would give the necessary performance. The spot diagrams are shown in Fig. 2. for the on-axis 1° field of view.

CASSEGRAIN PHOTOMETER

Mechanical Construction:

The photometer consisted of three identical magnesium alloy castings incorporating a strengthened 23cm aperture casting mounted between two 38cm diameter aluminium discs, to form a strong lightweight structure. Associated with each casting was a cell mount which provided a means of accurately locating one of the following sections:

Primary Mirror Mount:

In view of the large diameter of the primary mirror, considerable care was taken in designing a suitable mirror mount, which was capable of holding the primary mirror in accurate optical alignment and also enabling the mirror to be adjusted in three axes. The mount consisted of two magnesium alloy castings, which were screwed to the inside of the main central unit. Each mounting ring had three lugs spaced at 120° intervals, each containing

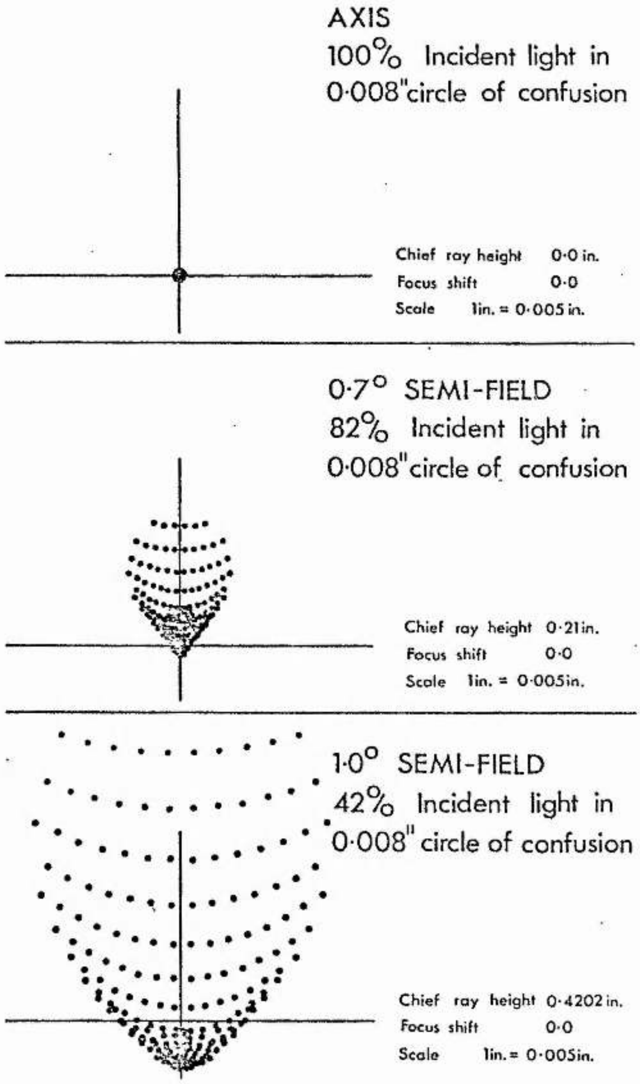


Fig. 2

SPOT DIAGRAM OF CASSEGRAIN OPTICAL SYSTEM a 1cm diameter nylon tipped Allen capped screw. The primary mirror was then mounted between the two rings and after optical alignment was locked in position by means of a number of nylon tipped screws which located on the edge of the mirror.

Secondary Mirror Mount:

This mount consisted of a 70mm diameter magnesium alloy cell, located centrally with the photometer optical axis, and attached to a cast magnesium alloy spider, which fitted inside the 23cm central aperture of the front support casting. The mirror was mounted within the cell by means of three sets of nylon tipped screws, in a manner similar to the primary mirror mount and locked in position by a number of nylon tipped screws locating on the edge of the mirror. The mirrors were made by G. HOLE & SONS, Brighton, using boro-silicate glass, and the optical performance was well within the required specification. Each set of mirrors was aluminised and overcoated with magnesium fluoride by PILKINGTON PERKIN ELMER, St. Asaph, and had a reflectance of eighty-four percent at 1470Å as measured by the author, using a 1470Å Xenon lamp of known intensity output.

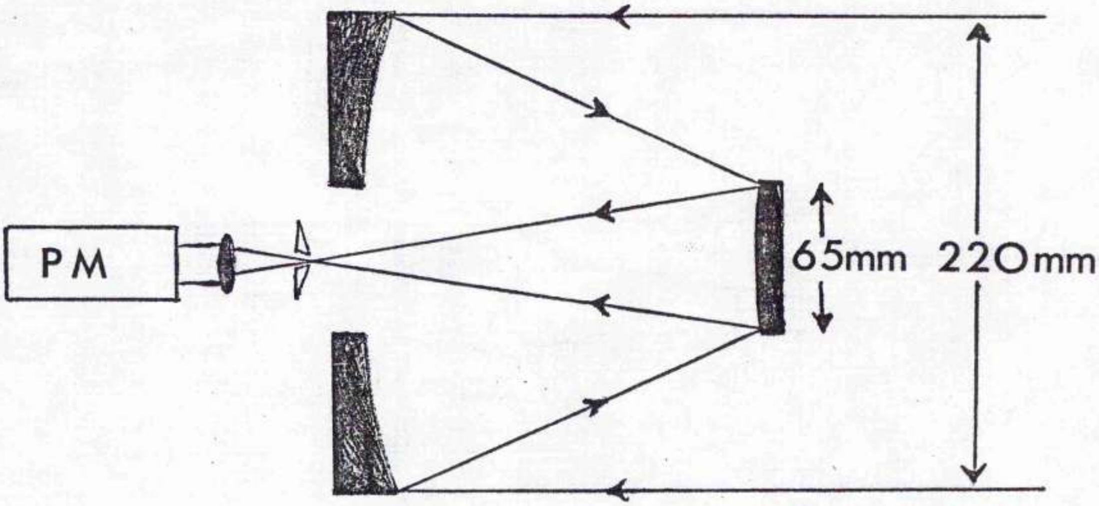
In order to minimise the effects of the non-uniformity of the photomultiplier cathode, a F/1 2.5cm diameter Fabry lens of lithium fluoride was placed in front of the photomultiplier together with a field defining diaphragm. A number of lenses were examined using the 1 metre normal incidence vacuum monochromator of PROF. W.R.S. GARTON, at Imperial College London, and the lens with the best transmission was selected for flight use. It was this component which determined the short wavelength cut-off of the photometer. The final optical system is shown in Fig. 3. and the mechanical structure in Plates 1, 2, and 3.

The Photomultiplier Mount:

Although some of the photomultipliers were designed to have a reasonable immunity to shock and vibration, it was felt that additional protection should be afforded if at all possible and this was achieved by mounting the detector in a cell, located as in the case of the secondary mirror, at the centre of a cast magnesium alloy spider. The space between the inside of the mounting cell and the outer case of the photomultiplier was filled with Sylguard encapsulant, providing a high degree of shock isolation. In addition, as it was intended to recover the photometers with a view to their recalibration, further protection against shock and vibration was obtained by mounting the photometer to the rocket section by means of eight rubber anti-vibration mounts, which effectively damped out all vibration above 40cps. The photometer electronics were also located on this mounting plate and the complete photometer assembly measuring 38cm in diameter by 36cm in height, was then bolted to the rocket section incorporating the jettisonable hatch.

ALTERNATIVE OPTICAL SYSTEMS

Although the preliminary computer print-out showed that it would be possible to obtain a satisfactory field

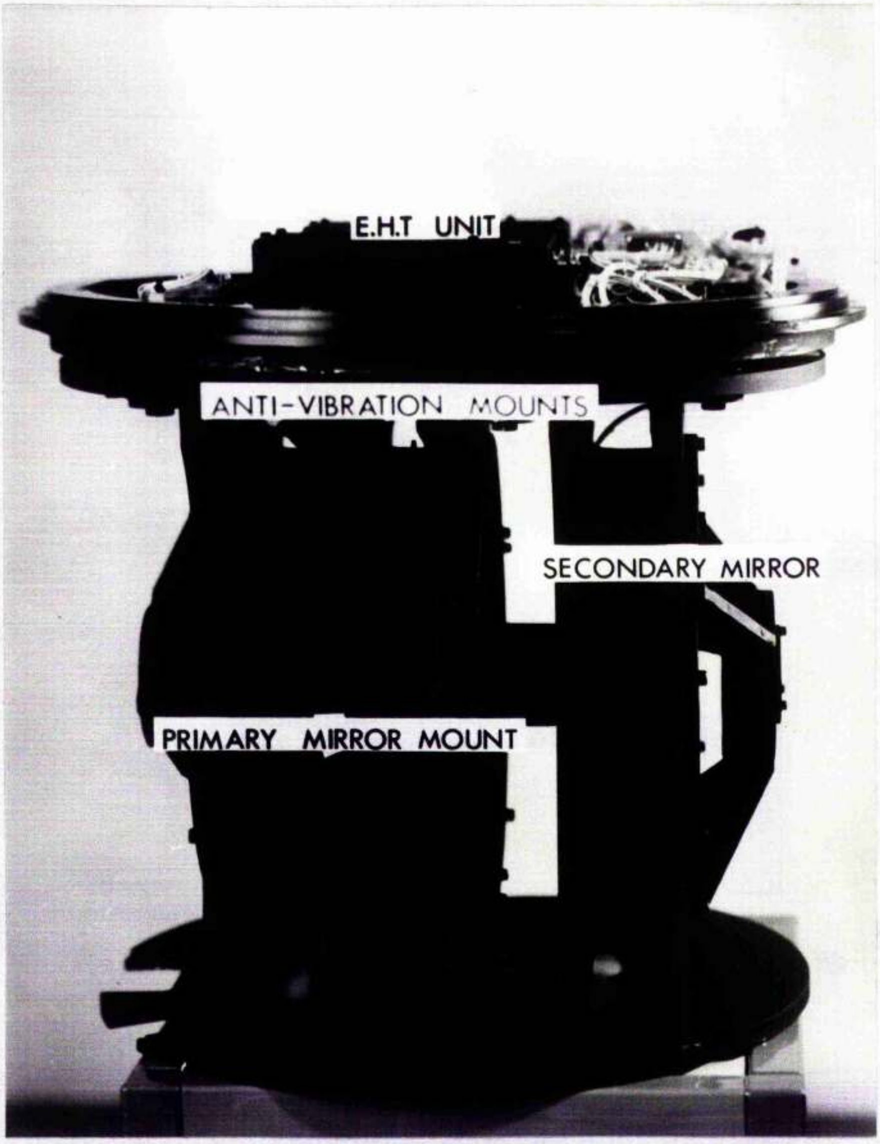


OPTICAL DIAGRAM OF CASSEGRAIN SYSTEM

Fig. 3.

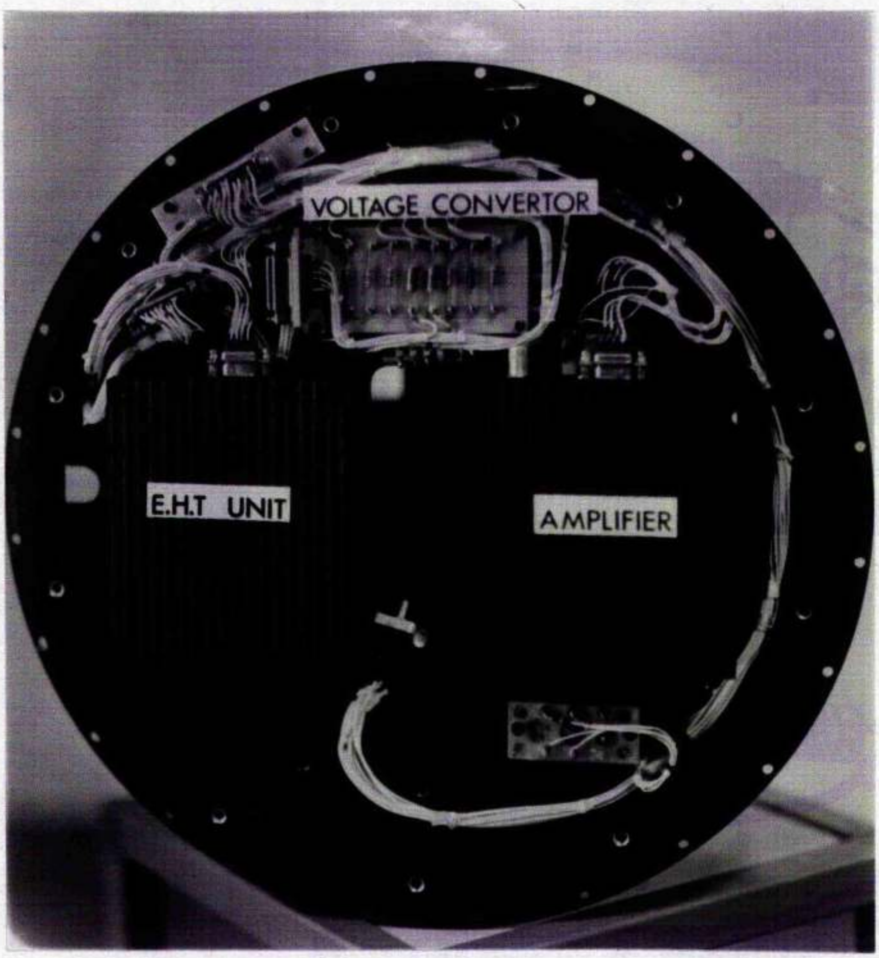
FRONT ELEVATION SINGLE CHANNEL STELLAR PHOTOMETER

PLATE 1



SIDE ELEVATION OF SINGLE CHANNEL STELLAR PHOTOMETER

PLATE 2



TOP ELEVATION OF SINGLE CHANNEL STELLAR PHOTOMETER

PLATE 3

coverage using the Cassegrain optical system, it became necessary to investigate other optical systems which although of smaller physical aperture, would allow more photometric channels to be accommodated in the rocket payload.

One possibility seemed to be a simple Newtonian optical system with the light from the primary parabolic mirror being directed to the detector by means of the Newtonian flat. Further investigations however, showed that individual systems would be difficult to mount satisfactorily without providing a special rocket section with large jettisonable panels. Additional schemes were explored utilising one large parabolic primary mirror with two Newtonian flats, but the problem of mounting the detectors in such a way that they did not view the sky directly through the port hole, indicated that further studies were necessary.

Finally, it seemed that by making two Newtonian systems from a large primary mirror and removing the central slice of the mirror it would be possible to mount the detectors, satisfactorily in the centre. A prototype system was built according to the layout in Fig.4. and seemed to be the ideal optical solution, both channels viewing the same area of the sky simultaneously.

NEWTONIAN PHOTOMETER

Primary Mirror Mount:

The purpose of this mount was to maintain the 18cm x 8cm plain edged primary mirrors in accurate optical alignment

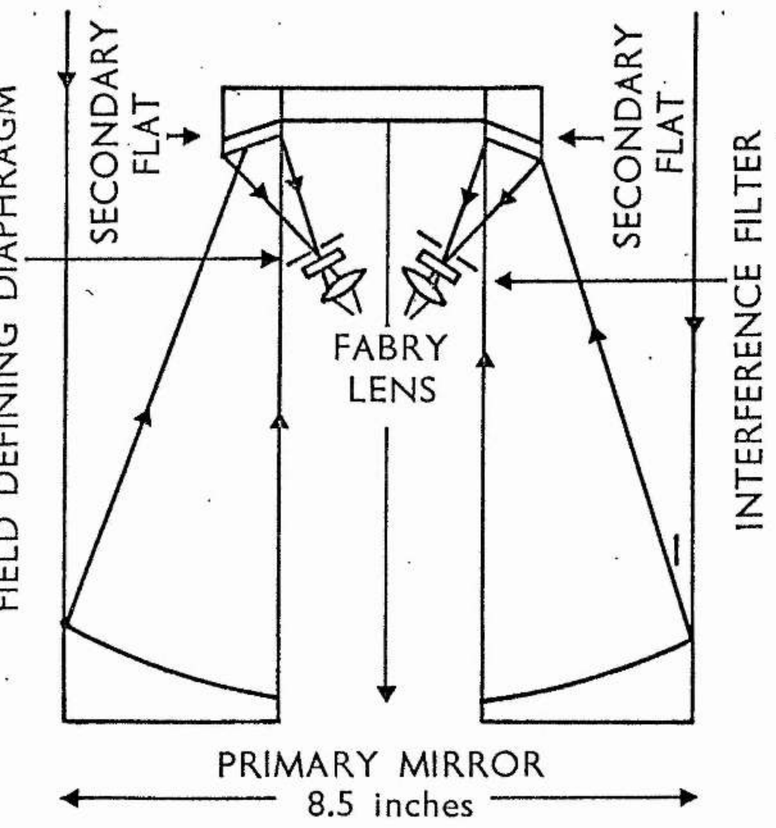


Fig. 4

OPTICAL DIAGRAM OF NEWTONIAN TELESCOPE

with the 6cm x 3cm Newtonian secondaries, without subjecting the mirrors to any strain. Each mirror was mounted in a magnesium alloy housing by means of three sets of nylon tipped screws located in such a manner as to provide accurate positioning of the mirrors in three axes. After accurate alignment, each primary mirror was then locked in position by means of a number of nylon tipped screws which located on each of the plain edges of the mirrors.

Secondary Mirror Mount:

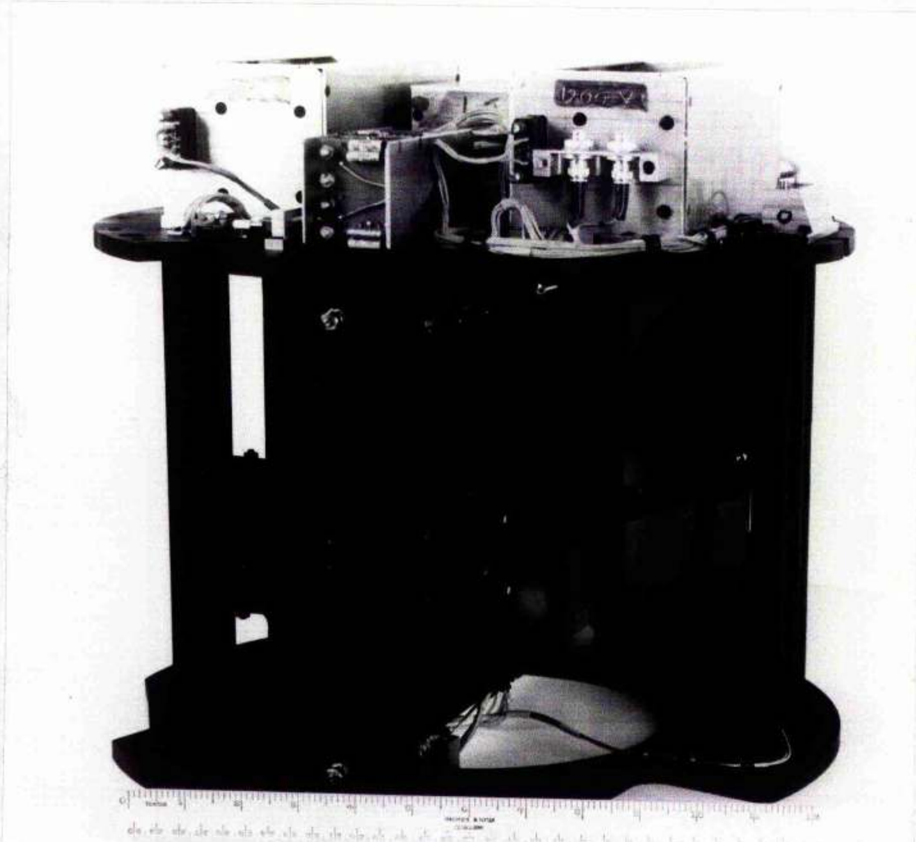
As in the case of the primary mirror mount, it was necessary to provide a three axis adjustment of the secondary flats and this was achieved by means of three sets of nylon tipped screws. In order to avoid any metallic contact between the mirrors and the mirror cells the internal surfaces of the cells were lined with nylon sheeting. Each cell block was then attached to a vertical cruciform support made of magnesium alloy. The mirrors were locked in position by means of nylon tipped screws locating against their inside faces.

Optical Block:

In order to facilitate the adjustment and location of the field defining diaphragm, interference filter and the Fabry lens, a detachable aluminium block was used as a combined lens and filter holder. This block, was located symmetrically about the focal plane of the telescope, and incorporated a central threaded brass insert. Each optical component was mounted in an individual nylon cell and locked in its final position by brass locking rings. In this way it was possible to accurately align the optical system without having the interference filter in place. The final mechanical structures are shown in Plate 1

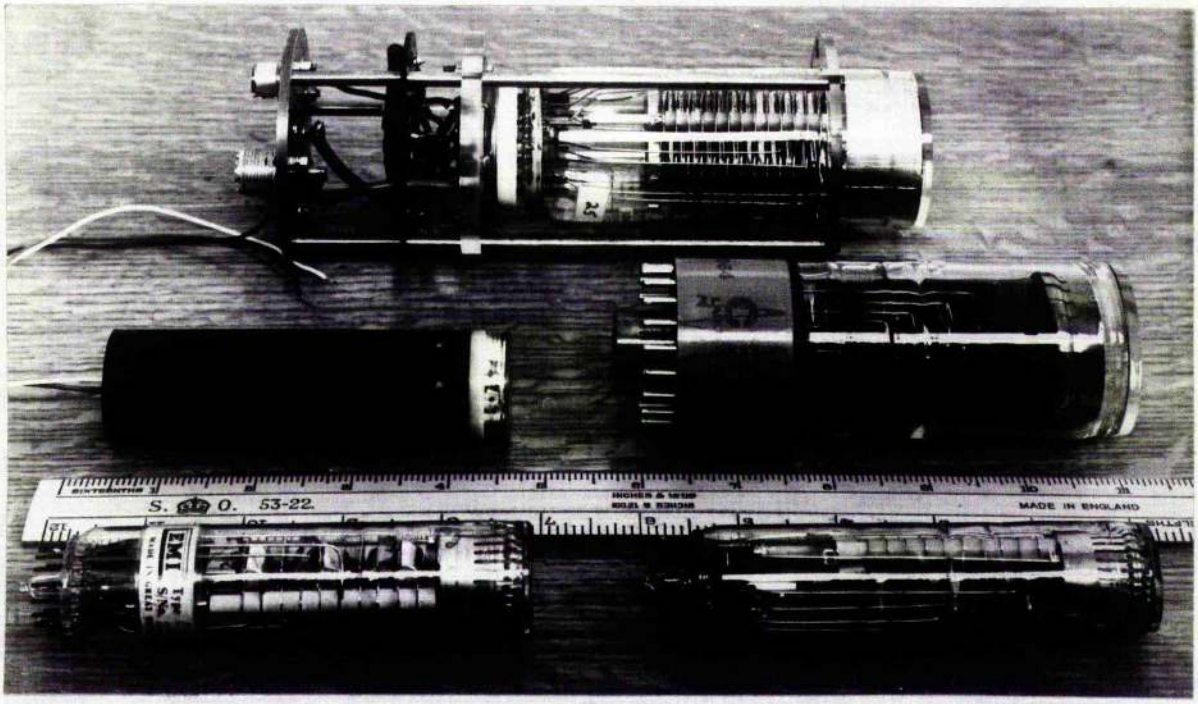
Photomultiplier Mount:-

A number of photomultipliers had been used in an earlier investigation which had a vibration specification but the cost of such detectors precluded their use on a routine basis and it was therefore necessary to develop a method of vibration and shock isolation which could be used to isolate any type of photomultiplier from the rocket launch environment. The method consisted of mounting the photomultiplier between a number of cast silicone rubber sections. Each section was individually cast to the photomultiplier envelope and the interface between the optical block and the detector faceplate cushioned by a thin layer of silicone rubber. In order to maintain the orientation of the photomultiplier identical to that used when it was calibrated, a key-way was inserted in the nylon mounting block, which mated with a corresponding slot in the metal backing plate of the detector housing. The author had the opportunity to test the performance of the photomultiplier mount in connection with another experiment which was recovered without damage to the photomultiplier, after impacting from an apogee of 192km. Several EMI detectors encapsulated for flight use are shown in Plate 5.



TWIN CHANNEL STELLAR PHOTOMETER

PLATE 4



SELECTION OF EMI EXPERIMENTAL DETECTORS
SHOWING ASCOP STANDARD

PLATE 5

DETECTORS FOR THE ULTRAVIOLET

The choice of a suitable detector for use in those photometers sensitive in the region 1000Å - 3000Å was totally dependent on the commercial availability of photomultipliers with the following characteristics.

(a) high quantum efficiency over the region of interest.

(b) high visible rejection above 3500Å.

(c) Low susceptibility to shock and vibration.

(d) Uniform photo-cathode response.

(e) Low dark current.

Although each of the above parameters was important the final choice was decided by the actual wavelength isolation technique used with the photomultiplier. In the case of the photometers employing reflective mirror surfaces the main requirement was for a high quantum efficiency in the isolated region; however, where interference filters were employed, it was of the utmost importance that the "visible rejection" of the detector was such as to eliminate any second order sensitivity of the filter in the visible region.

Unfortunately, at the time of this investigation no such "solar blind" detectors were available from European manufacturers and an extensive laboratory evaluation was undertaken of all other suitable detectors, mainly from the U.S.A.

NOTE: The term "solar blind" refers to a photo-cathode which is not sensitive to light radiation which passes through the Earth's atmosphere, i.e. wavelength longer than about 3200Å.

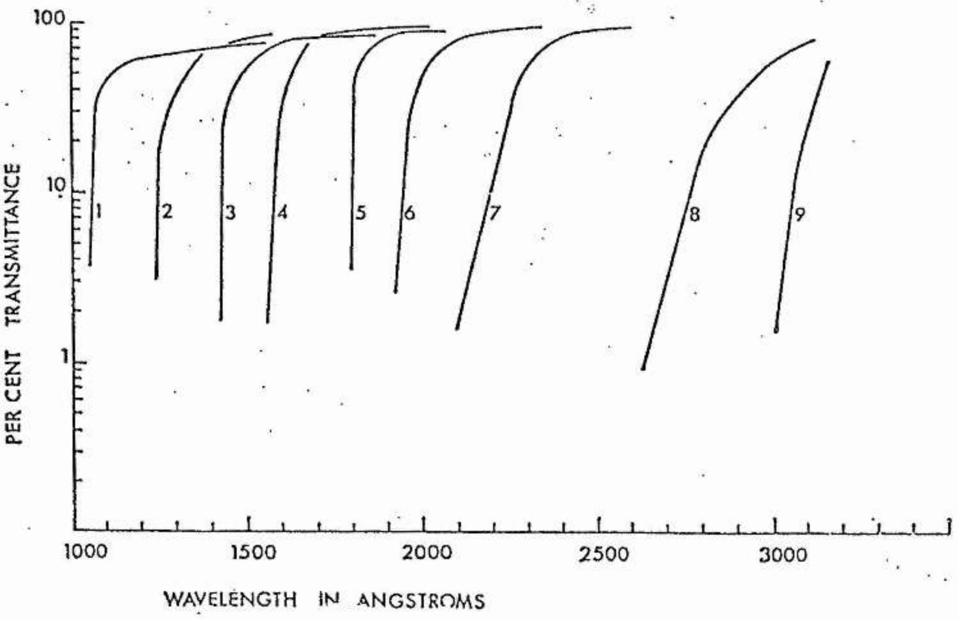
E.M.R. PHOTOMULTIPLIERS

By a strange coincidence, the drilling and surveying division of the SCHLUMBERGER Corporation, had a requirement for a photomultiplier to be used in scintillation studies of deep drill cores at depths up to 3000 feet. As a wide variety of wavelengths were of interest, it became necessary for the Company to develop a range of photomultipliers with a variety of crystalline windows not generally available from the more conventional photomultiplier manufacturers. In addition, because of the nature of their drilling operations it was also of utmost importance that their new detectors should be able to withstand high levels of shock and vibration. Thus the now well established range of photomultipliers known as ASCOP were born.

The advent of the Space Age and the hostile environment of typical rocket launches fostered the development of these shockproof detectors and led to the development of the more exotic "solar blind" cathodes. The detectors owed their shock resistance to a unique form of construction, where each dynode was welded at its periphery to a kovar ring which was an integral part of the envelope. The detectors employed silver magnesium dynodes of the LALLEMAND type, i.e. with spherically shaped focussing screens in front of each venetian blind. Detectors of this construction have withstood shocks up to 465g's for a millisecond in all three axes and vibration levels of up to 25g's when operating up to 3KHz. The complete dynode structure, including dynode resistors, was potted with silastic rubber type RTV.501. The choice of window to be used in such detectors was limited to a few crystalline materials shown in Fig.5 . The best transmission was obtained from LiF. using cleaved crystals generally obtained from the Harshaw Chemical Company and optically polished. Cleaved crystals have a better transmission and a 2mm thick crystal has a typical transmission of 60% at Lyman α. The LiF crystals were sealed to the glass envelope using a silver chloride seal and a silver cup. In this way the metal acted as a bellows and compensated for the large difference in thermal expansion between the window and the detector envelope. When a longer wavelength range was required, the window material was normally sapphire (aluminium oxide) which could be sealed with little difficulty to the glass envelope. In addition, the extended wavelength response to 1450Å, as opposed to 1650Å for quartz resulted in a detector generally unavailable from European manufacturers. The transmission of 1mm thick window was typically 60% at 1500Å.

Two types of photo-cathodes were available: Cs-Sb semi-transparent (Type A) and CsTe semi-transparent "solar blind" (Type F). The spectral response of each cathode is shown in Fig. 6 .

Quantum efficiencies of the order of five to fifteen percent have been measured for the stoechiometric combination of Cs_2Te at 2537Å, with a sensitivity of one thousandth or less at 3500Å. A high quantum efficiency could be obtained with CsTe by accepting an excess of Cs and values



1. LiF
2. CaF_2
3. Sapphire (Al_2O_2)
4. Fused silica
5. ADP
6. $NiSO_4(H_2O)_6$
7. Corning 9-54
8. Corning 9700
9. Corning 0-54

CRYSTALINE WINDOW MATERIALS IN THE ULTRAVIOLET

Fig. 5.

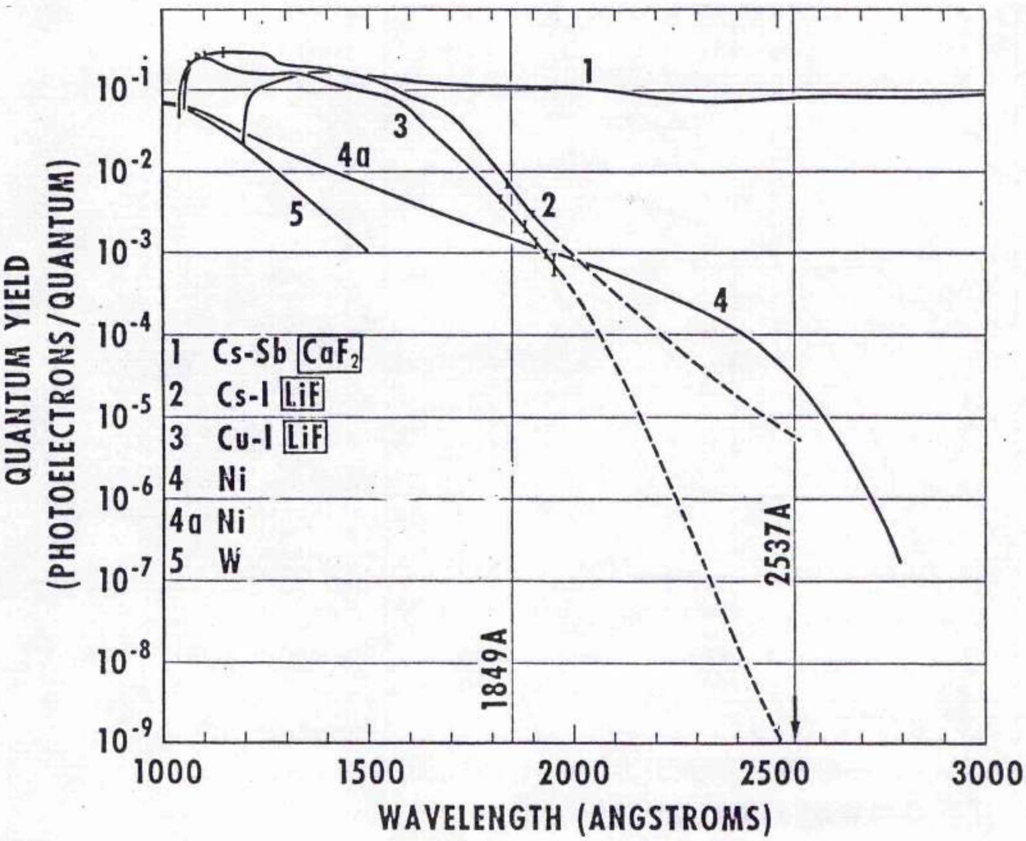


Fig. 6.

WINDOW PHOTO-CATHODE COMBINATION

as high as twenty percent had been obtained at 2537Å. There was, however, a corresponding increase in sensitivity of several orders of magnitude in the near ultraviolet.

The Cs_2Te (Type F) cathode had a very low thermal emission of the order of 10 electrons/cm ^{2}/sec at 20°C while Cs_2Te.(Cs) was similar to the Type A Cs-Sb (200 electrons/cm ^{2}/sec.) The only drawback of the Cs_2Te cathode was that no excess Cs could be tolerated in the photomultiplier and an increased number of silver-manganese stages were necessary rather than the normal number of caesiated stages. Table 1. shows the range of ASCOP detectors evaluated for the present application.

R.C.A. PHOTOMULTIPLIERS

This Company, although manufacturing a wide range of detectors for the visible region of the spectrum produced a somewhat limited range of "solar blind" detectors and only two types were examined. Each type utilised a Cs_2Te photo-cathode with a conventional photomultiplier base. Two window materials were available, one of quartz and one of LiF. A conventional box and grid dynode structure was employed and no attempt was made to ruggedise the envelope.

BENDIX PHOTOMULTIPLIERS

With the advent of the Channeltron system of electron multiplication it becamse possible to construct compact and rugged detectors and since the technique was pioneered by the Bendix Corporation of America, it seemed

NOTE: Cs indicates a photo-cathode with an excess of caesium.

TABLE 1

TABLE OF AVAILABLE DETECTORS

MANUFACTURER	ASCOP	ASCOP	ASCOP	ASCOP	EMI	EMI
TYPE OF PHOTO-MULTIPLIER	END ON	END ON	END ON	END ON	END ON	END ON
PHOTOCATHODE MATERIAL	Cs I	Cu I	Cs_2Te	CsI	Cs_2Te	Cs_2Te
WINDOW MATERIAL	LiF	LiF	LiF	LiF	SAPPHIRE	QUARTZ
SPECTRAL RANGE Å	1050-2500	1050-2300	1050-3500	1050-2500	1450-3500	1650-3500
DIAMETER - INCHES	1.25	1.25	2	2	1.25	1.25
OVERALL LENGTH INCHES	5⅜	5⅜	5½	5½		
NO. OF STAGES	18	18	18	18		
ACTIVE CATHODE DIAMETER m.m.	10	10	18	18		
PEAK QUANTUM EFFICIENCY %	7	3	6.5	8		
WAVELENGTH OR PEAK	1216	1216	1216	1216		
NOMINAL CATHODE TO ANODE VOLTAGE	2900	2900	2350	2900		
GAIN	10^6	10^6	10^8	10^7		
MODEL NUMBER	541G-08-18	541H-08-18	542F-08-18	542G-08-18		

likely that a suitable detector would be found from this source.

The detectors employed front surface (opaque) caesium iodide photo-cathodes deposited on the mirror surface of the extended cone of a channeltron. In order to avoid excess of caesium into the multiplier, the photo-cathode was processed externally. Two types of windows were available, sapphire and magnesium fluoride, giving useful spectral responses of 1450Å-1900Å and 1150Å - 1950Å. Both types of detector exhibited very low dark counts (1 count per ten seconds) without cooling. The detectors also had the advantage of having only three pins in contrast to the usual multi-pin base. Typical quantum efficiencies of seven percent were obtained at 1500Å.

C.B.S. PHOTOMULTIPLIERS

Although producing a wide range of visible response photomultipliers the company did not produce many "solar blind" type detectors and only one was of any interest. The detector incorporated a rubidium telluride photo-cathode with a quartz window. A box and grid dynode structure was used which was strengthened with the detector envelope to minimise the detector susceptability to shock and vibration.

DUMONT PHOTOMULTIPLIERS

A sample quartz windowed Rb-Te photomultiplier was considered but the gain of the detector was so low as to eliminate its inclusion in the laboratory evaluation programme. However, the detector characteristics are included for completeness.

HAMMAMATSU TELEVISION CO. PHOTOMULTIPLIERS

This Company, although well known in Japan, were very little known in Europe. However, a chance meeting with the managing director of the Company permitted a discussion of "solar blind" detectors in general, and although the Company produced only one such detector, it seemed so promising that a sample detector was sent by the manufacturers for immediate evaluation. The detector was the only side viewing multiplier examined and its squirrel cage dynode system produced a very compact detector. A quartz envelope and a caesium telluride photo-cathode resulted in a useful spectral response over the range 1650Å - 3200Å.

DETECTOR EVALUATION

The actual test procedure used to evaluate each detector type was too lengthy to report and the procedures indicated in this section on EMI photomultipliers should be taken to apply to the evaluation of the selected commercial detectors.

THE REGION 1000Å - 1600Å

Only three manufacturers produced detectors sensitive in this wavelength region, BENDIX, R.C.S. and E.M.R.. The BENDIX detectors, types BX 760, (sapphire window) and BX 762 (magnesium fluoride), although rugged and compact, had small photo-cathode areas and an inability to recover rapidly from signal overloads.

Since there was a possibility that during the flight, the photometer would view the Moon, it was felt that the possibility of detector paralysis ruled out the inclusion of such detectors for consideration. The detectors did have the advantage of having magnesium fluoride windows which were less susceptible to moisture than the normal lithium fluoride windows. Only one R.C.A. detector was available in this region, the type C70128, a lithium fluoride windowed Ca_2Te photo-cathode detector. The detector had a ¾" window and twelve stages of multiplication.

The writer was fortunate enough to acquire one of the first detectors of this type, however, preliminary tests indicated a very high dark current and low gain, indicative of a leak in the window seal. As the detector was in the development stage at the time of the investigation, no further tests were conducted on this particular model.

Contrary to the small number of detectors available from other photomultiplier manufacturers, the range produced by E.M.R. was a veritable Aladdin's cave, and in view of the very high cost of such detectors, typically (£1,500.0 each) great care was exercised in selecting detectors for evaluation, in order that they could be incorporated in the actual flight payloads. The problem was further complicated by the fact that prior to the author's return from a visit to Goddard Space Flight Centre, in February 1962, no knowledge of the E.M.R. detectors existed in the United Kingdom, let alone users experience of actual detectors.

It was decided to evaluate the sapphire windowed ceasium telluride range of detectors; the 541.F series. The customer had a number of options and it was possible to select:

(a) Maximum quantum efficiency.

(b) Lowest possible dark count.

(c) Lowest possible operating voltage for a specific gain.

In the case of the photometer employing interference filters, it was important to eliminate any sensitivity still present in the second order transmission band and in addition, to try to overcome the poor transmission of such filters, by using detectors of high quantum efficiency, and high visible rejection. From what has been said previously, this is usually a conflicting requirement and a compromise was adopted, for a high quantum efficiency in the filter passband. A total of six 541F-05M detectors and two 542G-08-18 were ordered. In addition, two 542J-08-18 detectors were purchased from the Meteorological Office, Bracknell, Berkshire, who had some surplus detectors from their satellite programme. An absolute spectral calibration was requested at a number of points throughout the overall spectral range.

As mentioned previously, the details of the actual detector evaluation were too extensive to be detailed in this section, however, the procedure adopted is mentioned in detail in the section dealing with the experimental E.M.I. detectors and the section on absolute calibration.

The results of the evaluation tests indicated that the manufacturer's information relating to the detectors gain and dark count was essentially correct, however, the actual absolute calibration data left much to be desired and an independent calibration was necessary for each of the flight detectors.

Because of the high cost of the ASCOP photomultipliers (typically £1,500.0) two developmental detectors were obtained from R.C.A. The detectora both used Cs_2Te photocathodes, but one employed a sapphire window and the other lif. Unfortunately, because of the high dark current and general instability of both detectors, and the lack of any sensitivity at 1450Å for the lif windowed model, the tests were abandoned and no additional detectors from this manufacturer were examined.

THE REGION 1600Å - 3200Å

Since both the lif and sapphire windowed ASCOP tubes were evaluated previously, no additional tests were necessary for the photometers employing detectors in the above wavelength range. However, a number of other detectors were also available. The CBS-1064 detector, quartz windowed, with Rb_2Te photo-cathodes were of interest and a batch of five were ordered from the manufacturers for possible flight use. The detectors, apart from the advantage of being ruggedized for space use, also were £1,200.0 cheaper than the equivalent ASCOP detector.

Again, the detectors were examined for quantum efficiency, dark current and gain. The tests were more exacting because of the lack of any individual detector performance data from the manufacturers and a number of discrepancies were revealed. The detector plugs into a large phenolic valve base and the surface leakage across this base gives rise to a false "dark current" the presence of which does not permit operating the detector at the correct gain. In addition, the effective cathode size was much less than the dimensions quoted by the manufacturers which precluded their use for the stellar photometers, but still allowed for their incorporation in a sky brightness experiment. By attaching the high voltage supply directly to the base of the detector, and totally encapsulating the base of the detector, it was possible to considerably reduce the "dark current" but it was still impossible to achieve a gain figure of 10^6 as quoted by the manufacturers. A further catastrophic defect was revealed when a number of detectors which had been kept unused in the laboratory, were found to have fractured along the junction of the quartz to glass graded seal. Because of the poor performance rating, the detectors were set aside.

EXPERIMENTAL E.M.I. PHOTOMULTIPLIERS

Although a number of American photomultipliers were used in the rocket photometers, it was clearly financially impossible to use such detectors for every instrument, since the author's programme called for more than forty such detectors and accordingly the author held a number of meetings with the technical director of E.M.I. Hayes, Middlesex. The outcome of these discussions was the specification of an entirely new photomultiplier to be manufactured by E.M.I. and the prototype to be evaluated by the author at Edinburgh prior to commercial manufacture.

The specification for this detector is summarised in Table 2, and it is very apparent that the parameters differ considerably from those relating to the normal antimony-caesium photomultiplier. As the rocket photometer requirements dictated the photomultiplier parameters, the laboratory investigations included tests which would at any early stage indicate whether or not a photomultiplier was suitable for use in the rocket borne stellar photometers. Accordingly, the conclusions should be interpreted with this in mind.

MECHANICAL CONSIDERATIONS

The vibration specification is shown in Table 3, and a detector having been subjected to the indicated levels, must show no degradation in physical or electrical performance. The preliminary assessment was conducted by mounting the photomultipliers between two rubber rings of silicone silastomer rubber of Shore Hardness 30. The rubber rings were then clamped to the vibrator table by means of two aluminium rings in such a way as to simulate the mounting conditions when the photomultiplier was incorporated in the rocket instrument.

A number of photomultipliers were vibrated in all three axes in this way and apart from small modifications to the dynode support structure, the basic structure was found to be suitable for flight use, when mounted as indicated. Several additional evaluations were then

EXPERIMENTAL DETECTOR SPECIFICATION

TABLE 2

Photocathode	Window diameter mm	No. of stages	Dynode material	Window material	Gain	Operating voltage V dc
CsTe	25	11–13	Be Cu	quartz (Spectrosil)	10^6	at gain 10^6 1400
CsTe	50	11–13	Be Cu	quartz (Spectrosil)	10^6	1800
CsTe	25	11–13	Be Cu	sapphire (Linde)	10^6	1400
CuI	50	13	Be Cu	quartz (Spectrosil)	10^6	1800
CsTe	25	13	Be Cu	lithium fluoride (Harshaw)	10^6	1400
Standard region 1450–3500 Å CsTe	25	14	Ag Mg	sapphire (Linde)	10^6	2300

Additional parameters

(a) over-all length: 11 stage max 14 cm; 13 stage max 15 cm

(b) output connections: (i) cathode separate (ii) D_1 separate (iii) D_{11} separate (iv) anode separate

(c) cathode: semitransparent on tungsten

QE at 2537 Å(%)	QE at 3500 Å(%)	Cathode uniformity at 2537 Å	QE at 1470 Å(%)	Manufacturer	Type No.	dc at 10^6
min 5.0	max 20×10^{-3}	±10% over 2 cm diam	N.A.	EMI	9705	5×10^{-11}
min 5.0	max 20×10^{-3}	±10% over 4.5 cm diam	N.A.	EMI	9616	2×10^{-11}
min 5.0	max 20×10^{-3}	±10% over 2 cm diam	min 5.0	EMI	9705	5×10^{-11}
max 20×10^{-3}	N.A.	±10% over 4.5 cm diam at 1470 Å	N.A.	EMI	9616	4×10^{-12}
min 5.0	max 20×10^{-3}	±10% over 2 cm diam	min 5.0	EMI	9705	5×10^{-11}
min 4.5	9×10^{-2}	±10% over 2 cm diam	min 5.0	ASCOP	541F05M-14	4×10^{-11}

Vibration:

Thrust and lateral axes: sinusoidal, 10–2000 Hz const acc 1 g sweep speed 2 oct/min

Thrust axis: random: 20–2000 Hz 8 g rms (density 0.031 g^2/Hz) 2 min

Lateral axes: random: 20–2000 Hz 5 g rms (density 0.013 g^2/Hz) 2 min

TABLE 3

VIBRATION SPECIFICATION FOR SKYLARK COMPONENTS

1. PROTOTYPE

Components, small parts

Thrust and Lateral Axes.

Sinusoidal, 10-50 cps. const. ampl. 2mm O-peak.

50-2000 cps. const. accel. 20g.
sweep Speed 2 oct/min

Subsystems, larger items, structure, bodies with Instrument.

Thrust Axis

Sinusoidal, 10-50 cps. const. ampl. 1mm O-peak

50-2000 cps, const. accel. 10g
sweep Speed 2 oct/min

Lateral Axes

Sinusoidal, 10-50 cps, const. ampl. 0.5mm. O-peak

50-2000 cps, const. accel. 5g
sweep Speed 2 oct/min.

2. DESIGN APPROVAL: complete assembled payload with prototype dummies or real instruments.

Thrust and Lateral Axes

Sinusoidal, 10-2000 cps, const. accel. 1g
sweep Speed 2 oct/min.

Thrust Axis

Random, 20-2000 cps, 8g RMS (density 0.031 g^2/cps) 2 min

Lateral Axes

Random, 20-2000 cps, 5g RMS (density 0.013 g^2/cps) 2 min

3. FLIGHT ACCEPTANCE, complete payload

Thrust Axis

Random 20-2000 cps, 5g RMS (density 0.013 g^2/cps) 2 min performed on photomultipliers which had the dynode resistors mounted within the glass envelope, with the same successful outcome.

ELECTRICAL QUALIFICATION TESTING

As can be seen from Table 2 there are several parameters which must be met before a photomultiplier is acceptable for flight use, and initially the window material and the visible light rejection were considered to be most important.

(a) Solar Blindness

For the purpose of the present application it was essential that the cathode sensitivity in the visible region of the spectrum be minimised. In addition, it was also a requirement that the detector should exhibit a high quantum yield of 2537Å; however, it is very easy to achieve this with CsTe photo-cathodes, merely by accepting a slight excess of caesium, and values as high as 20% have been achieved in this way. There is, however, a corresponding rise of several orders of magnitude in sensitivity in the region 3000Å - 4000Å.

Accordingly, because of the necessity of eliminating any excess of caesium in the detector, it was not possible to use caesiated dynodes, and copper beryllium dynodes were used in their place. This unfortunately, resulted in a longer photomultiplier, due to the additional number of dynodes required because of the low secondary emission yield of copper beryllium.

(b) Window Materials

Three window materials were specified, and in the case of sapphire and quartz, no undue difficulties were anticipated in the production of a satisfactory window seal. However, the sealing of lithium fluoride windows was unsuccessful and no useable detectors were produced.

Selection Criteria

In order to establish the acceptability of the early production photomultipliers, it was necessary to decide which of the photomultiplier parameters could be used to give an indication of the probably overall performance of the detector. The choice is not obvious when it is remembered that high quantum yield, low visible response and dark current are all equally important. However, in terms of expediency, it was decided to examine the dark current and the detector sensitivity at 2537Å, as it was felt that the quantum efficiency and the system noise level had perhaps the greatest effect on the scientific data.

A value of 5×10^{-10}A was chosen for the acceptable dark current of the photomultiplier as this value corresponded to the minium resolvable voltage increment on the rocket telemetry scale. Each of the forty-three evaluation photomultipliers was therefore placed in turn in a light-tight enclosure and the value of E.H.T. voltage necessary to establish this dark current noted. They were then operated for a period of twenty minutes at this voltage in order to check the operating stability. At this stage some fifteen detectors were found suitable, and arelisted in Table 4, which also includes a number of detectors with higher dark currents which were used for

TABLE 4
TEST DETECTORS

Ser. No.	Window material	No. of stages	Gain	Voltage	Dark current	Monitor output AR	Monitor output OX7	Monitor output OY10
5003	quartz	11	5×10^5	1200	2.8×10^{-10}	7.5	3.0	0.32
5005	quartz	11	2×10^4	1000		–	–	–
5006	quartz	11	6×10^3	1000		3.9	1.6	0.51
5008	quartz	11	2.6×10^4	1000		5.0	2.5	0.58
5009	quartz	11	3.7×10^4	1000	4×10^{-10}	9.5	4.5	0.36
5010	quartz	11	4×10^4	1000	–	2.5	1.5	0.14
5011	quartz	11	1.4×10^4	1000	$<1 \times 10^{-11}$	6.4	2.4	0.05
5213	quartz	13	4×10^5	1000	2×10^{-9}	20.5	7.5	0.48
5221	quartz		3.2×10^5	1500	1.4×10^{-10}	3.8	1.4	0.23
5230	quartz		5×10^5	1000	2×10^{-10}	3.2	1.1	0.22
5240	quartz	17	–	2000	1×10^{-10}	–	–	–
5241	quartz	17	–	1100	4×10^{-9}	–	–	–
5245	quartz	17	8×10^5	1500	1×10^{-10}	–	–	–
5246	sapphire	11	–	–	–	5.2	2.0	0.16
5247	quartz		1.6×10^6	1650	2.6×10^{-9}	4.8	2.0	0.06
5248	quartz	17	1.5×10^6	1800	2.2×10^{-9}	–	–	–
5250	quartz	–	1.6×10^5	1650	3×10^{-9}	–	–	–
5252	quartz	11	–	1400	2.2×10^{-10}	9.5	2.6	0.02
5253	quartz	11	5×10^5	1500	1×10^{-10}	3.2	1.6	0.04
5254	quartz	11	3.6×10^5	1250	3.8×10^{-9}	5.3	2.2	0.02
5261	sapphire	11	2×10^5	1700	2×10^{-9}	5.7	2.0	0.02
5266	sapphire	11		1200	8×10^{-10}	7.5	2.2	0.03
5291	quartz	13		1500	5×10^{-10}	–	–	–
5292	quartz	13		1400	5×10^{-10}	–	–	–
5293	quartz	13		1550	5×10^{-10}	–	–	–
5210	quartz	13		1200	2.8×10^{-10}	–	–	–
5613	quartz	13		1000	3×10^{-9}	–	–	–
2508	quartz	13		1000	3×10^{-10}	–	–	–

gain stability tests.

The detector sensitivities at 2537Å were then measured in the following way:

A low pressure mercury pea lamp (type 11SC1) manufactured by Black Light Eastern Co., Long Island, New York, was set up at a distance of 1m from the detector, in a well baffled light tight enclosure. Although CHILDS (1962) has stated that the output from this lamp was essentially monochromatic, there was still a small visible output which was eliminated by placing a narrow band interference filter centred on 2537Å in front of the pea lamp. In addition, a number of neutral density quartz filters was used to attenuate the rather high output intensity of the lamp at 2537Å (42μw $cm^{-2}sec^{-1}$ at 30cm) in order to avoid any fatigue of the detector photocathodes.

A comparison was then made between the output from the prototype detector when viewing the attenuated output from the low pressure mercury lamps, and that obtained from a "standard" detector of known spectral response. From this comparison a "gain quantum efficiency product" was obtained for each photomultiplier at the flight operating voltage.

Measurement of Spectral Response of Photomultiplier

There are three basic methods of measuring the spectral response of a photomultiplier, namely:

(a) Use is made of a monochromator whose throughput is accurately known as a function wavelength.

(b) A lamp of known spectral output, e.g. a tungsten ribbon filament, is calibrated with a set of wavelength isolation filters of suitable bandwidth. In this way the integrated output radiation over a number of passbands is known. Each photomultiplier is then exposed to the undispersed output from the lamp through the various isolation filters and the spectral response obtained.

(c) Use is made of a calibrated detector. The unknown detector is compared with a "secondary standard" which can be a thermocouple, ionisation chamber or calibrated photomultiplier. Using this method the spectral response of the unknown detector is then obtained by direct comparison with the standard detector, when using the same dispersed or undispersed source.

In general, method (a) is to be preferred, but normally requires the use of a second monochromator to measure the throughput of the original monochromator. Method (b) is only useful for coarse spectral response measurements and normally requires the use of a number of different lamps when making measurements over an extended wavelength range. However, for the purpose of the present investigation method (c) is more convenient.

The apparatus used for measuring the spectral response of the detectors consisted of a simple non-evacuable monochromator utilising an EBERT optical system. At the exit slit of the monochromator, an attachment was fitted which enabled the detector to be moved in two axes and allowed repeatable uniformity scans of the detector photocathode to be made.

The radiation source used was a PHILLIPS high pressure mercury lamp which provided under controlled operating conditions a rich source of lines of known relative intensity.

The comparison reference detector was an ASCOP 541F-05M photomultiplier with a sapphire window and a caesium telluride photocathode, having been calibrated by E.M.R. Princeton. The calibration was re-checked at Edinburgh with good agreement.

Use was also made of a monitor photomultiplier consisting of a glass windowed E.M.I. 9526 photomultiplier in front of which was mounted a sodium salicylated screen. This material has a reputedly constant quantum efficiency between 500Å and 3000Å, with the fluorescence occurring in the region of 4400Å. By means of this phosphor it is possible to use the same detector operating characteristics i.e. d.c. current measurement in the multiplication mode, as was used with the flight detectors. In addition, as only one waveband is viewed by the detector, namely 4400Å the cathode uniformity variation with incident wavelength is small.

In practice, sodium salicylate can be utilised either by (a) deposition of the material directly on to the face-plate of a glass windowed photomultiplier or (b) by viewing the reflected or transmitted fluorescence of the phospher when deposited on to a glass slide. Method (b) was adopted since method (a) does not provide as stable or uniform a film. The monitor was used to measure the relative line intensities from the dispersed mercury as a check on lamp output stability, and on the constancy of the reference ASCOP detector spectral calibration.

The following calibration procedure was adopted for each of the experimental detectors. The iris diaphragm at the monochromator exit slit was set to correspond to the size of the photocathode which would in practice be illuminated when the detector was mounted in the photometer, and the salicylated detector placed immediately behind this aperture. The signal from this detector was then taken to a KEITHLEY 410 electrometer, and the output fed to a Varian chart recorder, enabling a permanent record of the signal output from the monitor to be obtained as the spectrum of the high pressure mercury lamp was scanned across the exit slit of the monochromator.

The monitor photomultiplier was then replaced by the experimental detectors in turn and a spectral scan obtained for each. This procedure was interrupted at frequent intervals and a calibration scan obtained with the standard ASCOP photomultiplier.

The relative intensities as measured by the salicylated detector and the standard detector were in good agreement, such small disagreement as existed being attributable to the non-uniformity of the photocathodes. In this way the absolute spectral responses of the experimental photomultipliers were obtained by direct comparison with the standard photomultiplier response.

Determination of Absolute Quantum Efficiency at 2537Å

It has been previously mentioned that the standard ASCOP 541F-05M is supplied by the manufacturer with a set of calibration data. Included in these data is a measurement of the quantum efficiency at 2537Å of the detector when operated as a diode, and an accurate gain versus voltage curve. The figures were checked in the course of another calibration programme CAMPBELL (1968) and are in good agreement with measurements made at E.M.R. and the National Physical Laboratory, Teddington. As a consequence, it was therefore feasible to use the detector as an absolute detector at 2537Å and to cross-calibrate between the detector and the experimental detectors. This was achieved by setting up the low pressure mercury lamp at a convenient distance from the standard photo-multiplier and observing the output from the detector when operated as a photo-diode. The procedure was then repeated for each of the experimental detectors when operated similarly. By progressively increasing the optical attenuation between the pea-lamp and increasing the number of multiplication stages of the photo-multipliers in use, it was then possible to establish the gain operating voltage characteristics for each detector. In this way, from a knowledge of the incident flux level as measured by the standard detector, it became possible to measure the quantum efficiency of each experimental detector, as well as the gain at the operating voltage. As the relative spectral response of each detector had already been measured, it was then possible to obtain the quantum efficiency at any other wavelength in the region 2500Å - 3500Å.

The results of the quantum efficiency measurements at 2537Å are shown in Table 5, and the visible rejection characteristic in Fig. 7. The standard ASCOP 541F-05M detector response is also shown for comparison.

It was felt at this stage that enough was known of the general characteristics of the photomultipliers and that future evaluations should concentrate on examining the spectral response and visible rejection of the caesium telluride photo-cathodes, and what effect, if any, the method of cathode deposition had on the cathode uniformity and the visible sensitivity.

In order to examine the possible effect of the method of cathode deposition on the solar blindness of the photo-multipliers, it was decided to evaluate a number of caesium telluride photo-diodes. However, a number of such measurements had been conducted by MILLER (1965) who examined over thirty photo-diodes possessing caesium telluride cathodes. These photo-diodes manufactured by E.M.I. had an internal structure very similar to these photomultipliers with the first dynode structure being replaced by a rectangular plate. The first of these photo-diodes designated number 5341, although possessing good sensitivity, exhibited a poor electrical characteristic with voltage and subsequent photo-diodes

QUANTUM EFFICIENCY AT 2537Å

Table 5

PM serial number	QE % at 2537 Å	Gain	Voltage dc	Visible rejection (2537/3650)	dc	Voltage
5009	5.2	4.7×10^4	1100	333.3	5×10^{-11}	2 kV
5011	5.2	1.1×10^5	1500	90.5	4.2×10^{-10}	2 kV
5293	12.5	9.4×10^4	1550	219.2	4.0×10^{-10}	2 kV
5240	7.93	2.4×10^6	1400	610.0	1.0×10^{-10}	2 kV
5241	9.04	1.7×10^5	1100	86.9	1.2×10^{-9}	1100 V
5292	7.75	9.0×10^4	1400	430.5	5×10^{-10}	1400 V
5266	3.7	6.7×10^5	1200	142.3	7.0×10^{-10}	1200 V
Standard 4059	8.3	4.5×10^5	2600	638.5	2.4×10^{-12}	2120 V

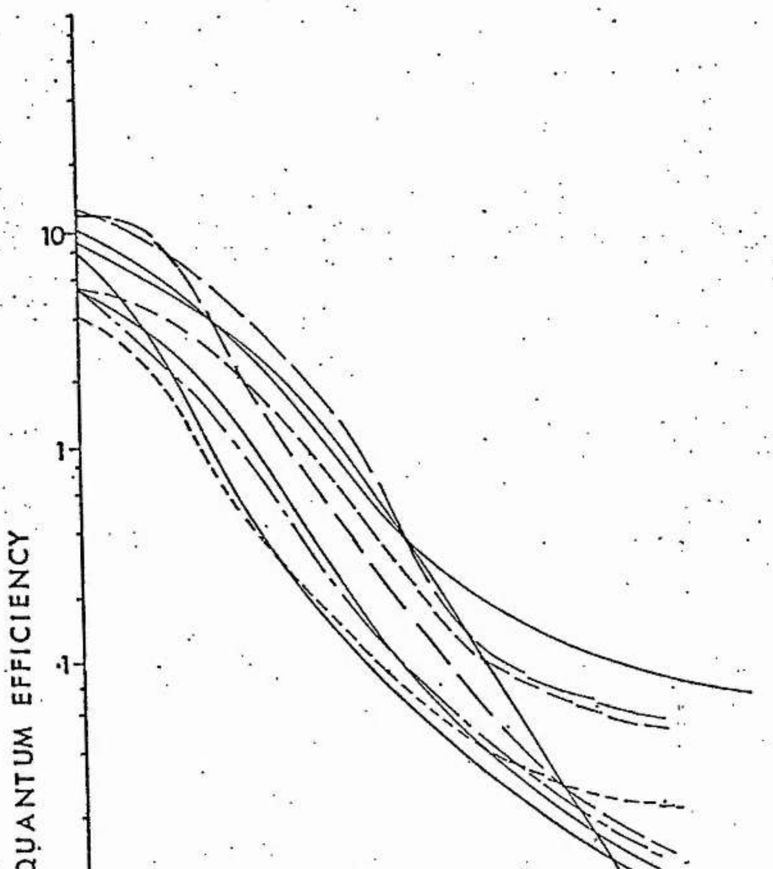


Fig. 7b.

VISIBLE REJECTION OF EMI DETECTORS

also showed this effect. An attempt was made by E.M.I. to improve the electrical characteristics by replacing the evaporation spirals. The improvement in the electrical performance was considerable, but the improvement also introduced an increase in the visible sensitivity. The absolute spectral sensitivity is shown in Fig. 8. for several selected photo-diodes, and MILLER reports that as yet, no photo-diode has surpassed No. 5341 for peak sensitivity.

Also shown in Fig. 9. is the spectral response of photomultiplier No. 5240 which had the best visible rejection of the flight detectors. It is apparent that the photo-diodes have a very much better visible rejection ratio than the photomultipliers. This is attributed to the more accurate deposition of caesium which is possible when manufacturing the photo-diodes.

Cathode Uniformity

In any application involving absolute photoelectric photometry it is most important to ensure that the illuminated cathode area has a uniformity commensurate with the required photometric accuracy. There are a number of methods in use and they range from masking off an area of the photo-cathode, to the use of Fabry lenses and scatter plates. A plot of the uniformity of an antimony-caesium photo-cathode is shown in Fig. 10. for a wavelength of 2537Å, and is typical for such cathodes. There is, however, very little published data available on the uniformity of "solar blind" cathodes and, in particular

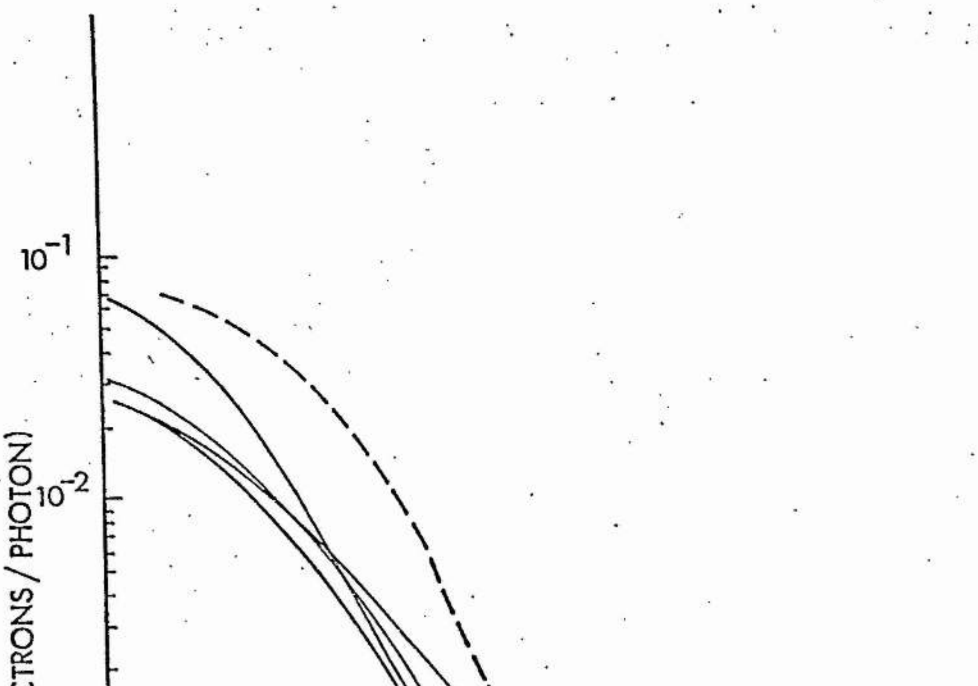
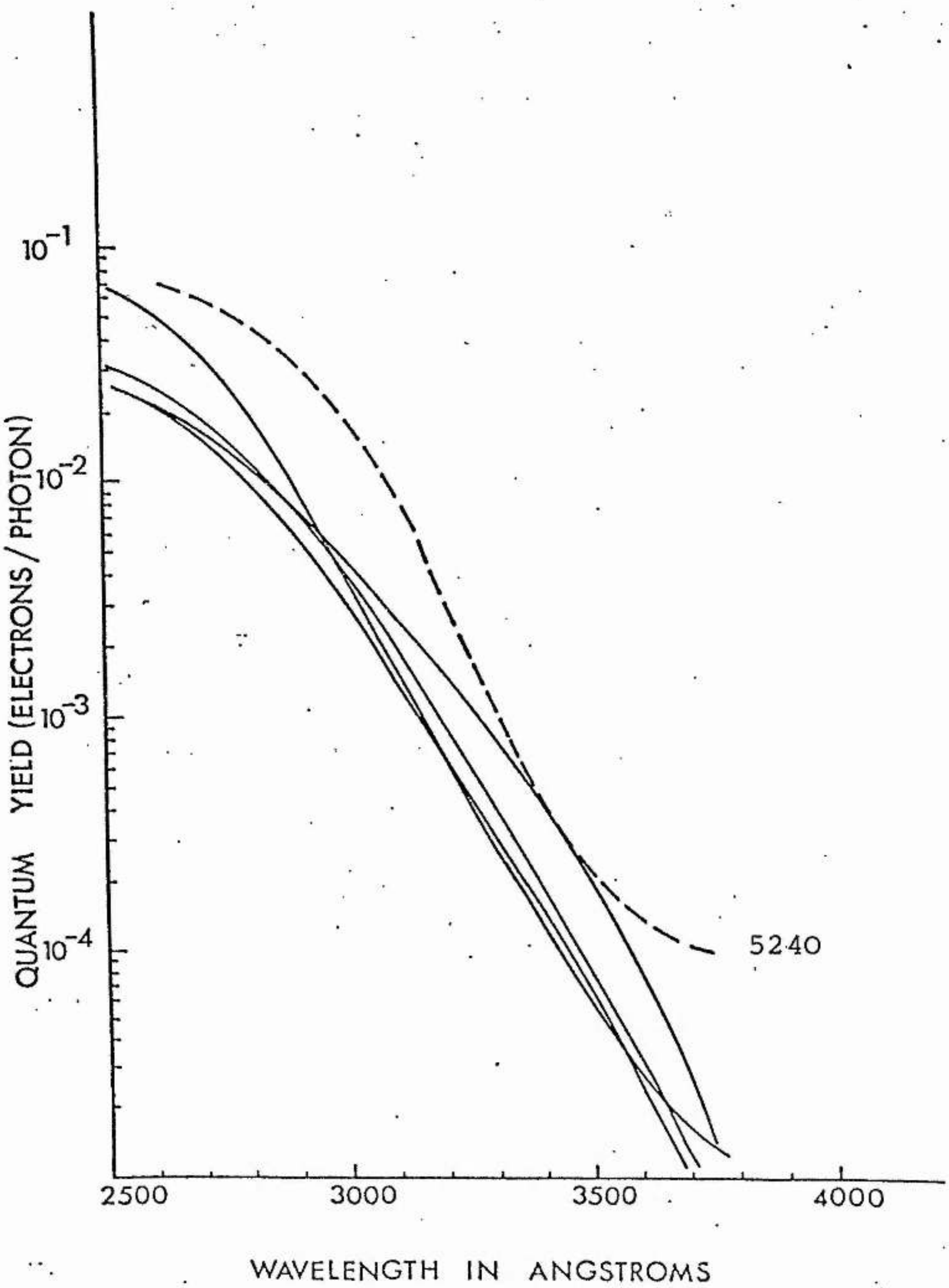


Fig. 8.

ABSOLUTE SENSITIVITY OF PHOTO-DIODES



<u>Fig. 9.</u>

SPECTRAL RESPONSE OF PHOTOMULTIPLIER 5240

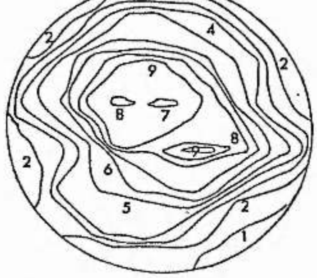


Fig 10 Ascop No. 1410: photocathode, antimony–cesium; source—2537 Å; faceplate diameter, 2.85 mm: 1, 1.2% uniformity; 2, 1.8% uniformity; 3, 25.9% uniformity; 4, 26.5% uniformity; 5, 64.7% uniformity; 6, 82.3% uniformity; 7, 88.2% uniformity; 8, 94.0% uniformity; and 9, 100.0% uniformity.

UNIFORMITY OF ANTIMONY-CAESIUM PHOTO-CATHODE AT 2537Å those made of caesium telluride. Accordingly, as this was a most important parameter in the present application, a number of measurements were made to see if there was any correlation between the cathode uniformity and other photomultiplier parameters. The measurements were made by scanning the faceplates of the experimental detector with a 100 micron pin-hole through which passed the light from a low pressure mercury lamp, situated at a distance of one metre from the detector. Although the output from the lamp was essentially monochromatic at 2537Å, an interference filter centred on 2537Å was placed in front of the lamp in order to eliminate all other radiation. The results of these measurements are shown in Figs. 11 and 12, for several caesium telluride photo-cathodes.

In order to examine the wavelength dependancy of the uniformity pattern, the measurements were repeated at one other wavelength using a sapphire windowed XENON lamp manufactured by E.M.R. Princeton, New Jersey. The lamp output was essentially monochromatic at 1470Å and because of the effects of atmospheric absorption, it was necessary to place the lamp very close to the detector. The results for this wavelength scan are shown in Fig.13. For comparison Fig.14 shows the cathode uniformity pattern at 2537Å for several photo-diodes measured by MILLER(1965) and although the uniformity of number 5341 was excellent, MILLER found that for those photo-diodes with the small anode plate, the uniformity pattern at 2537Å was angular in shape, i.e. with a ring of high sensitivity and a

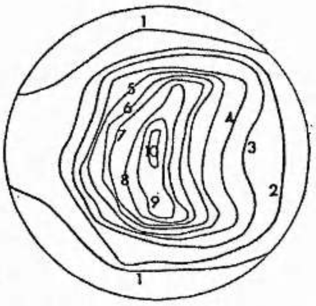


Fig. 11 . EMI CsTe SN 5301; window—sapphire; source—2537 Å; faceplate diameter 2.85 mm: 1, 5.0% uniformity; 2, 8.0% uniformity; 3, 6.5% uniformity; 4, 18.0% uniformity; 5, 40.0% uniformity; 5, 53.0% uniformity; 7, 63.0% uniformity; 8, 76.0% uniformity; 9, 86.8% uniformity; and 10, 100% uniformity.

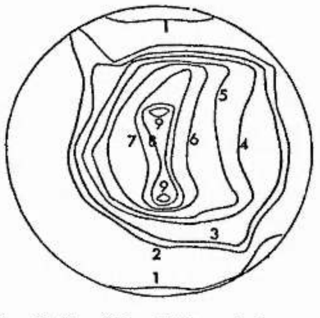


Fig 11 E.M.I. CsTe SN 5300; window-quartz; source—2537Å; faceplate diameter 2.85 mm: 1, 0.3% uniformity; 2, 1.0% uniformity 3, 2.0% uniformity; 4, 8.0% uniformity; 5, 35.0% uniformity; 6, 69.0% uniformity; 7, 86.0% uniformity; 8, 93.0% unformity; and 9, 100% uniformity.

UNIFORMITY OF CAESIUM TELLURIDE PHOTO-CATHODE at 2537Å

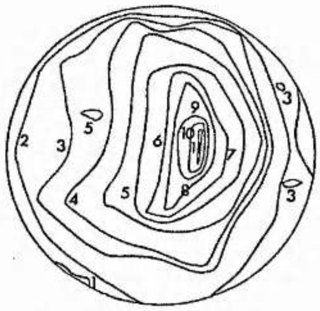


Fig. 12 E.M.I. CsTe SN 5243; window—quartz; source—2537 Å; faceplate diameter 2.85 mm: 1, 0.7% uniformity; 2, 1.0% uniformity; 3, 5.0% uniformity; 4, 22.0% uniformity; 5, 46.0% uniformity; 6, 71.0% uniformity; 7, 87.0% uniformity; and 8, 100% uniformity.

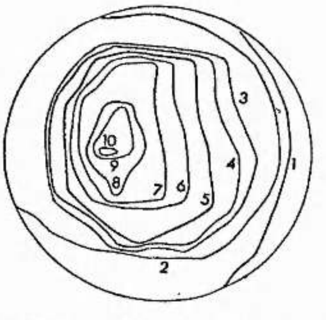


Fig. 12 E.M.I. CsTe 5293; window-quartz; source—2537 Å; faceplate diameter 2.85 mm: 1, 0.1% uniformity; 2, 2.0% uniformity; 3, 1.5% uniformity; 4, 1.0% uniformity; 5, 11.0% uniformity; 6, 31.0% uniformity; 7, 53.0% uniformity; 8, 100% uniformity; 9, 79.0% uniformity; and 10, 89.0% uniformity.

UNIFORMITY OF CAESIUM TELLURIDE PHOTO-CATHODE AT 2537Å

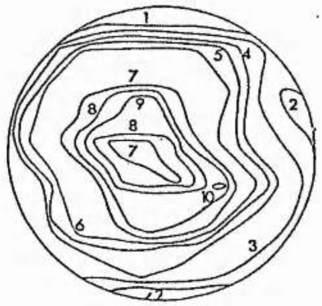
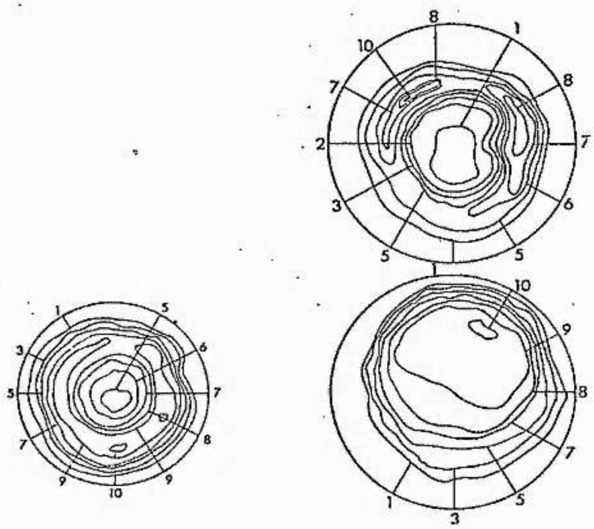


Fig. 13. ASCOP 10430 CsTe; window—sapphire; source—1470 Å; faceplate 2.85 mm: 1, 0.8% uniformity; 2, 4.2% uniformity; 3, 13.8% uniformity; 4, 44.4% uniformity; 5, 87.5% uniformity; 6, 94.4% uniformity; 7, 97.2% uniformity; and 8, 100% uniformity.

UNIFORMITY OF CAESIUM TELLURIDE DETECTOR AT 1470Å.



UNIFORMITY OF CAESIUM TELLURIDE PHOTO-DIODE AT 2537Å

Fig. 14.

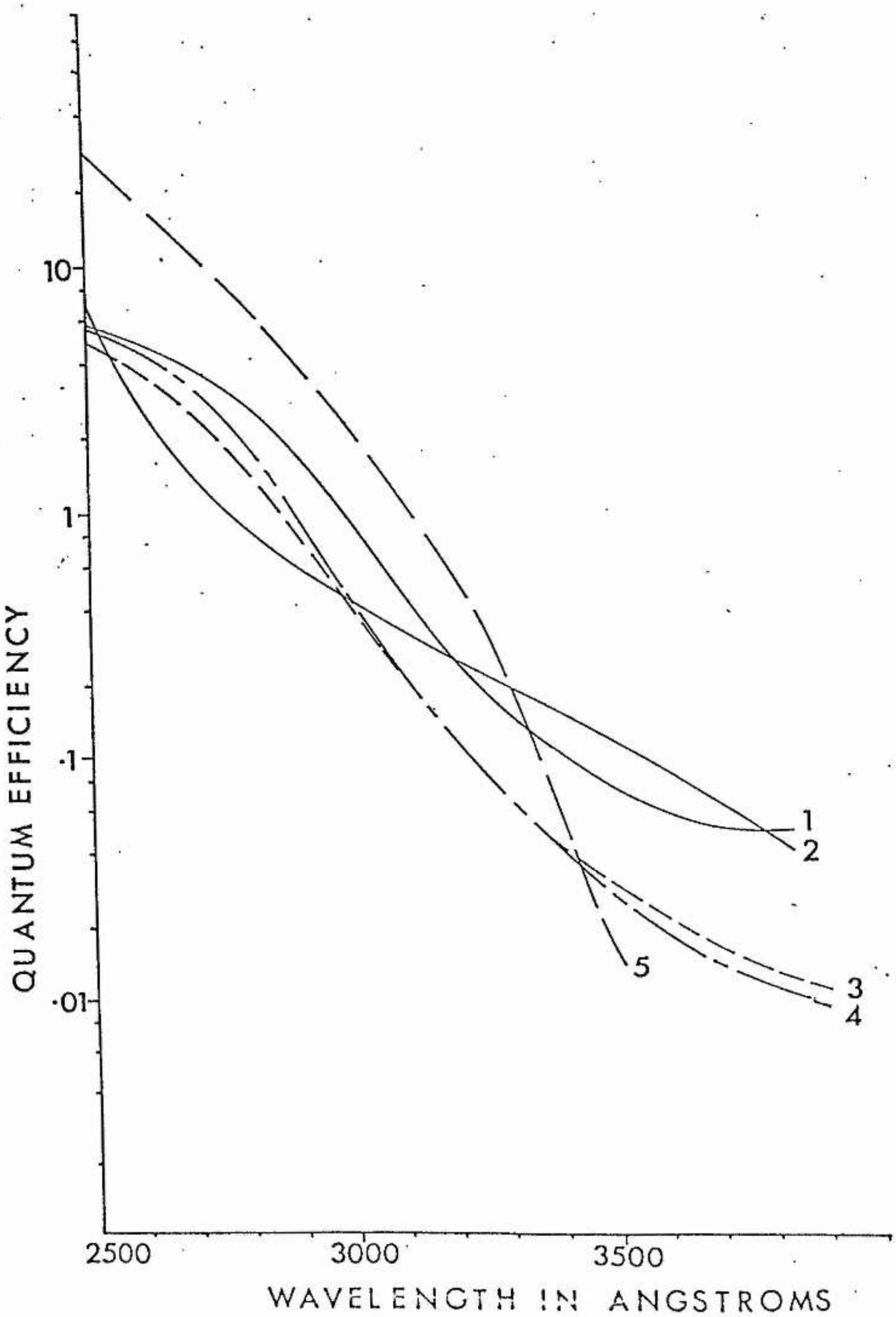
central region of low sensitivity. The photo-diodes with the enlarged collector plates had a peak uniformity which coincided with the location of the evaporation spirals. This effect was eliminated on later detectors by increasing the distance between the evaporation spirals and the cathode.

Discussion

It is of interest to compare the present results with those obtained independently by CHARMAN (1969) for similar caesium telluride photo-cathodes. CHARMAN'S results are concerned with the evaluation of seven caesium-telluride quartz-windowed photomultipliers manufactured by E.M.I., two detectors from the seven having been previously evaluated by the author. The two detectors in question were numbers 5009 and 5011. A comparison between the two evaluations shown in Fig. 15a shows a number of discrepancies. In particular, CHARMAN'S measurements of detector number 5011 exhibit greater visible sensitivity than the author's although a period of at least six months must have elapsed between the two measurements. It is unlikely that this could account for any increase in quantum efficiency, the reverse being normally the case. The value of the quantum yield at 2537Å is almost a factor of three greater than the best detector available for this type and in view of the normality of over twenty other production detectors of this type, it is difficult to account for the measurement although there is evidence of excess of caesium which could possibly have produced

Fig. 15a

COMPARISONS OF OBSERVATIONS OF CHARMAN AND CAMPBELL



2. CHARMAN
EMI 5009
4. CAMPBELL

1. CAMPBELL
EMI 5011
5. CHARMAN

a quantum yield similar to the high values of antimony caesium photo-cathodes.

The measurements at 2537Å for tube 5009, although in approximate agreement, do not agree for the visible rejection ratio, which indicates a much higher visible sensitivity than had previously been measured. In the case of the photo-diodes, the visible rejection was very much better than for the photomultipliers and there was a difference in spectral response between the photo-diodes with the modified anode collector plate and those without. The rejection appears to be better for the original assembly, but both types of photo-diode produce rejection ratios better than the best development photomultipliers.

The results of the environmental test programme indicate that the 25mm diameter photomultipliers employing the present box and grid structure and with internal dynode resistors are suitable for rocket-borne experiments, when subjected to the Skylark flight acceptance vibration levels.

The quantum efficiency at 2537Å was exceedingly variable and there would appear to be no possibility of obtaining repeatable characteristics from one photomultiplier to the next. Similar quantum yields were obtained from the photo-diodes.

From the measurements of cathode uniformity of the quartz and sapphire windowed photomultipliers, it is apparent that serious discrepancies could arise in measuring the quantum efficiency at 2537Å and other wavelengths, if large areas of the photo-cathode are utilised and again there is no repeatability of the uniformity from one detector to the next. It is also very significant that considerable variations in uniformity occur with wavelength and again this could introduce an additional source of error in both spectral response measurements and absolute quantum yield determination. This could account for the discrepancies between the CHARMAN data and the results reported here. The situation is very much worse for 25mm caesium-telluride cathodes than for 25mm antimony caesium detectors, although the 50mm caesium telluride photo-cathodes were much more uniform.

There is, however, a marked difference between the uniformity obtained with the photo-diodes (see Fig. 14.) and the photomultipliers Figs. 11, 12, the uniformity being very much better with the multiplier. Fig.15b. shows the uniformity of a photo-diode before and after processing, the reprocessing being carried out in order to reduce the visible sensitivity. Although additional tellurium was deposited, there was very little change in the overall uniformity pattern. In the case of the caesium telluride cathodes, all the photomultipliers exhibited the characteristic hysteresis effect which was present after the detector had been submitted to a high incident light level, the effect being more pronounced for detectors with a high visible sensitivity. The degree of visible rejection varied in an irregular manner, and in only two instances could

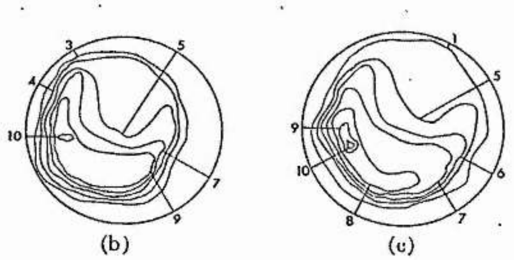


Fig. 15(b)

UNIFORMITY OF PHOTO-DIODES BEFORE AND AFTER RE-PROCESSING it be said to be truly representative of a caesium telluride photocathode.

SIGNAL DETECTION

There are three basic techniques for handling the output from photomultipliers: (a) Photon-counting; (b) A.C. modulation: (c) Current measurement;

(a) PHOTON COUNTING

In the case of photon-counting, it is possible to detect each photo-electric event and the system lends itself to high statistical accuracy and a wide dynamic range. However, such versatility is not achieved without a high degree of circuit complexity and if the total dynamic range is to be exploited, wide bandwidth amplifiers and pre-amplifiers are necessary. The accumulated photon count has to be displayed in a digital manner and recorded in the same digital format, although ratemeters are available which permit an analogue presentation to be obtained. However, although such a method is undoubtedly complex, it has been widely used for ground based instrumentation with a high degree of success where physical size and environment are of small consequence. But for space investigations, where size, power and data bandwidth are at a premium, alternative methods of detection are necessary, particularly when a large number of photometric channels are to be telemetered over comparatively small bandwidths.

(b) A. C. MODULATION

An alternative method which provides the same dynamic range and accuracy is the use of "chopping techniques" to modulate the incoming radiation at a known frequency. The signal is then amplified in a narrow bandwidth high gain amplifier and the modulated signal then rectified in a phase sensitive detector, using the frequency and phase of the modulation as the reference signal. In this way, all d.c. drifts and instabilities which occur after the modulators are eliminated and it is possible to detect signals well below the system noise level. Again, there are severe difficulties in applying the technique to space borne equipment, not the least being the difficulty of constructing mechanical modulators which can survive the rocket launch without incurring some damage. Electronic modulation would be possible, but the very small bandwidths available, would permit data acquisition from only the brightest of stars, since the observation period would be of the order of 50 milli-seconds.

(c) D.C. CURRENT MEASUREMENT

The dark current from the caesium telluride photomultipliers previously discussed, was of the order of 10^{-11}A, when operating at a gain of 10^{6} and of the order of 10^{-13}A, for rubidium telluride photomultipliers for the same gain and since the expected signal level from a fifth magnitude early type star was of the order of 5×10^{-9}A, it would appear that a much lower limiting magnitude would be possible. However, since the field of view of the photometer was 1° and the anticipated controlled rate of the rocket 20°/sec then the actual time during which the star was within the field of view of the instrument was 40 milliseconds and as the signal output current from the photomultiplier approaches the detector dark current, the stray capacitance and the associated time constant becomes the limiting factor. The simplest method of measuring the output from a photomultiplier is with an electrometer valve. A typical device of this type has an input or grid current typically less than 2×10^{-14} amperes, with an input resistance greater than 10^{-14} ohms and a voltage stability better than $50_{m}V$ per week. The input current noise is less than 2×10^{-15} amperes peak to peak. If such a valve is arranged as a voltmeter and the voltage drop across the input resistance measured, then it is possible to obtain a value for the input current. If no appreciable error is to be encountered, then the signal level must be greater than the 50mV stability figure and if we consider a practical case where the signal level is of the order of $5 \times 10^{-12}A$, then to produce a voltage of 5 Volts at the output, would require a 10^{12}ohm resistance, which is quite practicable. But such resistances are not without capacitance and it would be possible to have a total stray capacitance from all sources of the order of 10pf, producing a time constant of 10 seconds. This would be excessively slow in comparison with the observation time of 40 milli-seconds.

In addition, the voltage drop of 5 Volts would be a severe limitation. However, by the proper use of negative feedback, it is possible to drastically reduce the response time. The basic circuit is shown in Fig. 16. If Cin represents the input current stray capacitance; i_{in} the input circuit; e_o the output voltage; C_2 the stray capacitance across resistor R_1 the current measuring resistor. When i_{in} flows through R_1 then using amplifier A of gain K, we have:

$$e\ in = eo_{/K} \qquad (1)$$

and since all of i_{in} flows through R_1

$$\text{then } i_{in} = -\frac{eo}{R_1} + \frac{eo}{R_1 K} \qquad (2)$$

if K is large, then i_{in} is simply e_o/R_1 and the effective input resistance is simply:

$$e_{in}/i_{in}$$

therefore from (1) and (2) $R_{in} = \dfrac{R_1}{K + 1}$

thus by using negative feedback, it is possible to reduce the input voltage drift by a factor equal to the gain of the amplifier and since K can be large, the current sensitivity will be the same as when the current was measured using a voltage drop resistor and consequently, the zero drift of the amplifier will be the same. Additionally, since the effective input resistance has been reduced the response time will also be considerably reduced.

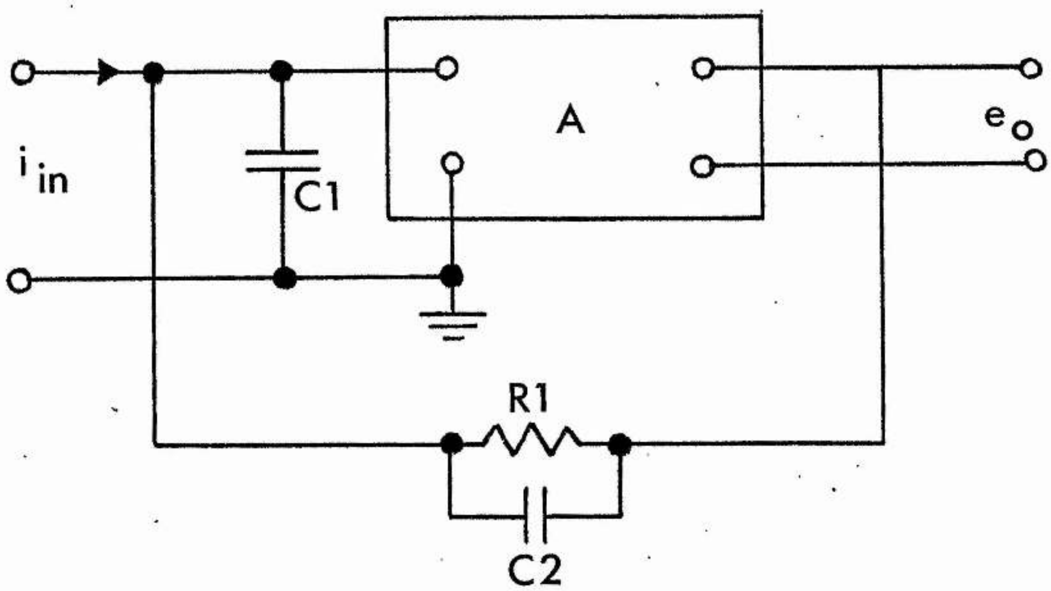


Fig. 16.

BASIC ELECTROMETER CIRCUIT

In view of the simplicity of the technique, it was decided to concentrate on this method of signal detection even although very few amplifiers of this type had been flown in a rocket.

The immediate disadvantage of a d.c. electrometer when used in a rocket is that it has only one linear range and although in the laboratory other range resistors can be switched in, this would obviously not be possible in a space application and a number of ways of extending the dynamic range were investigated.

One approach was to have several amplifiers simultaneously measuring a portion of the signal. The amplifier with the on scale producing the only valid reading at any given time. This approach however, required a considerable duplication of circuitry and power. An extension of this approach was to have several amplifiers operating simultaneously and to sample each one in a routine fashion. This method saves telemetering channels but increases the circuit complexity and lessens the reliability and bandwidth.

A further variation was to use one measurement amplifier with secondary amplifiers which multiplied the output by succeedingly large factors. A proportional output from each stage of amplification was then either sampled or fed to different telemetry channels. At least one of the stages would be on scale in the appropriate direction. The main disadvantage of this approach was the number of telemetry channels required.

The remaining approach was that of automatic ranging, where an automatic switching device was employed electronically to switch the measuring amplifier to one of several operating ranges. Each operating range was a small portion of the overall magnitude range, the accuracy required determining the actual number of operating ranges. Only two telemetry channels were required, one to indicate which range was in operation and the other to indicate the actual reading within the range.

ELECTROMETER CIRCUIT DESIGN

The amplifier circuit is shown in Fig. 17. The input stage was a CK 5886 sub-miniature electrometer tetrode valve connected as a triode. The anode load of the electrometer valve was the base of Q_1, one of a pair of 2N 1307 silicon PNP transistors having a common emitter load R_5. These two transistors had the bases of Q_3, as their collector loads. Q_3 and Q_4 were 2N 336 silicon NPN transistors. The collector of Q_3 was direct coupled to the base of Q_5, another 2N 336 operated as an emitter follower. The transistors Q_1, Q_2, Q_3, and Q_4 comprised a direct coupled differential amplifier which compensated for thermal drifts and voltage supply variations. The use of an electrometer valve of very low grid current (less than 10^{14}A) followed by a PNP stage, which was in turn followed by a complimentary

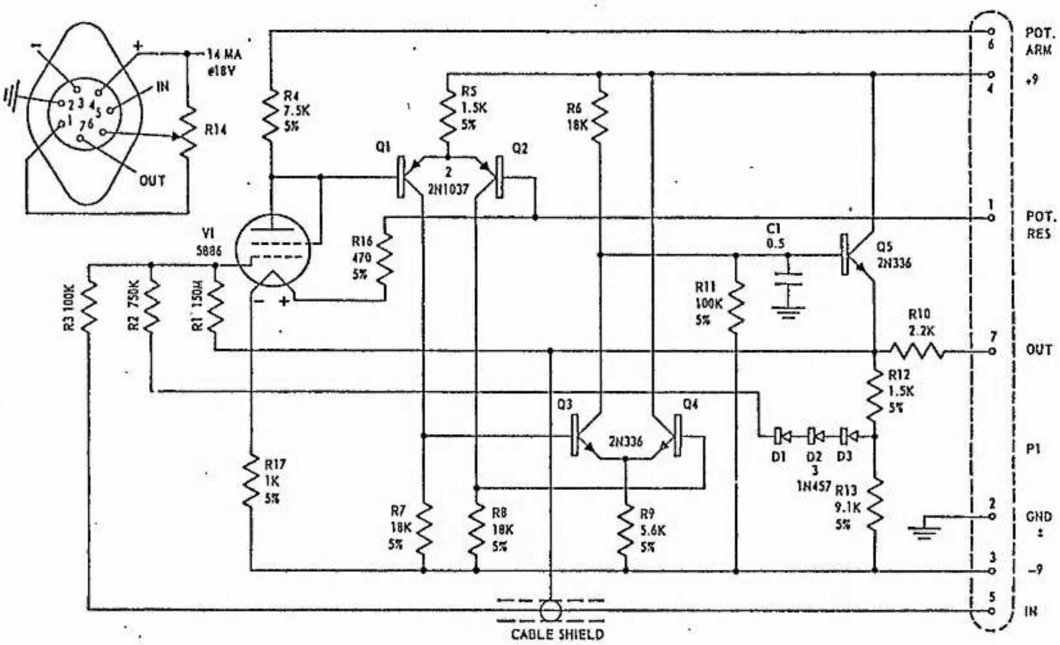


Fig. 17

EXPERIMENTAL ELECTROMETER CIRCUIT

NPN stage, allowed direct coupling and an output of zero volts when the input was at zero volts without the use of a voltage divider network. The use of an emitter follower permitted the use of a large collector load on Q_3 and hence a large voltage gain from this stage, the gain being independent of the output load. The output voltage was limited to 5 Volts by the network R_6, R_{11}, to protect the telemetry circuit. R_{10} protected Q_5 in the event of a momentary short circuit of the output and C_1 and R_{10} formed a filter network which prevented feedback of high frequency signals into the amplifier and limited the frequency response of the amplifier. Similarly, R_3 prevented high frequency signals reaching the grid of V_1. The voltage gain of the amplifier as a whole was about 3500 and the bandwidth was limited to about 10kc by capacitor C_1. Further bandwidth limitation was accomplished by attaching the shield of a short length of shielded input cable to the output terminal.

Since the voltage gain of the amplifier was high and the grid current very small (less than 10^{-14}A), the output voltage adjusted itself so that the current through the feedback resistor R_1, was equal to the photomultiplier current I_{pm} when the voltage at the input grid was very nearly zero. The output voltage was then $V_o = I_{pm}R$. When R_1 = 150M, $I_{pm/Vo} = 6.7 \times 10^{-9}$ amperes per volt output. To increase the dynamic range of the amplifier the 750K resistor R_2 was automatically cut into the circuit when the output voltage reached 2.5 Volt by means of the biased silicon diodes D_1, D_2, and D_3. The effect of this network was to reduce the sensitivity by a factor of about 200 when the photomultiplier output current exceeded 1.7×10^{-8} amperes.

In order to adjust for dark current a zero set control was provided for each amplifier. Most of the anode current of the CK 5886 flowed through the load resistor R_4. This resistor was fed from the top of the potentiometer R_{14}, which was placed across part of the voltage divider that supplied the filament power for the electrometer valve. Since the amplifier drift was less than 10mV/hour referred to the output, zero adjustment could be made several hours before the launch.

SOLID STATE ELECTROMETERS

Although considerable success had been achieved with the hybrid type of electrometer amplifiers on several flights, their assembly and test required a considerable amount of time and a search was made for a commercial equivalent, and since the input impedance and current offset were very important, only those amplifiers with the characteristics of electrometer valves were acceptable. With the advent of the field effect transistor (FET), it became possible to construct solid state amplifiers with characteristics very similar to that exhibited by the CK 5886 electrometer amplifiers. An extensive evaluation was made of all the available manufacturers data and tests were made on several different models which appeared to have the desired characteristics. The technical specifications are shown in Table 6.

K AND M ELECTRONICS CORPORATION

Although a very small American Company, their amplifiers were highly specialised and aimed at the low current measurement market. The amplifiers were designed to feature high stability and gain under severe environmental conditions. All silicon transistors and diodes were used in the amplifier construction and selected FET's were used in the input stages. The amplifiers were vacuum encapsulated providing a highly stable temperature environment and also a high immunity to vibration and shock.

The amplifier selected for evaluation was the type KM 41, an amplifier with an input impedance of the order of $10^{13}\,\Omega$ and with a current offset of less than 10pA

PHILBRICK/NEXUS RESEARCH

A well known Company, producing a wide variety of instrumentation amplifiers for a multitude of applications, however very few of their amplifiers seemed to combine the necessary technical performance, with a corresponding immunity to shock and vibration. For this reason, only two types were evaluated, one the well known chopper stabilized type SP 456 and the other an FET amplifier type 1009.

KEITHLEY INSTRUMENTS

As mentioned previously, this Company had provided most of the hybrid electrometer amplifiers used in the earlier investigations of American Space Programme, and as a consequence, were well placed to provide low current

COMMERCIAL LOW CURRENT AMPLIFIERS

TABLE 6

MANUFACTURER	K & M ELECTRONICS KM 41	PHILBRICK 1009	NEXUS SP 46	KEITHLEY 300	INSTRUMENTS 302	UNION CARBIDE H7 OOOA	ANALOG DEVICES 147 C
D.C. OPEN LOOP GAIN (10K load minimium	80,000	50,000	10^8	20,000	12,000	80,000	10^6
OPEN LOOP RESPONSE, small signal, unity gain, bandwidth, full power output.	>1MHZ	1.5MHZ	100MHZ	150KHZ	150KHZ	4.5MHZ	10MHZ
INPUT VOLTAGE RANGE Both inputs	±10W	±10V	0.IV	±11V	±11V	±10V	±9V
INPUT IMPEDANCE Differential	100GΩ	$10^{12}\Omega$	1MΩ	$10^{14}\Omega$	$10^{12}\Omega$	$10^{12}\Omega$	$10^{11}\Omega$
Common Mode	1TΩ	$10^{12}\Omega$	1MΩ				
INPUT VOLTAGE OFFSET (-25° - 85°C)	3mV	<1mV	±50 v	10mV	3mV	2.5mV	0.5mV
INPUT OFFSET $+10^\circ$c - + 60°c	1nA	0.1nA	0.1nA	3×10^{-14}A	2×10^{-14}A	0.05nA	50pA
WIDEBAND INPUT NOISE (F.M.S.) Voltage	5μV	2μV	1μV	5mV	100μV	2μV	12μV
OUTPUT Voltage	±11V	±11.5	±10V	±11V	±10V	±10V	±10V
Load	5KΩ	2KΩ	10KΩ	2KΩ	2KΩ	2KΩ	2KΩ
VOLTAGE requirement	±15V	±15V	±15V	±15V	±15V	±15V	±15V
CURRENT REQUIREMENT Quiescent	+5mA	+12mA	+5	+5mA	+5MA	+4.2mA	+22nA
Full Load	±6.8mA	±17mA	±27nA	±10nA	±10nA	±6.2mA	±32nA

measurement amplifiers with the required stability and shock immunity.

The amplifiers employed similar techniques to those used in the author's previous investigations, i.e. a combination of a balanced pair of electrometer valves (type CK 5886) with a highly stable d.c. amplifier and consequently, were much larger than the amplifiers with an all solid state construction. Nevertheless, their specification was excellent and a number of type 300 amplifiers were purchased for evaluation although the amplifiers were completely unruggedized. During the course of the evaluation, the model 302 was introduced which was an all solid state version of the type 300 but using a MOSFET input stage which provided an even better input impedance than the ordinary FET input stage. This new amplifier was completely encapsulated and was similar in size to the other solid state amplifiers.

UNION CARBIDE CORPORATION

Although not a specialist Company in the same sense as Keithley Instruments, the Company did manufacture one range of amplifiers with the necessary amplifier specification and as the amplifiers could be obtained directly in the United Kingdom, their type H 7000A was included in the investigation. This amplifier was the military version of a high input impedance FET amplifier fully encapsulated.

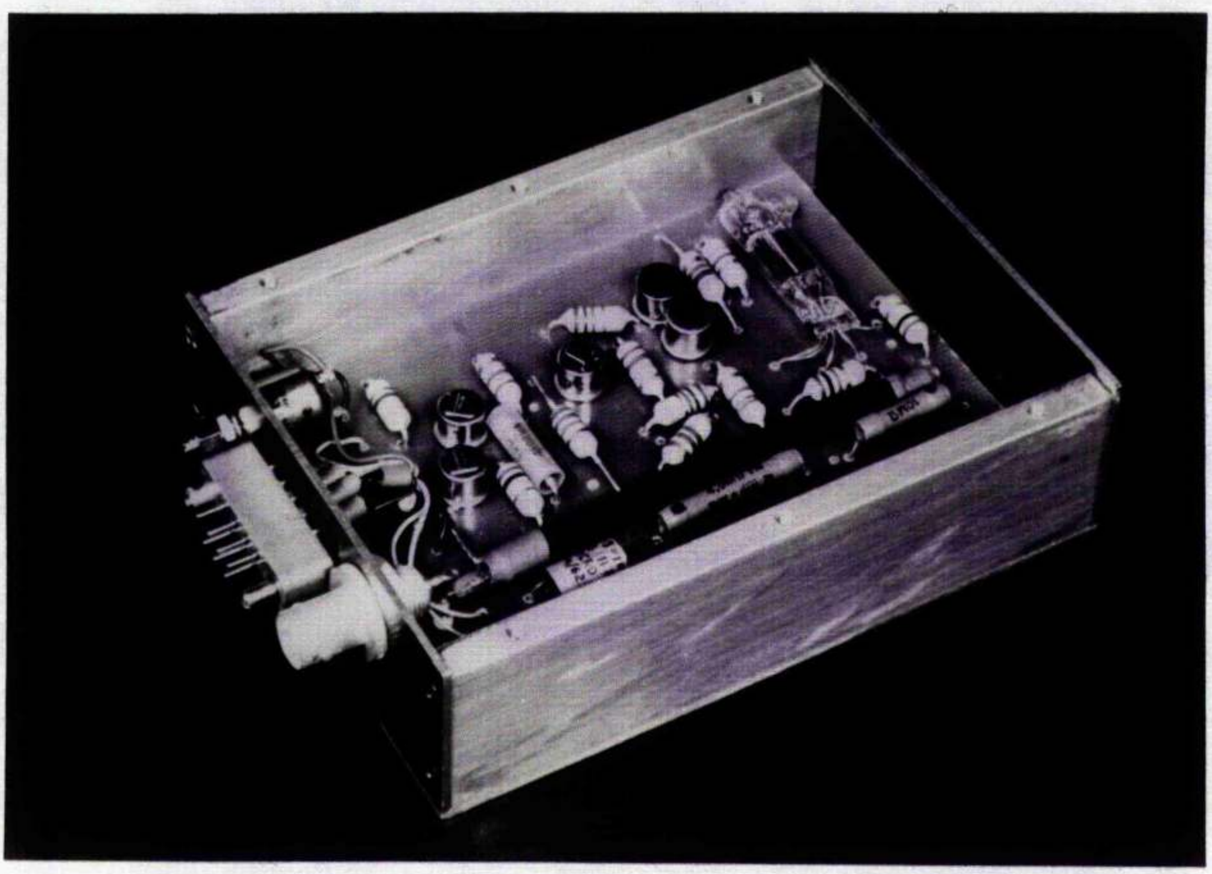
ANALOG DEVICES LTD

Again, a Company with a wide range of instrumentation amplifiers with one amplifier series, the type 147, which seemed to excel even beyond the specification of the other manufacturers already discussed. Selection for voltage drift and input bias current was available and the model 147C was selected for evaluation, having a voltage drift of only 2μV and an input bias current of 15pA maximum which for an FET input was excellent.

FLIGHT ELECTROMETERS

Since as stated in an earlier section, it was not feasible to employ any form of range switching or photon-counting techniques in the data handling system (due to the large number of telemetry channels required) it was decided to design an electrometer system with two ranges. In practice this was achieved by telemetering the output from the solid state electrometer to one telemetry channel and the output from a second amplifier having a gain of ten to a second telemetry channel. In this way it was possible to obtain a dynamic current range of a hundred.

A number of electrometers employing two range outputs were constructed and are shown in Plate 6. the circuit diagram for the flight amplifiers is shown in Fig. 18. These amplifiers employ low bias current solid state FET amplifiers instead of the original electrometer valve discrete component amplifiers permitting routine manufacture. Additional diodes were incorporated in the electrometer circuit to prevent any



FLIGHT ELECTROMETER

Plate 6

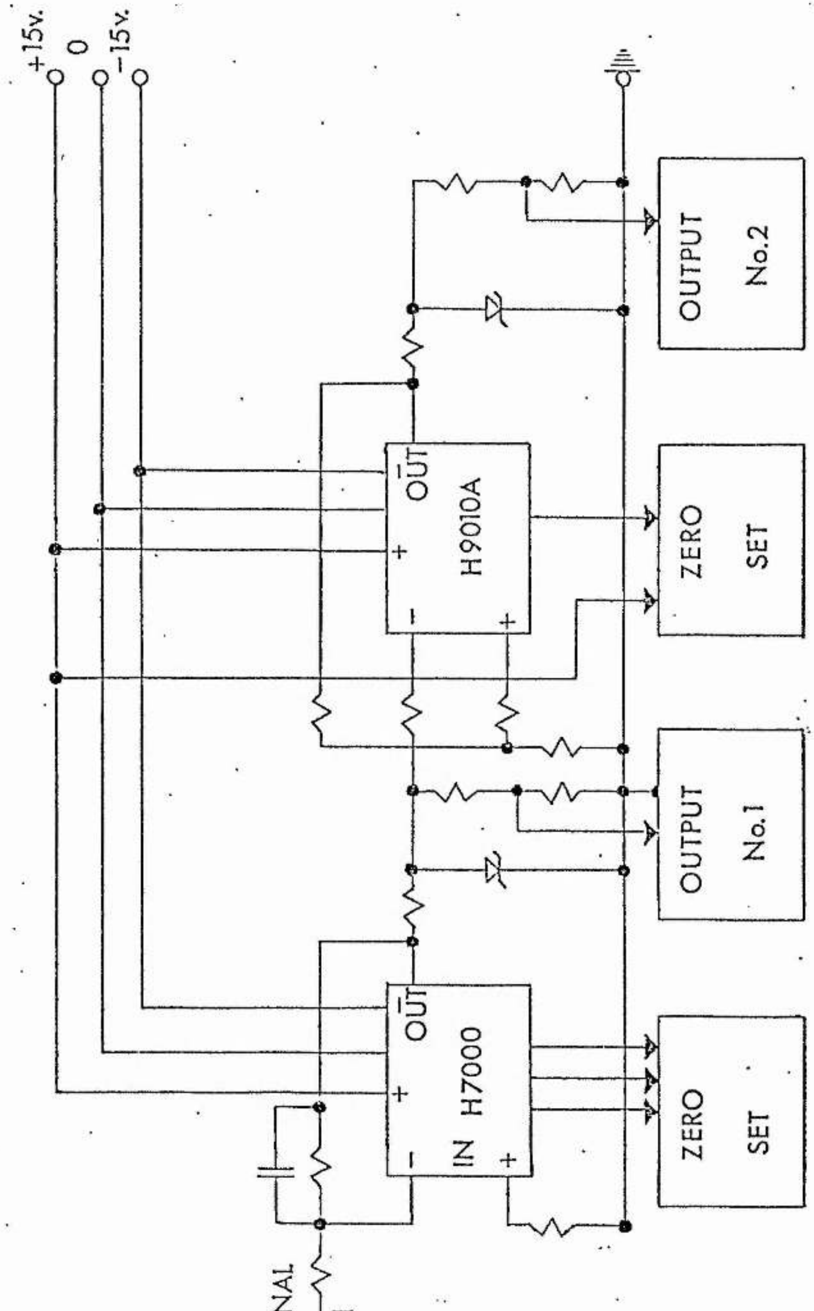


Fig. 18.

CIRCUIT DIAGRAM OF FLIGHT AMPLIFIER

voltage in excess of +10v.d.c. being fed into the telemetry sender, which apart from destroying the voltage to frequency convertor of the telemetry system, would have caused interference to be introduced into adjacent telemetry channels. This protection was conveniently provided by means of the zener diodes D1 and D2.

The dynamic range of the rocket electrometer amplifier is shown in Fig.19. and was typical of over thirty amplifiers of this type used in the rocket programme. The unit was calibrated periodically during the flight by switching to the input of the amplifier a small d.c. current generated from a mallory cell feeding a resistor of the order of 100M.Ω. In this way the correct operation and calibration of each rocket electrometer amplifier was monitored throughout the flight... The amplifier circuit boards were mounted in die cast magnesium alloy boxes which were filled with Sylgard encapsulant to minimise the vibration encountered during the rocket launch.

PROTOTYPE ROCKET POWER UNIT

When using ground based photo-electric photometers, there is seldom any problem in constructing a suitable electronic system since in general most of the items including the high voltage power supplies are off the shelf items. However, in the space environment it is not quite so easy, and the provision of suitable electronic units is solely dependent on the ingenuity of the experimenter. In the case of the Skylark rocket the main

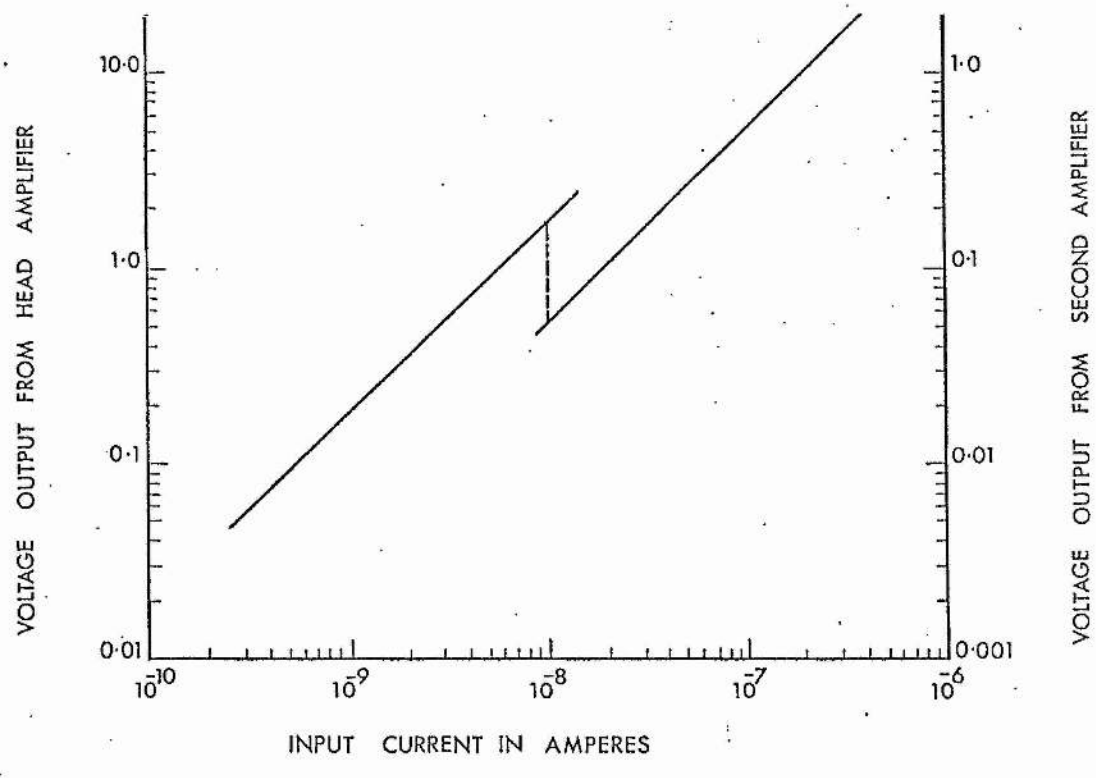


Fig. 19

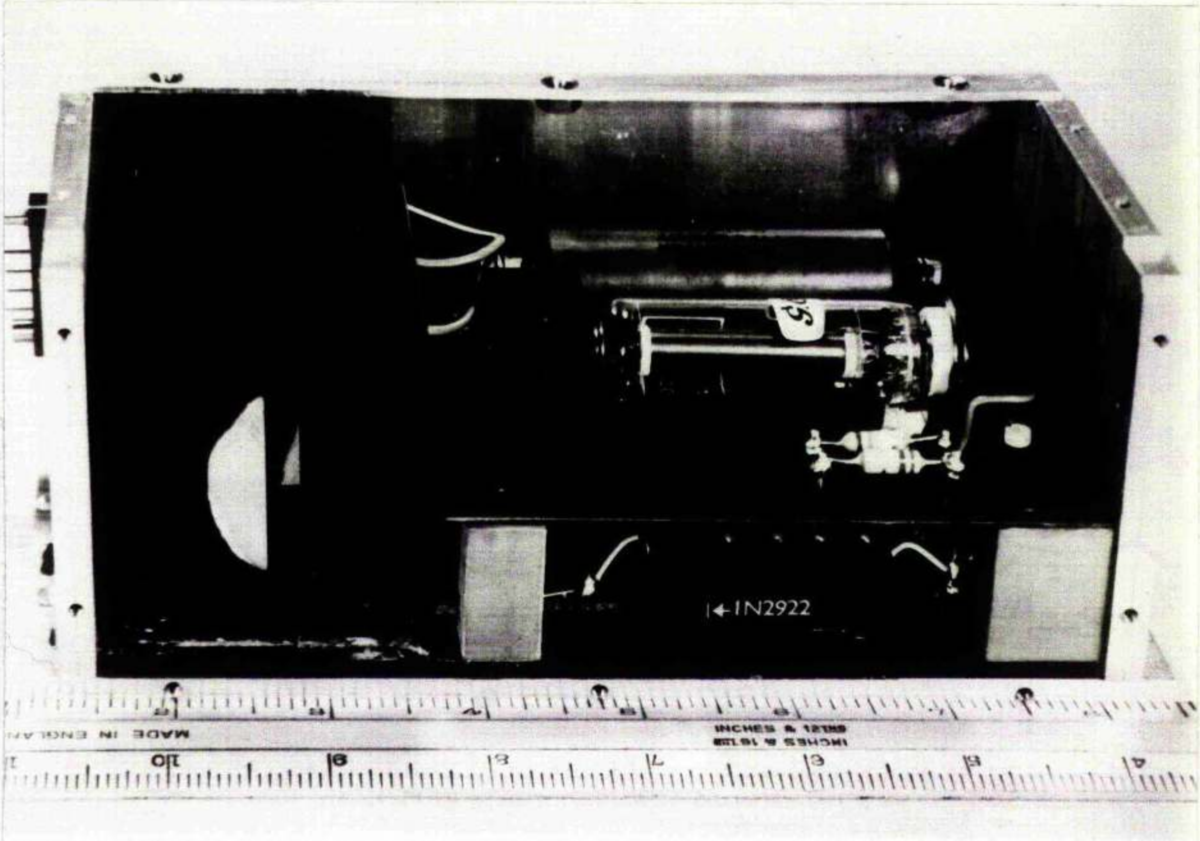
DYNAMIC RANGE OF FLIGHT AMPLIFIERS

problem is that since all the voltages must be derived from a stabilised 24d.c. battery system it is necessary to employ invertors to transform to any other voltage.

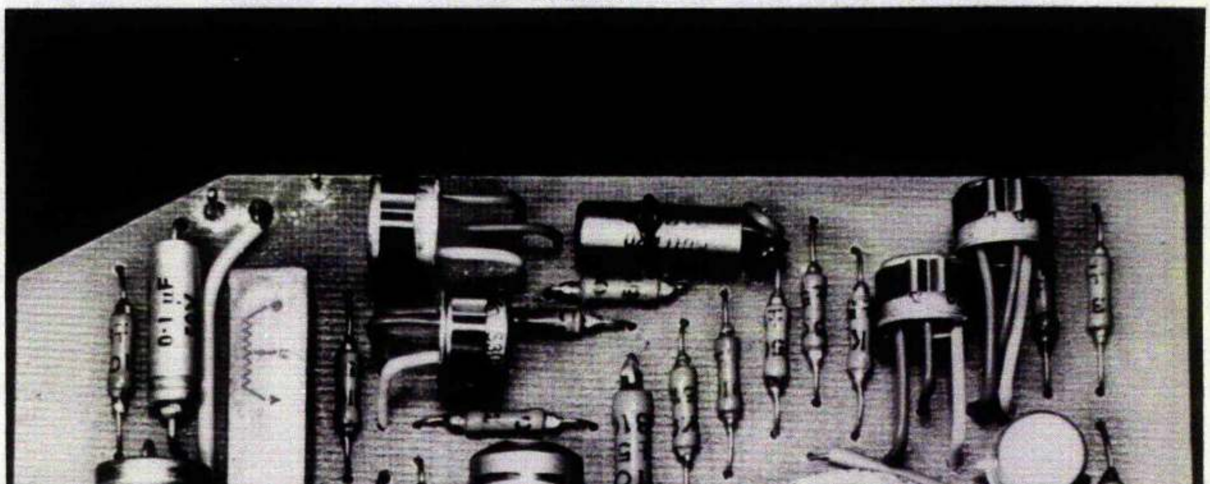
Fortunately over the years the Royal Aircraft Establishment at Farnborough, England, had developed a number of rocket convertors with such requirements in mind. It was therefore a comparatively simple matter for the author to design a high voltage power unit using such a convertor. The basis for the unit was a military convertor designated GW 10. The purpose of this unit was to regulate the high rocket battery voltage from an initial 38V d.c. to a stable 24V d.c. supply. A new transformer was wound which provided the normal 24V square wave and two additional isolated 18V windings. The 24V square wave was routed through a relay contact to an encapsulated step-up transformer with a number of secondary windings. After rectification with a high voltage bridge network the resultant d.c. was fed to a corona high voltage stabilizer valve made by the Victoreen Company of America. In this way it was possible to obtain a highly regulated, but fixed EHT voltage at a maximum current of 500μA. The purpose of routing the 24V square wave through the relay contact was to permit switching the EHT voltage to the photomultiplier when the rocket was above the Earth's atmosphere. The completed unit is shown in Plate 7,

LOW VOLTAGE STABILIZER SECTION

Since the solid state electrometer amplifier required highly regulated supplies at ±9V d.c. two simple voltage regulators were designed by the author and are shown in



PROTOTYPE EHT UNIT
PLATE 7



L.T. POWER REGULATOR CARD

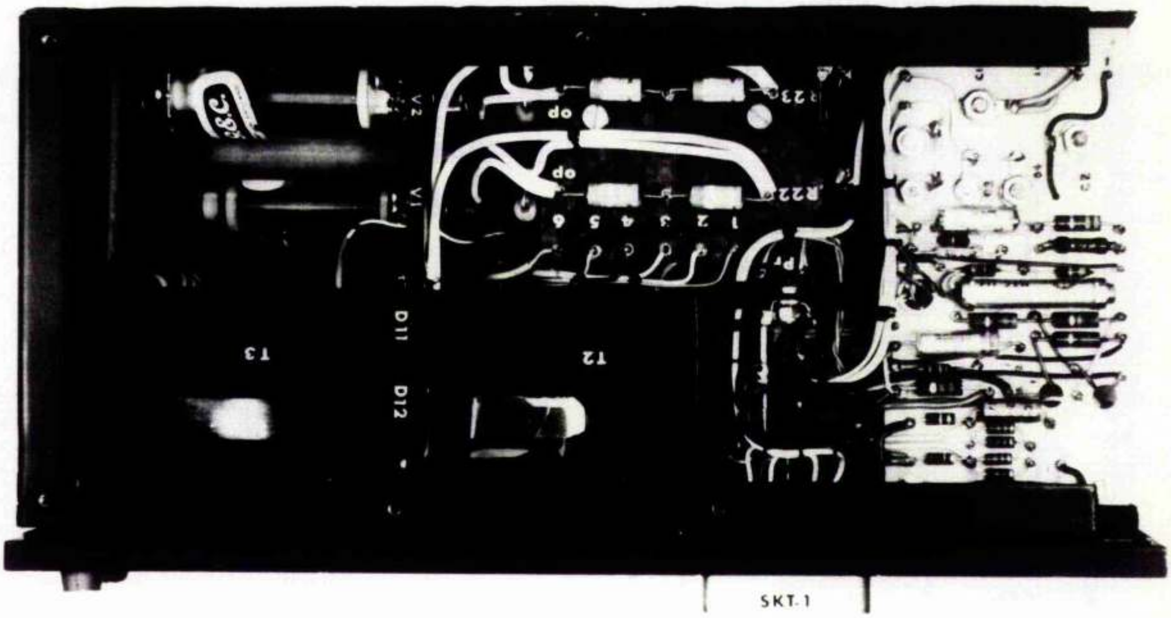
PLATE 8

Plates 8,9,10. The output from each unit was monitored by measuring the voltage across a resistor chain in the output and this voltage was telemetered to the ground station during the flight. After setting up the correct EHT voltage for the flight detector the high voltage section of the power unit was totally encapsulated with silastomer rubber and outgassed in vacuo. Subsequent operation of the flight unit in vacuum indicated no presence of corona breakdown in the unit.

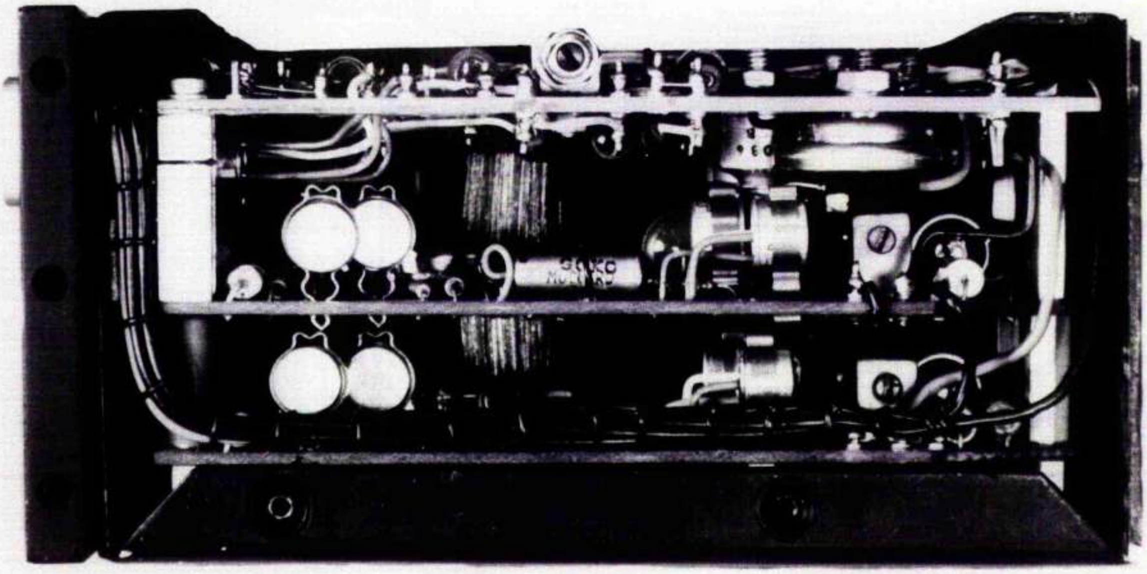
In order to obtain a realistic assessment of the high voltage power unit, electrometer amplifier and the associated low voltage power system, it was decided to construct several units which would be flown in a simple sky brightness experiment in the British Skylark Rocket programme. The experiment had all the requirements for a successful system evaluation since it consisted in the main of a filtered photomultiplier feeding a single range electrometer amplifier, the output from which was telemetered to the ground station in the normal manner. The photometer is shown in Plate

The sky brightness experiment incorporating these units was flown by the author from the Woomera Test Range, in Australia in February 1965 and although performing well, successful data was obtained from only one launch (due to the explosion of the second rocket) the electronic system worked perfectly and removed the need for future circuit development. Ten sets were manufactured under sub-contract and assigned to the ESRO Sounding Rocket Experiments.

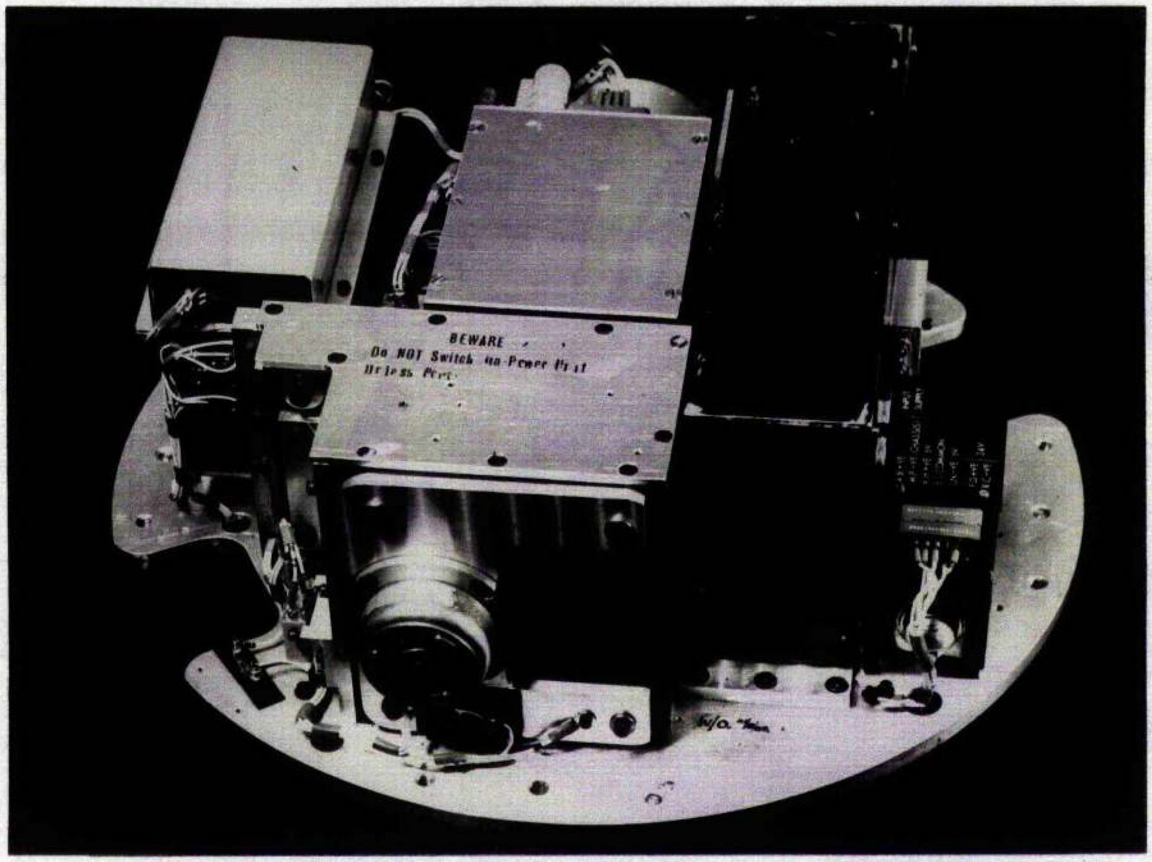
Although the power units performed satisfactorily



TOP ELEVATION POWER UNIT
PLATE 9



SIDE ELEVATION OF POWER UNIT
PLATE 10



SIDE ELEVATION OF SKY BRIGHTNESS EXPERIMENT

PLATE 11

during four instrumented launches, they did have certain disadvantages and in particular their heavy current consumption and fixed EHT voltage made their continued use undesirable and since several years had elapsed since their design it seemed profitable to investigate the availability of commercial power units of this type. No European manufacturer could be located but three suppliers in the U.S.A. seemed possible.

M.I.L. ELECTRONICS INC. Lowell, Maryland.

Although a small company they did produce a ruggedised compact EHT unit which had a vibration specification. This unit, type 3S41.1200 produced a 1100-1300 Volt d.c. supply at 2mA from a d.c. input of between 24V $\pm$ 4V and seemed suitable for the Hammatsu and EMI detectors.

TRANSFORMER ELECTRONICS COMPANY. Boulder, Colorado.

Again, a small company with considerable expertise in space technology. They produced a wide range of power units both for low voltage and high voltage applications and their series 9567 which produced 2500V d.c. $\pm$ 10% and their series 9584 which produced $\pm$ 15V d.c. seemed suitable.

ARNOLD MAGNETICS.Los Angeles

Although the EHT units were much bulkier than those made by T.E.C. and M.I.L. they had one very big advantage in that they produced a variable EHT voltage from zero to the upper specified voltage. This variation was achieved by using an external programme facility. The model SMU4P seemed to cater for all requirements by providing 0-4Kvd.c. at 1mA for an input voltage of 26-30V d.c.

ROCKET ATTITUDE PHOTOMETERS

The biggest problem when using unstabilised rockets for stellar studies was the determination of at which part of the sky the optical axes of the photometers were pointing and since such determinations were only possible after the actual launch, it was essential that all possible means of rocket attitude sensing were employed.

In the British National Skylark programme, only two rather crude methods were employed. The first, used a set of orthogonal magnetometers, the outputs from which were telemetered to the ground throughout the whole rocket flight, and as the rocket precessed and rolled, the relationship of each magnetometer to the Earth's magnetic field was monitored. The accuracy of such a system left much to be desired and typical attitude solutions were only good to $\pm 5^{\circ}$.

Because of such ambiguities, the magnetometer system was complimented for night flights by a set of four moon-sensors each of which had a wide angle of acceptance in one plane and a narrow angle in the other. By positioning each sensor at a different angle to one another it was possible to have complete acquisition of the Moon throughout the flight and hence no ambiguities could exist as to the rocket aspect in relation to the Earth. The addition of such lunar information made it possible to refine the magnetometer data to an accuracy of $\pm 3^{\circ}$ when all systems functioned satisfactorily. This accuracy was, however, still too coarse to establish an actual attitude solution and additional methods of sensing were investigated. At first it was felt that perhaps the signals from the ultraviolet stellar photometers would be sufficient to determine which stars were being observed. However, such an approach was defeated by the fact that in general the stars would be of fifth magnitude or less and the possible errors in spectral classification could not give an unambiguous solution. It was, therefore, decided to design a new attitude sensor with the specific purpose of detecting late type stars whose output would therefore be essentially in the visible region of the spectrum. As there would be many more stars now detectable and the sensor would also be sensitive to the lunar and Earth's albedoes, it seemed that sufficient additional data would then be provided to refine the attitude solution from $\pm 3^{\circ}$ to perhaps $\pm \frac{1}{4}^{\circ}$ better.

SENSOR DESIGN

Because most of the rocket payload capacity was devoted to the large aperture photometers it was essential that the new sensor should not add any appreciable weight to the already heavy payloads and it was decided to locate the sensors in a standard type III rocket section. This section normally housed the moon-sensors and as such had four apertures mounted into the casting, each spaced at 90° intervals.

The results of a previous investigation by the author indicated that contrary to the experience of the Meteorological Office, Bracknell, Berkshire, England, no contamination was encountered from rocket exhaust or outgassing during flight to quartz lenses mounted on the skin of the rocket, and it seemed possible to mount the new attitude sensors in a similar manner, thus avoiding the use of an ejectable hatch.

MECHANICAL DESIGN

Due to the appreciable precession of the rocket it was possible that the attitude solution delivered from the use of one narrow field sensor would not produce the desired attitude knowledge and it was decided to mount two sensors 180° apart in the Type $\overline{\underline{III}}$ section.

In order to keep the weight down, and in view of the fact that over ten rocket launches were anticipated, a set of magnesium alloy castings were designed. The main casting was fitted directly to the machined viewing ports in the type $\overline{\underline{III}}$ section which provided a solid but light bridge piece to mount both of the optical systems. In addition, a single photometer package was constructed using the same lightweight mounting technique, but attached to only one viewing point. All electronic units of the attitude sensors were then attached to this section and in this way the effects of vibration were minimised, as there was no central area to diaphragm during the launch phase.

OPTICAL SYSTEMS

The actual optical system employed was a modification of the system used in an earlier sky brightness experiment (Plate 11) and consisted of a quartz, single element 6.4 cm diameter f/2 objective with a 2.5cm diameter Fabry lens also of quartz. The quartz objective was mounted flush with the rocket skin sandwiched between an outer locking ring and a mounting cell of P.T.F.E. The field defining diaphragm and Fabry lens were mounted in a brass cell which was attached to the magnesium alloy bridge piece. An identical system was used for the "180°" channel. A variation was tried by using a 45° flat mirror, aluminised on both sides, as a means of directing the light to each photomultiplier. This system provided a much more rugged assembly and is shown in Plate 12. The mechanical design of the "in line" photometer is shown in Plate 13.

WAVELENGTH SENSITIVITY OF ATTITUDE SENSORS

In order to detect as many stars as possible it was decided to use the whole spectral range of the detector in one sensor and to curtail the response of the second sensor to produce information of astrophysical significance.

Because of space limitations, it was necessary to use as small a detector as possible and the RCA IP21, IP28 detectors seemed to be ideal. The IP21 is a selected 931A and as such, has a spectral response of 3000Å - 6500Å. The IP28 has the electrical performance of a IP21 but because it has an ultraviolet transmitting envelope, the short wavelength response was extended to 2100Å.

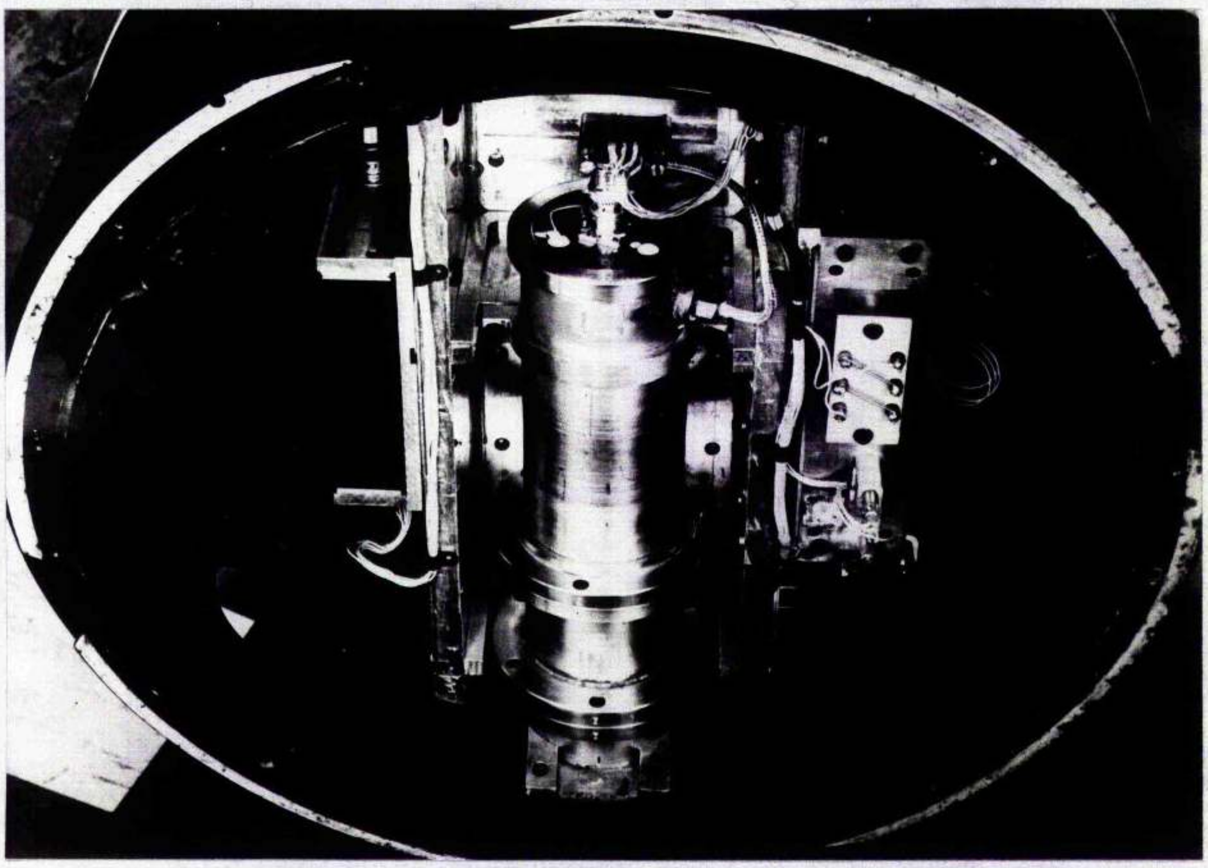
For the filtered photometer, a spectral region centred on the "B" band of the UBV photometry system was chosen.

ELECTRONICS

The IP21, IP28, types of photomultiplier were commercially available, plug-in devices, mating with a ten pin base. As delivered there was an appreciable leakage across the bases and the author arranged for RCA to deliver

TOP ELEVATION 45° TWIN PHOTOMETER

PLATE 12



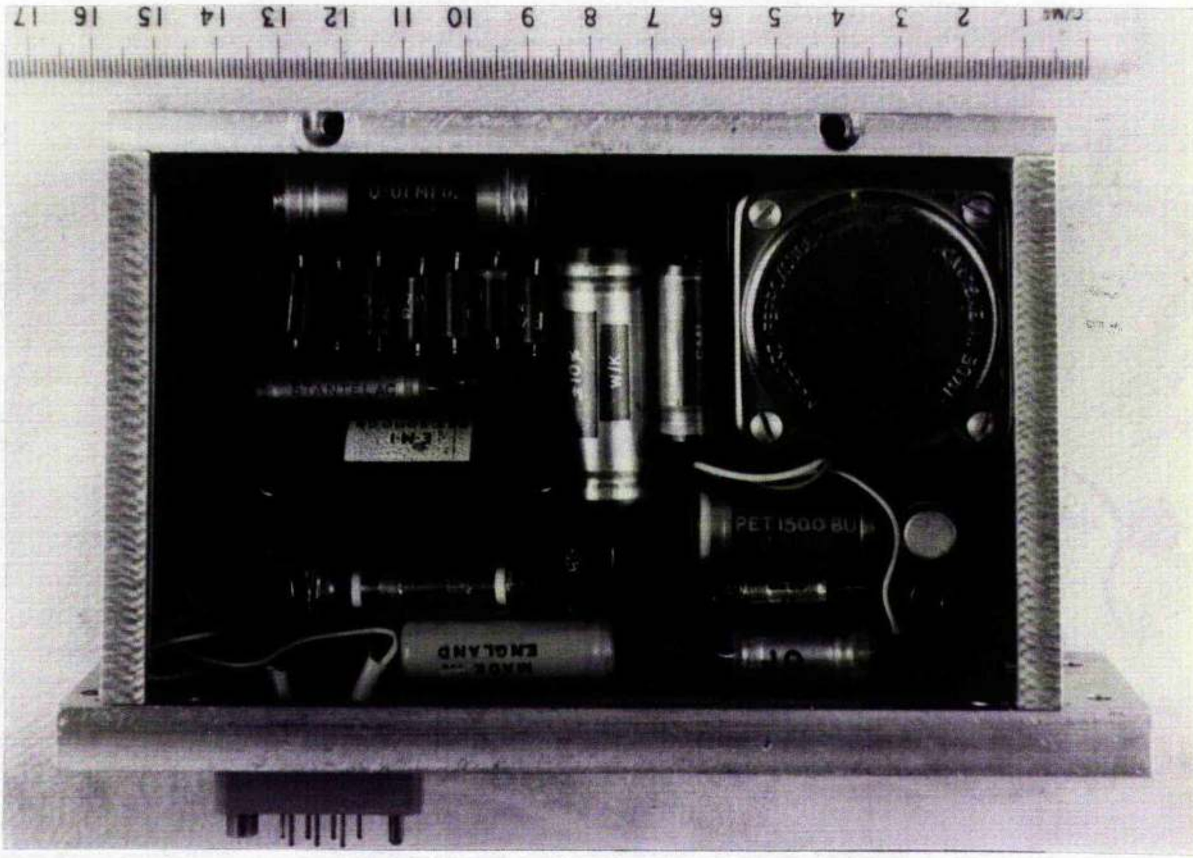
SINGLE CHANNEL STELLAR ATTITUDE SENSOR

PLATE 13

a number of detectors without any base pins, but with long wires from each dynode. The wires were then attached to a fibreglass printed circuit board on which were mounted the dynode resistors. The detector and associated printed circuit board were then mounted on an aluminium base piece and the assembly encapsulated with Sylguard to a level slightly below the start of the glass envelope. In this way, the detector was effectively isolated from the effects of vibration and a considerable reduction in leakage across the base resulted with the possibility of corona breakdown eliminated. An extensive series of vibration tests indicated just how satisfactory this method of shock proofing the detector was in practice. The IP21, IP28 detectors require voltages in the region 900V - 1100V d.c. and as no commercial miniature d.c.- d.c. convertors were available the author designed a simple EHT convertor (see Plate 14) using a corona regulator discharge tube as the stabilising element. Although it was still not possible to alter the output voltage without changing the stabilising tube, the resultant power unit was much smaller and more economical in comparison with the earlier unit designed for the sky brightness experiment.

WAVELENGTH ISOLATION - THE REGION 1400Å - 3000Å

In the visible region of the spectrum there are a number of optical glasses suitable for isolating narrow wavelength regions with passbands of the order of 100Å. However, below 3000Å the number of materials sufficiently non-absorbing is very small and those most frequently in



PROTOTYPE LOW POWER EHT UNIT

PLATE 14

use are also shown in Fig. 5. If we combine such filter materials with the normal photomultipliers having antimony-caesium photo-cathodes, then the wavelength regions thus isolated, are still too large for accurate photometry in the shorter wavelength region. If, however, use is made of photomultipliers which employ the so called "solar blind" photo-cathodes, then it is possible to define passbands with high throughput efficiency down to 1000Å. Typical combinations are shown in Fig. 20. Again the technique is only really useful in the region 1000Å-2000Å where the isolated passbands are narrow enough for accurate photometry.

In the region 2000Å-3000Å a conventional method of wavelength isolation has been to use metal dielectric interference filters which enable passbands typically 300Å wide to be obtained at any desired wavelength. The technique suffers from three basic disadvantages.

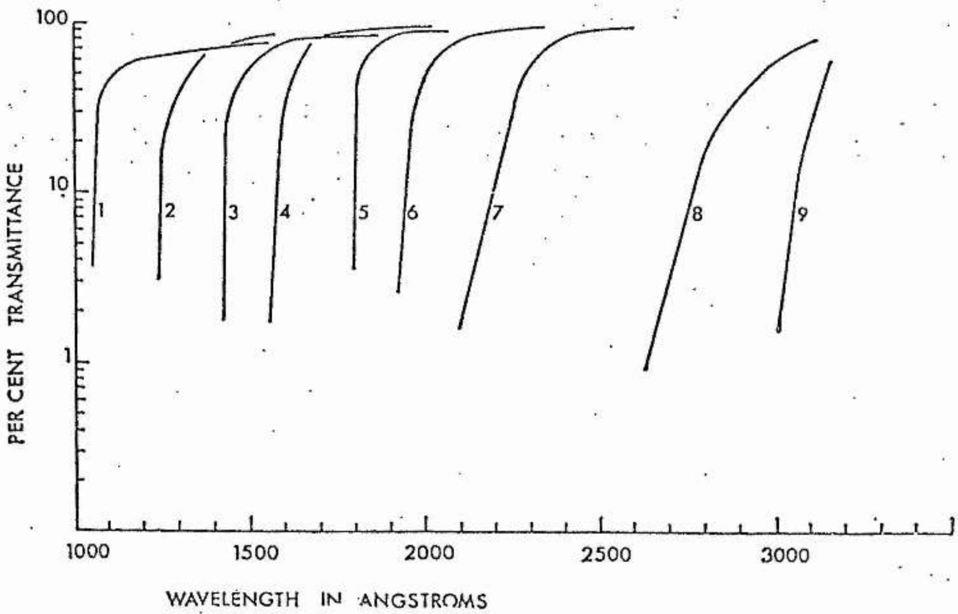
(a) The transmitted central wavelength intensity is typically only 20-25% of the incident radiation.

(b) The filter is very susceptible to changes in the angle of incidence the net result causing the filter passband to increase with increasing beam divergence.

(c) The primary isolation peak is accompanied by a second order peak in the visible.

Characteristics (a) and (b) can be optimised by careful optical design of the photometer and point (c) can normally be eliminated by means of a detector employing a "solar blind" photo-cathode.

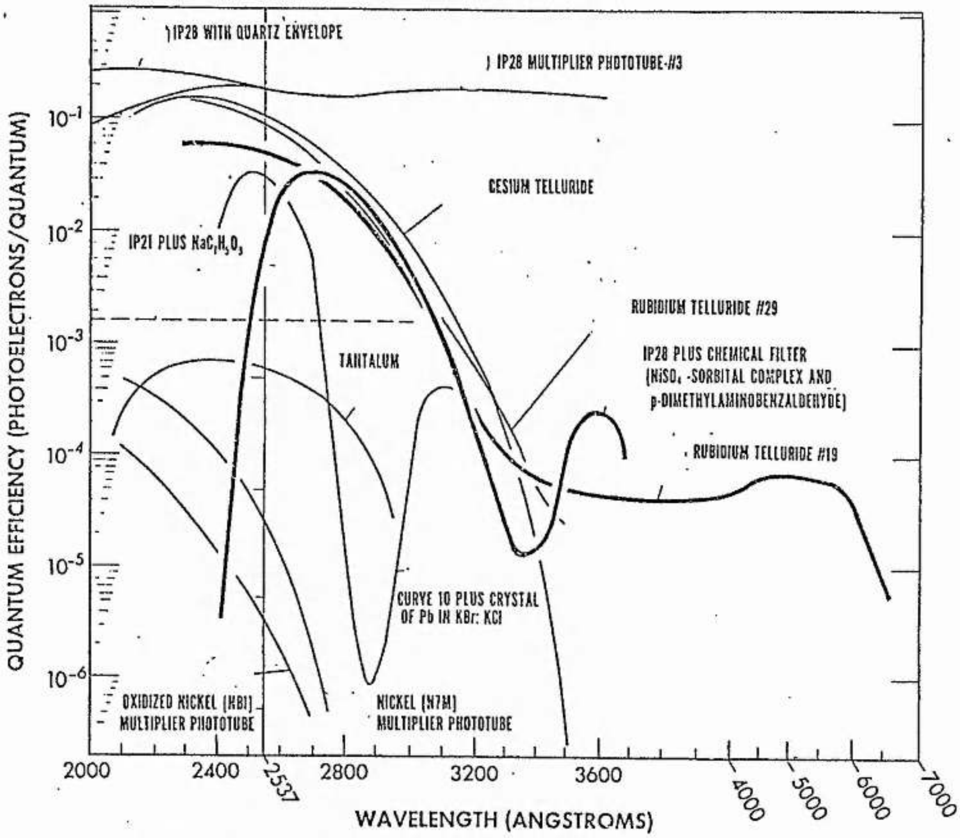
A number of filters of this type, manufactured by Barr and Stroud of Anniesland, Glasgow, were obtained and



1. LiF	4. Fused silica	7. Corning 9-54
2. CaF_2	5. ADP	8. Corning 9700
3. Sapphire (Al_2O_2)	6. $NiSO_4(H_2O)_6$	9. Corning 0-54

CRYSTALINE WINDOW MATERIALS IN THE ULTRAVIOLET

Fig. 20



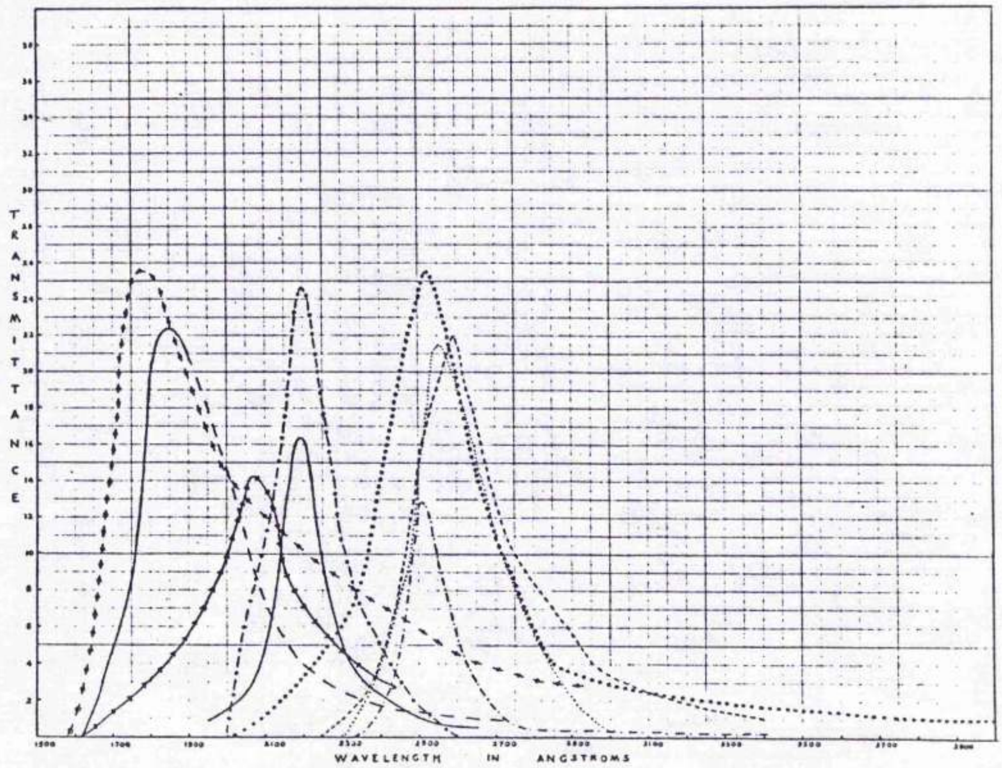
WINDOW PHOTO-CATHODE COMBINATIONS

Fig. 20.

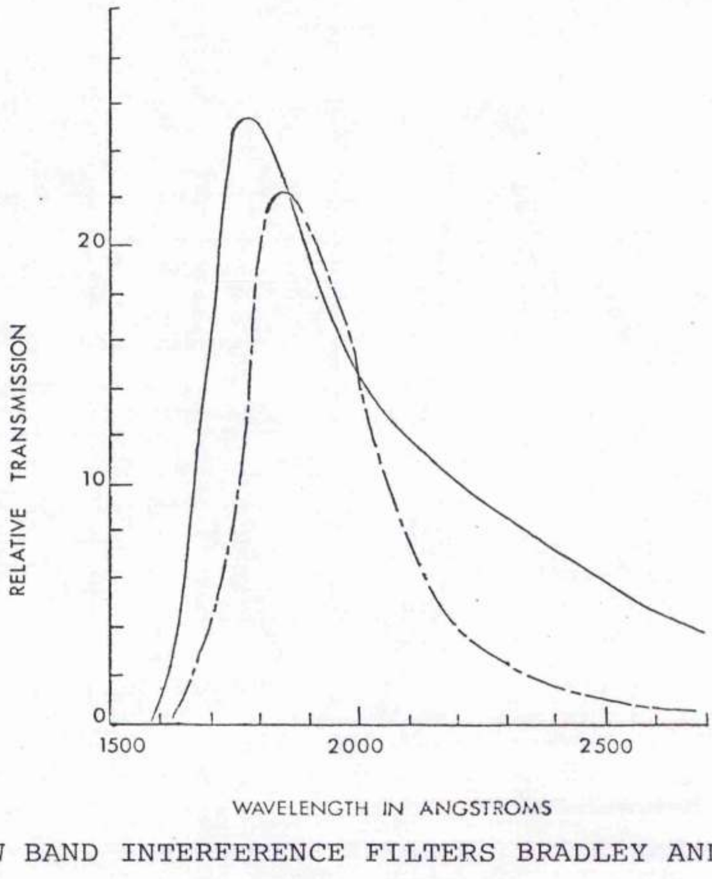
preliminary tests in the laboratory indicated their suitability for inclusion in the rocket proposals. Typical spectral responses are shown in Fig.21. for angles of incidence of about twenty degrees.

The technique was extended by BATES and BRADLEY(1966), who very generously produced several interference filters for the shorter wavelengths. The filters, Fig.22. employed magnesium fluoride layers deposited on quartz substrates, in a similar manner to that reported by SCHROEDER (1962)

In order to increase the throughput efficiency of the photometers, it was decided to investigate the possible use of selective reflective mirror surfaces, and an approach was made to Optical Coating Laboratories, Santa Rosa, with a view to obtaining a reflectance filter suitable for deposition on the primary and secondary elements of the telescope system. A suitable filter was produced with a number of dielectric layers of magnesium oxide and magnesium fluoride as the reflecting filter and a number of optical flats were coated for evaluation. It had been mentioned by JOCELYN that such filters became unstable in conditions of high humidity and a number of tests were conducted aimed at establishing the maximum humidity which could be tolerated without any deterioration of the filter surface. The tests were conducted over a period of four months and consisted of measuring the reflectance of a number of mirror samples at a wavelength of 2537Å, under a variety of humidity conditions, for a filter centered on 2600Å. No deterioration was observed and the tests were terminated after subjecting the filter to 100% humidity for twenty-four



INTERFERENCE FILTERS BARR AND STROUD
Fig. 21.



NARROW BAND INTERFERENCE FILTERS BRADLEY AND BATES
Fig. 22.

hours without loss of reflections.

The filter had, however, the following disadvantages:

(a) The deposition process subjected the optical components to temperatures in the region of 150°C over a period of forty minutes and there was therefore, the possibility that the optical performance of the optical system would be affected.

(b) There were two secondary peaks associated with the primary reflective peak of approximately half the maximum intensity and about twenty percent of the total bandwidth. Such peaks would have made accurate photometry difficult, however, this effect would be appreciably lessened by using a two mirror system without any great loss in overall efficiency and by employing "solar blind" photomultipliers.

(c) The cost of such filters was very much greater than that of a conventional interference filter, however, the cost was very much dependent on the number of components coated and was more of a "facility charge" than a component cost.

There were, however, a considerable number of advantages:

(a) The reflectance of each mirror surface was of the order of ninety-eight percent, and was therefore, higher than any other reflecting surface available.

(b) The isolation efficiency of the filter was also of the same order.

(c) The use of such filters enables less stringent visible rejection ratios to be required from the solar blind photomultipliers and would enable cheaper detectors to be used.

(d) It was possible to have the filters designed for most angles of incidence and there was no "opening up" of the passband for highly divergent beams.

A number of photometer optical systems were coated for high selective reflectance at 2150Å and 2550Å and the use of interference filters discontinued.

SELECTIVE PHOTOMULTIPLIERS

As stated earlier, it is possible to obtain detectors selective in their own right and use of this characteristic was made to isolate a waveband centered on 1450Å by means of copper iodide and rubidium iodide photo-cathodes. Unfortunately, because of the excessively high cost of such detectors it was only possible to instrument five channels using this technique and one such channel was allocated to each payload containing the 2150Å and 2550Å photometers.

ROCKET ROLL RATE CONTROL

The Skylark Rocket is a fin stabilized vehicle with unpredictable performance due in the main to the engineering tolerance existing in the mass produced rocket fin assemblies. Table 7, is a selection of performance figures for the Skylark Rocket up to the time of this investigation and it is clear that there is no predictable performance possible with this vehicle.

In the case of the stellar photometer, whose field of view is fixed prior to launch and where it was desirable to use the smallest field of view possible (in order to eliminate a large sky background contribution) there was a

TABLE 7

SKYLARK ROLL AND PRECESSION RATES IN FREE SPACE

The round numbers are given in order of firing. The sense of rotation is not given.

Firing Date	Round No.	Roll rate (deg/sec).	Precision Rate (deg/sec)	Separation	Motor Type
?	49	7.7	12.4	Down	
1. 5.61	43	93.7	2.0	No[x]	
27. 9.61	40	8.1	11.7	Up	
.11.61	33	20.9	11.5	Up	VA/C
5.12.61	42	103.4	1.6	No[xx]	
20. 6.62	45	219	2.9	Down	VA/C
11. 9.62	44	6.8	1.3	No	II/C
20. 9.62	108	Small Oscillatory	33.6	Up	II/B
15. 8.62	109	44.3	22.5	Up	II/B
13.11.62	114	19.4	1	No	VII A/C
1. 3.62	84	2.4	9.1	Down	VII A/C
11. 3.63	85	56.1	0.8	Down	VII A/C
23. 5.63	115	Small Oscillatory	25.1	Up	V_I A/C
29. 5.63	127	43.2	14.6	Up	VII A/C
18. 6.63	126	13.7	44.2	Down[x]	VII A/C
20. 6.63	46	37.7	0.8	No	VII A/C
30.10.63	134	8.5	16.4	Down	VII A/C
10. 3.64	129	27.0	10.6	Up	VII A/C
12. 3.64	128	17.5	14.4	Up	VII A/C
11. 4.64	136	4.6	39.3	No[x]	VII A/C
20. 8.64	121	7.0	12.5	Down	VII A/C
1. 9.64	137	127.8	49.0	Up	VII A/C
17. 9.64	120	3.3	8.8	Down	VII A/C
24. 9.64	133	30.4	6.2	Up	VII A/C
29. 9.64	132	Saml1 Oscillatory	17.2	Up	VII A/C
27.10.64	47	23.1	14.8	Down[xx]	VII A/C
23. 3.65	141	52.2	15.7	Up	VII A/C
		1	8.8	Separation)	
14. 5.65	139	4.8	12.7	at apogee)	VII A/C
		1	22.8	Separation)	VII A/C
19. 5.65	139	4.9	24.7	at apogee)	
1. 7.65	106	13.8	46.2	Down	VII A/C
14. 7.65	48	56.3	1	Down	VII A/C

NOTES:- Separation Column - x was intended to separate on way up
-xx was intended to separate on way down.

very real possibility that if the Skylark established a roll rate faster than the telemetry bandwidth available for each channel, then it would not be possible to make observations due to the insufficient length of time that the star remained in the field of view. The problem was not unique to the British Skylark rocket and had in fact also been troublesome in the American rocket programme.

A chance visit to the French Space Research Centre at CNES, near Paris, led to discussions between the author and a representative of the Space General Corporation of America who were at that time installing a roll rate stabilisation system on the French Veronique rocket. The outcome of these discussions led to the submission to ESRO in 1963, of a proposal for a modified roll rate control unit (originally developed for the Aerobee rocket) which would be compatible with the Skylark rocket. In 1964, a contract was placed with the Space General Corporation for five roll rate control units to be assigned to the author's payloads.

SPACE GENERAL ROLL RATE CONTROL UNIT

The Space General roll rate control unit developed for these experiments consisted of a nitrogen gas bottle and gas jet system with a rate gyro sensing the roll rate. The required roll rate was set by the manufacturers and it was not possible to set the roll rate direction. Prior to launch, the rate gyro was stabilised and at the required altitude the sensing circuits are activated. The direction of the roll rate was then sensed and a pyrotechnic squib was ignited in the gas lines which controlled the opposite roll rate direction. This was to avoid inadvertently spinning up the rocket. The rate gyro then controlled the gas demand valve and high pressure nitrogen then flowed into the gas jets until the required roll rate was achieved, at which point a second pyrotechnic squib was ignited and the gas demand valve was permanently closed. The unit was capable of despinning a complete Skylark rocket and payload in ten seconds. Units of this type were fitted to payloads S05, S11 and S27.

ELLIOT BROS. ROLL RATE CONTROL UNIT

It is clear from the above brief description of the Space General Control system that there were a number of disadvantages and in particular the following:-

(1) The inability to change the roll rate at will, since the rate gyro was set up by the manufacturers for one particular roll rate.

(2) The inability of the unit to provide a designated roll direction.

(3) The "one-shot" operation of the unit provided little safeguard should an appreciable precession cone develop after the required roll rate was initiated.

It was therefore, decided to investigate the possibility of obtaining a European supplier of a roll rate control unit which would eliminate the above limitations; accordingly, the author conducted discussions with representatives of Elliot Bros. Ltd. at Frimley, Surrey, (the manufacturers of stabilising systems for Skylark). The outcome of these discussions resulted in a roll rate control unit with a completely active sensing system, small gas impulses being initiated throughout the whole of the flight. In addition, since the unit employed an active sensing system it was possible to programme the unit to achieve the desired roll rate direction. The sensing system incorporated in the Elliot control unit was such as to permit any roll rate setting up to $\pm 50^{\circ}$ per second, with an accuracy of $\pm 1^{\circ}$ per second, from an initial maximum roll rate of $\pm$ 7 rev. per second. The despin time for this new unit, assuming an initial rate of 200° per second was less than six seconds. The only penalty incurred with the new system was an increase in overall unit length of 5cms and an increase in weight due to the increased nitrogen gas bottle capacity required for the control of the roll rate throughout the whole flight. The new units were fitted to payloads S11 and S47.

CHAPTER III

ABSOLUTE CALIBRATION

INTRODUCTION:

Absolute calibration in the vacuum ultra-violet is very difficult for many reasons not the least of which are the large transmission losses of many of the materials in use in the visible region. In addition, the availability of well defined, high output, stable ultra-violet sources is normally outwith the scope of most calibration laboratories and it is very much a question of the scientist developing his own calibration procedures, but always paying particular attention to the need for a traceable procedure to some National standard. Only in this way can results from different rocket flights be intercompared. The lack of any such traceable calibration procedures was clearly the major source of errors in the earlier American results.

Since it is also essential to calibrate the whole telescope package it is desirable to have a calibration facility capable of illuminating an optical system of at least 30cm in diameter with radiation of known intensity and spectral content, and to ensure that each time such a facility is utilised, its performance should be equateable with other calibrations previously conducted. The creation of such a facility is clearly no mean task.

ABSOLUTE INTENSITY STANDARDS

There are three basic methods in use for absolute energy calibration, all based on sources. The first method is the so called Branching Ratio method first developed by GRIFFIN and McWHIRTER (1961) of the Culham Laboratories, Berkshire, England. The second method is the synchrotron radiation method developed at DESY in Hamburg by LABS and LEMBKE (1967) and PITZ, (1969), and a third method using the Black Body source developed by BOLDT (1971) at the Max Planck Institute in Garching, Munich.

In the case of the Branching Ratio method, one needs to know two spectral lines coming from the same energy level. One of these lines is required to lie in the visible or near ultraviolet part of the spectrum and the energy of this line is measured by direct comparison with an approved intensity source such as a tungsten ribbon lamp or a quartz iodide lamp. The other line must lie in the vacuum ultra-violet. If the ratio of the transition probabilities between these two lines is known, and the plasma emitting these lines is optically thin, then the proportionality between the intensity and transition probability is known and therefore the intensity of the ultra-violet line can also be calculated. In the procedure advocated by GRIFFIN and McWHIRTER, the primary source is Zeta, and a grazing incidence monochromator is used in the vacuum ultra-violet and a conventional monochromator for the near ultraviolet. The light emerging from the plasma in the Zeta machine is split into two beams in such a way that the ultra-violet light and the visible light can be measured simultaneously. After this measurement has been concluded the Zeta source is replaced by a tungsten ribbon lamp or a quartz iodide lamp which enables the calibration of the monochromator in the visible to be obtained.

It is clearly not necessary to use such an elegant source as the Zeta machine and in fact others have used hollow cathode lamps and microwave discharges, which provide more lines than would be normally available from the Zeta source itself. The method is an excellent and convenient one for obtaining absolute energy calibrations from the visible into the vacuum ultraviolet and the only error in the method is that which is introduced by the uncertainty in the value of the transition probability ratios and any uncertainty due to the visible standard employed. In general, the calibration accuracy available from this method is of the order of between $\pm 10\%$ to $\pm 20\%$.

THE SYNCHROTRON RADIATION METHOD

By the correct application of the Schwinger theory which gives an indication of the radiation which is emitted from a circulating relativistic electron, this theory can be applied to synchrotron radiation with good accuracy and since the relative energy distribution in the circulating synchrotron source depends only on the radius of the synchrotron and on the exit energy of the electrons, it can therefore be simply calculated. If one restricts the observation of the synchrotron radiation to the vacuum ultraviolet only, then an exact knowledge of the energy distribution in the beam is not critical, making the synchrotron an excellent source for relative intensity calibration in the range between the visible and the vacuum ultraviolet. However, in order to get absolute intensity values of the synchrotron radiation, it is necessary to measure the number of electrons in the synchrotron, which is proportional to the absolute intensity of the radiation, and since the accuracy of such a measurement is not better than $\pm 25\%$, this introduces an error in the absolute intensity of the synchrotron radiation of the same order. If, however, the synchrotron radiation is calibrated in an absolute manner from the knowledge of the radiation in the visible, via approved intensity standards, (similar to the branching ratio method), then because of the good accuracy of the relative intensity standard it is possible to transfer the absolute calibration from the visible to the vacuum ultraviolet. This procedure has been adopted on the DESY machine, resulting in an accuracy in the vacuum ultraviolet of the order of $\pm 10\%$.

THE BLACK BODY RADIATION METHOD

An elegant form of black body radiation is the well stabilised cascade arc such as is shown in Fig. 1. This cascade arc, was developed by the late G. BOLDT at the Max Planck Institute, and consists of a plasma in an arc channel operating at a pressure of one atmosphere, is thermal in origin and consists mainly of nitrogen and carbon. The combination of these two elements provides a number of optically thick lines in the region 1100Å - 2500Å and these lines can leave the plasma without any absorption or self-absorption via an argon window which is provided by an argon plasma flow from the end of the arc channel to the gas outlet in the centre part of the channel. The absolute intensity in the centre of these

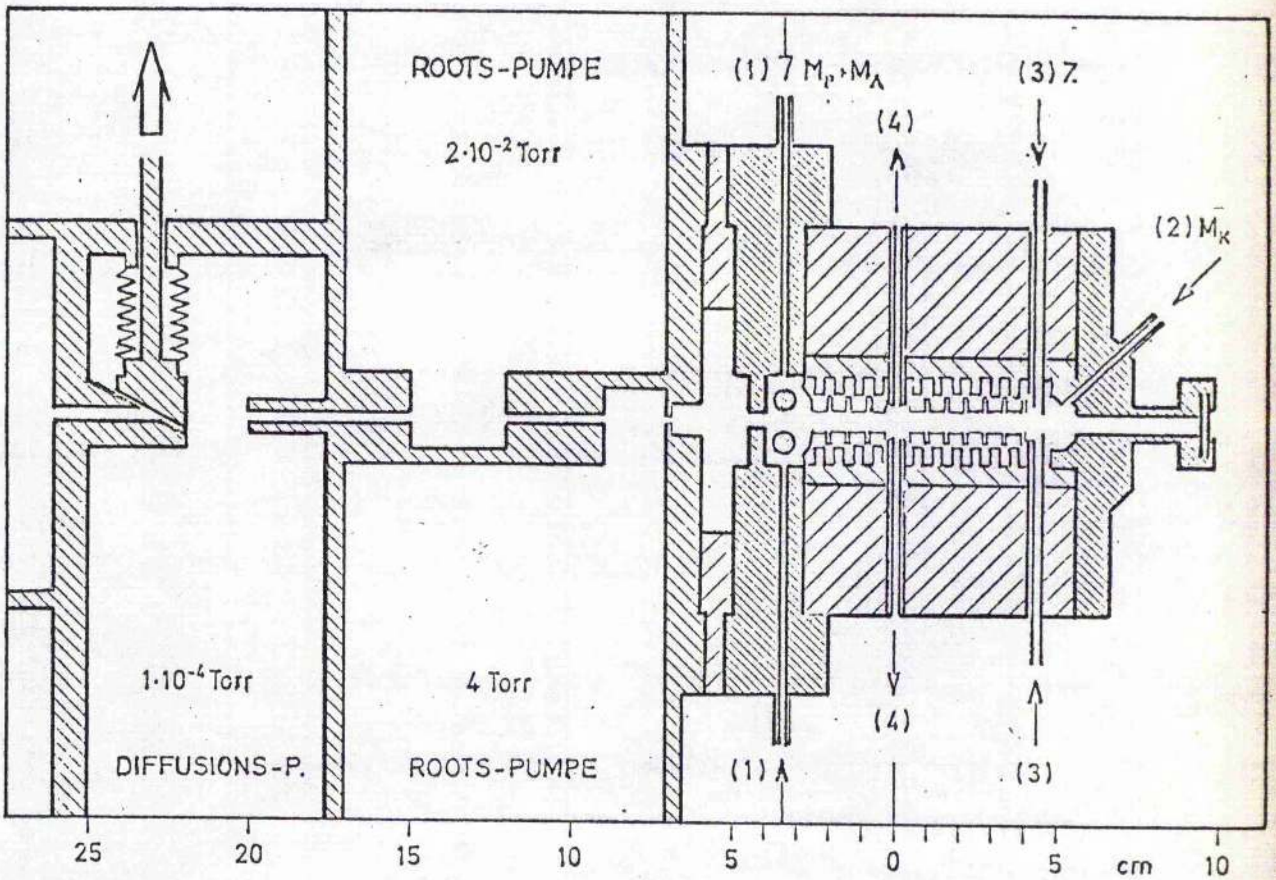


Fig. 1

CASCADE ARC OF BOLDT

optically thick lines is given by the Planck function and it is only necessary to measure the plasma temperature in order to obtain absolute intensity. The operation of such a source results in an operating temperature for the arc of 12,540^{o}K measured to an accuracy of $\pm$2%. As a consequence, the black body intensities are known to an accuracy of $\pm$10% to $\pm$20%. Fig. 2. indicates the Planck function for a source at 12,540^{o}K. It can be seen that for such a function there are several optically thick lines. By interpolation between these points it is possible to obtain an absolute energy scale at any wavelength between 1100Å and 2500Å, enabling the absolute energy distribution to be calculated for the whole of the arc spectrum over the same wavelength range. In the region between 1700Å-3100Å, the intensity of this continuum was measured between 1700Å and 2500Å and extrapolated out to 3100Å. Since there was no variation in continuum intensity to be expected in this region, it was felt that this procedure was justifiable. It was therefore possible to obtain an energy distribution for the arc spectrum between 1100Å and 3100Å without using any other source. BOLDT compared absolute energy distribution as produced by his plasma arc with that of the distribution of a well stabilised carbon arc in the region of overlap, namely 2500Å - 3100Å, and found an agreement to within 1% at 2500Å and 5% at 3100Å. From this BOLDT estimated the accuracy of the absolute intensity of the cascade arc to be of the order of $\pm$10% to $\pm$20%.

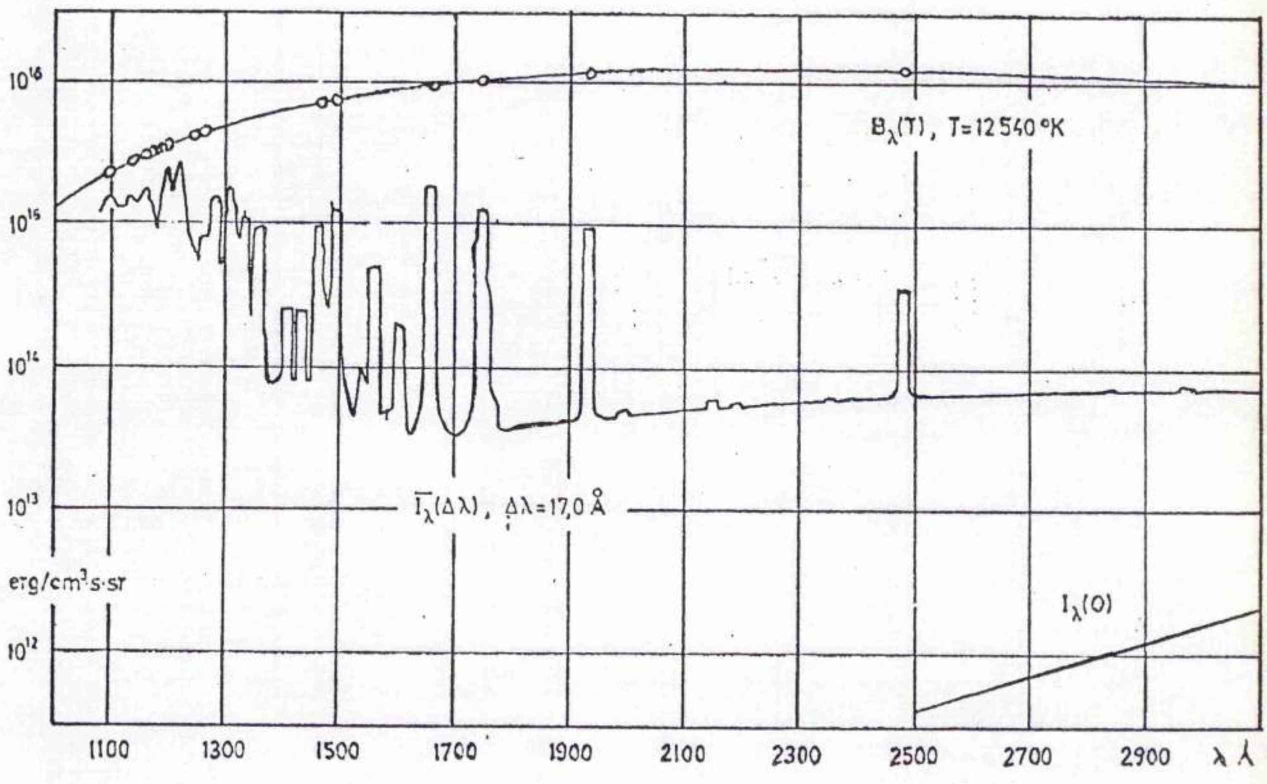


Fig. 2

BLACK BODY INTENSITIES OF CASCADE ARC

PRACTICAL, PORTABLE INTENSITY SUB-STANDARDS

The above absolute standards are clearly ideal for fixed laboratories, however they are in themselves major facilities and are too remote for routine calibration of rocket instrumentation, particularly when more than thirty rocket telescopes are involved over a period of several years. It was therefore, essential to develop a more practical form of calibration facility which would permit the calibration of the fully instrumented telescopes and permit the intercomparison of other rocket group standards. Accordingly, the author developed a calibration procedure based on the use of well calibrated detectors, using monochromatic light sources for periodic spot checks and range pre-flight calibrations.

The detector types chosen were the ASCOP 541F-05 (caesium telluride photocathode with sapphire window) the ASCOP 5426-09 (caesium iodide with magnesium fluoride window) and the diode type ASCOP 543-09 (rubidium telluride photocathode with magnesium fluoride window). The reason for the use of both photomultiplier and diode substandards was to permit the measurement of high and low light levels and also to enable checks to be made on the photo-cathode sensitivity of the photomultipliers when used as diodes. Three 541F, two 542G and one 543P detectors were purchased as substandards and the author supervised their calibration at the EMR factory at Princeton, New Jersey.

Selected detectors of known uniformity and gain were calibrated against double plate ion chambers, National

Bureau of Standards thermopiles and standard Xenon lamps, the gain and cathode uniformity of each detector being also measured. In this way each detector was intercompared and the author was then able to set up a substandard network relateable to the N.B.S. substandards.

In addition, five low pressure mercury pea lamps of the type mentioned earlier in the detector section were also calibrated at 2537Å and 1650Å at known temperature and operating current, against known laboratory standards. Two type EXP355 (25855) Xenon lamps were also calibrated at 1470Å.

By this means a complete portable calibration network was established and since most of the other U.S. groups used EMR detectors, the substandards could be easily shipped to other research laboratories for intercomparison with their standards.

THE VACUUM COLLIMATOR

In orderaccurately to calibrate the stellar photometers it was necessary to ensure that the performance of the optical system as a whole was evaluated, since the passband of any filter employed would be affected by the f/number of the incident light bundle and any reflective losses. Additonally, since the absolute calibration was required at 1470Å, 2200Å and 2550Å it was essential that such calibrations be carried out in vacuo in order to eliminate the effects of atmospheric absorption. Regretably, in 1961 no such vacuum calibration facility existed in the

U.K. and it was therefore necessary to construct such a facility at the Royal Observatory, where a large vacuum chamber was already in existence (the aluminium evaporator for the 36" telescope). The author designed an additional stainless steel adapter section which provided a 36" long 30" diameter cylinder with a removeable end plate, the section bolting on to the main vacuum tank. A 12" f/6 Cassegrain optical system was mounted rigidly in this section with the focal plane 9" outside the end plate of the adapter section. A rotary table was also constructed in the main vacuum chamber to facilitate the rotation of the photometers about the axis of the Cassegrain collimator for field sensitivity measurements.

Since it was also necessary to calibrate the passband of each photometer very accurately, a simple JOHNSON-ONAKA monochromator was constructed to match the f/number of the Cassegrain collimator and using the collimator it was possible to produce a monochromatic beam of 12" diameter, but unknown intensity. The single well trapped 16" oil diffusion pump of the main vacuum chamber provided an ultimate vacuum of the order of 3×10^{-5} Torr in the auxiliary chamber after two hours of pumping.

In order to determine accurately the absolute intensity of the monochromatic flux falling on the photometer, a simple X-Y framework was constructed inside the chamber which enabled the 12" calibration beam to be scanned at 1cm intervals. A previously calibrated Ascop 541F-05M detector was then placed in the frame and the intensity and uniformity of the beam measured periodically at each each calibration wavelength. During the actual calibration, the calibration detector also monitored the incident flux level, to ensure that any variation in source intensity was observed.

HIGH INTENSITY BROAD BAND ULTRAVIOLET SOURCES

Sources which are bright in the region 1000Å-3000Å were not commercially available in 1961 and it was necessary for the author to develop suitable sources for the vacuum collimator.

THE MICROWAVE DISCHARGE

Previous research of the author in 1957 in connection with the detection of centimetric emission of radio noise from active auorae had produced a method of exciting a column of argon gas by means of a continuous wave magnetron and it seemed that such a technique might well be capable of providing a compact medium output ultra-violet source if the correct gas filling was employed. However, a 1kw magnetron seemed somewhat over powerful and a hospital diathermy unit of 200watt power was obtained from Electro-Medical Supplies in London, the first commercially available unit being delivered to the author in 1963.

In the meantime discussions with Dr. H.P. BROIDA of the University of California led to a joint development of microwave cavity designs and ultimately in the use of designs of BROIDA and EVENSON (1965). Three such cavities are shown in Figs. 3, 4, 5.

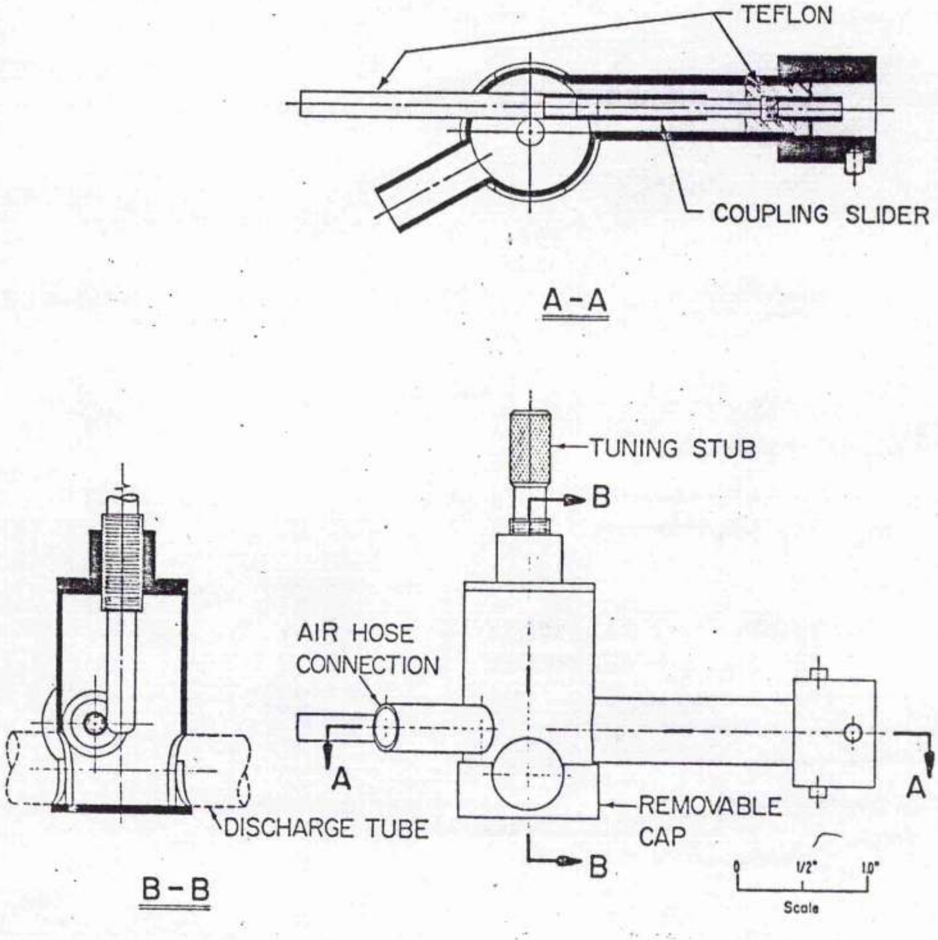


Fig. 3

BROIDA DISCHARGE TYPE 5

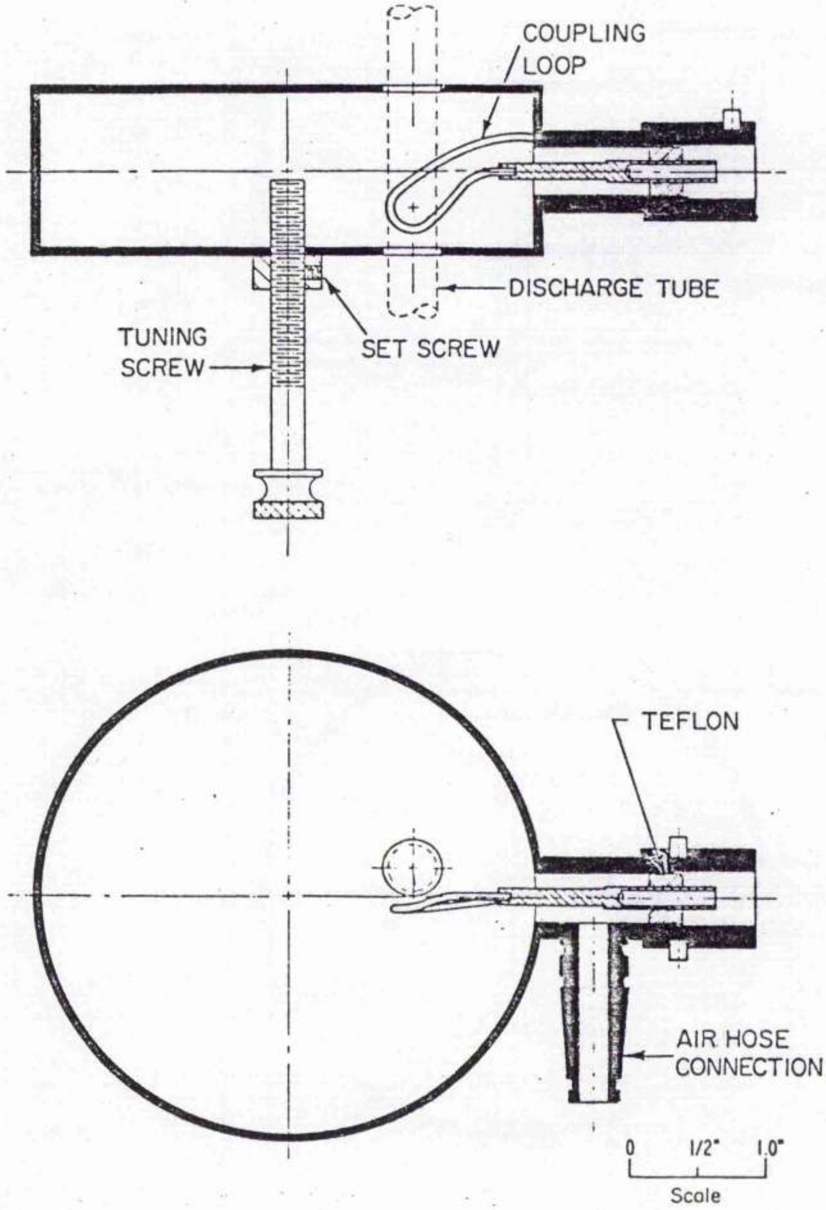
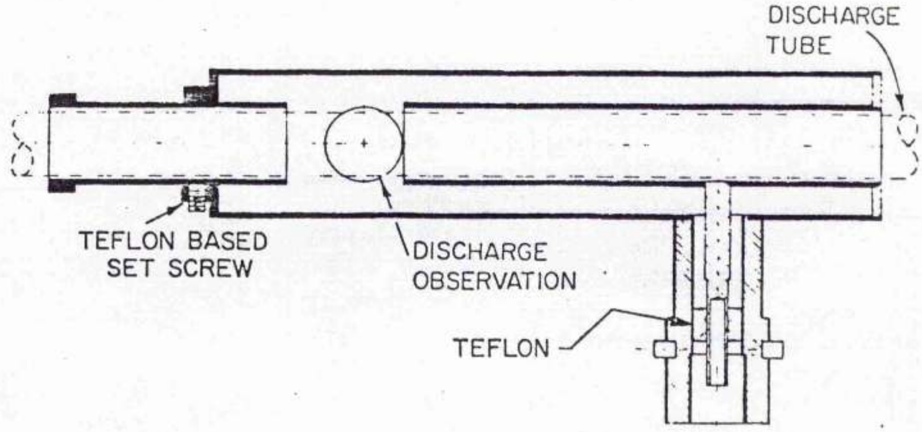


Fig. 4

BROIDA DISCHARGE TYPE 4



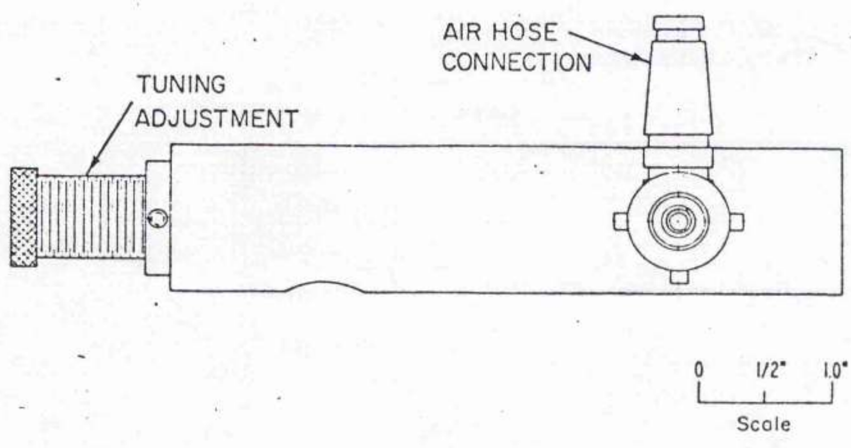


Fig. 5

BROIDA DISCHARGE TYPE 2a

The use of microwave energy to excite discharge tubes has a number of advantages:

(a) Ionisation of the filling gas is almost complete and a uniform discharge results.

(b) No electrodes are employed and there is therefore no resultant contamination of the spectral output such as occurs with d.c. excited sources.

(c) The method of excitation is simple, compact and non-hazardous.

(d) The power level required to excite normal gases is low and the output from such a source can be varied by altering the excitation power in a simple way.

Although the method of exciting the cavity is very straightforward the actual efficiency of the source is very dependent on the actual cavity design and in particular the matching of the cavity impedence to the impedence of the waveguide or cable and it was essential to use a standing wave indicator in series with the microwave generator in order to be able to "tune" the cavity for minimum standing wave ratio, i.e. ratio of reflected to incident power level.

The characteristics of the various cavities are listed in Table 1, and BROIDA type 2a and 3 were manufactured in the Observatory workshops.

The BROIDA type 2a cavity consisted of a tuned co-axial system, the discharge being initiated in the gap between the fixed and adjustable inner cylinders, the discharge tube being mounted through the centre of the

TABLE 1

CHARACTERISTICS OF BROIDA CAVITIES

	Cavity	Electrical Configuration	Frequency Adjustment	Coupling Adjustment	Removable from glass discharge system
	1	Tapered rectangular TE_{013}	No	Yes	Yes
	2a	Foreshortened 3/4 wave coaxial	Yes	No	No
Fig.5.	2b	Foreshortened 3/4 wave coaxial	Yes	Yes	No
Fig.4.	3	Foreshortened 1/4 wave radial	Yes	No	No
	4	Coaxial termination	No	Yes	Yes
Fig.3.	5	Foreshortened 1/4 wave coaxial	Yes	Yes	Yes

system. Adjustment of the inner cylinder permits matching the cavity to the excitation source. The cavity is very compact and when operating at maximum power, i.e. 200w level, it was necessary to blow cooling air across the discharge tube. A hole was cut in the side of the cavity to permit observation of the discharge.

The type 3 cavity was a shorter version of cavity 2a with the microwave energy launched into the cylindrical cavity by means of a loop antenna. An observation hole was also cut in the cylindrical wall of the cavity and a tuning stub inserted in the top section of the cavity.

OPERATING OBSERVATIONS

The microwave discharge was excited in a quartz capillary tube 13mm in diameter and with an overall length of 25cm, the last 5cm being drawn out in a bell shape of diameter 2.5cm, the edges being finely ground. This type of cavity enabled a number of window materials to be used and various gas fillings. The intensity distribution obtained using such a source is shown in Fig. 6, and the useful pressure range for the rare gas continua in Table 2. For most purposes the medium pressure (40-60torr) helium discharge was used.

D.C. COLD CATHODE DISCHARGE

A cold cathode discharge occurs when a voltage of sufficiently high potential exists between two discharge electrodes the discharge being initiated when free electrons become accelerated and when their energy is high enough, then ionization will occur within the gas and in order for the discharge to become self-sustaining

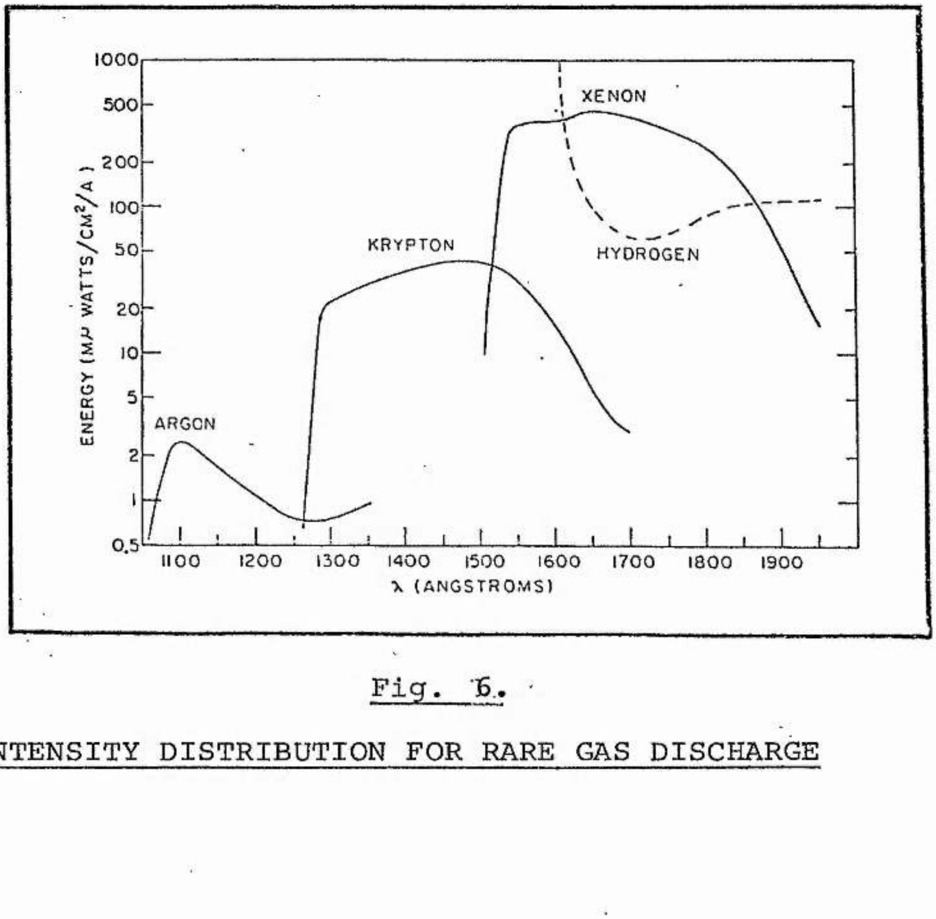


Fig. 6.

INTENSITY DISTRIBUTION FOR RARE GAS DISCHARGE

TABLE 2

PRESSURE RANGE OF CAVITIES

Cavity	Pressure Range (mm Hg) over which Discharge Source Operates				Percent Reflected Power in He			
	He		H_2					
	Low	High	Low	High	0.1	1	10	100 mm Hg
1	0.07	600	0.04	28	78	28	4	15
2a	0.01	700	0.03	240	50	30	18	10
2b	0.01	700	0.02	400	46	5	4	4
3	0.001	700	0.01	210	22	56	63	55
4	0.001	700	0.01	250	1	33	44	30
5	0.001	700	0.001	450	1	1	1	1

the positive ions must receive enough energy to provide secondary electrons when they impinge on the cathode.

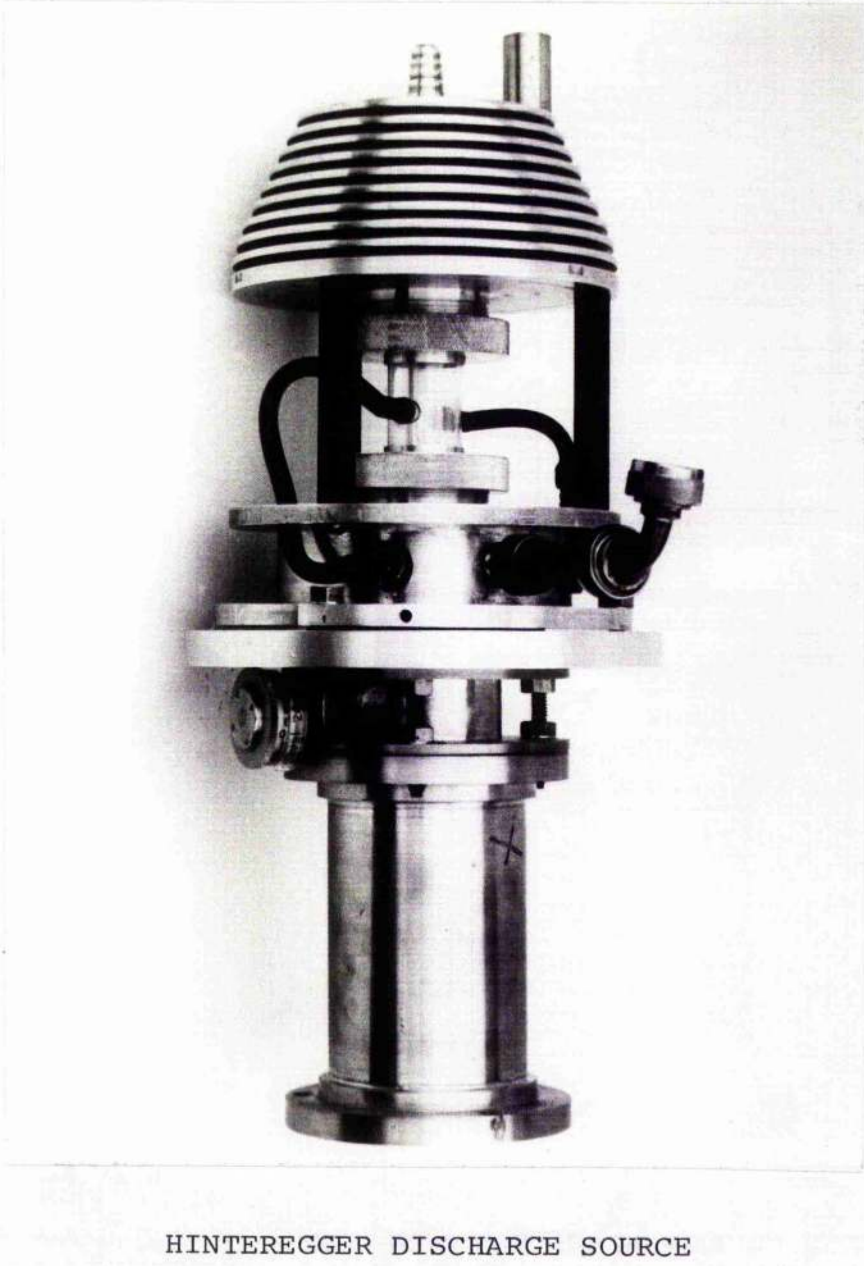
A source employing this principle was constructed by the author to investigate the possibility of using such a device for calibrating the rocket photometers. The design owed its origin to W.R. HUNTER of the Naval Research Laboratory, Washington, D.C. The design employed a water cooled cathode and had a quartz capillary sealed into the hollow cathode. This was opposite to the normal technique of cooling the capillary and permitted the quartz capillary to run hot and prevented water entering the vacuum system, should the capillary break. The source consisted of a 4" diameter quartz disc with a quartz capillary of 4mm bore sealed through its centre and with the centre faces ground to a finish suitable for O-ring seals. The cathode and anode sections clamped on either side of the disc, which acted as an insulator between them. A hollow aluminium cylinder was placed within the water cooled cathode and permitted easy replacement of the cathode when necessary. The whole assembly was clamped together with two Tufnol discs. The lamp was operated at an excitation voltage of 700vd.c. and at a current between 200mA to 300mA. Using such a source, it was possible to excite molecular lines and the resonance lines of atoms. The source was found to be excellent for producing the line spectrum of hydrogen in the region 900Å to 1675Å and the continuum above 1675Å.

THE HINTEREGGER DISCHARGE SOURCE

Perhaps one of the most useful ultraviolet sources was that of the d.c. discharge in helium at high pressure. The discharge was initiated by applying a d.c. voltage (typically 800v) across helium at a relatively low pressure (80mm Hg). When the pressure was increased, the discharge became self-triggering and produced a strong continuum from 1050Å - 4000Å. This phenomena was first discovered by TANAKA et al (1958) and further investigated by TANAKA, HUFFMAN and LARRABEE (1961). The continuum was strongly observed over the pressure range 100-600 mm above which pressure range very little advantage was obtained. The HeII line at 1640.4Å and several other lines at 3188Å and 3889Å were predominant. There were, in addition many different bands of helium produced in the region 500Å - 600Å as well as the HOPPFIELD continuum in the region 600Å - 1000Å. The continuum was extended from 1650Å to beyond 2000Å by using argon as the exciting gas, and operating the discharge at a pressure of 150mm Hg.

In practice the source, which owes its origin to Hinteregger utilised a water-cooled quartz capillary discharge tube mounted between an air cooled cathode made of 99.9% purity aluminium and a water cooled anode. The capillary tube was sealed to each electrode by knurled clamping flanges which were located on threaded extrusions on the electrodes, the seal being made of "O" rings recessed within the flanges. The whole assembly was rigidly supported by three Tufnol spacers and is shown in Plate 1.

PLATE 1



HINTEREGGER DISCHARGE SOURCE

In normal use such sources are employed in the "free flow" mode i.e. the exciting gas flows through the discharge into the monochromator and is then pumped out in the normal evacuation of the chamber, however, in the present application it was desirable to run the source independent of the calibration chamber and a window cell was fitted to the anode mounting flange. Using this cell, it was possible to mount a variety of 1" diameter windows, the windows being held in the cell between two "O" rings. The most commonly used window material was lithium fluoride and great care was taken to avoid bringing the window into contact with any cooling water, the crystal being very hygroscopic.

In practice, the gas entered the capillary tube via a vacuum coupling attached to the cathode. The pressure was measured on a Pirani gauge and the rate controlled by a Leybold calibrated leak valve. The power supply consisted of an unregulated d.c. supply originally used for discharge cleaning in the Observatory's 36" mirror coating plant. The supply had a current capacity of 500mA and was variable between 0-2Kv d.v. by means of a Variac transformer in the primary circuit. Typical operating conditions for the helium continuum were 700v d.c. and a current of 300mA. The author would like to acknowledge the assistance given by Dr. H. HINTEREGGER of the A.F.C.R.L. Cambridge, Mass.U.S.A. in developing this source.

ABSOLUTE PHOTOMETER CALIBRATION AT 1470Å and 2200Å

As previously indicated a commercial source of nearly monochromatic radiation was the EMR low pressure xenon lamp which when operated under carefully controlled conditions, produced a suitable source of radiation at 1470Å. Since the accuracy of calibration stated by the manufacturers was not good enough for the rocket photometer calibration the author supervised the re-calibration of two such lamps at the production plant in Princeton, New Jersey. In practice the EMR xenon calibration lamp was placed at the entrance slit of the collimator monochromator which was then set to 1470Å and in this way any residual radiation from the lamp other than 1470Å was effictively filtered out and only monochromatic 1470Å radiation filled the Cassegrain collimator. The incident flux on the stellar photometer was then measured by placing each of the EMR photo-diodes in the incident beam and monitoring the anode currents. In this way the incident flux could be accurately measured. The rocket convertors were then switched on and the EHT on the photometer photomultipliers set to the flight value and the output voltage from the detector electrometer amplifier noted. This procedure was repeated at different chamber pressures in order to ensure complete oxygen removal from the calibration path. This calibration procedure was repeated for the 2200Å photometer in order to establish the wing sensitivity of the photometer at 1470Å.

Since it was impossible to repeat the calibration at NPL due to the non-availability of a calibration service below 2537Å, the author arranged for a complete re-calibration of the rocket photometers to be carried out at the high temperature arc facility of the Max Planck Institute, Garching, Munich. As previously indicated this facility simulated a high temperature continuum source over the wavelength range 1100Å - 2500Å.

As part of the Institute's own stellar programme, the arc was usually attached to a Cassegrain collimator, similar to the one then in use at the Royal Observatory Edinburgh. In order to make as accurate a calibration as possible, the intensity of the plasma prior to filling the Cassegrain collimator was measured by means of the 543P diode for some twenty wavelengths and a comparison with those values measured independently at Princeton is shown in Table 3. The incident intensity falling on the stellar photometer, when using the Cassegrain collimator, was then measured with the standard 541F detectors operating as photomultipliers (this was necessary because of the low light levels). A comparison of the detector responses is shown in Table 4, and in view of the accuracies for the full and attenuated beams, as measured by the Max Planck staff, the agreement was excellent. The R.O.E. procedure for the calibration of the complete photometer was then repeated using the high temperature arc collimator and the output signal from the electrometer photometer noted at each wavelength. The photometers were then scanned $\pm 30^{\circ}$ to the incident beam to establish the field of view dependancy of the output signal. This was carried out at three wavelengths. The spectral response of each

TABLE 3

EMR v MAX PLANCK, PHOTO DIODE CALIBRATION

543P-08 PHOTODIODE

S/N 15698

WAVE-LENGTH Å	MAX PLANCK %Q.E.	%Q.E.
1216	11. 3	8. 8
1300	8.37	8.15
1400	5.43	6. 8
1500	4. 5	7. 5
1600	4.78	9. 5
1700	4.97	11. 8
1800	6.80	13. 4
1900		14. 4
1931	8.51	
2000		—
2100		
2200		
2300		
2400		
2478	9. 9	
2537	10.09	
2600	4.62	
2700	2. 5	
2800		
2900	2.34	
3000	3. 4	
3025		
3125		
3250		
3341		
3650	.01	
4046	,002	

TABLE 4

BOLDT ARC INTENSITIES

Tolerance of spectral intensities in the parallel beam of the UV-calibration facility derived from the cascade arc.

(Measurements of the single optical components of the equipment necessary)

(ÅU)	(Intensity cascade arc) $d\bar{J}_\lambda(\Delta_\lambda)/\bar{J}_\lambda(\Delta_\lambda)$	Accuracy (Efficiency of the equipment) $d\bar{E}_\lambda / E_\lambda$	Total Full beam	Total reduced beam
1000	18	20	38	41
1100	15	20	35	38
1163	15	10	25	28
1800	12	10	22	25
2200	11	15	26	29
2850	15	20	35	38
3250				

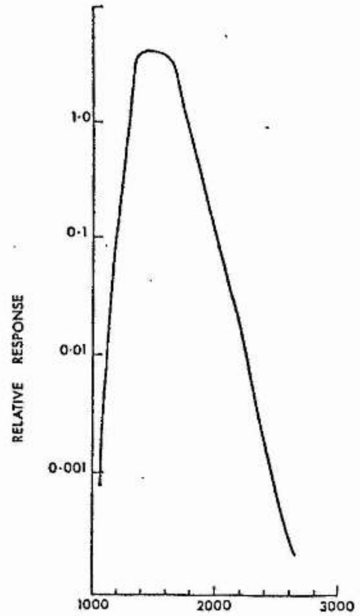


Fig. 7.

SPECTRAL RESPONSE at 1470Å and 2200Å

photometer at 1470Å and 2200Å is shown in Fig .

ABSOLUTE PHOTOMETER CALIBRATION AT 2500Å

Since there was very little output from the 1470Å Xenon source at 2500Å and the Max Planck arc output was also quite small, extensive use was made of the calibrated 2537Å pea lamp which replaced the Xenon lamp at the entrance slit of the calibration monochromator. The monochromator was then set at 2537Å to ensure purely monochromatic radiation illuminated the photometers. The calibrated EMR photo-diodes and photomultipliers were then used to measure the incident radiation and the rocket photometer calibrated as for the 1470Å calibration. The overall spectral response of the photometer was measured at over twenty wavelengths using the Hinteregger and Microwave discharge sources in place of the pea lamps. Angular sensitivity measurements were taken at $\pm 30^{\circ}$ to the optical axis of the photometer at several wavelengths in the passband.

FINAL FLIGHT CALIBRATION

During the period of developing the absolute calibration procedure the author was engaged in designing a vacuum simulator facility at the Observatory for the S/68 satellite experiment and having commissioned the new system without undue problems, its first use was the flight calibration of rocket payloads S27 and S47. The system employed ion pumps and a bake-out facility and reached an ultimate pressure of 3×10^{-6} torr in forty-five minutes. This ultimate pressure ensured very little residual oxygen in the system.

The original Cassegrain collimator/monochromator system was attached to the end of the new system and operated in the normal way. During the six months commissioning period of the new system no problems were encountered and the author would like to acknowledge the co-operation of the engineeering staff of General Engineering Ltd. Bury, Manchester, during the construction of this facility.

CHAPTER IV

PAYLOAD INTEGRATION AND FLIGHT PERFORMANCE

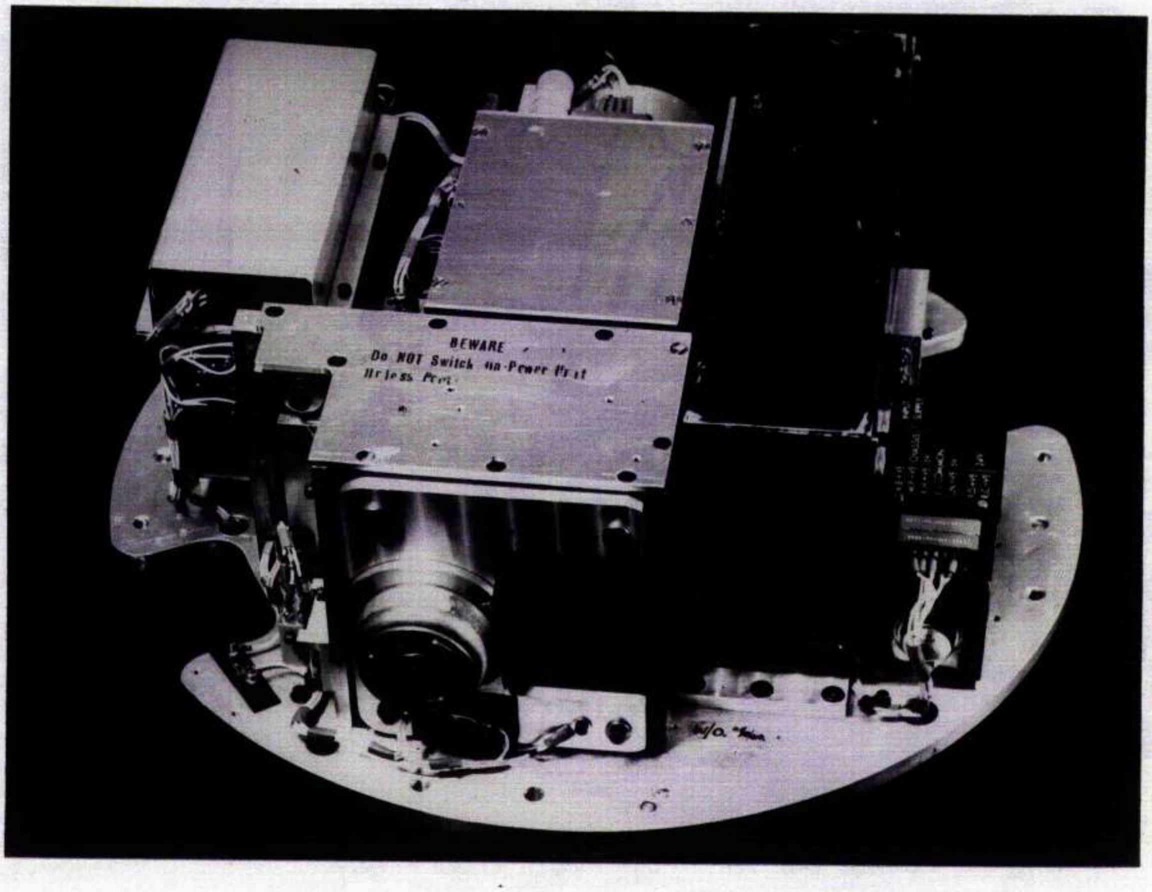
The material in this thesis covers a period of about a decade in rocket astronomy from 1962 to 1971 and since the results were the only ones to be obtained during this period, it is perhaps worthwhile to detail each payload separately and to indicate the developments which took place during this time from the first ESRO launch of a stellar payload (SO5/2) from Sardinia in 1967 to the last ESRO launch of a similar payload from WOOMERA in September 1971.

As ESRO was a very young organisation, it was probably predictable that there would have been teething troubles and what follows indicates just how difficult the early days of European rocket astronomy turned out to be.

SKY BRIGHTNESS MEASUREMENTS IN THE REGION 1650Å to 3200Å

Prior to getting involved in the ESRO programme the author collaborated with a fellow Royal Observatory scientist MR. G. C. SUDBURY, in an experiment to measure the sky brightness in the ultraviolet region by day and by night.

The instrumentation photometer was designed by the author and is shown in Plate 1, and consisted essentially of a rubidium telluride quartz windowed CBS photomultiplier, in front of which was periodically inserted cut-off glass filters, which progressively narrowed the measurement passband from 1650Å - 3200Å, to 2200Å - 3200Å and 2700Å - 3200Å. In this way, it was hoped to obtain stellar data as well as general ultraviolet sky brightness measurements. The



SKY BRIGHTNESS EXPERIMENT

PLATE 1

wheel positioning was achieved by the use of an indexing rotary solenoid every fourth position of which in the six position cycle, the amplifier sensitivity altered by a factor of ten. The signal output, wheel position and amplifier range were telemetered to the ground station. As there was a possibility of the photometer in the daytime experiment looking directly at the Sun, a solar sensor was placed in front of the photomultiplier which, when the optical axis pointed within $\pm 30^{\circ}$ of the solar vector inserted a shutter. Both the wheel indexing mechanismn and the solar shutters were designed by MR. G. C. SUDBURY of the Royal Observatory, Edinburgh. The photometer mounted easily within a Type III Skylark section and viewed the sky through a set of metal baffles.

Because of the simplicity of the experiment it was included as a secondary experiment on a pair of rockets assigned to the University of Sheffield. The rockets, designated SL 140 and SL 141 were integrated, without any vibration simulation by the British Aircraft Corporation, Bristol and shipped to Australia in September 1964. After an uneventful countdown SL 140 was launched at 0338. CST on March 17th. 1965, and rose to the low apogee of twelve miles impacting four and a half miles from the launcher. All experimental systems functioned correctly for approximately twenty-eight seconds and the author must have stood dumbfounded for at least another thirty seconds before being told that trial SL 140 was terminated due to round failure.

The crashed payload was recovered and since the Sheffield University antenna system was found in a deployed configuration and the jettisonable nose cone was not recovered it was assumed that the round malfunction was due to the premature ejection of the nose cone, causing the rocket to pitch over and crash. The daytime version SL 141, was launched at 0936. CST on March 25th 1965 and achieved an apogee of approximately 96 miles and a flight time of 550 seconds. The photometer worked well but the slow response of the solar sensor allowed sunlight to scatter within the baffles and very little meaningful scientific data was obtained.

From the author's point of view, considerable range experience was obtained and a high figure of confidence obtained in relation to the electronics designed for the stellar photometers in the ESRO programme.

THE ESRO ROCKET PROGRAMME

Prior to the launch of the two experiments flown in Woomera, the author had proposed to ESRO in 1963, a number of stellar experiments employing filtered optical telescopes of the types described in the chapter on instrumentation. These photometers were designed to obtain absolute stellar fluxes in the region 1350Å - 3200Å. The proposals were accepted and became the backbone of the ESRO stellar astronomy programme consisting of eight Skylark rockets to be launched in the period 1965 to 1971. Each payload had a different scientific aim and the technical configuration changed as the experience of both organisations increased.

Before the formation of the ESRO organisation, all rocket experiments from British groups were conducted at the Woomera Test Range in Australia and no observations had been carried out in the Northern Hemisphere. However, ESRO were given the use of the Italian sounding rocket range at Salto di Quirra, Sardinia, situated 39° 33' 54" north and 9° 29' 58" east and 672 metres above sea level. No telemetry receiving equipment was available and a portable receiving station was set up for the first ESRO launches.

ESRO PAYLOAD SO5/1,2.

This payload was the first fully instrumented payload to be undertaken by ESRO, previous launches being sodium grenade and barium release experiments and the new payload complexity seemed daunting to both the ESRO personnel and the experimenters. The technical configuration for the first payload is shown in Fig. 1.

Two stellar experiments were proposed, one to measure stellar fluxes at two wavelengths centred on 2150Å and 2550Å with passbands of the order of 200Å and the second experiment proposed by Mr. G. C. Sudbury, to obtain medium resolution spectra in the region 1450Å - 3000Å with a resolution of 120Å. The rocket attitude determination was to be obtained using an ESTEC moon sensor and an orthogonal set of magnetometers. The newly developed type $\overline{\text{VIII}}$ jettisonable hatch system was to be given its first flight trial. After preliminary integration at the ESTEC laboratories in Delft the payload was shipped to Sardinia

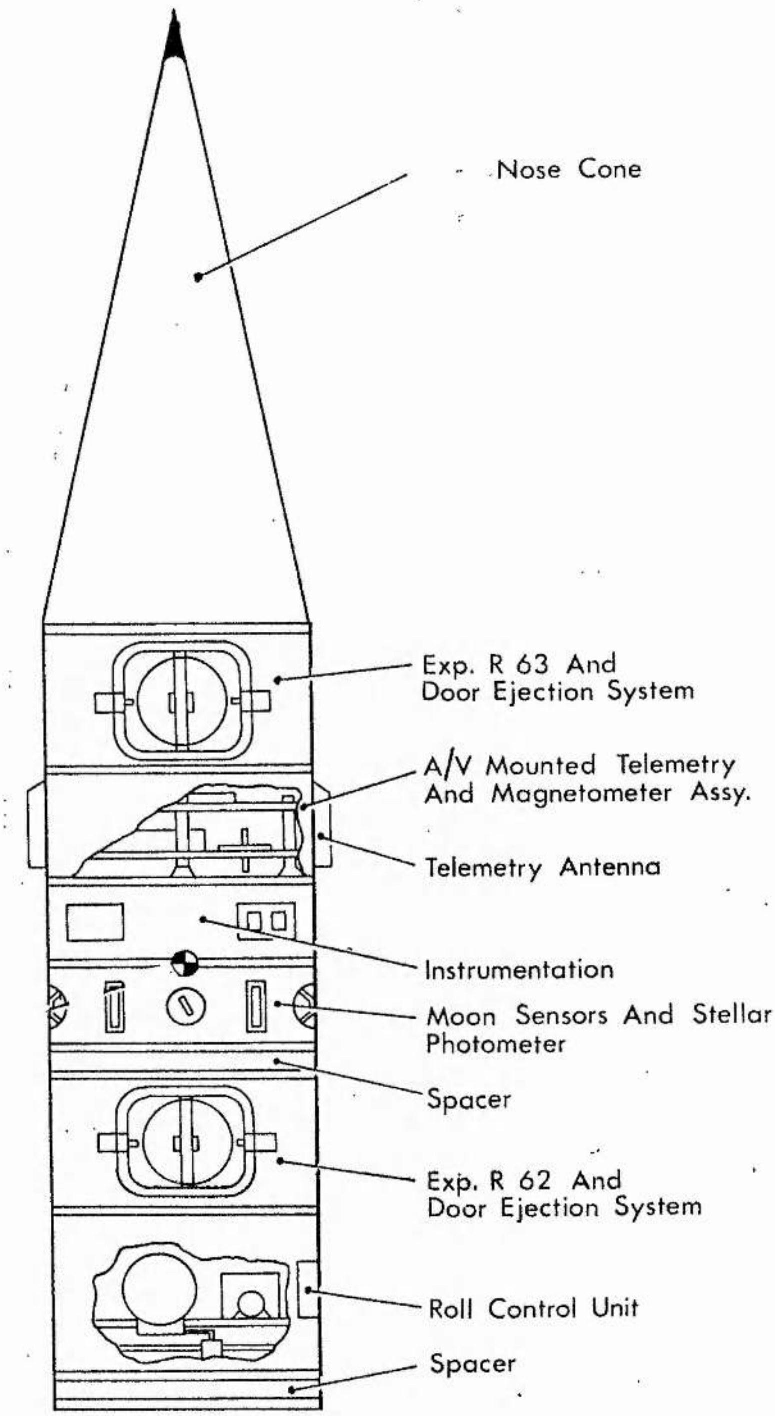


Fig. 1.

ROCKET BUILD S05/1

in July 1965 and assembled in an old military barracks on the range. The payload was installed with difficulty in the launcher on the 9th. August and after a far from uneventful countdown, including the two project scientists being arrested by the security guard on the range when trying to drive the 18km from the launcher to the telemetry station which incurred a hold in the countdown for 45 minutes ; the payload was launched on 11 August 1965. It is history that the launch was a disaster and indicative of the extreme difficulties which accompanied this first fully instrumented launch. A number of instrumentation failures occurred and in particular:

(a) The non-ejection of the twin photometer hatch cover did not permit a satisfactory working instrument to view the sky.

(b) The excessively high roll rate of 120 degrees per second did not allow the spectro-photometer to record a complete spectrum and no scientific data was obtained.

(c) The intermittent operation of the telemetry transmitter lost a lot of data due to corona breakdown in the electronics.

(d) The ESTEC moon sensor system failed after launch as did one of the magnetometers.

Because the first launch was so unsuccessful the experimenters requested that the second payload S05/2 should not be launched till an assessment of the technical malfunctions of the first rocket systems could be undertaken

The campaign Director MR S. J. POOLEY agreed and the campaign was abandoned. Although a grave disappointment it should be remembered that this was the first complex rocket payload which ESRO had constructed and with a very inexperienced team.

The technical specification of payload SO5/2 was completely revised and a new telemetry and attitude sensing system introduced. Extensive testing of the hatch release mechanism was undertaken by the B.A.C. Bristol, and simulated launch conditions showed the new design of hatch release mechanism to be satisfactory. A roll rate control unit similar to that proposed by the author for payload S11/1 was fitted to ensure a satisfactory roll rate of 25 degrees per second in flight.

The rebuilt SO5/2 payload was flight tested at ESTEC on 30th. June 1966 and despatched to Sardinia on 10th. July. Malfunctions of the ESTEC attitude sensing system during range integration made it impossible to guarantee its successful operation in space, and the payload was returned to ESTEC for a re-design of the moon sensors and the launch was re-scheduled for May 1967.

ESRO PAYLOAD S11/1, 2

During the delay period to payload SO5/2, the author had been preparing another set of experiments on two shared rockets with the University of Bologna and the configuration of these rockets is shown in Fig. 2. The experimental package was a twin channel photometer as before, but the payload was fitted with a new Space General roll rate

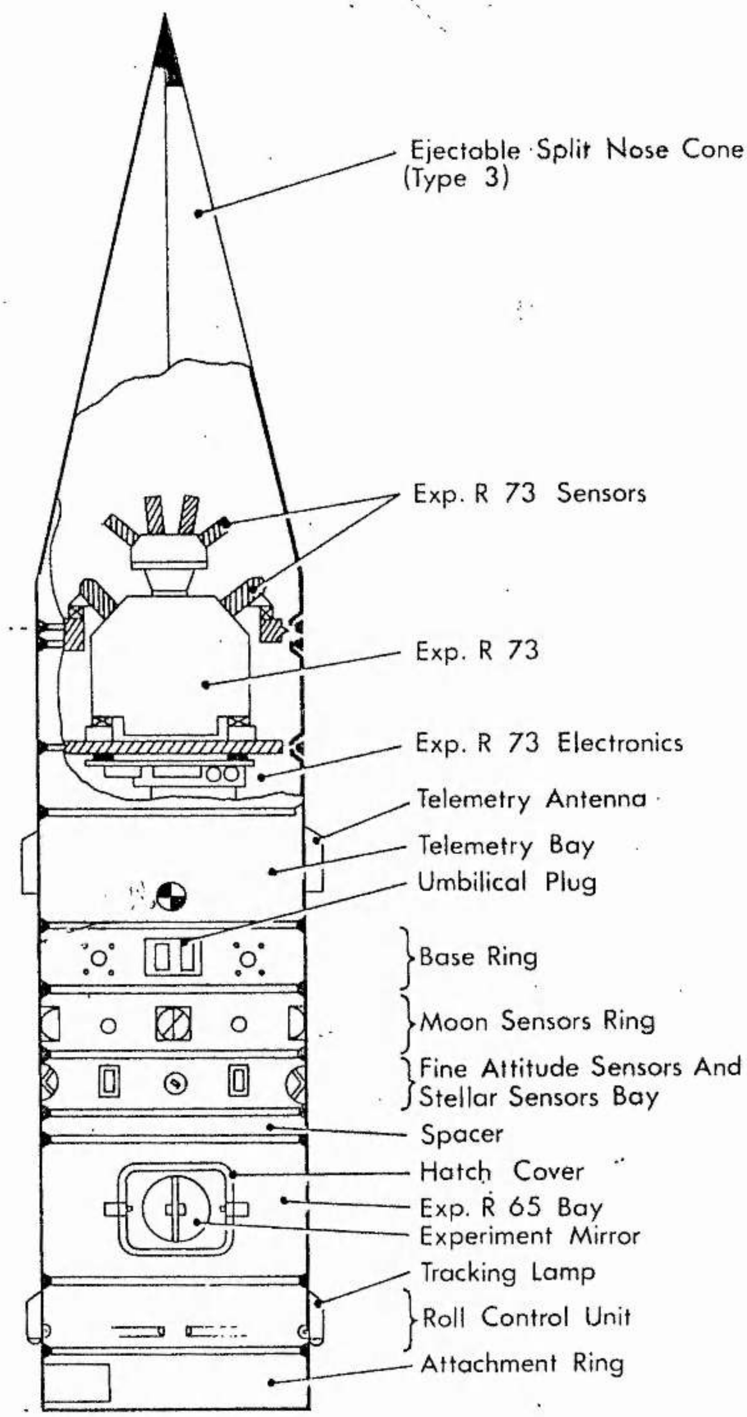


Fig. 2.

ROCKET BUILD S11/2

control unit specially designed for the experiment. In addition, because of the considerable modifications necessary to the ESTEC equipment on S05/2, the contract for payload construction was given to the British Aircraft Corporation, Bristol, the prime contractors for the U.K. National Programme. Such a decision was not without difficulty since the British telemetry system was totally different from that used by ESRO and delays were incurred in setting up a completely new telemetry station at Bristol. The Company did however, have considerable Skylark experience, and a speedy integration of the experimental equipment from both groups ensued. This was highly commendable in view of this being the first B.A.C. payload for ESRO and the large distances separating the two experimental groups.

The payload was shipped to the range on 8th. November, 1966 and tested in the draughty old military barracks. No incidents were incurred except the rafter of the roof caved in when the payload was undergoing attitude sensing tests. A further small incident occurred when the launch team removed the communal refrigerator which stored the soft drinks, stating that it was part of the launch facilities. Considerable difficulty was encountered in using the ESRO antenna on the telemetry station and a portable antenna was kindly loaned by SUD Aviation. The payload was finally launched on the 26th. November at 20.11 C.E.T. and the boosted RAVEN V1A motor left the launcher successfully.

After forty-three seconds the rocket impacted 1km down range and exploded, burning for over half an hour. Thus the author had the dubious honour of undertaking the first archaeological experiment for ESRO on Italian soil.
The effect of the rocket failure was unbelievable. The scientific groups were overcome with a feeling of disbelief and in particular Professor BRINI of the University of Bologna, who had witnessed the launch was thunderstruck. Everywhere, the stunned silence was noticeable and particularly the military authorities, who had never had a rocket explode on the base before, seemed unable to fully grasp the situation and an investigation was ordered for the following day. The outcome of the investigation indicated that although small pieces of the rocket motor were found, the booster and fin assembly were missing. The Raven burster disc which sealed the rocket venturi was found in position, indicating that the Raven V1A motor had not been ignited. Examination of the kinetheodolite and high speed camera records indicated that after ten seconds the Cuckoo booster appeared to fall away from the Raven. At nineteen seconds the Raven and payload reach apogee, and after forty-three seconds the motor and payload impacted. No Raven ignition was observed on the films.

The correct functioning of the telemetry and payload and the subsequent recovery of the nose cone seemed to indicate a malfunction of the Raven V1A motor and since this particular batch of motors was due for firing at

Woomera in the British National Programme, there was a considerable urgency to establish the probable cause of the motor failure.

The British Aircraft Corporation, who had supplied both the payload and the launch services, were given the task of ascertaining the cause of the malfunction and as it was proposed to fire the second S11 payload in the same launch window, time was of the essence. A search for the Raven ignition unit was unsuccessful and the ESRO authorities directed that the second payload should be launched. Both scientific groups disagreed with the decision, since the basis for a second possible disastrous launch was very flimsy. The onset of the Mistral wind resolved the situation making a launch totally impossible, and payload and motor were returned to Bristol. Subsequent examination of the recovered pieces of motor and the second motor and ignition unit, indicated a fault in the wiring of the ignition unit. Normally the second stage unit was armed with a "Plocket" i.e. a socket and plug connection. In the case of the second Raven motor, the ignition unit had two sockets and no plug. A more thorough search by the range authorities located the original ignition unit which also had two sockets. This meant in practice that although a firing pulse would be sent to the Raven ignition unit, since there was no connection, ignition would not have taken place. If the second rocket had been launched the outcome would have been the same and although an extra-ordinary amount of carelessness was evident in the wiring circuit of the first Raven, the decision to postphone the firing due to the high winds, showed that Someone was looking after the experimenters' interests. This further disastrous campaign after the abortive SO5/1 failure, made the writer strongly doubt the advisability of pursuing with this type of research until the ESRO system had become more organised.

Both campaigns were thoroughly investigated, introducing delays into the launching of SO5/2 and S11/1 which were eventually scheduled for launch in May 1967.

ESRO PAYLOAD S11/1

The flight configuration of the re-designed payload is shown in Fig. 3. and in place of the original telemetry antenna, a quadraloop antenna was fitted to ensure good ground reception during the flight. Temperature sensors were fitted to the moon sensors as a result of the poor temperature performance of the earlier SO5/1 moon sensors and a type III nose cone assembly was substituted for the earlier Type II system, which had become suspect, after several premature ejections during the U.K. National Programme launches. The pneumatically activated plungers on the type VIII hatch units were replaced by pyrotechnic activated valves. The flight acceptance checks were completed by the B.A.C. at ESTEC on 21st. April and the payload shipped to the range.

On the range, extreme changes had taken place, not the least of which was an entirely refurbished telemetry receiving station at Monte Cardiga. In addition the

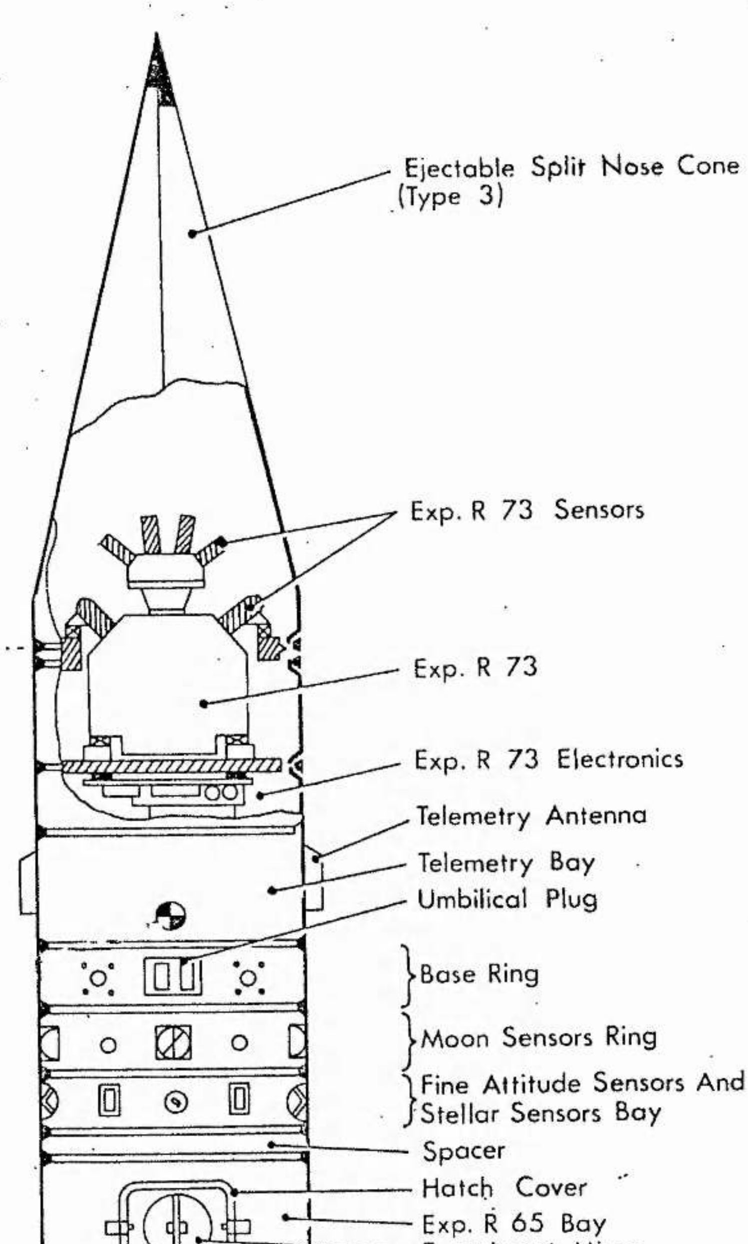


Fig. 3 .

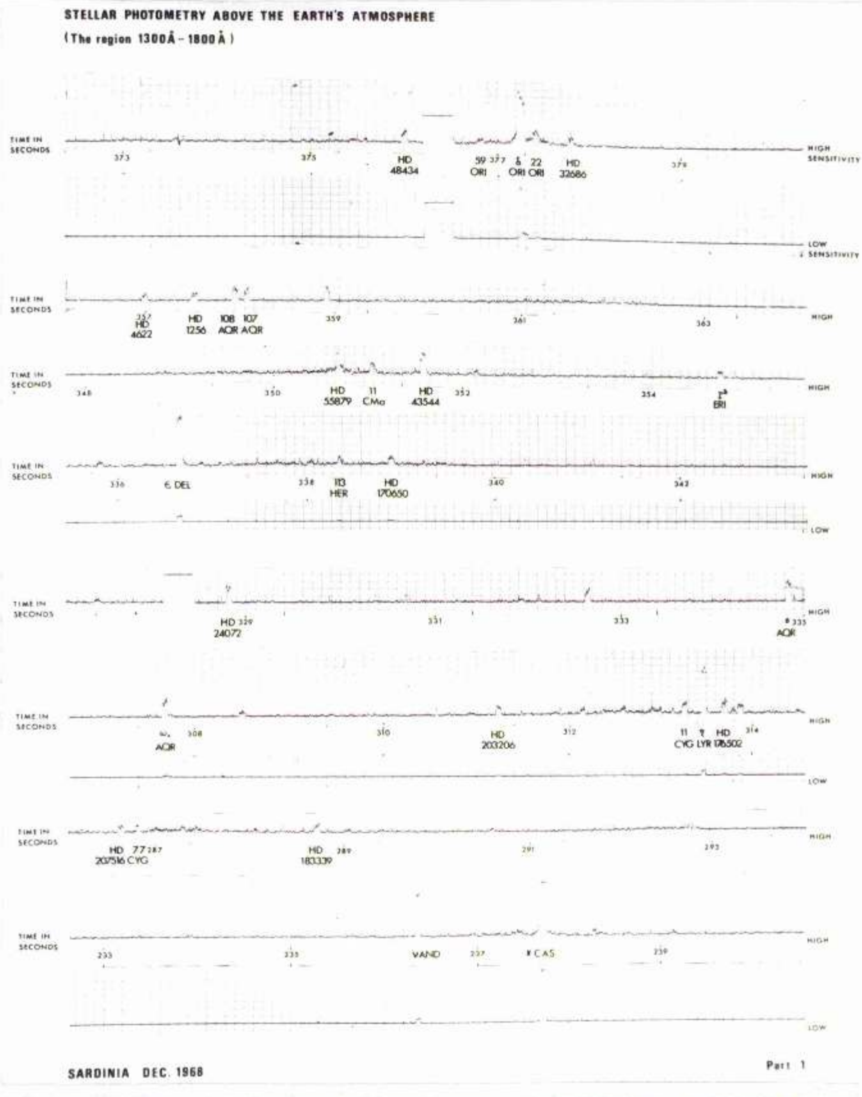
ROCKET BUILD S11/1

faithful old barracks building was turned over to the goats to be replaced by a strong, draughty, leaking, aluminium assembly hall. The hall had been erected in the winter and no one had checked the floor which had become corrugated with rises and falls of several feet. However the hall did permit the assembly of more than one payload at a time and this was a most useful development. The overall range preparation was undertaken without incident over a period of two weeks and the payload placed in the tower on the 16th. May. Unfortunately, heavy rain storms necessitated the removal of the payload and it was not replaced in the launcher until the 19th. May. During the countdown, one of the L.T. convertors failed and was replaced without removing the payload from the tower. The countdown was restarted but the gas in the roll rate control unit escaped and the payload was once more removed. The countdown was restarted on the night of 21st. May and the payload launched at 00.11.57 U.T. on 22nd. May 1967 under conditions of clear skies, low wind and one day before the full Moon. The payload had a spin rate of 30°/sec after +59 seconds, which decreased to 10°/sec at +70 seconds when the roll rate unit was fired. Within two seconds a roll rate of 18°/sec was established and remained until +385 seconds. An apogee of 144.2Km was achieved and the five radars tracked for +133 seconds. Good telemetry reception was achieved for 7 minutes 30 seconds and no reception faults were observed. The nose cone protecting the University of Bologna experiment was satisfactorily ejected at +65 seconds followed by the stellar photometer hatch cover at +67 seconds. The high voltage to the stellar experiment was switched on at +72 seconds and no corona was observed. Excellent stellar data was received at 2150Å and 2550Å for over fifty stars and thus the writer had the honour of obtaining the first European stellar photometry results from above the Earth's atmosphere. The standard moon sensors functioned satisfactorily until nose cone deployment, i.e. 65 seconds after which no further signals were detected. The thrust axis magnetometer failed, leaving only two magnetometer channels working. However, the two stellar attitude sensors designed by the author worked correctly permitting data to be obtained from the Moon, stars and the Earth's albedo which enabled an attitude solution to be achieved some eighteen months later by the data centre ESOC, at Darmstadt. The data from these sensors is shown in Plates, 2, 3.

In view of the depressing success rate of earlier launches, these first stellar results gave a boost to all concerned and made the events of the previous two years of less importance.

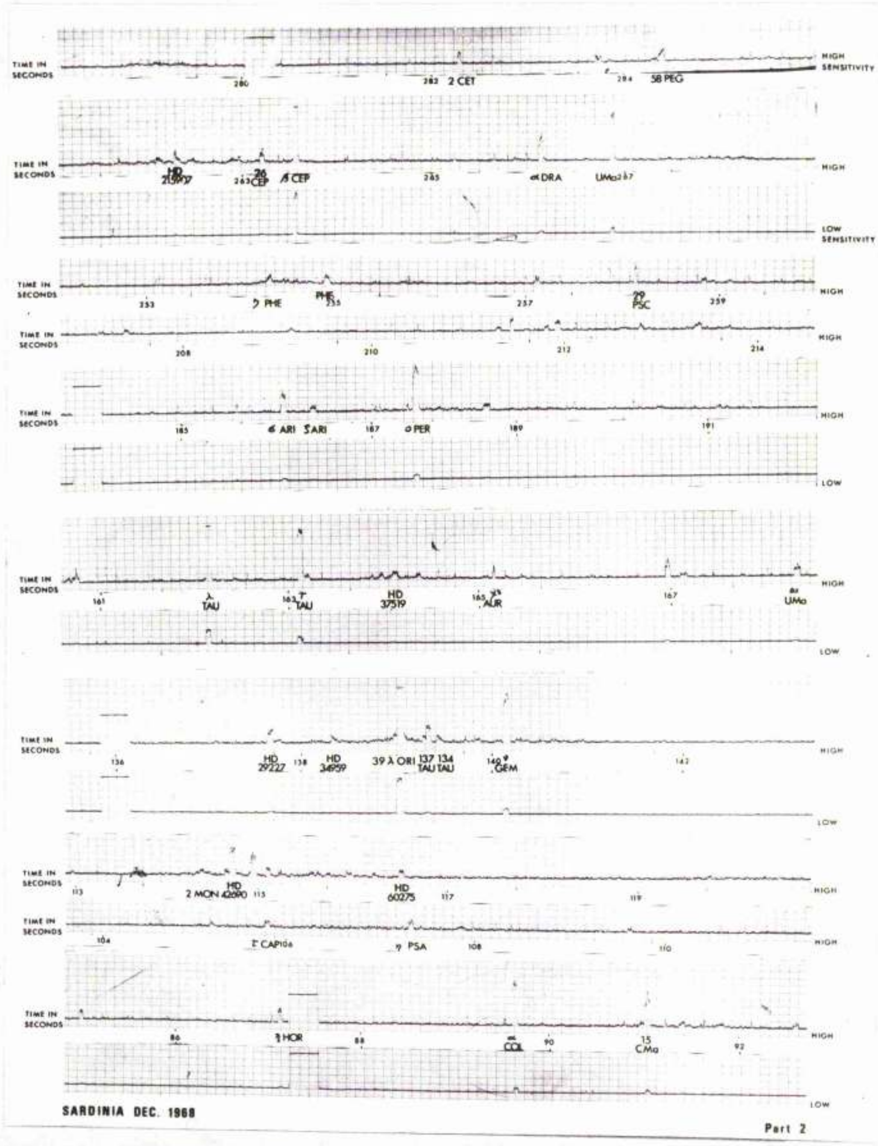
ESRO PAYLOAD S05/2

As stated earlier, this payload was delayed due to the malfunction of the ESTEC equipment and was scheduled for launch in May 1967 with S11/1. Extensive modifications were undertaken including the provision of new timers, new ejection system, new moon sensing equipment, new telemetry and the installation of a roll rate control unit by Space



STELLAR DATA FROM ABOVE THE EARTH'S ATMOSPHERE

PLATE 2



STELLAR DATA FROM ABOVE THE EARTH'S ATMOSPHERE

PLATE 3

General Co. set for 27°/sec. Additionally, in view of the earlier experience the author added a simple stellar attitude sensor. Flight acceptance tests were carried out at CNES, Paris. Additional tests were carried out at Delf at the beginning of April 1967 and the payload shipped to the range at the end of April. The flight configuration of the payload is shown in Fig. 4.

The payload was placed in the launch tower on 22nd. May after the successful launch of S11/1 but the countdown was abandoned after T-45 minutes because of interactive noise on the telemetry channels caused by "beating" of the different experimenters' convertors. The payload was removed from the launcher and separate battery supplies fitted. This simple modification cured the problem and the payload was returned to the launcher on 29th. May. High winds and rain prevailed and the countdown was abandoned after five hours. The conditions were similar on the 25th. May and the payload was eventually launched under marginal conditions at 00.24 L.T. on the 26th. May. The payload reached an apogee of 239Km and achieved a spin rate of 223°/second which was de-spun to 28°/second with the switch on of the Space General roll rate control unit. Telemetry reception was strong and clear for a total flight time of 530 seconds. All hatches were ejected and no corona observed when the photomultiplier EHT was switched on. The moon sensors and megnetometers functioned satisfactorily, as did the additional stellar attitude sensor. Good stellar data at 2150Å and 2550Å were

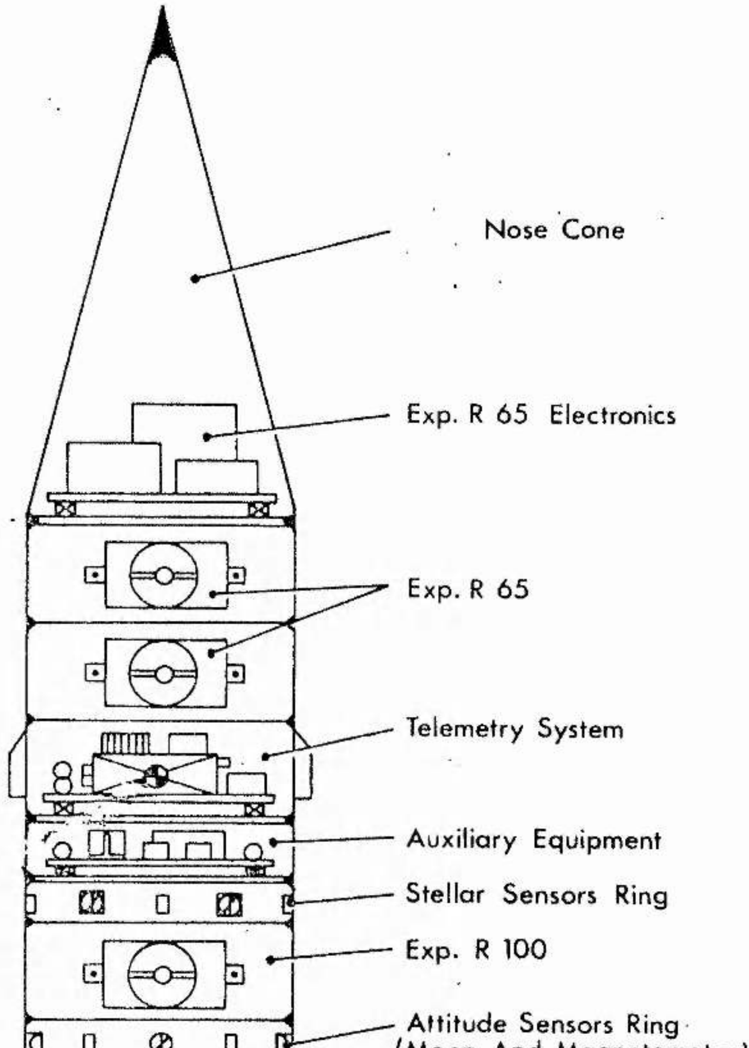


Fig. 4.

ROCKET BUILD OF SO5/2

received and the stars were subsequently identified when the attitude solution was obtained some twelve months later.

ESRO PAYLOAD S47/1

The considerable number of technical failures of equipment other than the experimental payloads had the effect of increasing the complexity of the experiments, since in a finite programme, aimed at getting scientific data in a realistic timescale, each launch became increasingly important, as the failure rate of the ESRO supplied equipment increased and every possible effort was made by the author to ensure that when a successful launch was achieved the maximum number of observing channels were operative. Such a desire made additional demands on the payload composition and S47/1 was the most complex to be engineered under the ESRO launch programme.

The selection of a new contractor for this payload caused some concern to the author, since if a well experienced contractor such as the British Aircraft Corporation was experiencing problems in the ESRO programme, then this, the most complex stellar payload to date, might cause the SAAB Aircraft Company, LINKOPING, Sweden, some problems. However, it was soon clear by the very professional way in which the preliminary meetings with SAAB were conducted, that although this was their first Skylark contract, their many years in the missile field made them admirably suited for the task. The payload configuration adopted for S47/1 is shown in Fig. and because of the large number of telemetry channels involved, it was necessary to use

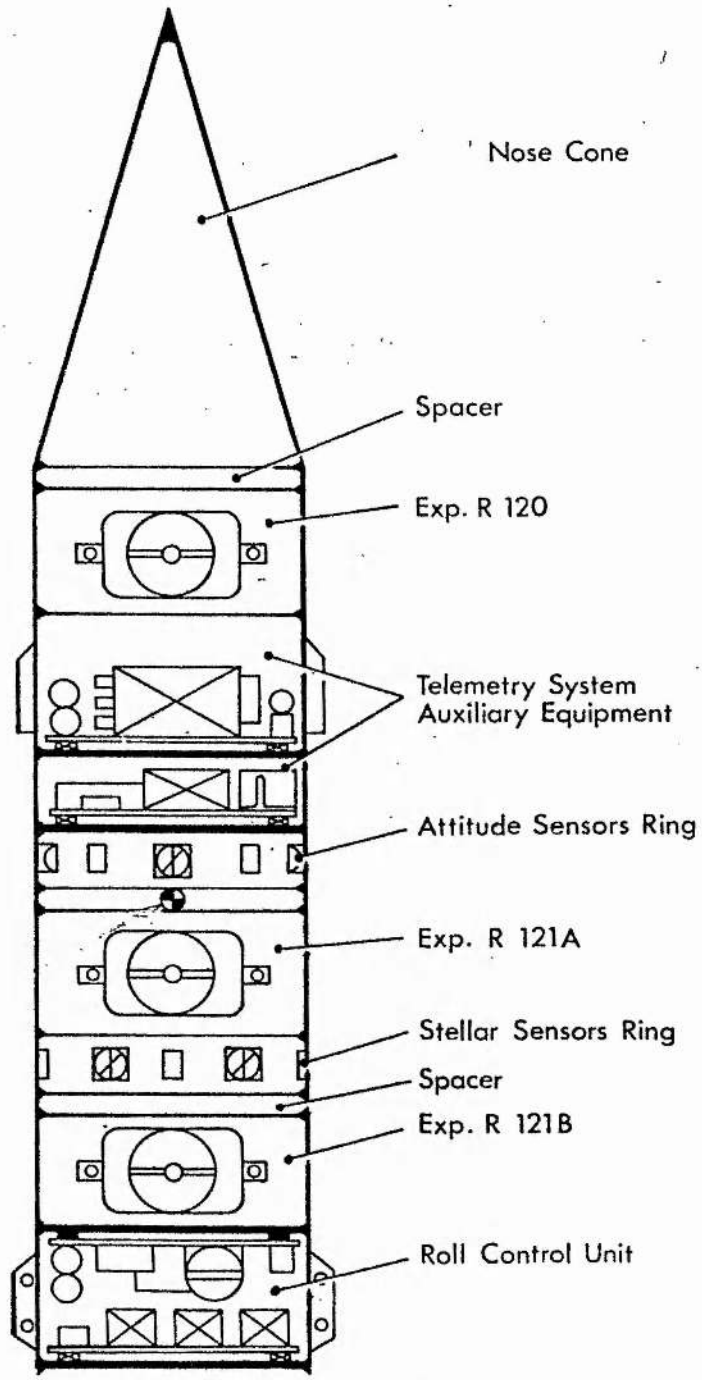


Fig. 5.
ROCKET BUILD S47/1

two transmitters, operating on different frequencies. In addition, one set of channels were multiplexed to give several 1KHZ bandwidth channels for a sky brightness experiment and two additional stellar attitude sensors. The total estimated weight of the payload was 257Kg and the overall length 4.65 metres.

As this was the largest payload yet to be launched the ESRO authorities insisted on a complete environmental analysis being conducted on the payload because of the possibility of high resonances which might be encountered with a payload of such a length. This rather exacting analysis was conducted on each sub assembly and several small design modifications to the stellar photometer was necessary. The expected high "Q" were encountered and resulted in the complete stellar photometers being anti-vibration mounted in each type VIII body section. A final vibration analysis indicated that no high resonances remained within the payload and it was shipped to ESTEC for final flight acceptance in September 1968. The payload was subsequently dispatched to Sardinia on the 23rd. of September.

As stated earlier, the wavelength isolation techniques used at 2150Å and 2550Å employed reflective mirror coatings which were susceptible to high humidity and as the launcher was constantly enveloped in heavy mists, a temporary heating structure was constructed round the upper part of the rocket containing the payload. By this means it was possible to ensure that the payload was kept very dry to eliminate the need for payload removal during bad weather as had been necessary with previous launches. The range preparation was carried out by the SAAB team in an efficient and incident free manner and apart from a faulty magnetometer which was replaced, very few problems were encountered. The payload was launched at 21.39.48. U.T. on 7th. October 1968 and reached an apogee of 208Km. Satisfactory telemetry transmission was received for 7 minutes 30 seconds. The sky brightness experiment observed more than fifty stars and made eleven brightness scans of the sky. The twin channel photometer centered on 2150Å and 2550Å transmitted no useful data since the Elliot Bros. roll rate control unit did not switch on and the natural roll rate of the rocket was ten times that calculated causing complete loss of data, since the multiplexed channels did not have sufficiently high bandwidth for the uncontrolled rocket. The large aperture Cassegrain photometer ceased to transmit useful data although prior to hatch ejection all monitors were normal and the amplifier calibration pulses were sent back normally up to the initiation of this event. It seemed highly probable therefore, that the loss of data was connected with the hatch ejection. The stellar attitude sensors worked exceedingly well.

A comparison of the expected stellar S4 magnitudes from the sensor against those predicted, is shown in Table 1 and the agreement although satisfactory, is not surprising since the emission from late type stars to which the photometers were sensitive, is clearly predictable from model atmosphere calculations.

TABLE 1

S-4 MAGNITUDES ABOVE THE EARTH'S ATMOSPHERE

B.S. No.	Sp. Type	Magnitude	B-V	Exp. Flux	Theoretical Flux
				$\times 10^{15}$ A cm^{-2}	
5867	A21V	3.67	+0.06	1.05	1.52
6771	A4V	3.73	+0.09	1.28	1.36
6431	B3III	4.6	-	0.525	0.67
5744	K2III	3.26	+1.17	0.584	0.92
5291	A01V	3.64	-0.05	1.05	1.76
3888	F21V	3.77	+0.30	0.525	1.18
7525	K311	2.62	-	0.80	1.27
8781	B9.5III	2.49	-	2.1	4.94
3975	AoIb	3.48	-0.02	1.75	2.0
4133	B1Ib	3.85	-0.14	1.75	2.14
4662	B8III	2.60	-0.11	3.5	5.28
5288	KOIII-IV	2.05	+1.02	2.5	-
5367	AOIV	4.04	-0.04	1.28	-
5107	A3V	3.36	+0.11	1.05	1.98
5338	F71V	4.07	+0.52	0.58	0.78
4248	AIV	4.75	-	0.876	0.66
4335	K1III	3.01	+1.13	0.934	1.21
4295	A1V	2.36	-0.02	3.56	5.51
8238	B2III	3.18	-0.25	3.15	4.08
8335	B3III	4.21	-0.13	1.46	1.31
4058	G7III	3.80	-	2.74	3.10
4031	FOIII	3.43	+0.31	1.34	1.53
403	A5V	2.68	+0.13	2.52	3.69
5028	A2V	2.76	+0.04	2.74	-
6175	O9.5V	2.56	+0.02	5.8	5.8
6075	G9III	3.24	+0.96	2.5	1.14
A7V	3.14	+0.18	1.63	2.19	
5788/9	dFO	5.16	-	1.28	1.21
	FO IV	4.23	-	-	-
5856	A5III	2.08	-	3.8	1.5
5193	B2V	3.47	-0.21	2.2	
5249	B2V	3.86	-0.21	0.6	

NOTE: S-4 is the manufacturer's type of photocathode used in the detector.

The systems failures were obviously very disappointing, but again were indicative of how difficult such observations were to achieve and the reason why in 1968 so few observations of this kind had been reported throughout the world. In view of the poor flight performance of the S47/1 launch of the second payload was postponed at the author's request and the payload returned to ESTEC.

The second launch was postponed for six months to enable a technical assessment of the modifications and any implications on the December launch of a new payload S27/1.

ESRO PAYLOAD S27/1

This payload, proposed in 1965, included a twin channel photometer of the earlier design, observing at 2150Å and 2550Å and a wide aperture single channel Cassegrain photometer centred on 1450Å. In addition, there was also a single channel medium resolution spectrophotometer prepared by MR. G. C. SUDBURY of the Royal Observatory. As was now standard, two stellar attitude sensors and a Space General Co. roll rate control unit set to achieve a controlled rate of 14° completed the payload build.

Because of the technical problems encountered with earlier ESRO launches, the launch of S27/1 was postponed from May 1968 until August 1969. During flight acceptance tests at ESTEC in September, the ASCOP photomultiplier which provided the 1470Å passband failed, and because there was a long delay in obtaining a replacement from the manufacturer in the U.S.A. the launch was postponed until early December. Flight acceptance tests were concluded in November, and the payload despatched to the range at the end of November. The payload build is shown in Fig.5, the contractor being the British Aircraft Co. Bristol.

Preparations at the range were uneventful and the heated payload assembly unit built round the launcher enabled the payload to be checked out directly in the tower. Unfortunately, a severe electrical storm on the 29th. November destroyed most of the blockhouse to launcher wiring, including the umbilical connectors and most of the range communication systems. After a considerable effort by the military and civilian personnel, the countdown was started on the 3rd. December and with some trepidation S27/1 was launched at 20.38.39. U.T. The payload reached an apogee of 198Km and good telemetry signals were received for 7 minutes 31 seconds. All events were initiated and a controlled roll rate of 14.3° per second achieved. Some thirty stellar spectra were obtained, fifty five stars observed at 1450Å and fifty-five stars observed at 2150Å and 2550Å. Good attitude signals were achieved from the moon sensors and magnetometers and also from the author's stellar attitude package. None--the-less it was eighteen months before the final reduced attitude solution was determined.

PERFORMANCE SURVEY

Although this thesis covers almost ten years of rocket astronomy, the time seems to have passed quickly and what has been described, represents almost ninety percent of the European effort in space astronomy using rockets. The failures were compensated by obtaining the first European stellar data and in fact the overall results obtained, more than equalled all the data published by all the other American groups during the same period. This was no mean feat considering that rocket telescope designs had to be developed and tested, roll rate control units designed, absolute calibration procedures investigated, hatches and other rocket hardware developed, attitude solutions derived and hardware built. The author flew over fifty photometers and only twenty-two actually looked out into space. The single channel 1470Å photometer equalled the observing data for the earlier U.S. satellite results of SMITH (1967) and were for many years the only far ultra-violet absolute stellar fluxes available.

The story is not altogether over, as another payload is yet to be launched (1971) and it is hoped that what will be ESRO's last stellar payload launch, may be their first Southern Hemisphere investigation from Woomera. However, the Northern Hemisphere saga is over and what better way to spend the author's early years in astronomy than the pursuit of that which was difficult and sometimes seemed impossible - the observation of stars above the Earth's atmosphere.

CHAPTER V

ABSOLUTE STELLAR FLUXES AT 2150Å and 2550Å

Although over 350 seconds of observation time above 80km was obtained during each flight, each star was on the average measured for less than 50 milli-seconds. One star, namely αLeonis, was observed twice on one flight and once on the other flight. The data were in good agreement indicating satisfactory internal consistency. All the observations were made above 140km and were uncorrected for oxygen absorption.

The telemetry records were reduced by measuring the amplitude of the stellar signals and comparing them with a standard current applied to the d.c. amplifier periodically throughout the flight. Each reading was converted into an absolute intensity using the known laboratory calibration for each photometer, and the value of the sky background subtracted in the same absolute units.

The reduced data are shown in Tables 1 and 2, where the (B-V) colour indices are from IRIARTE et al (1965) and the excesses E(B-V) calculated from the intrinsic values given by JOHNSON (1963). The ultraviolet colour indices are obtained from the relation

$$(m - m_V) = -2.5 \ (\log F - \log F_V)$$

where F_V is the monochromatic flux at a wavelength of 5475Å the effective wavelength as defined by the V filter of the UBV system. For early B stars, we have from

ABSOLUTE STELLAR FLUXES AT 2150Å and 2550Å

TABLE 1

Obsv. No.	H.D. Number	Star Name	Spectral Type.	M_V	(B-V) Obs	Observed Stellar flux Erg $cm^{-2} sec^{-1} Å^{-1} x10^{10}$ 5475Å	2150Å	2550Å	E(B-V)	$(M2150-M_V)$ Obs	$(M2550-M_V)$ Obs
1	358	α And	B8p	2.06	-0.11	5.70	16.4	12.5	+0.02	-1.15	-0.86
2	3360	ζ Cas	B2V	3.61	-0.20	1.37	14.5	6.2	+0.04	-2.57	-1.64
3	3369	π And	B5V	4.35	-0.16	0.69	-	2.3	+0.00	-	-1.29
4	3901	ζ Cas	B2V	4.79	-0.10	0.46	5.2	6.1	+0.12	-2.63	-2.80
5	4180	o Cas	B3V	4.57	-0.80	0.57	6.0	-	+0.16	-2.57	-
6	4727	ν And	B5V	4.53	-0.17	0.69	2.5	-	+0.01	-1.40	-
7	5394	γ Cas	B01Ve	2.41	-0.11	4.13	200.0	51.0	+0.10	-4.21	-2.73
8	11415	ε Cas	B31Vp	3.38	-0.18	1.69	6.7	3.9	+0.05	-1.50	-0.90
9	19356	β Per	B8v	2.2	-0.06	5.00	18.0	16.0	+0.03	-1.39	-1.51
10	87901	α Leo	B7V	1.35	-0.11	10.90	31.9	29.5	+0.01	-1.16	-1.08
				1.35	-0.11	10.90	31.4	33.8	+0.01	-1.15	-1.23
11	108767	δ Cor	B9.5Vn	2.95	-0.05	2.52	-	4.7	+0.00	-	-0.68
12	112413	α_2Cvn	B9.5pv	2.89	-0.12	2.66	6.1	3.9	+0.09	-0.90	-0.42
13	120307	ν Cen	B21V	3.40	-0.22	1.66	16.6	6.0	+0.00	-2.53	-1.46
14	121743	φ Cen	B21V	3.82	-0.21	1.2	5.7	6.2	+0.03	-1.76	-1.86
15	122980	χ Cen	B2V	4.35	-0.20	0.7	4.9	-	+0.04	-2.13	-
16	125238	ι Lup	B31V	3.56	-0.20	1.4	14.5	16.5	+0.00	-2.50	-2.57
17	128345	o Lup	B5V	4.04	-0.15	0.9	5.7	6.2	+0.01	-1.98	-2.07
18	129116		B3V	4.0	-0.18	0.96	6.8	6.0	+0.02	-2.13	-1.99
19	134687		B3III	4.82	-0.14	0.45	6.99	9.55	+0.06	-2.98	-3.32
20	136504	ε Lup	B31V	3.36	-0.18	1.72	6.2	12.3	+0.02	-1.39	-2.14
21	138690	γ Lup	B2Vn	2.77	-0.20	3.0	36.4	31.4	+0.04	-2.72	-2.56
22	149438	τ Sco	BOV	2.82	-0.27	2.8	82.0	40.3	+0.03	-3.65	-2.90
23	157056	θ Oph	B21V	3.27	-0.22	1.9	11.3	9.3	+0.02	-1.95	-1.74
24	157246	γ Ara	BIIII	3.33	-0.14	1.77	24.0	15.8	+0.12	-2.83	-2.38
25	175191	σ Sgr	B2V	2.10	-0.22	5.5	43.0	33.4	+0.02	-2.24	-1.96
26	198183	λ Cyg	B5Ve	4.54	-0.12	0.58	4.7	2.8	+0.04	-2.73	-1.70
27	202904	ν Cyg	B2Ve	4.42	-0.10	0.6	4.3	3.1	+0.14	-2.05	-1.70
28	218045	α Peg	B9.5III	2.47	-0.03	3.9	6.2	5.8	+0.00	-0.50	-0.44

COMPARISON OF ABSOLUTE MAGNITUDES WITH THEORETICAL MAGNITUDES

TABLE 2

									OTHER OBSERVERS		
OBSV No	H.D. Number	E(B-V)	X.2150 E(B-V)	X.2550 E(B-V)	Intrinsic M2150 Obs	Intrinsic M2150 theo	Intrinsic M2550 Obs	Intrinsic M2550 theo	Intrinsic M2150 theo	Intrinsic M2550 obs	AUTHOR.
1	358	+0.02	+0.12	+0.09	-1.27	-1.42	-0.95	-0.94	-1.30	-1.29	Bless (1968)
									-1.32	-1.07	Stecher (1969)
2	3360	+0.04	+0.24	+0.18	-2.81	-2.10	-1.82	-1.61			
3	3369	+0.00	-	+0.00	-	-	-1.29	-1.48			
4	3901	+0.12	+0.73	+0.55	-3.86	-2.50	-3.35	-2.03			
5	4180	+0.16	+0.98	-	-3.55	-2.13	-	-			
6	4727	+0.01	+0.06	-	-1.46	-1.73	-	-			
7	5394	+0.10	+0.60	+0.46	-4.81	-3.35	-3.19	-2.71			
8	11415	+0.05	+0.30	+0.23	-1.80	-2.14	-1.13	-1.68			
9	19356	+0.03	+0.18	+0.14	-1.57	-1.03	-1.65	-0.75	-1.53	-1.13	Stecher (1969)
10	87901	+0.01	+0.06	+0.05	-1.22		-1.13				
		+0.01	+0.06	+0.05	-1.21	-1.56	-1.28	-1.55	-0.84	-1.16	Stecher (1962)
11	108767	+0.00	-	+0.00	-	-	-0.68				
12	112413	+0.09	+0.55	+0.41	-1.45	-0.36	-0.83	-0.20	-1.02 (2110 Å)	-0.81 (2550Å)	Bless (1968)
13	120307	+0.00	+0.00	+0.00	-2.53	-2.24	-1.46	-1.74			
14	121743	+0.03	+0.18	+0.14	-1.94	-2.83	-2.00	-2.45			
15	122980	+0.04	+0.24	+0.18	-2.37	-2.27	-	-			
16	125238	+0.00	+0.00	+0.00	-2.50	-2.31	-2.57	-1.78			
17	128345	+0.01	+0.06	+0.05	-2.04	-1.94	-2.12	-1.05			
18	129116	+0.02	+0.12	+0.09	-2.25	-2.22	-2.08	-1.78			
19	134687	+0.06	+0.36	+0.27	-3.24	-2.18	-3.59	-1.77			
20	136504	+0.02	+0.12	+0.09	-1.51	-2.15	-2.23	-1.75			
21	138690	+0.04	+0.24	+0.18	-2.96	-2.46	-2.74	-2.02			
22	149438	+0.03	+0.18	+0.14	-3.83	-3.33	-3.04	-2.90	-3.1	-2.59	Boggess (1962)
23	157056	+0.02	+0.12	+0.09	-2.07	-2.02	-1.83	-1.74	-2.25	-2.05	Stecher (1969)
24	157246	+0.12	+0.72	+0.54	-3.55	-2.78	-2.92	-2.21			
25	175191	+0.02	+0.12	+0.09	-2.36	-1.98	-2.05	-1.46			
26	198183	+0.04	+0.24	+0.18	-2.97	-1.92	-1.88	-2.15			
27	202904	+0.14	+0.85	+0.64	-2.90	-2.80	-2.34	-2.40			
28	218045	+0.00	+0.00	+0.00	-0.50	-0.41	-0.44	-0.19	-0.5	-0.47	Stecher (1969)

CODE (1960), that a star with $m_v = 0$ produces a flux at the top of the Earth's atmosphere of

$$3.8 \times 10^{-9} \text{ ergs cm}^{-2} \text{ sec}^{-1} \text{ Å}^{-1}$$

at 5475Å.

Because of the small number of stars observed, it was not possible to compute an interstellar reddening curve directly from the measurements, and the extinction coefficient used in Table 2 was computed at 2150Å and 2550Å assuming that the ultraviolet colour excess was proportional to the (B-V) colour excess in such a way that:

$$E\ (m_\lambda - m_v) = X_\lambda E(B-V)$$

where the value of X was calculated from the experimental data of STECHER (1965) and BOGGESS and BORGMAN (1964), for 2150Å and 2550Å.

The values obtained in this way are:

$$X_{2150} = 6.08 \quad \text{and} \quad X_{2550} = 4.57$$

The intrinsic ultraviolet magnitude (i.e. the observed magnitude, thus corrected for interstellar extinction) is shown in columns 6 and 8 of Table 2 as is also the theoretically predicted intrinsic magnitude, in columns 7 and 9.

The actual absolute intensities measured in ergs cm^{-2} $\text{sec}^{-1}\text{Å}^{-1}$ are shown in columns 8 and 9 of Table 1 at 2150Å and 2550Å. Columns 6 and 8 of Table 2, show the same data corrected for interstellar absorption.

It is of interest at this point to consider the conclusions which may be drawn from previous published data. The available results do not permit direct comparison with many stars, and the accuracy of the measurements is not always stated.

In Fig. 1. the present data are plotted against those of BOGGESS and BORGMAN (1964), STECHER (1962, 1969) and BLESS et al (1968).

The agreement with the STECHER (1969) data at 2150Å and 2550Å is good. However, the present results for αLeonis do not support the STECHER and MILLIGAN (1962) spectral data for the same star which show a rapid falling off of ultraviolet flux below 2000Å.

In the case of the BLESS-BOGGESS data, although BLESS has reported agreement within ±0.25 magnitude for twelve stars in common with BOGGESS he does indicate that the WISCONSIN fluxes are systematically brighter. For the present data, the agreement with BLESS is satisfactory at 2150Å although differences do exist at 2550Å. It is possible that such differences may be explained as follows:

(a) the photometers flown by BLESS had fields of view 3° square and consequently some of his observations may have included energy attributable to more than one star. A reasonably bright late type star could contribute appreciable intensity at 2550Å.

(b) although the wavelength passbands were isolated by means of interference filters, the photomultipliers themselves were sensitive to radiation above 3000Å and any wings present in the filter response could produce an increase in the apparent ultraviolet flux of the same order as the difference between the present

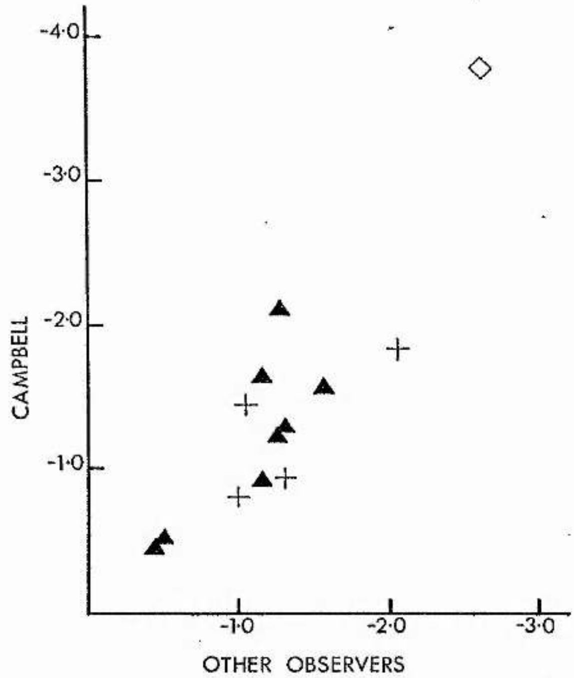


Fig. 1.

Comparison between present observed magnitudes with data of other observers for same stars. ▲ STECHER (1962 and 1969); + BLESS et al (1968); ◇ BOGGESS and BORGMAN (1964).

data and that of BLESS at 2550Å.

In order to include observational data at other wavelengths in the comparison, use was made of stellar model atmospheres. When selecting these models it was necessary to consider the possible effects of absorption lines, whose accumulative blanketing in the region 1900Å - 3000Å may have been significant. ELST (1967), GUILLAUME (1966), and UNDERHILL (1963) considered all absorption lines due to chromium and iron in the atmosphere of a B1 star. The resultant analysis showed that only in the region 2200Å - 1900Å was the cumulative effect significant, and was of the order of 0.132 magnitude. Above 2200Å the contribution was negligible. Below 1900Å the effects of ionised carbon, nitrogen, silicon, and the Lyman series of hydrogen, were the most significant and could account for the earlier reported ultraviolet deficiencies where comparisons were made with unblanketed theoretical models.

The temperature scales involved are shown in Tables 3, 4, and the actual model atmospheres used were those proposed by MIHALAS (1965), and modified to fit the temperature scale for early-type stars proposed by ADAMS and MORTON (1968).

The assumptions made in these calculations were that the ratio of the helium to hydrogen abundance $N(He)/N(H) = 0.15$ and that the surface gravity $g = 10^4 \text{ cm}^{-1} \text{sec}^{-2}$. In addition, the models were assumed to be in radiative equilibrium. By definition $\theta_e = 5040.2/Te$.

Columns 7 and 9 of Table 2, show the theoretically predicted flux intensities at 2150Å and 2550Å derived for

TEMPERATURE SCALE MIHALAS, MORTON, VAN CITTERS

TABLE 3

SPCTRL Type	Adams & Morton	θ_e	Mihalas	θ_e	Van Citters & Morton	θ_e	Bradley	& θ_e
BO	30900	0.163	30000	0.168	–	–	30730	0.164
BO.5	26200	0.192	28000	0.180	25200	0.20	–	–
B1	22600	0.223	24000	0.210	–	–	–	–
B2	20500	0.246	21900	0.230	20160	0.250	–	–
B3	17900	0.281	18000	0.280	–	–	–	–
B5	15600	0.323	15750	0.320	–	–	–	–
B6	14600	0.345	–	–	14400	0.350	–	–
B7	13600	0.370	14000	0.360	–	–	–	–
B8	12000	0.420	12600	0.400	–	–	–	–
B9	10700	0.471	11200	0.450	–	–	–	–
B9.5	10000	0.504	10080	0.500	–	–	–	–

TEMPERATURE SCALE ADAM AND MORTON, VAN CITTERS

TABLE 4

SPCTRL Type	Adams & Morton	θ_e	Mihalas	θ_e
BO	30900	0.163	30000	0.168
BO.5	26200	0.192	28000	0.180
B1	22600	0.223	24000	0.210
B2	20500	0.246	21900	0.230
B3	17900	0.281	18000	0.280
B5	15600	0.323	15750	0.320
B6	14600	0.345	–	–
B7	13600	0.370	14000	0.360
B8	12000	0.420	12600	0.400
B9	10700	0.471	11200	0.450
B(.5	10000	0.504	10080	0.500

the unblanketed models of MIHALAS for the range of θ_e shown in Table. 4.

A number of other stars had also been previously observed by STECHER and MILLIGAN (1962), BOGGESS (1964), SMITH (1967), YAMASHITA (1968) and BLESS et al (1968), and permitted an additional comparison with the present data to be made. The data for three of these stars are shown in Figs. 2,3,4. and in each case the comparison is against a MIHALAS (1965) unblanketed model.

Below 2000Å, there are large differences between the observed stellar fluxes and the theoretical fluxes, particularly for the measurements of YAMASHITA (1968) and BYRAM and CHUBB (1965). When corrections are made for line blanketing, the discrepancies are atill between one and two magnitudes, even though the same models appear to be satisfactory in the region 2000Å - 3000Å.

In Fig. 5, is shown a colour-colour plot of $(m_{2150}-V)$, corrected for interstellar reddening, against the intrinsic (B-V) colour of JOHNSON (1963).

The data consist of the present observational results and those of STECHER (1969) and BLESS (1968). Additionally, selected satellite observations of SMITH (1967) at 1346Å were used to compute a flux at 2150Å. The agreement with the other plotted data is good.

A plot of Δm (the difference between the observed ultraviolet magnitude and that derived from the theory) against spectral type is shown in Fig. 6. for the present observations of main sequence stars and the data from other observers for stars in common with this programme.

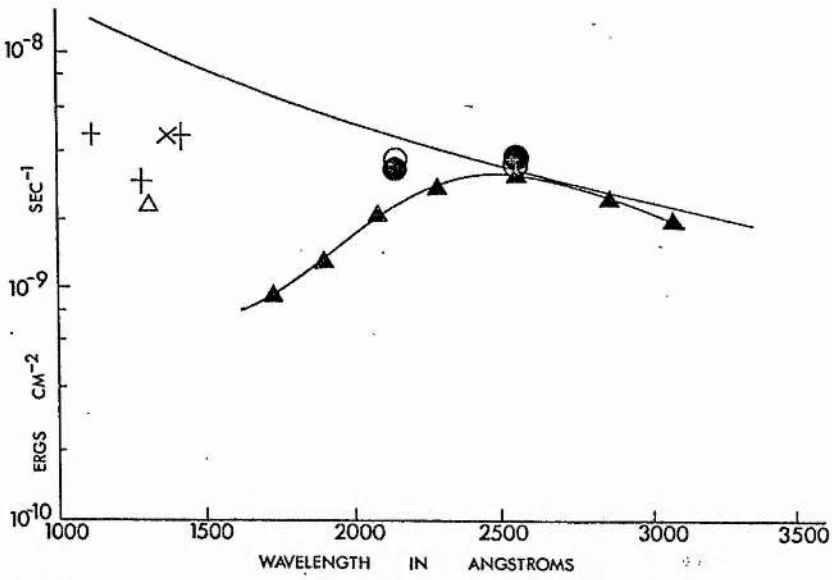


Fig.2. α Leonis Spectral Type B7 m = 1.35; – Continuum flux for unblanketed Mihalas model for θe = 0.37; ▲Observations of STECHER and MILLIGAN (1962); △Observations of BYRAM and CHUBB (1963); ○ Observations of CAMPBELL (1970) Rocket No. SO5/2; ● Observations of CAMPBELL (1970) Rocket No S11/1; + Observations of YAMASHITA (1968); X Observations of SMITH (1967).

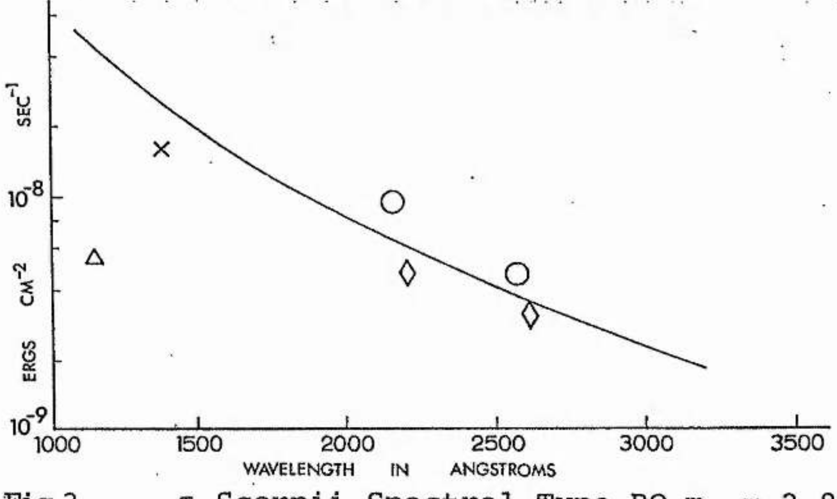


Fig.3. τ Scorpii Spectral Type BO m = 2.82; – Continuum flux for unblanketed Mihalas model for θe = 0.16; △ Observations of BYRAM and CHUBB (1963); X observations of SMITH (1967); ◇Observations of BOGGESS (1964); O Observations of CAMPBELL (1970).

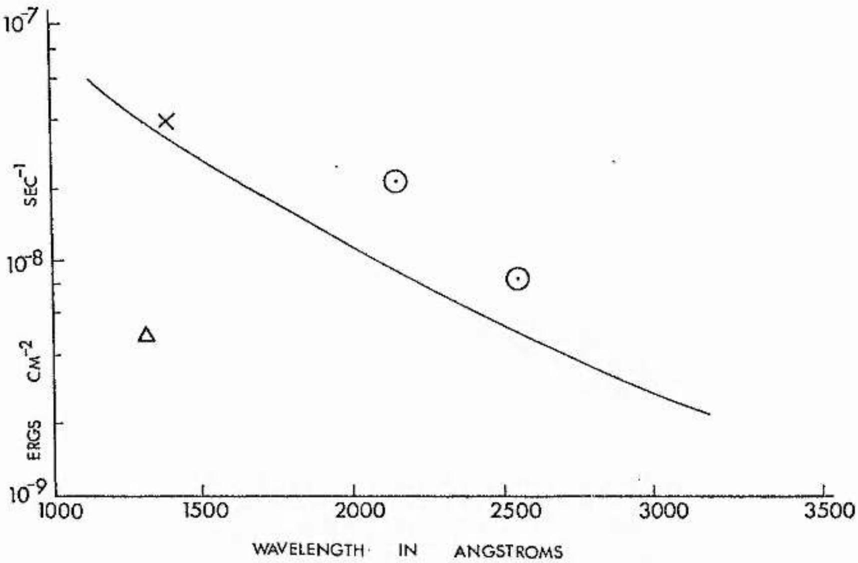


Fig.4. γCassiopiae Spectral Type BOe m_v=2.41; — Continuum flux for unblanketed Mihalas model for Θ_e=0.16; x Observations of SMITH (1967); ΔObservations of CHUBB (1963); ⊙ Observations of CAMPBELL (1970).

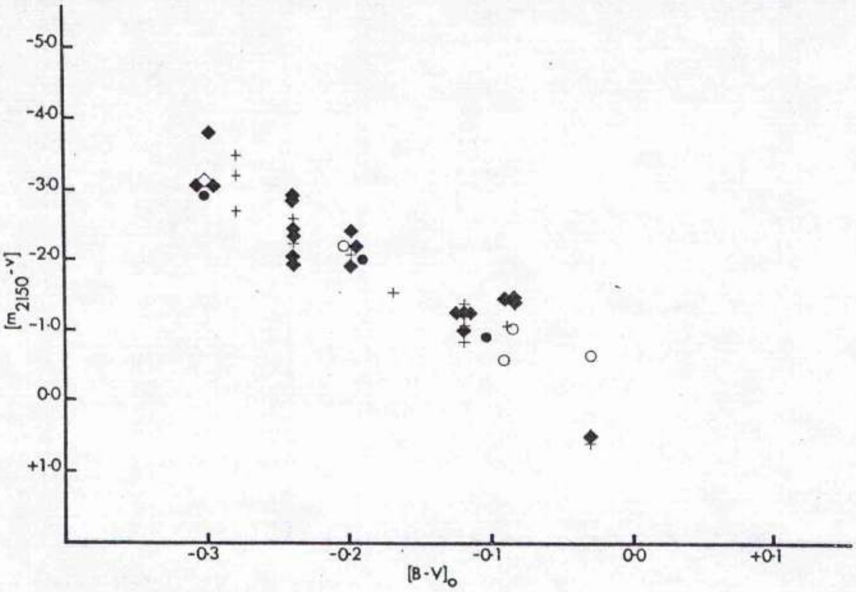


Fig. 5.

Colour-colour plot of (m_{2150}-v) observed vs (B-V) colour of JOHNSON (1963). ♦CAMPBELL (1970) 2150Å; + STECHER (1969) 2150Å; ○BLESS and CODE (1968) 2100Å; ◇BOGGESS (1964) 2150Å; ●BLESS and CODE OAO (1970) 1995Å.

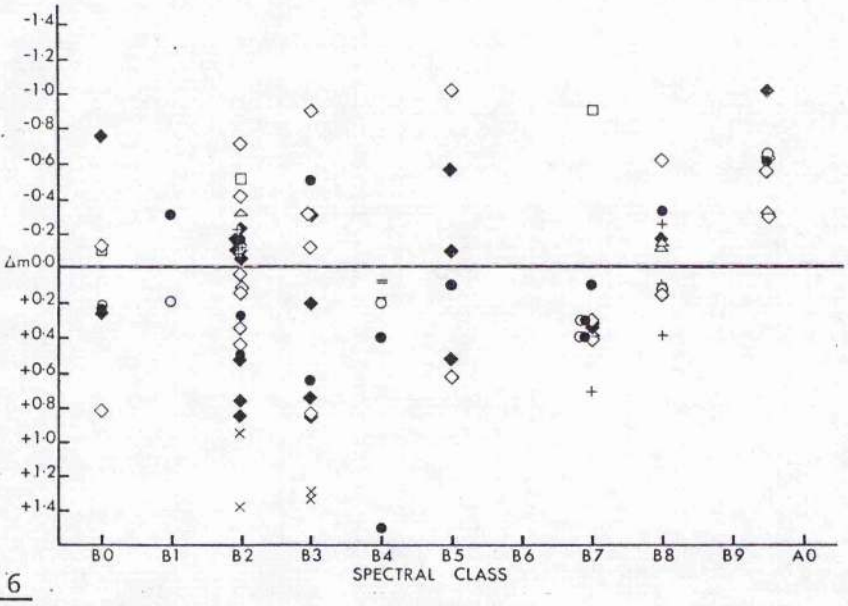


Fig. 6

Plot of Δm (difference between the observed ultraviolet magnitudes and theoretical magnitude) against other observations for the same stars - SMITH (1967) 1376Å; STECHER (1969) 2150Å; STECHER (1969) 2550Å; □ BLESS et al (1968) 2150Å ■ BLESS et al (1968) 2550Å; + YAMASHITA (1968) 1376Å; x BYRAM and CHUBB (1963) 1427Å; ◇CAMPBELL (1970) 2150Å; ♦CAMPBELL (1970) 2550Å.

CHAPTER VI

ABSOLUTE STELLAR FLUXES AT 1450Å

COMPARISON OF ABSOLUTE PHOTOMETRY

A variety of calibration methods have been used by the various investigators, and no common procedure has been employed. Consequently, there is quite a spread in the quoted absolute flux values and in the absence of stars common to each observer, a direct comparison is difficult. Below 2000Å, only STECHER, CARRUTHERS, SMITH and BOGGESS have made a serious attempt to calibrate their instruments in absolute units. STECHER (1970), has used an earlier observation of αCMa at 2600Å. as a basis for his absolute calibration and he states that his measurements for those stars in common with CARRUTHERS (1968) are in agreement to within a few percent at 1270Å. METZGER (1971), has made a number of observations at 1216Å from an OGO satellite and indicates a good agreement with STECHER (1970), and CARRUTHERS (1968). However, CARRUTHERS (1969) has corrected his 1968 observations by a factor of 1.35 at 1270Å and by a factor of 4.0 at 1115Å. The BOGGESS and KONDA (1968) observations have been normalised to the αCMa observations of STECHER.

The early observations of CHUBB and BYRAM (1963) and BYRAM (1965), are stated to be better than a factor of two at 1427Å and to have a fifty-percent probability that the absolute photometry at 1115Å is good to a factor two.

At 1376Å, the results of SMITH represent the major contribution of broad band photometric observations and are stated to have an absolute photometric accuracy of fifty percent. YAMASHITA has used the SMITH observations of αLeonis to normalise his data at 1376Å.

From the published data, there would seem to be reasonable agreement between the data of STECHER (1969, 1970), and SMITH (1967), for those stars in common at 1376Å, but that few other independent absolute calibrations have been made. An earlier investigation by the author at 2150Å and 2550Å has produced data which are in good agreement with the STECHER (1969) results.

The actual calibration procedure employed in the present investigation has been discussed in previous sections and by using a number of cross-calibration procedures, it has been possible to achieve an overall absolute calibration accuracy at 1450Å of twenty-five percent without undue difficulty. Fig.1. shows a comparison between the present data and those of SMITH, YAMASHITA and CHUBB for those stars in common. The agreement is good for the SMITH data at 1376Å and the YAMASHITA observations of δOrionis.

ABSOLUTE STELLAR FLUXES AT 1450Å

Tables 1,2,3, show the reduced data for ninety-two stars selected for analysis. The ultraviolet magnitude (m_{1450}-V) was obtained as for the 2150Å and 2550Å data by comparing the ultraviolet flux with that due to a zero magnitude AO star at 5560Å. A flux value of 3.8×10^{-9} ergs cm^{-2} sec^{-1} $Å^{-1}$ being attributed to such a star when

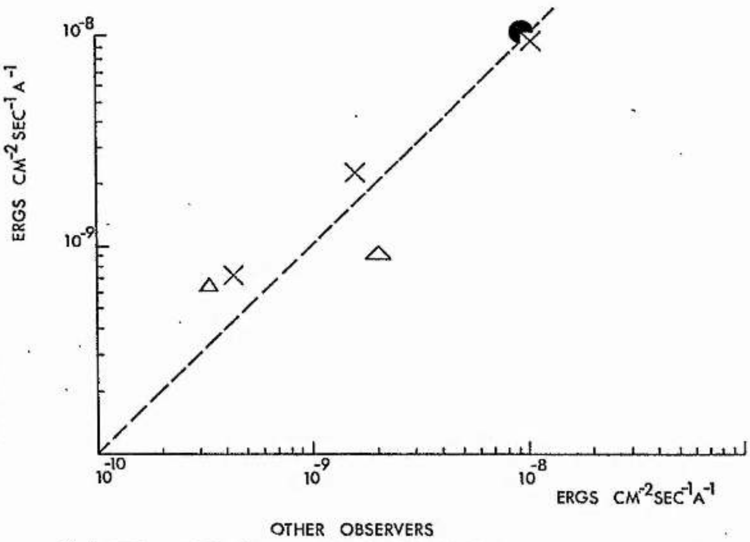


Fig.1. Comparison between present data and other observers, for those stars in common. Δ, CHUBB (1965), 1329Å, 15 CMa, βCepheus; O, YAMASHITA (1968), 1415Å, δOrionis; x, SMITH (1965), 1376Å, γCassiopeiae, λTauri, νGemini.

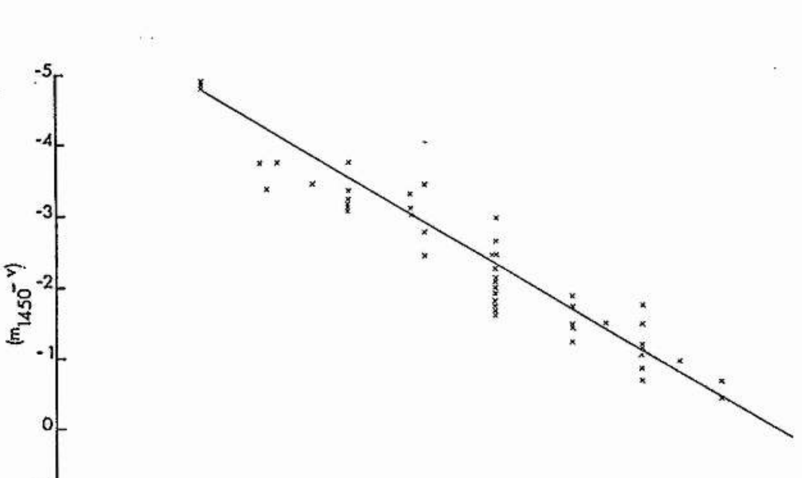


Fig.2. Colour array $(m_{1450}-V)$ versus $(B-V)_o$ for main sequence stars.

ABSOLUTE FLUXES AT 1450Å

TABLE 1

OBSV No	H.D. Number	Star Name	Spctrl Type	V	(B-V) Obs.	Reference (NRL.)	Stellar flux erg $cm^{-2} sec^{-1} Å^{-1}$ x 10^{+10} 1450A
1	1256		B8	6.50	-0.14	79	0.5
2	2834	λ^1 Phe	AOV	4.76	+0.01	68,75	1.4
3	4150	η Phe	AOV	4.36	0.0	75,208	1.4
4	4622	-	B9V	5.56	-0.06	75,208	0.9
5	4727	ν And	B5V	4.53	-0.15	1,6,10,120	10.1
6	5394	γ Cas	BO1V:e	2 65	-0.195	223,	112.0
7	6676	-	B8	5.68	-0.038	103	0.8
8	6829	31 Cas	AO	5.30	-0.02	122	0.9
9	16004	-	B81V	6.26	-0.10	49,79	0.8
10	16555	η Hor	A5	5.30	+0.28	62,	1.9*
11	17769	43 Ari	B7V	5.43	-0.084	203	3.1
12	18543	-	A2	5.24			0.9
13	18633	5 Eri	B9	5.48			1.2*
14	18978	τ3 Eri	A5V	4.10	+0.17		1.2
15	19268	-	B5	6.16			0.8
16	20150	58 Ari	AO1V-V	4.94	+0.02	49,122	0.9
17	23180	o Per -	BIIII	3.82	+0.05	9,12,120,& 252	7.5
18	24072	-	AO	4.86			2.6
19	25204	λ Tau	B3V	3.80	-0.12		24.8
20	27650	-	B9	5.96	0.0	79,	0.9
21	29227	-	B9	6.29	-0.12		1.7
22	29763	τ Tau	B3V	4.32	-0.14	120,	9.2
23	32686	-	B5	6.06	-0.12	61,	1.2
24	34959	-	B5P	6.52	-0.11	4,256	0.9
25	35007	-	B3V	5.67	-0.12		3.1
26	35600	-	B91b	5.63	+0.10	378,	0.9
27	36187	-	A1	5.56	+0.02	75,	0.8
28	36486	δ Ori	O9.511	2.20	-0.21		112.0
29	36861/2	λ Ori	O8	3.66	-0.21	200	62.0
30	37286	-	AO	5.72			0.8
31	37519	-	B7V	6.01	+0.02	49,79	2.3
32	37795	α Col	B8Ve	2.63	-0.12	75,	10.1*
33	38206	-	AO	5.72	+0.01		0.8
34	38899	134Tau	B91V-V	4.90	-0.05	333,	2.3
35	39317	137Tau	Ap	5.54			0.9
36	40372	59 Ori	A5	6.00	+0.22	415,	0.9*
37	40536	2 Mon	Am	5.02			0.9
38	42536	-	Ap	5.15			0.8
39	42690	-	B2V	5.06	-0.20	62,	5.1
40	43544	-	B5	5.93	-0.18	75,	3.9
41	45321	-	B3	6.14	-0.14	78,	1.4
42	45542	ν Gem	B71V	4.15	-0.11	212,	7.5
43	46349		A3	5.76			0.9
44	47100	ψ^3 Aur	B8III	5.26	-0.07	22,79,122	1.7
45	48434	-	BOIII	5.74	-0.02		1.2
46	49229	11 CMa	B8	5.28	-0.04	75	1.9
47	50707	15 CMa	BIIV	4.82	-0.21	120	9.2

TABLE 1 (continued)

ABSOLUTE FLUXES AT 1450Å

OBSV. No	H.D. Number	Star Name	Spctrl Type	V	(B-V) Obs.	Reference (NRL.)	Stellar flux erg $cm^{-2} sec^{-1}$ $Å^{-1}$ x 10^{+10} 1450Å.
48	52929	-	B8	5.95	-0.13	79	0.9
49	55111	-	AO	6.08	-0.02		0.8
50	55879	-	BO1V	5.99	0.18	98	4.6
51	56731	-	Am	6.23			1.2
52	59067	-	G81-11b+B	5.78	+0.58		0.8
53	60275	-	B9.5V	6.16	-0.01	22	1.2
54	65875	-	B3p	6.48	-0.08	212	0.8
55	77327	κ UMa	AO	3.66	0.00	122,381	1.9
56	94334	ω UMa	A1V	4.75	-0.04	122	1.4
57	116656	ζ UMa	A2V	2.40	+0.02	120	8.5
58	123299	α Dra	AOIII	3.64	-0.044	203	3.9
59	170650	-	B5	5.70			1.4
60	172187	-	A5	6.22			1.2
61	173936	-	B9	5.92	-0.12	79	0.9
62	175492	113Her	A3III+GO	4.49	+0.79		1.2
63	176502	-	B5	6.03			1.9
64	80163	20 Lyr	B21V	4.45	-0.14		8.4
65	180554	1 Vul	B31V	4.59	-0.04	120	1.2
66	183339	-	B8	6.44	-0.11	378	1.2
67	185037	11 Cyg	B8V	5.78			1.7
68	186901	-	B9.5	5.98			0.9
69	191639	-	B1V	5.64	-0.16	71	1.6
70	193472	-	A5	5.93	+0.32	378	0.8
71	195810	ε Del	B6III	3.98	-0.129	363	9.2
72	196662	τ Cap	B6III	5.30			2.1
73	200595	-	B7	6.49	-0.14	79	0.9
74	203206	-	B71V	6.15	-0.09	73	1.4
75	205021	Cep	B2II-III	3.18	-0.21		69.0
76	206644	77 Cyg	AOV	5.48	+0.01	216	0.9
77	207516	-	B8V	5.81	-0.09		1.0
78	209014	η Psa	B8V	5.42	-0.09	79	2.1
79	209409	o Aqr	B8Ve	4.79	-0.07	126	3.9
80	210418	θ Peg	A2V	3.52	+0.08		1.2
81	213087	26 Cep	BO.51b	5.46	:0.37	12	1.4
82	215907	-	AO	6.27			1.4
83	216057	-	B8	6.04	-0.07	79	0.9
84	218700	58 Peg	B8	5.32	-0.08	79,122,256	1.4
85	218700	58 Peg	B8	5.32	-0.08	79,122,256	0.8
86	220825	k Psc	Ap	4.95	+0.04		0.8
87	222661	ω^2 Aqr	B9.5V	4.48	-0.04		2.6
88	223024	107 Aqr	A5	5.74	+0.30	416	2.9
89	223640	108 Aqr	Asi	5.16			1.8
90	224103	26 Psc	A1	6.09			0.8
91	224926	29 Psc	B8III	5.10	-0.13	78, 79	2.6
92	225132	2 Cet	B91V	4.54	-0.05	75,	1.7

TABLE 2

EXPERIMENTAL DATA AT 1450Å

H.D. Number	Spectral Class	v sin i	(M1470-V) exp Continuum Fluxes	(M1470-V) theo Model 1 Mihalas	(M1470-V) theo Model 2 Van Citters and Morton.	(M1470-V) theo Model 3 Bradley and Morton.	OTHER OBSERVERS (M -V) exp	(M -V) exp
1256	B8V	-	1.71	1.74	-	-		
2834	AOV	134	1.26	0.76	-	-		
4150	AOV	-	0.76	0.76	-	-		
4622	B9V	42	1.52	1.22	-	-		
4727	B5V	71	3.19	2.76	3.01	-		
5394	BO1Vpe	300	4.88	4.60	-	4.51	SMITH 1376Å 4.91 ± 0.22	
6676	B8	-	2.06	1.74	-	-		
6829	AO	82	1.26	0.76	-	-		
16004	B81V	-	2.11	1.74	-	-		
17769	B7V	255	3.08	2.26	-	-		
19268	B5	-	2.12	2.76	3.01	-		
20150	AO1V-V	133	1.10	0.76	-	-		
23180	BIIII	148	2.38	4.04	3.62	-		
25204	B3Vvar	117	3.34	3.18	3.60	-	SMITH 1376Å 2.99 ± 0.18	STECHER 1630Å 2.65
27650	B9-AO11	-	2.53	1.22	-	-		
29227	B9	-	2.88	1.22	-	-		
29763	B3V	174	3.07	3.18	3.56	-	SMITH 1376Å 2.90 ± 0.37	
32686	B5	-	3.07	2.76	3.06	-		
34959	B5p	445	2.72	2.76	3.02	-		
35007	B3V	-	3.77	3.18	3.58	-		
35600	B91b	-	2.60	1.22	-	-		
36187	A1	-	1.92	0.48	-	-		
36486	O9.5II	168	4.28	4.60	-	4.65	YAMASHITA 1415Å 3.23 ± 0.31 SMITH 1376Å 4.69 ± 0.16	YAMASHITA 1290Å 3.22 ± 0.60 BOGGESS 1750Å 3.1

TABLE 3

EXPERIMENTAL DATA AT 1450Å

H.D. Number	Spectral Class	v sin i	(M1470-V) exp Continuum Fluxes	(M1470-V) theo Model 1 Mihalas	(M1470-V) theo Model 2 Van Citters and Morton.	(M1470-V) theo Model 3 Bradley and Morton.	OTHER OBSERVERS. $(M_\lambda-V)$exp	$(M_\lambda-V)$exp
36861/2	BO	100	4.90	4.60	-	4.65		
7519	B7V	-	3.62	2.26	-	-		
37795	B6Ve	151	0.55	1.74	-	-		
37295	AO	-	0.92	0.75	-	-		
38899	B9V	-	1.96	1.22	-	-		
39317	Ap	-	1.19	1.74	-	-		
42690	B31V	28	3.28	3.18	3.35	-		
43544	B5	-	3.45	2.76	3.01	-		
45321	B3	-	3.15	3.18	3.55	-		
45542	B71V B6IIIe	215	2.49	2.26	-	-	SMITH 1376Å 1.60 ± 0.22	
47100	B8III	190	2.05	1.74	-	-		
48434	BOIII	-	4.77	4.60	-	4.51		
49229	B8	315	2.55	1.74	-	-		
50707	B11V	69	3.79	4.04	3.37	-		
53929	B8	-	1.91	1.74	-	-		
55111	AO	-	1.93	0.75	-	-		
55879	BO1V	60	4.91	4.60	-	4.51		
60275	B9.5V	-	2.56	0.75	-	-		
65875	B2.5-3Ve	-	3.54	3.18	3.53	-		
77327	AO	247	0.42	0.75	-	-		
94334	A1V	20	1.15	0.48	-	-		
116656	A2V	-	0.77	0.43	-	-		
123299	AOIII	21	1.16	0.76	-	-		
173936	B9	-	1.77	1.22	-	-		
175492	(A3-A5)+GO	-	7.76	0.37	-	-		
176502	B5V	-	2.79	2.76	3.07	-		
180163	B21V	-	3.82	3.82	3.39	-		
180554	B3V	130	3.41	3.18	-	-		
183339	B8	-	2.64	1.74	-	-		

TABLE 3 continued

H.D Number	Spectral Class	v sin i	(M1470-V) exp Continuum Fluxes	(M1470-V) theo Model 1 Mihalas	(M1470-V) theo Model 2 Van Citters and Morton	(M1470-V) theo Model 3 Bradley and Morton	OTHER OBSERVERS. $(M_\lambda-V)$exp	$(M_\lambda-V)$exp
191639	B1V	-	3.42	4.04	3.46	-		
195810	B6	51	2.55	2.58	2.68	-		
200595	B7-B8	-	2.45	2.26	-	-		
203206	B71V	-	2.85	2.26	-	-		
205021	B2II-III	43	3.83	3.82	3.49	-	SMITH 1376Å 3.76 0.23	
206644	AO	88	1.54	0.75	-	-		
207516	B8V	-	1.77	1.74	-	-		
209014	B8	-	1.82	1.74	-	-		
210418	A2V	150	0.48	0.42	-	-		
216057	B8	-	2.20	1.74	-	-		
218700	B8	-	1.82	1.74	-	-		
222661	B9.5V	167	1.56	0.75	-	-		
224926	B8III	100	2.18	1.74	-	-		
225132	B91V	146	1.40	1.22	-	-		

viewed from above the Earth's atmosphere. CODE (1960).

The visual magnitude used was again from IRIARTE et al, (1965), and the colour excess (B-V) was obtained using the observed (B-V) colour indices of IRIARTE and the intrinsic colours of JOHNSON (1963). In order to obtain the ultraviolet colour excess, a linear relationship has been assumed between E(m-V) and E(B-V), such that:

$$E(m_\lambda - V) = X_\lambda E(B-V)$$

The value of X_{1450} was calculated using the interstellar extinction data of SMITH (1967) and STECHER (1969).

In column 3, are listed the available values of ν sin i from SLETTEBAK et al (1954) and in column 4 the ultraviolet magnitude at 1450Å corrected for interstellar absorption. For those stars in common, an ultraviolet magnitude has been computed from the other published data and is shown in columns 8 and 9. Fig.2. shows a colour array obtained by plotting the observed ultraviolet magnitude against the $(B-V_o)$ values of JOHNSON(1963), for main sequence stars and in Fig.3. a similar array for giants and supergiants.

A direct comparison between the present results and a number of model atmospheres is shown in columns, 4, 5, 6, and 7. In column 4, are shown the values obtained using a number of MIHALAS (1965) models, derived without taking into effect any line blanketing below 2000Å. Where available, a number of blanketed models are also shown due to BRADLEY and MORTON (1969) and VAN CITTERS and MORTON (1970). The effective temperatures used in each

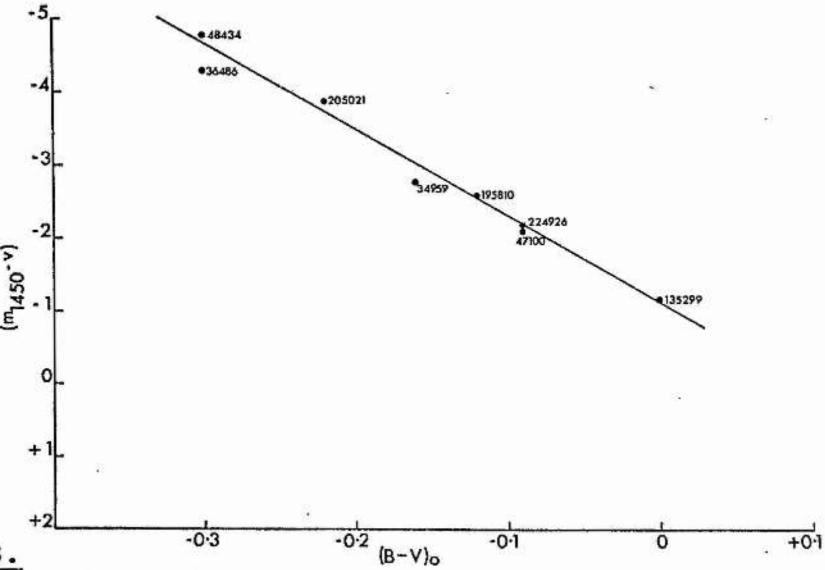


Fig. 3.

Colour array $(m_{1450}-V)$ versus $(B-V)_o$ for stars of luminosity class I and II.

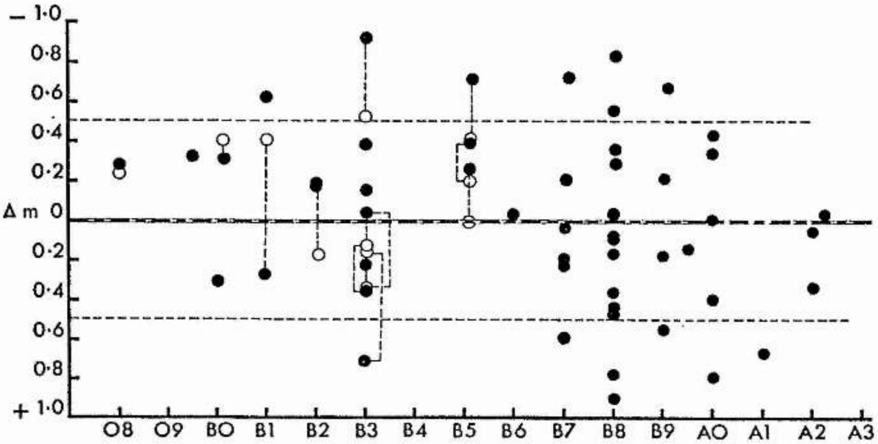


Fig. 4.

SPECTRAL TYPES

Plot of Δm (the difference between the theoretical and experimental ultraviolet magnitude at 1450Å) versus spectral type.

TABLE 4

EFFECTIVE TEMPERATURES OF ADAMS AND MORTON

SPCTRL Type	Adams & Morton	θ_e	Mihalas	θ_e	Van Citters & Morton	θ_e	Bradley	θ_e
BO	30900	0.163	30000	0.168	–	–	30730	0.164
BO.5	26200	0.192	28000	0.180	25200	0.20	–	–
B1	22600	0.223	24000	0.210	–	–	–	–
B2	20500	0.246	21900	0.230	20160	0.250	–	–
B3	17900	0.281	18000	0.280	–	–	–	–
B5	15600	0.323	15750	0.320	–	–	–	–
B6	14600	0.345	–	–	14400	0.350	–	–
B7	13600	0.370	14000	0.360	–	–	–	–
B8	12000	0.420	12600	0.400	–	–	–	–
B9	10700	0.471	11200	0.450	–	–	–	–
B9.5	10000	0.504	10080	0.500	–	–	–	–

TABLE 5

EFFECTIVE TEMPERATURES OF MIHALAS AND VAN CITTERS

SPCTRL Type	Adams & Morton	θ_e	Mihalas	θ_e
BO	30900	0.163	30000	0.168
BO.5	26200	0.192	28000	0.180
B1	22600	0.223	24000	0.210
B2	20500	0.246	21900	0.230
B3	17900	0.281	18000	0.280
B5	15600	0.323	15750	0.320
B6	14600	0.345	–	–
B7	13600	0.370	14000	0.360
B8	12000	0.420	12600	0.400
B9	10700	0.471	11200	0.450
B(.5	10000	0.504	10080	0.500

case are shown in Tables 4 and 5.

In Fig. 4, is shown the result of plotting Δm (the difference between the observed ultraviolet magnitude and that derived from the theory) against spectral type. The closed circles are obtained by using the continuum model atmospheres of MIHALAS (1965) and it is apparent that there are considerable differences particularly for stars in the spectral class B5-O8. If, however, a model is used which takes into account the effects of line blanketing, then there is a significant reduction in Δm, as is shown by the position of the open circles.

A number of MIHALAS (1965) continuum models are plotted in Figs. 6-11 for those stars in common. Where possible, all known observations have been plotted, together with some earlier data of BLESS et al (1968) and the present 2150Å, 2550Å data. In addition, a number of points at 1450Å are included for a line blanketed model, were available.

It is clear from Tables 2, 3, that there is good agreement between the present data and the observations of SMITH at 1376Å for γCAS, λTAU, τTAU and βCEP. However, in the case of δOrionis the observation of SMITH would indicate that the star is much brighter by about 0.7 of a magnitude and for γGEM, an emission star, his observations place the star about 1.0 magnitude fainter than the present data. YAMASHITA has obtained at 1415Å and 1290Å values less than those obtained by SMITH and by BOGGESS at 1750Å. The discrepancies could be explained on the basis of an earlier conclusion that SMITH'S calibration gives fluxes which are slightly higher than those obtained by other observers. In addition, SMITH'S observations show ζORI to be fainter than δORI by 1.2 magnitude at 1376Å and εORI to be fainter than δORI by 1.0 magnitude. However, STUART (1969) has found no significant difference between the spectra of ζORI and δORI and εORI fainter by only 0.6 magnitude than δORI. BOHLIN (1970) has found that ζORI is slightly fainter than δORI and very little difference in the spectra of δORI and εORI. In addition, the OAO data on γCAS and δORI indicates that their spectra are basically similar at 1450Å, which is in agreement with the present data and the observations of BOHLIN. Accordingly, it would appear that the SMITH observation of δORI is high by about 0.5 of a magnitude. This is confirmed by CARRUTHERS (1969) observations of δ and γORI.

Figs. 2, and 3, confirm the earlier reported conclusions by BLESS and SAVAGE (1970) that in general, stars of the same visual spectral type and luminosity class have the same intensity in the ultraviolet. A mean colour index at 1450Å is shown in Fig.5, with a theoretical plot from VAN CITTERS and MORTON. The agreement is good for the stars in the spectral class B1-B5 but becomes less satisfactory for the later types.

In Fig.6. is shown a spectrum for γCAS with a MIHALAS unblanketed model and a 1450Å data point for a blanketed model. Also shown are two earlier observations of CAMPBELL (1970), which indicate an increase in intensity at 2150Å.

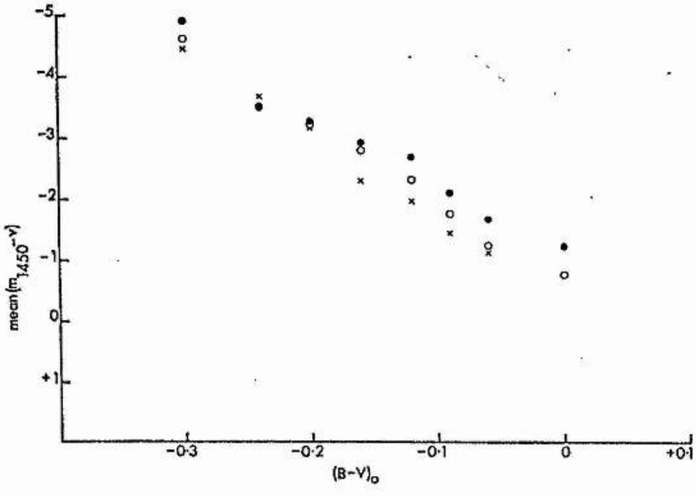


Fig.5

Mean colour indices at 1450Å versus $(B-V)_o$, ● CAMPBELL, 1450Å; O, Theoretical; x, SMITH, 1376Å.

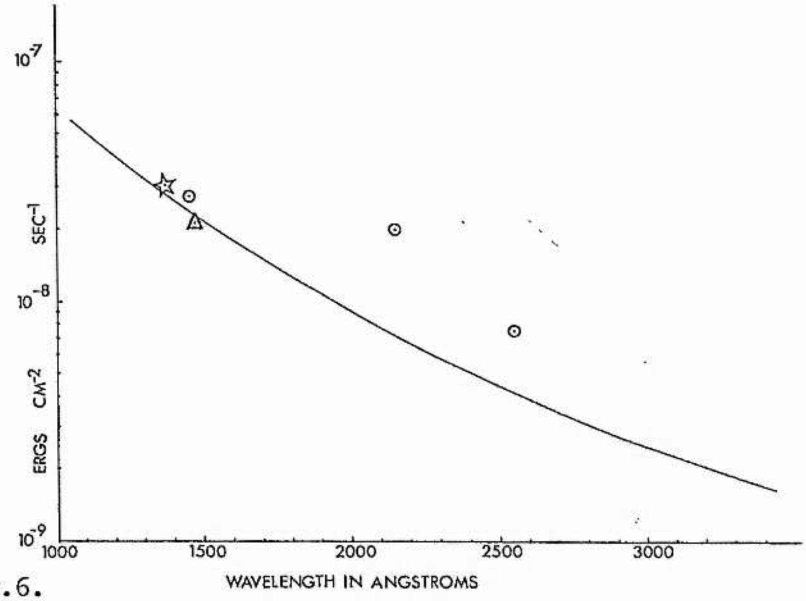


Fig.6.

Absolute stellar flux in ergs cm^{-2}sec^{-1}Å^{-1} for γ Cassiopeiae —, continuum model, Mihalas (1965), Θ_e=0.16; Δ, blanketed model, BRADLEY and MORTON, Θ_e=0.164; $\odot$, CAMPBELL (1970), 2150Å and 2550Å, 1450Å; *SMITH (1967), 1346Å.

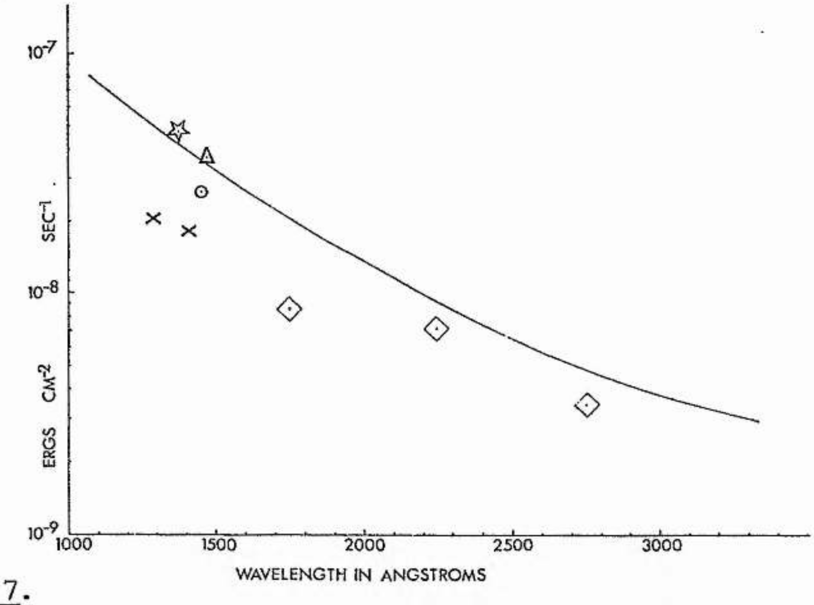


Fig.7.

Absolute comparison between experimental and theoretical absolute intensities for δ Orionis, —, continuum model, MIHALAS (1965), Θ_e=0.168; Δ, line blanketed model, BRADLEY and MORTON, θ_e=0.164; x, YAMASHITA (1968), 1415Å and 1290Å; $\diamond$, BOGGESS and KONDO (1968), 1750Å, 2250Å and 2750Å; O, CAMPBELL, 1450Å; *, SMITH (1967), 1346Å.

BOHLIN (1970) has also reported such an increase near 2050Å, but has suggested that it may be due to the second order spectrum. However, it is possible that the enhancement is real.

Fig.7, shows a plot of a number of observations of δORI. There is a good general agreement between the present observations at 1450Å and SMITH at 1376Å when compared with a line blanketed model. However, the observations of YAMASHITA indicate a much lower flux level which can only be attributed to an experimental error, as his data are all normalised to the αLEO observation of SMITH. The BOGGESS and KONDO data are also in good agreement at the longer wavelengths, but at 1650Å the observational flux level is much less than the model predicts and the general slope of the experimental data.

In the case of βCEPH Fig. 8. good agreement is obtained between the observations of SMITH at 1376Å, the present data at 1450Å and a line blanketed model of VAN CITTERS and MORTON. However, the observation of CHUBB, and BYRAM and CHUBB at 1314Å and 1115Å indicate a flux level much less than is predicted by even a blanketed model. The observations of BLESS et al at 2150Å and 2550Å are in agreement with the slope indicated by the shorter wavelength observations. The present observations for γGEM, Fig. 9, and λTAU Fig.10. indicate a flux level much higher than observed by SMITH at 1376Å and in the case of γGEM comparable to the level predicted by a simple continuum model. In the case of λTAU the experimental flux is a factor two greater than the

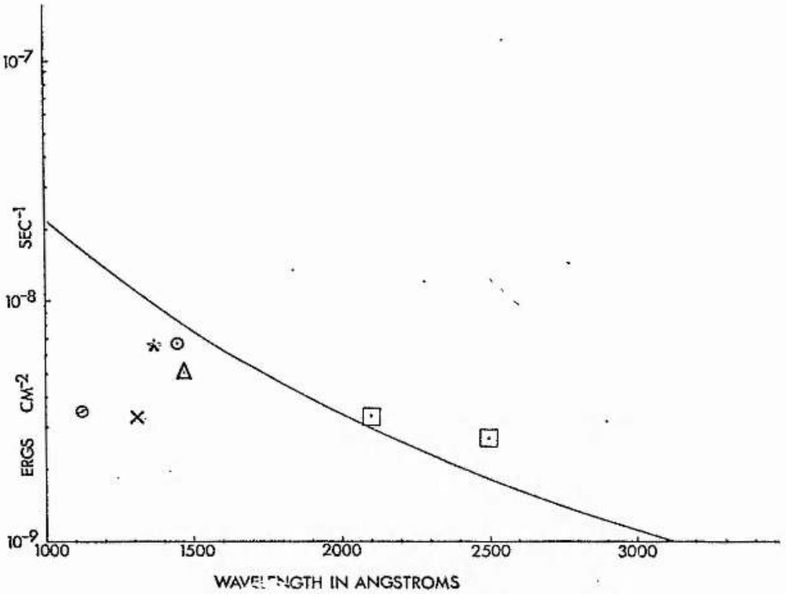


Fig.8. Comparison between experimental and theoretical absolute intensities for β Cephei. —, continuum model. MIHALAS (1965), $\theta_e = 0.230$; Δ, line blanketed model, VAN CITTERS and MORTON, $\theta_e = 0.230$; *, SMITH (1967), 1346Å; ⊡, BLESS et al (1968), 2150Å; x, CHUBB (1963), 1314Å; ∅ BYRAM and CHUBB (1965), 1115Å; O, CAMPBELL, 1450Å.

Fig.9. Comparison between experimental and theoretical absolute intensities for νGemini. -, continuum model, MIHALAS (1965), $\theta_e = 0.360$; *, SMITH (1967), 1346Å; O, CAMPBELL, 1430Å

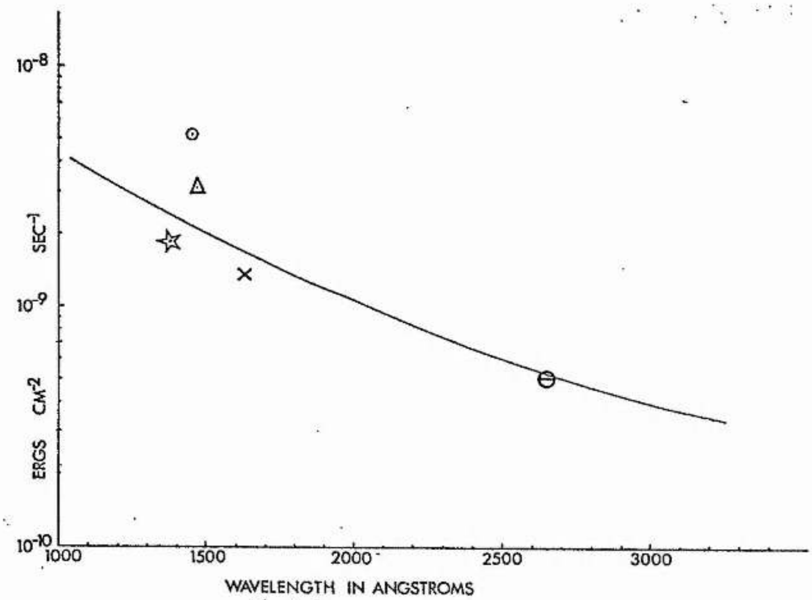


Fig.10. Comparison between experimental and theoretical absolute intensities for λTauri. —— , continuum model, MIHALAS (1965), θ_e=0.280; Δ , line blanketed model, VAN CITTERS and MORTON; *SMITH (1967), 1346Å; x, STECHER (1969), 1650Å; O , CAMPBELL, 1450Å; Θ , VITON (1970), 2600Å.

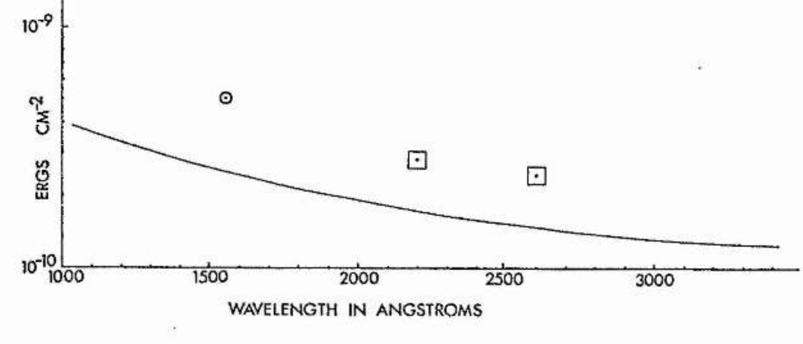


Fig.11 Comparison of experimental and theoretical absolute intensities for α Draconis. —, continuum model, MIHALAS (1965, =0.500; BLESS et al (1968),2150Å and 2550Å; CAMPBELL 1450Å.

theoretical value for a line blanketed model.

Fig.11. shows a comparison between a continuum model for αDRA and the present data and also the observations of BLESS et al at 2150Å and 2550Å.

CHAPTER VII

SUMMARY OF THE DATA AT 1450Å, 2150Å and 2550Å

It is apparent from the direct comparison of the 1450Å observations with those of other observers, Fig.1. that there is good general agreement.

The differences between the observed fluxes at 2150Å and 2550Å and the theoretically predicted fluxes, Fig. 2. indicate in general that the models are satisfactory for main sequence stars of types BO, B2, B3 and B5.

There are, however, a number of stars which appear to be somewhat anomalous or otherwise worthy of further consideration, as below:-

αLeonis (see Fig. 3.)

In the case of this star, observed by STECHER and MILLIGAN (1962), BYRAM and CHUBB (1963), SMITH (1967), and YAMASHITA (1968), intercomparison seems to indicate serious errors in the observations of BYRAM and CHUBB at 1427Å and of STECHER and MILLIGAN shortwards of 2150Å. This is born out by comparison with the model. SMITH'S results at 1376Å may be regarded as acceptable when compared with a model including a reasonable amount of blanketing. YAMASHITA is in agreement in the same manner at 1415Å although his values at shorter wavelengths are less certain.

τScorpii (see Fig. 4.)

The observations of BYRAM and CHUBB at 1150Å would again seem to be considerably in error when compared with the agreement between SMITH at 1370Å and a model with a small amount of blanketing. At 2150Å there is a

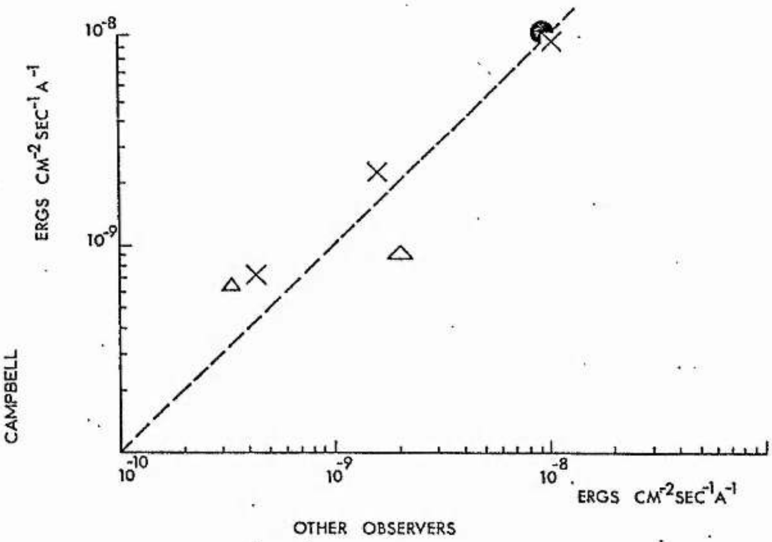


Fig. 1. Comparison between present data and other observers, for those stars in common. Δ, CHUBB (1965), 1329Å, 15 CMa, βCepheus; O , YAMASHITA (1968), 1415Å, δOrionis; x, SMITH (1965), 1376Å, γCassiopeiae, λTauri, νGemini.

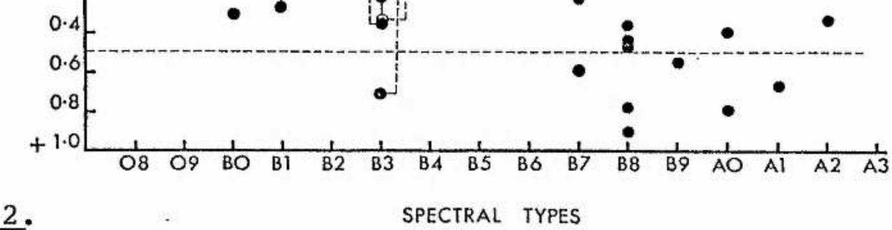


Fig. 2.

Plot of Δm (the difference between the theoretical and experimental ultraviolet magnitude at 1450Å) versus spectral type.

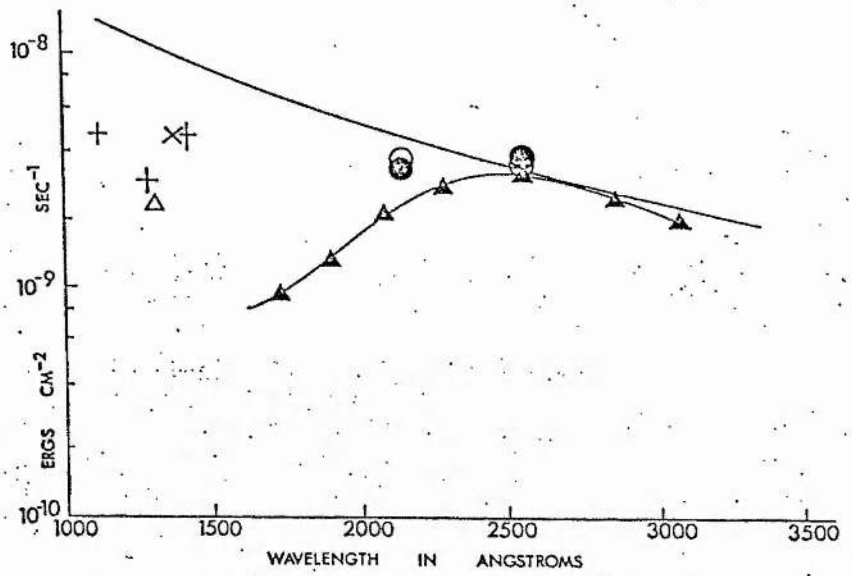


Fig. 3. α Leonis Spectral Type B7 m = 1.35; — Continuum flux for unblanketed Mihalas model for θe = 0.37; ▲ Observations of STECHER and MILLIGAN (1962); Δ Observations of BYRAM and CHUBB (1963); O Observations of CAMPBELL (1970) Rocket No. SO5/2; ⊗ Observations of CAMPBELL (1970) Rocket No S11/1; + Observations of YAMASHITA (1968); X Observations of SMITH (1967).

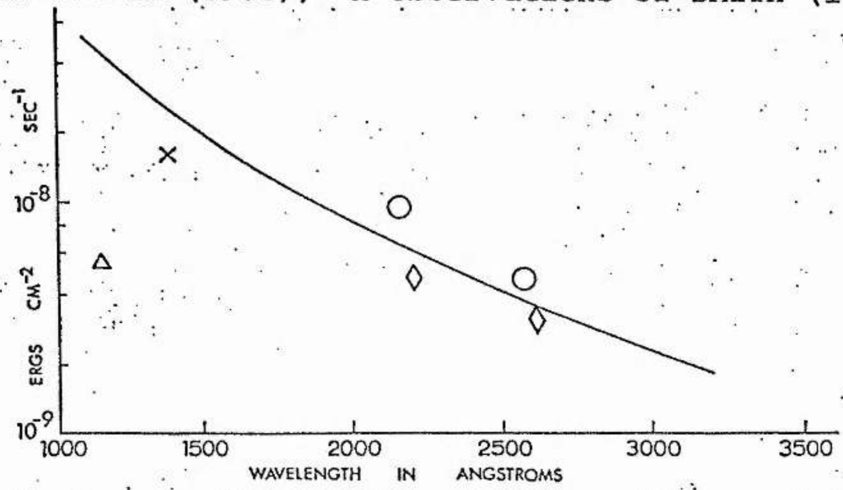


Fig.4. τ Scorpii Spectral Type BO m = 2.82; — Continuum flux for unblanketed Mihalas model for θe = 0.16; Δ Observations of BYRAM and CHUBB (1963); X observations of SMITH (1967); ◇ Observations of BOGGESS (1964); O Observations of CAMPBELL (1970).

difference between the results reported here and those of BOGGESS. Although BLESS et al (1968) reported agreement with several published observations of BOGGESS to within 0.25 magnitude, it is not clear whether the BOGGESS observations of τScorpii are included in this comparison.

γCassiopeiae (see Fig.5.

This star is a well known spectrum variable and there are observations in the visible, CHERRINGTON(1938) and HUFFER (1938), showing brightness changes of between 0.6 and 0.75 of a magnitude within a period of a few hours, although no well defined period has been observed. A veiling of the spectral lines was recently reported by SHELUS (1967). BYRAM and CHUBB'S data are again well below both SMITH'S and the assumed model. However, the results given here are significantly above the assumed model. The implication is either that the simple model does not well represent this unusual star in the ultraviolet or that there was a brightening of the star in the ultraviolet (and possibly in the visible), at the time of the observation and possibly after SMITH'S observation. The ultraviolet spectrum has been obtained by MORTON et al (1970), for the region 1060Å - 2120Å and they report no outstanding emission lines.

A number of conclusions are possible for these, the first European photoelectric observations at wavelengths of 1450Å, 2150Å and 2550Å. A number of stars were observed, which have not been previously observed at these wavelengths. A comparison with the other major

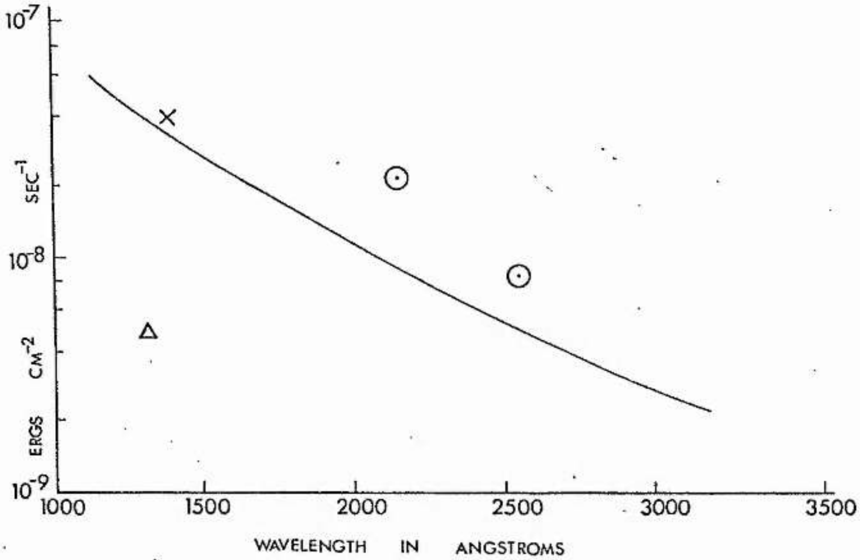


Fig. 5. γCassiopiae Spectral Type B0e m_v=2.41; — Continuum flux for unblanketed Mihalas model for Θ_e=0.16; x Observations of SMITH (1967); ΔObservations of CHUBB (1963); O Observations of CAMPBELL (1970).

sources of observations at these wavelengths, SMITH (1967), BOGGESS and BORGMAN (1964), STECHER (1969) and BLESS et al (1968), indicates a satisfactory agreement for those stars in common, and for stars of the same spectral class, although there are a number of differences, particularly in the observations of δ Orionis, and the observations of SMITH and the data of CAMPBELL, BLESS et al and CARRUTHERS.

The comparison between the present results and those of other observers indicates substantial agreement for those stars in common. The close agreement between the observations of α Leonis for both the rocket flights indicates a satisfactory self-consistency for the calibration and data reduction procedures.

By using the intermediary of simple unblanketed continuum model atmospheres to compare observations, it has been possible to associate stellar models with stars in the spectral classes, BO, B2, and B5 using the extinction co-efficients of STECHER and BOGGESS at 2150Å and 2550Å. In general, the observations indicate ultraviolet fluxes within 0.5 magnitude of the model prediction.

The reddening correction applied at 1450Å using the data of STECHER and BLESS gives values for the corrected experimental magnitudes which are in good agreement with theoretical models which include the effects of blanketing at the shorter wavelengths. However, because the accuracy of the absolute photometry is only twenty-five percent, it is not possible to ascertain separately the magnitude of the effect of stellar rotation, spacial variations in interstellar absorption and errors in spectral classification, and this will require a number of separate investigations using star pointing rockets.

For those stars exhibiting emission characteristics and with high rotational velocities, a significant increase in ultraviolet flux near 2150Å was observed, whereas, at 2550Å the intensity was in agreement with the simple continuum models.

In the case of α_2 CVn, which is classed as AOp, a comparison with a continuum model for the effective temperature appropriate to an AO star indicates an observed ultraviolet flux intensity at 2150Å far in excess of that predicted by the model. However, a comparison of the present results with a B8V model, which gives theoretical magnitudes of -1.08 and -0.77 at 2150Å and 2550Å would seem to support DEUTCH'S hypothesis that the effective temperature of this star corresponds to an earlier spectral type.

An earlier statement by BLESS that stars of the same visual spectral and luminosity class have the same intensity in the ultraviolet, is confirmed, as is also an earlier observation of CAMPBELL that early-type stars with emission characteristics are progressively brighter in the ultraviolet.

From Fig.6. it is evident that there is good agreement at 1450Å between the observational data and the line blanketed models over the range O8-B5. However, after B5 the agreement is less satisfactory and differences of up to a magnitude are evident. This had already been observed at 1470Å, 2150Å and 2550Å. There are a number

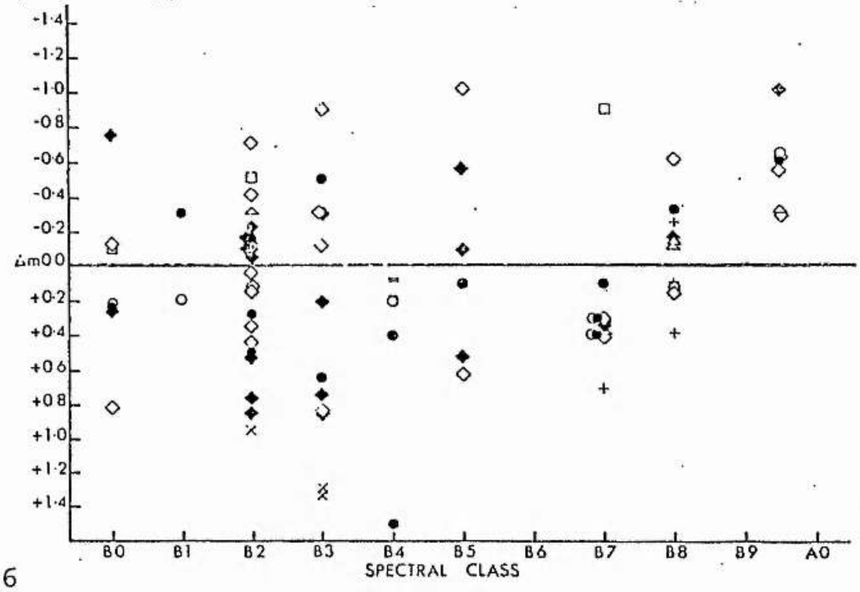


Fig.6

Plot of Δ m (difference between the observed ultraviolet magnitudes and theoretical magnitude) against other observations for the same stars - SMITH (1967) 1376Å; STECHER (1969) 2150Å; STECHER (1969) 2550Å; BLESS et al (1968) 2150Å BLESS et al (1968) 2550Å; + YAMASHITA (1968) 1376Å; x BYRAM and CHUBB (1963) 1427Å; CAMPBELL (1970) 2150Å; CAMPBELL (1970) 2550Å.

of possible sources which could contribute to such discrepancies and they are fully discussed in a paper by DAVIS and WEBB (1970).

The success of these rocket investigations has shown that it is possible to obtain significant astrophysical data on a reasonable time-scale and with an absolute accuracy unobtainable from satellite investigations.

SUBJECT UPDATE

Although the work described in this thesis was completed in 1972 several major investigations have since been carried out using sophisticated satellites and stabilised rockets and it is of interest to compare where appropriate the accuracy and the validity of the present data with these newer observations.

In the case of the satellite investigations there can be major sources of error in the absolute calibration which are due in the main to the long time-scale between the final calibration of the satellite instrument and its lanuch, and it has been usual for such investigations to be supported by the launch of a number of rocket payloads using similar instrumentation. Using rockets, the time-scale between laboratory calibration and launch could be as short as several hours and the long term calibration errors which were noticeable with the satellite payloads could be minimised. Unfortunately, a number of the groups preparing such satellite investigations have had little experience in the preparation of rocket payloads and their associated absolute calibration and the value of the data obtained to support the satellite data does not compare favourably with existing rocket observations for those stars in common.

An additional complication in comparing the present data with more recent observations arises from the fact that most of the more recent satellite observations were designed to permit very high resolution studies of bright stars and as a consequence although substantial information on line blanketing effects in early type stars and more accurate stellar classification is possible, such information can only be used to more accurately refine stellar models but provide little possibility of direct comparison with the broader passbands utilised in photometric observations. None-the-less, where such studies have associated rocket calibration programmes, this photometry can be used to compare the absolute calibration procedures used in relation to the main satellite observatories and thus permit such observations to be compared with the earlier rocket observations.

SATELLITE OBSERVATORIES

OAO2 (ORBITING ASTRONOMICAL OBSERVATORY)

This satellite was launched on the 7th. December 1968 and was the first of a series of sophisticated pointing observatories with a common design philosophy aimed at permitting a number of different observatories to be constructed using a standard engineering shell. The observatory incorporated experiments proposed by the Smithsonian Astrophysics Institution and the Space Astronomy Laboratory of the University of Wisconsin. In the case of the Smithsonian proposal, the observatory package (Celescope) comprised several uvicon television cameras which permitted two dimensional stellar maps to be obtained in four filtered passbands. Unfortunately, serious degradation of the vidicon cameras occurred during the orbital life of the observatory and although an ultraviolet catalogue was produced, the variation in the absolute fluxes obtained did not permit direct comparison with other data, even although some of the data was corrected using sounding rocket investigations.

The University of Wisconsin package was conventional in design and consisted of a number of filter wheel photometers and two objective grating spectrometers operating over a wavelength range 1200Å-4300Å. The data from each photometer and spectrophotometer were independent and provided a very accurate assessment of the long time stability of the observatory to be obtained. Unfortunately, due to the long delay (18 months) between the absolute calibration and the launch of the Wisconsin OAO2 experiment the resulting absolute data showed substantial differences with established data (CAMPBELL 1973). A number of rocket flights, (BLESS 1974) were used to recalibrate the observatory. The data from these flights were themselves inconsistent and a further recalibration of the OAO2 data was undertaken (FAIRCHILD 1976) giving new calibration absolute accuracies of ±30% at 1300Å, ±10% at 1800Å and ±5% at 3300Å. The new calibration was undertaken using the University of Wisconsin synchrotron radiation facility as the calibration source.

TD1A SATELLITE EXPERIMENT S2/68 (EDINBURGH-LIEGE)

The TD1A satellite was launched in March 1972 from the Western Test Range, California. The satellite contained several experiments and the S2/68 experiment was proposed by the Royal Observatory, Edinburgh and the Institut d' Astrophysique, Liege. The experiment has been described by BOKSENBERG (1973) and consisted of a 25cm off-axis parabolic mirror telescope feeding a single photometric channel centred on 2750Å and a plane grating spectrometer with three exit slits. As the star passed through the field of view of the telescope, the image moved across the spectrophotometer grating, producing a spectral scan at the exit slits. The spectrophotometric passbands were centered on 1550Å, 1850Å and 2250Å with a resolution of 36Å.

The satellite utilised a unique stabilising system which ensured that the optical axis of the telescope pointed at right angles to the earth at all times. The satellite precessed by approximately four minutes of arc per orbit and was designed to scan the complete celestial sphere in six months. The objectives were successfully achieved and a sky atlas of over one hundred and fifty thousand low resolution spectra were obtained. The absolute calibration was conducted at both laboratories but regretfully did not utilise a calibration procedure which would have allowed a direct comparison with other space observatories. The total lack of any supporting rocket programme after the satellite launch was very unfortunate and the absolute calibration below 1850Å did not agree with other observations. This disagreement was due in the main to the simplicity of the absolute calibration procedure adopted and the non-exchange of calibration standards with other space laboratories.

<u>OAO3 (ORBITING ASTRONOMICAL OBSERVATORY)</u>

OAO3 was launched in August 1972 and was subsequently named the COPERNICUS observatory. The scientific package was the most sophisticated of the series and was intended to compliment the low resolution spectrophotometric telescopes of the Goddard Space Flight Centre flown on OAO1. Both observatories employed 1m telescopes and thus had the capability of observing very faint objects, however, due to a technical malfunction of the pointing system and the power generation equipment on board the OAO1 observatory, the observatory ceased to function, and OAO3 became the first large optical space observatory. The project was undertaken by the Princeton University group and the observatory had the capability of obtaining high resolution spectra (0.12Å in 1st order and 0.05Å in the 2nd. order) between 1050Å and 3500Å.

Many excellent spectra have been obtained with the observatory but the high resolution achievable did not permit easy comparison with the broader photometric rocket data.

THE ANS SATELLITE

In August 1974 the Dutch astronomical satellite ANS was launched from the Western Test Range in California. This pointing satellite was designed to permit broad band spectrophotometric data to be obtained in five passbands centred on the following wavelengths: 1549Å, 1545Å, 1799Å, 2200Å, 2443Å, 3294Å with a resolution of the order of 175Å. The absolute calibration was undertaken using sub standards traceable to the University of Wisconsin observatory standards which was unfortunate because of the earlier problems with the OAO2 calibration data.

By the end of 1979, very little data relating to this satellite experiment had been published; however, in January 1980, a catalogue of over 3500 stars was published VAN DUINEN(1980). The original satellite calibration was updated using a sounding rocket experiment.

ROCKET OBSERVATIONS

By the end of 1972 the ESA rocket programme had been completed and rocket astronomy ceased within Europe apart from a very few launches in support of the then existing orbiting laboratories. Several groups participated in these calibration studies and Table (1) indicates those launches specifically aimed at calibrating one or other of the orbiting laboratories. Unfortunately, the European results were disappointing and although fully stabilised rockets were utlised with a capability of pointing at selected stellar targets, the calibration procedures were not sufficiently well developed to give any additional confidence to the previous rocket observations.

In the case of the rocket observations of HESSBERG(1975) although very similar instrumentation was used to that flown by the author, the calibration accuracy using the Boldt plasma arc at Garching, Munich, did not permit a valid absolute calibration of better than $\pm 25\%$ to be achieved and from the data obtained, the results indicated a calibration accuracy of nearer $\pm 50\%$. Recovery of the instrumentation package and its recalibration indicated that no deterioration of the original calibration had taken place. The difference between the observations of HESSBERG and other previous

EXPERIMENT	YEAR	WAVELENGTH REGION	RESOLUTION	ABSOLUTE CALIBRATION
OAO2	1968	1200Å - 4300Å	20Å	±30% @ 1300Å ±10% @ 1800Å ±5% @ 3300Å
TD1A S2/68	1972	1350Å - 2550Å	36Å	±30%
		2740Å	360Å	±30%
OAO3	1972	1000Å - 4200Å	0.12Å and 0.05Å	NOT STATED
APOLLO 17	1972	1180Å - 1680Å	11Å	±10%
BOHLIN	1974	1200Å - 3400Å	18Å	±25%
ANS	1974	1550Å - 3300Å	150Å	±35%
HESSBERG	1975	1100Å - 3400Å	100Å	±25%
FELDMAN	1977	900Å - 3100Å		±25%

TABLE (1) ROCKET AND SATELLITE INVESTIGATIONS rocket observations can be explained on the basis of the uncertainty in the Boldt arc calibration below 1850Å, i.e. beyond the wavelength range where a calibration could be obtained with tungsten ribbon sources. Such an uncertainty had been observed when the author calibrated a payload with the same facility but used in addition, monitor photomultipliers and photo-diodes which had been calibrated at the Princeton Observatory and the Goddard Space Flight Centre. The discrepancies between the calibrated arc intensities and those measured by the independently calibrated detectors indicated an absolute value nearer ±50% than the ±25% stated.

In the case of the rocket observations conducted by American astronomers and in particular those of BOHLIN(1976) there is a good agreement with the author's data for those stars in common and this is particularly important since an integral part of both calibrations was the use of NBS secondary standards in the form of calibrated solar blind photo-diodes similar to those used to calibrate the Max Planck plasma arc. In this way it was possible to inter-compare directly other independent observations with those of HESSBERG and BOHLIN and independently the OAO2 and ANS calibrations.

In the case of the author's southern hemisphere observations from Woomera, it was possible to recover the payload and recalibrate the photometers and thus check the constancy of the calibration during the observing phase of the flight. The observations of FELDMAN (1977) using a pointing rocket provided an opportunity of comparing those stars in common and with resultant good agreement. Again in this case an NBS secondary standard photo-diode was used for the range 1200Å - 1700Å, similar to that used by the author in 1968 and by BOHLIN in 1972 and 1976.

Although substantial developments in rocket astronomy have taken place since 1972 and in particular the advent of the stabilised pointing rocket, it is regrettable that such sophistication in the control of the rocket has not been accompanied by any real improvement either in calibration accuracy or indeed awareness of the actual problems associated with such calibrations and the situation is almost more confusing than was previously the case. It is, therefore, necessary to use pre 1972 rocket observations as standards and from these observations, to calibrate the orbiting satellite observatories themselves.

COMPARISON BETWEEN SATELLITE OBSERVATIONS AND ROCKET DATA

As stated earlier, from the comparison between the early observations of the OAO2 data and those observations in common with the authors, it was clear that the OAO2 observations were between ±25% and ±35% higher at wavelengths above 2150Å. Subsequent recalibration by BLESS (1976) lowered the OAO2 fluxes by about ±30% which gave a good agreement with the author's data above 2150Å. Comparing the revised OAO2 data with the TD1A S2/68 data indicated that the OAO2 data agreed within ±5% above 2150Å. The rocket data of HESSBERG (1975) was in agreement both with the author's data and the revised OAO2 data but to a lesser extent with the S2/68 data above 1850Å. Again, the rocket data of BOHLIN (1976) was not in agreement with the author's data above 2150Å. Table (2) shows several ultraviolet colours derived from rocket observation by BOGGESS and KONDO (1968), BLESS (1968), CAMPBELL(1970-71), SUDBURY (1971), EVANS (1972) and the S2/68 data. There is very good agreement between the data of EVANS, the S2/68 data and the author's data at 2550Å for spectral classes B2 - B8. The agreement between the data of the author and EVANS (1972) is excellent for spectral classes B2 - B8 at 2150Å. At 1470Å the author's data does not agree with the S2/68 data.

Below 2150Å where the calibration problems begin to become apparent, the errors in the S2/68 calibration produces fluxes much fainter than those measured by the author and the OAO2 observations, even although at 1470Å there is good agreement between the rocket data of BOHLIN (1976), CAMPBELL (1970) and FELDMAN (1972). The Apollo XVlldata at 1550Å is also about ±20% fainter than the rocket data.

Comparison of the new ANS data with the appropriate rocket data shows that above 2150Å the ANS gives much higher fluxes than the rocket data and also higher fluxes than the S2/68 data. Below 2150Å the ANS fluxes are also very much brighter than both the rocket data and S2/68 data. There is correspondingly little agreement with the revised OAO2 data which is very surprising since the calibration standards used to calibrate the OAO2 spacecraft were used to calibrate the ANS satellite.

It is clear therefore that below 2150Å those rocket

TABLE 2

ULTRA VIOLET COLOURS

Sp. type	Boggess & Kondo (1968)	Bless *et al.* (1968)	Campbell (1970, 1971)	Sudbury (1971)	Evans (1972)	TD1
	$m_{2750}-V$	$m_{2800}-V$			$m_{2800}-V$	$U1-V$
B0	−2·1					−1·9
B0·5	−2·1				−2·2 (κ Ori)	
B2		−1·9			−2·1 (γ Ori)	−1·5
B5		−1·3				−1·0
B7					−0·8 (α Leo)	
B8	−0·5	−0·8				−0·6
A0		−0·3				0·2
A1	0·2				−0·1 (α CMa)	
		$m_{2500}-V$	$m_{2550}-V$	$m_{2500}-V$	$m_{2550}-V$	$U2-V$
B0			−3·2	−2·4		−2·6
B0·5					−2·4 (κ Ori)	
B2		−2·2	−2·2	−1·9	−2·2 (γ Ori)	−2·0
B5		−1·6	−1·8	−1·2		−1·2
B7					−0·9 (α Leo)	
B8		−1·1	−1·2	−0·4		−0·6
A0		−0·5		0·0		0·1
A1					0·05 (α CMa)	
	$m_{2250}-V$	$m_{2100}-V$	$m_{2150}-V$	$m_{2200}-V$	$m_{2200}-V$	$U3-V$
B0	−3·1		−3·8	−2·8		−3·1
B0·5	−2·8				−2·4 (κ Ori)	
B2	−2·4	−2·4	−2·5	−2·3	−2·4 (γ Ori)	−2·4
B5		−1·6	−2·1	−1·4		−1·6
B7					−1·1 (α Leo)	
B8	−1·0	−1·1	−1·3	−0·6		−0·9
A0		−0·6		0·0		−0·2
A1	0·0				−0·2 (α CMa)	
			$m_{1470}-V$		$m_{1500}-V$	$U4-V$
B0						−4·1
B0·5					−3·0 (κ Ori)	
B2			−3·2		−2·9 (γ Ori)	−3·6
B5			−2·9			−2·7
B7					−1·4 (α Leo)	
B8			−2·0			−1·9
A0						−0·6
A1					0·3 (α CMa)	

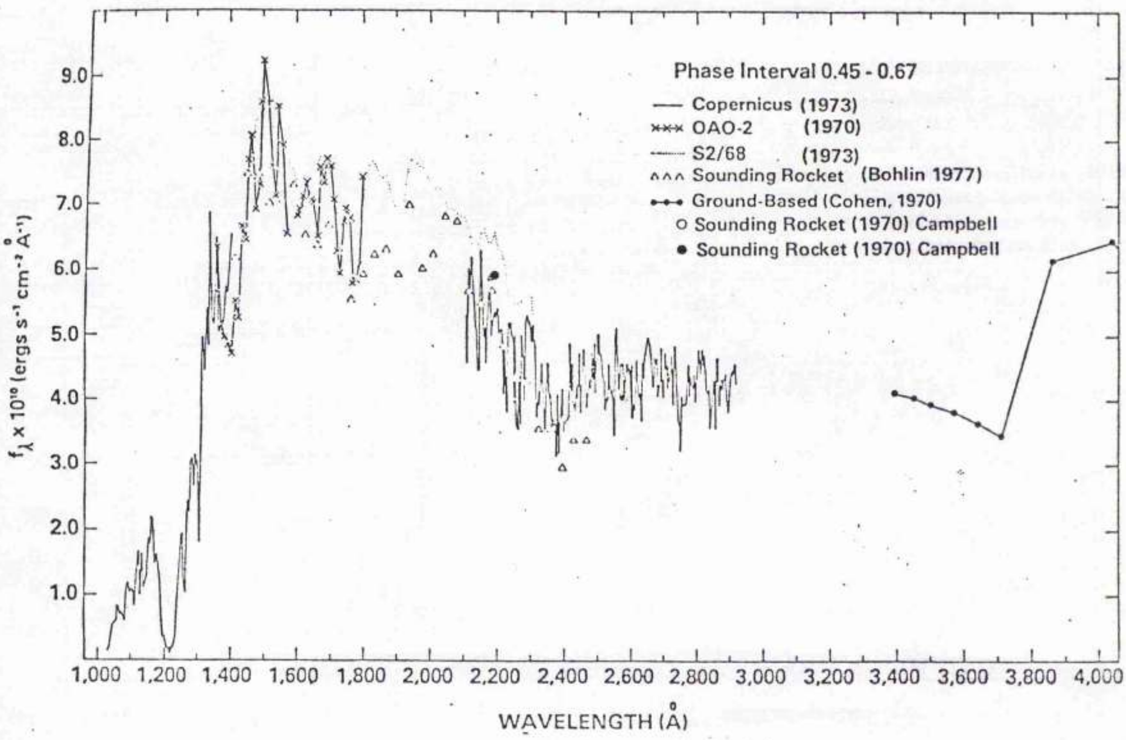


Fig. 7 . ABSOLUTE ULTRAVIOLET FLUX DISTRIBUTION

$\alpha^2 CV_n$ at rare earth minimum

calibrations which were based on transfer photo-diodes and detectors and which were inter-laboratory calibrated, have provided much more accurate data than the satellite observations, and the question of ultraviolet stellar standards in space must await the launch and recovery of absolutely calibrated spectro-photometers placed on board future space laboratory projects.

The launch of high resolution observatories such as OAO3 and the IUE (International Ultraviolet Explorer) provided the capability to refine spectral classification and to more accurately assess the effects of line blanketing in stellar models but provide little opportunity to obtain economically absolute stellar fluxes. The power of these new observatories is indicated in the observation of $\alpha_2 CV_n$ shown in Fig.(7) taken at the same phase as the rocket data. The agreement with the absolute flux determination at 2150Å and 2550Å is very satisfactory and when observing time permits it would be important to examine with the OAO3 spacecraft the large number of anomalous observations included in the ANS, S2/68, OAO2 data in order to determine if such anomalies are astrophysically significant. The determination of absolute ultraviolet stellar standards in space should be a priority for future spacelab investigations together with the establishment of an international calibration network of ultraviolet laboratory standards.

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FIGURES, TABLES AND PLATES

Figures, Tables and Plates (continued)........

CHAPTER III:

Figures, Tables and Plates continued................................

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