Photoionising the Milky Way in an interesting fine-tuning problem

Context

Observations of line emission from the Milky Way disc by the WHAM instrument (Haffner et al., 2009; Krishnarao et al., 2017) show extended emission from diffuse ionised gas (DIG) up to kpc scale above the plane of the disc. This leads to two important questions:
1. How did this gas get photoionised?
2. How did this gas get there?

Since the only likely source of ionisation is ionising radiation from young O stars in the disc, the presence of the DIG is a strong constraint on how much radiation makes it out of the dense disc, and puts a lower limit on the UV luminosity of young O stars. Full 3D radiation transfer modelling of numerically simulated disc galaxies (Barnes et al., 2014; Vandenbroucke et al., 2018) shows that this is indeed a likely scenario. Explaining the presence of the DIG at these high altitudes is more challenging, since its density is an order of magnitude more than what is expected from a disc that is in a large scale hydrostatic equilibrium with a disc potential. Some mechanism, likely feedback in the disc, is providing pressure support for the DIG.

Fine-tuning Problem

In a recent study (Vandenbroucke et al., 2018) we explored the effect of cosmic ray feedback on the scale height of the DIG by post-processing snapshots of the SLCC simulation (Girichidis et al., 2016). We found that cosmic ray feedback can provide sufficient support for the DIG (see Figure 1). However, when looking at the temperature structure of the DIG (as traced by lines of Hα 6584 Å and [Sii] 6716 Å forbidden line emission), we discovered an interesting fine-tuning problem: we were only able to reproduce the observed temperature structure when the ionising source luminosity (a free parameter in our model) has a value that is just large enough to ionise all the gas in the DIG (see Figure 2). This can be explained by spectral hardening of the ionising radiation field: low energetic photons are more easily absorbed at low heights above the disc, so that relatively more high energetic photons are left to ionise the higher regions of the DIG, depositing more energy and hence increasing the local temperature.

This fine-tuning problem hints at an elegant mechanism to explain the observed DIG scale height. If photoionisation itself provides pressure support for the disc, then this would naturally explain why the necessary ionising luminosity is correlated with the DIG scale height.

The original SLCC simulations did not include photoionisation. Peters et al. (2017) included photoionisation in a follow-up SLCC simulation, but they did not investigate the effect of their photoionisation model on the diffuse gas at high altitudes. To test our hypothesis, we hence need to run additional simulations with a self-consistent coupling of photoionisation to the gas dynamics.

RHD Simulations

We use the Monte Carlo radiation hydrodynamics (RHD) code MCoRN (Vandenbroucke & Wood, 2018) to run self-consistent RHD simulations of a 1 kpc × 1 kpc × 4 kpc disc galaxy slice. We use an external gravitational potential based on the potential in Creswye, Theuns & Bower (2013), with a gas surface density of 10 M⊙ pc⁻², a gas fraction of 0.1 and an equilibrium temperature of 10,000 K. We set up an initial gas distribution corresponding to the same potential with a temperature of 1,000 K, and assume a two temperature isothermal equation of state, with neutral gas assumed to have an equilibrium temperature of 1,000 K, while ionised gas is set to a temperature of 8,000 K. In the dense disc, we put a random distribution of UV sources with a lifetime of 20 Myr, an average of 6 sources kpc⁻², and a stellar disc scale height of 10 pc. We evolve the system in time for 200 Myr to make it settle into a dynamical equilibrium.

Figures 3 and 5 show preliminary low resolution (64x64x256 cells) results for the density distribution. We can clearly see an extended DIG caused by expanding photoionisation bubbles originating from the disc. We are still exploring the parameter space and have not analysed the properties of the DIG yet (temperature structure, forbidden line emission), so it is not yet clear if photoionisation alone is sufficient to explain the presence of the DIG. But these first results seem to indicate that photoionisation is at least capable of providing some pressure support.

Figure 4 shows the evolution of our randomly generated source distribution over time. There is clearly a lot of Poisson noise that might affect our capabilities of obtaining a dynamic equilibrium. This might require us to use a larger box size to obtain better statistics.

References

Vandenbroucke B., Wood K., 2016, ASCOM, 23, 40

https://github.com/bvwvdnbv/CMaclonize