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Dust & Abundances of Metal-Poor Planetary Nebulae in the Galactic Anti-Center

George J. S. Pagomenos[1], **Jeronimo Bernard-Salas**[1] **and G. C. Sloan**[2,3,4]

[1]School of Physical Sciences, The Open University, Walton Hall, Milton Keynes, Bucks, MK7 6AA, UK
email: george.pagomenos@open.ac.uk

[2]Space Telescope Science Institute, 3700 San Martin Dr., Baltimore, MD 21218, USA

[3]Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC 27599-3255, USA

[4]Cornell Center for Astrophysics & Planetary Science, Cornell Univ., Ithaca, NY 14853-6801, USA

Abstract. Much of the new dust in the local ISM is produced in the last phases of stellar evolution of low- and intermediate-mass stars on the Asymptotic Giant Branch (AGB). Despite its importance, our knowledge of how dust properties depend on metallicity is limited. Studies of planetary nebulae in irregular galaxies in the Local Group (mostly focused on the LMC and SMC) have revealed a diverse spectral zoo and shown that low metallicity favours carbon-rich dust production by AGB stars. However, at ~1/3 and ~1/5 times the solar metallicity respectively, they provide two snapshots of dust composition at low metallicity, emphasising the need to investigate a region with a range of metallicity values. With its abundance gradient, the Milky Way fits this criterion and provides a good opportunity to observe the dust composition over a large metallicity range. In particular the Galactic anti-center, which is largely unexplored beyond galactocentric distances of 10 kpc, allows us to study the AGB dust *a priori* assumed to be metal-poor as well as exploring the extent of the Galactic abundance gradient. We analyse a *Spitzer* spectroscopic sample of 23 planetary nebulae towards the anti-center in order to understand how the metallicity gradient extends beyond 10 kpc from the Galactic center and to observe the dust composition in this region of our Galaxy. We find that the abundance gradients of Ne, S and Ar continue to distances of around 20 kpc (albeit with a large scatter) and the dust emission shows a carbon-rich chemistry similar to that in the Magellanic Clouds.

Keywords. planetary nebulae, dust, abundances, metallicity

1. Abundances

We have investigated the neon, sulfur and argon abundances, which remain unchanged throughout low- to intermediate-mass stellar evolution, within a sample of planetary nebulae (PNe) at Galactocentric distances (R_{gc}) of 11–27 kpc. It is important to investigate within this region as studies of PNe (e.g. Pottasch & Bernard-Salas 2006) and H II regions (e.g. Martín-Hernández *et al.* 2002) in the disk of the Milky Way show the presence of a metallicity gradient up to $R_{gc} \sim 10$ kpc. In the anti-center, abundance studies have been rare, with one finding that the gradient flattened beyond 10 kpc (Costa, Uchida & Maciel 2004) and another suggesting it may steepen (Henry *et al.* 2010).

Our abundances are plotted in Figure 1 (open squares) alongside those in the sample from the solar neighbourhood analysed by Pottasch & Bernard-Salas (2006). The anti-center abundances show no clear decrease with distance by themselves but they follow well from those of the solar neighbourhood sample up to R_{gc} = 15–20 kpc, despite a

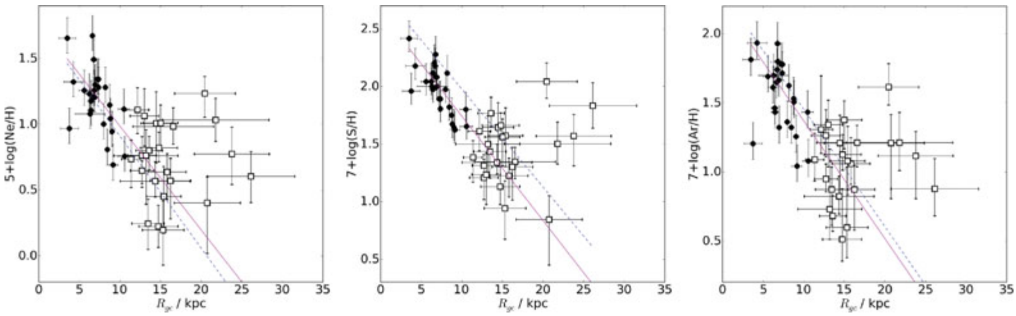

Figure 1. The abundance gradients of Ne, S and Ar in the Milky Way. Dashed lines represent the oxygen abundance gradient from within the solar neighbourhood, with a slope of −0.085 dex/kpc (Pottasch & Bernard-Salas 2006), passing through the solar elemental abundance at 8.0 kpc. Solid lines show the best fits in each plot, with slopes of −0.0788, −0.0906 and −0.0853 dex/kpc respectively. Distances are taken from Frew, Parker & Bojičić (2016). Abundance uncertainties range from 25% to 60%.

large scatter. Beyond these distances, the abundances appear to increase, potentially suggesting that these PNe are located outside the Galactic thin disk. With respect to the PNe in the solar neighbourhood, these sources are still relatively metal-poor.

2. Dust

In the solar neighbourhood, dusty PNe typically show either carbon-rich or oxygen-rich dust features (Pottasch & Bernard-Salas 2006). The central region of the Milky Way is more metal-rich, and dual-dust chemistry is relatively common (Gutenkunst *et al.* 2008). Studies show that the LMC and SMC are metal-poor and the dust in its PNe is mainly C-rich (e.g. Bernard-Salas *et al.* 2009; Sloan *et al.* 2014). Knowledge of the dust composition in the anti-center will give us insight into how dust evolves with metallicity.

From our sample of PNe in the anti-center, 17 of the 23 sources show C-rich dust emission features (e.g. PAHs), while the other six sources show no discernible dust features. Of the C-rich dust detections, there are five observations of SiC and four of C_{60} (three of which have already been detected by Otsuka *et al.* 2014), both of which are rare in the solar neighbourhood. The broad 30 μm feature that has been attributed to MgS but is also associated with aliphatic C-rich compounds has been found in six sources. We also find that O-rich dust emission and dual-dust chemistry are rare in the metal-poor anti-center with only one tentative detection of amorphous silicates. These findings agree well with those of Bernard-Salas *et al.* (2009) in the Magellanic Clouds, reinforcing the concept that low metallicity favours C-rich dust production.

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