Asymmetric Planetary Nebulae 5
(Ebrary, Cambridge, USA),
A.A Zijlstra, I. McDonald, eds.

Can Dust and Molecules Explain the Sulfur Anomaly in Planetary Nebulae?

Angela Speck

223 Physics Building, University of Missouri, Columbia, MO 65211-7010, USA

R. Henry

Recent studies of planetary nebulae have shown that their atomic/ionized sulfur abundances are lower than those for H II regions and blue compact galaxies for the same oxygen abundance. For optical-only observations, the abundance of triply-ionized sulfur must be inferred indirectly and could lead to underestimates of the total sulfur abundance. However, studies in the infrared (using ISO and SPITZER) show that the problem remains even when IR ionized emission lines are included in the calculated abundances. To resolve this problem, we consider the potential sinks for sulfur atoms. We investigate whether the observed sulfur anomaly can be explained by sequestering sulfur atoms into either solid state or molecular species.

Can Dust and Molecules Explain the Sulfur Anomaly in Planetary Nebulae?

Angela Speck[1] & Richard Henry[2]
[1]University of Missouri; [2]University of Oklahoma

I. Introduction:

Recent studies of planetary nebulae (PNe) have shown that their atomic/ionized gas sulfur-abundances are lower than those for H II regions and blue compact galaxies (H2BCG), based on comparison to oxygen abundances (see Figure 1). For optical-only observations, the abundance S IV must be inferred indirectly and could lead to underestimates of the total sulfur abundance. However, studies in the infrared (using ISO and Spitzer) show that the problem remains even when IR ionized emission lines are included in the calculated abundances. To resolve this problem, we have considered potential sinks for sulfur atoms.

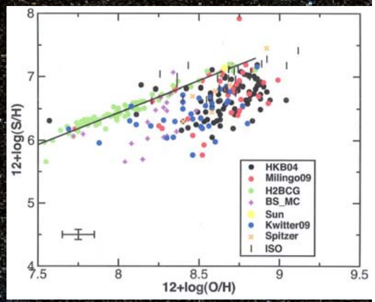

Figure 1: Plot of 12+log (S/H) vs. 12+log (O/H). Green circles are H II regions and blue compact galaxies (H2BCG) and represent the expected trend in S/O. Other colors indicate S-abundances in PNe from various studies.

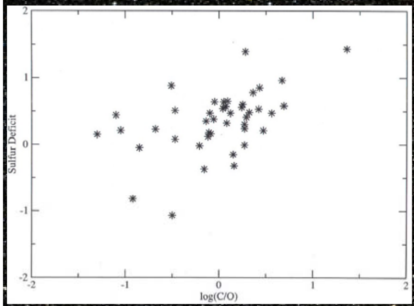

Figure 2: Sulfur deficit as a function of C/O ratio.. The sulfur deficit is defined as the amount (in dex) by which the sulfur abundance (relative to oxygen) is below that expected from the H2BCG trendline.

II Sequestering sulfur in dust

One possible sulfur sink would be dust. Dust formation for PNe occurs during the AGB phase, and its composition is determined, in large part, by the C/O ratio in the gas. Sulfur-bearing solids (e.g. MgS, FeS) are predicted to form in carbon-rich environments and have been tentatively observed in carbon-rich PNe (e.g. the "30um" feature). In oxygen-rich environments sulfur-rich grains are precluded by the abundant free oxygen, which will tend to oxidize any sulfides that form, releasing the sulfur back to the gas phase. Therefore, we should expect sulfur depletion in the gas phase to be highest in carbon-rich nebulae, which is not the case. There is no correlation between the apparent sulfur deficit and the chemistry of the nebula as shown in Figure 2. Oxygen-rich PNe show the same spread in sulfur deficits as their carbon-rich counterparts. Furthermore, some carbon-rich PNe which exhibit the MgS dust spectral also show low sulfur deficits or even enhanced sulfur abundances (see Figure 3). If sulfur-bearing dust does not exhibit spectral features and can exist in an O-rich environment, we would still expect to see a correlation between the dust abundance and the sulfur deficit. This is not the case. Figures 4 shows that there is no correlation between the S-deficit and the ratio of starlight to dust emission. This is further demonstrated by the ISO spectra of a selection of PNe in Figure 5). Thus we rule out dust formation as the source of the sulfur abundance anomaly.

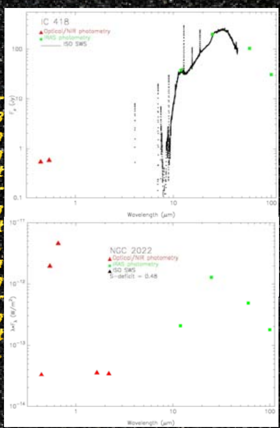

Figure 3: SEDs for two PNe. IC 418 has an enhancement in S-abundance but weak stellar emission compared to dust emission. NGC 2022 has a strong depletion but stronger stellar emission compared to dust emission.

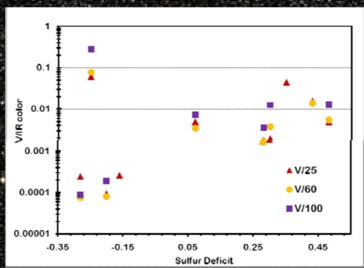

Figure 4: Sulfur deficit as a function of [V]/[25] which is used as a proxy for the ratio of stellar radiation to dust radiation.

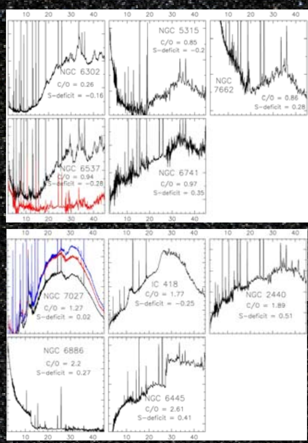

Figure 5: ISO Spectra of selected PNe in order of C/O ratio. Top five panels are all O-rich; bottom five panels are all C-rich. S-deficit and C/O ratio is included in each panel.

III Sequestering sulfur in molecules

Another potential sink for atomic/ionized sulfur gas is molecule formation. Molecules form during the AGB phase. As the star evolves towards the PN phase, the molecules will be destroyed by the increasingly high energy photons emanating from the star. However, molecules can survive in highly evolved PNe (e.g. the Helix Nebula) as long as they are shielded from the high energy photons by dust (possibly in clumps). Sulfur-rich molecules will not return their sulfur bounty to the gas if the dust shields them. In this case we would still expect to see a correlation between the dust abundance and the sulfur depletion. As shown above (Figure 4), this is not the case. However, dust emission in clumpy nebular (like the Helix Nebula) is weak.

IV Conclusions

Sulfur abundance anomalies cannot be attributed to sequestration of sulfur into dust grains. Formation and protection of sulfur-bearing molecules may provide a mechanism for sulfur sequestration. Further study of correlations between sulfur abundances and clumpiness of the host nebulae, and with evolutionary status of the nebulae are required.