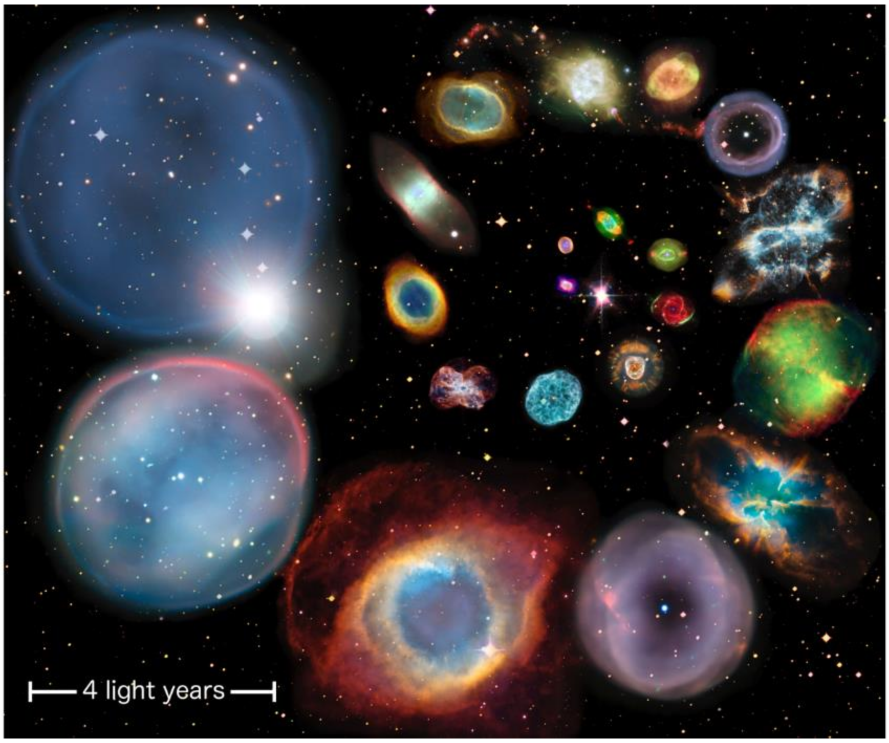
FACULTY OF SCIENCE
THE UNIVERSITY OF HONG KONG
香港大學理學院

DEAN
Professor Qiang ZHOU

**Press release** **For immediate release**
February 7, 2024

# HKU Astrophysicists Crack the Case of the "Disappearing" Sulphur in Planetary Nebulae




*A now iconic collage from our group showing 22 individual well-known PNe, artistically arranged in a spiral pattern by order of approximate physical size. The largest PNe have a surface brightness about a hundred thousand times fainter than the smallest and can reach up to 3 pc across. Image credit: ESA/Hubble and NASA, ESO, NOAO/AURA/NSF (see remark 1).*

Two astrophysicists from the Laboratory for Space Research (LSR) at The University of Hong Kong (HKU) have finally solved a 20-year-old astrophysical puzzle concerning the lower-than-expected amounts of the element Sulphur found in Planetary Nebulae (PNe) in comparison to expectations and measurements of other elements and other types of astrophysical objects.

The expected levels of Sulphur have long appeared to be "missing in action". However, they have now finally reported for duty after hiding in plain sight, as a result of leveraging highly accurate and reliable data. The team has recently reported their findings in *Astrophysical Journal Letters*.

## Background

PNe are the short-lived glowing, ejected, gaseous shrouds of dying stars that have long fascinated and enthused professional and amateur astronomers alike with their colourful and varied shapes. PNe live for only a few tens of thousands of years compared to their host stars, which can take billions of years before they pass through the PN phase on the way to becoming "white dwarfs". Consequently, PNe provide an almost instantaneous snapshot of stellar death throes. They are a vital, scientific window into late-stage stellar evolution as their rich emission line spectra enable detailed studies of their chemical compositions.

**The Enigmatic Sulphur Anomaly**

Past studies showed that PNe optical spectra appeared to have a varying deficit of the element Sulphur. This deficit was difficult to explain because Sulphur, known as an "α element", should be produced in lockstep with other elements like oxygen, neon, argon and chlorine in more massive stars. As a result, its cosmic abundance should also be directly proportional.

Surprisingly, while strong correlations between Sulphur and Oxygen abundances have been observed in H II regions (Hydrogen ionised region) and blue compact galaxies (see figure 2), PNe originating from low- to intermediate-mass stars consistently exhibit lower Sulfur levels, giving rise to the so-called mysterious "sulfur anomaly" that has perplexed and annoyed astronomers for decades.

**Our Work Solving the Mystery**

Ms Shuyu TAN, a graduate of HKU MPhil in Physics and Research Assistant at HKU LSR, along with her supervisor Professor Quentin PARKER, the Director of LSR, utilised an unprecedented sample of exceptional high signal to noise (S/N) optical spectra for approximately 130 PNe located in the centre of our Galaxy. This exceptional dataset had minimal background noise, allowing for a clear and detailed examination of the spectral features, helping the team effectively tackle and solve the mystery.

These PNe were observed using the world-leading European Southern Observatory (ESO) 8m Very Large Telescope in Chile. It turns out the anomaly was essentially a result of poor data quality for Sulphur emission lines in PNe spectra. It was found that using Oxygen as the base metallicity comparator to other elements was not accurate, and instead, Argon demonstrated a stronger correlation with Oxygen for Sulphur and has been suggested as a more reliable indicator of metallicity and a suitable comparison element.

So, when a large, carefully selected sample of PNe are spectroscopically observed at high S/N on a large telescope, not only did the data reveal a strong "lock-step" behaviour or Sulphur in PNe for the first time, as seen and expected for other types of astrophysical objects, but the anomaly itself effectively went away.
This is shown in the two key plots from the paper below:

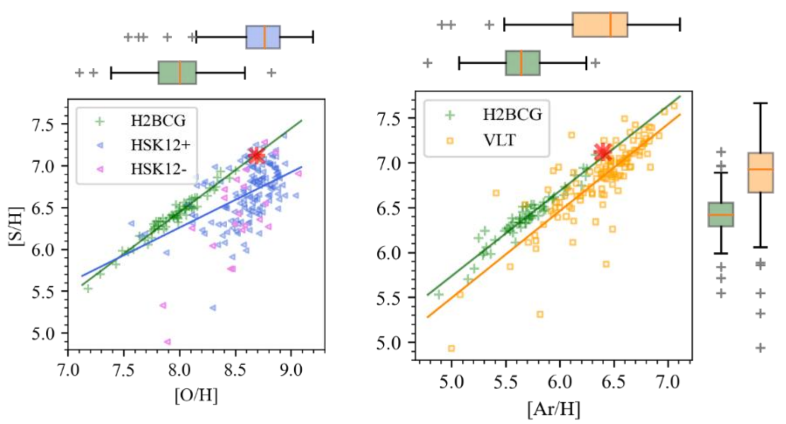



*Figure 2. The vertical axis for both plots – sulphur abundance relative to Hydrogen. Left plot – the sulphur anomaly (blue points are for PNe, green points for HII regions and blue compact galaxies) where Sulfur is shown relative to Oxygen. There is a large scatter for PN measure compared to the 1:1 lock-step behaviour expected and seen for other alpha elements in PNe.*

*Right plot: The green points are as before but this time the orange points are for the PNe from our VLT galactic centre PN sample and with sulphur plotted against Argon rather than Oxygen. There is now lock-step behaviour seen for sulphur for the first time and a parallel track and much tighter relationship where the anomaly is almost extinguished.*

*Image credit: Figure adapted from The Astrophysical Journal Letters, 961:L47(9pp),2024 February 1.*

Pokfulam Road, Hong Kong Tel: (852) 3917 2683 Fax: (852) 2858 4620 E-mail: science@hku.hk Website: https://www.scifac.hku.hk/

The authors have effectively disproven previous claims suggesting that the sulfur anomaly in Planetary Nebulae was a result of underestimated higher sulfur ionization stages or weak sulfur line fluxes. This finding underscores the critical importance of high-quality data in unraveling scientific mysteries.

*The Journal paper can be accessed here:* https://iopscience.iop.org/article/10.3847/2041-8213/ad1ed9/pdf

*Figure 3. Image from an ESO telescope in Chile of Planetary Nebulae PN NGC 5189. Some say it looks like a Chinese flying Dragon in space. Image credits: ESO*

*Remark 1: The image idea originated from Quentin Parker and Ivan Bojičić, and it was rendered by Ivan Bojičić with input from David Frew and Shuyu Tan. The names of all these iconic PNe in the figure starting at the top left-hand corner and following the spiral are: Abell 33, K 1–22, NGC 7293, IC 5148/50, NGC 2818, NGC 6853, NGC 5189, IC 4406, Shapley 1, IC 289, Fleming 1, NGC 3132, IC 4406, NGC 6720, NGC 2440, NGC 1501, NGC 2392, NGC 6543, NGC 6826, NGC 7009, IC 418, NGC 7027, HD 44179.*

For media enquiries, please contact Ms Casey To, External Relations Officer (tel: 3917 4948; email: caseyto@hku.hk / Ms Cindy Chan, Assistant Director of Communications of HKU, Faculty of Science (tel: 3917 5286; email: cindycst@hku.hk).

**Images download and captions:** https://www.scifac.hku.hk/press