The Astrophysics of Gaseous Nebulae and HASH Database Exploitation

Supervisor: Prof. Q. A. Parker

Author: Zou Xiang (Simba)

Major: Physics (Intensive)

Summer Research Fellowship (SRF) 2020 for Science Students

Poster No.: D15
Name: Zou Xiang
University No.: 3035692280
Student's Major: Physics (Intensive)

Planetary Nebulae

Planetary Nebulae (PNe) are the **ejected outer envelope of dying stars** with masses less than about 8 solar-mass. As PNe are expanding, they will eventually become too faint to be observable in about 25,000 - 35,000 years.

For confirming a PN, a widely used method is inspecting the emission line ratios in their spectra, for instance looking for a high value of the [O III] / Hβ ratio.

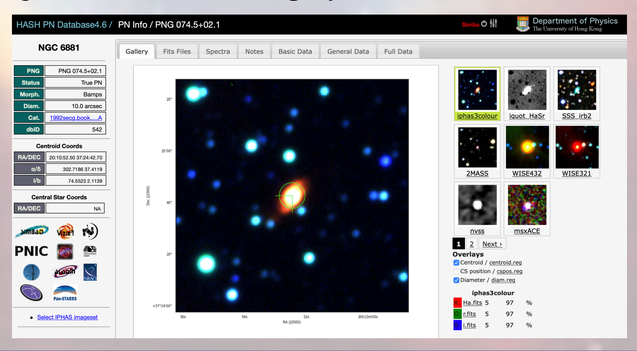
PNe provide precious records of the mass loss off the Asymptotic Giant Branch (AGB) and post-AGB stage of late-stage stellar evolution. The central star of a PNe (CSPN) is the dying star that creates the PN by ionising the previously ejected envelope. It is is usually a White Dwarf, with the temperature about 100,000K, Hence, it is a **blue star** in most cases. As a typical White Dwarf is only Earth-sized, therefore its luminosity is lower than a normal star.

the luminosity can be very low and hence **difficult to observe** even with large telescopes. Central stars of PNe may also be Wolf-Rayet stars with fast winds. The study of CSPNe is important and can provide us with deep knowledge of stellar evolutionary stages and enrichment processes of the Inter-Stellar Medium.

The "HASH" Database

HASH is an HKU-LSR bases internet accessible **database** containing recorded data for approximately 3500 **planetary nebulae**, including Galactic coordinates, CSPN coordinates, spectra, multi-band images using different filters and other crucial information. HASH integrates the best current data of all known PNe, aiming to uphold the highest standards of integrity of manually measured characterisric and information. It **provides a reliable platform** for Planetary Nebulae Researchers worldwide. Currently, about 800 of the PNe in HASH have recorded CSPNe.

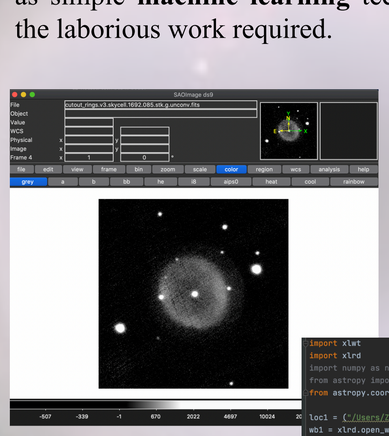
Throughout the summer, I have inspected and re-assessed 2 newly established independent CSPN catalogues with their proclaimed CSPN positions, with the help of the various imaging files available in HASH, including **PanSTARRS** images, and the **Hubble Legacy Archive** etc.



Methodology

All the imaging data used in my project are processed using **FITS** files and the graphical application **SAOImage: DS9**

Python programming, especially the **astropy** module as well as simple **machine learning** techniques, have greatly reduced the laborious work required.




```
import xlwt
import xlrd
import numpy as np
from astropy import units as u
from astropy.coordinates import SkyCoord

loc1 = ('/Users/ZOUXIANG/Desktop/HKU/Summer Research Fellowship 2020/locating central stars/We
wb1 = xlrd.open_workbook(loc1)
sheet1 = wb1.sheet_by_index(0)
workbook = xlwt.Workbook()
sheet2 = workbook.add_sheet("sheet 2", cell_overwrite_ok=True)
for i in range(1,361):
    if sheet1.cell_value(i,4)!='':
        c1 = SkyCoord(str(sheet1.cell_value(i, 2)), str(sheet1.cell_value(i, 3)), frame='fk5')
        c2 = SkyCoord(str(sheet1.cell_value(i, 4)), str(sheet1.cell_value(i, 5)), frame='fk5')
        sepc1.separation(c2)
        sepsep.arcsecond
        sep=float(sep)
        sheet2.write(i,0,sep)
workbook.save('Deviation of Weidmann from Gaia rough.xls')
```

Catalogues Investigated

- **Weidmann (2020 catalogue):** 619 CSPN coordinates (Integrated from various sources)
  - All CSPN candidates individually inspected
- **Gaia Planetary Nebulae Central star catalogue**
  - Sampling (37.4%) of the coordinates with Gaia reliability quoted as ≥0.85

Weidmann's Catalogue

Objects classified as Non-PN

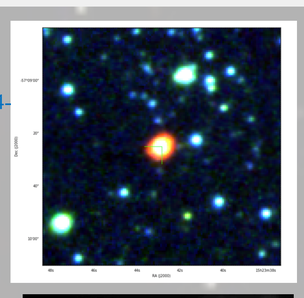
- 45 objects are **not characterized as PNe in HASH** (7.27%)
  - 15 symbiotic binary stars
  - 14 ionized inter-stellar medium (ionized ISM)
  - 6 ionized hydrogen region (H II)
  - 3 transition object
  - 7 others (e.g. Cataclysmic Variable Stars)

Unlocatable Central Stars

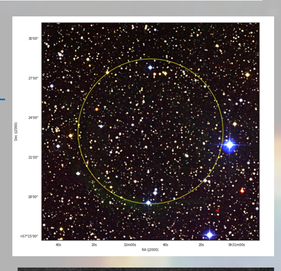
There are 202 CSPNe in Weidmann's catalogue where I could not manually locate their position in the available HASH data.

Reason	Frequency
The Planetary Nebulae is **too compact so** that its central star cannot be seen against the PNe itself	106
The Planetary Nebulae is **too faint** that the central star location cannot be properly determined	12
There are **too many blue stars** within the region of the planetary nebulae, so we cannot tell which is the real PN central star	41
The central star is **not visible** even if the planetary nebula is visible	23
others (e.g. Possible or likely PNe)	20
Total	**202**

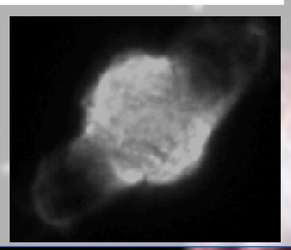
Pe 2-8
PNG 322.4-00.1
Too Compact



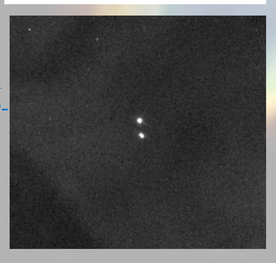
Sh 2-176
PNG 120.2-05.3
Too Faint



NGC6886
PNG 060.1-07.7
Central Star is not Visible



NGC 650/1
PNG 130.9-10.5
Too many Stars

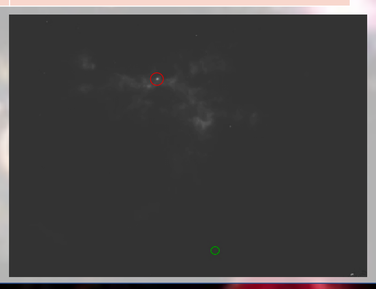


Astrometry Issue

Some of the remaining 370 PNe with central star coordinates manually determined display deviations with the recorded value in the Weidmann catalogue. In the table below, 'x' is the **angular difference** between the two measurements.

Angular distance (arcseconds)	Frequency
$x \leq 1$	263
$1 < x \leq 3$	72
$3 < x \leq 5$	15
$x \geq 5$	20
Total	370

Example:
Red circle: CSPN located in this work
Green circle: CSPN recorded in the Weidmann catalogue



Discussion: Error Obtained

- **Year of the Measurement and Measurement Errors**
  - Weidmann's catalogue has integrated results from papers published in the 1990s or even as early as the 1970s.
  - Shifts of 1 arcsecond for PNe at 10kpc distsance from us implies movement at one-tenth of the speed of light and this is unfeasible, so these are **measurement errors.**
- **Images' Coordinate System**
  - Small FITS image cut outs may have a **less accurate coordinate system**.
  - The Hubble Legacy Archive has high resolution images but not so accurate coordinate system.
  - PanSTARR images usually have lower resolution but have excellent astrometry.
- **Quality of the Images**
  - Distant stars appeared to be a **bright "disk"**.
  - In general hard to precisely locate the star.

Gaia Central Star Catalogue

Introduction to Gaia

- Gaia Space satellite Mission Statement:
  - Make the **largest, most precise** 3D map of our Galaxy by surveying more than a thousand million stars.
- Advantage:
  - Has vastly superior (**the most accurate**) astrometry, if the correct CSPN is identified.

Result and Findings

Gaia currently has positions for 1935 CSPNe but only those with a reliability ≥ 0.85 are investigated here for a total 904 stars. For this study 338 out of the 904 CSPNe are individually investigated, as an ~1/3rd random sample.

Reliability	Frequency	Constituent %
0.85 ~ 0.90	82	9.1%
0.90 ~ 0.95	134	14.8%
0.95 ~ 0.99	232	25.7%
0.99 ~ 1.00	456	50.4%
Total	**904**	**100%**

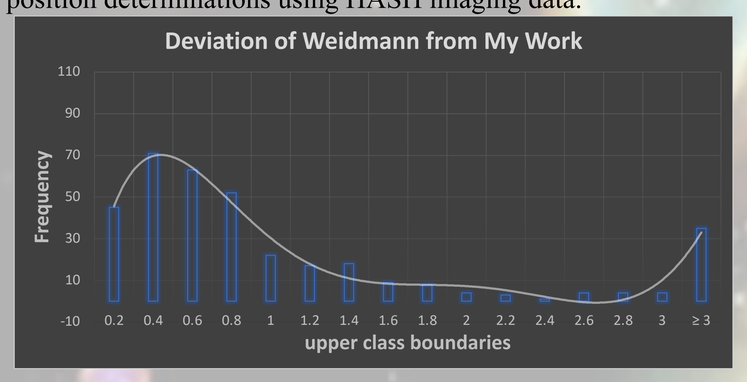
The Reliability Distribution of the CSPNe

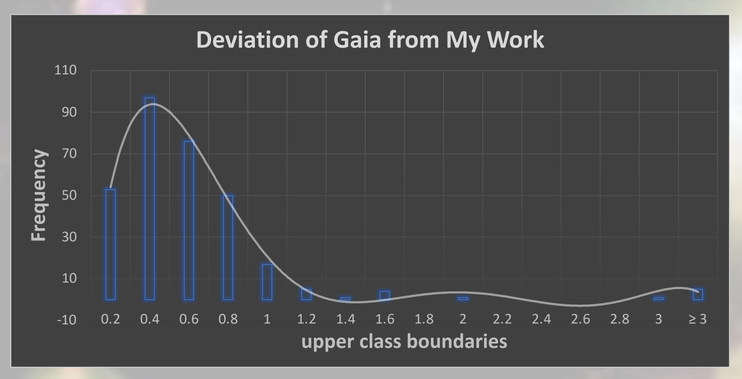
Reliability	Frequency of CSPNe that I can determine	Frequency of CSPNe that I cannot determine	Percentage of "can determine"
0.85 ~ 0.90	22	23	48.9%
0.90 ~ 0.95	18	23	43.9%
0.95 ~ 0.99	39	48	44.8%
0.99 ~ 1.00	111	54	67.3%
Total	**190**	**148**	**56.2%**

CSPNe in Gaia's catalogue that I can or cannot determine

Summary and Comparison

The following charts illustrate the **angular deviations** of the two inspected catalogues with respect to my work. One can easily see that **Gaia have higher agreement** with my own position determinations using HASH imaging data.





What I learnt over the Summer

- **The importance of maintaining data integrity**
  - The number of researchers in a specific field is generally small, so any act of carelessness may cause huge loss to the progress of chasing the truth.
- **Do not trust published data to the full extent**
  - The paper or experimental results published by another author **should not be 100% trusted.**
  - They may contain various kinds of errors.
  - A good case is made **to check data and results ourselves** and contact the original author to discuss if possible.

Key References:

Frew, D. J., & Parker, Q. A. (2010). Planetary Nebulae: Observational Properties, Mimics, and Diagnostics.

Parker, Q. A., Bojicic, I. S., & Frew, D. J. (2016). HASH: the Hong Kong/AAO/Strasbourg Hα planetary nebula database.

Weidmann, W. A., Mari, M. B., Schmidt, E. O., Gaspar, G., Miller Bertolami, M. M., Oio, A. G., Gutiérrez-Soto, L. A., Volpe, M. G., Gamen, R., & Mast, D. (2020). Catalogue of central stars of planetary nebulae Expanded edition