Title: GALEX Observations of Planetary Nebulae.
Author: Prof. Ananta C. Pradhan,
Department of Physics and Astronomy, NIT Rourkela.

Abstract

A planetary nebulae consists of a hot, luminous central star and an expanding glowing shell of gas and dust. The central star of most of the planetary nebulae (PNe) is a very hot object which is bright in ultraviolet (UV) and hence, UV observations explore the properties of these objects. We present the UV images of 108 PNe using observations made by Galaxy Evolution Explorer (GALEX). We have determined the angular diameter of PNe in NUV and also in FUV for whichever source detection exists considering a 3σ emission level above the background. We determine the morphology and many other physical parameters related to UV observations of PNe.

GALEX Observations of Planetary Nebulae

Ananta C. Pradhan

Department of Physics & Astronomy
NIT Rourkela

About The Conference

The Conference :

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Nebulae

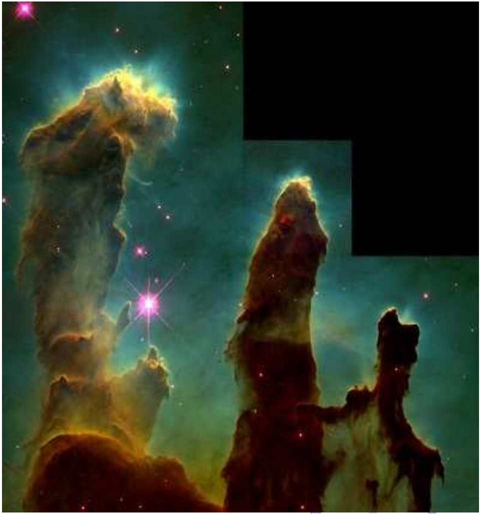
- The word **nebula** referred to almost any extended astronomical object (other than planets and comets). Today, we reserve the word nebula for extended objects consisting mostly of gas and dust.
- **Most nebulae can be described as diffuse nebulae, which means that they are extended and contain no well-defined boundaries**.

Types of Nebulae

1. **Emission nebulae**
2. **Reflection nebulae**
3. **Planetary nebula**

1. Emission Nebulae

Emission nebulae are clouds of high temperature gas. The atoms in the cloud are energized by ultraviolet light from a nearby star and emit radiation as they fall back into lower energy states. Emission nebulae are usually red, because hydrogen, the most common gas in the universe, most commonly emits red light.



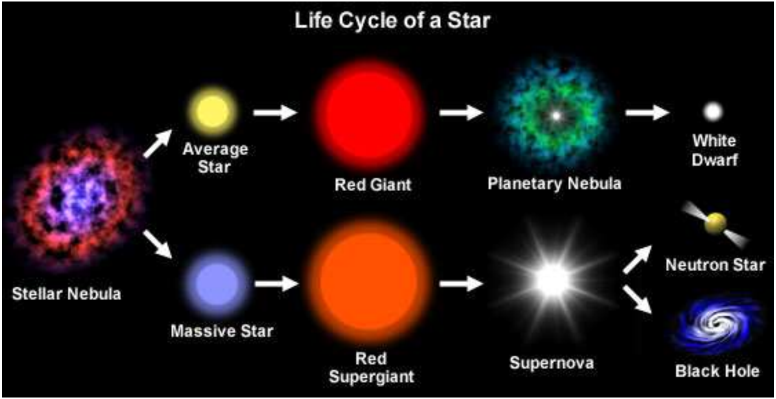
2. Reflection nebulae

Reflection nebulae are clouds of interstellar dust which might reflect the light of a nearby star or stars. The energy from the nearby stars is insufficient to ionize the gas of the nebula to create an emission nebula, but is enough to give sufficient scattering to make the dust visible. Reflection nebulae are usually blue, because blue light scatters more easily.

Stars

- A star is a hot ball of mostly hydrogen gas. In the core of the star, **the temperature and densities** are high enough to sustain nuclear fusion reactions, and the energy produced by these reactions works its way to the surface and radiates into space as heat and light.
- When the fuel for the nuclear fusion reactions is depleted, the structure of the star changes.
- **The process of building up heavier elements from lighter ones by nuclear reactions, and adjusting the internal structure to balance gravity and pressure, is called stellar evolution.**
- Observations allow us to find the luminosity of the star, or the rate at which it radiates energy as heat and light.

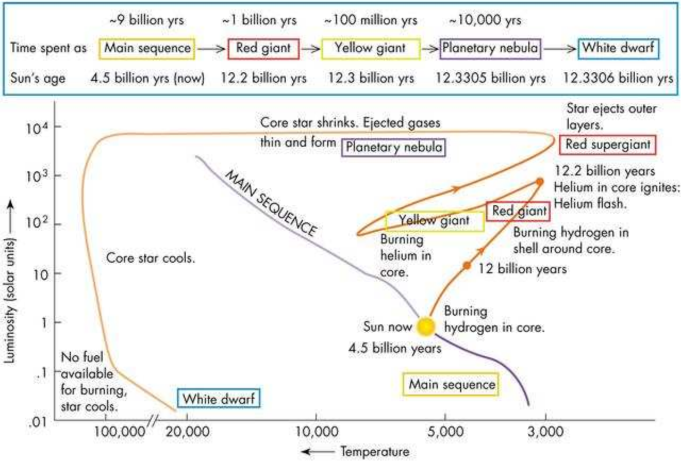
Stellar Evolution



Stars are not static objects. As a star consumes fuel in its nuclear reactions, its structure and composition changes, affecting its color and luminosity.

Hertzsprung-Russell (HR) diagram

The HR diagram not only shows us the colors and luminosities of many stars, it shows their different evolutionary stages.



Planetary nebulae

Planetary nebula results from the death of a star. When a star has burned the material, it can no longer sustain its own fusion reactions, the star's gravity causes it to collapse. As the star collapses, its interior heats up. The heating of the interior produces a stellar wind that blows away the outer layers of the star. When the outer layers have blown away, the remaining core remnant heats the gases, which are now far from the star, and causes them to glow. The resulting "planetary nebulae" are shells of glowing gas that surround a small core. Planetary nebulae are part of the normal stellar life cycle, but they are short-lived, lasting only about 10,000 years.

Planetary nebulae

The word planetary is really misleading, as these objects have nothing to do with the planets in our solar system. Rather, they acquired the name because when they were first observed in the 19th century their extended appearance reminded astronomers of the way planets like Uranus and Neptune appear in a telescope.

Why ?? Planetary nebulae

- What's so interesting about planetary nebulae? Astronomers are drawn to study these objects because they provide opportunities to analyze material that was once a part of a shining star.
- For example, by studying the chemical composition of the nebula we can gain an understanding about the material out of which the star originally formed.
- In addition, the abundances of certain elements such as carbon and nitrogen in the nebula reveal details about the physical processes that occurred within the star during its nuclear fusion lifetime.
- Studying planetary nebulae helps us to understand how a star changes, or evolves, during its lifetime.

Planetary nebulae

- A planetary nebula (PN) consists of a hot, luminous central star and an expanding glowing shell of gas and dust.
- More than 3000 PNe have been detected in the Milky Way which are catalogued by **Parker et al. (2006)** and **Acker et al. (1992)**.
- The central star of most of the PNe (CSPNe) is very hot object which is bright in UV and hence, the UV observations explore the properties of these objects.

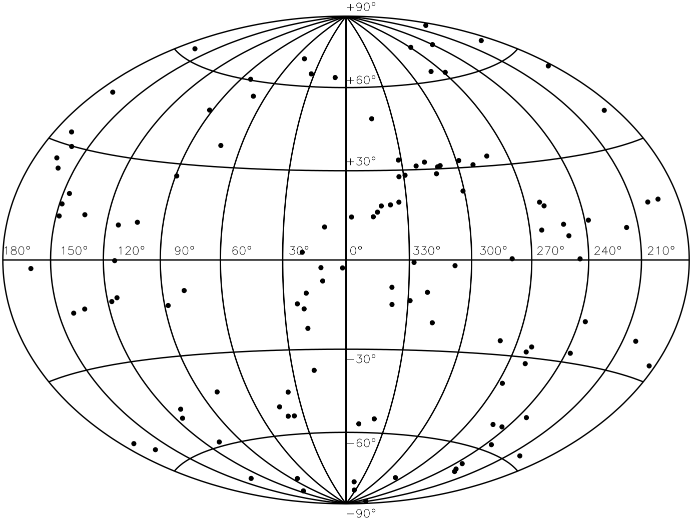
Planetary nebulae in UV

- The UV spectral region of PNe contains important nebular emission lines due to C, N, Si, Ne, Ar, etc., and P-Cygni type stellar wind profiles of C IV, N V, etc., from the hot CSPNe.
- UV spectra of large number of PNe were studied with IUE satellite covering the wavelength region 1150 Å to 3200 Å and FUSE covering the wavelength region 905 Å to 1187 Å
- UV spectral features provide information about all the basic parameters: effective temperature (T_{eff}), radius (R), luminosity (L), mass of the star (M), terminal wind velocity, and mass loss rate.

GALEX Obervation

- Due to the high resolution and deep sensitivity, GALEX data are well suited to studying the large extended objects like PNe.
- GALEX has covered 75% of the sky in two UV bands, FUV and NUV, simultaneously, with spatial resolution of $4.2''$ and $5.3''$, respectively **(Morrissey et al. 2007)**.
- We searched the GALEX data base using the Vizier catalogue of galactic PNe by **Acker et al. (1992)** and the MASH catalogue of PNe by **Parker (2006)**. We detected a total of 108 PNe in NUV band of GALEX database.
- However, 28 of the PNe in the list have both the FUV and NUV detections.

Distribution of PNe detected by GALEX



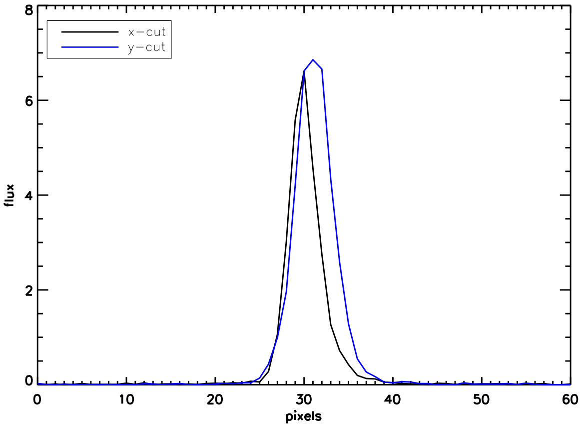
Measurement of angular size of PNe

- The angular size of PN is one of the most important observational entity, which is required for the study of crucial PN parameters such as linear dimensions, lifetimes, distances and masses.
- The dimension of the PNe solely depend upon the maximum extension of the respective recorded emission.
- Several methods such as direct measurements at the 10% level of the peak surface brightness, Gaussian deconvolution, second-moment deconvolution, etc., have been employed to measure the angular dimension of PNe that are observed by varoius techniques **(Tylenda et al. 2003, van Hoof et al. 2000)**.

Measurement of angular size of PNe

- We have determined the angular sizes of the PNe in NUV and FUV for whichever sources the detection exists.
- Initially, we used the direct measurements at the 10% level of the peak surface brightness but the GALEX images are very deep and the nebular emission extends beyond 10% contour.
- So, we measured the actual dimension of the nebula considering a 3σ emission level above the background.
- We have measured the angular diameter of 108 PNe which were detected by GALEX survey.

Variation of flux across a PN



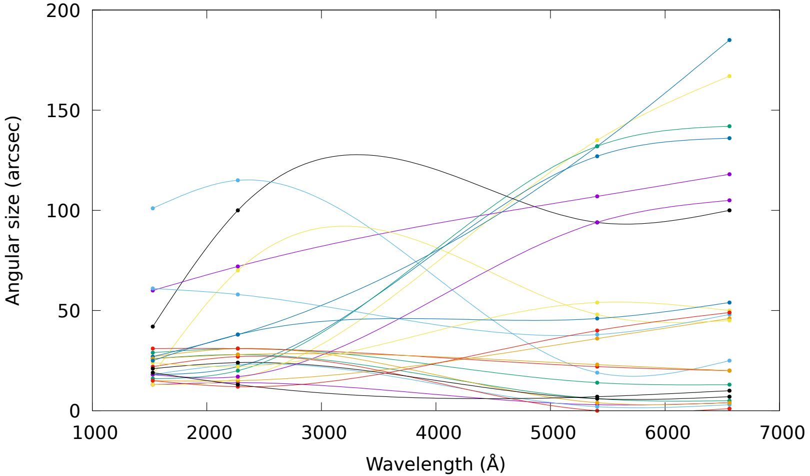
Variation of NUV flux (Counts/Sec) across a PNe, PNG146.7+07.6.

Morphology of PNe

- Many PNe show bi-polar structures, collimated out flows, jets and knots. The morphological classification of PNe depends upon these structural appearance in imaging surveys.
- Taking the method proposed by Manchado (2004), we try to classify our nebulae based on their NUV sizes either as round or elliptical. This method uses only the values obtained for the angular extensions as semimajor and semi-minor axes, and thus ignores the visual detection leading to categorising some PNe as bipolar.
- The morphology of planetary nebulae is estimated from axial ratio a/b (if $0.94 \leq a/b \leq 1.06$ then the PNe is said to be circular, if $a/b > 1.06$ it is marked as elliptical).
- We have 24 round-type, 74 ellipticals by this analysis and 10 are bipolar.

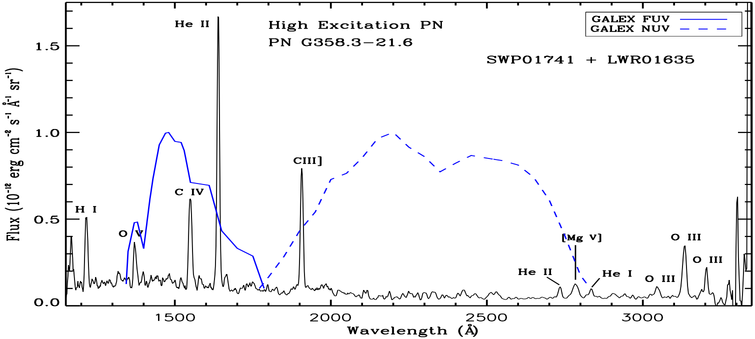
PNG No.	Ra (J2000) hr min sec	Dec (J2000) deg min sec	NUV (mag)	FUV (mag)	NUV size (arcsec)	FUV size (arcsec)	V size (arcsec)
005.2-18.6	19 14 23.37	-32 34 17.63	17.59	17.21	11.22x12.07	8.50x9.18	4.98
012.5-09.8	18 50 26.01	-22 34 22.45	17.18	17.07	12.92x15.82	14.79x12.75	3.6
013.3+32.7	16 21 4.47	0 -16 9.92	13.76	13.45	27.89x30.10	24.15x29.76	3
028.0+10.2	18 6 0.72	0 22 39.13	17.39	16.87	14.45x16.83	16.83x14.28	36
032.1+07.0	18 24 44.50	2 29 28.35	18.91	19.11	8.50x8.50	8.1x6.8	2.82
032.9+07.8	18 23 21.69	3 36 28.71	19.05	19.40	12.07x11.73	6.97x6.46	4.98
044.3+10.4	18 34 2.61	14 49 20.51	17.31	16.56	14.79x18.19	14.62x12.92	13.5
059.7-18.7	20 50 2.15	13 33 28.93	14.51	13.80	22.96x21.25	20.91x15.64	127.38
061.9+41.3	16 40 18.20	38 42 20.56	14.44	14.18	27.55x27.89	20.24x24.32	1.08
066.7-28.2	21 36 52.93	12 47 20.97	12.77	12.02	96.59x105.10	40.81x44.72	94.8
072.7-17.1	21 16 52.31	24 8 51.49	15.73	15.17	20.40x17.85	15.81x16.15	830.4
081.2-14.9	21 35 29.48	31 41 46.74	12.66	12.06	70.23x75.17	59.86x62.07	106.98
096.4+29.9	17 58 33.66	66 37 58.15	19.33	11.11	115.30x115.98	101.70x102.04	38.22
107.6-13.3	23 22 58.00	46 53 58.25	14.19	13.81	30.44x32.14	24.82x30.61	27.42
120.0+09.8	0 13 1.16	72 31 19.76	12.53	12.79	68.19x73.64	18.0x18.0	36.42
153.7+22.8	6 43 55.37	61 47 22.67	17.78	17.24	13.09x13.43	13.26x13.09	141
165.5-06.5	4 39 47.90	36 45 43.37	19.03	18.95	9.69x9.69	8.67x8.84	15
165.5-15.2	4 9 17.11	30 46 33.35	12.78	13.05	39.58x37.58	30.10x24.48	100.8
167.4-09.1	4 36 37.27	33 39 30.33	18.22	18.02	13.94x10.20	8.67x7.99	2.22
70.3+15.8	6 34 7.30	44 46 37.93	15.46	14.58	31.29x32.65	28.57x33.84	22
190.3-17.7	5 5 34.30	10 42 22.26	13.81	13.64	23.97x25.34	22.10x20.40	7.2
211.4+18.4	7 55 11.29	9 33 9.62	15.99	15.48	17.00x18.53	17.68x18.53	94
228.2-22.1	5 55 6.58	-22 54 2.19	15.85	15.31	20.74x19.38	16.83x16.32	132
239.6+13.9	8 33 23.44	-16 8 57.42	13.28	12.41	57.99x59.01	64.45x58.33	34.38
243.8-37.1	5 3 1.64	-39 45 43.83	14.11	13.44	26.53x29.76	28.40x25.0	23
255.8+10.9	9 5 5.37	-30 33 13.19	15.27	14.55	19.21x20.74	16.32x16.83	964.8
270.1+24.8	10 34 30.64	-29 11 14.16	14.86	14.38	23.46x20.91	27.72x21.42	54
286.8-29.5	5 57 1.94	-75 40 22.46	14.57	14.11	40.64x35.54	25.85x25.68	46
340.4-14.1	18 0 59.43	-52 44 20.17	16.21	16.22	26.87x27.89	25.00x30.78	16.2
341.6+13.7	16 1 20.91	-34 32 37.87	15.24	13.58	10.88x13.43	15.0x15.0	33.78
358.3-21.6	19 17 23.37	-39 36 45.79	13.87	13.50	11.73x14.79	19.0x19.0	7.02

Variation of angular size of PNe with wavelengths



We found 24 PNe in the list which have angular sizes data in four wavelength bands , in FUV (1538.6 Å), NUV (2315.7 Å), V (5448 Å) and Hα (6562.8 Å).

IUE Spectra of a PN and GALEX filters



The prominent emission lines seen in the spectrum are H I, O V, C IV, He II, CIII], He II, [Mg V], and O III.The emission lines contributing to GALEX FUV flux are strong OV, C IV, and He II while the emission line contributing to the NUV flux are C III] and He II.

Intrinsic luminosities of PNe

- Assuming the visual extinction from Schlegel et al. (1998) and then using the extinction law of Cardelli et al. (1989), the extinction coeffiecients: $A_{FUV} = 8.16 \times E(B-V)$ and $A_{NUV} = 8.90 \times E(B-V)$ have been calculated. We have determined L_{FUV} for 17 PNe and L_{NUV} for 65 PNe depending on the availability of distance R for our sample.
- The luminosities for the PNe are found to lie within the range of 7.83×10^{39} erg/s to 1.87×10^{47} erg/s in FUV and 1.09×10^{37} erg/s to 1.89×10^{47} erg/s in NUV band, assuming that most of the contribution to the flux is from the CSPNe only.
- The CSPNe temperature range from 40 to 120 kK and emit bulk of their fluxes in UV. It is anticipated that the stellar wind of the sources with high value of FUV flux may produce X-rays emission in its proximity.
- We found six X-ray detections in our sample which contain point like sources. The X-ray luminosities of the sources which likely to be coming from the CSPNe are measured. We found that the derived $L_{FUV/NUV}$ are 10^7 to 10^{15} times that of the corresponding X-ray luminosities.

Estimation of Ionized mass of PNe

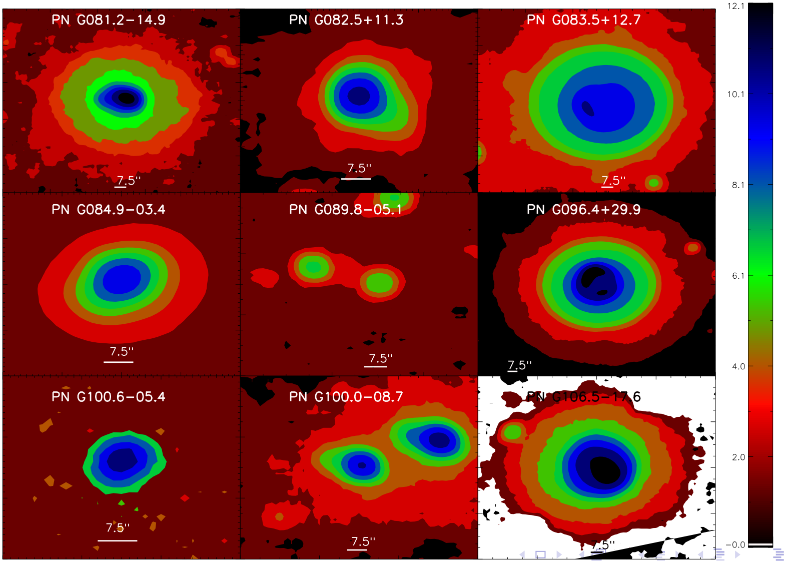
- We have estimated the ionized masses for 12 PNe in our list using the NUV size (θ).
- we compute the ionizing masses of the selected PNe using the equation from Gathier et al. (1987).

$$\frac{M_i}{M_\odot} = 1.18 \times 10^{-8} n_e D^3 \theta^3 \epsilon \left(\frac{1 + 4y_1}{1 + y_1 + y_1 y_2} \right)$$

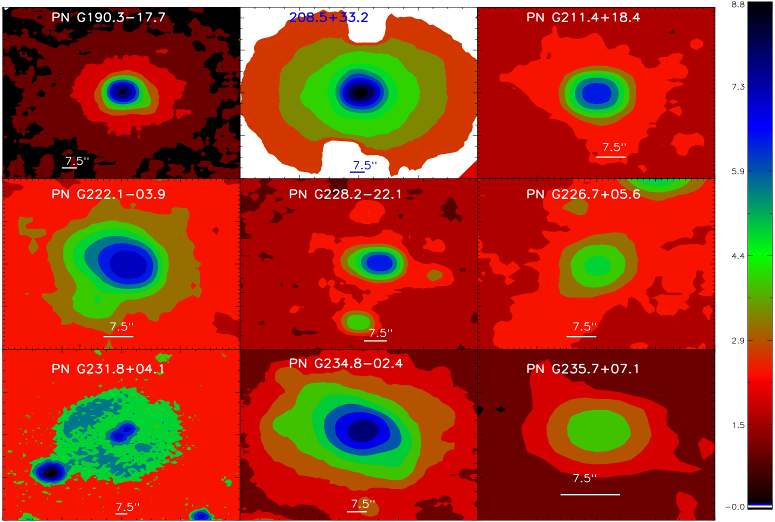
  The filling factor (ϵ) = 0.75, n_e = electron density, D=distance, y_1 = He abundance and y_2 fraction of doubly ionized He as per Gathier et al. (1987).

- The value of ionized masses of PNe stellar evolution calculations and observations ranges from $< 2 \times 10^{-3}$ to ≥ 0.5 $M_\odot$. The values we obtained from this calculations are 2.75×10^{-4} $M_\odot$ to 0.35 $M_\odot$.

NUV images of a few PNe



FUV images of a few PNe



Summary & Conclusions

- We present the ultraviolet (UV) images of planetary nebulae (PNe) using archival data of Galaxy Evolution Explorer (GALEX). We found about 108 PNe detected by GALEX in near-UV (NUV) and also 28 of them in far-UV (FUV).
- We determined their angular diameters from the images considering a 3σ surface brightness level above the background. Of the PNe, 74 are elliptical, 24 are circular and 10 are bipolar in NUV.
- It is revealed from the size distribution of PNe that most of them have larger extension in UV than their corresponding radio, Hα and optical sizes.
- We derived luminosities in FUV for 17 PNe and in NUV for 65 PNe and found that most of the sources are very bright in UV. The L_{UV} are found to be 10^7 to 10^{15} times that of the available X-ray luminosities for whichever PNe X-ray detection exists.
- In case of a high excitation PNe, the emission lines contributing to GALEX FUV flux are strong O V, C IV, and He II while the emission line contributing to the NUV flux are C III] and He II.
- Using the NUV sizes in PNe stellar evolution calculations we have estimated the ionized masses for 12 PNe which comes out to be in the range form 2.06×10^{-4} $M_\odot$ to 3.5×10^{-1} $M_\odot$. We have also provided brief details of the PNe in UV.

THANK YOU