Kinematics Of Flow And Shock Waves In Planetary Nebulae

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The aim of the present paper is to characterize nebula NGC6543 and IC4634 shockwaves. We have worked with OIII, Hα, NII, SII and OI ionization light values from Hubble telescope images (only OIII, Hα and NII for IC4634). The study is performed both in the different emission lines profile at the shockwave and comparing different nebula regions average ratios values of duly corrected data.

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Keywords: Nebulae, NGC6543, IC4634

I. INTRODUCTION

Low and intermediate mass (0.8 to 8 M_{Sun}) stars end their life as planetary nebulae (PNe) after evolving off the Asymptotic Giant Branch (AGB)[**1**]. As the star evolves off the AGB, its huge mass loss strips off the stellar envelope and exposes the hot stellar core. The subsequent fast stellar wind (1000– 4000 km/s) sweeps up the slow AGB wind to form a PN (planetary nebula). The interaction between the fast wind and the AGB wind produces a PN structure similar to that of a wind-blown bubble.

This simplified view of PNe formation has been posed into question due to the overwhelming number of observations of PNe showing small-scale features, collimated bipolar outflows [**2**], and point symmetric morphologies, including multiple point-symmetric bubbles.

A fundamental aspect to be studied about PNe is their shaping mechanisms. In this context, the observational issue that mass loss in the AGB is essentially spherical, but proto-PNe (PPNe) are bipolar and, furthermore, most older PNe are elliptical seems especially surprising.

It is believed that fast collimated outflows or jets (which existence is evident in high resolution sensitive observations of many PPNe), generated in the late AGB and post-AGB phases play an important role in the shaping of PNe.

The study of the dynamics of this jets and it's interaction with the interstellar medium is the objective of this research.

When these fast collimated outflows suffer a perturbation or rapid changes in the velocity of ejection, there will be an adjustment of the downstream region of the jet. In highly supersonic jets two shocks are formed: an upstream (towards the source) and a downstream (towards the source) shock (also known as bow shock.

In the shock fronts some non-thermodynamical conditions must be accomplished by the gas: the junction conditions. These are: mass , momentum and energy conservation. When the gas goes through the shock front, it suffers a shock heating and an increase in entropy. The gases aren't ideal, therefore it exists a certain viscosity which make the shock fronts to have a characteristic width (proportional to the mean free path).

There are different types of shock waves, the ones which involve adiabatic compressions (previously explained), but also luminous shock waves in which the region immediately behind the shock front emits radiation (due to the relaxation of excited states generated when the gas enters the shock front, and also electron-ion Bremsstrahlung) which is detectable.

In the following, we will characterize the morphology and excitation mechanism of the bow shock-like features observed in a selected group of PNe based on HST images.

II. OBSERVATIONAL DATA: HUBBLE SPACE TELESCOPE IMAGES

The planetary nebulae that we have selected to study are NGC 7009, NGC 6543 and IC 4634. These nebulae have bow-shock features outside the main body of the nebula and have been observed with the WFPC2 onboard the HST.

We have downloaded the HST images from the Hubble Legacy Archive (HLA). The WFPC2 (Wide Field and Planetary Camera 2) camera can get images with different filters that correspond to transitions of atoms or ions of Hydrogen, nitrogen, oxygen, sulphur etc. Particularly, we used the following filters:

Table 1:

Filter	Element ionization	Wavelength
F502N	[O III]	5007 Å
F656N	H_α	6563 Å
F658N	[N II]	6590 Å
F673N	[S II]	6716+6731 Å
F631N	[O I]	6300 Å

- F502N includes the [O III] 5007 Å emission (corresponding to a transition of double ionized oxygen). This is a high excitation line.
- F656N is the filter for Hα.
- [N II] and [S II] correspond to transitions of singly ionized nitrogen and sulfur respectively, and the filter for [O I] corresponds to neutral oxygen. The [S II] and [O I] emission lines are low-excitation lines, since the ionization potential of these ions are of the order of that of H (13.6 eV). The [N II] emission lines are of intermediate excitation (see Table 2).

Table 2:

Ion produced by ionization	**Ionization potential (eV)**	**Associated transition**
H^+	13.6	Hα
S^+	10.4	[S II] 6717+6731 Å
O^+	13.6	[O II] 3727 Å
O^{+2}	35.1	[O III] 5007 Å
N^+	14.5	[N II] 6583 Å

III. CORRECTION TO IMAGES

Images of the selected PNe obtained with the WFPC2 (HST) were not all centered at the same point and they had different orientation, so to be able to use them properly we need to align all images of each nebula (i.e., we need to convert all images of each PN into a common reference system). To do so we have used two programs commonly used in Astronomy: IRAF [**3**] and DS9 [**4**].

First we must determine the coordinates of common stars on both images using an iraf task named imexamine[**5**]. The pixel positions of several field stars (x_{ref}, y_{ref}, x_{in} *and* y_{in}) are listed in a text file. This text file is introduced to geomap[**6**], an iraf task, that computes the spatial transformation function to be applied to the image. To register all images we use the IRAF task geotran[**7**]. Then the images are ready to use.

Dust grains scatter and absorb electromagnetic radiation. The combined process is called extinction. The extinction is strongest toward the blue wavelength, so that the spectrum appears to be reddened. For an accurate measurement of the intensity emitted by the nebula this effect has to be correct. Applying an empirical law, we dereddened the image ratios using:

$$\frac{I(\lambda)}{I(H\alpha)} = \frac{F(\lambda)}{F(H\alpha)} 10^{c(H\beta)(f(\lambda)-f(H\alpha))}$$

where F is the observed flux, I is the emitted intensity and c(Hβ) is the reddening coeficient (which is a measure of the amount of interstellar dust), and f(λ) depends on the extinction law adopted.

IV. Results: Emission line and emission line ratio in shockwaves

Figure 1 shows the Hα, [O III] and [N II] surface brightness distributions projected along the axis that passes through the bow shock and the central source of IC 4634, obtained from the narrowband HST images. Let us now present an example of the surface brightness distributions in the bow-shock region of the nebulae IC4634.

This bow shock has single-peaked distributions in the three emission lines shown in figure 1. From these distributions, it is clear that the [O III] and Hα extent away from the head of the bow shock. Both differ from the [N II] emission which shows a more compact structure. Similar results are found in NGC 7009 and NGC 6543.

From figure 1, it is clear that the [N II] distribution peaks at larger distances from the central source than the Hα and [O III] distributions. We also note that the Hα distribution peaks at larger distances from the central star than the [O III].

The mean spatial displacement between the Hα and the [NII] peaks in the bow-shocks of IC 4634 is ~ 10^{15} cm (adopting a distance of 2.5 kpc), while the spatial displacement between the [O III] and [N II] is ~ 5 x 10^{15} cm. Similar values have been obtained for the other nebulae.

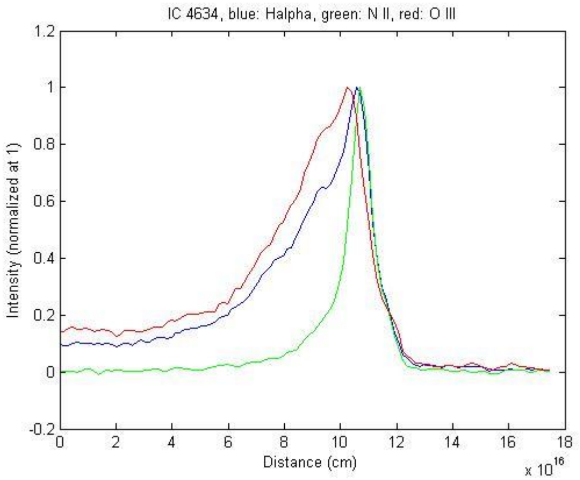

FIG. 1. Intensity of radiation (vertical axis, normalized to the maximum intensity) vs spatial coordinate (horizontal axis in relative units) of IC 4634 nebula. The radiation intensity from the Hα line is in blue color, the one from the [O III] line is in red color and the one from [N II] line is in green color.

V. EMISSION LINE RATIOS IN DIFFERENT NEBULA REGIONS

Several nebula rectangular regions have been chosen (figures 2 and 3) and the average ratios between the considered emission lines and Hα within these areas have been plotted in figures 4 - 7. For the reddening correction of data we have chosen the Witford's model [**8**] f(λ) and the reddening coefficients are 0.20 for NGC6543 and 0.34 for IC4634.

Although both nebulae's OIII and NII emission exact values differ, an overall tendency has been observed: OIII values are always low in jet areas (1-8 in NGC6543 and 1, 2, 4, 5 in IC4634) and increases towards the center of the star. Also, NII emission lines intensities are very high in all the jet areas. This way, in the NII versus OIII diagram, jets are characterized by being concentrated in the upper left and the center regions in the bottom right "corner".

And finally, inner regions (9, 1 and 6, 3 respectively) present very low levels in all the considered emission lines, while the star centers happen to be very pronounced peaks in OI and SII emission.

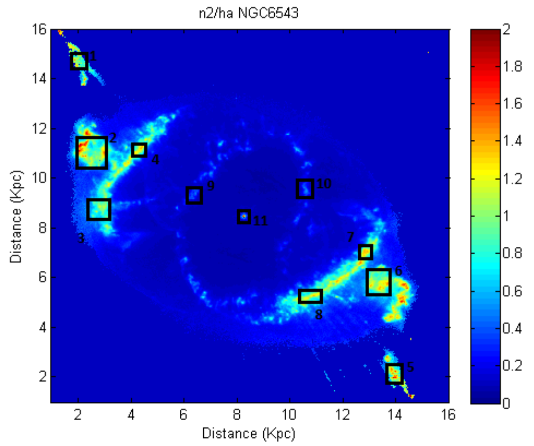

FIG. 2. Regions chose for NGC6543

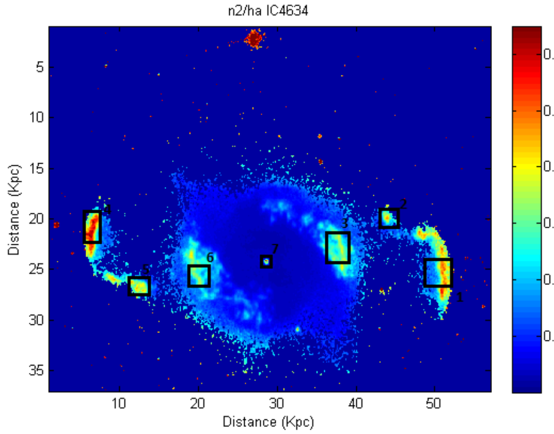

FIG. 3. Regions chose for IC4634

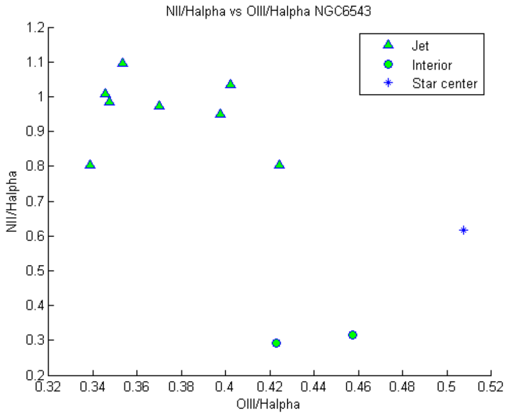

FIG. 4. NII vs OIII emission lines diagram

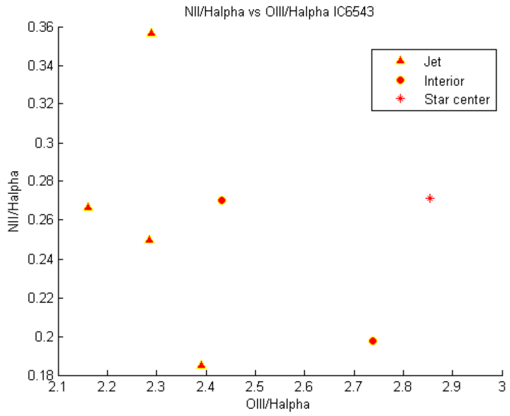

FIG. 5. NII vs OIII emission lines diagram

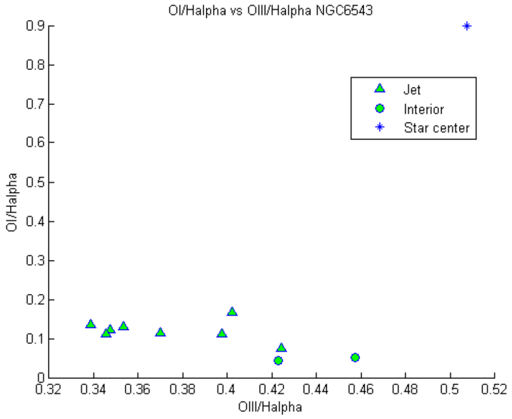

FIG. 6. OI vs OIII emission lines diagram

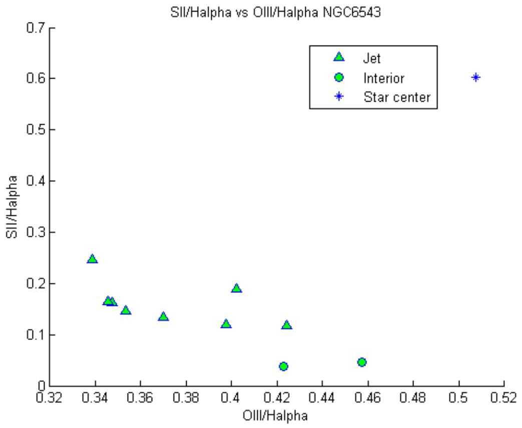

FIG. 7. SII vs OIII emission lines diagram

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[**1**] The asymptotic-giant-branch (AGB) is a period of stellar evolution of low or medium-mass stars.An AGB star will appear as a bright red giant with a luminosity thousands of times the Sun.

[**2**] A Bipolar outflow is a continuous gas flow from the poles of a star.

[**3**] http://iraf.noao.edu/

[**4**] http://ds9.si.edu/site/Home.html

[**5**] http://stsdas.stsci.edu/cgi-bin/gethelp.cgi?imexamine

[**6**] http://iraf.net/irafhelp.php?val=immatch.geomap&help=Help+Page

[**7**] http://iraf.net/irafhelp.php?val=immatch.geotran&help=Help+Page

[**8**] Young-Ik Byun, *Interstellar Reddening for Planetary Nebulae toward Galactic Bulge*, Chinese Journal of Physics (August 1996).