NGC 2371: Mapping its physical and kinematic structure

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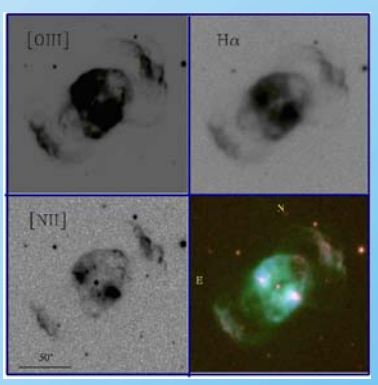
ABSTRACT

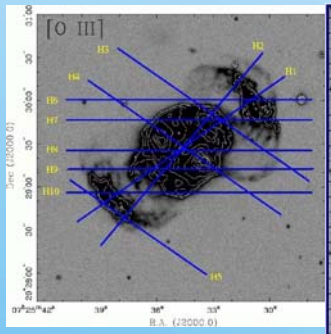
We present narrow band CCD images and low and high dispersion long-slit spectra for planetary nebula NGC 2371. This is a type I bipolar nebula with two extended faint lobes with brighter ends and two very bright central knots. Using the high dispersion spectra we obtained the kinematic structure, whereas the low dispersion spectra have been used for mapping the physical conditions through the nebula. We show preliminary results about the complex internal kinematic structure, and present maps of physical parameters found in this object.

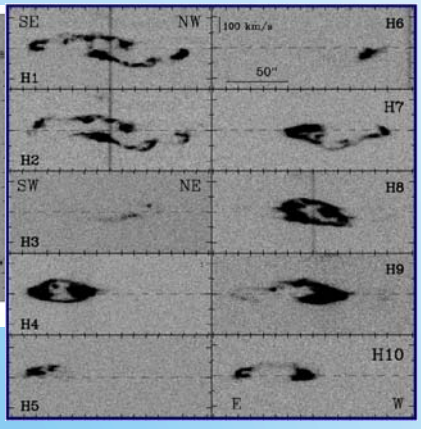
Fig. 1



Logarithmic grey scale of narrow band images, and a RGB composition: red ([NII]), green (H), blue ([OIII]).

Fig. 4





Left panel: grey scale [OIII] image were the slit positions using for high dispersion spectroscopy are shown. Right panel: grey scale Position-Velocity diagrams in [OIII] Å.

Longslit high-dispersion spectroscopy: High-dispersion optical spectra were obtained with the Manchester Echelle Spectrometer (MES-SPM) in the 2.1-m telescope at the San Pedro Mártir observatory (OAN-SPM) during January 7, 2002; February 24, 2003; February 25, 2005. A CCD SITe 1024x1024 pixels was used as a detector. Slit width was set to 150- m (2"). Spatial and spectral scales are 0.6"/pixel and 0.1Å/pixel, respectively. Slit positions and position-velocity maps for the [OIII] Å emission line are shown in Fig. 4 .

Systemic velocity of the nebula was determined in 11.3 km/s (LSR). NW lobe is blueshifted and SE lobe is redshifted .

Expansion velocity from the SE and NW lobes is 40 km/s , from faint emission on H1, H2, H8 and H9 (left panel in Fig. 4); whereas the internal shell expands to 67 km/s (H1, H2, H4 and H8).

There are two *bow-like* structures at both sides of the internal shell, which correspond to the NW and SE shell edges, on the PN axis at PA=55° (H1, H2 and H7). These structures are diametrically opposite, located to 35" from central star; Fig. 5 shows their approximated position drawing two colored arcs. These bows have V=53 km/s in |95| km/s, respect the systemic velocity.

The kinematic behavior of the NW and SE lobes shows the lobe ends as polar cap structures. Near to equatorial plane the lobes are part of closed bubble. However, the absence of blueshifted emission in the NW lobe, and redshifted emission in the SE lobe, indicate an open shell.

The kinematics of the internal shell is difficult to interpret, we found an open shell with a complex knotty internal structure .

OBSERVATIONS AND RESULTS

CCD imaging: Narrow band CCD images were obtained with the 2.1-m telescope at Observatorio Astronómico Nacional San Pedro Mártir (OAN SPM) in March 10, 2004. We used the filters [O III] 5007Å (=50Å), and [N II] 6584Å (=10Å) and a CCD SITe 1024x1024 pixels as detector. The H image was obtained with the 1.5-m telescope at Observatorio de Sierra Nevada (OSN) in February 19, 2004, using a filter centered in H 6563Å (=10Å), with the CCD VersArray 2048x2048 pixels. Fig. 1 shows four panels containing these images in logarithmic scale, as well as an RGB composition.

Images show a bipolar nebula composed by two bright central knots inside an internal elongated shell and two faint lobes whose ends have filamentary brighter structure like a polar cap morphology.

The NW edge of the internal elongated shell and the ends of the lobes (NW and SE), show structures like bow-shocks (see the [NII] image in Fig. 1).

The SE edge of the internal elongated shell shows a remarkable lack of [NII] emission.

SUMMARY

The morphology of this object shows a bipolar nebula with a blueshifted NW lobe and redshifted SE counterpart, where the lobe ends are like polar caps. There is an internal expanding shell (V_{ex}= 67 km/s) with a dense central core. We found a filamentary gas structure that in some case shows features like bow-shocks.

Kinematics is very complex. There are a system of open shells (internal shell and lobes) expanding with different velocities: 67 km/s and 39 km/s, respectively.

From low dispersion spectra we found variations in the values determined for Ne and Te, specially to brighter central knots. In contrast, the extinction shows a flat distribution with very low values. This is interpreted as the absence of internal extinction.

The emission line from bow-shocks like structures does not show a clear evidence of a shocked gas origin.

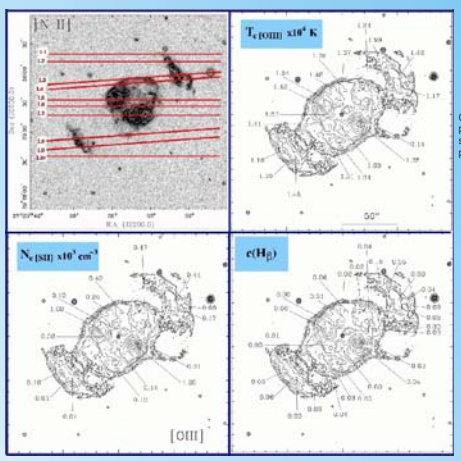


Fig. 2

Contour [OIII] images with the physical parameters derived from the low-dispersion spectroscopy. Upper left panel shows the slit positions on a grey scale [NII] image.

Longslit low-dispersion spectroscopy: Optical spectra were obtained using the Boller & Chivens spectrometer on 2.1-m telescope at OAN-SPM in December 12, 2002; January 31 and February 2, 2003. We used a CCD SITe 1024x1024,a 400 lines/mm diffraction grating and the slit width was set to 200- m (2.5"). Spatial and spectral scale are 1.05"/pix and 3Å/pix, respectively. Ten different slit positions were obtained as shown in the upper left panel in Fig. 2. Spectra were bias-substracted, flat-field corrected, and flux-calibrated using the standard techniques. Dereddening and physical conditions were derived using ALIEN (Cook & Vázquez, 2002, RevMexAASC, 12, 38).

The electron density is low through the whole nebula, N_e< 500 cm^{-3}, however, it rises remarkably in regions around central knots, 1000 cm^{-3}< N_e< 3100 cm^{-3} (see lower left panel in Fig. 2). The lower densities found in this work agree with previous reported values for this PN (e.g. Kingsburgh & Barlow , 1994, Mon. Not. R. Astron. Soc., 271, 257).

Electron temperature ranges 11000 K < T_e< 22000 K. There is no clear trend for the Te variations found, see upper right panel in Fig. 2. Our maximum values are higher than previous reported values (e.g. Kingsburgh & Barlow , 1994, Mon. Not. R. Astron. Soc., 271, 257).
Extinction, c(H), is practically constant through the whole nebula, and near to zero within the errors.

Diagnostic diagrams of some analyzed regions are shown in Fig. 3.

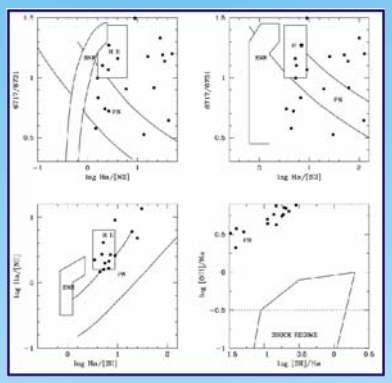


Fig. 3

Diagnostic diagrams for NGC2371 (Sabbadin, Minello & Bianchini, 1977, Astron. Astrophys., 60, 147)

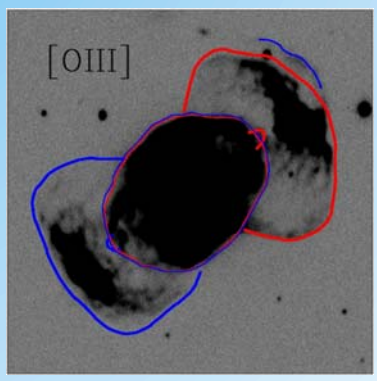


Fig. 5 Grey scale [OIII] image shown features described in the text.

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