3-D Structure of the H_2 emission of CRL 2688 and NGC 7027

D. Mékarnia

Observatoire de la Côte d'Azur, Nice, France*
email: mekarnia@obs-nice.fr

Abstract

We present the spatial structure of the post-AGB star CRL 2688 and the young planetary nebula NGC 7027 reconstructed from a series of images of high spatial resolution ($\sim 0.2''$) allowing observations from different line of sights and, with an unprecedented clarity, the true structure of these nebulae. Evidence of a presence of a high velocity outflow is clearly seen in our NGC 7027 data.

1. Introduction

The late evolution of low and intermediate mass stars is characterized by an extreme variety of planetary nebular morphologies. Different mechanisms (stellar rotation and/or precession, magnetic fields, winds interactions ...), acting before, during and after the nebula ejection, can contribute to generating the observed morphologies. So far the interpretation of structures exhibited by PPN and PNe in terms of detailed three-dimensional structures and physical conditions of the gas was limited by projection effects. In order to disentangle the physical processes forming and shaping the envelope, the apparent, bi-dimensional image should be de-projected, and the accurate spatial distribution of the gas recovered. In order to achieve this goal we have obtained the spatial distribution of the post-AGB star CRL 2688 and the young planetary nebula NGC 7027 using a near infrared high angular resolution Fourier transform spectro-imager.

CRL 2688, *the Egg Nebula*, is a source known to be in the rapidly evolving transition from the AGB to the PN phase. CRL 2688 is a bright infrared source with a bipolar optical and near-infrared nebula scattering the light of the cool central star. NGC 7027 is a nearby well studied young planetary nebula which displays a remarkably complex morphology. Optical images reveal a rectangular shape dominated by a bright knot that is situated to the north-west of the nebular emission, whereas in the near infrared and radio the ionized region is revealed to be an elliptical shell.

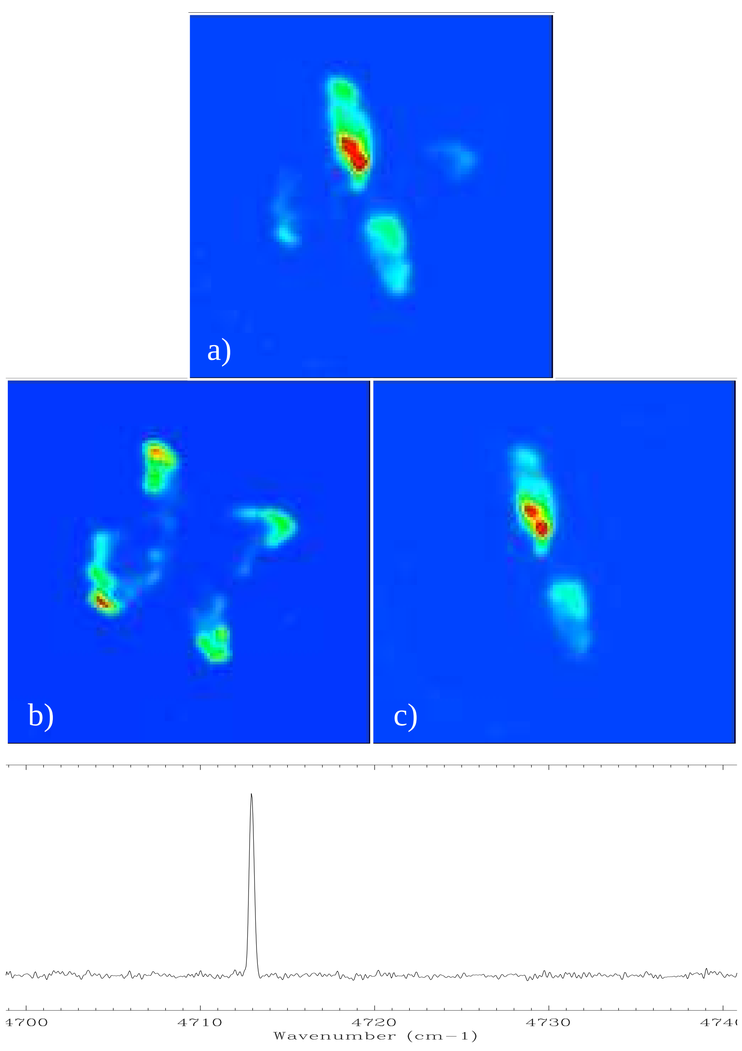

Figure 1: Images of CRL 2688 in the 1-0 S(1) transition of H_2. a) Image integrated from 4700 to 4740 cm^{-1} (H_2 + continuum emissions), b) Image in H_2, the continuum emission being subtracted and c) Image in the continuum emission integrated from 4699 - 4711 cm^{-1} and 4715 - 4740 cm^{-1}. In the bottom, spectrum at an emission peak of the nebular region in CRL 2688 as measured from 4699 to 4741 cm^{-1}.

2. Observations and Data reduction

The 3-D data of CRL 2688 and NGC 7027 were obtained in October 24, 1999 using the BEAR imaging spectrometer at the f/35 focus of the 3.6-m CFH Telescope. A detailed description of this instrument has been given by Maillard (2000). A narrow-band filter which include the $H_2\,1-0$ S(1) line (2.12 μm) was used to reach a velocity resolution of $8.9\,km\,s^{-1}$. In order to reach a higher angular ($\sim 0.2''$) and spectral (~ 1 km s^{-1}) resolutions, the raw frames were spatially deconvolved, using a PSF, and spectrally oversampled by a factor of $\sim$6 from the initial cube.

The 3-D structure of the nebulae was recovered assuming that the expansion velocity (V) is proportional to the distance (r) from the central star.

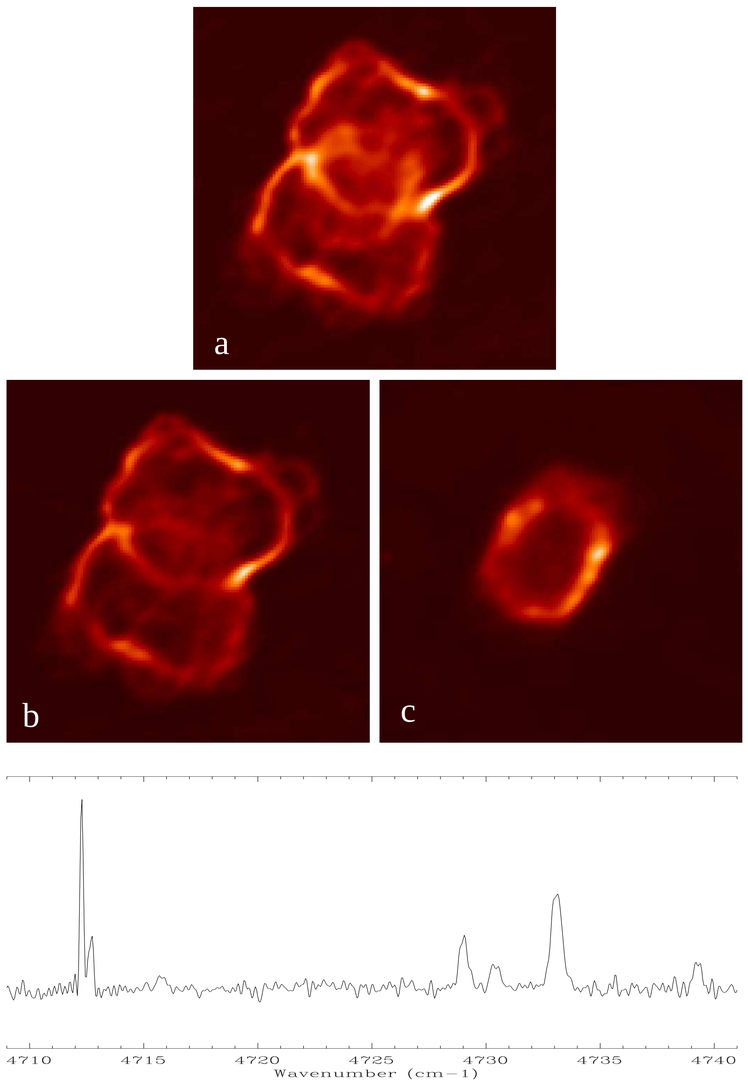

Figure 2: Images of NGC 7027 in the 1-0 S(1) transition of H_2. a) Image integrated from 4700 to 4728 cm^{-1} (H_2 + continuum emissions), b) Image in H_2, the continuum emission being subtracted and c) Image in the continuum emission integrated from 4700 - 4711 cm^{-1} and 4715 - 4728 cm^{-1}. In the bottom, spectrum at an emission peak of the nebular region in NGC 7027 as measured from 4700 to 4741 cm^{-1}.

3. Continuum and H_2 emissions

Figures 1 and 2 show a typical high resolution spectrum extracted at a bright spot of the nebulae from the H_2 data cube, and the images in the H_2 emission lines. Besides the strong H_2 line, the spectra include the continuum and, in the case of NGC 7027, a series of weaker emission lines. The distribution and the kinematics of each emission line could be derived together with the spatial distribution of the continuum emission. Each spectral image contains no other contribution, either from the continuum or from nearby emission lines from the ionized gas.

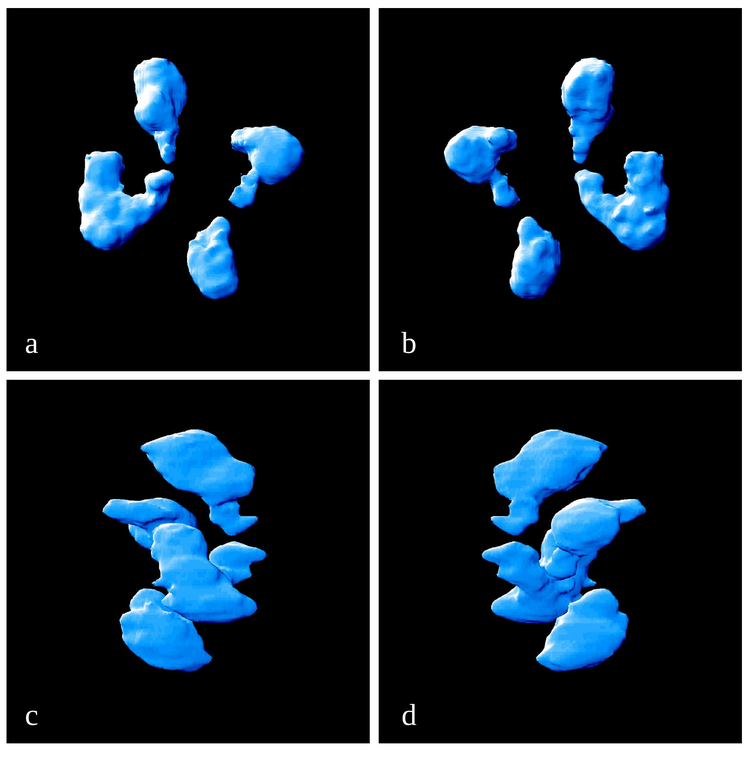

Figure 3: 3-D representation of CRL 2688 in H_2 emission line as seen from 4 directions separated by 90^o. The line of view is identifi ed by (θ, ϕ), where θ is the zenith angle and ϕ the azimuthal angle. a) The (0,0) image is the nebula as seen from the Earth, b) from the opposite direction (0,180), c) from the direction (0,90) and d) from the direction (0,-90). Spatial dimensions of the H_2 emission are : $\sim$ 14" $\times$ 15" $\times$ 9".

4. The spatial structure

The 3-D structure of the molecular gas of CRL 2688 and NGC 7027 as seen from the Earth and from different orientations are shown in Figures 3 and 4. The main results of these observations are the following:

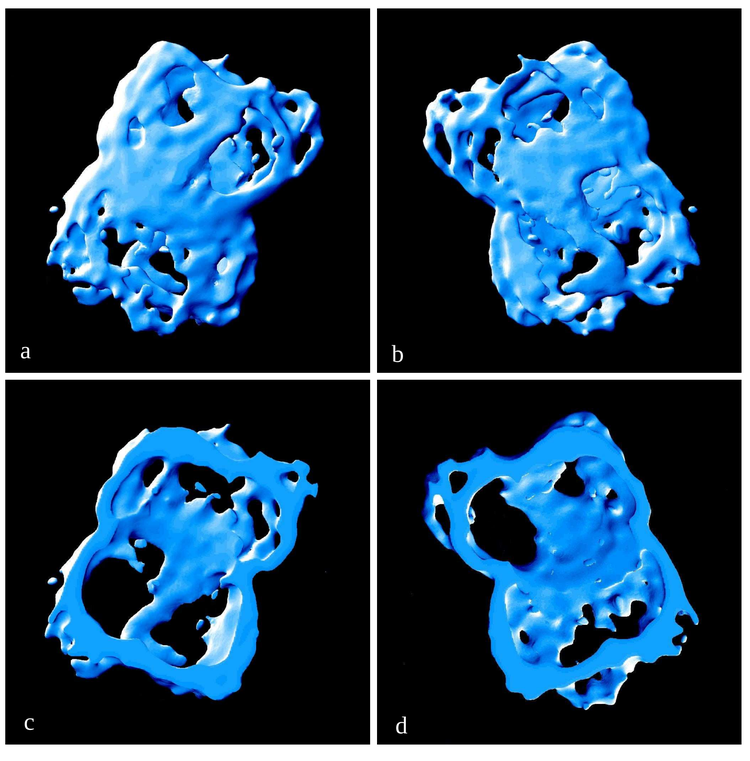

Figure 4: 3-D representation of NGC 7027 in H_2 emission line: a) as seen from the earth (0,0) and b) from the opposite direction (0,180). In c) and d) are shown cuts in the H_2 envelope to better represent the inner parts of the H_2 emission. Spatial dimensions of the H_2 emission are : 18"$\times$ 12" $\times$ 10".

- The H_2 molecular envelope of CRL 2688 is represented by four clumps with a 3-D complex structure.
- 3-D view in the (0,90) and (0,-90) directions show that the envelope of CRL 2688 presents a helicoidal structure. This structure could be interpreted as resulting from a bipolar outflow in the north-south direction linked to the rotation of the nebula along its polar axis.
- The structure of the molecular gas could be linked to the series of concentric rings observed in the optical image of CRL 2688 and which probably trace the episodic mass-loss events during this evolution phase of the nebula.
- The H_2 molecular envelope of NGC 7027 presents a bipolar structure, with a density enhancement clearly seen in the equatorial region of the nebula. The H_2 bipolar structure is probably caused by a dust annulus surrounding the PN and causing a pinching effect which gives its observed form to the nebula.
- Evidence of the presence of a breach in the nearside of the nebula and a "counter breach" opposite to it is clearly seen in H_2 envelope of NGC 7027. Such a breach may be caused by the interaction of a high velocity outflow with the nebula shell and support the suggestion that the north-west bright knot visible in the WFPC images is a temperature effect due to the outflow.
- We have determined the orientation ($\theta = 50^o$, $\phi = 40^o$) of the high velocity outflow which passes through the ionized and the molecular breaches of the nebula. This orientation is consistent with the observed alignment of the X-ray (Kastner et al. 2001) and the Brγ emissions.
- The molecular envelope presents a series a small condensations and openings. A breach is present in the north with no evident presence of a "counter breach" in the south suggesting that the direction of the jet which has disrupted the nebula in the past has changed. This leads us to speculate that the disturbed morphology of NGC 7027 is the result of a precessing, collimated jet.

References

Kastner et al. 2001 ApJ, 550, 189

Maillard, 2000 in Imaging the Universe in 3 Dimensions, ASP Conf. Ser. 195, 185

*Address for correspondence: OCA, Département Cassiopée, CNRS-UMR 6202, BP 4229, F-06304 Nice Cedex 4, France