

---

# The H<sub>2</sub> Amazing Life of NGC 6881

Gerardo Ramos-Larios<sup>1</sup>, Martín A. Guerrero<sup>2</sup>, and Luis F. Miranda<sup>2</sup>

<sup>1</sup> Instituto de Astronomía y Meteorología,  
Av. Vallarta No. 2602, Col. Arcos Vallarta, C.P. 44130 Guadalajara, Jalisco,  
México.

([gerardo@astro.iam.udg.mx](mailto:gerardo@astro.iam.udg.mx))

<sup>2</sup> Instituto de Astrofísica de Andalucía, IAA-CSIC,  
C/ Camino Bajo de Huétor 50, 18008 Granada, Spain.  
([mar@iaa.es](mailto:mar@iaa.es), [lfm@iaa.es](mailto:lfm@iaa.es))

**Summary.** The H<sub>2</sub> and optical (H $\alpha$ , [N II]) morphology of NGC 6881 are very different. Here we present a preliminary report of the analysis of new optical (H $\alpha$  and [N II]) and near-IR (Br $\gamma$  and H<sub>2</sub>) images and intermediate resolution *JHK* spectra of this nebula. Our observations confirm the association of the H<sub>2</sub> bipolar lobes to NGC 6881 and reveal that H<sub>2</sub> is predominantly shock excited in this nebula. We conclude that NGC 6881 has multiple bipolar lobes that formed at different phases of the nebular evolution and that the collimation conditions or even the collimating agent changed from one ejection to the other.

**Key words:** infrared: ISM: continuum — ISM: molecules — planetary nebula: individual (NGC 6881)

## 1 Introduction

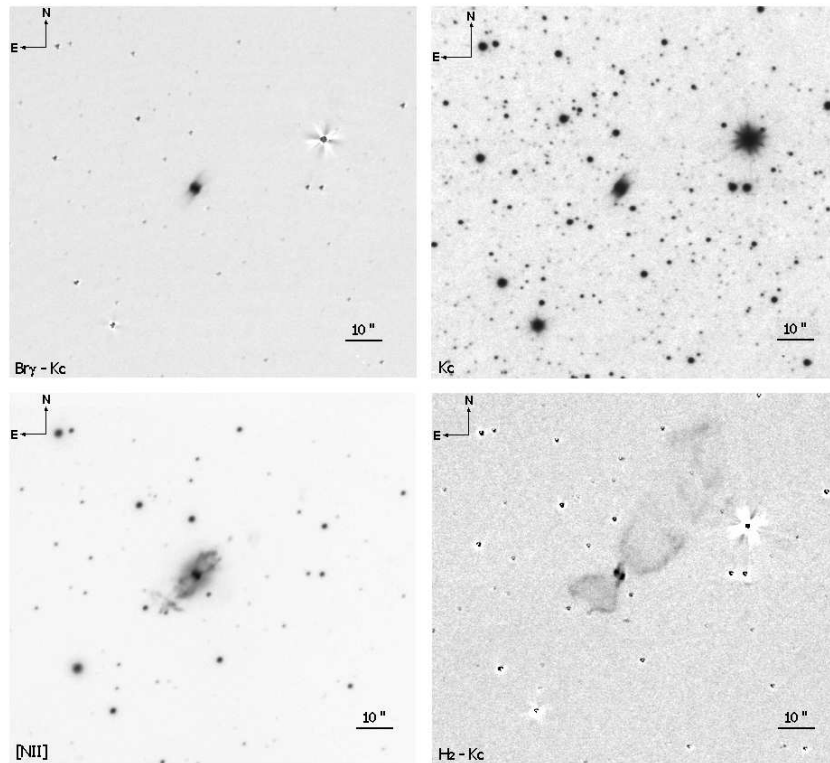
Bipolar planetary nebulae (PNe) with multiple bipolar lobes have begun to be common. These objects are of great interest as they require multiple bipolar ejections with changes in the ejection direction in many cases. NGC 6881 displays in the optical a quadrupolar morphology consisting of two pairs of highly collimated bipolar lobes aligned along different directions [1]. There is also evidence that the axis of the central ring or torus has precessed in the last stages of PN formation [3]. The distribution of the emission of the molecular hydrogen is very different from this of the ionized material [2]. Molecular hydrogen emission in NGC 6881 is detected mainly in the equatorial region and in wide hourglass bipolar lobes that are much more extended than the ionized bipolar lobes.

The H<sub>2</sub> bipolar lobes of NGC 6881 may represent an early bipolar ejection that took place before the formation of the two pairs of ionized bipolar lobes. To investigate in detail the spatial distribution of molecular hydrogen and ionized material within NGC 6881 and to determine the prevalent excitation mechanism of the H<sub>2</sub> emission, we have obtained new near-IR Br $\gamma$  and H<sub>2</sub> (1,0) S(1) images, optical H $\alpha$

and [N II] images, and intermediate resolution *JHK* spectra of NGC 6881. Preliminary results of our analysis are presented here. A more detailed analysis will be presented elsewhere (Ramos-Larios, Guerrero, & Miranda, in prep.).

## 2 Observations

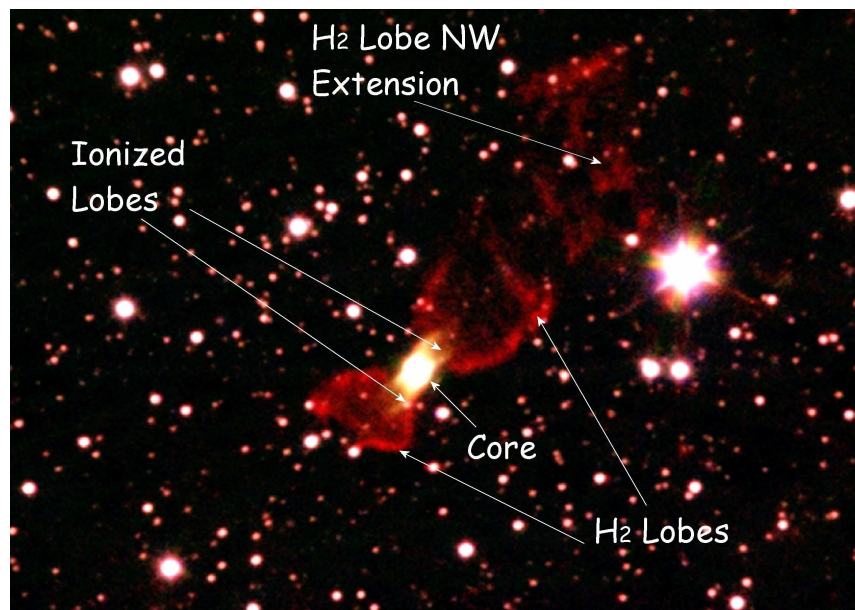
$H\alpha$  and [N II] narrow-band images of NGC 6881 were obtained with ALFOSC at the 2.5-m *NOT* with total exposure times of 900 s and 1,800 s, respectively.  $H_2$  (1,0) S(1),  $Br\gamma$ , and  $Kc$  (continuum at  $\lambda = 2.270 \mu\text{m}$ ) narrow-band images were obtained with LIRIS at the 4.2-m *WHT*. Total exposure times were 1,000 s for  $Br\gamma$  and  $Kc$ , and 900 s for  $H_2$ . The images are presented in Figure 1.



**Fig. 1.** Images of NGC 6881 in the  $Br\gamma$  (*top-left*),  $Kc$  (*top-right*), [N II] (*bottom-left*), and  $H_2$  (*bottom-right*) narrowband filters.

Intermediate resolution *JHK* longslit spectroscopy was obtained using NICS at the 3.5-m *TNG*. The longslit was placed along the central star at PA's  $113^\circ$  and  $137^\circ$ . At PA  $113^\circ$ , spectra were obtained using the  $JH$  and  $K_B$  grisms with exposure

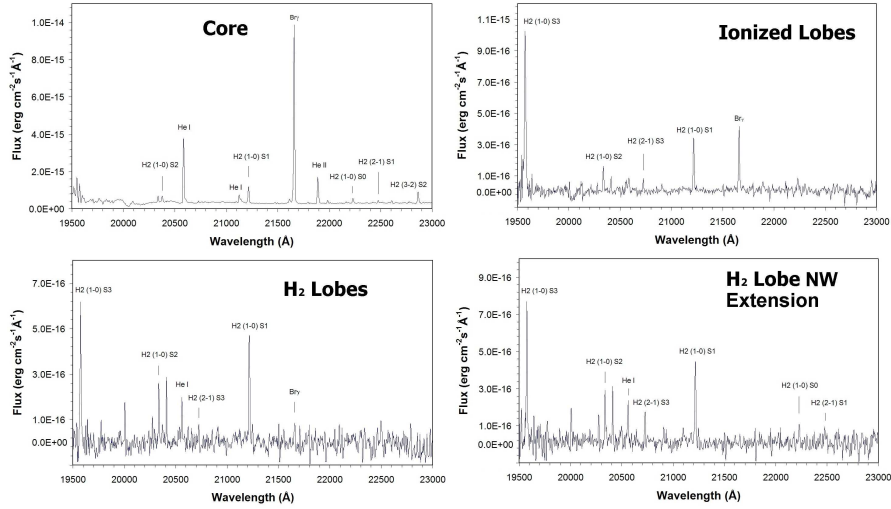
times 1,800 s and 3,000 s, respectively. At PA 137°, only the  $K_B$  grism was used with exposure time 1,200 s.



**Fig. 2.** *WHT* LIRIS composite three-color picture of NGC 6881 in the filters of H<sub>2</sub> (red), Br $\gamma$  (green), and  $Kc$  (blue). The picture is overlaid with regions of interest.

The new H<sub>2</sub>, Br $\gamma$ , and [N II] images of NGC 6881 confirm the notable differences in the spatial distributions of ionized material and molecular hydrogen within this nebula [2]. Moreover, the better spatial resolution, depth, and accurate background subtraction in the H<sub>2</sub> image presented here and the invaluable information contained in the near-IR spectra have allowed us to obtain a more detailed view of the distribution and excitation of the molecular hydrogen in NGC 6881. Both the images and spectra show that the outermost regions are H<sub>2</sub>-dominated, while the central region and ionized bipolar lobes are emitting predominantly through lines of ionized species. This is clearly illustrated in the composite picture shown in Figure 2. Guided by this picture, we have defined four different regions of interest: the central region or core, the ionized bipolar lobes, the H<sub>2</sub> hourglass bipolar lobes, and the extension of the Northwest H<sub>2</sub> lobe. Individual spectra of these regions are shown in Figure 3, and the line identifications and fluxes are listed in Table 1.

The central region of NGC 6881 shows the spatial distribution expected for a ring of molecular material surrounding the innermost ionized region. He II emission is confined to this central region. The ionized lobes show both prominent Br $\gamma$  and H<sub>2</sub> emission, although their spectrum is probably contaminated by this of the H<sub>2</sub>-dominated bipolar lobes. The H<sub>2</sub> lobes share the same orientation than the ionized lobes, but are less collimated and display a distinct hourglass shape. The Northern H<sub>2</sub> lobe extends 5 times farther than the ionized lobes, but the Southern H<sub>2</sub> lobe



**Fig. 3.**  $K_B$  spectra along  $PA=137^\circ$  of the different regions of NGC 6881 described in the text and overlaid in Fig. 2: core, inner ionized lobes,  $H_2$  lobes, and extension of the Northwest  $H_2$  lobe. Some lines are overlaid on the spectra.

has a reduced extension. This asymmetry suggests the interaction of the nebula with an inhomogeneous interstellar medium. Intriguingly, the edge of the Southern  $H_2$  lobe is coincident with the loop of ionized material seen in the  $[N\ II]$  image, thus suggesting that it is not a precessing collimated outflow, as proposed by [1], but the outer edge of the Southern  $H_2$  lobe.

The  $H_2$  1–0 S(1)/2–1 S(1) line ratio (see Tab. 1) derived for the different regions implies shock excitation even in the innermost regions of NGC 6881. Excitation diagrams obtained using transitions from higher vibrational levels of the  $H_2$  molecule confirm this result (Ramos-Larios et al., in prep.).

### 3 Conclusions

The very different morphologies of the ionized and molecular bipolar lobes of NGC 6881 imply different bipolar ejections that most likely occurred at different times in the nebular evolution. While the direction of the bipolar ejection has only suffered small variations, especially at the very end of the nebular evolution [3], the degree of collimation has increased drastically. This suggests notable changes in the collimation conditions or even in the collimation mechanism during the formation of NGC 6881.

*Acknowledgement.* This work is funded by grant PNAYA2005-01495 of the Spanish MEC. GRL thanks the IAA for his hospitality. We thank G. Gómez and J. Acosta for taking the LIRIS images of NGC 6881.

**Table 1.** Line fluxes at PA 137° with  $K_B$  grism

$\lambda$ [Å]	Line Identification	Regions			
		Central Region	Ionized Lobes	H <sub>2</sub> Lobes	H <sub>2</sub> Lobe NW Extension
		[ ergs cm <sup>-2</sup> s <sup>-1</sup> Å <sup>-1</sup> ]			
19446	Br8 HI	$6.3 \times 10^{-14}$	...	...	...
19549	He I	$1.6 \times 10^{-14}$	...	...	...
19574	H <sub>2</sub> (1,0) S(3)	$1.2 \times 10^{-14}$	$1.7 \times 10^{-14}$	$1.1 \times 10^{-14}$	$9.2 \times 10^{-15}$
19703	H <sub>2</sub> (8,6) O(2)	$2.1 \times 10^{-15}$	...	...	...
20338	H <sub>2</sub> (1,0) S(2)	$4.2 \times 10^{-15}$	$2.1 \times 10^{-15}$	$3.8 \times 10^{-15}$	$4.6 \times 10^{-15}$
20377	?	$4.7 \times 10^{-15}$	...	...	...
20587	He I	$4.7 \times 10^{-14}$	$1.3 \times 10^{-15}$	$4.2 \times 10^{-16}$	$2.4 \times 10^{-15}$
20732	H <sub>2</sub> (2,1) S(3)	$1.2 \times 10^{-15}$	$8.1 \times 10^{-16}$	$1.3 \times 10^{-15}$	$2.8 \times 10^{-15}$
20763	?	$8.5 \times 10^{-16}$	...	...	...
21126	He I	$5.1 \times 10^{-15}$	...	...	...
21138	He I	$2.2 \times 10^{-15}$	...	...	...
21218	H <sub>2</sub> (1,0) S(1)	$1.2 \times 10^{-14}$	$4.7 \times 10^{-15}$	$5.6 \times 10^{-15}$	$6.2 \times 10^{-15}$
21542	H <sub>2</sub> (2,1) S(2)	$4.1 \times 10^{-16}$	...	...	...
21614	He I ??	$2.9 \times 10^{-15}$	...	...	...
21658	Br7 HI (Brg)	$1.1 \times 10^{-13}$	$5.5 \times 10^{-15}$	$1.3 \times 10^{-15}$	...
21793	Br I	$1.1 \times 10^{-15}$	...	...	...
21887	He II	$1.7 \times 10^{-14}$	$8.3 \times 10^{-16}$	...	...
21985	?	$2.1 \times 10^{-15}$	...	...	...
22235	H <sub>2</sub> (1,0) S(0)	$3.3 \times 10^{-15}$	$1.2 \times 10^{-15}$	...	$1.5 \times 10^{-15}$
22477	H <sub>2</sub> (2,1) S(1)	$1.6 \times 10^{-15}$	...	...	$9.6 \times 10^{-16}$
22872	Br I ??	$7.1 \times 10^{-15}$	...	...	...

## References

1. Guerrero, M. A., & Manchado, A. 1998, ApJ, 279, 125
2. Guerrero, M. A., Villaver, E., Manchado, A., García-Lario, P., & Prada, F. 2000, ApJS, 127, 125
3. Kwok, S., & Su, K.Y.L. 2005, ApJ, 635, L49