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FABRY-PEROT KINEMATICS OF HH 202–204 IN THE ORION NEBULA: ARE THEY PART OF A BIG BIPOLAR OUTFLOW?

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RESUMEN

Se presenta un estudio cinemático de los objetos HH 202, 203 y 204 usando mapas de velocidad Fabry-Perot en Hα y [N II]. En el caso de HH 202 se encuentran nebulosidades que podrían estar asociadas a este objeto o bien, dada sus altas velocidades (superiores a 100 km s^{-1}), formar un flujo HH aún no catalogado. Se encuentran movimientos internos violentos en las regiones débiles de HH 203 y HH 204 al igual que cierta evidencia sobre la existencia de gradientes de densidad transversos. Se muestra que el ápex de HH 204 corresponde a la zona de velocidad máxima, lo cual está en acuerdo con los modelos de choque de proa. Nuestros estudios cinemáticos nos hacen sugerir que HH 202 y HH 203/204 son parte de un único flujo HH bipolar gigante ($\sim$ 0.55 pc).

ABSTRACT

We present a kinematic study of the Herbig-Haro objects HH 202, 203 and 204 using Hα and [N II] Fabry-Perot velocity maps. For HH 202 we find new features that could belong to this HH object or that perhaps are associated with an outflow different from HH 202. Because of its high velocity (up to 100 km s^{-1}) this outflow probably can be a HH flow not catalogued previously. Large internal motions are found in the fainter regions of HH 203/204, as well as evidence of transverse density gradients. We show that the apex of HH 204 is the zone of maximum velocity in agreement with bow shock models. From our studies, we find kinematic evidence that suggests that HH 203/204 and HH 202 are part of a single and large ($\sim$ 0.55 pc) HH flow.

Key Words: **ISM: INDIVIDUAL (ORION NEBULA, HH 202, HH 203, HH 204) — STARS: FORMATION — STARS: MASS LOSS**

1. INTRODUCTION

The Orion Nebula is one of the most interesting H II regions that still reveals intriguing phenomena. Indeed, Orion is one of the nearest star forming regions (located at a distance of 450 pc) and, consequently, the phenomena can be studied with the highest angular resolution. In the Orion region several phases of the interstellar medium coexist, such as molecular, neutral, and ionized gas. With the development of near IR imaging and spectroscopy in recent years, new phenomena have been revealed that constitute important clues to the understanding of the process of star formation and the evolution of shocks in a molecular environment.

In this work we show the results of a Fabry-Perot kinematical study of the Orion Nebula that was mainly motivated by:

- The excellent *HST* image coverage of the Orion Nebula that reveals a plethora of new objects like Herbig-Haro (HH) objects and proplyds (O'Dell et al. 1997a).
- The discovery of giant ($\sim$ 1 pc) HH flows that challenge our ideas of the energetics and timescales involved in the star formation process (Reipurth, Bally, & Devine 1997). These giant HH flows are constituted of two or more HH objects that, in the past, were thought to be isolated.
- The interest in studying jets which are photoionized by external sources such as the jet discovered in the Trifid Nebula (Cernicharo et al. 1997). This kind of jet has complex emission and kinematical properties, which are now being studied theoretically.

With the aim of obtaining a global view of the kinematics of HH objects and jets in Orion that allows us to search for large scale features that link the HH objects already known, we undertook the study of the inner 5′ of the Orion Nebula by means of Fabry-Perot observations at Hα and [N II] λ 6583 Å. Here we present some of the results derived from this study.

2. OBSERVATIONS AND DATA REDUCTION

The Fabry-Perot (FP) observations were carried out at the f/7.5 Cassegrain focus of the 2.1-m telescope of the Observatorio Astronómico Nacional at San Pedro Mártir, B.C., México using the

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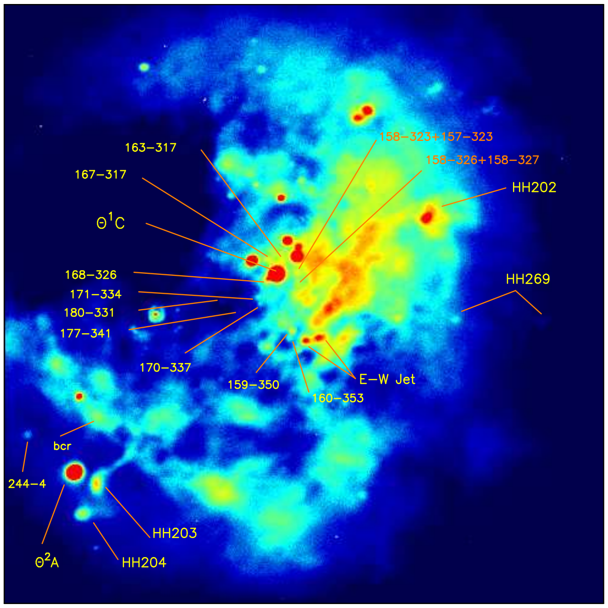

Fig. 1. Hα velocity map at $V_{\rm helio}$ = –90 km s^{-1} of the Orion Nebula obtained with the PUMA FP observations. Some of the important stars, HH objects and proplyds are marked. NOTE: THIS FIGURE IS AVAILABLE IN COLOR IN THE ELECTRONIC VERSION OF THIS ARTICLE, OBTAINABLE FROM `http://www.astroscu.unam.mx/~rmaa/`.

UNAM Scanning Fabry-Perot Interferometer PUMA (Rosado et al. 1995). We used a 1024 × 1024 thinned Tektronix CCD detector, with an image scale of 0.59 arcsec pixel^{-1}. The interference filters used in the observations are centered at Hα and [N II] λ6583 Å with bandpasses of 20 and 10 Å, respectively. The main characteristics of this interferometer are: interference order of 330, free spectral range of 19.89 Å (equivalent to a velocity range of 908 km s^{-1}) and sampling spectral resolution of 0.41 Å (equivalent to 18.9 km s^{-1}), at Hα, achieved by scanning the interferometer gap at 48 positions. Thus, the resulting data cubes have dimensions of 512 × 512 × 48.

With this setup, we have obtained two nebular data cubes at Hα and [N II] with total exposure times of 48 and 144 minutes, respectively. The data reduction and analysis were performed using the data reduction package CIGALE (Le Coarer et al. 1993).

3. KINEMATICAL RESULTS

Figure 1 shows the velocity map in Hα at $V_{\rm helio} = -127$ km s^{-1} (i.e., 150 km s^{-1} blueshifted relative to the velocity of the intense nebular background), in which we have identified the different objects present in the inner 5′ region of the Orion Nebula: the HH objects HH 202, HH 269 (barely seen in Hα), HH 203 and HH 204, the E-W jet mentioned by O'Dell et al.

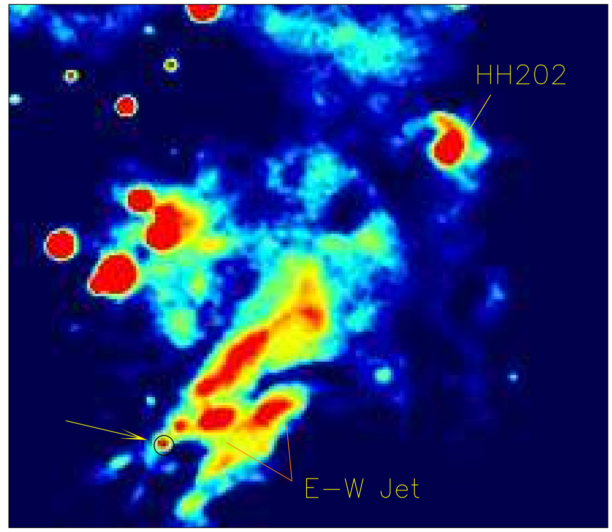

Fig. 2. Close-up of the [N II] λ6583 Å velocity map at $V_{\rm helio} = -90$ km s^{-1} showing the field near to HH 202 which is located at the NW corner. The arrow to the SE corresponds to one of the ends of the lobe.

(1997b). In what follows, we will describe some of our results on the kinematics of the HH objects HH 202, HH 203 and HH 204 and discuss the possible existence of a large HH bipolar outflow.

3.1. *HH 202*

HH 202 was discovered by Cantó et al. (1980) as an emission line object showing two knots embedded in an arc-shaped nebulosity. Herbig & Jones (1981) obtained proper motions for the knots, finding that the proper motion vectors were parallel and pointing towards the concave side of the curved shell and that there was a considerable dispersion in the tangential speeds of several of the knots: from 100 to 294 km s^{-1}. More recently, O'Dell et al. (1997a) have obtained wonderful *HST* images of the HH 202 region in the [S II], Hα and [O III] lines showing that the arc-shaped nebulosity is visible in [S II], Hα and [O III] lines. O'Dell et al. (1997b) obtained [S II] and [O III] FP spectroscopy of the Trapezium region. They found a blueshifted portion of HH 202 that extends towards the NW.

Figure 2 shows a close-up of the [N II] velocity map at $V_{\rm helio} = -90$ km s^{-1}, showing the field near to HH 202, which is located at the NW corner. Comparing with the Hα velocity map (shown in Fig. 1) we see that the HH 202 object has different morphologies in Hα and [N II]. Indeed, while in [N II] we see the arc-shaped nebulosity ending to the SW in the southern knot, in Hα we detect the arc-shaped nebulosity but the southern knot is not easily disentangled from the emission of a bright nebulosity and

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several knots. Instead, we see a bright head of irregular shape (somewhat like an arrow head) pointing in the E-W direction, with three faint filamentary extensions also oriented in the E-W direction. The longest filamentary extensions seem to form a rotated spur, or Ω-shape.

Another interesting feature revealed in Figures 1 and 2 is that HH 202 seems to be part of a larger scale lobe (of $82 \times 25''$ and aperture angle of $\sim 40°$), oriented in the NW-SE direction, ending at the position of HH 202 on one side, and in a point close to the E-W jet in its SE end. The [N II] emission shows that, inside this lobe, two elongated cavities (one of $35 \times 9''$ and other of $55 \times 12''$, both with aperture angles of $\sim 20°$), somewhat similar to bow shocks are detected. In Hα, the walls of the lobe are clearly seen but the elongated cavities interior to the lobe (hereafter called 'fingers') are confused with the bright background nebula.

Our FP data show that high internal motions of the known regions of HH 202 reach blueshifted velocities of up to 100 km s^{-1}. The spur also shows this range of velocities indicating that it should belong to HH 202. On the other hand, the lobe and the 'fingers' inside it also have high blueshifted velocities reaching up to 100 km s^{-1}. This shows that these new features are related to a high-velocity flow, probably an HH flow, not catalogued as such because of the difficulties of disentangling it from the bright nebular background. It is unclear whether this flow is associated with HH 202 or whether it constitutes another HH system.

3.2. *HH 203 and HH 204*

These objects were discovered by Munch & Wilson (1962). Taylor & Munch (1978) give radial velocities and velocity dispersions for several different features within these objects. However, it was Cantó et al. (1980) who identified these objects as HH objects. Hu (1996) has measured tangential velocities of 0 and 70 km s^{-1} for HH 203 and HH 204, respectively, directed towards the apex of the bow.

There are at least two important questions related to these objects: are HH 203 and HH 204 parts of the same object? and, why does HH 204 show an asymmetry in its brightness distribution?.

Our kinematical results show that:

- HH 204 has a conical shape (resembling a bow shock) that is better appreciated at extreme heliocentric velocities: at $V_{\rm helio} = -50$ km s^{-1} and $V_{\rm helio} = +45$ km s^{-1}.
- The apex of HH 204 has a complex velocity profile showing a splitting of the main velocity components (at $V_{\rm helio} = -24$ and $+20$ km s^{-1}) and a blueshifted wing at $V_{\rm helio} = -120$ km s^{-1}. Thus, the apex of HH 204 has the maximum blueshifted velocity of the region, in agreement with the predictions of bow shock models.
- HH 203 is more jet-like and it seems to be a different entity colliding with a lateral wall of HH 204.
- We distinguish a pronounced asymmetry in brightness between the bow side of HH 204 near to the star θ^2 Ori A and the side located away from this star. Henney (1996) has proposed that a transverse density gradient in the ambient medium where a bow shock propagates, could lead to an asymmetry in brightness of the bow shock. We find some evidence of a transverse density gradient because we find that there is a slight velocity gradient running perpendicular to the axis of HH 204 in the sense that the fainter regions have larger velocities.
- HH 203 and HH 204 seem to be part of a structure of large dimensions or lobe. Indeed, Figure 3 is a close-up of the [N II] velocity map at $V_{\rm helio} = -14$ km s^{-1} showing the field around HH 203 and HH 204, which are located in the SE of this figure. A careful inspection of this figure suggests the detection of an incomplete lobe ending in HH 204 on one side, and at the mark shown in Fig. 3 on the other side. This lobe is $132''$ or 0.29 pc long and it is more intense in its northern half. The possible existence of this lobe is also revealed in O'Dell's image of the Orion Nebula published in the National Geographic Supplement (Grosvenor, Allen, & Shufe 1995).

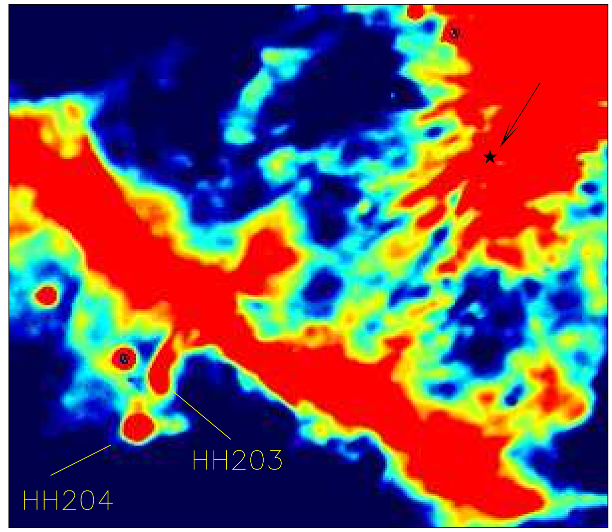

Fig. 3. Close-up of the [N II] λ6583 Å velocity map at $V_{\rm helio} = -14$ km s^{-1} showing the field near to HH 203 and HH 204 which are located near the SE corner. The mark corresponds to one of the ends of the lobe and it is the same mark as in Figure 2.

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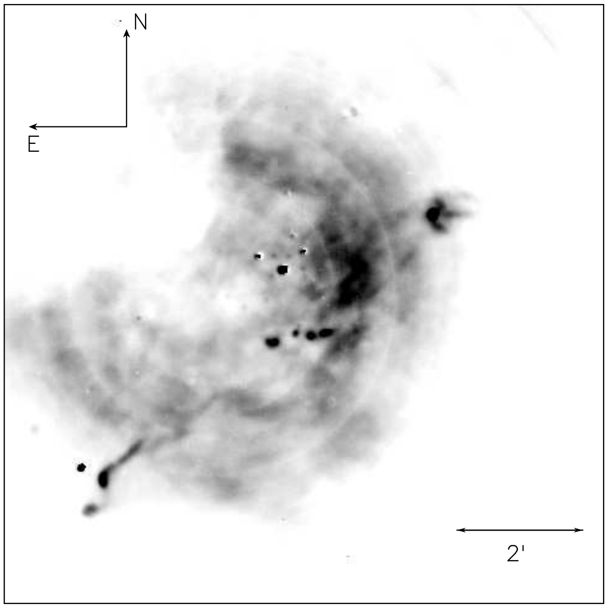

Fig. 4. Hα velocity map, at $V_{\mathrm{helio}} = -50$ km s^{-1}, of the inner $5'$ of the Orion Nebula. At this blueshifted velocity, the NW lobe, the E-W jet and the jet-like appearance of HH 203 are appreciated. The nebulosity to the W of the E-W jet (marked with an arrow in Figures 2 and 3) corresponds to the location of the possible exciting source of the bipolar flow.

4. DISCUSSION

Our results show that HH 202 seems to be part of a larger scale lobe. This lobe is blueshifted relative to the main H II region velocity and shows the large internal motions characteristic of HH flows. The [N II] velocity cubes show that this lobe (NW lobe) is formed by two 'fingers' starting from a region close to the E-W jet discovered by O'Dell et al. (1997a). HH 203 and HH 204 also seem to be part of a large structure or lobe (SE lobe) of similar dimensions to the ones of the NW lobe. HH 204 is at one of the ends while the other end is located close to the E-W jet, as in the case of the NW lobe. Furthermore, the SE lobe shares the same orientation as the NW lobe. Considering the results presented in the previous sections, we suggest that HH 202 and HH 203/204, are part of a large bipolar outflow, 0.55 pc long, that arises from an object close to the E-W jet. Besides, a preliminary analysis suggests that the NW lobe is blueshifted relative to the background nebula while the SE lobe is redshifted. The measured proper motions of HH 203/204 agree with this interpretation while the proper motions measured a long time ago for HH 202 (Herbig & Jones 1981) do not support this idea. On the other hand, the region close to the E-W jet is so rich in objects that it is difficult to identify, by means of the existing stellar data, the object that could be the source of this suggested bipolar outflow. Figure 4 shows the Hα velocity map at $V_{\mathrm{helio}} = -50$ km s^{-1} of the inner $5'$ of the Orion Nebula which allows us to have a global view of both lobes. At blueshifted velocities the NW lobe is better detected than the SE lobe. However, jet-like features (such as HH 203 and the 'fingers' inside the NW lobe) are detected inside these lobes. Further studies of the stellar content close to the E-W jet and of proper motions of the HH 202 knots would be quite interesting for confirming or rejecting this suggestion.

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