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Astrophysical Plasmas: Codes, Models, and Observations (Mexico City, 25-29 October 1999)
Editors: Jane Arthur, Nancy Brickhouse, & José Franco

KINEMATICS AND IONIZATION OF THE PROPLYD M42 177–341

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RESUMEN

Los proplyds brillantes en la nebulosa de Orión (M42) son el resultado de la fotoevaporación de discos de acreción, debido a alrededor de las estrellas de baja masa en el cúmulo del Trapecio la radiación ultravioleta de las estrellas O del cúmulo. Henney & O'Dell (1999) presentaron espectroscopía de líneas de emisión óptica de alta resolución para cuatro proplyds y encontraron una correlación entre el ancho de línea y el potencial de ionización, lo cual indica la aceleración de un flujo fotoevaporado con ionización estratificada. Aquí presento datos suplementarios sobre 177–341, uno de los proplyds en el estudio de Henney & O'Dell.

ABSTRACT

The bright proplyds in the Orion nebula (M42) are the result of accretion disks around low-mass stars in the Trapezium cluster being photoevaporated by the ultraviolet radiation from the O stars in the cluster. Henney & O'Dell (1999) presented high resolution optical emission line spectroscopy of four proplyds and demonstrated a correlation between line width and ionization potential, indicative of acceleration in an ionization-stratified photoevaporating flow. Here I present previously unpublished supplementary material concerning 177–341, one of the proplyds in the Henney & O'Dell study.

Key Words: **CIRCUMSTELLAR MATTER — H II REGIONS — ISM: INDIVIDUAL (ORION NEBULA) — STARS: FORMATION**

Of all the proplyds in the Orion nebula, 177–341 (also known as HST 1) is perhaps the object best-suited to detailed study because of its large size and symmetric appearance, together with its location in a relatively low-brightness region of the nebula. The most striking feature of the line profiles in this object is the dramatic increase in the line width of the proplyd as one passes from low to high ionization species. This is apparent even in the raw spectra (Fig. 1*a*–*c*) and is discussed at length in Henney & O'Dell (1999).

1. THE NEBULA-SUBTRACTION PROBLEM

The single most important limiting factor in attempting to extract more information about the proplyd from the spectra is the strong and variable background emission from the Orion nebula itself. Although the proplyd is considerably brighter than the nebula in all lines when observed at a resolution $< 0.1''$ (Fig. 1*d*), this is no longer the case when the proplyd has been smeared by the $> 1''$ seeing typical of ground-based observations. For the [O I] 6300Å line, the proplyd is so much brighter that it is relatively easy to separate its contribution from that of the nebula (Fig. 1*a*). However, this is no longer the case for the higher ionization lines (Figs. 1*b* and *c*), where the proplyd brightness is comparable to or less than that of the nebula.

The problem is compounded by the fact that the nebular line can vary along the slit, both in intensity and in velocity. It is apparent from Figure 1*d* that the nebular environment of the proplyd is far from homogeneous. In particular, a bright "shelf" of emission lies to the south of the proplyd and crosses the spectrograph slit just behind the end of the tail. In the lower ionization lines in particular, the velocity of the nebular emission in this region is quite different from that in front of the proplyd. This can be seen as a curve of the line profile towards higher heliocentric velocities in the lower portion of the spectrograph slit in Figures 1*a* and *b*.

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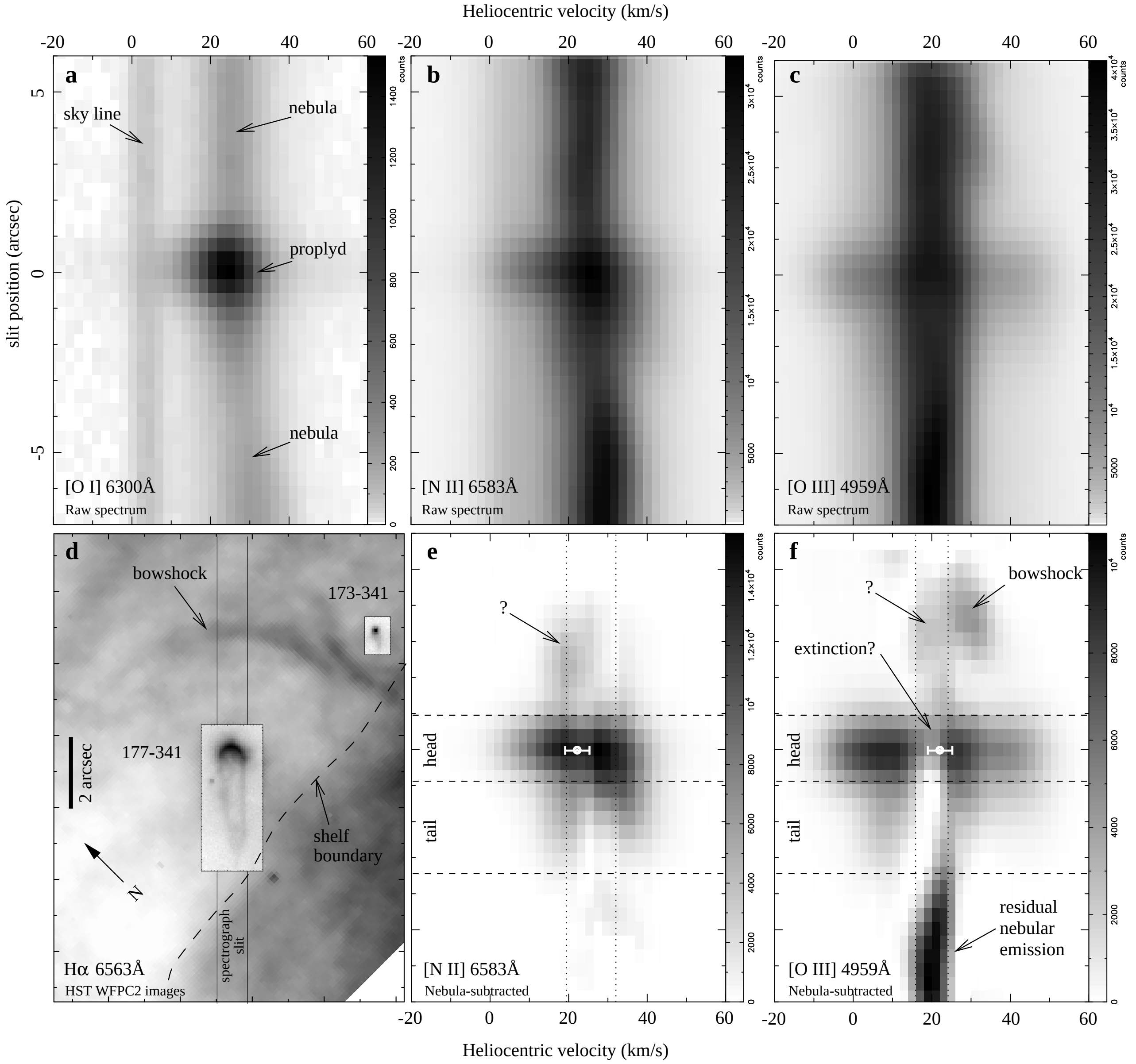

Fig. 1. *(a)–(c)* Keck HIRES longslit spectra, taken with the slit along the axis of the proplyd 177–341, in the emission lines [O I] 6300Å, [N II] 6583Å, and [O III] 4959Å. The velocity resolution is approximately 6 km s^{-1} and the seeing was approximately 1.5″. *(d)* An HST WFC image of the proplyd with the same spatial scale as the slit spectra and with a linear intensity mapping (min: 1.7×10^{10}, max: 5.0×10^{10} photons cm^{-2} s^{-1} sr^{-1}). Insets show higher resolution HST PC images at the same spatial scale and with a logarithmic intensity mapping (min: 1.7×10^{10}, max: 2.2×10^{11} photons cm^{-2} s^{-1} sr^{-1}). *(e)–(f)* Residual [N II] and [O III] spectra after attempting to remove the nebular contribution to the line profile. This was done by fitting low order polynomials to the spatial dependence of the background emission in each velocity channel independently. Vertical dotted lines mark the velocity range in which the nebular background is strong, leading to considerable uncertainty in the residual emission. The systemic heliocentric velocity of the proplyd, as determined by model fits to the line profiles, is 22 ± 3 km s^{-1} and is marked by the filled white circle with error bars.

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Henney & O'Dell (1999) resolved this problem by using multiple exposures with different slit orientations in order to obtain a best estimate of the line profile of the bright head of the proplyd, together with an estimate of the uncertainty in this profile due to variations in the nebular background. One disadvantage of this approach is that it throws away information about the spatial variation of the proplyd line profile. Figures 1*e* and *f* show the results of a complementary approach, in which polynomials are fitted to the spatial variation of the background emission in each velocity channel. It can be seen that this technique works well at velocities where the nebula line is not too strong, revealing features that are hard to distinguish in the raw spectra.

2. FEATURES AND ARTIFACTS IN THE RESIDUAL SPECTRA

In the upper portion of the residual [O III] spectrum (Fig. 1*f*) a red-shifted emission feature can be seen that coincides spatially with the faint arc of emission visible in front of the proplyd in Figure 1*d*. This arc is probably the bowshock where the flow from the proplyd ionization front interacts with the fast wind from the ionizing star (Bally et al. 1998; García-Arredondo, Henney, & Arthur these proceedings; O'Dell & Bally these proceedings). Since the bowshock lies in the highly-ionized interior of the nebula, it is not visible in low- and medium-ionization lines such as [O I] or [N II]. The emitting gas on the axis of such a bowshock should be almost stationary, which is consistent with the velocity of the red-shifted feature of about 28 km s^{-1}, very similar to the systemic velocity of the molecular cloud that lies behind the nebula (O'Dell et al. 1993).

The faint "bridge" of emission between the proplyd head and the bowshock, marked by a "?" in Figure 1*f*, may well be an artifact of the nebula-subtraction process. On the other hand, a similar feature is also visible in the [N II] spectrum (Fig. 1*e*), where the redder velocity of the dominant nebular line means it is less affected by the subtraction process, and a faint counterpart is also discernible in [O I]. Nonetheless, even if the feature is real, it is almost certainly associated with the nebula rather than the proplyd since there should be no [N II] or [O I] emission from so far in front of the proplyd head.

A dip in the residual [O III] emission from the proplyd is evident in Figure 1*f* at the velocity of the nebular line (18–22 km s^{-1}). It is hard to judge whether this effect is real or is due to imperfect background subtraction, but similar dips are seen for other slit orientations and for other proplyds. If real, the effect is almost certainly due to extinction of background nebular emission by dust in the proplyd, since it is impossible to produce such a dip by kinematic effects alone. Independent evidence for the importance of dust extinction in the proplyd comes from the variation along the slit of the $H\beta/H\alpha$ ratio. Using the extinction curve from Baldwin et al. (1991), this implies that the combined proplyd+nebula emission at the proplyd position suffers an extra extinction $\delta A_V \simeq 0.2$ magnitudes, over and above that of the adjacent nebula. Further work is required to disentangle the extinction of the proplyd from that of the the nebula and to control for possible variations in the intrinsic $H\beta/H\alpha$ ratio due to deviations from strict Case B conditions.

Finally, significant differences are evident between the [N II] and [O III] line profiles from the proplyd tail (Figs. 1*e*, *f*). In [N II], the tail emission is slightly redshifted with respect to the proplyd systemic velocity, while in [O III] it is blueshifted. Given the constraints on the inclination of 177–341, this suggests that the ionized gas leaving the tail has a velocity component along as well as perpendicular to the tail.

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