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Hα FABRY-PEROT STUDY IN THE ORION NEBULA (M 42): PROTOPLANETARY DISKS

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RESUMEN

Se presenta un resumen de los resultados cinemáticos obtenidos del estudio Fabry-Perot en Hα de algunos proplyds en la nebulosa de Orion. Estos resultados se presentan en detalle en de la Fuente et al. (2003 a,b). Se obtienen velocidades sistémicas, tasas de pérdida de masa, edad de los discos y perfiles de velocidad radial. Encontramos que la interferometría Fabry-Perot constituye una técnica efectiva para la detección de proplyds. Se discuten algunos aspectos astrobiológicos de estos resultados que ilustramos usando los proplyds 168-326, 167-317, 163-317, 158-323, 158-327 y 161-314.

ABSTRACT

We summarize the kinematical results obtained from an Hα Fabry-Perot study of some proplyds in the Orion nebula. These results are presented in detail in de la Fuente et al. (2003 a,b). We obtained heliocentric systemic velocities, mass loss rates, disks life-times and radial velocity profiles, finding that Fabry-Perot interferometry constitutes an effective technique for the detection of proplyds. We also present a brief summary of some astrobiological aspects presented by Throop et al. (2001, 2002). We illustrate our results using the proplyds 168-326, 167-317, 163-317, 158-323, 158-327 and 161-314.

Key Words: **H II REGIONS — ISM: INDIVIDUAL (ORION NEBULA) — STARS: MASS LOSS — STARS: PRE-MAIN SEQUENCE**

1. INTRODUCTION

The proplyds (PROtoPLanetarY DiskS) were discovered by Laques & Vidal (1979) in the trapezium region of M 42. The term proplyd was coined by C.R. O'Dell to name the 6 nebulosities called LV(1-6) objects identified by these authors. They were imaged in 1993 with HST to show, for the first time, their morphology: silhouettes, bow shocks and even circumstellar disks (O'Dell et al. 1993, O'Dell & Wen 1994). Indeed they were identified as compact disks around YSOs using this excellent imagery. Therefore, they are photoevaporating circumstellar disks around young stellar objects (YSO). Their shapes are created when the UV photoionizing flow from a hot external star interacts with a photoevaporated flow from the circumstellar disk: the photoionizing flux infringes on the disk producing a slow ($\sim$ 3 km s^{-1}) photodissociated flow. The flow passes through a weak D-type ionization front (IF) and is accelerated to transonic velocities ($\sim$ 10 km s^{-1}) producing a weak shock that lies just inside the IF, generating a slight density and column density enhancement that is seen in silhouette (head). The proplyds were identified as young stars with circumstellar clouds photoionized from the exterior by Θ^1 Orionis C by means of VLA observations (Churchwell et al. 1987, Garay et al. 1987) and IR K-band images (Meaburn 1988). Recently the proplyds have been designated according to the notation of O'Dell & Wen (1994). This designation system is based on the proplyds equatorial (J2000) coordinates. For example, the proplyd 231-739 has coordinates (α=5^h 35^m 23.123^s, δ=-5° 27^m 38.9"). The actual proplyd formation schemes (Henney & O'Dell 1999; HO99 hereafter and Bally et al. 1998a) propose that the proplyds in M 42 ($\sim$ 150; O'Dell & Wong 1996, Bally et al. 2000) are formed and detected due to the photoevaporation of the protoplanetary disk by the intense UV radiation of the external stars: Θ^1 Orionis C (mainly) and Θ^2 Orionis A. It is assumed that the protoplanetary disk is surrounded by a neutral envelope probably formed by a slow photodissociated wind from the disk. It is also assumed that an IF forms in this envelope and that the newly ionized gas flows away from the proplyd with an initial velocity v_0. Pressure gradients in the ionized gas accelerate the flow away from the IF. The amount of the acceleration depends on the type of the IF, being maximal when the flow leaving the IF surface is sonic (D-critical IF). The density in the ionized photoevaporated flow is highest at the point on the IF

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closest to the ionizing star, n_0, and decreases towards the sides. Assuming the flow to be isothermal and r_0 the radius of the IF at the point of maximum density, then the photoevaporated flow initial velocity, v_0, is related to the disk's photoevaporation mass-loss rate via the relation: $\dot{M} = 4\pi\ {r_0}^2\ v_0\ n_0\ m_I$ (where $m_I = 1.35\ m_H$) or $[\dot{M}/10^{-7}\ M_\odot\ \ yr^{-1}] = 0.44\ [r_0/10^{15}\ cm]^2\ [v_0/km\ s^{-1}]\ [n_0/cm^{-3}]$ and the life time, τ, of the protoplanetary disk is given by $\tau \sim M_{disk}/\dot{M}$ (Johnstone et al. 1998, HO99). Thus, to obtain the radial velocity profiles of proplyds is important because it allows us to constrain the photoevaporated flow velocity. This quantity gives us an estimate of the mass-loss rates of the protoplanetary disks and of the life time of those disks. The scheme described above is also presented by Henney & Arthur (1998), García-Arredondo et al. (2001), HO99, and is based on the photoevaporating flow models developed by Dyson (1968), Bertoldi (1989), Sargent (1996), Henney & Arthur (1998), and Johnstone et al. (1998).

The proplyds have $\dot{M}$ of 10^{-6} - 10^{-7} $M_\odot$ yr^{-1} (Churchwell et al. 1987, HO99), radial velocities of 24 to 30 km s^{-1} (HO99), diameters of 10^{-4} - 10^{-3} pc (O'Dell, 1998) and disk masses of 0.005 - 0.02 $M_\odot$ (Bally et al. 1998b, Johnstone et al. 1998). These values are estimated from extinction measures of the silhouette disks on the background HII region emission (Throop et al. 2001) or from CO milimetric observations of the thermal dust emission from their disks (Bally et al. 1998b).

2. ASTROBIOLOGICAL ASPECTS

Given that, in protoplanetary disks, planet formation can occur and, as a consequence, it is possible that the formation of life can also occur there, the interest in astrobiological studies of the proplyds stems from the fact that proplyds unveil the otherwise elusive protoplanetary disks. In this sense, proplyds are an important laboratory for determining, at high spatial resolution, several properties of the protoplanetary disks such as: masses, velocities and extensions. The proplyds are also useful in statistical studies on these issues. Furthermore, the protoplanetary disks revealed by the proplyds are subject to the strong UV flux of the exterior star that makes them visible. Thus, the photoevaporation of the protoplanetary disk of the proplyd could inhibit planet formation or change its conditions. Recent studies (Bally et al. 1998b, Throop et al. 2001) have shown that planet formation in irradiated protoplanetary disks as proplyds can only occur in special situations and conditions: disk mass $\geq 0.13\ M_\odot$ and dust (silicates+ices) particle radius $\geq 5\ \mu$m. The possibilities for a planetary system to form in M 42 are described by Throop et al. (2002). Furthermore, Throop et al. (2001) through Hα and Paα HST images, obtained an extintion curve of the biggest (in terms of disk size) proplyd 114-426 finding that a theoretical extinction curve dominated by dust grains $\geq$5 μm fitted the observations well. They also present 1.3 mm OVRO observations suggesting that the dust growth reaches radius values of a few mm, and developed a numerical model to explain the behavior and evolution of dust grains in proplyds irradiated externally including the photo-destruction process. With this, they have shown that after 10^5 yr, small grains are entrained in the photoevaporative flow resulting in disks with maximum sizes of 40 AU. In less than 10^5 yr, in disk masses as large as 0.2 $M_\odot$, the grain growth reaches a radius of meters at 10 AU from the YSO and of 1 mm at 500 AU from it. These sizes allow the dust to resist the photoevaporation process. By 10^6 yr, nearly all ice and gas are removed by photosputtering inhibiting the Kuiper belts formation and leaving only the possibility of rocky planet formation. Therefore, it is possible that in the environments of star forming places like M 42, Jupiter-like planets are not formed in the standard way because it would require 10^6 to 10^7 yr (Ruden 1999 and references therein). Such Jovian planets could be present if they form on 10^3 yrs time-scales (Boss 1997) for disk masses $\geq 0.13\ M_\odot$. Since a large proportion of the stars seems to be formed in large and dense clusters such as Orion, this leads to the conclusion that planet formation models should be revised in order to include the destructive effects of the UV flux of newly formed massive stars in star forming environments like Orion. The possibilities for planetary system to form in M 42 are described by Throop et al. (2002). The important parameter to determine the planet formation time scales is $\dot{M}$. Indeed, the typical values suggest a life time for the protoplanetary disks of 10^5 yrs and even shorter. This last indicate that in many of these proplyds, planet formation can not occurr.

3. FP OBSERVATIONS AND RESULTS

Scanning Fabry-Perot (FP) data cubes were obtained from November 30 to December 5, 1996 with the "PUMA" FP spectrograph (Rosado et al. 1995) at the f/7.5 Cassegrain focus of the 2.1m telescope of OAN-SPM (see Rosado et al. 2001). The data reduction was perfomed using the software CIGALE (Le Coarer et al. 1993). Knowing the systemic velocities and the radial velocity profiles of the proplyds we can compare the observations

TABLE 1

PIXEL POSITIONS IN OUR DATA CUBES, RADIAL VELOCITIES, MASS-LOSS RATES AND DISK LIFE TIMES OF 6 PROPLYDS

Proplyd Name	x (pix)	y (pix)	$\dot{M}$ (10^{-7} $M_\odot$)	V_{hel} (km s^{-1})	τ (10^4) yrs
168-326(LV1)	228	235	8	24	2.8
167-317(LV2)	231	218	13.8	30	1.7
163-317(LV3)	242	218	2.6	25	8.1
158-323(LV5)	254	228	7.94	25	1.2
158-327(LV6)	255	235	6.6	25	9.7
161-314	246	211	2	27	51

with the existing theoretical models in order to present arguments in favor of the existence of accretion disks in them, and study the behavior of the interaction between the photoevaporated material and the photoionizing winds. Also, from the determination of the velocity of the gas we can derive the $\dot{M}$ in combination with observations of the surface brightness in Hα (O'Dell 1998). As we can see in Figure 1 of de la Fuente et al. (2003 a, b), 16 proplyds were identified in M 42, 8 protrude from the nebular emission and 8 are brought out after application of an un-sharp masking technique. In Figure 1 we present radial velocity profiles for 6 proplyds. Other preliminary profiles are also presented in de la Fuente et al. (2003a). More detailed profiles are presented in de la Fuente at al. (2003b). From these profiles we measured heliocentric systemic velocities between 25-38 km s^{-1}. With the v_0 obtained by us (∼13 km s^{-1}) and taking n_0, r_0 and M_{disk} values from the literature (Henney & Arthur 1998, Johnstone et al. 1998), we estimated $\dot{M}$ to be between 10^{-6} to 10^{-7} $M_\odot$ yr $^{-1}$ and $\tau \sim 10^4$ yrs (except for 161-314) from our proplyds sample.

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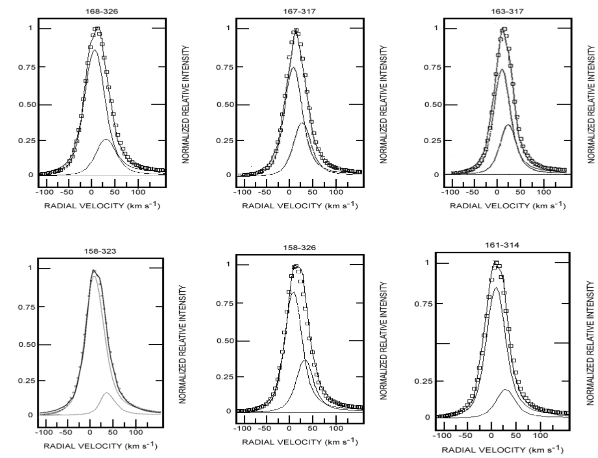

Fig. 1. Preliminary radial velocity profiles of proplyds 168-326, 167-317, 163-317, 158-323, 158-327 and 161-314 (brightest component). The squares represent the combined fit of two components: the brighter for the HII region and the fainter is related to the proplyd (to the right)

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