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A Herschel view of the photoevaporation and gas chemistry in PROPLYDS

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Proplyds (PROtoPLanetarY DiskS)

Proplyds are low-mass young stellar objects (YSOs) surrounded by Solar System-sized protoplanetary disks and found embedded within or near a HII region. They were first discovered in the Trapezium cluster (0.1-1 Myr, 400pc) in the Orion Nebula. The UV radiation from the OB stars evaporates the disk/envelope and creates their typical cometary morphology resolved in Hα, [OIII], [SII] and [NII] optical images from the *Hubble Space Telescope*. The photo-evaporation determines the mass-loss rate and hence the lifetime of the disks, which may result in severe constraints for planet formation.

Fig. 1

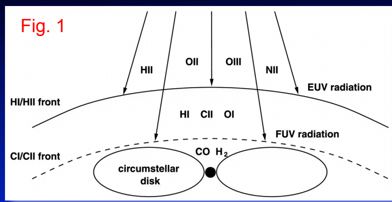


Figure 1: PDR structure in proplyds (Richling & Yorke 2000)

Motivation

The photo-evaporation flow results from the formation of a high-density (~ 10^6 cm^{-3}) photo-dissociation region or PDR (Fig.1) at the surface of the disk where FUV photons heat the gas. The cooling occurs by the emission of far-IR lines of atomic and molecular species such as [OI], [CII] and high-J CO. The [OI] and [CII] line intensity ratio is particularly sensitive to the density (in high UV and high density regime) of the atomic gas and the observation of several transitions in the CO ladder from (J=7-6) to (J=19-18) allow to severely constrain the temperature and the density of the warm molecular layer. These lines are observable with Herschel and hence the ideal tracers to understand the mechanisms at play in the dense and highly irradiated PDRs of proplyds.

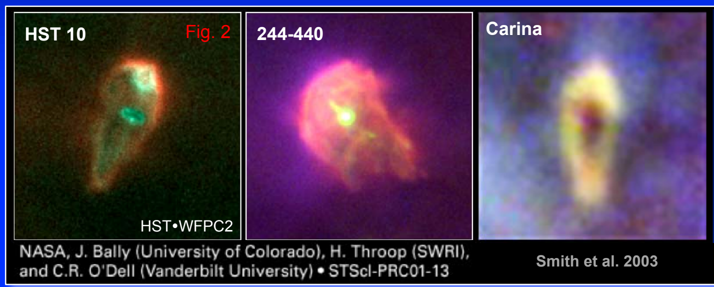
The sample

A sample of 3 proplyds (Fig. 2) from the Orion and Carina nebulae have been observed with PACS and HIFI as part of the open time program "A Herschel survey of PDRs in proplyds" (PI, Olivier Berné). In this poster we report the observational results and discuss them on basis of PDR models (Le Petit et al. 2006) and thermochemical models of protoplanetary disks (ProDiMo; Woitke et al. 2009, Kamp et al. 2010, Thi et al. 2011).

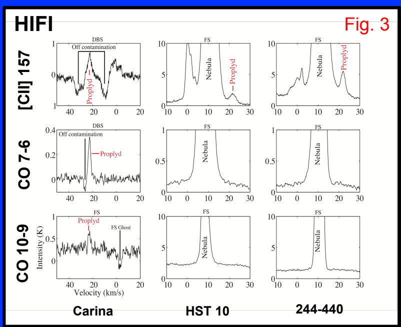
Table 1: Properties of the 3 selected proplyds

Object	Size	FUV field (G_0)	Distance (kpc)	$V_{helio.}$* ($km\,s^{-1}$)
HST 10	1.3 × 2.″7	3.0 × 10^5	0.4	26
244-440	5.6 × 6.″4	2.4 × 10^5	0.4	25
Carina proplyd	3.7 × 9.″5	2.2 × 10^4	2.3	–

* in [OI]6300, Henney & O'Dell 1999



Observational Results



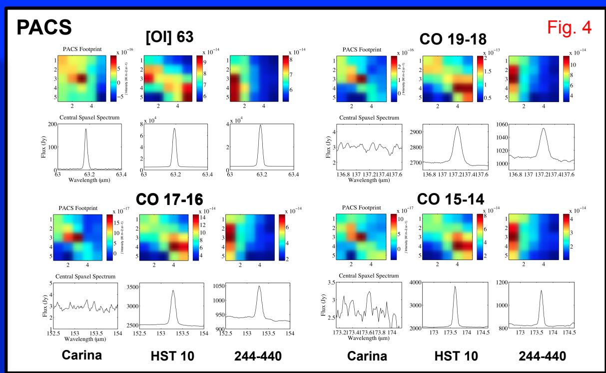
RESULTS

Carina proplyd:

- Detected in all HIFI lines but [CII]157 is contaminated by off nebula emission (Fig. 3)
- Detected at [OI]63 with PACS but no CO lines detected (Fig. 4)

Orion proplyds (10x smaller):

- Detected in [CII]157 but not CO(10-9) and CO(7-6) due to beam dilution (Fig. 3)
- No detections with PACS due to large contamination from the nebula and small proplyd sizes. (Fig. 4) Proplyds are not resolved spatially nor spectrally (strongest emission does not come from the central spaxel)



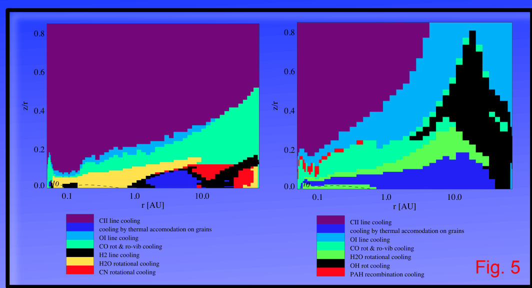
Meudon PDR model and ProDiMo disk model

ProDiMo thermo-chemical models can be used to interpret the Herschel observations of proplyds. The code provides as output the chemical abundances, disk radial profiles, the dominant heating and cooling mechanisms, and emission line profiles.

The external environment of HST10 was simulated with two disk halfs cut along the disk midplane. The upper-half was exposed to a strong FUV field while the lower-half to a typical ISM UV field. The input model parameters are in the table aside. The external irradiated disk shows stronger line fluxes in [OI] 63, [CII] 157 and CO (Fig. 4), which makes them good tracer species for proplyd disk structure and composition.

Stellar parameters	
M⋆	0.5 M⊙
L⋆	0.83 L⊙
Teff	3770 K
d_{Orion}	400 pc
Disk parameters	
R_{in}	0.05 AU
R_{out}	70.0 AU
ϵ	1.0
a_{min}	0.03 μm
a_{max}	$1 \times 10^5 \mu m$
$a_{power\ law}$	3.5
i	80°
β_{max}	50°
dust/gas	0.01
f_{PAH}	0.25
G_0(up)	2.4×10^4
G_0(down)	ISM

Figure 5: Illustrates the dominant cooling mechanisms for both cases. In the external irradiated disk (right graph) the [OI] line and OH rotational cooling are dominating over the [CII] line cooling which is most prominent in the ISM-irradiated case (left) graph.



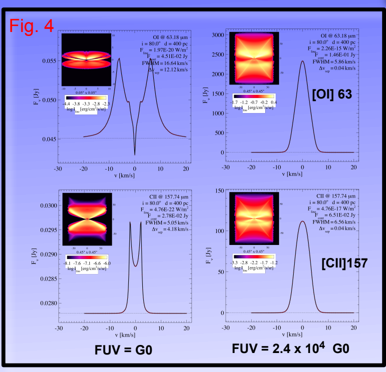


Figure 6: The disk model with high FUV predicts a [OI]63 μm flux of ~ 1E-15 Wm^{-2}, comparable to flux levels detected in young outflow sources.

In the Meudon PDR model we considered a density of 5 x 10^6 cm^{-2} typical for evaporating PDRs in disks (Gorti & Hollenbach 2009), a radiation field of 2 x 10^5 G0 , an ISM small grain distribution and an emission surface of 1.0 $arcsec^2$, which is conservative given the proplyd sizes in Table 1. The results are presented in Table 2.

Table 2: Results of the Meudon PDR and ProDiMo models

Instrument	Line	λ (μm)	Meudon ($W\,m^{-2}$)	ProDiMo (HST10) ($W\,m^{-2}$)	Observed (HST10) ($W\,m^{-2}$)
HIFI	[CII]	157	8.0E-18 (0.47 K km s^{-1})**	4.76E-17	4.0E-18
HIFI	CO (7-6)	368	5.2E-18 (0.8 K km s^{-1})*	–	–
HIFI	CO (10-9)	259	1.1E-17 (0.95 K km s^{-1})*	–	–
PACS	[OI]	63	1.5E-15	2.26E-15	< 6.0E-14
PACS	CO (15-14)	173	2.4E-17	–	–
PACS	CO (17-16)	153	3.0E-17	–	–
PACS	CO (19-18)	137	3.4E-17	–	–

* 1.″0 × 1.″0 emission diluted in HIFI beam
** 1.″3 × 2.″7 emission in HIFI beam since [CII] is more extended than CO

The computed intensity for the [OI]63 line is comparable in both PDR and ProDiMo disk models but fainter by an order of magnitude compared to the observed value in the central spaxel of the PACS detector for HST10. This is due to contamination from the Orion Nebula which is very bright in [OI].
The [CII]157 line emission from the PDR model agrees with the observed value in HST10 but it is overestimated by an order of magnitude in the ProDiMo disk model.

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