Origin and excitation mechanisms of the warm CO, OH, and CH⁺ in PDRs

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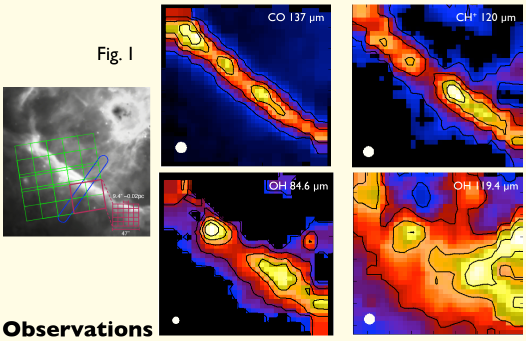
Introduction

Spatially resolved studies of photodissociation regions (PDRs), where physics and chemistry are driven by FUV photons, are essential in enabling us to understand the molecular cloud structure and characterize the physical and chemical processes that control the energetics in a region of active star formation. Our goal is to examine the spatial distribution of CO, CH^+, and OH as a function of the local conditions in the Orion Bar, one of the nearest nearly edge-on luminous PDRs. We are interested in the main excitation and formation processes of these key molecules and their dependencies on vibrationally excited H_2 and the strong UV radiation. The spatially resolved studies also give the possibility to examine the evolution of dense cores in the irradiated warm environment.

Fig. 1

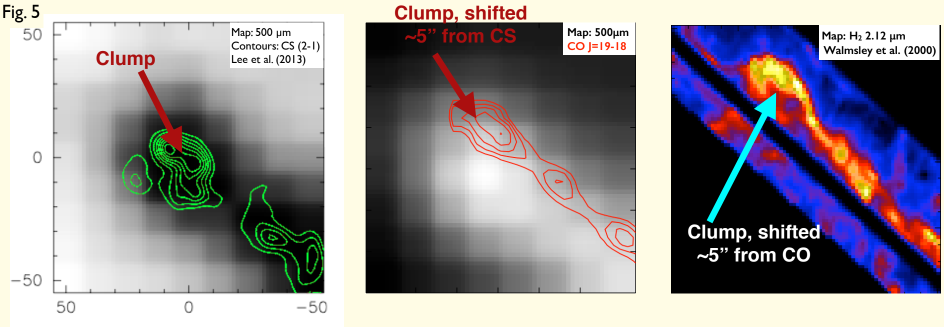


Observations

- Fully sampled observations with PACS: area of ~100"x100".
- Spatial resolution between 6" to 10" (0.01-0.02 pc)
- Targeted lines: CO J=19-18 (137 µm), CH^+ J=3-2 (120 µm, cube includes: OH 119 µm), and OH 84 µm (PACS)
- SPIRE observations on ^{12}CO (transitions: J=5-4 to J=13-12) and ^{13}CO (transitions: J=5-4 to J=11-10)
- HIFI observations on CH^+ J=2-1 (342 µm, strip marked in blue)

Spatial distribution of the warm CO

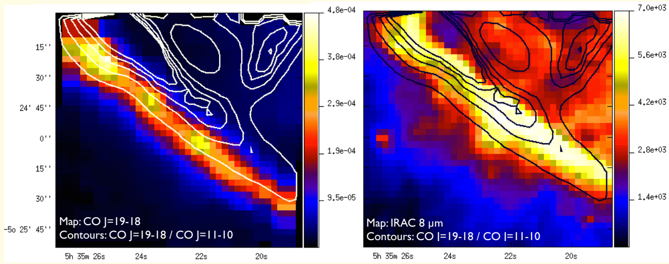
Fig. 5



The edge of CO J=19-18 emission agrees well with FUV-pumped excited H_2. Like excited H_2, high-J CO directly traces the irradiated dense structures.

The same clumps (10"-15") are seen in CS, tracing the densest part of the clump, and CO J=19-18 and excited H_2, tracing the edge of the dense clumps.

Fig. 6



Excitation of the warm CO

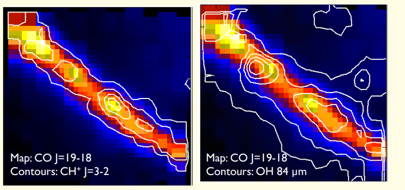
The excitation temperature is high at the PDR edge, where the PAH emission peaks due to UV heating. This puts strong constraints on the origin of the CO excitation: UV heating dominates.

Cosmic rays are excluded as a dominant heating mechanism as their effect would penetrate also inside the Bar.

CH⁺ and OH in the Orion Bar

CH^+ J= 3-2 and OH 85 µm have similar critical densities (~10^{10} cm^{-3}) and upper energy levels (~250 K) which make them ideal for comparison.

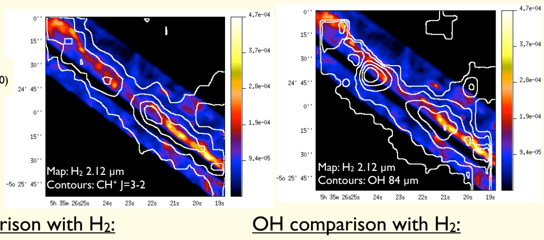
Fig. 2



CH^+ and OH are comparable to CO J=19-18 in spatial morphology. They trace the irradiated dense structures like the high-J CO. Thus, they originate in the clumpy structures of the Bar.

Fig. 3

H2 map: Walmsley et al. (2000)



<u>CH^+ comparison with H_2:</u>

CH^+ formation:
$H_2 + C^+ \Rightarrow H + CH^+$
(endothermicity: 4300 K)

To overcome the energy threshold to form CH^+, H_2 ro-vibrational energy can be used when available.

CH^+ correlation with H_2^* suggests that the formation process of CH^+ depends on H_2^* (in agreement with Lambert & Danks 1986, Agundez et. al 2010)

<u>CH^+ J=2-1 (HIFI) line width resolved observations</u>

CH^+ shows broader line width, ~3.5-4 km/s, than excited CO (HIFI <2.5 km/s). Since they spatially coincide, the different line width should be due to a specific excitation process.

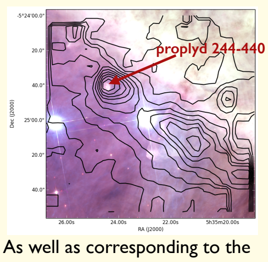
The line broadening results from the excess energy of the nascent CH^+, equivalent to 5360 K after reaction with vibrationally excited H_2, corresponding to a FWHM of Doppler motion of 4.4 km/s.

<u>OH comparison with H_2:</u>

OH formation:
$H_2 + O \Rightarrow H + OH$

The less good correlation between OH and H_2^* suggests that the formation process of OH is less dependent on H_2^* (in agreement with Agundez et. al 2010).

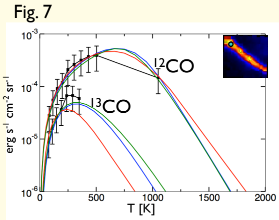
Fig. 4



As well as corresponding to the irradiated structures (Goicoechea et al. 2011), the OH emission seems to also correspond with a bright young object, identified as a proplyd.

Physical properties of the Orion Bar: cooling curve analysis

Fig. 7



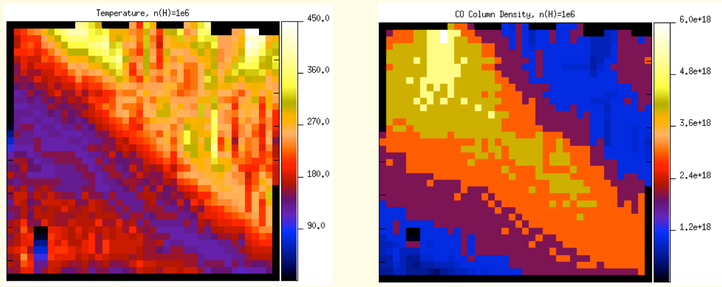
n [cm	N	T [K]	F	P [K cm	L [pc]	L ["]
1e5	1e19	230	0.3	2.3e7	0.58	230
1e6	4e18	160	0.4	1.6e8	0.026	13
1e7	4e18	120	0.5	1.2e9	0.003	1.3

Using RADEX we derive the gas temperature, CO column density, filling factor, thermal pressure, and the length of the Bar along the line-of-sight for each pixel in the map.

Comparing the length along the line-of-sight to the observed projected emission width (~20", see Fig. 1) of the excited CO, we determine that the gas density must be of the order of 10^6 cm^{-3}.

We use the ratio of CO J=19-18/CO J=11-10 and the ratio of CO J=8-7/^{13}CO J=8-7 to derive the temperature and CO column density in the whole mapped area assuming a uniform density of 10^6 cm^{-3}.

Fig. 8



Clear trends are shown in map: temperature is higher closer to the ionizing stars and decreases towards behind the Bar. The column density is higher in the Bar and lower in front and behind it.

Results

- High-J CO, OH and CH^+ trace the dense irradiate structures in the Orion Bar
- UV heating dominates the CO excitation
- CH^+ formation is dependent on the excited H_2
- Chemical pumping is important to CH^+ excitation
- OH emission also corresponds to a known proplyd in the region

Related poster: 2.02 - Jeronimo Bernard-Salas

<u>REFERENCES:</u>
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