# ISO-LWS GRATING SPECTROSCOPY: THE CASE OF R CrA STAR FORMING REGION

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**Abstract.** We present the far infrared spectra of the R CrA star forming region obtained with ISO-LWS. We collected a pointed observation on the Herbig Ae star R CrA and a raster scan covering the surrounding region, where HH100 (with its exciting source) and the pre-Main Sequence star T CrA are located. The [OI]63$\mu$m and the [CII]158$\mu$m lines have been detected in all the pointed positions, with a ratio consistent with PDR excitation. CO rotational lines (between $J_{up}$=14 and $J_{up}$=19) are detected on R CrA; from their intensities we derived, using a LVG model, the density and temperature of the emitting region. Other molecular transitions (OH and $H_2O$) have been detected on the investigated objects; the derived cooling of all the molecular species is in agreement with C-shock as the likely excitation mechanism. The continuum emission of R CrA peaks around 100$\mu$m (as expected for a Herbig star) while the other sources (T CrA, HH100) show increasing continua up to $\sim 200\mu$m, indicating that they are probably less evolved sources.

## 1. The R CrA region

The Corona Australis (CrA) molecular cloud is an active center of intermediate and low mass star formation (Graham 1991), located at high galactic latitude ($l$=0$^o$, $b$=-18$^o$) at a distance of $\sim$ 150 pc. It contains several pre-Main Sequence stars (S CrA, T CrA, TY CrA, VV CrA), some presumably less evolved objects (IRS 7, HH100IR) and manifestations of mass ejection (HH 98, HH99, HH100, HHs101, HHs104). The $^{12}$CO map (J=2$\rightarrow$1) (Levreault 1988) revealed a complex structure explained with a superposition of two separate bipolar outflows: a strong compact one, E-W oriented, centered on the deeply embedded source IRS 7 (Anderson et al. 1997), and a more extended one centered on the source HH100-IR (Strom et al. 1974).

## 2. Observations and Results

We observed the R CrA region with the LWS set in grating mode (wavelength range 43 - 196.7 $\mu$m, R $\sim$ 200, FOV $\sim$ 80", oversampling of 4 of the resolution element). We pointed R CrA itself and made a 3×1 raster map covering T CrA, HH100 and an *off* position.

Table 1. **Observed line intensities**

| $\lambda$ (obs.) ($\mu m$) | Line ident. | R CrA | T CrA | HH100 | off |
|---|---|---|---|---|---|
| | | F$\pm\Delta$F$^{\dagger}$ ($10^{-19}$ $Wcm^{-2}$) | | | |
| 63.2 | [OI] $^3P_2 \rightarrow ^3P_1$ | 58 ± 1 | 19 ± 1 | 9.4 ± 0.4 | 2.1 ± 0.3 |
| 71.2 | OH $^2\Pi_{1/2,J=7/2} \rightarrow ^2\Pi_{1/2,J=5/2}$ | <2.4 | 1.7± 0.5 | - | - |
| 79.2 | OH $^2\Pi_{1/2,J=1/2} \rightarrow ^2\Pi_{3/2,J=3/2}$ | 4 ± 1 | - | <1.1 | - |
| 84.6 | OH $^2\Pi_{3/2,J=7/2} \rightarrow ^2\Pi_{3/2,J=5/2}$ | 9 ± 2 | - | <1.3 | |
| 99.5 | o-$H_2O$ $5_{05} \rightarrow 4_{14}$ | - | 1.8 ± 0.5 | - | - |
| 137.2 | CO 19→18 | 4 ± 1 | - | - | - |
| 144.8 | CO 18→17 | <6.8* | - | - | - |
| 145.5 | [OI] $^3P_1 \rightarrow ^3P_0$ | <4.3* | 2.4 ± 0.7 | < 1.6 | 0.3±0.1 |
| 153.2 | CO 17→16 | 5.8 ± 0.9 | 4 ± 1 | 1.8 ± 0.6 | <0.3 |
| 157.7 | [CII] $^2P_{1/2} \rightarrow ^2P_{3/2}$ | 3 ± 1 | 4 ±1 | 2.3 ± 0.9 | 0.7±0.1 |
| 162.8 | CO 16→15 | 6.4 ± 0.9 | <2.3 | 2.5±0.5* | 0.39±0.07 |
| 163.4 | OH $^2\Pi_{1/2,J=3/2} \rightarrow ^2\Pi_{1/2,J=1/2}$ | - | - | 2.0±0.5* | - |
| 173.7 | CO 15→14 | 5.8 ± 0.6 | 2.5 ± 0.6 | 1.9 ±0.3 | - |
| 174.7 | o-$H_2O$ $3_{03} - 2_{12}$ | - | - | <1.2 | - |
| 179.6 | o-$H_2O$ $2_{12} - 1_{01}$ | - | 2.1 ± 0.4 | - | - |
| 186.0 | CO 14→13 | 4.6 ± 0.6 | <1.2 | - | - |

Notes: $^{\dagger}$ 1$\sigma$ statistical error, * lines deblended with a two gaussian fit.

The identified transitions and the corresponding integrated intensities are listed in Table 1. The [OI] and [CII] lines are detected in all the pointed positions, while the molecular emission is dominated by the CO rotational lines along with the OH and $H_2O$ transitions.

## 3. Line Diagnostics

In Figure 1a the observed line intensities ratios of [OI]63$\mu$m/[OI]145$\mu$m *vs.* [OI]63$\mu$m/[CII]158$\mu$m are superposed to PDR emission models for different values of density and interstellar fields strengths (Luhman M., private communication).The line intensities result from ON-OFF subtraction and their ratios indicate that the emission is consistent with a PDR mechanism; R CrA is associated with a density higher than the other objects in the region. PDR emission is also supported by comparing $\dot{M}_{CO}$, derived from the literature, with $\dot{M}_{[OI]}$, *i.e.* the mass loss derived assuming that all the OI emission is shock excited (Hollenbach 1985) (Table 2). In all objects $\dot{M}_{[OI]}$ is sistematically larger than $\dot{M}_{CO}$, indicating a probable excess of [OI] emission due to PDR.

We have modelled the CO lines observed in the R CrA by using a large velocity gradient (LVG) code in the plane-parallel geometry (Nisini et al. this issue). Figure 1b shows the CO fluxes as a function of the rotational quantum number $J_{up}$. The dashed and solid lines give the range of the possible model fits

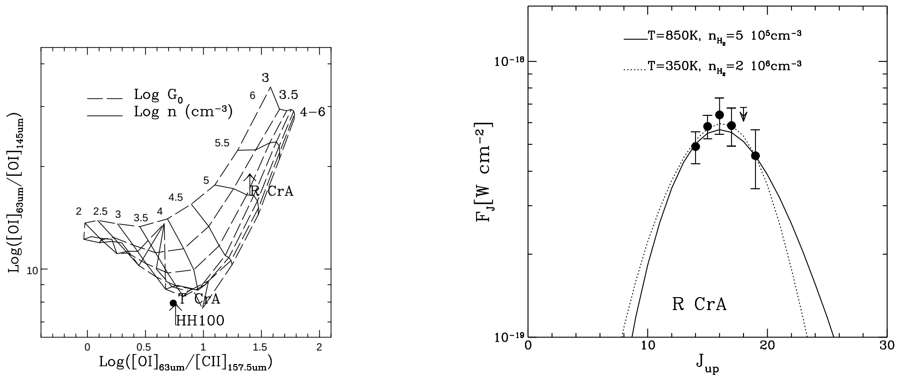


Figure 1. a) Observed line ratios superposed to PDR models. The arrows indicate $3\sigma$ upper limits. b) CO line fluxes observed by LWS in R CrA *vs.* $J_{up}$. The lines give the possible fits through the data.

to the data and the relative parameters are indicated. Although we observe only few CO transitions, they seem to trace the peak of the distribution, allowing a stringent constraint to the parameters. The possible ranges of temperature and density are T=350 $\div$ 850 K and $n_{H_2} = 2\times10^6 \div 5\times10^5$ cm$^{-3}$. For the low temperature model we derived a CO column density of 6 $\times10^{18}$ cm$^{-2}$ and an emitting region of 5 $\div$ 6 arcsec.

To recognize the mechanism responsible for the molecular emission we plot in Figure 2a the luminosity ratio of OI/CO and CO/OH as a function of the density for different shock velocities, according to the model of Draine et al.(1983). Both ratios indicate that the C-shock is likely the mechanism for molecular line excitation. The ratio L(OI)/L(CO) (top panel) is overestimated because of a possible contribution from PDR emission, not taken in account in the model. In the case of R CrA the indication of a post-shock density $n_{post-shock} \sim 10^6$ cm$^{-3}$ (by the CO LVG model) allows to derive a shock velocity 20 $\div$ 40 Km s$^{-1}$, assuming a shock compression factor $n_{post-shock}/n_{pre-shock} \sim$ 10-100.

Table 2. **Derived PDR Parameters**

| Source | Density ($cm^{-3}$) | Field ($G_o$) | $\dot{M}$ ([OI] 63 $\mu$m) ($M_\odot yr^{-1}$) | $\dot{M}$ (CO) ($M_\odot yr^{-1}$) |
|---|---|---|---|---|
| R CrA | $>10^5$ | $< 10^4$ | 3.8 $10^{-6}$ | 3.8 $10^{-7}$ |
| T CrA | 3 $10^3 \div 10^4$ | $\sim 10^4$ | 1.2 $10^{-6}$ | 3.8 $10^{-7}$ |
| HH 100 | $>$3 $10^3$ | $< 10^4$ | 5.0 $10^{-7}$ | 1.4 $10^{-7}$ |

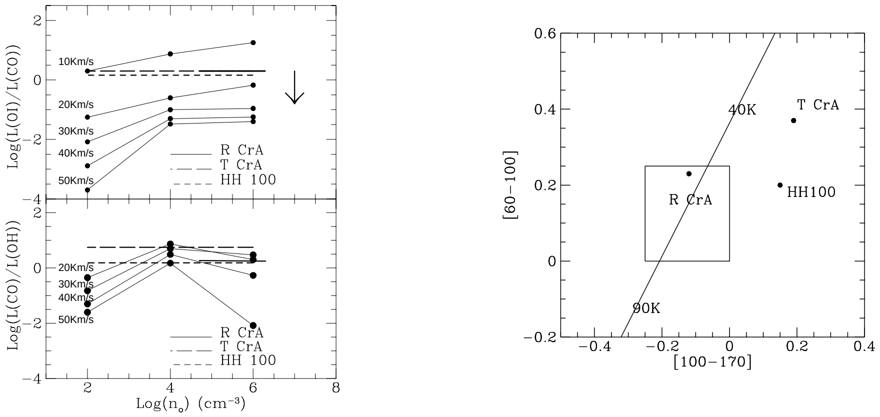


Figure 2. a) Luminosity ratios of OI/CO and CO/OH compared with **C-shock** models. b) ISO two colours diagram.

## 4. The continuum data

In Table 3 the flux densities of R CrA, T CrA and HH100 at 60, 100 and 170 $\mu$m (and the relative colours) are reported. As expected for a Herbig star, the continuum of R CrA peaks around 100 $\mu$m, while the other objects peak at longer wavelengths, thus revealing an ealier stage of evolution.

Table 3. **FIR flux densities and ISO colours**

| Source | Flux (60$\mu$m) | Flux (100$\mu$m) (Jy) | Flux (170$\mu$m) | [60-100] | [100-170] |
|---|---|---|---|---|---|
| R CrA | 729 | 1227 | 937 | 0.23 | -0.12 |
| T CrA | 190 | 300 | 427 | 0.20 | 0.19 |
| HH 100 | 151 | 353 | 546 | 0.37 | 0.15 |

In Figure 2b an ISO two colours diagram is given. The temperatures of different blackbodies (BBs) are reported as a solid line, while the square indicates the locus of the Herbig stars (Tommasi et al., this issue). We note that the R CrA colours are consistent with an envelope of T$\sim$ 50K, while the other observed colours are not fitted with a single BB, but at least two thermal components are required.

## References

Anderson I.M., Harju J., Knee L.B.G., Haikala L.K. 1997, A&A, 321, 575

Draine B.T., Roberge W.G., Dalgarno A. 1983, ApJ, 264, 485

Graham J.A. 1991, ESO Report N.11,Reipurth B. (ed.), pp 185-196

Hollenbach D.J. 1985, Icarus, 61, 36

Levreault R.M. 1988, ApJS, 67, 283

Strom K.M., Strom S.E., Grasdalen G.L. 1974, ApJ, 187, 83