A science case for velocity-resolved mid-J CO and ^{13}CO and [NII]

Yoko Okada[1], Volker Ossenkopf-Okada[1], Markus Röllig[1], Robert Simon[1], Jürgen Stutzki[1]
[1]Universität zu Köln

SFB 956 Cologne | Bonn

Introduction

We present a science case for AtLAST being built on Cerro Chajnantor. The location at the high site enables us to perform more efficient observations at frequencies above 490GHz, in particular of CO(4-3), (6-5), (7-6), (8-7), ^{13}CO(6-5), ^{13}CO(8-7), and [CI] 492GHz and 809GHz compared to the ALMA plateau (Fig. 1) . Under best weather conditions, the higher altitude location will open up the possibility to observe up to CO(13-12) and to access [NII] at 205µm.

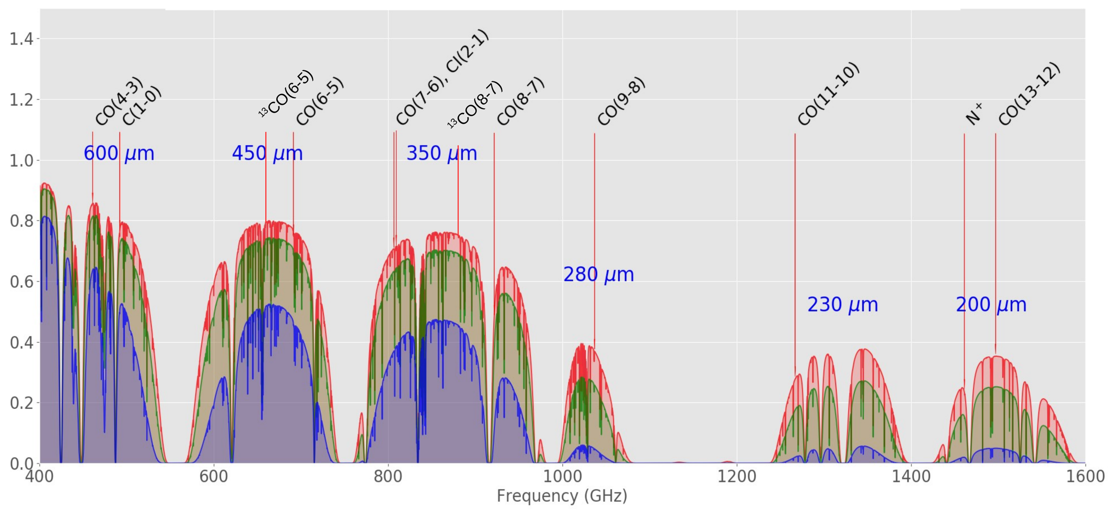

FIGURE 1: Atmospheric transmission at the ALMA and the high site of Cerro Chajnantor. Blue is for pwv of 0.6 mm (ALMA 25%), green is for pwv of 0.28 mm (Chajnantor 25%), and red is for pwv of 0.2 mm (Chajnantor 10%).

Shock or PDR?

In many photon-dominated regions (PDRs) strong mid-J CO emission is observed and the contribution of shocks to these lines is often debated. Plane-parallel PDR models fail to reproduce them, frequently leading to the conclusion of a shock contribution. On the other hand, clumpy PDR models predict a flatter CO ladder in agreement with observations (Fig. 2)

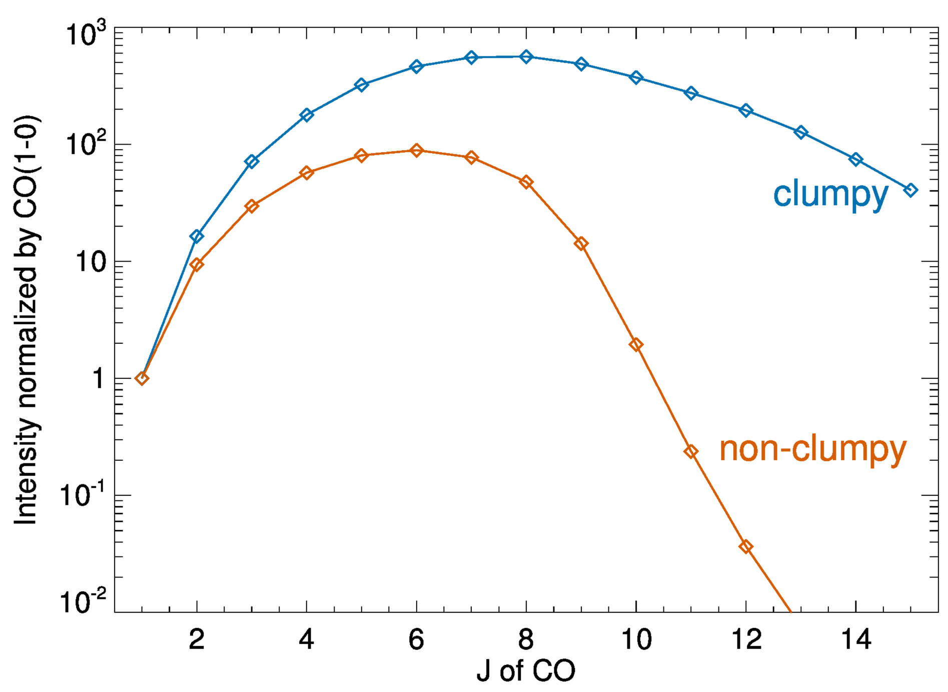

FIGURE 2: CO-ladder calculated by KOSMA-τ PDR model (Röllig et al. 2013) with a mean density (n) of 10^4 cm^{-3}, an UV field (χ) of 10^3 Draine units, and the total mass (m) of 10^2 M_{solar} for the LMC. The red line shows the model of single clump, the blue line is the model of clump ensemble with a mass range of 10^{-3} to 10 M_{solar}.

The velocity profile of the mid-J CO lines provides a critical information on their origin. Moreover, the optically thin mid-J ^{13}CO lines can be useful to disentangle optical depth and excitation effects.

References

Lee et al. 2016, A&A 596, A85
Okada et al. 2015, A&A, 580, A54
Okada et al. 2018, in prep.
Röllig et al. 2013, A&A 549, A85

Example case - LMC/N159

In the N159 star-forming region in the Large Magellanic Cloud (LMC), PDR models can reproduce most of the CO, ^{13}CO, [CI], [CII], [OI], and the continuum intensities, but some line intensities cannot be matched simultaneously. Lee et al. (2016) model the FIR fine structure lines by a PDR model and the CO emission by low-velocity shocks. Okada et al. (2018) model the optically thin emissions (^{13}CO, [CI] and [OI] 145µm) with a clumpy PDR model and attribute the model overestimate for CO, [CII] and [OI] 63 µm to the optical depth between clumps.
On one hand, the similar velocity profiles between CO and [CI] emissions used in Okada et al. favor a common origin. On the other hand, the flat CO ladder beyond CO(10-9) shown in Lee et al. (observed by Herschel/SPIRE, not velocity-resolved) cannot be reproduced by the PDR model that Okada et al. propose. Velocity-resolved high-J CO lines are critical to resolve the contradiction.

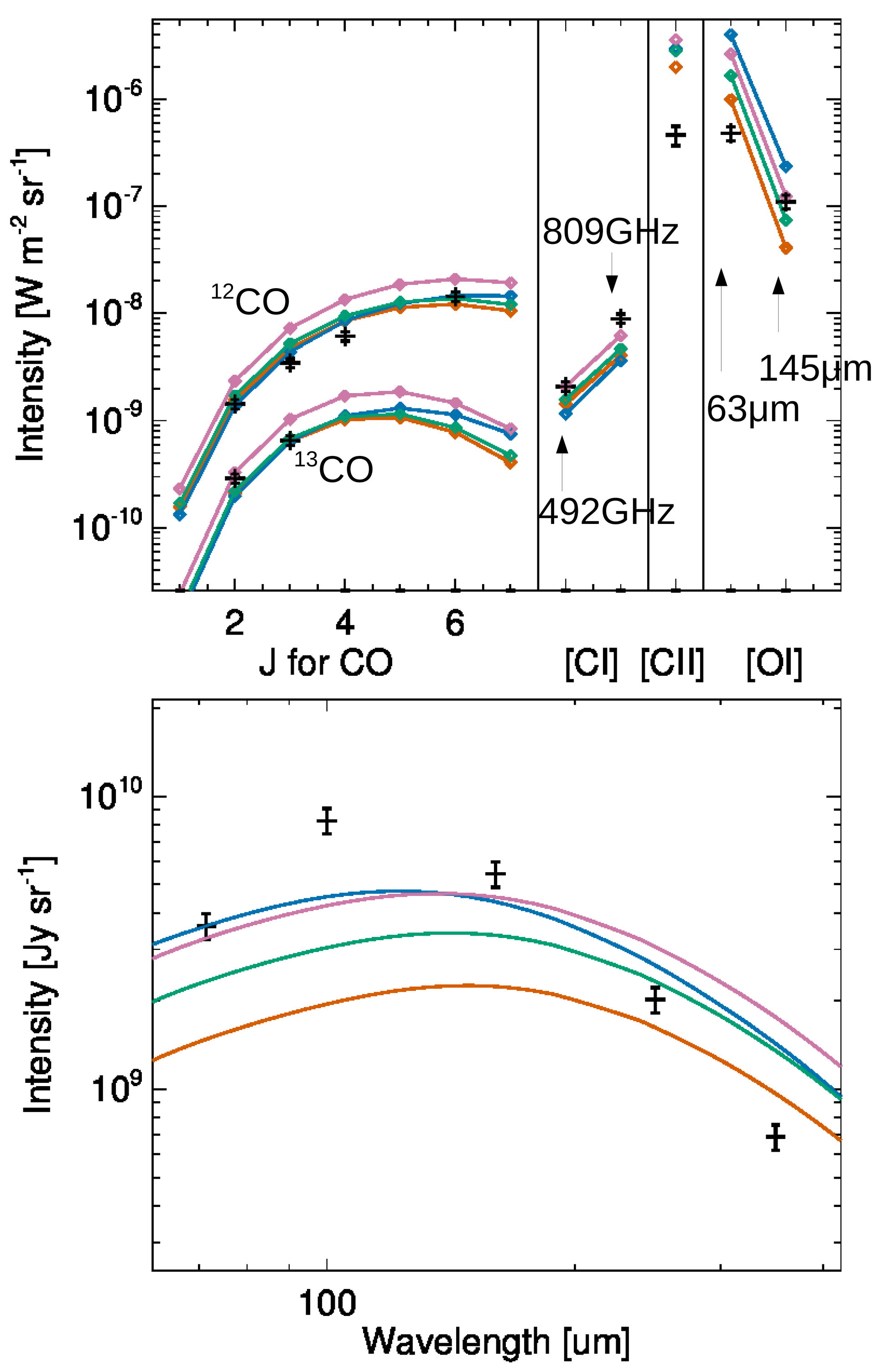

FIGURE 3: Result of fitting line and continuum emission at the CO peaks in N159W in 30" resolution. Black data points are the observed data and colors are the models (see the table below). The top panel is the line SED, the bottom panel is the continuum SEDs. The red line shows the fit without continuum. The blue line presetents the fit without [OI] lines. The pink line is the fit with only optically thin lines, The green line shows the fit with all lines and continuum.

model in Fig. 3	log(n)	log(m)	log(UV)
red (w/o continuum)	3.5	4.9	1.3
blue (w/o [O I])	3.7	4.9	1.8
redpurple (thin)	3.6	5.1	1.5
green (all)	3.5	5.0	1.4

TABLE 1: The derived physical parameters (mean density, total mass, the UV field strength) of the fits in Fig. 3.

Ionized gas contribution to the [CII] emission

The [CII] 158µm emission line is one of the dominant cooling lines in PDRs, but it can originate in the ionized gas as well. To estimate the ionized gas contribution to [CII], the velocity-revolved [NII] 205µm is a useful tool. Since the second ionization potential of N and C is close (29.6 eV and 24.4 eV), and the critical density for collisions with electrons is low (180 cm^{-3} and 40 cm^{-3} for the [NII] 205µm and [CII] 158µm, respectively), both lines are emitted from the same gas in ionized regions. The [NII] 205µm / [CII] 158µm ratio is relatively constant, independent of the electron density.
With velocity-resolved [NII] 205µm observations, we can subtract the ionized gas contribution in the spectrum of the observed [CII] emission.

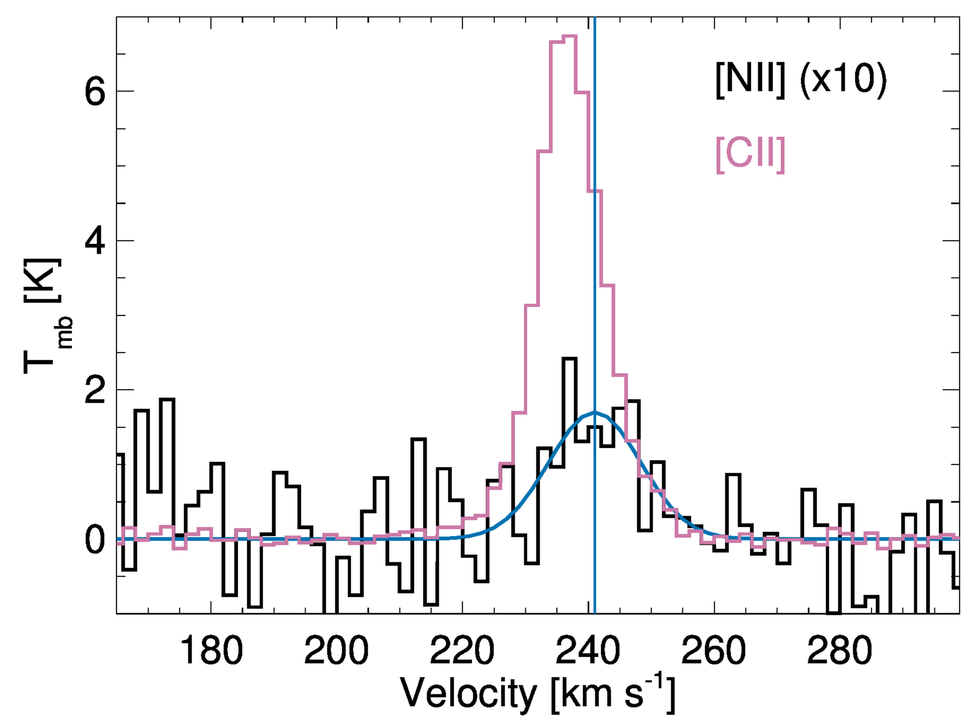

FIGURE 4: [CII] (purple) and [NII] (black, scaled by 10) spectra in N159 (Okada et al. 2015). The blue line shows the result of a single Gaussian fit to the [NII] emission. Its center is indicated as a vertical line.

Conclusions

A large single dish telescope on Cerro Chajnantor serves an important science case in PDR studies.

- Velocity resolved mid-J CO spectra are useful to distinguish their origin (PDR or shock) by comparing their line profiles with those of the low-J CO and fine structure lines.
- Optically thin mid-J ^{13}CO lines are needed to disentangle optical depth and excitation effects.
- The velocity-resolved [NII] 205µm can be used to distinguish the ionized gas contribution in the spectrum of the [CII] 158µm.
- The ratio of two [CI] lines gives a good estimate of the gas temperature.

It also provides the following synergy with interferometric observations.

- With a flexible operation, the bad weather can be used to complement interferometric observations at low frequencies (< 400 GHz) by zero-spacing observations.
- When comparing mapping observations by a single dish telescope at different frequencies, it is always required to convolve all data to the worst spatial resolution. We can reduce this loss of resolution if we combine interferometric observations at lower frequencies with high angular resolution mapping observations by a large single dish telescope at high frequencies that ALMA cannot cover. This is especially important for nearby galaxy studies.

This work is partly carried out within the Collaborative Research Centre 956, funded by the Deutsche Forschungsgemeinschaft (DFG).