A sensitive spectral survey of Orion KL at wavelengths between 6 and 7 mm

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About Orion KL

The Orion KL source has been widely recognized as a close and well-known star-forming region, and one of the richest molecular reservoirs known in our Galaxy.

It hosts newly formed protostars, with strong interaction between outflows and their outskirts. It results in a series of complex chemical processes currently carrying out. Indeed, this is the site where many molecular species have been discovered for the first time (see e. g. the methyl acetate in Tercero et al. 2013).

In a very small volume, it is possible to identify at least four well-known components in this source: a hot core, a compact ridge, and a plateau, all of them immersed within the ambient cloud (the extended ridge).

The Orion KL region is therefore an excellent testbed for the search of new molecules and also for the characterization of those already known.

In recent years a series of spectral surveys have been conducted in this source in spectral ranges from 1 to 3 mm. The 6 to 8 mm window, however, remains almost unexplored; the most complete survey up to date is that of Goddi et al (2009), which only covers the frequency range from 42.3 to 43.6 GHz.

The spectral range from 6 to 8 mm of wavelength is potentially reach in several complex organic molecules, and also host several transitions from molecules identified in 3 mm, at lower energy levels. It is also remarkable the presence of a number SiO masers and RRLs.

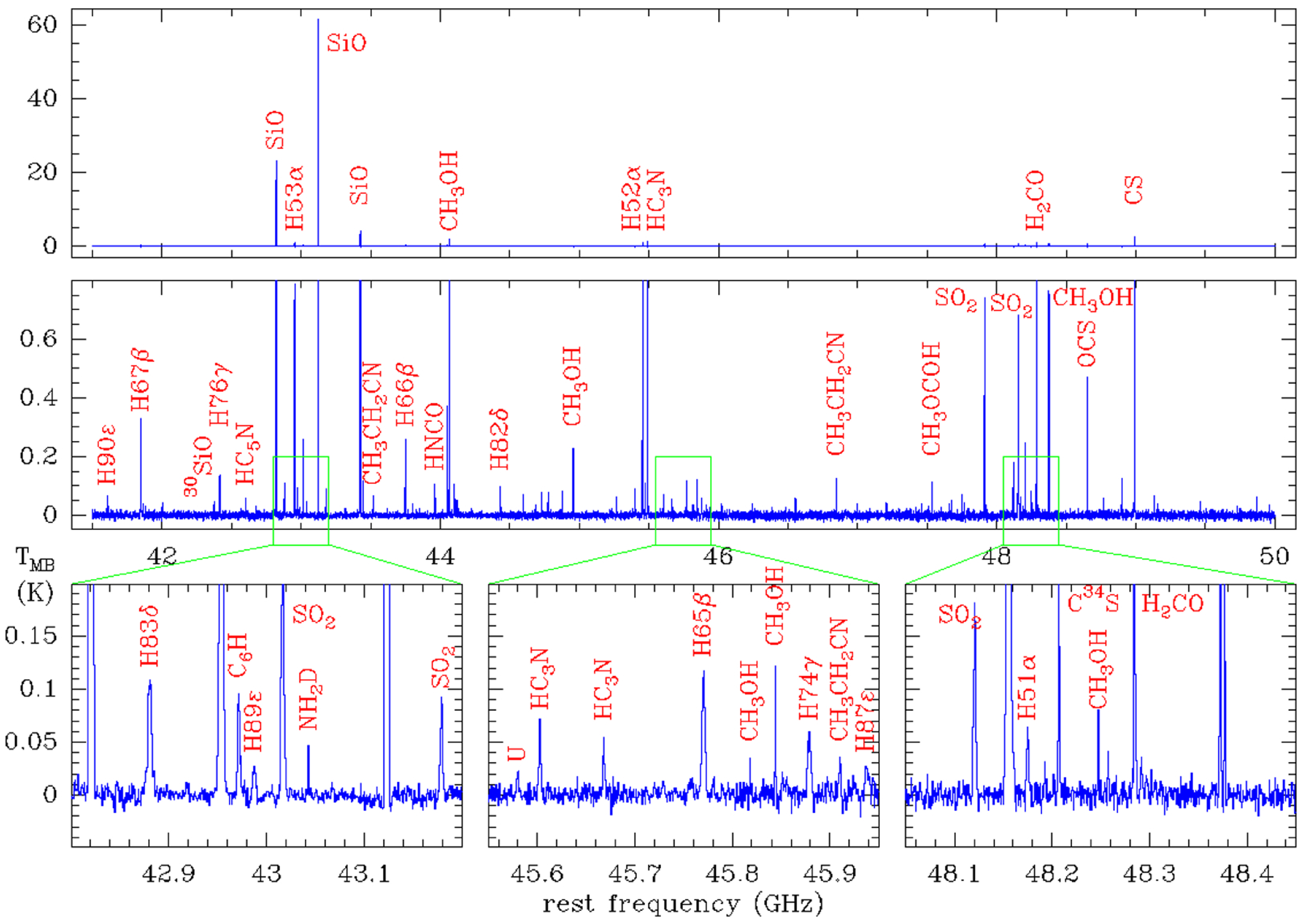
The survey

We used the DSS-54 antenna, one of the 34m dishes available at the NASA's Madrid Deep Space Communications complex, to complete a sensitive spectral survey of Orion KL, in the frequency range from 41.5 to 50.0 GHz. The observations were done in different runs from December 2013 to February 2014.

We used the new Q-band cooled receiver, which has an approximate temperature of 40K. The backend employed was the new wideband backend (Rizzo et al. 2012), which provides 1.5 GHz of instantaneous bandwidth, with a resolution of 180 kHz, for each circular polarization.

The survey was conducted in position switching mode in six sub-bands, with a superposition of 100 MHz between two consecutive sub-bands, in order to check consistency and eliminate possible image band effects.

Total integration time was 1490 minutes (on source). For each sub-band the integration time varied from 97 to 422 minutes, in order to keep a uniform rms of about 6 mK, on a main beam scale.



Results

The figure on the left shows the resulting spectrum. The upper panel displays the full range both in frequency and in intensity. We see that the 6-7mm spectrum is dominated by the emission of SiO masers and RRLs; some simple molecules (CS, H_2CO, HC_3N, methanol) also appear, tracers of low density and cold gas.

The middle panel depicts a zoom in intensity, where it is possible to distinguish a number of other, more complex molecules, particularly SO2, CH_3CH_2CN, and CH_3OCOH, and OCS. As we see in the model, these molecules are associated to the hotter parts of the region.

The three lower panels are small spectral windows (indicated in green in the middle panel) which display the richness of spectral lines, as well as the varied morphology. More than 200 spectral lines have been identified, corresponding to 39 species.

The model

Most of the lines have been identified which correspond with abundant molecules detected previously in this region (Blake et al. 1987, Sutton et al. 1995, Schilke et al. 2001, Goddi et al. 2009, Tercero et al. 2010, 2011). In addition, a total of 21 lines remain unidentified (U-lines) over the 5-sigma threshold.

The figure on the right depict two selected windows, in order to illustrate the results of the modeling. The observed spectrum (smoothed to 500 kHz) is shown in blue, while the model is shown in red.

In the upper panel, from 44.7 to 44.9 GHz, the spectrum is dominated by CH_3CH_2CN lines, of different vibrational states. On the other hand, the lower panel displays a variety of molecular species, including a CH_3OH maser and an U-line.

A total of 250 lines have been identified. Besides the RRLs, these lines correspond to 20 different molecules -39 species when considered different isotopologues and vibrational states-. Neither the SiO species (due to the maser effects) nor H and He RRLs have been introduced in this model.

We used the MADEX code (Cernicharo, 2012) which solves simultaneously the radiative transfer and the statistical equilibrium equations in both LTE and non-LTE approximations for 1107 families of molecules (5020 species in total). We initially assumed the physical parameters found in the cloud (T_k, n(H_2), d_sou, v_LSR, and Delta_v) according with either the typical values found in the literature or our previous analysis of the lines by Gaussian fits to the line profiles, rotational diagrams, and maps performed with the data of the 2D-survey of Orion KL (Marcelino et al. in preparation).

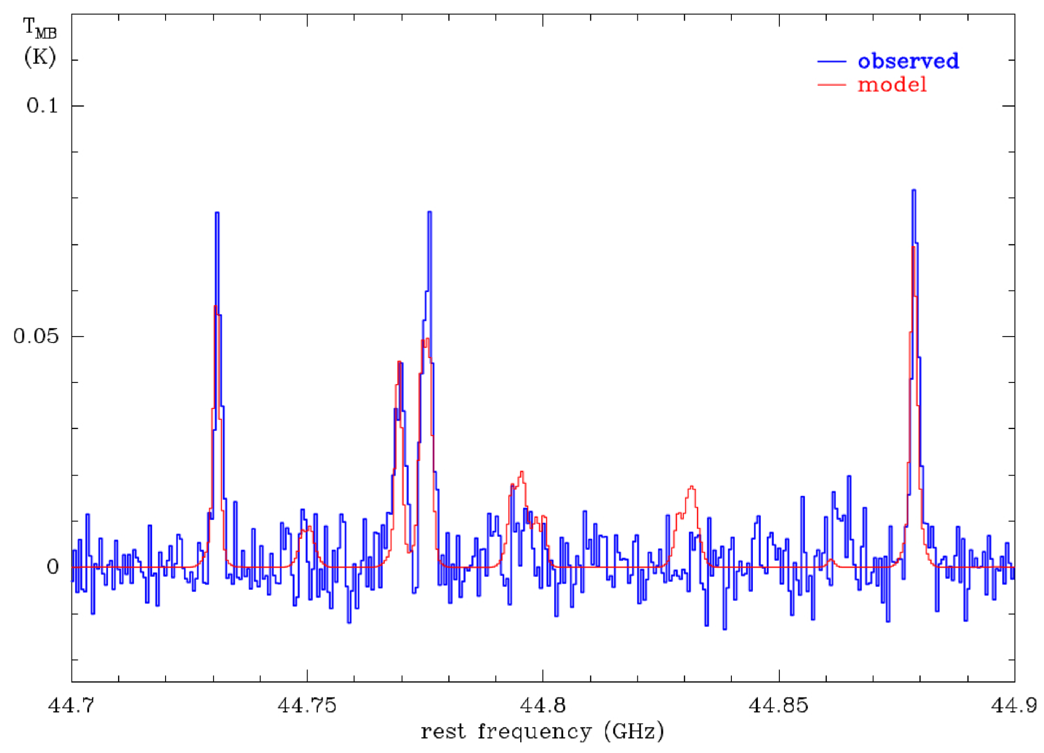
The 7mm model is also based on the result of the fitting of some species at 3, 2, and 1.3 mm, detected in a recent survey using the IRAM 30m radio telescope (Tercero et al. 2010, Daly et al. 2013, Esplugues et al. 2013, López et al. 2014). These species are CH_3CH_2CN, CH_2CHCN, $^{34}SO_2$, $^{33}SO_2$, and HCS^+.

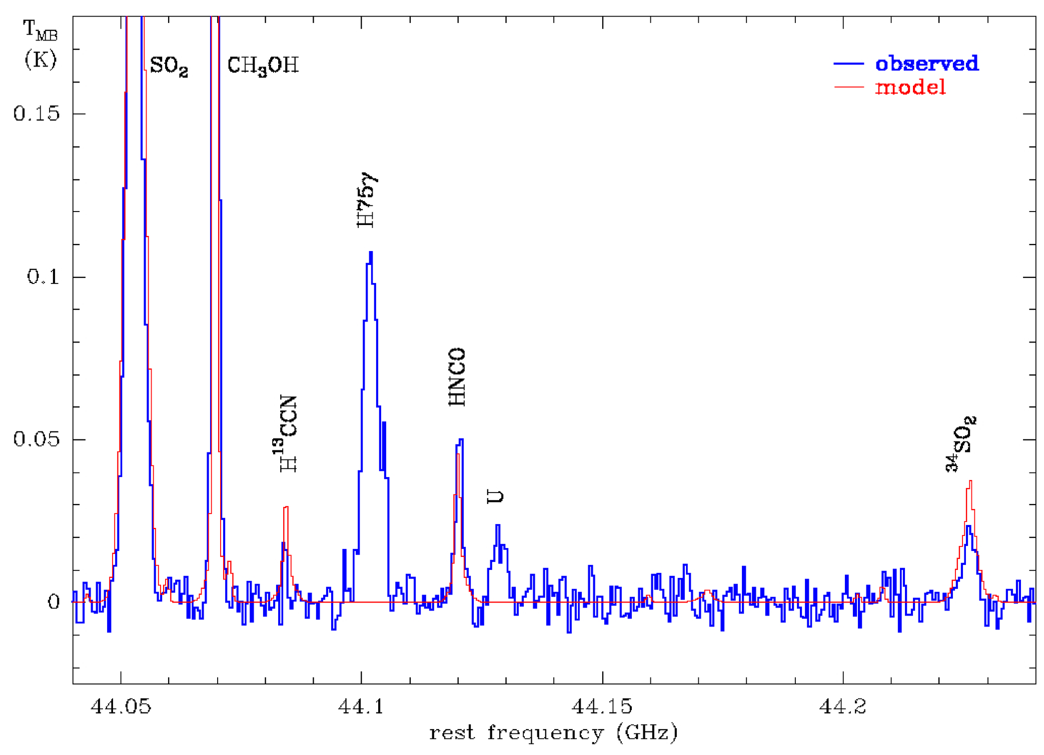
All these species, except HCS^+, mainly emit from the hottest component of this source (the hot core, at T_k ~ 250 K). We also noted a significant lack of emission from the coldest region (the extended ridge, at ~ 40-60 K).

For other molecules (SO_2, $^{13}CH_3OH$, HC_3N, HC_5N, OCS, CS, NH_2CHO, and CH_3OCH_3), we had to adapt existing models (Esplugues et al. 2013a, Kolesniková et al. 2014, Esplugues et al. 2013b, Tercero et al. 2010, Montiyenko et al. 2012) or even build new ones in order to properly fit the observed lines. We have performed new models for the remaining species.

Table 1: Physical properties of the Orion KL components.

Componet	Extended ridge	Cold compact ridge	Hot Compact ridge	Plateau	Hot core
d_{source} (")	120	15	7	30	10 5
T_k (K)	40 60	110	300	150	90 300
n(H_2) (cm^{-3})	1×10^5	1×10^6	1×10^7	1×10^6	5×10^7
Δv_{FWHM} ($km\,s^{-1}$)	4	4	4	25	5 10
v_{LSR} ($km\,s^{-1}$)	8 9	7.5	7.5	6	5.5





Concluding remarks

A survey of the Orion KL region, in the almost unexplored range from 6 to 7 mm in wavelenghts, has been finished. The high sensitivity of the spectral survey (6 mK), allows the identification of more than 250 transitions from 20 molecules. The total number of molecular species, after considering different isotopologues and vibrationally excited cases, grows up to 39.

The spectrum has been modeled by computing the emission of most of the detected molecules. RRLs and SiO masers have not been included. The model is based on results previously gathered in similar surveys at 1, 2, and 3 mm.

Some complex organic molecules, such as CH_3CH_2CH and CH_2CHCN, arise from the hot core; CH_3OHCHO and CH_3NH_2 are probably in the same group, but are close to the detection limit.

Most of the other molecules seem to arise from the coldest parts of the source, with surprisingly high column densities.

21 spectral lines remain unidentified (U-lines).

Therefore, the range from 6 to 7 mm (Q-band) is a valuable electromagnetic window tu pursue chemical studies which complement those at higher frequencies.

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