# Hunting for the Origins of Oxygen-bearing Complex Organic Molecules with Orion

# Olivia H. Wilkins<sup>1</sup>, P. Brandon Carroll<sup>2</sup>, Geoffrey A. Blake<sup>1,3</sup>

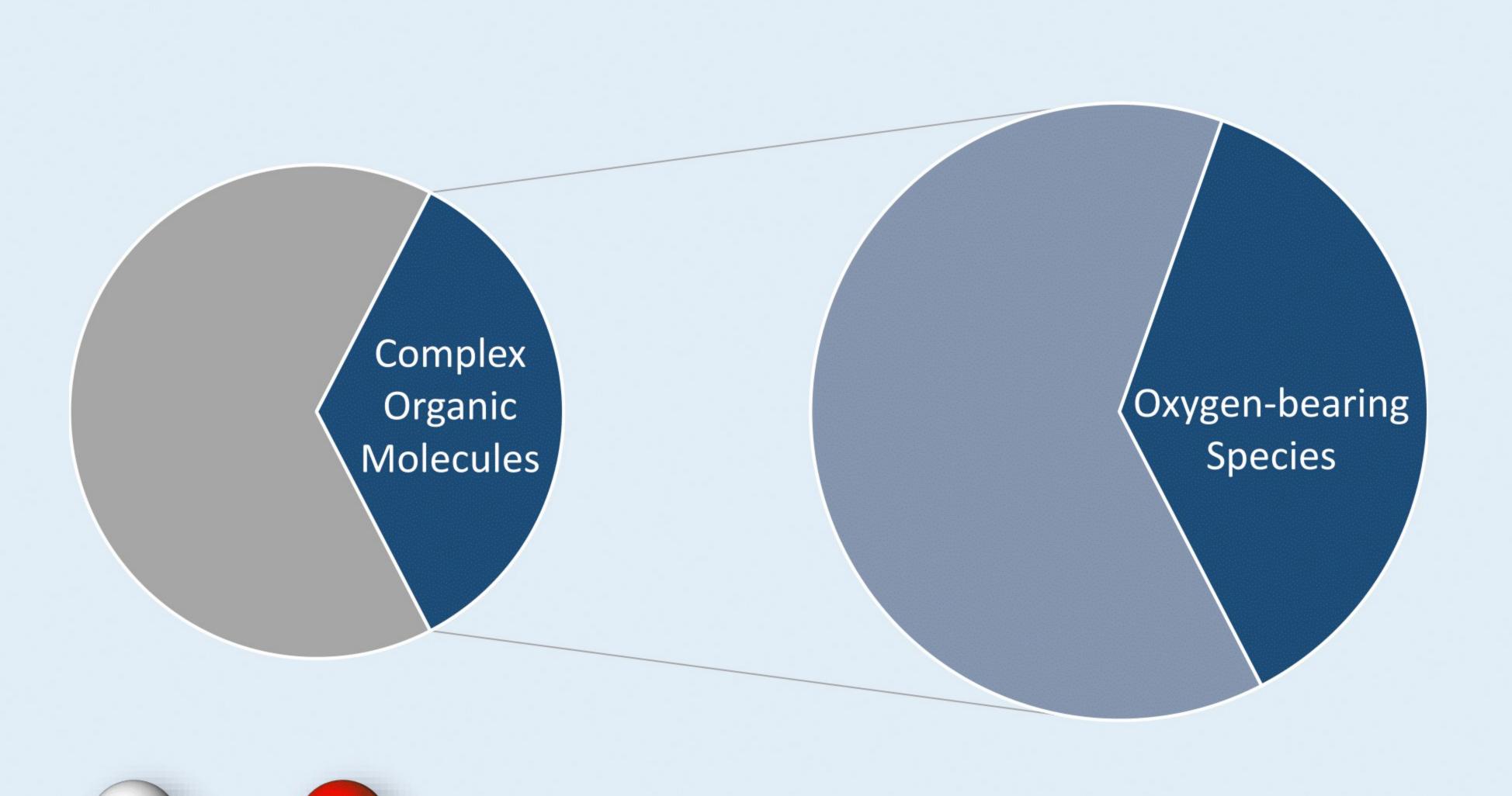
[1] Division of Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, CA

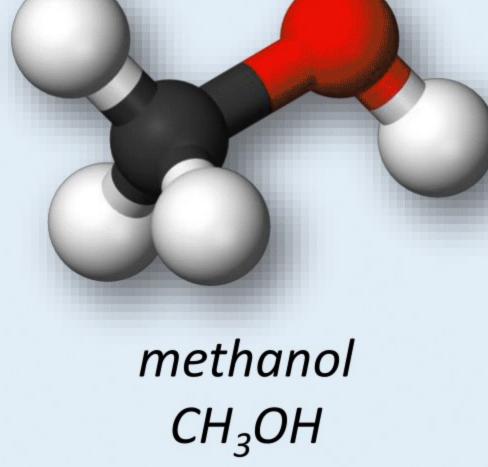
- [2] Harvard-Smithsonian Center for Astrophysics, Cambridge, MA
- [3] Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA

Orion Constellation: Hubble, ESA, Akira Fu

#### The target: Methanol

Nearly 200 molecules have been detected in interstellar space.<sup>1</sup> L Of these, about one-third are "complex," or have ≥6 atoms.<sup>2</sup>

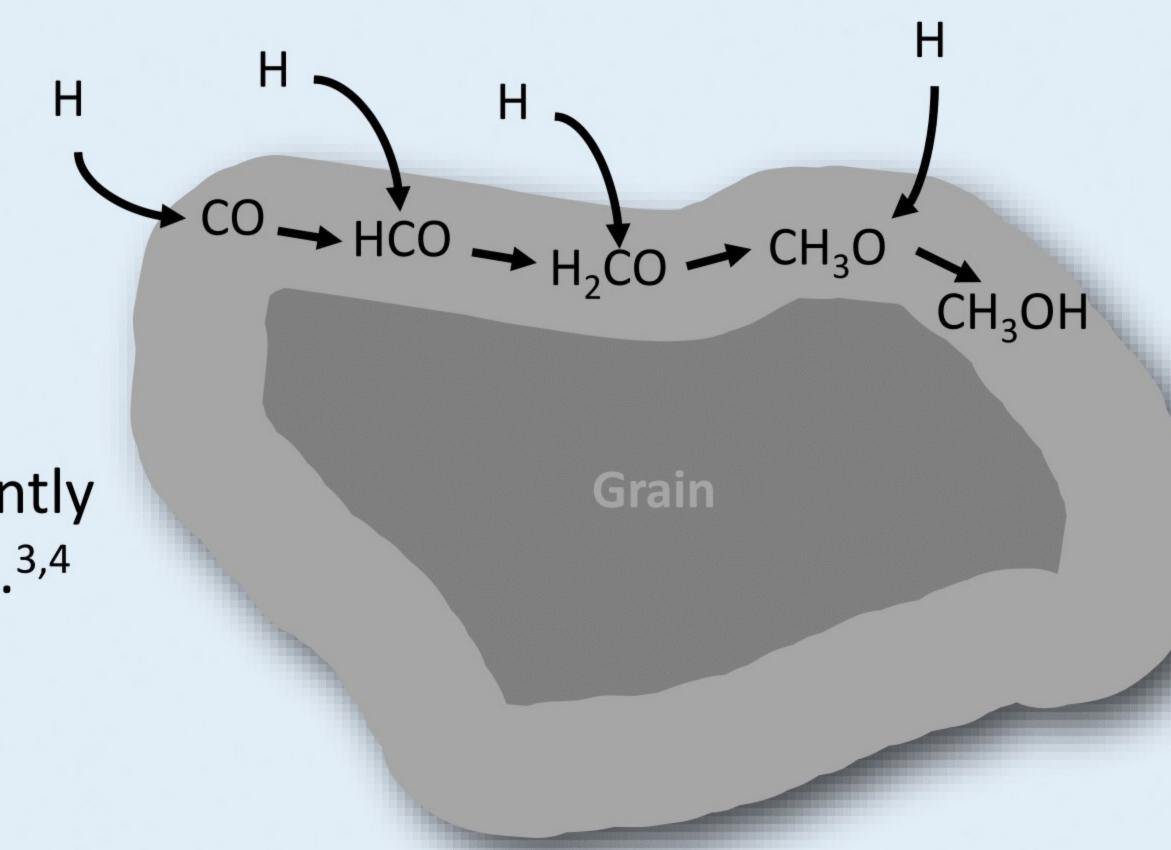




Formation of more complex oxygen-bearing species—such as methyl formate and dimethyl ether—are not well-constrained, but methanol formation is thought to be central to this more complex chemistry.

Understanding the formation of methanol is thus the first step towards answering the question: What are the mechanisms by which complex oxygen-bearing species are formed in the interstellar medium?

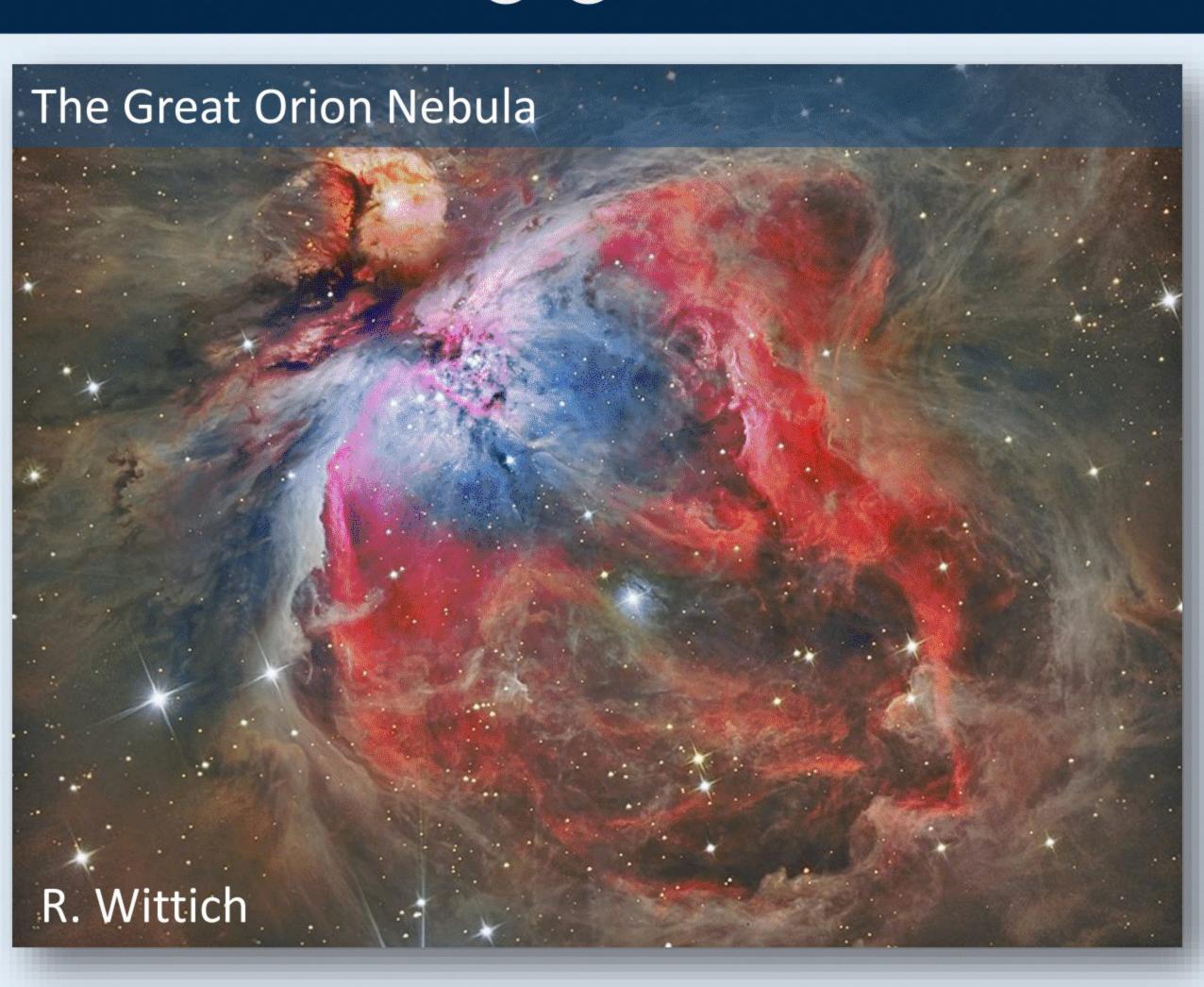
Models and laboratory experiments suggest that methanol forms predominantly on the surfaces of icy grains.<sup>3,4</sup>



To better understand the formation pathways of methanol, and the nature of D/H fractionation in icy mantles, we have obtained ALMA Cycle 5 data (ADS/JAO.ALMA#2017.1.01149.S) to measure:

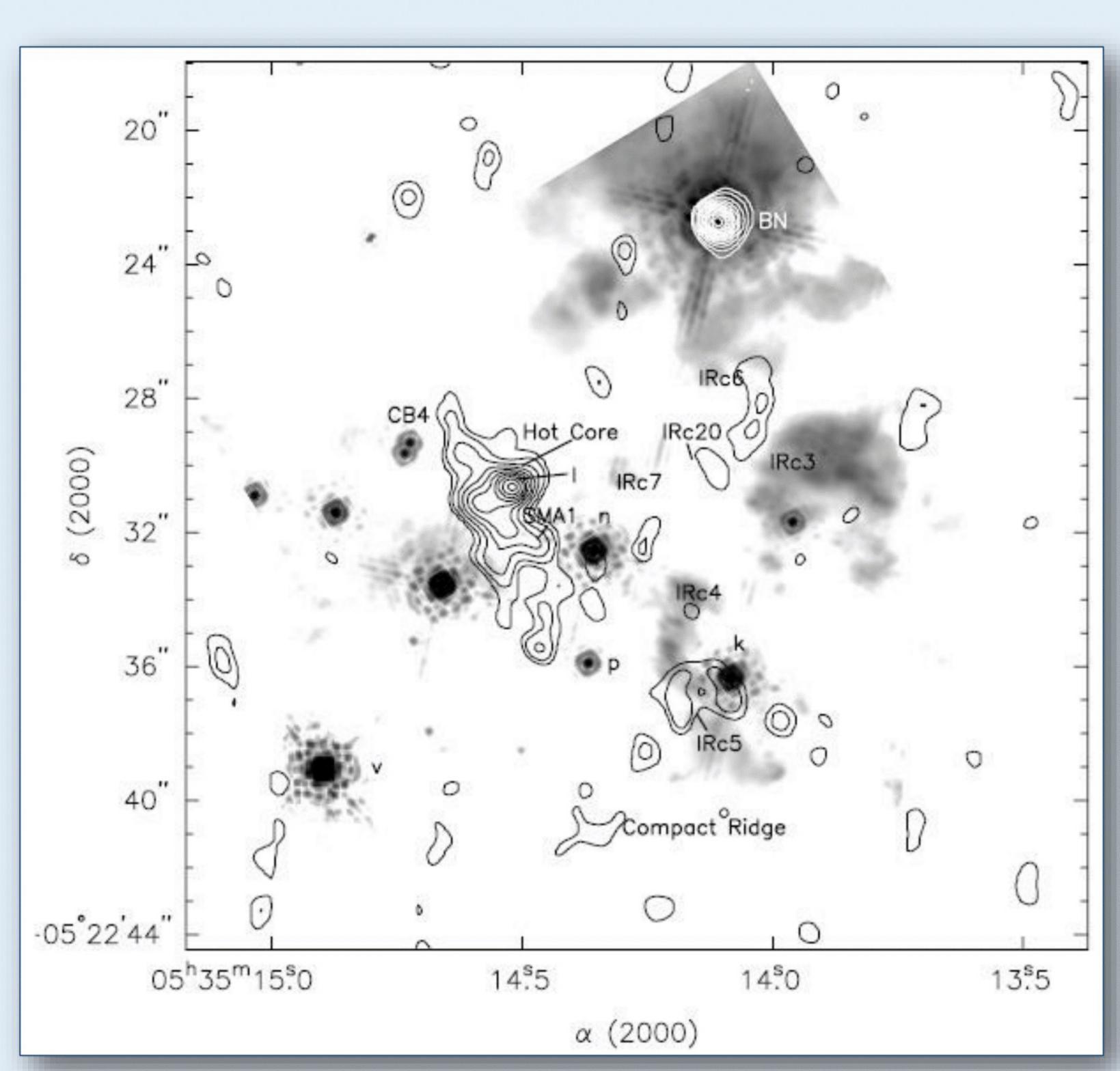
- [CH<sub>2</sub>DOH]/[<sup>13</sup>CH<sub>3</sub>OH]
- [CH<sub>3</sub>OD]/[<sup>13</sup>CH<sub>3</sub>OH]
- Nature of deuteration at each hydrogen site
- [CH<sub>3</sub>OD]/[CH<sub>2</sub>DOH]
- Persistence of deuterium

#### The hunting grounds: Orion KL



The Orion Kleinmann-Low nebula—more commonly referred to as Orion KL—is an archetype of high-mass star-forming regions in the Milky Way and the closest such region to Earth.

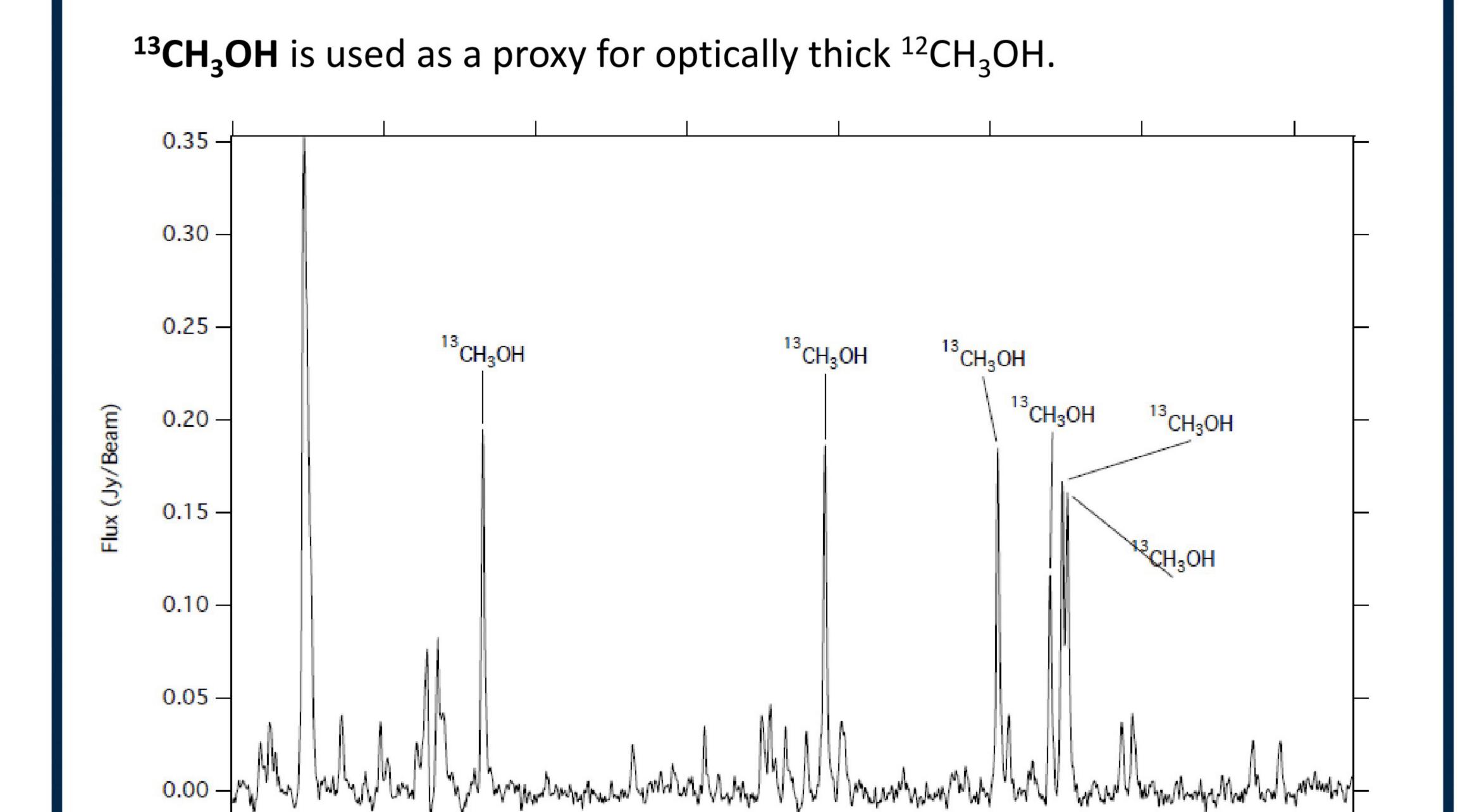
The continuum morphology and spatial distribution of molecular line emission of Orion KL are both complex.

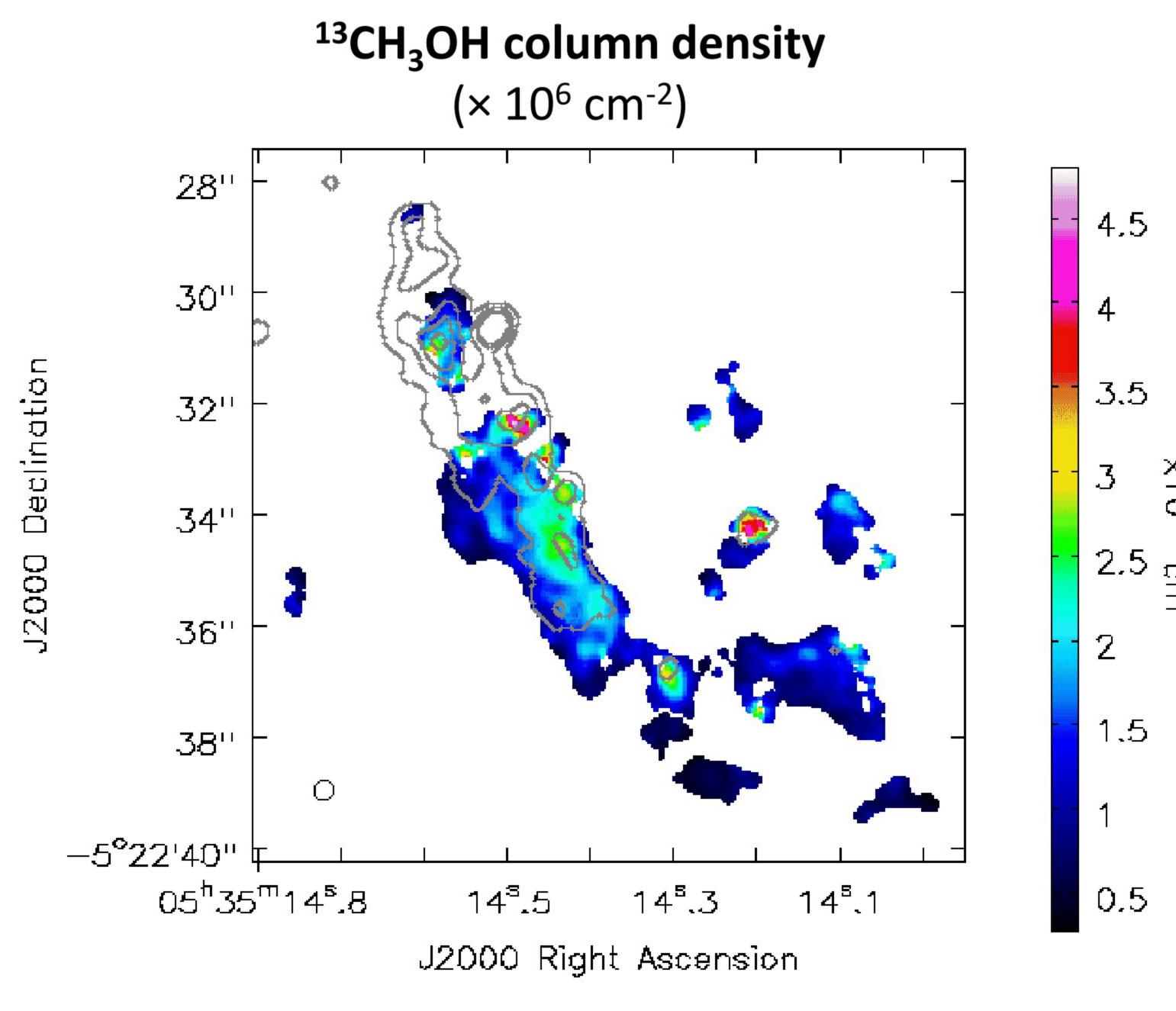


Continuum image at  $\lambda = 3$  mm (CARMA, B configuration:  $1.1'' \times 0.9''$ ) for the Orion KL region overlaid on a 2  $\mu m$  Hubble/NICMOS image. Contours are  $4\sigma$ ,  $6\sigma$ ,  $9\sigma$ ,  $12\sigma$ , ... ( $\sigma = 2.4$  mJy beam<sup>-1</sup>).<sup>5</sup> Sources of particular interest include the Hot Core (near the center of the image) and the Compact Ridge (center bottom).

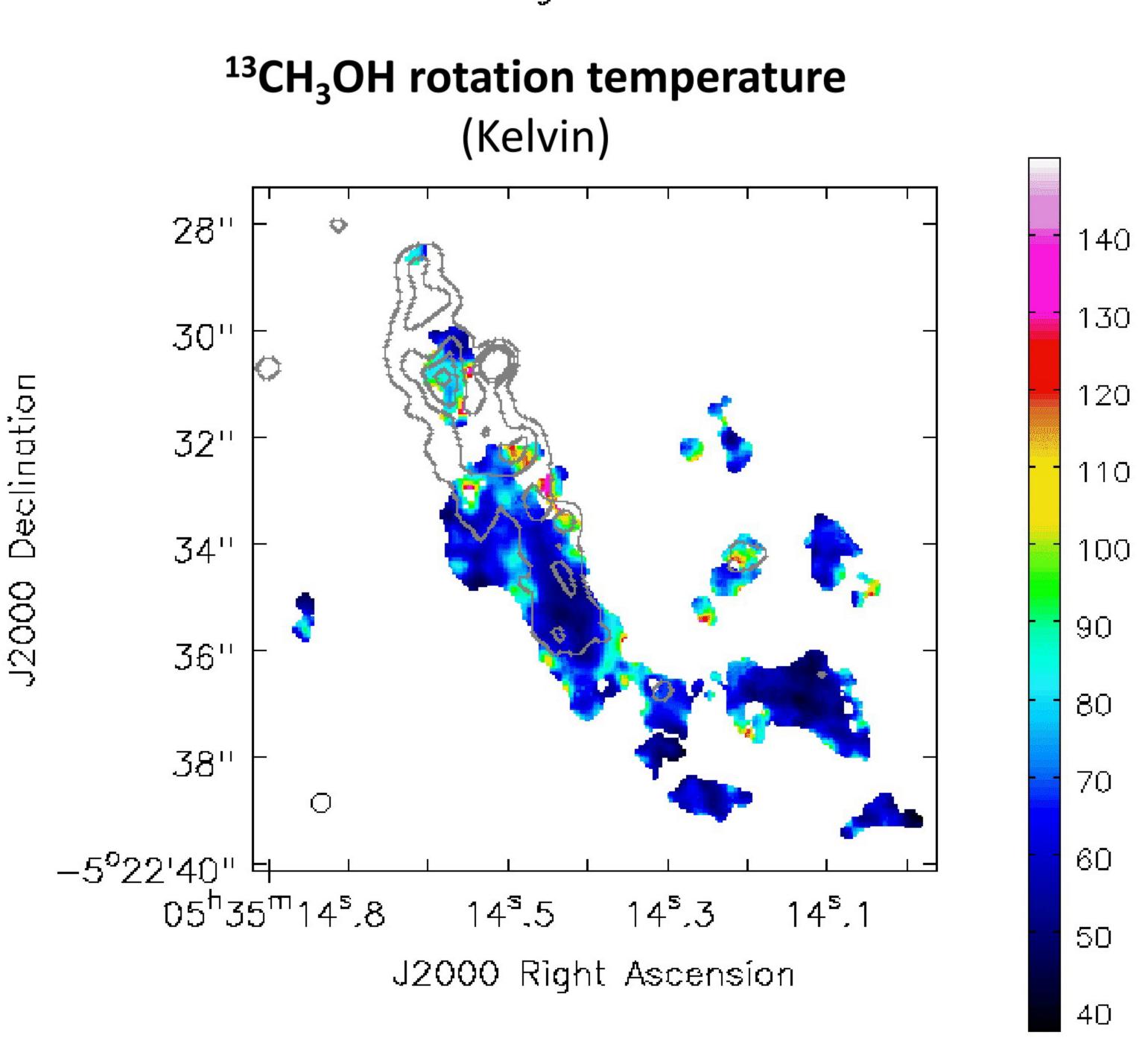
The relatively warm Hot Core and Source I are the traditional locations of nitrogen-bearing molecules (e.g. CH<sub>3</sub>CH<sub>2</sub>CN). The colder Compact Ridge is the traditional location of oxygen-bearing species (e.g. HCOOCH<sub>3</sub>).<sup>5</sup>

#### Methanol isotopologues in Orion KL





Frequency(MHz)



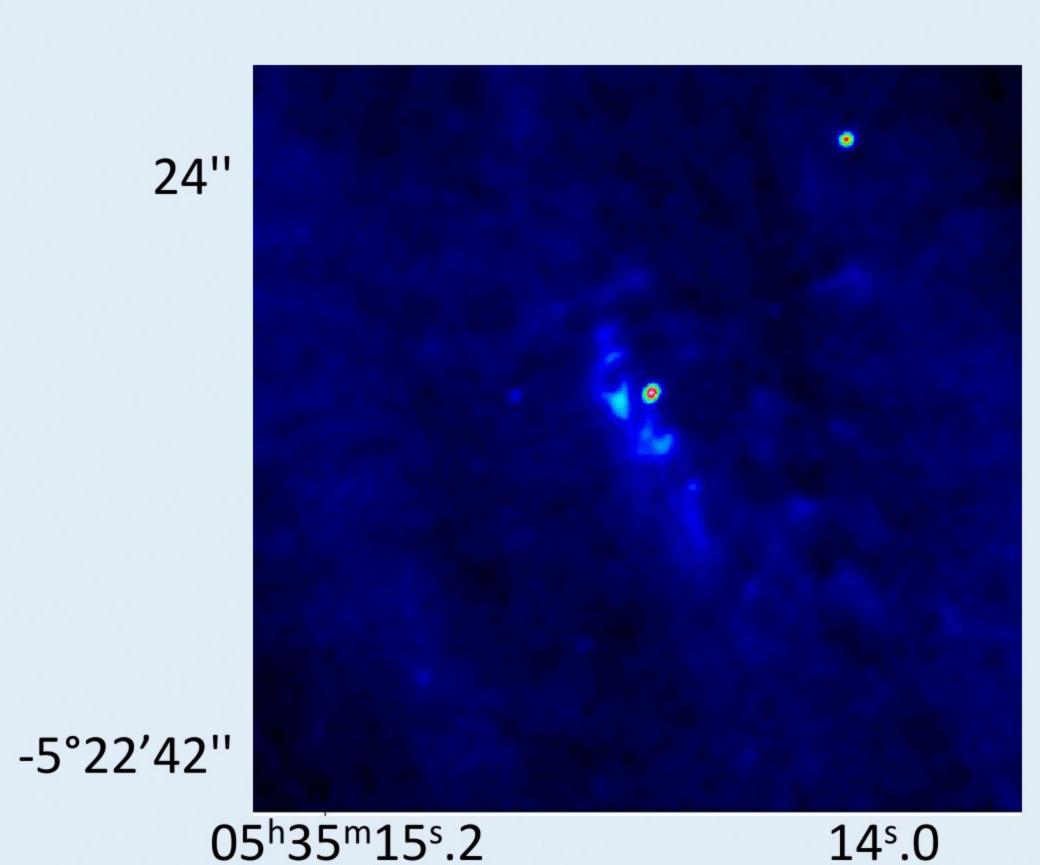
CH,DOH and CH,OD have both been detected toward Orion KL, with a measured [CH<sub>2</sub>DOH]/[CH<sub>3</sub>OD] ratio of 1.1-1.5 (expected value: 3) toward the Compact Ridge.<sup>6,7</sup> More accurate observations are required to ascertain why.

## The tools: Observations with ALMA

#### High angular resolution: ~0.3"

L Corresponds to high spatial resolution of 120 AU, assuming Orion KL is at a distance of about 414 pc.8

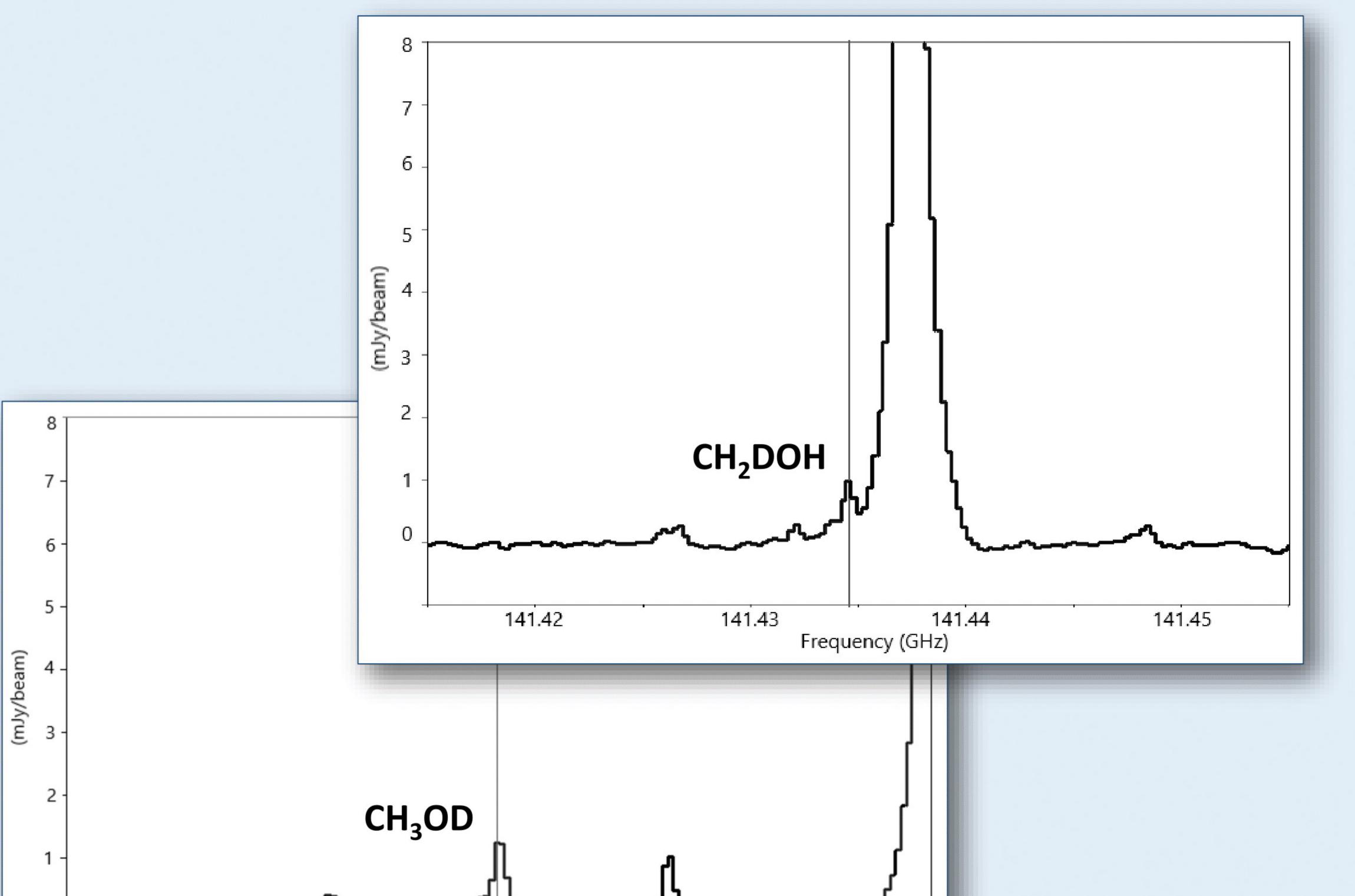
L Resolved spatial structure on scales commensurate with circumstellar disks which lie within radii typically associated with abundance enhancements brought on by heating from embedded protostars as modeled by so-called "jump models." 9,10

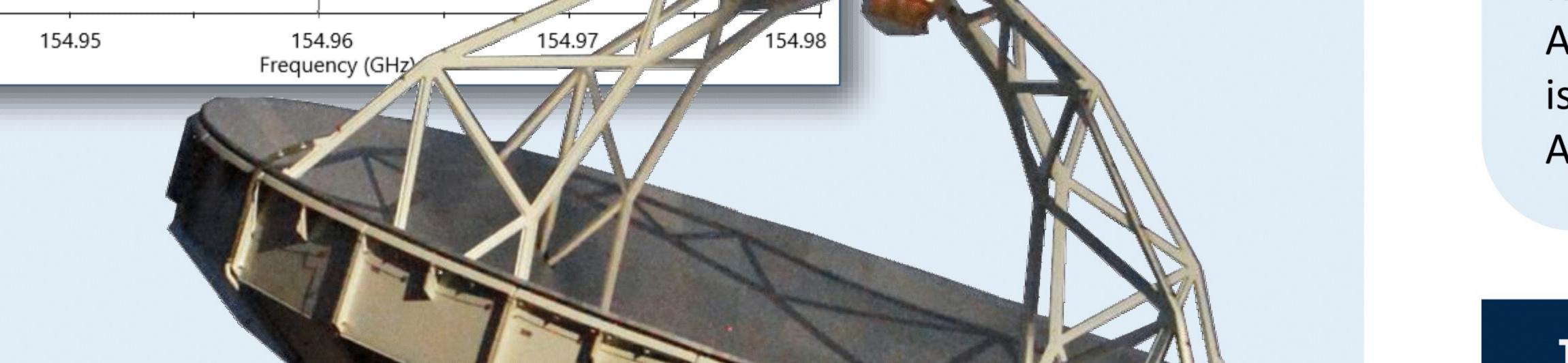


Isotopologues observed simultaneously in a single spectral configuration to minimize uncertainty in the derived ratios. Ly The objective of this study is to investigate relative abundances.

Molecule	# lines	E <sub>υ</sub> [K]
<sup>13</sup> CH <sub>3</sub> OH	6	19-189
CH <sub>2</sub> DOH	2	184-285
CH <sub>2</sub> OD	4	163-250

Rotation temperature  $T_{rot}$  will be derived from maps of  $^{13}CH_3OH$ . Ly Given the high density of the Hot Core  $(n_{H2} = 10^7 \text{ cm}^{-3})$ , we assume





### Acknowledgements

O.H.W. is supported by the National Science Foundation (NSF) Graduate Research Fellowship under Grant No. DGE-1144469. This work makes use of the following ALMA data: ADS/JAO.ALMA#2013.1.01034.S and #2017.1.01149.S. ALMA is a partnership of ESO (representing its member states), NSF (USA), and NINS (Japan), together with NRC (Canada), MOST and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO, and NAOJ. The National Radio Astronomy Observatory (NRAO) is a facility of the NSF operated under cooperative agreement by Associated Universities, Inc. (AUI).

# References

- [1] CDMS (http://astro.uni-koeln.de/cdms/molecules)
- [2] Herbst and van Dishoeck, 2009, *ARA&A*, 47, 427
- [3] Nagaoka et al., 2005, *ApJ*, 624, L29
- [4] Garrod et al. 2006, Faraday Discuss., 133, 51
- [5] Friedel and Widicus Weaver, 2011, ApJ, 742, 64 [6] Charnley, Tielens, and Rodgers, 1997, ApJ, 482, L203
- [7] Neill et al., 2013, ApJ, 777, 85
- [8] Menten et al., 2007, A&A, 474, 515
- [9] Boonman et al., 2001, ApJ, 553, L63
- [10] Schöer et al., 2002, A&A, 390, 1001 [11] Genzel and Stutzki, 1989, ARA&A, 27, 41

