

Exploring the origins of nitrogen on terrestrial worlds

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Nitrogen Fractionation in Space – Copenhagen

Earth's nitrogen and carbon were likely delivered by chondrites



Chondrites have “hot spots” of D, ^{15}N enrichment

Veins of “insoluble organic matter” (IOM) contain most C, N in these meteorites

Isotopic ratios give hints to
history & formation

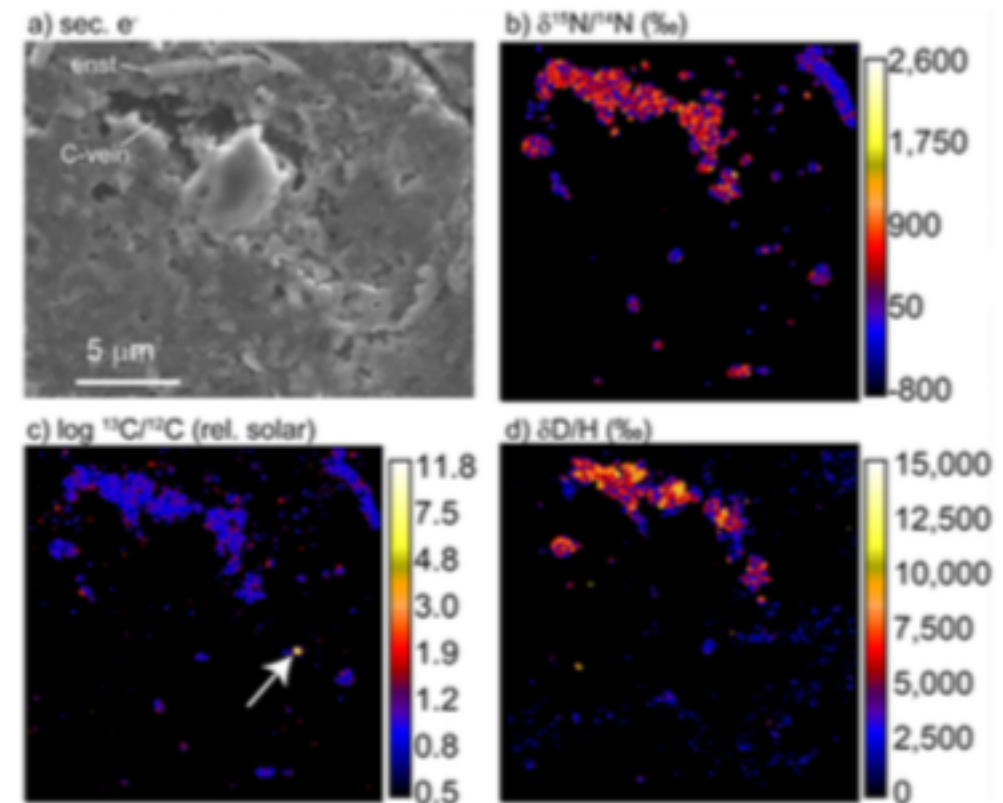


Fig. 2. Images of an area of QUE 99177 (CR2) matrix: (a) a secondary electron scanning electron micrograph, (b) a N isotope ratio map, (c) a C isotope ratio map, and (d) a H isotope ratio map. The isotopic maps were all measured by NanoSIMS. A relatively large ^{15}N - and D-rich “vein” of organic matter is visible. Arrow in (c) indicates a highly ^{13}C -enriched presolar SiC grain with no obvious spatial relationship to the organic matter.

C.Alexander et al. 2017
Chemie der Erde

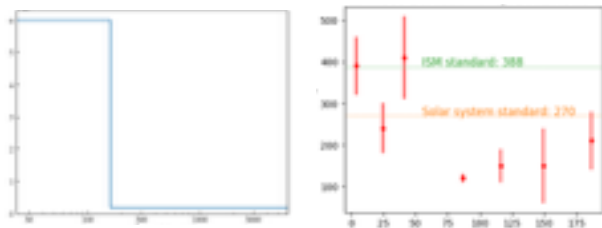
Candidate precursors to N in IOM: organic N carriers, and NH_3

- Atomic N, molecular N_2 are too volatile to contribute much to formation of solids

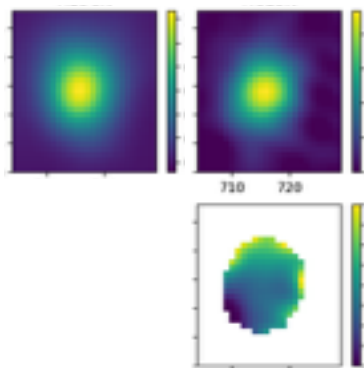
Exploring the origins of nitrogen



Accounting the N in organics
in high-mass hot cores



Modeling HCN abundance & emission
in a famous low-mass protostar

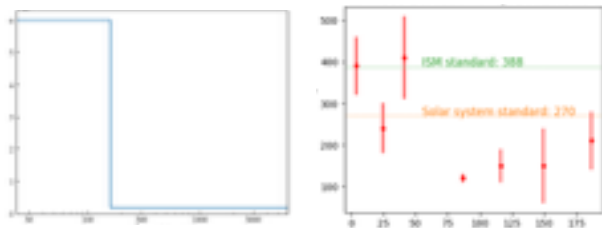


My dissertation: HCN abundances around
5 protostars with interferometry

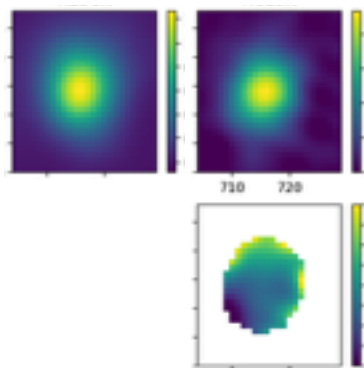
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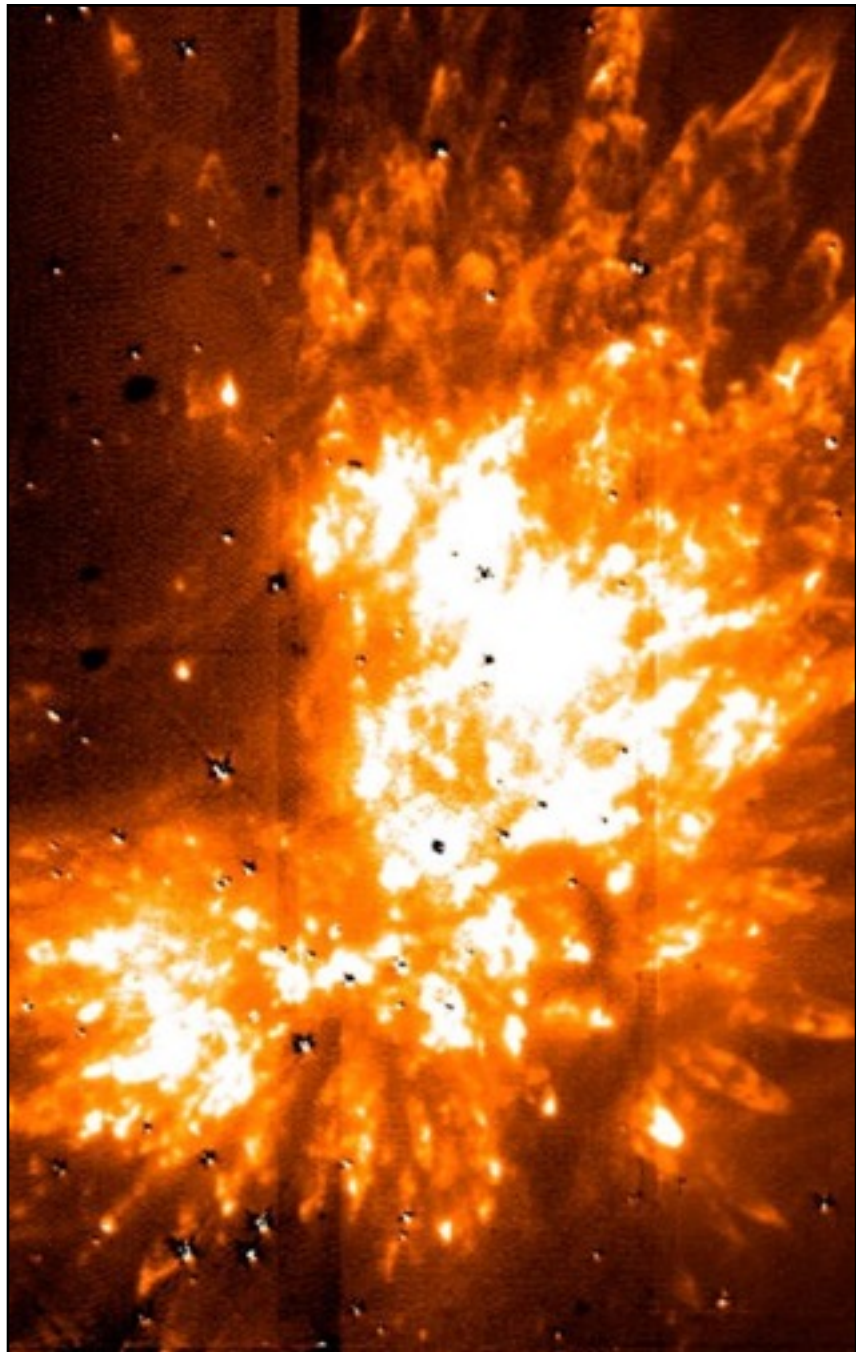


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Orion KL: nearest chemically rich high-mass hot core



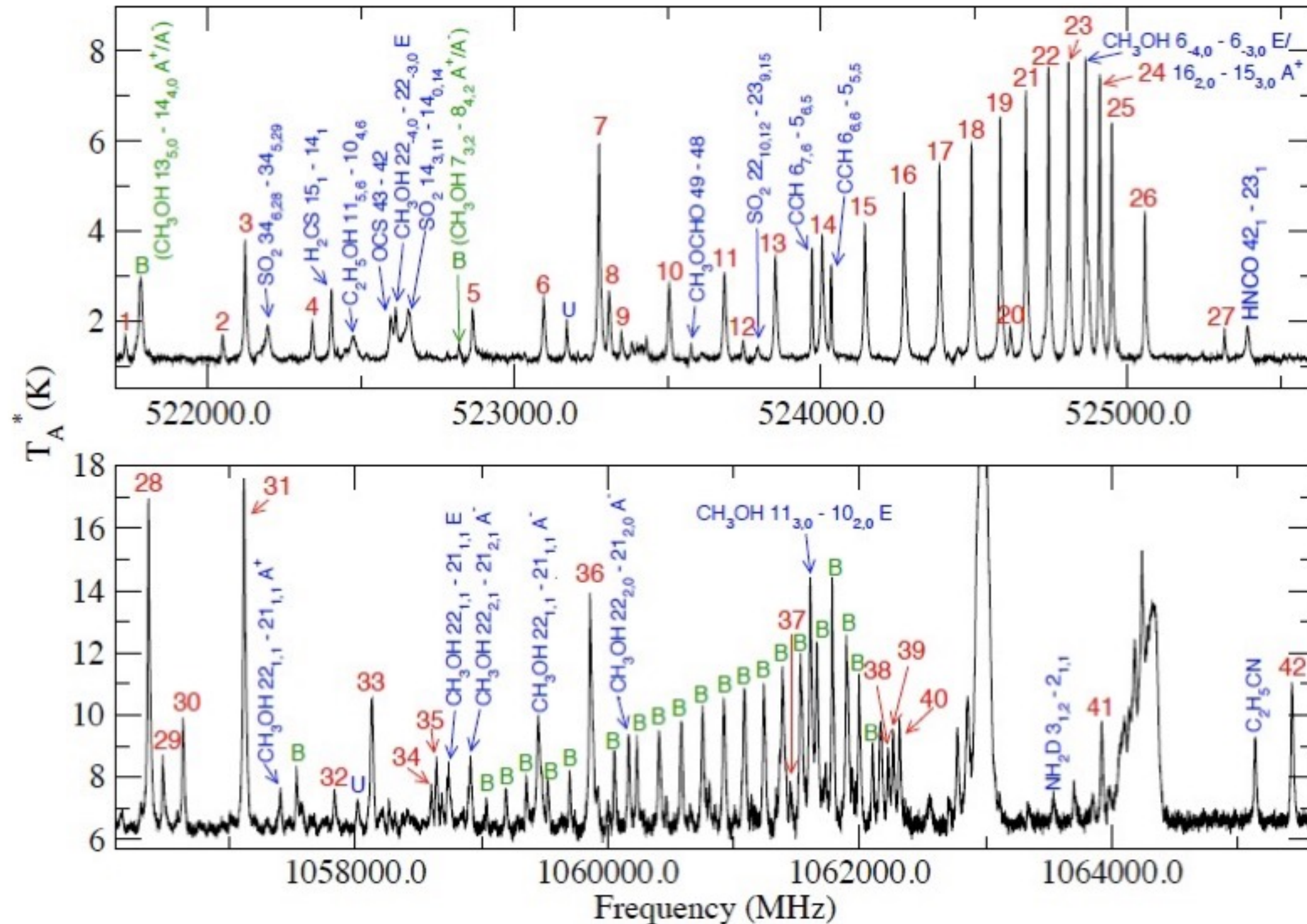
$d \sim 420 \text{ pc}$

A “hot core” of high-temperature gas

Perfect target for molecular line emission studies

Studied in depth by Herschel, e.g. in Crockett et al. (2014, 2015) and Plume et al. (2012)

Herschel observed Orion KL in depth,
producing a rich spectrum (1% shown here)

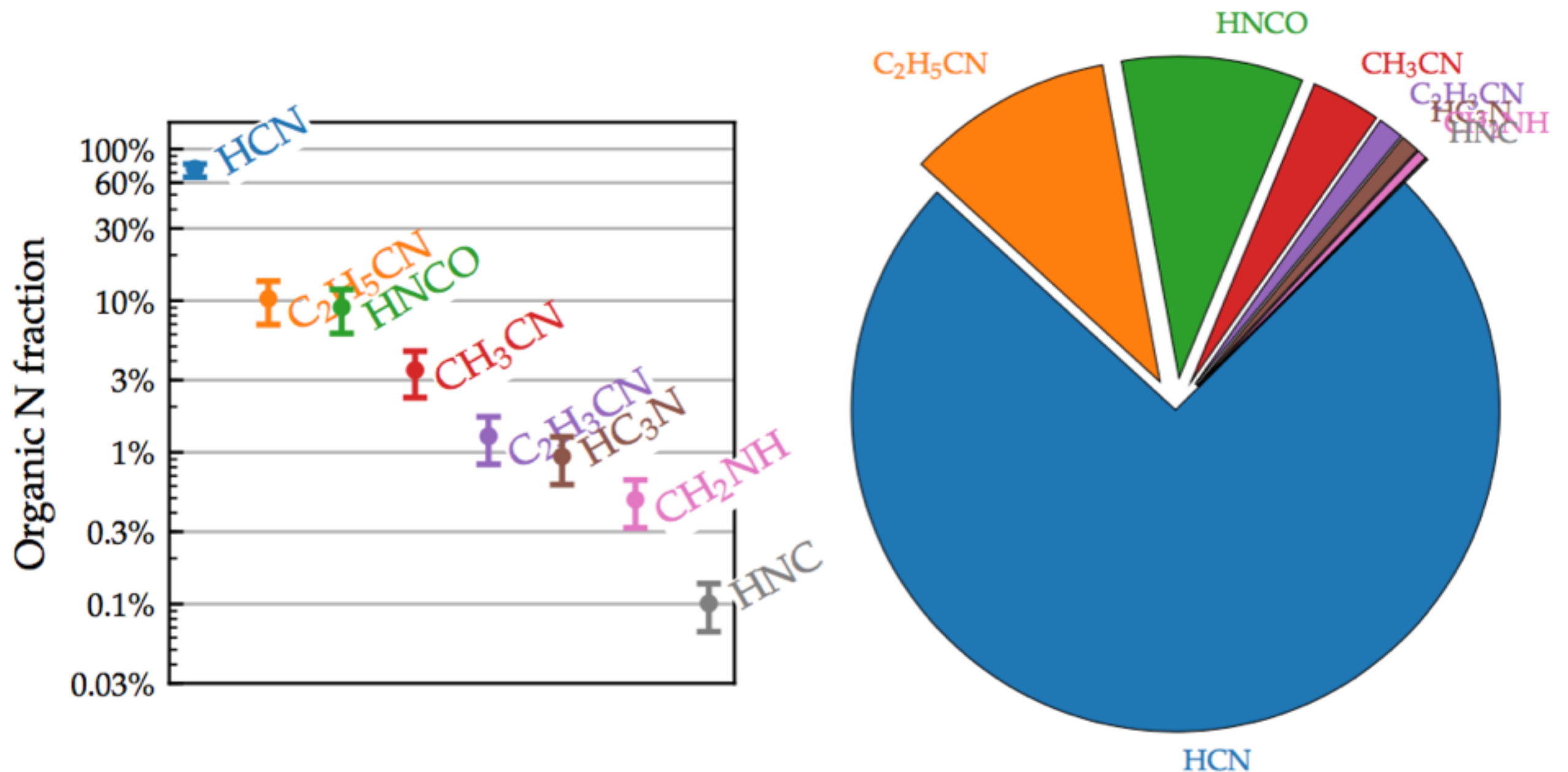


Bergin et al. 2010,
Wang et al. 2011

Crockett+14 modeled Orion KL's *Herschel* spectra, measuring abundances for 39 molecules

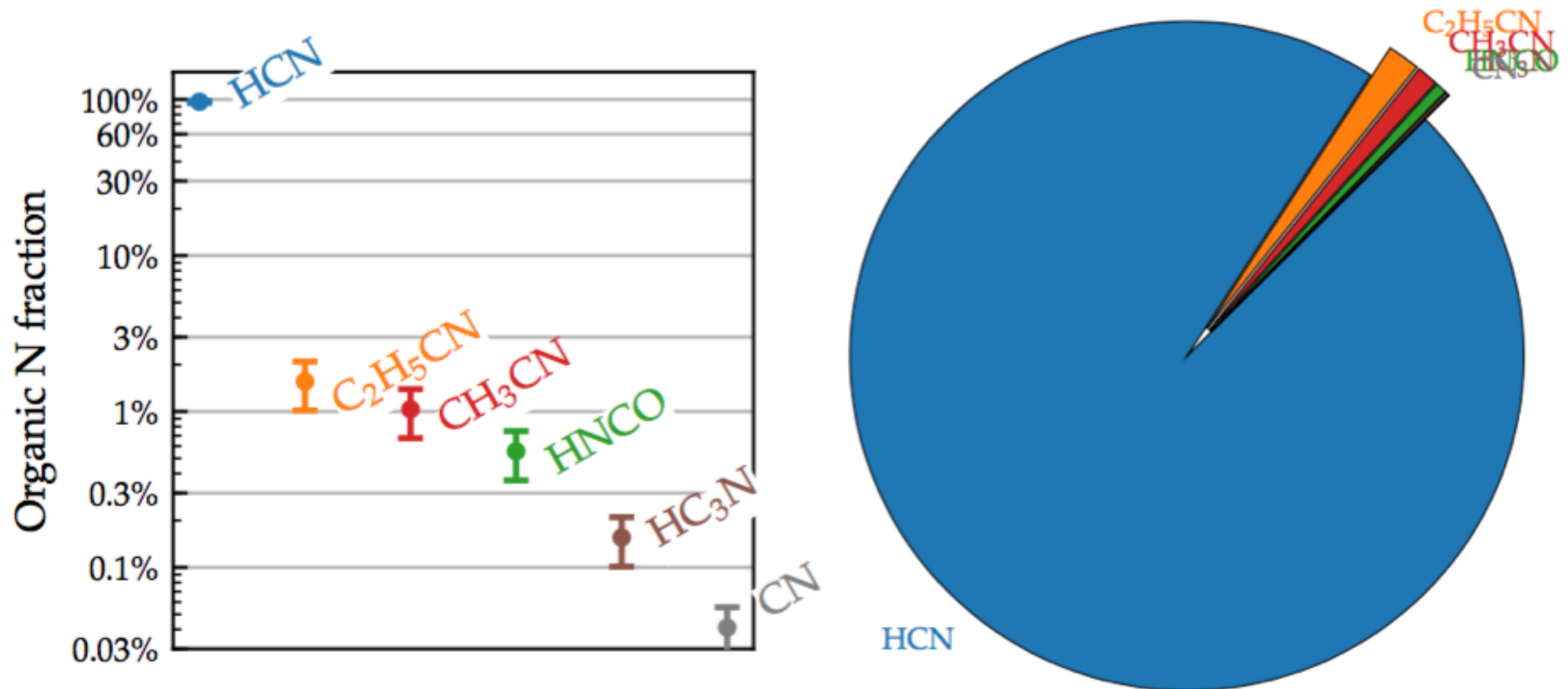
- NH_2CHO
- SiS
- $\text{C}_2\text{H}_5\text{OH}$
- H_2CS
- NO
- NS
- SO , ^{34}SO , ^{33}SO , S^{18}O
- SO_2 , $^{34}\text{SO}_2$, $^{33}\text{SO}_2$
- HCN , H^{13}CN , HC^{15}N
- HNC , H^{15}NC , HN^{13}C
- SiO
- CH_3CN , $^{13}\text{CH}_3\text{CN}$, $\text{CH}_3^{13}\text{CN}$
- NH_3 , $^{15}\text{NH}_3$, NH_2D
- HCl , H^{37}Cl
- H_2S , H_2^{33}S , H_2^{34}S
- H_2CO , H_2^{13}CO , HDCO
- HCOOCH_3
- CCH
- CN
- HC_3N
- H_2O , HDO , HD^{18}O , D_2O , H_2^{18}O , H_2^{17}O
- CH_3OH , $^{13}\text{CH}_3\text{OH}$, CH_3OD , CH_2DOH
- $\text{C}_2\text{H}_5\text{CN}$
- HNCO , HN^{13}CO
- HCS^+
- H_2CCO
- OCS
- CH_3OCH_3
- CS , C^{34}S , C^{33}S , ^{13}CS
- CO , ^{13}CO , C^{17}O , C^{18}O
- HCO^+

We made an inventory of organic carriers of N in Orion KL

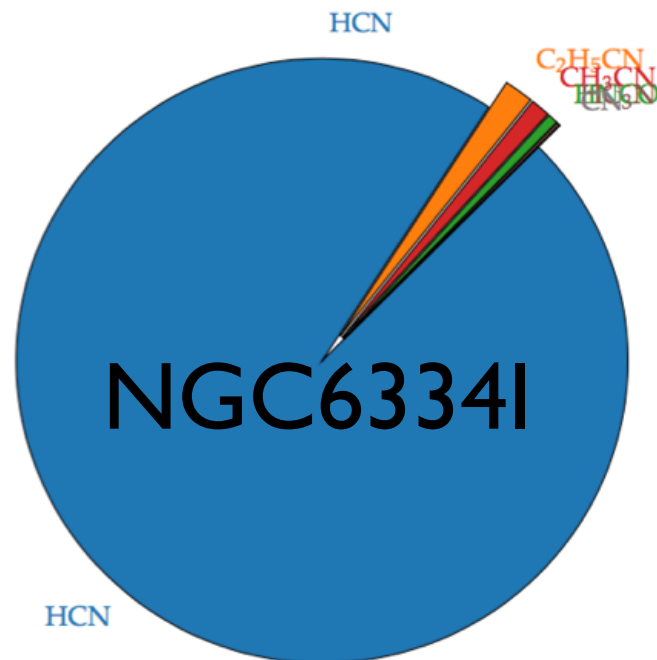
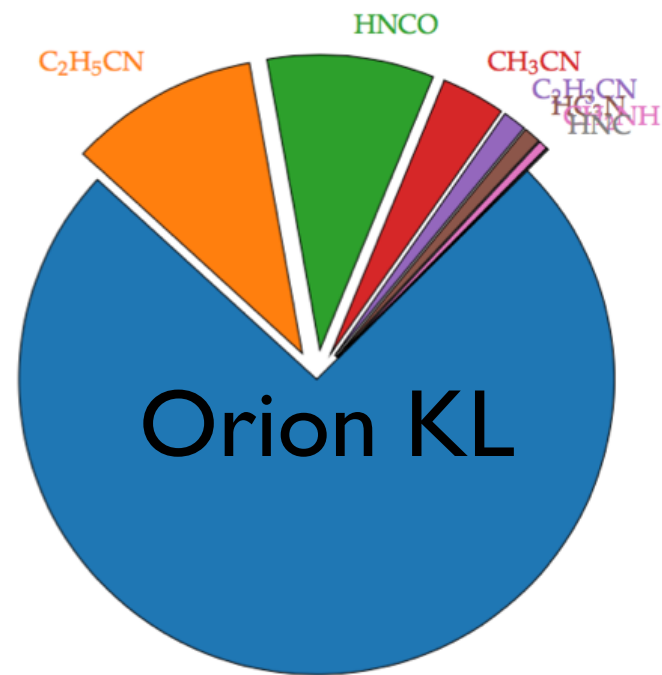


Rice *et al.*, in prep.

In the high-mass hot core NGC6334I,
again most organic N is in HCN

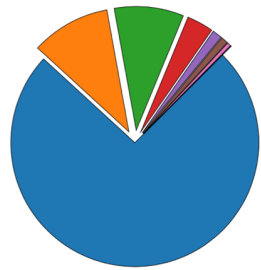


HCN is the main organic carrier of N in high-mass hot cores

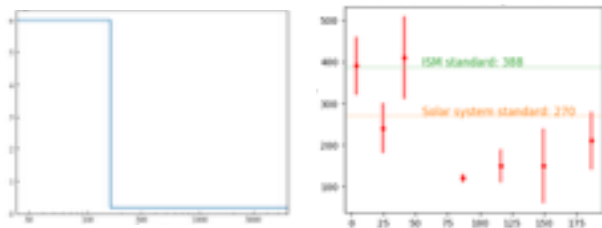


- HCN contains 65–98% of N in organic carriers

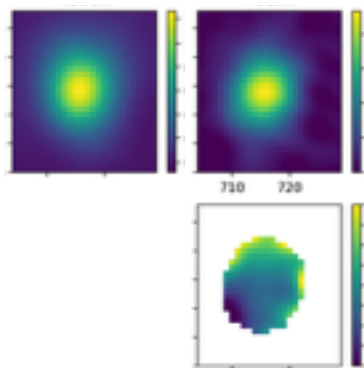
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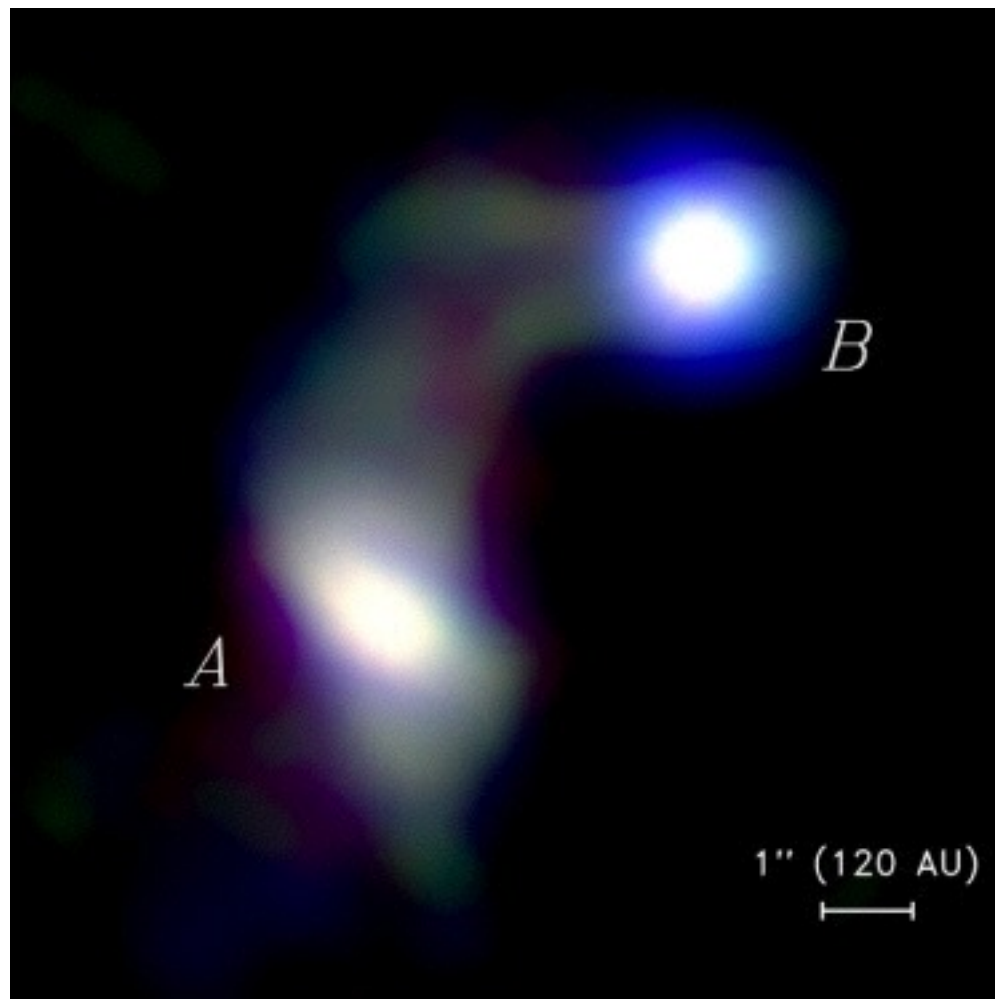


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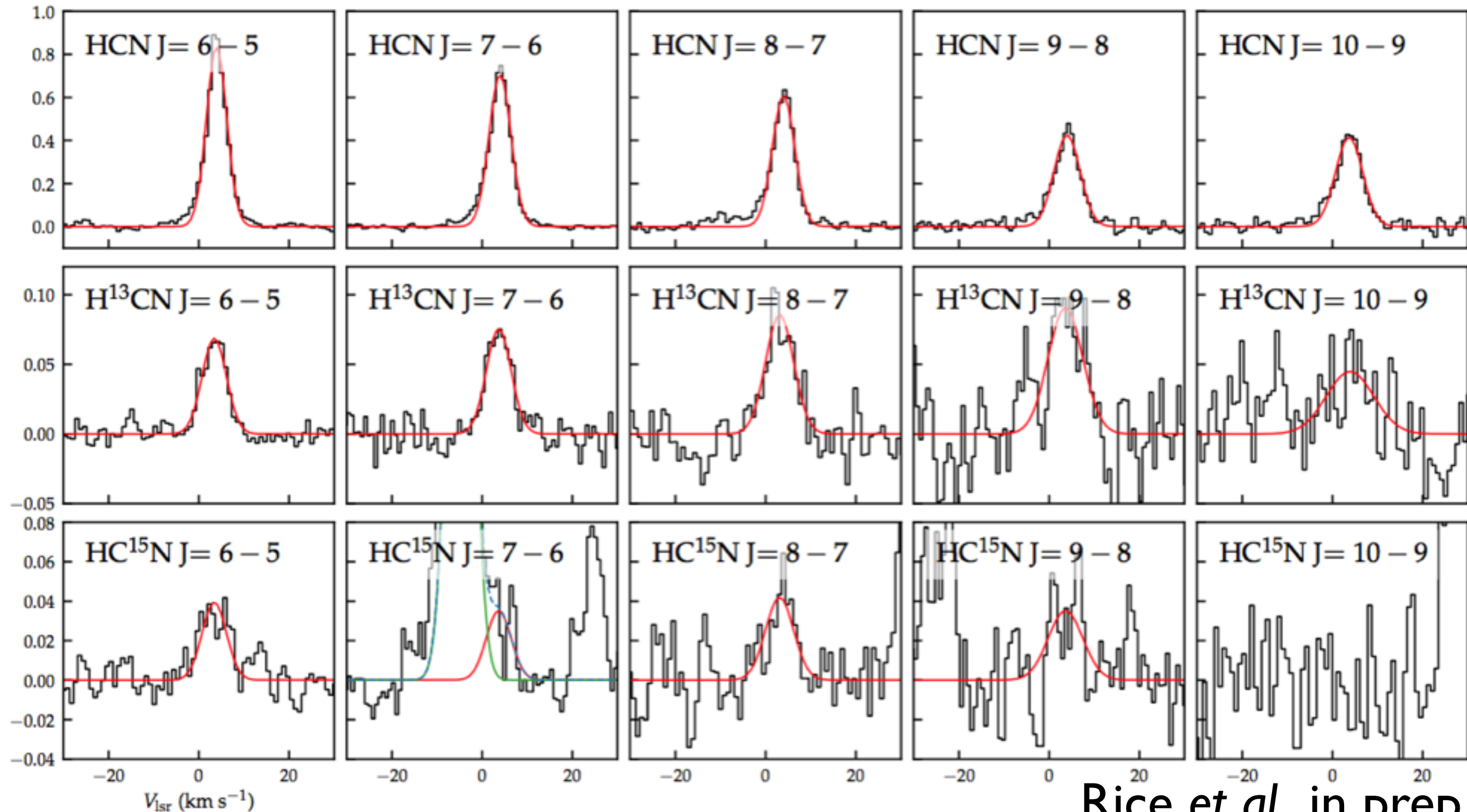
IRAS 16293: Low-mass protostar, astrochemical laboratory



- $d \sim 120$ pc
- Well-studied by single-dish ground-based studies (TIMASS), space (CHESS/*Herschel*), and ALMA (PILS)

(Caux+11, Ceccarelli+10, Jørgensen+16)

I reduced the CHESS HIFI spectrum and measured HCN, H^{13}CN , HC^{15}N lines



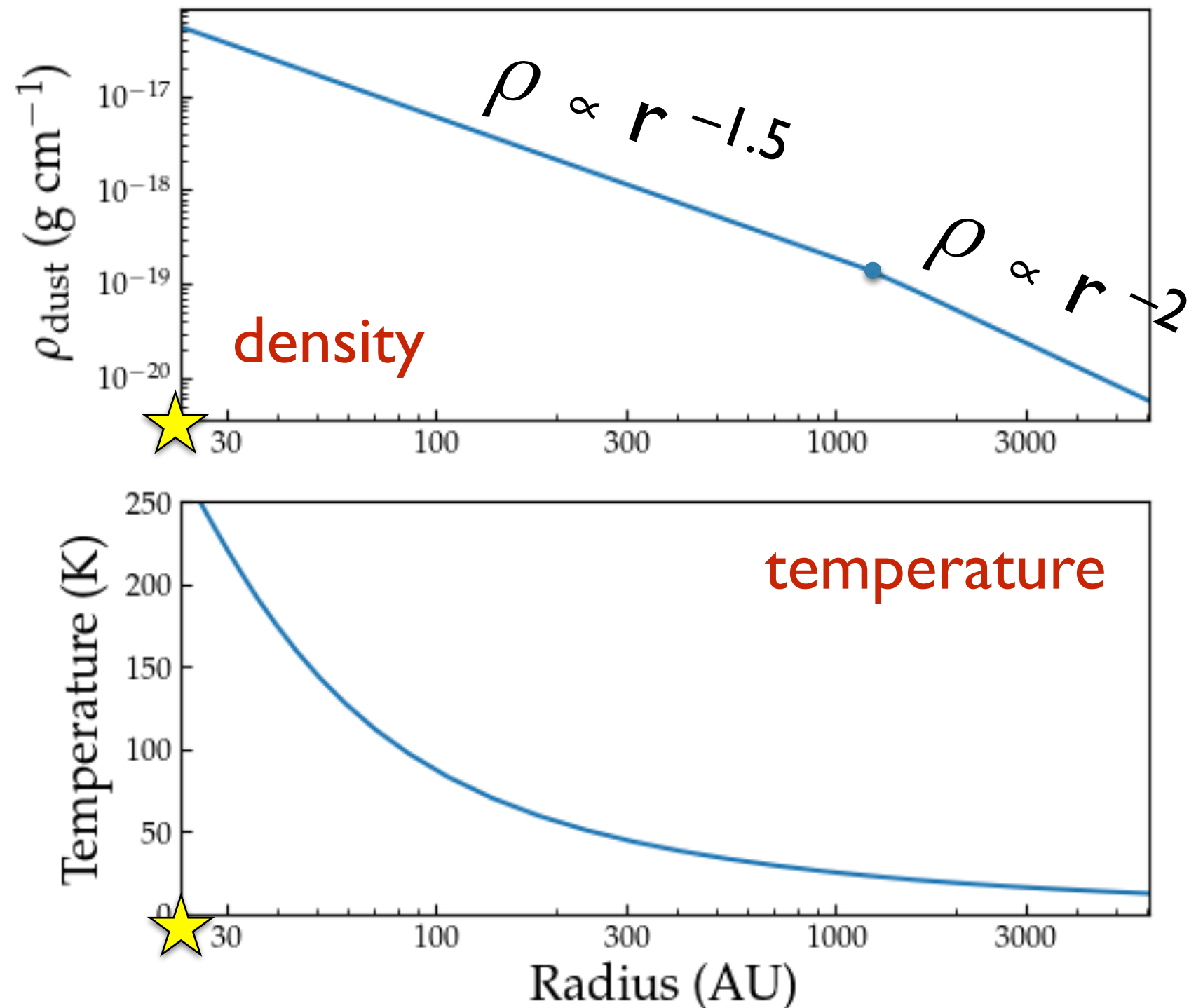
Rice *et al.*, in prep.

We adopted sph. symmetric physical model parameters from Crimier+10

$$L_* = 22 L_{\text{sun}}$$

$$R_{\text{infall}} = 1280 \text{ AU}$$

$$M_{\text{env}} = 1.9 M_{\text{sun}}$$



Modeling approach: Transphere + Ratran

```
Last login: Sun Nov  5 15:41:14 on ttys009
→ ~ cd Documents/Code/coutens_model_h13cn
→ coutens_model_h13cn git:(master) ✕ ipython --pylab
%Python 3.6.0 |Anaconda custom (x86_64)| (default, Dec 23 2016, 13:19:00)
Type "copyright", "credits" or "license" for more information.

IPython 5.1.0 -- An enhanced Interactive Python.
?          -> Introduction and overview of IPython's features.
%quickref  -> Quick reference.
help       -> Python's own help system.
object?    -> Details about 'object', use 'object??' for extra details.
runUsing matplotlib backend: TkAgg

In [1]: %run
```

Transphere (C. Dullemond):
given a density structure and stellar parameters, reproduce temperature structure

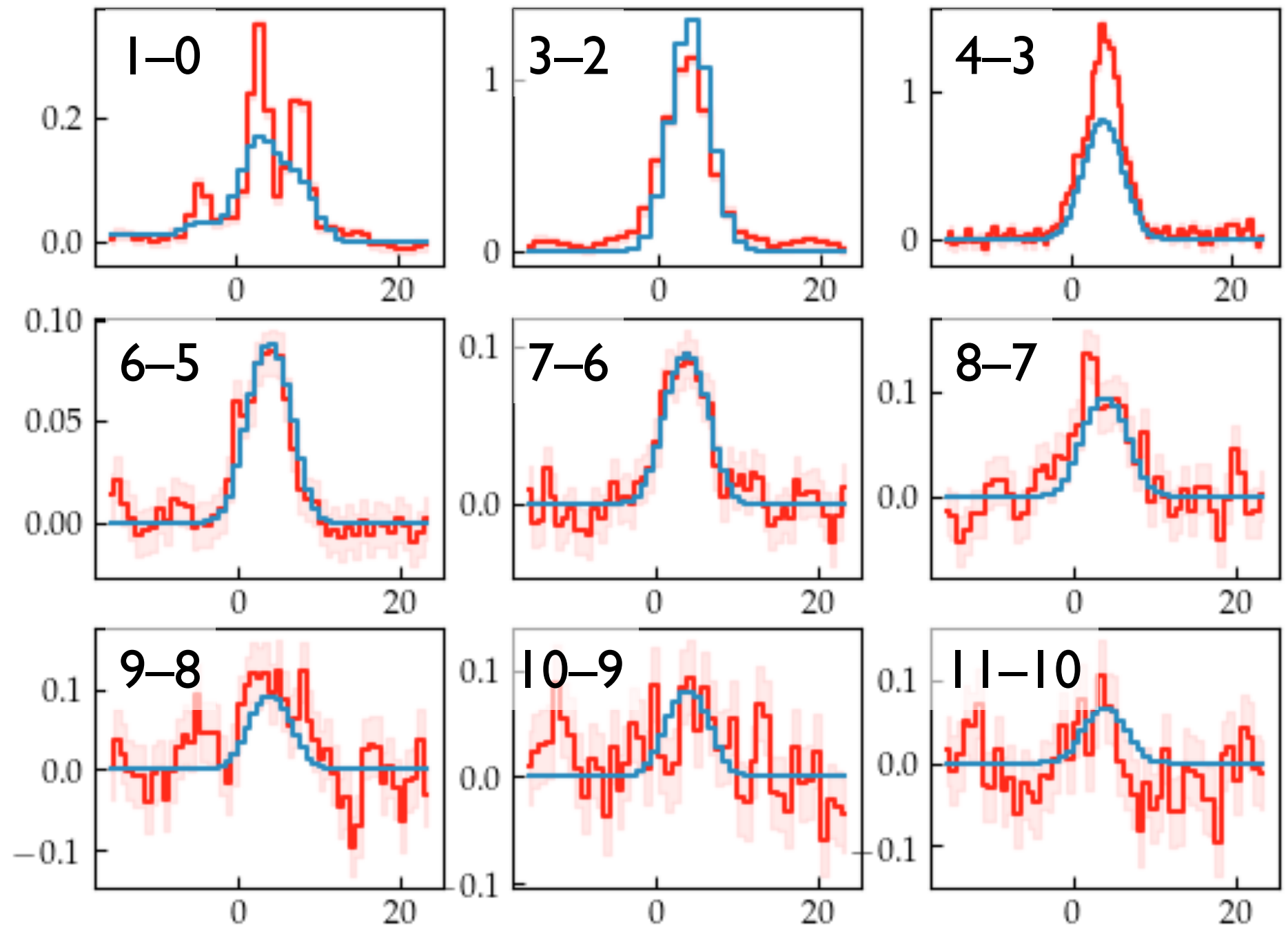
Ratran
(M. Hogerheijde & F. van der Tak):
given temps, densities, abundances, solve molecular population states & ray-trace line emission

We model the emission, varying inner & outer HCN abundances

H¹³CN lines

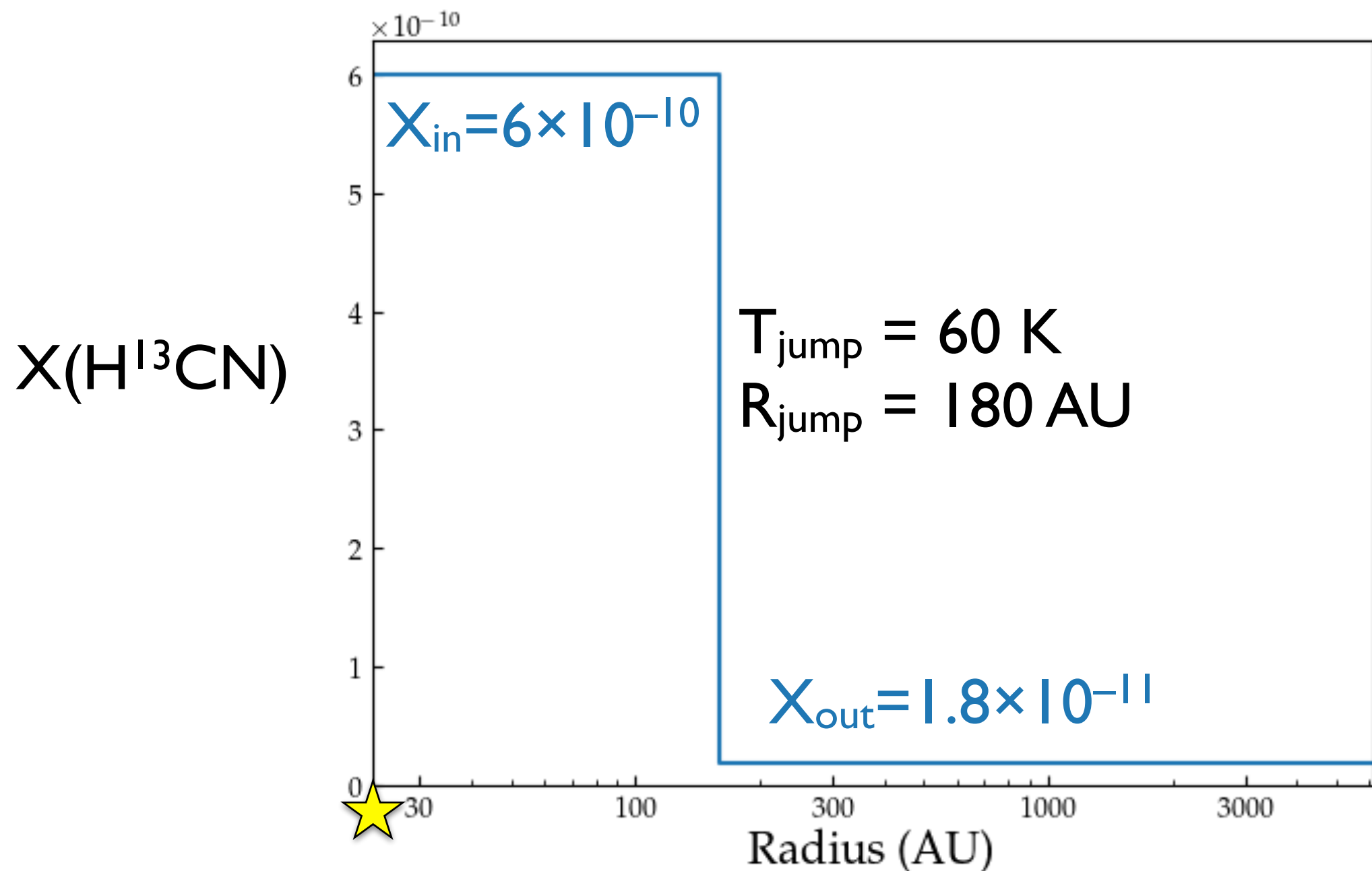
data —

model —



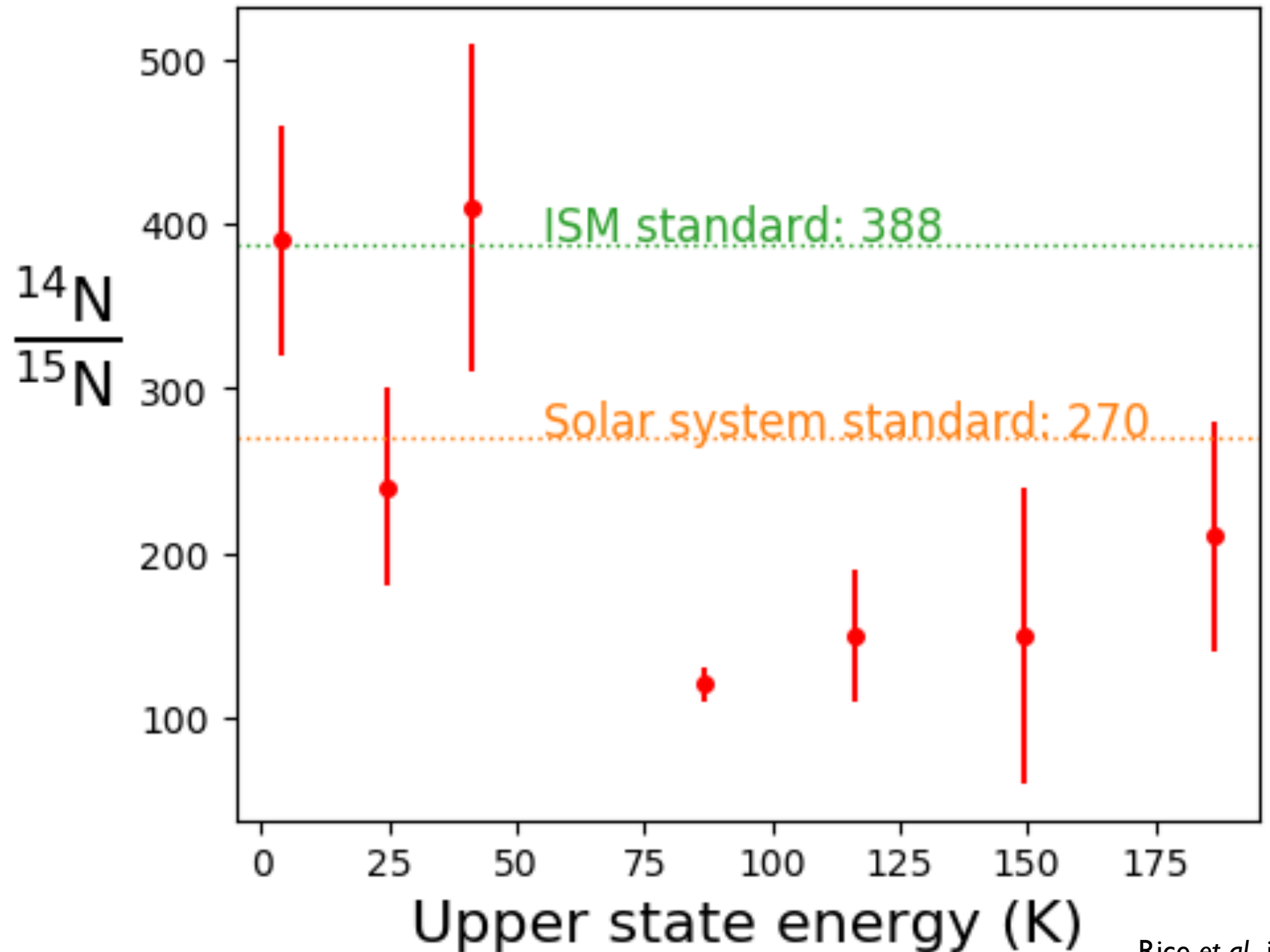
Rice *et al.*, in prep.

We derive an abundance structure
with a 30× increase where $T > 60$ K

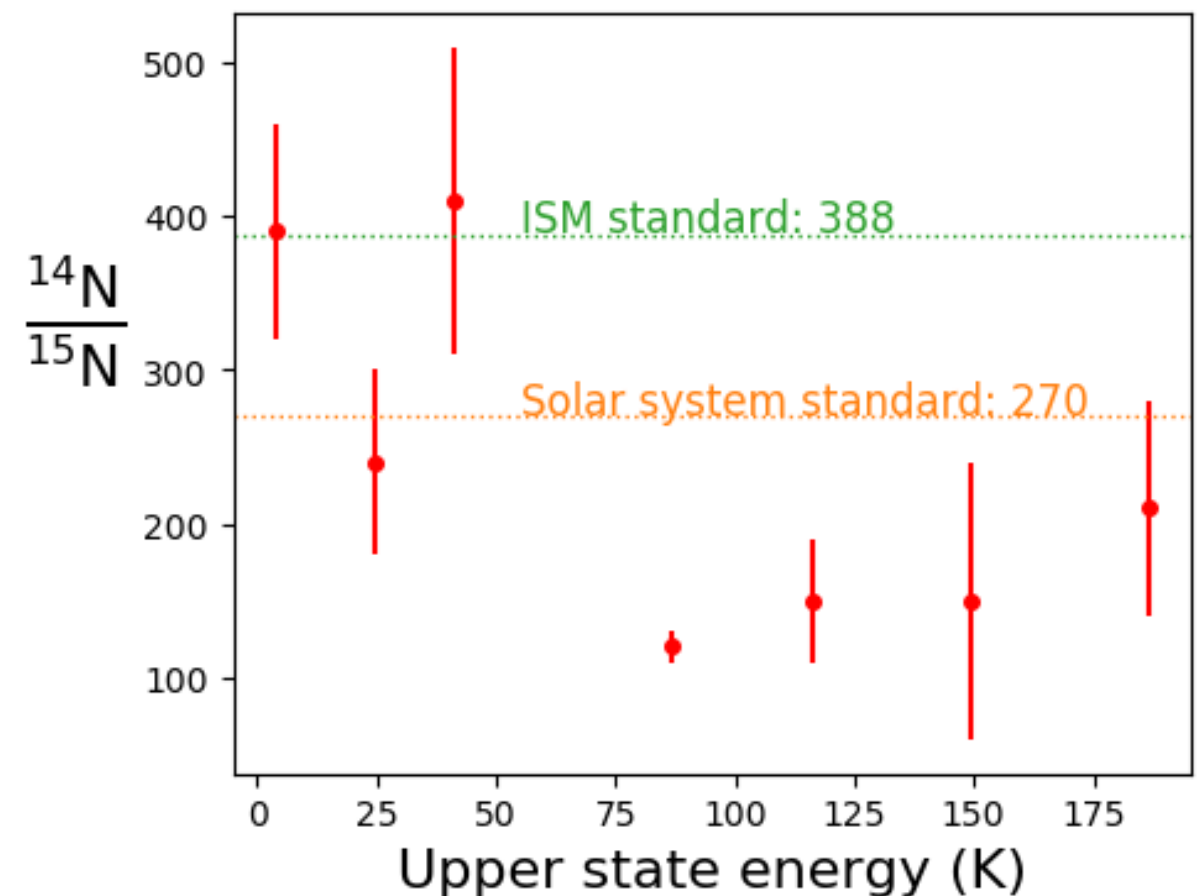
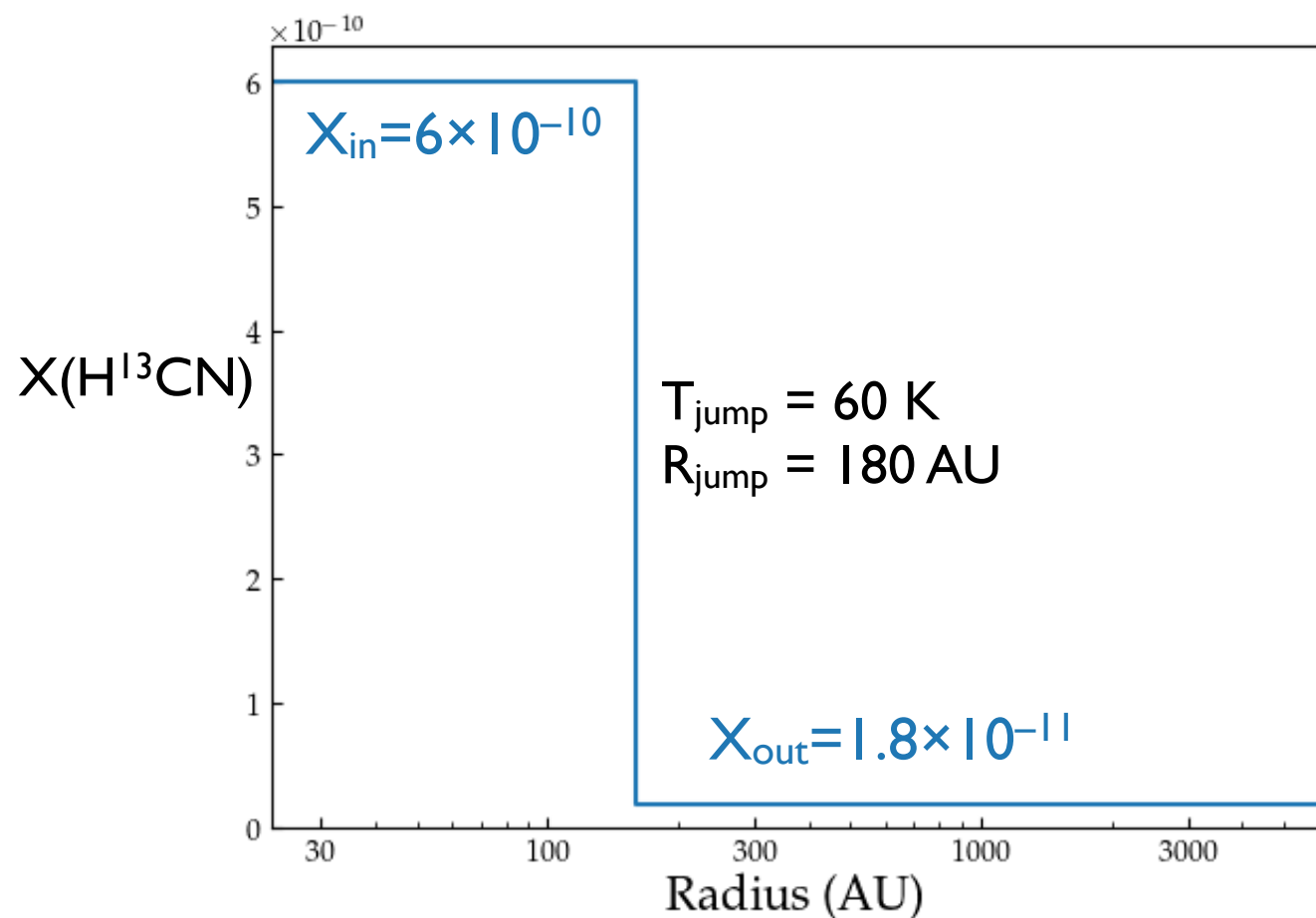


Rice *et al.*, in prep.

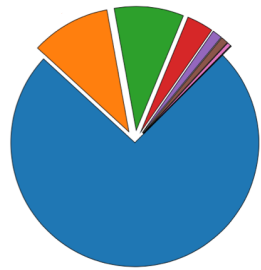
We see ^{15}N enrichment in the high- J lines (model-independent)



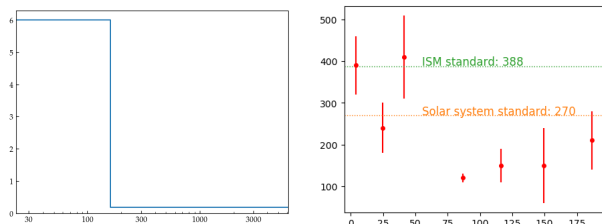
The abundance jump plus selective ^{15}N enrichment suggests ice HCN formation



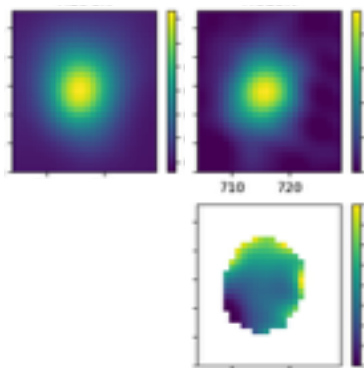
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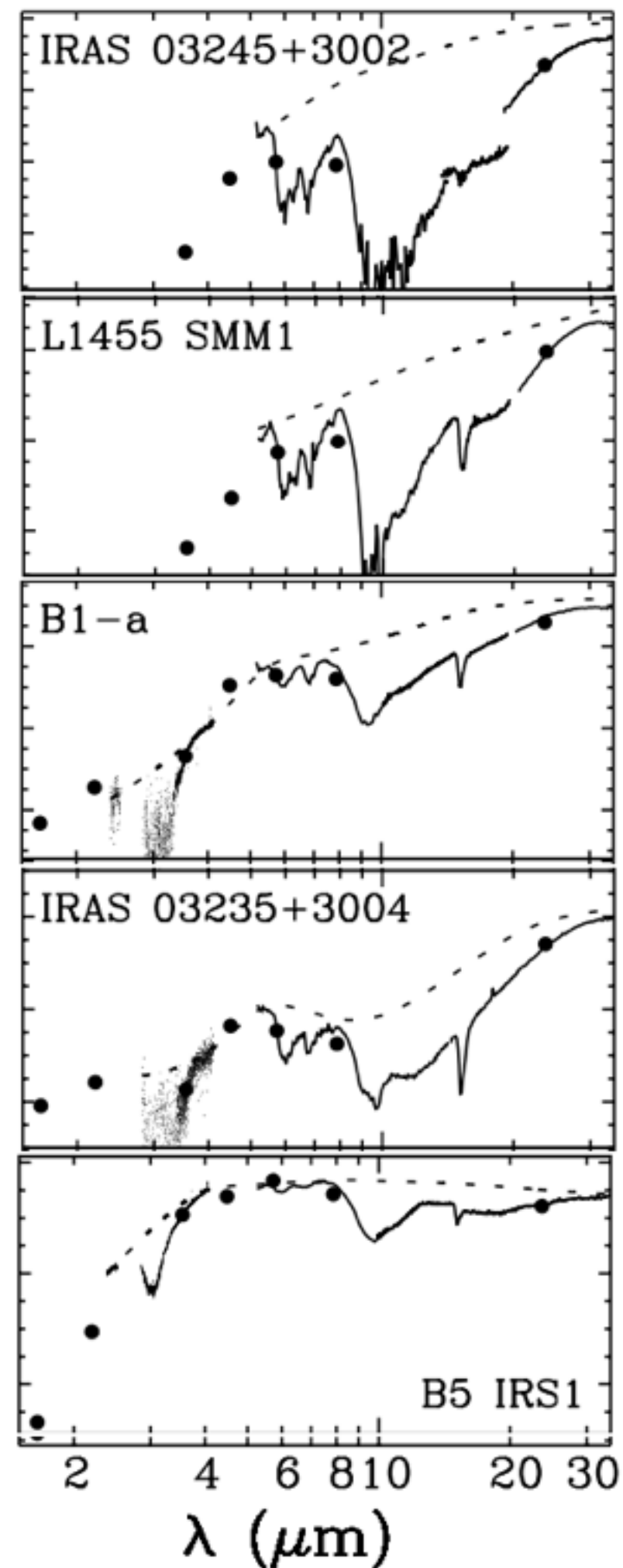
Further work on protostars with NOEMA, ALMA, IRAM-30m, and VLA



Targets: 5 protostars in Perseus (d~230pc)

name — luminosity (L_{sun})

LI455-IRS1	7.0
LI455-IRS4	3.1
B1-a	1.3
IRAS03235	1.9
B5IRS1	4.7



Boogert+08

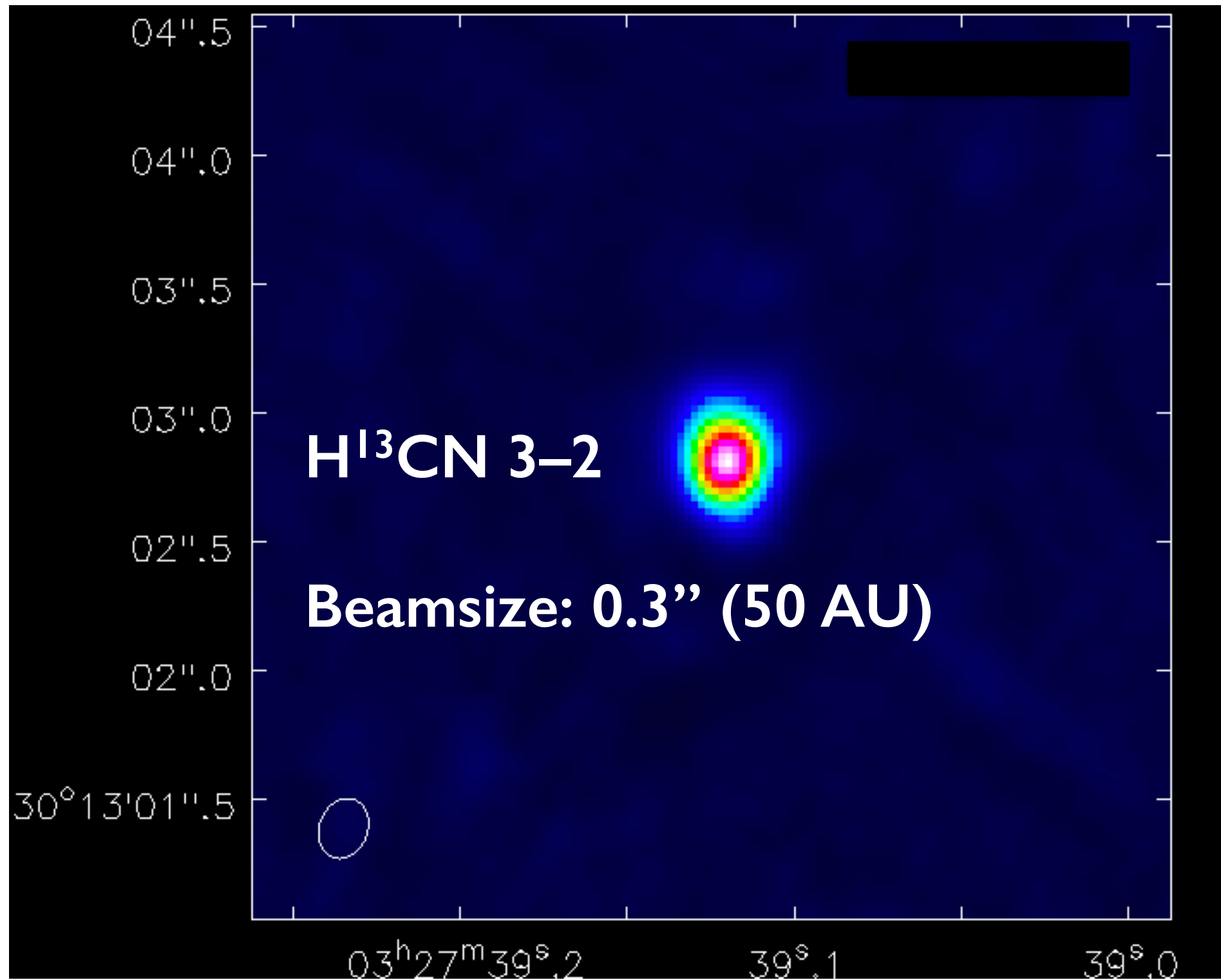
Description of data

- IRAM 30m — 1x  — $\text{H}^{13}\text{CN}, \text{HC}^{15}\text{N}$ — 1–0, 3–2
- NOEMA — 8x  @ 1.5'' — $\text{H}^{13}\text{CN}, \text{HC}^{15}\text{N}$ — 1–0, 3–2*
- ALMA — 40x  @ 0.3'' — $\text{H}^{13}\text{CN}, \text{HC}^{15}\text{N}$ — 3–2
- VLA — 27x  @ 1.5'' — NH_3 — (1,1)–(5,5)

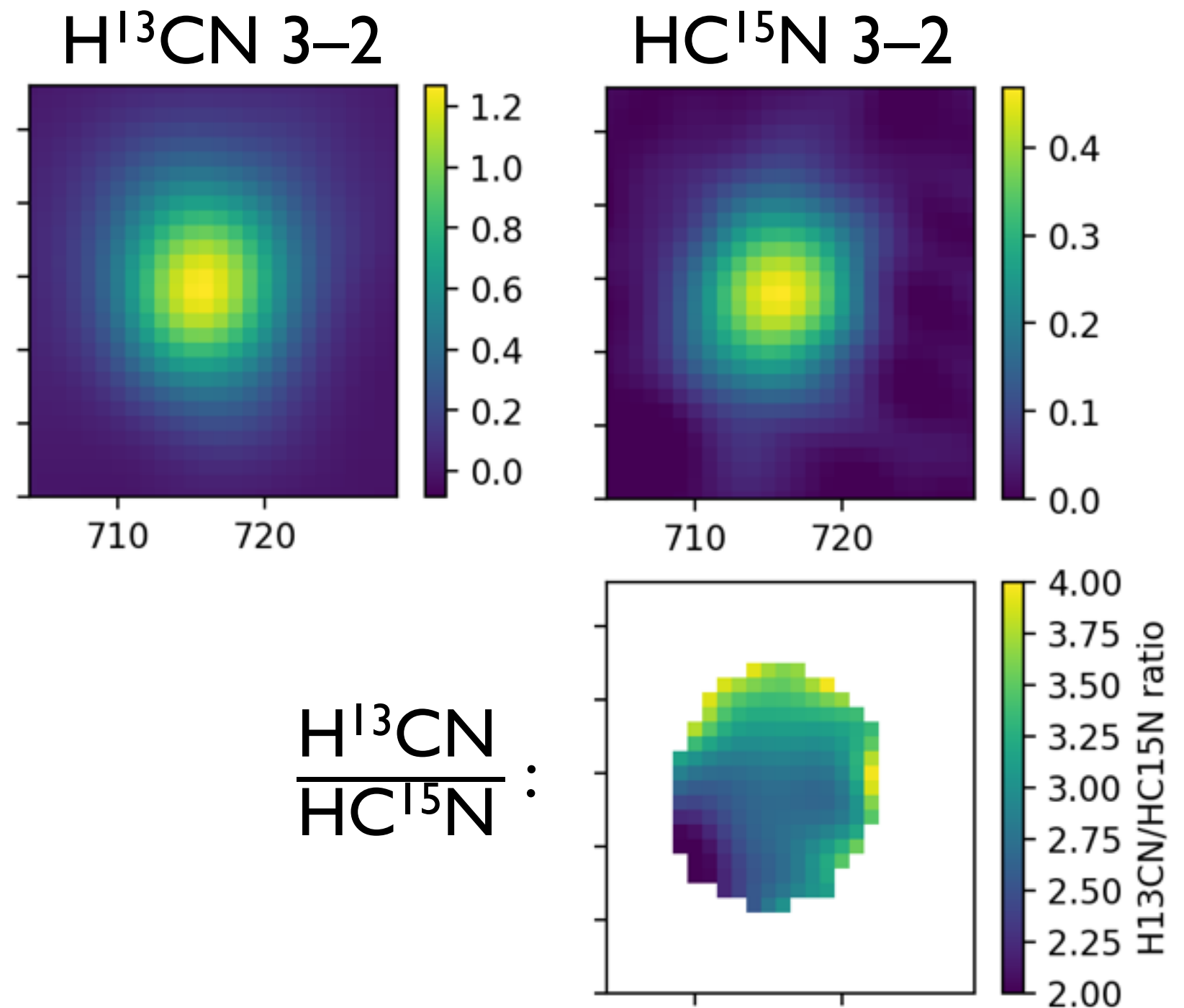
Data x targets

	IRAM 30m	NOEMA (shallow)	NOEMA (deep)	ALMA	VLA
LI455-IRS1	Yes	Yes	Yes	Yes	Yes
LI455-IRS4	Yes	Yes	No	No	No
BI-a	Yes	Yes	No	No	No
IRAS03235	Yes	Yes	No	No	No
B5IRS1	Yes	Yes	No	No	No

Maps from ALMA

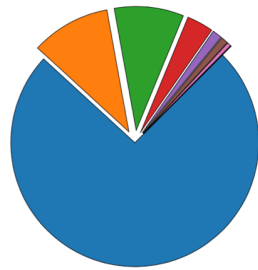


Maps from ALMA

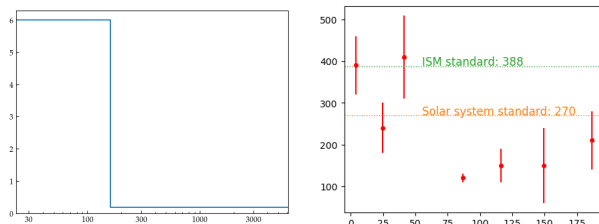


→ $^{14}\text{N}/^{15}\text{N} \sim 140\text{--}280$

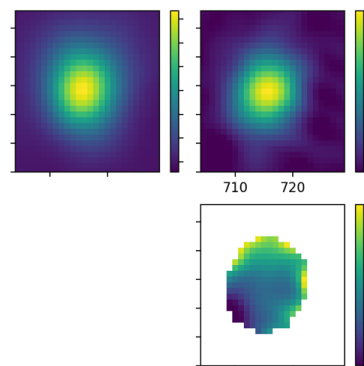
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Something interesting is going on with HCN, so let's see where it takes us.