Below the Surface of Embedded Protostars

envelope structure and kinematics

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EAO seminar
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Collaborators

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DIGIT and COPS teams

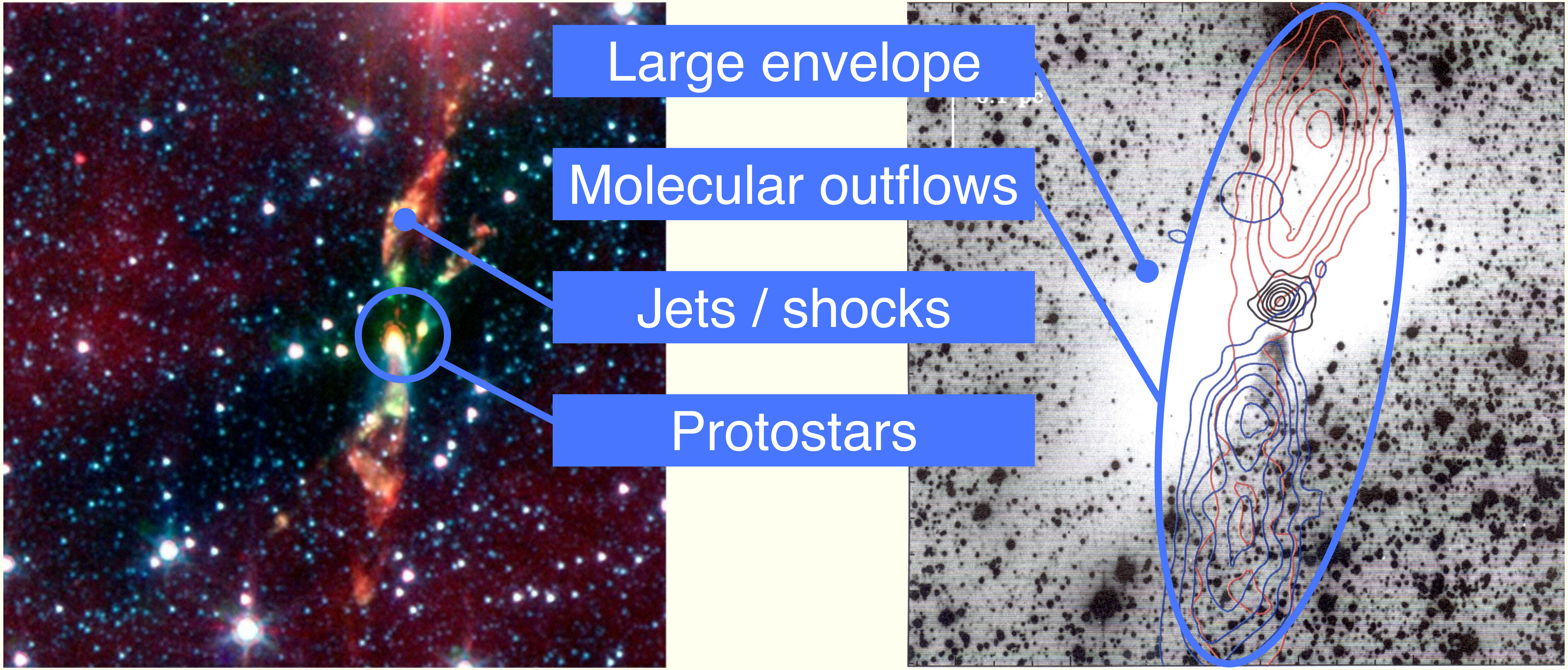
Image credit: NAOJ


30 Doradus
NASA, ESA, D. Lennon and E. Sabbi (ESA/STScI)+

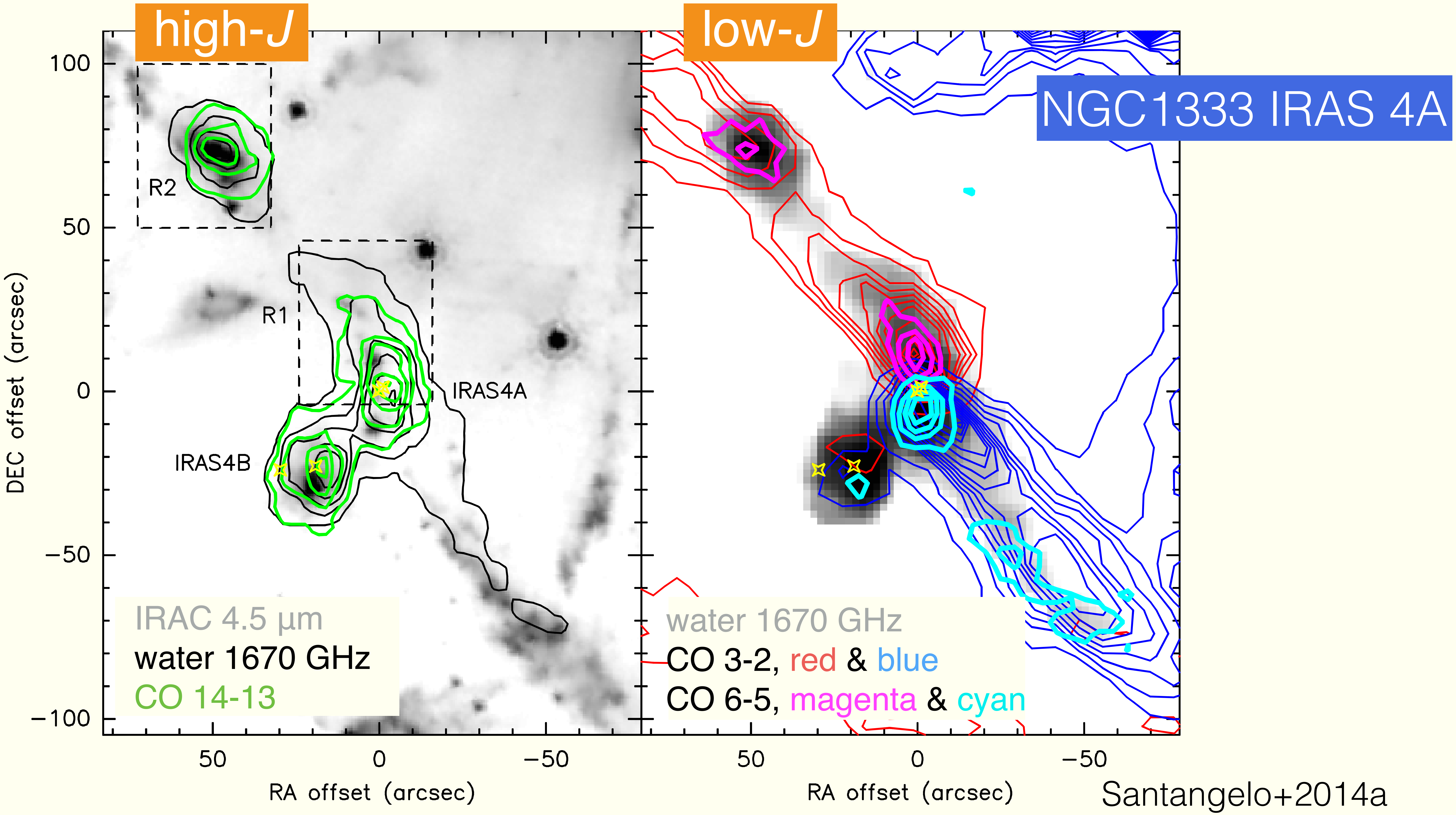

Taurus Molecular Cloud
Credits:
Optical: Iñaki Lizaso
Far-IR: ESA/Herschel/PACS, SPIRE/
Gould Belt survey Key Programme/
Palmeirim et al. 2013


NGC 1333
R. A. Gutermuth et al. JPL/NASA (*Spitzer*)

Characterize the youngest protostars with *Herschel*

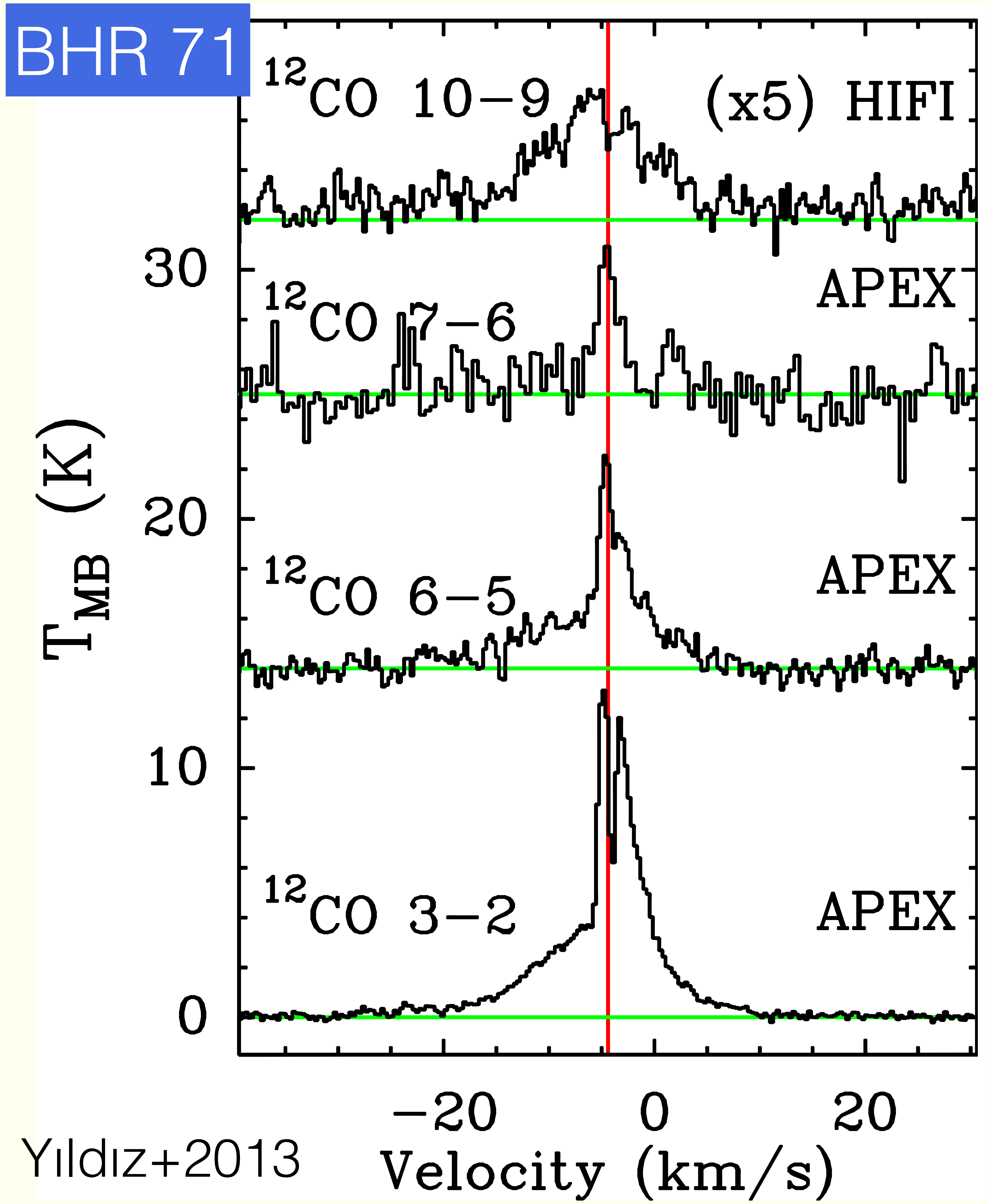


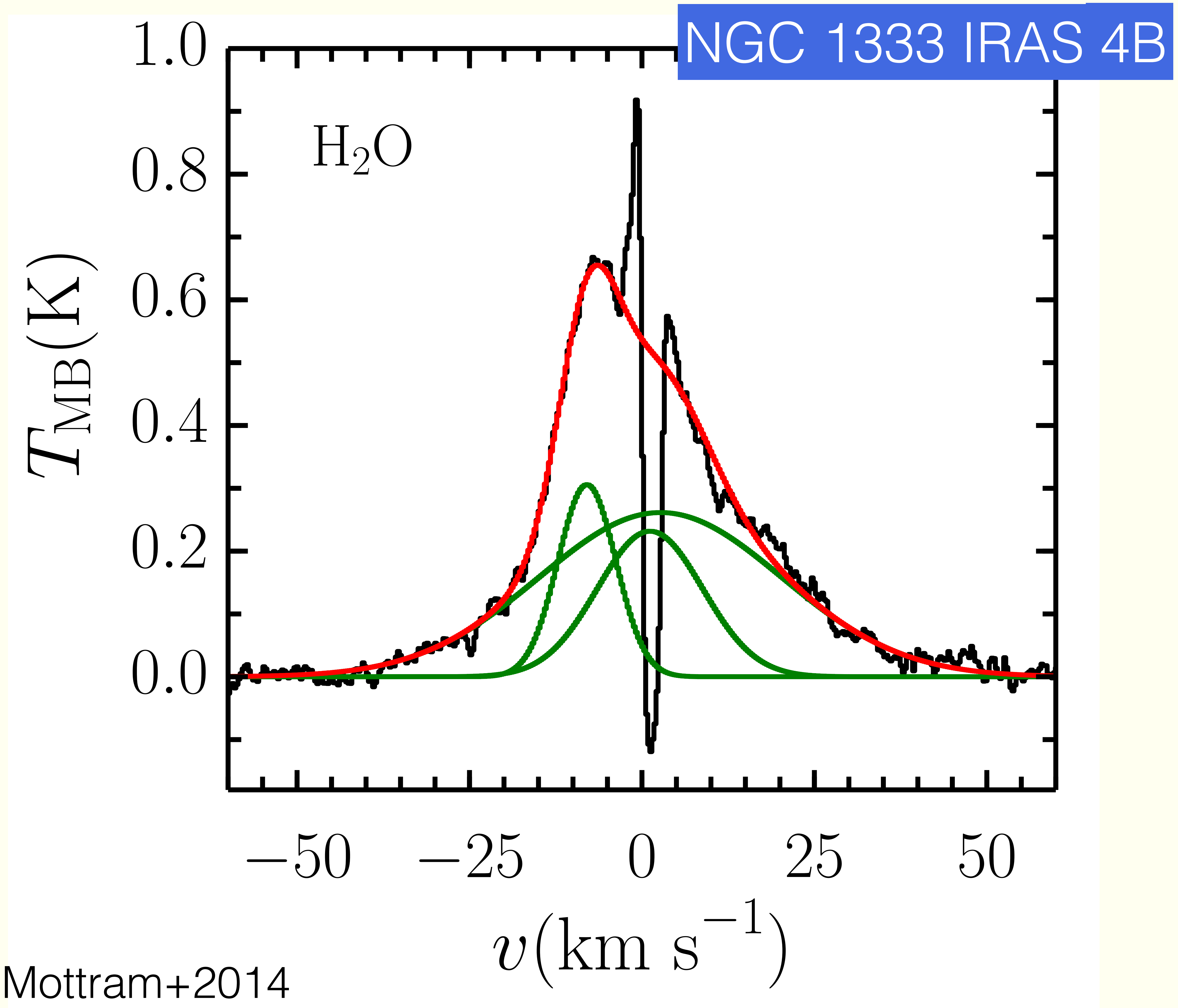
Far-IR emission of CO and water tracing outflows and shocks



Santangelo+2014a

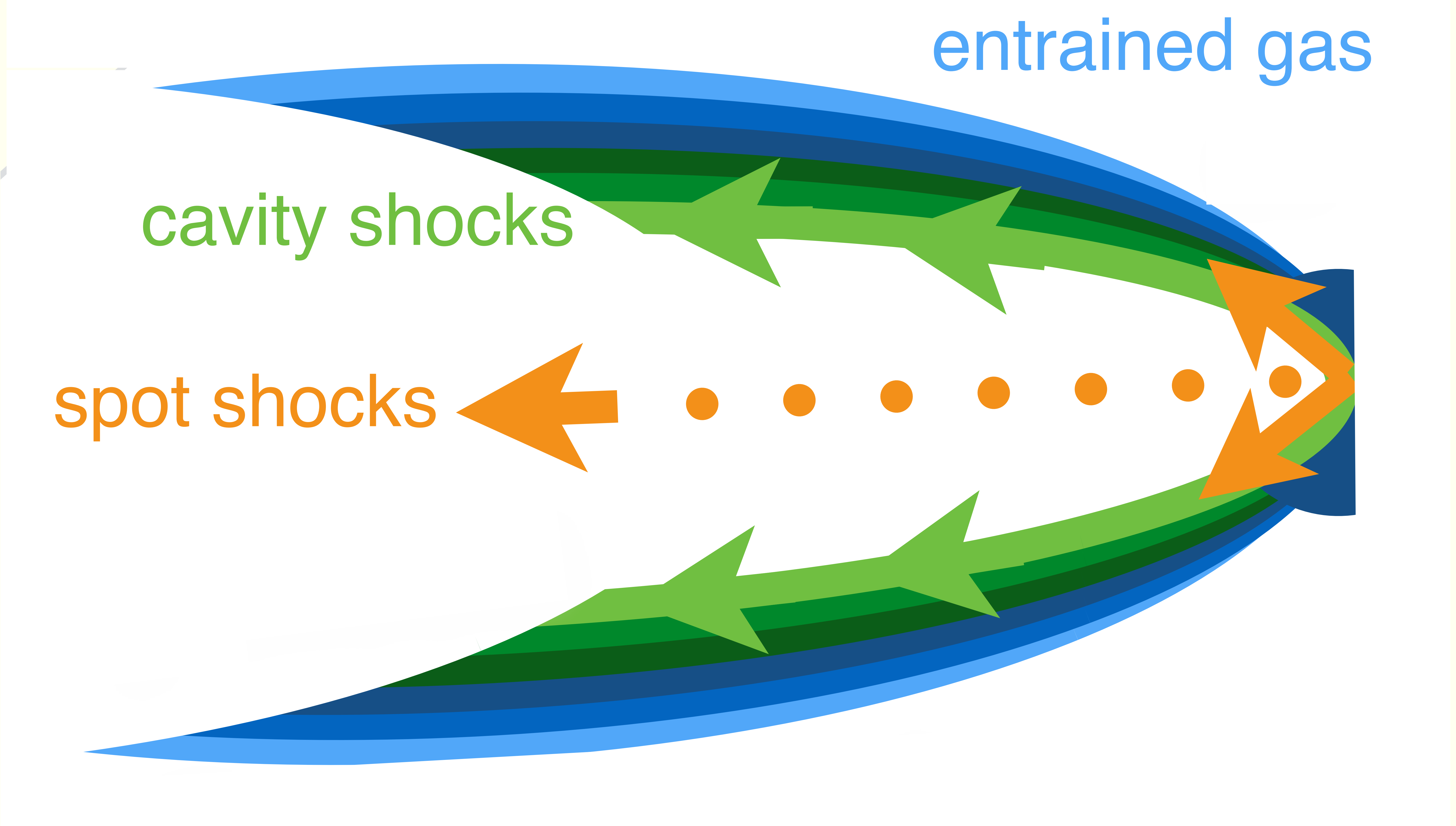
Resolved emission unveils the origins of CO and water





The origin of CO emission

Proposed by Mottram+2014



Modified from Fig. 10 in Kristensen+2017

DIGIT COPS to solve the cases

Dust, Ice, and Gas In Time
(PI: Neal Evans)

Herschel-PACS: 50-200 μm

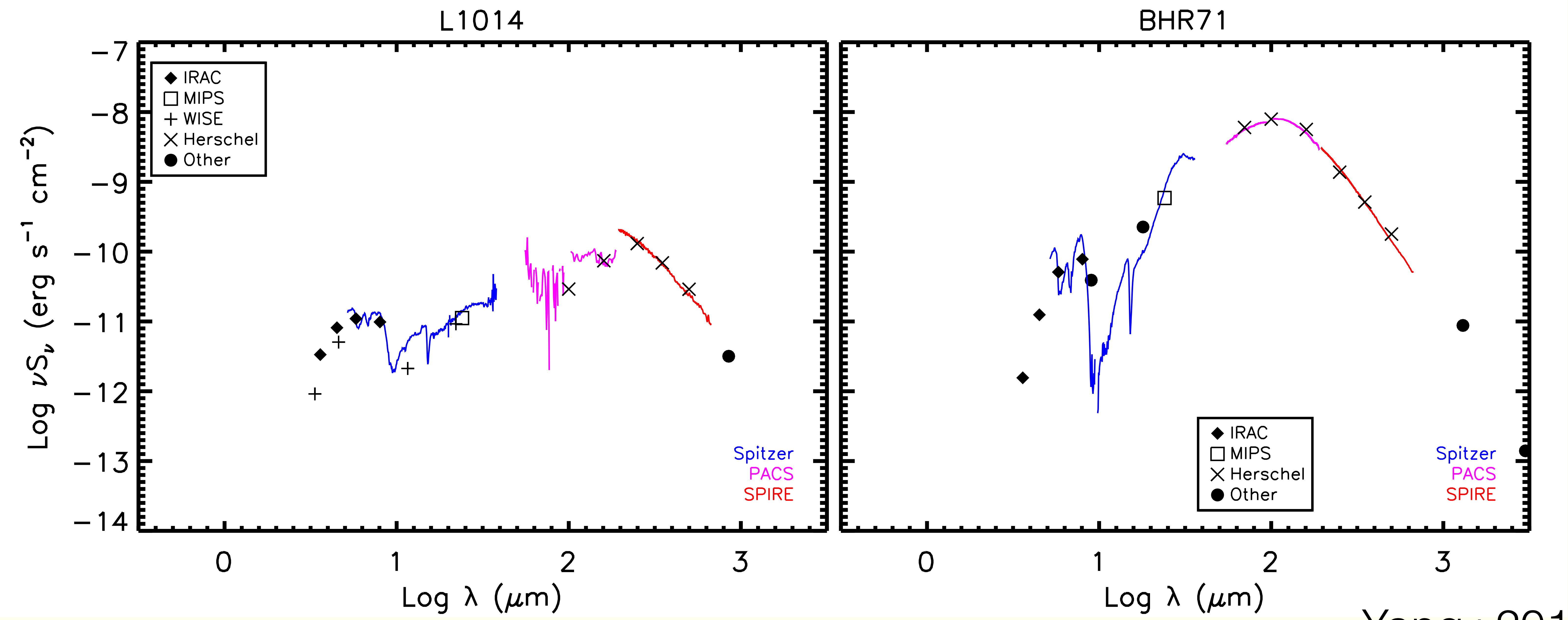
CO in ProtoStars
(PI: Joel Green)

Herschel-SPIRE: 200-670 μm

- **30 embedded protostars (Green+2013)**
- 24 Herbig Ae/Be
- 6 T Tauri stars

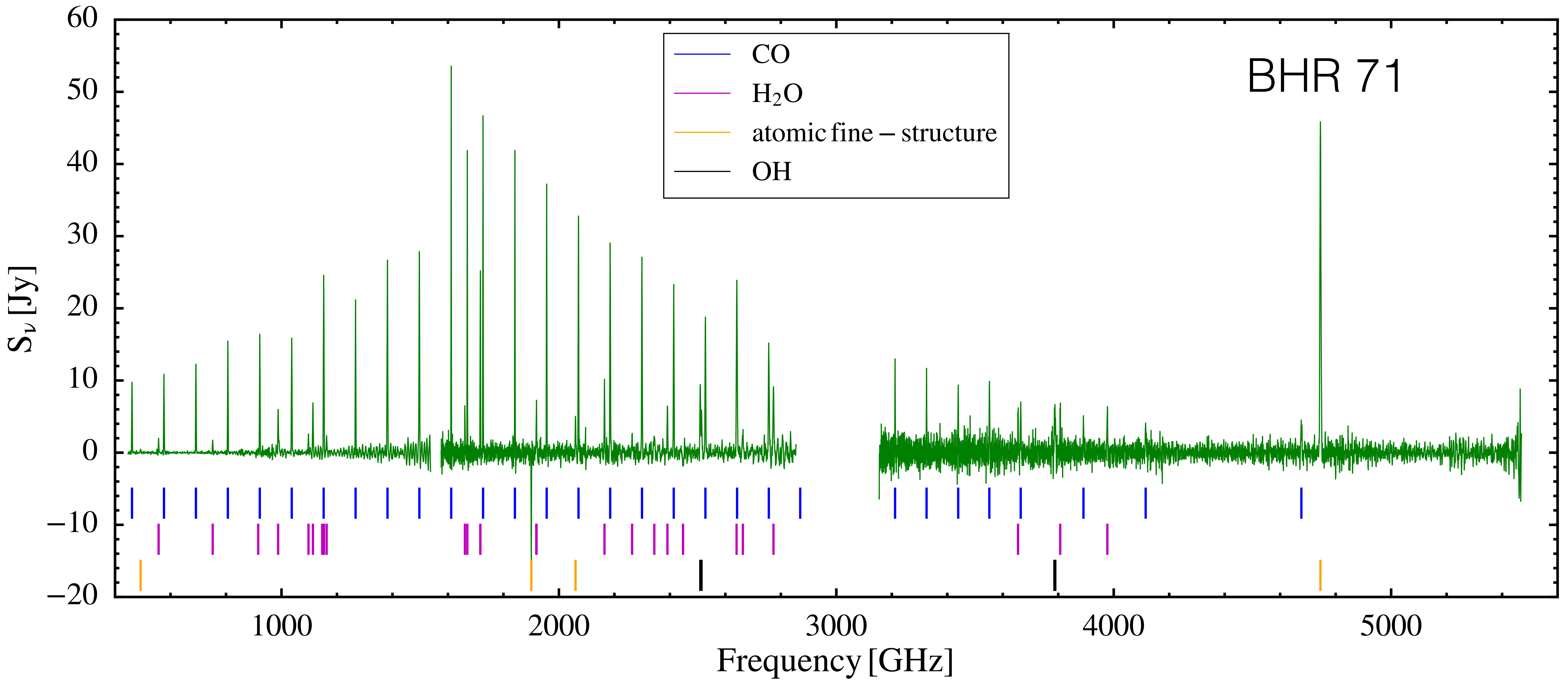
- **25 embedded protostars (Yang+2018)**

Reduced data and line fitting results released to *Herschel* Science Archive and with Yang+2018



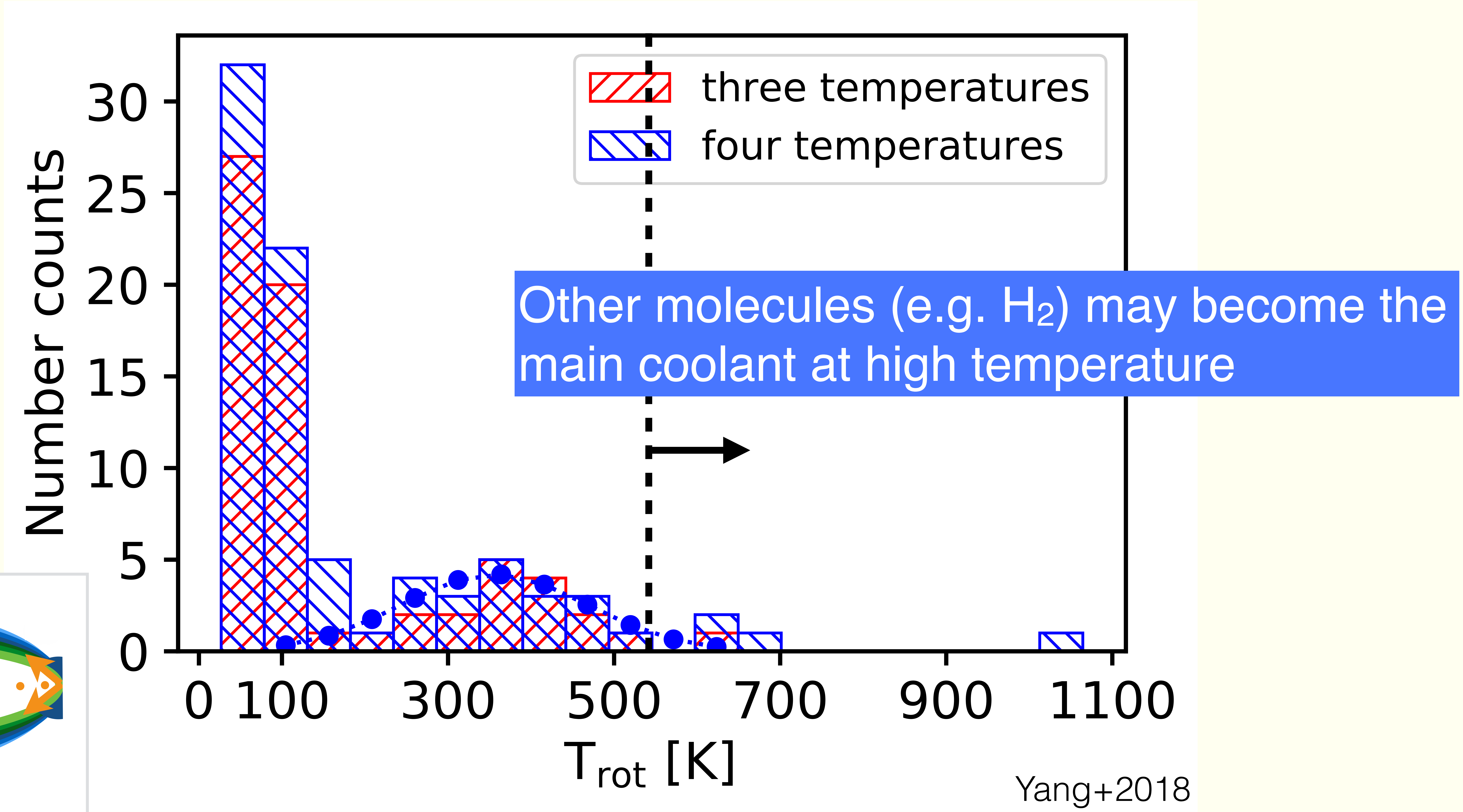
Yang+2018

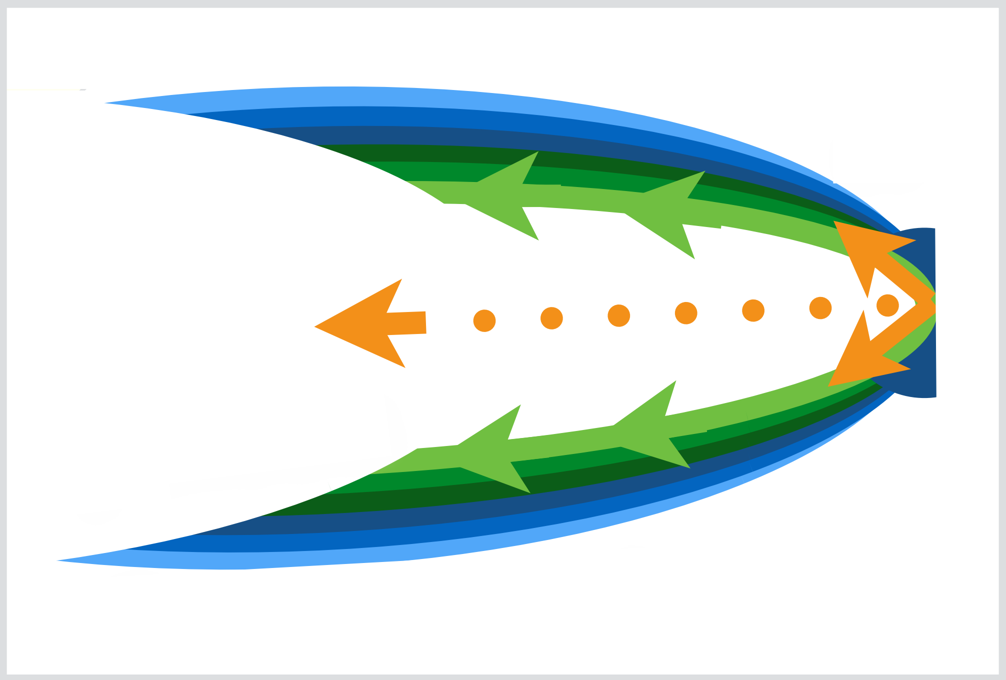
An inventory of molecular and atomic emission lines



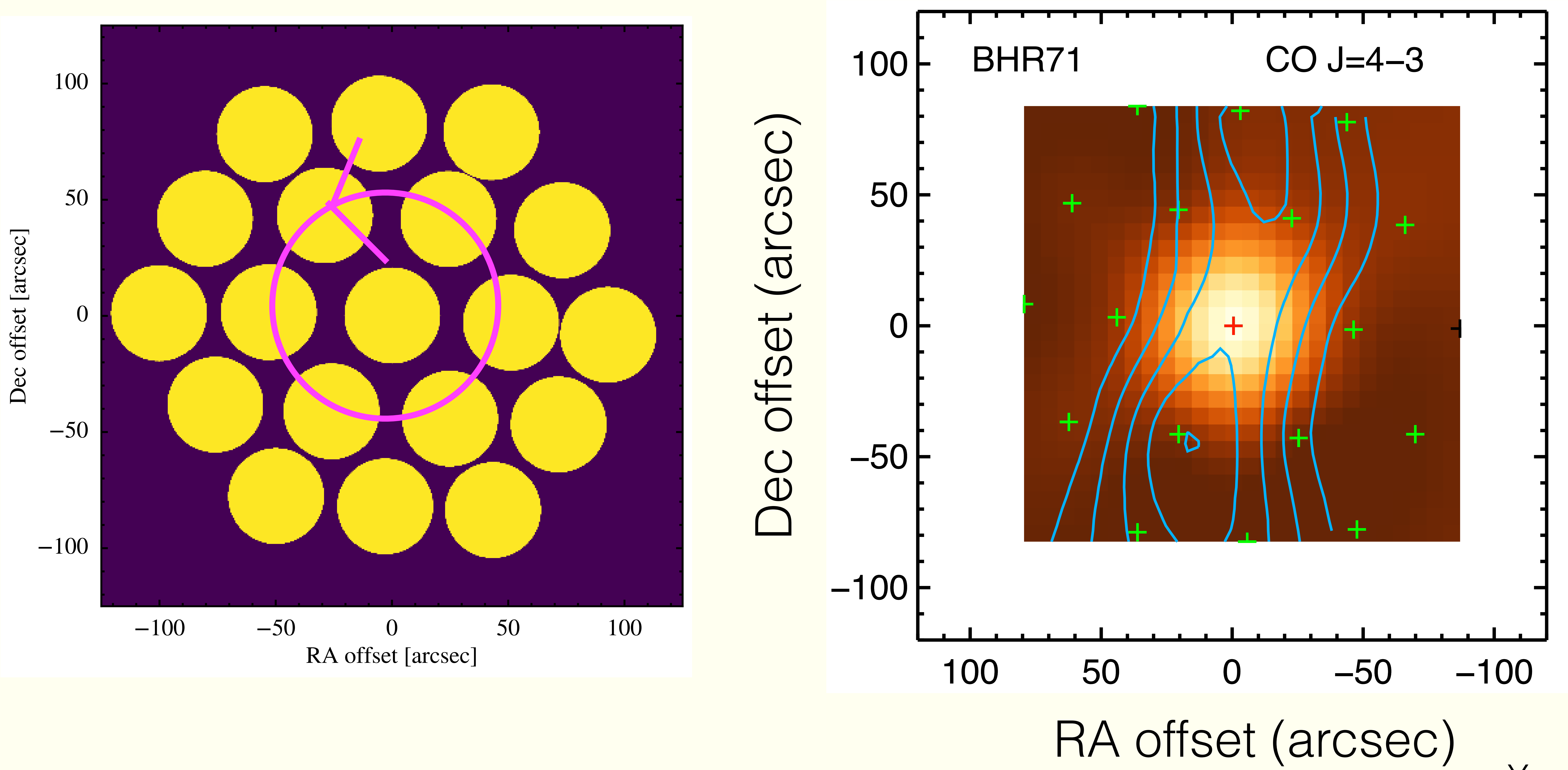
Yang+2017

Two distinct populations of rotational temperatures



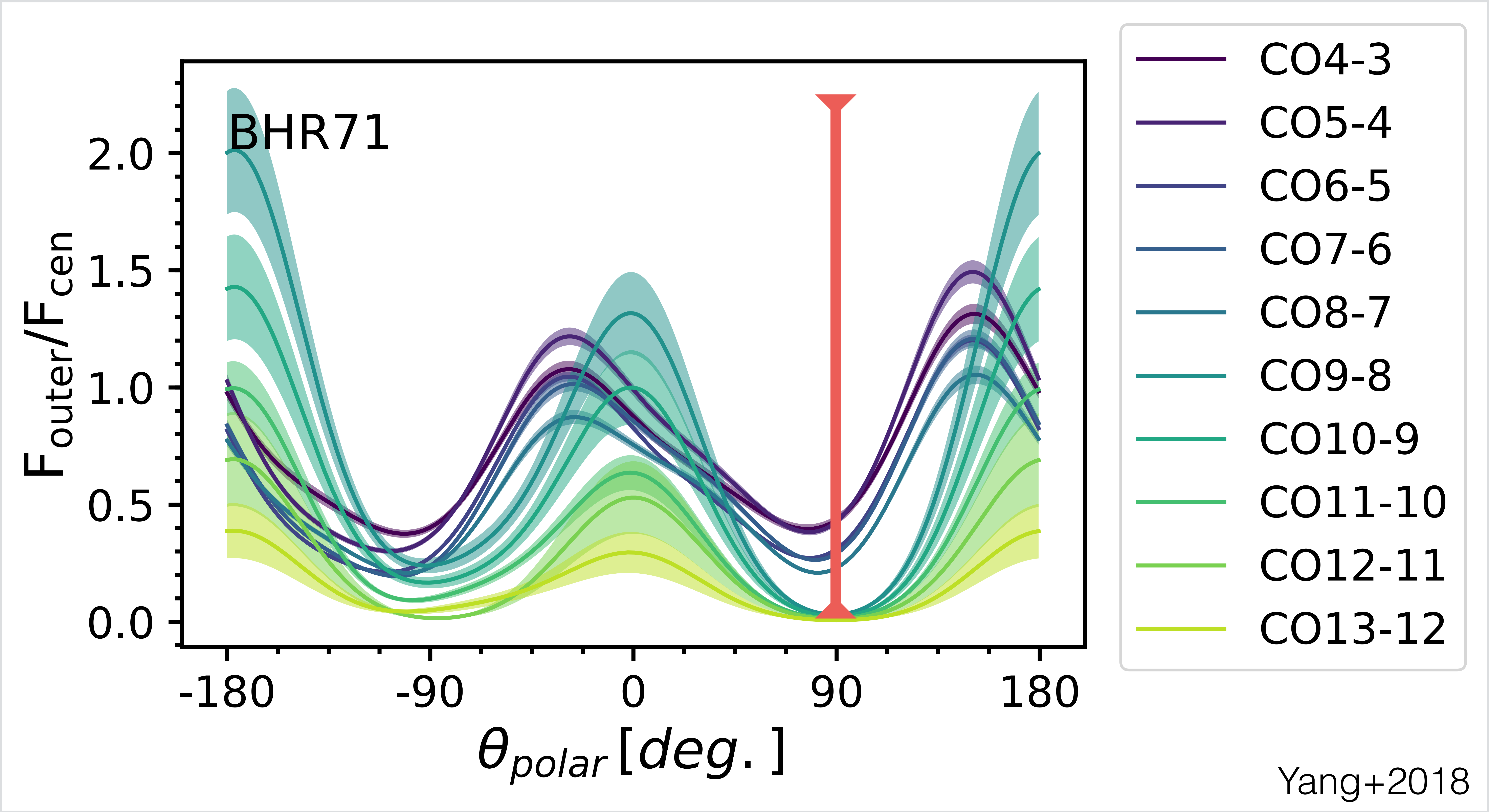


Spatial extent of the CO emission

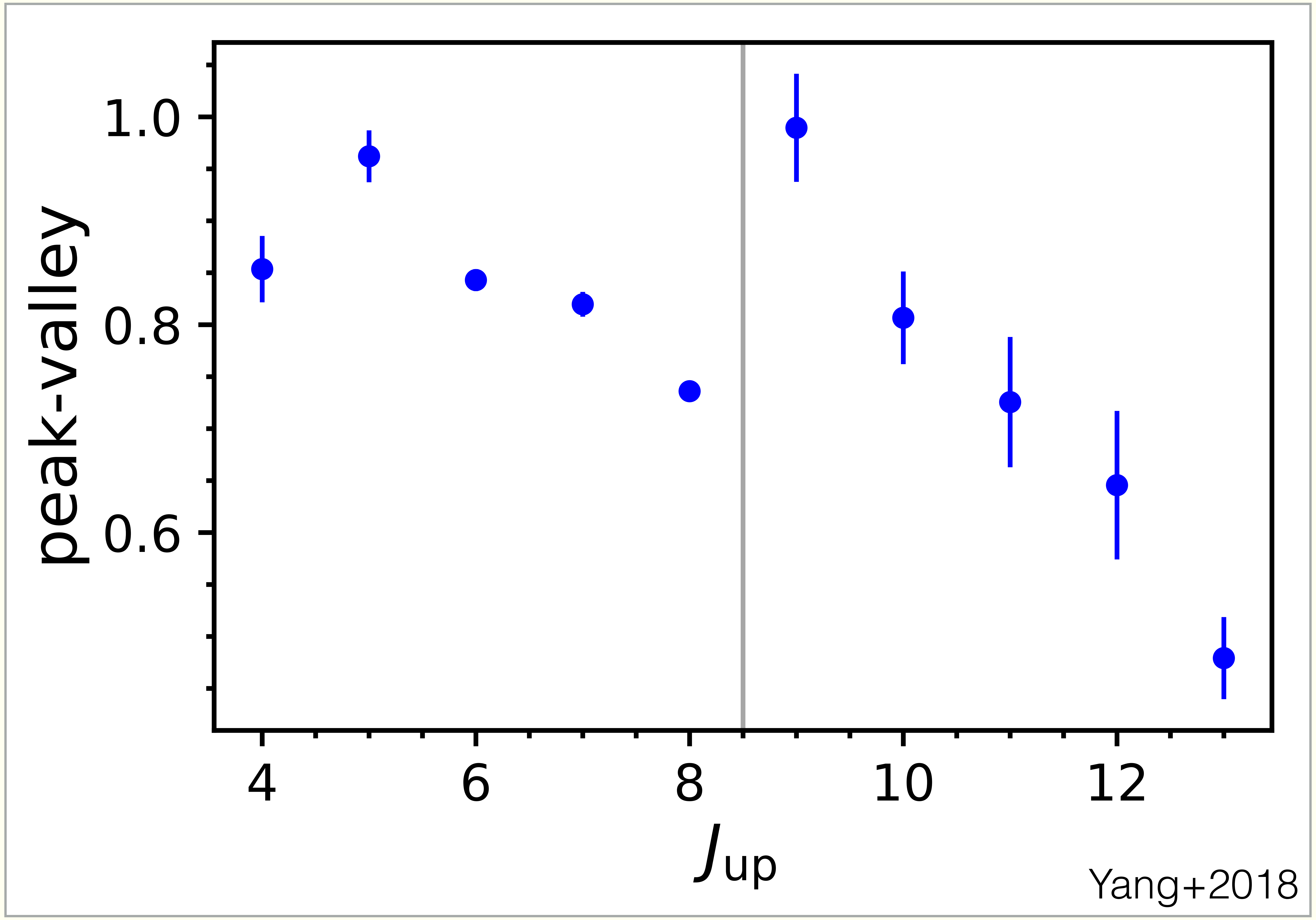


Yang+2018

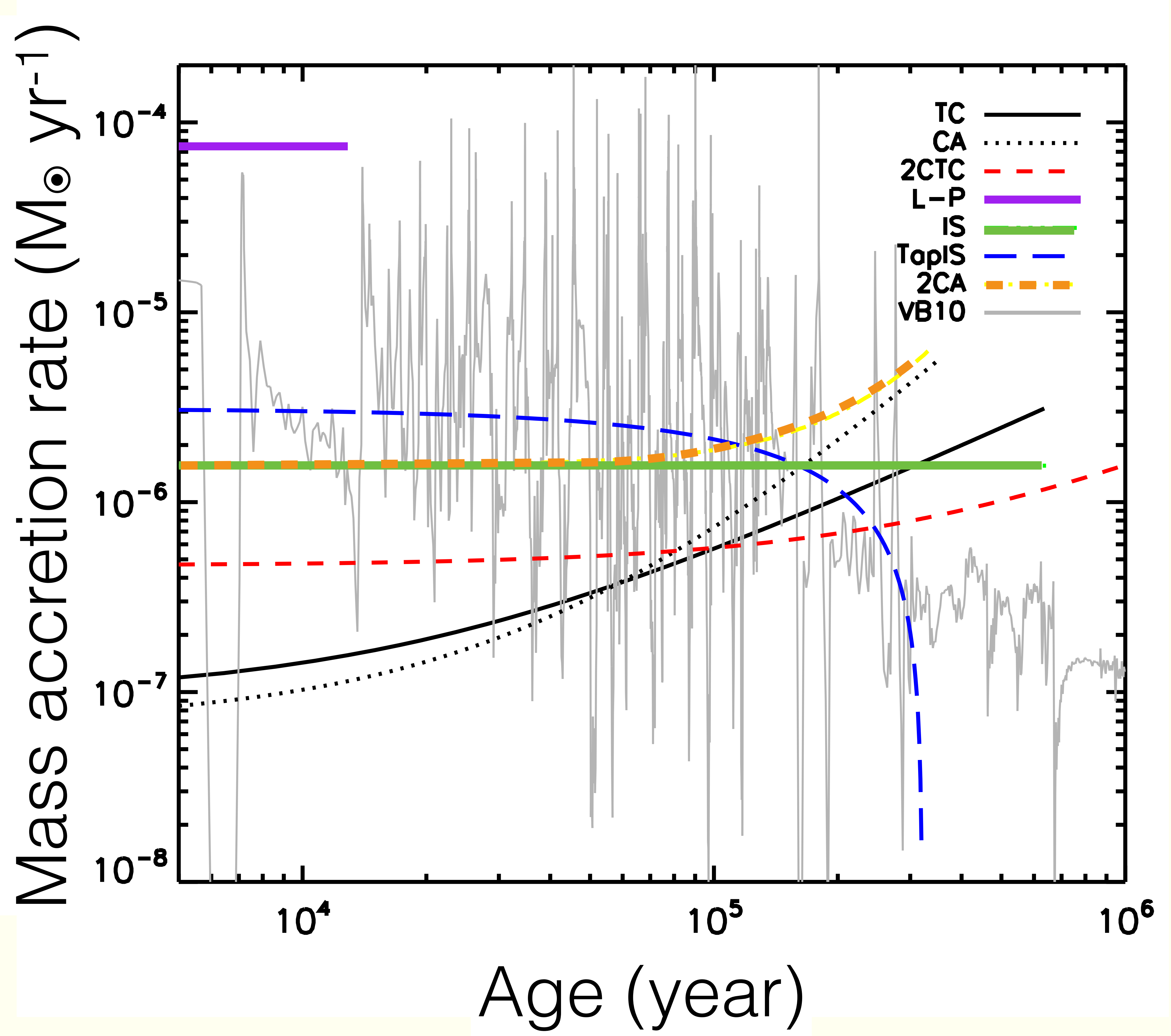
Azimuthal flux distribution to quantify bipolarity

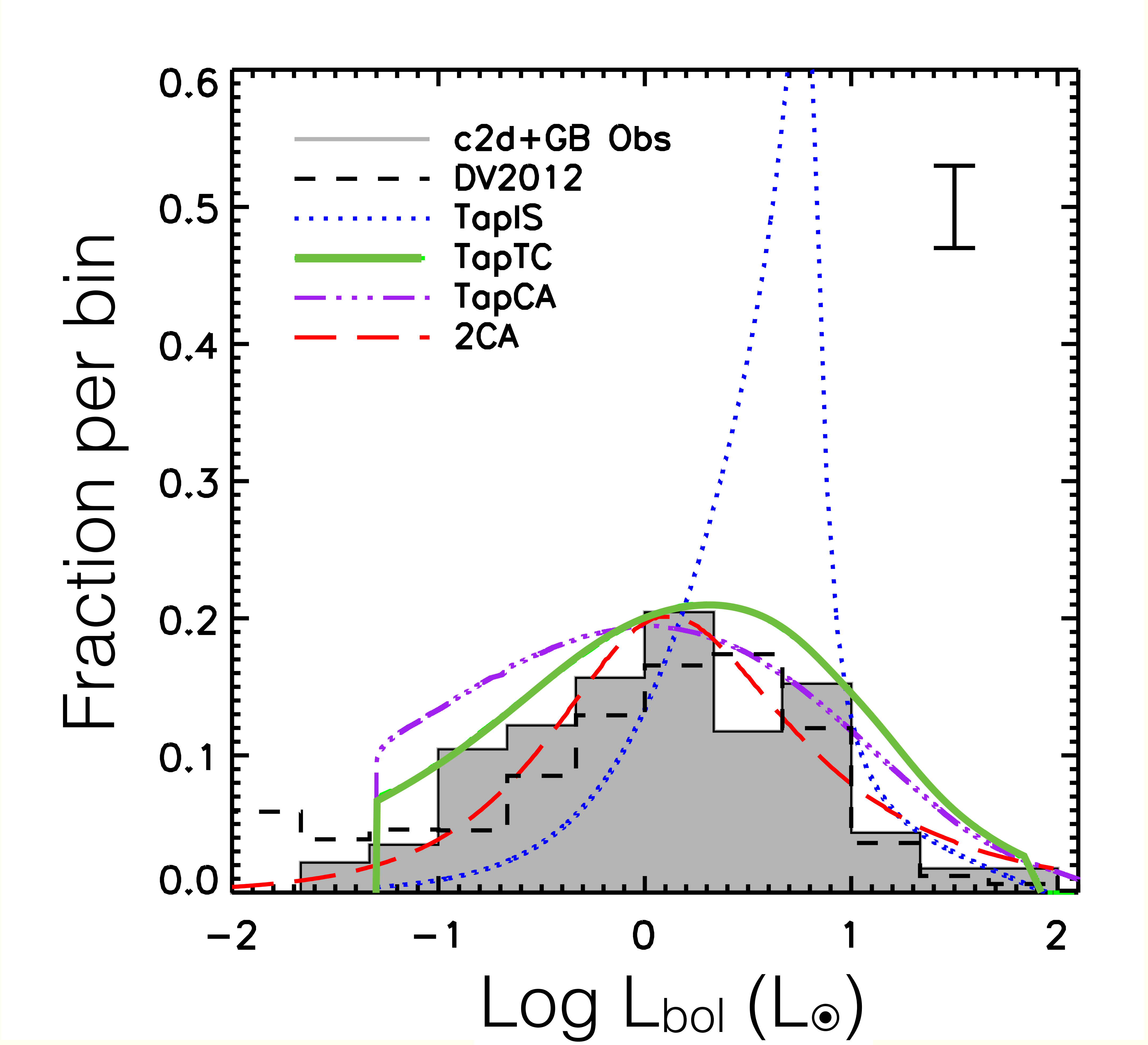


The extent of CO emission decreases at higher-*J*



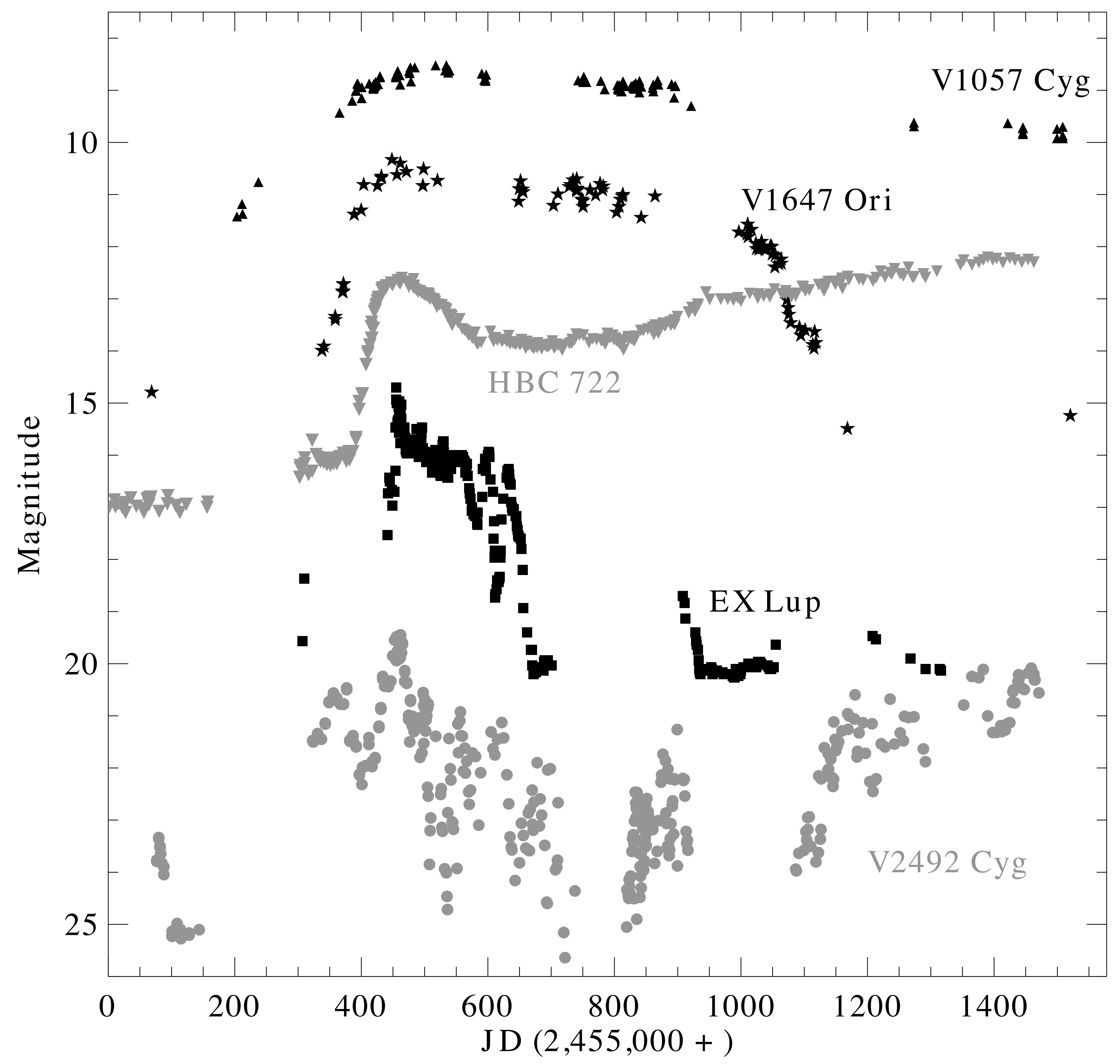
How does the dense core collapse?



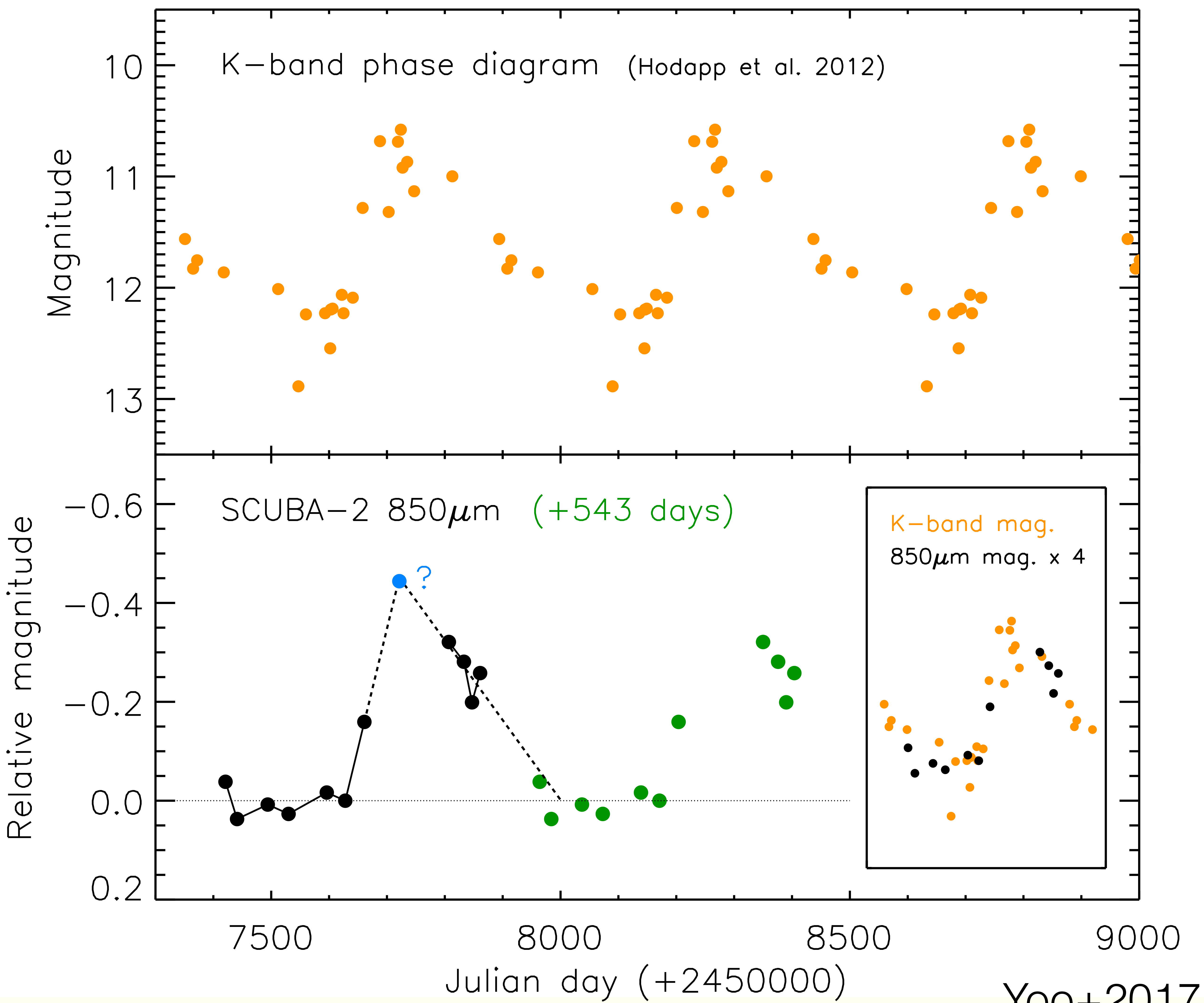


Dunham+2014 (PPVI review)

Accretion variability

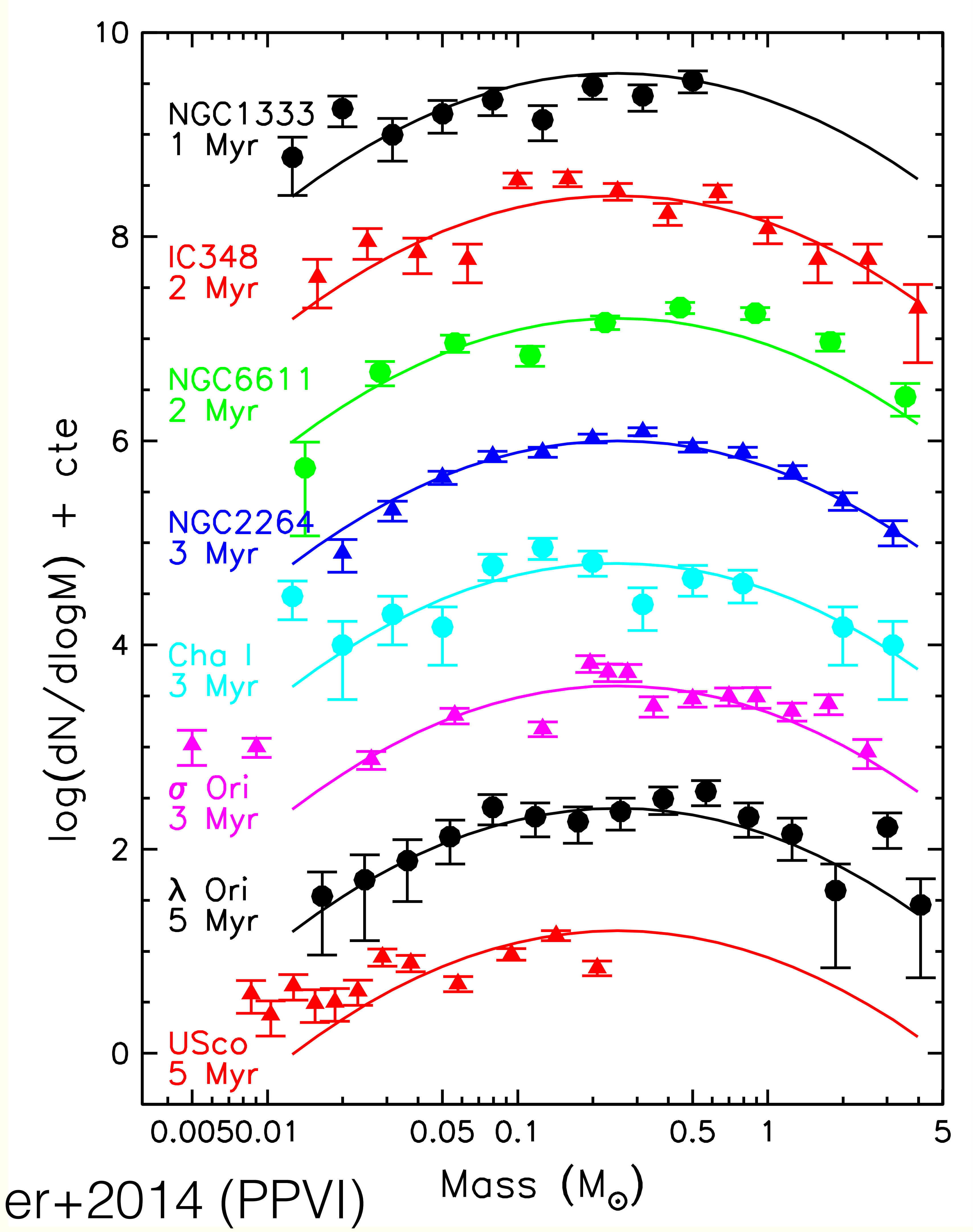


Audard+2014 (PPVI)



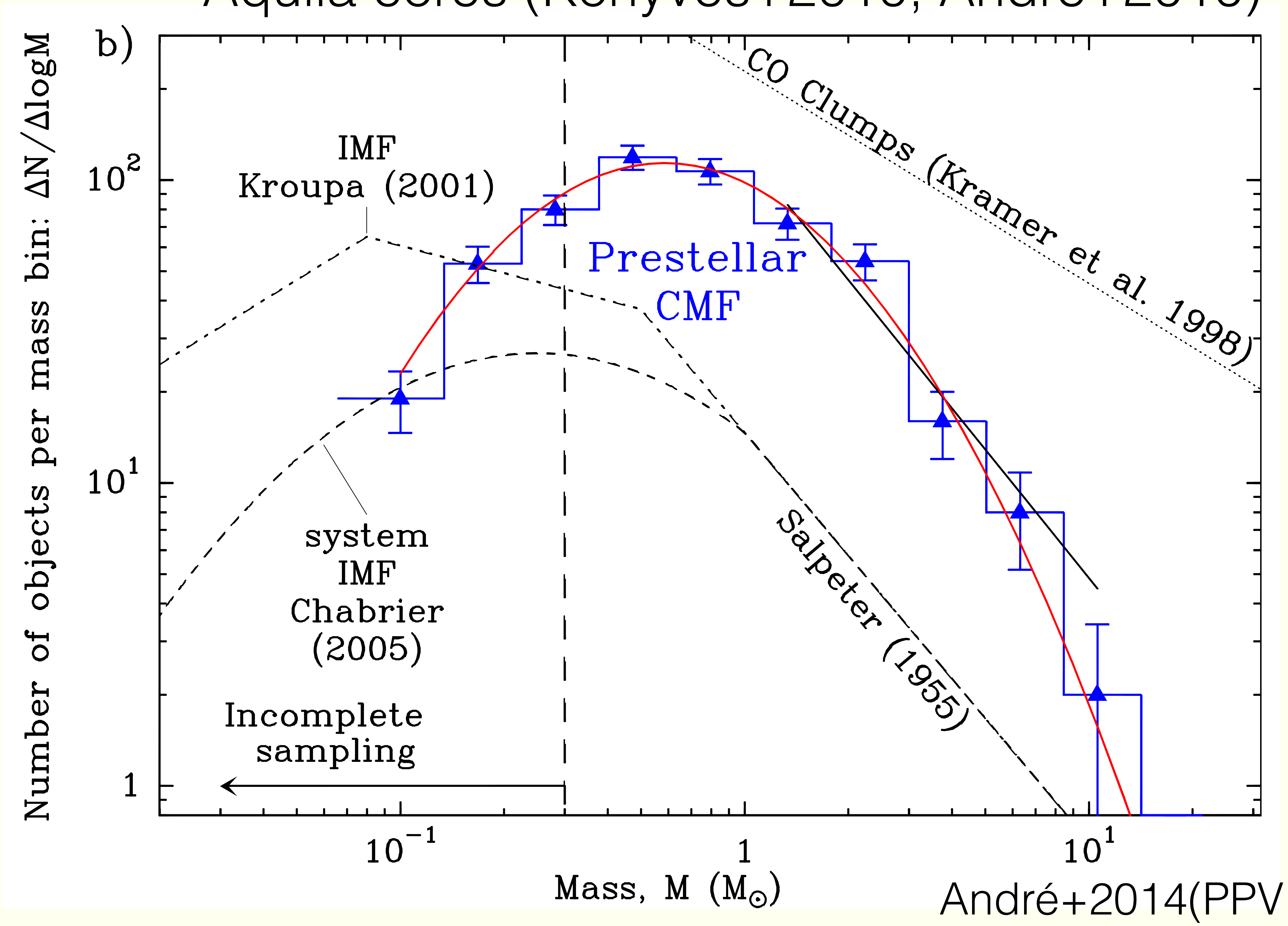
Yoo+2017

Initial Mass Function



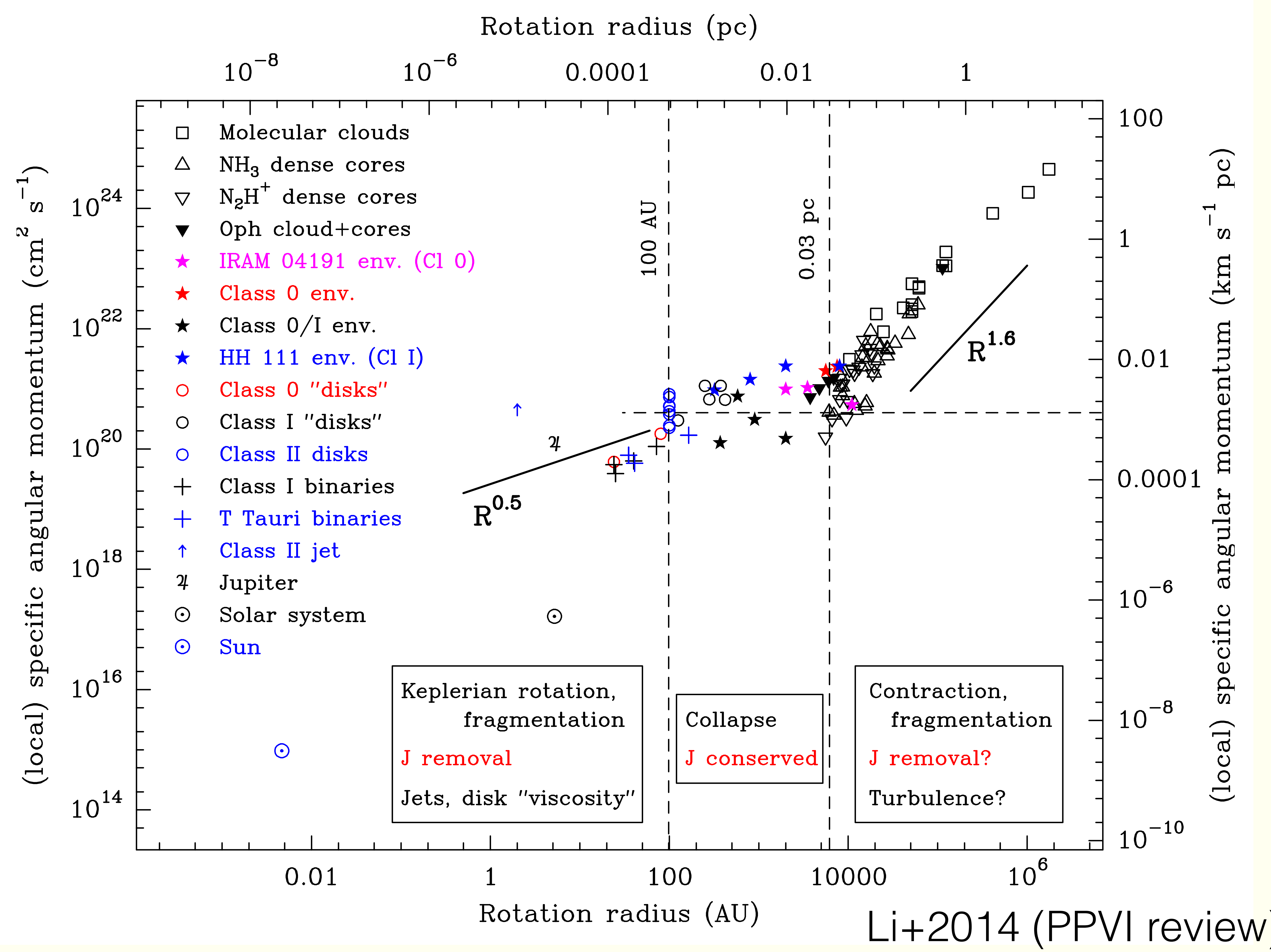
Offner+2014 (PPVI)

Aquila cores (Könyves+2010, André+2010)



André+2014(PPVI)

The evolution of angular momentum during the collapse



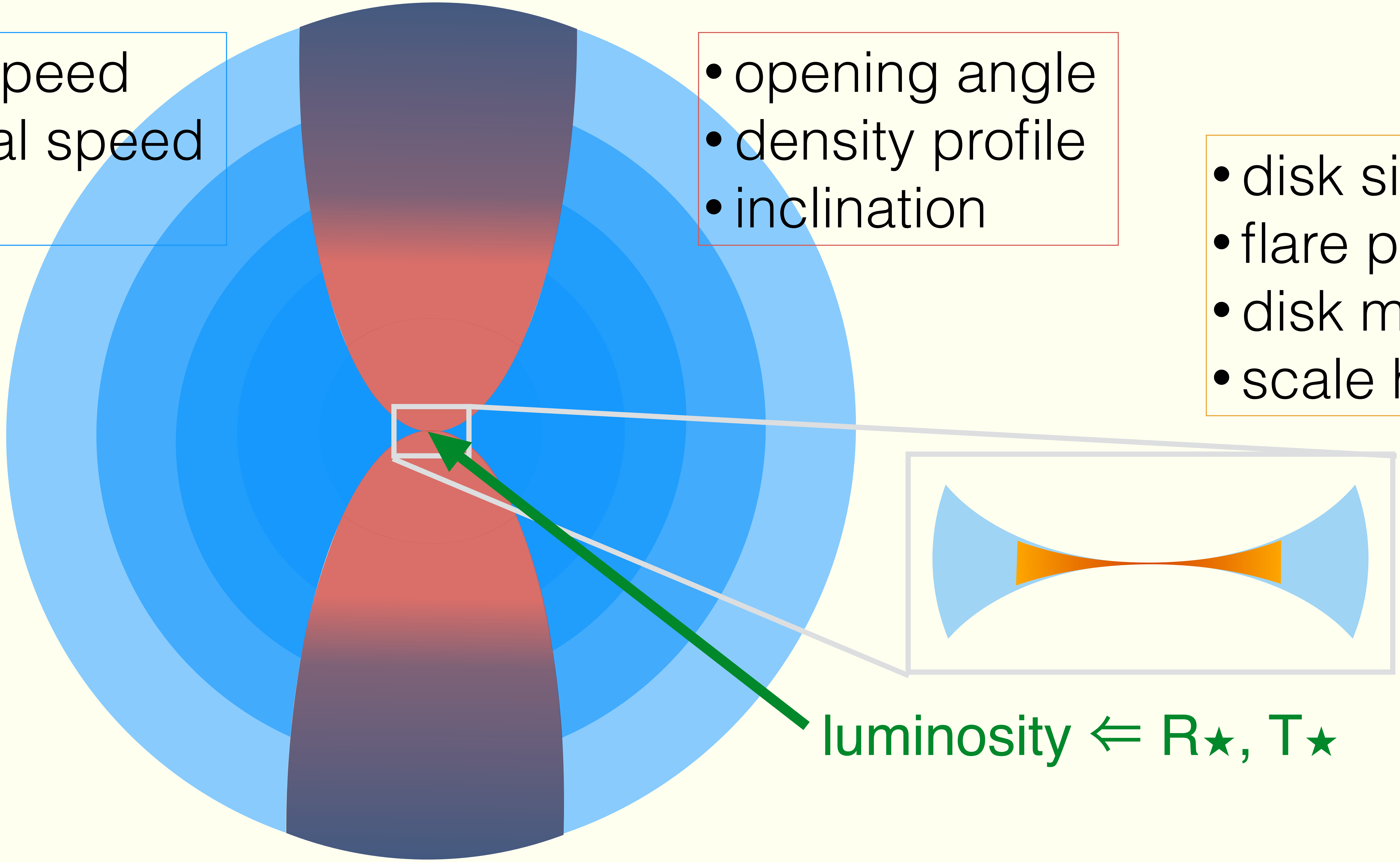
Li+2014 (PPVI review)

Model the structure of protostellar envelope

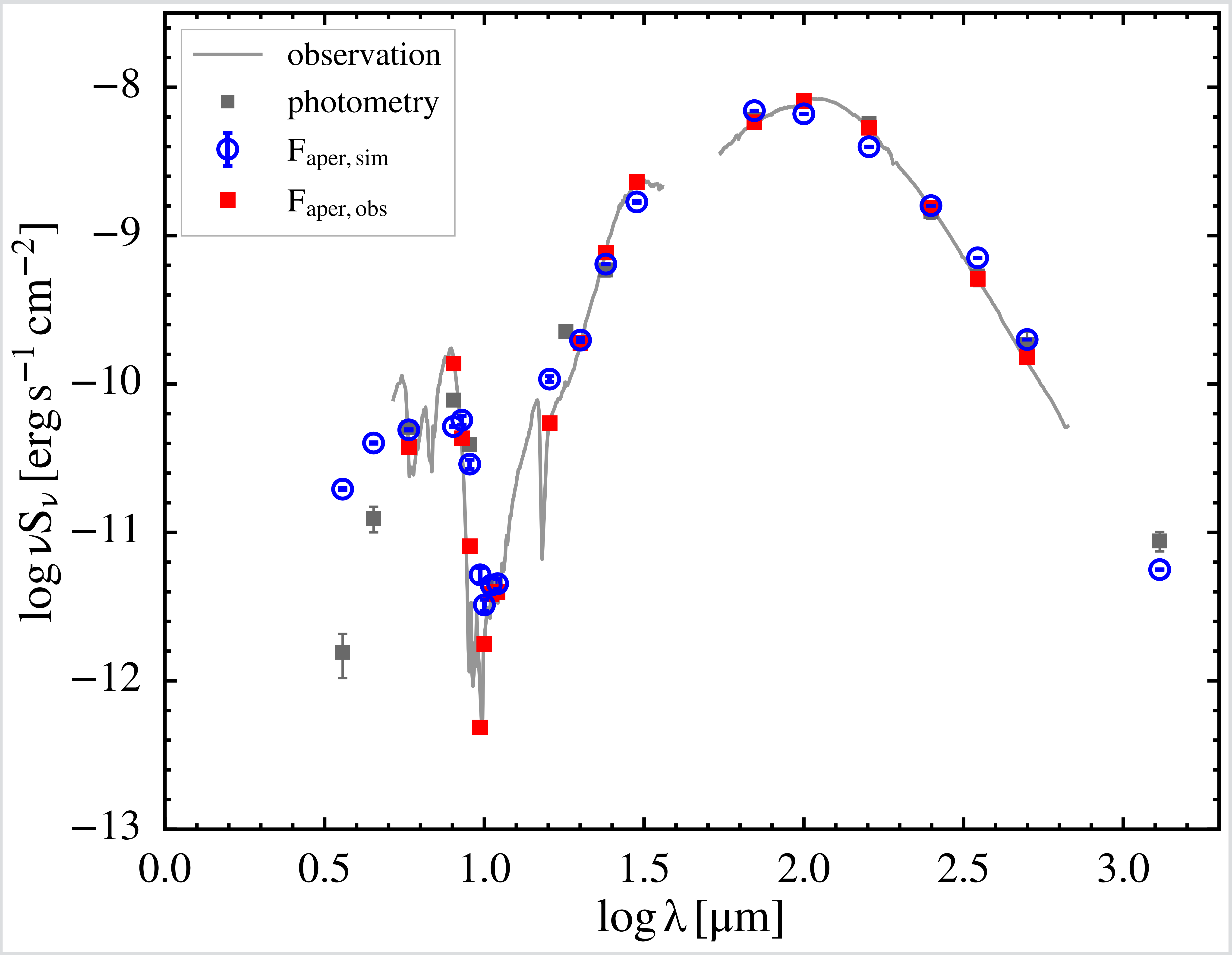
- sound speed
- rotational speed
- age

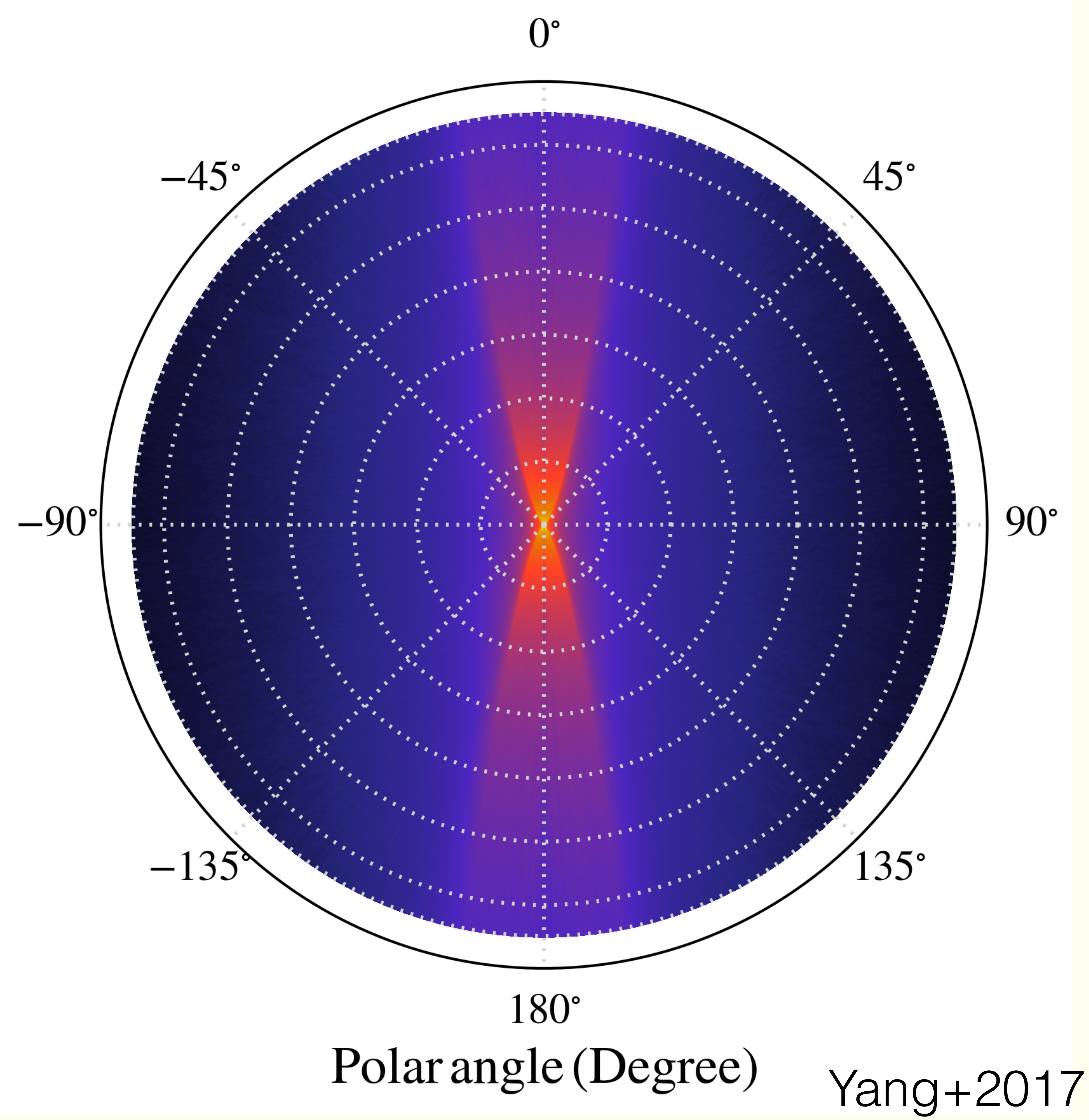
- opening angle
- density profile
- inclination

- disk size
- flare power
- disk mass
- scale height



Model the structure of protostellar envelope

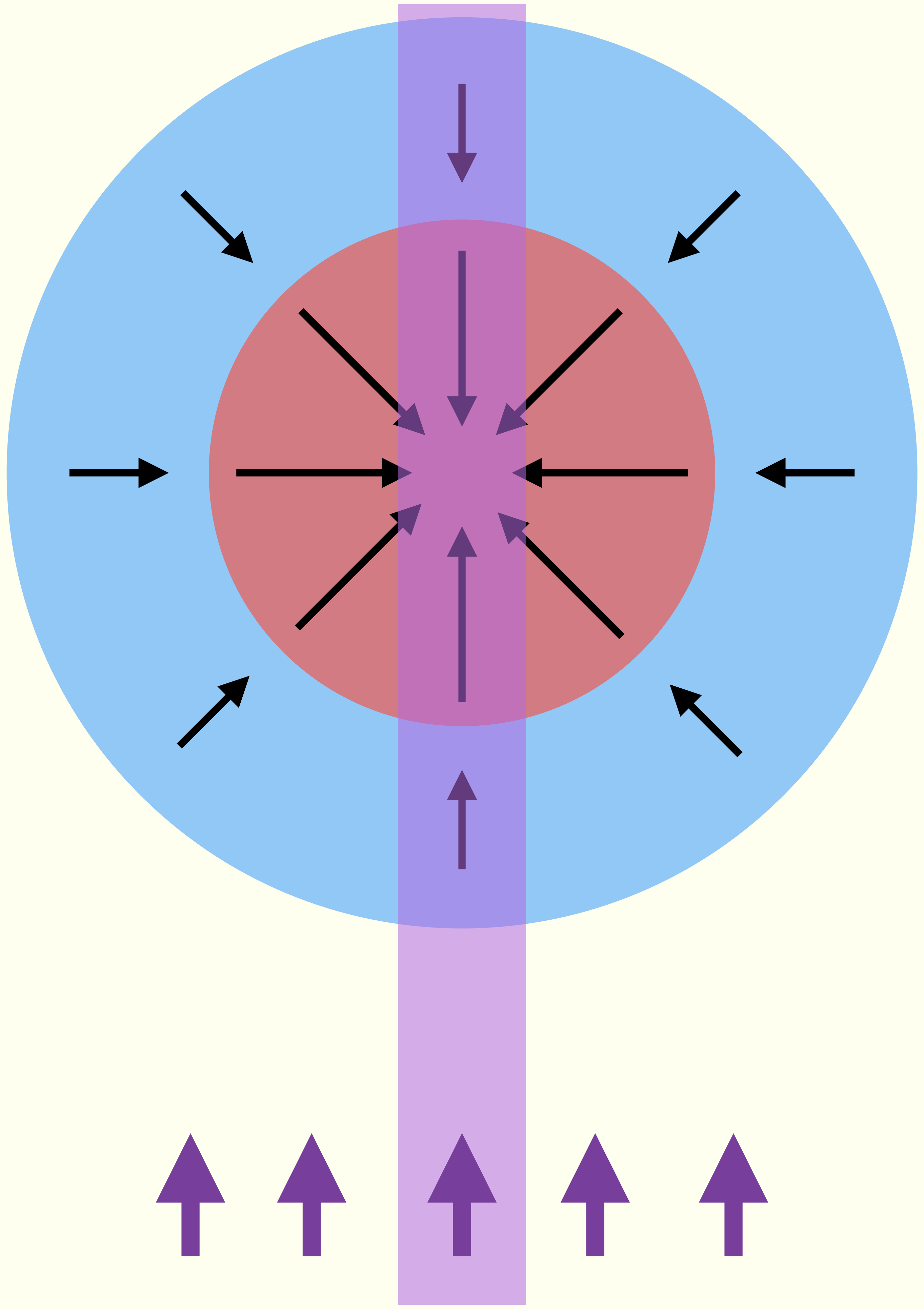




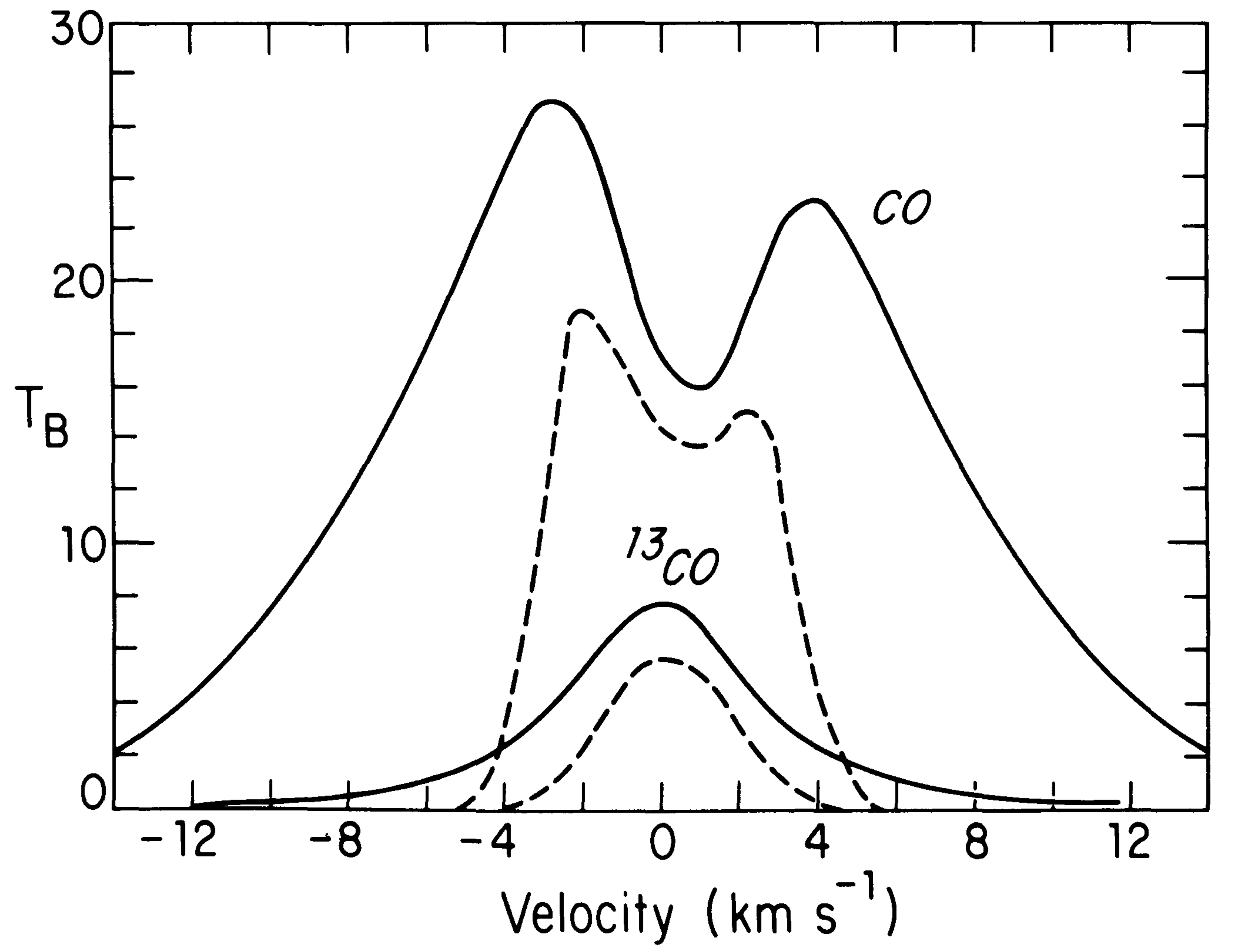
Yang+2017

The “smoking gun” evidence of the collapsing envelope

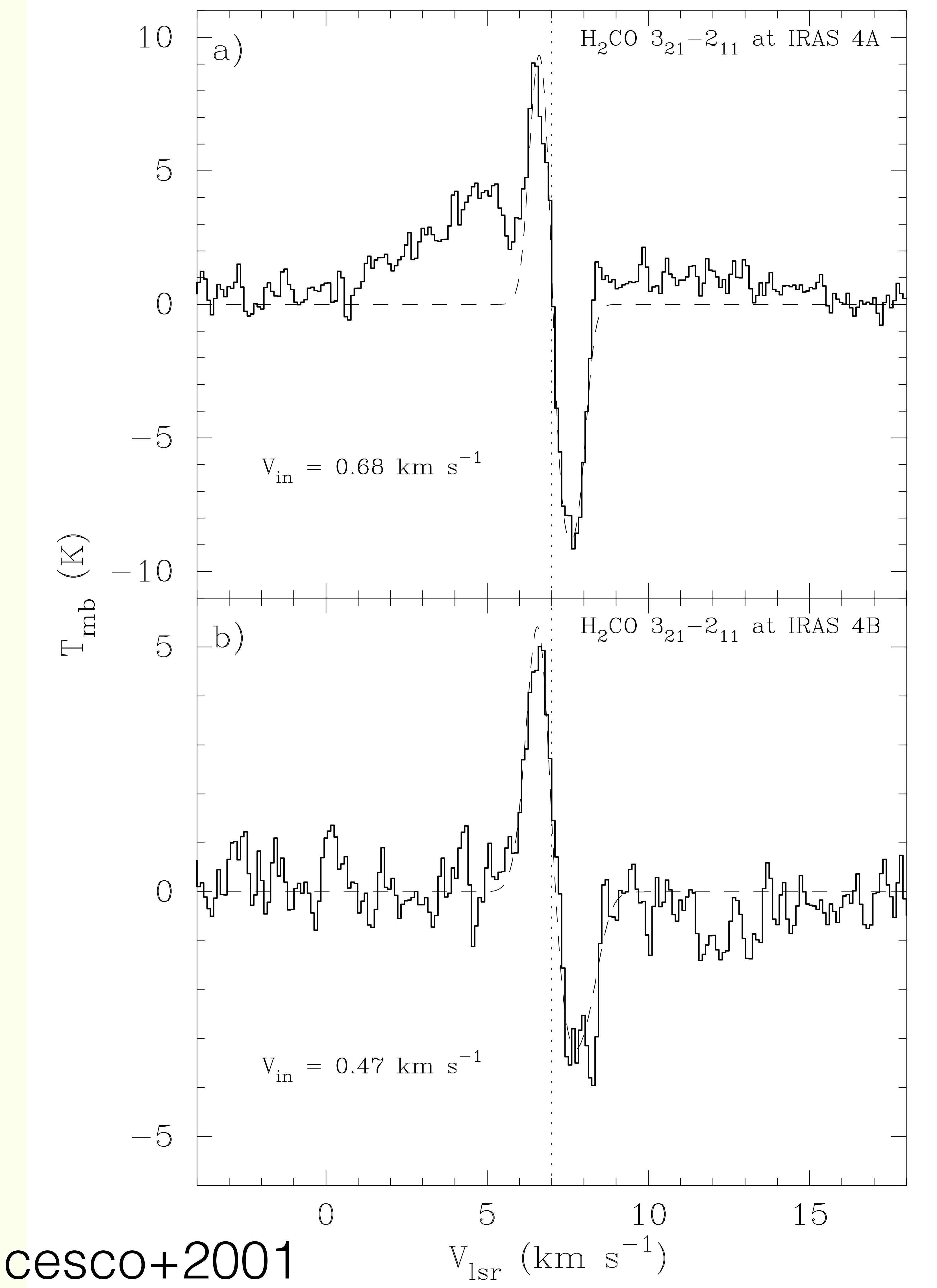
Kinematics is the key!



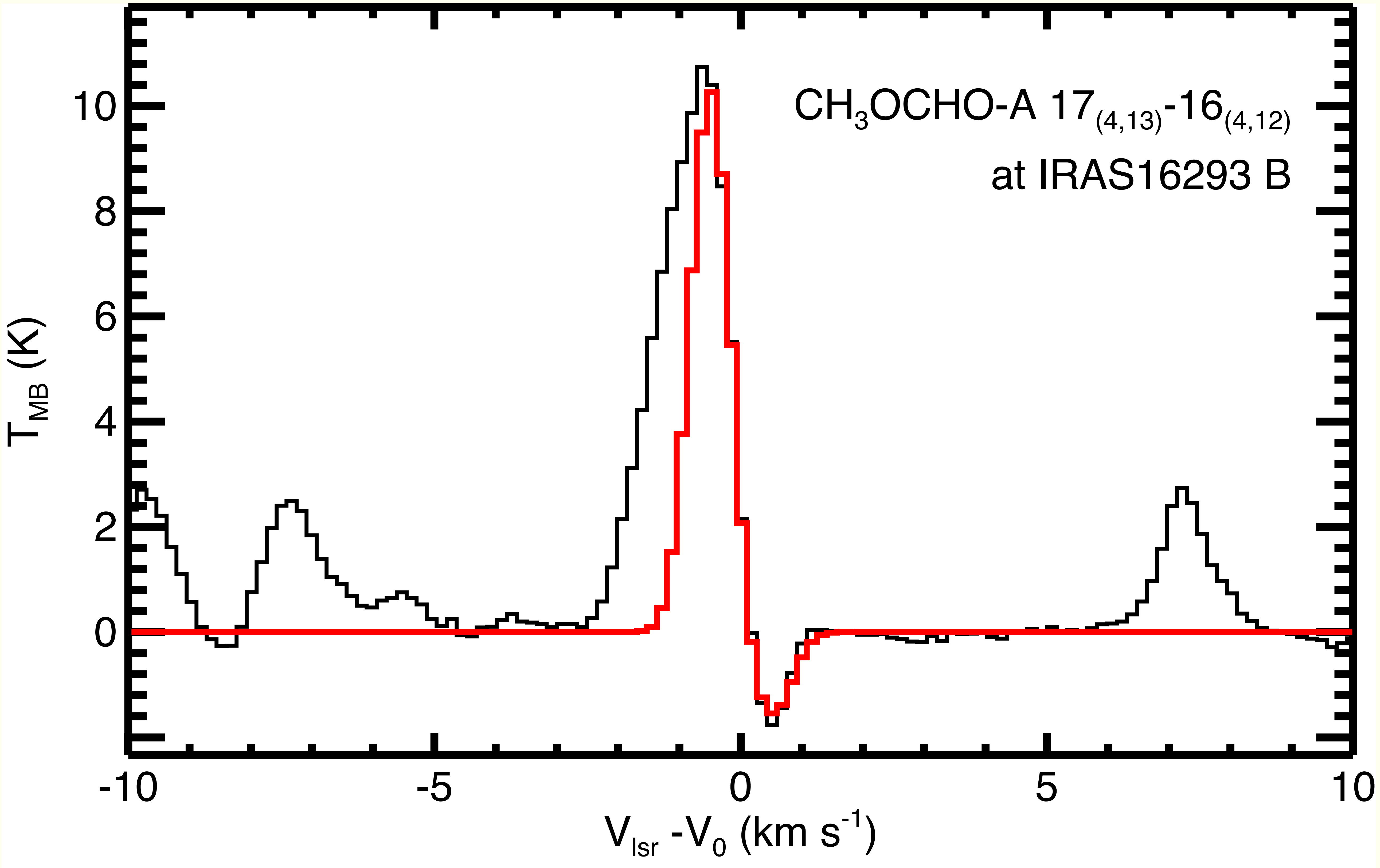
Leung & Brown 1977



A problem awaits ALMA to solve



Di Francesco+2001



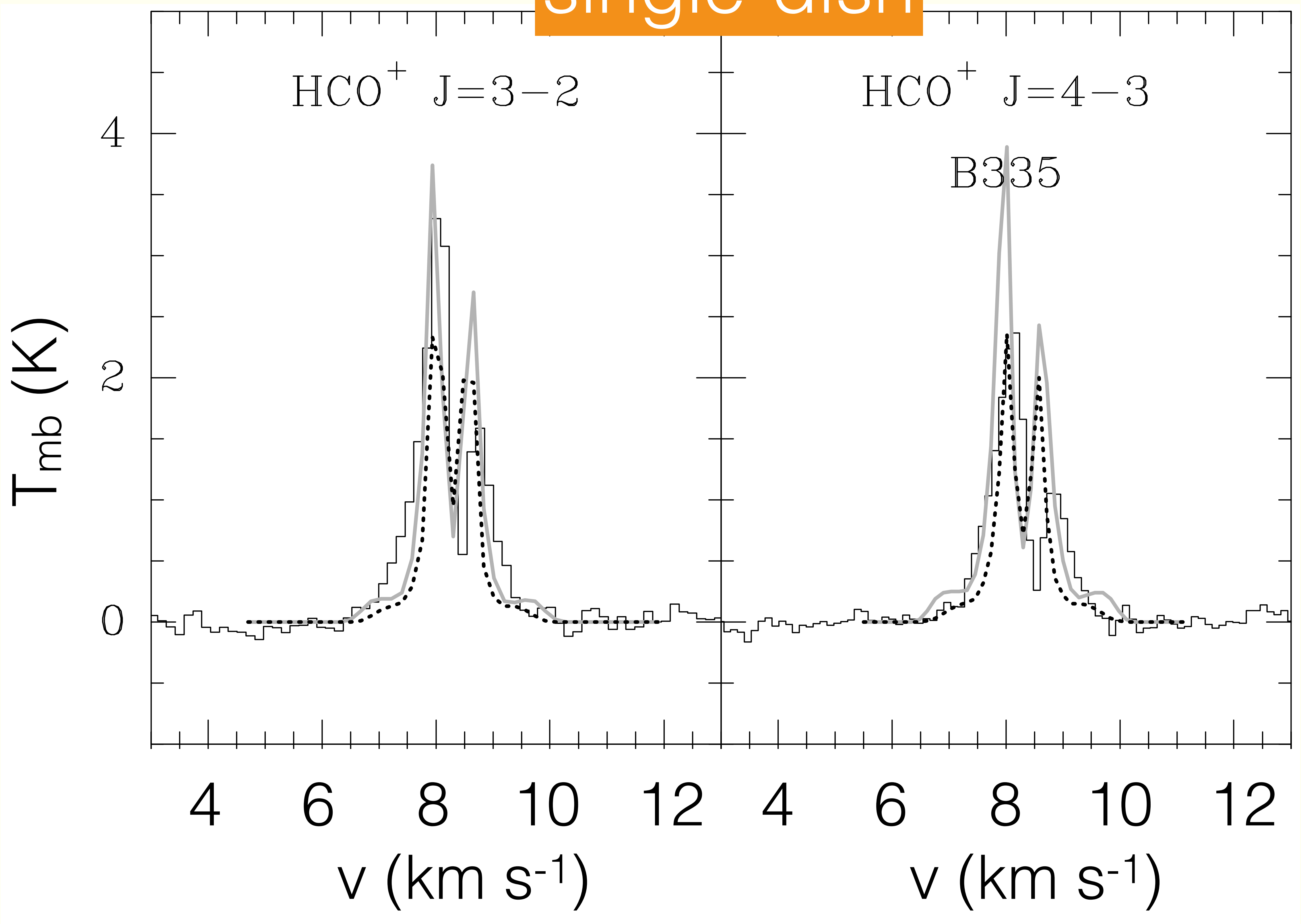
Pineda+2014

The “smoking gun” evidence of the collapsing envelope

Observe the redshifted absorption **against** the continuum

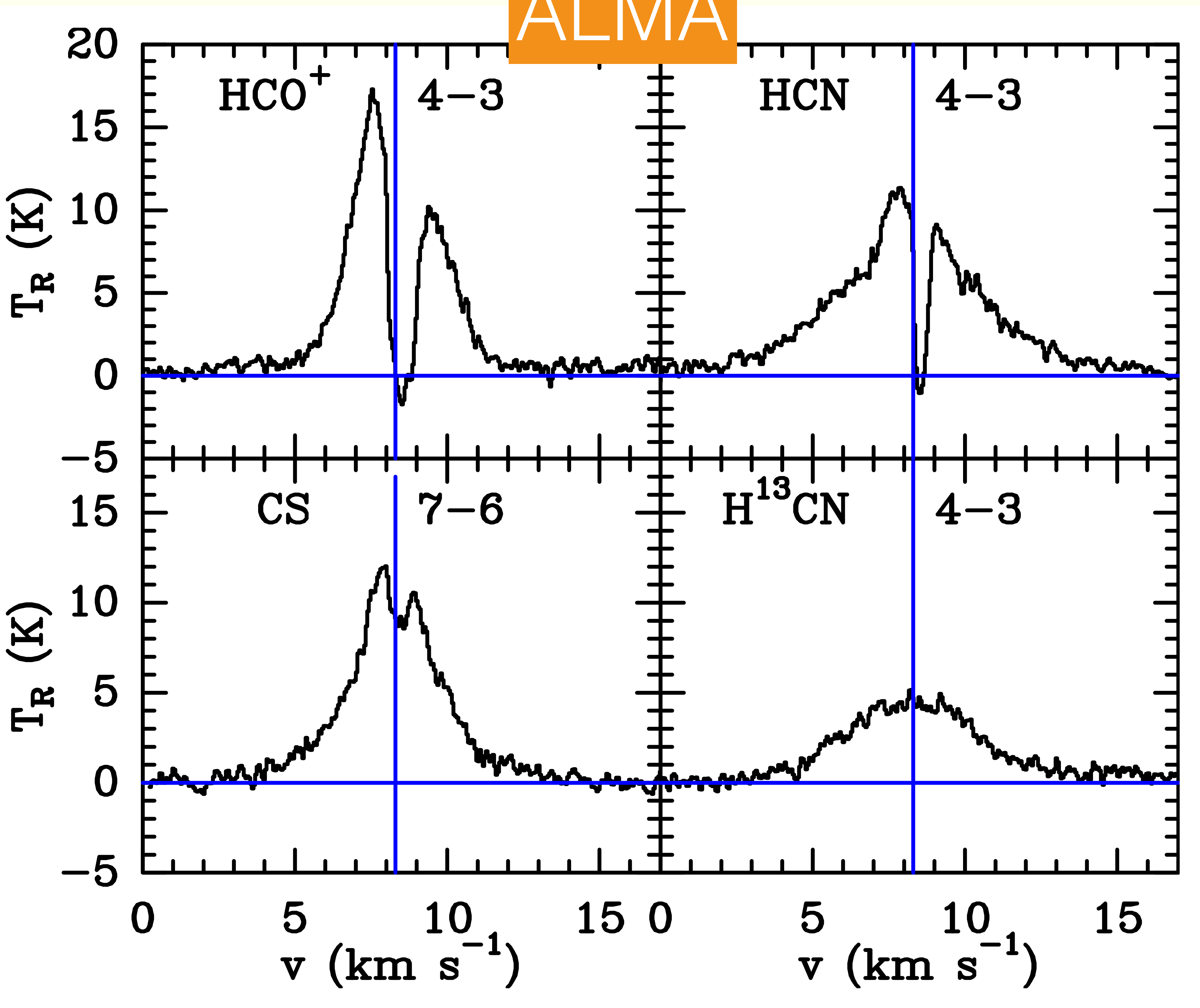
B335

single-dish



Evans+2005

ALMA

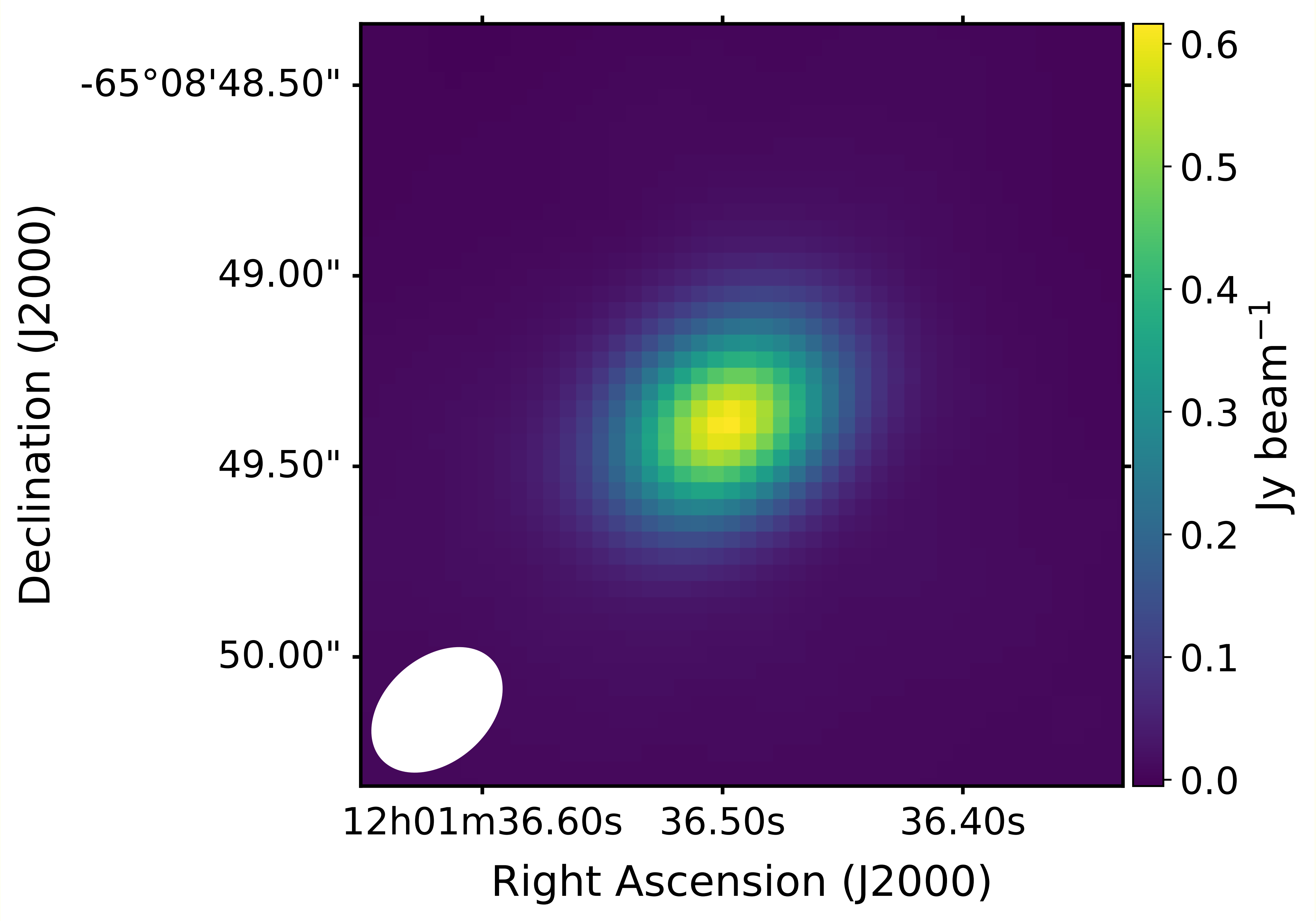


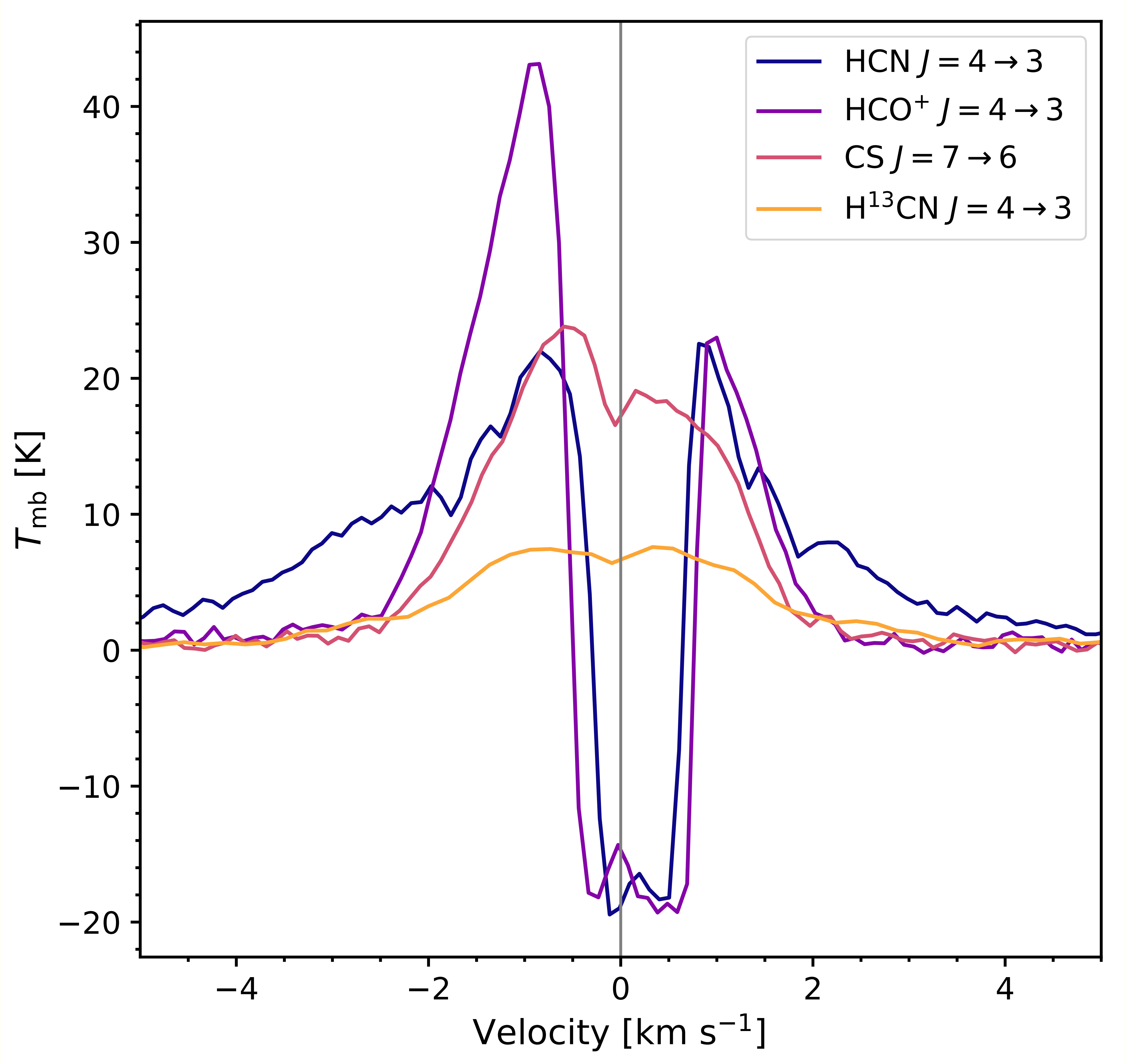
Evans+2015

Probe the infalling envelope of BHR 71

A case study with BHR 71 - an isolated embedded protostar

ALMA Cycle 4
Band 7 observation (PI: Y.-L. Yang)
with a beam of 0.39″×0.27″

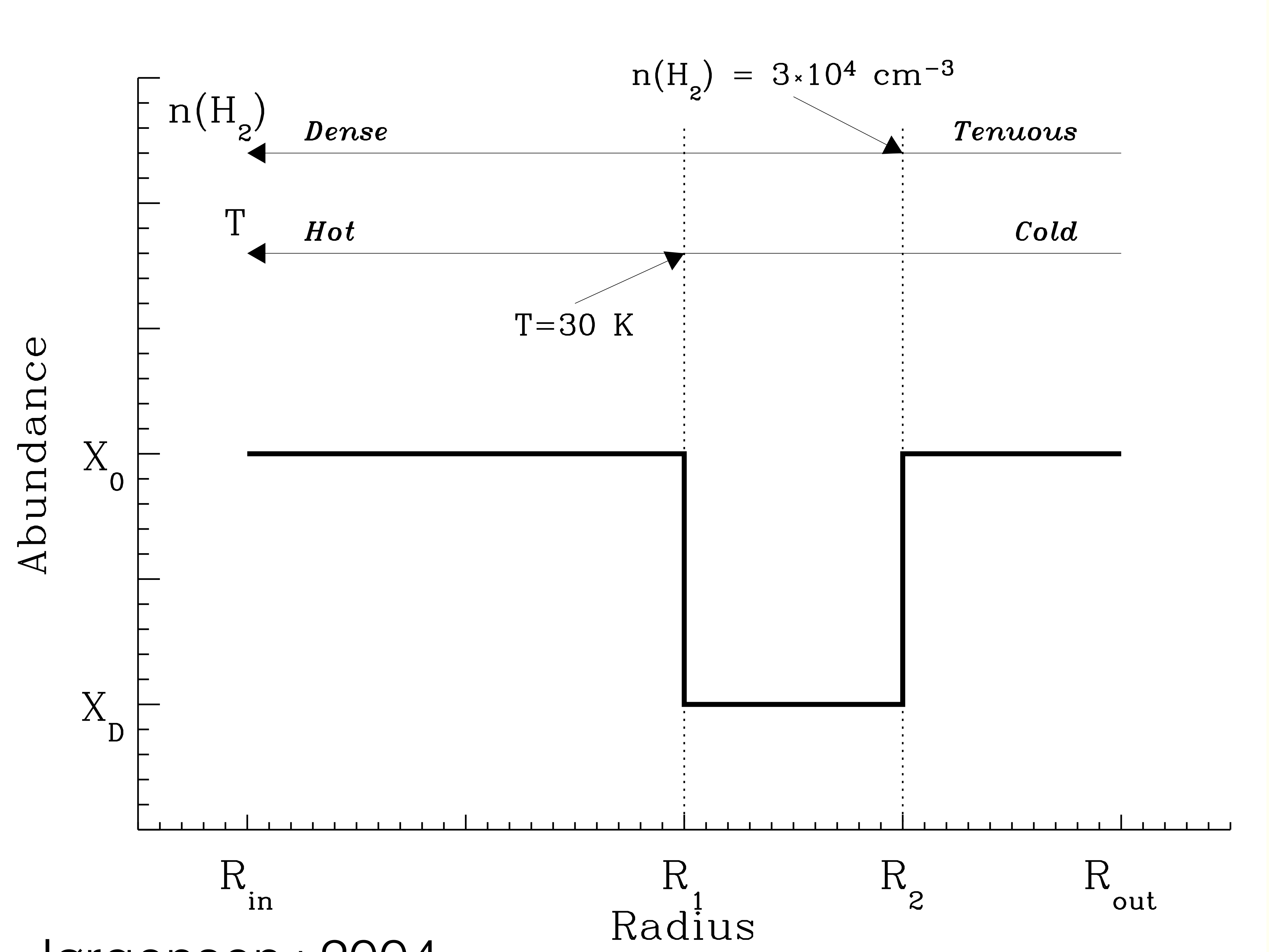




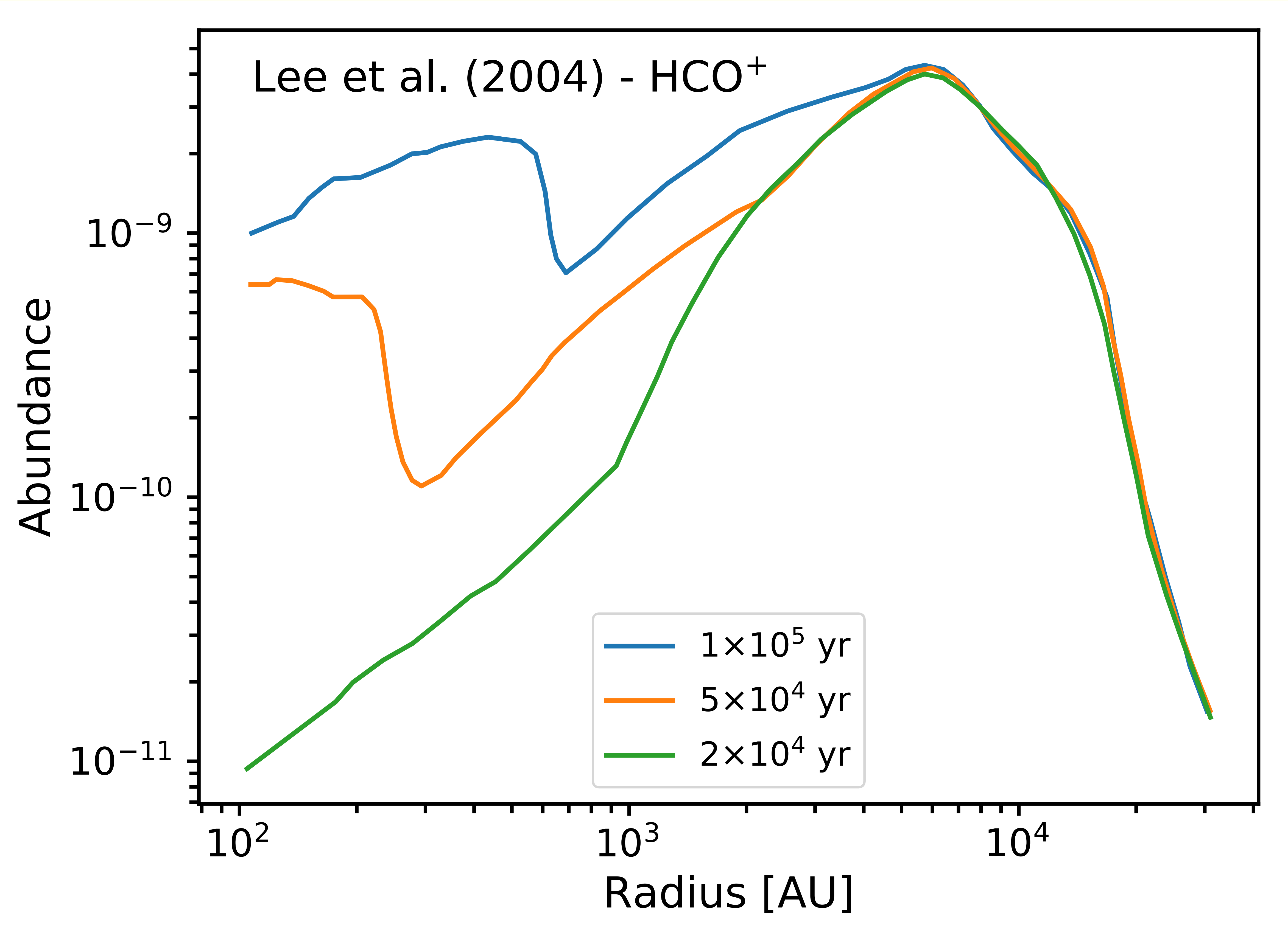
Where are the molecules and can we see them?

Take HCO^+ as an example

Freeze-out - **high density** and **low temperature**

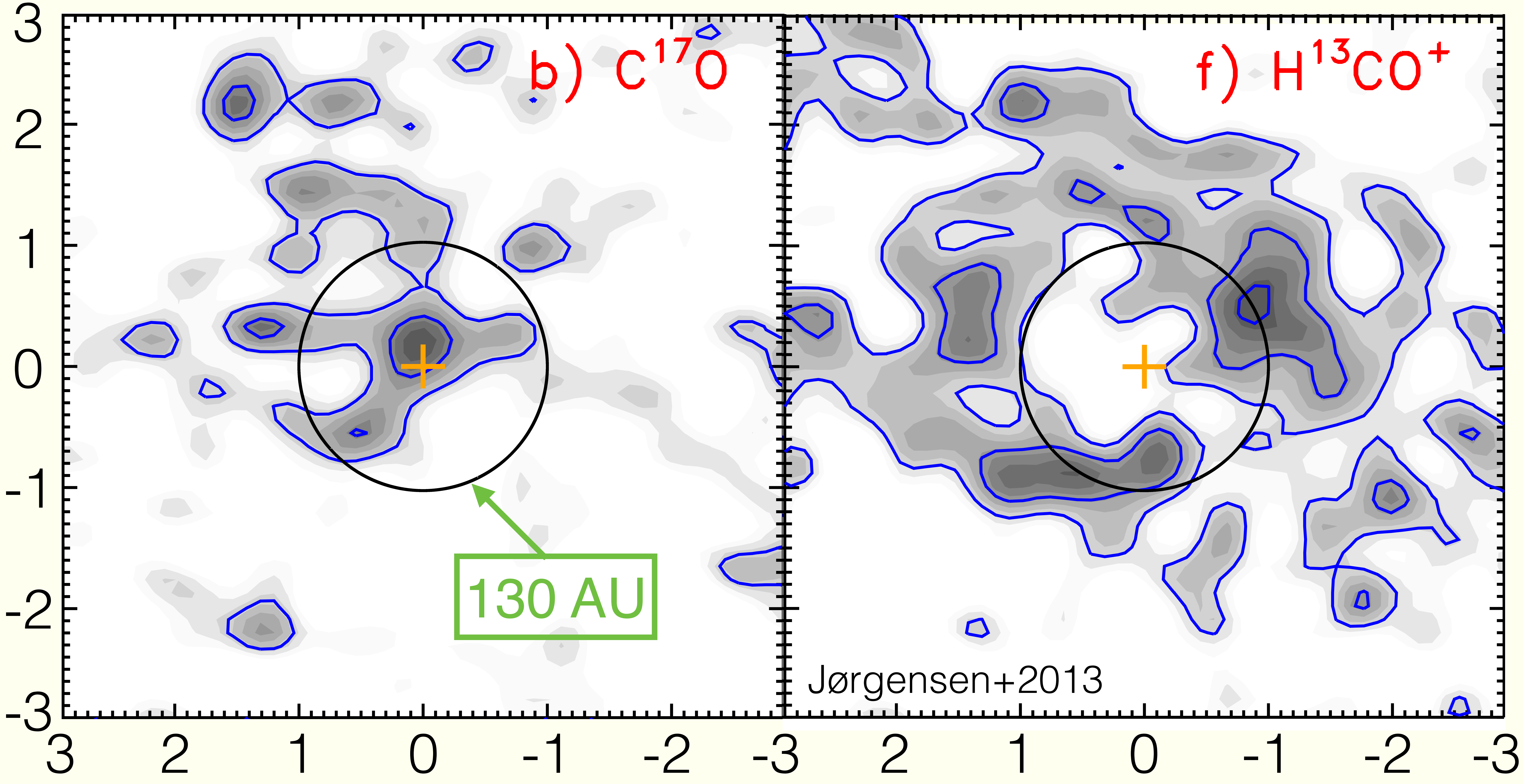


Jørgensen+2004

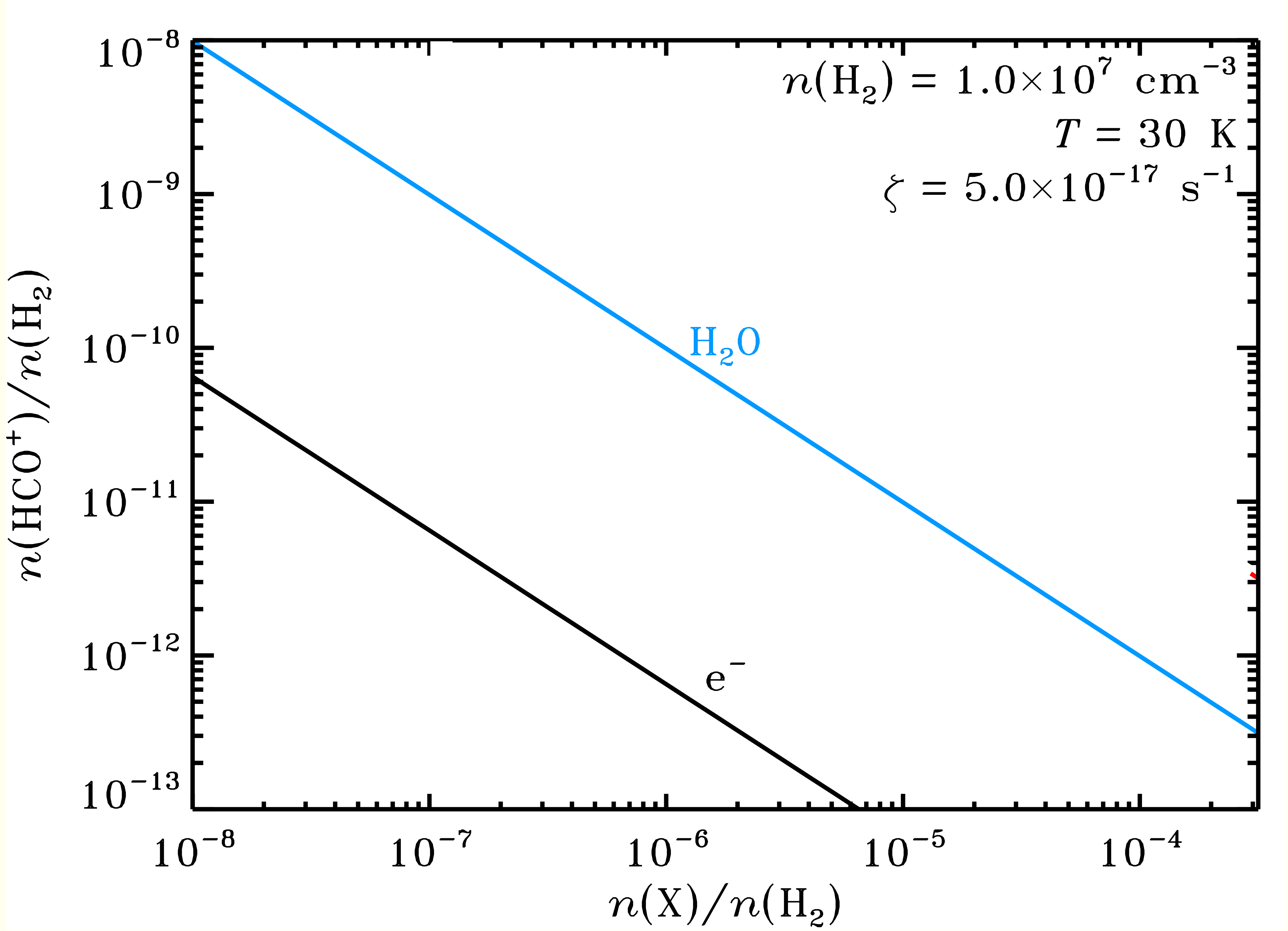


HCO+ depletion at the inner region

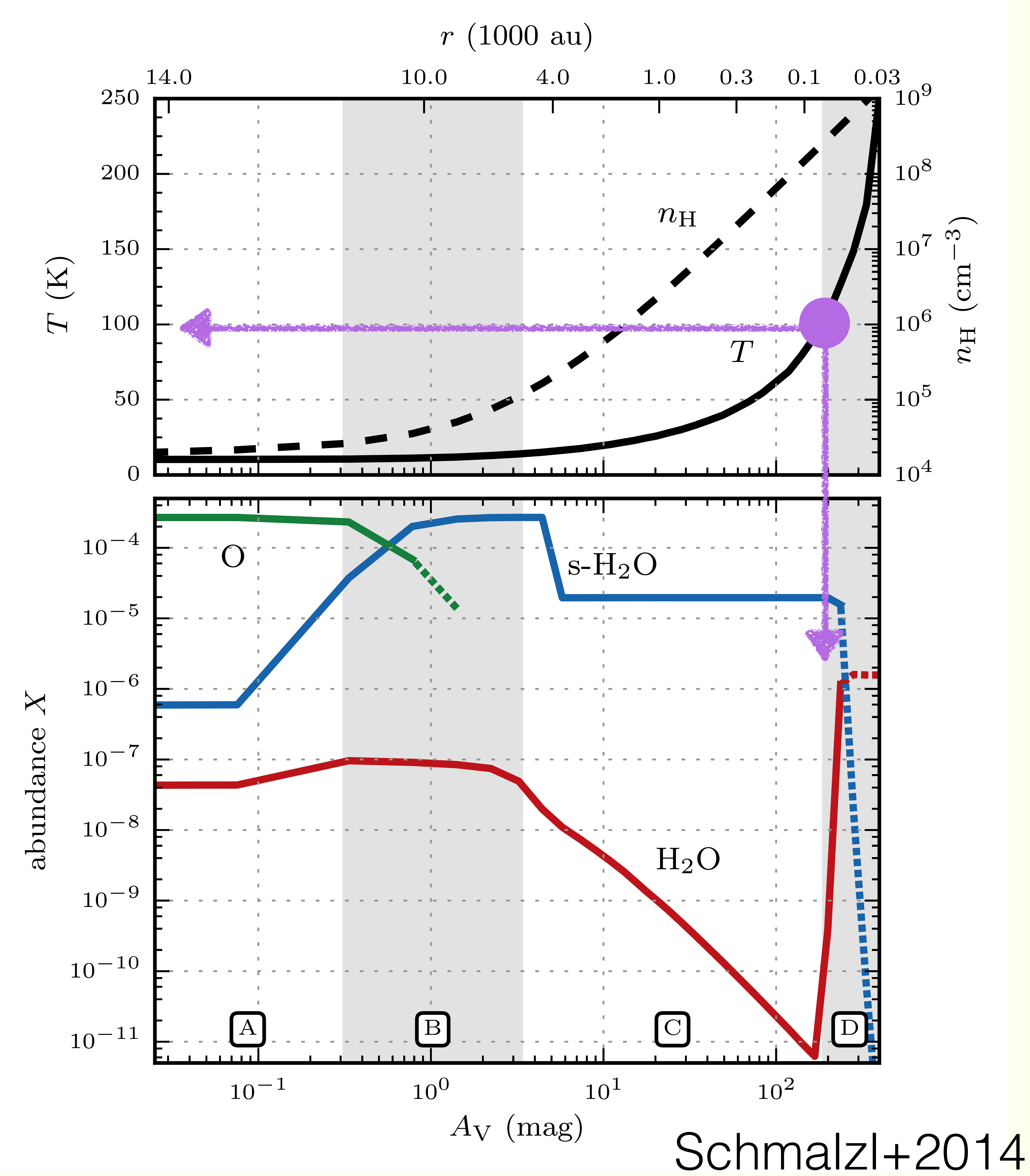
IRAS 15398–3359



Gaseous water destroys HCO^+



Modified from Jørgensen+2013

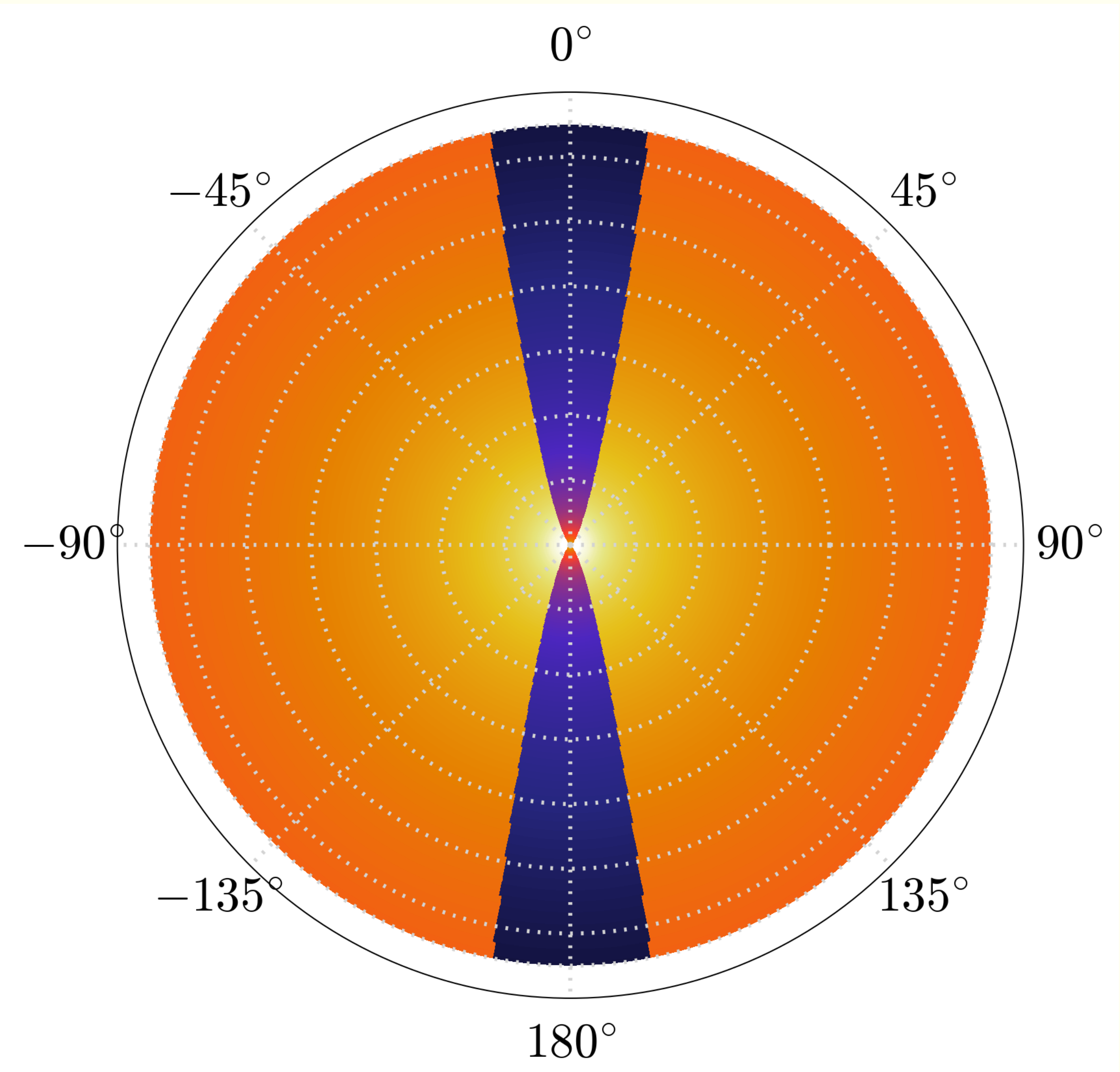


Schmalzl+2014

Model the HCO^+ profile due to the infall

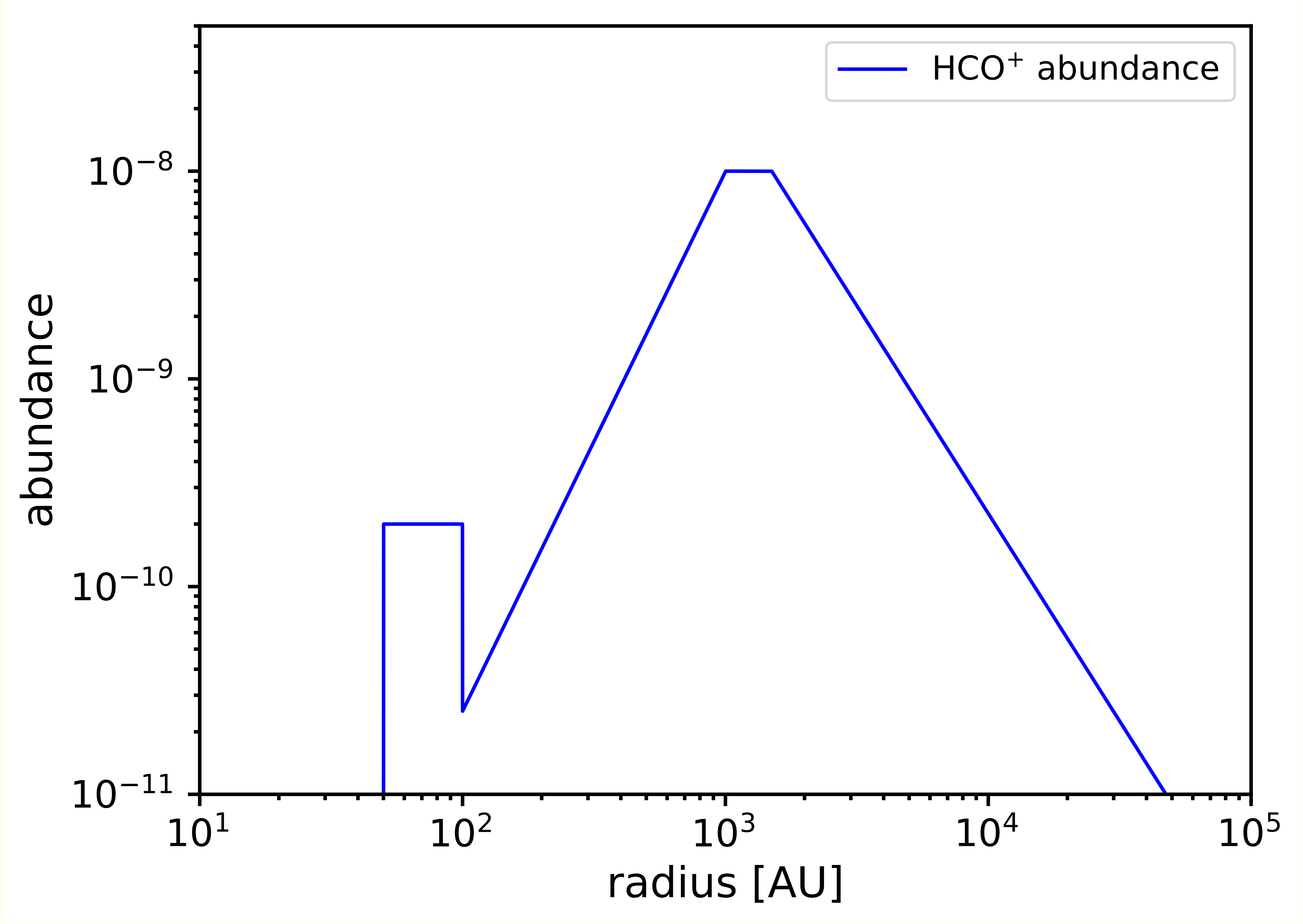
Dust model constrained by *Herschel* spectra (Yang+2017)

density, temperature, velocity

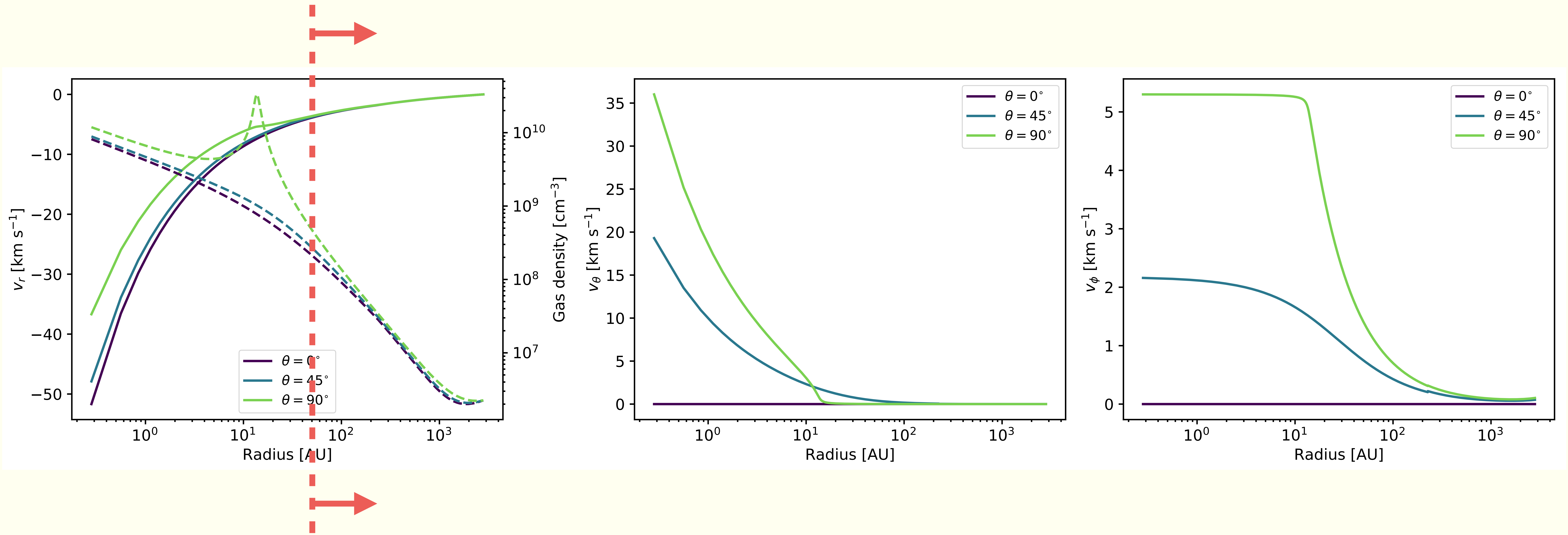


+

chemical abundance

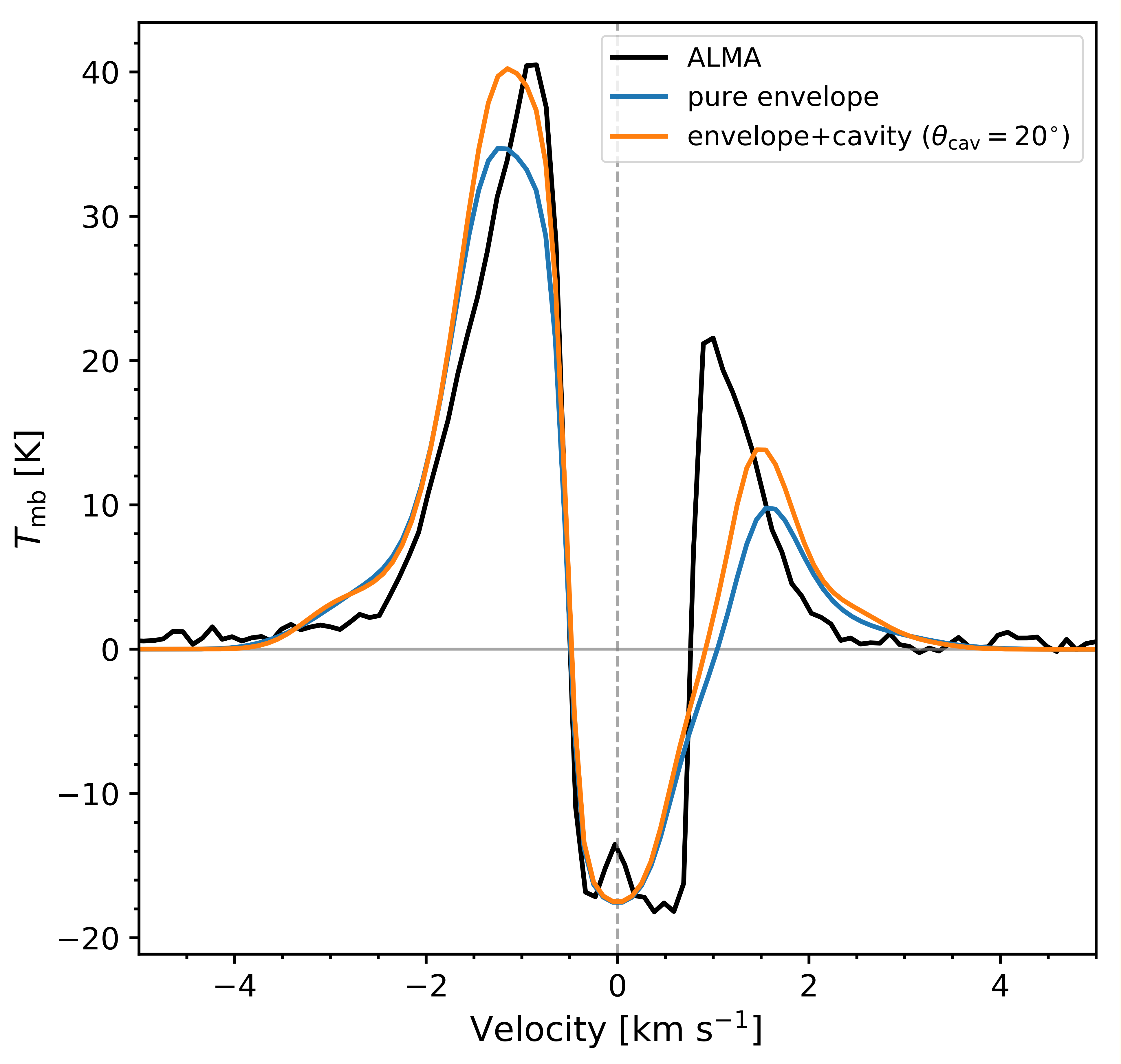


The kinematics of the rotating infalling envelope

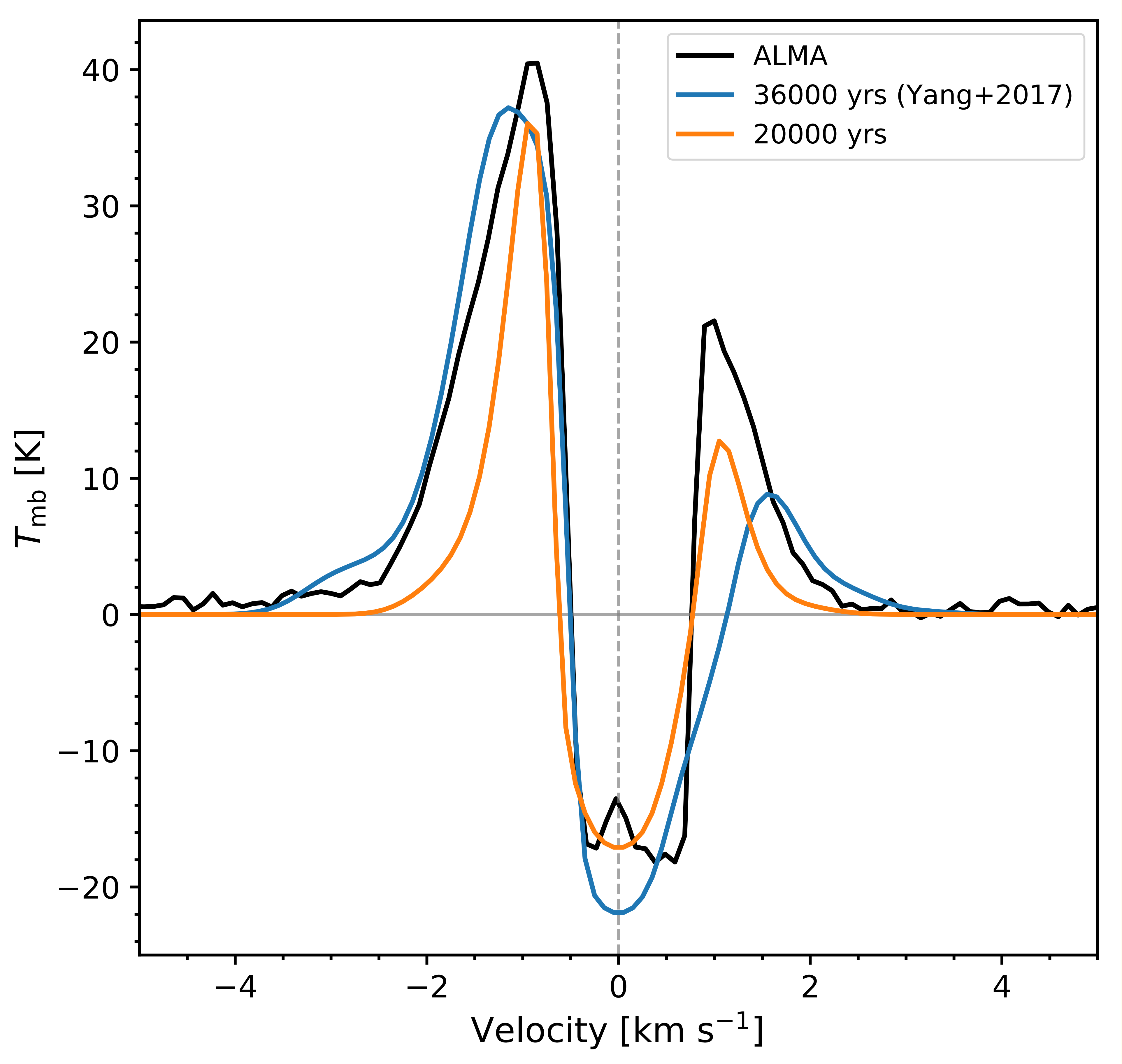


Model the HCO+ profile due to the infall

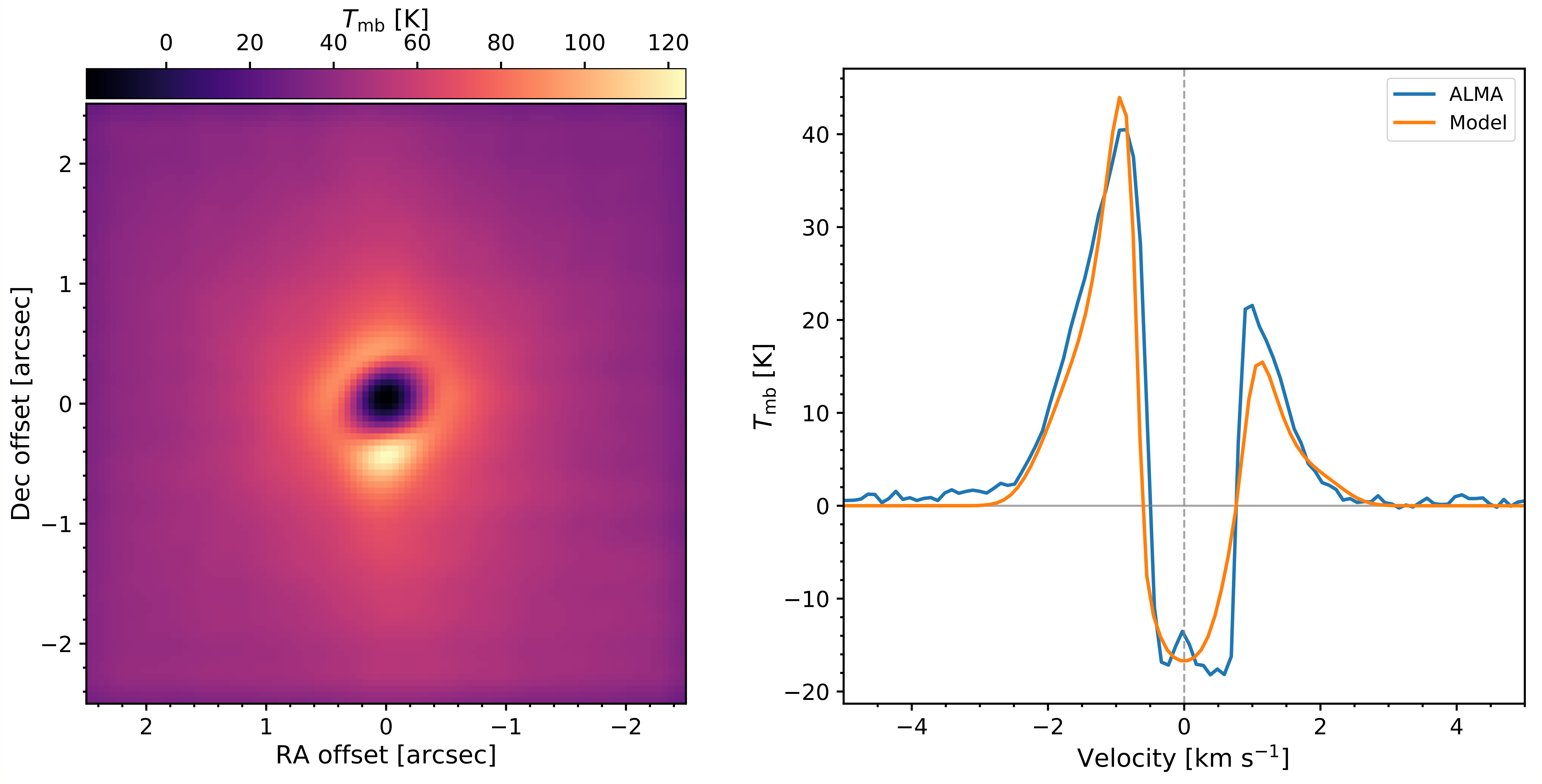
Outflow cavities



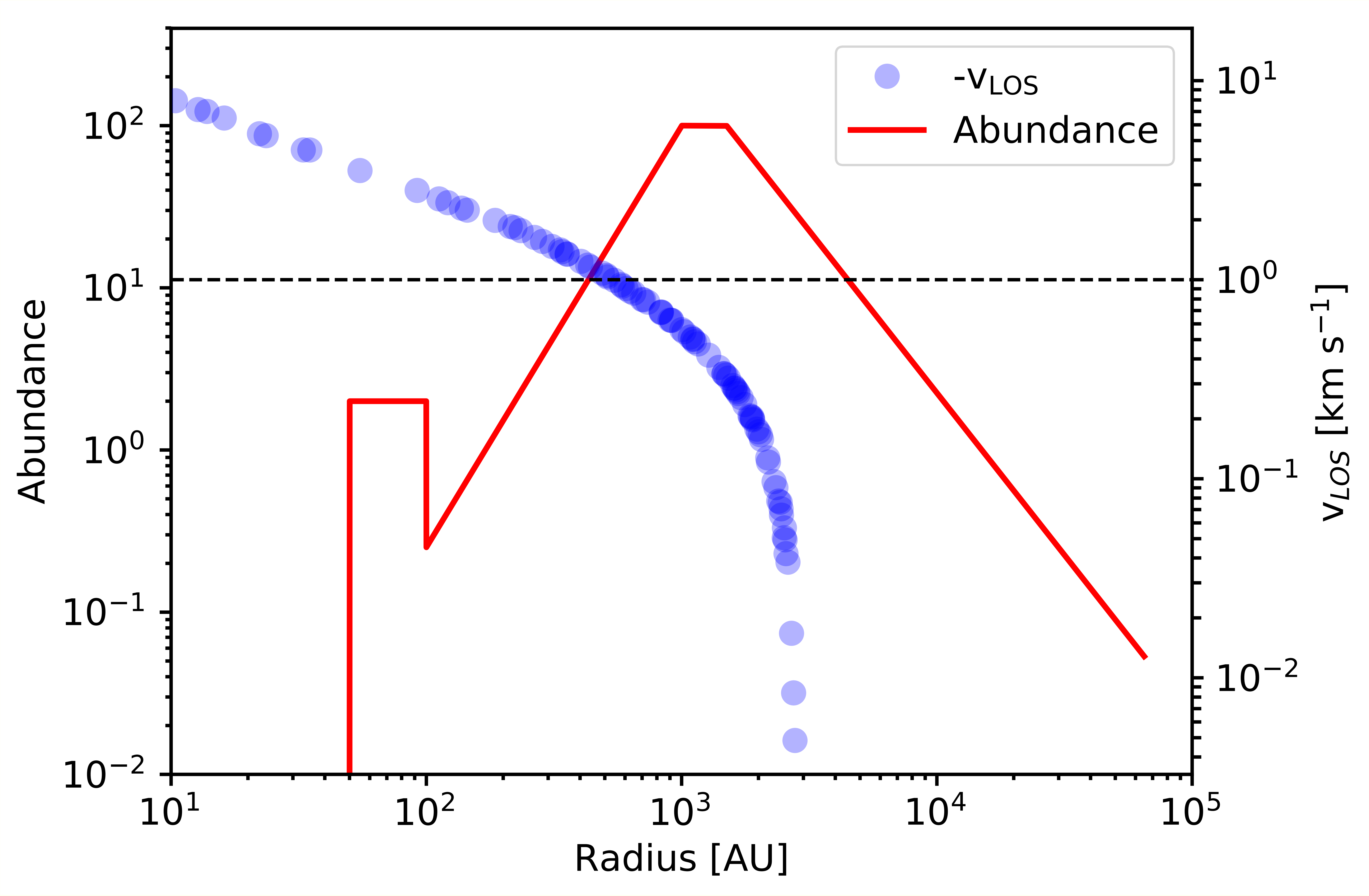
HCO+ prefers a younger envelope



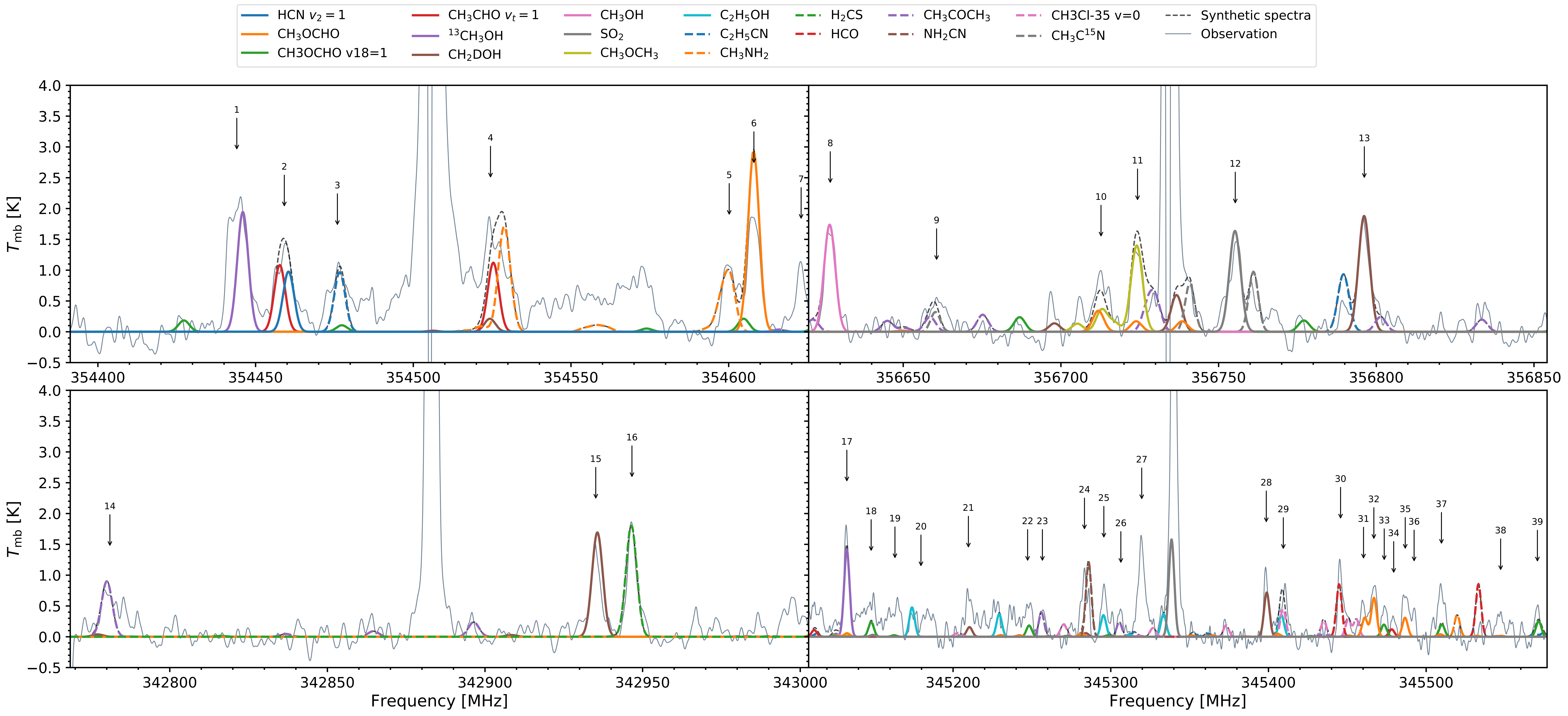
Model the HCO^+ profile due to the infall



Velocity and abundance at the freeze-out zone is critical

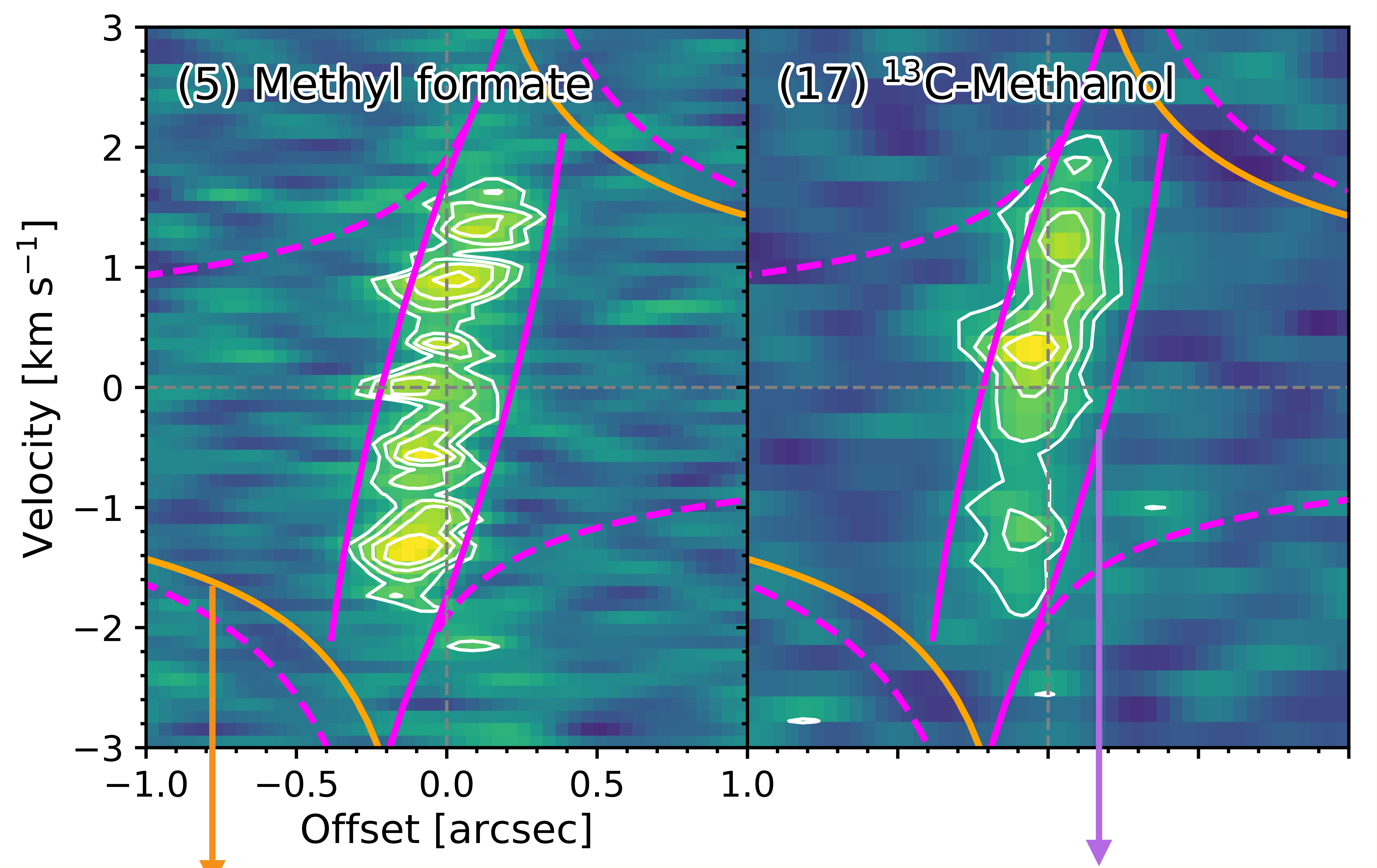


There are more molecules tracing different physical environment



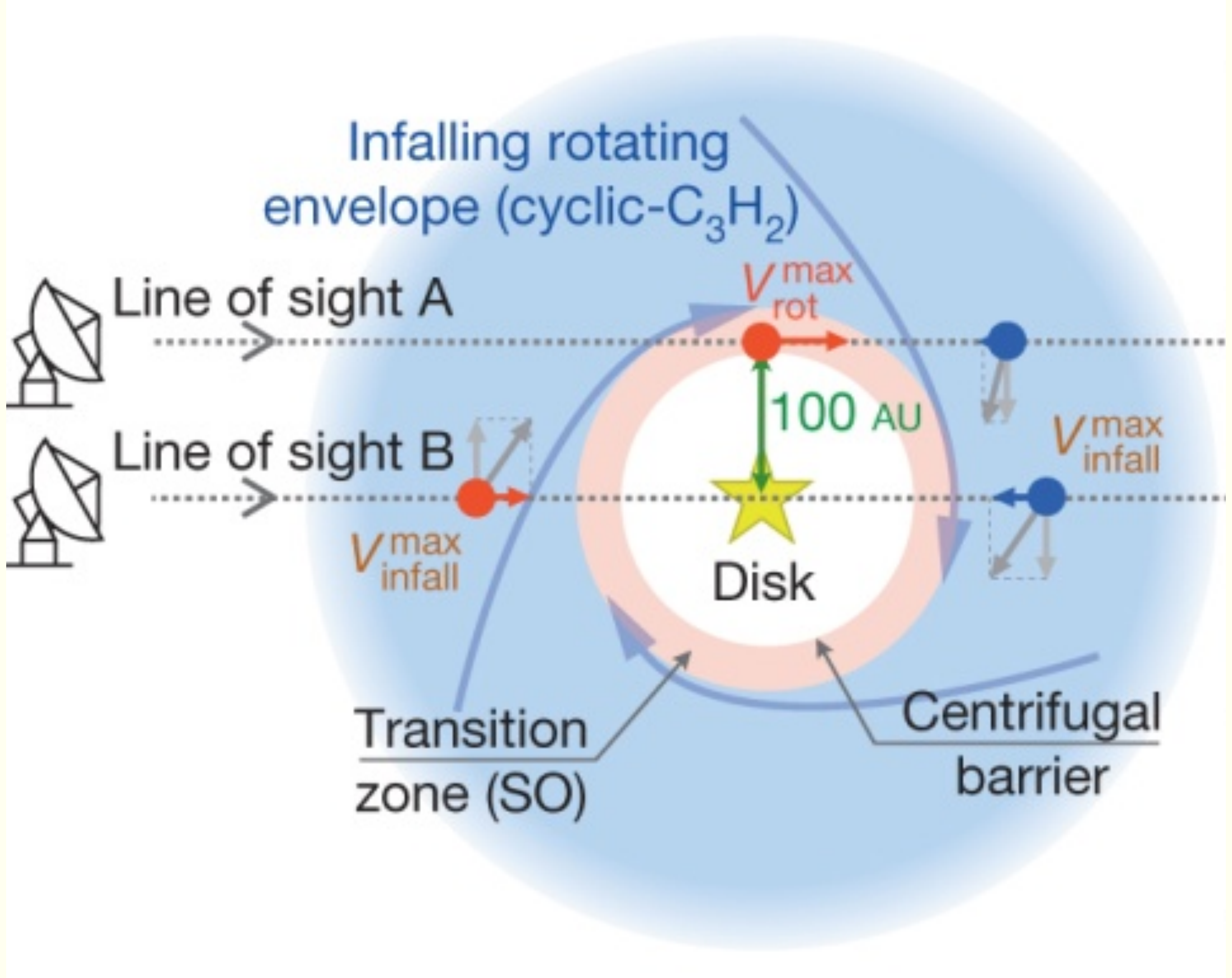
Complex organic molecules (COMs) emission traces the kinematics of the inner 100 AU

COMs trace a rotating ring



Keplerian rotation

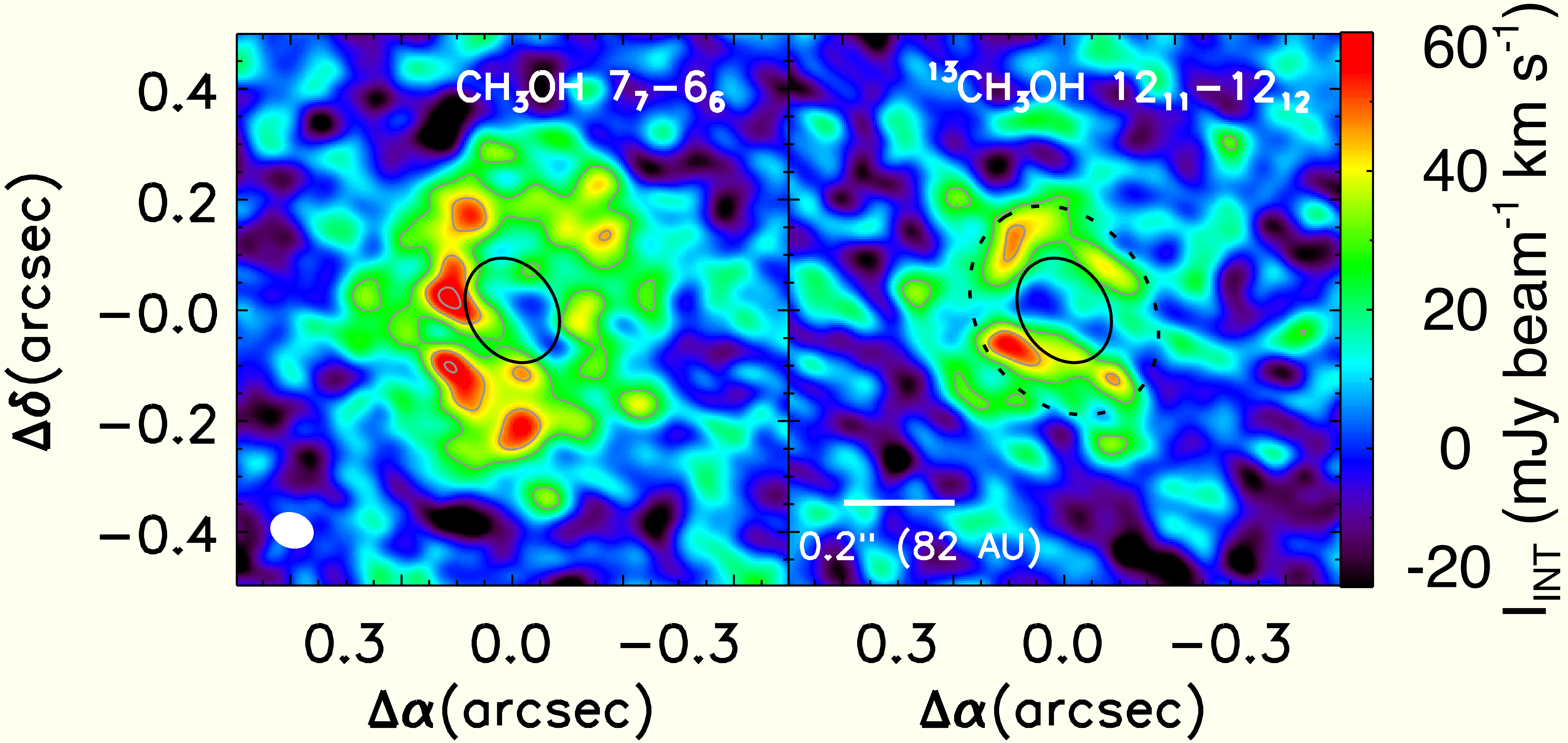
Angular-momentum-conserved rotating infalling ring



Sakai+2014a

Methanol indeed can form a ring

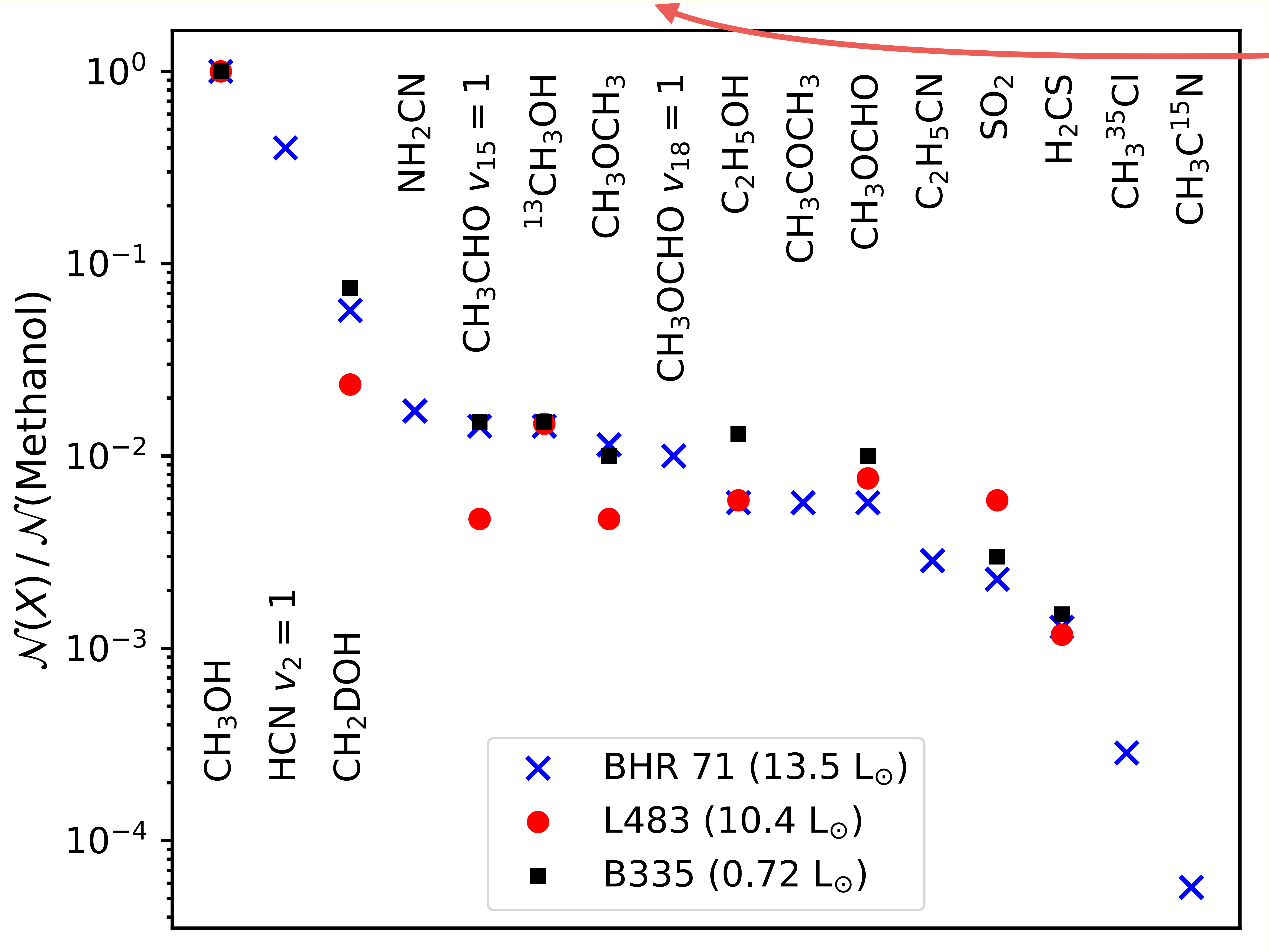
V883 Ori



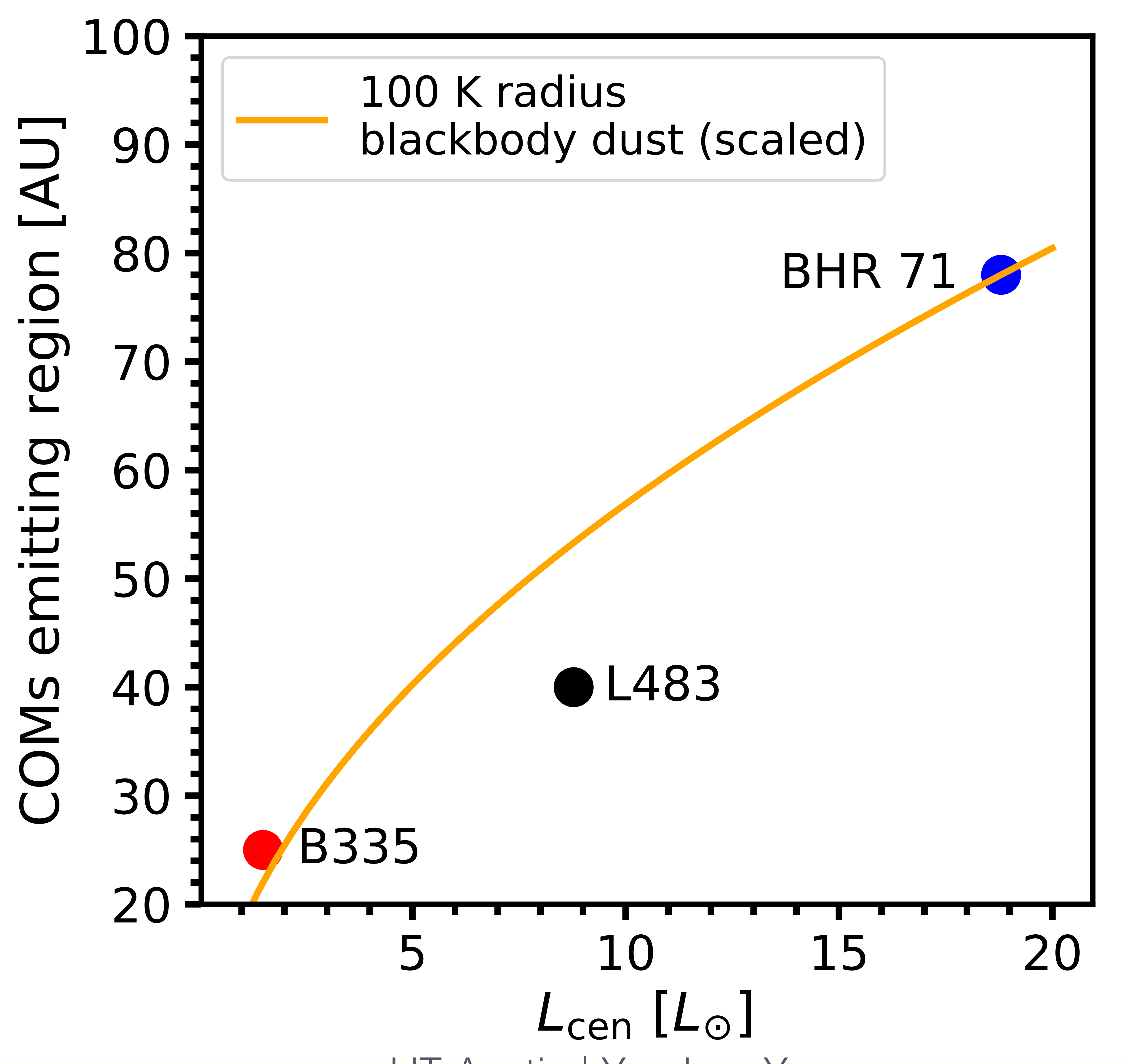
Lee+2018

Sources with different L_{bol} have a similar chemistry

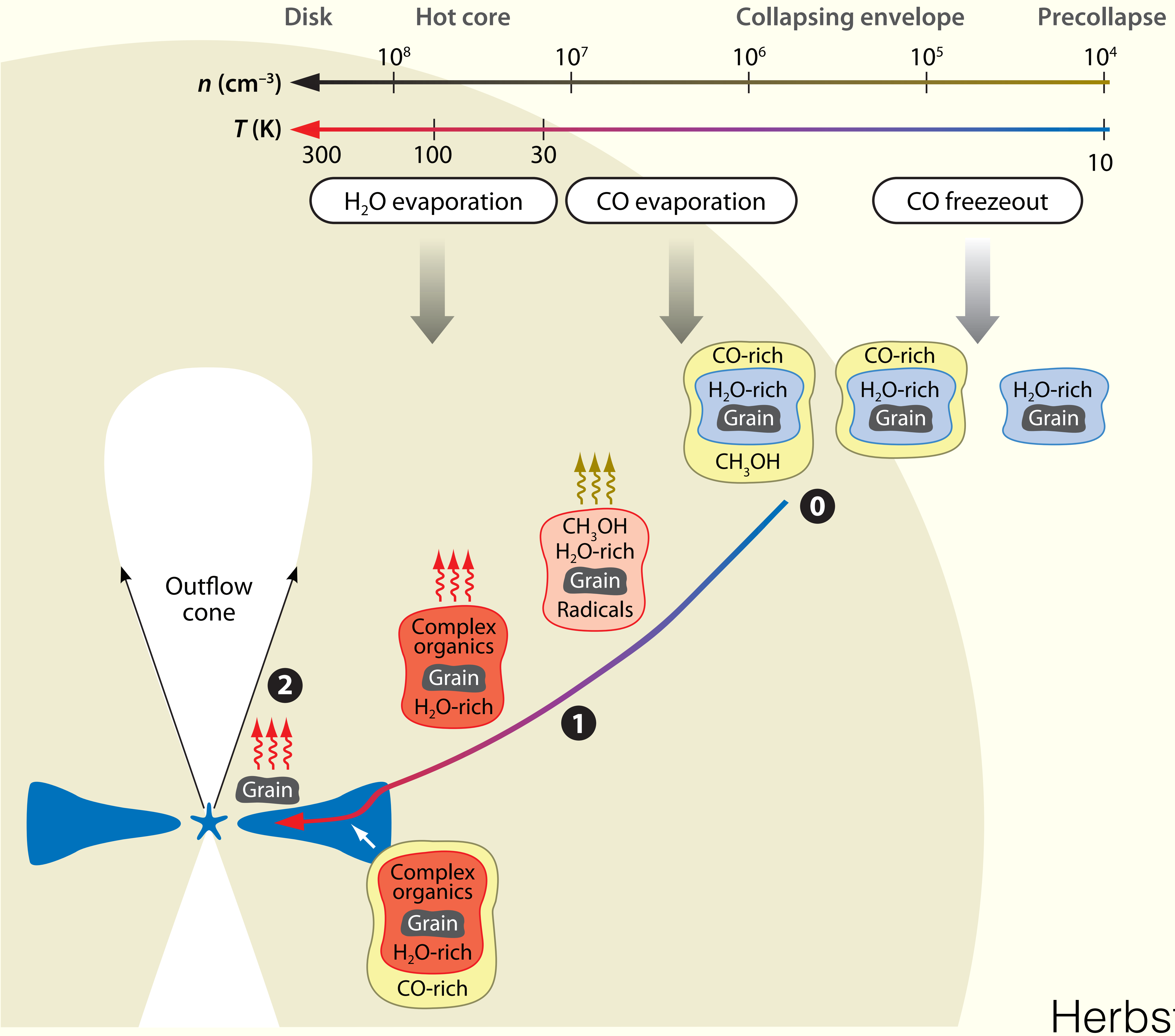
~Accretion



Sources with different L_{bol} have a similar chemistry

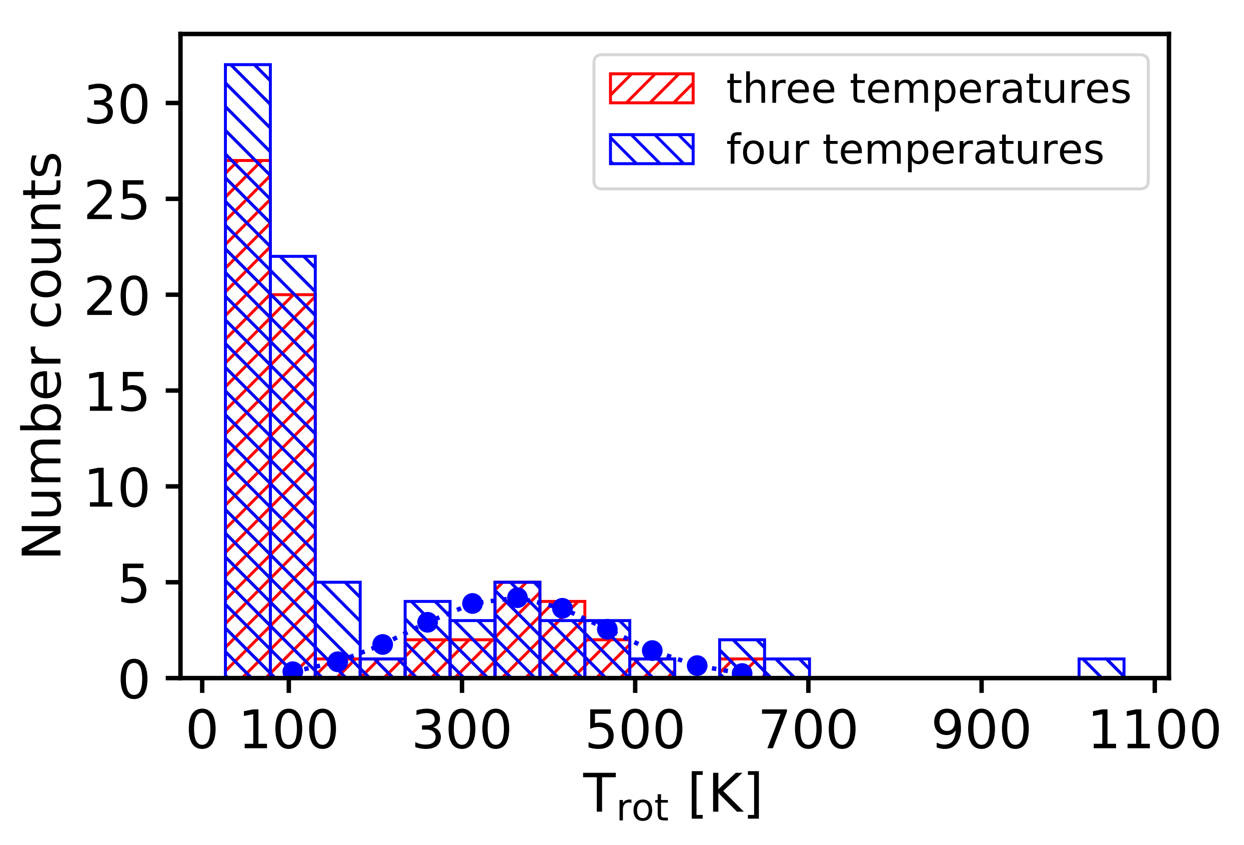


A formation journey starts from the ices on dust grains



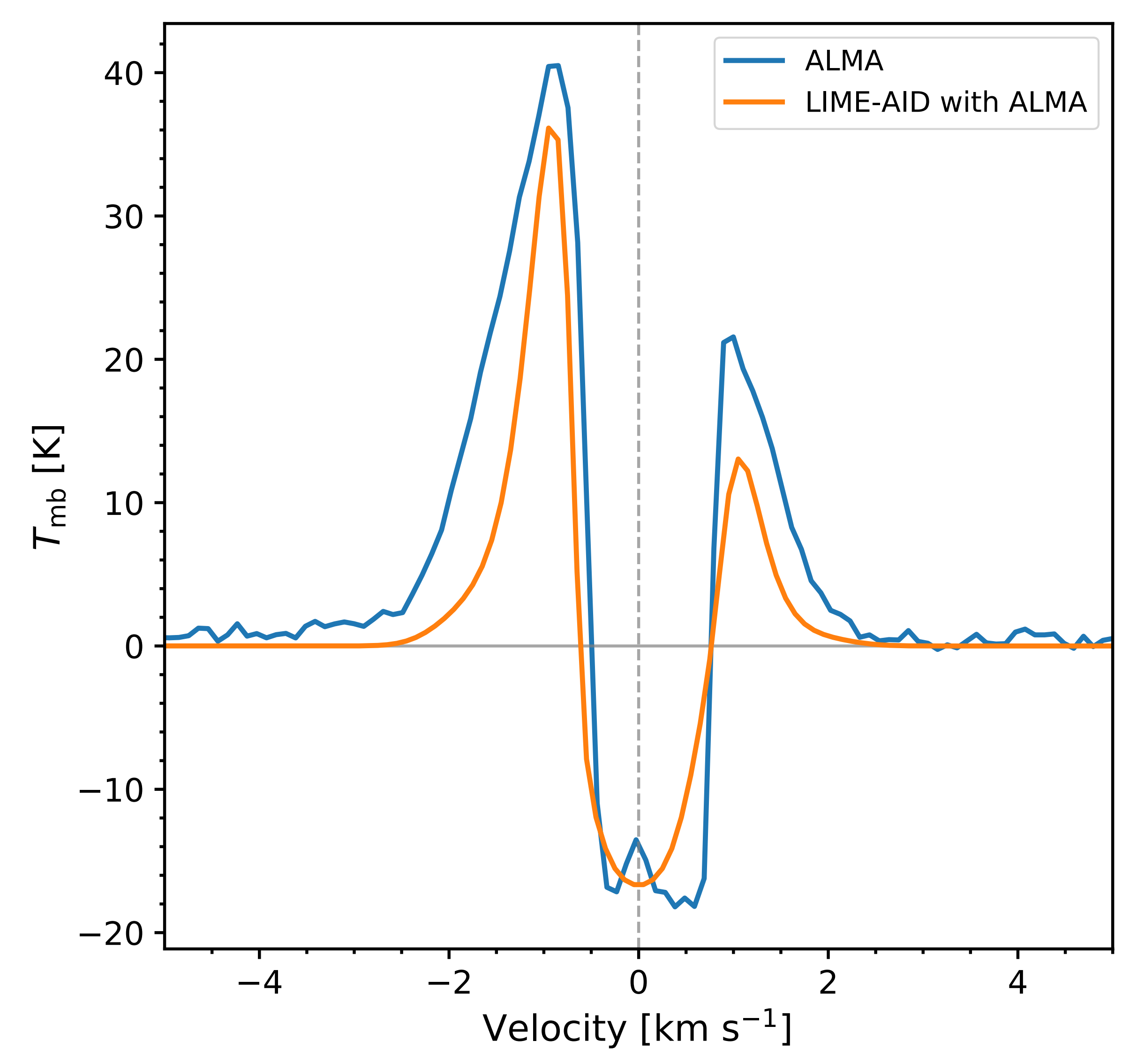
Herbst & van Dishoeck 2009

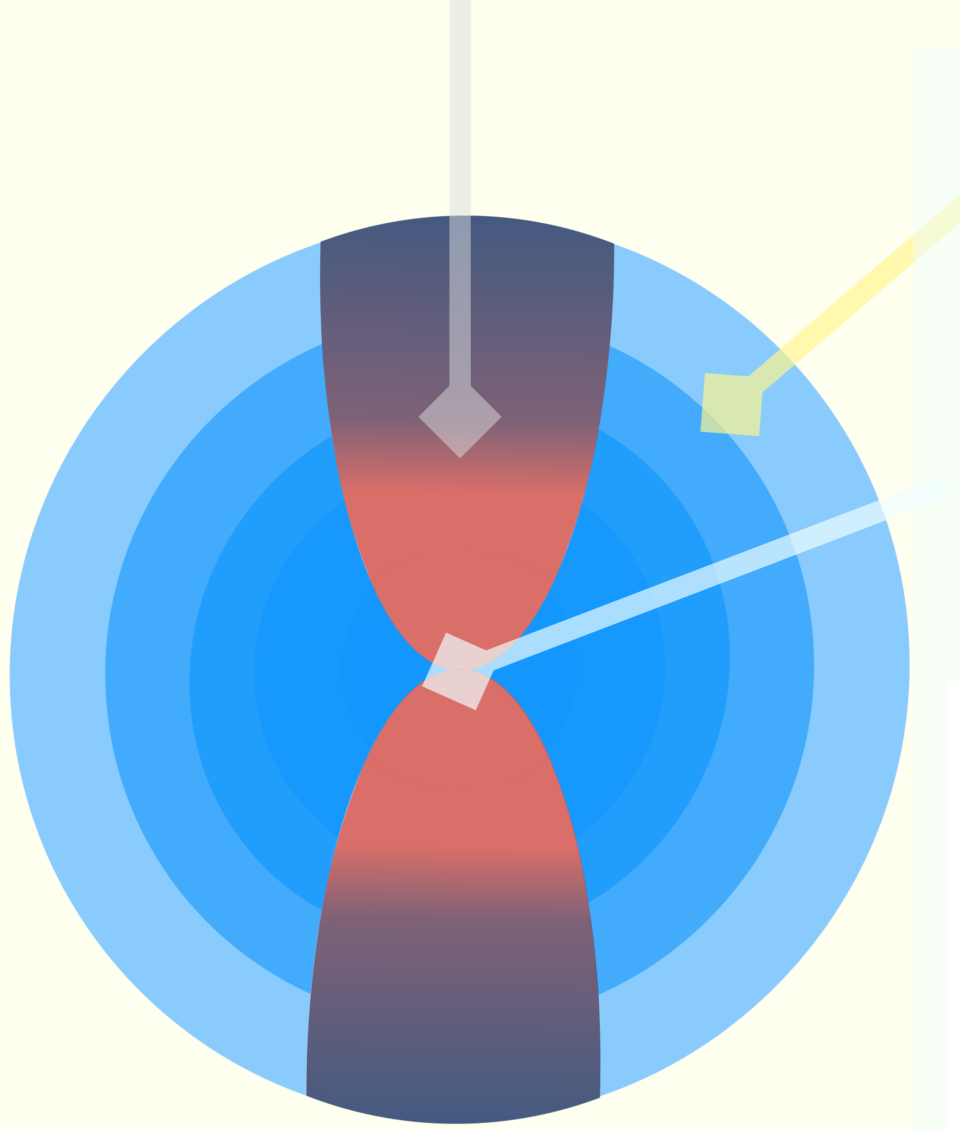
Summary



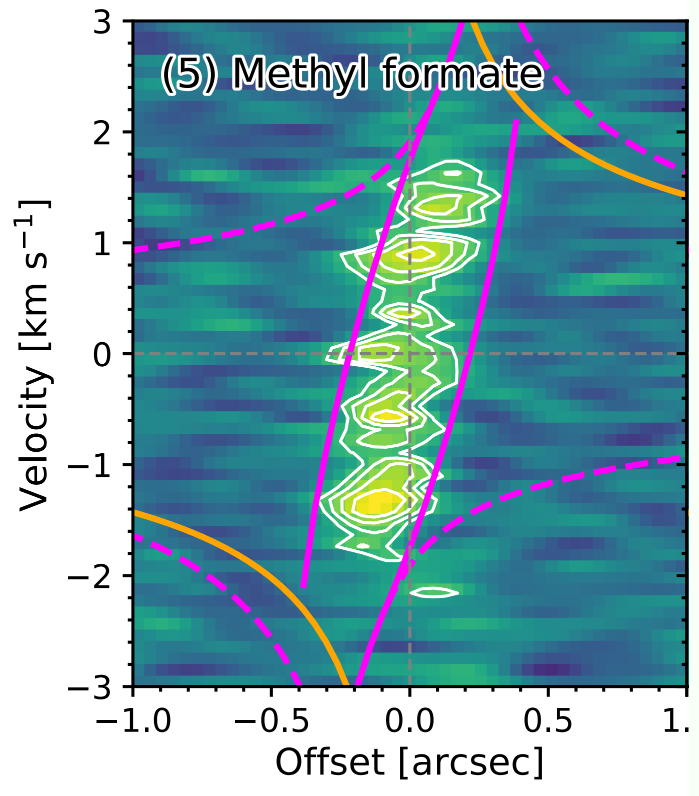
The CO ladder traces the the shocked gas and entrained gas from high-*J* to low-*J* transitions.

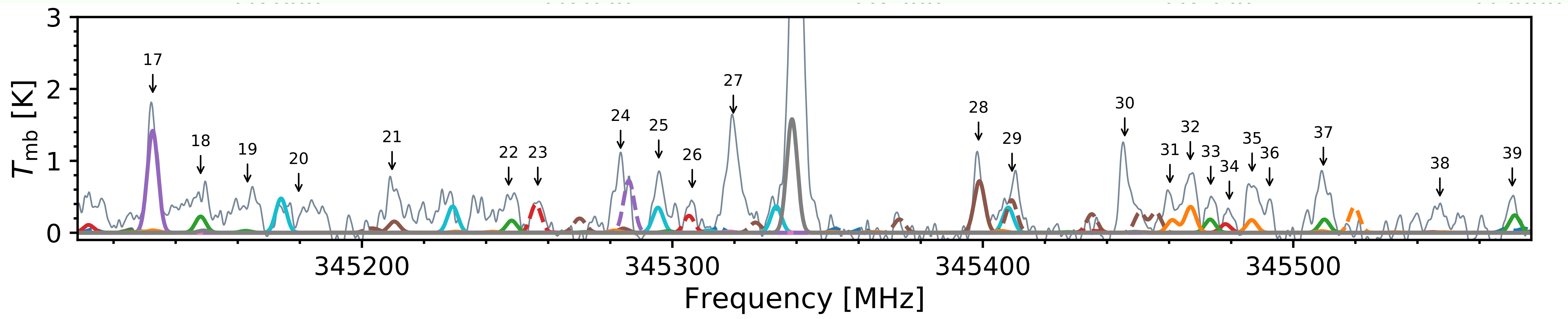
The 3D radiative transfer model suggests a younger envelope, smaller infall velocity, for the HCO^+ profile.





We detect 13 species of COMs toward BHR 71, and two of them show the kinematics of a rotating ring.





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