Jets, winds and accretion shocks around the protostellar system HH212

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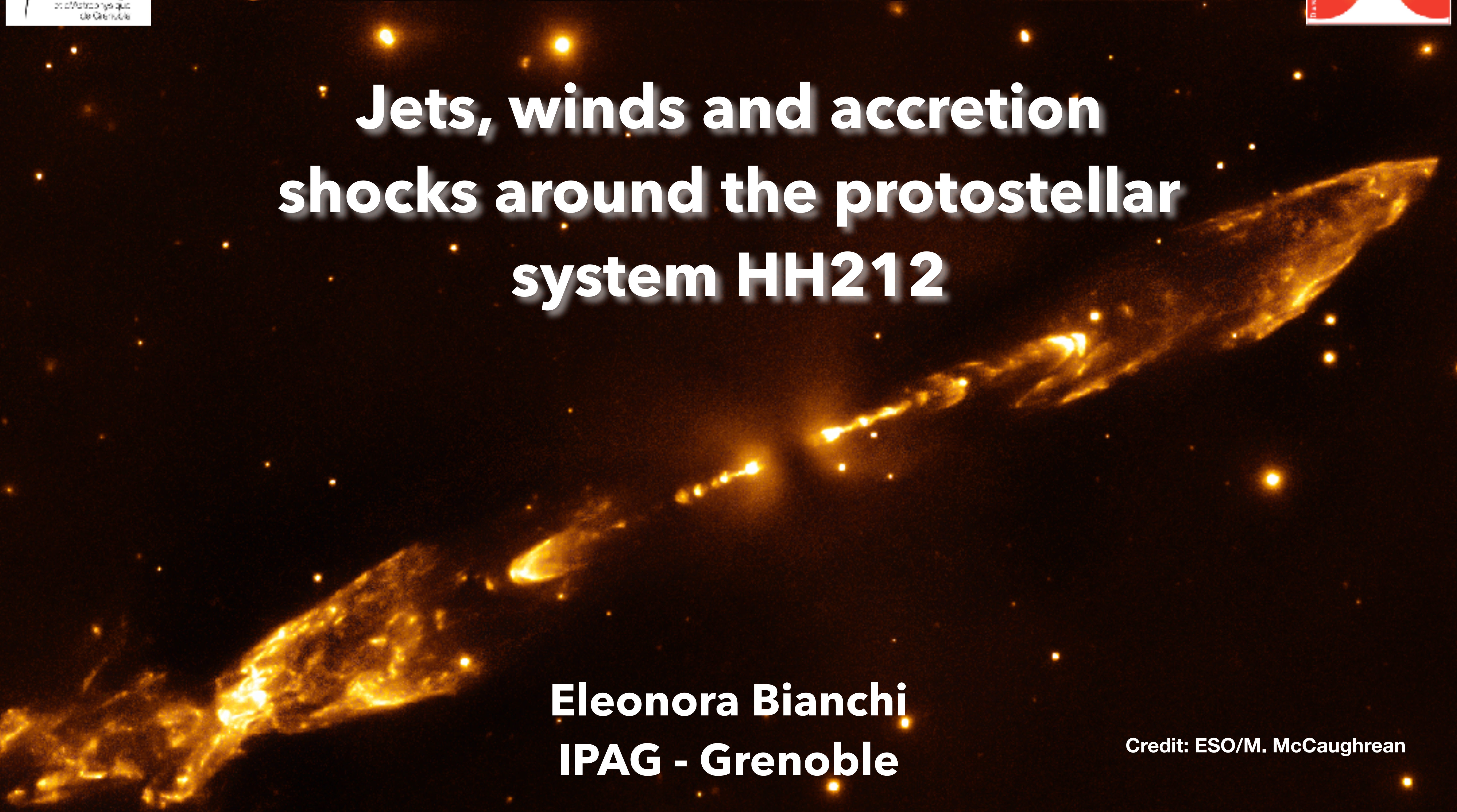
IPAG - Grenoble



Credit: ESO/M. McCaughrean

OUTLINE

- **Scientific context:**

  - The formation of a Sun-like star
  - The jet/disk system
  - Fast and slow shocks
  - The HH212 laboratory

- **Deuteration on a Solar System scale in HH212**

  - Methanol D/H as a tool to recover the pre-stellar physical conditions

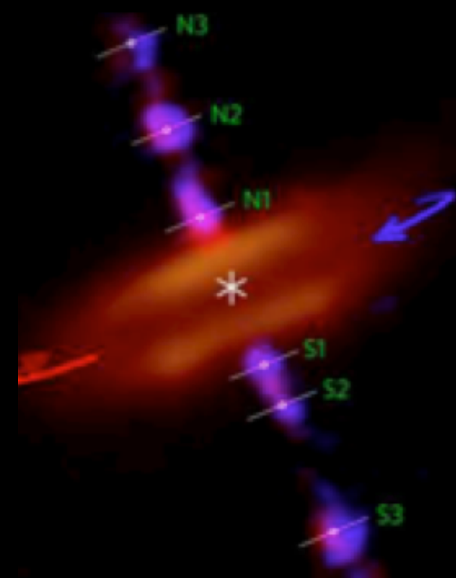
- **iCOMs and Water in HH212**

  - iCOMs as a tool to explore the jet/disk system

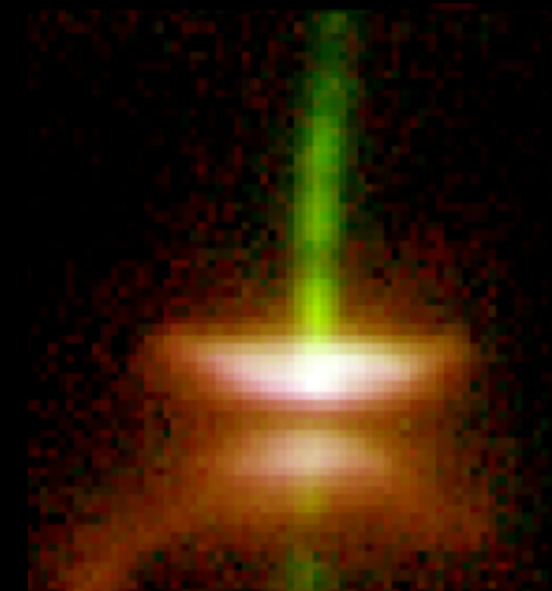
The formation of a Sun-like star

Prestellar core

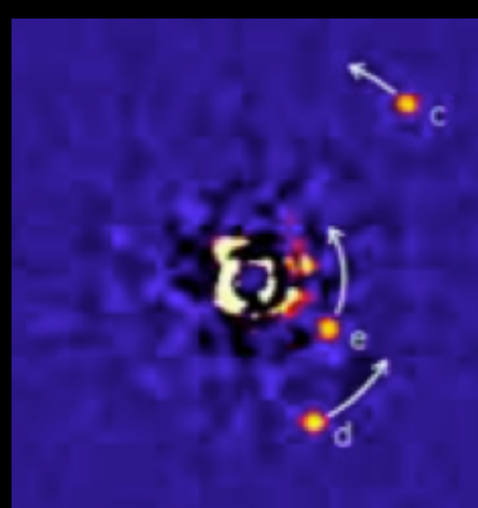
Class 0 protostar

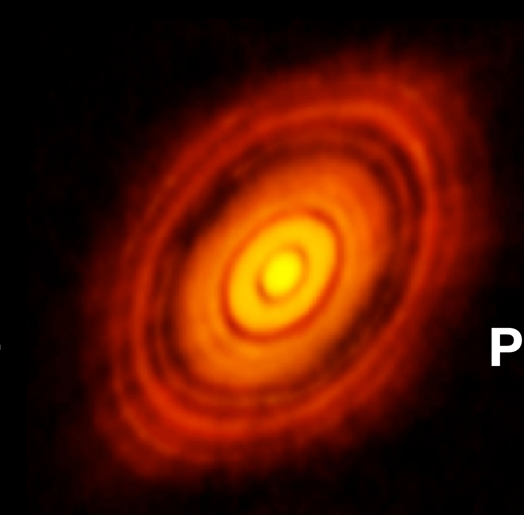


Class I protostar



Planetary system

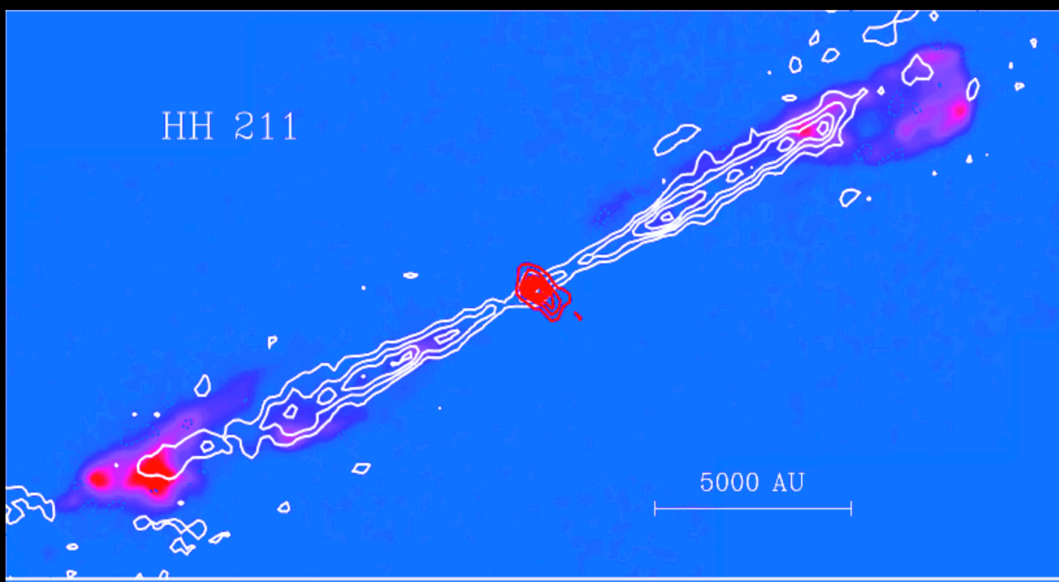




Protoplanetary disk

Fast vs slow protostellar shocks

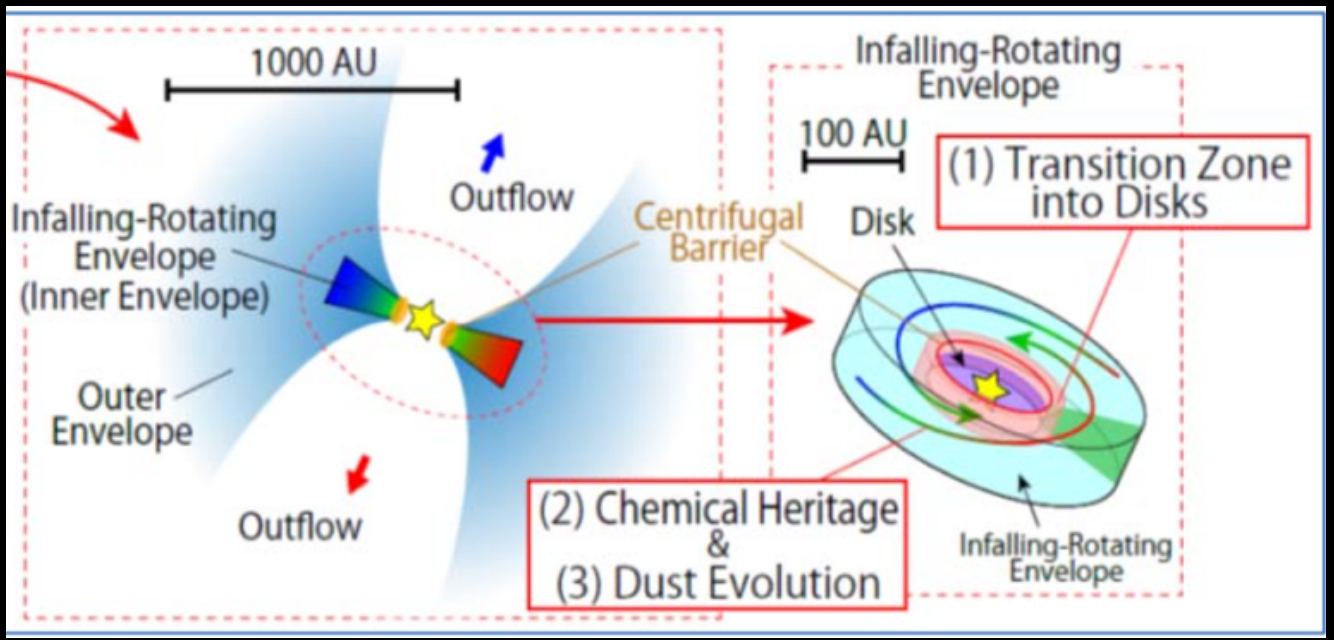
1. Jet-driven high velocity shocks



Gueth & Guilloteau (1992), Codella et al. (2009)

Rapid heating (from ~10 K to a few 1000 K) and compression of the gas —> "Shock chemistry"

2. Slow-shocks

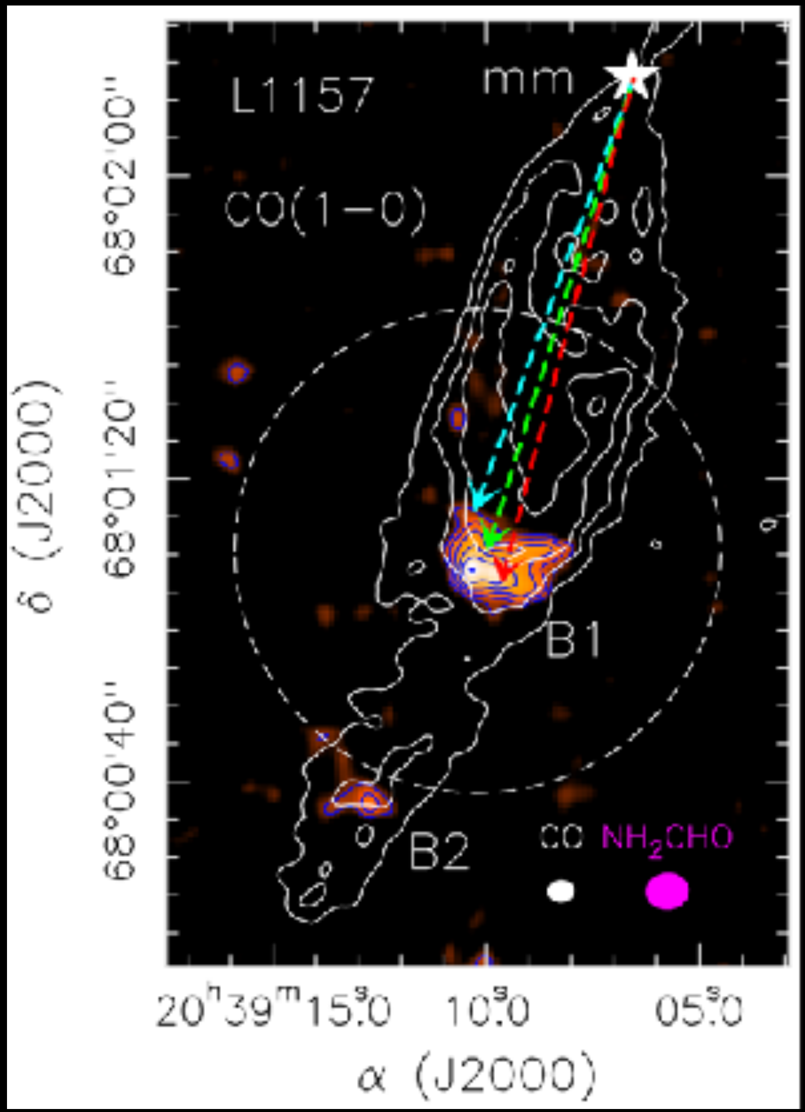


Sakai et al. (2014, 2017)

Keplerian disk-free fall envelope interface:
accretion shocks
Inner 50 au

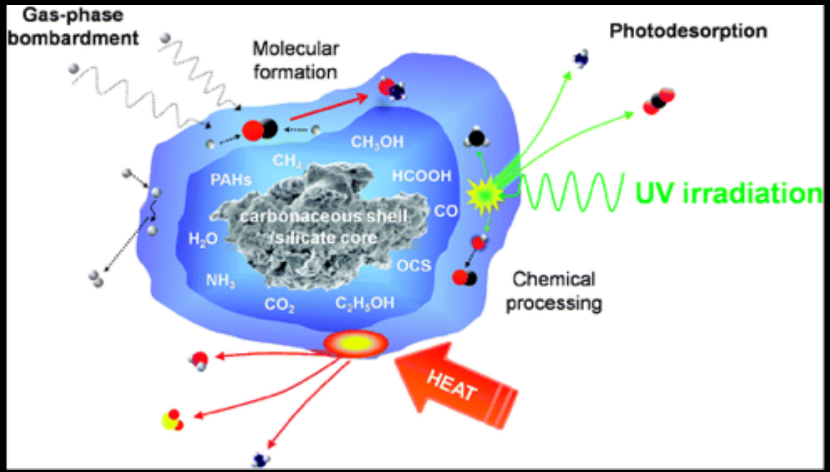
iCOMs to trace the shocks

1. Jet-driven high velocity shocks



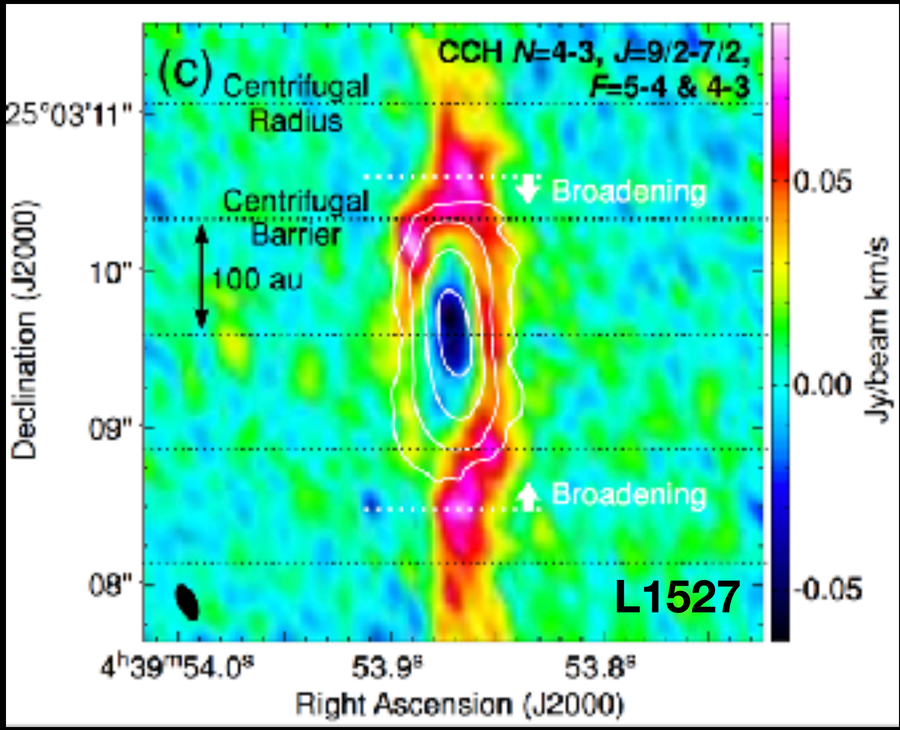
Codella et al. 2017

Shocks sputter/shutter dust grains



Garrods & Herbst 2006

2. Slow-shocks



Sakai et al. 2014

Release of Si-, S-, P-, Cl-, D- bearing species

Deuteration

Deuterium is formed during the Big Bang, and destroyed into stars

Deuteration (D/H) = abundance ratio between a molecule and its deuterated form,

e.g. HDO/H_2O

GAS

Roberts & Millar 89; Gerlich+02; Asvany+04; Gerlich & Schlemmer 02; Flower+06

If T is low $H_3^+ + HD \rightarrow H_2D^+ + H_2 + 230$ K

If $n(H_2)$ is high $H_2D^+ + CO \rightarrow DCO^+$

$H_2D^+ + N_2 \rightarrow N_2D^+$

$H_2D^+ + CN \rightarrow \ldots \rightarrow DNC$

$H_2D^+ + NH_3 \rightarrow \ldots \rightarrow NH_2D$

$H_2D^+ + H_2CO \rightarrow \ldots \rightarrow HDCO$

GRAINS

Hasegawa et al. 1992; Roueff et al. 2007; Caselli & Ceccarelli 2012; Ceccarelli et al. 2012, PPVI

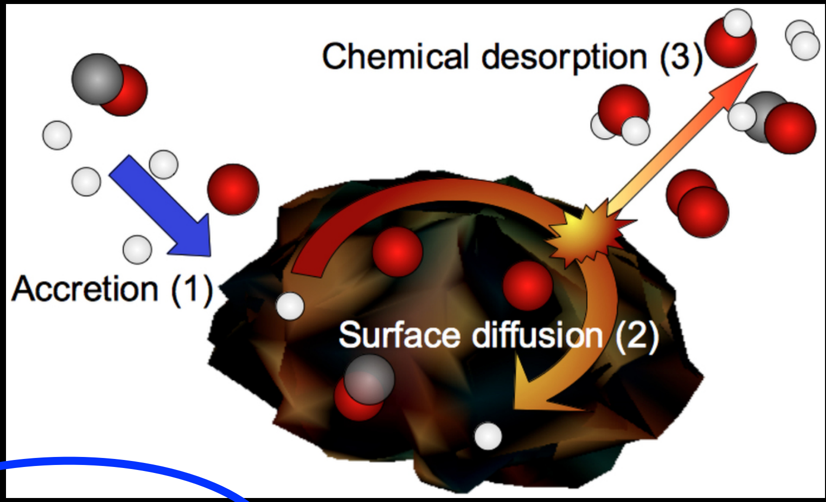
$O \rightarrow OH/OD \rightarrow H_2O/HDO$

$C \rightarrow CH/CD \rightarrow \ldots \rightarrow$

$N \rightarrow NH/ND \rightarrow \ldots \rightarrow$

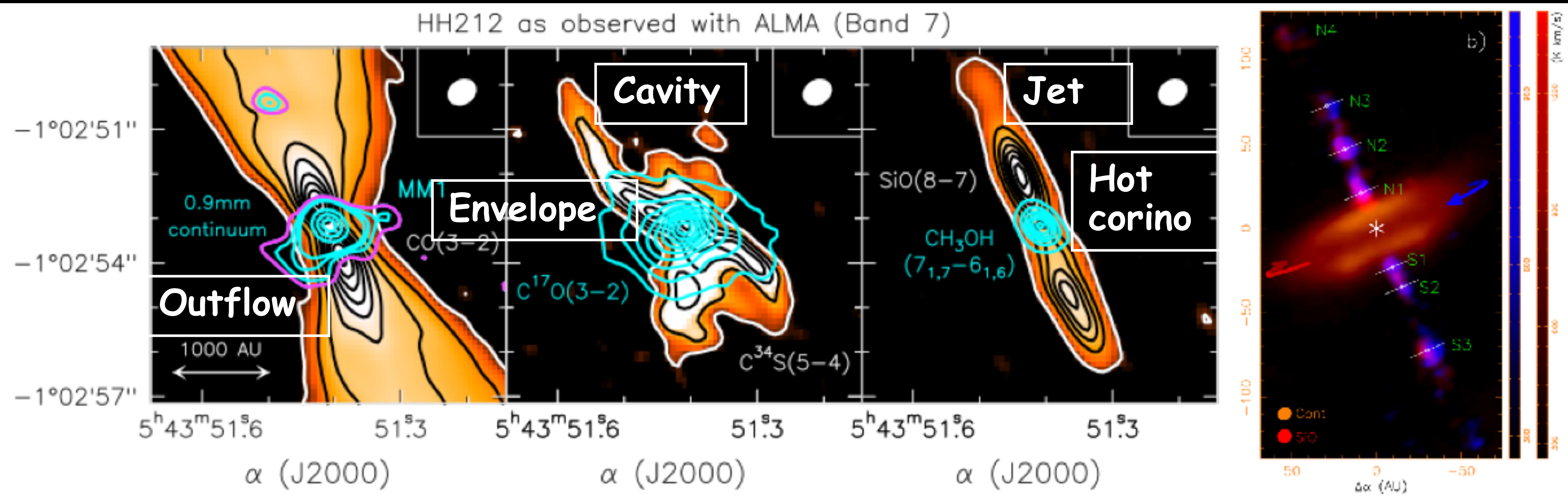
$CO \rightarrow HCO/DCO \rightarrow H_2CO/HDCO \rightarrow \ldots \rightarrow CH_3OH/CH_2DOH$

$CN \rightarrow HNC/DNC$



Grains only!

The HH212-mm laboratory



Codella et al. (2007, 2014, 2016), Cabrit et al. (2007, 2012), Podio et al. (2015), Leurini et al. (2016), Bianchi et al. (2017), Tabone et al. (2017), Lee et al. (2017, 2018)

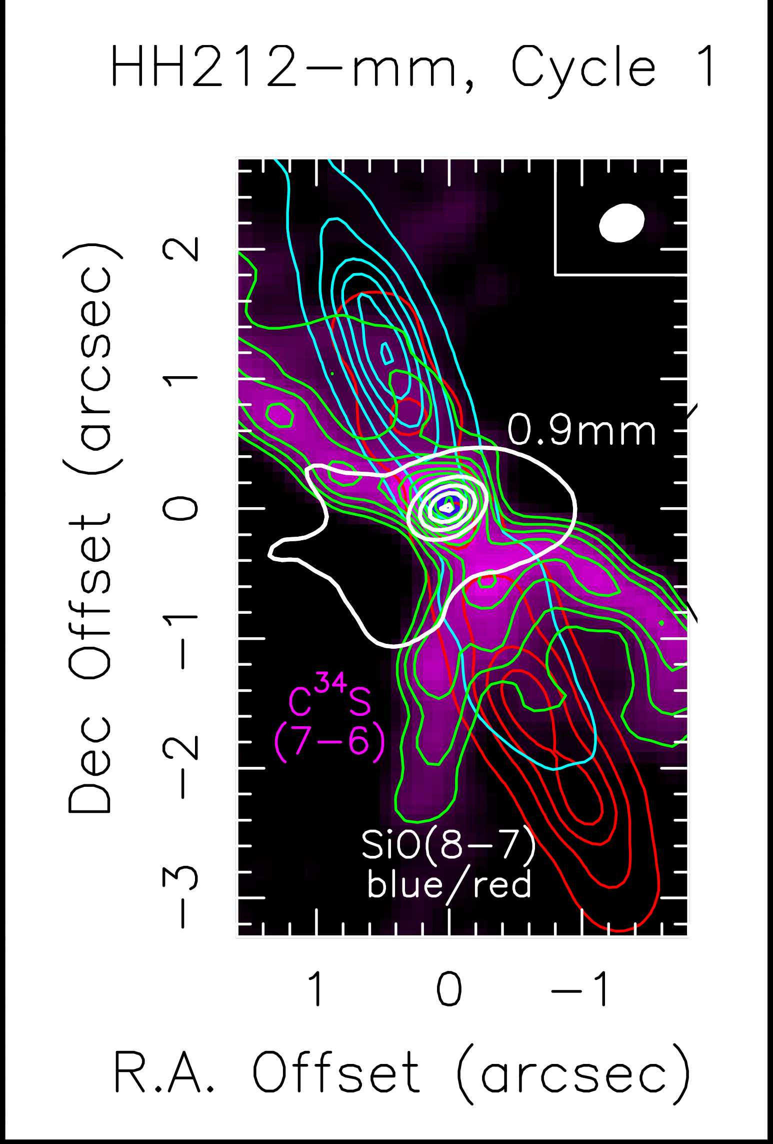
d = 405 pc (Orion B)

Inclination ~ 4°

- Large scale envelope $C^{17}O$
- Rotating outflow SO, SO_2
- Spinning jet SiO
- Cavity $C^{34}S$

- Hot-corino CH_3OH, CH_2DOH, CH_3CHO
- Dusty accretion disk "hamburger" shaped r ~ 60 au

ALMA Cycle 1 and Cycle 4 observations



Codella et al. 2014, 2015, 2016;
Podio et al. 2015
Leurini et al. 2016

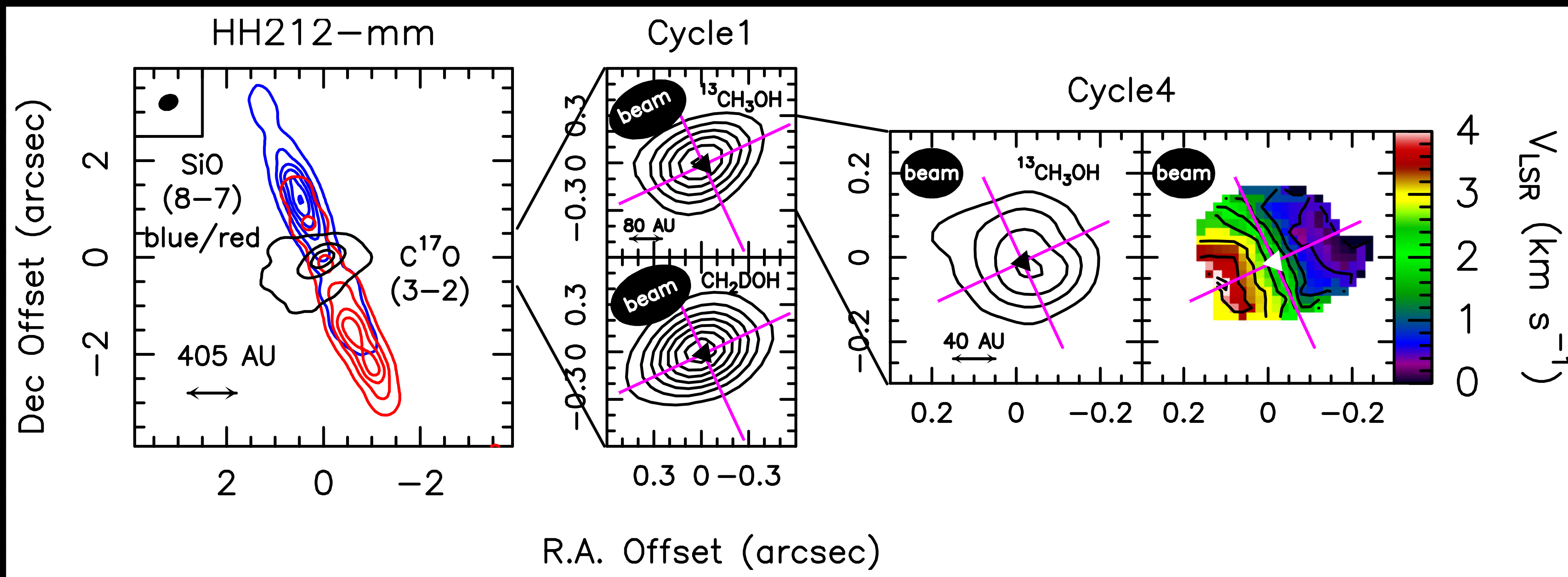
All the components in a single setup!

ALMA BAND 7 observations

Cycle 1
337.1 – 338.9 GHz & 348.4 – 350.7 GHz
HPBW ~ 0.4” x 0.3”
rms ~ 5 – 6 mJy/beam

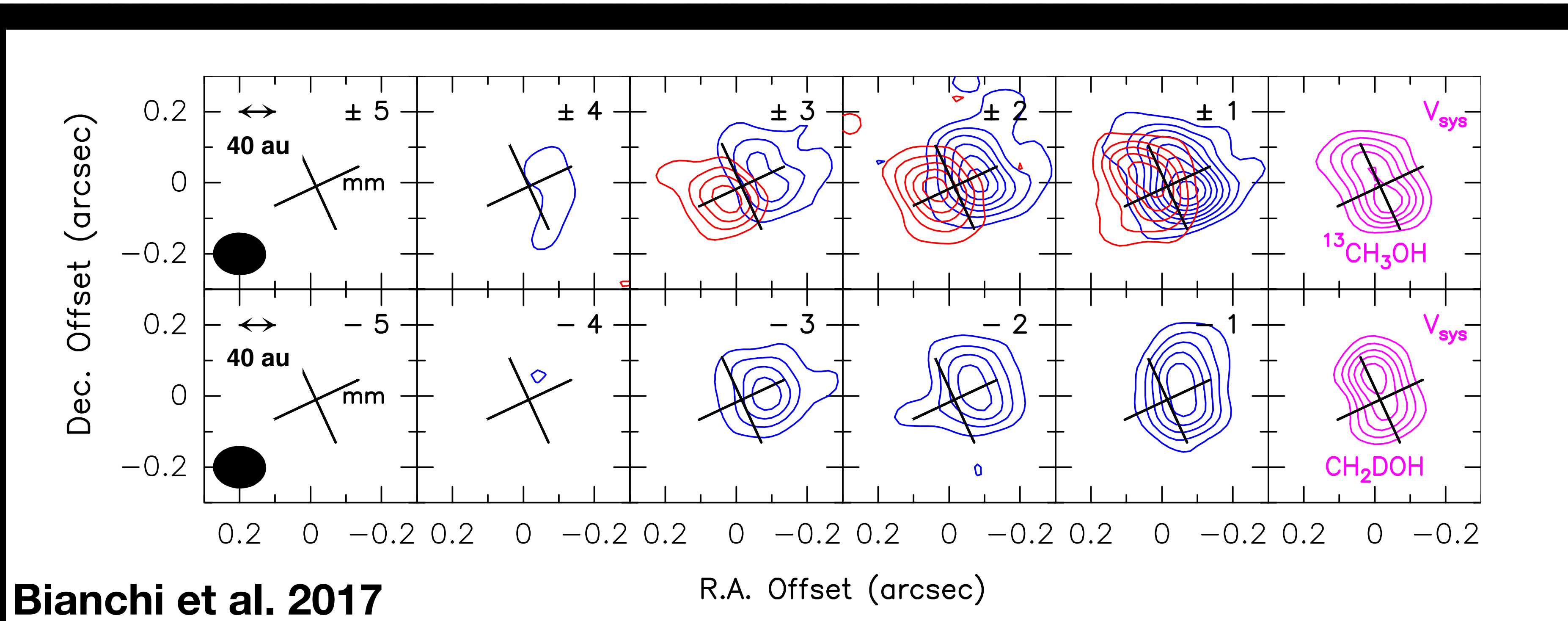
Cycle 4
335.0 – 337.4 GHz
HPBW ~ 0.15” x 0.12”
rms ~ 4 – 5 mJy/beam

D/H in HH212



Velocity gradient along the equatorial plane

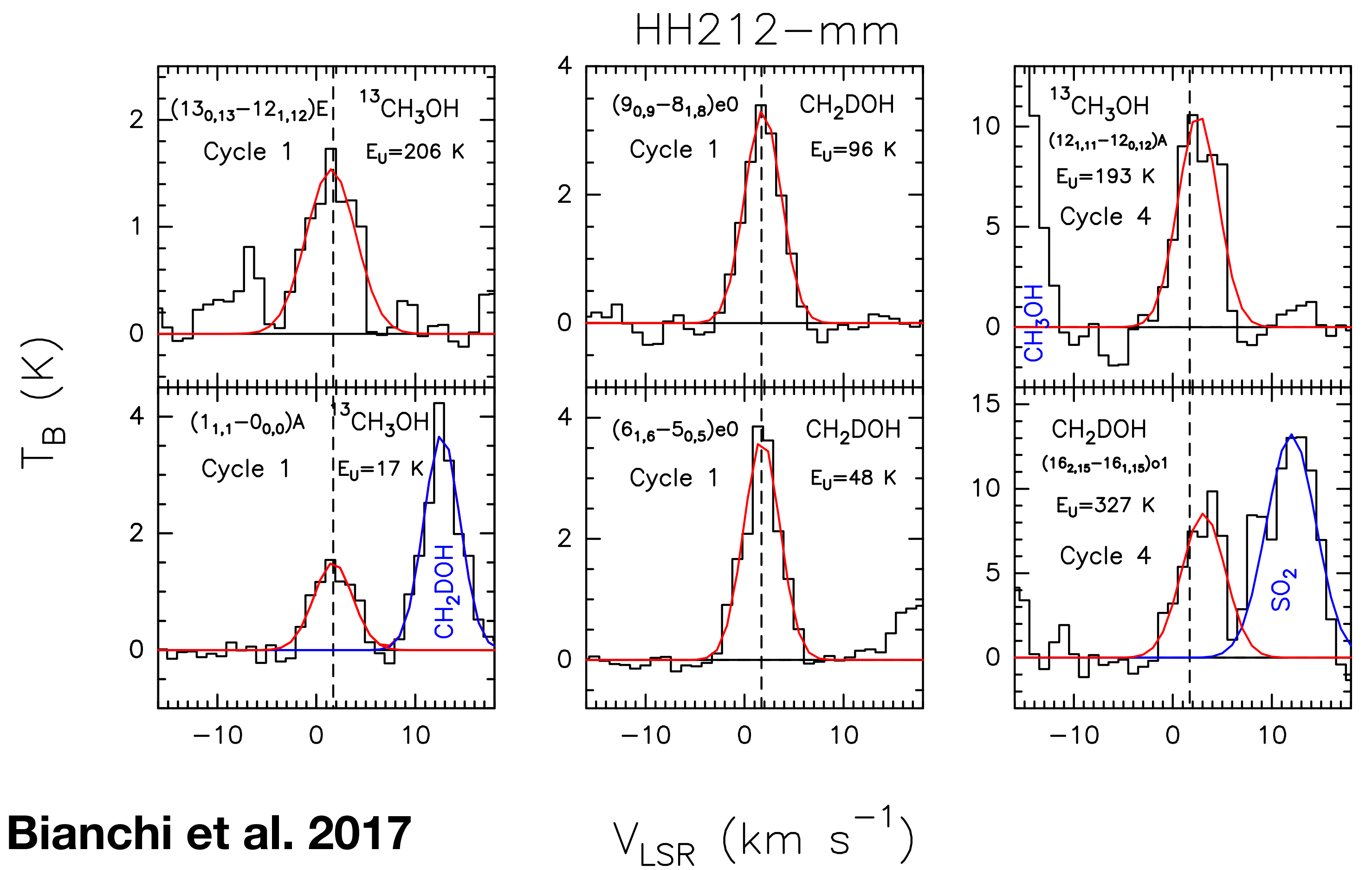
Material associated with the disk



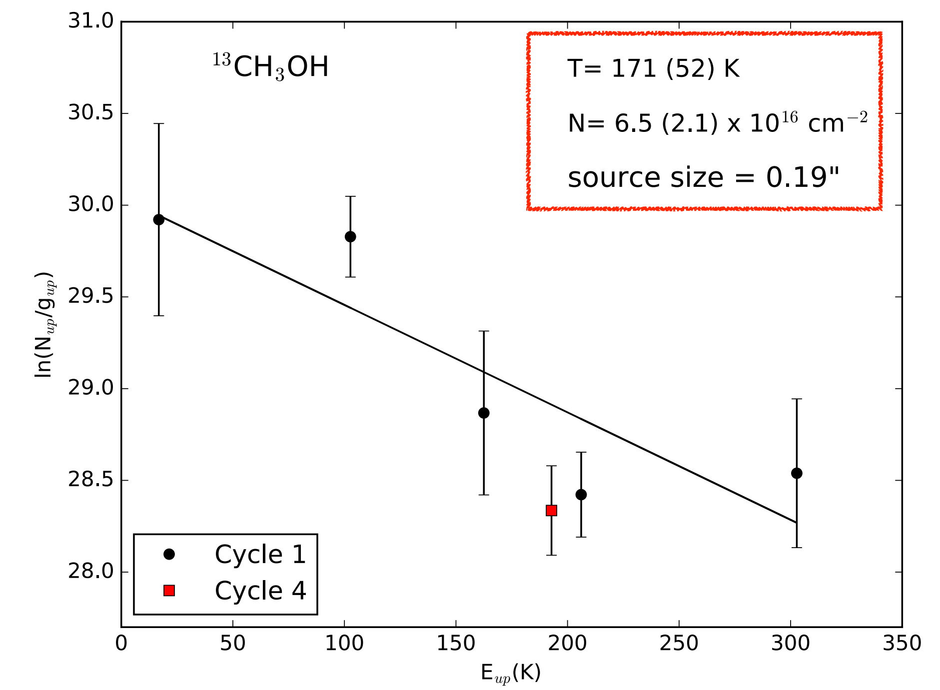
Bianchi et al. 2017

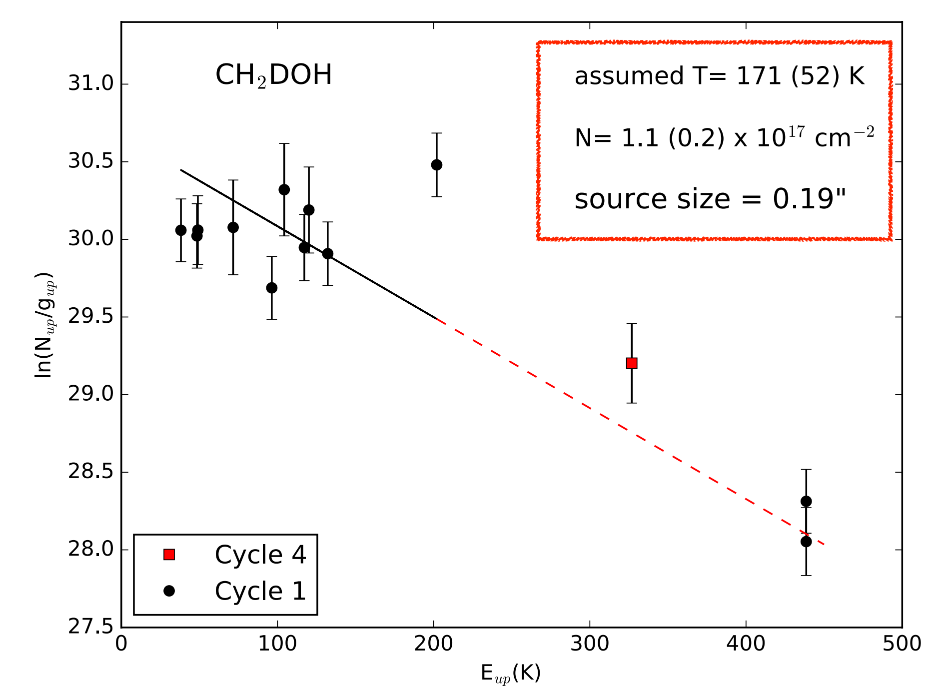
ALMA Cycle 4 maps show a size of 0.19” (i.e. radius of 38 au) kinematics shows association with disk (rotation)

D/H in HH212



Bianchi et al. 2017





Methanol deuteration for the first time on a Solar System scale:

D/H ~ 2.4 (0.4) x 10^{-2}

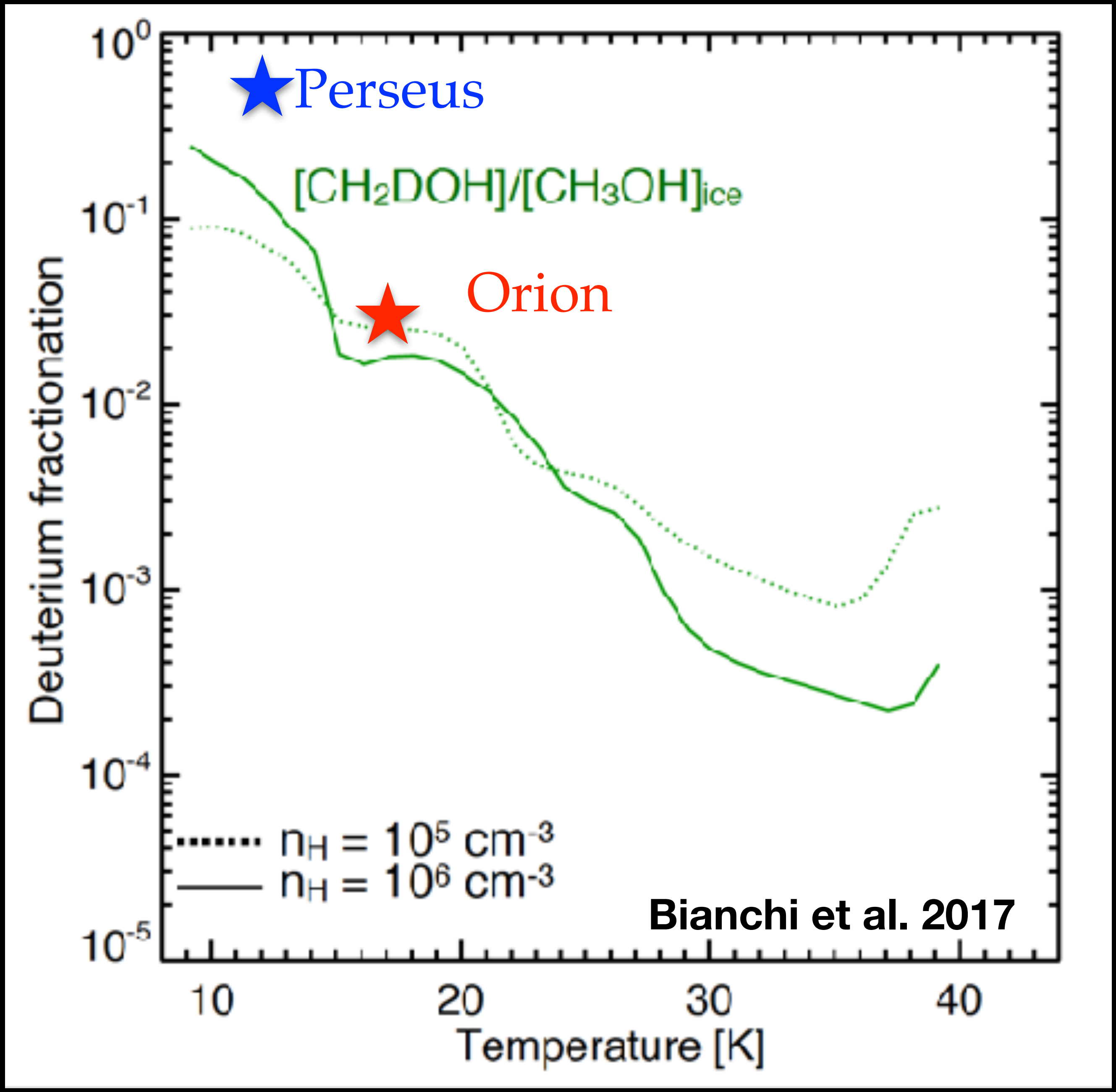
D/H in HH212

Orion vs Perseus star forming regions

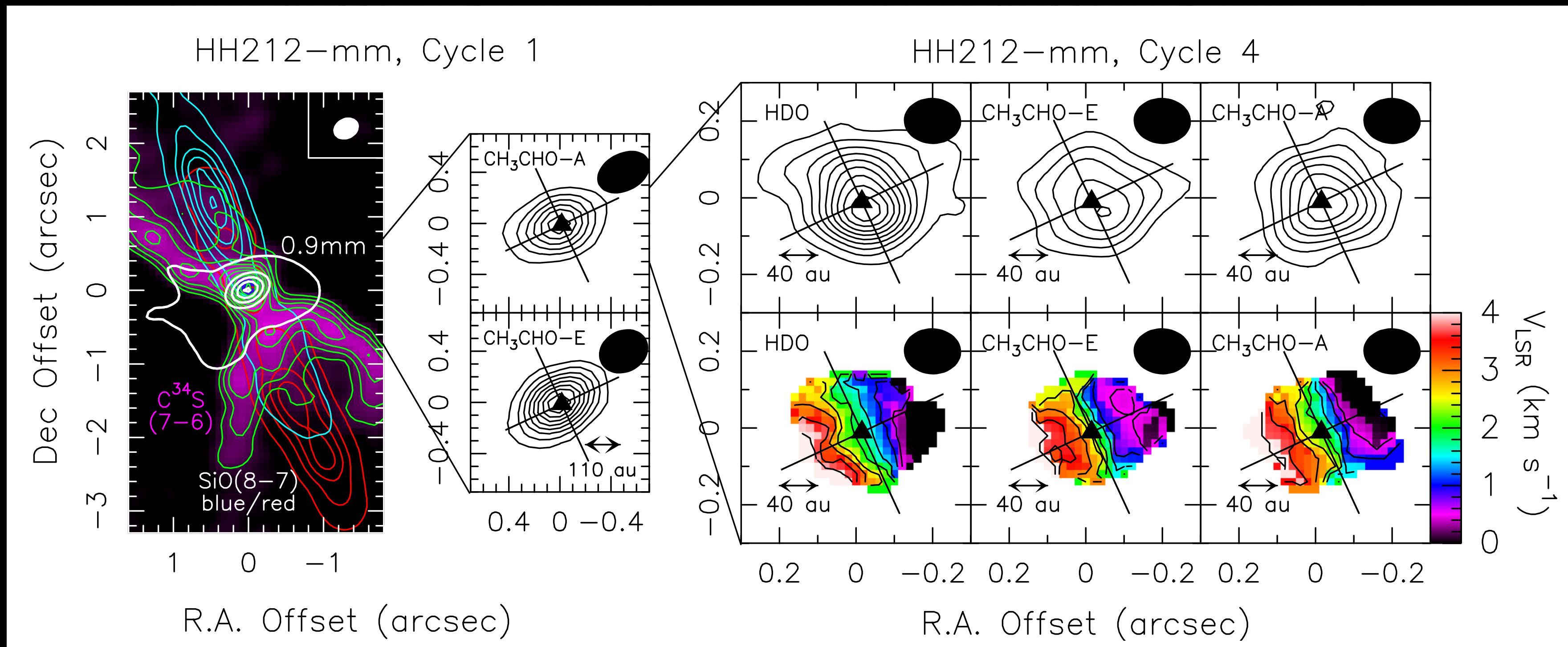
D/H Class 0 protostars in
Perseus ~ 0.4-0.6 T_{dust} ~ 12 K
(Zari et al. 2016)

D/H Class 0 protostar in
Orion ~ 2.4 (0.4) x 10^{-2} T_{dust} > 16 K
(Lombardi et al. 2015)

In agreement with a higher gas temperature in the prestellar phase
GRAINOBLE model
(Taquet et al. 2012a, 2013, 2014)



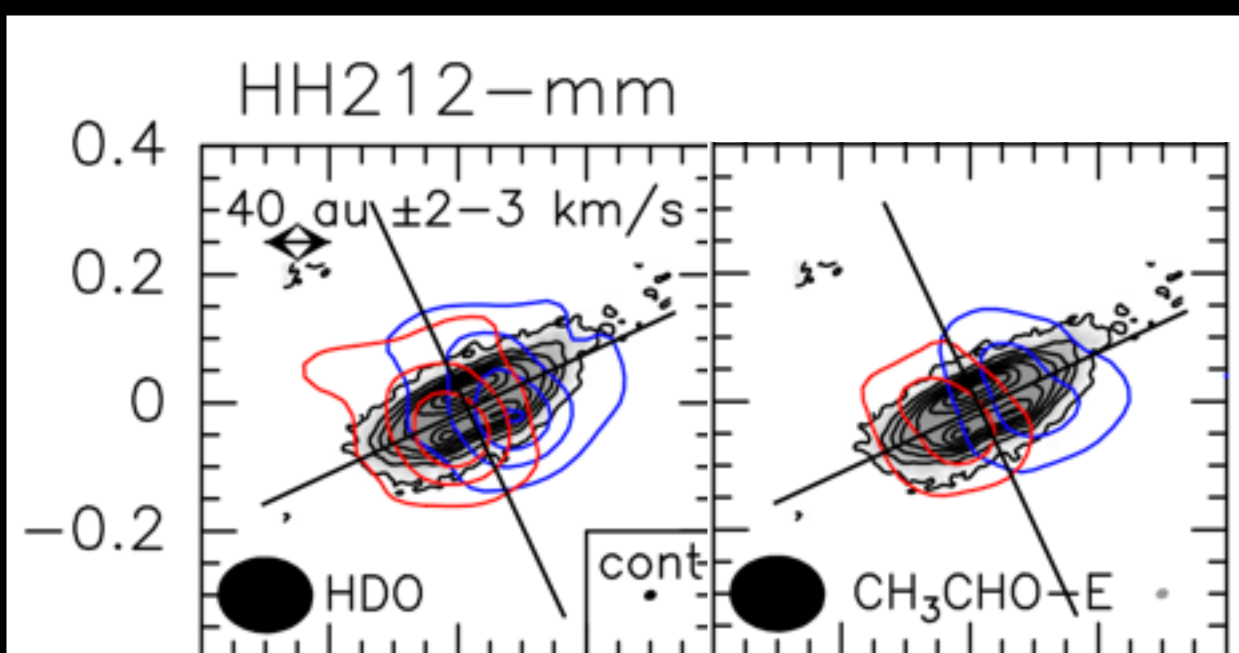
iCOMs and water in HH212

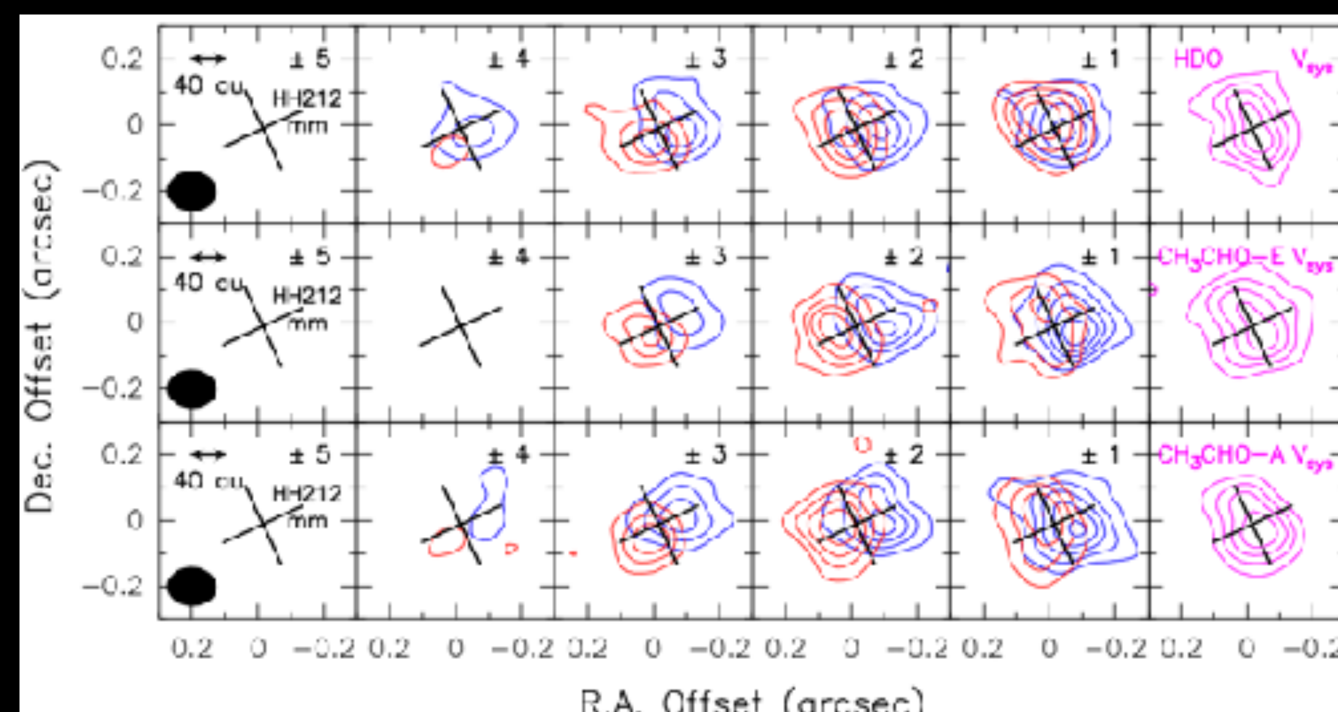


Velocity gradient along the equatorial plane

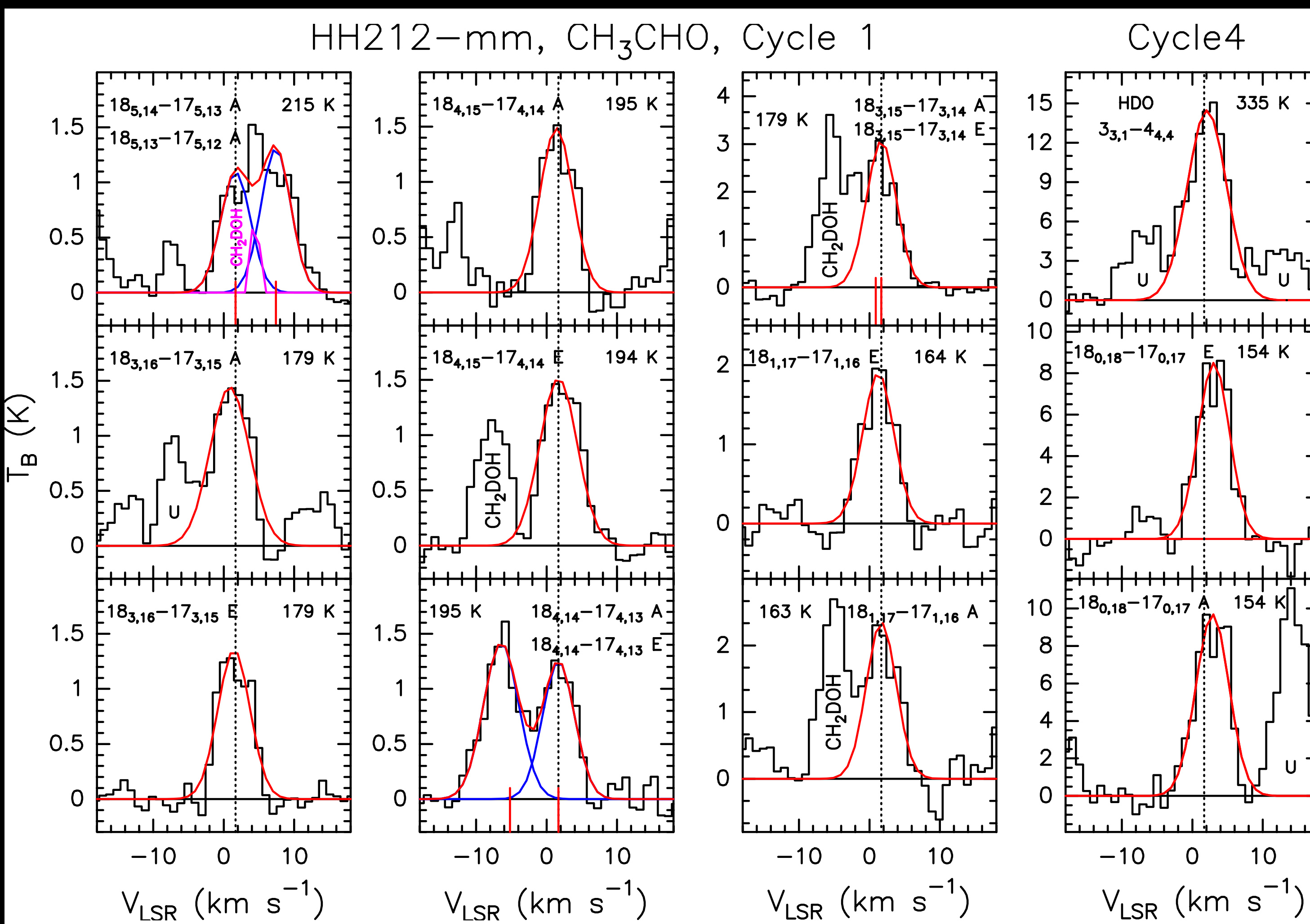
Material associated with the disk

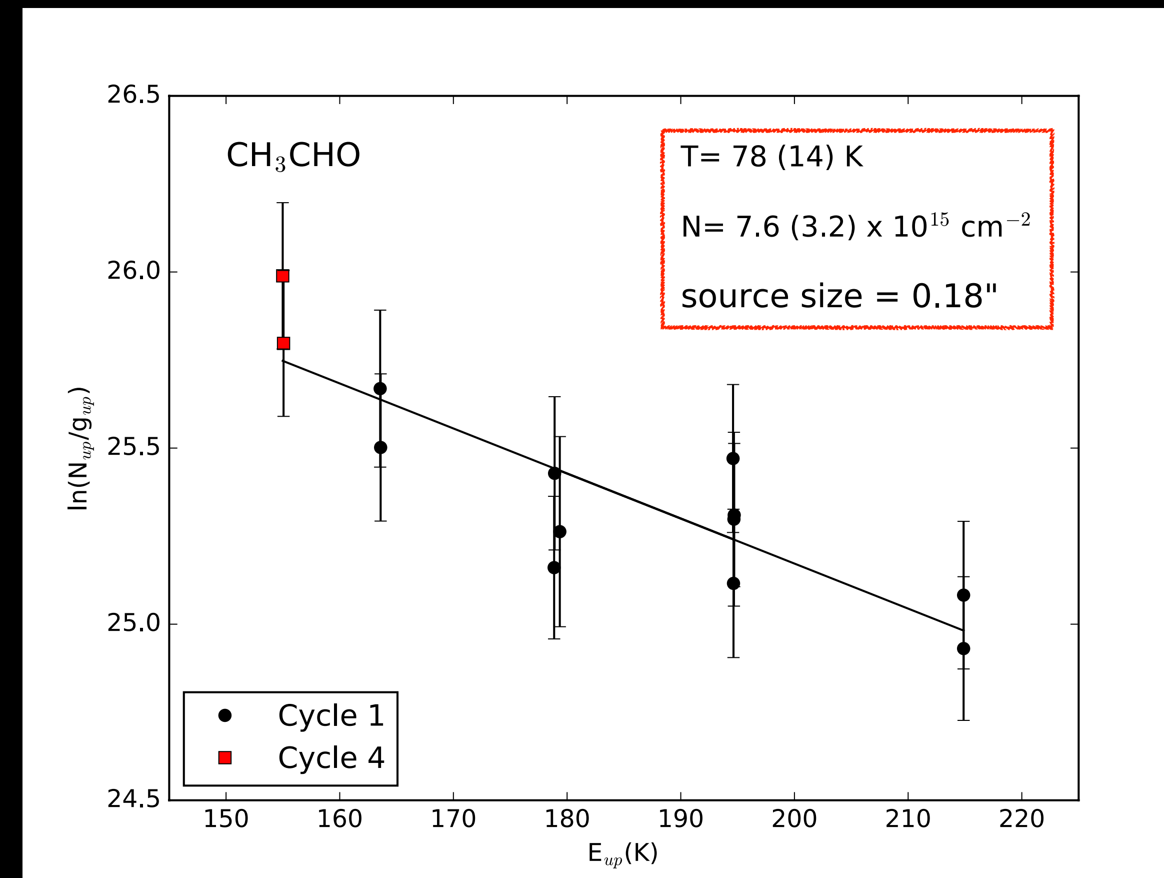
Codella et al. 2018





iCOMs and water in HH212

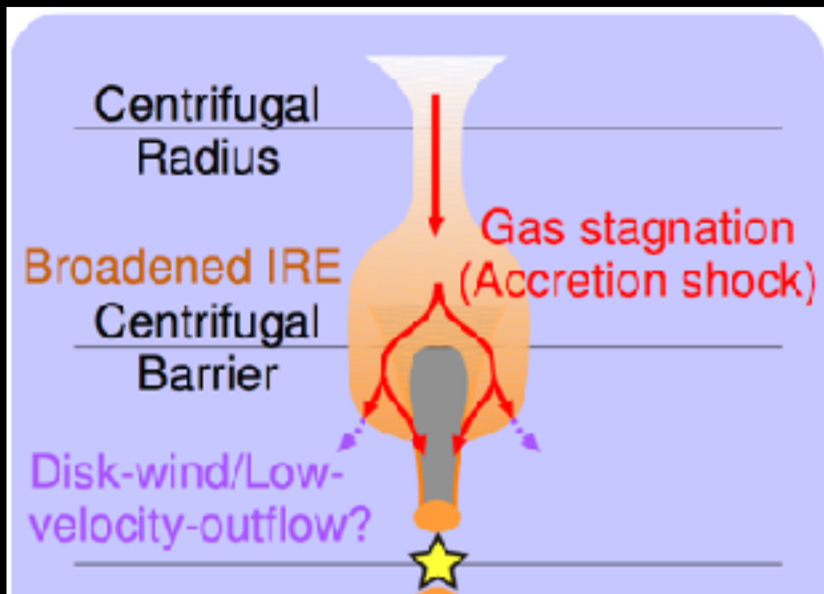




Codella et al. 2018

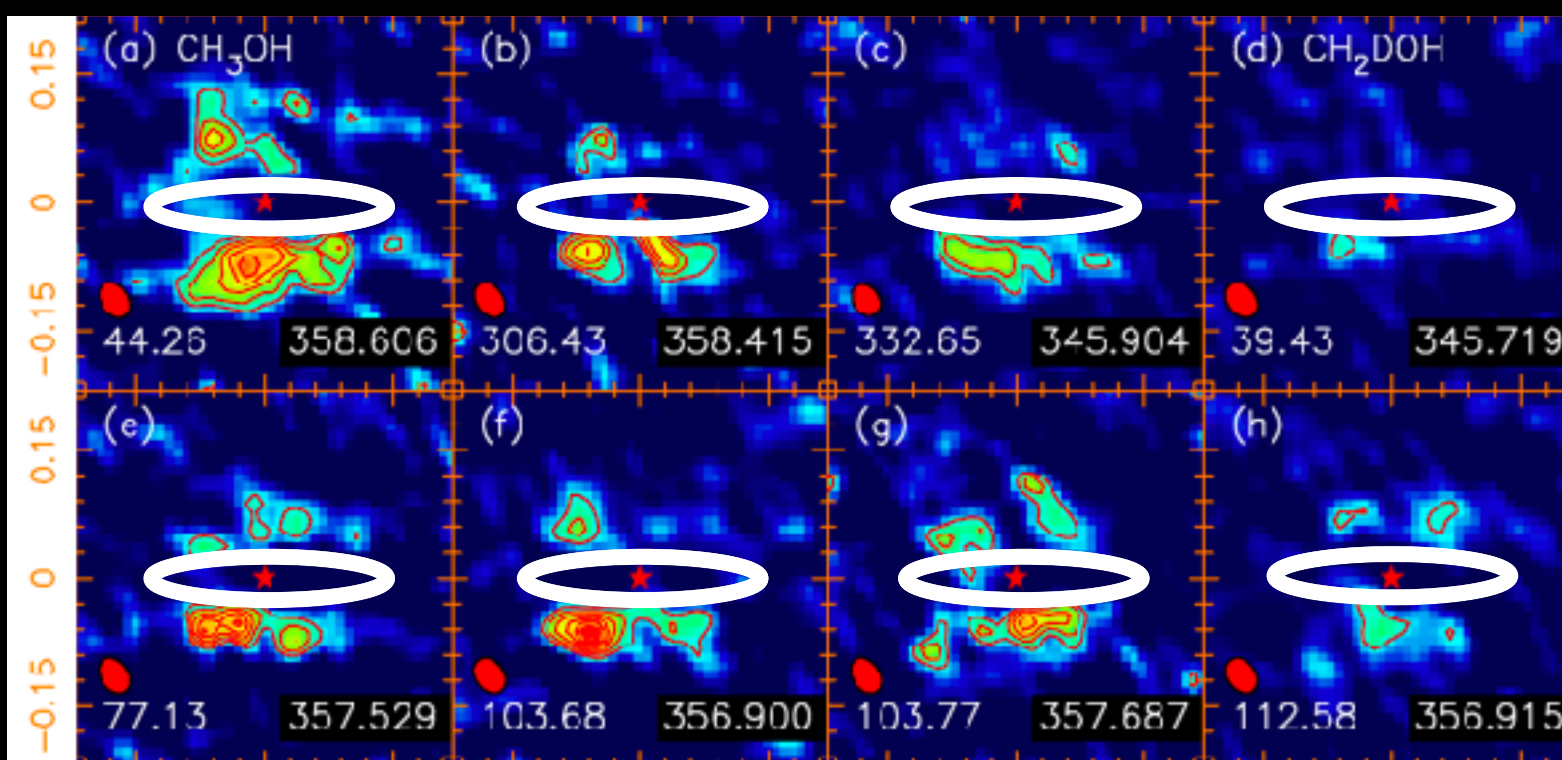
Size ~ 70 au
(i.e. Solar System scale);
T ~ 80-100 K;
n > 10^8 cm^{-3}

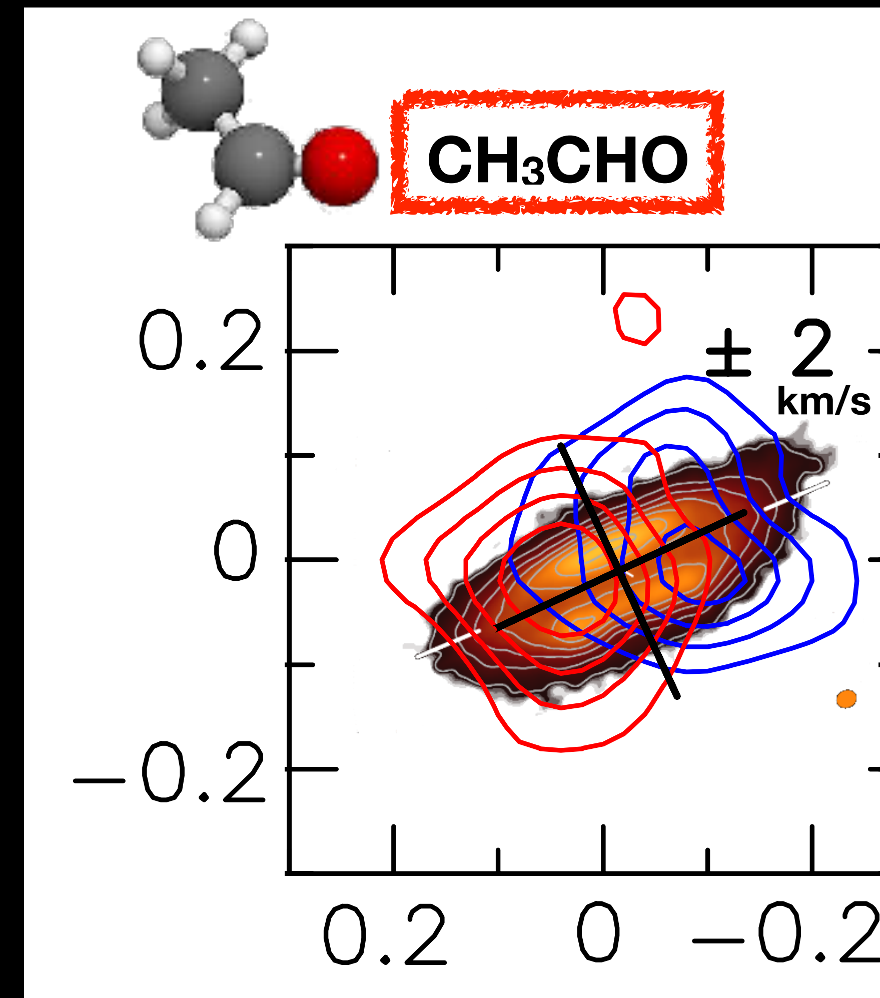
iCOMs associated with the disk



Gas launched at the centrifugal barrier ? (Sakai et al. 2017)

Disk atmosphere ? (Lee et al. 2017)





CH_3CHO + dust continuum

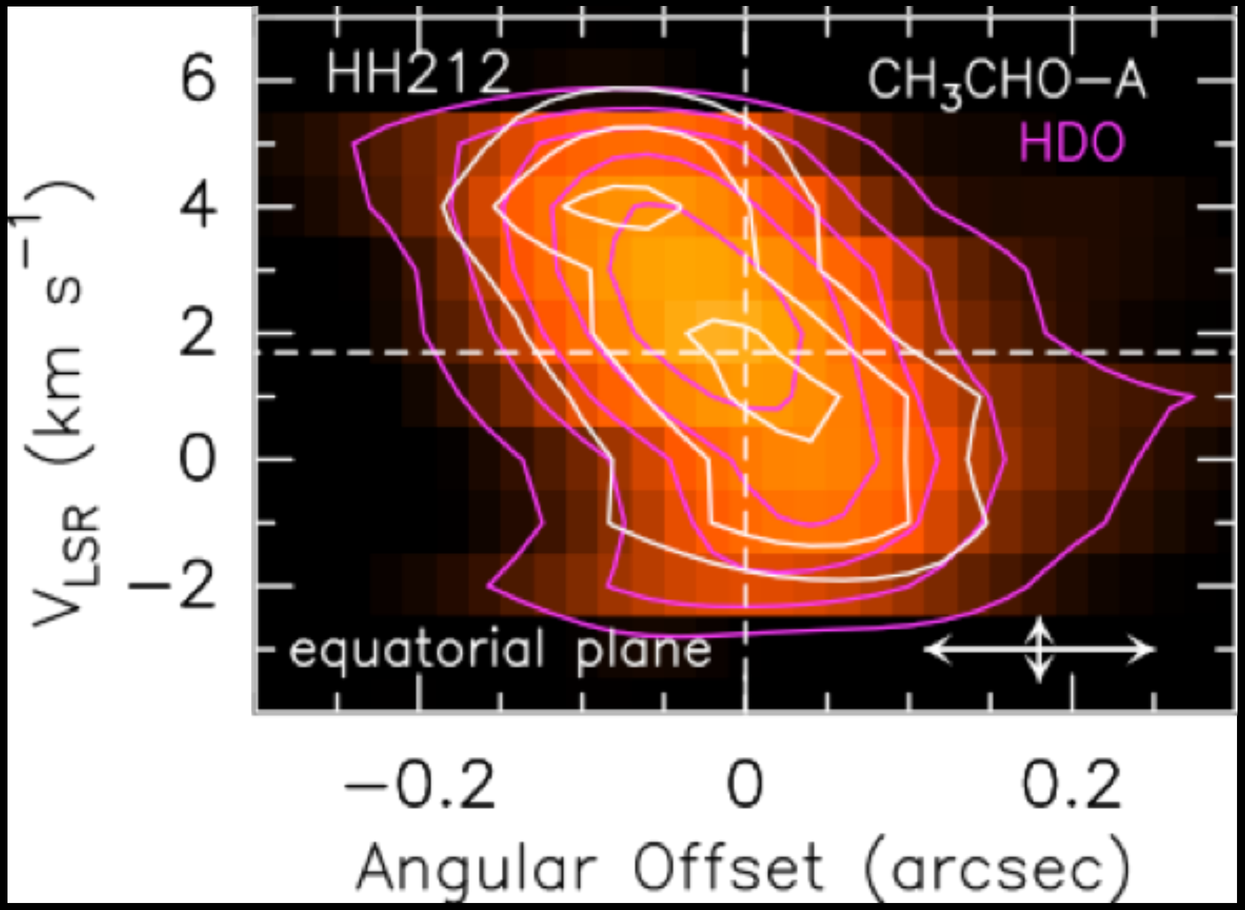
Codella et al. 2018

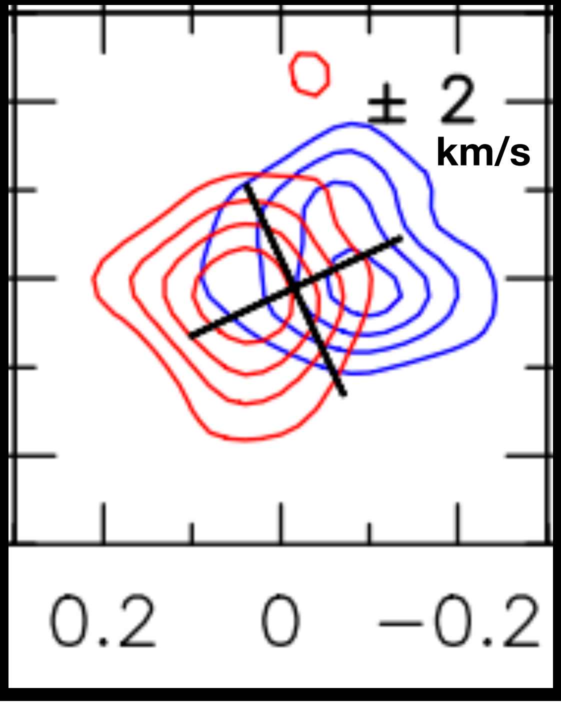
Lee et al. 2017

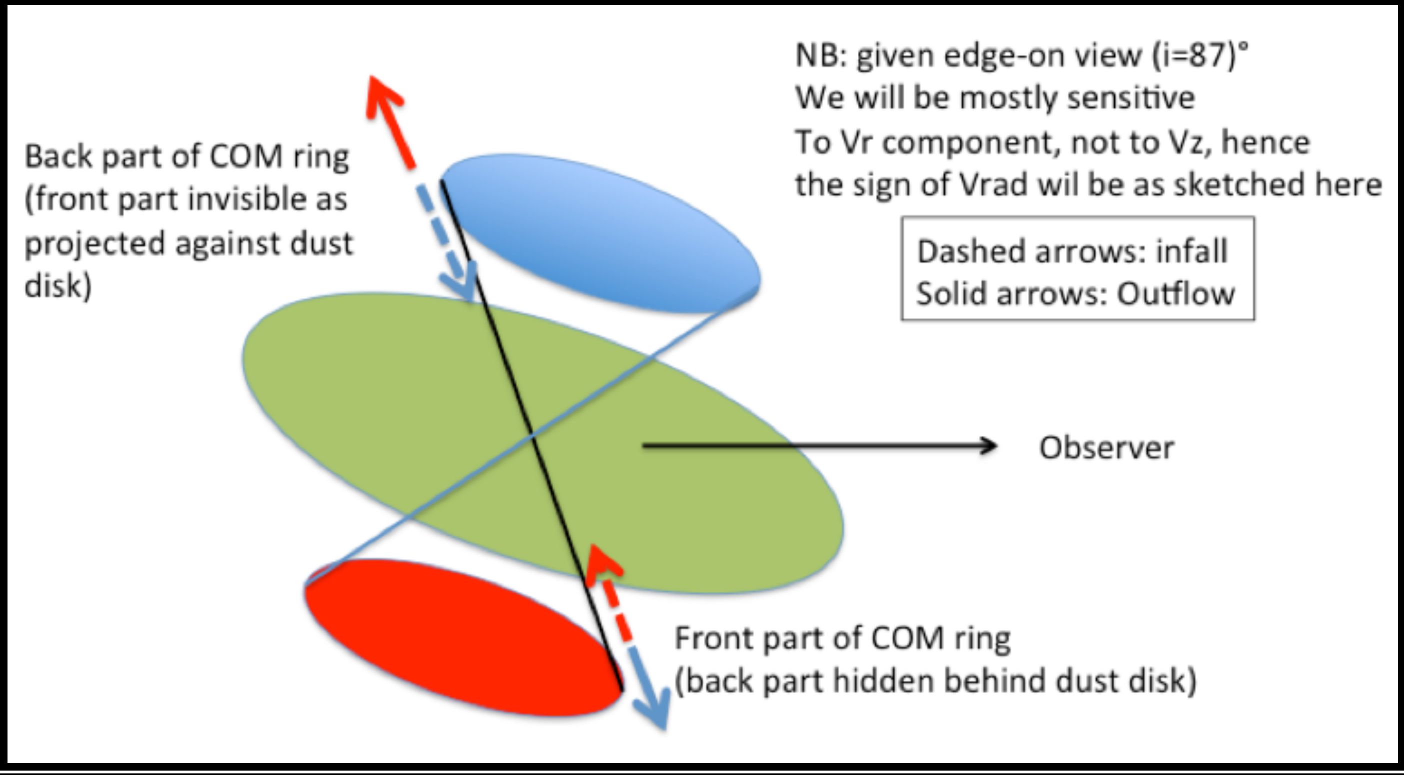
Bianchi et al. 2017

iCOMs associated with the disk

Centrifugal barrier + outflowing rotating rings



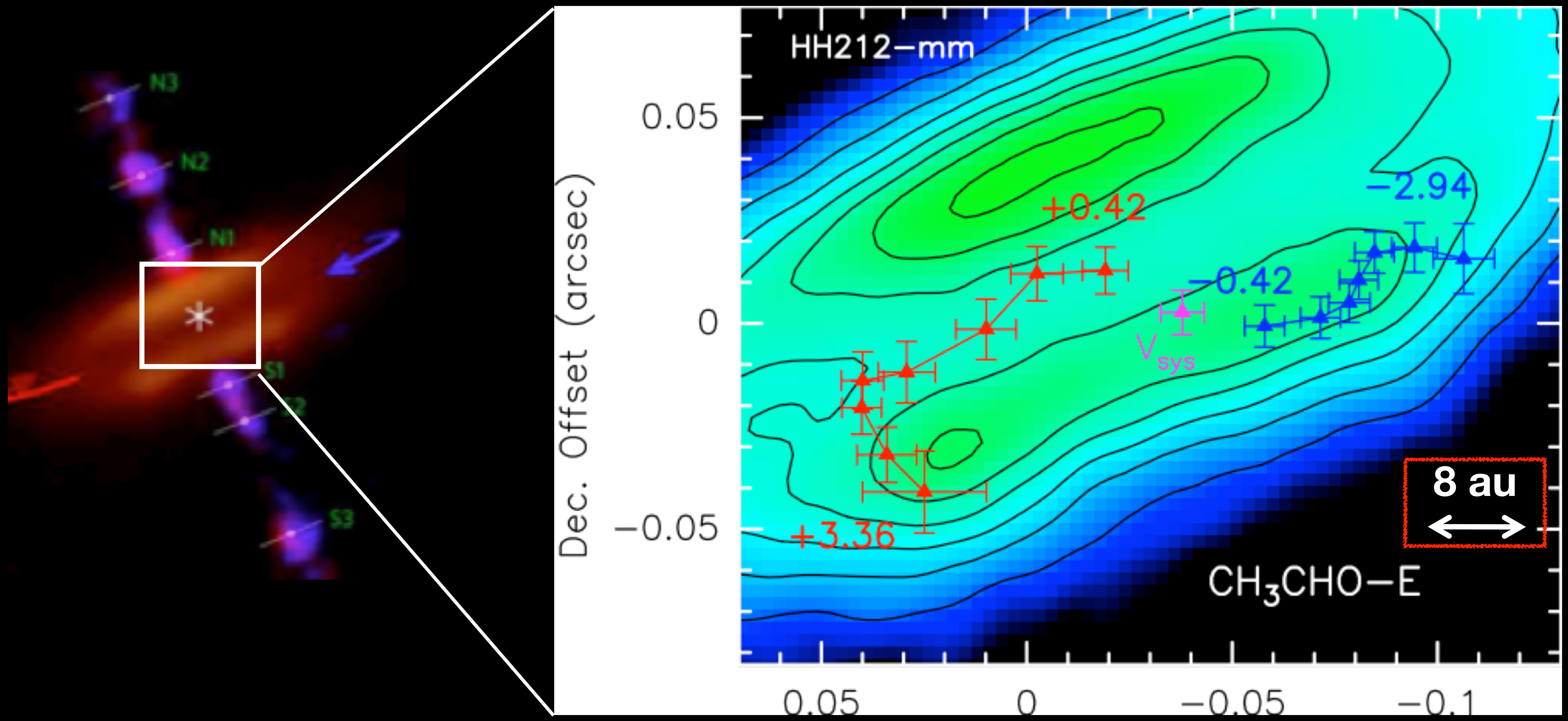




Codella et al. 2018

iCOMs associated with the disk

Outflowing and expanding rings



Codella et al. 2018

The FAUST synergy

Fifty au study of protosun analogs
ALMA & VLA Large Programs

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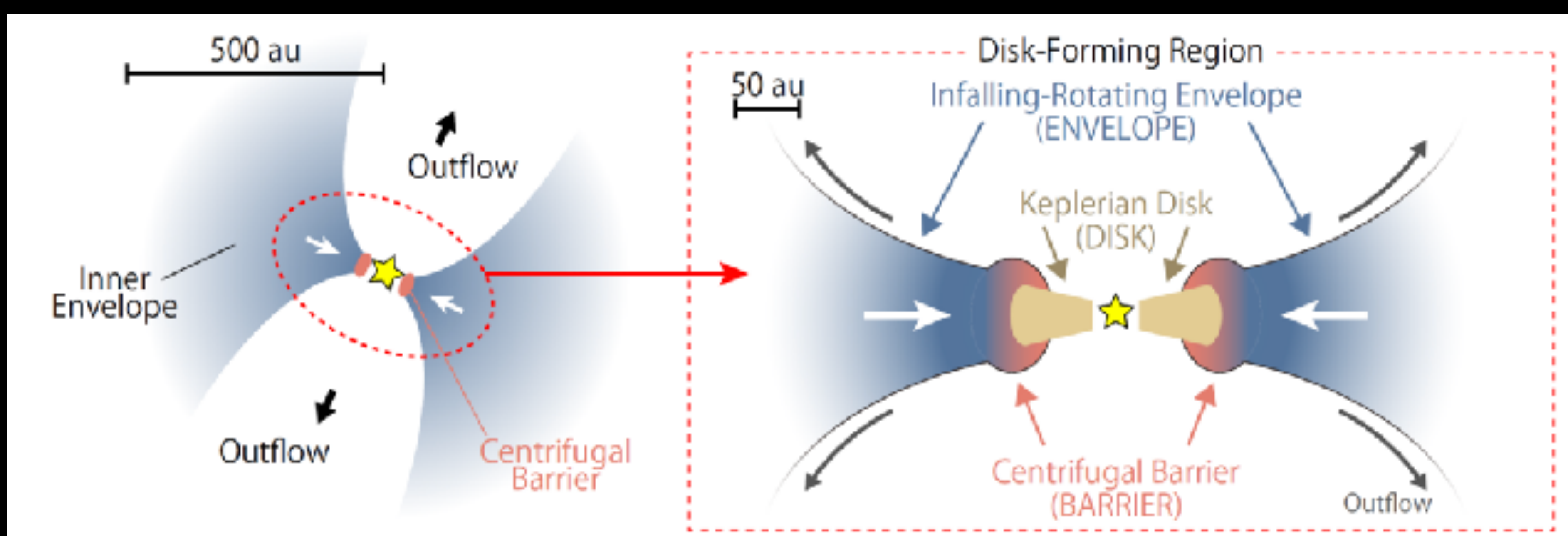
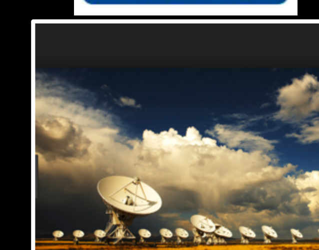
S. Yamamoto (Tokyo University)
N. Sakai (RIKEN)

C. Chandler (NRAO)





Take home messages

- **Discovery the inner regions of Sun-like protostars: much more than a hot-corino!**

  The scales < 100 au are dominated by the jet/disk interactions
  Accretion shocks and disk wind are important processes to be considered

- **Deuteration on a Solar System scale in HH212**

  Deuteration can be used as a fossil record to recover the prestellar phase physical conditions (temperature & density)

- **iCOMs and Water in HH212**

  iCOMs are unique tool to explore the inner protostellar regions