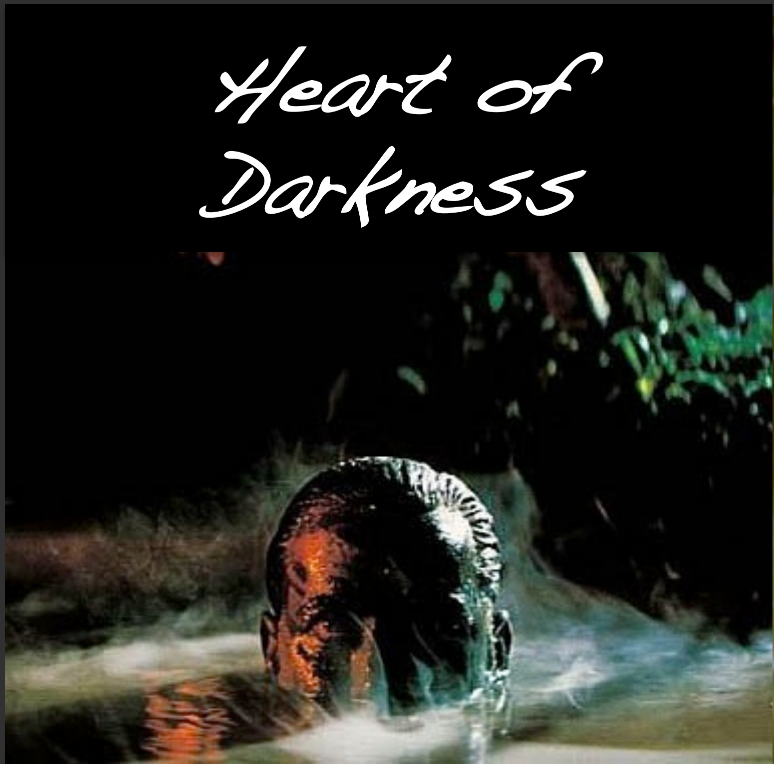
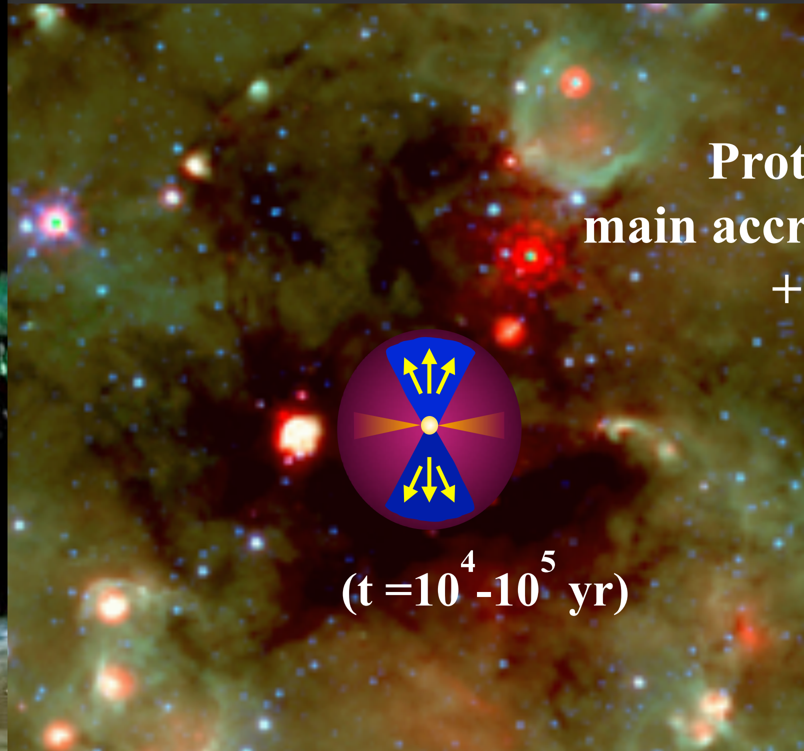
# The chemistry of protostellar jet-disk systems

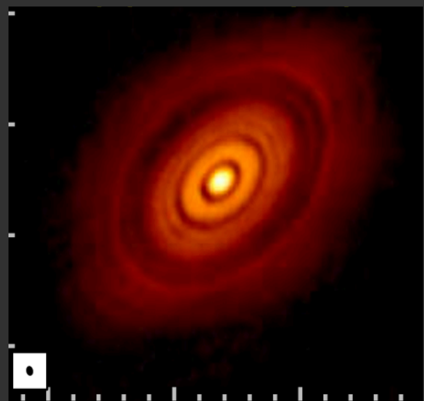
C. Codella (INAF, OA Arcetri)

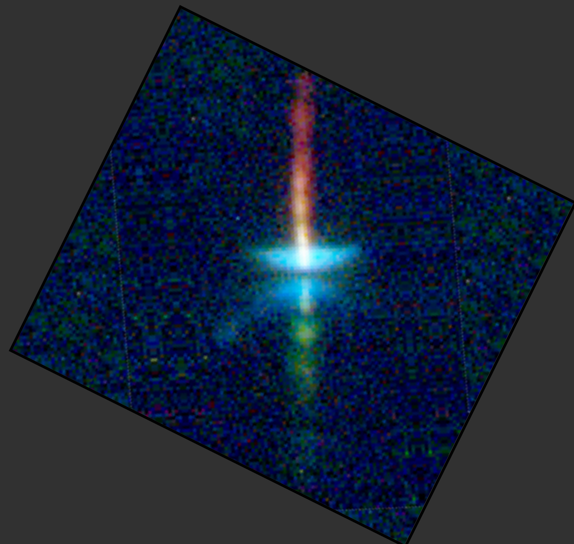



**Protostar:**
**main accretion phase**
**+ jet**

**T-Tauri Star:**
**accretion disk + jet**
**(t =$10^6$-$10^7$ yr)**

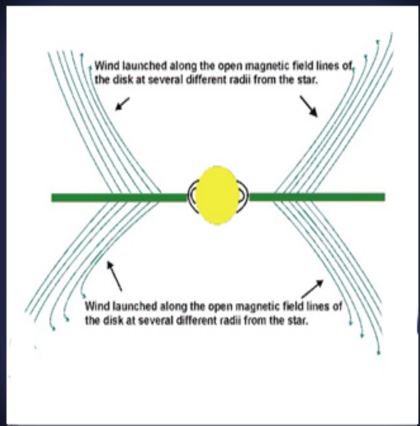




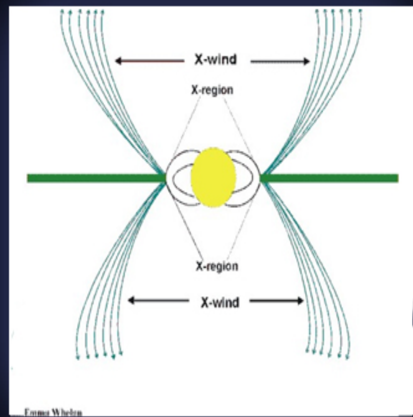
# The launching and collimation of jets

MHD models predict that jets extract excess angular momentum from the star/disk system

**D-wind**

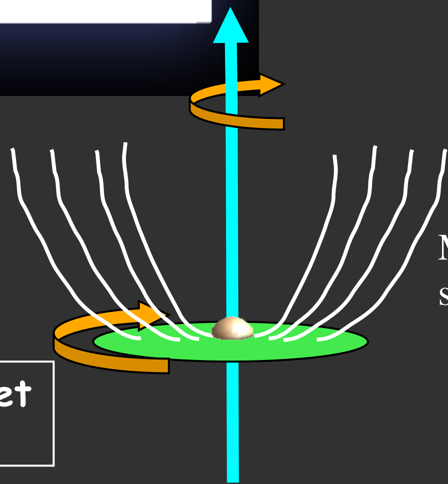



**X-wind**




Origin of the jet in the disk plane: 0.03 to a few AU

Acceleration and collimation of jet: within 20-100 AU above the disk

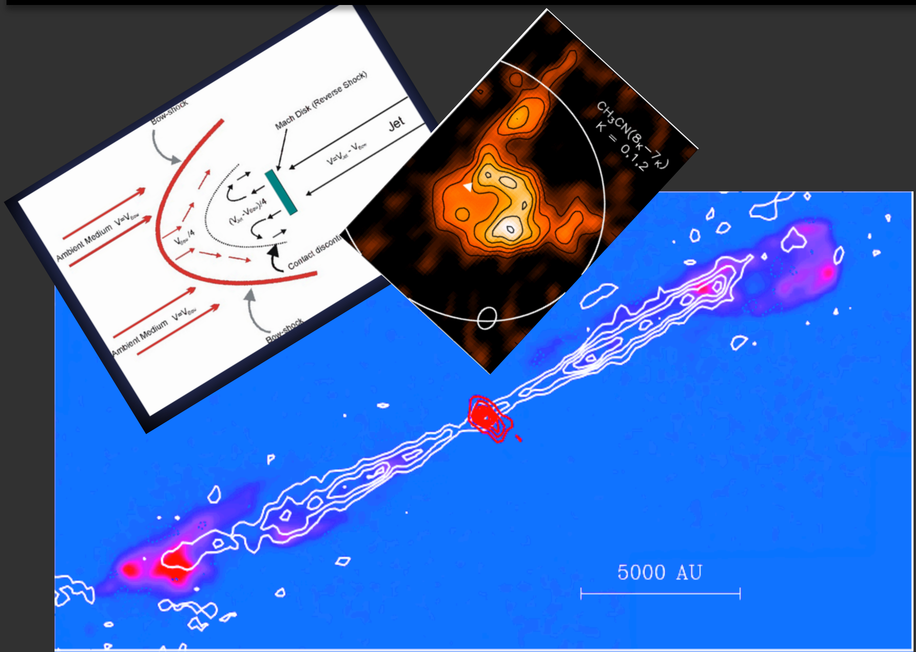


Magnetic surfaces

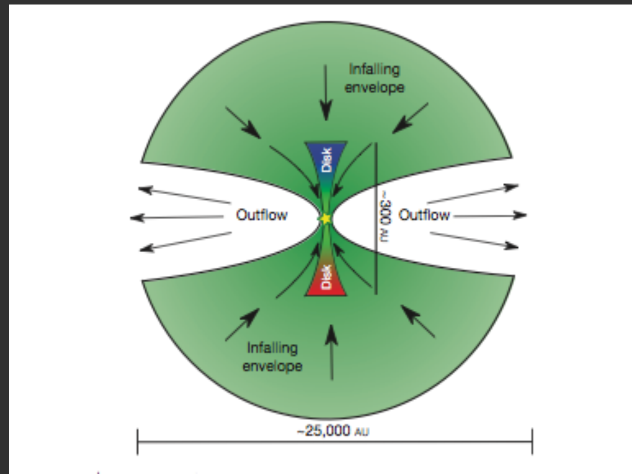
Rotation is transferred to the jet from the disk

PPVI: Li et al.; Frank et al.

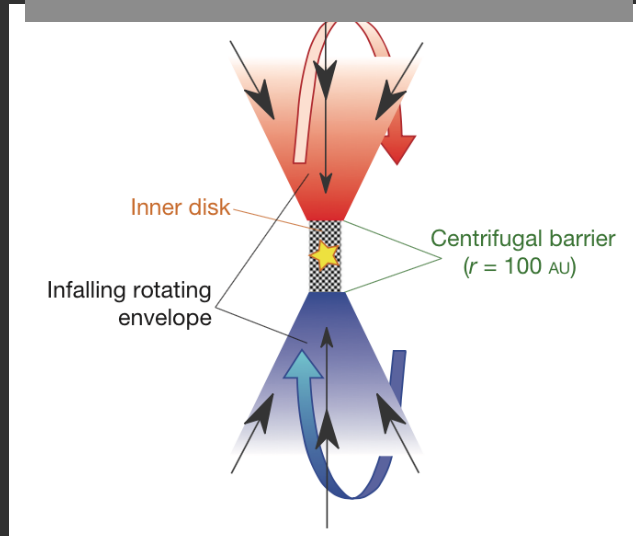
# Ingredients for the Sun-like star formation recipe




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




accretion shock
at disk-envelope interface




Lee et al. 2014, Sakai et al. 2014

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

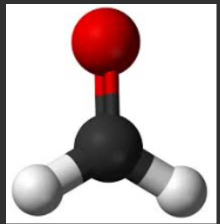
High-T chemistry: endothermic reactions

Ice sublimation & grain disruption

The gas acquires a chemical composition distinct from that of the unperturbed medium

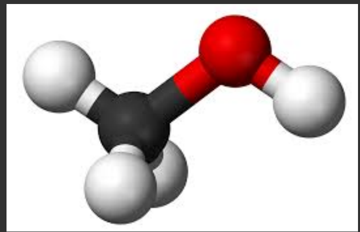
# The interstellar complex organic molecules (iCOMs) zoo

$H_2CO$



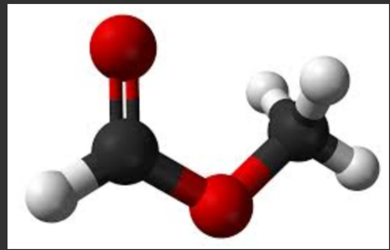
formaldehyde

$CH_3OH$



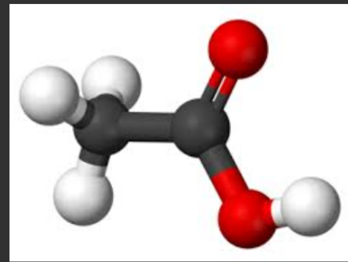
methanol

$CH_3OCHO$



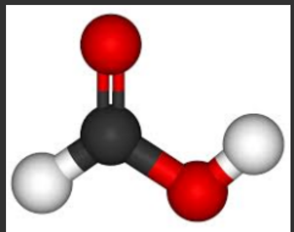
methyl formate

$CH_3COOH$



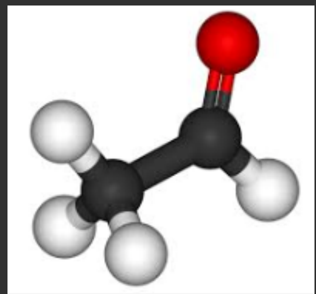
acetic acid

$HCOOH$



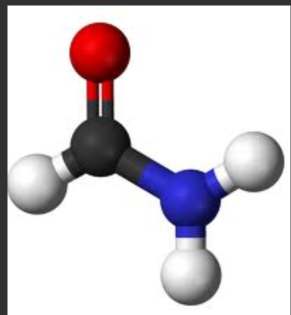
formic acid

$CH_3CHO$



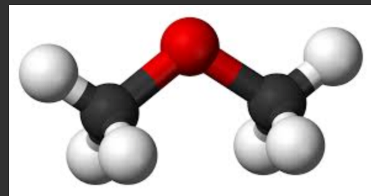
acetaldehyde

$NH_2CHO$



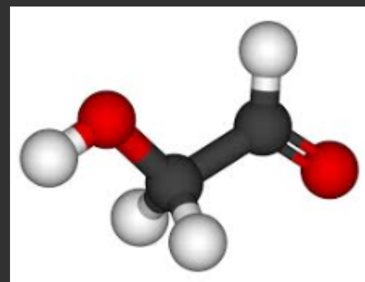
formamide

$CH_3OCH_3$

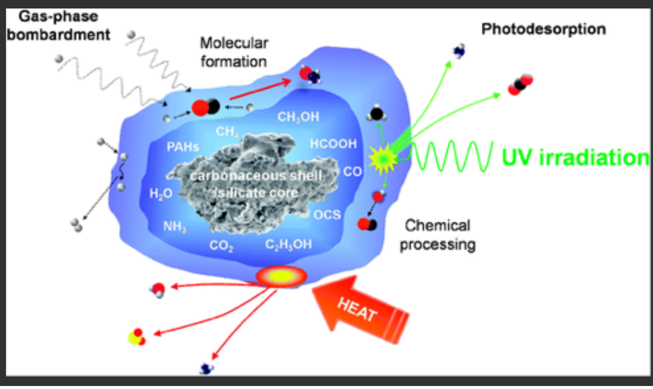


dimethyl ether

$HCOCH_2OH$



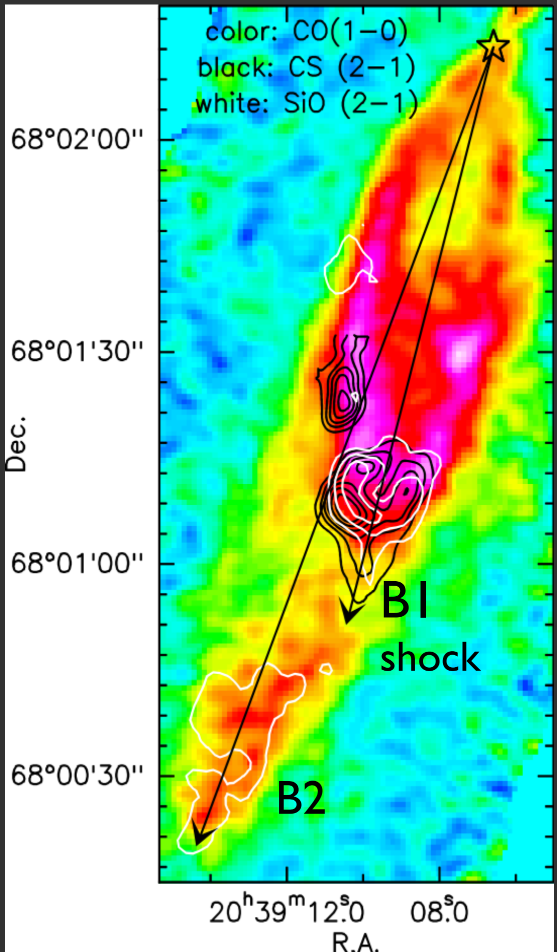
glycoaldehyde

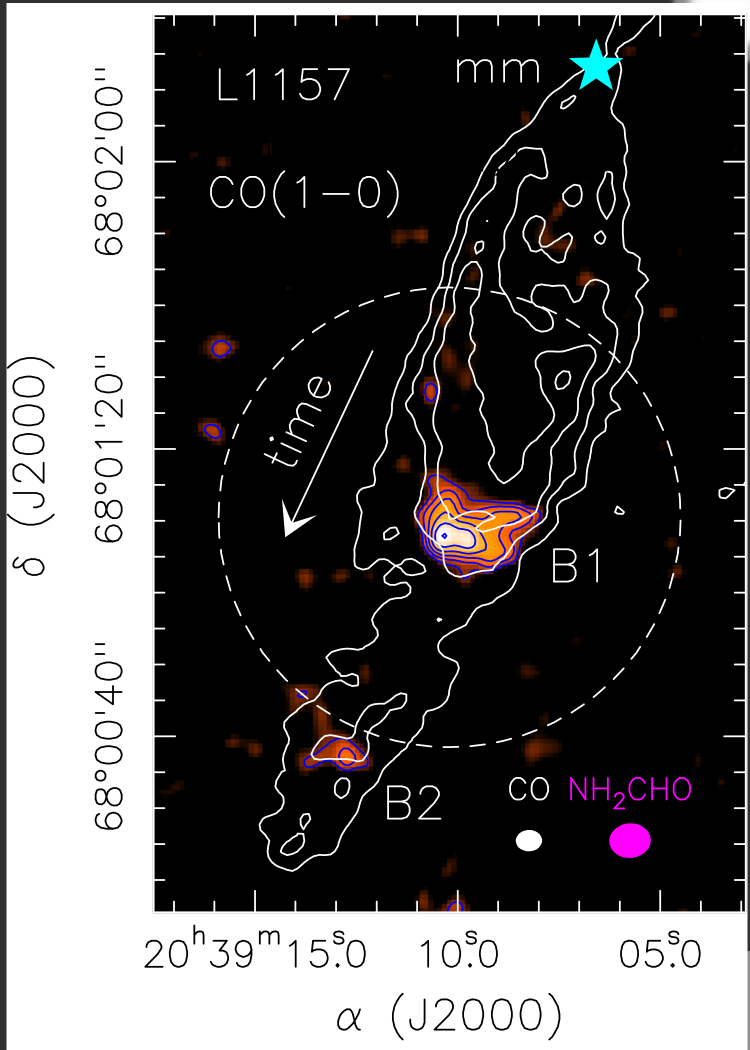



Gas phase or surface chemistry ?

# Outflows/Jets shocks as chemical laboratories (as seen by NOEMA)

NH$_2$CHO (colour scale) detected towards the B1 bow structure….



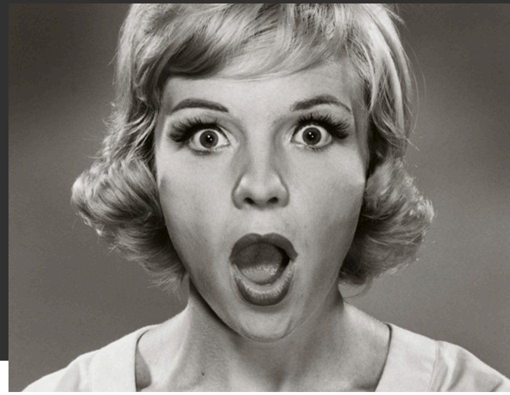




NOEMA
x12
NOrthern Extended Millimeter Array

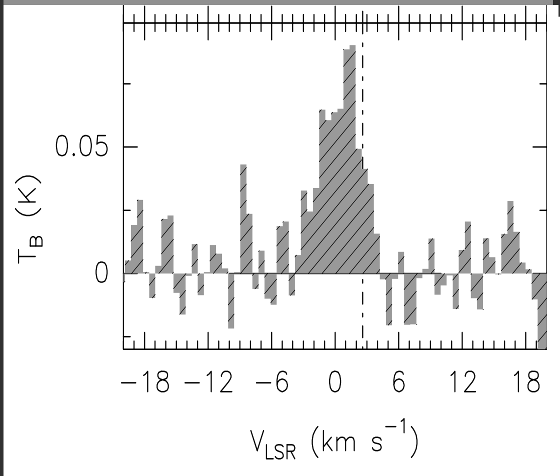
Podio et al. (2016)
Codella et al. (2017a)
Feng et al. (2017)

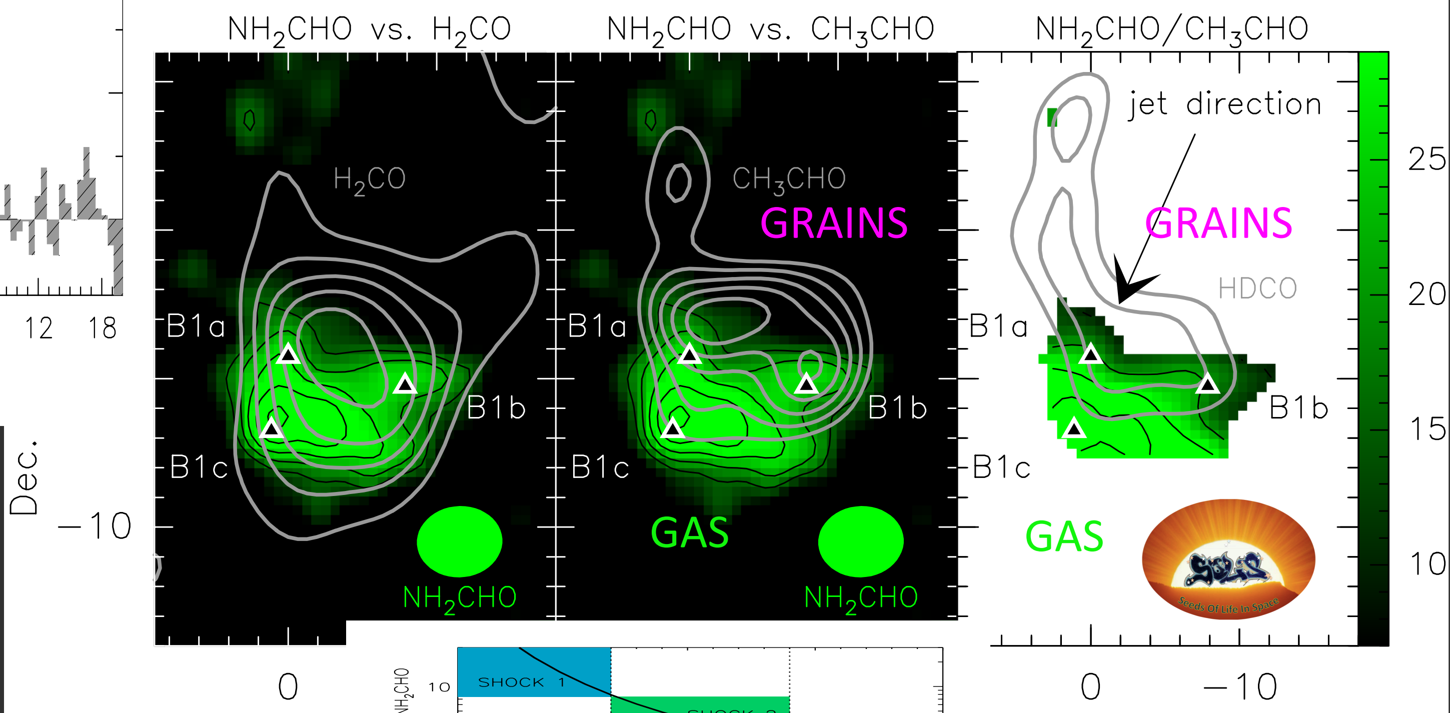
.....Surprise surprise....

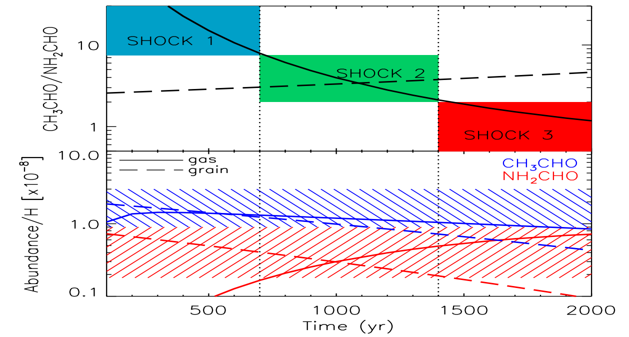
$NH_2CHO$ looks anticorrelated wrt $CH_3CHO$.......



**Codella et al. (2017a)**



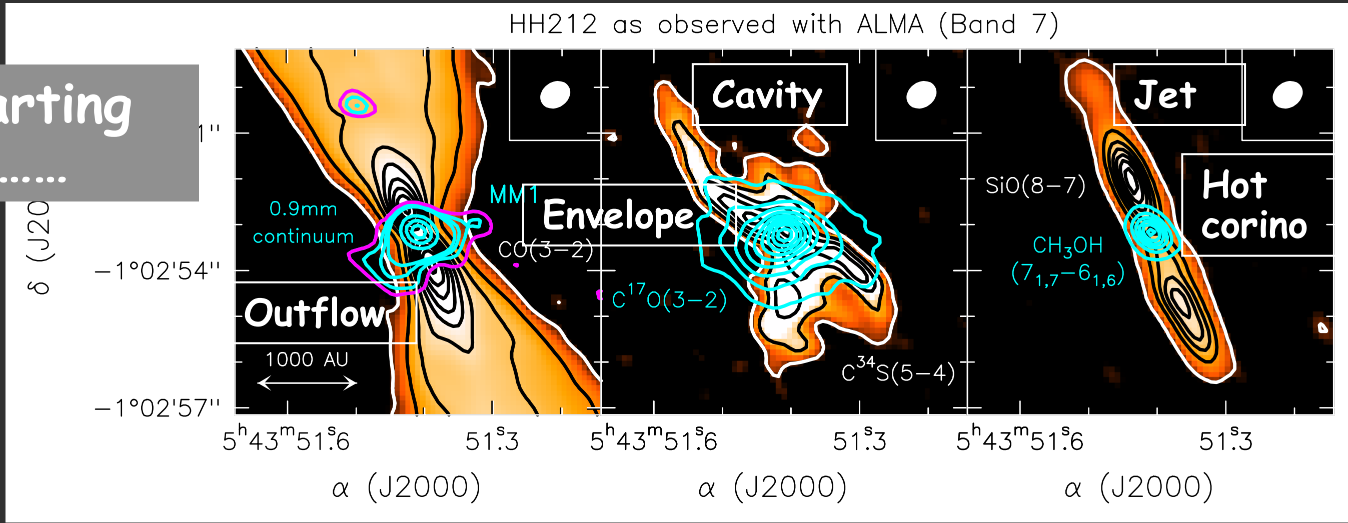




**The smoking gun of gas-phase at work**

# How ALMA can reveal a pristine jet/disk protostellar system

# The inner 50 AU of a Sun-like protostar, as seen by ALMA

The starting point……



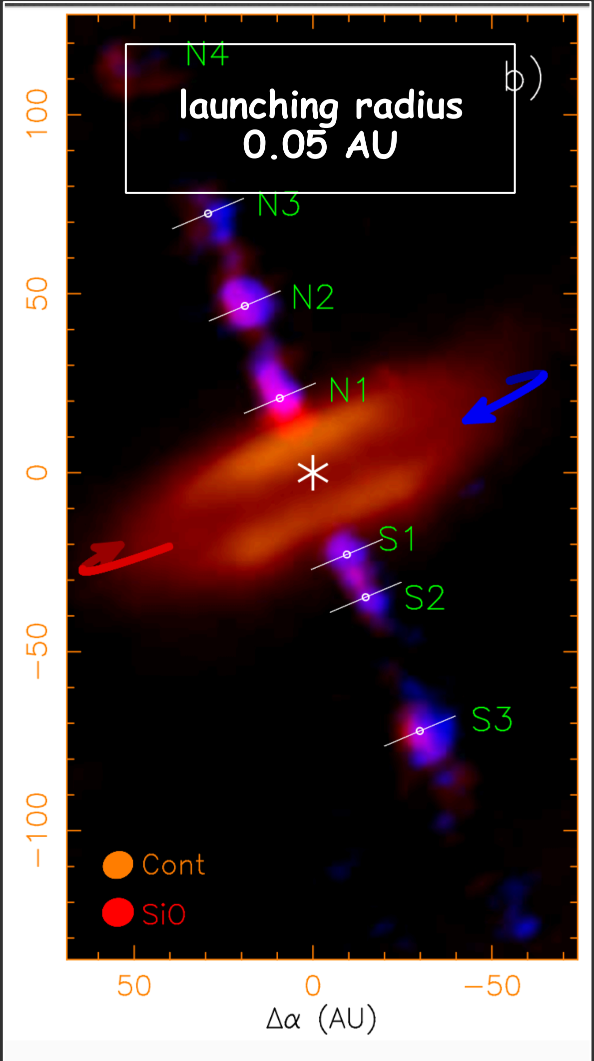

All the ingredients of the Sun-like star formation recipe imaged with a single spectral set-up:

1. The flattened (dust & molecules) envelope
2. The hot-corino (iCOMs) heated by the protostar
3. The forming disk
4. The hot and fast collimated jet
5. The cold, slow, and extended swept-up outflow
6. The cavity as interface between outflow and static cloud

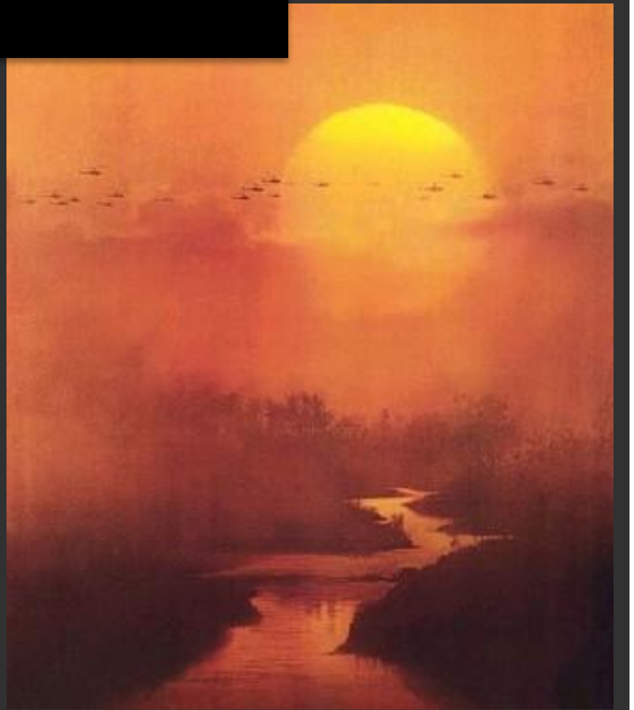
See Bianchi et al. POSTER !

Codella et al. (2014, 2016, 2017), Podio et al. (2015), Leurini et al. (2016), Bianchi et al. (2017), Tabone et al. (2017)

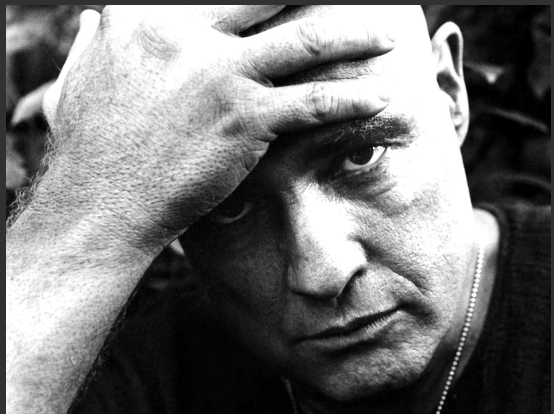
# Upriver toward the launching radius



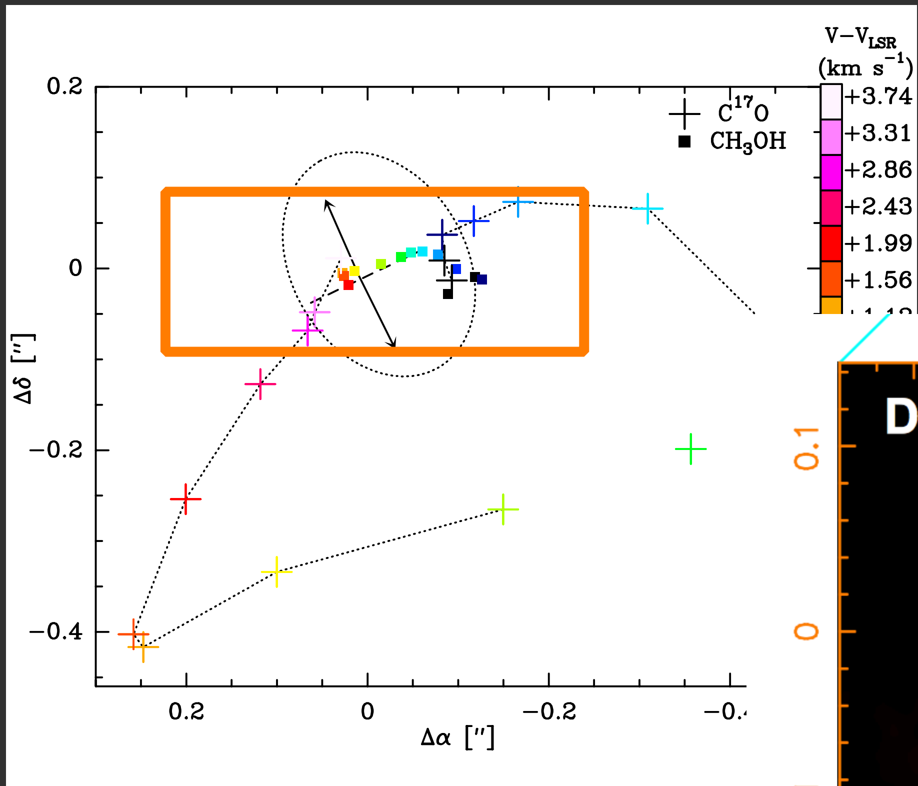

Lee et al. (2017ab)



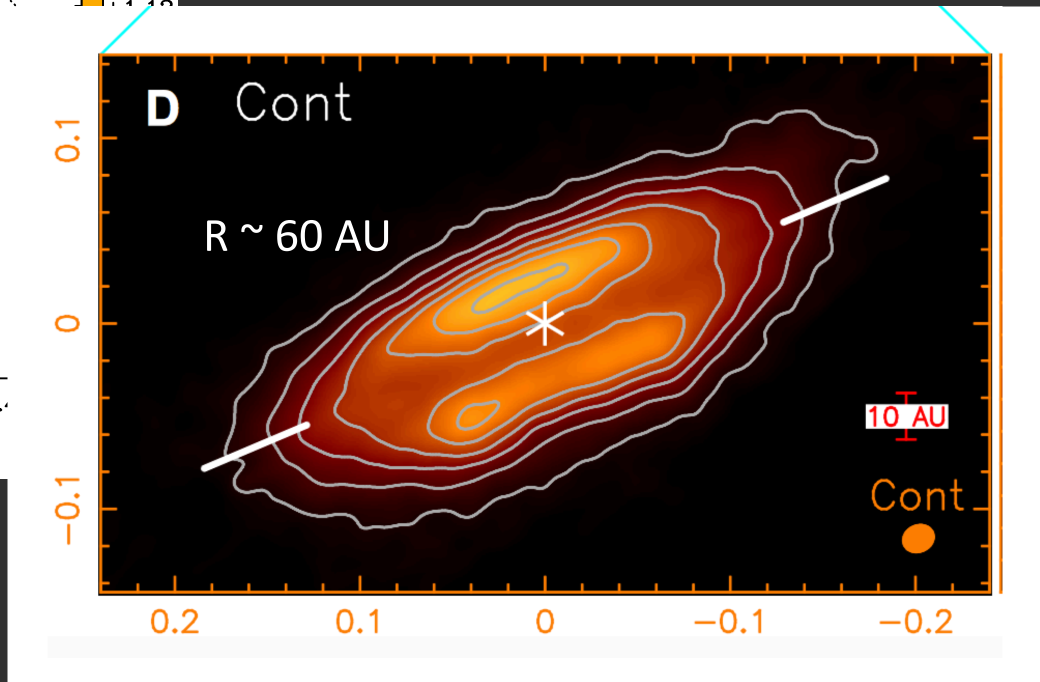
Where is the disk wind ?



# We need to explore the inner 50 AU.....

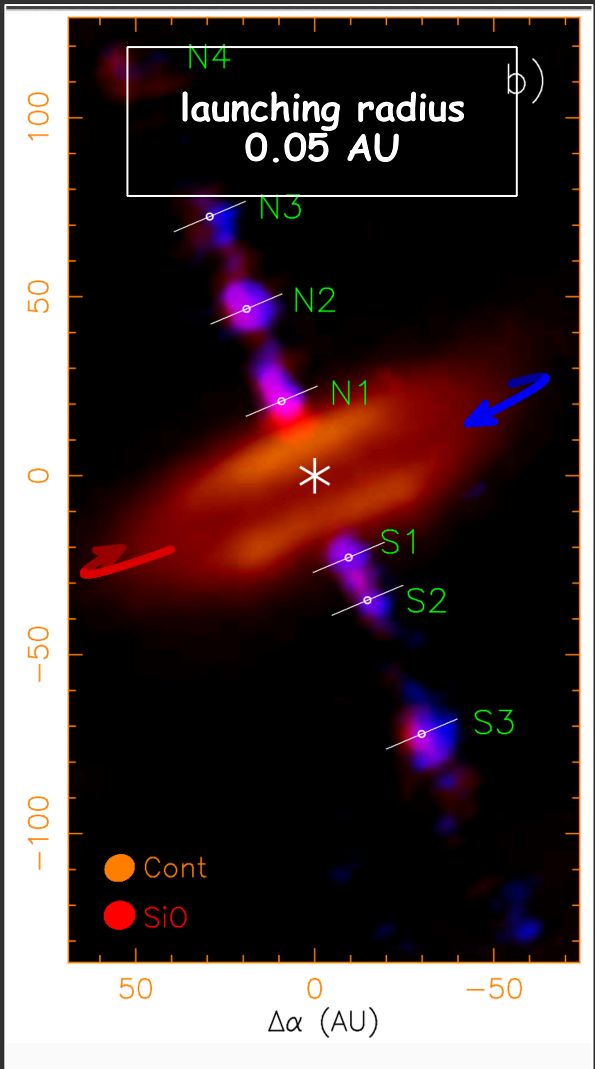



Leurini et al. (2016)

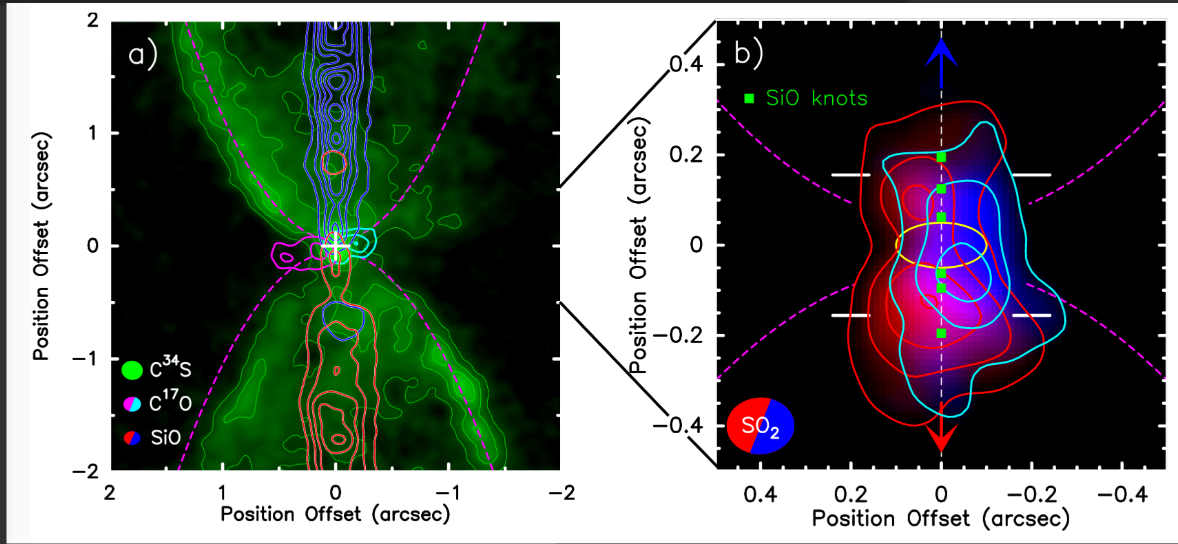



Lee et al. (2017)

# *Upriver toward the launching radius*

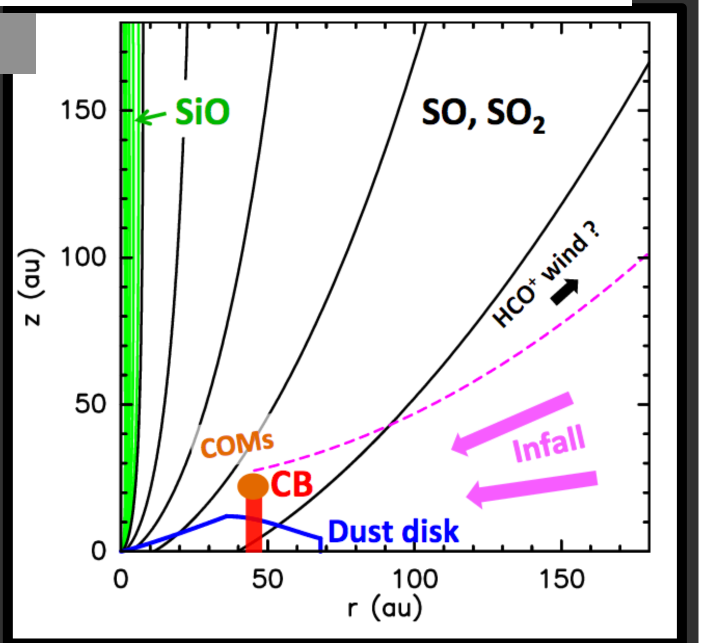



Lee et al. (2017ab)



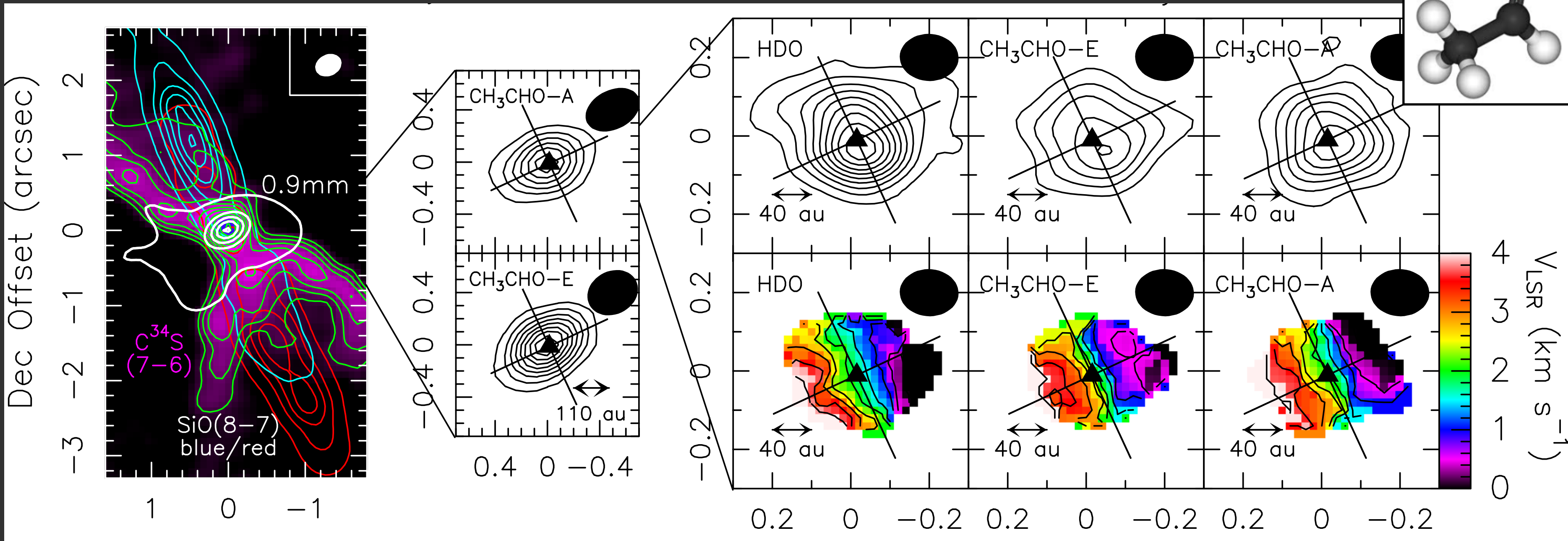

Tabone et al. (2017)

Rotating flow in $SO$ and $SO_2$

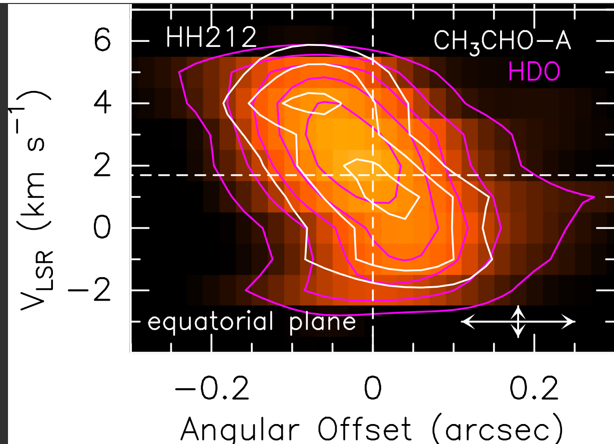


# iCOMs associated with …….

**Emission related with the extended rotating disk**

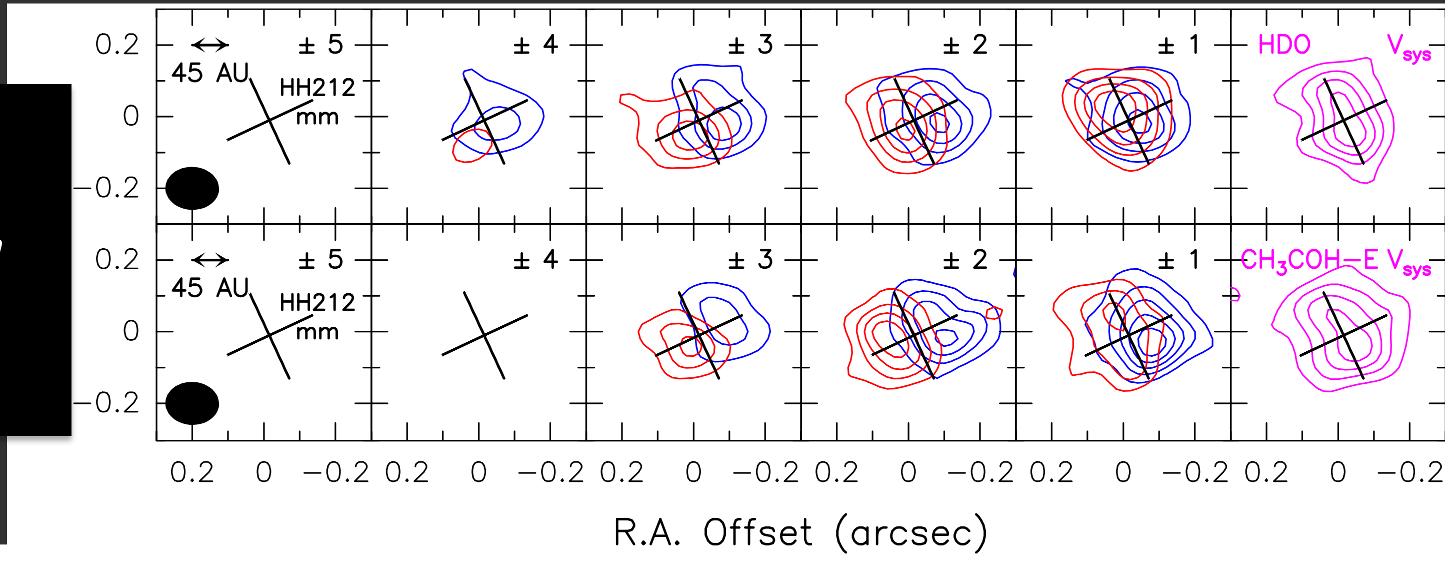


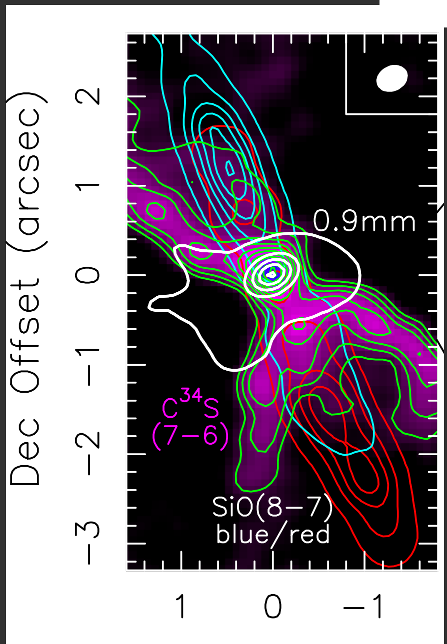

Codella et al. (2017b)
Lee et al. (2017)

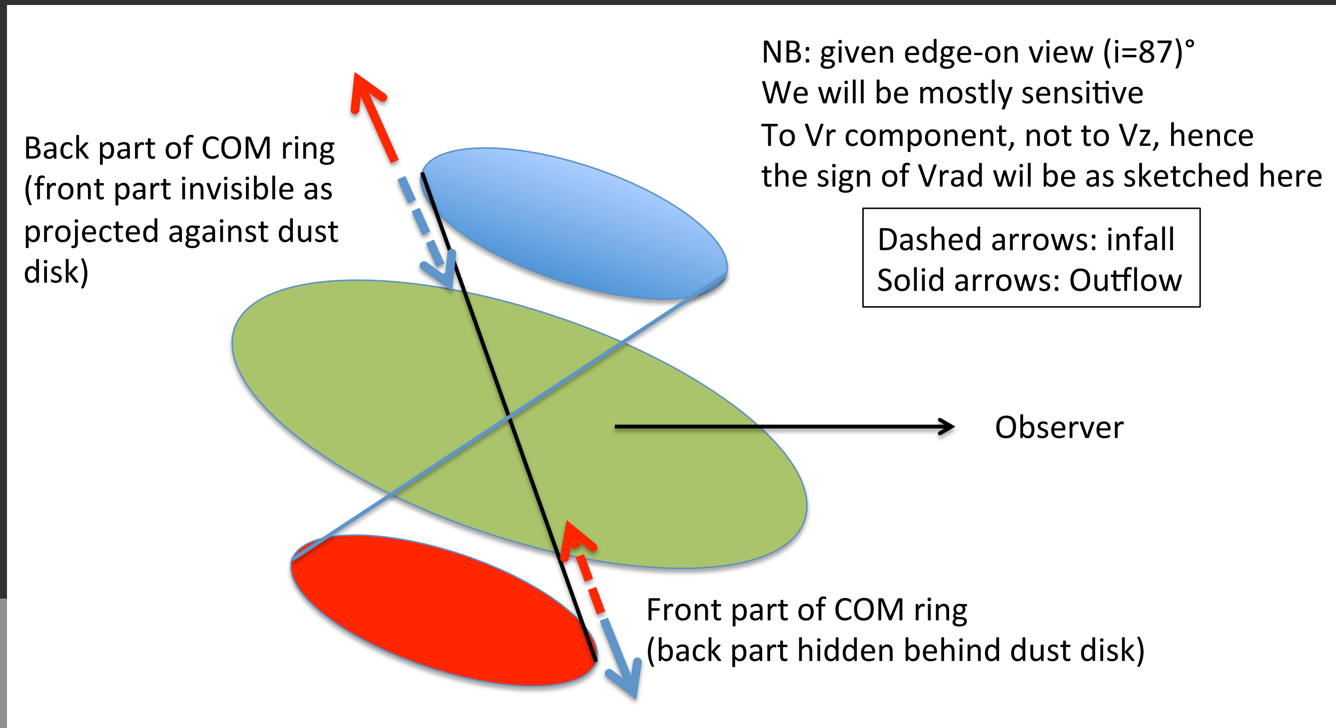



Rotating structure extending up to 50 AU from the jet axis and elengated by 90 AU along the jet

# *iCOMs associated with …*



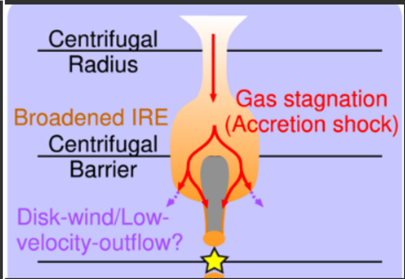



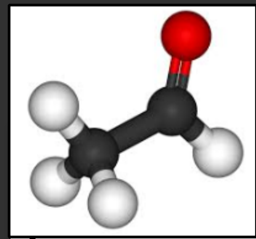

Codella et al. (2017b)
Lee et al. (2017)
Tabone et al. (2017)

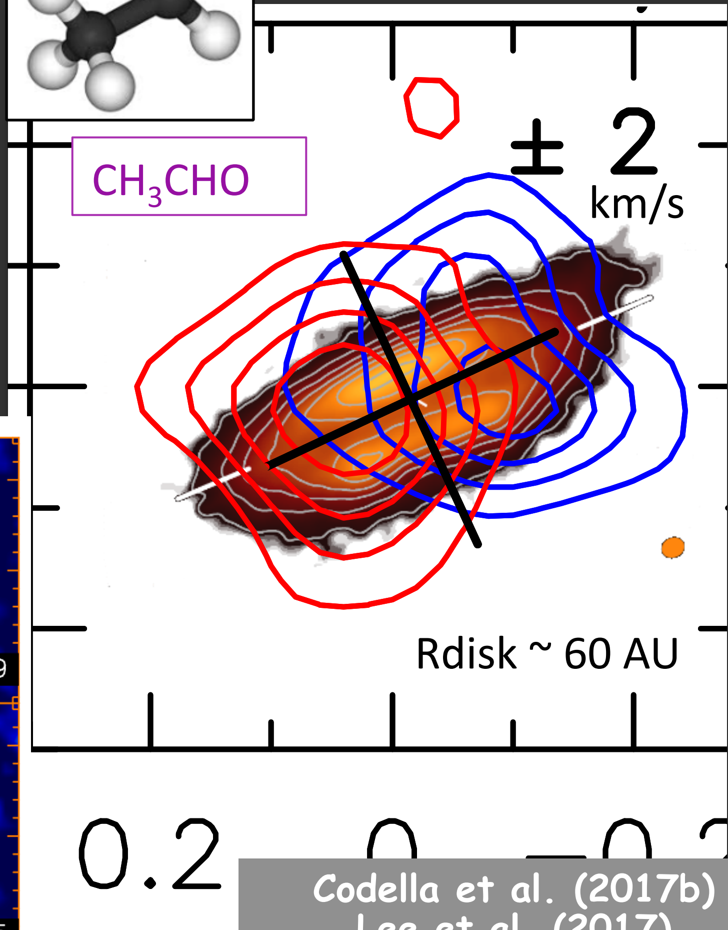
# iCOMs associated with the disk

Emission related with the extended rotating disk

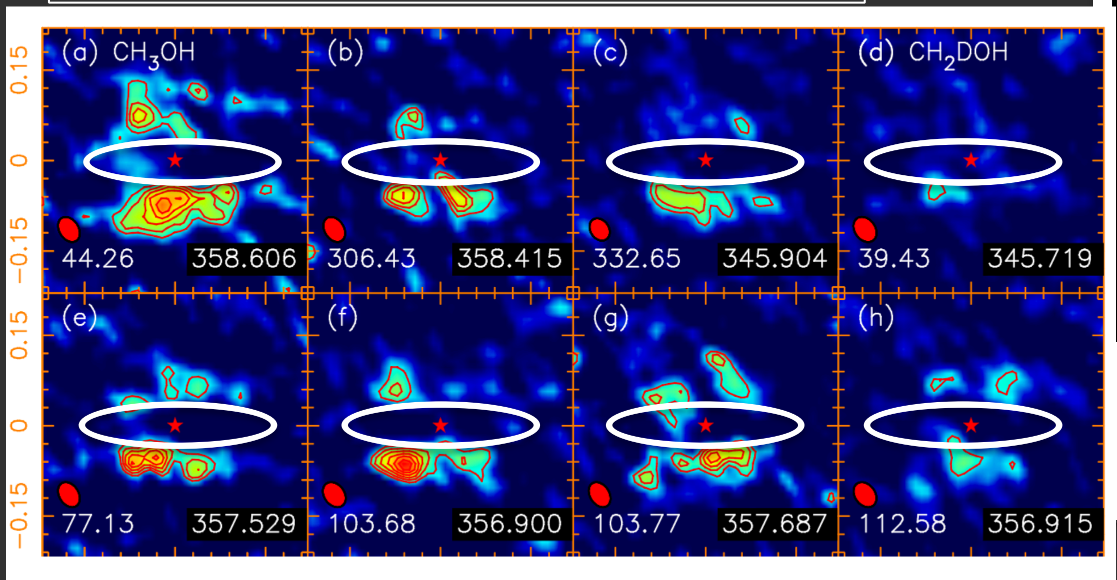
Gas launched by the centrifugal barrier ? (Sakai et al. 2017)





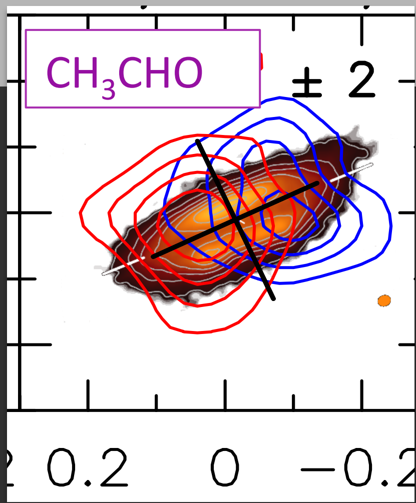

Disk atmosphere ? (Lee et al. 2017)




Codella et al. (2017b)
Lee et al. (2017)
Bianchi et al. (2017)

# Conclusions

iCOMs ARE KEY TOOLS TO OBSERVE FUNDAMENTAL PROCESSES (ACCRETION, EJECTION) SCULPTING THE CRADLE WHERE A STAR (AND ITS PLANETARY SYSTEM) IS GOING TO FORM




*Multiple (excitation) components;*
*We need (unbiased) spectral surveys;*
*(sub-mm)*
*Large Programs needed….*

*The use of interferometers is a must:*
*e.g. ALMA, NOEMA.*