Protostellar shocks as factories of interstellar complex organic molecules

C. Codella (INAF, OA Arcetri)

Seeds Of Life In Space

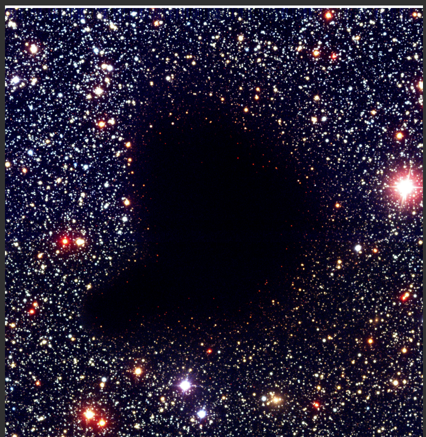
INAF - Arcetri

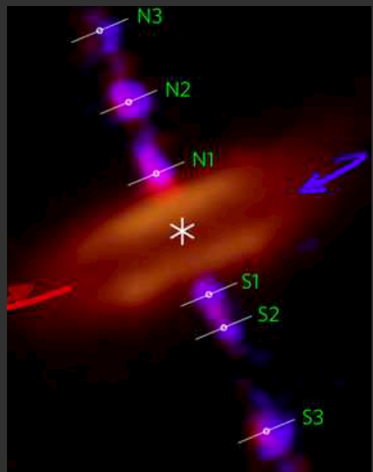
Genesis - SKA

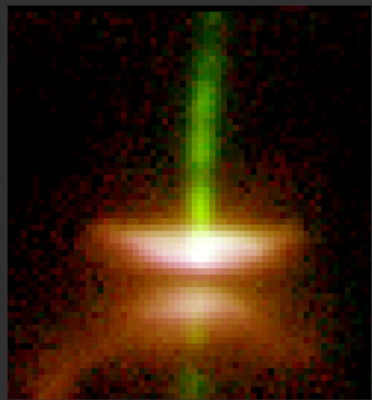
JEDI

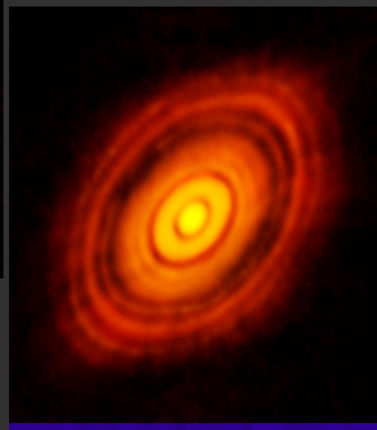
iALMA

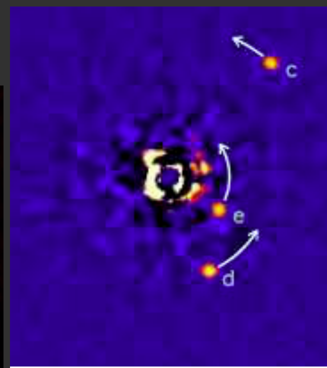
The formation of a Sun-like star





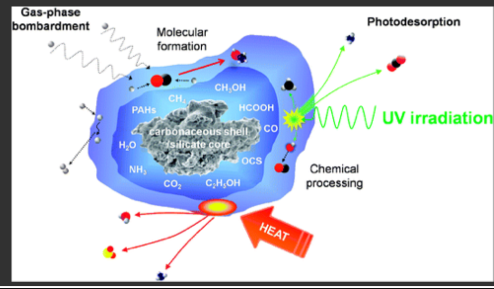






PROTOSTELLAR SHOCKS !

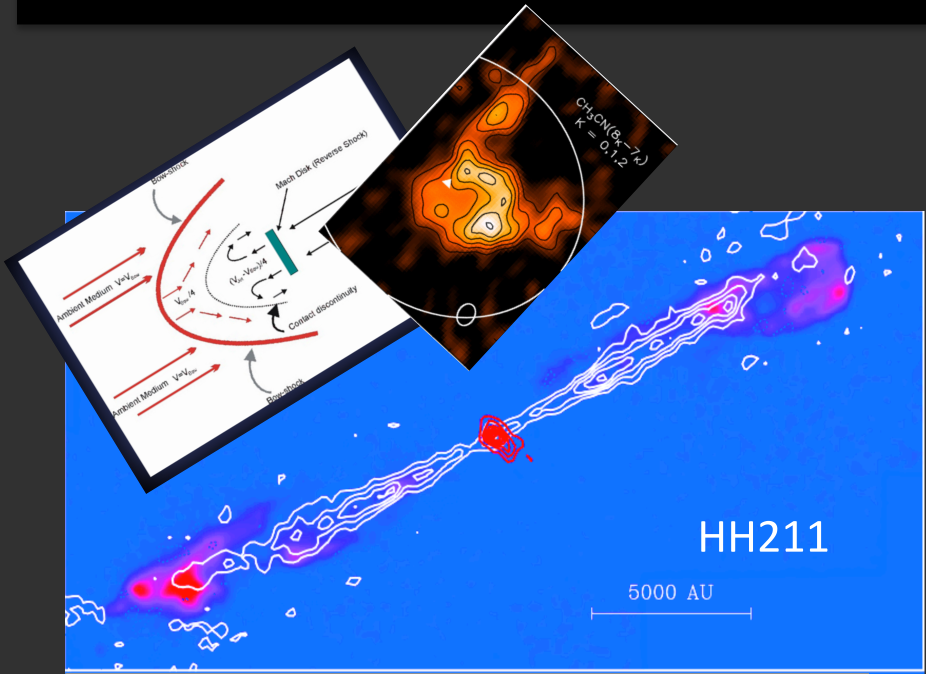
iCOMS factories



Why?
Because shocks sputter/shutter dust grains

Plus:
Si-, S-, P-, Cl- bearing
D/H, Ions, ….
(a long saga of discoveries & papers…)

1. Jet-driven high-velocity shocks



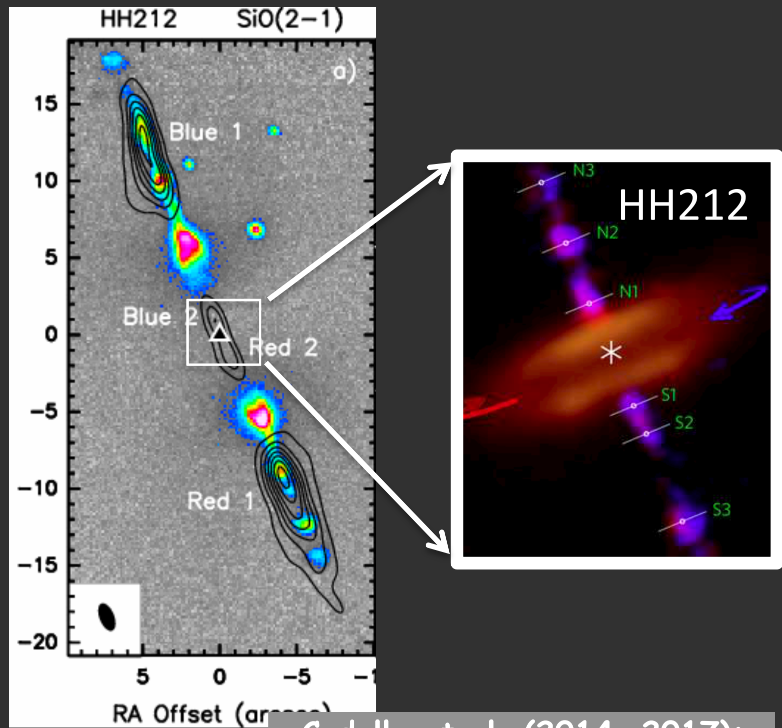
Gueth & Guilloteau (1992), Codella et al. (2009)

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

High-T chemistry: endothermic reactions

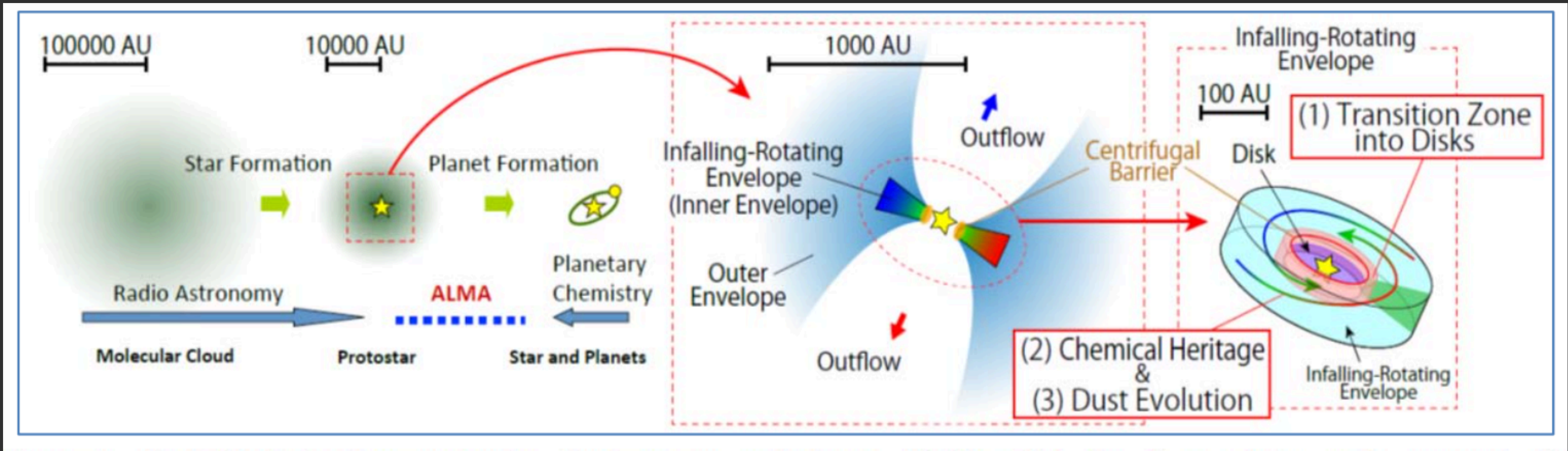
Ice sublimation & grain disruption

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



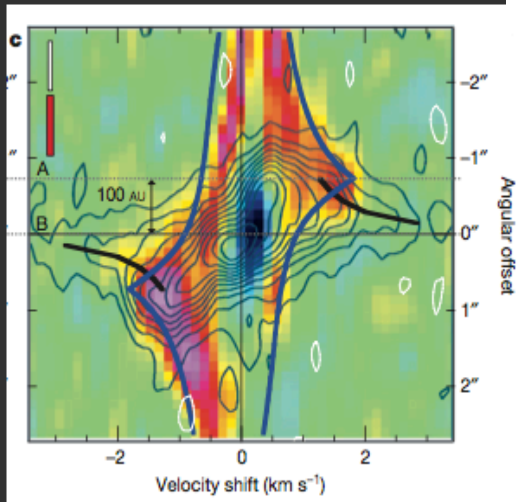
Codella et al. (2014, 2017); Lee et al. (2014, 2017ab)

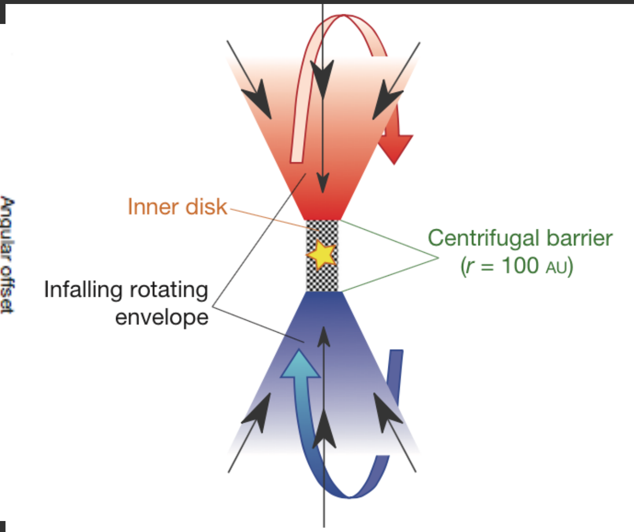
2. Slow accretion shocks



Keplerian disk-free fall envelope interface: Accretion shocks

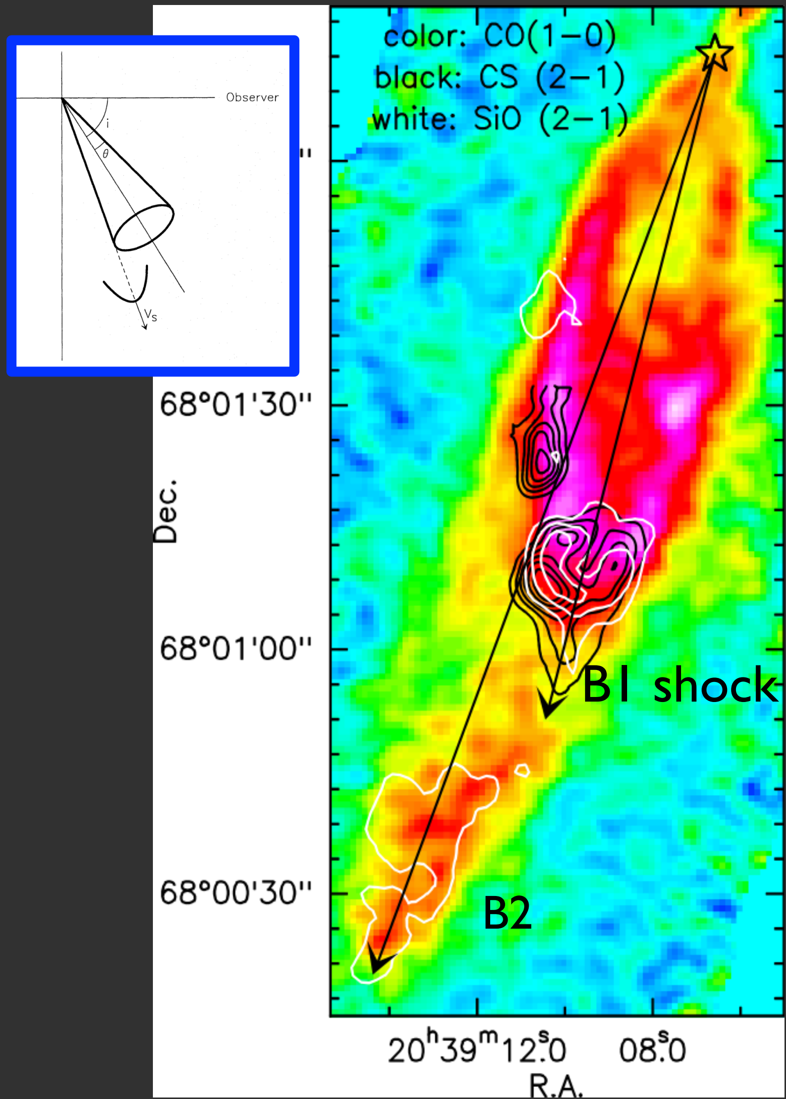
Inner 50 AU





Sakai et al. (2014, 2017)

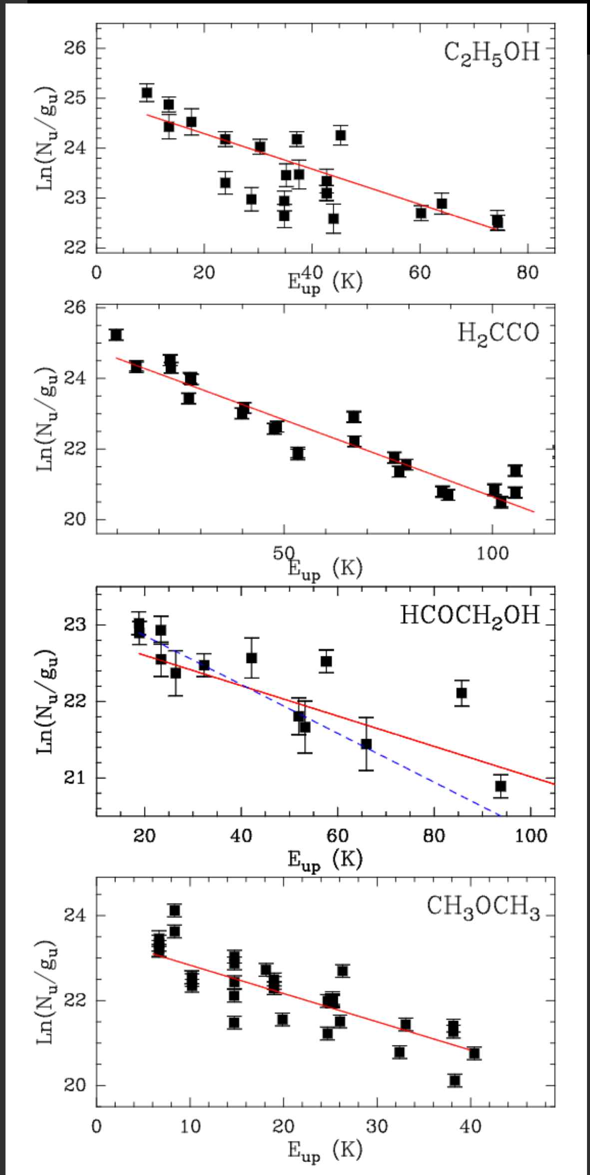
First case: Jet-driven shocks: L1157-B1



Complex and clumpy structure, with typical shock tracers peaking at different positions (multiple shocks)

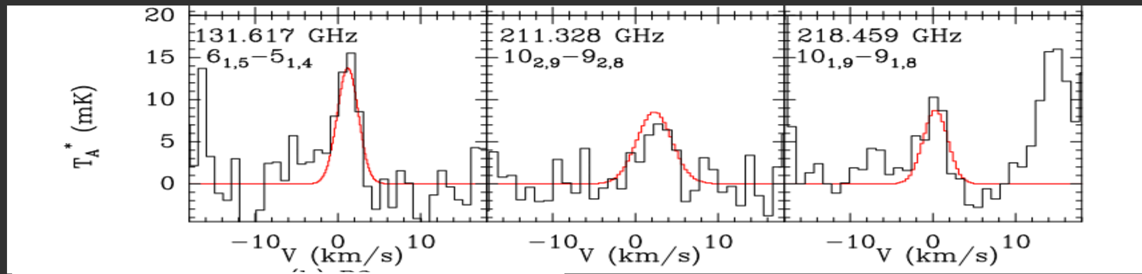
Gueth et al. (1996, 1998)

iCOMs in L1157-B1

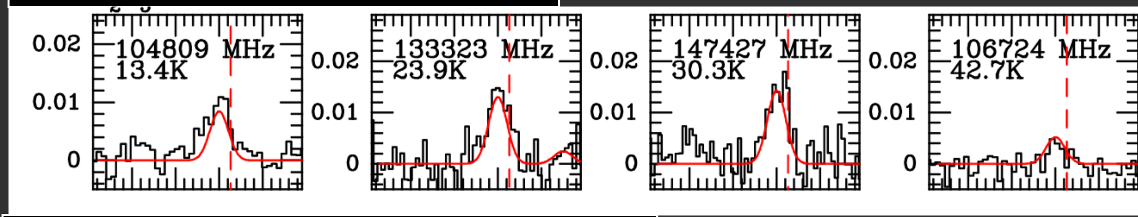


iCOMs: from 10 to 80 lines/species

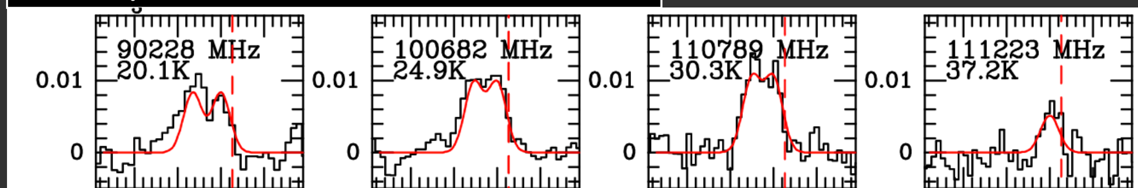
Formamide (NH_2COCH_3)



Ethanol (C_2H_5OH)



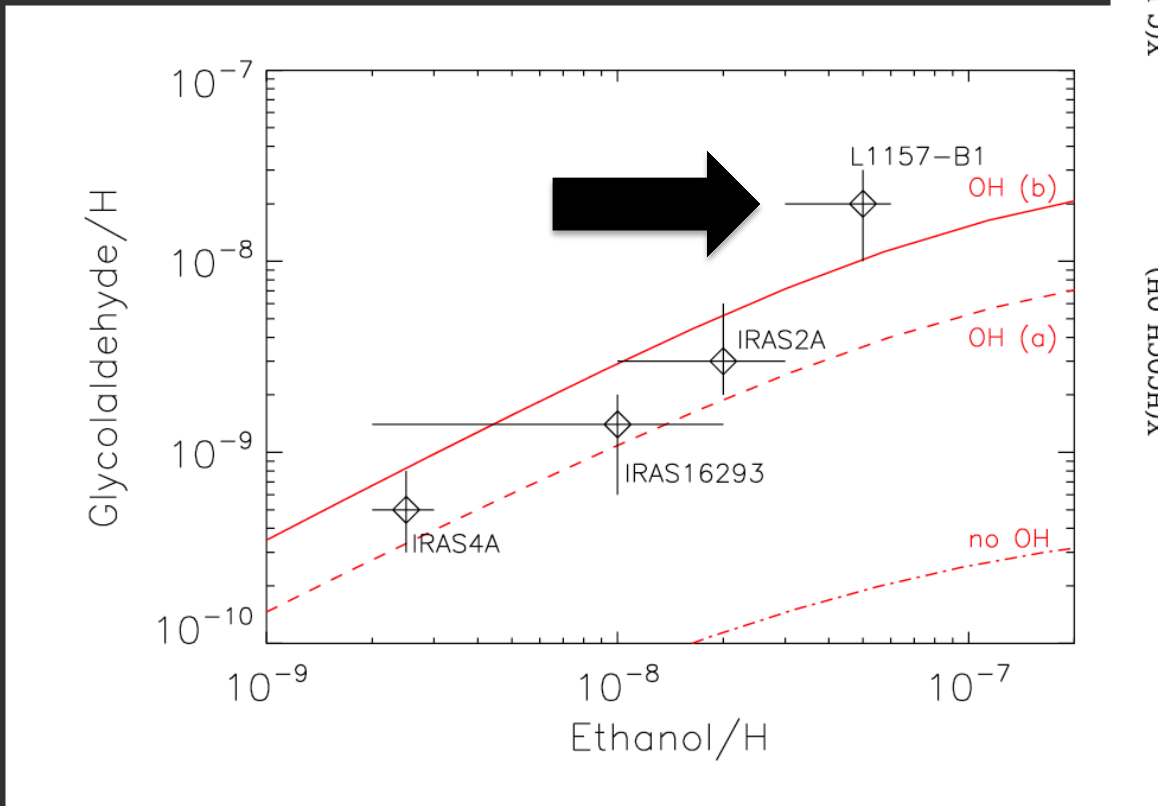
Methyl Formate (CH_3OCHO)

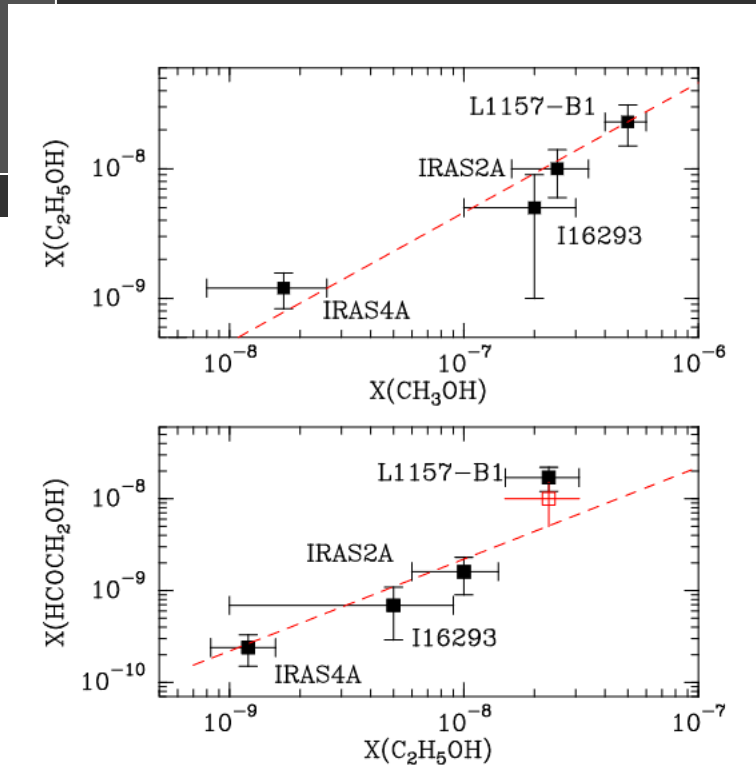


Mendoza et al. (2014)
Lefloch et al. (2017)

The genealogical tree of Ethanol

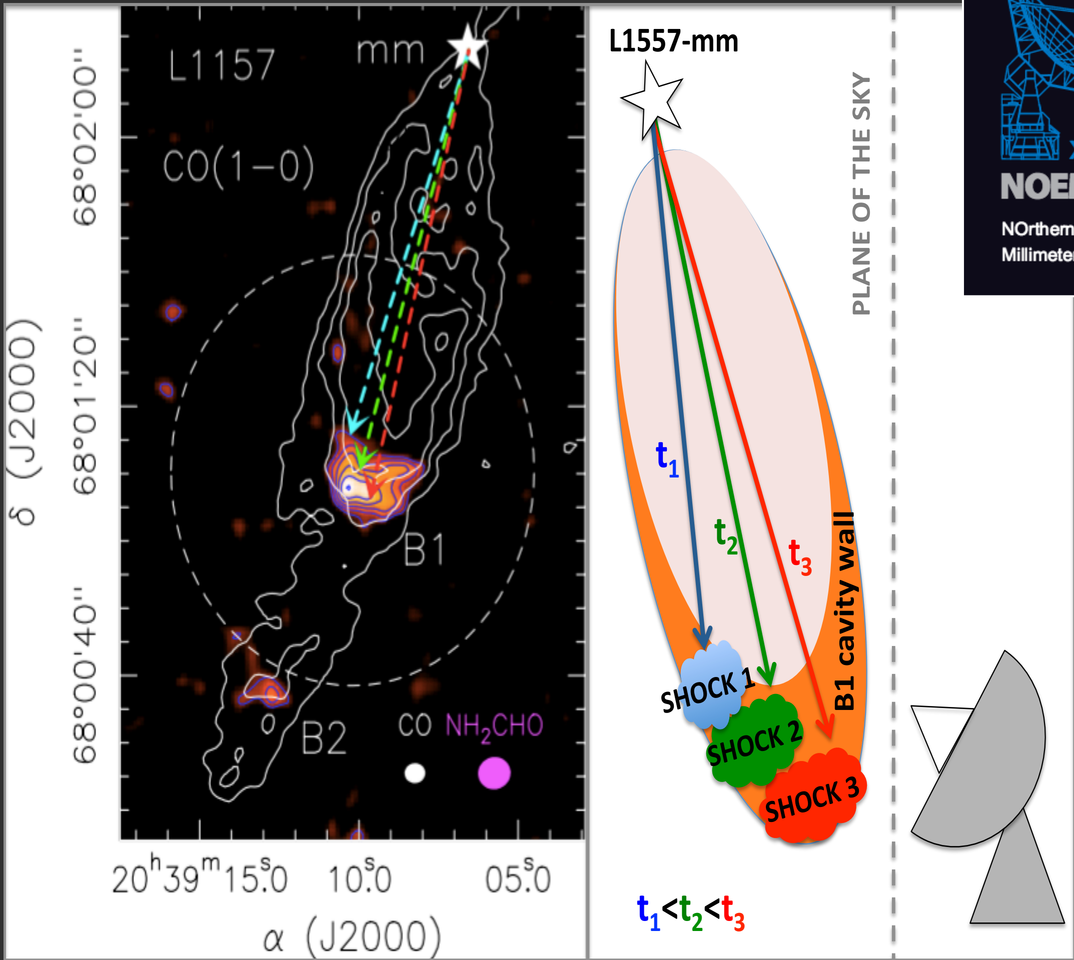
Physics + Chemistry
Road maps to
Glycolaldehyde
in gas-phase





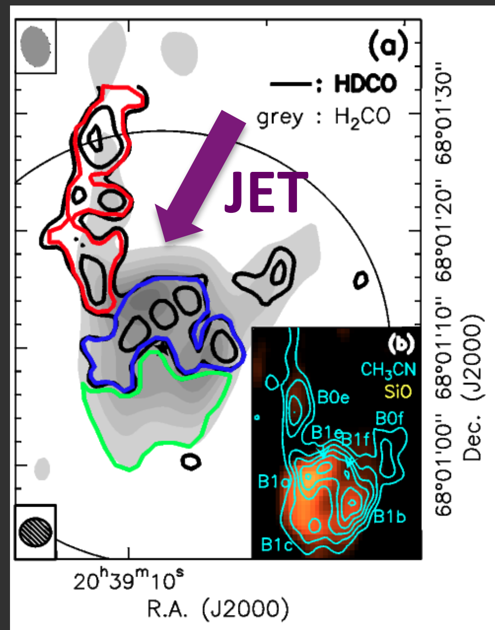
Lefloch et al. (2017)
Skouteris et al. (2017)
Bianchi et al. (submitted)

NH_2CHO (colour scale) detected towards the B1 bow structure.



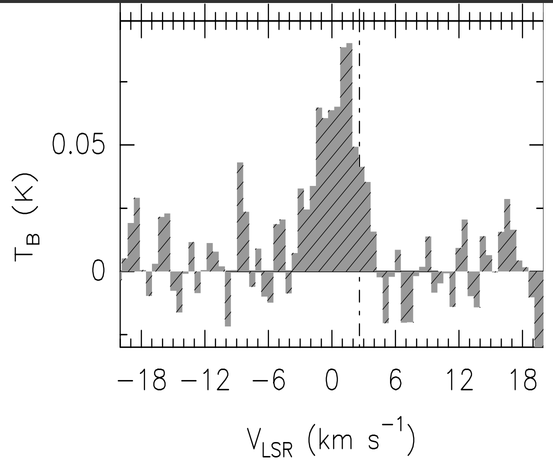
x12
NOEMA
NOrthern Extended Millimeter Array

Seeds Of Life In Space

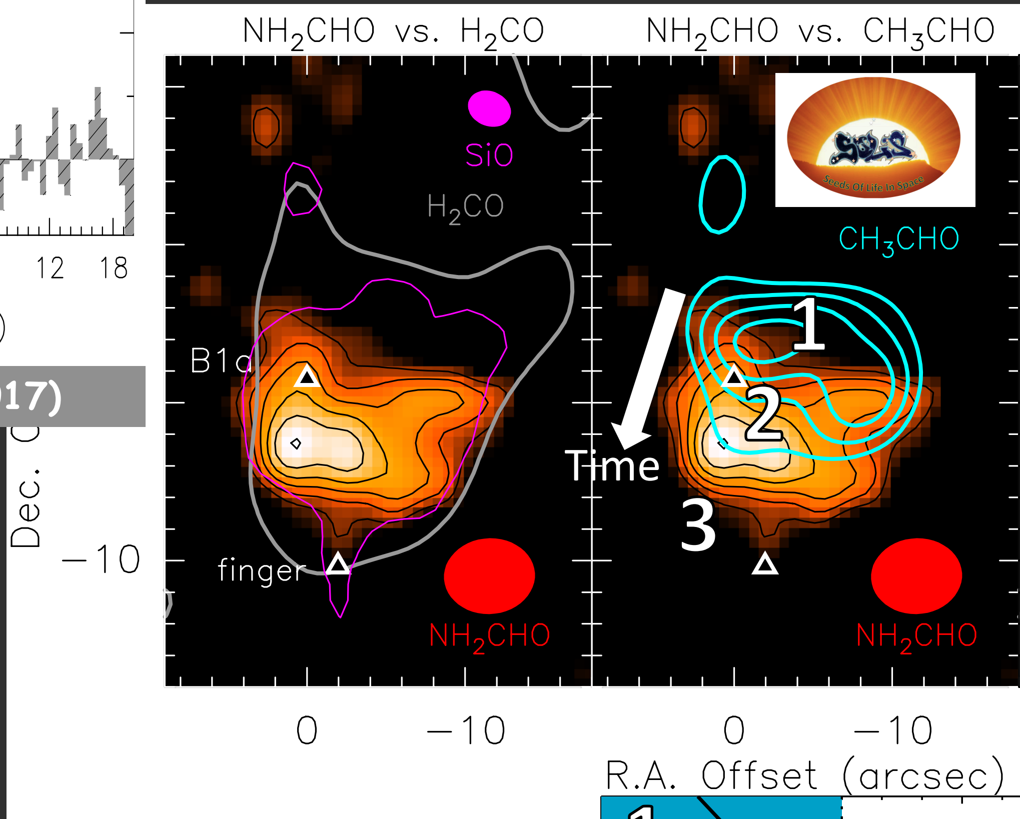


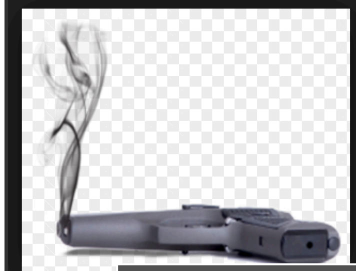
Fontani al. (2015)
Podio et al. (2016)
Codella et al. (2017)

NH_2CHO is anticorrelated wrt CH_3CHO

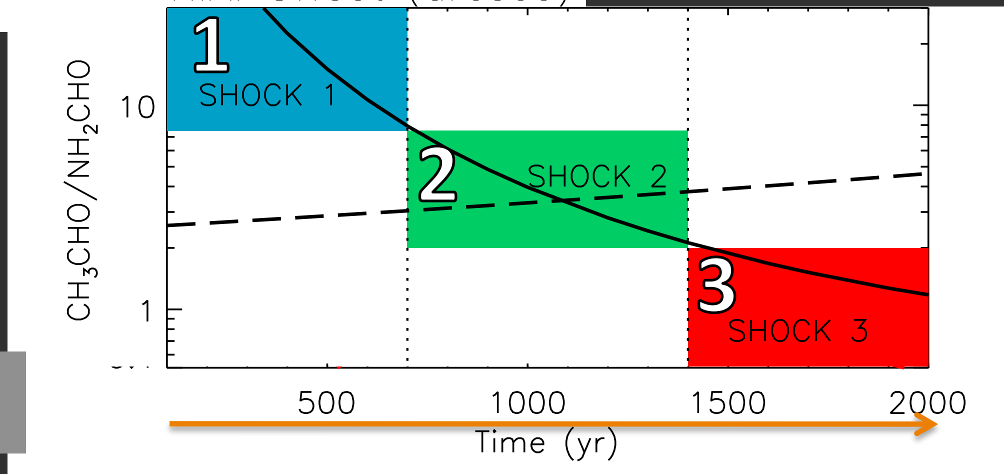


Codella et al. (2017)



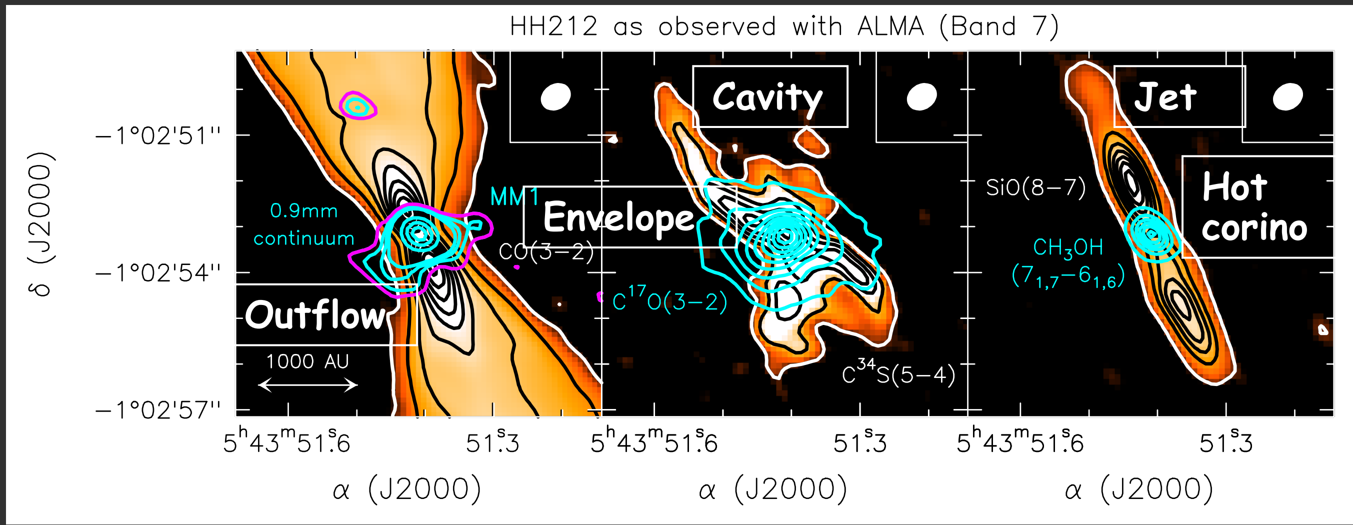


The smoking gun
of gas-phase at work
(at least in L1157-B1)



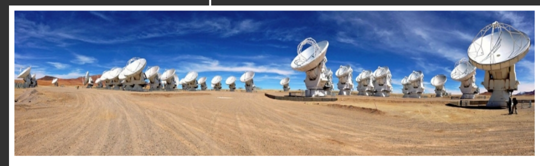
Barone et al. (2015)
Vazart et al. (2016)

Second case: The inner 50 AU of a Sun-like protostar: accretion shocks



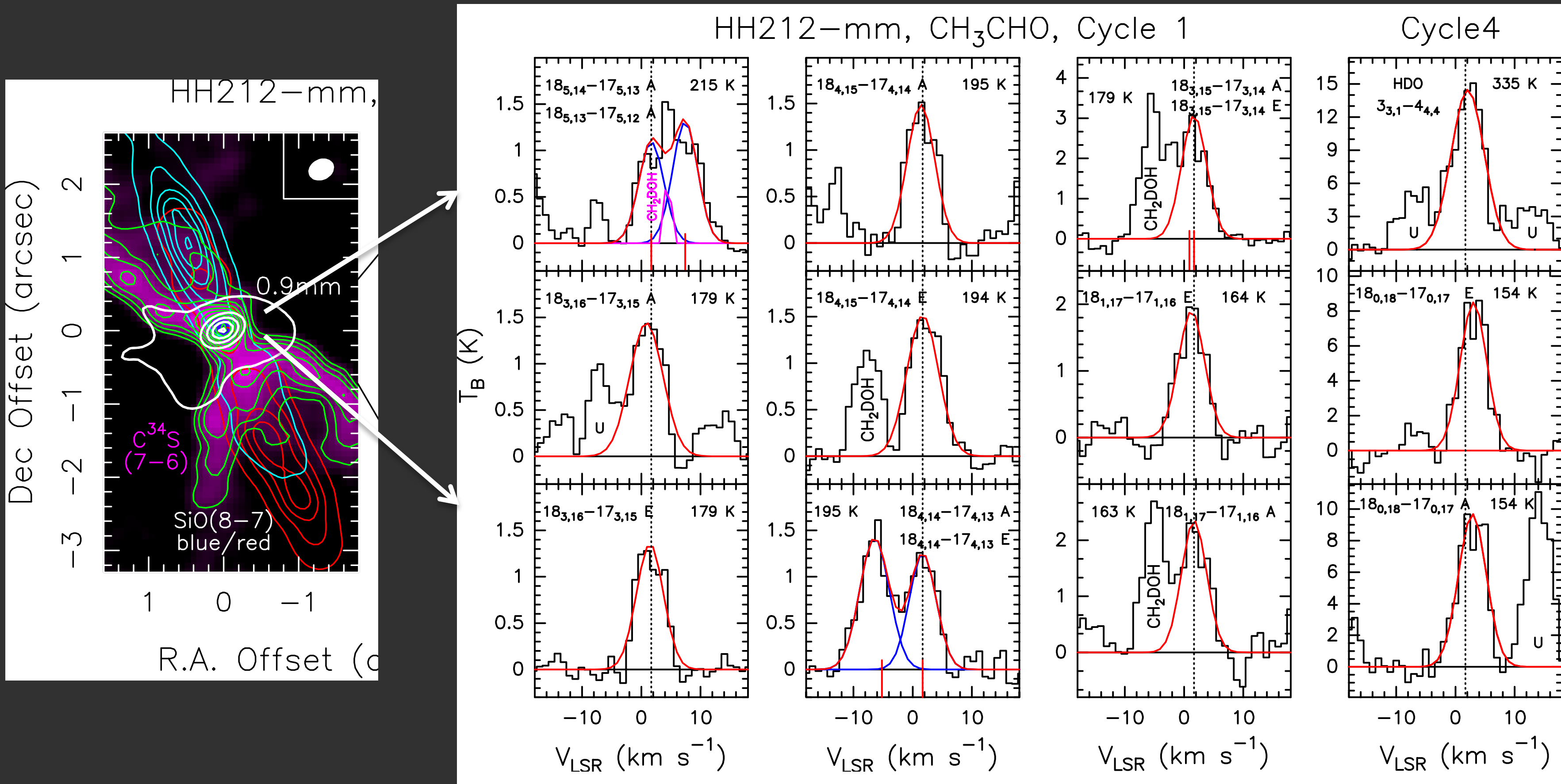
All the ingredients of the Sun-like star formation recipe imaged with a single spectral set-up:

1. The flattened (dust & molecules) envelope
2. The hot-corino (COMs) 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



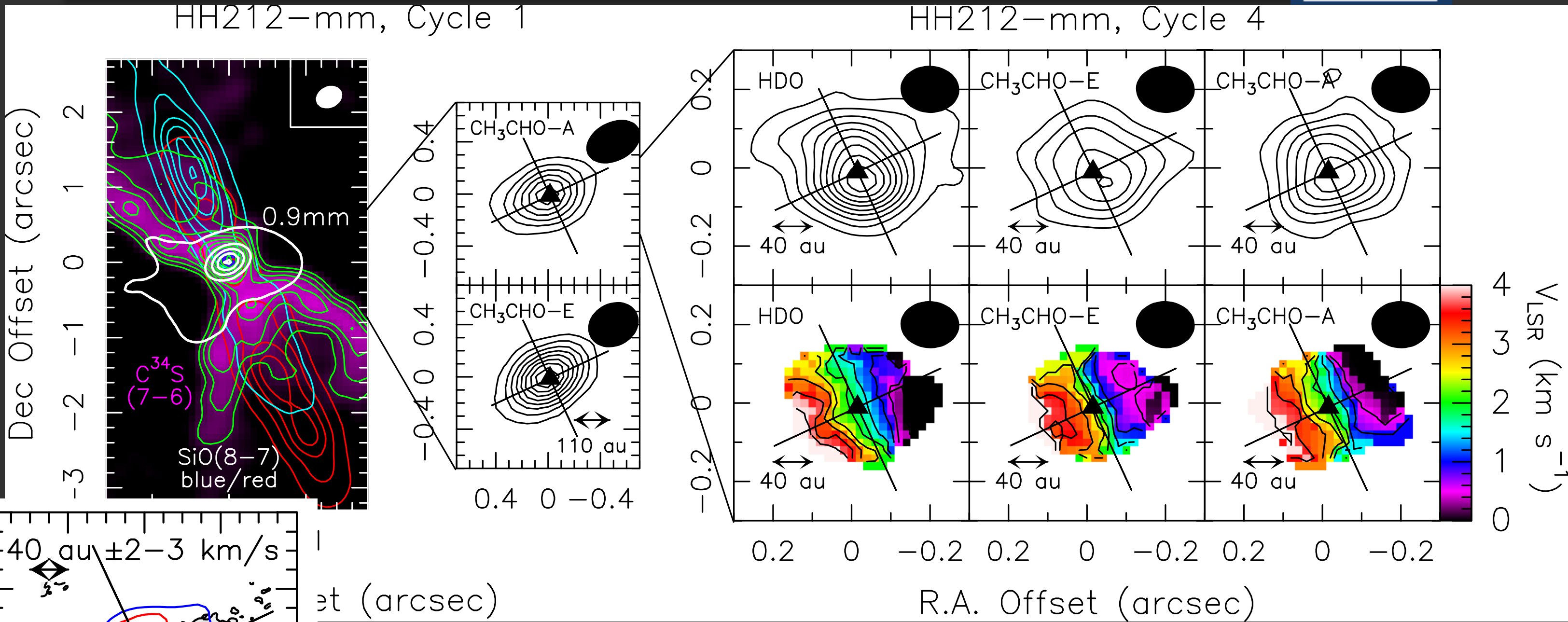
Codella et al. (2007, 2014, 2016), Cabrit et al. (2007, 2012), Podio et al. (2015), Leurini et al. (2016), Bianchi et al. (2017), Tabone et al. (2017), Lee et al. (2018)

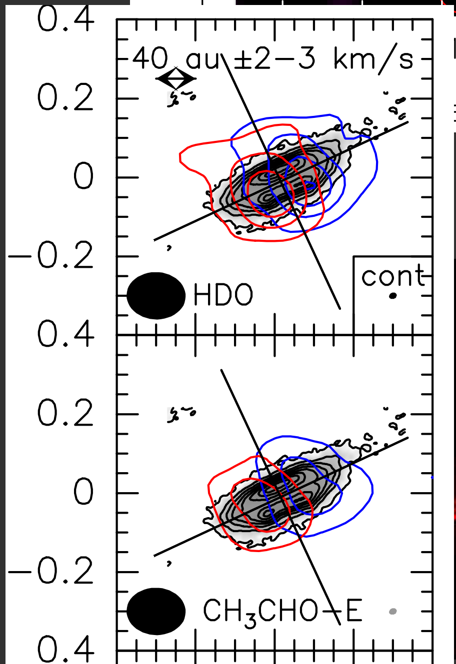
The inner 50 AU of a Sun-like protostar: HDO & CH_3CHO

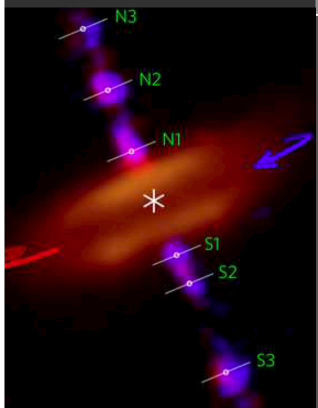


Codella et al. (2018)

The inner 50 AU of a Sun-like protostar: HDO & CH_3CHO







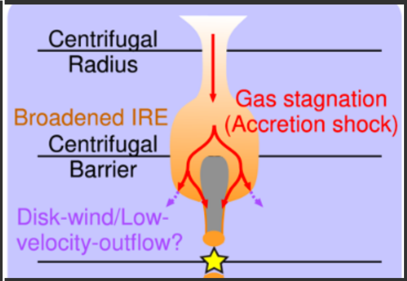
Lee et al. (2017)
Codella et al. (2018)

Size, about 70 au
(i.e. Solar System scale);
T ~ 80-100 K;
n > 10^8 cm^{-3};
Velocity gradient along the equatorial plane (connected with the disk)

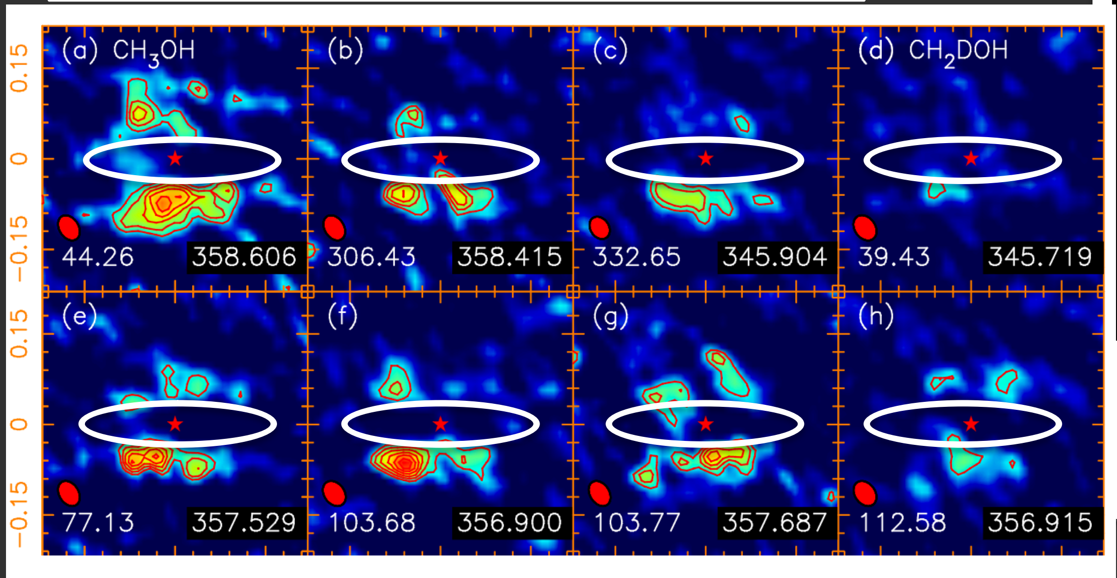
iCOMs associated with the disk

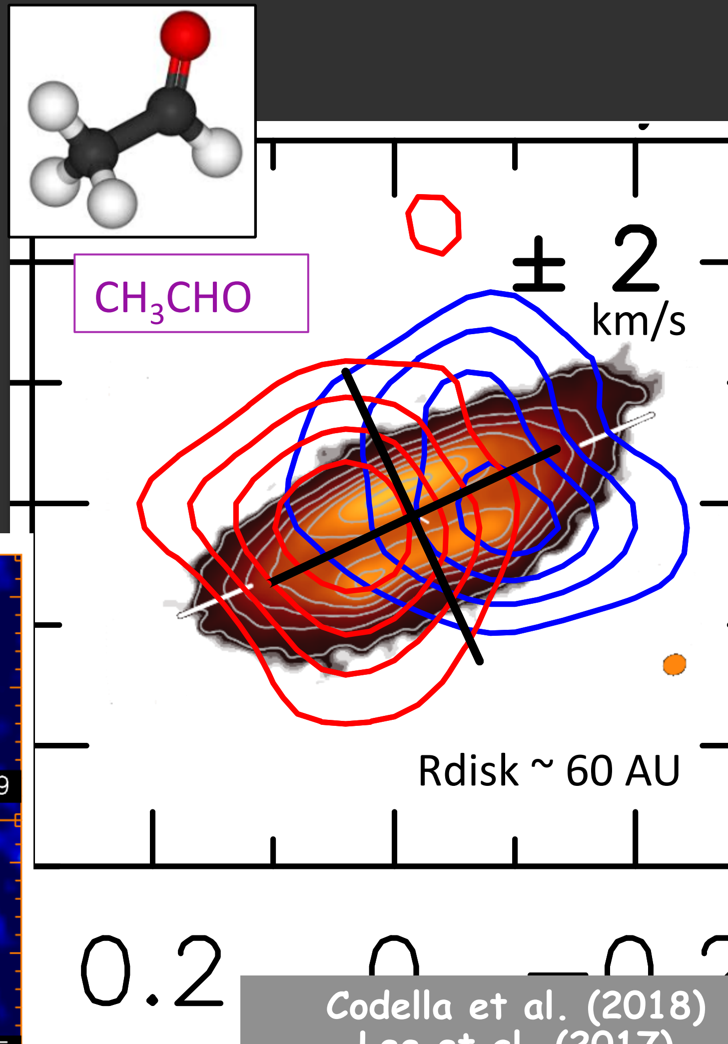
Emission related with the extended rotating disk

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



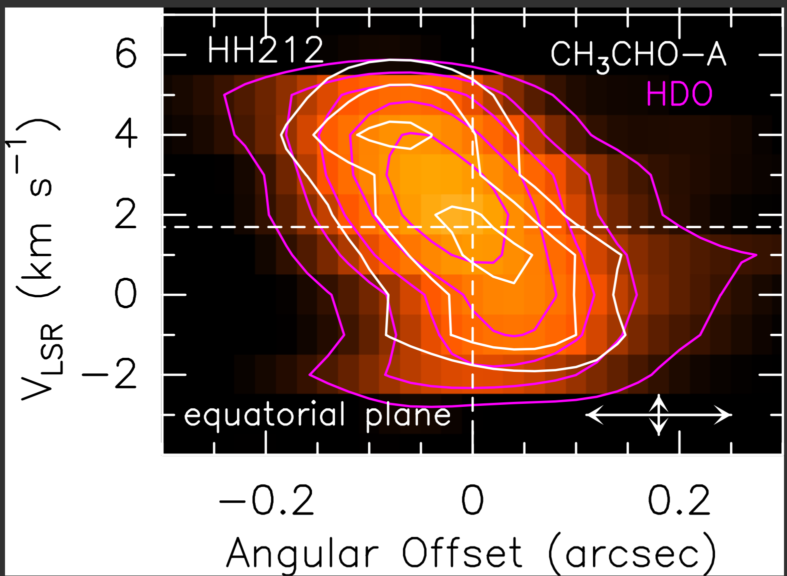
Disk atmosphere ? (Lee et al. 2017)

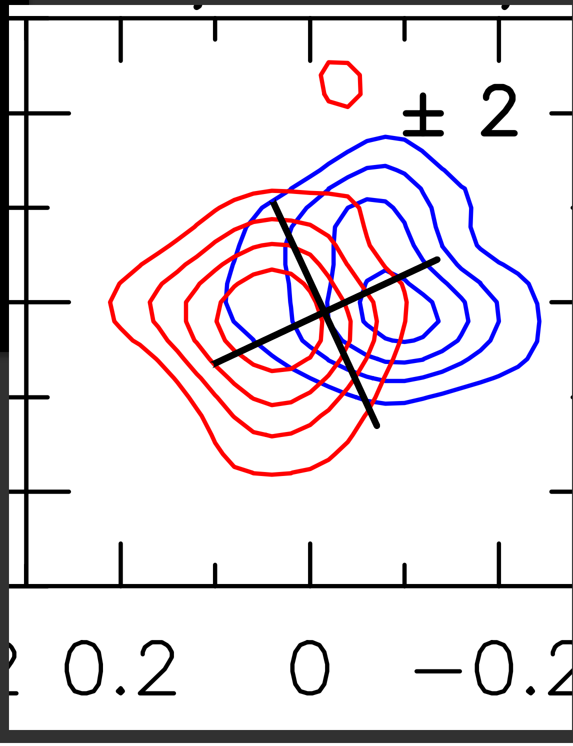


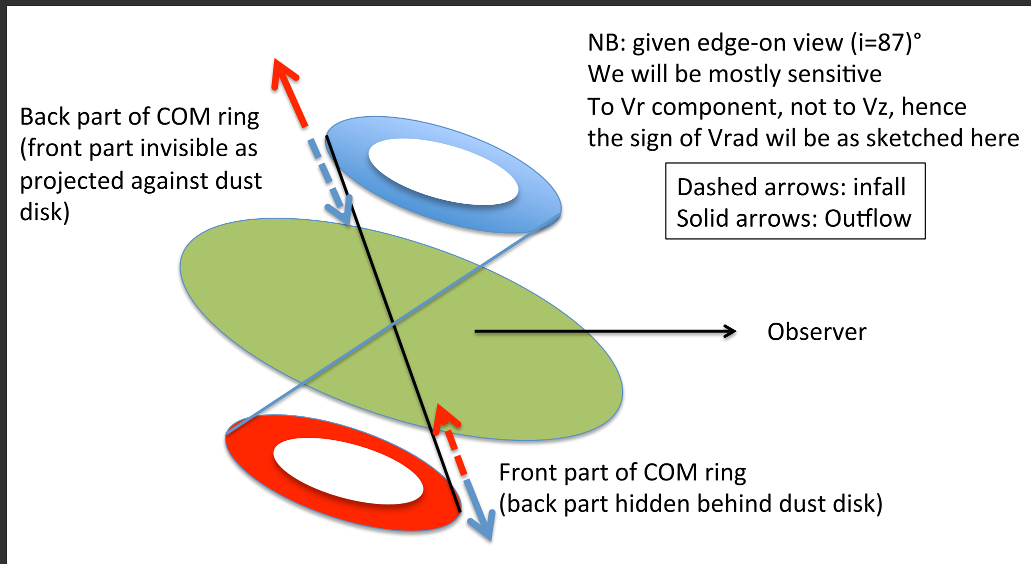


Codella et al. (2018)
Lee et al. (2017)
Bianchi et al. (2017ab)

the centrifugal barrier + outflowing and expanding rings

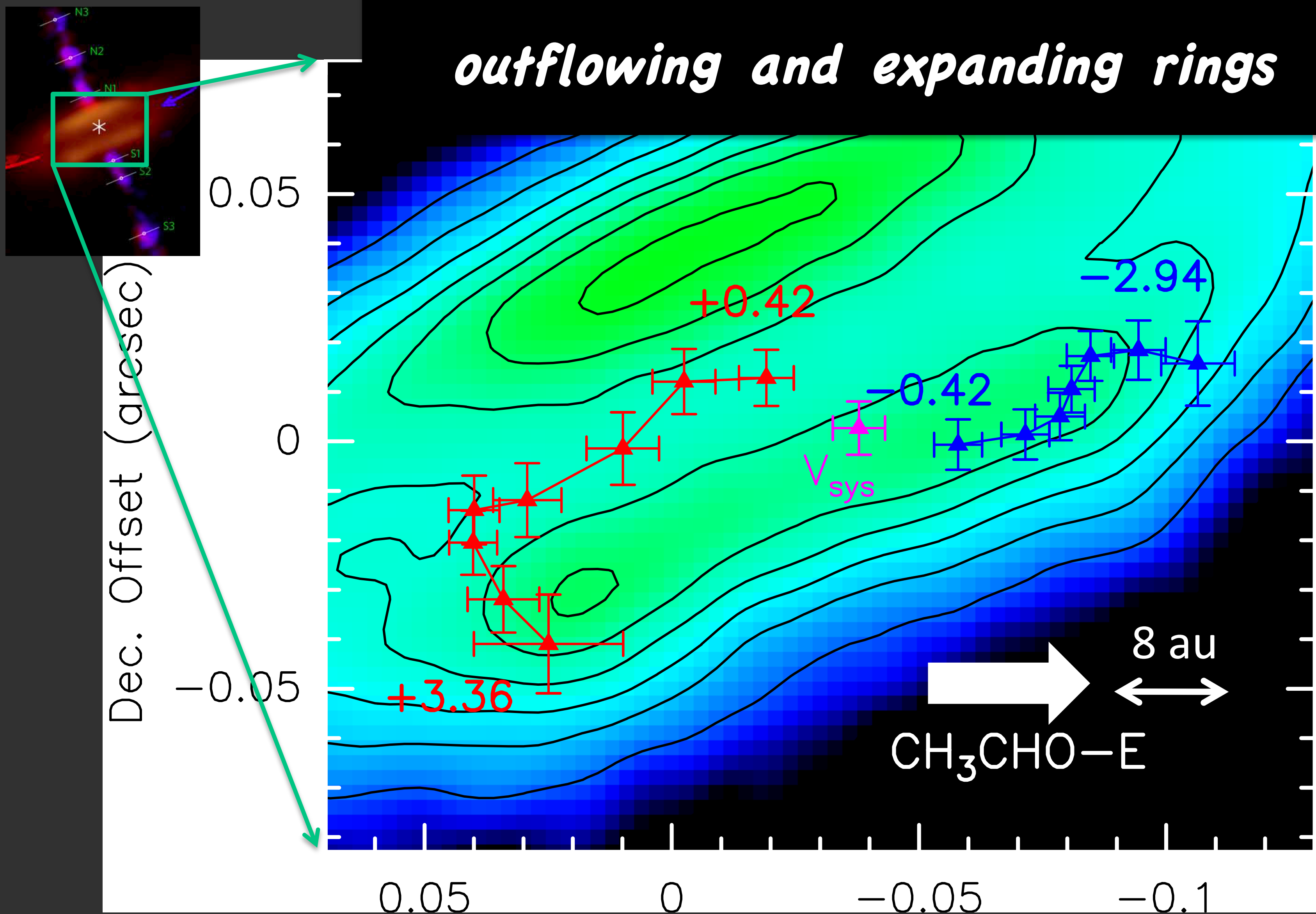






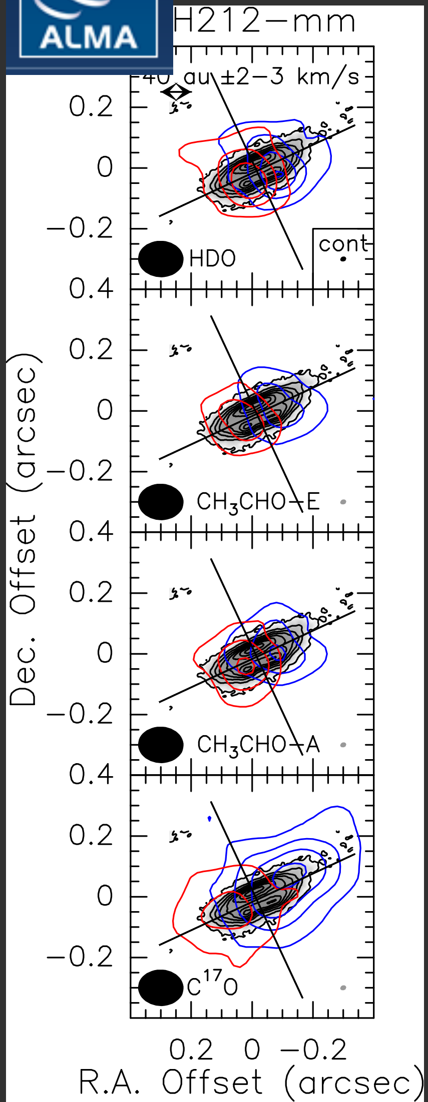
Codella et al. (2018)

outflowing and expanding rings



Codella et al. (2018)

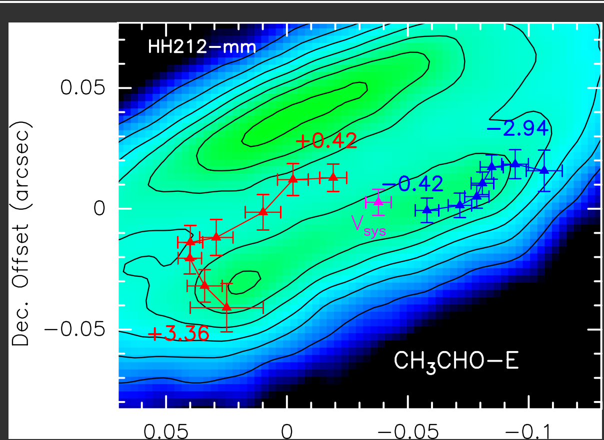
Conclusions

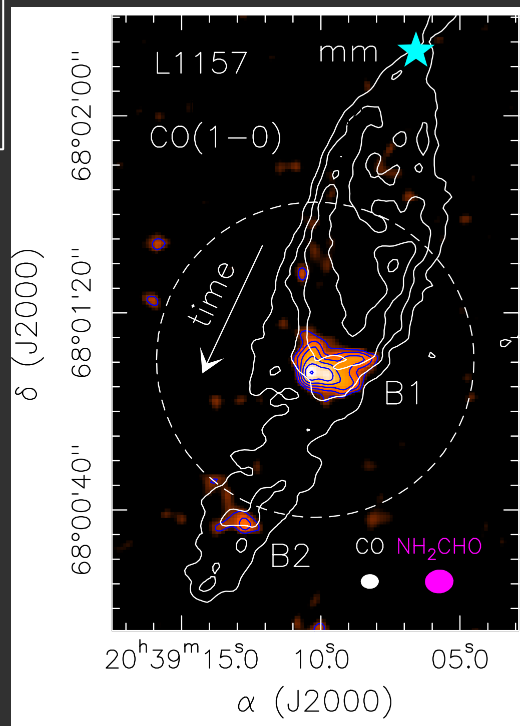


iCOMs are key tools to observe the fundamental processes (accretion, ejection) sculpting the cradle where a star (and its planetary system) is going to form

….and viceversa….

The jet/disk protostellar system is the ideal place to understand when the seeds of life form





Be prepared to the advent of SKA !!