Results of the CALYPSO survey of young solar-prototars: chemistry, dynamics and disk formation

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Why studying Class 0 protostars?

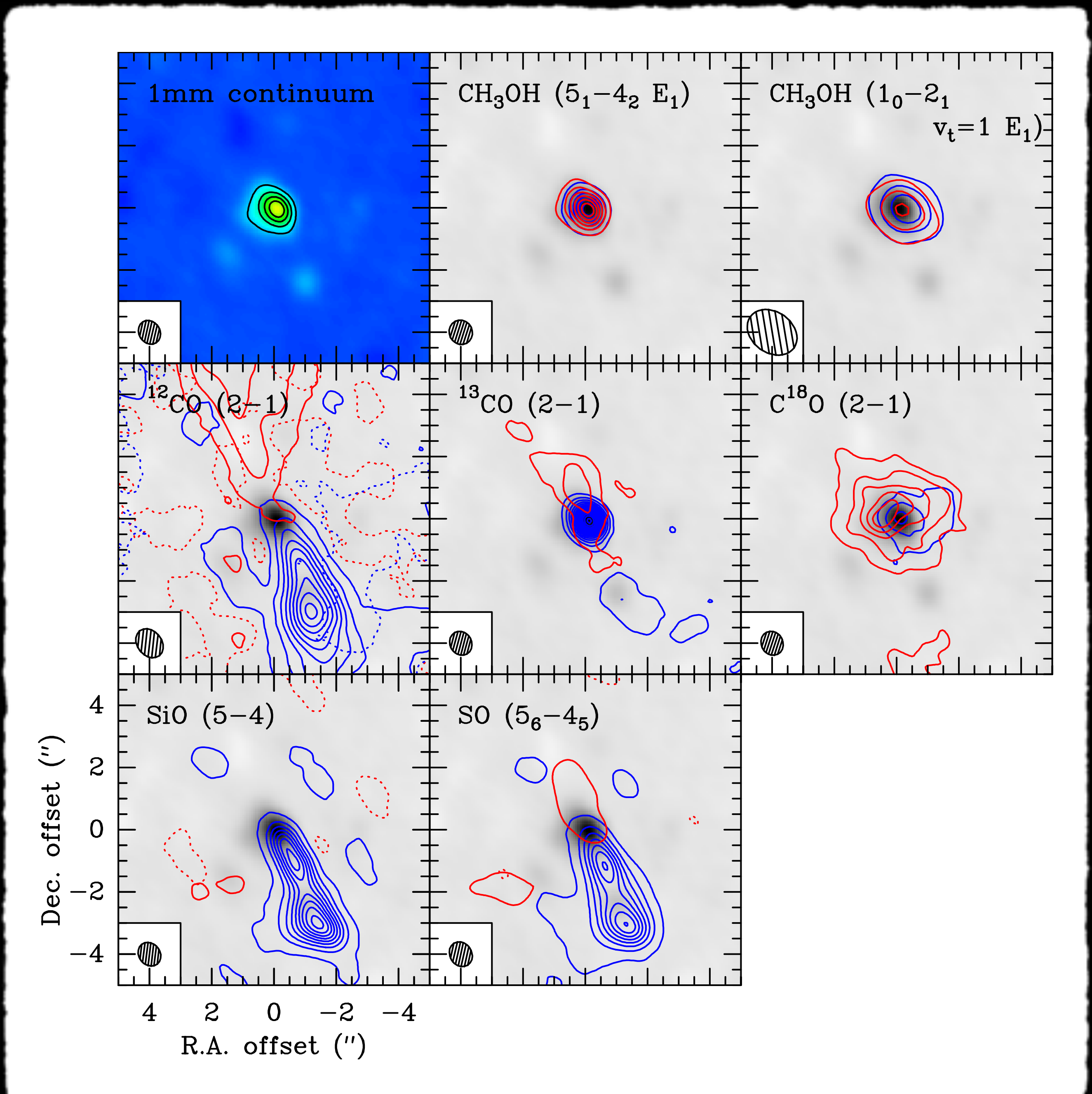
- Youngest protostars: initial conditions for star formation
- Crucial phase for the future evolution of the star: final mass, formation of the protoplanetary disk
- Yet, their structure on 100 AU scales is poorly known:
  - Are protostars single or multiple? Are disks present?
  - What is the launching mechanism of outflows?
  - What is the physical and chemical structure of the envelopes?

CALYPSO

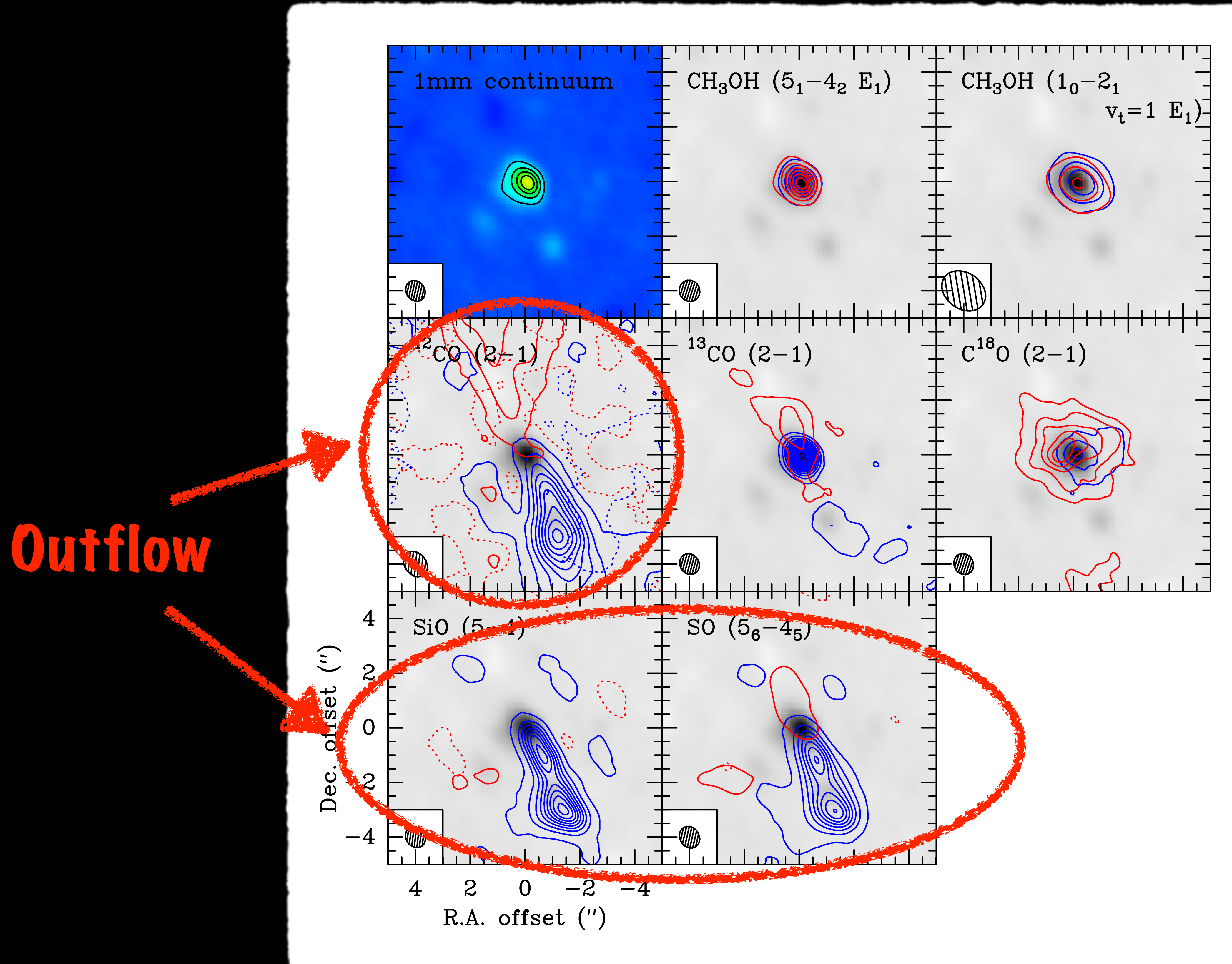
- IRAM *Large Program* (PI Philippe André)
- Survey of the 17 of the closest Class 0 protostars (d < 300 pc)
- 8 lines and continuum at 1 and 3 mm
- Spatial resolution at 1 mm of 1'' or better (i.e. between 100-300 AU)

NGC1333-IRAS2

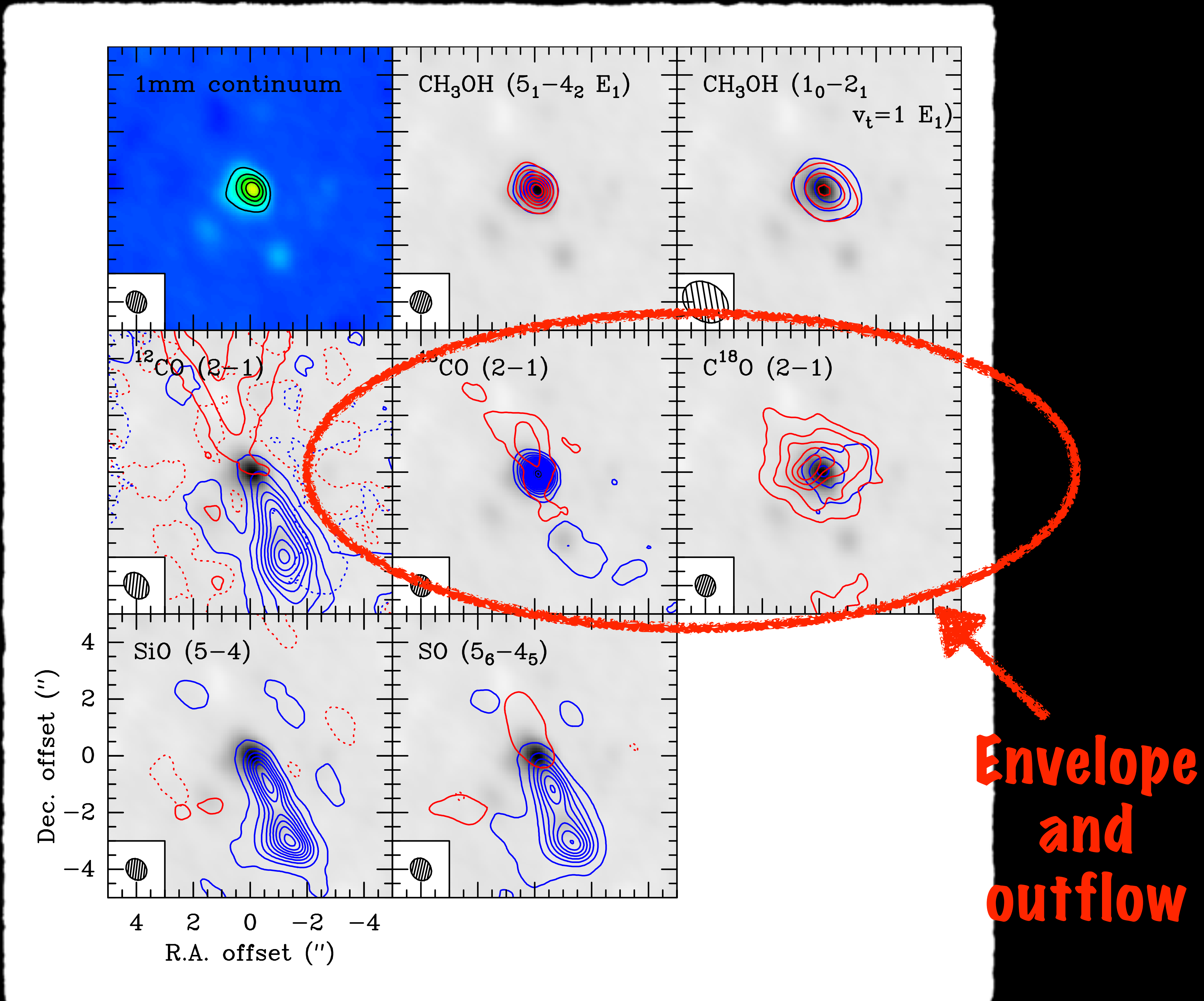
- Class 0 protostar located in Perseus (235 pc)
  - $L_{bol} \simeq 20\, L_{\odot}$
  - $M_{env} \simeq 1.7\, M_{\odot}$
- Observed with the Plateau de Bure interferometer at 0.8” resolution (~200 AU)



Maret et al.; Maury et al.; Codella et al. (2014)



1mm continuum
CH$_3$OH (5$_1$−4$_2$ E$_1$)
CH$_3$OH (1$_0$−2$_1$ v$_t$=1 E$_1$)
^{12}CO (2−1)
^{13}CO (2−1)
C^{18}O (2−1)
SiO (5−4)
SO (5$_6$−4$_5$)
Dec. offset (″)
R.A. offset (″)
4
2
0
−2
−4
Outflow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CH_3OH (5_1-4_2 E_1)
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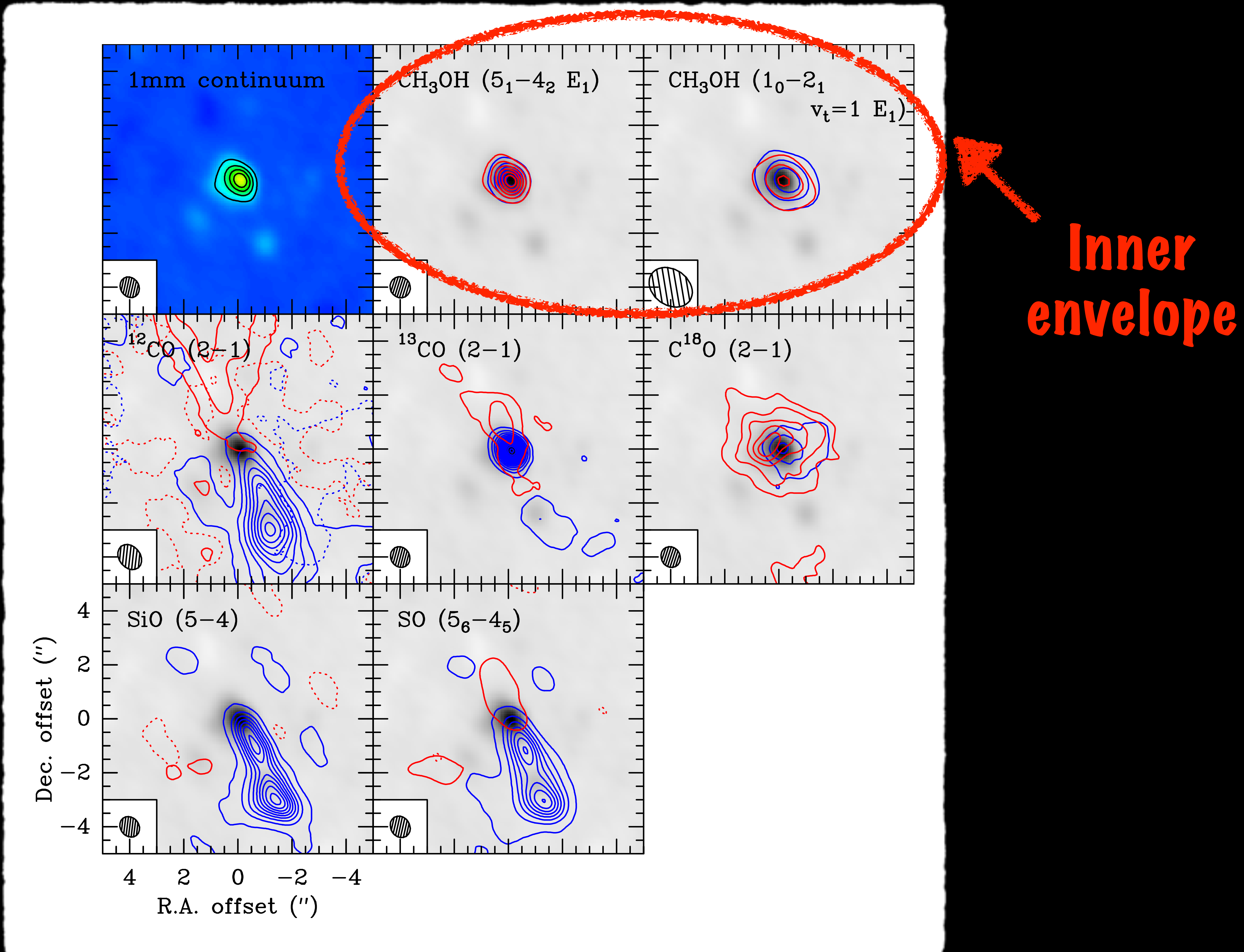
Envelope and outflow



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SO (5_6−4_5)
Dec. offset ($''$)
R.A. offset ($''$)
4
2
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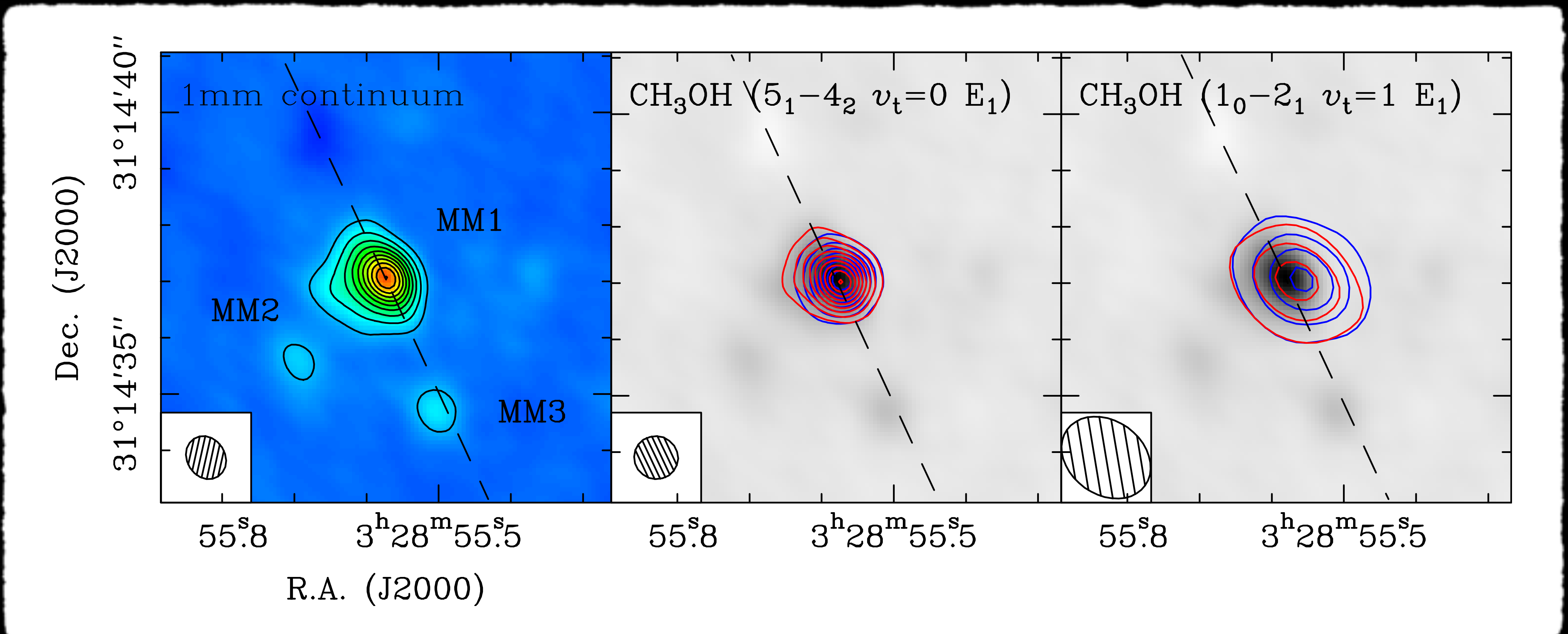
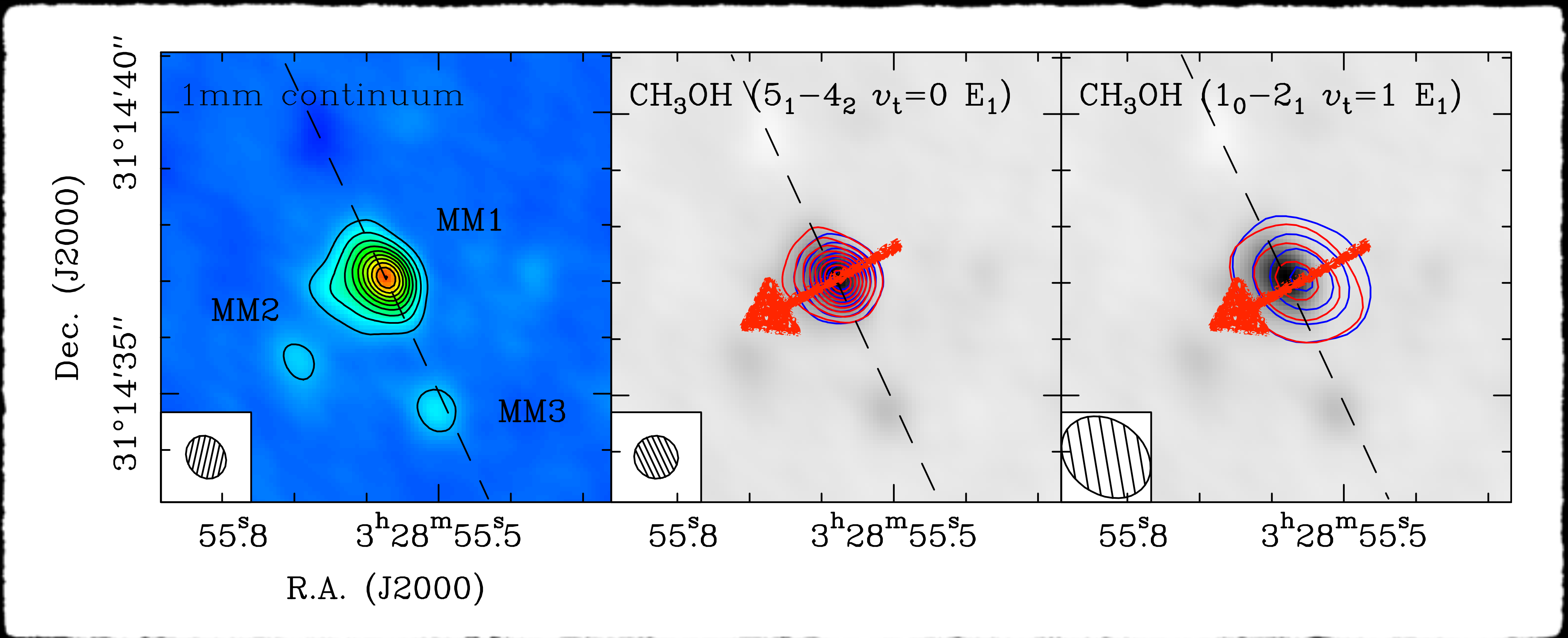
−2
−4
Inner envelope

Methanol emission



- Compact (0.4" i.e 90 AU) methanol emission centered on the main continuum source (MM1): good probes of the inner envelope
- First moment map hints at a velocity gradient perpendicular to the outflow, but PV diagrams are inconsistent with a Keplerian disk

Methanol emission



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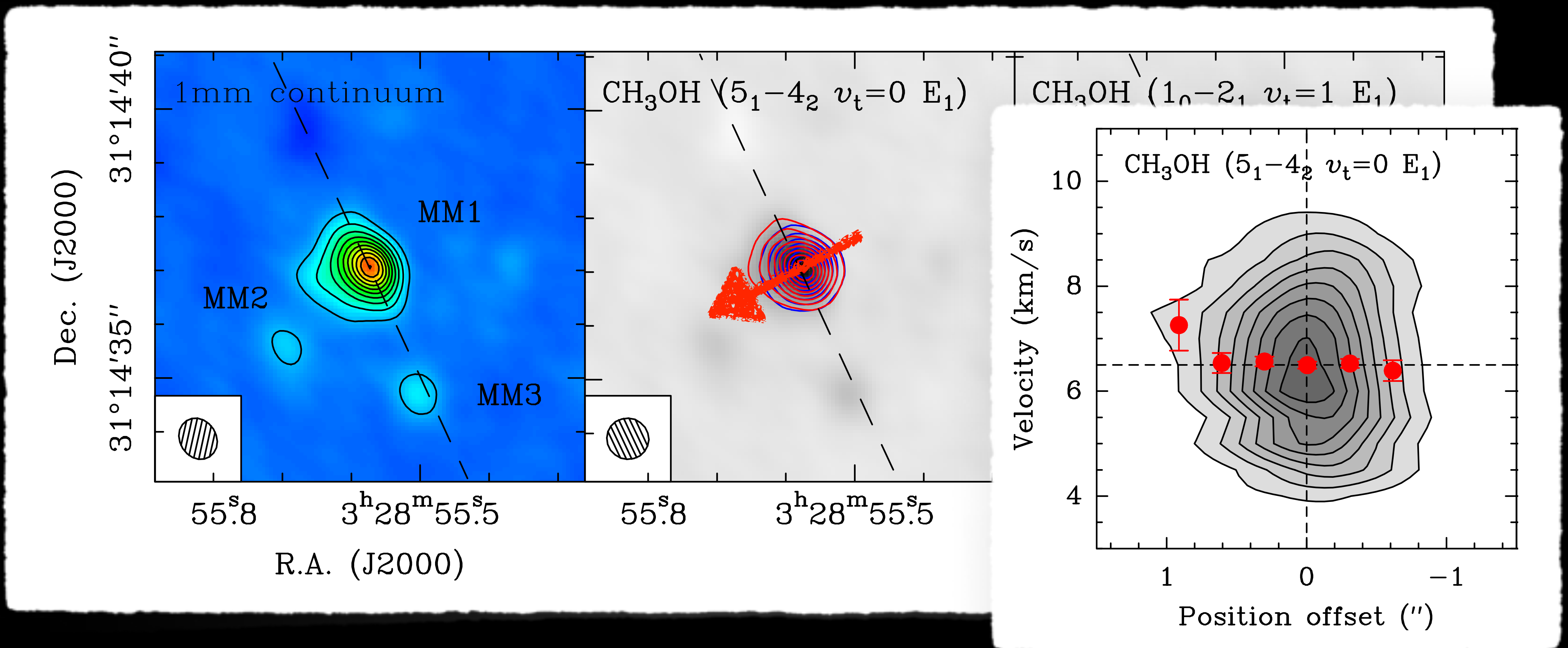

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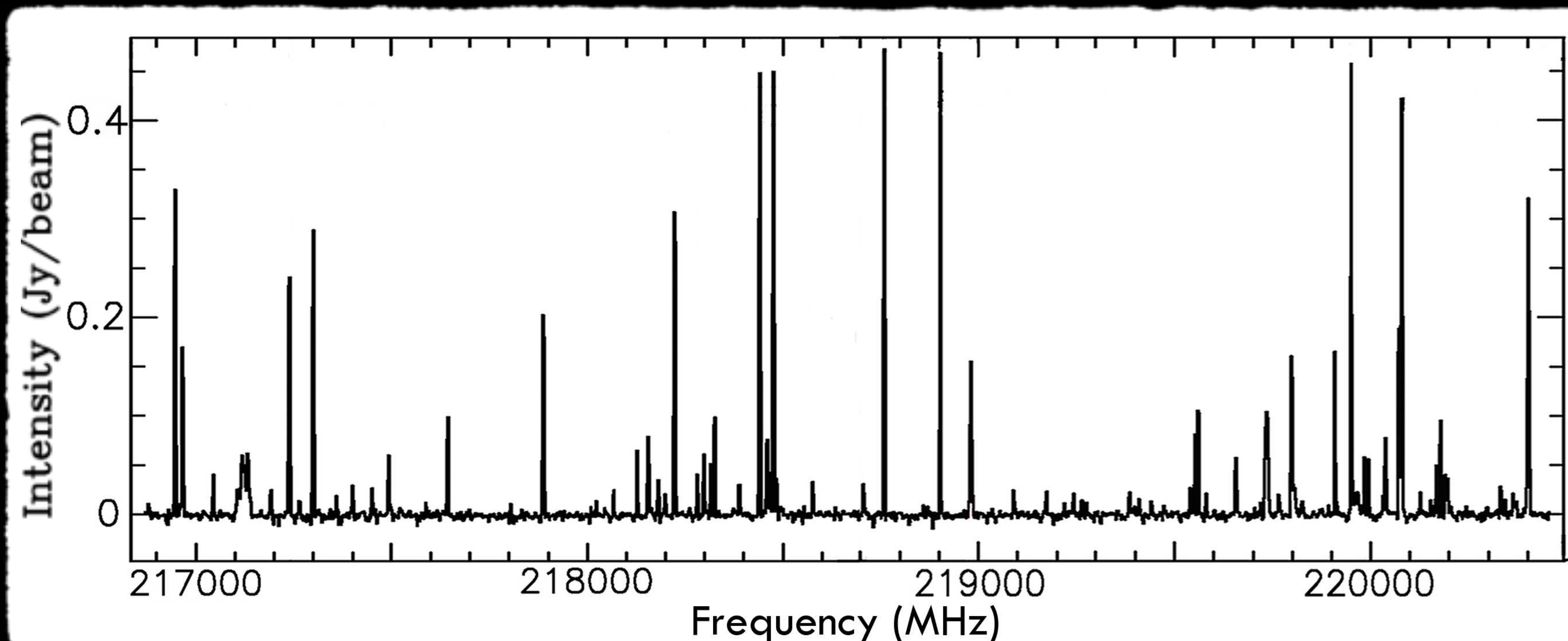
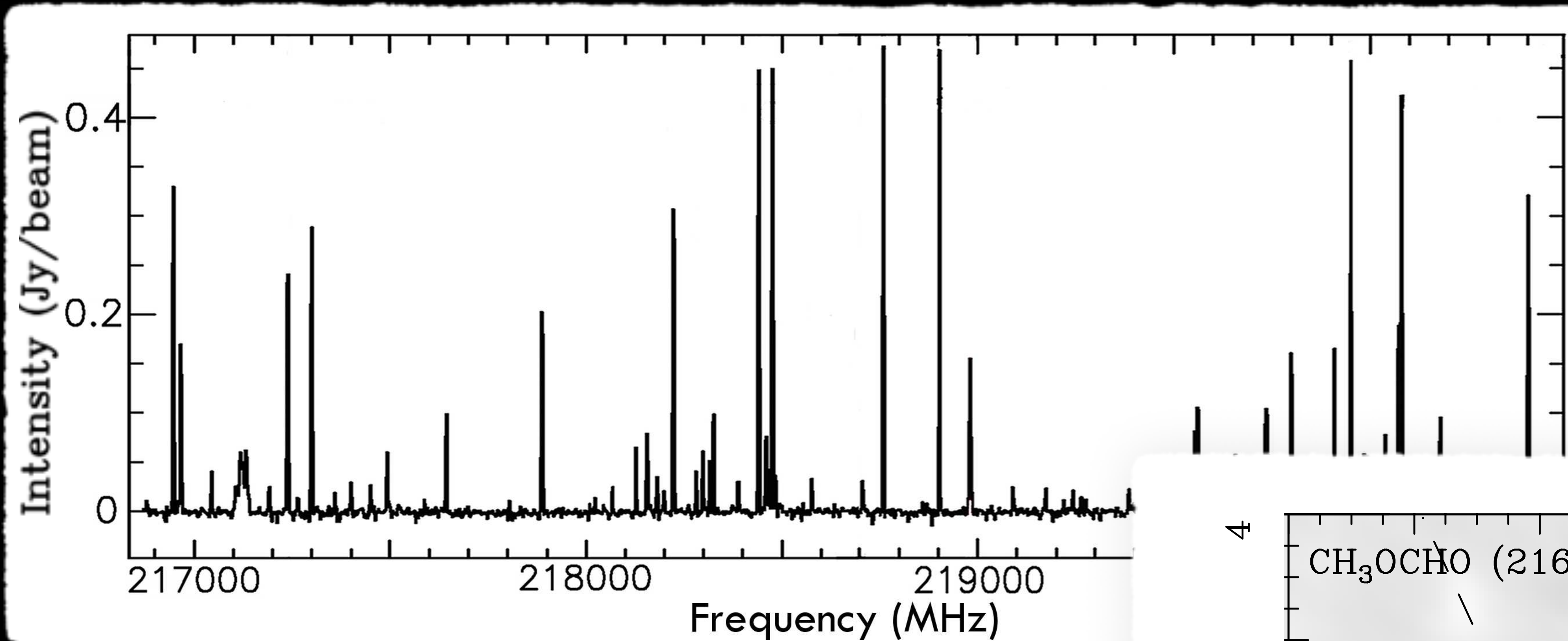
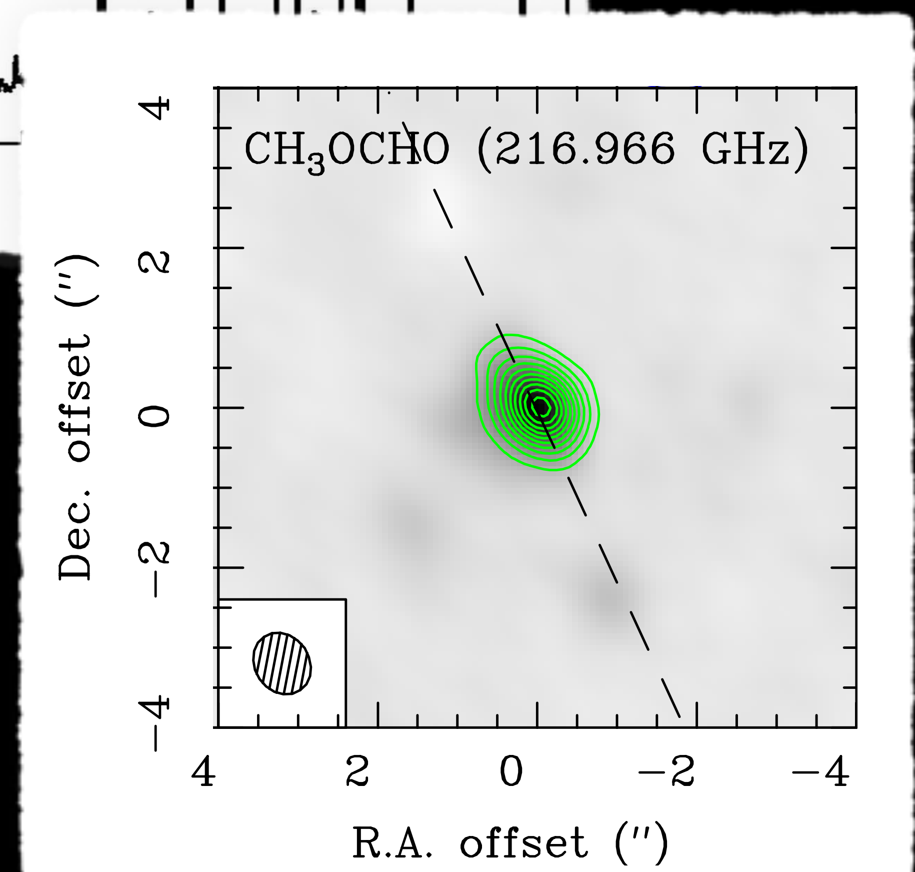
Complex organics emission



- Many complex organics are detected and resolved spatially
- Emission sizes are consistent with the ice sublimation radius: hot corino

Complex organics emission





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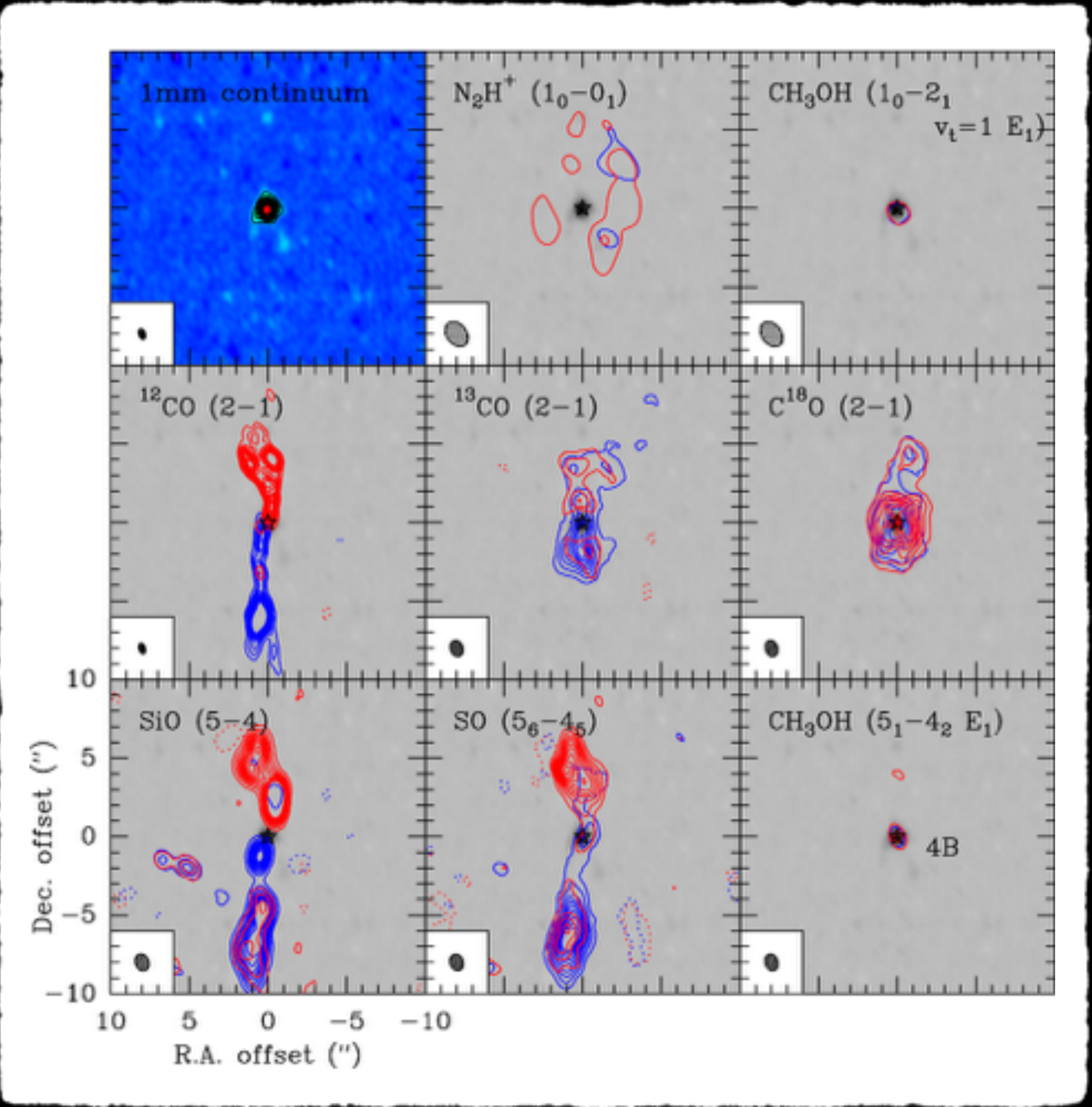
NGC1333-IRAS4B

- Class 0 protostar located in Perseus (235 pc)
  - $L_{bol} \simeq 17\, L_{\odot}$
  - $M_{env} \simeq 3.1\, M_{\odot}$
- Anticorrelation between N_2H^+ and $C^{18}O$: due to the CO ice evaporation



Anderl et al. in prep.

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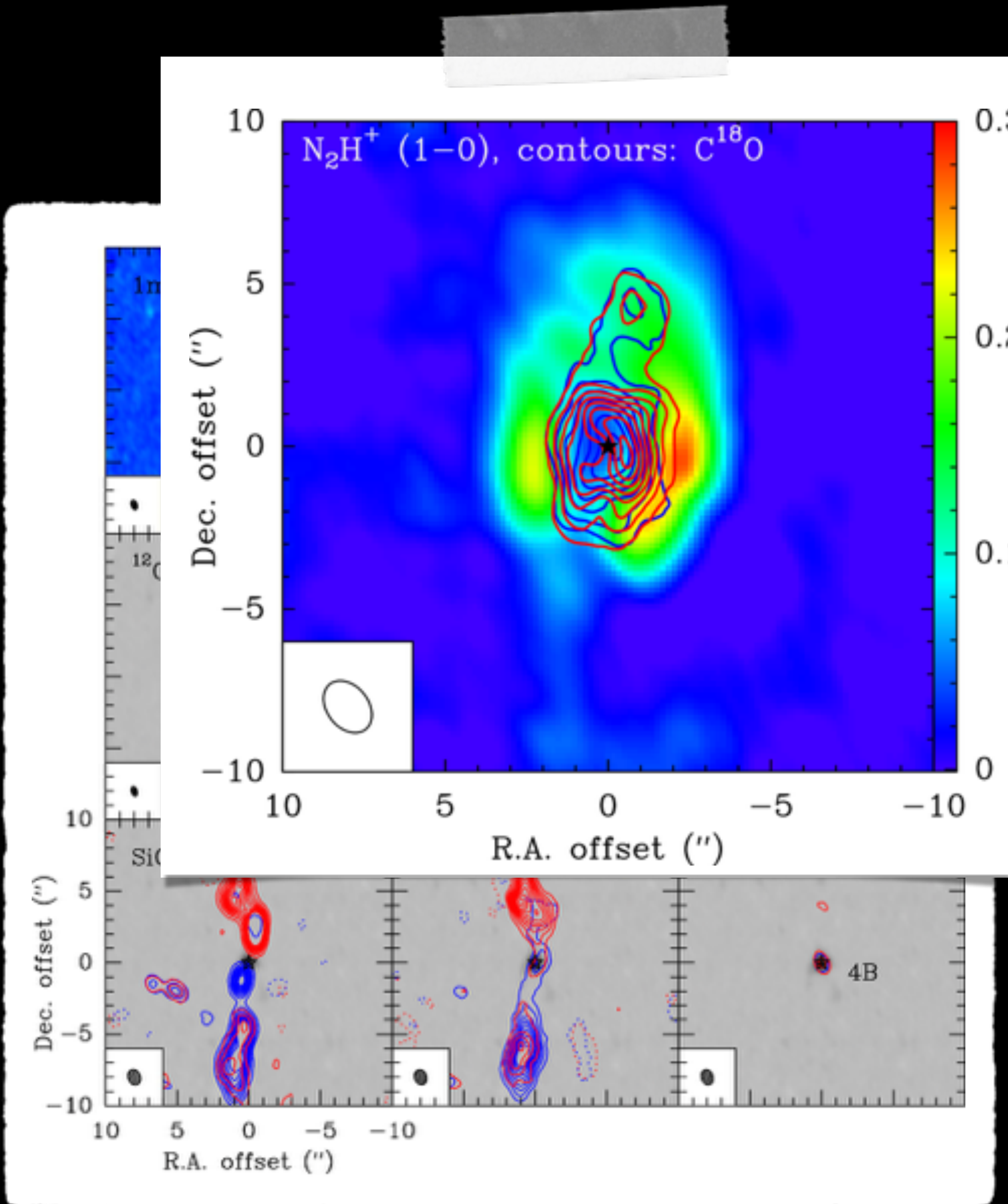

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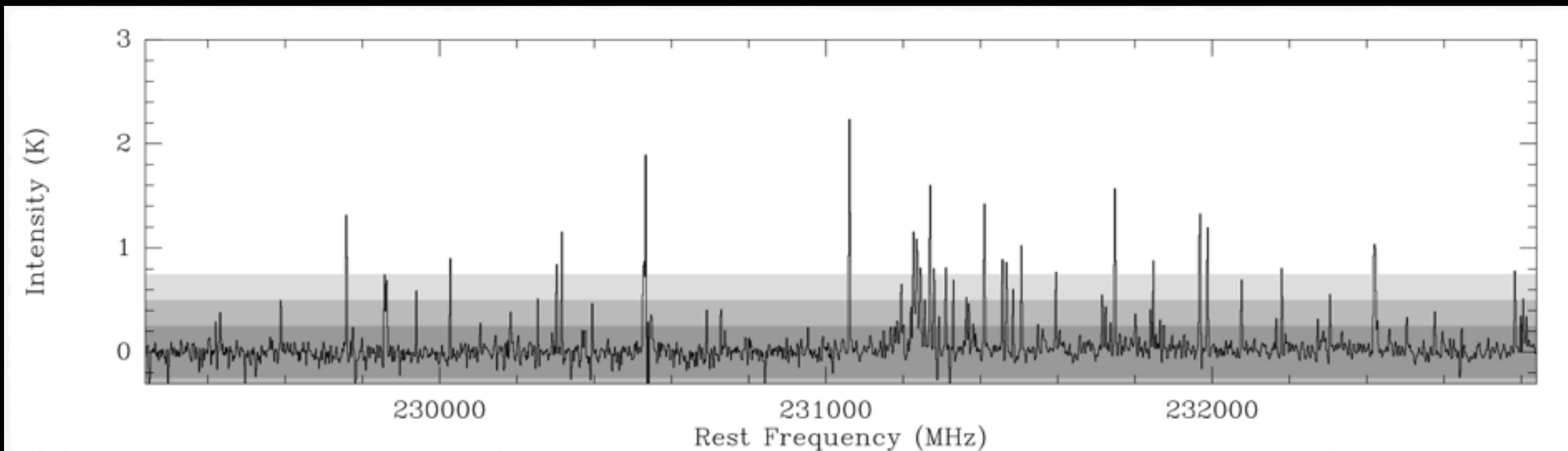
Complex organics emission



- 22 species (mostly COMs) are detected
- The chemical composition of IRAS4B is similar to that of IRAS2
- Most COMs lines arise in the hot corino, but some of the low excitation lines are also present along the outflow

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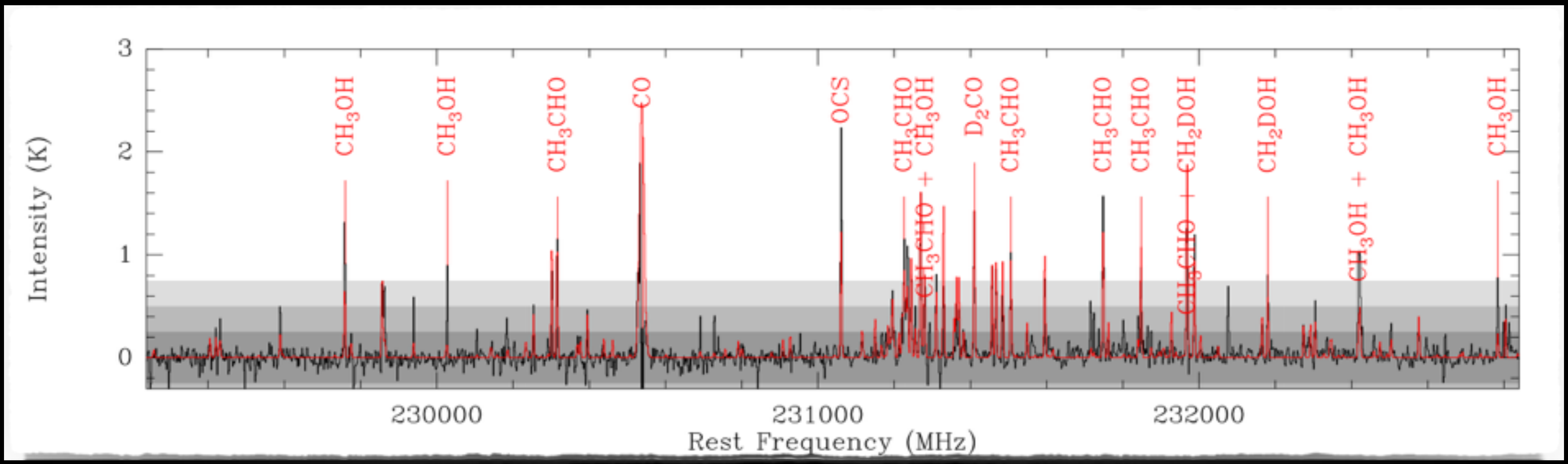

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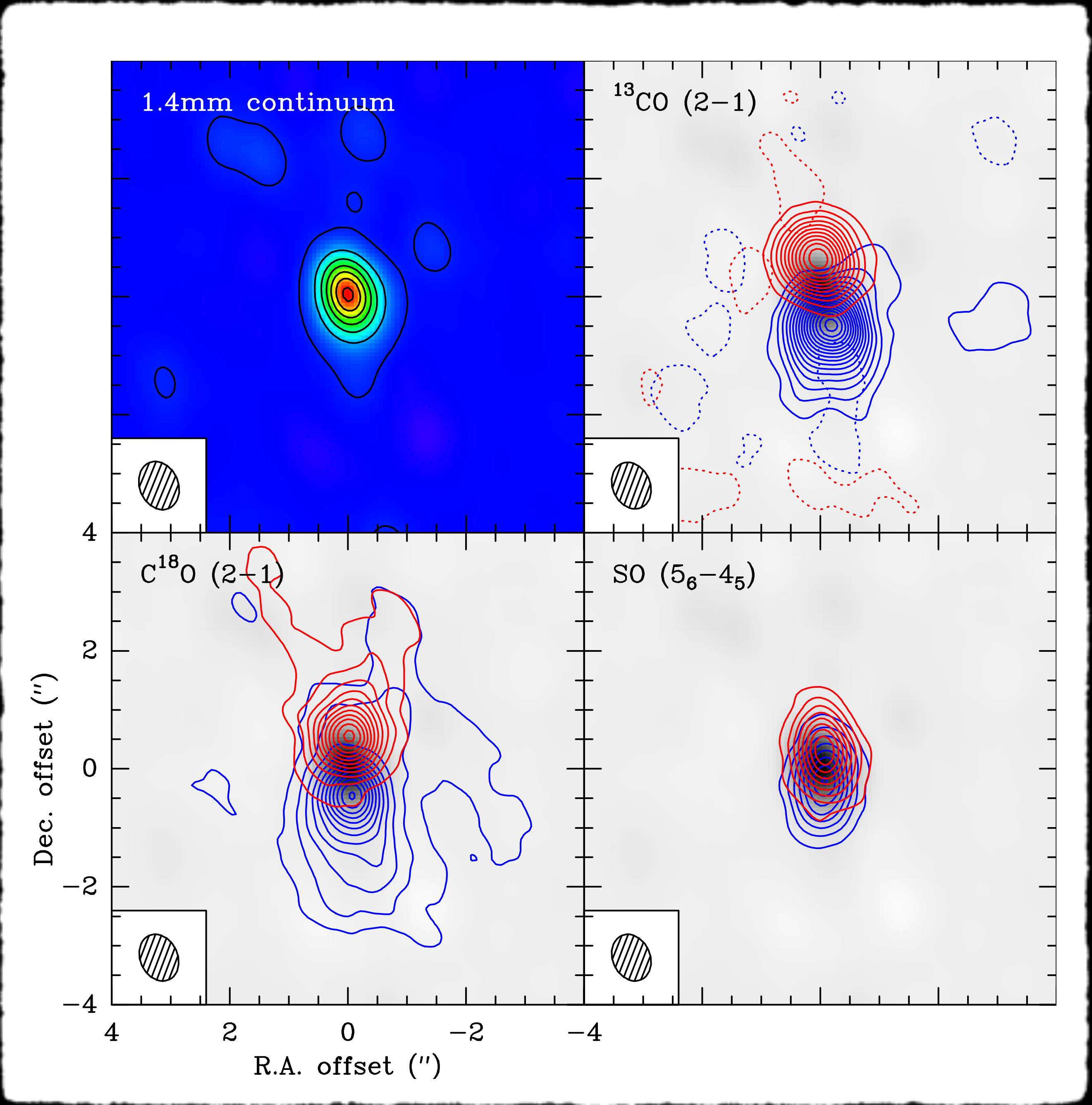
L1527

- Class 0 protostar located in Taurus (140 pc)
  - $L_{bol} \simeq 1.6\, L_{\odot}$
  - $M_{env} \simeq 0.8 - 1.7\, M_{\odot}$
- Tobin et al. (2012): Keplerian disk seen in ^{13}CO (2-1)



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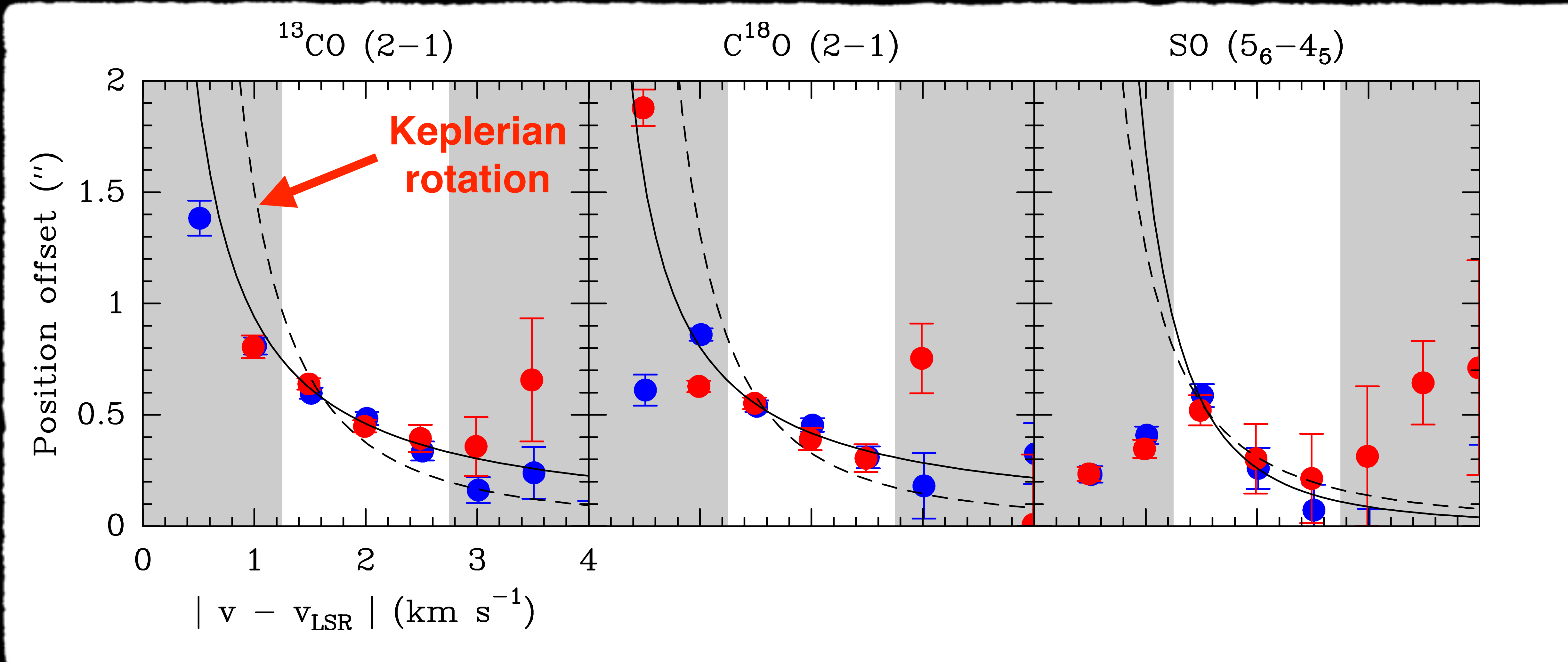
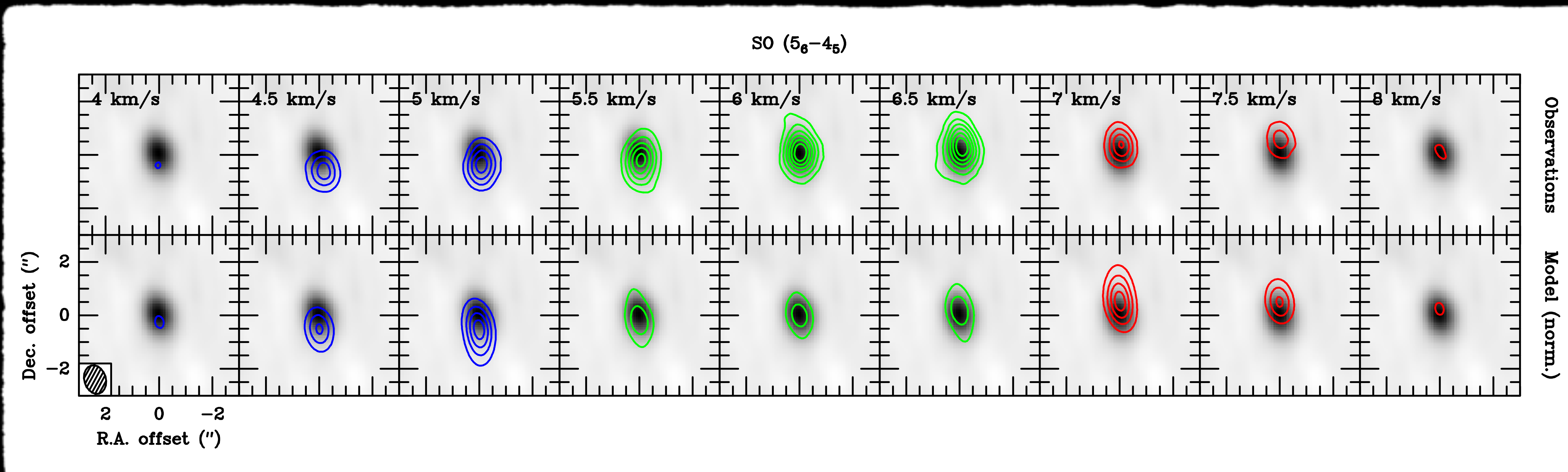


- ^{13}CO and C^{18}O emission are inconsistent with Keplerian rotation, but originate in the rotating and infalling envelope:

$$|v - v_{\rm LSR}| \propto 1/r^{\beta} \text{ with } \beta \approx 1$$

- SO emission is consistent with Keplerian rotation

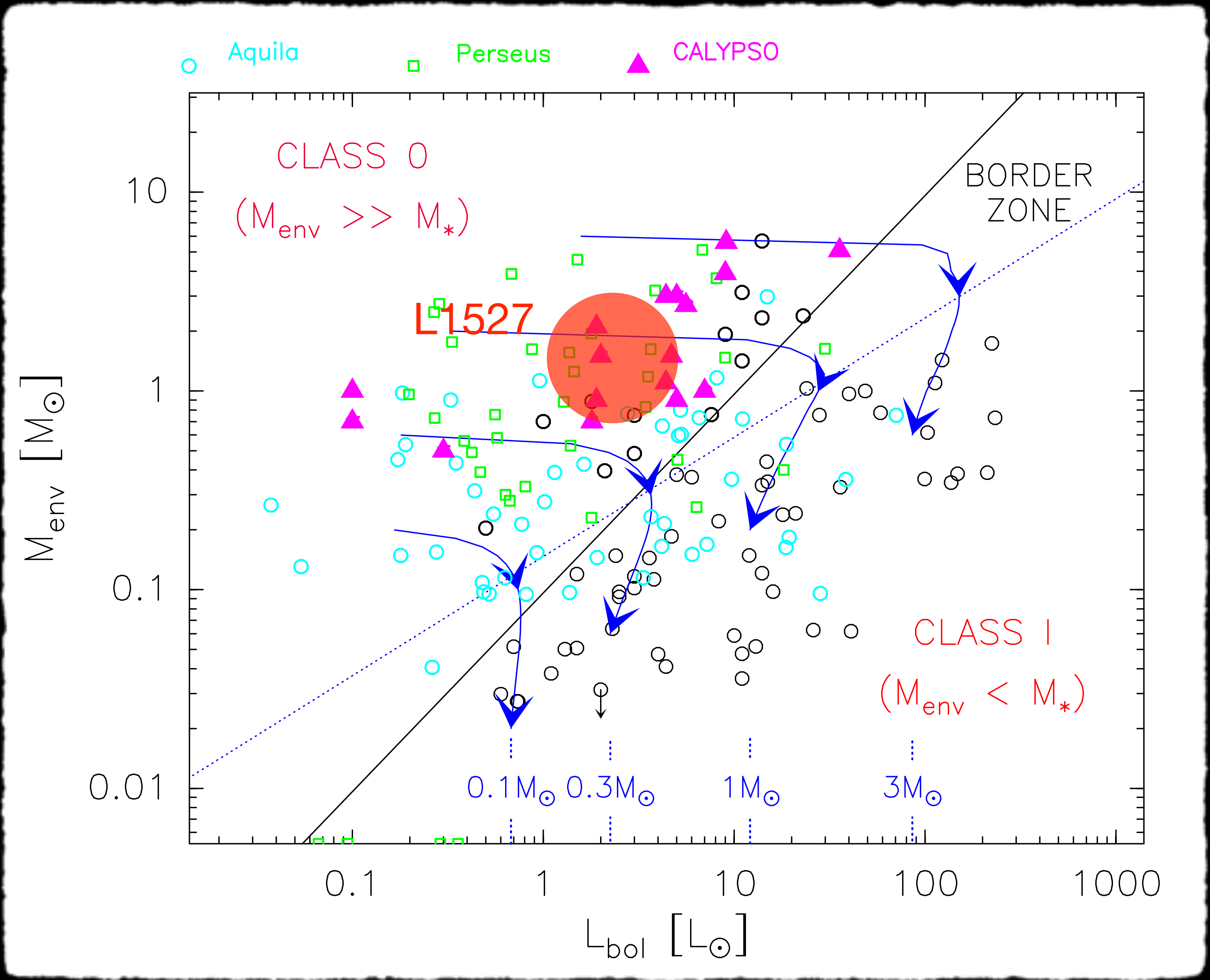
$$|v - v_{\rm LSR}| \propto 1/r^{\beta} \text{ with } \beta \approx 0.5$$



- SO emission is well reproduced by a Keplerian disk model with a central mass of 0.2 Msun, and a centrifugal radius of 150 AU (see also Sakai et al. 2014)

First statistical results: disks

- Only one source with a large (> 100 AU) Keplerian disk
- Large Keplerian disks are uncommon in Class 0 protostars !
- L1527 is probably more evolved than other Class 0 protostars
- Evolutionary effect?

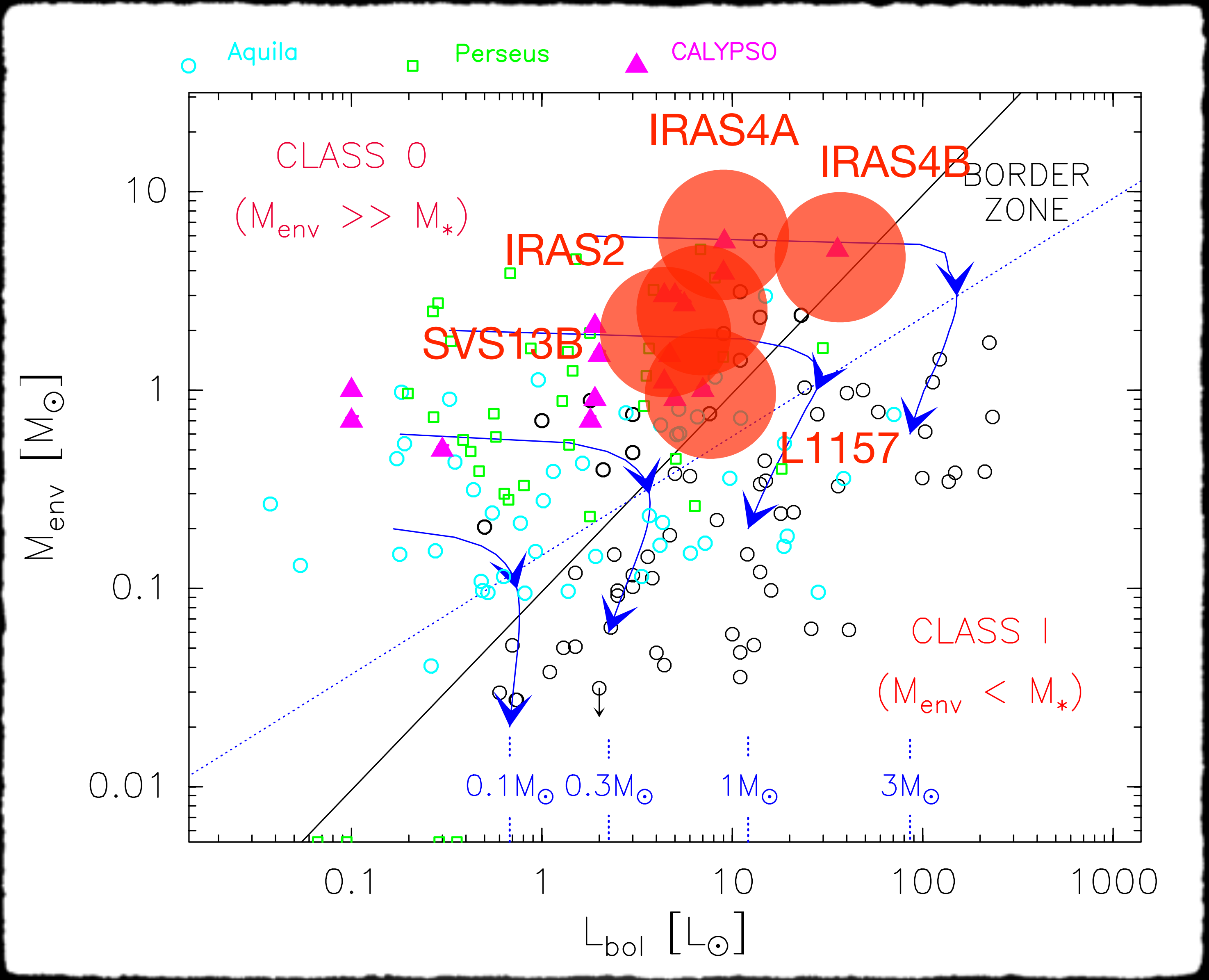


First statistical results: COMs

- Five sources have complex organic molecule emission
- High luminosity sources:

$$L_{bol} \geq 6\, L_{\odot}$$

- Sensitivity effect?
- Chemical variations from one source to the other



Conclusions

- Diversity among the physical and chemical properties of the Class 0 protostars
  - Keplerian disks are uncommon
  - Complex organics are detected only in the most luminous protostars
  - Outflow properties also vary (e.g collimation)
- (Sub-)millimiter surveys are important to understand the formation and evolution of these objects