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)
  - $L_{bol} \approx 20 L_\odot$
  - $M_{env} \approx 1.7 M_\odot$
- Observed with the Plateau de Bure interferometer at 0.8” resolution (~200 AU)

Maret et al.; Maury et al.; Codella et al. (2014)
Outflow
Envelope and outflow
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
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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
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NGC1333-IRAS4B

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  - $L_{bol} \simeq 17 L_\odot$
  - $M_{env} \simeq 3.1 M_\odot$
- Anticorrelation between $N_2H^+$ and $C^{18}O$: due to the CO ice evaporation

Anderl et al. in prep.
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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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Anderl et al. in prep.
L1527

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

Maret et al. in prep.
• $^{13}\text{CO}$ and $^{18}\text{CO}$ emission are inconsistent with Keplerian rotation, but originate in the rotating and infalling envelope:

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

• SO emission is consistent with Keplerian rotation

$$|v - v_{\text{LSR}}| \propto 1/r^\beta \text{ with } \beta \approx 0.5$$
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-)millimeter surveys are important to understand the formation and evolution of these objects