Fire it up

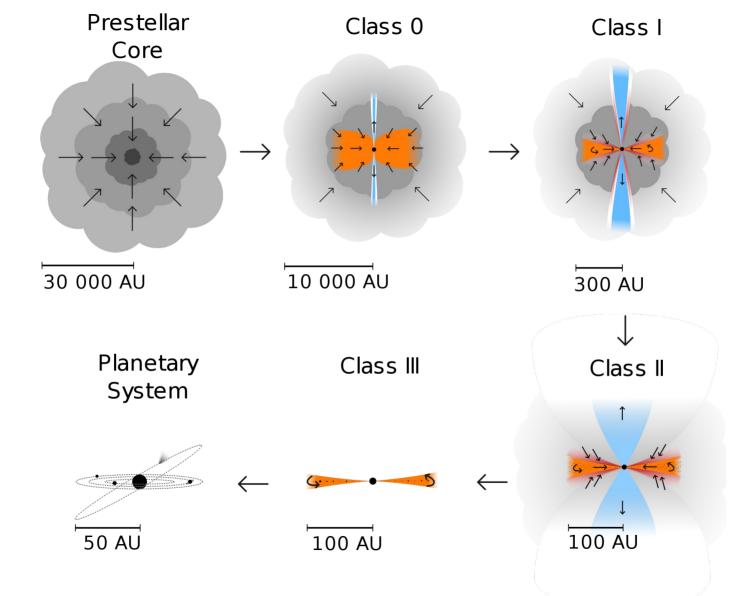
Using accretion outbursts to study the chemistry of protoplanetary disks

Fernando Cruz Sáenz de Miera

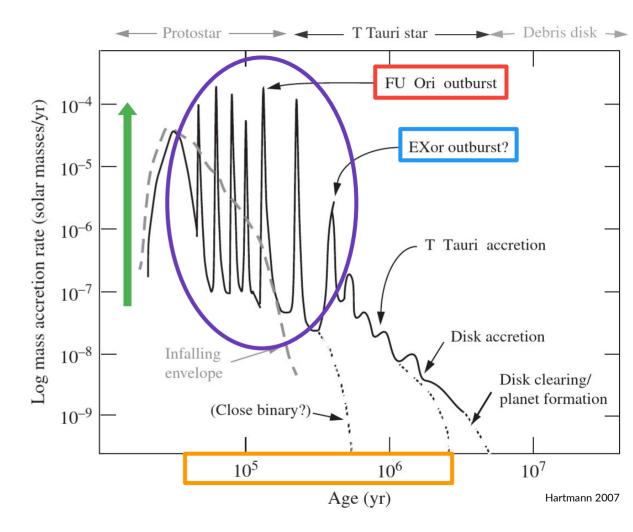
Collaborators:

Audrey Coutens, Ágnes Kóspál, Péter Ábrahám, Anne Dutrey, Stéphane Guilloteau, Antoine Espagnet

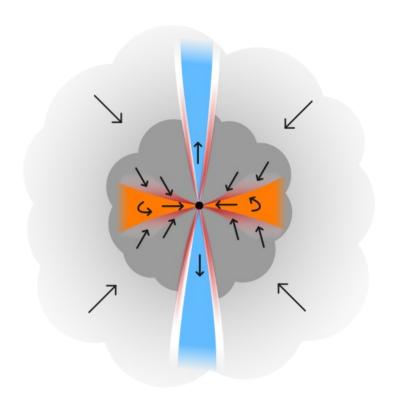




- Accretion is not smoothly decreasing but episodic
- Mass accretion rate increases
 - 10⁻⁸ up to 10⁻⁴ M_☉ year⁻¹
- Increase in Lbol
 - $L_{bol} = L_{star} + L_{acc} + L_{disk} + L_{env}$
- Mostly occur in Class I or II YSOs
- Typically detected as a brightening in optical/NIR photometry
 - Between 1 and 4 mag
- Divided into two main sub-categories
 - FUors & EXors



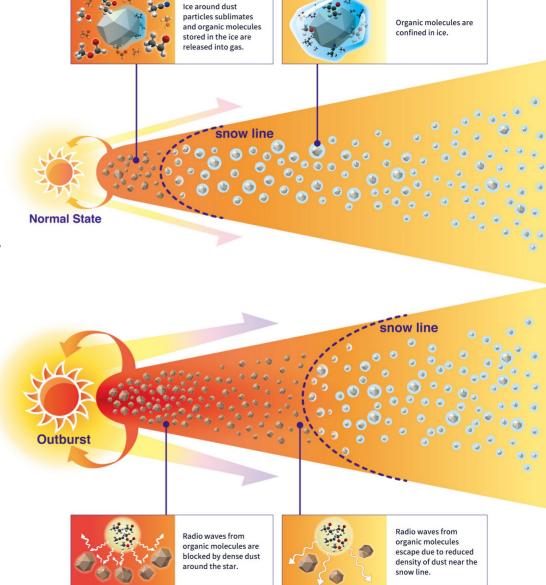
- <200 outbursting YSOs (Contreras-Peña, in prep.)
- Prevalence is unknown (Fischer+2019; Contreras-Peña+2019)
- Have a significant impact on
 - Total mass of the star (Fischer+2019; Cruz-Sáenz de Miera+2023b)
 - Envelope depletion (Fehér+2017)
 - Jets and outflows (Whelan+2010; Cruz-Sáenz de Miera+2023a)
 - Disk structure (Mosoni+2013)
 - Disk temperatures
 - Planet formation
 - Mineralogical evolution (Ábrahám+2009)
 - Chemical evolution

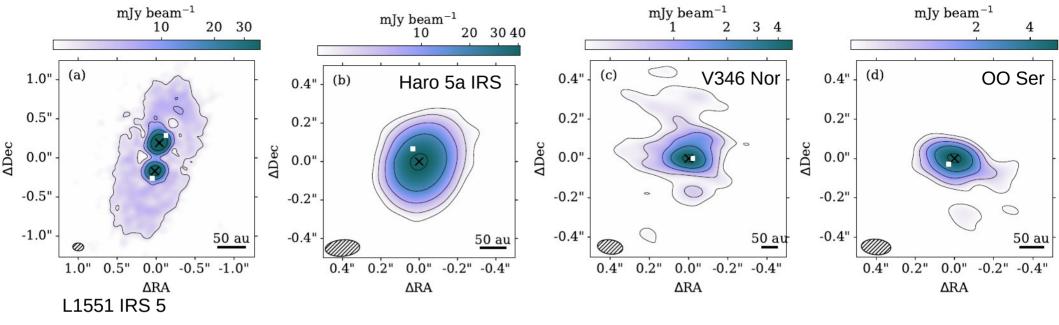


300 AU

What role do outbursts have on the chemistry?

- Planets inherit chemical composition from disk.
- Hot corinos are the hot, compact, chemicallyrich (COMs) inner regions of Class 0 YSOs.
- As the YSOs cool down, molecules freeze and are harder to detect.
- Outbursts can sublimate them and make them detectable.
- But do outbursts affect the chemical evolution?





Cruz-Sáenz de Miera (2025, A&A, 696, A18)



Three FUor-like targets + 1 "peculiar"

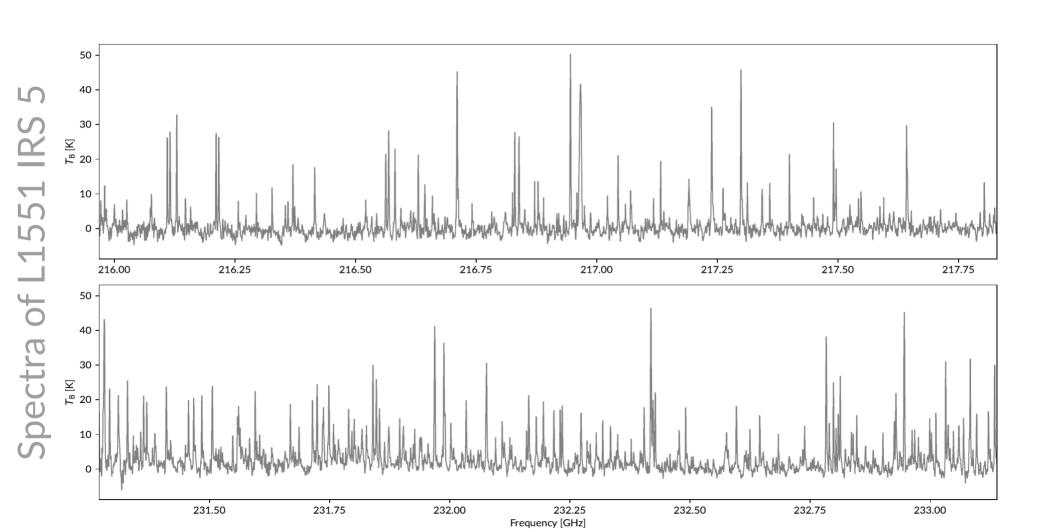
ALMA Band 6

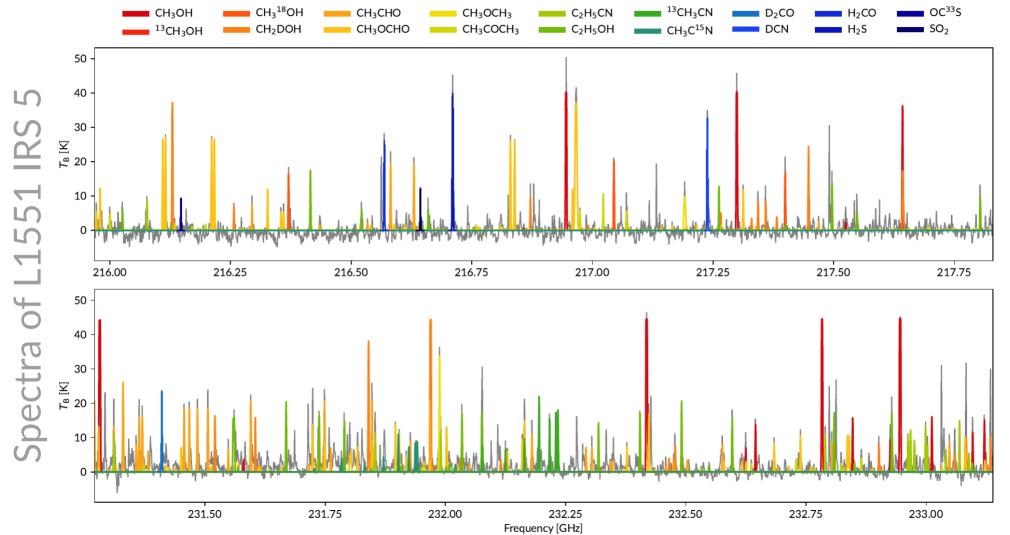
"Continuum" spws (0.977 MHz)

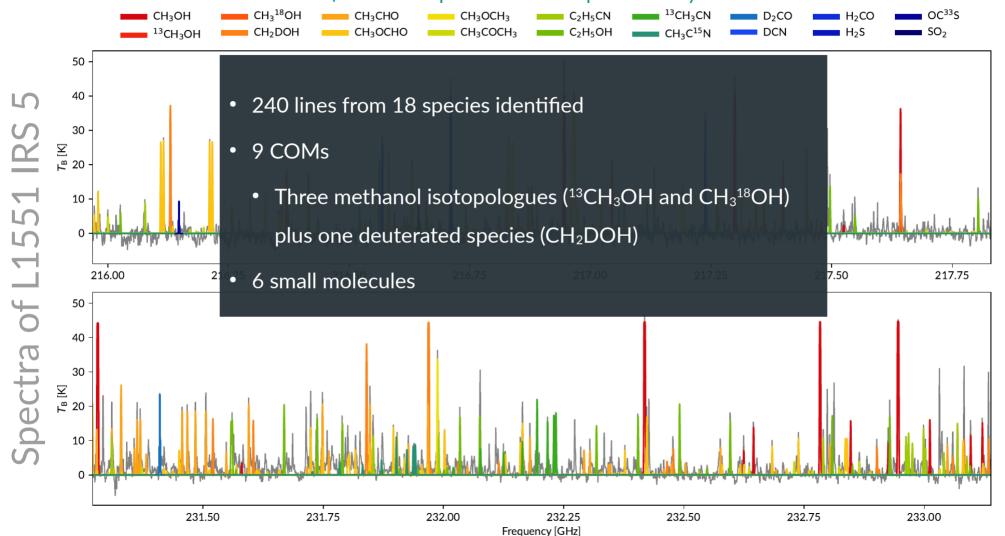
Two ALMA conf. + ACA

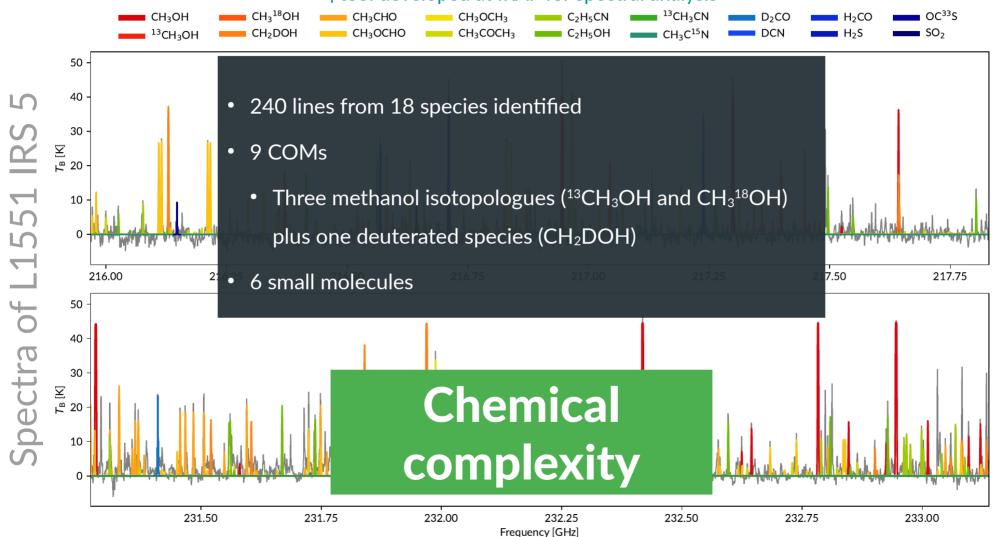
"Close" distances (140 - 700 pc)

36 ≤ Lbol ≤ 160 L_☉





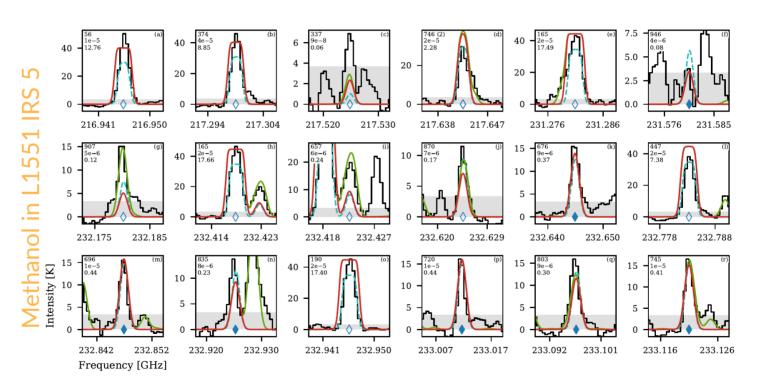




Used CASSIS to fit LTE models on the line profiles

†tool developed at IRAP for spectral analysis

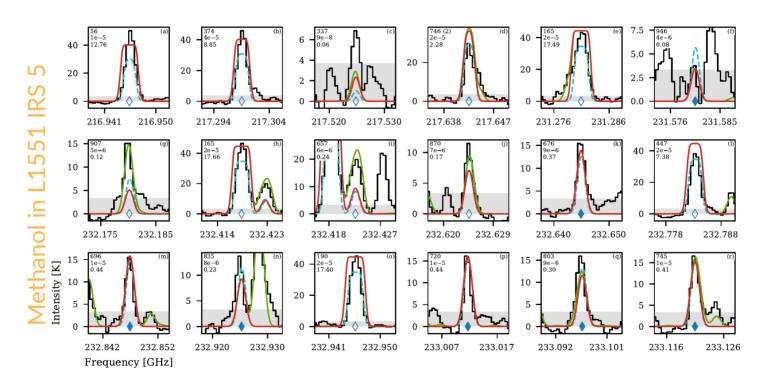
Obtained source size, FWHM, v_{LSR}, column density, excitational temperature for each species in each target



Used **CASSIS** to fit LTE models on the line profiles

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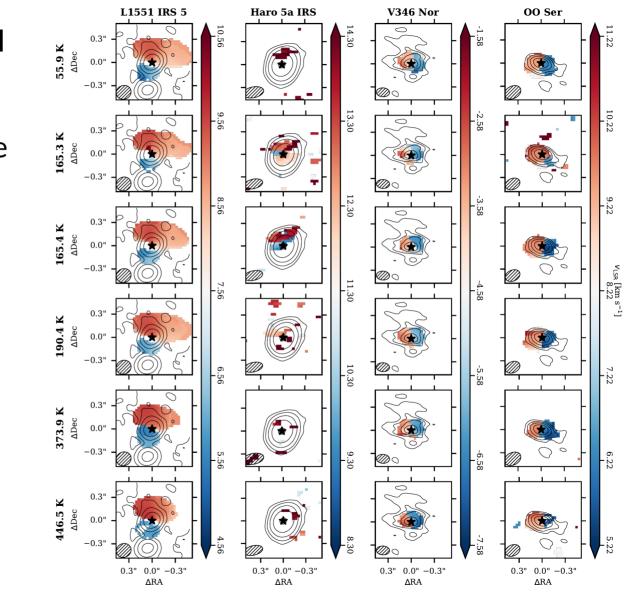
Obtained source size, FWHM, v_{LSR}, column density, excitational temperature for each species in each target



COMs have $T_{ex} > 100 \text{ K}$

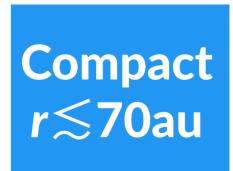
Spatial distribution of Methanol and other COMs

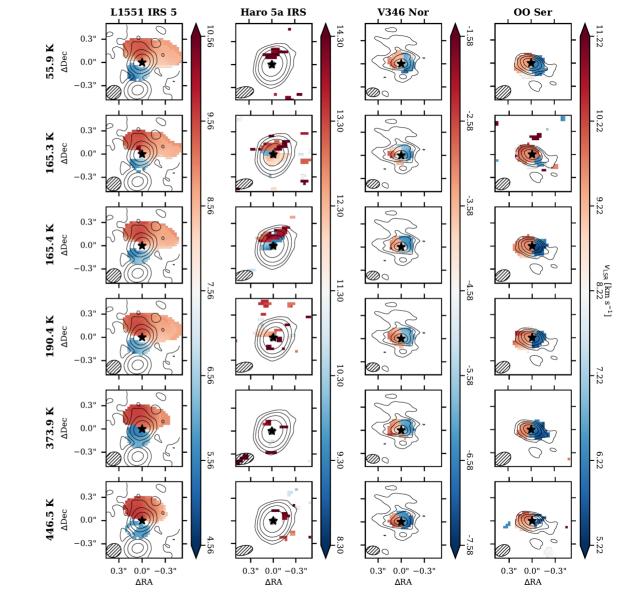
Moment maps of COMs indicate the extension of the warm chemically rich region.



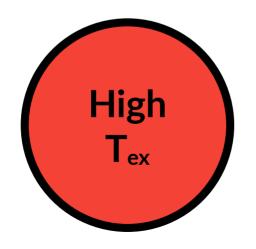
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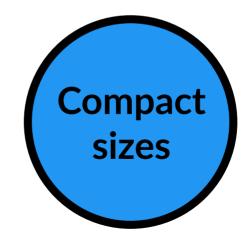
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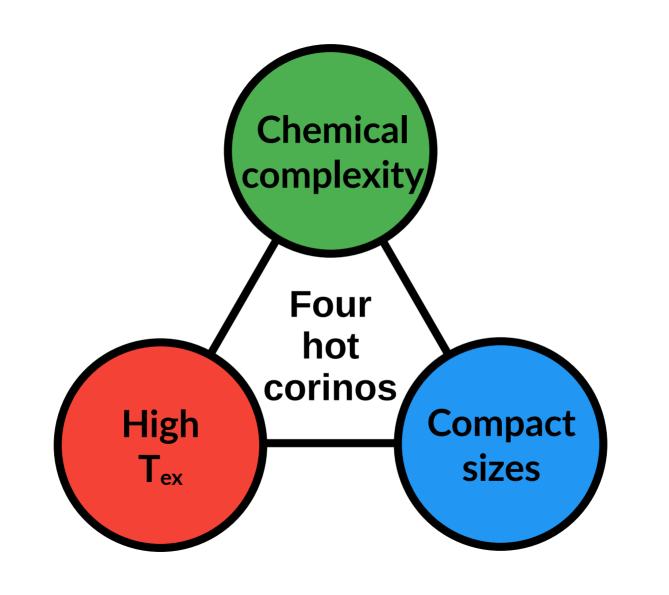


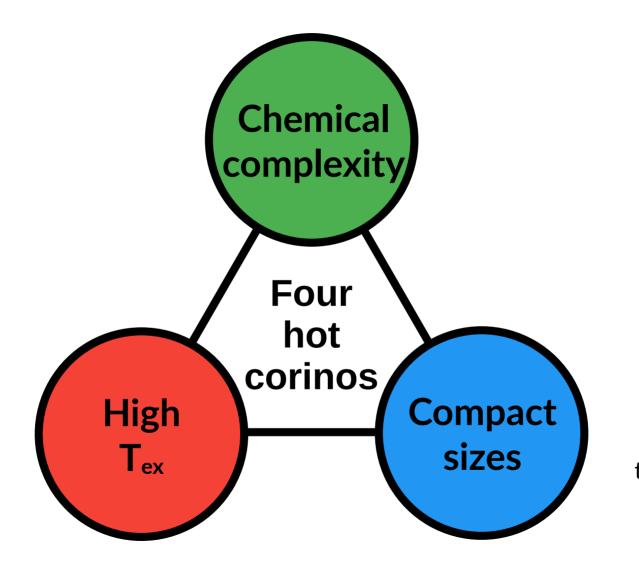




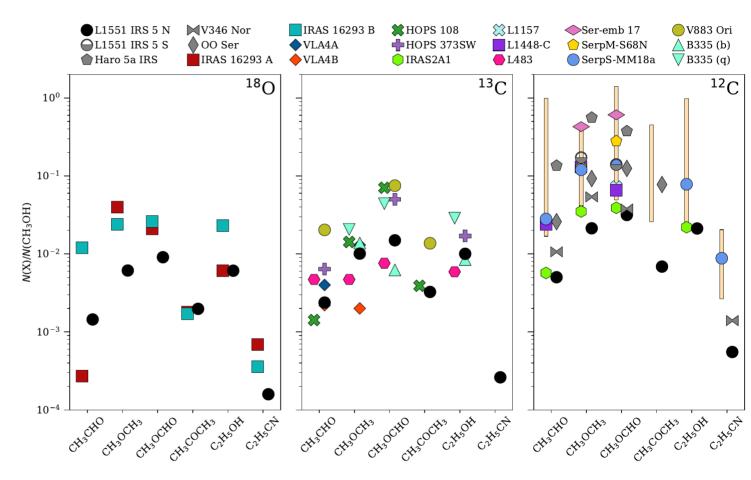




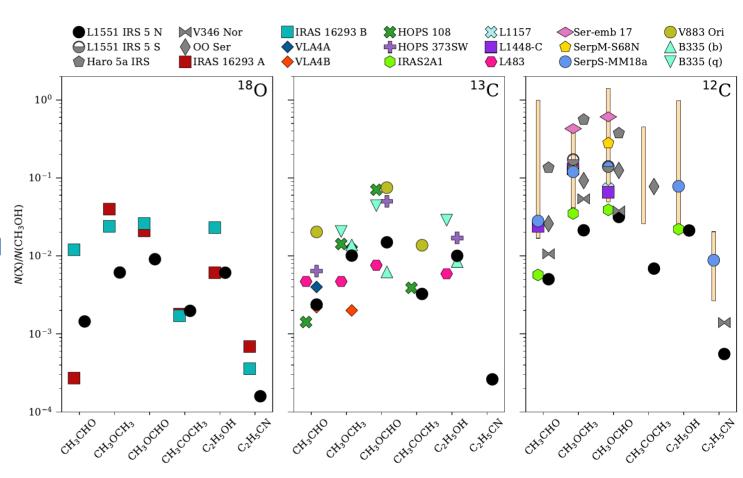




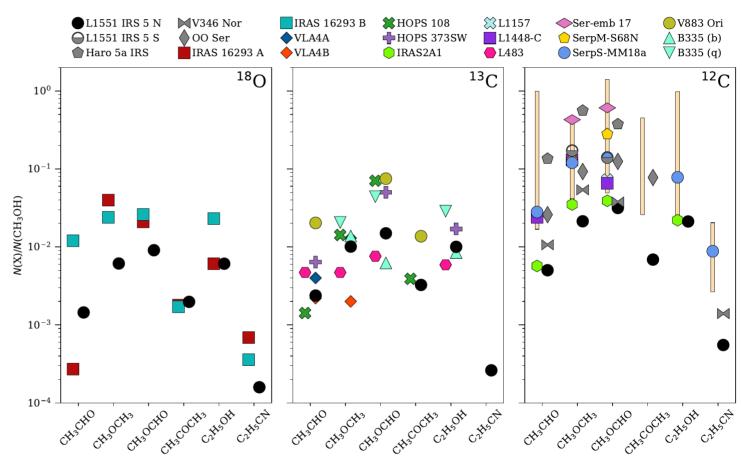
...so how do the abundances in these FUor-likes compare with those in other hot corinos?



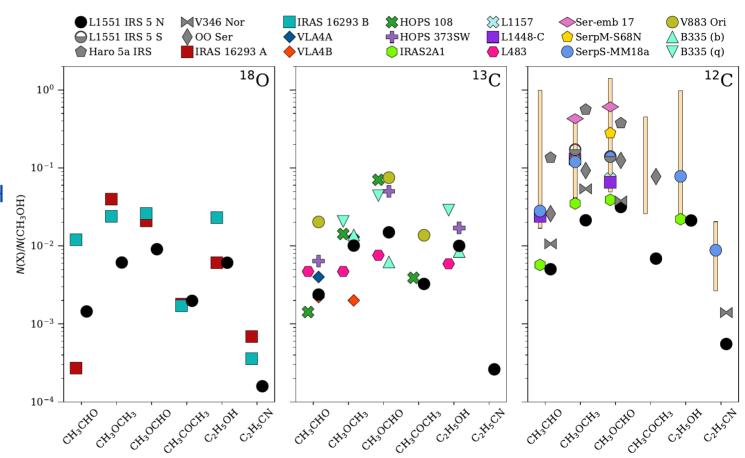
 Lines of CH₃OH are optically thick so ¹³CH₃OH or CH₃¹⁸OH are better



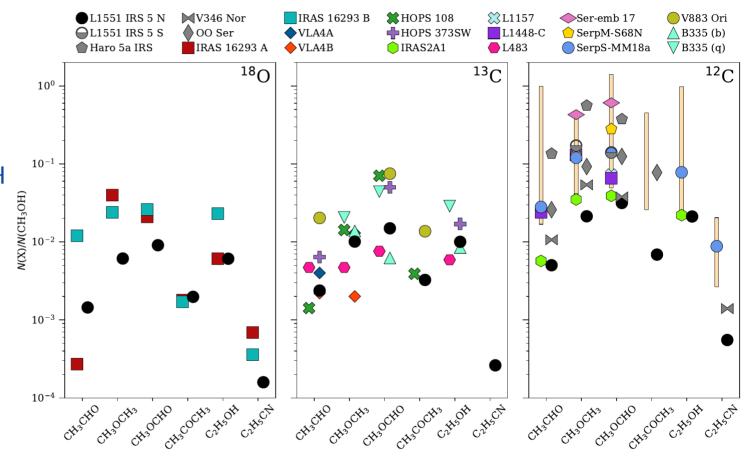
- Lines of CH₃OH are optically thick so ¹³CH₃OH or CH₃¹⁸OH are better
- Other COMs might also be dominated by optically thick lines

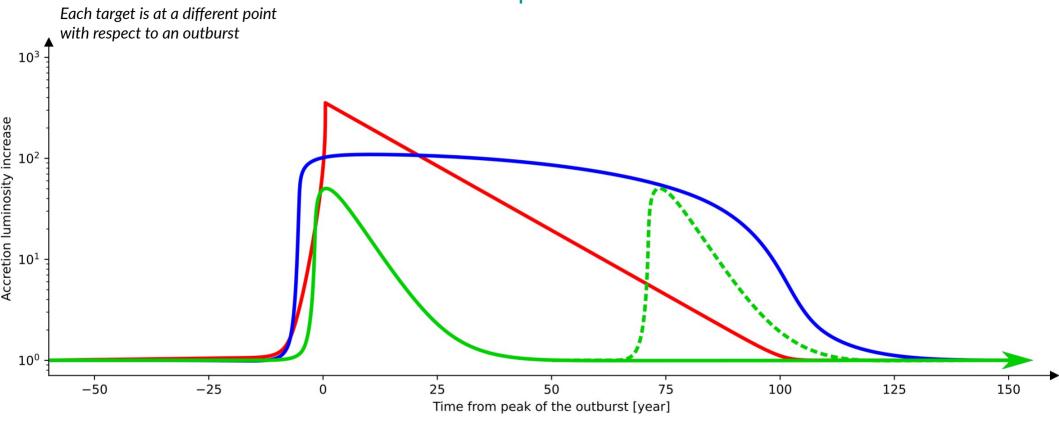


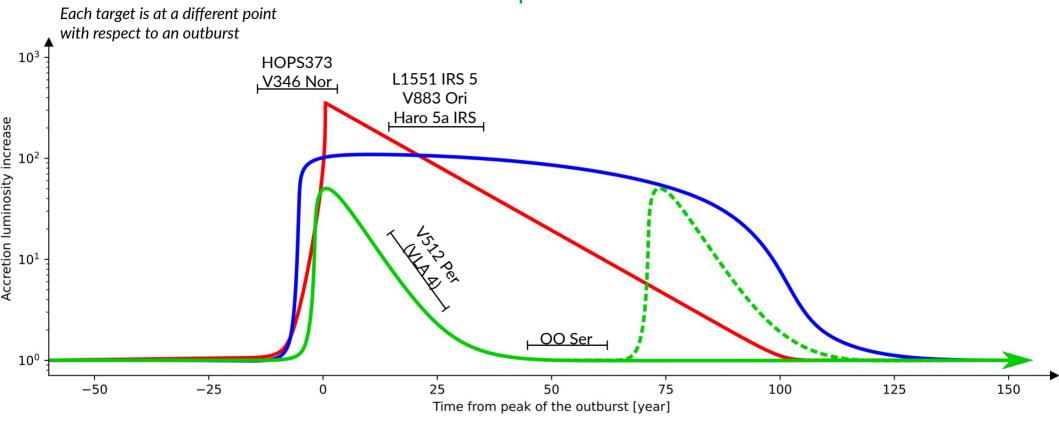
- Lines of CH₃OH are optically thick so ¹³CH₃OH or CH₃¹⁸OH are better
- Other COMs might also be dominated by optically thick lines
- Different surroundings and age

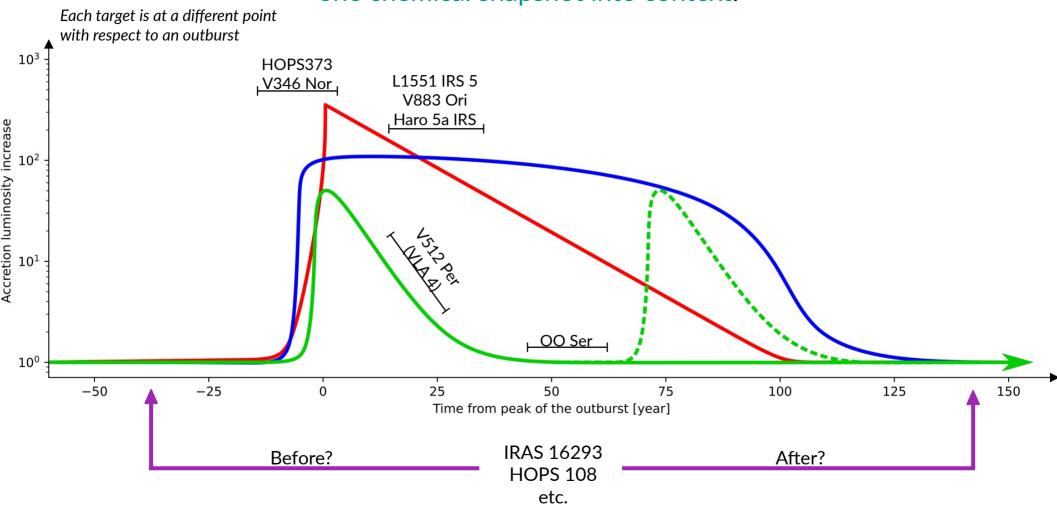


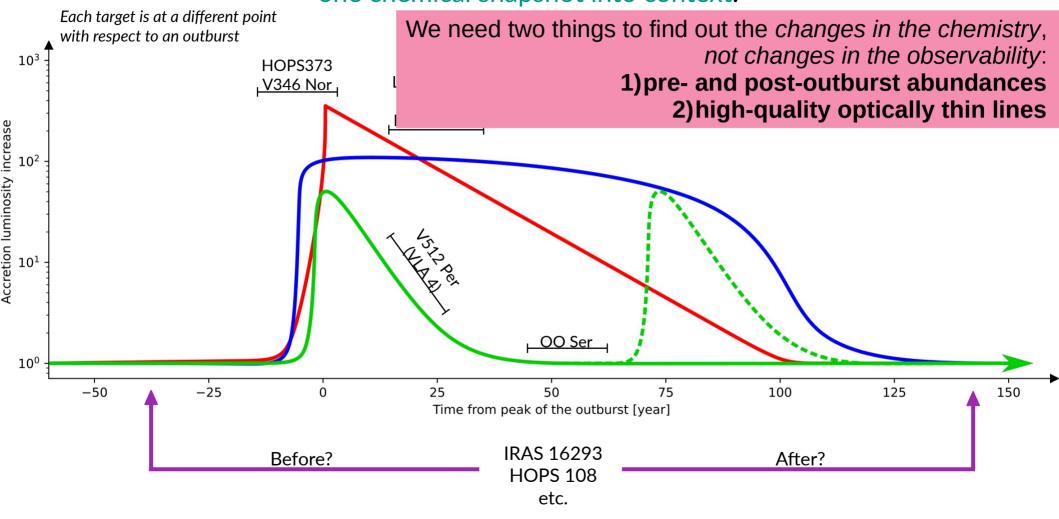
- Lines of CH₃OH are optically thick so ¹³CH₃OH or CH₃¹⁸OH are better
- Other COMs might also be dominated by optically thick lines
- Different surroundings and age
- Unknown accretion histories

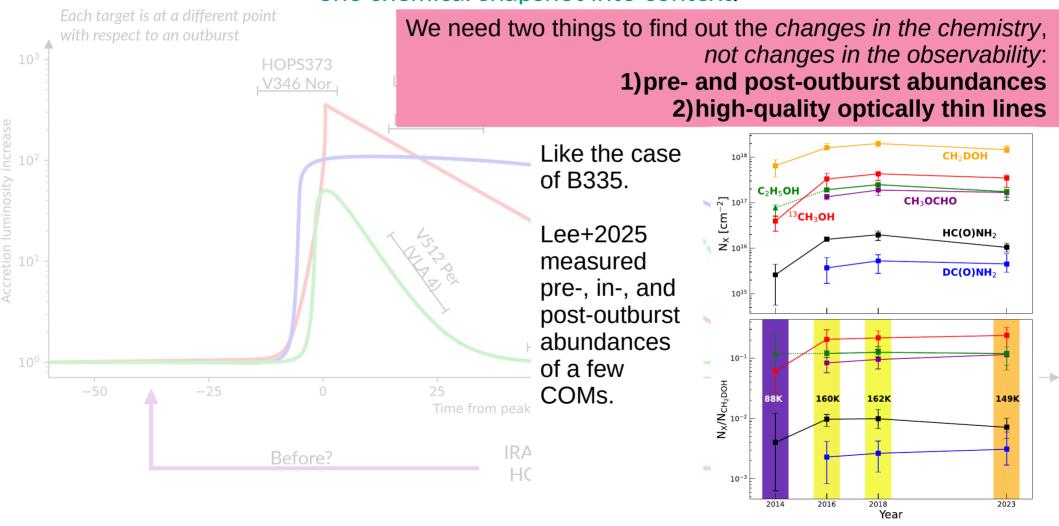












APE: providing physical conditions for chemical models and synthetic observations

Antoine Espagnet¹, Pierre Marchand¹, Audrey Coutens¹, Fernando Cruz-Sáenz de Miera Llean-Christophe Loison² and Valentine Wakelam What der Sciencer Moléculaires (ISM) Bordeaux France





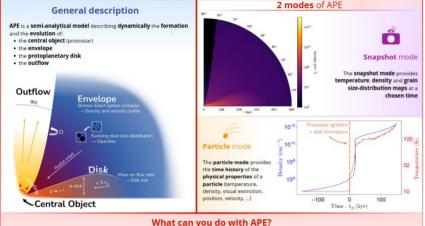




ABSTRACT

Chemical models and synthetic observations are of paramount importance to interpret and predict observations. Coupled together they offer a great opportunity to increase our understanding of the processes involved in star formation

The new publicly available Analytical Protostellar Environment (APE) code (Marchand et al. 2025) has been designed for this purpose. It allows simulations and synthetic observations to be performed at low computational cost, providing a powerful approach to interpret and predict observations. APE use a semi-analytical model describing dynamically the formation and the evolution of the protostar and its environment from the onset of the prestellar collapse to the end of the Class I stage. It includes the central object, the envelope, the protoplanetary disk and the outflow. The APE code itself directly allows to work with different modes to either produce density and temperature mans at a given time, or to follow the physical history of individual particles. The code is provided with interfaces to other publicly available codes to perform chemical simulations (Nautilus), radiative transfer calculations (RADMC-3D) and synthetic interferometry imaging (Imager)



APE provides interfaces to work with the following codes APE RADMC-3D Nautilus Observations Physical model Chemical model Radiative transfer Telescope simulation Synthetic observation hyperspectral ruhe

Marchand et al. (submitted) The evolution of complex organic molecules during star formation Marchand et al. (in preparation) Biases in the observation of protostars: insights from synthetic observations

with APE Espagnet et al. (in preparation) Modeling the Chemical Impacts of Luminosity Outbursts in Protostellar Envelopes

Alternatively, we can let the computers do the work.

(Marchand et al. 2025a, submitted, in prep) (Espagnet et al., in prep)

(e.g., Taquet+2016, Rab+2017, Molyarova+2018, Zwicky+2024)

Modeling the Chemical Impacts of Luminosity Outbursts in Protostellar Envelopes

Antoine Espagnet¹, Audrey Coutens¹, Pierre Marchand¹, Fernando Cruz-Sáenz de Miera¹, Jean-Christophe oison² and Valentine Wakelam³



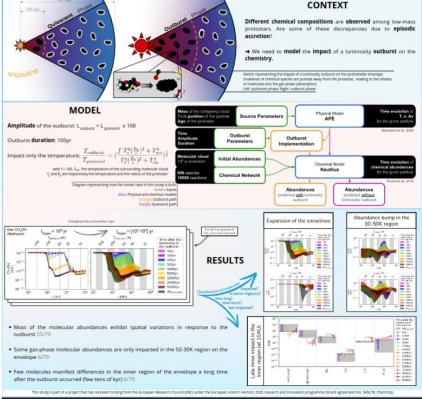






ABSTRACT

More and more large spectral surveys are carried out in the radio/submm/mm range to characterize the molecular composition of star forming regions. The observational studies carried out so far seem to indicate that the chemical content differs between protostars. With chemical models, it is possible to test different scenarios and better understand the possible origins of these differences. In this study, we investigate the impact of luminosity outbursts on the chemical composition of solar-type protostars. Accretion bursts and consequently luminosity outbursts are experienced by some young stellar objects. The sudden rise in temperature caused by luminosity outbursts can sublimate the molecules frozen on the dust grains. The release of new molecules into the gas phase with the temporary increase in temperature could affect the long-term evolution of the chemical composition of protostellar systems. We used the dynamic physical APE code (Marchand et al. 2025) to calculate the 1D evolution of particles in a protostellar envelope. We also can models implementing luminosity outbursts by modifying the previously determined temperature. The physical evolution of the density and temperature was then used as inputs of the Nautilus gas-grain chemistry code (Ruaud et al. 2016) (updated to take into account a better description of the complex organic molecules) to predict the evolution of the molecular abundances from the cold outer regions to the warm inner regions. This poster summarize our results on the predicted impact of luminosity outbursts on the



We need a systematic study of more protostars to put chemical evolution into context. Including different ages, histories and surroundings.



Complex Organic Molecules in Protostars from ALMA Spectral Surveys

ALMA Large Program

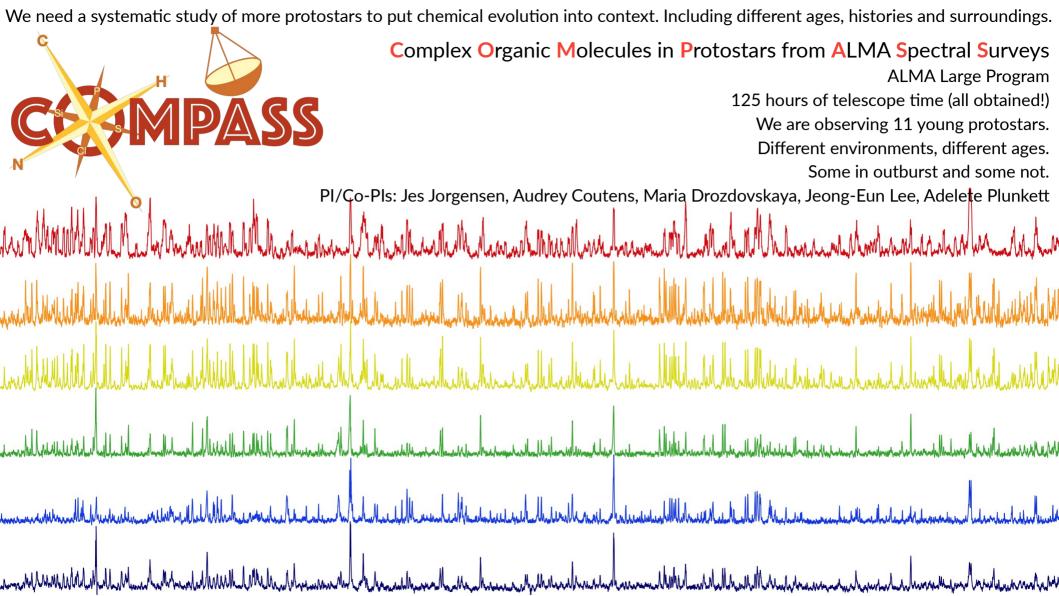
125 hours of telescope time (all obtained!)

We are observing 11 young protostars.

Different environments, different ages.

Some in outburst and some not.

PI/Co-PIs: Jes Jorgensen, Audrey Coutens, Maria Drozdovskaya, Jeong-Eun Lee, Adelete Plunkett



Takeaway messages

- 1) Accretion outbursts cause significant changes in their systems.
- 2) Accretion outbursts affect the morphology, temperatures and chemistry of the disks.
- 3) Complex organic molecules in FUors suggest these YSOs have hot corinos (hot, compact and chemically rich inner regions).
- 4) Little to no difference in column density ratios between hot corinos in quiescence and outburst. Unclear whether a change occurred.
- 5) Comparison limited due to lack of information about sources and of multi-epoch measurements.
- 6) More computational and observational work is needed.