Pristine protostellar jet-disk systems: from darkness to the cradle of life

C. Codella (INAF, OA Arcetri)
From a diffuse cloud to a planetary system
From atoms & simple molecules to life

1- PRE-STEMELLAR PHASE: cold and dense gas
FORMATION OF SIMPLE MOLECULES

2- PROTOSTELLAR PHASE: collapsing, warm dense gas
FORMATION OF COMPLEX MOLECULES

3- PROTOPLANETARY DISK PHASE:
cold and warm dense gas
SIMPLE & COMPLEX MOLECULES

4- PLANETESIMALS FORMATION: grains agglomeration

5- PLANETS FORMATION AND THE “COMETS/ASTEROIDES RAIN”
CONSERVATION AND DELIVERY OF OLD MOLECULES + LIFE

What is the role of the pre-solar chemistry in the present Solar System chemical composition?

Caselli & Ceccarelli (2012)
The ASTRONOMICAL COMs zoo

- Formaldehyde ($\text{H}_2\text{CO}$)
- Methanol ($\text{CH}_3\text{OH}$)
- Methyl formate ($\text{CH}_3\text{OCHO}$)
- Methyl formic acid ($\text{CH}_3\text{COOH}$)
- Methyl acetate ($\text{CH}_3\text{OCH}_3$)
- Formic acid ($\text{HCOOH}$)
- Methanal ($\text{CH}_3\text{CHO}$)
- Glycine ($\text{NH}_2\text{CH}_2\text{COOH}$)
- Glycoaldehyde ($\text{HCOCH}_2\text{OH}$)
- Formamide ($\text{NH}_2\text{CHO}$)
The formation of COMs

COMs are formed on ices and then released into the gas phase?

Or are daughter species, i.e. are formed in gas phase following the release of parent species such as methanol and formaldehyde?
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

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

Ingredients for the Sun-like star formation recipe

Lee et al. 2014, Sakai et al. 2014
We need interferometry

We need spatial resolutions of < 30 AU:
210 mas @ Taurus; 125 mas @ Perseus; 70 mas @ Orion
COMs in shocks

Acetaldehyde (CH$_3$CHO)

CH$_3$CHO spatial distribution follows the young (2000 yr) cavity produced by the impact of the jet with the ambient medium.

COMs associated with the region enriched by iced species evaporated from dust mantles and released into the gas phase.

Fontani et al. (2014)
Codella et al. (2015)
COMs in shocks

CH$_3$OH & CH$_3$CN

Formamide (NH$_2$COCH$_3$)

Codella et al. (2009, 2010)
Mendoza et al. (2014)
**COMs in shocks**

**Formamide (NH$_2$COCH$_3$)**

- **IRAM-NOEMA Large Program**
- **SOLIS (Seeds Of Life in Space)**
- **COMS in Sun precursors**

**PI: Ceccarelli - Caselli**

**Codella et al. (2009, 2010)**
**Mendoza et al. (2014)**
The inner 100 AU:
The jet, the disk, and the wind

At low-velocity blue & red peaks along disk axis similar to $^{17}$O (Keplerian) rotating inner disk?

High-Eu (143 K) SO emission

Codella et al. (2014), Podio et al. (2015)
Asymmetric HDO profile indicating outflowing (and compact) gas: Evidence for a disk wind?

VERY High-Eu (up to 335 K) CH$_3$CHO and HDO emission

Asymmetric HDO profile indicating outflowing (and compact) gas: Evidence for a disk wind?

Codella et al. (submitted)
Conclusions

COMs 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 vice versa....

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

Interferometry (ALMA, NOEMA) is needed (as well as large bandwidths)

SOLIS started: COMs in Sun precursor

Be prepared to the advent of SKA!!