New Perspectives on the Physics and Chemistry of Planetary Birth

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What are we made of?

- Oxygen is from water
- Carbon is the basis for the chemistry of life - organic molecules
- Where did the molecules of life originate
The Earth is mostly made of silicates (sand/glass) -- Silicon and Oxygen
where did our planet come from?
Other talks in this session.
What happens next?

Meteorites contain:
- over 100 amino acids
- DNA base
- hydrated minerals

Comets contain:
- abundant water
- simple organics
- amino acids?
The beginnings of organic chemistry and water formation in space
Before Star Birth

- 20+ years of mm-wave observations probing larger scales.
- Chemistry dominated by:
  - gas-phase CO
  - simple ices: H$_2$O, CO, CO$_2$, CH$_3$OH
- Knowledge of chemistry allows for targeted study.

Organics in Space

Frequency (GHz)

Organic species detected in space include:
- $^{15}$CH$_3$CN
- $^{33}$SiO$_2$
- CH$_2$CN
- CH$_2$CN, $v_0=1$
- SiO
- SiO$_2$
- SiH$_2$H$_2$
- C$_2$H$_2$OH
- all molecules
ALMA & Organics

Favre et al. in prep.

ALMA & Organics

- ALMA is illuminating the origins of (pre-biotic?) organics in space.
- The wealth of chemical and physical information in its sensitive spectra will be vast.
- We will discover an array of new interstellar organics and characterize the extent of the rich chemistry associated with stellar birth.

Organics and water in the planet-forming disk - the seeding of planetesimals
Water & the Early stages of star birth

- ALMA can detect water on small scales (< 100 AU)
- Early detections: water vapor abundance is $< 10^{-4}$ -- water is mostly as ice

General Molecular Structure

- **Warm Molecular Layer**
- **Freeze-Out**

**General Molecular Structure**

- **High-T Chemistry**
- **Ice Evaporation**

**Snow-Line**
(Presence of ices posited as fostering planet formation)

**Dust Optical Surface**

**Warm Molecular Layer**

**Freeze-Out**

**Photodissociation Region**
ALMA: the first Snowline image

Qi et al. 2013, Science, 341, 630

- CO detected - but emits from surface not midplane
- N$_2$H$^+$ traces gas where CO is frozen (CO is a major destroyer)
- Inside midplane CO snow line, N$_2$H$^+$ is destroyed
C/O Distribution

Inside water snow-line:
voltiles in gas. \( \frac{C}{O} = \left( \frac{C}{O} \right)_\odot \sim 0.5 \)

- Giant planets accrete gas - C/O ratio can hint at birth location and be compared to exoplanet atmosphere composition (Jupiter!)
- Terrestrial world made from solids -- inside snow lines trace composition of material provided to forming rocky worlds.

Caveat: assuming some O in silicates but does not include organics (C-rich + O) and additional unidentified oxygen component

CO, CO\(_2\) in gas, water in ice
Gas: \( \frac{C}{O} \sim 2/3 \)
Ice: \( \frac{C}{O} \ll \left( \frac{C}{O} \right)_\odot \)

Oberg+, Mousis++
ALMA - the cusp of Discovery

• ALMA is now tracing the starting materials from their interstellar source and probe subsequent alteration in the planet-forming disk.

• Its developing legacy will inform us about our own origins from the initial simple organics and water that were created before our planet was born.