New Perspectives on the Physics and Chemistry of Planetary Birth

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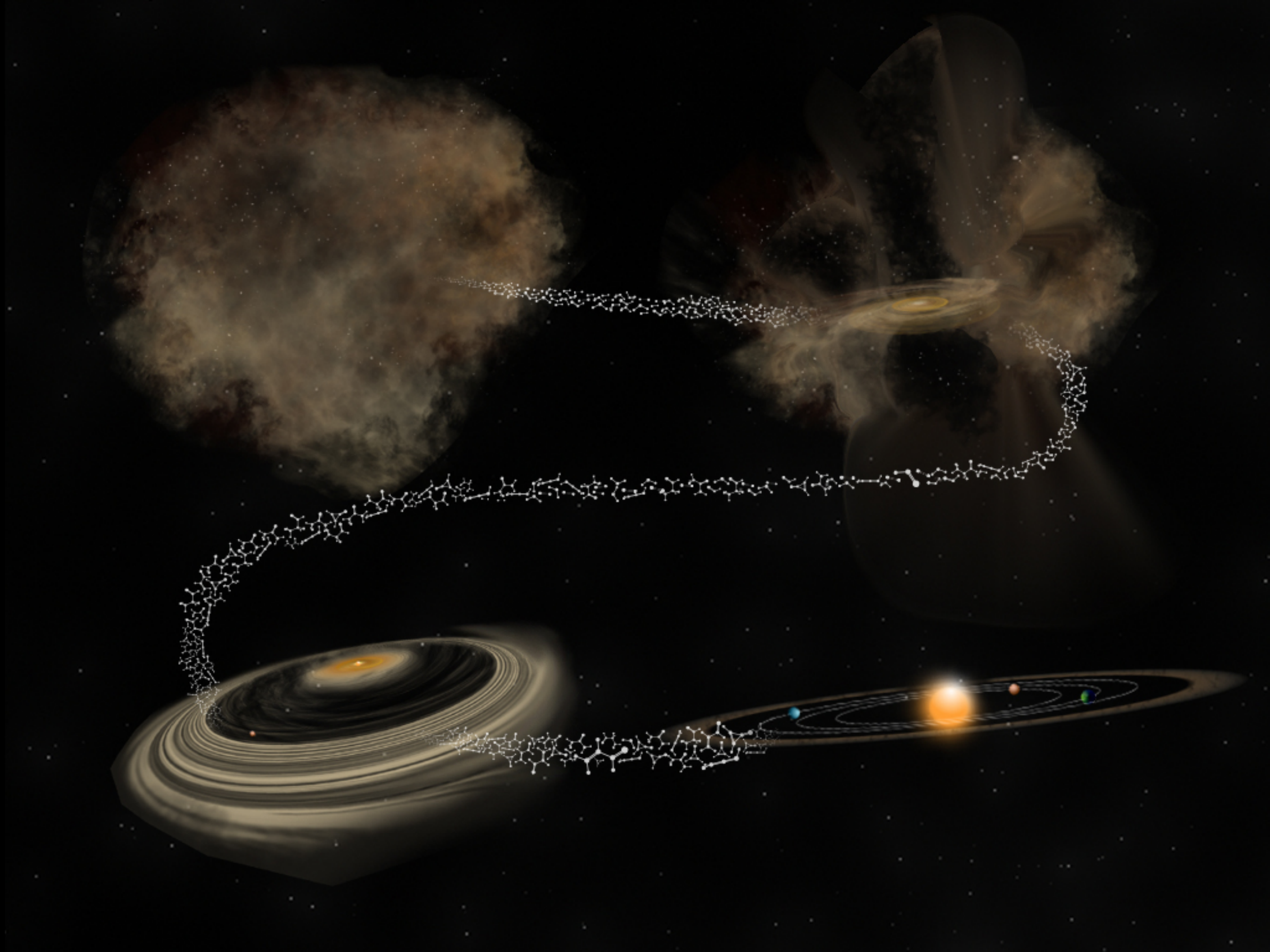
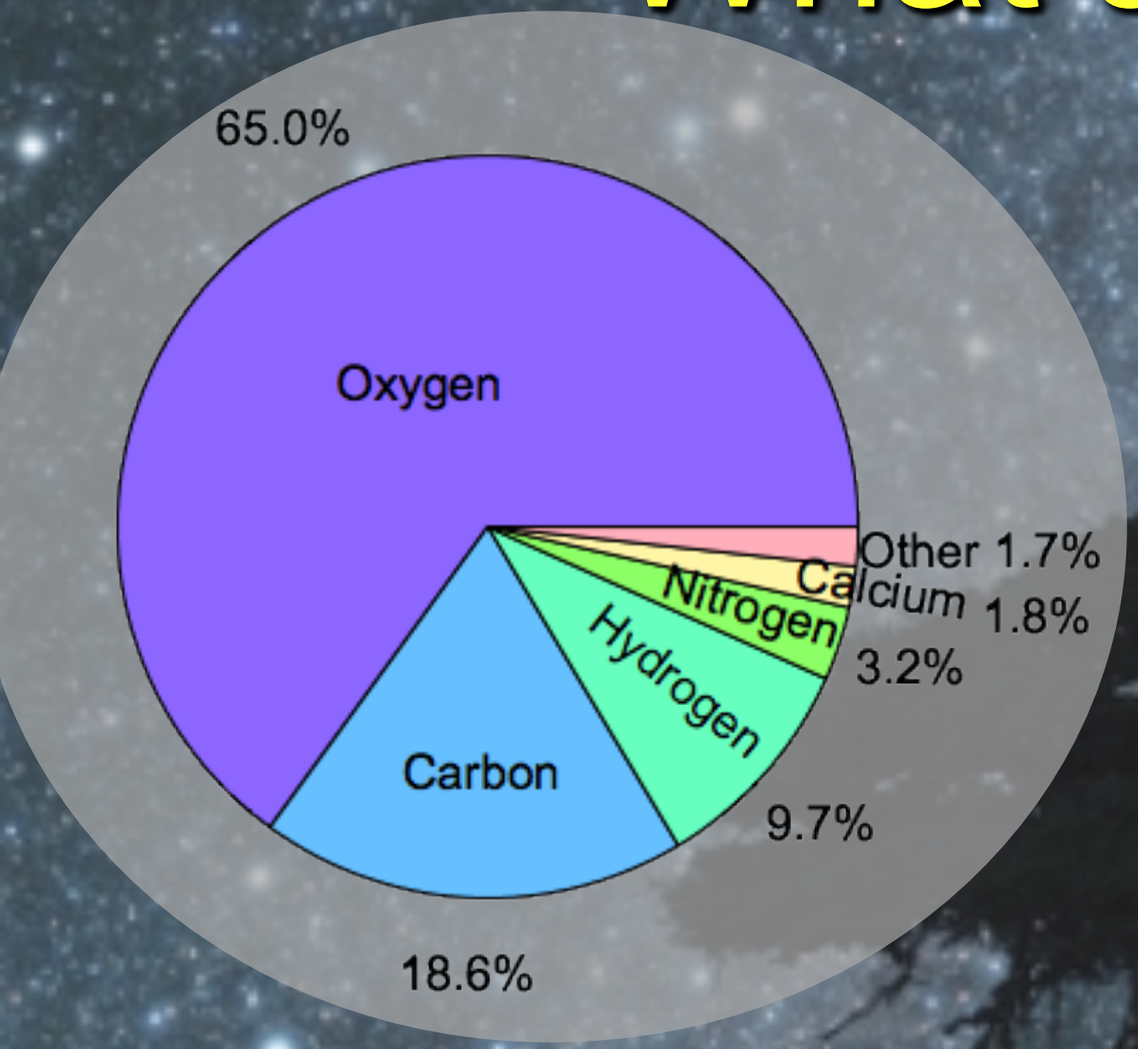


What are we made of?



- oxygen is from water
- carbon is the basis for the chemistry of life - organic molecules
- where did the molecules of life originate

What is our planet made of?

The Earth is mostly made of silicates (sand/glass) -- Silicon and Oxygen

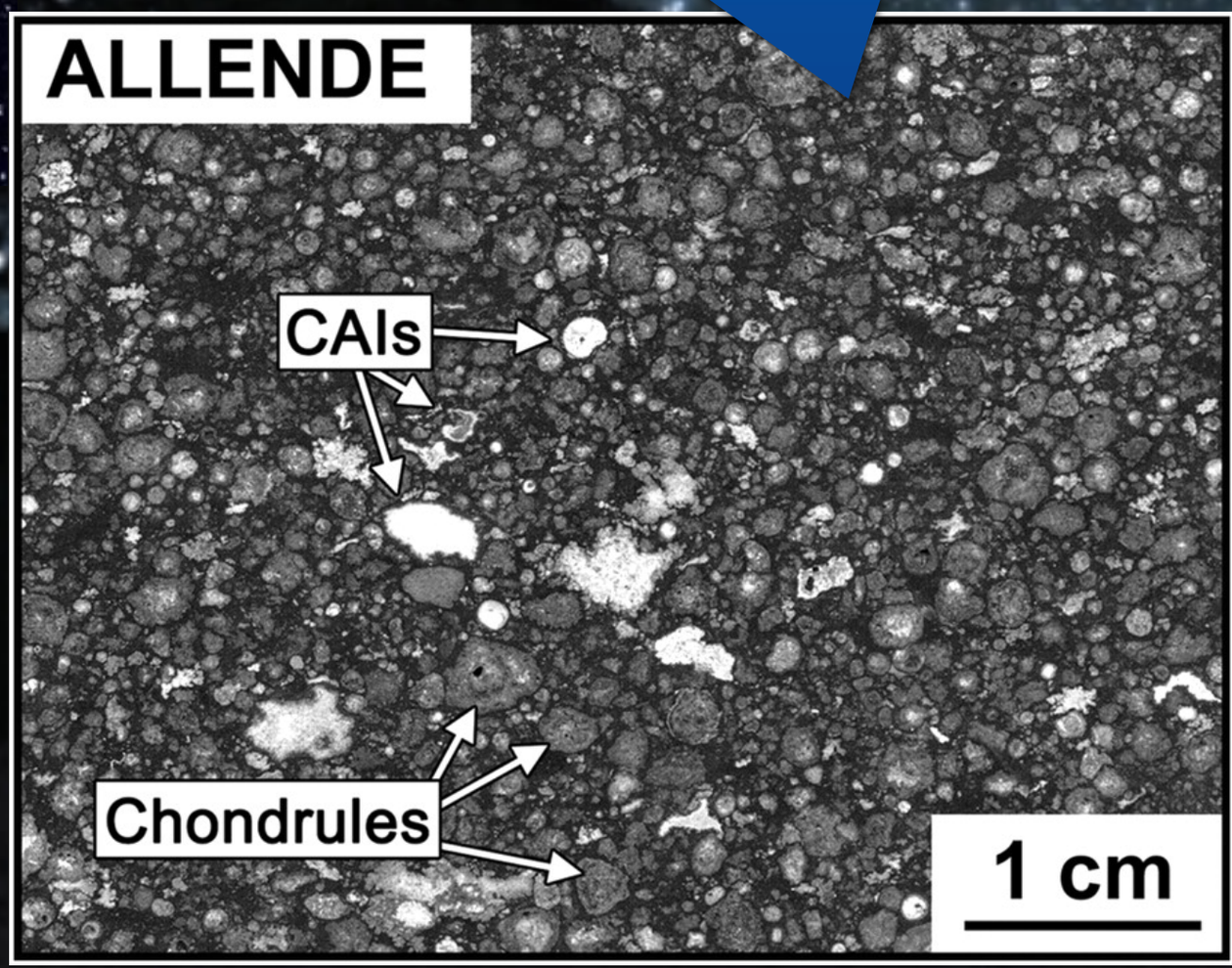
where did our planet come from?

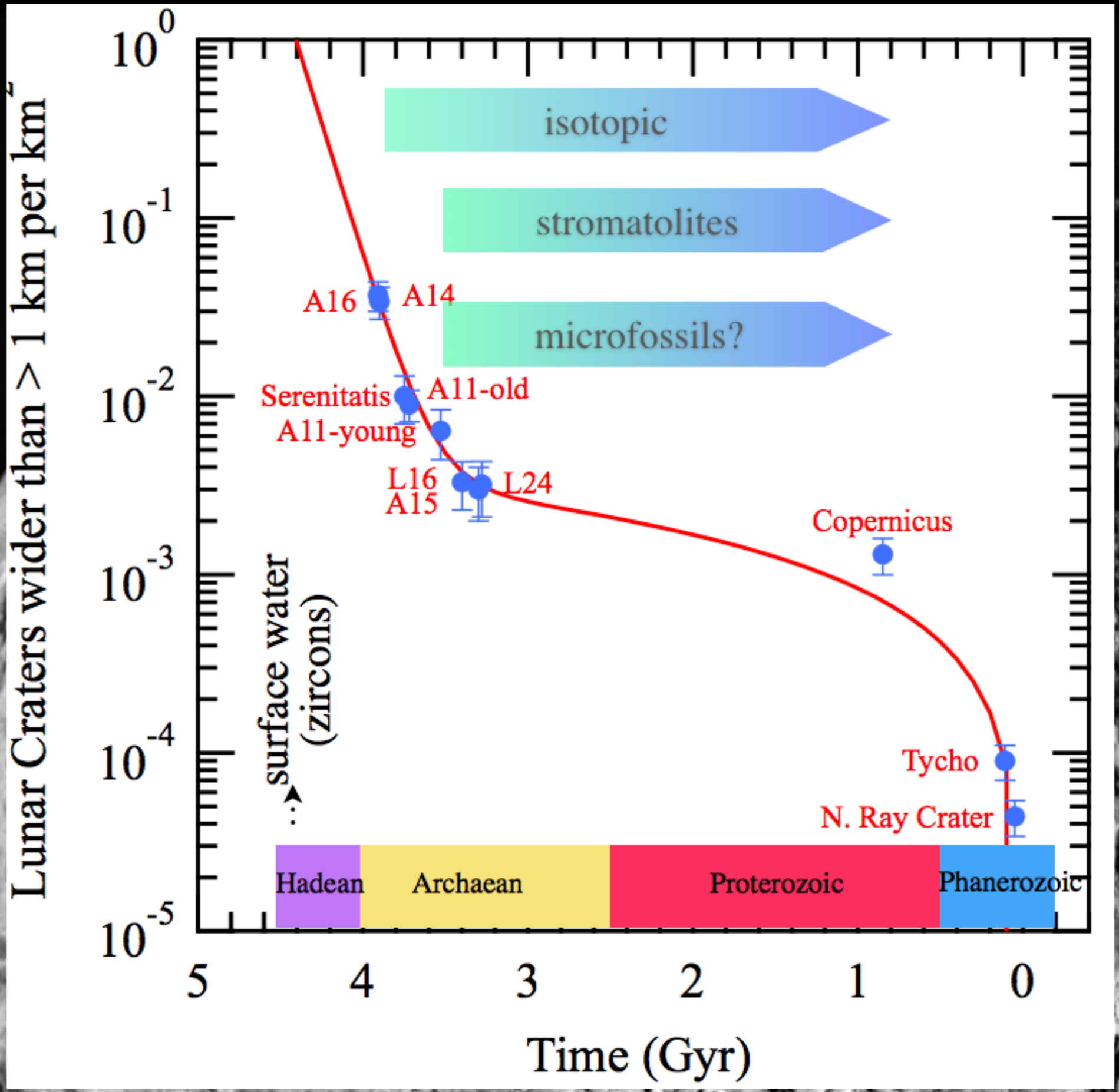
Other talks in this session.

What happens next?

<u>Comets</u>
contain:
abundant water
simple organics
amino acids?

<u>Meteorites</u>
contain:
over 100 amino acids
DNA base
hydrated minerals



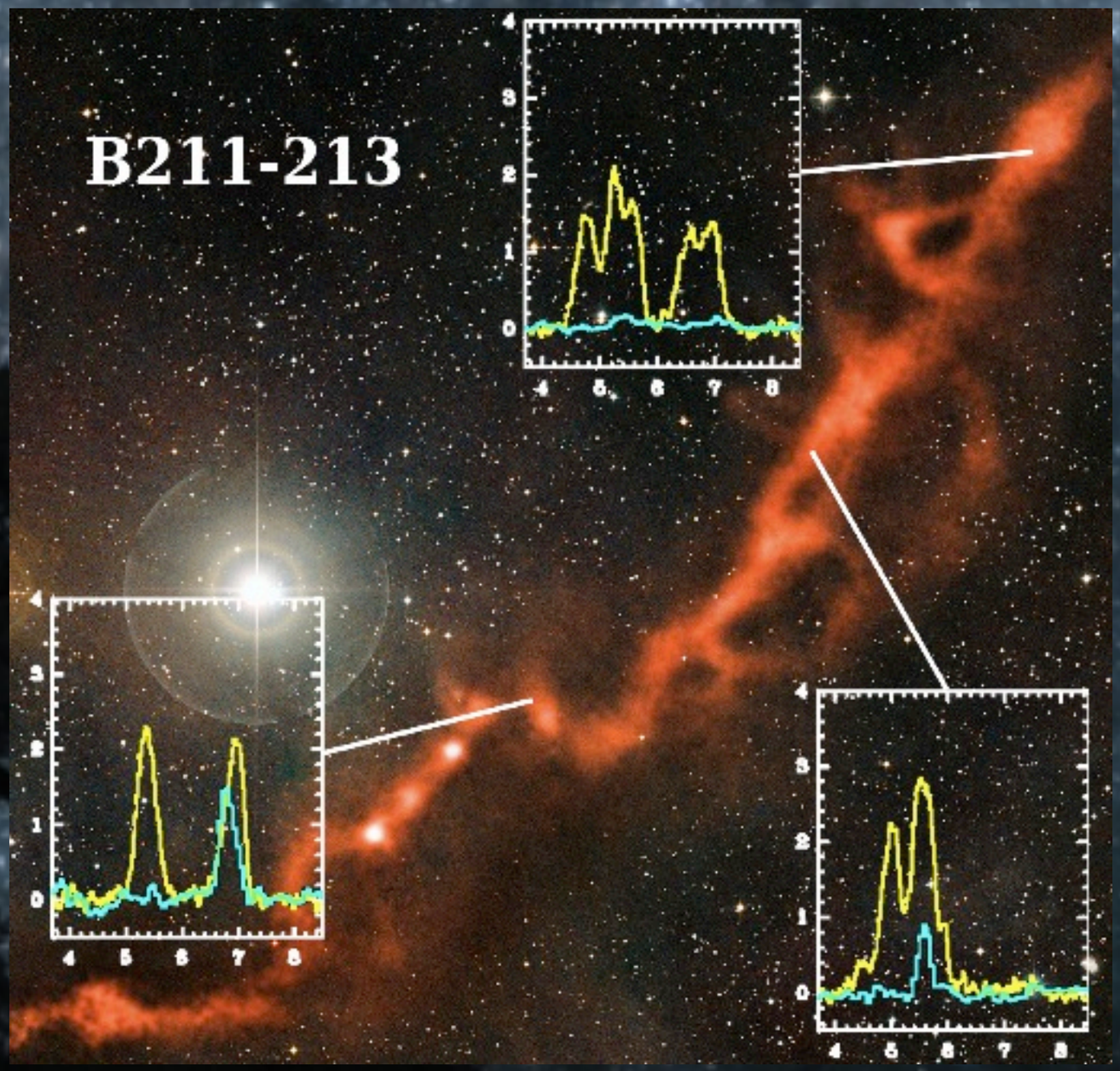


Bergin 2013,
Special Courses National Obs. Rio de Janeiro
arXiv:1309.4729

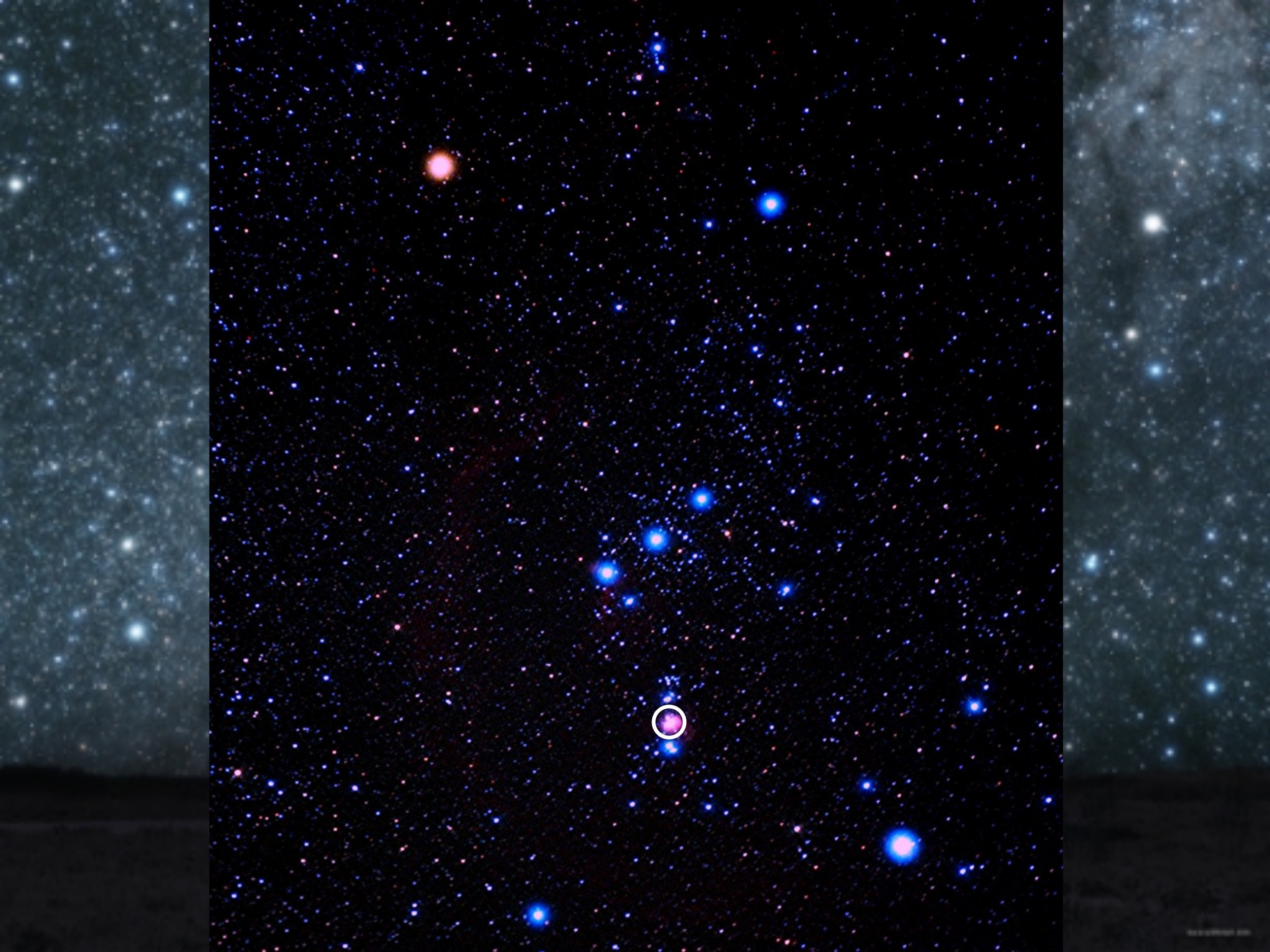
The beginnings of organic chemistry and water formation in space

Before Star Birth

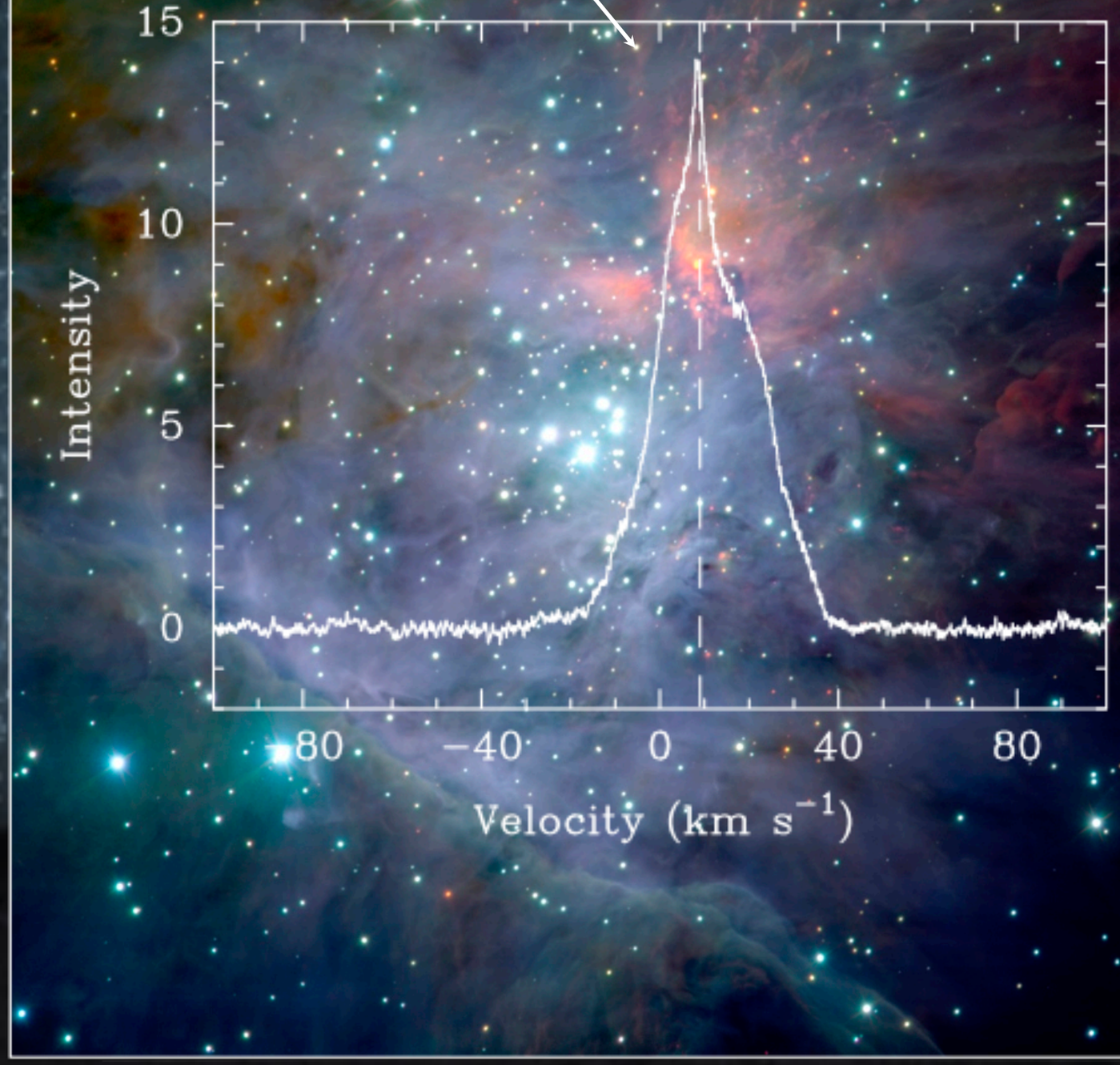
- 20+ years of mm-wave observations probing larger scales.
- Chemistry dominated by
  - ➡ gas-phase CO
  - ➡ simple ices: H_2O, CO, CO_2, CH_3OH
- Knowledge of chemistry allows for targeted study.

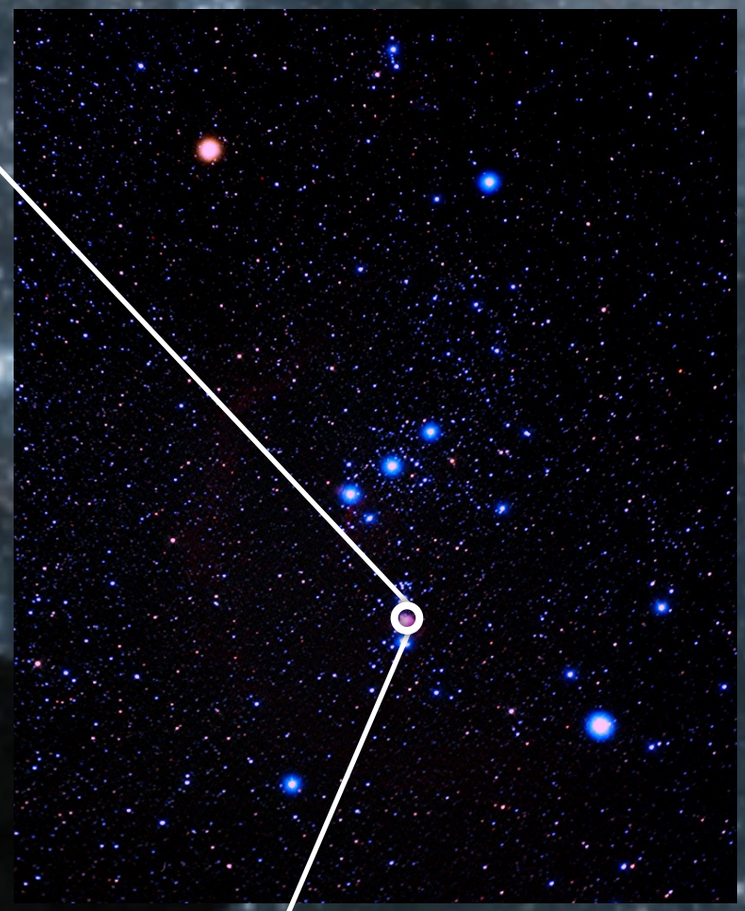


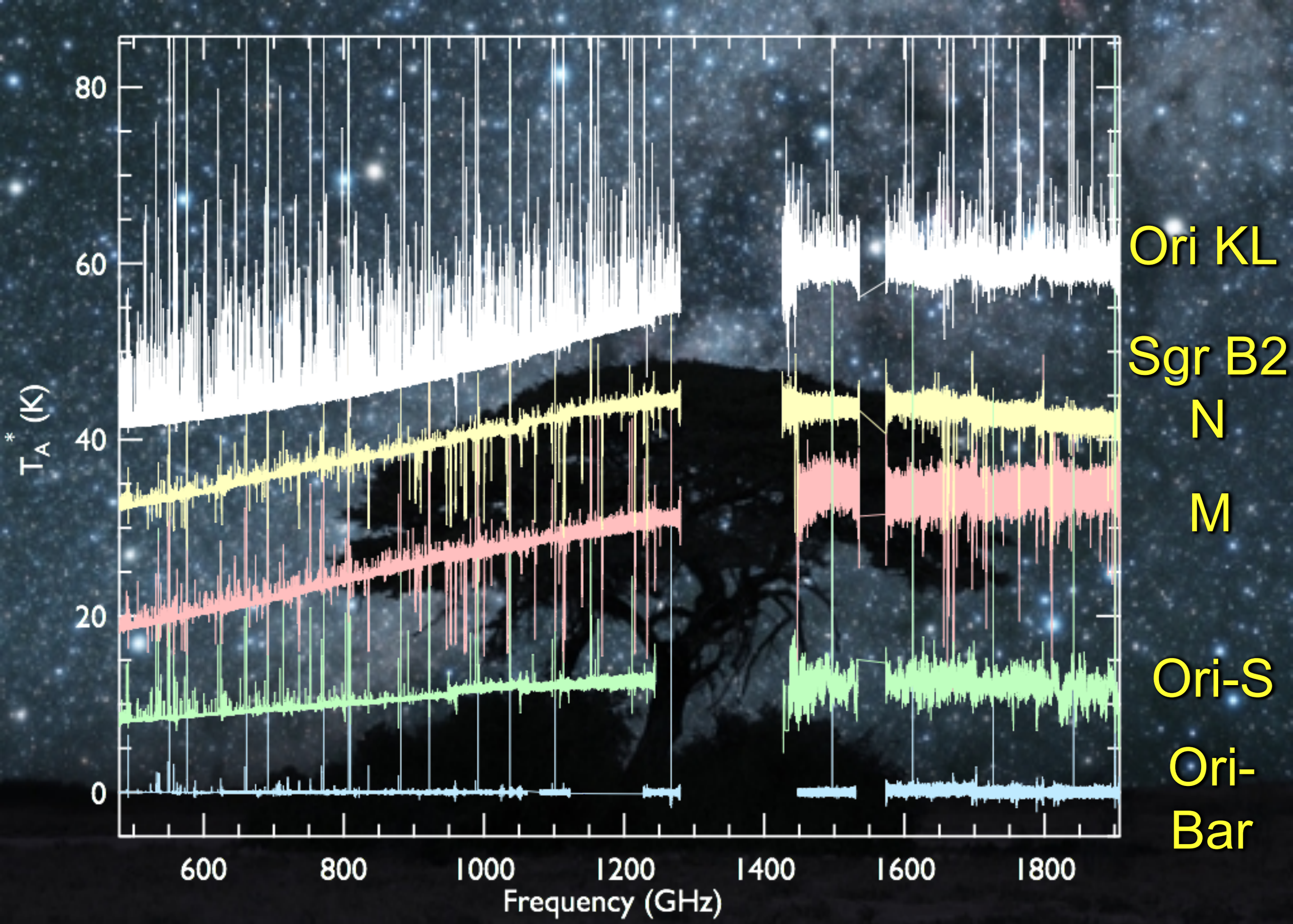
Hacar et al. 2012, A&A, 554, 55



~10,000 Oceans



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T_A^* (K)
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Frequency (GHz)
Ori KL
Sgr B2 N
M
Ori-S
Ori-Bar

CO J=5-4
CO J=6-5
CO J=7-6
CO J=8-7
CO J=9-8
CO J=10-9
CO J=11-10
CO J=13-12
CO J=14-13
CO J=15-14
CO J=16-15

Ori KL

Sgr B2 N

Ori-S

Ori-Bar

H_2O
H_2O
H_2O
H_2O
H_2O

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T_A^* (K)

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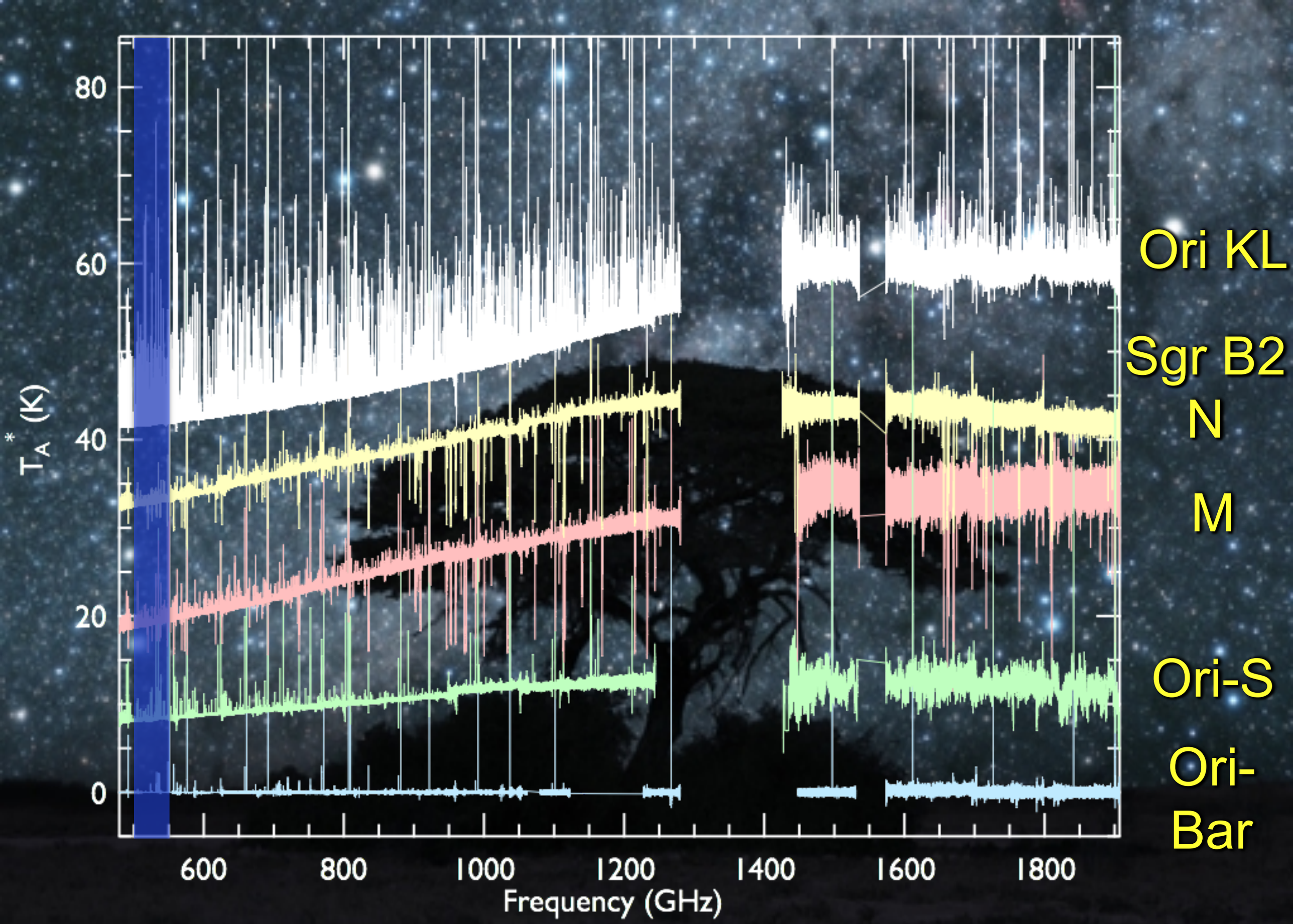
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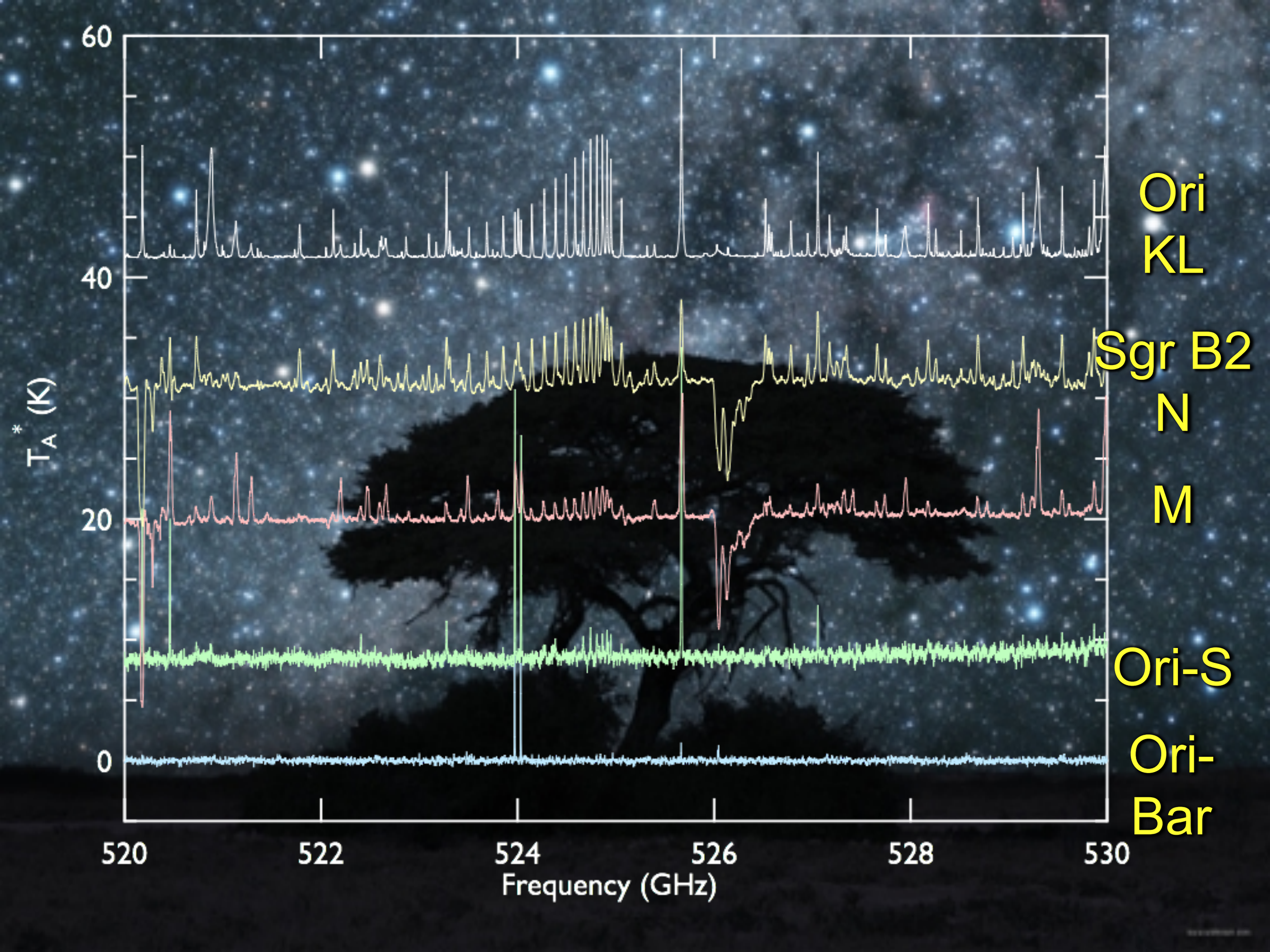
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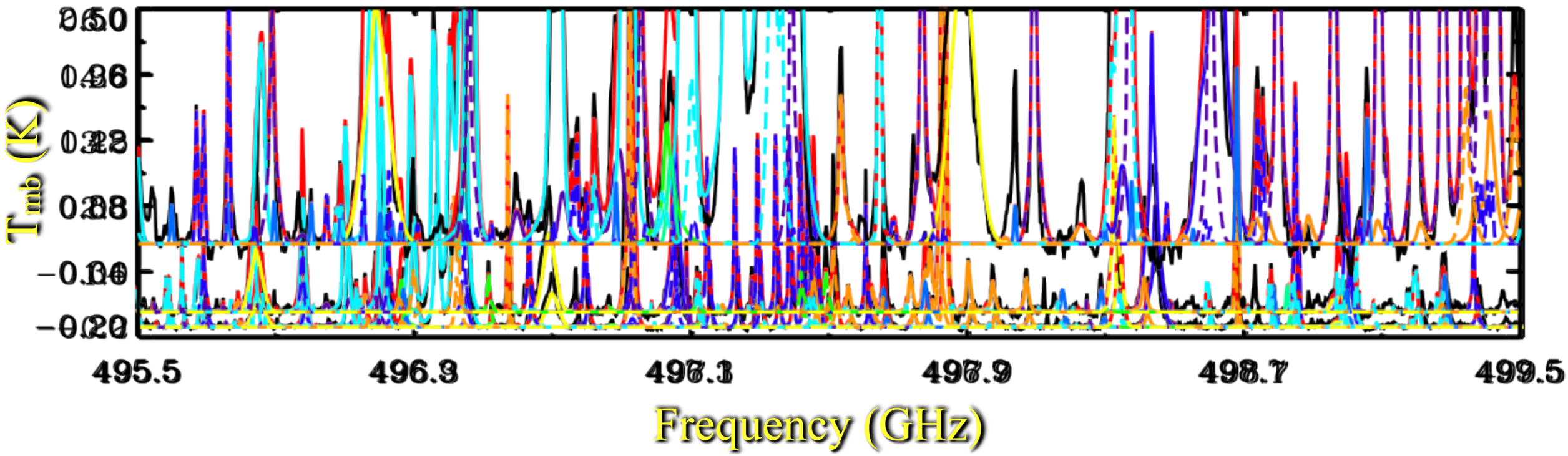
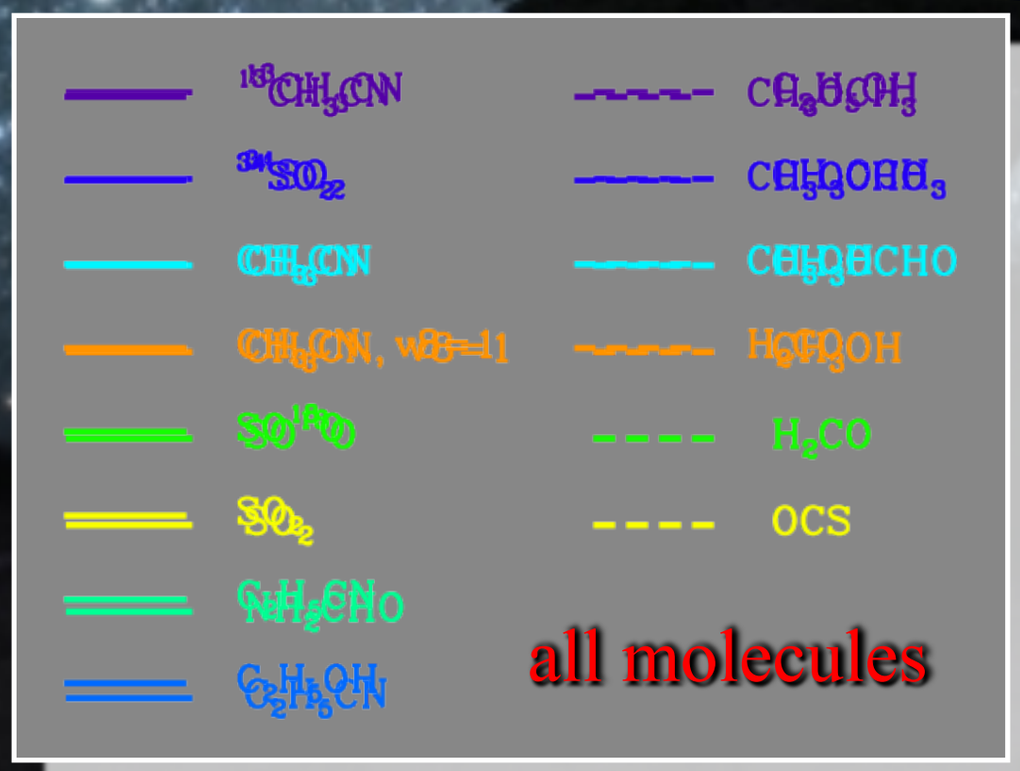
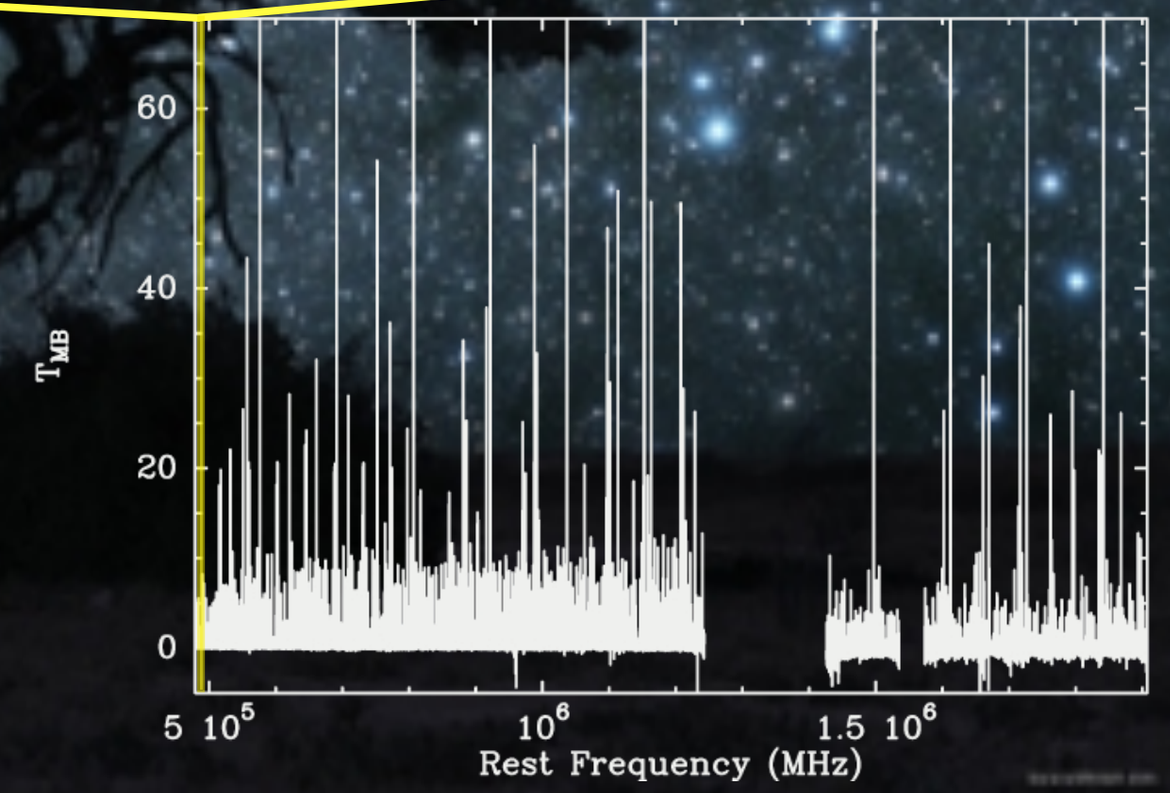
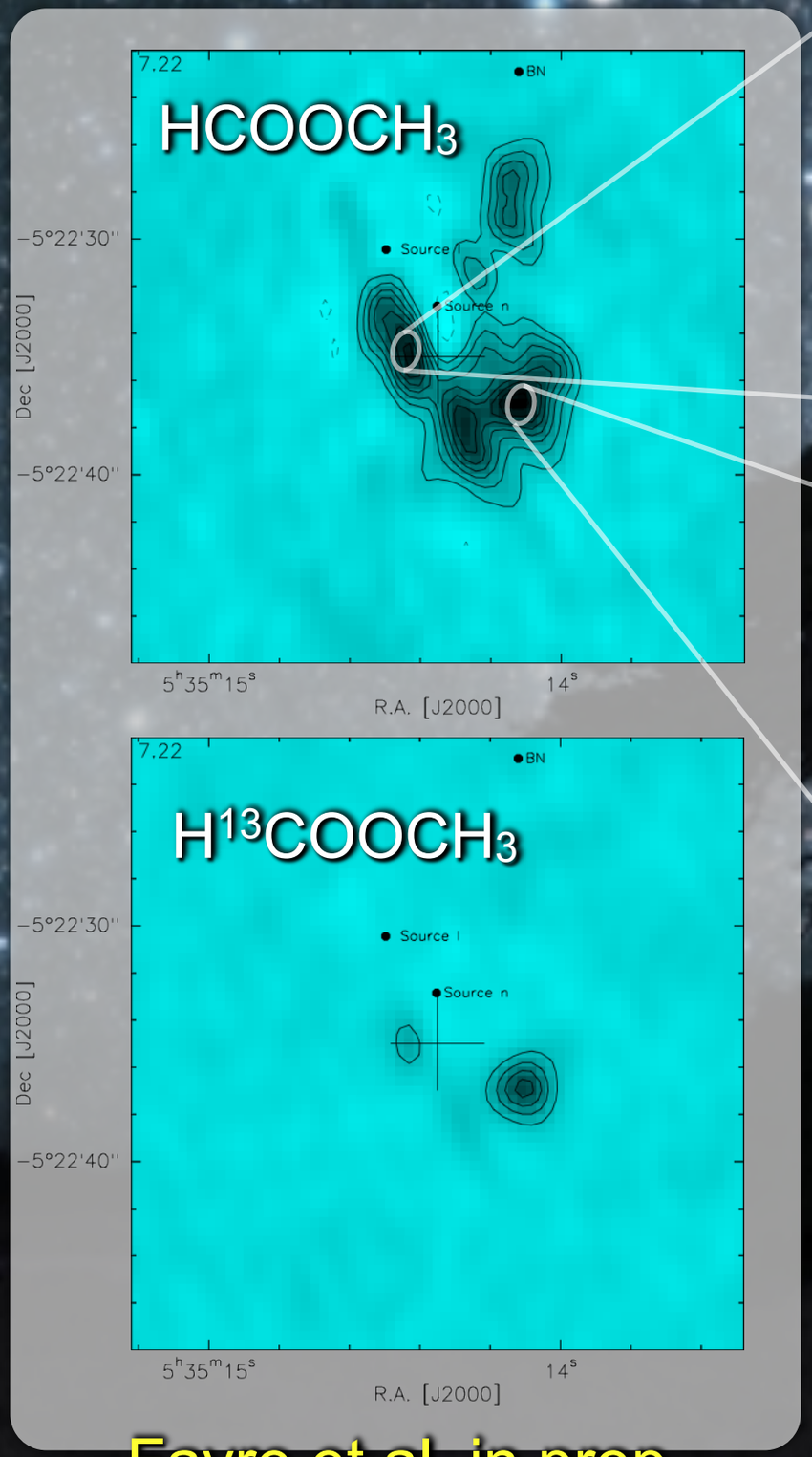
Organics in Space

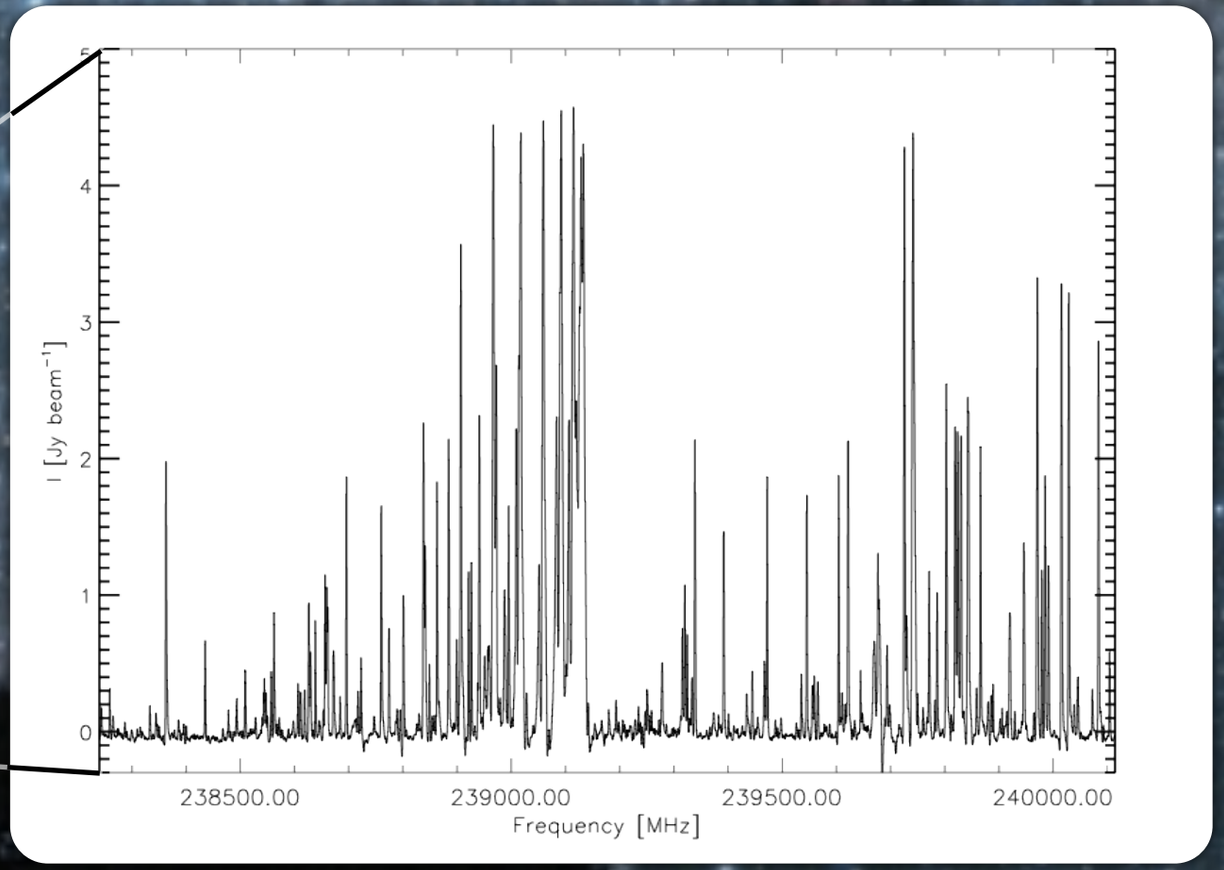


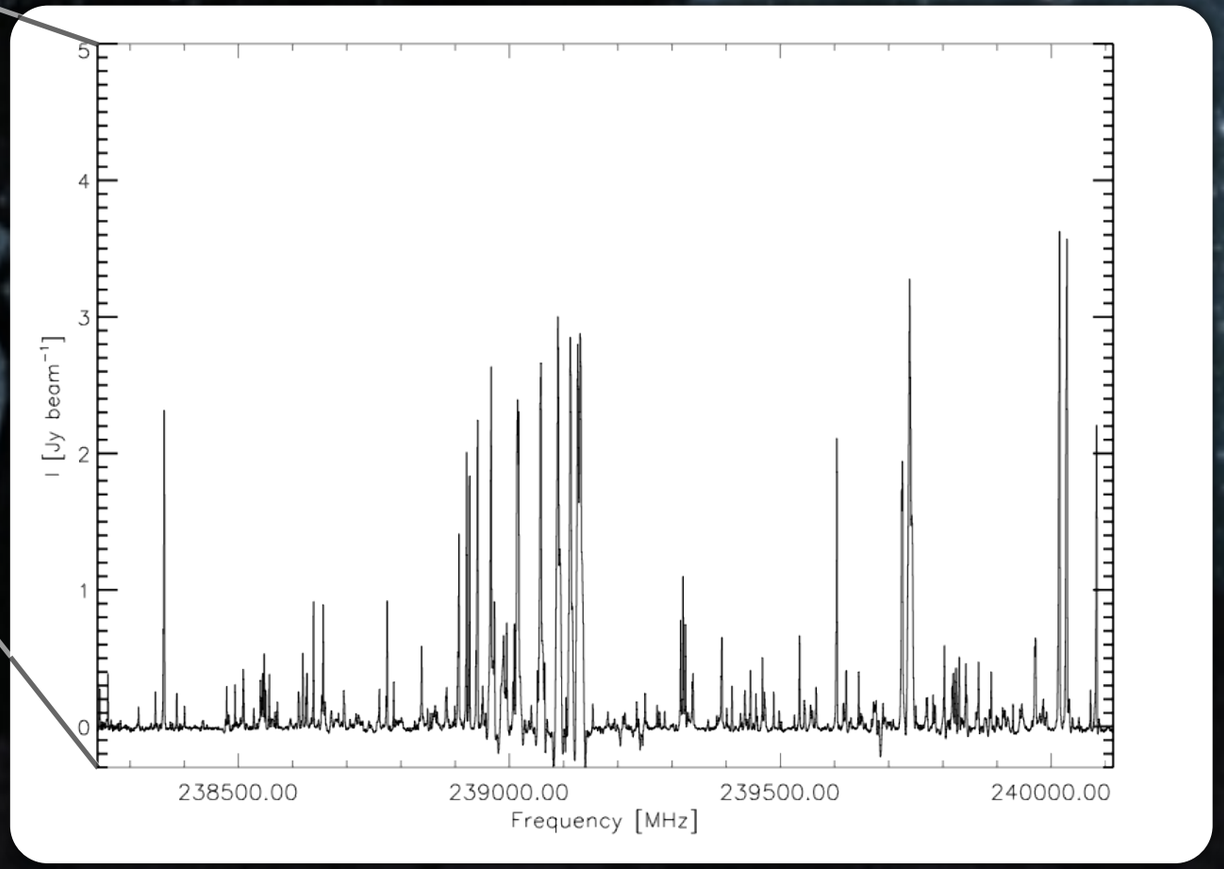




ALMA & Organics





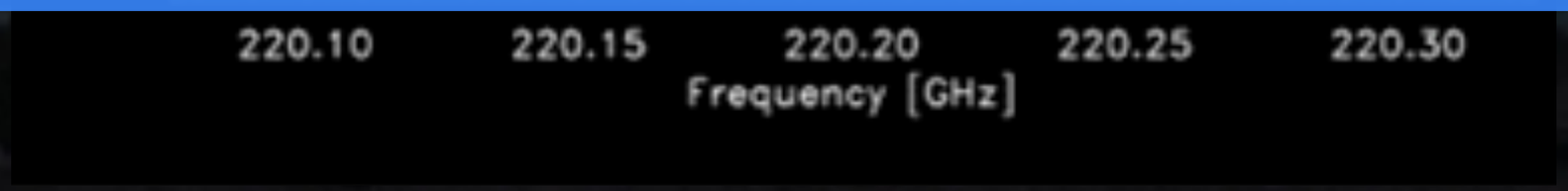


Favre et al. in prep.

Fortman et al. 2012, J.Mol.Spec. 280, 11

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.

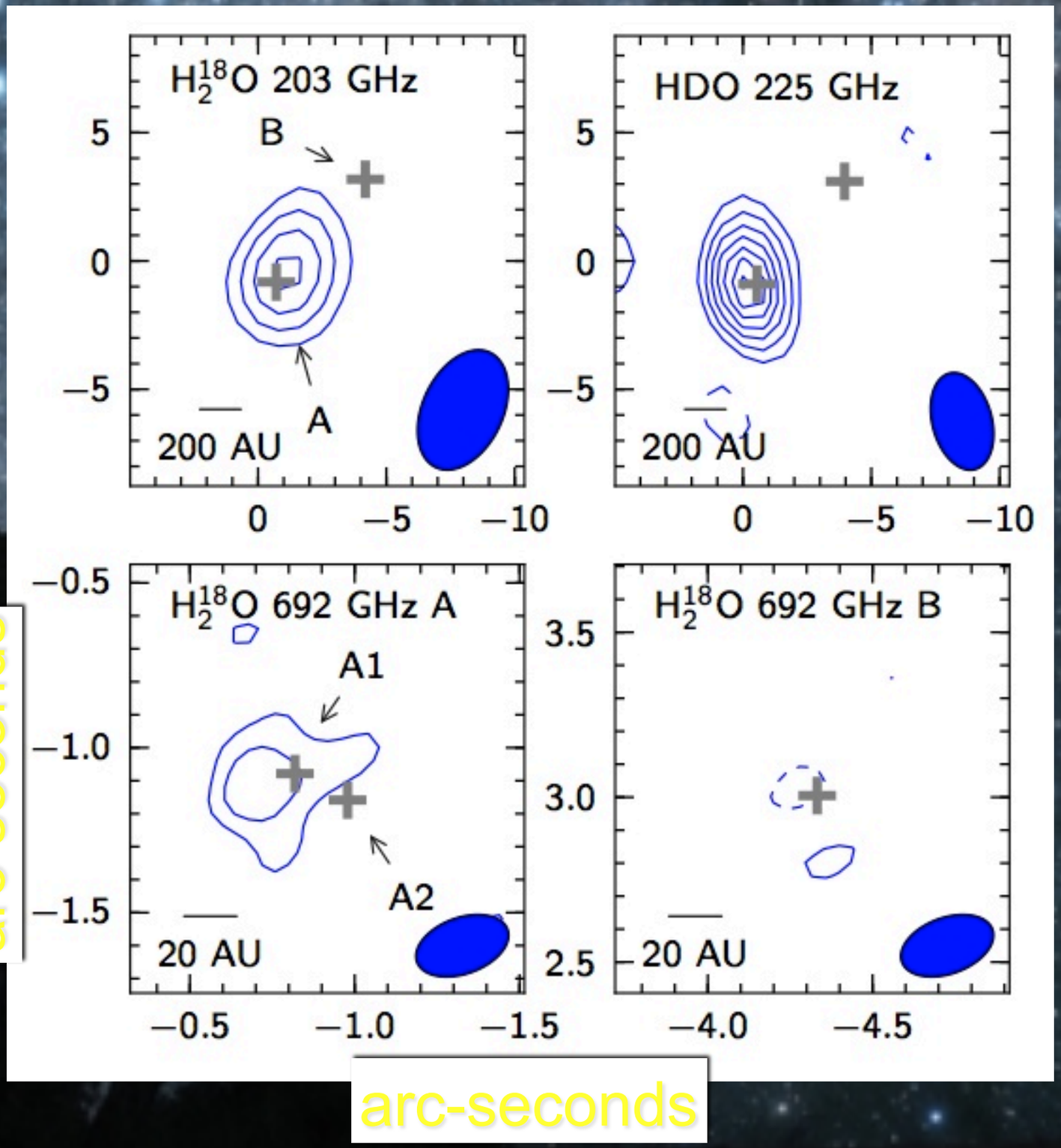


Jørgensen et al. 2012, ApJ, 757, L4

Organics and water in the planet-forming disk - the seeding of planetesimals

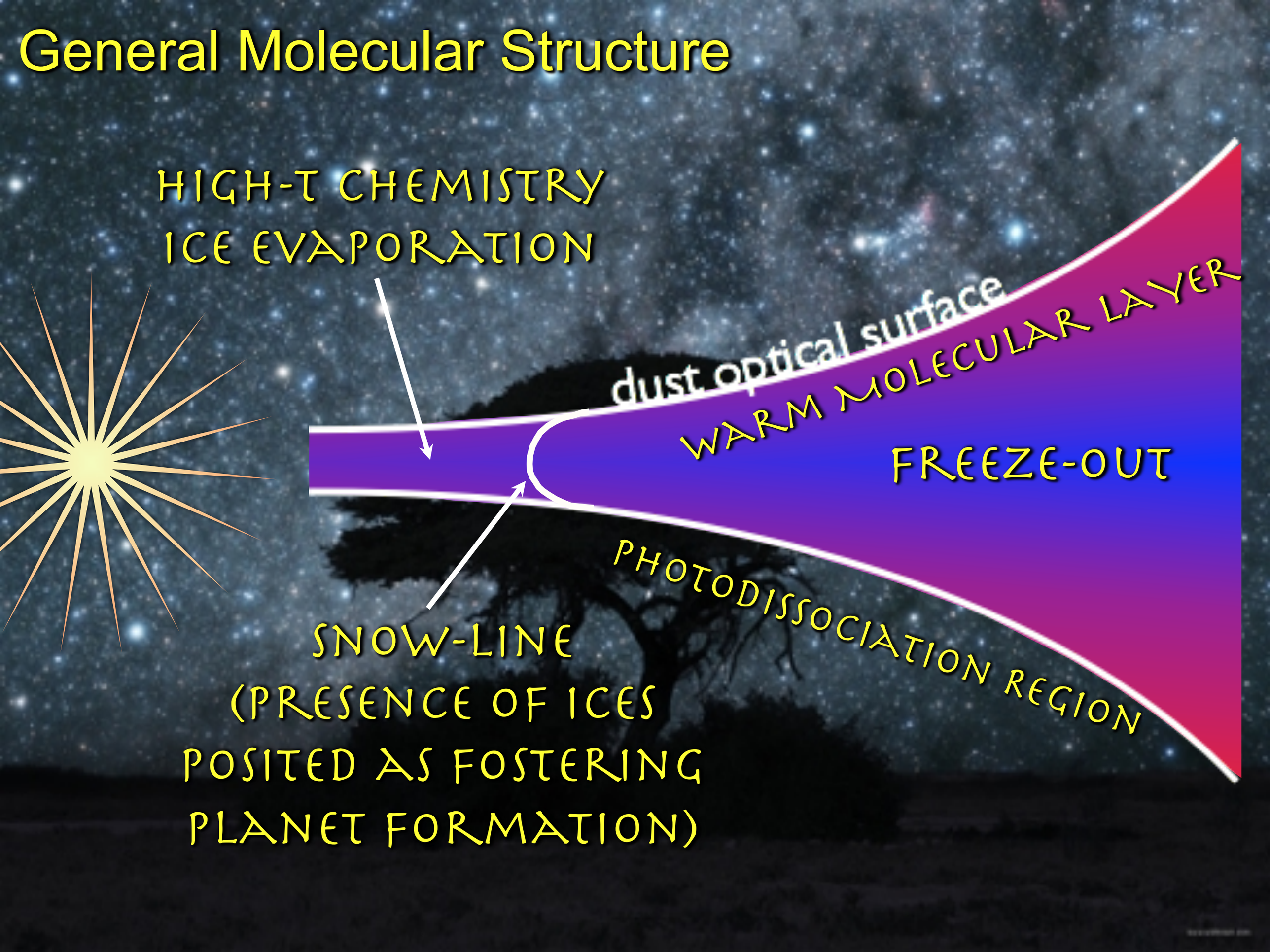
Water & the Early stages of star birth

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

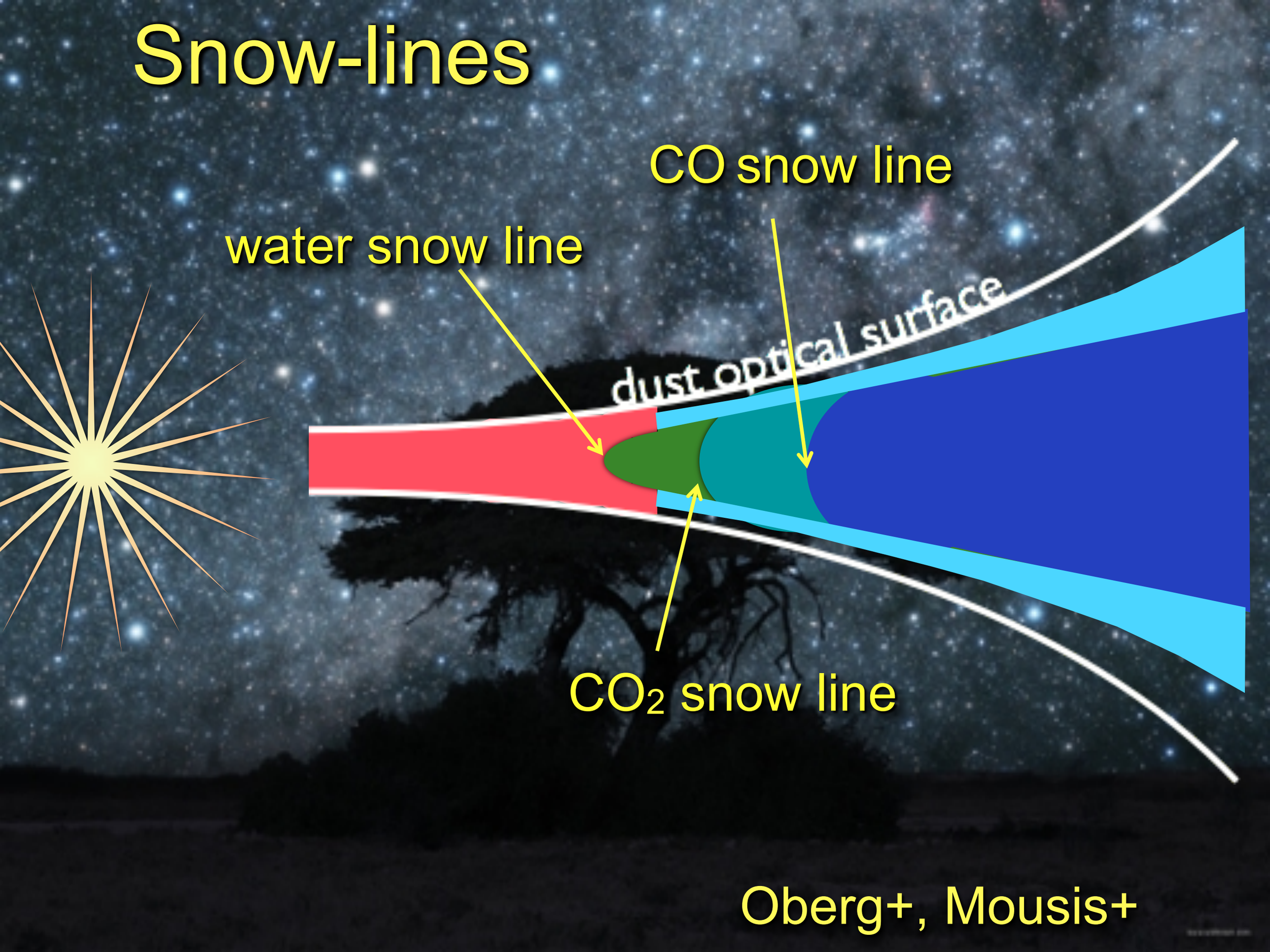


Persson et al. 2013, A&A, 549, L3
Persson+ 2012, A&A, 541, A31
Taquet+ 2013, A&A, 768, L29

General Molecular Structure



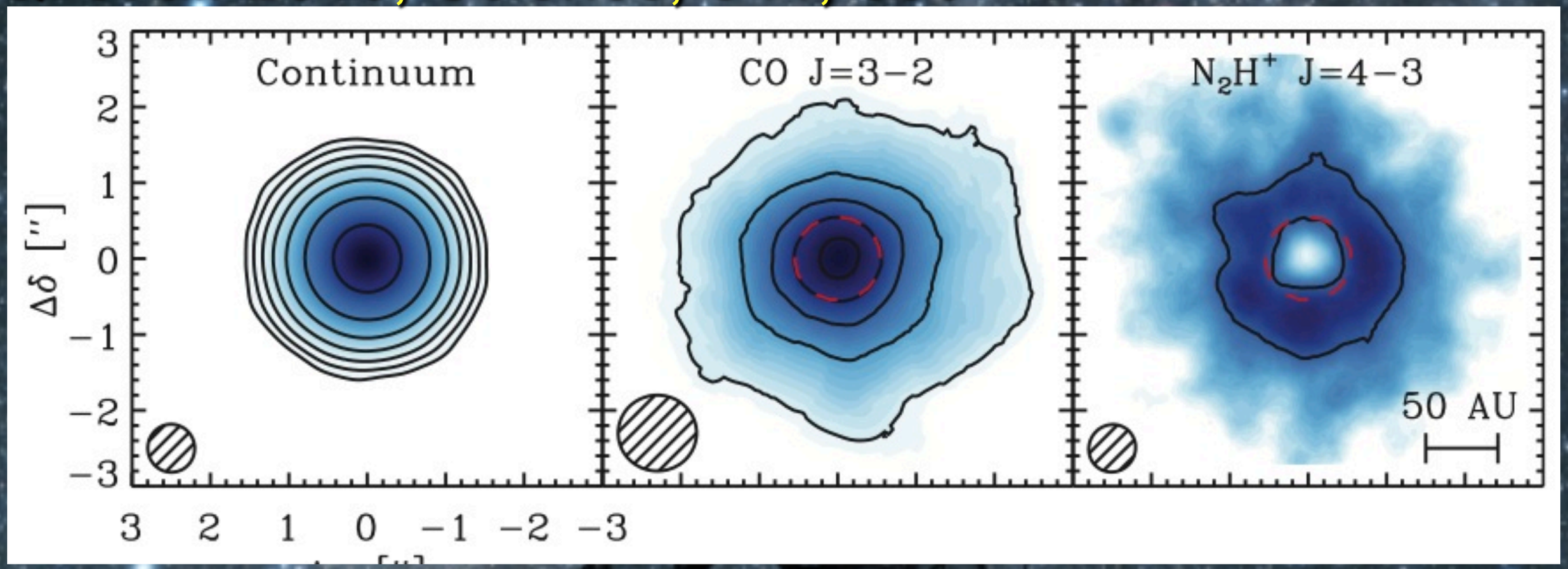
Snow-lines



Oberg+, Mousis+

ALMA: the first Snowline image

Qi et al. 2013, Science, 341, 630



- CO detected - but emits from surface not midplane
- N_2H^+ traces gas where CO is frozen (CO is a major destroyer)
- Inside midplane CO snow line, N_2H^+ is destroyed

C/O Distribution

Inside water snow-line: volatiles in gas. C/O = $(C/O)_\odot$ ~ 0.5

CO in gas, water, CO_2 in ice
Gas: C/O ~ 1
Ice: C/O < $(C/O)_\odot$

- 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.

CO, CO_2 in gas, water in ice
Gas: C/O ~ 2/3
Ice: C/O << $(C/O)_\odot$

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

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.