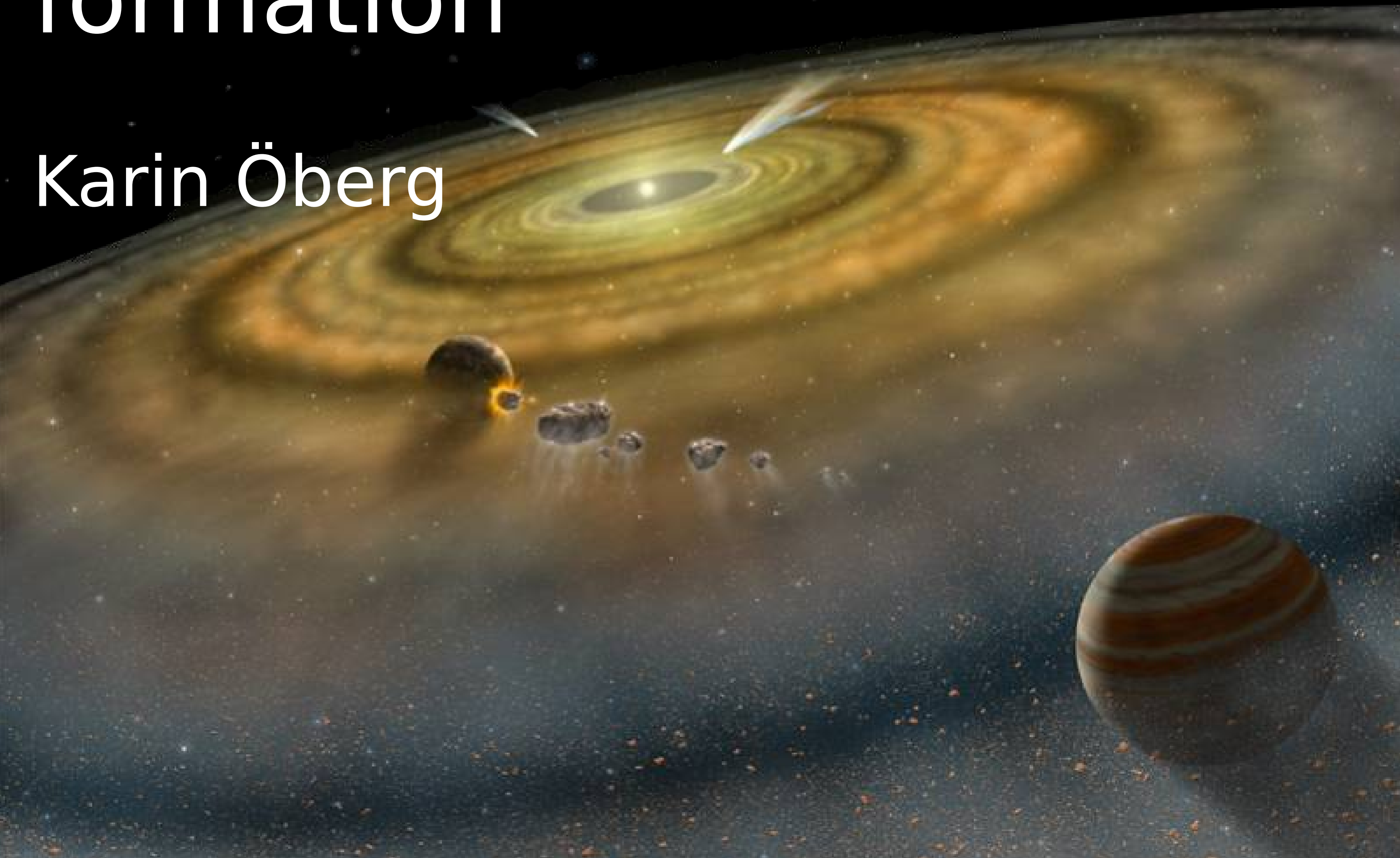
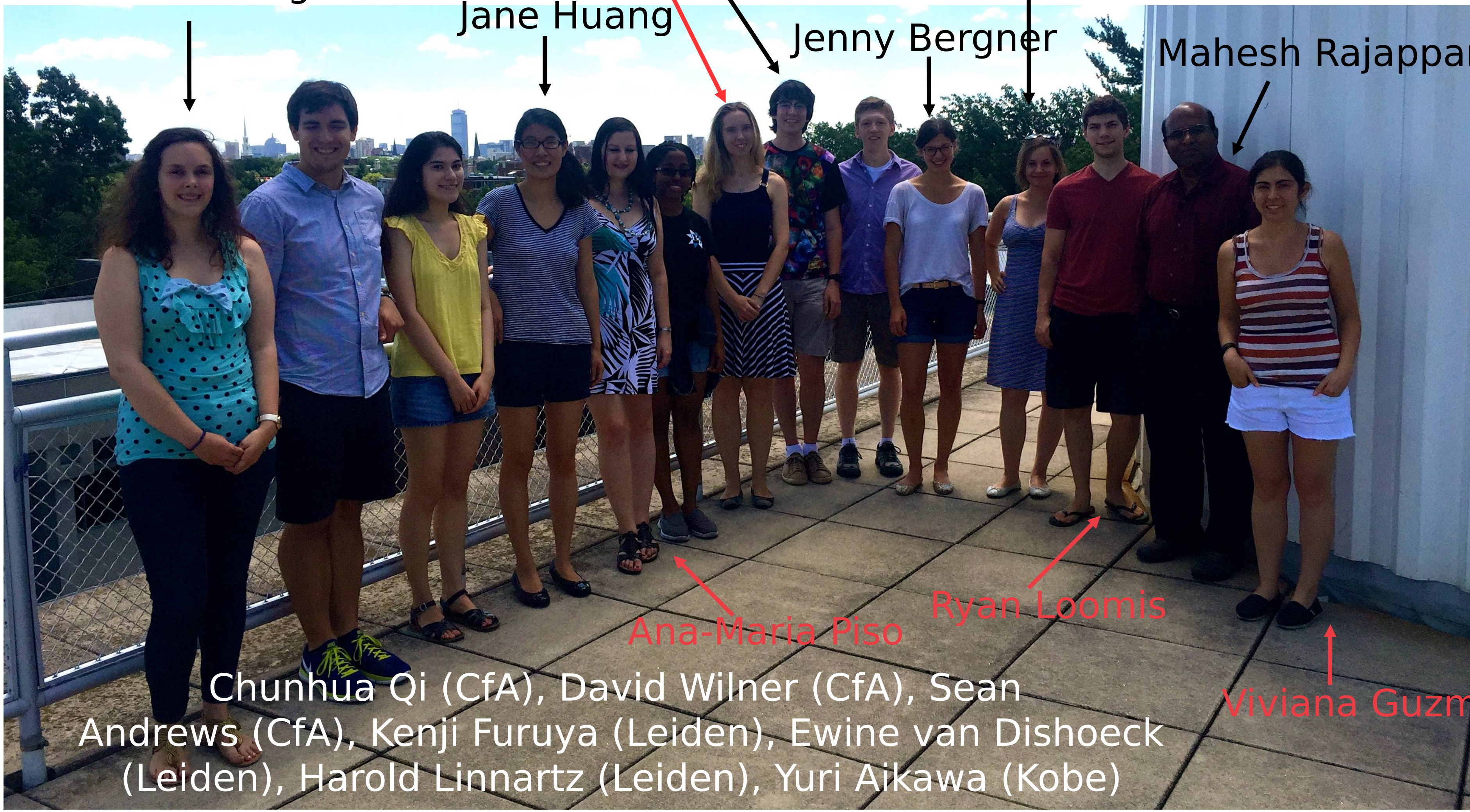
The chemistry of planet formation

Karin Öberg



Acknowledgements



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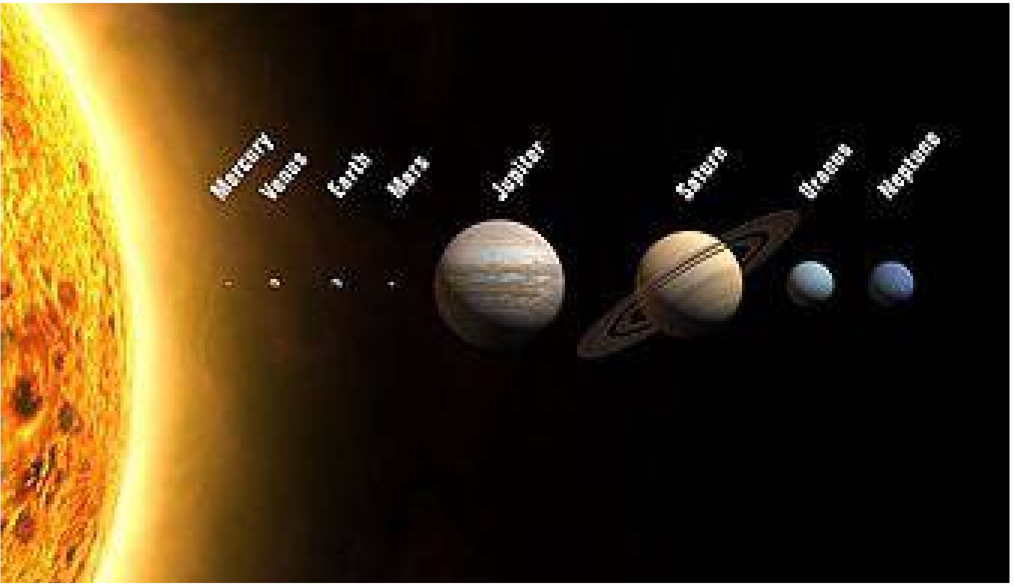
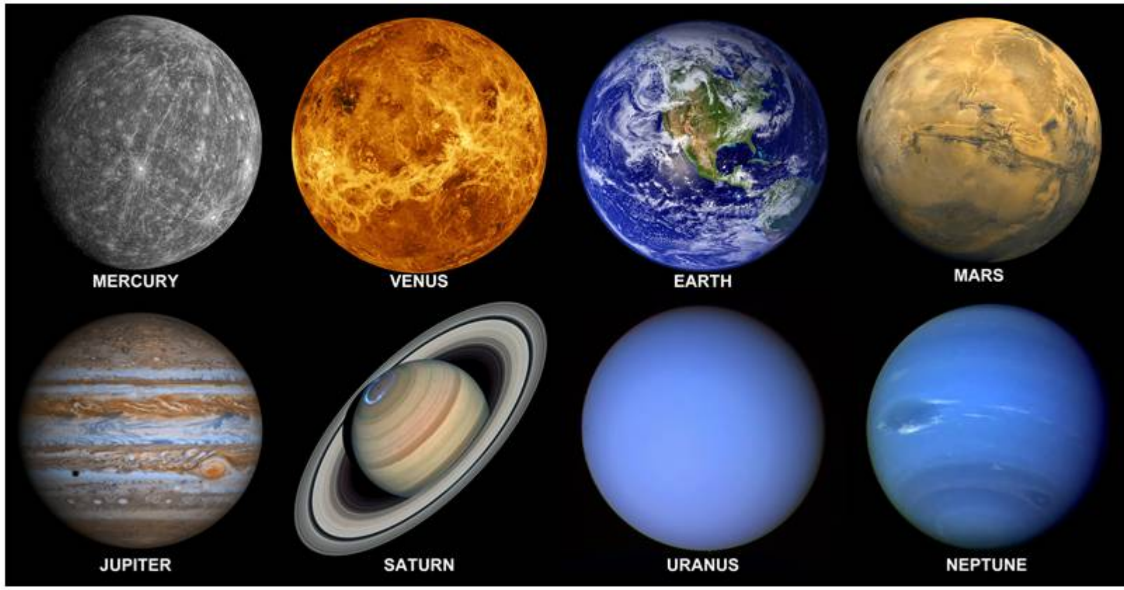
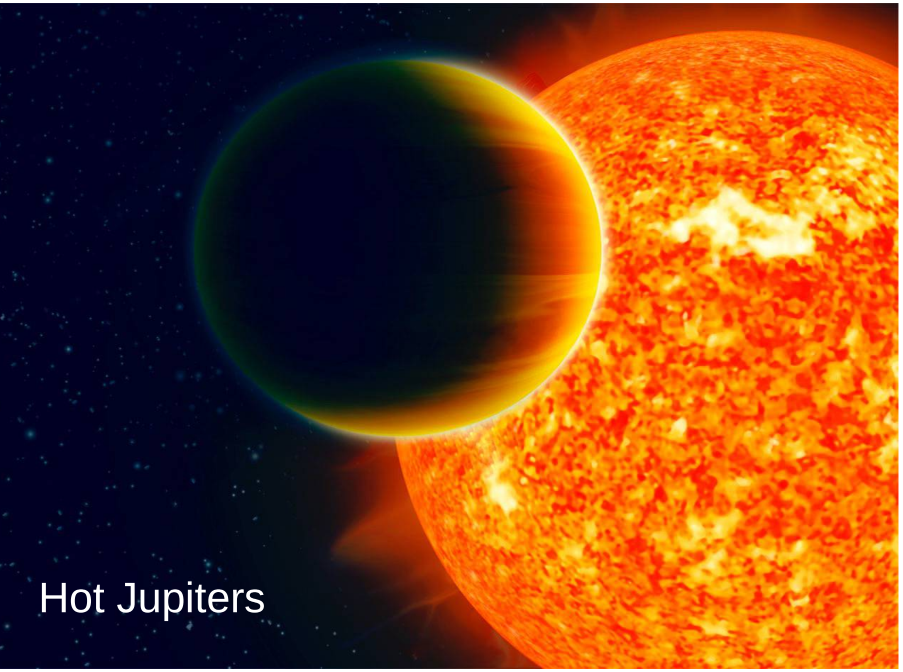
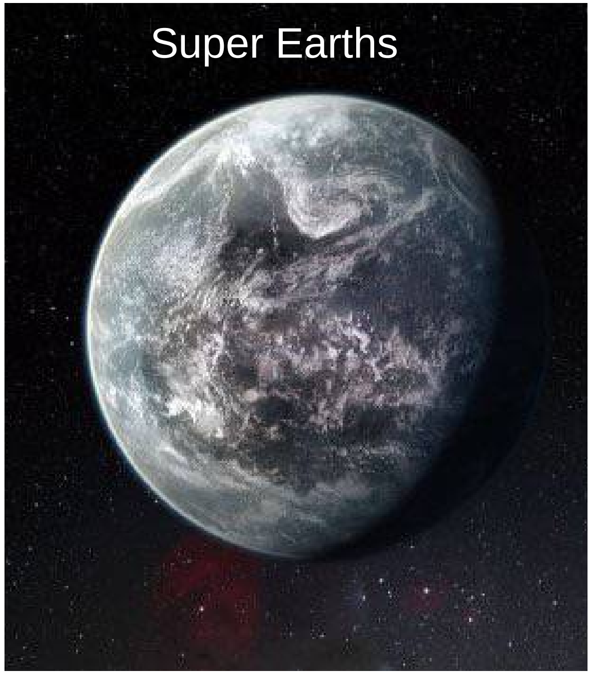
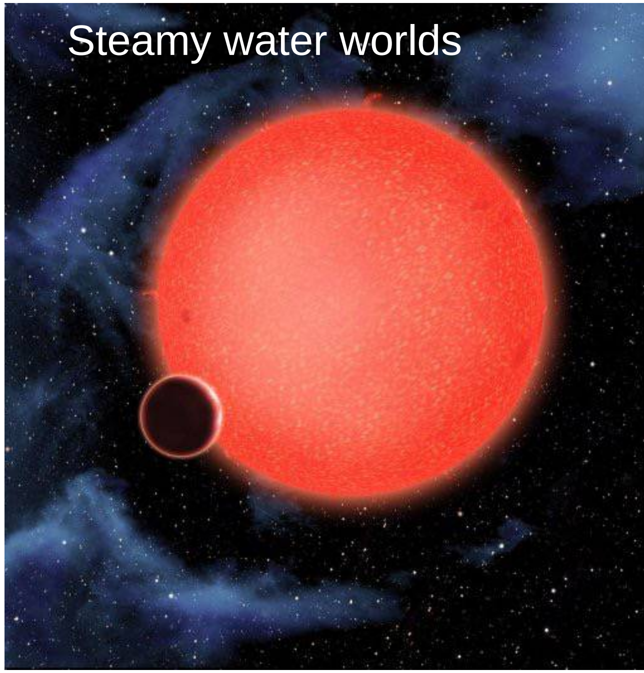
A diversity of planet compositions

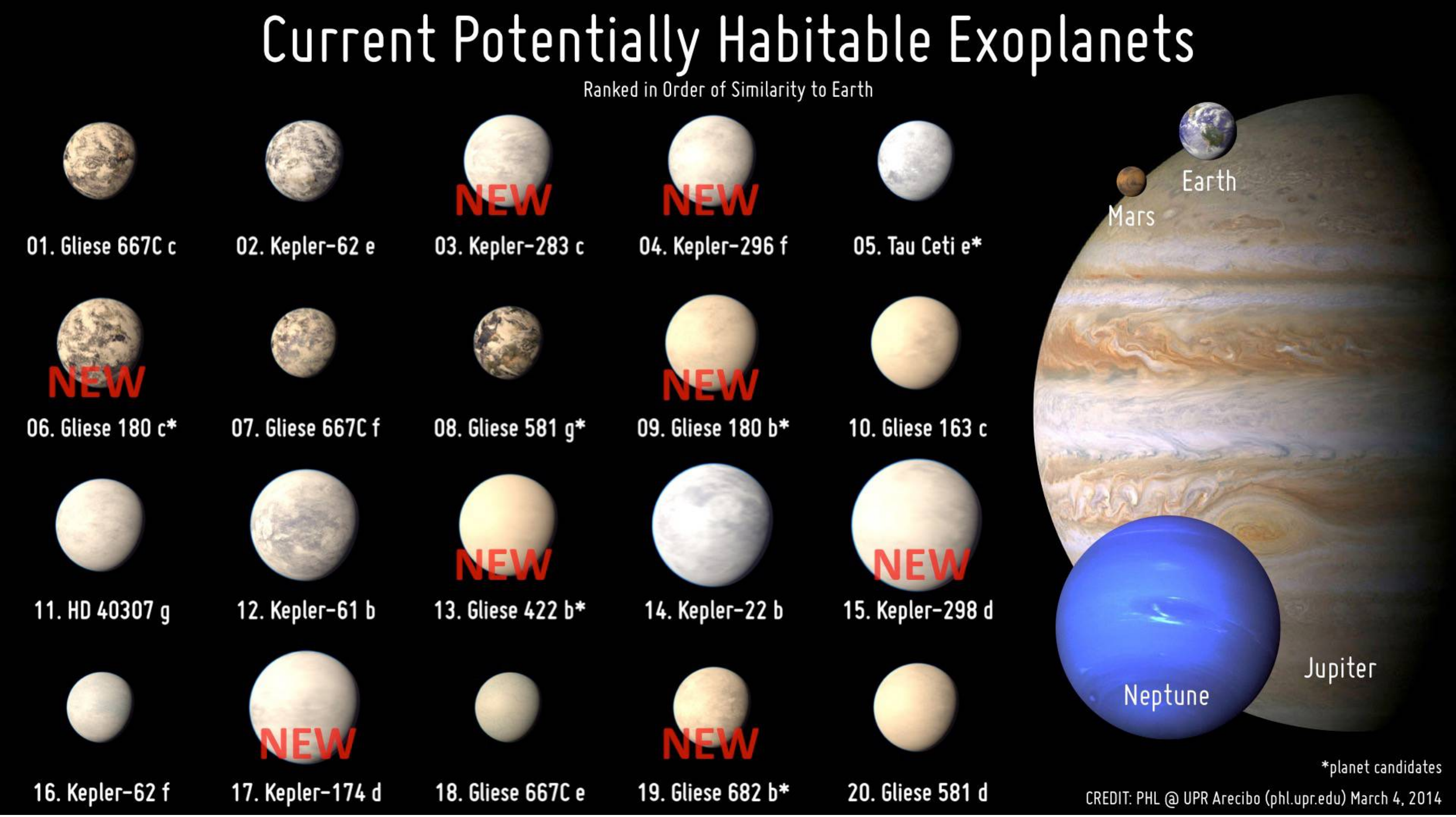






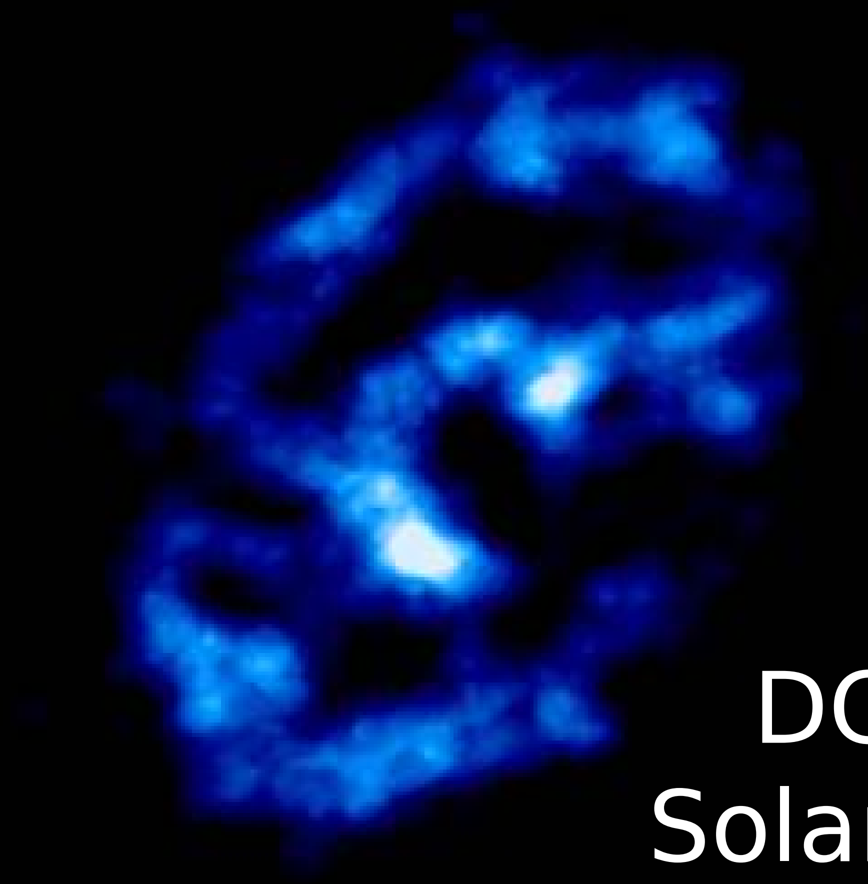


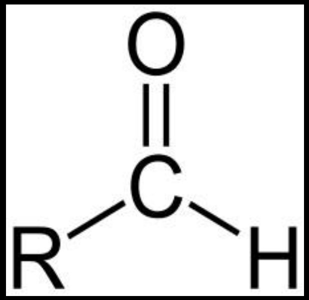




Habitability beyond rocky surfaces and liquid water temperatures… Chemical habitability: access to water, reactive organic molecules… How common is access to the ingredients of life on ‘habitable planets’?

Isotopic labeling



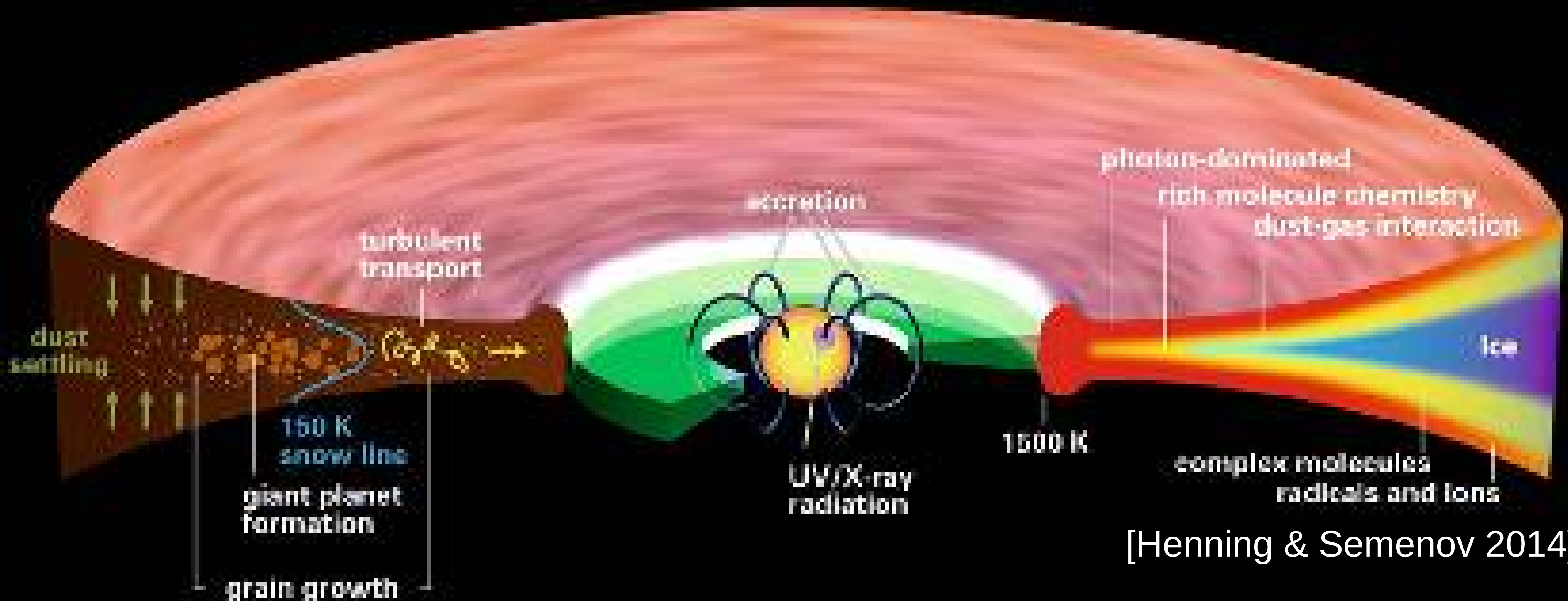


Aldehyde Ion

DCO^{+} in a Solar nebula analog

Protoplanetary disks

are characterized by radial and vertical temperature gradients, grain and gas dynamics and an evolving chemistry



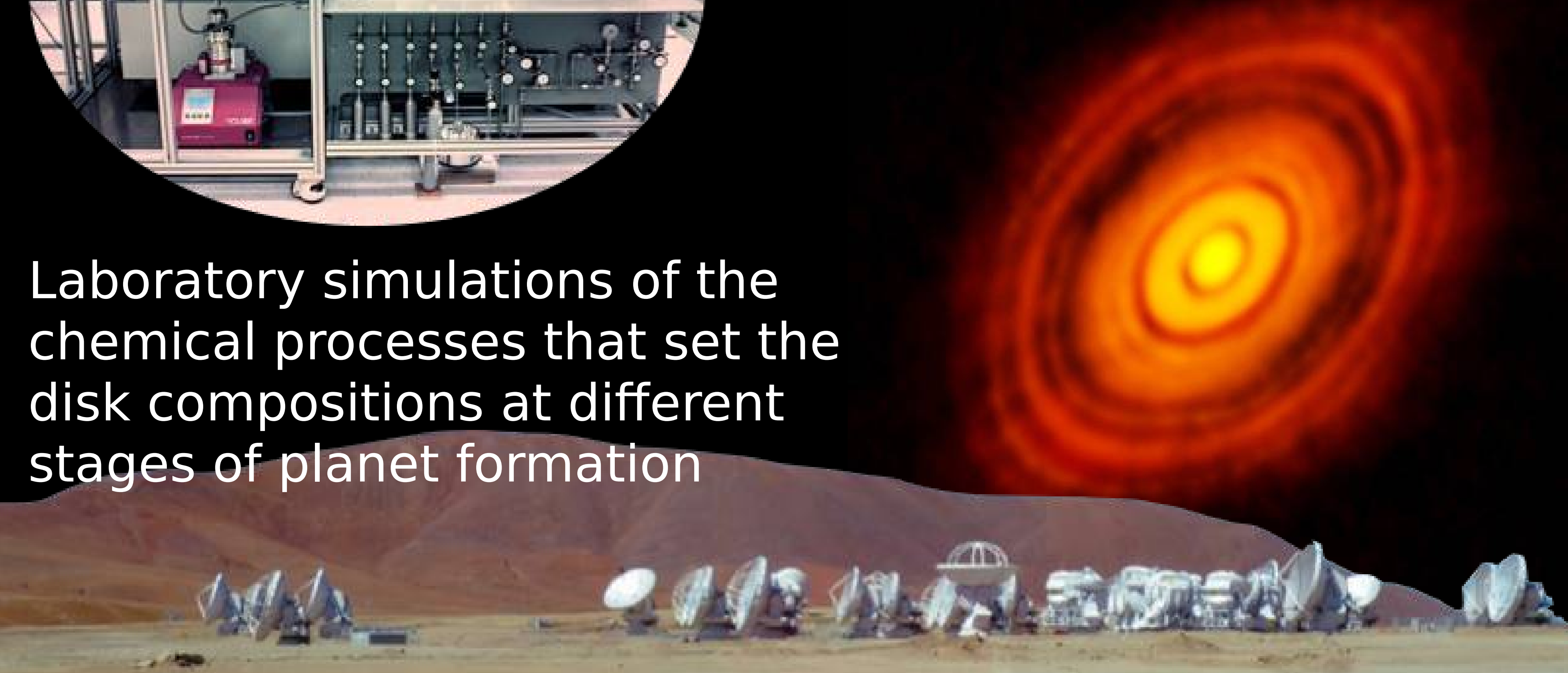
[Henning & Semenov 2014]

Proposition: the size, elemental composition (e.g. O/H and C/O) and chemical habitability of a nascent planet depends on the chemical composition of the disk material it forms from!

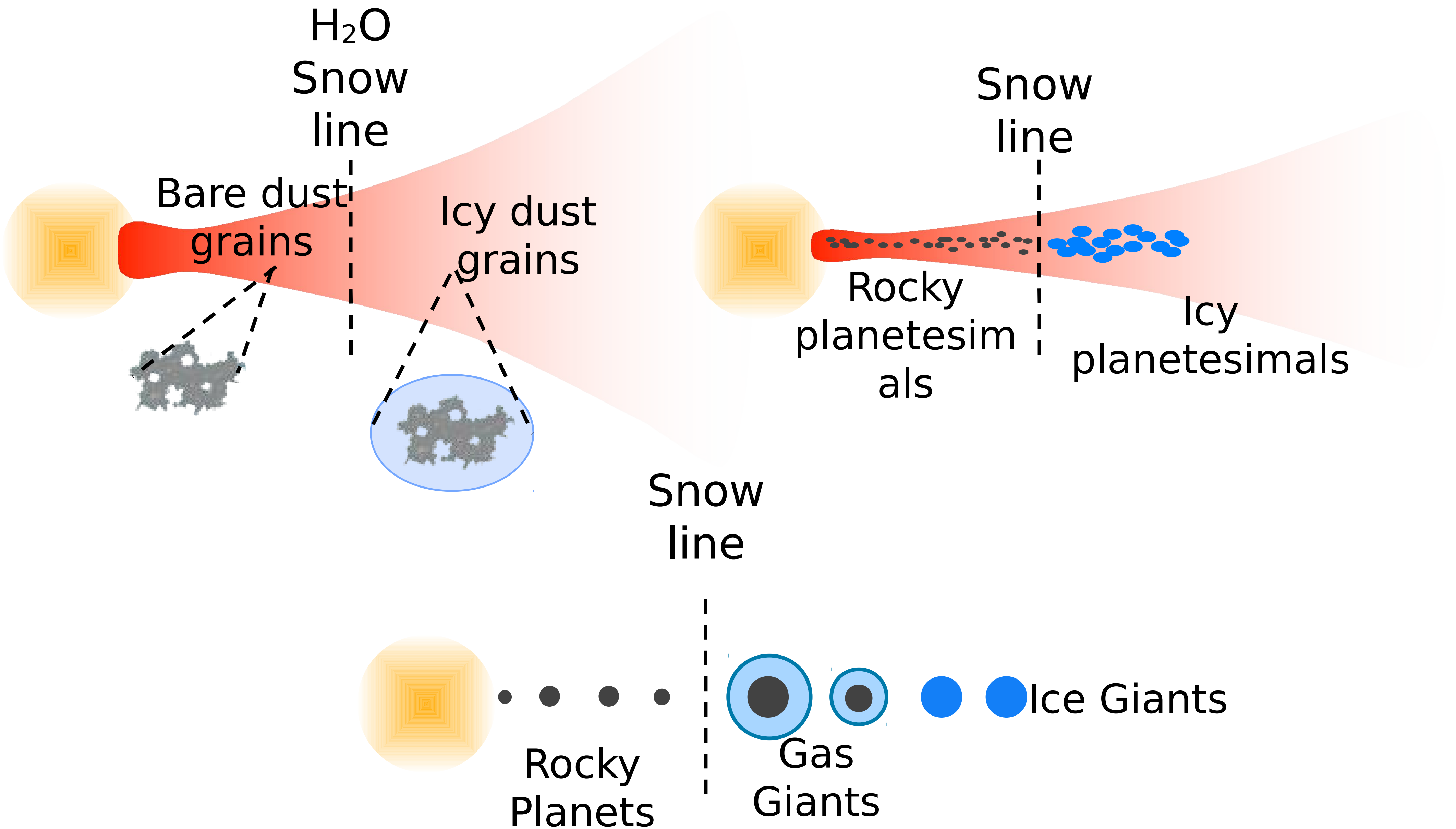
Characterizing the chemistry of planet formation

Direct observations of the chemical/molecular compositions of protoplanetary disks and related astronomical objects

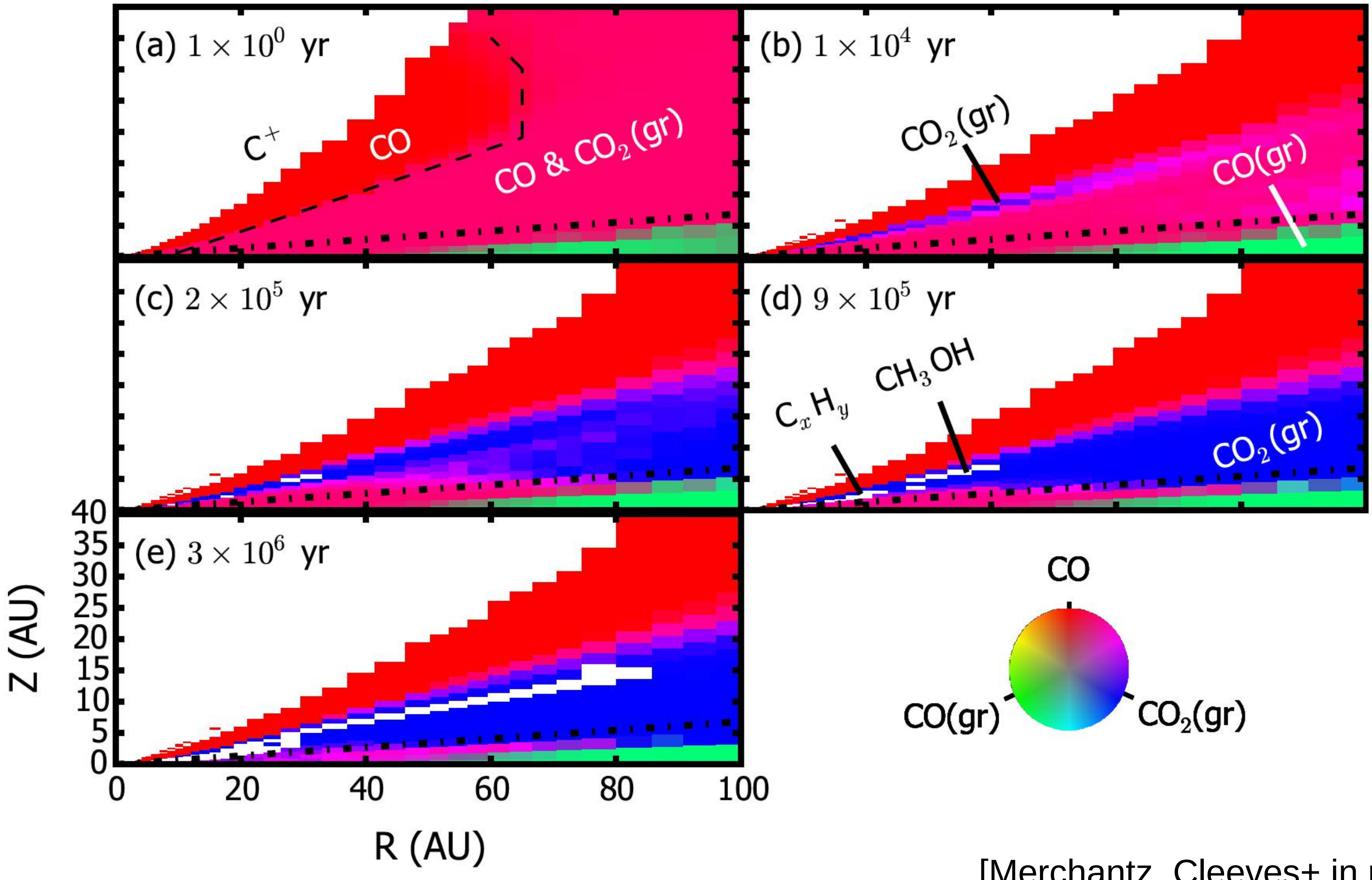
Laboratory simulations of the chemical processes that set the disk compositions at different stages of planet formation



Planet formation and disk snow lines

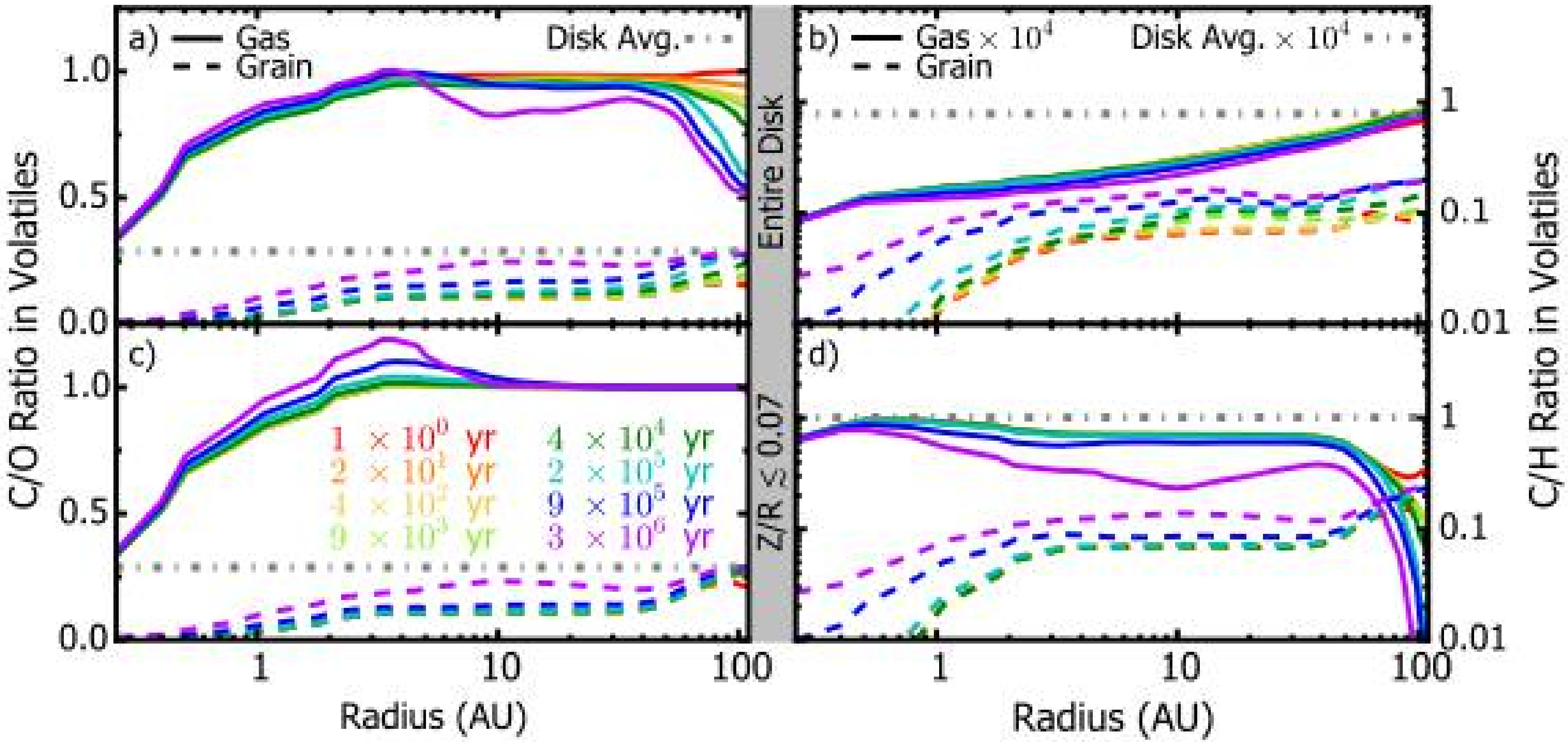


An evolving chemistry: an evolving gas-ice interaction



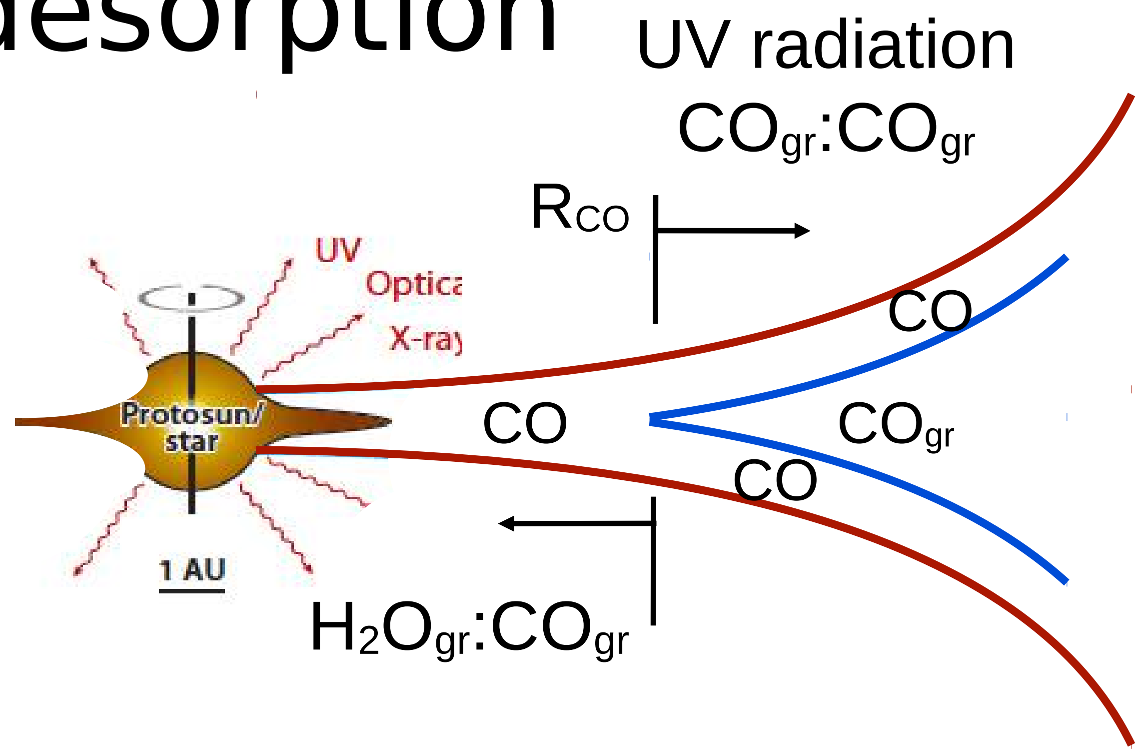
[Merchantz, Cleeves+ in prep.]

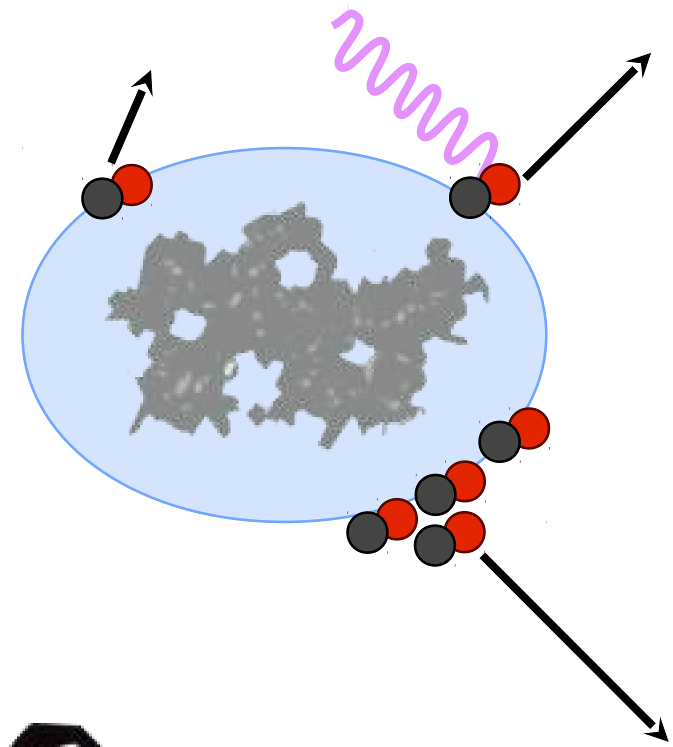
C/O in a chemically evolving disk

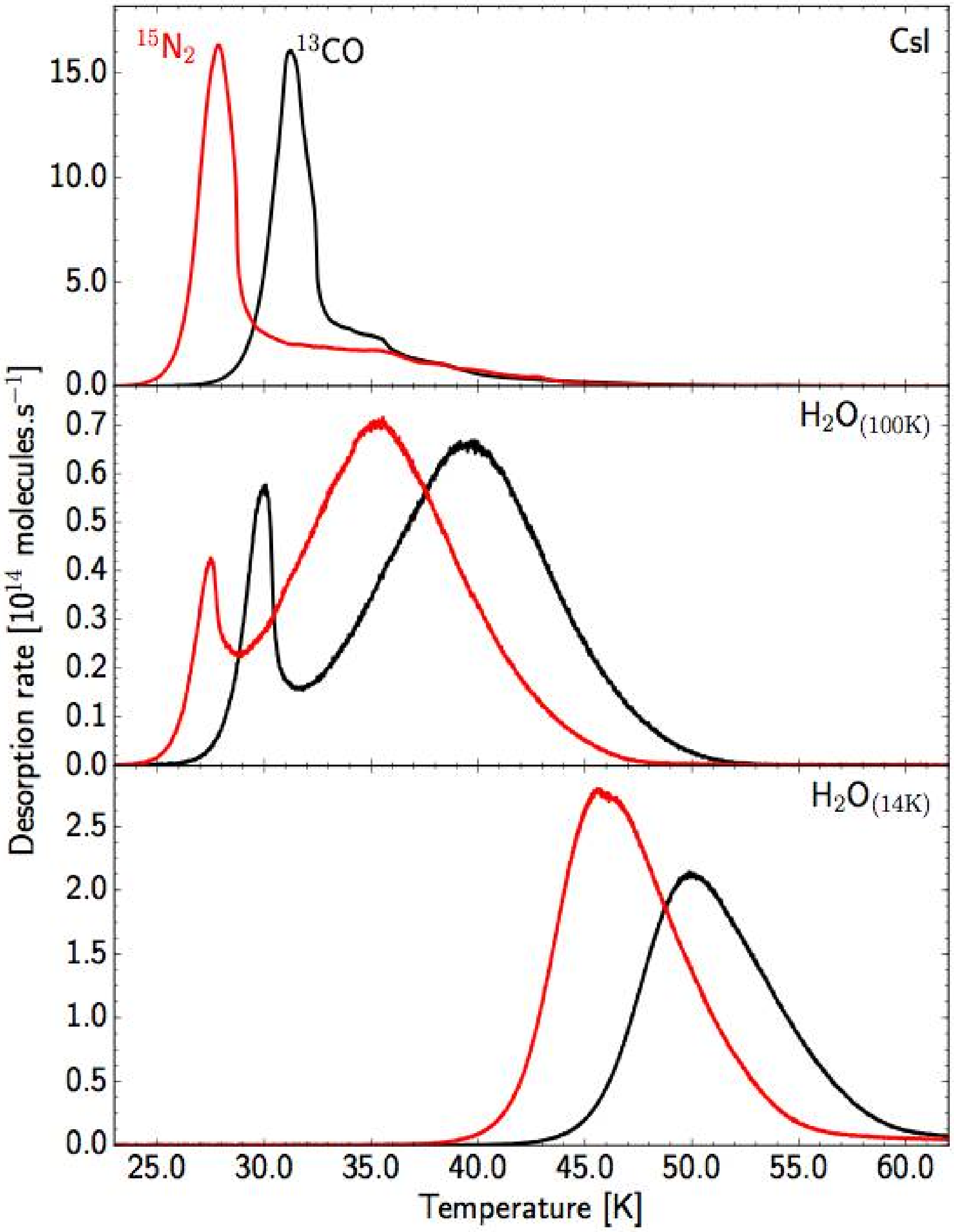


[Merchantz, Cleeves+ in prep.]

Setting the CO snowline location: binding energies and non-thermal desorption







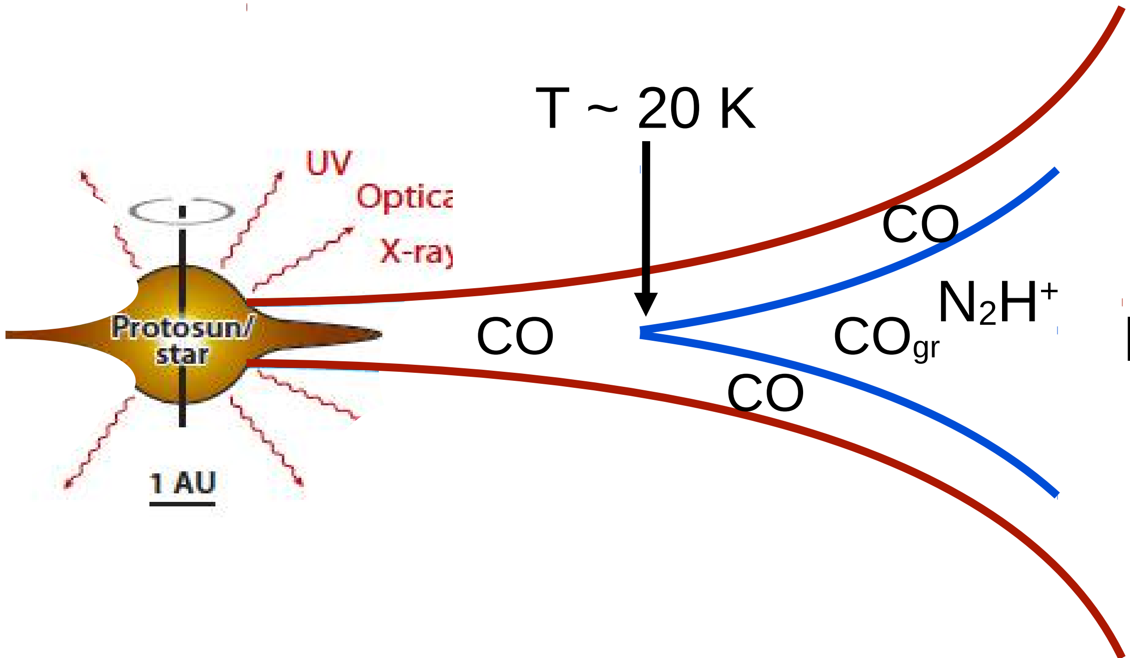
CO:CO desorbs ~30 K, N_2:N_2 ~27 K

CO and N_2 desorption energies can vary by a factor of 2

CO:H_2O desorbs ~50 K, N_2:H_2O ~45 K

[Fayolle, Balfe+ in prep]

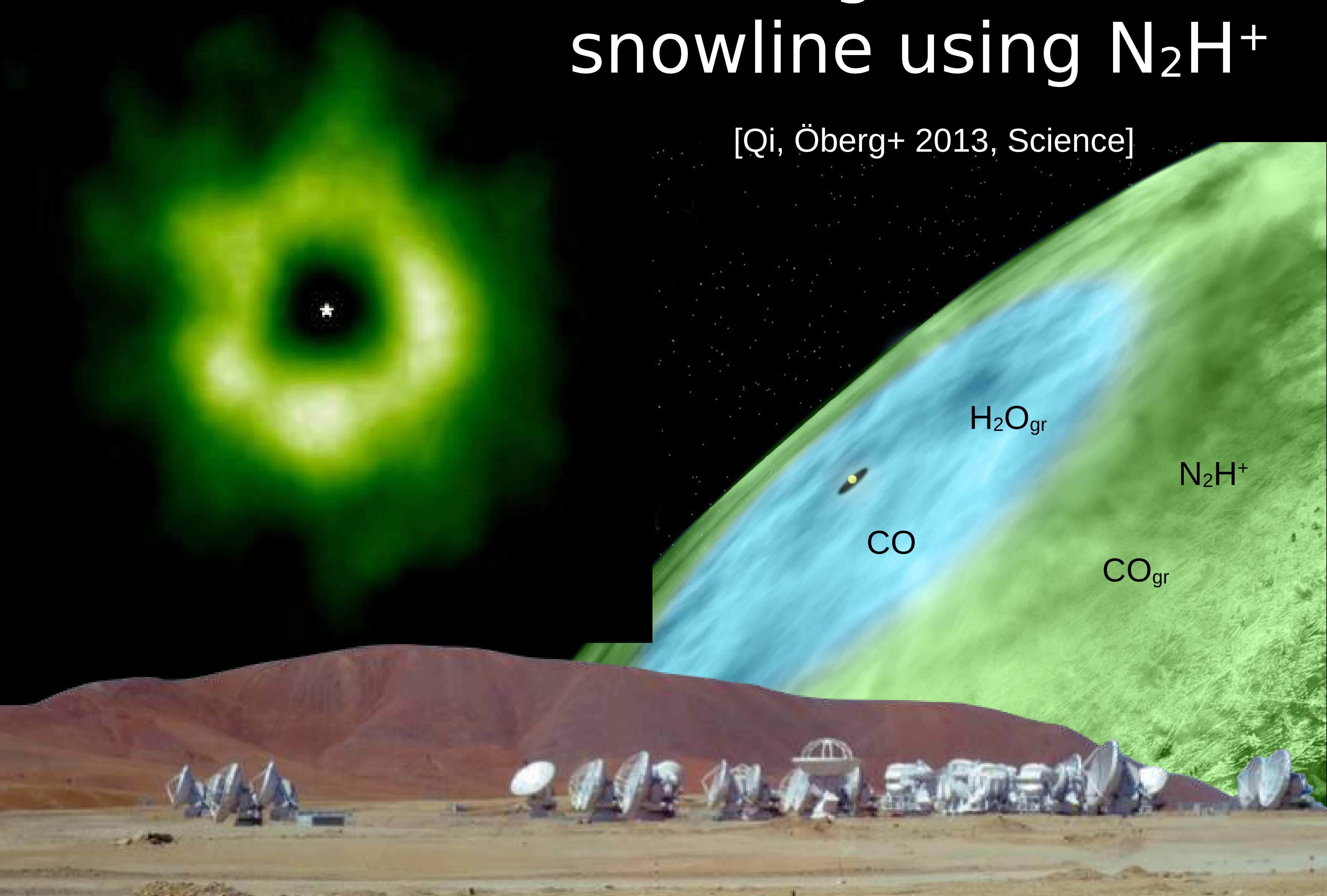
Imaging the CO snowline in a disk



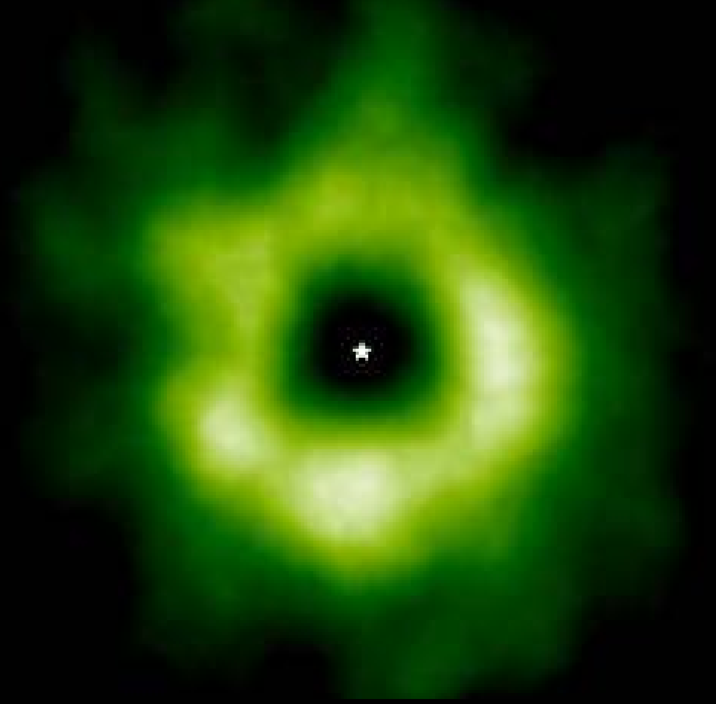
$$N_2 \underset{e^-}{\overset{H_3^+}{\rightleftharpoons}} N_2H^+ \xrightarrow{CO} N_2 + HCO^+$$

A chemical image of the CO snowline using N_2H^+

[Qi, Öberg+ 2013, Science]

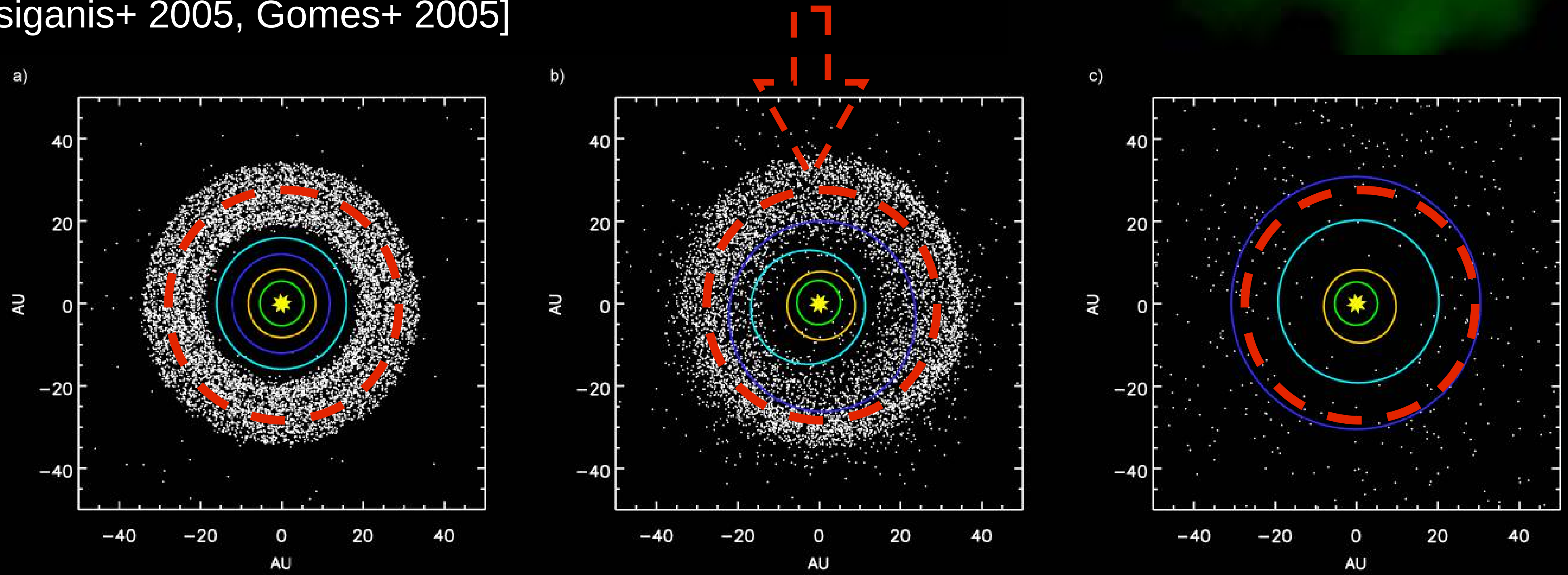


CO snow line radius implications for the Solar System



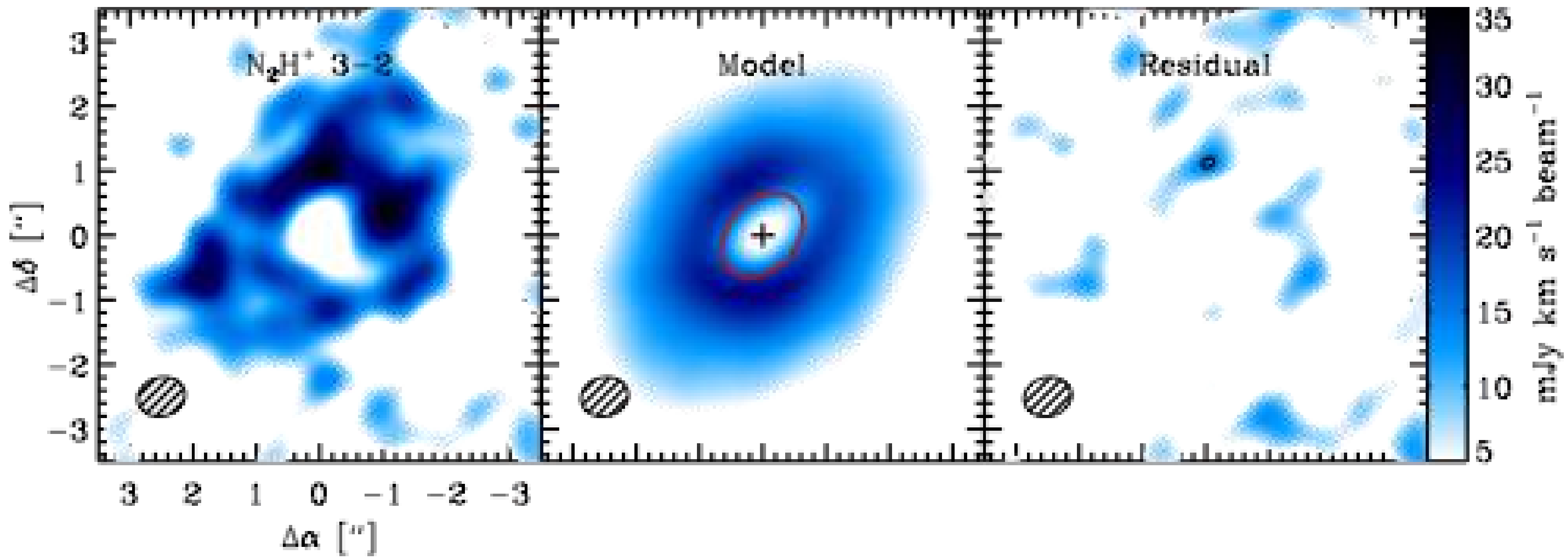
CO snow line

[Tsiganis+ 2005, Gomes+ 2005]



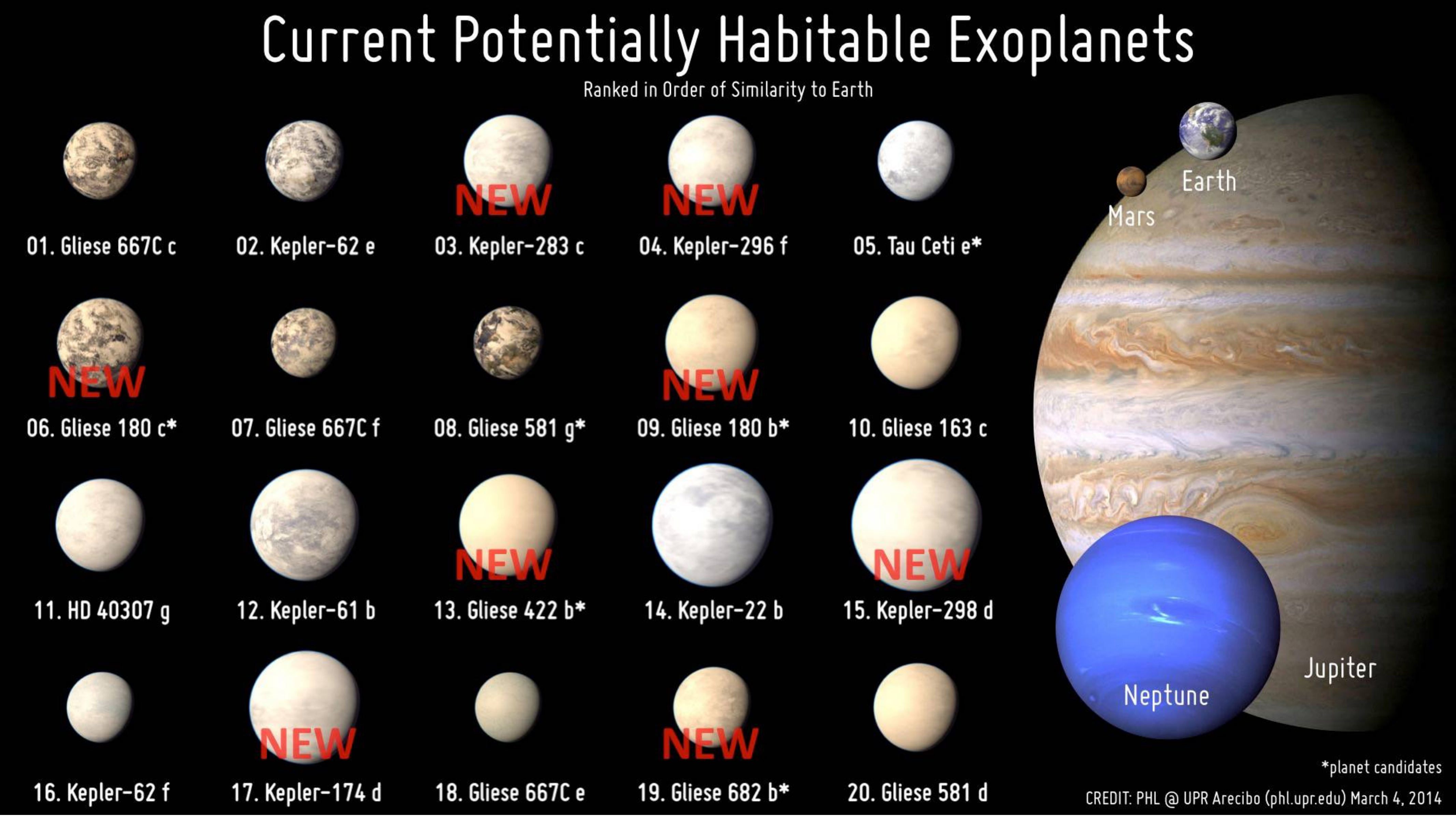
CO snow line is outside of Ice Giant formation zone according to Nice model. Some comets and KBOs should be CO rich.

CO snowlines in other disks?



[Qi, Öberg+ ApJ subm.]

CO snowline in HD 163296 is at ~90 AU, corresponding to CO freeze-out at 25 K (cf 18 K in TW Hya)



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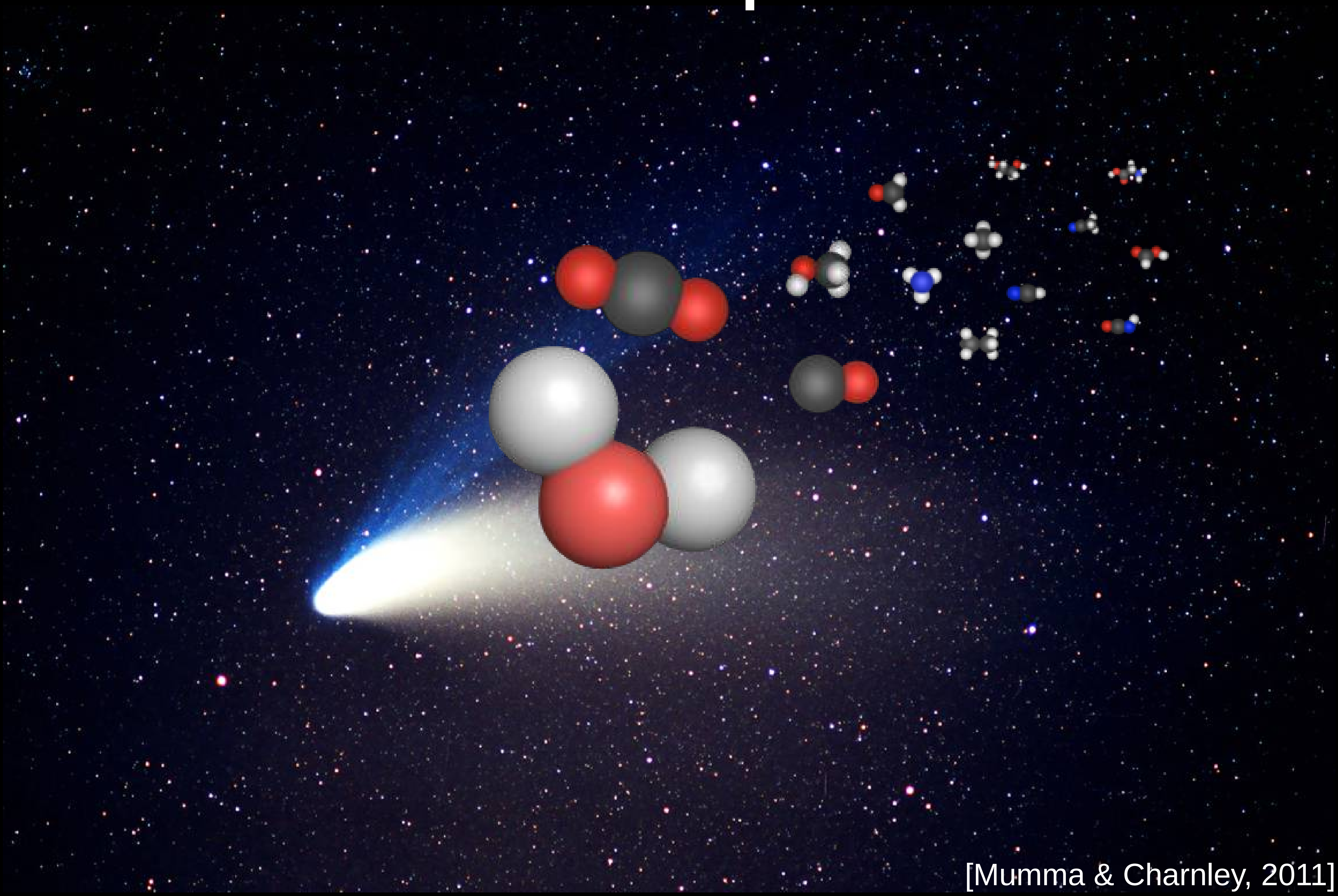
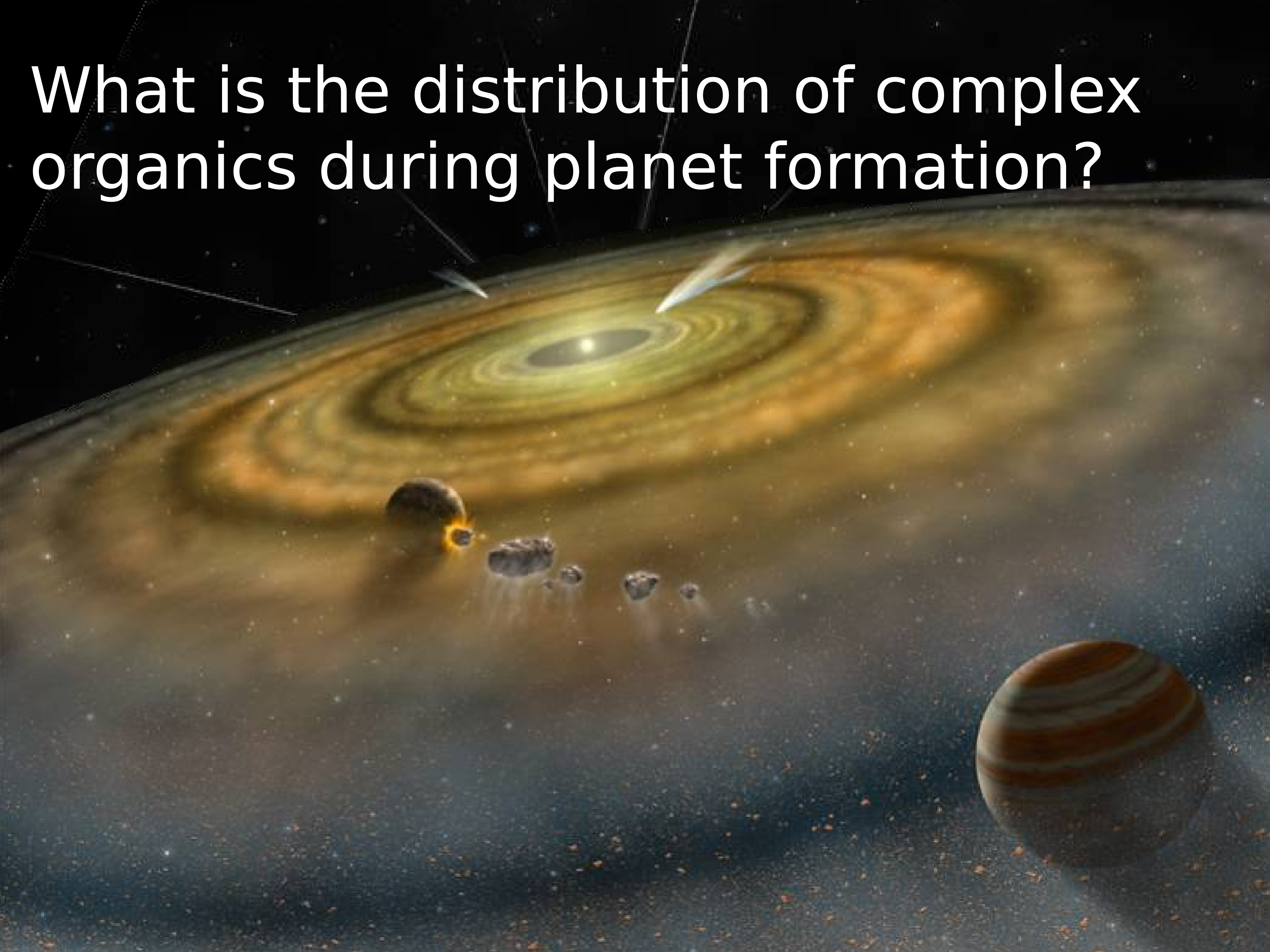
Comet Compositions



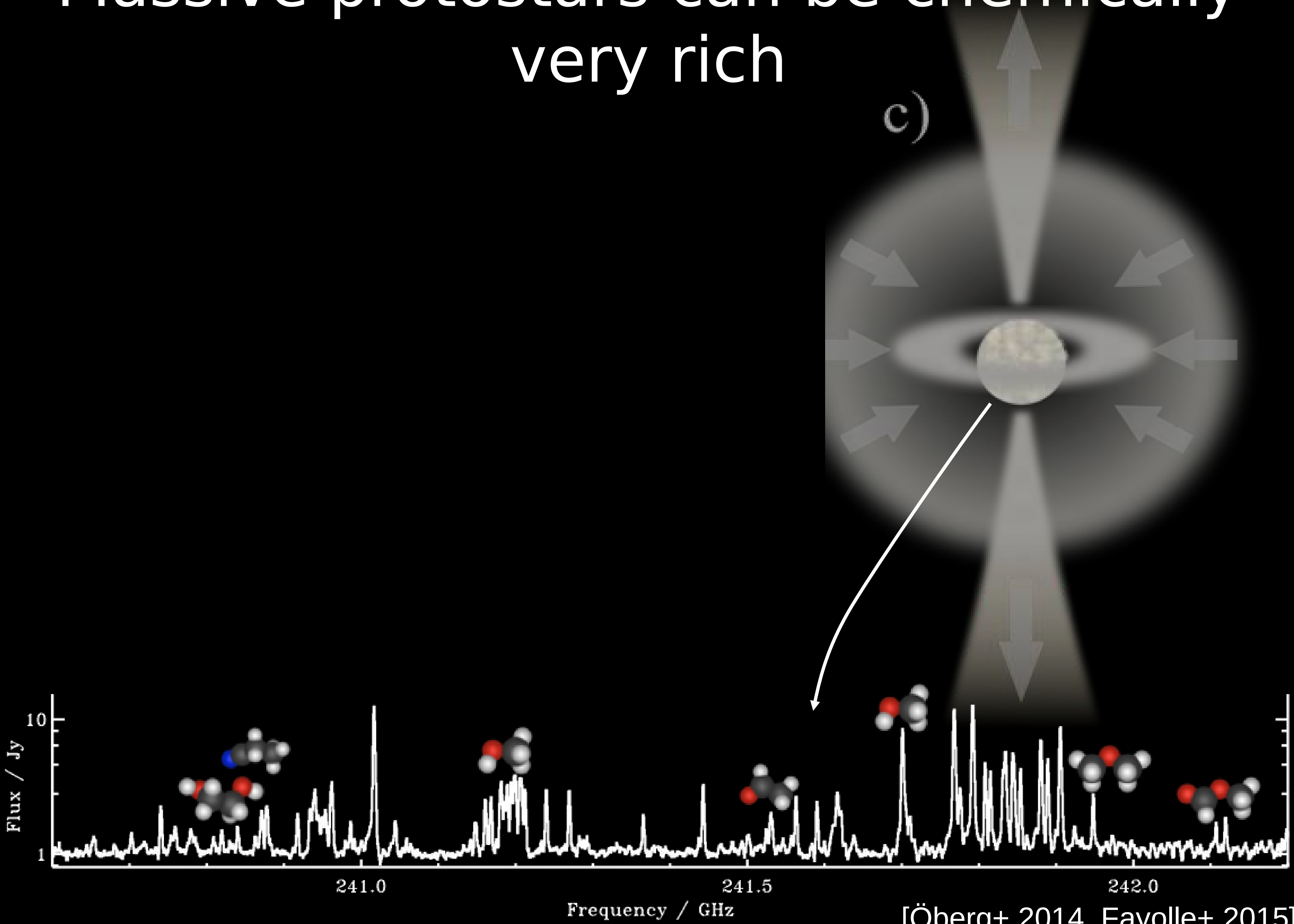
[Mumma & Charnley, 2011]

Making a chemically habitable planet

What is the distribution of complex organics during planet formation?



Massive protostars can be chemically very rich



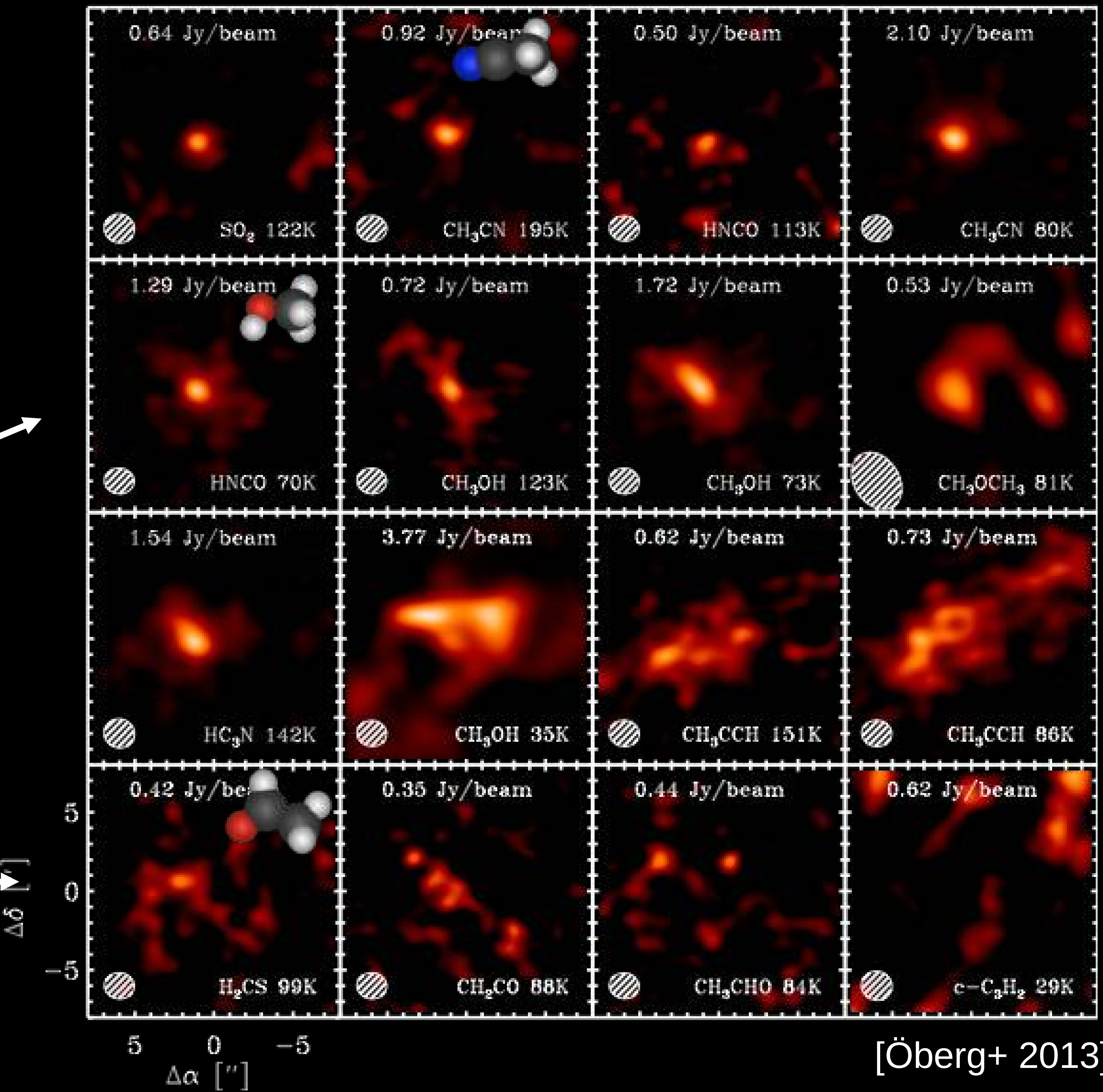
[Öberg+ 2014, Fayolle+ 2015]

Complex Organic Chemical Images

Compact, unresolved emission, e.g. hot CH_3CN

Resolved emission, e.g. CH_3OH

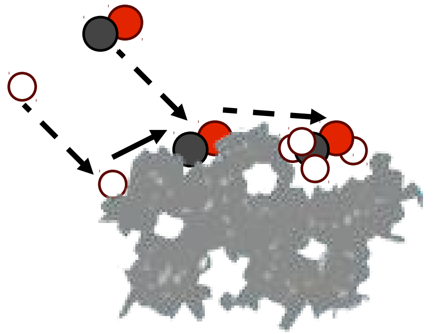
Resolved out emission, e.g. CH_3CHO



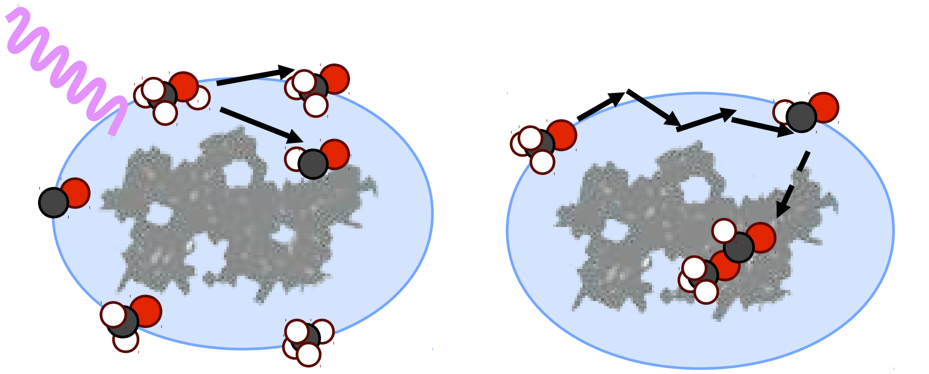
[Öberg+ 2013]

Formation of complex organics in space

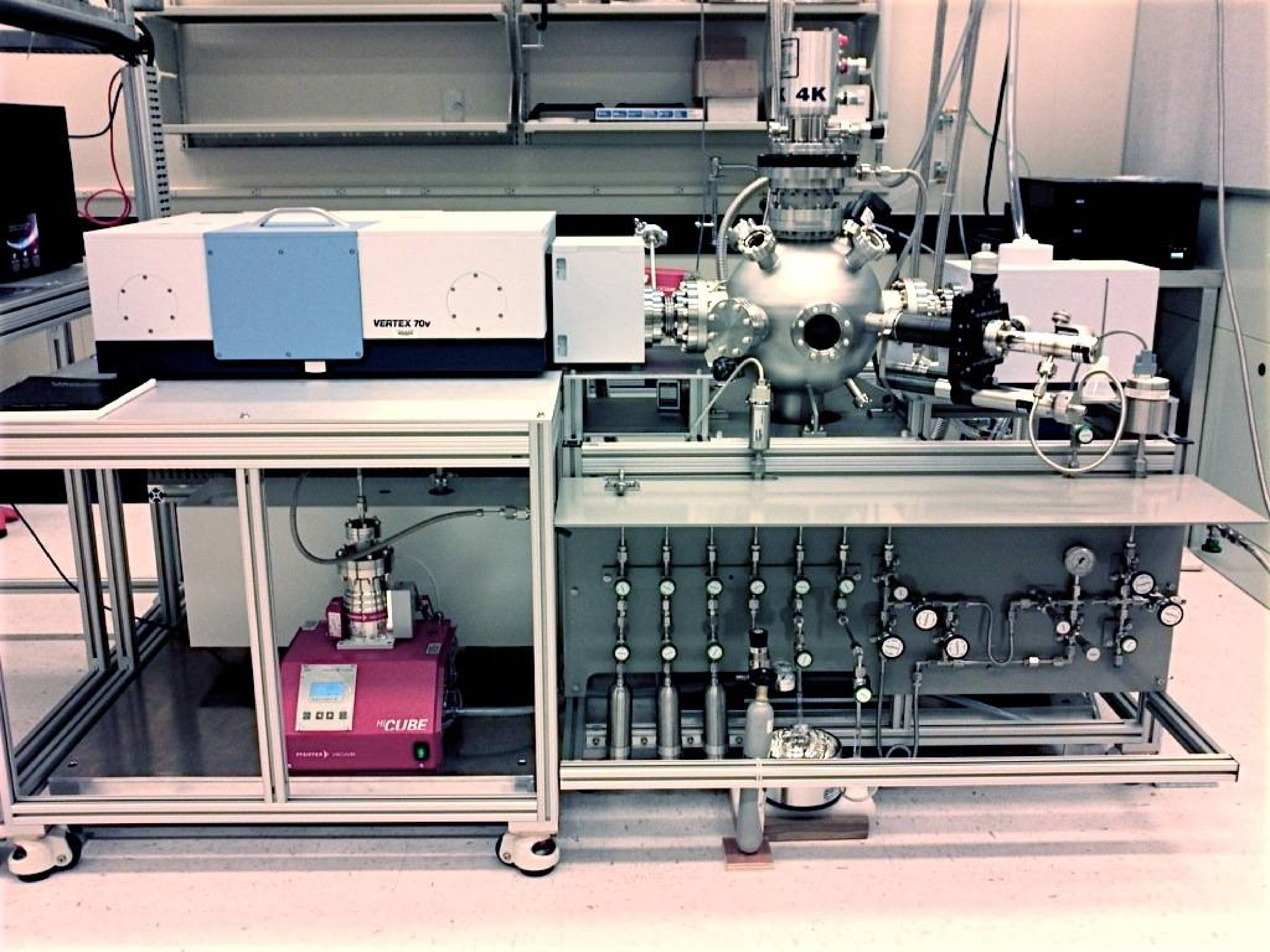
1. Atom and molecule accretion onto grains, accompanied with atom addition reactions



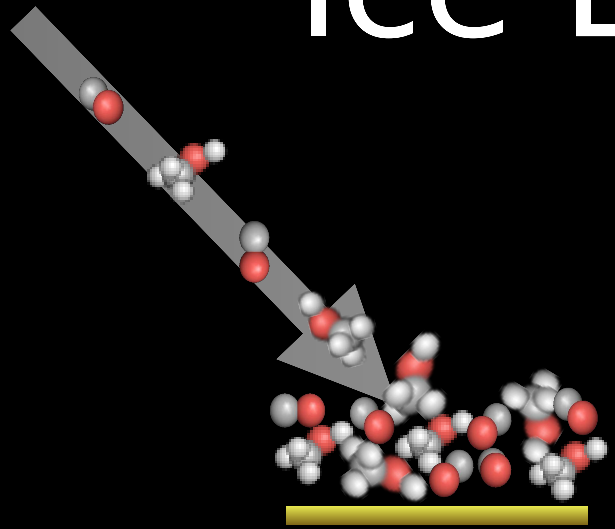
2. Ice photochemistry: ice dissociation, radical diffusion + recombination



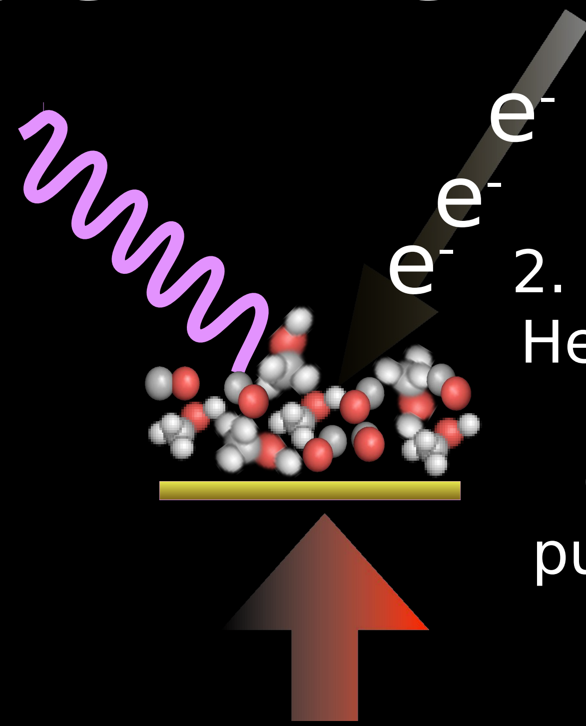
[Garrod+ 2008, Öberg+ 2009]


4K
VERTEX 70v
HiCUBE

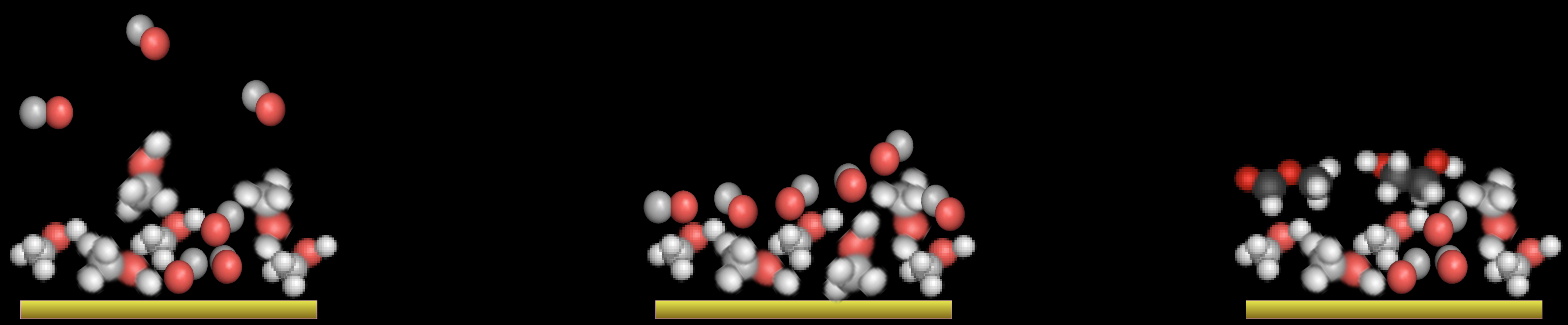
Ice Experiments



1. Ice deposition: can regulate ice composition, porosity, thickness



2. Ice manipulation: Heat, UV, electrons, X-rays
Continuous and pulses, broad-band and frequency resolved

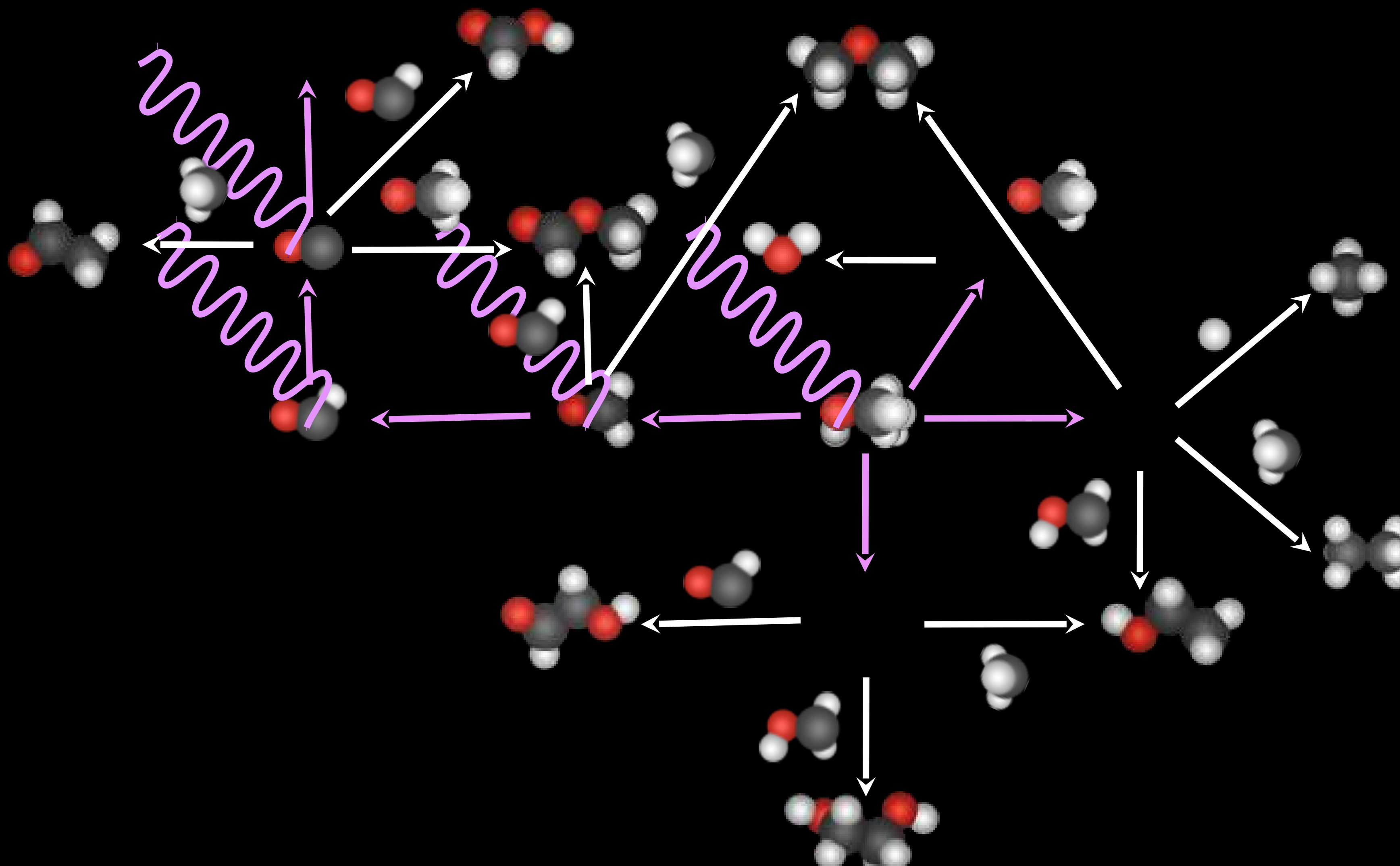


3a. Ice desorption: Thermal and non-thermal

3b. Ice diffusion

3c. Ice chemistry

CH_3OH ice is a source of chemical complexity



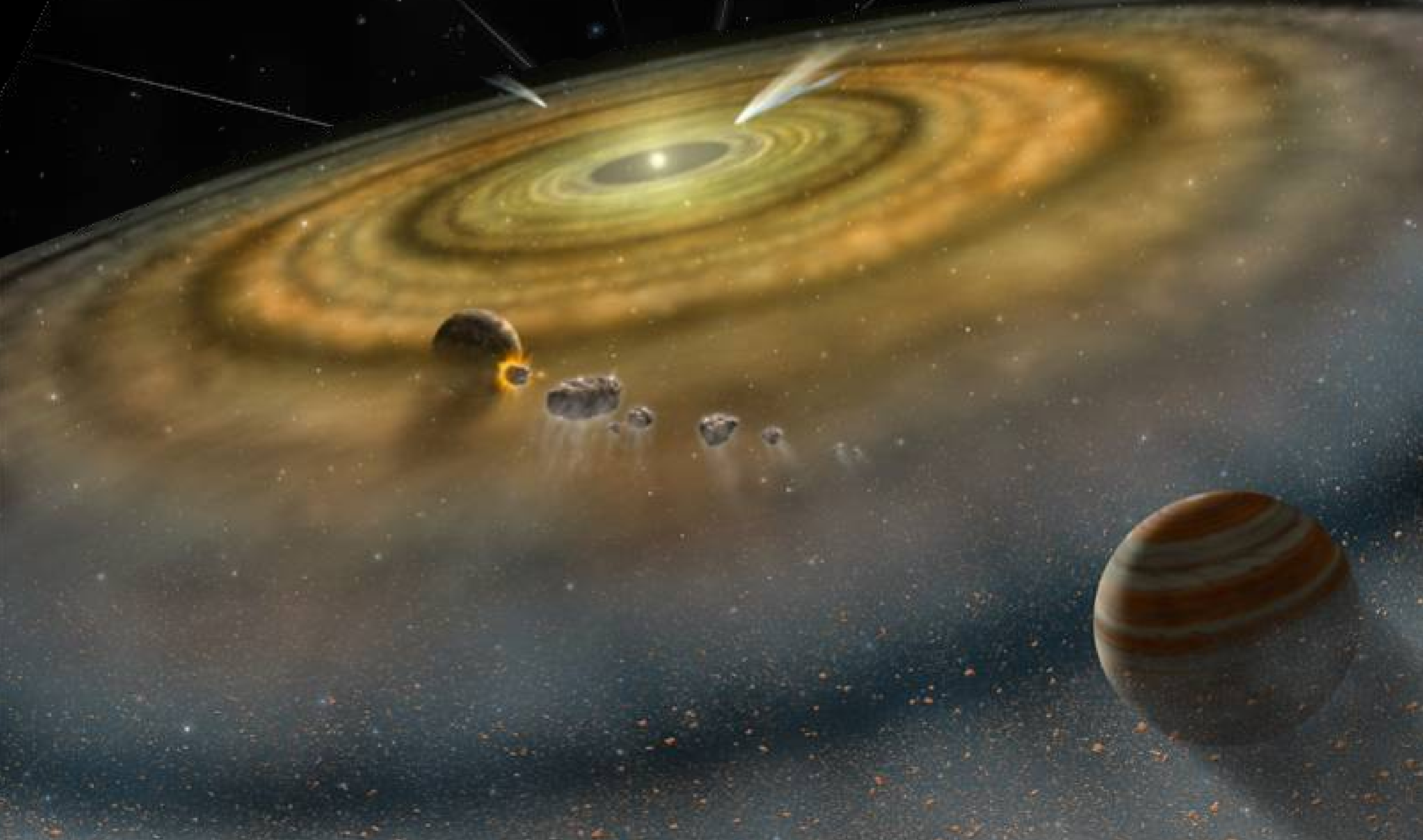
Complex organics in space

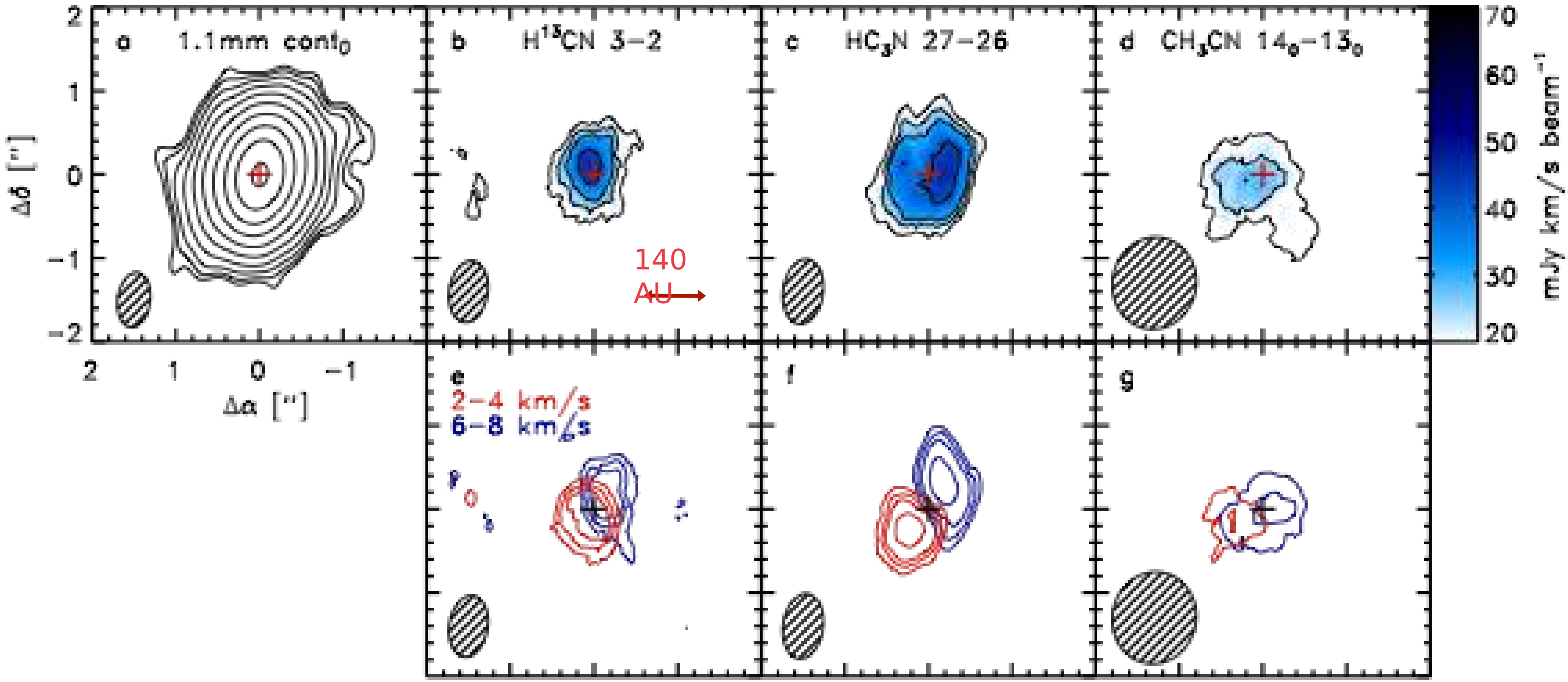
Complex organics are present in all kinds of dense interstellar environments from Hot Cores to Cold Prestellar Cores

The spatial patterns and compositional trends across samples support an ice origin (though many questions remain).

Chemical richness measured as COM/CH_3OH varies my orders of magnitudes between sources.

What is the distribution of complex organics during planet formation?





ALMA sees first complex organic molecule in a protoplanetary disk!

[Öberg+ 2015, Nature]

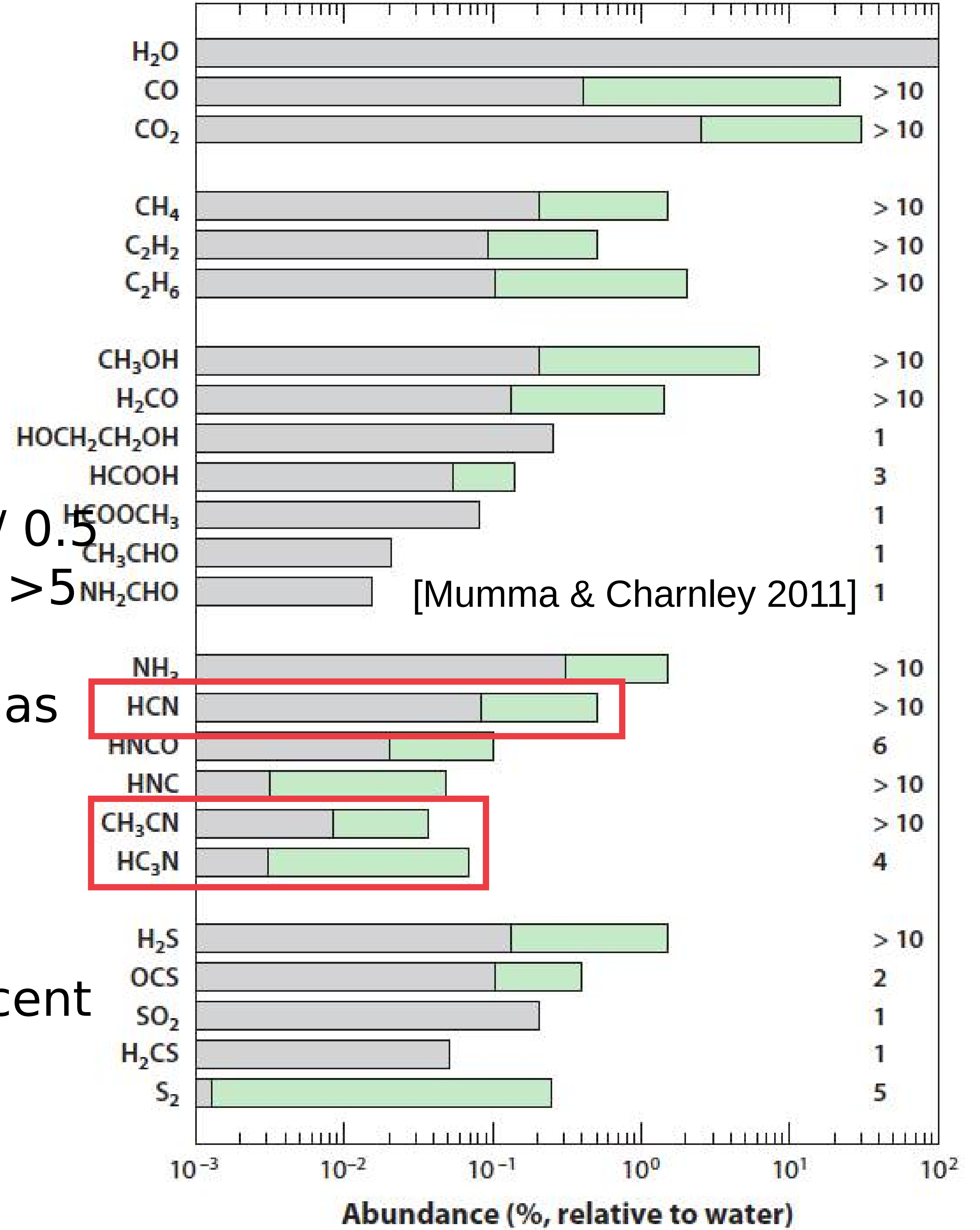
Comet-disk comparison

HCN / HC_3N / CH_3CN

Comets: 10 / 1 / 1
Disk gas 30 AU: ~10 / 4 / 0.5
Disk ice 30 AU: ~10 / 4 / >5

The MWC 480 disk looks as comet in its cyanide composition

The prebiotic conditions characteristic of the nascent Earth may be common?



The Chemistry of planet formation

The efficiency of planet formation, the final composition of nascent planets, and the access to water and volatile organics (chemical habitability) at planet surfaces are regulated by chemistry in protoplanetary disks

The study of disk chemistry reveals:

- the location of snowlines (through N_2H^+)
- the distribution of complex organic chemistry (discovery of methyl cyanide in a disk)

Through laboratory experiments and interstellar COM observations we can uncover the processes that govern these distributions