國立清華大學
NATIONAL TSING HUA UNIVERSITY

NSTC 國家科學及技術委員會
National Science and Technology Council

Origin and evolution of the building blocks of planets



JWST ERS Ice Age
NASA, ESA, CSA,
M. Zamani

Daniel Harsono
National Tsing Hua University



NASA/MODIS/USGS

Daniel Harsono, EAMA 2025

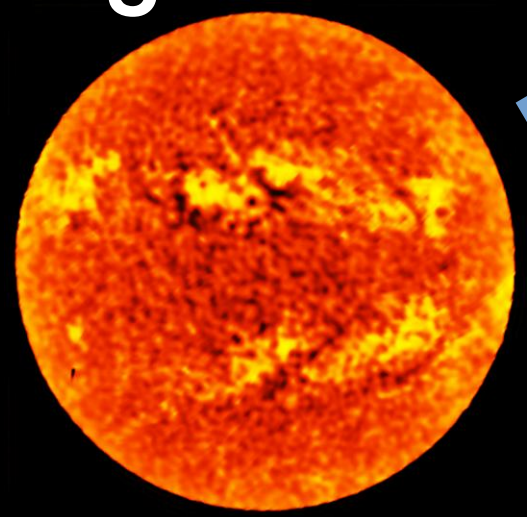
How did Earth get its water?



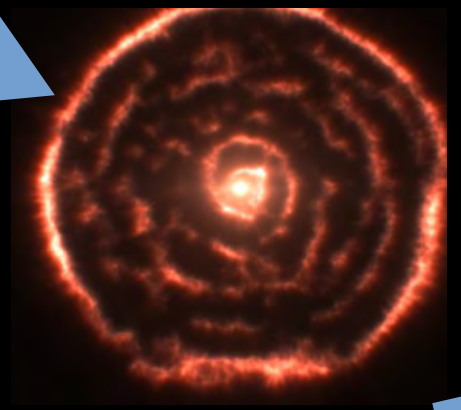
How water and organic molecules were delivered to terrestrial planets like the Earth?

NASA/MODIS/USGS

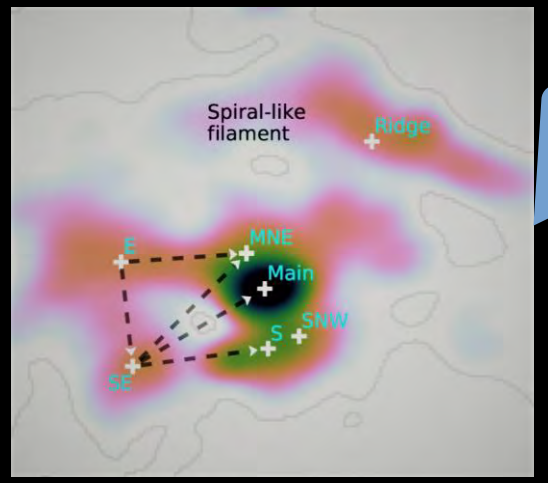
Cycle of dust and gas



Stellar evolution

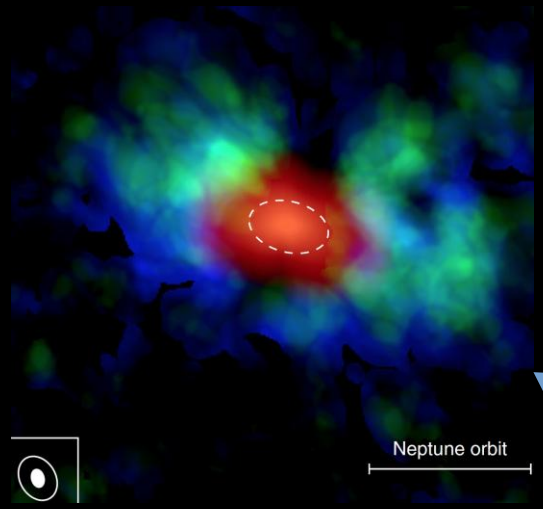


Production of dust and gas by AGBs and processing in the ISM



ALMA (ESO/NAOJ/NRAO)
Maercker et al. 2012
Izquierdo et al. 2018

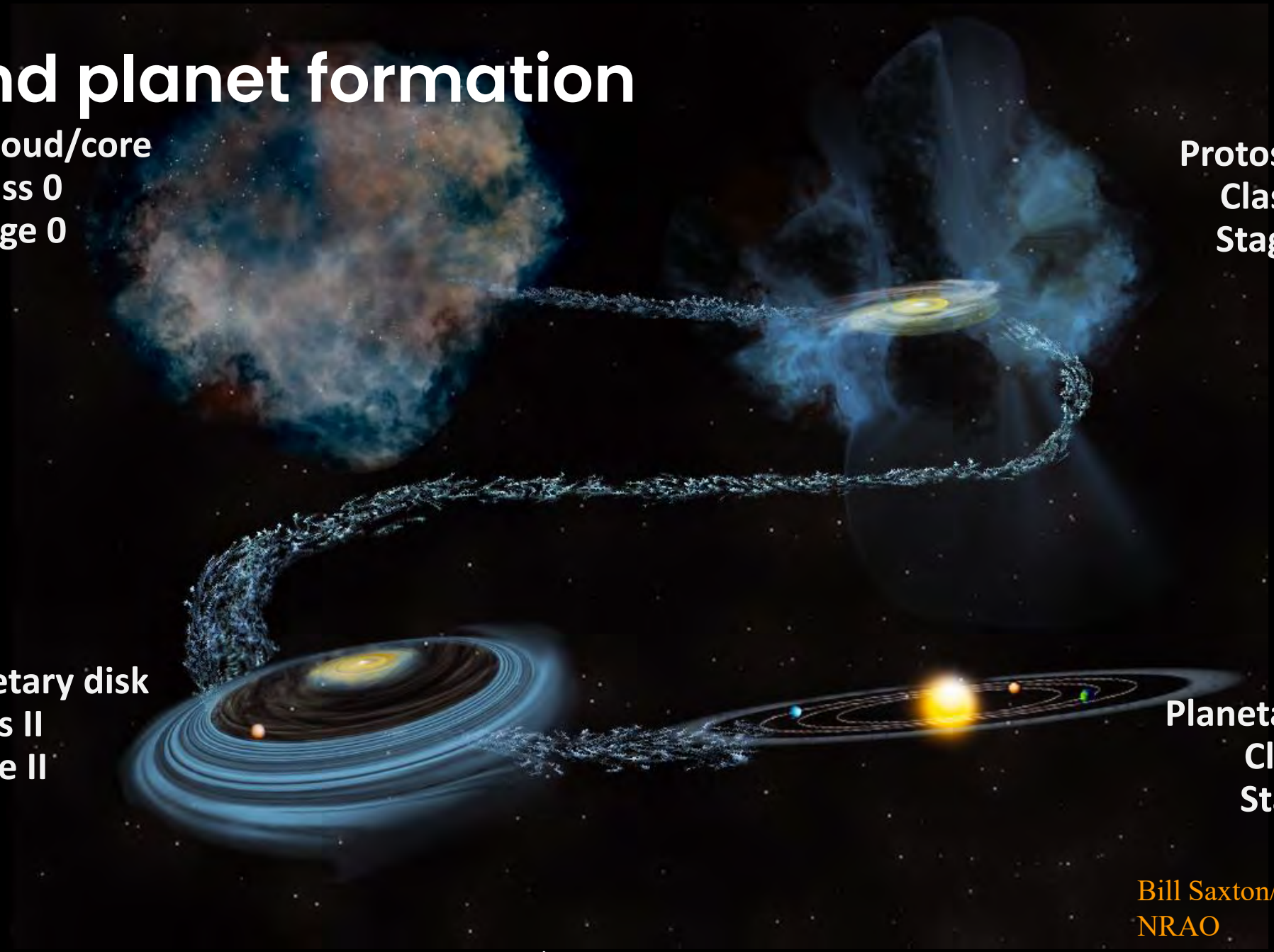
Delivery of matter from molecular cloud to planet-forming regions



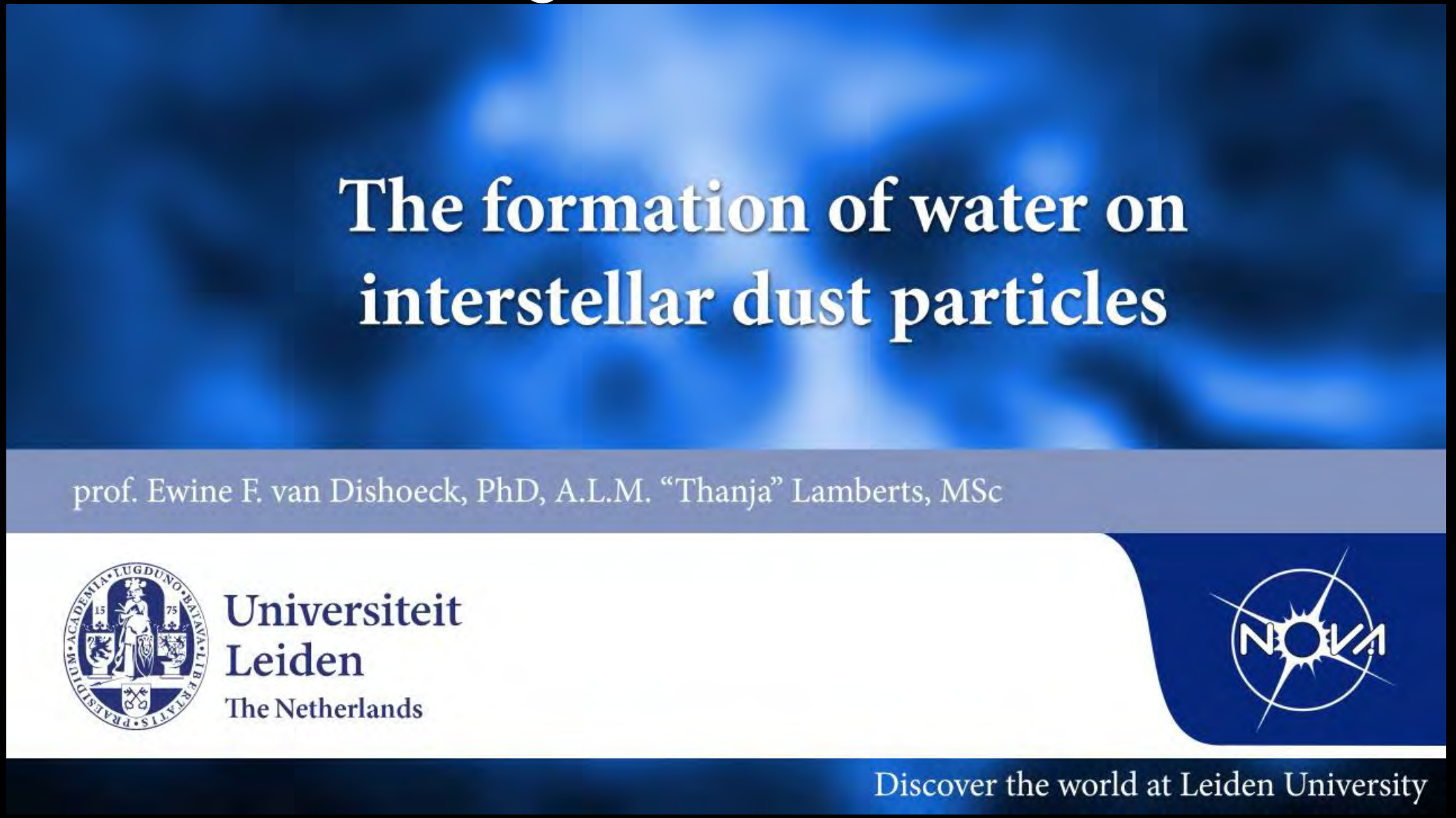
Harsono+ 2018

Planetary system

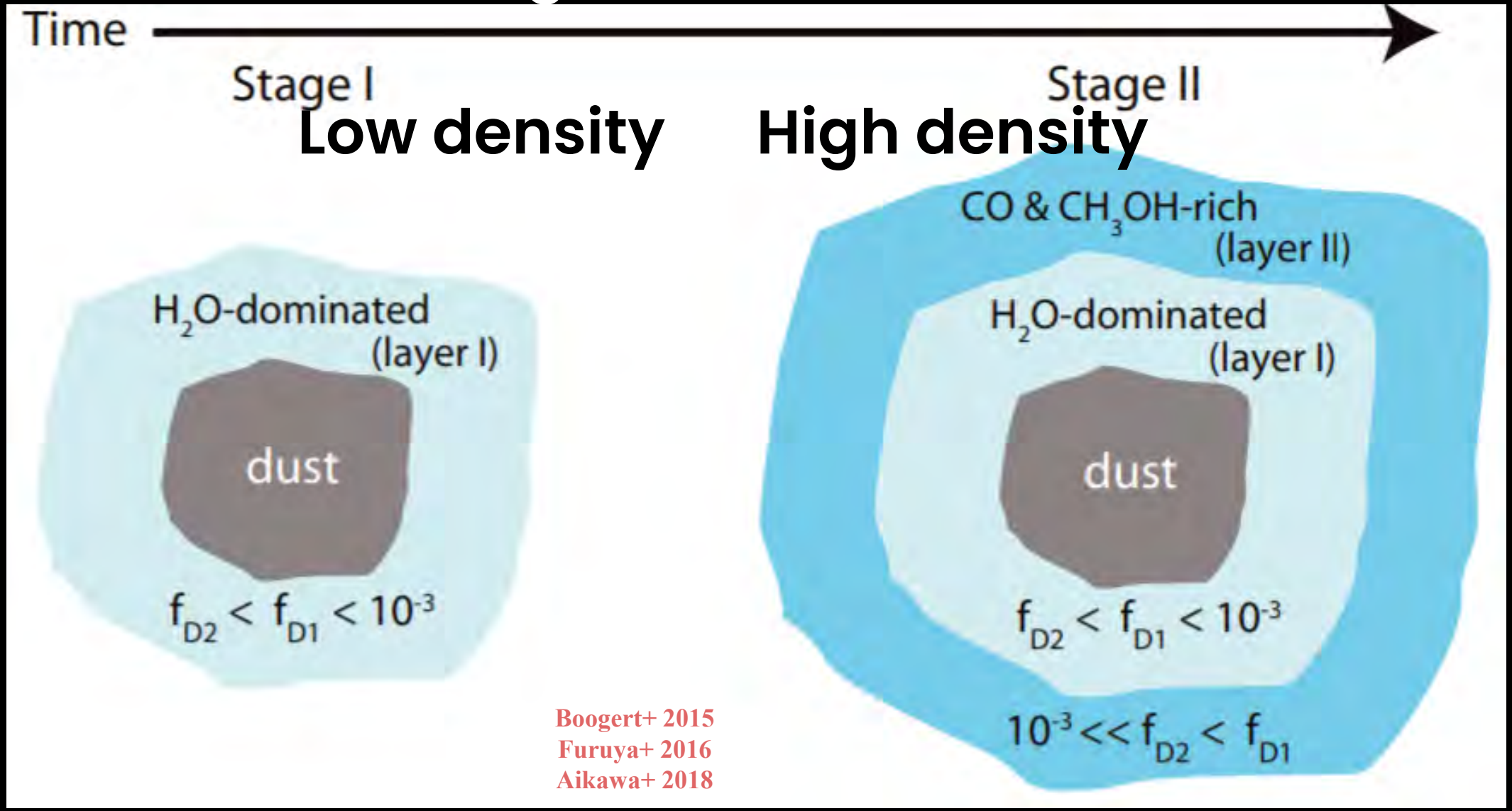
Star and planet formation



Water forms on dust grains

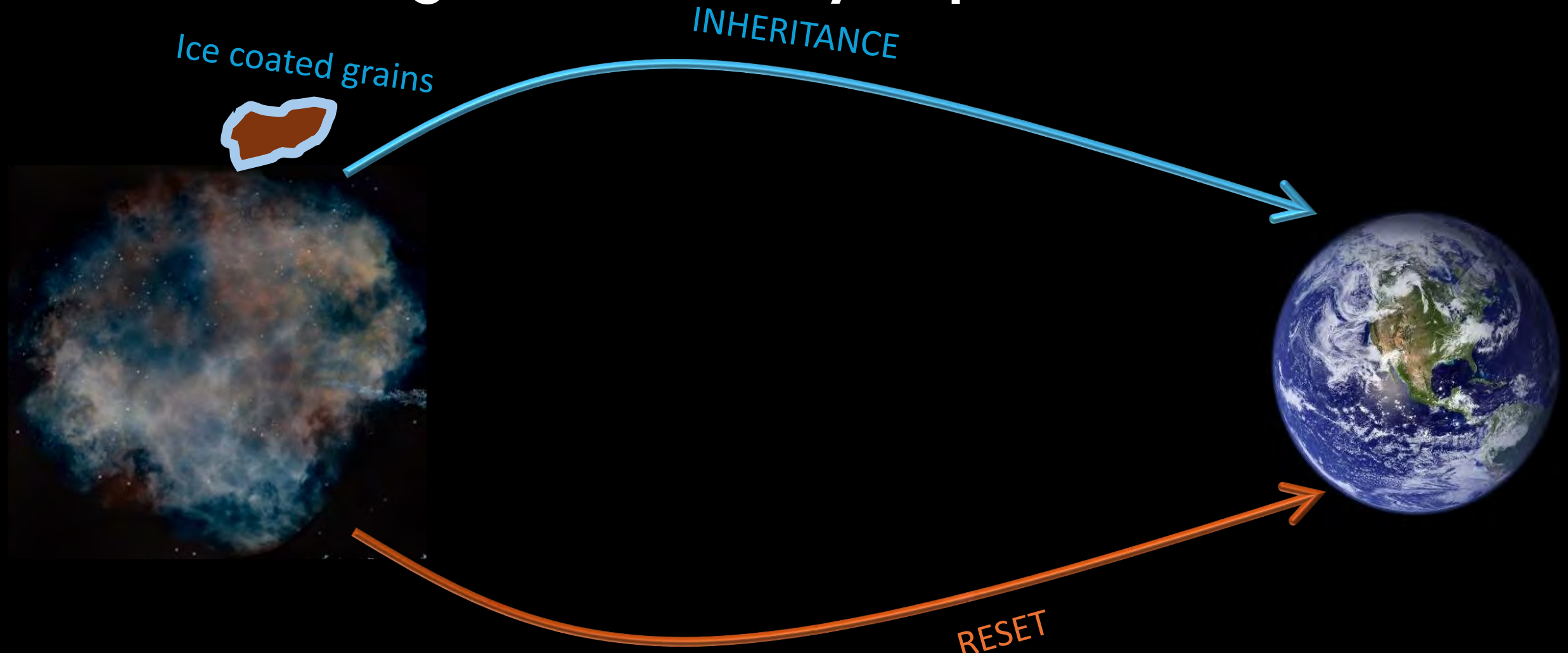


Water forms on dust grains



Boogert+ 2015
Furuya+ 2016
Aikawa+ 2018

Water and organics delivery to planets



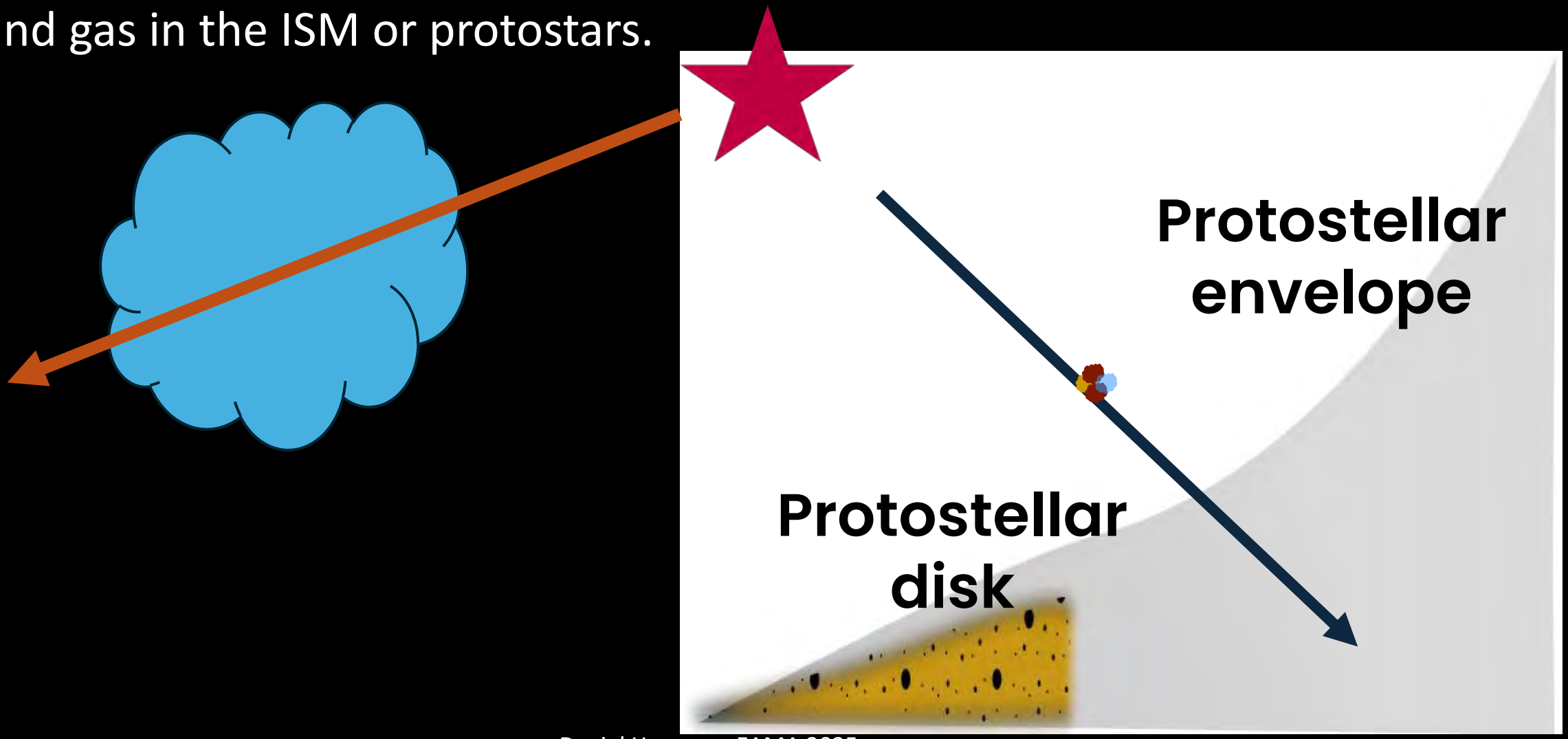
Infared: James Webb Space Telescope





Ice composition studies in infrared

Observations toward background stars can reveal the composition of dust and gas in the ISM or protostars.



Ice mapping

Wide field slitless spectroscopy across a field.

Instead of having 2—5 (ish) sightlines per star-forming region, we can get ~44 sightlines.

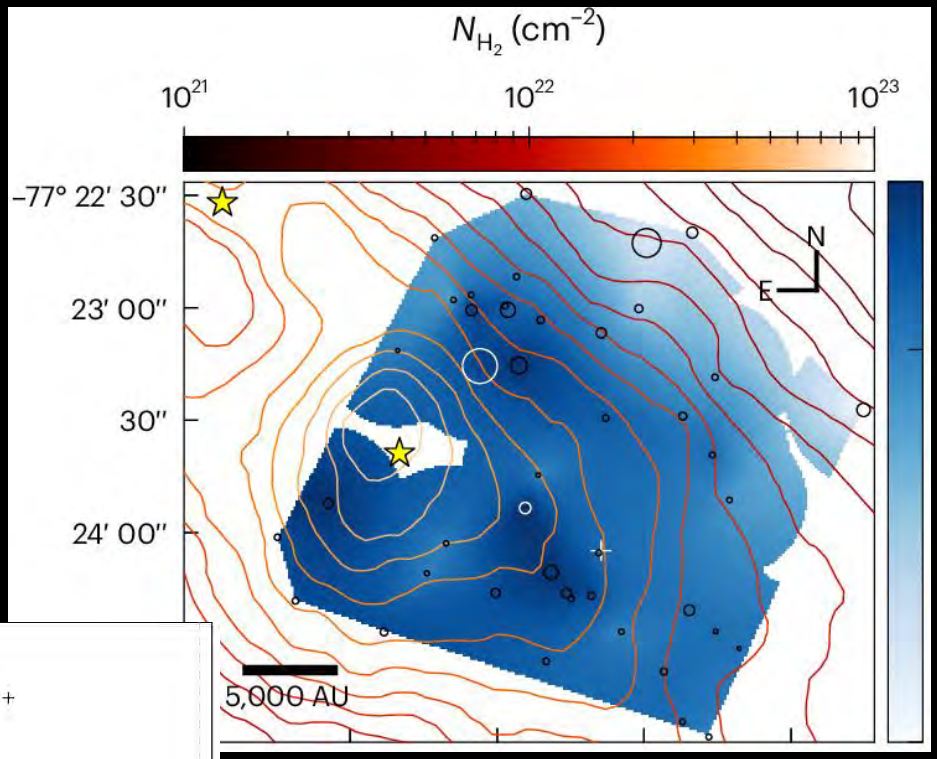


Z. L. Smith+ 2025, Nature Astronomy

Ice mapping of Cha

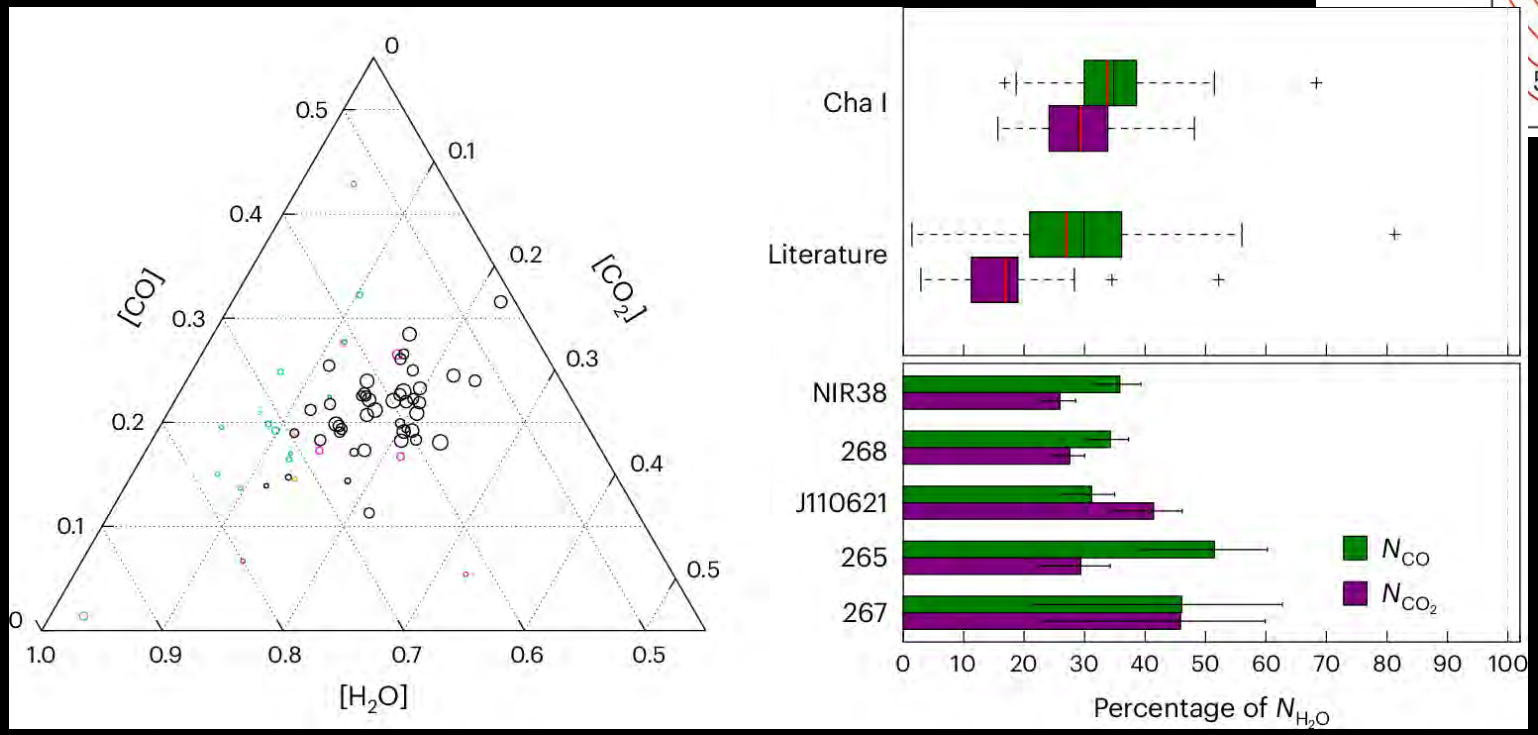
Correlations with A_v indicate **more CO_2 ice than previously thought**.

JWST observations probe higher densities, which are expected **to contain more CO and CO_2**.





Z. L. Smith+ 2025, Nature Astronomy



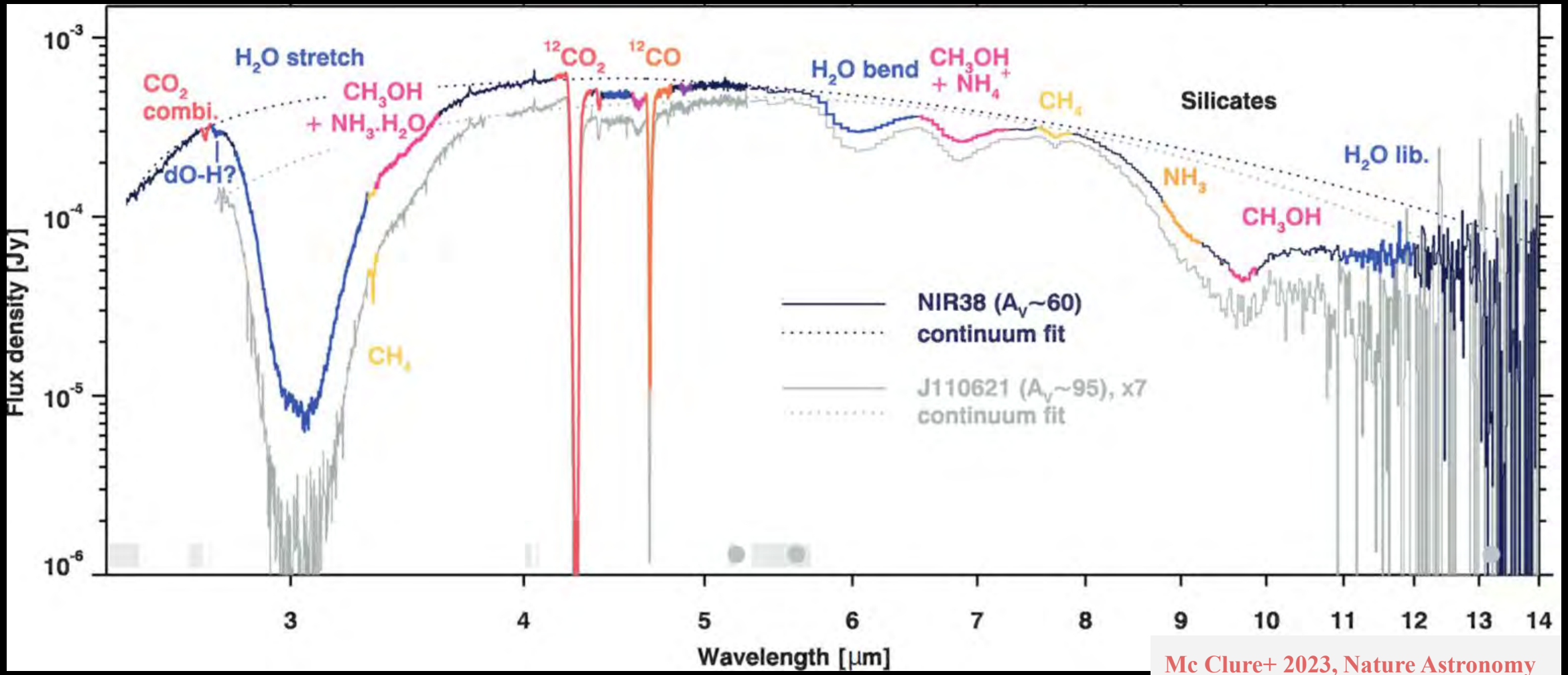
Daniel Harsono, EAMA 2025

Ice composition of a dense cloud (Cha)



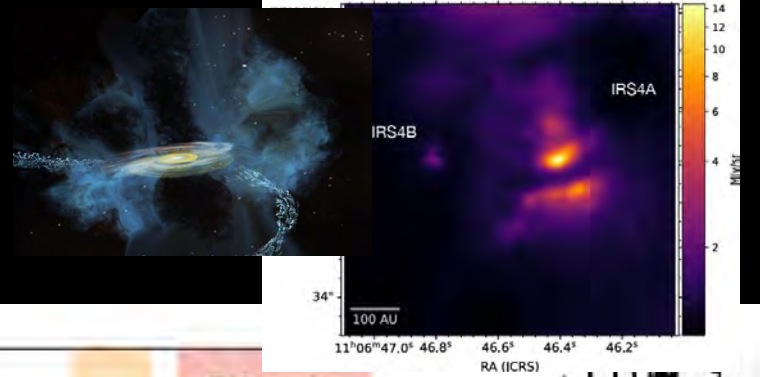
Detections of solid **water**, **simple**, and **complex organics**.

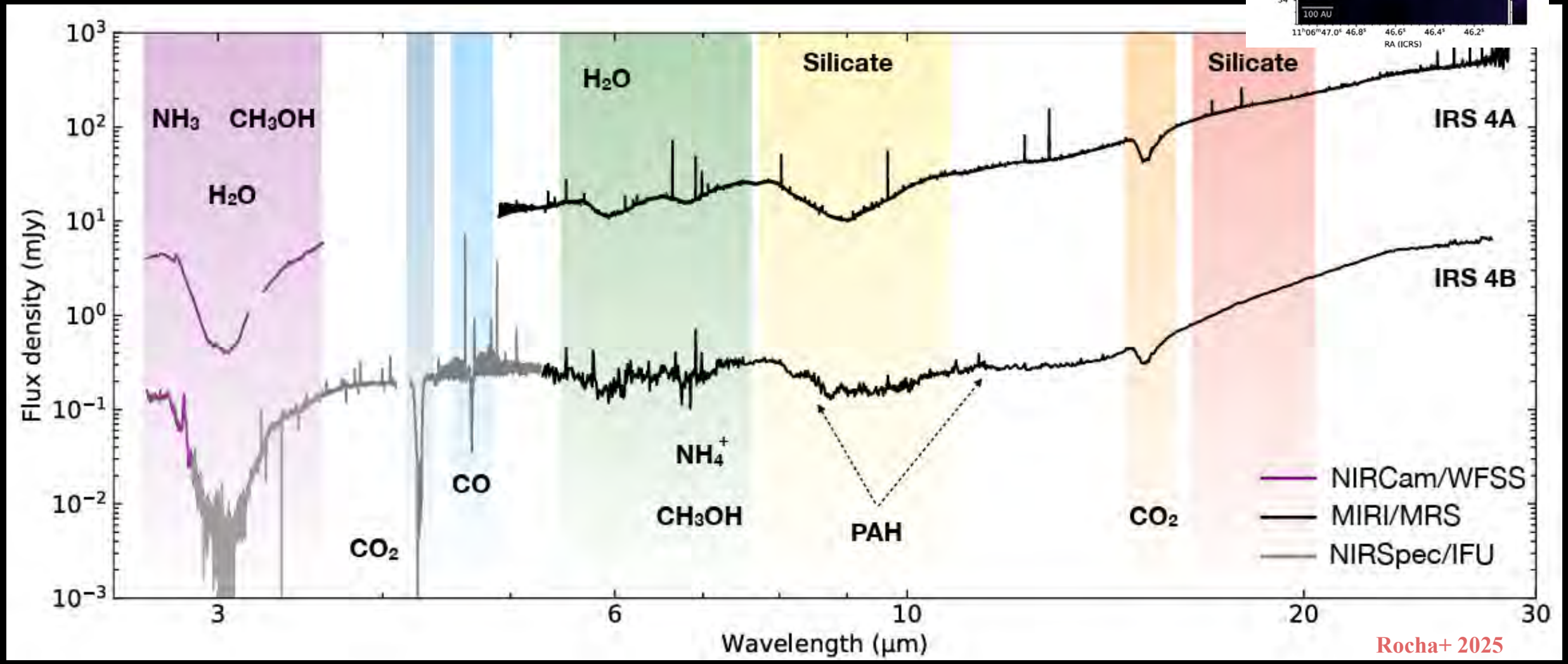
It shows that **the ice contains complex molecules (>6 atoms)** before the dense core forms.



Mc Clure+ 2023, Nature Astronomy
see Yang+ 2023

Some processing of ice is seen toward the Class I protostar



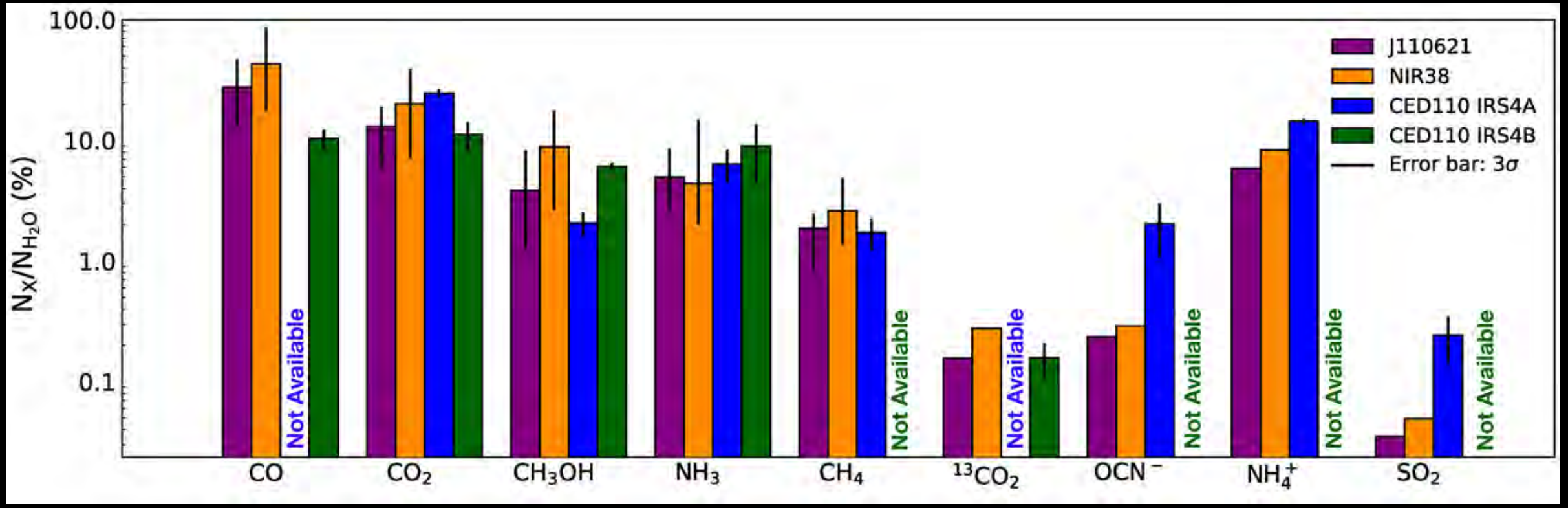


Rocha+ 2025

Ice composition of a Class I protostar (Cha)

Overall, protostars show **similar ice mixtures, which suggests that the ice composition is set at earlier stages**.

Thermal processing of the ice is seen toward the CO_2 ice.

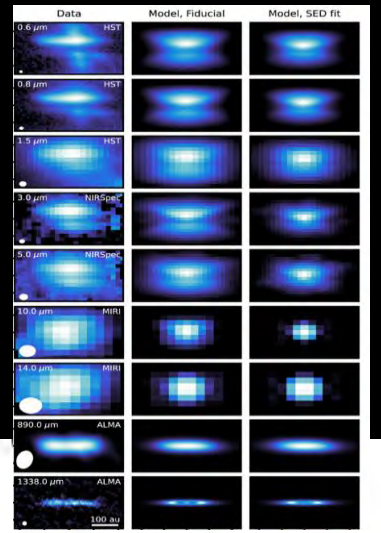


Rocha+ 2025

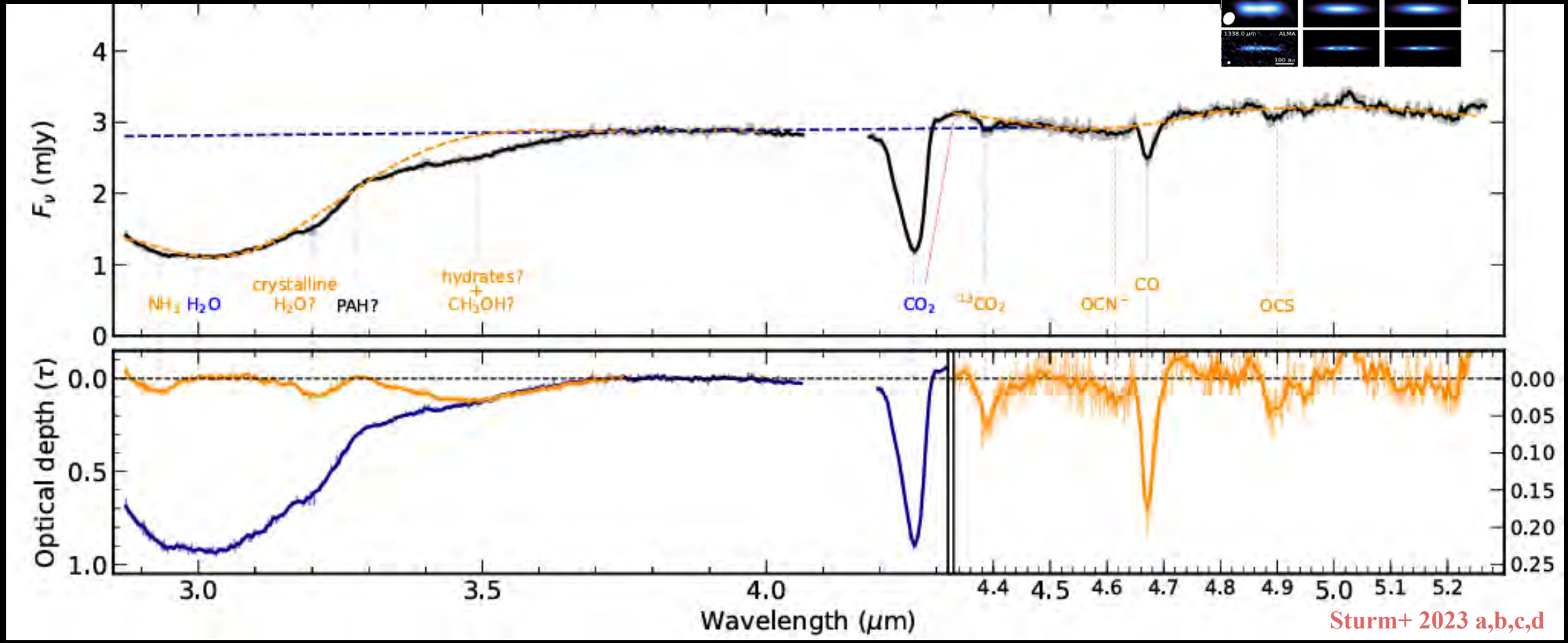
Ice composition of a protoplanetary disk

Detections of **water, NH_3, CO_2, CO, OCS, and OCN^-**.

Possible hints of crystalline water, hydrates, and methanol.

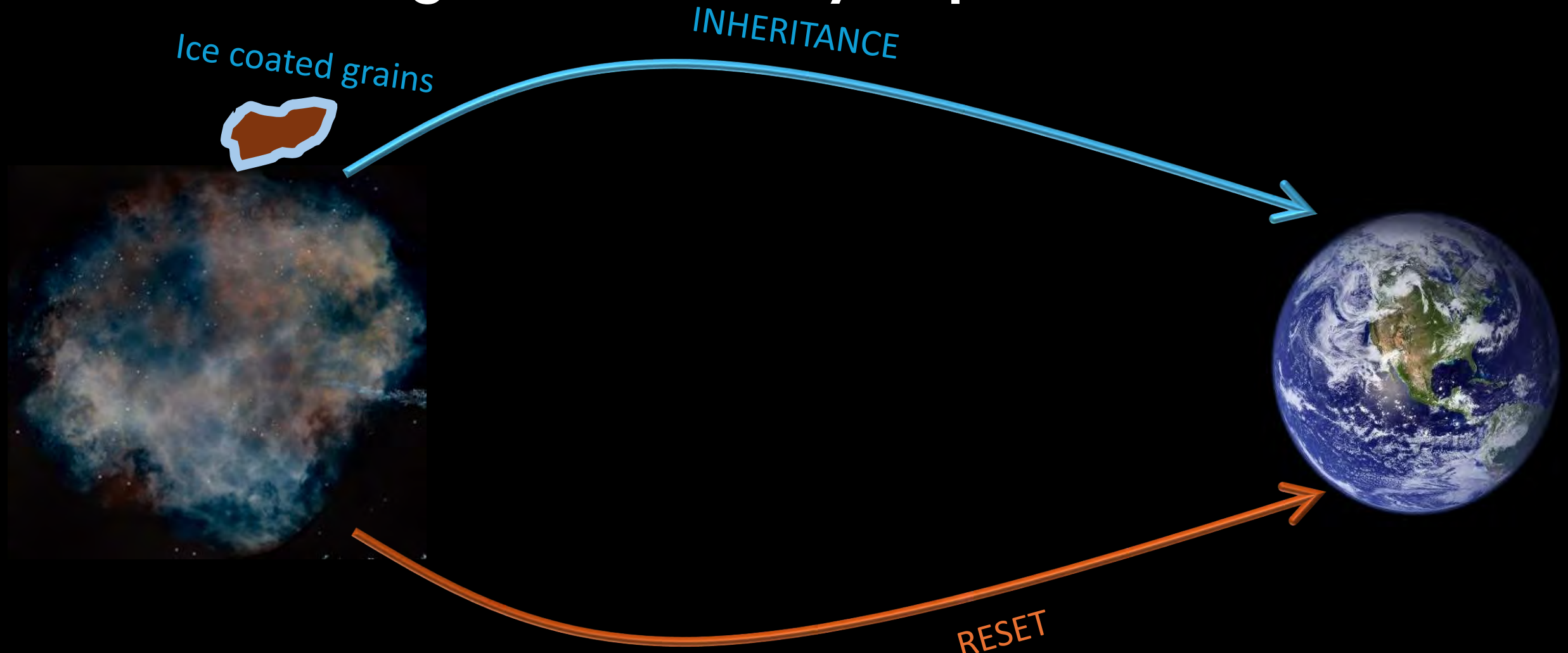






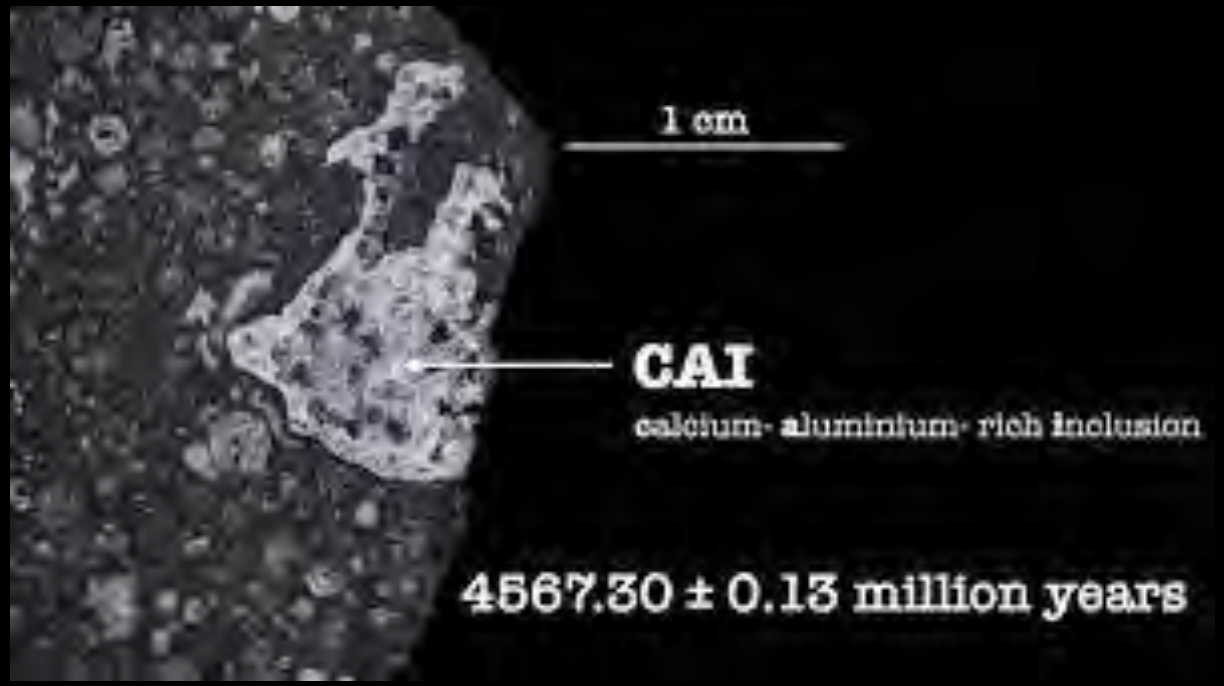
Sturm+ 2023 a,b,c,d

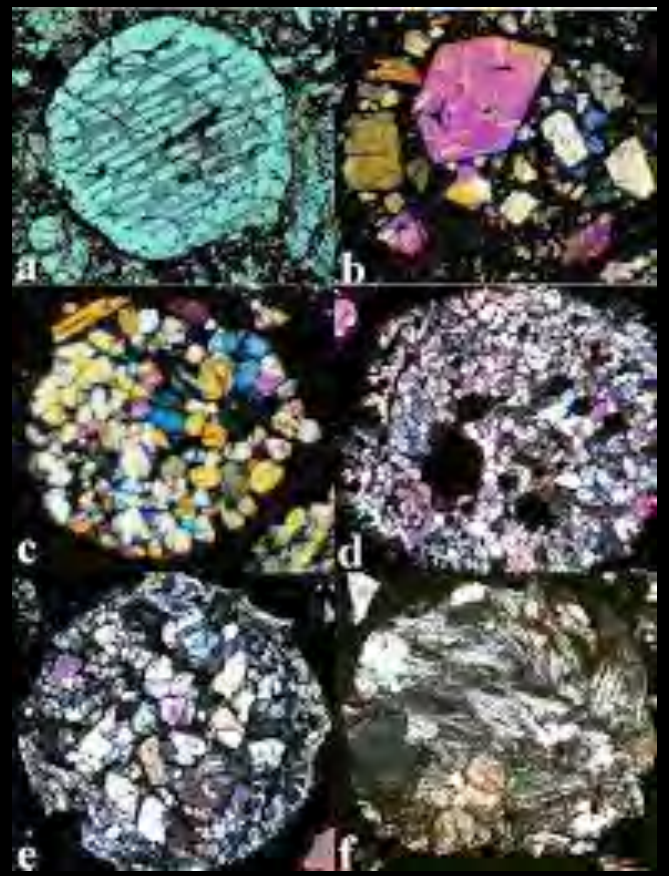
Water and organics delivery to planets



CAIs indicate some processing

Calcium-Aluminum-rich Inclusions (CAIs) typically mark the beginning of planet formation. It also indicates that the composition goes through a "reset" before planets form.

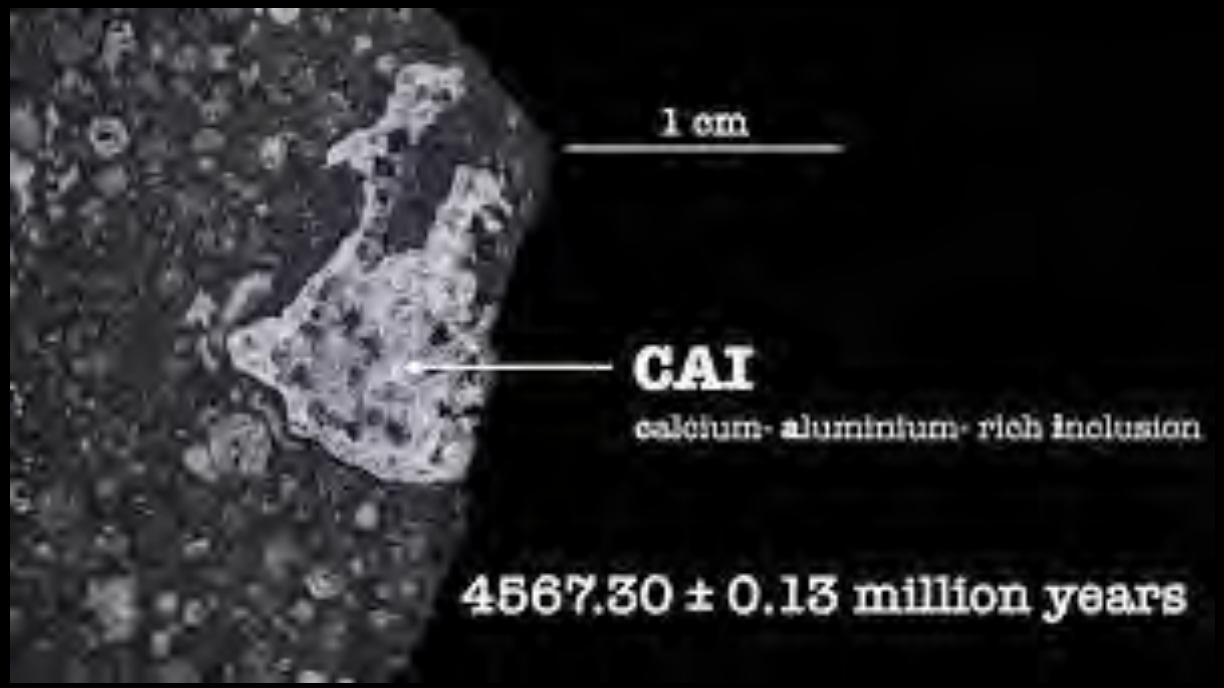


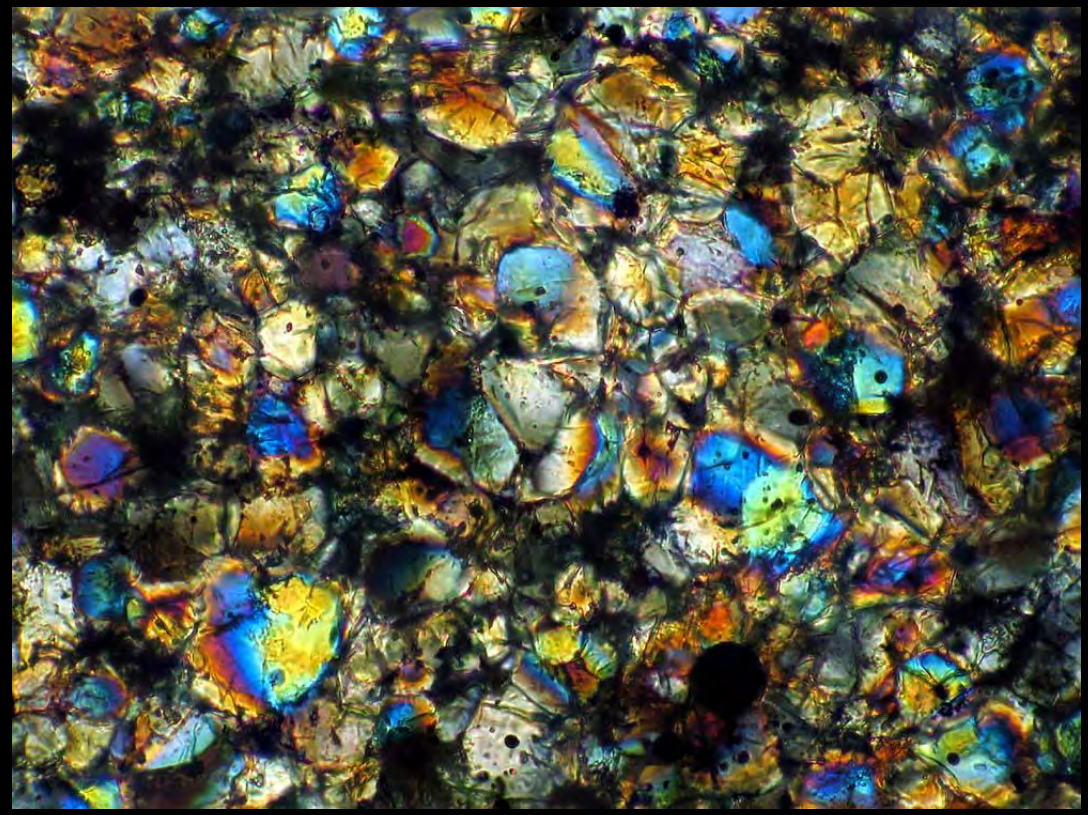


Hewins+

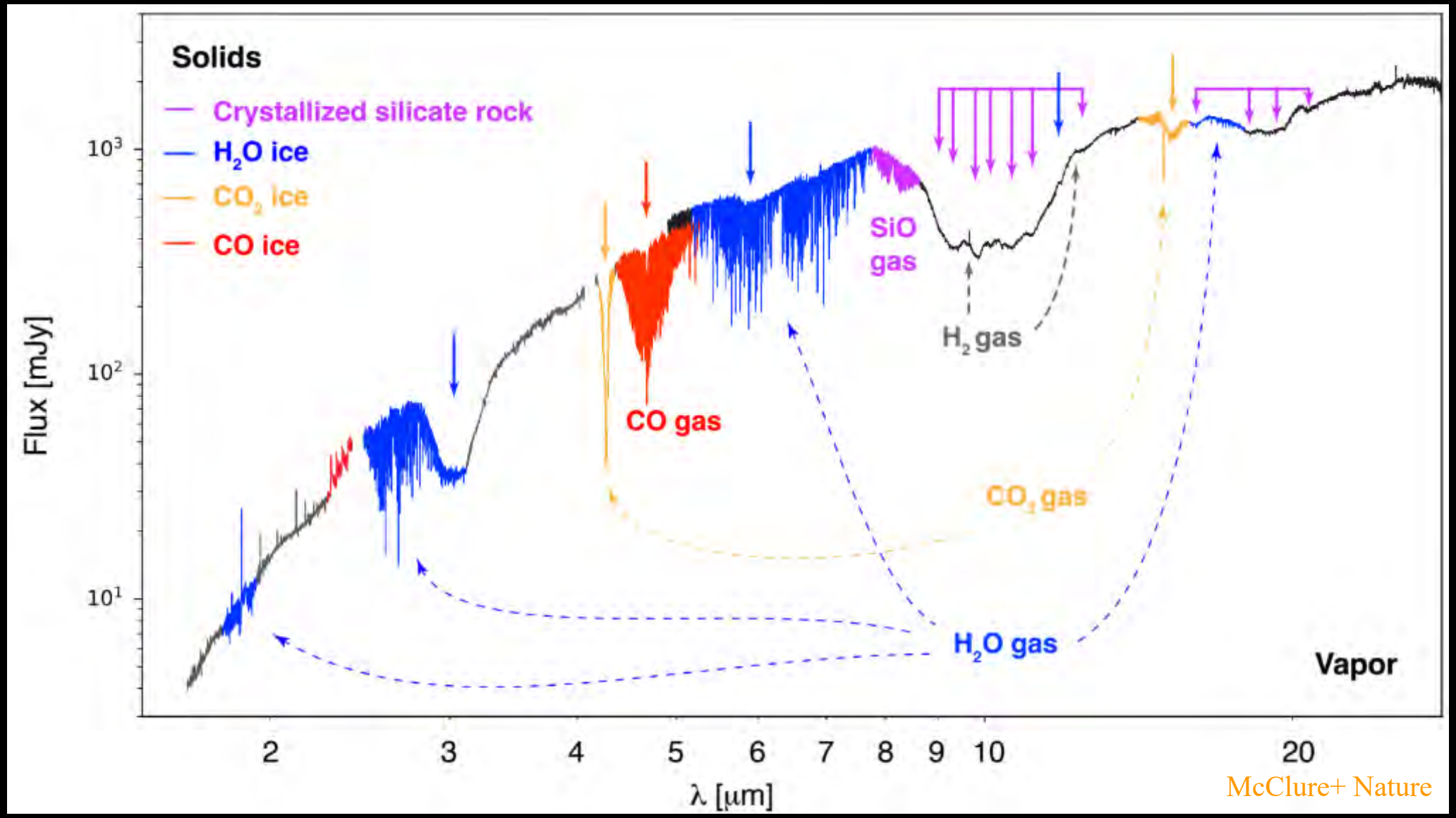
AOAs condense at a lower temperature

In addition to CAIs, AOAs (Amoeboid Olivine Aggregates) condense at a lower temperature, but they share **a similar isotopic composition** to CAIs – they form in similar regions.



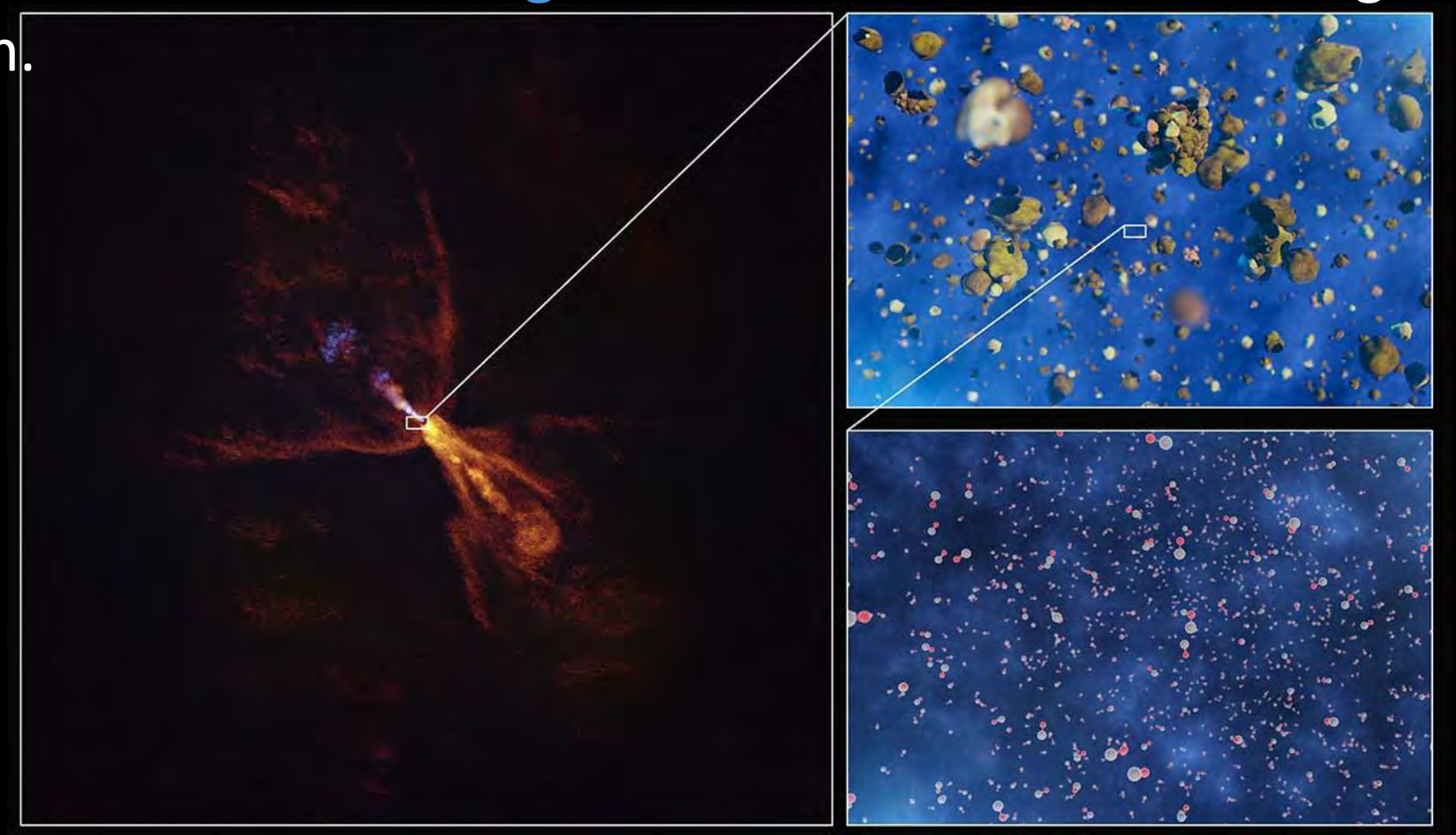


JWST observations observe the condensation



JWST observations toward HOPS 315

We are witnessing a process that happened in the solar system: **condensation of dust grains in the inner regions of disks** that mark the beginning of planet formation.

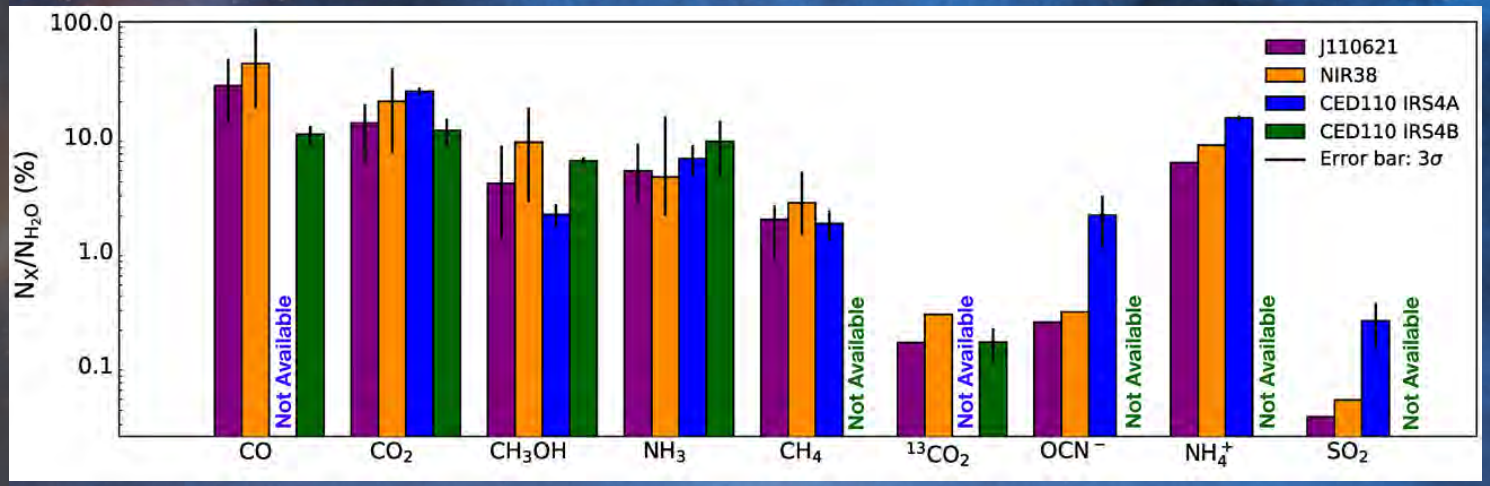


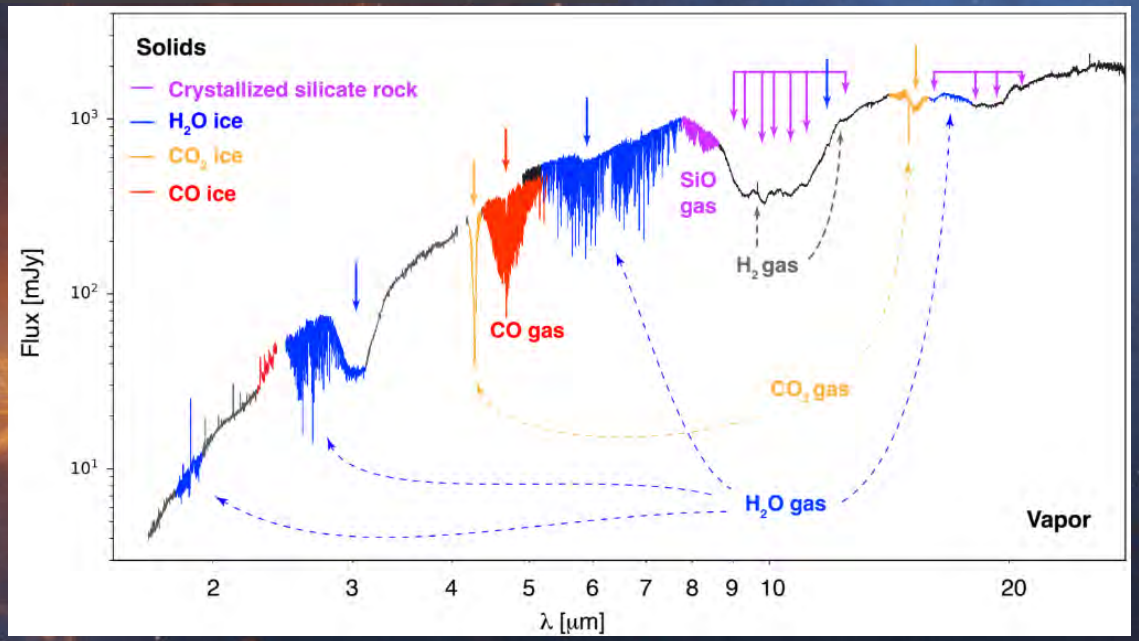
McClure+ Nature
L. Calçada/ESO

Summary

Ice evolution in the star and planet formation has been studied for many protostars and star-forming regions.

Ice chemistry is complex that starting early and largely inherited.





Planet formation starts in the earliest stages of star formation.

JWST has provided us with observational evidence of the dust condensation in the inner regions of the young protoplanetary disk.