STAR & PLANET FORMATION WITH JWST

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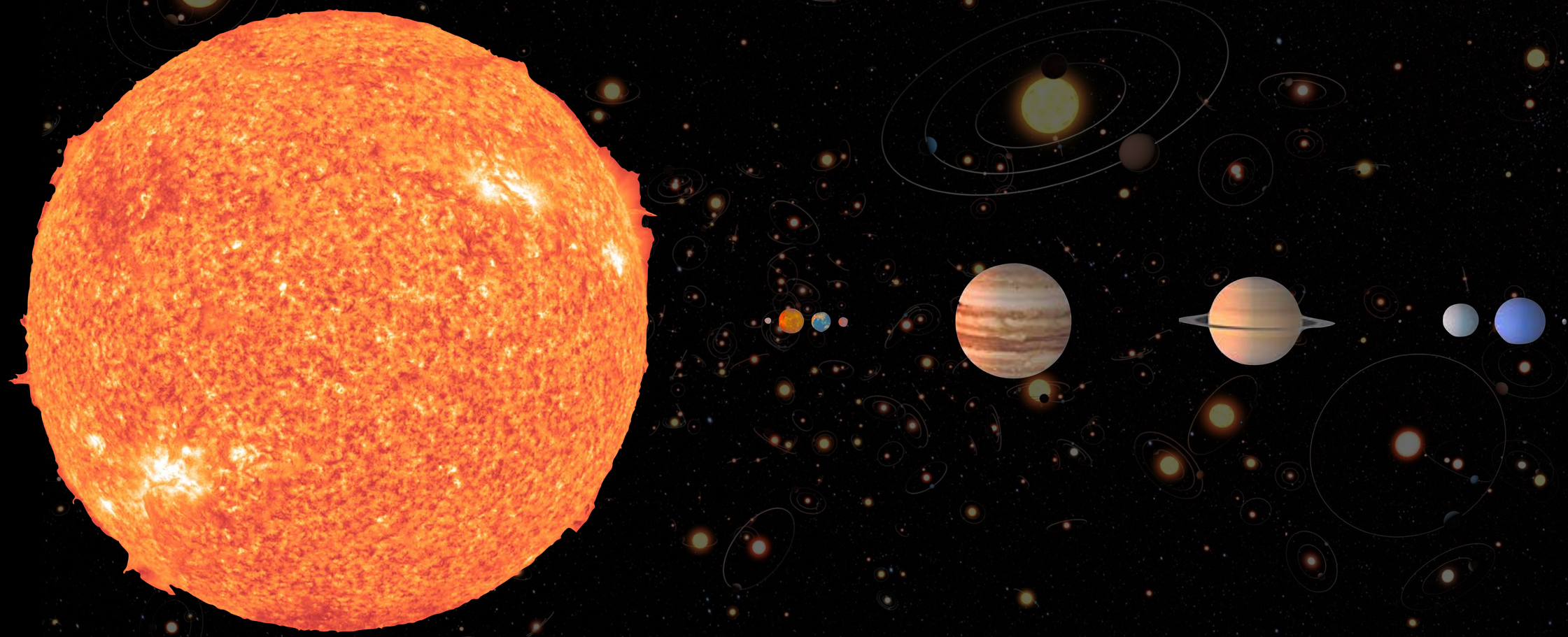
June 8, 2021

Image Credit: University of Copenhagen/Lars Buchhave, W. Garnier, ALMA (ESO/NAOJ/NRAO)

ARE WE ALONE?

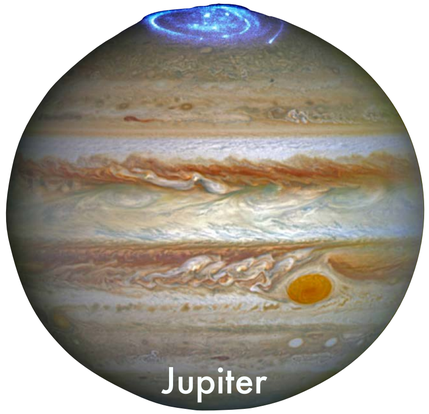


HOW OFTEN DO PLANETS HAVE THE "RIGHT STUFF?"

Hydrogen and Helium

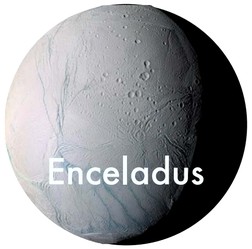
Ammonia + H_2O clouds.

Oxygen still a puzzle. Juno!



Rocky with CO_2 and H_2O ice caps

Icy crust, subsurface ocean, rocky core (e.g., Thomas+2015). Plumes!



Dense atmosphere of CO_2, sulfuric acid, N_2

98.4% N_2 atmosphere the rest in CH_4 and H_2. H_2O "crust"

Image credit: NASA, J. Bell (Cornell U.) and M. Wolff (SSI), ISAS, JAXA, Cassini, ESA, J. Nichols (University of Leicester)

TWO KEY QUESTIONS

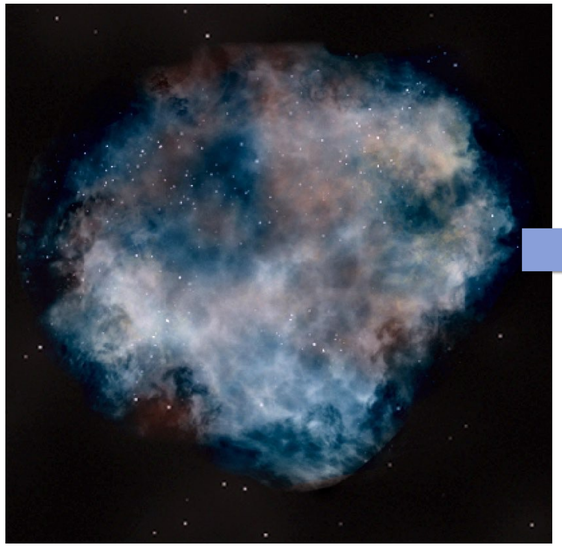
1. *How* do stars and planets assemble?

2. *What* is the chemical make up *and* history of the interstellar medium from which stars & planets form?

NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA), the Hubble Space Telescope Orion Treasury Project Team and L. Ricci (ESO)

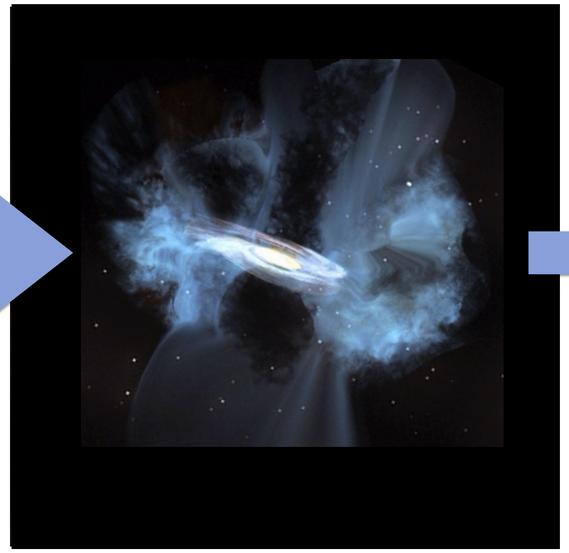
THE STANDARD "RECIPE"

Interstellar Cloud



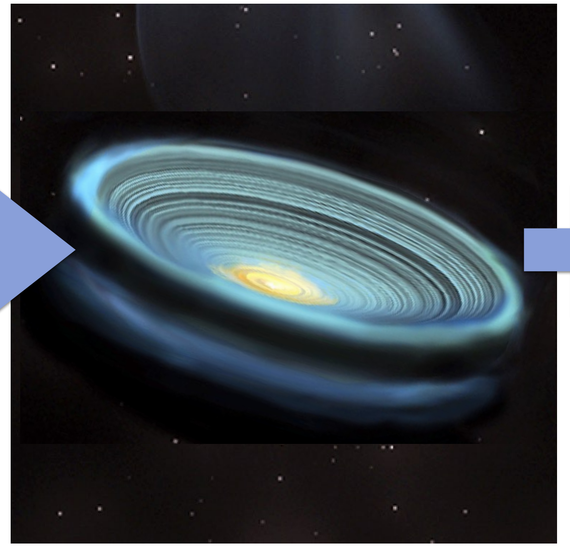
~10s of Myr

Protostar



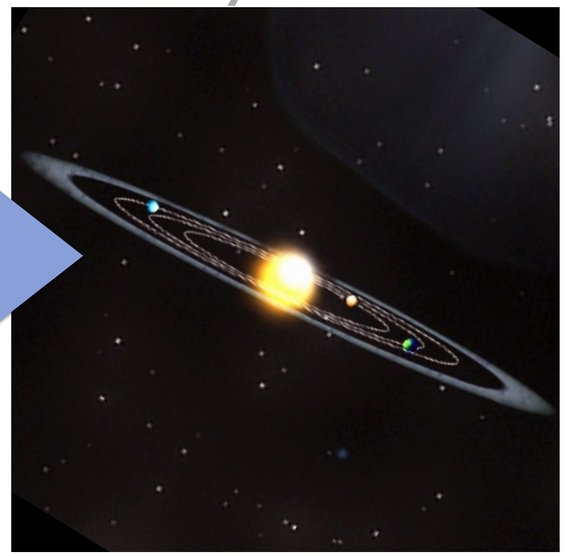
~100s of kyr

Protoplanetary Disk



~1-20 Myr

Planetary/Debris System

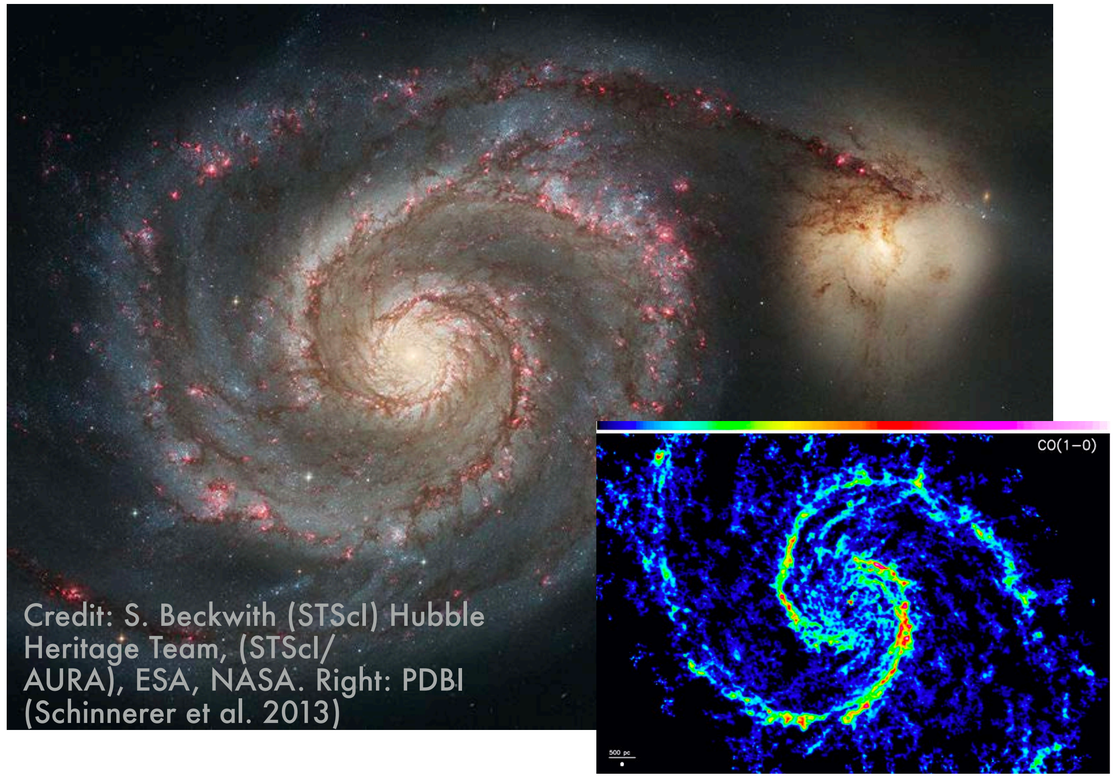


> Myr - Gyr

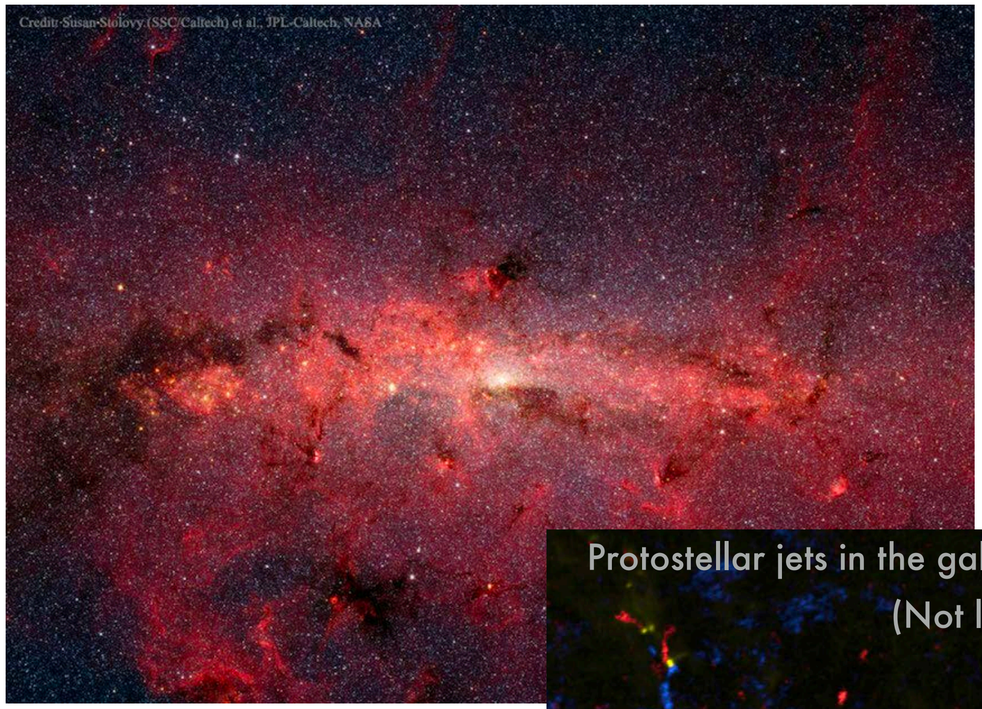
What we know…

STAR FORMATION: A WIDE VARIETY OF ENVIRONMENTS

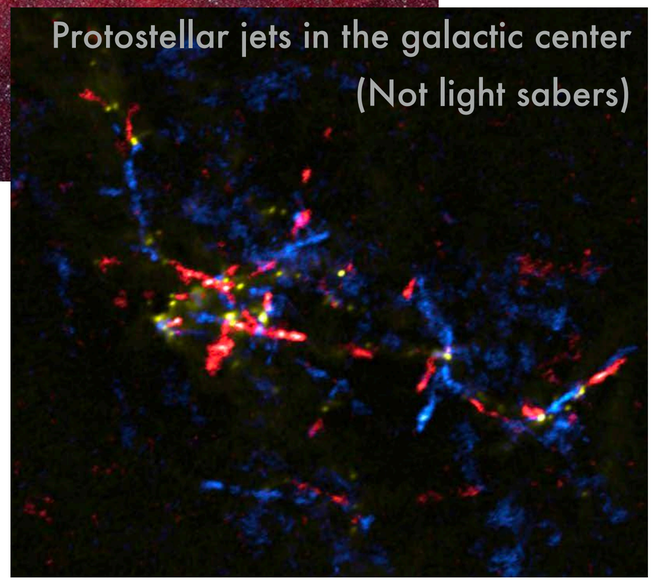
In spiral arms and between interacting galaxies…



Credit: S. Beckwith (STScI) Hubble Heritage Team, (STScI/ AURA), ESA, NASA. Right: PDBI (Schinnerer et al. 2013)



Even in our galaxy's center (Spitzer/ IRAC; top), seen in the radio with outflows/jets (Lu et al; ALMA; right)



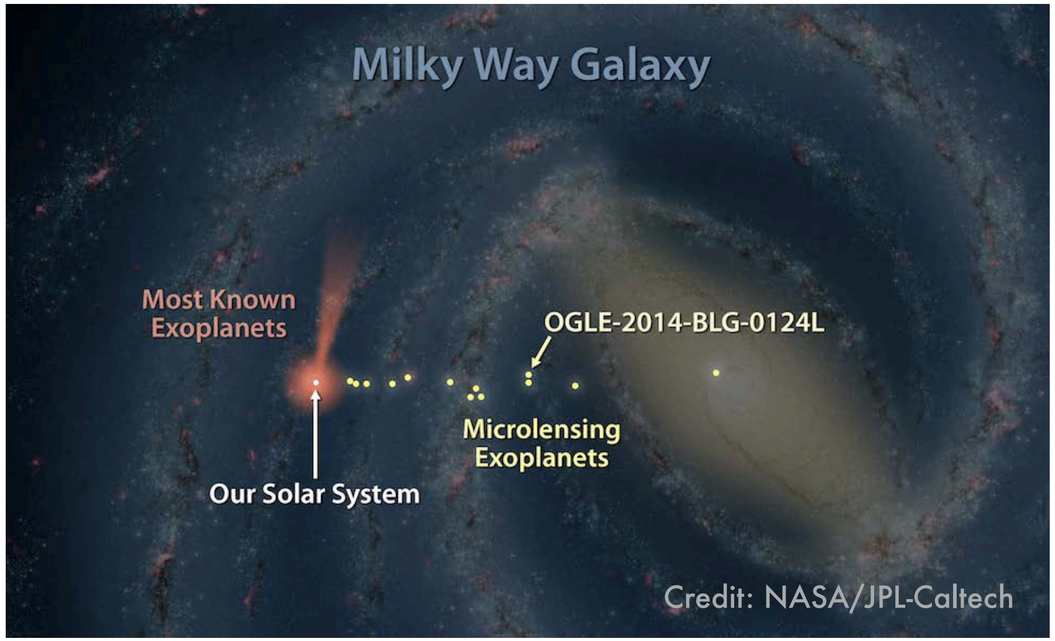
Protostellar jets in the galactic center

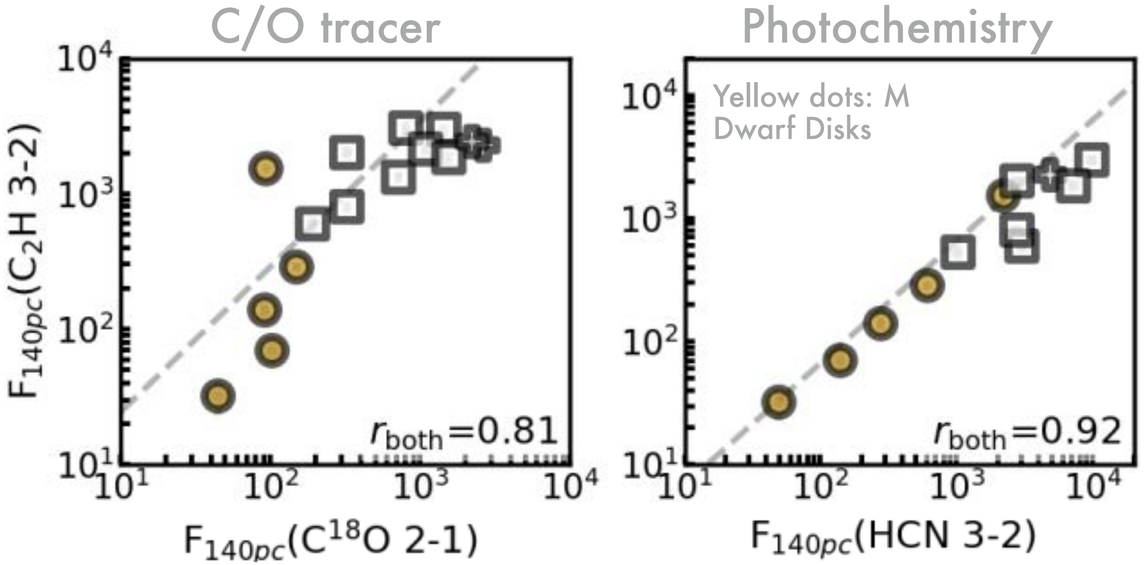
(Not light sabers)

What we know…

PLANET FORMATION: UBIQUITOUS(?)

Exoplanets seem to be **everywhere** we look Even in the galactic center (e.g., Udalski et al. 2015).

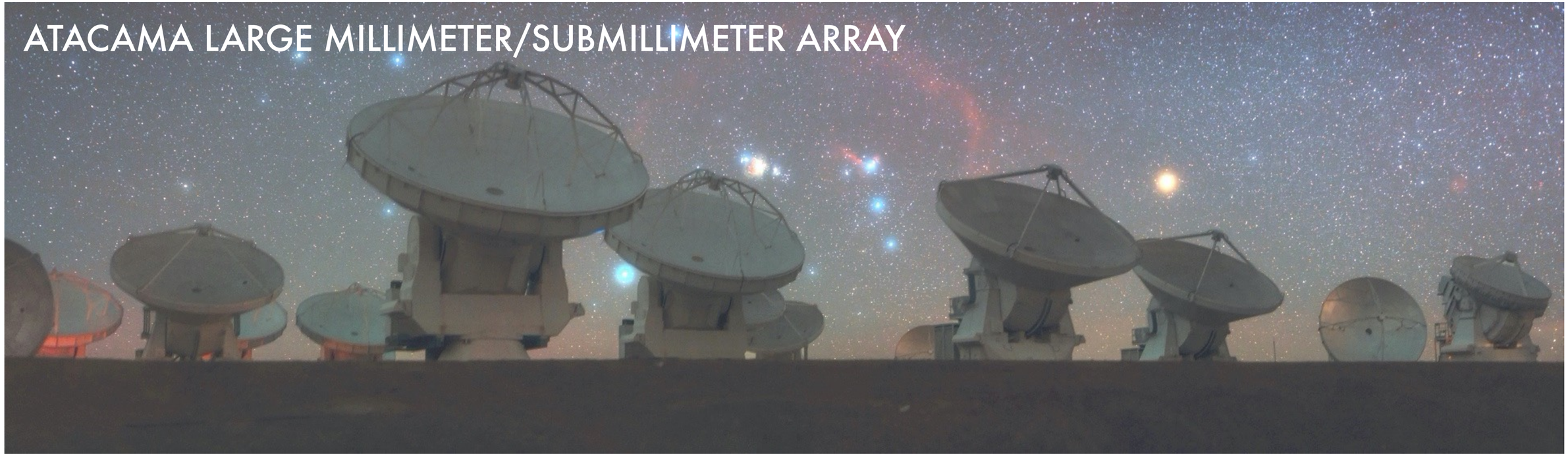




Circumstellar disks also seem to be common, and may even have **commonalities** in their chemistry across the stellar mass spectrum; top (Pegues et al. 2021, ApJ)

What we know…

NOW: THE ERA OF ALMA

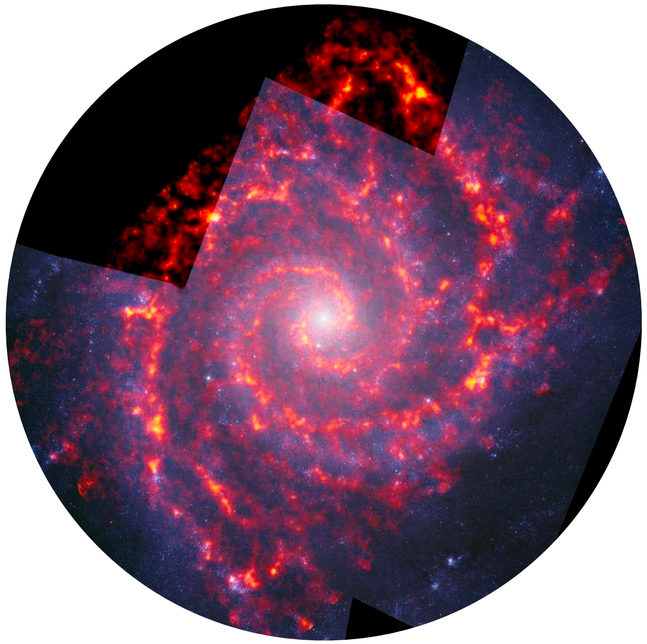


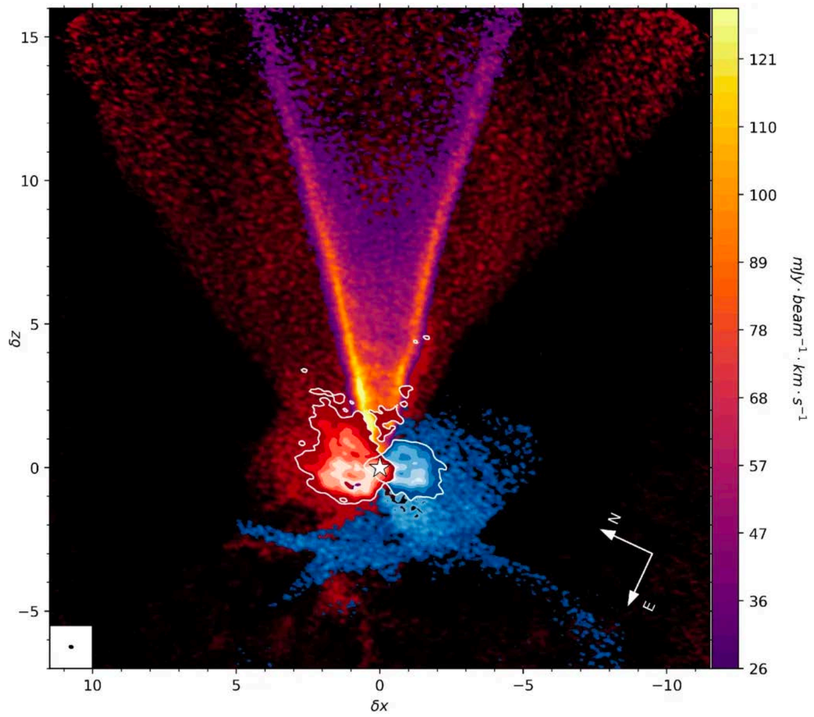
Chajnantor plateau, Atacama Desert, Chile (5000 meters)

Credit: ESO/B. Tafreshi (twanight.org)

AN ALMA PICTURE OF STAR AND PLANET FORMATION

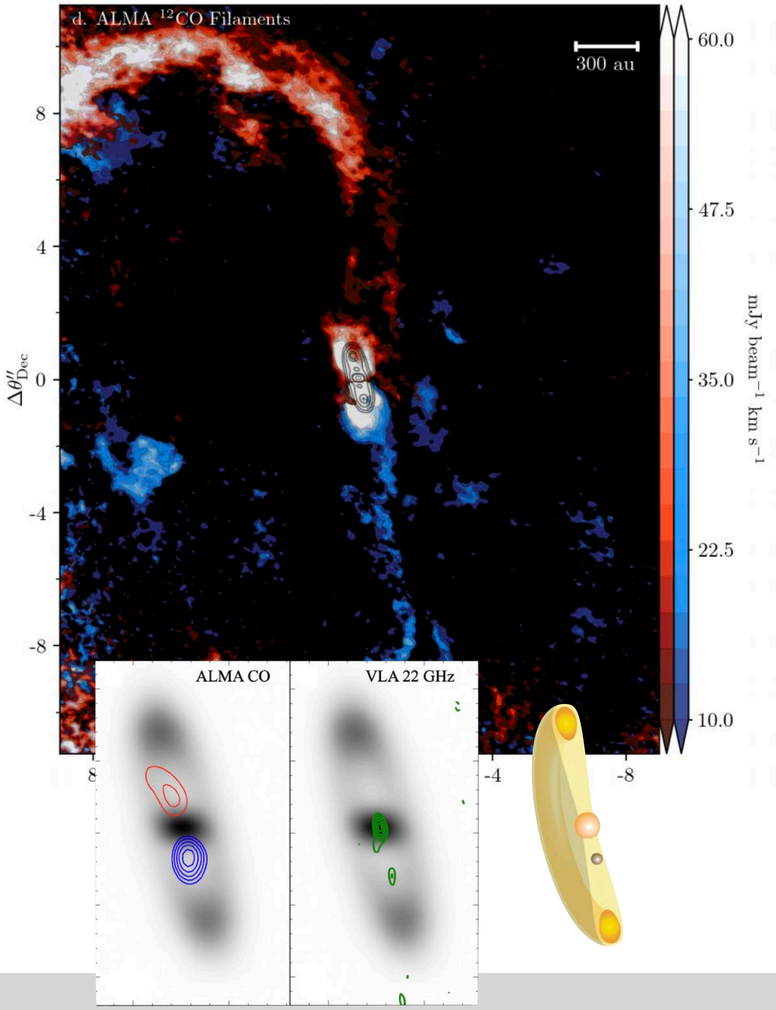
Star formation on galactic scales (e.g., PHANGS collaboration)





Outflows and jets from Young Stars (DG Tau; de Valon+20)

Planets forming alongside stars (BHB07-01; Alves+20)



What we know…

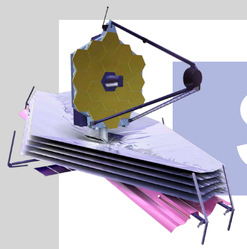
(A FEW) OPEN QUESTIONS IN SF AND PF SCIENCE

PHYSICAL:

- How long are disks around?
- What is the mass spectrum of disks?
- How does the mass spectrum relate to the stellar mass?
- Role of binarity?
- Role of the environment?
- How do you form a terrestrial planet? A super earth?
- Or a jupiter?
- Or anything >1 meter?
- And how do we detect them?
- When does planet formation begin?
- What sets planetary systems' architecture?
- What is the disk surface density in gas and dust?
- How do we measure it?
- What sets disk kinematics? Turbulence?
- How do disks accrete?
- Meaning of dust disk structure?
- Magnetic fields?!?!

CHEMICAL:

- Is disk composition set by inheritance (from the cloud) or in situ disk chemistry?
- What are the primary forms of carbon, nitrogen and oxygen? Spatially?
- Where are the vapor/ ice phase transitions (snow lines)?
- Are these important in forming planets?
- What kind of chemistry is necessary to make a habitable planet?
- What is the ionization balance (electron fraction) in the disk?
- What is the role of chemical mixing?
- What is the composition of solids? Silicates? Iron rich or Mg rich? What about the carbonaceous grains?
- What are the main chemical processes and what molecules are tracers?
- Meaning of chemical structure?



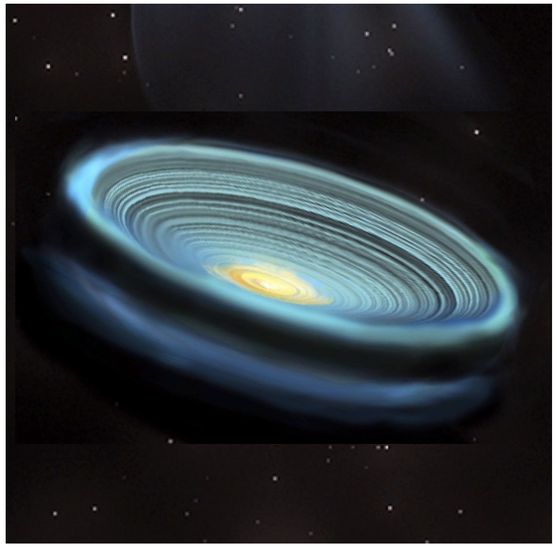
STAR AND PLANET FORMATION WITH *JWST*

JWST provides a unique tool to help us answer many of these questions in greater detail than previously possible.

Where and how do stars form?

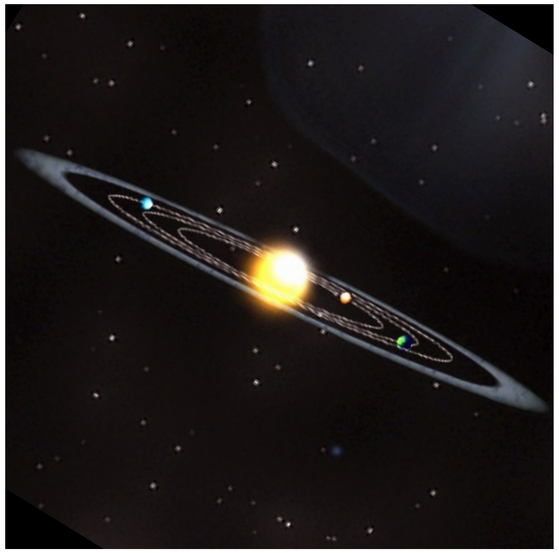
How do stars assemble?

How do they disrupt their environment?



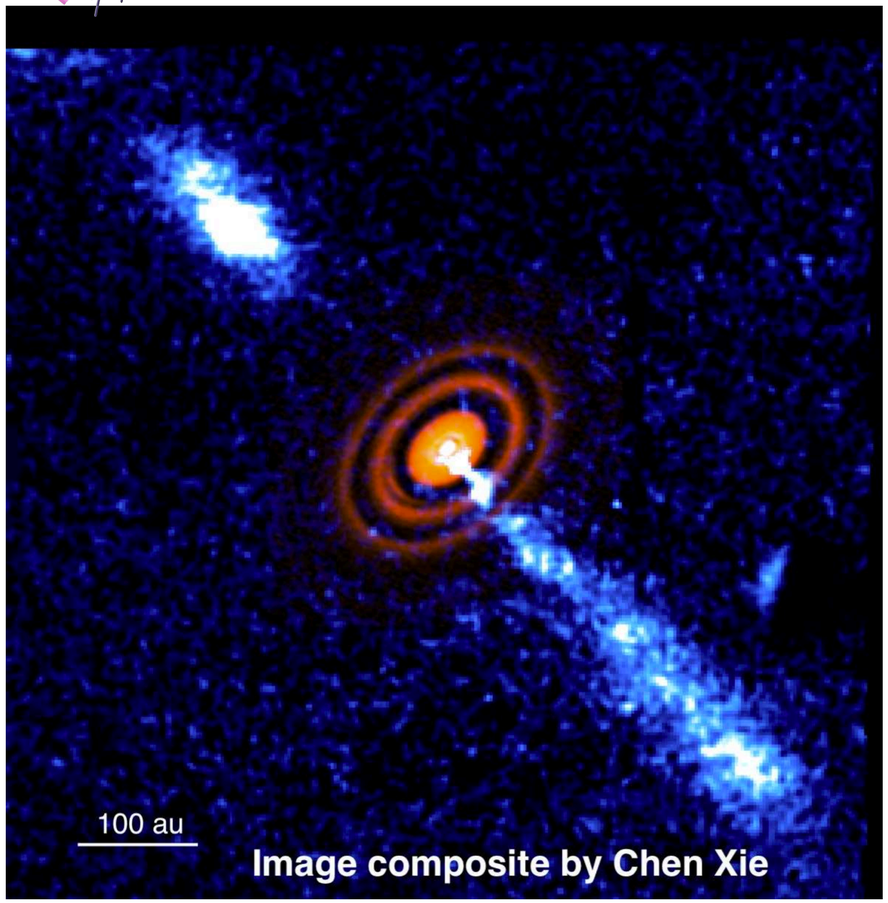
Where do planets form and with what?

How much is nature vs. nurture?



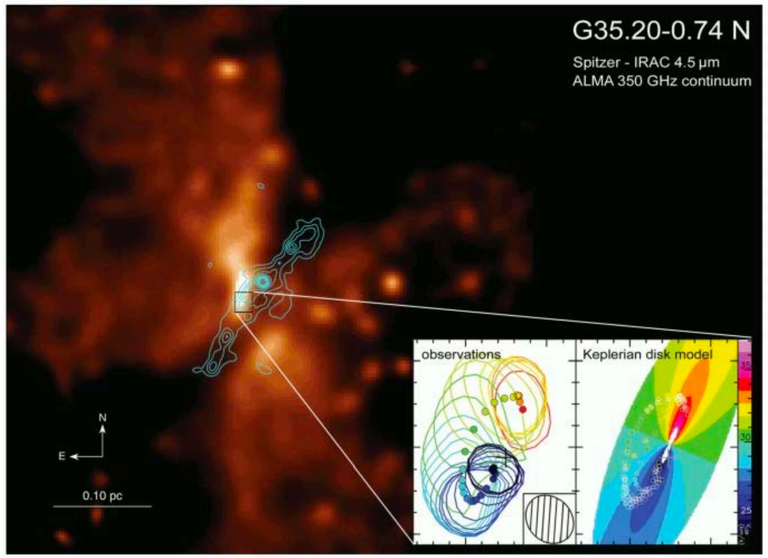
What do the final "messy" assembly steps look like?

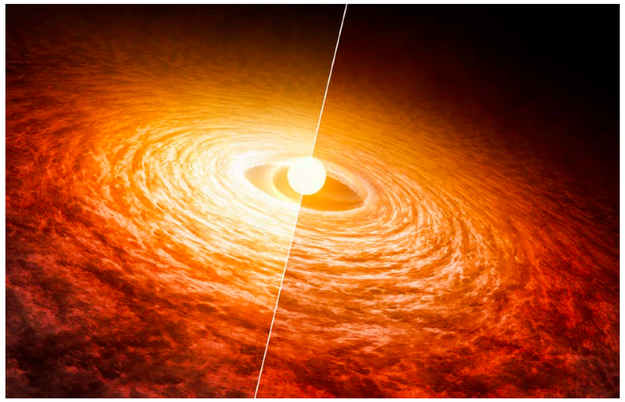
HIGHLIGHTS: STELLAR ASSEMBLY



HD 163296's jet seen in optical [SII] emission (Xie+21)

Massive star outflows: powerful shapers of SF regions (Sánchez-Monge +13)

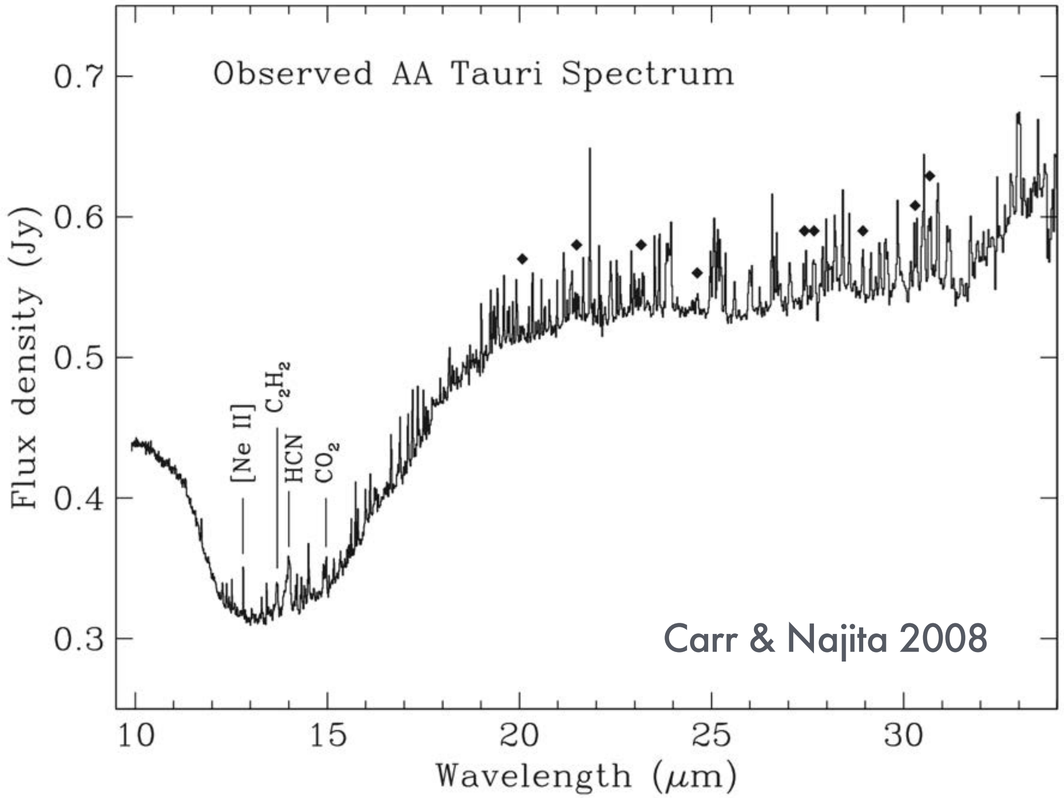


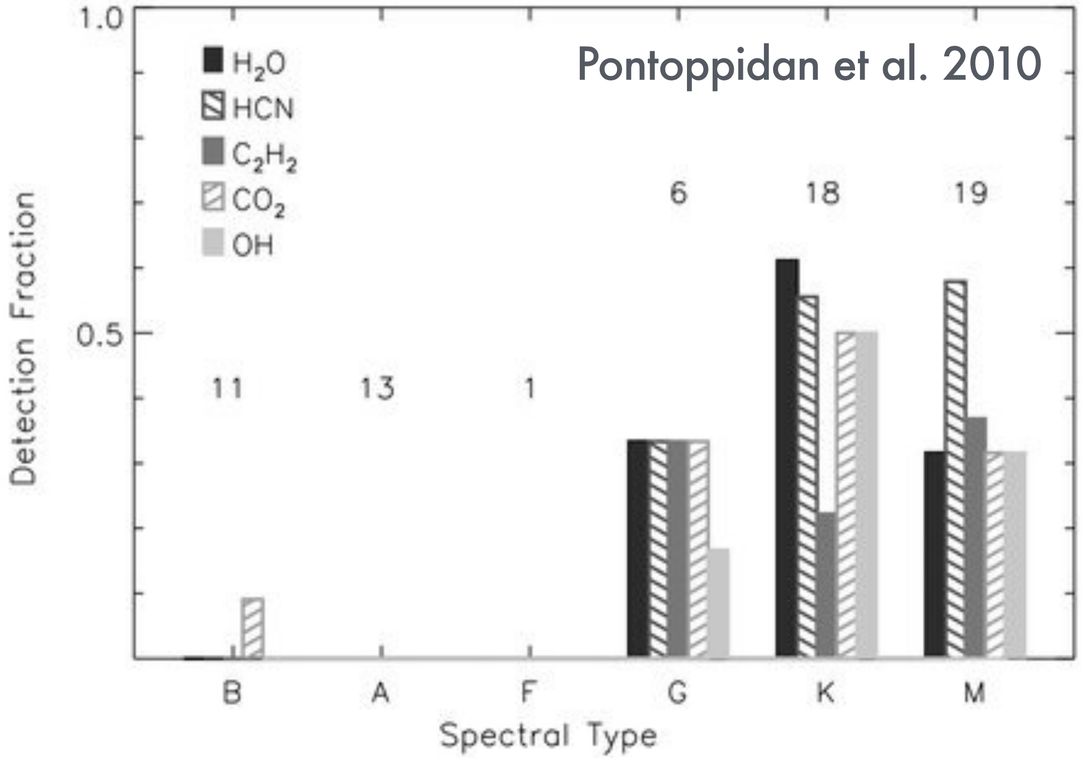


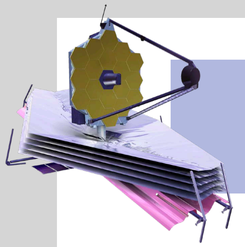
Early stellar assembly likely 'bursty.' JWST is poised to investigate the chemistry and even map the mineralogy post outburst.

CHEMISTRY OF THE TERRESTRIAL PLANET FORMING REGION

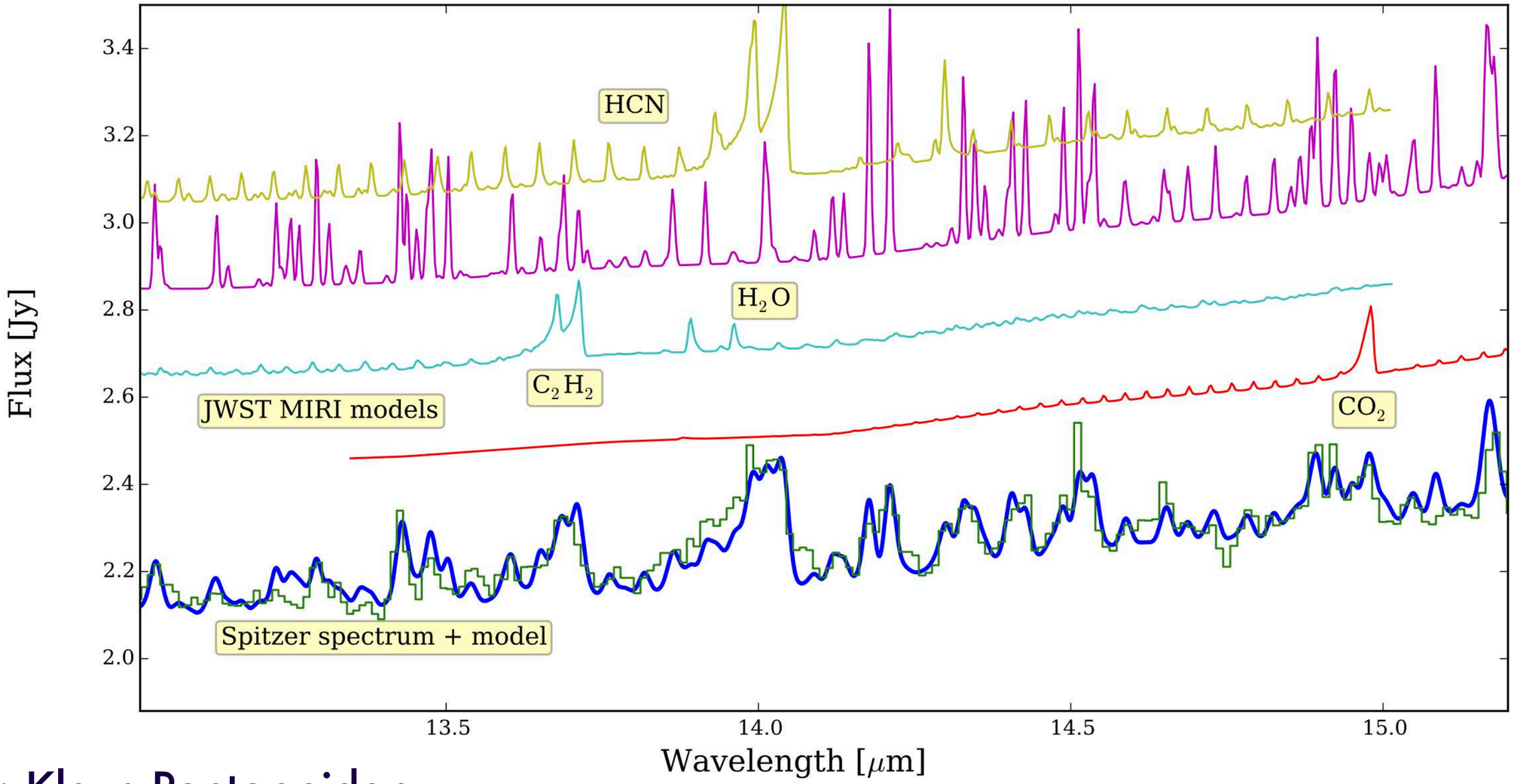
Spitzer discovered water, organics, hydrocarbons within a few AU.



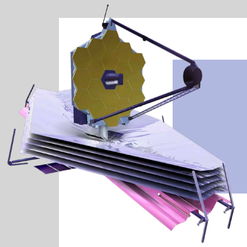




CHEMISTRY OF THE TPFR: JWST



Credit: Klaus Pontoppidan



HIGHLIGHTS: THE ICY UNIVERSE

ICY MOLECULAR CLOUDS

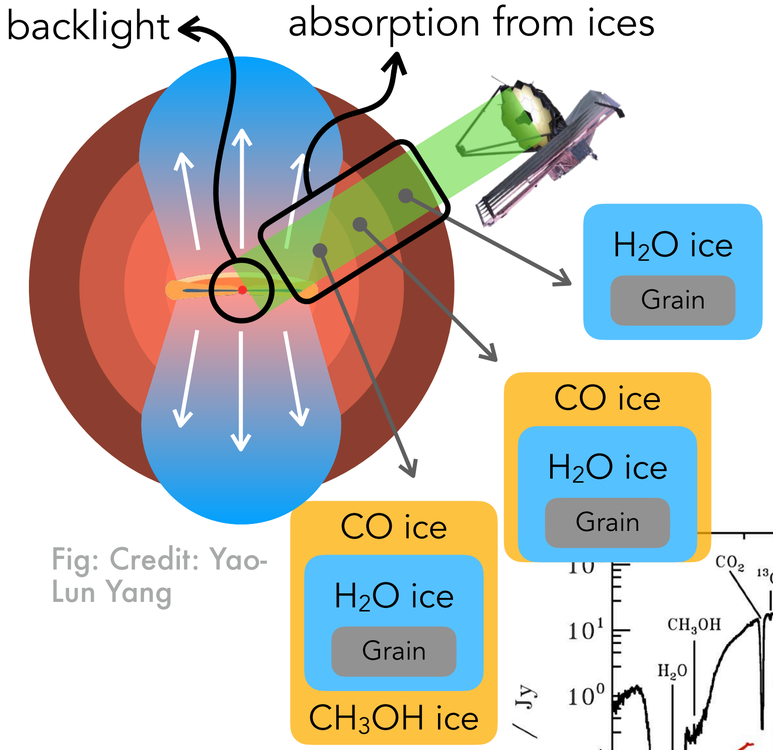
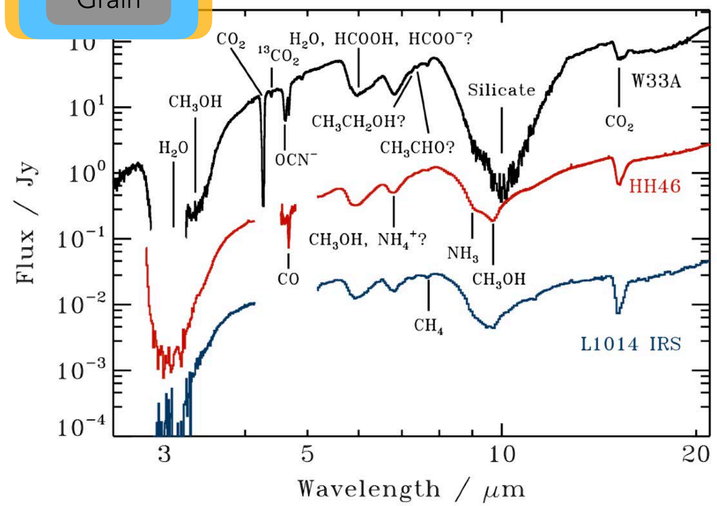


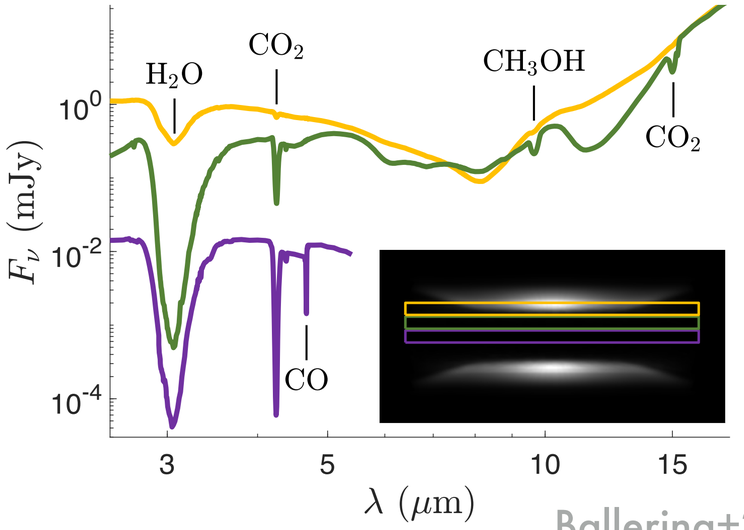
Fig: Credit: Yao-Lun Yang

The ISM is cold! Ices are a major constituent seen by Spitzer, but limited information.

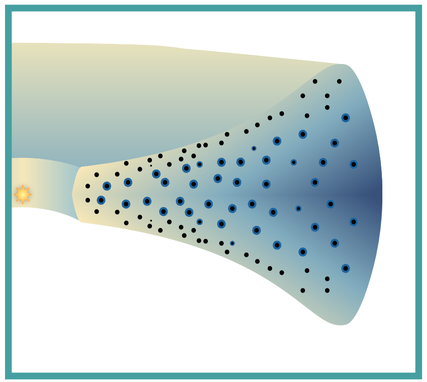
JWST's unprecedented sensitivity unlocks ice on both star and planet forming scales.

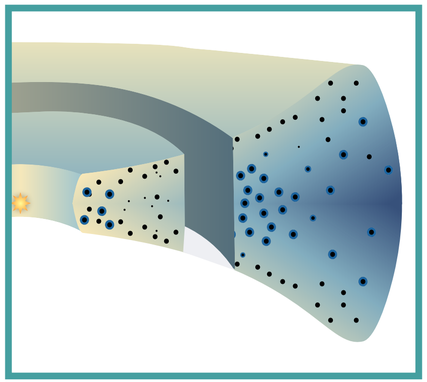


PLANET FORMING ICES



Ballering+21





SUMMARY

- The last decade has brought major advances in the characterization of planets both at home and abroad, and around a wide variety of stars.
- Over this decade, improvements in observations and modeling have brought major changes to our view of star & planet formation - and many questions!
- *JWST* has both the key imaging *and* sensitive spectroscopic capabilities to revolutionize our understanding of star and planet assembly on many fronts.
- Through multi-wavelength observations, we can truly "fill out" the picture to answer big questions like "how common is habitable planet formation?"

Image Credit: University of Copenhagen/Lars Buchhave, W. Garnier, ALMA (ESO/NAOJ/NRAO)