Origins of Stars, Planets, and Life (?) with JWST

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With thanks to C. Beichman, M. Clampin, T. Greene, D. Lafreniere, & J. Lunine

9 October, 2014, JWST Italian Information Day, INAF Rome

Context for JWST in Kourou:

Kepler/WISE/Herschel are nice memories.

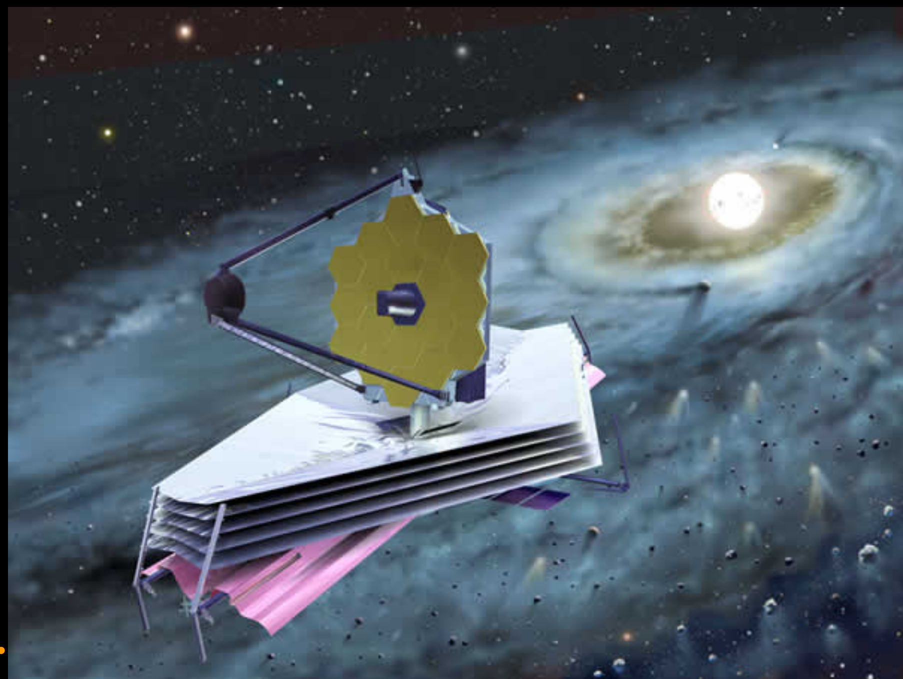
SPHERE/GPI/LBTI surveys complete.

GAIA mission on-going.

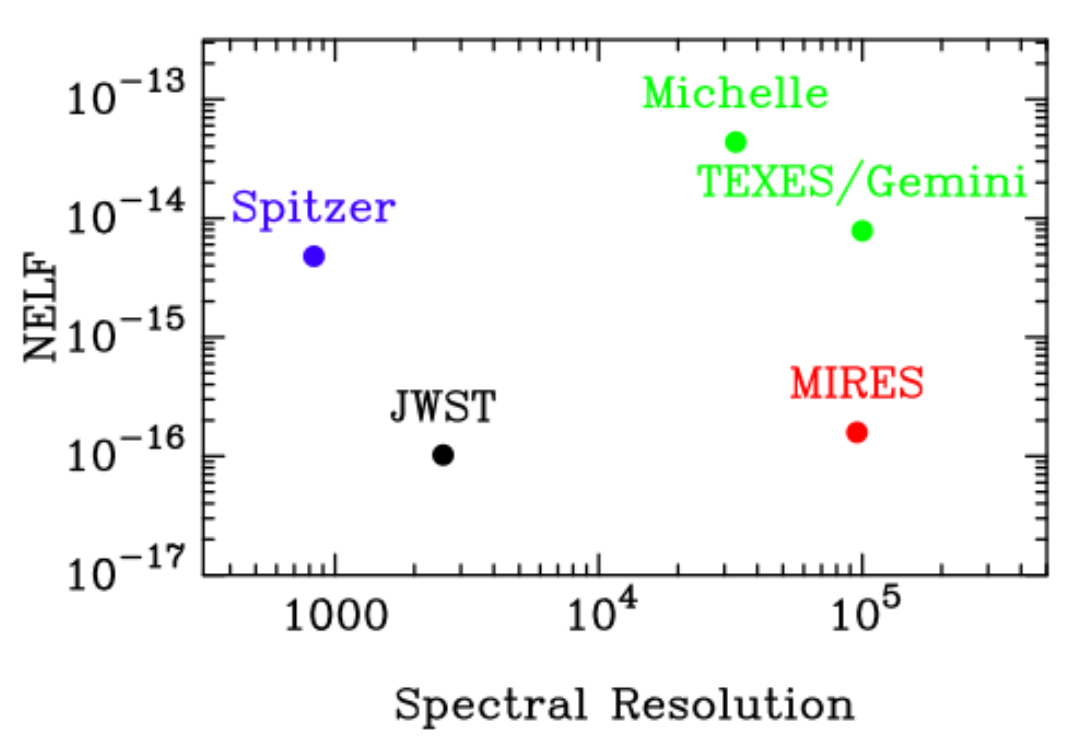
SOFIA?/ALMA normal operations.

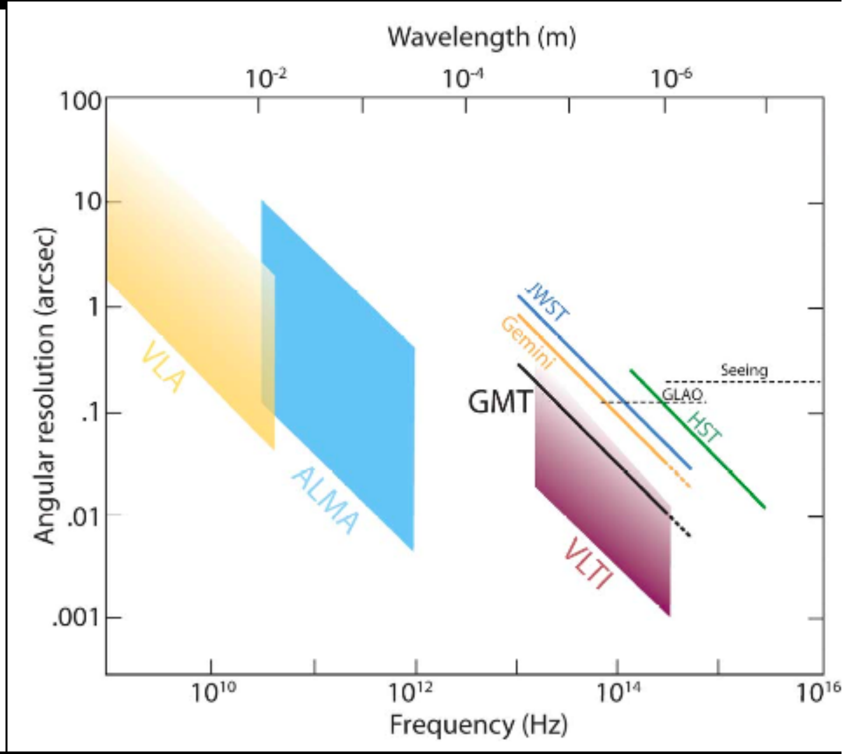
CHEOPS/TESS underway!

LSST/EUCLID/ELTs coming soon…

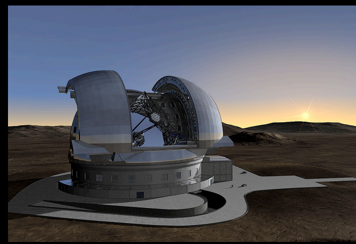


2020: Complementary Capabilities:





JWST => sensitivity & field of view.
ELT => resolution (spatial & spectral).



Courtesy L. Simard (TMT) and P. McCarthy (GMT)

Frontier Science Opportunities with JWST

Formation of Stars and Clusters

Structure and Evolution of Planet-Forming Disks.

Detection and Characterization of Exoplanets.

Origin and Evolution of our Solar System.

Evolution of Ingredients Needed for Life.

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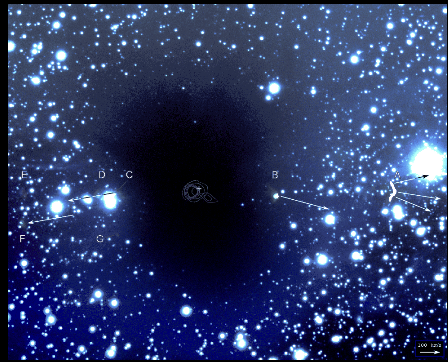
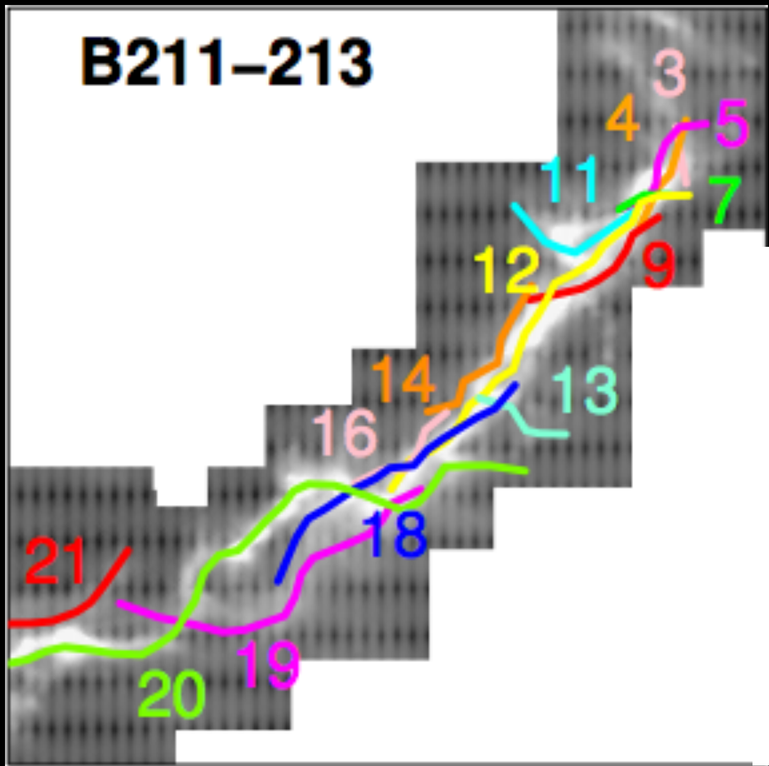
Structure of Pre-/Proto-stellar" Cores:

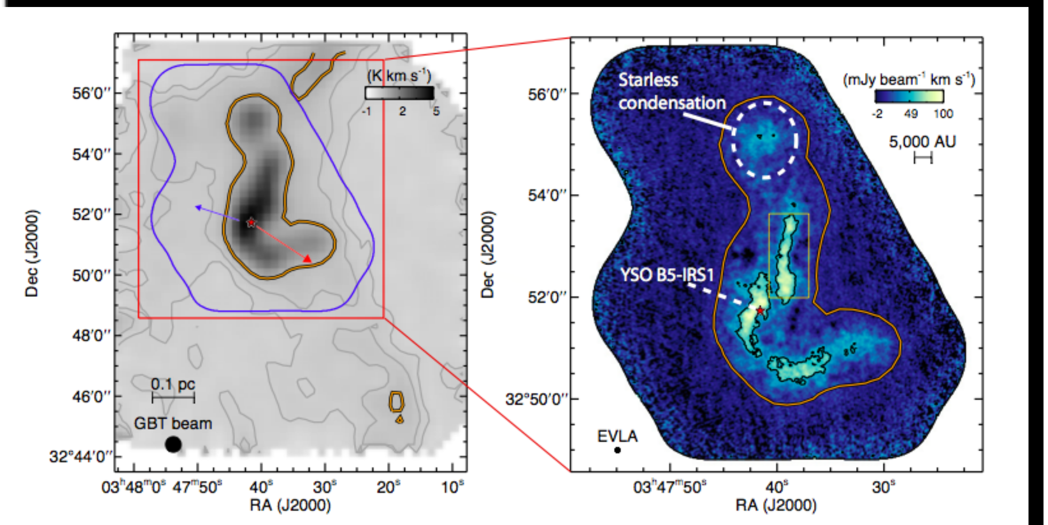
Extinction Mapping and optical depth in solid state features



Stutz et al. (2009)

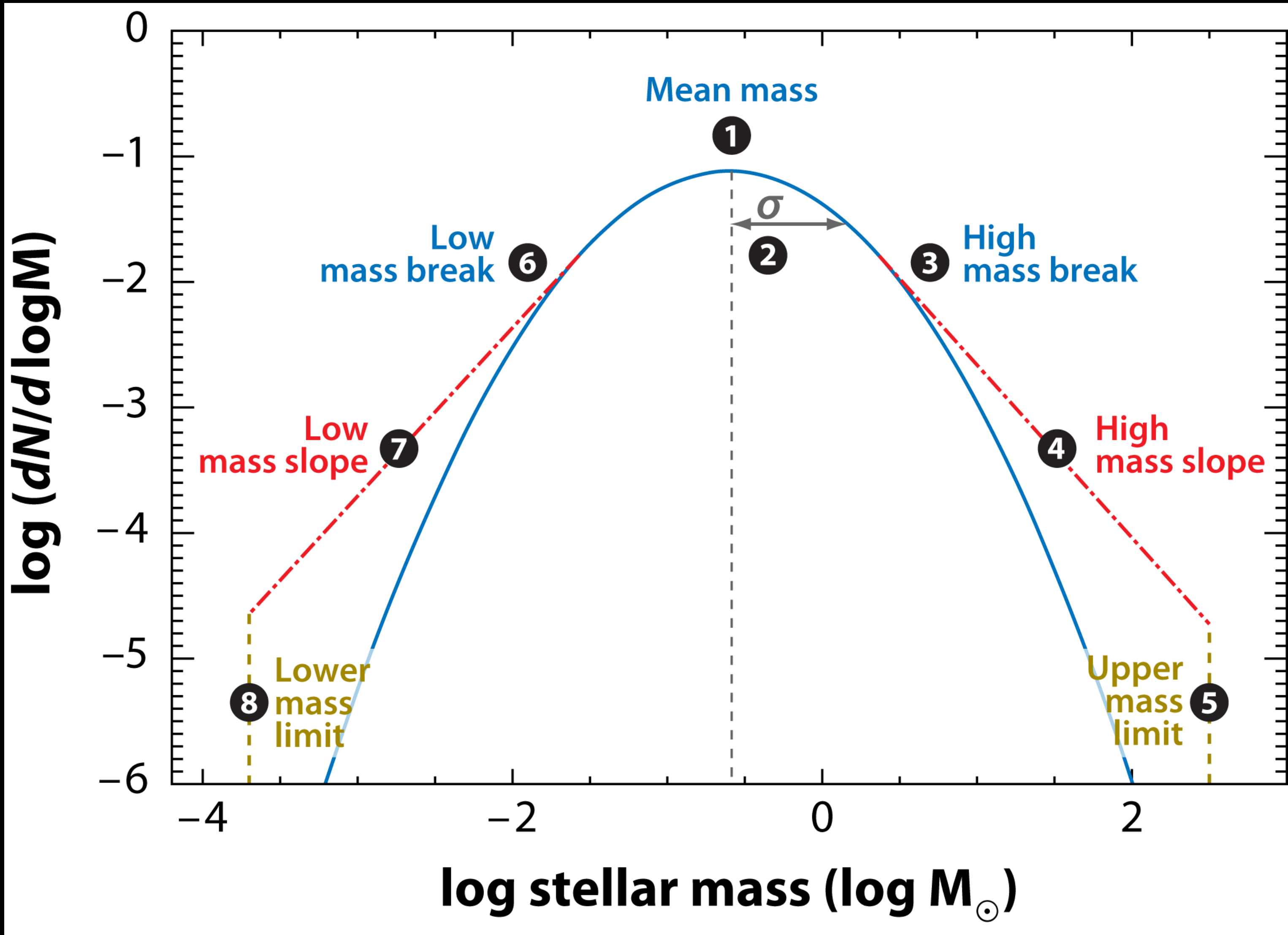


Hacar et al. (2013) single dish



Pineda et al. (2013) EVLA

Initial Mass Function of Stars and Sub-stellar Objects



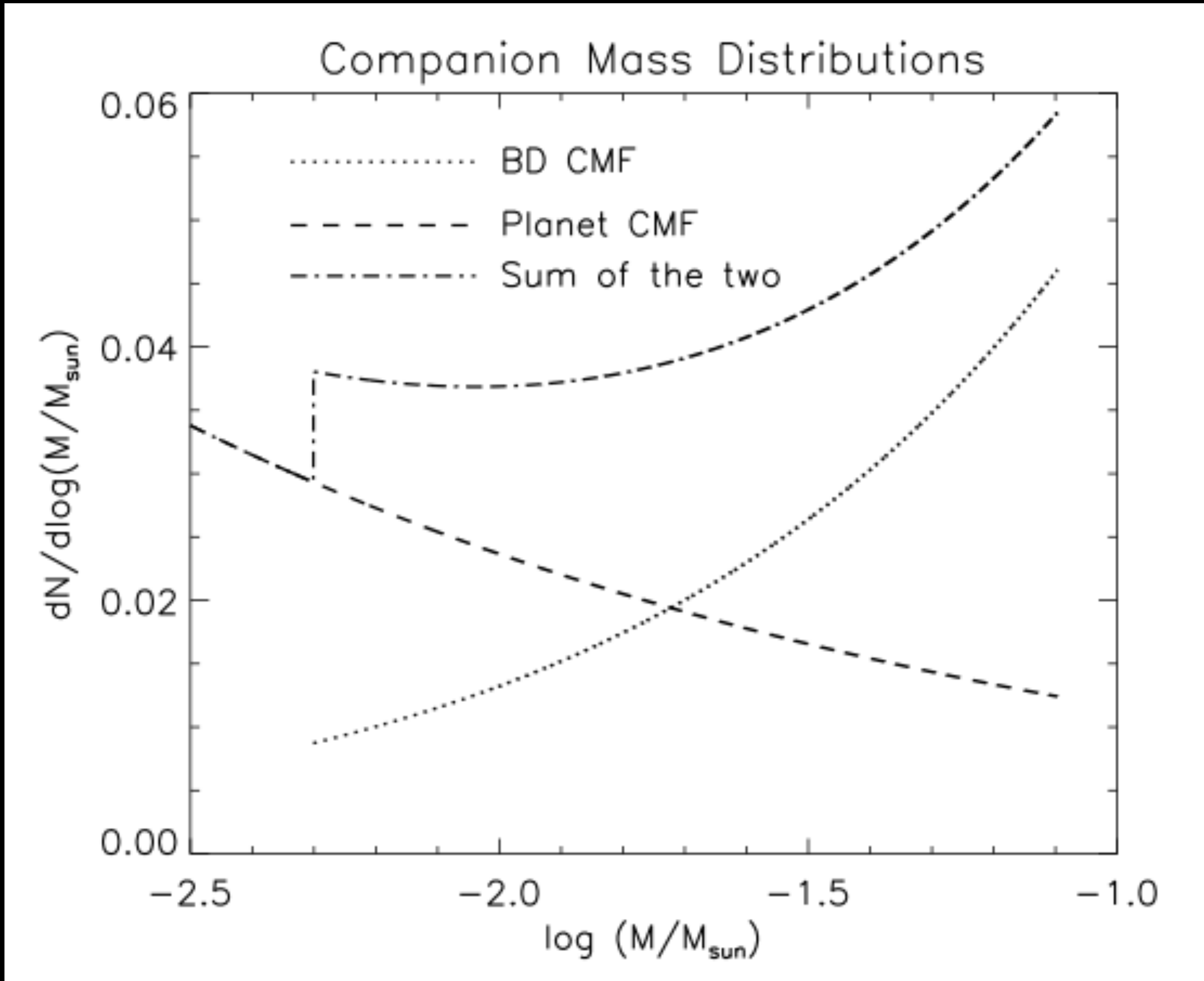
Bastian, Nate, et al. 2010;
Annu. Rev. Astronomy & Astrophysics vol. 48

NIRCam/NIRSPEC Observations of Young Clusters

"Extreme" clusters within Local Group: Below hydrogen burning limit.

Nearest embedded clusters to go deep: <1 Jupiter mass

The CMRD and Planet Populations



Reggiani et al. (2014)

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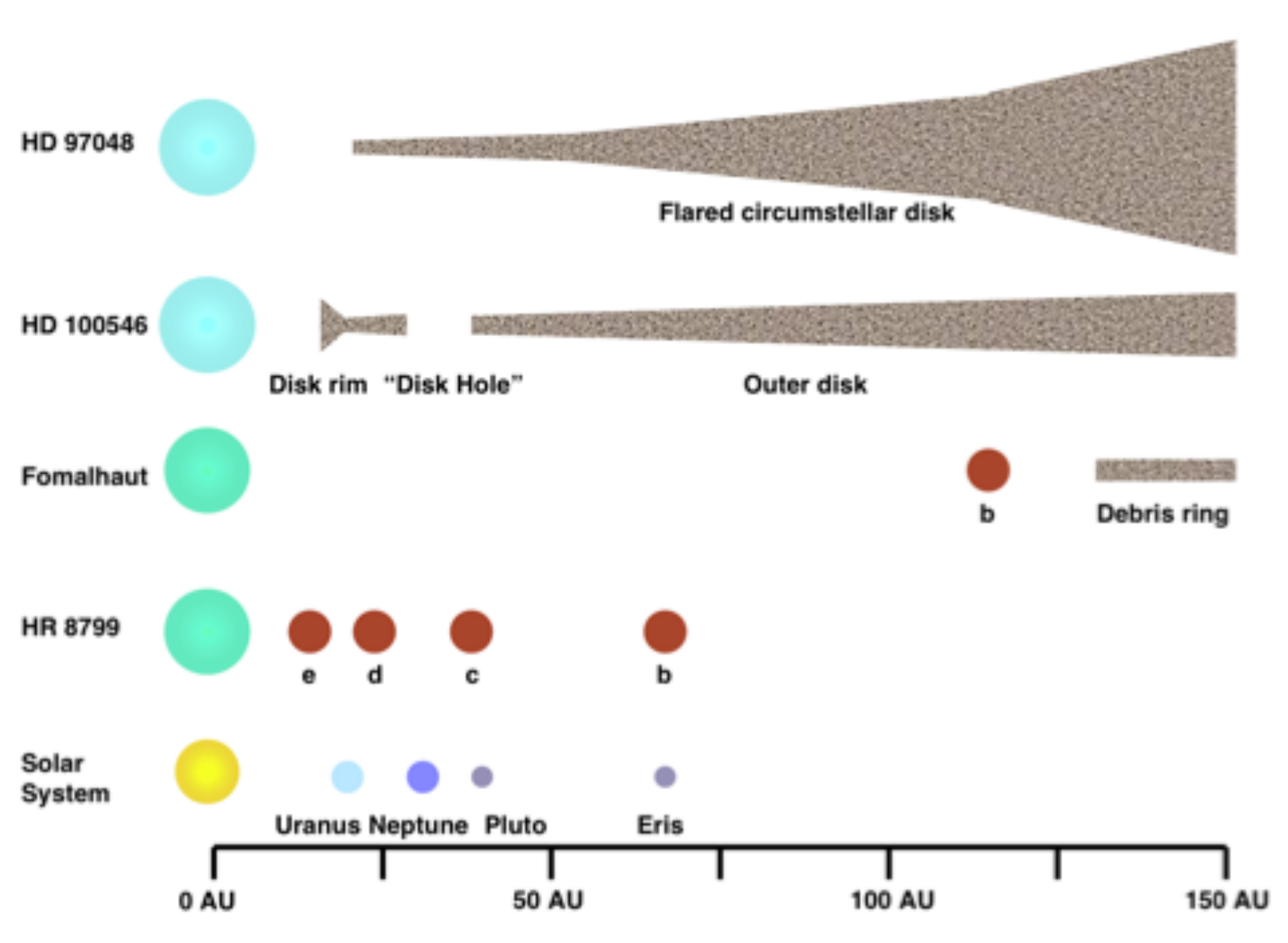
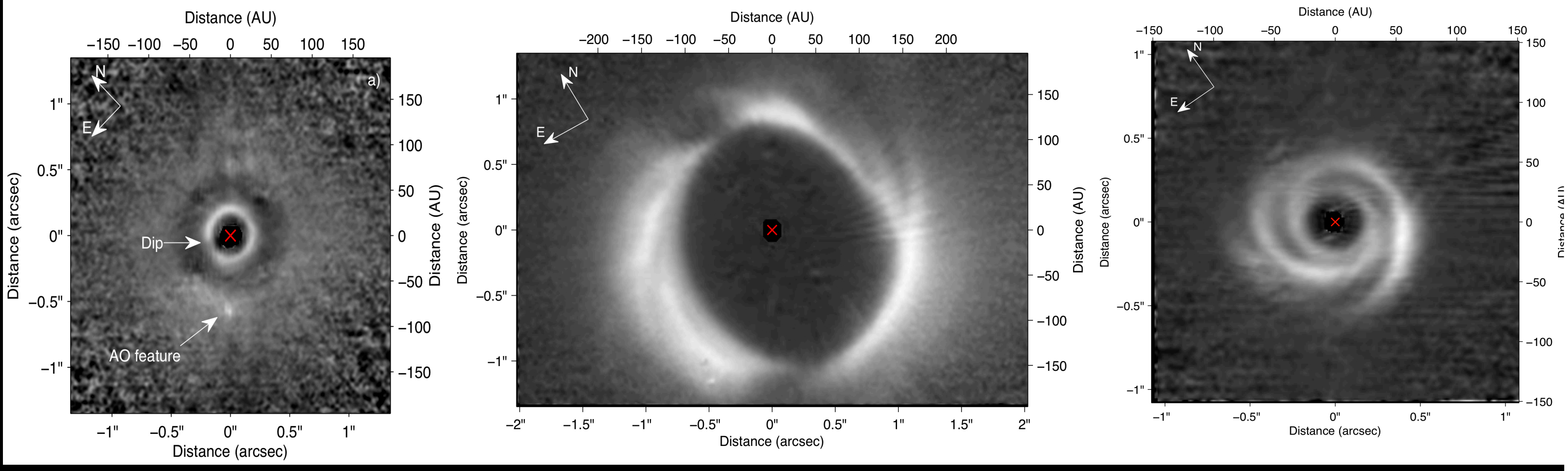
Planetary System Architectures



(Quanz et al. 2011)

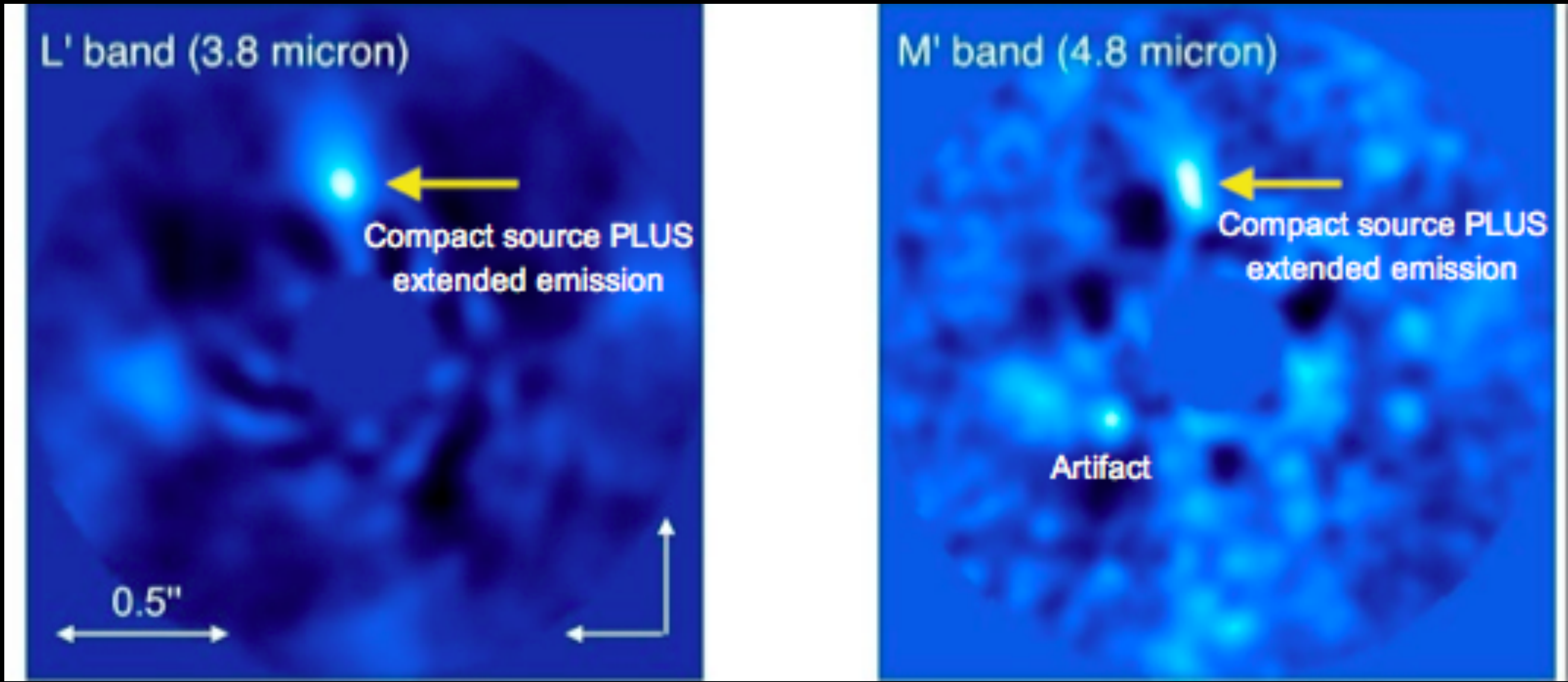
The Power of Resolved Images…



Obtained with NACO with PDI on the VLT, but only precursor for SPHERE! Comparison with ALMA yields location of pressure bumps, which are dust traps that form planets…

Quanz et al. (2013); Avenhaus et al. (2014); Garufo et al. (2013)

(Multiple) Planet Forming Disks: HD 100546

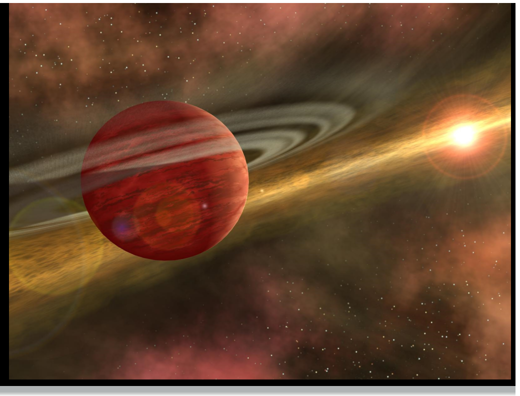


(Quanz et al. 2013; Quanz et al. submitted)

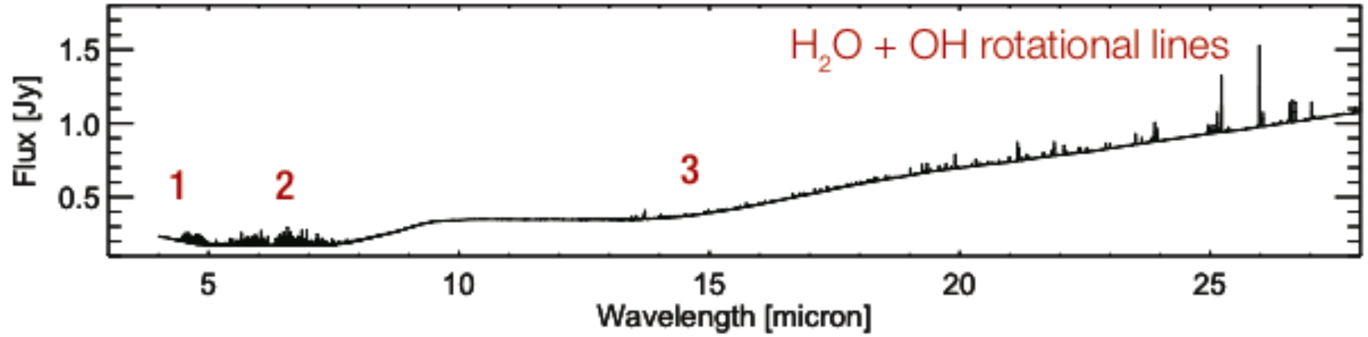
We are now detecting and characterizing forming protoplanets and (soon) circumplanetary disks. Stay tuned…

Composition of Forming Planets

(Courtesy STScI)



Molecular spectroscopy of protoplanetary disks with JWST



Model parameters

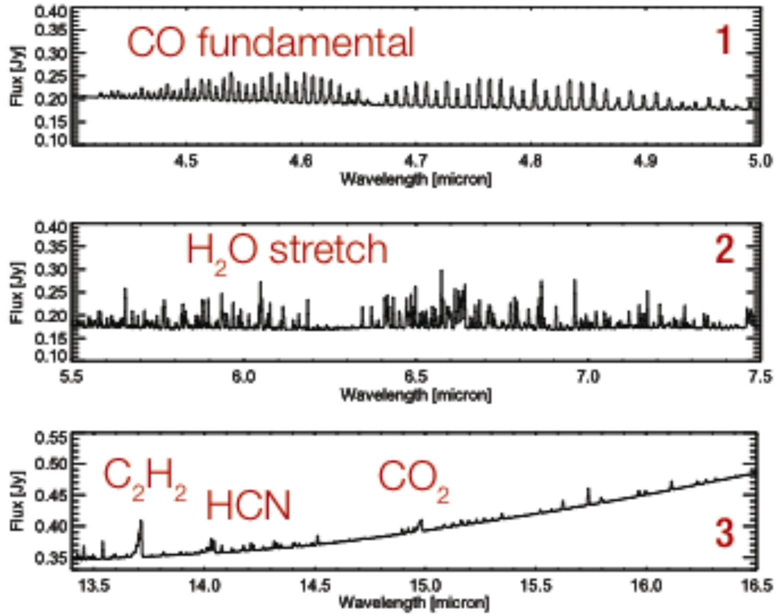
Protoplanetary disk around a young solar-type star: Teff=4250 K; L=1 L_{sol}; 0.01 M_{disk}=M_{sol} disk, distance=125 pc.
Abundances based on Spitzer and ground-based IR spectroscopy

What does it mean?

The mid-IR molecular lines from protoplanetary disks are formed in the disk surfaces at 1-10 AU.

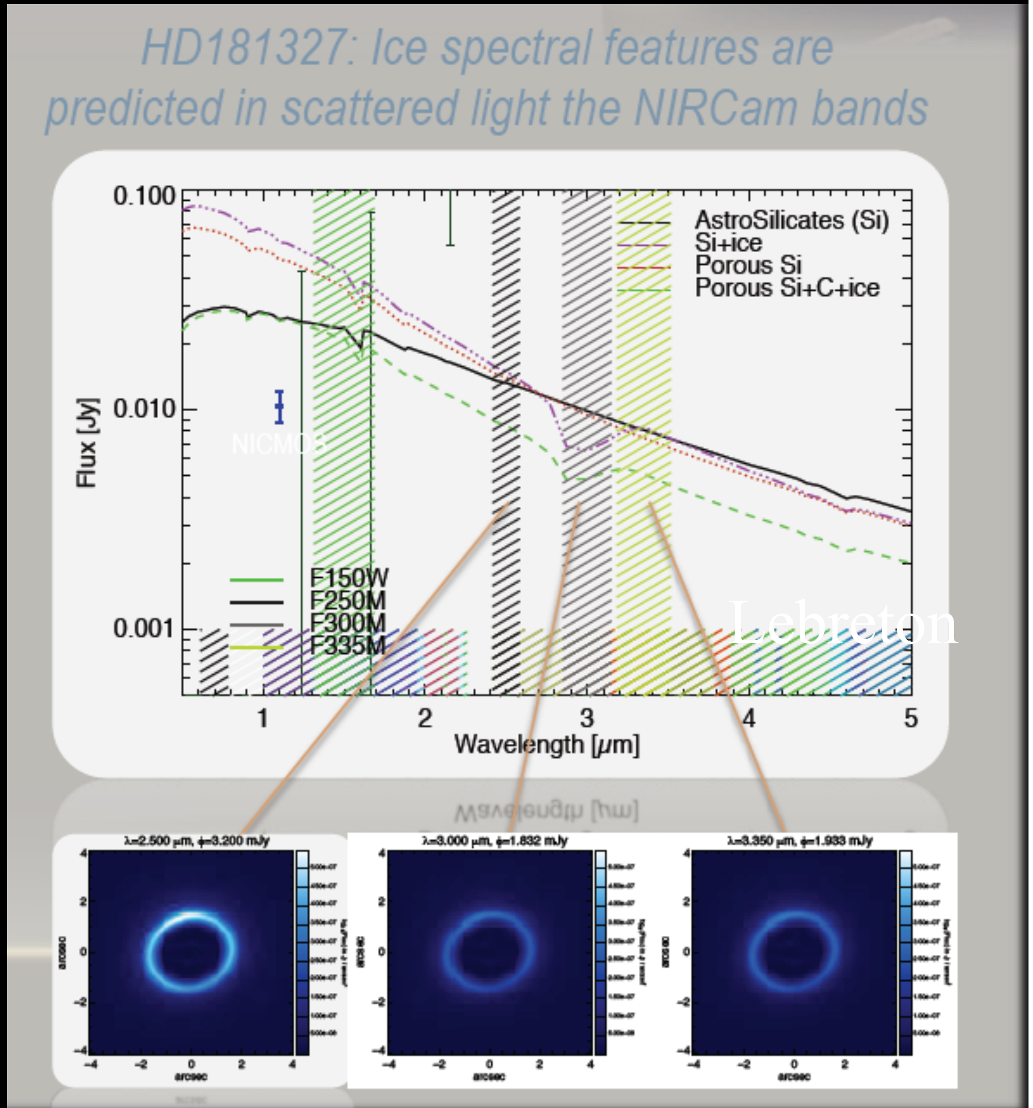
JWST observing modes

NIRSpec: 1-5 micron @ R~2700
MIRI: 5-28 micron @ R~2700



Structure & Composition Of Debris Disks

- H_2O ice at 3 μm
- Constrain grain sizes & composition, structure.
- JWST + ALMA
- Infer planets via disk morphologies.



(Courtesy J. Lebreton)

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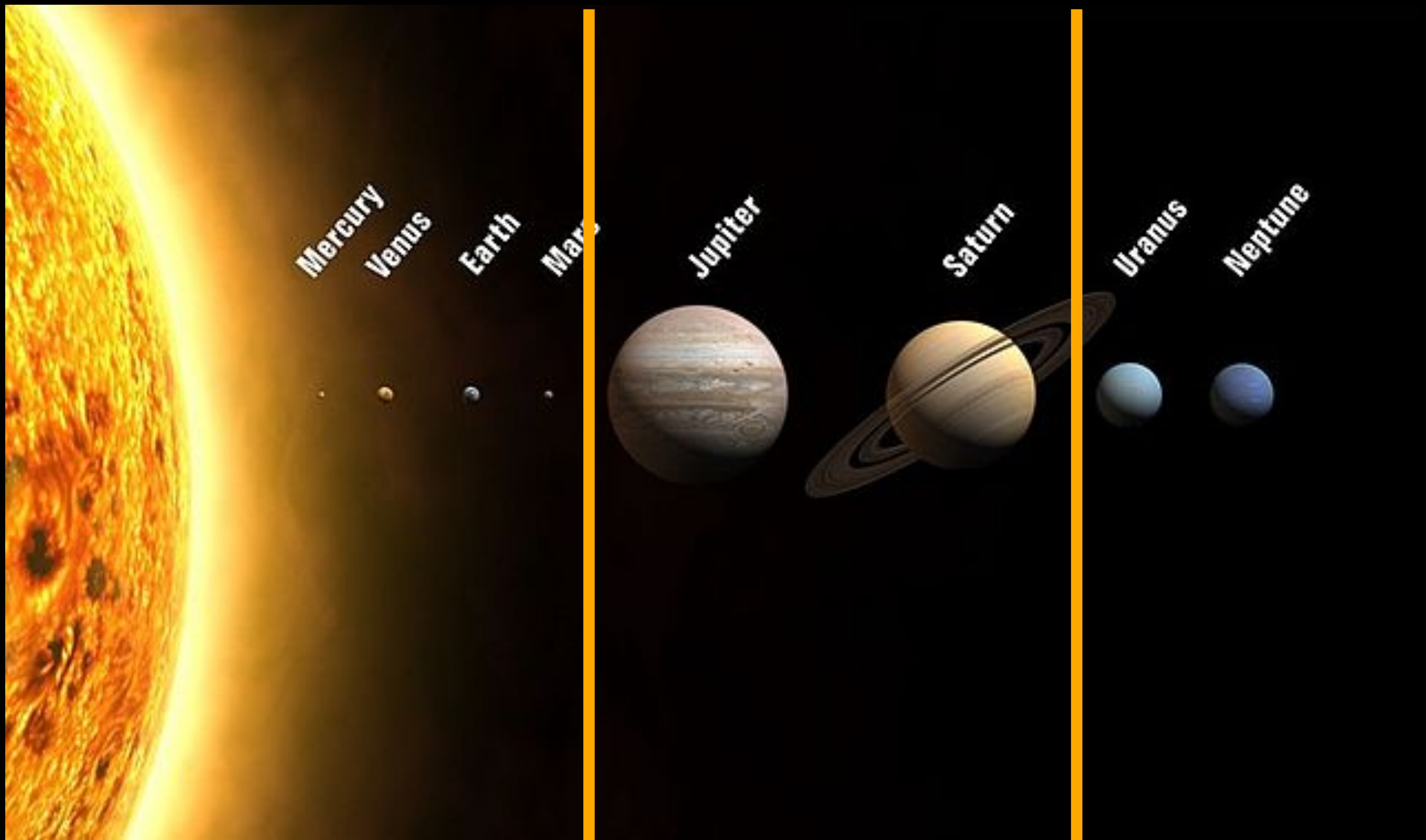
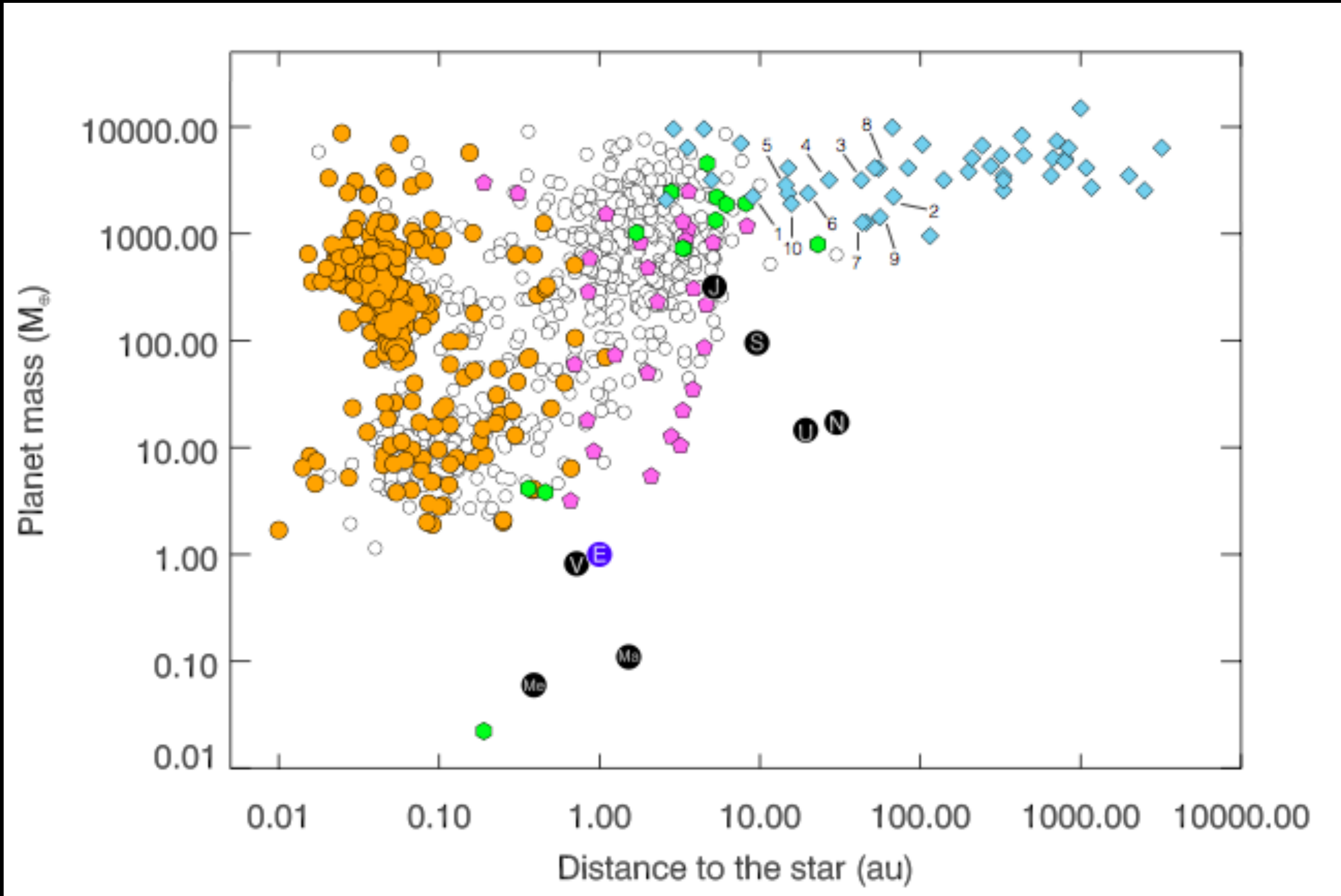
Different Flavors of Planet Formation



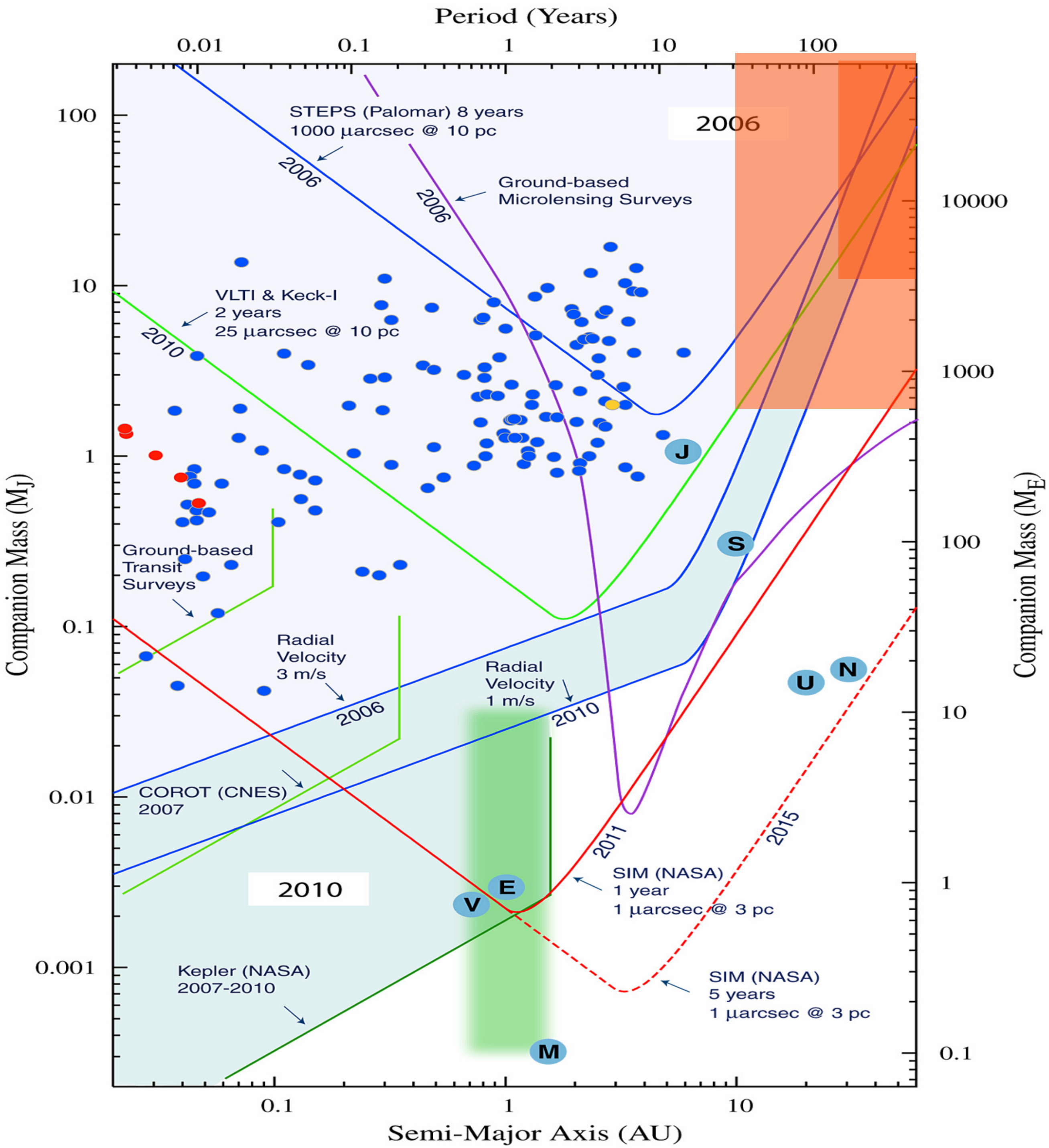
Observed Planet Populations:



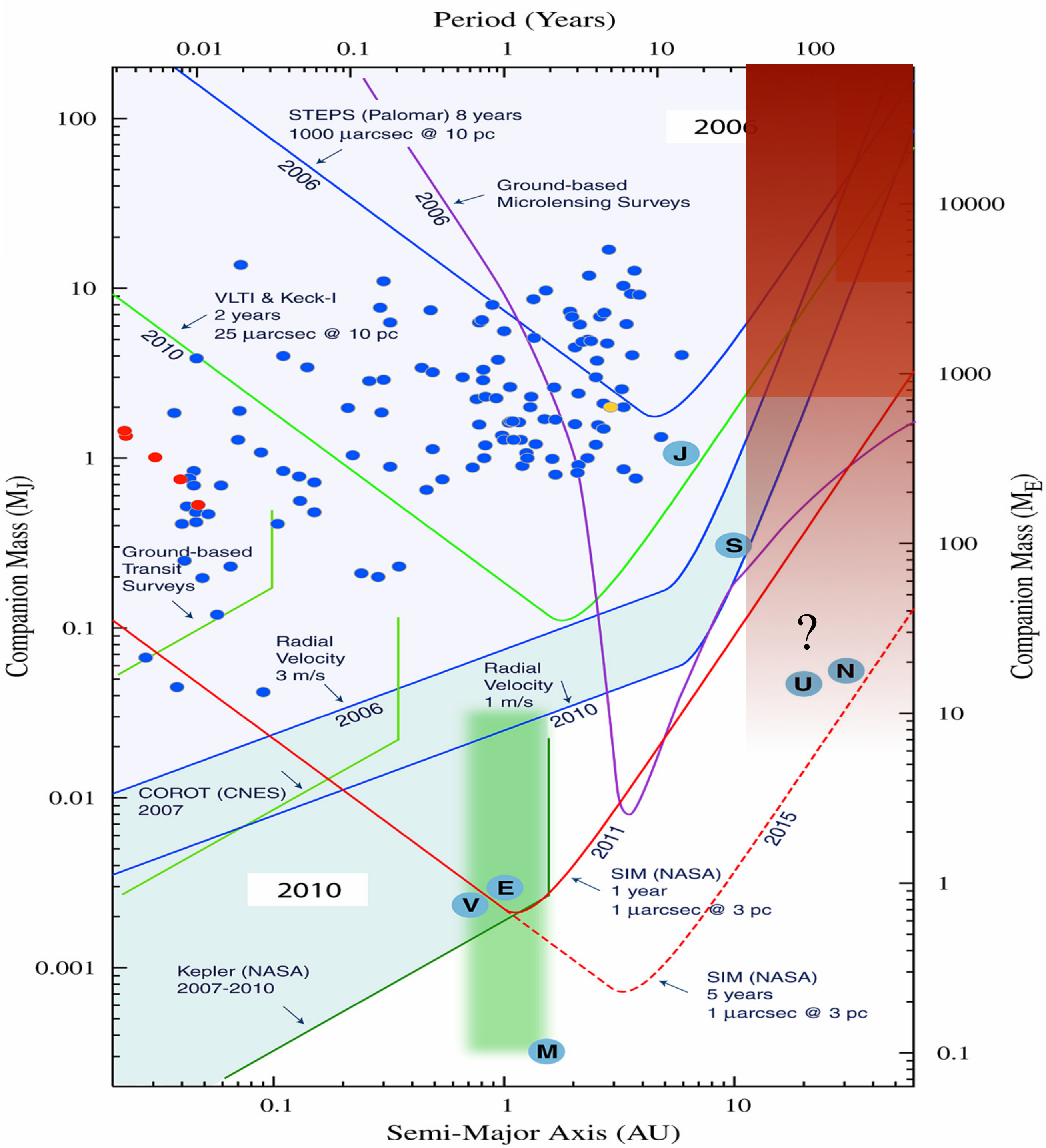
(Pepe, Ehrenreich, & Meyer, 2014, Nature, V513, 358)

Direct Imaging Today:

GPI
SPHERE
LBT



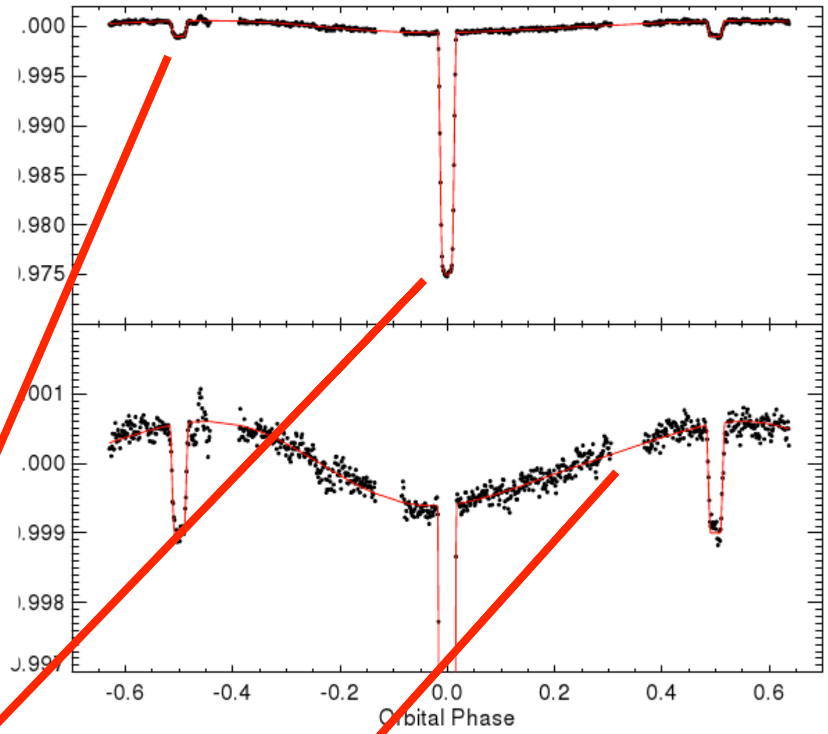
JWST Discovery Space

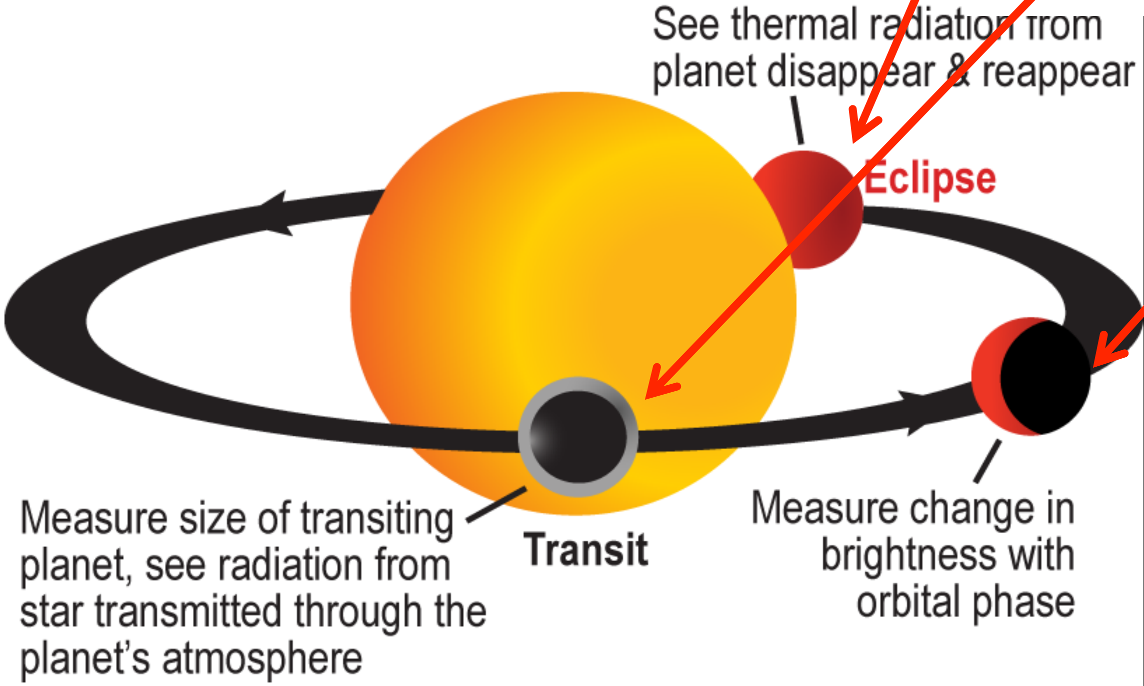


Detect very low mass planets at large radii about the nearest stars. (cf. Beichman et al.)

JWST Transit Science

- High SNR/precision will revolutionize transits obs.
- 7.6 x (Spitzer), 2.7x (HST)
- Wide spectral coverage (0.5-20 μm) and R~5-2,000

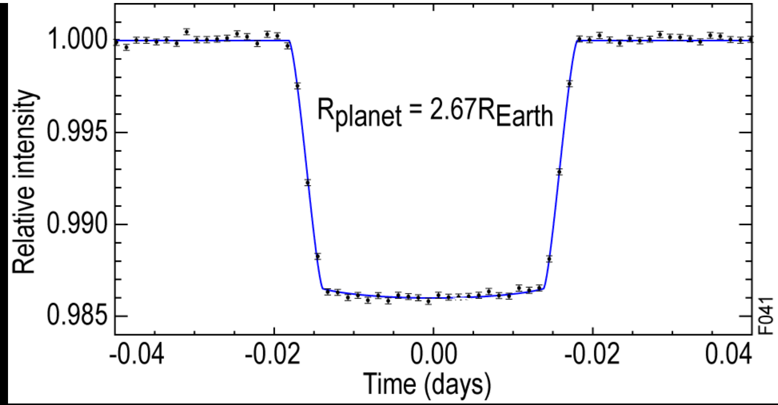


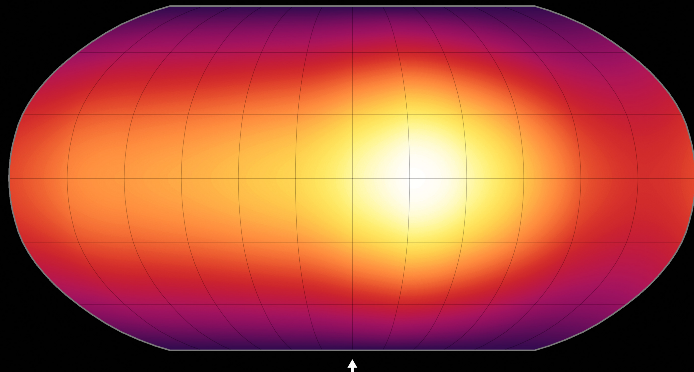


- NIRCam: phot: $K \geq 7^m$ [Grism R ~1700 $K \geq 3^m$]
- NIRISS Grism $K \geq 4.5^m$

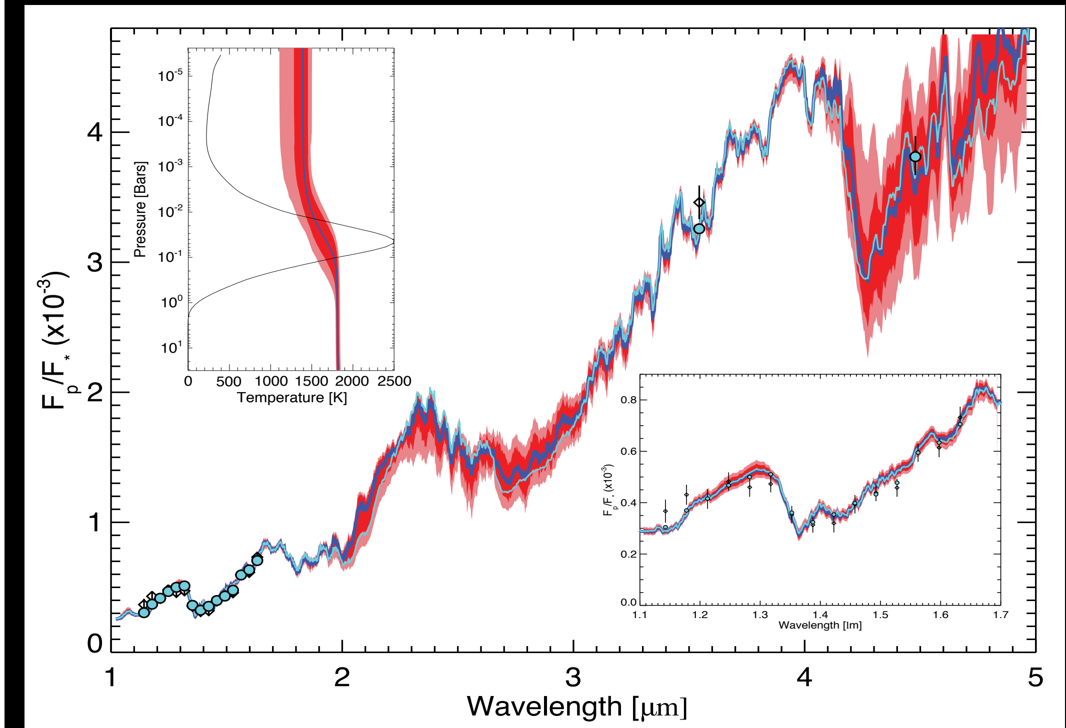
Transit Opportunities

- Radius, mass, density: giants to Super Earths
- Temp, comp, and structure
- Global atmospheric circulation

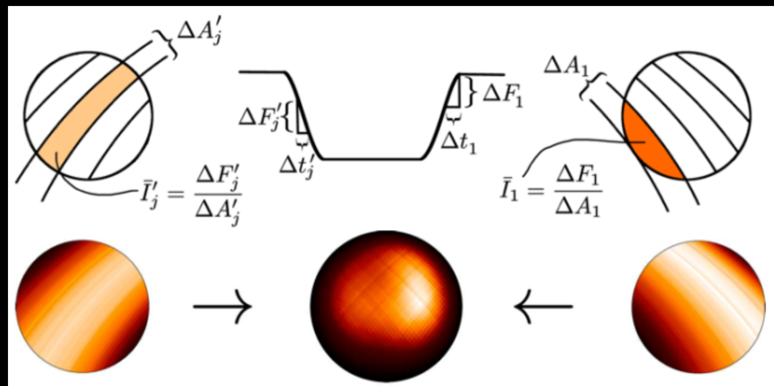




Knutson et al 2010



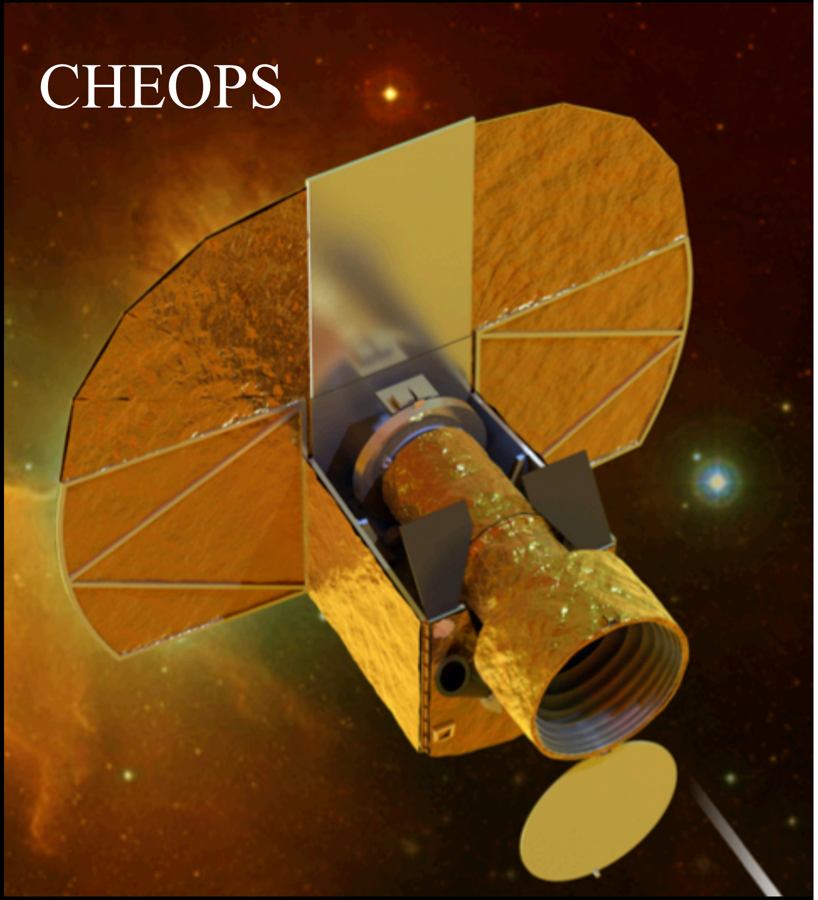
Kreidberg, Line, Stevenson, Bean, et al. (in prep)



Majeau, Agol & Cowan 2012

Transit Opportunities: Synergies

- Radius, mass, density:
  giants to Super Earths
- Super-earth and terrestrial
  targets (?) for JWST follow-up!



(Benz et al. + Italian CHEOPS Team)

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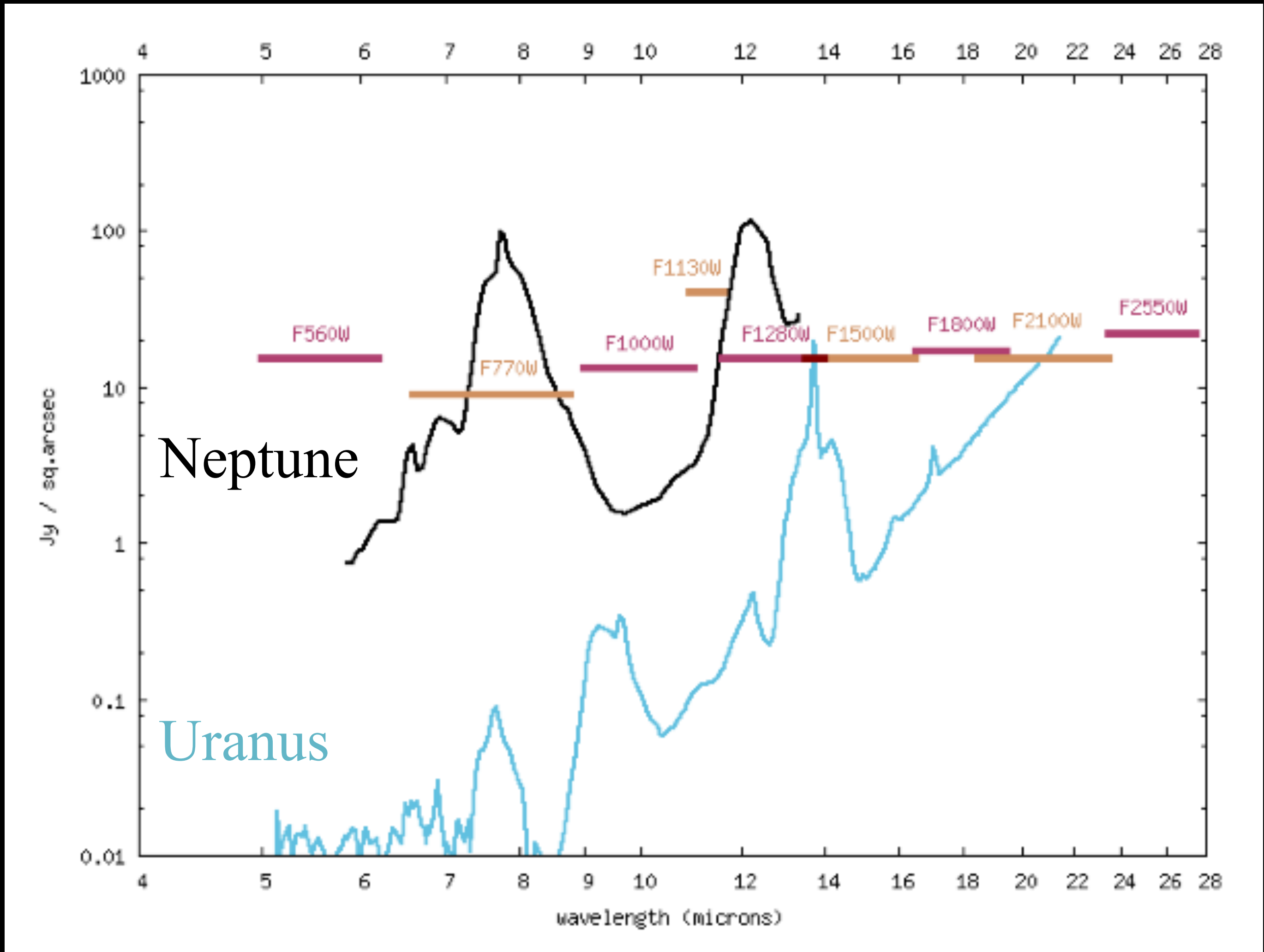
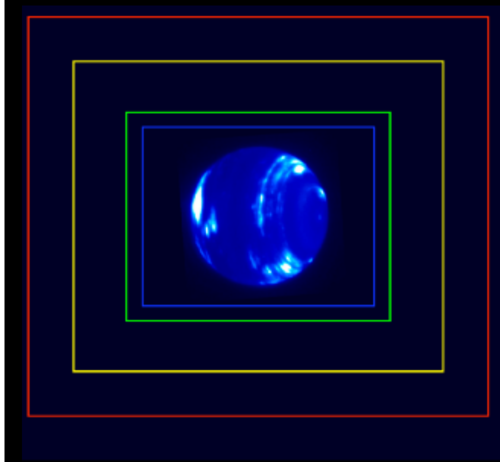
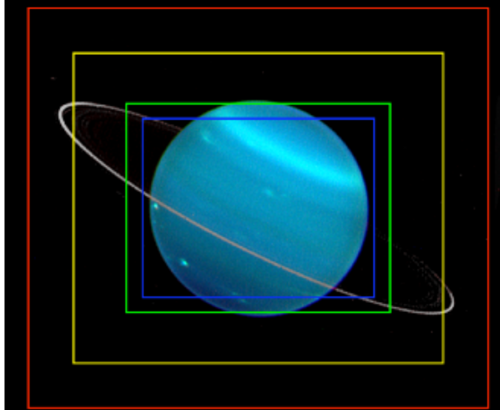
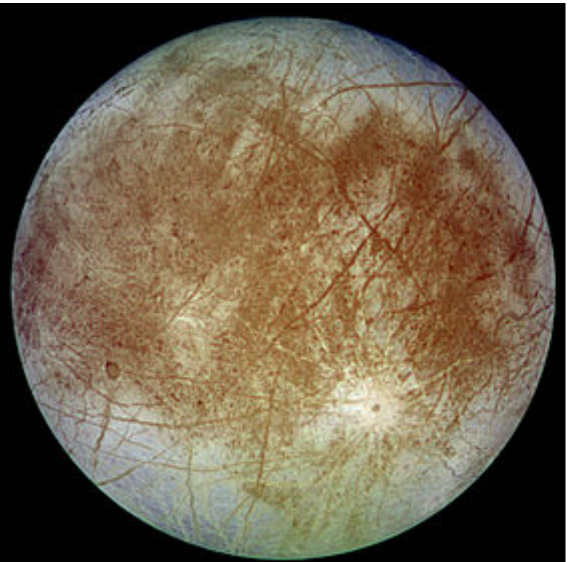
JWST: Mission to the Ice Giants



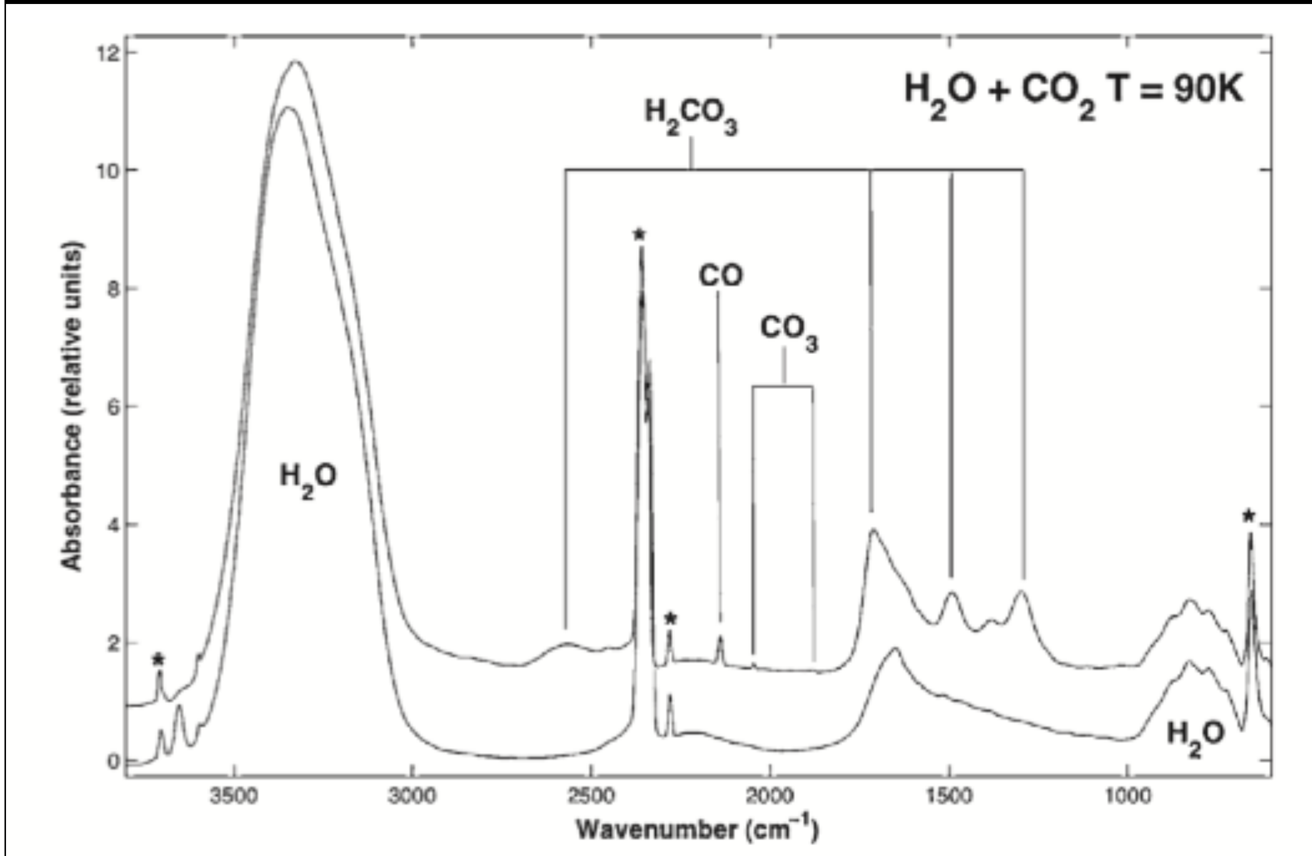




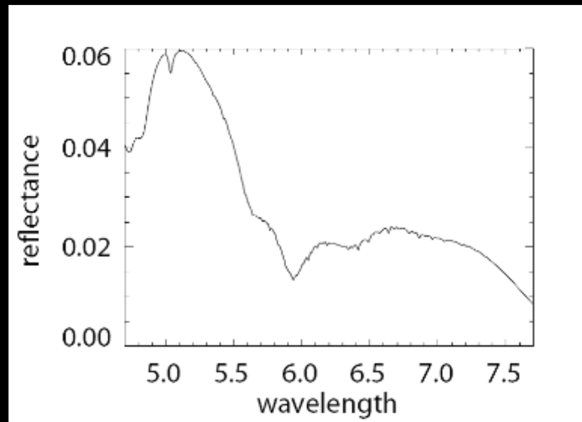
JWST: Mission to Europa



Evidence for Radiolytic Carbon Cycle

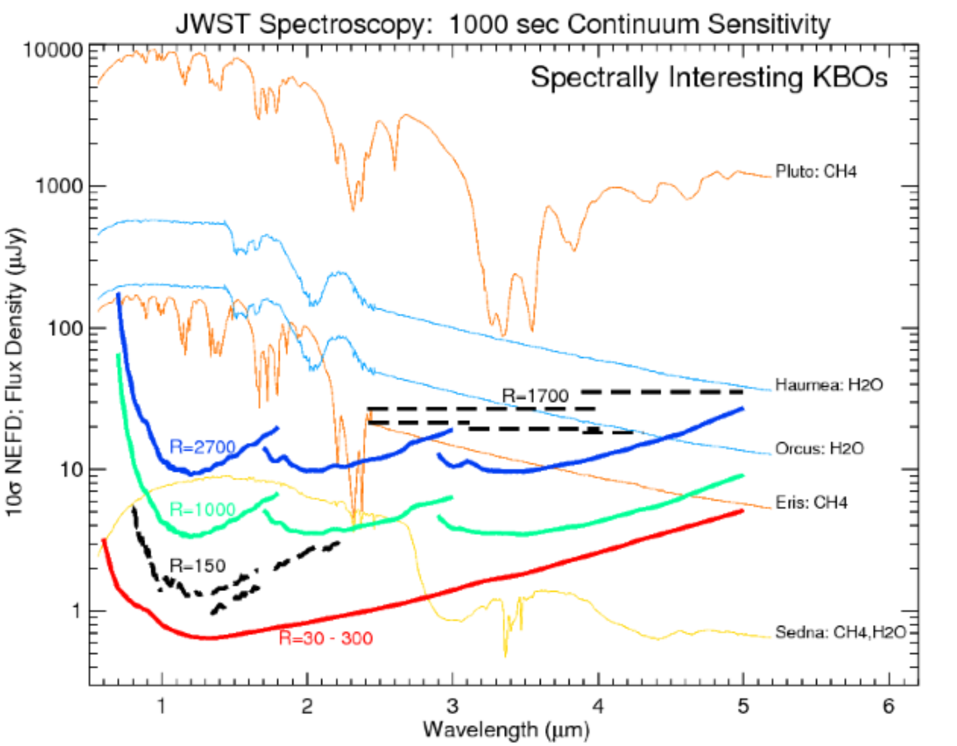


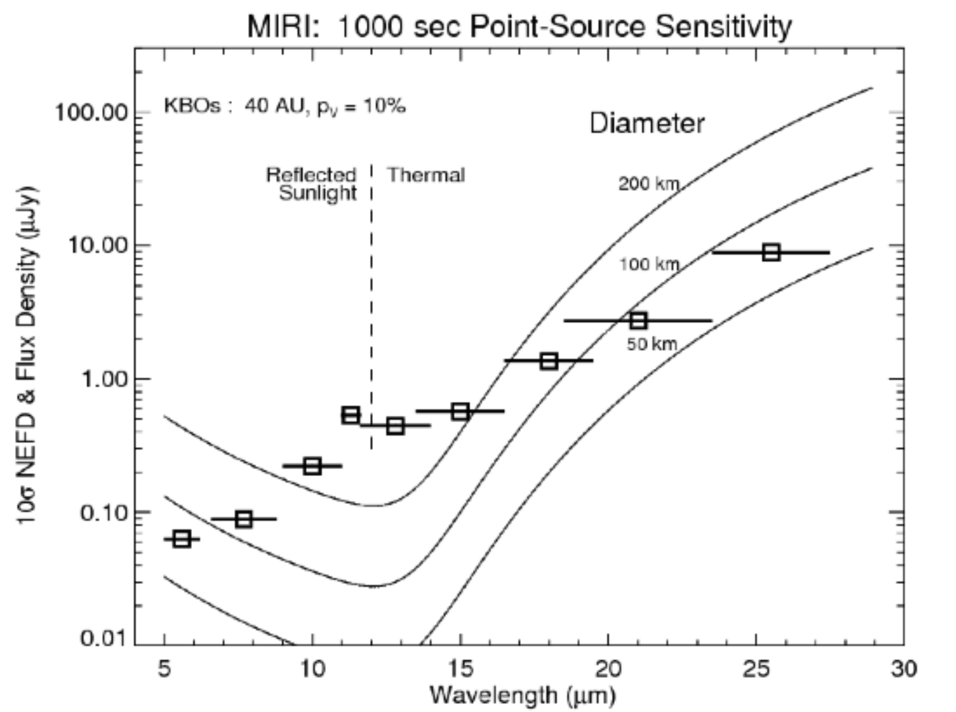
Bloedite
(hydrous evaporate)



Kuiper Belt Objects

Spectra of dynamical classes =>





<= Separating albedo and radius.

Norwood et al. (2014)

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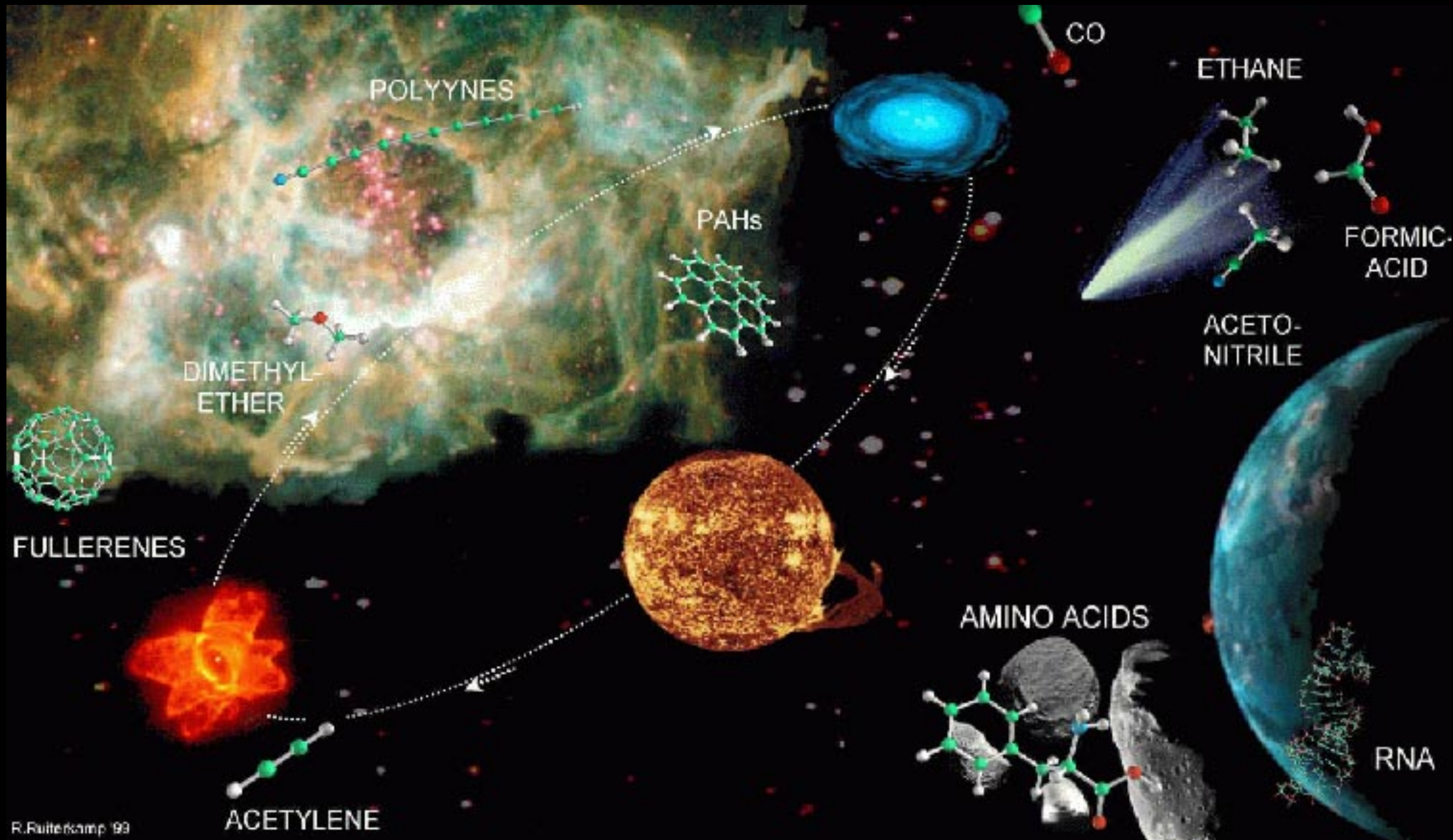
Follow the Water and the Carbon with JWST



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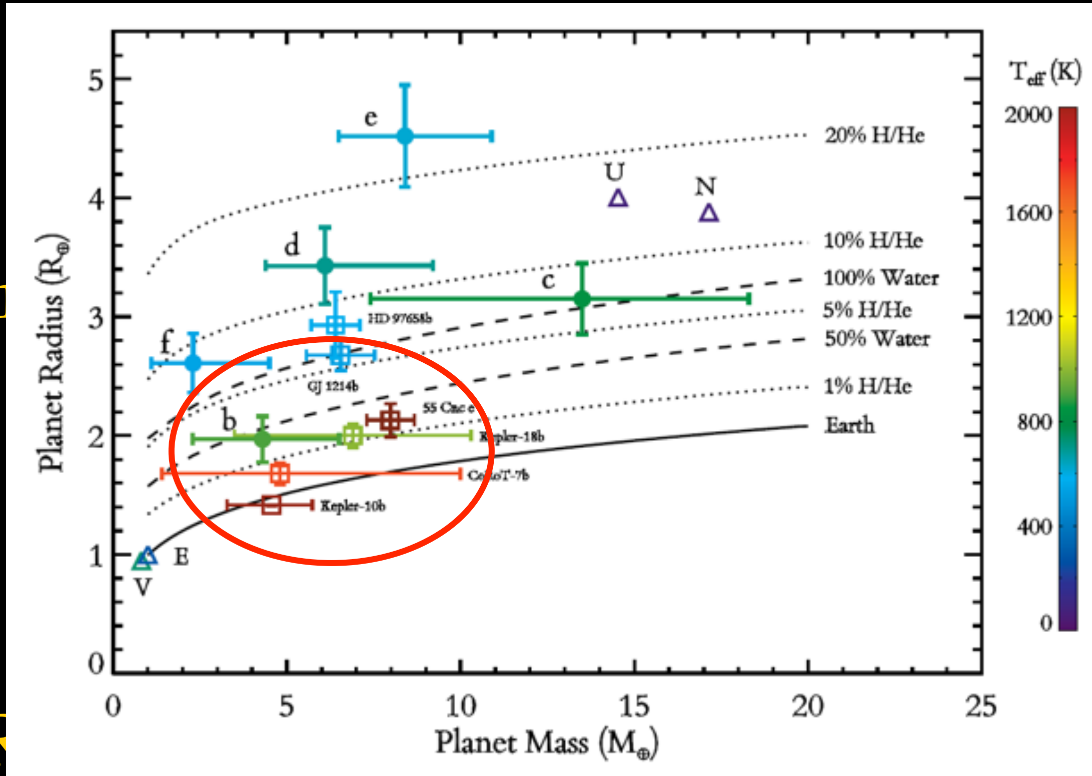
JWST will play transformational roles in understanding star and planet formation.

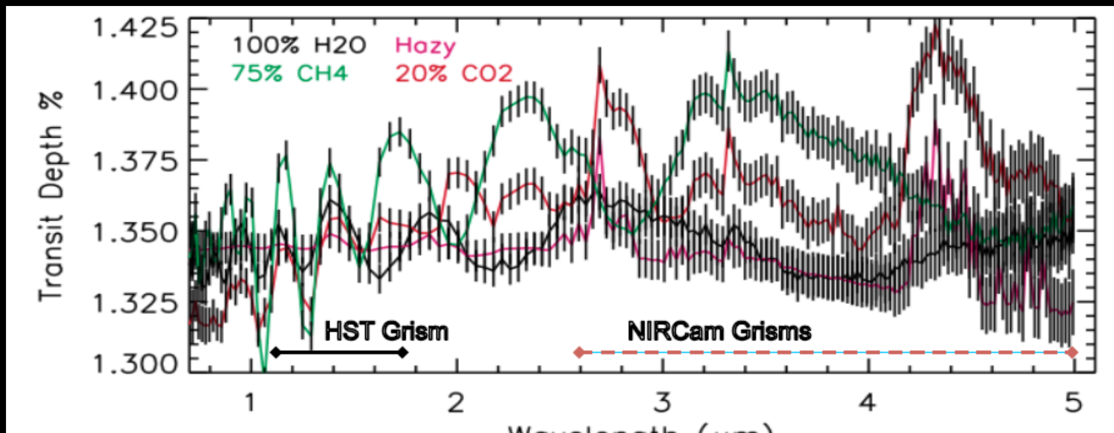
Back-up slides

Mini-Neptunes

- Planet type not in solar system:
  - » 2-3 $R_\oplus$, 3-10 $M_\oplus$
- Rock / Icy / Water / Fe core: low density, **H-rich atmosphere** OR high density **H_2O-rich atmosphere**
- Spectrum determined by scale height (molec weight, T), clouds, composition

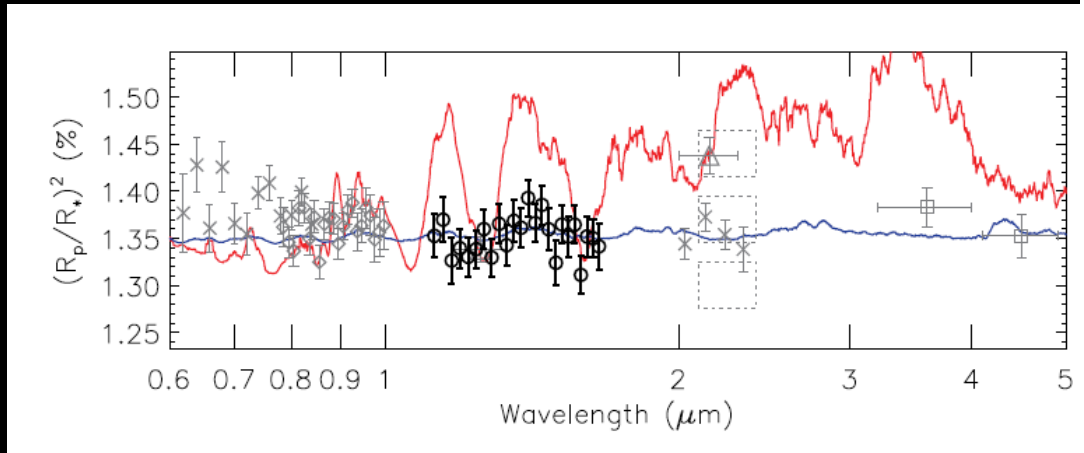


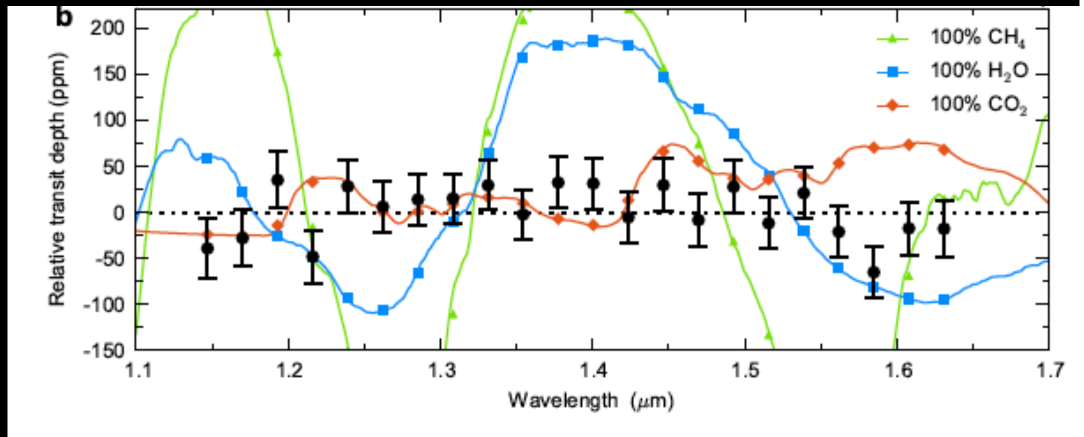
Lissauer et al., *Nature*, 2011
(modified c/o E. Lopez et al.)



GJ1214b Spectrum is FLAT!!!

- Best example GJ1214b (6.5 Me, 2.7 Re, T=550 K) 1.6 d orbit V=14.7 mag M star
- Spitzer and HST/ WFC3 (<35 ppm) show no strong features
- Water World or Cloudy World?
- Higher sensitivity? Longer Wavelengths?

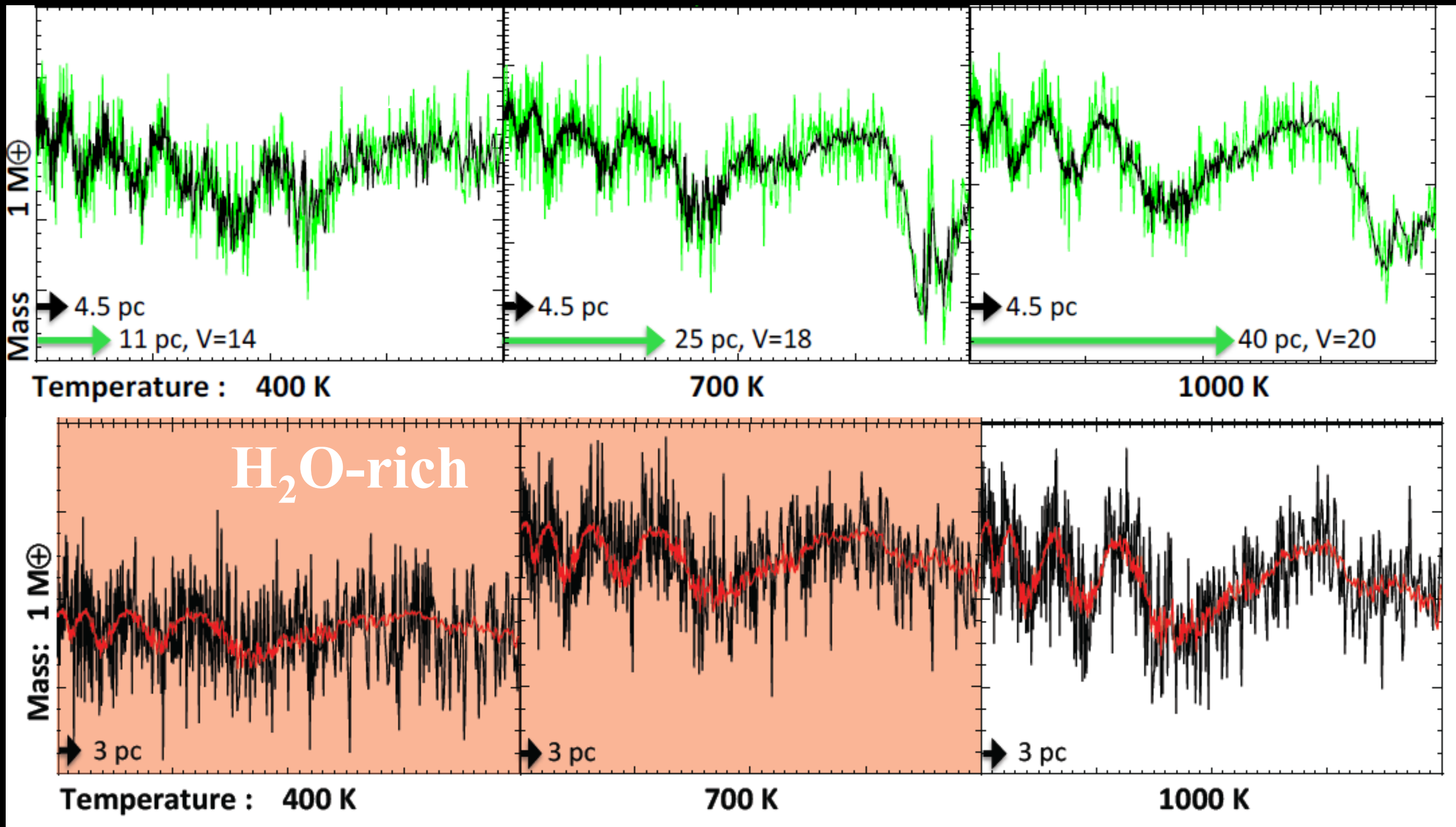




Berta et al., *ApJ* 2012
Kreidberg et al., *Nature* 2013

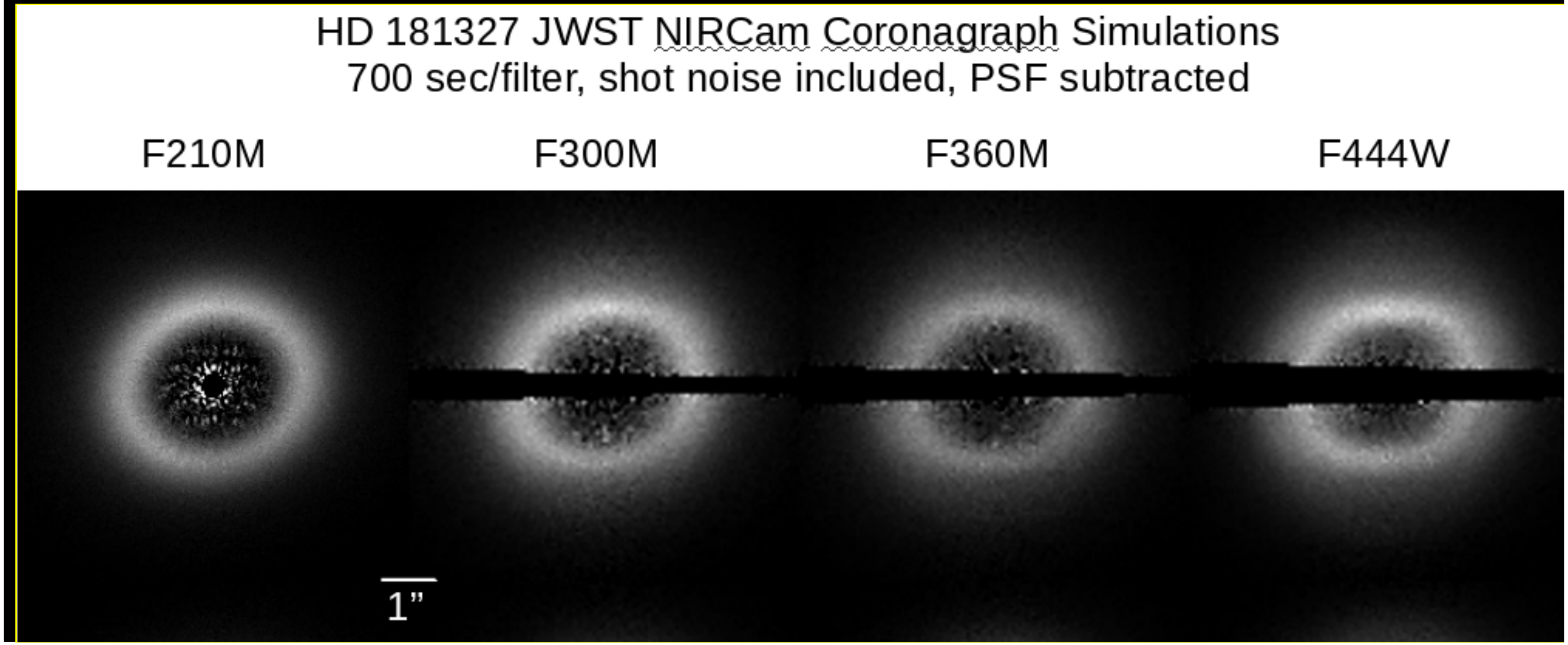
How Low Can JWST go?

- NIRSpec sims of 1 $M_\oplus$ planets (Batalha et al 2013) orbit G1214-type star need ~25 transits for hydrogen-rich atmos. (H_2O and CH_4). NIRCam and NIRISS grisms similar
- **Higher density atmospheres almost impossible…**



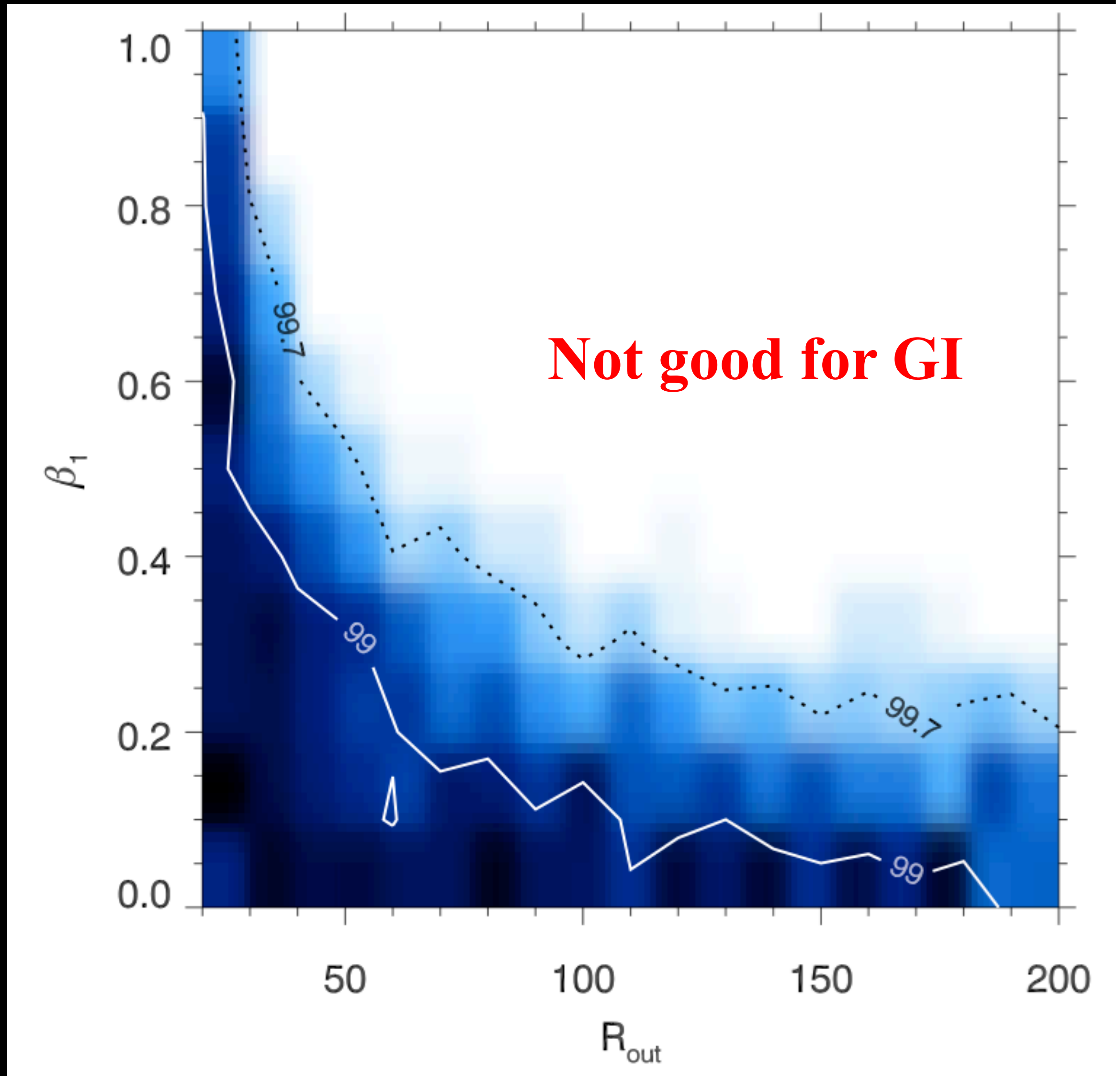
JWST Simulation of 'Real' Disk

- Combine Lebreton disk model with Krist performance model, including PSF subtraction and 5 nm of WFE drift between target & reference



Direct (Non) Detections of Gas Giant Planets

NACO-LP: Chauvin et al. (2014)



Few massive planets at large orbital radii.

[>3 Mjup @ > 50 AU]

$dN/da \sim a^{\beta}$

Lafrenerie et al. (2007);

Nielssen & Close (2009);

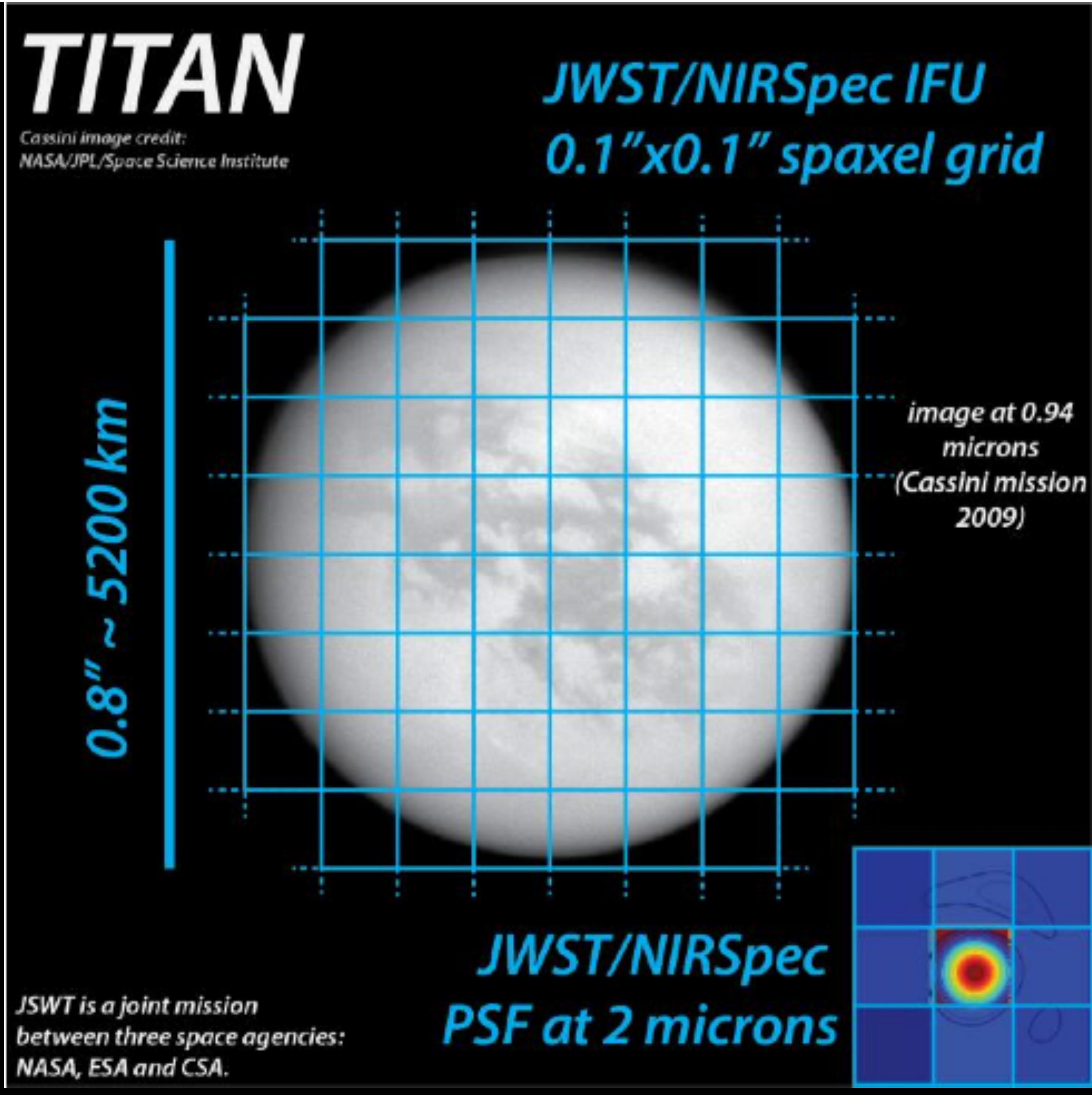
Heinze et al. (2010);

Chauvin et al. (2010);

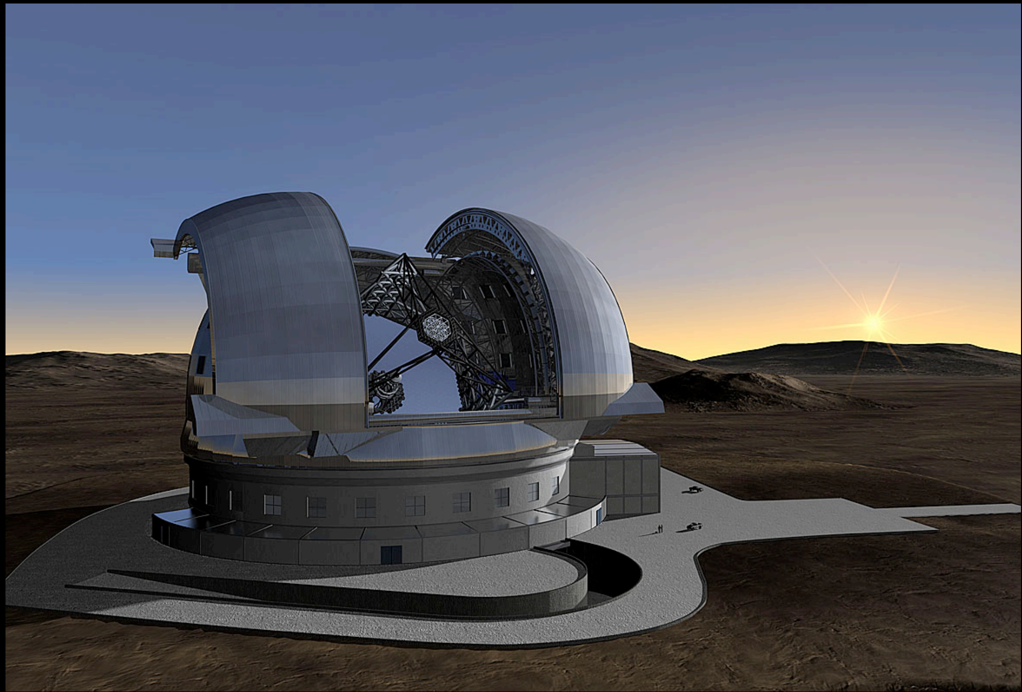
Delorme et al. (2011);

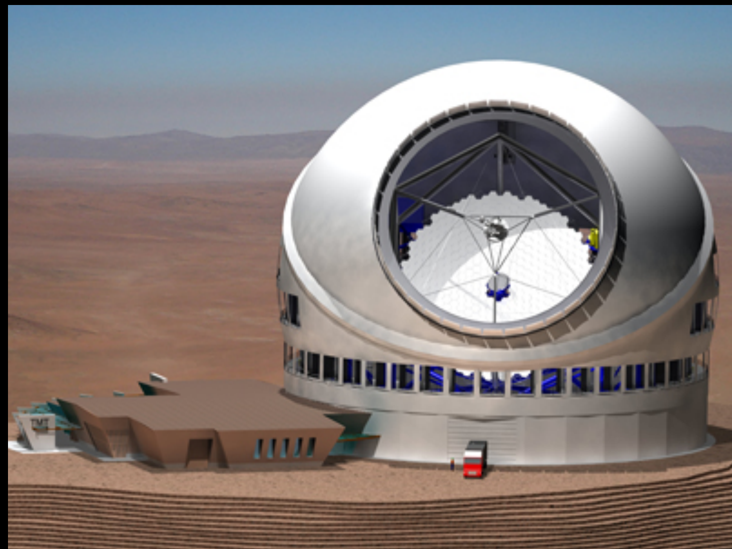
Vigan et al. (2012);

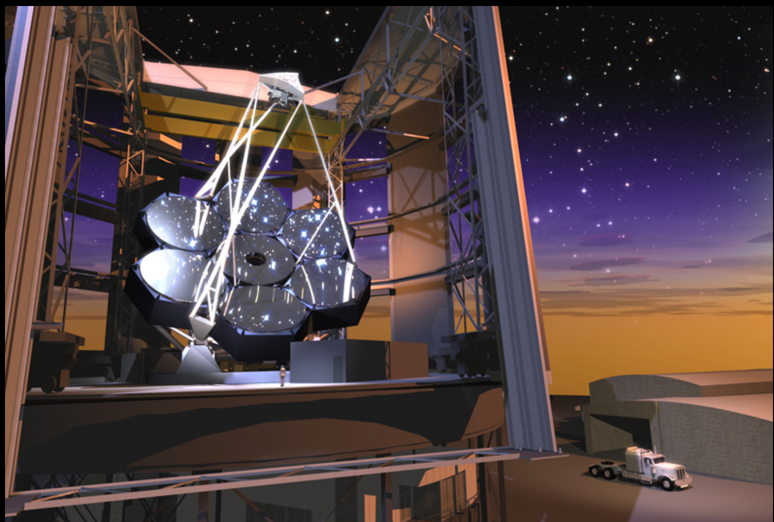
Reggiani et al. (2014); Janson et al. (2012)



TITAN
Cassini image credit:
NASA/JPL/Space Science Institute
JWST/NIRSpec IFU
0.1"x0.1" spaxel grid
0.8" ~ 5200 km
image at 0.94
microns
(Cassini mission
2009)
JWST/NIRSpec
PSF at 2 microns
JSWT is a joint mission
between three space agencies:
NASA, ESA and CSA.







Objects consisting of many mirrors may be SLIGHTLY Smaller OR arrive later than they CURRENTLY appear.

Science Goals lead to Design Requirements

Physical Resolution:

		15 pc	50 pc	150 pc	450 pc
JWST	1.65 μm	1 AU	3 AU	10 AU	30 AU
	10 μm	7 AU	20 AU	60 AU	180 AU
ELT	1.65 μm	.2 AU	.5 AU	1.5 AU	5 AU
	10 μm	1 AU	3 AU	10 AU	30 AU

Spectral Resolution :

R = 100 (molecular features)	JWST
R = 1000 (atomic features)	JWST
R = 10,000 (30 km/sec)	ELT
R = 100,000 (3 km/sec)	ELT

Field of View:

2' (star clusters within 1 kpc)	JWST
1.5" (circumstellar disk at 150 pc)	ELT