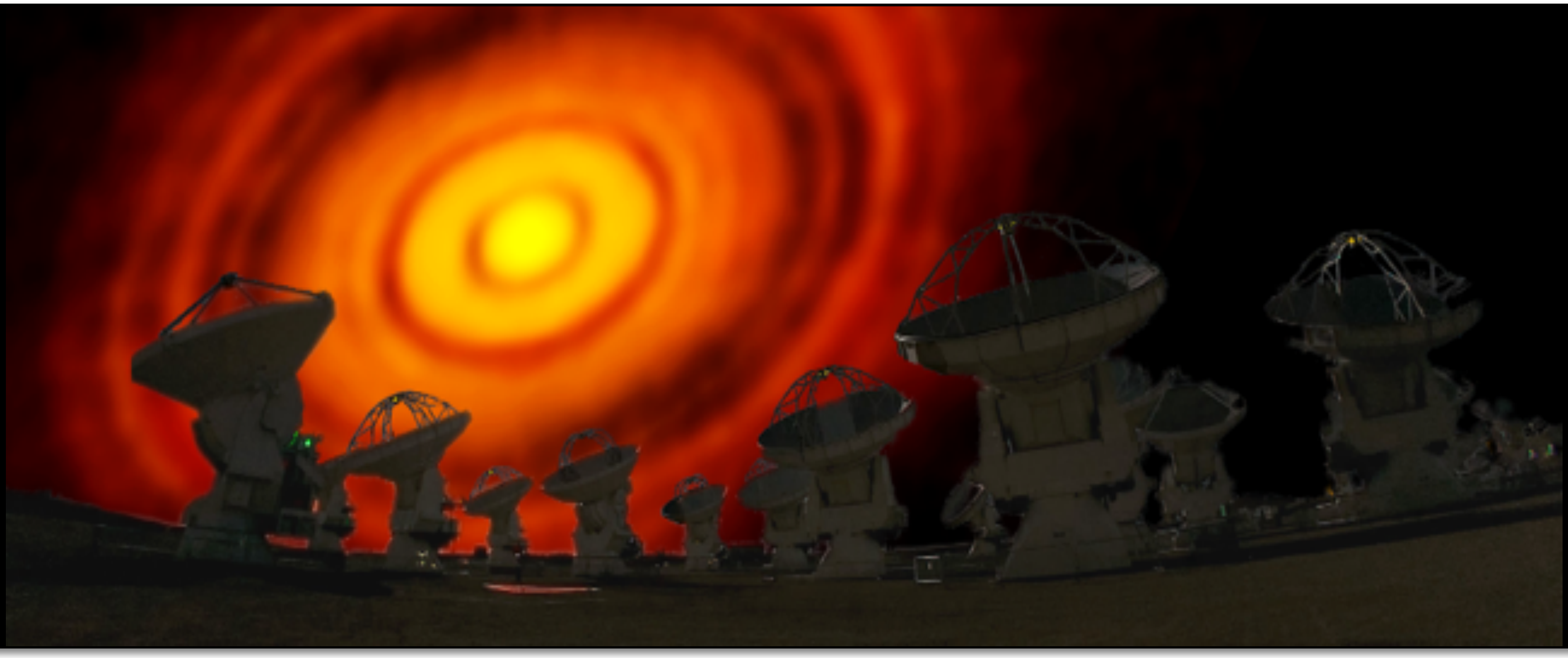
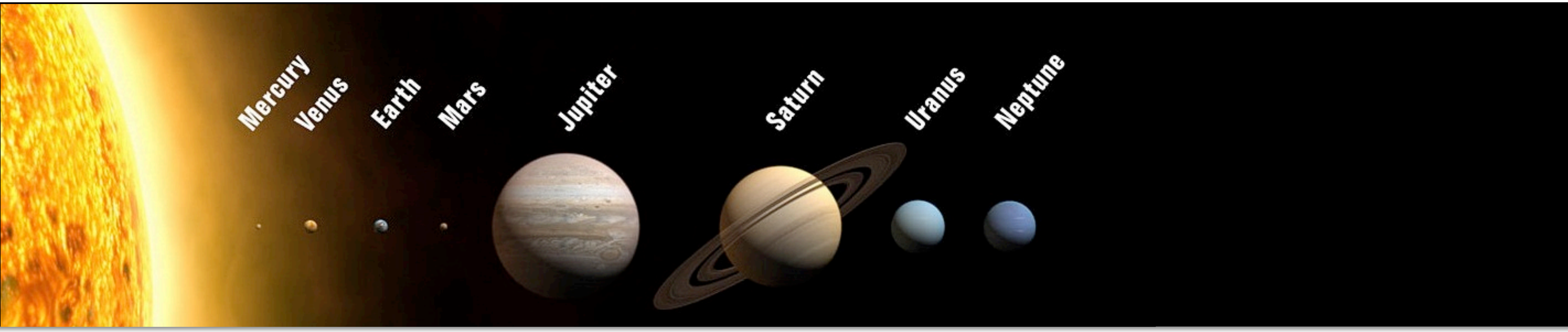
Planet Formation Seen with Radio Eyes

Andrea Isella (Rice University)

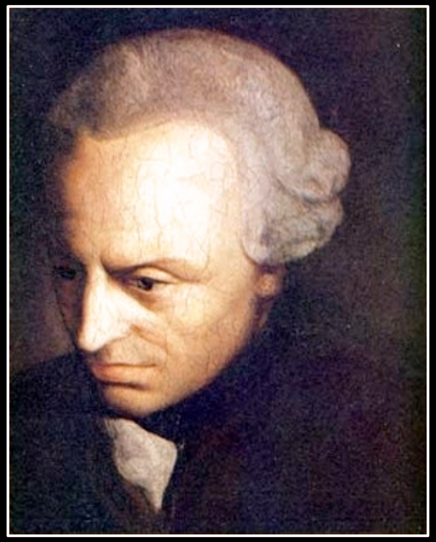
planetformation.rice.edu

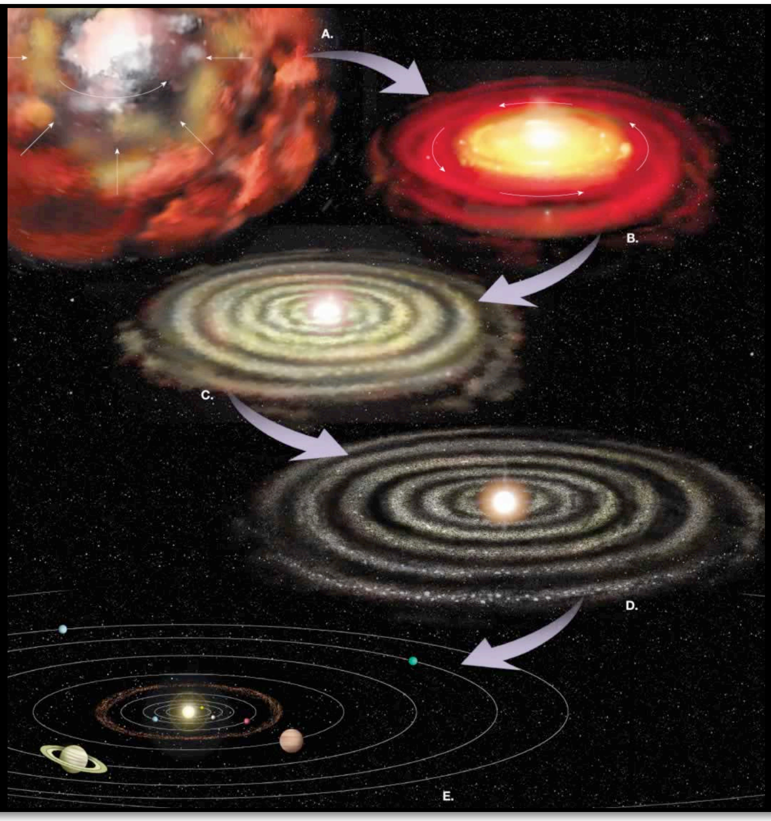


Solar Nebular hypothesis

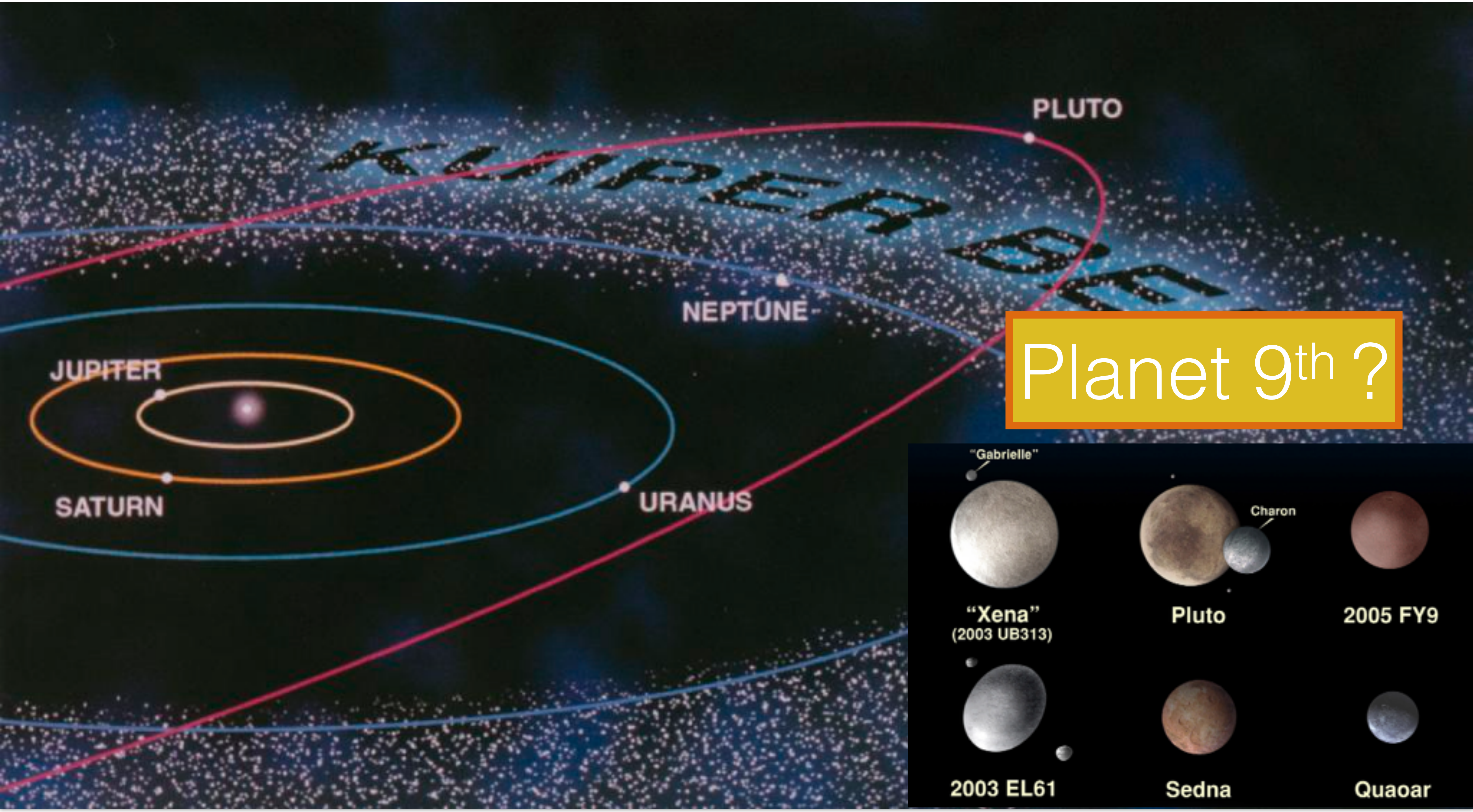


the German philosopher
Immanuel Kant (1724-1804)

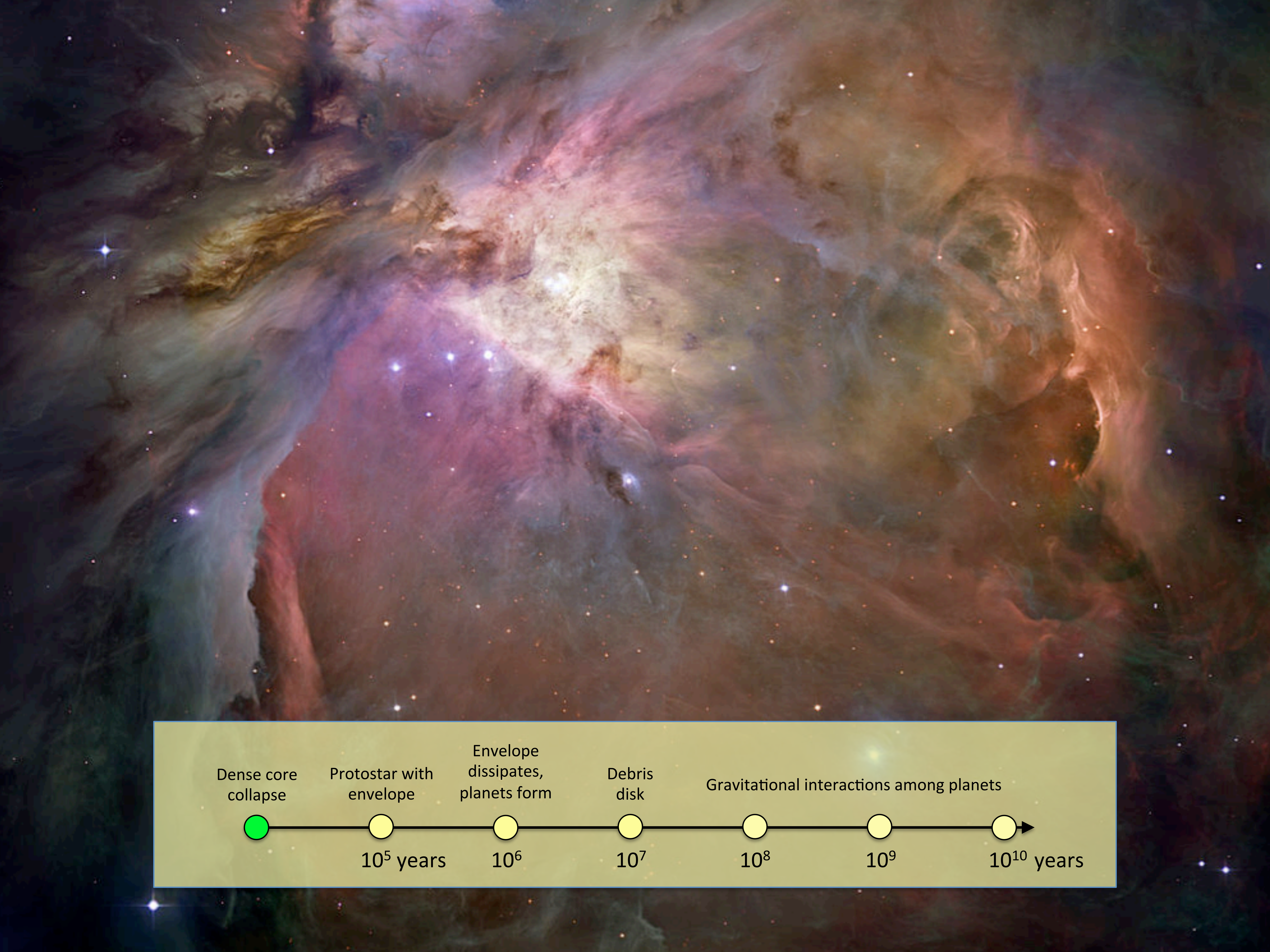


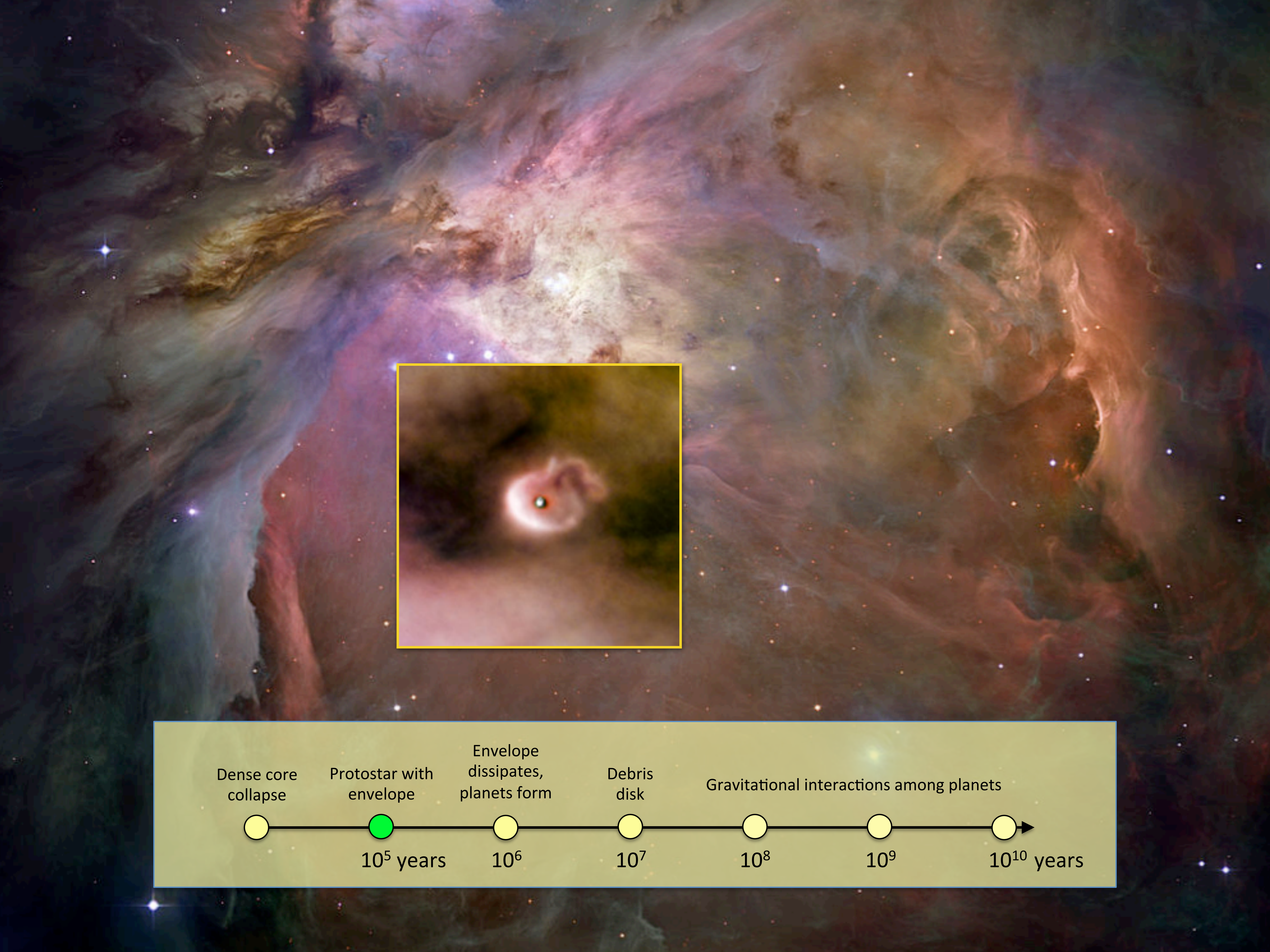


The Unknown Solar System



Planet 9th ?


Dense core collapse
Protostar with envelope
Envelope dissipates, planets form
Debris disk
Gravitational interactions among planets
10^5 years
10^6
10^7
10^8
10^9
10^{10} years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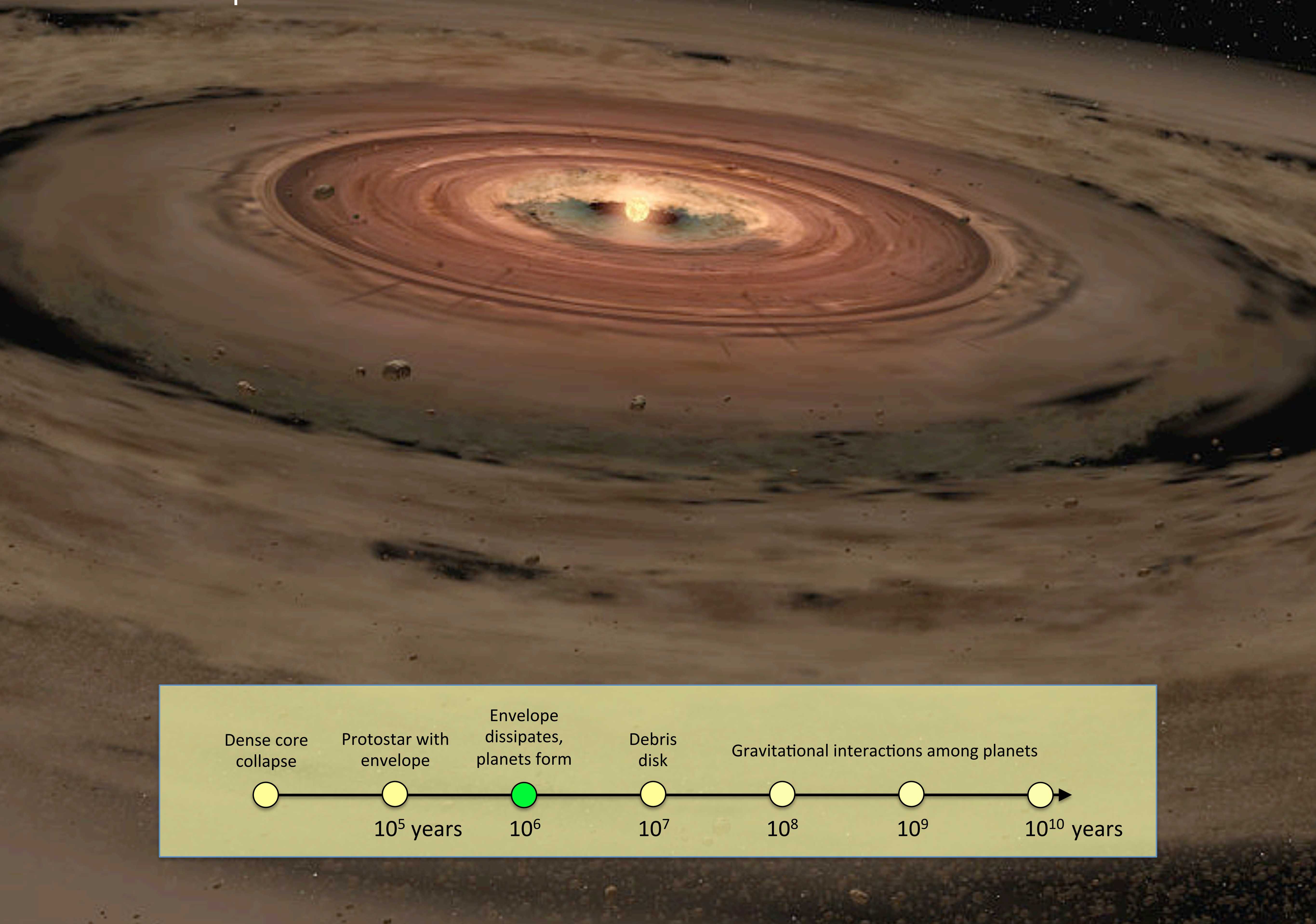
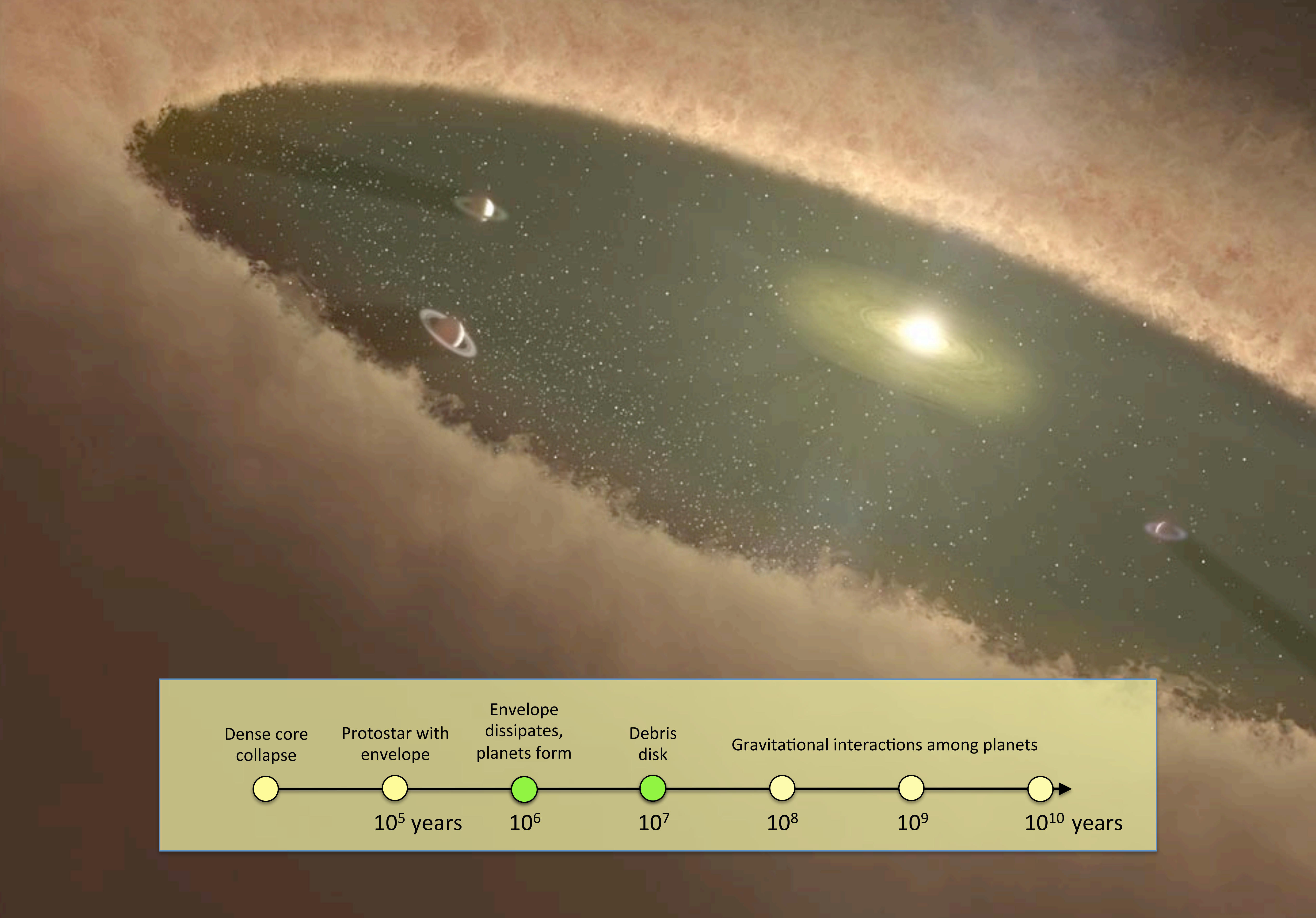
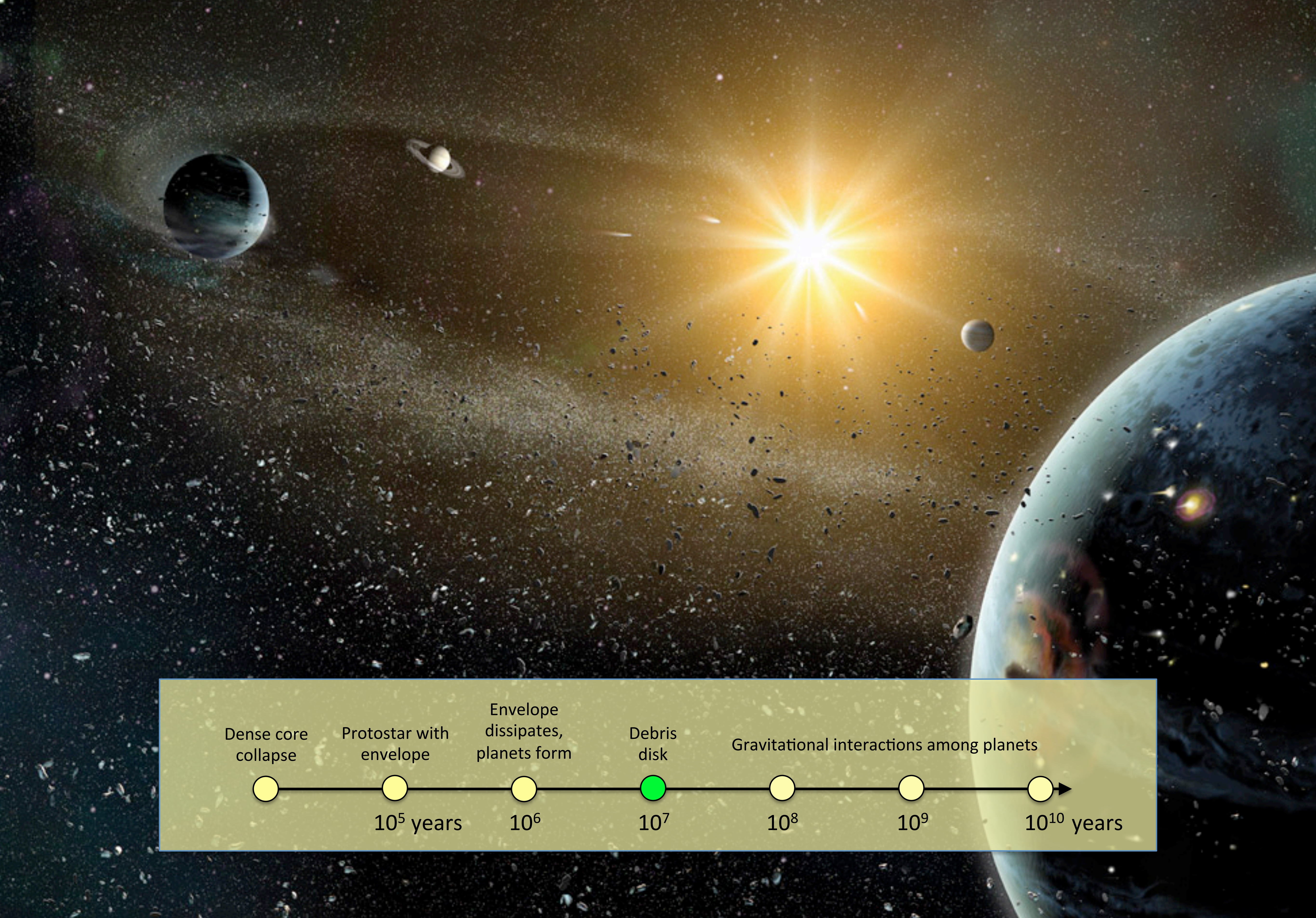
Artistic impression

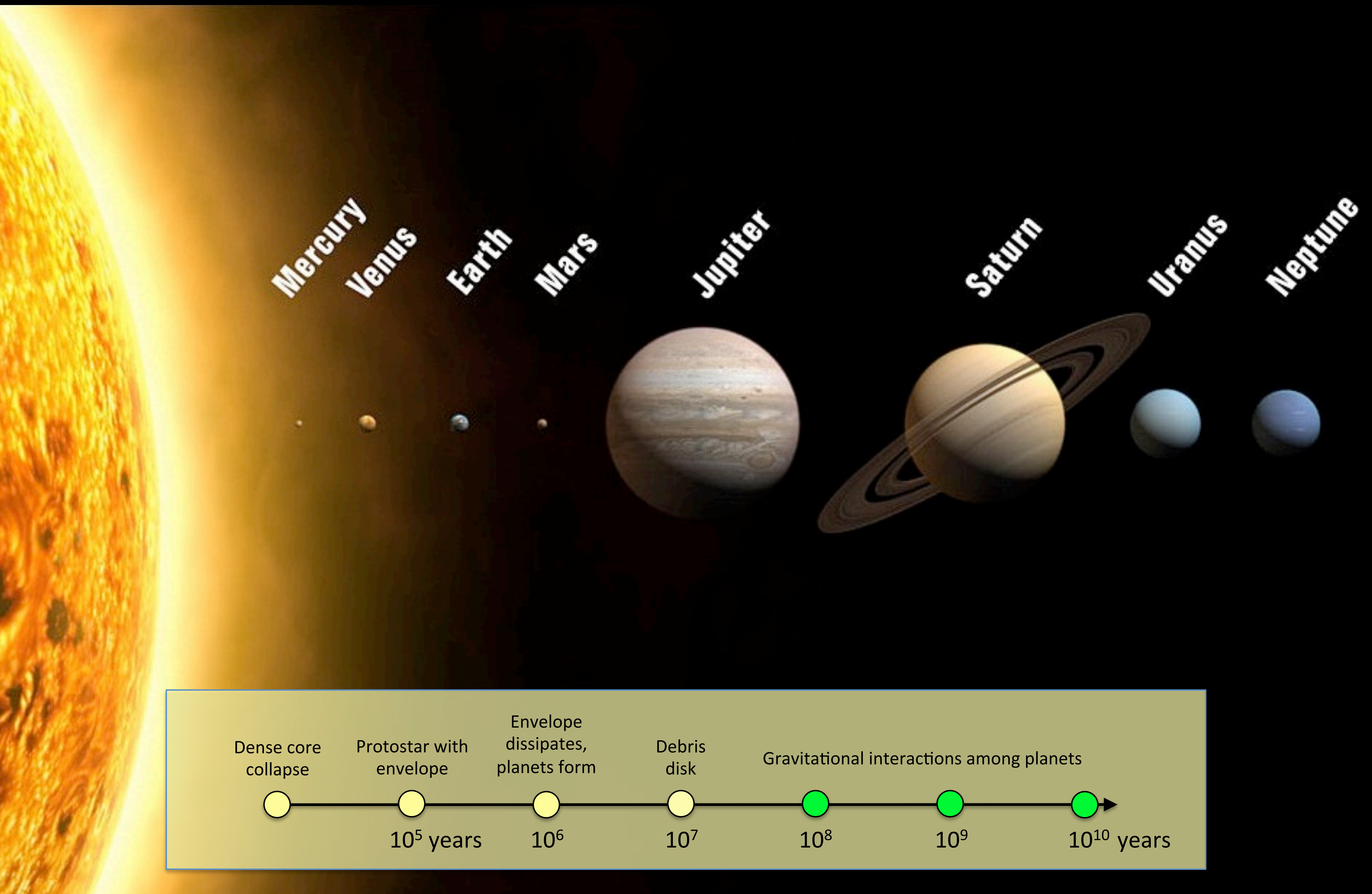


Artistic impression



Artistic impression




Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Dense core collapse
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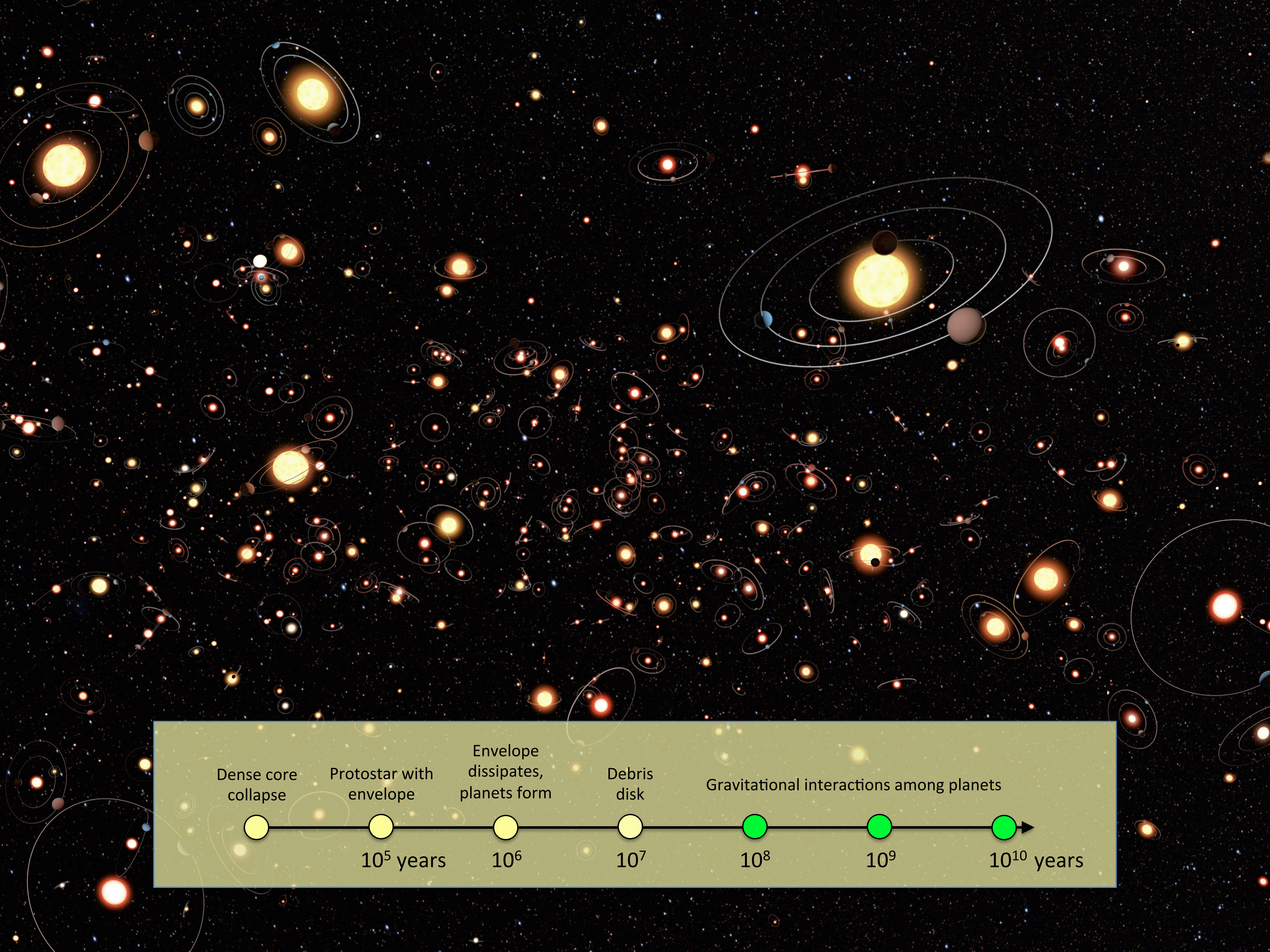
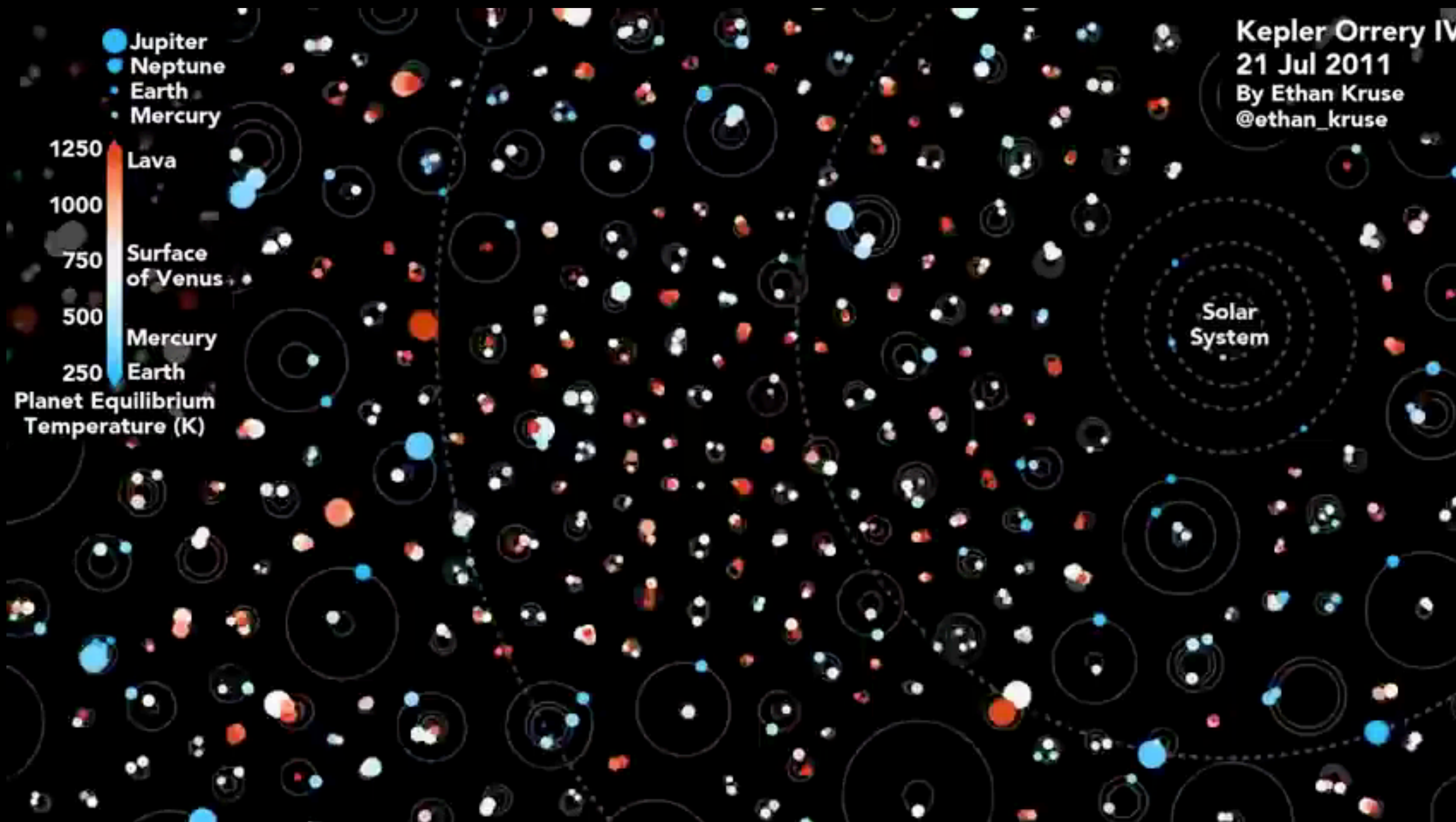

Dense core collapse
Protostar with envelope
Envelope dissipates, planets form
Debris disk
Gravitational interactions among planets
10^5 years
10^6
10^7
10^8
10^9
10^10 years

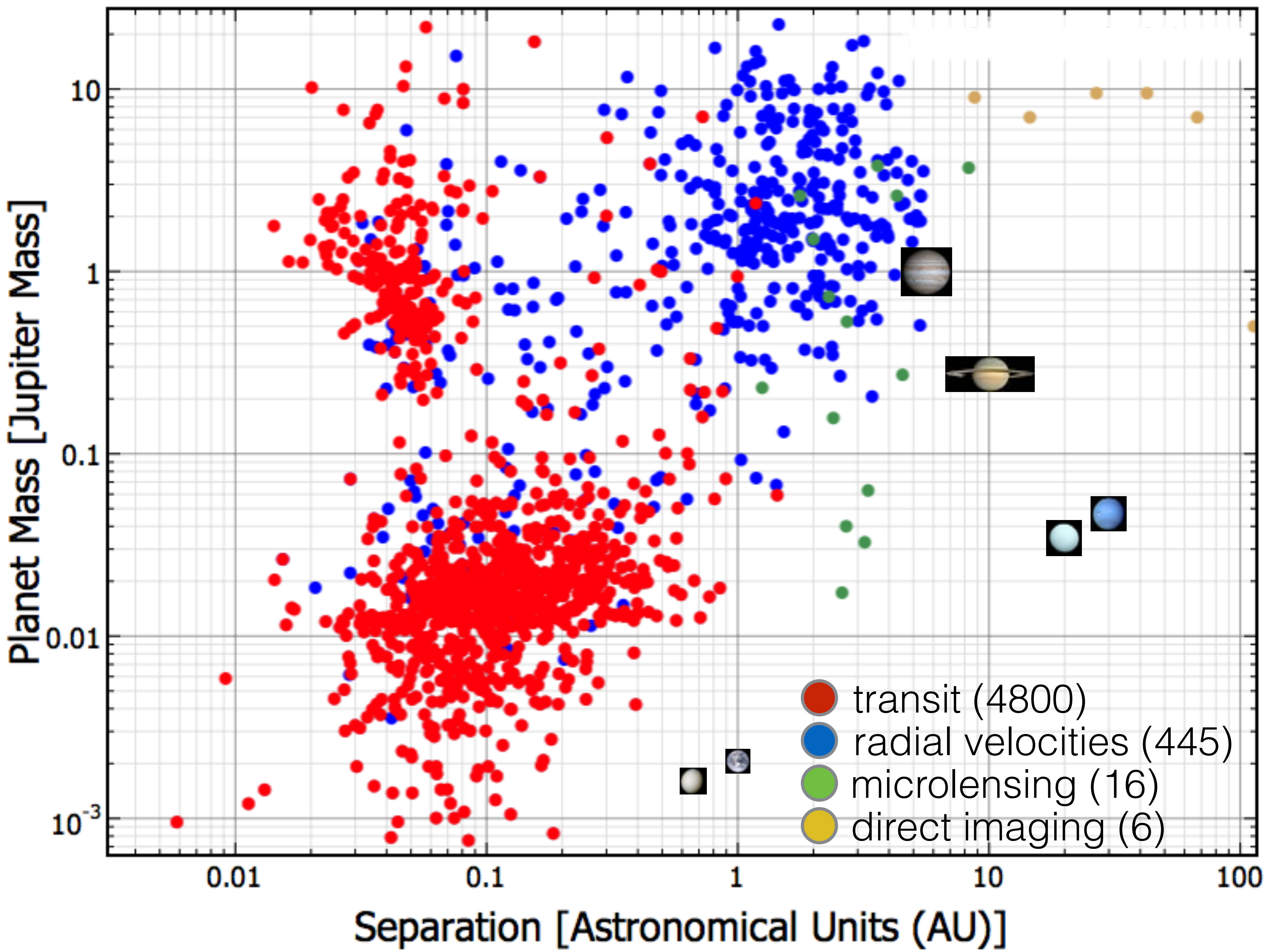
Understanding the other planetary systems

As of today, astronomers have discovered 3510 planets outside the Solar system

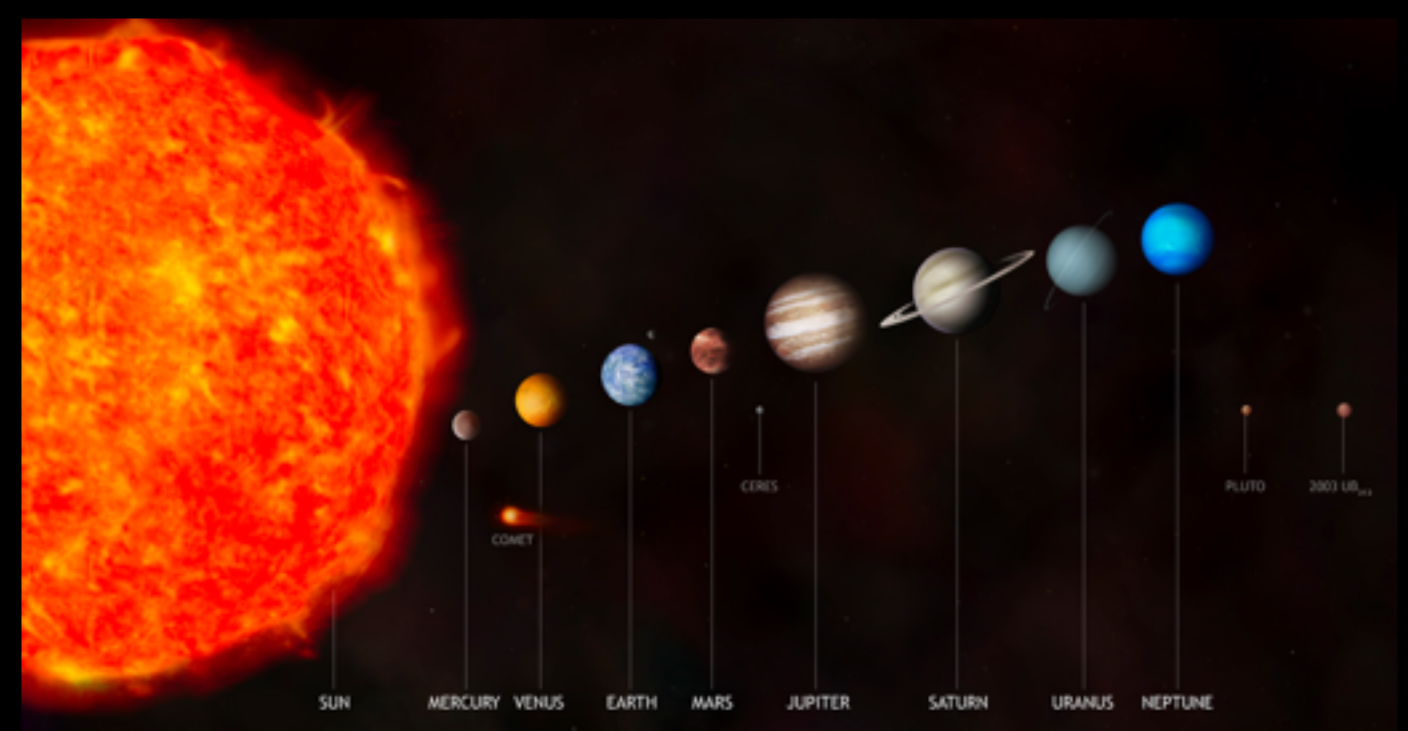


https://exoplanets.nasa.gov/

Demographics of extrasolar planets



Looking back in time to understand our origins



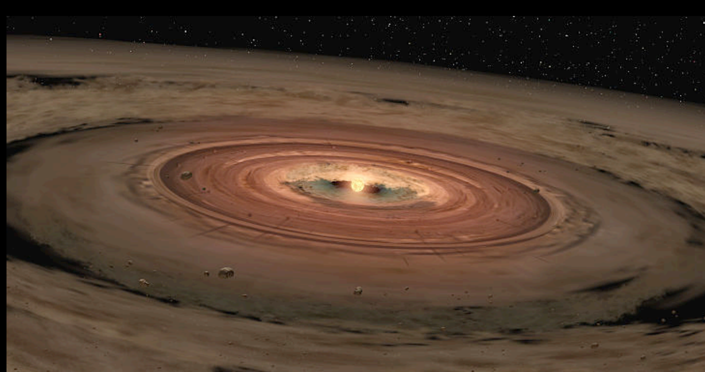
Three stages evolution

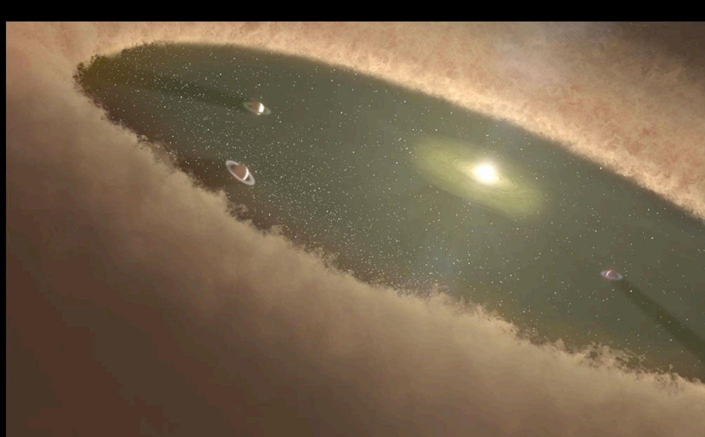
Formation stage

Birth - Infancy - Childhood

age < 10 Myr

The parent disk is still present
planet-disk interaction



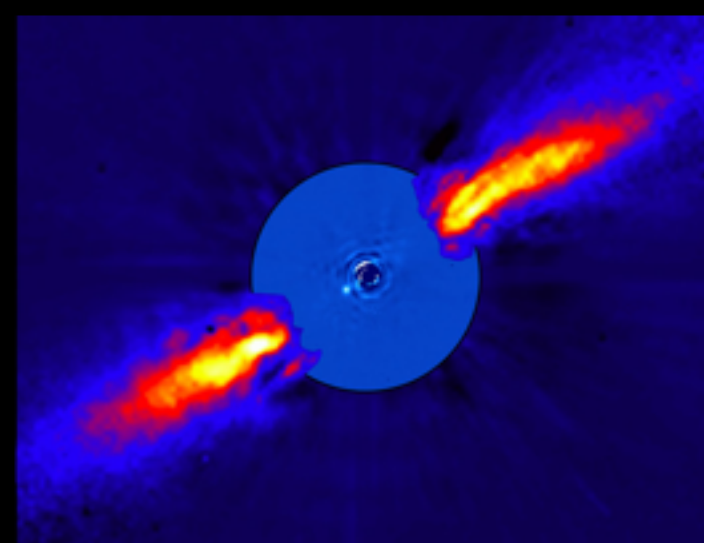


Early evolution

Adolescence

10 Myr < age < 1 Gyr

Debris disk
planet-planet interaction

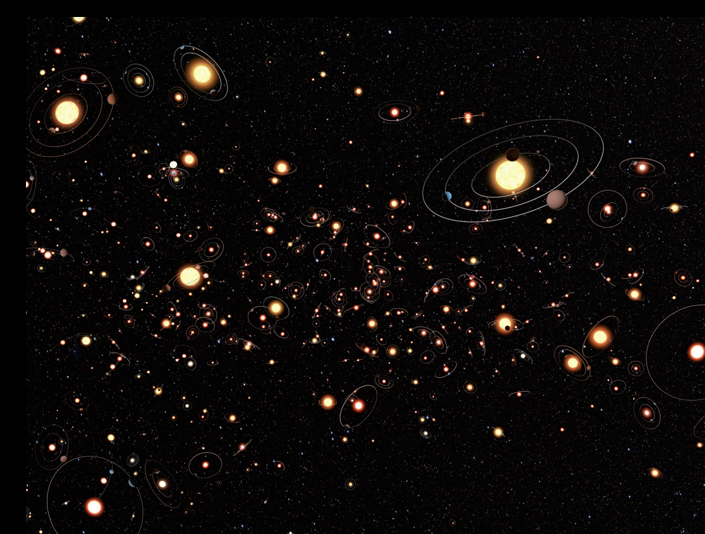


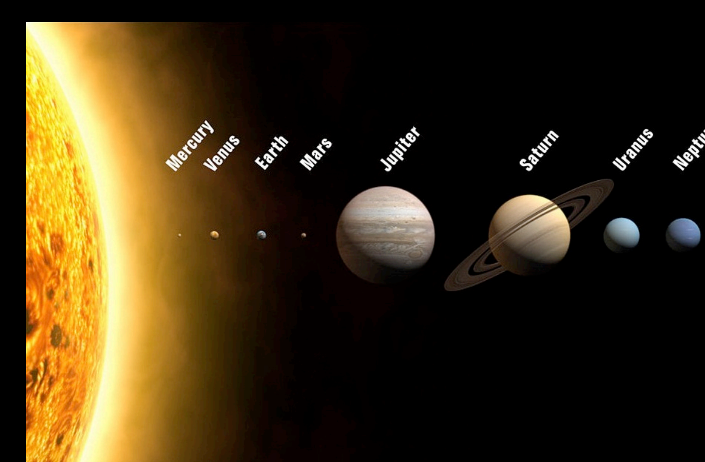
Late evolution

Adulthood

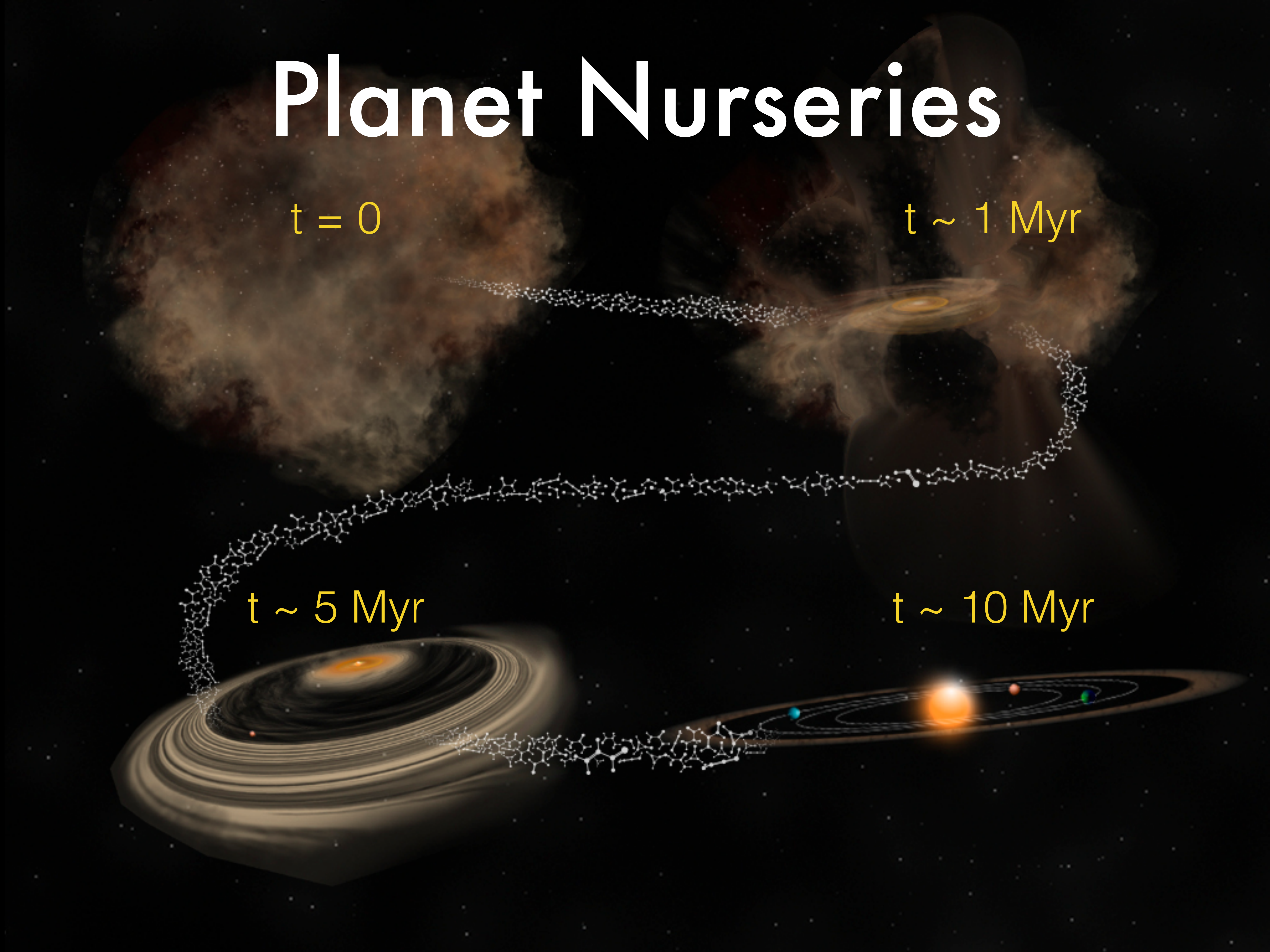
age > 1 Gyr

Debris disk
planet-planet interaction

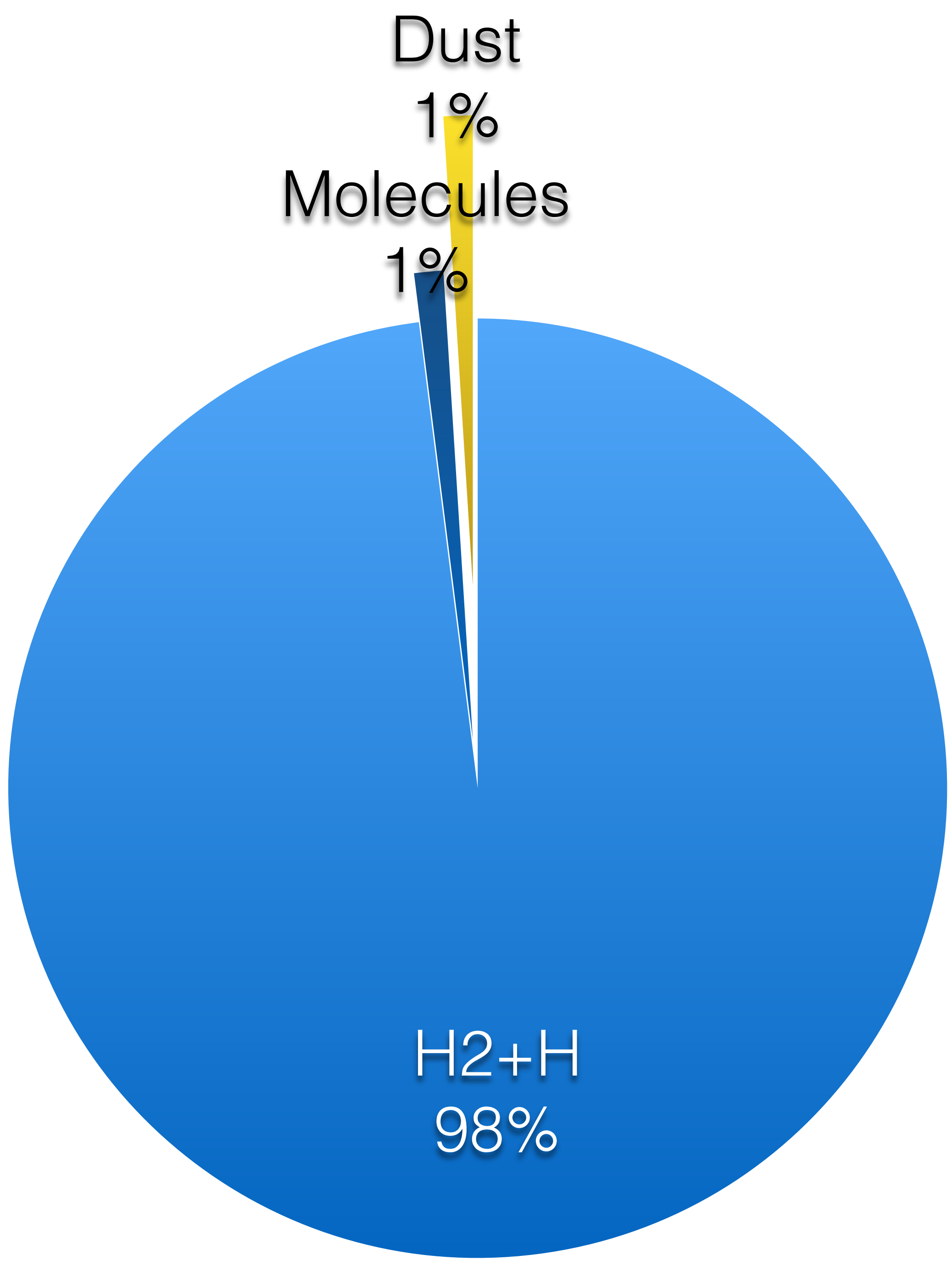


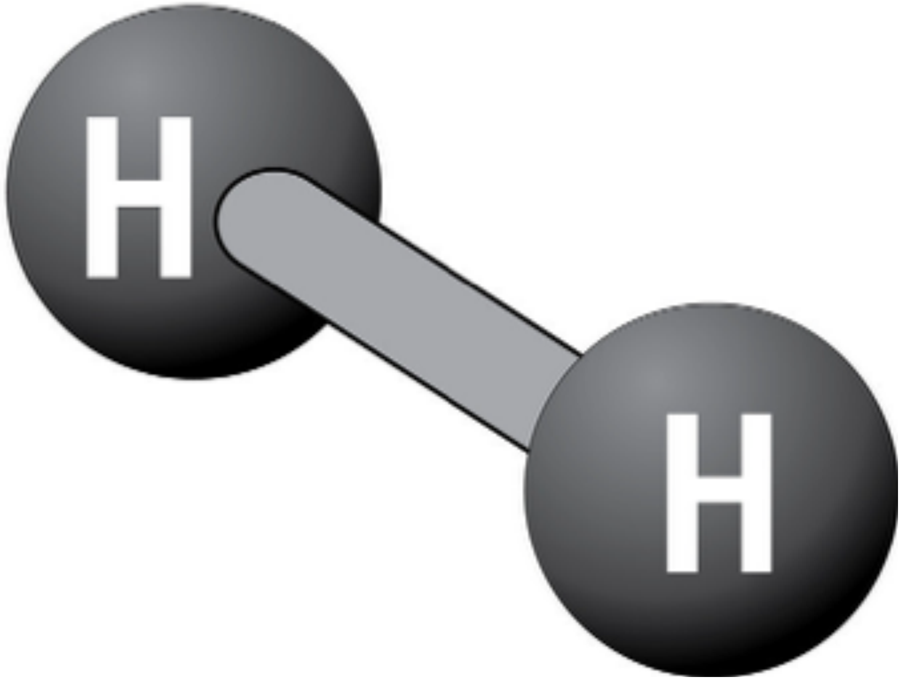


Planet Nurseries



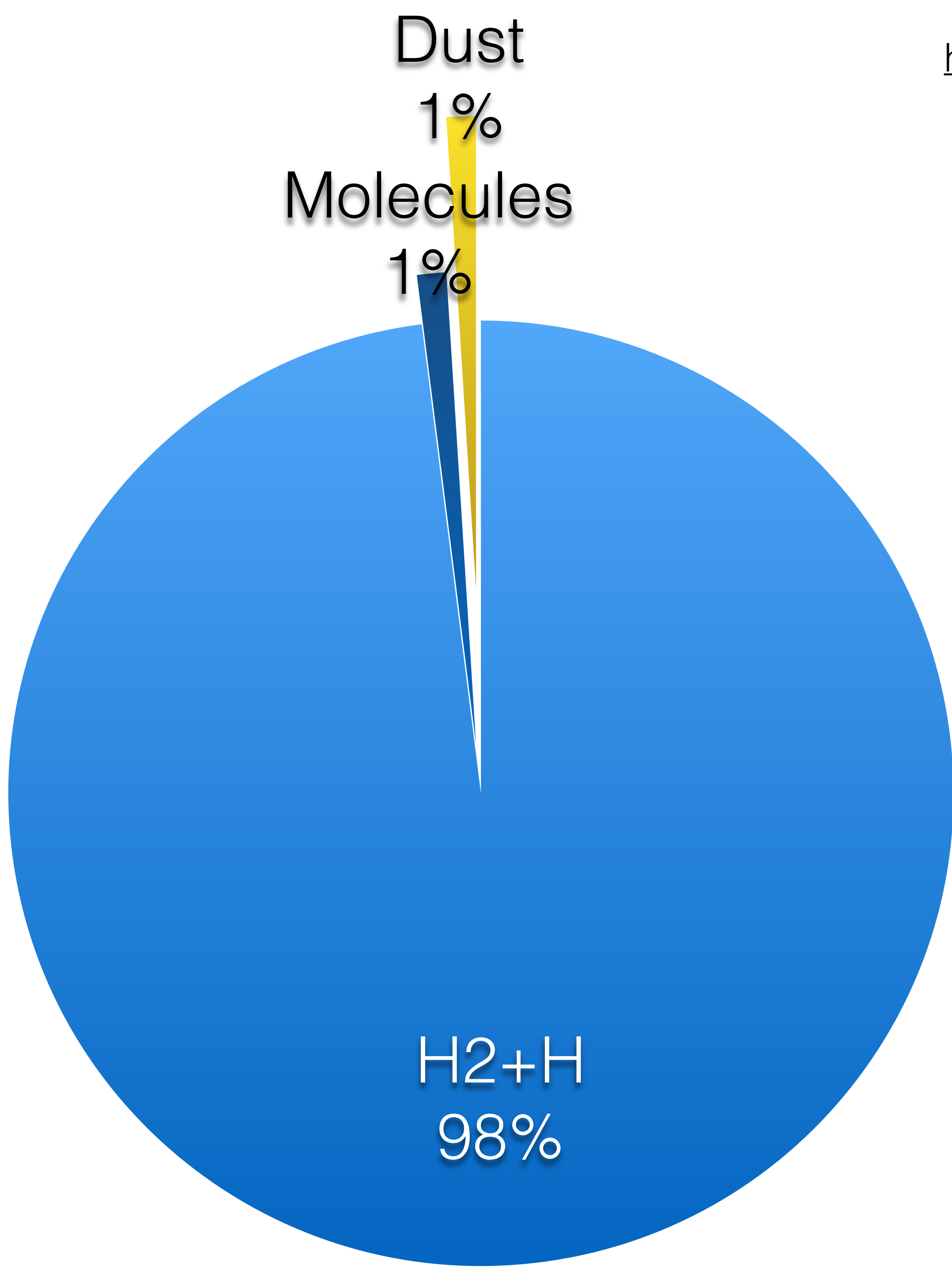
The Composition of Protoplanetary Disks





H2 emits very little radiation and is practically invisible

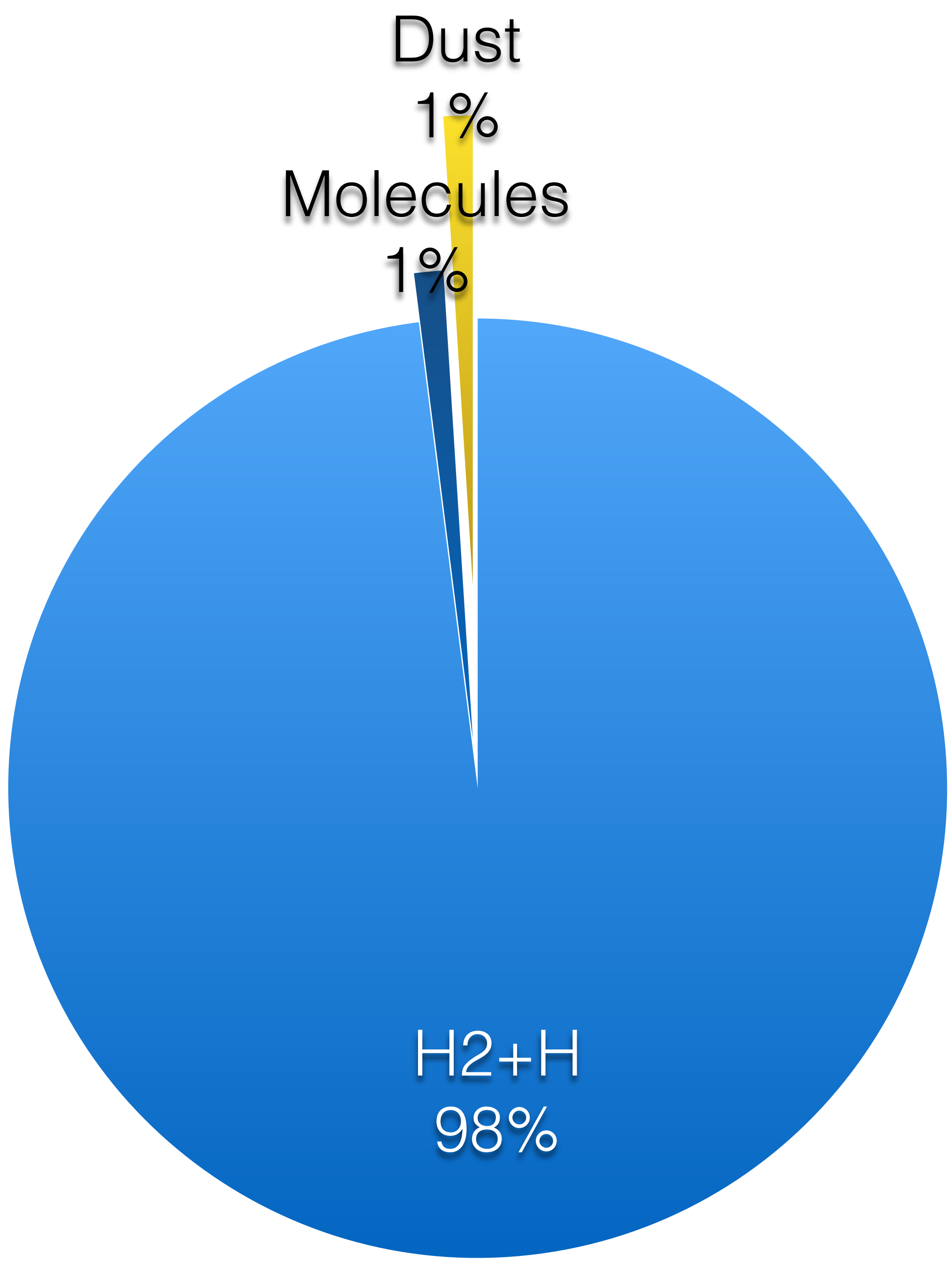
The Composition of Protoplanetary Disks



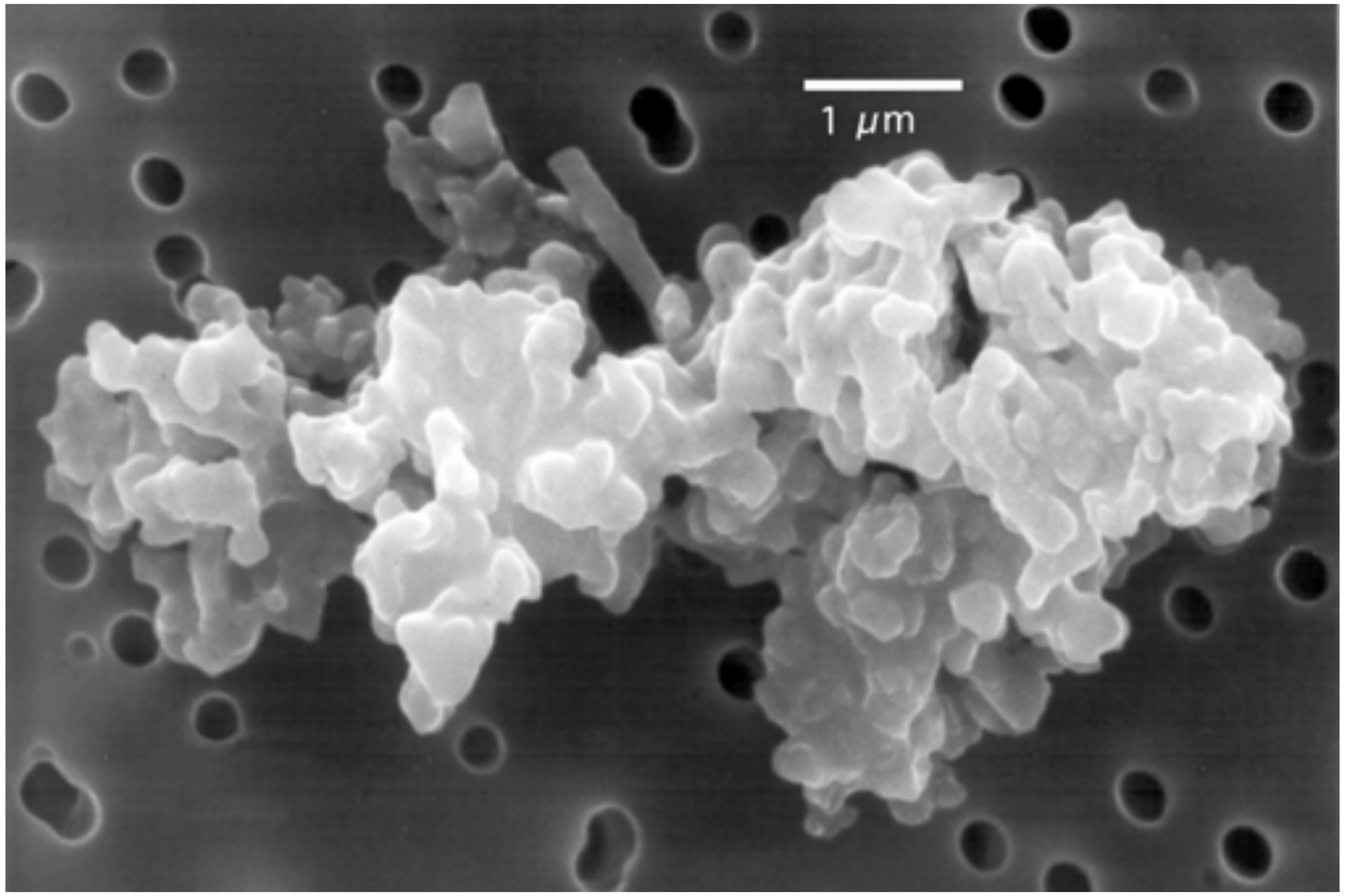
https://en.wikipedia.org/wiki/List_of_interstellar_and_circumstellar_molecules

2 Atoms	3 Atoms	4 Atoms
CO	HCN	H
CS	H	NH
CN	HCN	
HD	HNC	
	HCO	
	DCO	
	DCN	
	N2H	

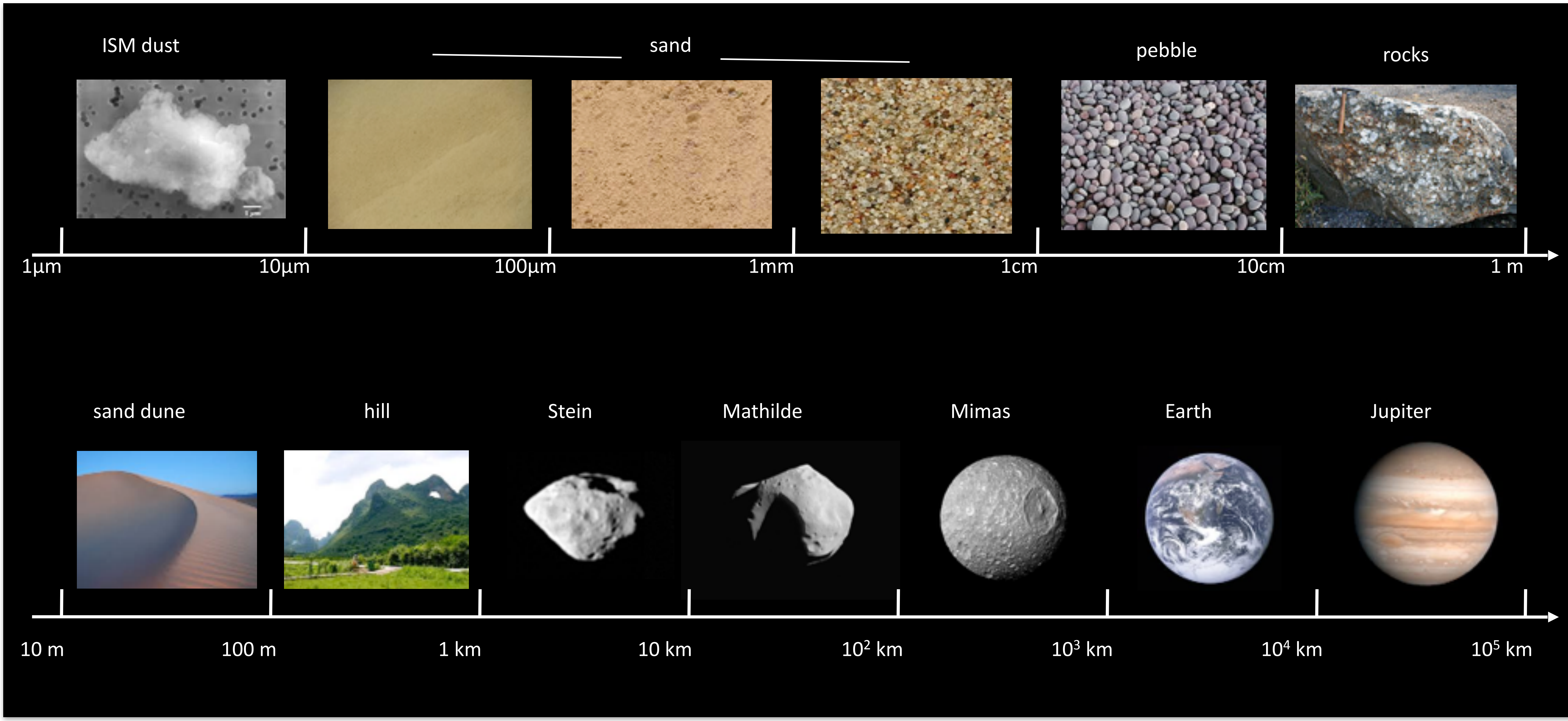
The Composition of Protoplanetary Disks



Interplanetary dust



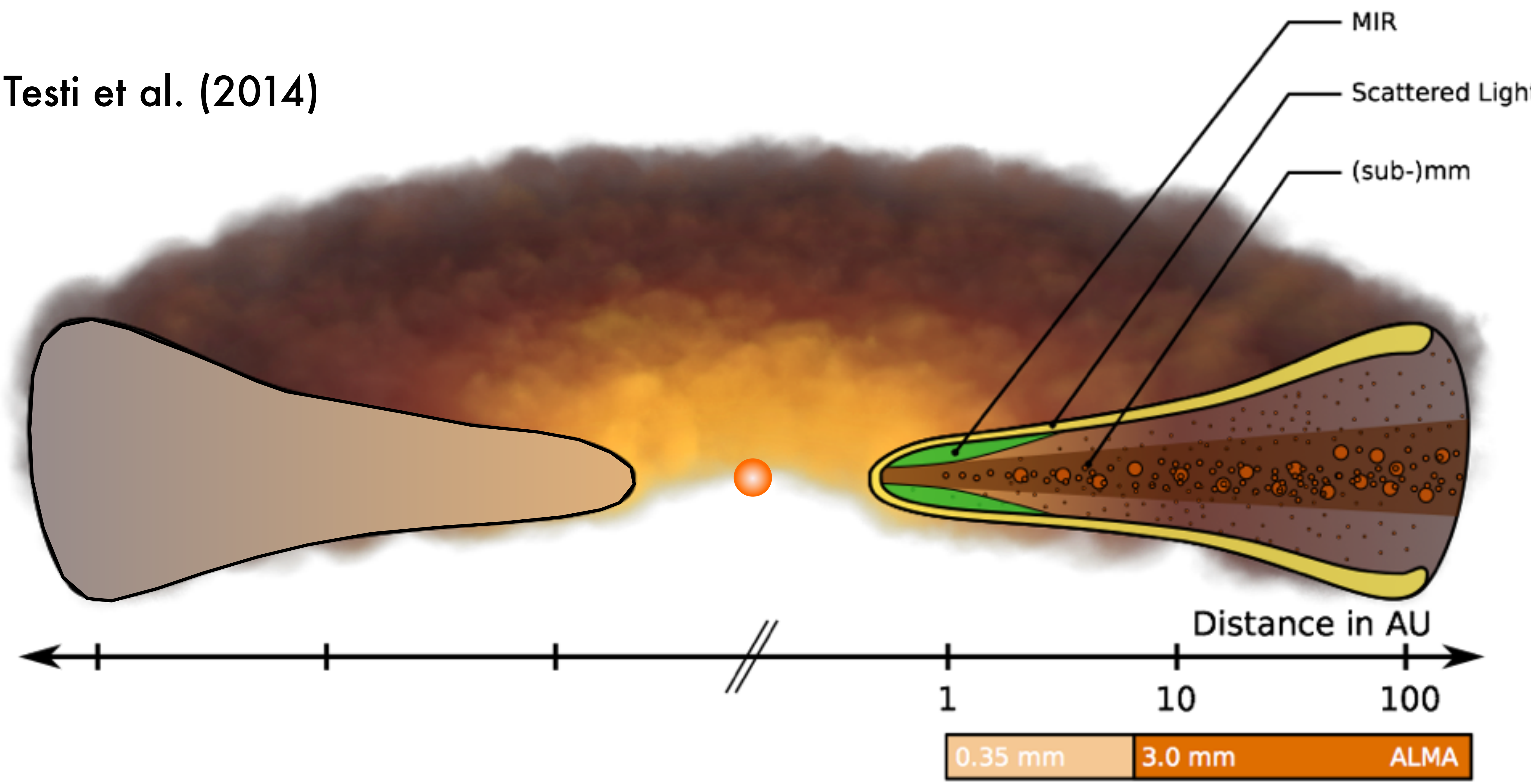
From Dust to Planets



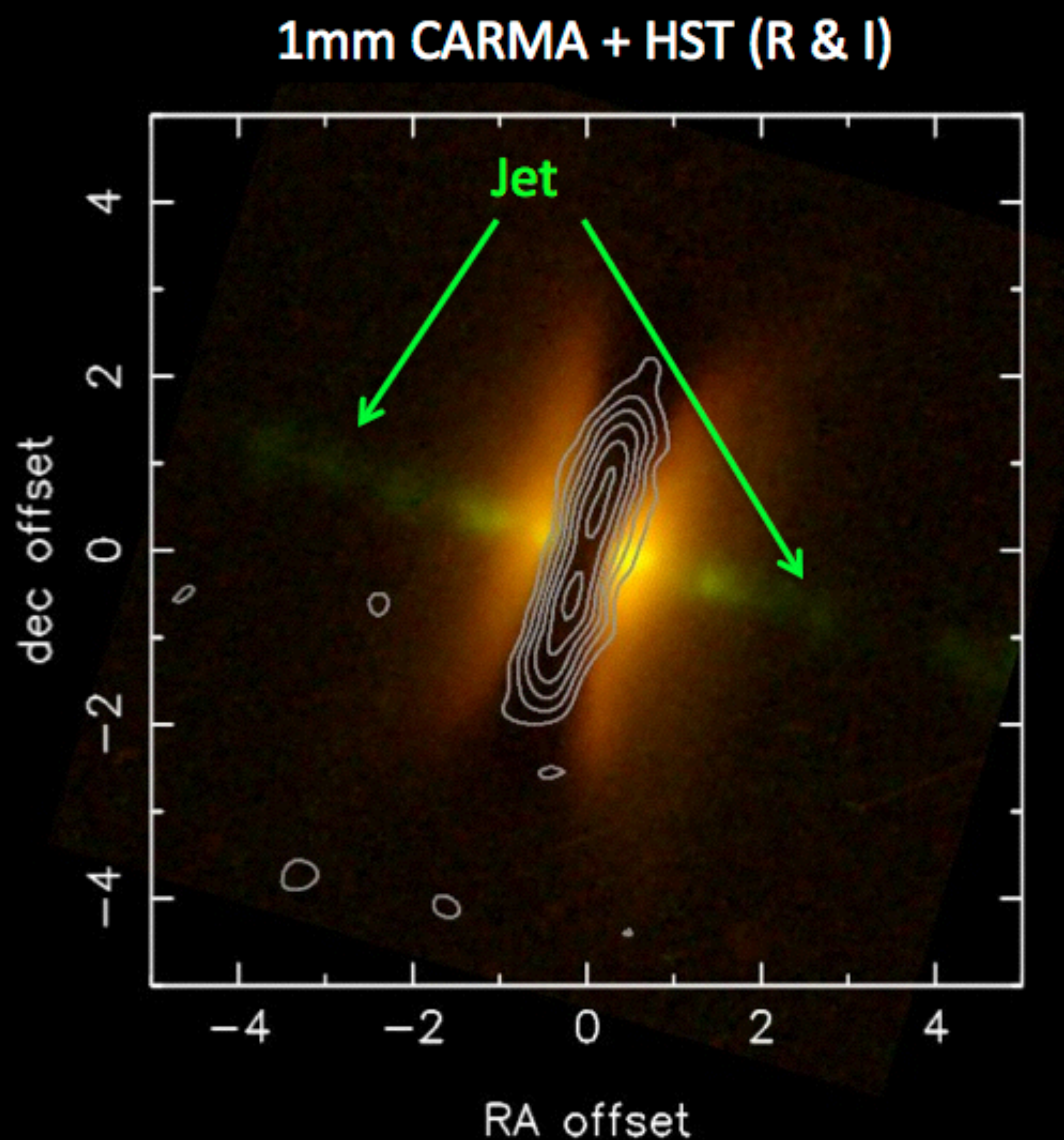
Core accretion model (Safranov 1976, Pollack 1996)

The Structure of Protoplanetary disks

Testi et al. (2014)

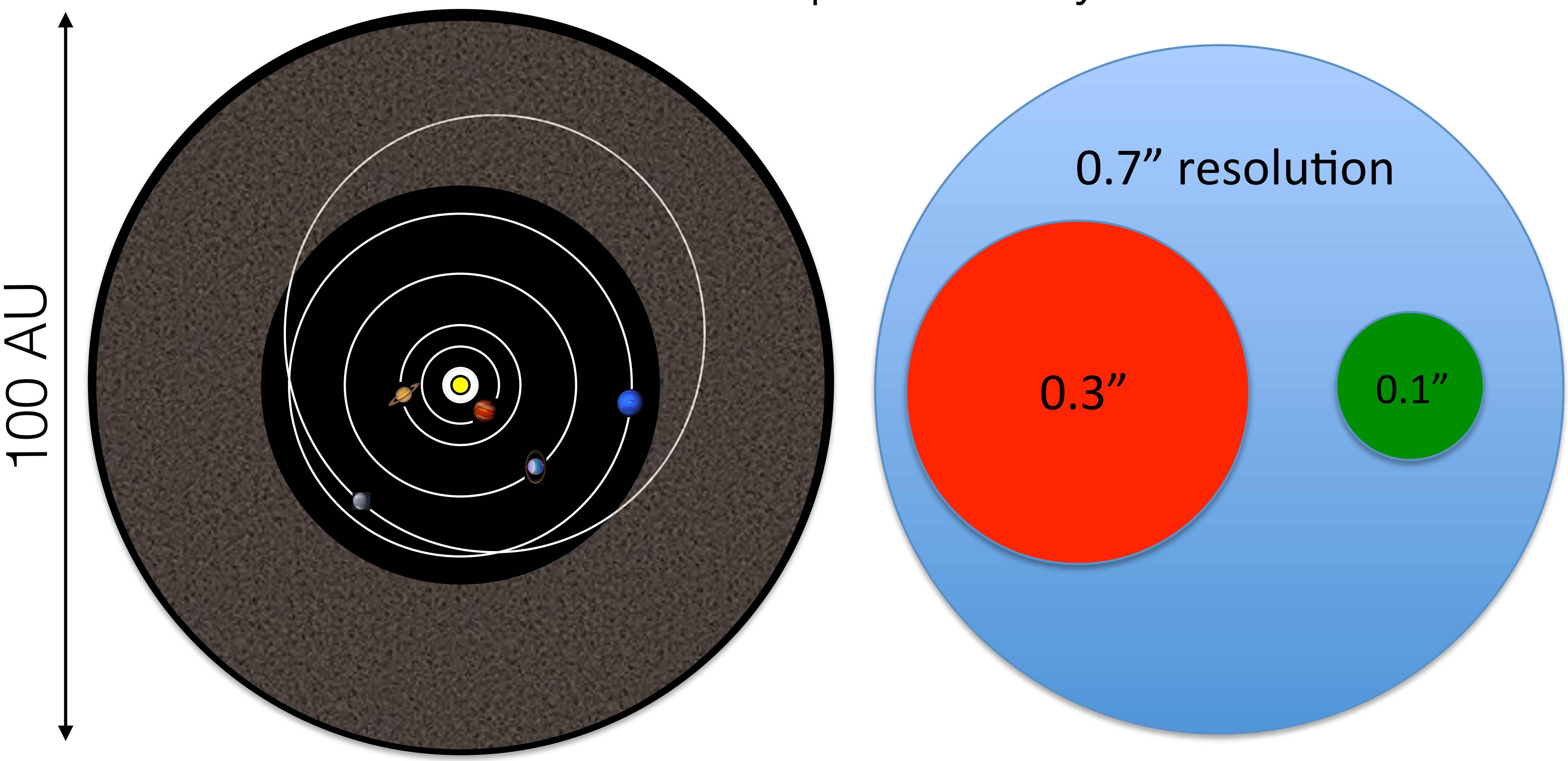


The Structure of a Protoplanetary disk



Angular Resolution is Critical

d=150 pc ~ 490 ly



Angular Resolution is Critical

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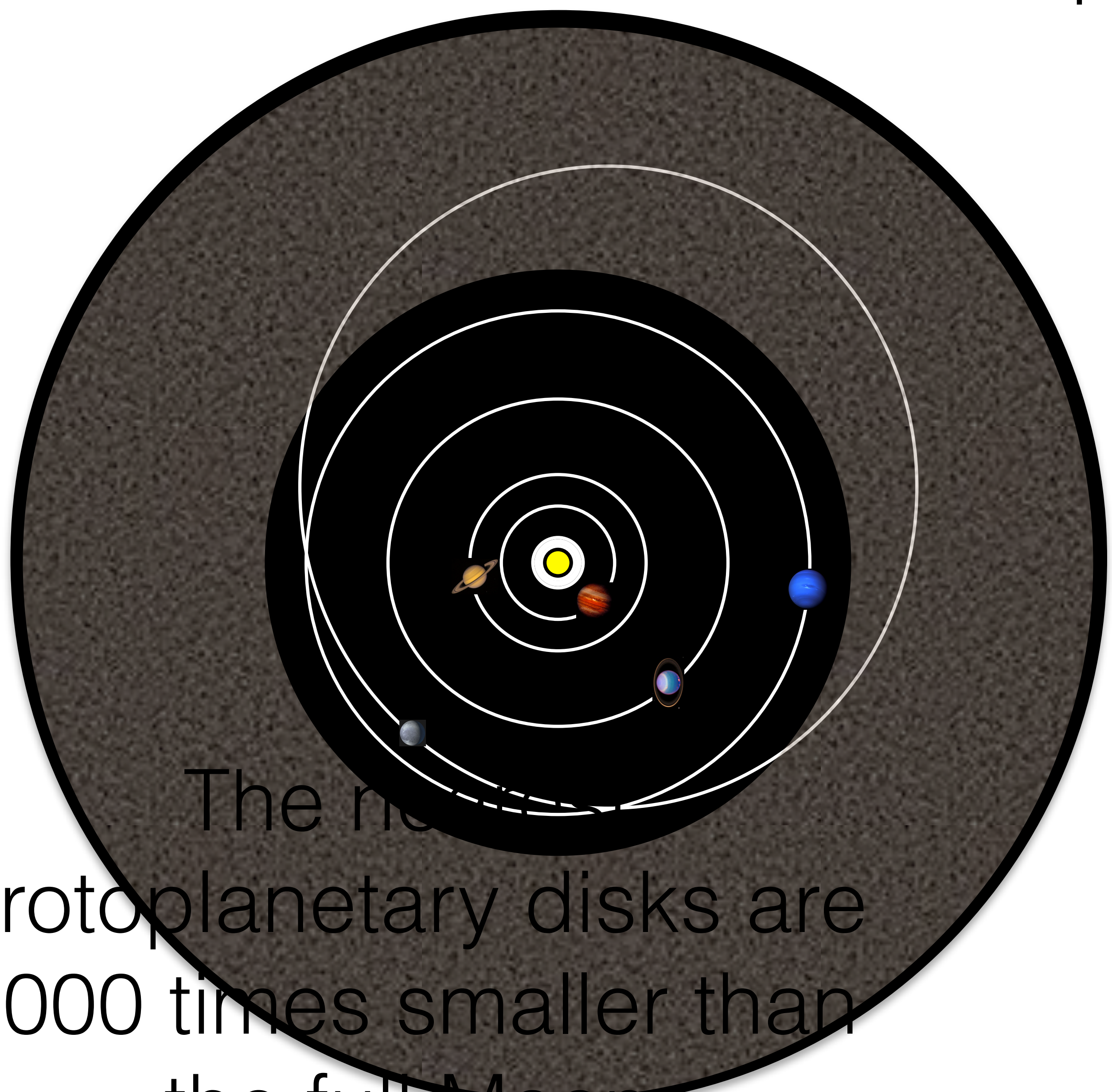
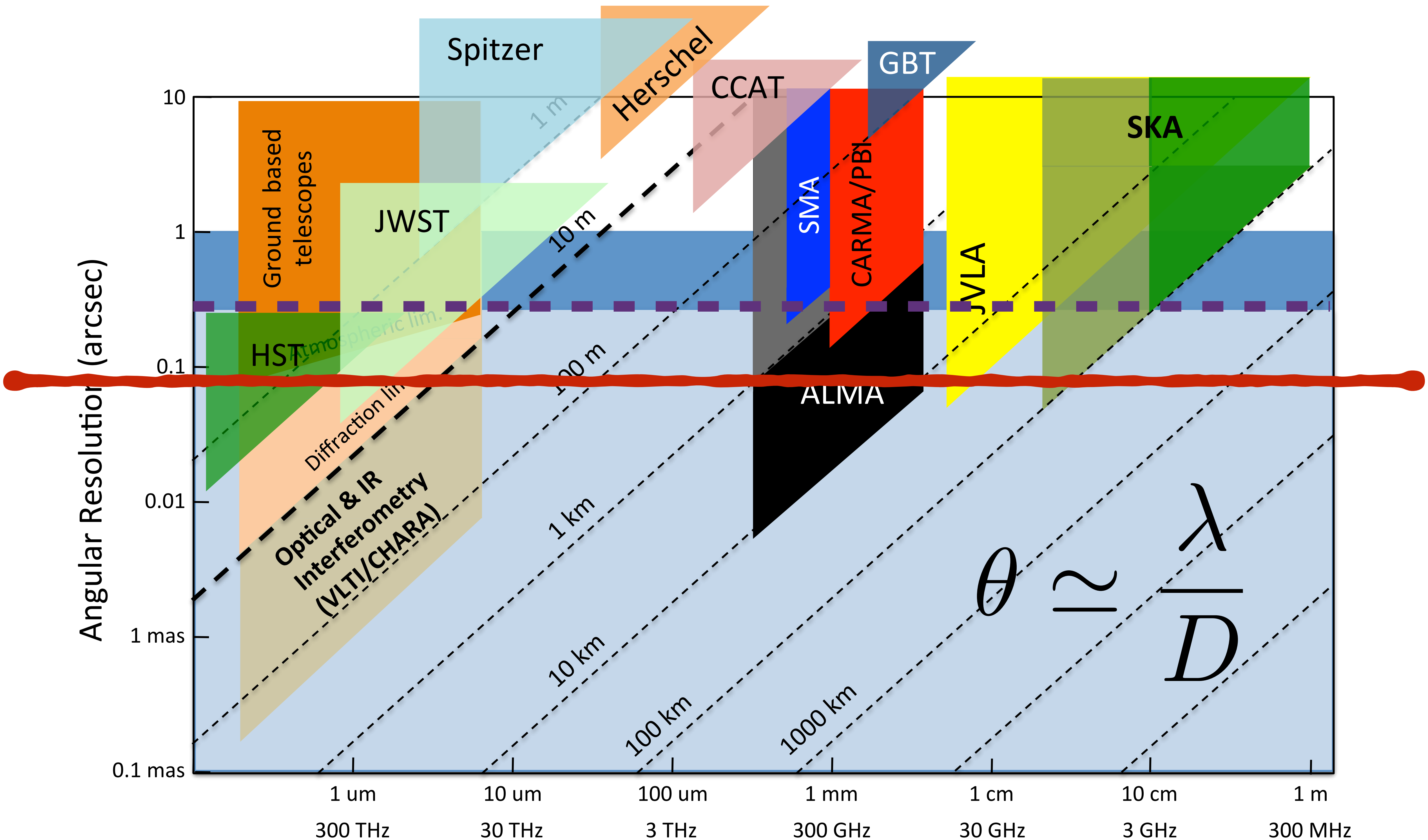
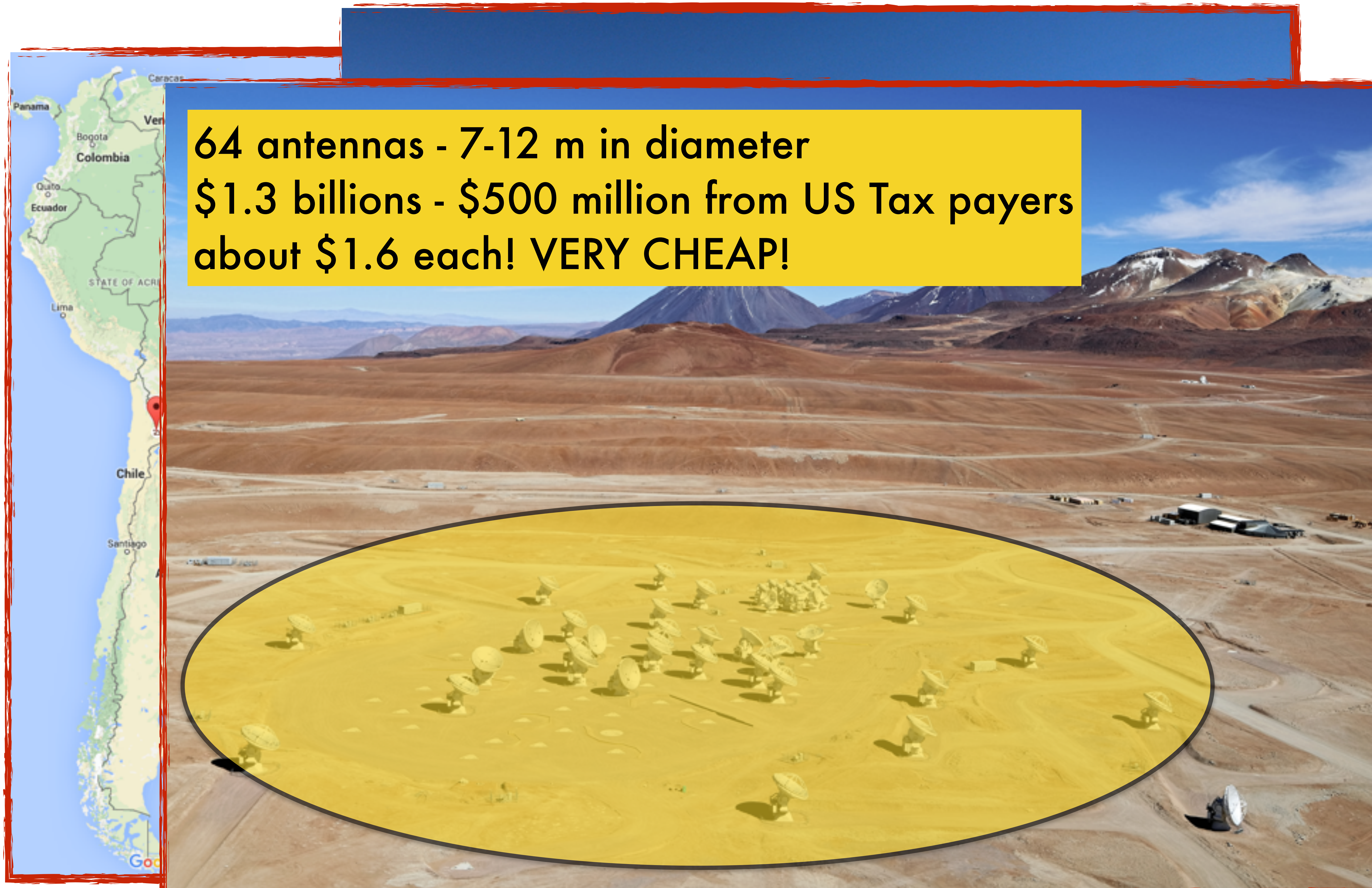


The n[illegible]
protoplanetary disks are
3000 times smaller than
the full Moon

Angular resolution delivered by existing telescopes



Atacama Large Millimeter Array

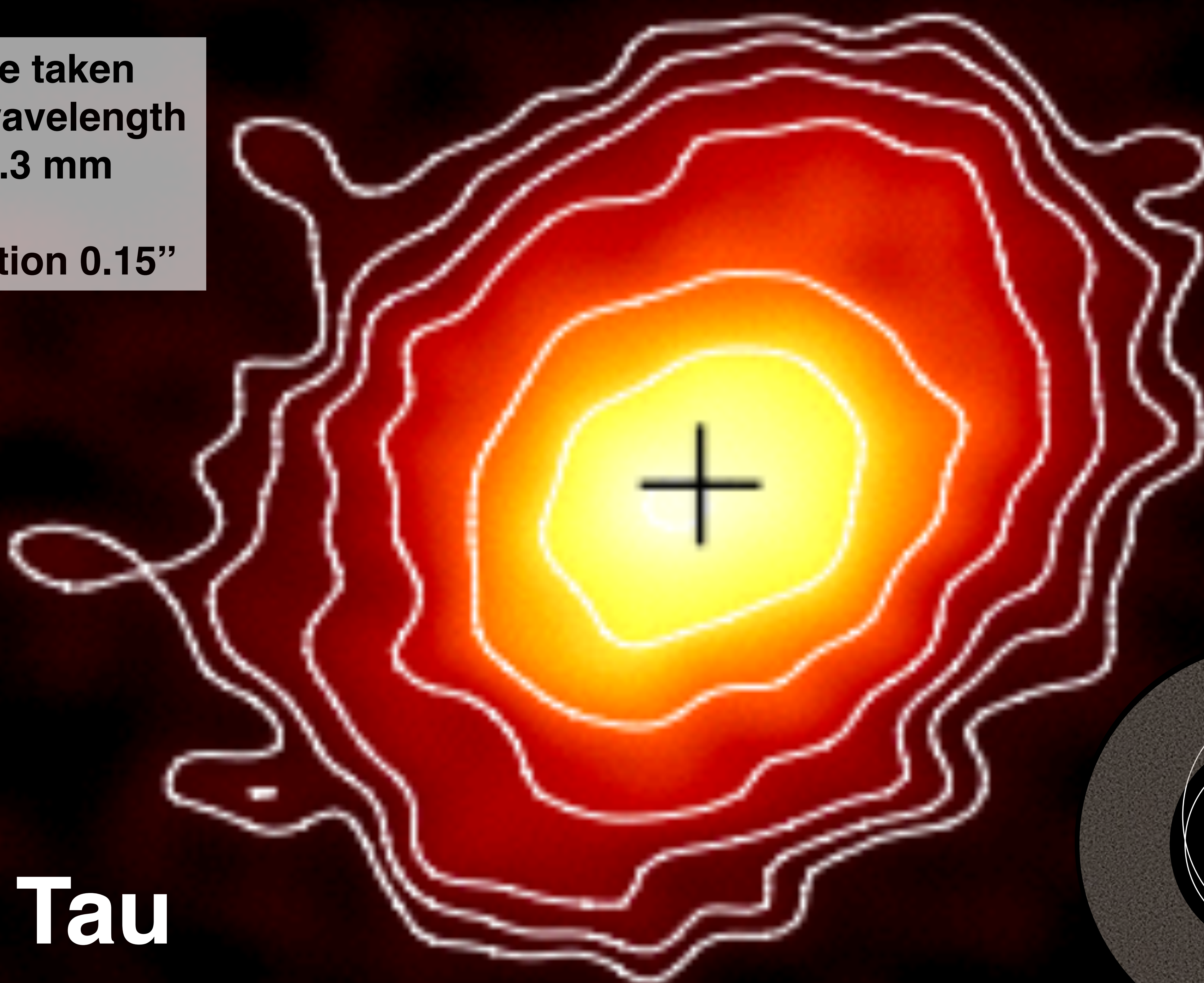


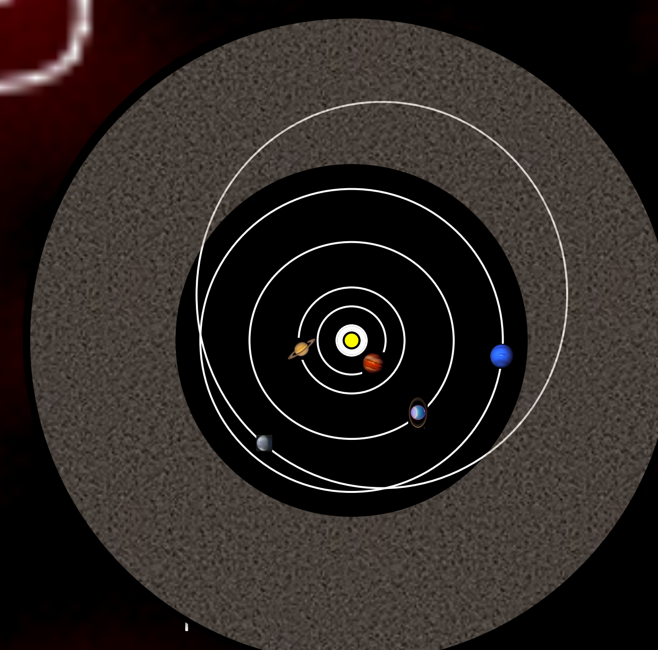
64 antennas - 7-12 m in diameter
$1.3 billions - $500 million from US Tax payers
about $1.6 each! VERY CHEAP!

Imaging Protoplanetary Disks before ALMA

Image taken
at the wavelength
of 1.3 mm

Resolution 0.15”





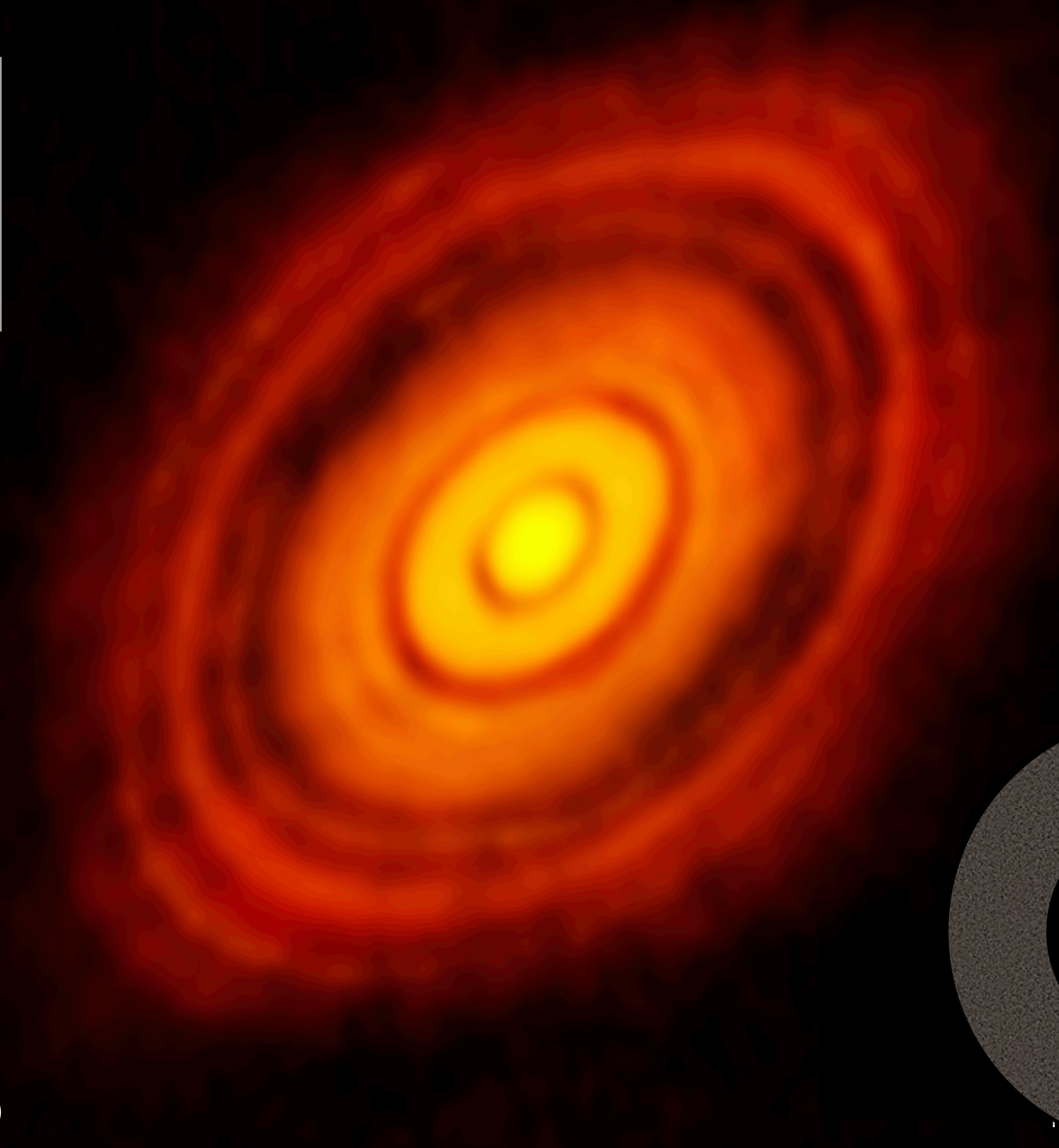
HL Tau

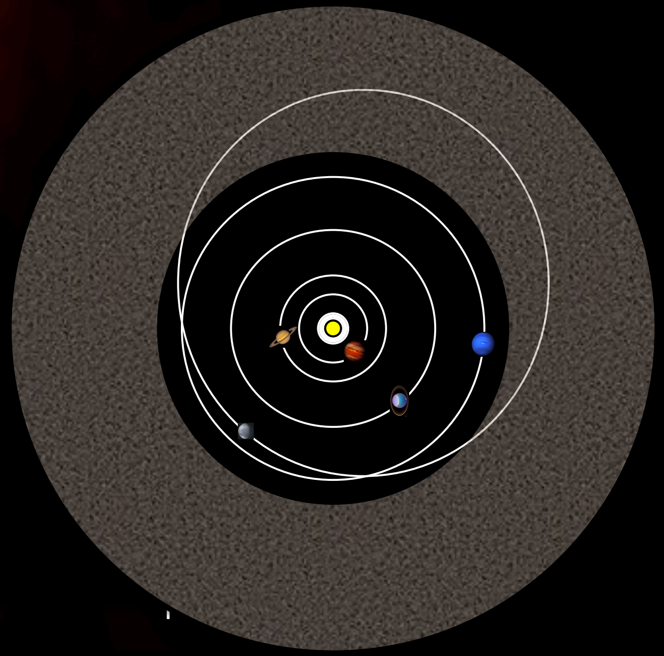
Kwon et al. (2011)

Imaging Protoplanetary Disks with ALMA

Image taken at the wavelength of 1.3 mm

Resolution 0.03”

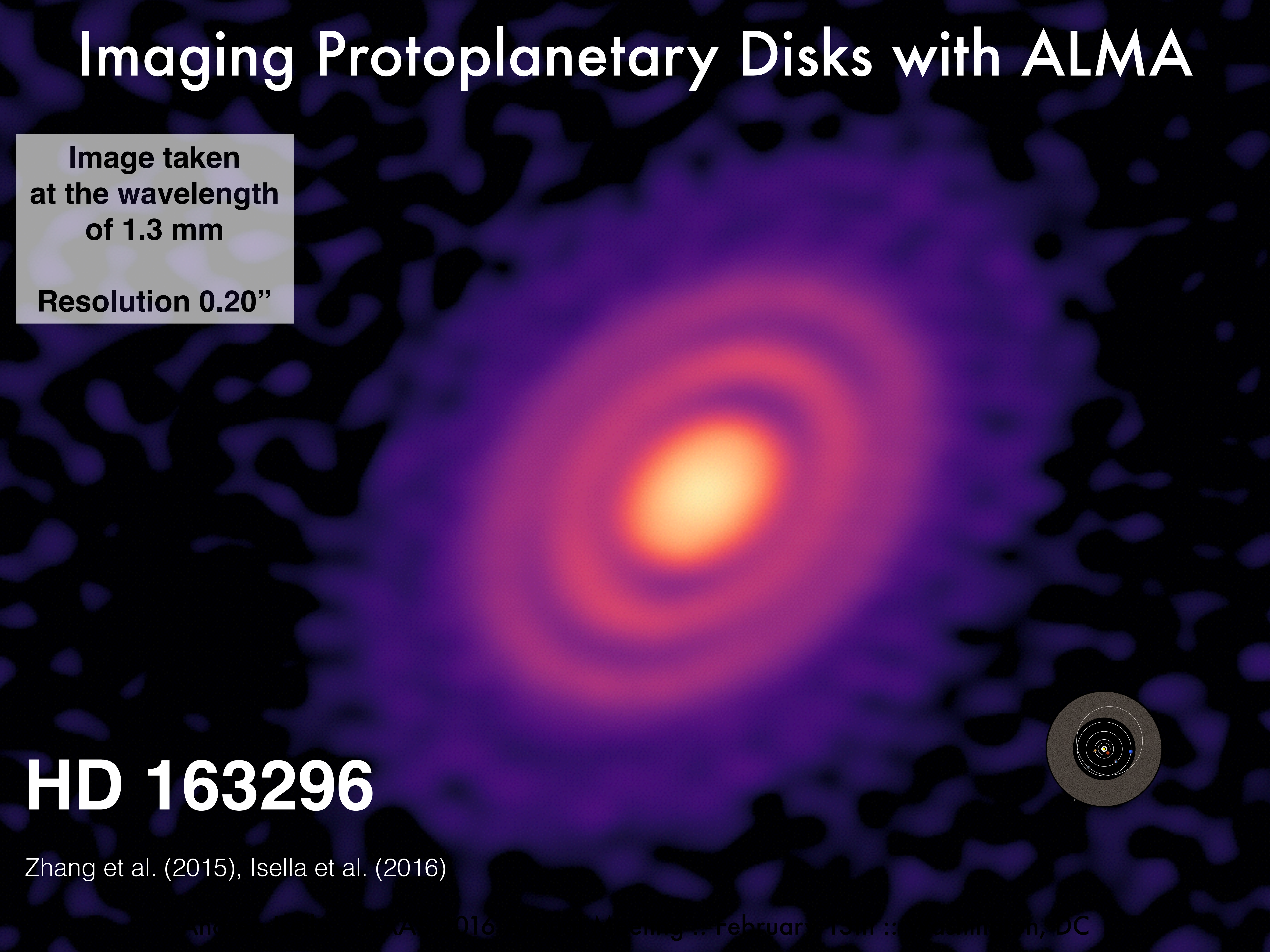




HL Tau

ALMA partnership (2015)

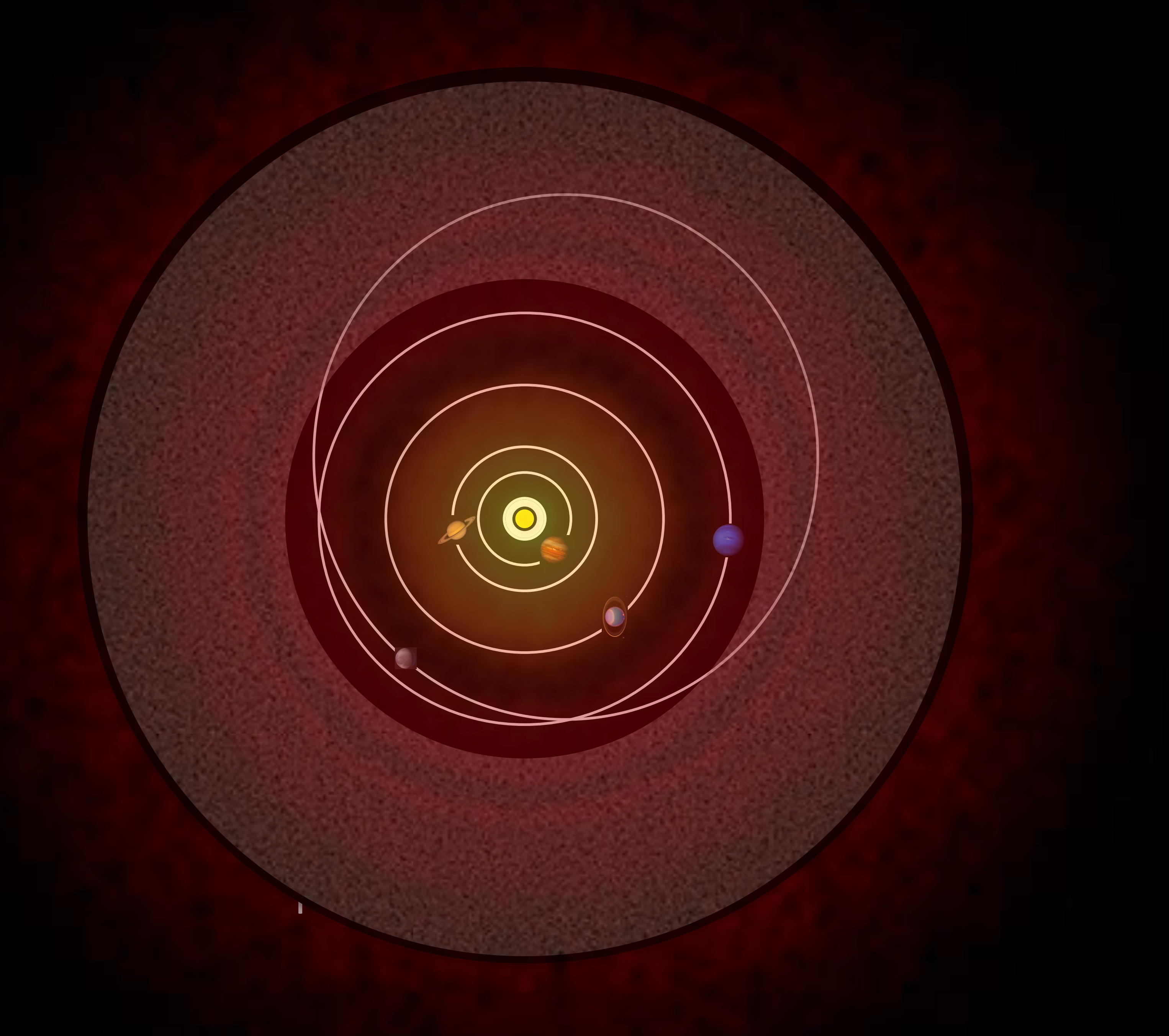
Imaging Protoplanetary Disks with ALMA



Mapping Protoplanetary Disks with ALMA

Image taken at the wavelength of 1.3 mm

Resolution 0.02"



TW Hya

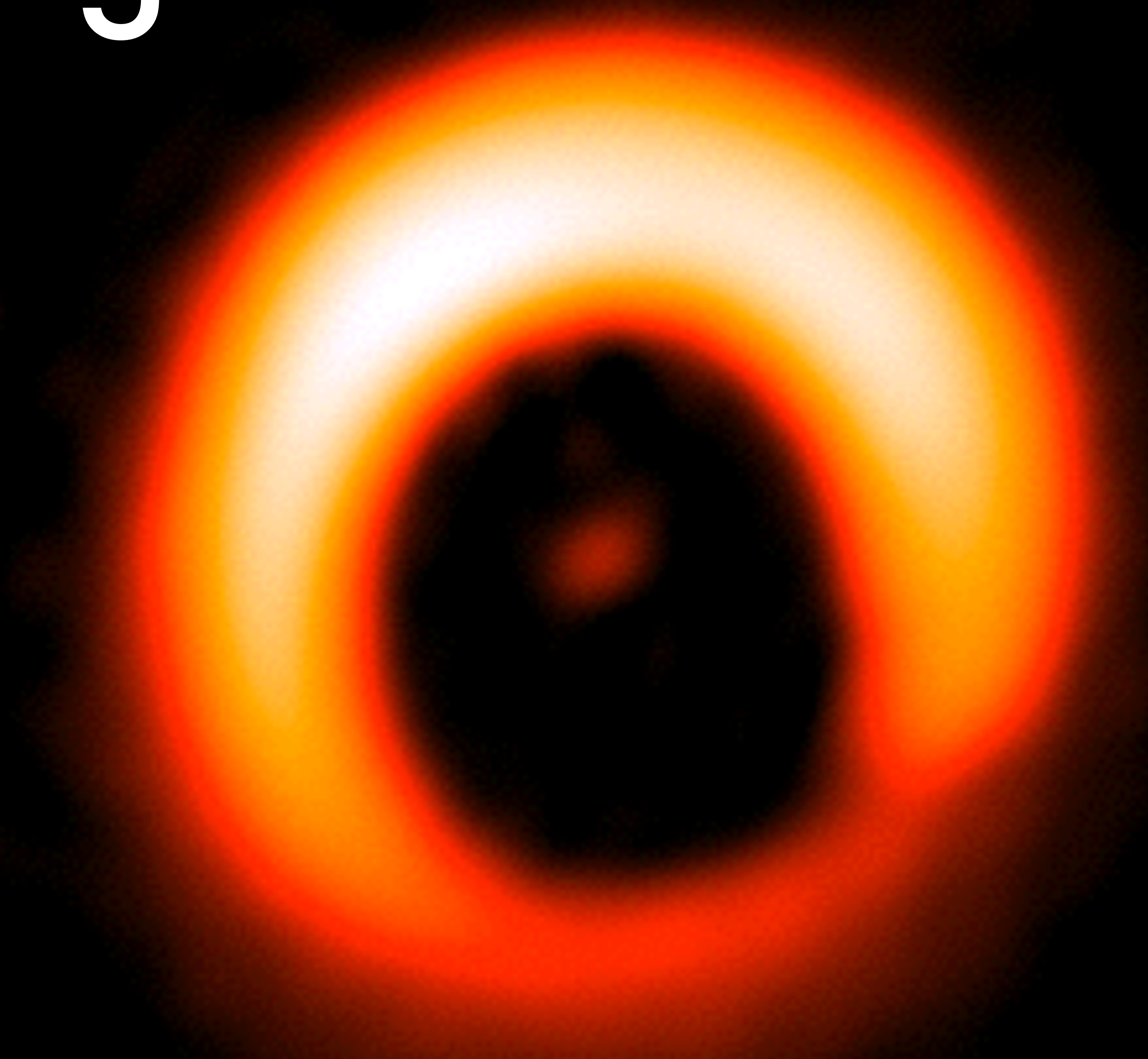
Andrews et al. (2016)

Not only rings: crescents

Image taken at the wavelength of 0.8 mm
Resolution 0.15”

MWC 758

Boehler et al., (2018)



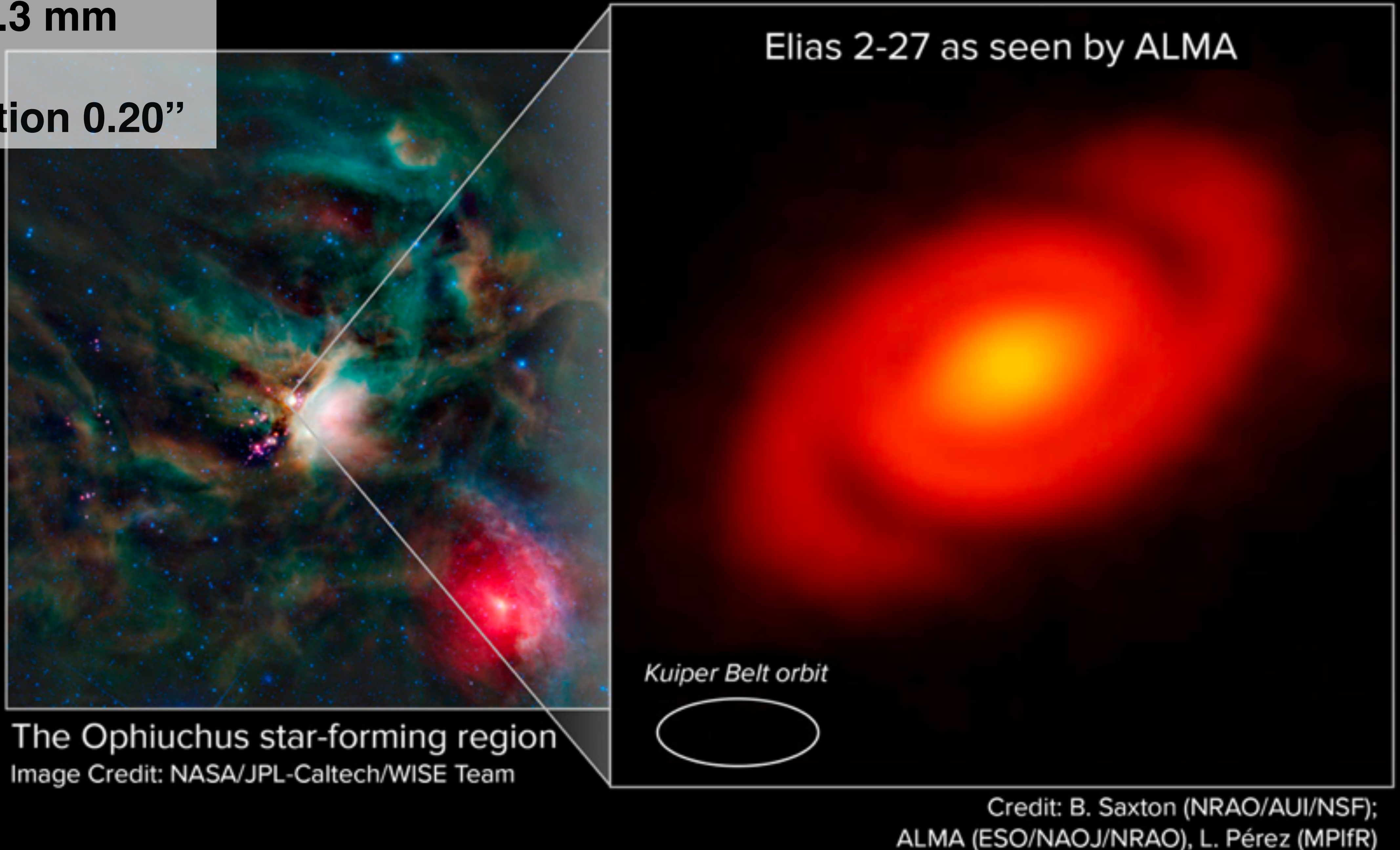
HD 142527

Boehler et al., (2017)

Not only rings: spirals

Image taken at the wavelength of 1.3 mm

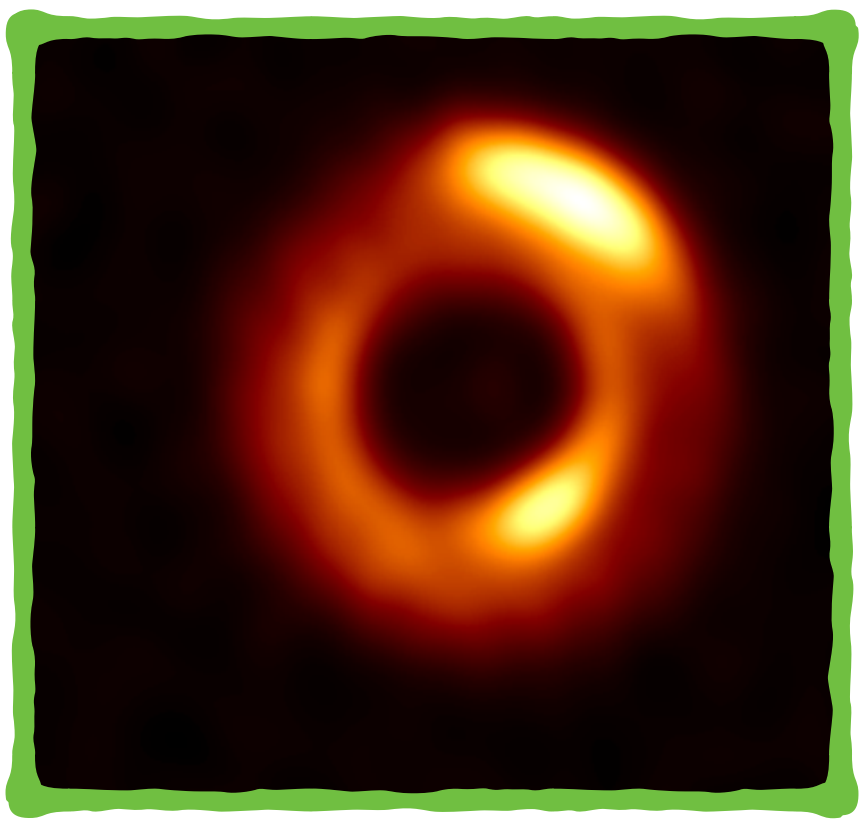
Resolution 0.20”



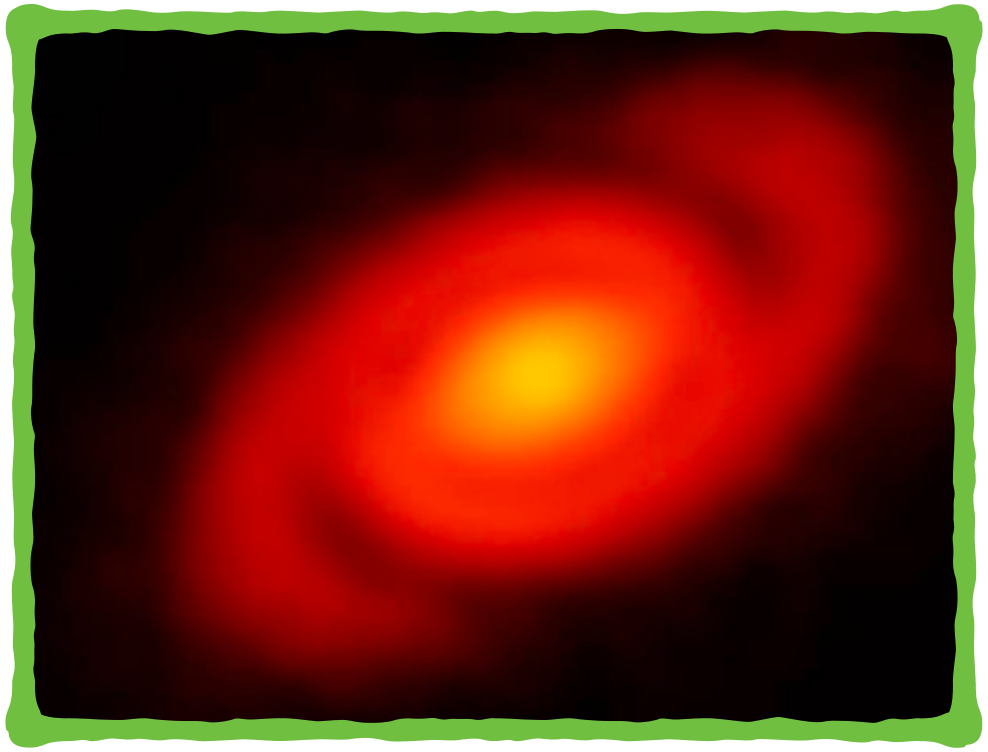
Pérez et al. 2016, Science, 353, 6307

Structures in Protoplanetary disks

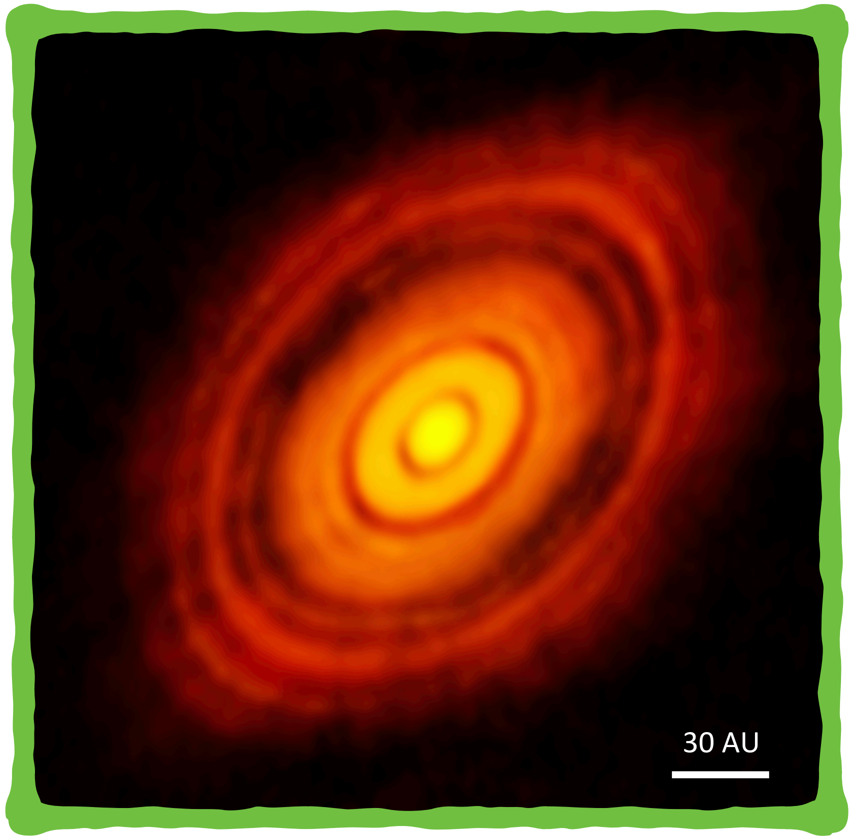
Nearly all disks observed with ALMA show substructures (< 10 - 30 AU)



Crescents

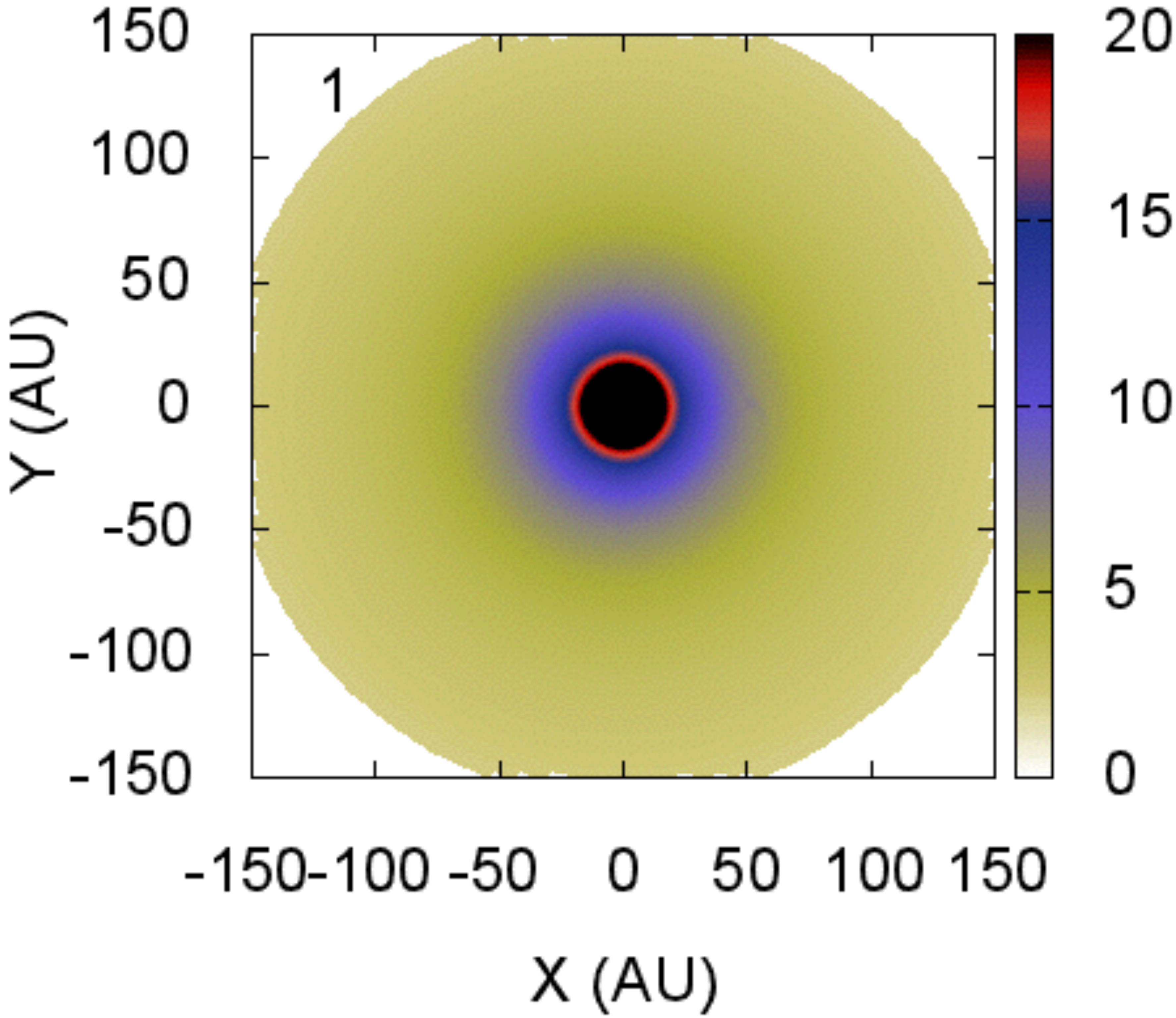


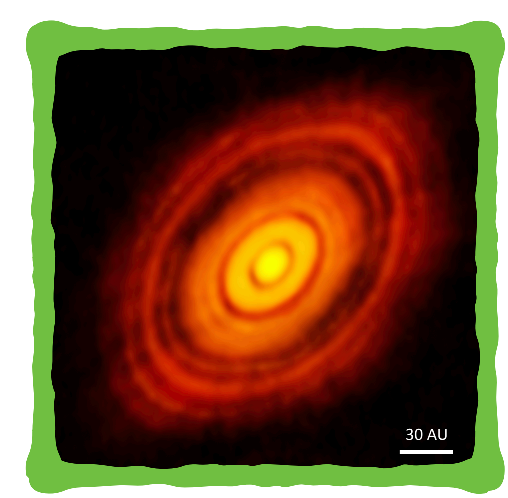
Spirals



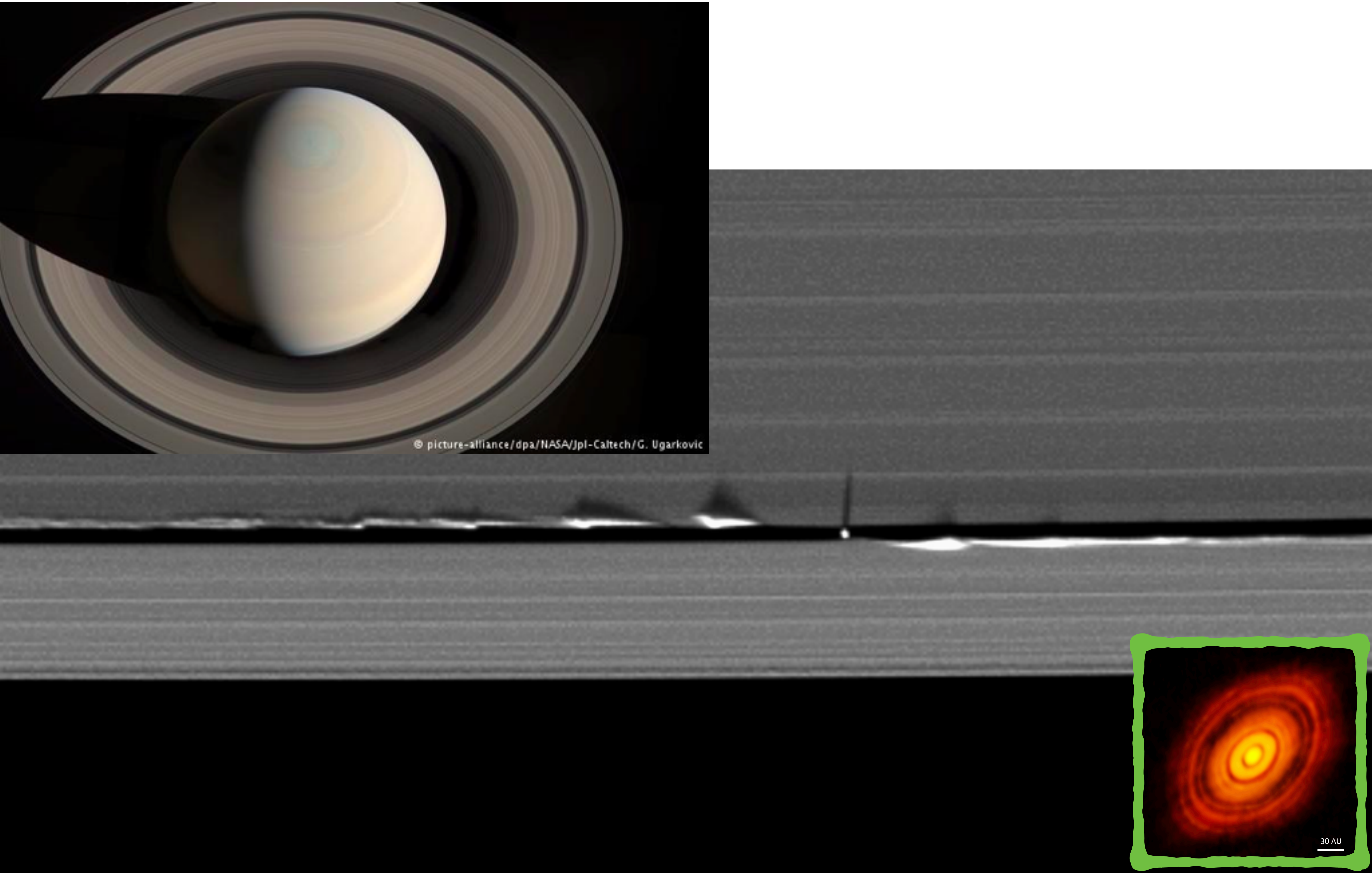
Rings

Rings created by newborn planets

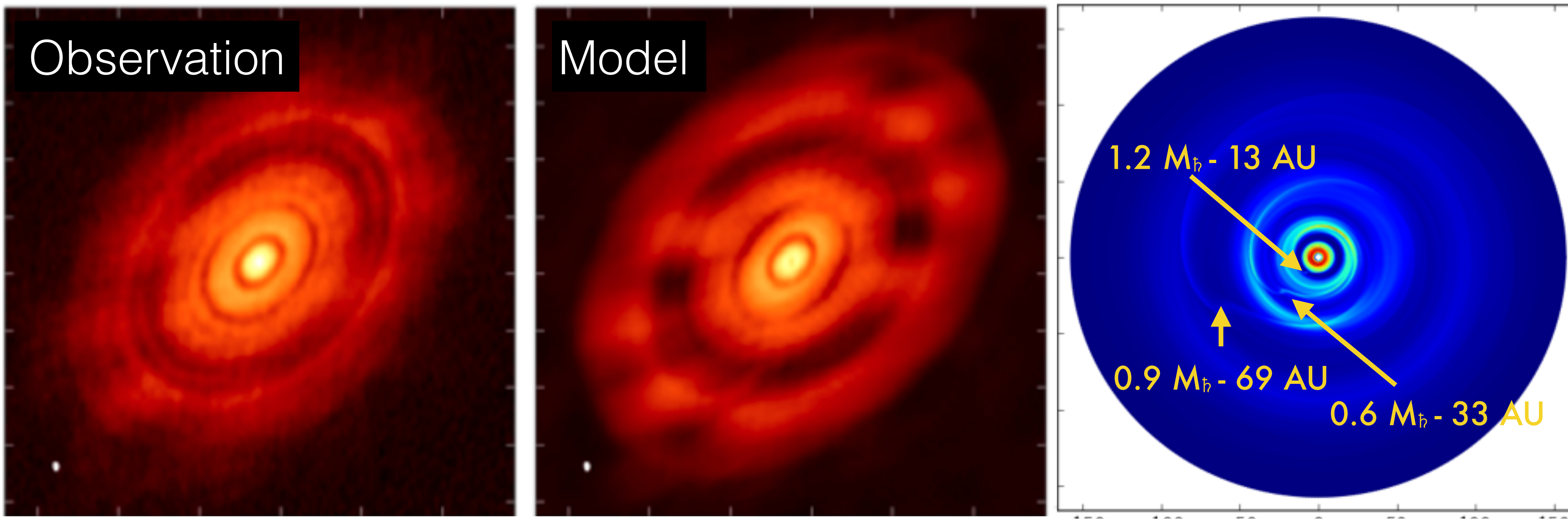




Structures in Saturn rings



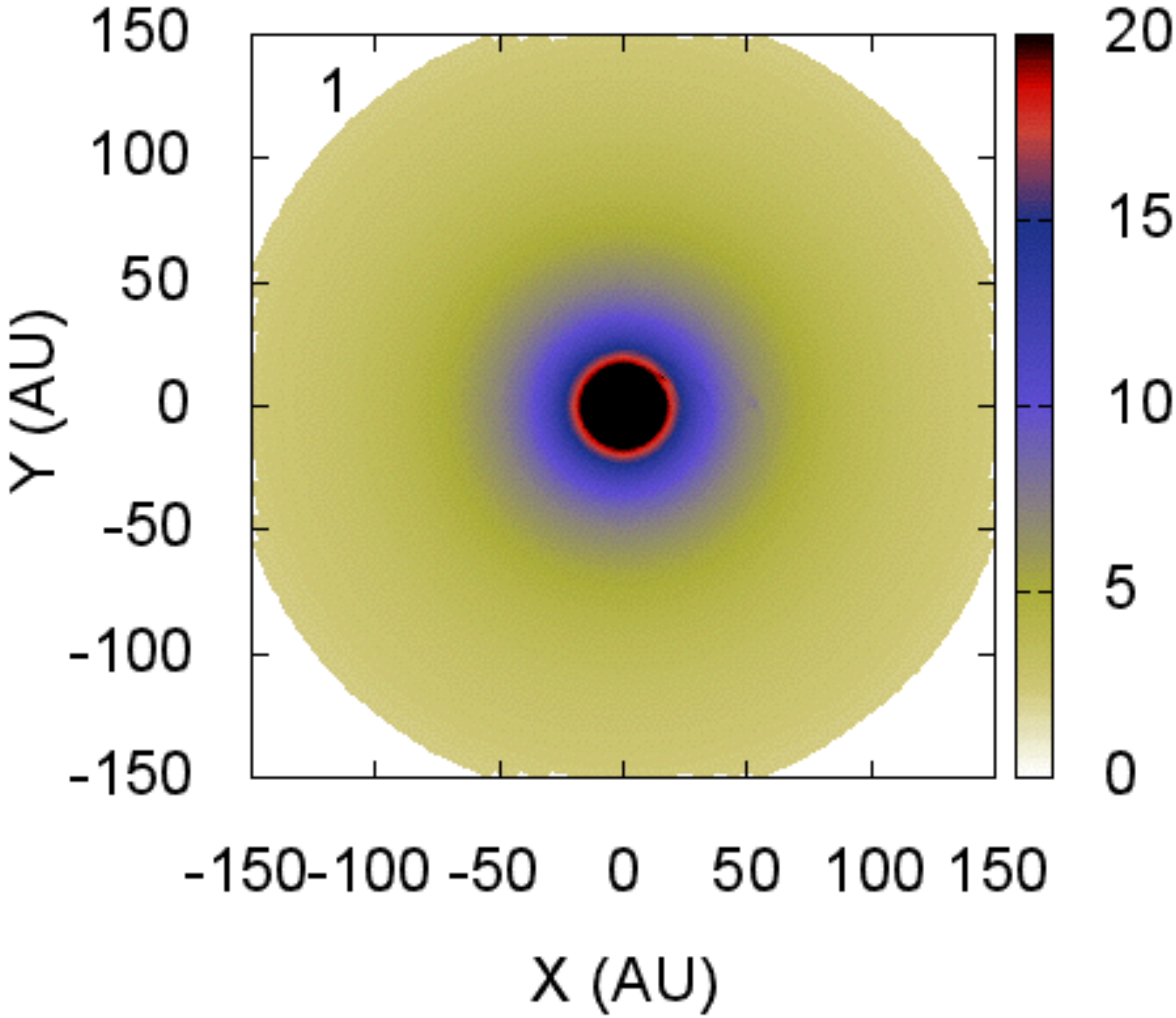
The HL Tau planet forming system

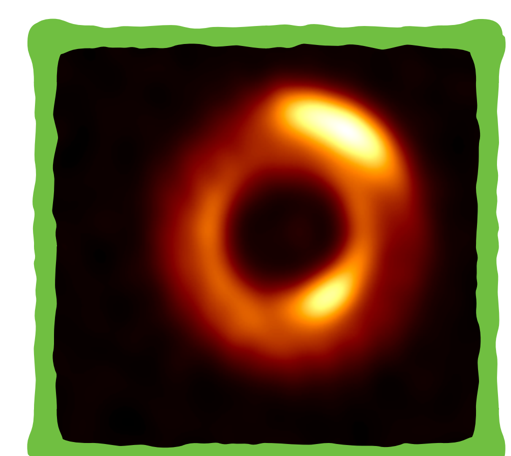


The rings suggest the presence of three planets with masses similar to that of Saturn at 13 AU, 33 AU, and 69 AU from the central star.

Sheng Jin, Shengtai Li; Andrea Isella; Hui Li; Jianghui Ji, ApJ, 818, 76

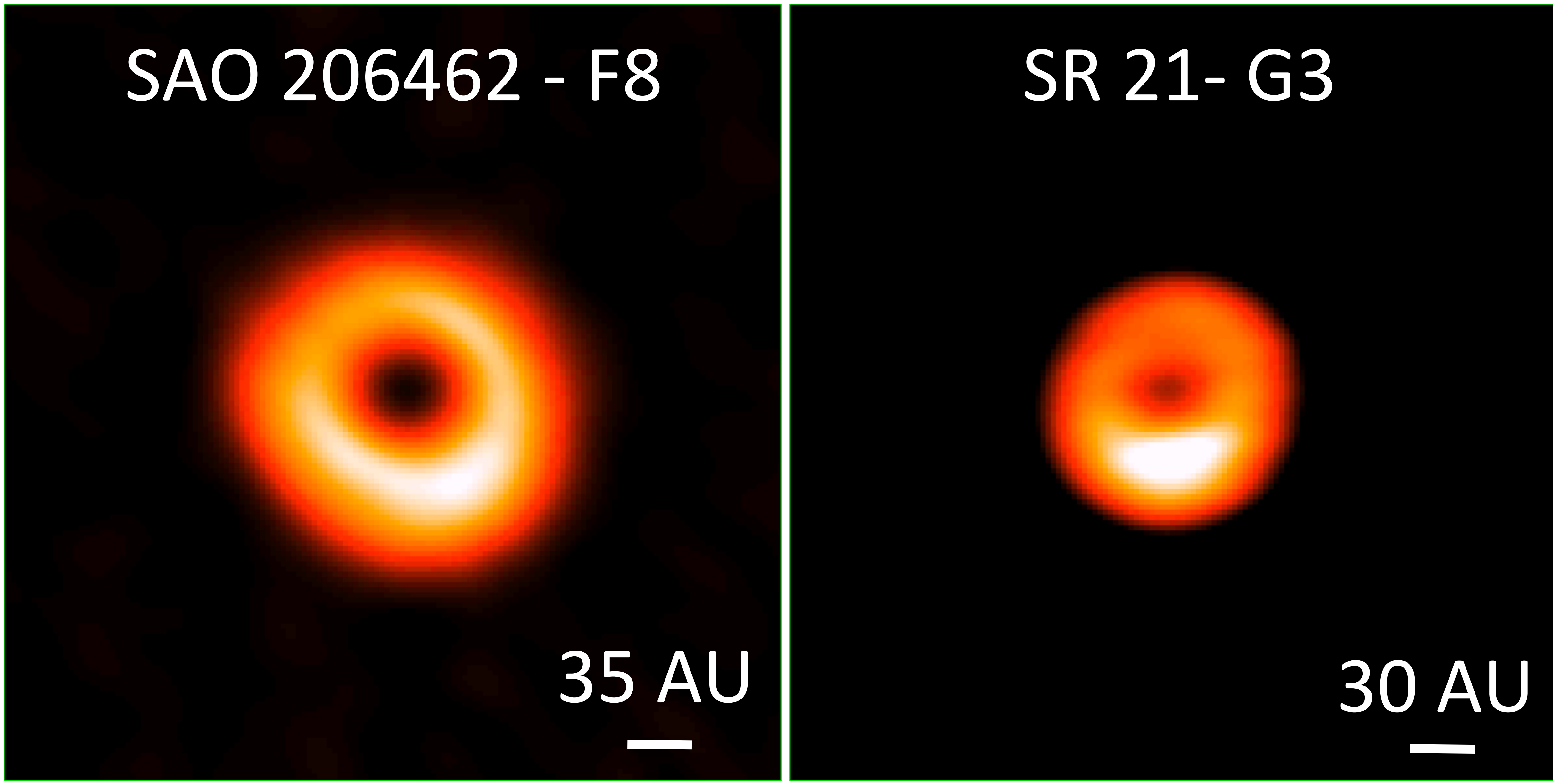
Crescents created by newborn planets





Crescents created by newborn planets

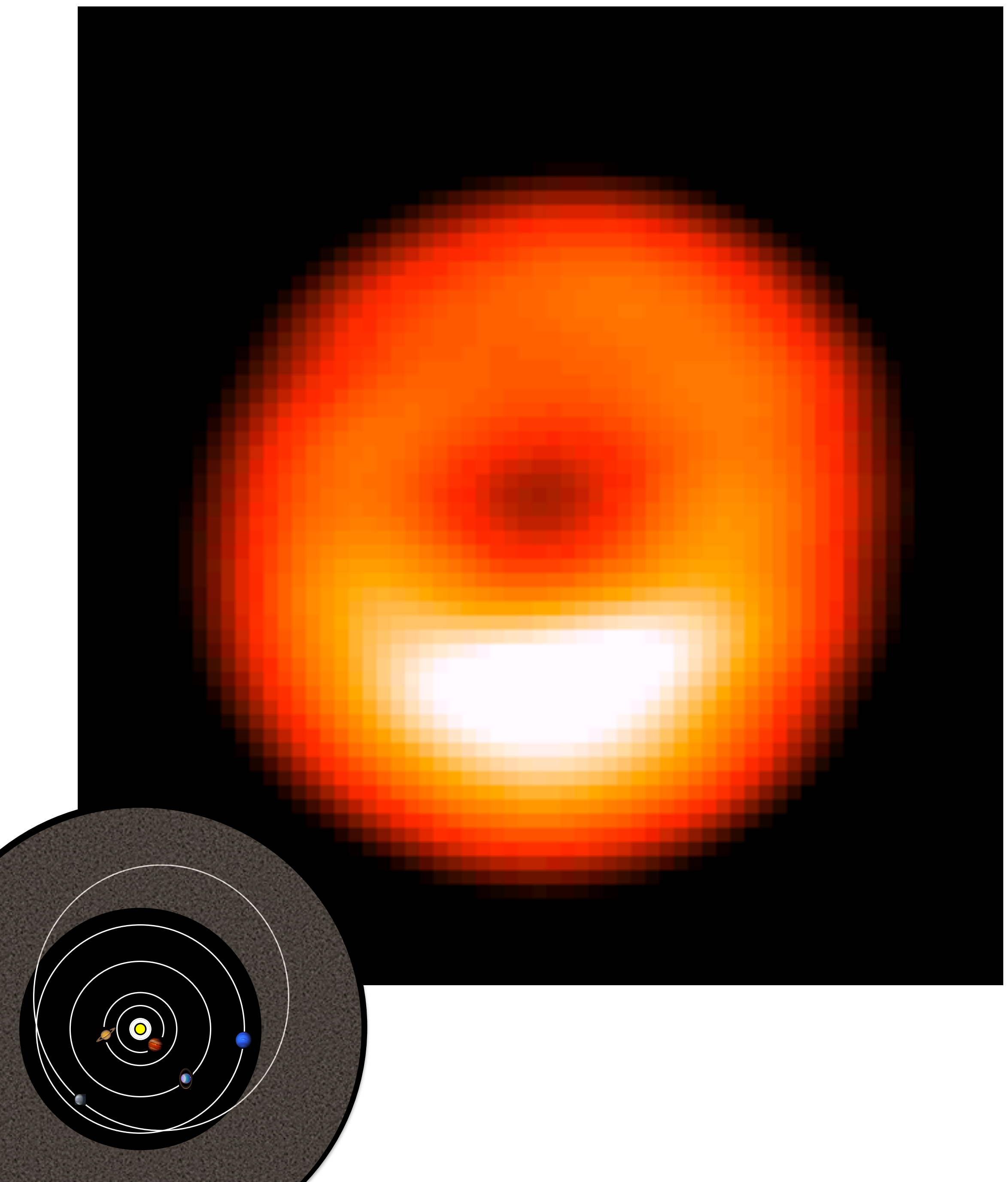
Continuum @ 450 μm

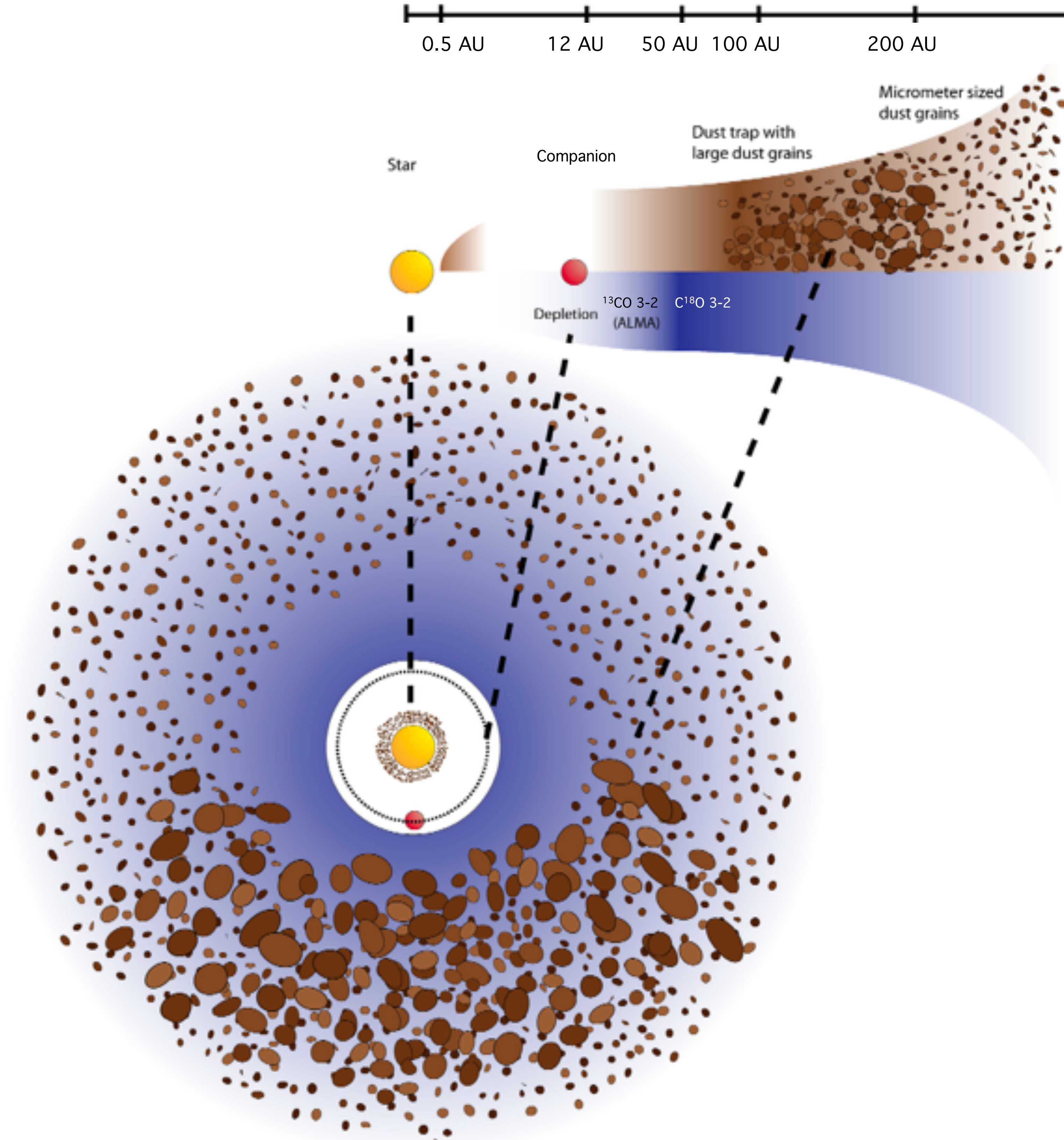


Perez et al. (2014)

Dust Crescents and Dust Traps

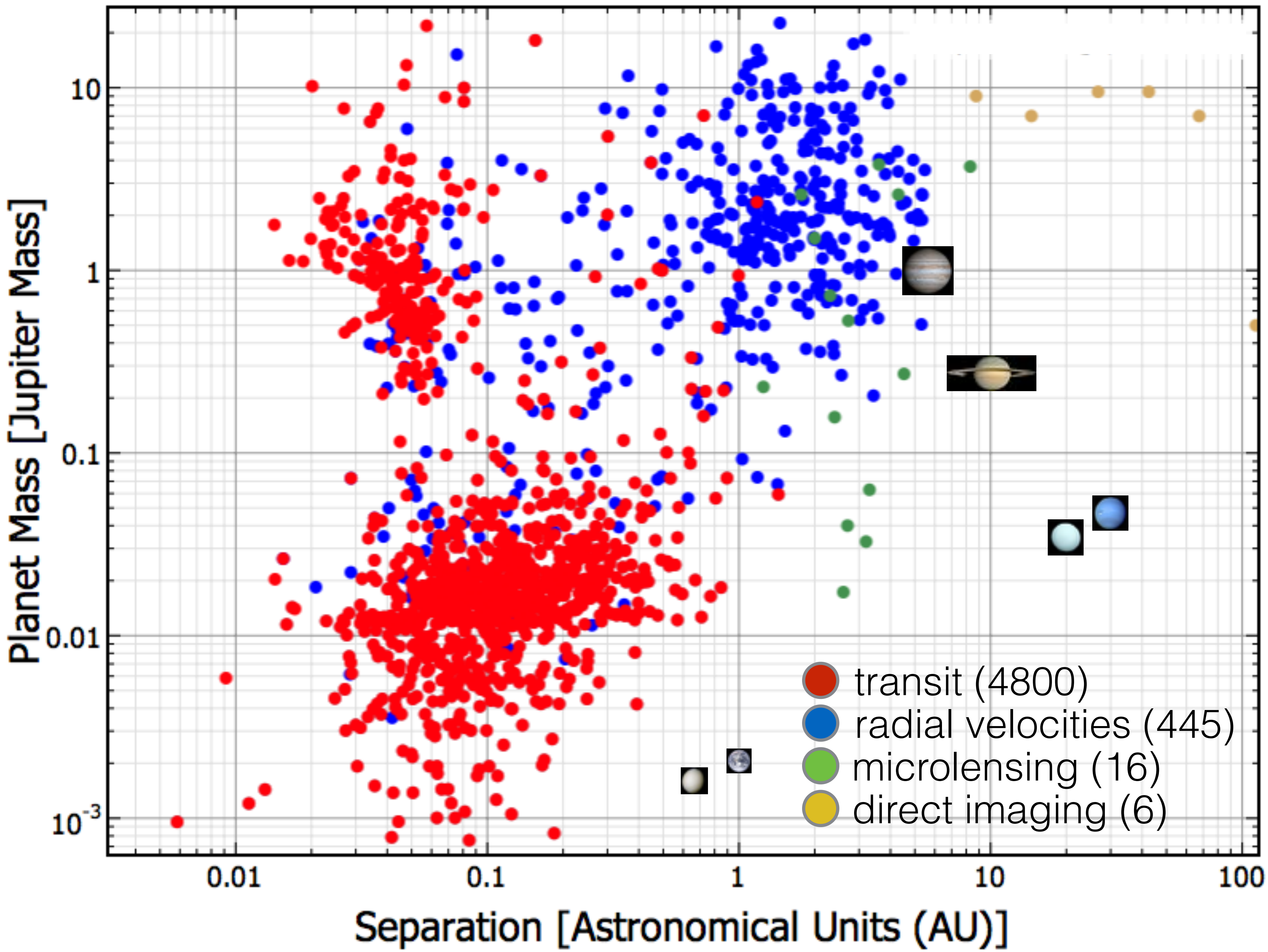
SR 21
(G3 - similar to the young Sun)





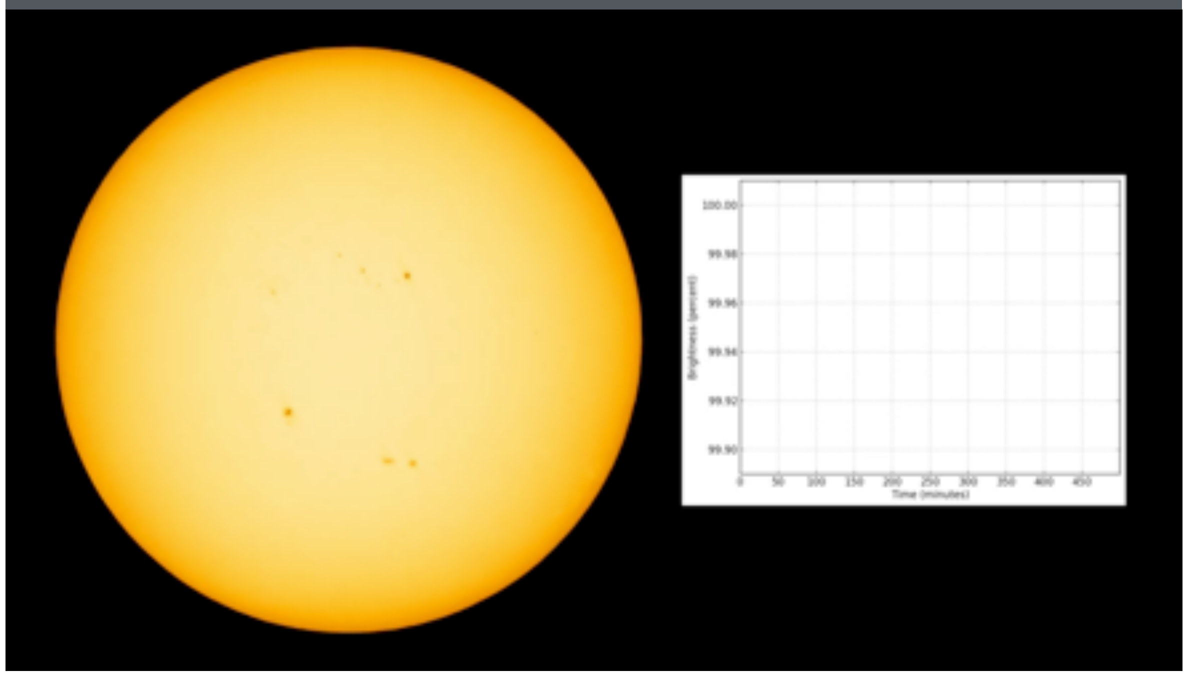
But, can we directly see these baby planets?

Demographics of extrasolar planets

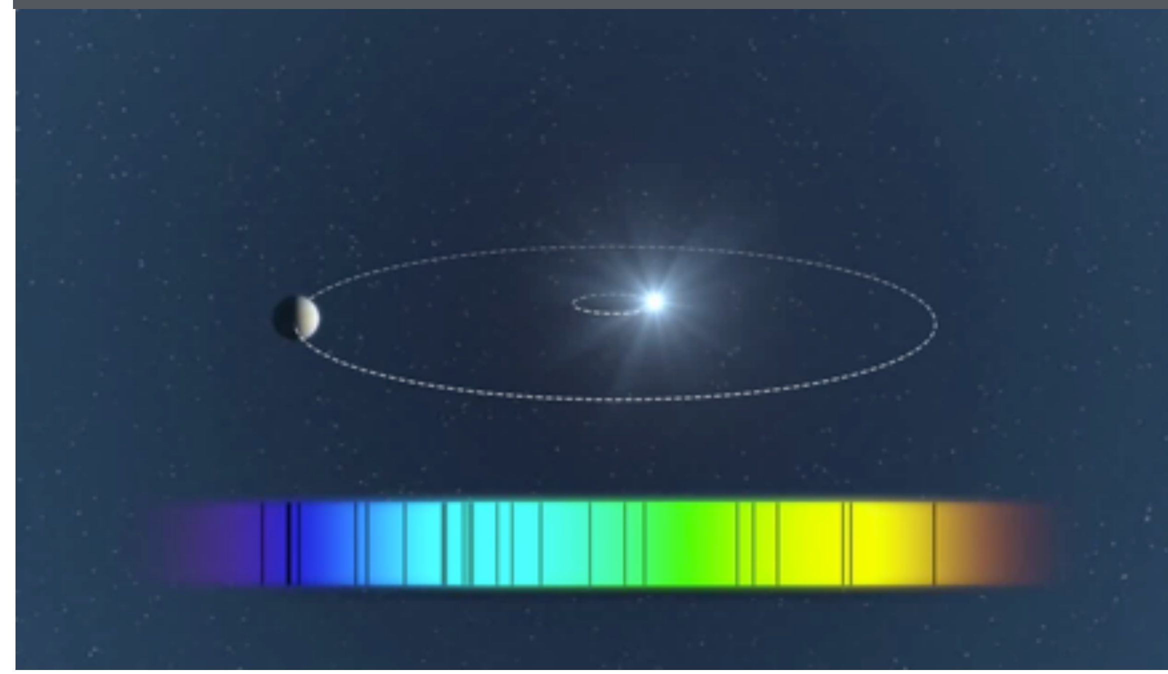


Planet Detection Techniques

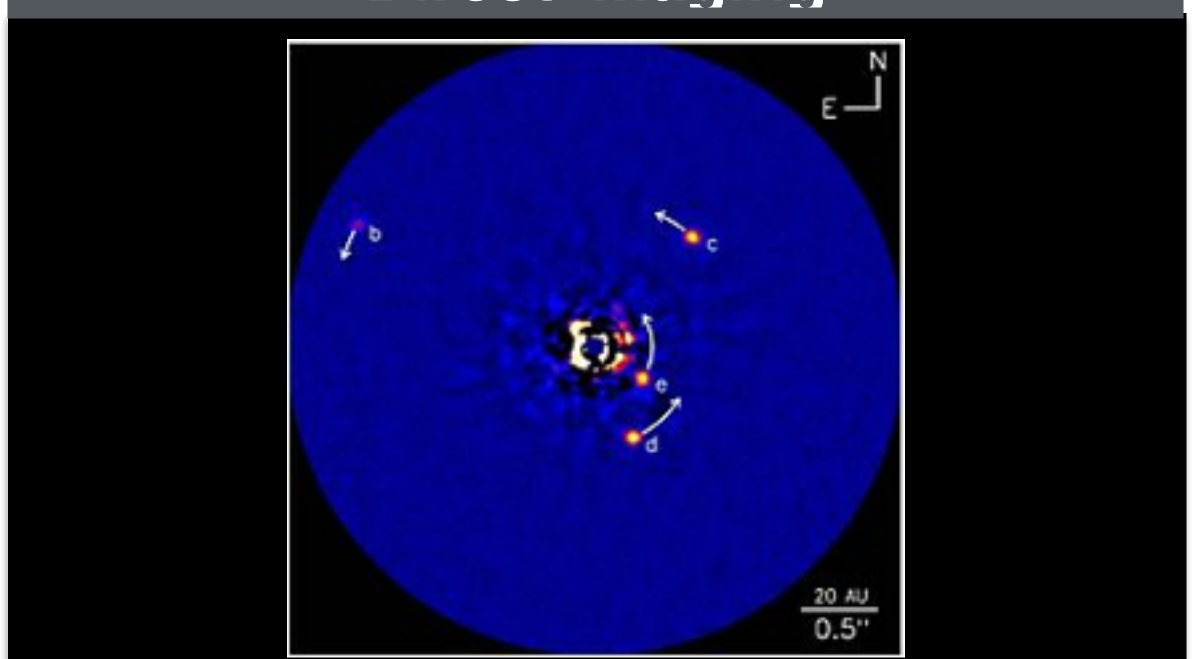
Planet Transit



Radial Velocity

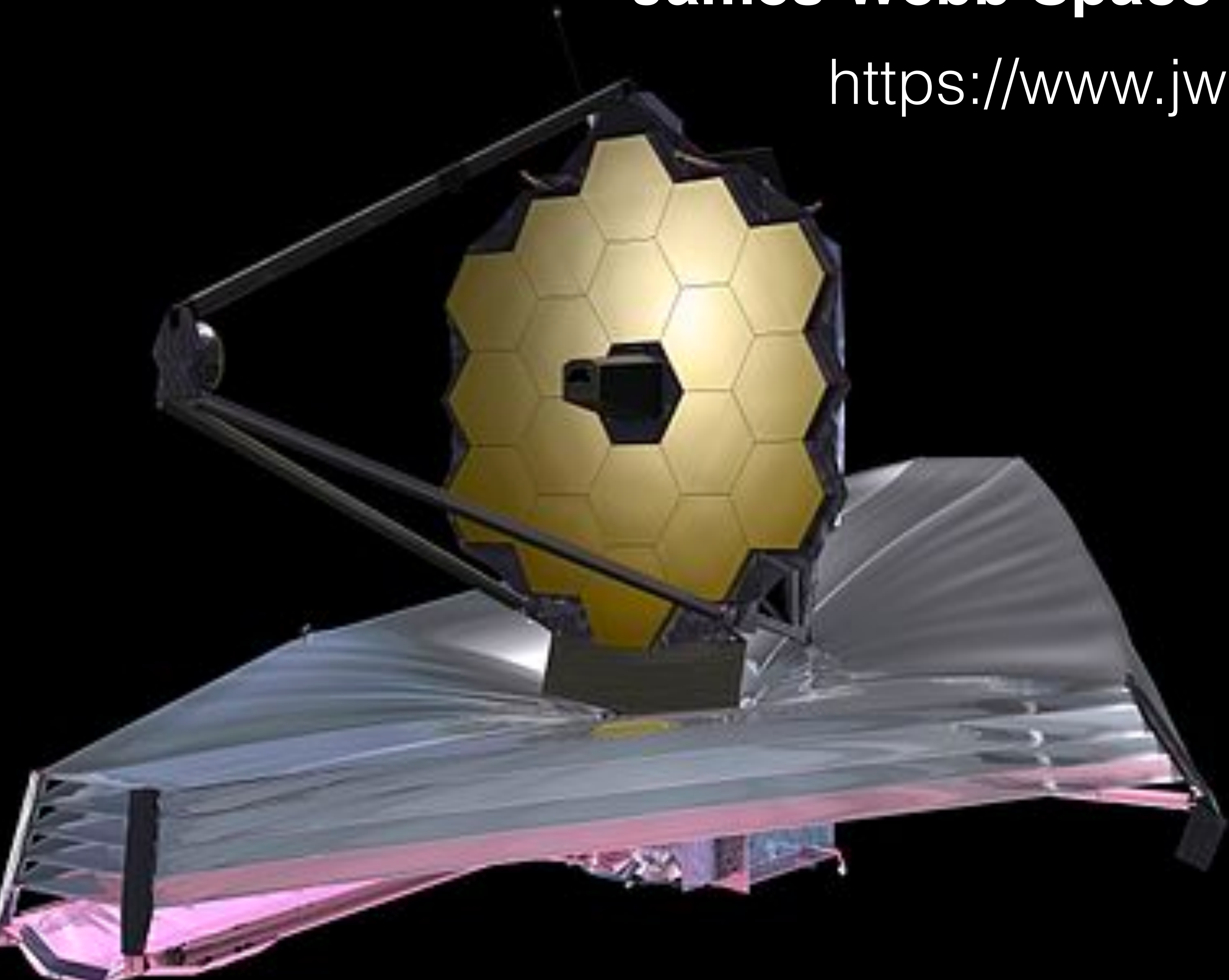


Direct Imaging

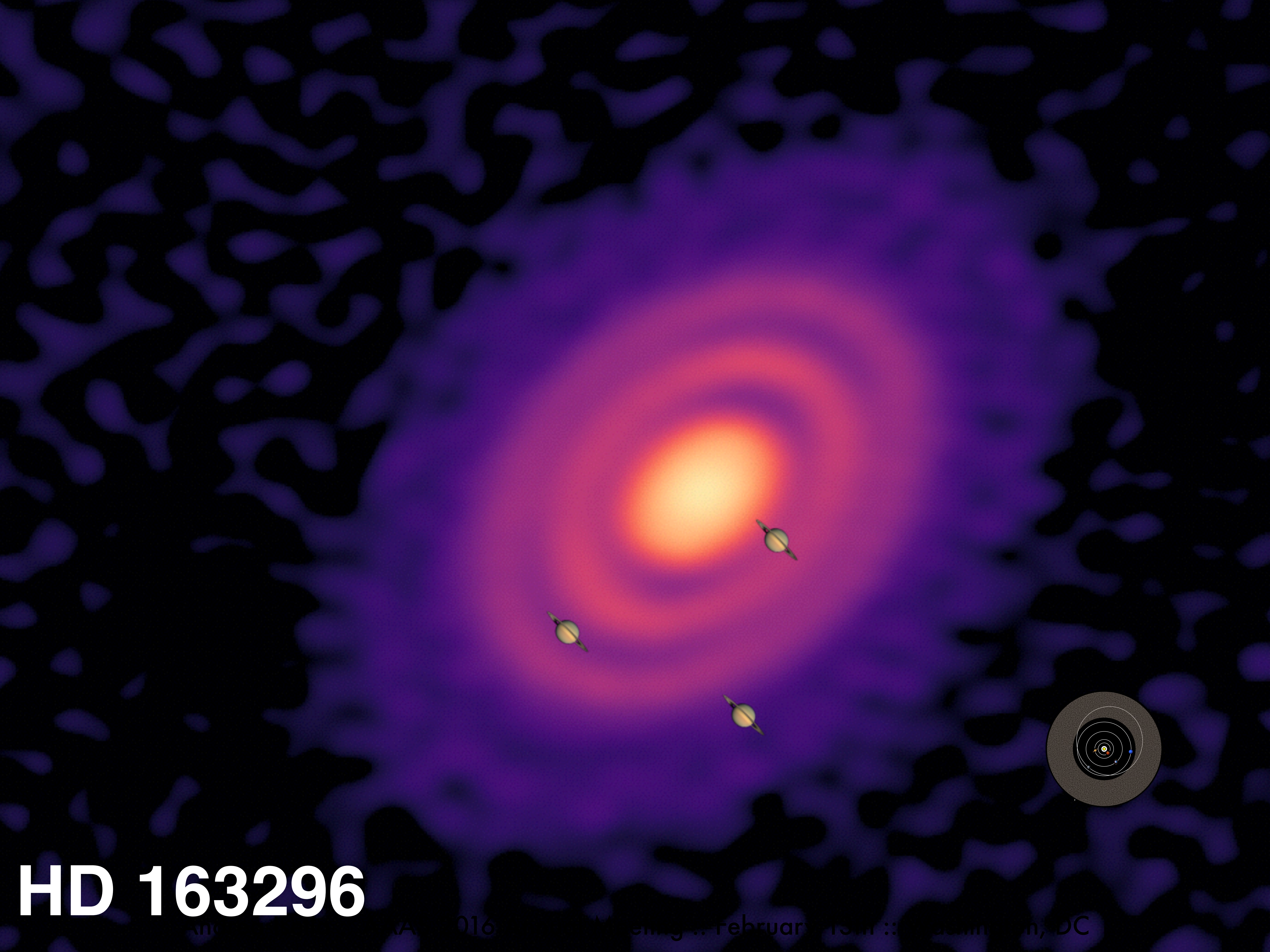


James Webb Space Telescope (JWST)

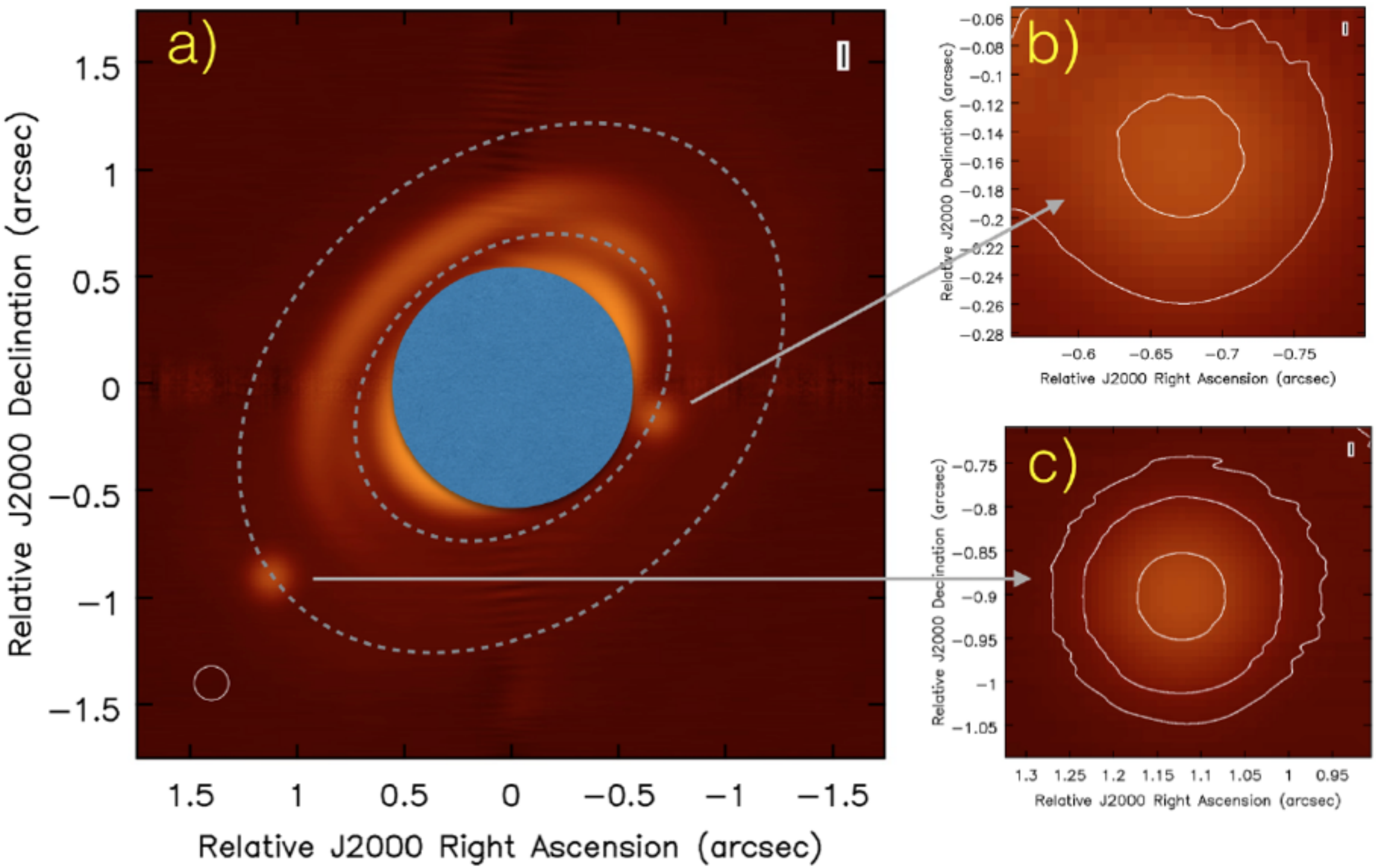
https://www.jwst.nasa.gov/

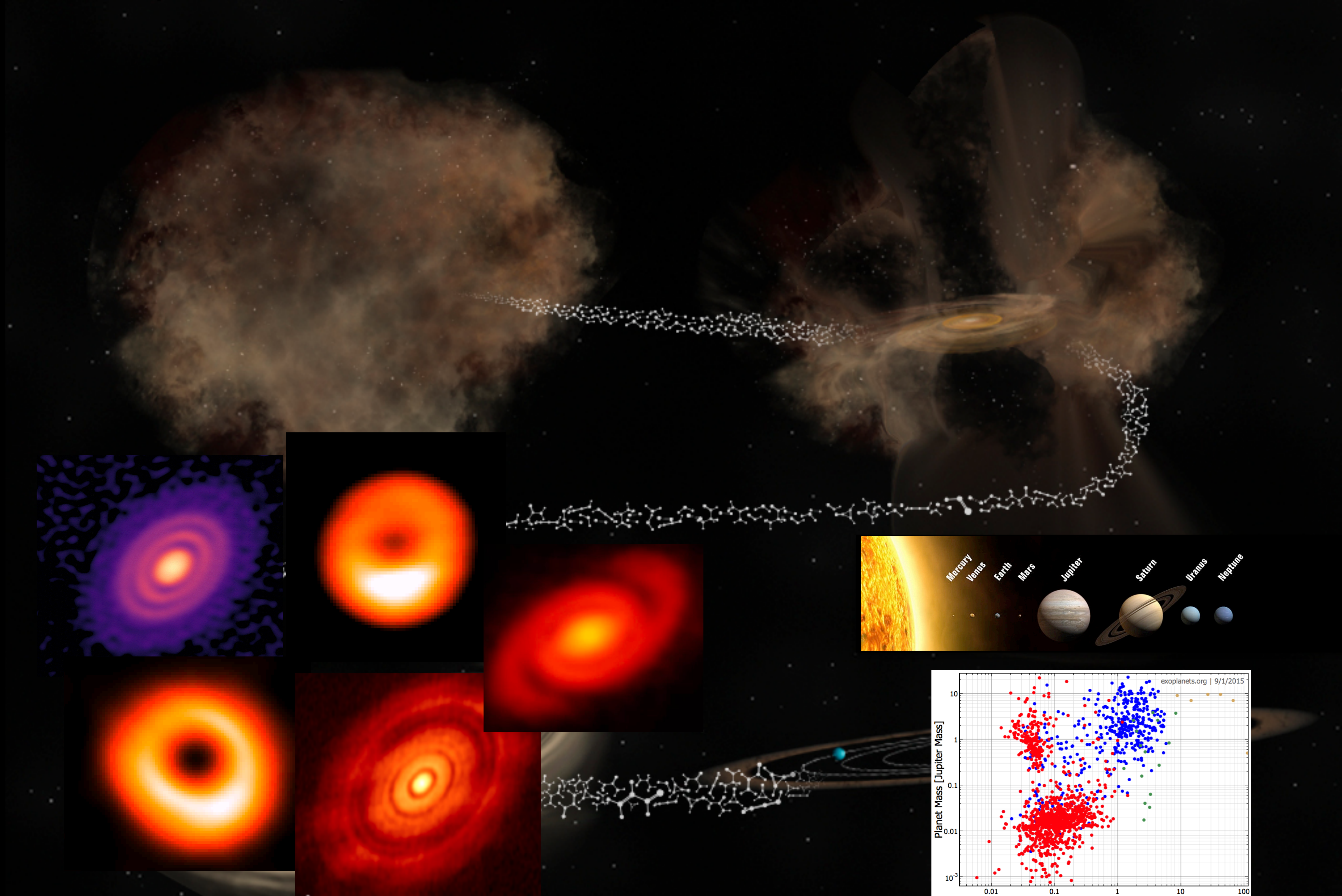


Launch planned for Spring 2019


HD 163296

SIMULATED JWST OBSERVATIONS





And many more will come soon!