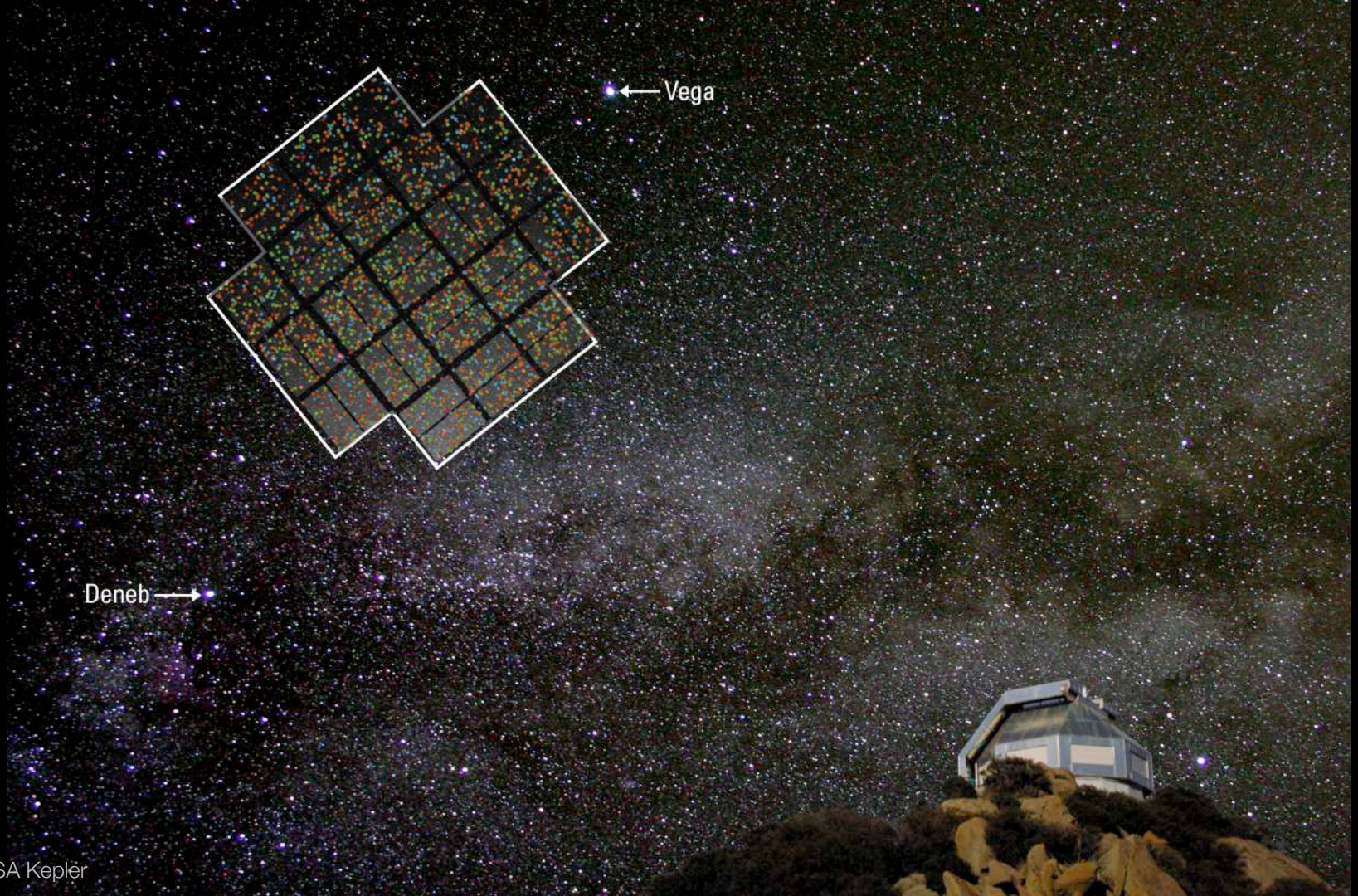
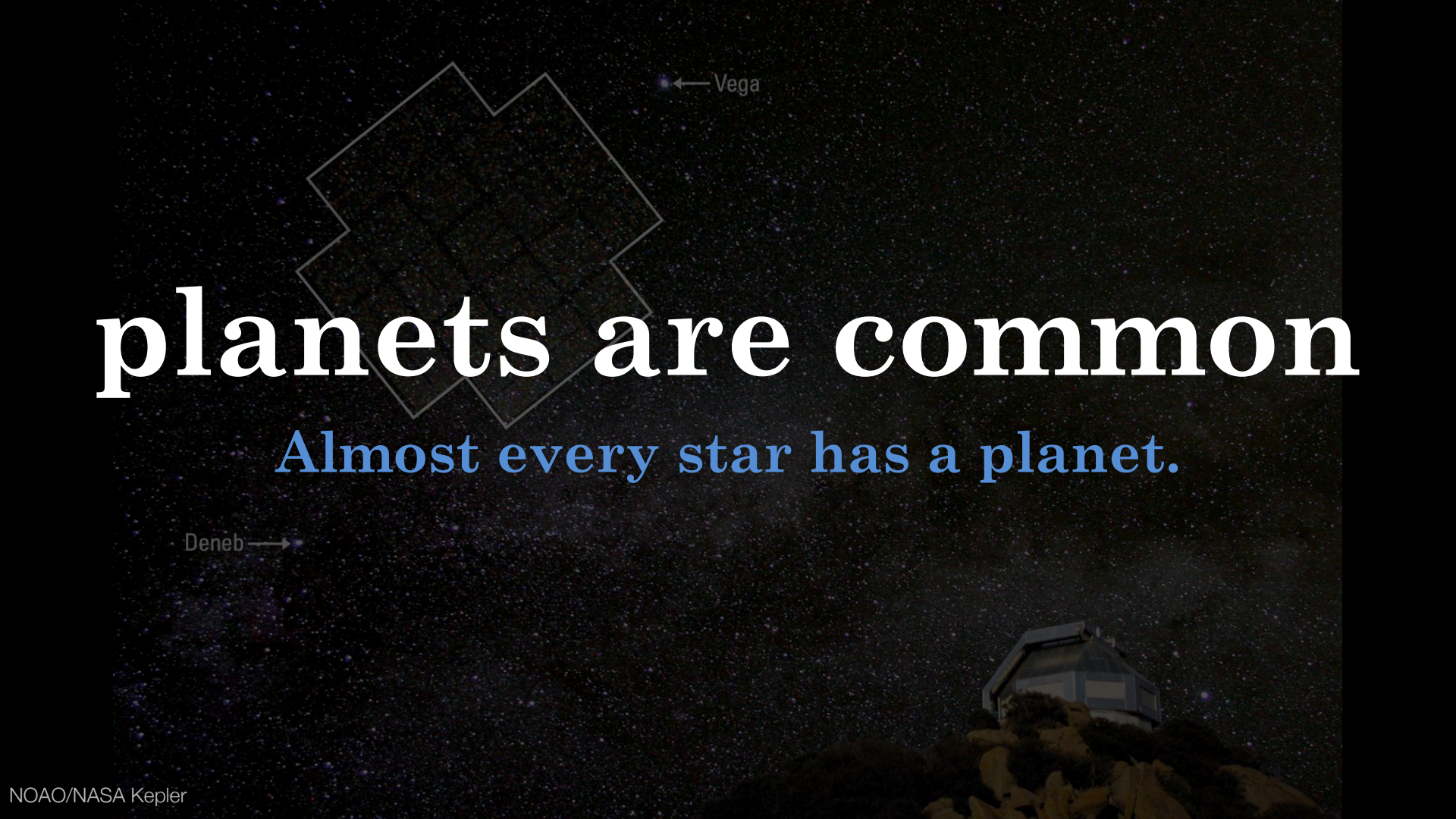
Where do **planets** come from?

Anjali Tripathi, Harvard University

March 17, 2016



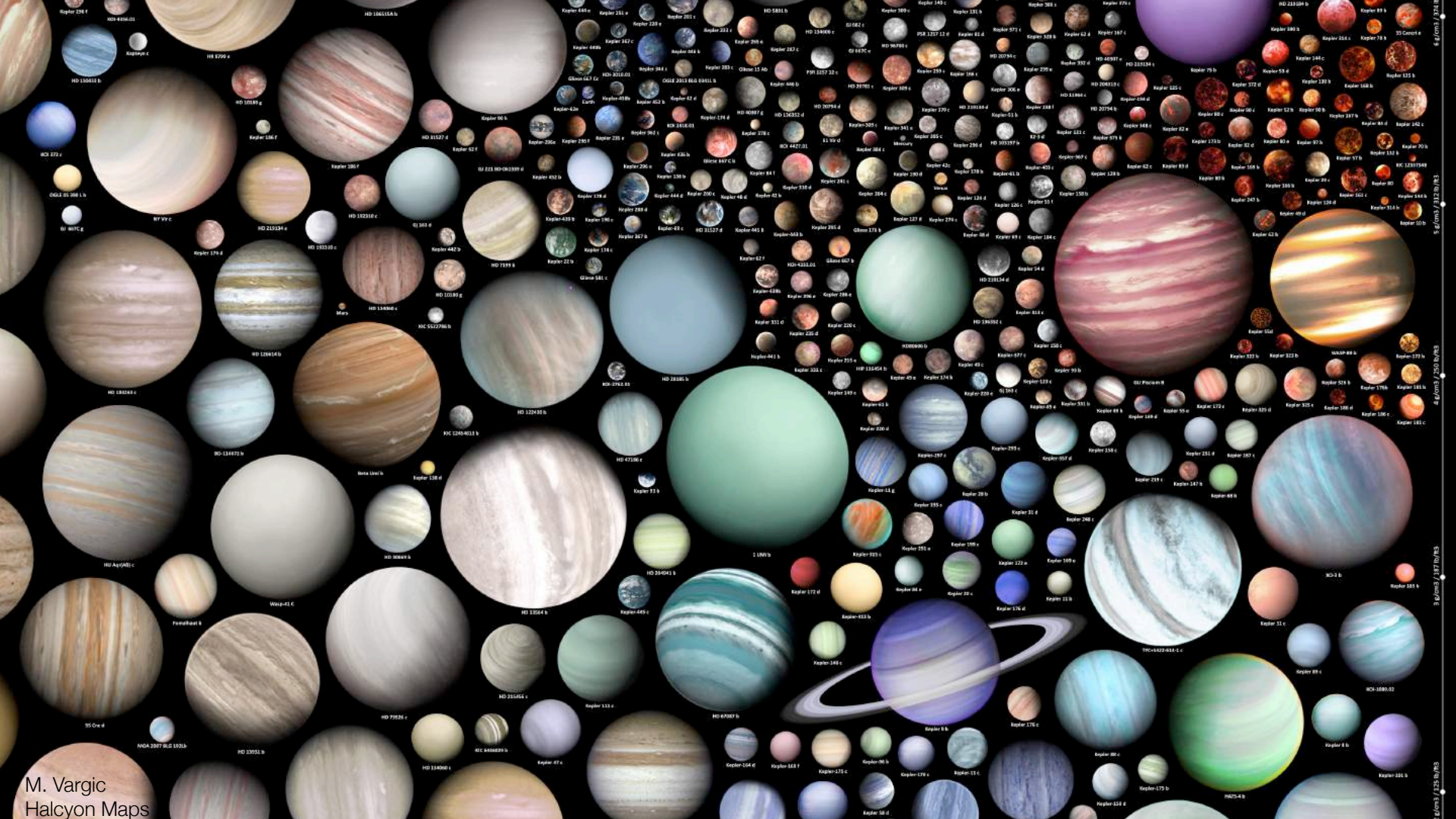
NOAO/NASA Kepler

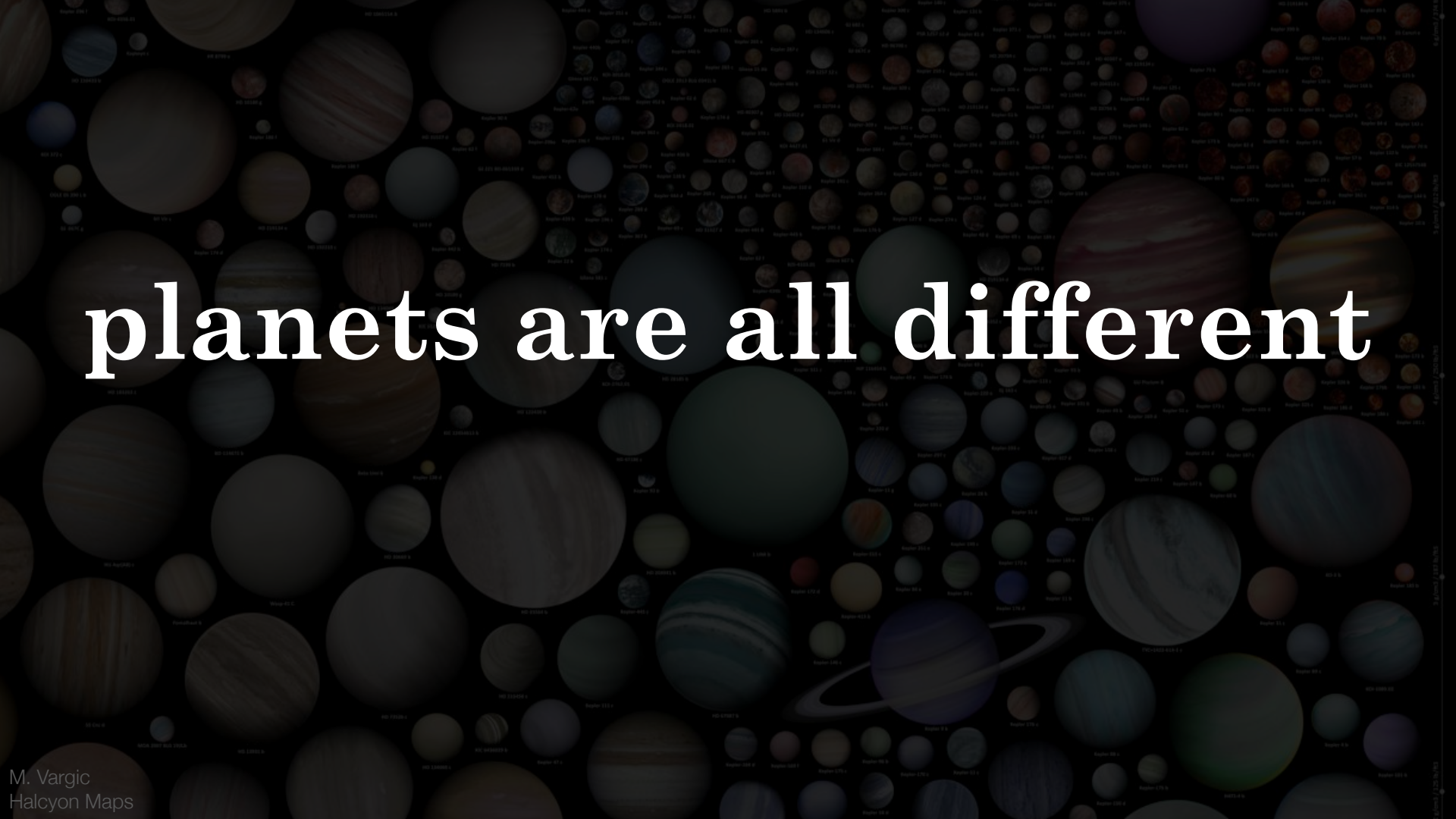


planets are common

Almost every star has a planet.

NOAO/NASA Kepler


M. Vargic
Halcyon Maps



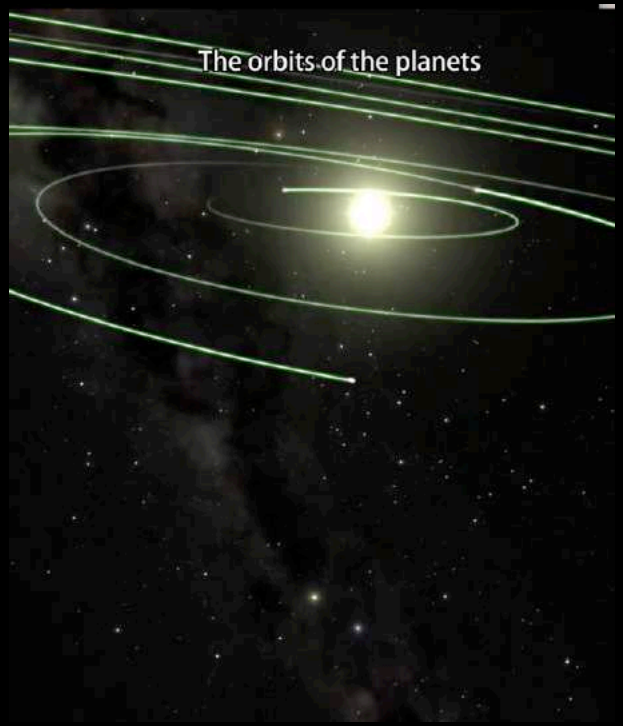
M. Vargic
Halcyon Maps

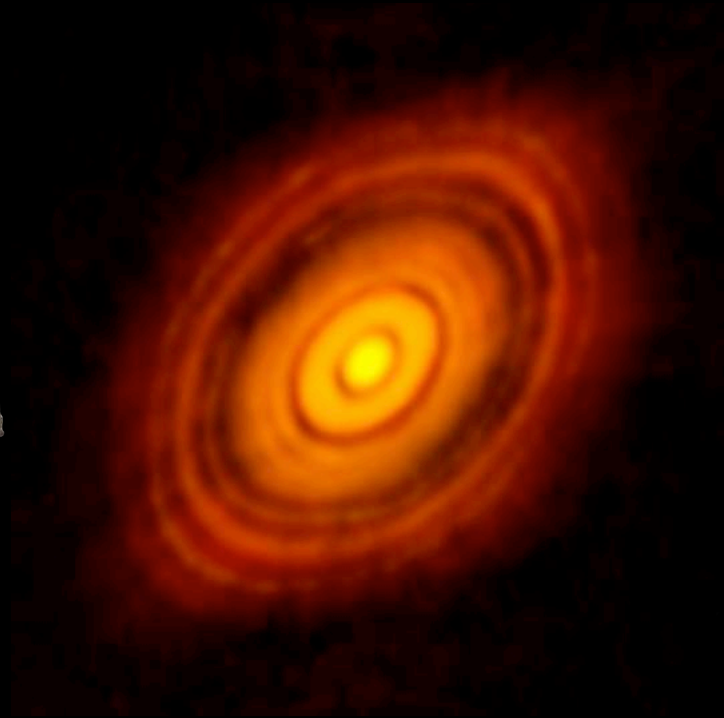
Where do
planets
come from?

Where do
planets
come from?

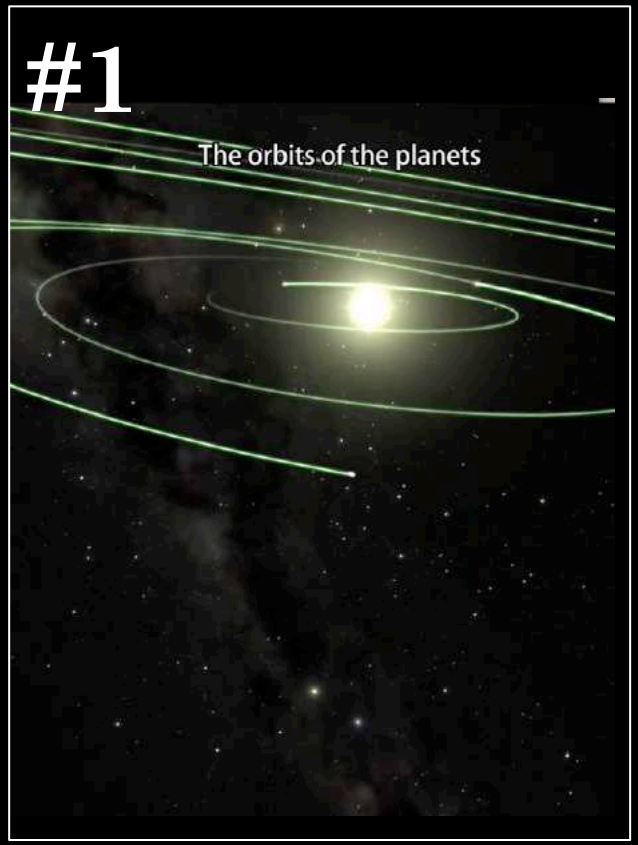
How do we know?

How do we know?

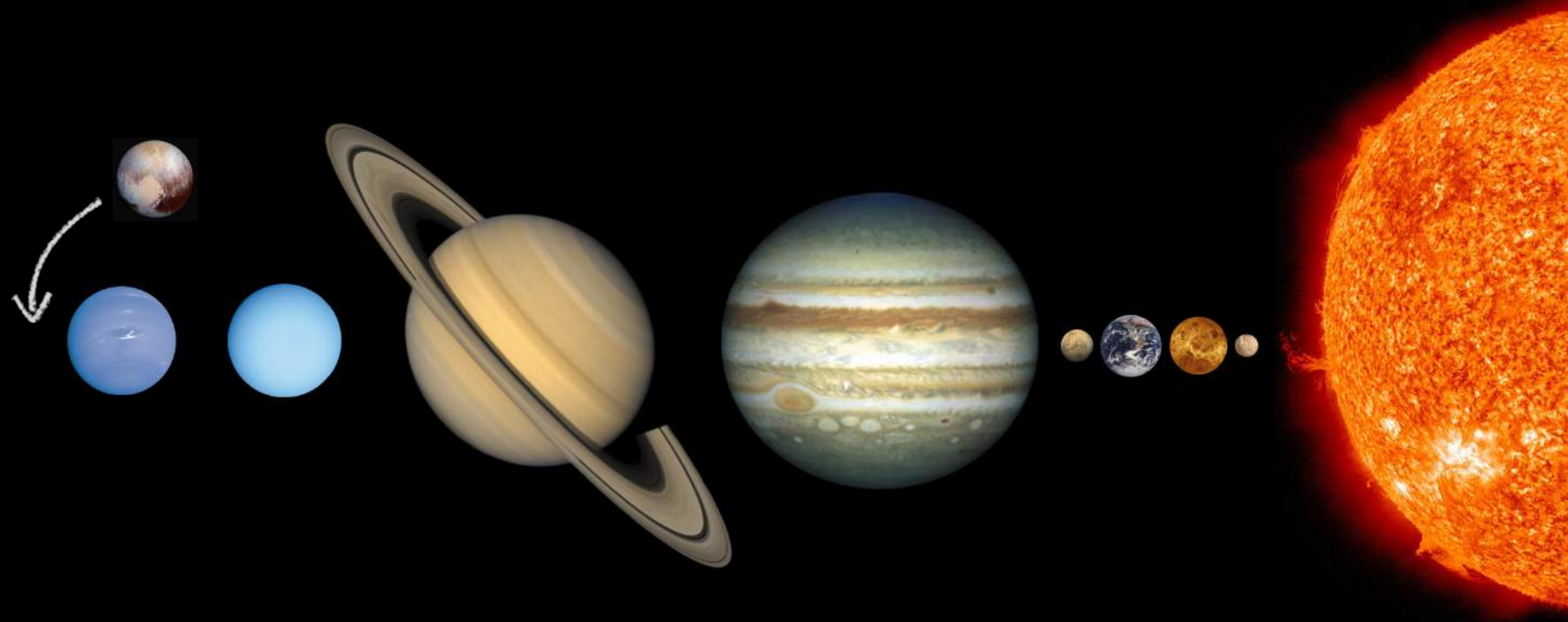




How do we know?



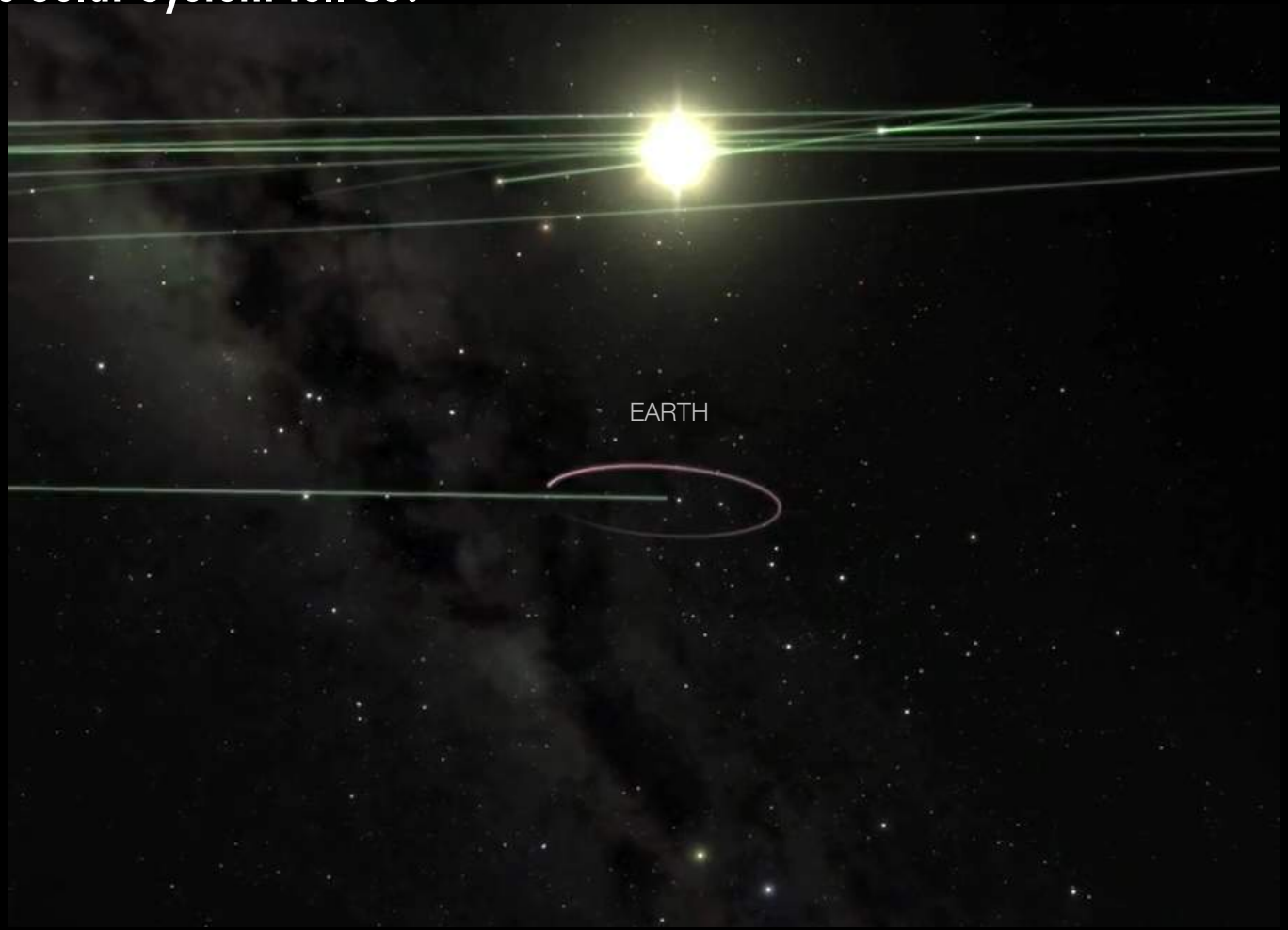
Planets



NASA

orbit stars

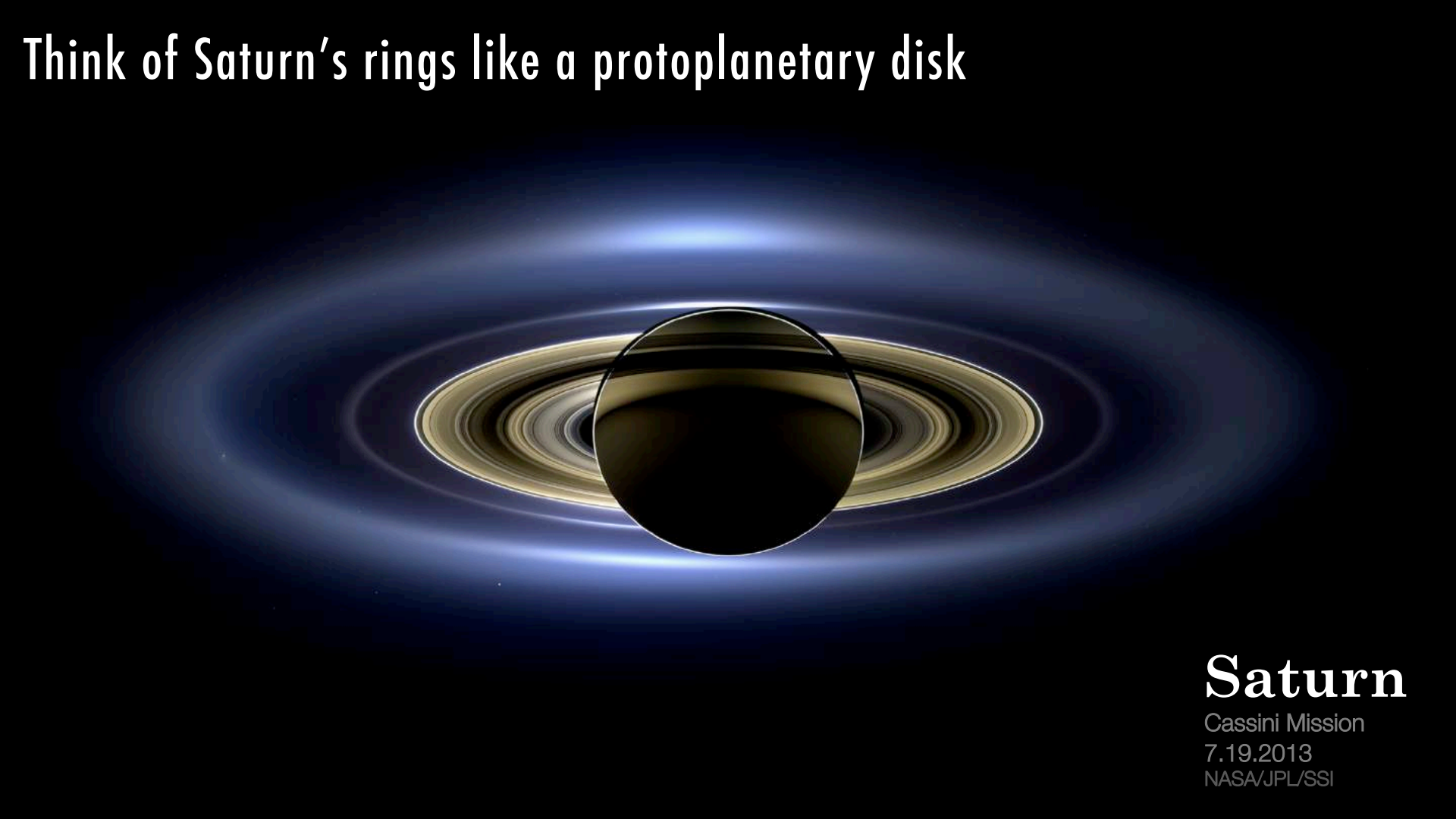
What can the Solar System tell us?



AMNH/Rubin Art

protoplanetary disk

Think of Saturn's rings like a protoplanetary disk

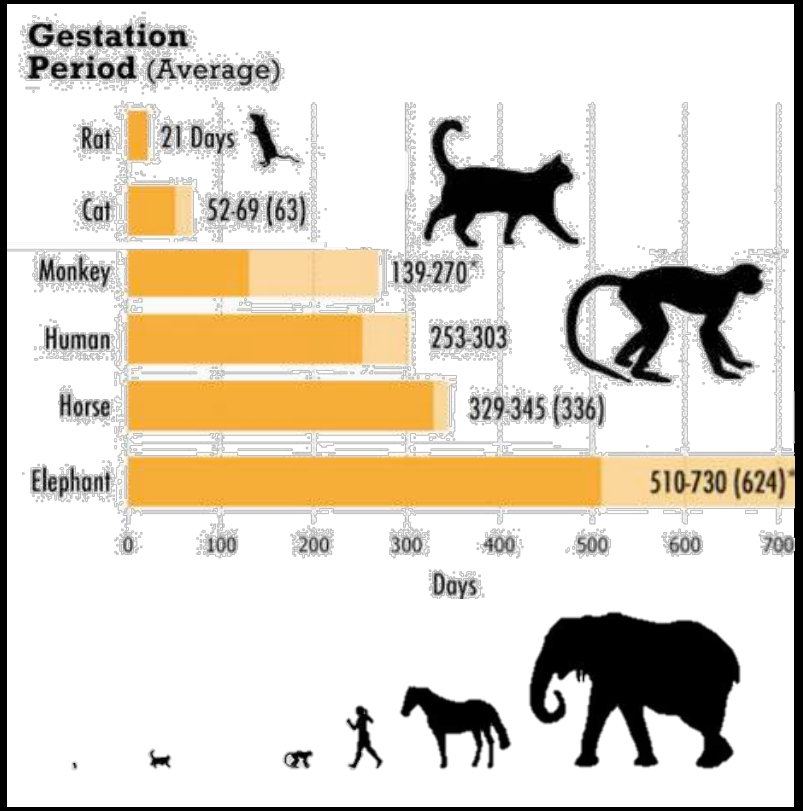


planets form around a **star** in a

protoplanetary disk


From collapsing cloud to new star and disk
Leftover gas and dust can become planets

How long?



Expect a planet in ~10 million years

(short compared to a star's lifetime)

If we can’t watch it form,

How do we know?

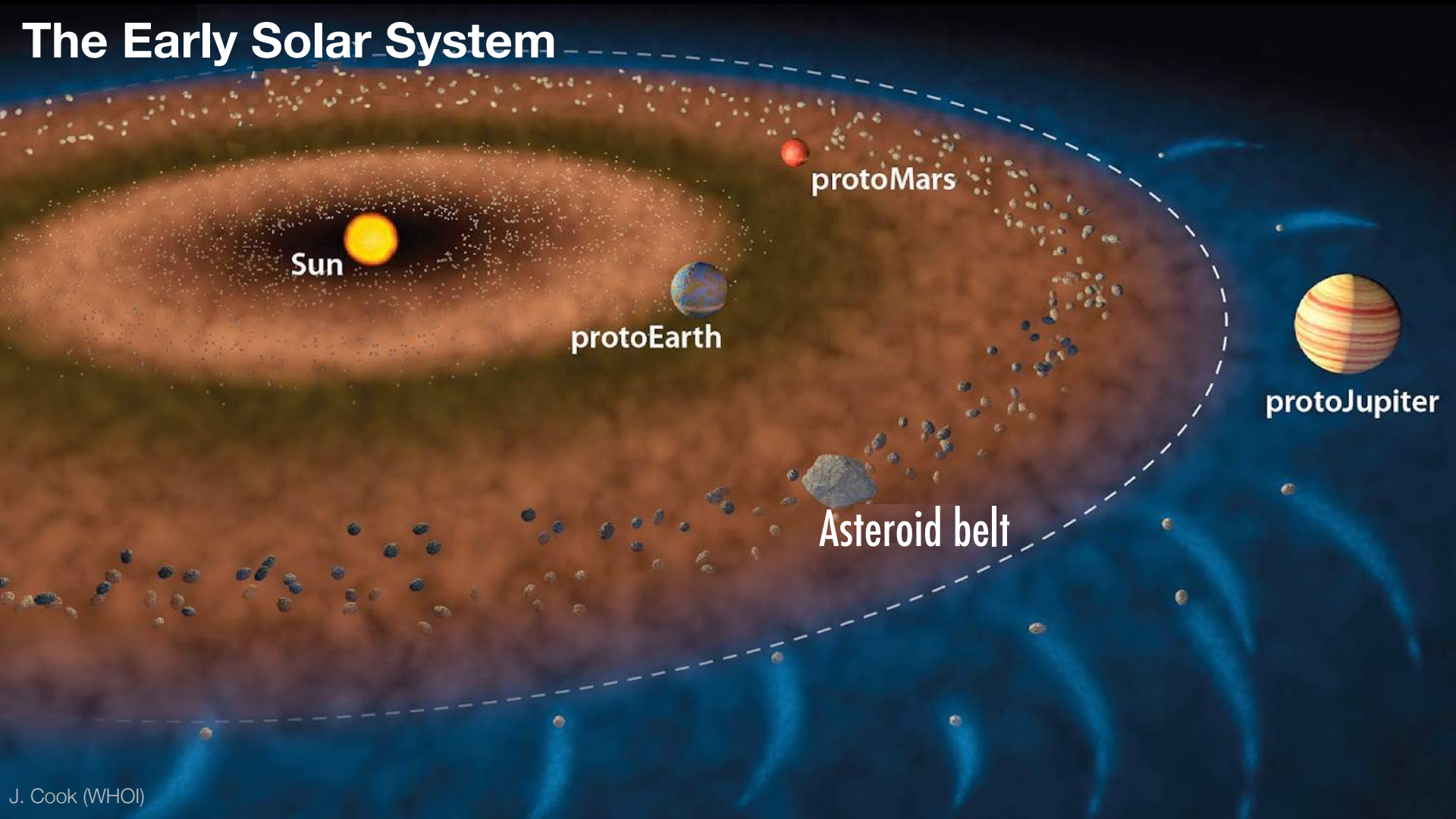
If we can't watch it form,

How do we know?

meteorites

leftover from planet formation

The Early Solar System



J. Cook (WHOI)

Meteorites

Harvard Geological Museum

Meteorites

older than the Earth

Meteorites

Stony

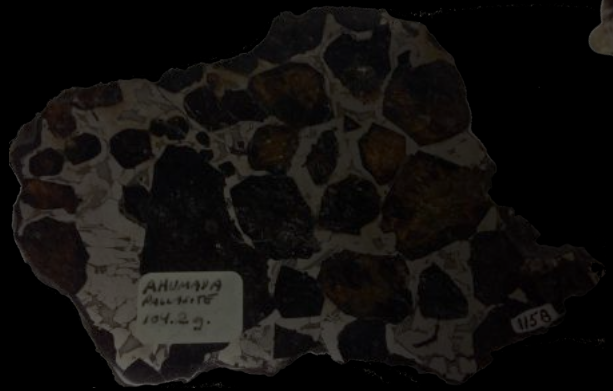
Stony-Iron

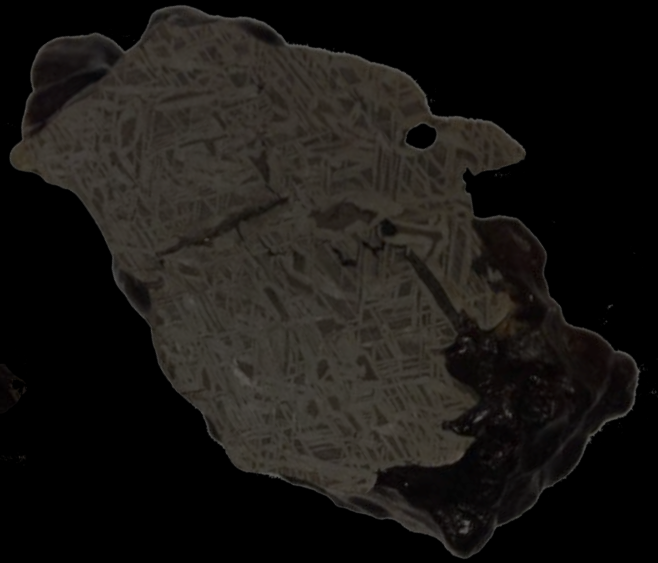
Iron

composition is important

Meteorites

chondrules



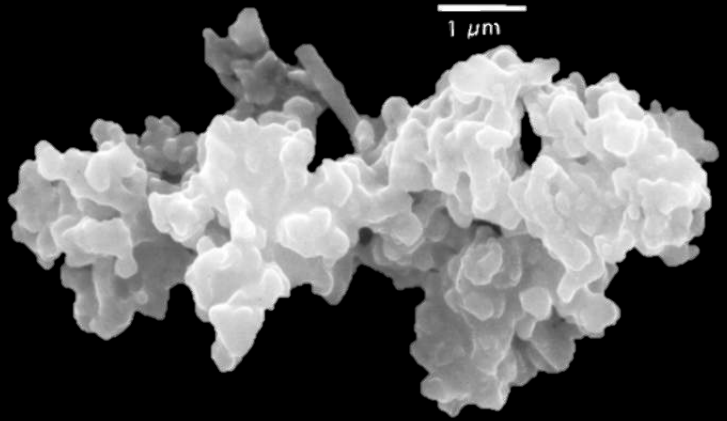


composition is important

planets form from

dust, gas, & ice

dust



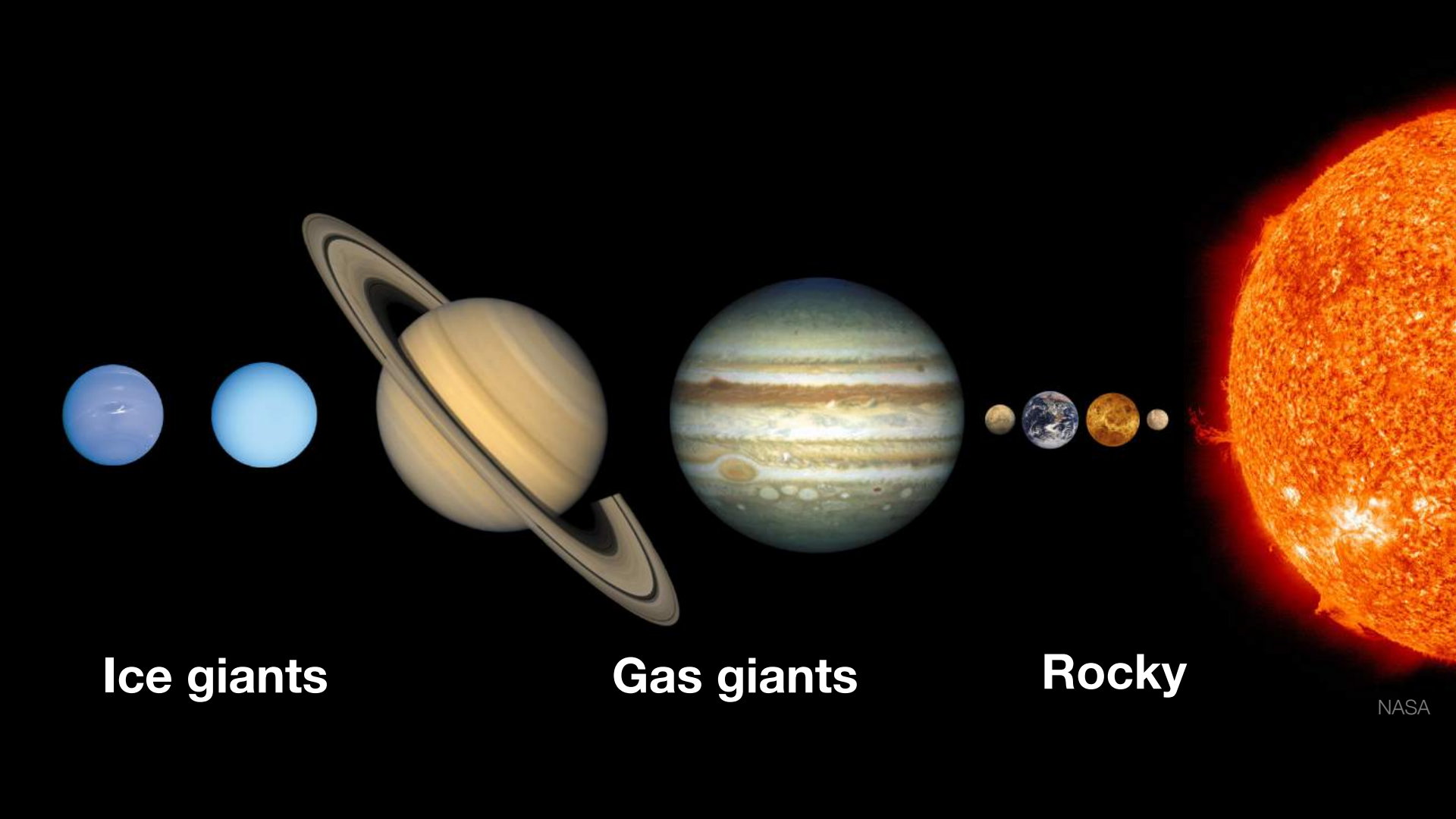
Brownlee & Jessberger

planet growth

10^{-6} m

10^{7} m

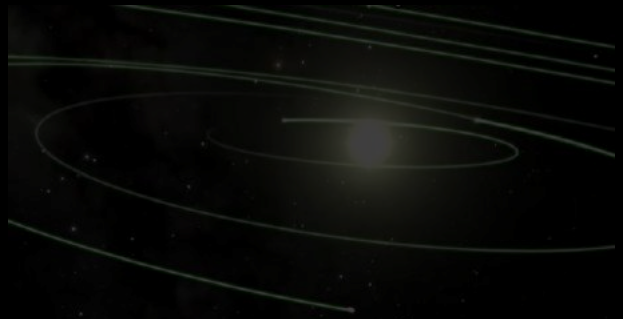
ESO

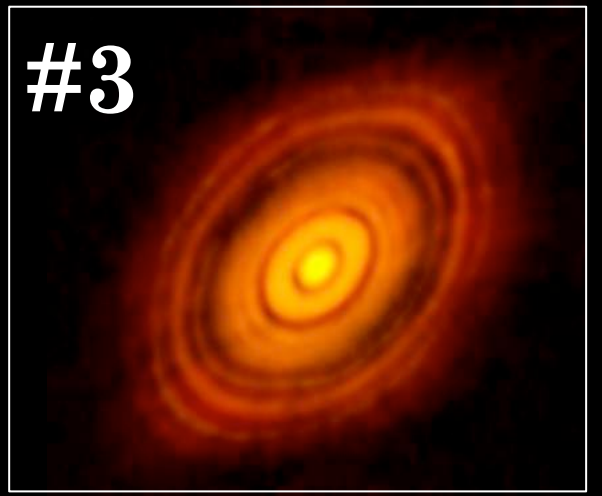

Ice giants
Gas giants
Rocky
NASA

atmosphere addition

Orbits and meteorites aren't enough.

How do we know?

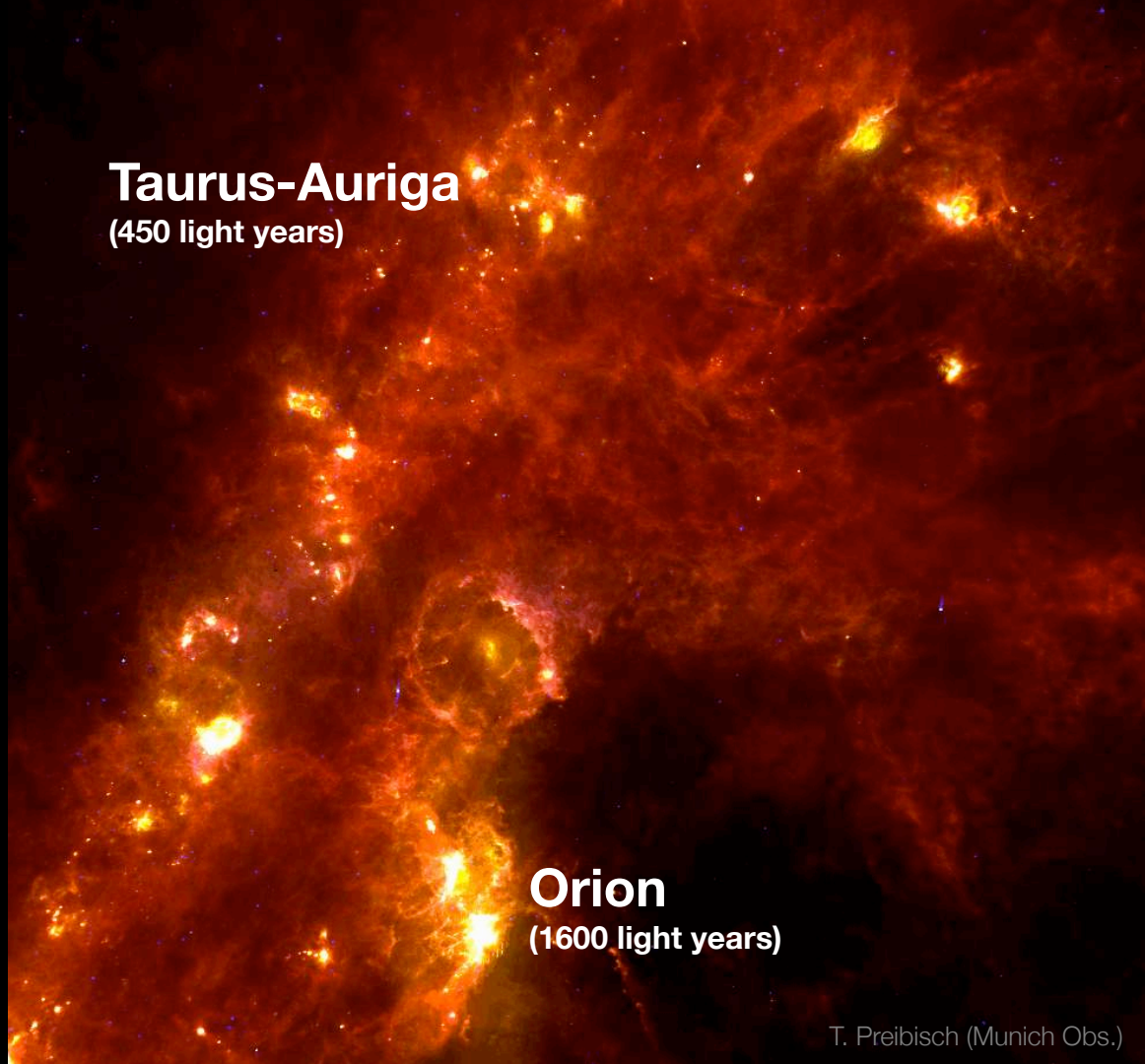




Directly observe
protoplanetary disks

Where to look?

star forming regions



ESA/HST/R. Gendler, A. Fujii

proplyd

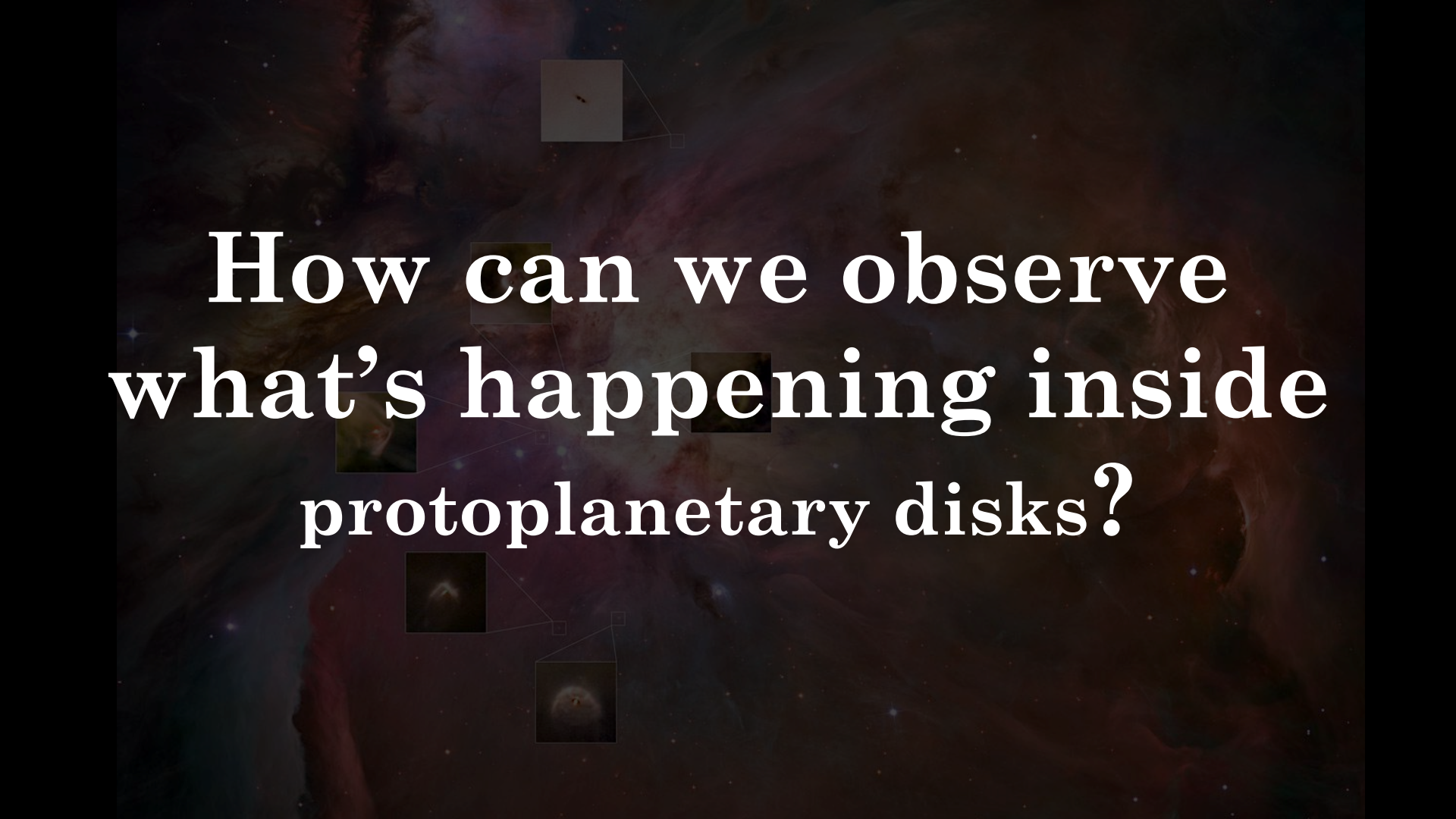
protoplanetary disk

NASA/ESA/L. Ricci

proplyd

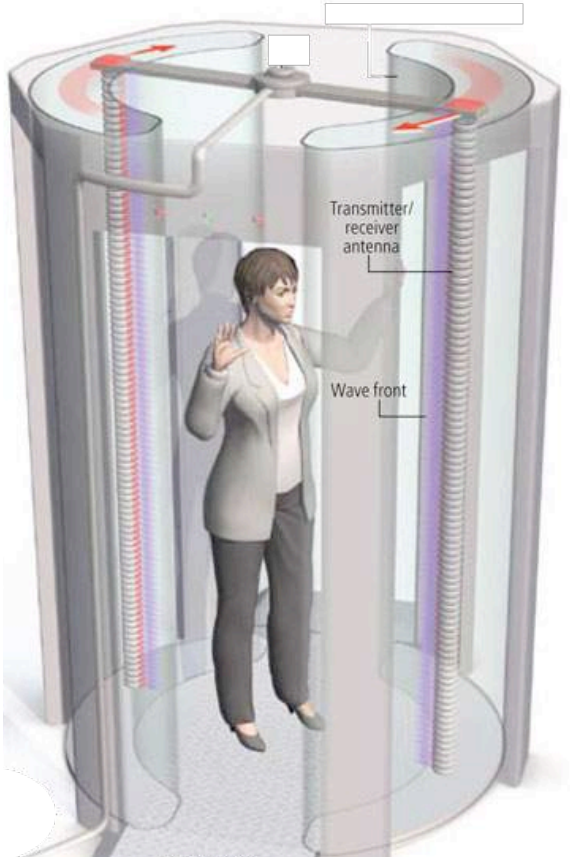
surface seen in silhouette

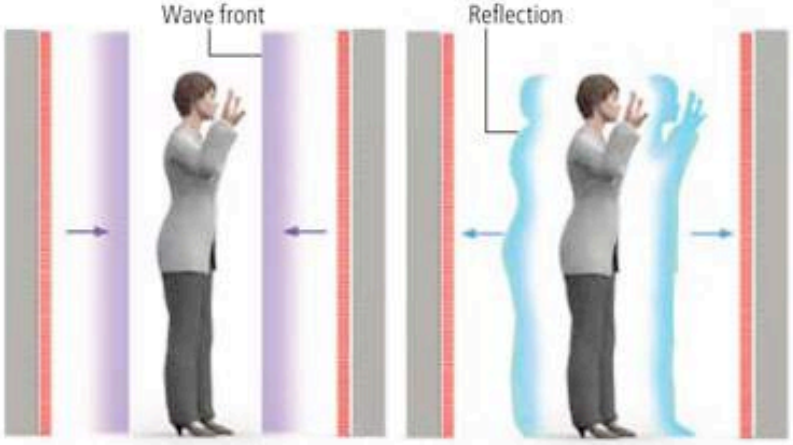
NASA/ESA/L. Ricci

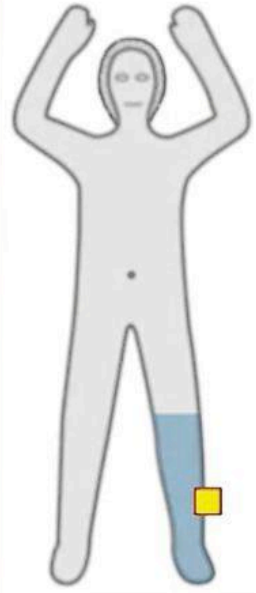


How can we observe what's happening inside protoplanetary disks?

millimeter waves



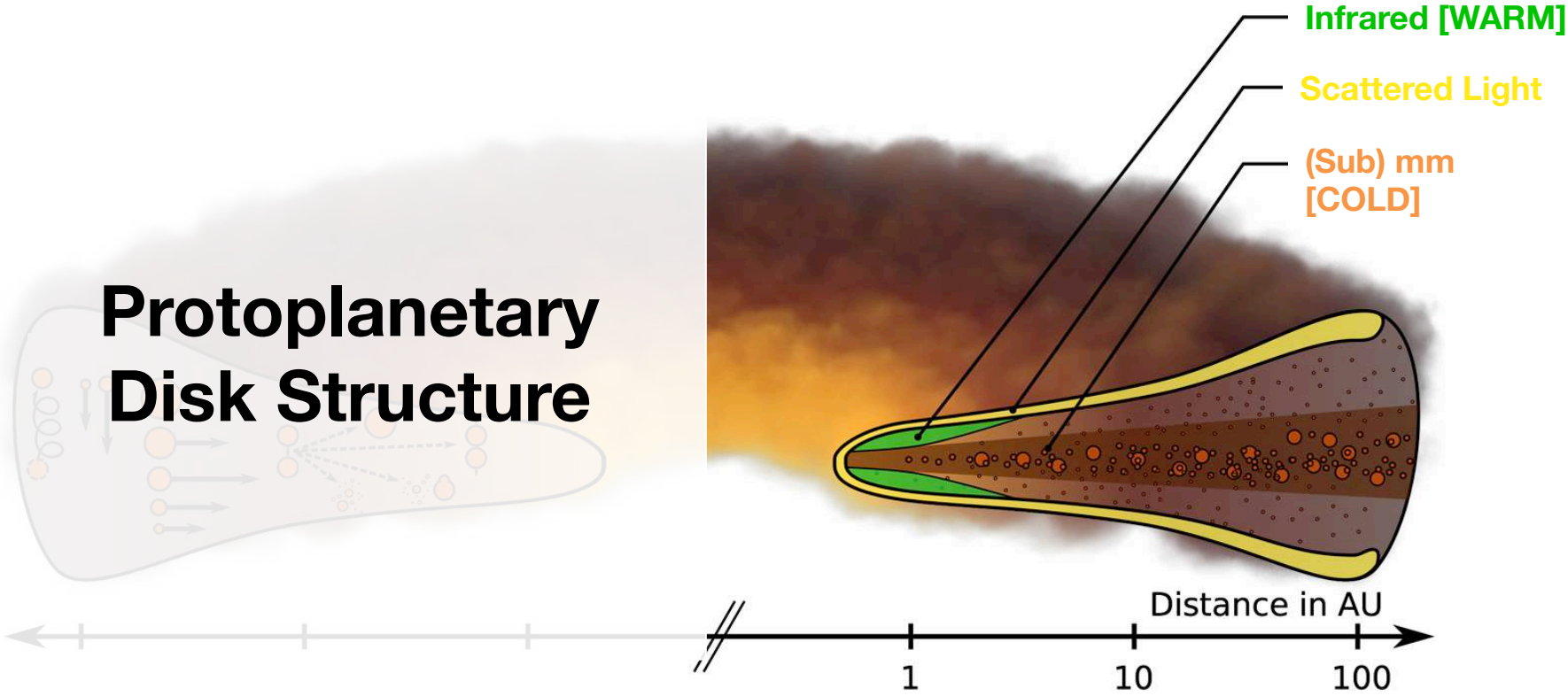




let us look below the surface

Scientific American

Protoplanetary Disk Structure



Testi et al. 2014

How can we resolve disks?

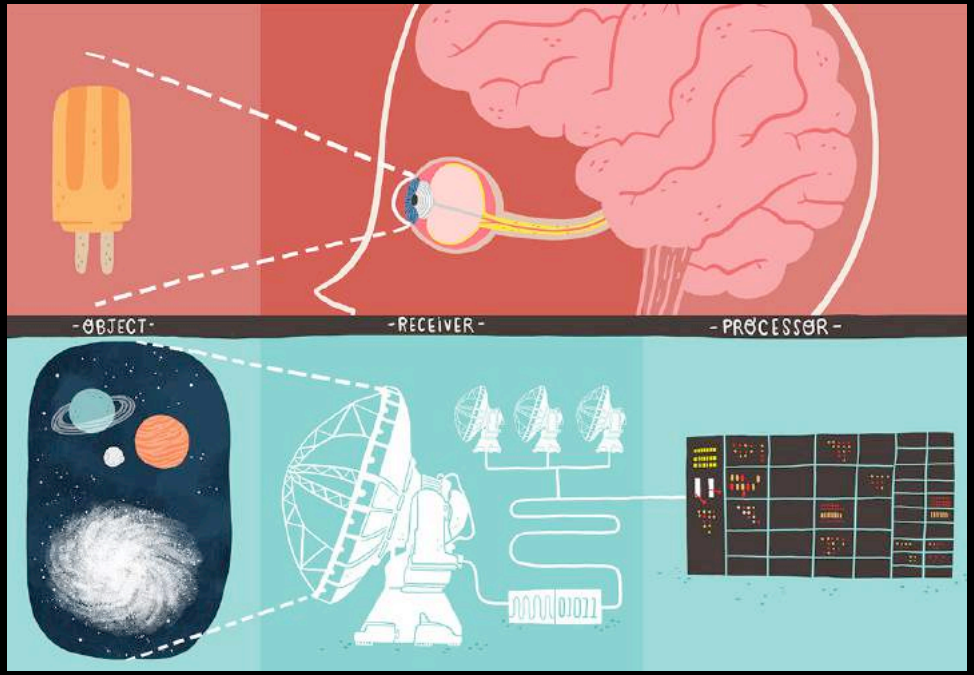
480m (1mm)

$$\text{Telescope size} = \frac{\text{Wavelength}}{\text{Disk size}} =$$

Taurus Distance: 450 ly
Neptune's Orbital Diameter: 60 AU

900m (3mm)

Radio interferometry



ALMA

Telescope size needed

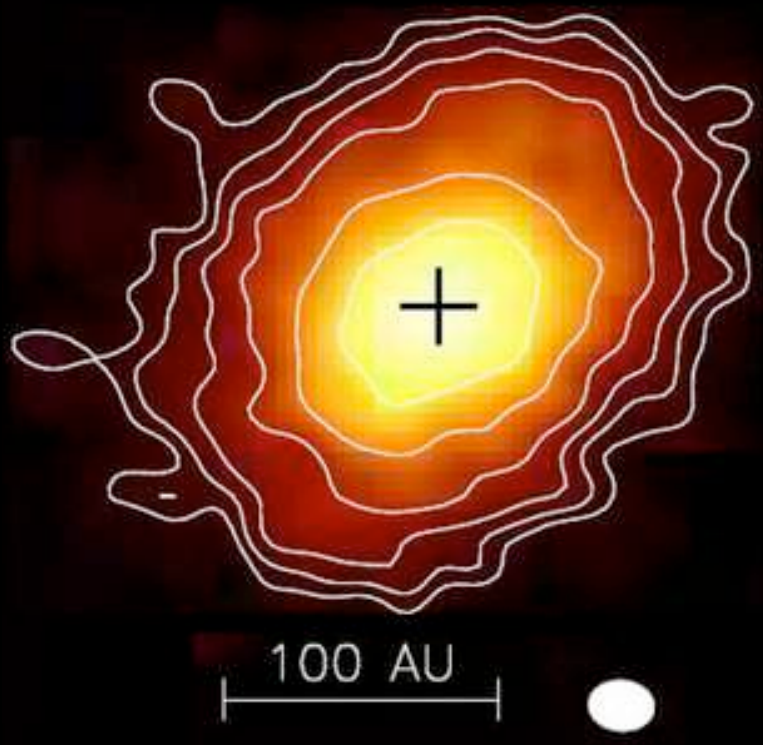
$$= \frac{\text{Wavelength}}{\text{Disk size}}$$

~1000m (1mm)

Neptune's orbit at the distance of Taurus

Many antennae = 1 bigger antenna

Seeing the midplane



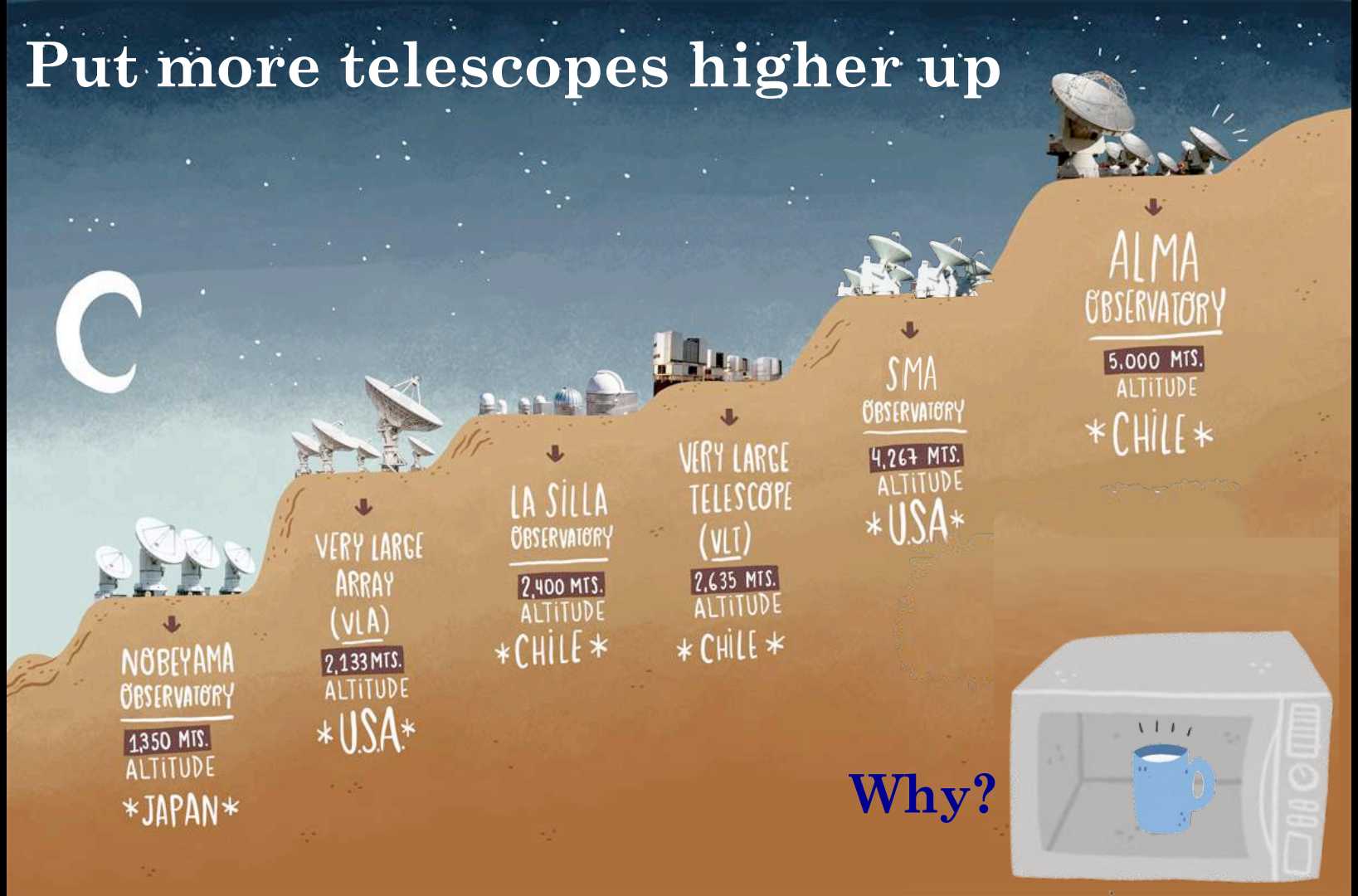
HL Tauri

CARMA (~2km)

(1 AU = Earth-Sun distance)

Kwon, Looney, & Mundy

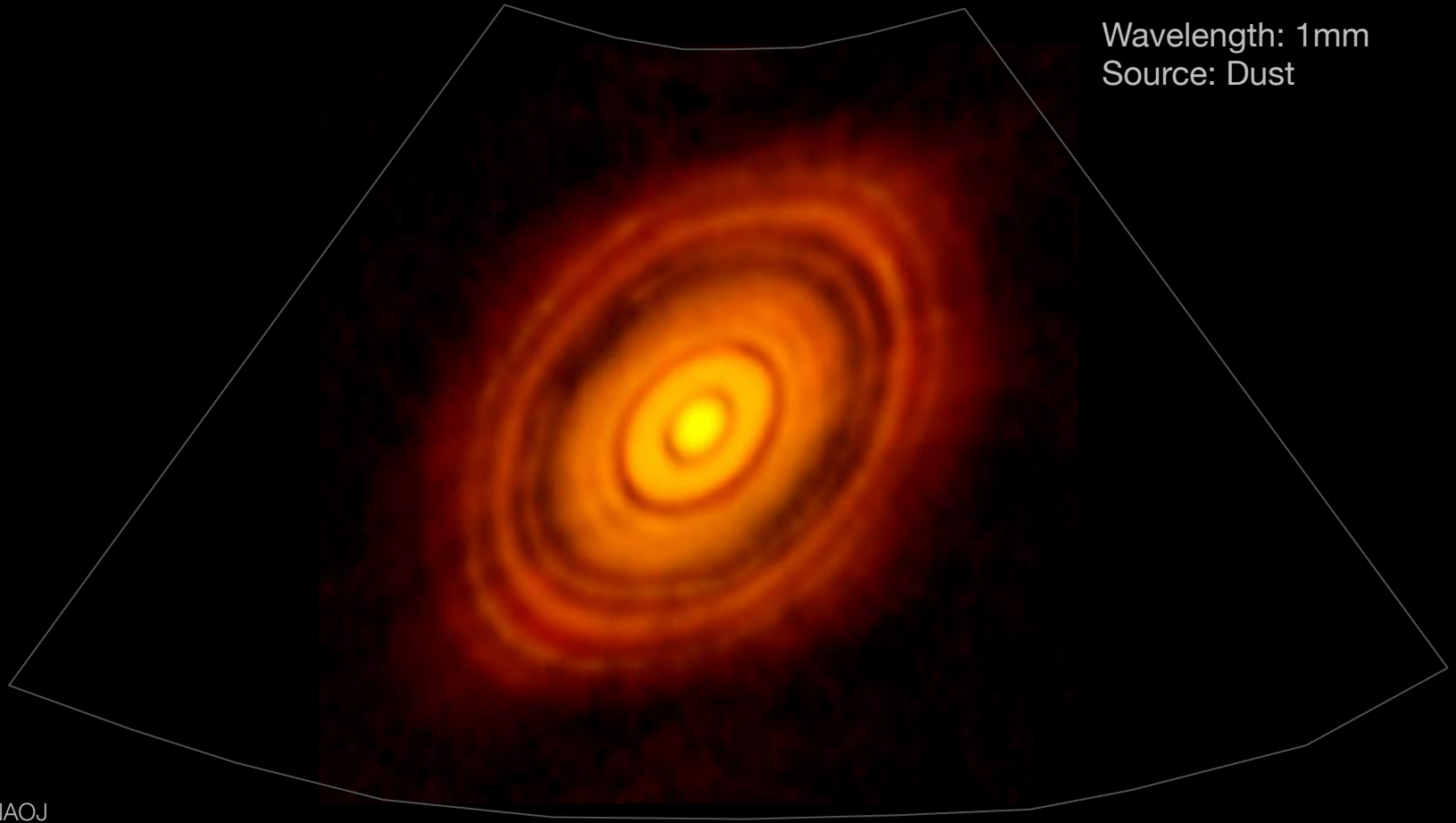
Put more telescopes higher up



ALMA (Atacama Large Millimeter Array)

Planet's First Picture

Name: **HL Tauri** Size: 200 AU November 2014



Wavelength: 1mm
Source: Dust

NRAO/ESO/NAOJ

Planet's First Picture

Name: **HL Tauri** Size: 200 AU November 2014

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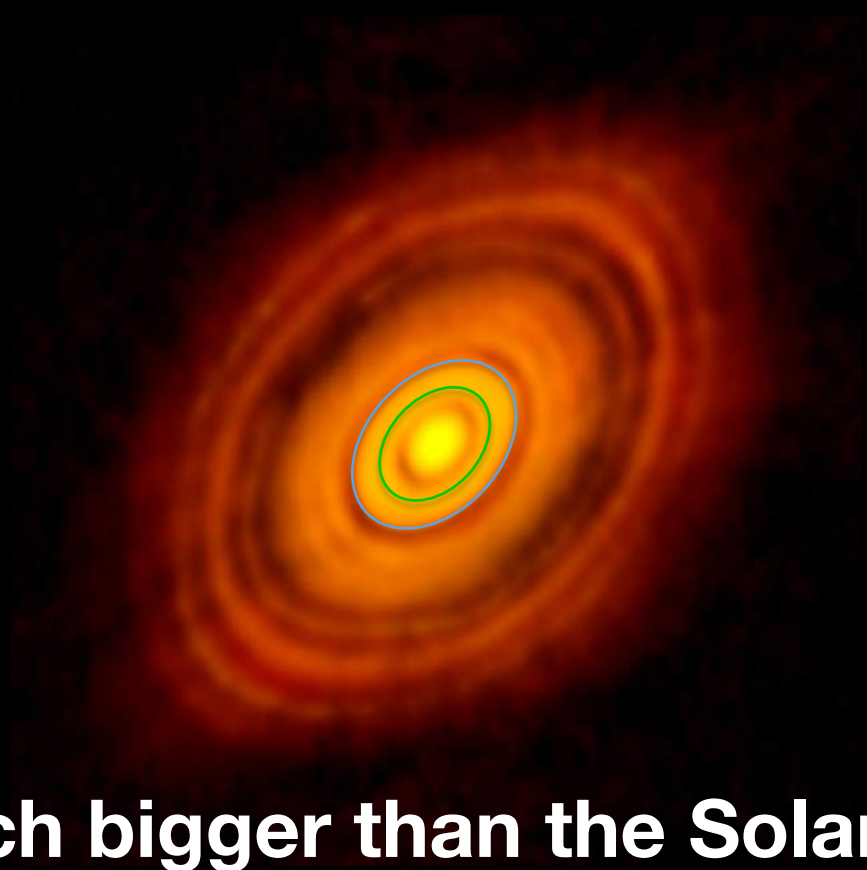
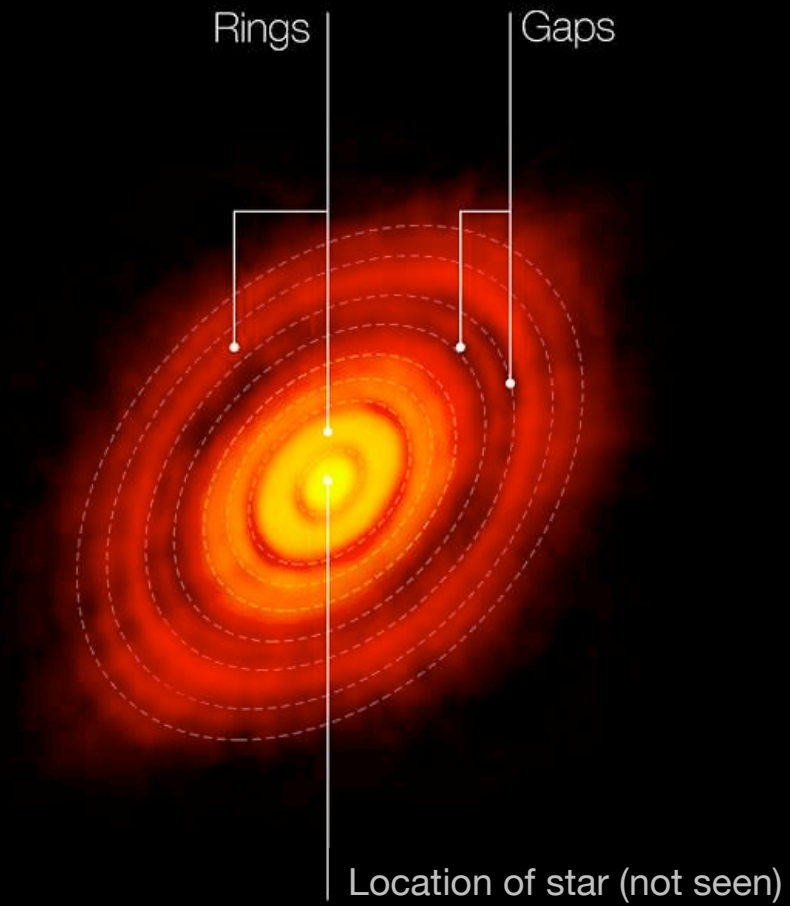


Much bigger than the Solar System

NRAO/ESO/NAOJ

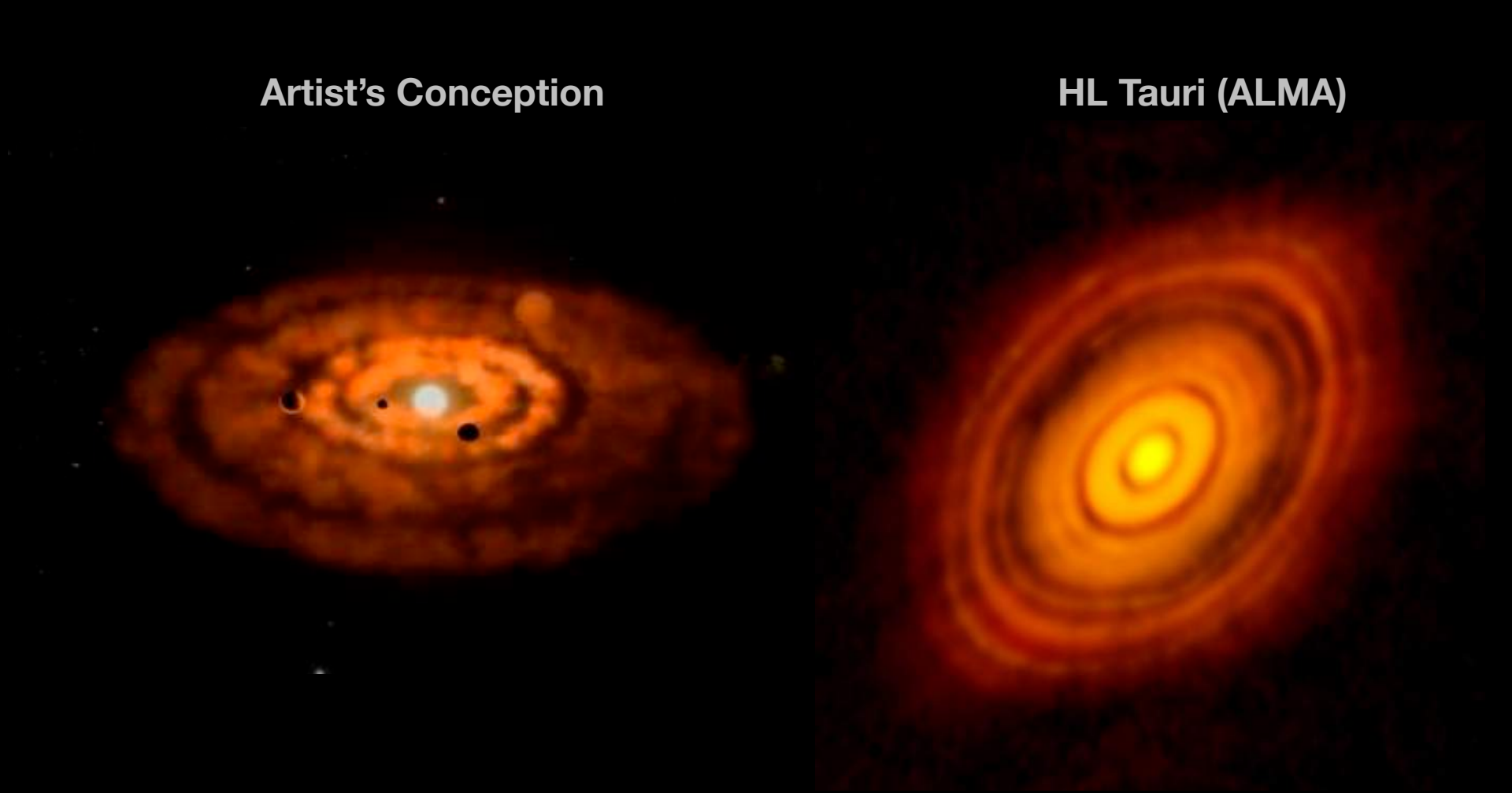
Visible gaps



NRAO/ESO/NAOJ

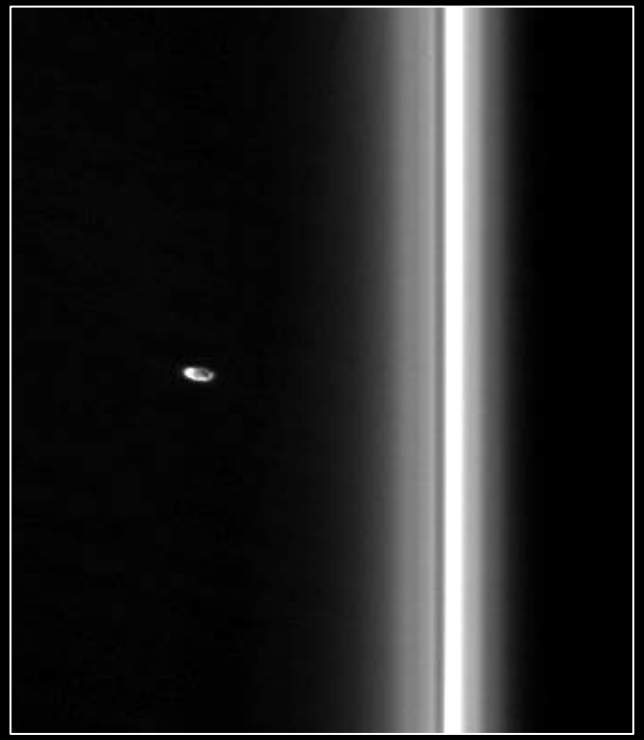
Artist's Conception

HL Tauri (ALMA)



Gemini/STSci

Big gaps caused by little actors



Prometheus interacting
with Saturn's ring

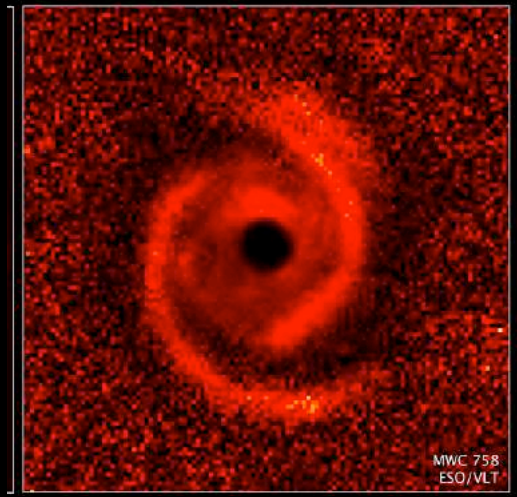
NASA/JPL/SSI

Other indications of planets?

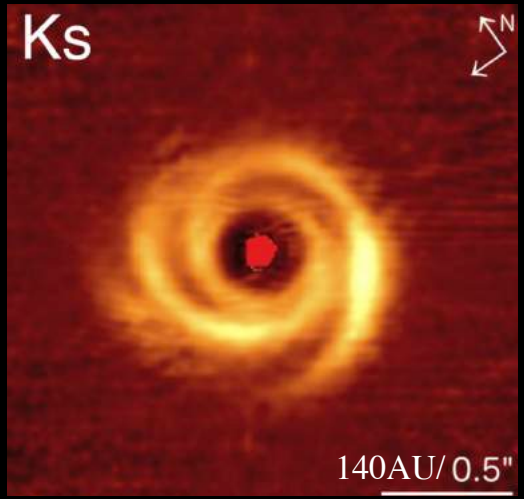
Indications of planets?

spiral arms

MWC 758

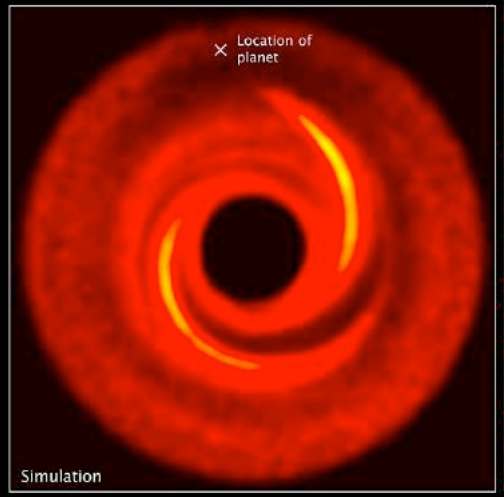


SAO 206462



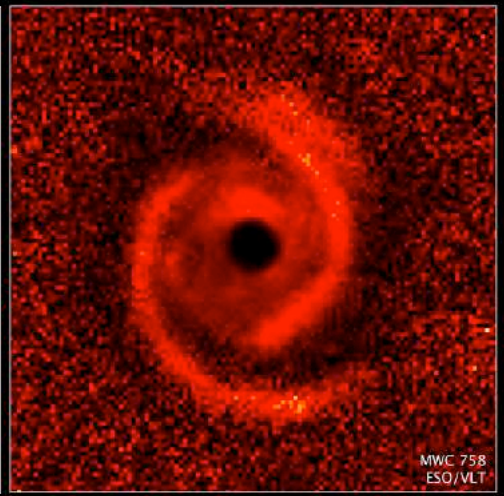
Indications of planets?

Simulation

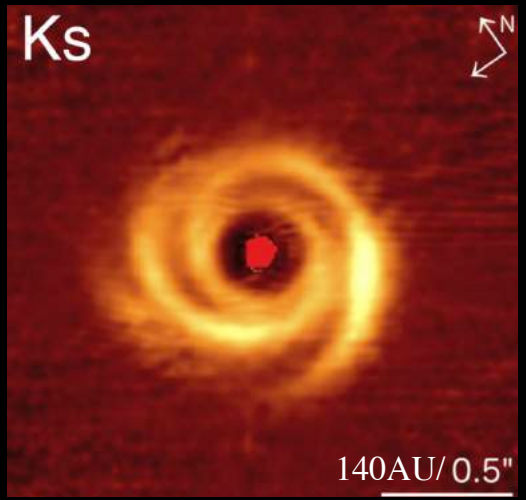


Dong & Zhu 2015

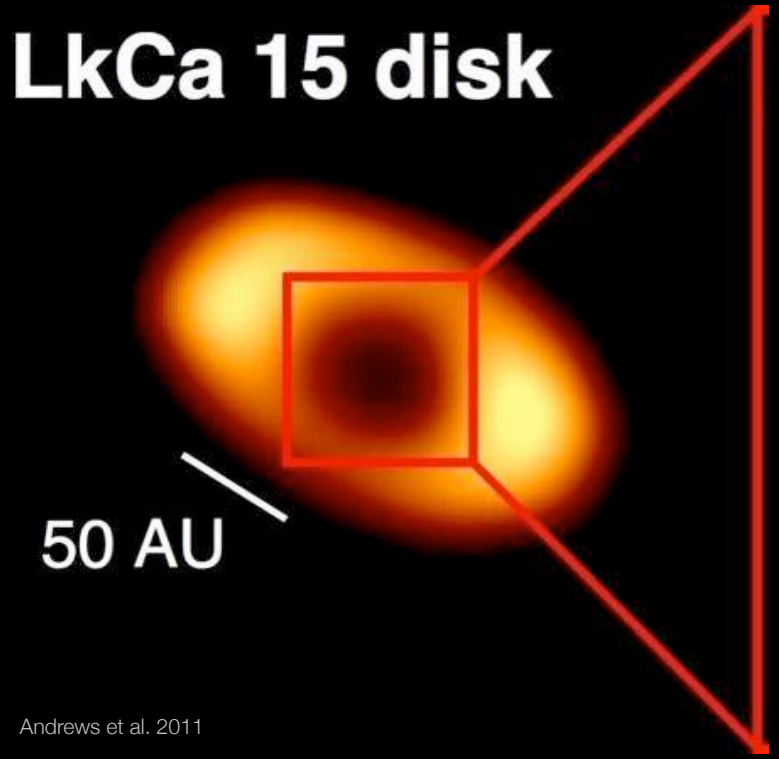
MWC 758



SAO 206462

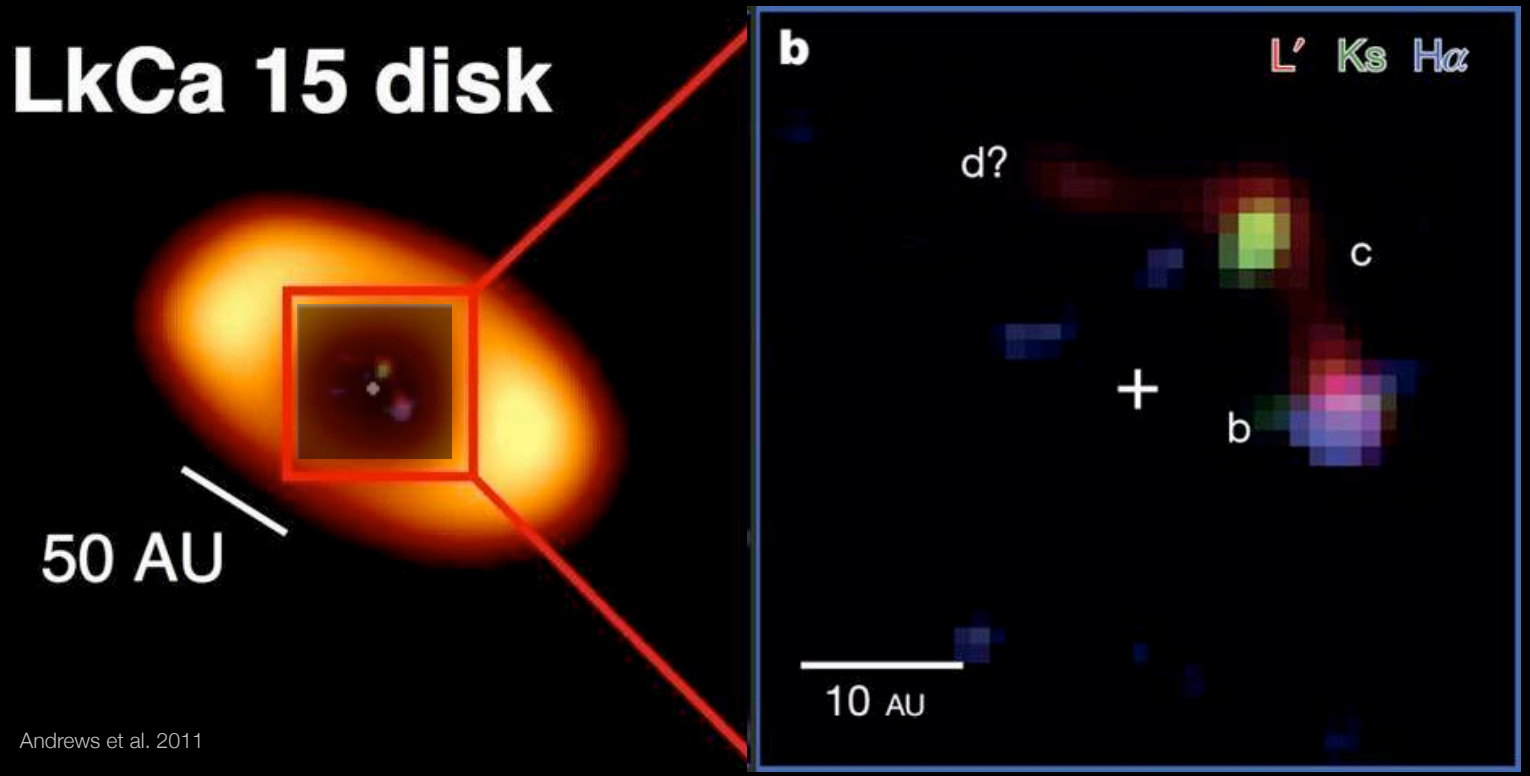


Simulations can create spirals due to planets



Andrews et al. 2011

Can we see forming planets?



Andrews et al. 2011

Sallum et al. 2015

Forming planets?

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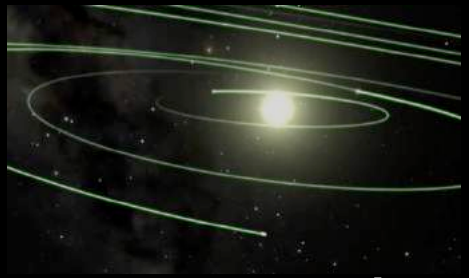
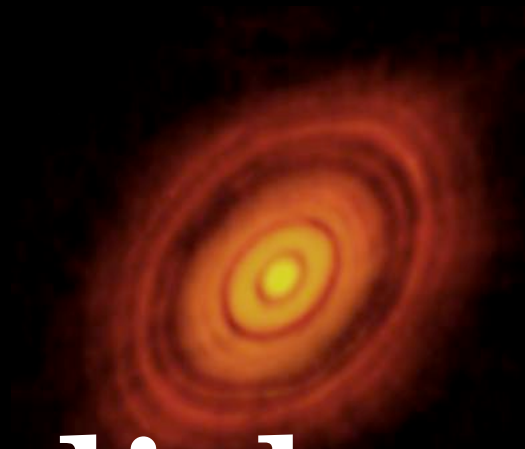
How do we know?

Planets come from

dust, gas, & ice

in





protoplanetary disks

(our best prospect for future study)

Come see the meteorites in the auditorium.

Please don’t touch the samples.

Harvard Geological Museum