

**Stars form in molecular clouds
composed of gas and dust in
a 100:1 ratio**

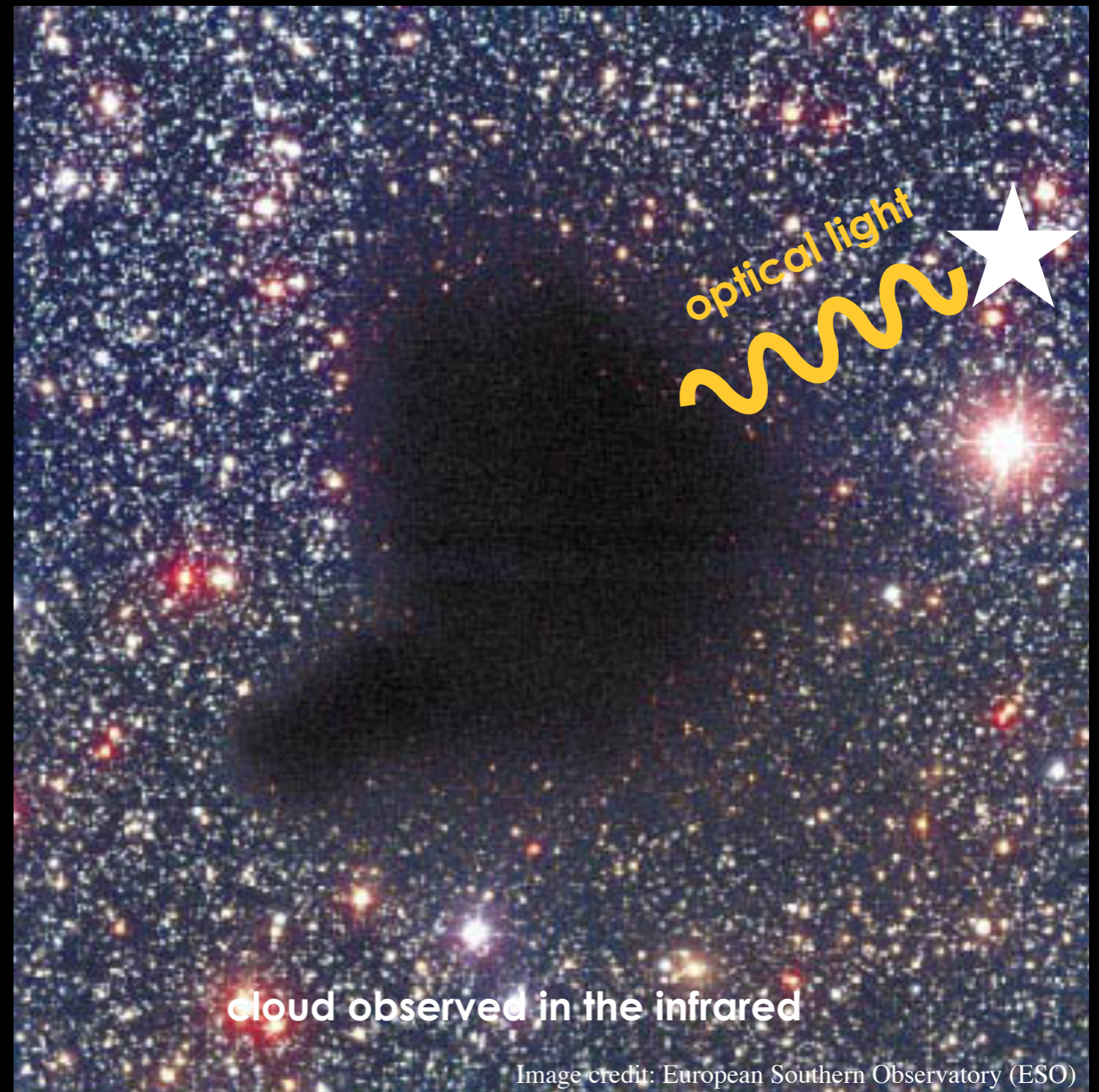
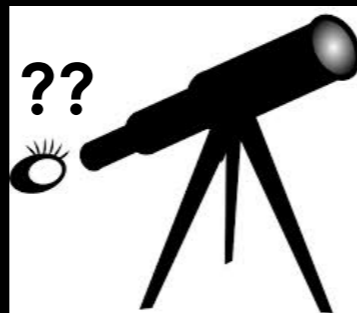


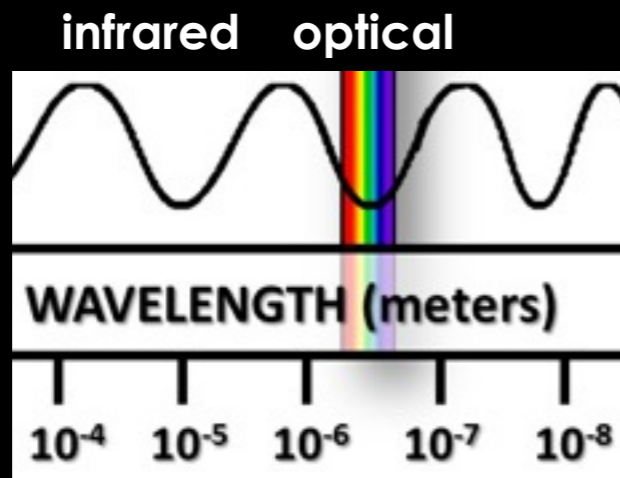
**this molecular cloud
has about 15 times
the mass of the Sun**

Image credit: NASA y The Hubble Heritage Team (STScI/AURA)

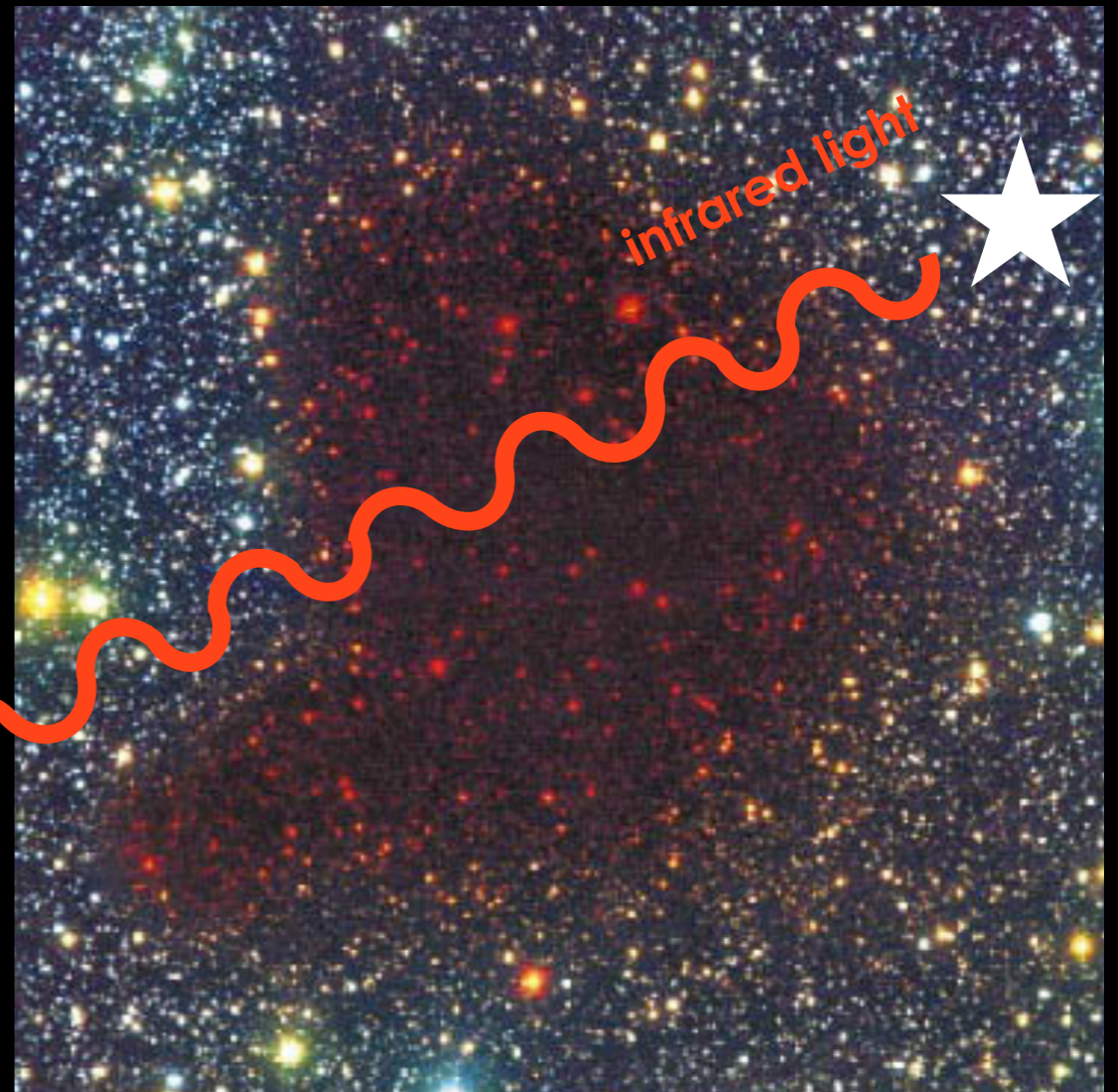
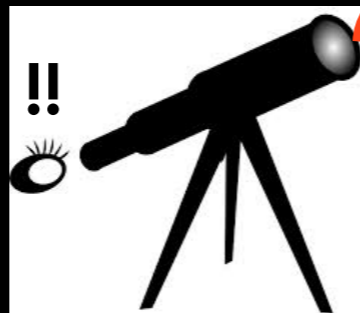
The dust particles in the cloud are about 1 micron in size

Optical light cannot get through the cloud so we don't know what's going on inside





Infrared light can get through the cloud and this allows us to study how stars and planets are born



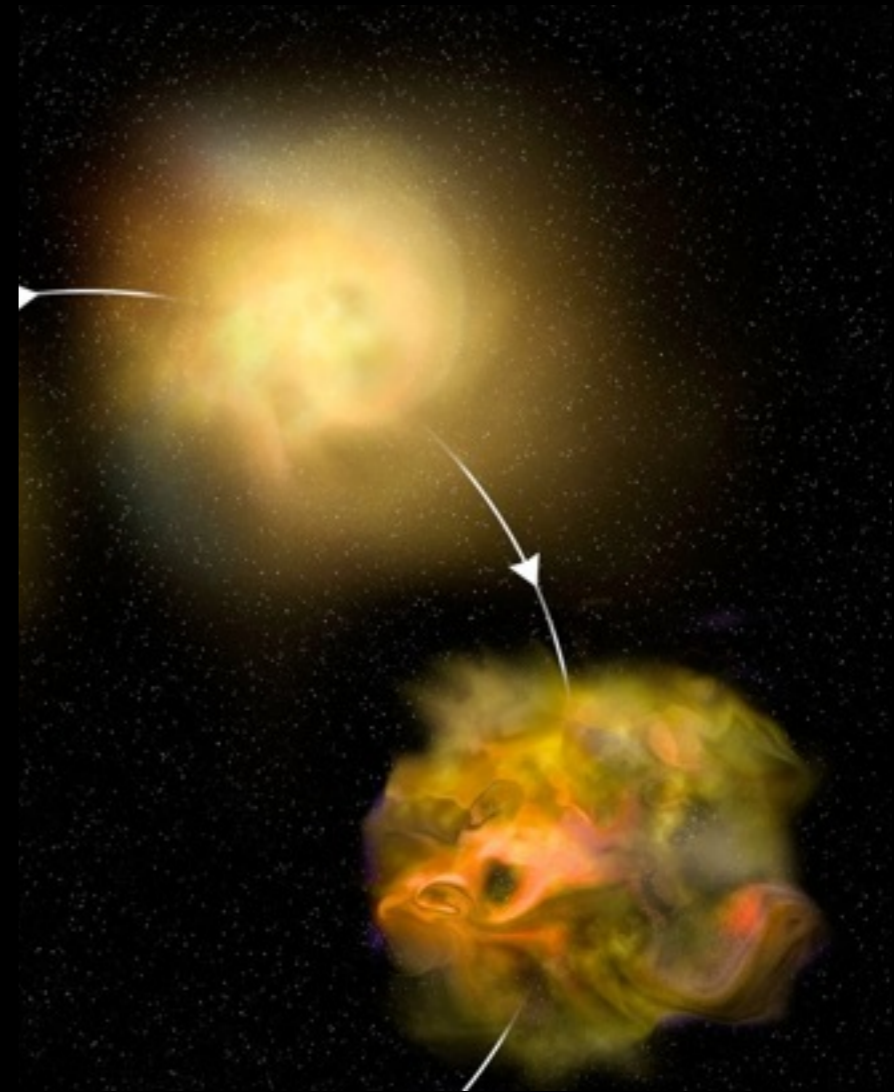
same cloud observed in the infrared

Image credit: European Southern Observatory (ESO)

How are stars and planets are formed?

A fragment of the cloud becomes more dense (maybe due to shocks) and contracts under its own gravitational pull

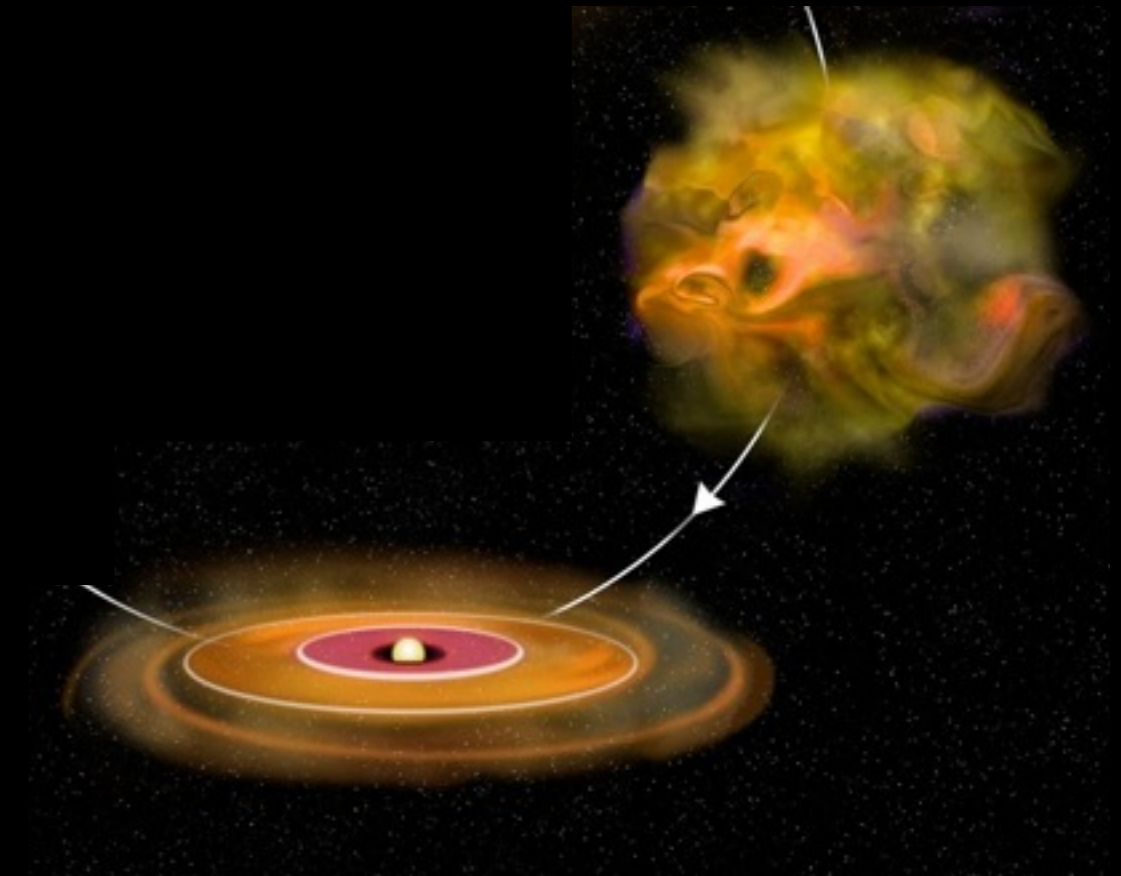
This forms a nascent star in the middle (a protostar)



How are stars and planets are formed?

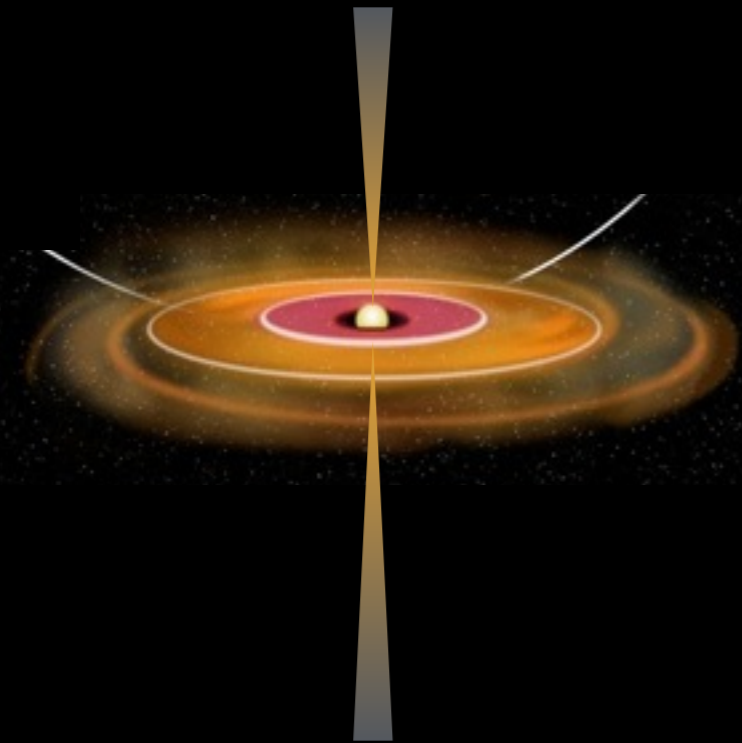
The protostar is surrounded by a slowly-rotating envelope of gas and dust (from the cloud).

This envelope forms a disk around the protostar due to conservation of angular momentum.



How are stars and planets are formed?

Part of the mass of the disk falls into the nascent star, while another part is ejected in jets (this is thought to be due to viscosity and magnetic fields).



this is a picture of a
real disk with a jet

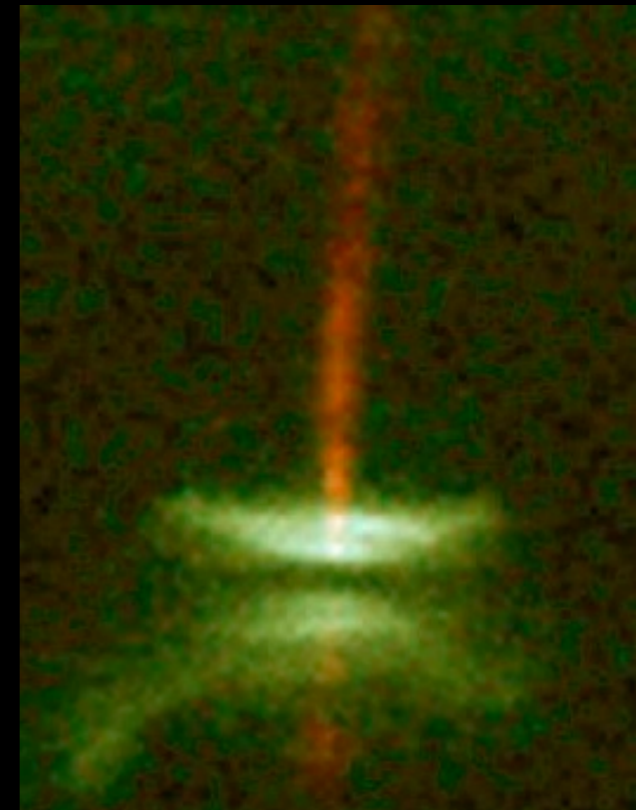


Image credit: Hubble Space Telescope, NASA.

**How are stars and planets
are formed?**

**Images of nascent stars
surrounded by disks in the
Orion Nebula**

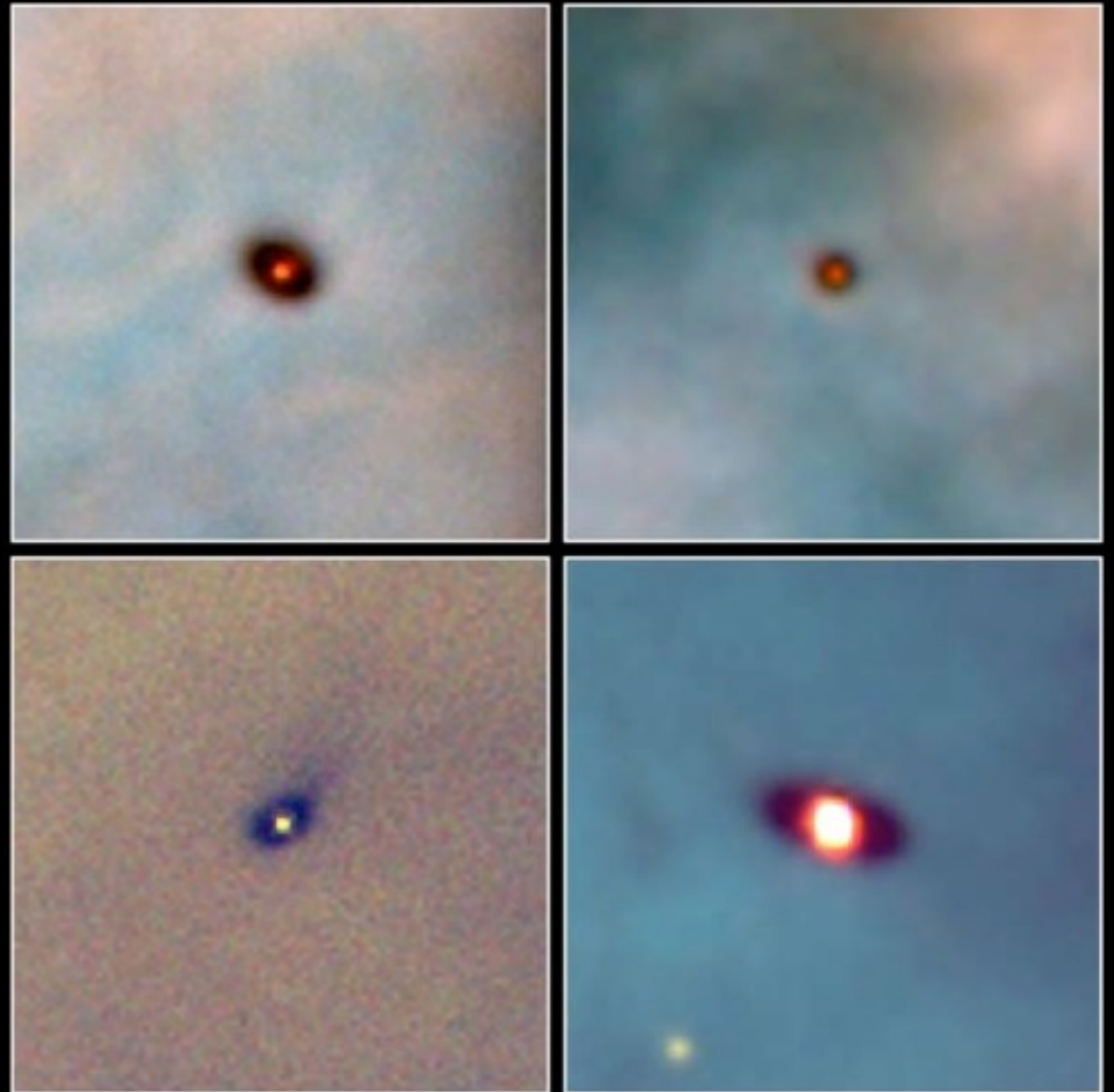


Image credit: Hubble Space Telescope, NASA.

How are stars and planets are formed?

In the disk, dust grains collide with each other frequently.

Some collisions are destructive; others result in the formation of dust aggregates.

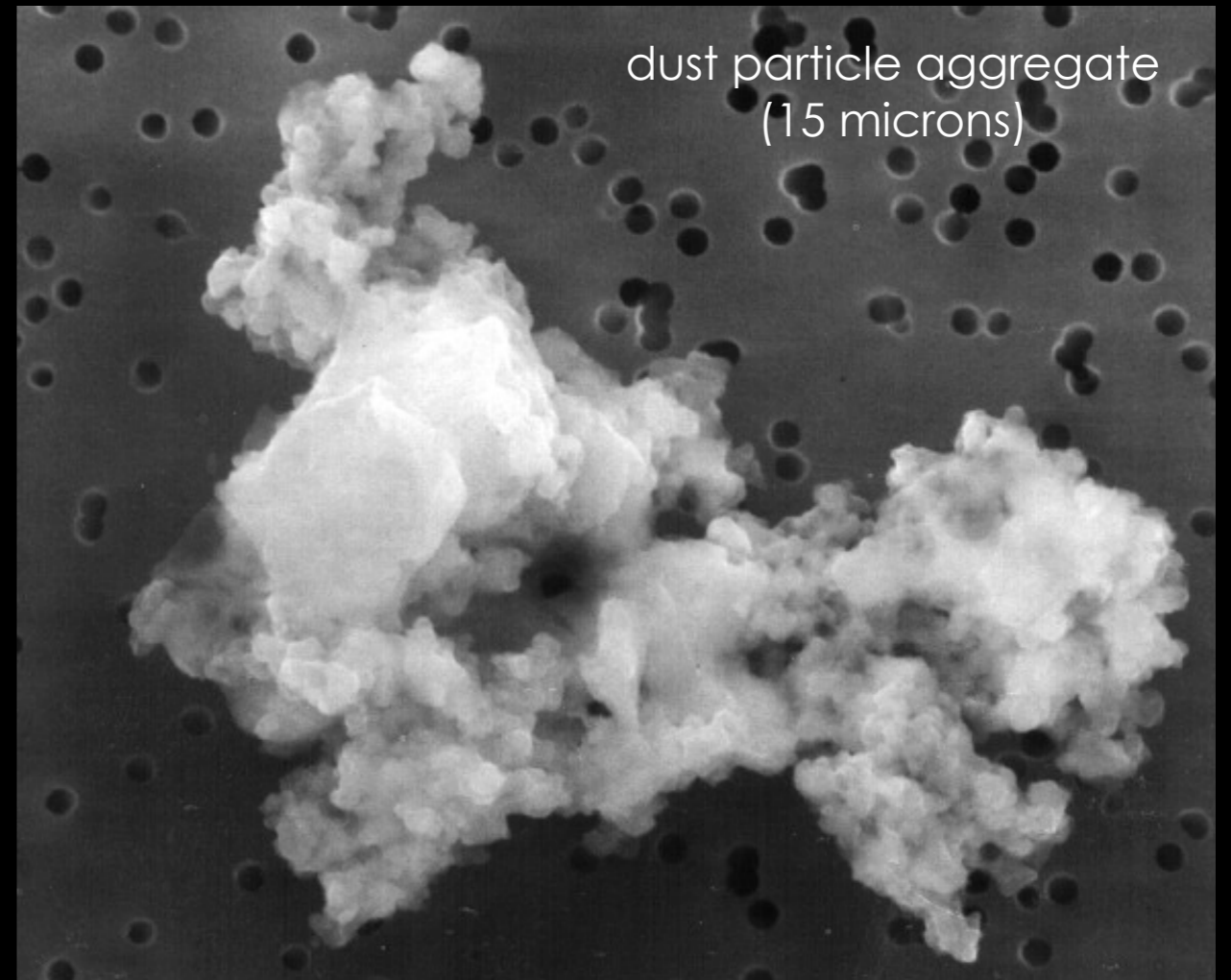
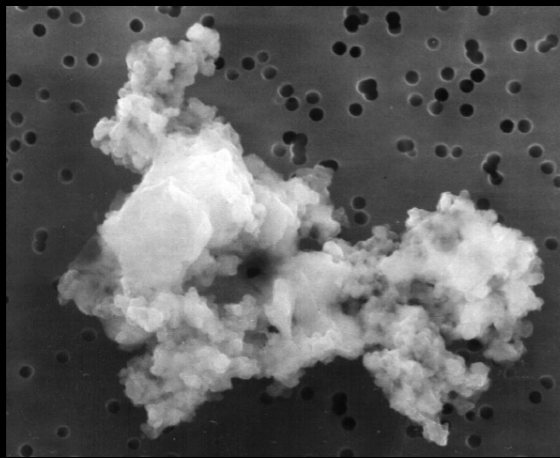


Image credit: Brownlee et al. NASA

How are stars and planets are formed?

These aggregates become larger and larger forming rocks, then planetesimals (like asteroids and comets), then the terrestrial planets, and finally the cores of the giant planets.



dust particle aggregate
(15 microns)



Asteroid Itokawa
(500 m)



Earth
(radius = 6370 km)

Image credits: Brownlee et al. (left), JAXA (center), NASA (right)

How are stars and planets are formed?

The largest cores (about 10 times the mass of the Earth) attract gas from the disk (thanks to its gravitational pull) forming a massive atmosphere.

This is how the giant planets (like Jupiter and Saturn) are form.



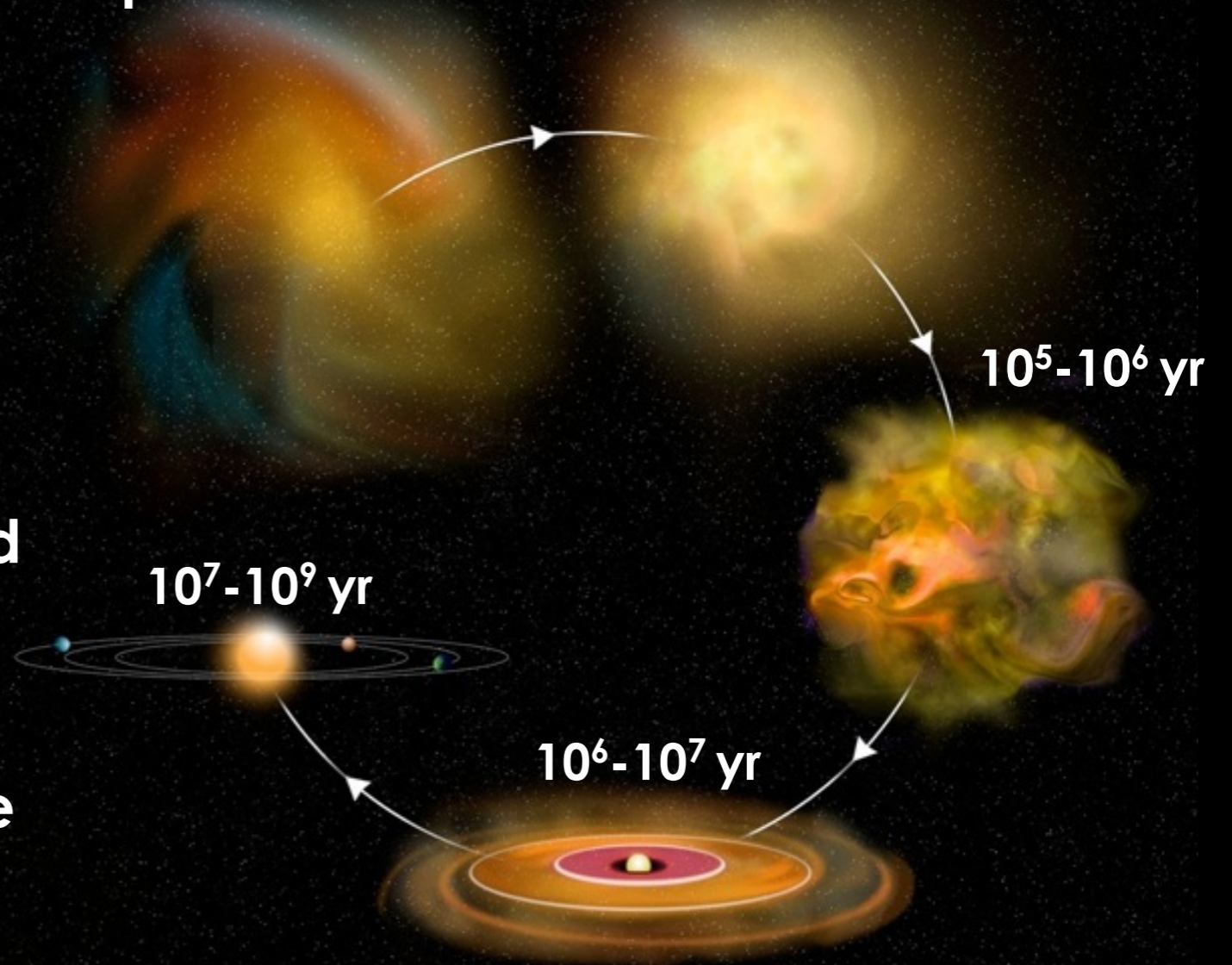
Image credit: National Geographic.

How are stars and planets are formed?

The gas in the protoplanetary disks dissipates in about 6 million years.

Giant planets can only form before this happens (they need the gas for their atmospheres).

Terrestrial planets can continue forming after.



After about 10 million years all the gas and dust from the protoplanetary disk should be all gone



- **Grains collide with each other and break into small particles that are pushed by the light (radiation pressure).**
- **Grains spiral into the star and get ejected when they cross the orbit of a large planet or sublimate as they get too close to the star.**

**But there is evidence of dust around stars
much older than 10 million years!!**

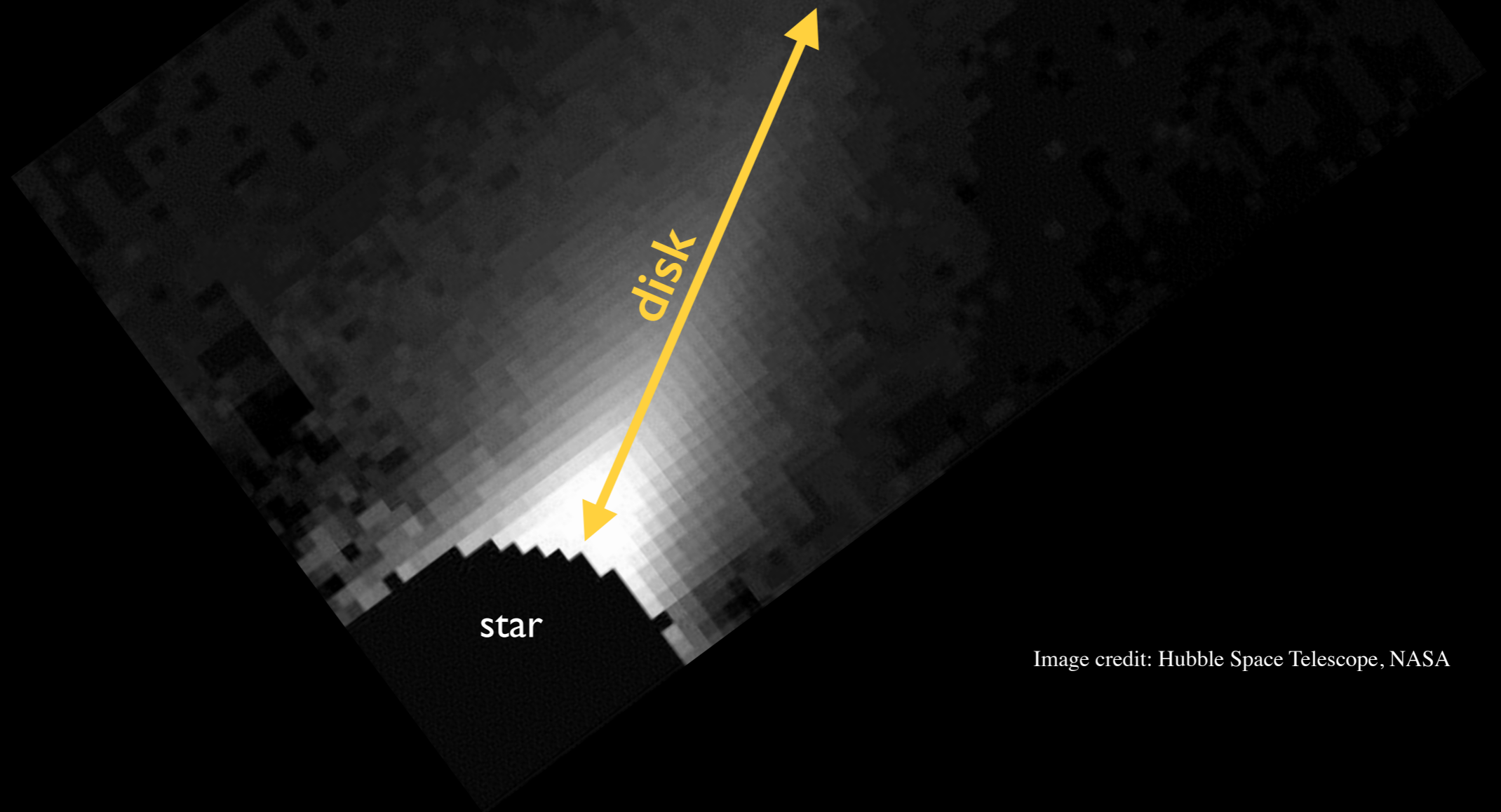


Image credit: Hubble Space Telescope, NASA

**But there is evidence of dust around stars
much older than 10 million years!!**

**This dust cannot be
primordial (coming
from the protoplanetary
disk), but is evidence of
on-going dust
production.**

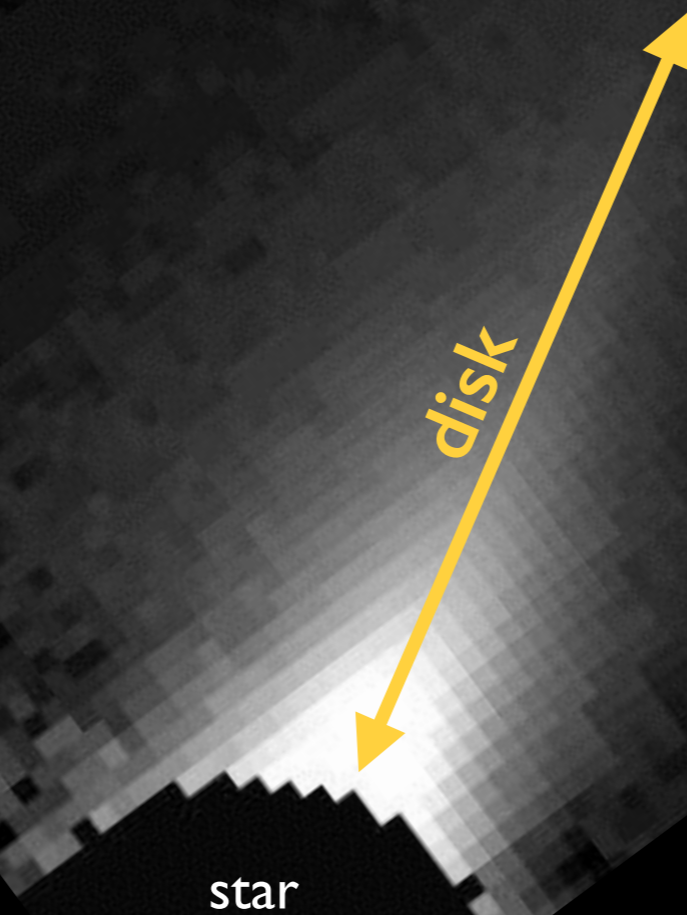


Image credit: Hubble Space Telescope, NASA

**But there is evidence of dust around stars
much older than 10 million years!!**

**This dust is likely
generated from the
collision and sublimation
of planetesimals.**

We call this debris dust.

star

disk

Image credit: Hubble Space Telescope, NASA

The planetesimals producing the debris disks are similar to the asteroids, comets and Kuiper belt objects in our Solar system

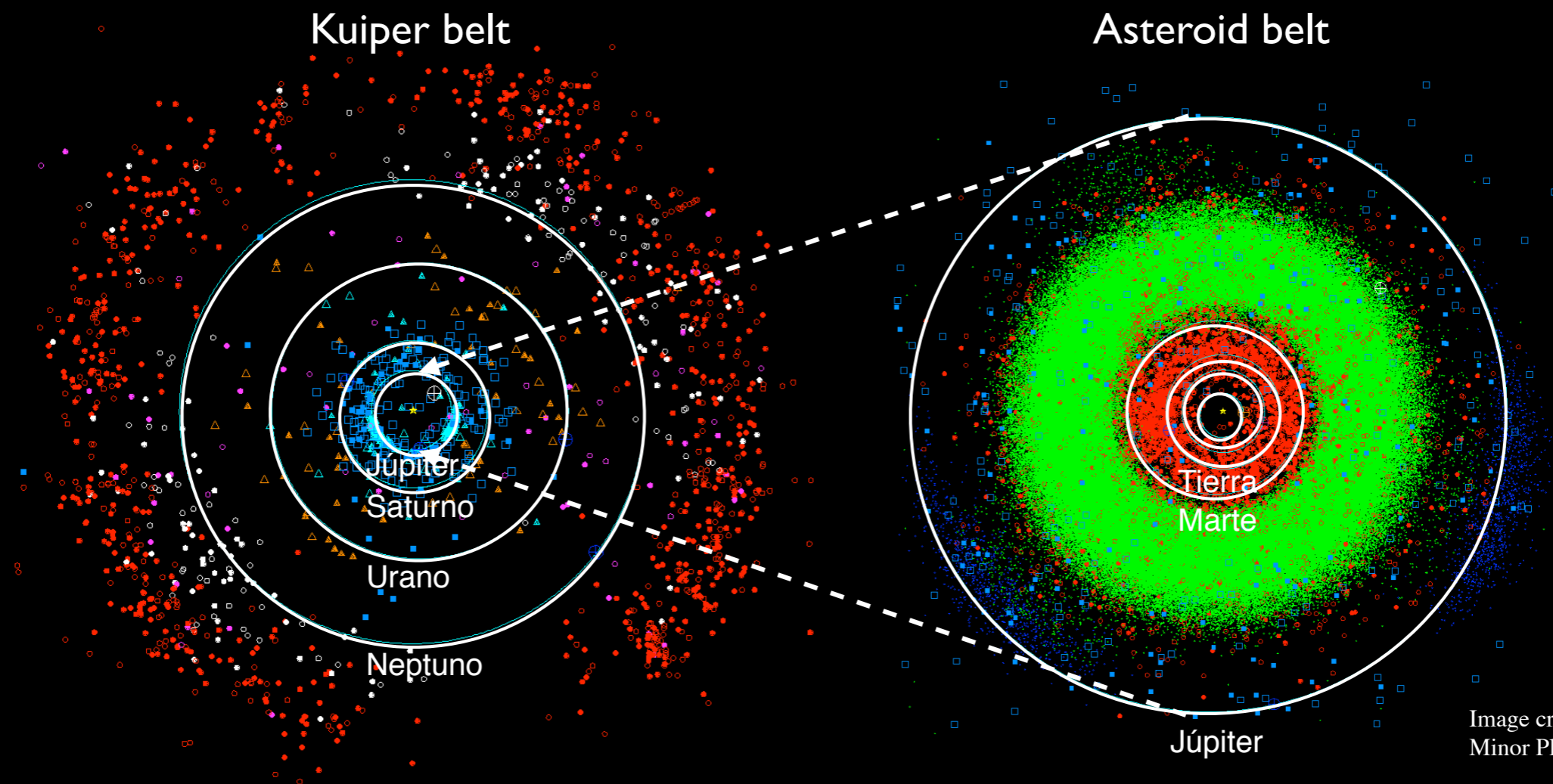
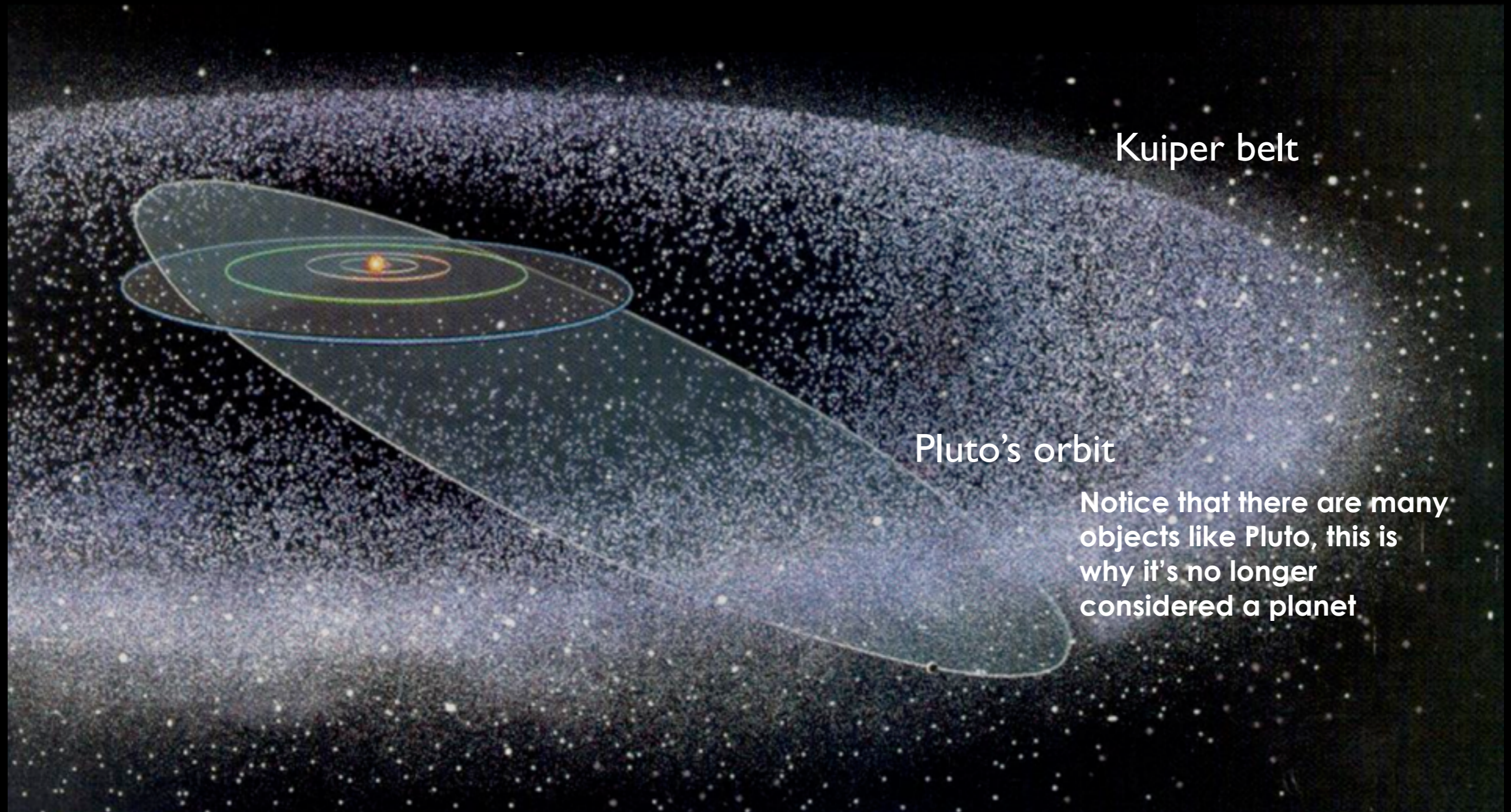


Image credit: G. Williams, Minor Planet Center.

There is dust production in the outer Solar system



Kuiper belt

Pluto's orbit

Notice that there are many objects like Pluto, this is why it's no longer considered a planet

**And there is dust production in the inner Solar system
(this is not a comet, it is Asteroid P/2010)**



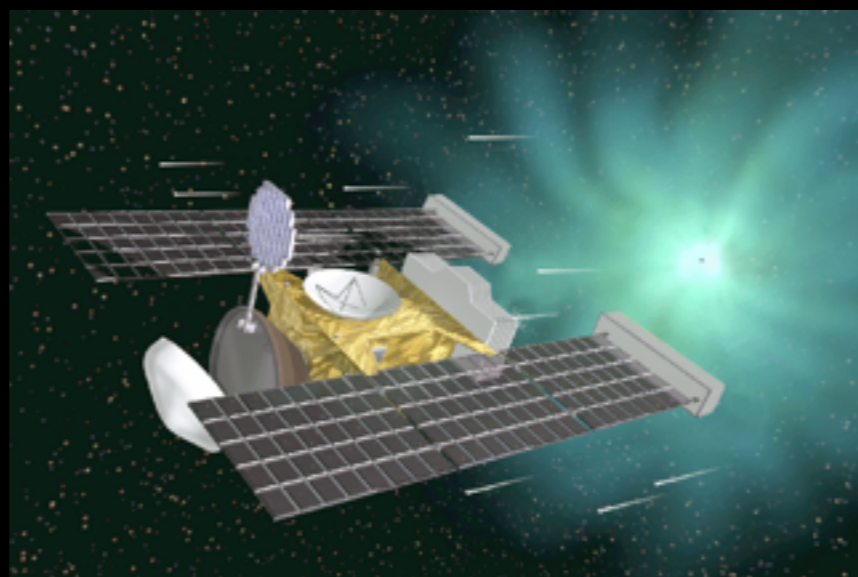
Image credit: Jewitt et al.,
Hubble Space Telescope.

Solar system dust particles can be captured and analyzed in the lab

...the aerogel is then returned to the lab...

...using spacecraft or high-flying planes...

They are captured very gently using aerogel...



...where the dust is extracted from the aerogel

Image credits: NASA

Dust particle from our Solar system captured in the upper atmosphere

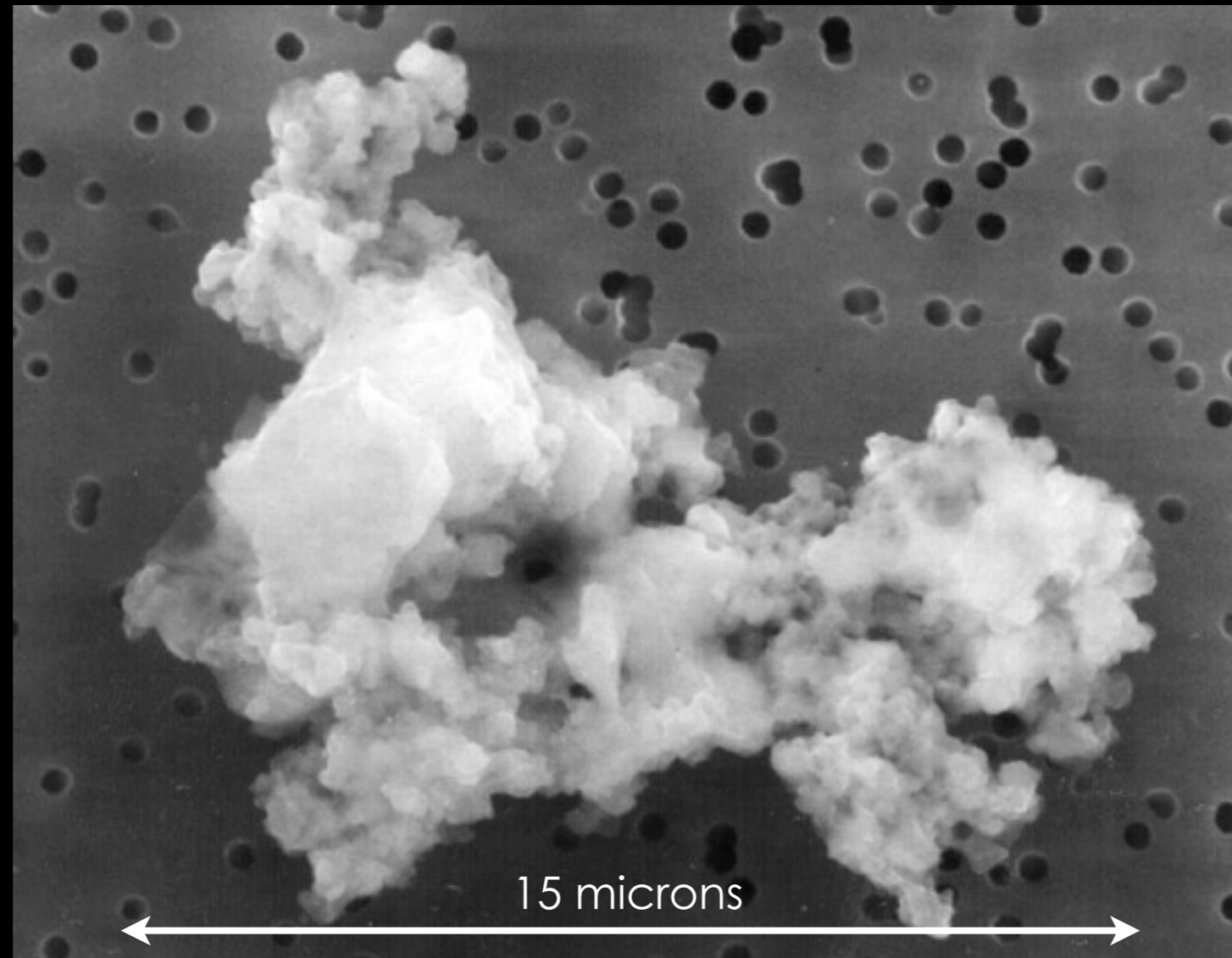


Image credit: Brownlee et al. NASA.

The dust in the Solar system also forms a debris disk

It can be seen with the naked eye near sunset or sunrise if we are away from light pollution (it's the zodiacal light)



A night sky filled with stars and a zodiacal light arc, with a birdhouse in a field in the foreground.

The dust in the Solar system also forms a debris disk

**We see it because
the dust particles
disperse the light
from the sun.**

At least 20% of all stars harbor debris disks.

This means that at least 20% of stars are surrounded by dust-producing planetesimals.

This is interesting because planetesimals are the building blocks of planets.

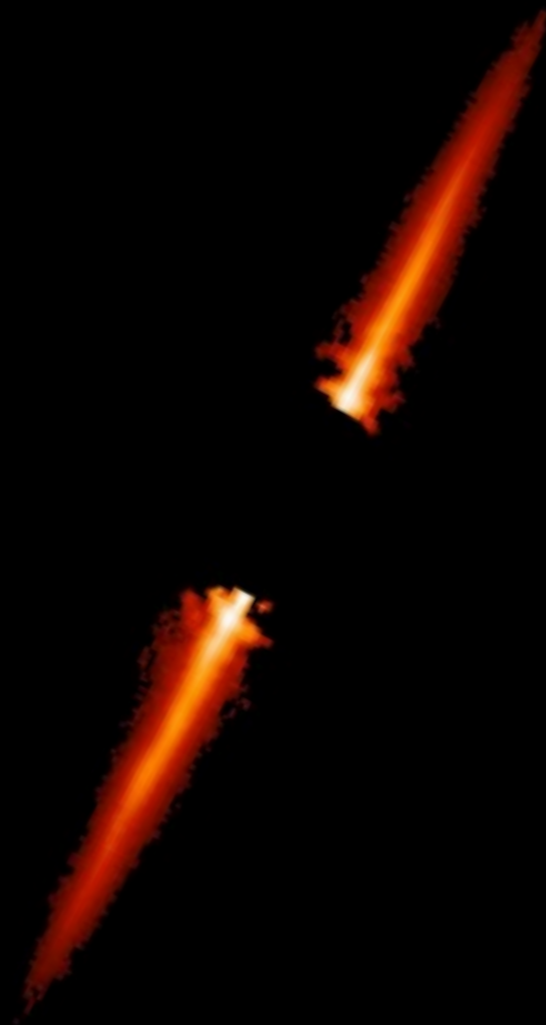
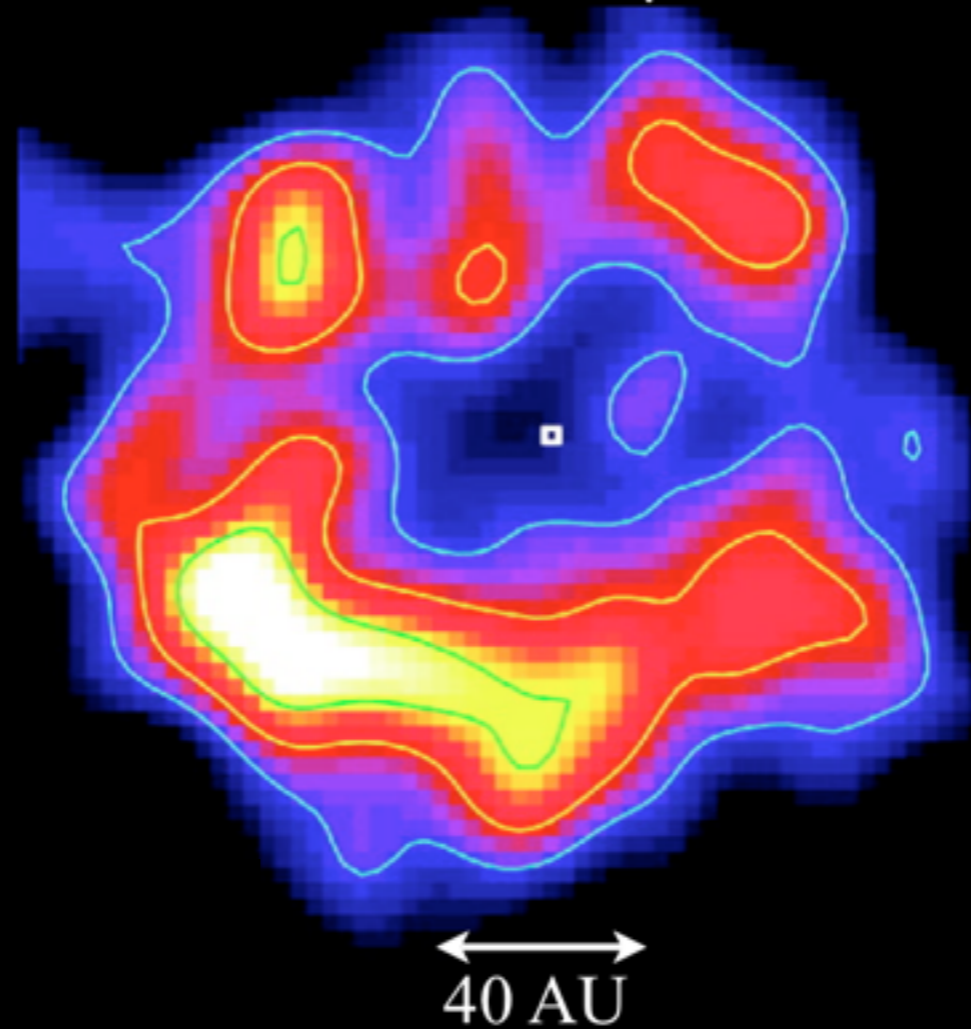


Image credit: Hubble Space Telescope, NASA

Debris disks can have very complex spatial features

ϵ -Eri 850 μm

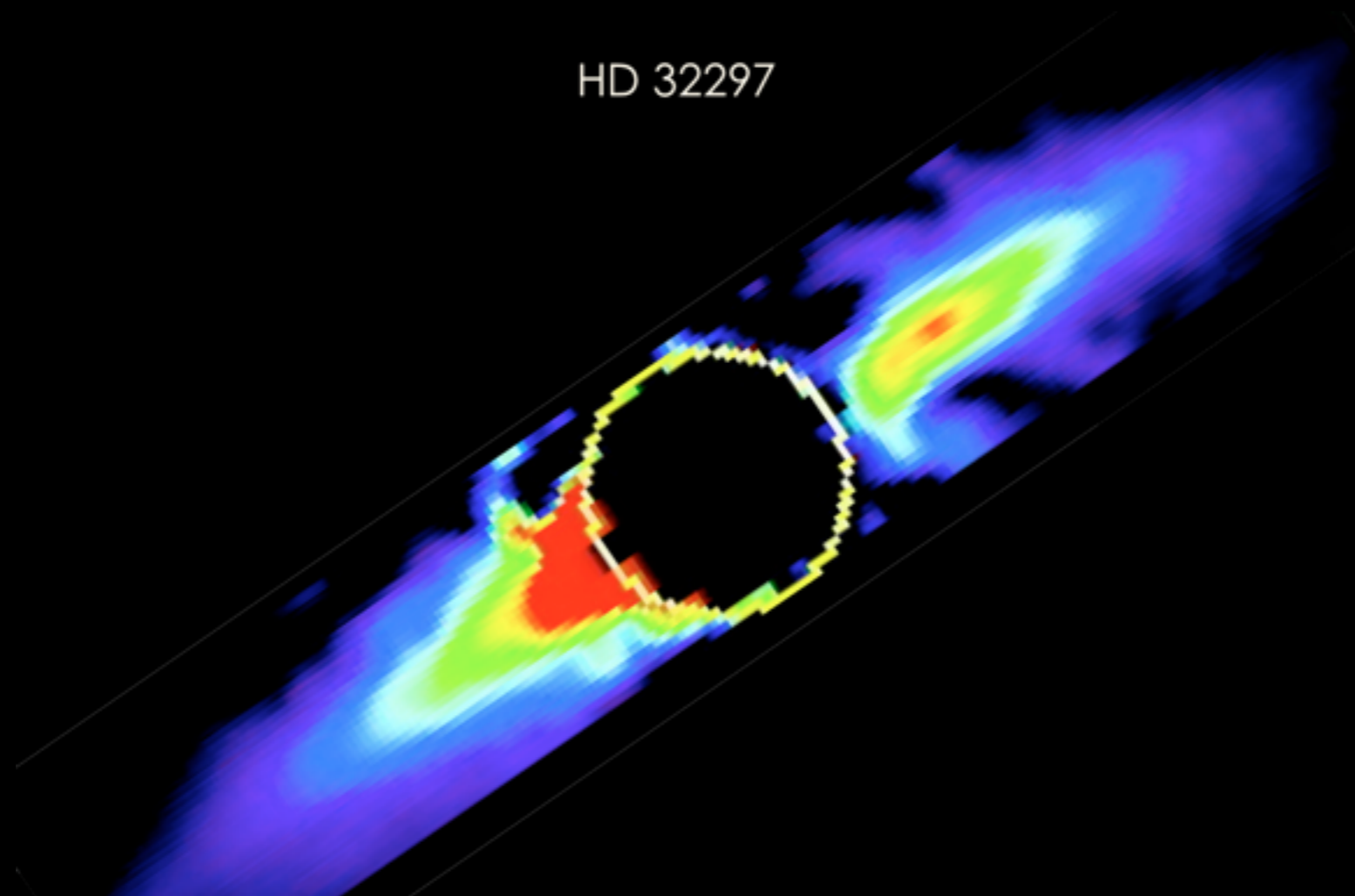


Irregular rings
Off-centered disks

Image credit: Hubble Space Telescope, NASA

Debris disks can have very complex spatial features

HD 32297



Brightness asymmetries

Image credit: Hubble Space Telescope, NASA

Debris disks can have very complex spatial features

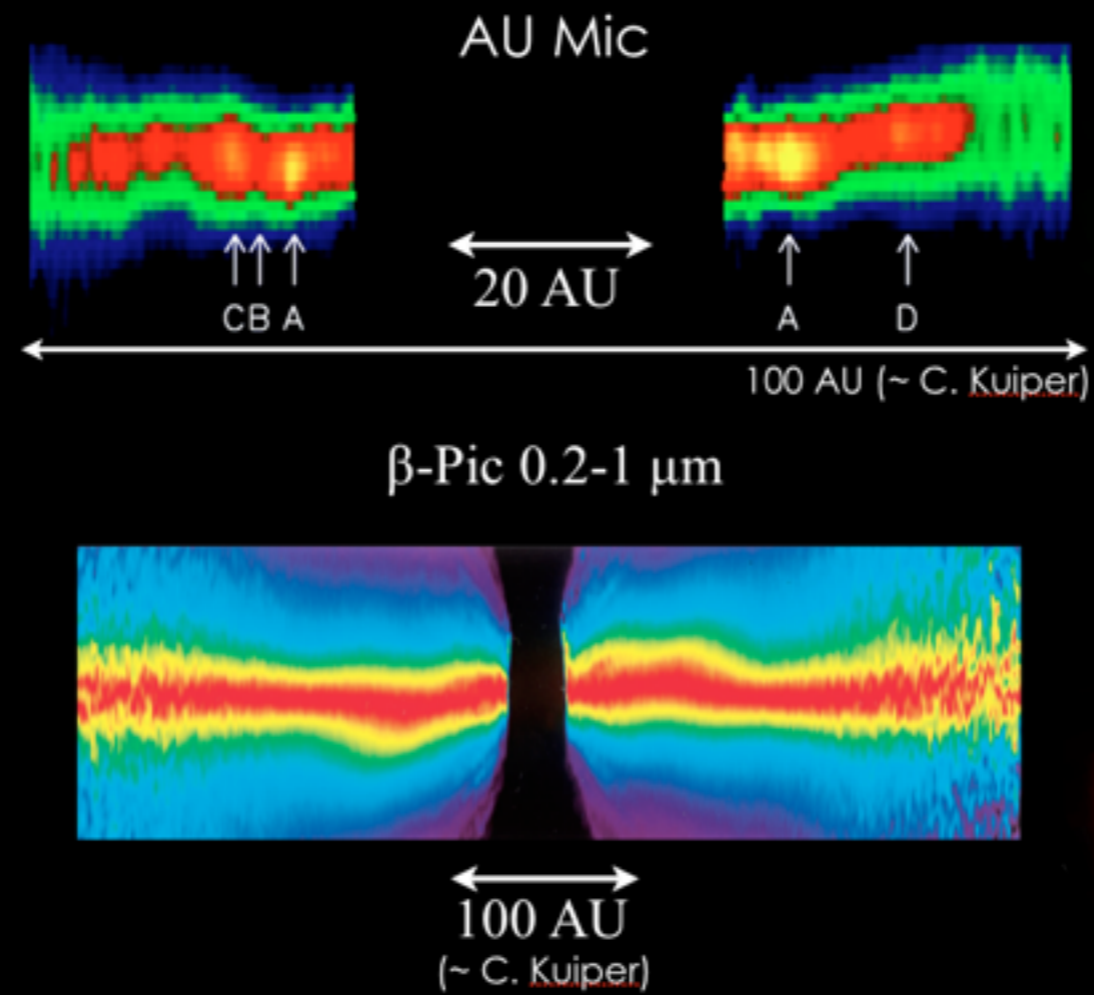
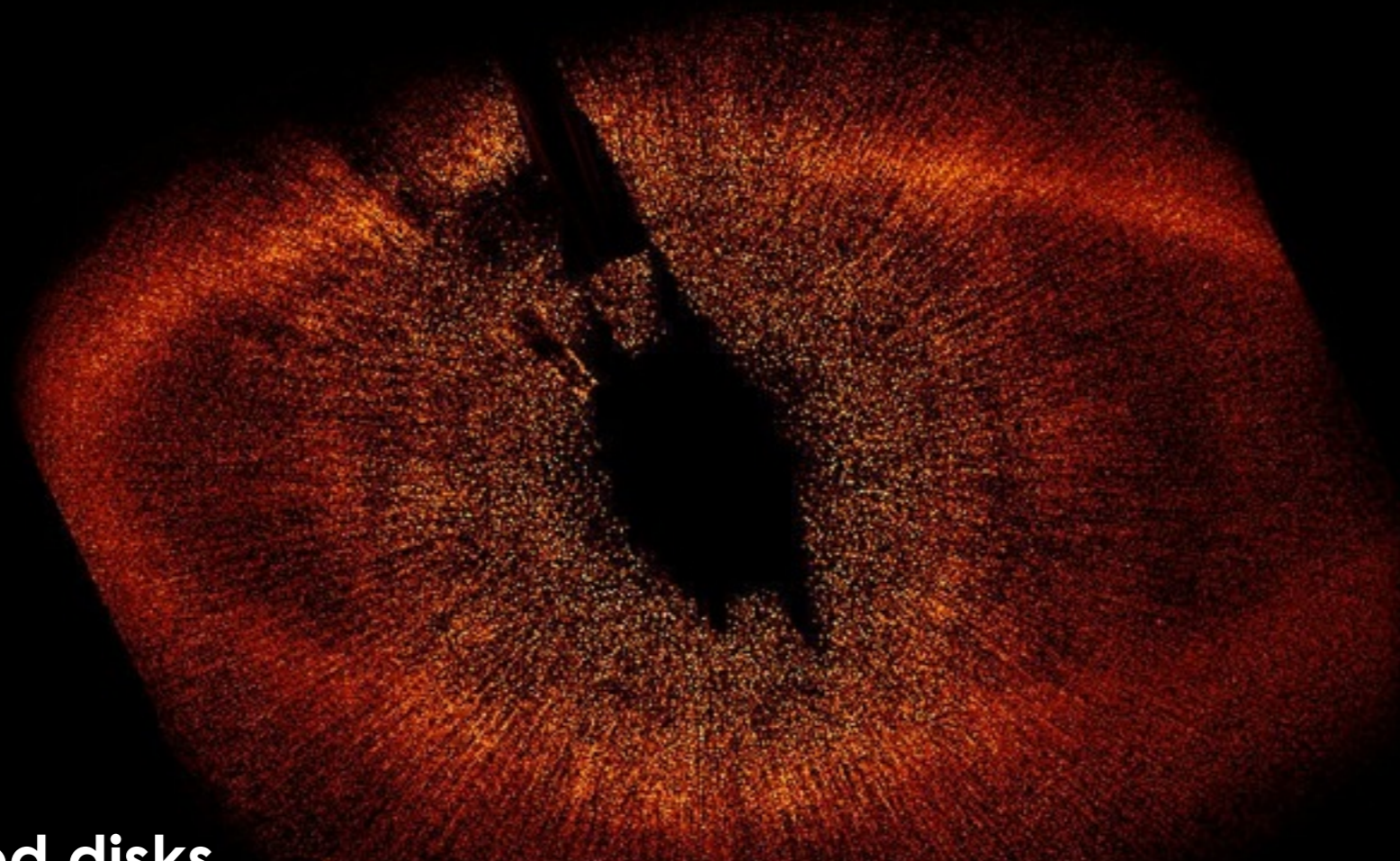


Image credit: Hubble Space Telescope, NASA

Debris disks can have very complex spatial features

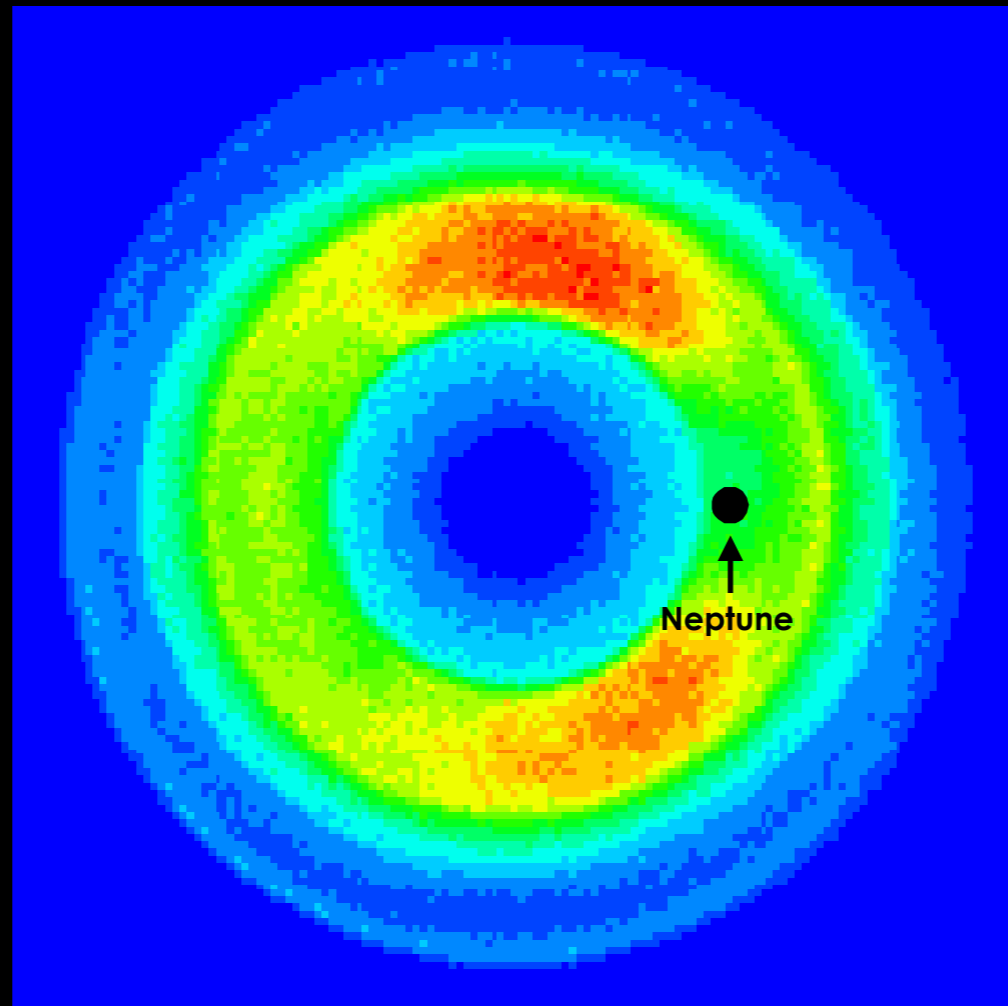


Off-centered disks
Sharp inner cavities

←→
50 AU

Image credit: Hubble Space Telescope, NASA

Debris disks can have very complex spatial features



Irregular
rings
Brightness
asymmetries

Model of the
Kuiper Belt

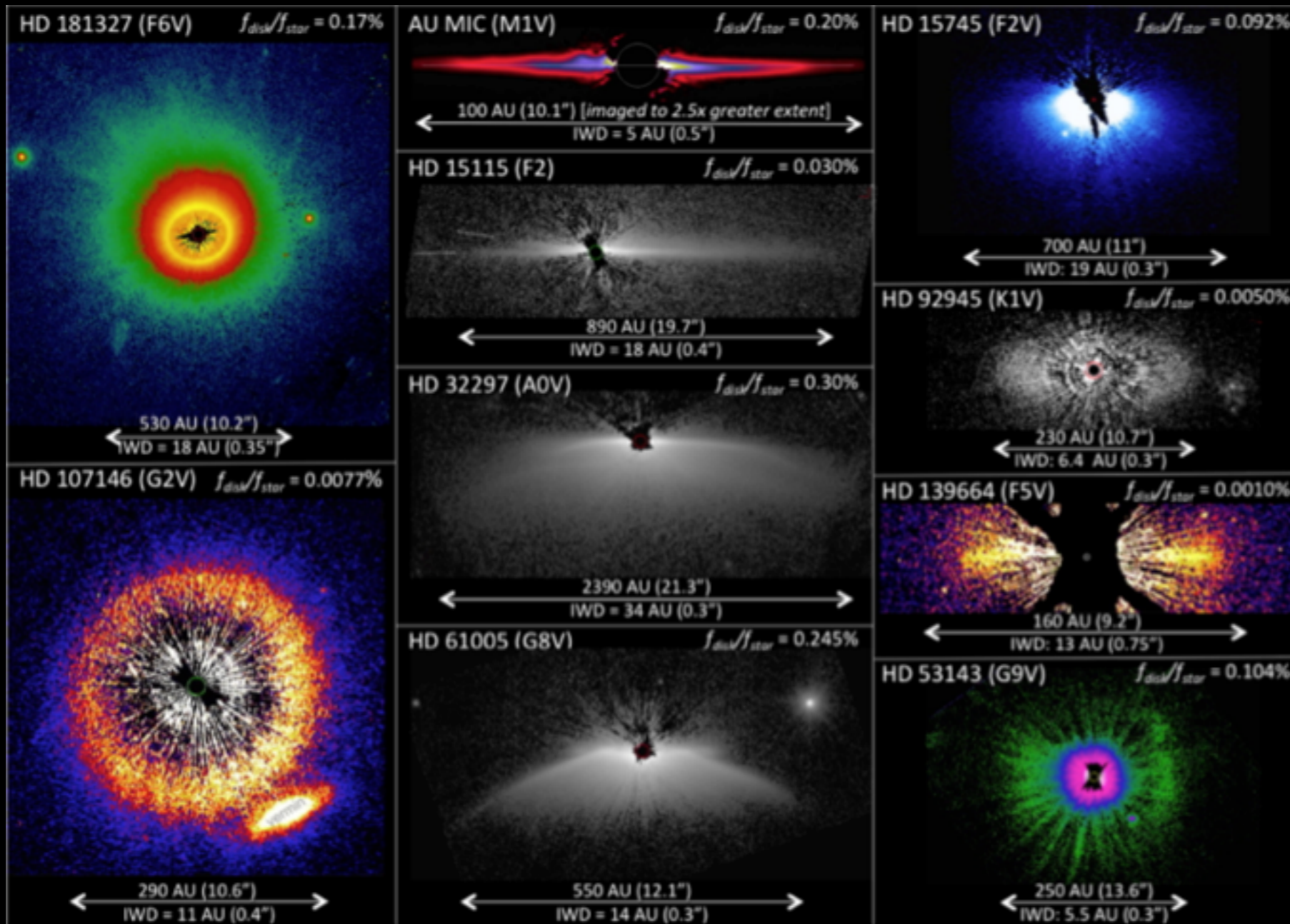



Image credit: Hubble
Space Telescope,
NASA

A 3D rendering of a protoplanetary disk system. In the center, a bright yellow star is surrounded by a glowing, multi-layered disk of gas and dust. The disk shows concentric rings of varying colors, from yellow to green. In the foreground, a large gas giant planet with brown and white bands is visible. To the right, a debris disk contains several rocky bodies of various sizes, some with bright spots indicating collisions or impacts. The background is a dark space filled with distant stars.

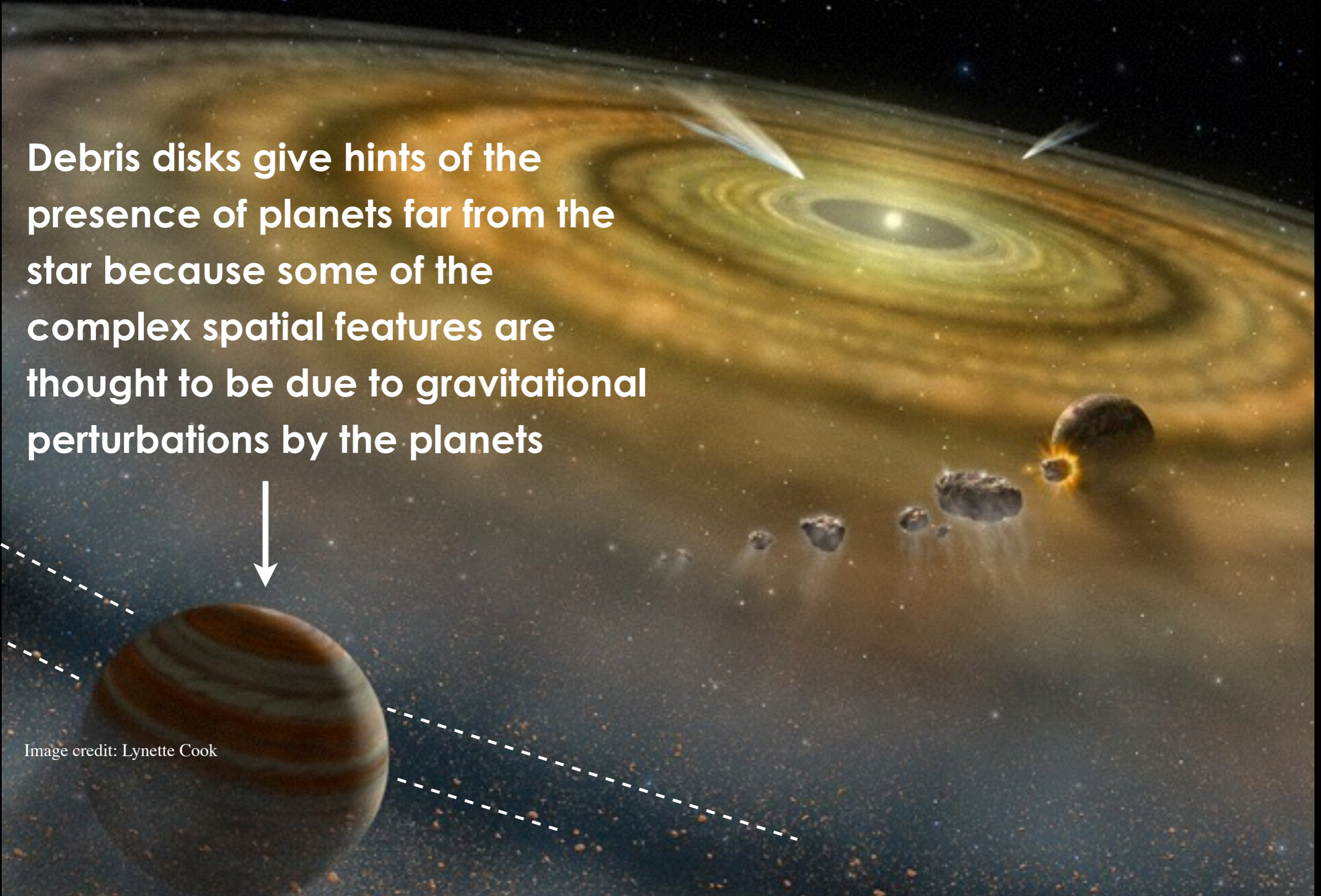
**Debris disks can help us place
our Solar system into context**

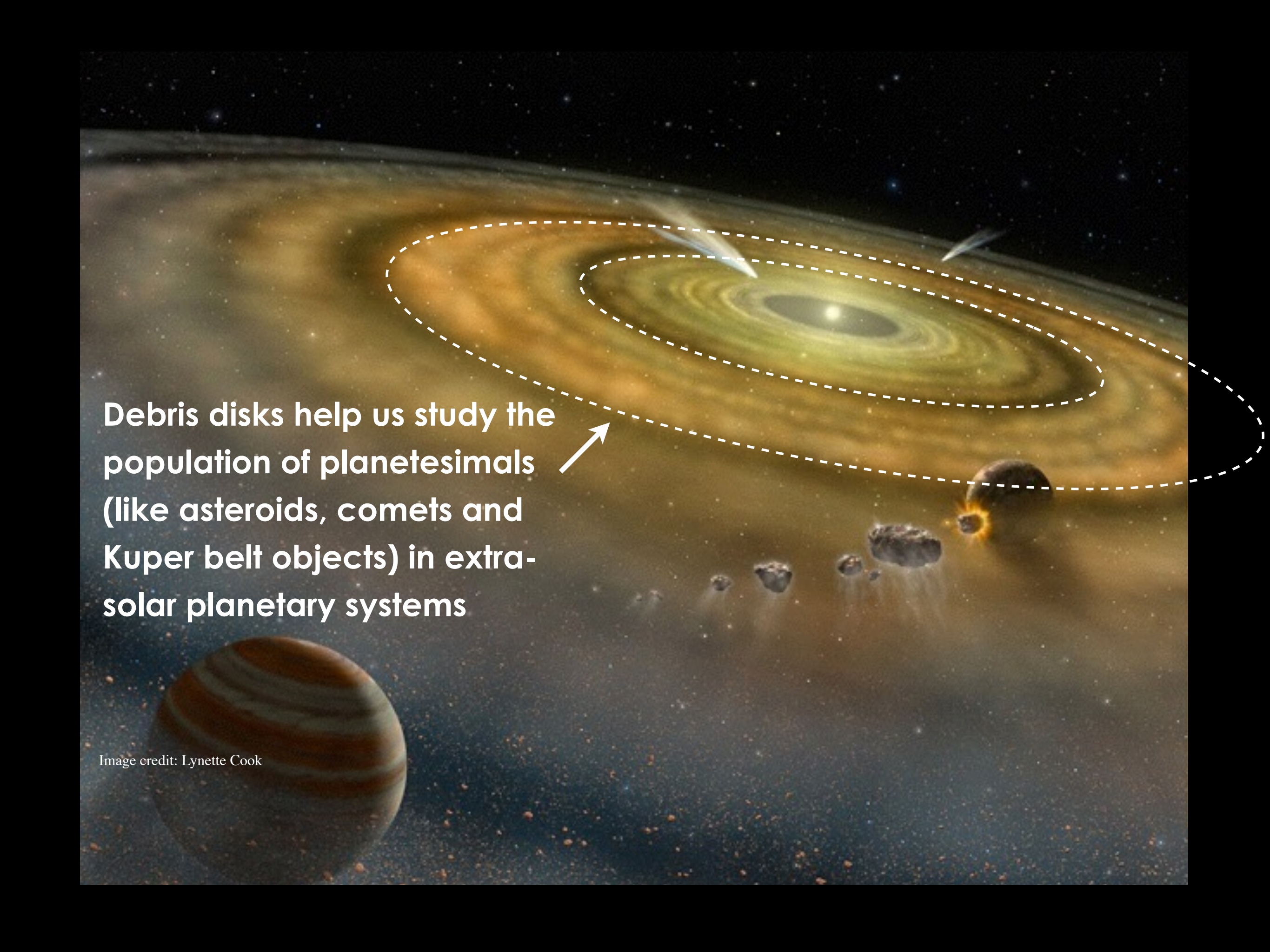
Image credit: Lynette Cook

Debris disks give hints of the presence of planets far from the star because some of the complex spatial features are thought to be due to gravitational perturbations by the planets



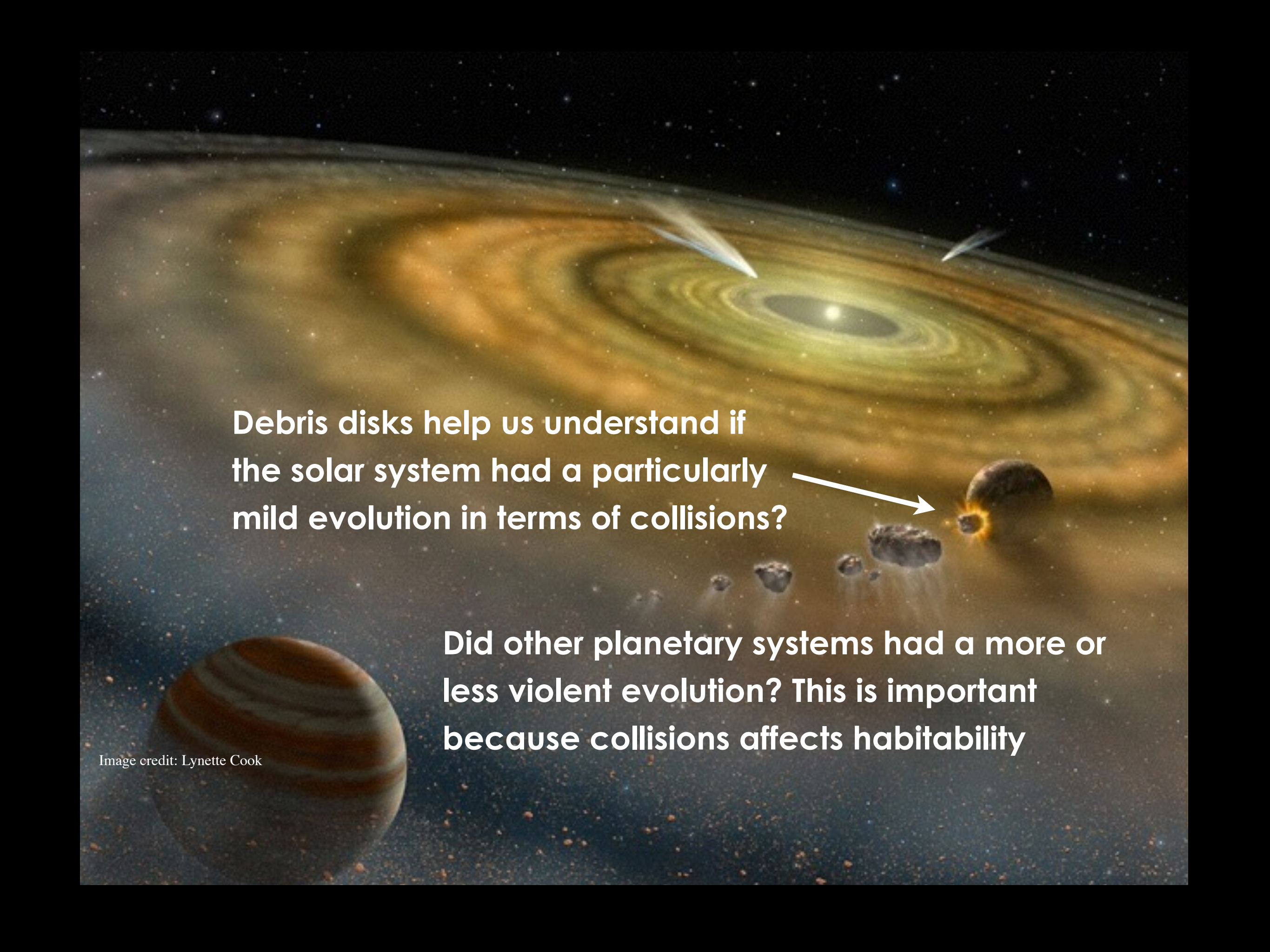
Image credit: Lynette Cook





Debris disks help us study the population of planetesimals (like asteroids, comets and Kuper belt objects) in extra-solar planetary systems

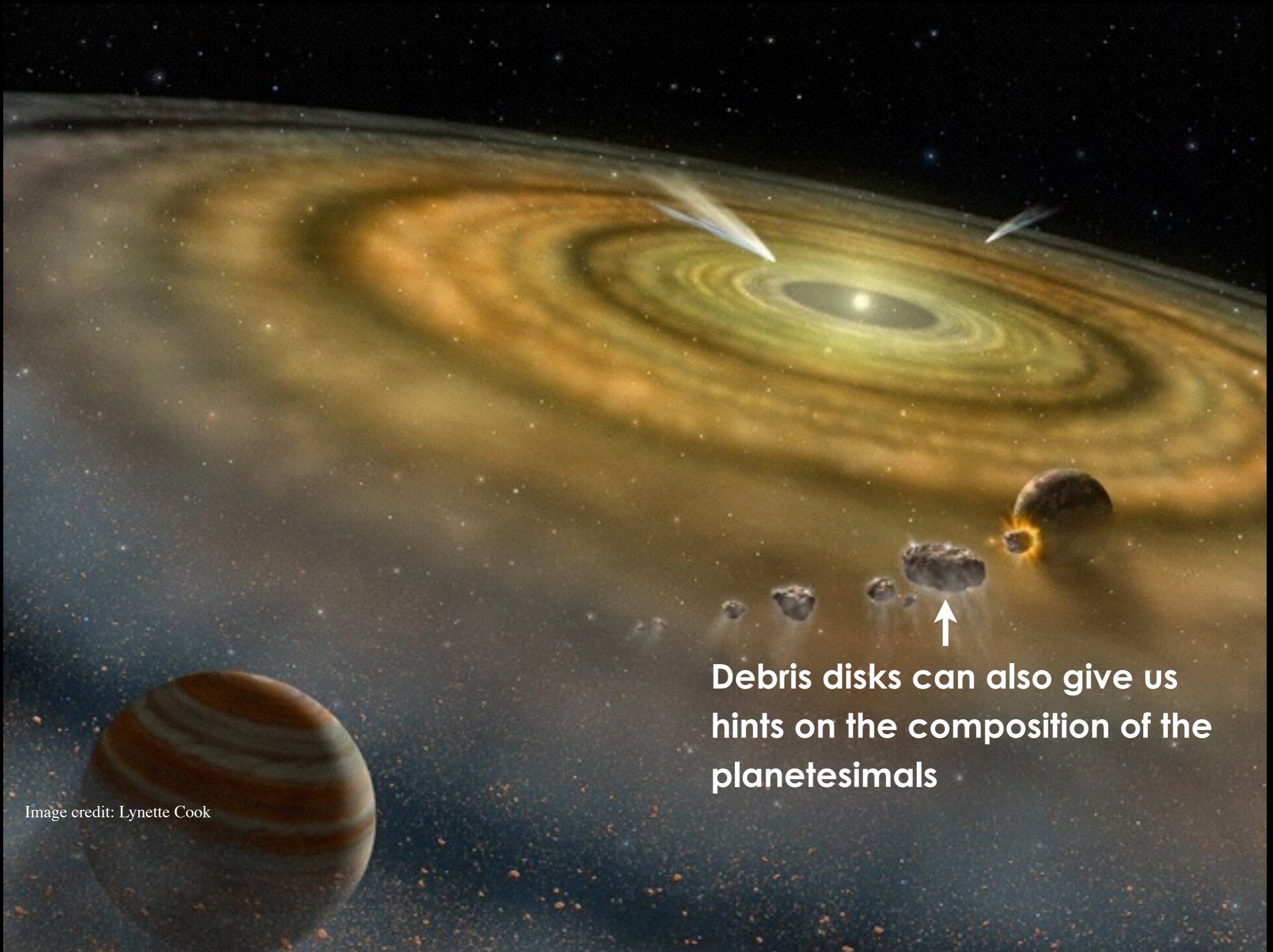
Image credit: Lynette Cook

A 3D rendering of a protoplanetary disk. The central star is a bright yellow-white point source. The disk is a flat, rotating disk of gas and dust, showing concentric rings of varying colors from blue to red. In the foreground, a large gas giant planet with brown and white bands is visible. In the mid-ground, two rocky bodies are colliding, with a bright orange glow at the point of impact. A white arrow points from the text to this collision site.

Debris disks help us understand if the solar system had a particularly mild evolution in terms of collisions?

Did other planetary systems had a more or less violent evolution? This is important because collisions affects habitability

Image credit: Lynette Cook



Debris disks can also give us hints on the composition of the planetesimals

Image credit: Lynette Cook

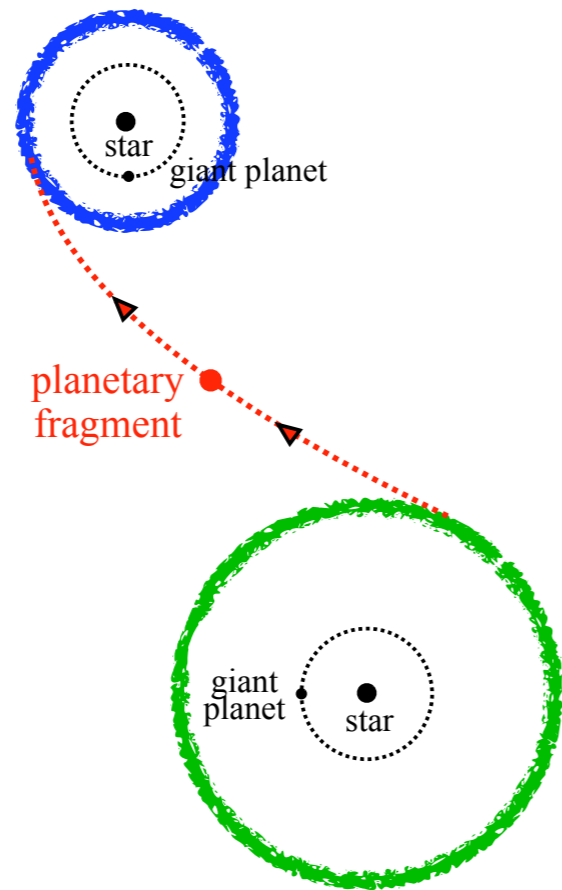
**Debris disks can shed light
on the frequency of
terrestrial planet formation
(because as planets form
they produce a lot of dust)**



Image credit: Lynette Cook

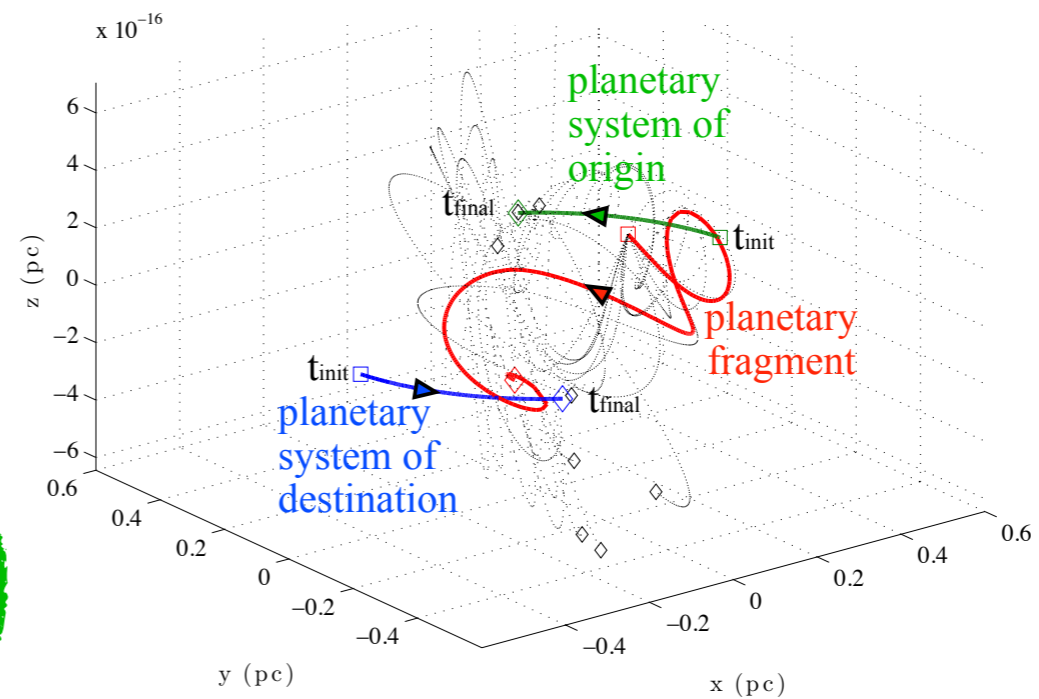
Debris dust and rocks can be exchanged between nearby planetary systems when they are young

planetary system of destination



planetary system of origin

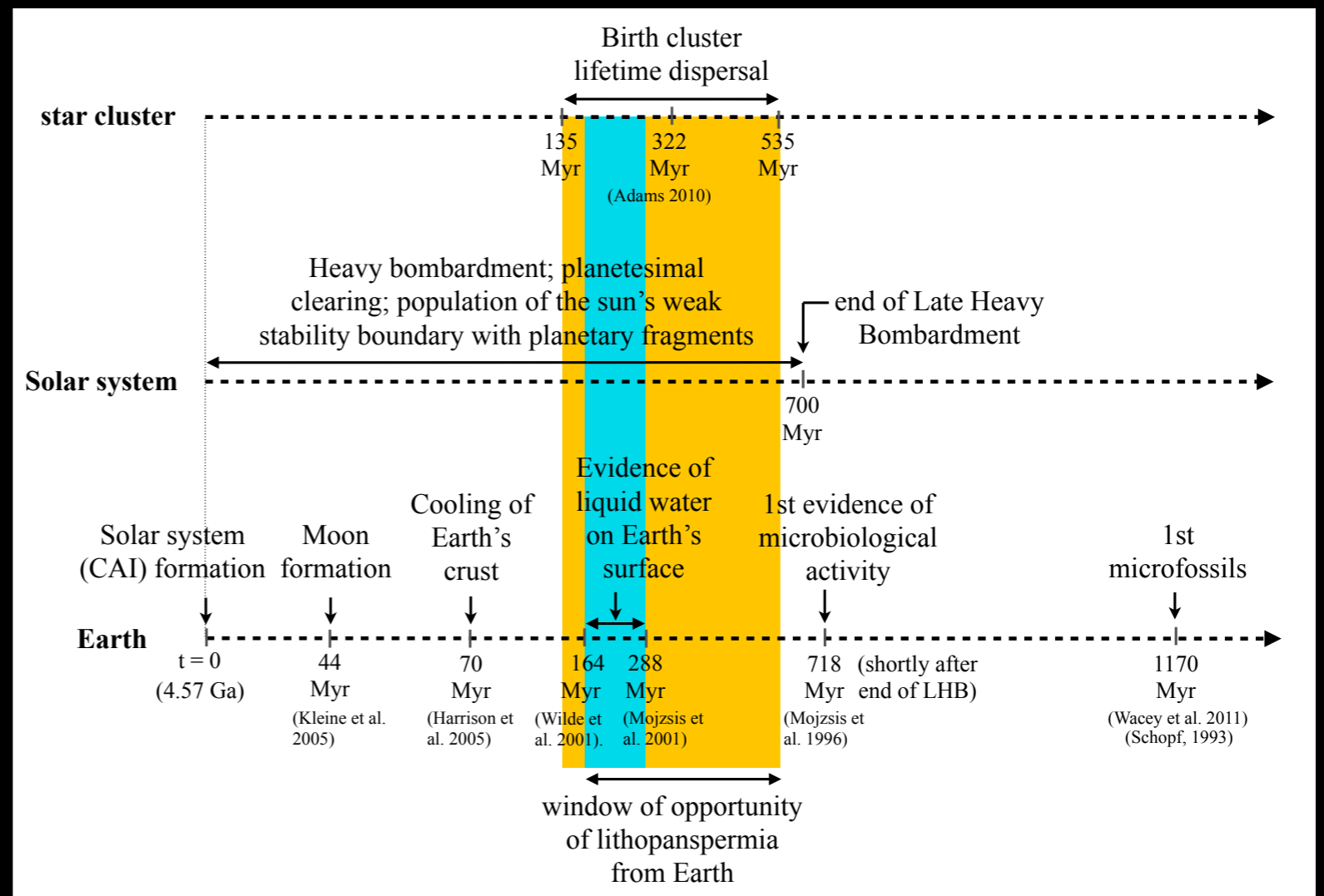
the exchange looks more like this
(following a chaotic orbit)



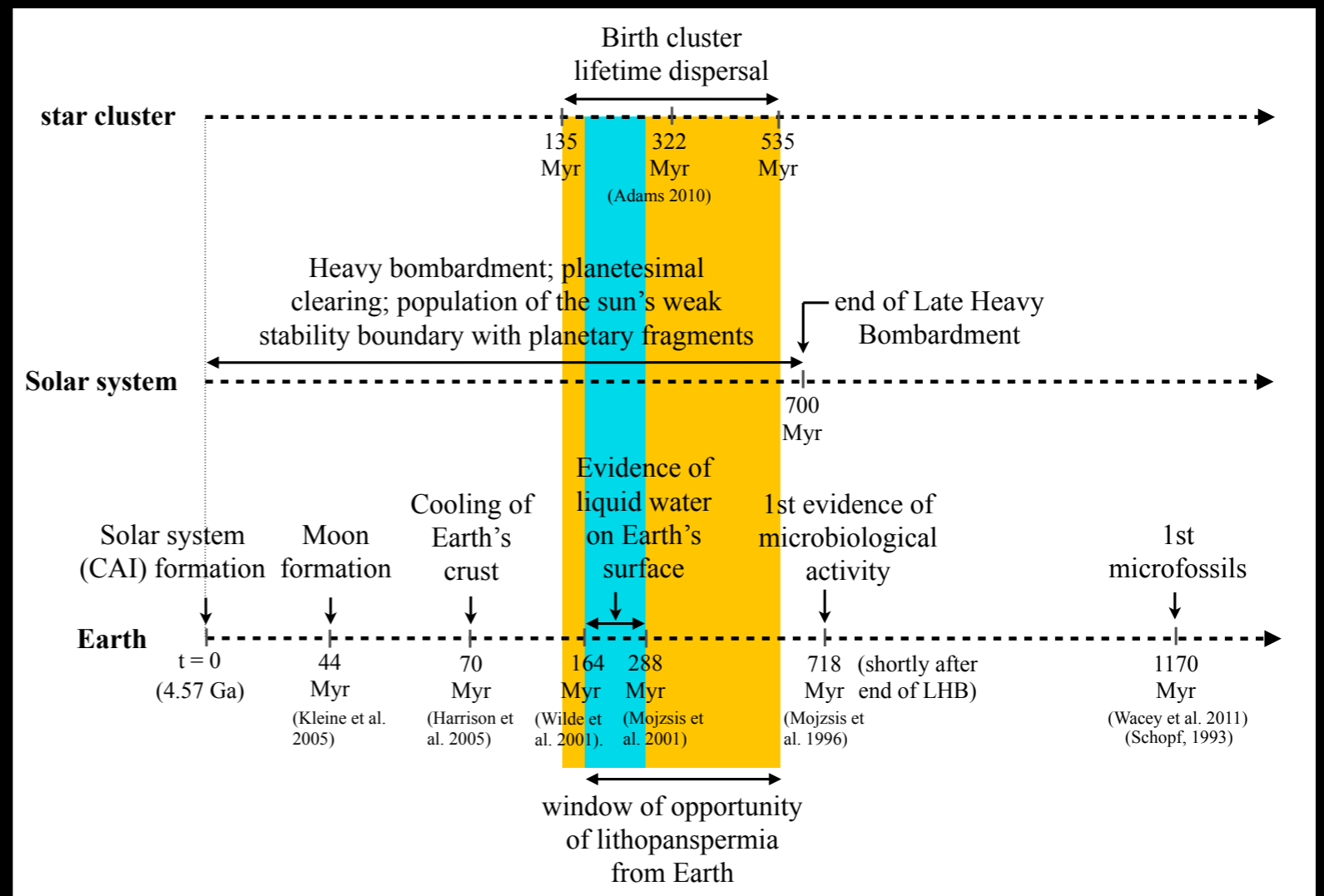
The exchange of rocks between planetary system may have contributed to the dispersal of life from one planetary system to another



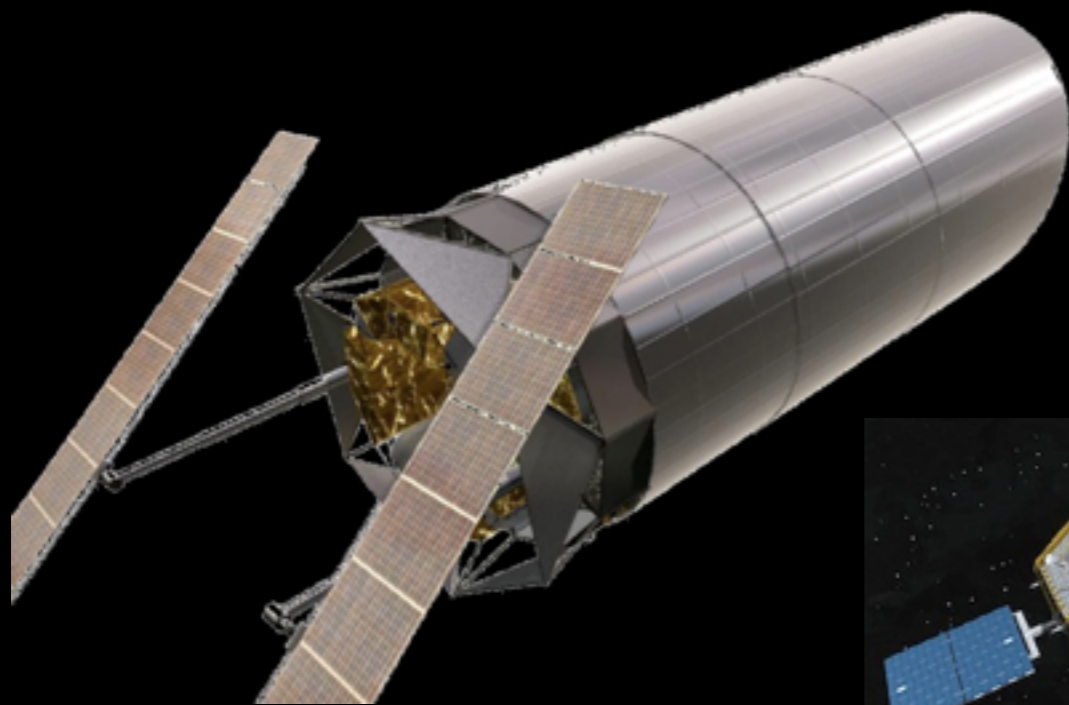
If life on Earth had an early start (shortly after liquid water was available), life could have been transferred to other systems



And vice versa. If life had a sufficiently early start in other planetary systems, it could have seeded the Earth



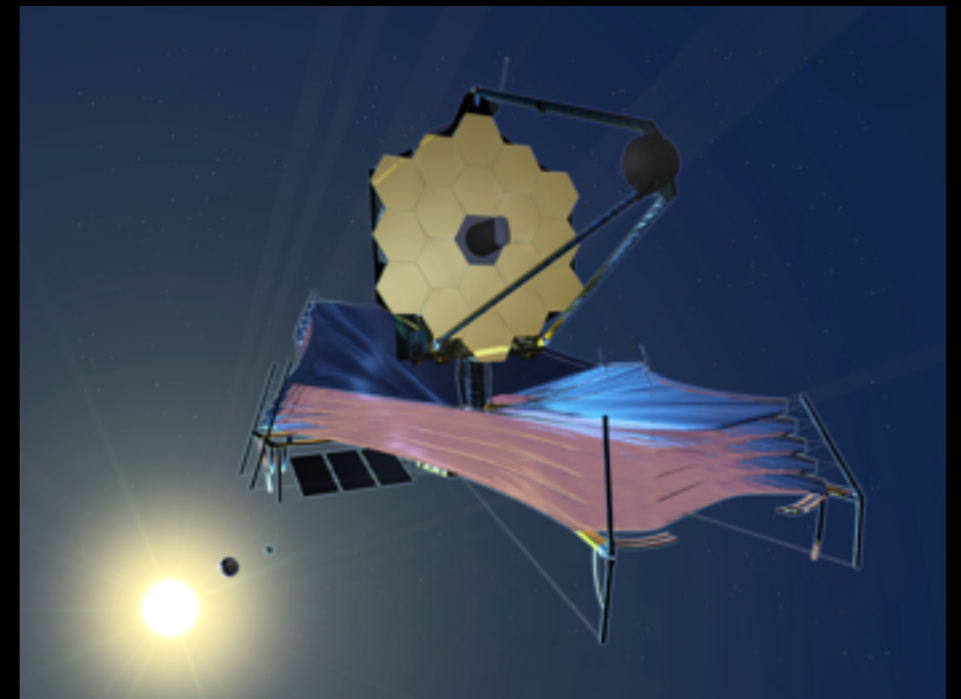
There could be many habitable planetary systems out there
and we will search for them



ATLAST
(2030?)



TESS
(2017)



JWST
(2017)

Image credit: NASA