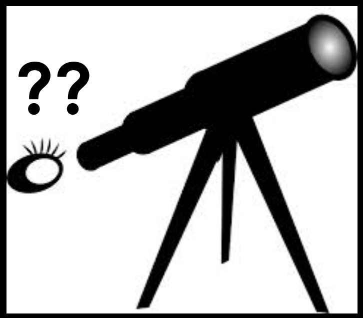
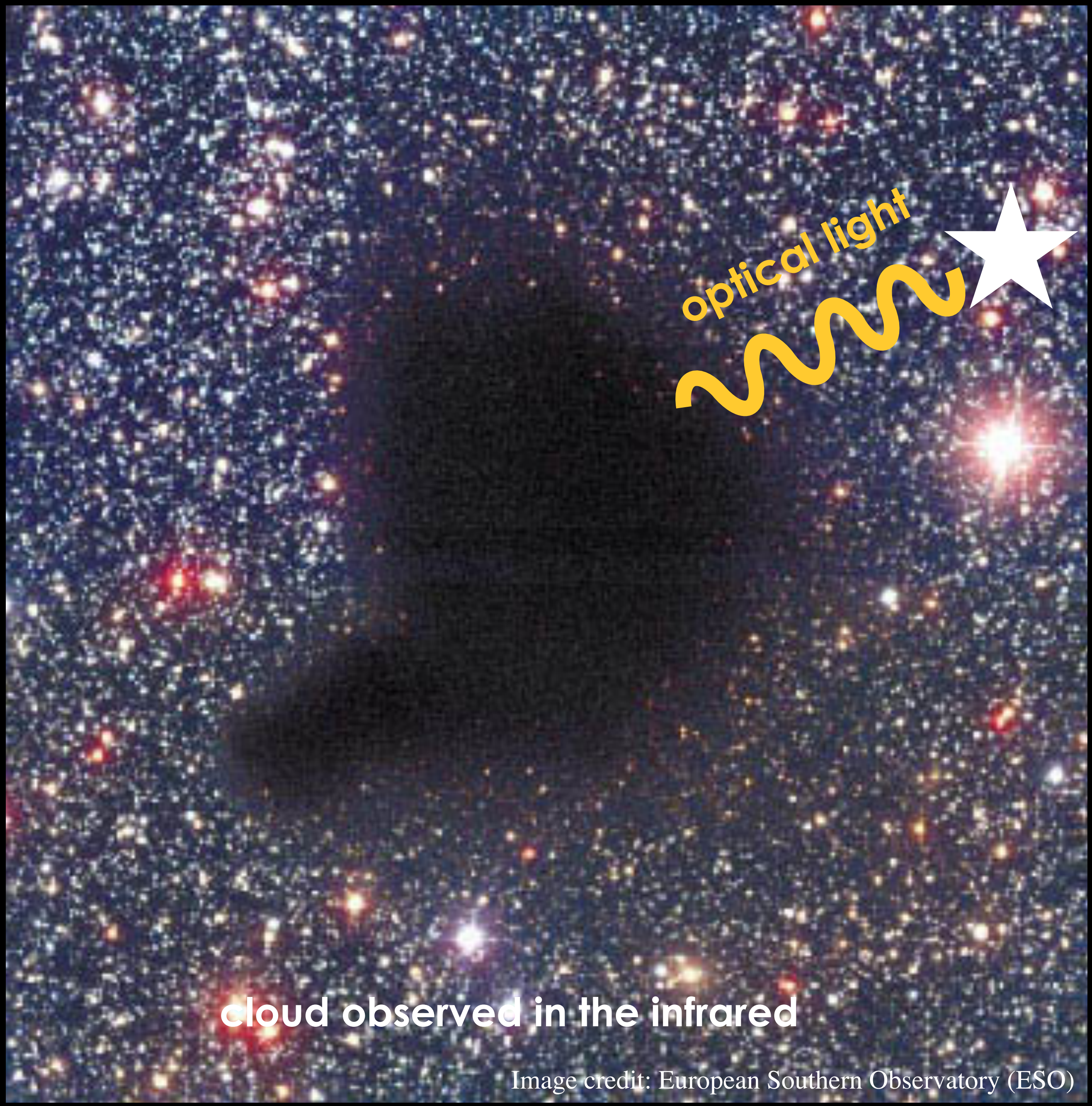
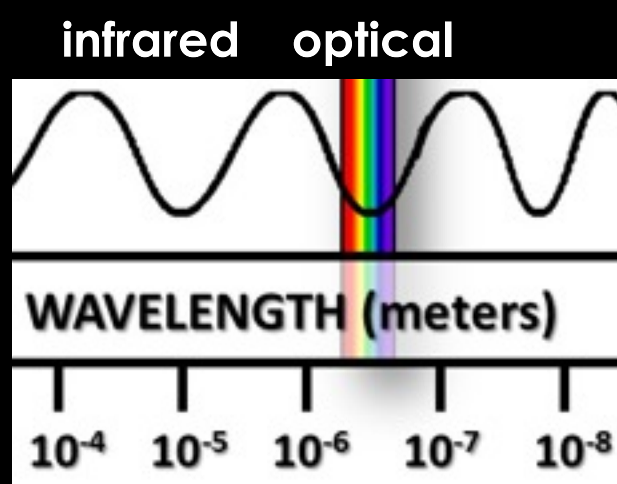
Stars form in molecular clouds composed of gas and dust in a 100:1 ratio

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

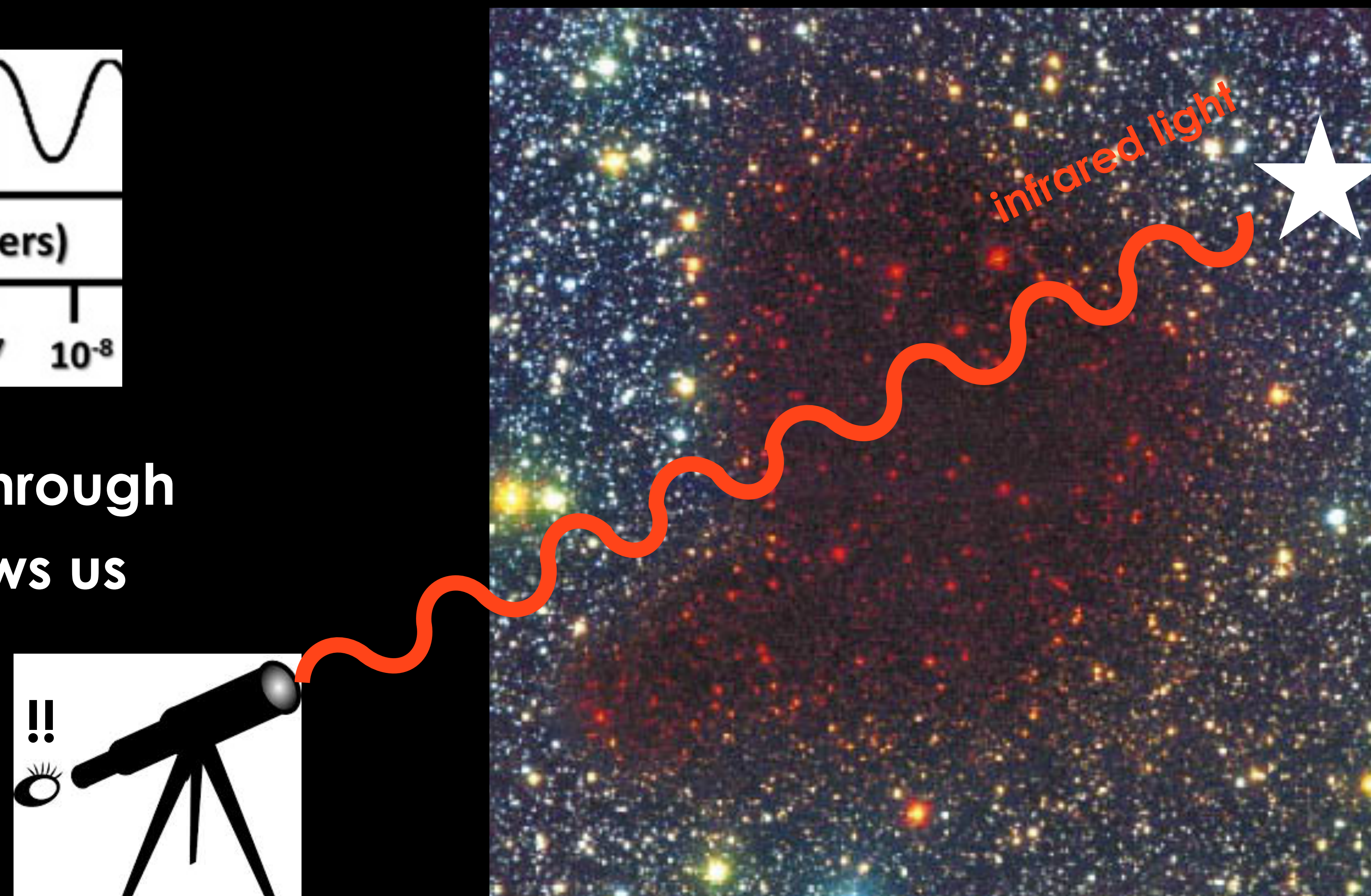
Optical light cannot get through the cloud so we don't know what's going on inside







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



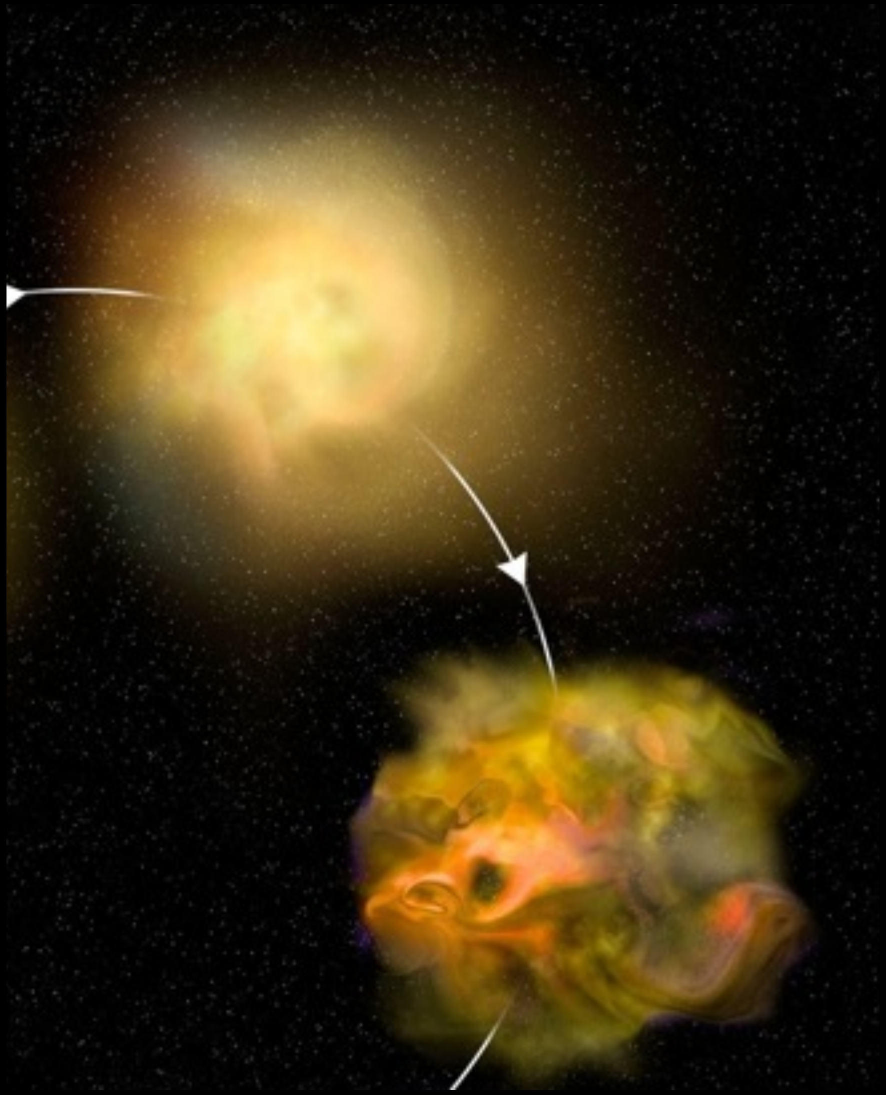
same cloud observed in the infrared

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

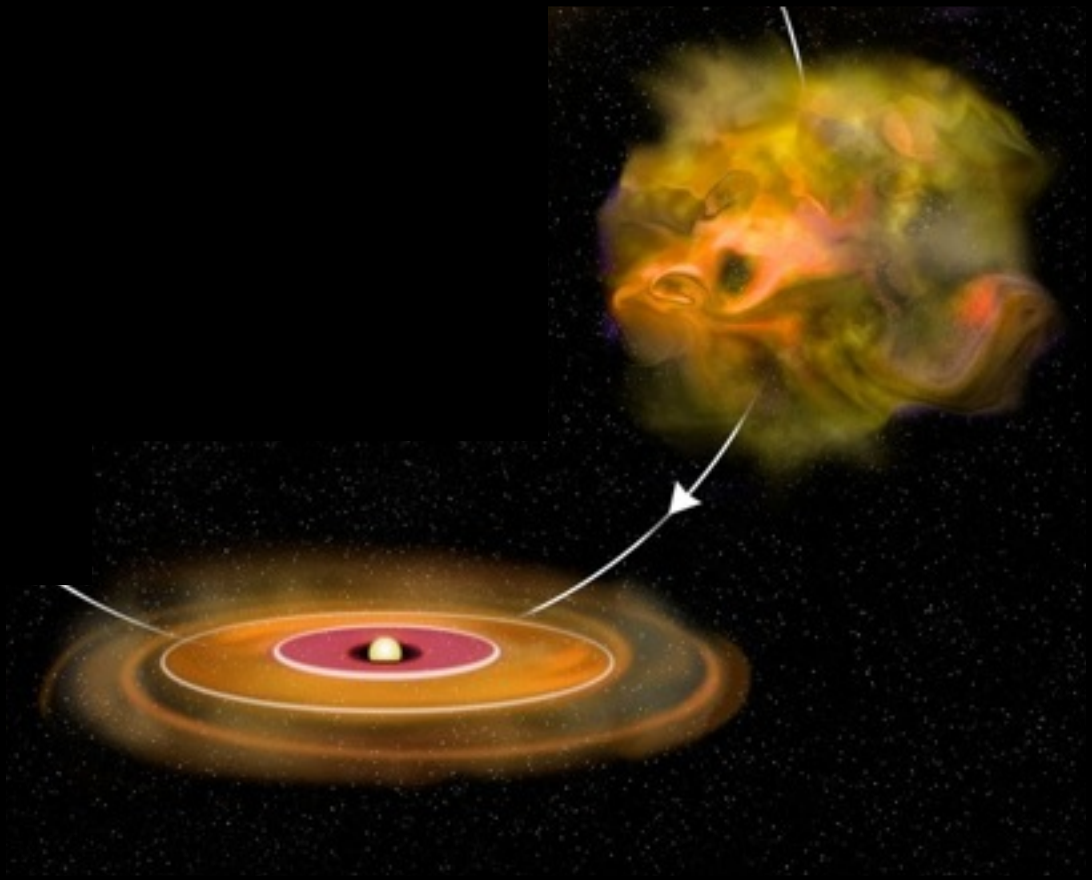
This forms a nascent star in the middle (a protostar)



How are stars and planets are formed?

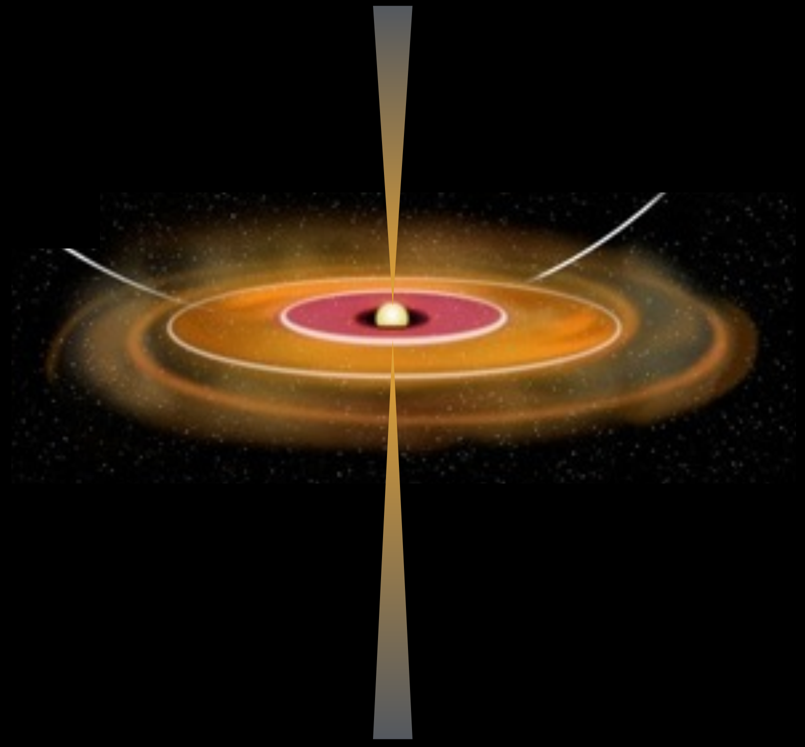
The protostar is surrounded by a slowly-rotating envelope of gas and dust (from the cloud).

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

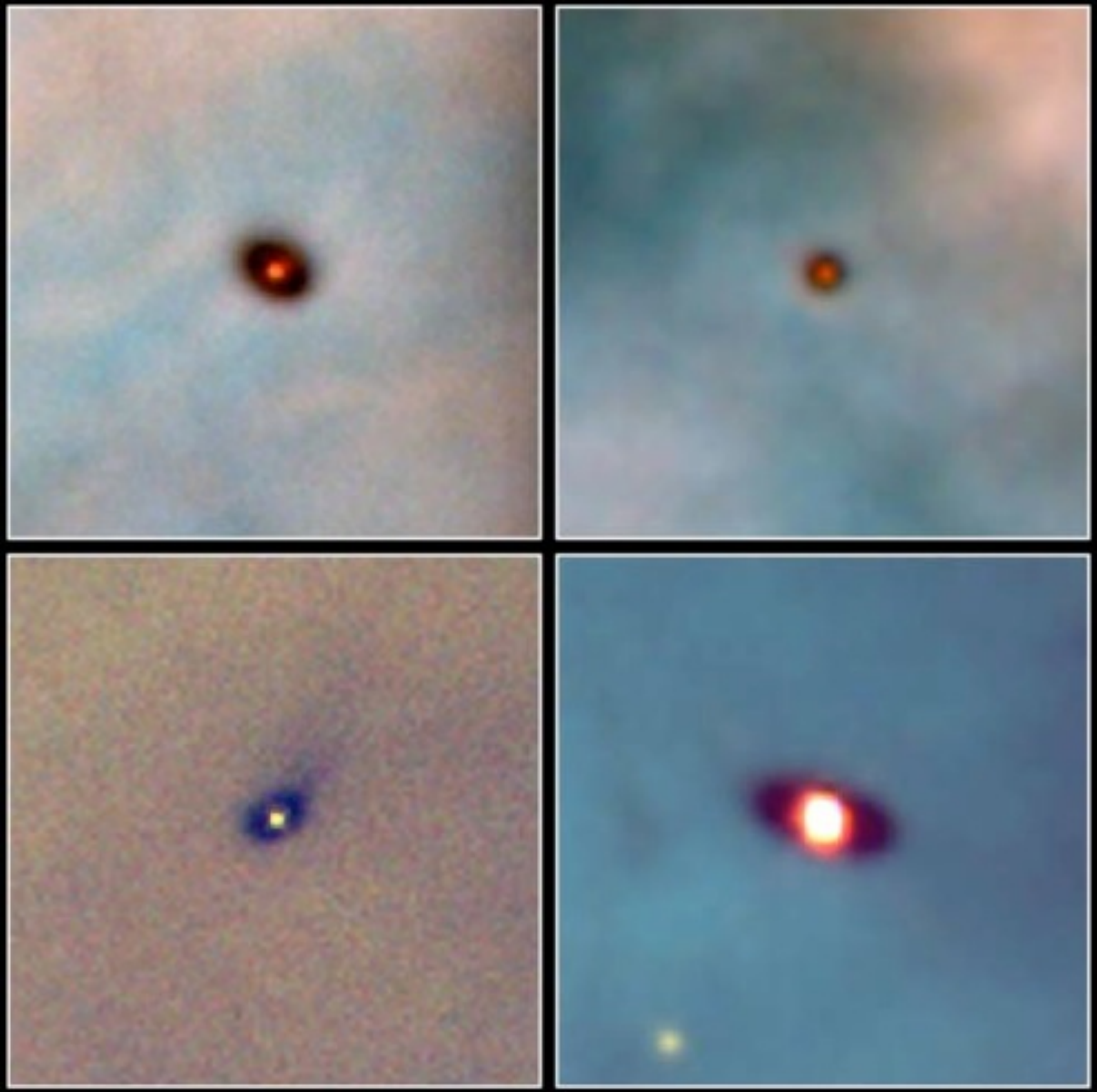


Image credit: Hubble Space Telescope, NASA.

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.

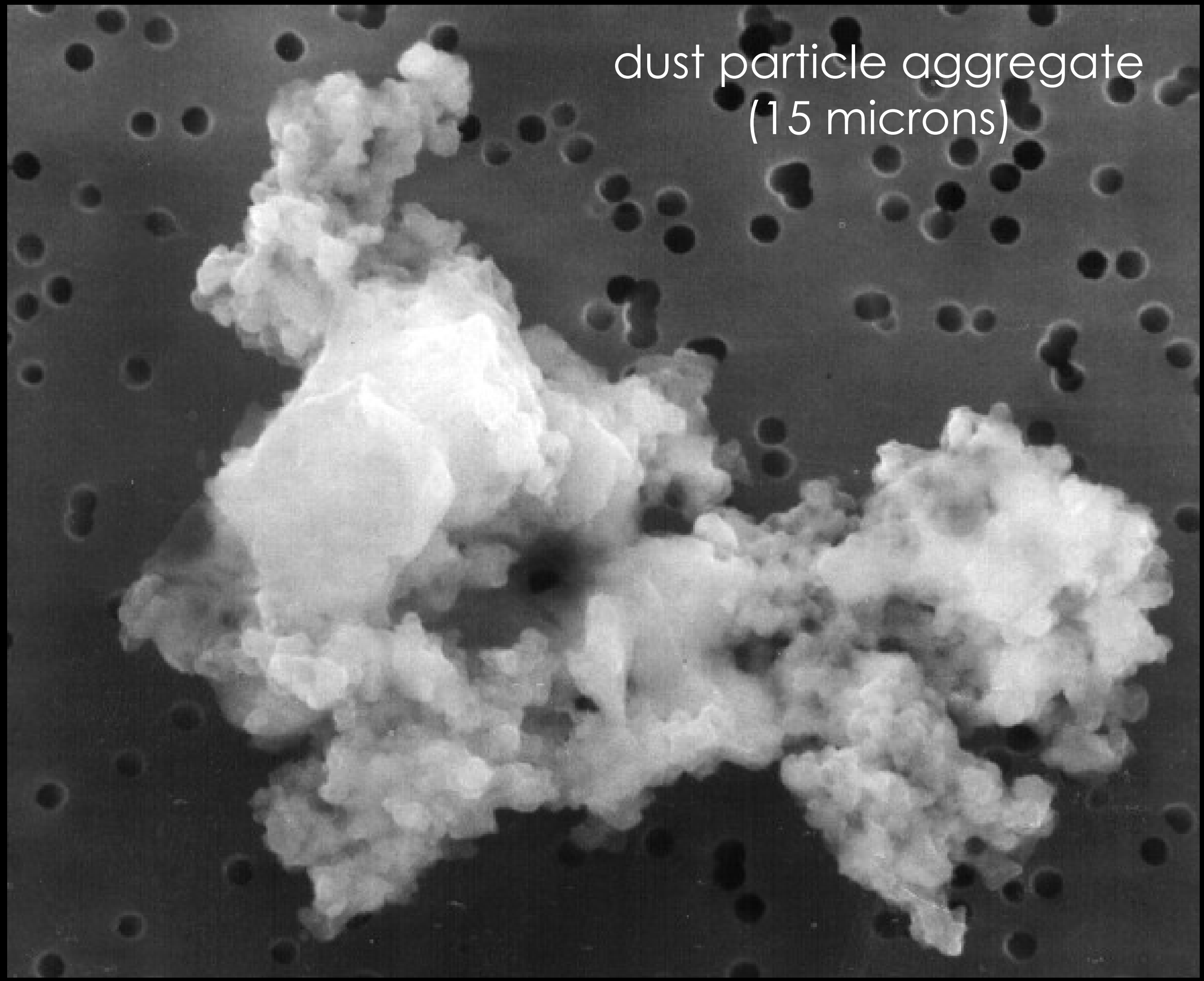


Image credit: Brownlee et al. NASA

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.

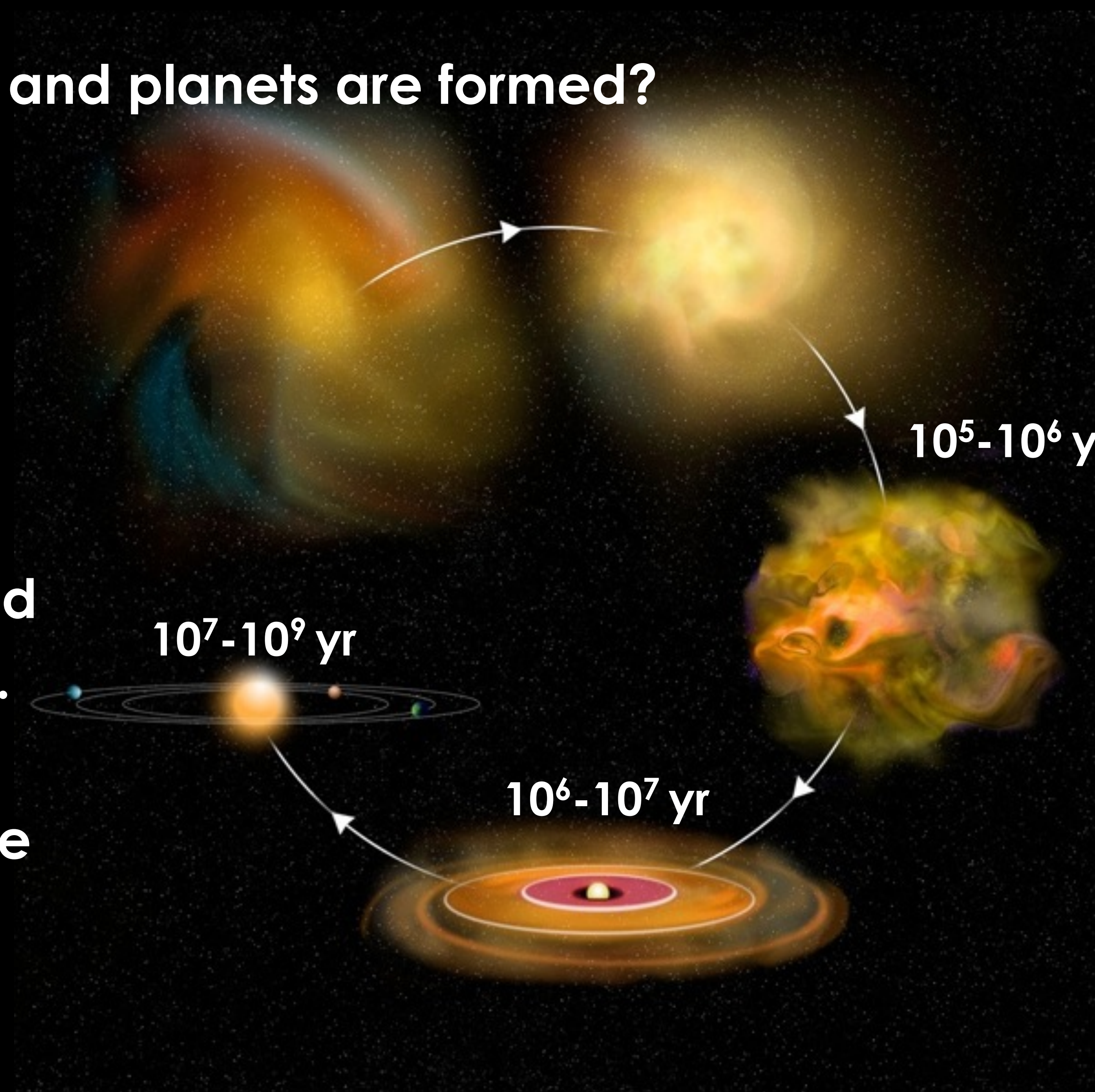
Image credit: National Geographic.

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!!

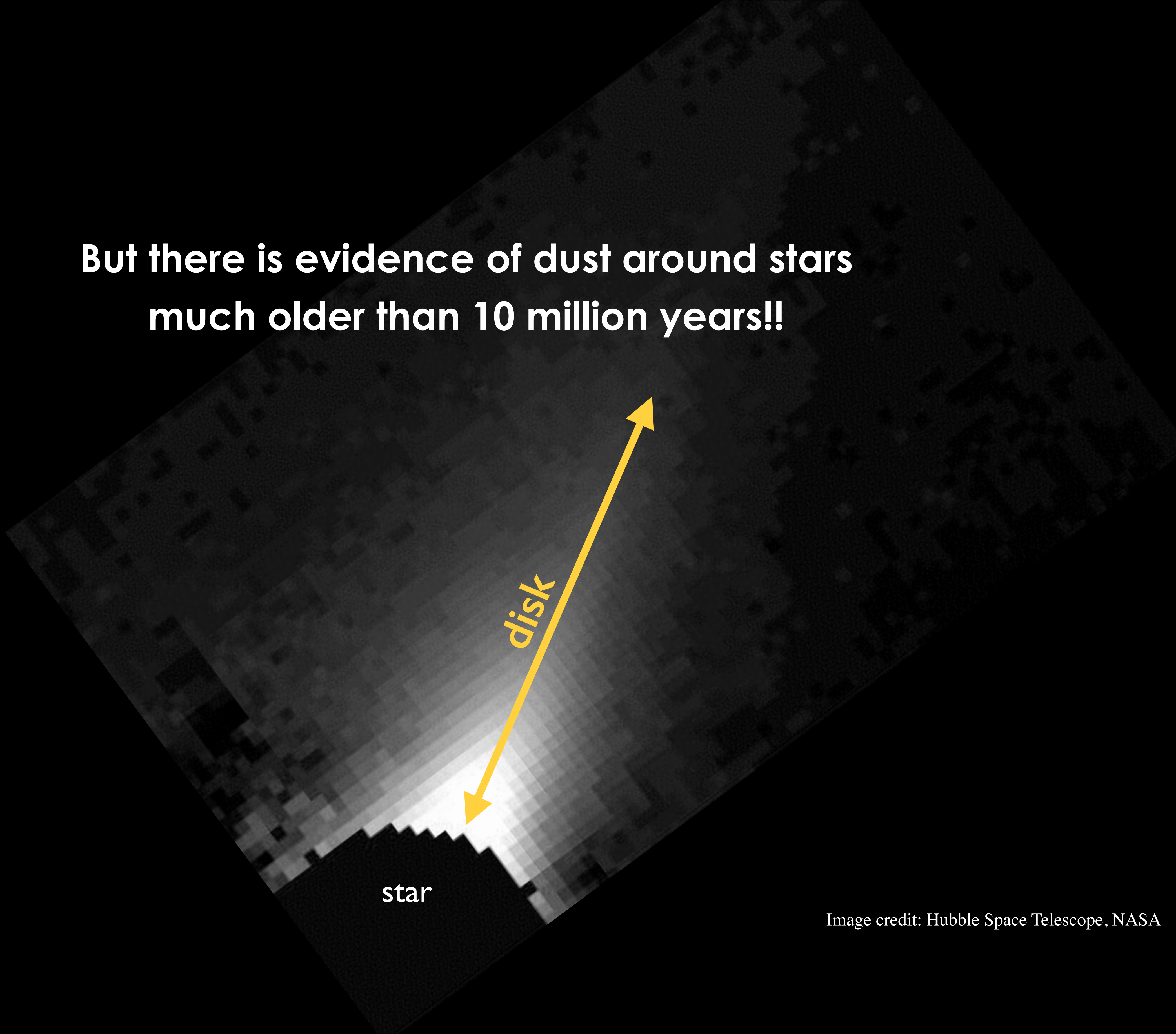


Image credit: Hubble Space Telescope, NASA

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.

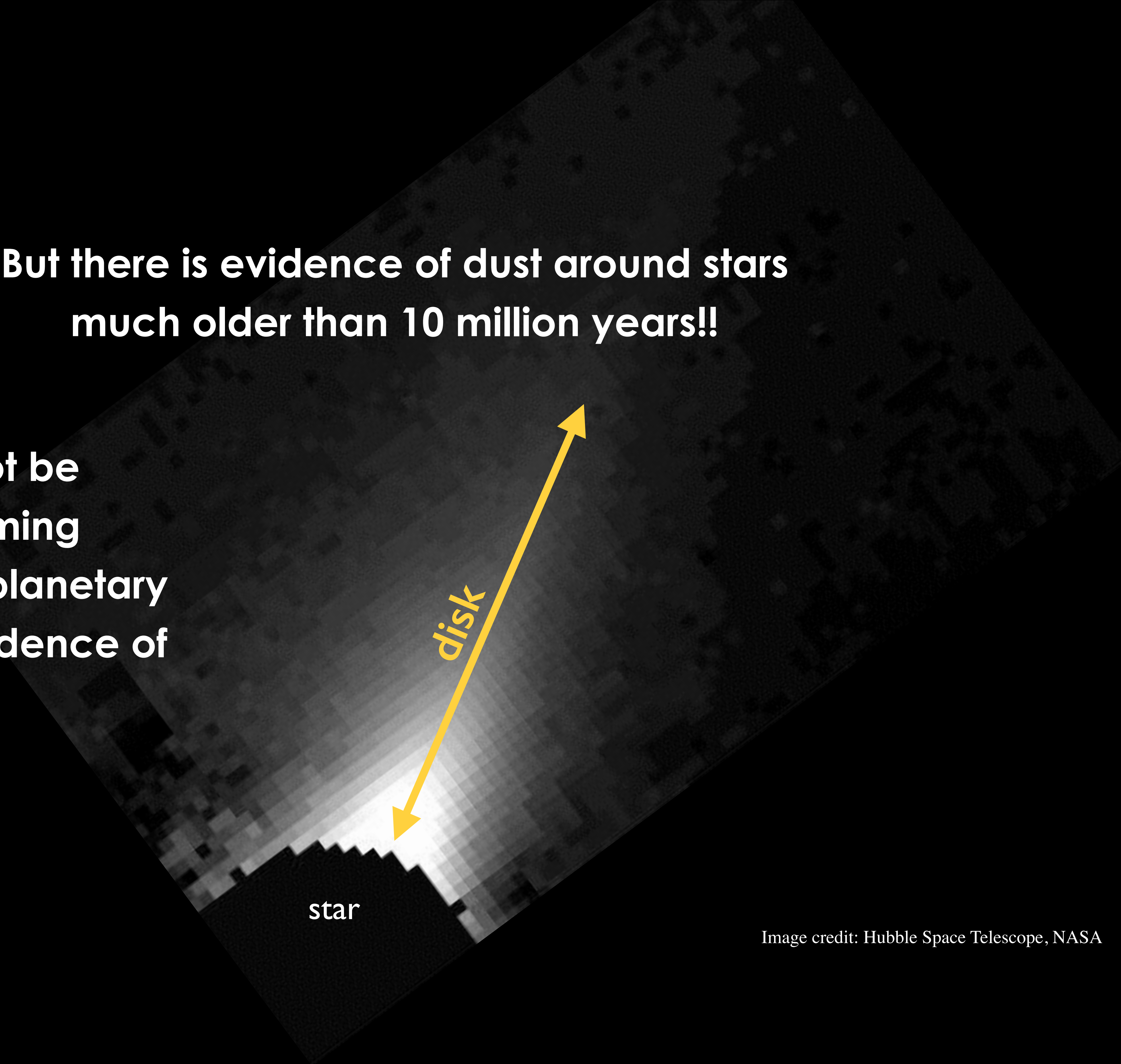
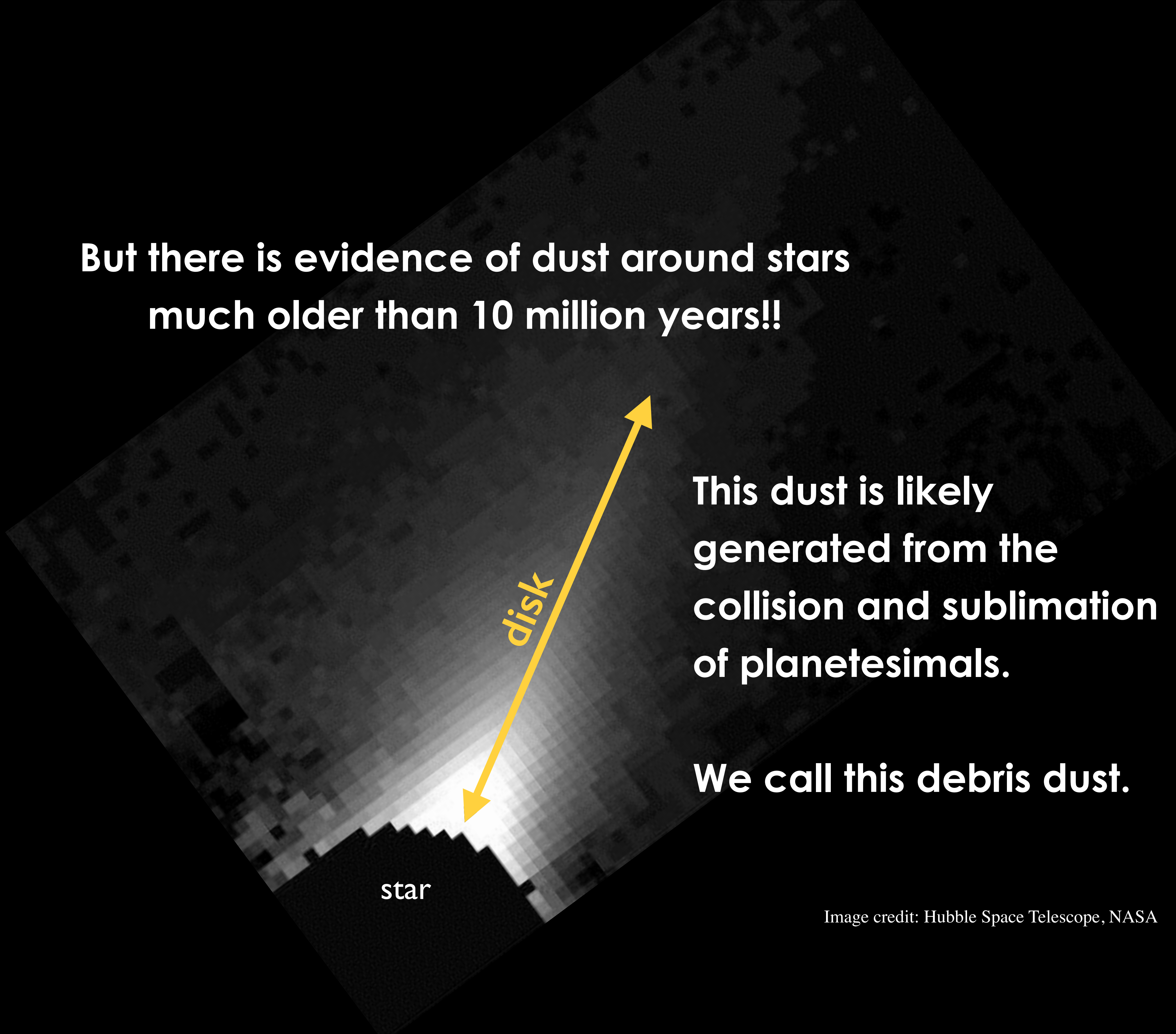


Image credit: Hubble Space Telescope, NASA

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.

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

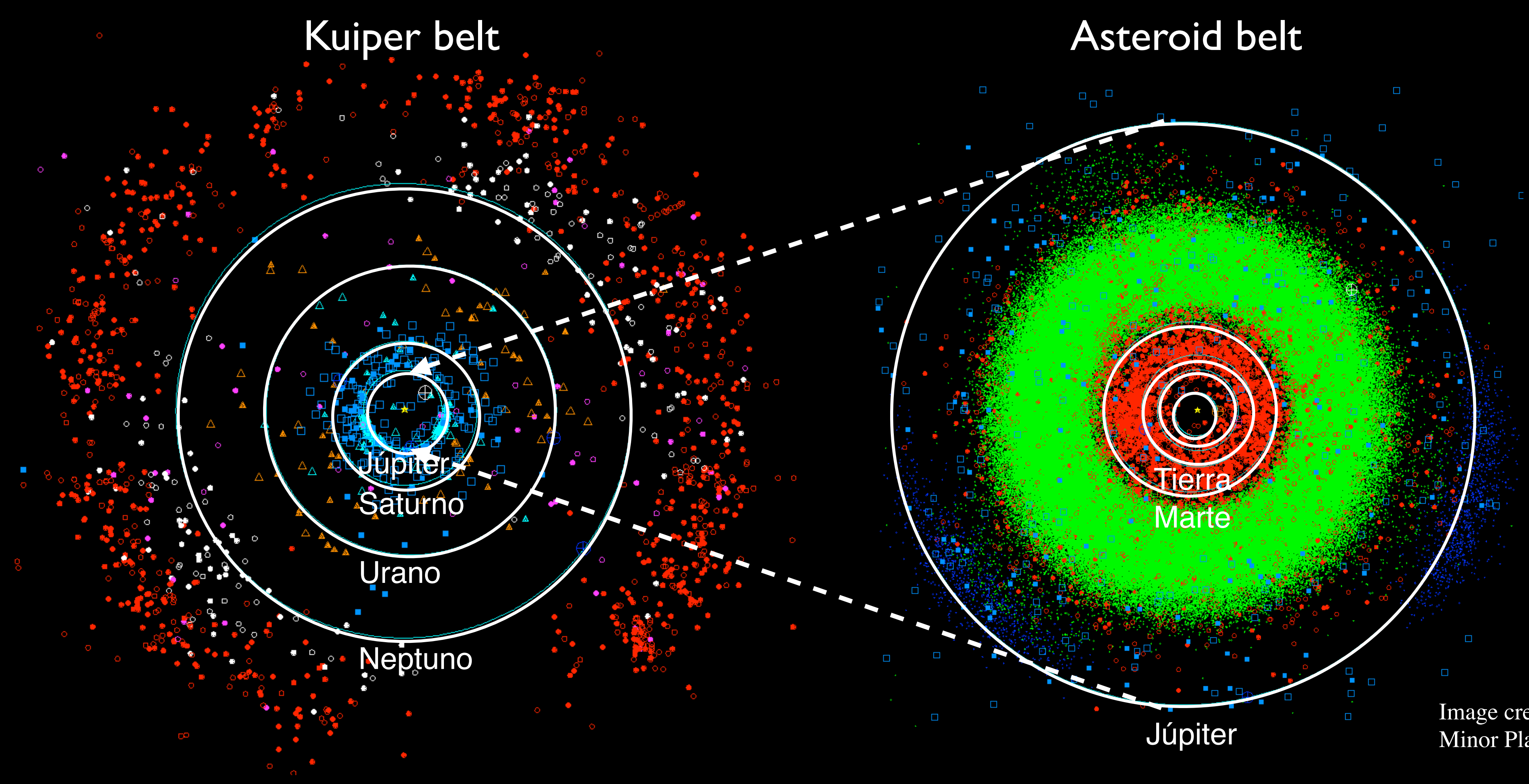
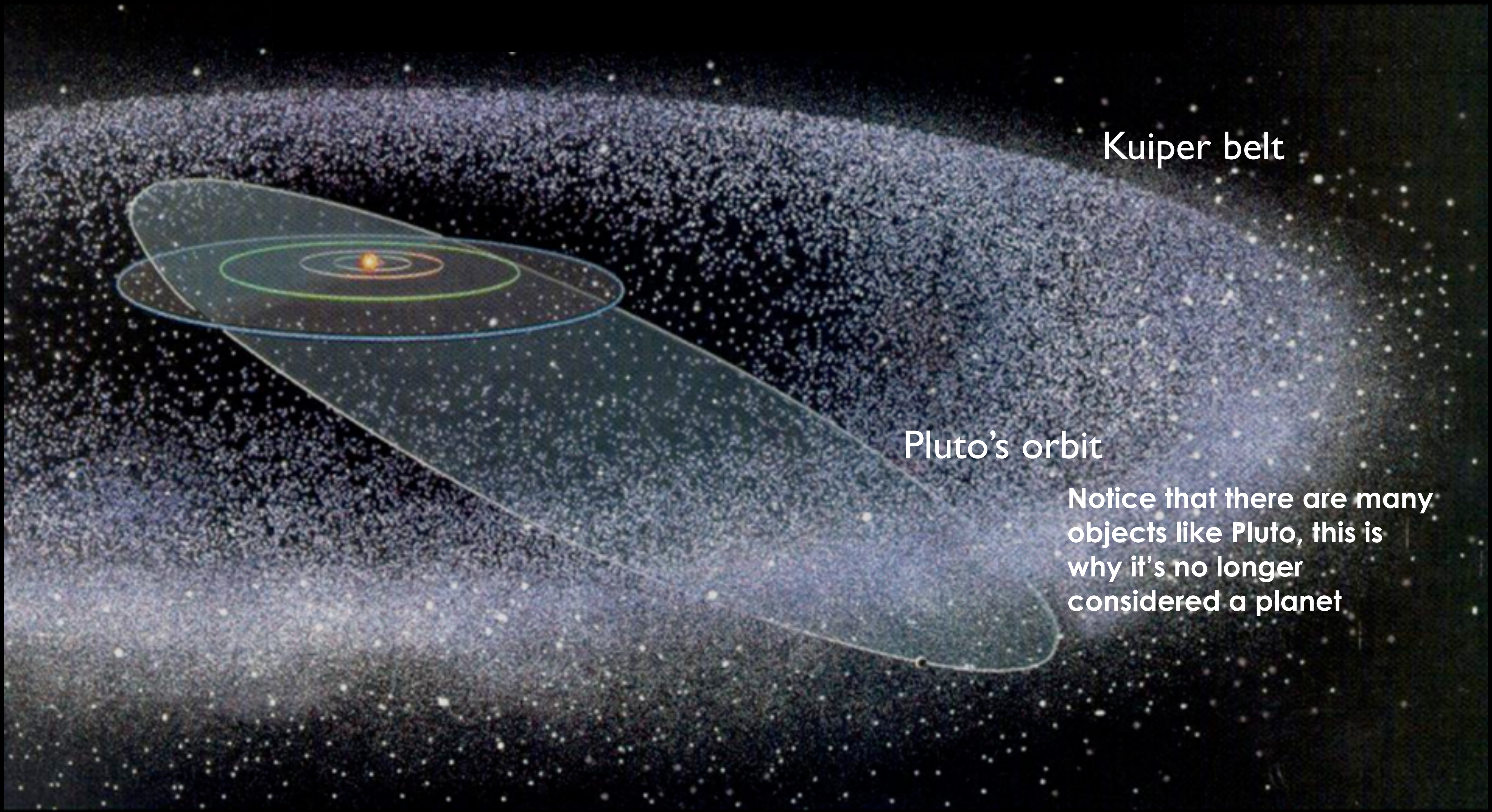


Image credit: G. Williams, Minor Planet Center.

There is dust production in the outer Solar system



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

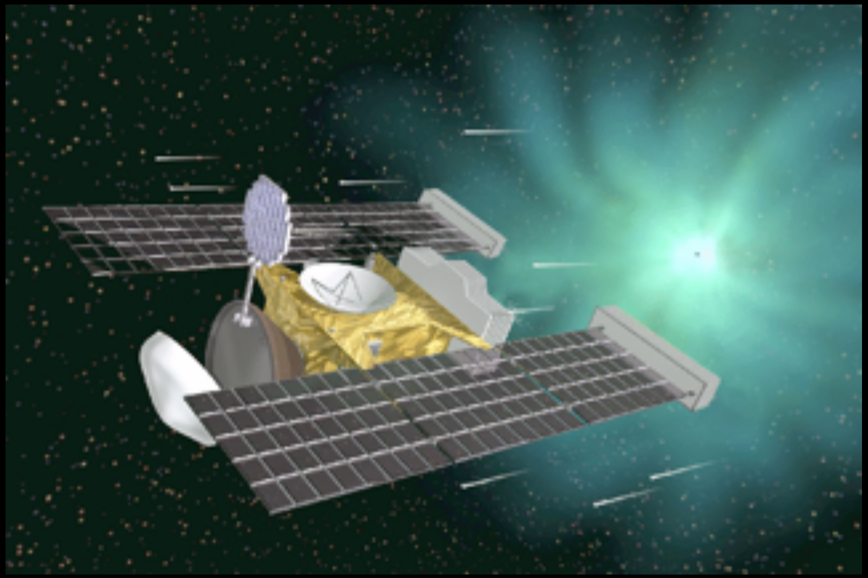
Image credit: Jewitt et al., Hubble Space Telescope.

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

They are captured very gently using aerogel…

Image credits: NASA

…using spacecraft or high-flying planes…



…the aerogel is then returned to the lab…

…where the dust is extracted from the aerogel

Dust particle from our Solar system captured in the upper atmosphere

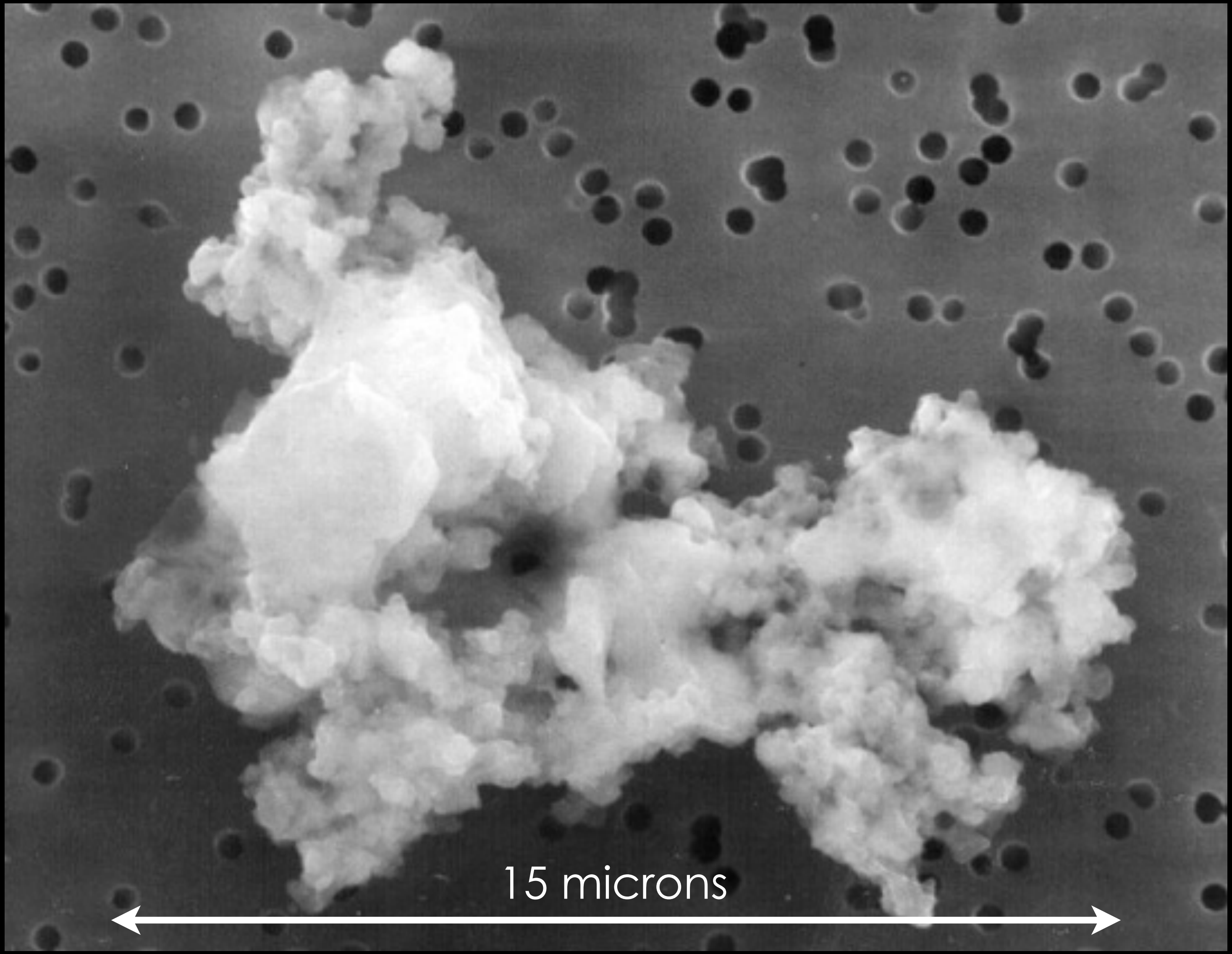
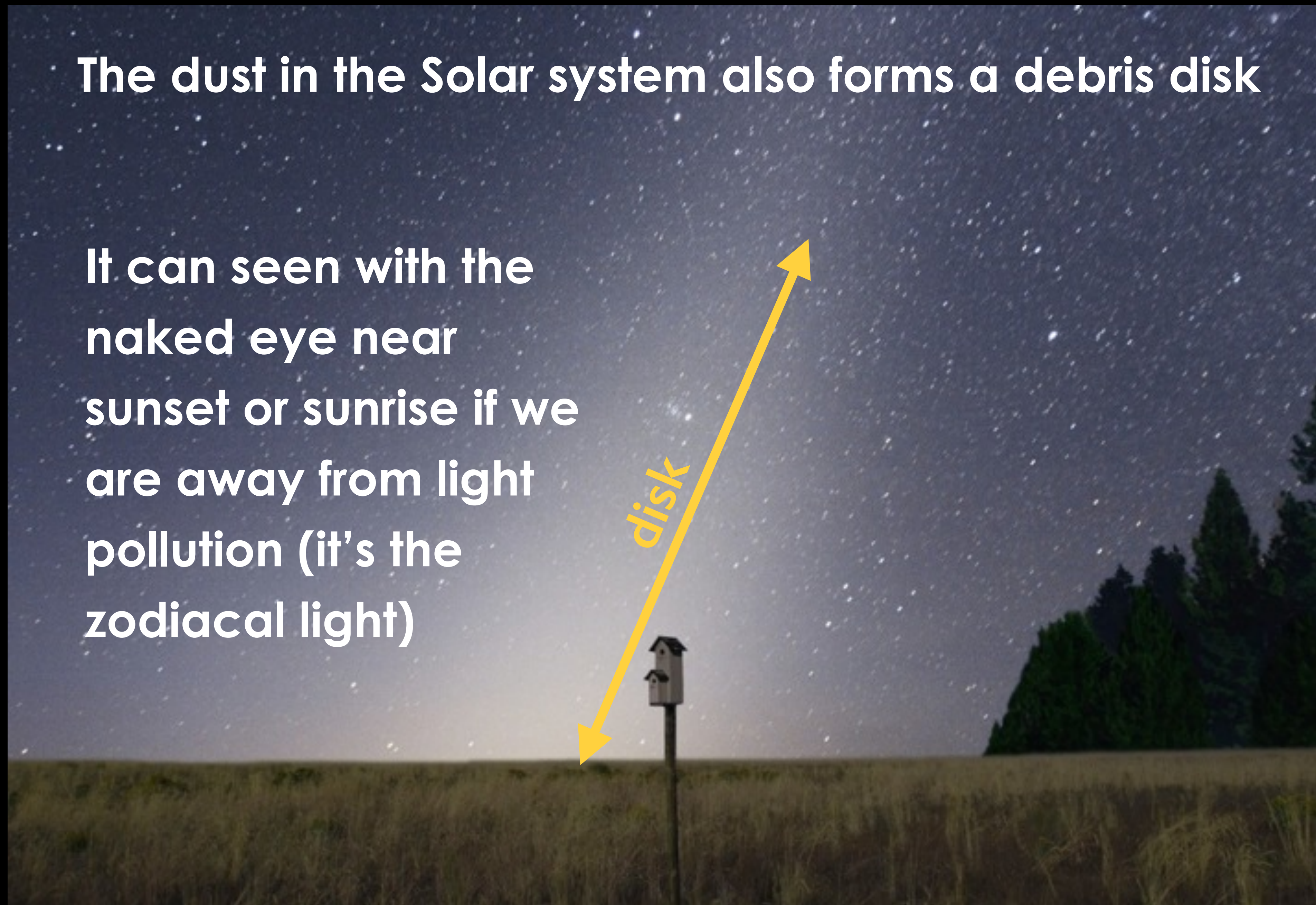
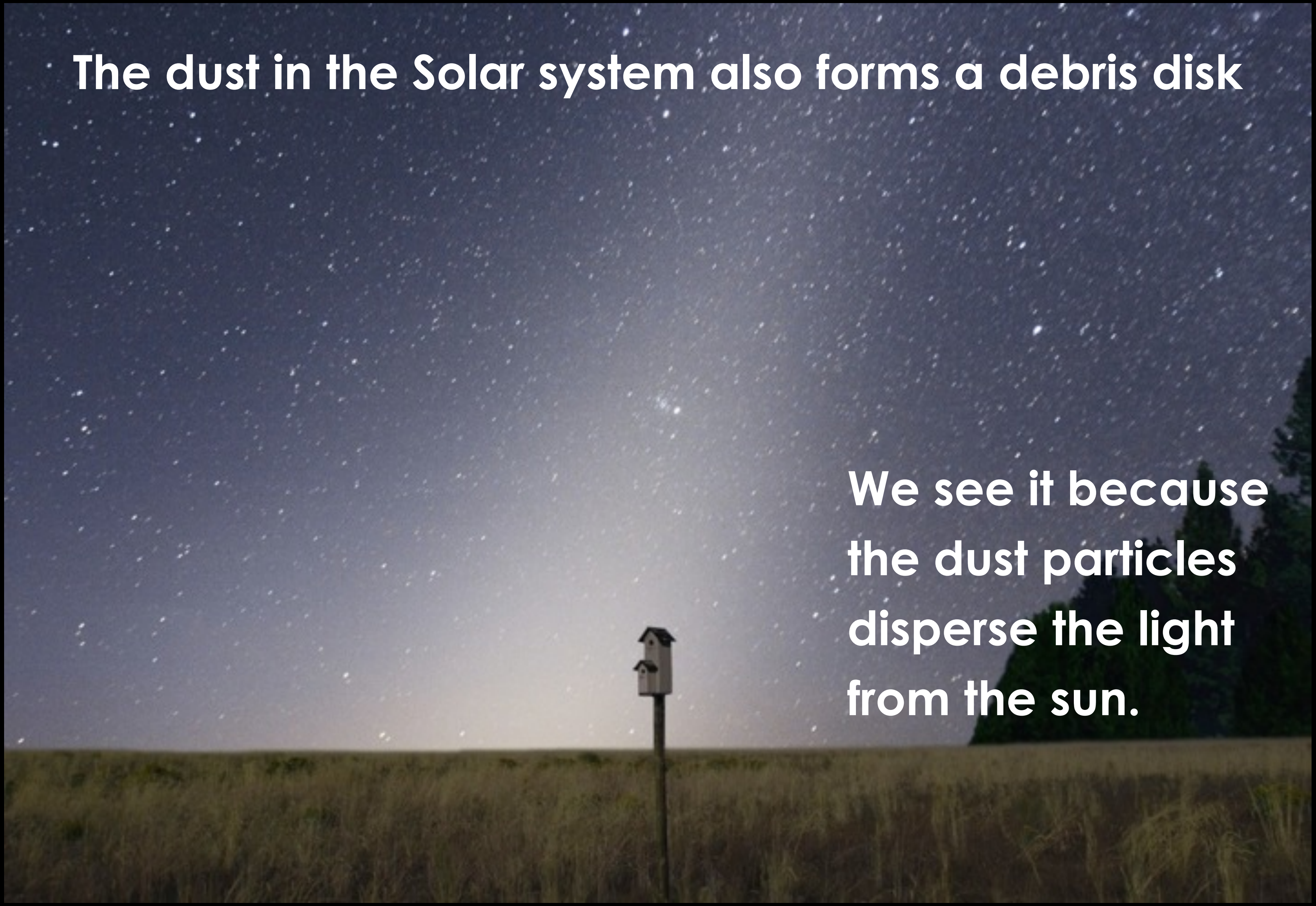


Image credit: Brownlee et al. NASA.


The dust in the Solar system also forms a debris disk
It can seen with the naked eye near sunset or sunrise if we are away from light pollution (it's the zodiacal light)
disk


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.

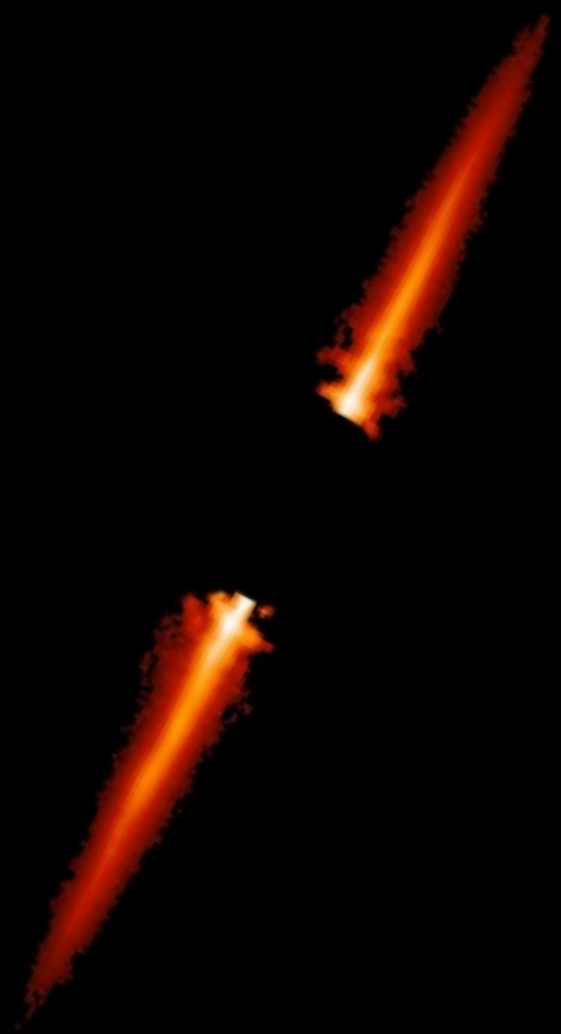
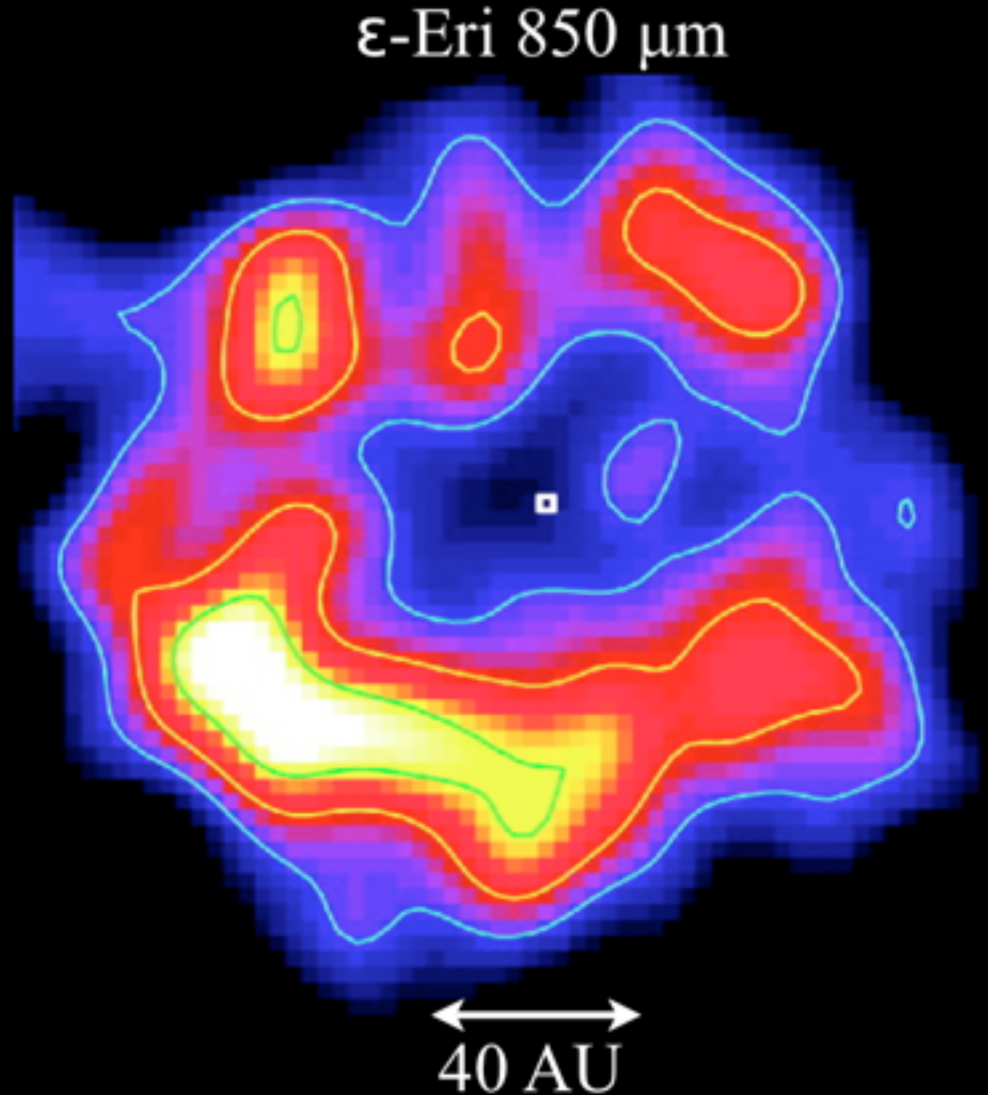


Image credit: Hubble Space Telescope, NASA

Debris disks can have very complex spatial features

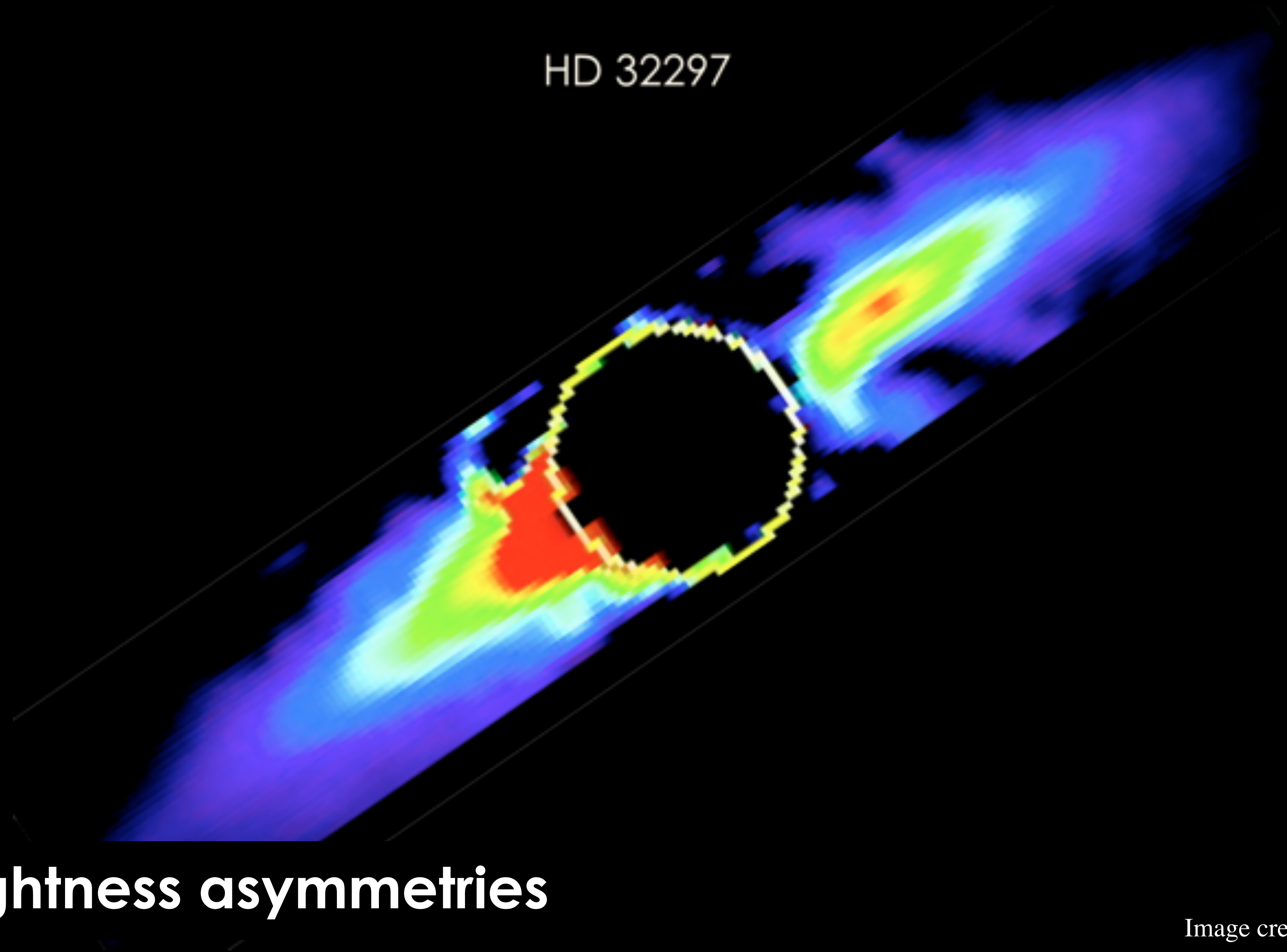


Irregular rings

Off-centered disks

Image credit: Hubble Space Telescope, NASA

Debris disks can have very complex spatial features



Brightness asymmetries

Image credit: Hubble Space Telescope, NASA

Debris disks can have very complex spatial features

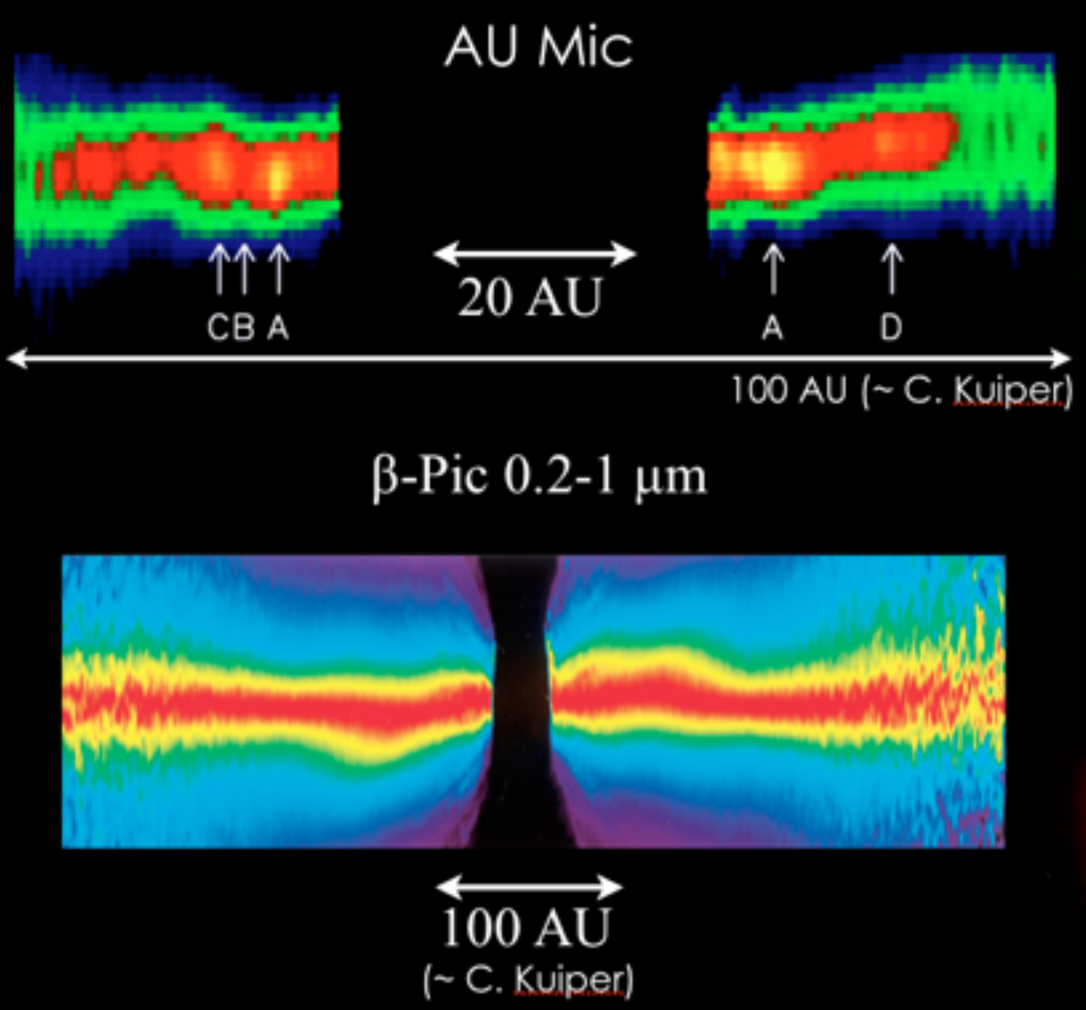


Image credit: Hubble Space Telescope, NASA

Debris disks can have very complex spatial features

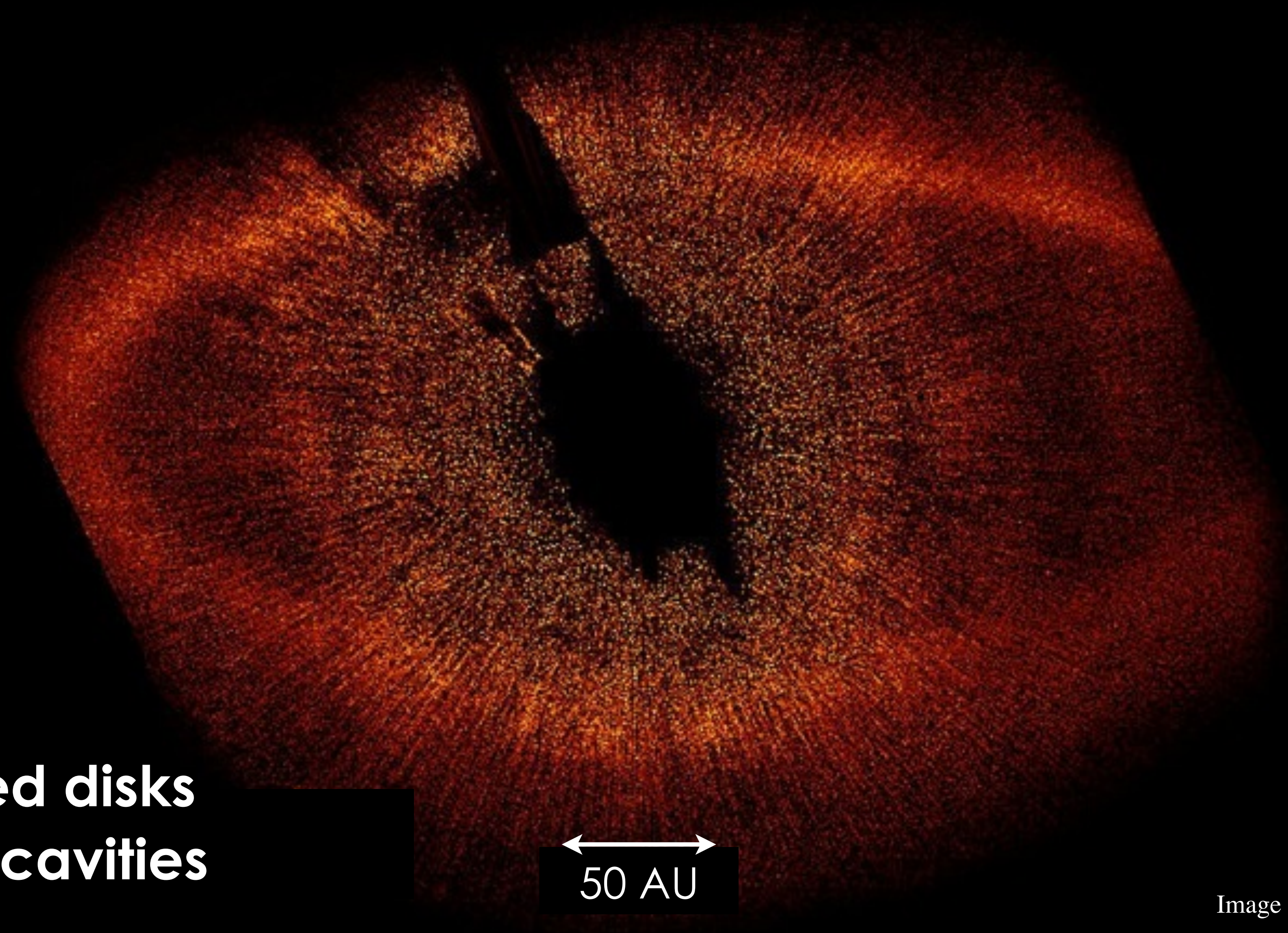


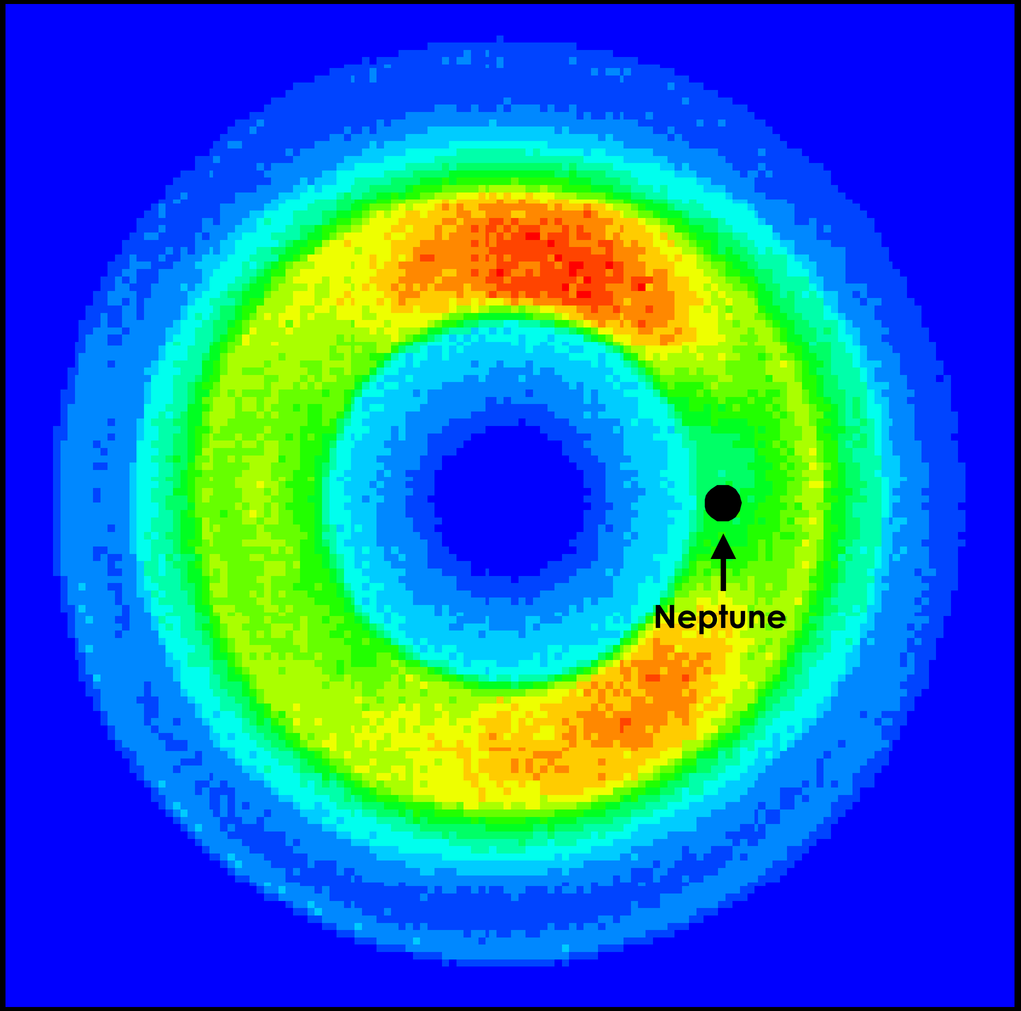
Image credit: Hubble Space Telescope, NASA

Off-centered disks
Shap inner cavities

Debris disks can have very complex spatial features

Irregular rings

Brightness asymmetries



Model of the Kuiper Belt

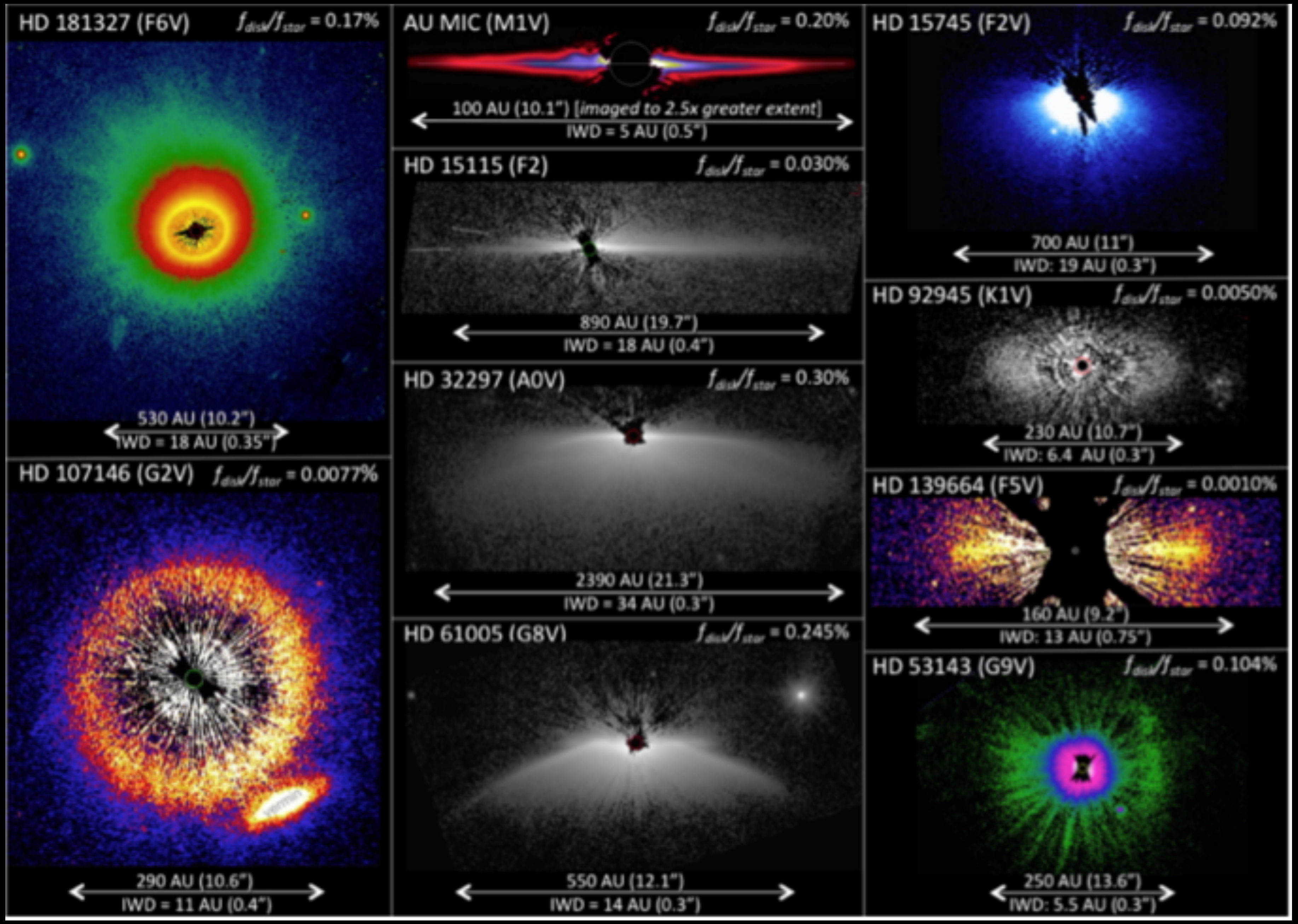


Image credit: Hubble Space Telescope, NASA


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

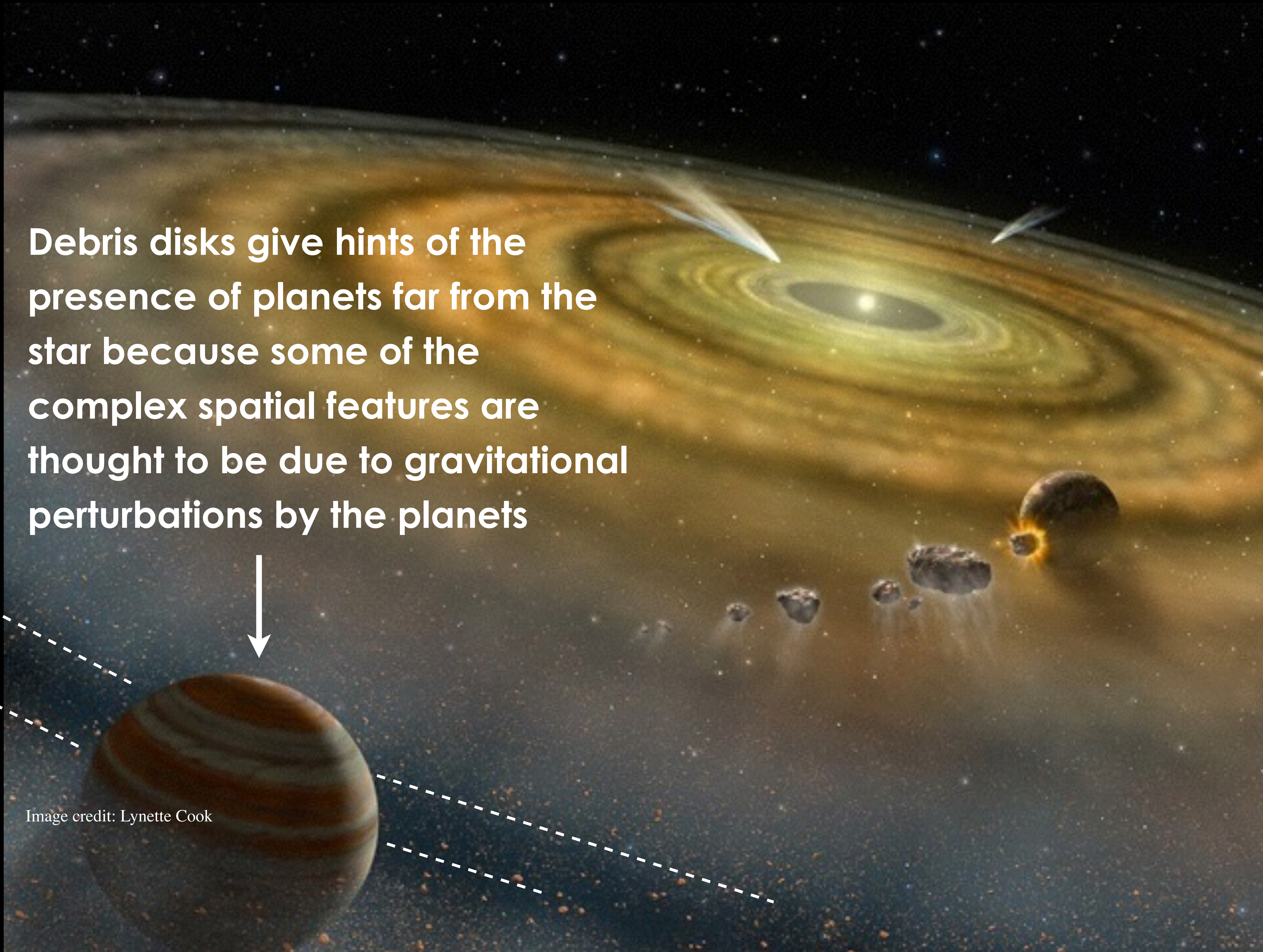


Image credit: Lynette Cook

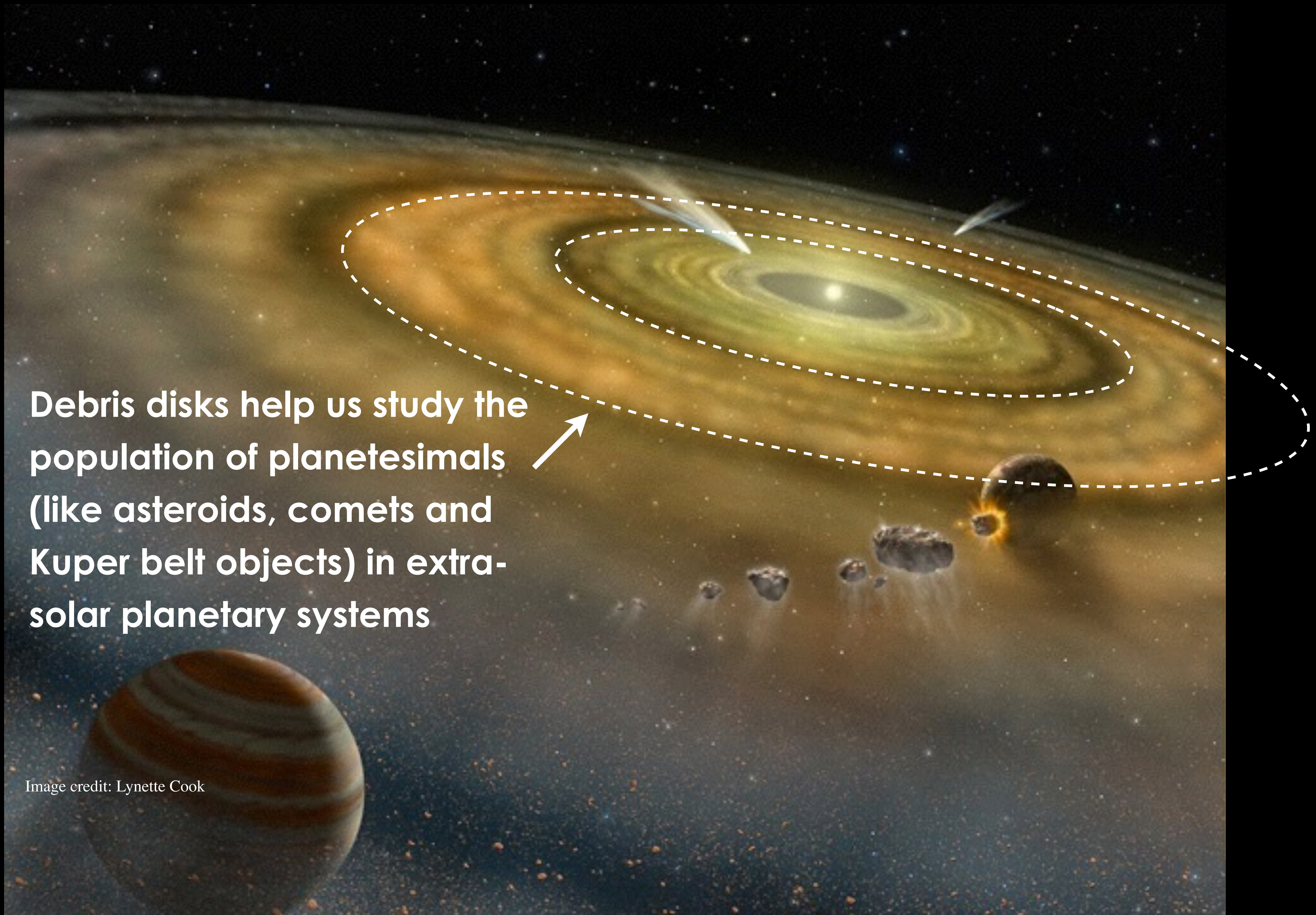
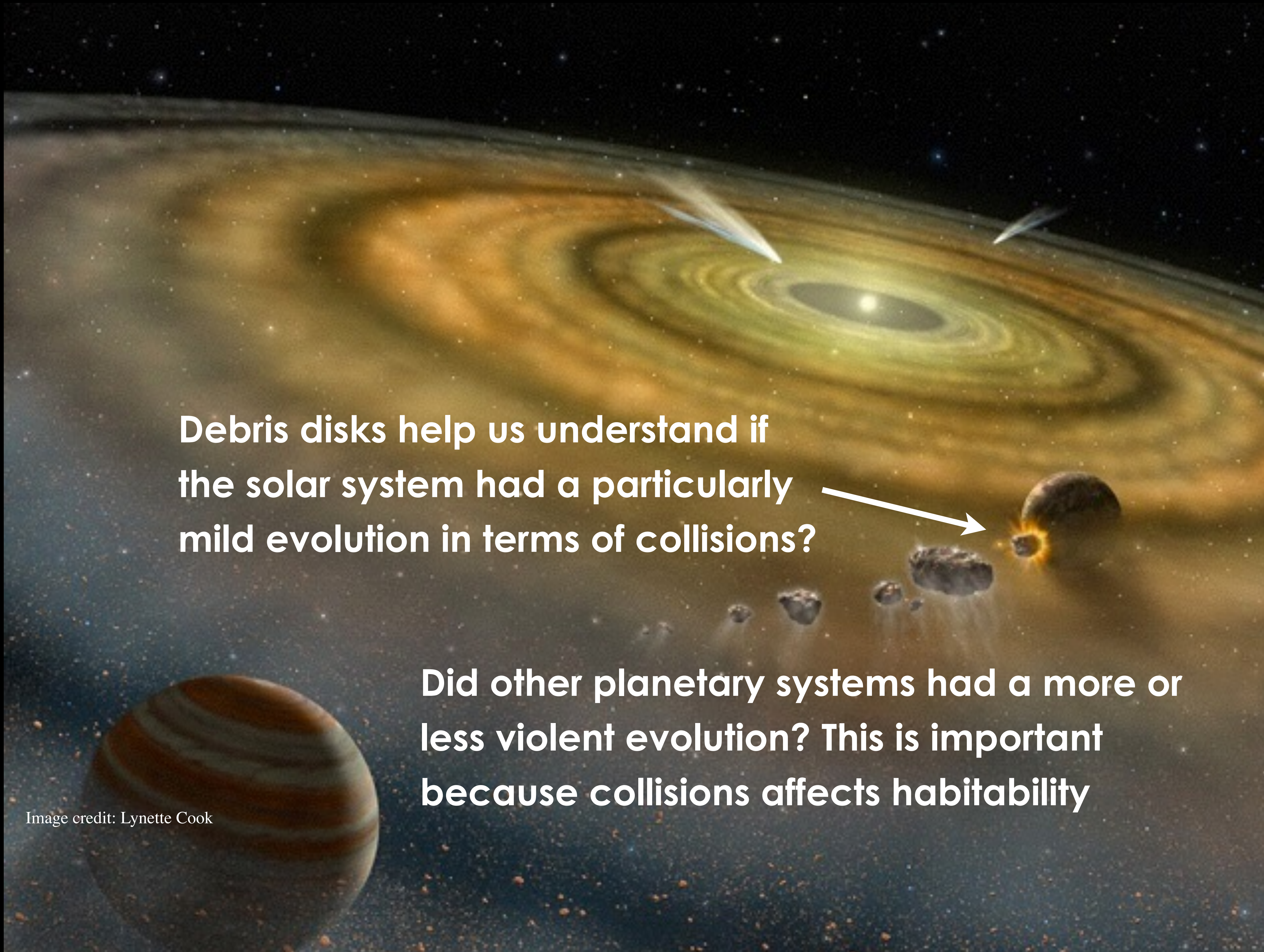
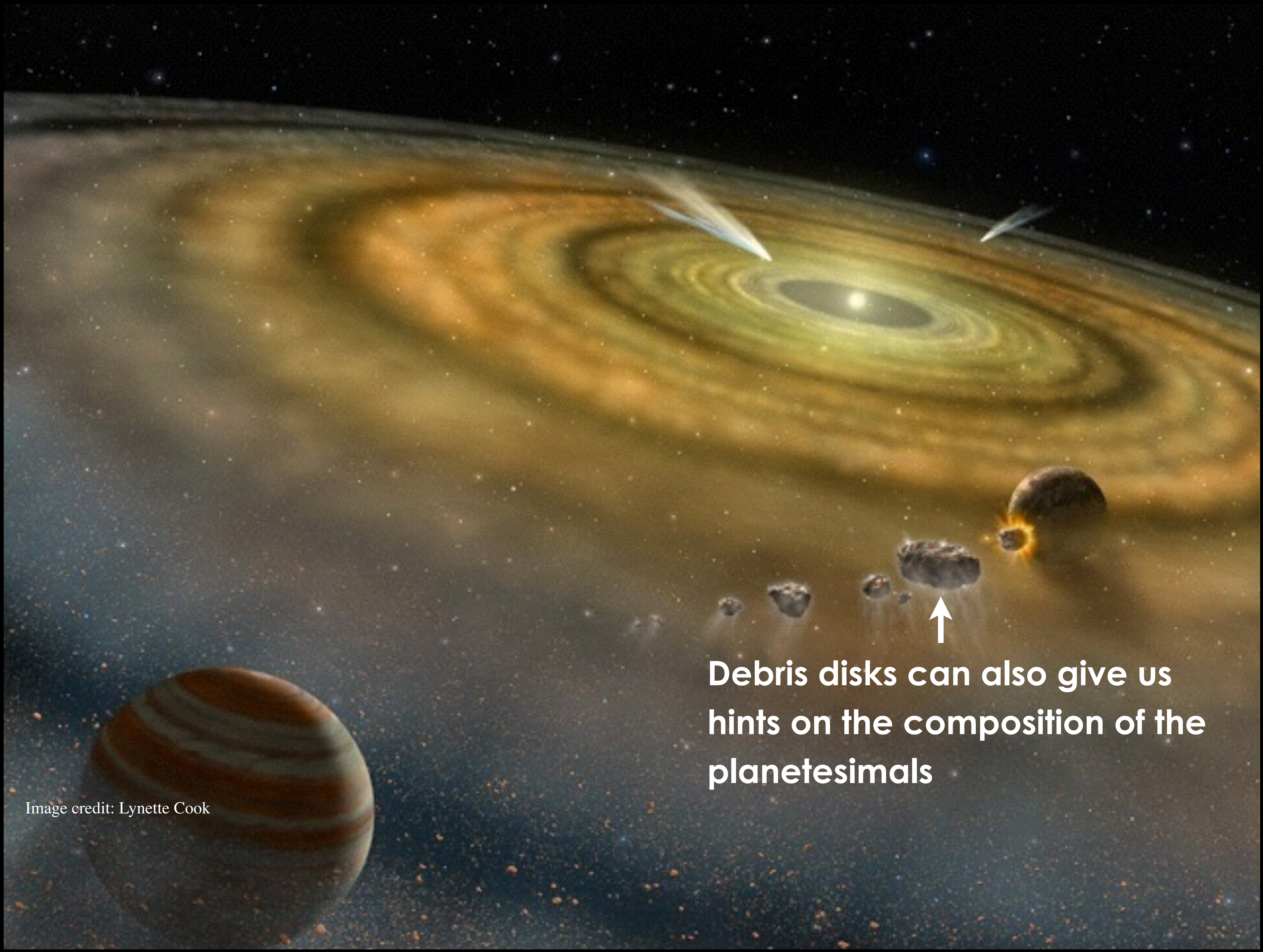
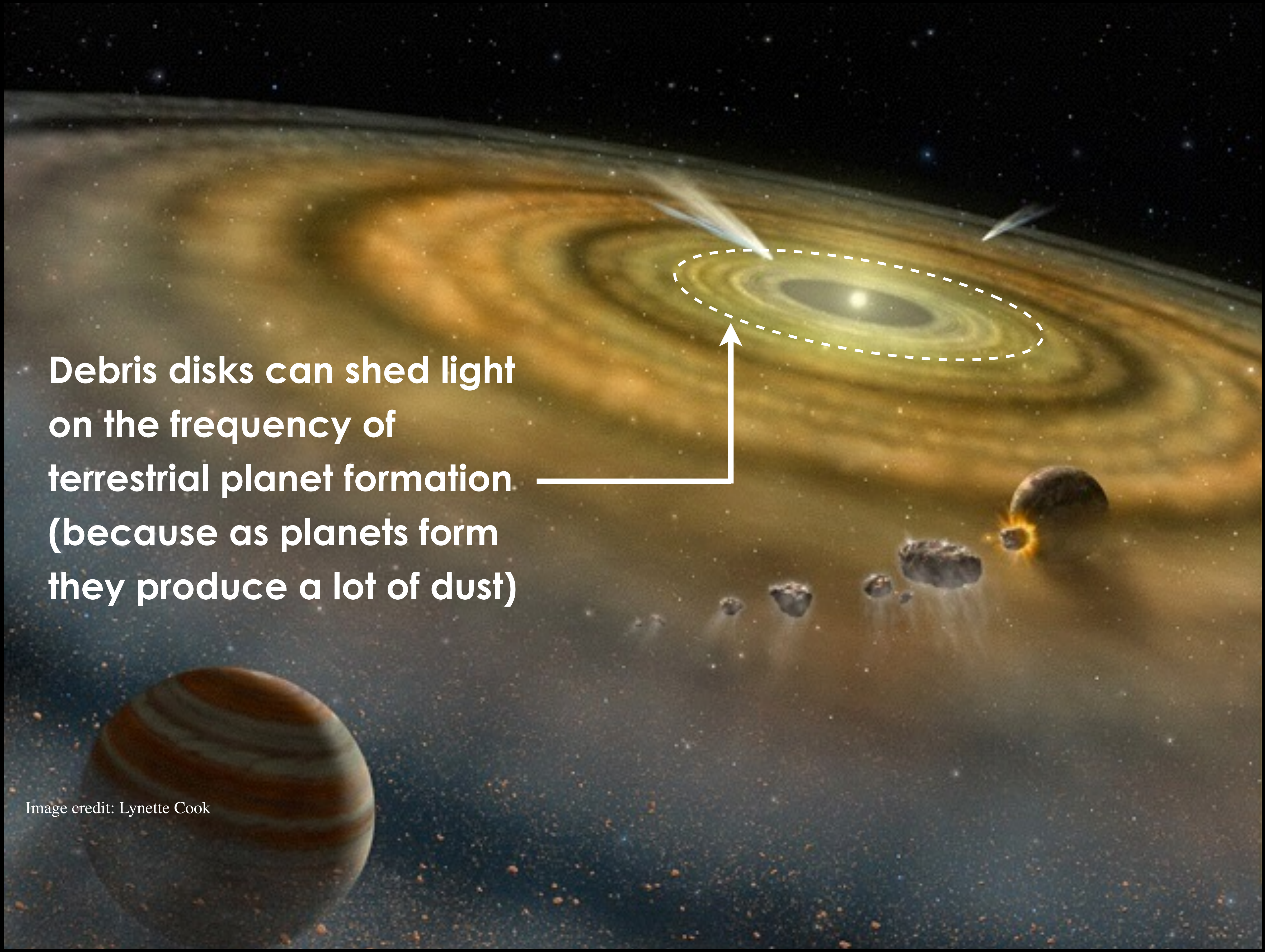


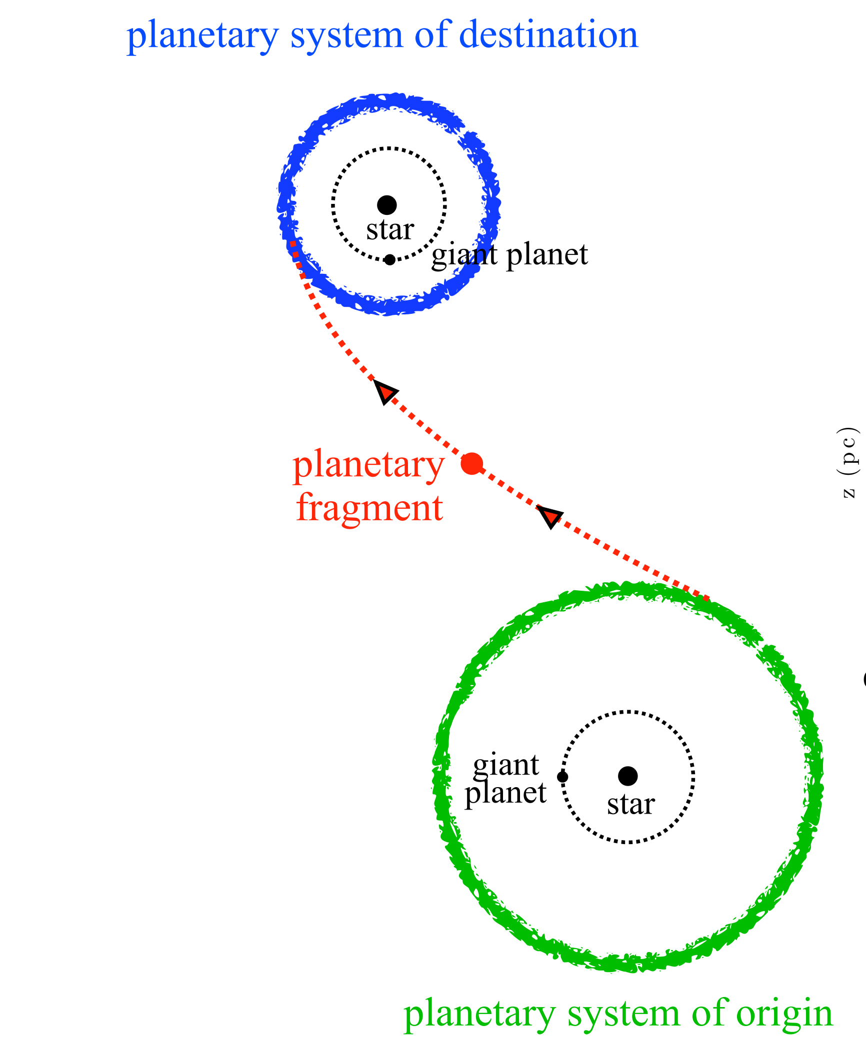
Image credit: Lynette Cook

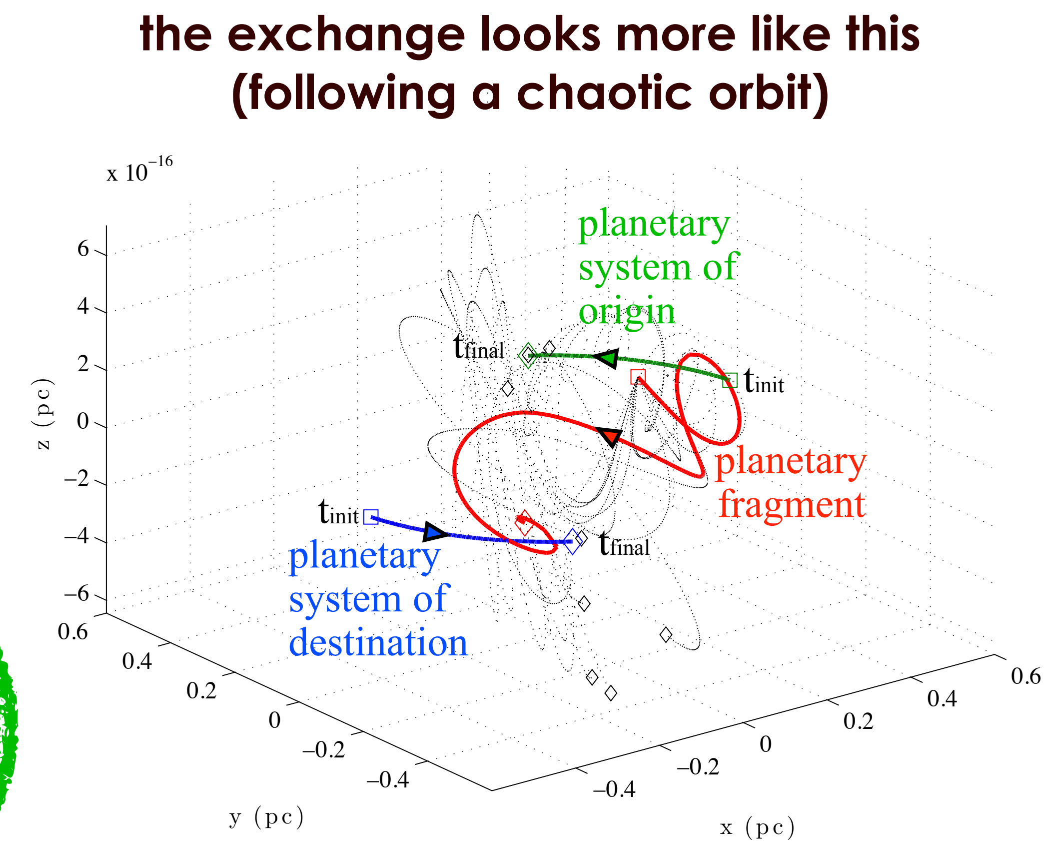

Debris disks help us understand if the solar system had a particularly mild evolution in terms of collisions?
Did other planetary systems had a more or less violent evolution? This is important because collisions affects habitability
Image credit: Lynette Cook


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

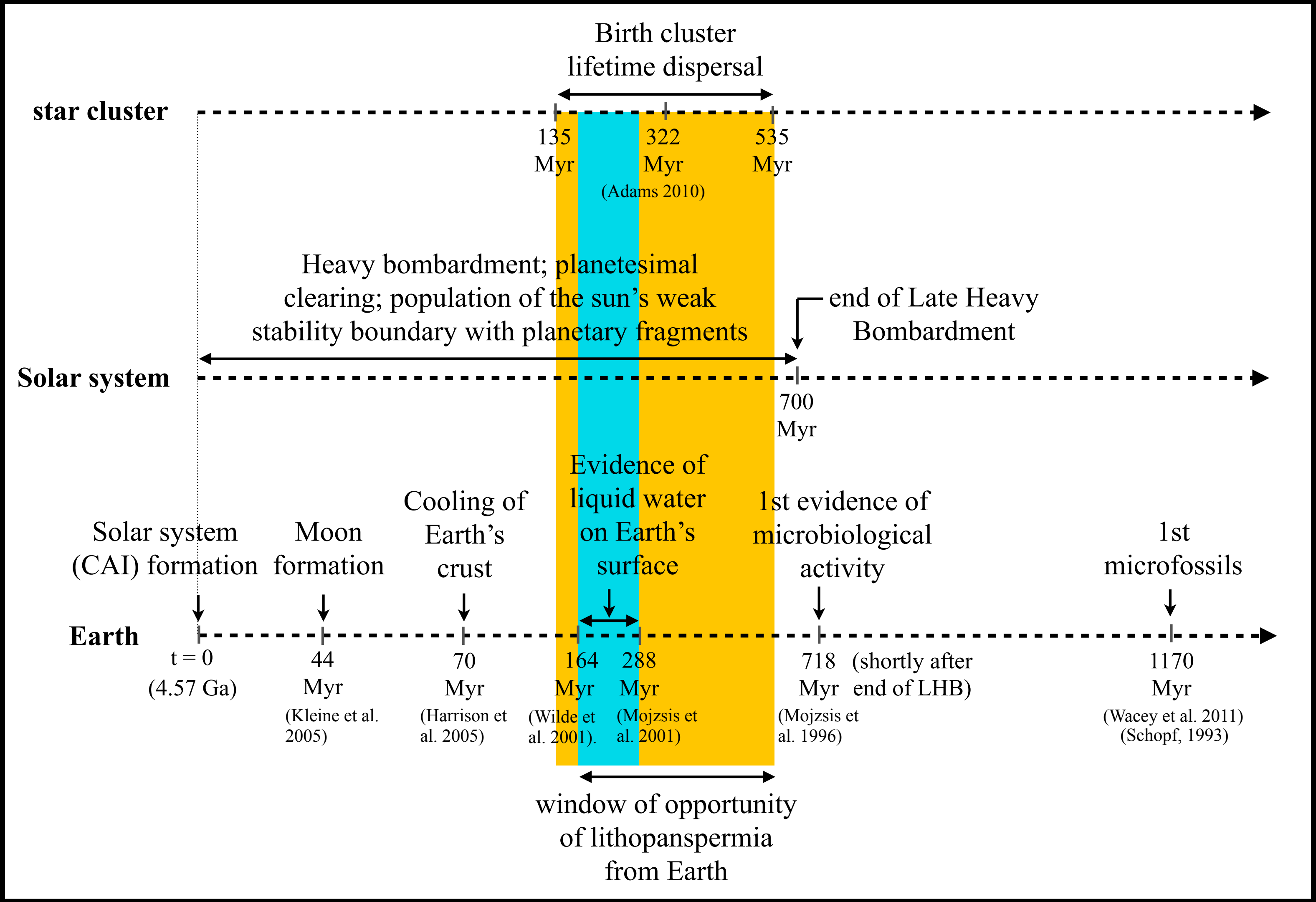
Debris dust and rocks can be exchanged between nearby planetary systems when they are young



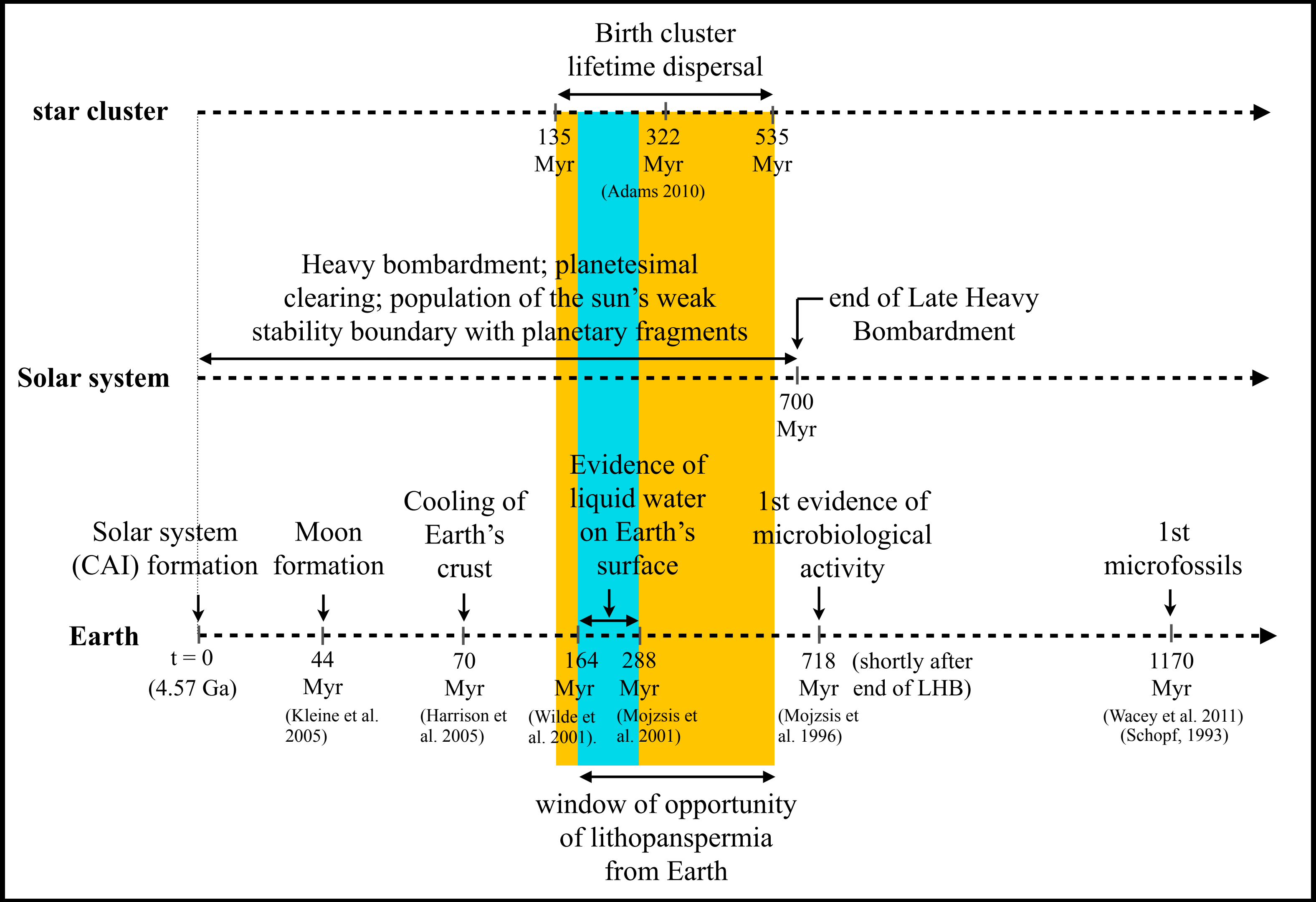


The exchange of rocks between planetary system may have contributed to the dispersal of life from one planetary system to another

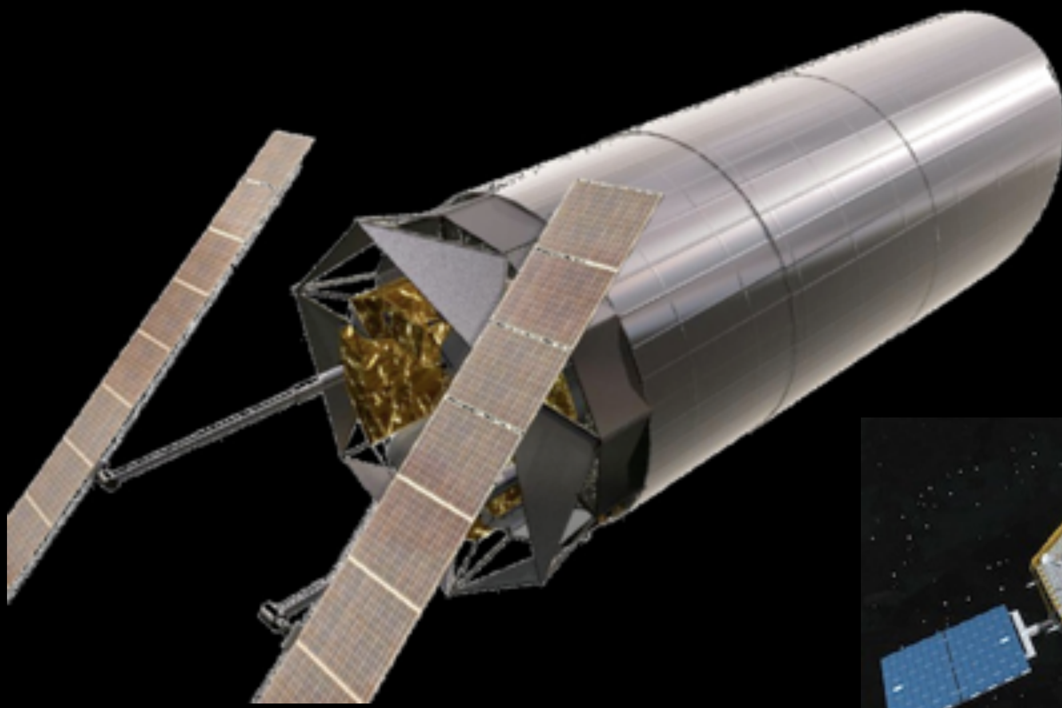
If life on Earth had an early start (shortly after liquid water was available), life could have been transferred to other systems



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

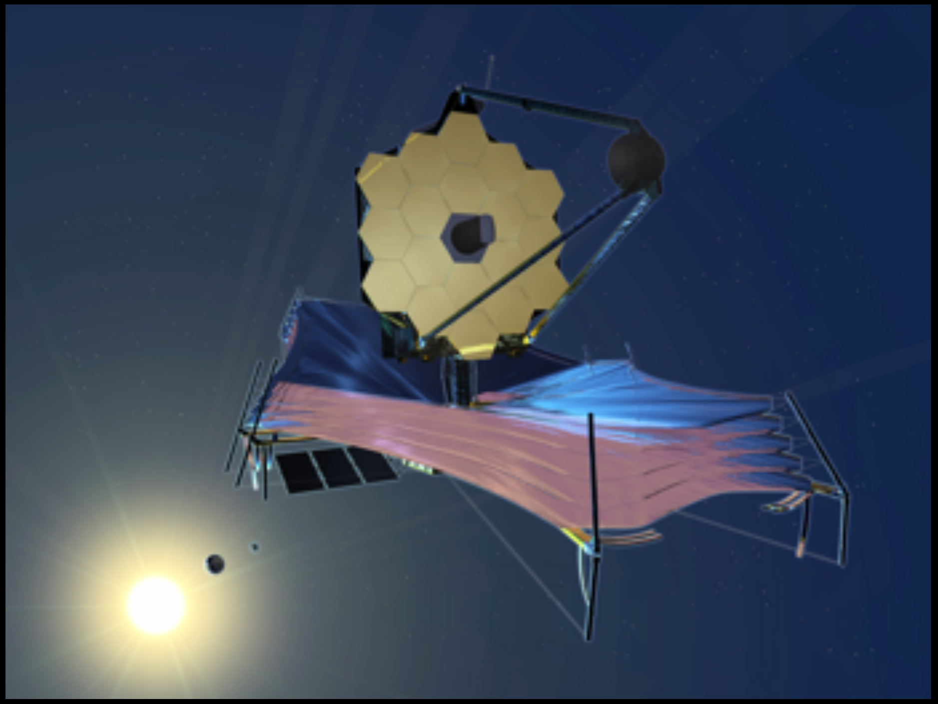


There could be many habitable planetary systems out there and we will search for them



ATLAST
(2030?)

TESS
(2017)



JWST
(2017)

Image credit: NASA