

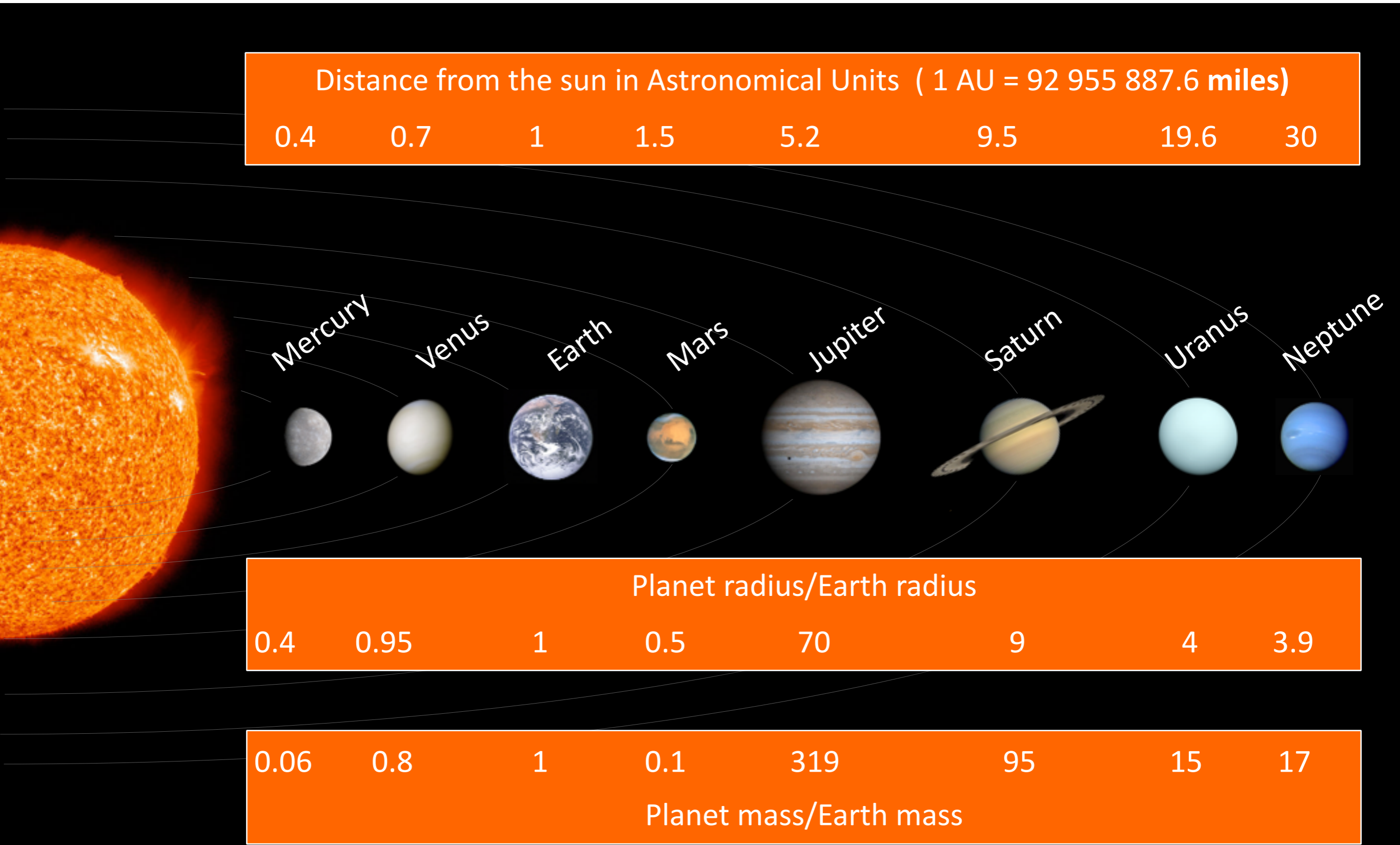


# How Do Planets Form?

How did we get here?

**Andrea Isella**  
**Department of Physics and Astronomy**  
**Rice University**

# The Solar System



# We are not alone: 51 Peg b (1995)

ARTICLES

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## A Jupiter-mass companion to a solar-type star

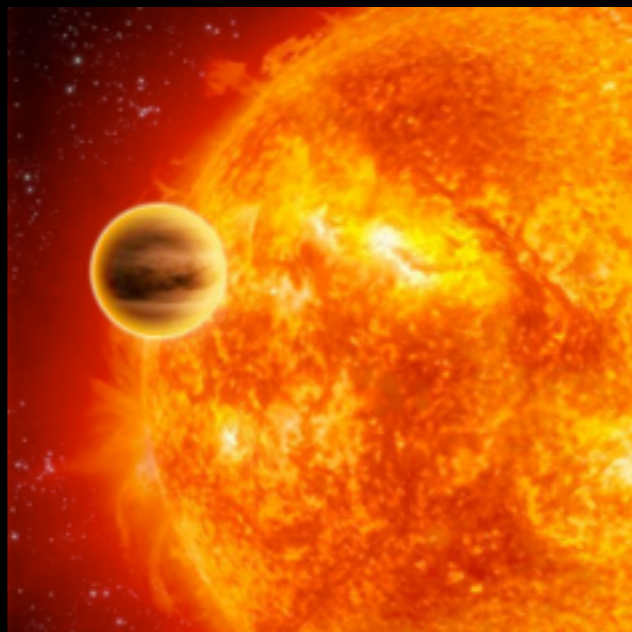
**Michel Mayor & Didier Queloz**

Geneva Observatory, 51 Chemin des Maillettes, CH-1290 Sauverny, Switzerland

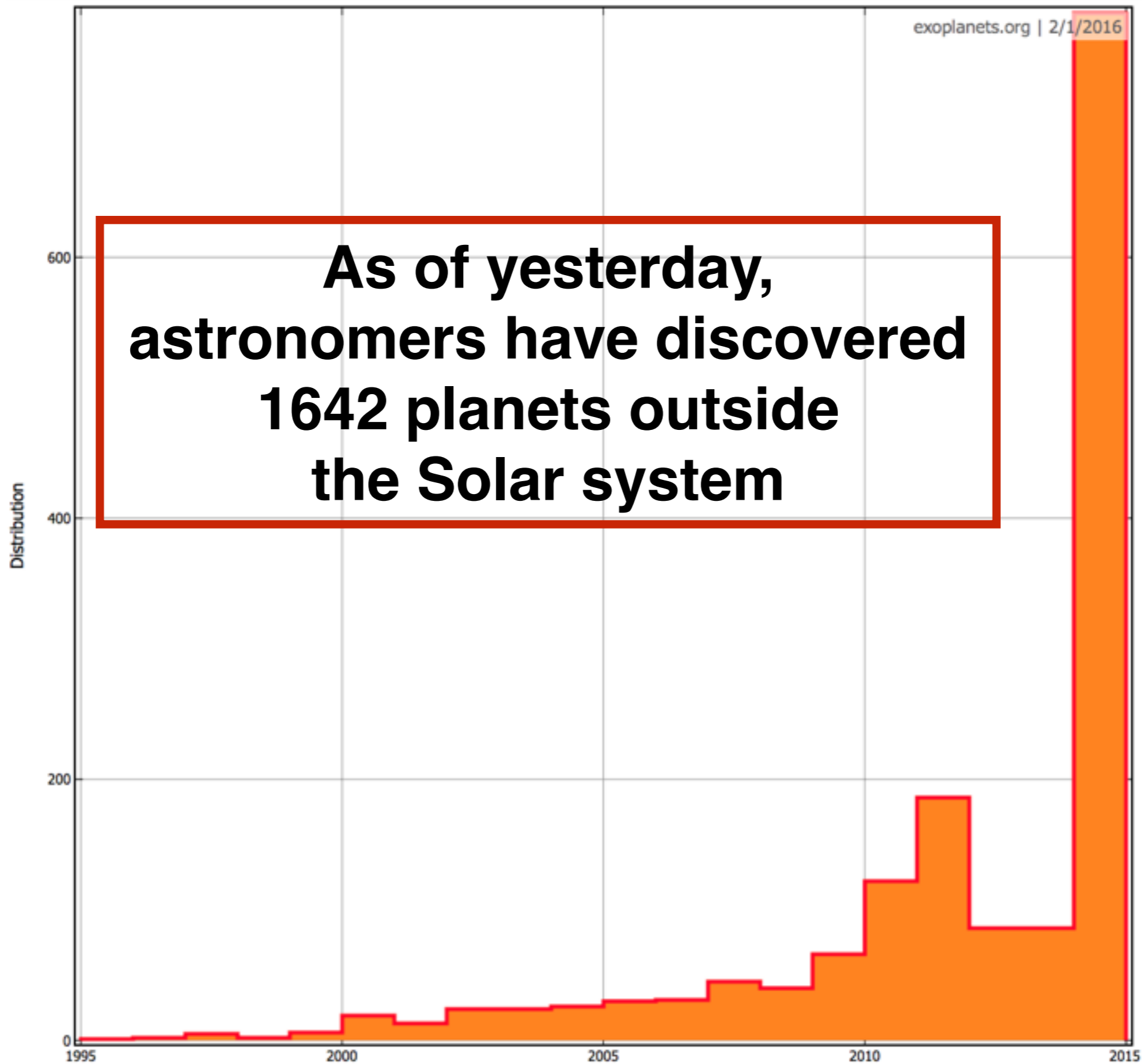
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**The presence of a Jupiter-mass companion to the star 51 Pegasi is inferred from observations of periodic variations in the star's radial velocity. The companion lies only about eight million kilometres from the star, which would be well inside the orbit of Mercury in our Solar System. This object might be a gas-giant planet that has migrated to this location through orbital evolution, or from the radiative stripping of a brown dwarf.**

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# an Explosion of Discoveries



Can we take pictures of these  
planetary systems?

Do they look like  
own Solar System?

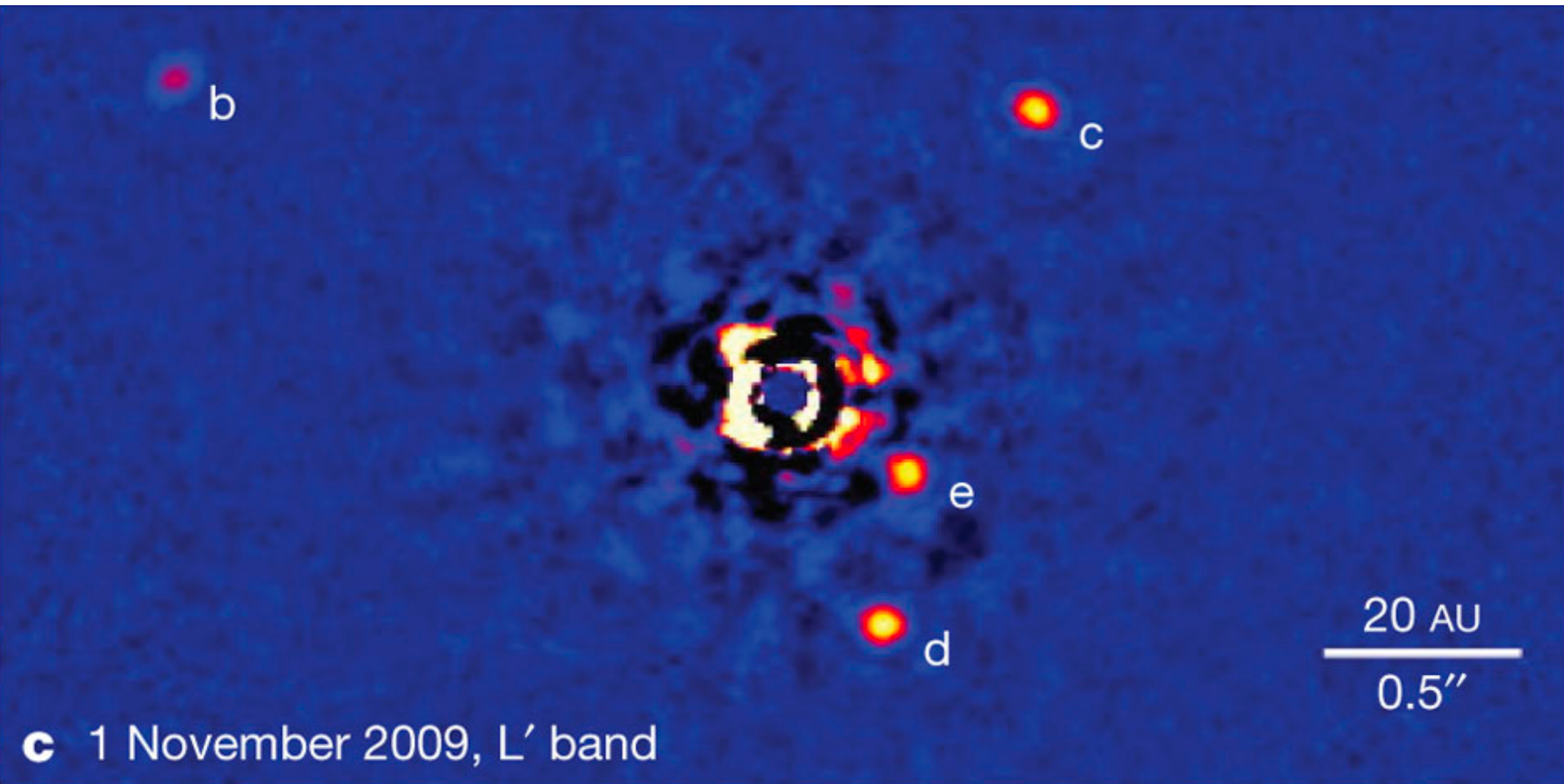
Are these planets habitable?

Can we take pictures of these  
planetary systems?

Do they look like  
own Solar System?

Are these planets habitable?

Only in a few cases and when the planets  
are far away from their star



**c** 1 November 2009, L' band

**HR 8799**

Can we take pictures of these  
planetary systems?

Do they look like  
own Solar System?

Are these planets habitable?



Not really !



Kepler 186f is the first Earth-size planet discovered in the potentially habitable zone<sup>1</sup> around another star, where liquid water could exist on the planet's surface. Its star is much cooler and redder than our Sun. If plant life does exist on a planet like Kepler 186f, its photosynthesis could have been influenced by the star's red wavelength photons, making for a color palette that's very different than the greens on Earth. This discovery was made by Kepler, NASA's planet-hunting space telescope.

Can we take pictures of these  
planetary systems?

Do they look like  
own Solar System?

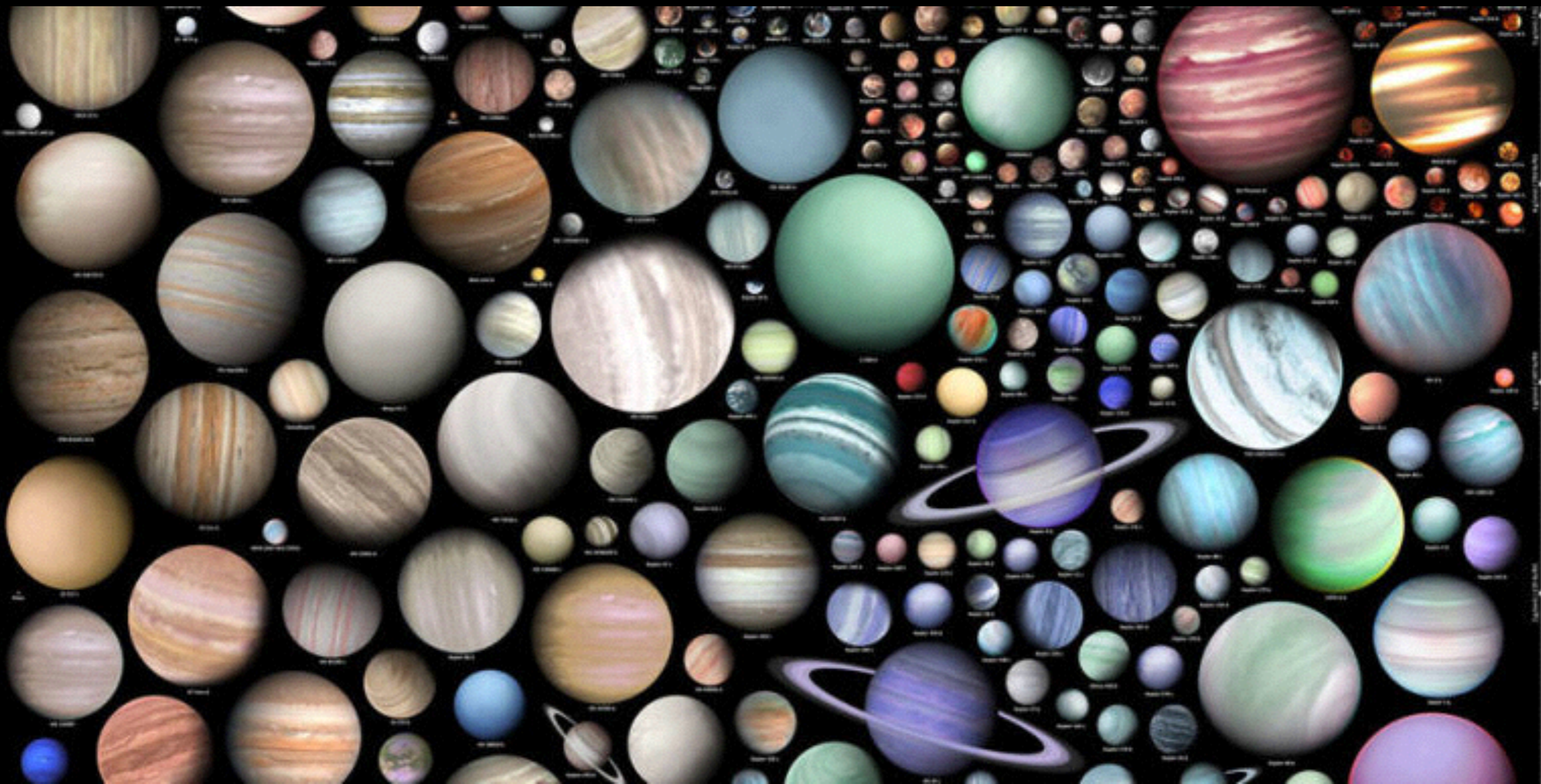
Are these planets habitable?

Most of them  
are not! They  
are either too  
cold or too hot.

A few might be  
habitable!

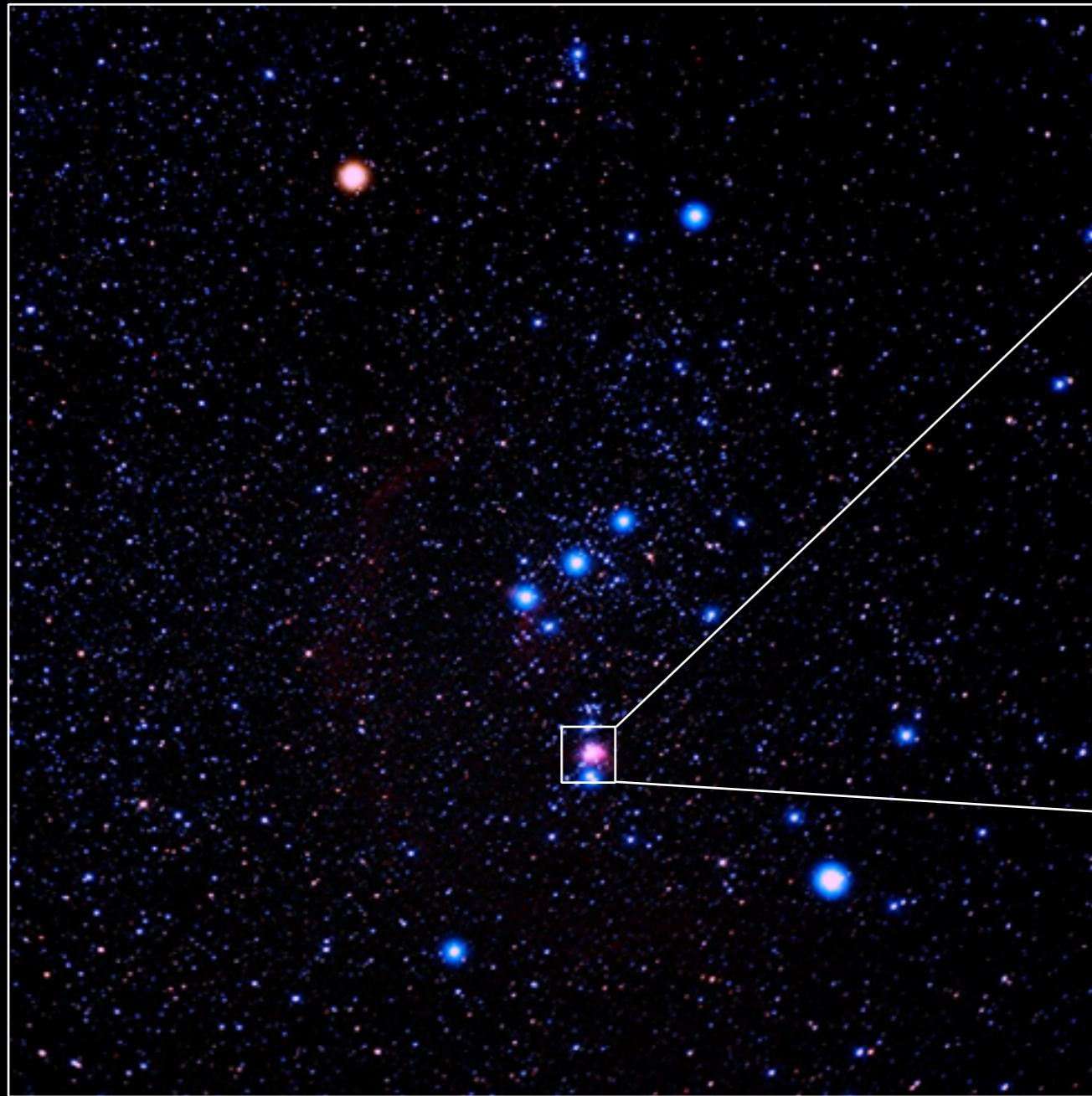


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How do planets form?

# A Planet Nursery



Orion Nebula

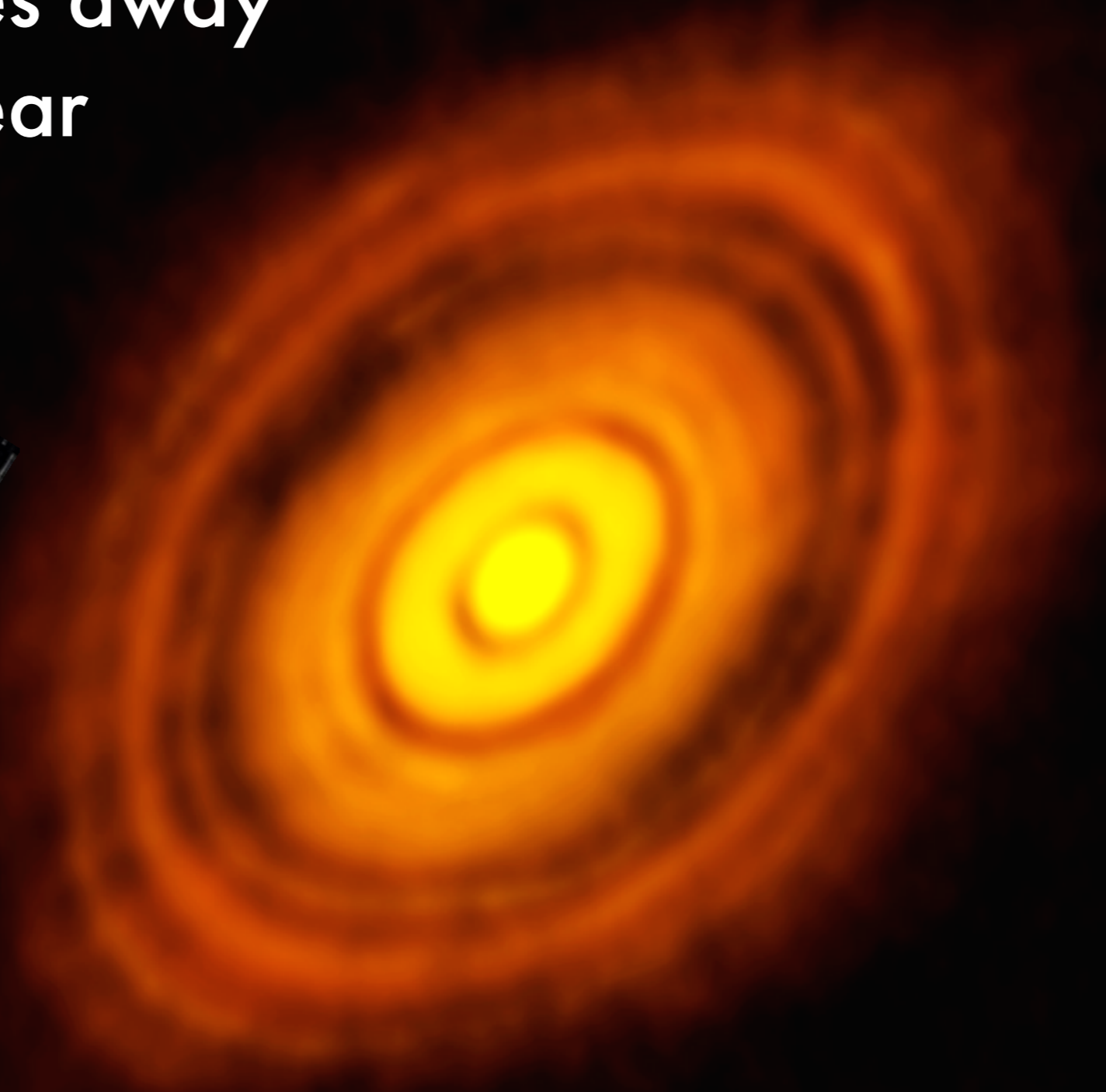


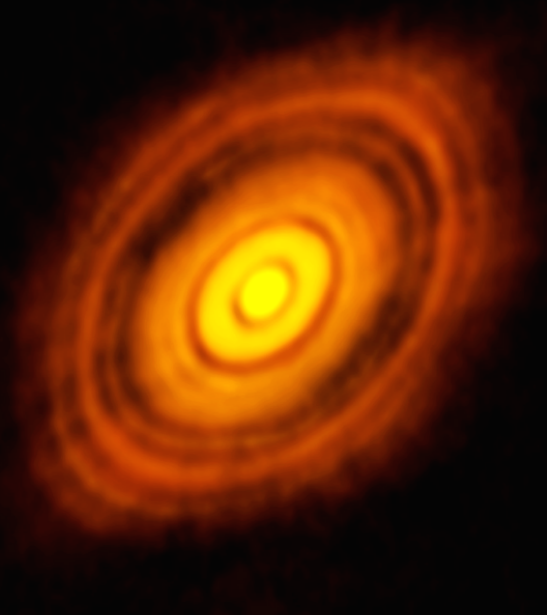
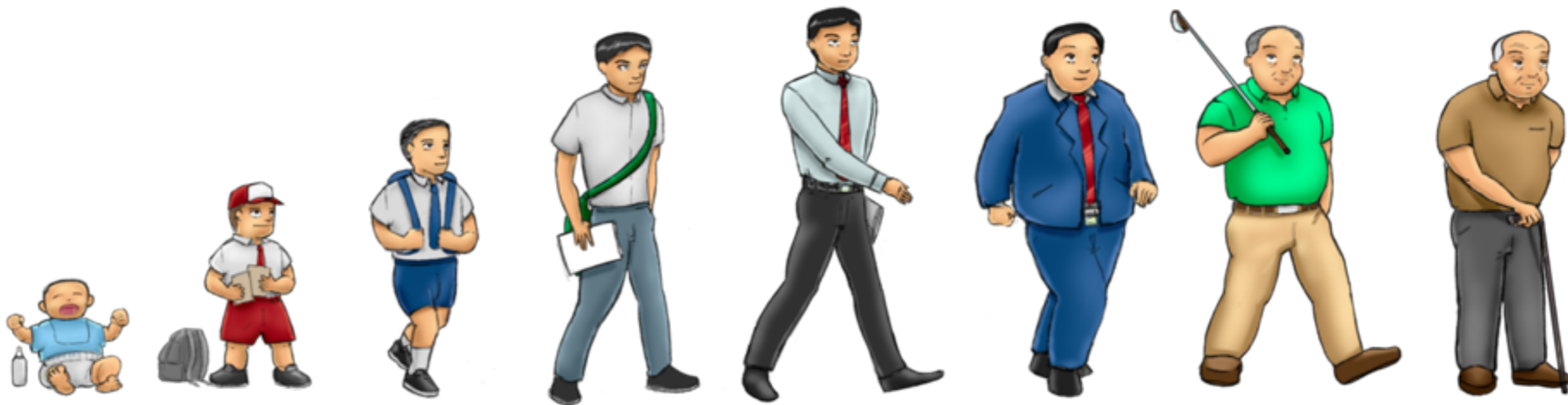
# HL Tau

400 light years away

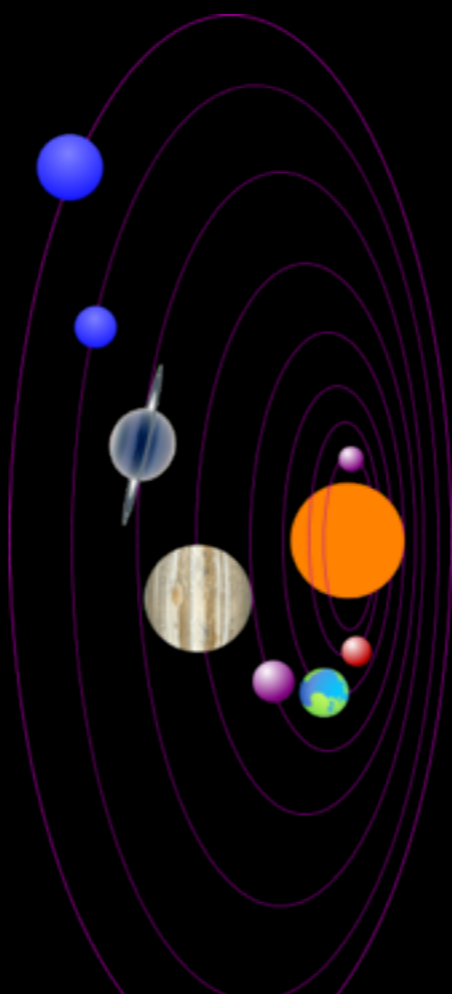
20000000000000000 miles away

age? less than 1 million year

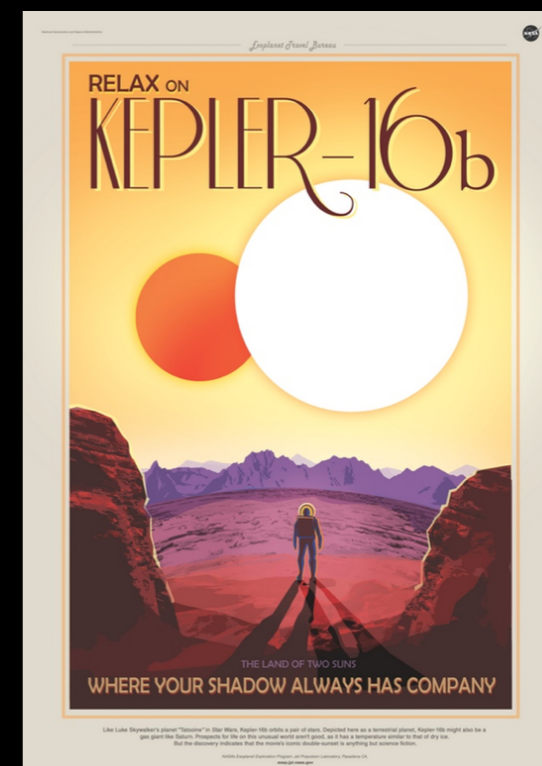




1 Million years

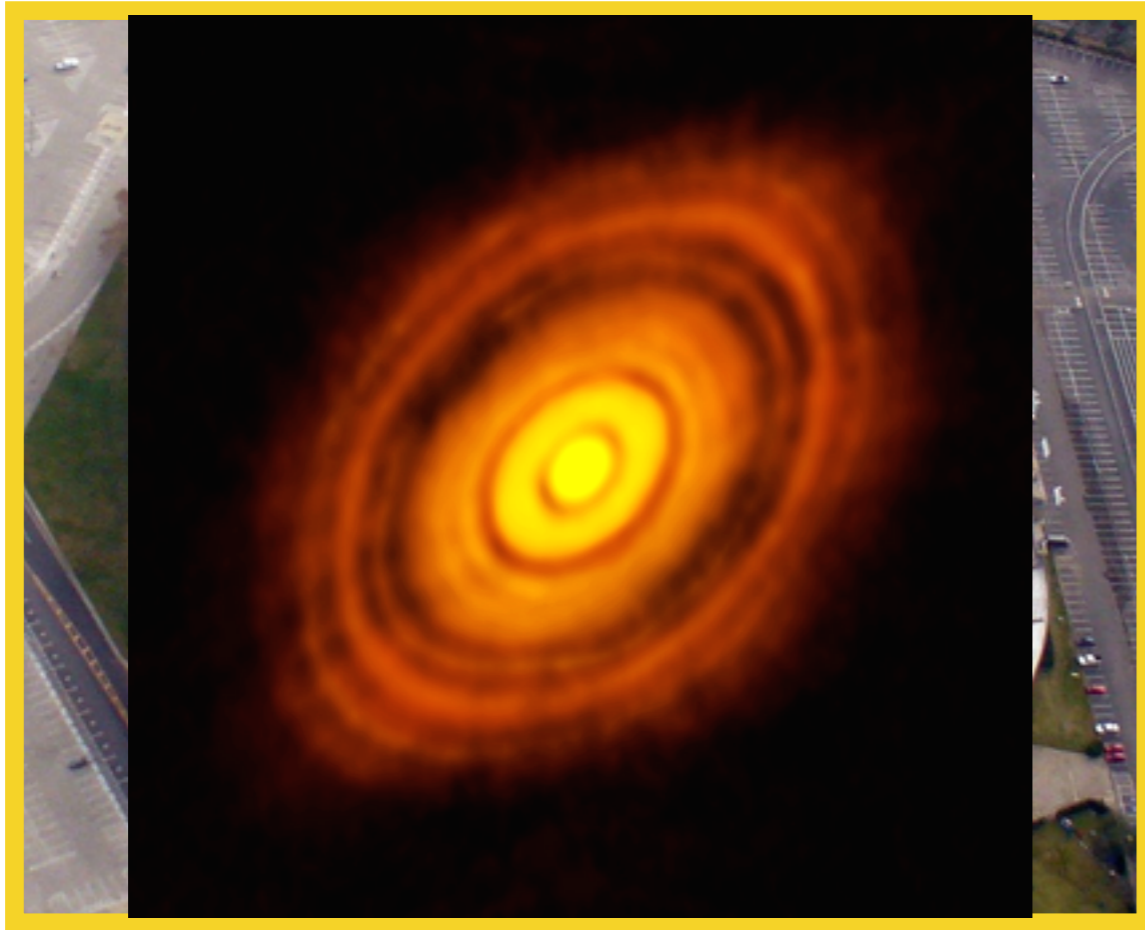


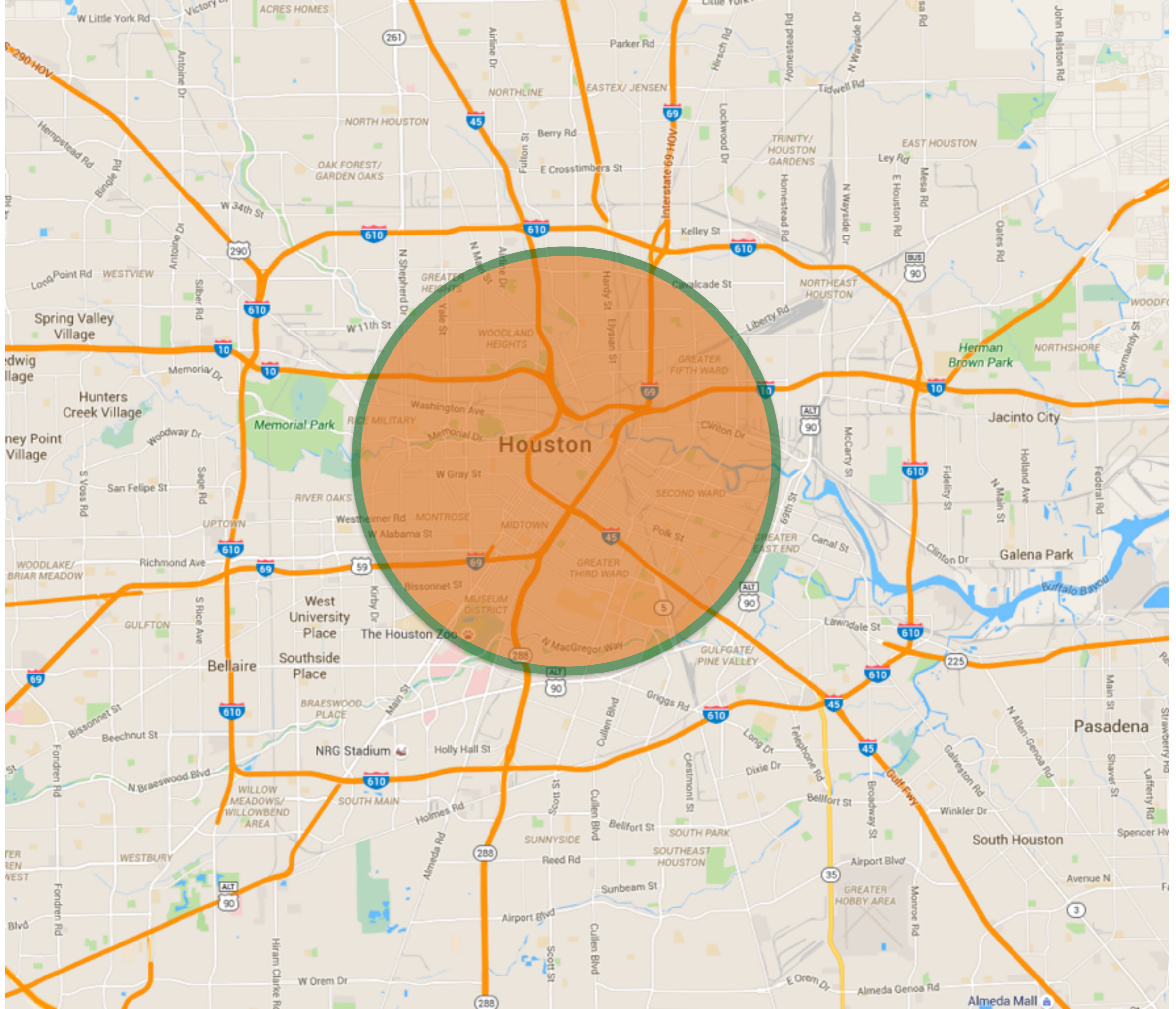
4.6 Billion years





# Tiny tiny!

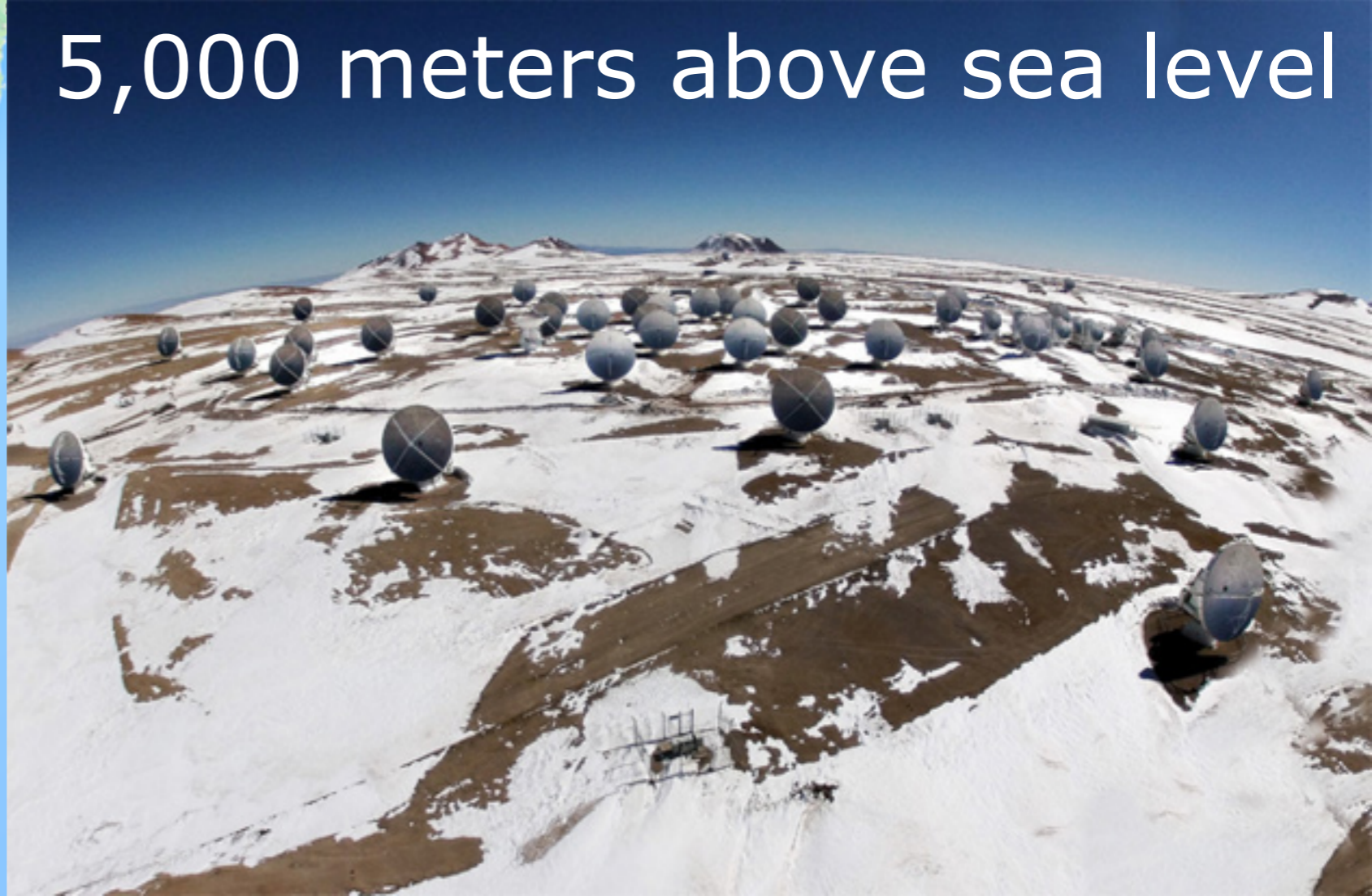
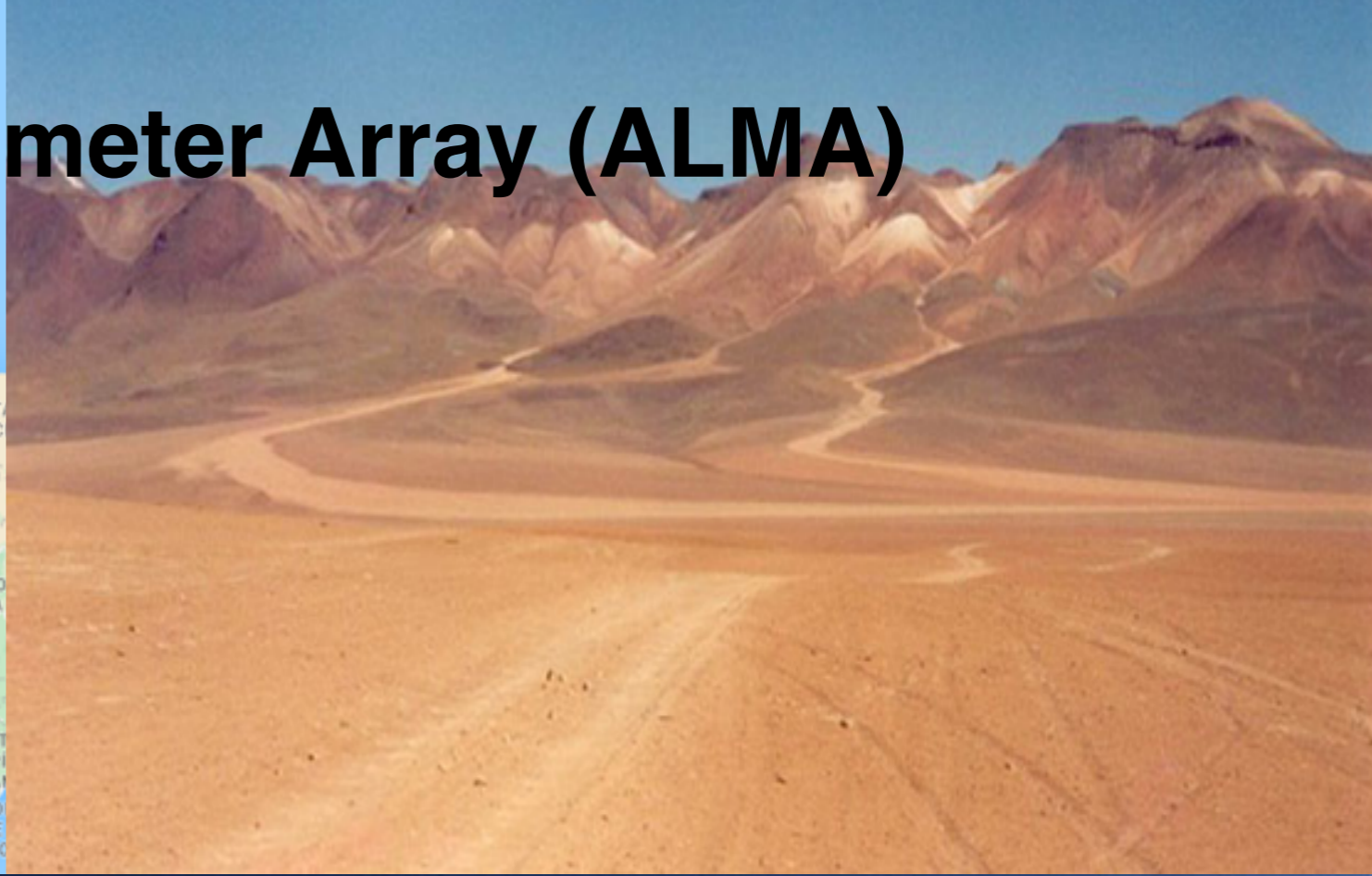




# The Atacama Large Millimeter Array (ALMA)



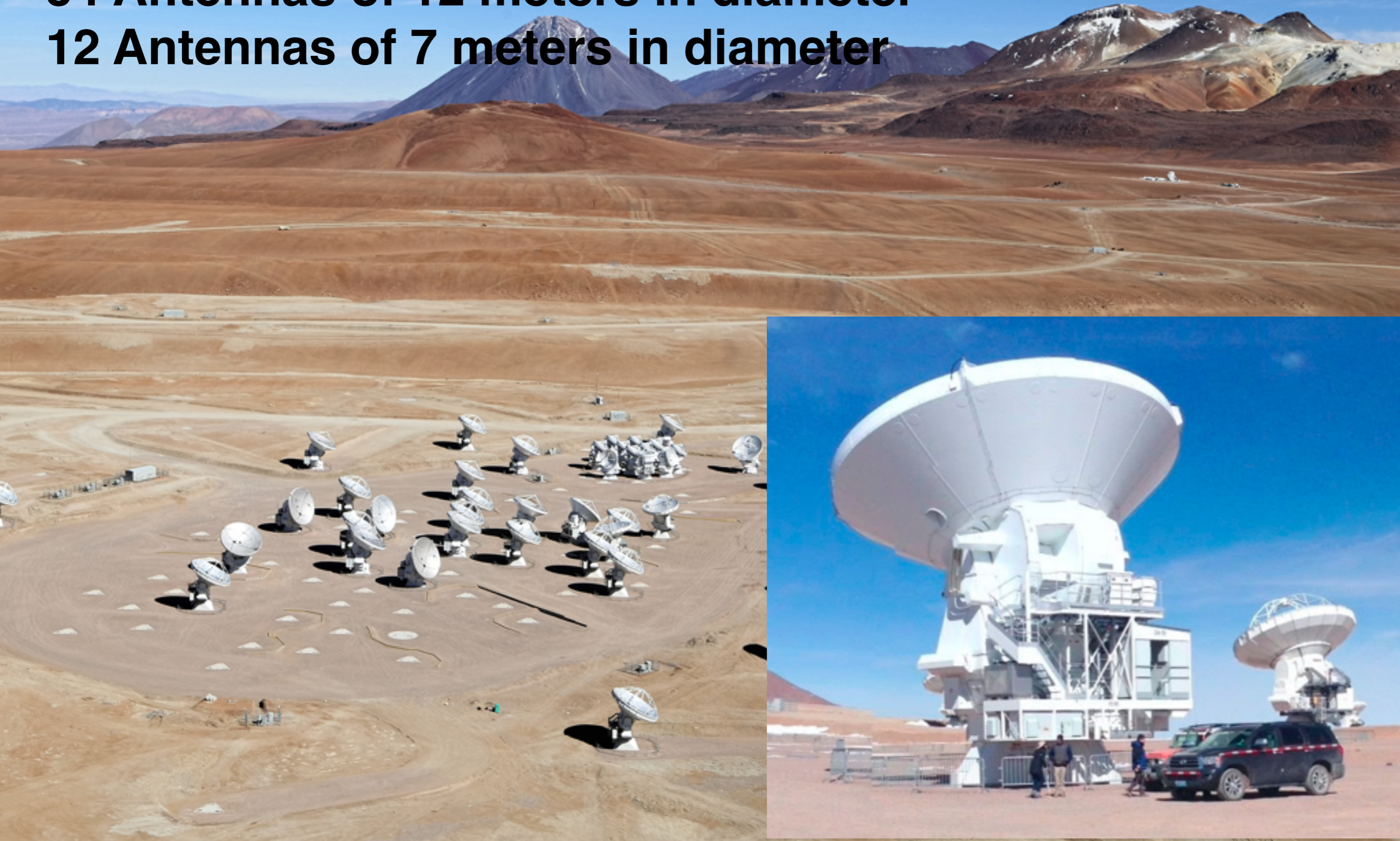
# The **Atacama** Large Millimeter Array (ALMA)



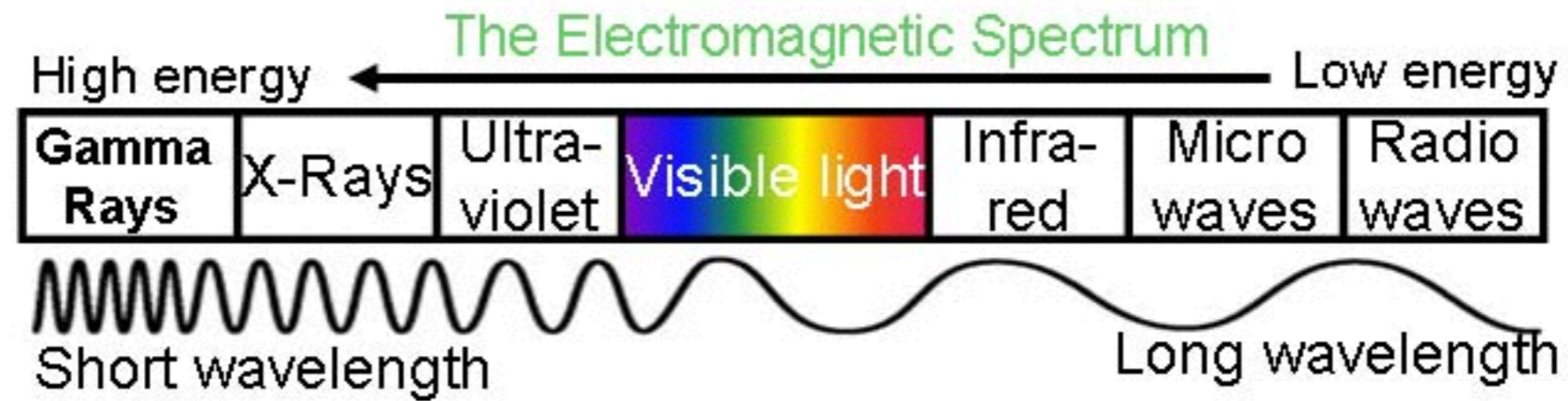
5,000 meters above sea level

# The Atacama **Large** Millimeter **Array** (ALMA)

**54 Antennas of 12 meters in diameter**  
**12 Antennas of 7 meters in diameter**



# The Atacama Large **Millimeter** Array (ALMA)



**ALMA observes light at wavelengths between 0.2 mm to 3 mm.**

**We cannot see this light with our eyes!**



# The Atacama Large Millimeter Array (ALMA)



NRAO = National Radio Astronomy Observatory

NSF = National Science Foundation

US Tax Payers !

# The Atacama Large Millimeter Array (ALMA)

NSF contribution: \$0.5 B over 11 years + \$34 M yearly  
\$0.3 per US tax payer PER YEAR over a period of 15 years



ALMA Science Portal at NRAO



ALMA Science Portal at ESO

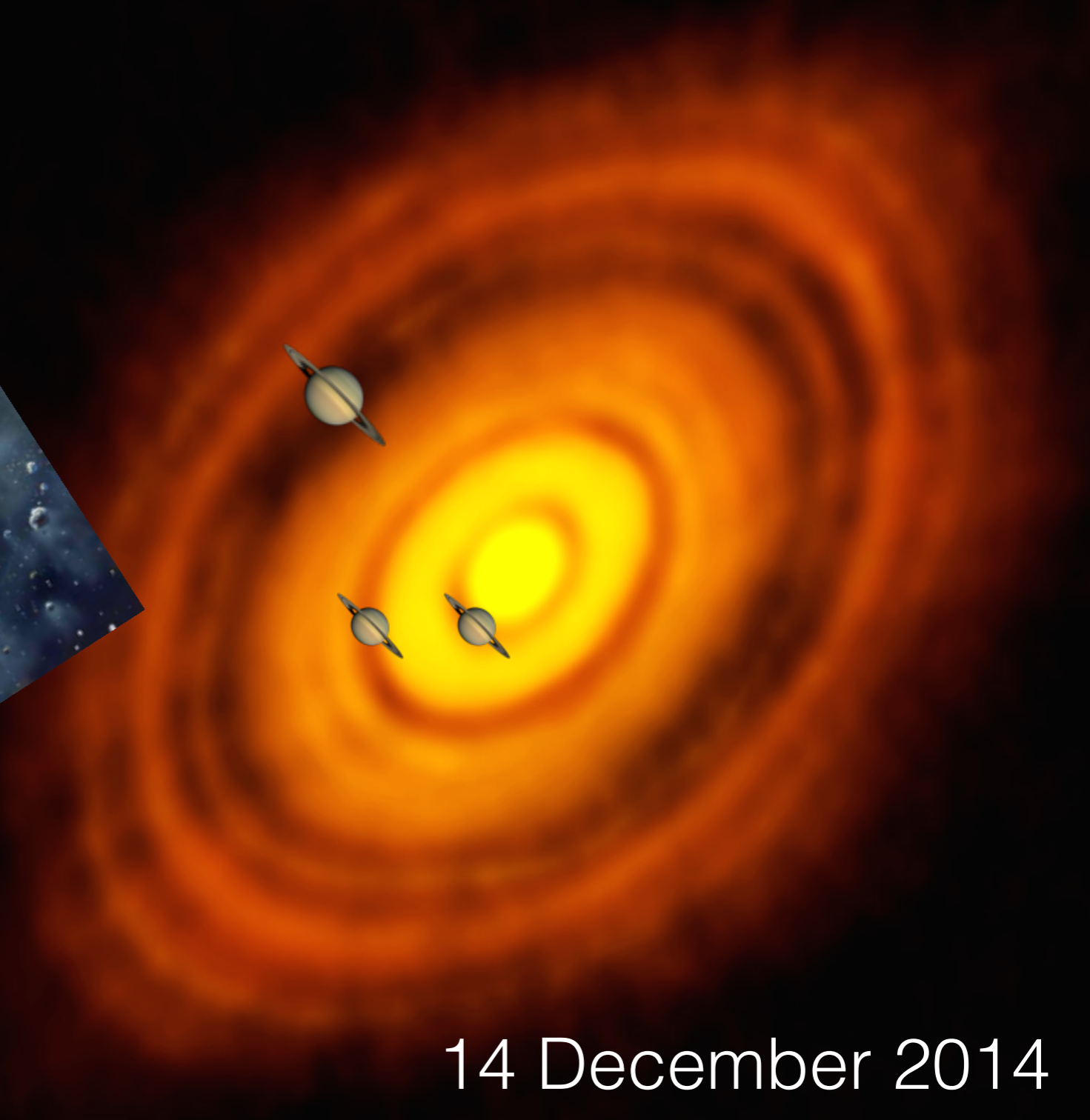
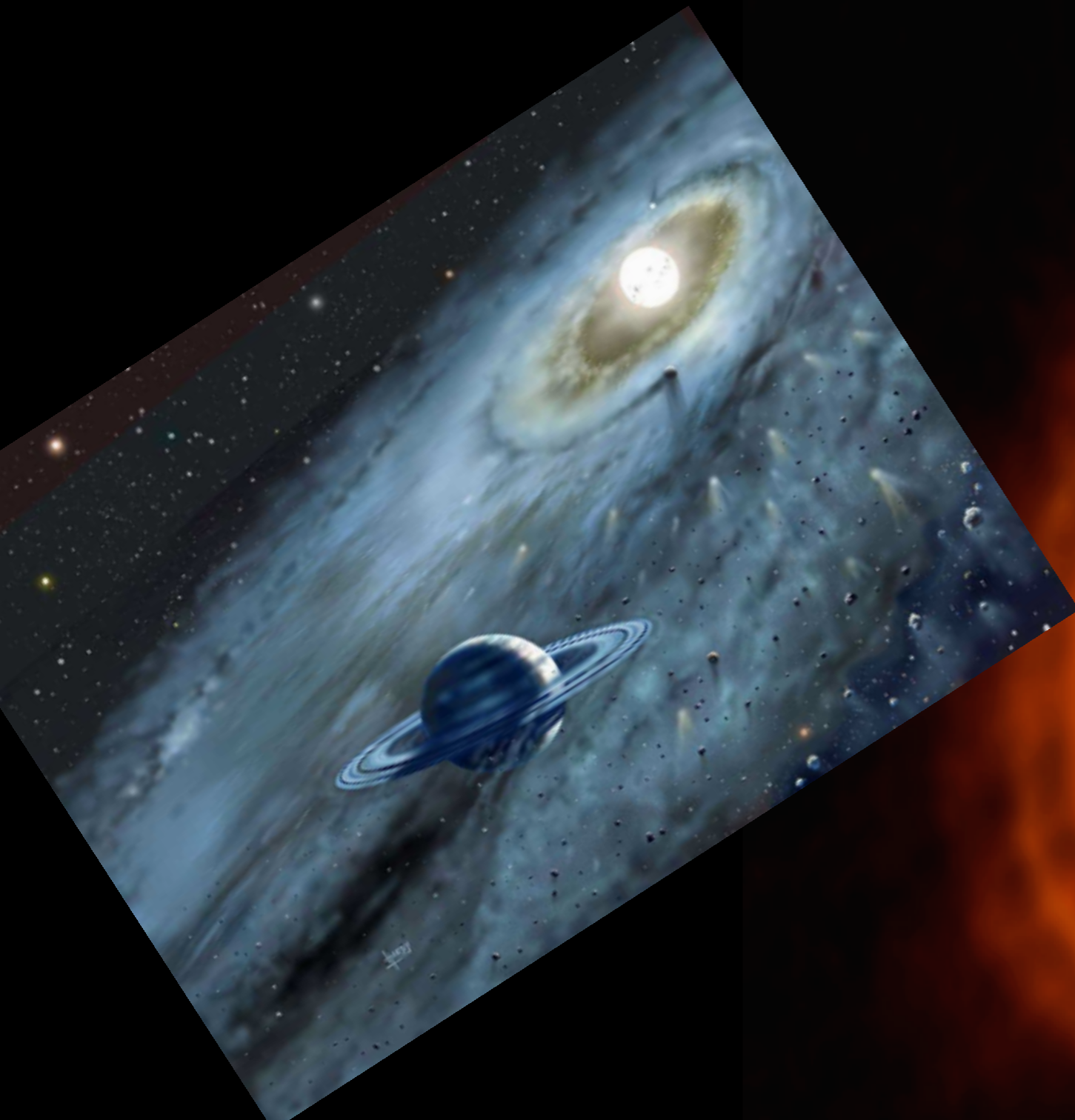


ALMA Science Portal at NAOJ

NRAO = National Radio Astronomy Observatory  
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US Tax Payers !



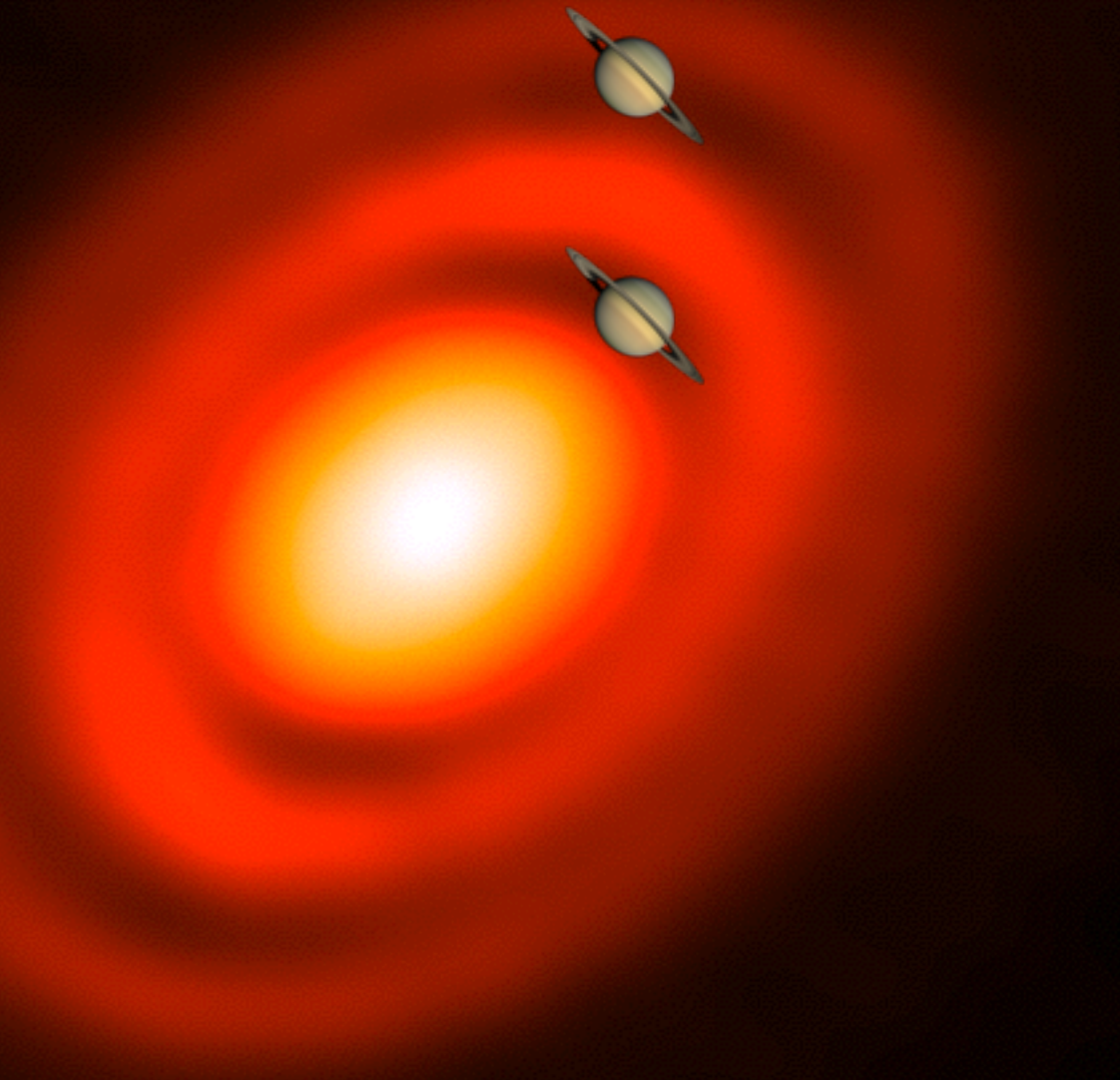
# HL Tau: A new born planetary system



14 December 2014

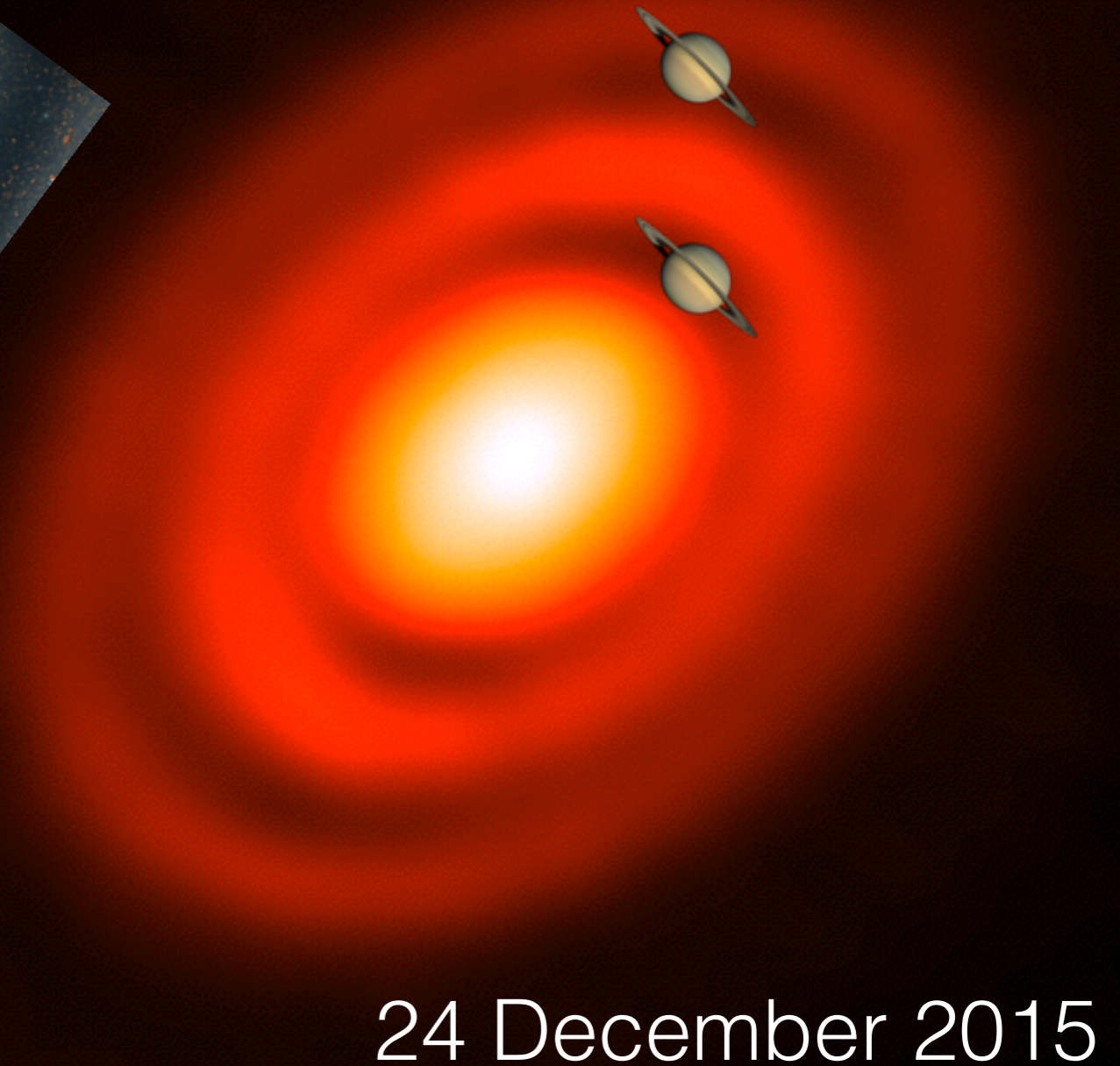
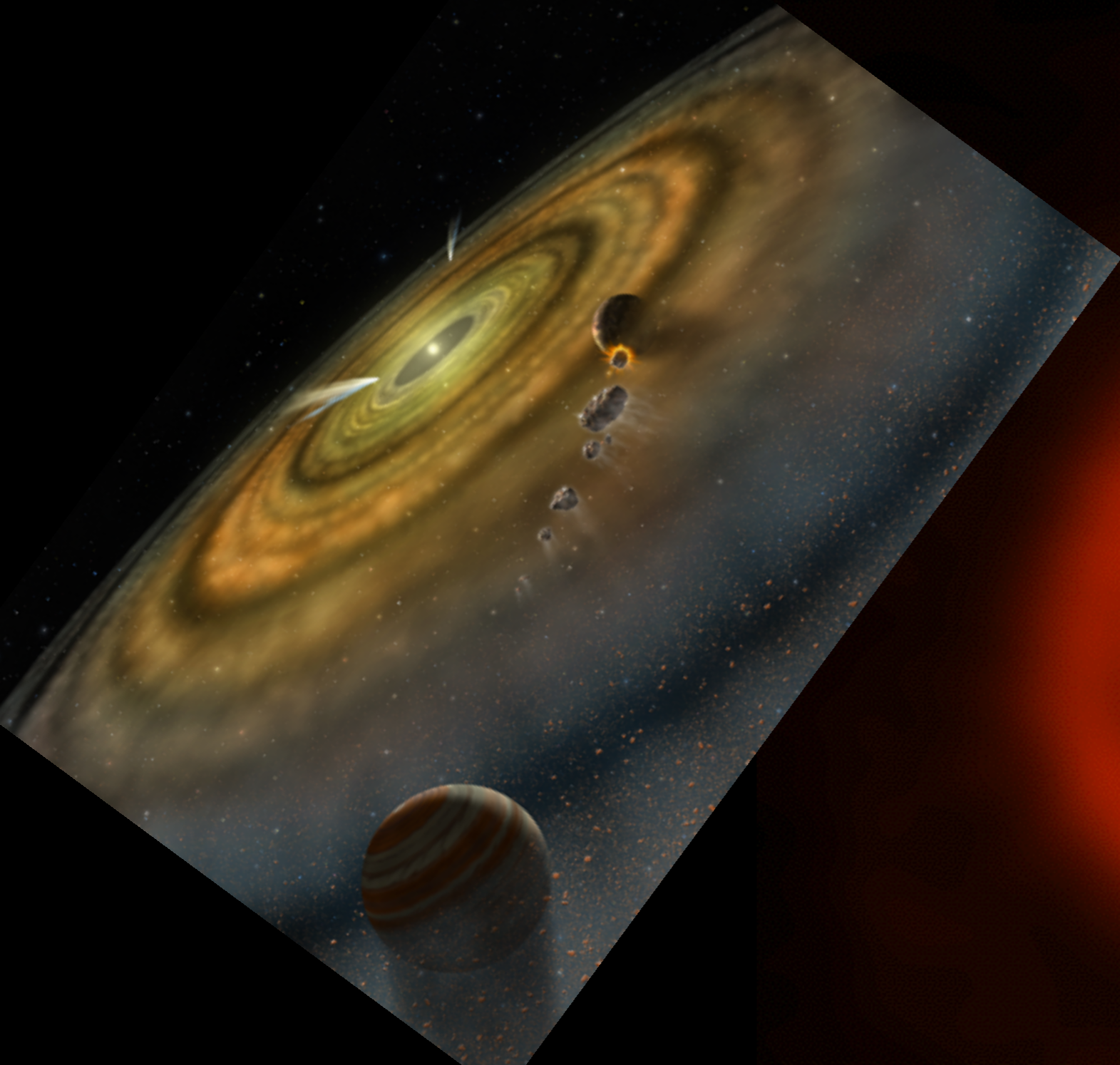


# HD 163296: A new born planetary system



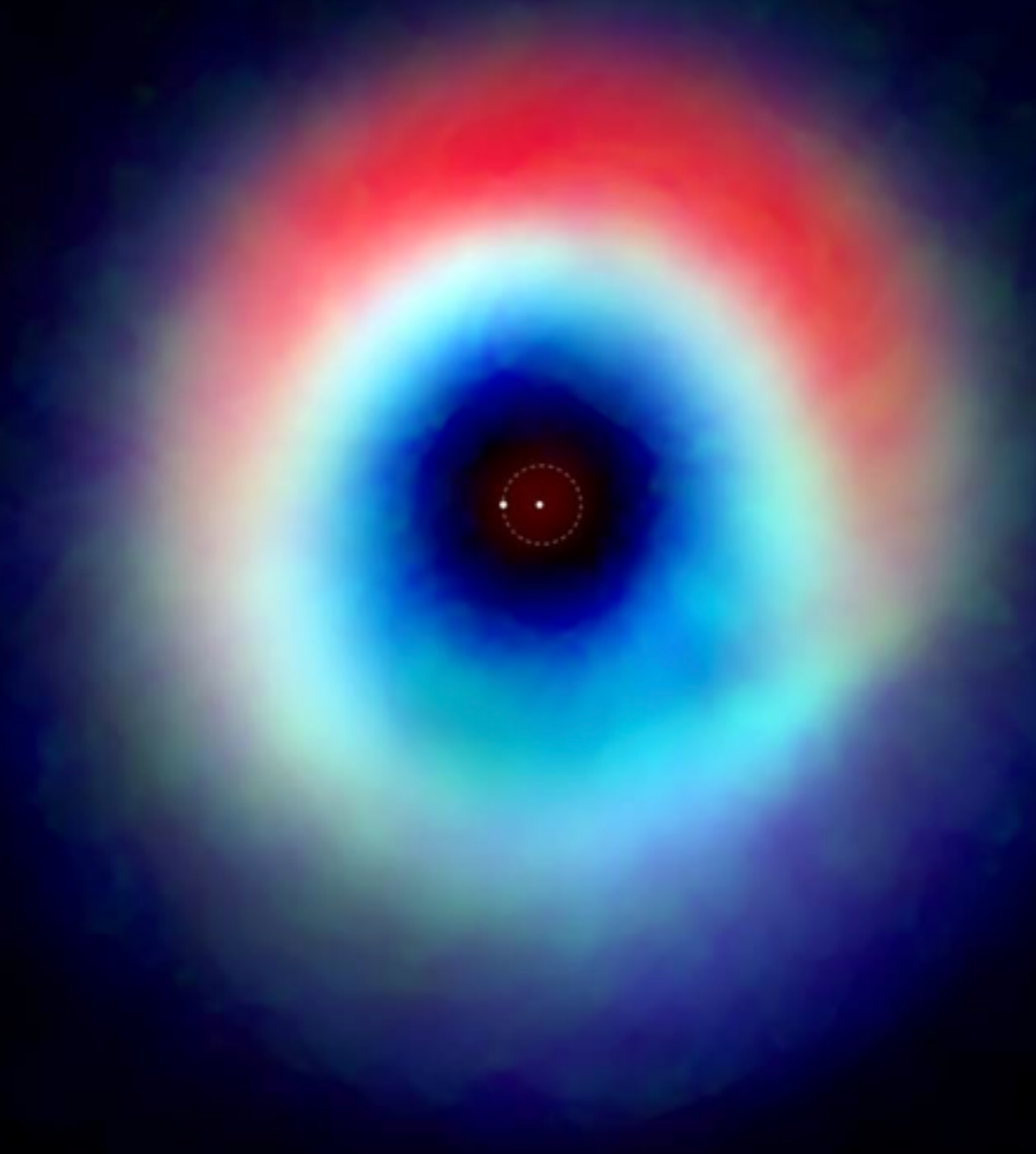
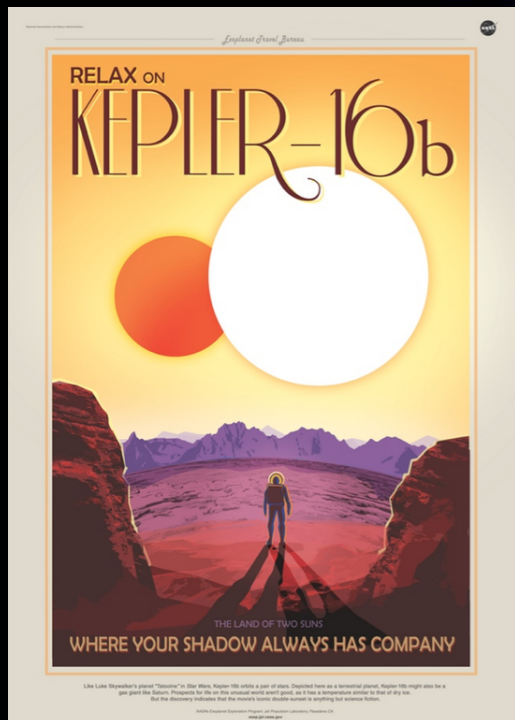
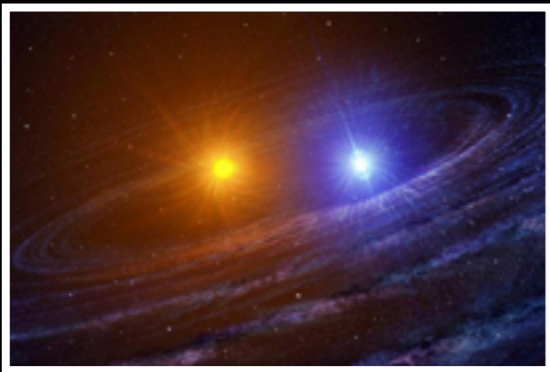
24 December 2015

# HD 163296: A new born planetary system

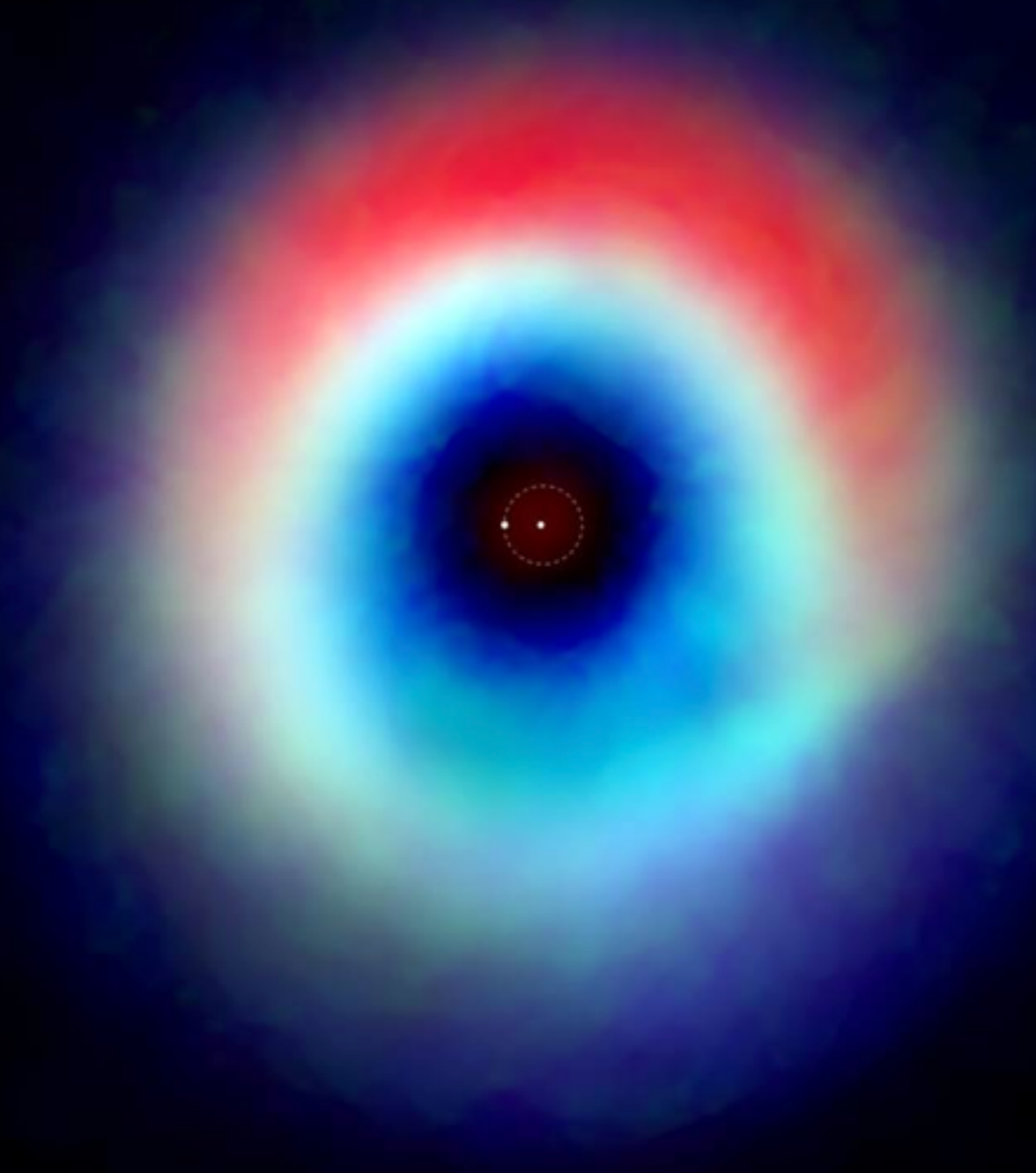
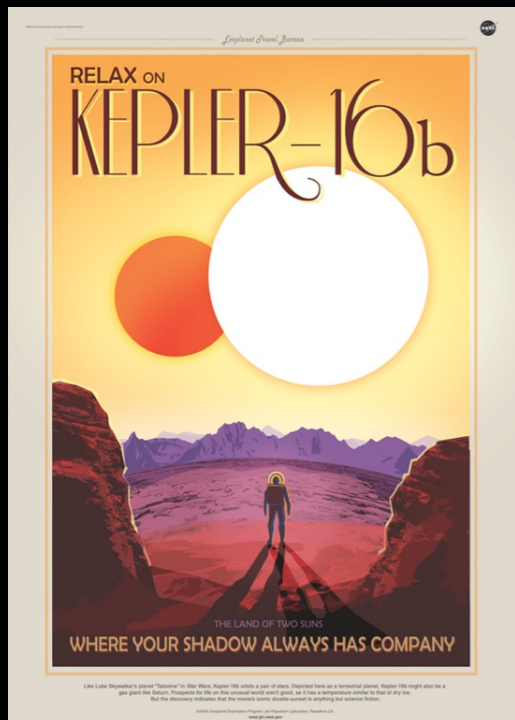


24 December 2015

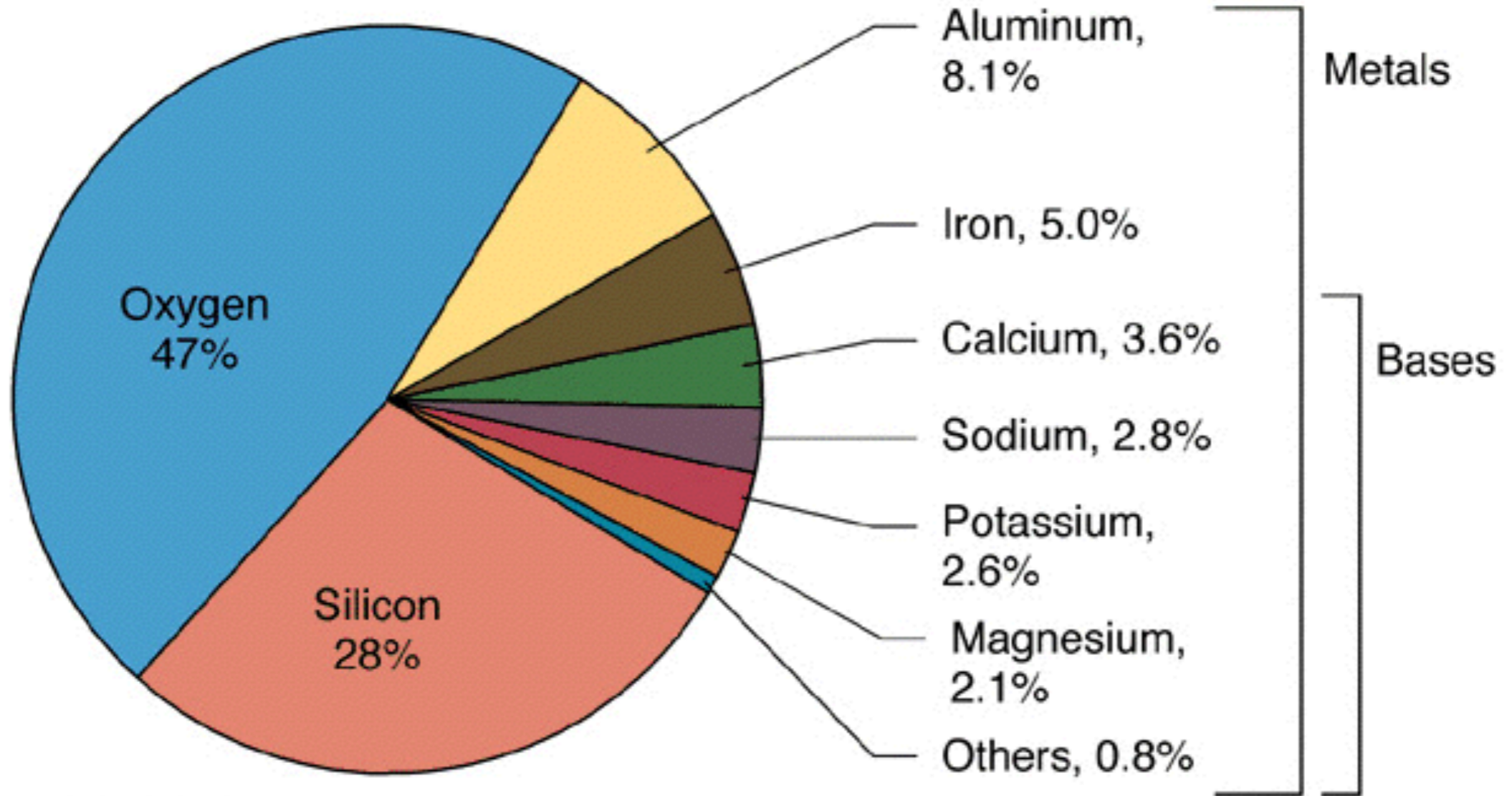
# HD 142527: A planetary system in formation around a binary star



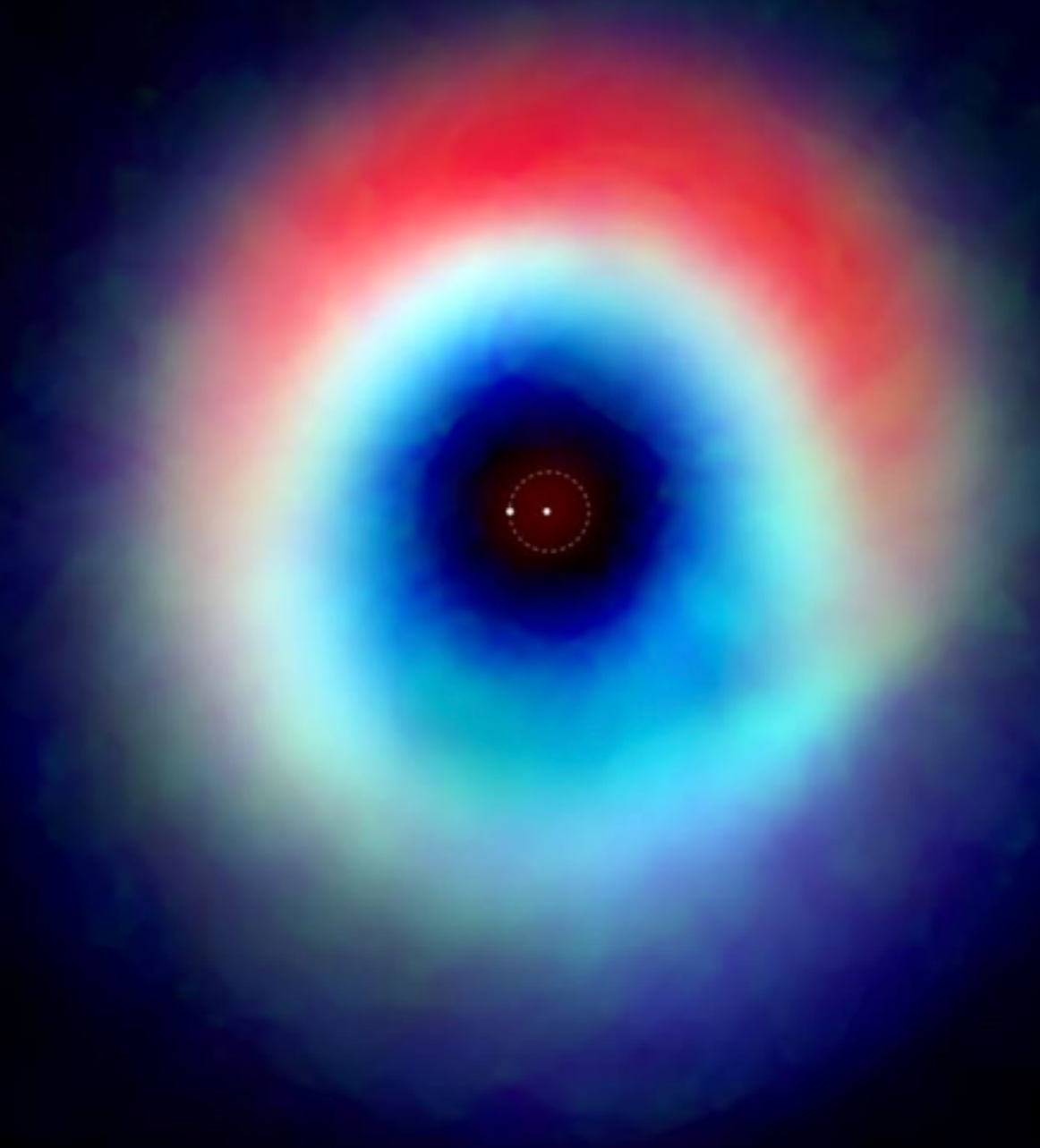
# HD 142527: A planetary system in formation around a binary star



# The Composition of the Earth crust

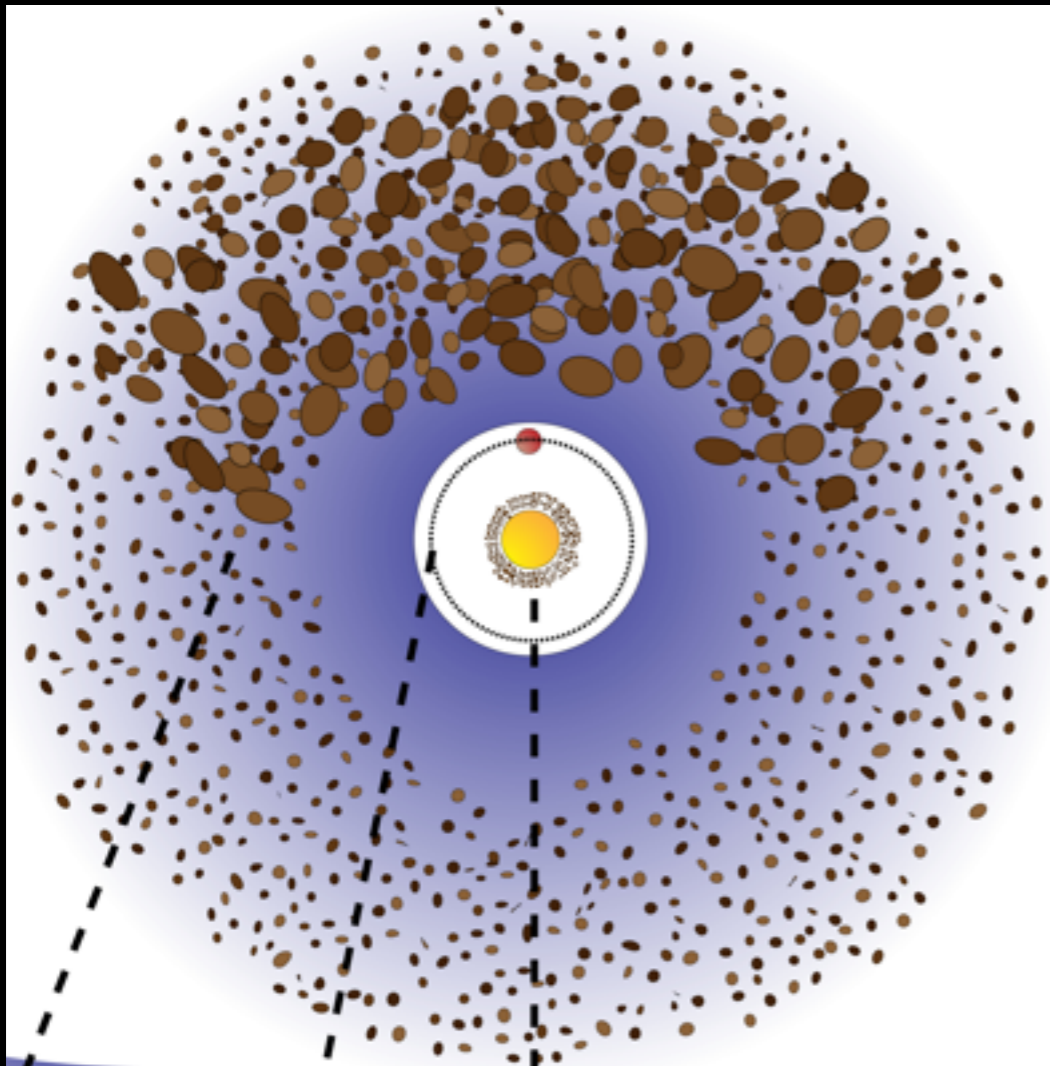


# HD 142527: A planetary system in formation around a binary star



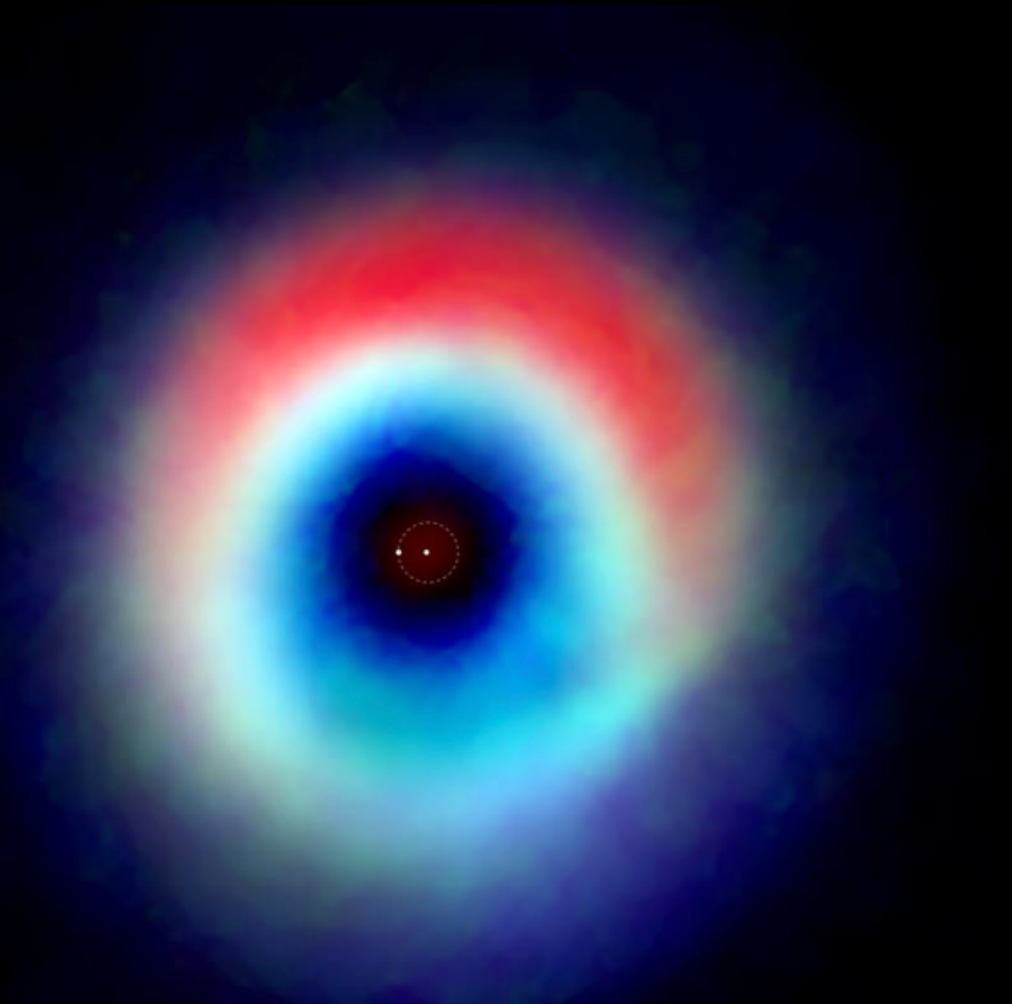
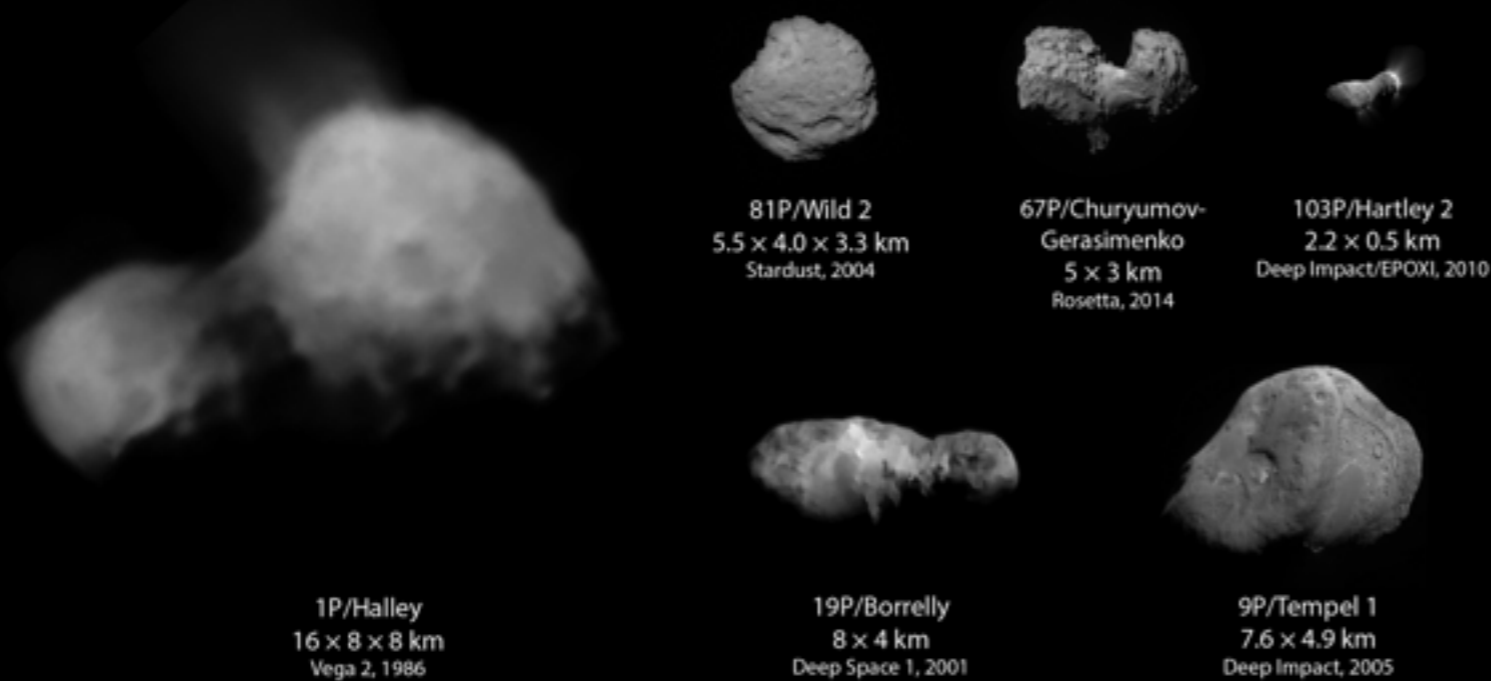


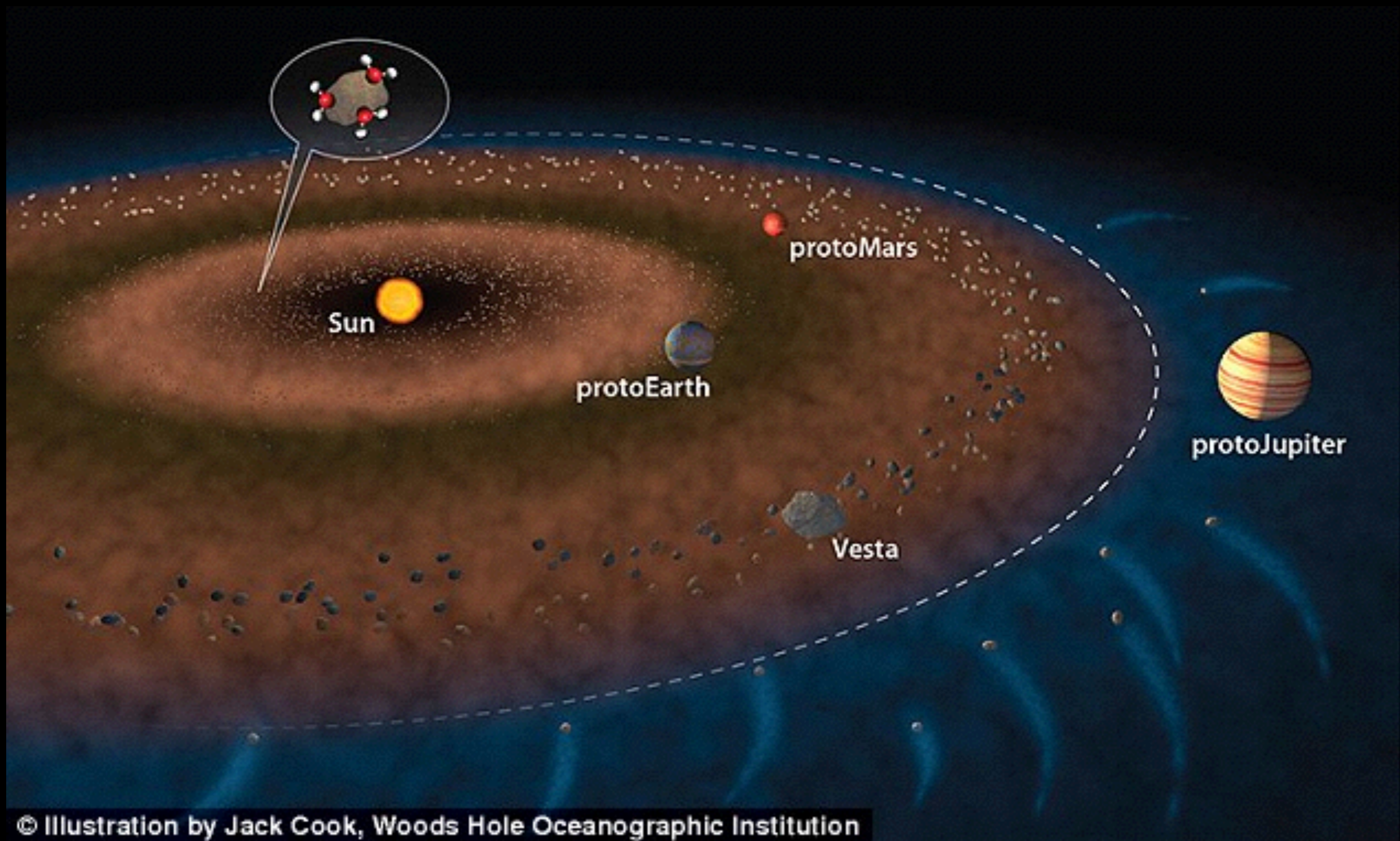
# HD 142527: A planetary system in formation around a binary star



# HD 142527: A planetary system in formation around a binary star

## COMETS VISITED BY SPACECRAFT





© Illustration by Jack Cook, Woods Hole Oceanographic Institution

**Thank you!**