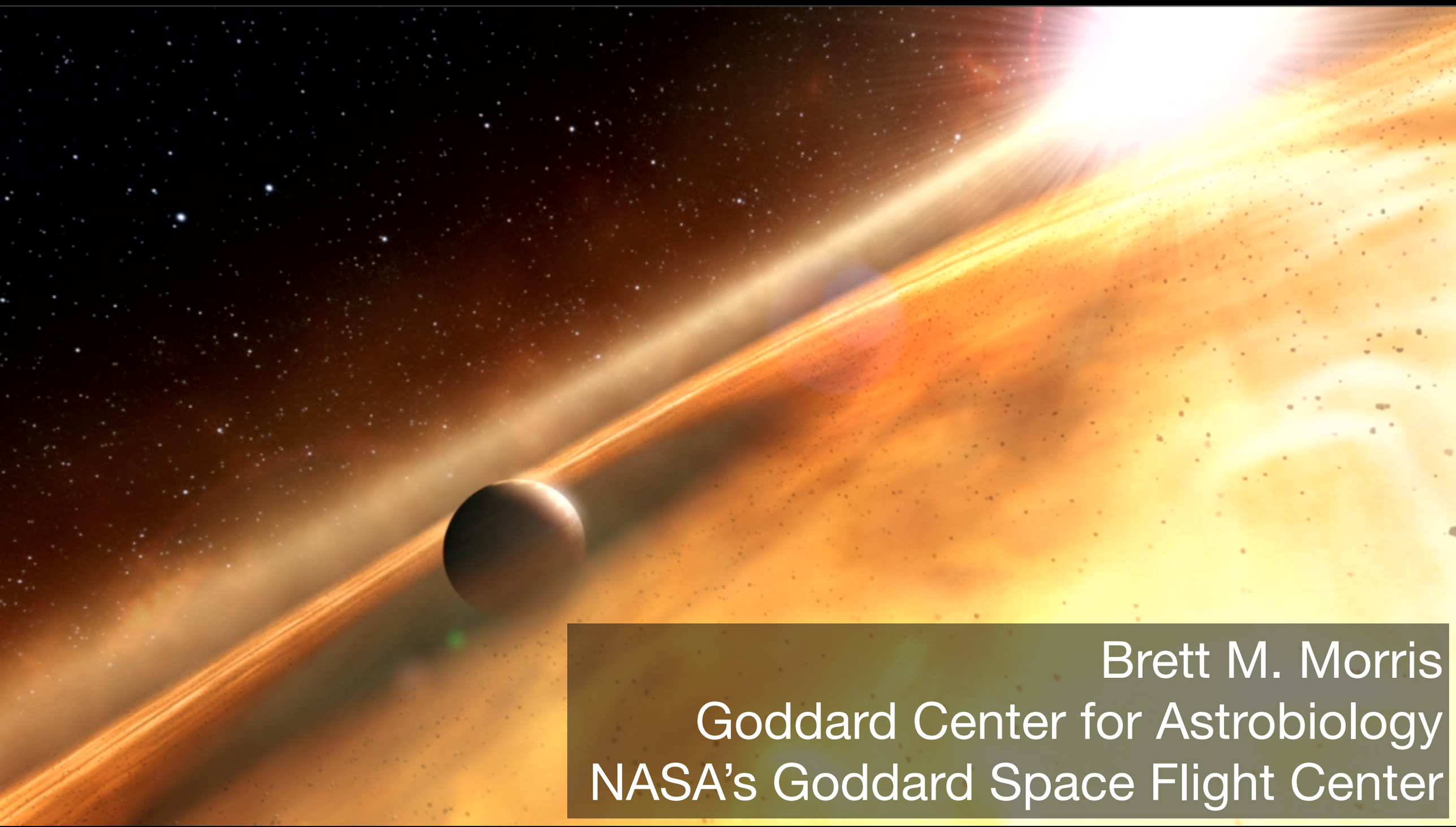
Exoplanets: How to find them and their inhabitants

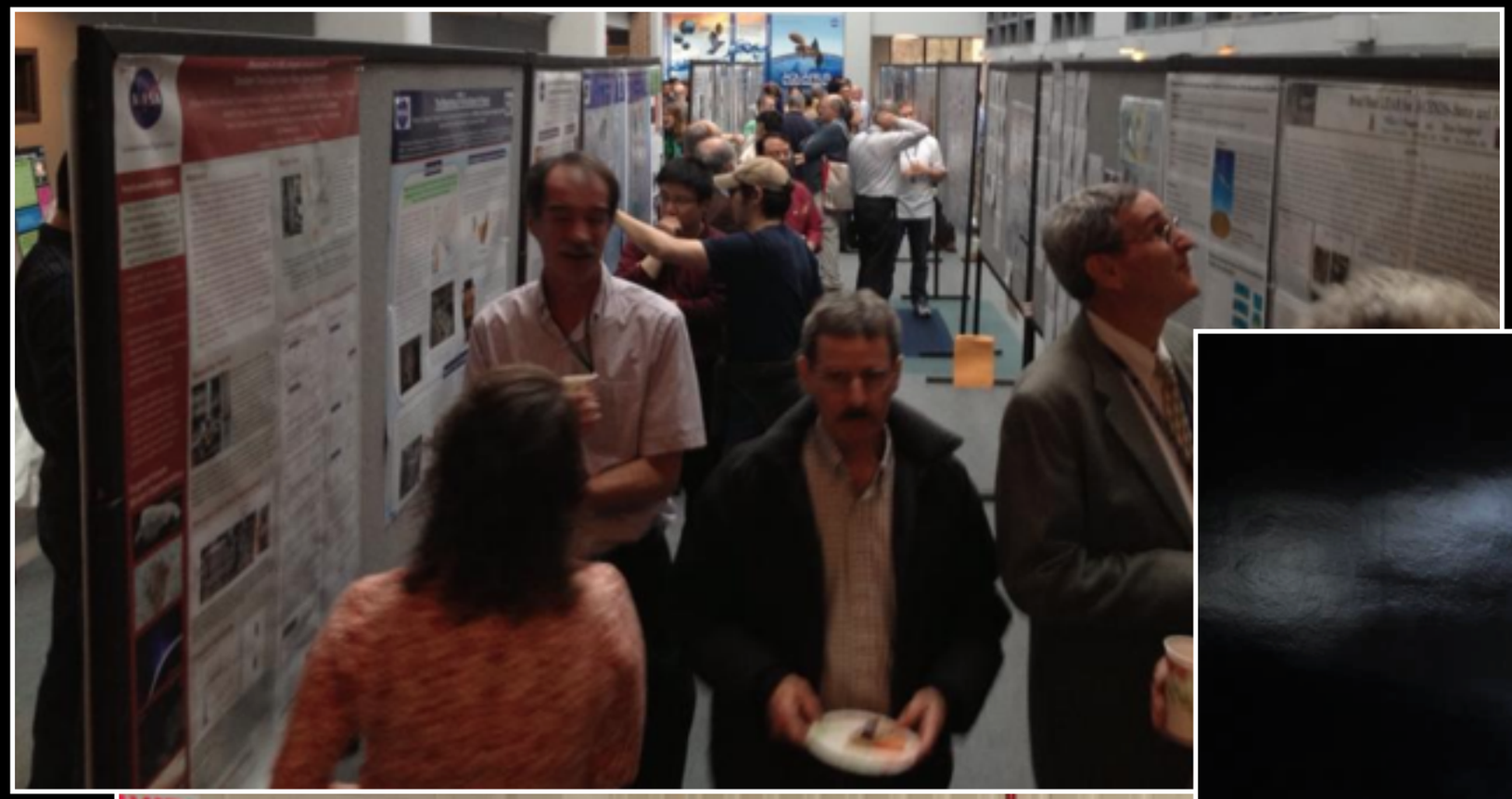


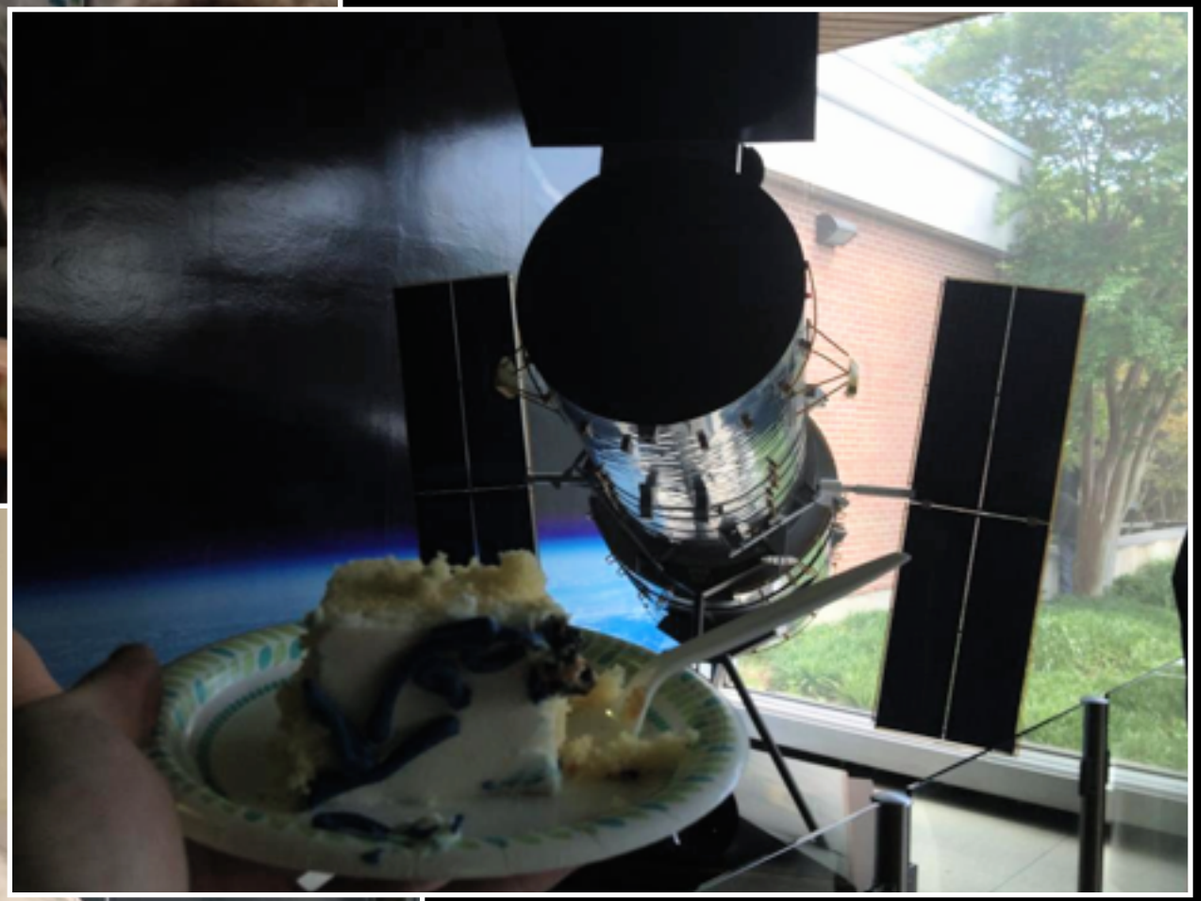
Brett M. Morris
Goddard Center for Astrobiology
NASA's Goddard Space Flight Center

KOPERNIK

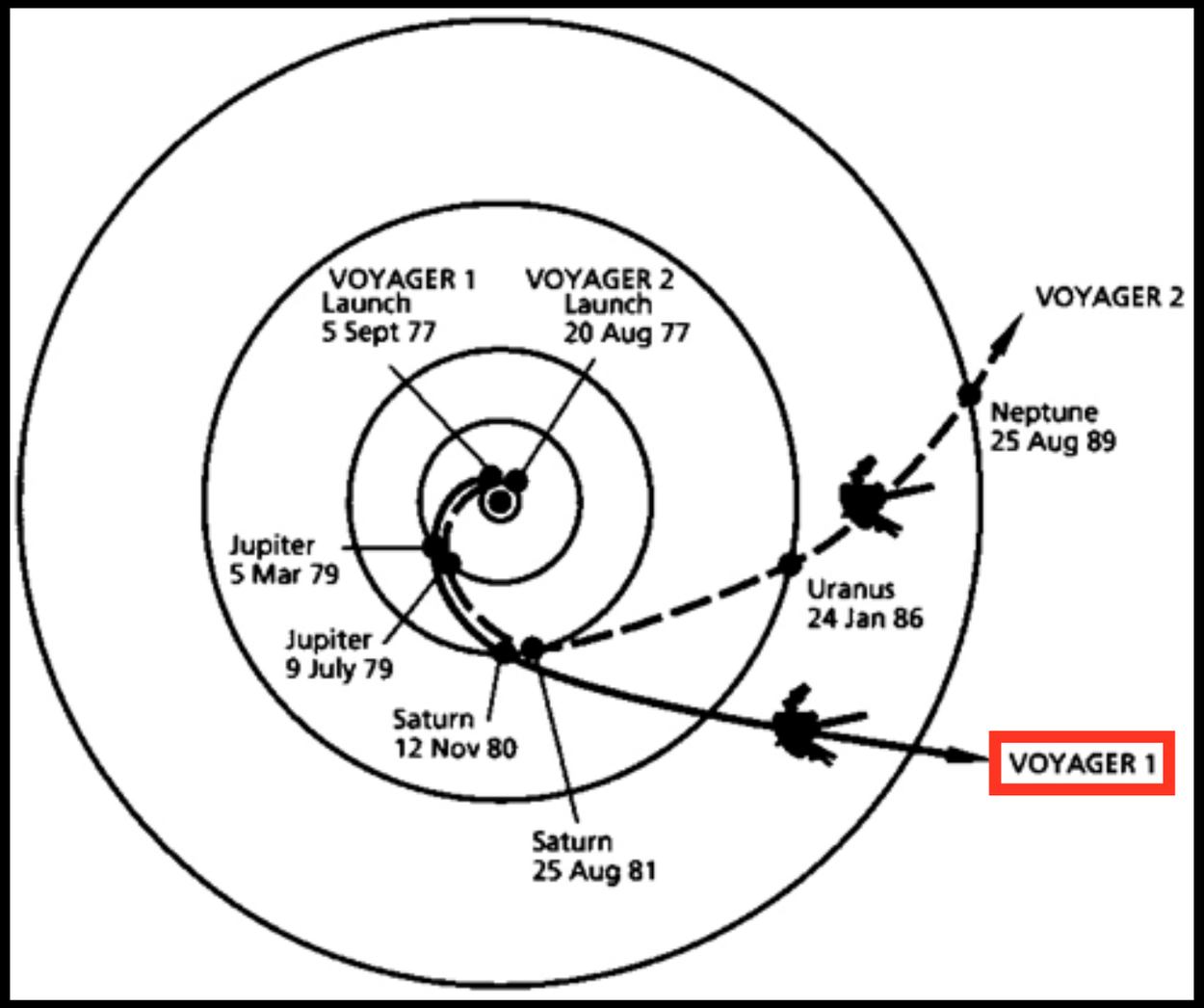
Kopernik Alum 2006 & 2007


AÉROPOSTALE

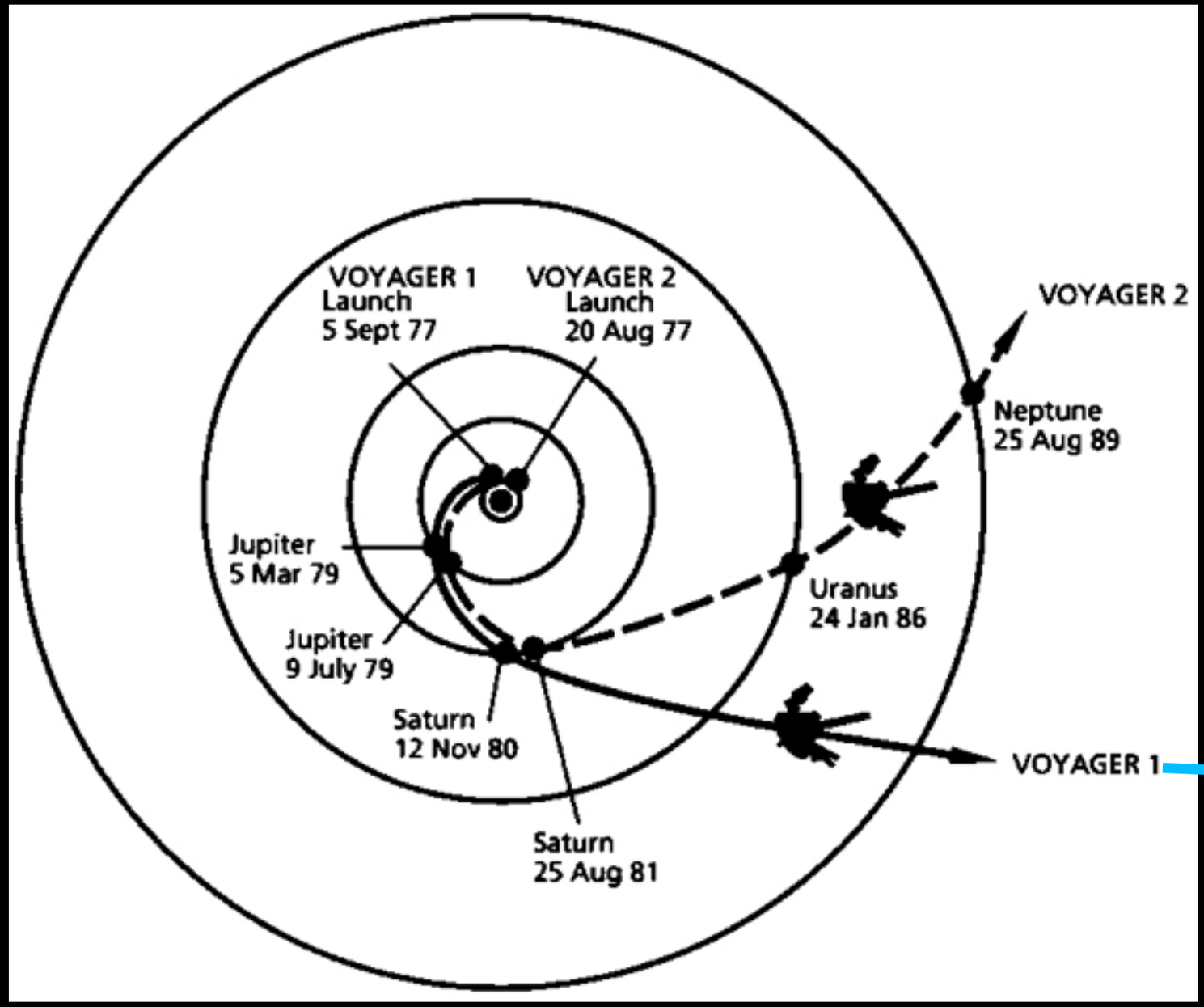




MOTIVATION



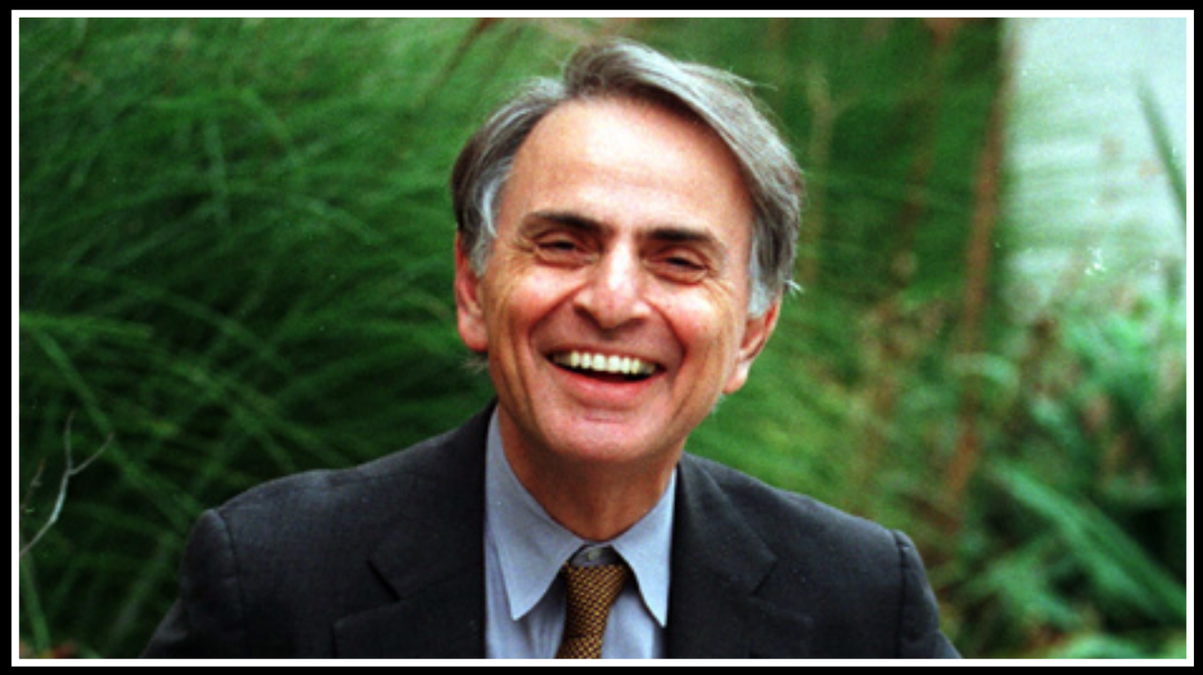
Voyager 1 left Earth on Sept 5 1977
and *flew by* Jupiter and Saturn



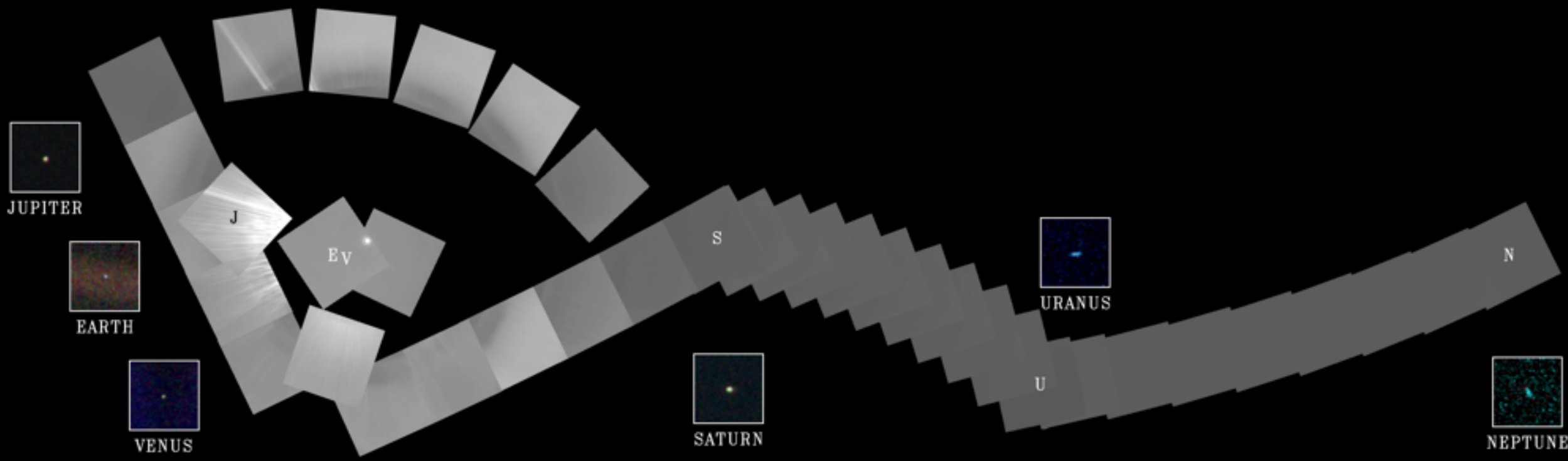
...and then what?

Wait guys - what if we looked back at ourselves?

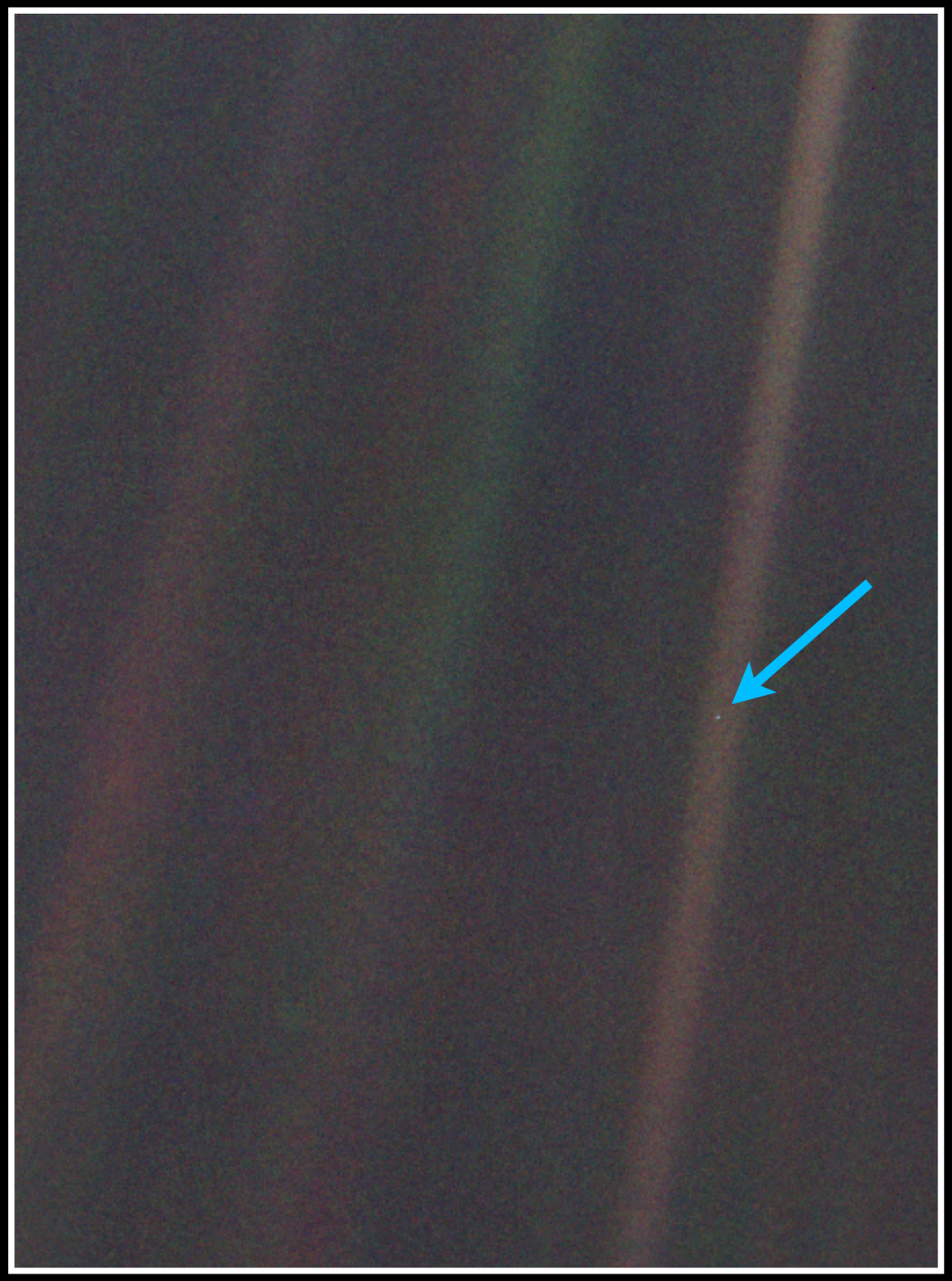
(SELFY-TIME! LOLZOAR)



- Carl Sagan



1990



“Pale Blue Dot”

“The Earth is the only world known, **so far**, to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment, the Earth is where we make our stand.”

- Carl Sagan

“**The Earth is the only world known, so far, to harbor life.** There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment, the Earth is where we make our stand.”

- Carl Sagan

“CHALLENGE ACCEPTED.”

- Brett Morris

EXOPLANETS

Exoplanets

What are exoplanets?

Any planet that orbits a star other than the Sun

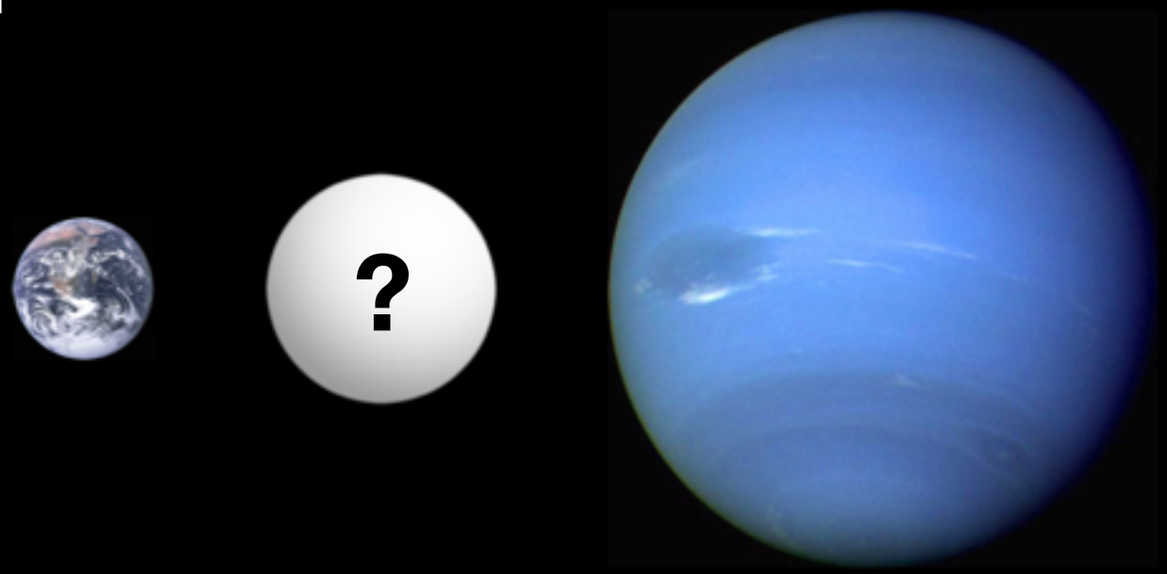
How many are there?

So far, about **4200** have been discovered

What do they look like?

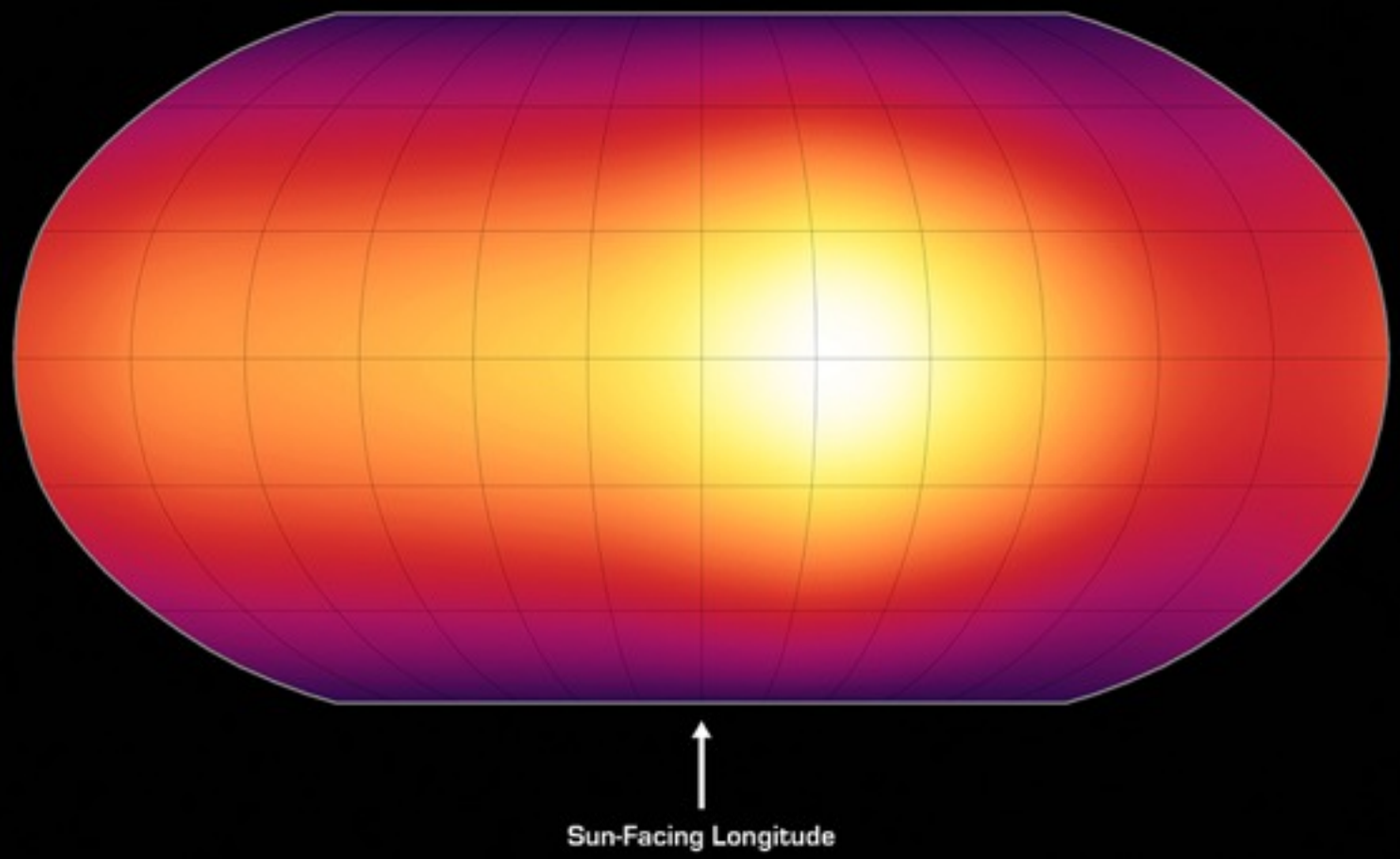
Hot Jupiters: Jupiter sized planets that orbit near to their stars

Super Earths: Slightly bigger than Earth-sized planets



What do they look like?

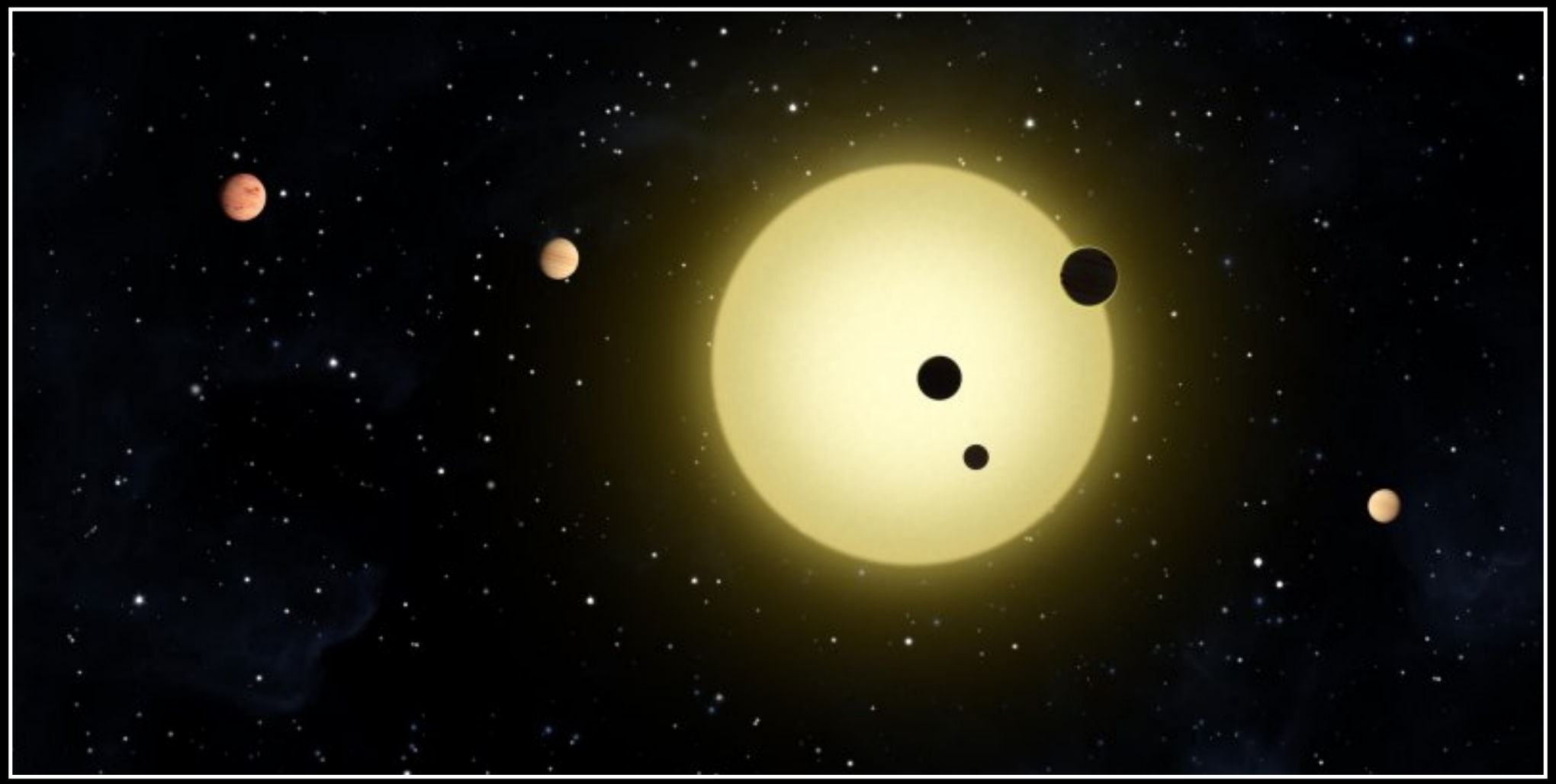
HD 189733 b



This is a
temperature map
of the cloud tops

What do they look like?

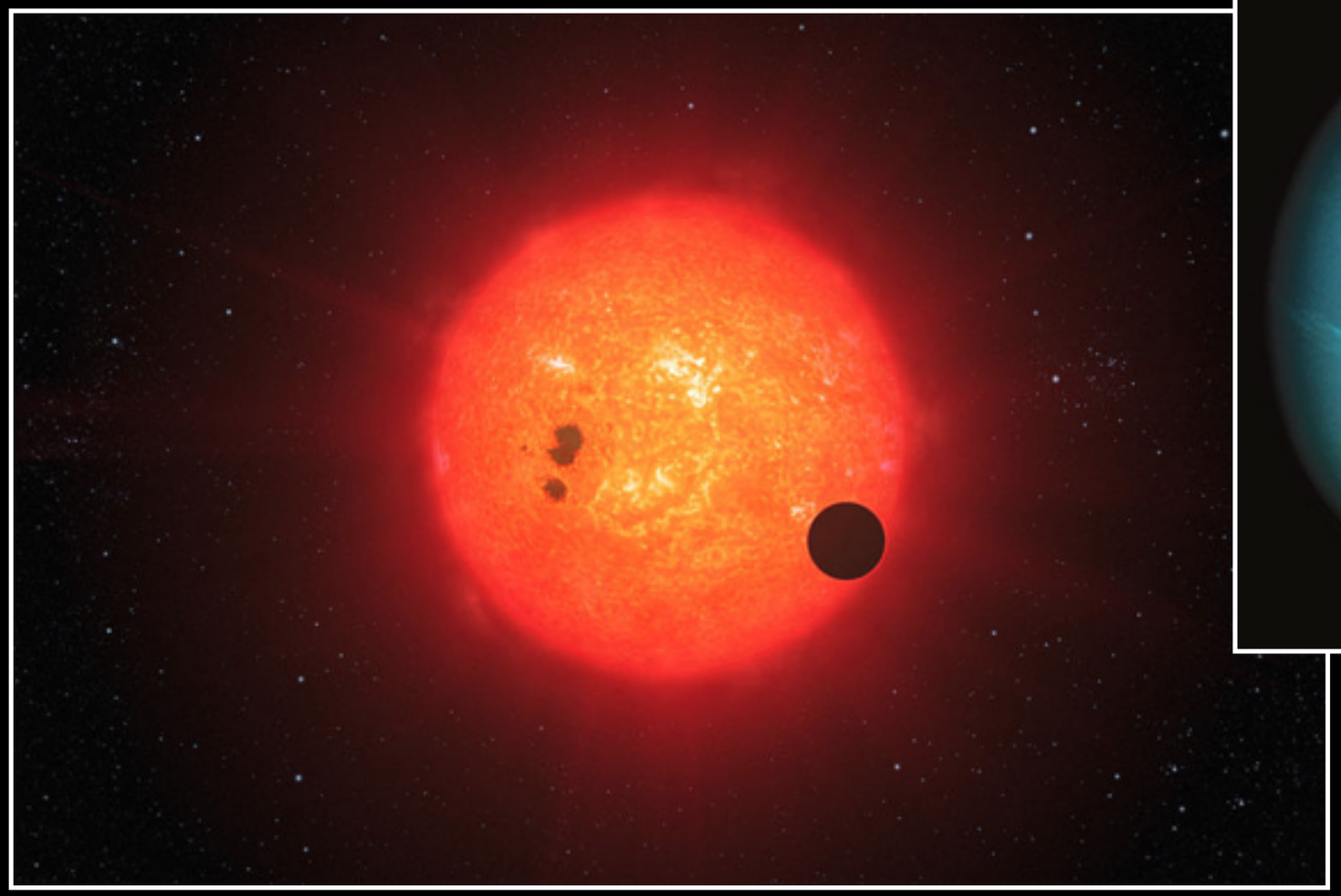
Kepler-11

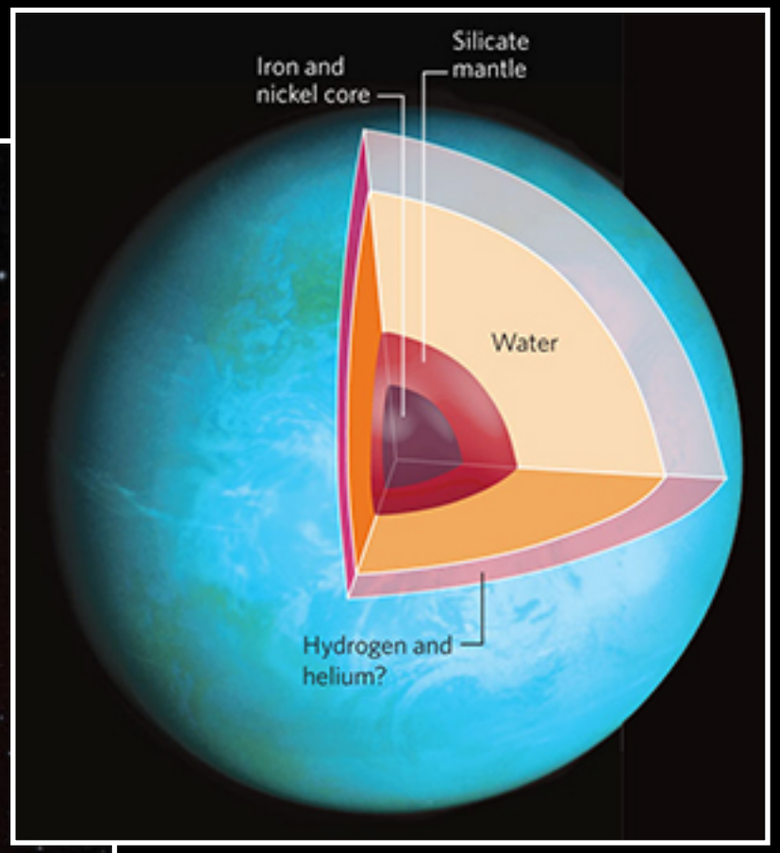


Multi-planet systems aren’t rare

What do they look like?

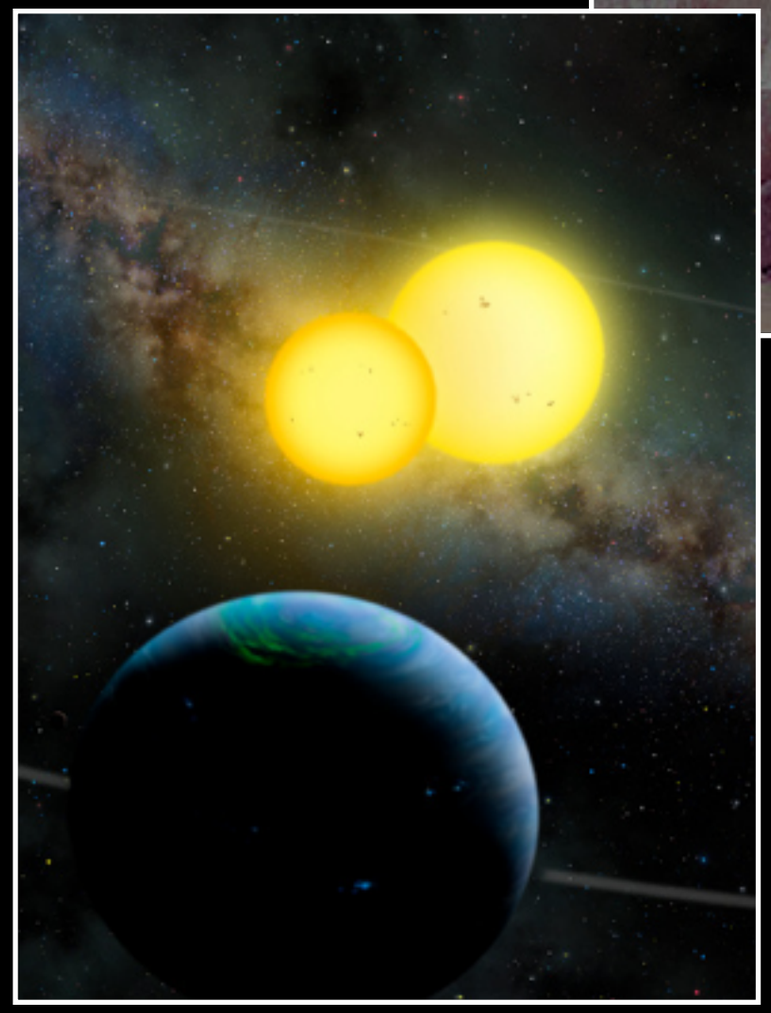
GJ 1214 b





May have a *water vapor* atmosphere

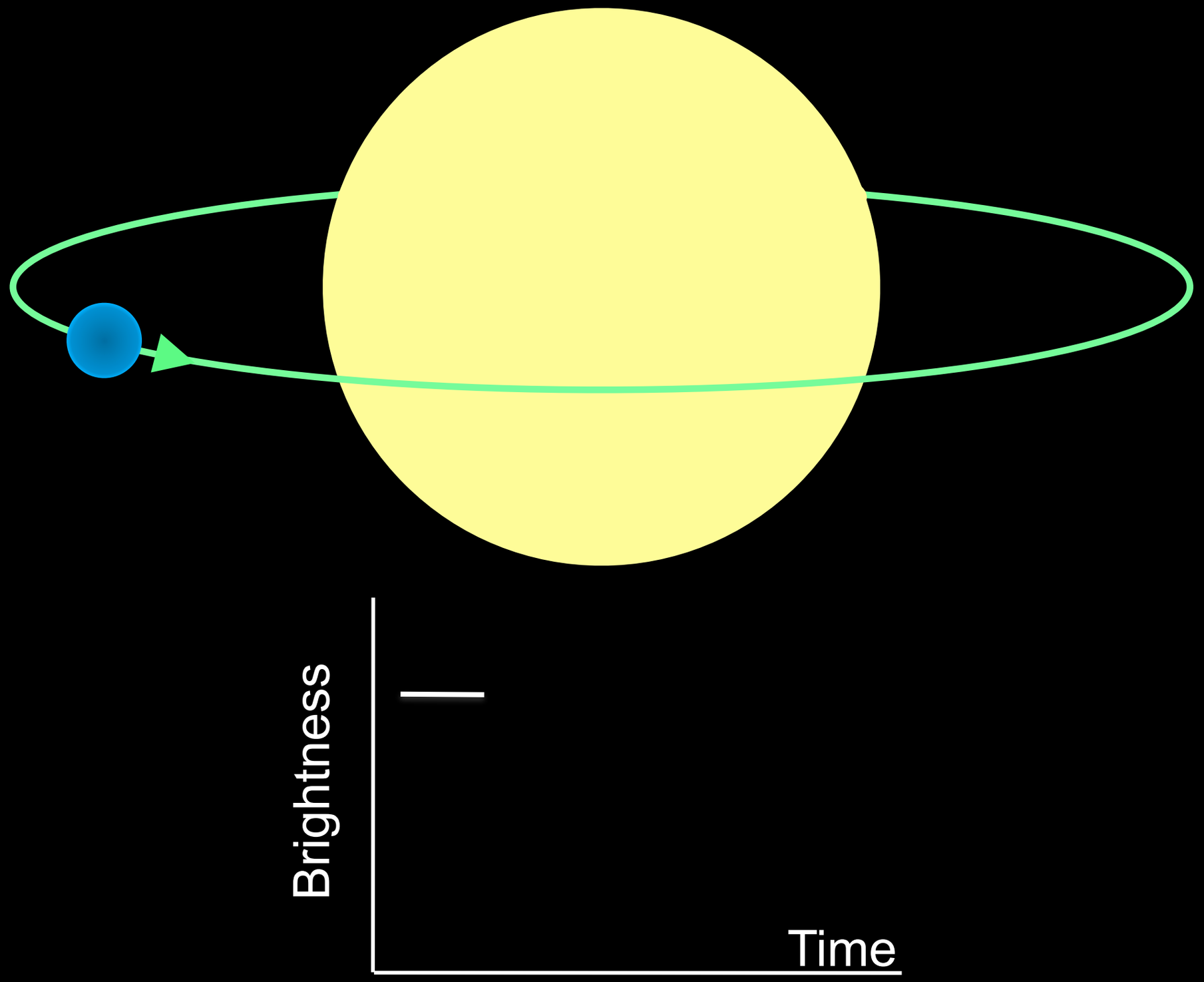
Circumbinary Planets



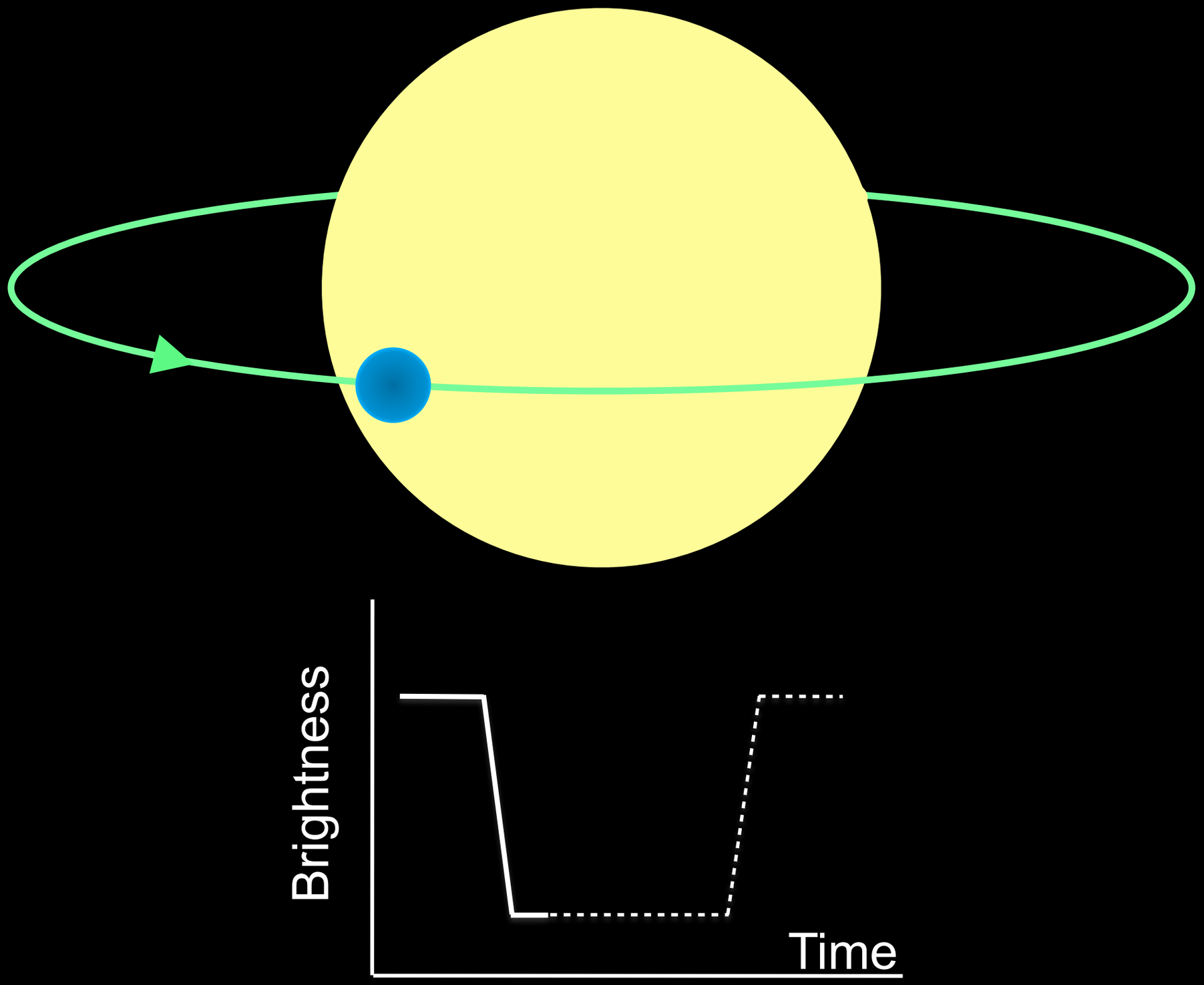
We've discovered
16 of these
systems so far

DISCOVERY

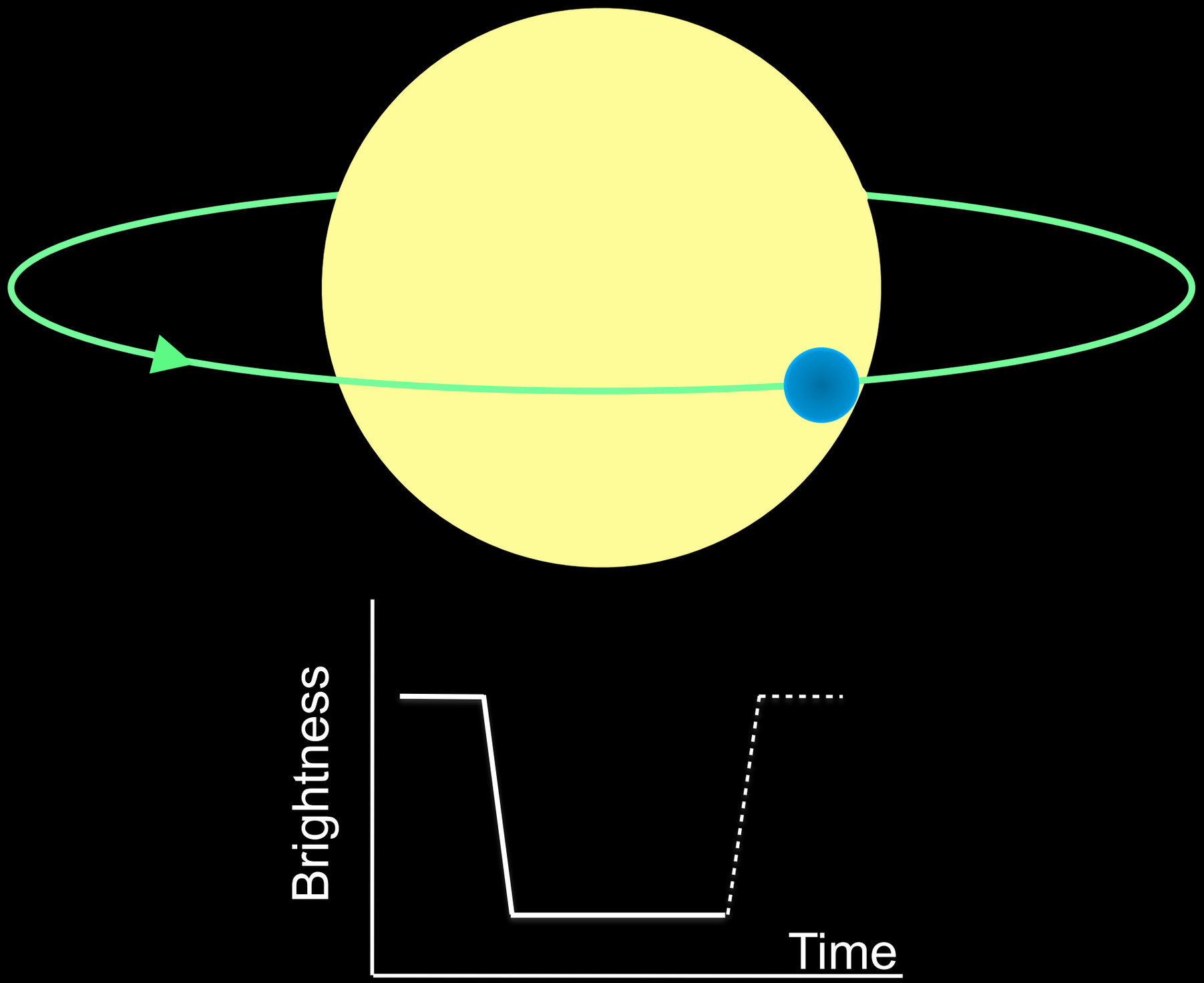
Finding Planets: Transit Method



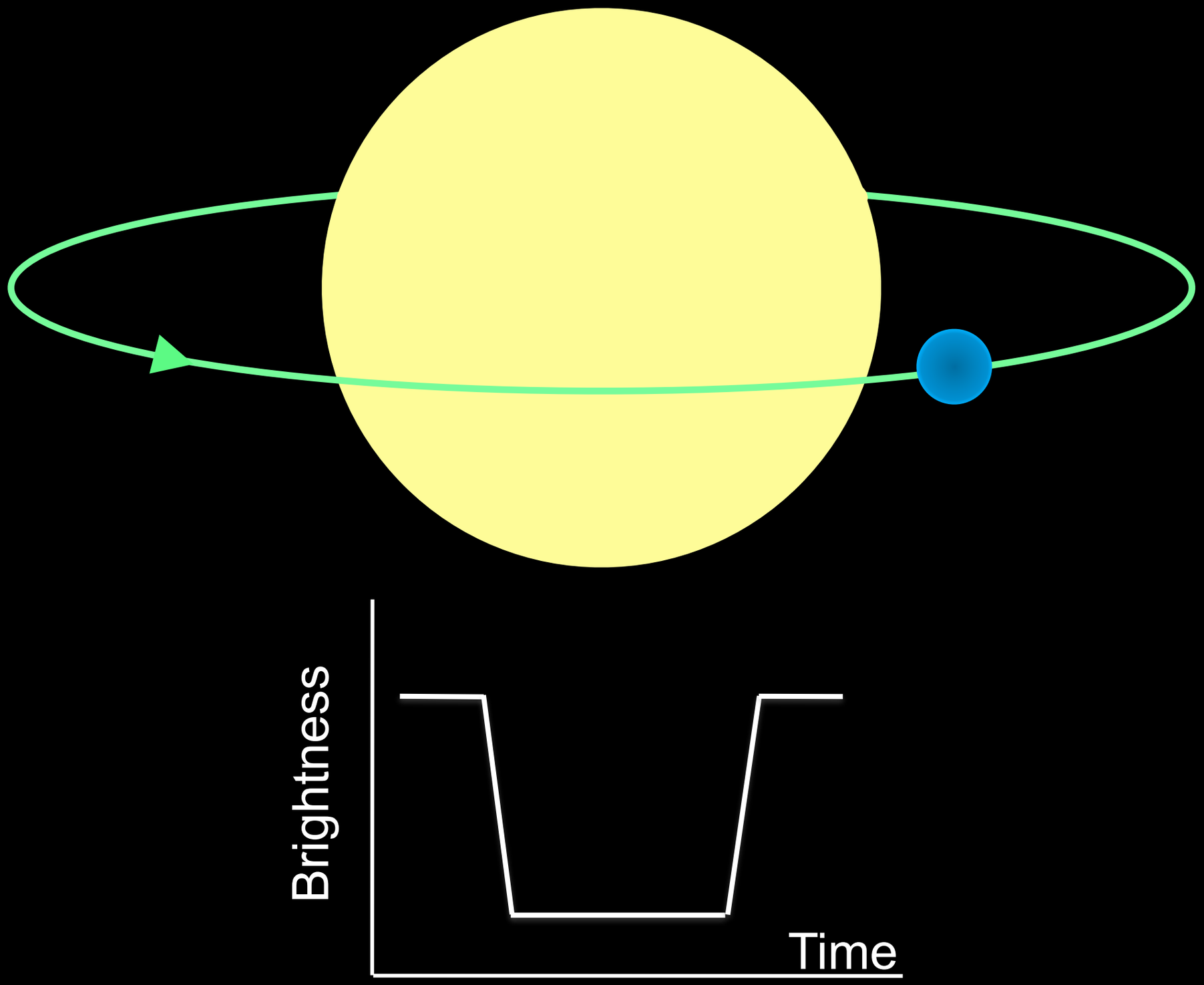
Finding Planets: Transit Method



Finding Planets: Transit Method

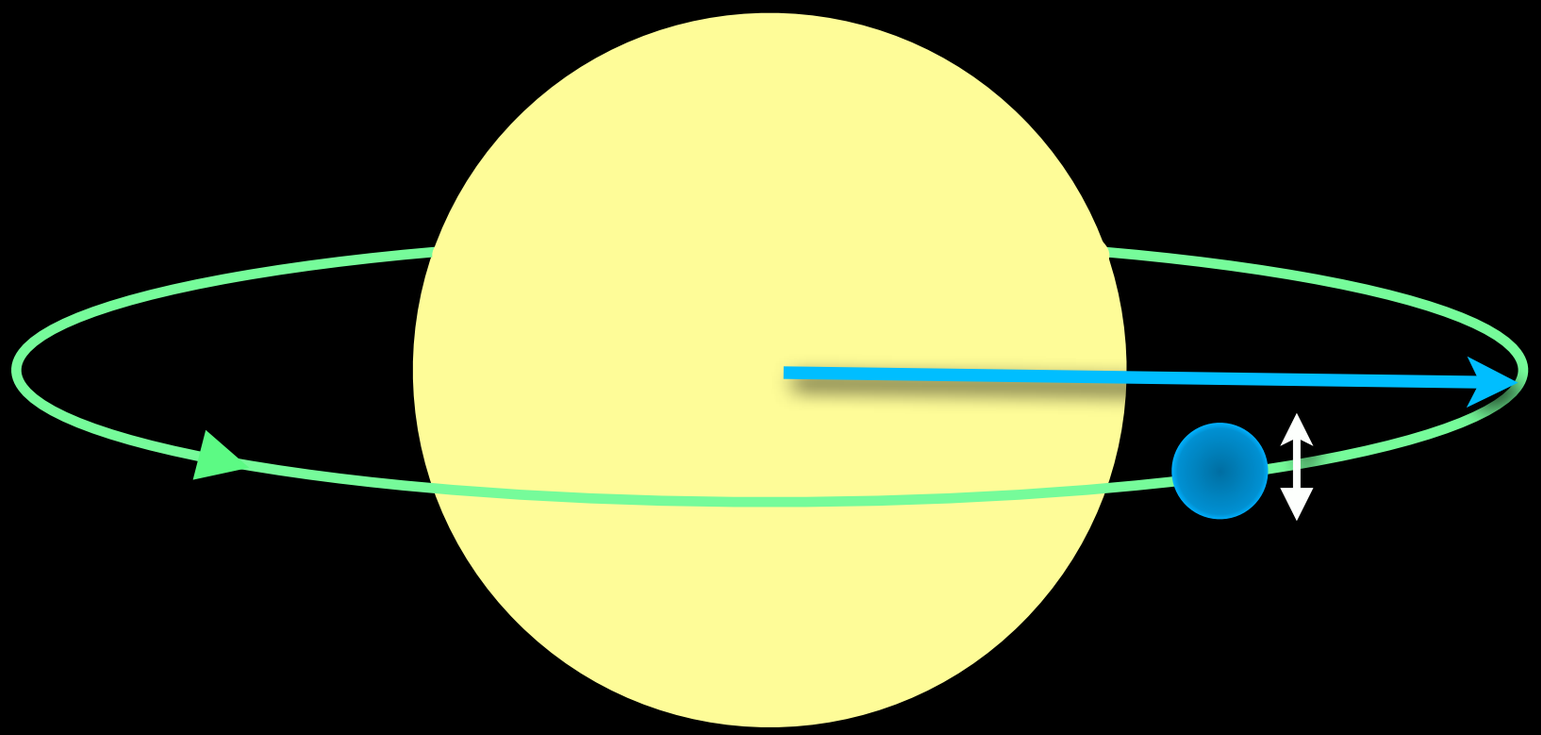


Finding Planets: Transit Method



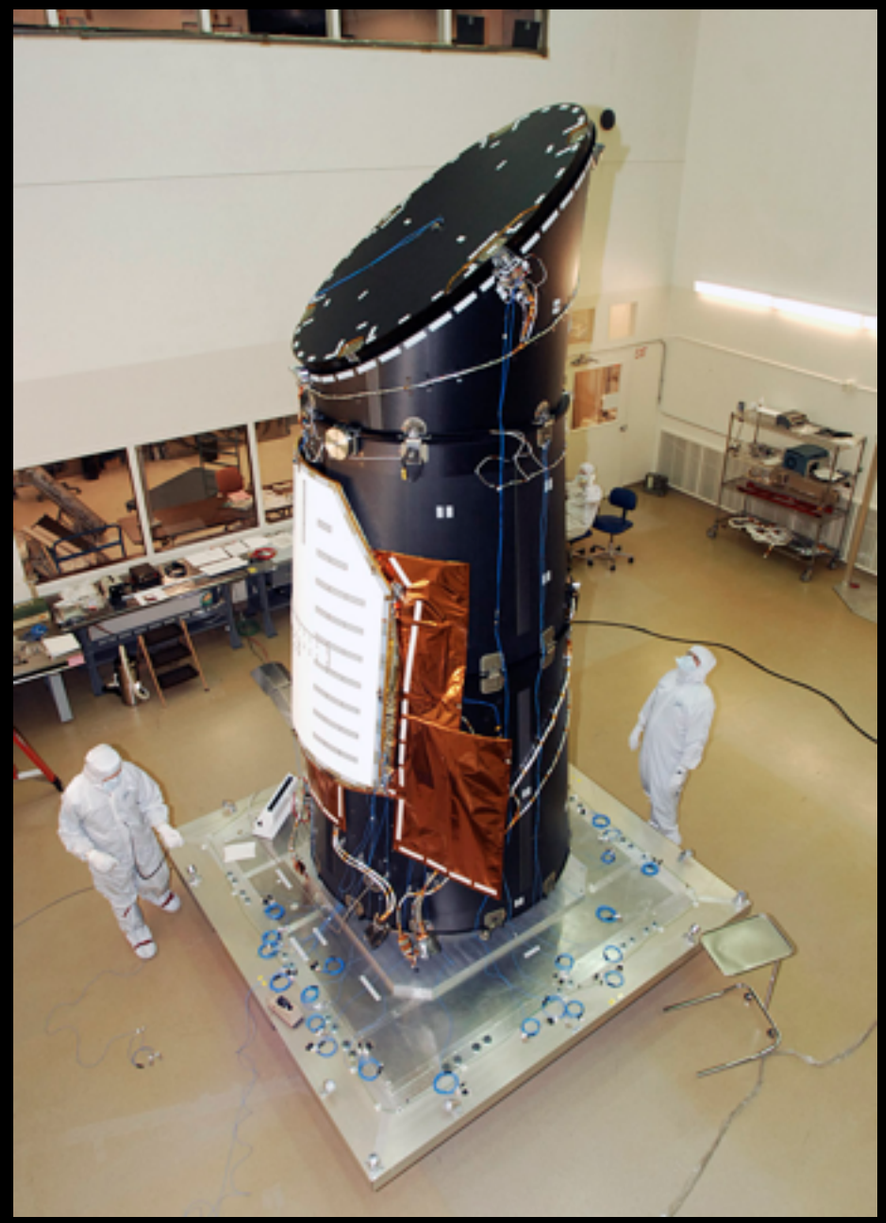
What do transits tell us?

- The planet's **radius**
- The **distance** from the planet to the star
- The **orbital period** -- how long the planet's "year" is



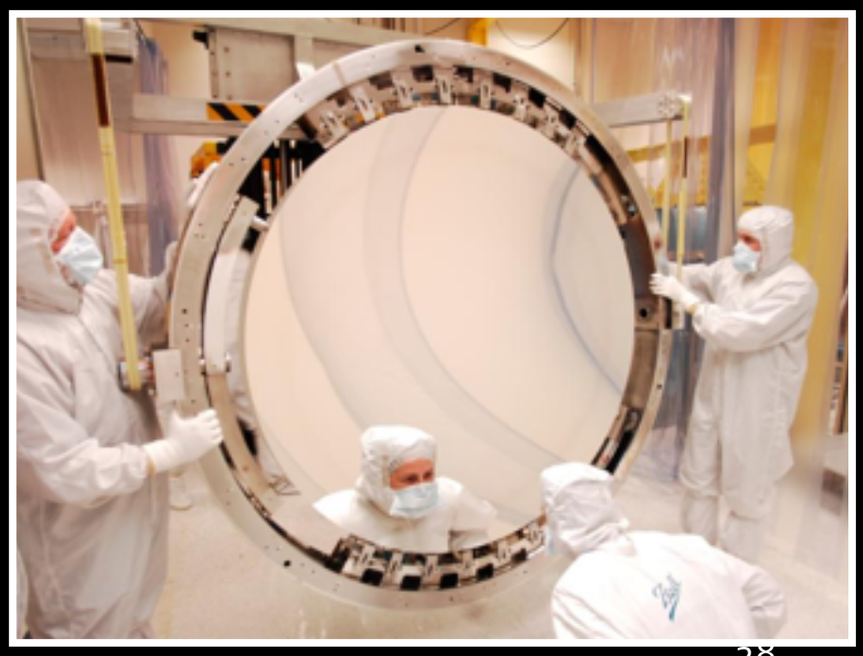
Kepler Space Telescope

- 95 megapixel camera
  - Each picture it takes has as many pixels as 12 pictures taken by an iPhone 5
- Measures brightness changes with **exquisite precision**

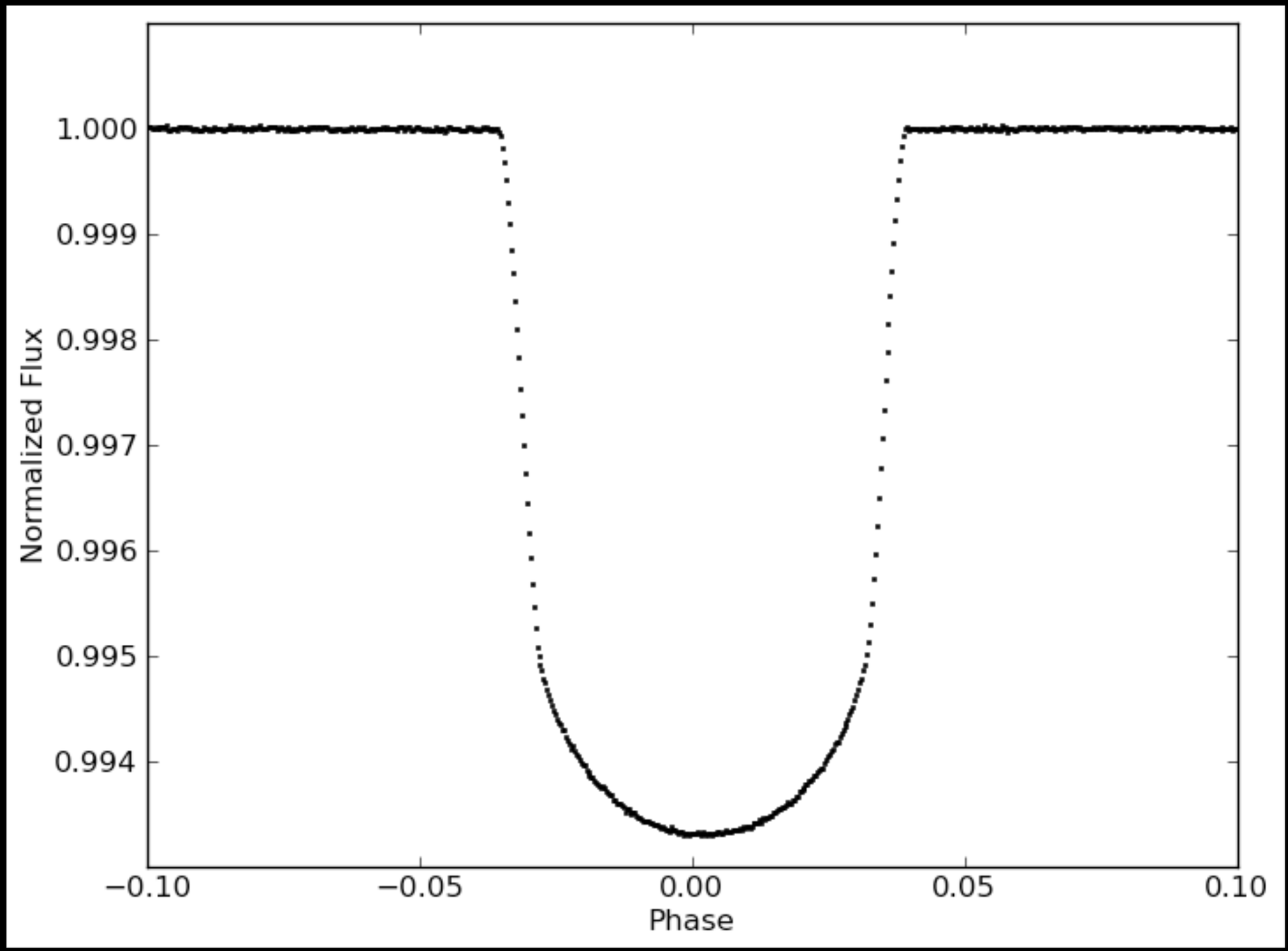


"If *Kepler* were to look down at a small town on Earth at night from space, it would be able to detect the dimming of a porch light as somebody passed in front."

- James Fanson, *Kepler* project manager, NASA JPL



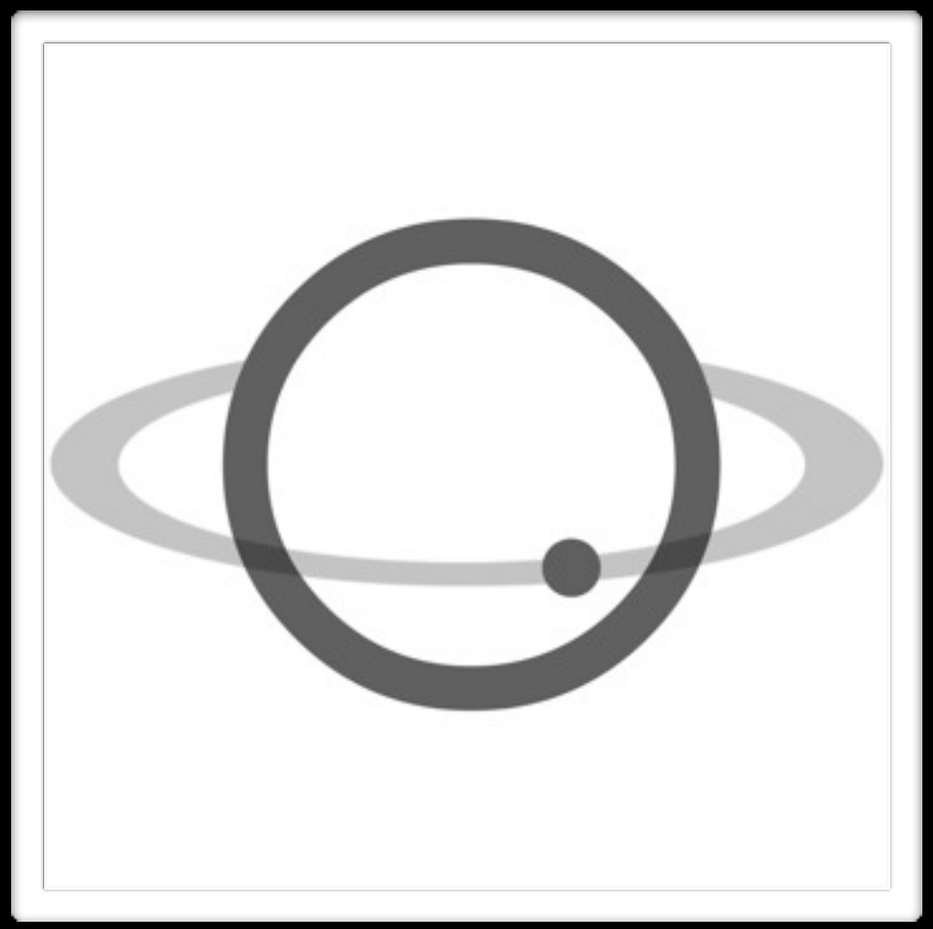
Kepler Transit Light Curve



Brightness

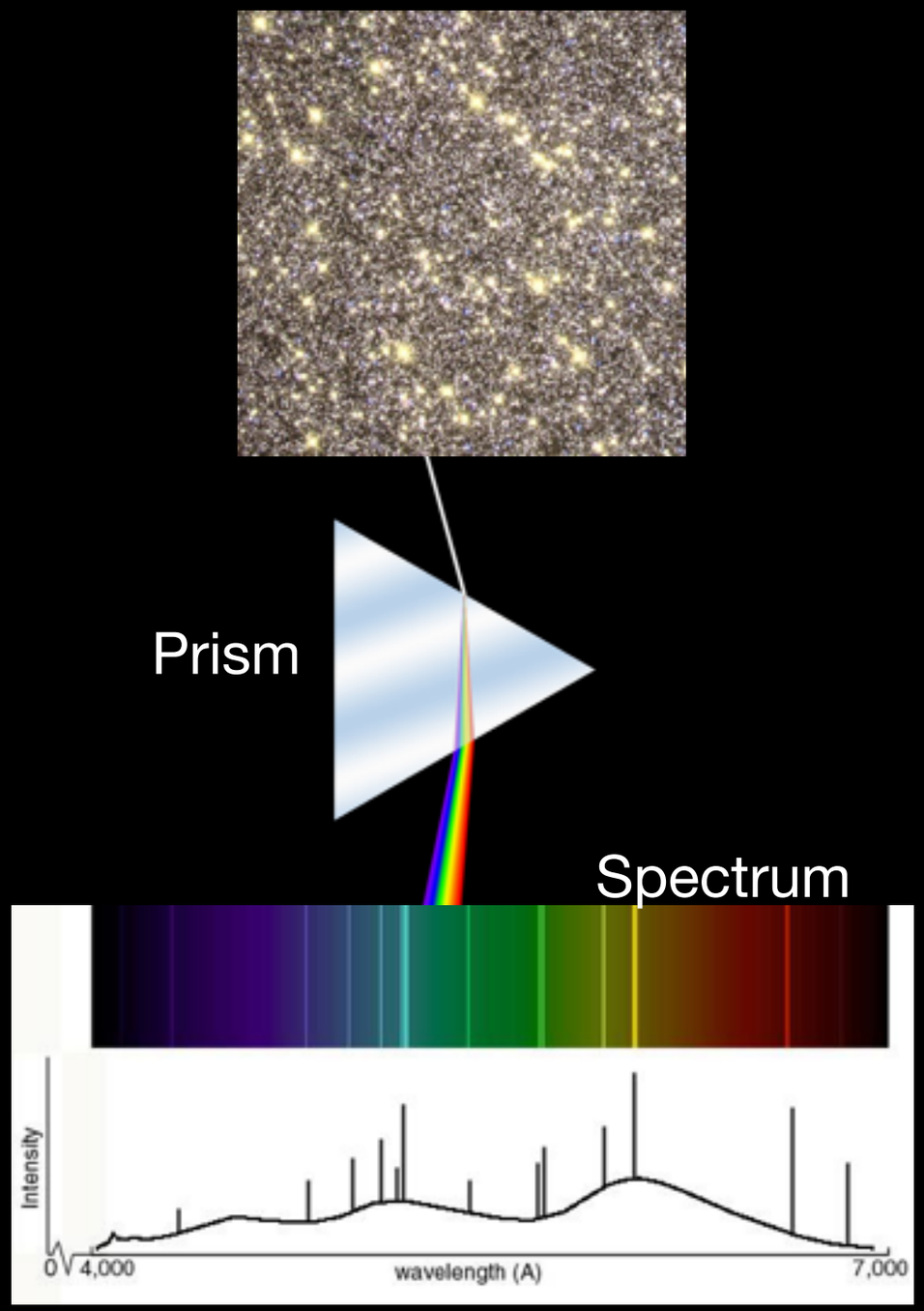
Time

OSCAAR (Some Self-Promotion)



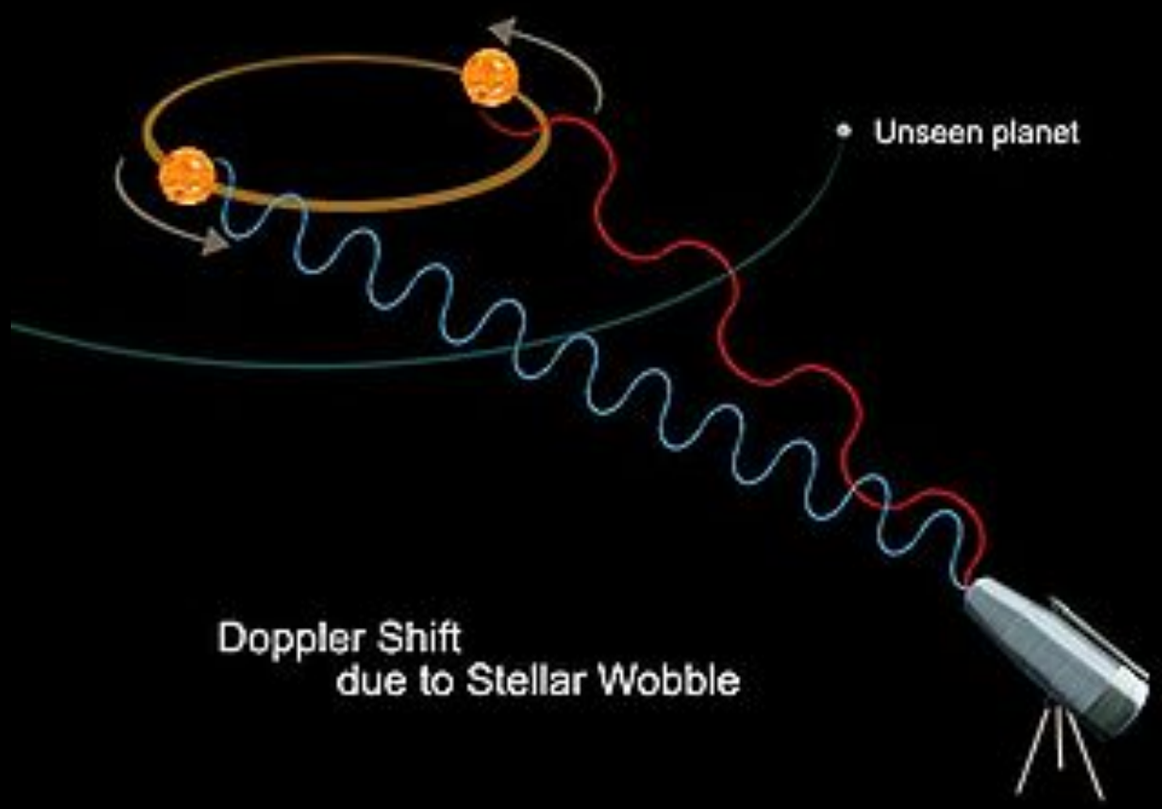
- If you have a telescope and a CCD, you can make light curves on your own with OSCAAR
- OSCAAR takes your raw observations and does all of the work you need to measure the planet's radius and its distance from its star and more

Finding Planets: Doppler Method



- Send light from a star through a prism
- The “rainbow” that comes out is uneven -- there are *lines* in it
- The lines wiggle towards red if the star moves away from you and blue if the star moves towards you

Finding Planets: Doppler Method

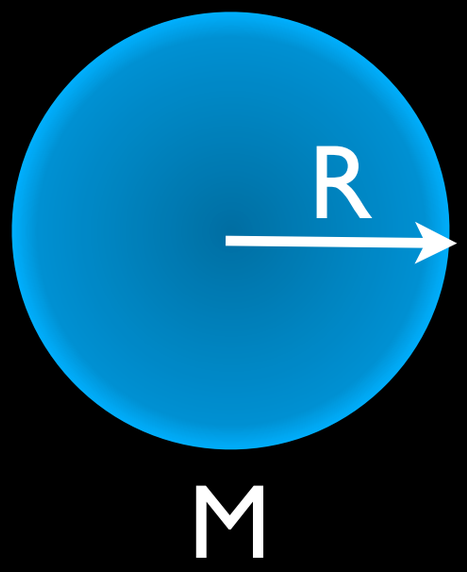


- Based on how hard the planet pulls on the star, we can find the planet's **mass**
- We don't need to have a lucky alignment with other planetary systems to see this effect (unlike the transit method)

CHARACTERIZATION

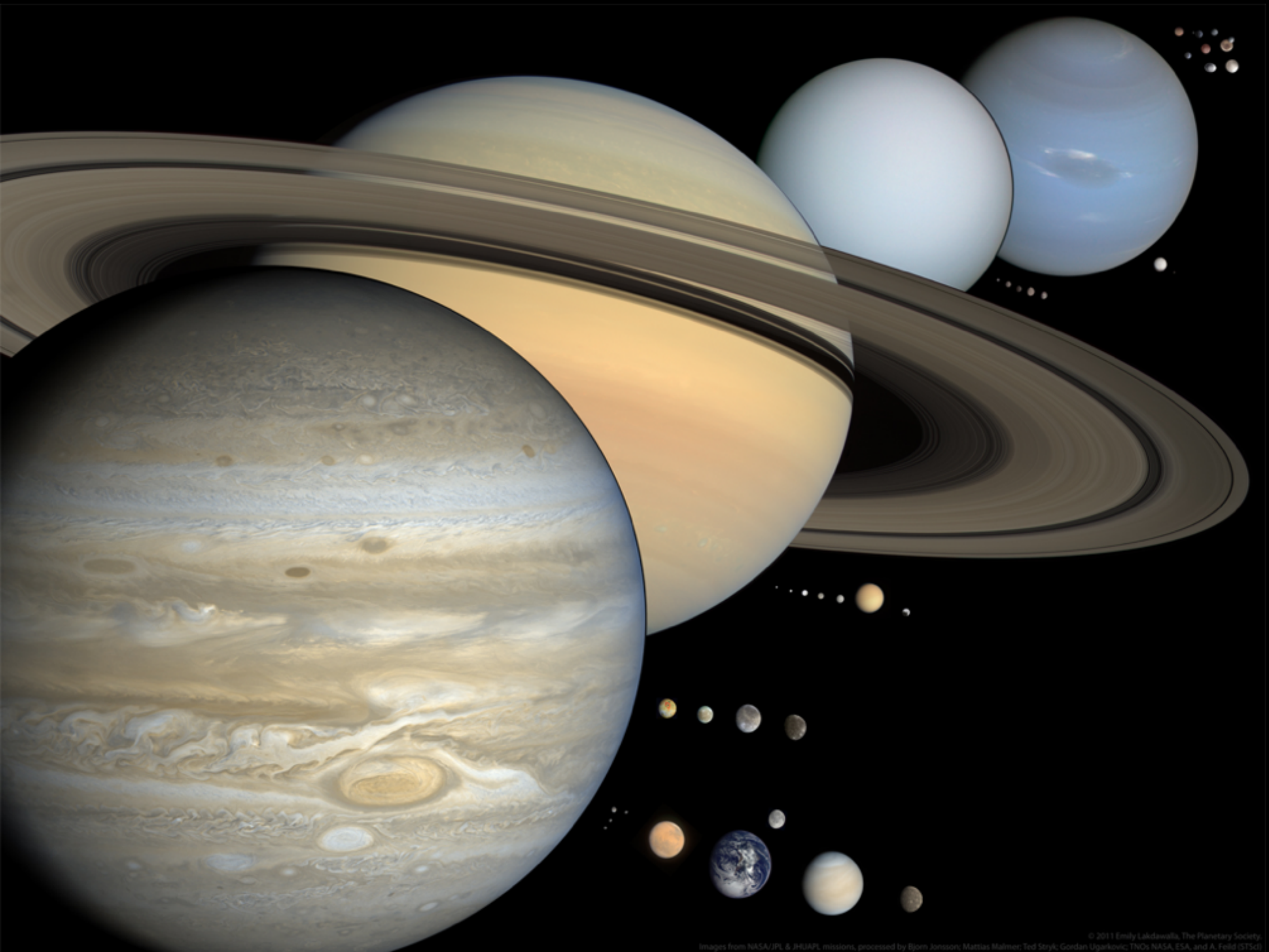
Planet Composition

With only the mass (M) from the doppler method and the radius (R) from the transit method:



Volume of a sphere: $V = 4\pi R^3/3$

Density: $D = M/V$



Planetary Composition

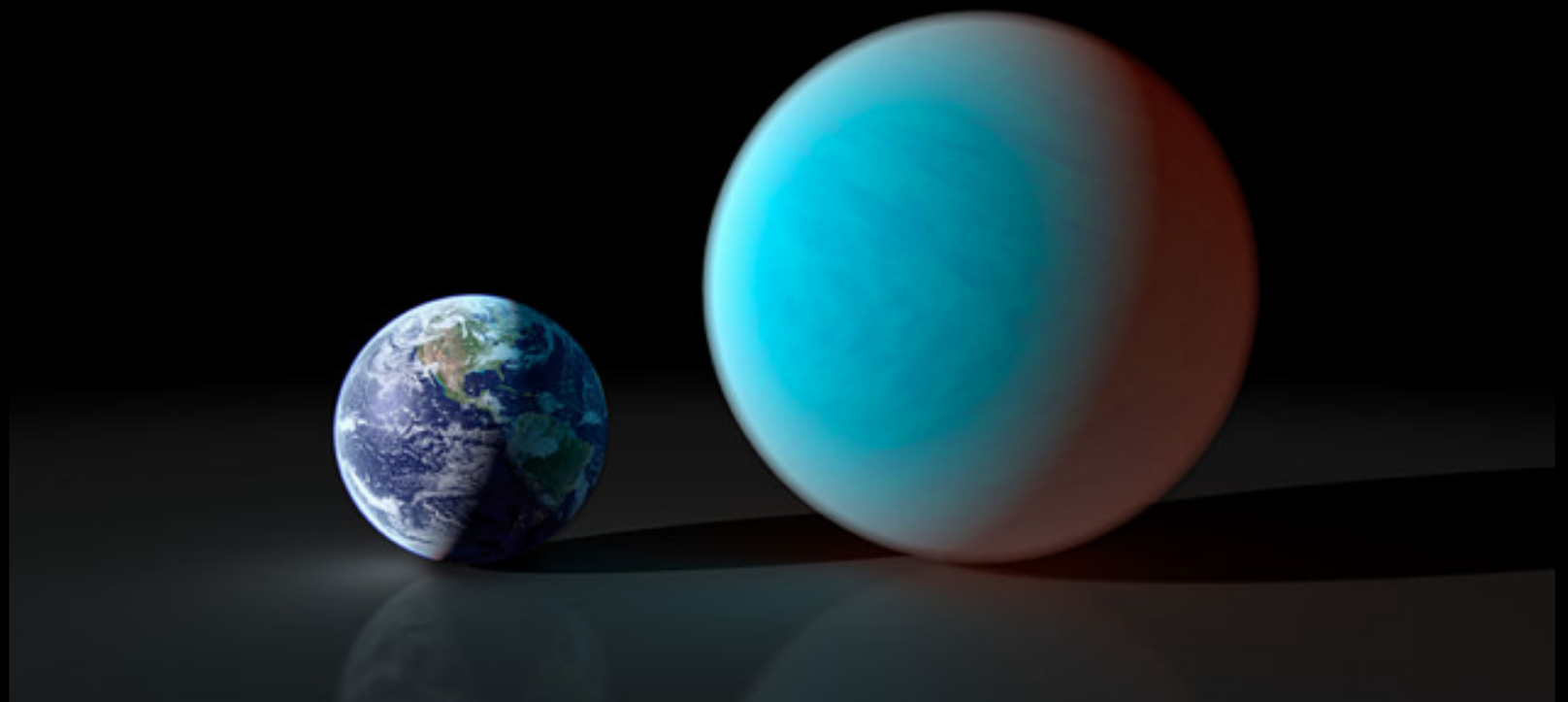
Planet	Density (10^3 kg/ m^3)
Mercury	5.4
Venus	5.2
Earth	5.5
Mars	3.9
Jupiter	1.3
Saturn	0.6
Uranus	1.2
Neptune	1.6

Terrestrial - rocky

Jovian - gaseous

Sample Exoplanet: **55 Cancri e**

- Radius: 2.0 times greater than Earth’s
- Mass: 8.6 times greater than Earth’s
- Density: **6.0** 10^3 kg/m^3
- This means the planet must be rocky!



BETTER CHARACTERIZATION

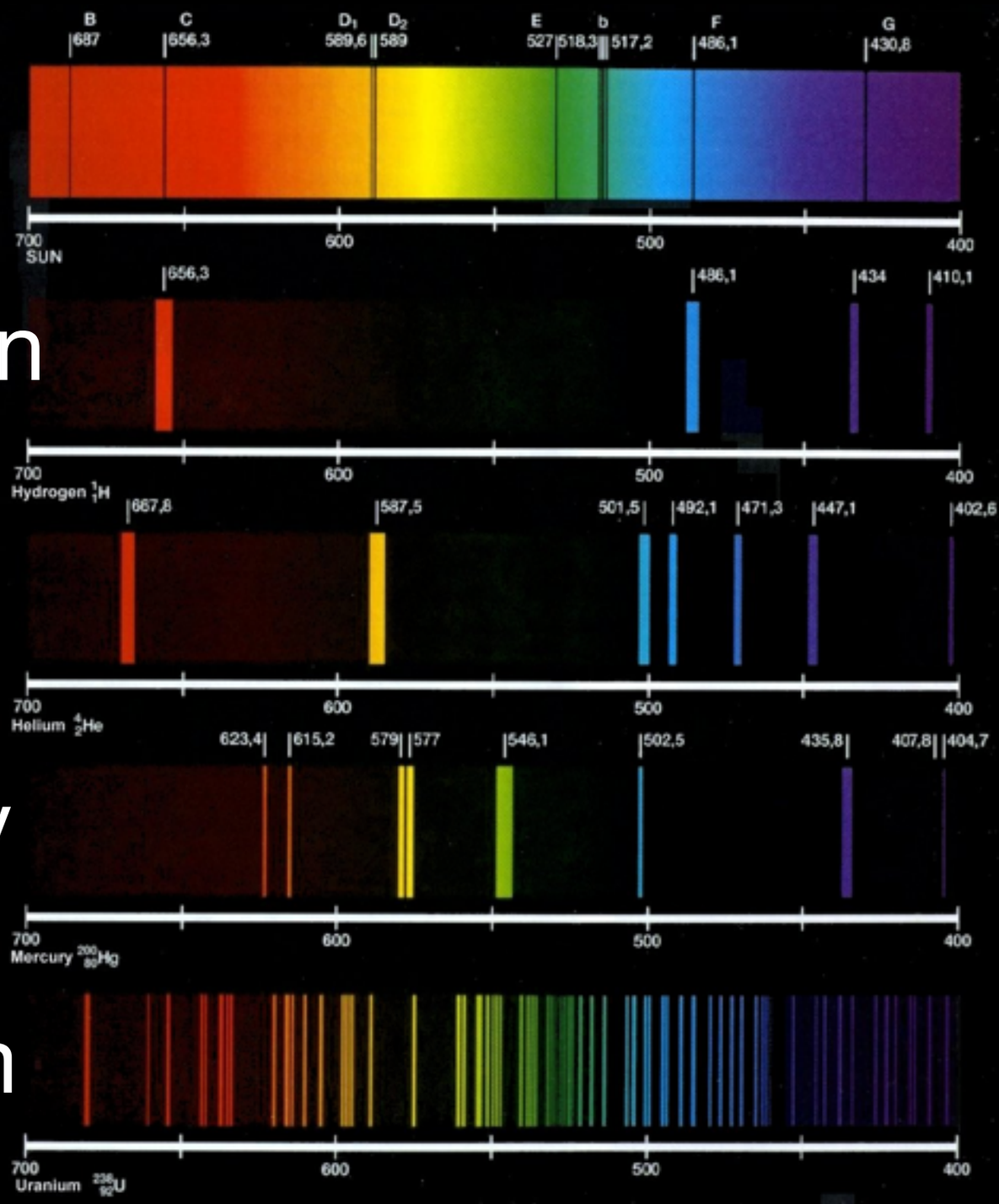
How do we identify elements and molecules remotely?

Hydrogen

Helium

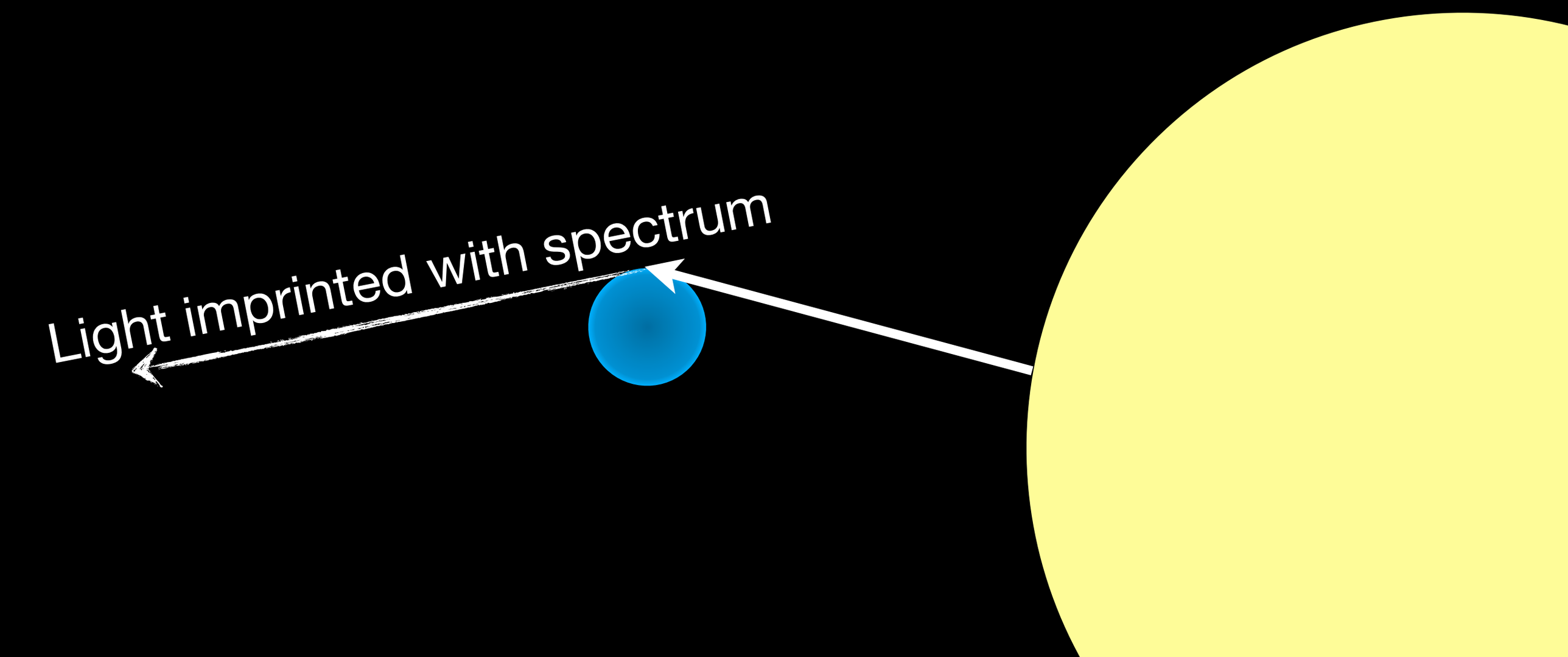
Mercury

Uranium



Fingerprinting a planet

If you can see some of the light that passes through the atmosphere, you can measure the **spectrum of the atmosphere**



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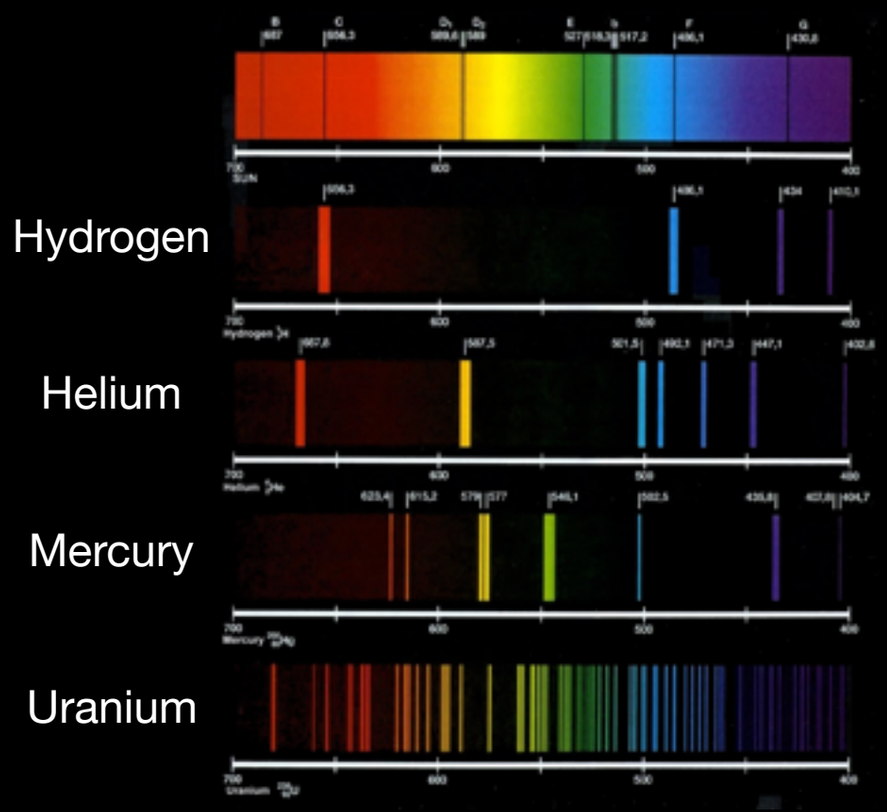
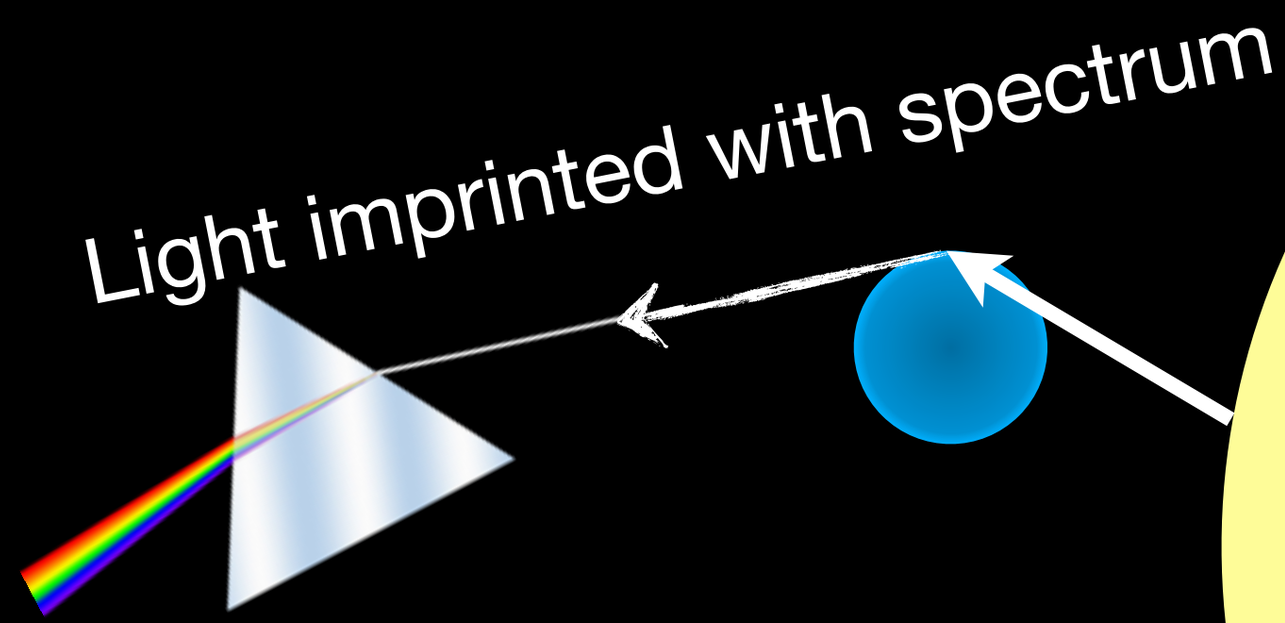




ASTROBIOLOGY

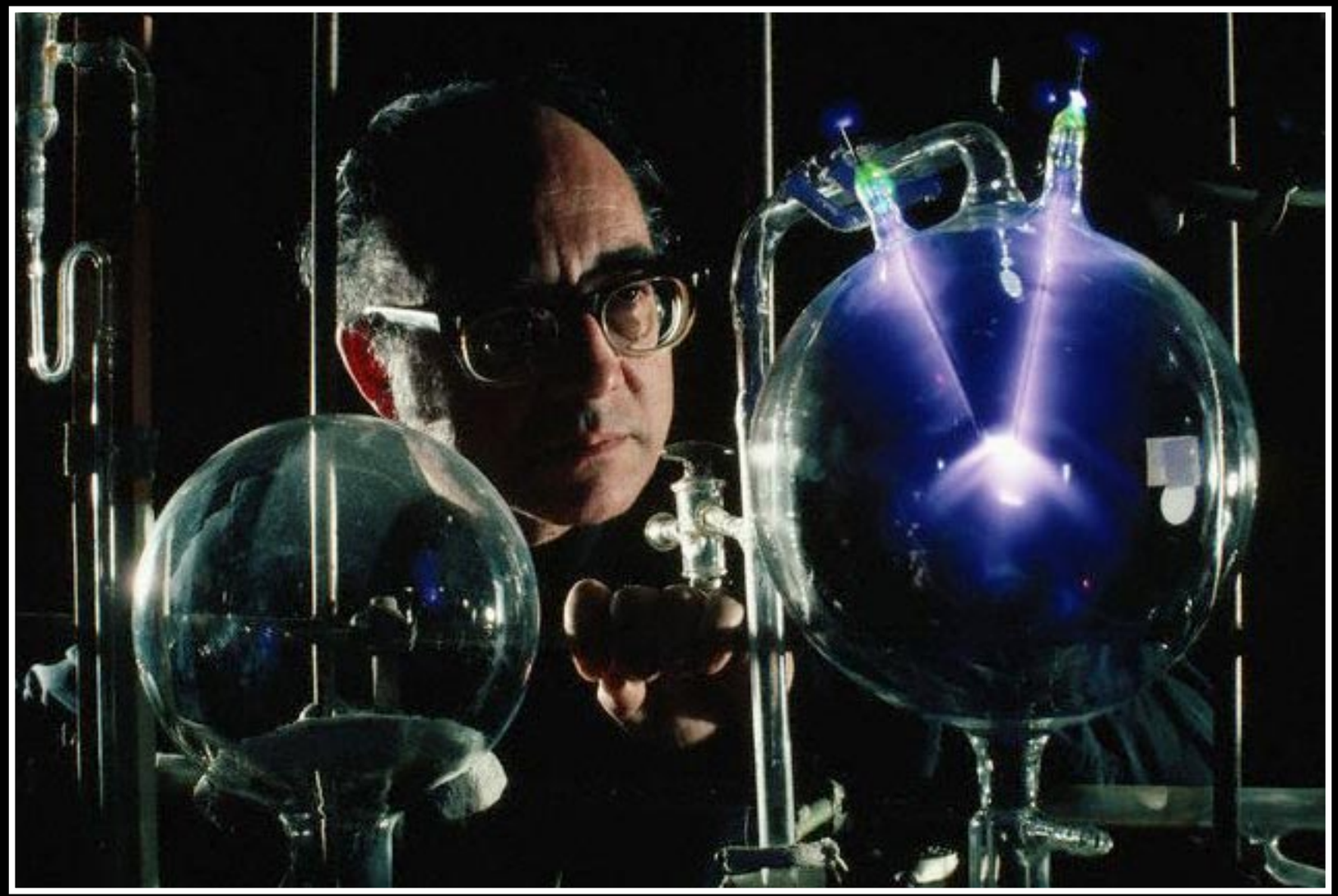
Elements in DNA

hydrogen 1 H 1.0079												boron 5 B 10.811	carbon 6 C	nitrogen 7 N	oxygen 8 O	fluorine 9 F 18.998	helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122																neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 ✶	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 ✶ ✶	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

What molecules are markers for life?

How much of them were there on early Earth?

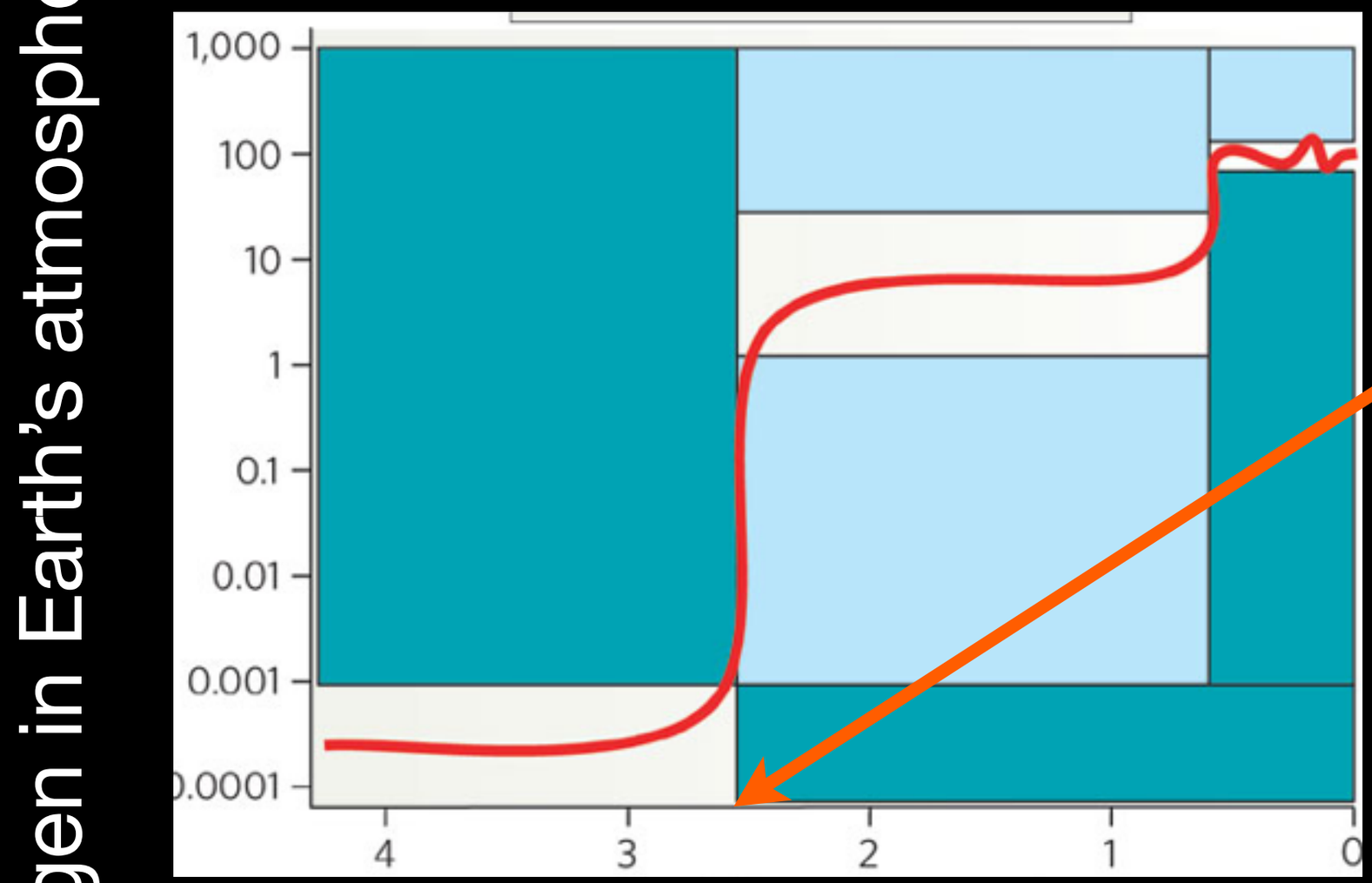
How did they *become alive*?



Abiogenesis:
Miller-Urey Experiment

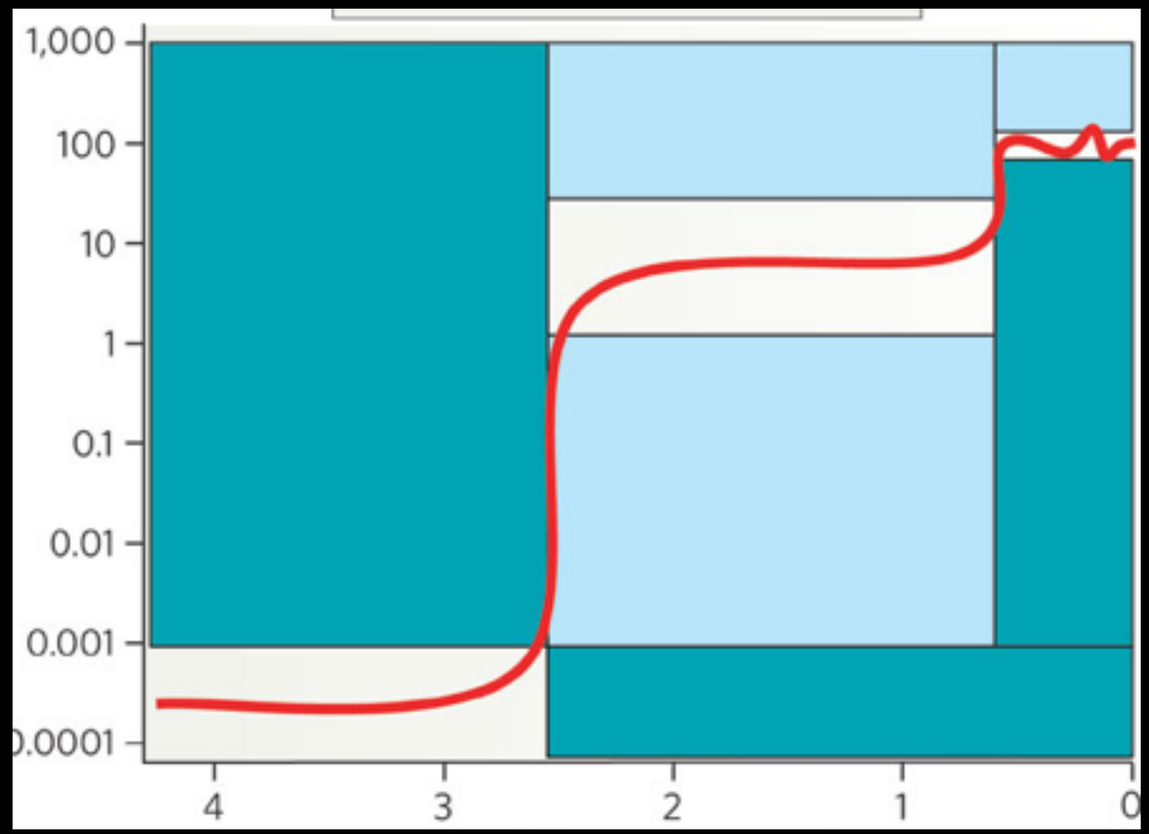
Put primitive gas in tubes, zap it,
amino acids pop out!

Looking For Life



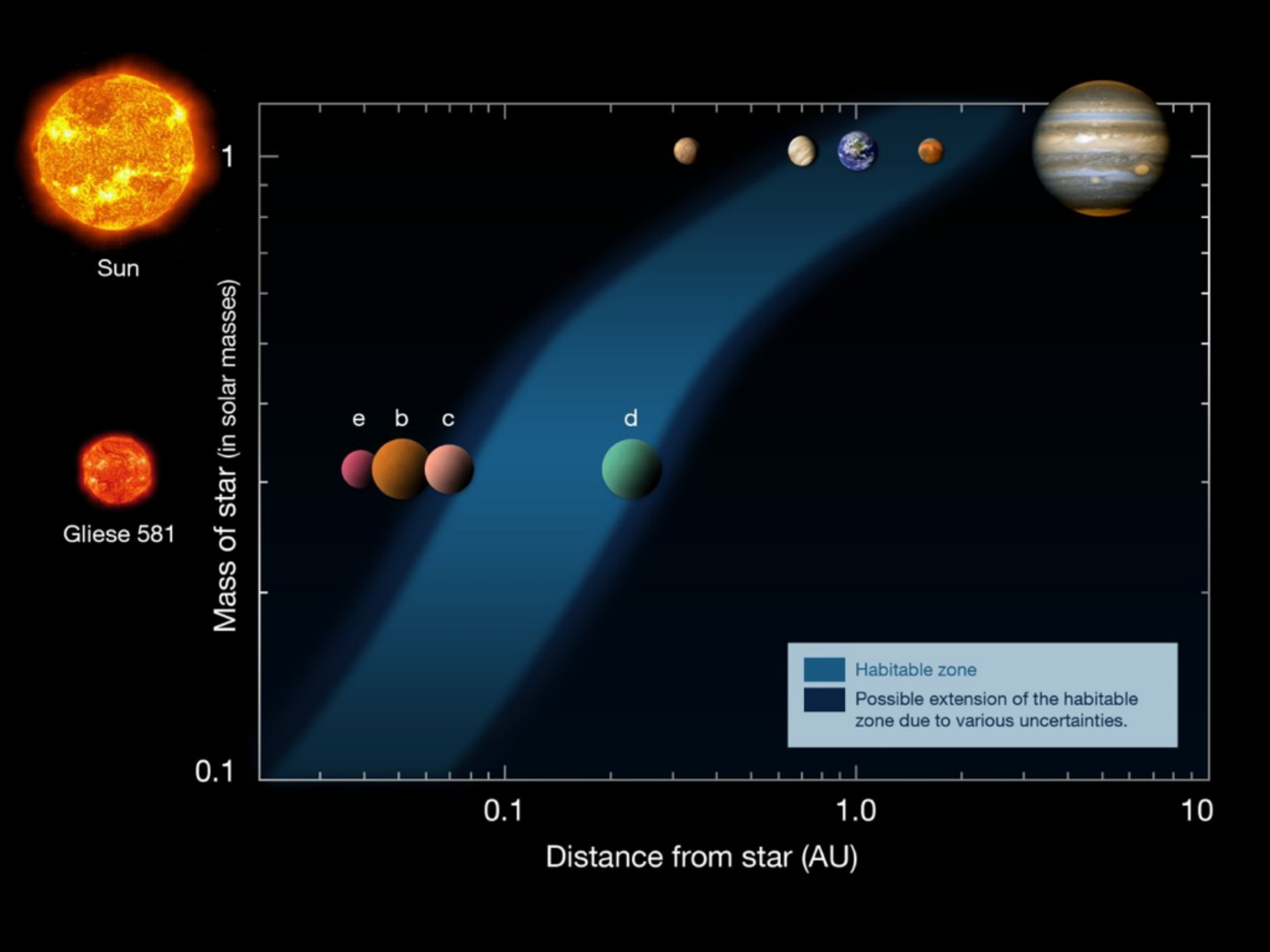
This is when life figured out how to turn CO_2 into O_2

Atmospheric O_2



Billions of years ago

We could guess this planet
is doing something special


Sun
Gliese 581
1
0.1
Mass of star (in solar masses)
e
b
c
d
Habitable zone
Possible extension of the habitable zone due to various uncertainties.
0.1
1.0
10
Distance from star (AU)

The "Drake Equation"

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

R^* = the average number of star formation per year in our galaxy
f_p = the fraction of those stars that have planets
n_e = the average number of planets that can potentially support life per star that has planets
f_l = the fraction of planets that could support life that actually develop life at some point
f_i = the fraction of planets with life that actually go on to develop intelligent life (civilizations)
f_c = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space
L = the length of time for which such civilizations release detectable signals into space