

Title: Exoplanets and the Search for Habitable Worlds

Date: Jun 23, 2015 04:10 PM

URL: <http://pirsa.org/15060043>

Abstract: Thousands of exoplanets are known to orbit nearby stars, with further evidence that every star in our Milky Way Galaxy has planets. Beyond their discovery, a new era of exoplanet characterization is underway with an astonishing diversity of exoplanets driving the fields of planet formation and evolution, interior structure, atmospheric science, and orbital dynamics to new depths. The push to find smaller and smaller planets down to Earth size is succeeding and motivating the next generation of space telescopes to have the capability to find and identify planets that may have suitable conditions for life or even signs of life by way of atmospheric biosignature gases. After thousands of years of people wondering "Are we alone?", we are the first generation in human history to be able to make quantitative progress in answering this age-old question.

The Search for Habitable Worlds

- ✓ Thousands of exoplanets are known and small (rocky) planets are common
- ✓ Habitable planets are anticipated
- ✓ The next generation telescopes will each have a chance at finding and/or identifying a habitable world



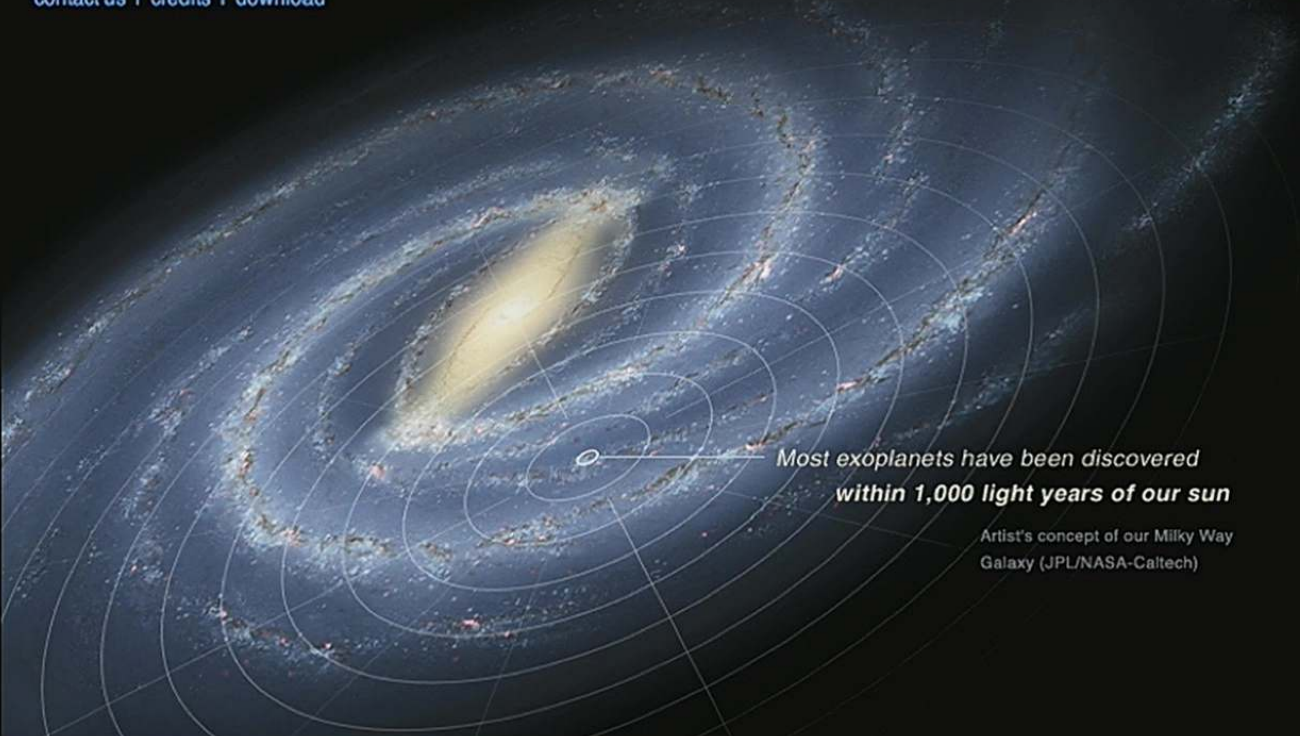
EYES ON EXOPLANETS ^{beta}

Explore a 3D simulation of all planets that have been discovered around other stars

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START

VIDEO TUTORIALS



Most exoplanets have been discovered
within 1,000 light years of our sun

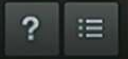
Artist's concept of our Milky Way
Galaxy (JPL/NASA-Caltech)

NASA EYES ON EXOPLANETS beta

EXPLORE

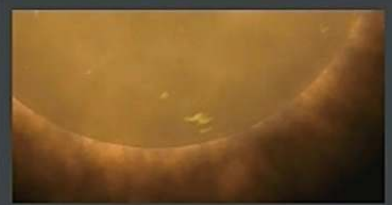
Mercury Earth
Venus Kepler
Spitzer
Mars Uranus

PLANET COUNT 1767 STARS WITH PLANETS 1082 EARTHLIKE PLANETS 0



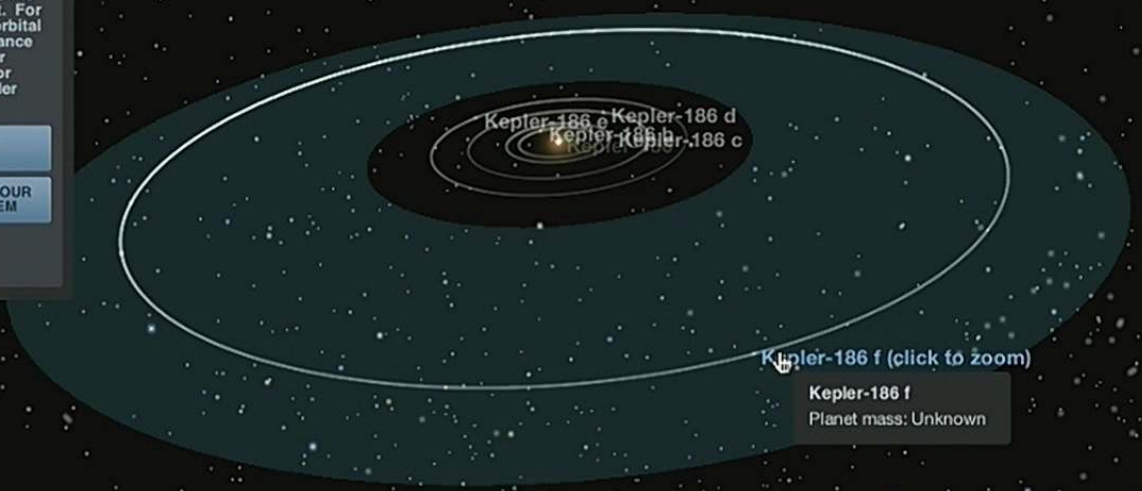
EXPLORE

About the Star



The "habitable zone" of a planetary system refers to the band of orbits where liquid water could exist on a planet's surface, a condition is considered necessary for life as we know it. For the sun, that zone ranges from about the orbital distance of Venus to about the orbital distance of Mars. Compared to the sun's zone, other stars' zones are more distant and thicker for hotter stars and closer and thinner for cooler stars.

- PLANETARY SYSTEM VIEW
- STAR VIEW
- HOW LONG TO TRAVEL HERE?
- COMPARE WITH OUR SOLAR SYSTEM
- HABITABLE ZONE

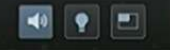


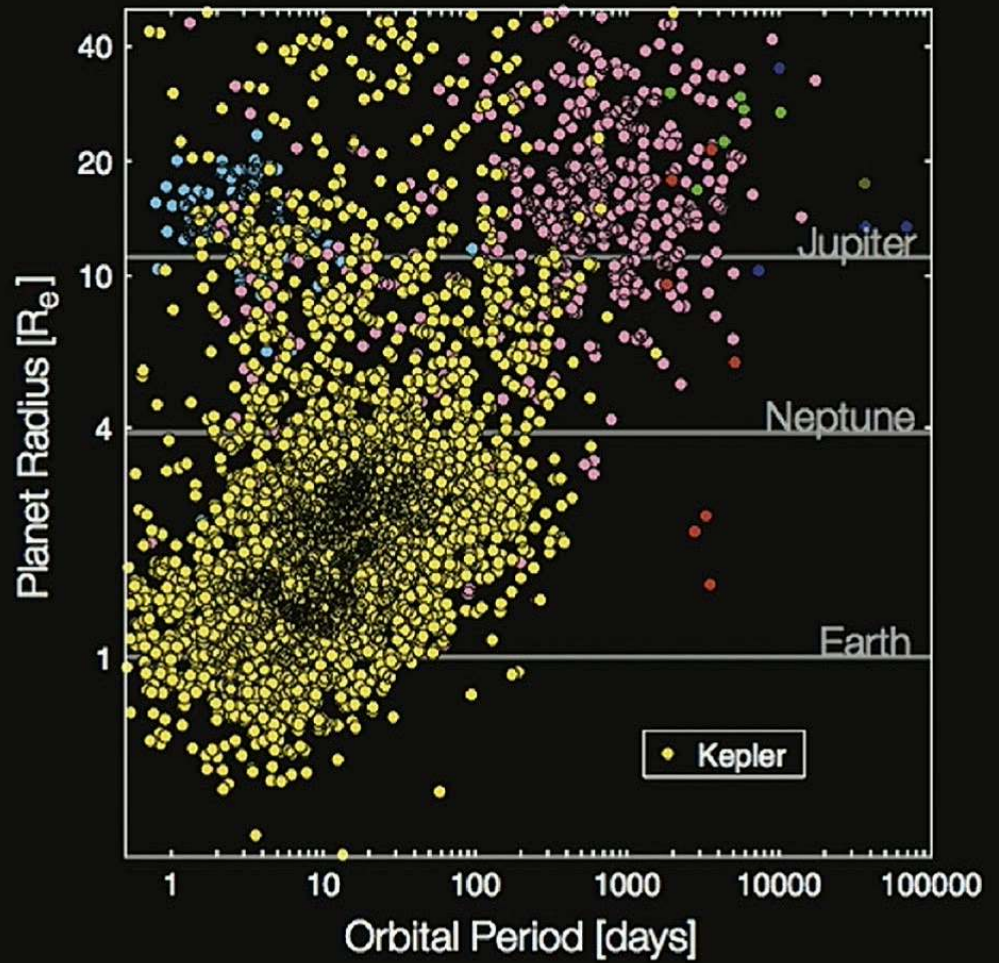
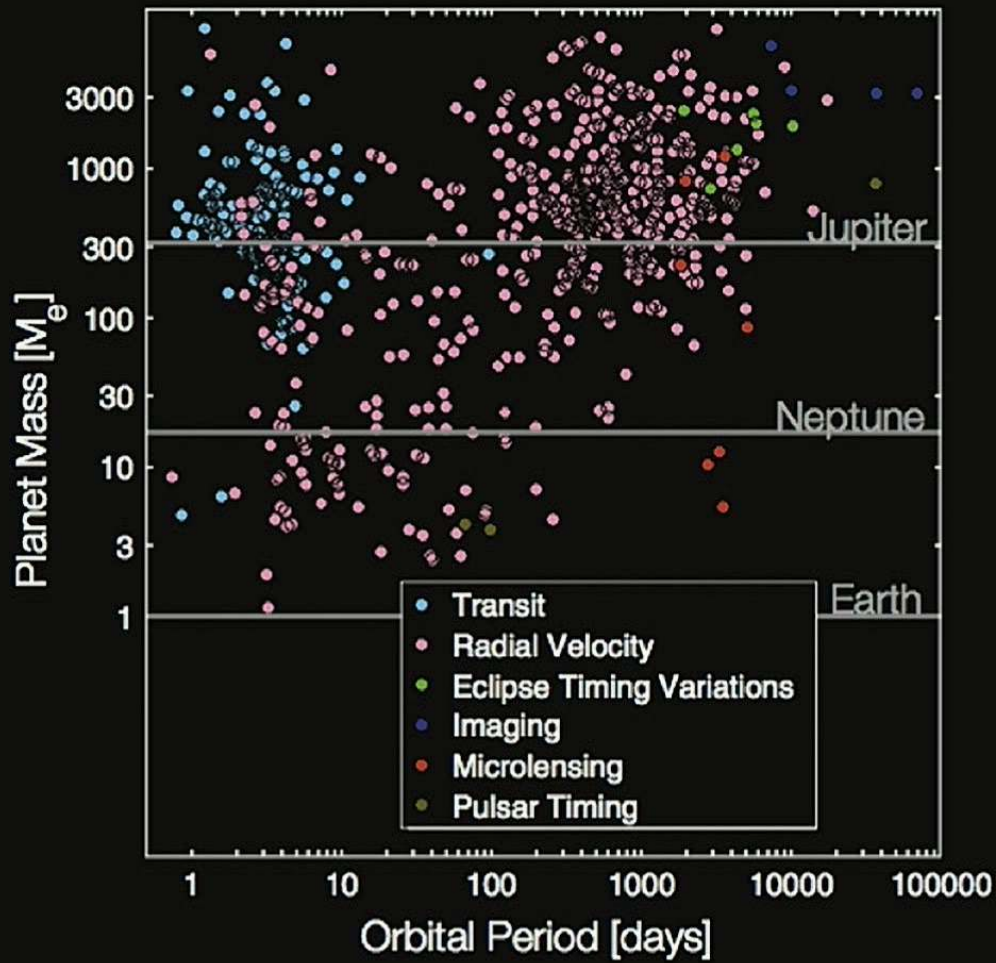
Kepler-186 f (click to zoom)

Kepler-186 f
Planet mass: Unknown

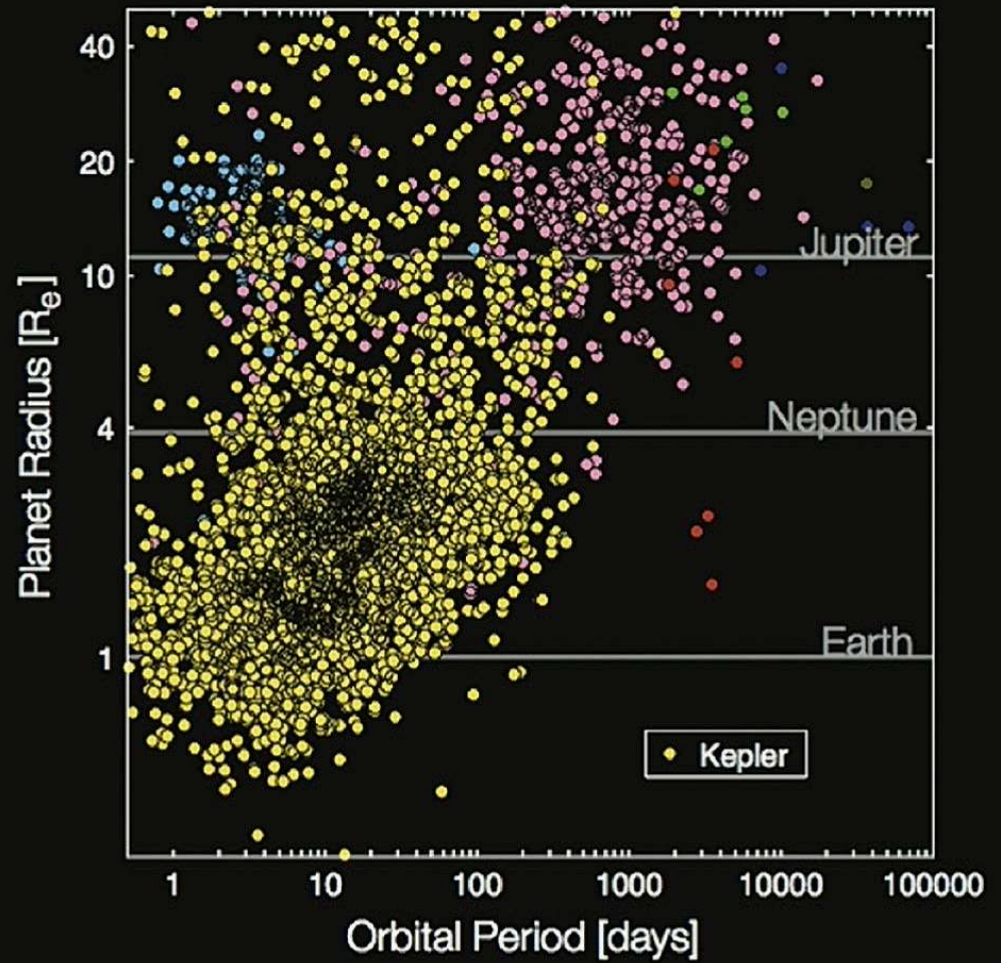
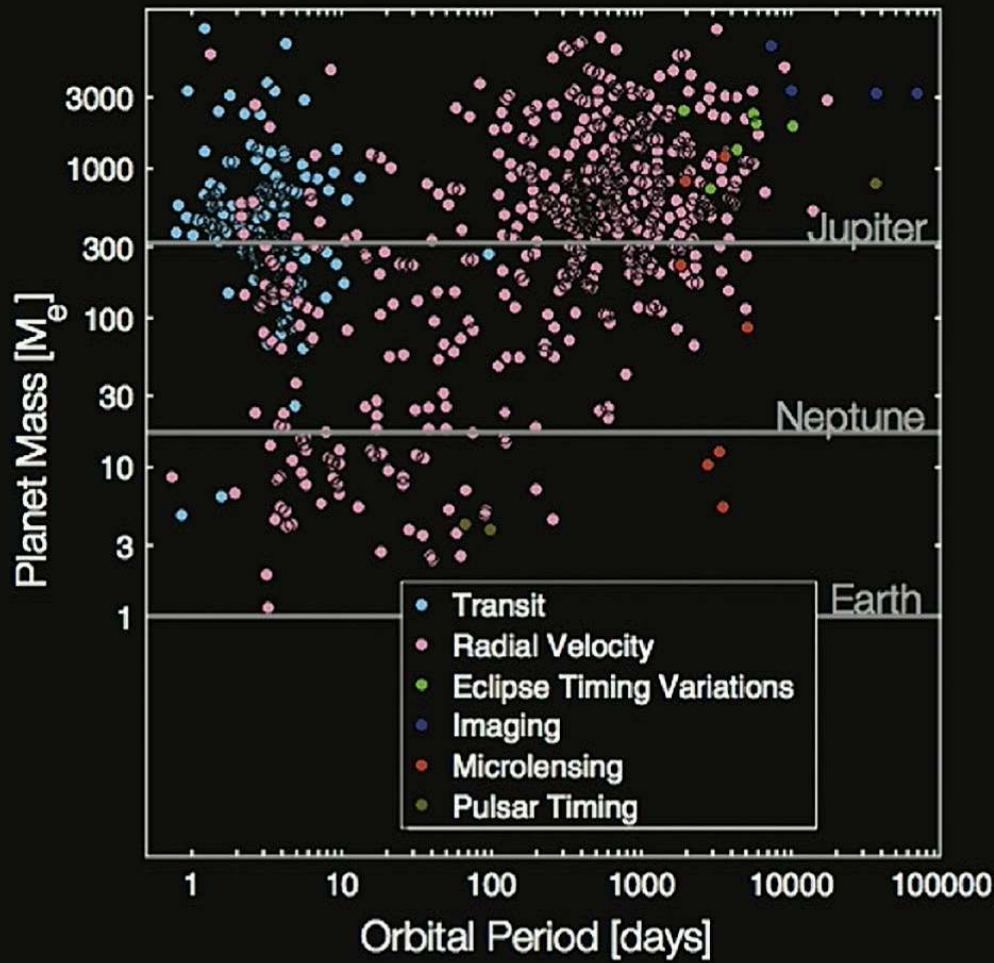
SPEED [Slider] Paused

REAL RATE

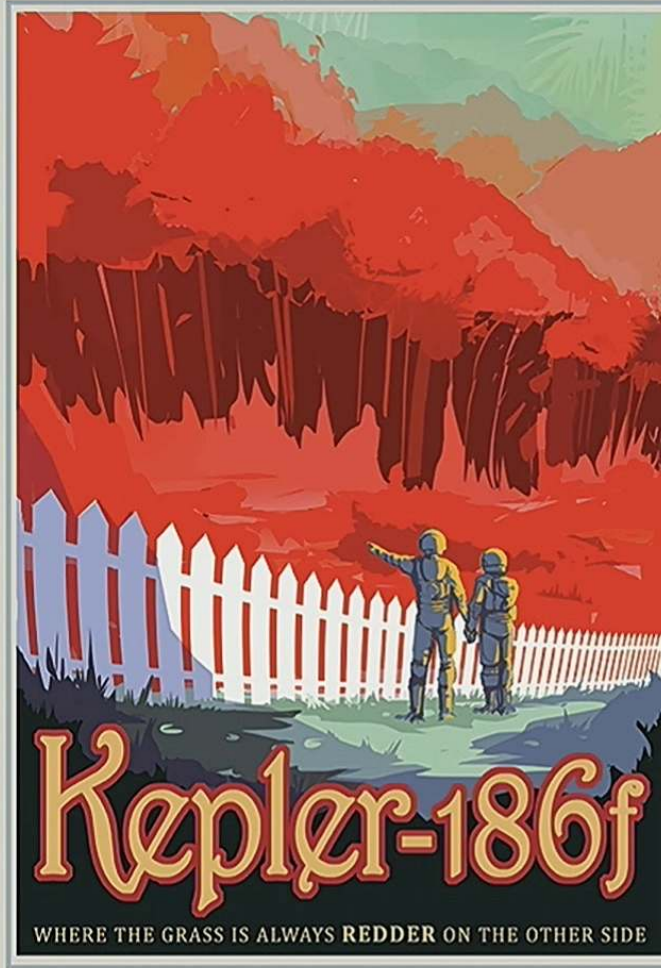




Batalha 2014



Batalha 2014

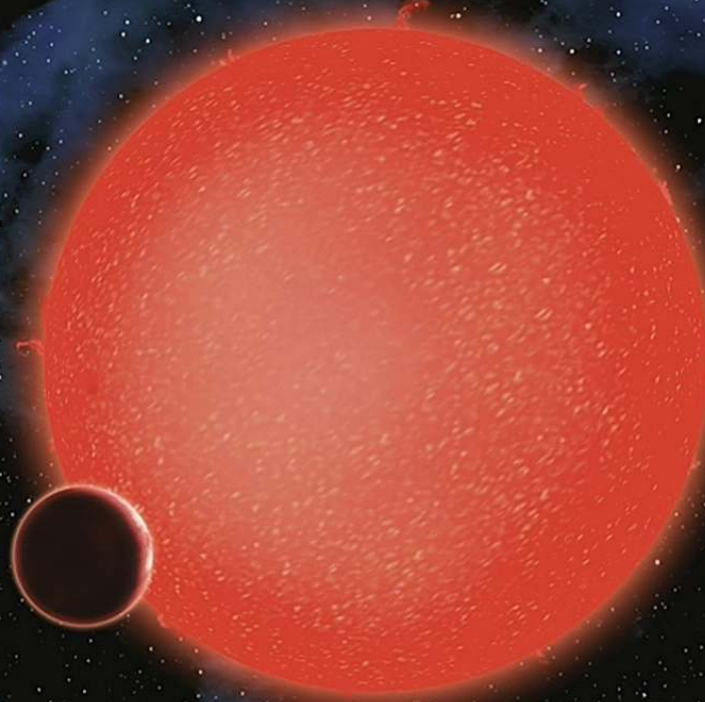


Kepler 186f is the first Earth-size planet discovered in the potentially habitable zone around another star, where liquid water could exist on the planet's surface. Its star is much cooler and redder than our Sun. If giant life does exist on a planet like Kepler 186f, its photosynthesis could have been 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.

www.nasa.gov

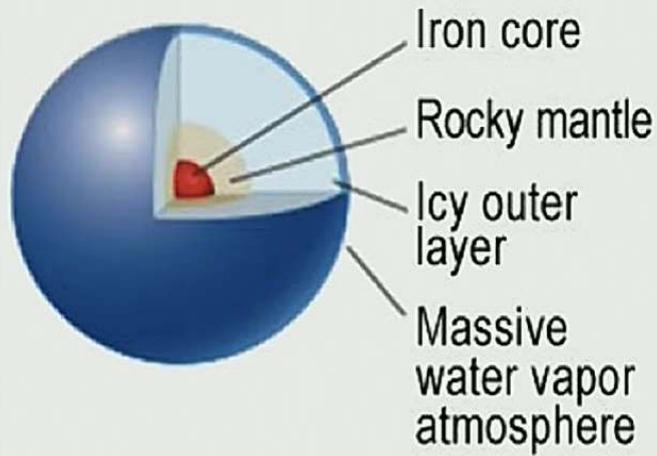
NASA's Kepler 0 program. Jet Propulsion Laboratory, Pasadena, CA
www.jpl.nasa.gov

GI 1214b

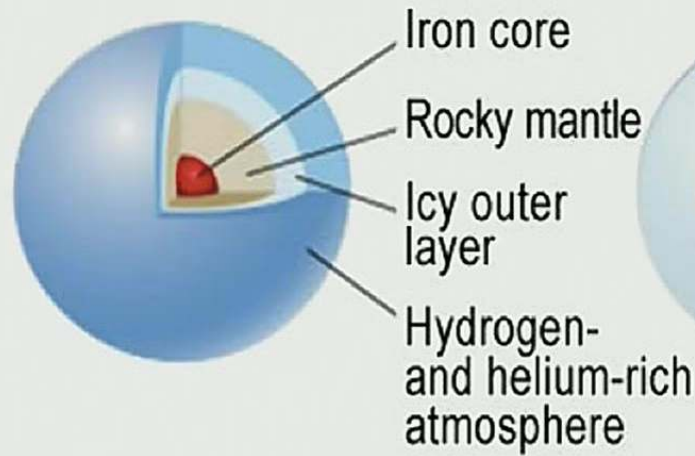


Credit: NASA, ESA, and D. Aguilar (Harvard-Smithsonian Center for Astrophysics)

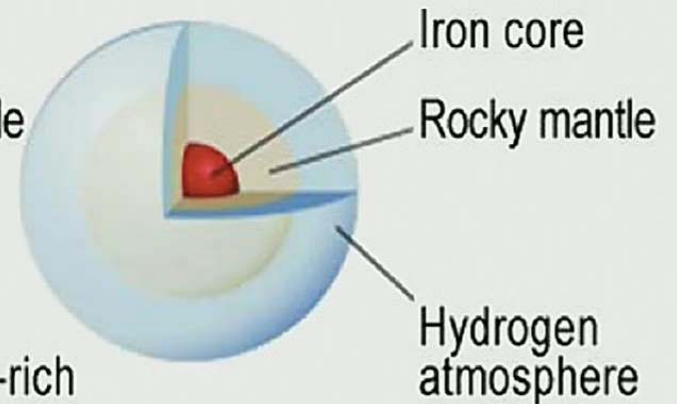
GI 1214b



Water planet



Mini-Neptune



Rocky planet

We work to quantify the range of interior compositions possible given a planet mass, size, and incident energy and under the assumption of a spherically symmetric, differentiated planet and common planetary materials

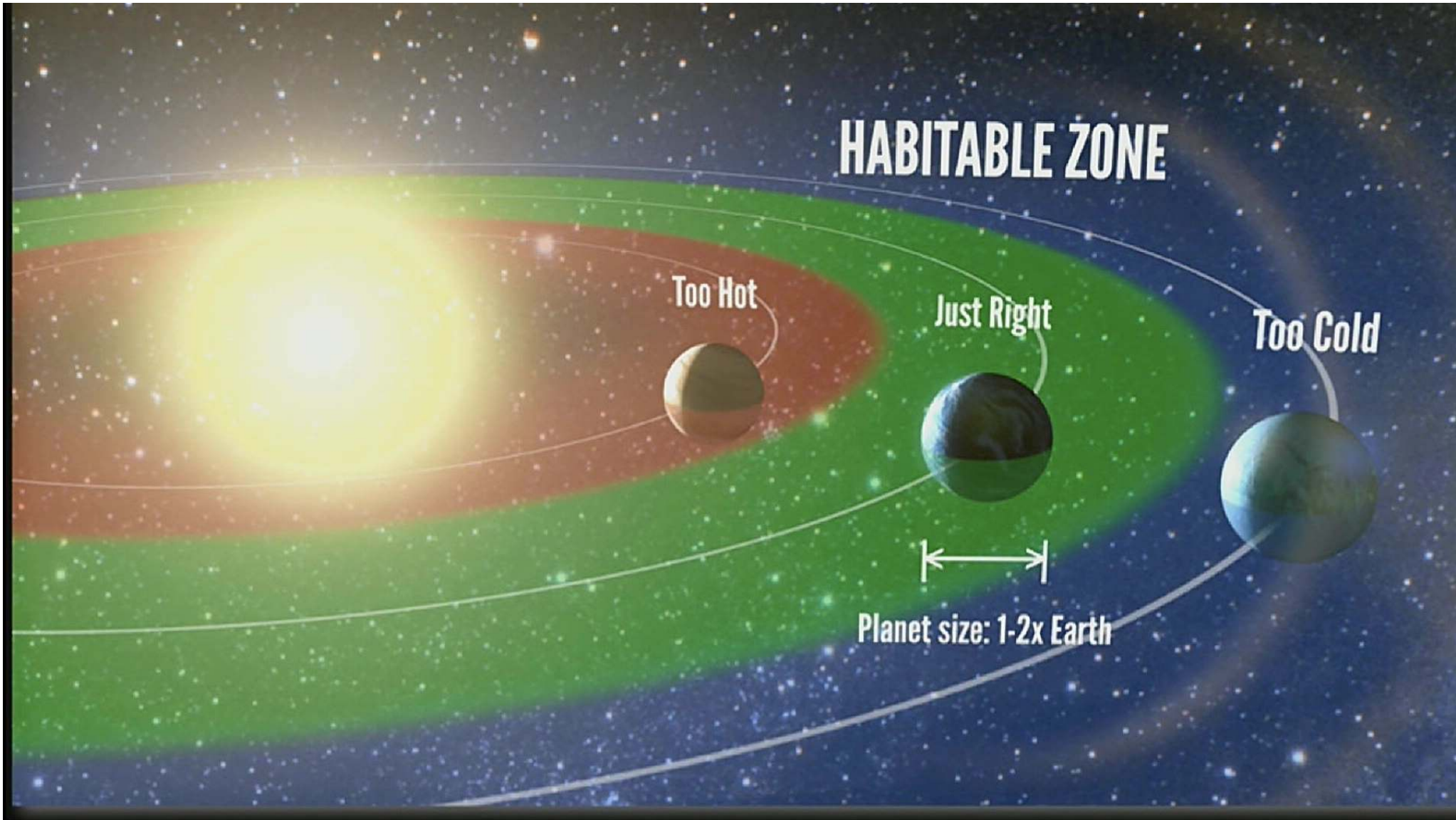
Rogers and Seager (2010)

Credit: NASA, ESA, and D. Aguilar (Harvard-Smithsonian Center for Astrophysics)

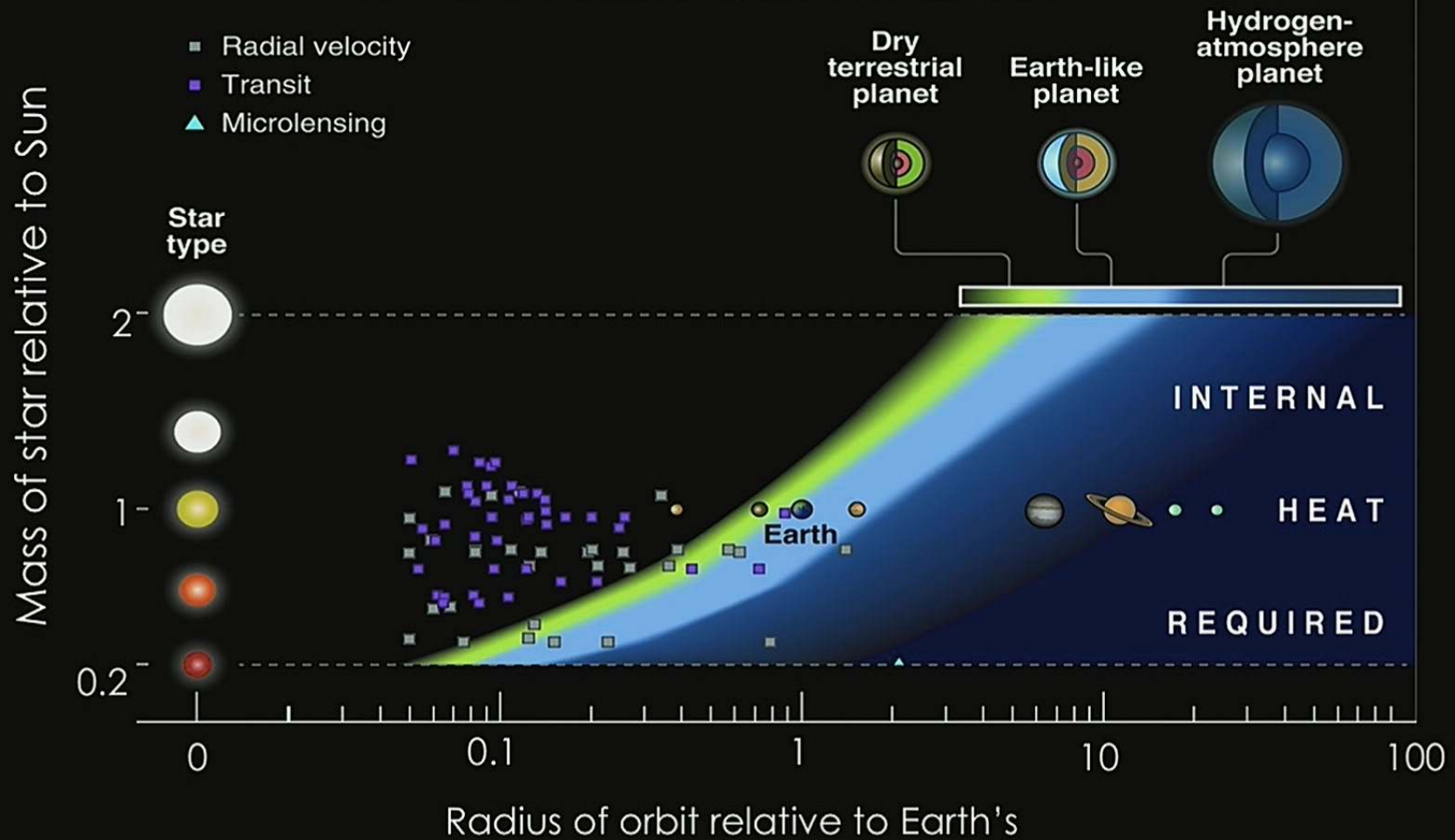
TOP: ELIZABETH LAGANA/SPACE.COM; BOTTOM

Thousands of exoplanets are known

- Exoplanets are diverse, covering nearly all masses, sizes, orbits possible
- Small planets (~twice Earth's size) are nearly ten times as common as Jupiter-size planets, challenging formation theory
- For many planets, despite having measured masses and radii, ambiguity remains

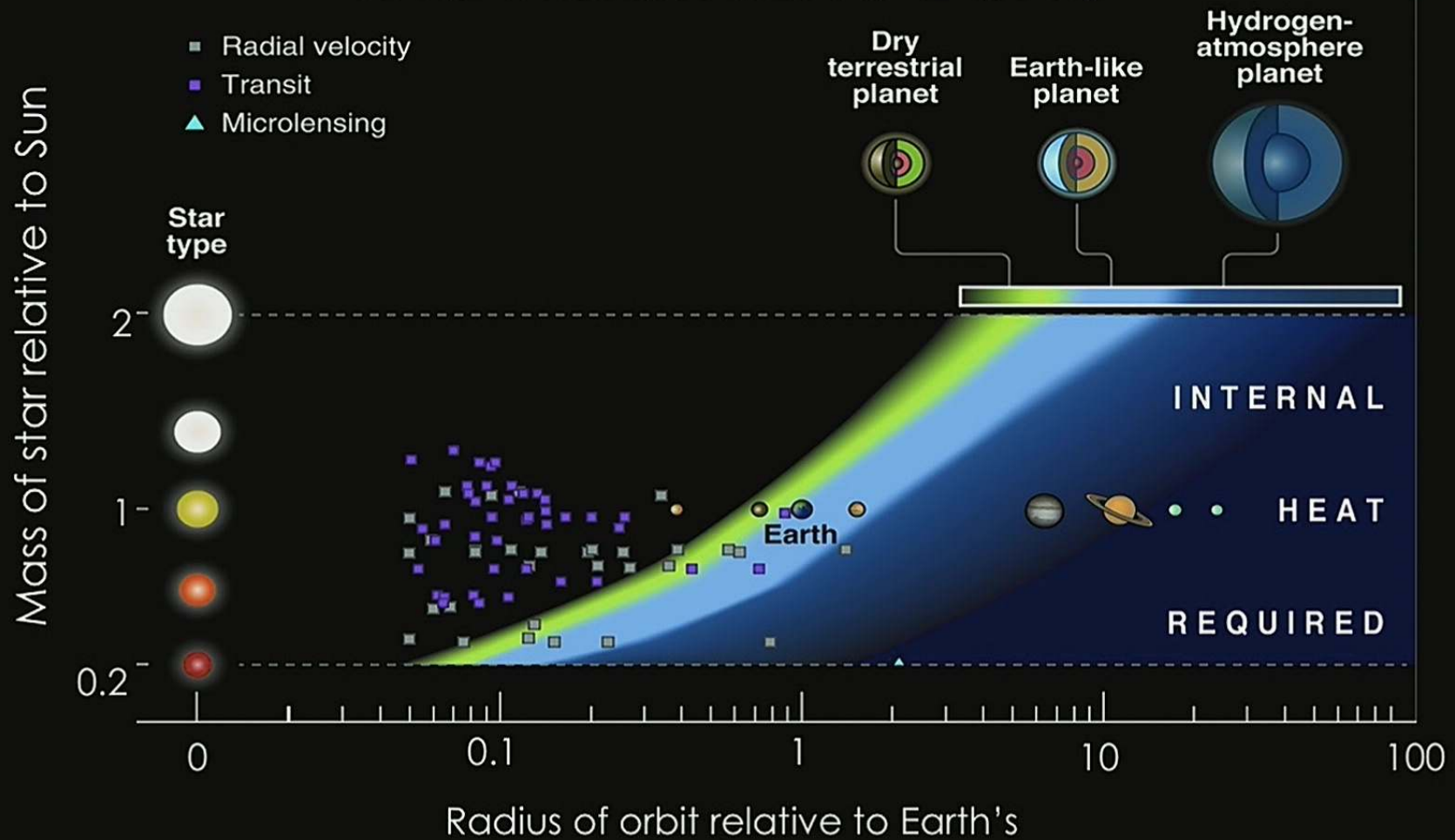


The Habitable Zone

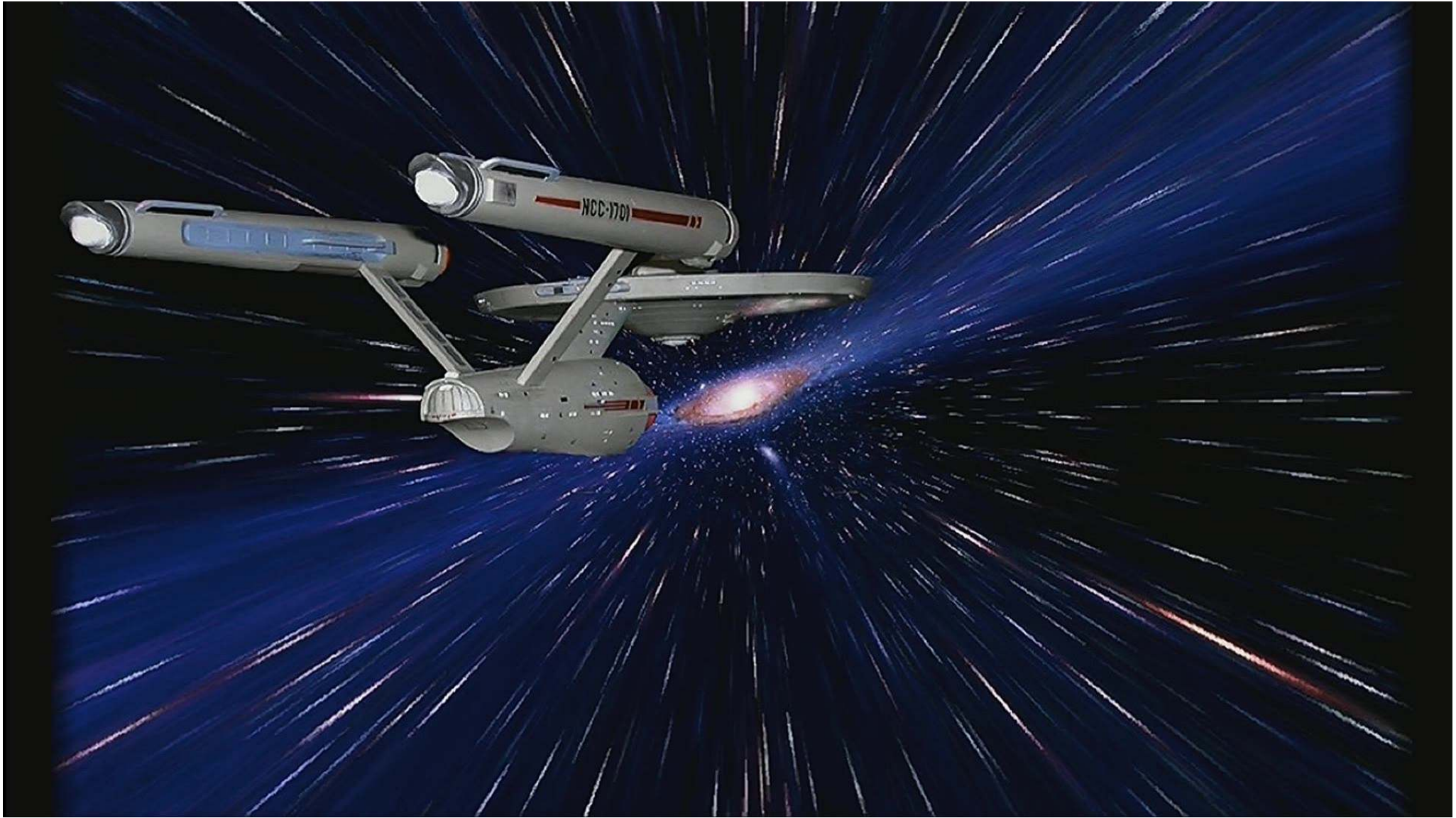


See Seager, "Exoplanet Habitability", Science May 2013, Pierrehumbert & Gaidos 2011, Zsom et al. 2013, Abe et al. 2011

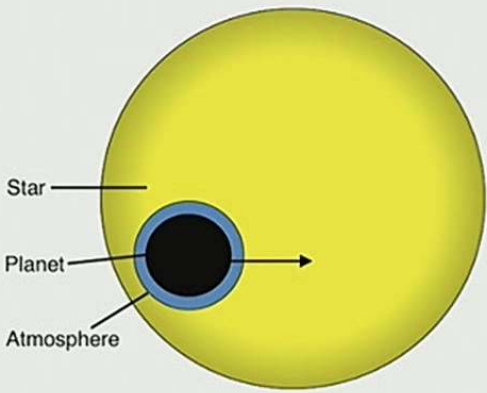
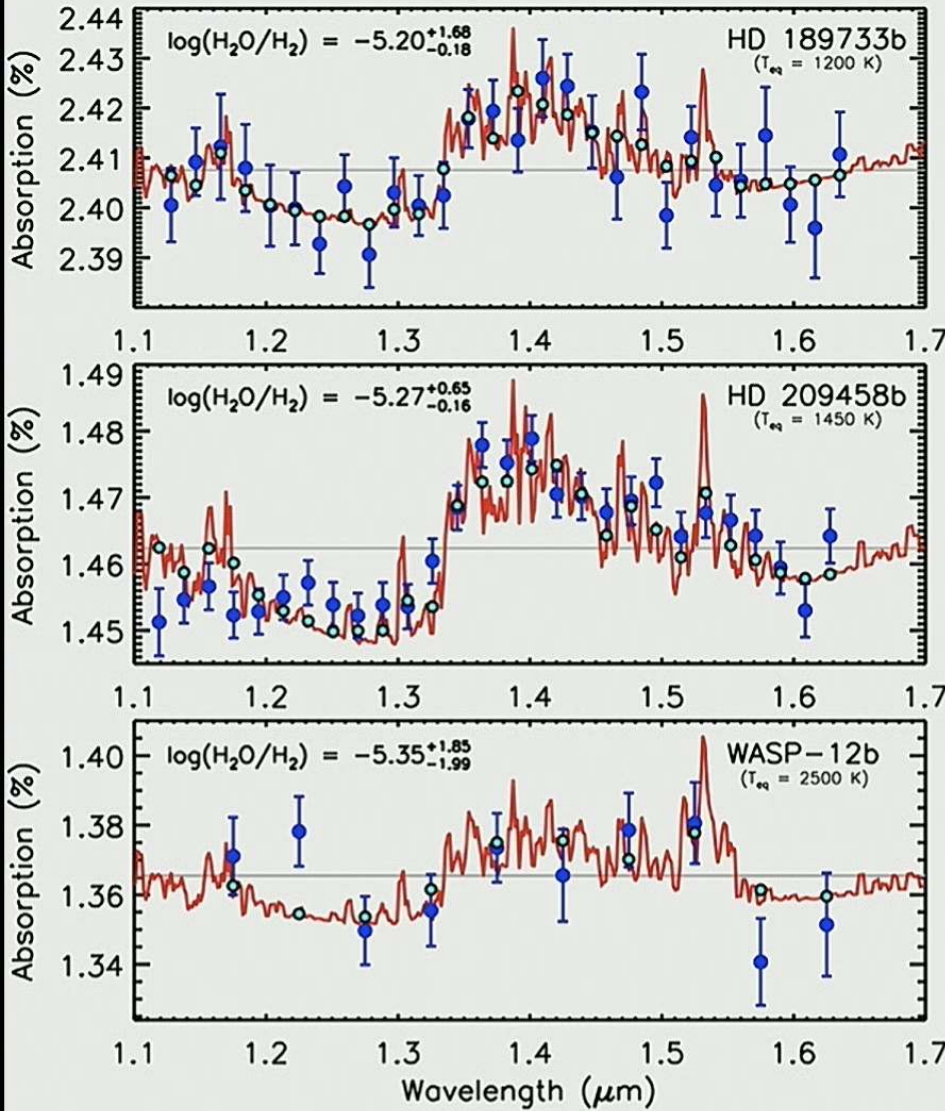
The Habitable Zone



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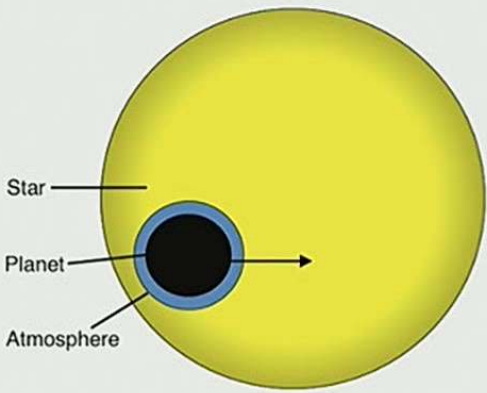
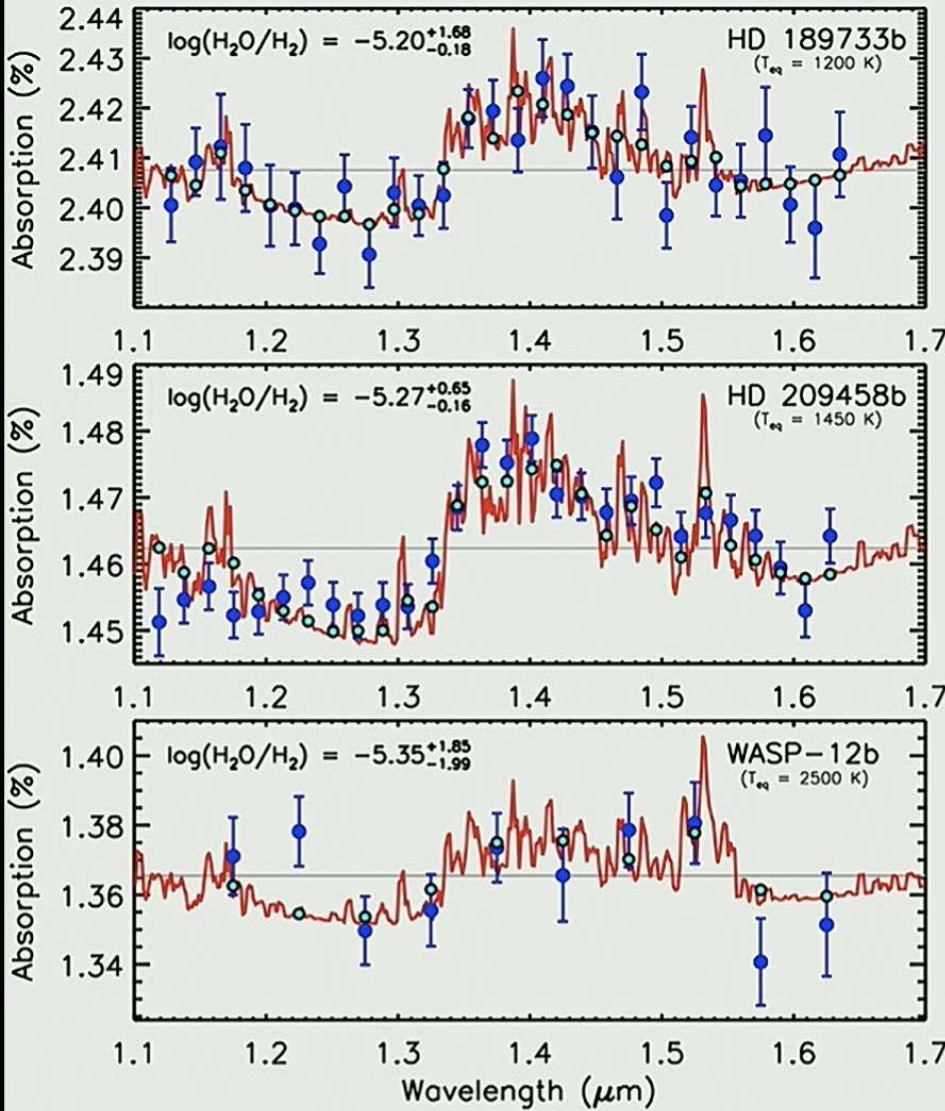


Water Vapor in Three Hot Jupiters



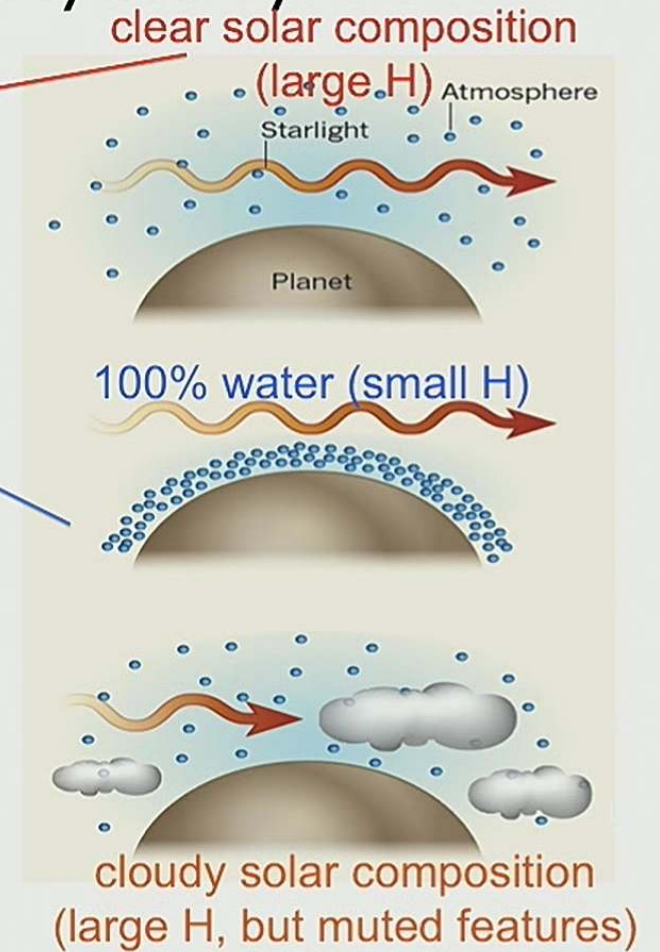
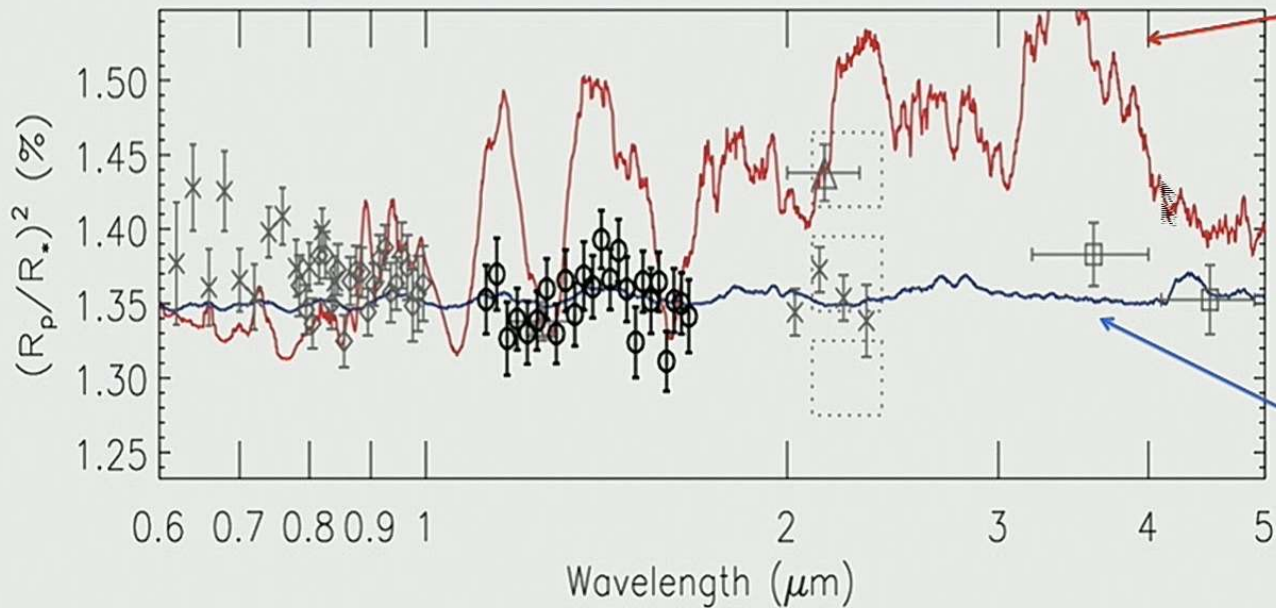
Madhusudhan et al. 2014

Water Vapor in Three Hot Jupiters



Madhusudhan et al. 2014

GJ1214b: A Current Mystery



strength of spectral features:

$$\Delta D \sim \frac{5HR_p}{R_*^2} \quad H = \frac{kT}{\mu m_H g}$$

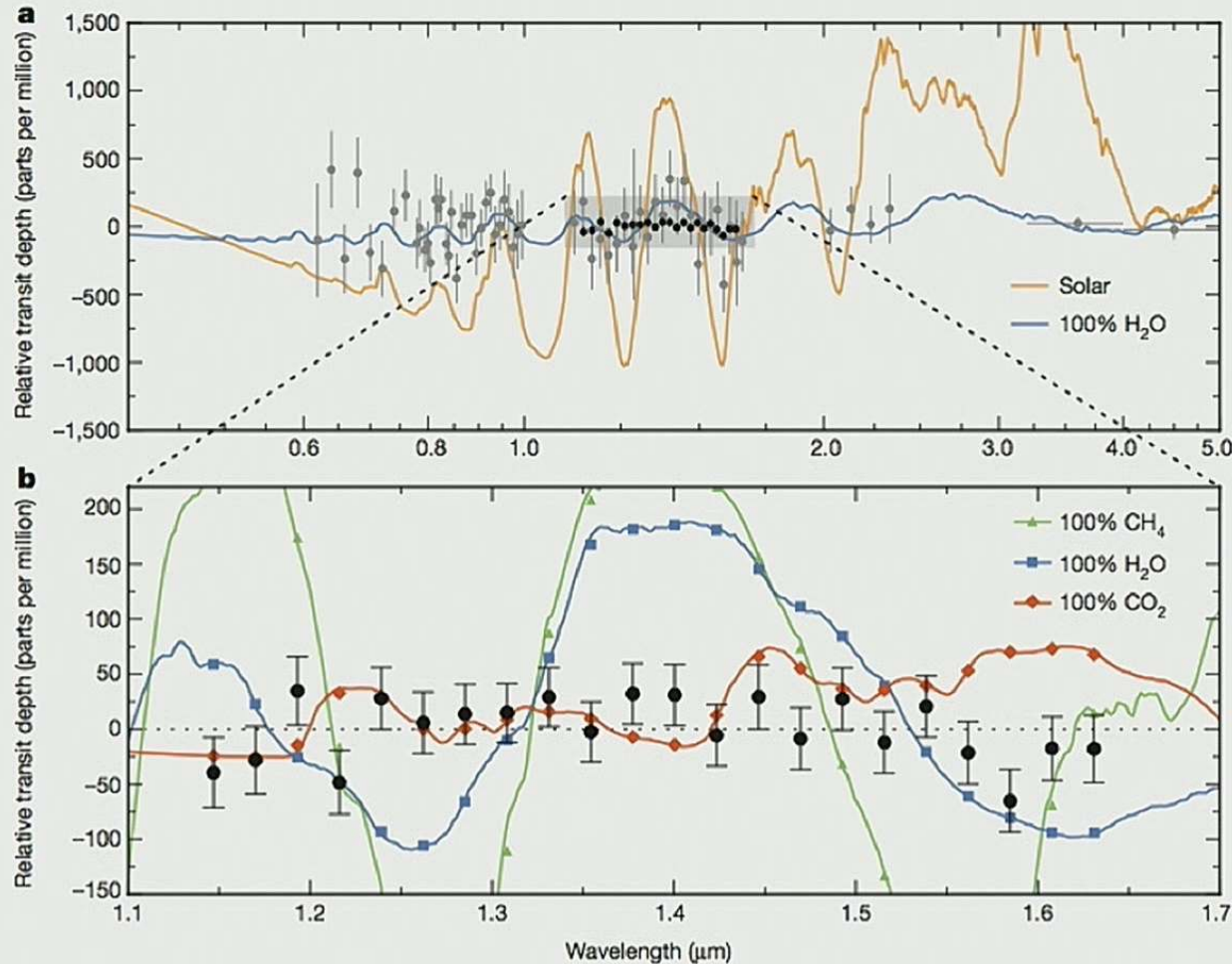
- ◇ VLT (Bean et al. 2010)
- △ Spitzer (Desert et al. 2011)
- CFHT (Croll et al. 2011)
- × Keck (Crossfield et al. 2011)
- VLT/Magellan (Bean et al. 2011)
- WFC3 (this work)

Courtesy J. Bean

GJ 1214b HST WFC3

A permanent mystery?

For many exoplanets, ambiguity remains in bulk interior or atmospheric composition or both. Interpretation will remain limited even with precision measurements



Kreidburg et al. 2014

Compound name	Formula	Typical atmospheric concentration	Primary terrestrial atmospheric source	Example of biological production
Nitrogen	N ₂	78%	-	Denitrifying bacteria
Oxygen	O ₂	21%	Photosynthesis	Photosynthesis
Water	H ₂ O	1% - 4%	Evaporation	Respiration
Argon	Ar	9340 ppm	Outgassing	<i>Not produced</i>
Carbon dioxide	CO ₂	350 ppm	Outgassing, biology, anthropogenic	Respiration
Neon	Ne	18.18 ppm	Outgassing	<i>Not produced</i>
Helium	⁴ He	5.24 ppm	Outgassing	<i>Not produced</i>
Methane	CH ₄	1.7 ppm	Biology	Methanogenesis
Krypton	Kr	1.14 ppm	Outgassing	<i>Not produced</i>
Hydrogen	H ₂	0.55 ppm	H ₂ O photolysis	Hydrogenase H ₂ production in phototrophs
Nitrous Oxide	N ₂ O	320 ppb	Biology	Ammonia oxidation (nitrification)
Carbon monoxide	CO	125 ppb	Photochemistry	Mammalian CO signaling
Xenon	Xe	87 ppb	Outgassing	<i>Not produced</i>
Ozone	O ₃	10 – 100 ppb	Photochemistry	Inflammation in animals
Hydrogen chloride	HCl	~1 ppb	Sea salt	Halocarbon metabolism (as chloride)
Isoprene	C ₅ H ₈	1 – 3 ppb	Plants	Trees
Ethane	C ₂ H ₆	0.2 – 3 ppb	Fires, oceans, anthropogenic	Oceanic bacterial metabolism
Benzene	C ₆ H ₆	0.1 – 1 ppb	Anthropogenic	Made by mushrooms, trees
Ammonia	NH ₃	0.1 – 3 ppb	Biology	Nitrogen fixation by many bacteria
Nitric acid	HNO ₃	0.04 – 4 ppb	Photochemistry	Nitrifying bacteria (as nitrate)
Methyl chloride	CH ₃ Cl	612 ppt	Biology	Oceanic bacteria
Carbonyl sulfide	OCS	500 ppt	Biology	Lichens in soils
Nitric oxides	NO, NO ₂	30 – 300 ppt	Biology	Ammonia oxidizing bacteria
Difluorodichloro methane	CCl ₂ F ₂	300 ppt	Entirely anthropogenic	Anthropogenic
Trichlorofluorom ethane	CClF ₃	178 ppt	Entirely anthropogenic	Anthropogenic
Trichloroethane	CH ₃ CCl ₃	157 ppt	Anthropogenic	Seaweed
Tetrachlorometh ane	CCl ₄	121 ppt	Anthropogenic	Seaweed
Tetrafluorometha ne	CF ₄	69 ppt	Entirely anthropogenic	Anthropogenic
Chlorodifluorom ethane	CHClF ₂	59 ppt	Entirely anthropogenic	Anthropogenic
Hydrogen sulfide	H ₂ S	30 – 100 ppt	Biology	Sulfide reducing bacteria
F 113	C ₂ Cl ₃ F ₃	30 – 40 ppt	Entirely anthropogenic	Anthropogenic
(...)				

All gases present in Earth's atmosphere to ppt levels (except noble gases) are produced by life.

O₂ is the most robust biosignature gas

CH₄, N₂O, and other "abundant" gases have false positives

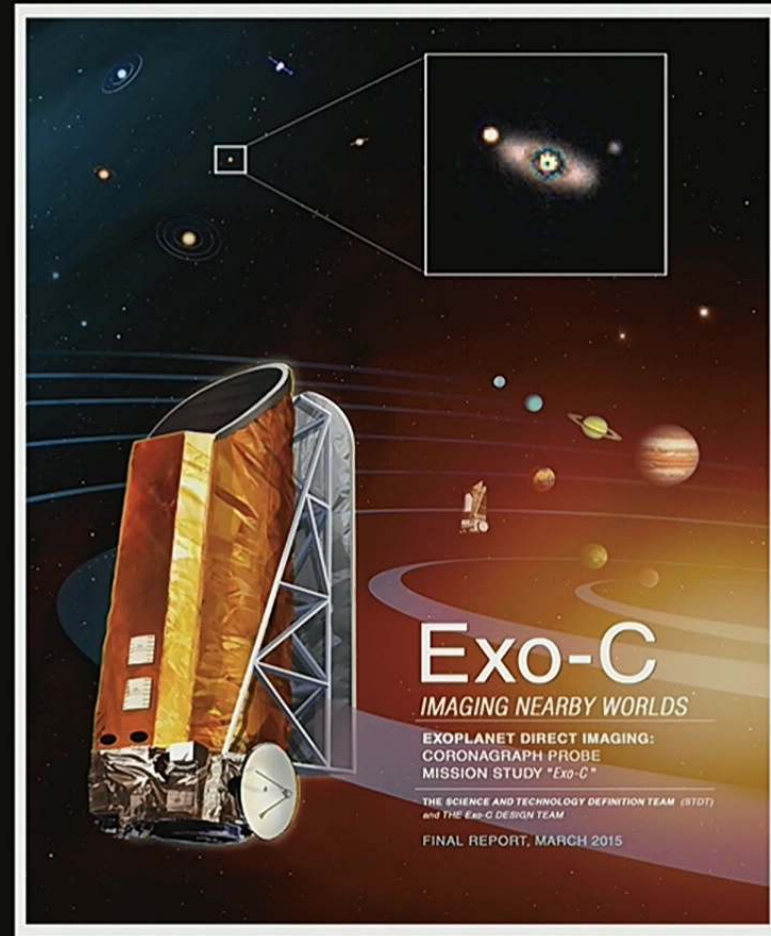
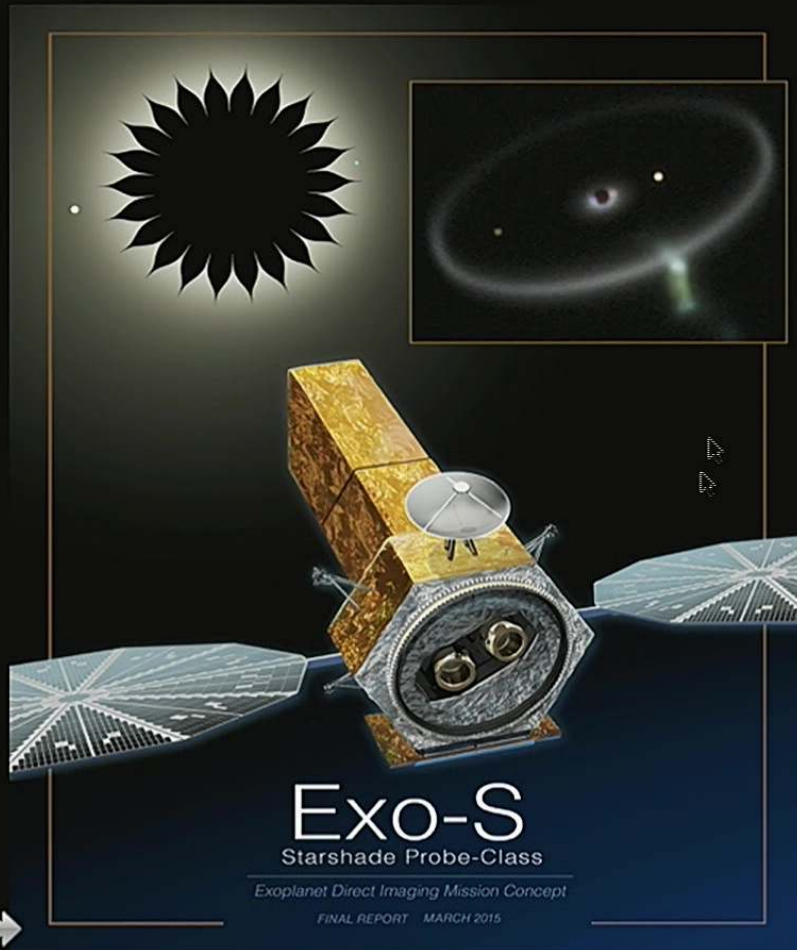
CH₃Cl, DMS, and many others are produced in tiny quantities

	C3H6O2	488368	O=C(C@@H)OC
	C3H6O2	103073	CC(=O)OC
	C3H6O2	388473	O=C(C@H)OC
	C3H6O2	388368	O=C(C@@H)OC
	C3H6O2	4573978	OC(C@H)OC1
	C3H6O2	388473	O=C(C@H)OC
	C3H6O2	8117729	C1C(CO)O
	C3H6O2	4573978	OC(C@H)OC1
	C3H6O2	24590984	C/C=C/OO
	C3H6O2	8117729	C1C(CO)O
	C3H6O2	8009645	OC1OCC1
	C3H6O2	24590984	C/C=C/OO
	C3H6O2	67601	O=C=CO
	C3H6O2	8009645	OC1OCC1
	C3H6O2	832	O=CC(O)C
	C3H6O2	67601	O=C=CO
	C3H6O2	82676	COCC=O
	C3H6O2	832	O=CC(O)C
	C3H6O2	10303481	O=C=C/OO
	C3H6O2	82676	COCC=O
	C3H6O2	28705258	C(C=CO)O
	C3H6O2	10303481	O=C=C/OO
	C3H6O2	9301293	O/C(O)C=C
	C3H6O2	28705258	C(C=CO)O
	C3H6O2	121835	O1OCCC1
	C3H6O2	9301293	O/C(O)C=C
	C3H6O2	8488625	O=C=C/OO
	C3H6O2	121835	O1OCCC1
	C3H6O2	21106125	CC(=O)CO
	C3H6O2	8488625	O=C=C/OO
	C3H6O2	10303281	CC1COO1
	C3H6O2	21106125	CC(=O)CO
	C3H6O2	9157685	O(O)C=C
	C3H6O2	10303281	CC1COO1
	C3H6O2	4417663	OC(O)C=C
	C3H6O2	9157685	O(O)C=C
	C3H6O2	141532	OC1(O)CC1
	C3H6O2	4417663	OC(O)C=C
	C3H6O2	26667354	C/C=C/OO
	C3H6O2	141532	OC1(O)CC1
	C3H6O2	5344354	OC(C@@H)OC1
	C3H6O2	26667354	C/C=C/OO
	C3H6O2	14823306	C=C/OO
	C3H6O2	5344354	OC(C@@H)OC1
	C3H6O2	13472118	C=C(O)CO
	C3H6O2	14823306	C=C/OO
	C3H6O2	13472118	C=C(O)CO

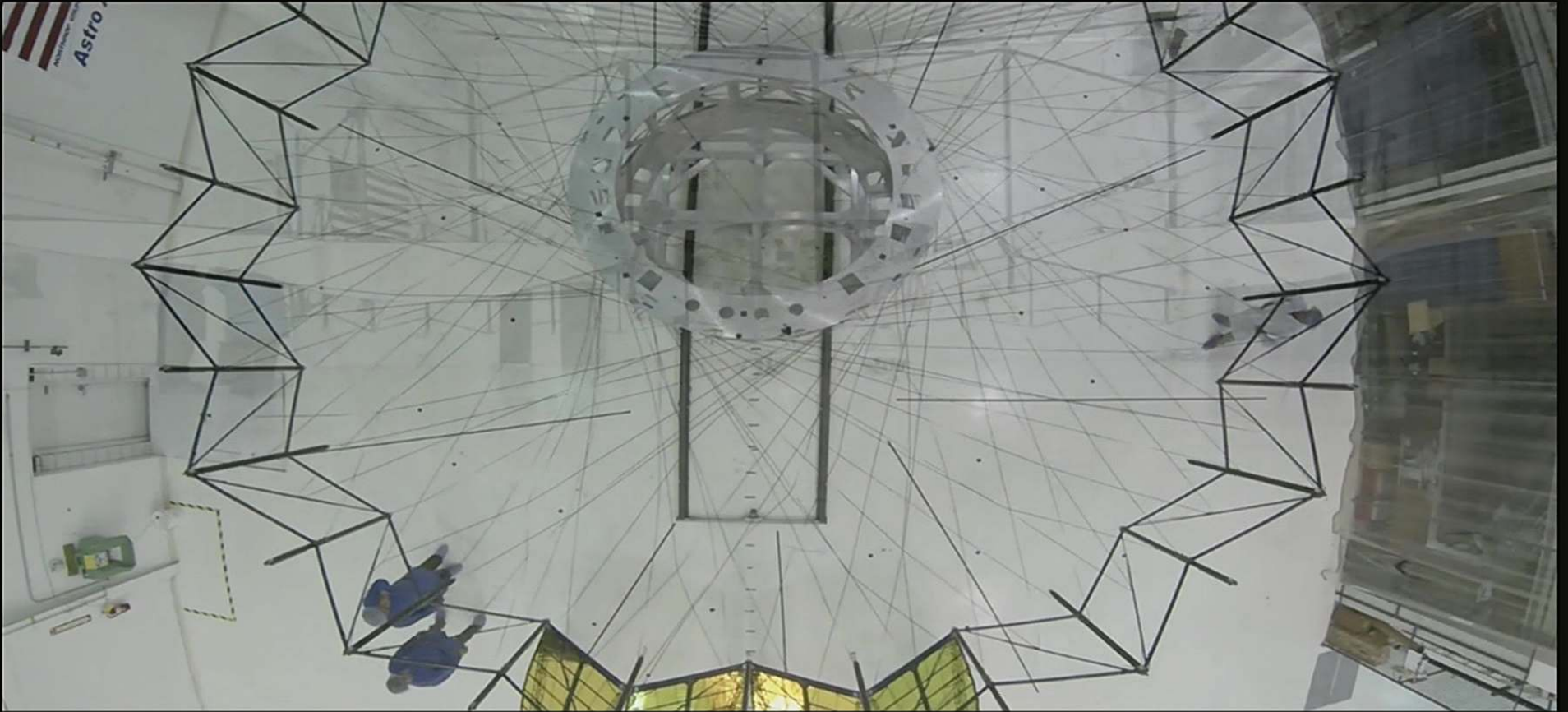
Direct Imaging: Suppress Starlight to Find Planets

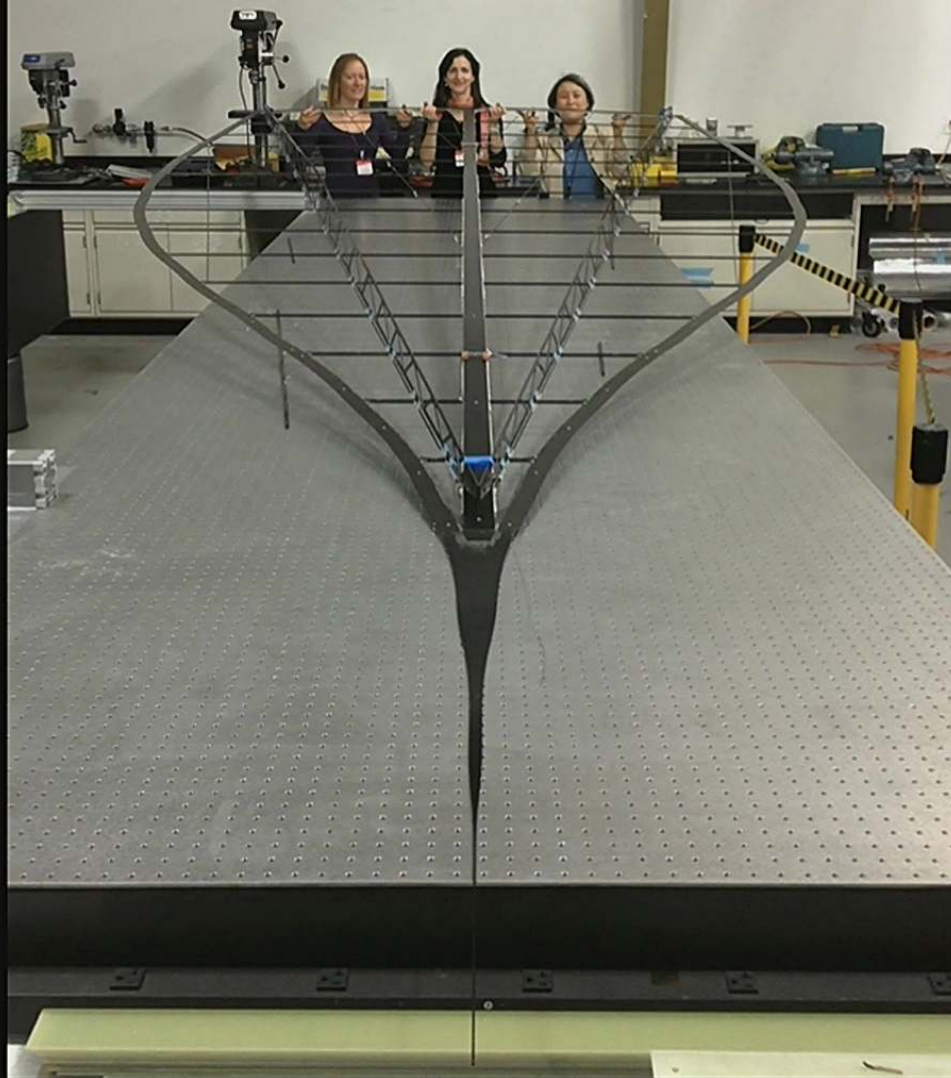


NASA Probe-Class Studies 2015









Petal prototype used for manufacturing tolerance verification tests. Credit: NASA/JPL