



Art Worlds: Designing the Look of the TRAPPIST-1 System

Robert Hurt (Caltech/IPAC)



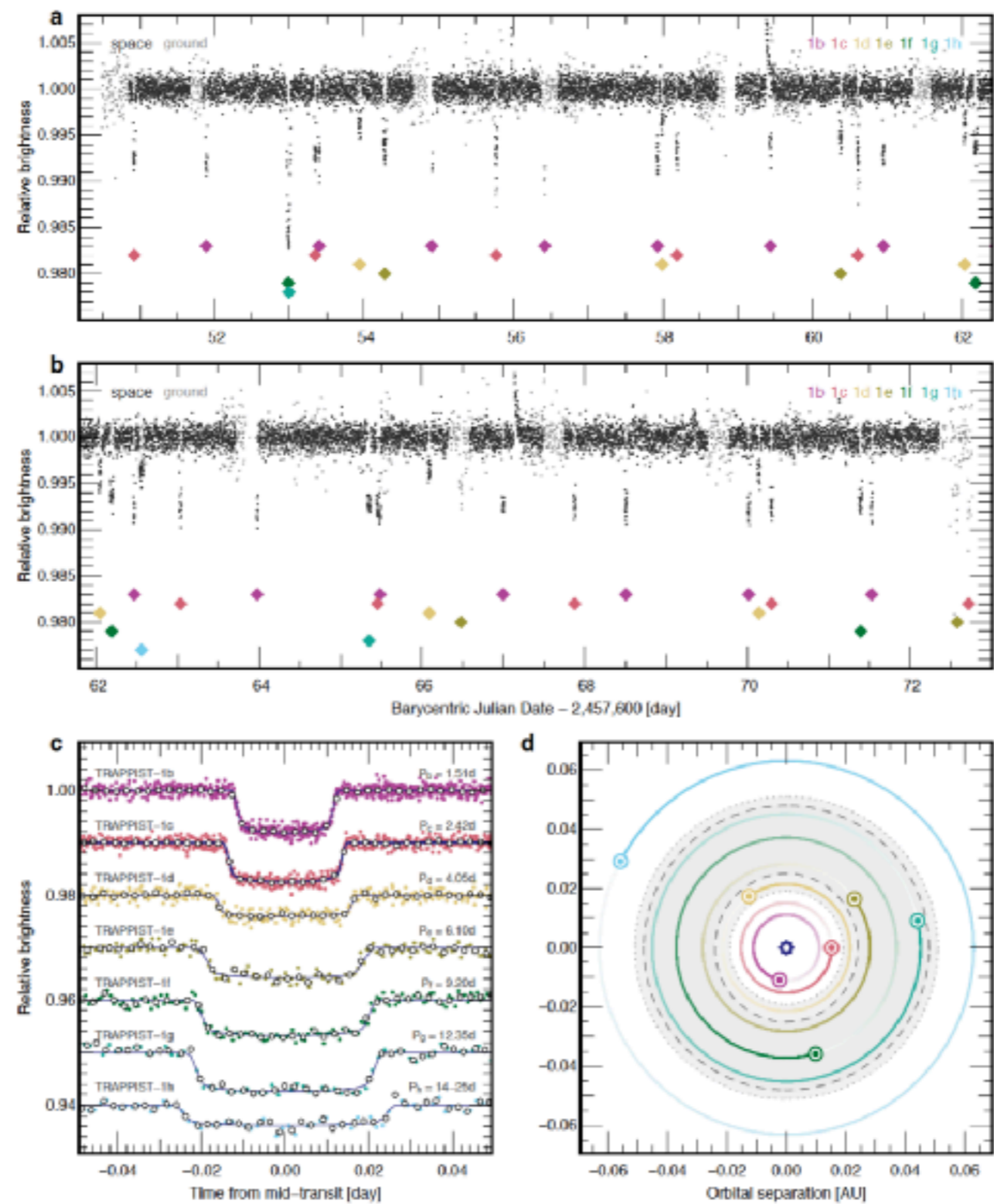
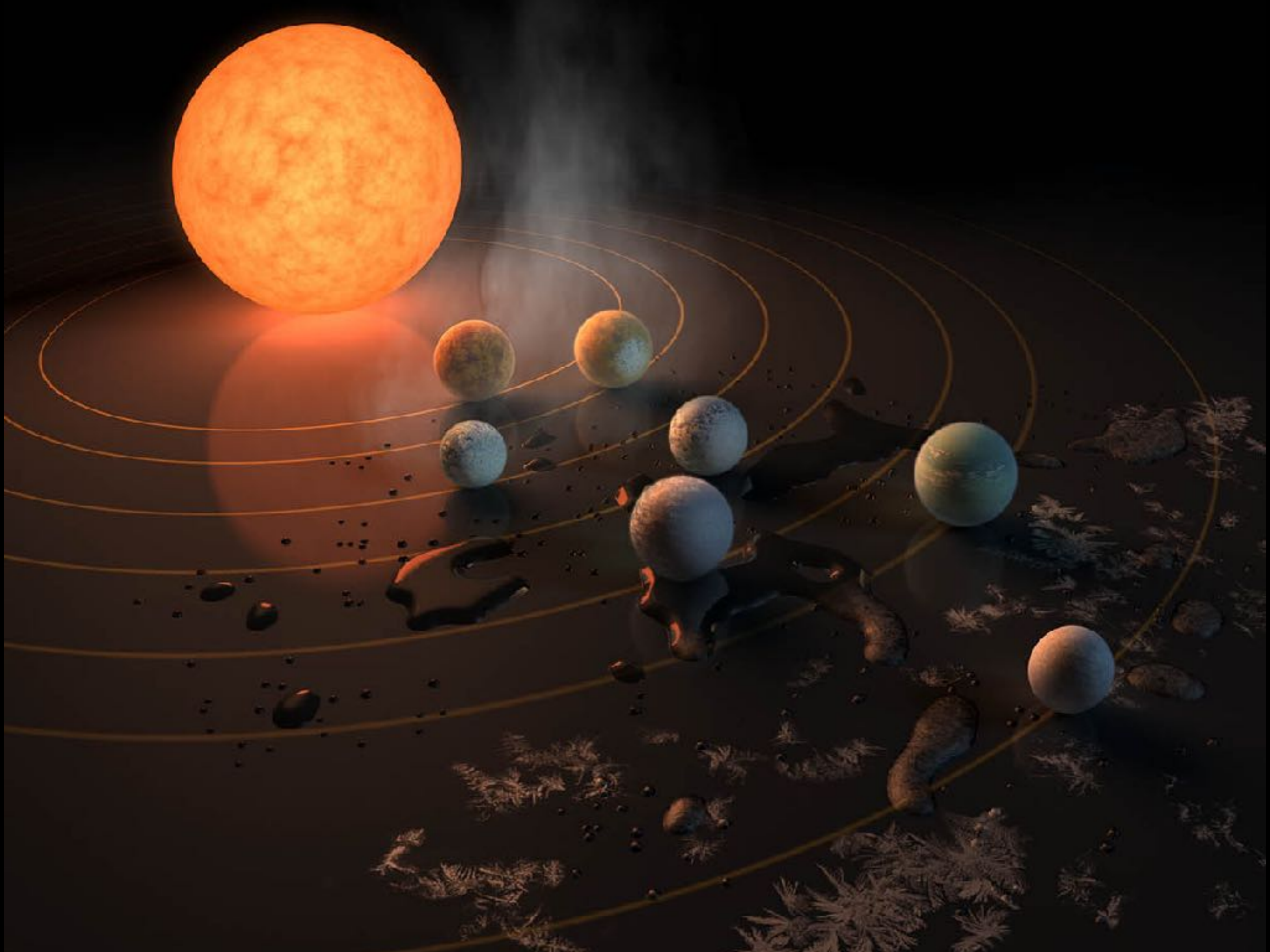


Figure 1 | The TRAPPIST-1 system as seen by Spitzer. *a* and *b*. Spitzer photometric measurements (dark points) resulting from the nearly-continuous observation of the star from 19 September to 10 October 2016. The ground-based measurements (binned per 5 min for clarity) gathered during the Spitzer gaps are shown as light grey points. The position of the transits of the planets are shown as coloured diamonds. *c*. Period-folded photometric measurements obtained by Spitzer near transits of planets TRAPPIST-1b-h corrected for the measured TTVs. Coloured dots show the unbinned measurements, whereas the open circle depict binned measurements for visual clarity. The best-fit transit models are shown as coloured lines. 16-11-5-2-3-2-1 transits were observed by Spitzer and combined to produce







nature

THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE

*Seven potential
Earth-like worlds
orbiting low-mass
star TRAPPIST-1*

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PLANET SUITE

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Trappist 1 System Properties

	a (mAU)	Period (d)	R (Re)	Mass (Me)	Density (ρ)	* Size (θ_{sun})	Delta d (mAU)	Delta e (mAU)	Delta f (mAU)	Delta d (aMoon)	Delta e (aMoon)	Delta f (aMoon)	Size d (moon)	Size e (moon)	Size f (moon)	Tidal d	Tidal e	Tidal f	Analogue
b	11.11	1.51	1.086	0.85	0.88	10.5	10.3	17.1	26.0	4.0	6.6	10.1	1.0	0.6	0.4	1.2	0.3	0.1	Large Io
c	15.21	2.42	1.056	1.38	1.17	7.7	6.2	13.0	21.9	2.4	5.0	8.5	1.6	0.8	0.5	8.3	0.9	0.2	Dry rocky
d	21.44	4.05	0.772	0.41	0.89	5.5	0.0	6.7	15.7	0.0	2.6	6.1	-	1.1	0.5	-	1.4	0.1	Wet Eyeball
e	28.17	6.10	0.918	0.62	0.80	4.2	6.7	0.0	8.9	2.6	0.0	3.5	1.3	-	1.0	2.6	-	1.1	Water/Icy
f	37.1	9.21	1.045	0.68	0.60	3.2	15.7	8.9	0.0	6.1	3.5	0.0	0.6	1.1	-	0.3	1.4	-	Water/Icy
g	45.1	12.35	1.127	1.34	0.94	2.6	23.7	16.9	8.0	9.2	6.6	3.1	0.4	0.6	1.3	0.2	0.4	4.1	mini-Neptune
h	69	20.00	0.755			1.9	41.6	34.8	25.9	16.2	13.6	10.1	0.2	0.2	0.3	0.0	0.0	0.0	Europa Iceball

Closest approach between planet X and neighbors (in thousandths of AU and Earth-moon distance)

Angular size of neighboring planets at closest approach relative to size of Moon in Earth sky

Relative strength of tides induced by neighboring planets scaled by $(R1 \cdot M2)/r^3$

Solar System Properties

	a (mAU)	R (km)	R (Re)	M (Me)
Moon	2.57	1737.1	0.27	0.012
Mercury	387	2439.7	0.38	0.055
Earth	1000	6371.0	1.00	1.000

Trappist-1 Star Properties

Distance (ly)	39.47
Mass (Ms)	0.0802
Radius (Rs)	0.117
Luminosity (Ls)	0.00052
Temperature (K)	2560

Trappist 1 System Properties

Delta d (AU)	Delta f (mAU)	Delta d (aMoon)	Delta e (aMoon)	Delta f (aMoon)	Size d (moon)	Size e (moon)	Size f (moon)	Tidal d	Tidal e	Tidal f	Analogue
17.1	26.0	4.0	6.6	10.1	1.0	0.6	0.4	1.2	0.3	0.1	Large Io
13.0	21.9	2.4	5.0	8.5	1.6	0.8	0.5	8.3	0.9	0.2	Dry rocky
6.7	15.7	0.0	2.6	6.1	-	1.1	0.5	-	1.4	0.1	Wet Eyeball
0.0	8.9	2.6	0.0	3.5	1.3	-	1.0	2.6	-	1.1	Water/Icy
8.9	0.0	6.1	3.5	0.0	0.6	1.1	-	0.3	1.4	-	Water/Icy
16.9	8.0	9.2	6.6	3.1	0.4	0.6	1.3	0.2	0.4	4.1	mini-Neptune
34.8	25.9	16.2	13.6	10.1	0.2	0.2	0.3	0.0	0.0	0.0	Europa Iceball

Closest approach between planet X and neighbors (in units of AU and Earth-moon distance)

Angular size of neighboring planets at closest approach relative to size of Moon in Earth sky

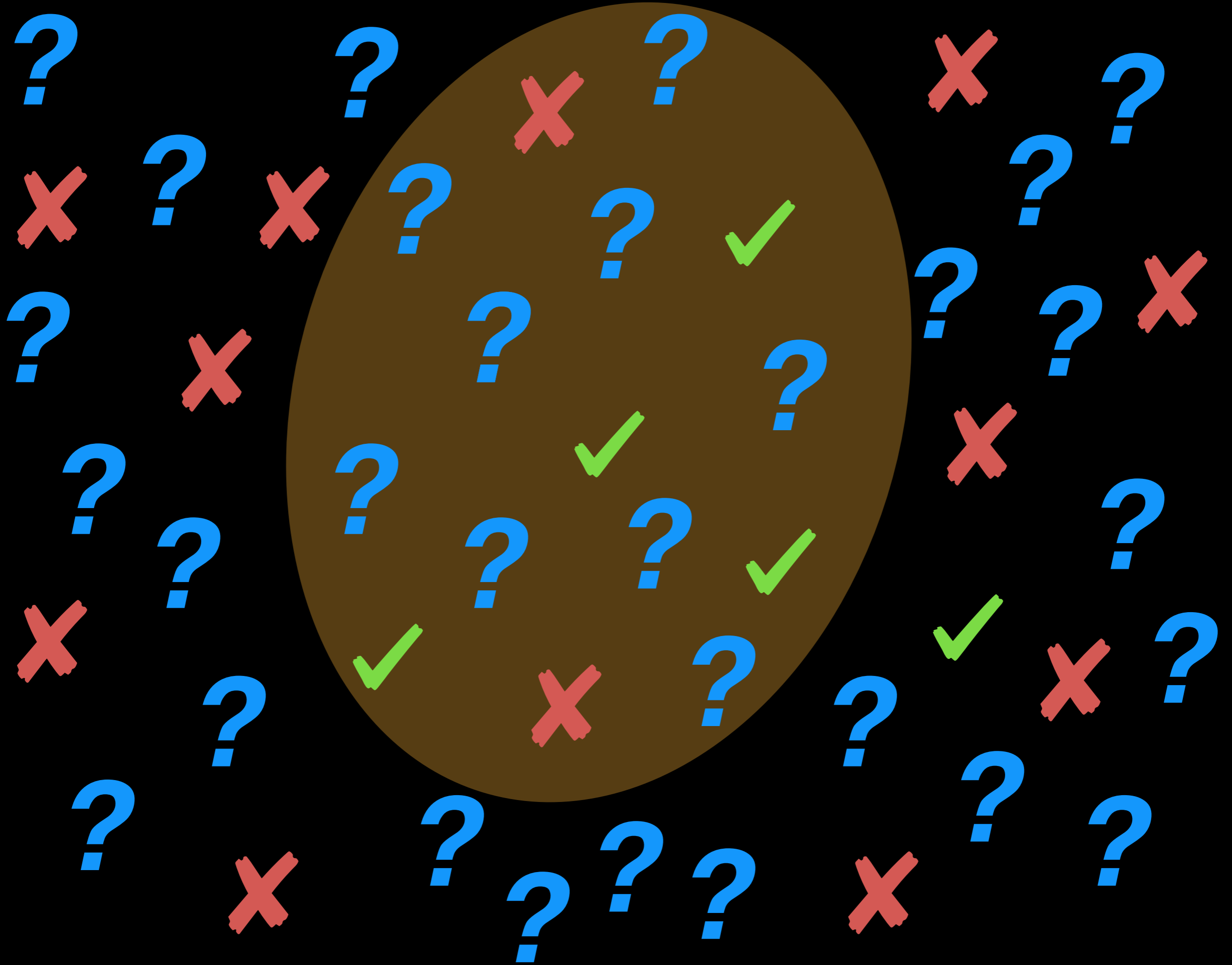
Relative strength of tides induced by neighboring planets scaled by $(R1 \cdot M2) / r^3$

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TRAPPIST-1 System



Orbital Period
days

Distance to Star
Astronomical Units (AU)

Planet Radius
relative to Earth

Planet Mass
relative to Earth

	b	c	d	e	f	g	h
Orbital Period	1.51 days	2.42 days	4.05 days	6.10 days	9.21 days	12.35 days	~20 days
Distance to Star	0.011 AU	0.015 AU	0.021 AU	0.028 AU	0.037 AU	0.045 AU	~0.06 AU
Planet Radius	1.09 R_{earth}	1.06 R_{earth}	0.77 R_{earth}	0.92 R_{earth}	1.04 R_{earth}	1.13 R_{earth}	0.76 R_{earth}
Planet Mass	0.85 M_{earth}	1.38 M_{earth}	0.41 M_{earth}	0.62 M_{earth}	0.68 M_{earth}	1.34 M_{earth}	—

Solar System
Rocky Planets



	Mercury	Venus	Earth	Mars
Orbital Period	87.97 days	224.70 days	365.26 days	686.98 days
Distance to Star	0.387 AU	0.723 AU	1.000 AU	1.524 AU
Planet Radius	0.38 R_{earth}	0.95 R_{earth}	1.00 R_{earth}	0.53 R_{earth}
Planet Mass	0.06 M_{earth}	0.82 M_{earth}	1.00 M_{earth}	0.11 M_{earth}

Illustrations

TRAPPIST-1 System



b

c

d

e

f

g

h

Orbital Period
days

Distance to Star
Astronomical Units (AU)

Planet Radius
relative to Earth

Planet Mass
relative to Earth

1.51 days	2.42 days	4.05 days	6.10 days	9.21 days	12.35 days	~20 days
0.011 AU	0.015 AU	0.021 AU	0.028 AU	0.037 AU	0.045 AU	~0.06 AU
1.09 R_{earth}	1.06 R_{earth}	0.77 R_{earth}	0.92 R_{earth}	1.04 R_{earth}	1.13 R_{earth}	0.76 R_{earth}
0.85 M_{earth}	1.38 M_{earth}	0.41 M_{earth}	0.62 M_{earth}	0.68 M_{earth}	1.34 M_{earth}	—

Solar System Rocky Planets



Mercury

Venus

Earth

Mars

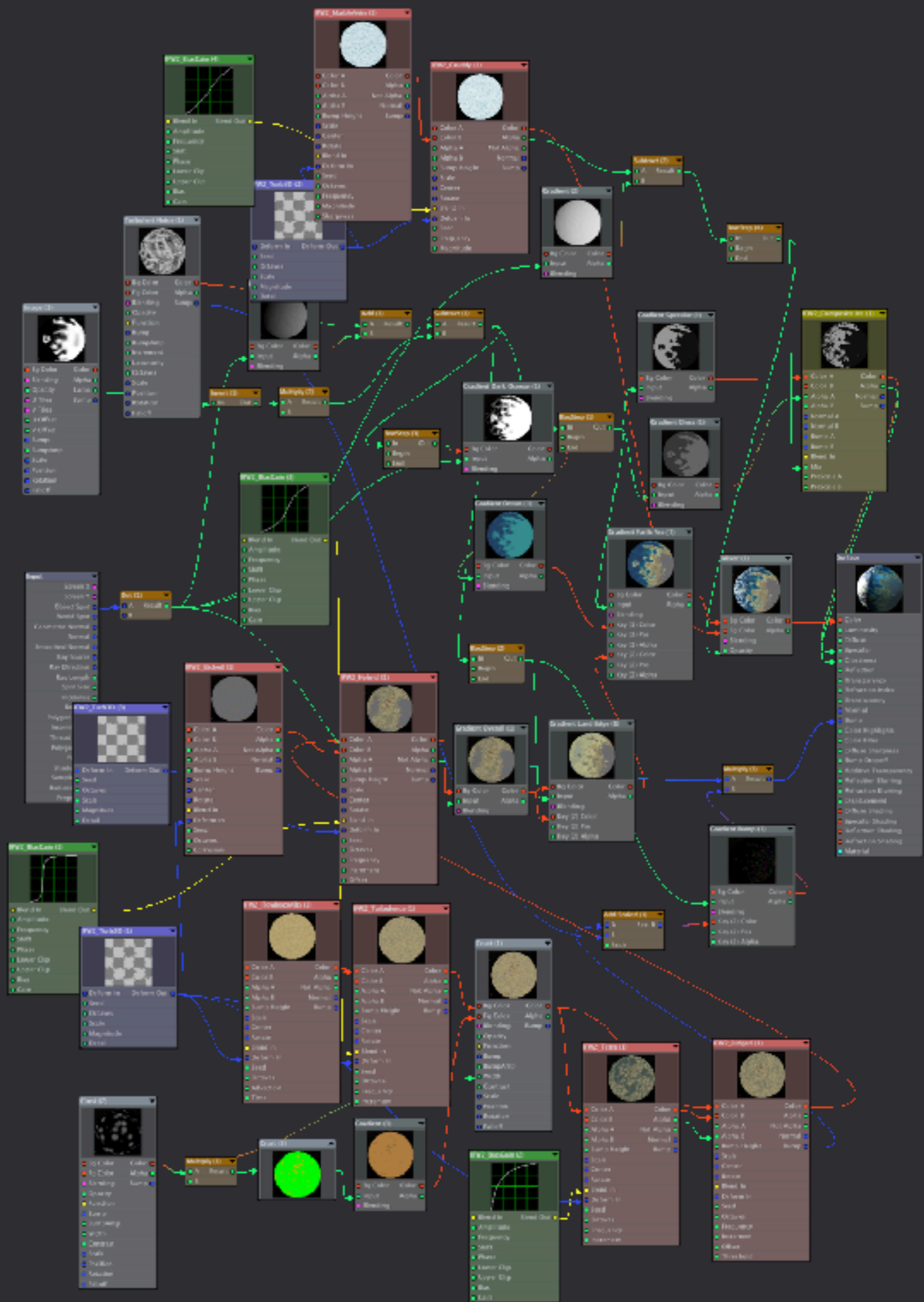
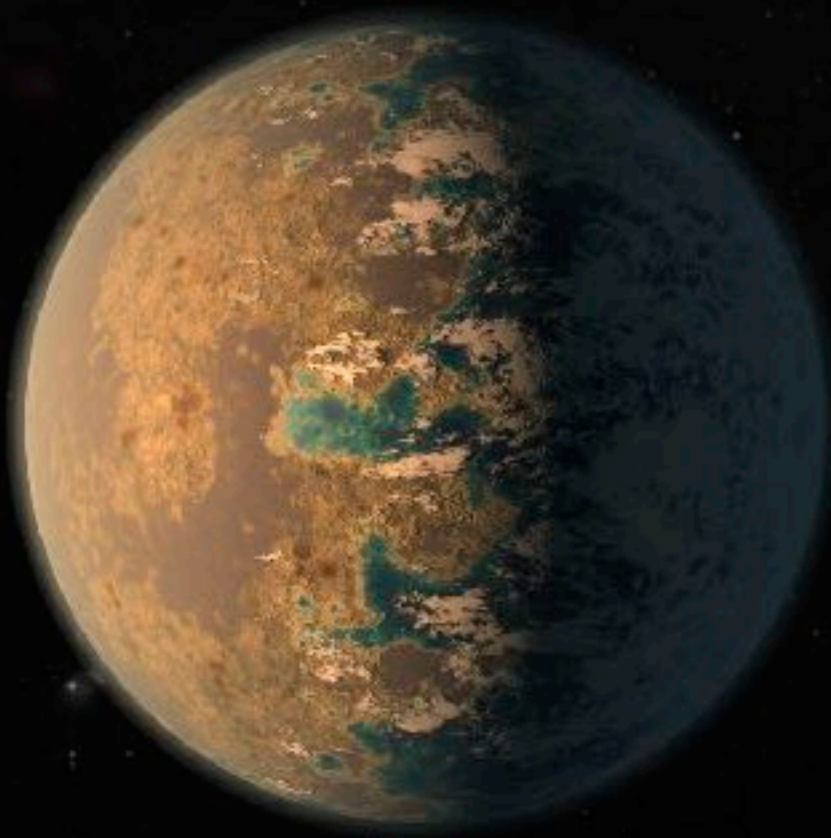
Orbital Period
days

Distance to Star
Astronomical Units (AU)

Planet Radius
relative to Earth

Planet Mass
relative to Earth

87.97 days	224.70 days	365.26 days	686.98 days
0.387 AU	0.723 AU	1.000 AU	1.524 AU
0.38 R_{earth}	0.95 R_{earth}	1.00 R_{earth}	0.53 R_{earth}
0.06 M_{earth}	0.82 M_{earth}	1.00 M_{earth}	0.11 M_{earth}





"All the News
That's Fit to Print"

The New York Times

Late Edition

Today, partly sunny; fog, partly sunny, warm, high 64. Tonight, mostly cloudy, mild, low 52. Tomorrow, clouds and sunshine, showers, high 66. Weather map is on Page B1.

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A rendering of newly discovered Earth-size planets orbiting a dwarf star named Trappist-1 about 40 light-years from Earth. Some of them could have surface water.

Circling a Star Not Far Away, 7 Shots at Life

By KENNETH CHANG

Not just one, but seven Earth-size planets that could potentially harbor life have been identified orbiting a tiny star not too far away, offering the first realistic opportunity to search for signs of alien life outside the solar system.

The planets orbit a dwarf star named Trappist-1, about 40 light-years, or 235 trillion miles, from Earth. That is quite close in cosmic terms, and by happy accident, the orientation of the orbits of the seven planets allows them to be studied in great detail.

One or more of the exoplanets in this new system could be at the right temperature to be awash in oceans of water, astronomers said, based on the distance of the planets from the dwarf star.

"This is the first time so many planets of this kind are found around the same star," Michael Gillon, an astronomer at the University of Liege in Belgium and the leader of an international team that has been observing Trappist-1, said during a telephone news conference organized by the

Continued on Page A17

Uber's Culture Of Gutsiness Under Review

By MIKE ISAAC

SAN FRANCISCO — When new employees join Uber, they are asked to subscribe to its core company values, including making bold bets, being "obsessed" with the customer, and "always be hustlin'." The ride-hailing service particularly emphasizes "meritocracy," the idea that the best and brightest will rise to the top based on their efforts, even if it means stepping on toes to get there.

Those values have helped propel Uber to one of Silicon Valley's biggest success stories. The company is valued at close to \$70 billion by private investors and now operates in more than 70 countries.

Yet the focus on pushing for the best result has also fueled what current and former Uber employees describe as a Hobbesian environment at the company, in which workers are sometimes pitted against one another and where a blind eye is turned to infighting from top performers. Interviews with more than 30 current and former Uber

Continued on Page A18

Migrants Hide, Fearing Capture on 'Any Corner'

By VIVIAN YEE

No going to church, no going to the store. No doctor's appointments for some, no school for others. No driving, period — not when a broken taillight could deliver the driver to Immigration and Customs Enforcement.

It is happening in the Central Valley of California, where undocumented immigrants pick the fields for survival wages but are keeping their children away from school; on Staten Island, where fewer day laborers haunt street corners in search of work; in West

IMMIGRATION A police department worries a crackdown will harm work to fight gangs. PAGE A18

MEXICO The secretary of state pays a visit at a time of rising tensions. PAGE A18

Phoenix's Isaac School District, where 13 Latino students have dropped out in the past two weeks; and in the horse country of northern New Jersey, where one of the many undocumented groomers who rack out the stables is thinking of moving back to Hon-

duras.

If deportation has always been a threat on paper for the 11 million people living in the country illegally, it rarely imperiled those who did not commit serious crimes. But with the Trump administration intent on curbing illegal immigration — two memos outlining the federal government's plans to accelerate deportations were released Tuesday, another step toward making good on one of President Trump's signature campaign pledges — that threat, for many people, has now begun to disorient every movement.

Continued on Page A14

TRUMP RESCINDS OBAMA DIRECTIVE ON BATHROOM USE

ENTERING CULTURE WARS

Question of Transgender Rights Splits DeVos and Sessions

This article is by Jeremy W. Peters, Jo Rauber and Irlin Hirschfeld Davis.

WASHINGTON — President Trump on Wednesday rescinded protections for transgender students that had allowed them to use bathrooms corresponding with their gender identity, overruling his own education secretary and placing his administration firmly in the middle of the culture wars that many Republicans have tried to leave behind.

In a joint letter, the top civil rights officials from the Justice Department and the Education Department rejected the Obama administration's position that nondiscrimination laws require schools to allow transgender students to use the bathrooms of their choice.

That directive, they said, was improperly and arbitrarily devised, "without due regard for the primary role of the states and local school districts in establishing educational policy."

The question of how to address the "bathroom debate," as it has become known, opened a rift inside the Trump administration, pitting Education Secretary Betsy DeVos against Attorney General Jeff Sessions. Mr. Sessions, who had been expected to move quickly to roll back the civil rights expansions put in place under his Democratic predecessors, wanted to act decisively because of two pending court cases that could have upheld the protections and pushed the government into further litigation.

But Ms. DeVos initially resisted signing off and told Mr. Trump that she was uncomfortable because of the potential harm that rescinding the protections could cause transgender students, according to three Republicans with direct knowledge of the internal discussions.

Mr. Sessions, who has opposed expanding gay, lesbian and transgender rights, pushed Ms. DeVos to relent. After getting nowhere, he took his objections to the White House because he could not go



500 Hours:

Exploring the 7 Exoplanets of TRAPPIST-1
with NASA's Spitzer Space Telescope

