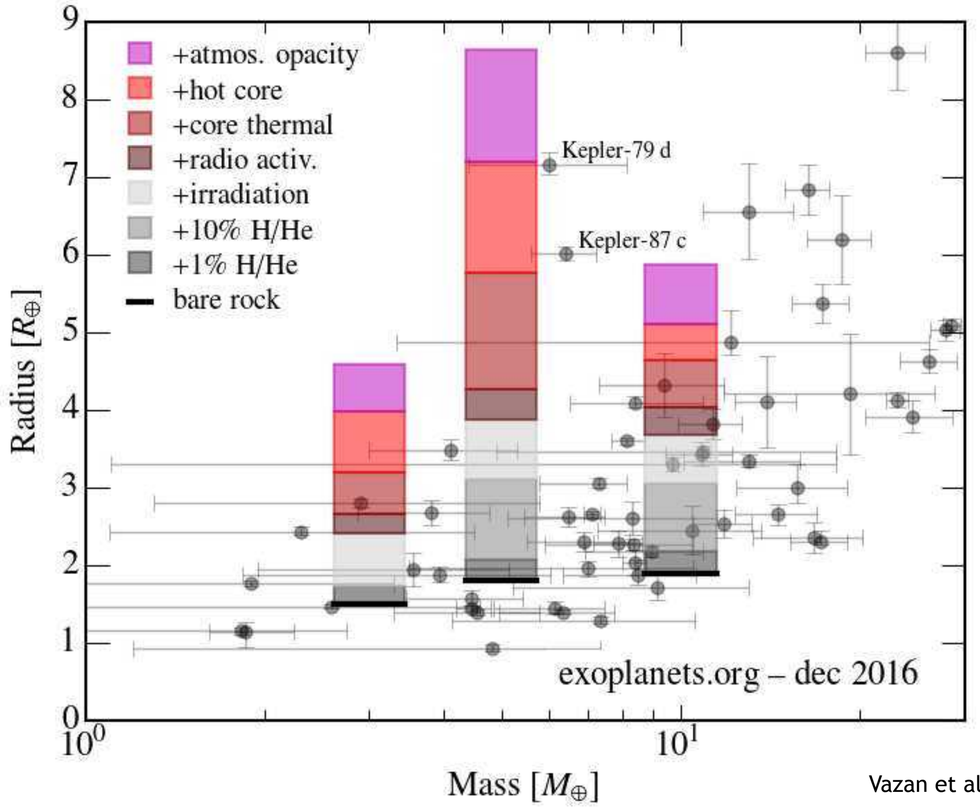
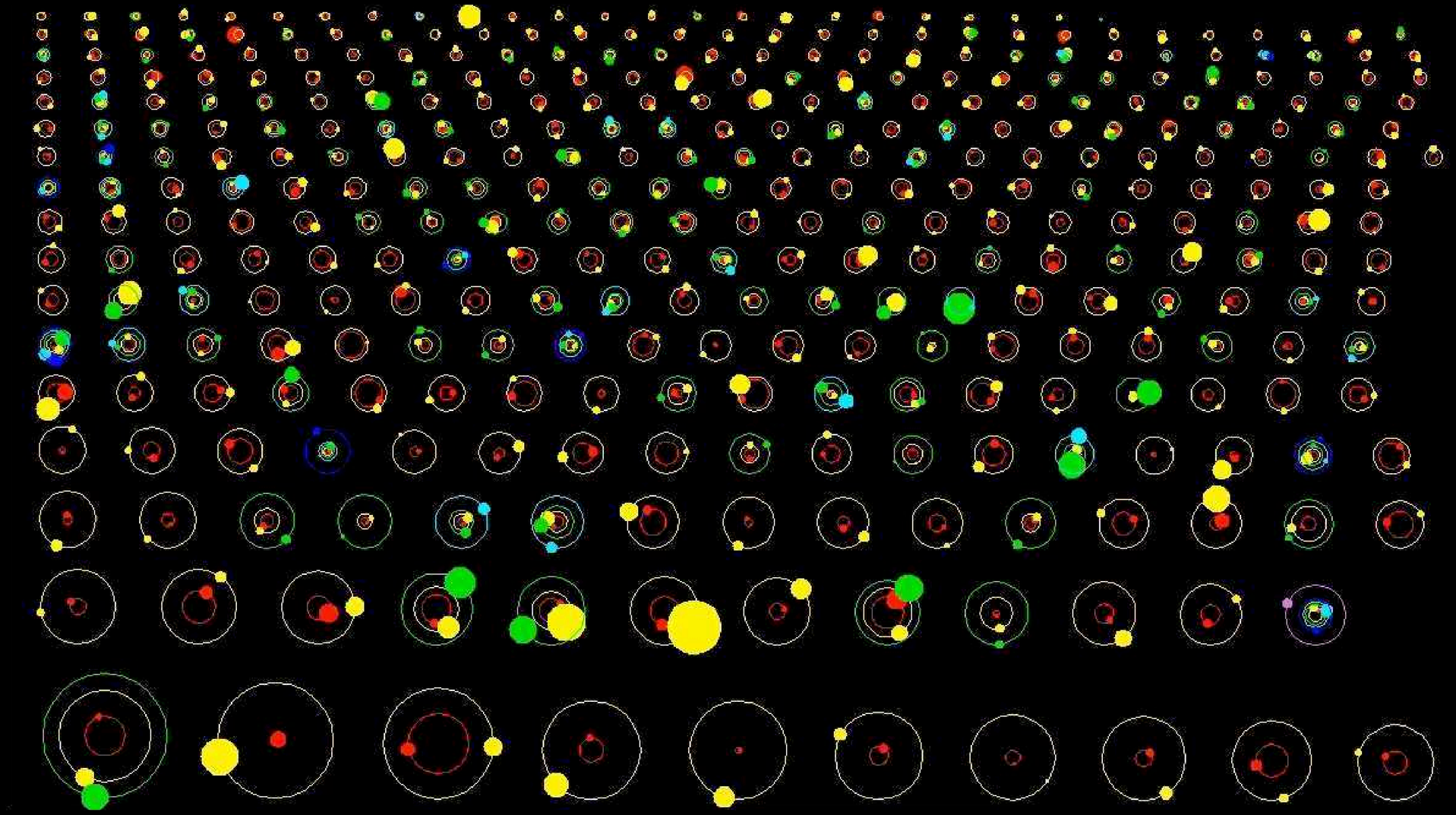
Superaardes kunnen rotsachtig, water- or gasrijk zijn



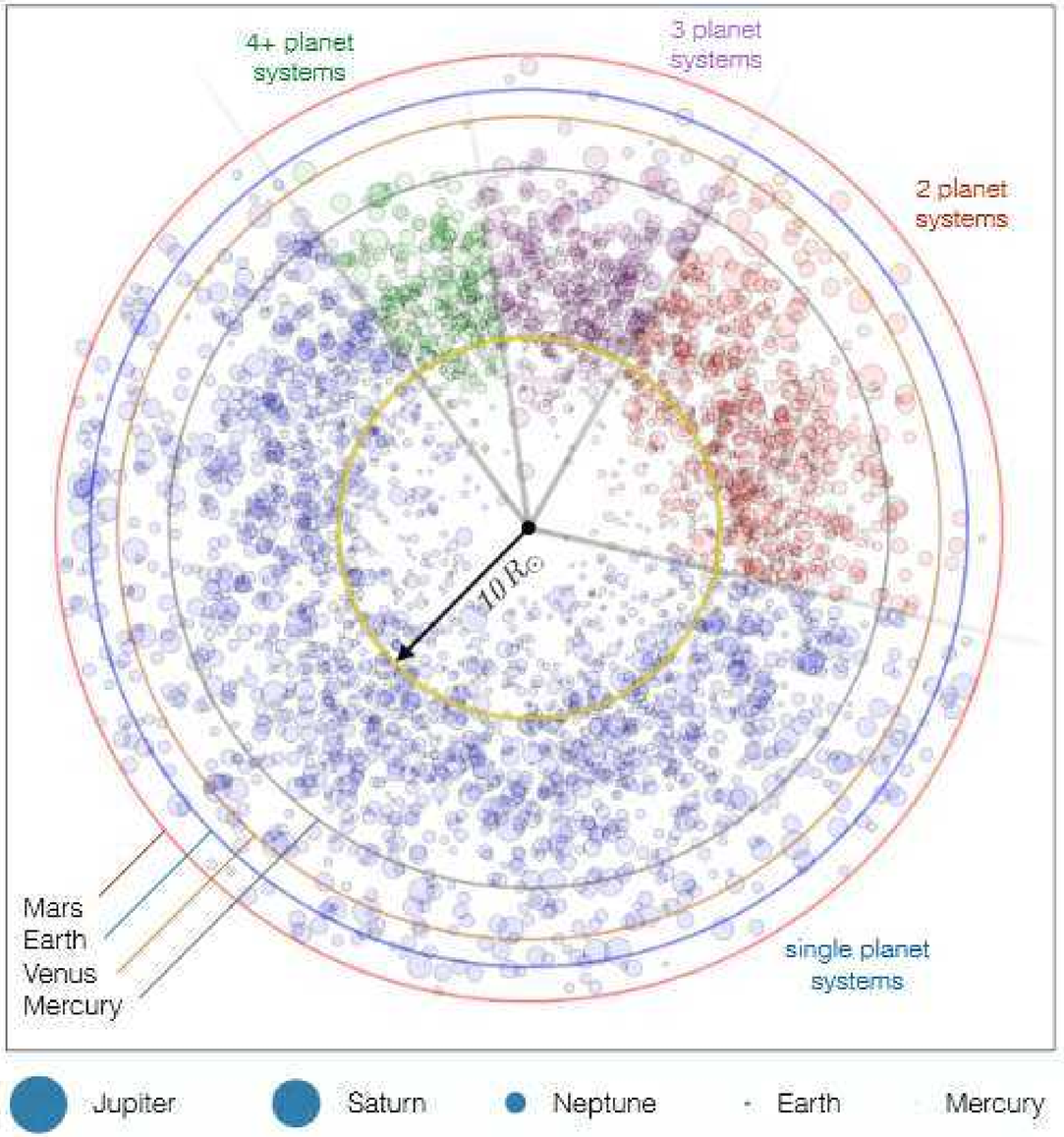
Vazan et al. 2017 - submitted

Niet alleen **samenstelling**, maar ook **vorming** en **thermische evolutie** van planeten geeft grote spreiding in dichtheid

De planeten-oogst van Kepler



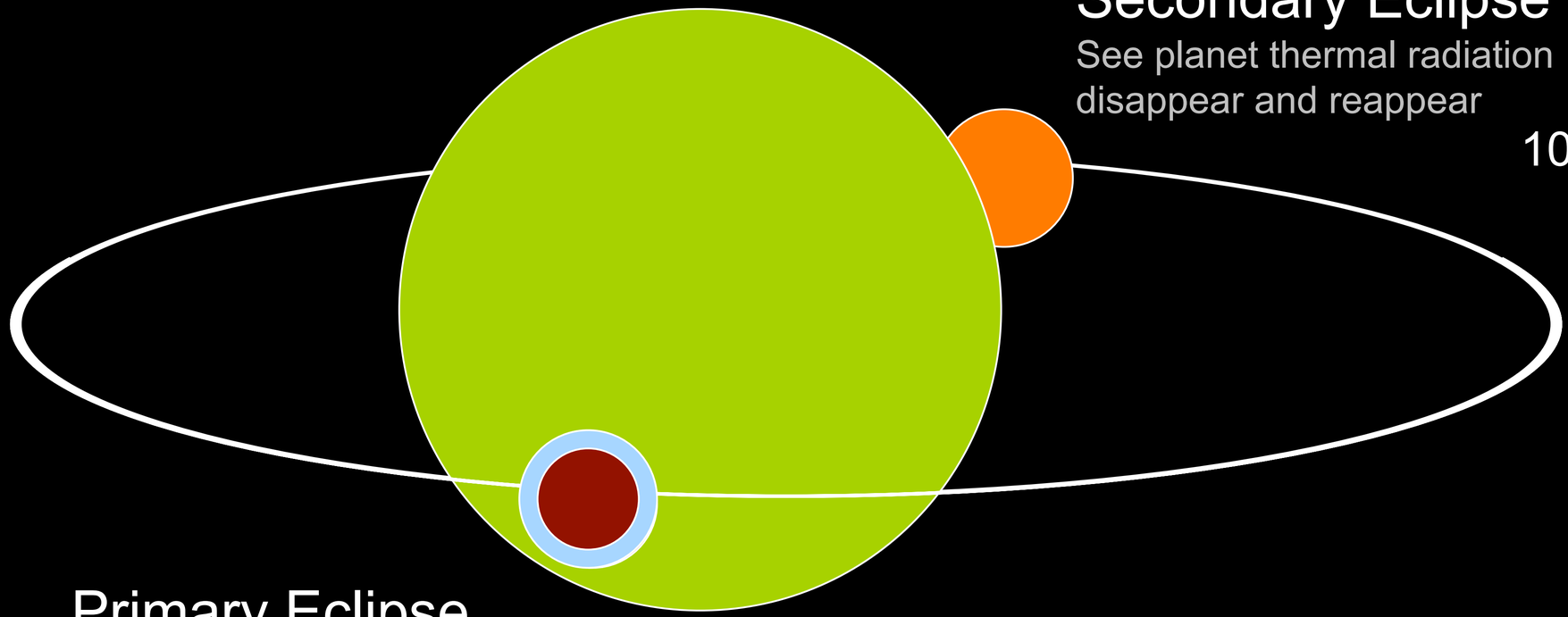
Alle exoplaneten op een kluitje...



PLANEETATMOSFEREN

- Atmosferen in ons zonnestelsel
- Exoplaneten
- Transmissiespectroscopie
- Zoektocht naar leven
- Toekomstperspectief

Transiting Planet Science



Secondary Eclipse

See planet thermal radiation disappear and reappear

10^{-3}

Primary Eclipse

Measure size of planet

See star's radiation transmitted through the planet atmosphere

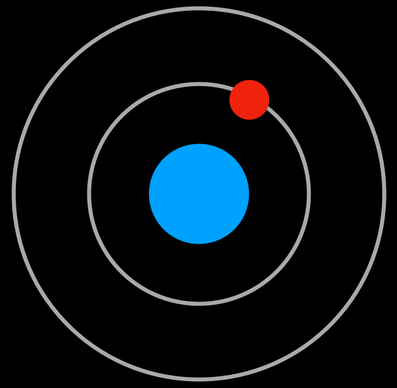
10^{-2}

10^{-4}

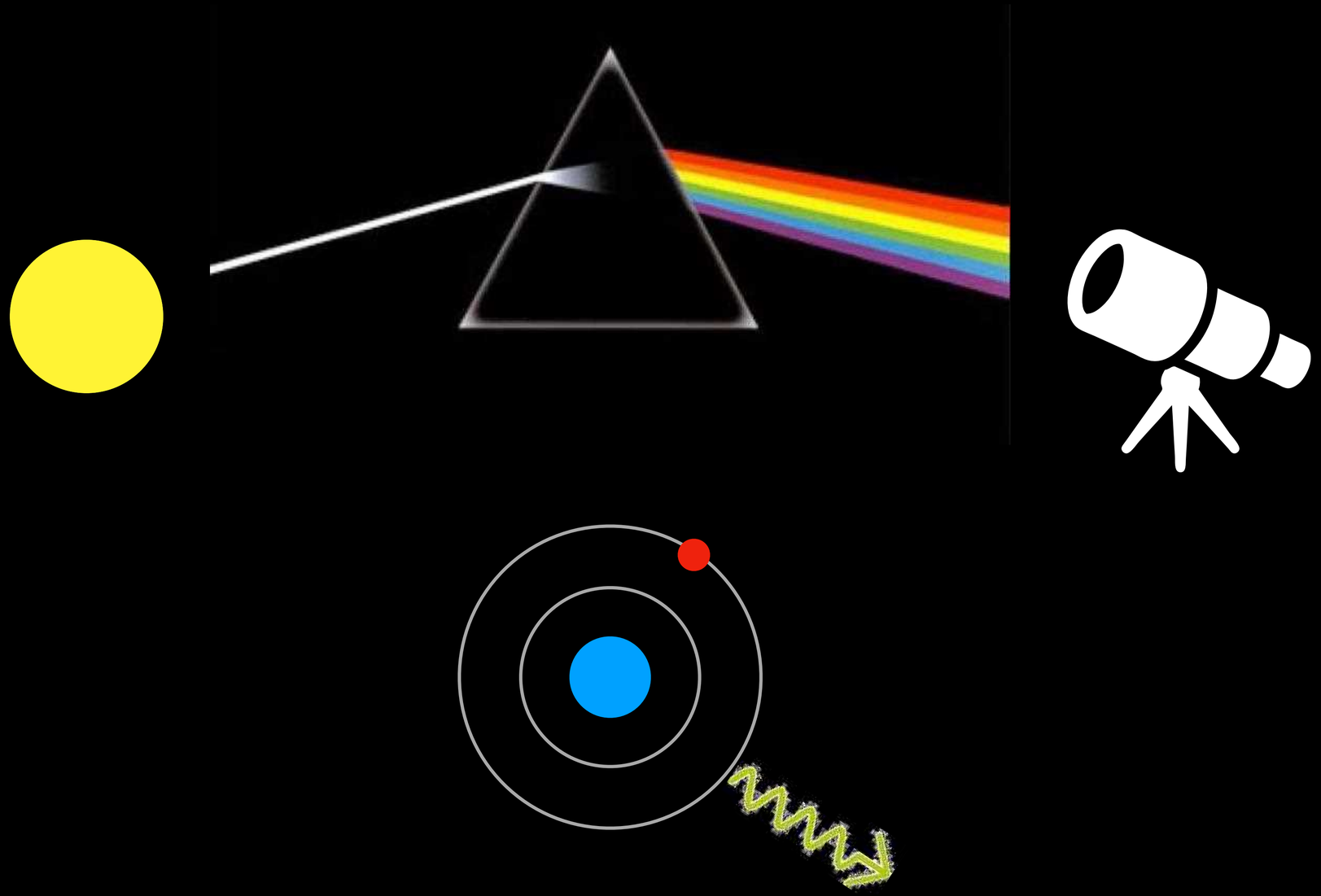
Learn about atmospheric circulation from thermal phase curves

credit: Sara Seager

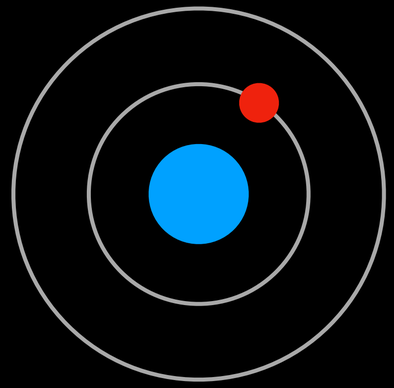
Spectroscopie



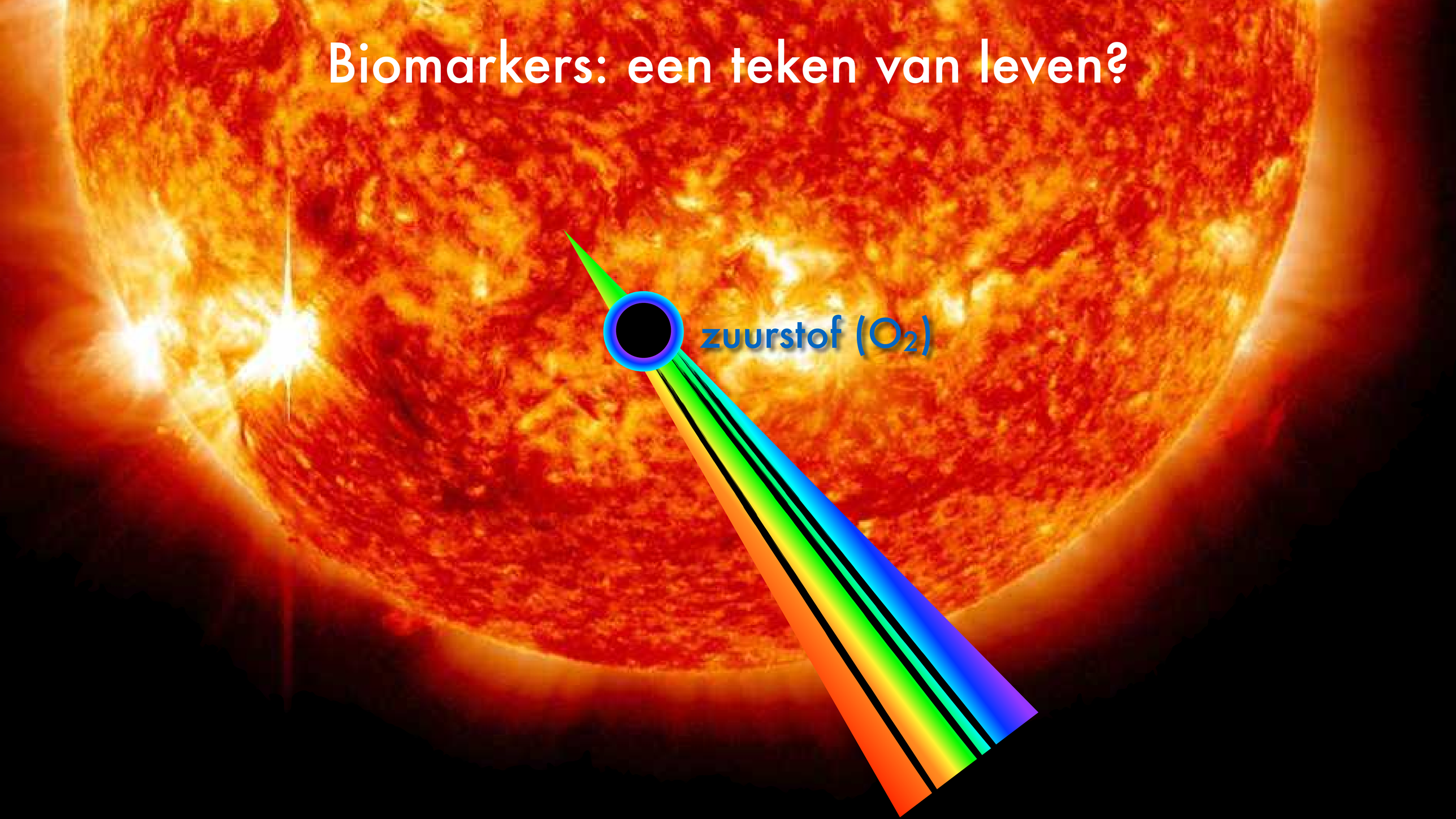
Spectroscopie



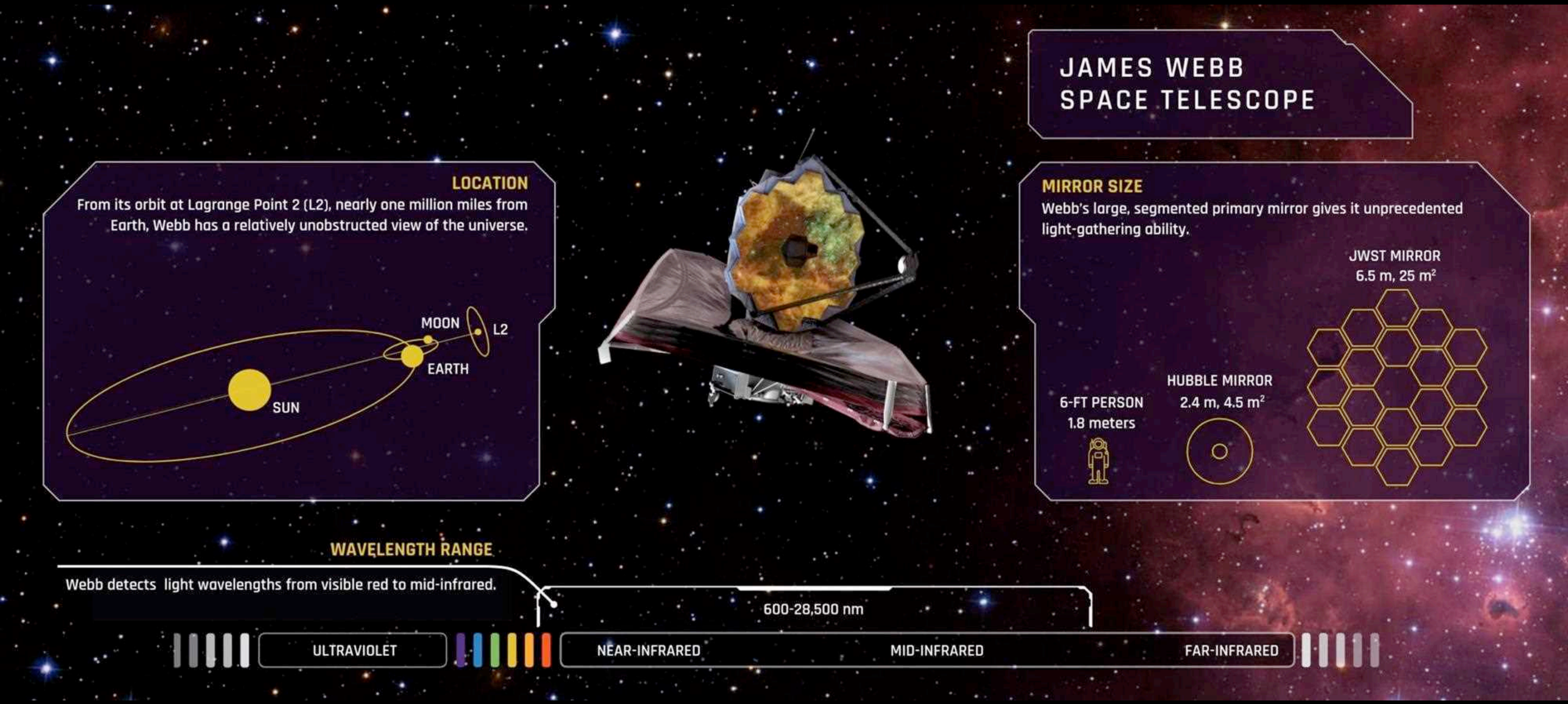
Spectroscopie



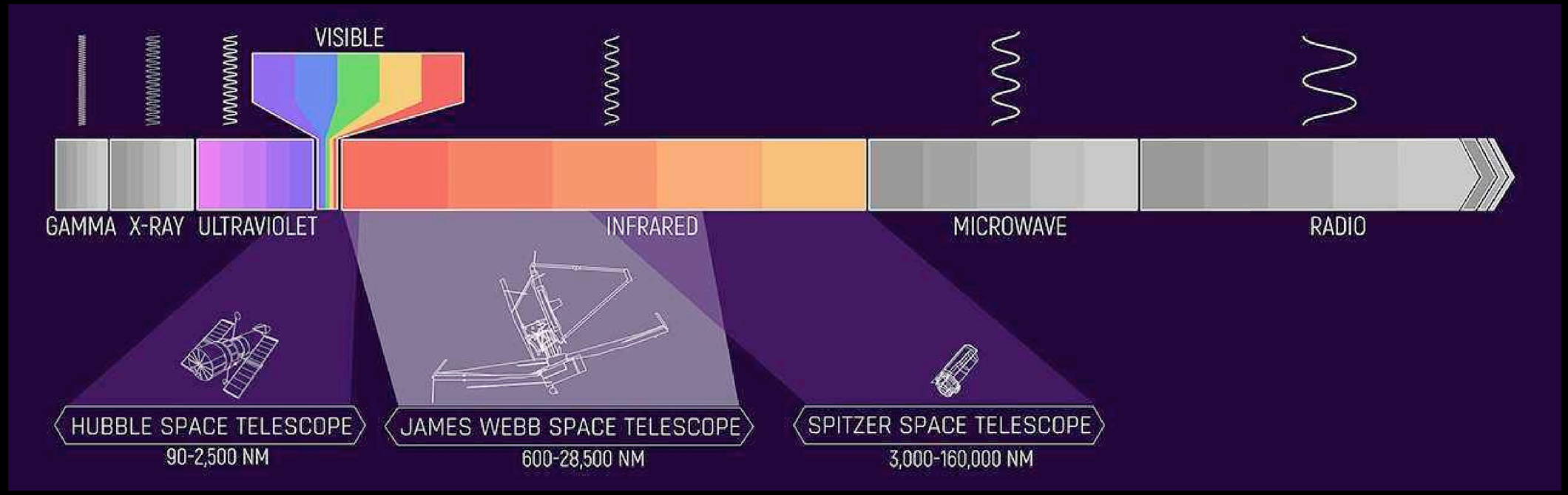
Biomarkers: een teken van leven?



James Webb: het vlaggenschip van de sterrenkunde



Blik op het infrarood



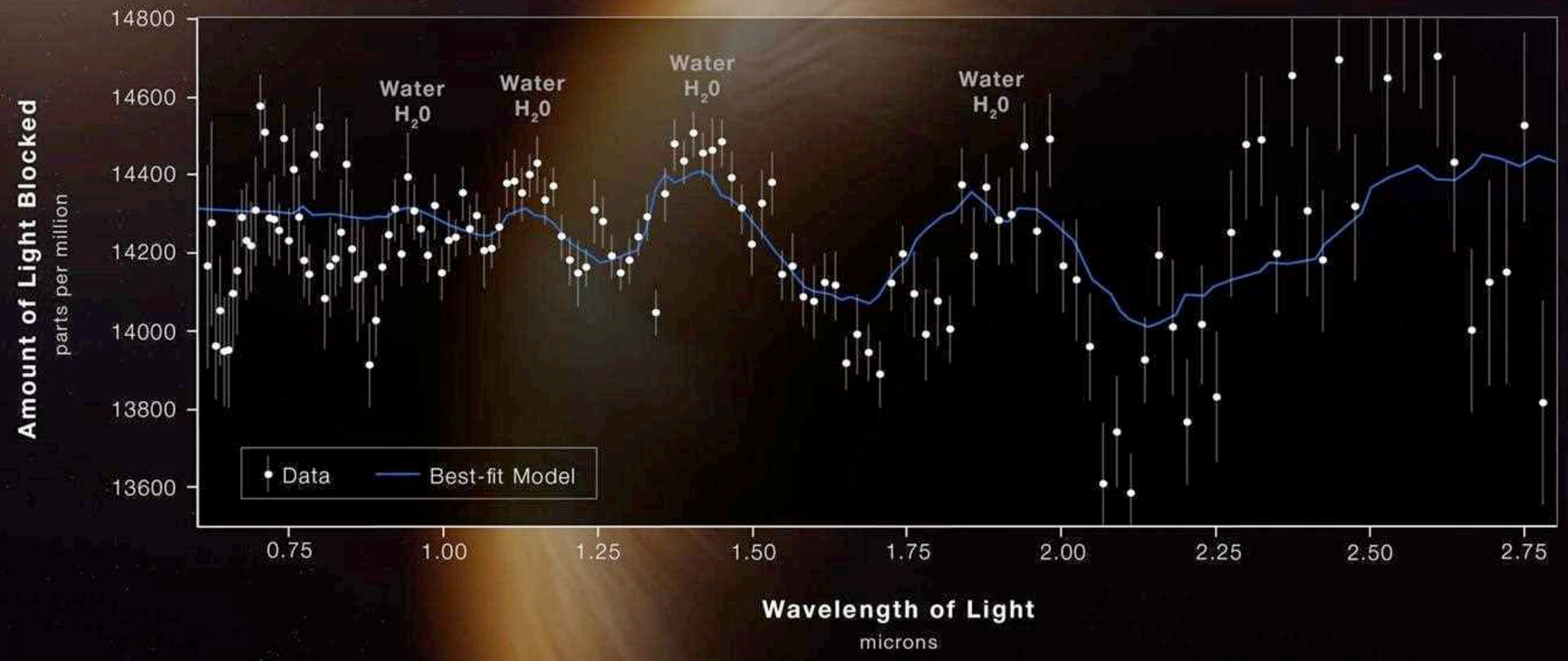
HOT GAS GIANT EXOPLANET WASP-96 b

ATMOSPHERE COMPOSITION

$R = 0.5\ R_{Jupiter}$

$a = 0.05$ au

NIRISS | Single-Object Slitless Spectroscopy



WEBB SPACE TELESCOPE

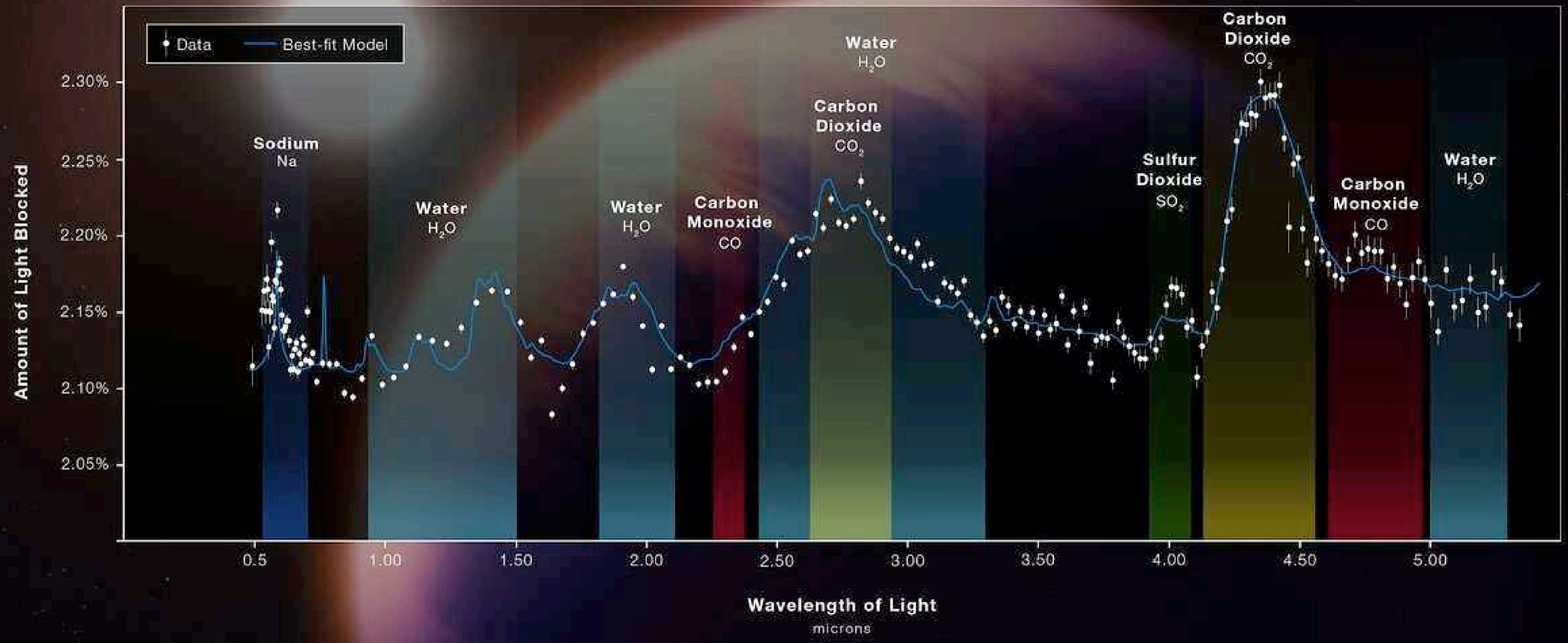
HOT GAS GIANT EXOPLANET WASP-39 b

ATMOSPHERE COMPOSITION

$R = 1.3\ R_{Jupiter}$

$a = 0.05$ au

NIRSpec PRISM



WEBB
SPACE TELESCOPE

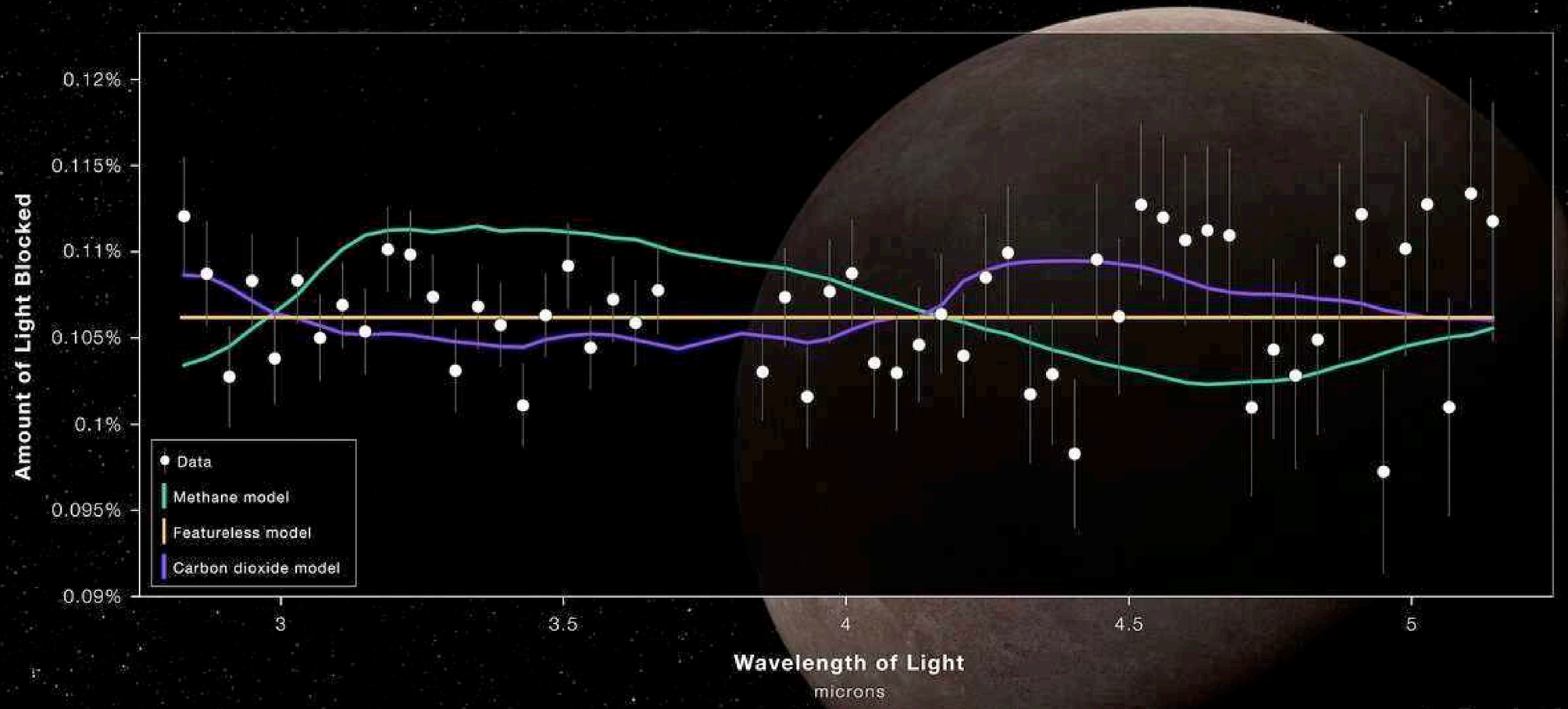
ROCKY EXOPLANET LHS 475 b

TRANSMISSION SPECTRUM

$R = 1.0\ R_{Earth}$

$a = 0.02$ au

NIRSpec | Bright Object Time-Series Spectroscopy

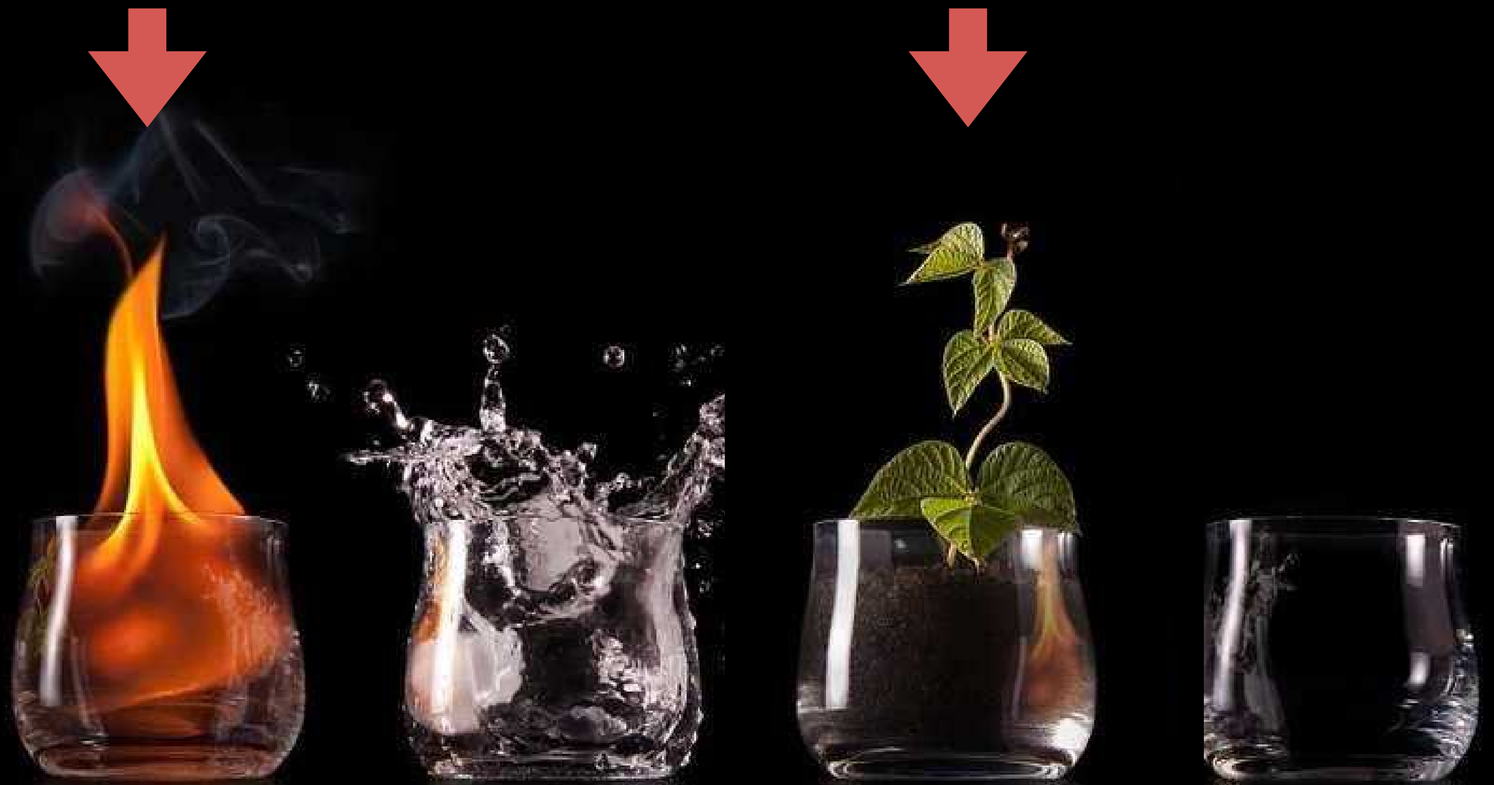


WEBB
SPACE TELESCOPE

PLANEETATMOSFEREN

- Atmosferen in ons zonnestelsel
- Exoplaneten
- Transmissiespectroscopie
- Zoektocht naar leven
- Toekomstperspectief

Vereisten voor leven

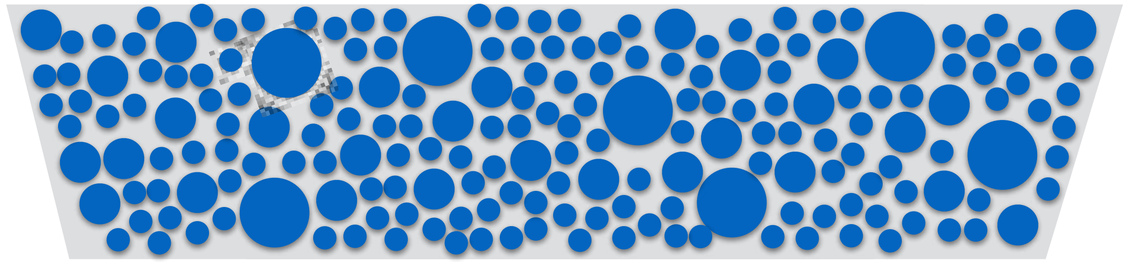


Energiebron voor metabolisme-reacties

Oplosmiddel om deze reacties te faciliteren

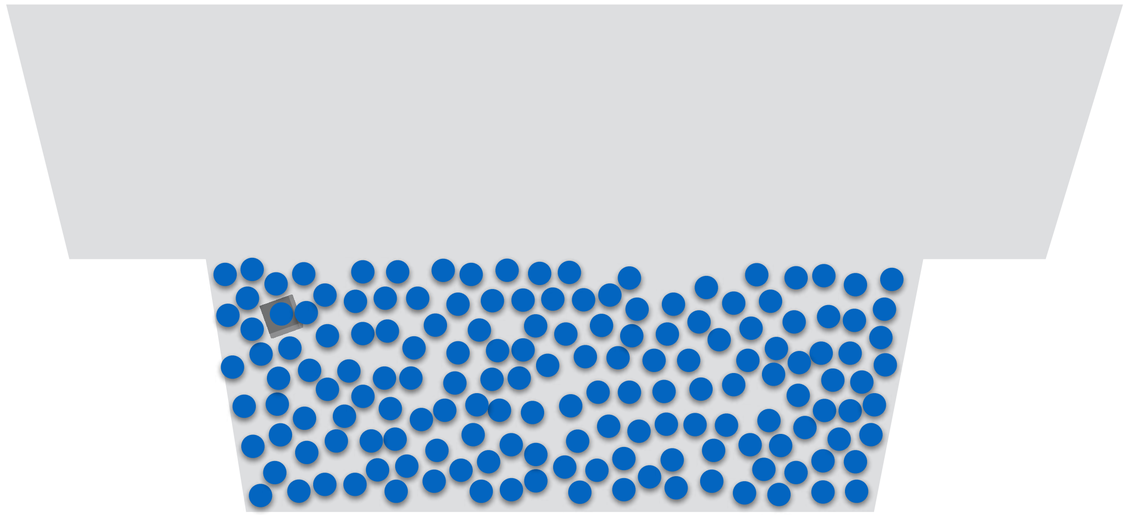
Voedingsstoffen voor biomassa en als katalysators van metabolisme

Op jacht naar een bewoonbare exoplaneet



Alle exoplaneten

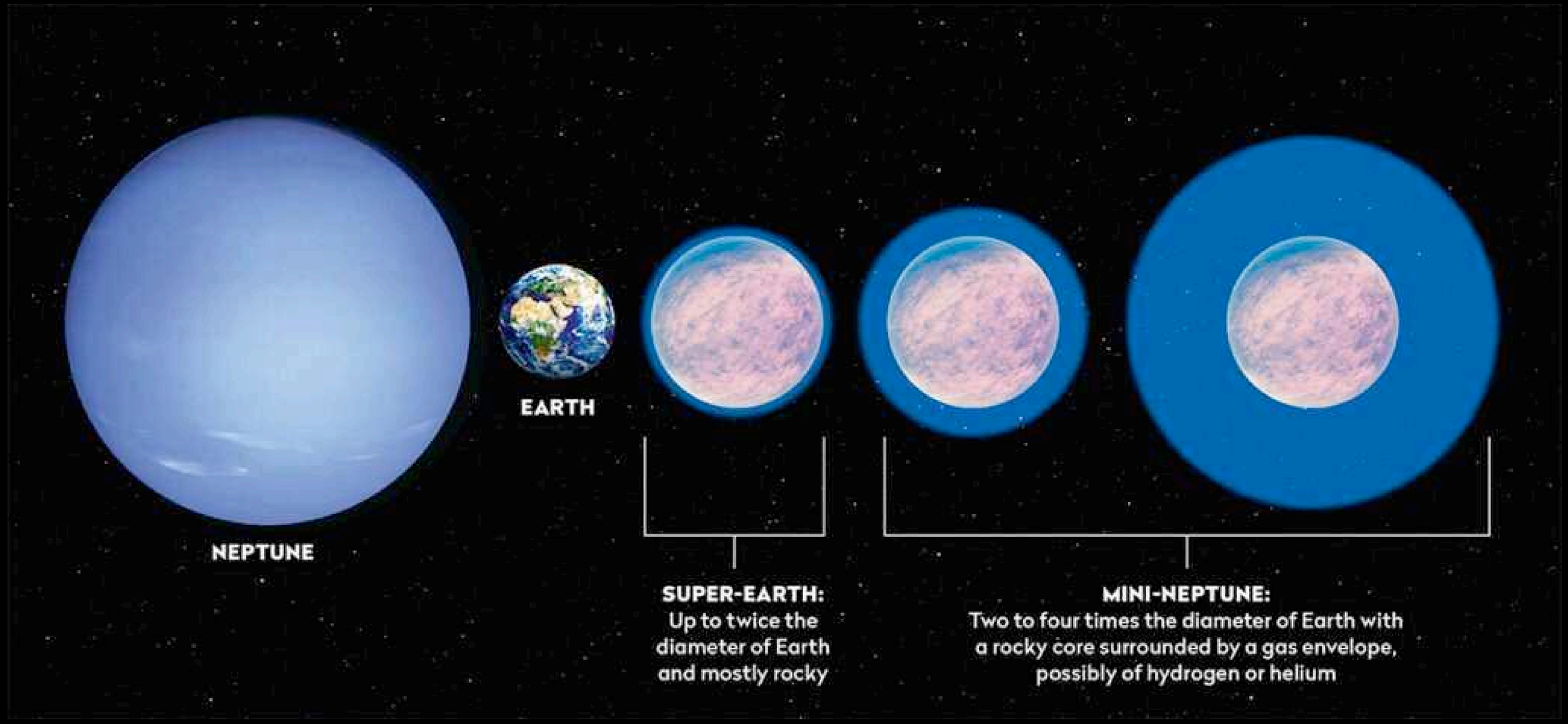
Op jacht naar een bewoonbare exoplaneet



Alle exoplaneten

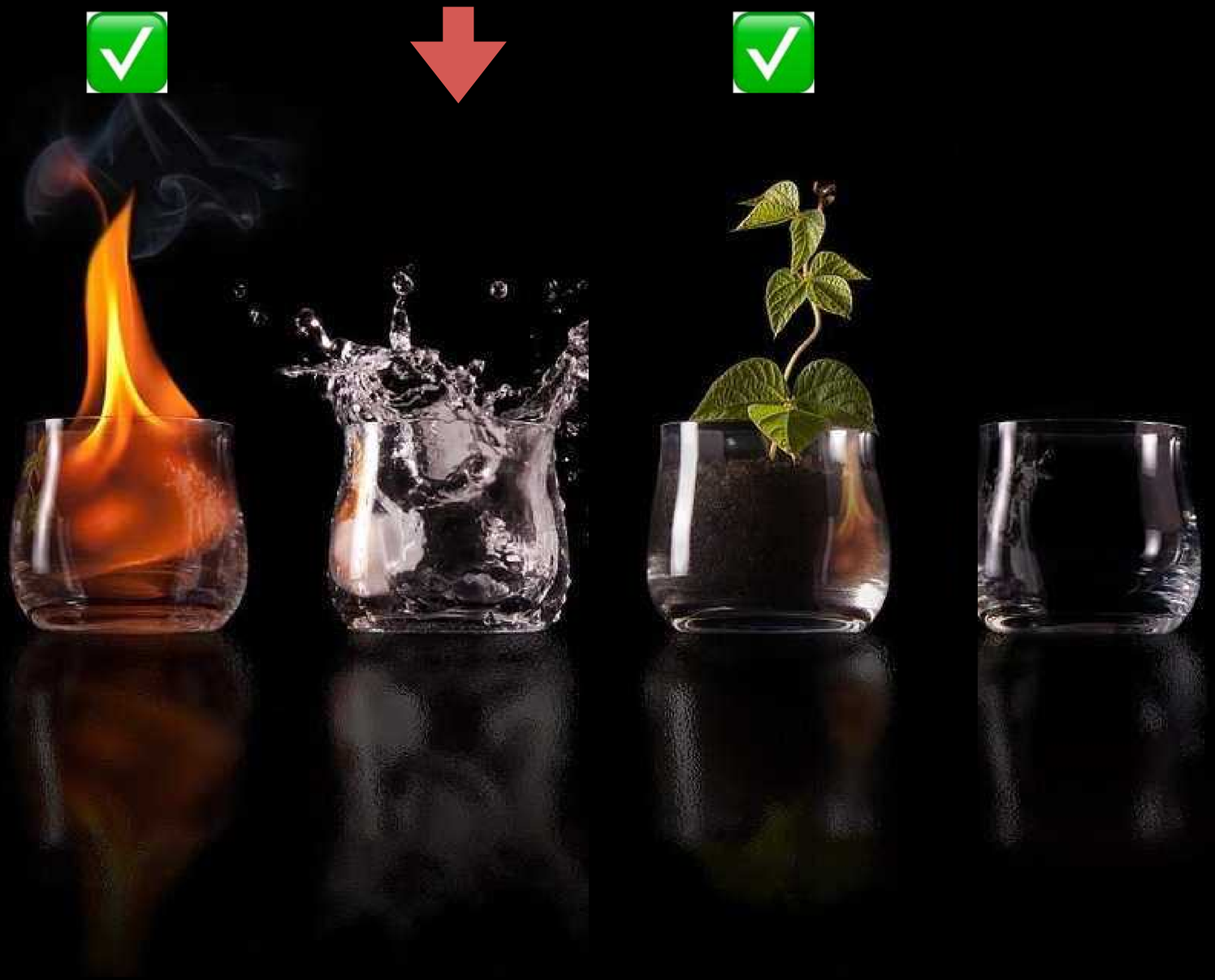
Kleine exoplaneten

Kleine exoplaneten



Vereisten voor leven

✅ ✅



Mercury
Venus
Earth
Mars

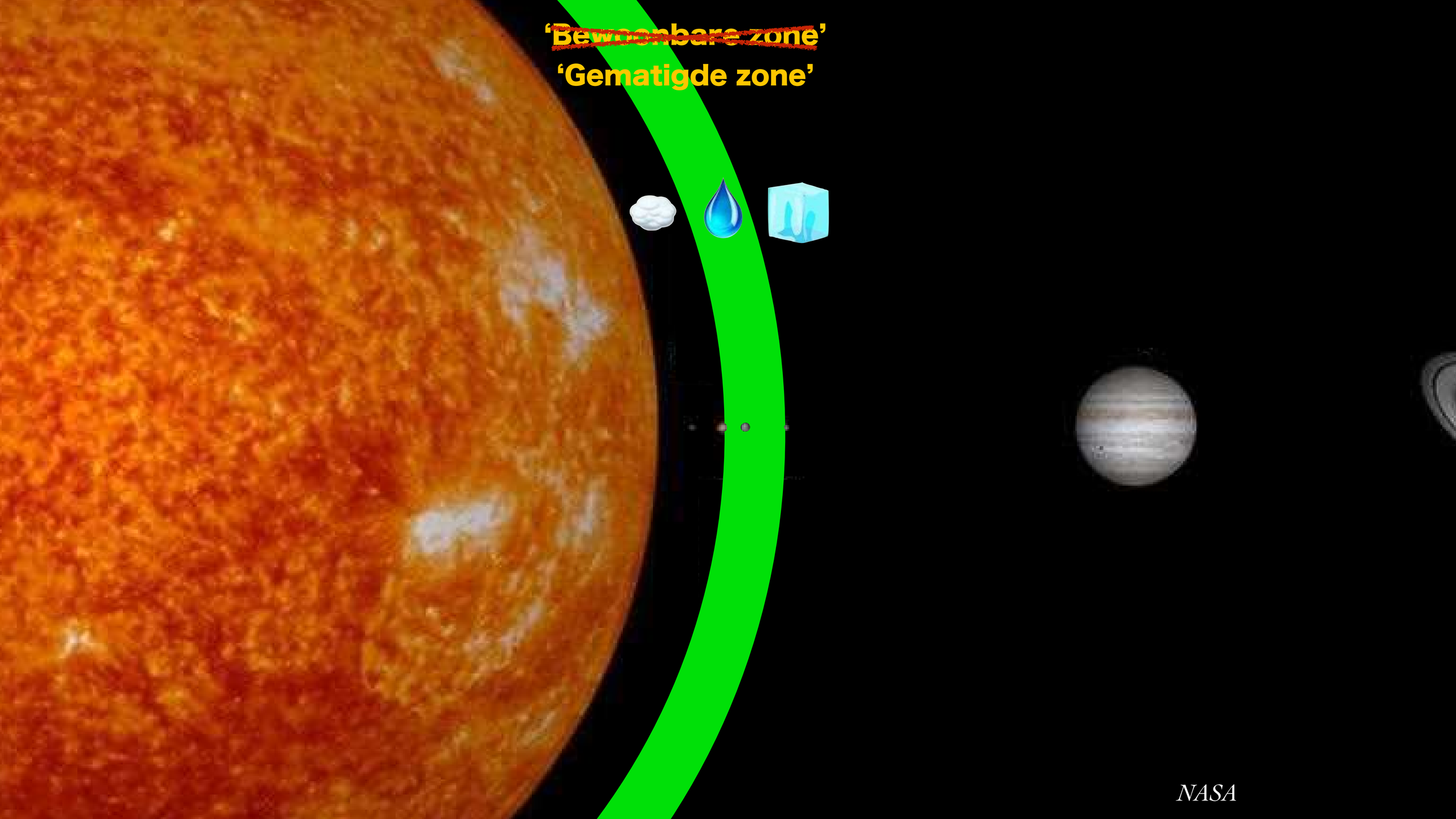
Jupiter

Saturn

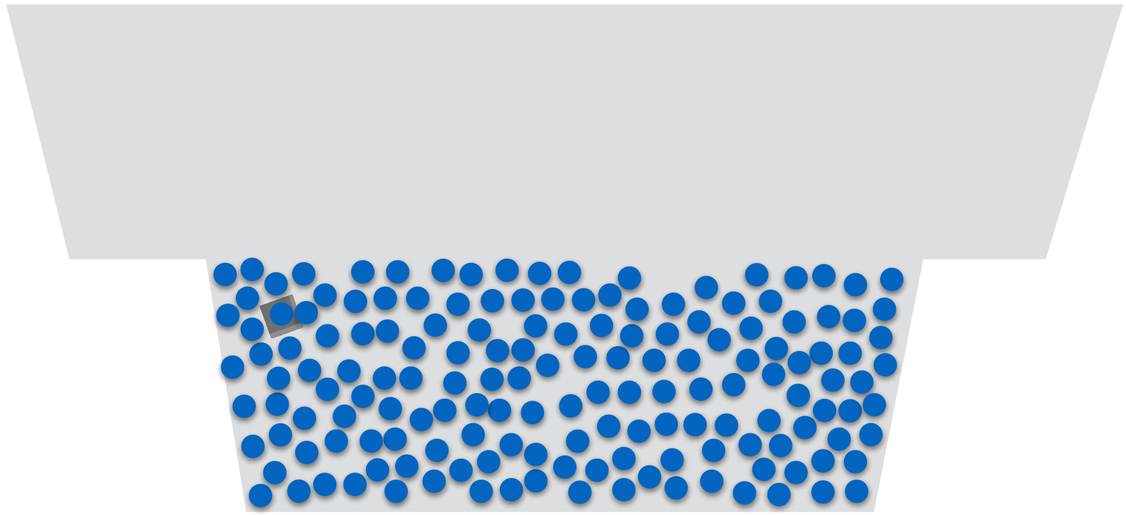
Uranus

Neptune

NASA


~~'Bewoonbare zone'~~
'Gematigde zone'
NASA

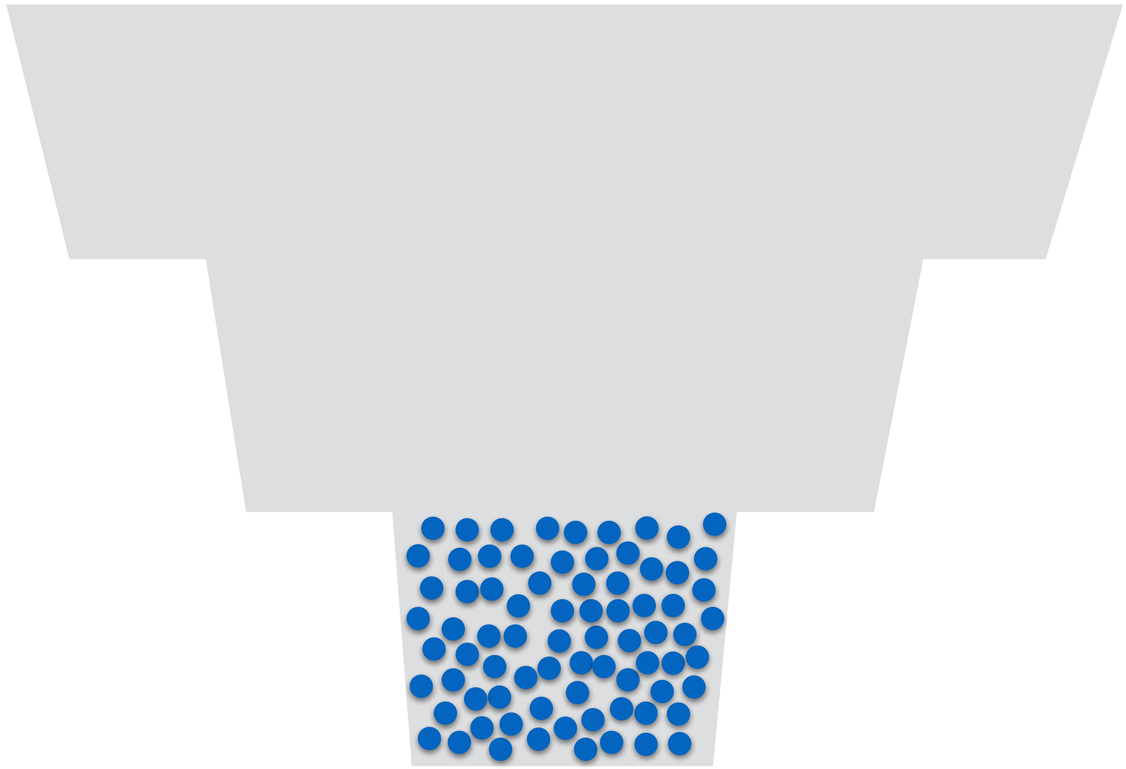
Op jacht naar een bewoonbare exoplaneet



Alle exoplaneten

Kleine exoplaneten

Op jacht naar een bewoonbare exoplaneet



Alle exoplaneten

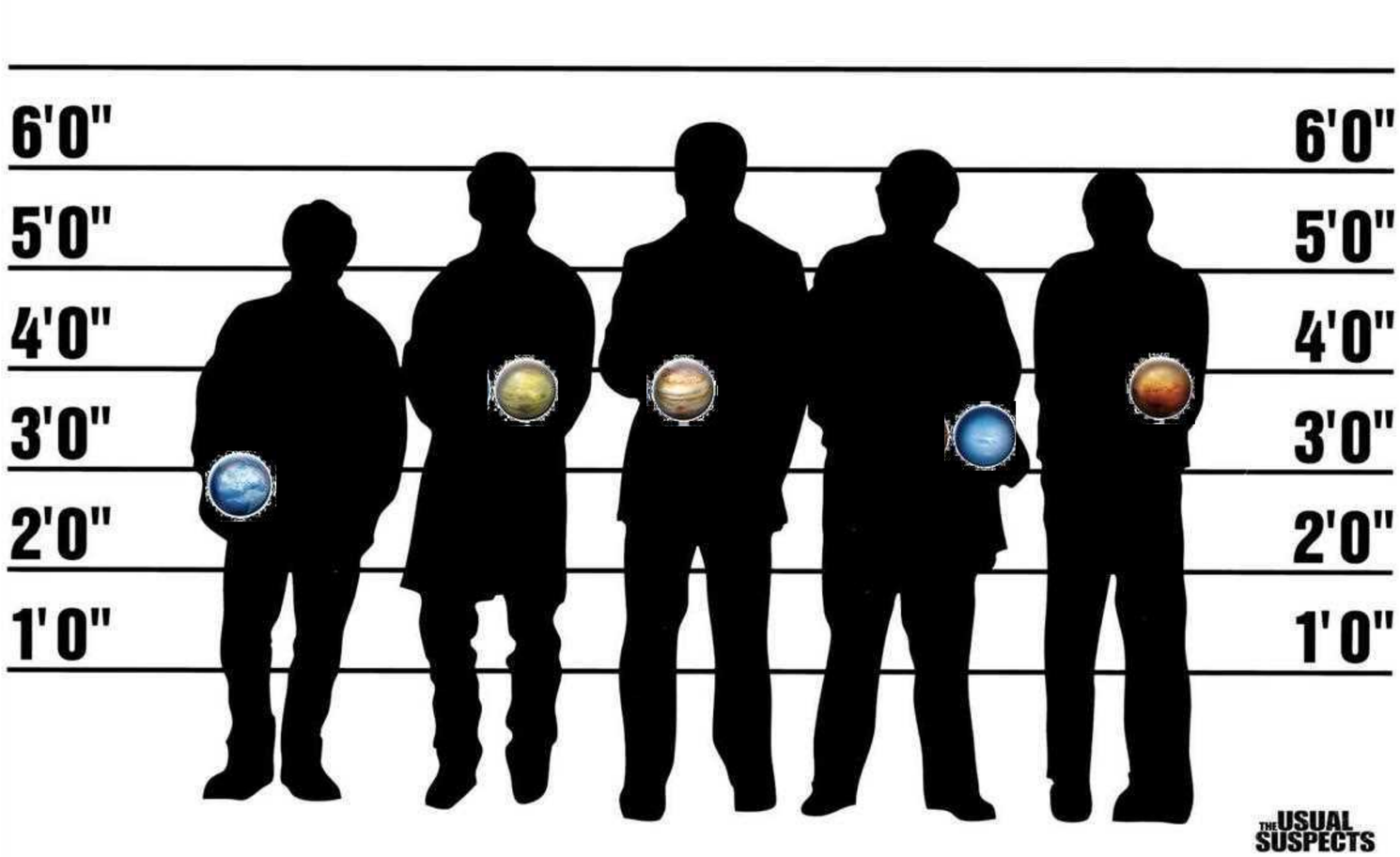
Kleine exoplaneten

Bewoonbare zone

Vereisten voor leven

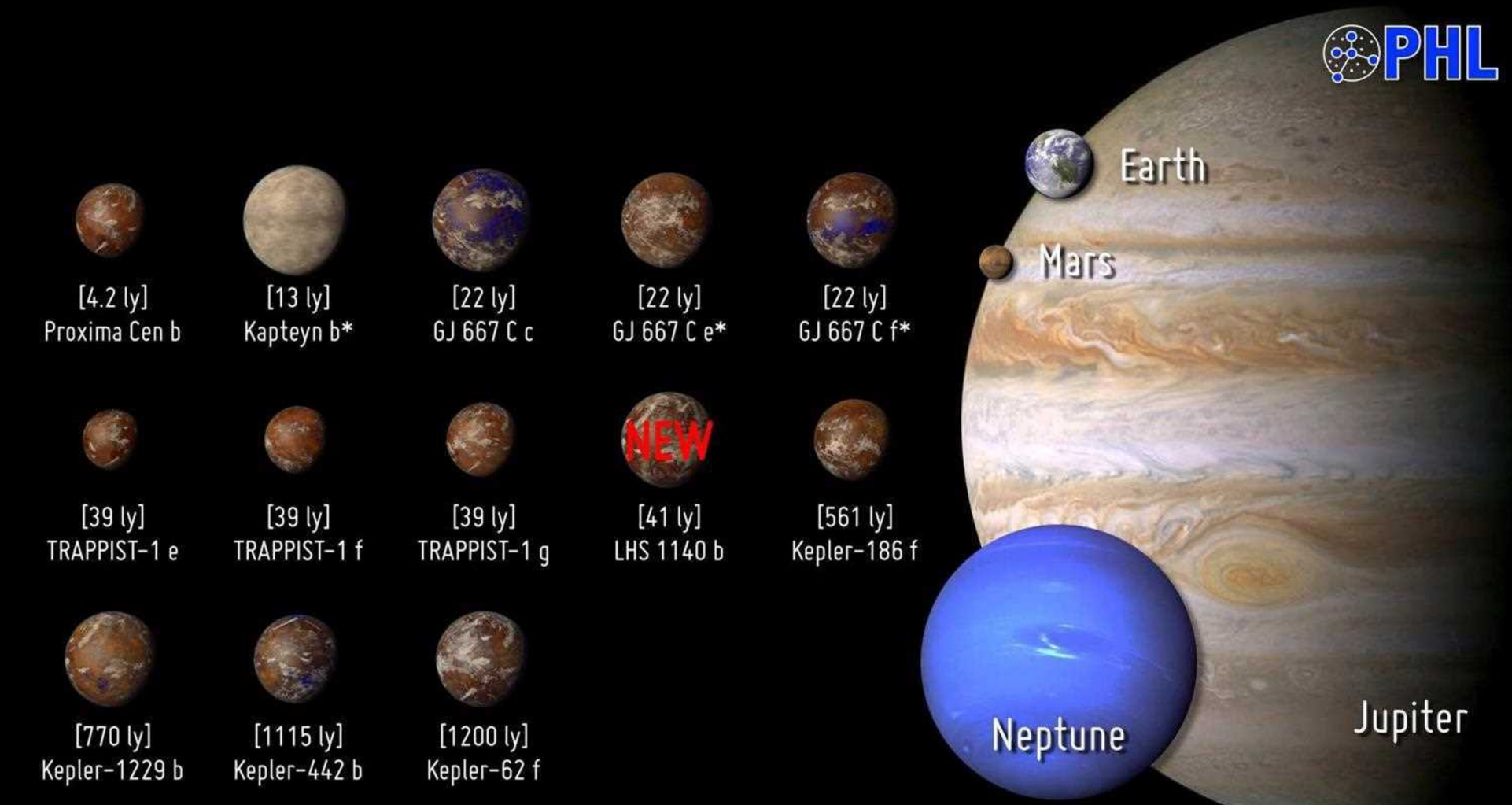
✅ ✅ ✅

Een paar kandidaten blijven over



"Potentieel bewoonbare

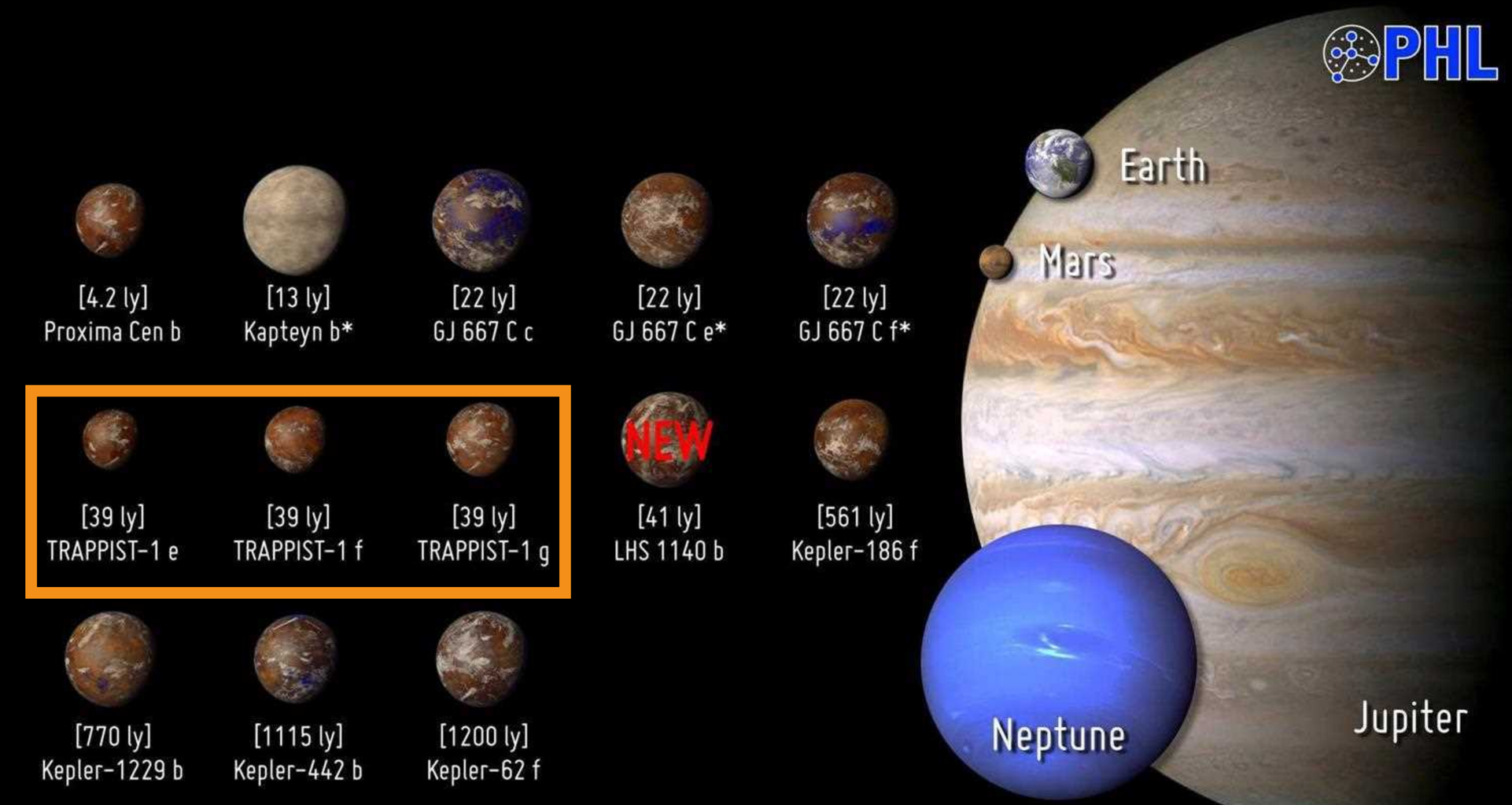
Mogelijk bewoonbare exoplaneten



Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. Distance from Earth is between brackets. Planet candidates indicated with asterisks.

CREDIT: PHL @ UPR Arecibo (phl.upr.edu) May 11, 2017

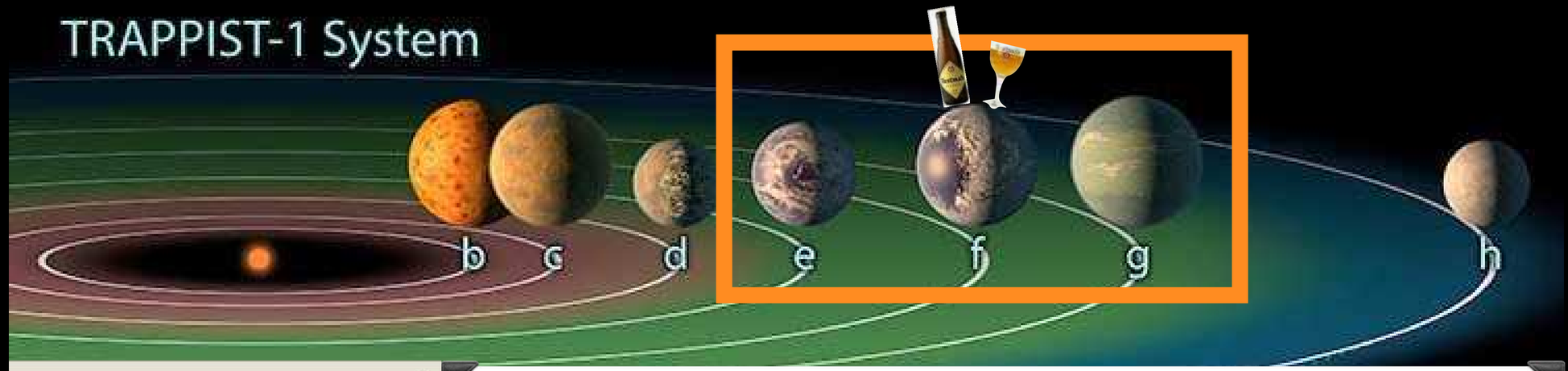
Mogelijk bewoonbare exoplaneten

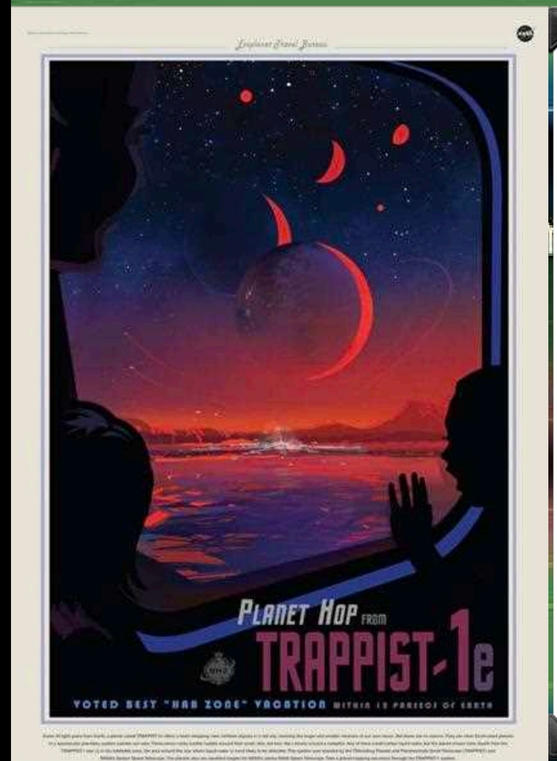


Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. Distance from Earth is between brackets. Planet candidates indicated with asterisks.

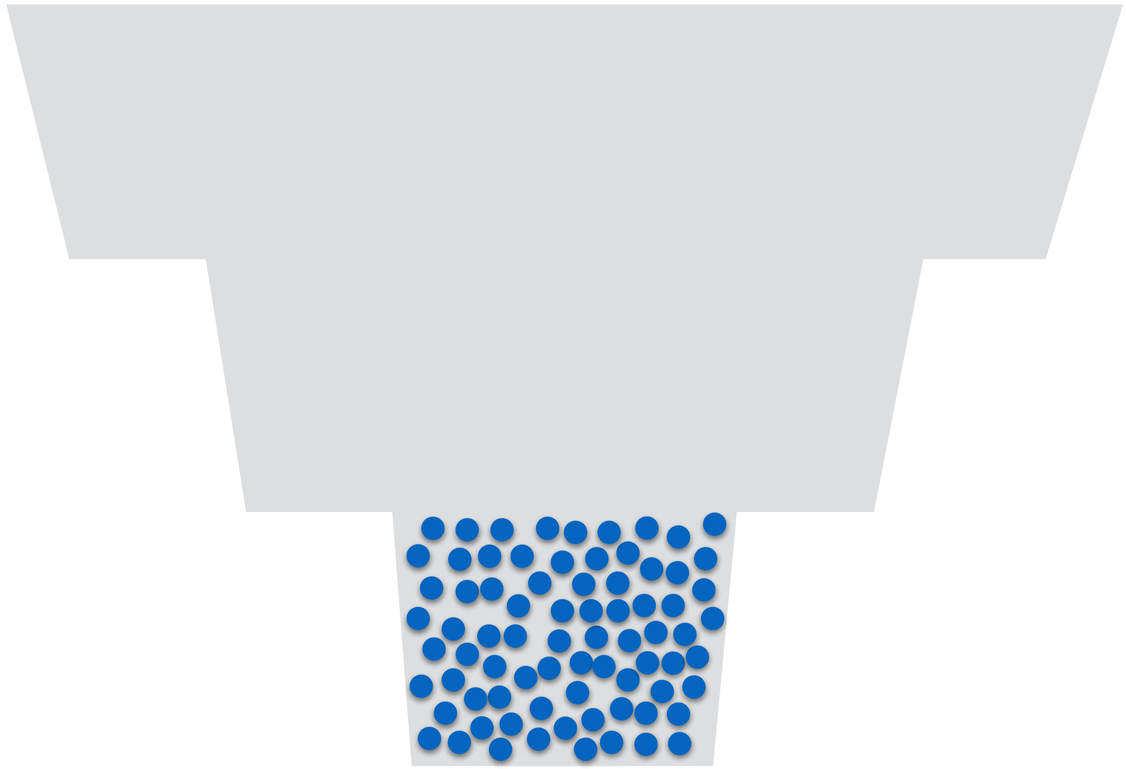
CREDIT: PHL @ UPR Arecibo (phl.upr.edu) May 11, 2017

7 planeten rond Trappist-1





Op jacht naar een bewoonbare exoplaneet

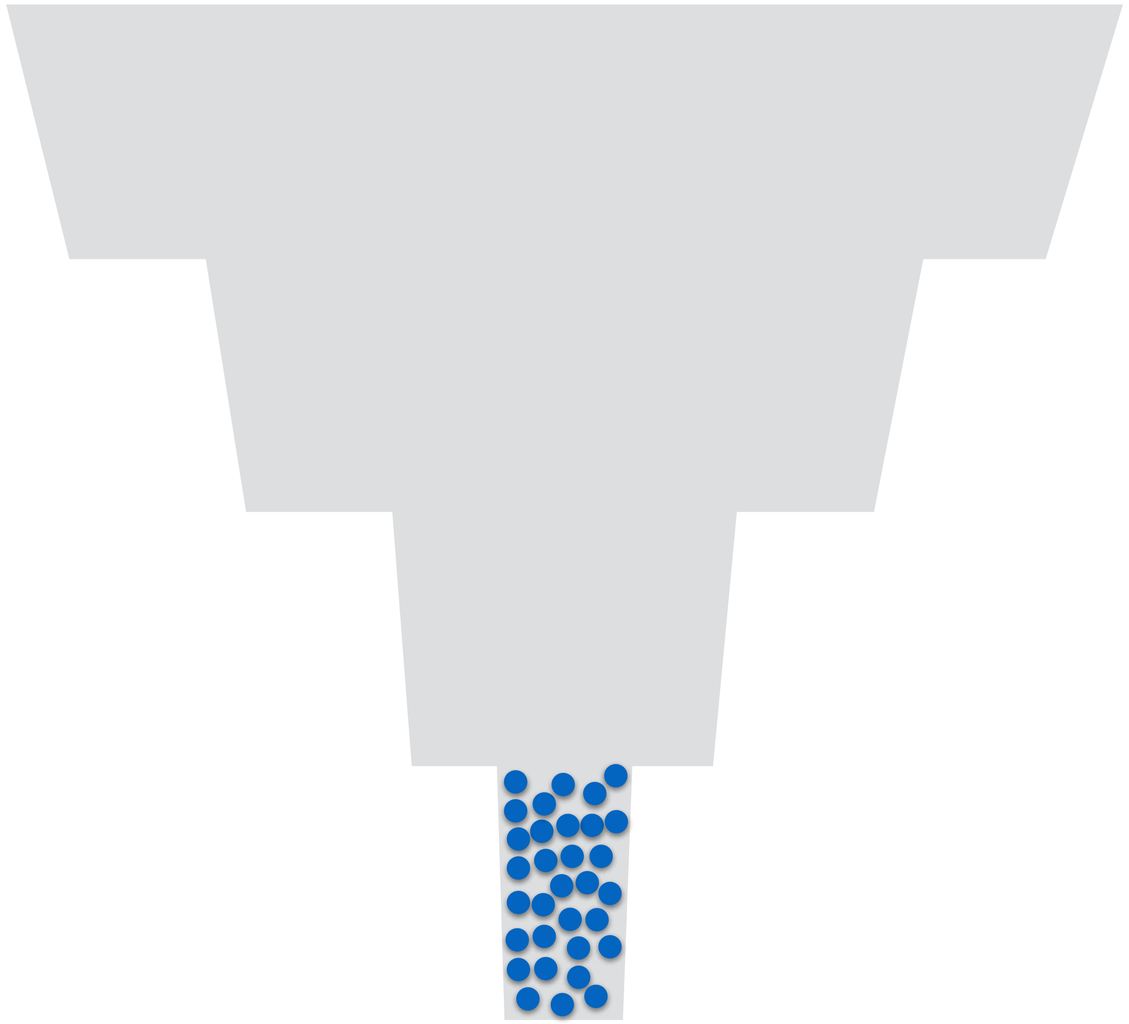


Alle exoplaneten

Kleine exoplaneten

Bewoonbare zone

Op jacht naar een bewoonbare exoplaneet



Alle exoplaneten

Kleine exoplaneten

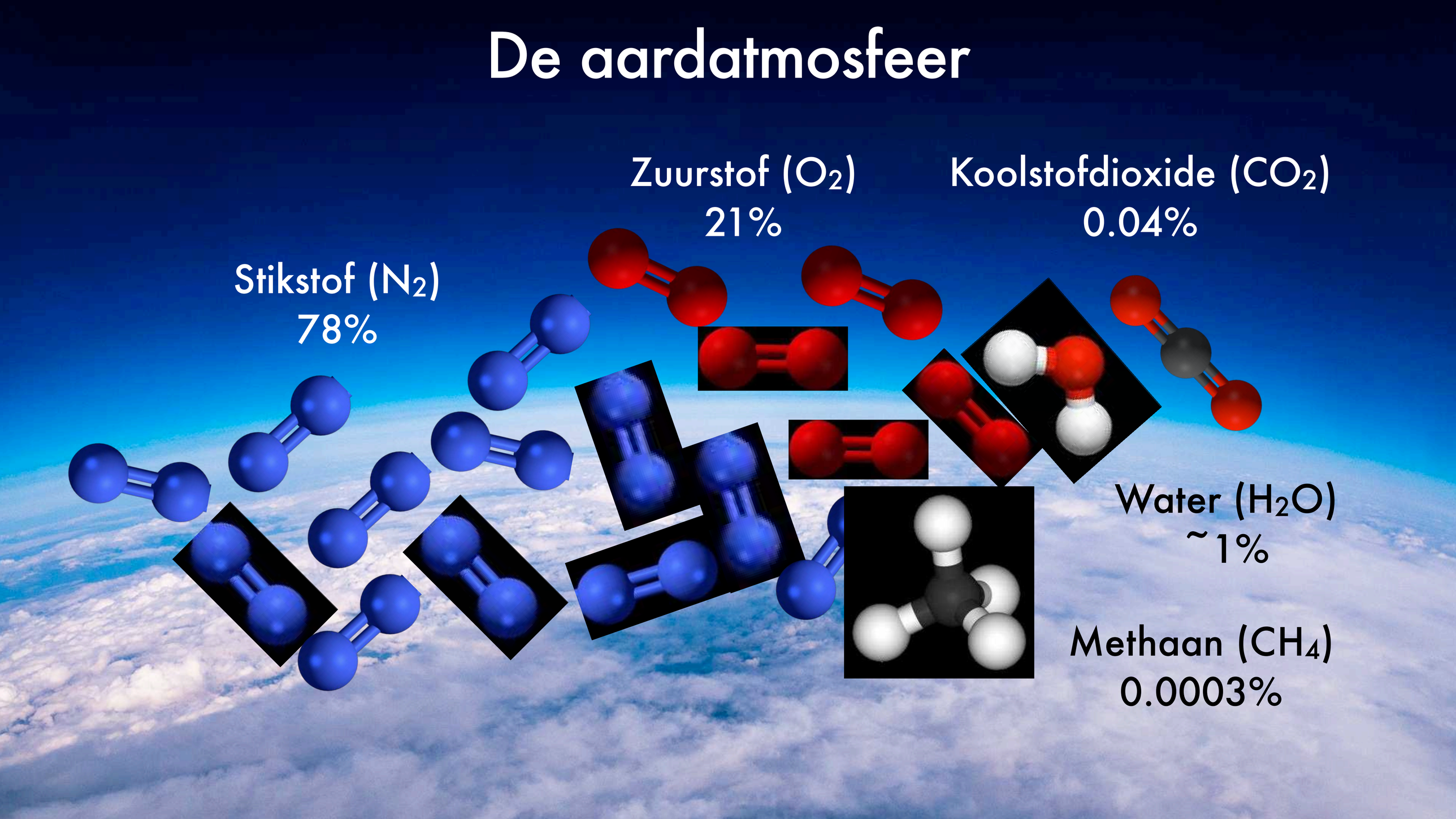
Bewoonbare zone

Bewoond

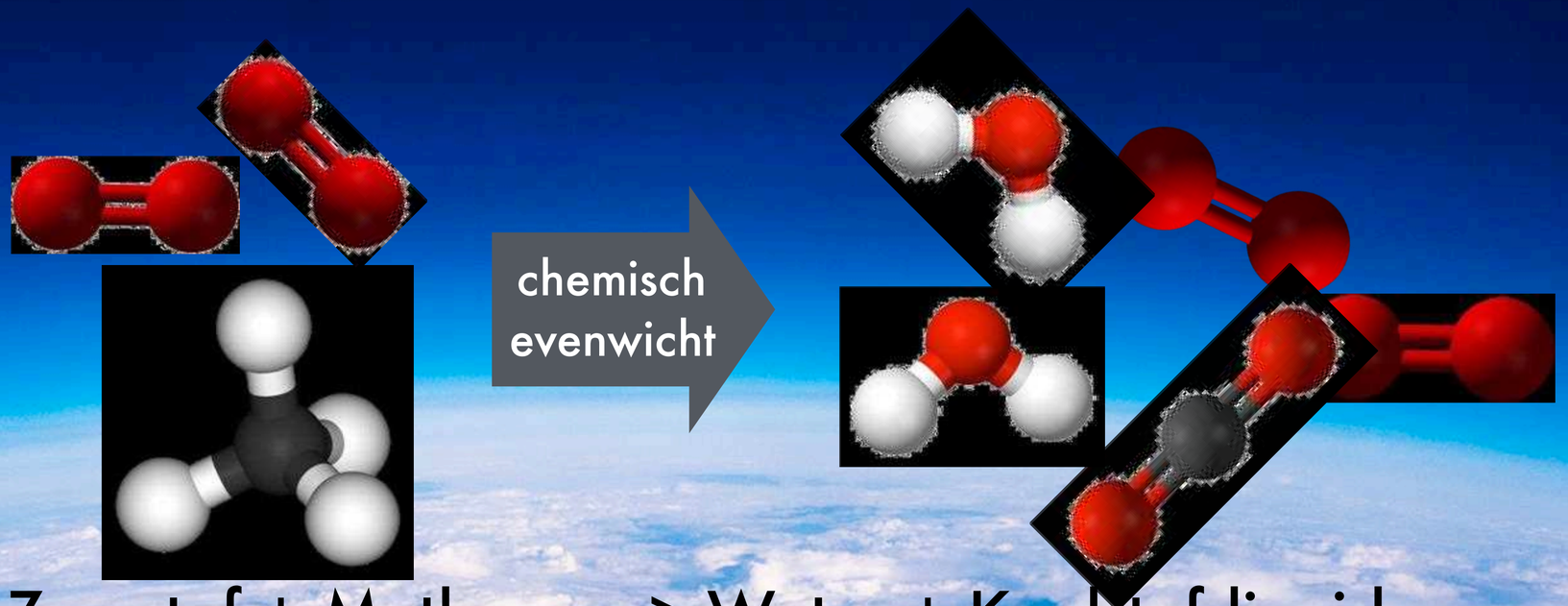
Vereisten voor leven

✅ ✅ ✅ ⬇

De aardatmosfeer



De aardatmosfeer



Zuurstof + Methaan –> Water + Koolstofdioxide

$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$

Zuurstofgehalte van de atmosfeer duidt op verstoring chemisch evenwicht, door leven.

De aardatmosfeer

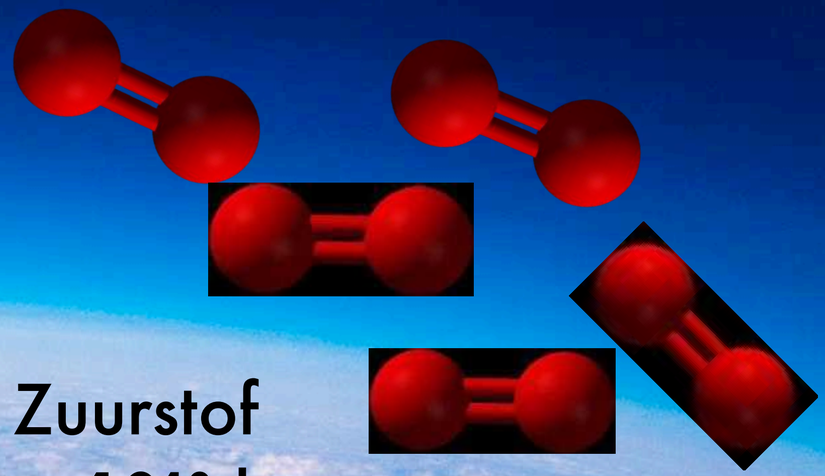
Aarde

6×10^{24} kg

Atmosfeer

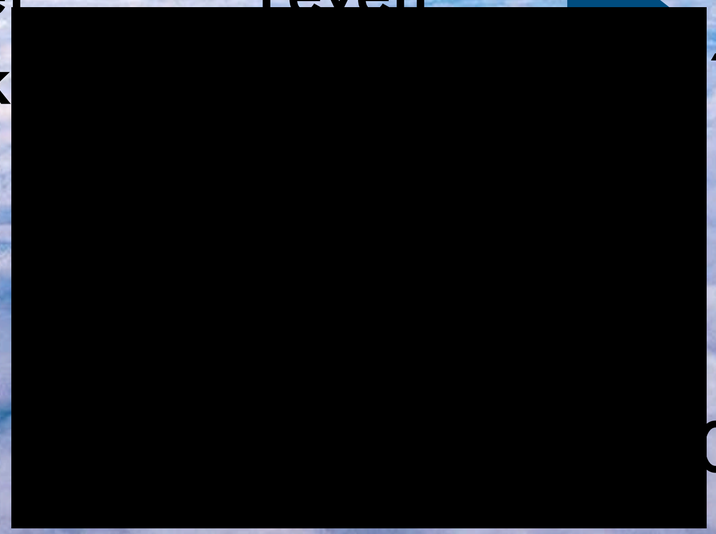
5×10^{18} k

Leven



Zuurstof

1 x 10^{18} kg

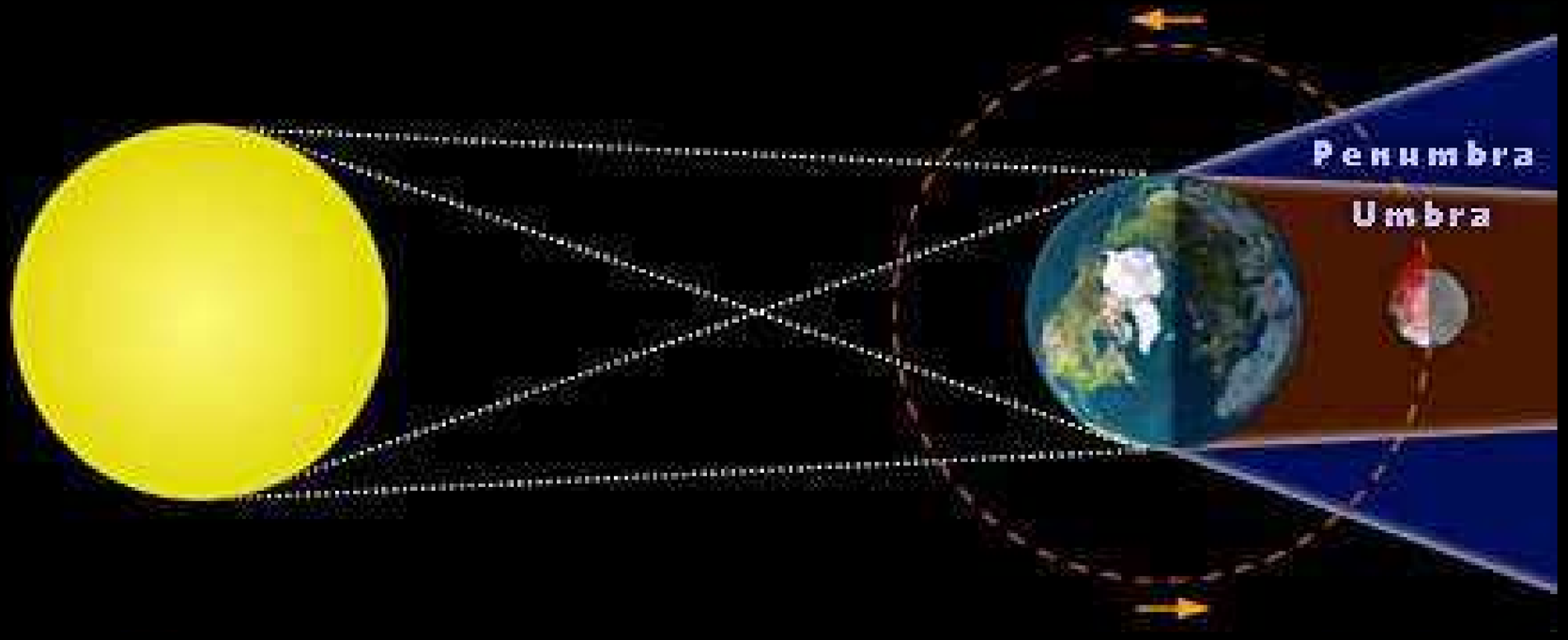


0 x P_{el} = 3x P_{aarde})

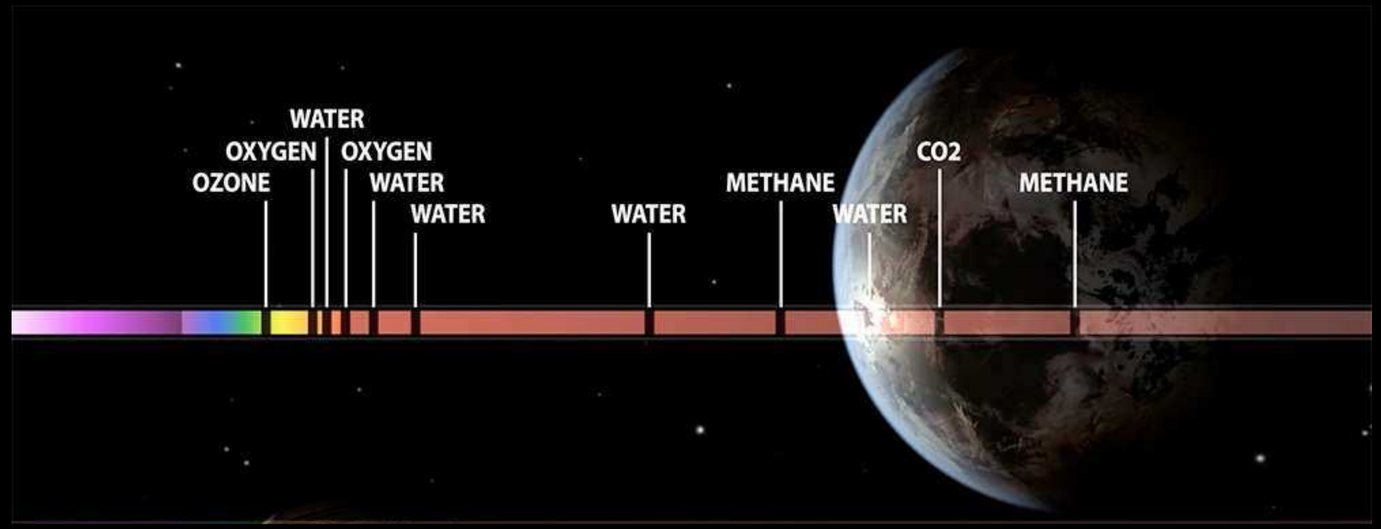
Een blik op de aardatmosfeer

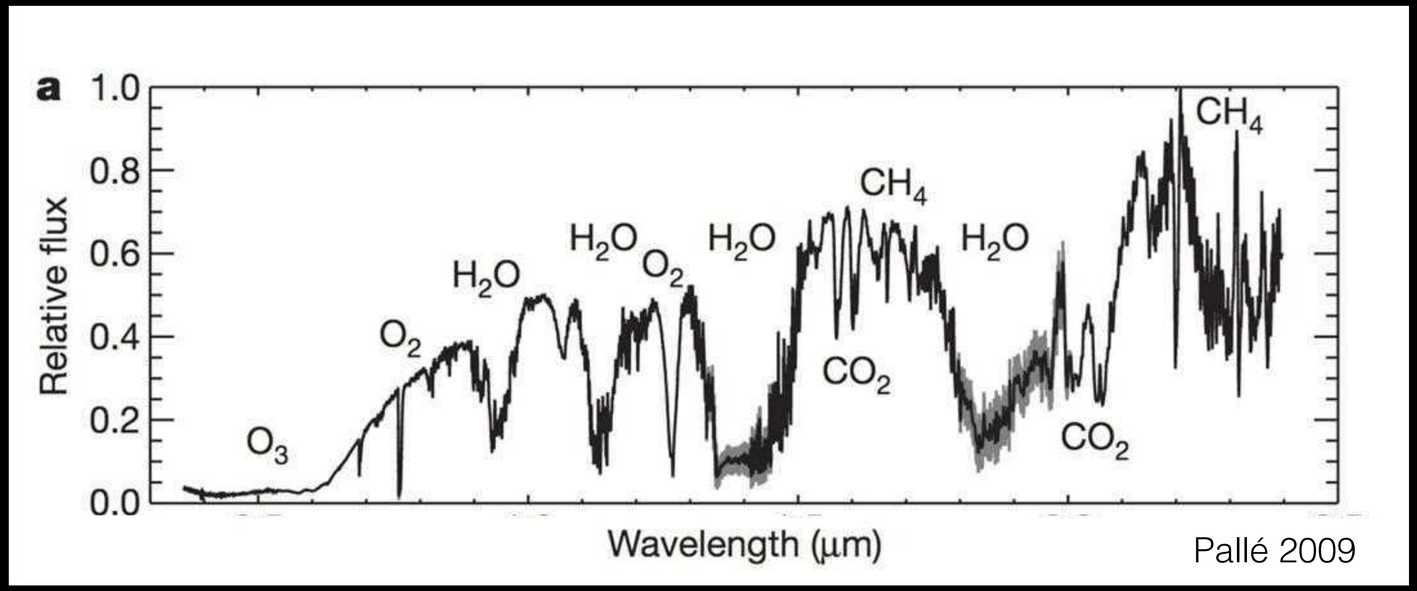
Amsterdam, 27 juli 2018

Een blik op de aardatmosfeer



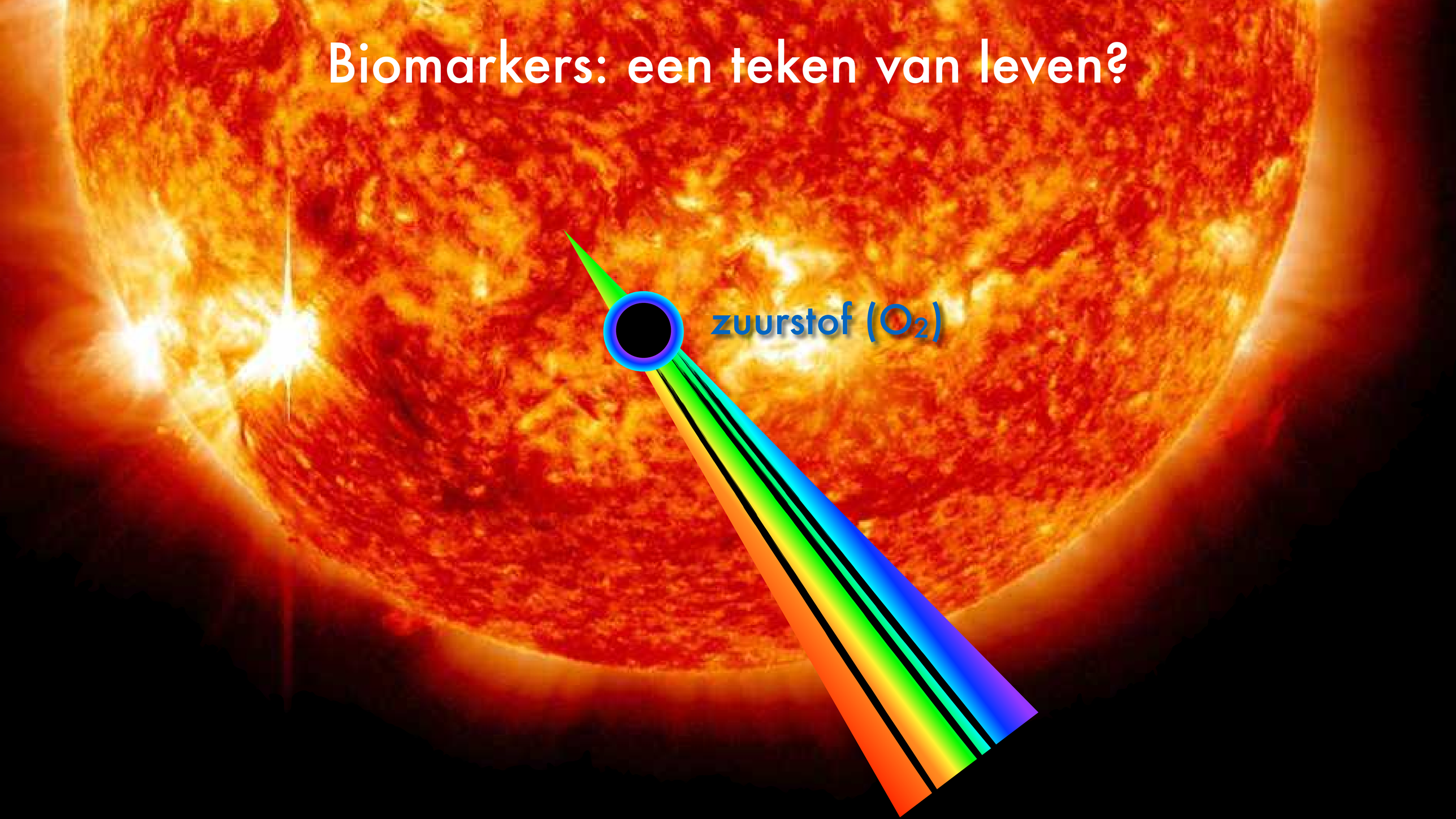
Een blik op de aardatmosfeer

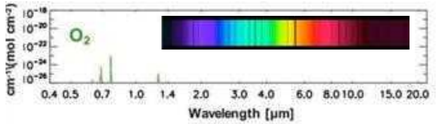
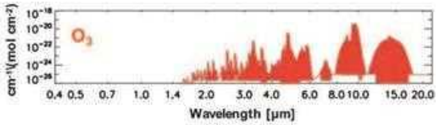
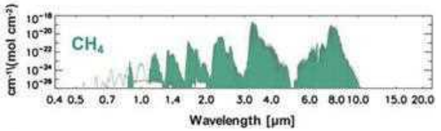
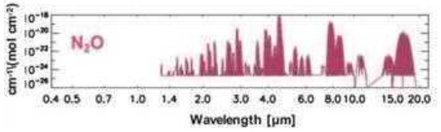
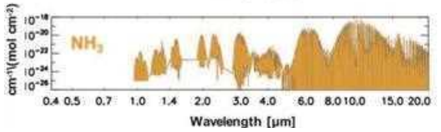
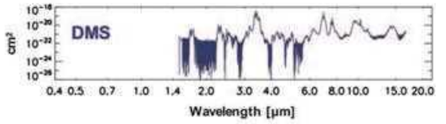
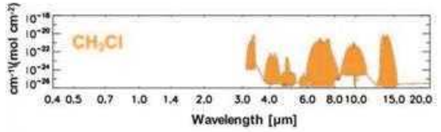
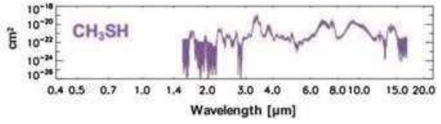
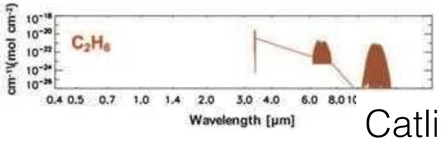




Pallé 2009

Biomarkers: een teken van leven?



	Productie door leven (direct / indirect)	Productie door andere processen	‘Vingerafdruk’ in spectrum atmosfeer
Zuurstof (O_2)	fotosynthese	(water / CO_2 + zonlicht)	
Ozon (O_3)	O_2 + zonlicht	(water / CO_2 + zonlicht)	
Methaan (CH_4)	fermentatie door actieriën in runderen (koeienwinden)	(geothermische processen + vulkanisme)	
Distikstofoxide (lachgas, NO_2)	bacteriën, algen	(blikseminslagen)	
Ammoniak (NH_3)	vertering van uitwepselen / planten door bodembacteriën	(overblijfsel van vorming aarde)	
Dimethylsulfide (DMS, $(CH_3)_2S$)	plankton, algen	(weinig/geen)	
Chloormethaan (CH_3Cl)	algen, tropische vegetatie	(vulkanisme)	
Methaanthiol (CH_3SH)	cyanobacteriën	(weinig/geen)	
Ethaan (C_2H_6)	bijproduct van vorming CH_3 en CH_3SH	(overblijfsel van vorming aarde)	

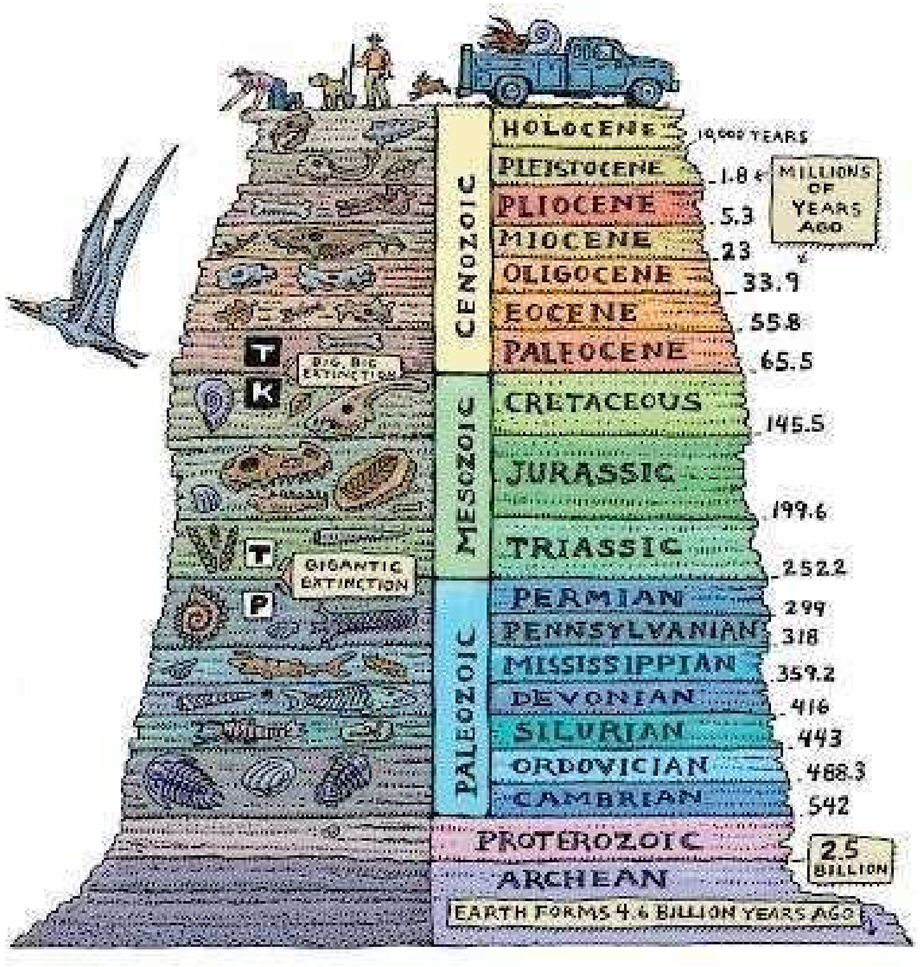
Catling et al. (2018)

credit: C. Sousa-Silva, S. Rugheimer

Hoe zag de aarde er vroeger uit?

meest recente
500 miljoen jaar

eerste 4 miljard jaar

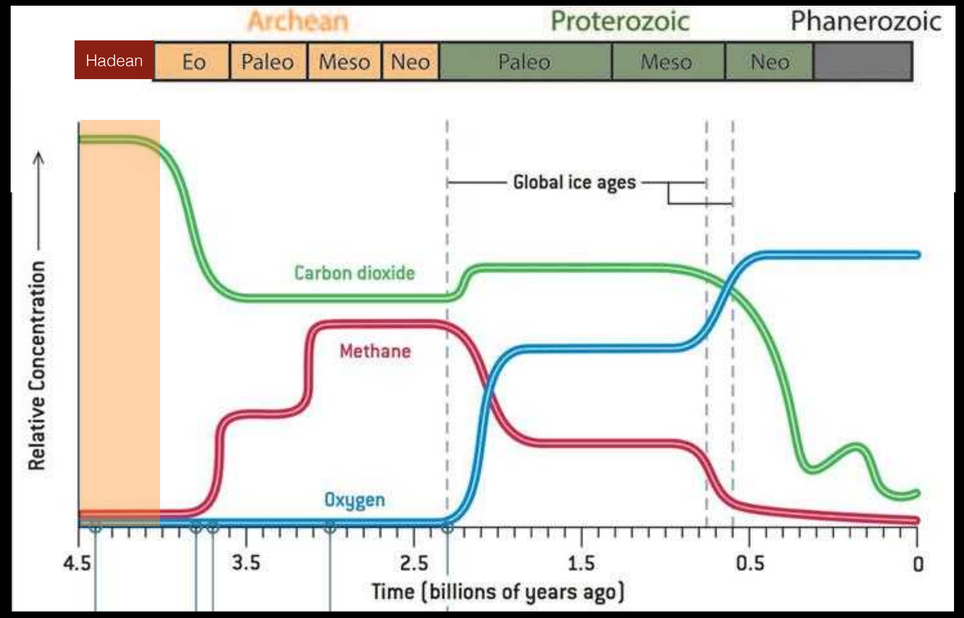


Weinig overblijfselen van de eerste 90%
van het bestaan van de aarde!

De aarde heeft vele gezichten gekend...

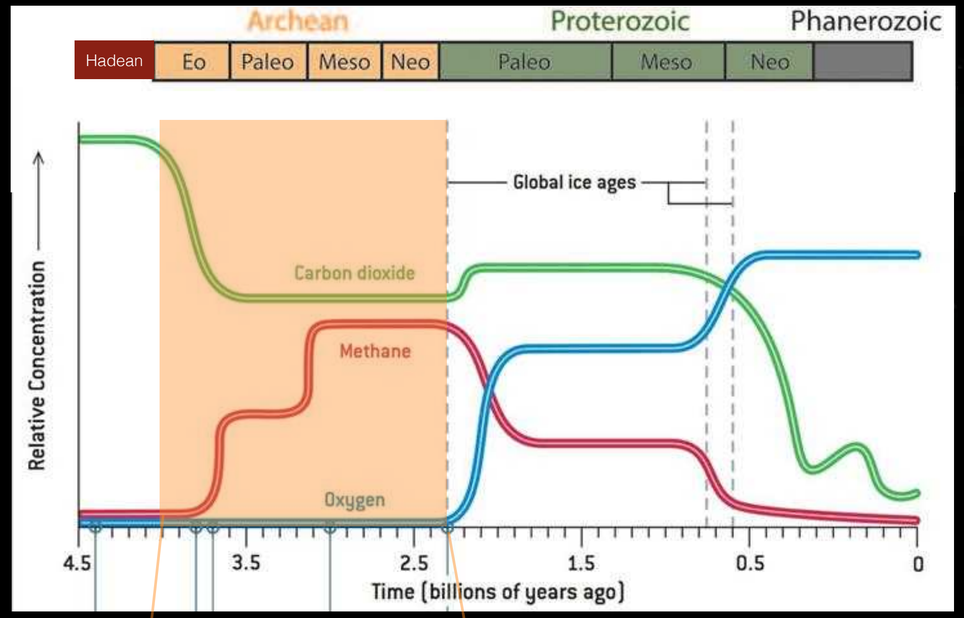
credit: C. Sousa-Silva, S Rugheimer

Hadeïcum

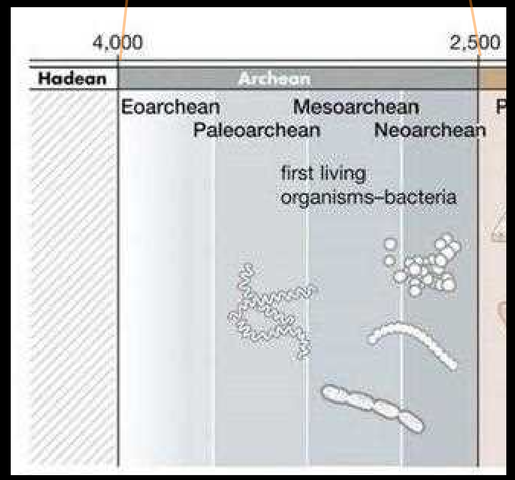


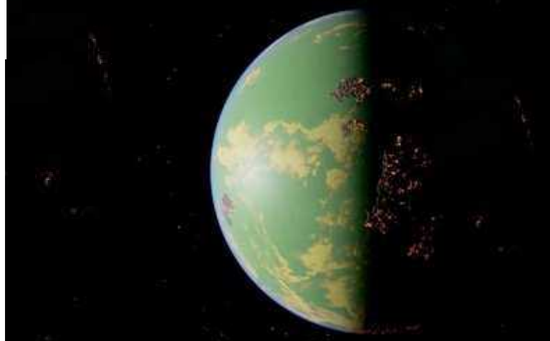
Kasting et al. (2018)

Archeaïcum

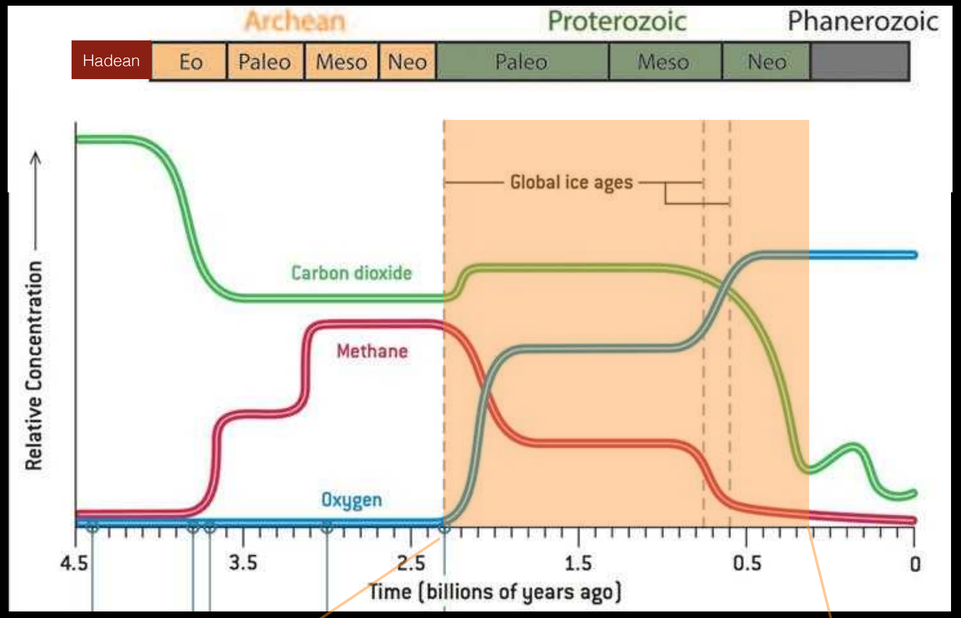


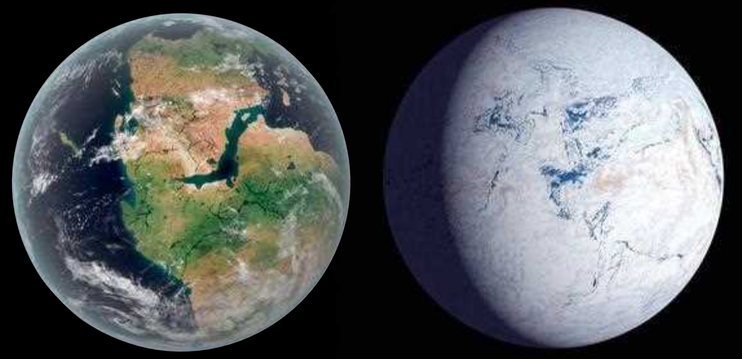
Kasting et al. (2018)



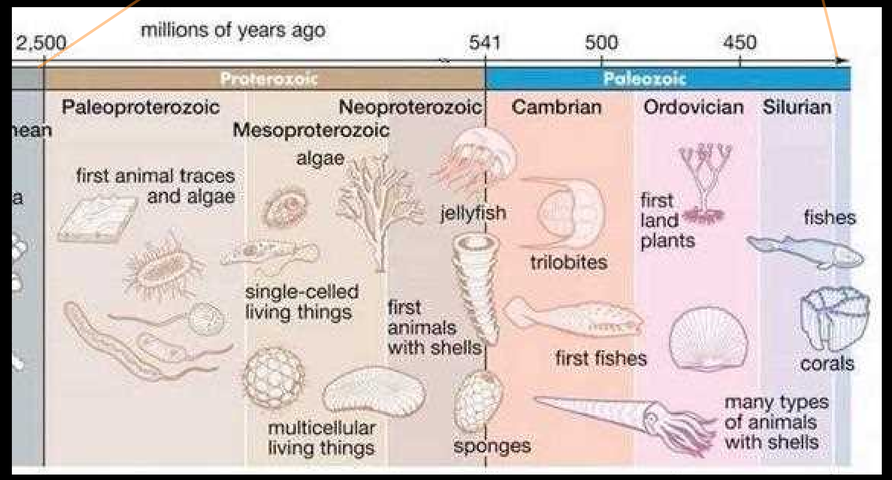


Proterozoïcum

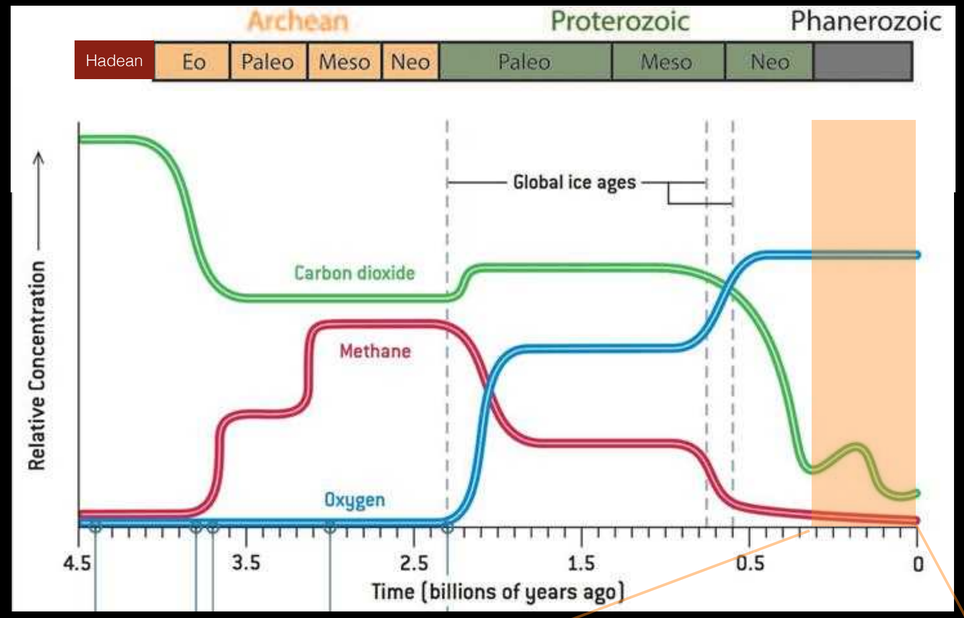




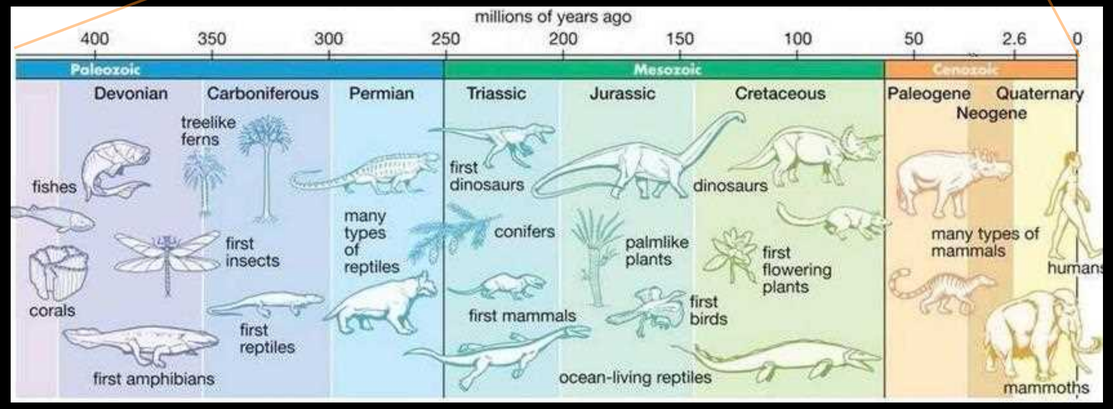
Kasting et al. (2018)

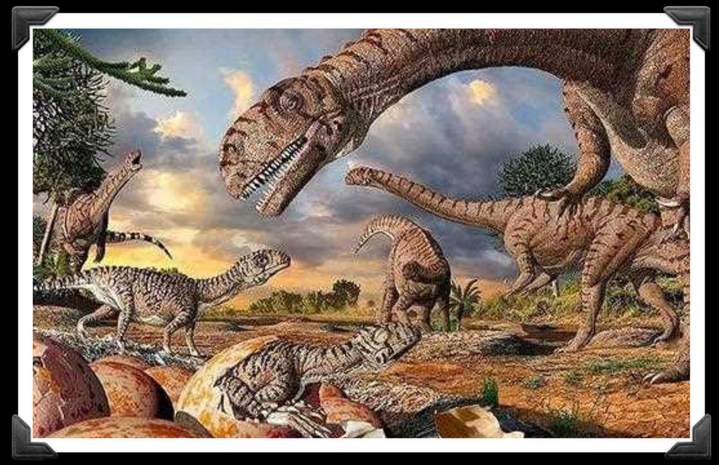


Phanerozoïcum



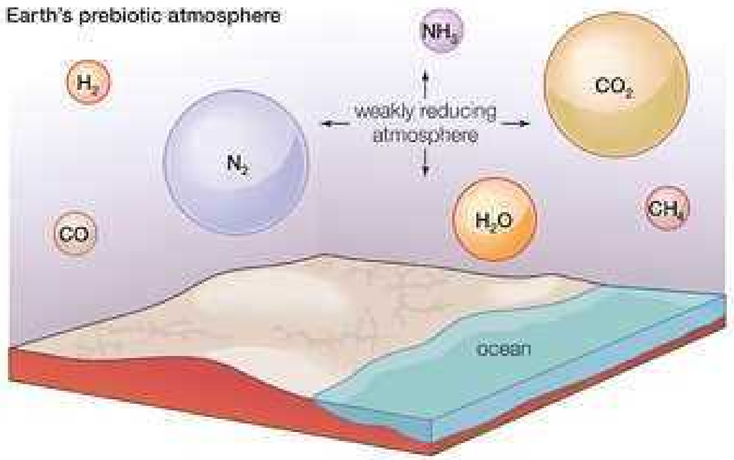
Kasting et al. (2018)



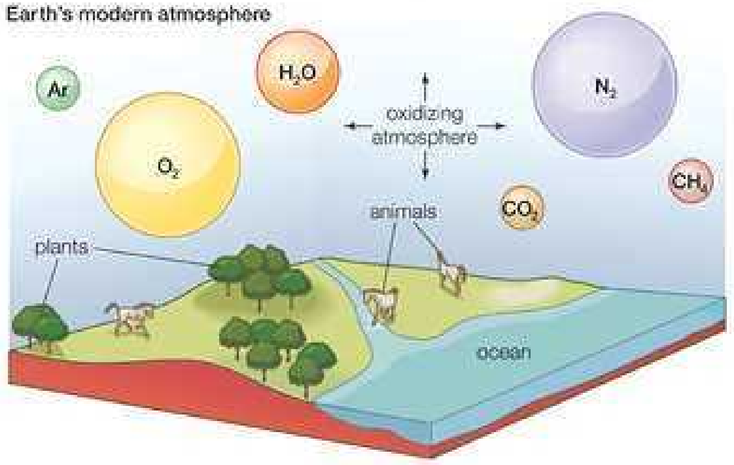


De veranderende aardatmosfeer

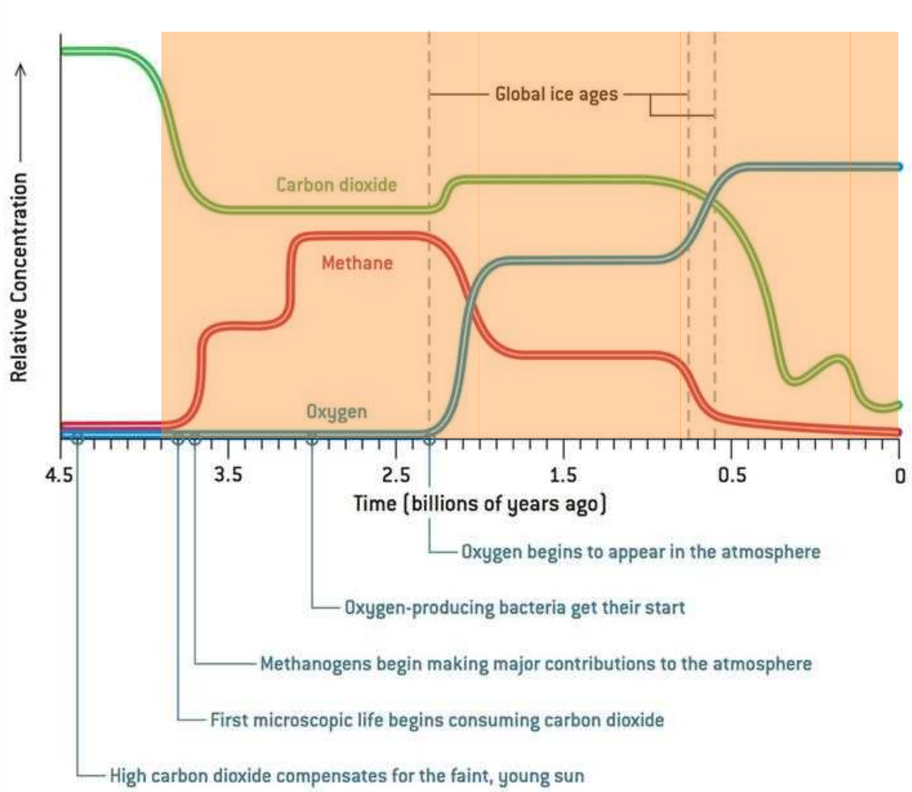
4 - 2.5 miljard jaar geleden

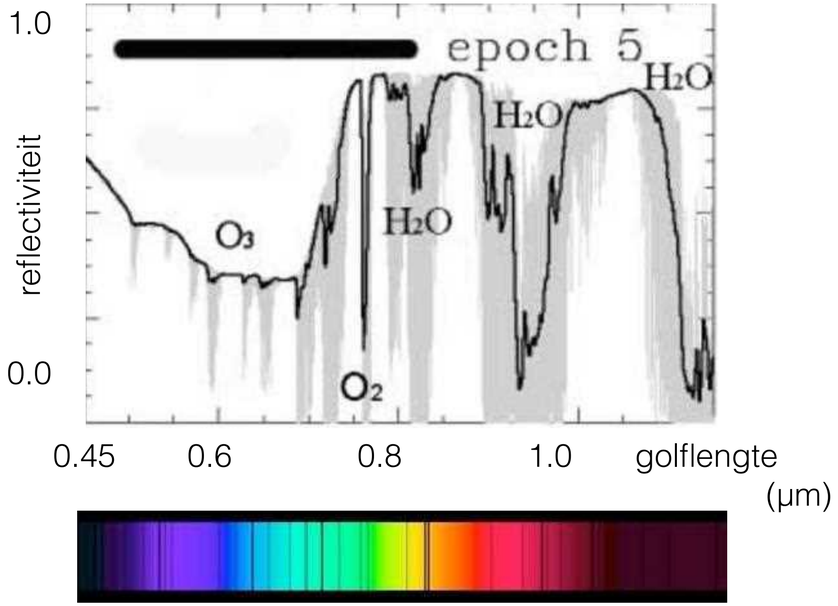


Nu



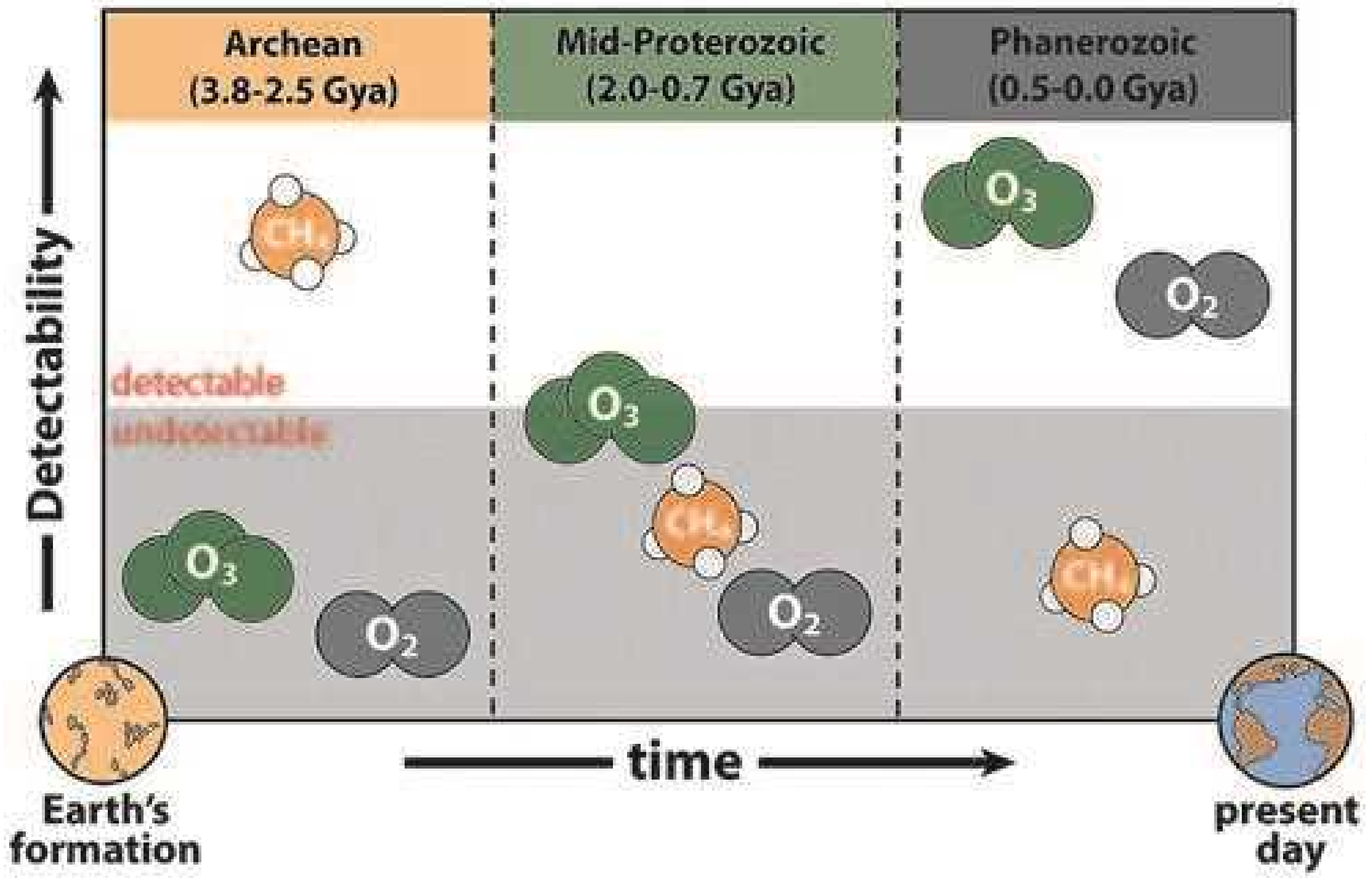
De veranderende aardatmosfeer

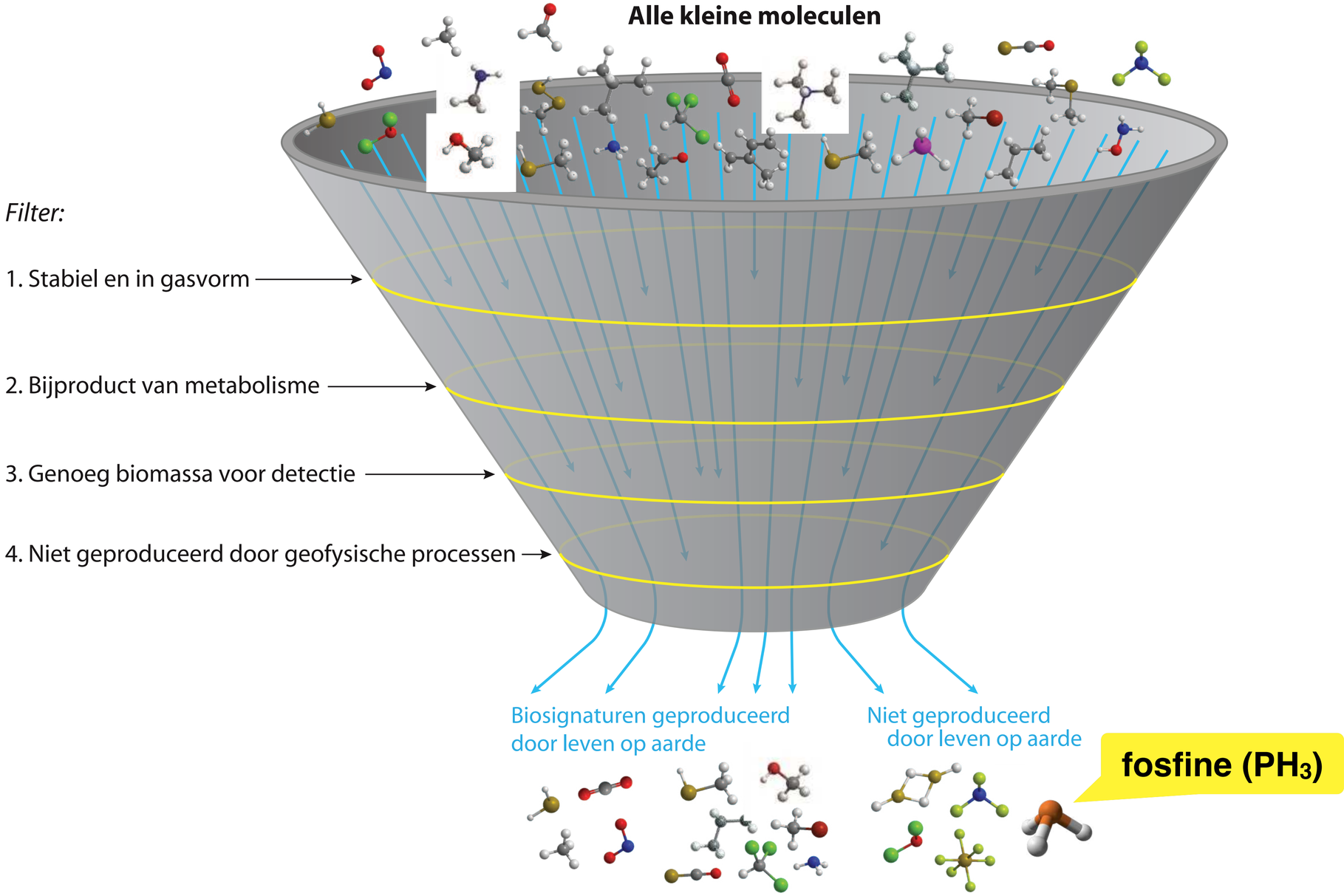




Kasting (2004), Kaltenegger et al. (2007)

De veranderende aardatmosfeer

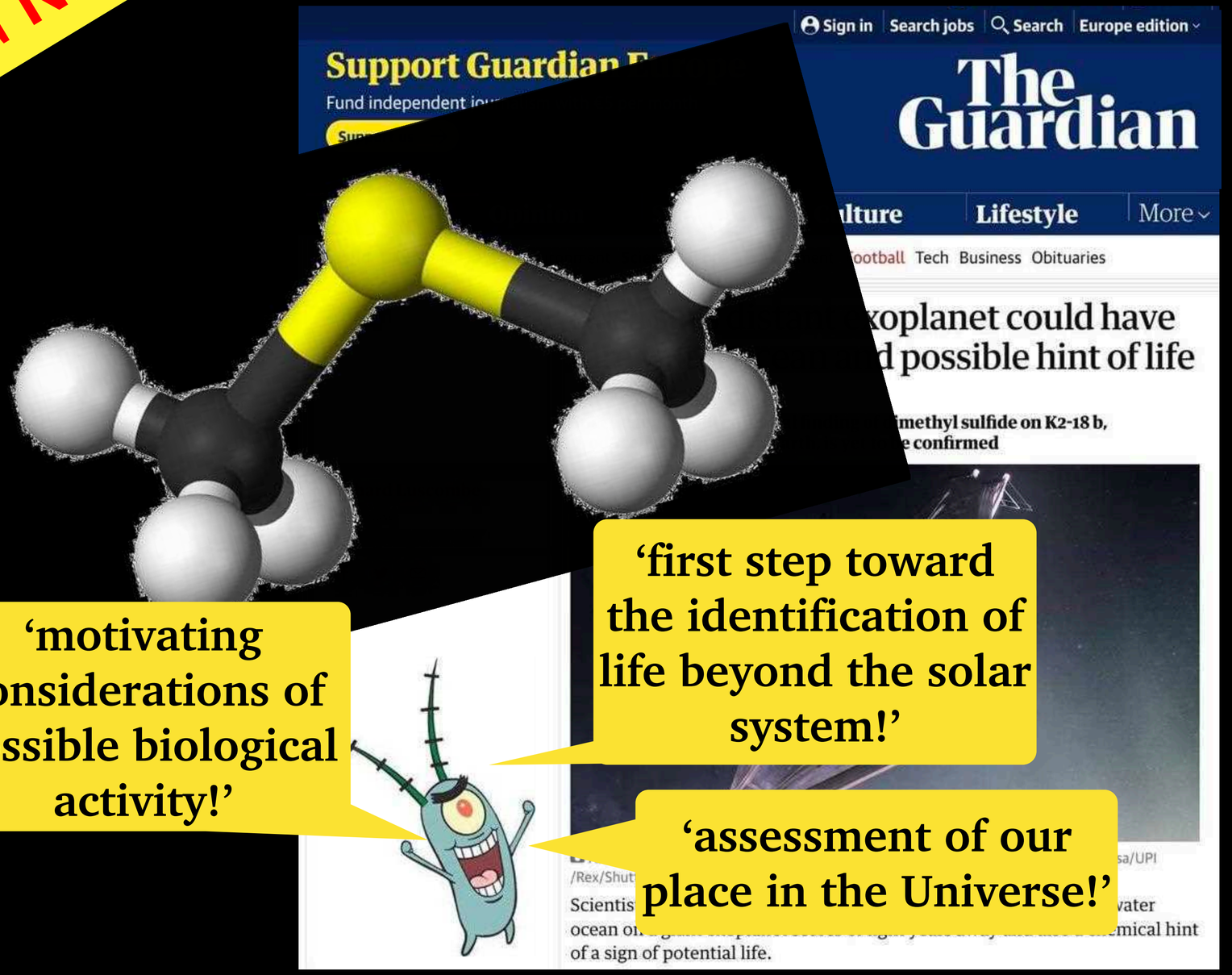




Beeld: S. Seager, D. Beckner

BREAKING NEWS

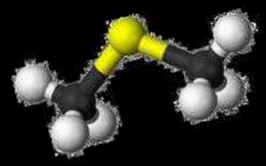
Een teken van leven gevonden?



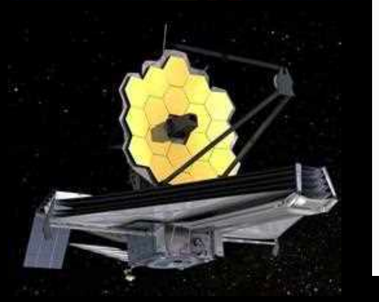
‘motivating considerations of possible biological activity!’

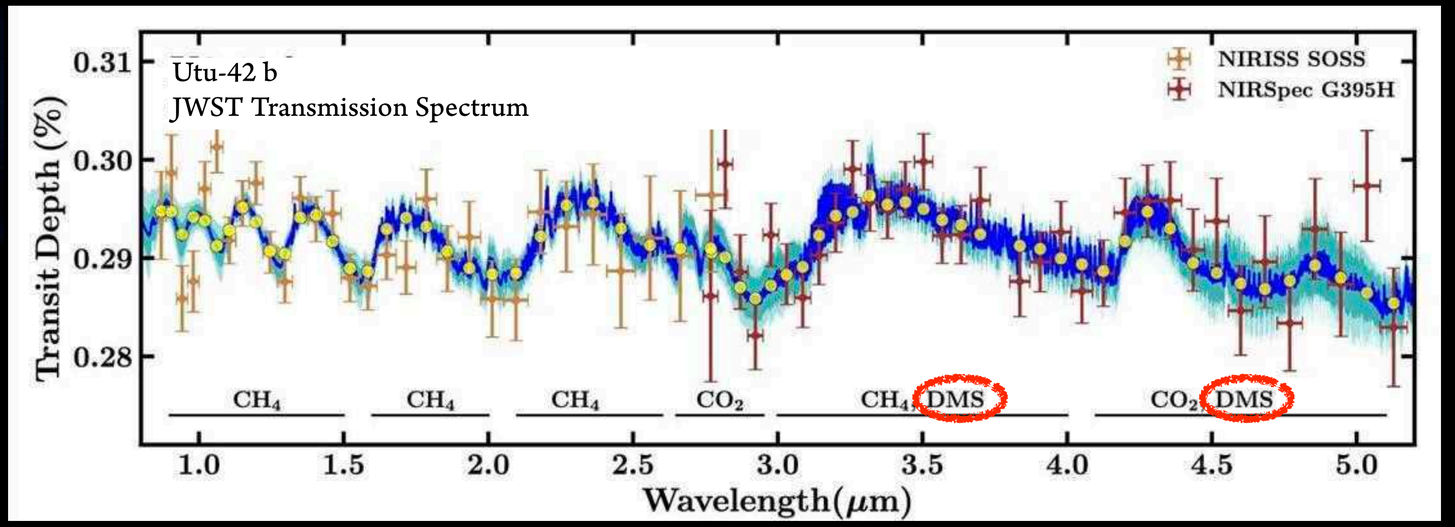
‘first step toward the identification of life beyond the solar system!’

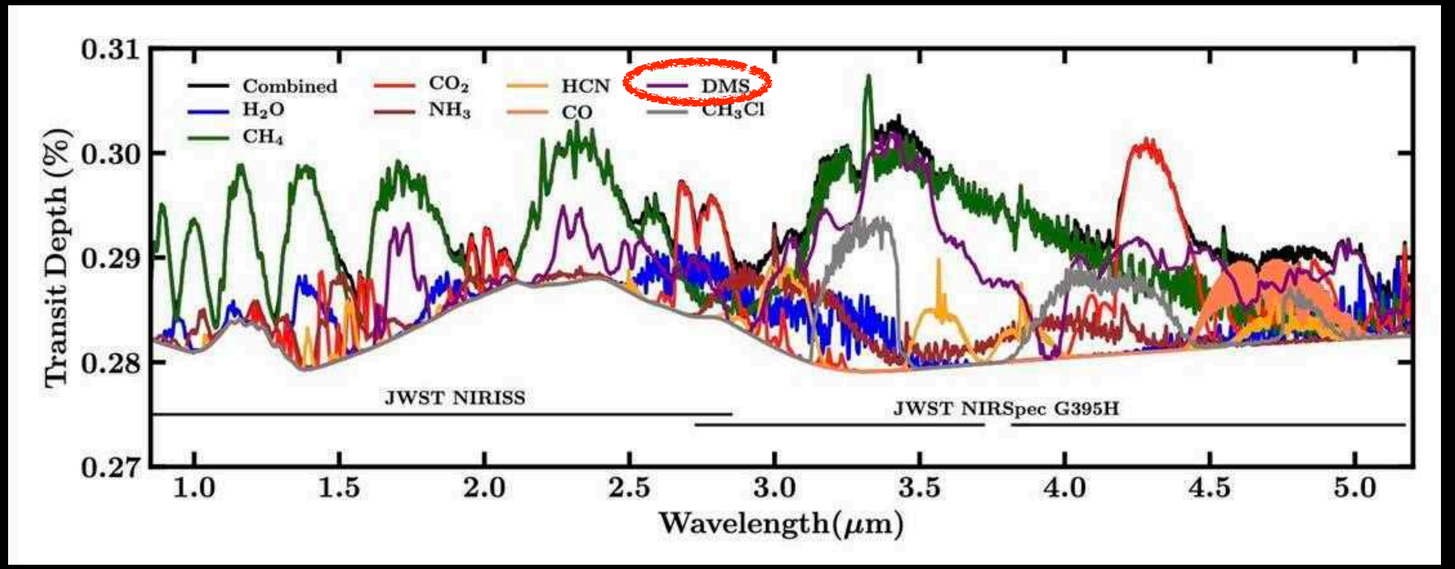
‘assessment of our place in the Universe!’



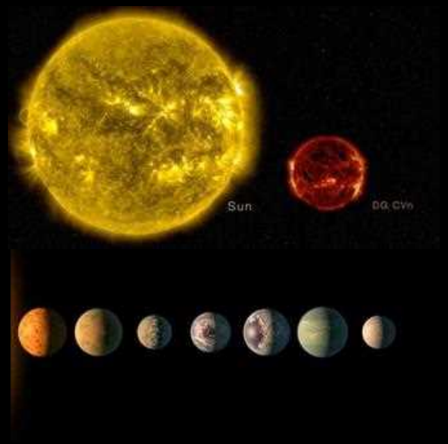
Een teken van leven gevonden?



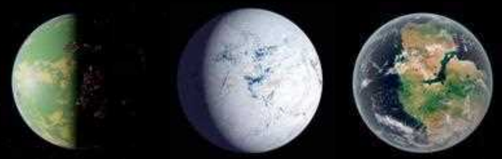




Drie uitdagingen van biomarkers



Biomarkers zijn afhankelijk van context



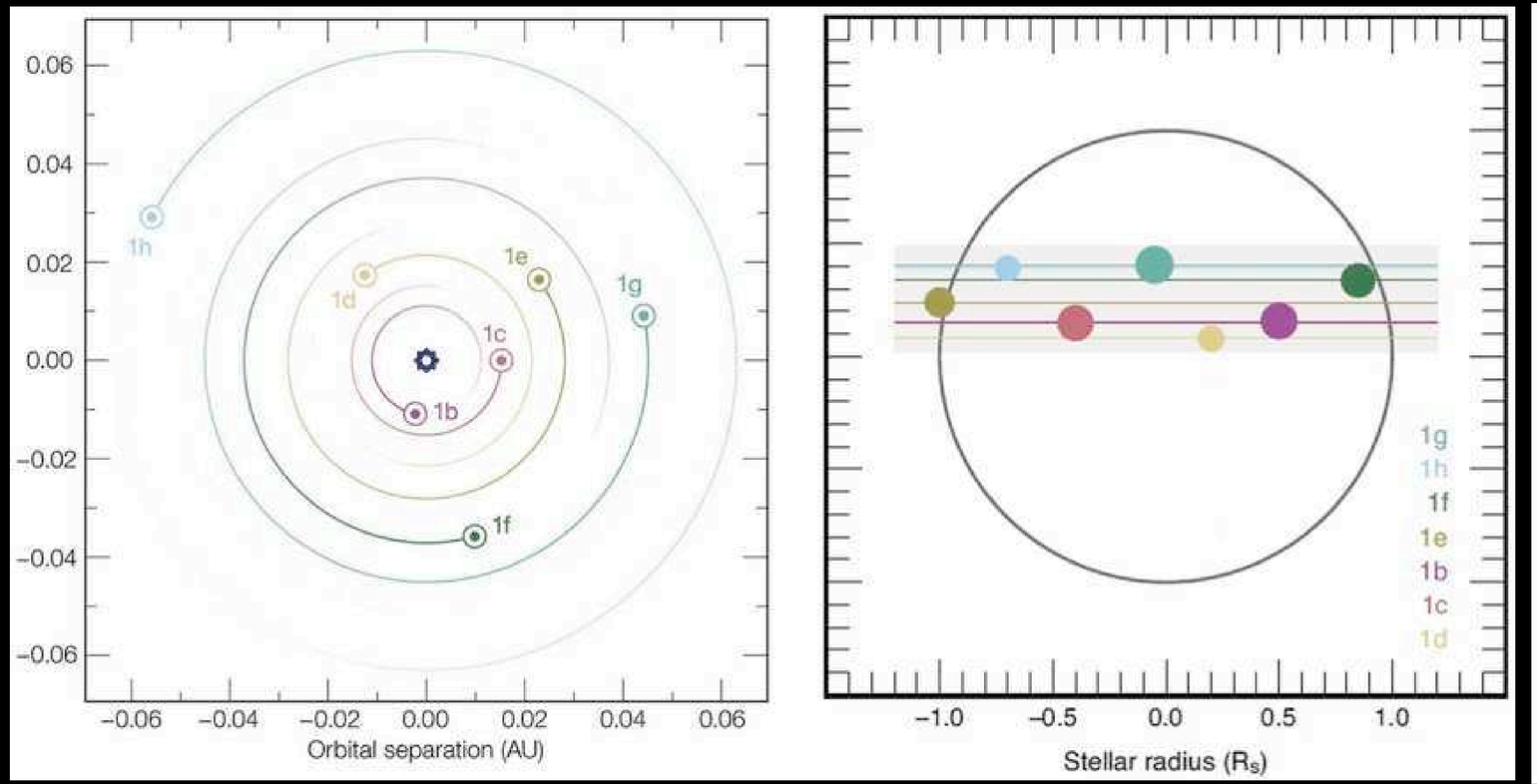
Biomarkers zijn veranderlijk

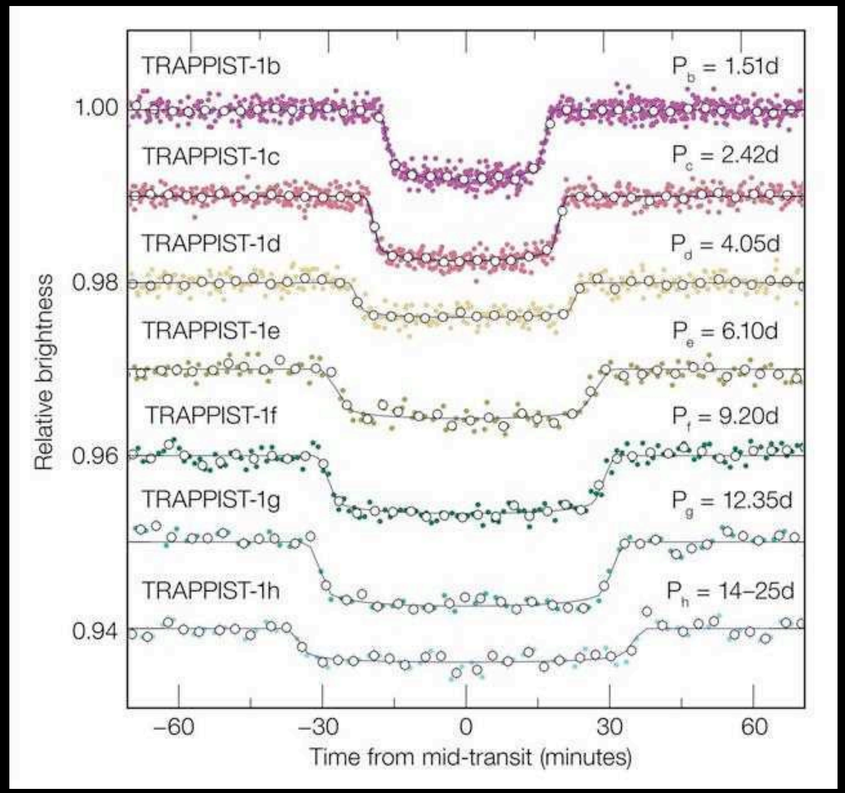
Onbekend leven, onbekende biomarkers?

PLANEETATMOSFEREN

- Atmosferen in ons zonnestelsel
- Exoplaneten
- Transmissiespectroscopie
- Zoektocht naar leven
- Toekomstperspectief

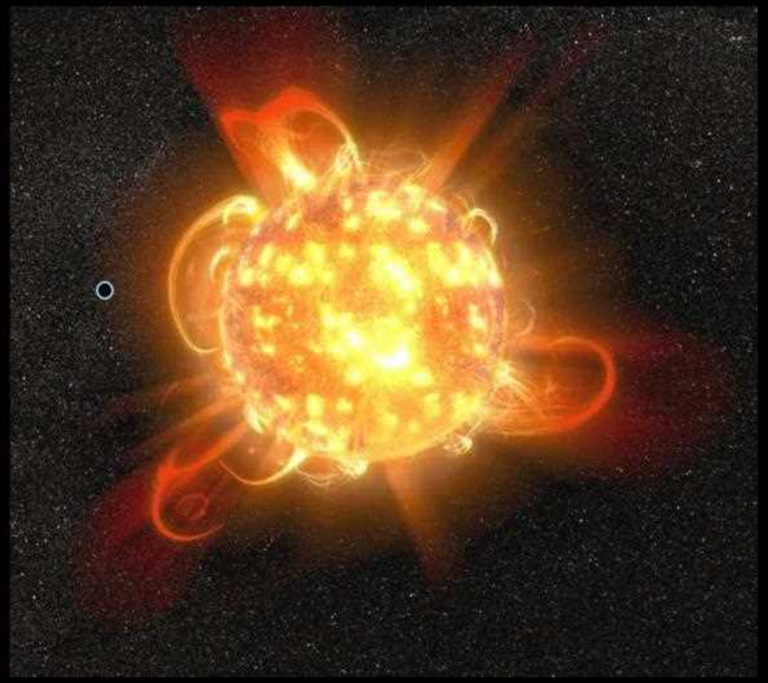
2025: alle ogen op Trappist

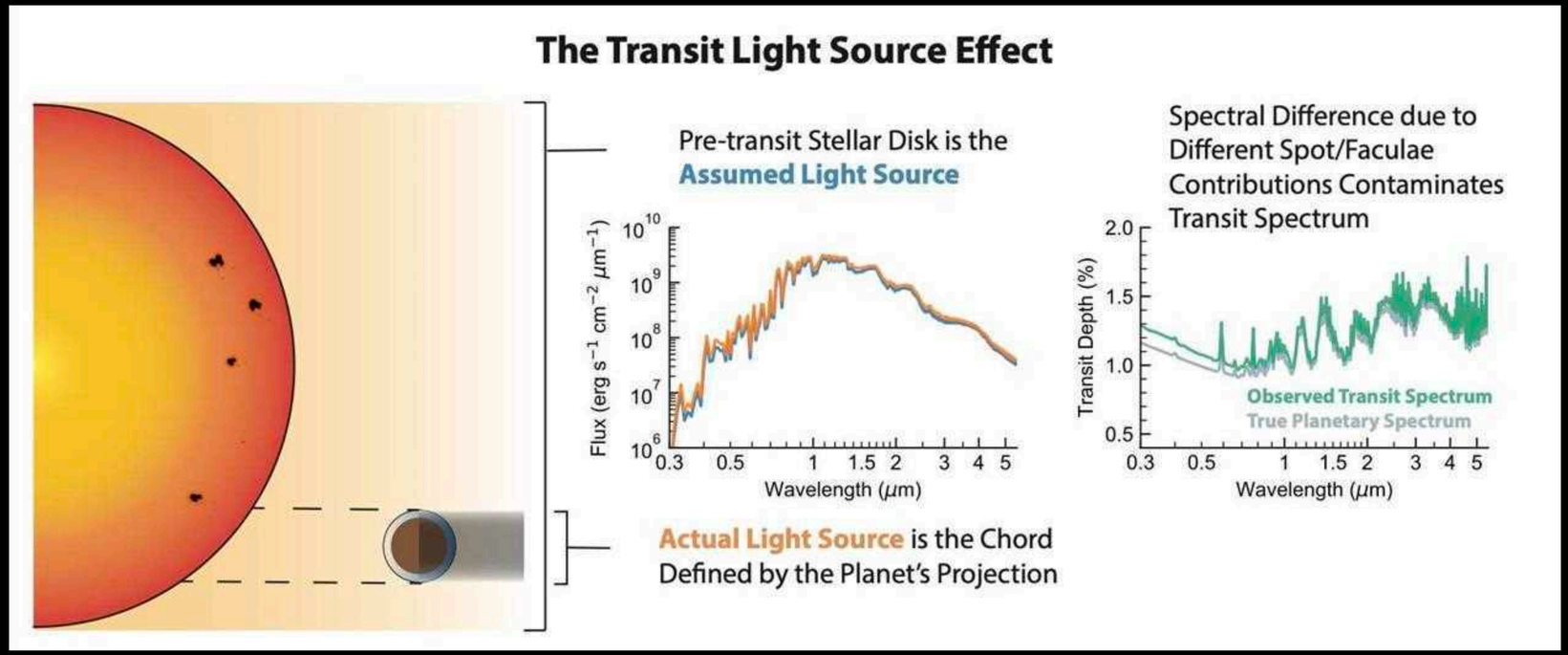




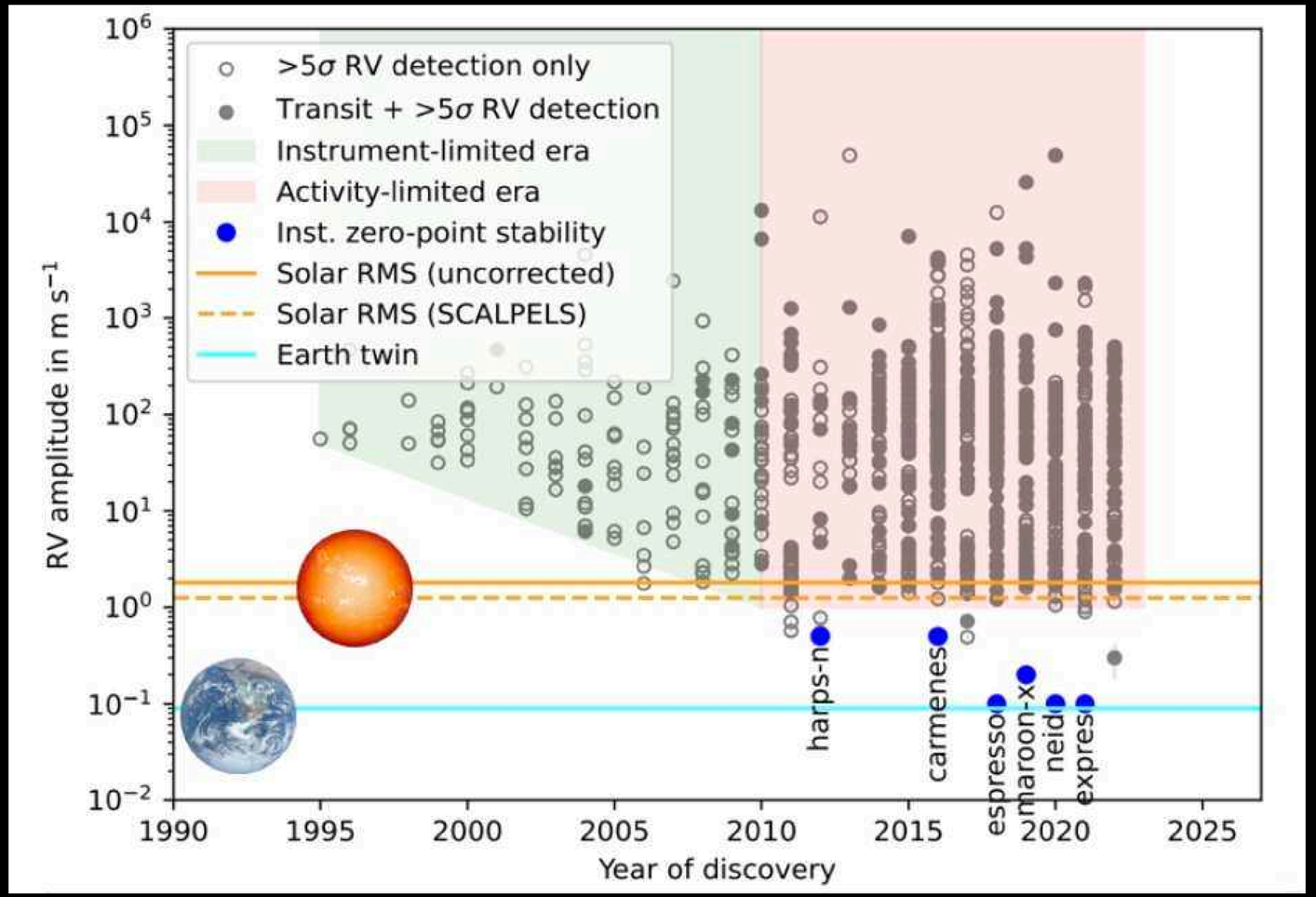
Planeten? Leven? Eerst moeten we sterren beter begrijpen

We want to discover Earth twins.
The world gave us JWST.
Nature gave us M-dwarfs.





Niet instrumentatie, maar steractiviteit begrenst ontdekkingen



REVEAL

Prof. Dr. Andrew Collier Cameron

Discovering Earth "twins" with extreme precision RV ground-based spectroscopy and new methodology for its analysis.

Prof. Dr. Sara Seager

Characterizing Earth "cousins" atmospheres with JWST via transmission spectroscopy and new atmospheric retrieval methodology.

Dr. Alexander (Sasha) Shapiro

Modelling stellar signals in RV and transmission spectrosocopy with frontier computer simulations.

MAX PLANCK INSTITUTE FOR SOLAR SYSTEM RESEARCH

REVE[illegible] SIGNATURE[illegible] OF HABITABLE WORLDS HIDDEN BY STELLAR ACTIVITY

Gaat de James Webb Space Telescope aarde 2.0 vinden?

PNAS Proceedings of the National Academy of Sciences of the United States of America

Main Manuscript for

Prospects for Detecting Signs of Life on Exoplanets in the JWST Era

Sara Seager[1,2,3,*], Luis Welbanks[4], Lucas Ellerbroek[5], William Bains[1,6], Janusz J. Petkowski[1,7,8]

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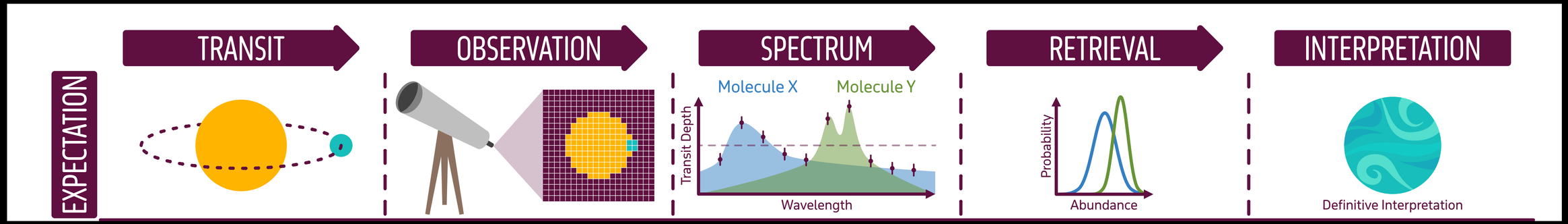

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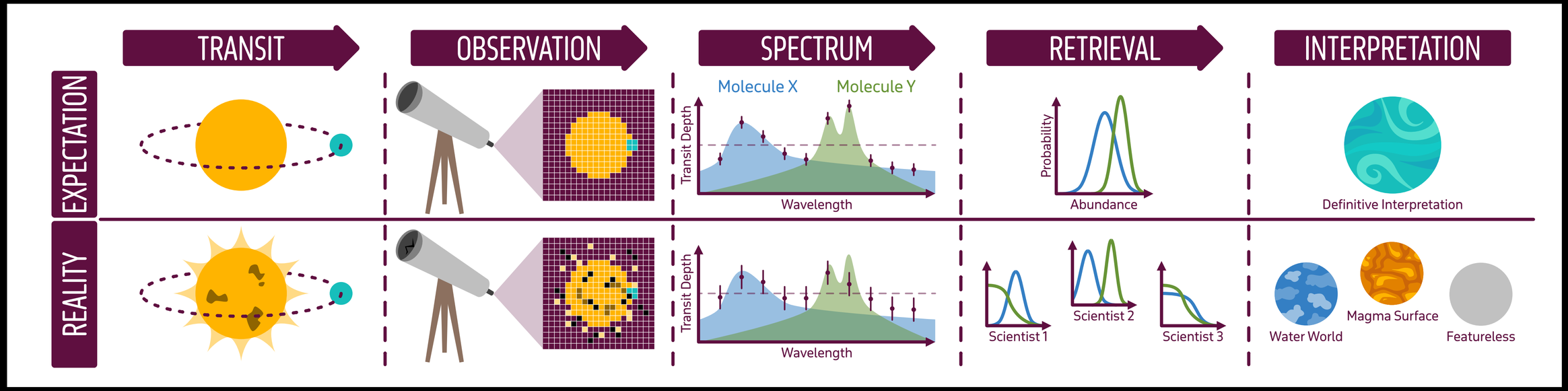

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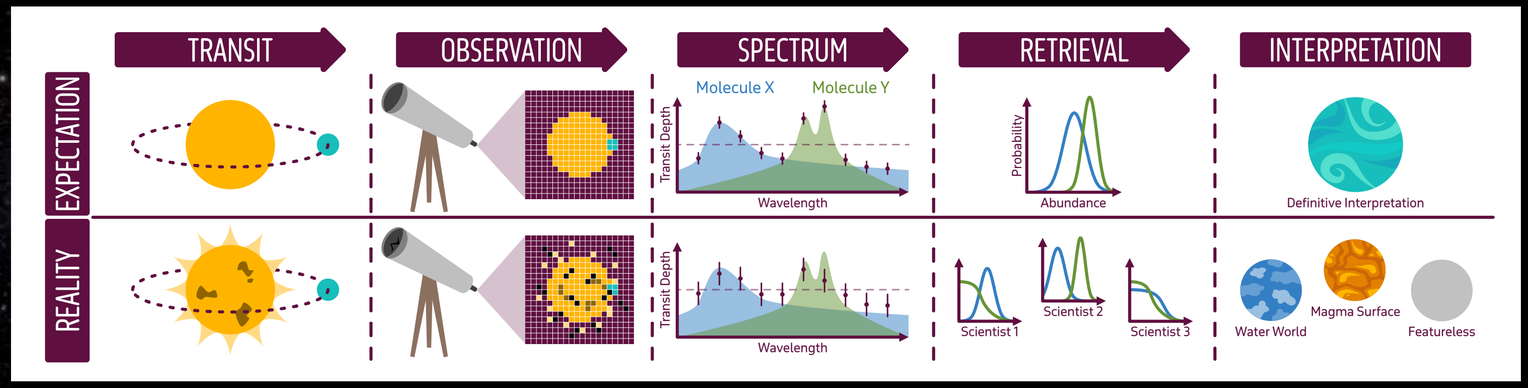
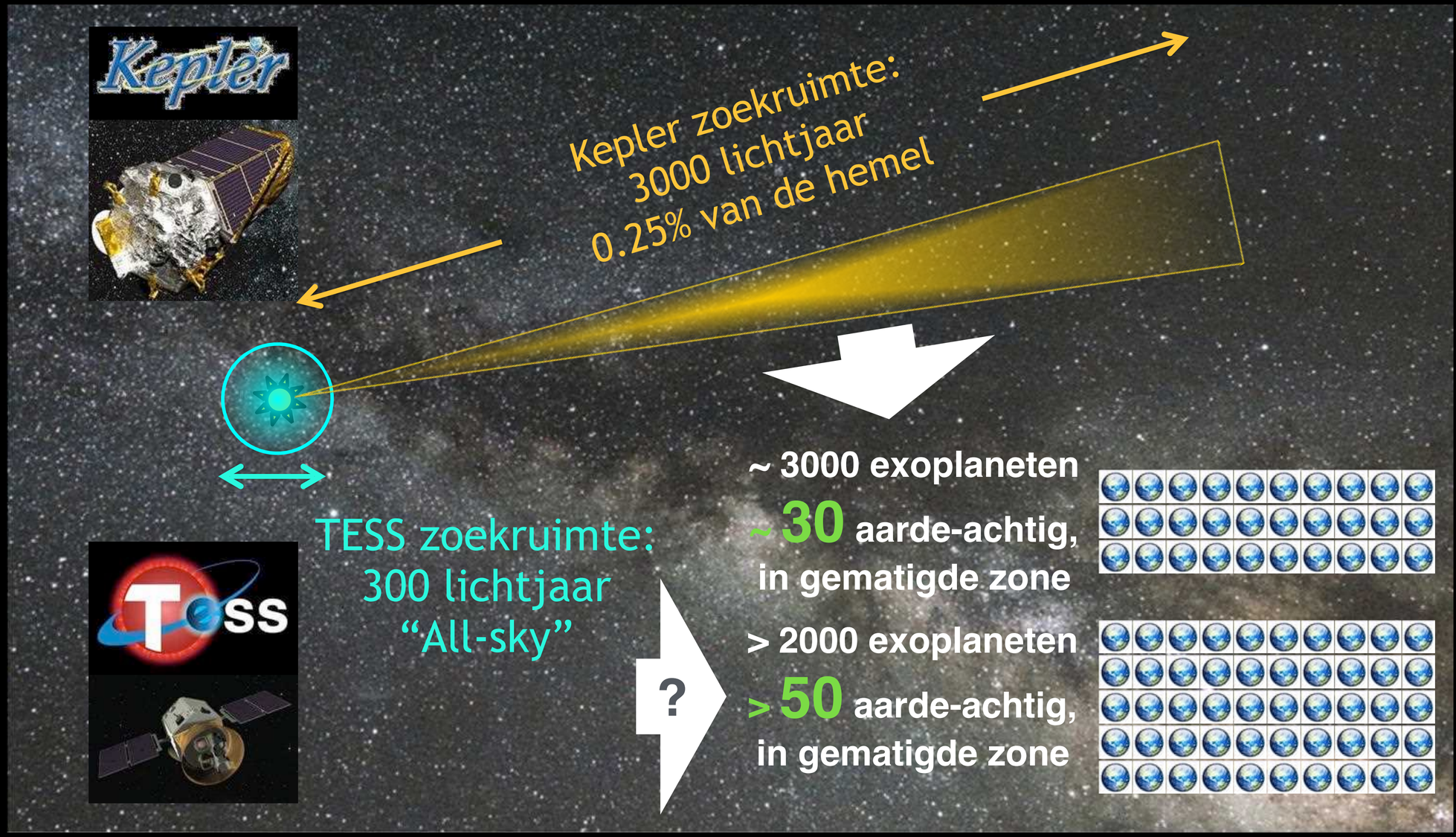
'We conclude with the sobering realization that with JWST we may never be able to *definitively* claim the discovery of a biosignature gas in an exoplanet atmosphere.'

'Ultimately, we seek fundamentally new technological approaches for exoplanet observations. Real breakthroughs will come from audacious projects like the Solar Gravitational Lense Telescope'

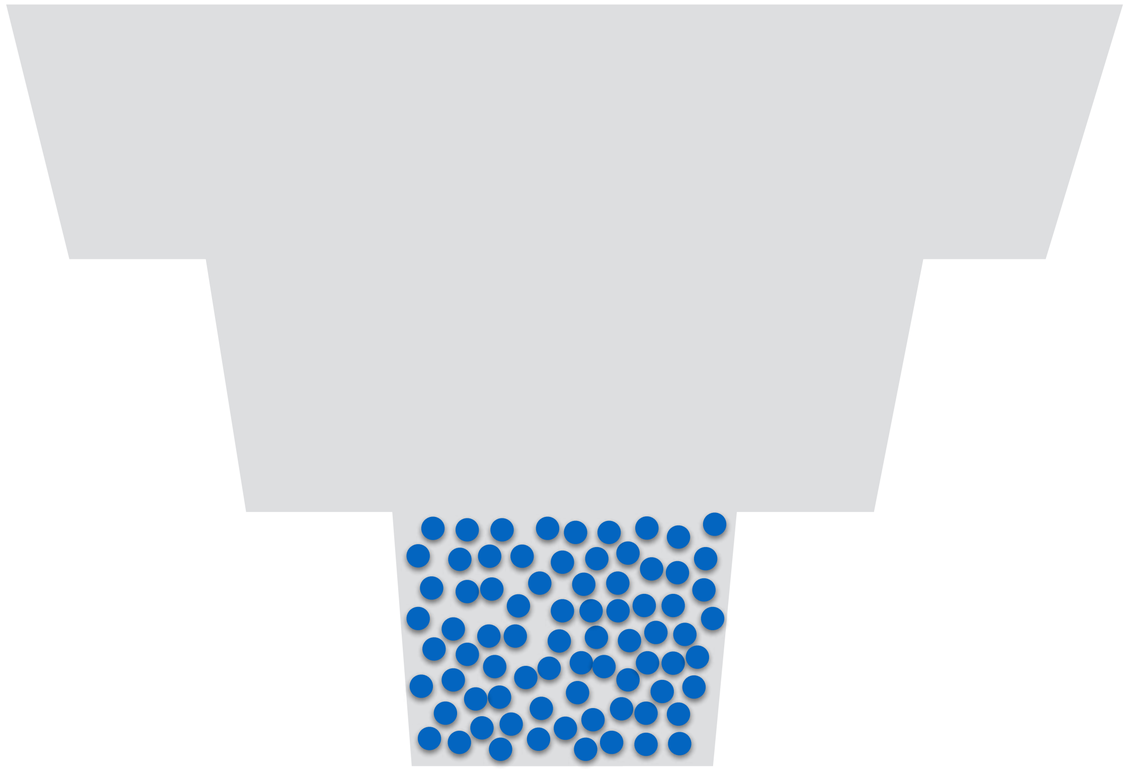


We beginnen nog maar met kijken...



via J Burt

Op jacht naar een bewoonbare exoplaneet

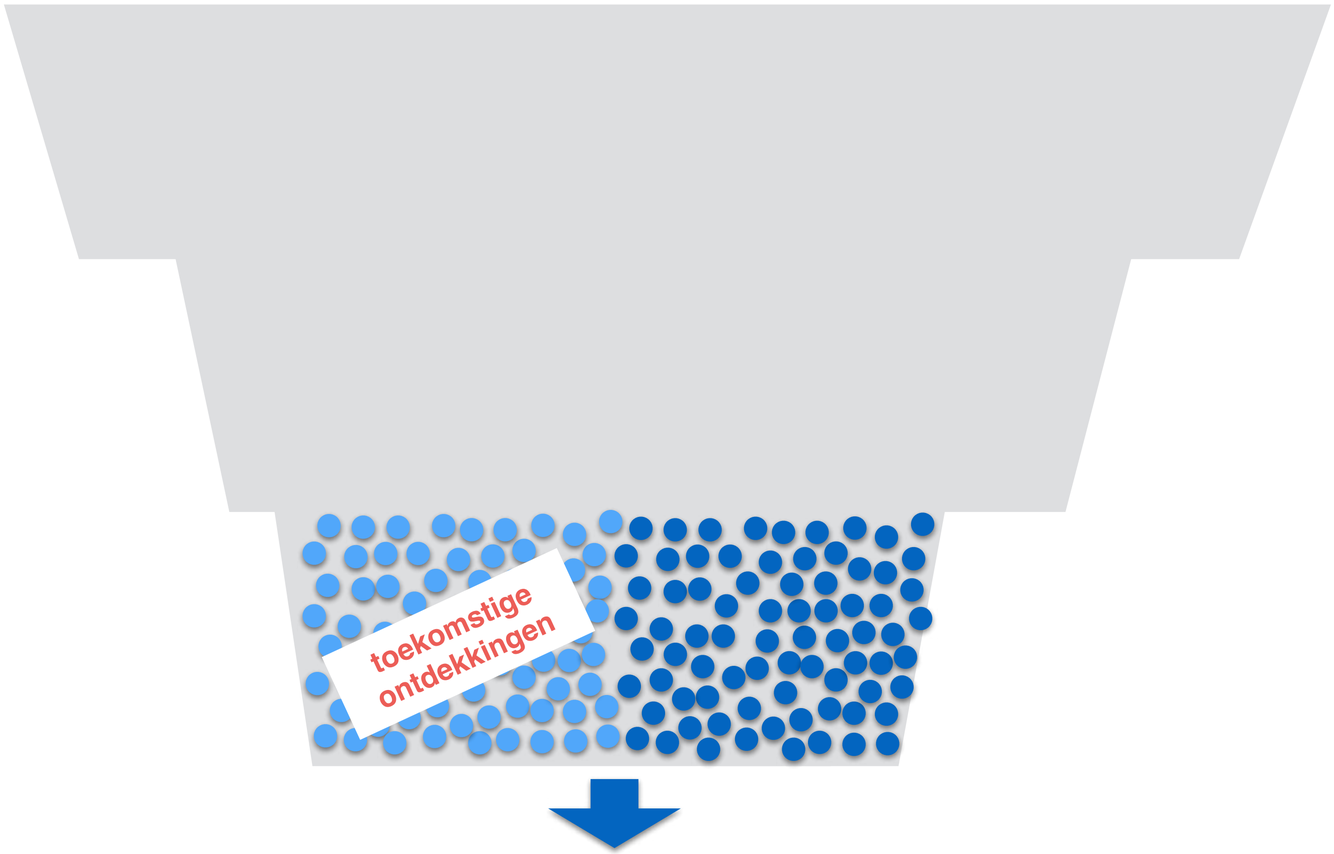


Alle exoplaneten

Kleine exoplaneten

Bewoonbare zone

Op jacht naar een bewoonbare exoplaneet



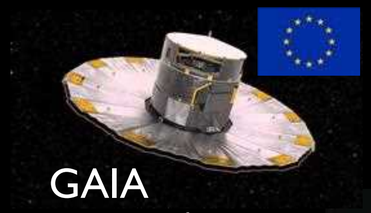
Alle exoplaneten

Kleine exoplaneten

Bewoonbare zone

Bij deze exoplaneten zoeken we naar biomarkers

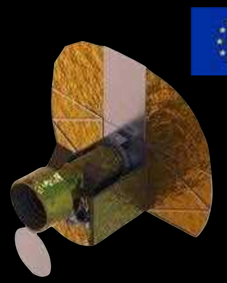
Vinders…



GAIA

TESS

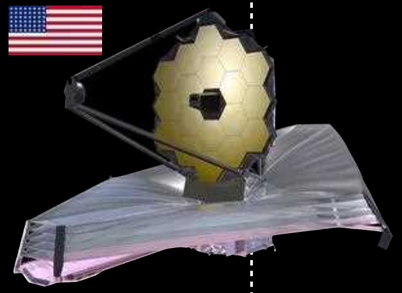
PLATO



CHEOPS

Onderzoekers…

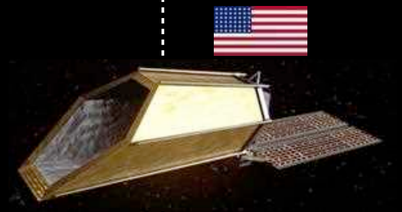
ARIEL



JWST

E-ELT

TMT?

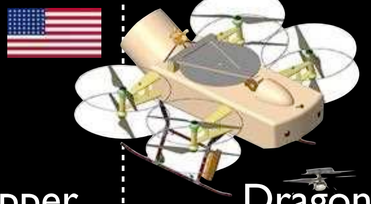


HWO

Verkenners…

JUICE

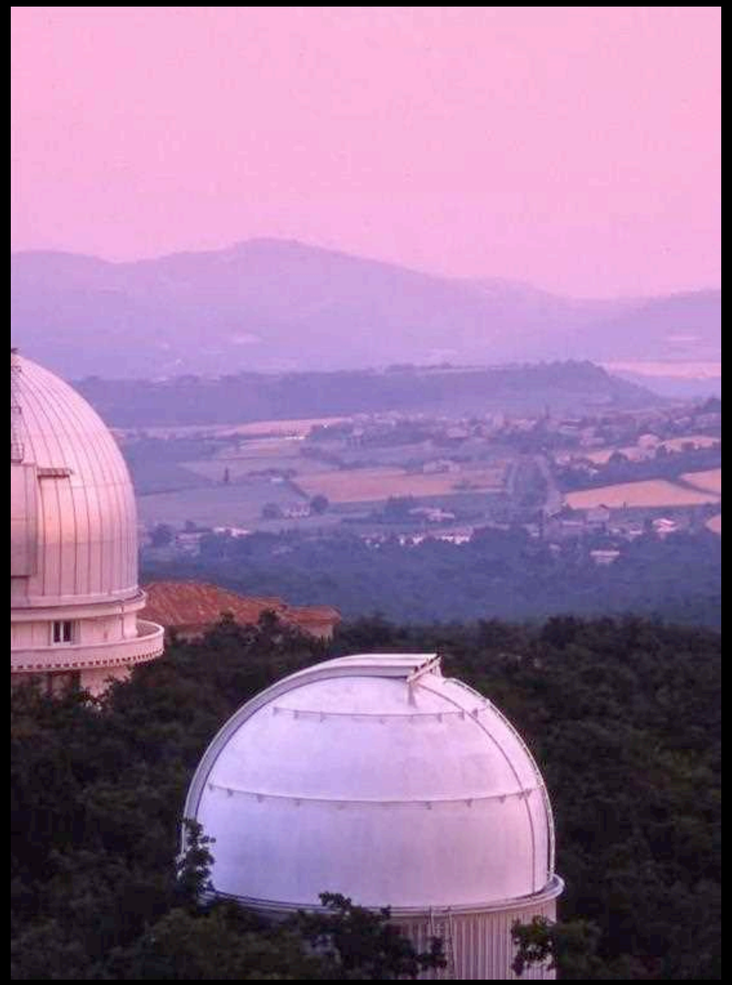
Europa Clipper



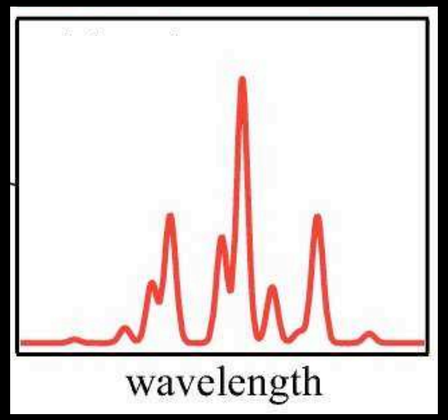
Dragonfly

2016 2020 2025 2030 2035 2040

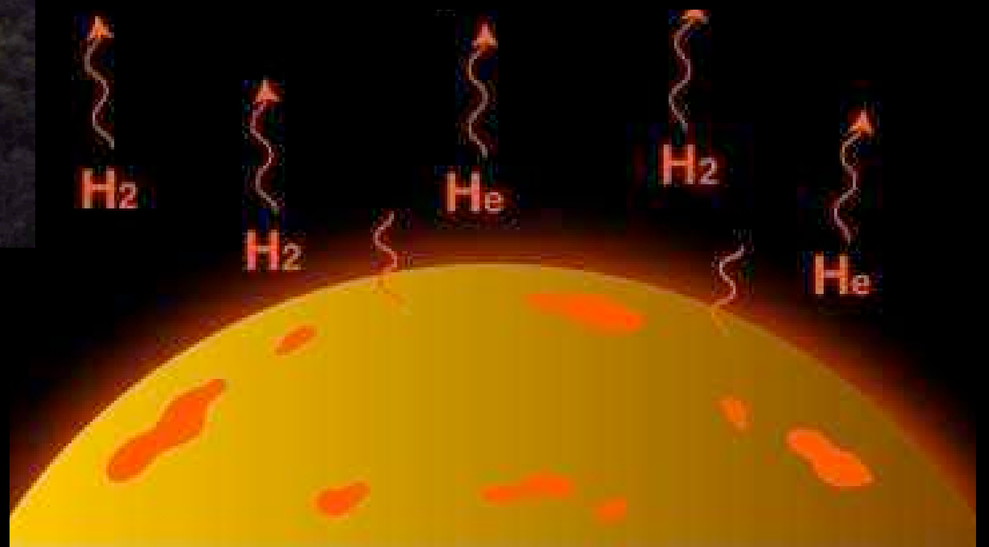
NIGHT: Near Infrared Gatherer of Helium Transits



Observatoire de Haute-Provence



Hoe ontstaan de Neptunuswoestijn
en straalvallei?
Survey van >100 planeten



Casper Farret Jentink

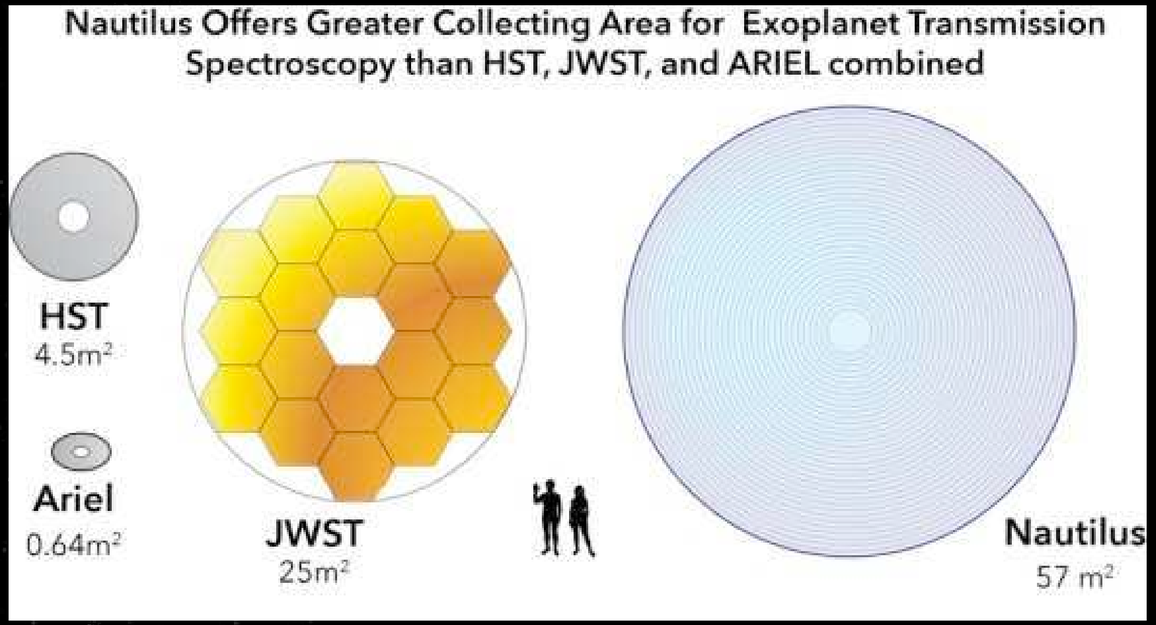
nrc

26 april
in NRC!

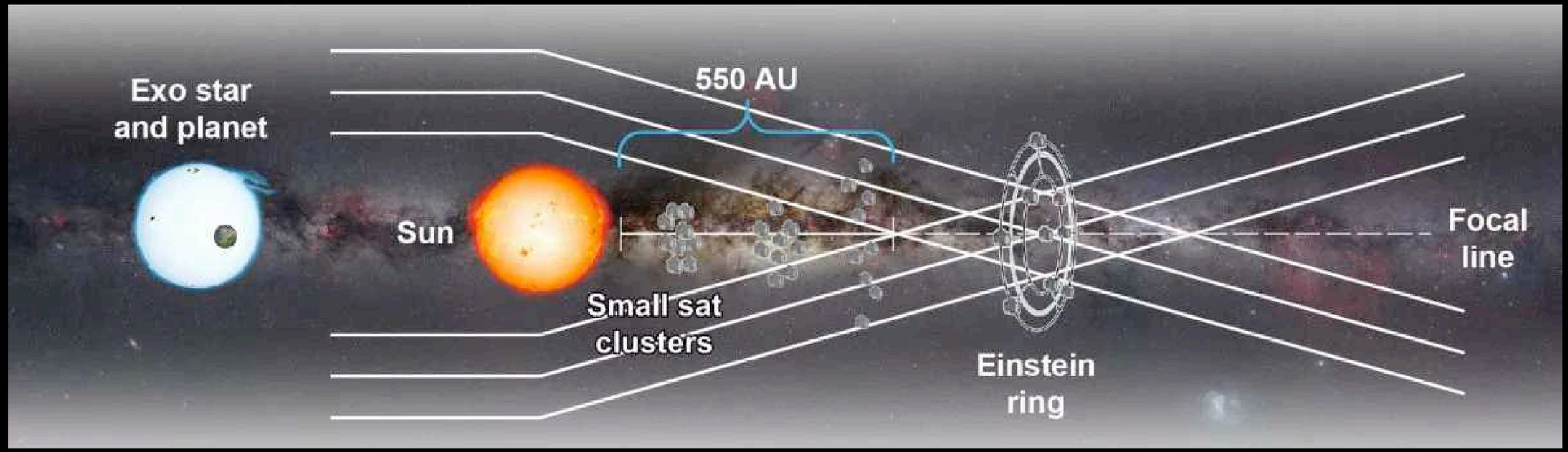
Starshade

Nautilus

A Very Large Aperture, Ultralight Space Telescope for Exoplanet Exploration, Time-domain Astrophysics, and Faint Objects



Solar Gravitational Lense Telescope: de zon als telescoop



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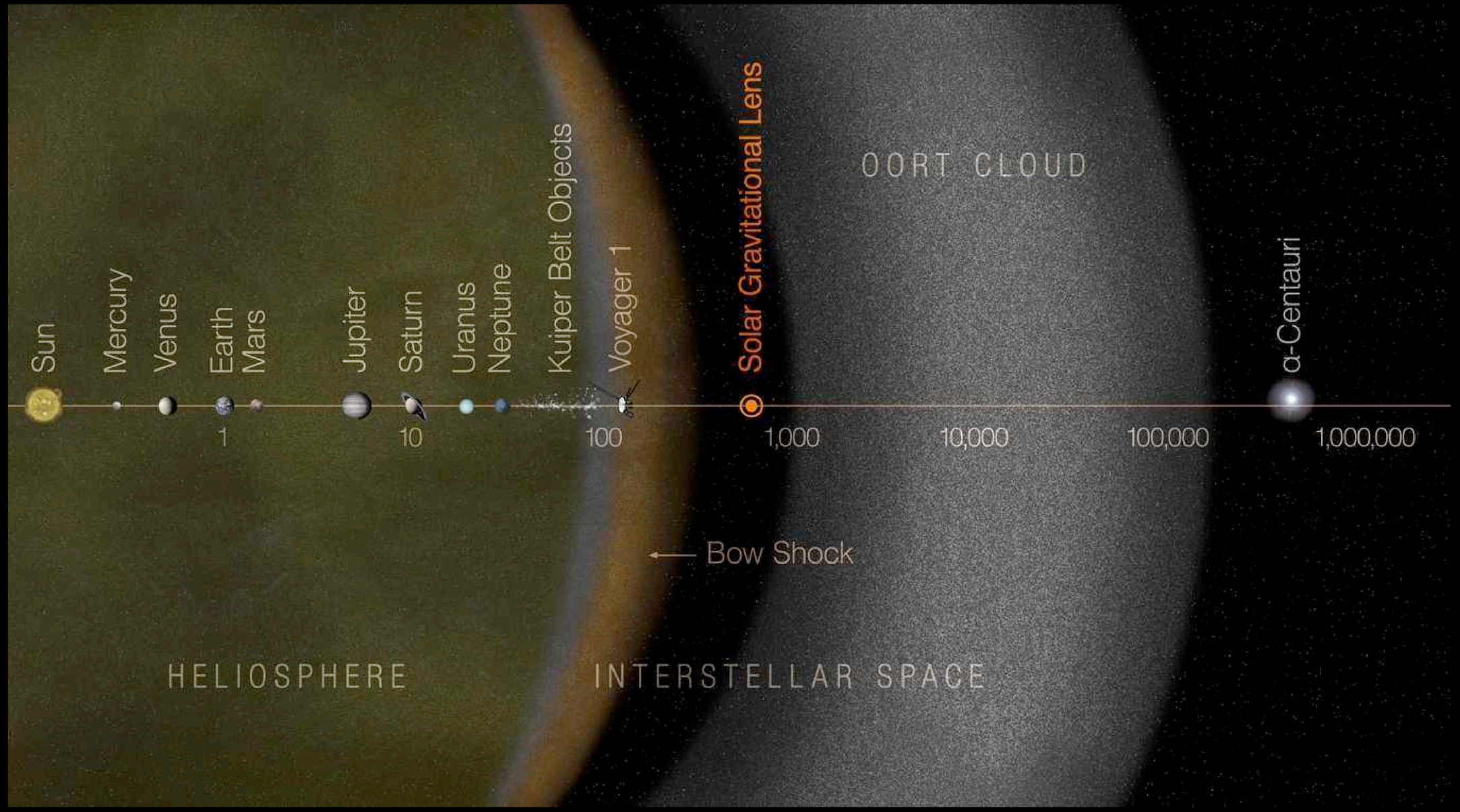

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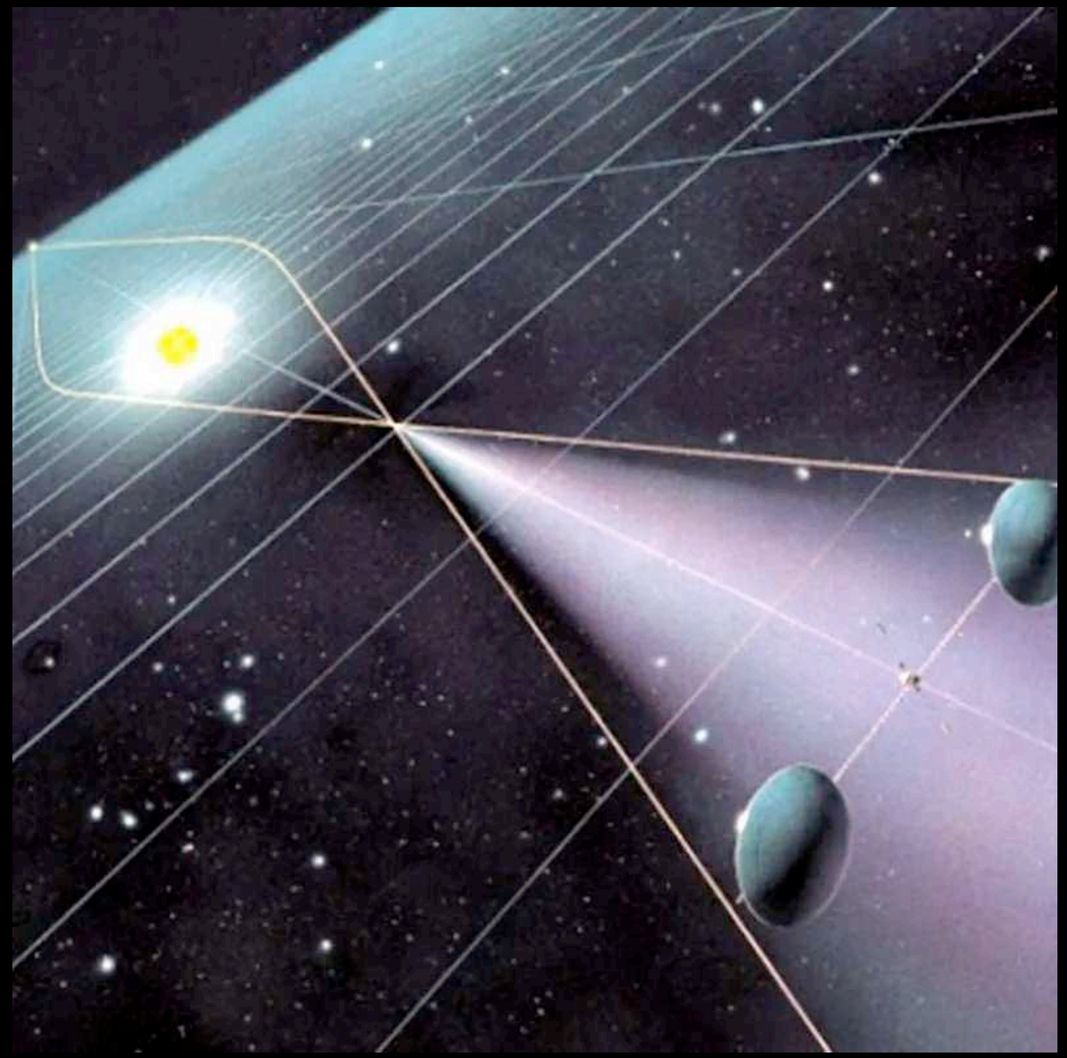

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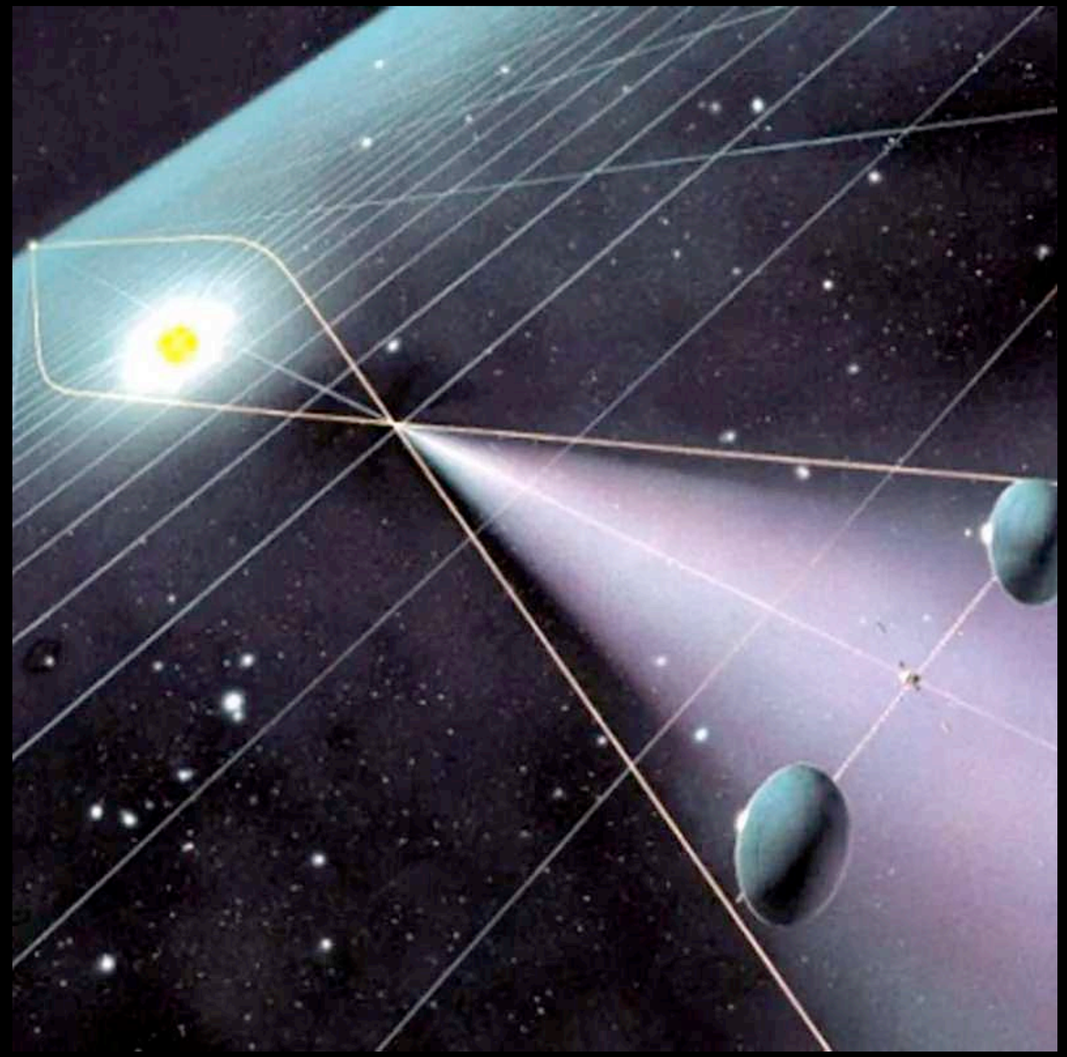

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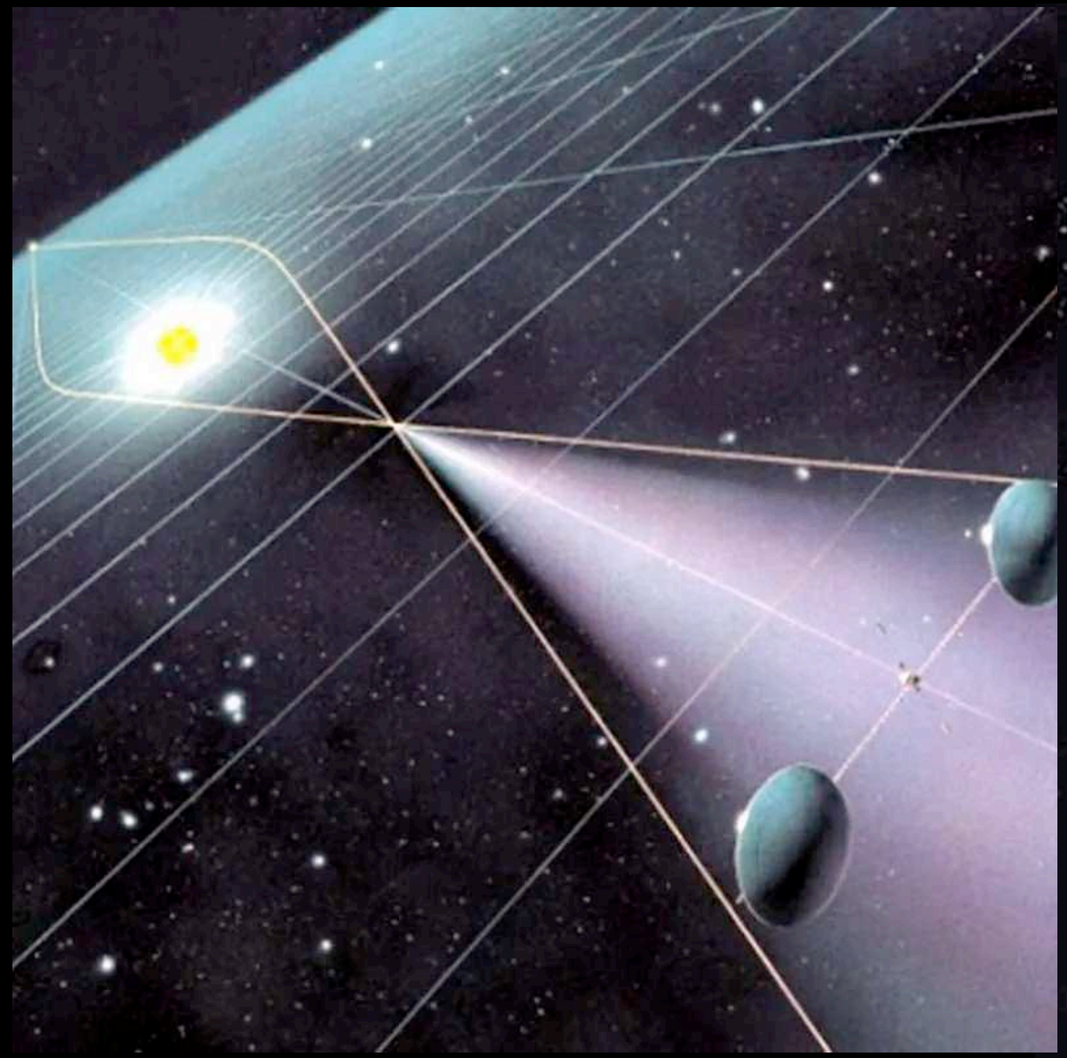
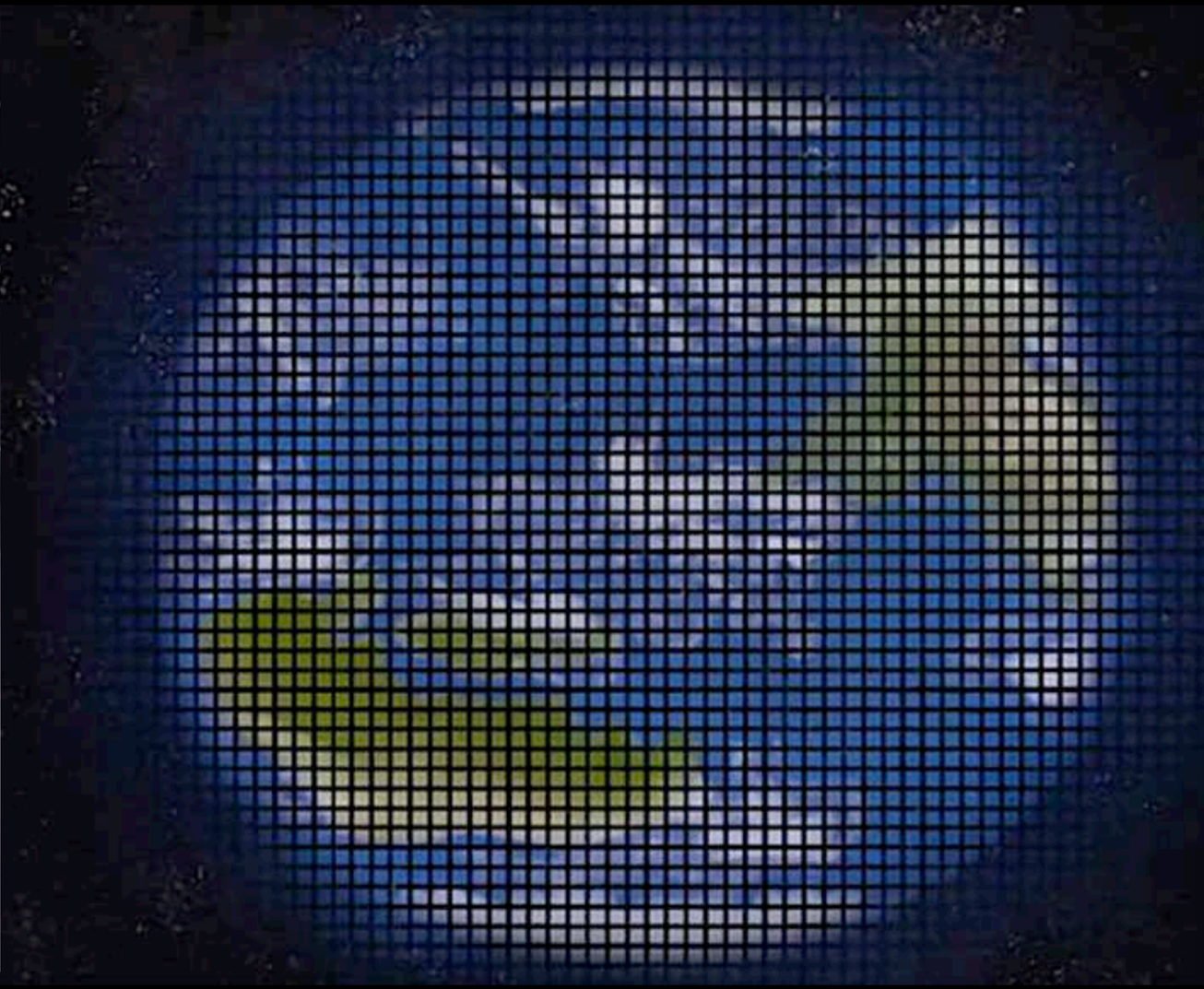
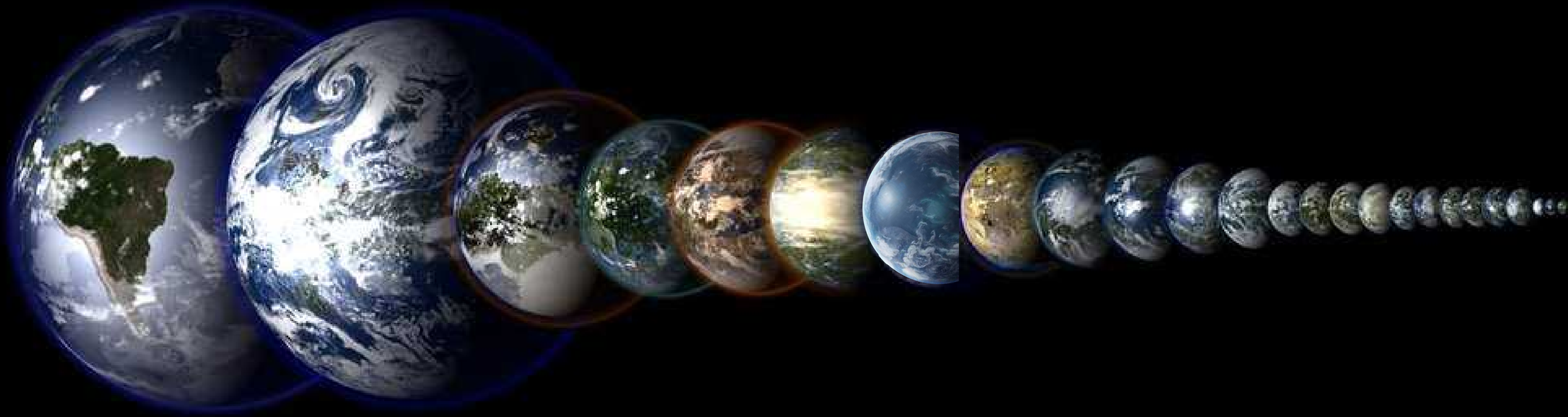
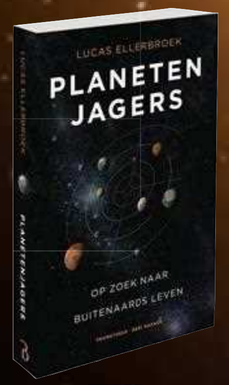






TO INFINITY, AND BEYOND!



★★★★ - VOLKSKRANT ★★★★ - NRC

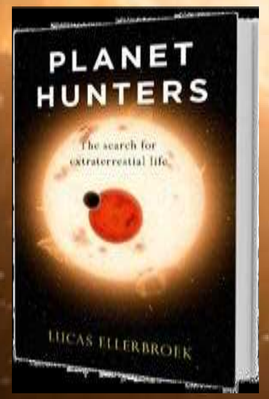
★★★★ - KIJK

‘Een meeslepend avontuur vol verrassende details dat laat zien waarom sterrenkundig onderzoek zo fascinerend is.’

- ROBBERT DIJKGRAAF

‘Ellerbroek is de Jacques Cousteau van het heelal’

- JELLE BRANDT CORSTIUS



Selected for Books of the Year 2017

- THE TIMES

‘A delightful scientific chronicle of humanity’s quest for “other worlds”’

- NATURE

‘Ellerbroek is particularly skilled at inserting the “astronomy backstory”

- SCIENCE

Selected for Best Science Books of Summer 2017 - UNBOUND WORLDS

Selected for Best Space Books 2017

- **SPACE.COM**

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