

Looking at Earth

in the cosmic perspective

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Left: Mergui Archipelago, Myanmar. Credit: NASA Landsat 5

Right: Witch Head Nebula. Credit: NASA/STScI Digitized Sky Survey/Noel

The exploration of the Cosmos
is a voyage of self-discovery

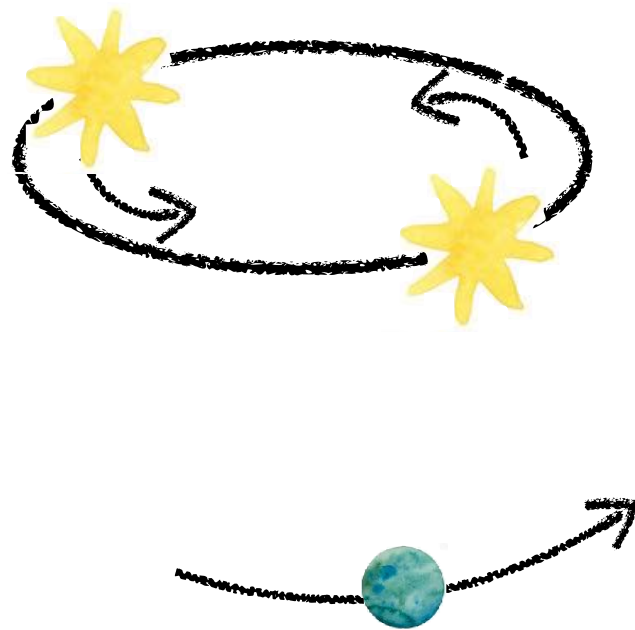
– Carl Sagan in *Cosmos* (1980)

What I do in my research:

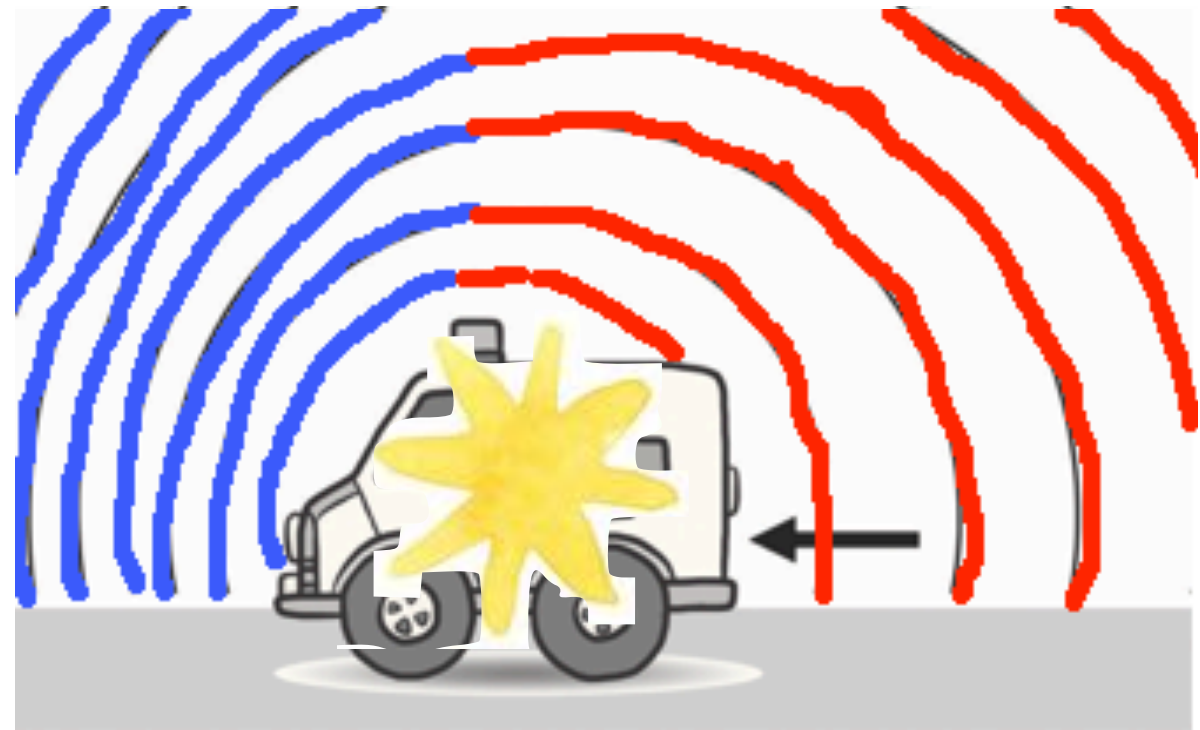
I determine the masses of exoplanets



The planet makes the star wobble

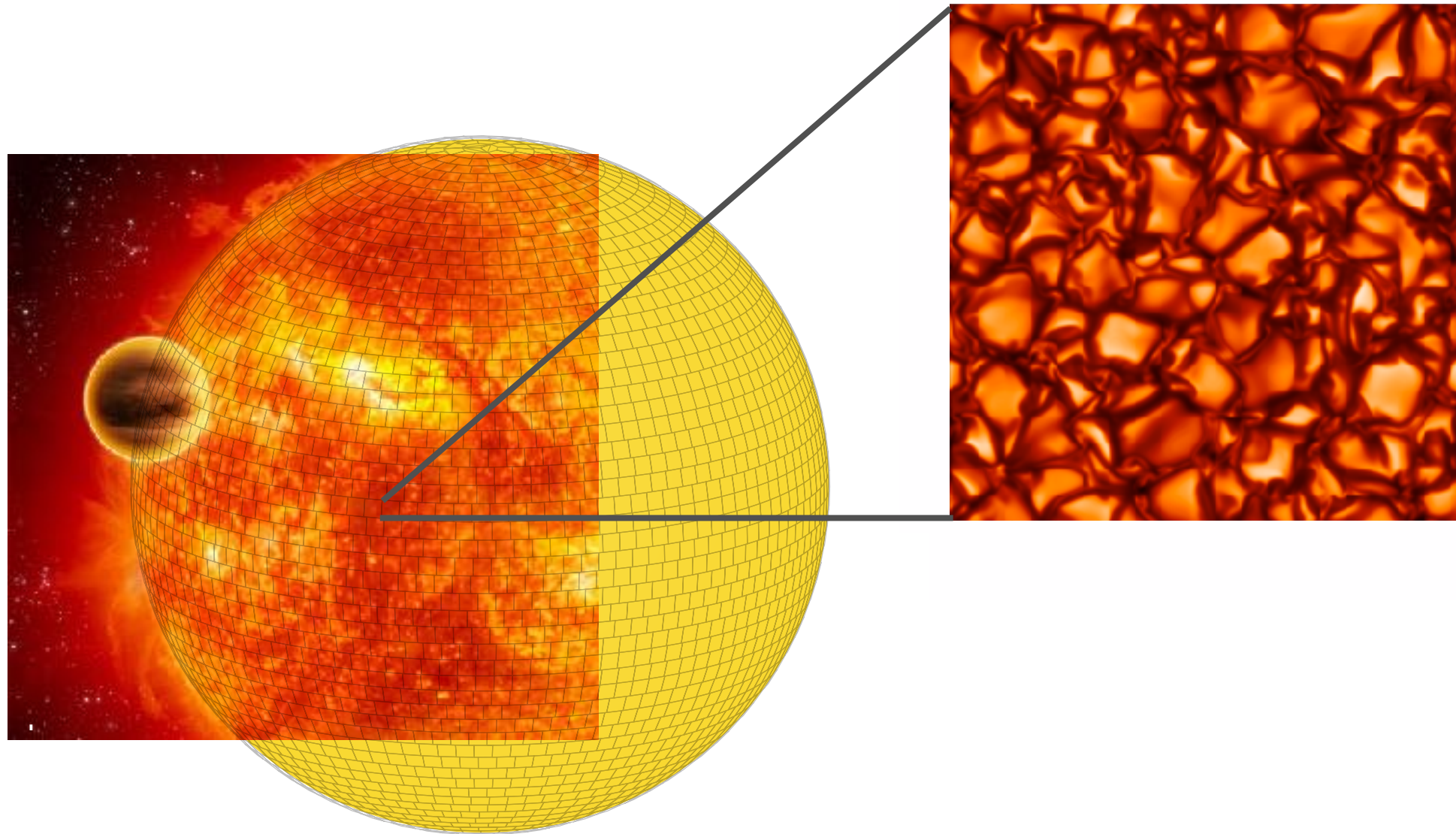


This creates a Doppler effect

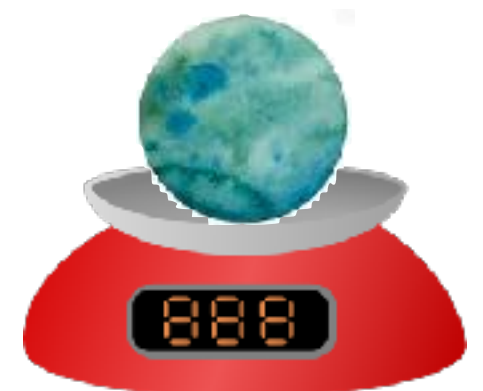


What I do in my research:

I study the surfaces of the stars that host planets



To better characterise the planets that orbit them



Star cartoon: Heather Cegla, Raphaëlle Haywood, ESA
Granulation simulation: Cegla et al. (2013)

Exoplanets are very diverse



Hot Jupiters



Super Earths



Mini Neptunes



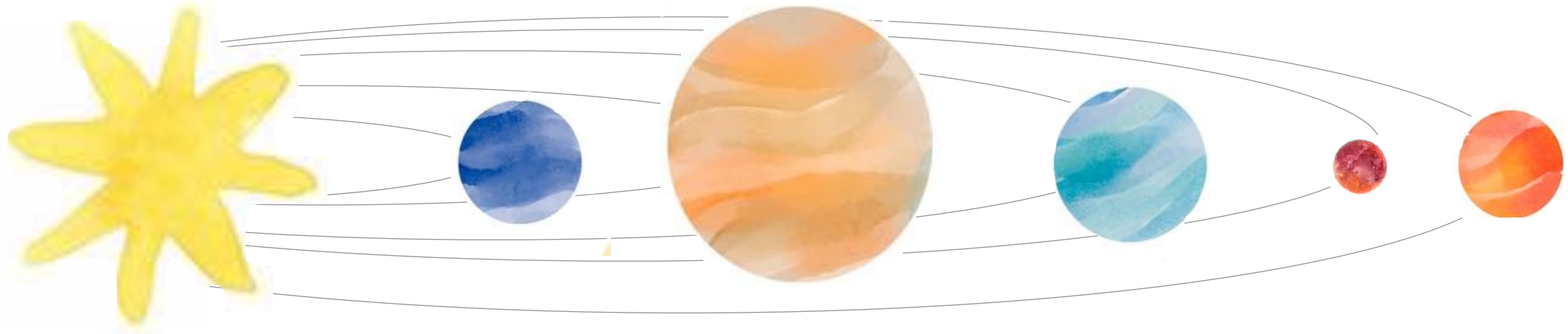
Earth-size planets



eg. Batalha (2014),
Fulton et al. (2017)

Planets are very common

There are more planets than stars in our galaxy!



Most stars host several planets

eg. Ballard & Johnson (2016),
Zhu et al. (2018),
Cassan et al. (2012)

Occurrence rate of Earth-like planets

In the "habitable zone":
30%-100% of the heat
received by Earth from
the sun



$\frac{1}{2}$ -1 x Earth radius



Pessimistic
estimate

9%

1 in 10 stars

21%

1 in 5 stars

100%

All stars

Optimistic
estimate

Kopparapu et al. (2018)

See also Dressing & Charbonneau (2015),
Burke et al. (2015), Petigura et al. (2013)

21%

1 in 5 stars

There are 300 billion stars in our galaxy

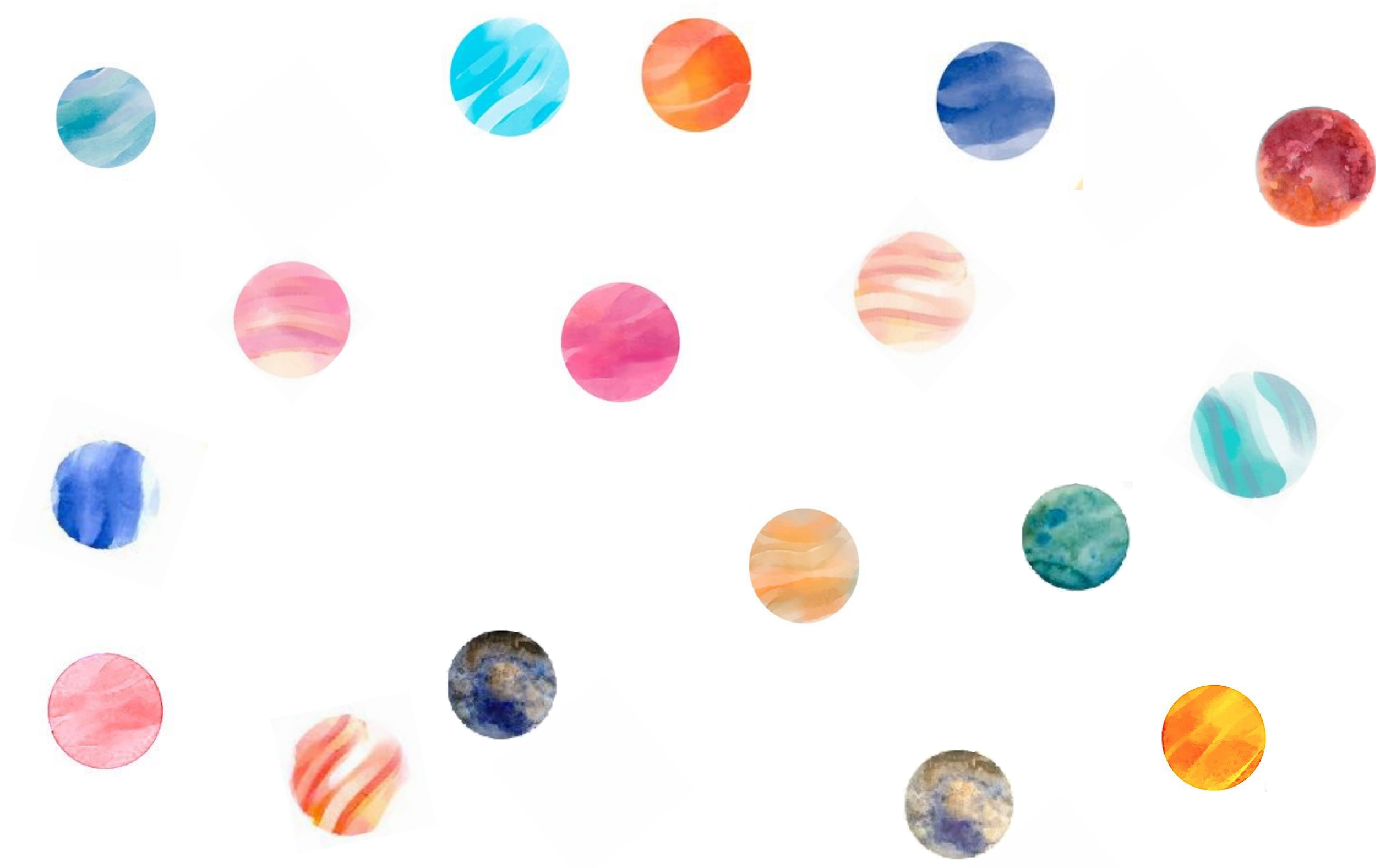


... so that's 63 billion Earth-like planets!

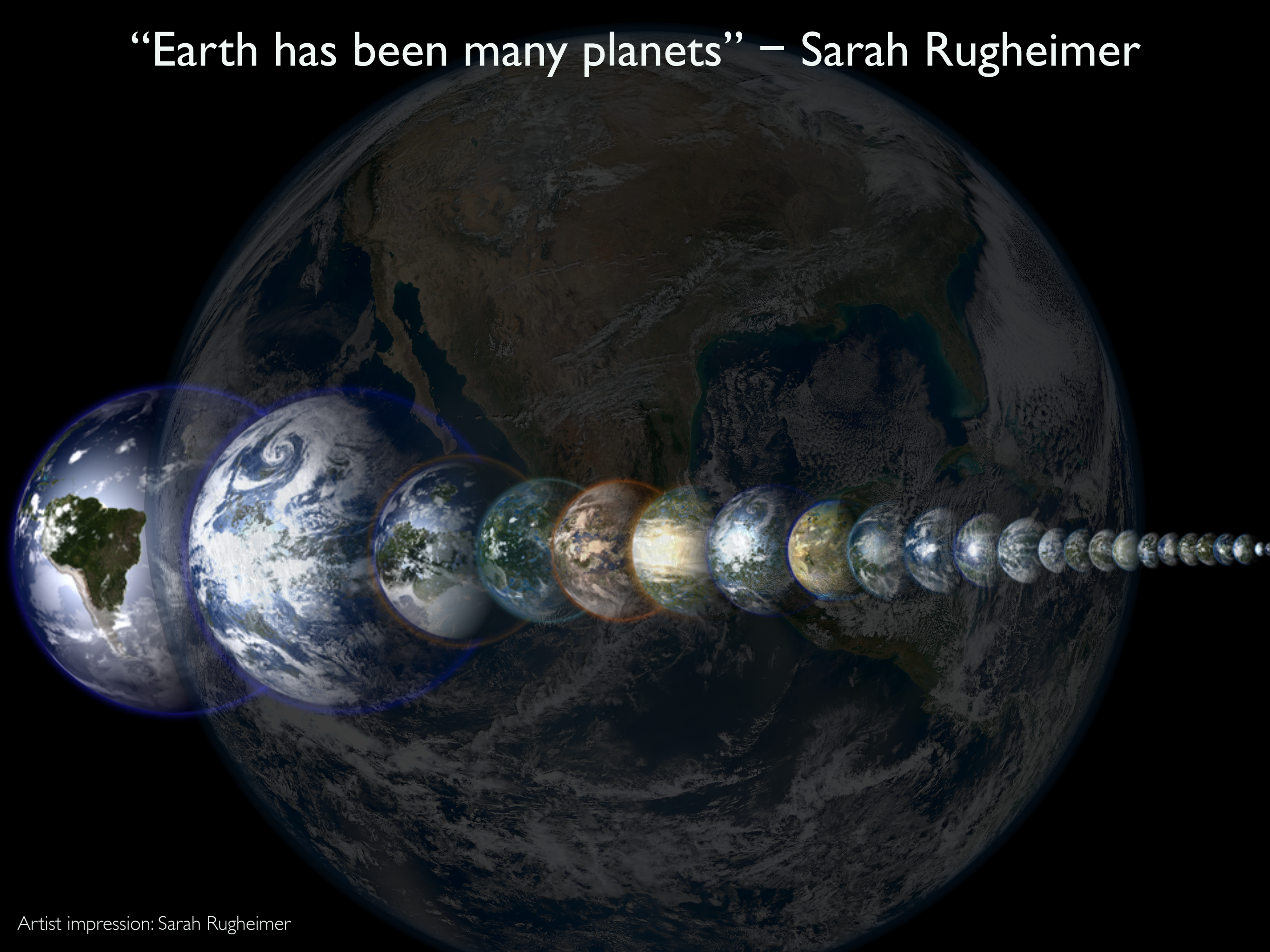


eg. Frank, 2018,
Light of the Stars

Just as every one of us is different and unique, so is every Earth



“Earth has been many planets” – Sarah Rugheimer



“Earth has been many planets” – Sarah Rugheimer



Just as every one of us is different and unique, so is every Earth



Where are these Earth-like planets?

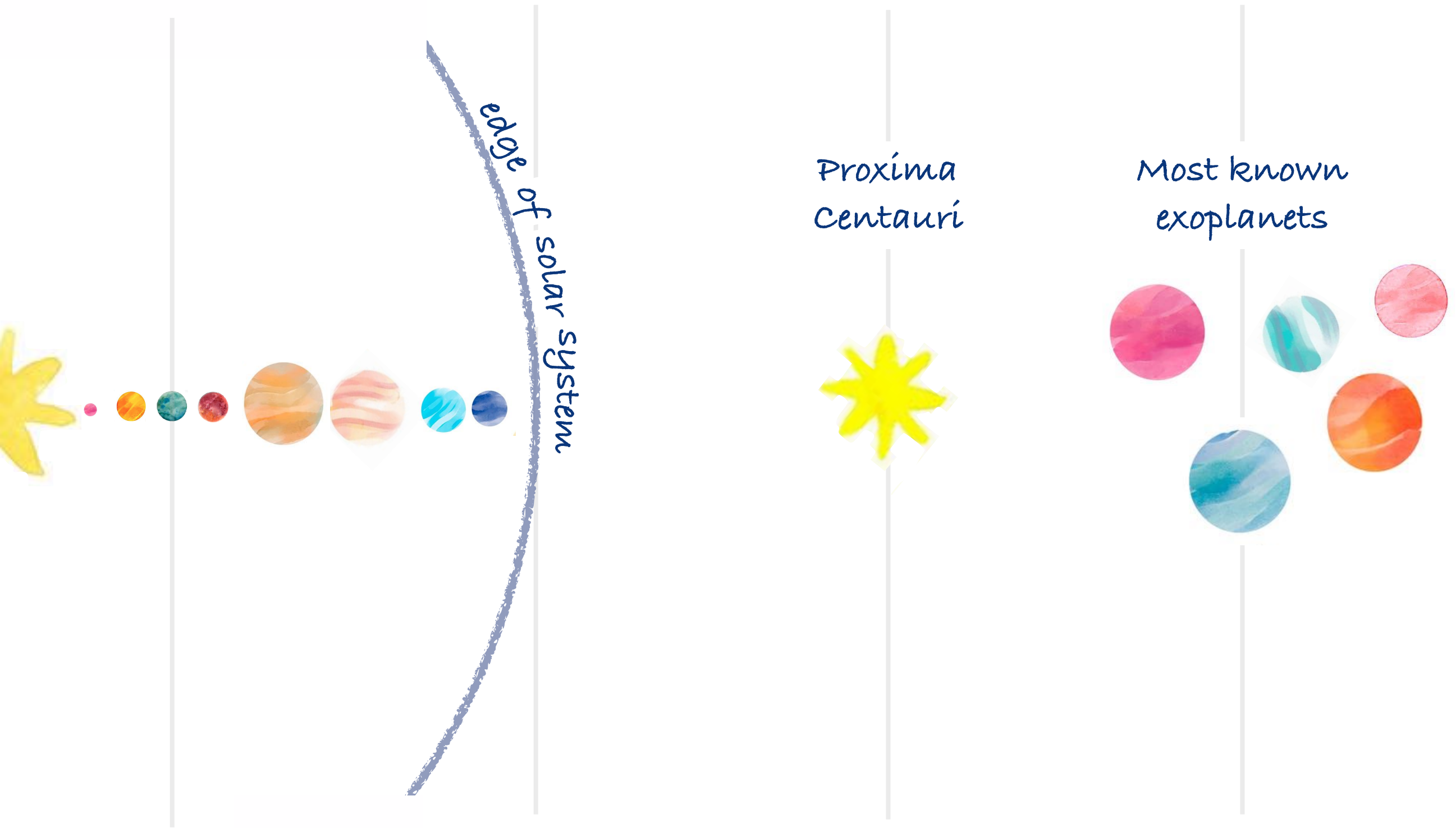
Sunlight travel time:

8 min

140 hours

4 years

50-3000 years



Yes, there are 63 billion Earth-like planets in the galaxy, but...

There is no planet “B”



What does Earth look like from space?



From orbit, onboard the International Space Station



Southeast Asia, July 2019

Photo: NASA/edited by Mark Garcia

From orbit, onboard the International Space Station



Rio de Janeiro and São Paulo, June 2014

Photo: NASA/Reid Wiseman

Earth seen from the Moon: Apollo 11 Mission



Photo: NASA/JSC. Published 2018. Taken 20 July 1969

Earth seen from the edge of the solar system

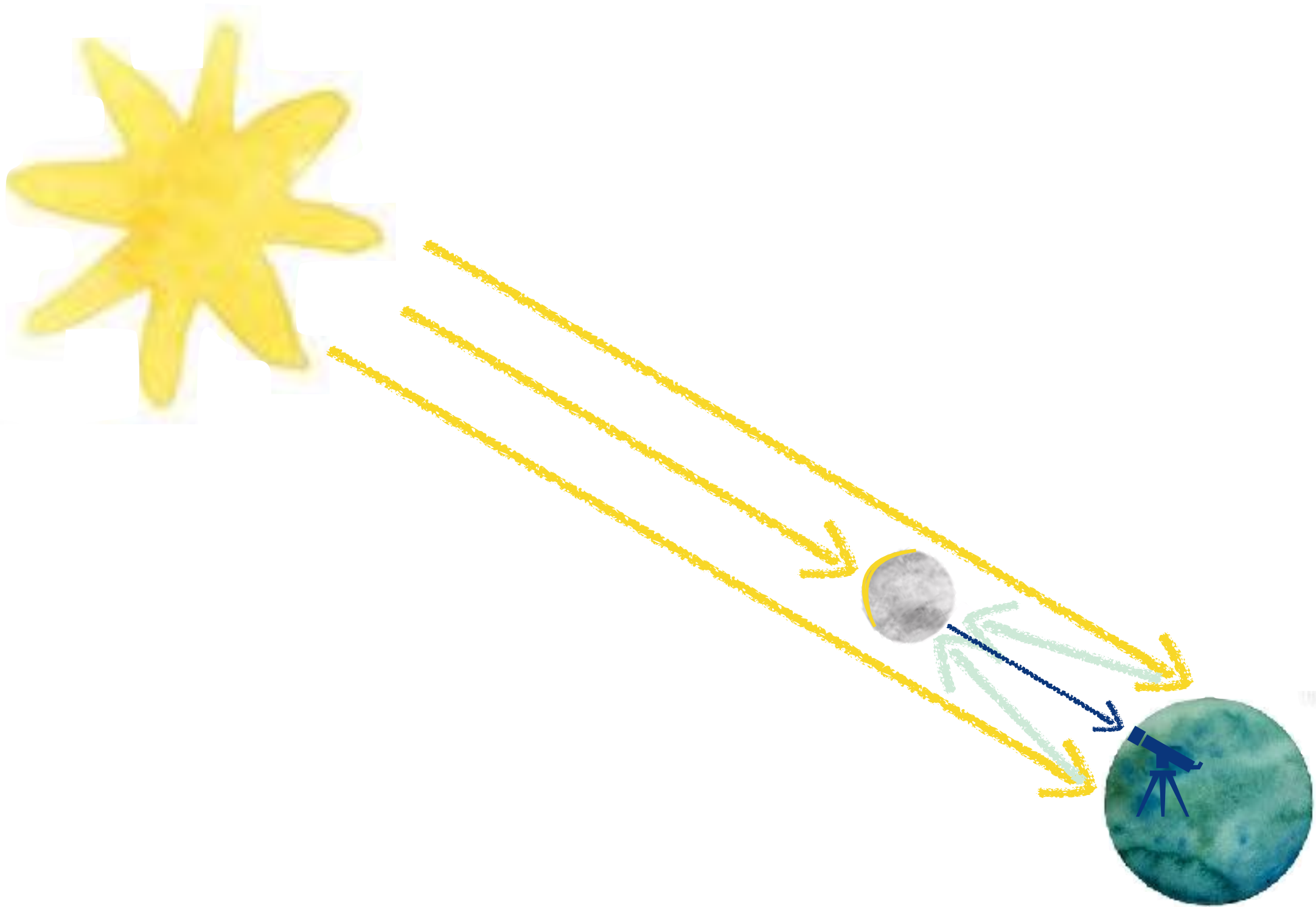
“Pale Blue Dot” – Carl Sagan, 1994

**Can we observe Earth's biosignatures
from space?**

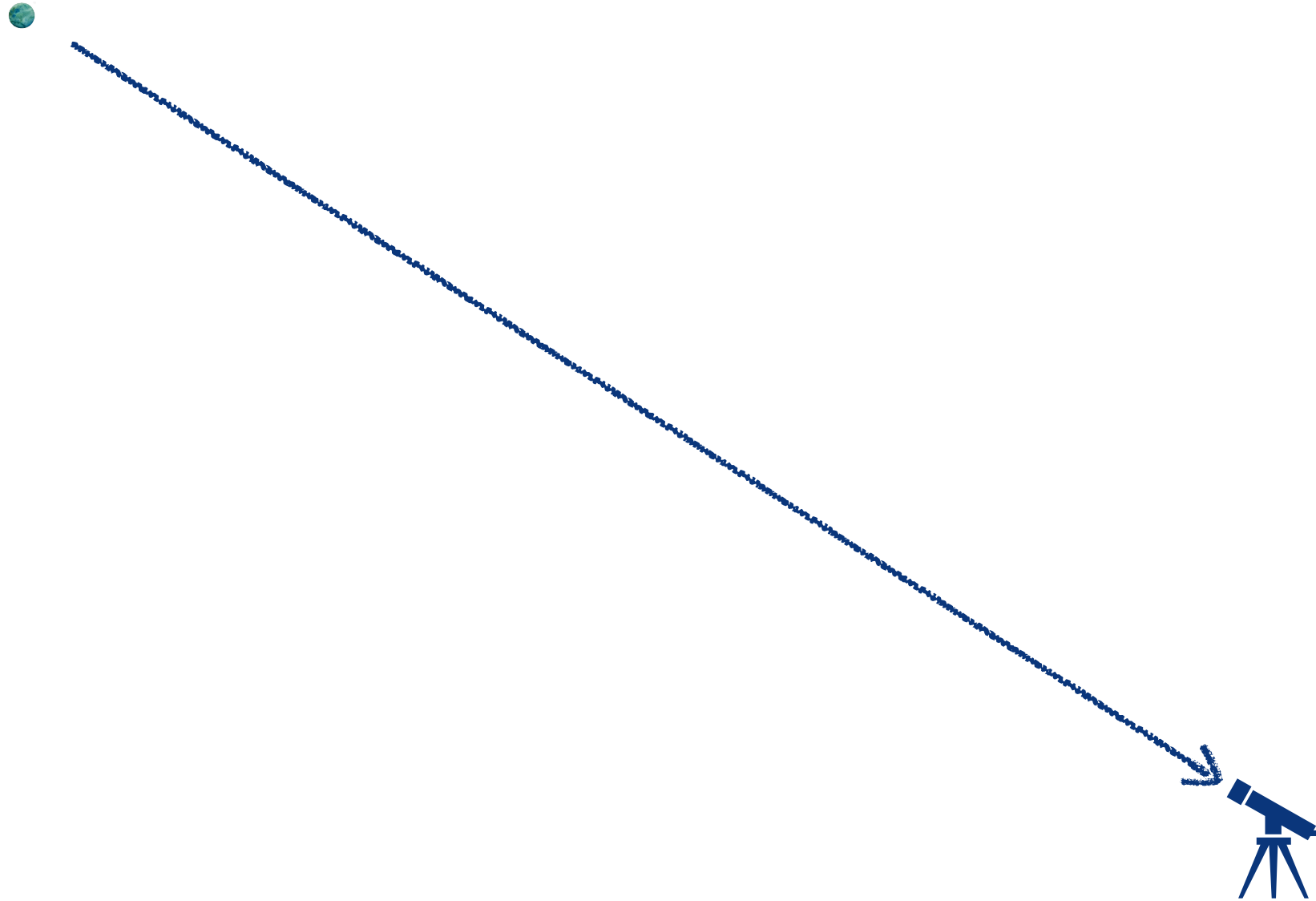
Earthshine



Observing earthshine



Earth seen as a point of light



Observing the spectrum of Earth

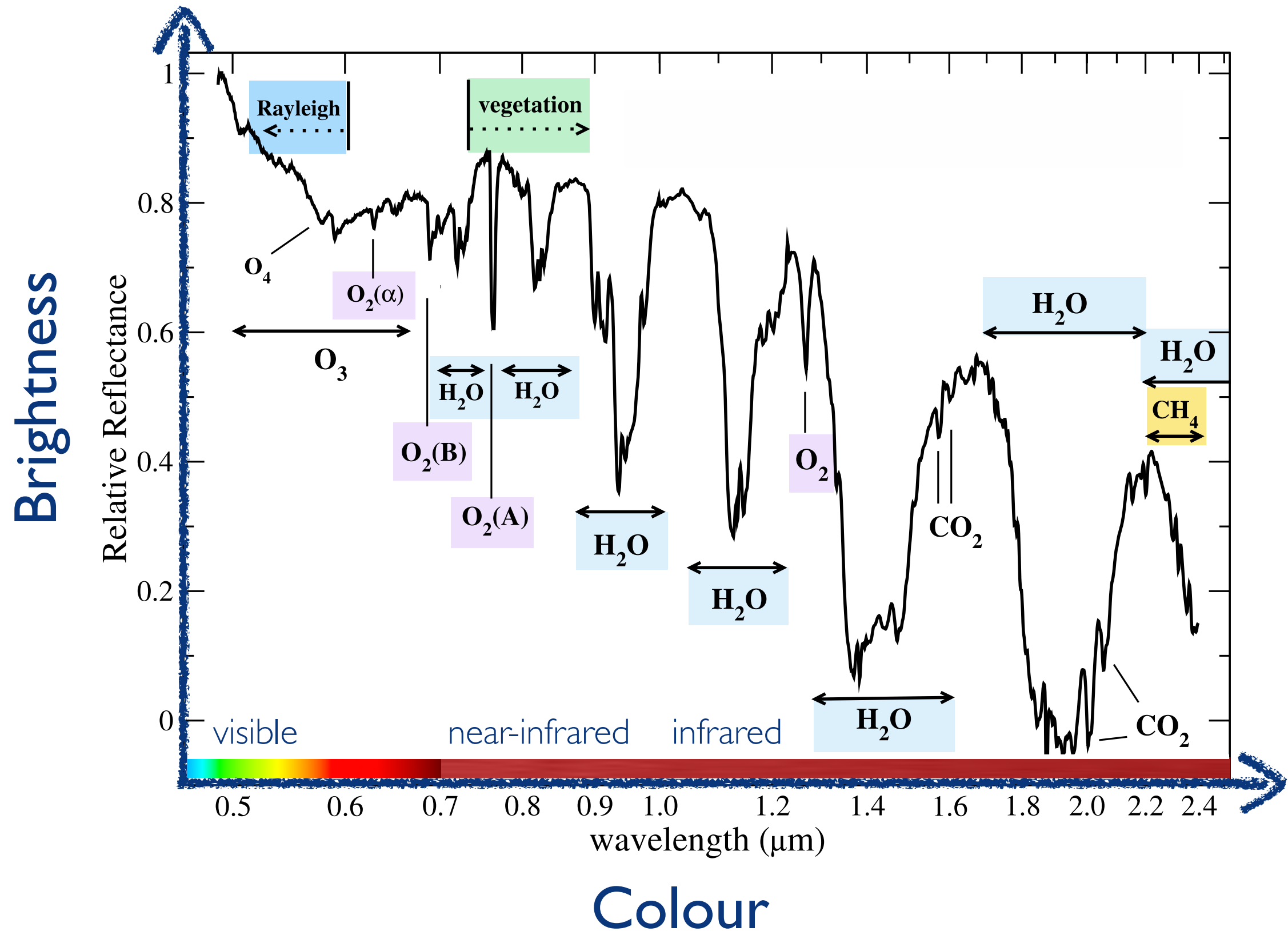
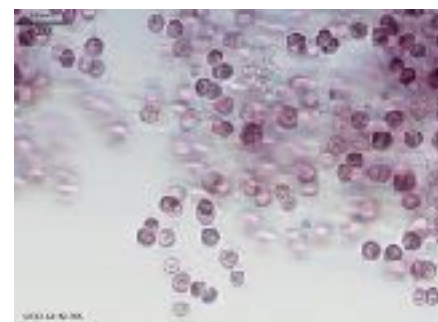
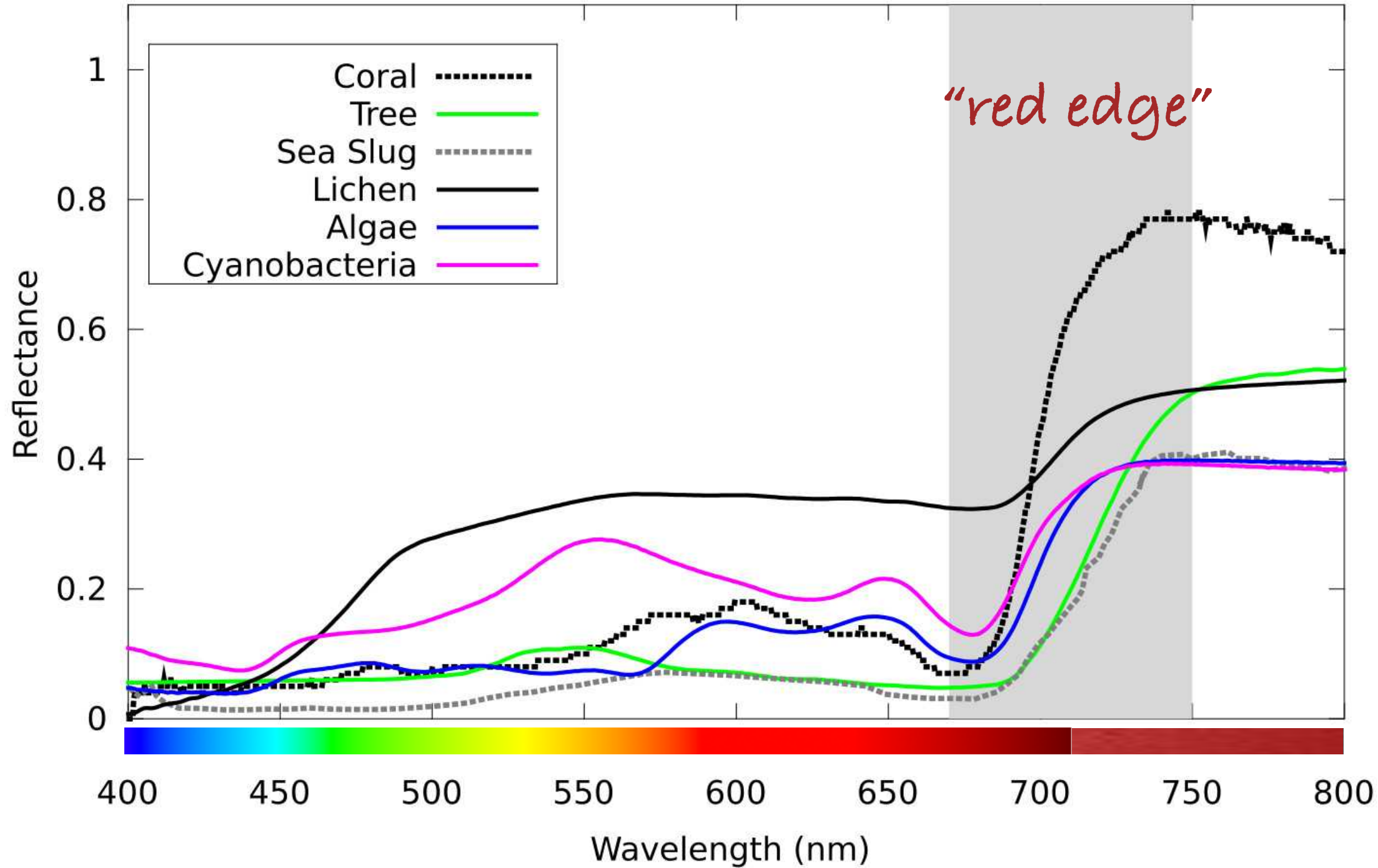
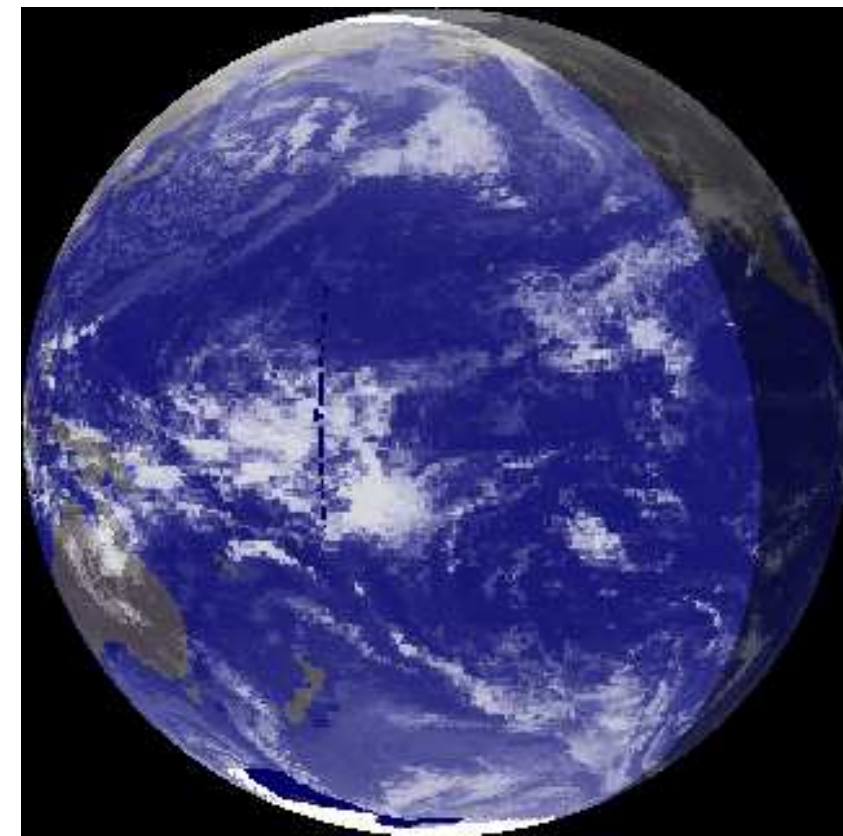


Figure 7 from Turnbull et al. (2006)

The signature of vegetation



The signature of vegetation



Brightness



visible

near-infrared

Colour

0.6

0.7

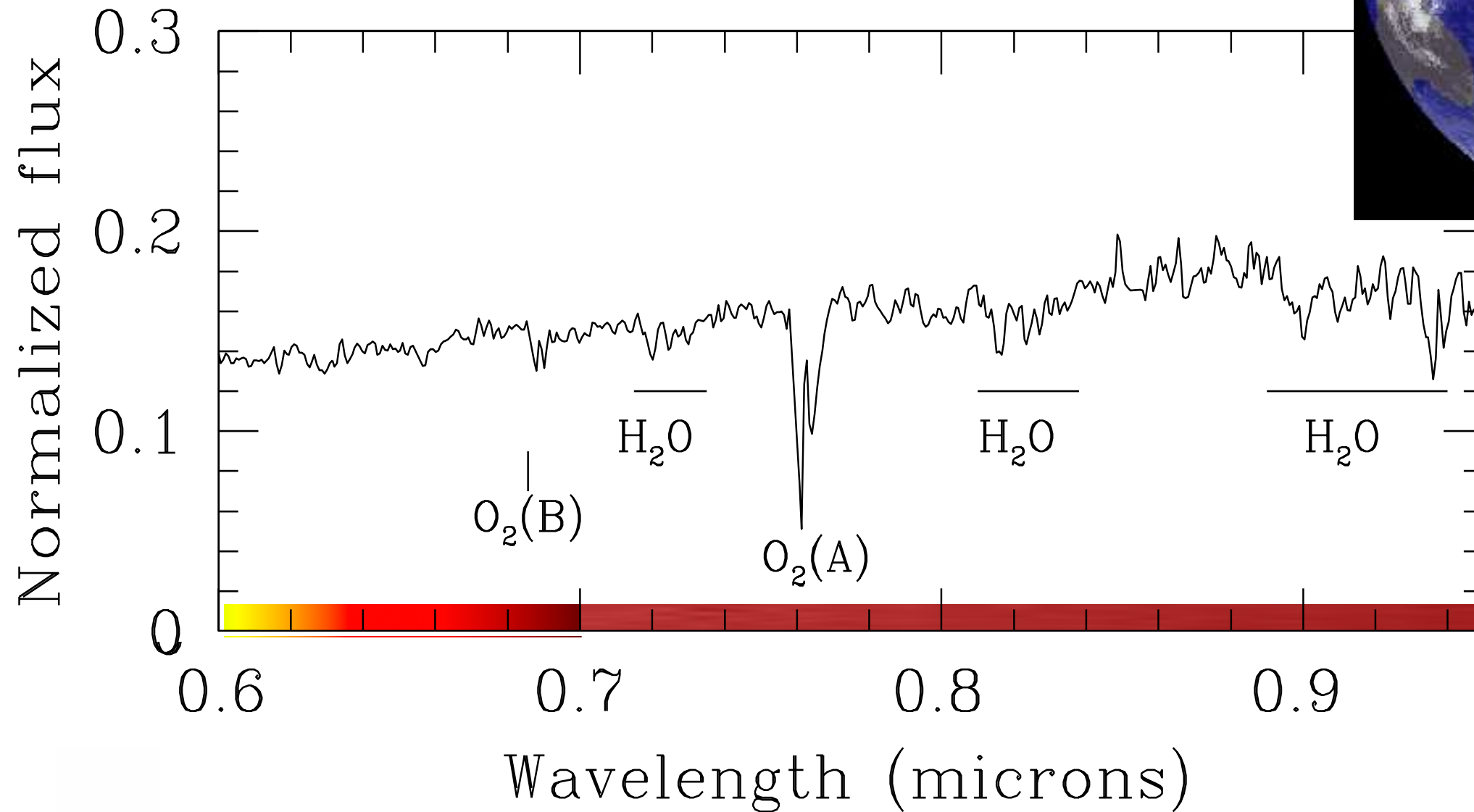
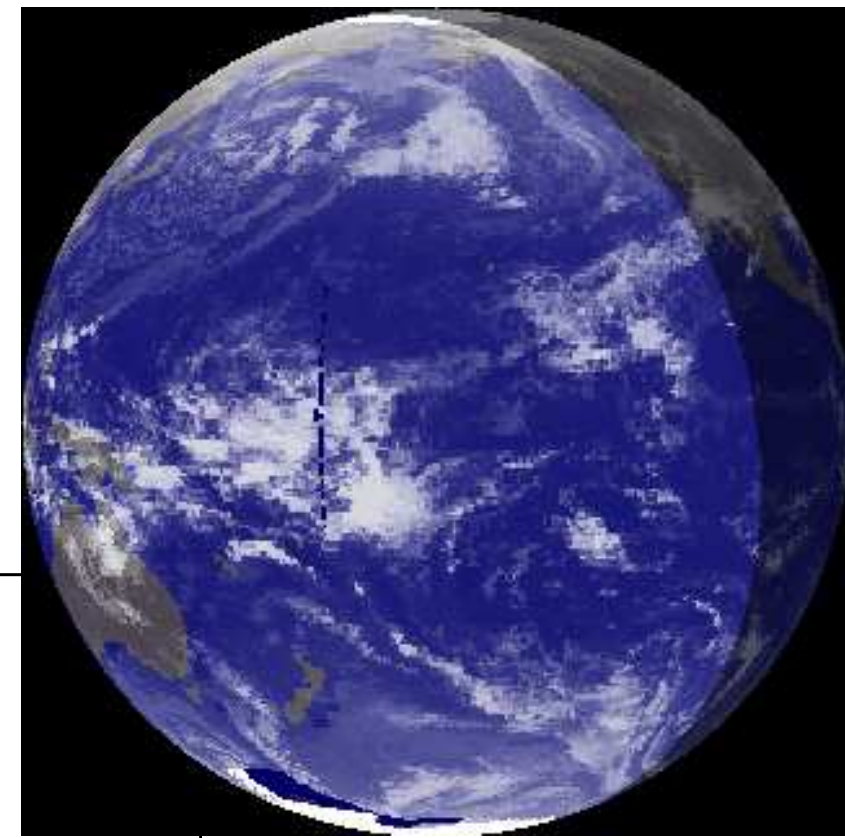
0.8

0.9

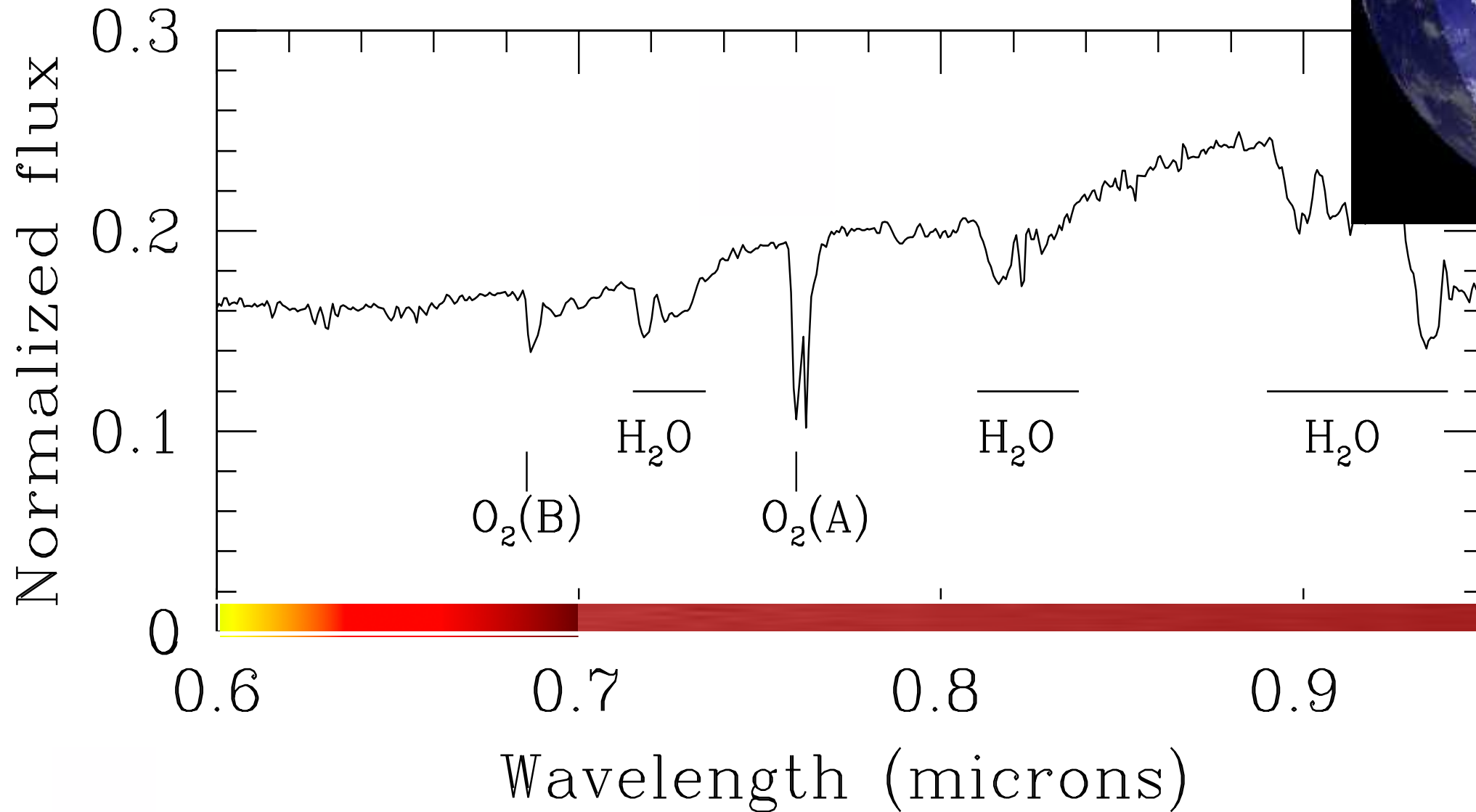
Wavelength (microns)



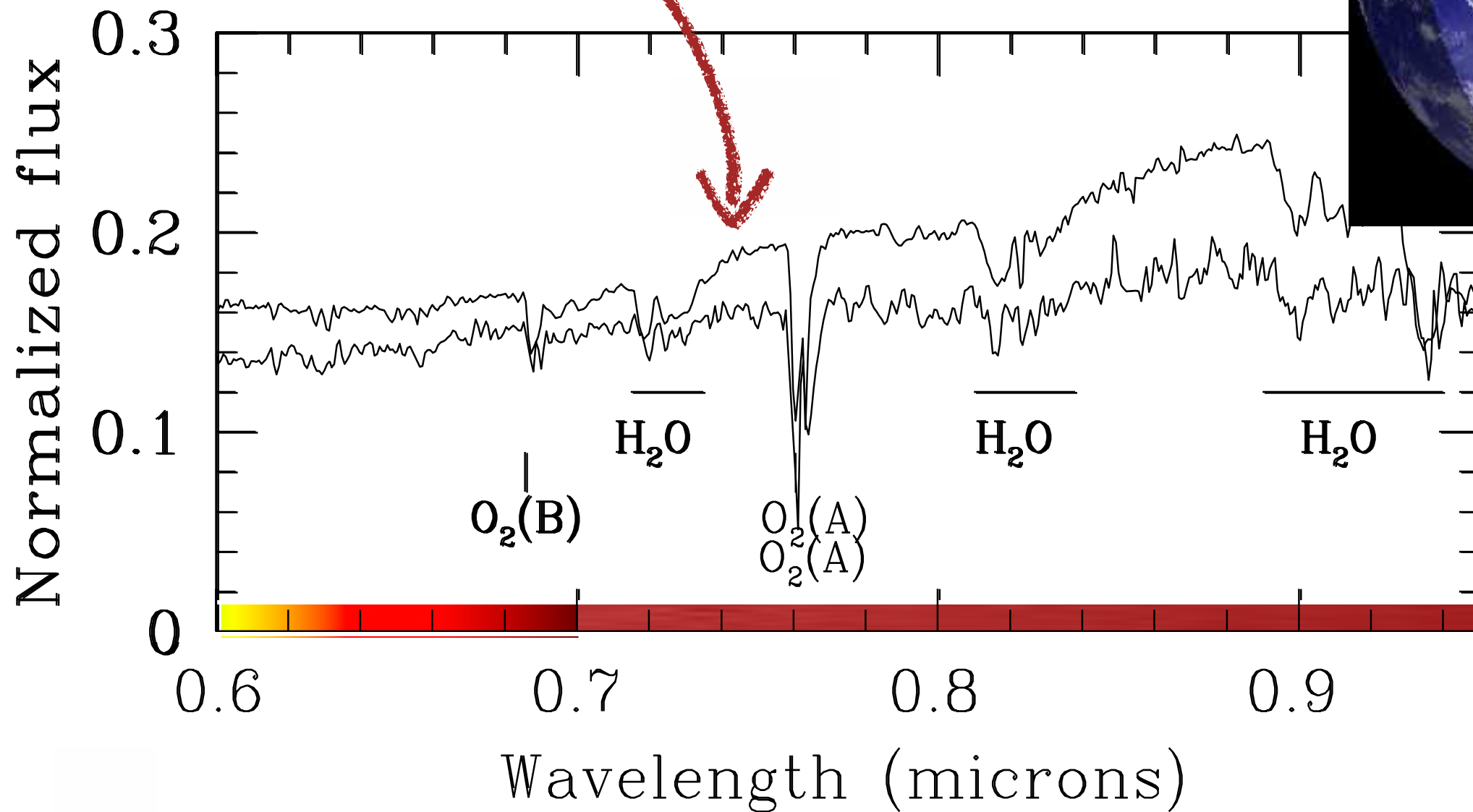
The signature of vegetation

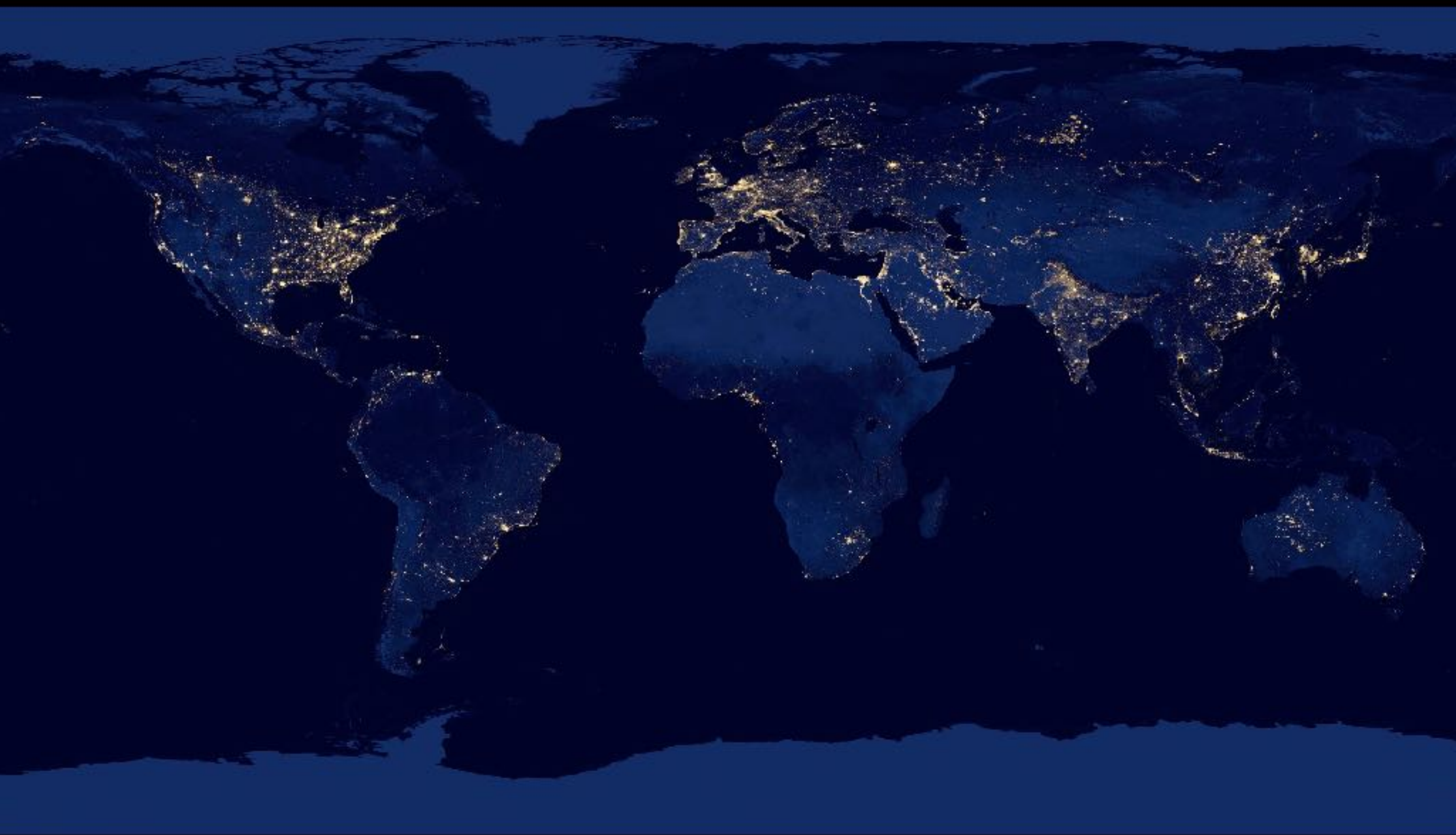


The signature of vegetation

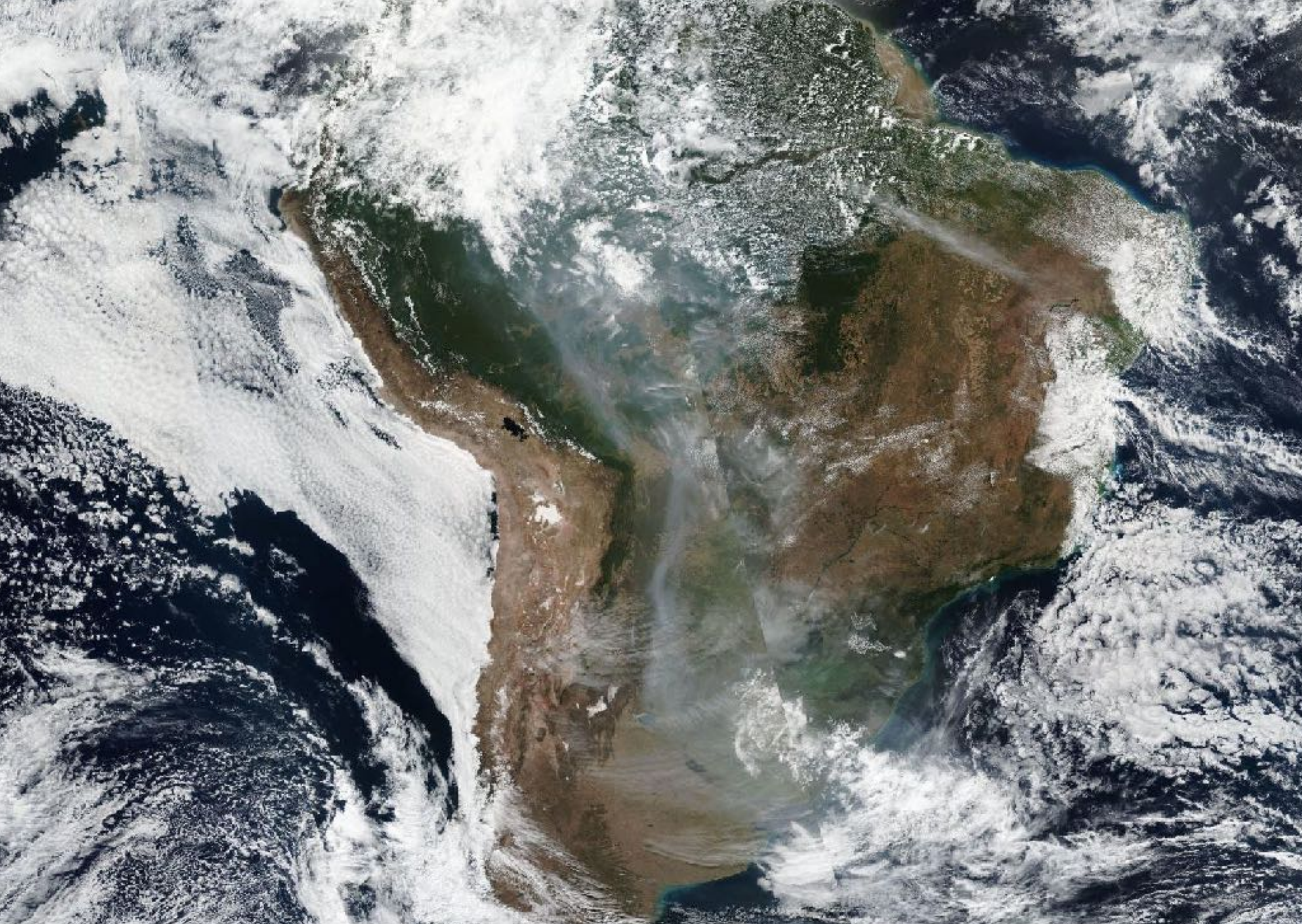


The Amazon rainforest is part of Earth's cosmic identity



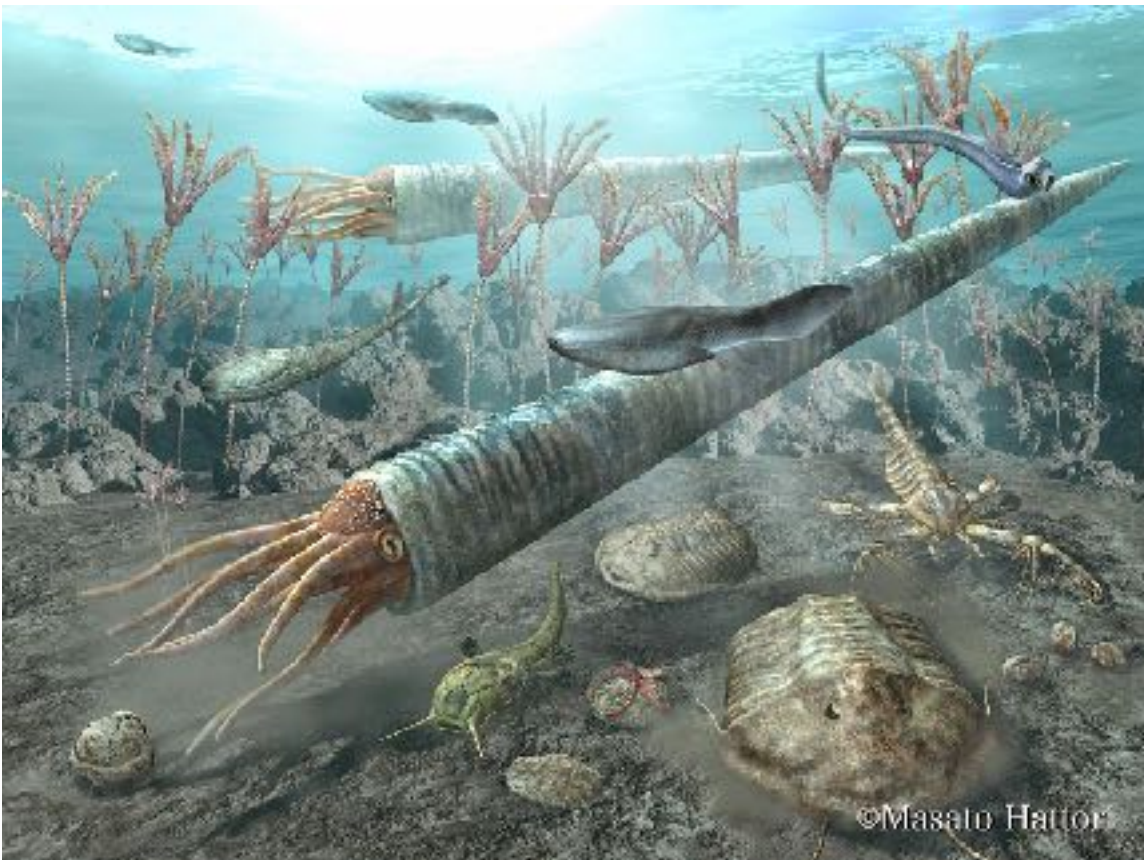


VIIRS data. Available on NASA Worldview. 2012



VIIRS & MODIS data. Available on NASA Worldview. | 6 August 2019

Life has shaped the Earth on a planetary scale before



The rise of cyanobacteria on early Earth

“*Biological planetary change*”

– Grinspoon (2016)
Earth in Human Hands

Atmospheric
concentration
in oxygen

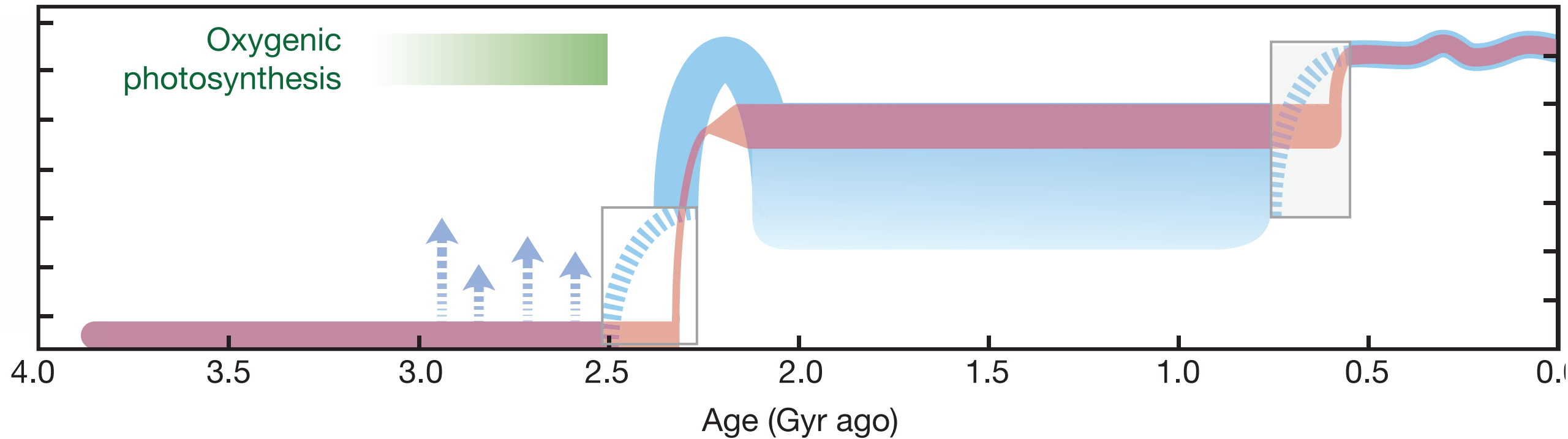


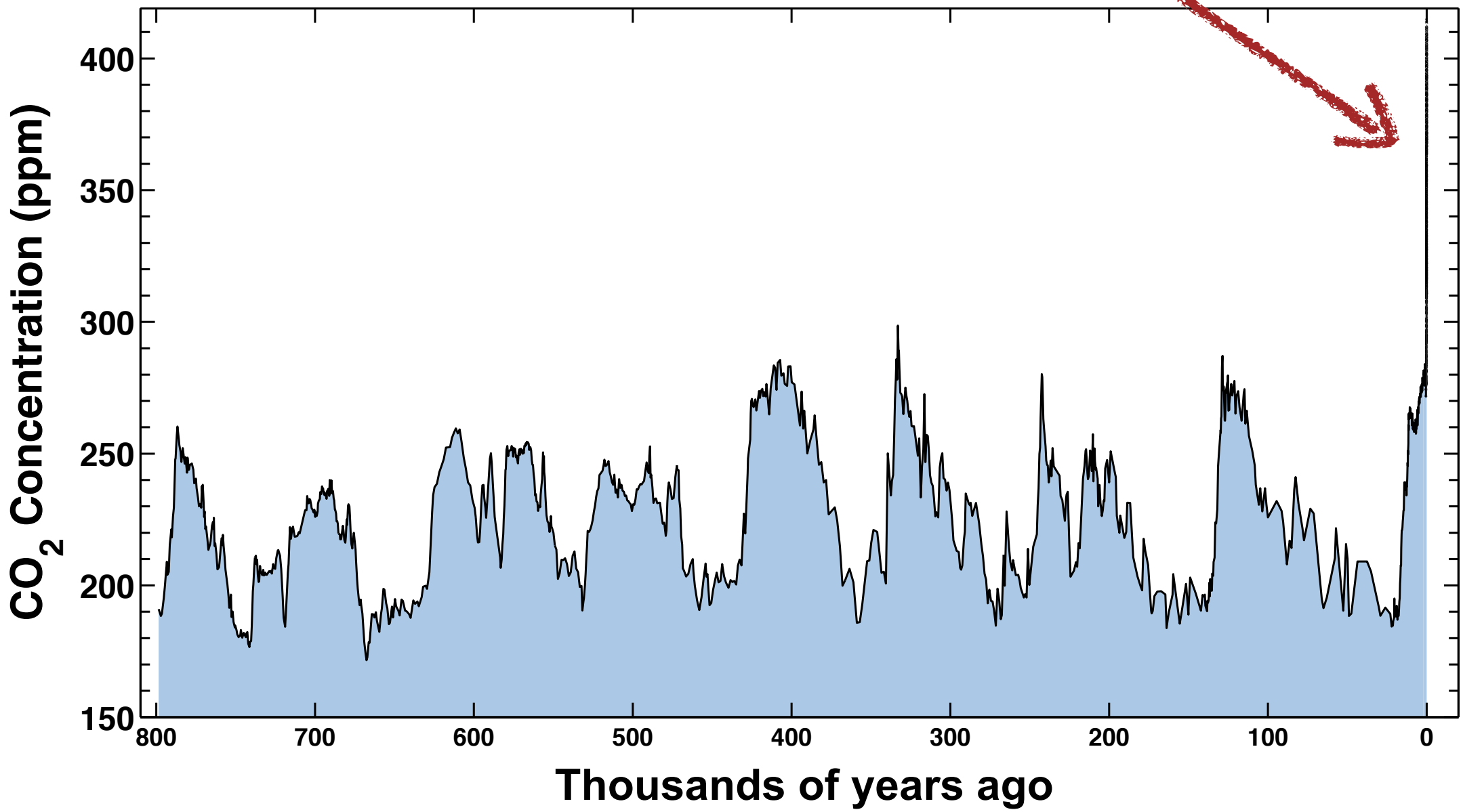
Figure from Lyons et al. (2014).
See also Berner et al. (1989),
Kump (2008), Bergman et al. (2004).

The rise of humans on modern Earth

“Inadvertent planetary change”

Atmospheric concentration in carbon dioxide

– Grinspoon (2016)
Earth in Human Hands



Keeling Curve from the Scripps Institution of Oceanography, UC San Diego
Ice-core data before 1958 (Lüthi et al., 2008). Mauna Loa data after 1958 (Keeling et al., 2001).

We must transition
from *inadvertent* to *intentional* planetary change



Grinspoon, 2016, *Earth in Human Hands*

The Cosmic Perspective:



The Cosmic Perspective:

There are 63 billion Earth-like planets in our galaxy



**“Anything that seems set in stone or inalterable
can indeed change”**

– Angela Merkel, Harvard Commencement Address (May 2019)



Earth in the cosmic perspective:

Recent observations show:

- There are **63 billion Earth-like planets** in our galaxy;
- There is only **one Earth**.
- The Amazon rainforest is part of Earth's cosmic identity.
- Earth is constantly changing.



What will Earth's cosmic identity be tomorrow?