EXOPLANETARY SCIENCE

A GLOBAL ENDEAVOUR

GIOVANNA TINETTI

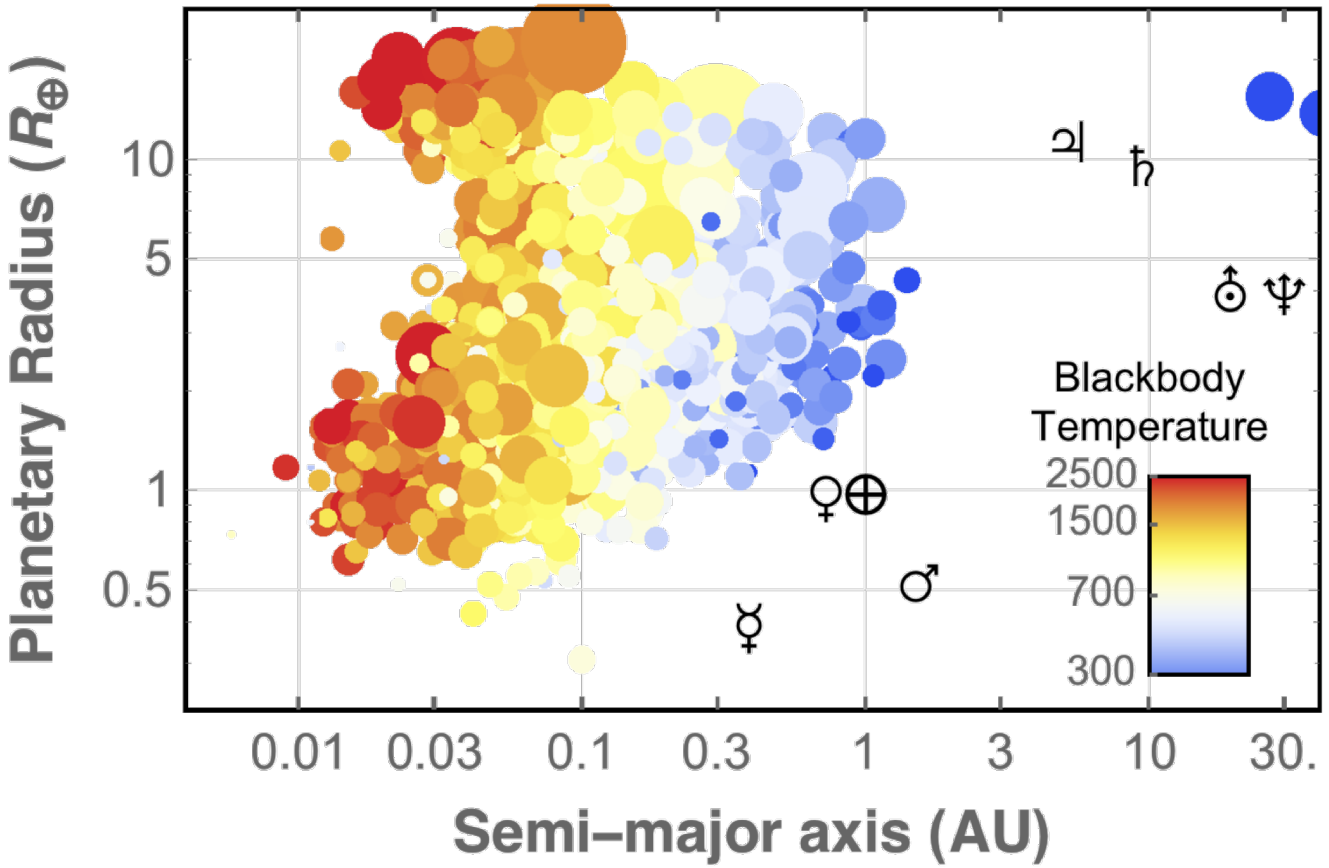
Planets are ubiquitous!

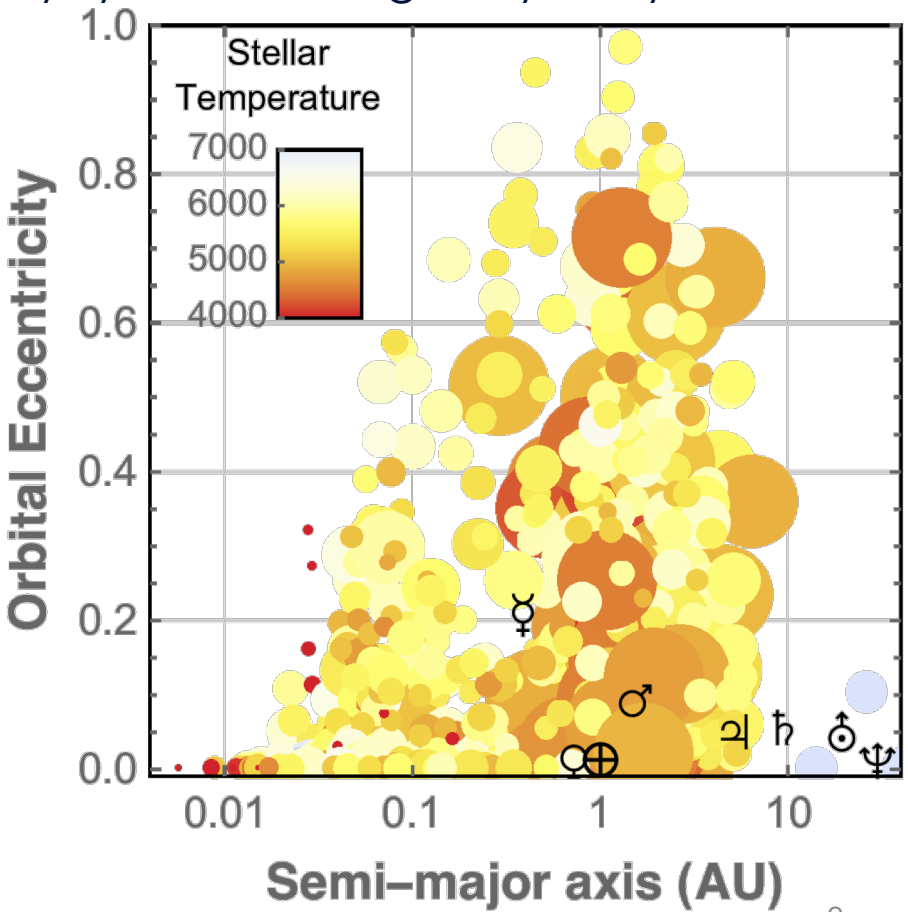
4800+	Confirmed planets
3500+	Planetary systems
1	Moon candidates

There are at least as many planets as stars…

Planets are very diverse

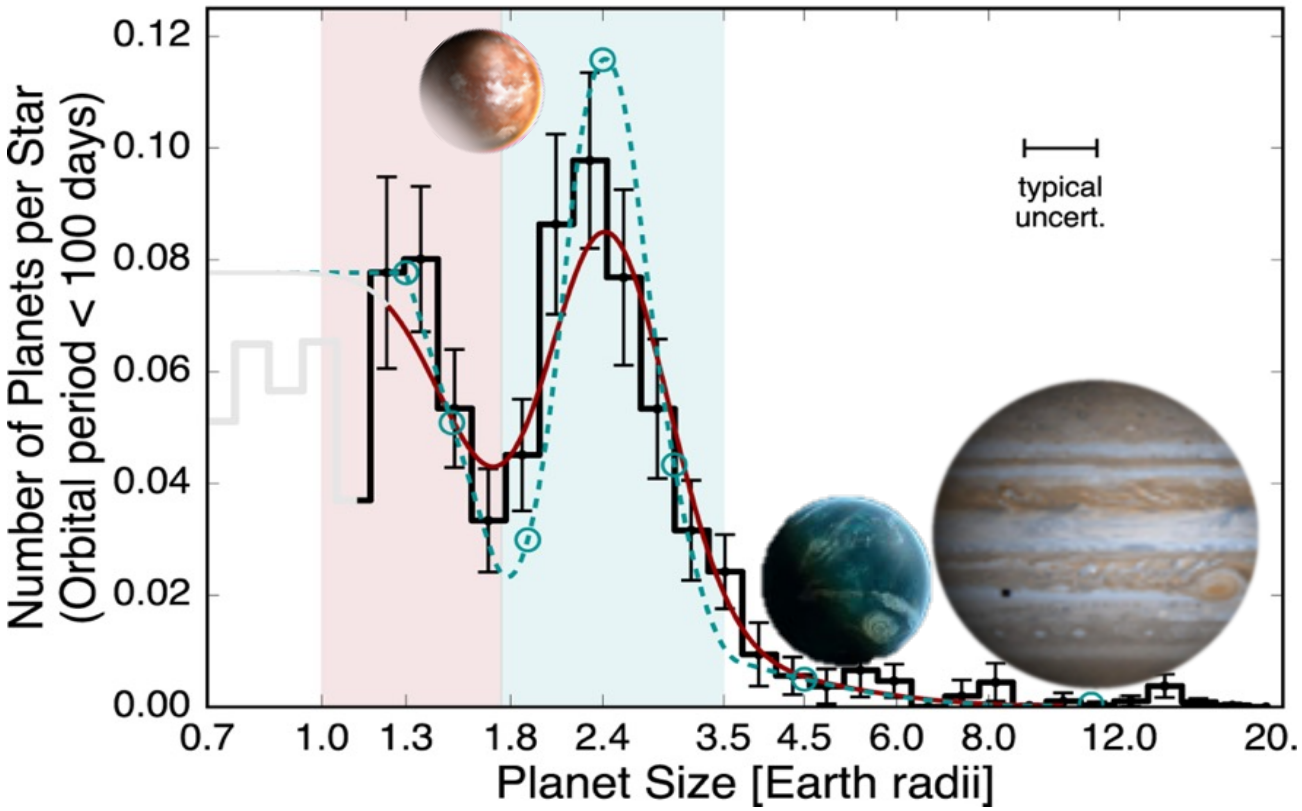
The solar system is not the paradigm of planetary system in our galaxy. Why?



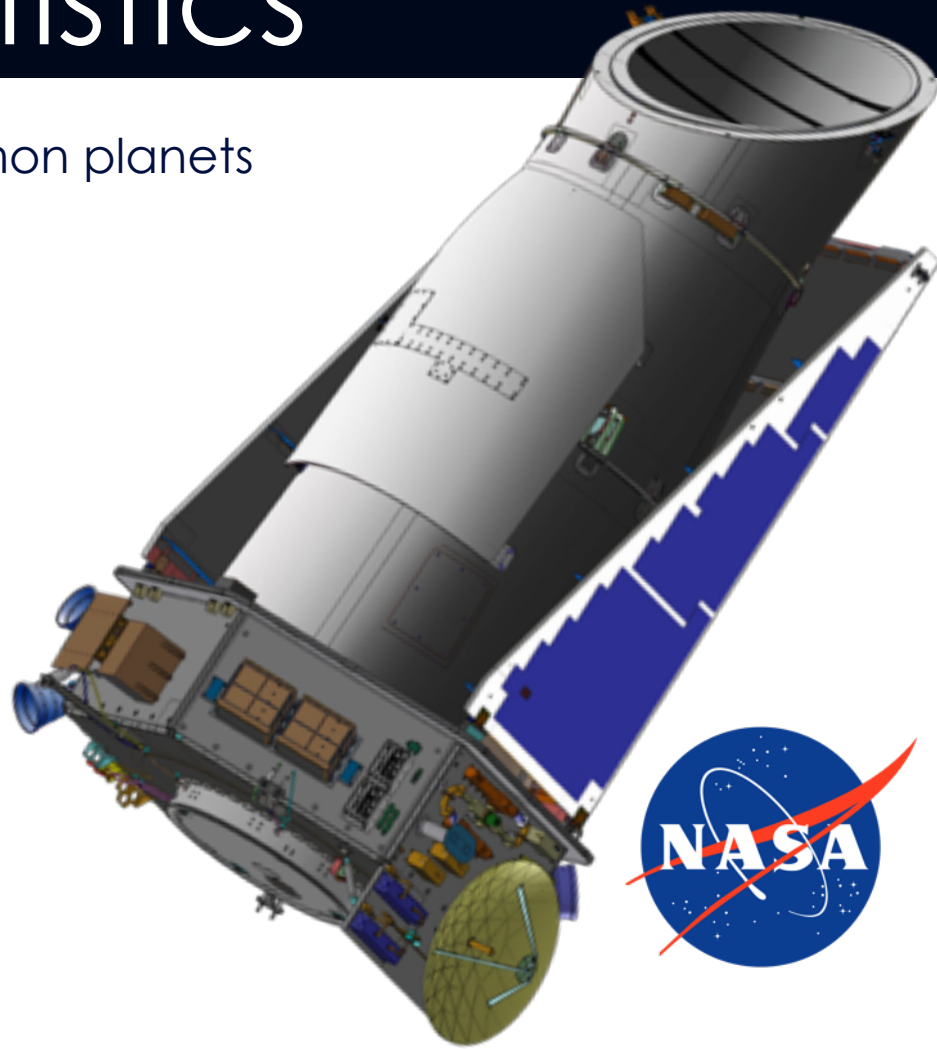


Galactic statistics

Small planets are the most common planets



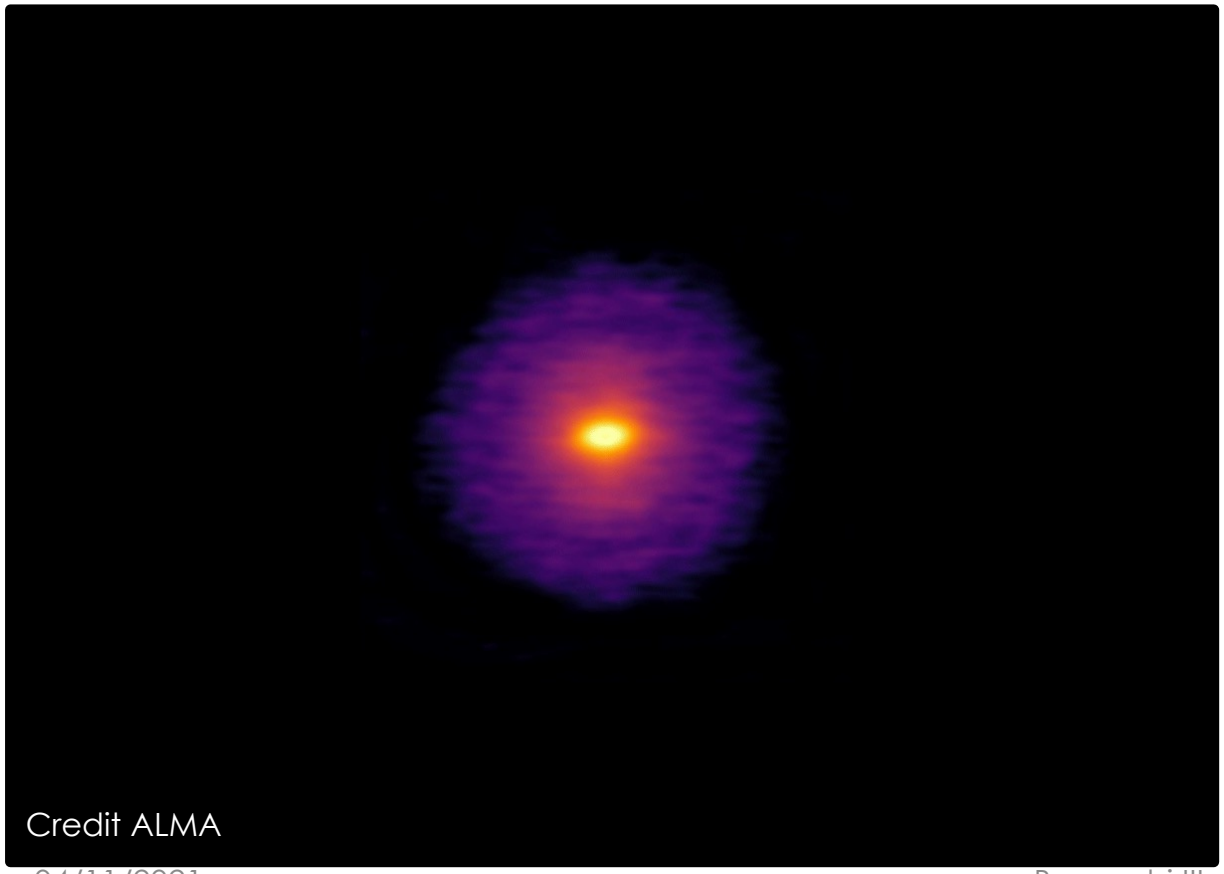
Fulton et al., 2017; 2018



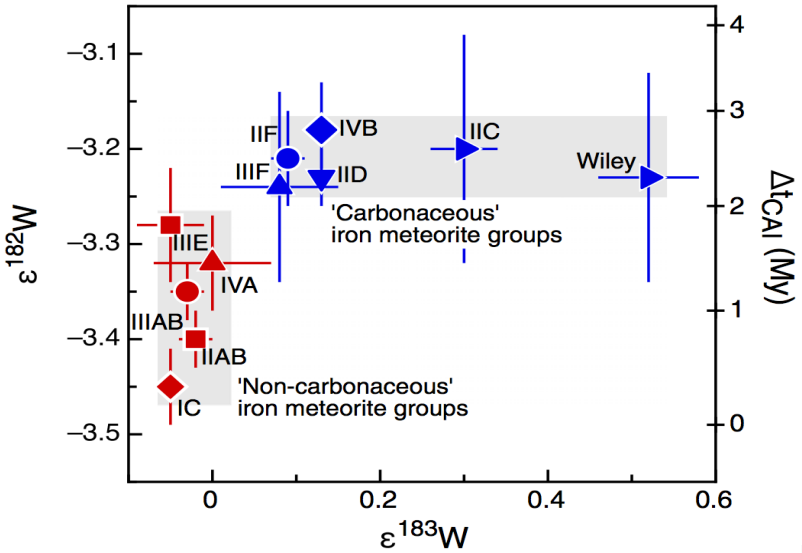
NASA Kepler mission, 2009-2019

Constraints on planet formation

Giant planets need to form fast, in < 1Myear



- ☆ Structure and chemistry of discs from ALMA + direct imaging instruments in NIR
- ☆ Isotopic ratios from meteorites + in-situ measurements in solar system



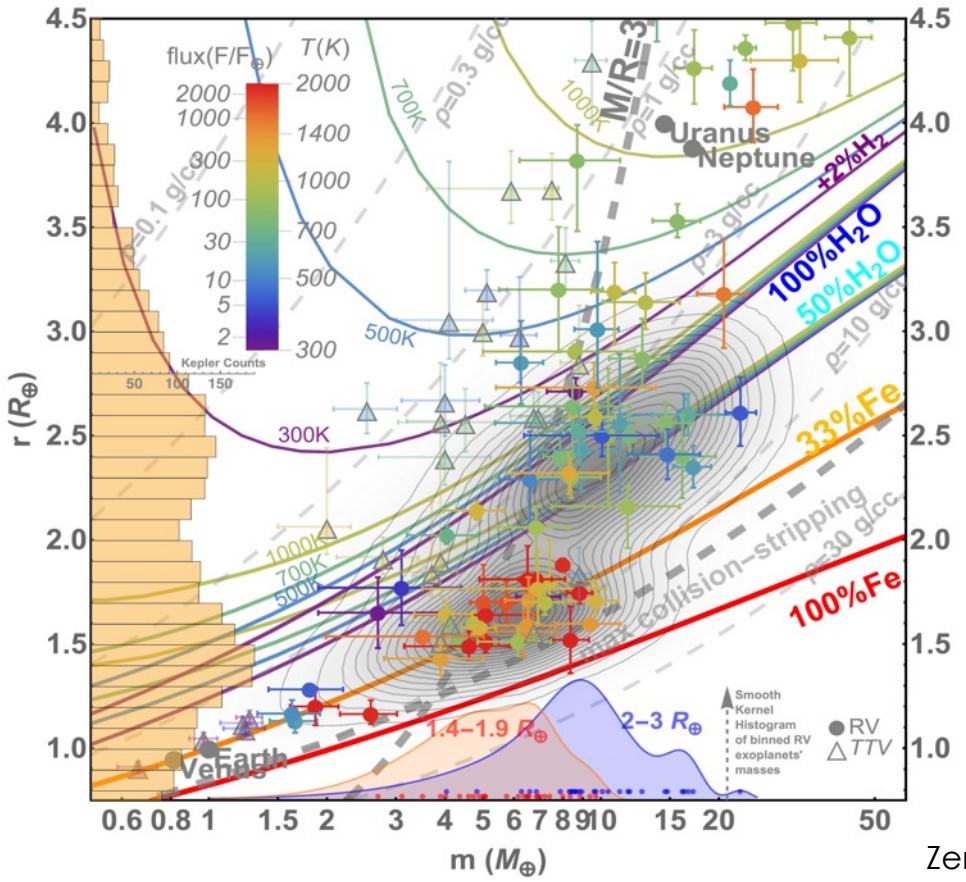
Kruijer et al. (2017); Desch et al. (2018)

Constraints on planet formation

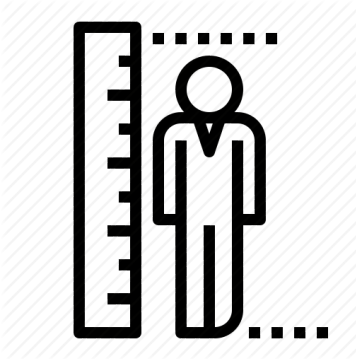
- ☆ SKA in the future will help identifying cm-size objects.
- ☆ Constraints to pebble accretion

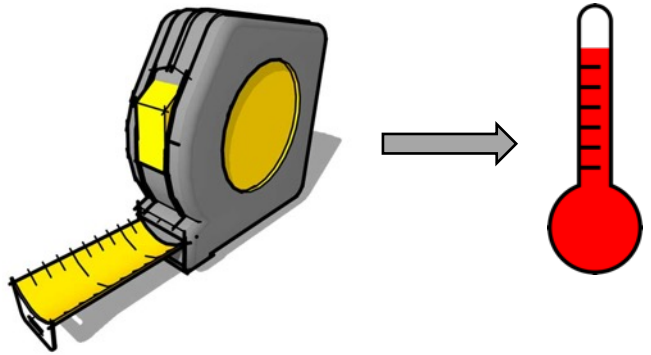
What do we know?

Very little so far…



Zeng et al., 2019





Measuring the mass

Toowoomba's eye on the sky: Minerva Australis

INAF Telescopio Nazionale Galileo: HARPS-N

New questions

- Why the Solar System is as it is?
- What are exoplanets made of?
- What's the weather like there?
- Why are they so diverse?
- How did they form?
- Are they habitable?

Atmospheric composition

A tracer of the nature and history of planets in our galaxy

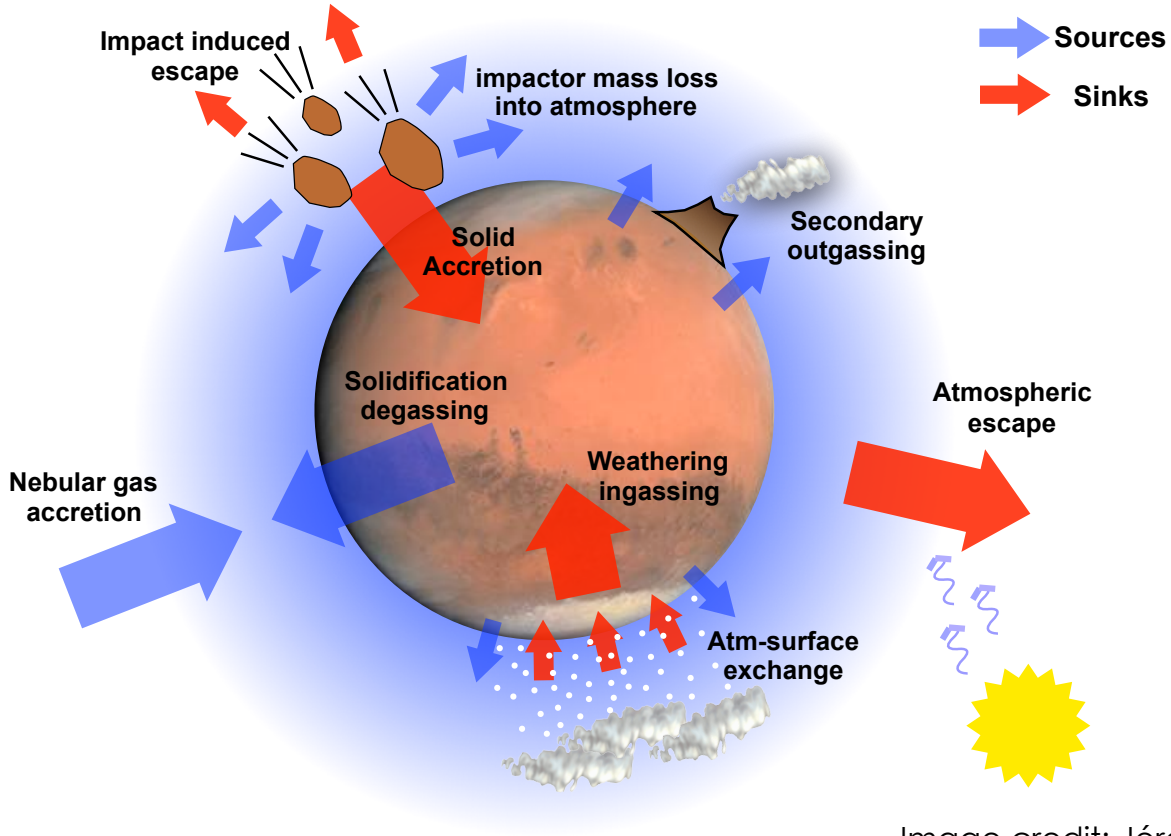
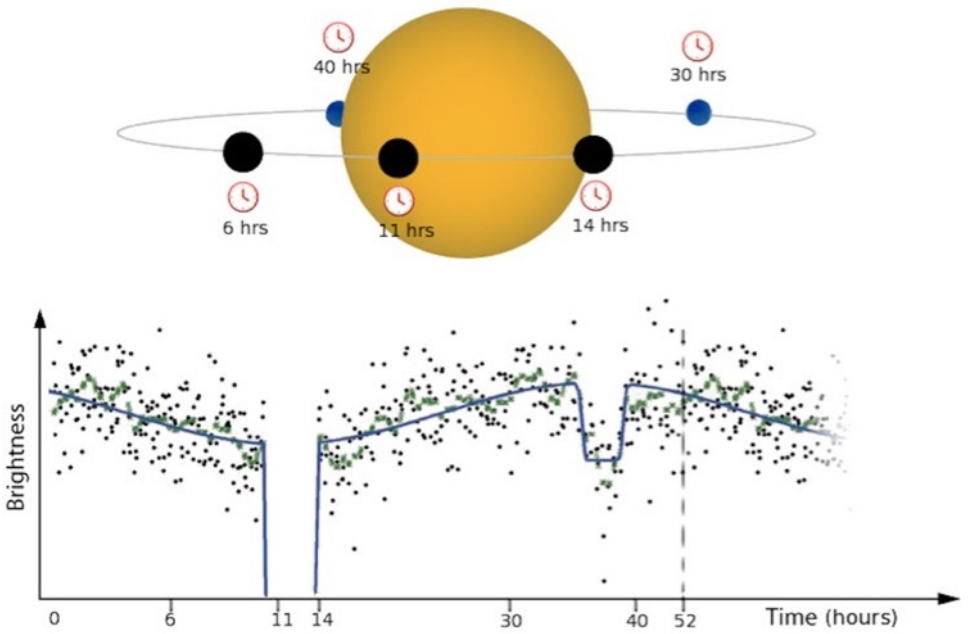


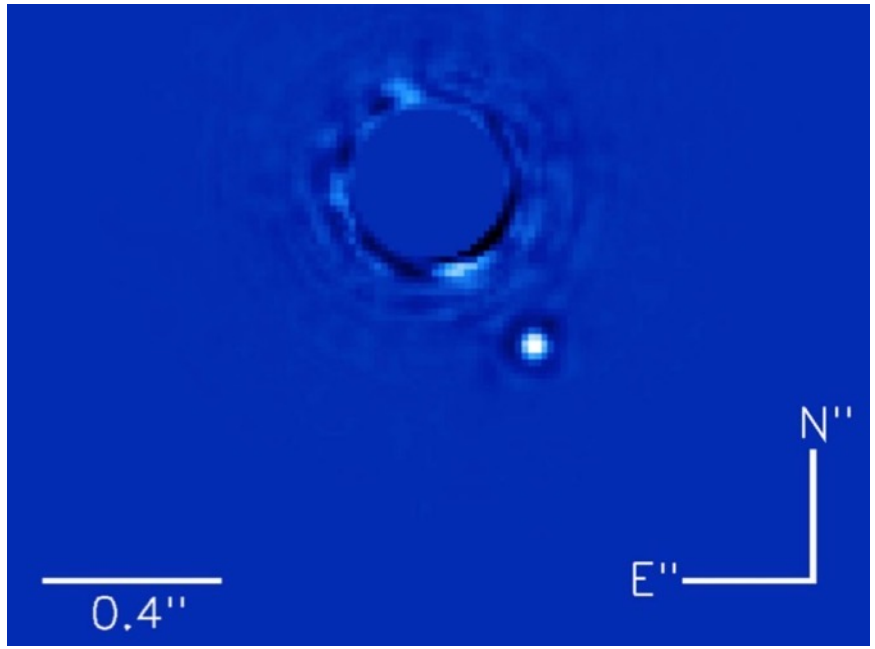
Image credit: Jérémy Leconte

Atmospheric composition

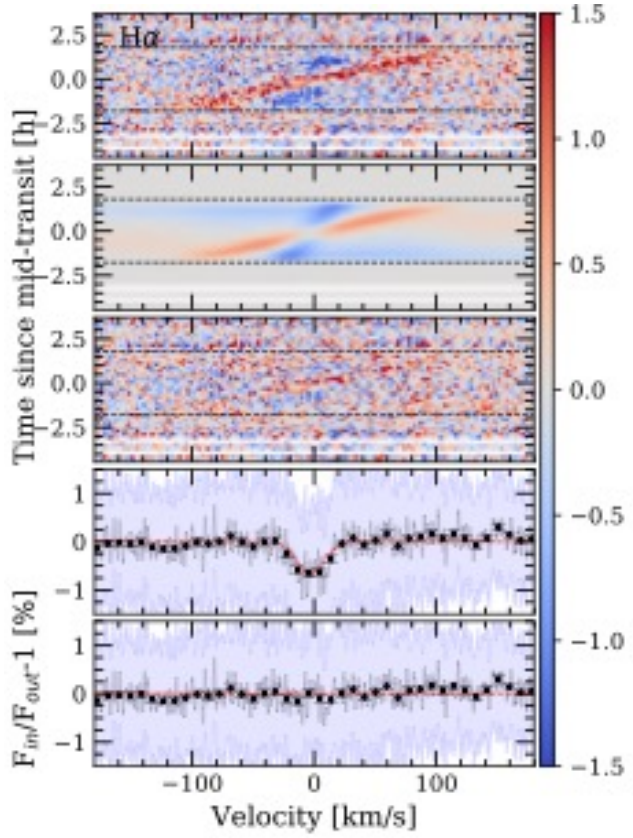
Many different techniques…



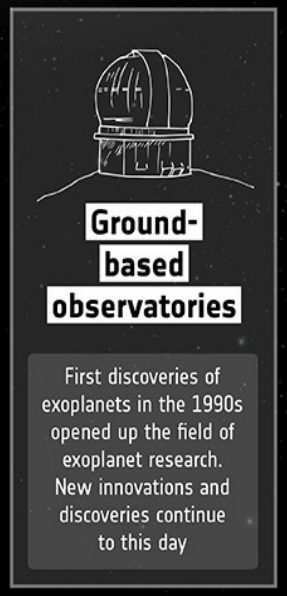
Transit



Direct imaging



High-dispersion



Ground-based observatories

First discoveries of exoplanets in the 1990s opened up the field of exoplanet research. New innovations and discoveries continue to this day

Pioneering stellar seismology and exoplanet hunting mission

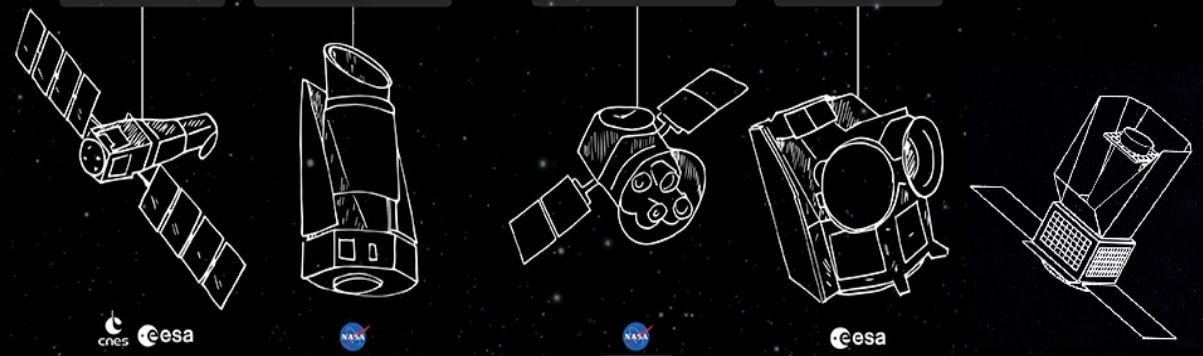
A targeted search for terrestrial and larger planets in or near the habitable zone of a wide variety of stars

First all-sky transit survey satellite

First step characterisation of known Earth-to-Neptune size exoplanets

Studying terrestrial planets in orbits up to the habitable zone of Sun-like stars, and characterising these stars

Performing a chemical census of a large and diverse sample of exoplanets by analysing their atmospheres



Launch 1990 — Hubble

2003 — Spitzer

2006 — Corot

2009 — Kepler/K2

2013 — Gaia

2018 — Tess

Cheops

Twinkle

Plato

Ariel

Dedicated exoplanet missions

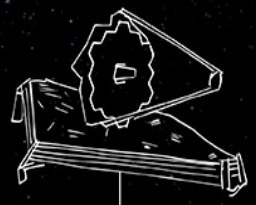
Exoplanet-sensitive missions

Probing the composition of exoplanet atmospheres

Studying exoplanet signatures in infrared light

Revealing exoplanets through its all-sky survey of the position, brightness and motion of over one billion stars

Webb



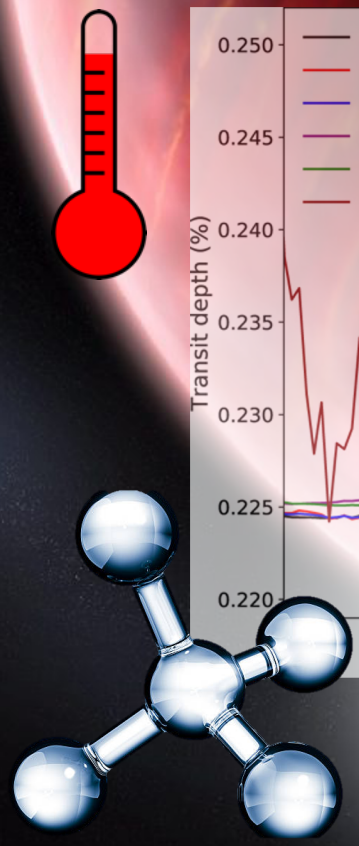
Detailed characterisation of exoplanet atmospheres through transit studies and direct imaging

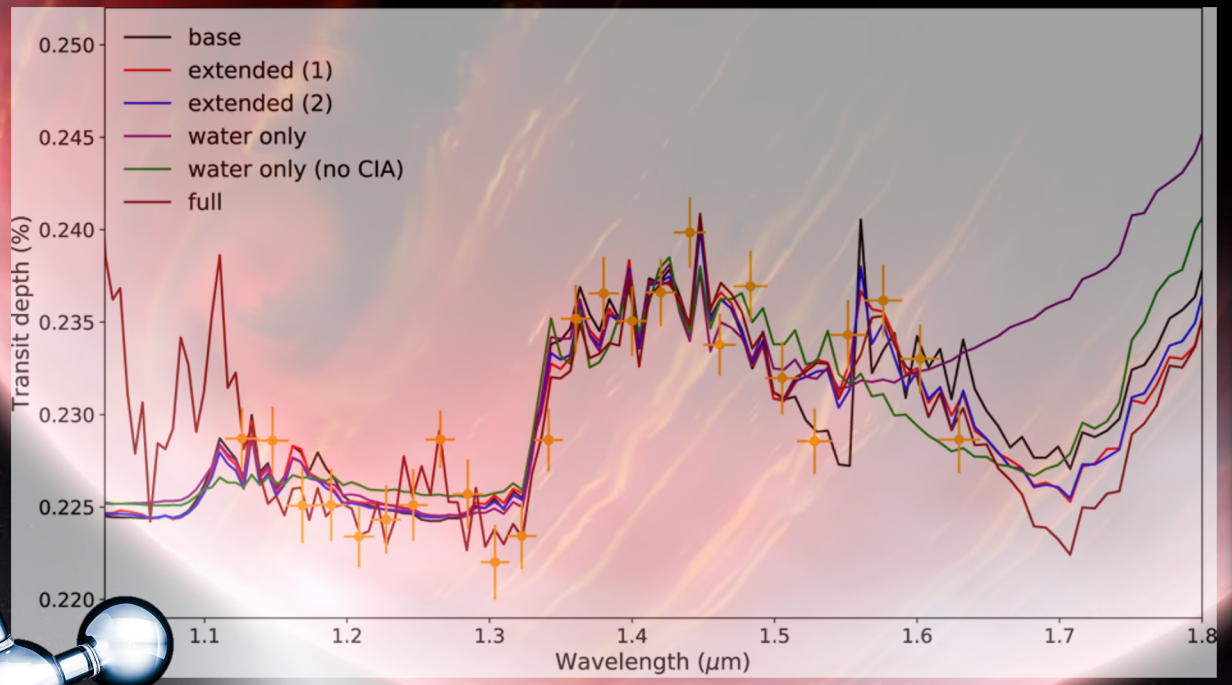
Image credi ESA

Exo-atmospheres observed… so far

Water vapour & other molecules observed in ~60 Jupiter-type, hot exoplanets

NASA Spitzer, NASA-ESA Hubble

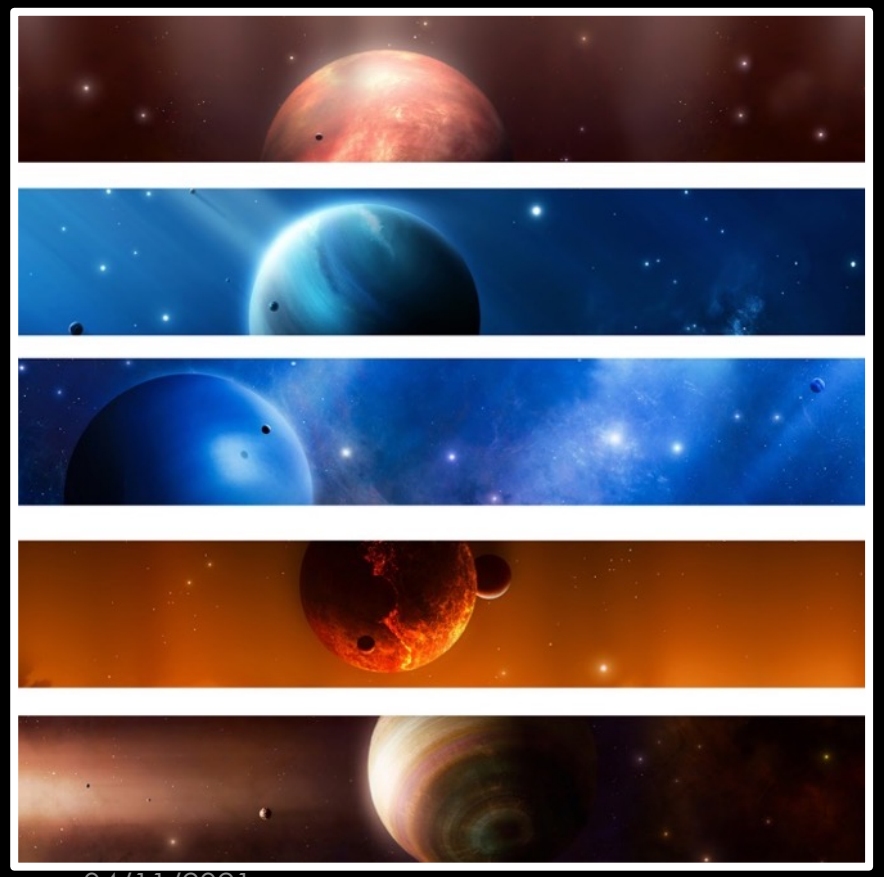


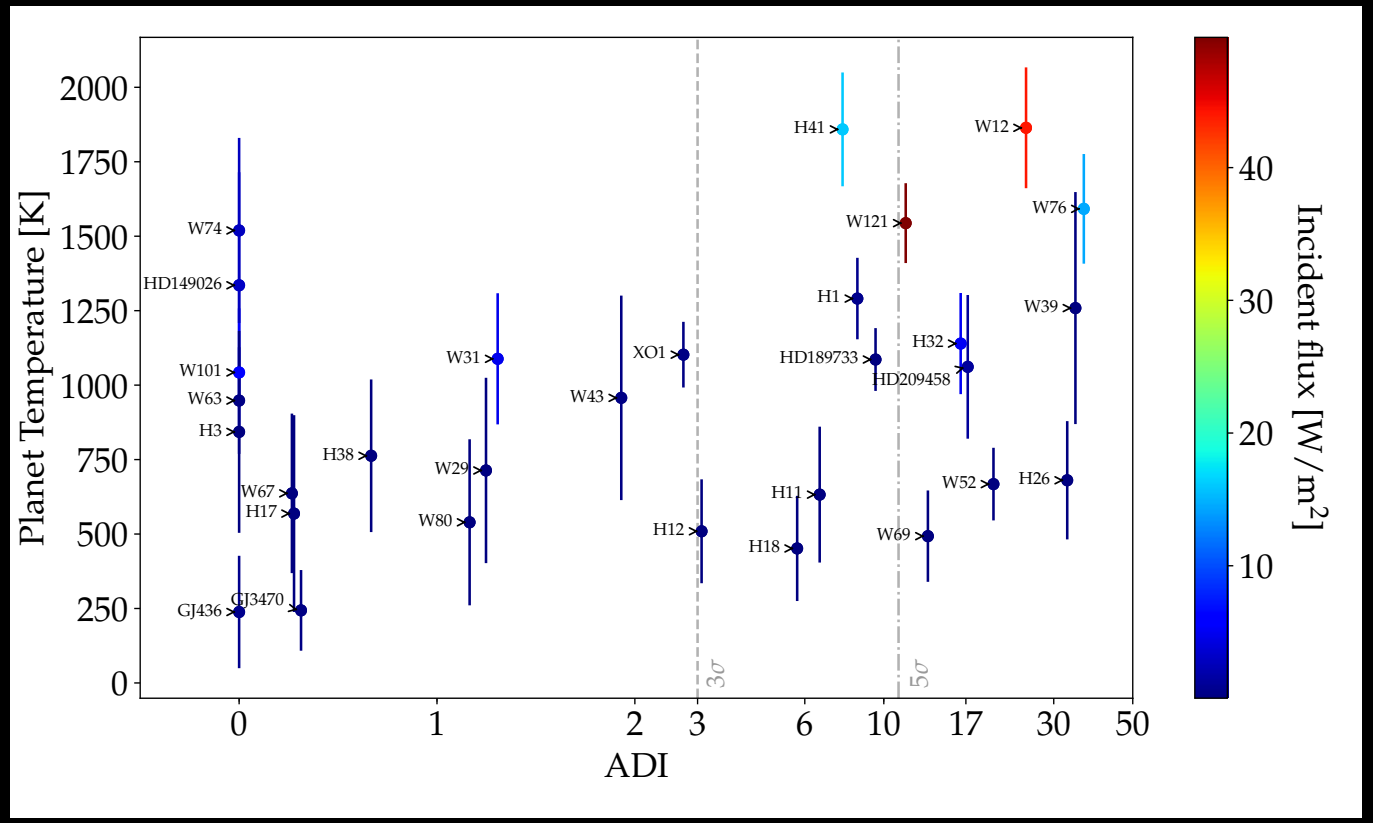


Changeat et al. 2021

Population studies

Beyond individual planets….



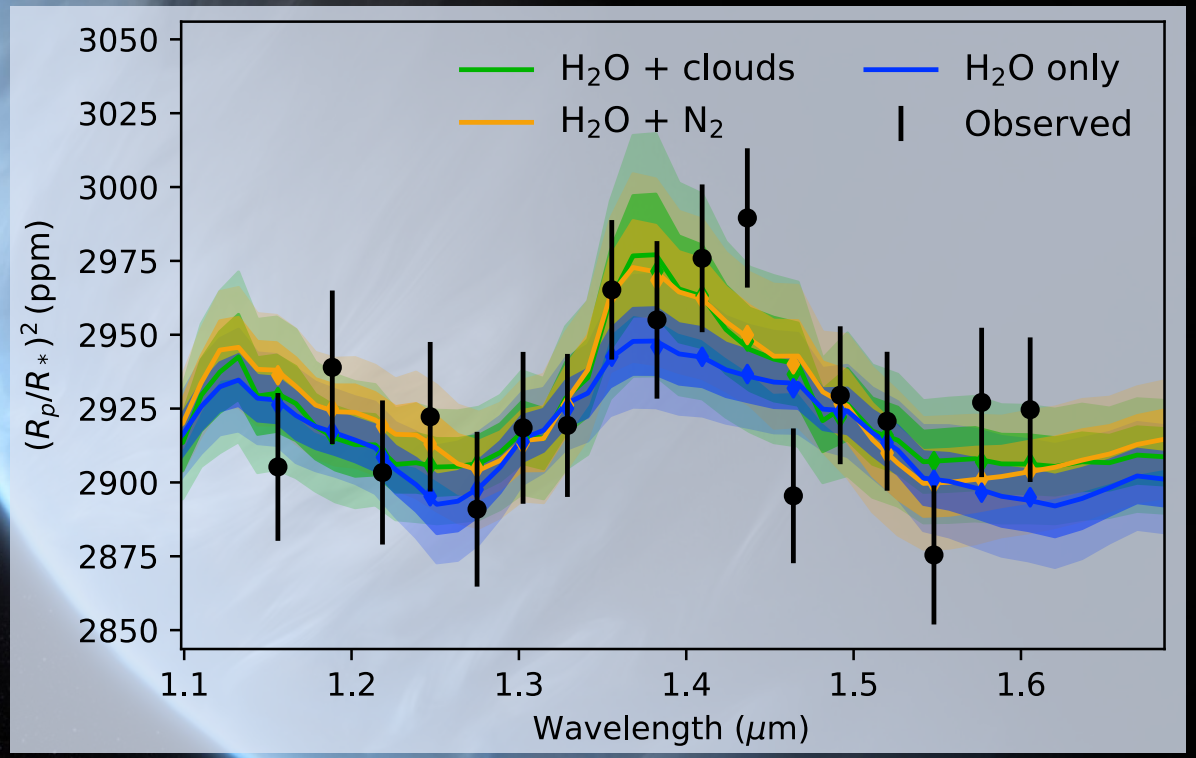


Tsiaras et al. 2018

The signature of water on K2-18 b

Temperate transitional planet (ocean world? sub-Neptune?)

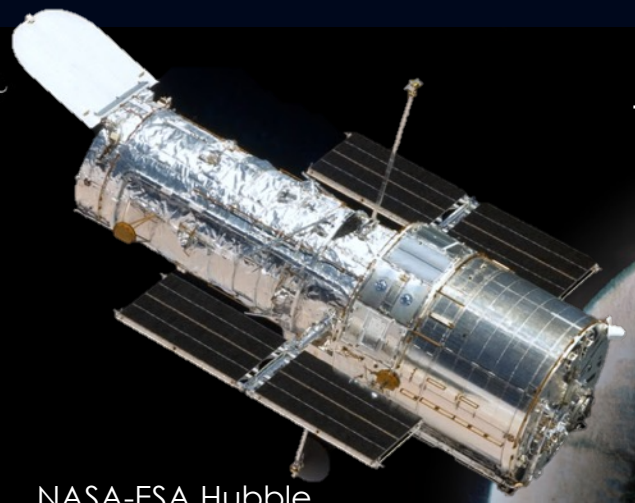
NASA-ESA Hubble



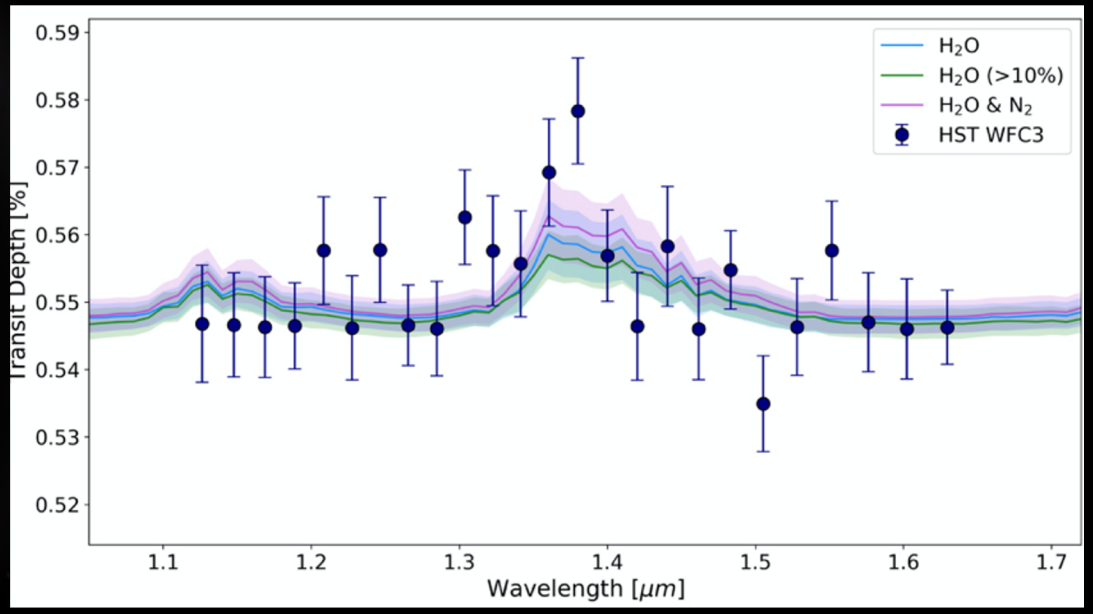
Tsiaras et al., *Nature Astron.*, 2019

LHS1140b

Temperate super-Earth: atmospheric signal or stellar activity?



NASA-ESA Hubble



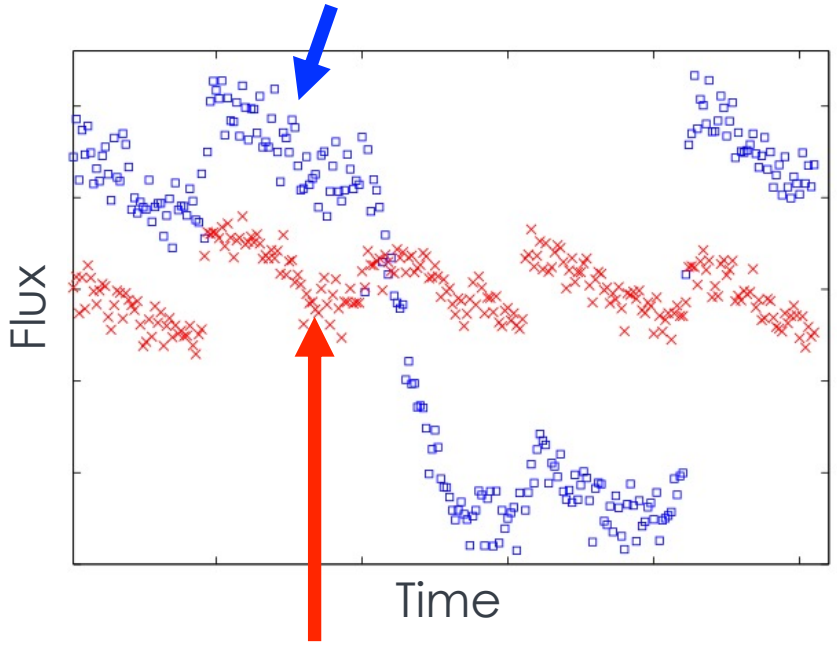
Edwards et al. 2021

Picture credit Lea Changeat

Machine learning

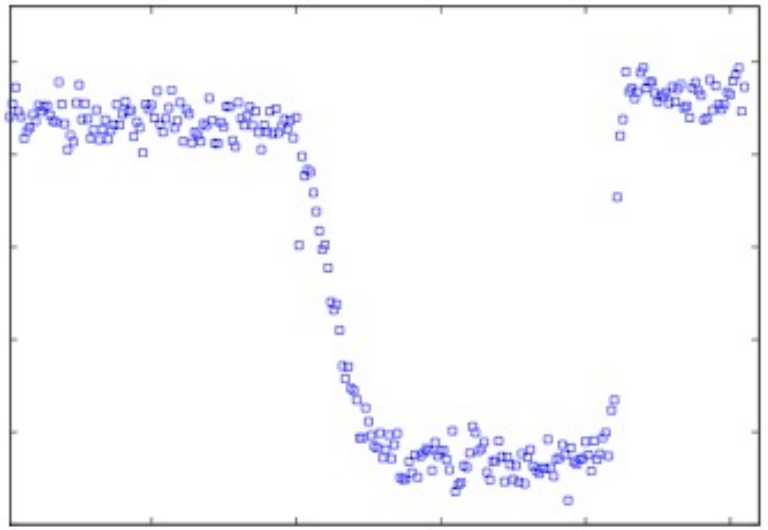
To correct for instrument systematics

Raw observed data



Machine Learning Noise model

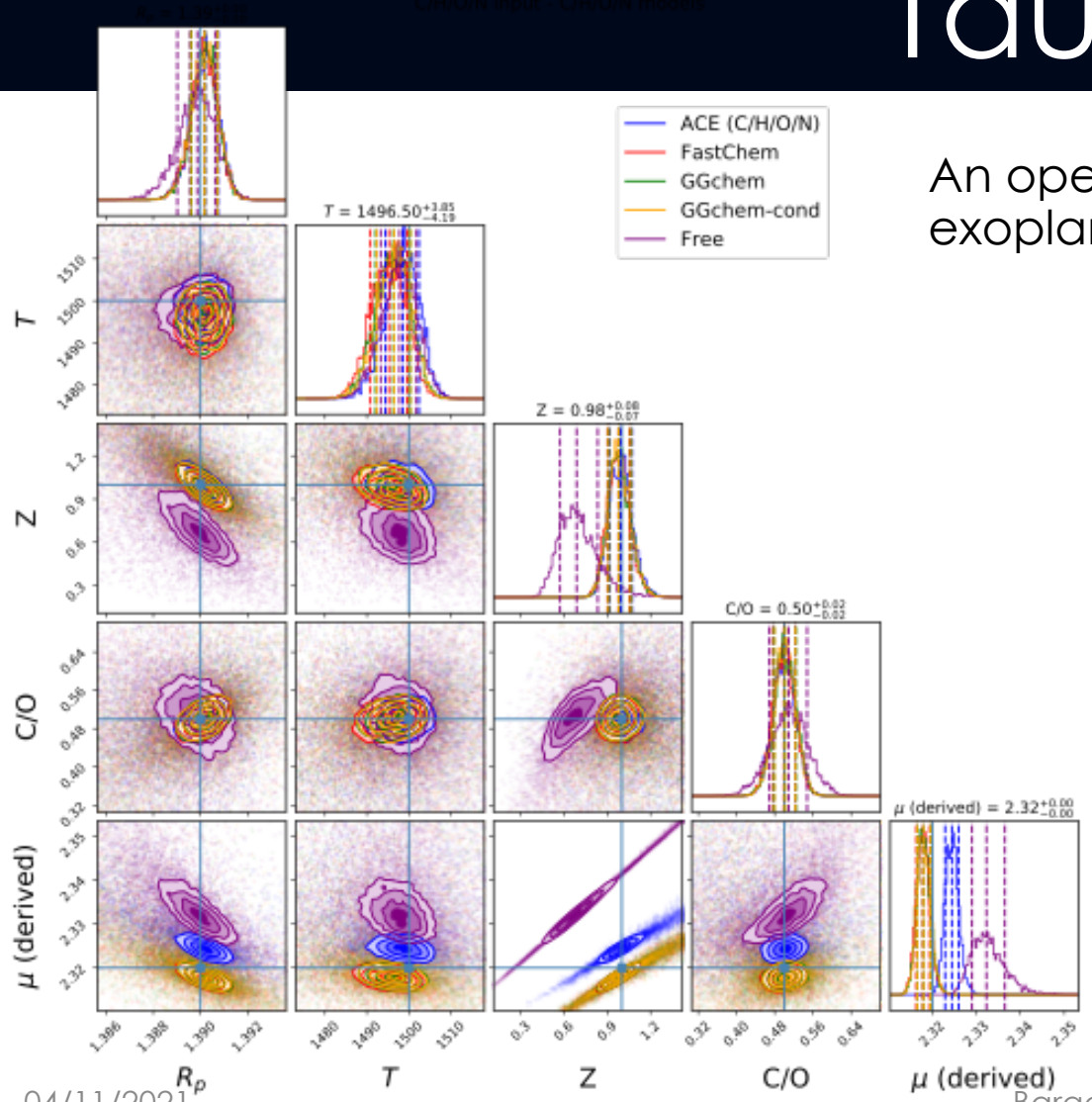
Corrected data



https://github.com/ucl-exoplanets

Waldmann, 2012, 2013, 2014, 2015; Morello +, 2014, 2015a, b, 2016; Tsiaras+ 2016; 2018; Damiano +2017; Morvan+2020; Yip+2020

TauREx



An open source platform to interpret exoplanetary spectra

Article: https://arxiv.org/abs/2110.01271
PyPi: https://pypi.org/project/taurex/
Github: https://github.com/ucl-exoplanets/TauREx3_public

Al-Refaie+2020,2021; Waldmann+2015a,b;

James Webb Space Telescope

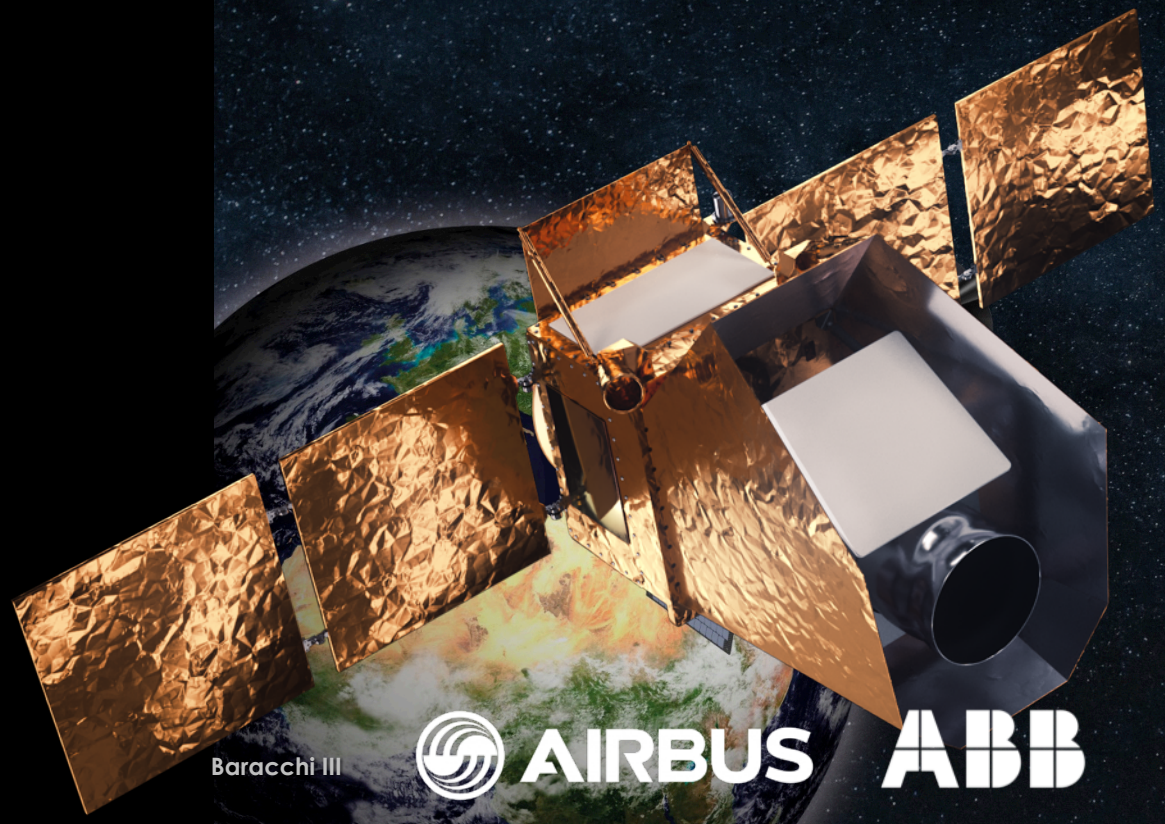
Ideal for cold rocky planets around M-dwarfs

6.5 m telescope in L2
Very broad infrared coverage
Launch 2021

Twinkle

BLUE SKIES SPACE

http://www.twinkle-spacemission.co.uk/



nature astronomy

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Comment | Published: 06 November 2020

A sustainable path for space science

Richard Archer, Marcell Tessenyi, Giovanna Tinetti, Jonathan Tennyson, Martin Charles Faulkes, Giorgio Savini, Philip Windred, Dan Brown, Billy Edwards, Ian Stotesbury, Max Joshua & Ben Wilcock

Nature Astronomy **4**, 1017–1018 (2020) | Cite this article

308 Accesses | **7** Altmetric | Metrics

High-performance scientific satellites are currently the exclusive domain of government-funded agencies. The team behind the Twinkle Space Mission is developing a new class of small and sustainable science satellites that leverages recent innovations in the commercial space sector.

SPACE AUSTRALIA

FEATURE NEWS EVENTS OPINIONS ABOUT US

NEWS

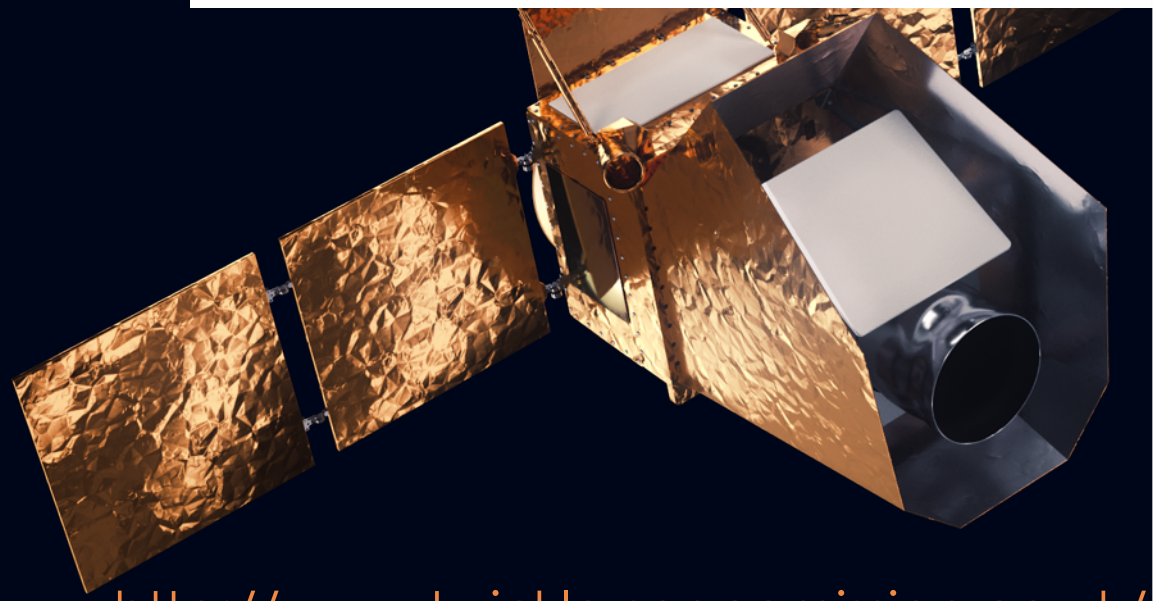
8 MINS READ · 08 OCT 2020

AN EXOPLANETARY TWINKLE IN USQ'S EYE

#Science #Astronomy #Exoplanets #Observatories #Telescopes

WRITTEN BY PROF. JONTI HORNER

How do you study the atmosphere of an alien world, orbiting a distant star? By looking for the twinkle in the host star's light! A new space telescope, currently scheduled to launch in 2023 or 2024, will do just that — and today, it was announced that Australian researchers at the University o
part of the new and exc



http://www.twinkle-spacemission.co.uk/

Baracchi III

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Next-gen mission to explore skies above alien worlds

Space scientists from across the world are taking giant steps in the search for new planets, building their own

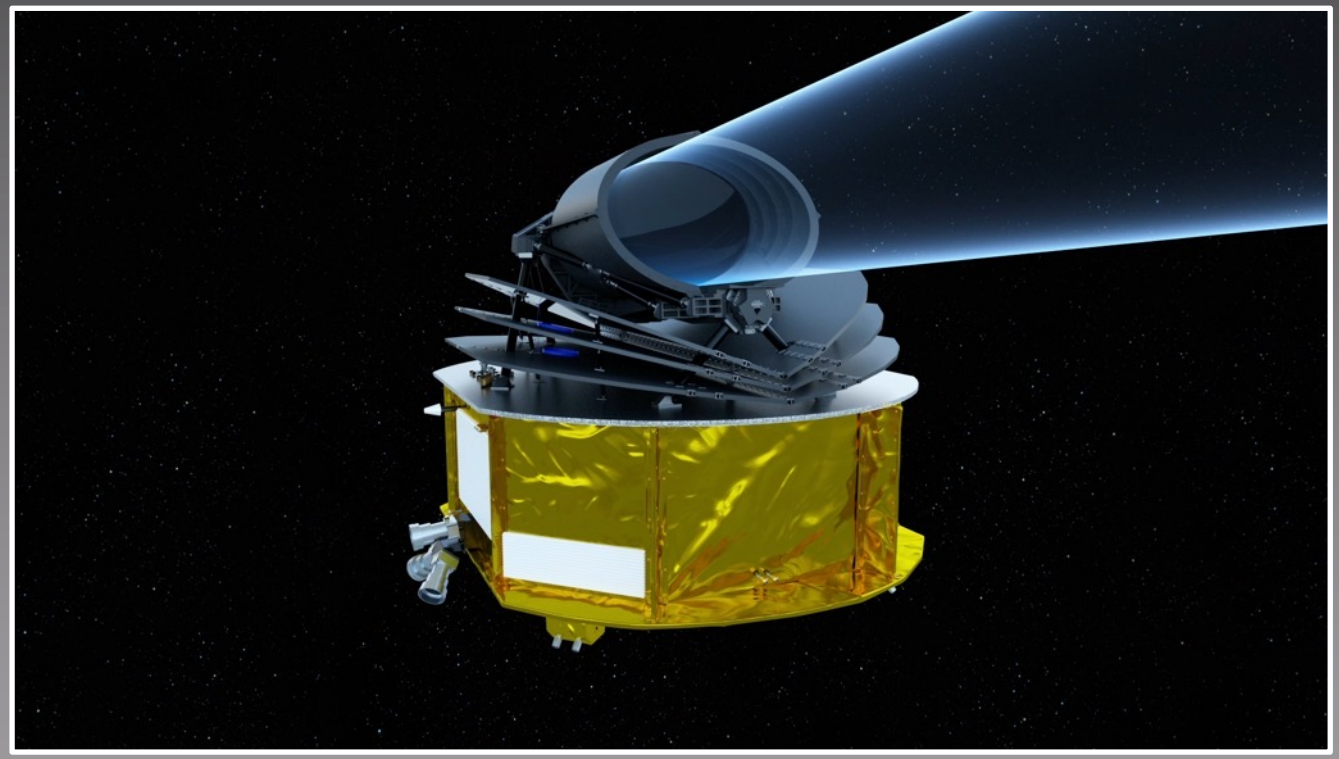
Live Chat

Ariel

- Adopted as ESA M4 in Nov. 2020
- Launch 2029 in L2 with CI

- 1m-class telescope
- Simultaneous coverage 0.5-7.8 μm

- ~1000 exoplanets observed
  - Rocky + gaseous; 300-3000K; stars A-M



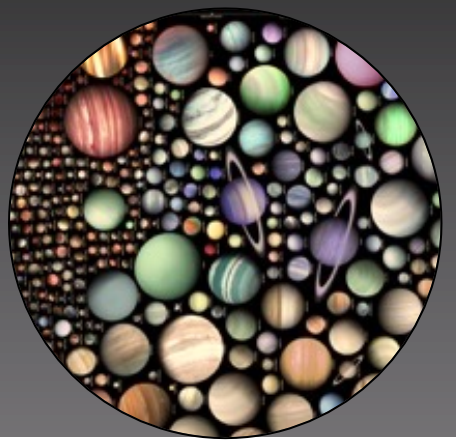
https://www.youtube.com/watch?v=38YfVgAVUVs

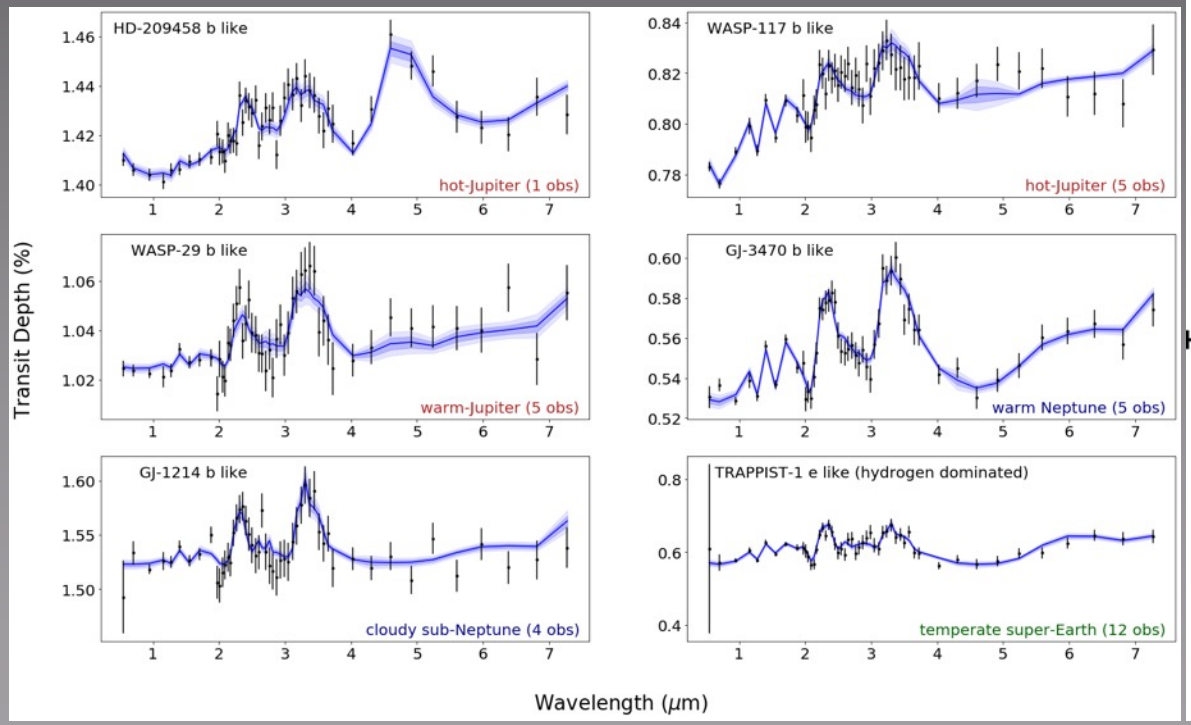
Ariel payload consortium

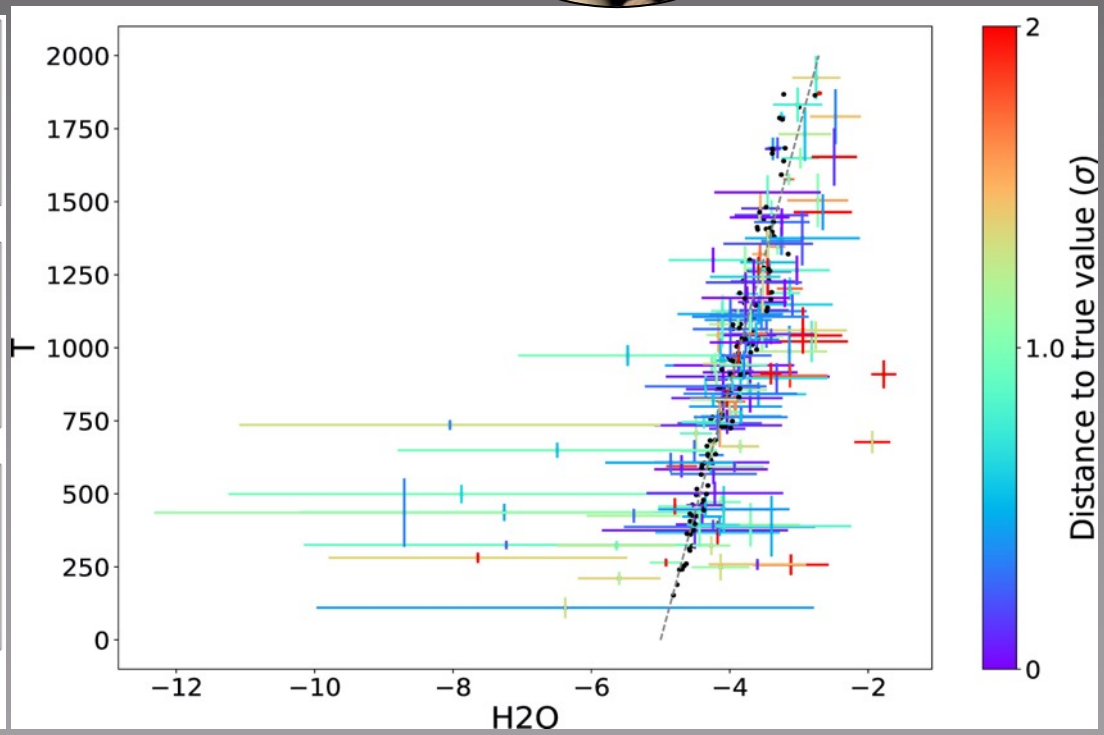
~500 SCIENTISTS AND ENGINEERS FROM 16 ESA COUNTRIES + NASA, JAXA PARTICIPATION

Chemical trends?

SEARCHING FOR CHEMICAL AND CLOUD TRANSITIONS





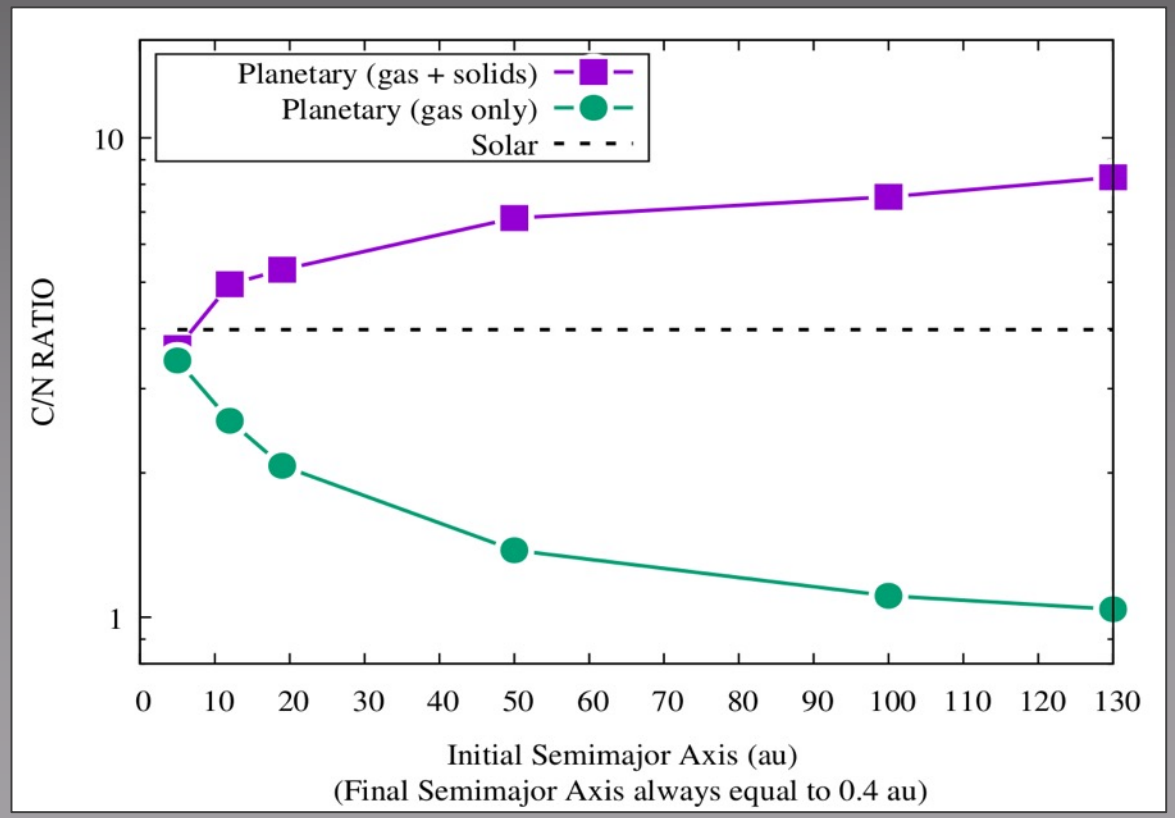


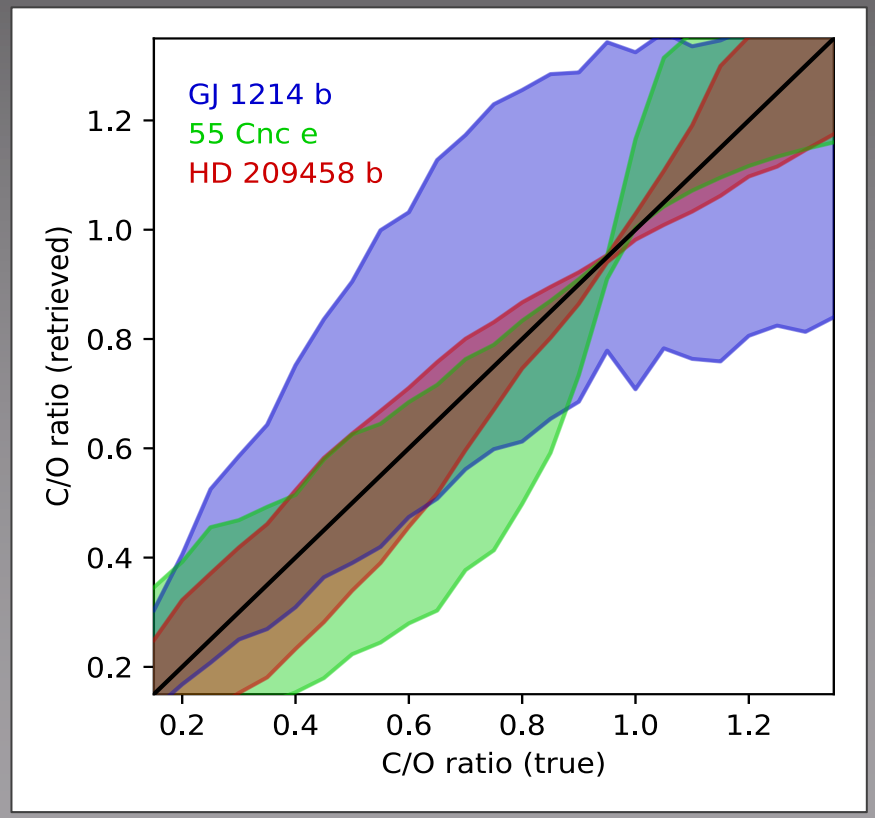
Changeat et al. 2020

Link with planet formation

KEY MOLECULAR SPECIES/ELEMENTAL RATIOS CONNECTING ATMOSPHERES AND FORMATION

Ariel Formation WG

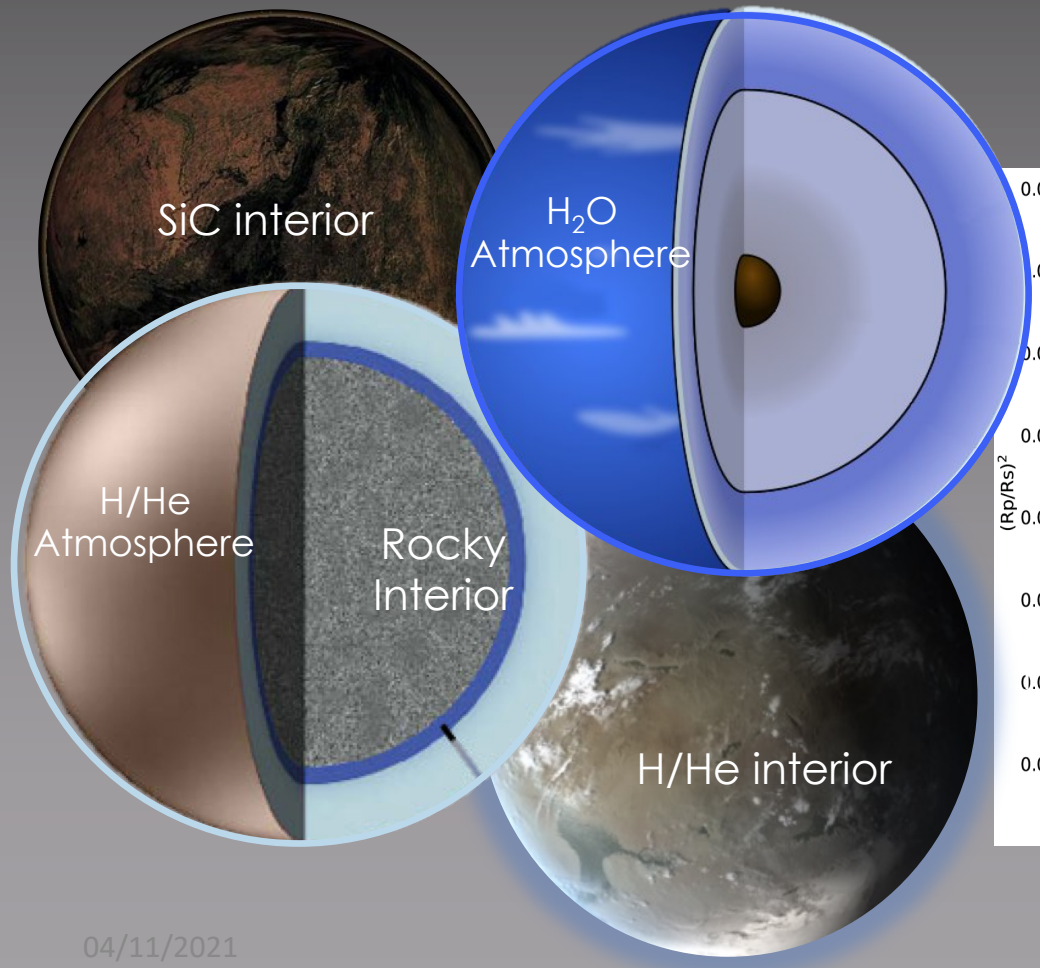




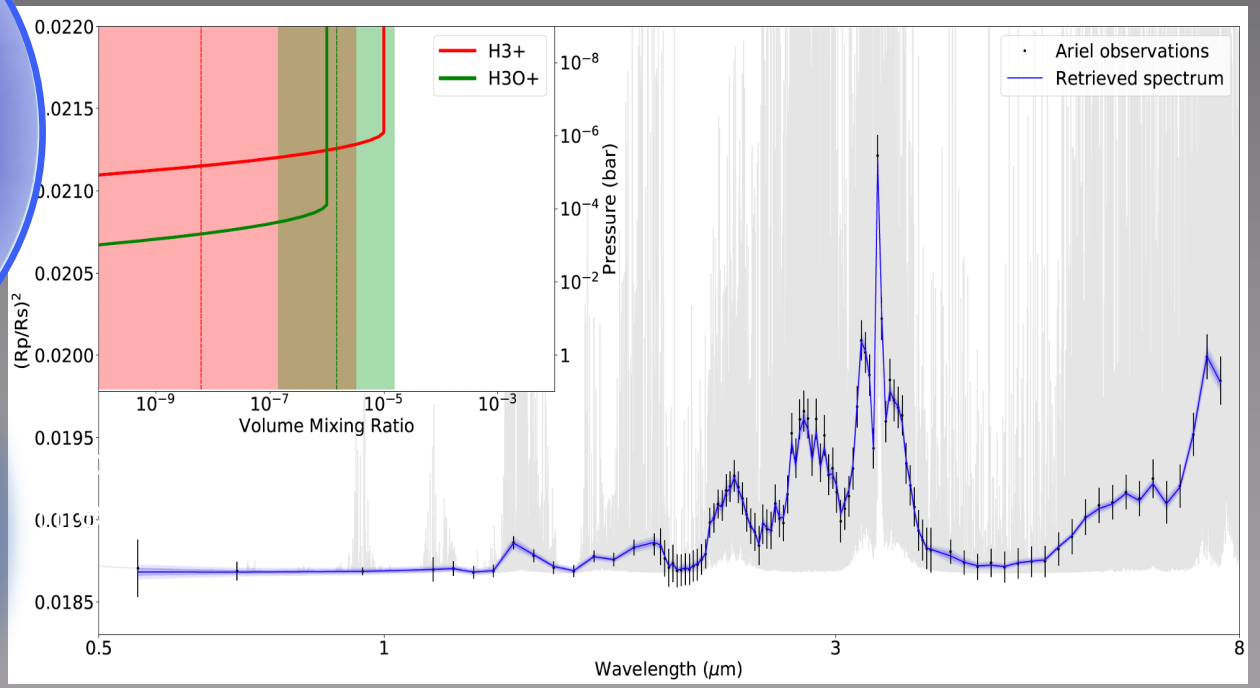
Turrini et al. 2020; Min et al., 2020;

Small planets: what is their nature?

IS H2 STILL THERE? IS THERE A SECONDARY ATMOSPHERE? HOW THICK IS THE ATMOSPHERE? WHAT ARE THE TRACE GASES?



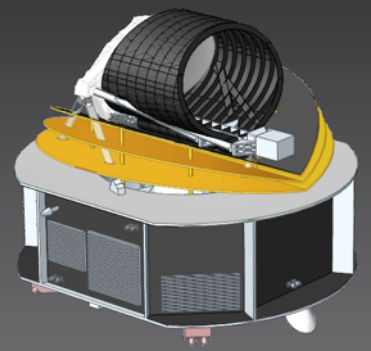
Ariel Retrieval, Chemistry WGs

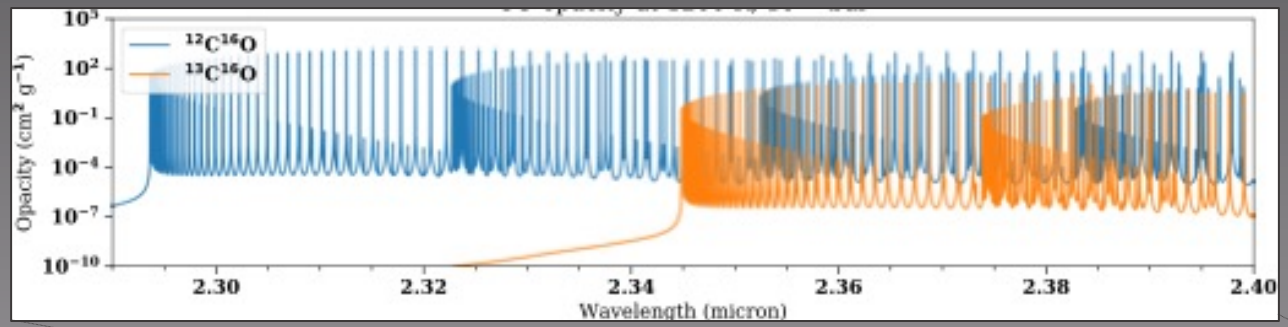


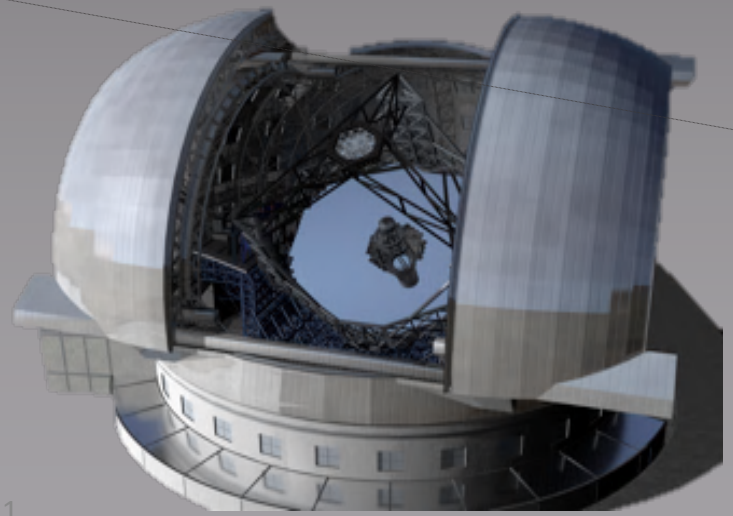
Bourgalais et al. 2020

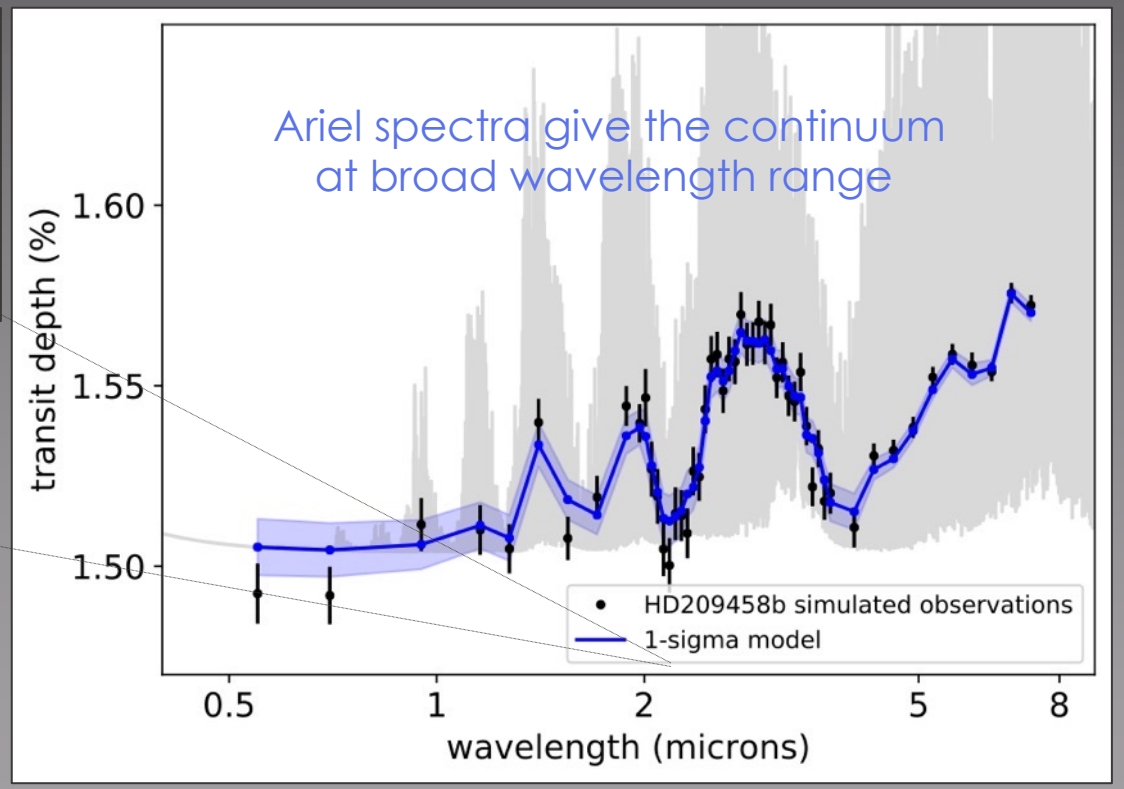
Synergies ground

HIGHLY COMPLEMENTARY TO LARGE, GROUND-BASED FACILITIES









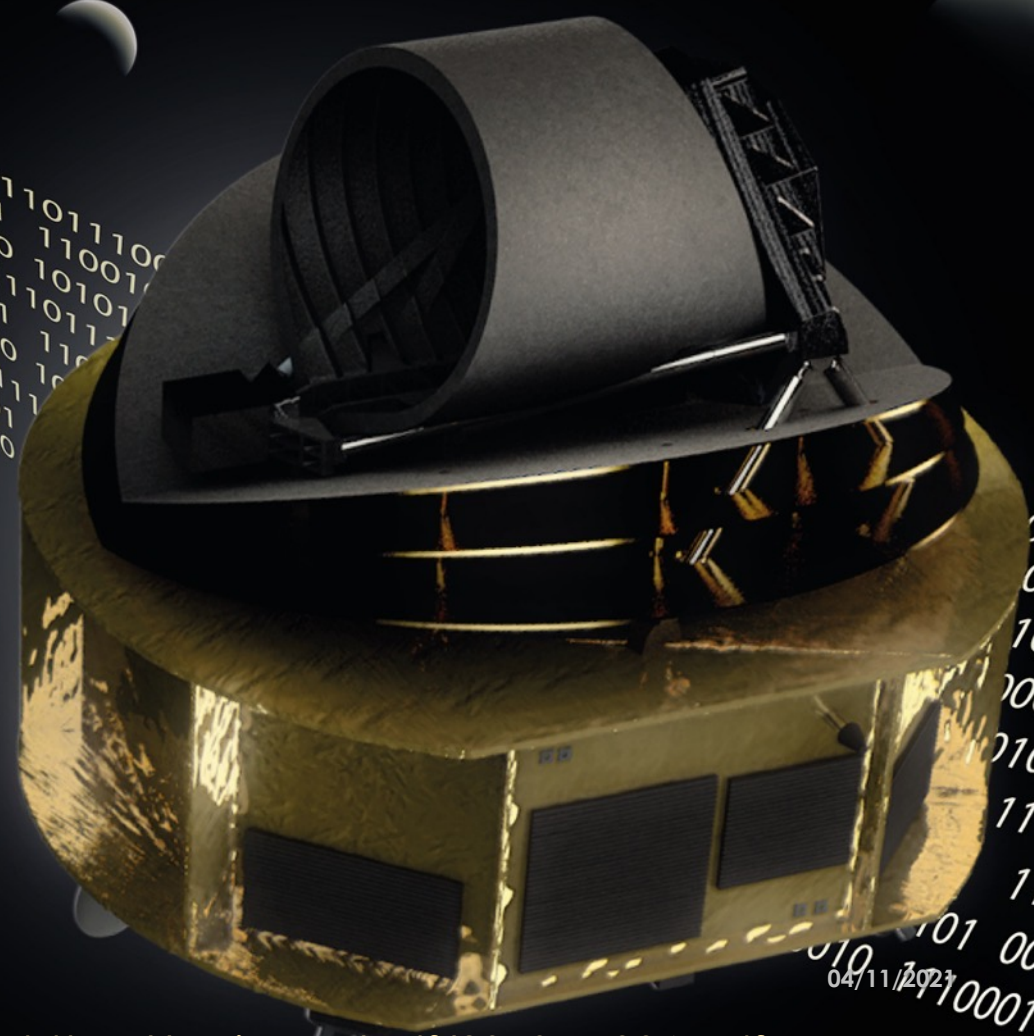
The Ariel Data Challenges

ariel-datachallenge.space

- The ML Data Challenge in 2019 & 2021 had 100+ international teams of professionals and amateurs participating

- Organised with European Conference of Machine Learning

SCAN ME

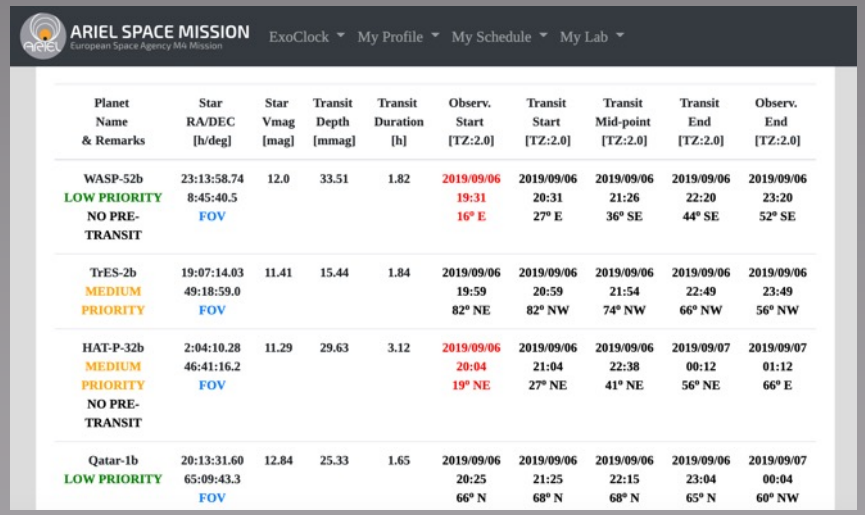


https://arxiv.org/pdf/2010.15996.pdf

Citizen-science programs

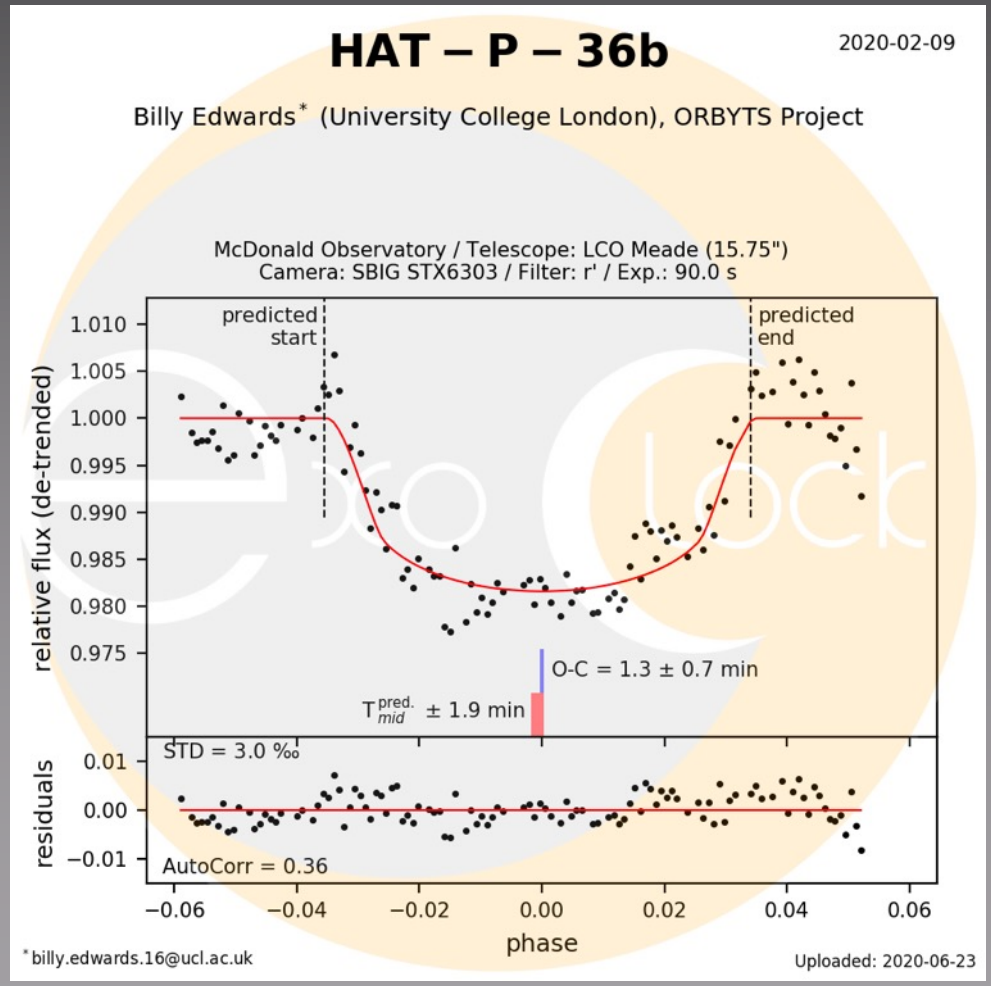
exoclock.space

- Open platform to monitor the ephemerides of Ariel targets with contributions from the public.
- Huge global success, hundreds of active participants!
- Used to engage school students in scientific research.



Planet Name & Remarks	Star RA/DEC [h/deg]	Star Vmag [mag]	Transit Depth [mmag]	Transit Duration [h]	Observ. Start [TZ:2.0]	Transit Start [TZ:2.0]	Transit Mid-point [TZ:2.0]	Transit End [TZ:2.0]	Observ. End [TZ:2.0]
WASP-52b LOW PRIORITY NO PRE-TRANSIT	23:13:58.74 8:45:40.5 FOV	12.0	33.51	1.82	2019/09/06 19:31 16° E	2019/09/06 20:31 27° E	2019/09/06 21:26 36° SE	2019/09/06 22:20 44° SE	2019/09/06 23:20 52° SE
TrES-2b MEDIUM PRIORITY	19:07:14.03 49:18:59.0 FOV	11.41	15.44	1.84	2019/09/06 19:59 82° NE	2019/09/06 20:59 82° NW	2019/09/06 21:54 74° NW	2019/09/06 22:49 66° NW	2019/09/06 23:49 56° NW
HAT-P-32b MEDIUM PRIORITY NO PRE-TRANSIT	2:04:10.28 46:41:16.2 FOV	11.29	29.63	3.12	2019/09/06 20:04 19° NE	2019/09/06 21:04 27° NE	2019/09/06 22:38 41° NE	2019/09/07 00:12 56° NE	2019/09/07 01:12 66° E
Qatar-1b LOW PRIORITY	20:13:31.60 65:09:43.3 FOV	12.84	25.33	1.65	2019/09/06 20:25 66° N	2019/09/06 21:25 68° N	2019/09/06 22:15 68° N	2019/09/06 23:04 65° N	2019/09/07 00:04 60° NW

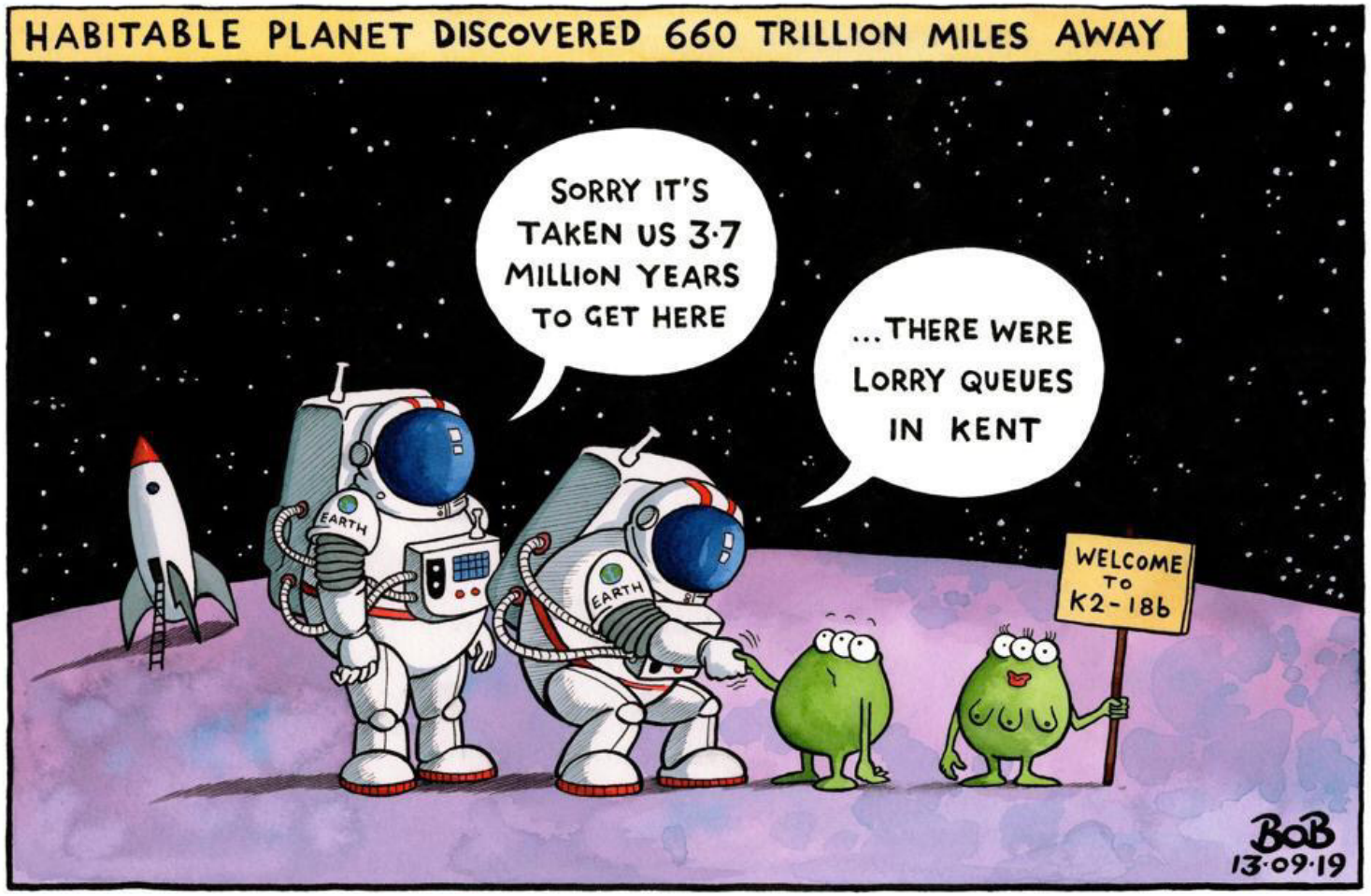
Kokori, et al. 2020, 2021; Edwards et al 2020a,b



CONCLUSIONS

- Exoplanets appear to be ubiquitous in our Galaxy
- The number of discovered exoplanets is increasing exponentially, but we still know very little about them
- We will have a suite of dedicated space missions in the next decade to discover more and more interesting targets (TESS, Cheops, PLATO)
- ALMA and SKA (will) give important contributions to our understanding of planet formation
- We have large facilities from the ground (ELT, TMT) and satellites in space (JWST, Twinkle) + dedicated missions (Ariel) to observe the atmospheric composition and structure of a large number of exoplanets
- **Exoplanetary science is and will continue to be a global endeavour!**

…we can't go there yet!



We need to take care of this one!