UNIVERSITÉ DE GENÈVE

PlanetS
National Centre of Competence in Research

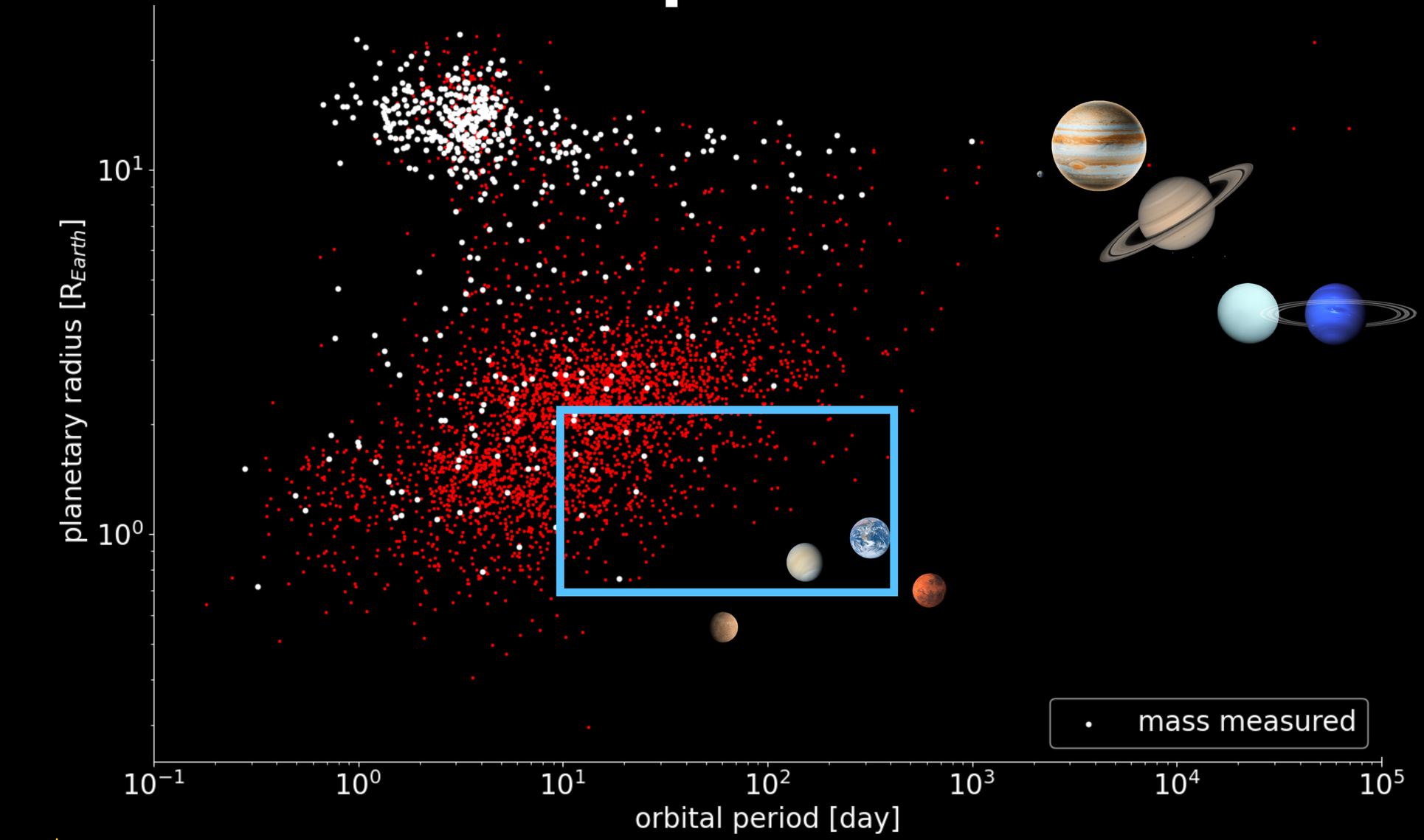
Swiss National Science Foundation

CARES-RIVERS

Characterisation of the Architecture of (nearly-) Resonant Exoplanetary Systems

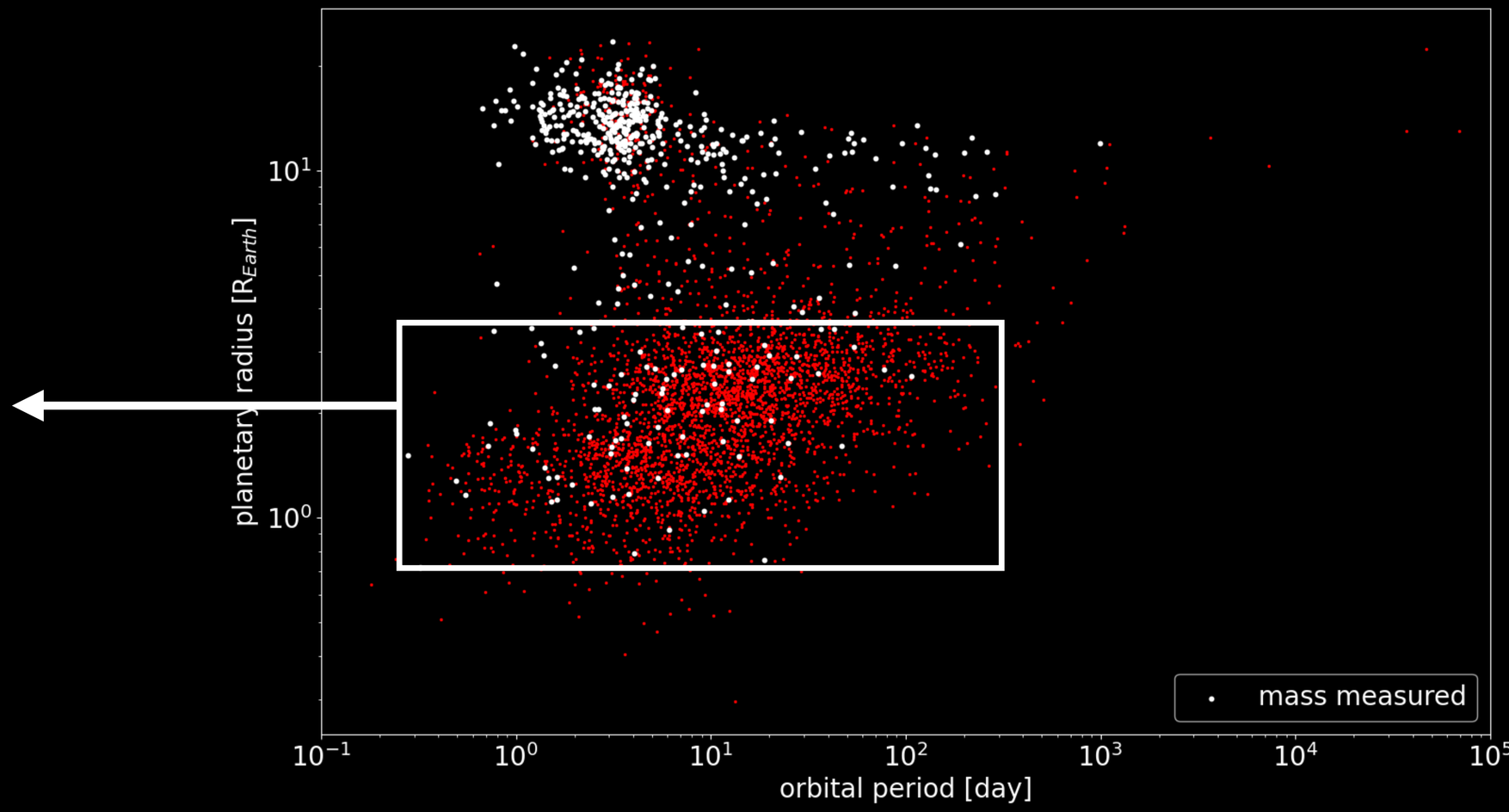
Adrien Leleu

Exoplanets


planetary radius [R_{Earth}]
10^1
10^0
10^{-1}
10^0
10^1
10^2
10^3
10^4
10^5
orbital period [day]
mass measured


cooler planets

Scientific Objectives - Statistics

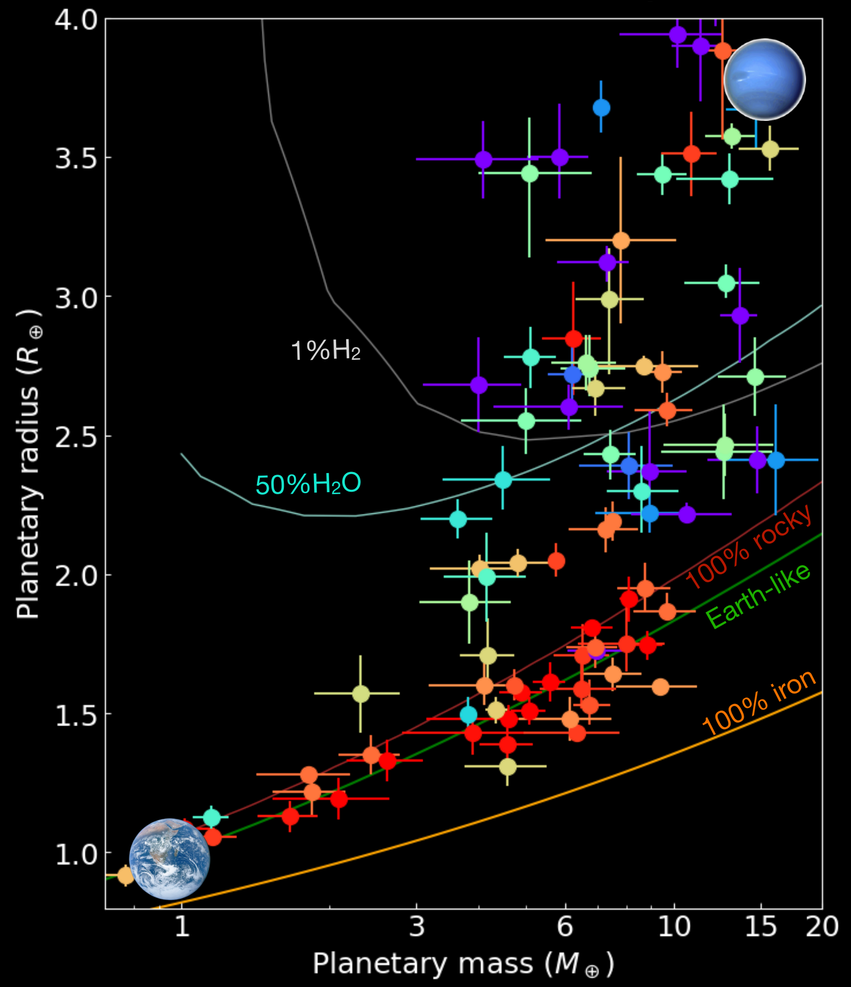


O1: Significant increase in the number of well **characterised small planets**

WP1: RIVERS

Scientific Objectives - in-depth characterisation

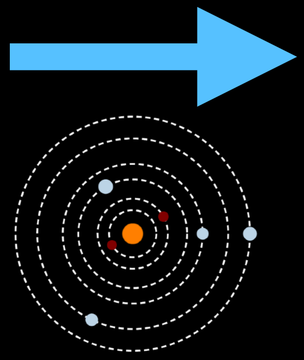
Mass/Radius sub-Neptunes



O1: Significant increase in the number of well **characterised small planets**

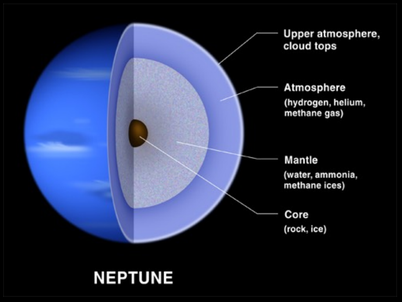
WP1: RIVERS

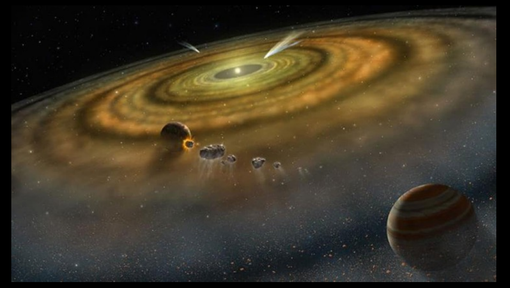
O2: Key **system architectures** (masses, radii, orbits)



WP2: CARES

O3: New constraints on **internal structure**



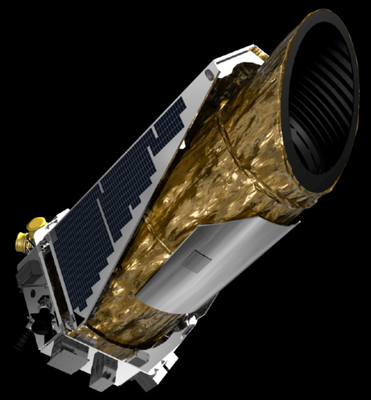


O4: New constraints on **systems formation**

WP3: Tides and migration

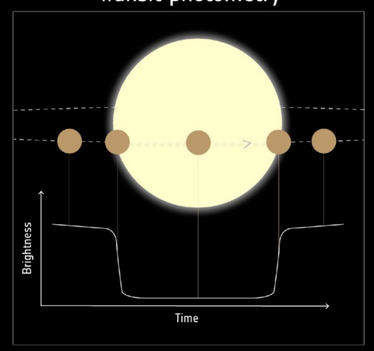
Transit method

Kepler (2009-2014)

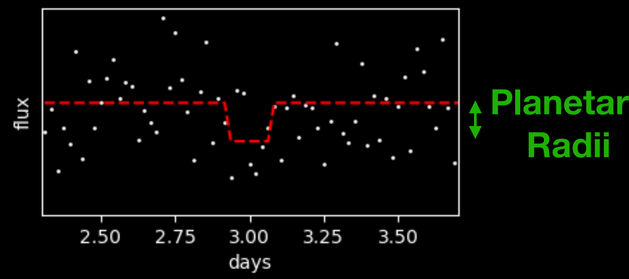


thousands of validated planets

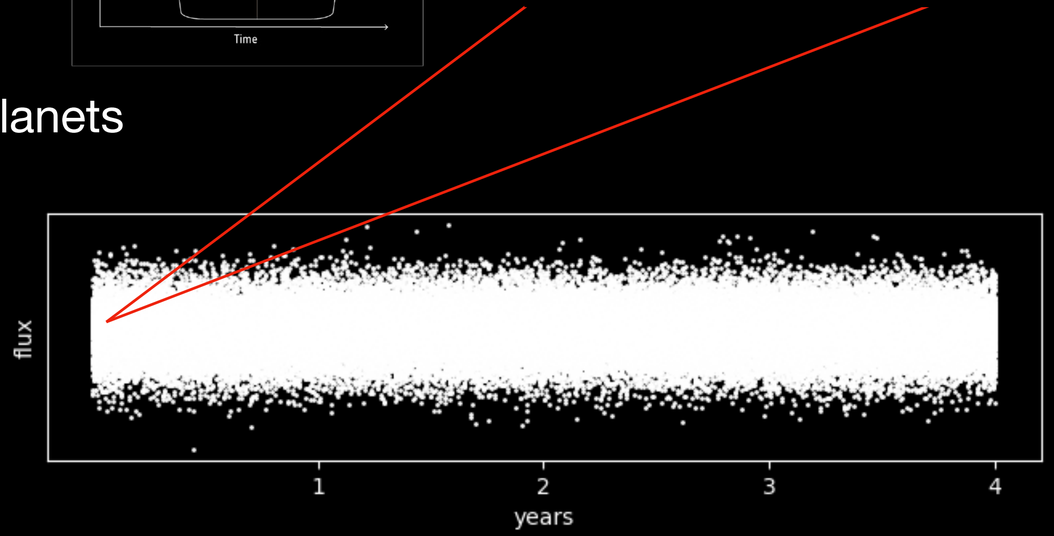
TESS (2019-)

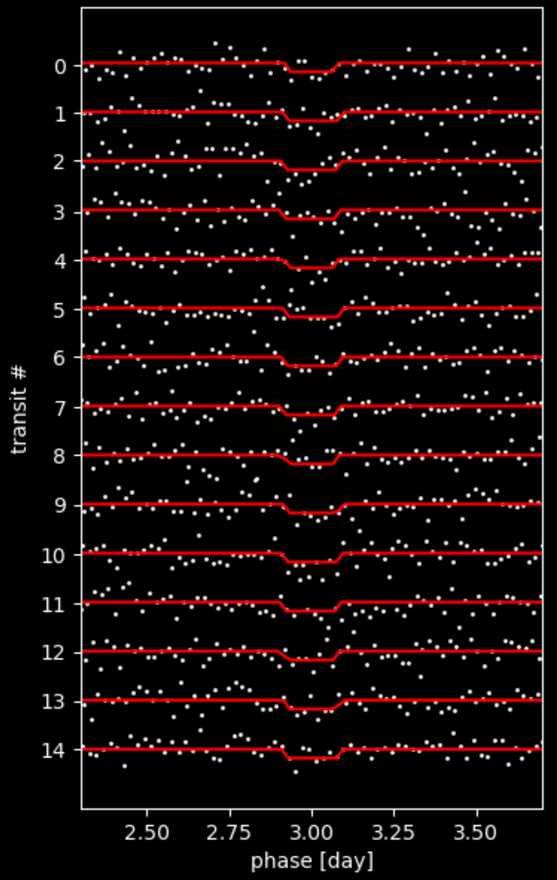


Signal/Noise~1

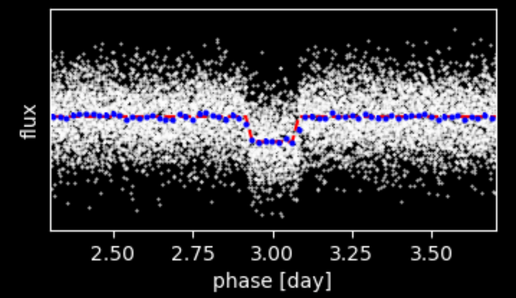


Planetary Radii

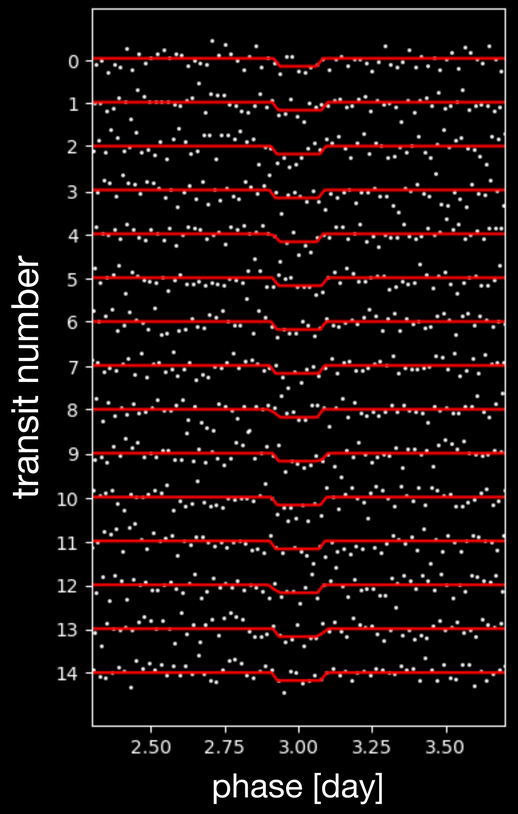


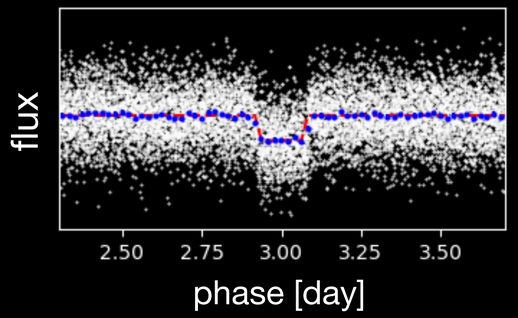


Signal/Noise~12

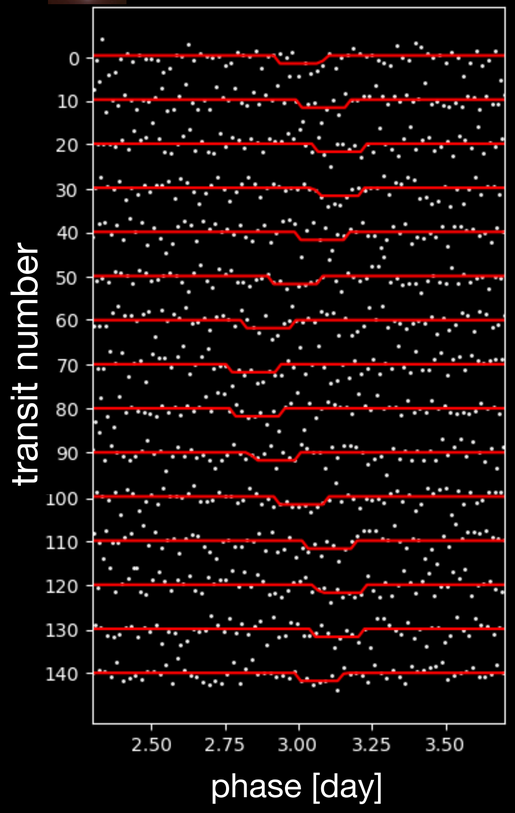


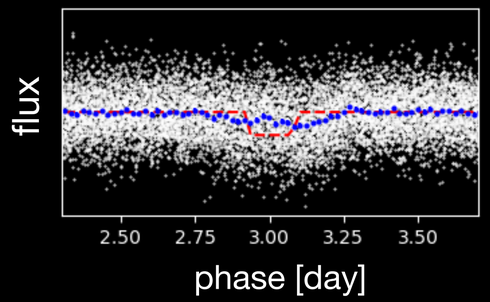
Transit Timing Variations (TTVs)





Planet-planet gravitation





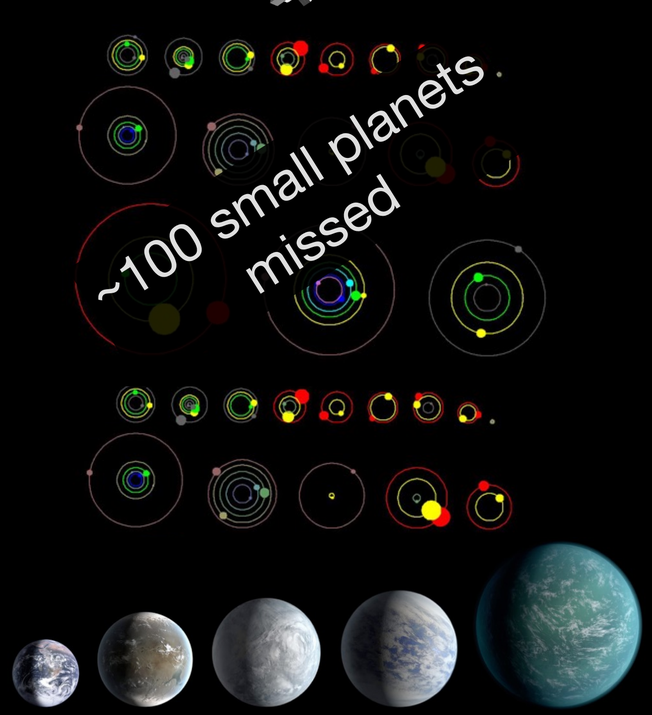
Mis-characterised

Non-detection

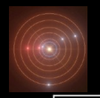
all (nearly)-resonant

$P_{out}/P_{in} \approx (k+q)/k$

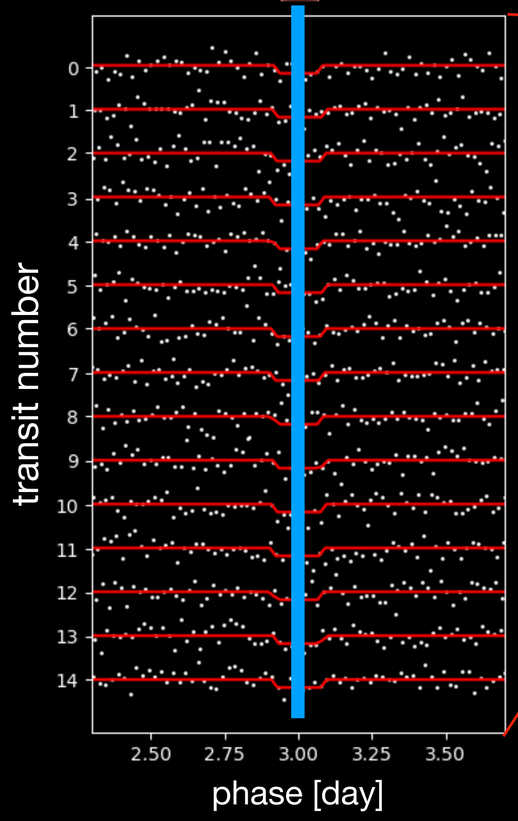
Impact on comparison with synthetic population

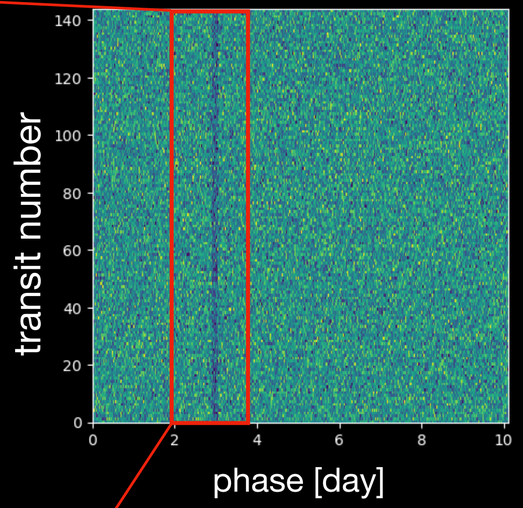


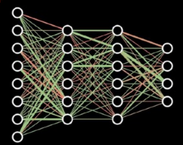
RIVERS method



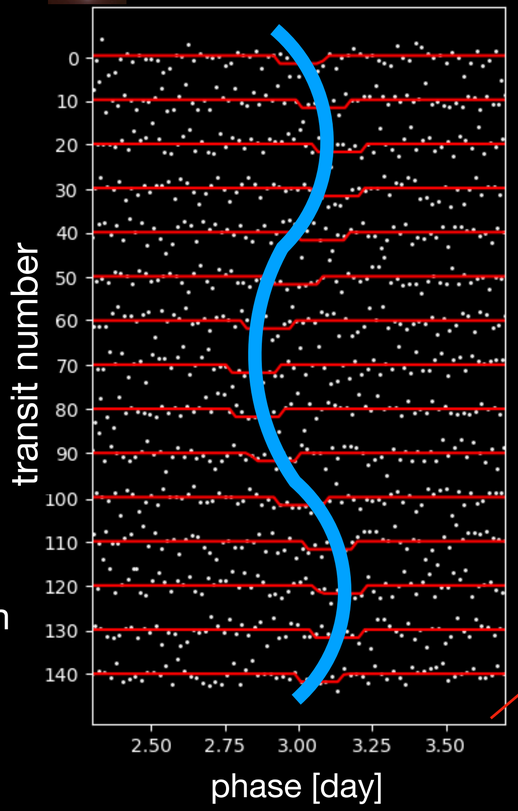
Planet-planet gravitation

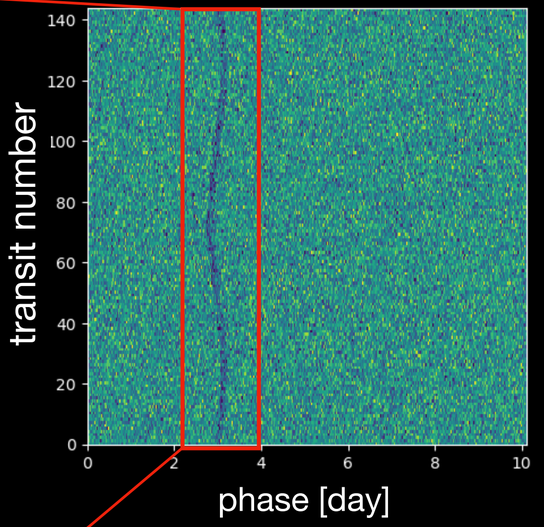


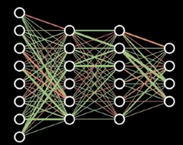




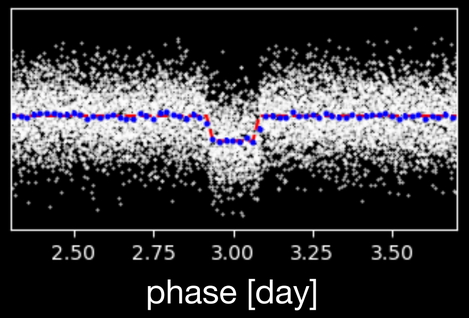
Pattern recognition

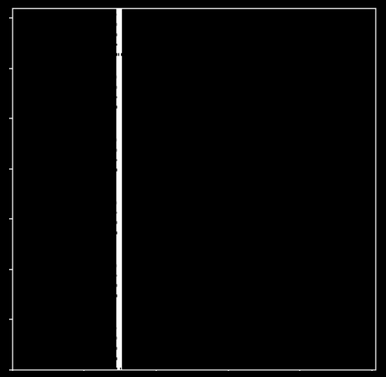




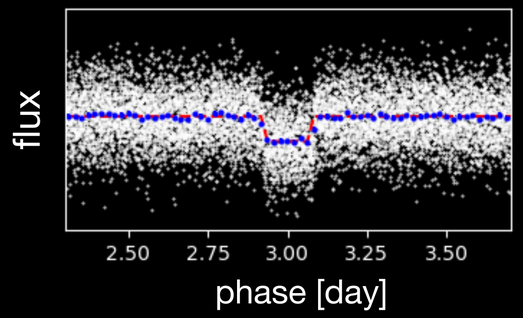


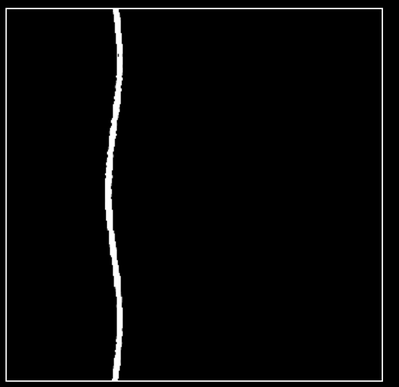
Pattern recognition





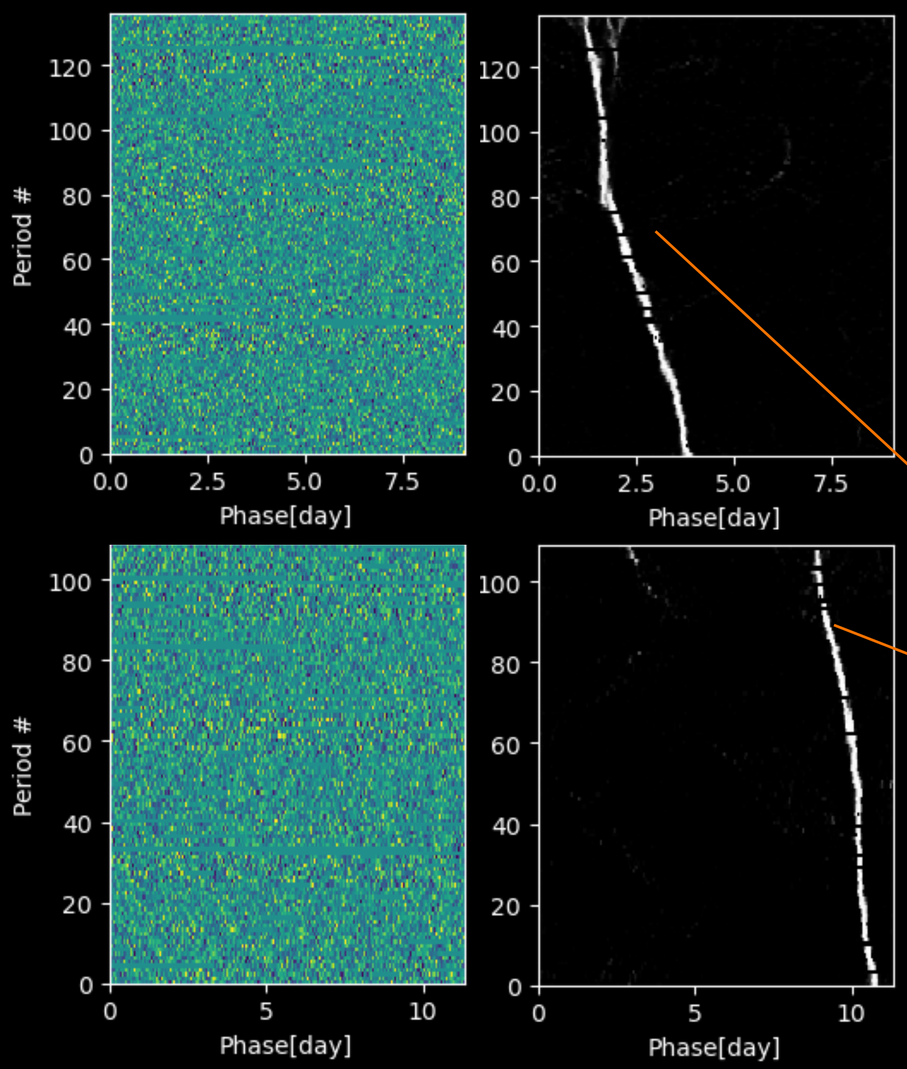
Semantic segmentation



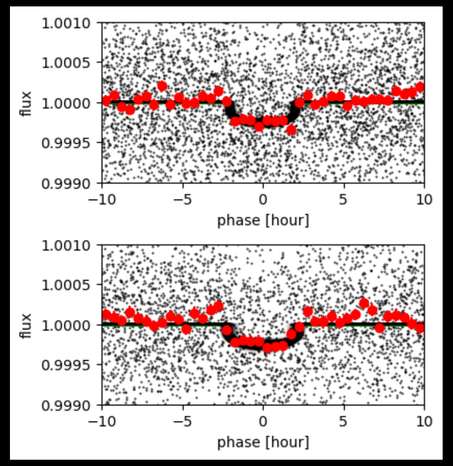


Semantic segmentation

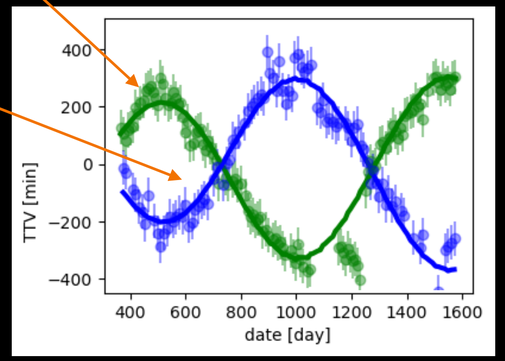
RIVERS Discoveries



Kepler-1705 - Leleu et al (2021b)



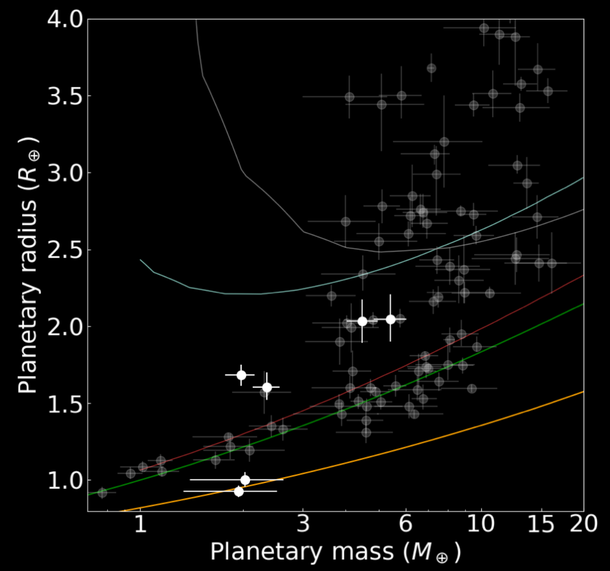
Planetary Radii

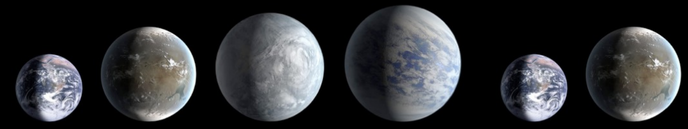


Planetary masses

TTVs allow for mass measurements of small planets at large orbital periods

6 new characterised planets

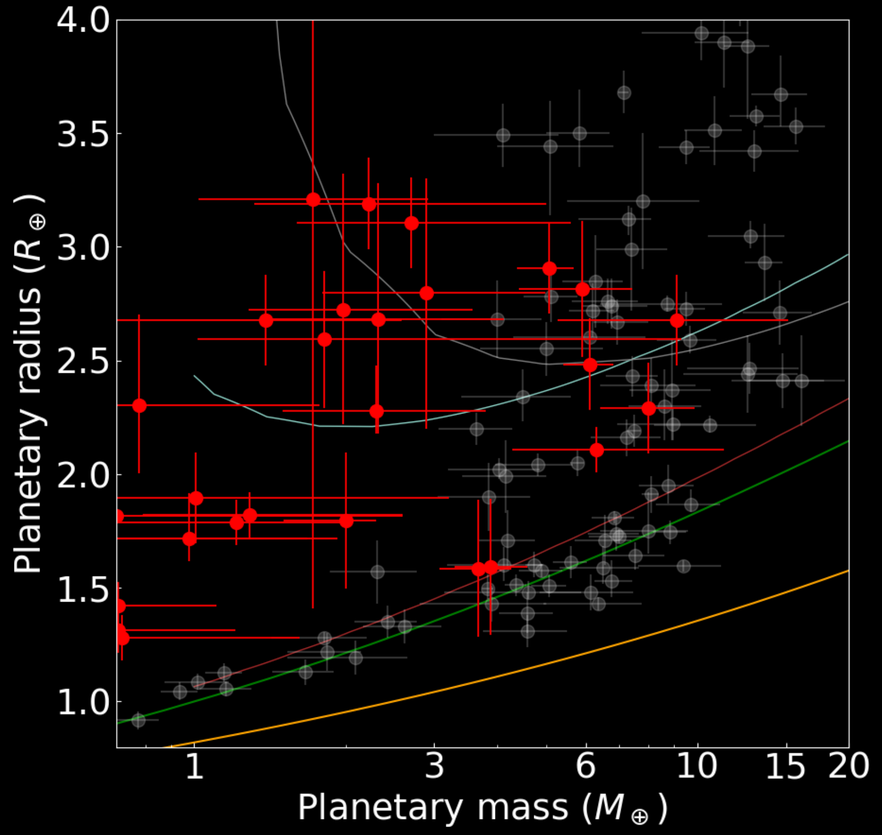




RIVERS discoveries

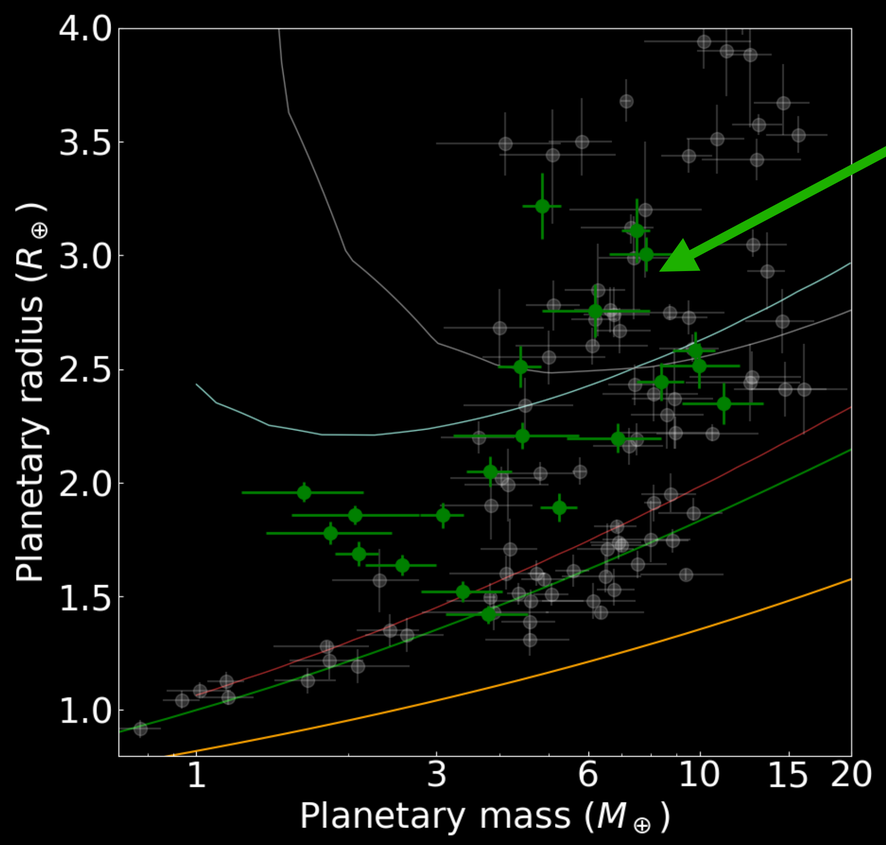
Leleu et al (2021b,2022a)

Un-biasing the masses and radii of Kepler systems



Subset of 24 published Kepler planets

Leleu et al (2023)

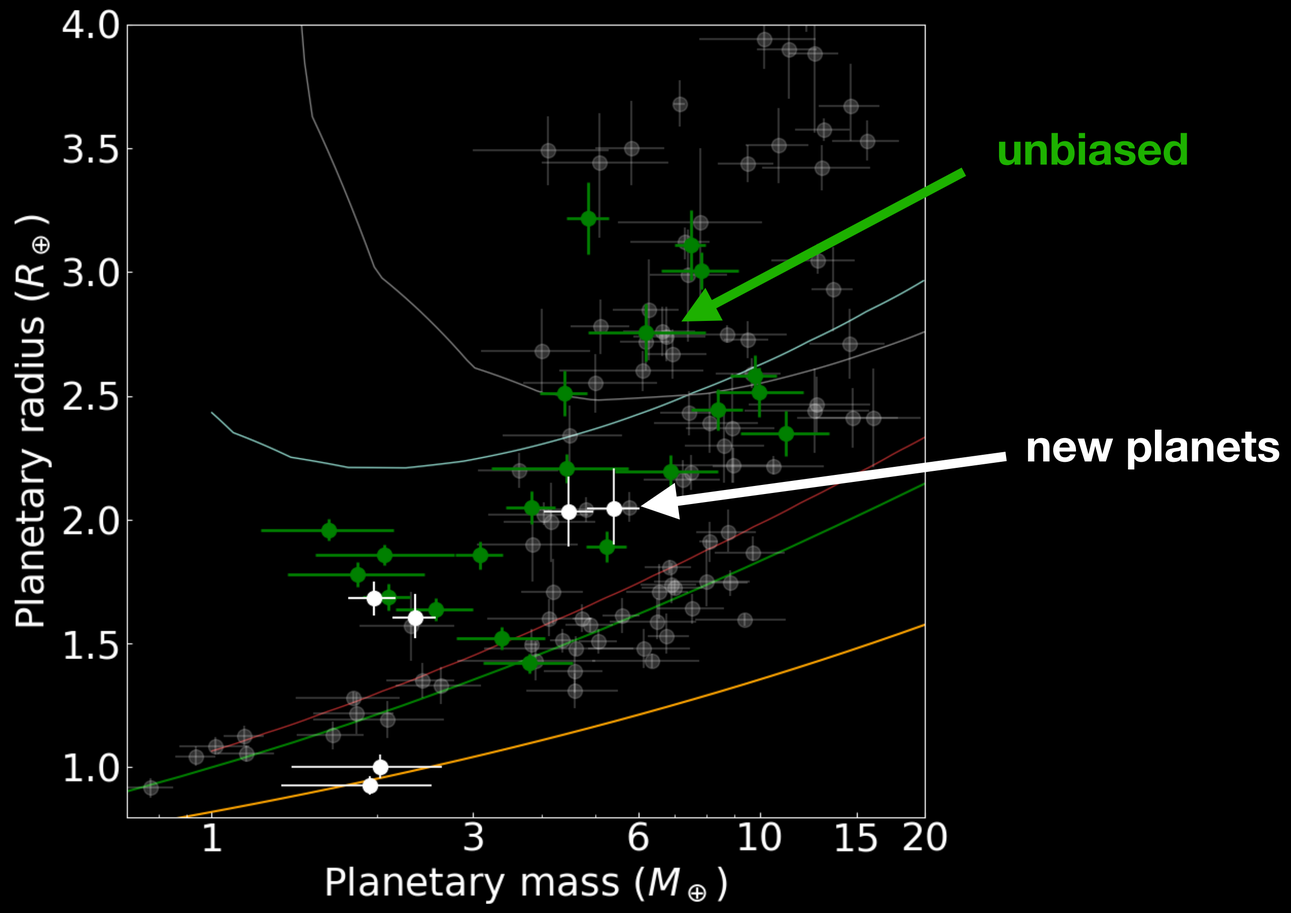


unbiased

RIVERS characterisation

Result of RIVERS' proof of concept

Leleu et al (2021b, 2022a, 2022b)

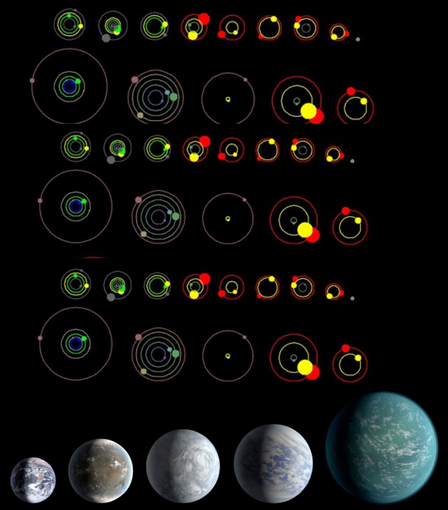


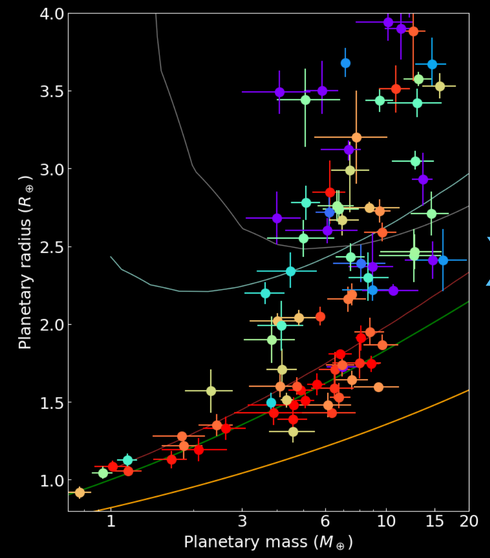
the proof-of-concept of RIVERS was applied to 2000 Kepler stars thus far

WP1: RIVERS

Project goals

Detect and characterise

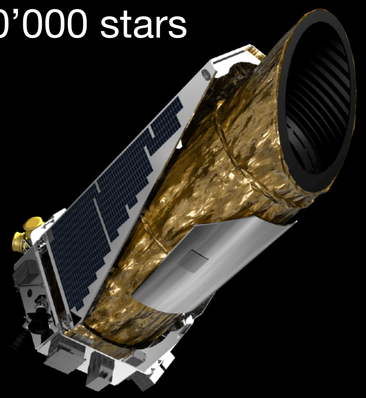




X2

Kepler (2009-2014)

200’000 stars



Long baseline:

✓ Ideal for TTV characterisation

✗ Especially subject to TTV biases

thousands of detected planets

Short baseline / full sky:

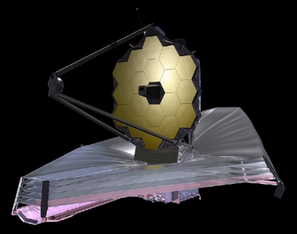
✗ Requires follow-up

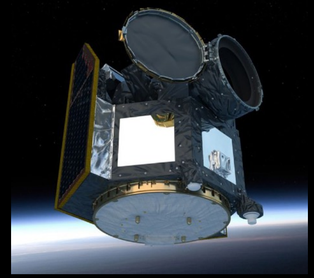
✓ Targets ideal for follow-up

TESS (2019-)

200’000 stars

Key systems for **WP2**: in-depth characterisation





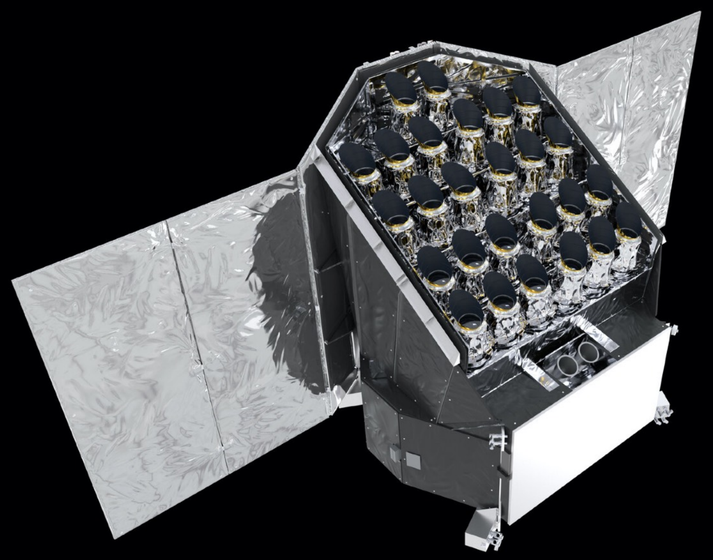
CHEOPS

PI in charge of **System Architecture** program

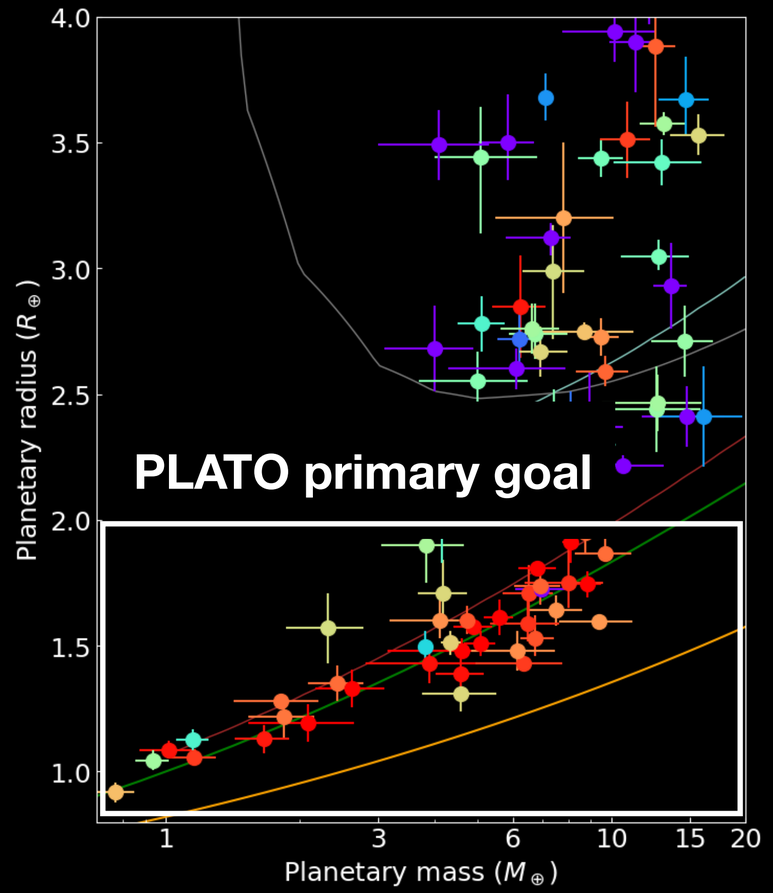
WP1: RIVERS

PLATO (2026-)

>200’000 **bright** stars



- ✓ Long baseline ideal for TTVs
- ✓ Targets ideal for follow-up
- ✓ Unprecedented precision
- ✗ Especially subject to TTV biases



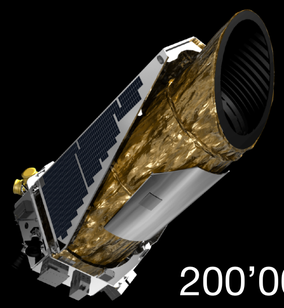
PLATO workpackage:

RIVERS

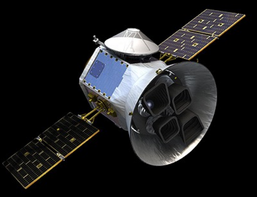
MISSION CRITICAL

Leader: Adrien Leleu

CARES-RIVERS flow



200’000 stars

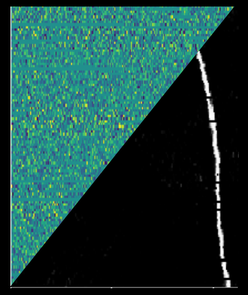


200’000 stars

>200’000 stars

~1’000’000’000 frames/mission

Big data/ machine learning

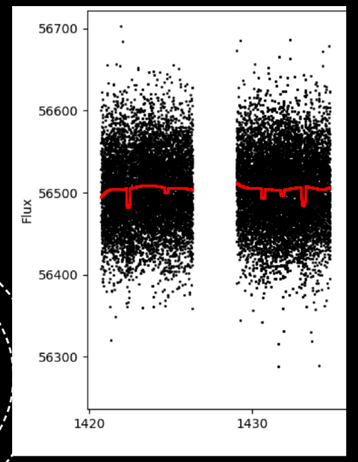


Database

+RV

Data modeling

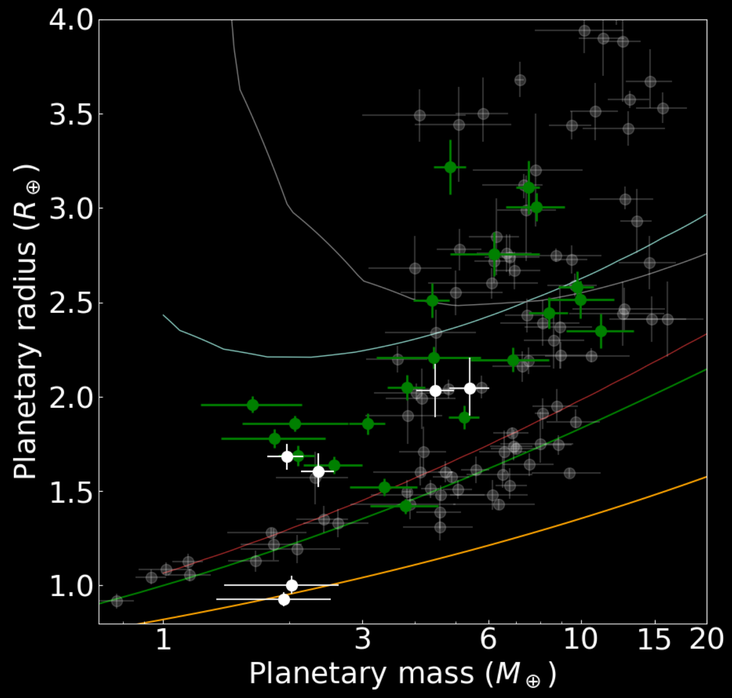
Planetary Radius



Planetary masses

Dynamical modeling

Fully characterised planets

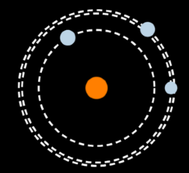


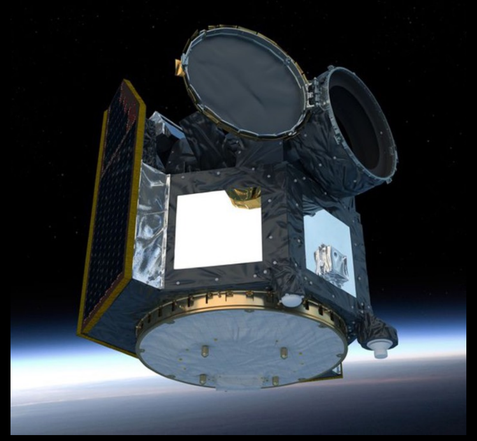
WP1 - RIVERS - PHD

WP2 - CARES - Postdoc 1

UNIVERSITÉ DE GENÈVE | SIP stochastic information processing

WP2 : CARES - Example: TOI-178





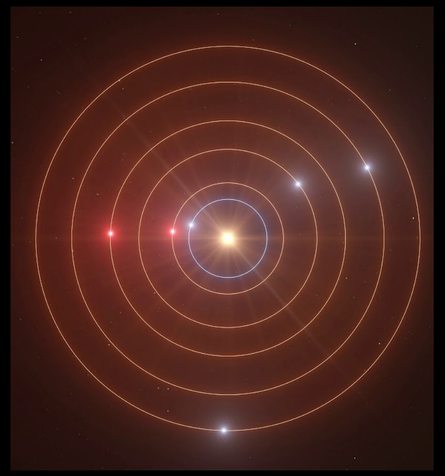
CHEOPS

State-of-the-art follow-up facilities

TOI-178
Leleu et al (2019)

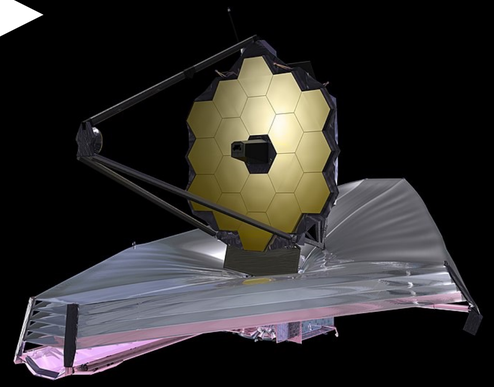
\+

Orbital dynamics



TOI-178
Leleu et al (2021)

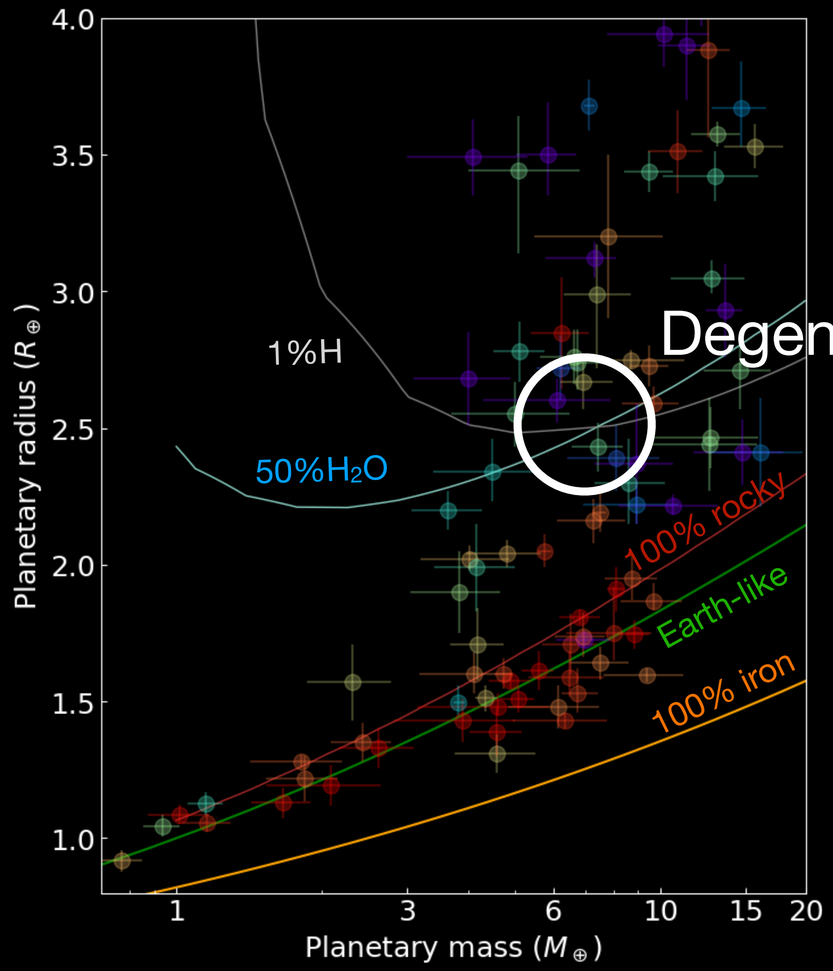
Enable
atmospheric characterisation



CO-I of James Webb Space Telescope observations

Apply to other key systems : WP2 - CARES - Postdoc 1

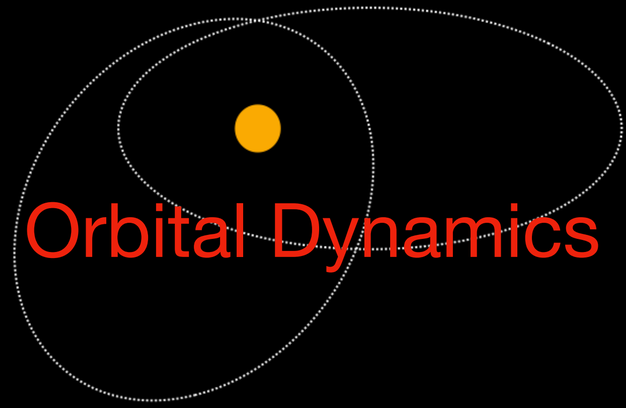
WP2 and WP3: Beyond the mass/radius relationship



Degeneracies

See also Paolo's talk!

Need new constraints

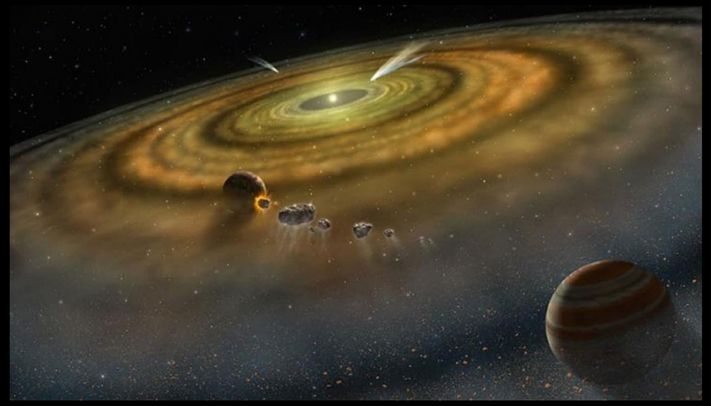


WP3 : System formation and planet internal structure

Transit Timing Variations from **WP1** and **WP2** is the only method to characterise resonant architectures

General case: system formation

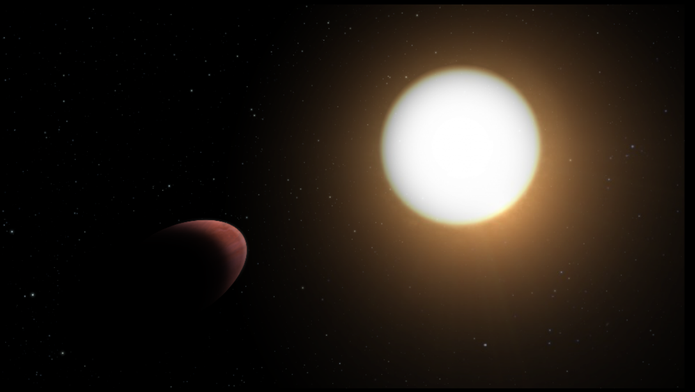
Leleu et al (2019b)



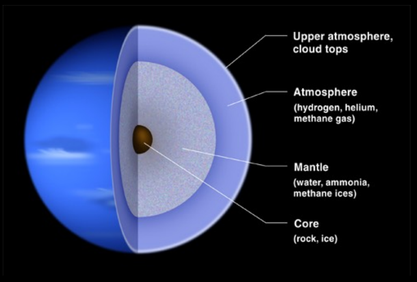
Resonances are footprints of proto-planetary discs

Close-in planets: tidal evolution

Leleu et al (2016, 2018b)



Observed resonant architecture constrains planet internal structures



Need for new analytical models of orbital dynamics : WP3 - Postdoc 2

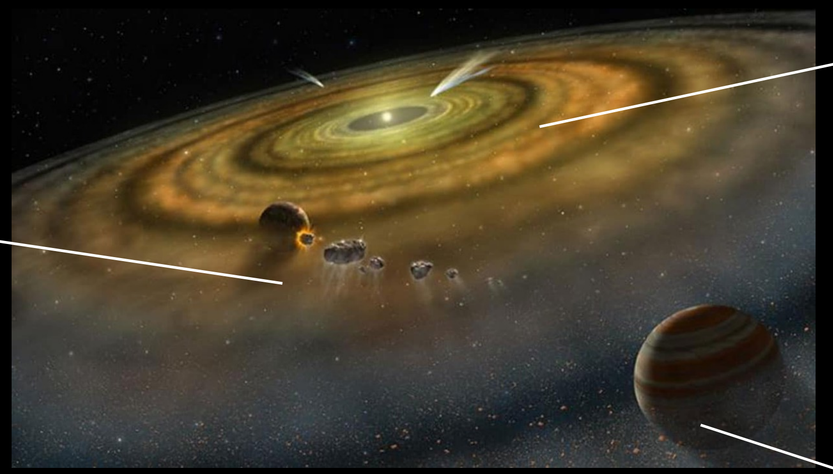
Project outcome: knowledge on rocky and Earth-like planets

New key systems

Architecture

order of capture

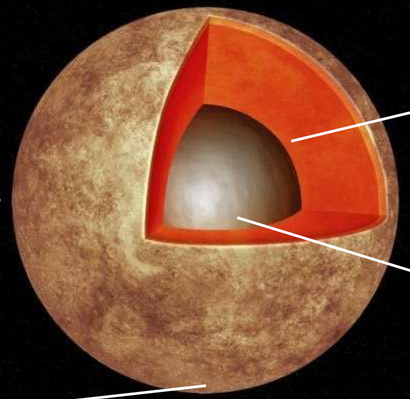
shape of the disc



location of planets at formation

Formation

Composition

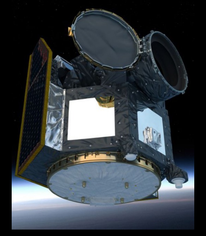


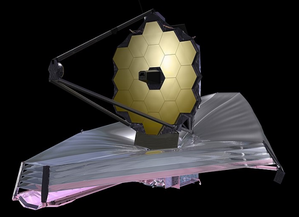
tidal response

atmospheric composition

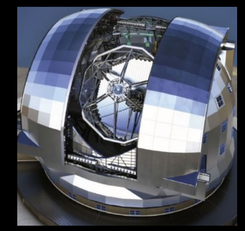
mass

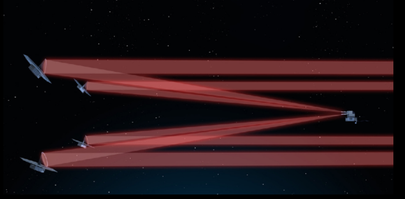
radius





To select target for Flagship missions





NCCR PlanetS

Swiss Institute of Planetary Science

Kepler+TESS

CHEOPS: System Architecture

PLATO: RIVERS critical

CARES-RIVERS

New key systems

open source

PLATO

Orbital Dynamics

Multi-Disciplinary Team

Innovative data analysis

In-depth characterisation

2020

2025

2030

2035

PLATO

TESS

CHEOPS

ARIEL

JWST

Extremely Large Telescope

Ground-based: ESPRESSO / NGTS / HARPS-NIRPS / …