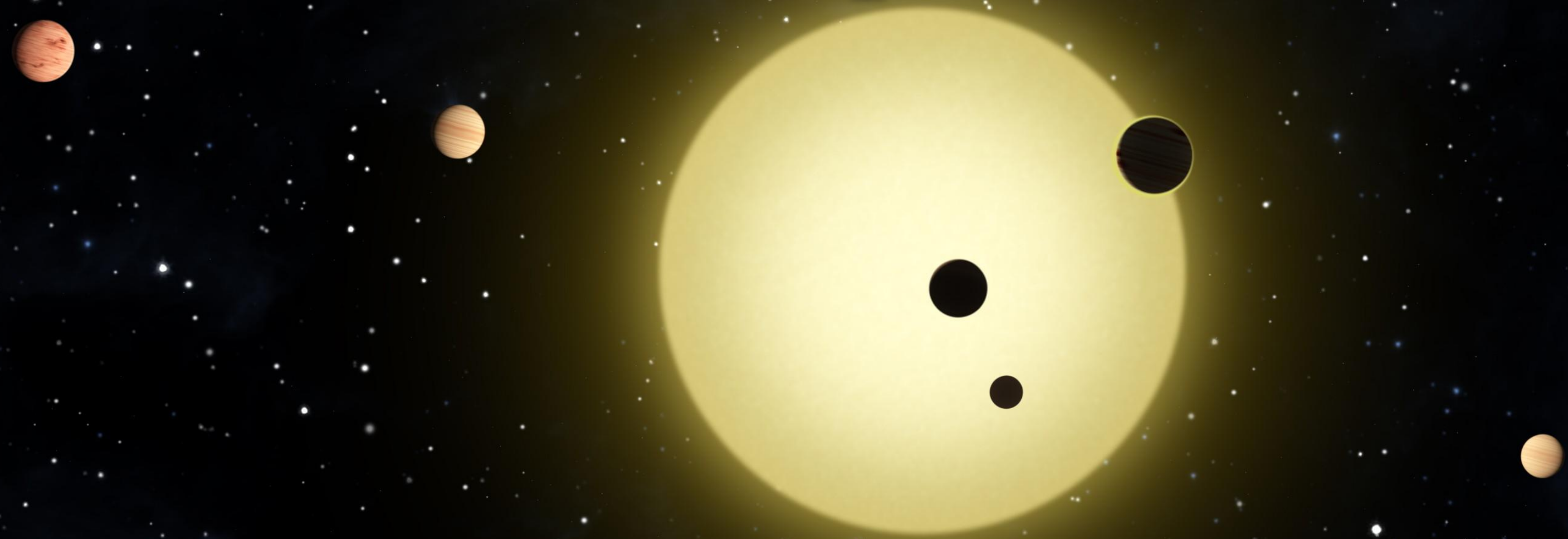
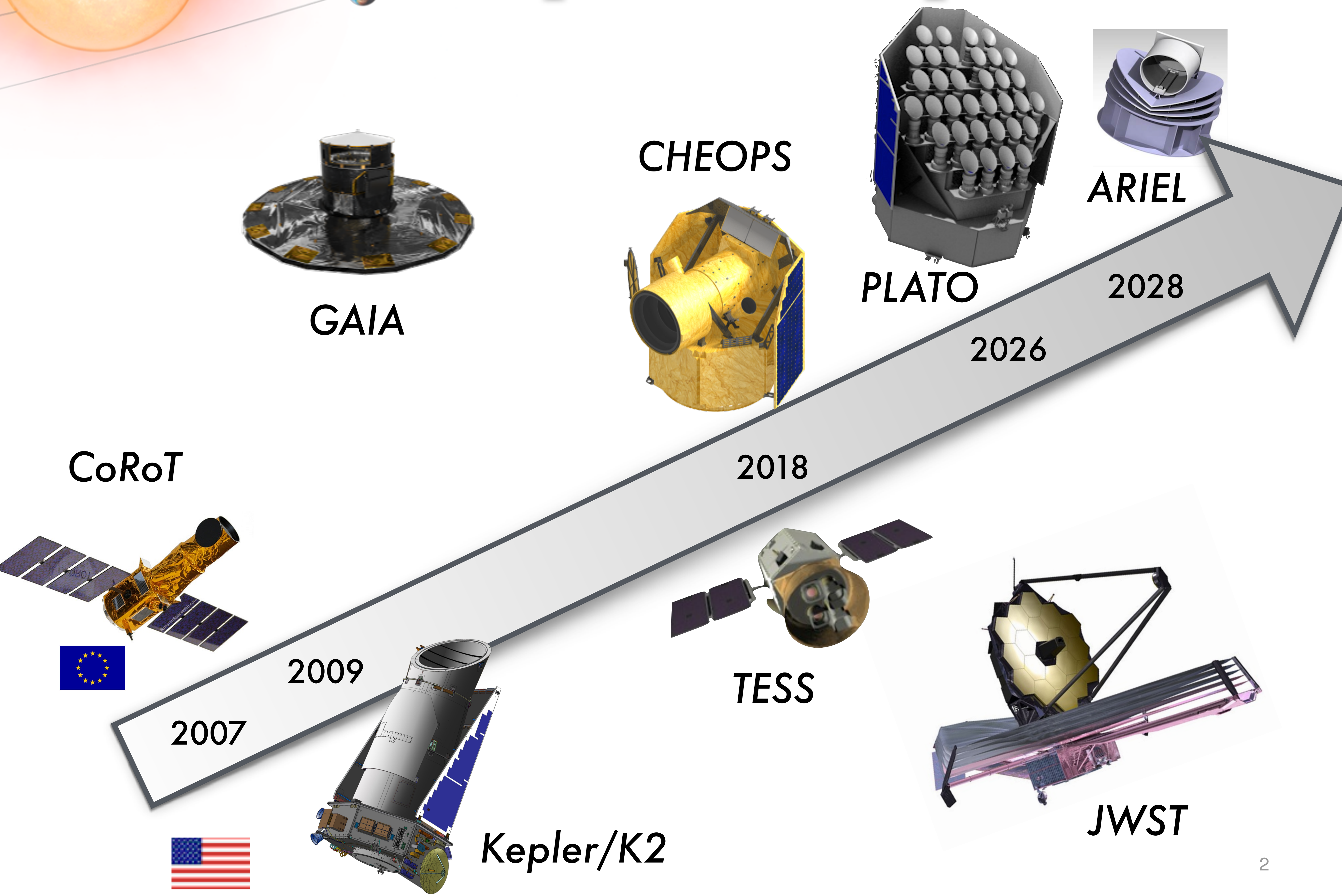
La mission spatiale PLATO ou l'apport de la physique stellaire à l'étude des planètes



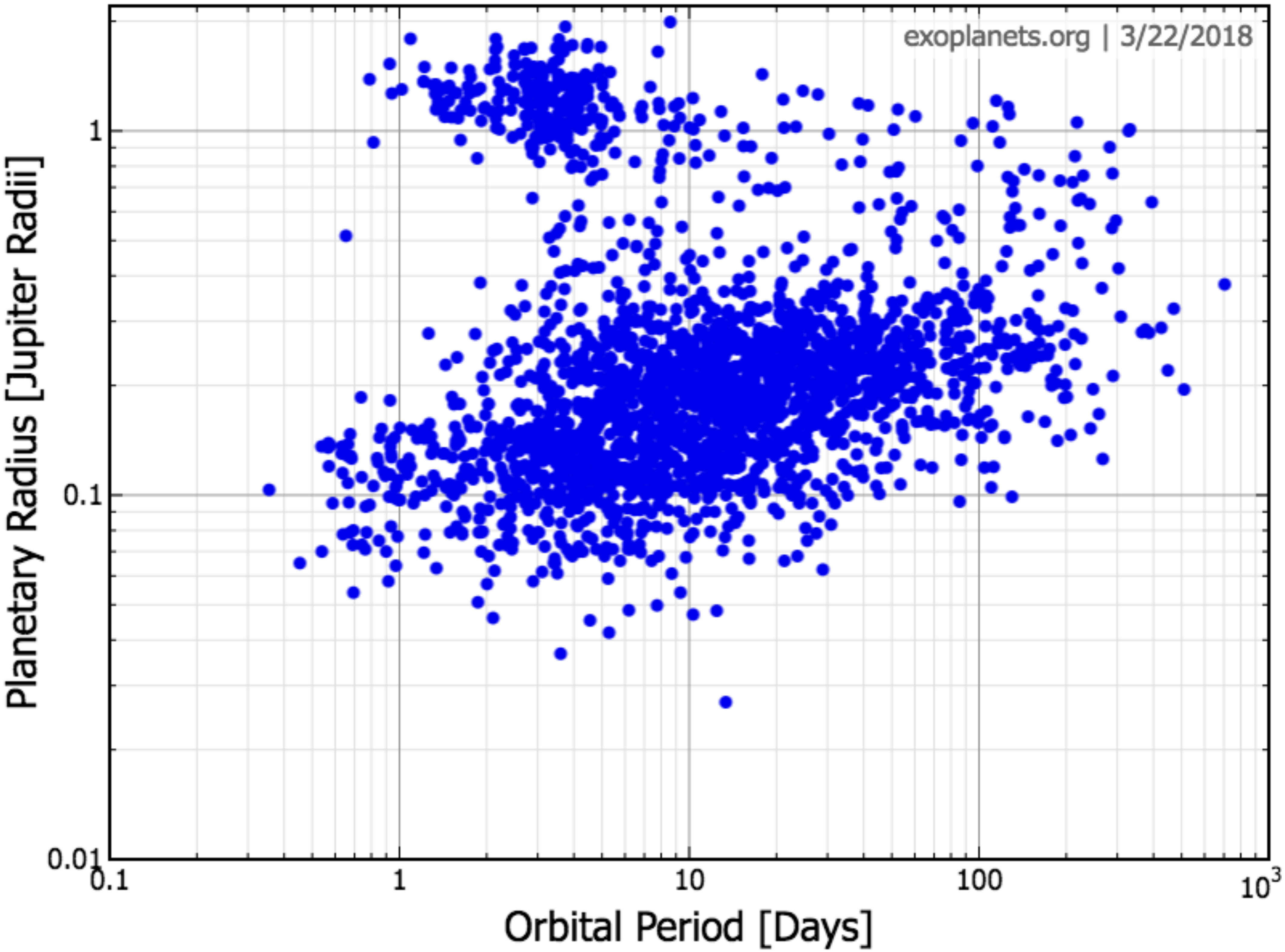
M.-J. Goupil, LESIA
M. Deleuil, LAM

Missions spatiales exoplanètes



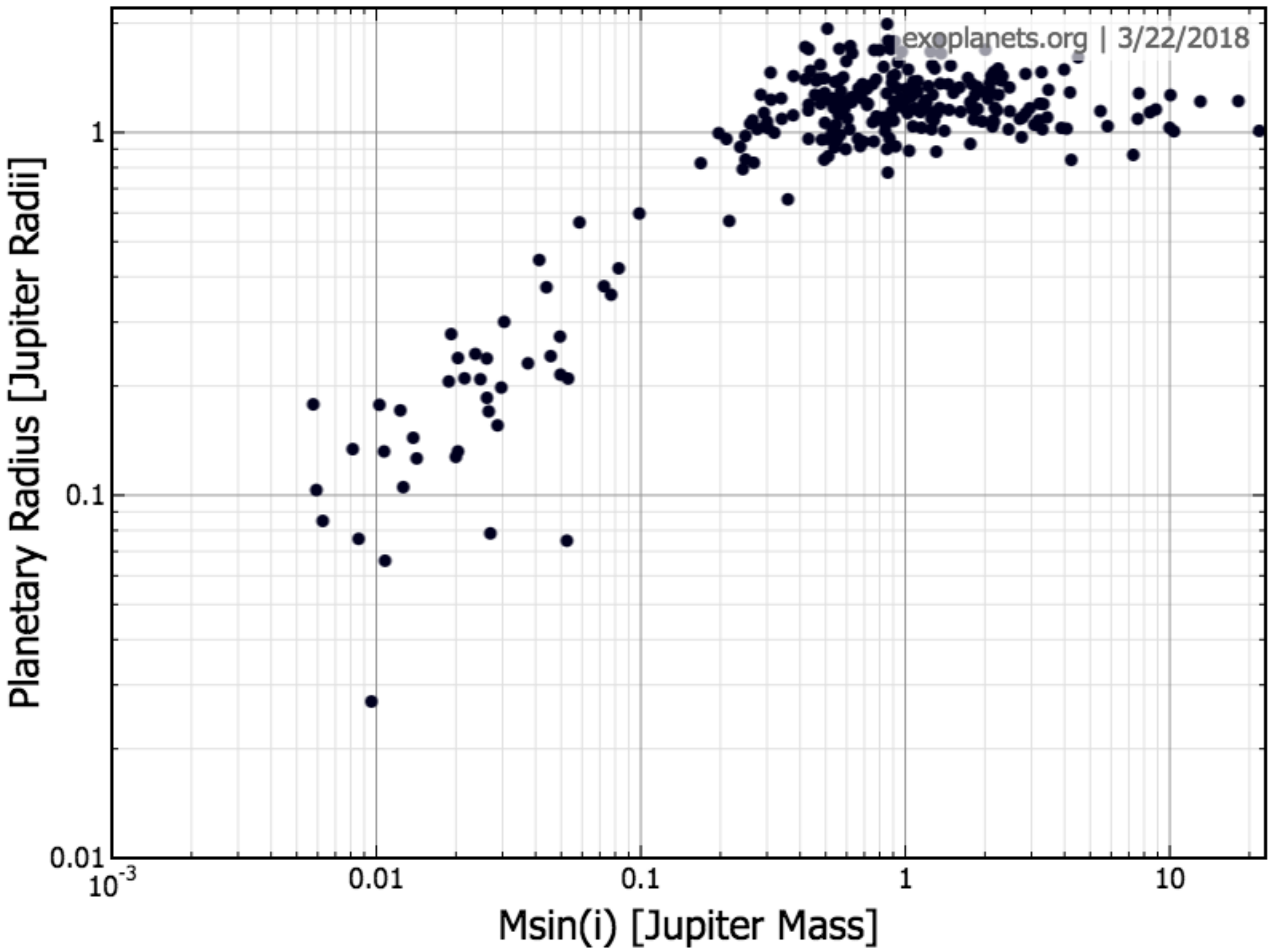
Détection: état de l'art

3706 planètes détectées



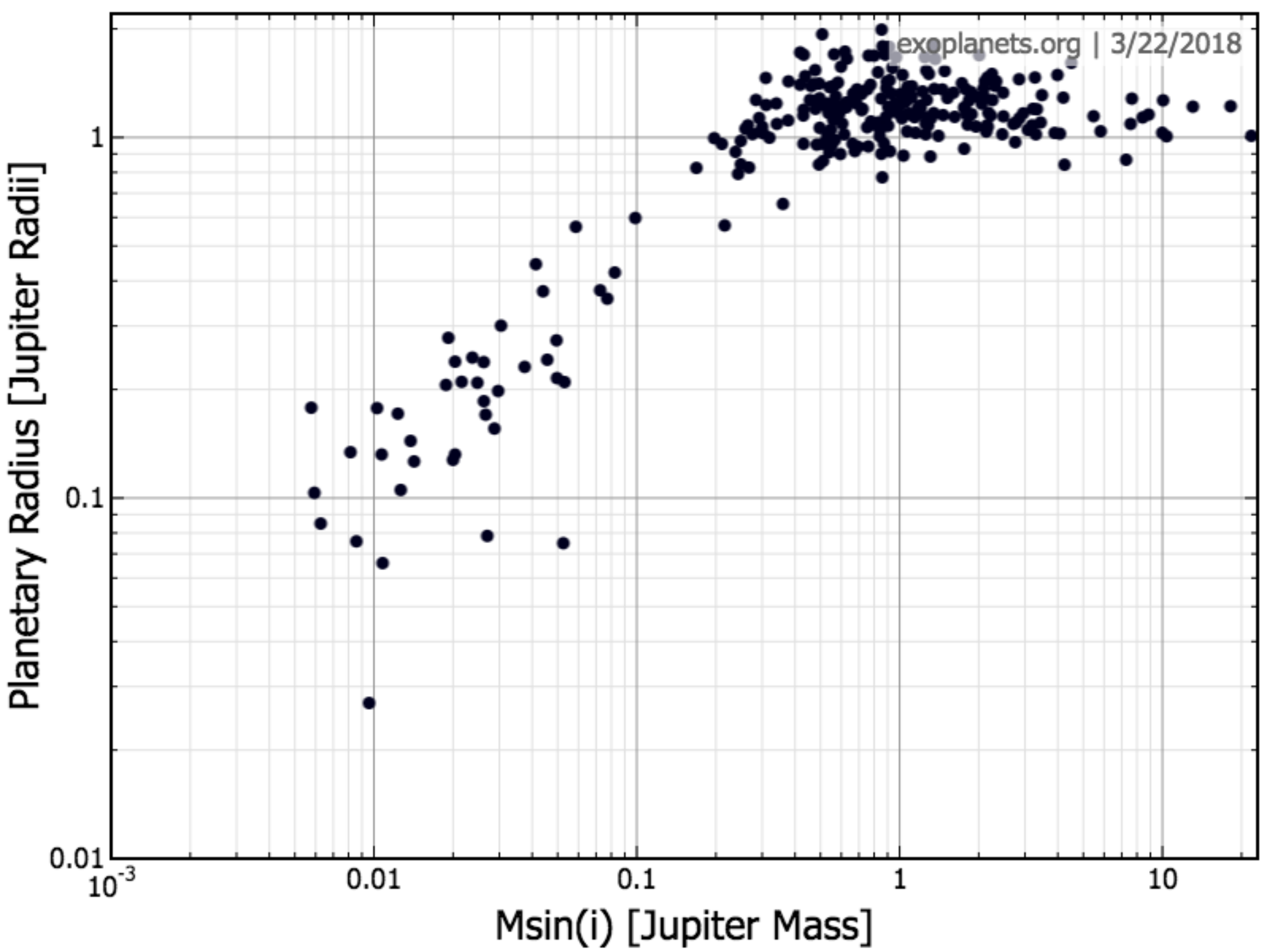
Détection: état de l'art

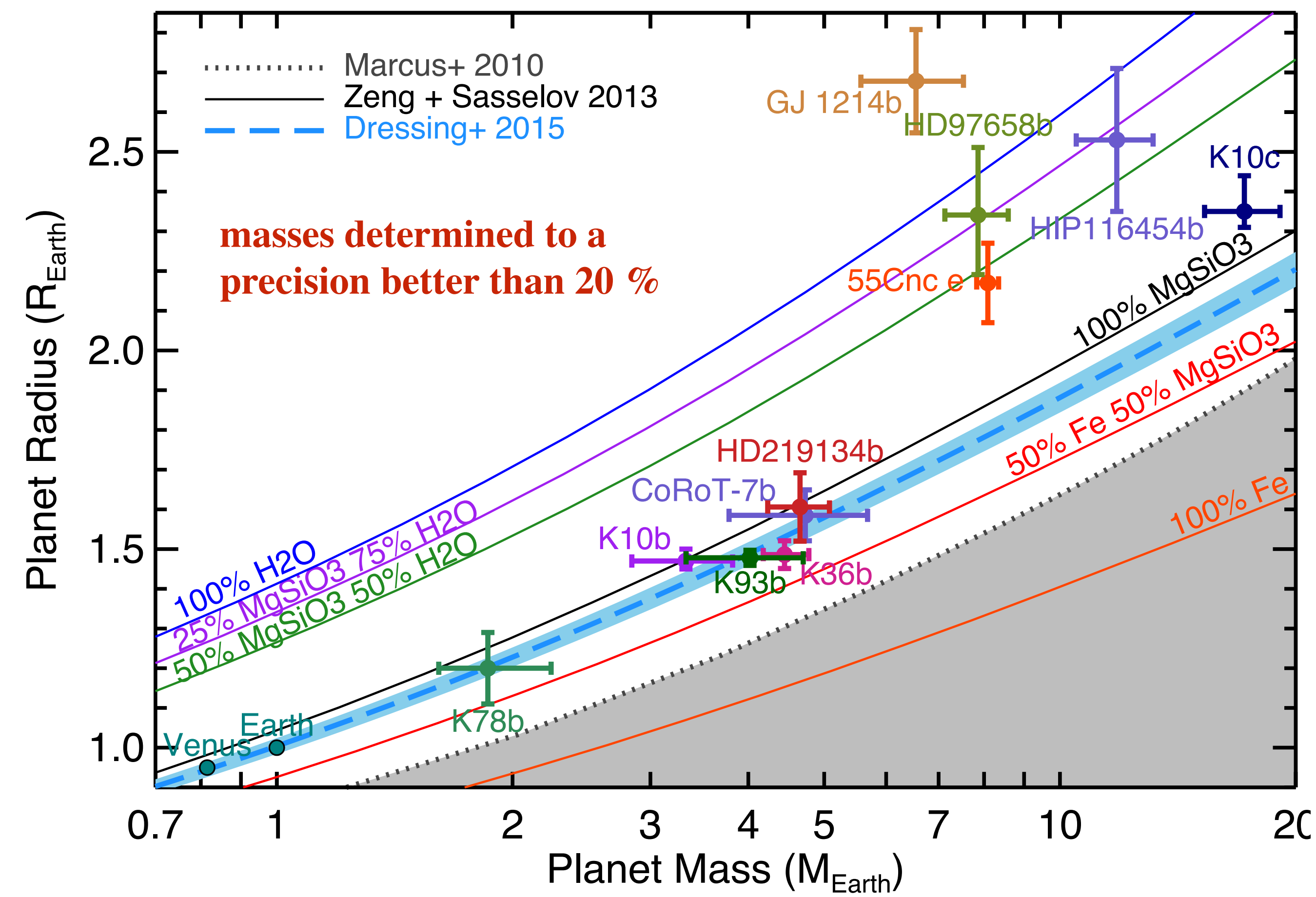
720 planètes



Détection: état de l’art

720 planètes



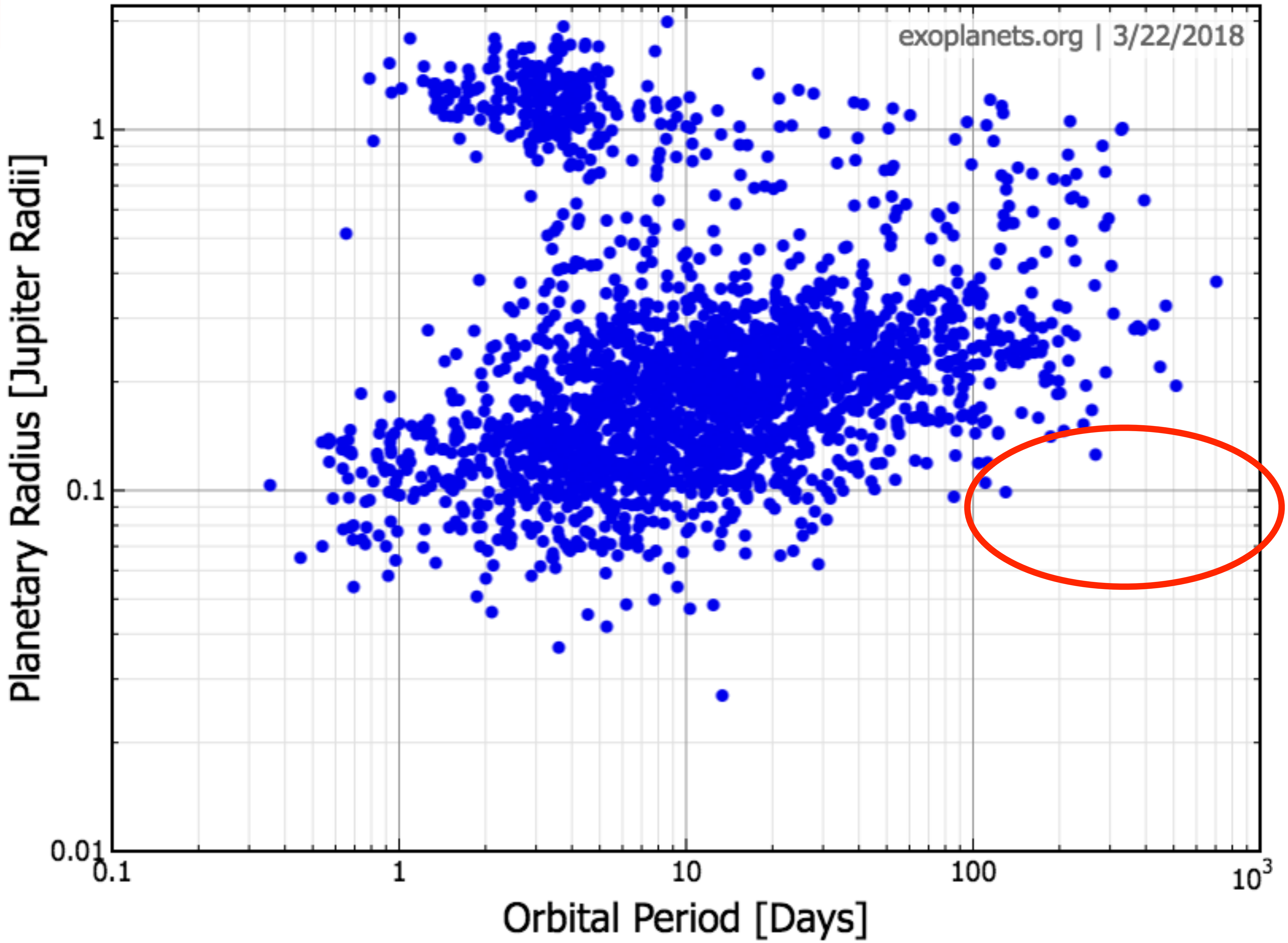


Batalha et al., 2010
Pepe et al., 2013
Howard et al, 2013
Marcy et al. 2014

Dumusque et al., 2014
Dressing et al., 2015;
Motalebi et al., 2015

Détection: état de l'art

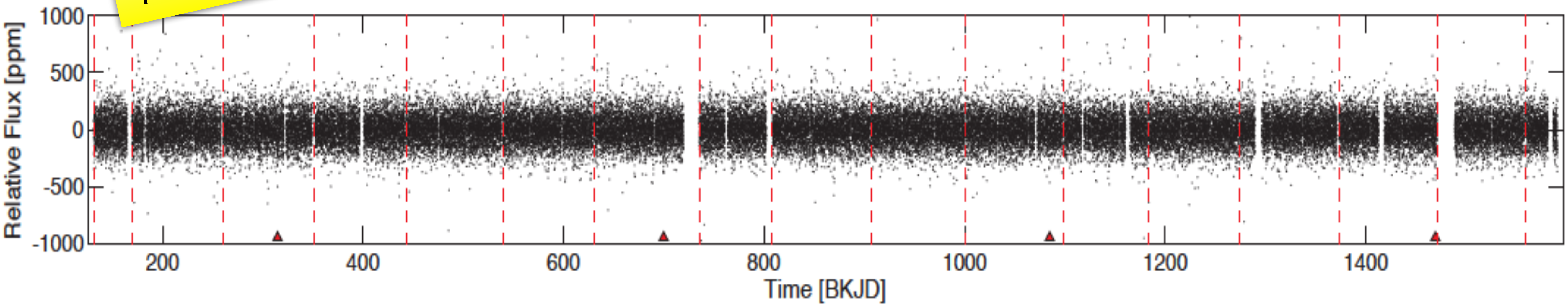
3706 planètes détectées



Super Terre à longue période orbitale

Type spectral: G2
période orbitale~ 385j

Jenkins et al 2015

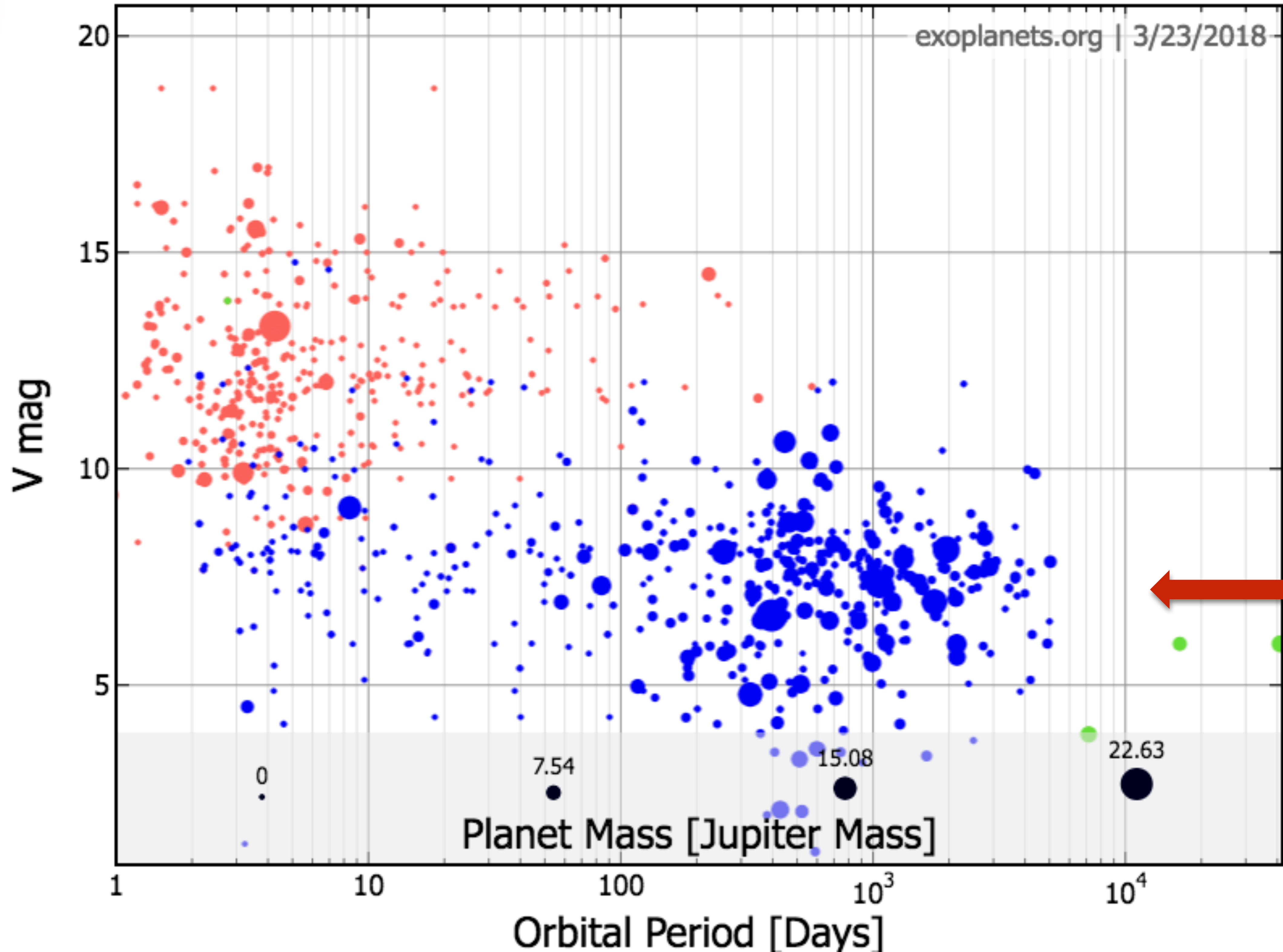


Kepler-452b :

Rp ~ 1.6 R⊕

Mass ???

Difficulté 1: la magnitude



Etoiles brillantes requises pour mesurer précisément masses et rayons

η-Earth - occurrence

η Earth: fraction d’étoiles avec une planète similaure à la Terre dans leur zone habitable.

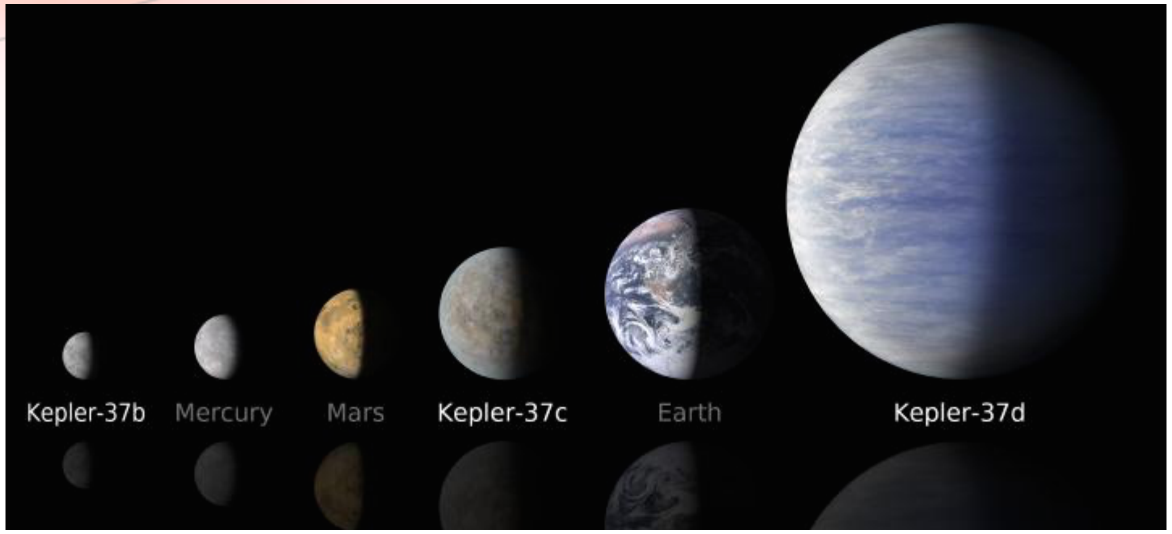
From Kepler and radial velocity surveys:

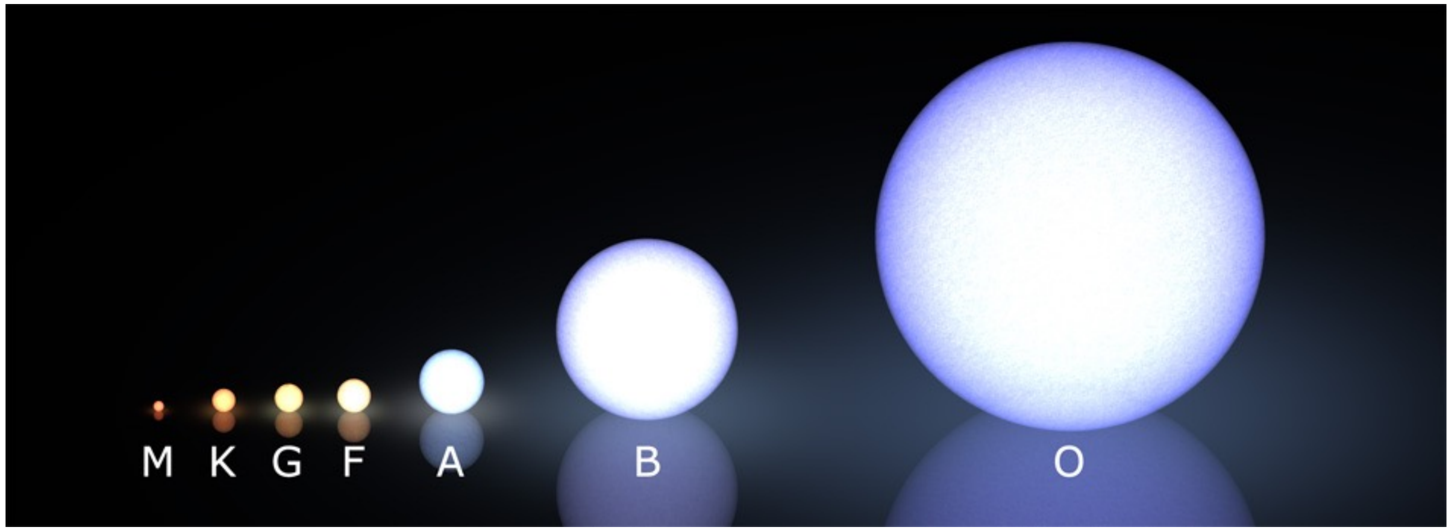
reference	planet frequency	host stellar type
Catanzarite & Shao (2011) ApJ, 738, 151	1%- 3%	Sun-like stars
Traub (2012) ApJ, 745, 20	20%-58% (34%)	FGK stars
Gaidos (2013) ApJ, 770, 90	31%-64% (46%)	dwarf stars
Bonfils et al. (2013) A&A, 549, A109	28%-95% (41%)	M stars
Dressing & Charbonneau (2013) ApJ, 767, 95	9%-28% (15%)	M stars
Kopparapu (2013) ApJ, 767, 8	24%-60% (48%)	M stars

Batalha et al., 2014	7 – 22%	Sun-like stars

➙ La fréquence des (super)-Terres dans la zone habitable des étoiles reste inconnue.

Difficulté 2: l'étoile

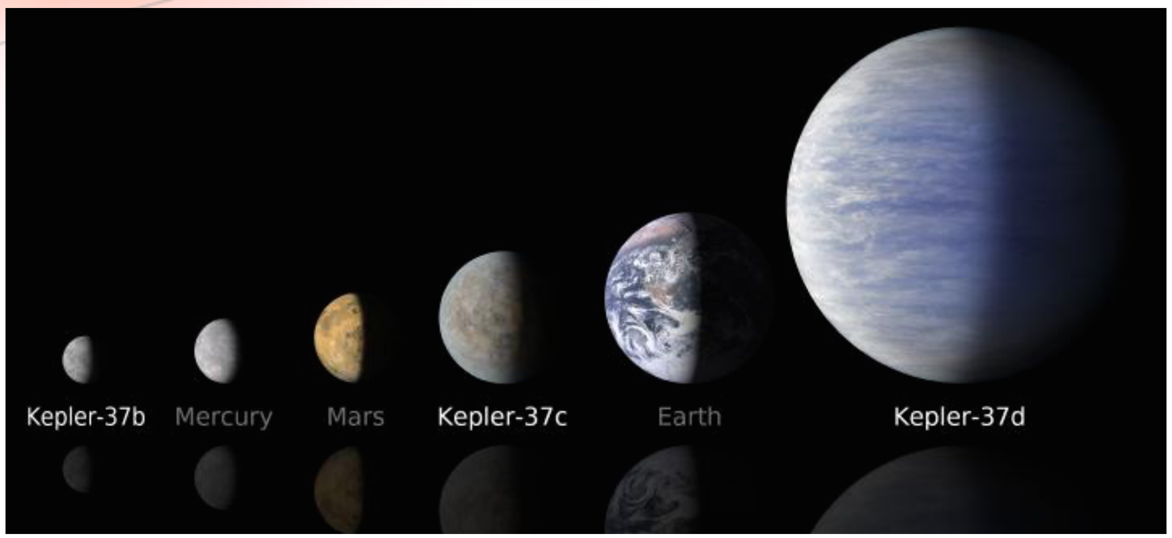


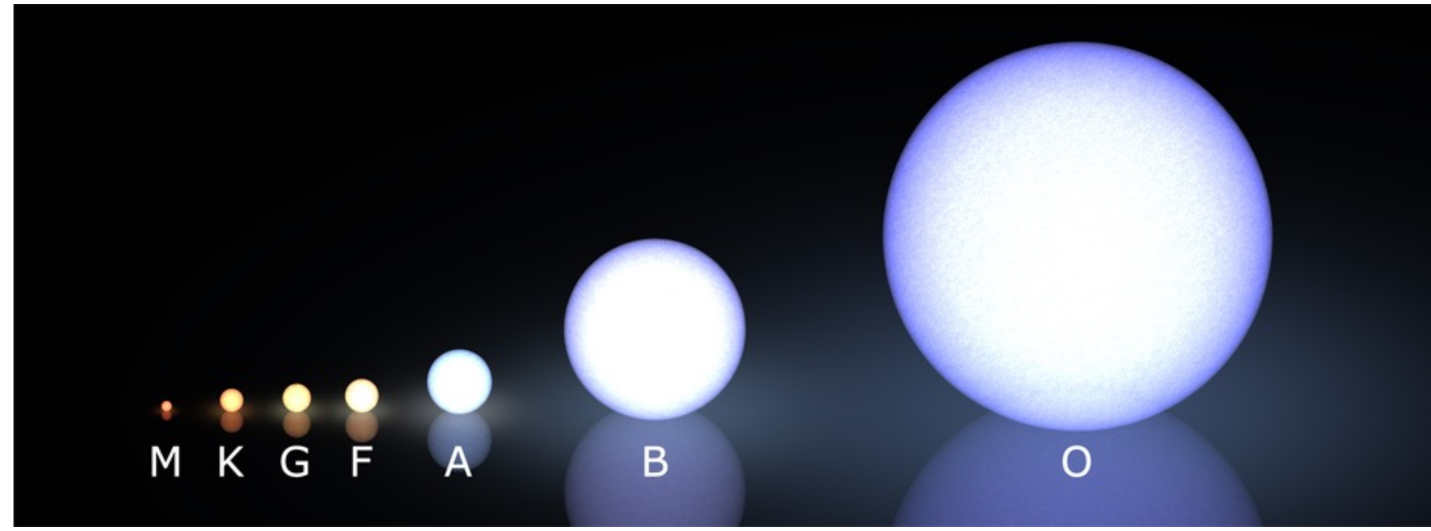


Charactériser les exoplanètes …

excellente connaissance de l'étoile requise !

Difficulté 2: l’étoile





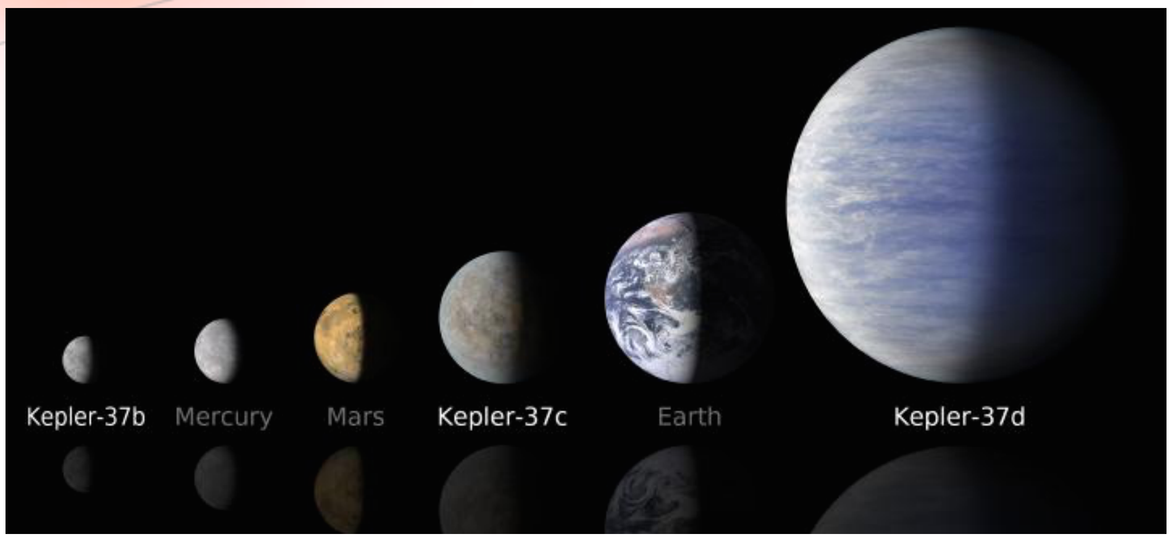
Charactériser les exoplanètes …

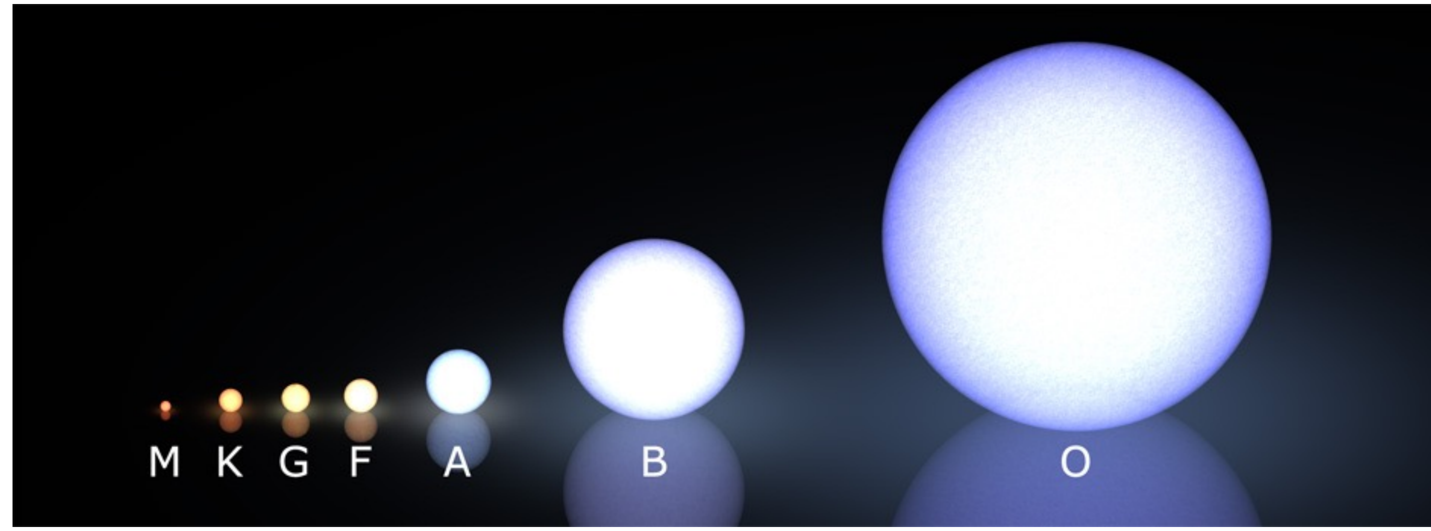
excellente connaissance de l’étoile requise !

- Masse + rayon ➙ densité moyenne ➙ masse et rayon de l’étoile

gaseuse vs rocheuse, structure interne

Difficulté 2: l'étoile





Charactériser les exoplanètes …

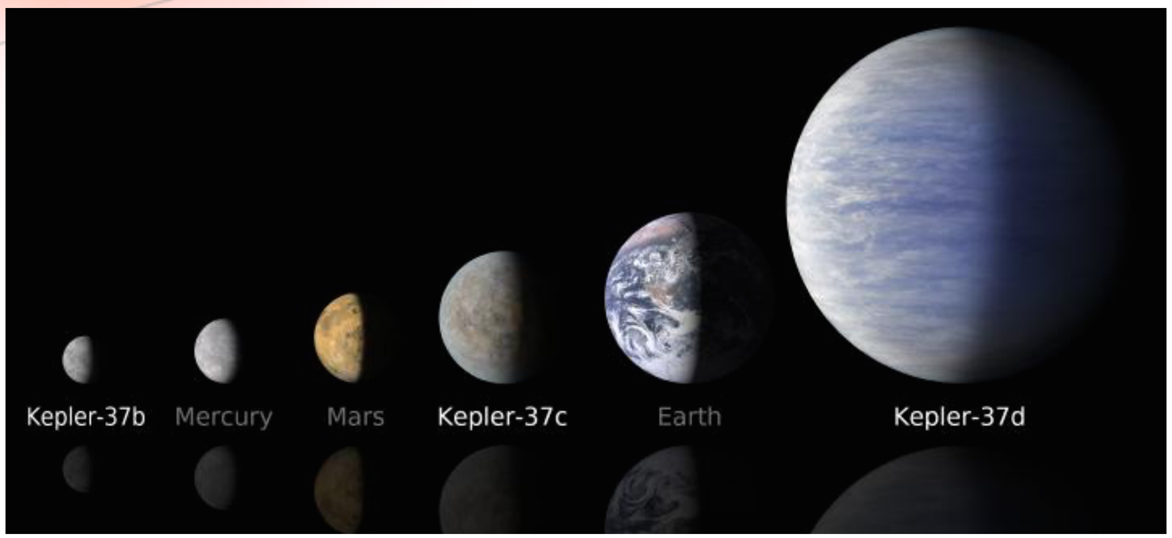
excellente connaissance de l'étoile requise !

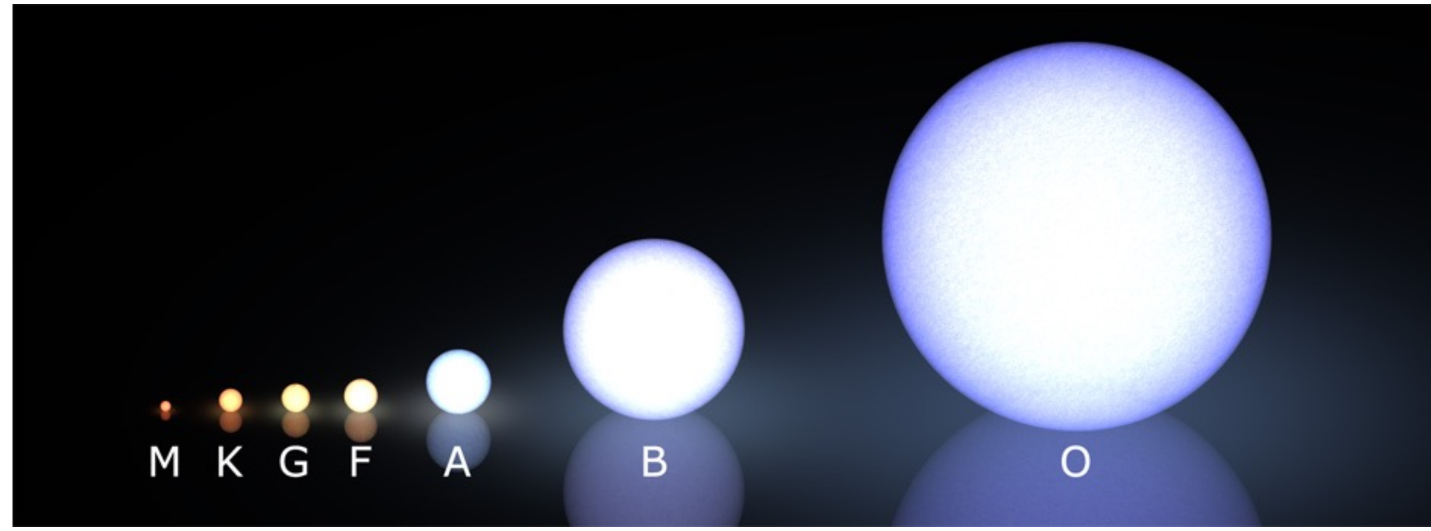
- Masse + rayon ➙ densité moyenne
  gaseuse vs rocheuse, structure
- Composition ➙ formation

➙ masse et rayon de l'étoile

➙ composition de l'étoile

Difficulté 2: l'étoile





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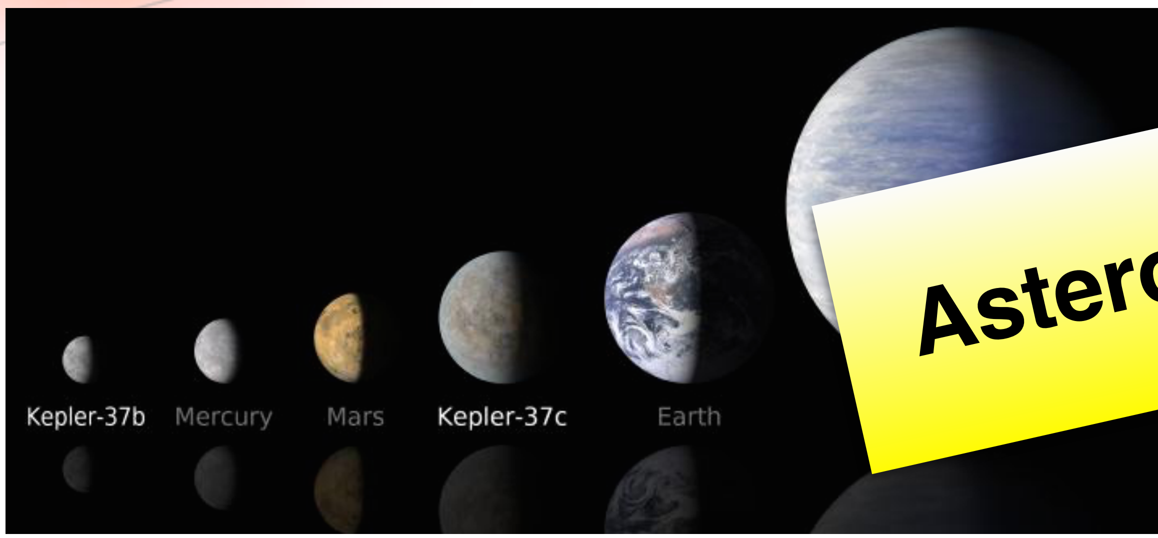
➙ composition de l'étoile

- Propriété de l'atmosphère
  habitabilité

➙ propriétés de l'étoile, insolation

Difficulté 2: l'étoile



Asteroseismologie de l'étoile hôte

Charactériser les exoplanètes …

excellente connaissance de l'étoile requise !

- Masse + rayon → densité moyenne
  gaseuse vs rocheuse, structure

→ masse et rayon de l'étoile

- Composition → formation

→ composition de l'étoile

- Propriété de l'atmosphère
  habitabilité

→ propriétés de l'étoile, insolation

- Age → évolution

→ age de l'étoile

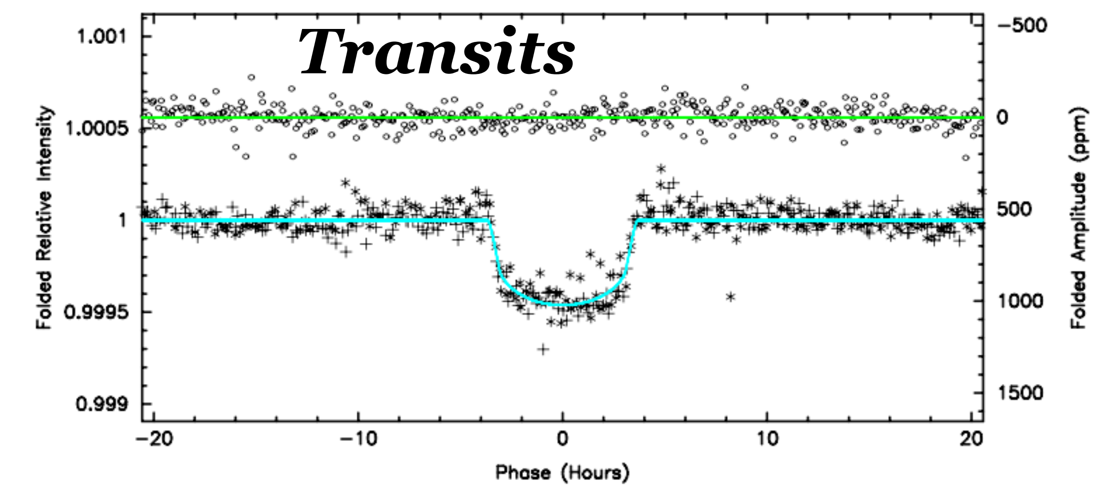
→ évolution des systèmes planétaires

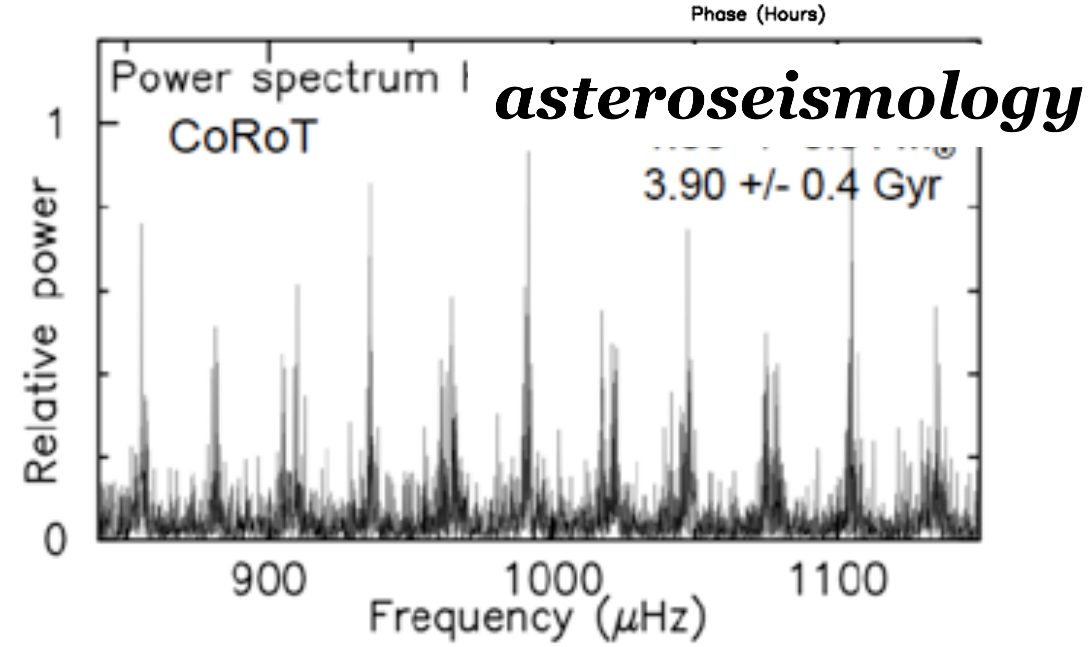
PLATO 2.0 : the method

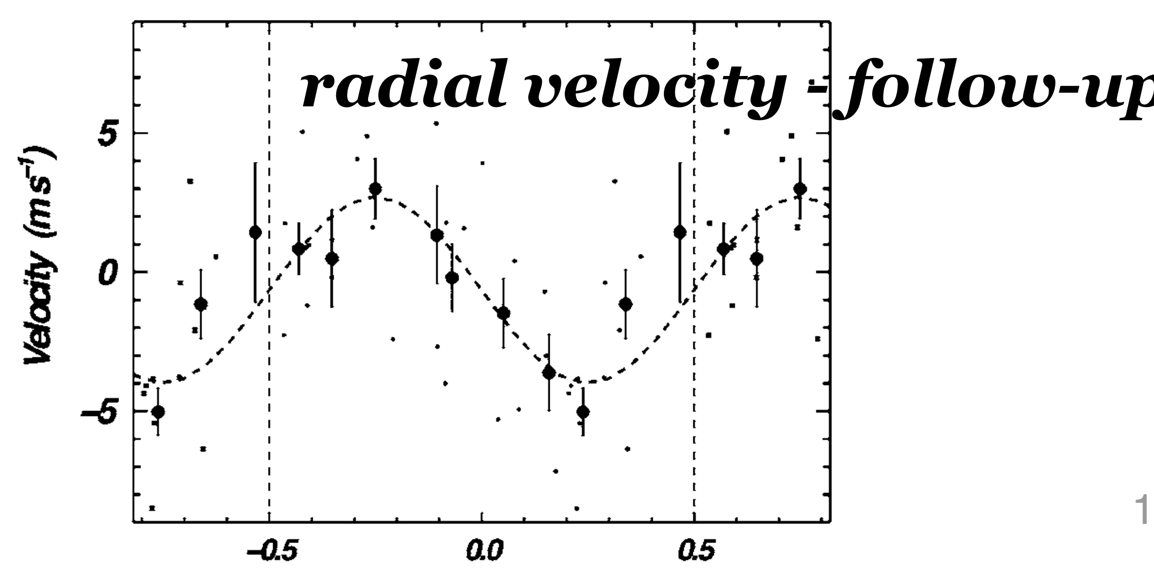
Measure accurate planet parameters, including all orbital parameters

Goal: acccuracy for Earth-like planets around solar-like stars:

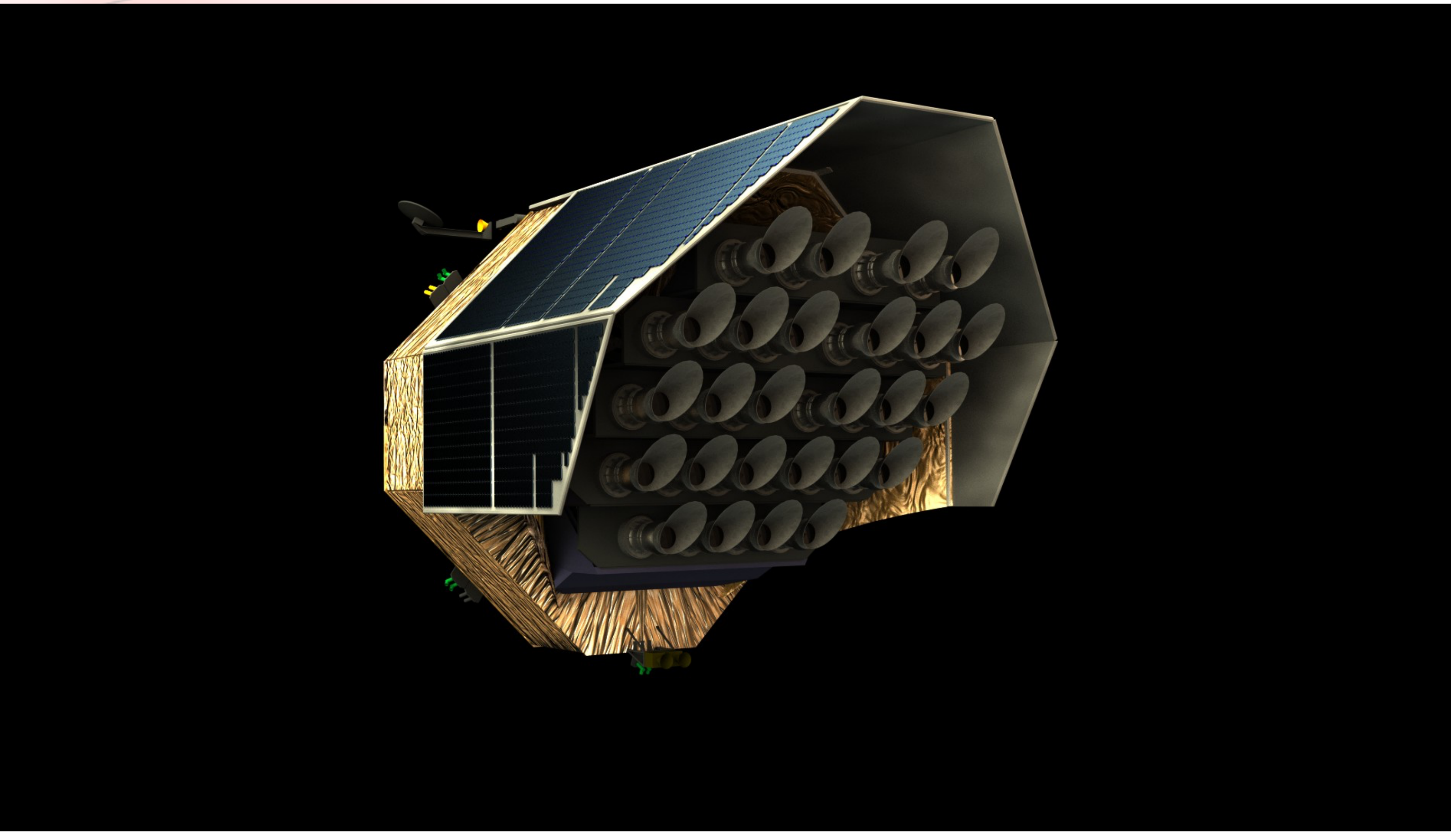
- radius ~3%
- mass ~10%
- age known to 10%







PLATO 2.0 instrument



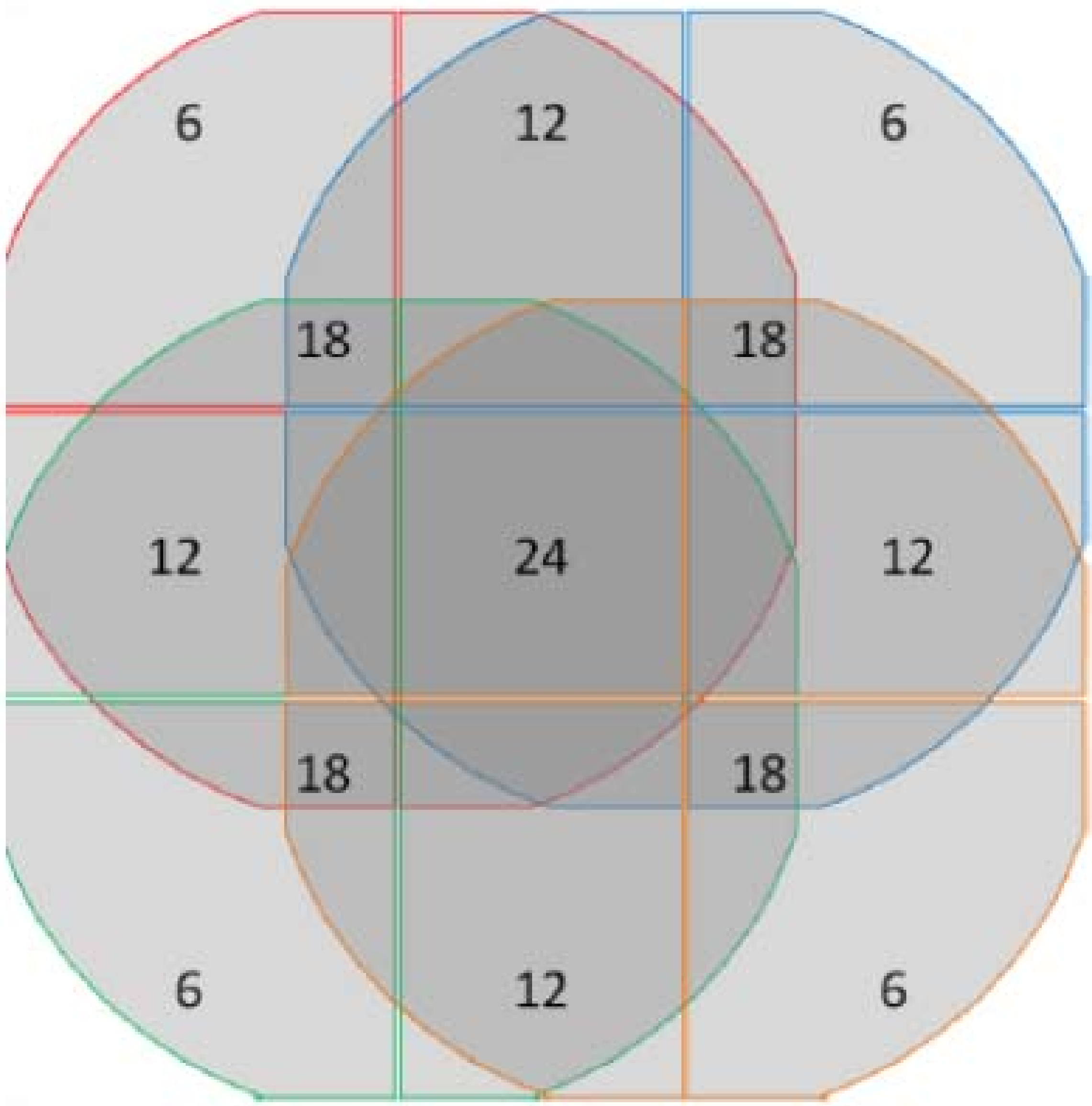
ESA M3 mission
Launch 2026

Very wide field + large collecting area: **multi-instrument approach**

Goal :
optimize the number of stars and their brightness : $4 \leq m_V \leq 16$

Detect transits of an Earth-size planet around a solar-type star up to 1 au and allow its complete characterization

PLATO 2.0 instrument



- 24 **normal** cameras in groups of 6 camera each
- Offset to increase FoV
- 12 cm aperture telescopes
- Operate in “white” light
- range ~$8 \leq m_V \leq 13$
- FOV ~ 49^o x 49^o
- 4 CCD each 4510 x 4510 px
- Pixel size 18 μm square
- Read-out cadence: 25 sec

Total FOV ~2232 deg^2

PLATO 2.0 instrument

- 2 "**fast**" camera used for pointing
- Each with one broadbad filter
  "red" and "blue" telescope
  otherwise identical to normal
  camera
- Read-out cadence: 2.5 sec

Purpose:

- Fine guiding
- Photometry of the brighest stars
  (< 8 mag)

- 24 **normal** cameras in groups of 6 camera each
- Offset to increase FoV
- 12 cm aperture telescopes
- Operate in "white" light
- range $\sim 8 \leq m_V \leq 13$
- FOV ~ 49^o x 49^o
- 4 CCD each 4510 x 4510 px
- Pixel size 18 μm square
- Read-out cadence: 25 sec

Total FOV ~2232 deg^2

Objectifs stellaires

Stellar science (core program):

- precise and accurate characterization of planet host stars (in particular ages)
- As best as possible characterization of all target stars (in particular ages)
- Identify and characterize a large sample of benchmark stars
- Improve our knowledge of the internal structure and evolution of low-mass stars
- Inclination of stellar rotation axis
  Measurement of **spin-orbit angle** (constraints on scenarios of planet migration)

Complementary science:

- Seismology of A to early F, gamma Dor, of massive B,O stars, of evolved stars
- All types of micro-variability and/or variability of times scales up to 1- 2 years
- Galactic population studies

and much more…

Methodology for the stellar science of the core program

✓ Oscillating stars

Seismology (model independent relationships and/or based on stellar models and.or inversion)

✓ Non oscillating stars or non detected oscillations

Classical methods

- Physical relationships (Black body,..)
- HR and isochrone fitting
- empirical prescriptions (gyrochronology)

In any case, GAIA, & ground surveys are crucial

Stellar Data Products

INPUT

1) PLATO light curves
interferometry

2) Catalogs and follow-up

* V1 : before launch
* V2-V3 during operation and after

Intermediate data products

OUTPUT

DP3 : oscillation mode parameters + seismic mean internal rotation + inclination angle
DP4 : stellar activity and surface rotation measurements
DP5 : mass, radius and age of the (core program) F5-K7 stars + M dwarfs

Stellar Data Products

INPUT

1) PLATO light curves
interferometry

2) Catalogs and follow-up

* V1 : before launch
* V2-V3 during operation and after

Intermediate data products

- Classical parameters : Teff, log g , log L (V,Mv(d), BC,AV), surface chemical abundances
- Scaling laws
- Stellar models and frequency calculations → grids of stellar models + on the fly for specific cases
- Surface boundary conditions for stellar models and oscillation frequencies
- Model atmospheres + convective flux/entropy tables + surface effects
- Stellar activity model → scaling laws for 1D stellar models
- Spot modelling, gyrochronology
- Simulated light curves – Tests cases/benchmarks
  (Plato noise (V, B-V,Ntel) + spots+low freq. Activity + granulation + oscillation)
- Limb darkening
- Inclination of stellar rotation axis

OUTPUT

DP3 : oscillation mode parameters + seismic mean internal rotation + inclination angle
DP4 : stellar activity and surface rotation measurements
DP5 : mass, radius and age of the (core program) F5-K7 stars + M dwarfs

PLATO - target stars : simulation of the north reference field

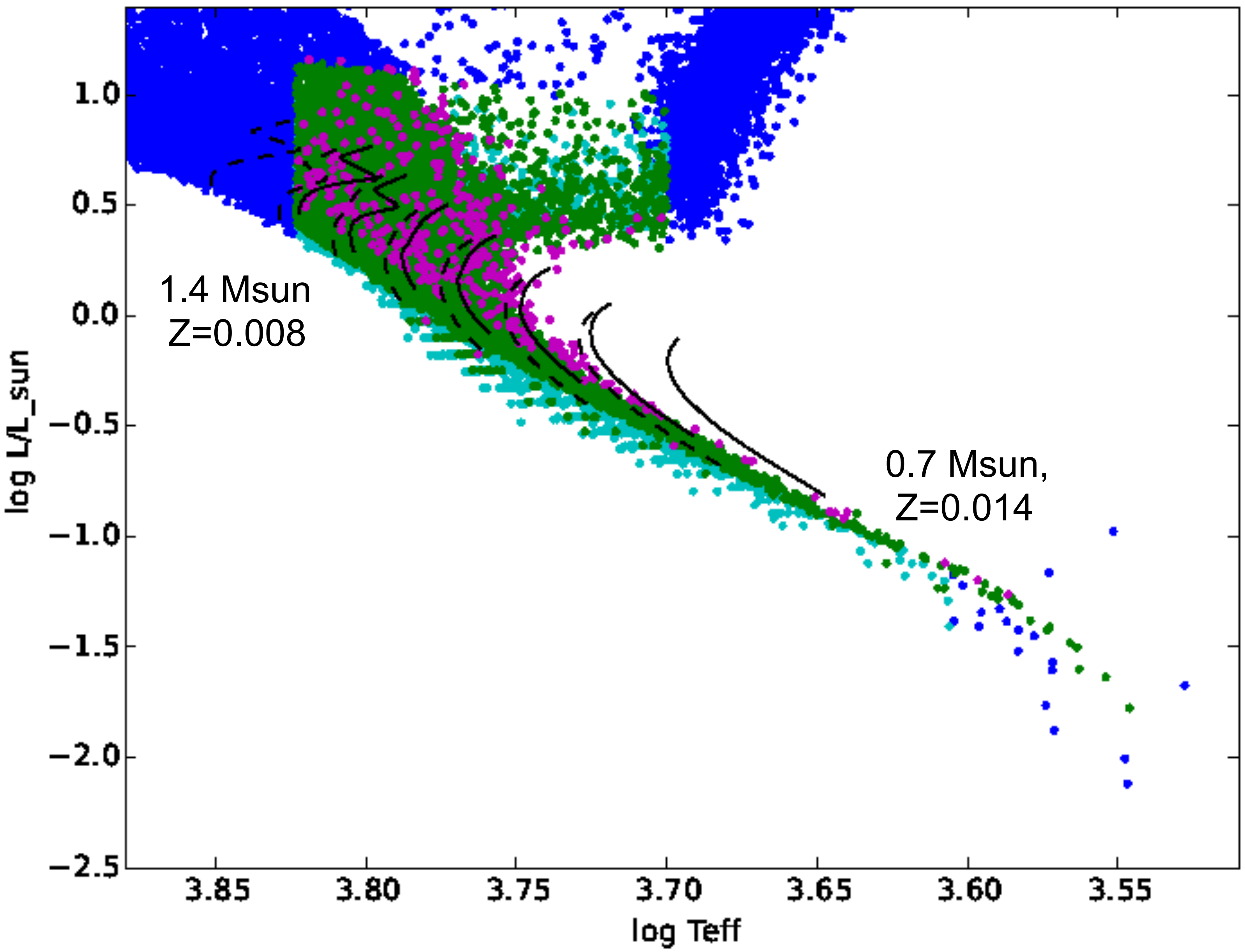
The Input Catalog is being built using existing star catalogues.

A field of reference (TBC) was defined

For that field, the star count yields :

- about 13 000 dwarfs and subgiants, spectral type F5-K7, 8 ≤ *mag* ≤ 11, noise ≤ 34 ppm.√h, time sampling 25s
- about 29 000 dwarfs and subgiants with V ≤ 11, 34 ppm/h < NSR ≤ 80 ppm/h
- about 80 000 stars dwarfs and subgiants with V < 13, NS R < 80 ppm/h.

Etoiles de P1
Intervalles de masse et métallicité



PLATO - main requirements for the stellar core program

✓ **Requirements for DP5 and P1**: for a G0V star with $V \leq 10$ *(Reference star : 1$M_\odot$,1$R_\odot$,6000 K)*

- $\Delta R_{star}/R_{star} \leq 3\%$
- $\Delta M_{star}/M_{star} \leq 10\%$
- $\Delta Age/Age \leq 10\ \%$

→ This translates into

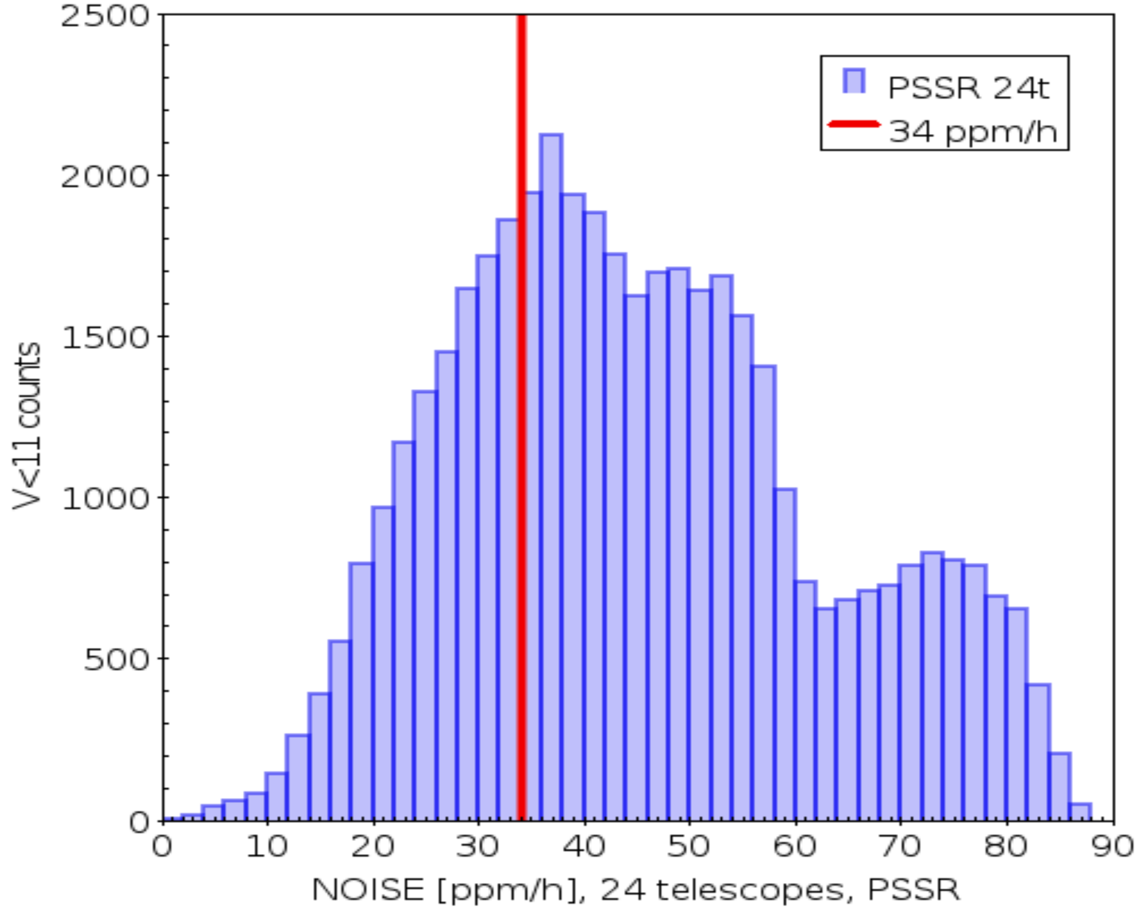
✓ **Requirements for DP3 and P1**: ~0.1–0.2 μHz uncertainties around ν_{max}

PLATO - noise

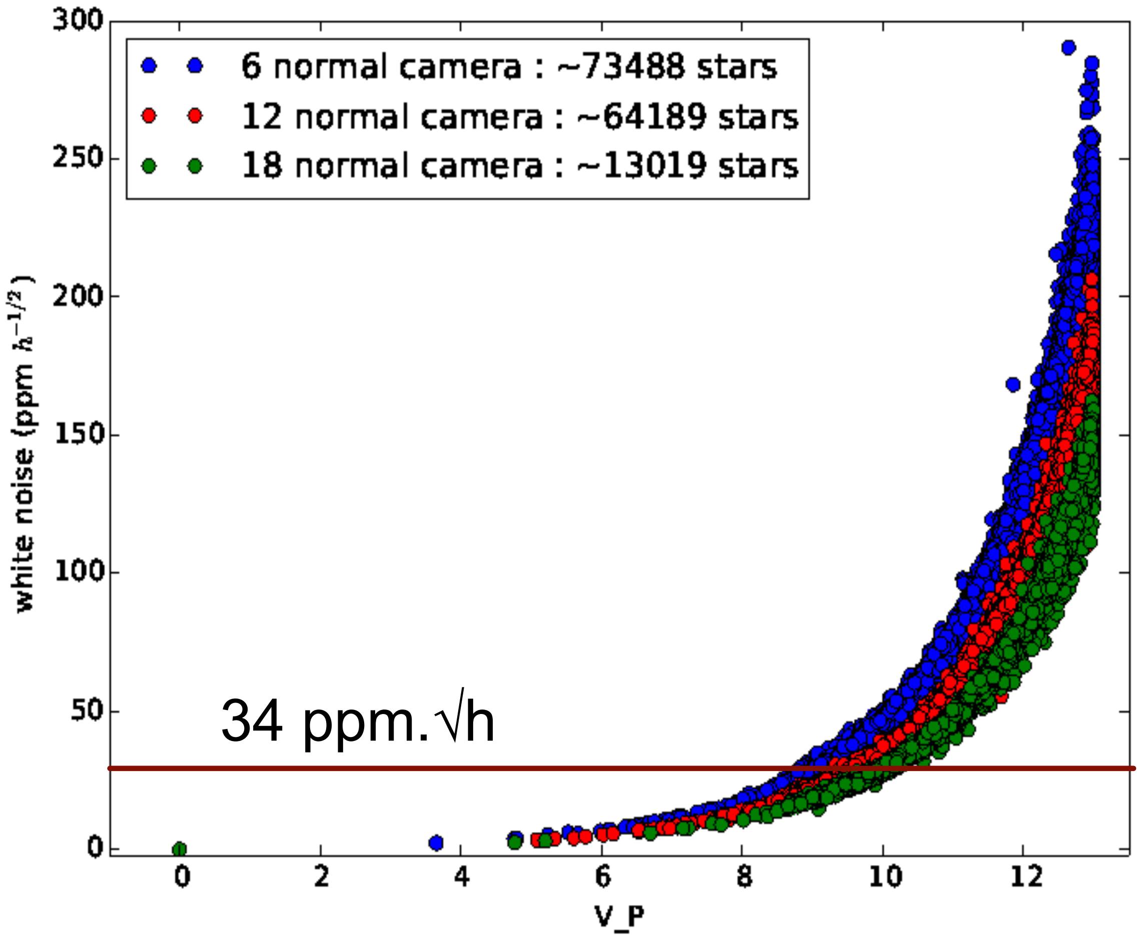
✓ The noise level for a target depends on the apparent magnitude and on the number of cameras

- Target photon noise
- Random noise from the instrument
- Residual noise after correction from systematics

PIC



Simulation from the Besançon galactic model



PLATO will be able to detect solar-like stars from the main-sequence to the red giant branch

Where are we and what efforts in the forcoming years ?

✓ Most of the tools required for (seismic and non –seismic) modeling are already available
➙ Need to test/select them to organize the pipelines

- Identify benchmark stars, case studies, simulation Identify case studies, simulations
- Identify characterize benchmark stars (eclipsing binaries, cluster stars, Kepler legacy stars…)

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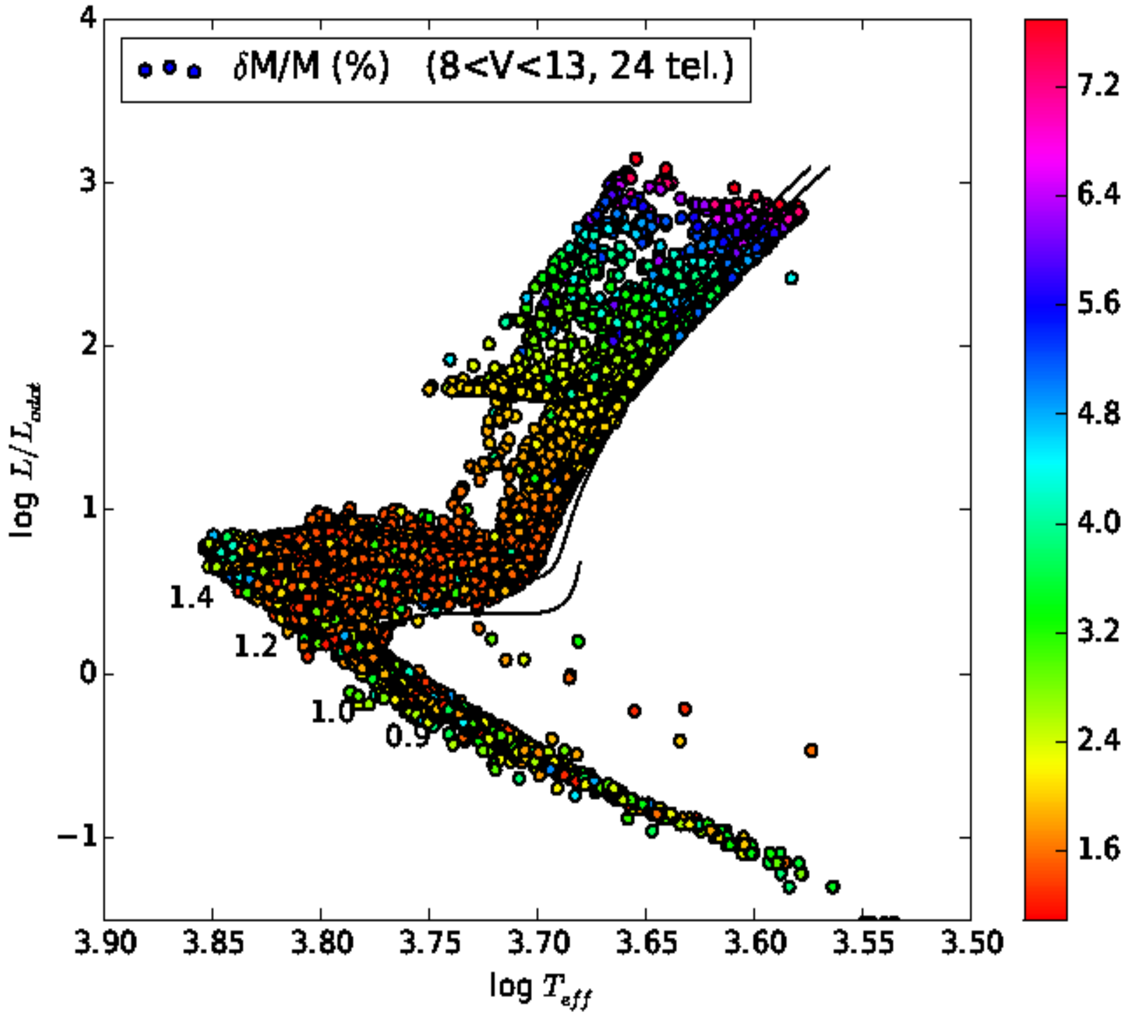
  - Feasibility convincingly shown for PLATO reference star (Sun at V = 9) and for Kepler stars (blind tests, Kepler legacy stars)

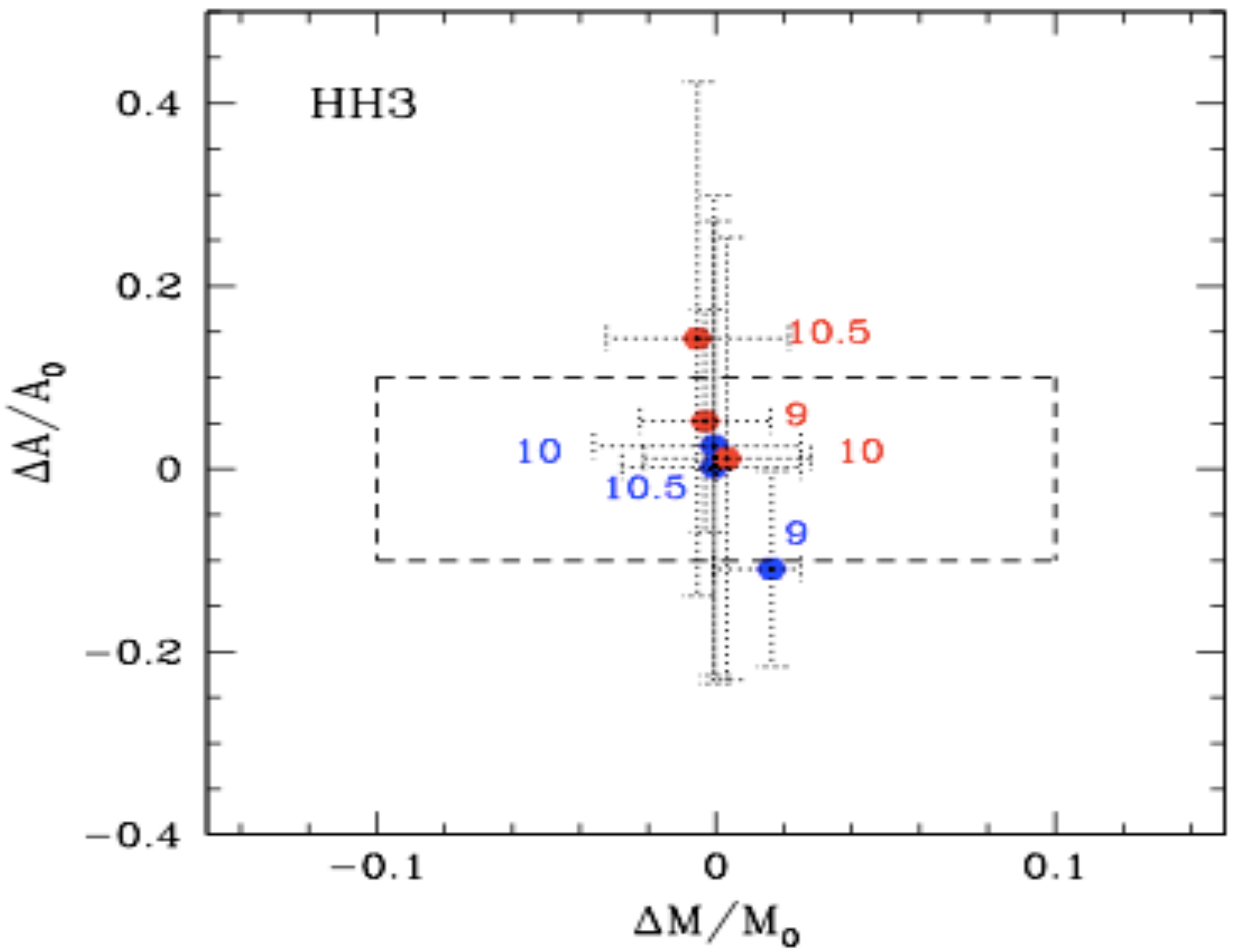
Where are we and what efforts in the forcoming years?

Expected seismic performances



Based on Trilegal galactic simulation
Oscillation detection level based on scaling relations (B. Mosser)
Rescaled to fit the Sun seismic precision

Blind test performed by several groups in WP#12



G0V star with $V \leq 10$
(Reference star : 1M☉,1R☉,6000 K)

Almost compliant with the requirements on the age

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- ✓ Age precision/accuracy harder to reach for higher-mass stars (1.2 $M_\odot$ à ~ 1.4 $M_\odot$ <= core program)
- ✓ Development of complementary seismic diagnostics that will increase the precision on the stellar (and therefore planetary) parameters
- ✓ Main contribution to age incertainties mainly due stellar models : improving/implementing/ testing the physics: atomic diffusion et autres transports, enveloppe and core overshoot, surface effects

Where are we and what efforts in the forcoming years?

✓ **One must expect a variety of cases to deal with :**

- a large diversity of planet-host stars and the stars without planets
- F5 to K7 stars in clusters, eclipsing binaries, etc…
- solar-like oscillating red giants,
- the particular case of bright stars

✓ **Lessons from CoRoT/Kepler**

From: bright spectroscopic eclipsing binaries with solar-like oscillations (graal !) : 16 Cyg A and B mag, …

To Kepler-11 (mag 13.9) host star of 6 planets , Trappist (M dwarf), retired A host star

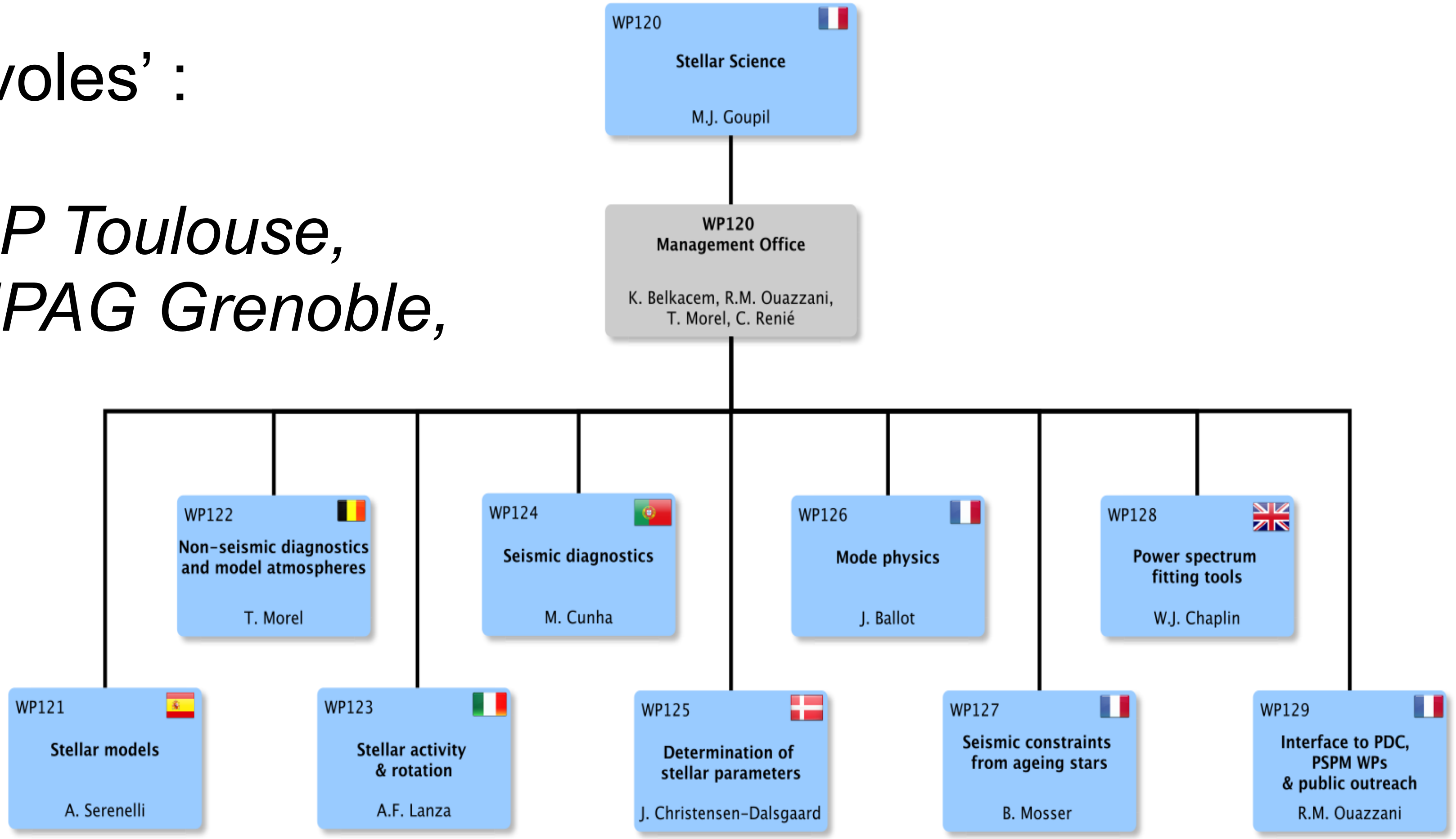
Support from ground-based observations are crucial

Implication française pour la partie stellaire de PLATO

✓ WP12 (PSM) : 23 pays, > 202 participants (mars 2017, en augmentation)

47 français ‘enrollés’ ou ’bénévoles’ :

Paris (OP,CEA,IAS), OCA, IRAP Toulouse, Besançon, LUPM Montpellier, IPAG Grenoble, Lyon …..



✓ Interfaces avec ‘exoplanétistes’

✓ WP37 Implémentation (PDC)

✓ L0 ➛ L1 R.Samadi :traitement bord et sol

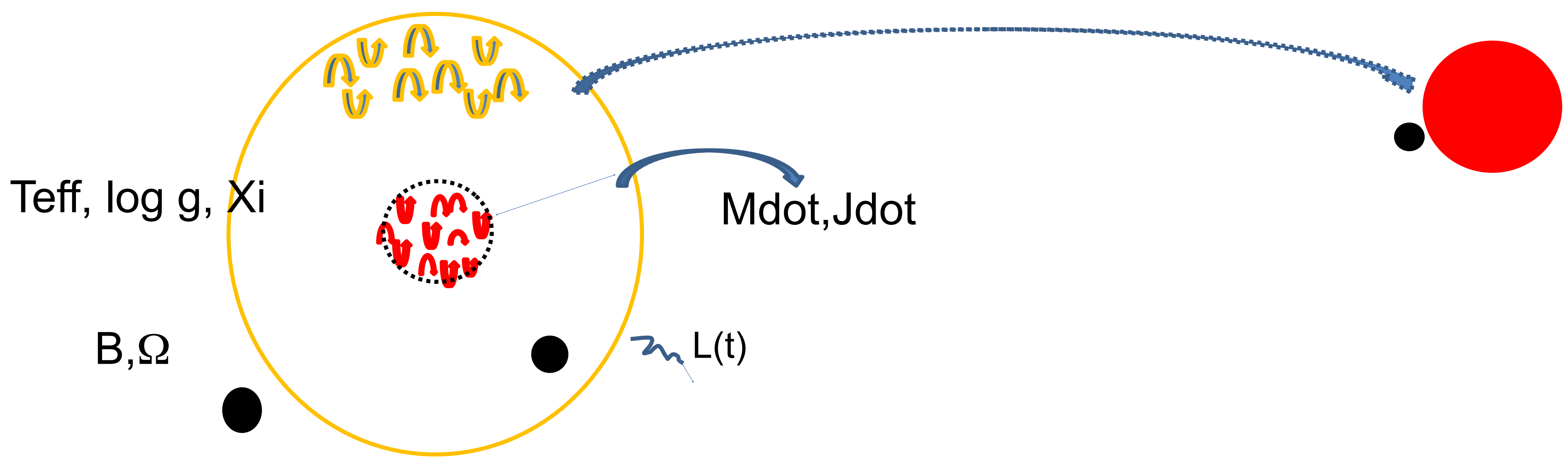
Implication française pour la partie stellaire de PLATO

Premier instrument à détecter et caractériser des planètes comme la Terre autour d'étoiles solaires proches

Implication française pour la partie stellaire de PLATO

Premier instrument à détecter et caractériser des planètes comme la Terre autour d'étoiles solaires proches

*Le succès de PLATO reposera beaucoup sur **TOUS** les développements en physique stellaire des années à venir !*



En retour, PLATO (précision photométrique, durée d'observation, nombre d'étoiles) devrait ouvrir une nouvelle ère de développement pour la physique stellaire !