PLATO

PLAnetary Transits and Oscillations of Stars

The exoplanetary system explorer

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and the PLATO Study Science Team

PLATO

Objective: Detect and characterise planetary systems, particularly earth-like in habitable zone

Instrument: Multi-telescopes
very wide field of view

Techniques: Detection by transits
+ asteroseismology
+ ground based spectroscopy

Targets: >20,000 Bright cool dwarfs (noise<2.7 10^{-5})
>50,000 Bright cool dwarfs (mv<11)
>250,000 (mv<13) +…

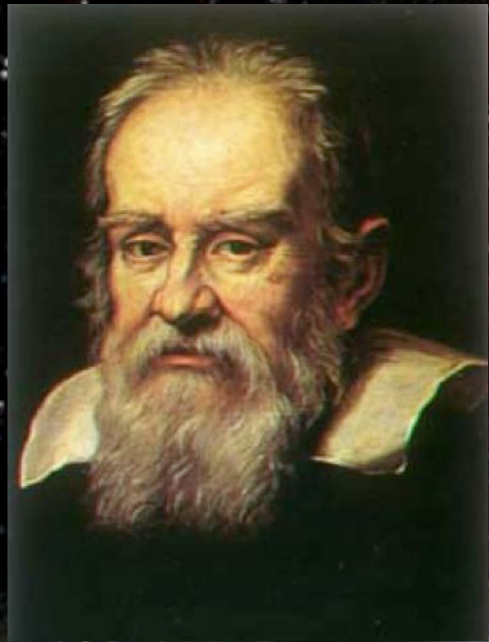
Observing strategy: 2 long runs (2-3 years) + several short runs

Outline

- Introduction
- Science goals
- Tools
- Science requirements
- Payload and mission
- Performances
- Science impact
- Conclusion

The birth of comparative planetology

“There are infinite worlds both like and unlike this world of ours…”
Epicurus (c 300 BC)



“… false and damnable …”
G.Galilei (born 1564)

“There are countless suns and countless earths all rotating around their suns in exactly the same way as the seven planets of our system… The countless worlds in the universe are no worse and no less inhabited than our Earth”

Giordano Bruno, 1584
in *De l'infinito universo et Mondi*

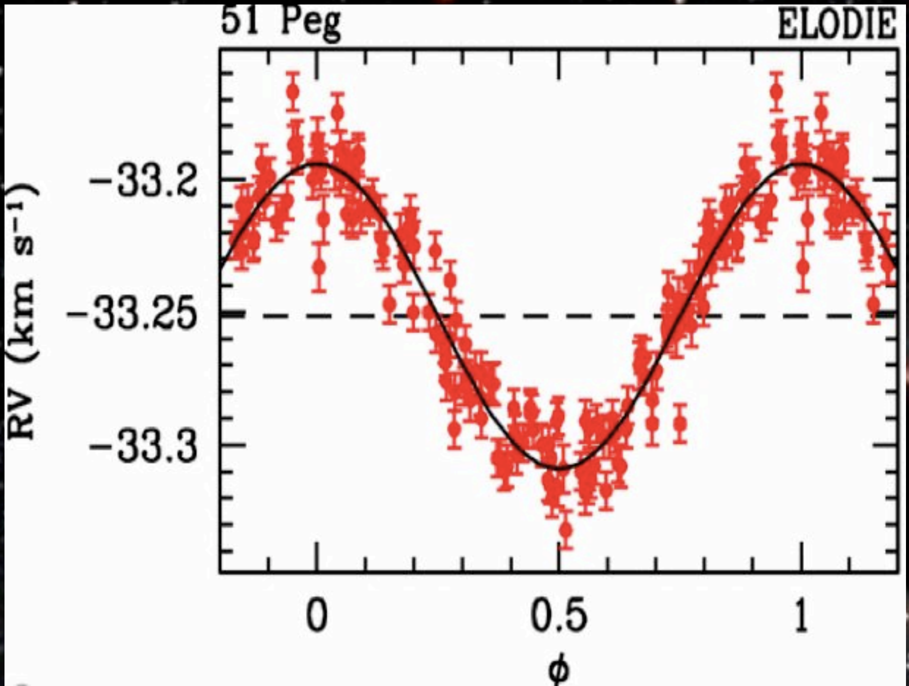
The Goals of Exoplanet Research

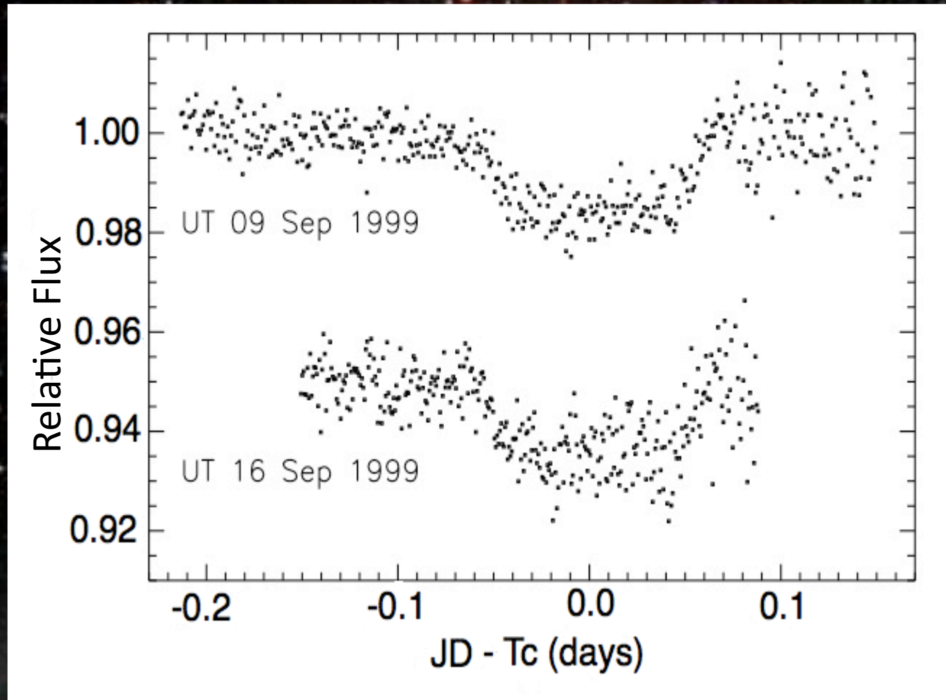
Understand how planetary systems form and evolve in order to understand habitability.

Need to detect planetary systems around different types of stars and at all ages. In particular we need to characterise rocky planets in the habitable zones of their stars.

Modern Discoveries

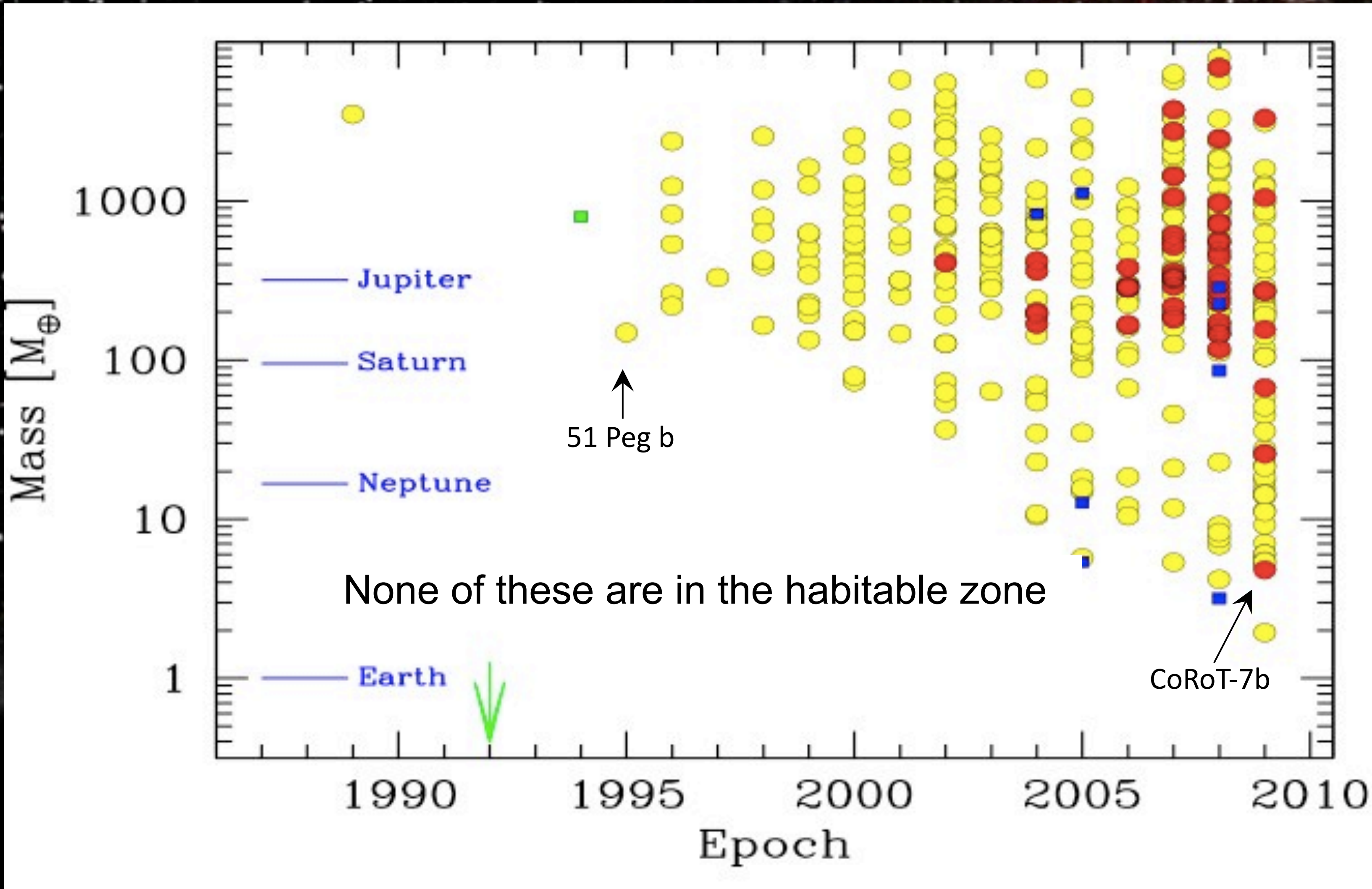
- Pulsar planets
  Wolszczan & Frail 1992
- 51 Peg b First Gas Giants
  Mayor & Queloz 1995





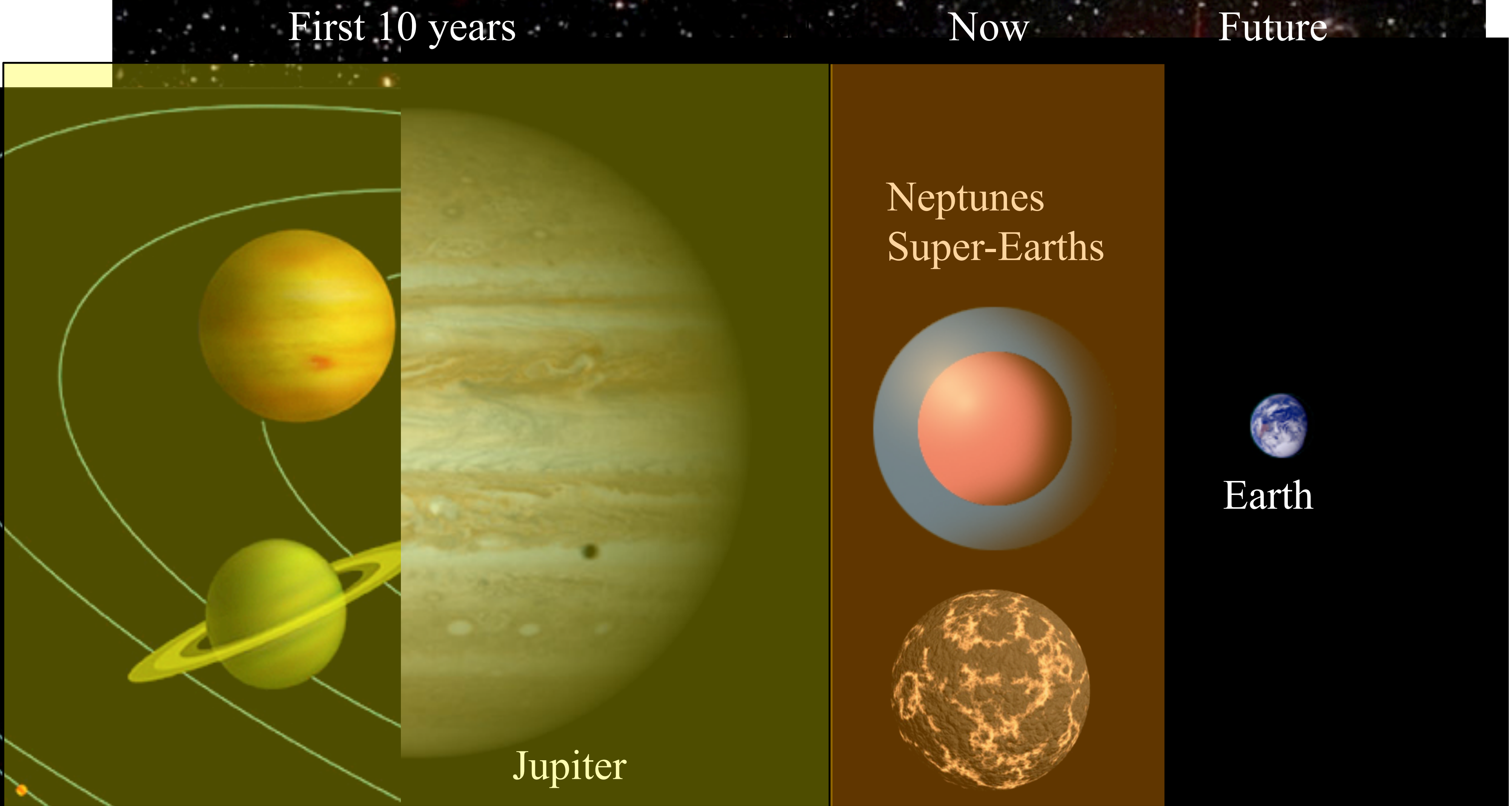
- First Transits
  Charbonneau et al 2000,
  Henry et al 2000

The Pace of Discovery

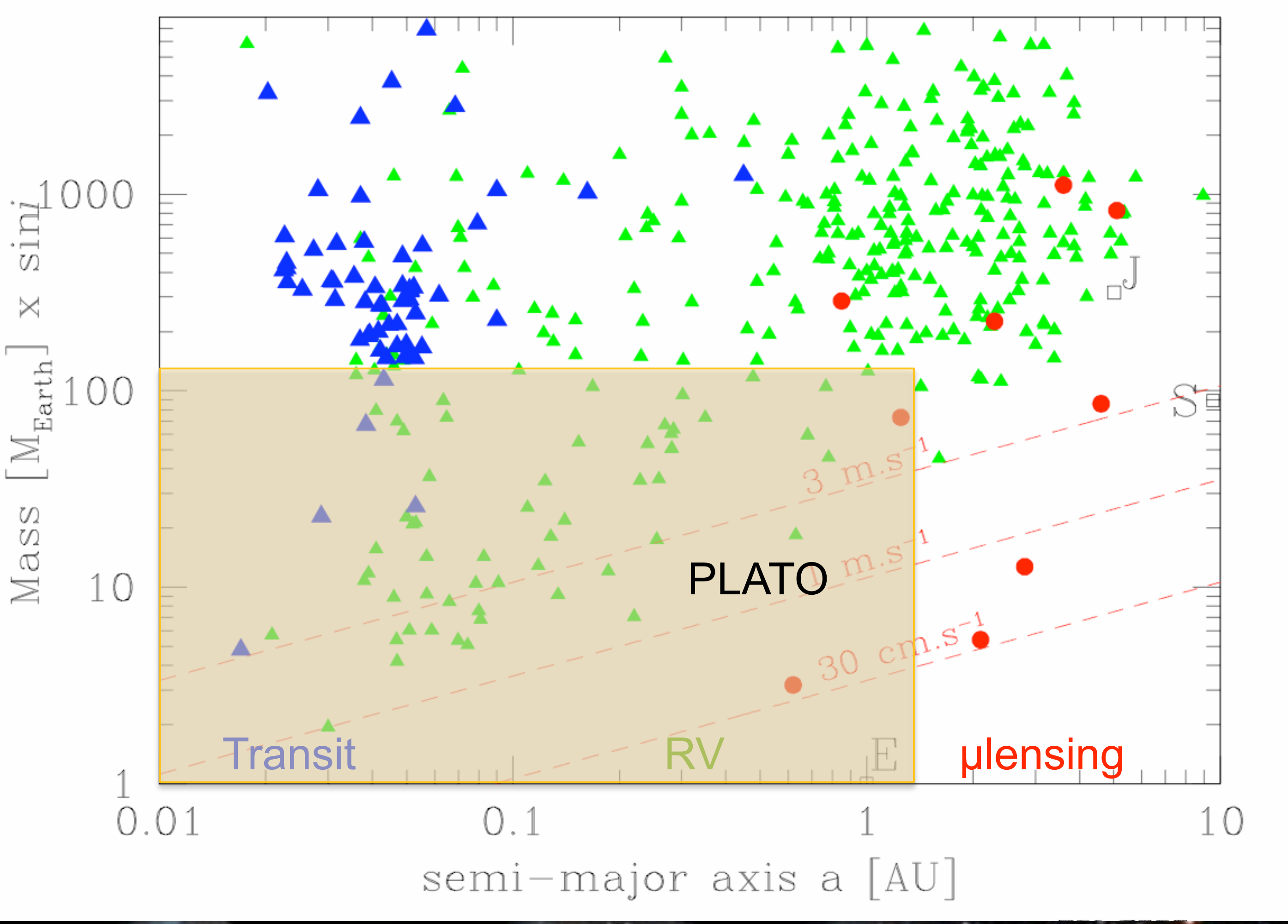


Temporal evolution of the discoveries

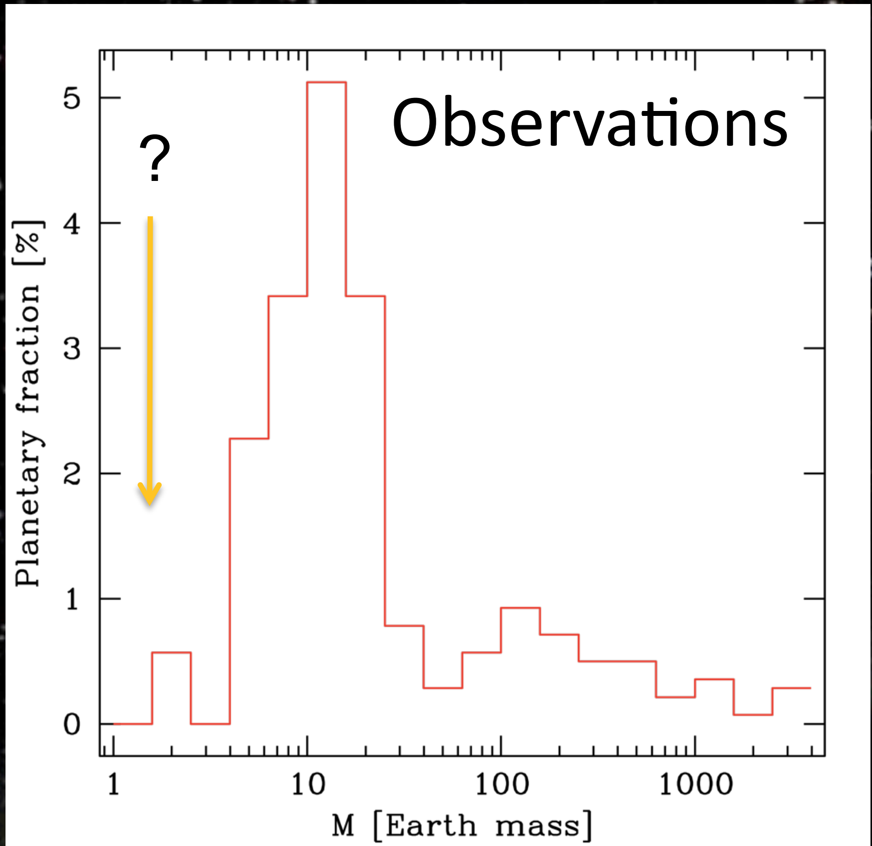
Towards lower masses

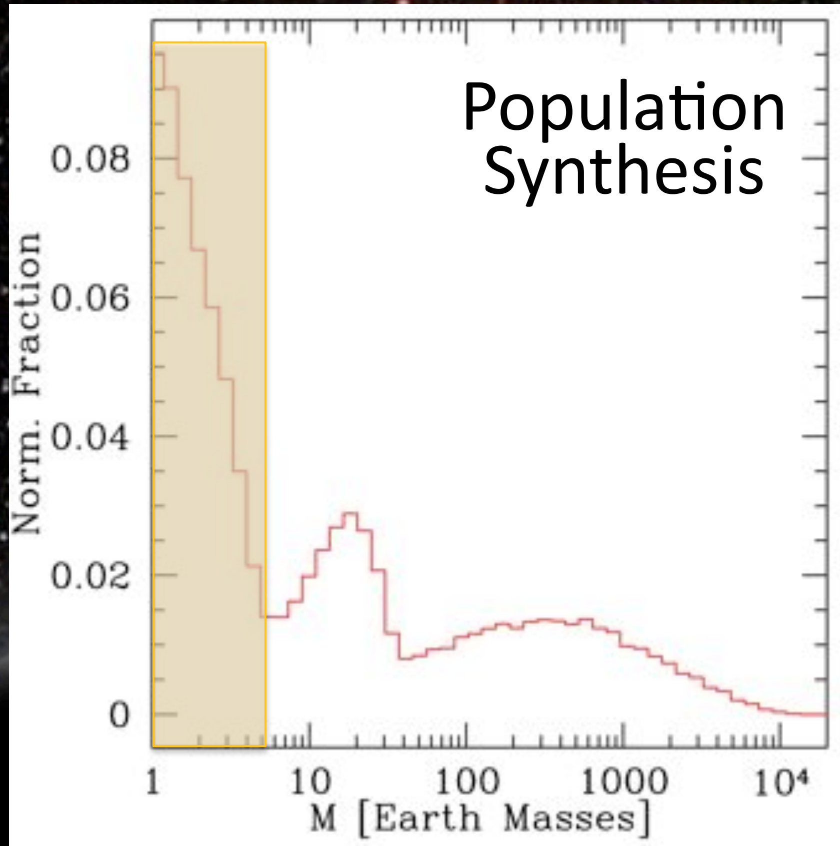


The Discovery Space



Planet population predictions





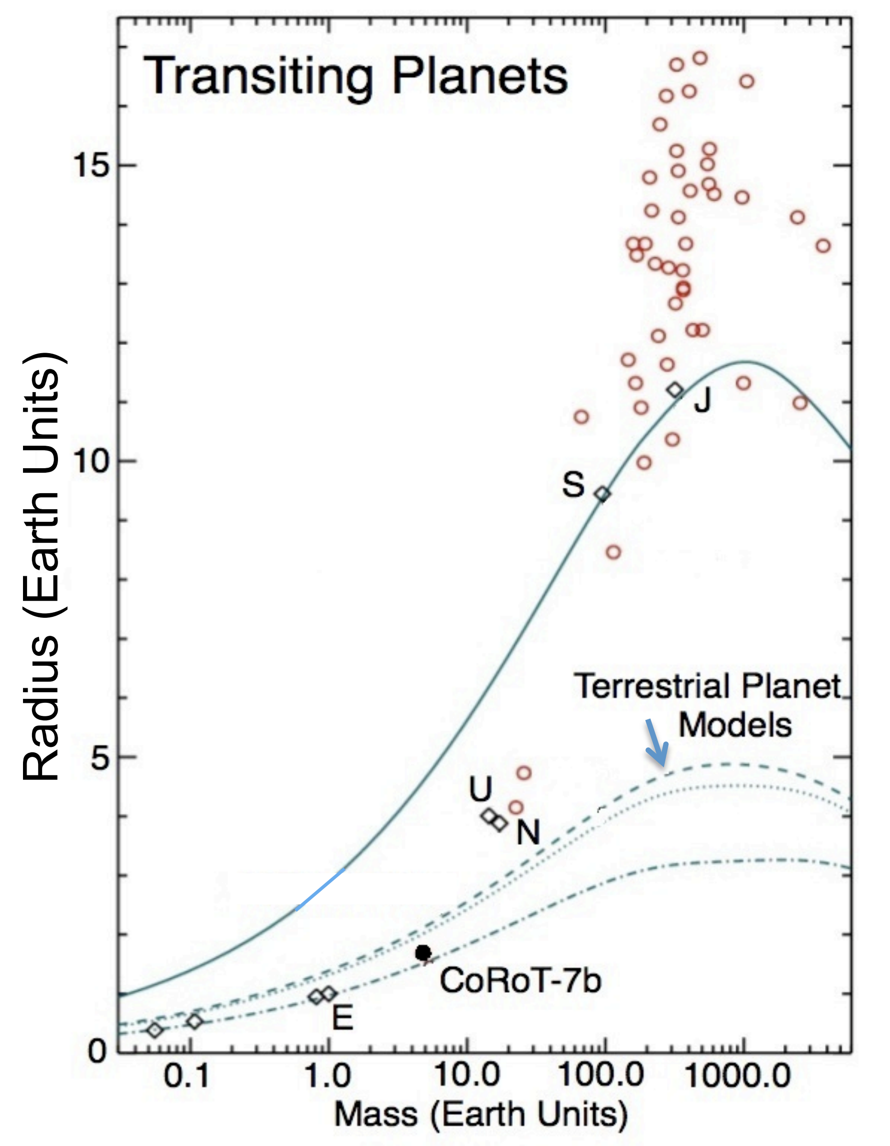
Small planets expected to be very common

Planet diversity

CoRoT, M-Dwarf surveys

- Transit → fractional radius
  (relative to host star)
  → inclination.
- RV → planetary mass
- Solid planet:
  - CoRoT-7b : Period ~ 0.85 d

=> More to come



The PLATO leap forward

Need Radius and Mass

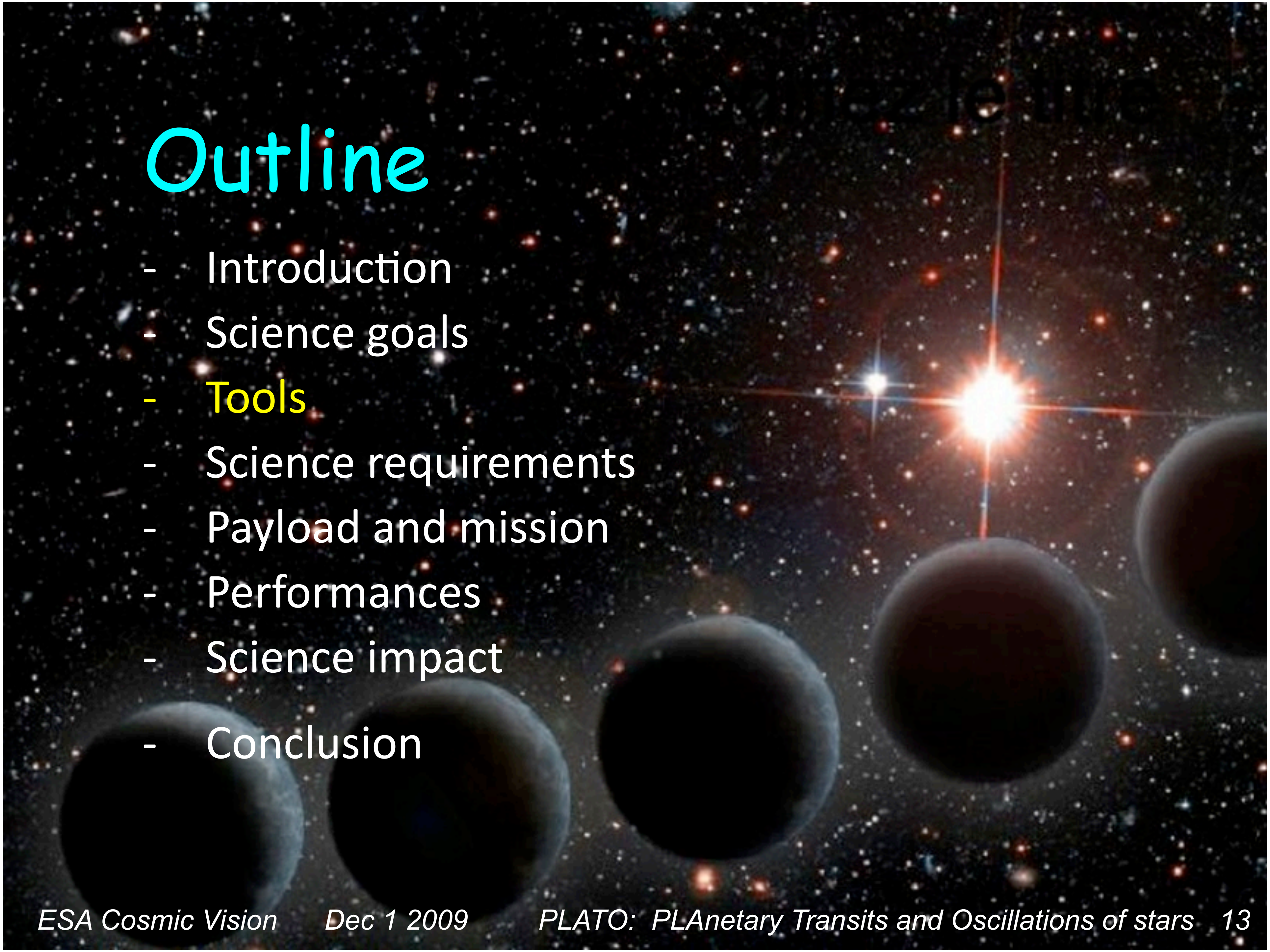
=> Bulk Density <= Models

Radius <= Transit

Mass <= Radial Velocity

Small Variations, photon limited => BRIGHT STARS (V<11 mag)

All other follow up studies (e.g. planetary atmosphere/biomarkers), need BRIGHT STARS (CoRoT/Kepler stars too faint)



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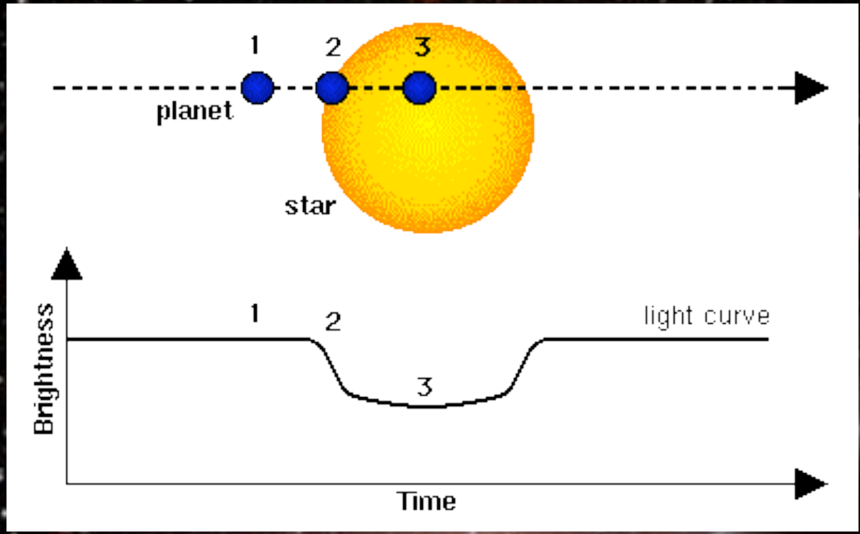
Planetary radius - Tools

Mostly geometry

→ radius of planet/star, inclination.

Kepler's 3rd law => semi-major axis

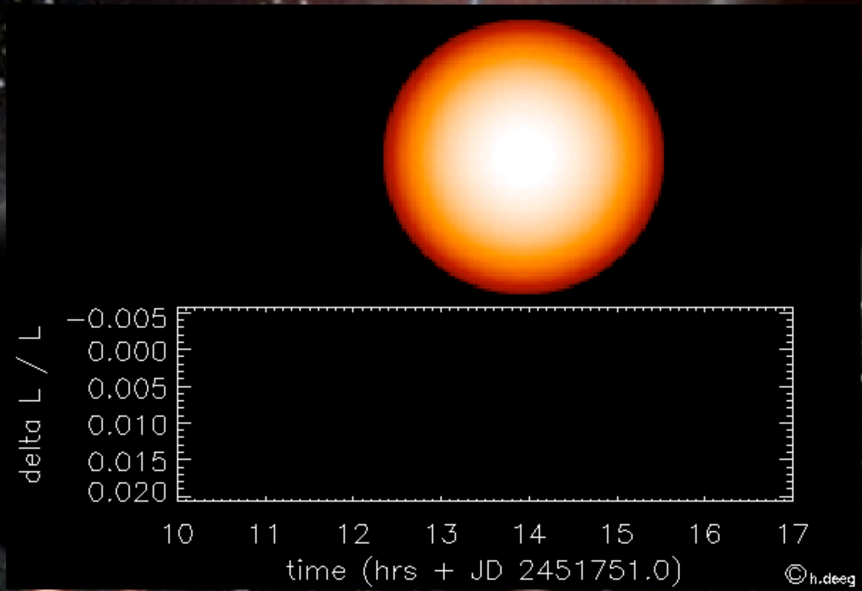
$$\frac{\Delta F}{F_*} \propto \left(\frac{R_{Pl}}{R_*}\right)^2$$



Only needed physics: limb darkening

Sun + Jupiter : ~ 1% dip

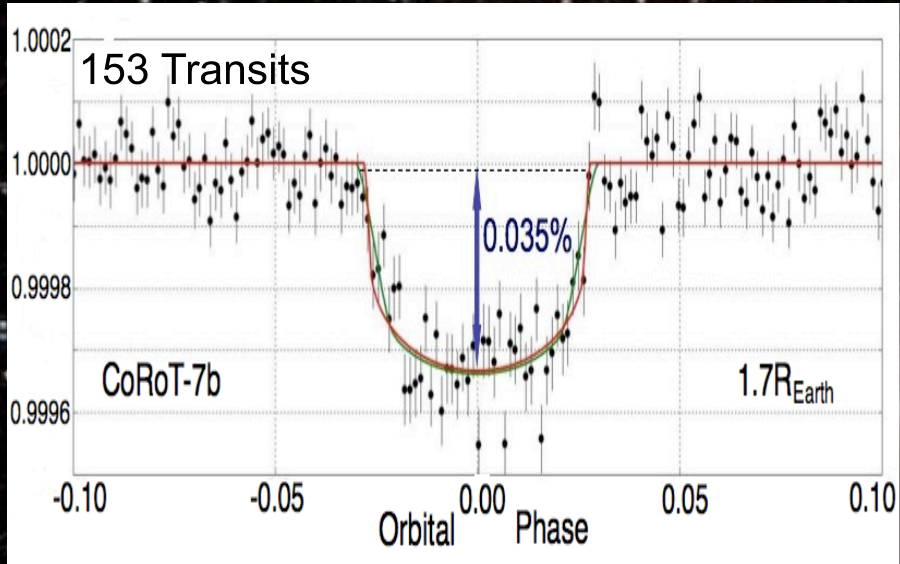
Sun + Earth : ~ 0.01% dip



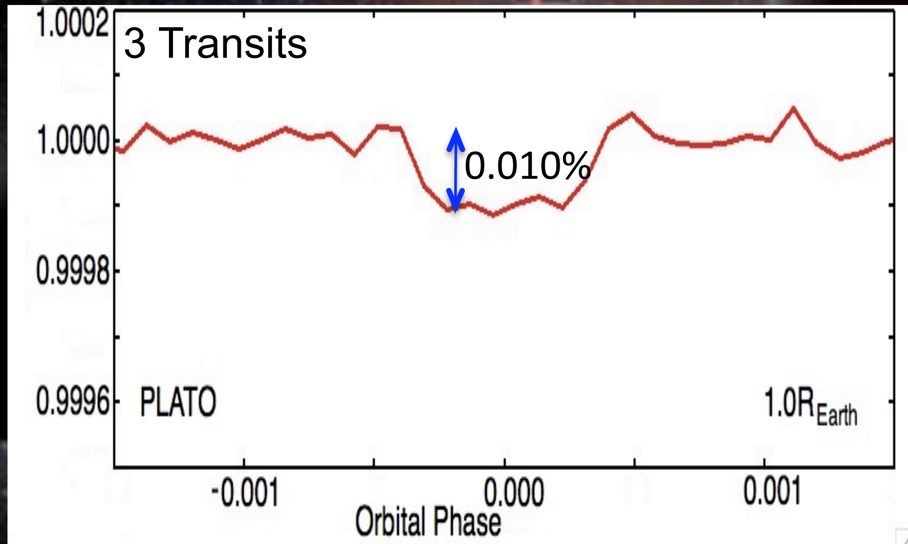
Planetary radius - Tools

Light curves from space:

CoRoT-7b
the first confirmed rocky extrasolar planet.



Simulation
1 M_{earth} planet around a solar type star.

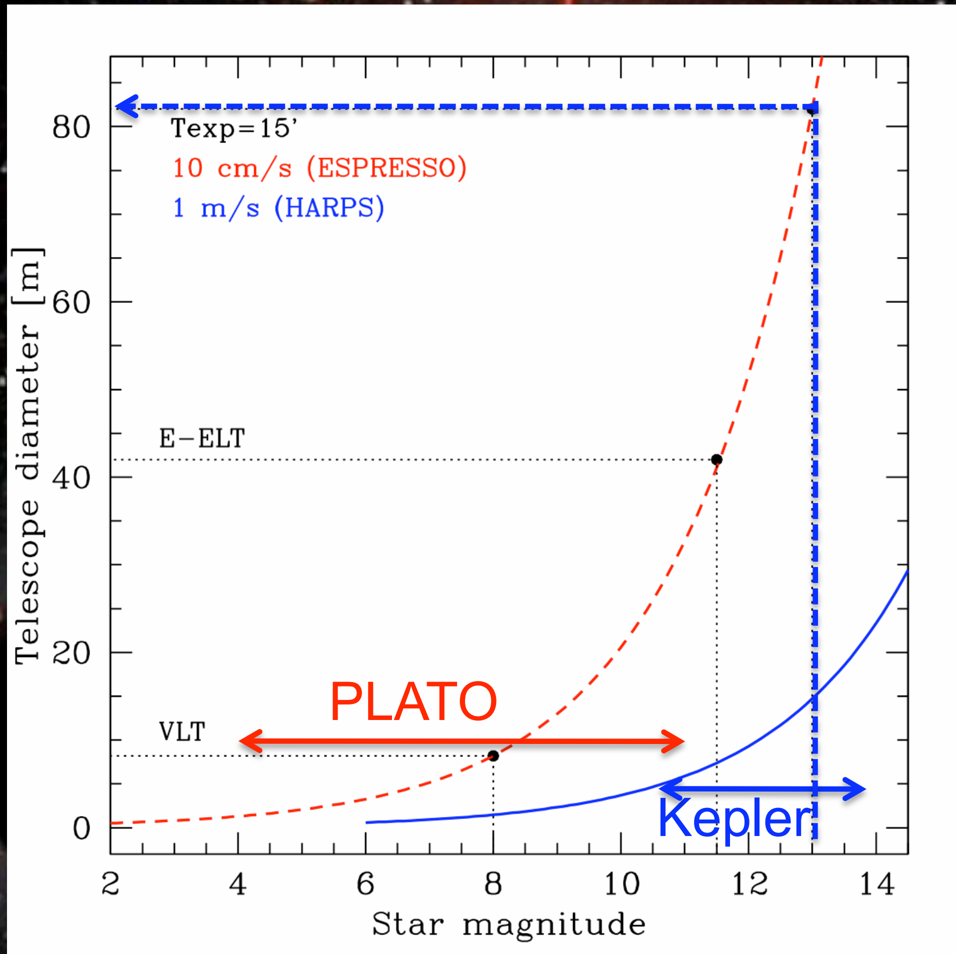


Planetary mass - Tools

RV Amplitude 10cm/s for Earth analog

Planet	Separation (AU)	RV Amp. (m/s)
Jupiter	1	28.4
Neptune	0.1	4.8
Neptune	1	1.5
SuperEarth	0.1	1.4
SuperEarth	1	0.5
Earth	1	0.1

Radial velocity: photon starving



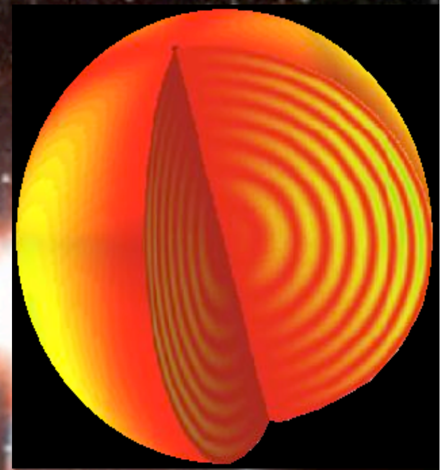
Observation strategy:

→ minimize stellar “noise”

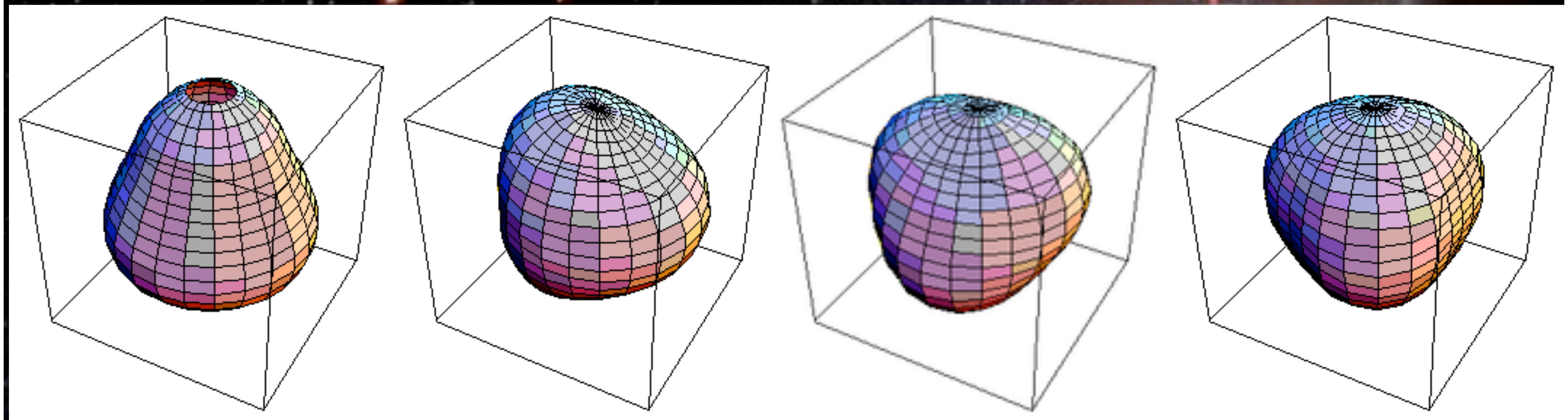
Characterisation of host stars - Tools

Planet parameters ← stellar parameters (asteroseismology)

Solar-like stars oscillate in many modes, excited by convection. Sound waves trapped in interior



Resonant frequencies determined by structure:
→ frequencies probe structure
→ gives mass, angular momentum, age



Asteroseismology

Power spectrum of light curve gives frequencies ν

Large separations $\Delta \propto \sqrt{M/R^3}$
→ mean density

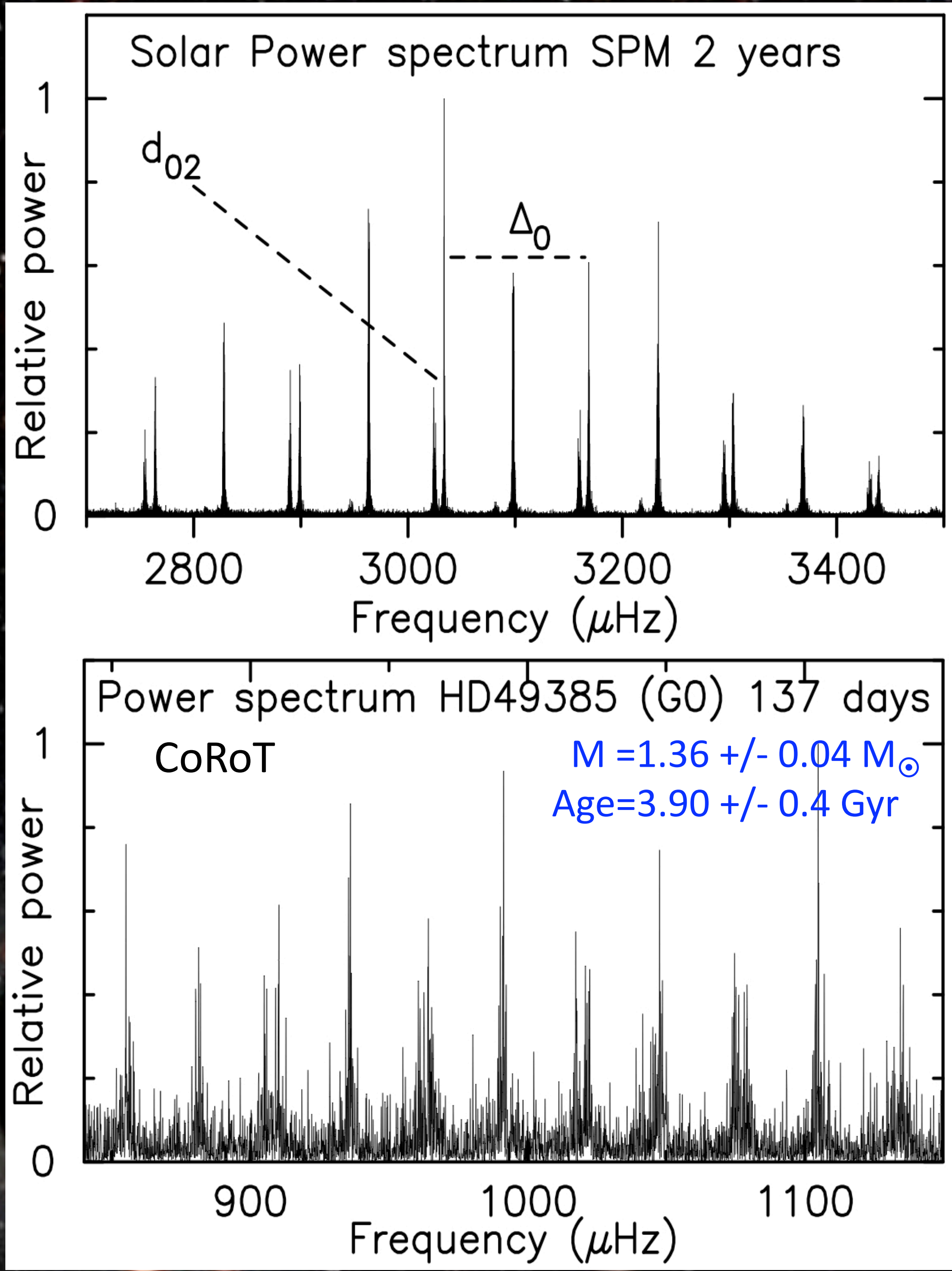
Small separations d_{02}
→ probe the core → age

Inversions + model fitting + ν
→ consistent ρ, M, Ω, J, age

PLATO will provide:

Uncertainty in Mass ~ 2%

Uncertainty in Age ~ 10%



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PLATO objectives and products

Identification of planetary systems
detection and characterisation
of planet transits

+

Characterisation of host stars
detection and characterisation
of stellar oscillations

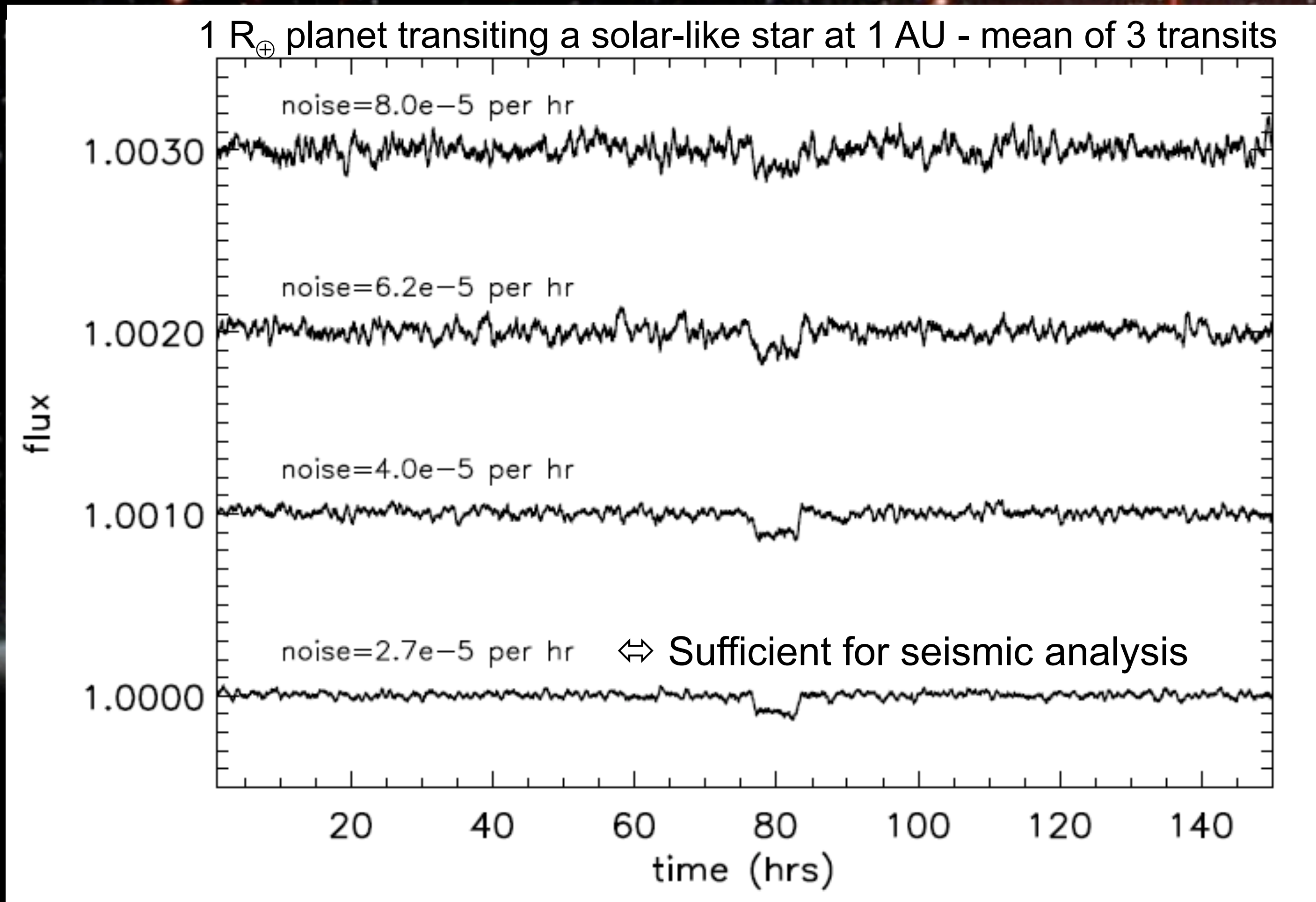
↓

ultra-high precision, high duty cycle, long duration
photometric monitoring
of large samples of bright stars

Noise requirements: transit search

≤ 2.7 x 10^{-5} per hr for high S/N transit measurement

≤ 8.0 x 10^{-5} per hr for marginal transit detection



Why we need to focus on bright stars

1. need to detect transits from small planets:

   planet identification, R_p/R_*:

   ultra-high S/N photometry

2. need for high precision RV follow-up:

   planet confirmation, $M_p/M_*^{2/3}$:

   high res, high S/N spectroscopy

3. need for precise characterization of host stars:

   radius, mass, age: asteroseismology

   chemical composition, rotation, activity, magnetism: high res, high S/N spectroscopy, …

4. further observations of detected systems:

   Planetary atmosphere:

   secondary transits

   on-off transit spectroscopy

   interferometry, …

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   chemical composition, rotation, activity,
   magnetism: high res, high S/N spectroscopy, …

4. further observations of detected systems:

   Planetary atmosphere:
   secondary transits
   on-off transit spectroscopy
   interferometry, …

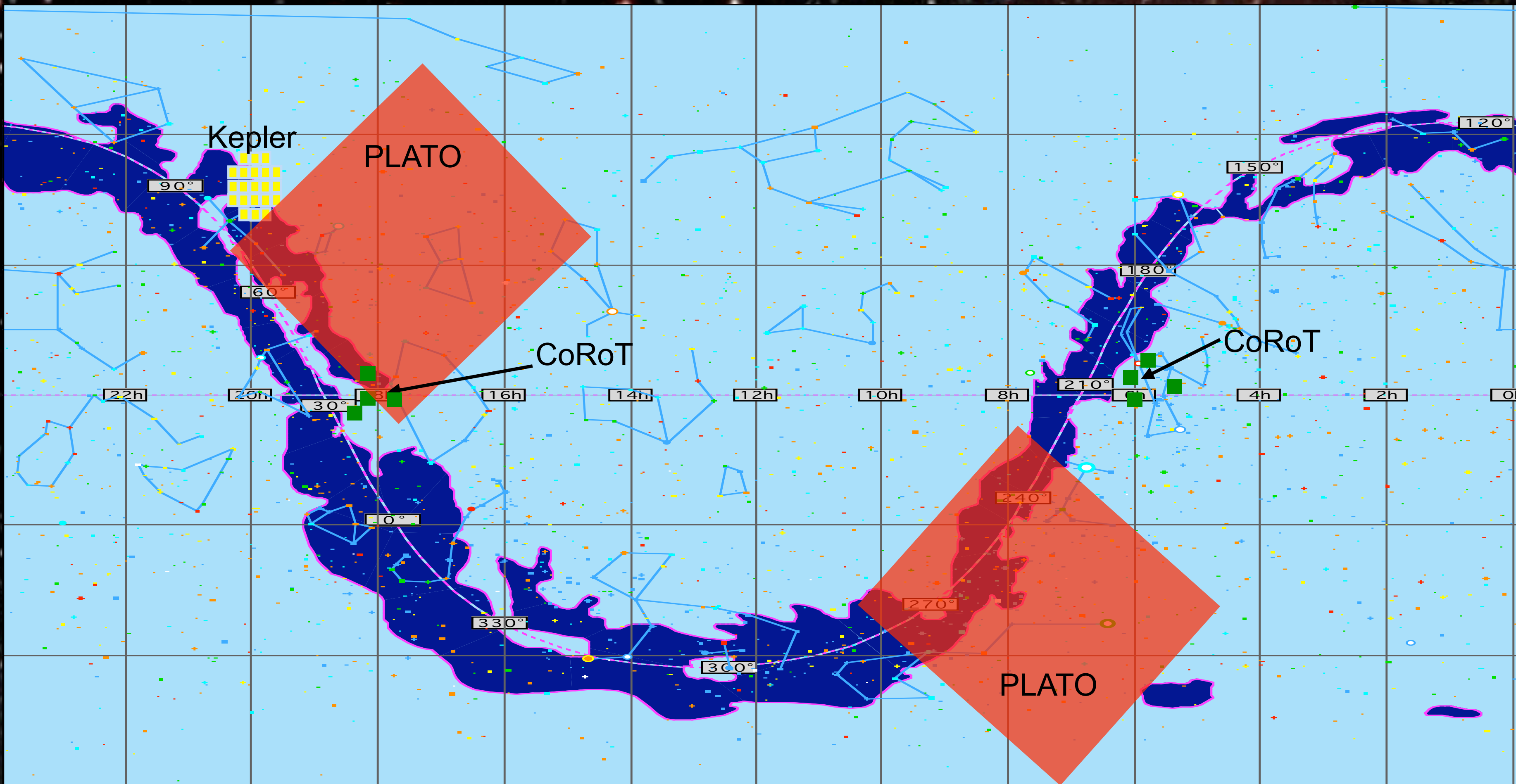
bright/nearby stars are privileged targets

challenge = survey of large samples of bright stars

Basic observation strategy

very wide field + 2 successive long monitoring phases:

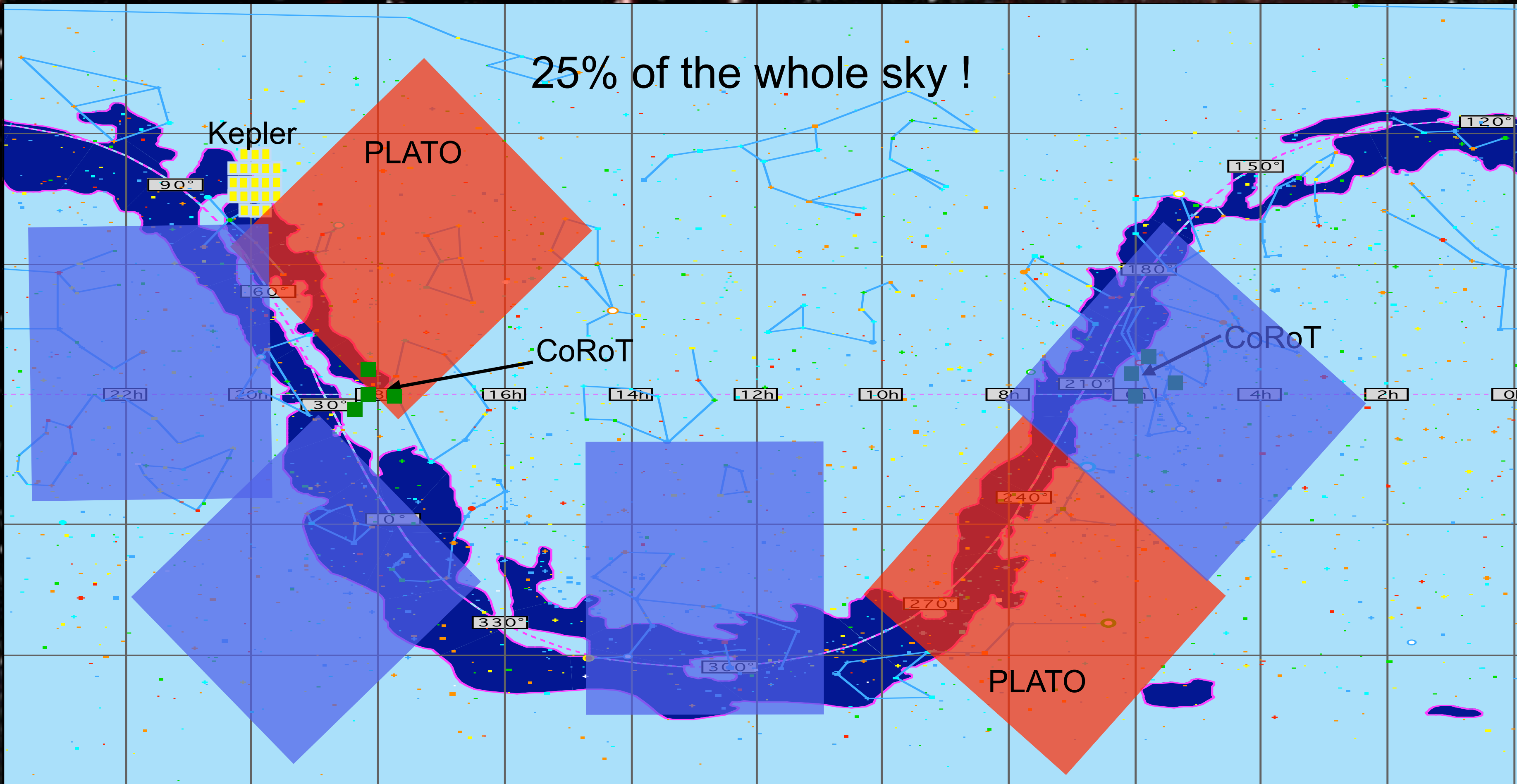
3 years + 2 years comply with duration requirement



Basic observation strategy

step and stare phase (1 year) : N fields for 3-5 months each

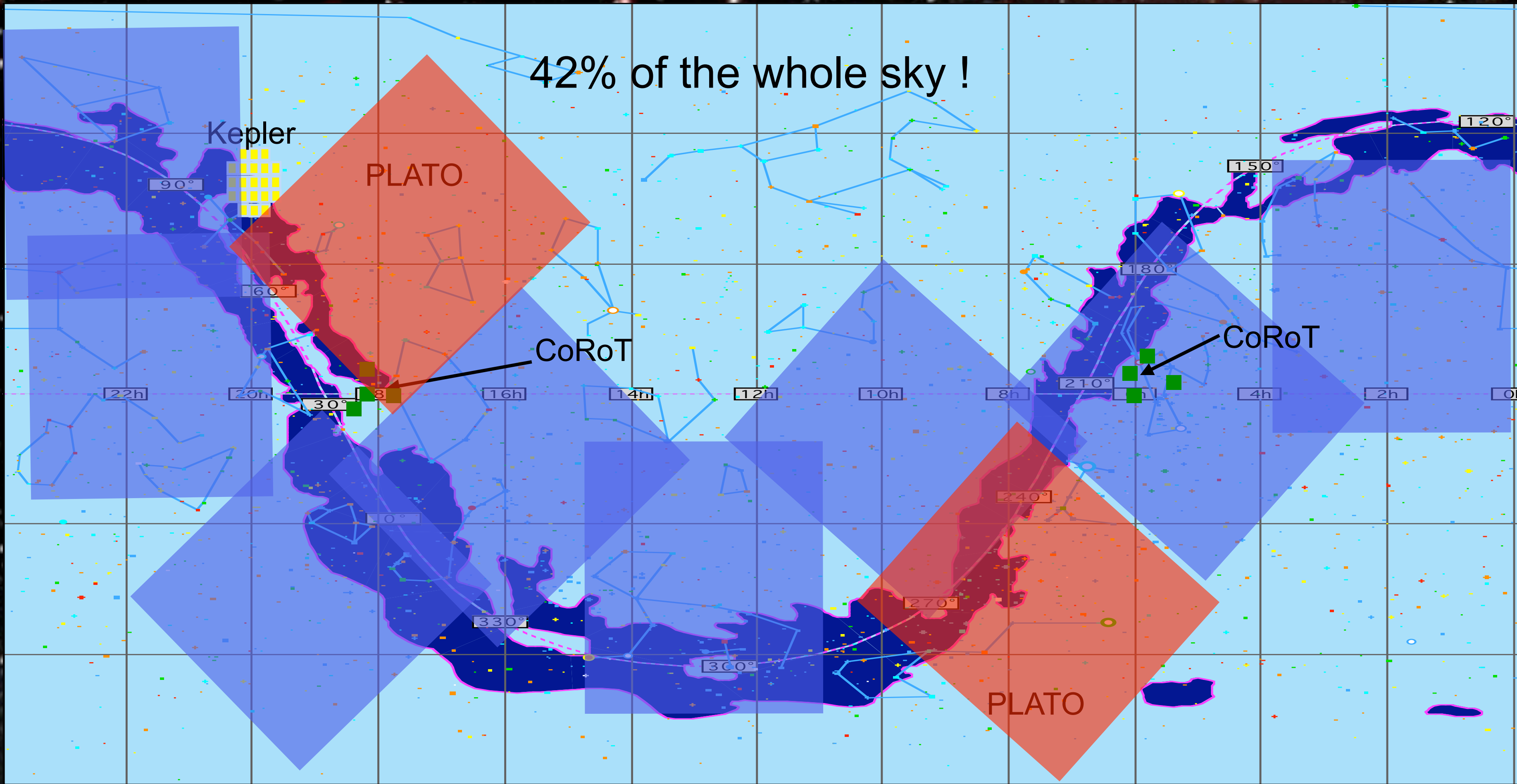
- increase sky coverage
- potential to re-visit interesting targets
- explore various stellar environments



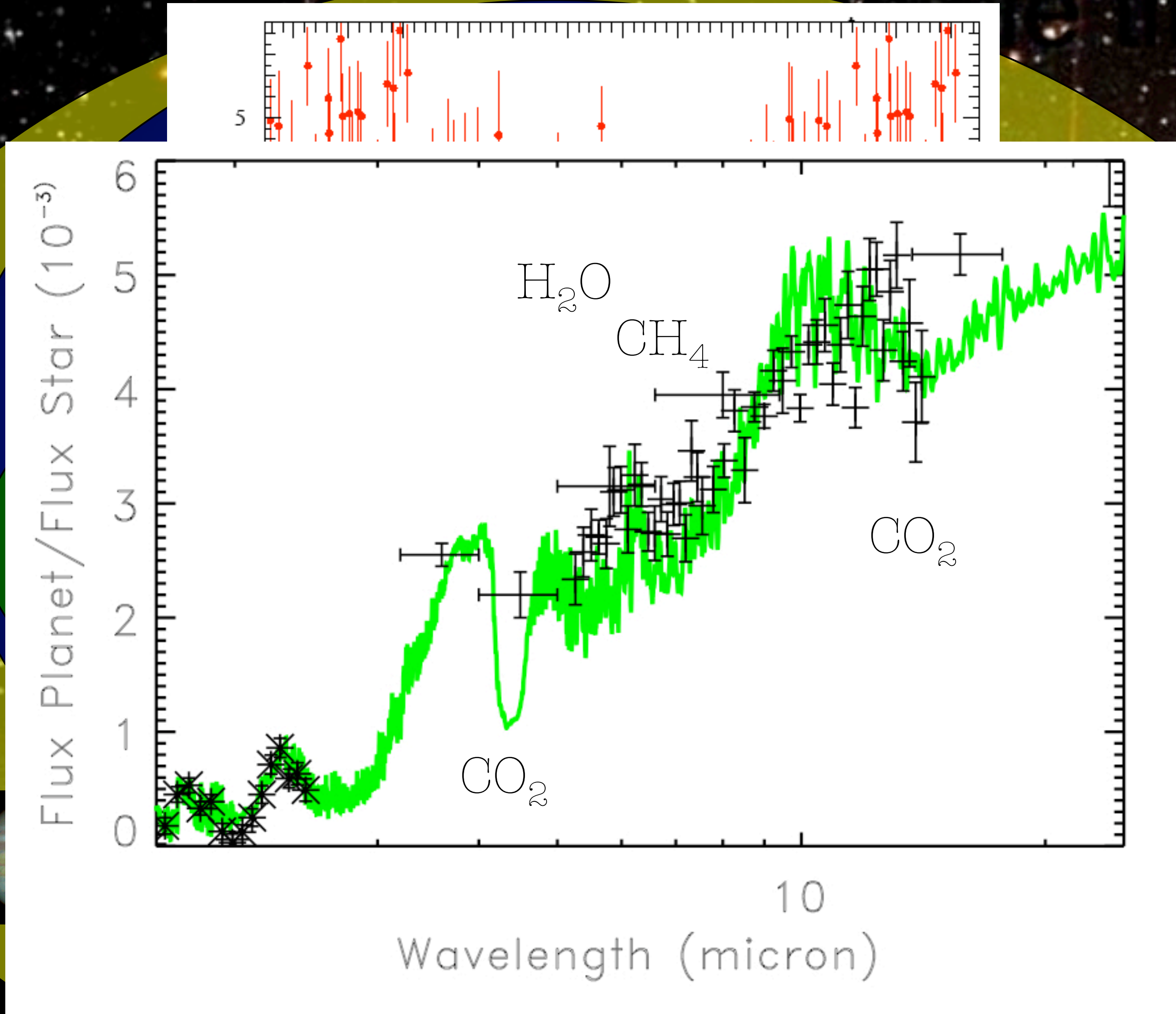
Basic observation strategy

step and stare phase (2 years) : N fields for 3-5 months each

- increase sky coverage
- potential to re-visit interesting targets
- explore various stellar environments



The PLATO star samples



≥ 250,000 cool dwarfs & subgiants

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Mission Assumptions (1/2)

- Assessment phase include 2 industrial studies and 1 instrument consortium study
- Want to observe many stars to improve statistics
  - → Maximize Field of View
  - → Maximize collecting area
  - → Extend mission lifetime to observe several sky fields

PLATO combines these requirements focusing on the large Field of View (bright stars)

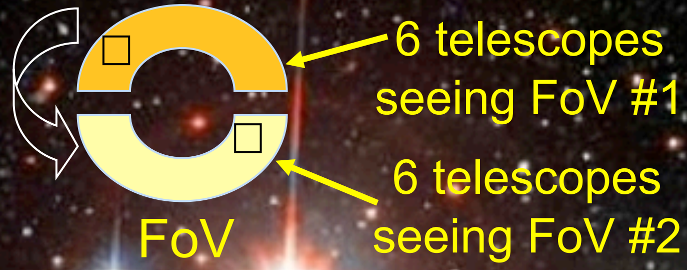
- Multi-aperture approach to allow for large Field of View

Mission Assumption (2/2)

- 6 year mission: 3 phases (2 long-duration + 1 step&stare)
  - 3-axis stabilized
  - Rotation around Line of Sight for continuous observation (power, stray-light)
- Direct insertion into large amplitude orbit around L2 using Soyuz 2-1b (payload capability: 2146 kg)
- Optics and detectors (CCD) operating at cold temp. (~150-190K)
- Classic Service Module and Payload Module approach
- X-band, 8.7Mbps 4h/day ground station contact (109 Gb/day)

Design Concept A (1/2)

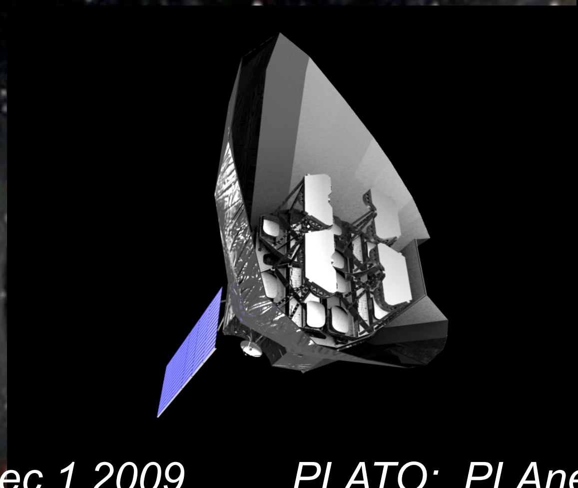
- 12-telescopes with two simultaneously observed sky areas (sub-fields)
  - Field of View: ~1800 deg²
  - 0.15 m^2 collecting area per sub-field
  - Rotation every 6 months around the LoS
  - 14 CCDs per focal plane with 27 µm pixels
  - 2080 x 2574 pixels per CCD
  - Very bright stars are observed via CCDs operating in frame-store mode to increase dynamic range

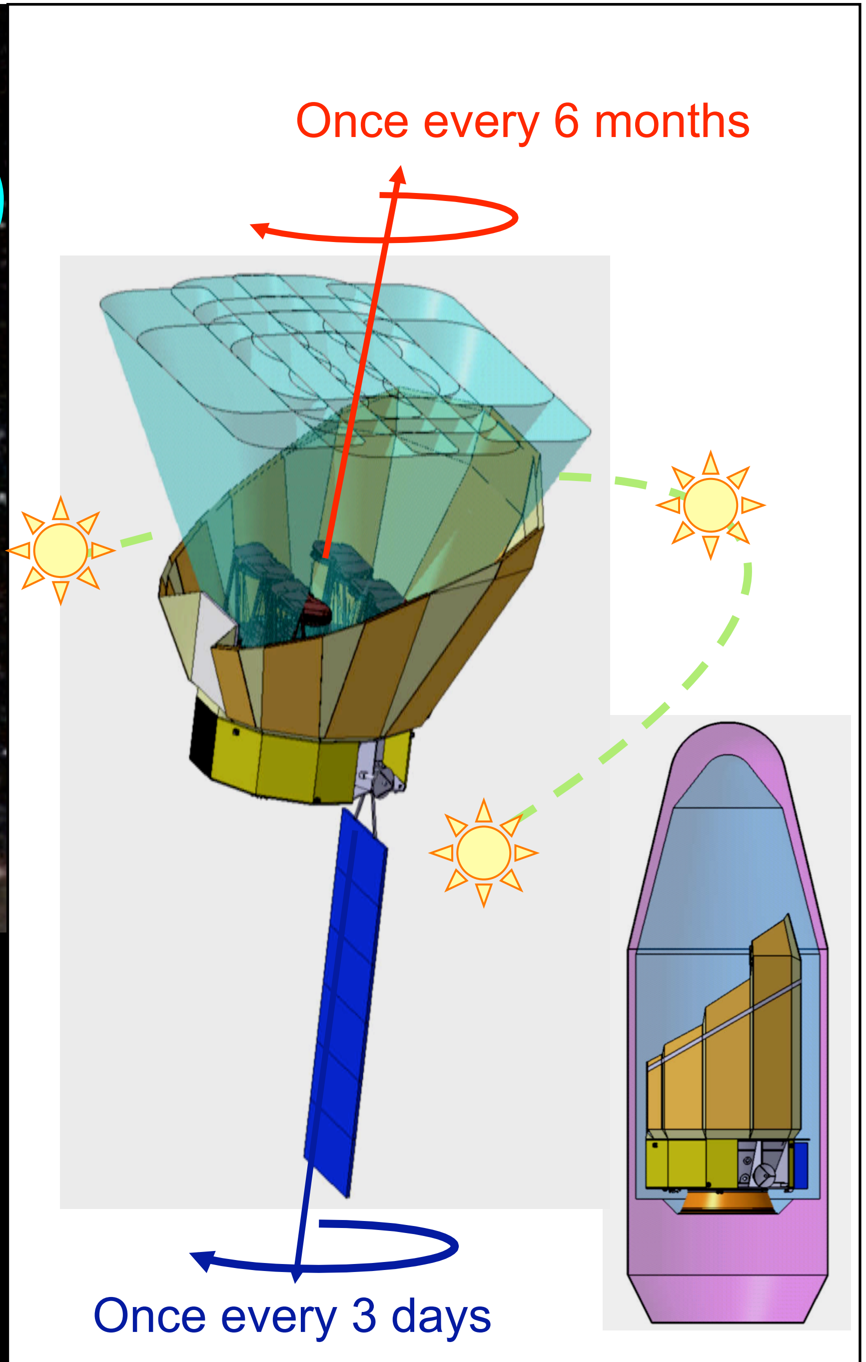


A module of 3 telescopes

Design Concept A (2/2)

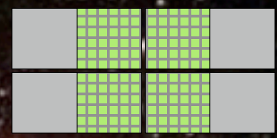
- Reflective 2-mirror telescope
  - 169 mm diameter entrance pupil
- Deployable sunshield
- Deployable and steerable solar array
- 2 steerable high-gain antennae



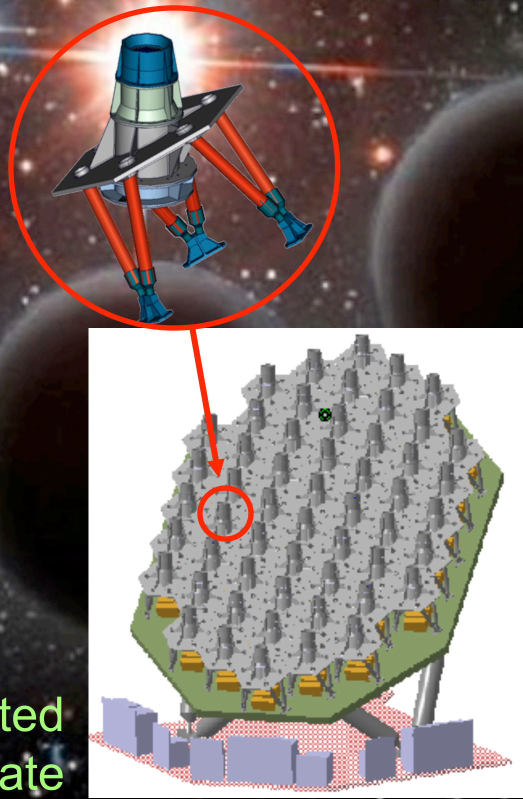


Design Concept B (1/2)

- 54 refractive telescopes mounted individually on tilted base plate
  - Total Field of View: ~625 deg^2
  - 0.3 m^2 collecting area
  - Circular FoV allows for monthly rotation around LoS with cont. observation of field
  - 2 CCDs per focal plane with 18 μm pixels.
  - 3000 x 6000 pixels per CCD
  - 6 dedicated telescopes for bright stars with 4 CCDs operating in frame-store mode



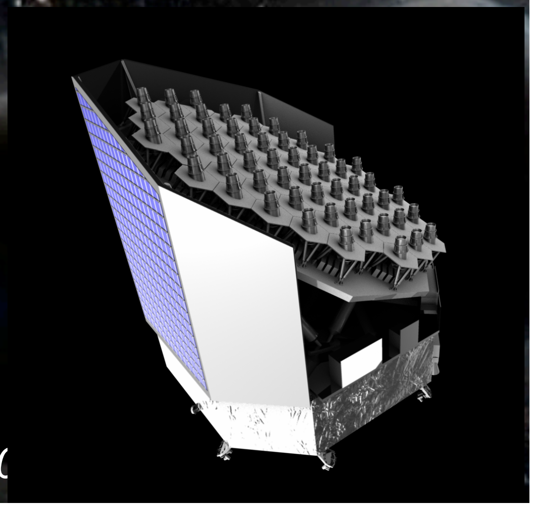
FPA with frame-store CCDs

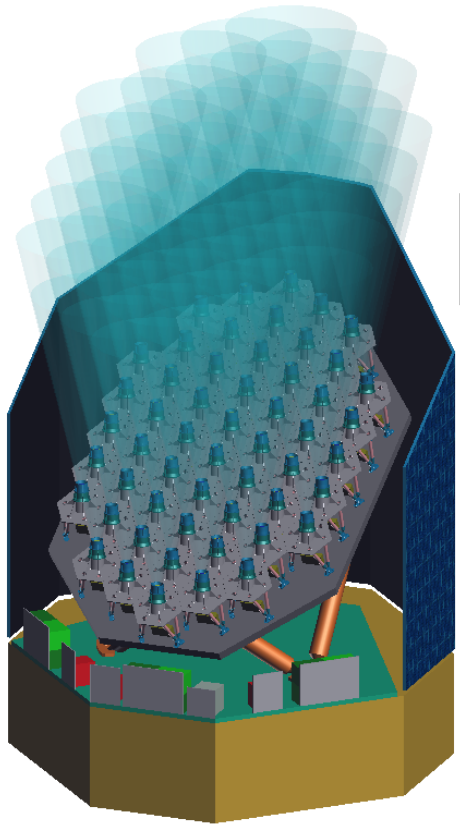


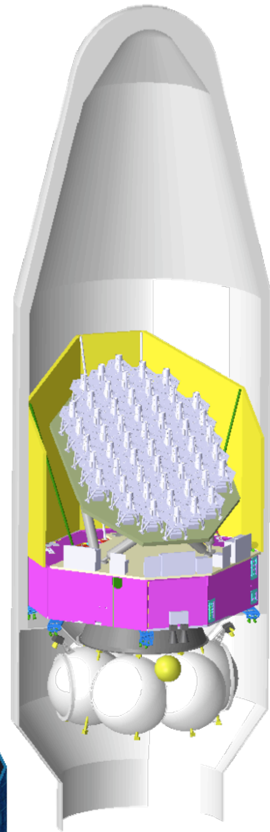
Telescopes mounted on optical base plate

Design Concept B (2/2)

- Refractive system with 6 spherical lenses
  - 83 mm diameter entrance pupil
- Fixed semi-encompassing sunshield
- Body-mounted solar array (sunshield + Service Module)
- 1 steerable HGA possible (monthly rotation)





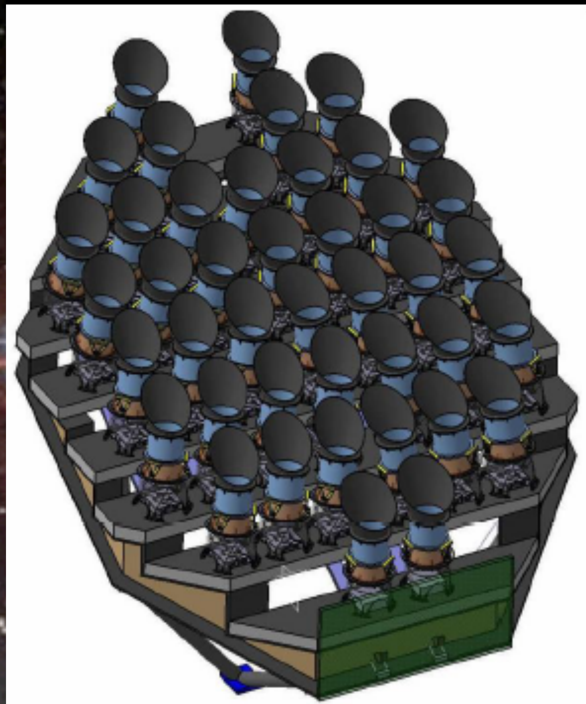


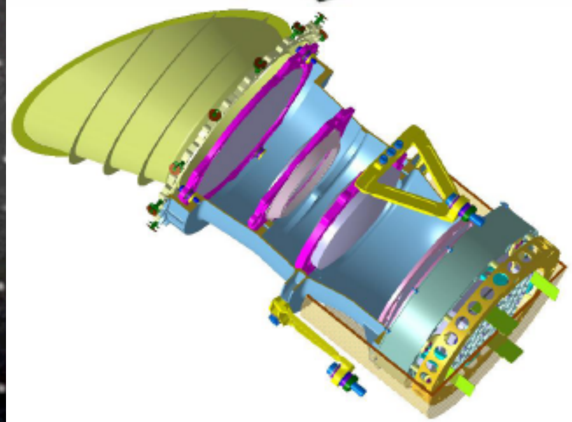
Design Concept C (1/2)

- 42 refractive telescopes mounted individually on stair case base plate
  - Field of View ~1800 deg^2 in 4 groups partially overlapping
  - Total collecting area is 0.475 m^2
  - FPA is encircled by FoV → needs quarterly rotation
  - 4 CCDs per FPA with 18 μm pixels
  - 3584 x 3584 pixels per CCD
  - 2 dedicated telescopes for bright stars with CCDs operating in frame-store mode

Design Concept C (2/2)

- Refractive system with 6 lenses (2 aspherical)
  - 120 mm entrance pupil
  - Grouping of telescopes gives access to large Field of View





Technical Summary

The scientific objectives of PLATO can be achieved through the 3 different concepts

PLATO is technically feasible with available, demonstrated technologies

ESA Review – Risk Elements

- Mission technically ready to go
- Schedule risk due to industrial series production
- Pre-development of CCDs and optics needed to secure launch date
- Optimization of payload design needed to increase system mass margin
- ESA Review points towards a refractive design for possible future phases

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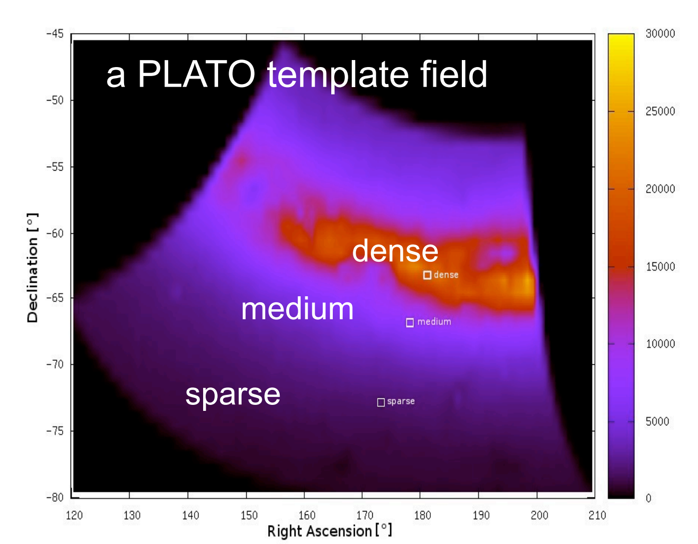
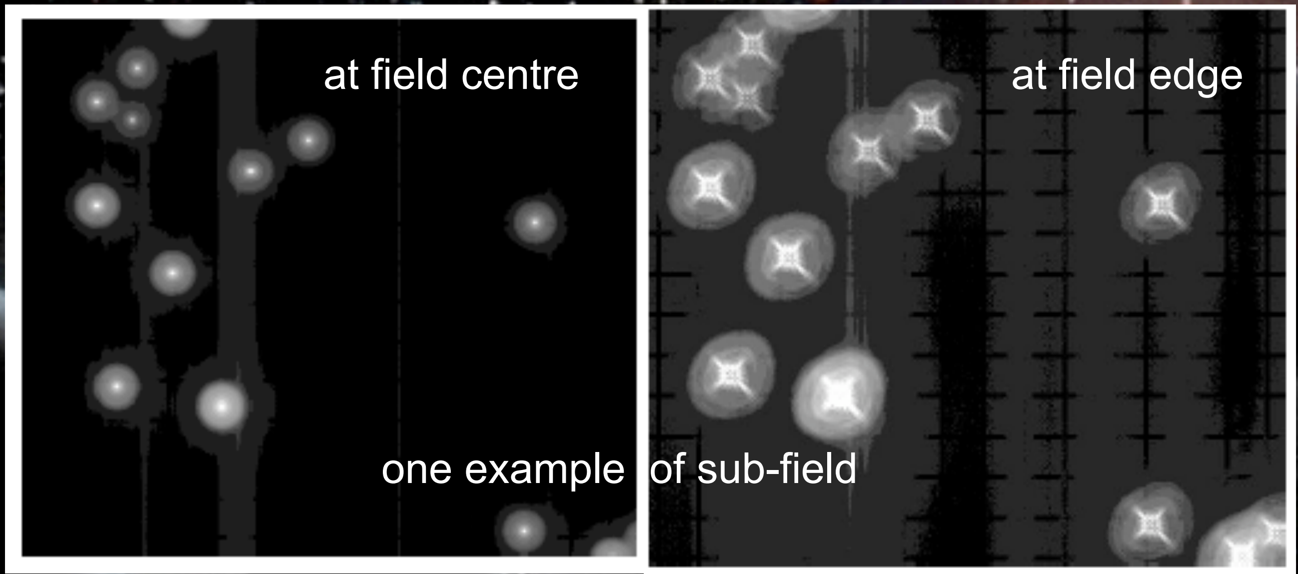
The end-to-end simulator

inherited from Eddington study, fully adapted to PLATO
- used for concept C,
- similar performances for other two concepts

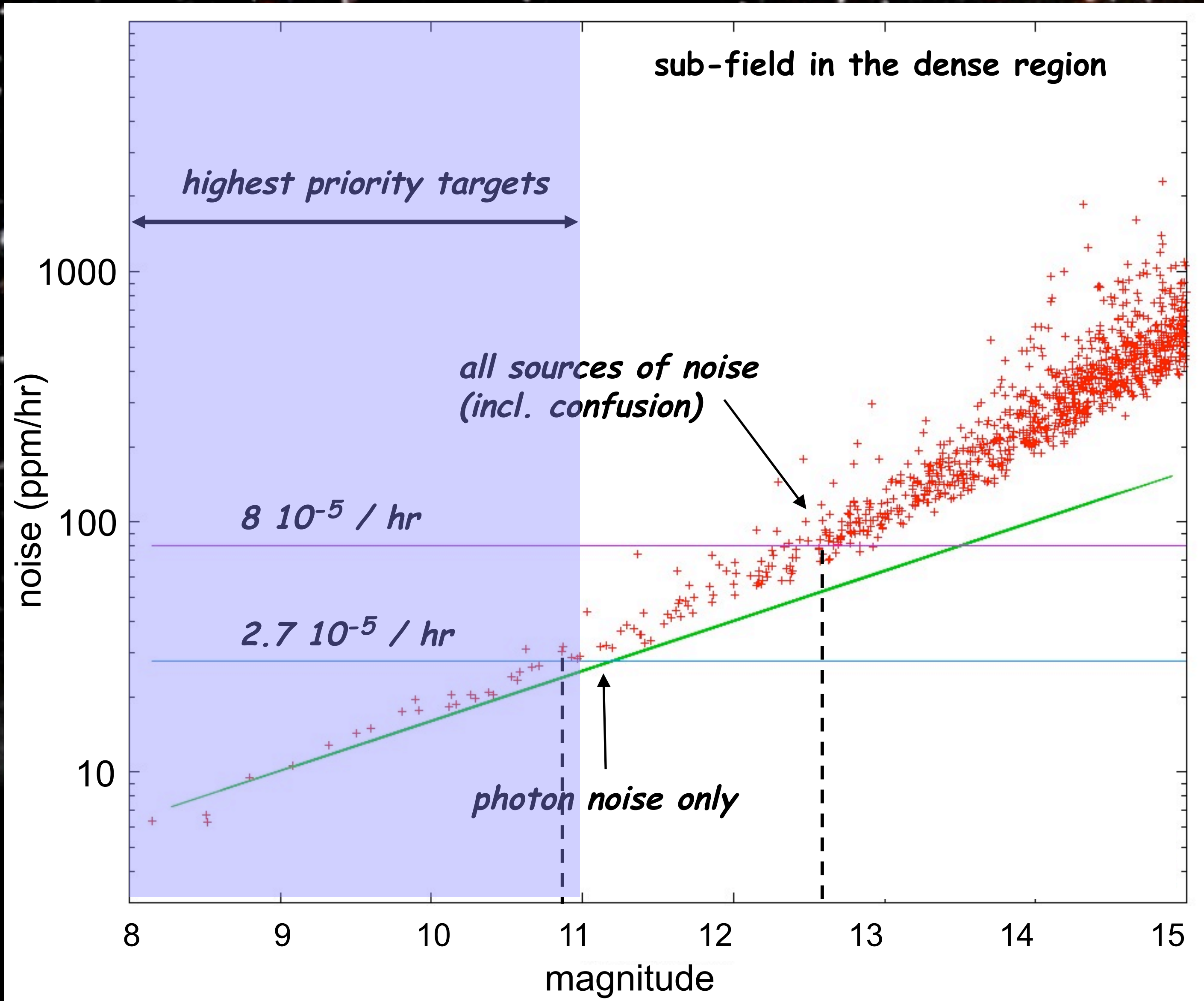
includes all known ingredients:
- *realistic field (confusion)*
- *optics (PSF at various positions in the field)*
- *detectors (readout, smearing, saturation)*
- *data treatment (photometric algorithms, jitter correction)*





Expected noise level

results from end-to-end simulator: ***field (confusion), optics (PSF), detectors, algorithms***



Expected numbers of stars

as a function of noise level

science req: ≥ 20,000

design & surveyed area	PLATO concept A 3600 deg^2		PLATO concept B 1250 deg^2		PLATO concept C 3600 deg^2		Kepler 100 deg^2	
noise level (10^{-5}/hr)	# cool dwarfs & subgiants	mag lim	# cool dwarfs & subgiants	mag lim	# cool dwarfs & subgiants	mag lim	# cool dwarfs & subgiants	mag lim
2.7	22,000	10.4	21,000	11.1	21,000	9.8-11.1	1,300	11.2
8.0	260,000	12.7	257,000	13.5	238,000	11.8-12.9	25,000	13.6

design & surveyed area	PLATO concept A 3600 deg^2	PLATO concept B 1250 deg^2	PLATO concept C 3600 deg^2	Kepler 100 deg^2
magnitude	# cool dwarfs & subgiants	# cool dwarfs & subgiants	# cool dwarfs & subgiants	# cool dwarfs & subgiants
6			90	0
8	1,350	675	1,350	30
9	3,800	1,320	3,800	100
10	13,500	4,700	13,500	370
11	48,300	16,800	48,300	1,300
…	…	…	…	…

as a function of magnitude

for two long pointings

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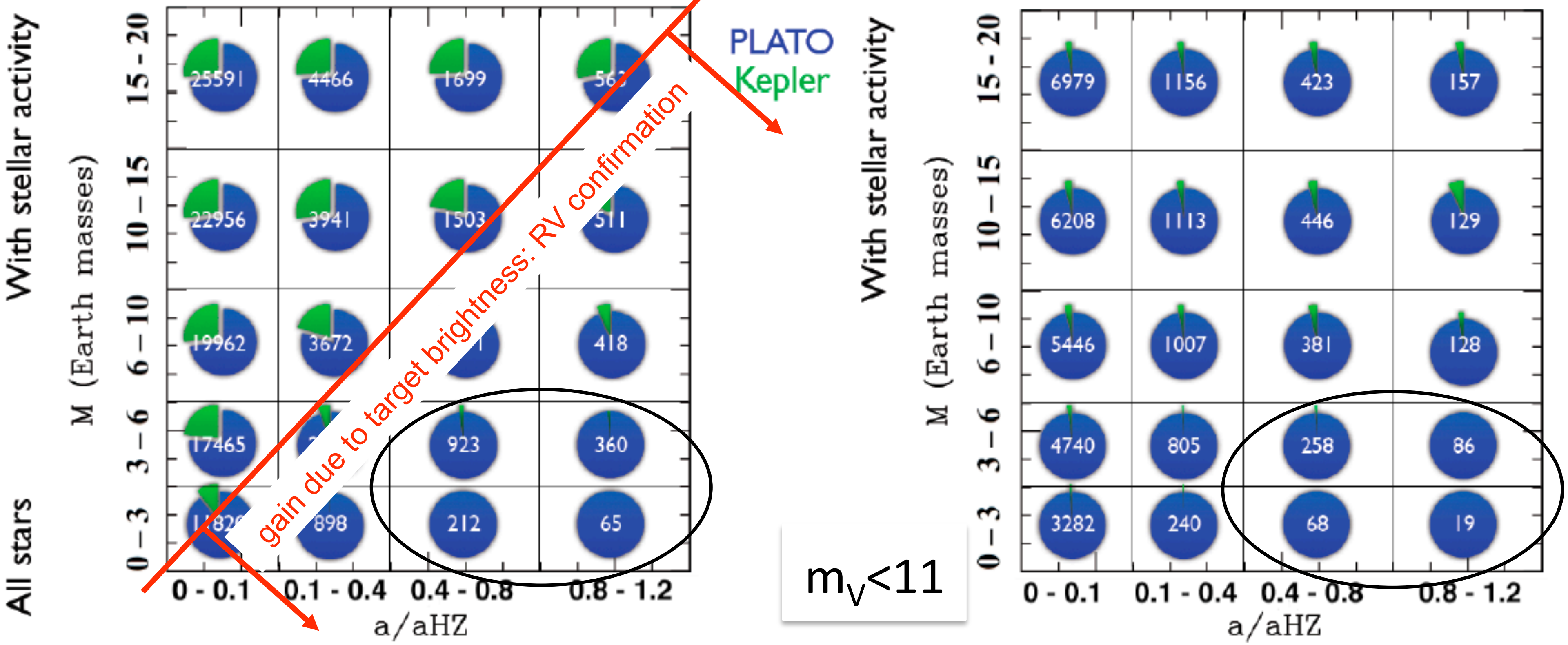
Expected number of confirmed planets

Expected numbers of detected transiting planets for PLATO (2 long runs) and Kepler

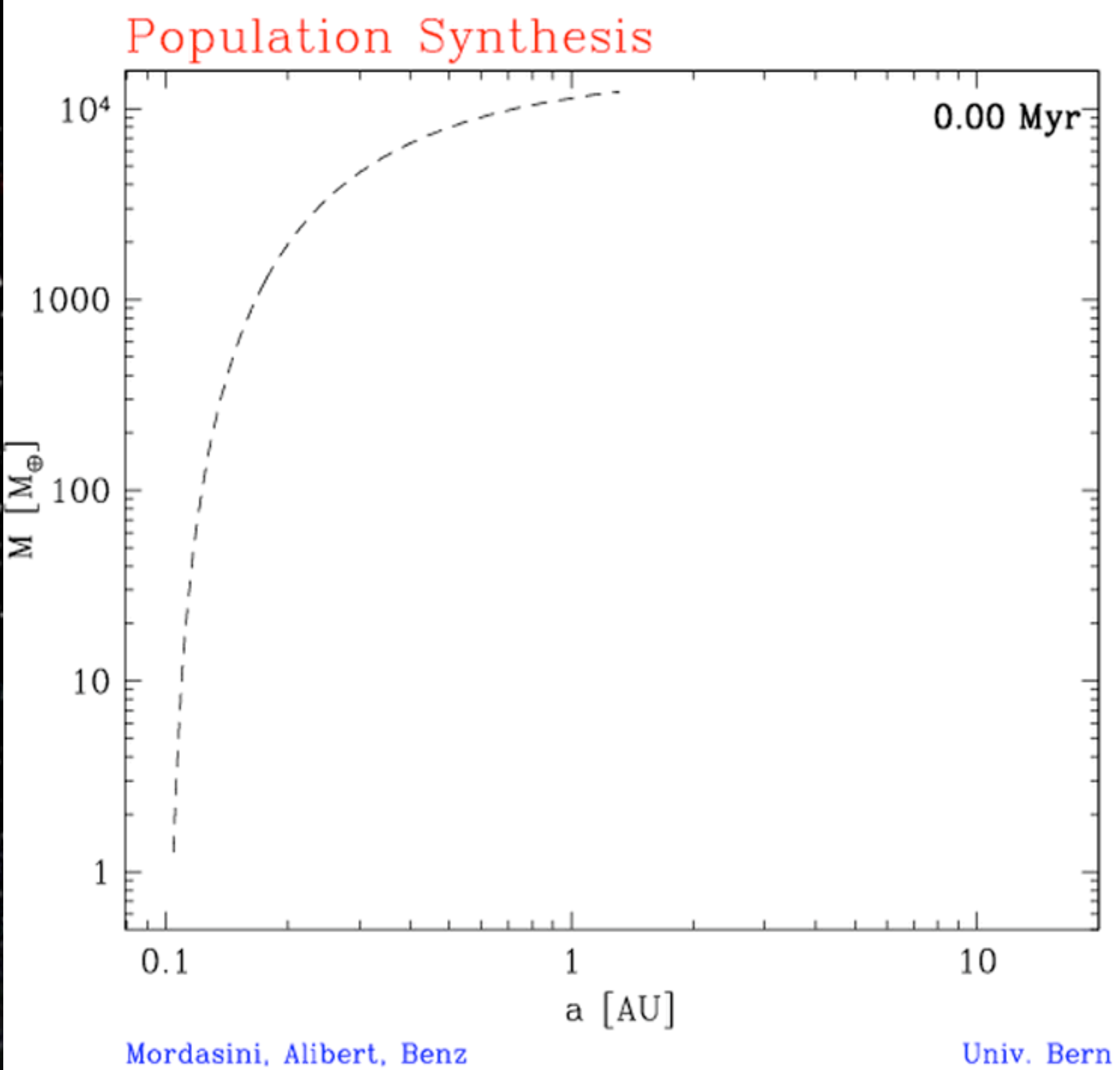
- each star has one and only one planet in each considered cell
- planet is assumed detected if transit signal AND radial velocity signal can be measured
- stellar intrinsic « noise » taken into account



bright stars that can be characterised seismically

lower right corner of the (orbit,mass) plane = terrestrial planets in the HZ, not covered by Kepler, will be explored by PLATO thanks to its priority on bright stars

Testing formation and evolution models



M_{star}=1 $M_\odot$
Nominal model

Type I migration

Type II migration
(Disk dominated: $M_p < M_{disk,loc}$)

Type II migration
(Planet dominated: $M_p > M_{disk,loc}$ &
disk limited gas accretion)

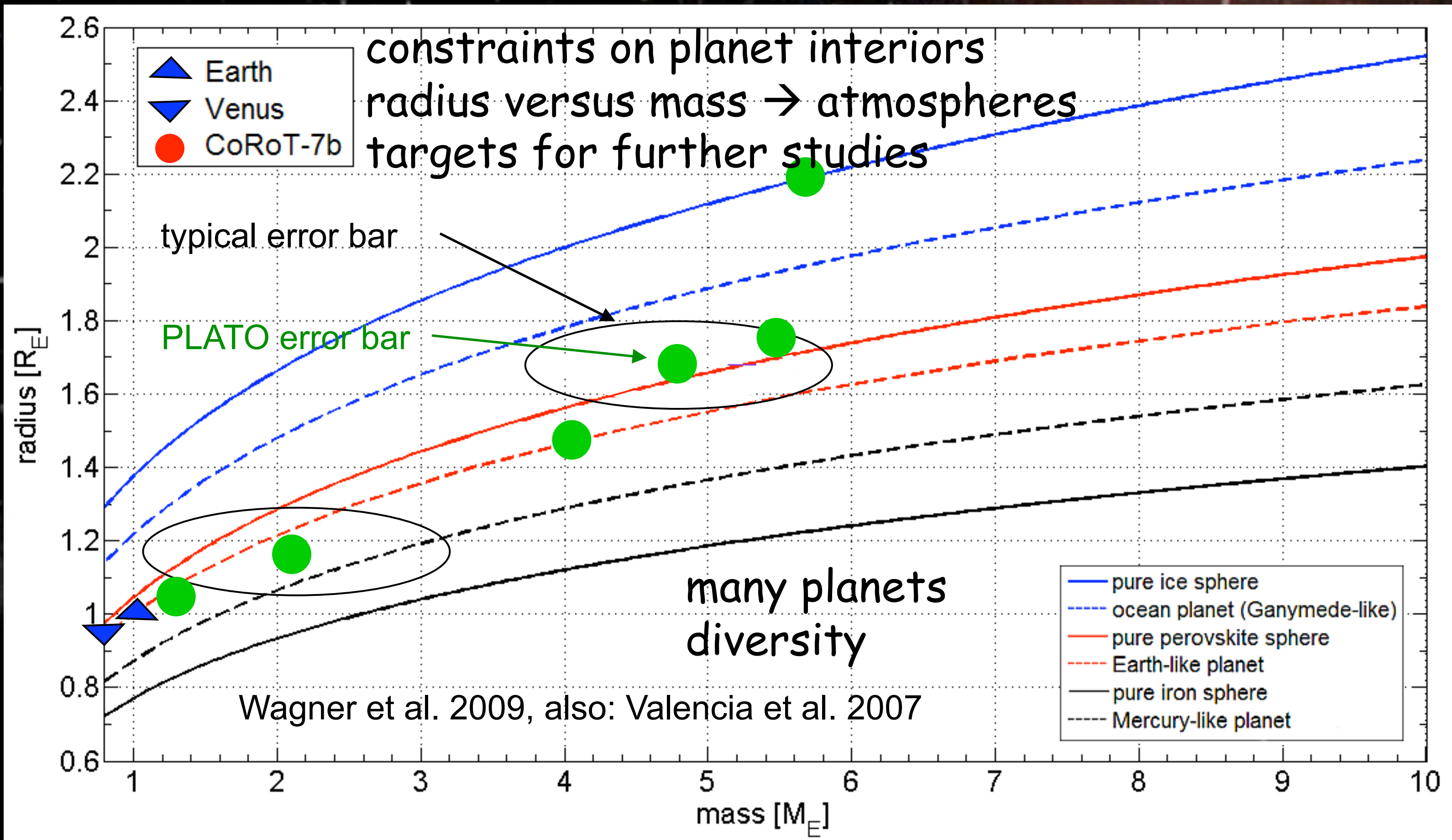
PLATO results will test predictions of models

Impact of mass and radius measurements

PLATO transit photometry + Gaia stellar radii → planet radii within few %

RV curves + PLATO seismology → planet masses within few %

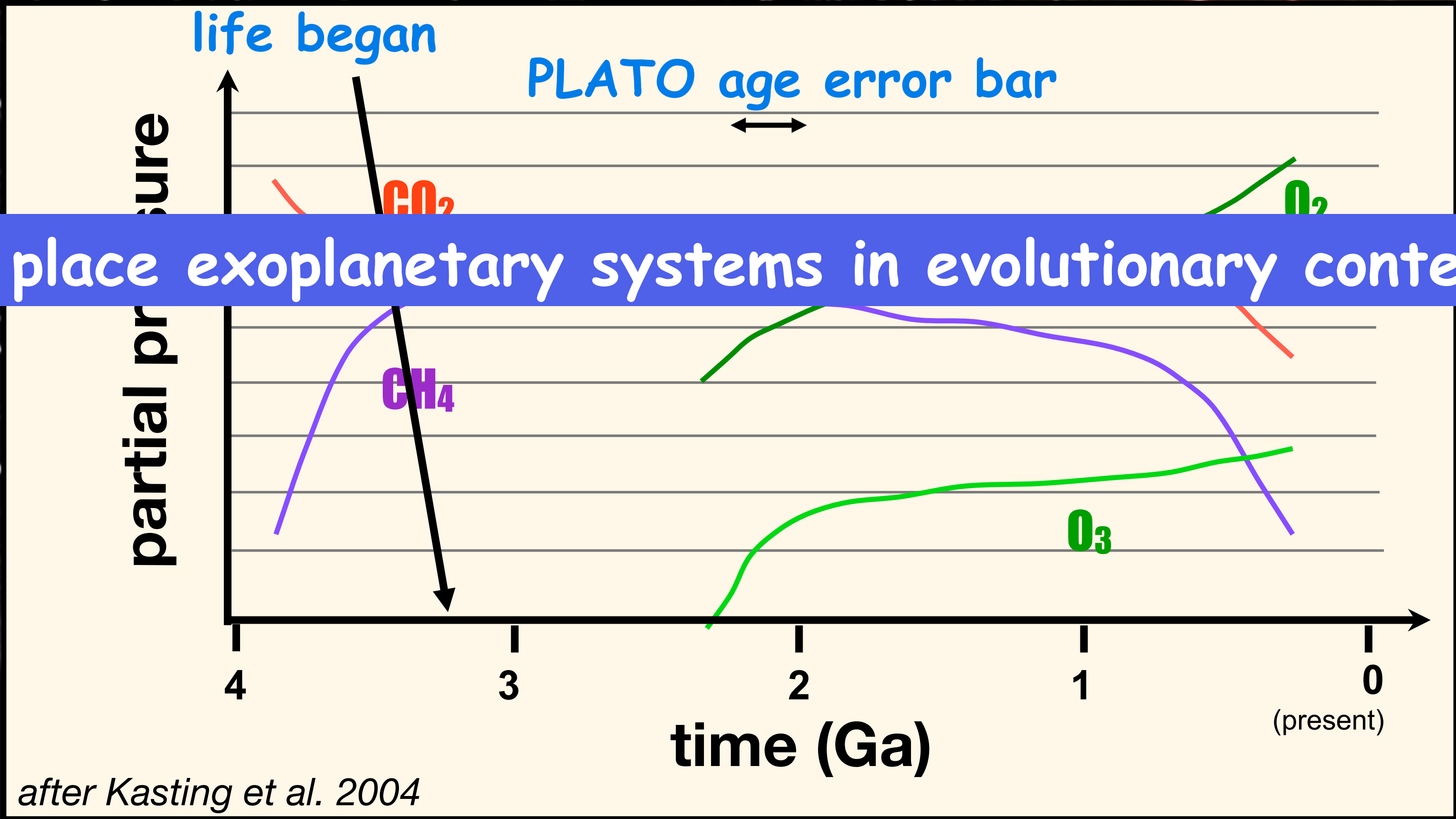
Planet characterisation to unprecedented accuracy



Impact of age measurement

PLATO: compare Earth-like exoplanets with age scale of Earth

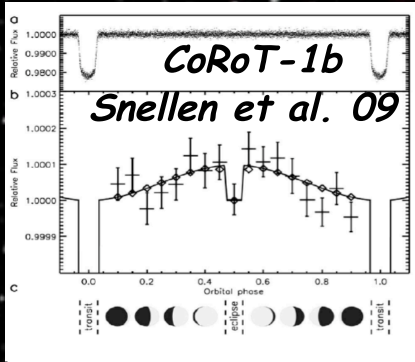
- precision better than timescale for chemical evolution
- targets of future characterisation studies with age from PLATO

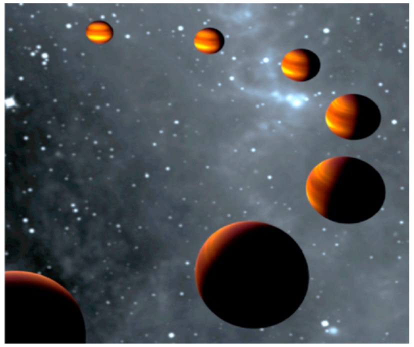


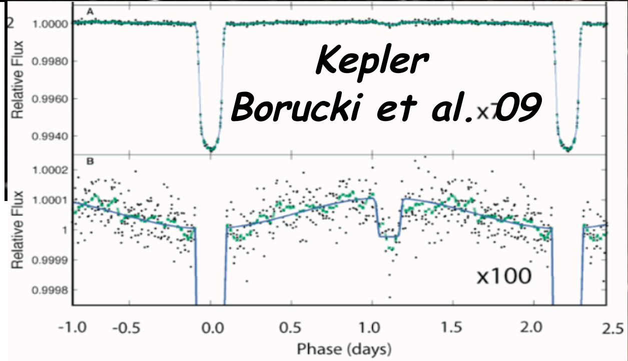
place exoplanetary systems in evolutionary context

Stellar reflected light and secondary transits

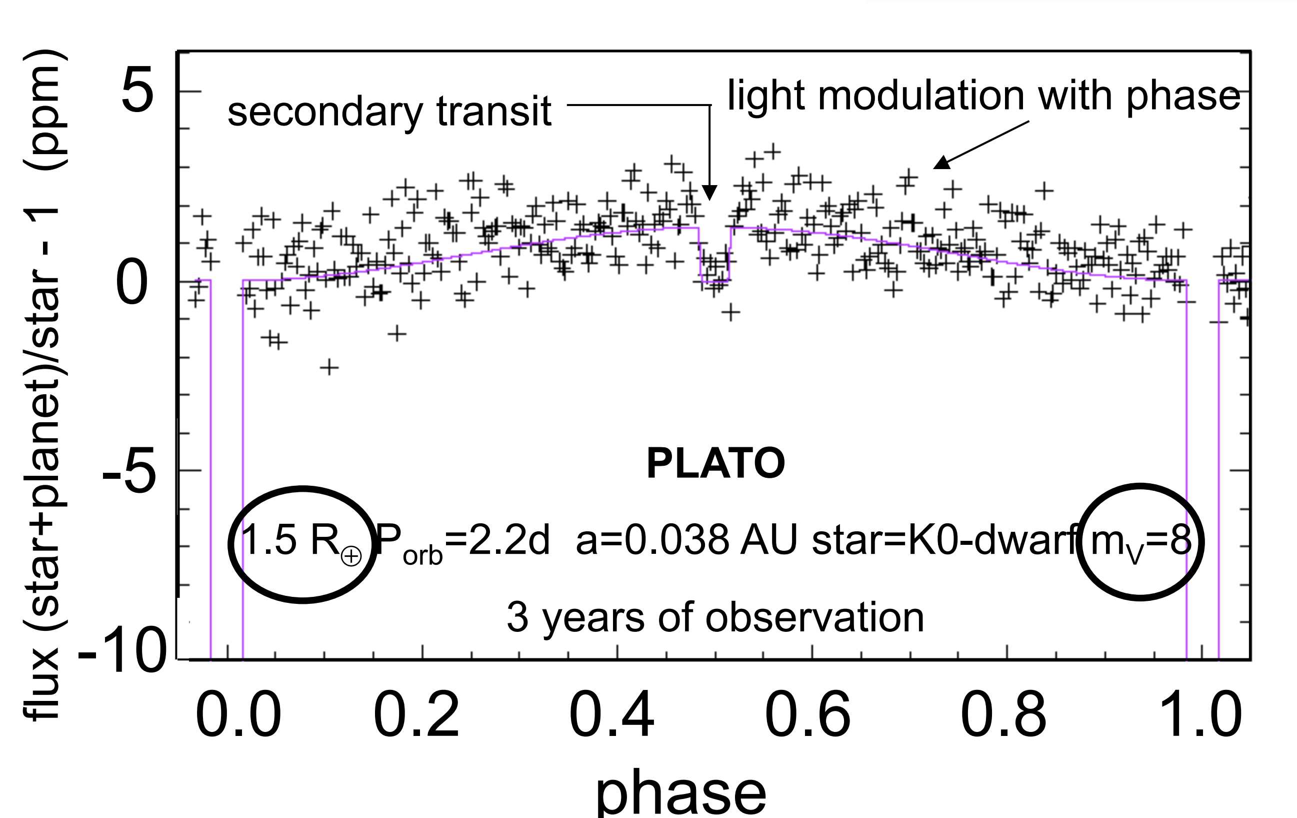
measurement of albedo and T = characterisation of planet surface/atmosphere







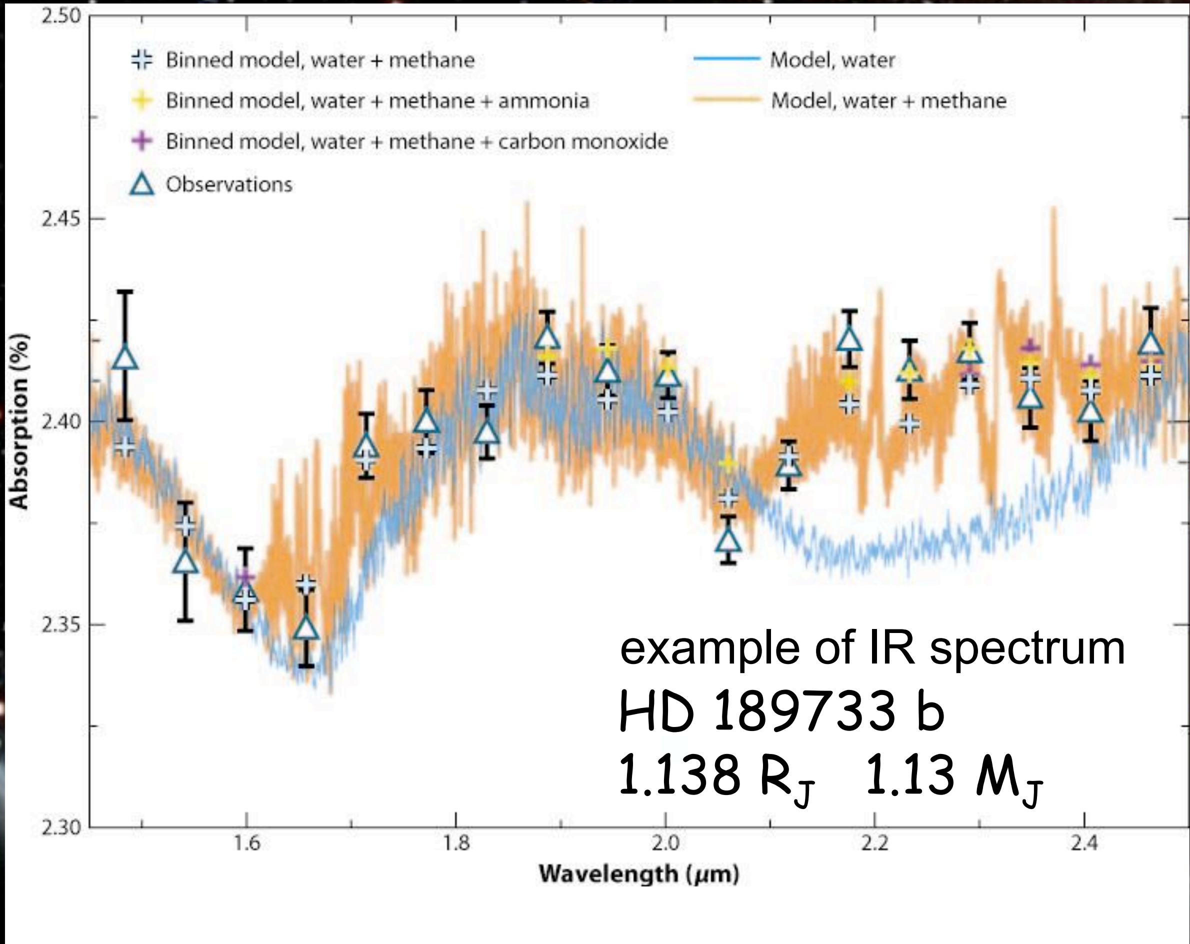
HAT-P-7b
130 ± 11 ppm
m_V = 10.5
15.3 $R_\oplus$
0.038 AU
P = 2.2 days
duration: 10 days



PLATO:
>1,000 such stars
many transiting planets expected

Atmospheric studies of transiting planets

PLATO planets around very bright stars = prized targets for future atmospheric studies



Tinetti et al. 2007

Additional science

PLATO: unique database of stellar variability for bright ($6 \leq m_V \leq 13$) stars on time scales from one minute to months

→ many additional science programmes involving different aspects of stellar physics

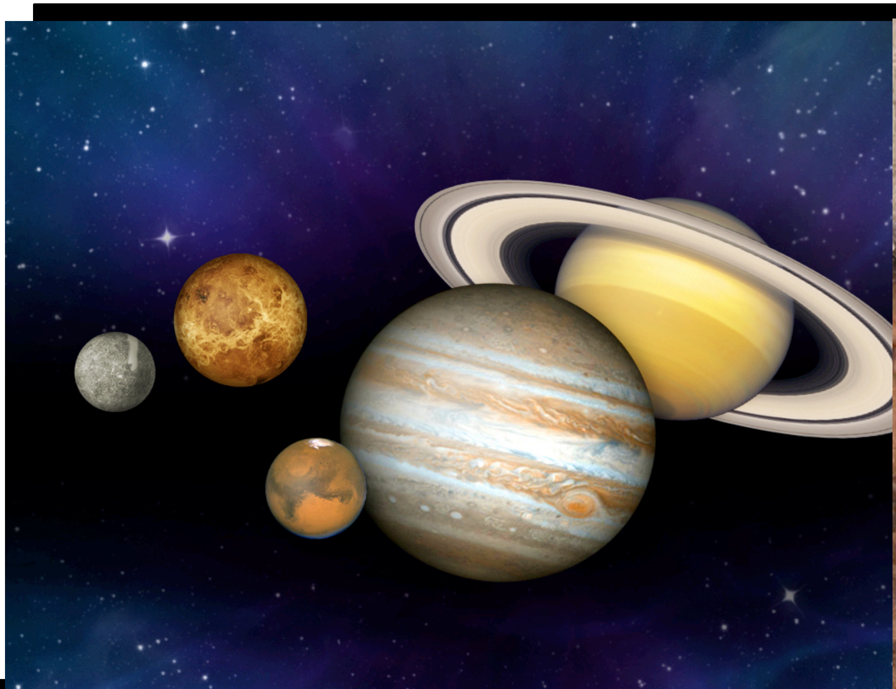
a couple of examples:

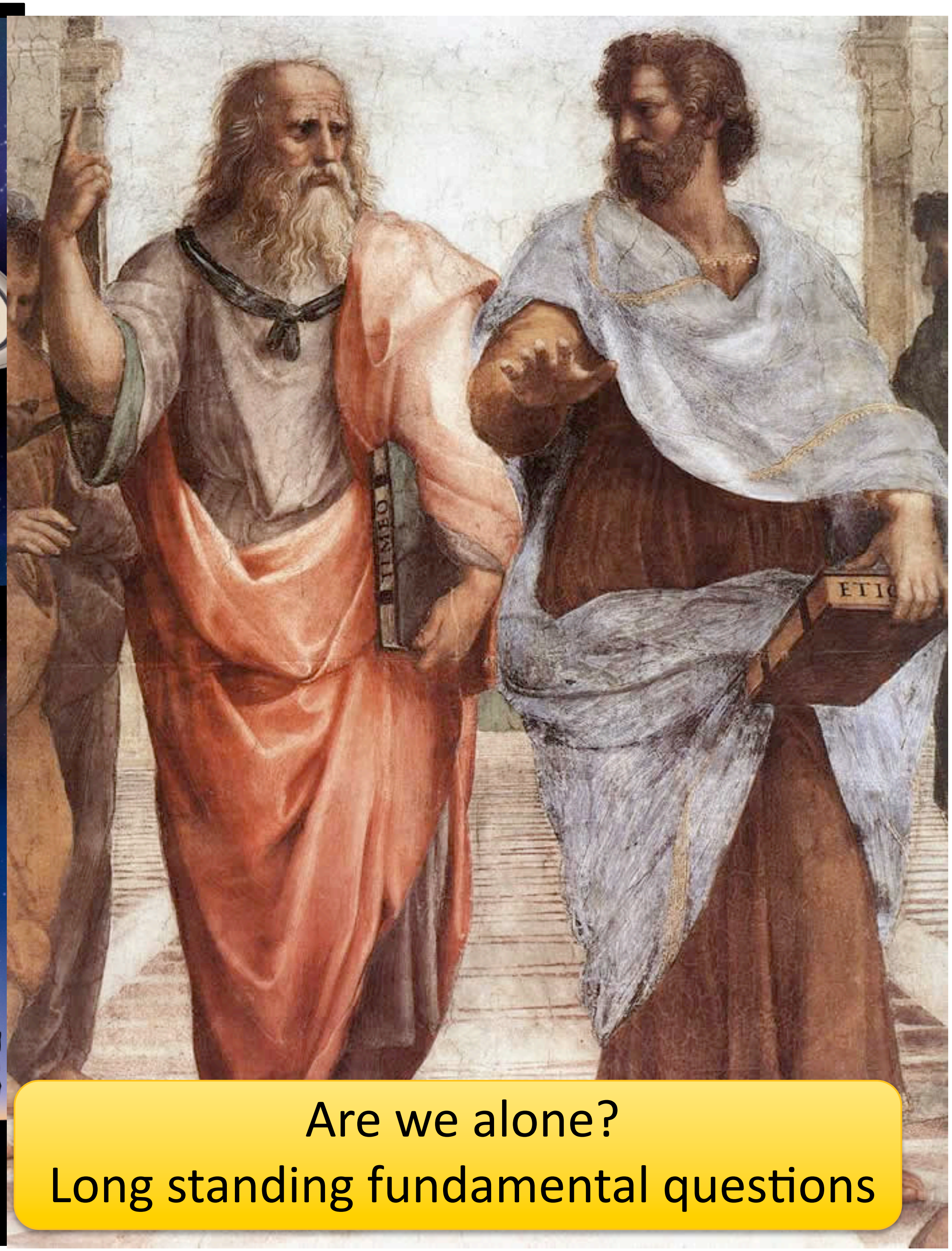
- ✓ asteroseismology across the HR diagram,
  e.g. stars in open clusters: full understanding of stellar evolution
- ✓ stellar activity and rotation: full census as a function of age

…

Outline

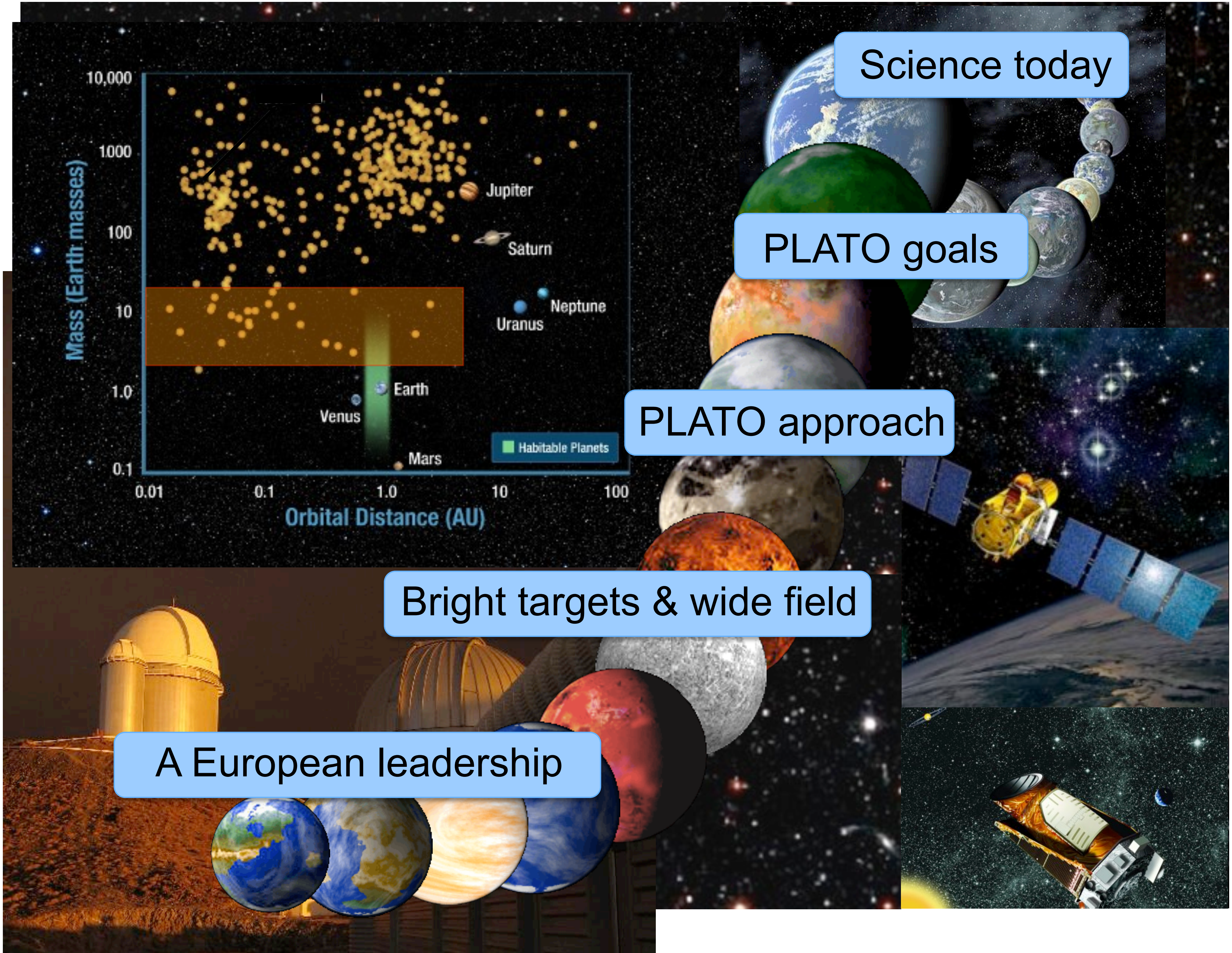
- Introduction
- Science goals
- Tools
- Science requirements
- Payload and mission
- Performances
- Science impact
- Conclusion

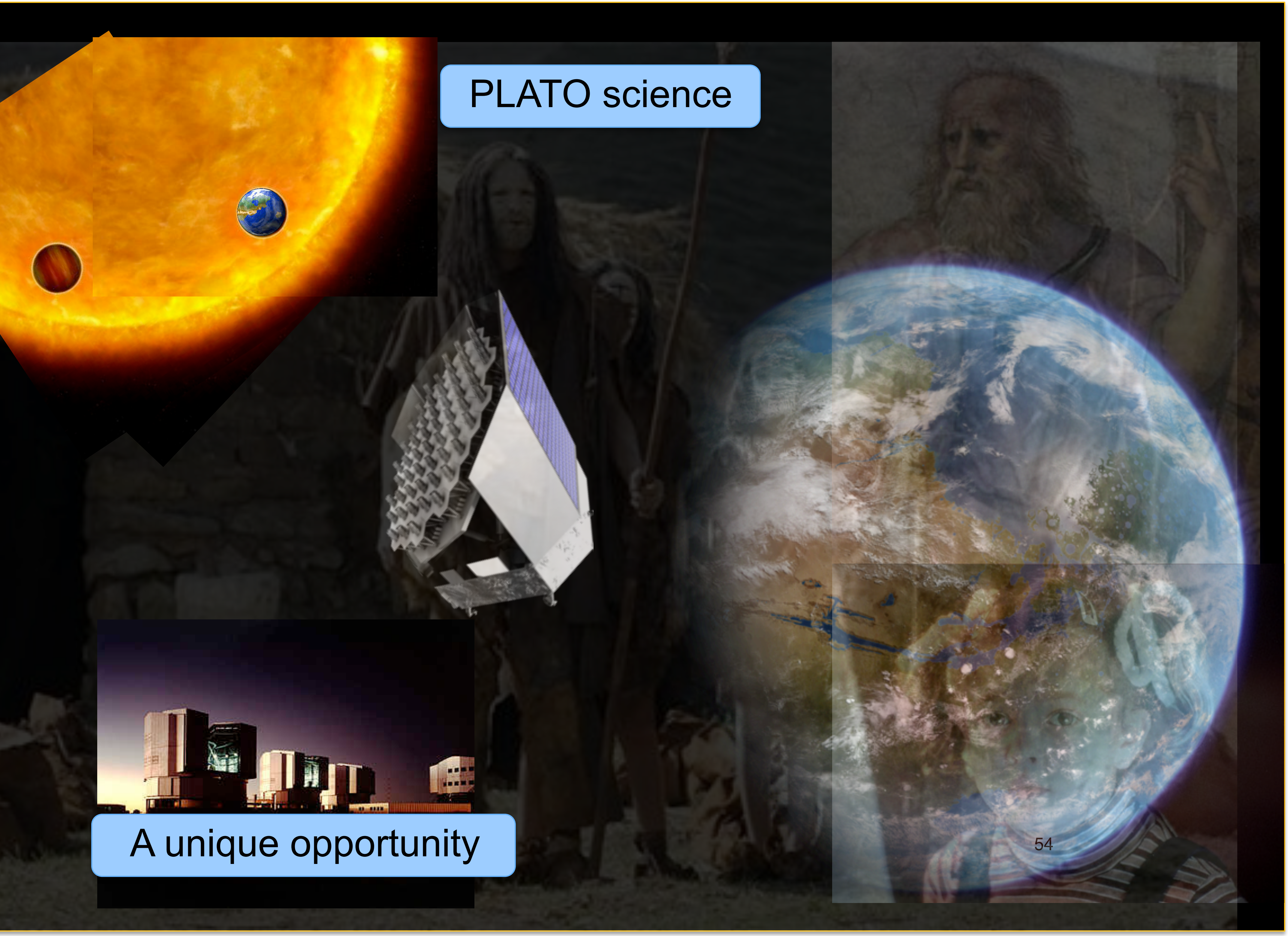




Are we alone?

Long standing fundamental questions


Science today
PLATO goals
PLATO approach
Bright targets & wide field
A European leadership
Mass (Earth masses)
10,000
1000
100
10
1.0
0.1
0.01
0.1
1.0
10
100
Orbital Distance (AU)
Jupiter
Saturn
Neptune
Uranus
Earth
Venus
Mars
Habitable Planets


PLATO science
A unique opportunity

PLATO

Objective: Detect and characterise planetary systems, particularly earth-like in habitable zone

Instrument: Multi-telescopes
very wide field of view

Techniques: Detection by transits
+ asteroseismology
+ ground based spectroscopy

Targets: >20,000 Bright cool dwarfs (noise<2.7 10^{-5})
>50,000 Bright cool dwarfs (mv<11)
>250,000 (mv<13) +…

Observing strategy: 2 long runs (2-3 years) + several short runs