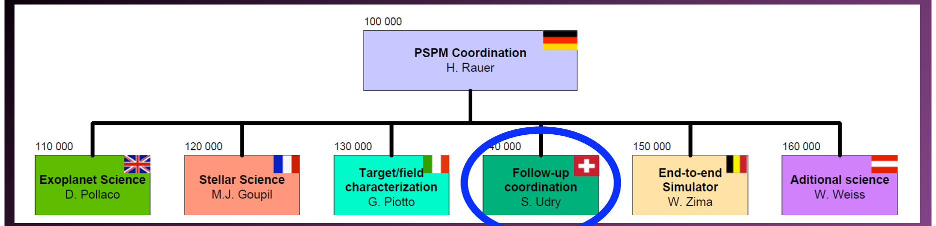
PLATO Follow-up activities



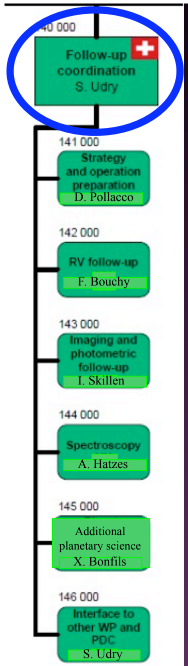
Overall PSPM structure

The prime science product of PLATO = sample of fully characterized planets
(various masses, sizes, temperatures, and ages)
=> terrestrial planets in the habitable zone of their parent stars.

=> in addition to the photometric transit detections and asteroseismic characterization,
a ground-based follow-up support is absolutely required

PLATO Follow-up activities in practice

- Definition of the needs (strategy, tools) in terms of science achievements
  - Planet masses (from RVs)
  - Science extension (system geometry, atmosphere, etc)
  - Tools for optimal planning and operation
  - Understanding of false positives
- Observing facilities related activities
  - Estimate of the planet yield of the mission
  - Telescope time estimate for planet confirmation
  - Estimate the false positive impact on the required telescope time
  - List of available/planned facilities
- Organization of the Follow-up work packages
  - work breakdown
  - data: interfaces with the PDC



WP 140 000
Preparation of PLATO follow-up observations
Stéphane Udry (Switzerland)

1. Coordination of the preparation for the follow-up observations of PLATO transit candidates

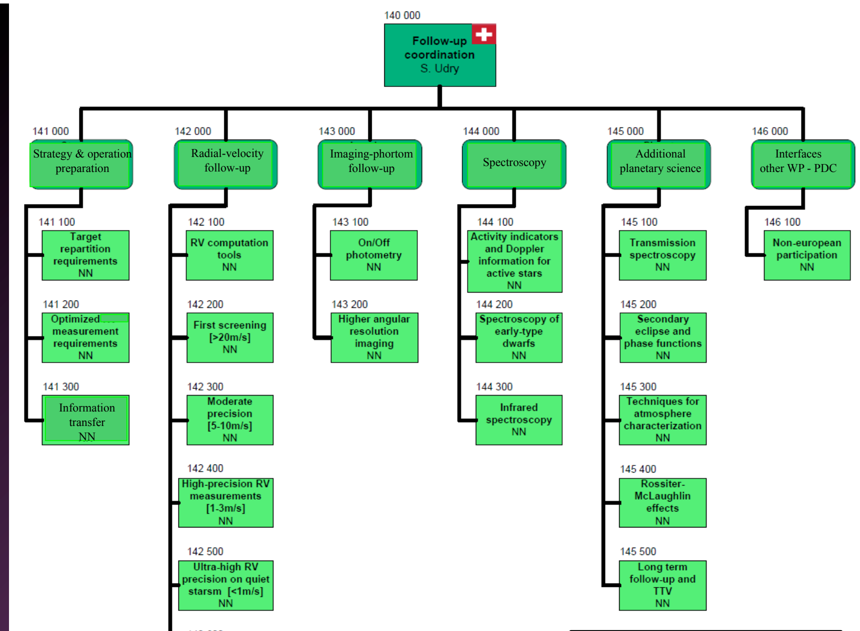
2. Identify and list all the existing and in-development facilities which will be in operation during the PLATO mission (2019-2027).

3. If existing (and in development) facilities are not sufficient, define the strategy to build new facilities or/and upgrade existing ones.

→ Letter of intent

4. Estimate planet yield of the mission and the corresponding telescope time to characterize the planets

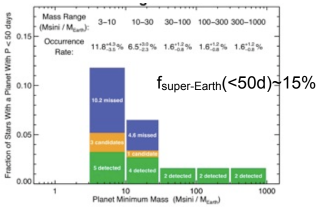
5. Identify false positives (type and occurrence) and estimate telescope time to discard the corresponding cases



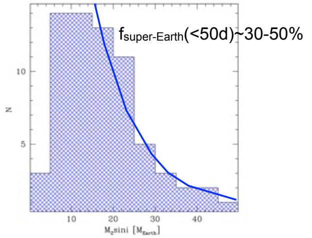
→ Letter of intent

Low-mass planets...
Small-size planets...
....are numerous!

Keck (Howard et al. 2010, Science)

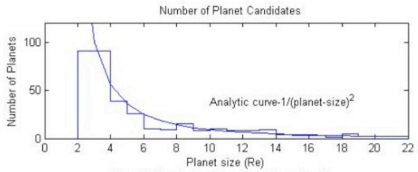


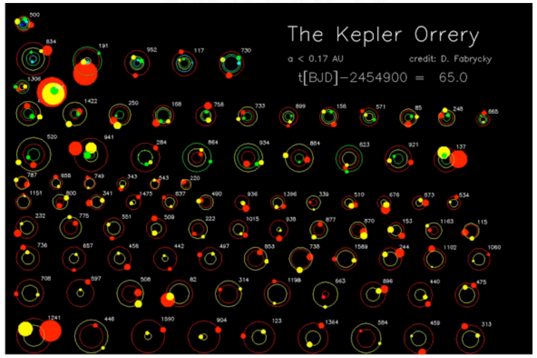
HARPS (Lovis et al. 2009) (Mayor et al. in prep)



Kepler (Borucki et al. 2010)

Abstract. On 1 February 2011 the *Kepler* Mission released data for 156,453 stars observed from the beginning of the science observations on 2 May through 16 September 2009. There are 1235 planetary candidates with transit like signatures detected in this period. These are associated with 997 host stars. Distributions of the characteristics of the planetary candidates are separated into five class-sizes; 68 candidates of approximately Earth-size ($R_p < 1.25\ R_\oplus$), 288 super-Earth size ($1.25\ R_\oplus < R_p < 2\ R_\oplus$), 662 Neptune-size ($2\ R_\oplus < R_p < 6\ R_\oplus$), 165 Jupiter-size ($6\ R_\oplus < R_p < 15\ R_\oplus$),





Requirements for the organization of the follow-up (1)

One of the main aspects of the ground-based follow-up of PLATO resides in the basic planet characterization through radial-velocity measurements.

- Large number of expected transit candidates
  => systematic observation of all transits with large telescopes unfeasible
  => an optimized follow-up scheme has to be organized

Same level of precision cannot be reached for all stars due to various sources of stellar intrinsic limitations: spectral type, luminosity class, activity, brightness

- Strategy for the follow-up: efficient approach
  - some directives to observers for matching targets and adequate facilities
  - freedom of target choice by the observers having needed information in hand
  - minimum number of used facilities per target

Basic idea: i) automatic distribution of the targets in boxes according to the needs
ii) given facilities will only have access to some of the boxes matching their capabilities.

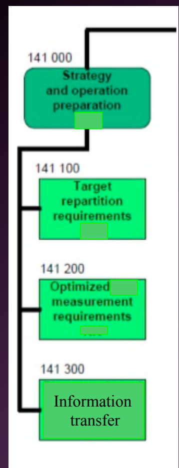
Requirements for the organization of the follow-up (2)

Targets can move from one box to the next, in an evolutionary way, depending on results of previous observations

In practice => a multi-step approach
from moderate to high-precision instruments
- already successfully used in most of the on-going surveys
- will also nicely apply to PLATO candidates.

To achieve this goal we need to design and develop
- efficient tools for the target repartition
- user interface and tools for the observers
- interface between the PDC and the observer able to accept input from the observer as well (web interface)

WP 141 000
Tool requirements for strategy and operation preparation
Don Pollacco (UK)

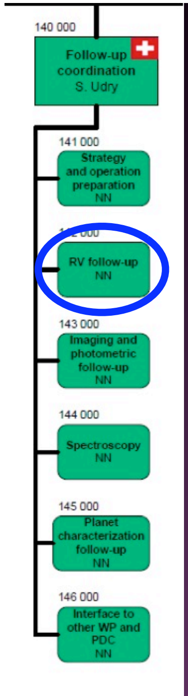


Requirements for an efficient spread of the PLATO candidates to adequate follow-up facilities and definition of the tools to be used by observers for efficient follow-up observations.

WP 141 100 - Tools for target repartition
- Automatic dynamical repartition of the targets in boxes adapted to given types of follow-up facilities (type of observations, precision of the facility, etc).

WP 141 200 – Tools for optimized measurements
- Tools to optimize in real time the choice of the targets for a considered facility (RV, photometry) and do the actual observations (e.g. ephemerides, orbit fit, ..)
- Specific sets of tools might be defined for different characteristics of host stars and for different observational techniques.

WP 141 300 - Tools for information transfer
- Tools to provide the observer with useful information (user interface)
- Feedback into the data center (night quality, faint close companions, etc).



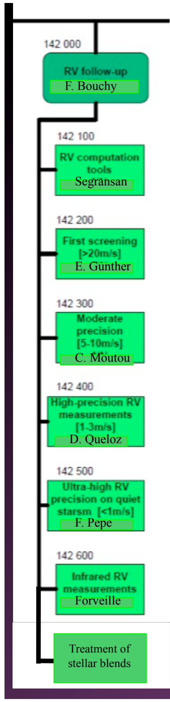
WP 142 000 – Radial-velocity follow-up

François Bouchy (France)

- Coordination of sub-work packages related to radial-velocity measurements.
- Identify existing and future RV facilities for the PLATO FU
  - with a significant amount of available time
  - competent teams
  - efficient data reduction systems

Definition of benchmarks

- Estimate the numbers of RV facilities and nights required to follow-up the expected transiting candidates.
- If existing and in-development facilities are estimated to be not sufficient, define the strategy to build new facilities or/and upgrade existing ones.



WP 142 000 – Radial-velocity follow-up

WP 142 100 – Radial velocity computation and analysis tools (Damien Segransan, CH)
- Tools to compute the RV on solar-type stars (WP 142110), on binaries (WP 142120), on early type stars (A and F stars) or/and high rotating stars (WP 142130).
- Tools allowing the combining of data of different nature (astrometric, photometric, spectroscopic) and offset between instruments (WP 142140)

WP 142 200 – First screening [> 20 m/s] (Eike Guenther, D)
- Use existing information (light curve, star) to estimate expected RV amplitude of candidates.
- Efficient screening (1-2 low-precision RVs [20-100 m/s].
- Appropriate criteria to continue or stop (e.g. exclude binaries).
- Tools to estimate from these first RVs the most appropriate instrument for the next step.
- Characterize massive Jupiters and brown dwarfs.

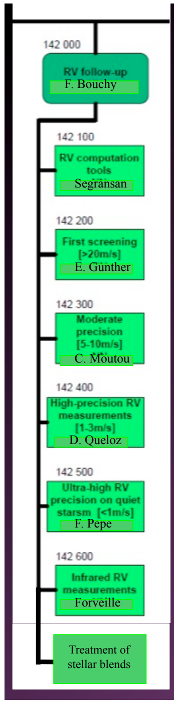
WP 142 300 - Moderate precision [5 – 10 m/s] (Claire Moutou, F)
- RV FU with RV precision in the range 5–10 m/s for screening.
- Tools to identify the blend scenarios (bisector analysis, mask effect, ...)
- Characterize giant planets with moderated RV precision [5–10 m/s].

WP 142 400 - High-precision RV measurements [1 - 3 m/s] (Didier Queloz, CH)
- RV follow-up with RV precision in the range 1 – 3 m/s to characterize Neptune like planets, and hot super-Earths.
- Tools to identify blends scenarios.

WP 142 500 - Ultra-high RV precision on quiet stars [10 cm/s - 1m/s] (Francesco Pepe, CH)
- Ultra-high RV precision measurements (< 1 m/s) to characterize Earth and super-Earth candidates around quiet stars, out to the habitable zone.

WP 142 600 – Infra-Red RV measurements (Thierry Forveille, F)
- RV estimate in IR for active stars and low-mass stars (M dwarfs)

WP 142 700 – Treatment of stellar blends (NNN, CC)
- Simulation of stellar blends
- Define tests to rapidly identify stellar blends from all available information (RV, photom, astrom)



WP 142 000 – Radial-velocity follow-up

Individual facilities => sub-WPs

First screening [> 10-20 m/s]
- Tautenburg (Germany) - in use
- Hermes on Mercator (La Palma) - in use
- LCOGT: 6 x 1m + 3 x 2m telescopes with spectrographs - project

(non European)

Moderate precision [5 – 10 m/s]
- Coralie on Euler 1.2-m Swiss telescope (La Silla, Chile) - in use
- FEROS on the 2.2m (La Silla, Chile) - in use
- SOPHIE on the 193-cm telescope (OHP, France) - in use
- NOT (La Palma, Spain) - in use
- HET (Texas, USA) - in use
- AAT (Siding Spring, Australia) - in use

Key facilities

High-precision RV measurements [1 - 3 m/s]
- HARPS on the ESO 3.6m telescope (La Silla, Chile) - in use ⟸
- HARPS-N on the TNG (La Palma, Spain) - on the sky in April 2012 ⟸
- HIRES on Keck (Hawaii, USA) in use
- Carnagie Planet Finder at Magellan (Las Campanas, Chile) - starting

Ultra-high RV precision on quiet stars [10 cm/s - 1m/s]
- ESPRESSO on the ESO VLT (Paranal, Chile) - on the sky in 2016 ⟵
- New spectrograph on the GranTCan (La Palma, Spain) - project
- CODEX on the E-ELT (Los Armazones, Chile) - project
- GCLEF on GMT (La Campanas, Chile) - project

Infra-Red RV measurements
- CRIRES on the VLT (Paranal, Chile) - in use
- SPIROU on the CFHT (Hawaii, USA) - project
- CARMENES on 4m telescope (Calar Alto, Spain) - project

Planet Detectability with radial velocities

$$k_1 = \frac{28.4\ \mathrm{m\ s^{-1}}}{\sqrt{1-e^2}} \frac{m_2 \sin i}{M_{\mathrm{Jup}}} \left(\frac{m_1 + m_2}{M_{\mathrm{Sun}}}\right)^{-2/3} \left(\frac{P}{1\ \mathrm{yr}}\right)^{-1/3}$$

Jupiter	@ 1 AU	: 28.4 m s^{-1}
Jupiter	@ 5 AU	: 12.7 m s^{-1}
Neptune	@ 0.1 AU	: 4.8 m s^{-1}
Neptune	@ 1 AU	: 1.5 m s^{-1}
Super-Earth (5 $M_\oplus$)	@ 0.1 AU	: 1.4 m s^{-1}
Super-Earth (5 $M_\oplus$)	@ 1 AU	: 0.45 m s^{-1}
Earth	@ 1 AU	: 9 cm s^{-1}

A few m/s precision OK for giant planets e.g. Jupiters out to > 5 AU

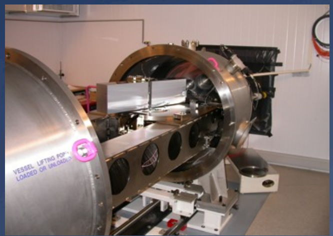
Need to go below 1 m/s for close super-Earths!

Required an order of magnitude improvement for Earth twins

Limitations of RV precision
1. Instrumental stability

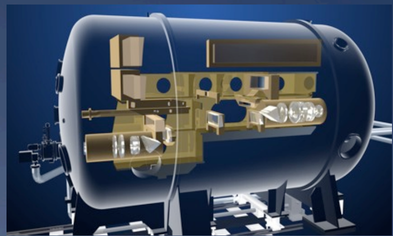
HARPS-N

- HARPS copy for northern hemisphere
- Follow-up of KEPLER candidates
- Search for Earth analogs
- Etc.



ESPRESSO@VLT

- Better precision on larger telescope
- Aim: 10 cm/s instrumental and photon noise
- Search for Rocky planets in habitable zone & variability of fundamental constants, etc.
- Up to 4 UTs incoherently



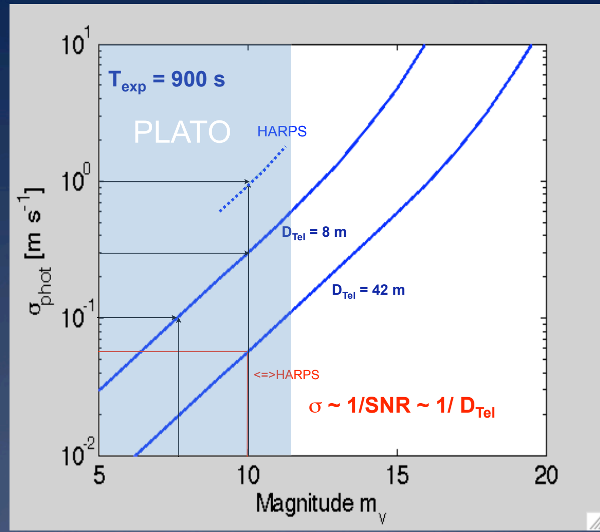
Limitations of RV precision
2. Photon collection capacity

HARPS-type spectro:
(R > 100'000, ε_{Tot} = 6%)

Precision:

Texp=15' on V=10 star

=> ~1m/s on 3.6m telescope
=> ~50 cm/s on VLT
=> ~10 cm/s on E-ELT

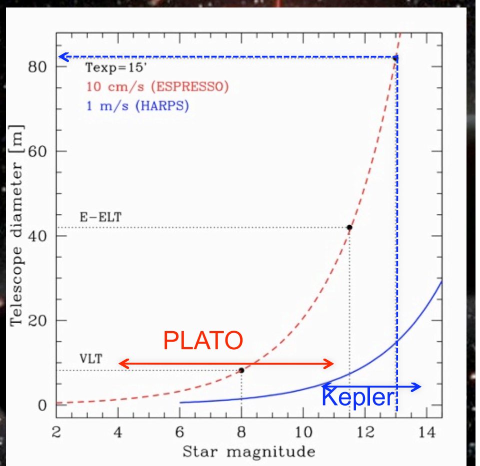


Planetary mass

RV Amplitude 10cm/s for Earth analog

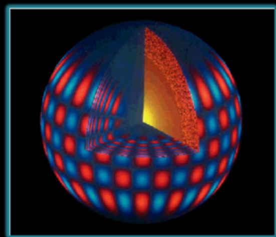
Planet	Separation (AU)	RV Amp. (m/s)
Jupiter	1	28.4
Neptune	0.1	4.8
Neptune	1	1.5
SuperEarth	0.1	1.4
SuperEarth	1	0.5
Earth	1	0.1

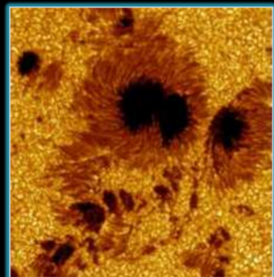
Radial velocity: photon starving

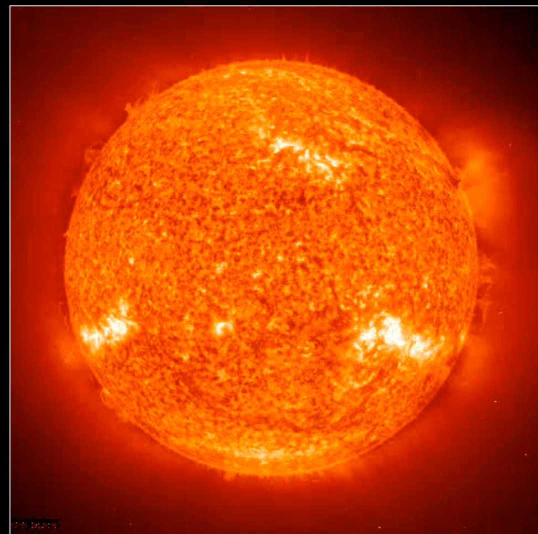


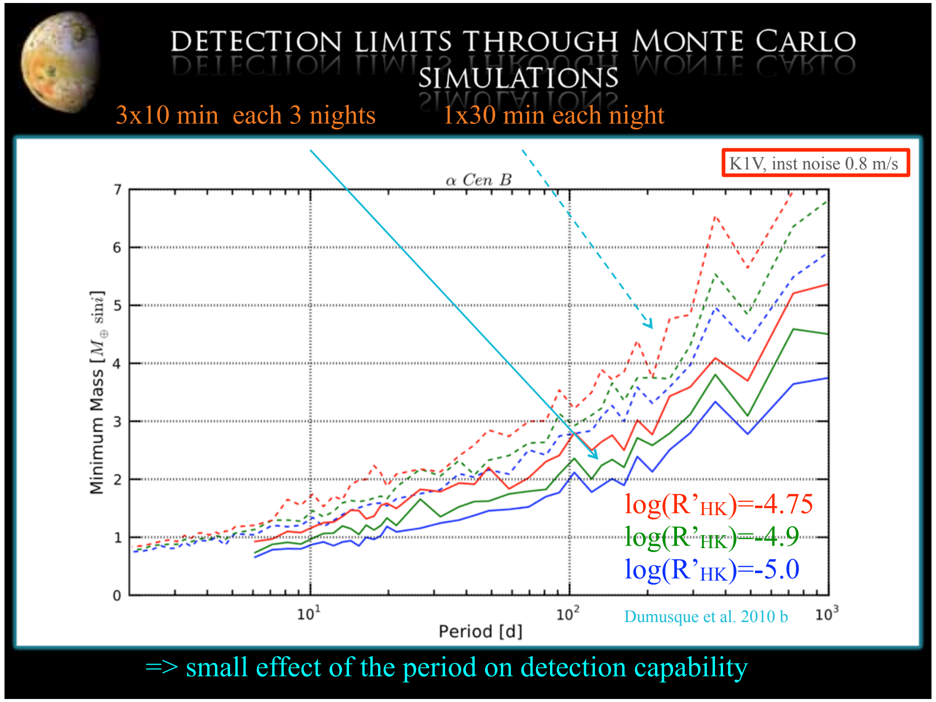
Observation strategy:
→ minimize stellar "noise"

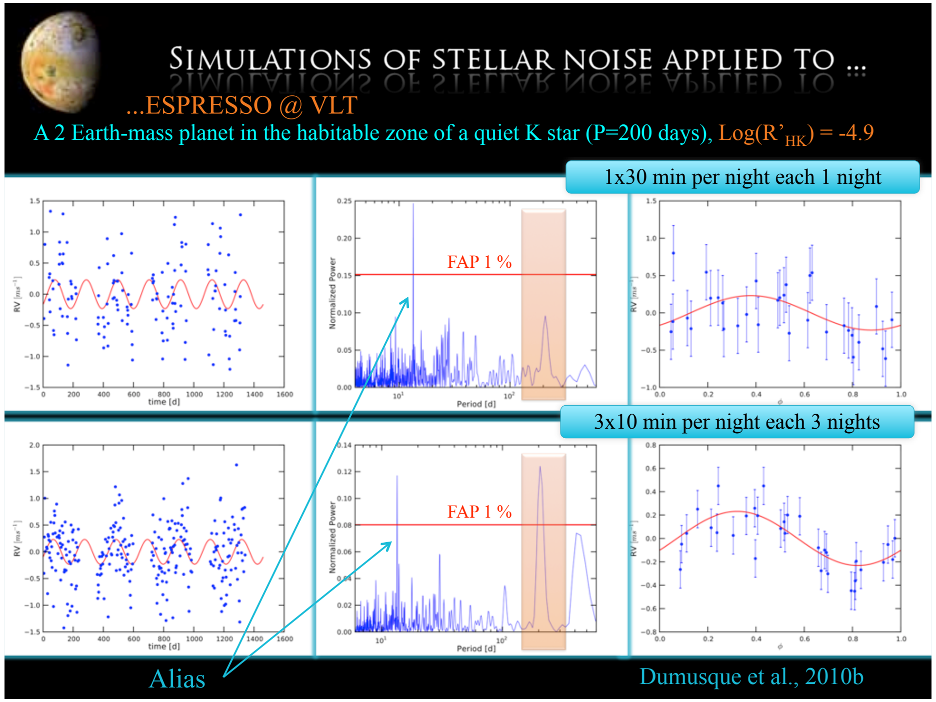
3. Stellar intrinsic limitations

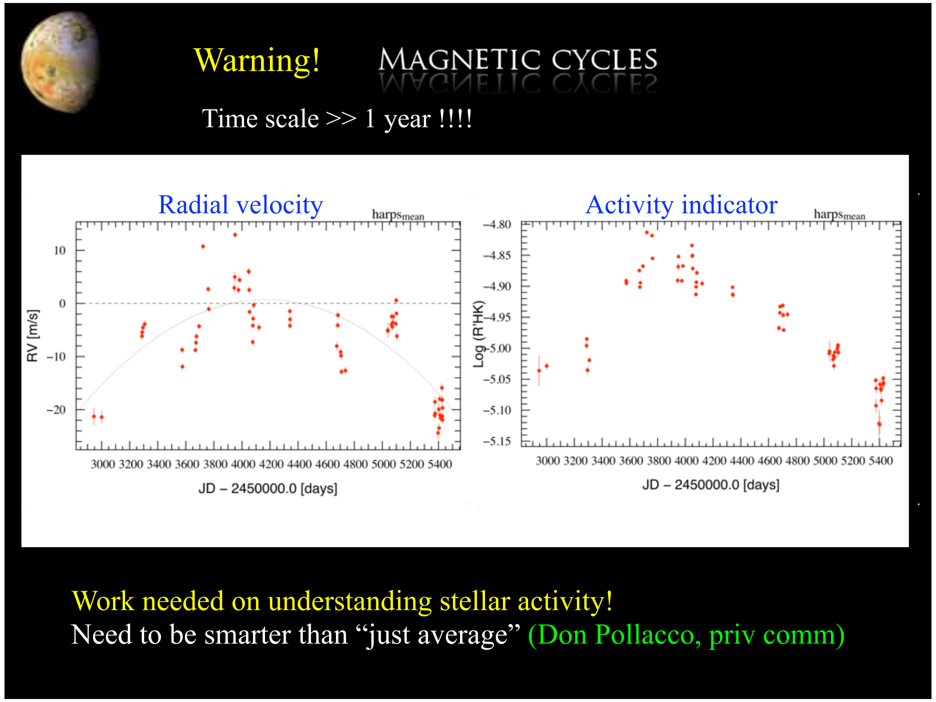


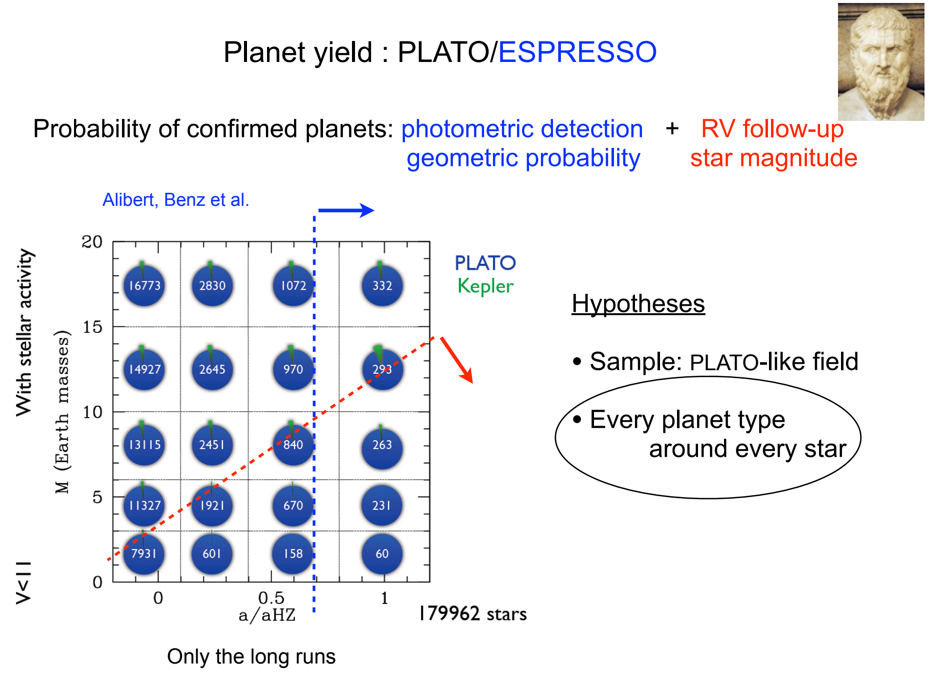


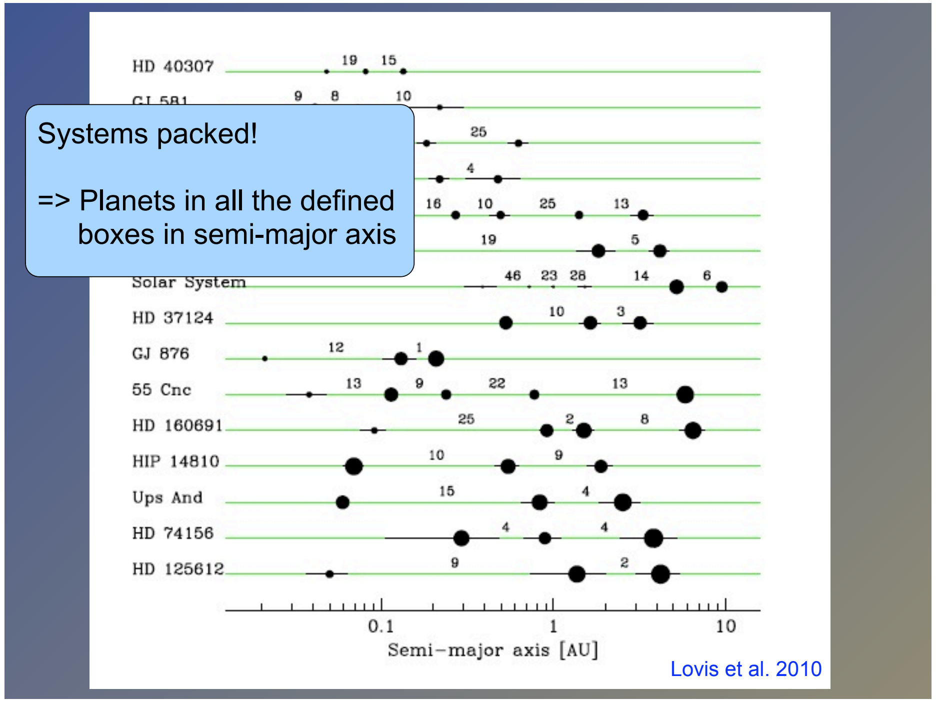



Detection limits through Monte Carlo simulations
3x10 min each 3 nights
1x30 min each night
K1V, inst noise 0.8 m/s
α Cen B
Minimum Mass [$M_\oplus$ sin i]
Period [d]
log(R'HK)=-4.75
log(R'HK)=-4.9
log(R'HK)=-5.0
Dumusque et al. 2010 b
=> small effect of the period on detection capability


Simulations of stellar noise applied to ...
...ESPRESSO @ VLT
A 2 Earth-mass planet in the habitable zone of a quiet K star (P=200 days), Log(R'HK) = -4.9
1x30 min per night each 1 night
3x10 min per night each 3 nights
FAP 1 %
FAP 1 %
Alias
Dumusque et al., 2010b

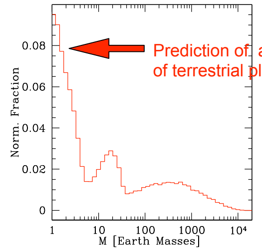

Warning!
Magnetic cycles
Time scale >> 1 year !!!!
Radial velocity
Activity indicator
RV [m/s]
Log (R'HK)
JD – 2450000.0 [days]
JD – 2450000.0 [days]
Work needed on understanding stellar activity!
Need to be smarter than "just average" (Don Pollacco, priv comm)


Planet yield : PLATO/ESPRESSO
Probability of confirmed planets: photometric detection + RV follow-up
geometric probability
star magnitude
Alibert, Benz et al.
With stellar activity
M (Earth masses)
a/aHZ
V<11
PLATO
Kepler
179962 stars
Only the long runs
Hypotheses
• Sample: PLATO-like field
• Every planet type around every star

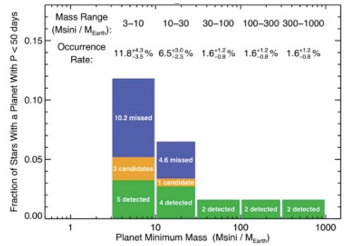


Mass distribution

Population synthesis (Mordasini et al. 2010)

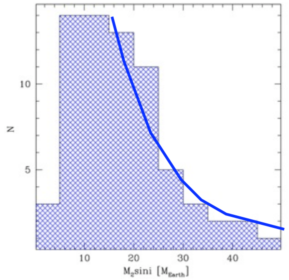


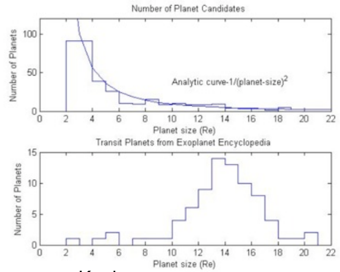
Keck (Howard et al. 2010, Science)



$P_{super-Earth}(P<50d) = 30\text{-}50\%$
Kepler <=> HARPS prediction

HARPS (Mayor et al. in prep)





Kepler (Borucki et al. 2010)

PLATO expected numbers of planets

158

planets that potentially can be detected and confirmed

assuming every star has a planet

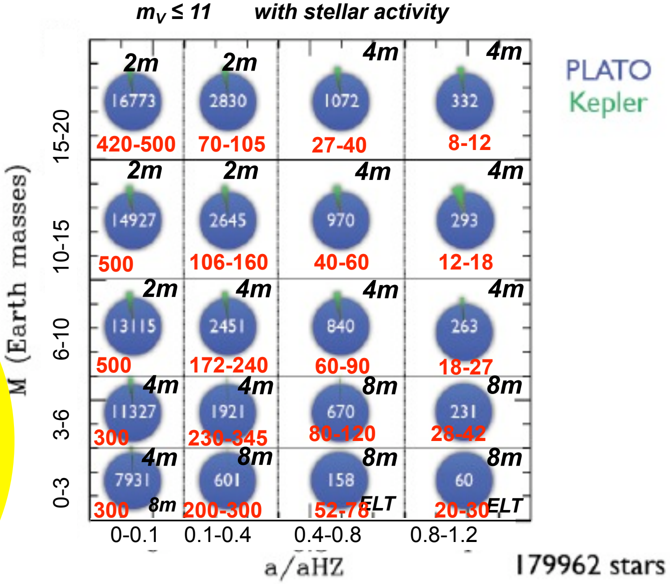
300

planets that can be monitored in RV in 8 years with reasonable allocation of telescope time

And

Assuming planet occurrence rate decrease in function of m from Howard et al. 2010 & HARPS normalisation

$m_V \leq 11$ with stellar activity



# of planets to follow-up limited to 300 per bin for 4m telescopes and to 500 for 2m-class telescopes

Radial velocity follow-up - Characterization

- adopt subsidiarity principle: optimized use of 1-2m-, 4m-, 8m-class telescopes

- $m_V \leq 11$ stars, with average level of activity, assuming 15 min x 15-20 obs. per star

- *1-2m-class telescopes*: 10m/s ; giant planets on short/medium orbits
1750 stars : **~900 nights** = ~50 nights/year x 6 years x 3 telescopes

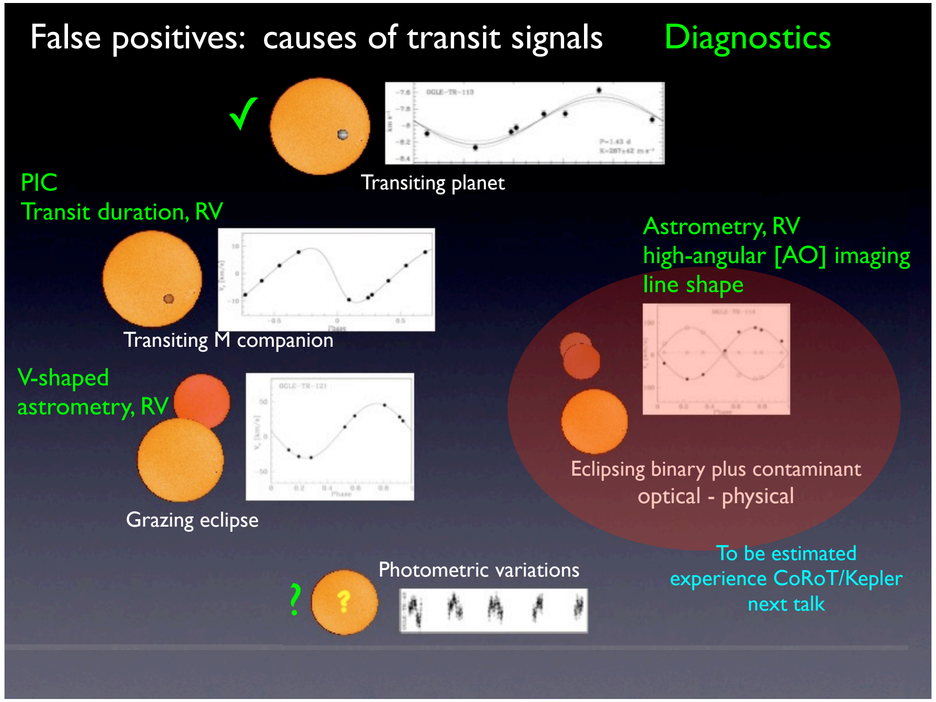
- *4m-class telescopes*: 1 m/s ; giant planets on long orbits, super-earths on short/medium orbits
1400 stars : **~700 nights** = ~40 nights/year x 6 years x 3 telescopes

- *8m-class telescopes*: 10cm/s ; super-earths on long orbits, earths on short/medium orbits, earths on long orbits around brightest stars (m_V < 10)
550 stars : **~240 nights** = ~40 nights/year x 6 years x 1 telescope

- *ELT*: earths on long orbits around faintest stars (m_V~11)

- secure dedicated access to 1-2m- & 4m-class tel, and sufficient access to 8m-class tel, via early agreements with ground-based agencies and organizations

- groundbased follow-up = world-wide effort

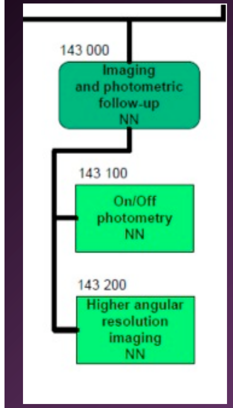


WP 143 000 – Imaging and photometric follow-up
Ian Skillen (Spain)

Preparation for observational check that the transit is well on the main target in the field.

- False positives related to stellar diluted blends will usually not display large radial velocity variations.
- PLATO pixel size => often the case

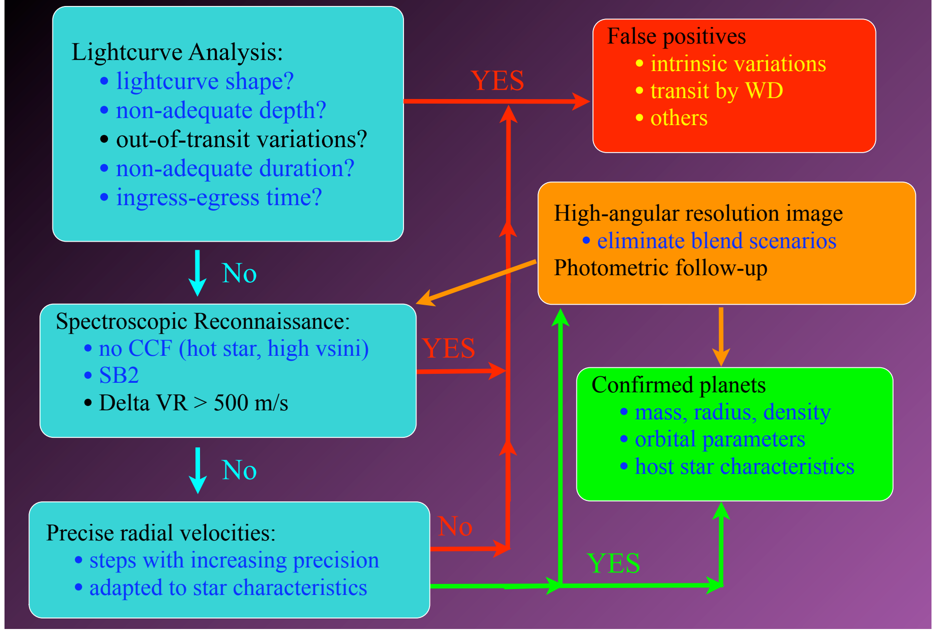
=> check that the low-depth transit is not due to a fainter stars close to the target



WP 143 100 – On/Off Photometry (Roi Alonso, CH/E)
- Coordination of sub-work packages related to the planning of the photometric follow-up on higher-resolution telescopes.
- On/Off photometry

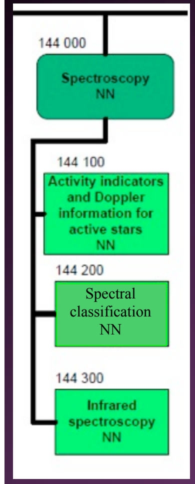
WP 143 200 – Higher angular resolution imaging (Silvano Desidera, I)
- Coordination of the sub-work packages related to the high-resolution imaging of the environment of the targets.

PLATO follow-up observations: decision chart



WP 144 000 – Spectroscopy
Artie Hatzes (Germany)

- Preparation of an on-line automatic 1st order spectroscopic analysis, including estimates of activity indicators, chemical abundances, etc.
- Examine the effect of star properties on high-resolution spectra and the subsequent determination of RVs.



WP 144 100 – Activity indicators and Doppler information for active stars (Christophe Lovis, CH)
- Activity indicators to be estimated from the spectra.
- Strategies to improve the RV estimate in the visible from spectra of active stars

WP 144 200 – Tool for spectral classification (NNN, CC)
- 1st order (on site) estimate of spectral type from FU spectra

WP 144 300 – Infrared spectroscopy (Nuno Santos, P)
- Tools for radial-velocity measurements in the infrared.
- Activity indicators in the IR.

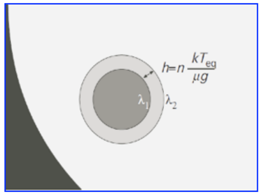
WP 144 400 – more?

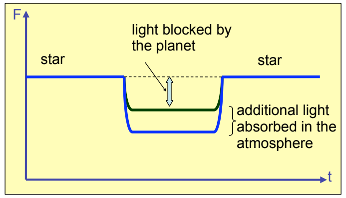
WP supposed to evolve

Additional planetary science

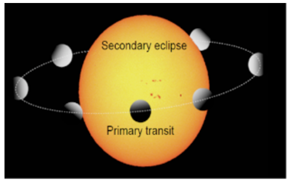
I. Atmospheres characterization (talk by D. Ehrenreich)

Primary eclipse: transmission in visible range

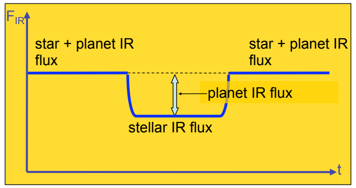




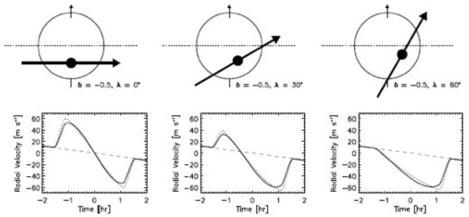
Transiting planets



Secondary eclipse: IR emission



II. System alignment (talk by G. Hebrard)

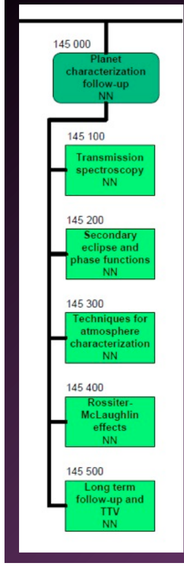


III. and more....

WP 145 000 – Planet additional science follow-up

Xavier Bonfils (France)

- Preparation and optimization of FU observations (ground and space) to increase the scientific return of the mission.
- Review of the literature: tools and strategies for the FU



WP 145 100 – Transmission spectroscopy (David Ehrenreich, F)
- Examine the best targets for transmission spectroscopy.
- Define a merit function to prioritize the planets for follow-up.
- Evaluate the amount of telescope time needed.
- Make the inventory of available facilities (ground + space).
- Organize the observations.
- Interface observations and modeling.

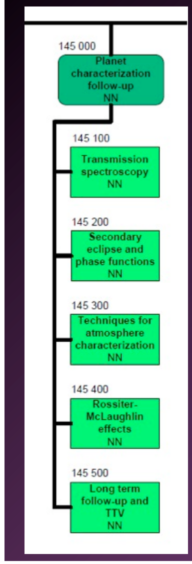
WP 145 200 – Secondary eclipses and phase functions (Roi Alonso, E/CH)
- similar to transmission spectroscopy for *in* and *out* of secondary eclipse observations and phase function measurements.

WP 145 300 – Techniques for atmosphere characterization (Xavier Bonfils, F)
- Define in which configurations the Doppler information (R > 10,000) may help to recover the planet spectra.
- Define in which cases the spectra is best recovered, compared to secondary eclipses or phase functions techniques.
- Survey new technical developments for the characterization of planets (closure-phase interferometry, aperture masking, adaptive optics, nulling, ...).

WP 145 000 – PLATO planet characterization follow-up

Xavier Bonfils (France)

- Preparation and optimization of FU observations (ground and space) to increase the scientific return of the mission.
- Review of the literature: tools and strategies for the FU



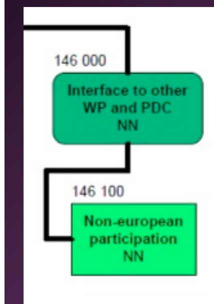
WP 145 400 – Rossiter-McLaughlin effects (Guillaume Hebrard, F)
- Define in which configurations the Rossiter-McLaughlin measurements help to determine the true nature of the transiting candidates.
- Define in which configuration RM amplitude is larger than Keplerian one.
- Organize the observations of the RM curves.

WP 145 600 – Long-term follow-up, Transit Timing Variations (François Bouchy, F)
- Organize the search for additional planets in the system (RVs are sensitive to non-transiting long-P planets).
- Prioritization of the systems to follow.
- Evaluate benefits of TTV monitoring to detect additional planets or satellites.

WP 146 000 – Specifications for interface to other work packages and PDC

Stephane Udry (Switzerland)

- Specification for the information required from other work packages, primarily in the stellar area and light-curve analysis, in order to meet the aims of the mission.
- Data and tool interfaces with the PDC



WP 146 100
Non-European participation to the PLATO follow-up
Dave Latham (CfA)
- Identify Non-European facilities to possibly participate to the PLATO follow-up.
- Act as the interface between European and non European follow-up activities.