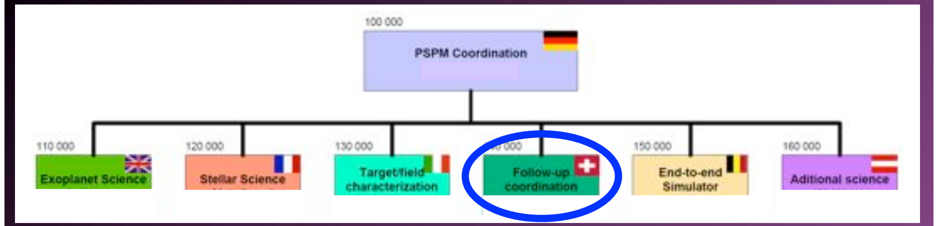
PLATO-2.0 Follow-up

Context and organisation

S. Udry
University of Geneva

A next generation transit mission
will be efficient
only with ground-based help

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.

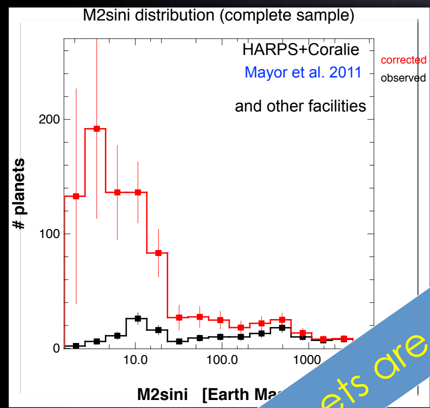
=> in addition to the photometric transit detections and asteroseismic characterization,
a ground-based follow-up support is absolutely required

Questions addressed

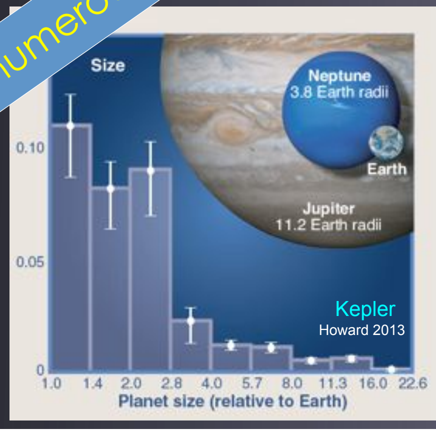
- Needs
  - confirmation (false positives)
  - planet masses (from RVs)
  - tools for optimal planning and operation
- Organization of the Follow-up work
  - strategy
  - work breakdown and interfaces
- Observing facilities
  - yield of the mission and telescope time estimate
  - impact of the recent change in the "space-transit" landscape
  - available/planned facilities
- Future improvements

Mass distribution

Spectroscopy



Small mass planets are numerous => huge work



Photometry

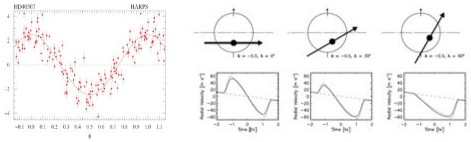
Size distribution

Importance of the follow-up

Goals – Necessity – Organisation

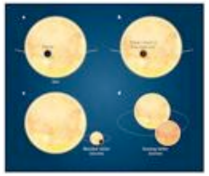
1) Planet parameters

Not obtained from the light curves
- mass, density
- temperature, geometry
- others



2) False positives

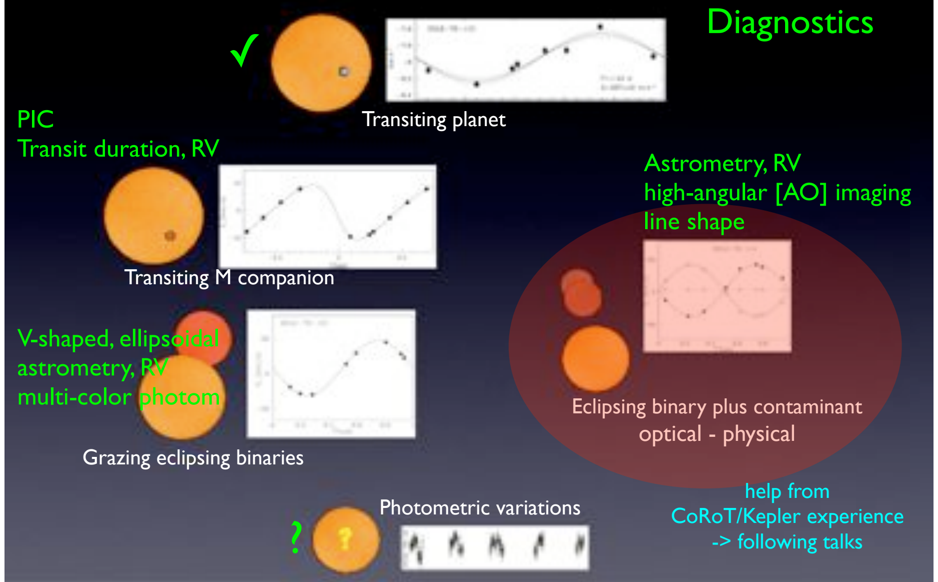
Experience gained from
- ground-based => giant planets
- space => small planets



3) Optimisation

Enhanced science return
- strategy, organisation
- synergies

1) False positives: causes of transit signals: giant planets



1) False positives: causes of transit signals: giant planets

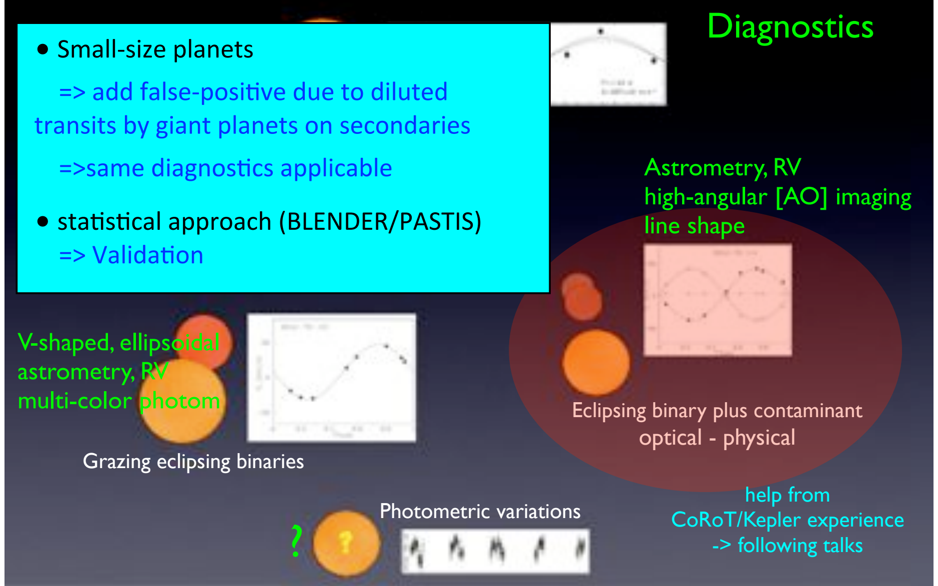
- Small-size planets

  => add false-positive due to diluted transits by giant planets on secondaries

  =>same diagnostics applicable

- statistical approach (BLENDER/PASTIS)

  => Validation



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

Two main aspects of the ground-based follow-up of PLATO reside in
- i) the basic planet characterization through radial-velocity measurements
- ii) discarding false positives -> RV & high angular imaging + photometry

1. Large number of expected transit candidates
   => systematic observation of all transits with large telescopes unfeasible
   => an optimized follow-up scheme has to be organized
2. Same level of precision cannot be reached for all stars
   (spectral type, luminosity class, activity, brightness)
3. Same is true for the RVs and high-contrast imaging
4. Strategy for the follow-up: efficient approach
   - 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)

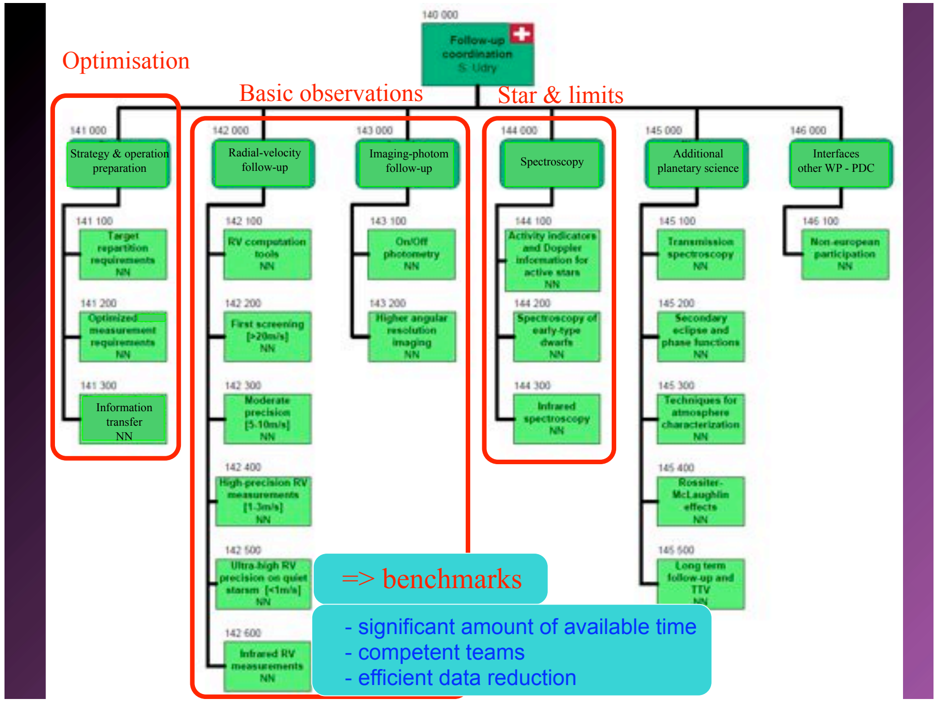
Targets can move from one box to the next, in an evolutionary way,
depending on results of previous observations

In practice => a multi-step approach
from moderate to high-precision instruments

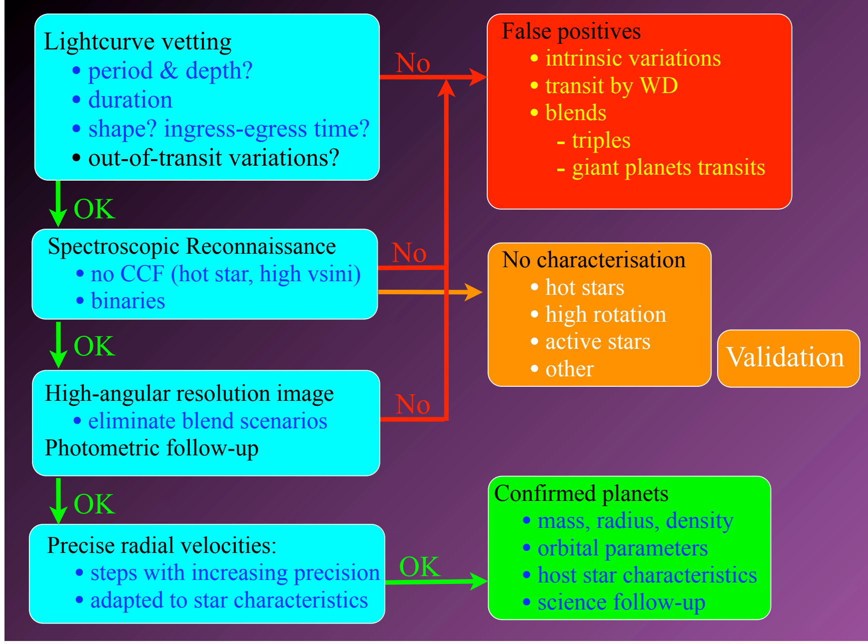
- already successfully used in most of the on-going surveys
- will also nicely apply to PLATO candidates.

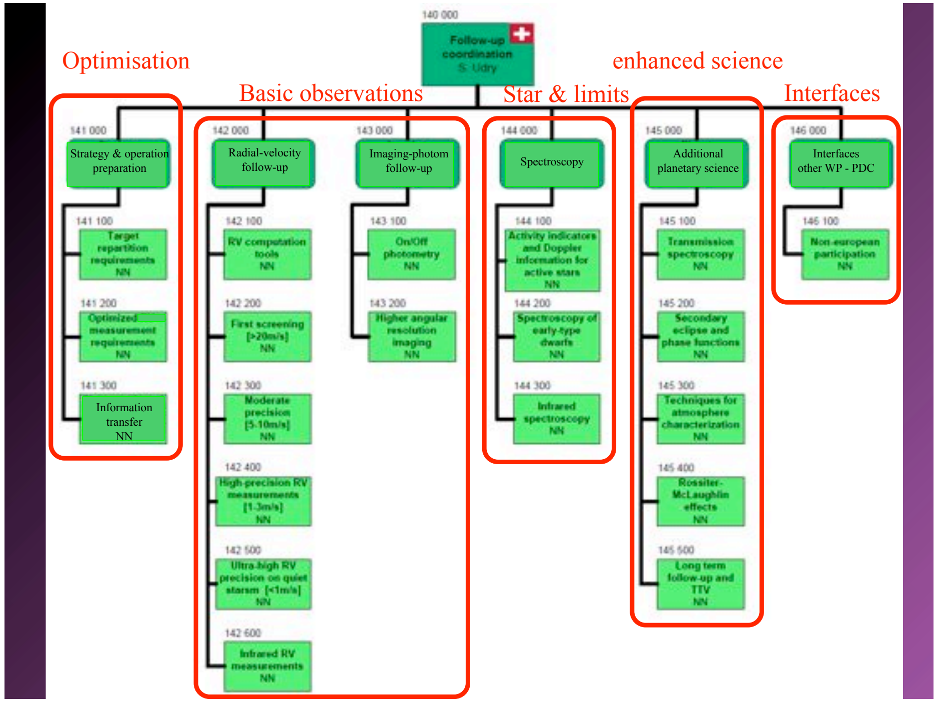
To achieve this goal we need to design and develop

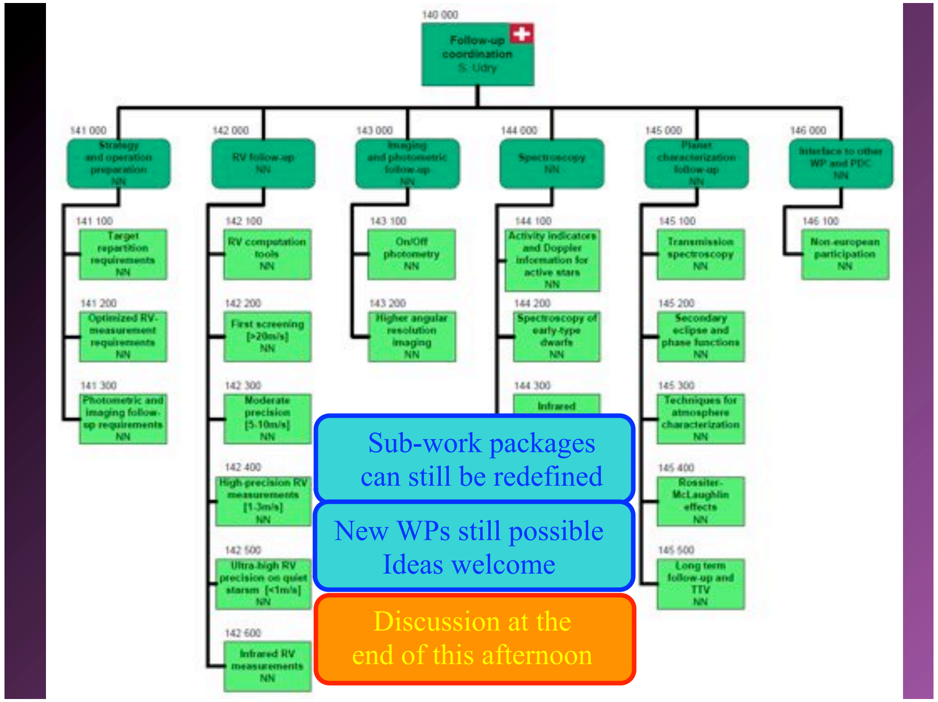
- efficient tools for the target repartition
- user interface and tools for the observers
- interface between the PDC and the observer
  able to accept input from the observer as well (web interface)



PLATO follow-up observations: decision chart



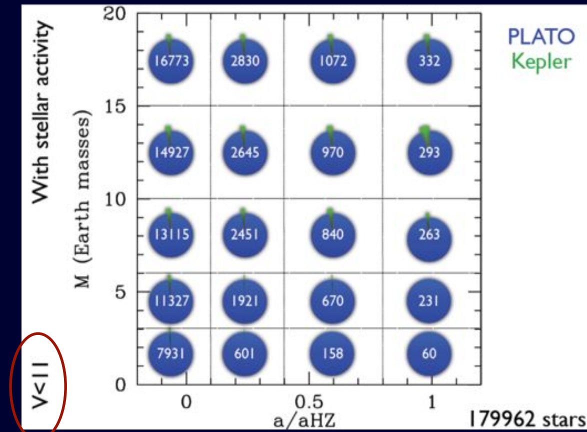




Expected number of confirmed planets

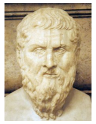
Assumptions:

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



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

PLATO expected numbers of planets



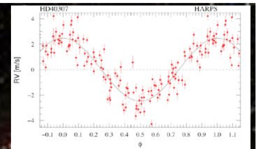
Simulations (Y. Alibert et al.)

1) Catalog of stars: actual PLATO field or Besançon model
   - Mass, magnitude
   - Radius
   - Metallicity, activity level
   (from distributions in the HARPS GTO volume-limited sample)

2) Transit probability and S/N (transit detection) for all (sep,M_{pl}) planets
   - depends on R_{star} and magnitude
   - depends on planet mass and semi-major axis

3) Calculate RV effect and probability to confirm the signal
   - depends on stellar magnitude and activity level (and vsini)
   - depends on planet mass and semi-major axis
   - RV precision estimate:
     - stellar noise simulations
     - observed HARPS precision from early-type and active stars

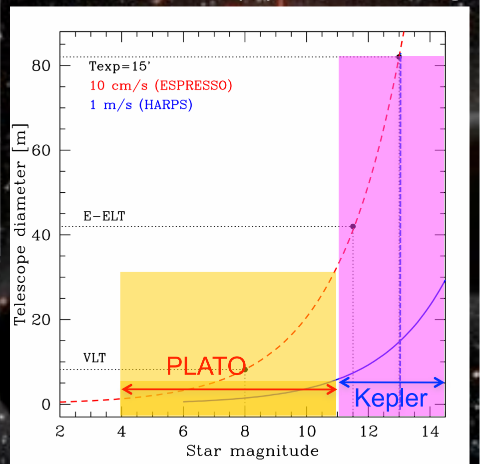
Planet mass



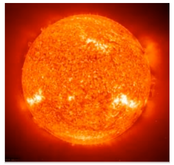
RV Amplitude 10cm/s for Earth analog

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

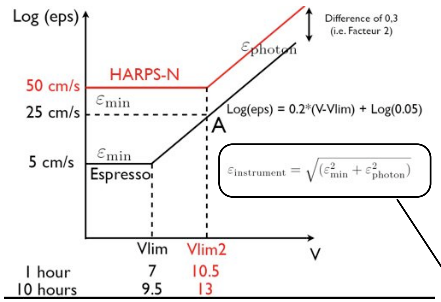


Observation strategy:
→ minimize stellar "noise"



Radial-velocity precision

Instrument + photon noise



+ activity & granulation effects
(Dumusque et al. 2010a, 2010b)

HARPS-N - 15 minutes

activity	1 day	2 days	5 days	10 days
-5.0	1.07	0.75	0.48	0.35
-4.9	1.18	0.87	0.60	0.40
-4.8	1.25	0.97	0.70	0.45
-4.7	3.0			
-4.6	6.0			
-4.5	10.0			
-4.4	15.0			
-4.3	20.0			
-4.2	25.0			
-4.1	30.0			

$\sqrt{N_{binning}}$ decrease

Espresso - 45 minutes

activity	1 day	2 days	5 days	10 days
-5.0	0.25	0.18	0.11	0.07
-4.9	0.52	0.47	0.37	0.23
-4.8	0.68	0.63	0.50	0.31
-4.7	2.85			
-4.6	5.90			
-4.5	9.90			
-4.4	14.95			
-4.3	20.0			
-4.2	25.0			
-4.1	30.0			

$\sqrt{N_{binning}}$ decrease

$$\varepsilon = \sqrt{(\varepsilon^2_{instrument} + \varepsilon^2_{activity})}$$

Expected number of confirmed planets

Assumptions:
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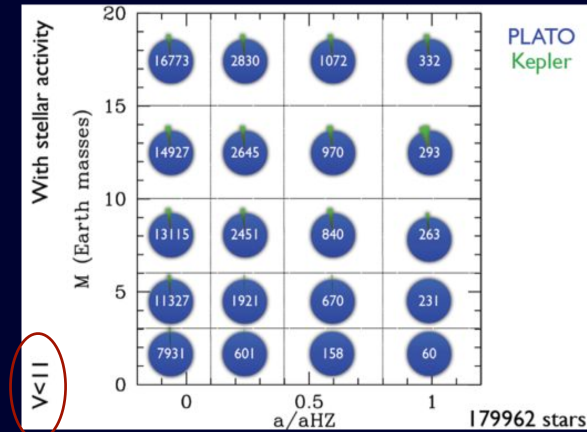
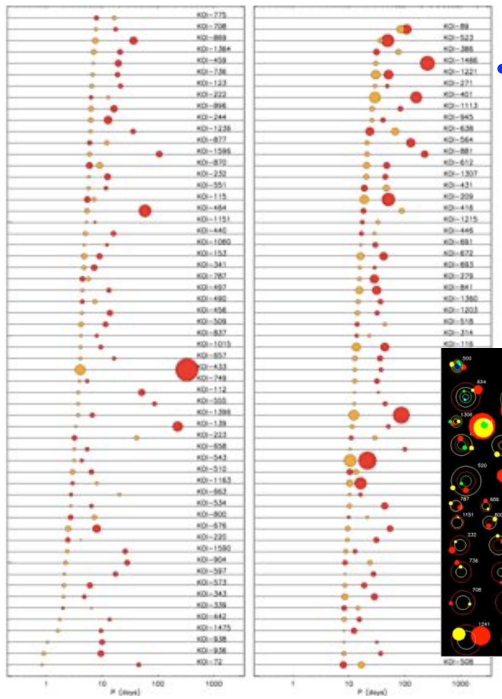
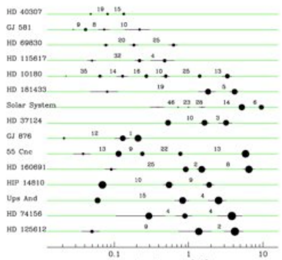


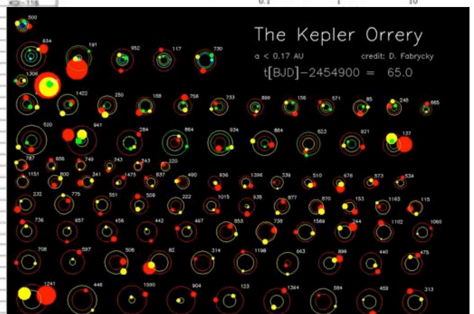
lower right corner of the (orbit,mass) plane = terrestrial planets in the HZ, not covered by Kepler, will be explored by PLATO thanks to its priority on bright stars

Kepler systems

- Same features as RV systems







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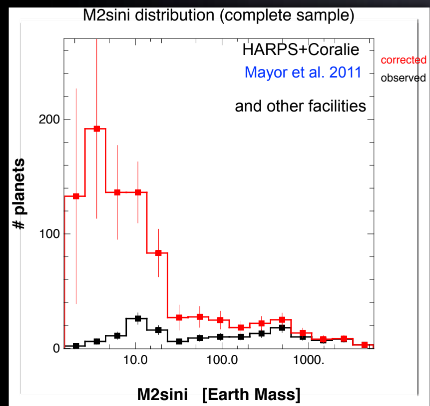
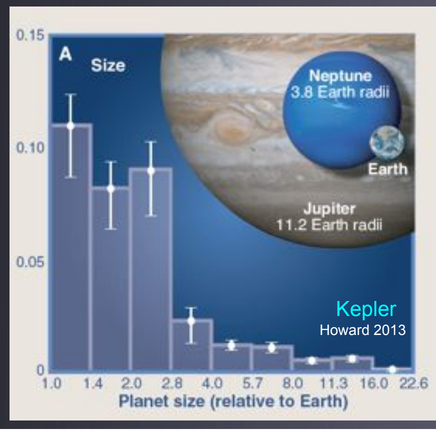
Mass distribution

Spectroscopy



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



Photometry

Size distribution

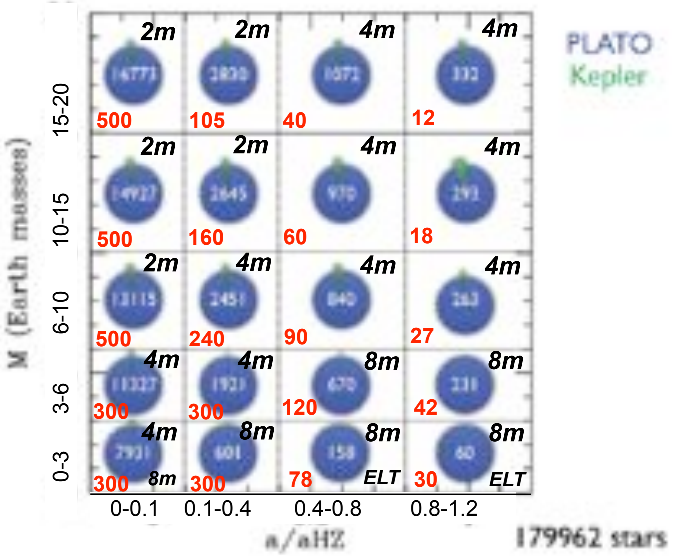
PLATO expected numbers of planets

$m_V \leq 11$ *(with stellar activity)*

Not all short-period planets followed-up

↓

Planet legacy on top of stellar physics



Rem: # 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 20 observ. per planet

- *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

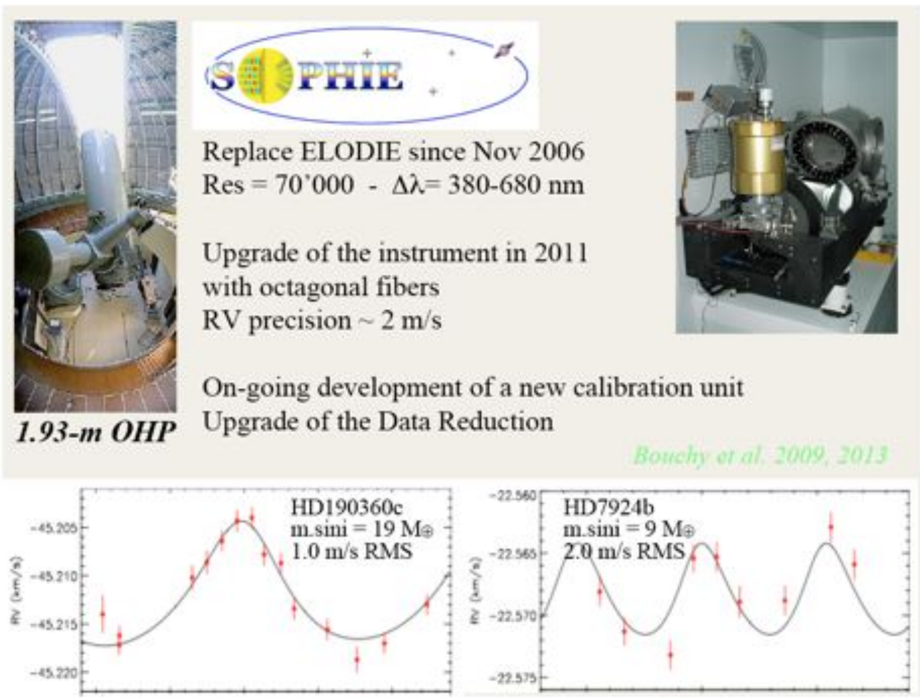
- *8m-class telescopes:* 10cm/s ; super-earths on long orbits, earths on short/medium orbits, earths on long orbits around brightest stars (m_V < 10)
550 stars : ~**240 nights** = ~40 nights/year x 6 years x 1 telescope

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

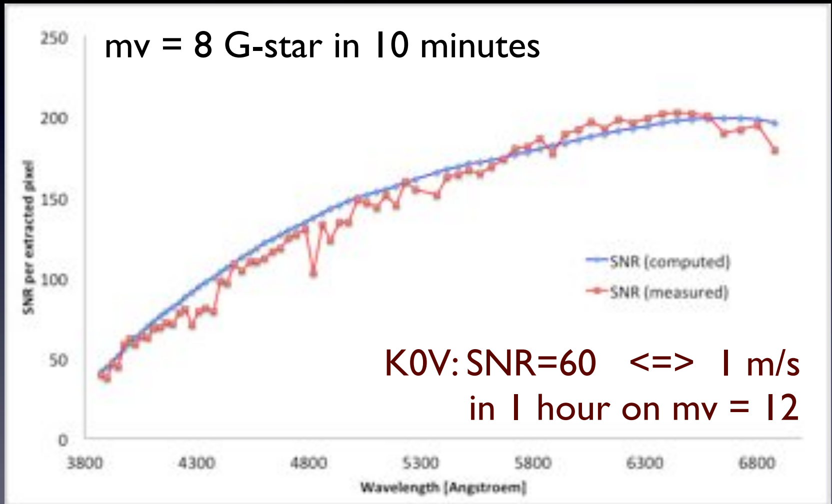
- secure dedicated access to 1-2m- & 4m-class te[lescopes] via early agreements with ground-based agencie[s]

- groundbased follow-up = world-wide effort

Doable with existing and soon to be available facilities

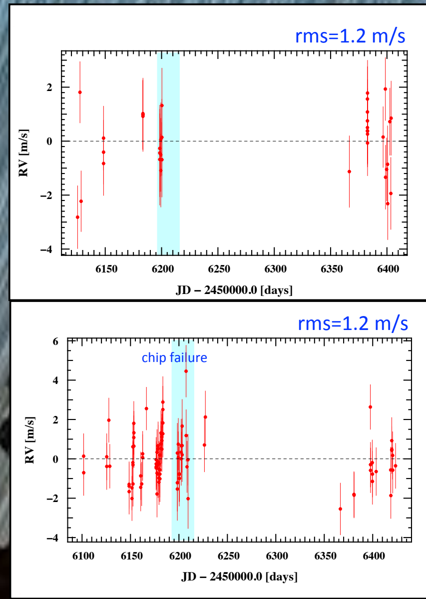


Efficiency & bench mark



The first season of the HARPS-N programs

- Start: summer 2012
  still "young"
  Precision: ~1 m/s
- GTO: 80 nights/yr
  - kepler candidate FU
  - Rocky Planet Search
- RPS GTO Survey
  - ~40 stars
  - very precise observations



- HARPS-N TNG + INT La Palma — < 1 m/s
- Sophie OHP — ~2 m/s
- Coralie + FEROS La Silla
- 2m Tautenburg + ...
- PARAS on Mount Abu
- Carnegie Planet Finder at Magellan — < 2 m/s
- Chiron at CTIO — => 0.5-1.5 m/s
- ESPRESSO on VLT — => < 10 cm/s in 2016
- LCOGT
- Harvester on Palomar
- Pathfinder on HET
- GCLEF on GMT
- HiRES on E-ELT 2-3 cm/s

in development

- UKIRT Planet Finder
- NAHUAL on GranTeCan
- CARMENES at Calar Alto
- SPIROU on CFHT

IR spectrographs

- and more...

ESPRESSO on ESO VLT

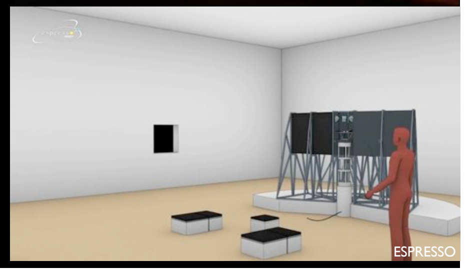
«**E**chelle **SP**ectrograph for **R**ocky **E**xoplanets and **S**table **S**pectroscopic **O**bservations»

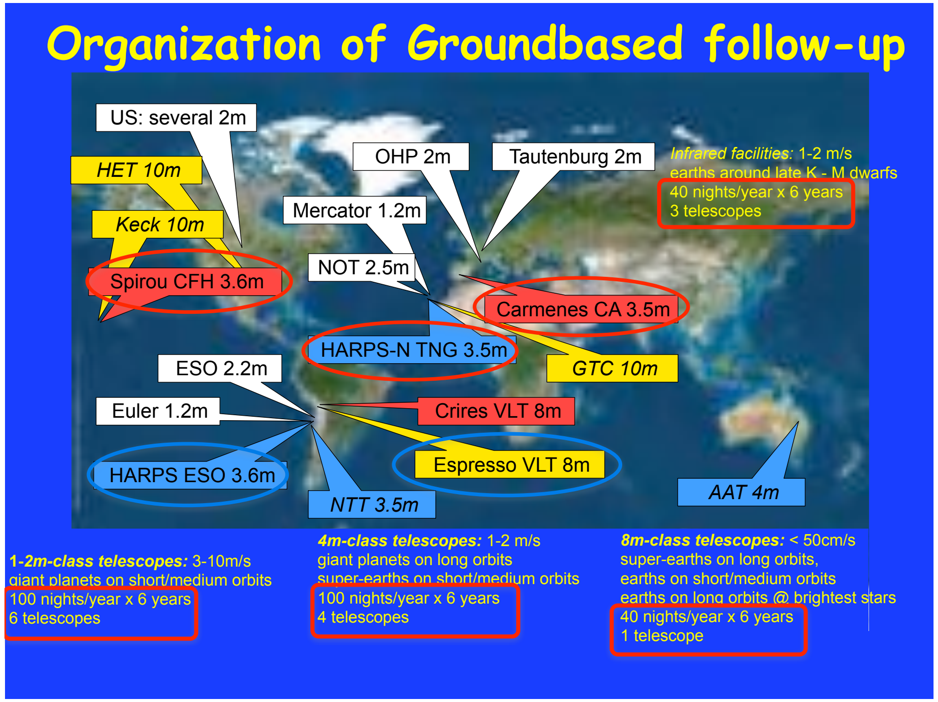
- Ultra-stable spectrograph for the VLT
- R=120'000
- visible: blue + red arms
- can use any of the UTs (coudé train)

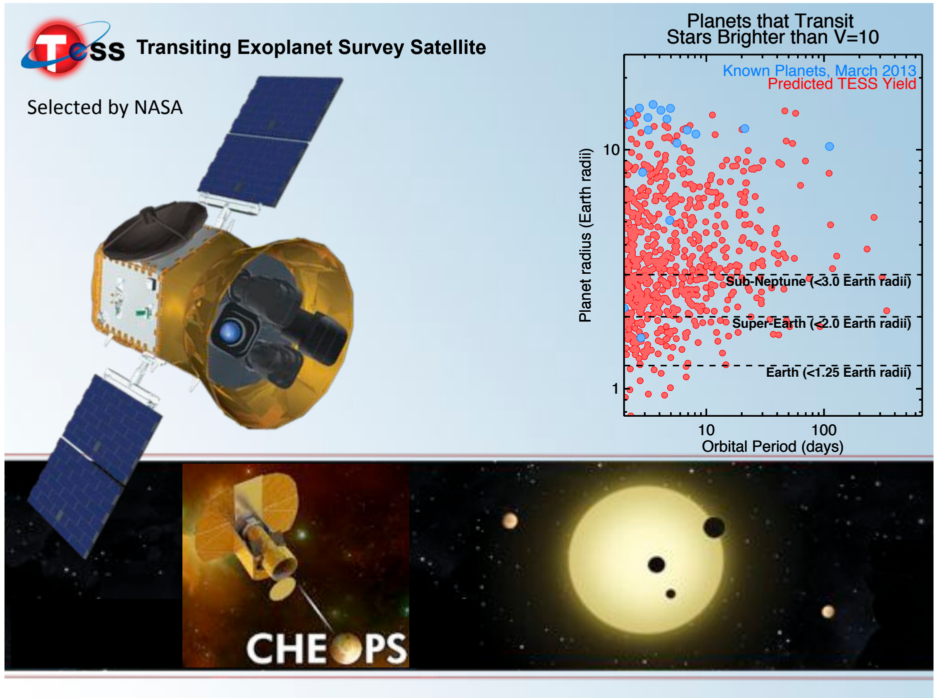
- Consortium : CH, Italy, Portugal, Spain
- FDR in June 2013
- On the sky : 2016

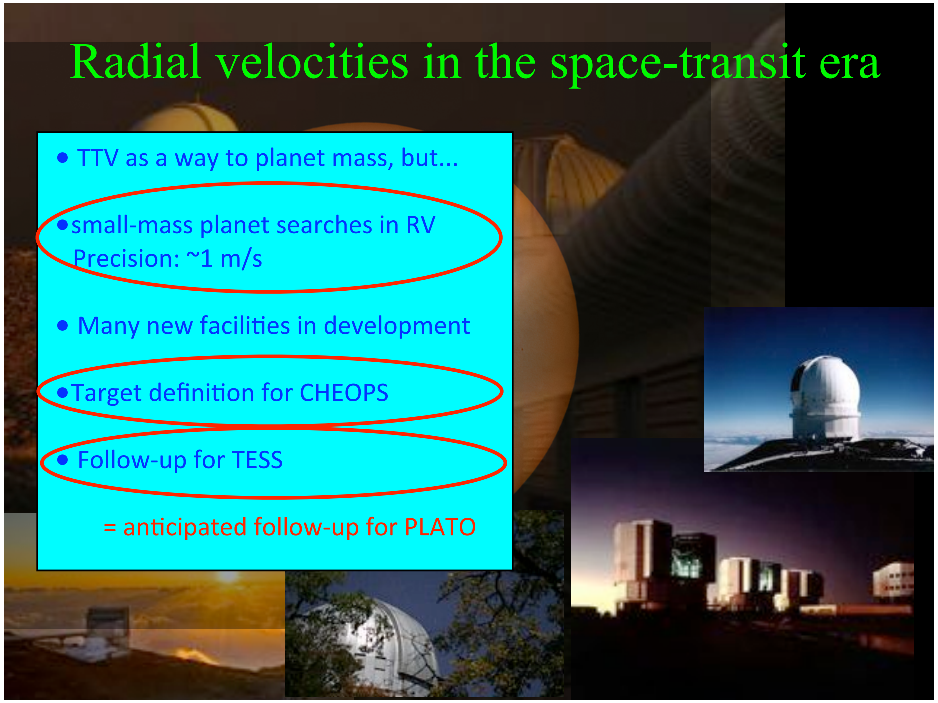
- Precision in RV : < 10 cm/s
- Goal : Very low-mass planets

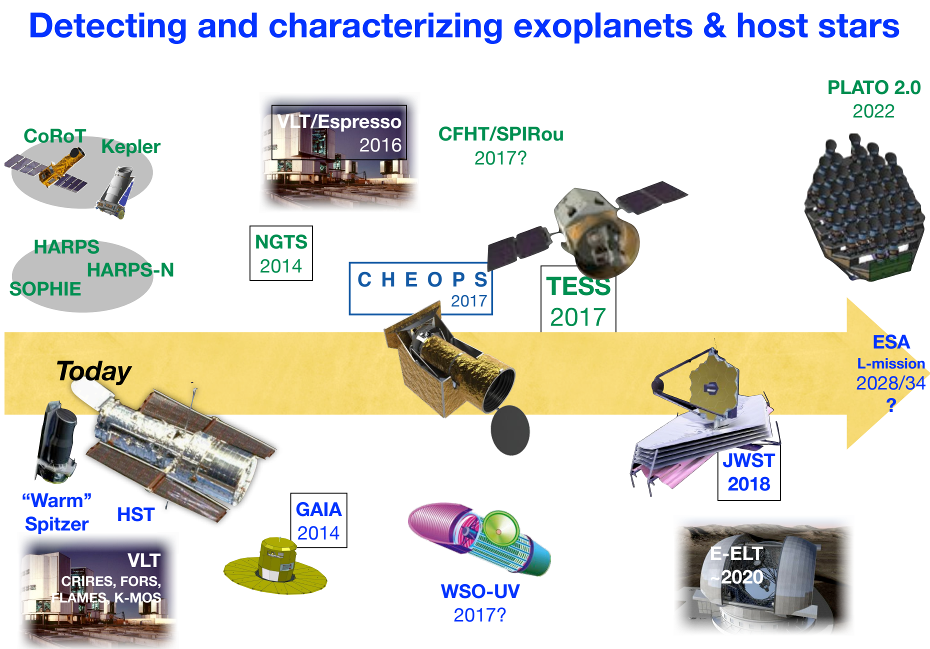
- Sample : 50-100 quiet dwarfs (K-M)
- GTO : 200 nights
- Expected: 25-50 planets




Organization of Groundbased follow-up
US: several 2m
HET 10m
Keck 10m
Spirou CFH 3.6m
OHP 2m
Tautenburg 2m
Mercator 1.2m
NOT 2.5m
Carmenes CA 3.5m
HARPS-N TNG 3.5m
GTC 10m
ESO 2.2m
Euler 1.2m
Crires VLT 8m
HARPS ESO 3.6m
Espresso VLT 8m
NTT 3.5m
AAT 4m
Infrared facilities: 1-2 m/s
earths around late K - M dwarfs
40 nights/year x 6 years
3 telescopes
1-2m-class telescopes: 3-10m/s
giant planets on short/medium orbits
100 nights/year x 6 years
6 telescopes
4m-class telescopes: 1-2 m/s
giant planets on long orbits
super-earths on short/medium orbits
100 nights/year x 6 years
4 telescopes
8m-class telescopes: < 50cm/s
super-earths on long orbits,
earths on short/medium orbits
earths on long orbits @ brightest stars
40 nights/year x 6 years
1 telescope


TESS Transiting Exoplanet Survey Satellite
Selected by NASA
Planets that Transit
Stars Brighter than V=10
Known Planets, March 2013
Predicted TESS Yield
Sub-Neptune (<3.0 Earth radii)
Super-Earth (<2.0 Earth radii)
Earth (<1.25 Earth radii)
Planet radius (Earth radii)
Orbital Period (days)
10
1
10
100
CHEOPS


Radial velocities in the space-transit era
• TTV as a way to planet mass, but…
• small-mass planet searches in RV
Precision: ~1 m/s
• Many new facilities in development
• Target definition for CHEOPS
• Follow-up for TESS
= anticipated follow-up for PLATO


Detecting and characterizing exoplanets & host stars
CoRoT
Kepler
VLT/Espresso
2016
CFHT/SPIRou
2017?
PLATO 2.0
2022
HARPS
HARPS-N
SOPHIE
NGTS
2014
CHEOPS
2017
TESS
2017
Today
ESA
L-mission
2028/34
?
"Warm"
Spitzer
HST
GAIA
2014
WSO-UV
2017?
JWST
2018
VLT
CRIRES, FORS,
FLAMES, K-MOS
E-ELT
2020