PLATO Ground-based Follow-up

a) Follow-up and Stellar science synergies

b) Information about Follow-up

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Questions addressed

Main goals of (ground-based) follow-up observations:

- Establish the nature of the transit events and identify/reject false positives
- Characterise the companion mass and eccentricity from Earth to brown-dwarfs.

Vetting

Science

- Science from Follow-up
  - Primary science (e.g. mass), bonus science, enlarging science return
  => planet and stellar science
- Vetting and validation
  - false positives and diagnostics => requirement from stellar science
- Ground-based Observation Organisation
  - Inclusion in the consortium overall activities
  - PDC - PIC - Ancillary database - FU specific tool:
  => how do stellar parameters fit in

plato

Scientific Objectives 1-7

S1 - Determine the bulk properties (M, R and mean ρ) of planets in a wide range of systems (including HZ Earths)

S2 - Study how planets and planet systems evolve with age

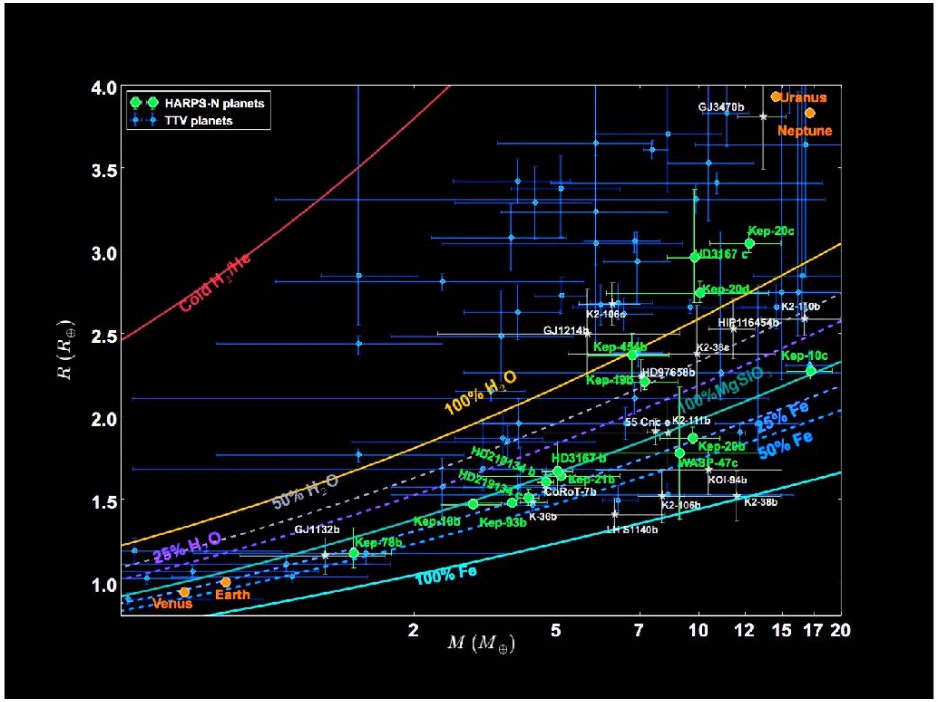
S3 - Study the typical architectures of planetary systems

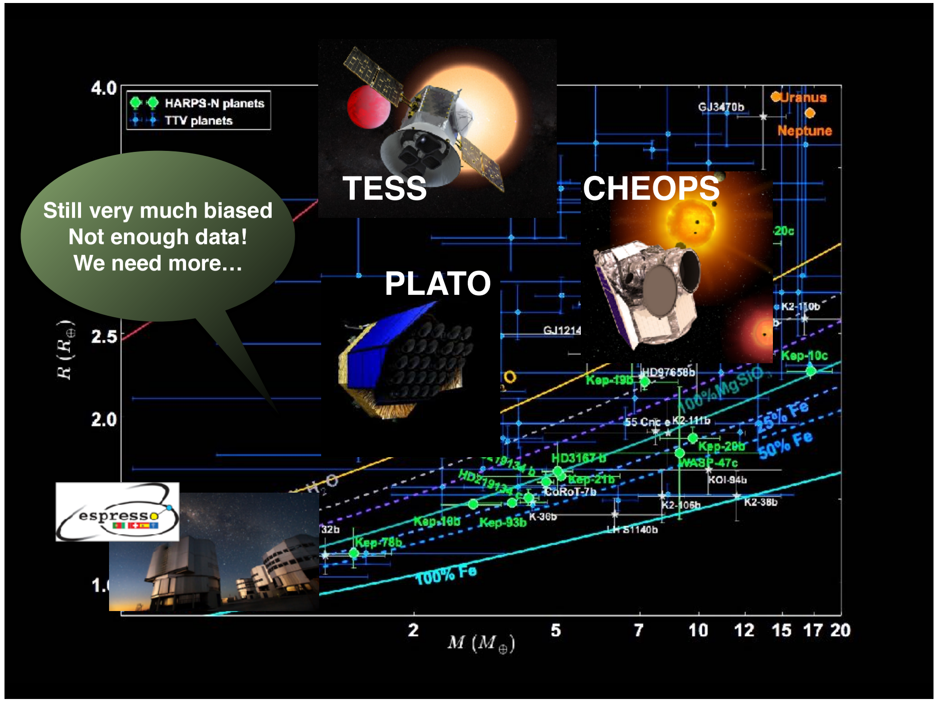
S4 - Analyse the correlation of planet properties with stellar parameters (e.g., stellar metallicity, stellar type)

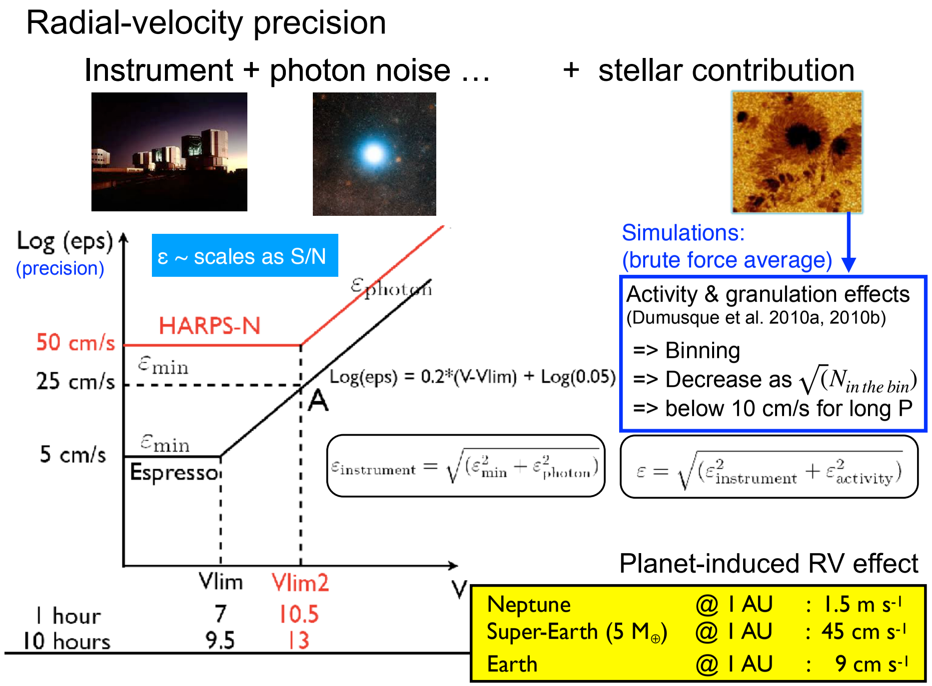
S5 - Analyse the dependence of the frequency of terrestrial planets on the environment in which they formed

S6 - Internal structure of stars and how it evolves with age

S7 - Identify good targets for spectroscopic follow-up measurements to investigate planetary atmospheres







Challenge of characterising small planets

- Multi-planet systems: superposition of signals
  => sample various time scales

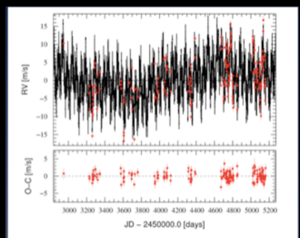
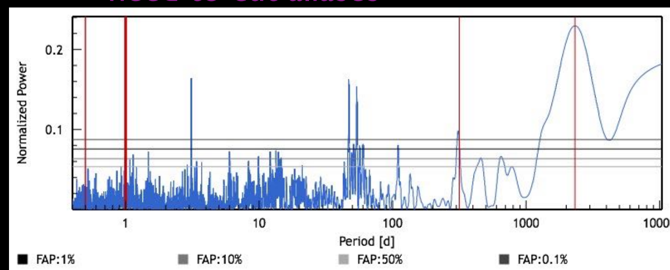


Fig. 5. Radial velocity time series with the 7-Keplerian model overplotted. The lower panel shows the residuals to the model.

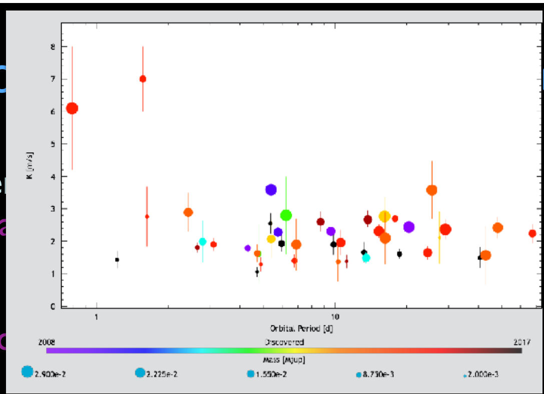
Challenge of characterising small planets

- Multi-planet systems: superposition of signals
  => sample various time scales
- Sampling effects:
  => need to cut aliases



Challenge of c… ets

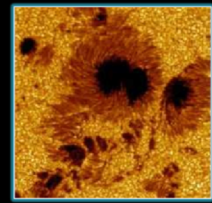
- Multi-planet syste…
  => sample va…
- Sampling effects:
  => need to c…



- Data analysis, confidence level
  => need to increase signal to noise

Challenge of characterising small planets

- Multi-planet systems: superposition of signals
  => sample various time scales
- Sampling effects:
  => need to cut aliases
- Data analysis, confidence level
  => need to increase signal to noise
- Stellar effect
  => beat down the noise (by brute force averaging?)



The community is very active
(including PLATO FU members)

1) Modelling stellar effects
- Solar telescopes
- Activity indicators
- Activity modelling (GP,…)

2) Telluric contaminations

3) Statistical approaches
- Robustness
- Criteria for trust in detections
- Non-gaussian effects ?

4) Instrumental challenges
- Hardware (light injection, thermo-mechanical stability,…)
- calibration (LFC, FP, lamps …)

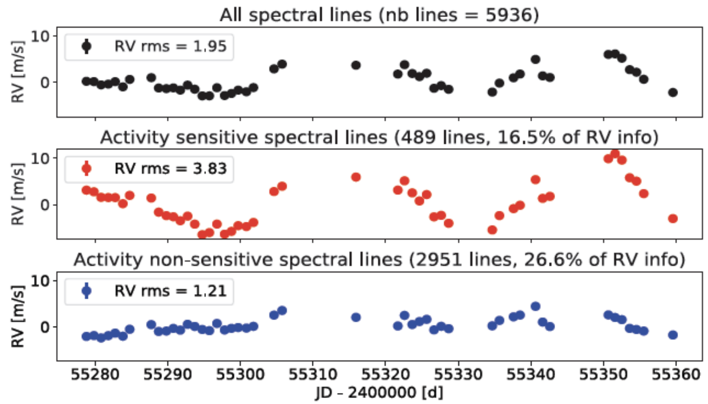
5) new instruments
- Visible (ESPRESSO, NEID, EXPRESS, PEPSI, VELOCE,…)
- NIR (CARMENES, SPIRou, NIRPS)

Two examples to illustrate some of the approaches

1. Selected choice of spectrale lines or spectral chunks

Alpha Cen A

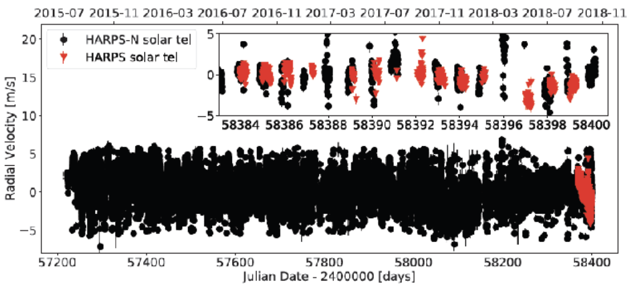
Using different sets of lines

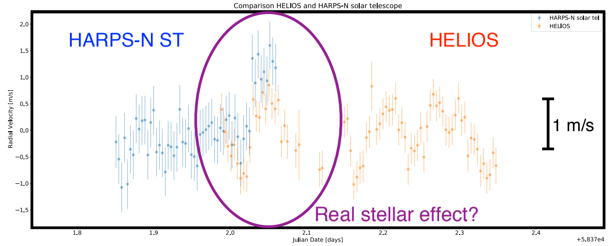


Also Rajpaul, Aigrain, et al. 2019
Blind, machine learning, selection of "non-variable" part of the spectrum

Two examples to illustrate some of the approaches

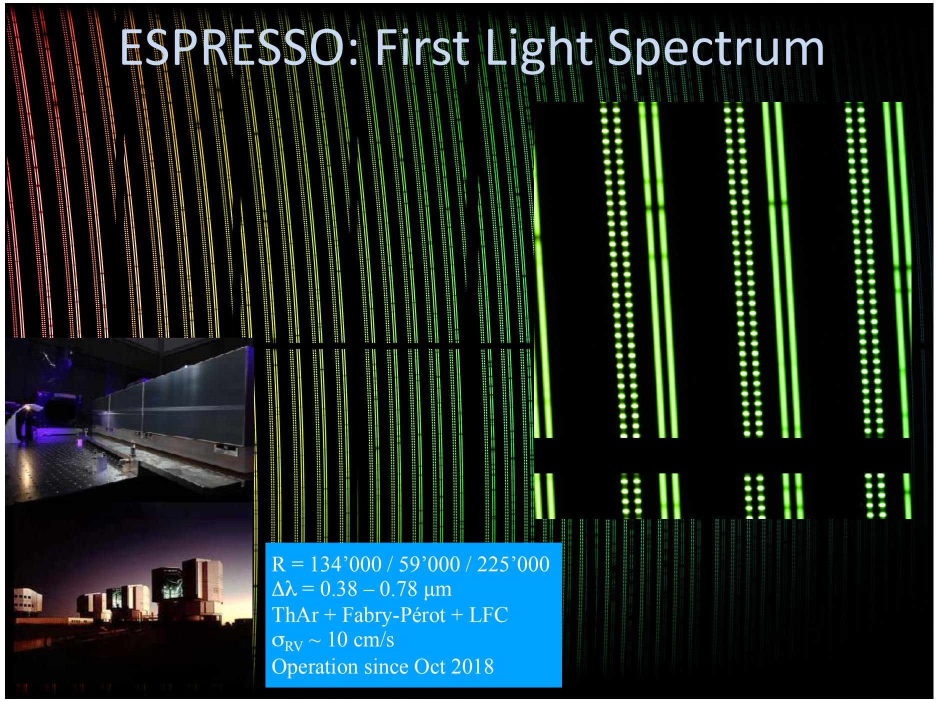
2. Solar telescopes on HARPS-N and HARPS (Helios)





First 3 years of the HARPS-N Solar telescope data public => summer 2020. Official announcement soon.

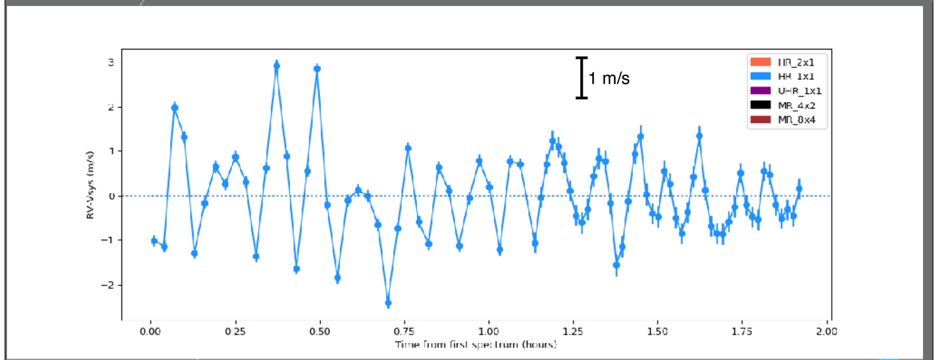
ESPRESSO: First Light Spectrum



R = 134'000 / 59'000 / 225'000
$\Delta\lambda$ = 0.38 – 0.78 µm
ThAr + Fabry-Pérot + LFC
σ_{RV} ~ 10 cm/s
Operation since Oct 2018

Short-term precision

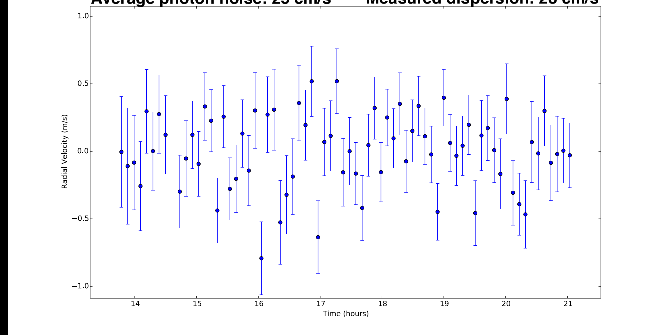
HD 190248
V=3.6, G8IV



Rocky planets in HZ with ESPRESSO

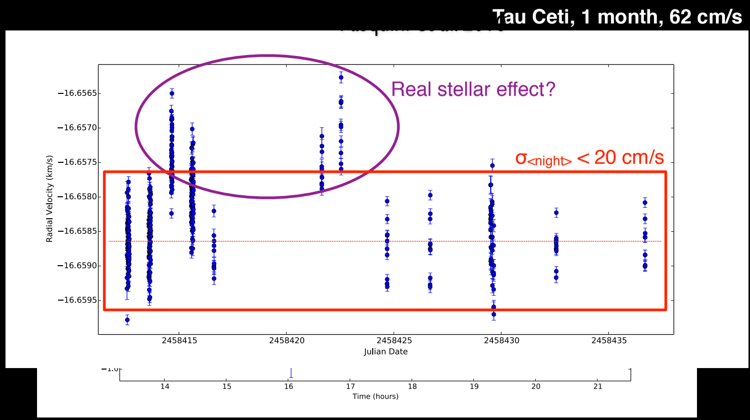
HD85512

Average photon noise: 25 cm/s Measured dispersion: 28 cm/s



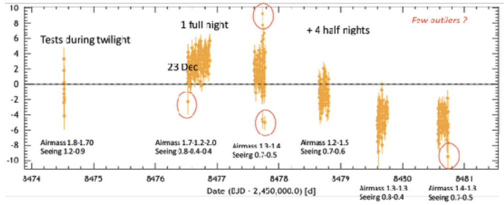
Rocky planets in HZ with ESPRESSO

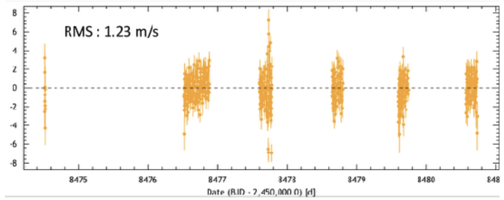
Tau Ceti, 1 month, 62 cm/s



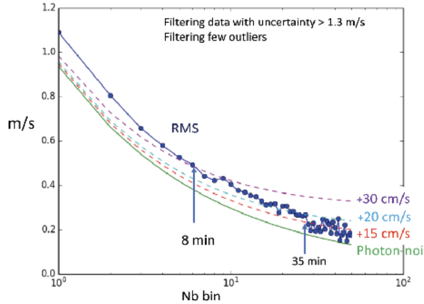
HD40307 (K2V, V=7.15): a 4-planet system (P=4.3d, 9.6d, 20.4d, 51.6d)
449 HARPS points (Diaz et al 2017)

ESPRESSO continuous observations over 5 nights: 1150 measurements



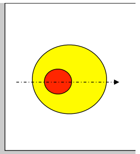


Texp = 30s (Duty cycle=78s)
Total coverage = 6.23 nights
<RV uncertainty> = 97 cm/s
RV global rms = 3.27 m/s
Residuals = 1.23 m/s

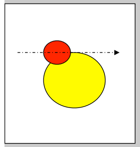


Bouchy, private comm

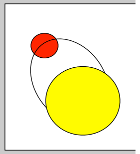
A zoo of false positives => Vetting



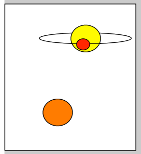
Eclipsing M dwarfs



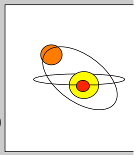
Grazing eclipsing binaries



Secondary-only eclipsing binaries



Background eclipsing binaries (inside PLATO window)

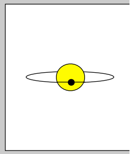


Blended eclipsing binaries (inside seeing)

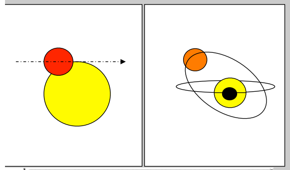
?

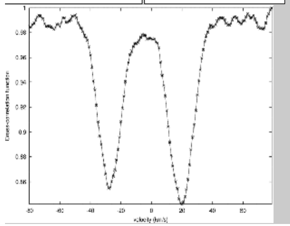
Hot and fast Rotating star no signif. RV variations

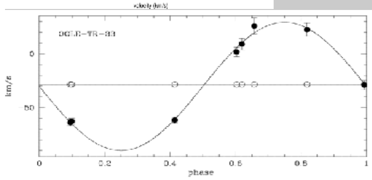
Transiting planets



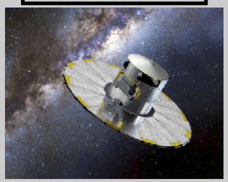
Grazing EBs & triple systems



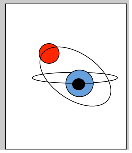


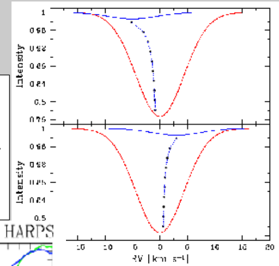


Astrometry

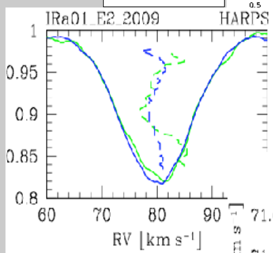


Blended Eclipsing Binaries

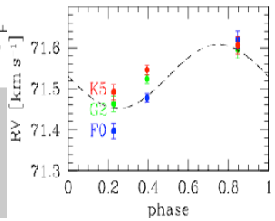




Amplitude change With CCF template



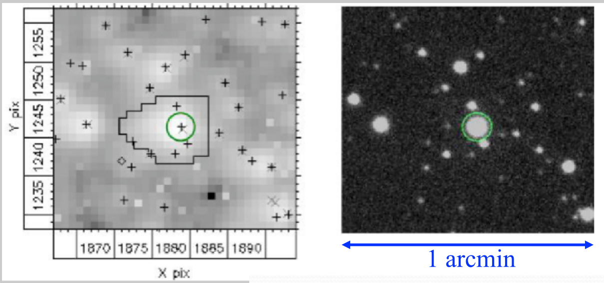
Bisector Span



Spectroscopy

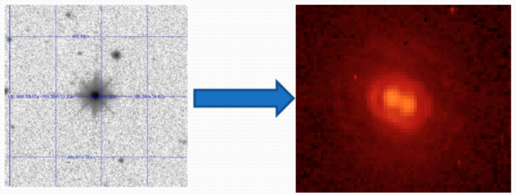
Ground-based photometric & imaging follow-up

- To estimate dilution factor within photometric mask
- To exclude diluted eclipsing binaries with ON-OFF photometry
- To identify close contaminant at high angular resolution



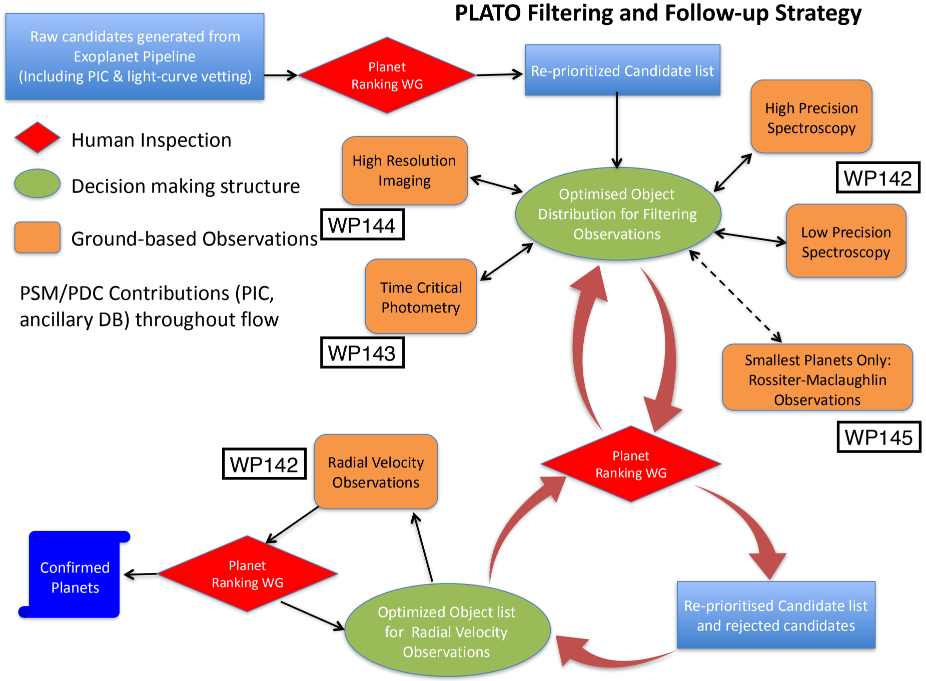
CoRoT example

KOI 1422 is binary: R = 1.5 Re → R = 2.1 Re



Kepler example

PLATO Filtering and Follow-up Strategy



Follow-up organization of the work

- Large number of expected transit candidates
  => systematic observation of all transits with large telescopes unfeasible
  => an optimised follow-up scheme has to be organised
- Same level of precision cannot be reached for all stars (spectral type, luminosity class, activity, brightness)
- Same is true for the RVs and high-contrast imaging
- Strategy for the follow-up: efficient approach
  => matching targets and adequate facilities
  => minimum number of used facilities per target

In practice => a multi-step approach from moderate to high-precision (filtering)
=> a "guided" approach

=> need to design and develop tools (WP141):
- automatic distribution of targets in boxes according to their needs
- optimum match between participating facilities and target needs (boxes)
- efficient interface between observers and target information (PIC, ancillary DB)

=> information needed in catalogs (PIC, ancillary, …)
to run and optimise the Follow UP

FU science+vetting needs

1. Basic stellar parameters
   - coordinates, mag, spectral type, mass, radius, age…
   - specific for the reduction pipeline: star RV
   - … others ?
2. System properties: environment
   - binarity, known planets and their parameters
   - contaminants
3. Best radial-velocity measurements
   - vsini, activity level (RV precision, choice of instrument)
   - optimised scheduling
4. Time series from previous obs/surveys (with uncertainties)
   - RVs: known or long-P planets
   - Activity proxy: star-planet disentangling

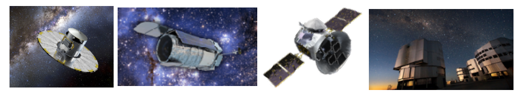
STESCI

STESCI

=> in PIC

=> in ancillary database

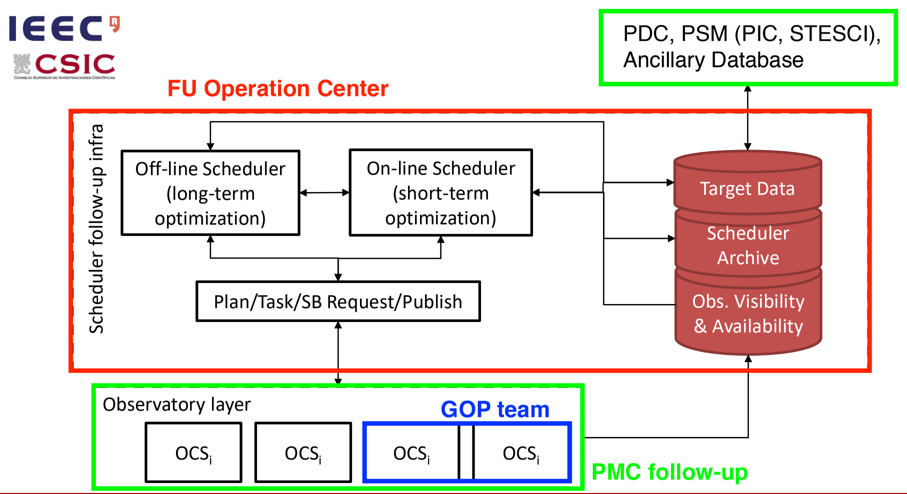
=> use existing archive data



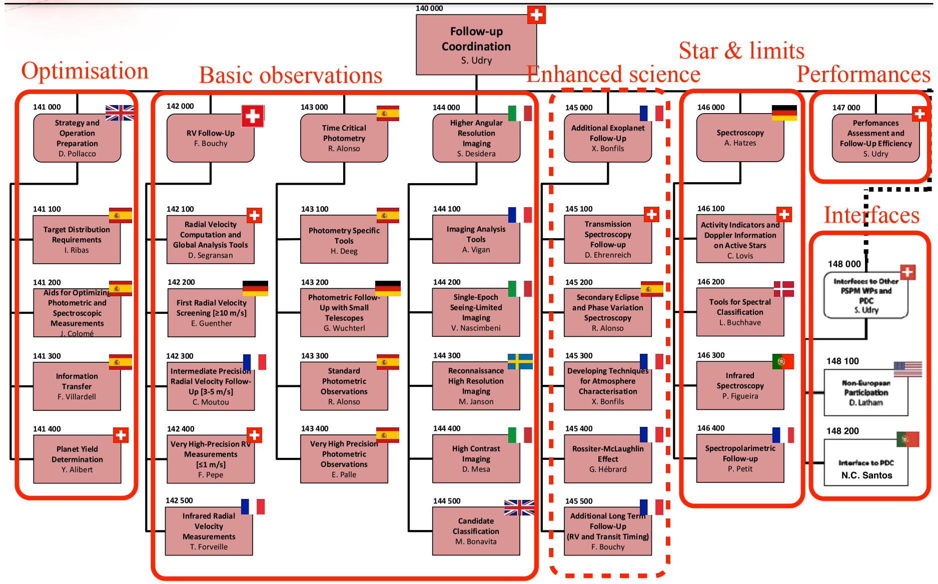
(From surveys: Gaia, TESS, RVs, etc)

Rem: FU will provide
- Time series with BJD, RV, Sig_RV, CCF bisector, activity index,
- High resolution, high S/N spectra: *v*sin*i*, Fe/H, Teff, mean activity level (various indexes)

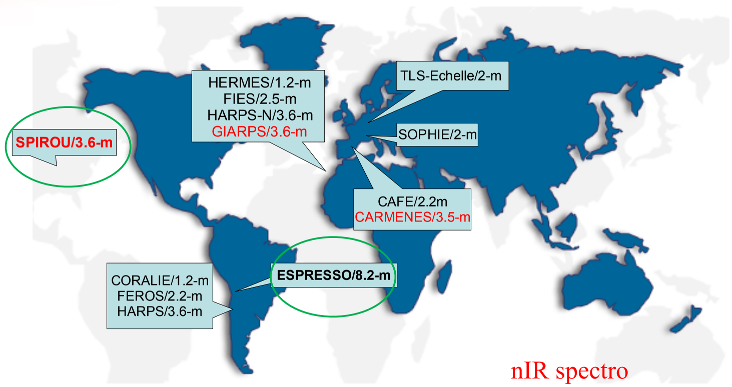
PLATO Follow-up Organisation



Follow-up WP structure



European RV facilities in operation



nIR spectro

Non-European RV facilities

Non-European RV facilities in operation

PFS2@Magelan (6.5m)
HRS@SALT (11m)
CHIRON@CTIO (2.5m)
HIRES@Keck (10m)
APF@Lick (2.5m)
Veloce@AAT (3.9m)
ISHELL@IRTF (3m)
PARVI@Palomar (5.1m)
iLocater@LBT (2x8m)
HPF@HET (10m)
IRD@Subaru (8m)
EXPRES@HappyJack (4.3m)

Active in TESS follow-up

Reports at EPRV IV

Most of them already at the 2-3 m/s level

Non-European RV facilities in development or *in project*

MAROON-X@Gemini-N (8m)
NEID@KittPeak (3.5m)
KPF@Keck (19m)
GCLEF@GMT (25m)