PLATO Follow-up
Organisation & Progress Report

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

S. Udry
University of Geneva
(Geneva Observatory)

Importance of the follow-up

Goals - Necessity - Organisation

1) Planet parameters
   - Not obtained from the light curves
     - mass, density
     - temperature, geometry
     - others

2) added science return
   - stellar parameters
   - non-transiting planets
   - binaries
   - other

The next step: characterization!

What is characterizing a planet?

- Host star and Orbit \rightarrow incident stellar flux
- Mass, Radius \rightarrow mean density, bulk composition
- Atmosphere \rightarrow scale height, composition
- Age \rightarrow evolution (dynamics)
- Biosphere \rightarrow life

Questions addressed

- Needs
  - planet parameters (masses from RVs)
  - confirmation (false positives)
  - tools for optimal planning and operation

- Observing facilities
  - yield of the mission and telescope time estimate
  - available/planned facilities
  - impact of the recent change in the "space-transit" landscape

- Organization of the Follow-up work
  - work breakdown and interfaces
  - strategy
  - involvement of the community

Importance of the follow-up

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1) Planet parameters
   - Not obtained from the light curves
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2) False positives
   - Experience gained from
     - ground-based \Rightarrow giant planets
     - space \Rightarrow small planets
A zoo of false positives

Grazing eclipsing binaries

Eclipsing M dwarfs

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 Eclipsing binaries & triple systems

Eclipsing M dwarfs

Secondary-only 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

KOI 1422 is binary: $R = 1.5$ Re $\rightarrow$ $R = 2.1$ Re

A zoo of false positives

- Small-size planets
  - => add false-positive due to diluted transits by giant planets on secondaries
  - => same diagnostics applicable
    - Consistency checks (duration, etc)
    - Light curve shape (V, ellipsoidal, etc)
    - Astrometry, RVs, line bisector
    - Imaging (dilution), on-off photometry

- 10% - 30% false positives (from Kepler)
  small - giant planets

- statistical approach (BLENDER/PASTIS)
  - => Validation

- Validation of Earths via Rossiter-McLaughlin

Blended Eclipsing Binaries

- To estimate dilution factor within photometric mask
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   - ground-based => giant planets
   - space => small planets

3) Optimisation
   Enhanced science return
   - strategy, organisation
   - synergies

FU Organisation

Basic facts

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
   => minimum number of used facilities per target

In practice => a multi-step approach from moderate to high-precision
   => a “guided” approach

FU Requirements

Large and dynamic list of potential targets to be followed: to achieve this goal
=> efficient organisation and coordination

Basic idea:

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

=> 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)

=> part of WP activities

WP 140 000

Optimisation

Basic observations

Star & limits

enhanced science

Interfaces

D. Pollacco
F. Bouchy
X. Bonfils
S. Udry
A. Hatzes

TBD
### PLATO: # of Light Curves

For the baseline observing strategy:

<table>
<thead>
<tr>
<th>Noise level</th>
<th>Magnitude limit</th>
<th>Number of cool stars [long stare fields]</th>
<th>Number of cool stars [plus step and stare fields]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ppm/√hr)</td>
<td>$m_v$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>11</td>
<td>22,000</td>
<td>85,000</td>
</tr>
<tr>
<td>80</td>
<td>13</td>
<td>267,000</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

- **Core science**
  - Detection of Earth-sized planets
  - Asteroseismology
  - Radial velocity
  - Detection of Earth-sized planets

- **Legacy**

### 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

### Radial-velocity precision

- Log (eps) vs. Separation ($a/a_HZ$)
- Difference of 0.3 (i.e., factor 2)
- Log(eps) = 0.2$(V-Vlim) + Log(0.05)$
- $\varepsilon_{\text{min}}$
- $\varepsilon_{\text{max}}$
- $\varepsilon_{\text{phot}}$
- $\varepsilon_{\text{instrument}} = \sqrt{(\varepsilon_{\text{min}}^2 + \varepsilon_{\text{phot}}^2)}$
- $\varepsilon = \sqrt{(\varepsilon_{\text{instrument}}^2 + \varepsilon_{\text{activity}}^2)}$
- + HARPS results
- + Simulations
- + Binning
- + Activity & granulation effects
- (Dumusque et al. 2010a, 2010b)

### Total numbers of characterized planets in core sample

Number of characterized planets (Earth to Neptune mass) after detailed model of radial velocity efforts and the impact of stellar activity:

- Mass ($M_{\oplus}$)
- Separation ($a/a_HZ$)
- Habitable zone

- $>$1000
- 265
- 100
- 30
- $>$800
- 540
- 210
- 70
- $>$300
- 300
- 78
- 30
- 0
- 0.5
- 1.0
hundreds of systems similar properties for RV & Kepler systems

The size is known rather than the mass but periods OK

Kepler multi-transiting systems

PLATO expected numbers of planets

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     - stellar noise simulations
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Follow-up time needed

Follow-up is tractable with existing/planned facilities with reasonable allocation of time

Rest: Legacy

Full follow-up of the expected planet yield from core sample

<table>
<thead>
<tr>
<th>Radial velocity precision</th>
<th>Telescope</th>
<th>Type of objects</th>
<th>Example time distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m/s</td>
<td>4 m</td>
<td>Giant planets, long orbits: Super-Earths on short medium orbits</td>
<td>40 nights/yr for 6 yrs on 3 tel.</td>
</tr>
<tr>
<td>&lt;20 cm/s</td>
<td>8 m</td>
<td>Earths/Super-Earths on long orbits</td>
<td>40 nights/yr for 6 yrs on 1 tel.</td>
</tr>
</tbody>
</table>

Follow-up activities include favouring the development of new facilities
**In operation**
- HARPS-S/3.6m, HARPS-N/TNG $< 1$ m/s
- INT+NOT+HERMES/Mercator, La Palma
- Sophie/193cm OHP $\sim 2$ m/s
- Coralie + FEROS/2.2m, La Silla
- 2m Tautenburg
- PARAS/Mount Abu (1.2m telescope)
- Carnegie Planet Finder at Magellan $< 2$ m/s
- Chiron at CTIO $\gg 0.5$–1.5 m/s
- LCOT/photom (2x2m + 9x1m)
- HRS/HET, Texas
- HIRES/Keck, Hawaii
- UCLES/AAT, siding spring...
- APF/Lick
- Pepsi/LBT

**ESPRESSO on ESO VLT**
«Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations»

- 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 : 2017

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

- Very important for the FU of very small-mass planets

**In well-advanced development**
- ESPRESSO on VLT $\gg < 10$ cm/s, 2017
- LCOT/spectro (within a few years)
- Pathfinder on HET
- CARMENES at Calar Alto, 2015
- SPIROU on CFHT (budget OK)
- ...

**ESPRESSO integration -> end 2015**
vacuum tank in Geneva (Dec 2014)
CARMENES
Visible and IR arms covering the range 550 - 170 nm

Vacuum tanks: tests on-going in Granada and Heidelberg
Commissioning: 2nd half of 2015
Deal: 600 useful nights at Calar Alto

(Courtesy: A. Reiners)

Organization of Groundbased follow-up

**In operation**
- HARPS-S/3.6m, HARPS-N/TNG < 1 m/s
- INT+NOT+HERMES/Mercator, La Palma
- Sophie/193cm OHP < 2 m/s
- Coralie + FEROS/2.2m, La Silla
- 2m Tautenburg
- PARAS/Mount Abu (1.2m telescope)
- Carnegie Planet Finder at Magellan < 2 m/s
- Chiron at CTIO => 0.5-1.5 m/s
- LCOGT/photom (2x2m + 9x1m)
- HRS/HET, Texas
- HIRES/Keck, Hawaii
- UCLES/AAT, siding spring...
- APF/Lick
- Peps/LBT

Yesterday: ESO council
GO forward for E-ELT

**In well-advanced development**
- ESPRESSO on VLT \(< 10 \text{ cm/s, 2017}\)
- LCOGT/spectro (within a few years)
- Pathfinder on HET
- CARMENES at Calar Alto, 2015
- SPIROU on CFHT (budget OK)
- Song network
- ...

**Progressing ideas**
- ESPRESSO-North (GranTecan/IAC, Espresso+USA)
- NIRPS/NTT (proposal going to 2nd phase)
- UKIRT Planet Finder
- GCLEF on GMT
- Harvester on Palomar
- HIRES on E-ELT 2-3 cm/s (AO call soon)
- THE: HARPS-3 on INT/La Palma (50% of the time)
- ...

**Satellites targeting bright stars**

Lack of transiting planets around bright stars

Planets that Transit Stars Brighter than \(V=10\)

Known Planets, March 2013

<table>
<thead>
<tr>
<th>Orbital Period (days)</th>
<th>Planet radius (Earth radii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Earth (&lt;1.25 Earth radii)</td>
</tr>
<tr>
<td>10</td>
<td>Super-Earth (&lt;2.0 Earth radii)</td>
</tr>
<tr>
<td>100</td>
<td>Sub-Neptune (&lt;3.0 Earth radii)</td>
</tr>
</tbody>
</table>

1-2m-class telescopes: 3-10m/s
- 100 nights/year x 4 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 4 years
- 4 telescopes

8m-class telescopes: < 50cm/s
- super-earths on long orbits
- super-earths on short/medium orbits
- 200 nights/year x 4 years
- 1 telescope

1-2m-class telescopes: < 1 m/s
- giant planets on short/medium orbits
- 100 nights/year x 4 years
- 6 telescopes

4m-class telescopes: < 2 m/s
- giant planets on short/medium orbits
- super-earths on long orbits
- 40 nights/year x 6 years
- 1 telescope

HARPS ESO 3.6m
HARPS-N TNG 3.5m
NTT 3.5m
AAT 4m

Carnes CA 3.5m
Tautenburg 2m
OHP 2m
NOT 2.5m
GTC 10m
Spirou 3.8m
Keck 10m
HET 10m
ESO 2.2m
Euler 1.2m

1-2m-class telescopes: < 1 m/s
- giant planets on short/medium orbits
- 40 nights/year x 6 years
- 1 telescope

4m-class telescopes: < 2 m/s
- super-earths on long orbits
- earths on short/medium orbits
- 200 nights/year x 4 years
- 1 telescope

8m-class telescopes: < 50cm/s
- super-earths on long orbits
- earths on short/medium orbits
- 200 nights/year x 4 years
- 1 telescope

From TESS team

K2
CHEOPS
TESS
PLATO

Lack of transiting planets around bright stars

Satellites targeting bright stars
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

=> Very important activities for the mission adoption

Follow-Up web site

Direct link from PLATO main web page
www.plato-mission.eu
also
obswww.unige.ch/plato-follow-up/

Registration for facilities participating to the PLATO follow-up efforts

The next steps

- ESA: main important points concerning the follow-up
  - (1) Solid and convincing organization of the follow-up
  - (2) Involvement of the Community
  - (3) Data right and publication policy <= same as for the satellite data

- Consortium:
  - (1) consolidate the WP break-down
    ‣ most of the coordinators confirmed
    ‣ define and describe preparation and operation strategy
    ‣ precise activities of the WP, in the light of the changes in the field
  - (1) more precise estimate of the planet yield & telescope time required
  - (2) available/planed facilities (landscape)
    ‣ web interface for registration for participation: facilities & individuals
      (3) involvement of leading organizations in ground-based observations
  - (2) organize soon a workshop involving the community
**FU registration interface**

### Instrument
- **Instrument name**
- **Instrument status**
  - Existing
  - Project
  - Development
- **Starting date of operation**
- **Location (Observatory, Coordinates)**
- **Telescope/Observatory director**
- **Telescope diameter (meters)**
- **Median seeing (arcsec)**
- **Expected # of nights/year for PLATO Follow-up**
- **Time Allocation**

### Spectrograph/Radial Velocity
- **Spectral domain start - end (nanometers)**
- **Radial velocity precision (m/s)**
  - RV: $\pm 10 \text{ km/s}$ for 1h exposure on $V-r$ 11 dwarf
- **Additional Notes**

### Photometry
- **Wavelength band(s) or filters (nanometers)**
- **Field of view (arcmin)**
- **Angular resolution (arcsec)**
- **Pixel scale (arcsec)**
- **Photometry precision (mmag) on a M=11 star on 5 minutes**
- **Additional Notes**

### High Angular Resolution Imaging
- **Wavelength band(s) or filters (nanometers)**
- **Field of view (arcmin)**
- **Angular resolution (arcsec)**
- **Pixel scale (arcsec)**
- **Dynamic range**
- **Adaptive optic mode**
- **Coronograph mode**
- **Additional Notes**
Spread the news to the responsible of potentially contributing facilities.

Registration for individual participants to join a given WP effort
=> Soon, after final consolidation of WP

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Feedbacks about the web site are very welcome.