Stellar pulsation timing

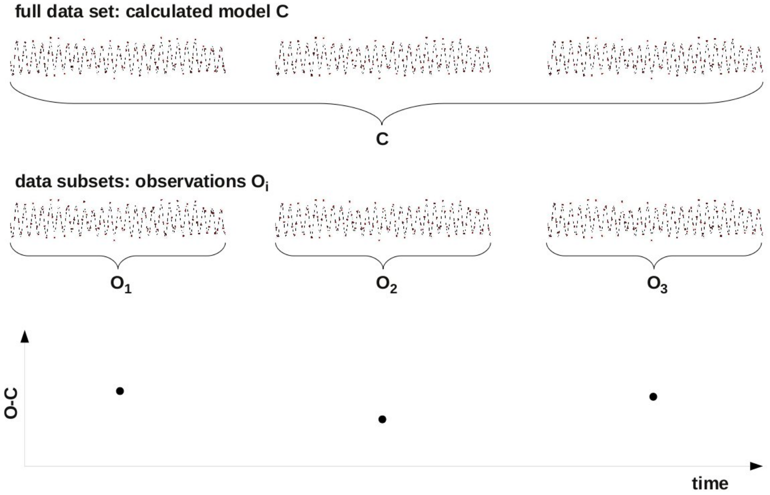
A complementary science case for the PLATO mission

Sonja Schuh

2017-03-07

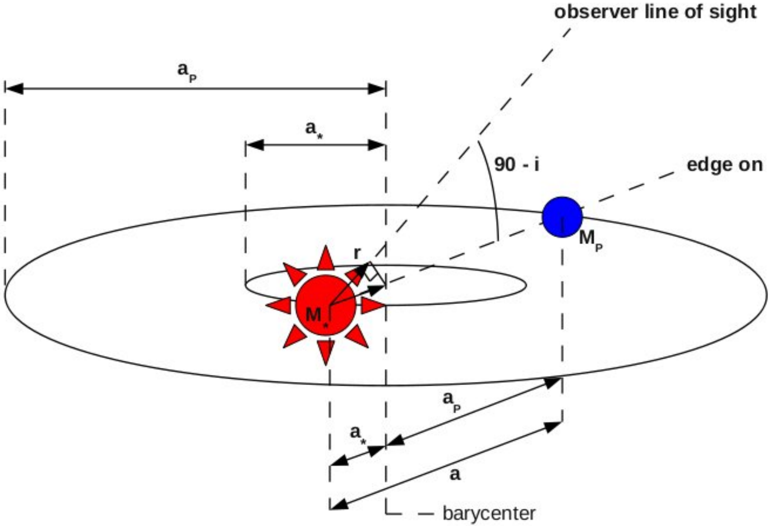
MPS Max Planck Institute for Solar System Research

Pulsation timing: "Observed minus Calculated" diagrams

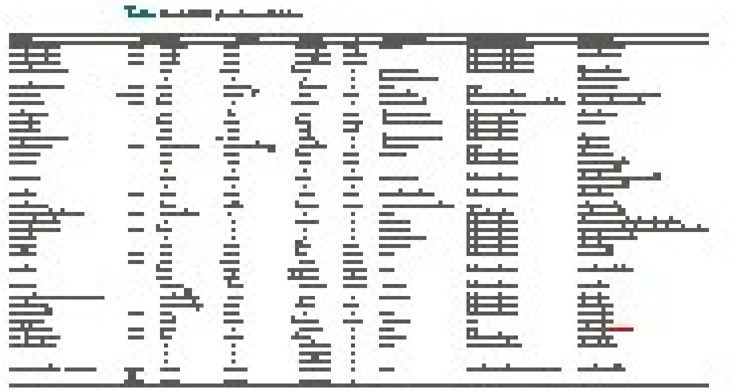


Figures from Lutz (2009), Dissertation, University of Göttingen

Light travel time effect

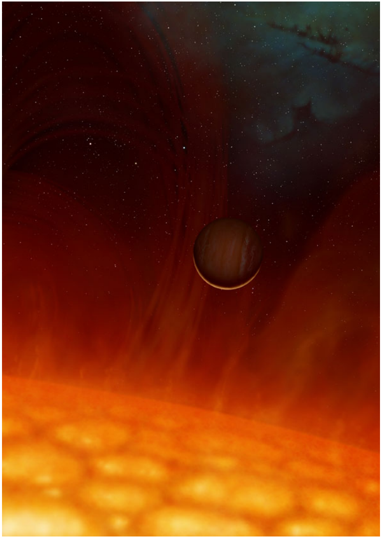


Post-RGB planet candidates



EXOTIME

Extra-solar planet search with the timing method



- **A giant planet orbiting the 'extreme horizontal branch' star V391 Pegasi**
  Silvotti, Schuh, Janulis et al. 2007, Nature 449, 198
- **EXOTIME: searching for planets around pulsating subdwarf B stars**
  Schuh, Silvotti, Lutz et al. 2010, Ap&SS 329, 231
- **The Potential of the Timing Method to Detect Evolved Planetary Systems**
  Silvotti, Szabó, Degroote, Østensen, Schuh 2011, AIPC 1331, 133
- **The search for substellar companions to subdwarf B stars in connection with evolutionary aspects**
  Lutz 2011, PhD thesis, University of Göttingen
- **EXOTIME: Searching for planets and measuring Pdot in sdB pulsators**
  Lutz, Schuh, Silvotti 2012, AN 333, 1099
- **The EXOTIME Monitoring Program Discovers Substellar Companion Candidates around the Rapidly Pulsating Subdwarf B Stars V1636 Ori and DW Lyn**
  Schuh, Silvotti, Lutz, Kim, Exotime Collaboration 2014, ASPC 481, 3

The need for confirmation

- Confirmation is difficult
  - consistency between independent pulsation frequencies?
  - prediction power of model fit?
  - reproducibility of results? with independent re-analysis and/or new data?
- Need for simulation of time-series
  - Interpretation of sparsely-sampled ground-based data
- Independent confirmation is very difficult
  - radial velocities
  - colour excess
  - direct imaging
- Pulsation timing
  - in principle, O–C method is simple
  - in practice, it is not a well-establish planet detection method

Poster Mackebrandt

The Stellar Pulsation Timing Detection Method for Substellar Companions

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Abstract

We want to make use of the rapid pulsations in subdwarf B stars (sdBs) to detect substellar companions from periodic variations in the expected arrival times of the pulsations. This timing method is particularly sensitive to planets at large distances and complementary to other exoplanet detection methods because they are not as efficient for stars with small radii and high gravities. Thus, the timing method opens up a new parameter range in terms of the host stars. To date, substellar candidates in sdB systems are for example V391 Peg b (Silvotti et al., 2007), HW Vir b, c (Lee et al., 2009), HS 0705+67003 b (Qian et al., 2009) and Kepler-429 b, c, d (Silvotti et al., 2014).

sdB Stars

Subdwarf B stars are located at the extreme horizontal branch in the Hertzsprung-Russel diagram. They have a helium-fusion core but no hydrogen-shell fusion in their thin hydrogen shells. The mass-loss leading to such thin shells can be well explained in close binary systems but is difficult for single sdBs. Planets have been proposed to be responsible for the formation of single sdBs.

Some subdwarf B stars exhibit pulsation instabilities driving acoustic modes of a few minutes period. They can be used as a clock signal to detect periodic changes in the arrival time caused by a substellar companion.

Light Travel Time Effect

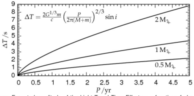
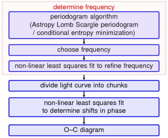


Figure: Expected amplitude of the Light Travel Time Effect as a function of planetary orbital period P for a host star of mass $M = 0.5\,M_\odot$, $\sin i = 1$ and different planetary masses m.

Python Pipeline



References

Lee, J. W., Kim, S.-L., Kim, C.-H., Koch, R. H., Lee, C.-U., Kim, H.-I., and Park, J.-H. (2009). The sdB+M Eclipsing System HW Virginis and its Circumbinary Planets. *AJ*, 137:3181–3190.

Lutz, R. (2011). *The search for substellar companions to subdwarf B stars in connection with evolutionary aspects.* PhD thesis, Georg-August-Universität Göttingen.

Qian, S.-B., Zhu, L.-Y., Zola, S., Liao, W.-P., Liu, L., Li, L.-J., Winiarski, M., Kuligowska, E., and Kreiner, J. M. (2009). Detection of a Tertiary Brown Dwarf Companion in the sdB-Type Eclipsing Binary HS 0705+6700. *ApJ*, 695:L163–L165.

Silvotti, R., Charpinet, S., Green, E., Fontaine, G., Telting, J. H., Østensen, R. H., Van Grootel, V., Baran, A. S., Schuh, S., and Fox Machado, L. (2014). Kepler detection of a new extreme planetary system orbiting the subdwarf-B pulsator KIC 10001893. *A&A*, 570:A130.

Silvotti, R., Schuh, S., Janulis, R., Solheim, J.-E., Bernabei, S., Østensen, R., Oswalt, T. D., Bruni, I., Gualandi, R., Bonanno, A., Vauclair, G., Reed, M., Chen, C.-W., Leibowitz, E., Paparo, M., Baran, A., Charpinet, S., Dolez, N., Kawaler, S., Kurtz, D., Moskalik, P., Riddle, R., and Zola, S. (2007). A giant planet orbiting the 'extreme horizontal branch' star V391 Pegasi. *Nature*, 449:189–191.

Acknowledgements

We would like to thank the International Max Planck Research School for Solar System Science at the University of Göttingen (IMPRS, Solar System School) and the Volkswagen Foundation (project grant number VWZN3020) for funding this project.

Simulated Data

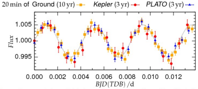


Figure: Excerpt of the artificial observations for ground-based-like, *Kepler*-like and *PLATO*-like noise and timing. Fast pulsating host star (~ 14 mag) with a period of 6 min and amplitude of 5000 ppm. Ground-based observations for three consecutive nights per month, cadence 25 s and noise level of 1000 ppm. *Kepler*- / *PLATO*-like observations with a cadence of 60 s / 50 s and noise level of 1620 ppm / 850 ppm, respectively.

Linear drifting Period

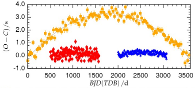


Figure: $O - C$ diagram for an injected linear change in stellar pulsation period $\dot{P} = 10^{-13}\,\mathrm{d\,d^{-1}}$, hence $\dot{P}/P = 2.4 \times 10^{-11}\mathrm{d}^{-1}$. Fitted parameters for ground-based: $\dot{P}/P = (2.5 \pm 0.5) \times 10^{-11}\mathrm{d}^{-1}$, *Kepler*-like: $\dot{P}/P = (2.3 \pm 0.3) \times 10^{-11}\mathrm{d}^{-1}$, *PLATO*-like: $\dot{P}/P = (2.2 \pm 0.2) \times 10^{-11}\mathrm{d}^{-1}$.

Planetary Signal

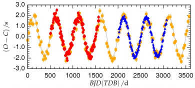


Figure: $O - C$ diagram for an injected planet with $P = 500\,\mathrm{d}$ and $m = 1\,M_♃$, hence $\Delta T = 1.862\,\mathrm{s}$. Fitted parameters for ground-based: $P = (499.839 \pm 0.007)\,\mathrm{d}$, $\Delta T = (1.87 \pm 0.03)\,\mathrm{s}$, *Kepler*-like: $P = (500.76 \pm 0.02)\,\mathrm{d}$, $\Delta T = (1.84 \pm 0.02)\,\mathrm{s}$, *PLATO*-like: $P = (500.46 \pm 0.01)\,\mathrm{d}$, $\Delta T = (1.85 \pm 0.01)\,\mathrm{s}$.

Outlook

Our target catalogue will consist of re-analysed *EXOTIME* objects (Lutz, 2011; `http://www.oato.inaf.it//silvotti/exotime/`) and selected *Kepler* stars. The *Kepler* field contains only few rapid pulsating sdB variables but the oscillations of slow pulsating sdBs and δ Scuti stars can be investigated with our pipeline.

In consideration of future photometric space missions like *TESS* and *PLATO* it is essential to enhance the diversity of potential exoplanet host stars that can be probed.

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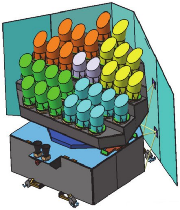
Planetary Systems beyond the Main Sequence II – Haifa 2017

The need to go beyond ground-based data

- Ground-based data has very very low filling factors
- *Kepler* data for fast pulsators is desperately under-sampled
- Need near-continuous well-sampled data!

PLATO

PLAnetary Transits and Oscillations of stars



- ESA's planet-hunting mission
- selected as M3 mission of the Cosmic Vision 2015-2025 program in February 2014
- mission adoption expected in June 2017
- launch expected in December 2025

Figures and quoted or paraphrased text from PLATO Definition Study Report (2016)

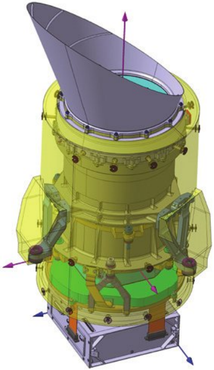
PLATO Definition Study Report (2016)

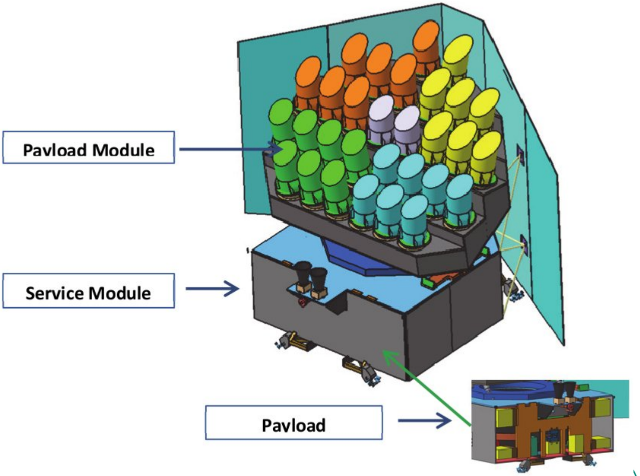
Revealing habitable worlds around solar-like stars

Transit survey mission detecting and providing bulk characterisation for new planets around bright stars. Design optimised to:

- Determine
  the bulk properties (mass, radius, mean density) of planets in a wide range of systems, including **terrestrial planets in the habitable zone of solar-like stars**.
- Study how planets and planet systems evolve.
- Study the typical architectures of planetary systems.
- Analyse the correlation of planet properties and their frequencies with stellar parameters (e.g. stellar metallicity, stellar type).
- Analyse the dependence of the frequency of terrestrial planets on the environment in which they formed.
- Study the **internal structure of stars** and how it evolves with age.
- Identify good **targets for spectroscopic follow-up** measurements to investigate **planet atmospheres**.

Multi-telescope design that makes PLATO unique





One of two proposed spacecraft designs for PLATO (OHB concept)

Multi-telescope design that makes PLATO unique

- PLATO compared to *Kepler* and Corot:
  - larger field of view
  - same performance for fainter stars
  - higher dynamic range due to multi-telescope approach
    $\rightarrow$ bright stars
- PLATO compared to TESS and CHEOPS:
  - PLATO: time base up to 3 years per target
  - TESS: short-orbit planets only (<20 days, i.e. no Earth-like orbits!)
  - CHEOPS: pointed observations at previously known planet host stars (i.e. not a discovery machine)

Multi-telescope design that makes PLATO unique

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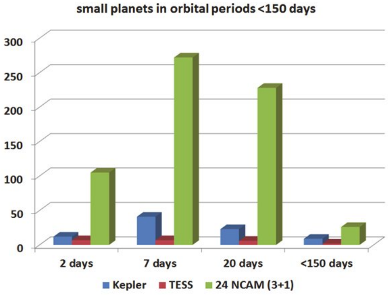
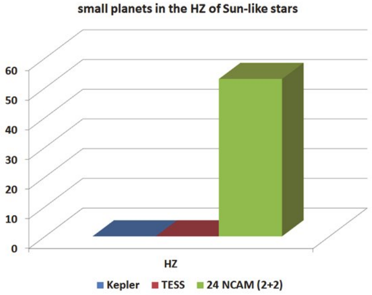
    → bright stars

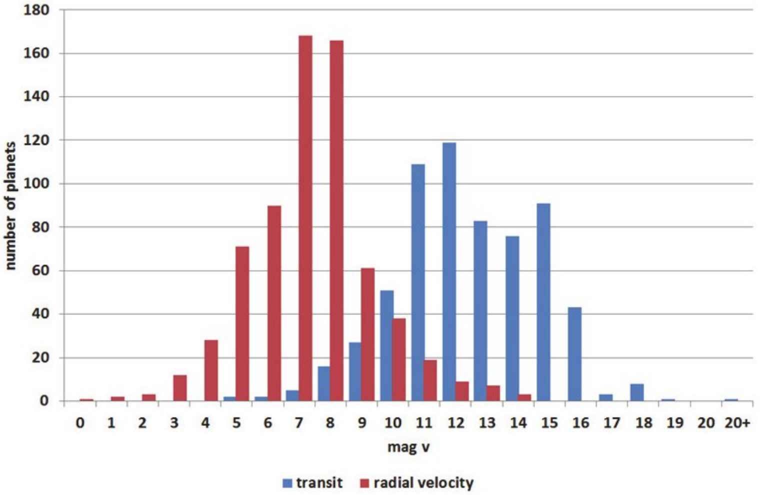
- PLATO compared to TESS and CHEOPS:





Filling the gap

Large FOV, bright stars, long orbital periods

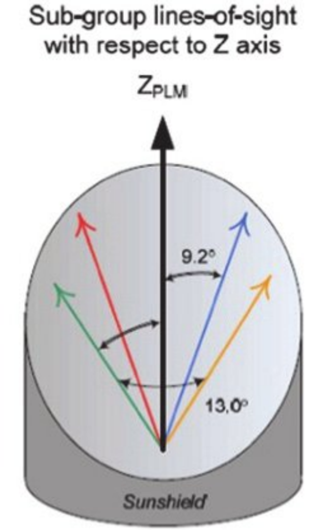


RV follow-up for bright solar-like stars with transiting planets in HZ

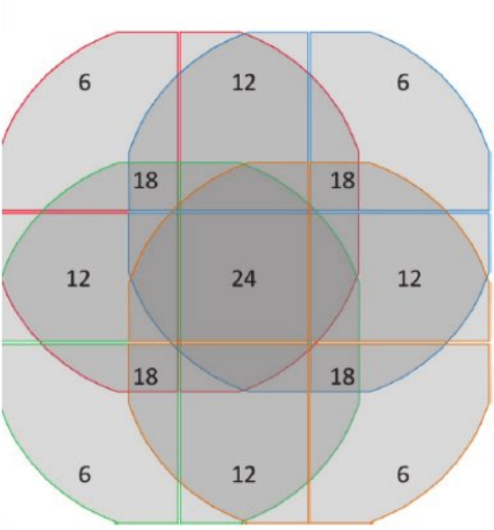
Prototype of a single telescope

H. Rauer, DLR, PLATO PI

Sensitivity varies over the field of view

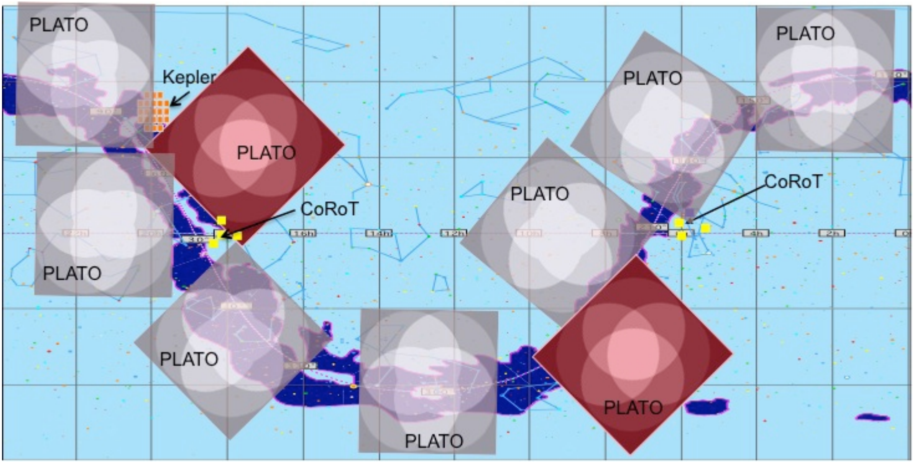


Overlapping line-of-sight concept



Resulting field-of-view configuration

PLATO Search Space



More than half the sky accessible

PLATO mission

Planned mission launch		Dec 2025
Planned mission duration		(2+2) years:
2 Long-Duration Observation Phases OR		2yr LOP + 2yr LOP
LOP+Step-and-stare Observation Phase		3yr LOP + 1yr SOP
Planned orbit		L2
90° degree rotation		every three months
Normal telescopes (for stars fainter V=8)	#	24
Normal telecopes aperture		120mm
Normal telescopes cycle time		25s
Normal telescopes passband		wideband
Normal telescopes FOV (combined)		$47.2^\circ \times 47.2^\circ$
Fast telescopes (for stars from V=4 to V=8)	#	2
Fast telecopes aperture		120mm
Fast telescopes cycle time		2.5s
Fast telescopes passband		one colour per telescope

Filling the gap

Large FOV, bright stars, long orbital periods

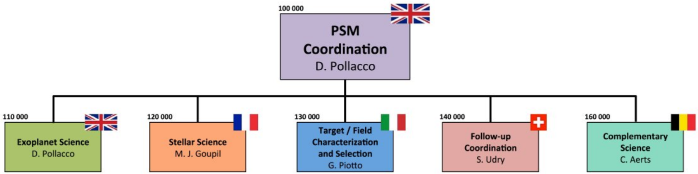
Large FOV & access to long orbital periods

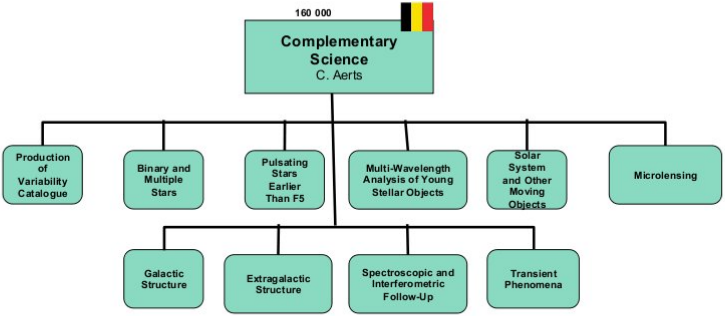
$\Rightarrow$

Also great to look for planets around evolved stars,

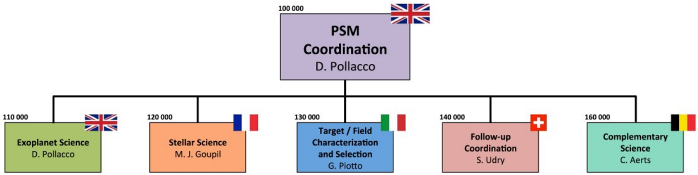
including via pulsation timing!

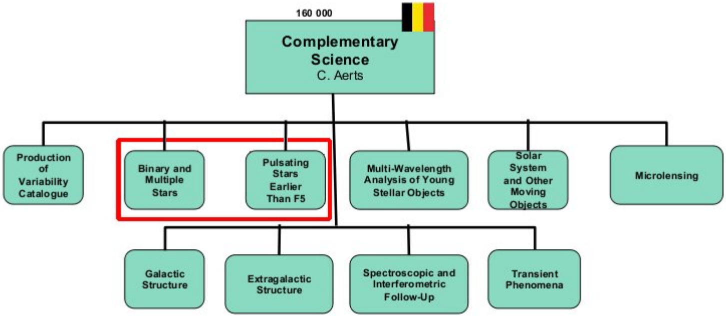
PLATO Science Management





PLATO Science Management





Evolved stars with PLATO

Exoplanet science

PLATO Definition Study Report (2016)

2.1.9 Planets around post-RGB stars

- new sdB planets from illumination effects
- first sdB planets from transits
- first WD planets from transits

+ sdB/WD asteroseismology allows very good characterisation of these stars and their planets

Evolved stars with PLATO

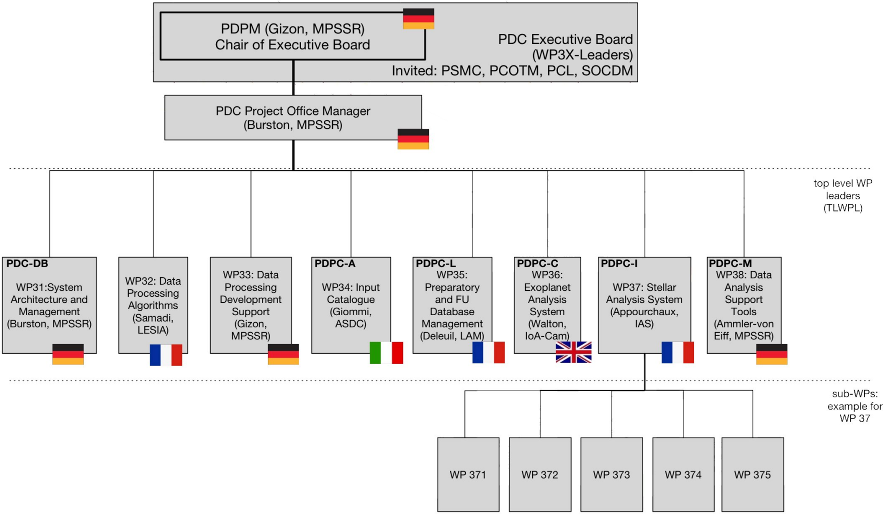
Complementary science

PLATO Definition Study Report (2016)

2.3.1.2 Hot OB sub-dwarf stars

[. . .] Thanks to the combination of its rapid observing cadence and bright targets, PLATO will be the only space-based facility able to develop the science of deep seismic probing of sdB stars. It will provide high-quality data on g-mode pulsations in these stars that cannot be obtained from the ground. Thereby, PLATO will increase the number of sdB stars that can be modelled by asteroseismology. It will also discover new planets around these objects, enabling us to disentangle the question of the origin of such stars and explore star-planet interactions in the advanced stages of stellar evolution.

PLATO Data Center



PDC at Max Planck Institute for Solar System Research

PDC is under the responsibility of the PLATO Mission Consortium.
PDC supports the production of the L1 data.
PDC-DB at MPS will hold the PLATO scientific data products.

Summary

- Understand currently available pulsation timing better with simulations
- Establish pulsation timing as an exoplanet detection method with PLATO

⋆ Do you have students who want to get involved with PLATO science?

$\longrightarrow$ http://www.solar-system-school.de

Outlook

PLATO Science Conference

5-7 September 2017 Warwick, UK

http://www2.warwick.ac.uk/fac/sci/physics/research/astro/research/meetings/plato_mission_conference2017/

http://tinyurl.com/plato2017