PLATO CompSci: pulsations and binarity

website: fys.kuleuven.be/ster/Projects/plato-cs/home

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More than 250 registered scientists

Rauer et al. (2024) for all recent info

On behalf of the PLATO-CS team

Andrew Tkachenko

Institute of Astronomy, KU Leuven (BE)

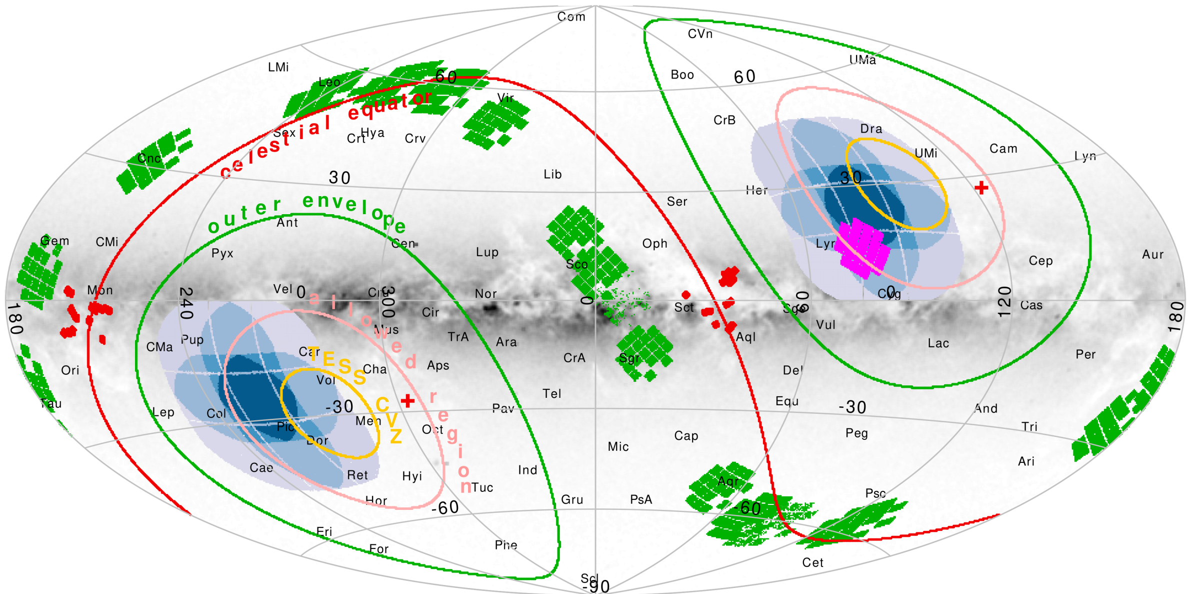
PLATO mission

More info on <u>ESA pages</u>

26 cameras:
24 N-Cams + 2 F-Cams

2250 squared degrees FoV

2-4 years of ppt-precision white light photometry



Nascimbeni et al. (2022, 2024)

PLATO mission

More info on <u>ESA pages</u>

26 cameras:
24 N-Cams + 2 F-Cams

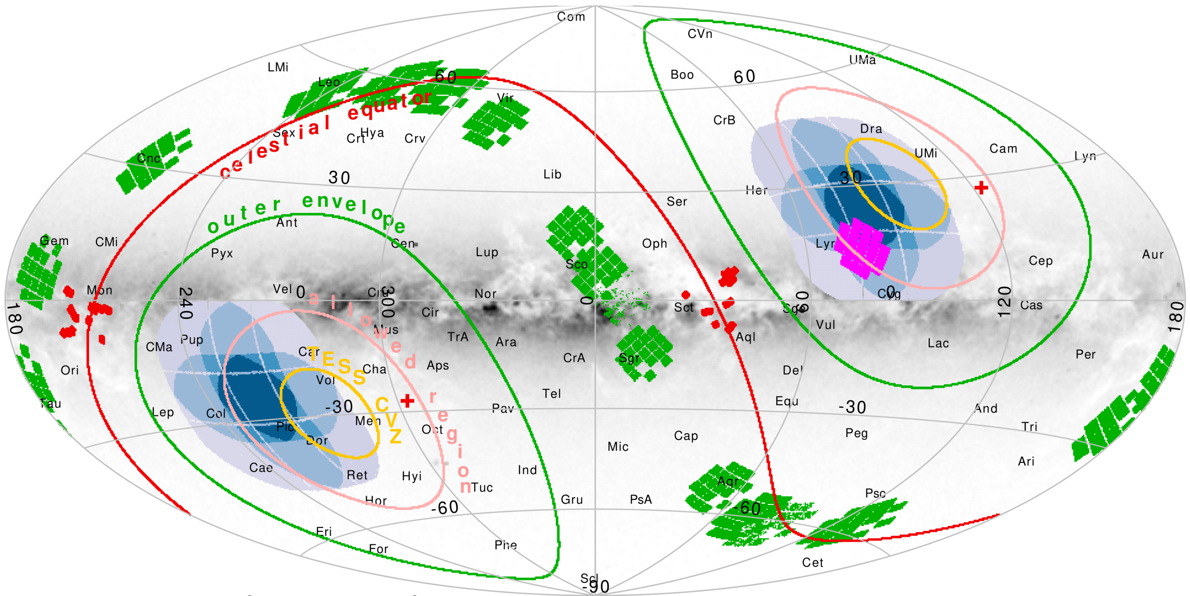
2250 squared degrees FoV

2-4 years of ppt-precision white light photometry

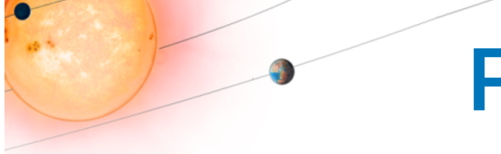
PLATO is NOT a survey

Core Science:
exoplanets and their host stars

Complementary Science:
everything else



Nascimbeni et al. (2022, 2024)



PLATO mission: Core Science

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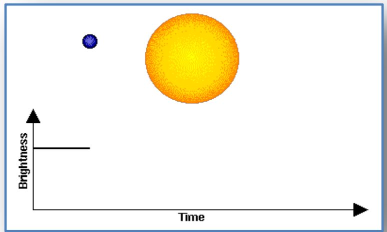
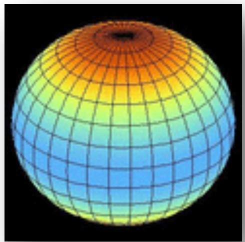
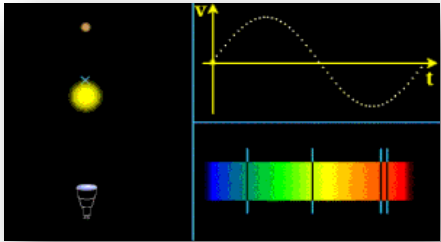
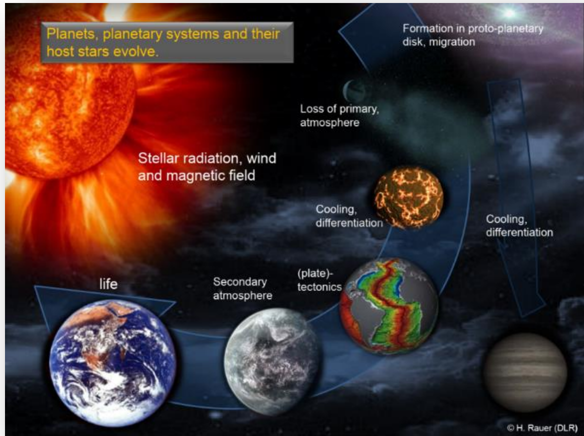
<u>Prime mission goals</u>:

- Detect a large number of extrasolar transiting planets, including **Earth-sized planets up to the habitable zone of solar-like stars;**
- Determine precise **planetary radii, masses**, hence **mean densities;**
- Investigate seismic activity in stars, enabling the precise characterisation of the planet-host star, including its **age.**









Transit detection
→ Planet/star radius ratio
→ Inclination

\+ Asteroseismology
→ Stellar radius, mass
→ Stellar age

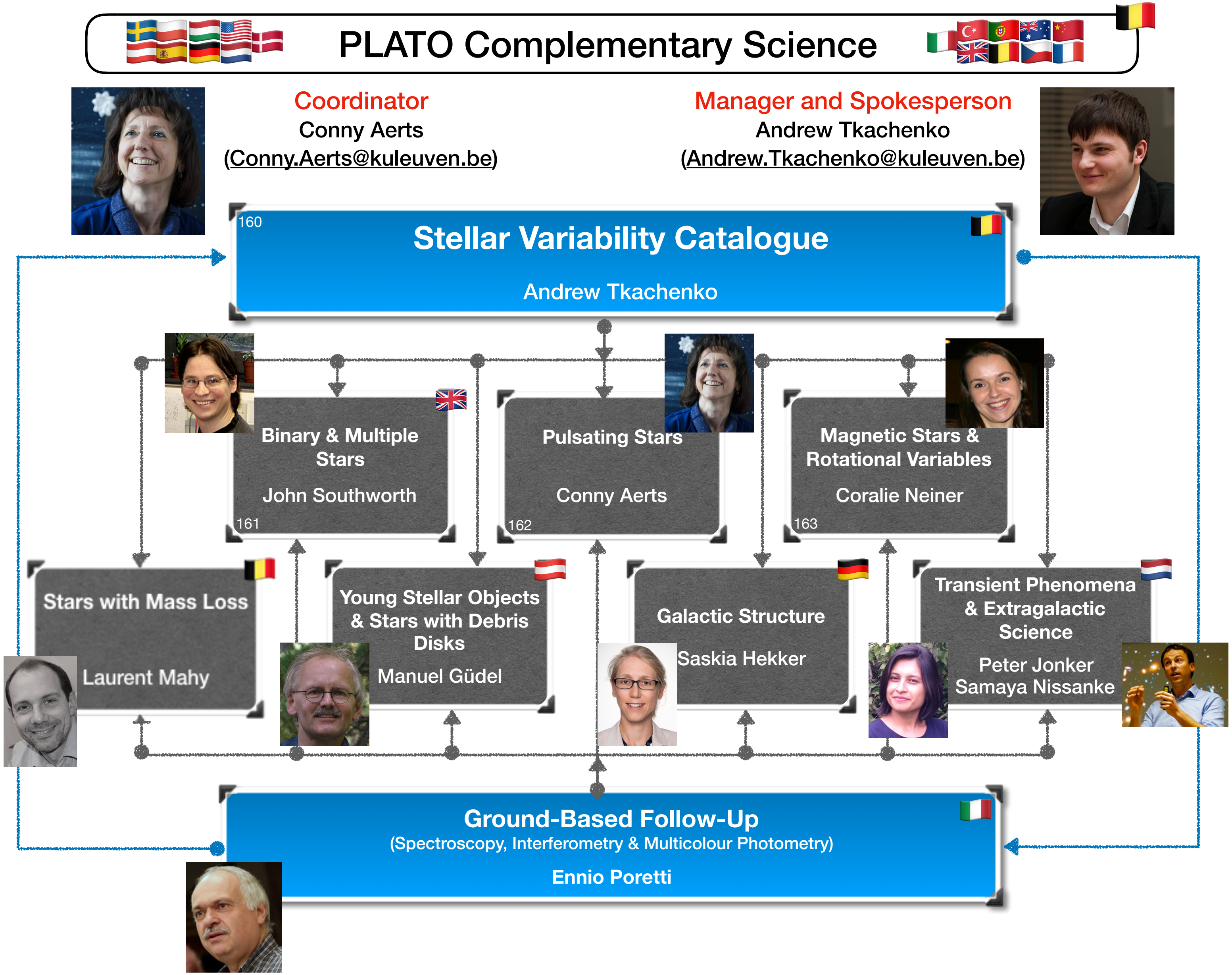
\+ Ground-based observations
→ Planet mass

→ **Mean density**
Age

Slide courtesy: Thierry Morel

PLATO Complementary Science

website: fys.kuleuven.be/ster/Projects/plato-cs/home



Objectives

- Scientific programmes distinct from the Core Science
- Unique database of variable phenomena

How

- **Guest Observer** (GO) programme (call and selection by ESA)
- GO is assigned 8% **of the science data** (10th of thousands objects)

Task

Make sure community is ready for optimal GO proposal submission

PLATO Complementary Science

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Confluence Wiki pages: documentation, information, etc.

S2E2 Confluence | SOCCI | Spaces | People | Glossaries | Calendars | Document Management | Help | Create | ··· | Search

PLATO Science Manage-ment

- Pages
- Blog
- Calendars

PLATO Science Management

PAGE TREE

- PSM Work Packages
  - WP10: PSM Management
  - WP11: Exoplanet Science
  - WP12: Stellar Science
  - WP13: Target / Field Characteris
  - WP14: Ground-based Observatic
  - WP16: Complementary Scienc
    - PLATO Complementary Scienc
      - Binary & Multiple Stars (WP
      - Galactic Structure (WP 166 (
      - Ground-based follow-up (W
      - Magnetic Stars & Rotational
      - PLATO Complementary Scie
      - Pulsating Stars (WP 162 00(
      - Stars with Mass Loss (WP 16
      - Transient Phenomena & Extr
      - Young Stellar Objects & Star
    - WP 16 Members
    - WP 16 Members N
  - PSM WPDs: Development
  - PSM WPDs: Operations
  - PSM WPDs: Post-Operations

Space tools

Pages / PLATO Science Management / PSM Work Packages

Edit | View inline comments | Save for later | Watching | Share | ···

WP16: Complementary Science

Created by Unknown User (pwilson), last modified by Andrew Tkachenko on 12 Aug, 2024

- Webpage
- PLATO mission
- PLATO Complementary Science
- Organisation chart
  - Organisation chart download links

You do NOT need to be a Consortium member to apply for GO time

BUT

Webpage

PLATO Complementary Science webpage: PLATO-CS webpage.

PLATO mission

PLATO (PLAnetary Transits and Oscillations of stars) has been selected by the ESA Science Programme Committee as the M3 mission of the Cosmic Vision 2015-2025 program in February 2014. Although currently approved for 4 years of the nominal science operations, the satellite is built and verified for 6.5 years of in-orbit operations and accommodates consumables for a total of 8.5 years. The payload consists of 24 "normal" and 2 "fast" cameras that read out at the cadence of 25 s and 2.5 s, respectively. Fast cameras are designed for accurate pointing of the mission and will also be used for science observations of bright stars in the range of Vmag = ~4-8, also offering color information. Normal cameras are arranged in four groups of six and will provide white light photometric monitoring of stars in the magnitude range from Vmag = ~8-16. Per pointing, PLATO allows to survey a large total field of 2250 squared degrees.

The main focus of the PLATO mission (a.k.a. PLATO Core Science) is to detect and characterize exoplanets and exoplanetary systems around solar-type stars, with an emphasis on planets found in the habitable zone. Ultra-high photometric precision, high duty cycle, and long pointing of at least two years will allow for the determination of the radius of an Earth-like planet orbiting a G0 dwarf of Vmag = 10 (PLATO reference star) with an accuracy of 3%. Ground-based spectroscopic follow-up observations will provide complementary information in the form of the radial velocity (RV) measurements, enabling the determination of the mass of a planet with an accuracy of 10% or better. The method of asteroseismology will be employed for detailed characterization of host stars in terms of their masses, radii, and ages, where the latter will be derived with an accuracy of 10%. This way, PLATO is the first mission to make systematic use of asteroseismology for characterization of planet host stars and to establish a link between planetary and stellar evolution. The key scientific questions the PLATO mission will be answering are: 1) how do planets/planetary systems form and evolve; 2) is our solar system unique or is it one of many? 3) do potentially habitable planets exist and if so, how frequent are they?

Want to learn more about the PLATO mission? Please check the following sources:

- ESA PLATO mission home page and latest news
- Mission summary and timeline
- History and current status of the mission
- Short summary of the science goals
- Spacecraft and payload
- PLATO Definition Study Report

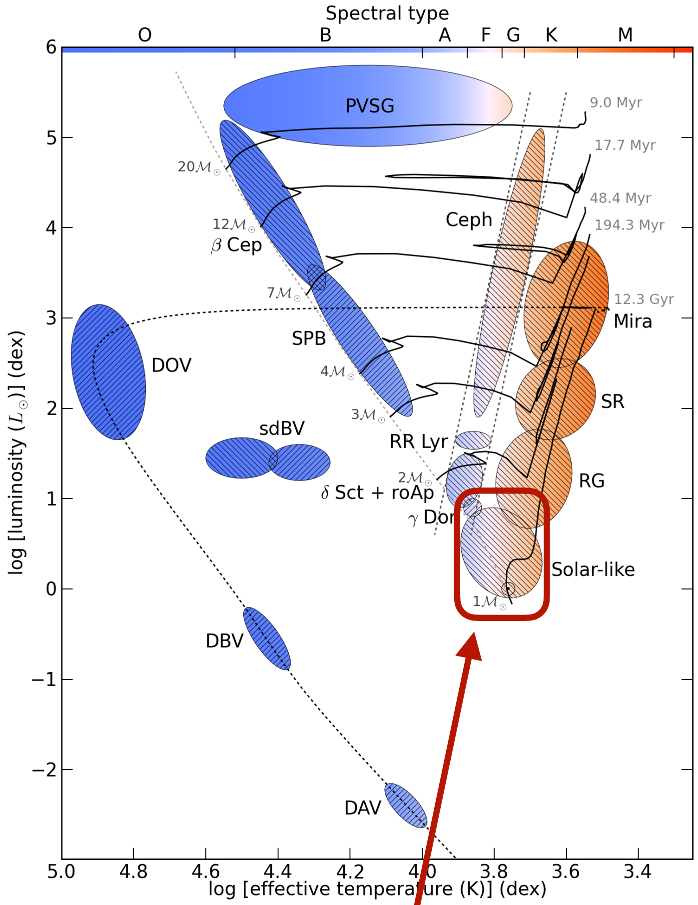
You can't access internal info, documents, PIC, etc. Signing the NDA is an (easy) solution!

PLATO Complementary Science

PLATO will provide us with a large number (between 300,000 and some 1,000,000) of light curves with precision of the order of a few tens of ppm per hour. The PLATO photometric cadences as well as access to both imagettes (the same kind of data product as Kepler "postage stamp") and on-board reduced light curves allows us to study temporal variability of astrophysical objects and phenomena in a large range of time scales, from seconds to a couple of years. Experience from dedicated photometric space missions like MOST, CoRoT, *Kepler*, and TESS clearly indicates that the scientific significance and information content of observations optimized for the primary science of each mission reach well beyond those goals. The main objective of the Complementary Science branch of the PLATO Science Managament (WP160 000) is thus to exploit the full potential of PLATO for scientific topics that are distinct from the core science of the mission, extending the scientific

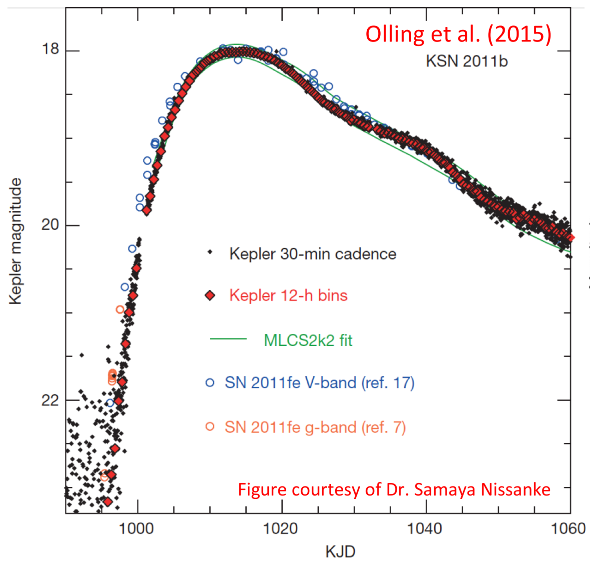
PLATO-CS: Science component

Stellar Science → **Extragalactic Science** → **Transient phenomena**



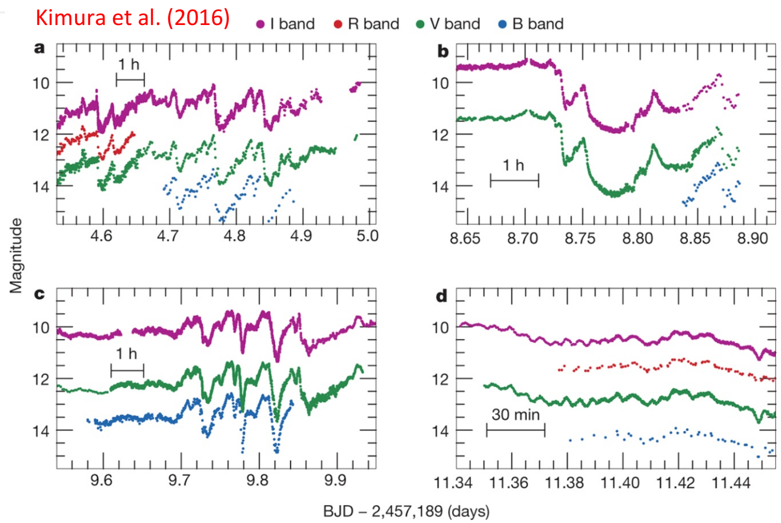
Core Science

Asteroseismology of solar-like pulsators



Extragalactic Science

- **SNe explosions in distant galaxies:** progenitor shock-breakout physics
- **Monitoring cores of 1000s AGNs** to understand SMBH accretion & variability



Transient Universe

- **Mapping and understanding of accretion physics near YSOs**
- **White dwarfs, black holes, and neutron stars:** monitoring in fast cadence asap after transient

PLATO Science Calibration & Validation

Validation

Adjustment of the free parameters for a given **fixed description** of the input physics

Assessment of how good or bad the chosen input (physics) description is

Calibration

Discovery and inclusion of **new and improved** input physics descriptions and profiles in stellar models

Minimize systematic uncertainties of the mass, radius, and age of a star

The Science Calibration and Validation PLATO Input Catalogue (scvPIC)

38402 targets in the v1 version of the catalogue

PLATO scvPIC: Binary Stars

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(Sub-)sample	Priority 1	Priority 2	Priority 3	Total
SCV1a	85	76	686	847
SCV1b	217	878	444	1539
SCV1c	54	176	430	660
SCV1d	1	0	0	1
SCV1e	53	0	0	53
SCV1 total	410	1130	1560	3100

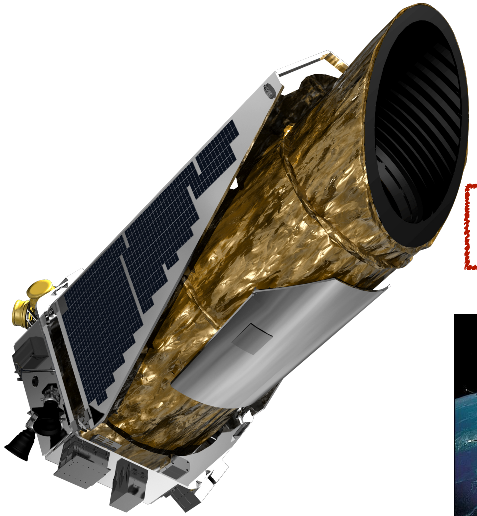
- **SCV1a** – *Detached eclipsing binaries*
  - Calibration of stellar models
  - Validation of masses and radii
- **SCV1b** – *Astrometric binaries*
  - Validation of stellar masses
  - Combined modelling of two coeval stars
- **SCV1c** – *Wide binaries*
  - calibration and validation of age estimates
- **SCV1d** – *AA Dor or HW Vir-type*
  - astrophysical clock for end-to-end test of time stamps
- **SCV1e** – *Wide white dwarf binaries*
  - calibration and validation of age estimates

Interested?
Train is leaving!

Slide courtesy: Konstanze Zwintz

Towards target selection for PLATO

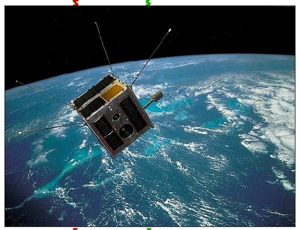
“Yesterday”



Kepler

Legacy

“Today”

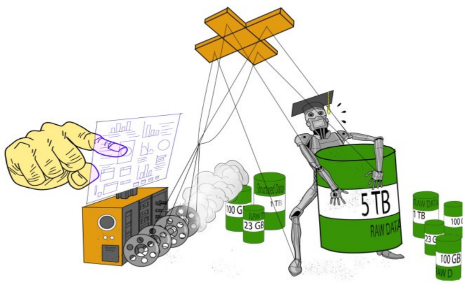


TESS (+), BRITE, CHEOPS

Legacy

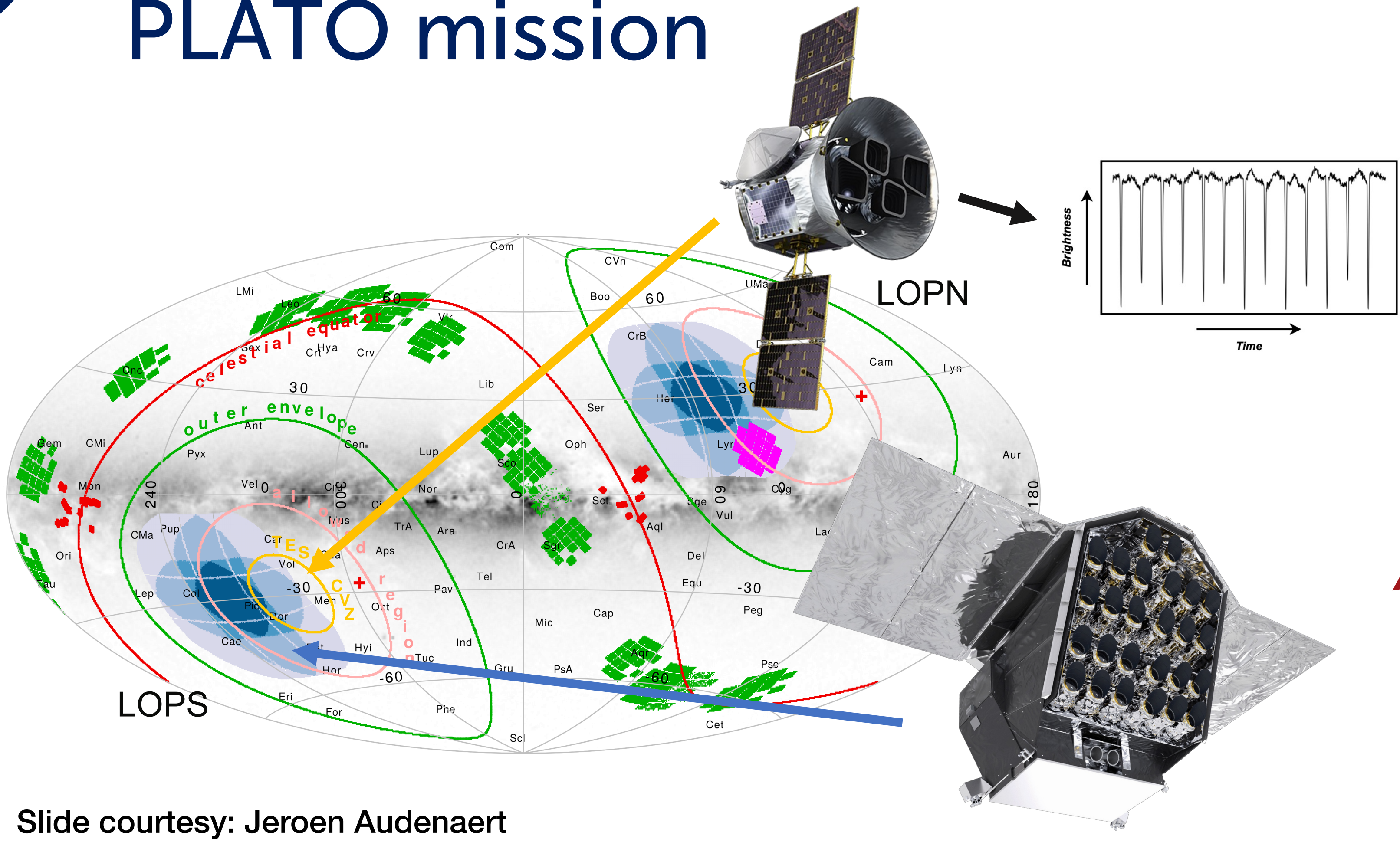
“Tomorrow”

PLATO

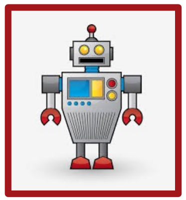


Millions of objects and light curves, Terabytes of data → **Stellar (Astro)physics**

TESS classifications to inform ESA PLATO mission



Classifications



?

Informs PLATO community which stars to observe

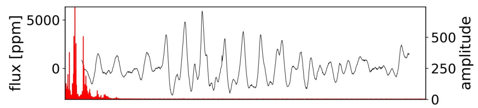
Slide courtesy: Jeroen Audenaert

Towards target selection for PLATO

Slide courtesy: Jeroen Audenaert

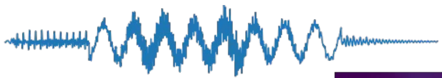
Architecture (2)

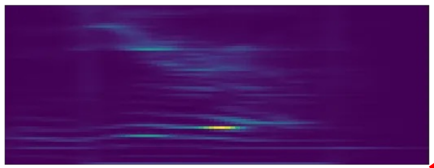
1. Light Curve



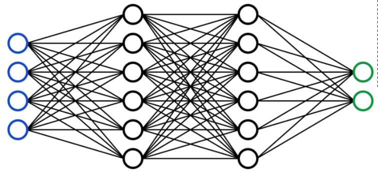
2. Creating a representation of the light curve (latent space)

Wavelet Scattering Transform





3. Output layer



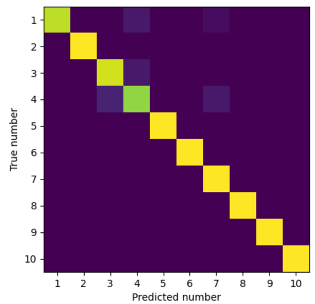
Training a fully connected neural network to map latent space to the variability classes

4. Predictions

Predicting the class for each light curve

Probabilistic classifications

80%	*γ Dor*
4%	*δ Sct*
3%	*hybrid (γ Dor/δ Sct)*
10%	*rotational variables*
3%	*other*

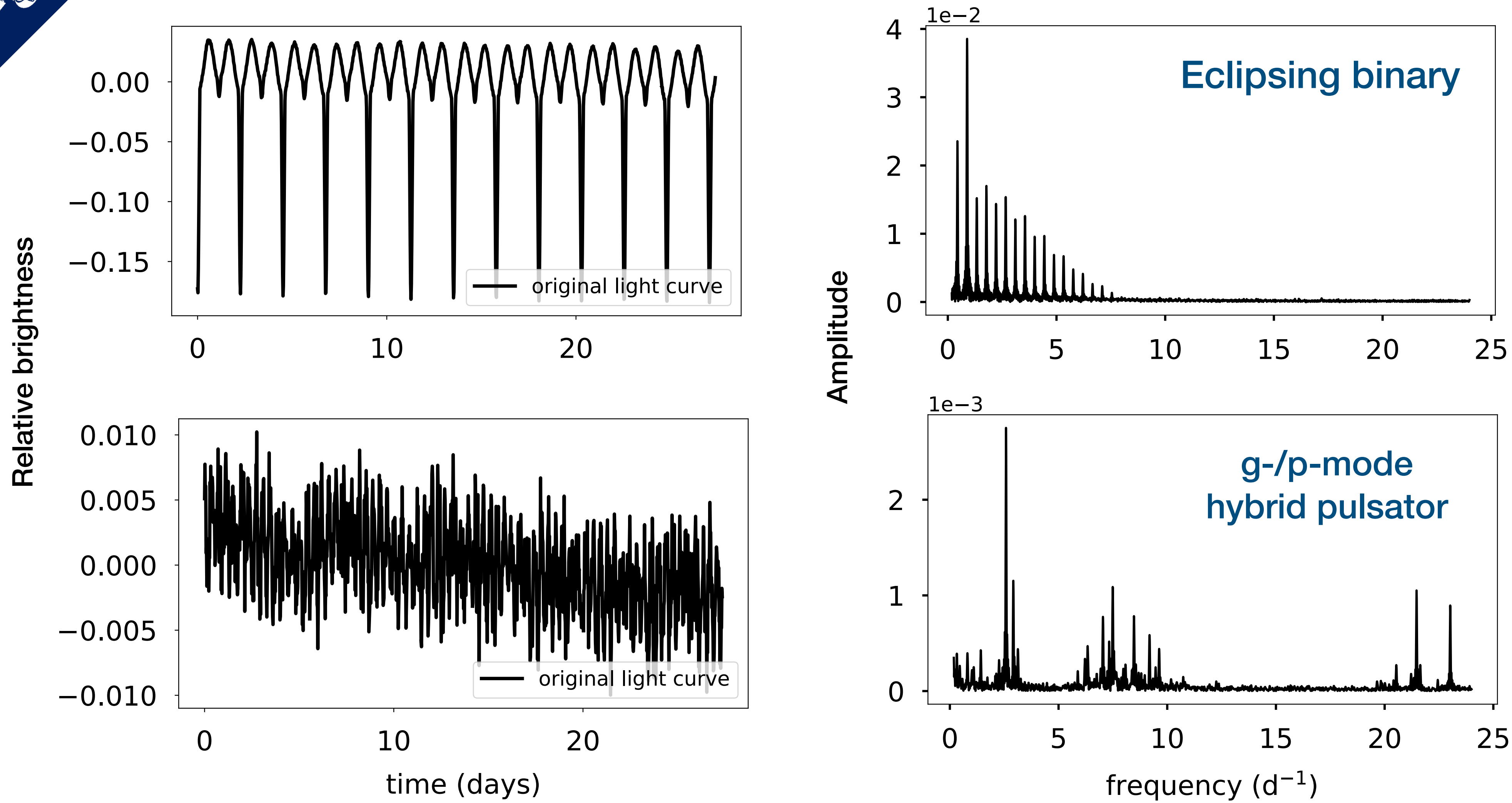


Kymatio - Andreux et. al (2019) - arXiv 1812.11214

Celis (2021); Audenaert et al. (in prep.)

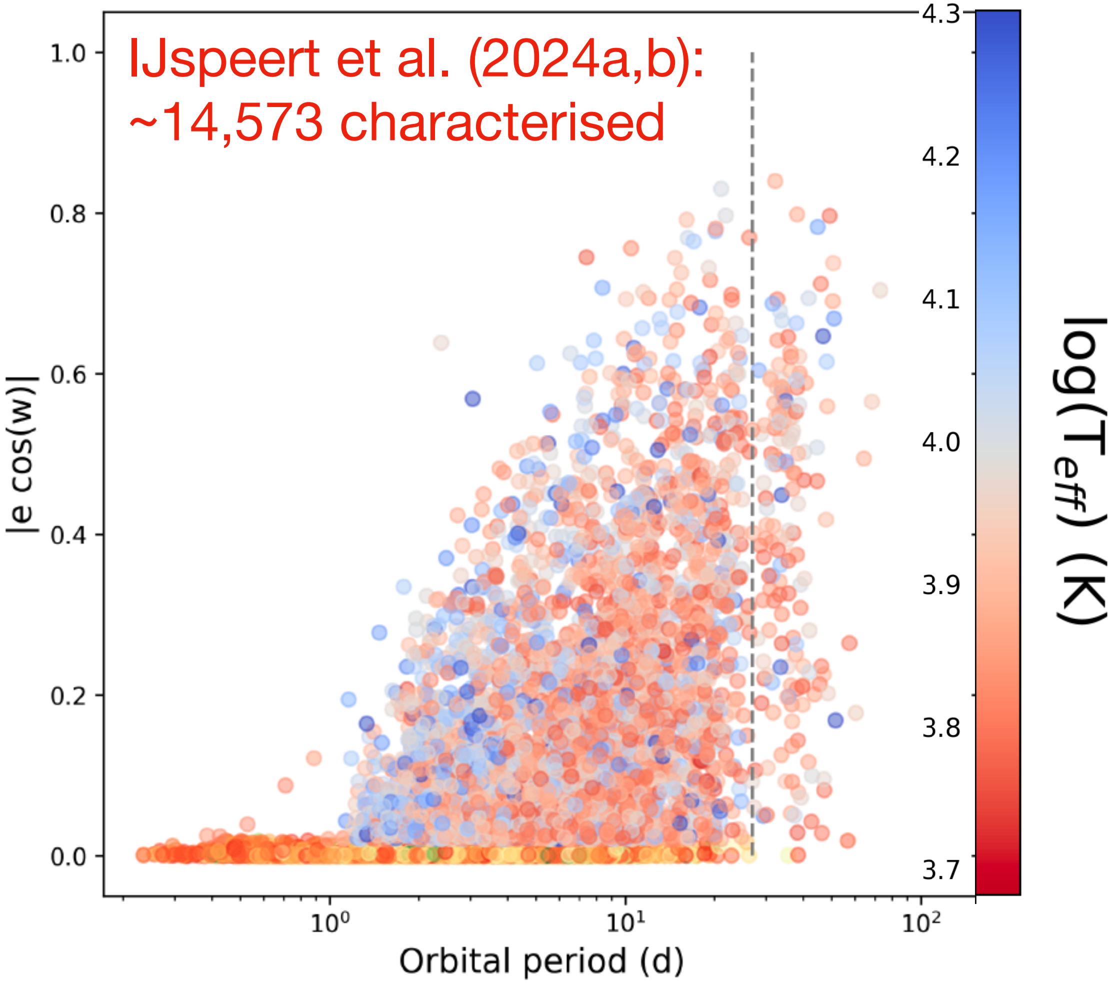
Classification Examples

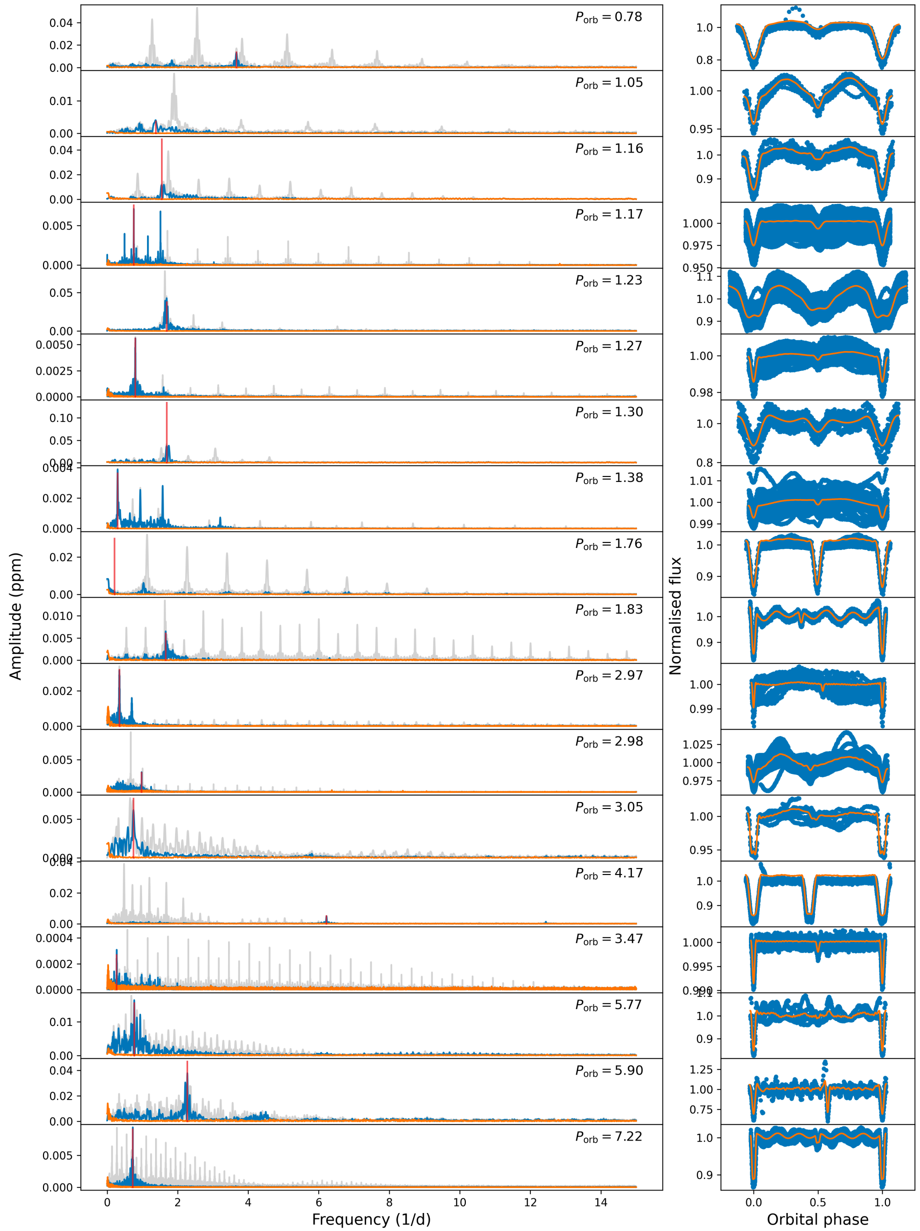
Slide courtesy: Jeroen Audenaert



Towards target selection for PLATO

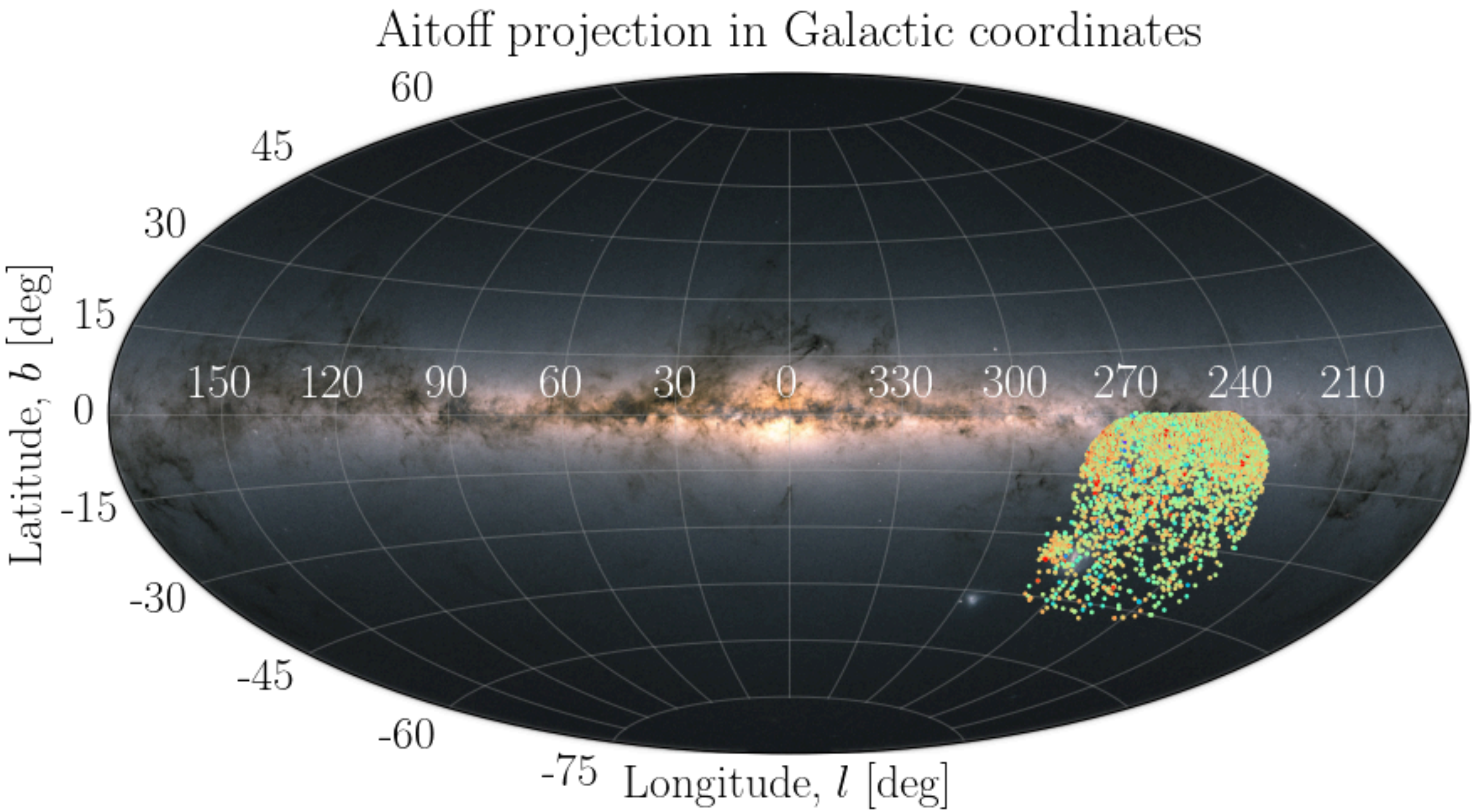
~69 000 discovered EBs from TESS QLP



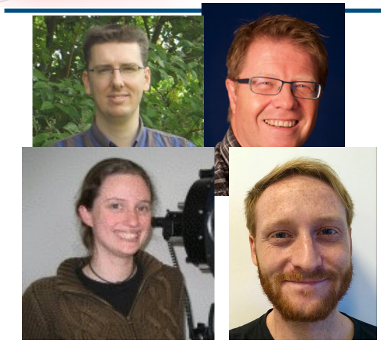


Towards target selection for PLATO

6500 of 69 000 discovered EBs are found in LOPS2. ~500 of those contain at least one pulsator

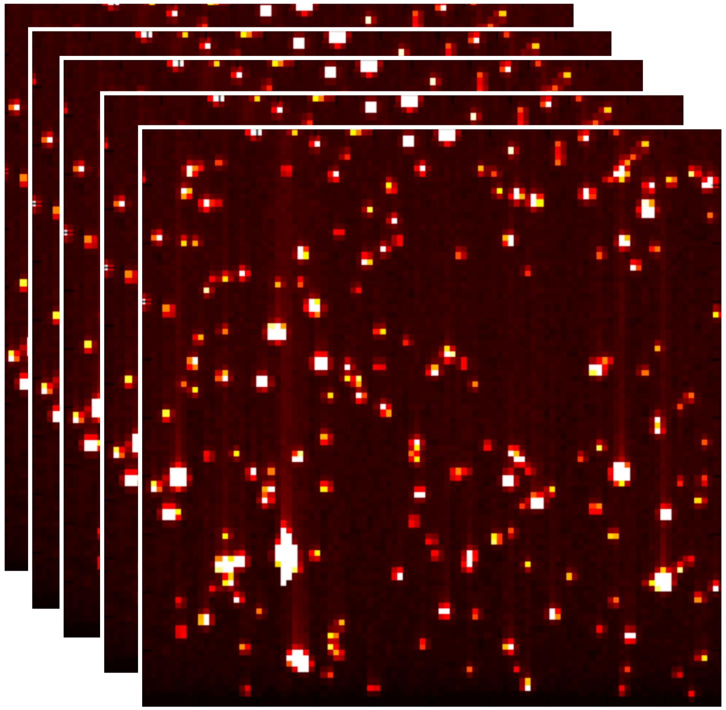


PlatoSim: PLATO CCD Image Simulator



- Generates time-series of CCD images
- Including realistic instrumental noise
- More and more effects are included - hard to put them on one slide in a decent font

http://ivs-kuleuven.github.io/PlatoSim3/



35000 exposures - Normal Cam

- Realistic star field
- Jitter
- Thermo-elastic drift
- Position dependent PSF
- Cosmics
- Sky background
- Variable sources
- Transmission degradation
- Kinematic aberration
- Optical distortion
- Photon noise
- Blooming
- Charge diffusion
- CTI
- CCD half dependent gain
- Geometrical vignetting
- Spatial PRNU noise
- Angle dependent QE
- Polarization
- Particle contamination
- Brighter-Fatter effect
- Dark signal
- Readout noise
- Open shutter smearing

PLATO-CS: stellar variability simulations

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PlatoSim
(http://ivs-kuleuven.github.io/PlatoSim3/)

+

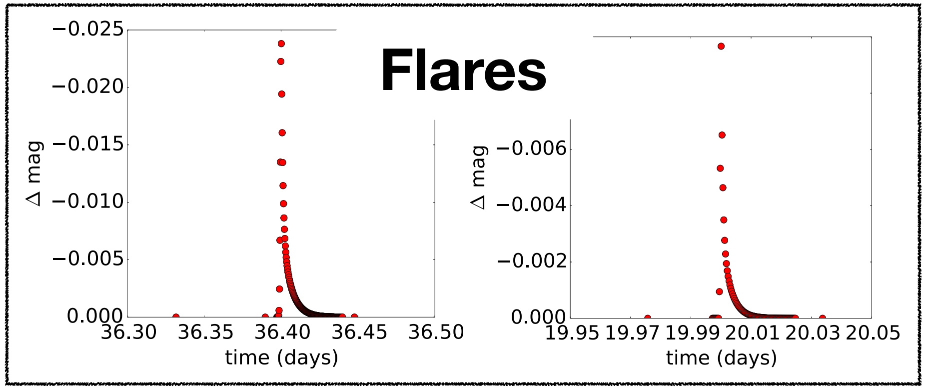
Stellar Variability

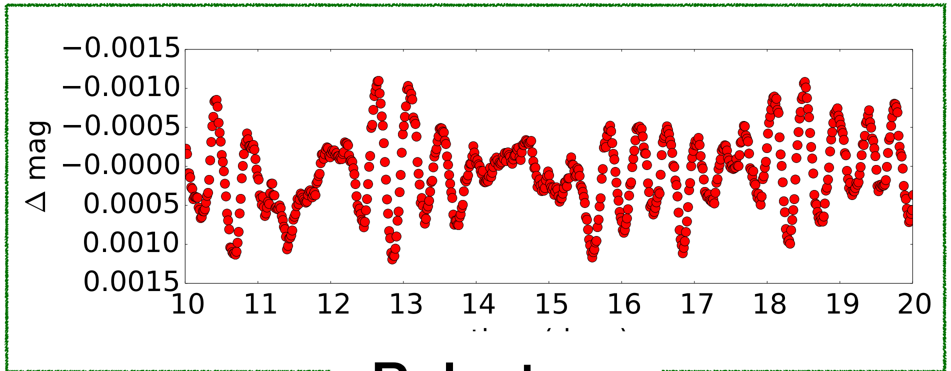
=

Instrument/pipeline capabilities

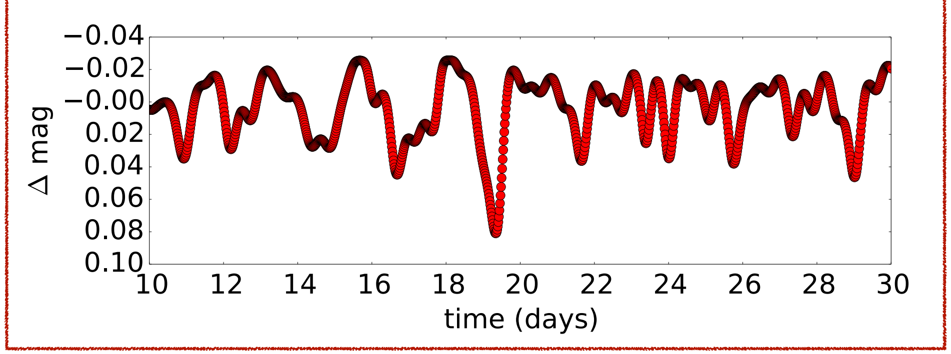
Variable phenomena (PLATO-CS)

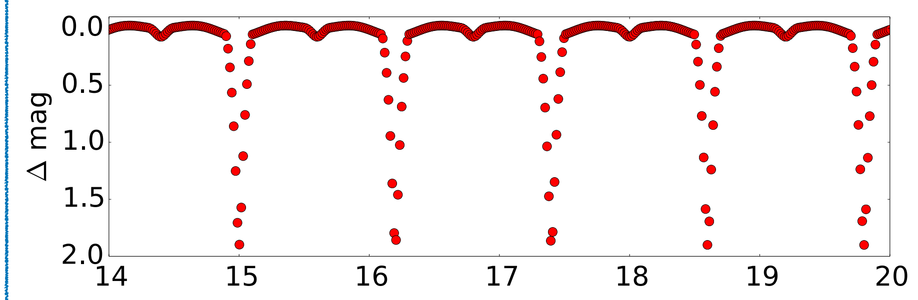
Flares



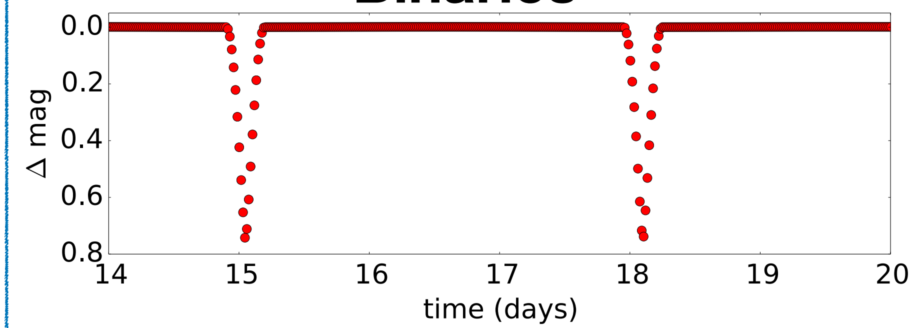


Pulsators





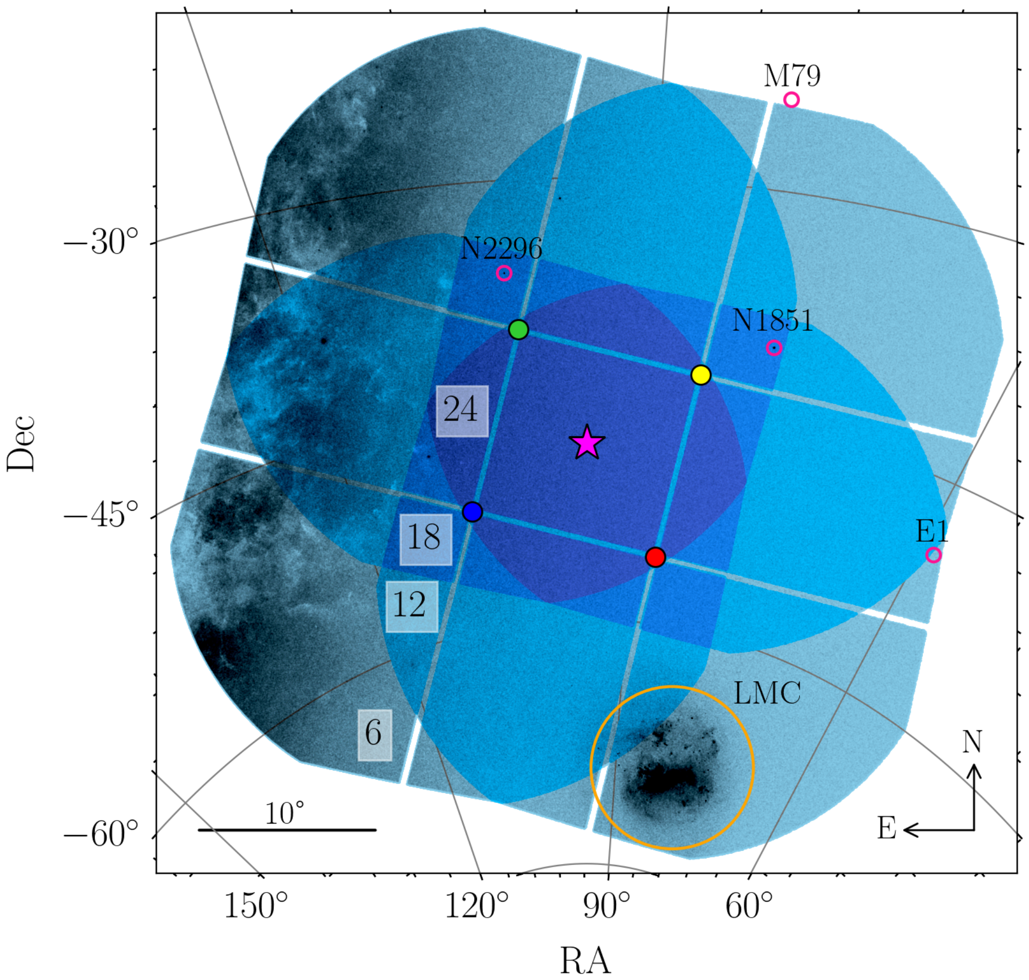
Binaries



For details see Jannsen et al. (2024)

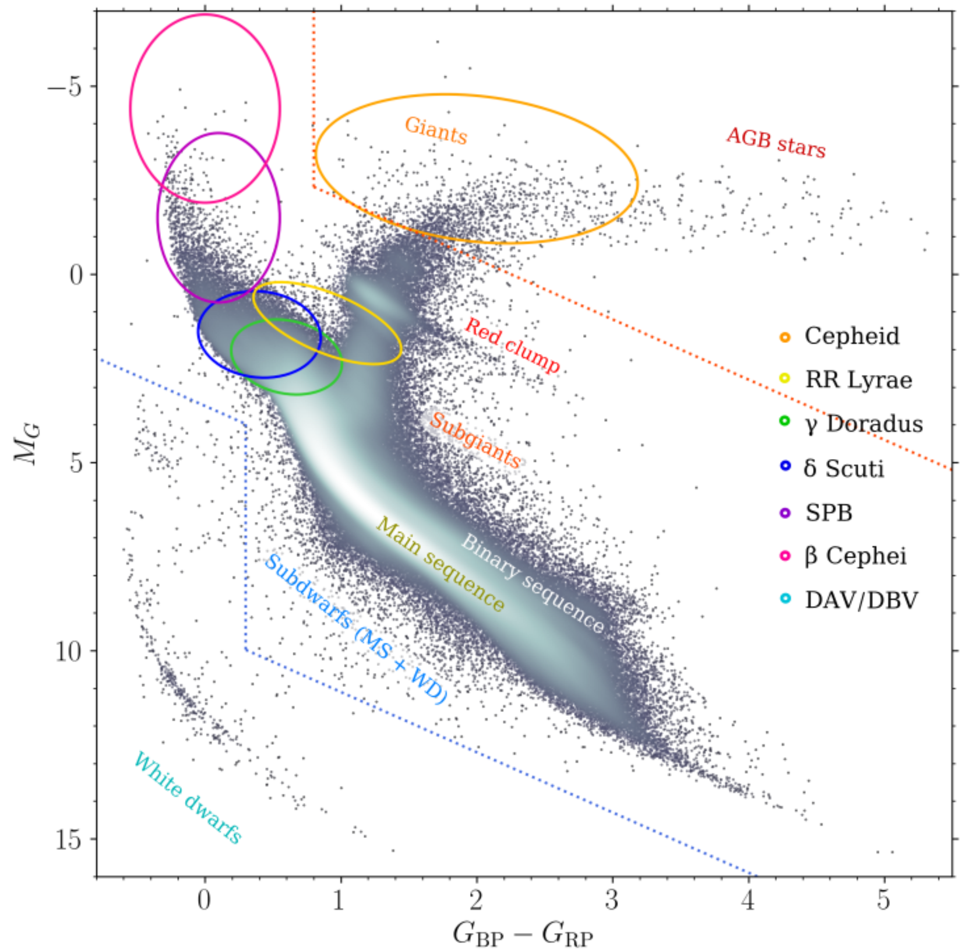
PLATO-CS: stellar variability simulations

MOCKA: a mock catalog of pulsating stars



PlatoSim (Jannsen et al. 2024)

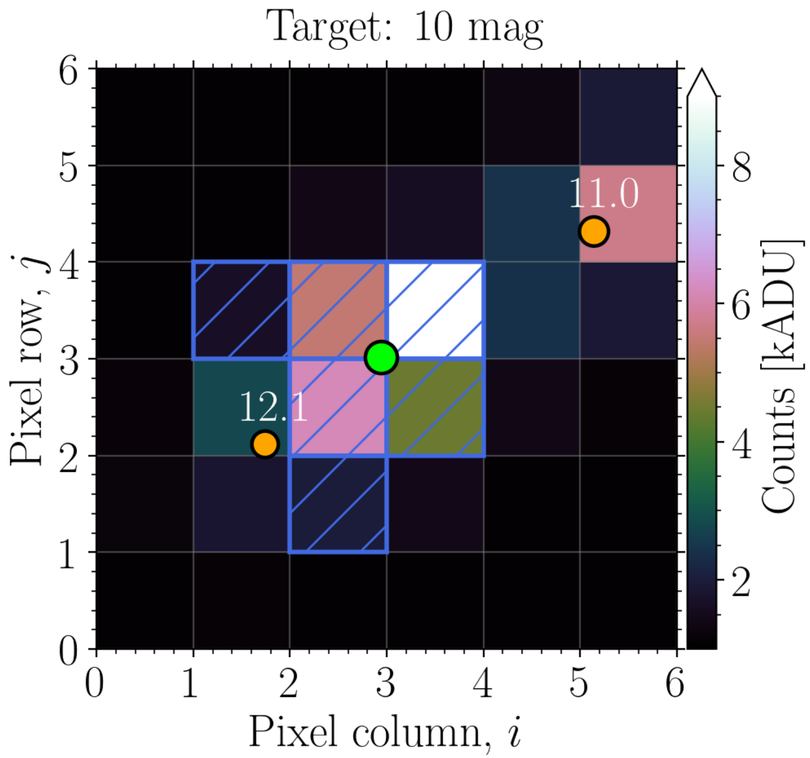
Gaia DR3-based, G < 17 catalogue



PLATO-CS: stellar variability simulations

MOCKA: g-mode pulsators as (will be) seen by PLATO

Pixel-based simulations with
PlatoSim (Jannsen et al. 2024)

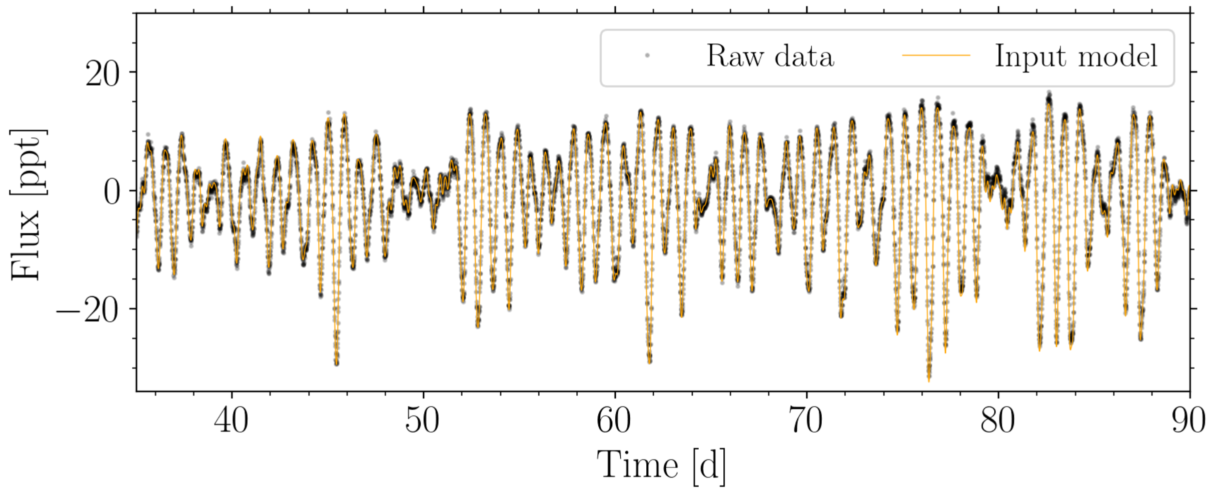


Three realisations of the sims:

- Specs-driven level of systematics
- Inflated systematics
- Contaminants variability: heavy

Light curve extraction & post-processing:

- a faster version of the PLATO pipeline
- custom made (rather simple) detrending
- outlier detection/rejection



PLATO-CS: stellar variability simulations

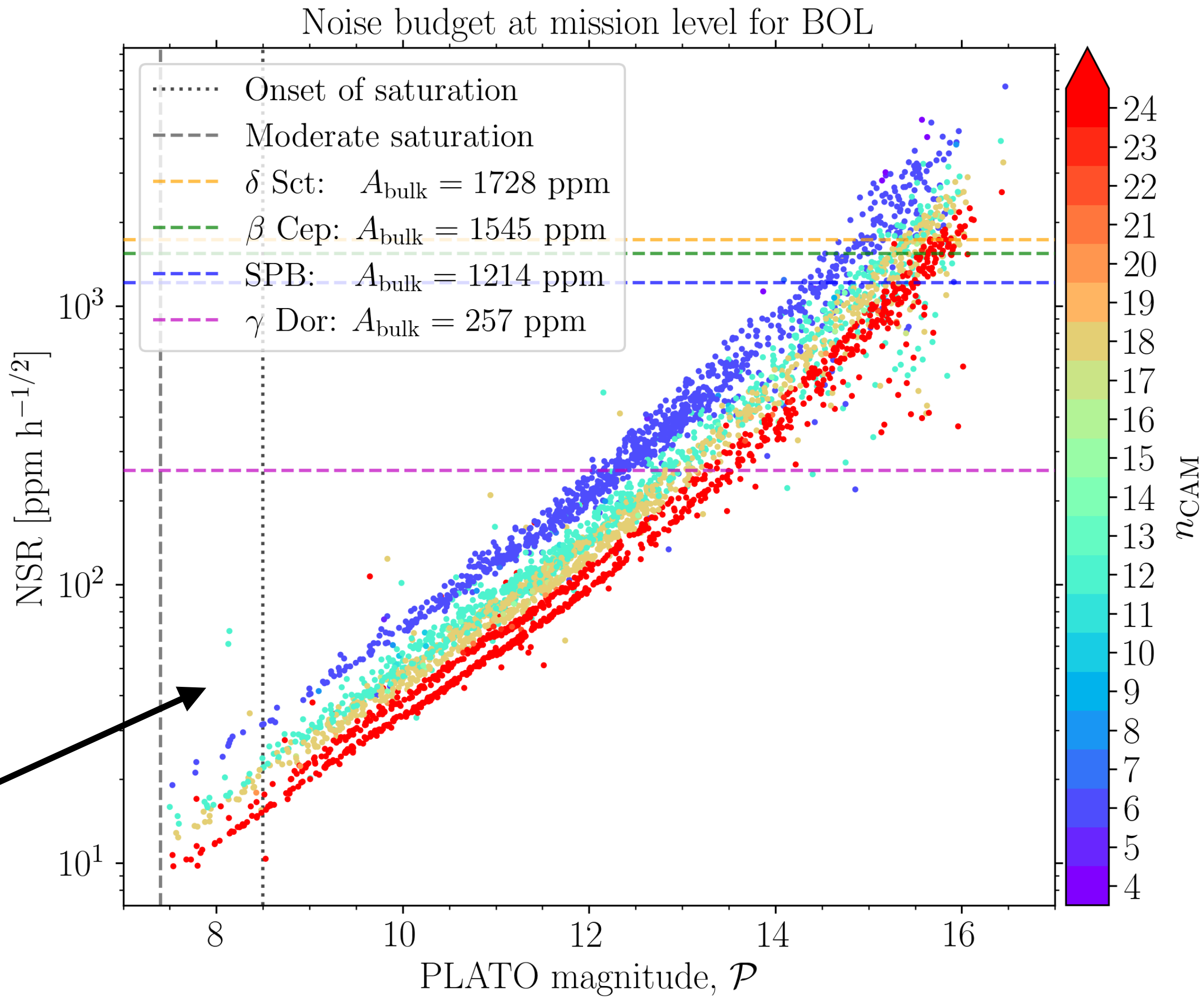
MOCKA: noise budget & detection efficiency

Rauer et al. (2024)

Ultra-high precision, long, uninterrupted phot. monitoring of **bright (V < 11-13) stars**

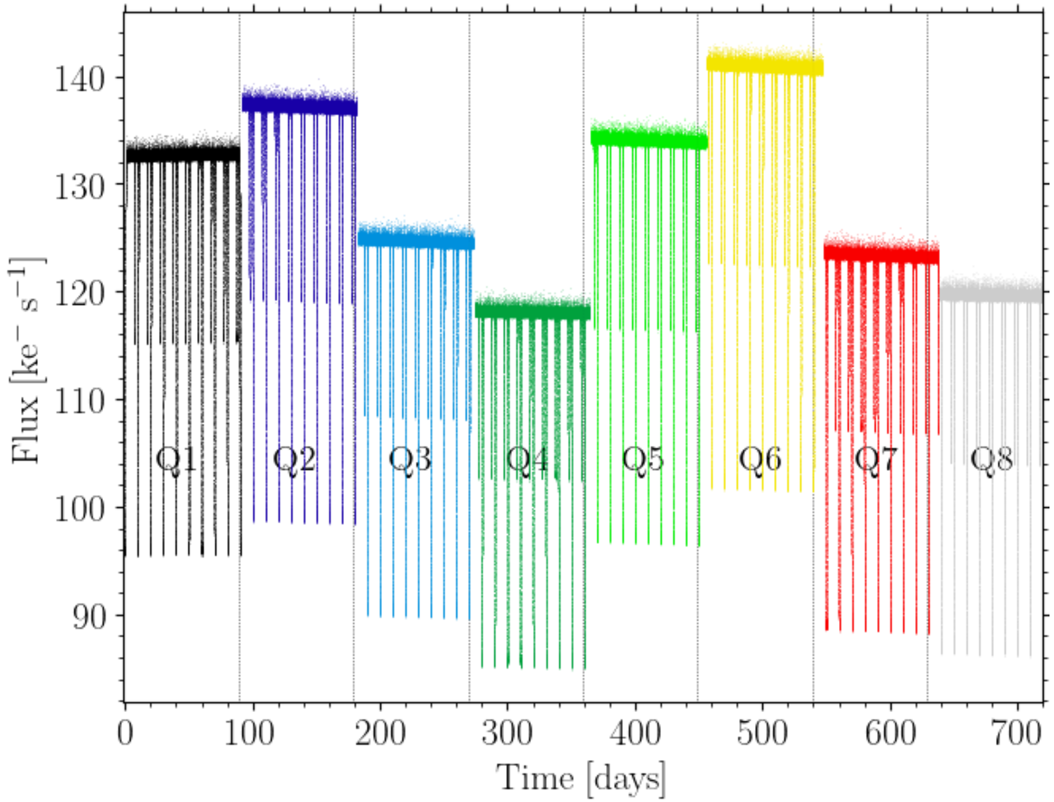
BUT

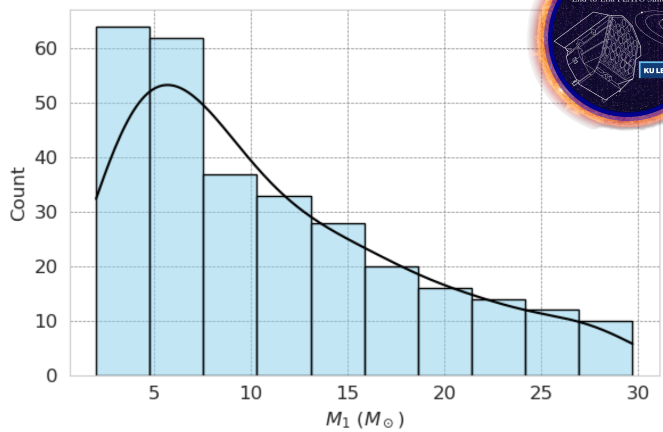
It depends on exact science question!

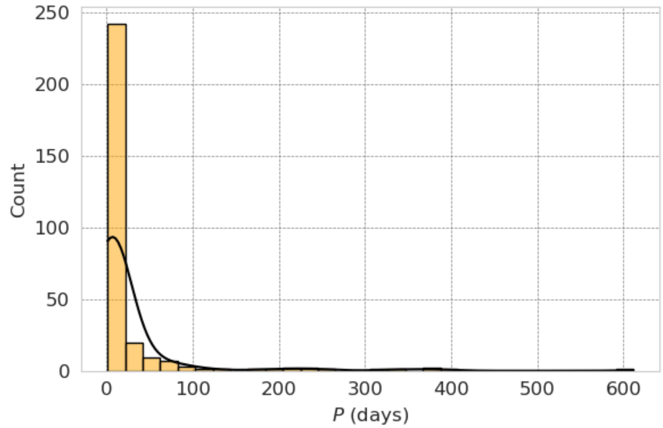


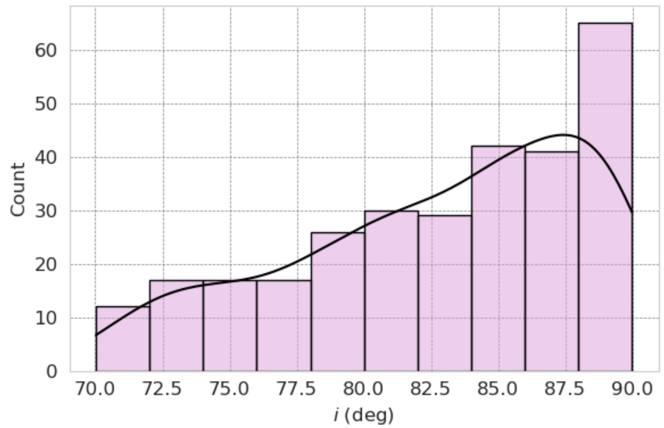
PLATO-CS: simulations of EBs

Synthetic population of binaries → **Selection of EB systems**





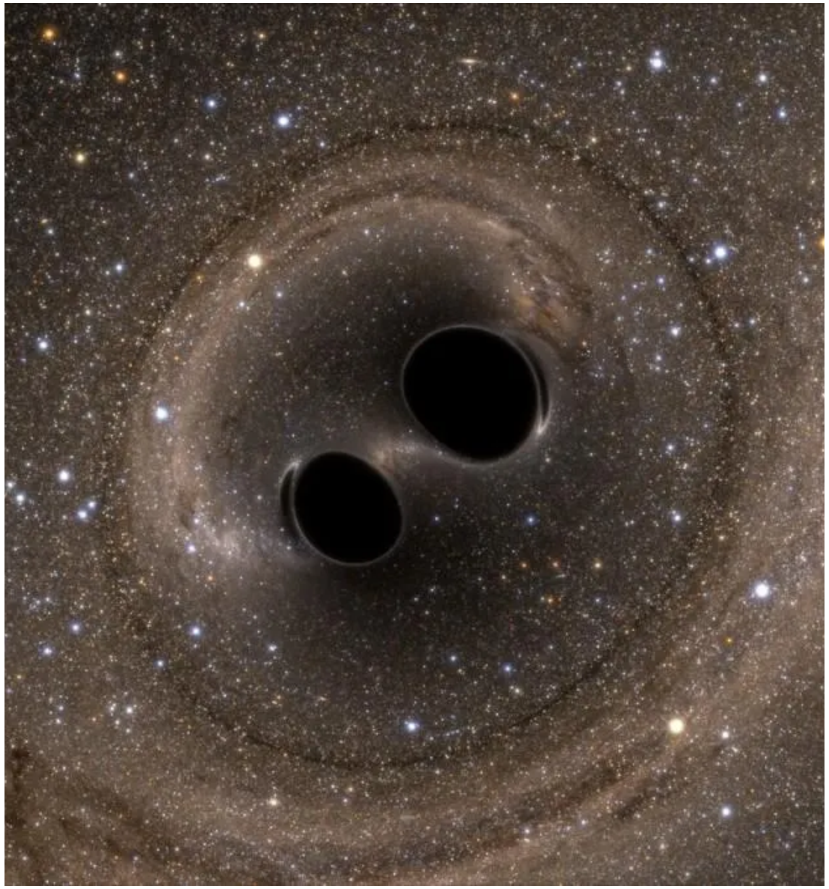




(Optimistic) detection efficiency: > 90%

Credit: Sharon James, Master thesis, KUL

Super Massive Black Hole Binaries (SMBHBs)




Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **495,** 4061–4070 (2020) doi:10.1093/mnras/staa1312
Advance Access publication 2020 May 11

Spikey: self-lensing flares from eccentric SMBH binaries

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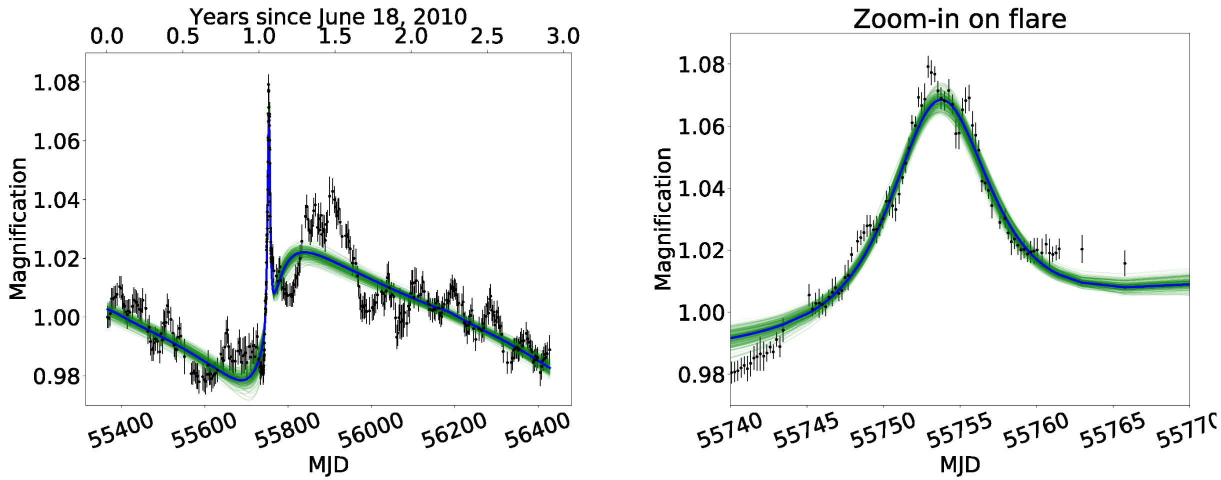
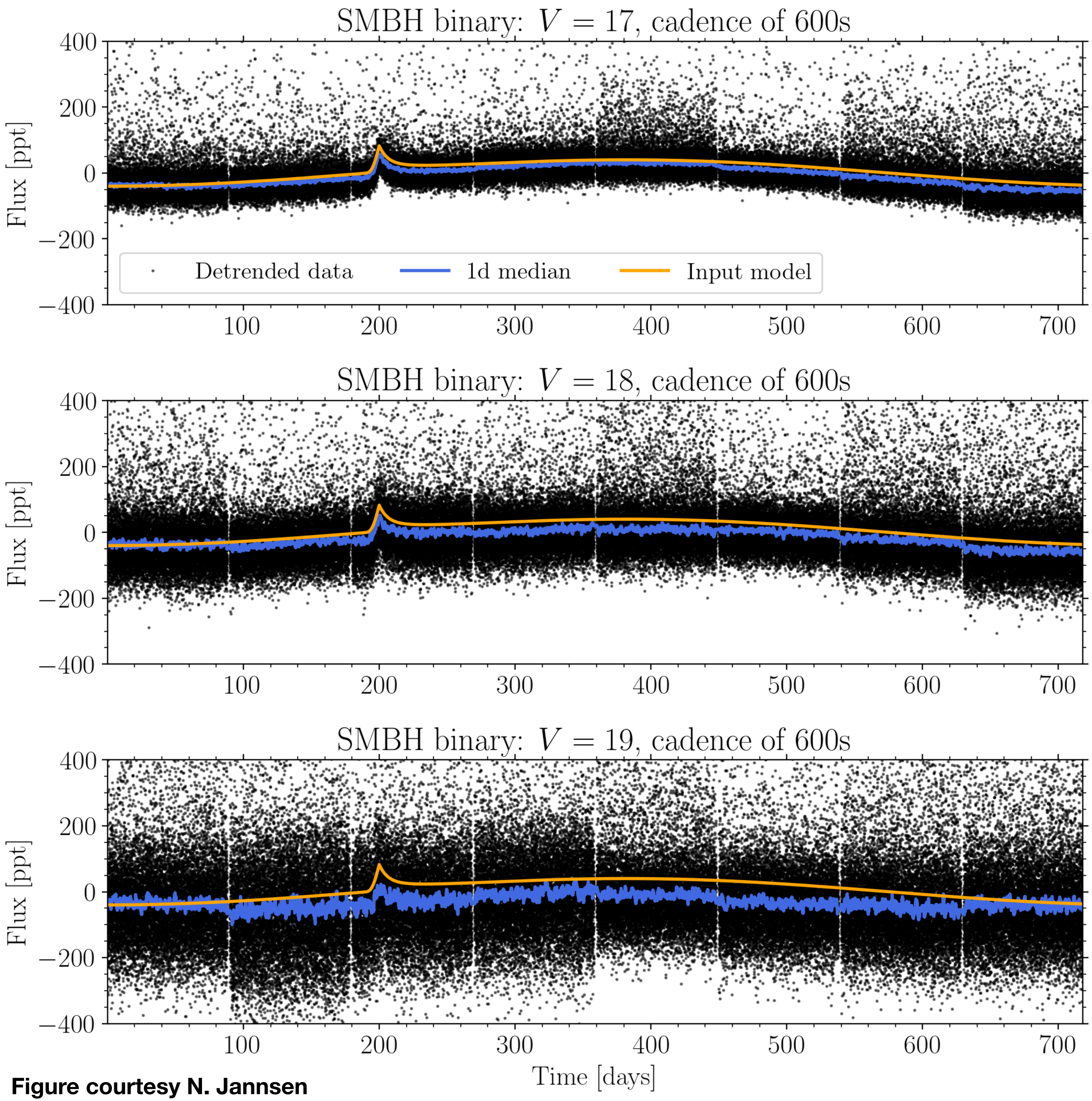


Spikey Vmag = 17.8

Can PLATO do it?

SMBHBs as (will be) seen by PLATO



"Spikey" SMBHB as a prototype (Hu + 2020)

Variability timescales: ~2 years orbital + ~30 d self-lensing

8Q of PlatoSim data at 600s cadence

No contaminants b/c question is: "can PLATO do faint extragalactic sources?"

Figure courtesy N. Jannsen

tomysl, Czech Republic

You can/should “design" PLATO

PLATO is NOT a surveyor, let’s design its since together

PLATO can be and should be pushed beyond the limits

PLATO has a lot to offer to the binary (and multiple) star community

"PLATO can fly… show must go on"

Questions to an astrologist?