PLATO Performance

PLATO Conference
14 October 2021

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PLATO Mission

- **Prime mission goals**:
  - detect and characterize a large number of extrasolar transiting planets including **Earth-sized planets up to the habitable zone of solar-like stars**
  - investigate seismic activity in stars, enabling the precise characterisation of the planet host star, including its **age**

- **Payload design drivers:**
  - **Planet detection**

    → large number of target stars
  - **Planet and star characterization**

    → bright target stars → wide field-of-view

  → **multi-camera approach:**
    - 24 normal cameras (<u>photometry</u>)
    - 2 fast cameras (<u>fine-guidance</u>, photometry (red and blue))

Image credit: OHB

Payload design drivers

planet detection
(up to HZ solar-like stars)

- 80 ppm 1h — (planet yield)
- long baseline (>2yr)
- 600s sampling

stellar characterization
(up to 10% age for Sun-like star)

- 25s sampling
- noise requirements in the Fourier domain — requirements on the residuals of systematic noise
- 34 ppm in 1h (3% Rp; 10% age)

600s sampling, 25s sampling → telemetry and data processing requirements

planet characterization
(down to 3% uncertainty in radius for Earth-Sun analogs)

- 34 ppm in 1h (3% Rp; 10% age)
- 50 ppm in 1h (5% Rp; 20% age)
- V<11 (radial velocity) — P1 sample requirements

34 ppm in 1h, 50 ppm in 1h → random noise requirements

requirements on the residuals of systematic noise, random noise requirements, P1 sample requirements → pointing requirements

P1 sample requirements → FOV requirements

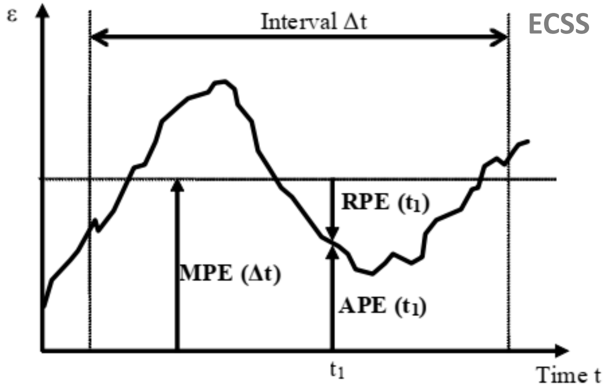

Figure A-1: Example showing the APE, MPE and RPE error indices

APE: Absolute Performance Error of the pointing.
PDE: Performance Drift Error of the pointing.
MPE: Mean Performance Error of the pointing.
PRE: Performance Repeatability Error of the pointing.
RPE: Relative Performance Error of the pointing

Payload design drivers

planet detection
(up to HZ solar-like stars)

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- long baseline (>2yr)
- 600s sampling — telemetry and data processing requirements

stellar characterization
(up to 10% age for Sun-like star)

- 25s sampling — telemetry and data processing requirements
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- 34 ppm in 1h (3% Rp; 10% age) — random noise requirements — pointing requirements

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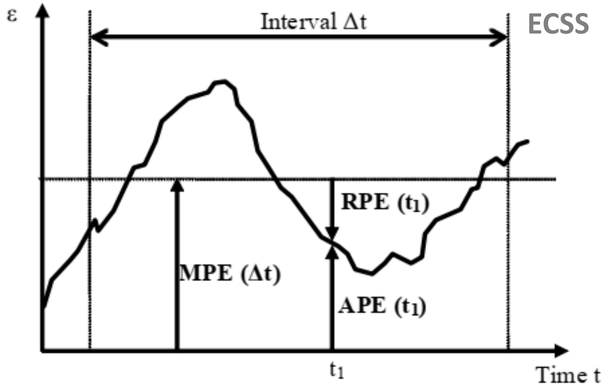
- V<11 (radial velocity) — P1 sample requirements — pointing requirements; FOV requirements



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pointing requirements

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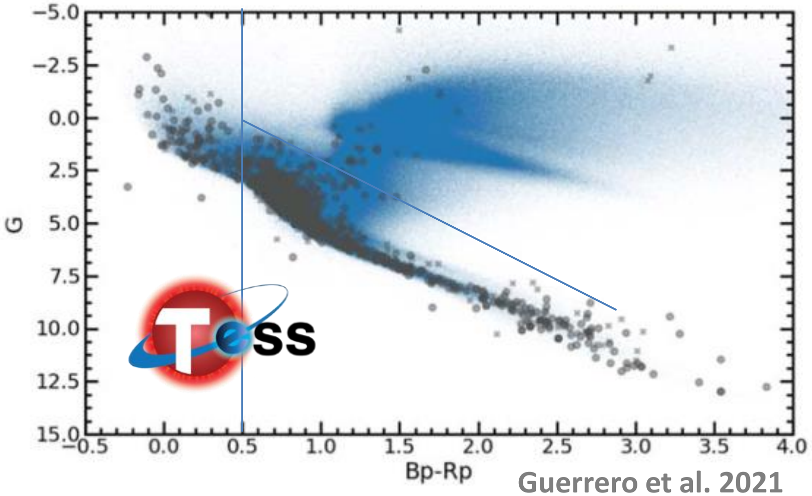
FOV requirements

disclaimer: detailed planet characterization (even atmospheres!) is possible with all missions (see Wong et al. 2021; von Essen et al. 2021, Hooton et al. 2021; etc.)

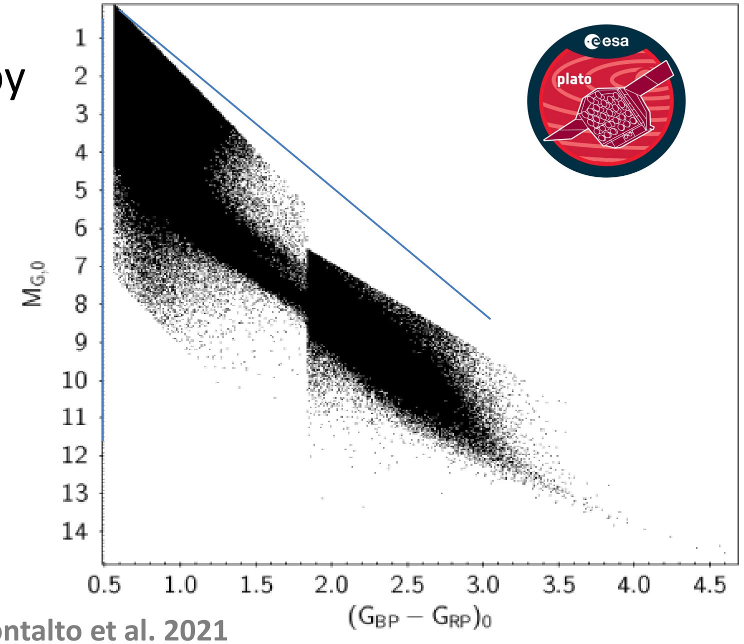
planet detection

TESS Objects of Interest

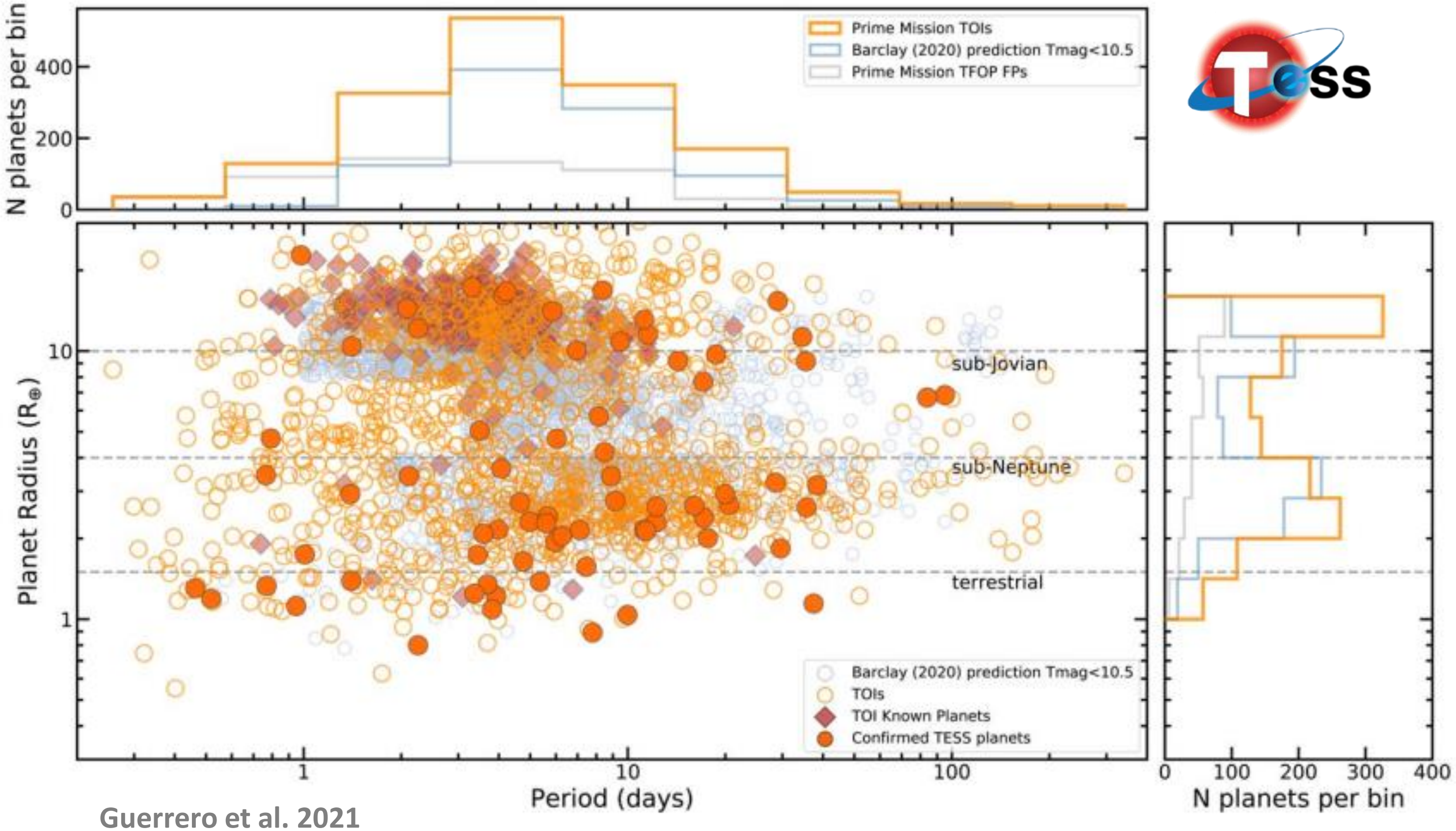


Guerrero et al. 2021

see talk by G. Piotto



Montalto et al. 2021



Guerrero et al. 2021

planet detection

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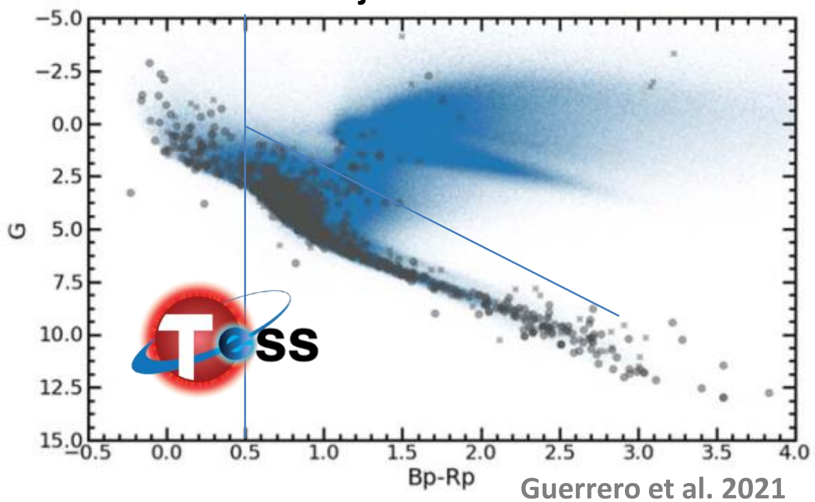

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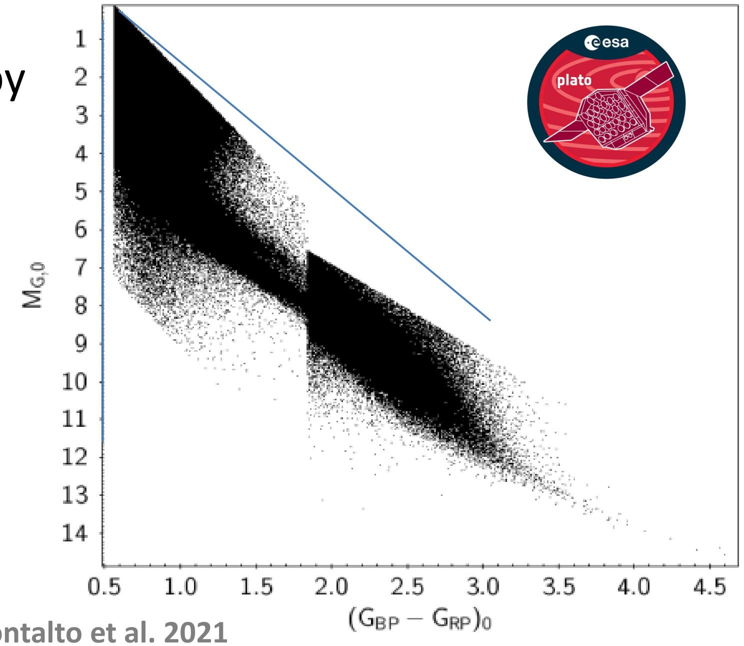
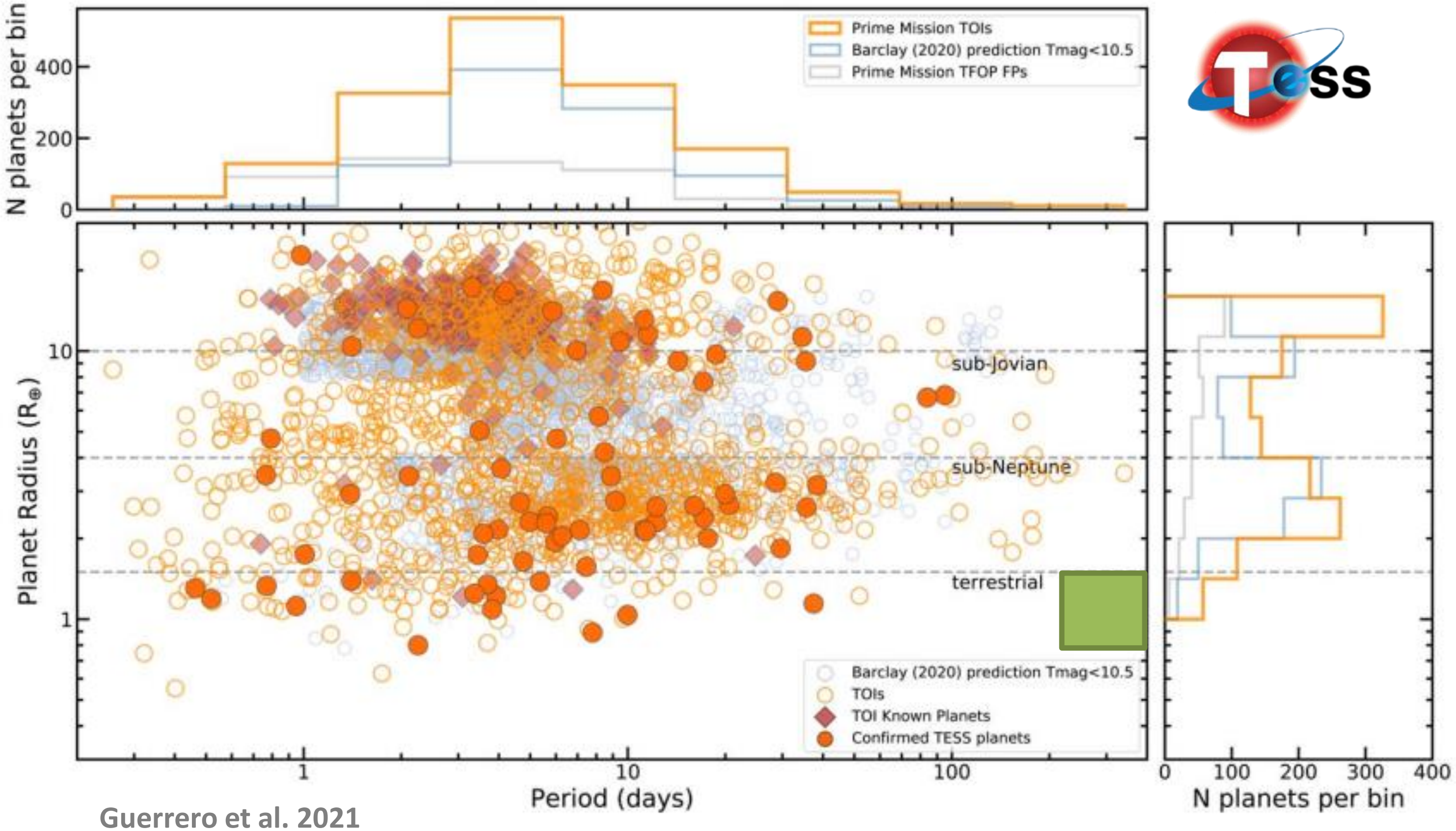


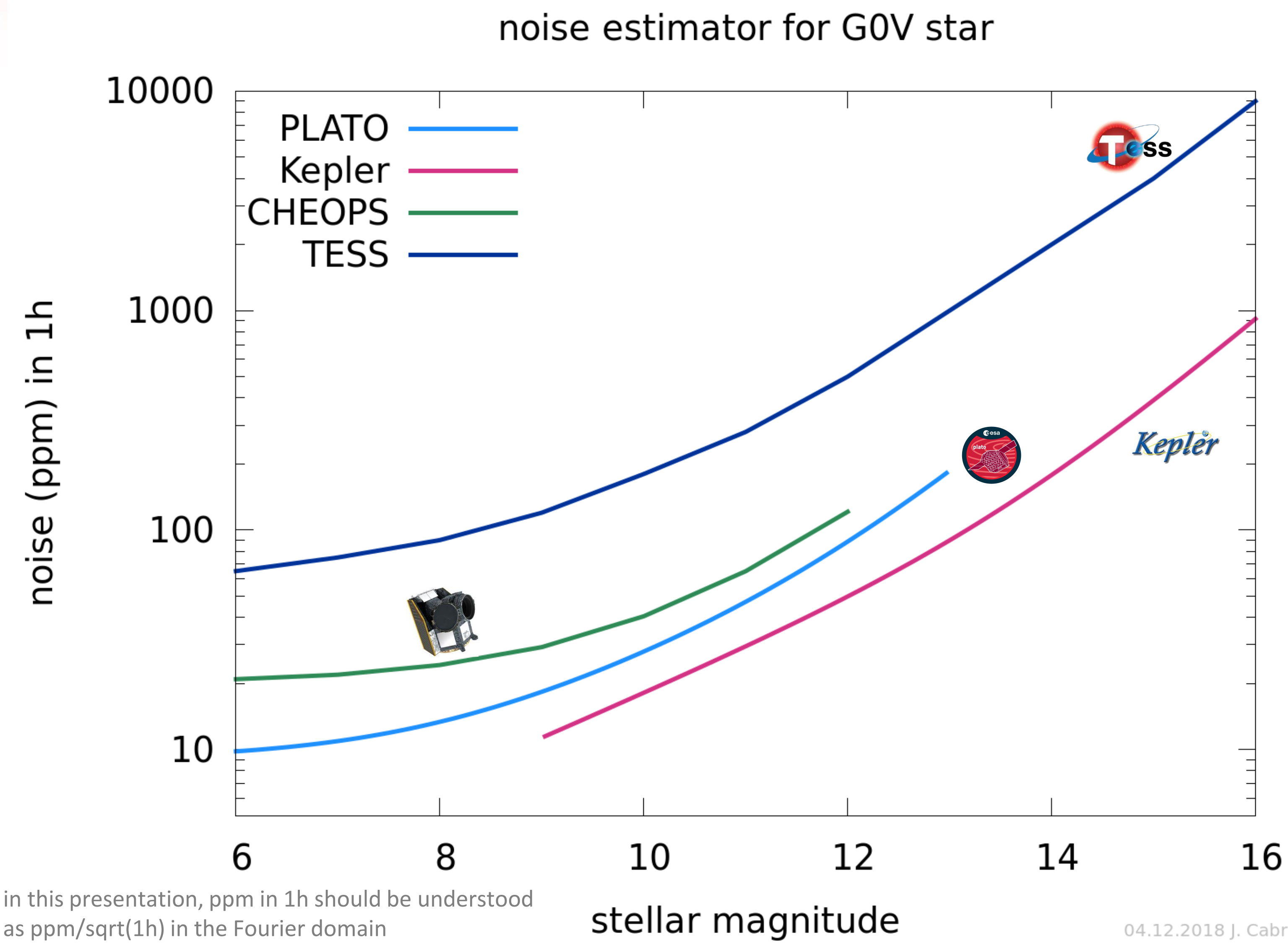
Montalto et al. 2021



Guerrero et al. 2021

The detection of Earth-sized planets in Earth-like orbits requires the dedicated approach by PLATO

planet detection performance



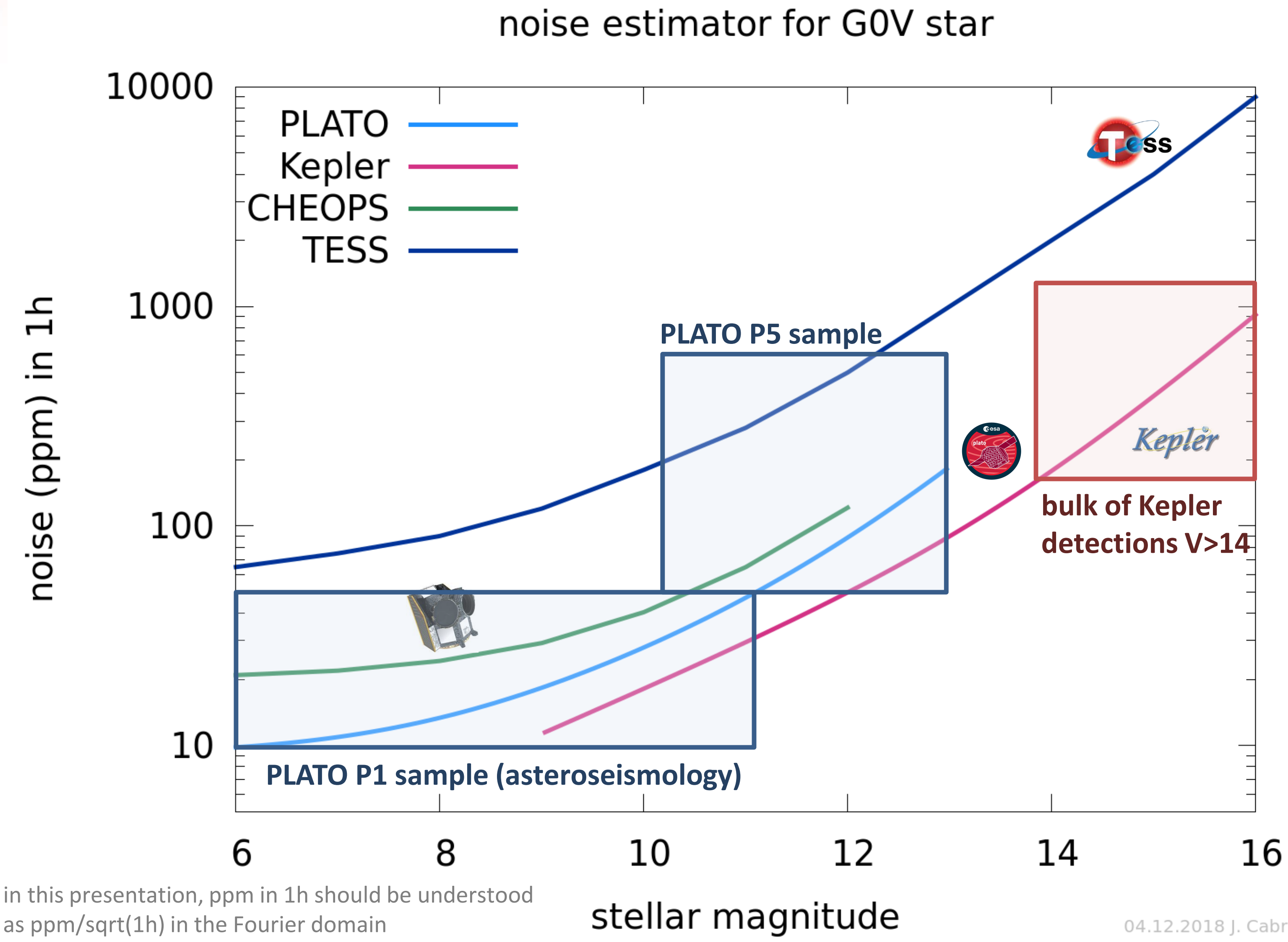
in this presentation, ppm in 1h should be understood as ppm/sqrt(1h) in the Fourier domain

The detection efficiency is a (non-linear) function of the signal-to-noise ratio, duty cycle... (see paper by Christiansen et al. 2016).

- Observing strategy allowing uninterrupted observations for at least 2 years (see FOV discussion later).
- Duty cycle requirements are >93% in-flight (Kepler ~88%, see Burke et al. 2015)
- Noise budget dominated by:
  - jitter in the bright end
  - background and readout noise in the faint end
  - photon shot noise everywhere else

  (note the particular architecture of the FOV)

planet detection performance



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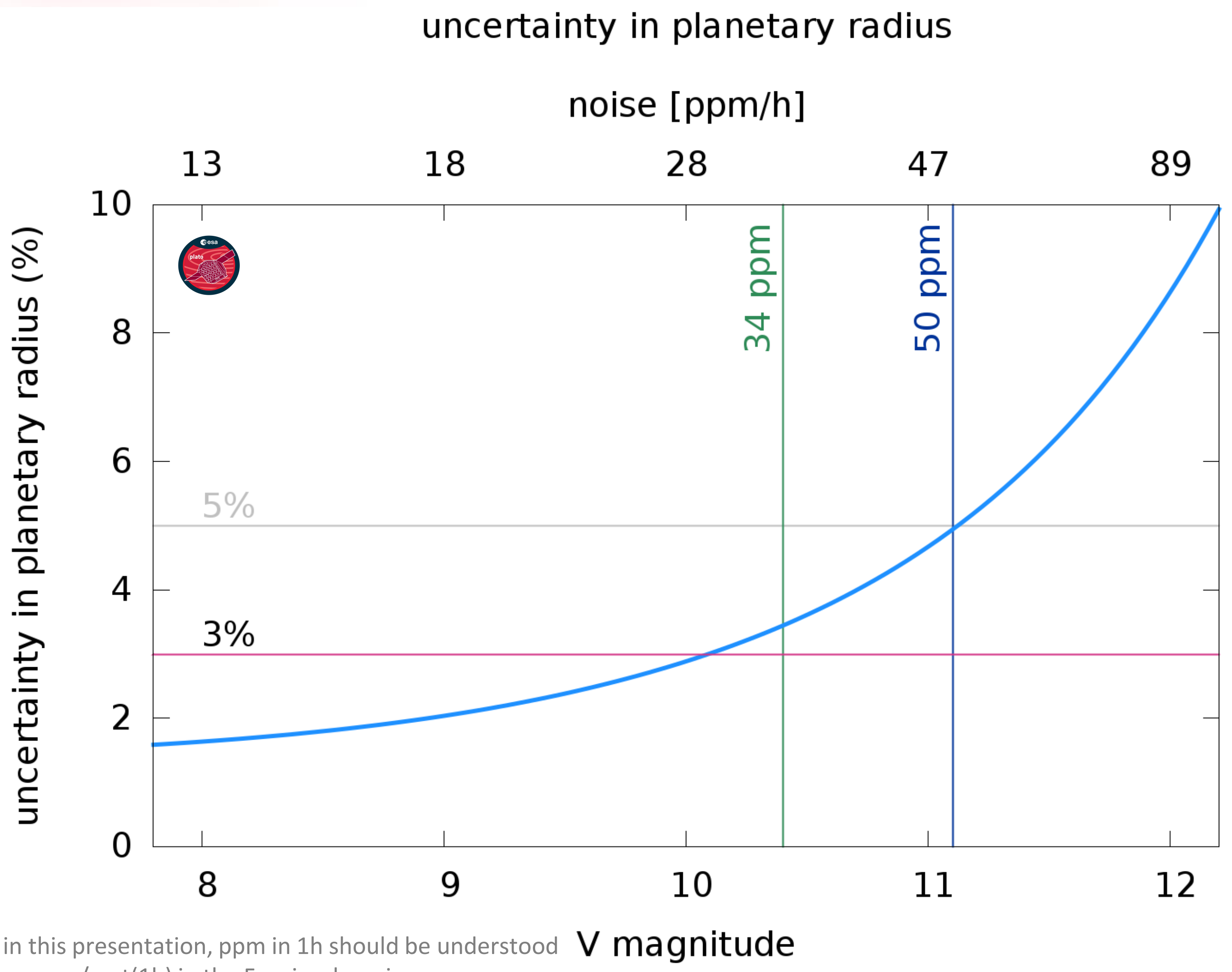
planet characterization performance



The current instrument design is compatible with the performance requirements for characterization of small planets

→ 3% planet radius precision for stars <10.3 mag (Earth around Sun case)

→ 5% radius precision for stars <11 mag

There are studies on how to deal with stellar variability, including planets in the HZ of solar-like stars, that deserve separate analysis, see Barros et al. 2020; Sulis et al. 2020; Brett et al. 2020; Csizmadia et al. 2021; etc.

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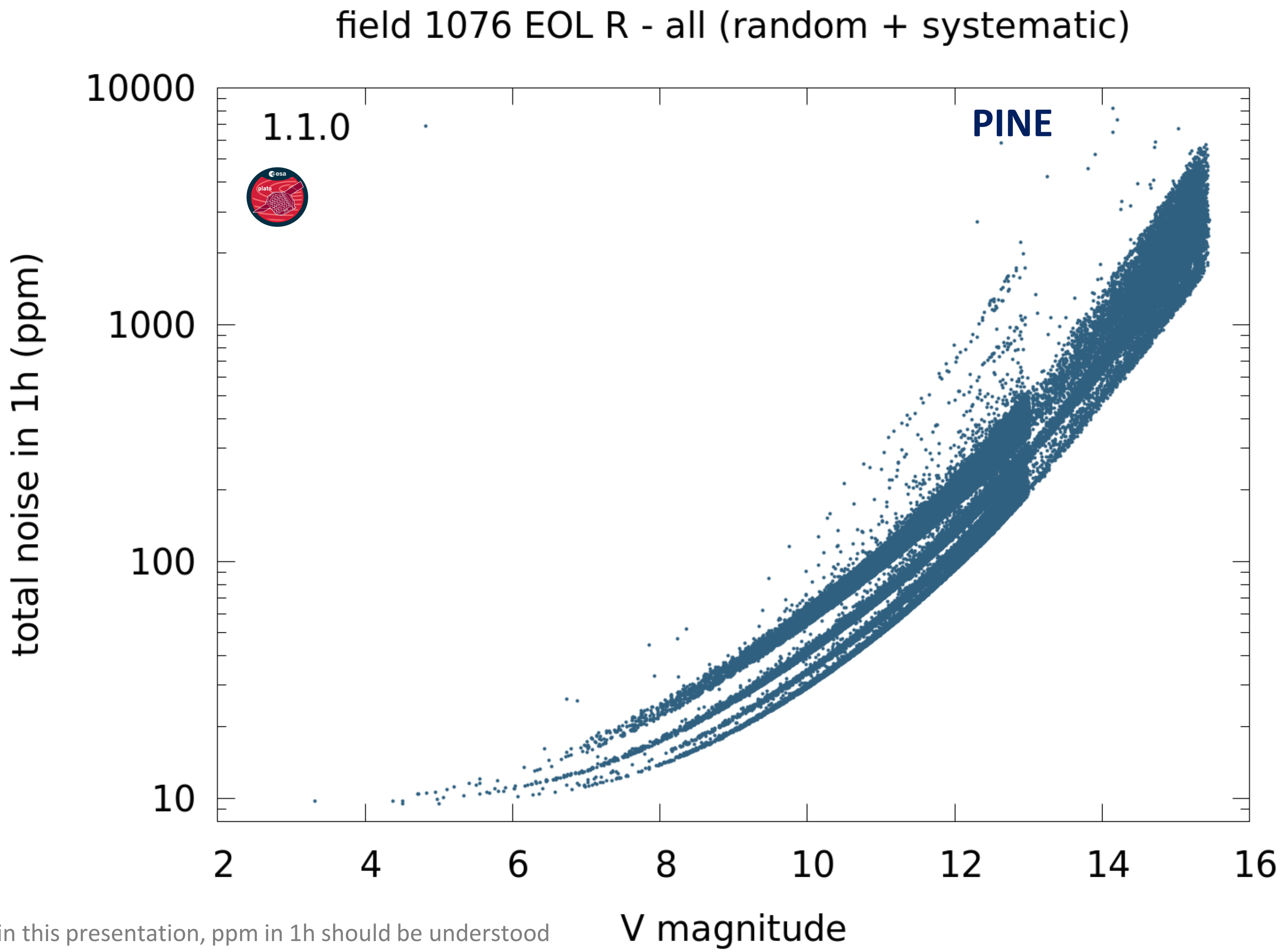
noise budget performance



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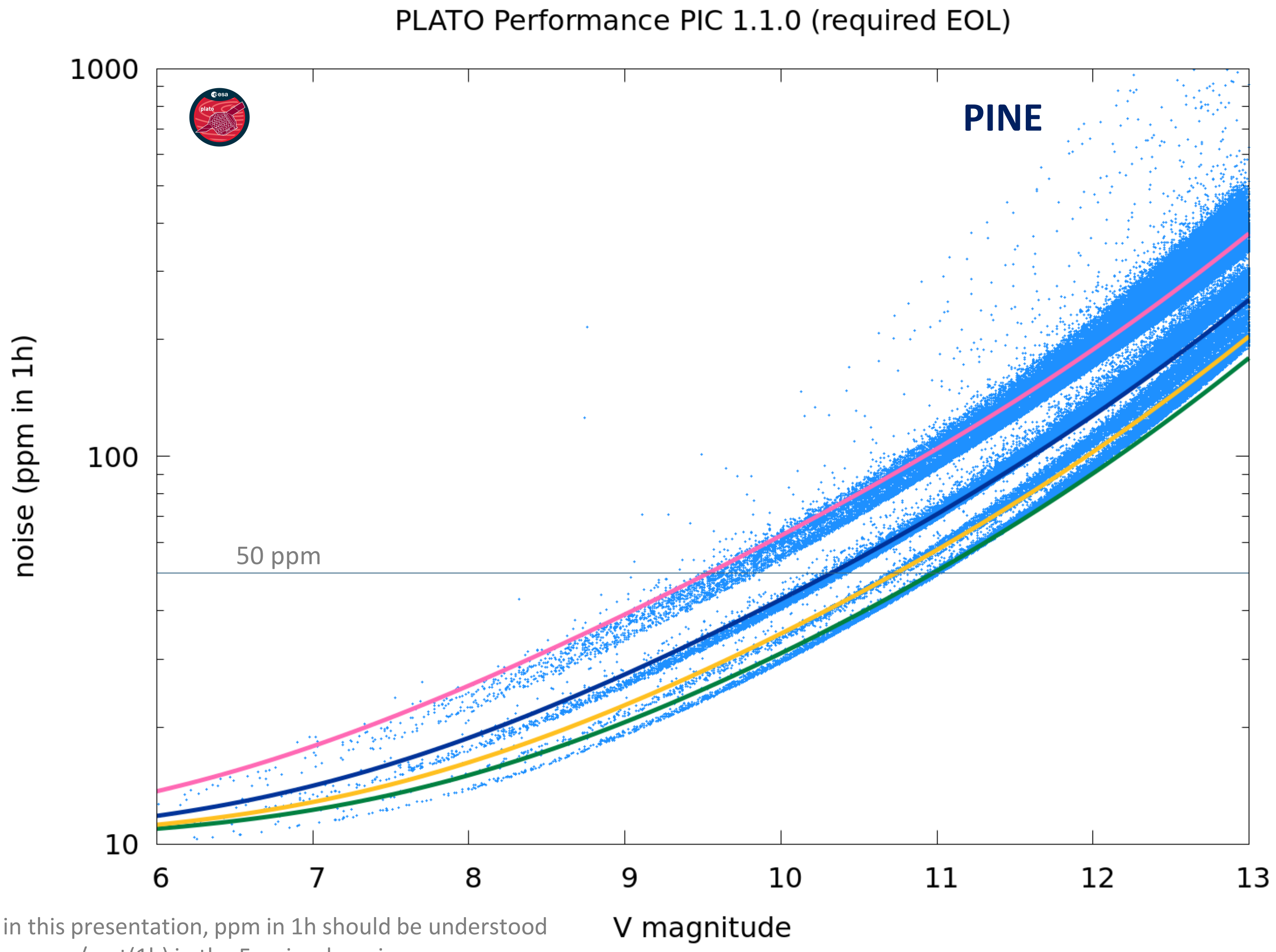
Because of the particular geometry of the PLATO Payload, the noise budget of a star depends on its position in the field of view (in contrast to telescopes like Kepler or missions without overlap of cameras like TESS).

Still, the following approximation is not bad:
- jitter in the bright end
- background and readout noise in the faint end
- photon shot noise everywhere else

The values on the left were calculated by PINE (Börner et al. in prep) using the latest knowledge of the instrument design. PINE values were used by U. Padova for field selection (see talk G. Piotto).

For PLATOSim, in this conference see poster by Jannsen & Seynaeve but also De Ridder et al. in prep.

noise budget performance



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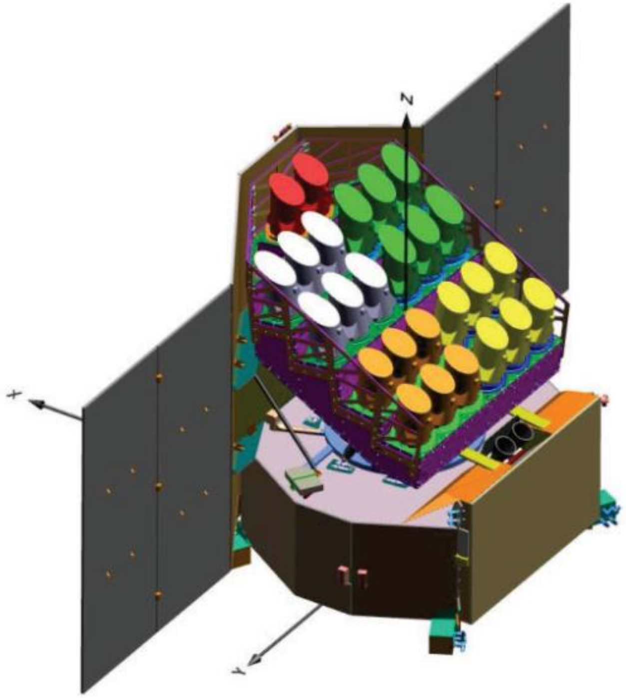
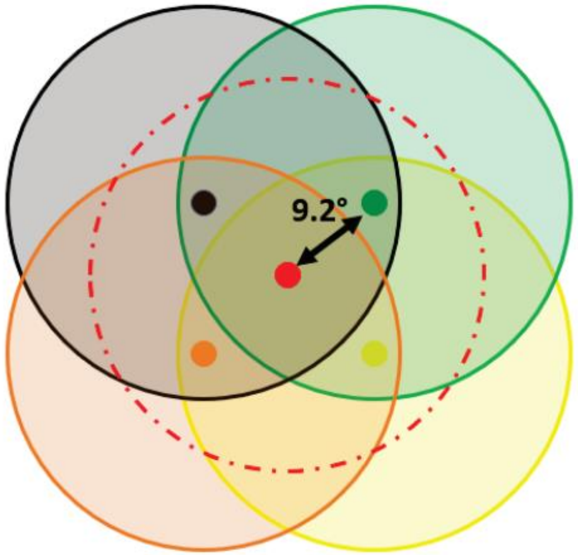
the unique field of view of PLATO

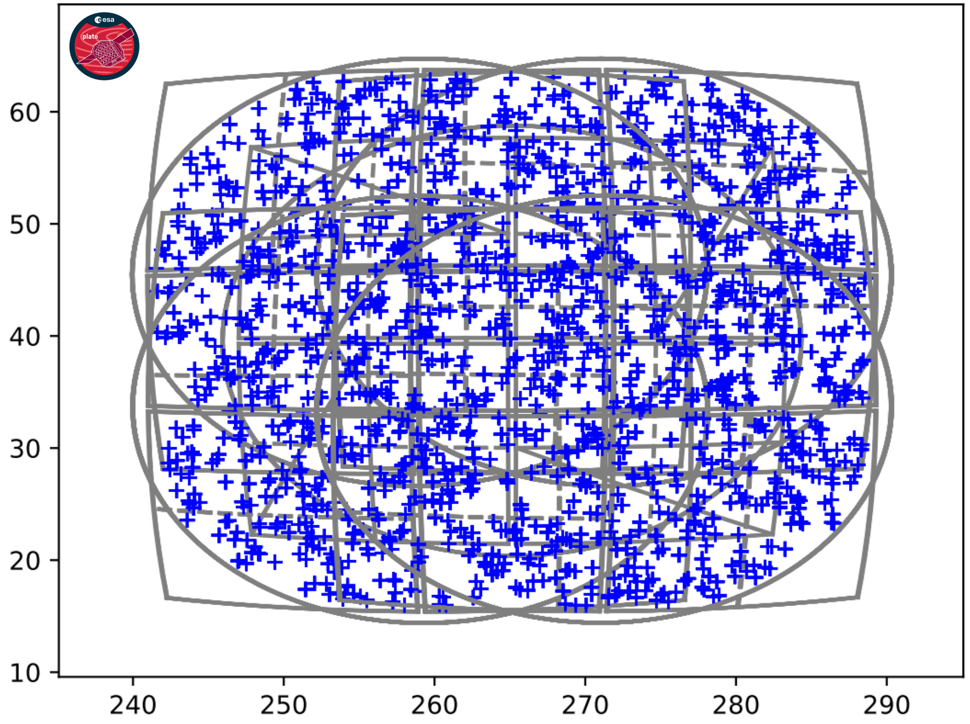
The total estimated field of view is estimated to be approximately 2132 deg², with 294 deg² observed by 24 cameras, 171 deg² observed by 18 cameras, 796 deg² observed by 12 cameras, and 871 deg² observed by 6 cameras.





Pertenais et al. 2021

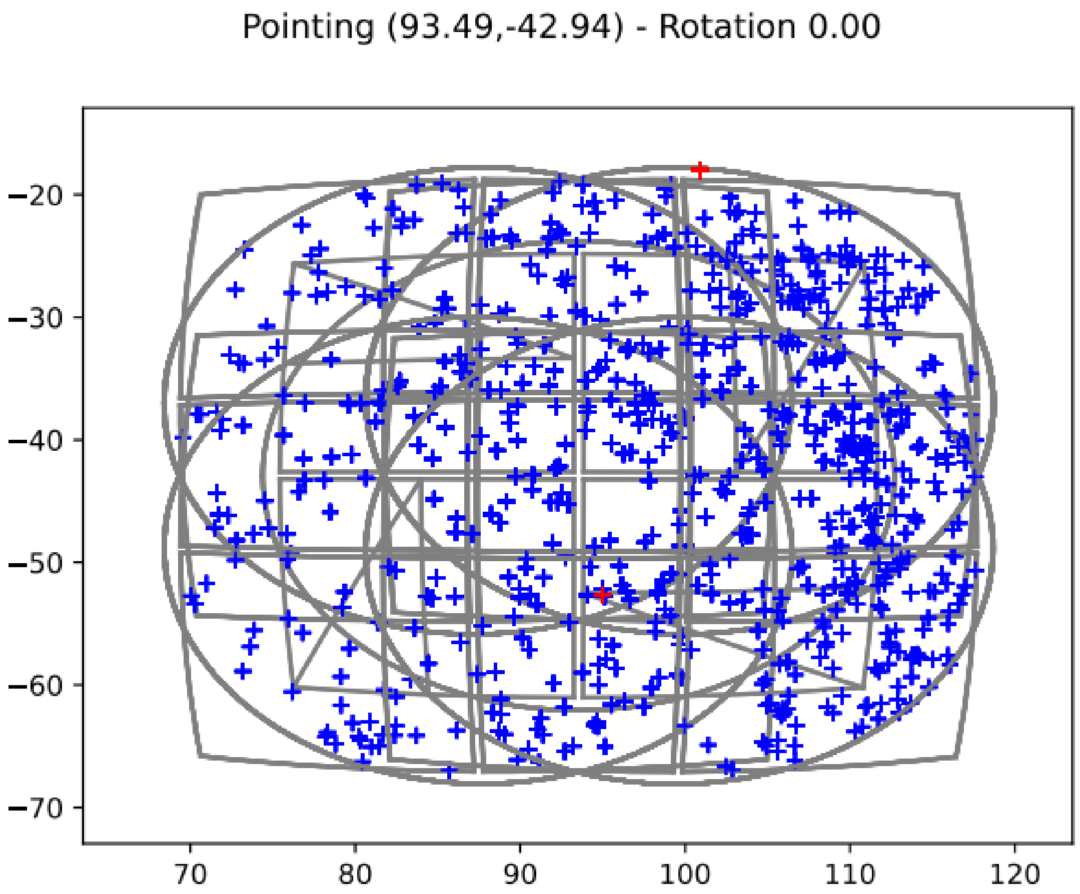
realistic instrument distortion and absolute pointing error included



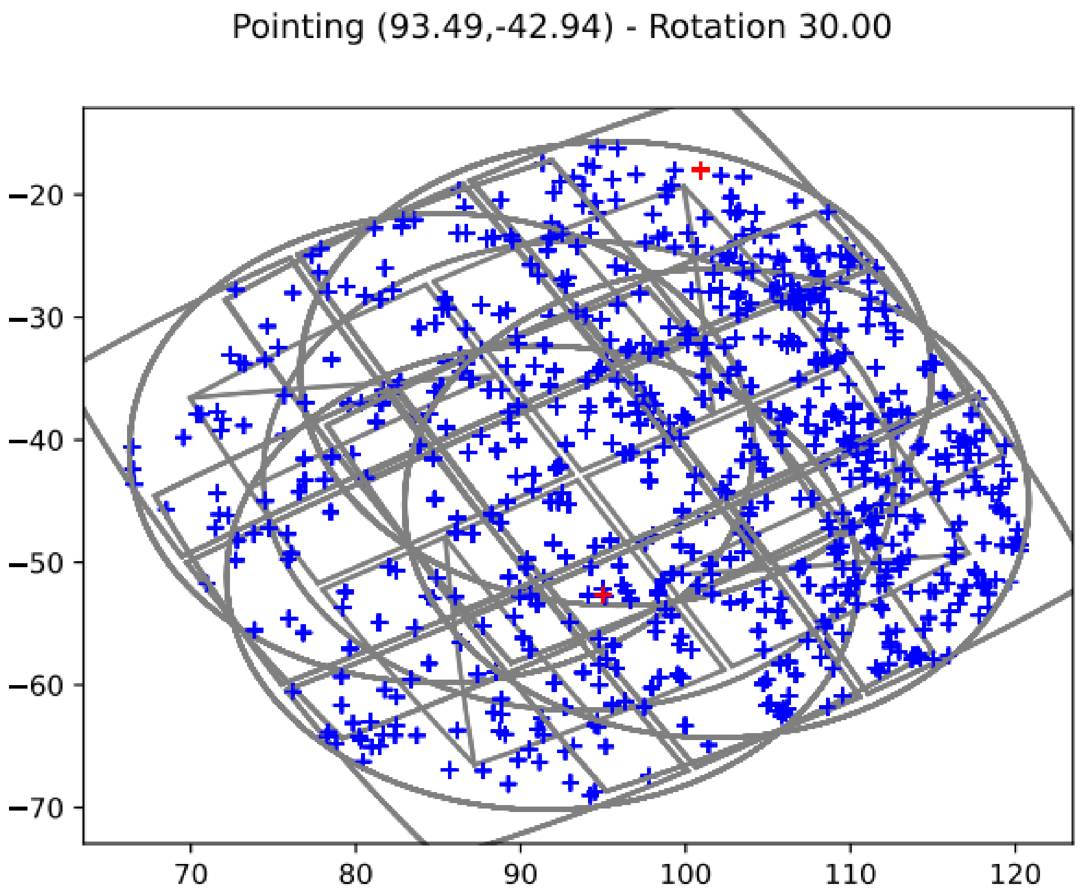
only V<9 stars in Montalto et al. 2021

the unique field of view of PLATO

There are operational constraints linked to this rotation that are currently under study within the Performance Team



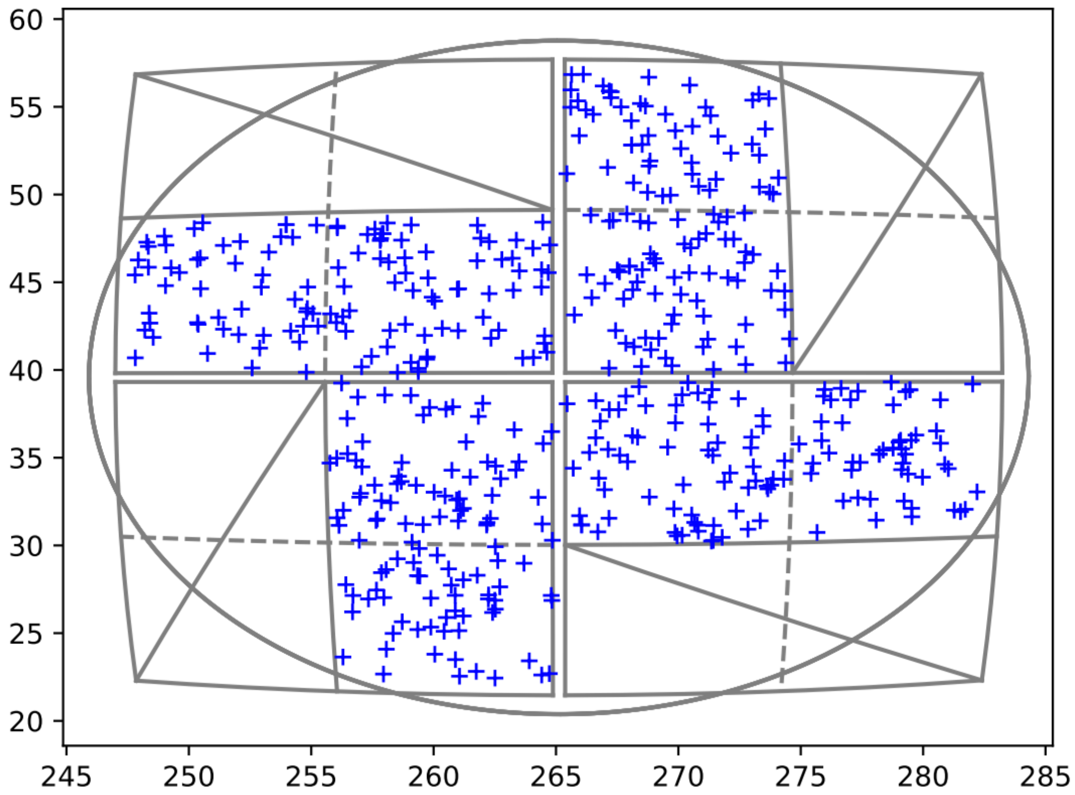
Sirius is *not* in the field of view



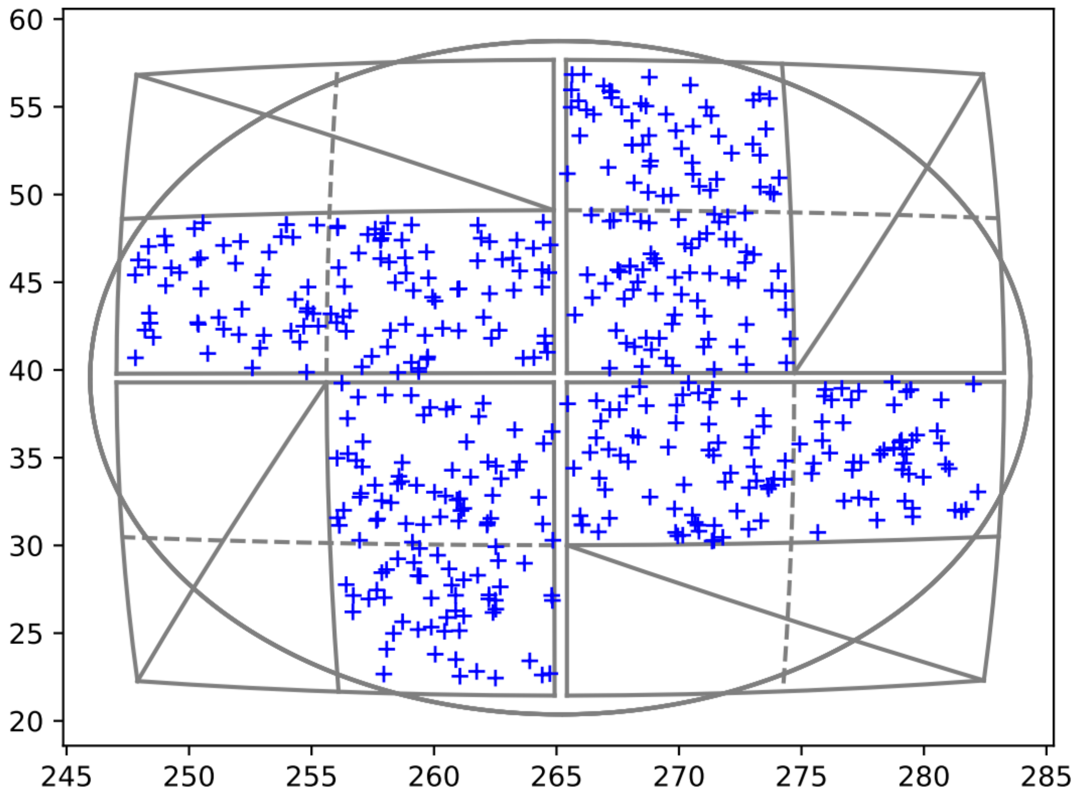
Sirius is in the field of view of N-CAMs 21 to 26

the unique field of view of PLATO

F-CAM 1



F-CAM 2



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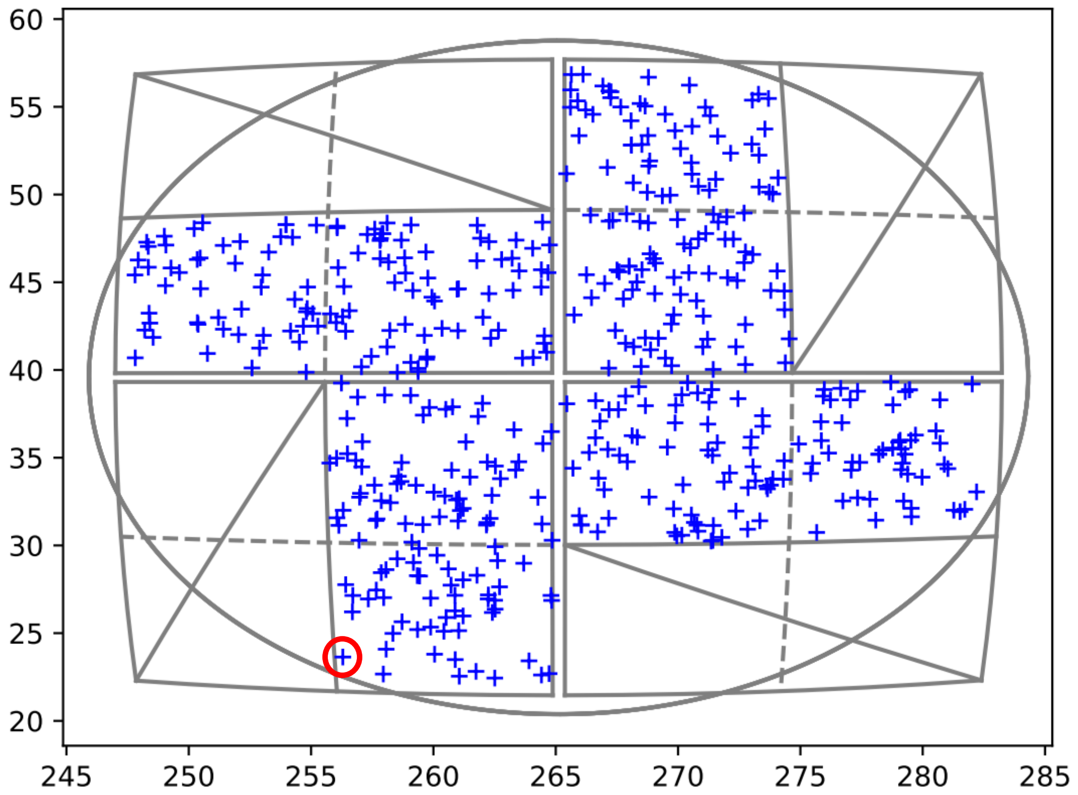
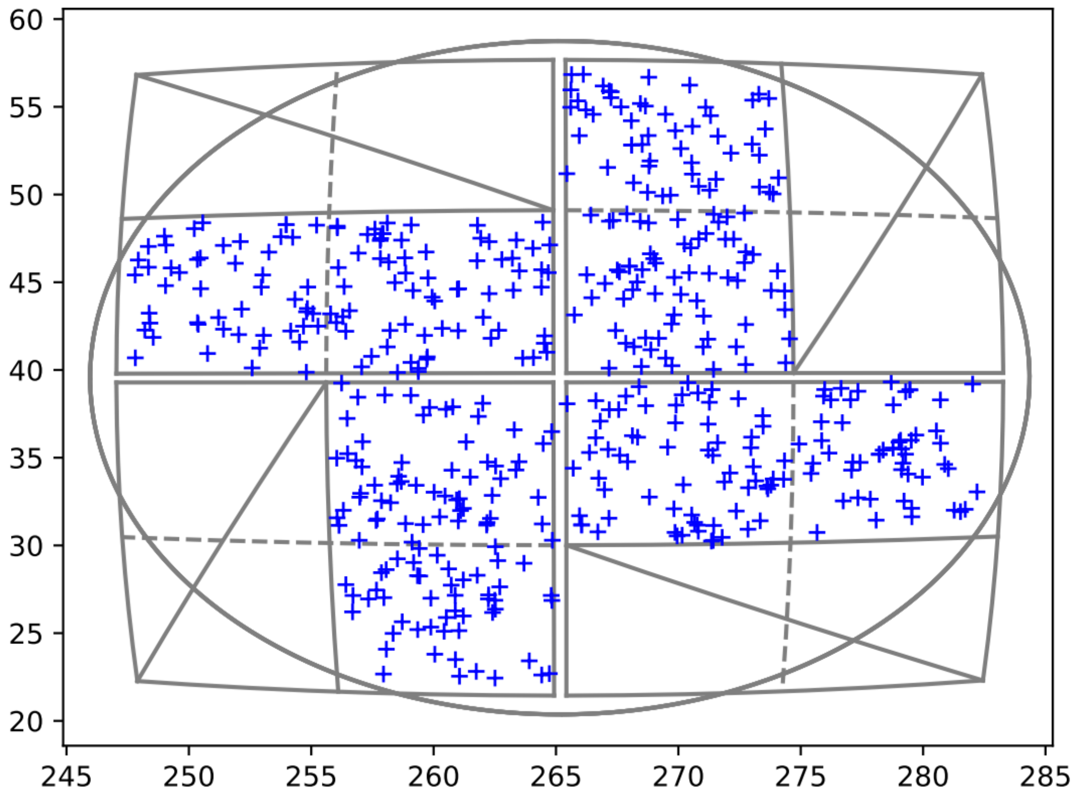
the unique field of view of PLATO

F-CAM 1



F-CAM 2



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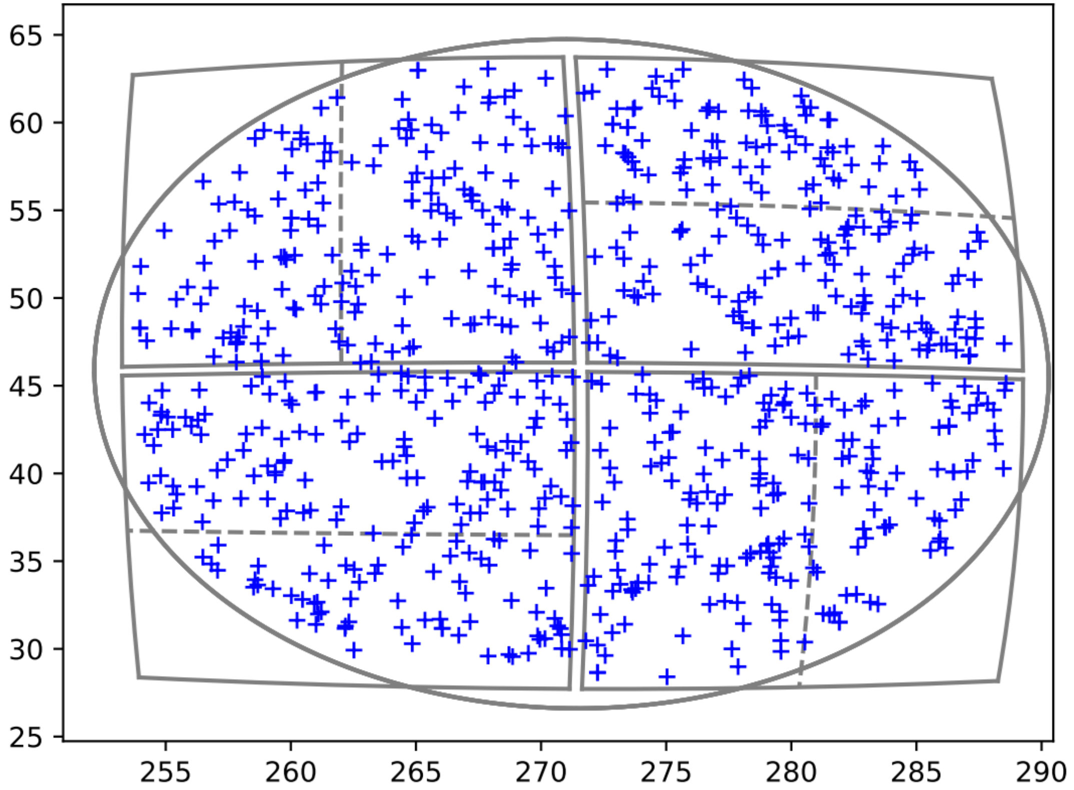
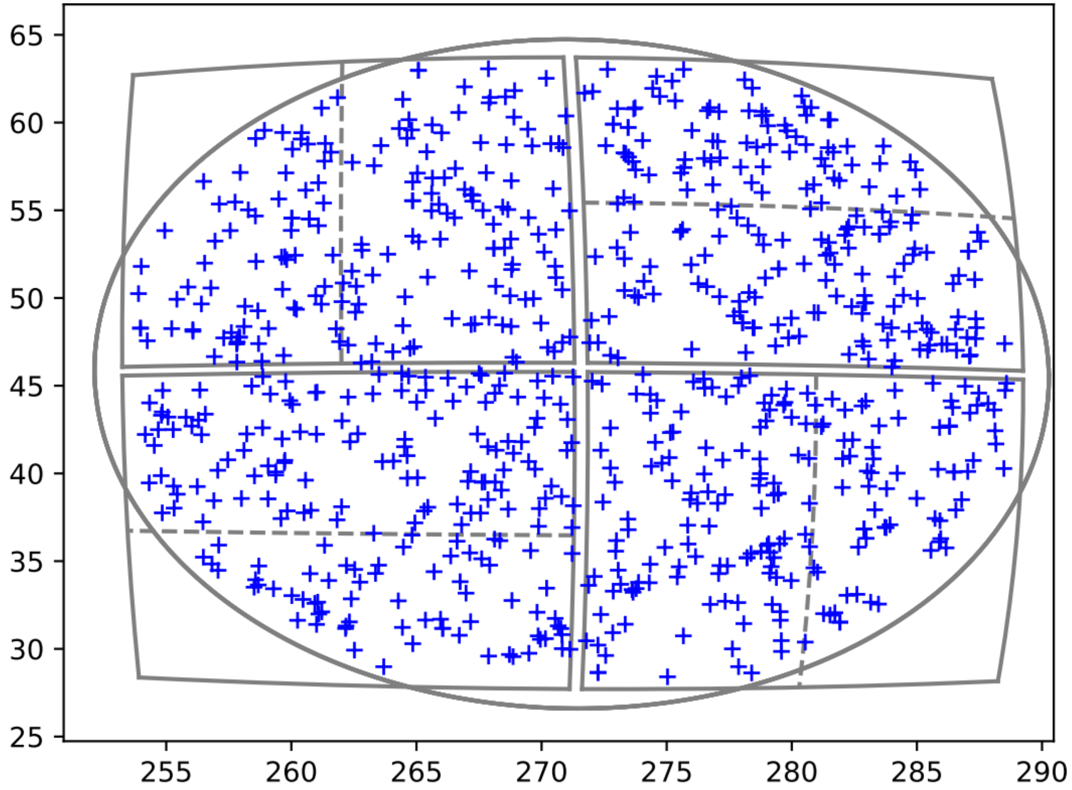
the unique field of view of PLATO

N-CAM 11



N-CAM 12



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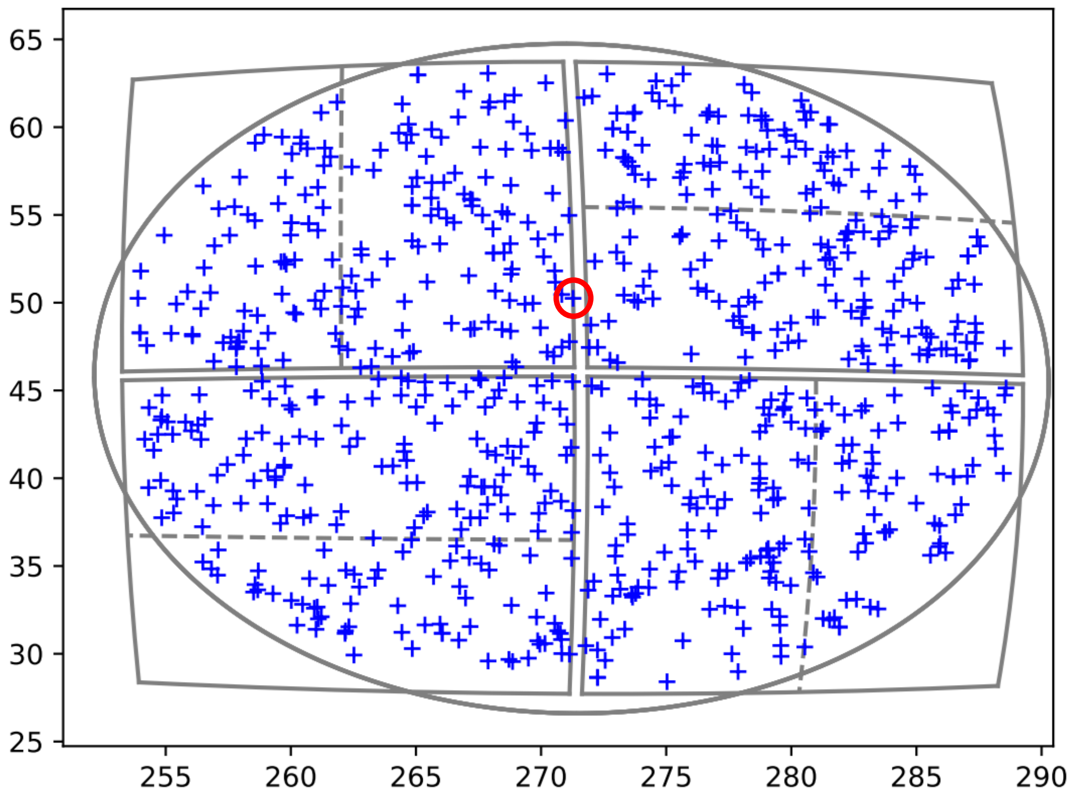
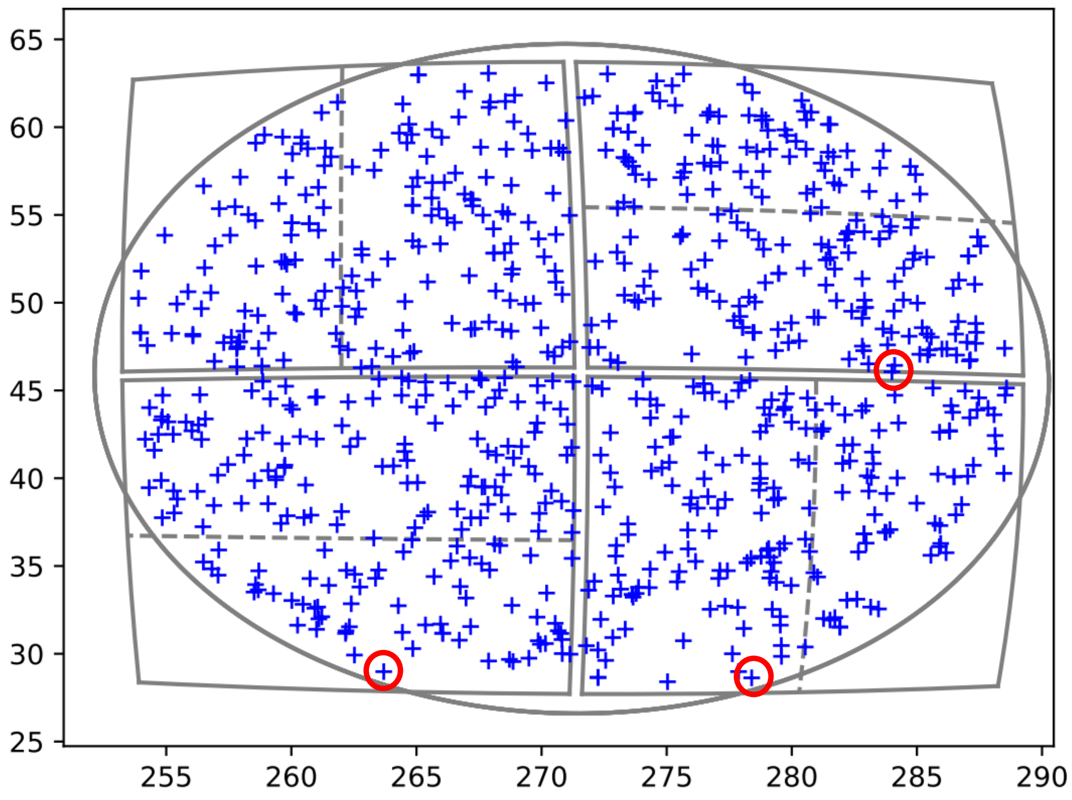
N-CAM 11



N-CAM 12



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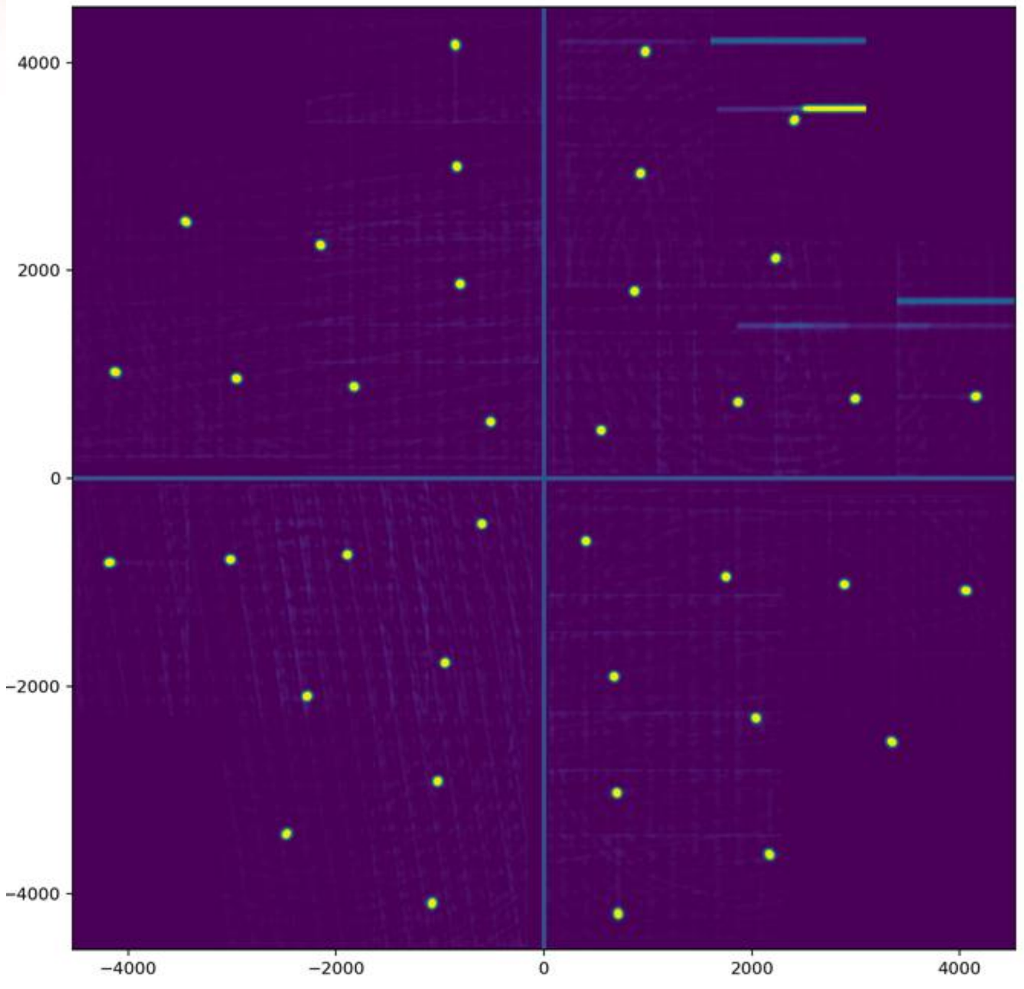


full field of view mosaic. Credit: P. Royer (KUL)

We will calibrate PLATO camera models on-ground (see left).

But part of the misalignment budget will only appear in-flight (e.g. gravity release).

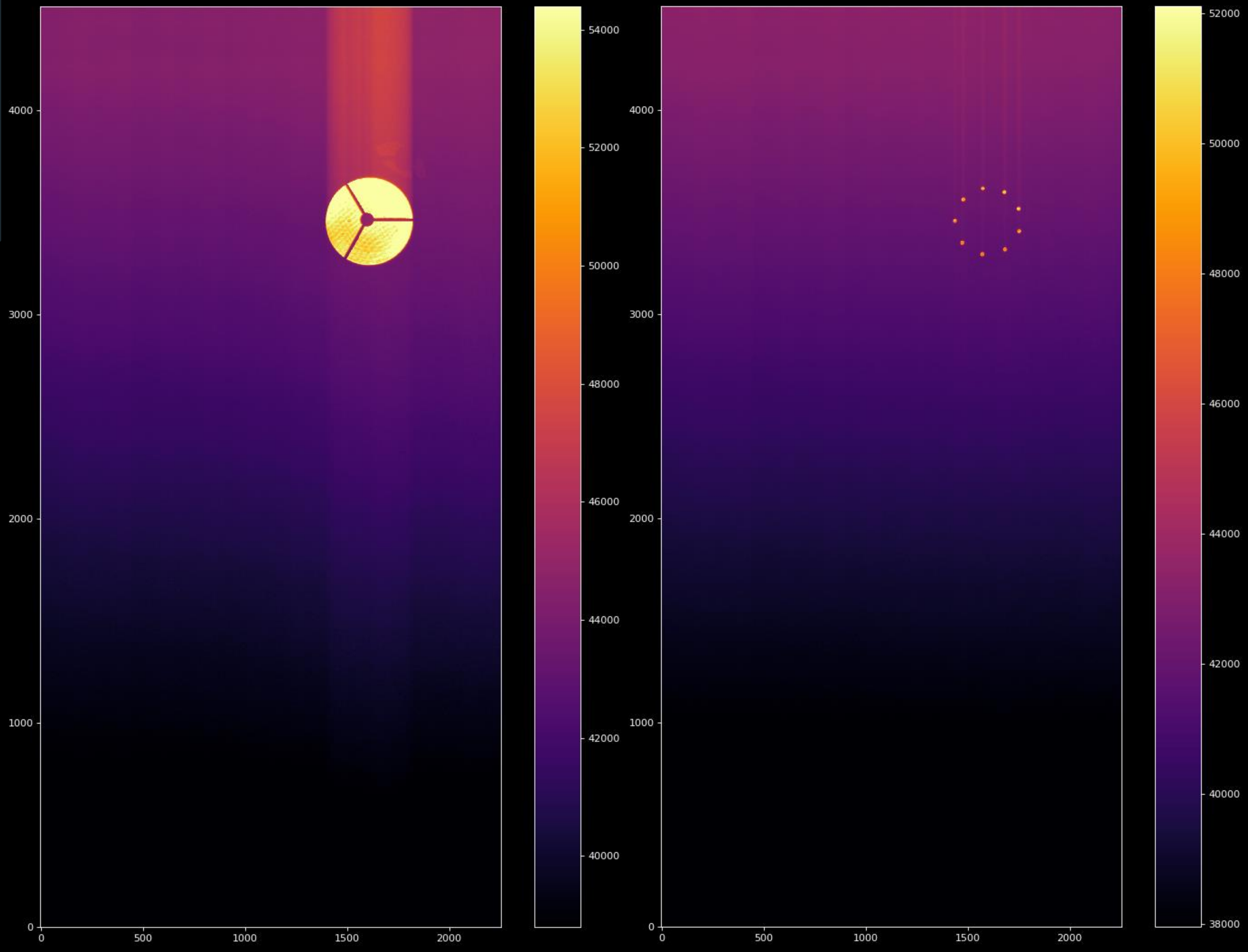
During commissioning phase we will:

– re-calibrate in-fight the camera models and verify the absolute pointing of each camera
– re-calibrate the best focus position for each camera and keep camera temperature constant (within few mK) to guarantee photometric performance

With this information, we will obtain the final in-flight NSR values for each star in the FOV of PLATO!

Big <u>thank you</u> to teams building cameras, integrating, and testing cameras so we can all do the great science of PLATO!

FIRST LIGHT FROM A PLATO CAMERA



PLATO Camera EM First light
19 august 2021

CSL and KU Leuven teams are assembling and aligning the first engineering model of the PLATO cameras. With the PLATO CCD sensors still 2cm away from the focal plane of the telescope they recorded the first photons imaged through the telescope and detected by the PLATO CCD sensors.

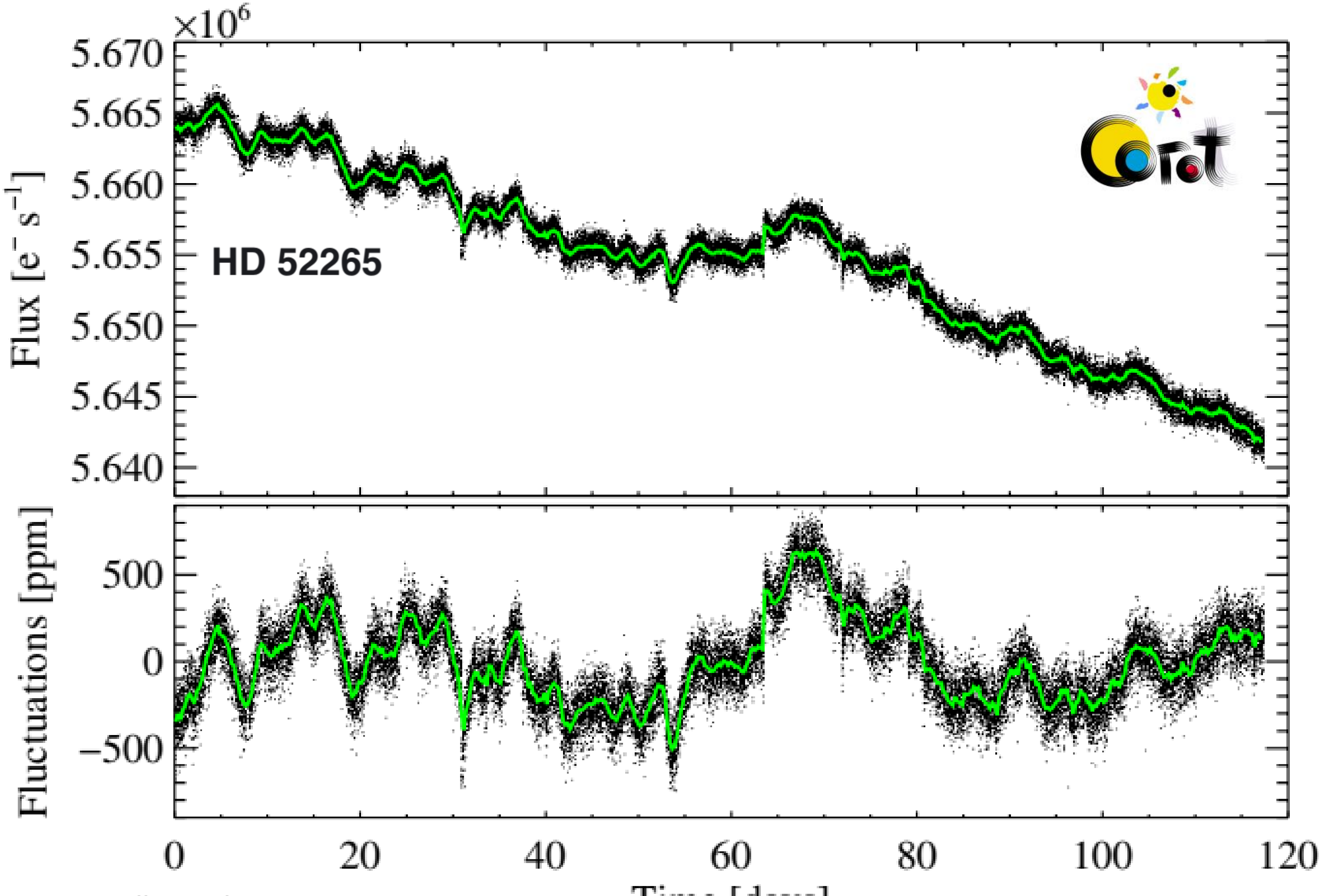
The left picture shows the unfocussed image of a point source injected into the camera through the collimator provided by the colleagues of the university of Lisbon.

The right picture shows the image of the collimator masked with a Hartmann focusing mask. As the teams will move the focal plane array with the CCD sensors closer to the telescope focus, the spots in the Hartmann pattern will come closer together.

KU LEUVEN


CSL
CENTRE SPATIAL DE LIEGE
KU LEUVEN

noise in the Fourier domain



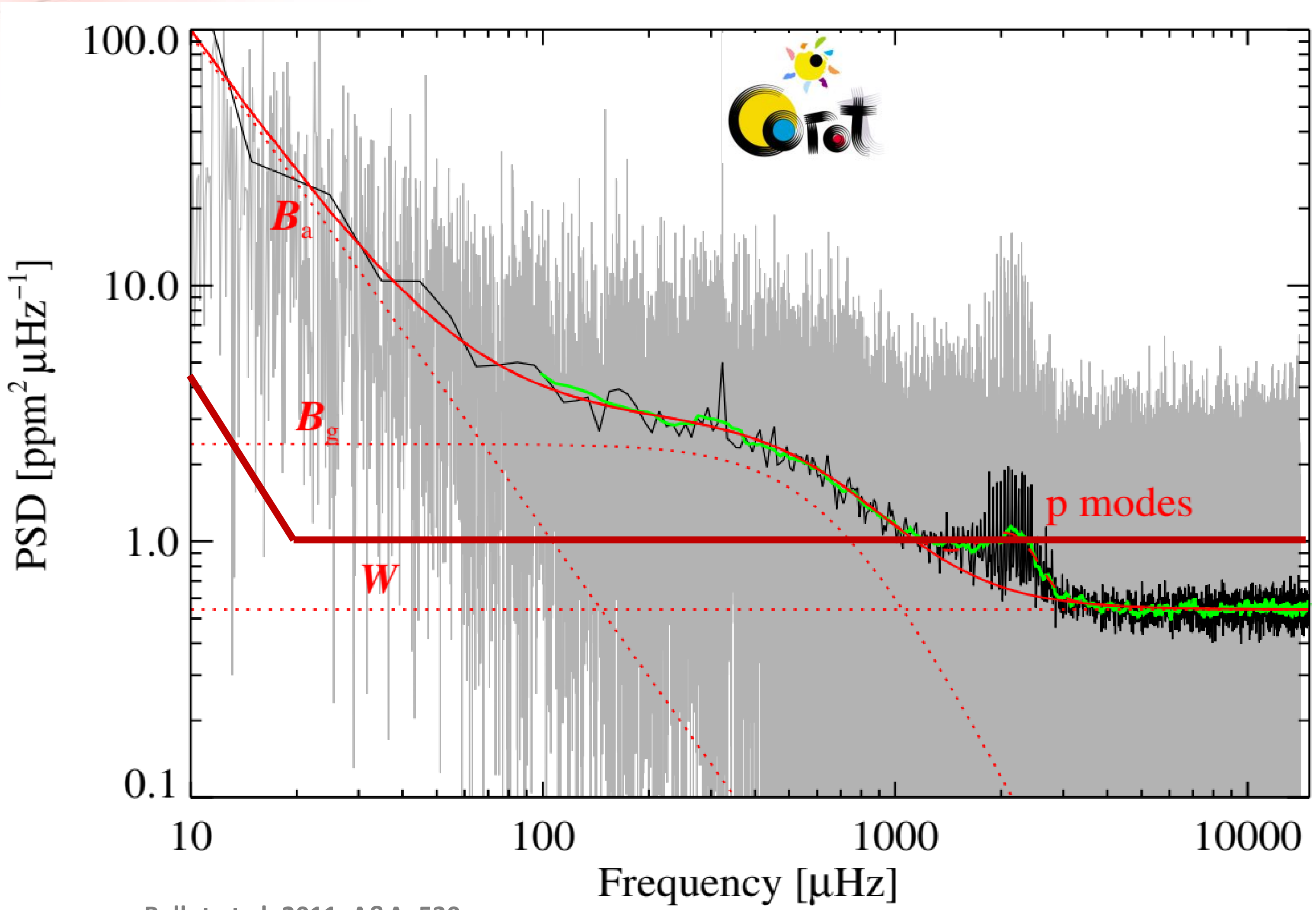
Ballot et al. 2011, A&A, 530

Stellar variability acts at very different time-scales. This can be seen in a power spectral density (PSD) as signal distributed across the Fourier domain.

"But that is another story and shall be told another time."

PLATO asteroseismology performance compared with CoRoT, Kepler, and TESS: in this conference see the talks by Cunha, Davies, Deheuvels, Deal, Boulet...

noise in the Fourier domain

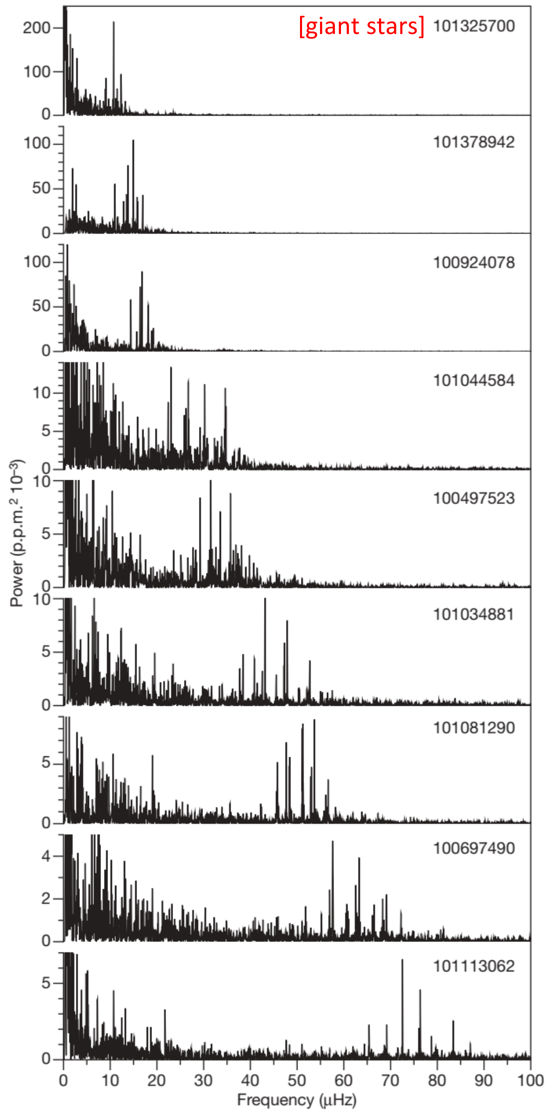


Ballot et al. 2011, A&A, 530

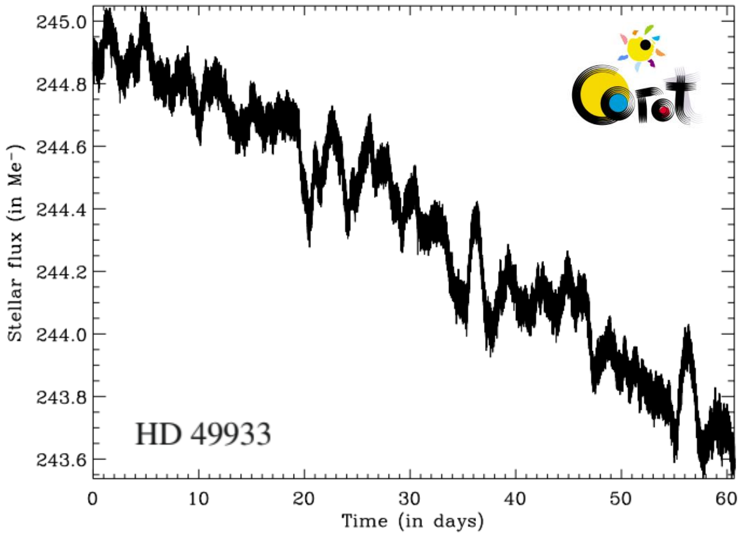
Stellar variability acts at very different time-scales. This can be seen in a power spectral density (PSD) as signal distributed across the Fourier domain.

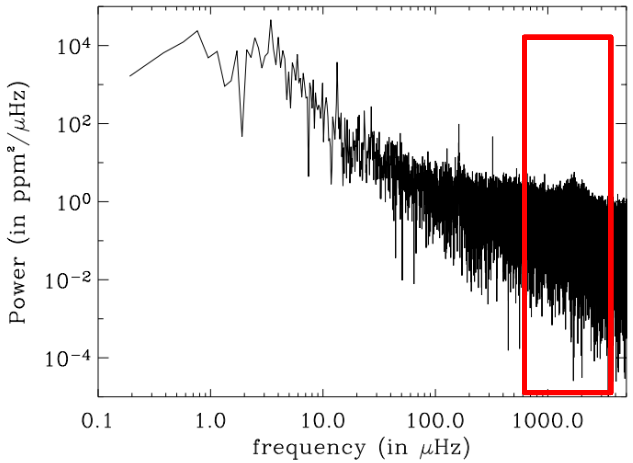
Stellar variability is distributed across the Fourier domain. Here it is described as: long-term variability $\mathbf{B_a}$, granulation $\mathbf{B_g}$, and **p-mode** oscillations; **W** is the photon noise component.

noise in the Fourier domain

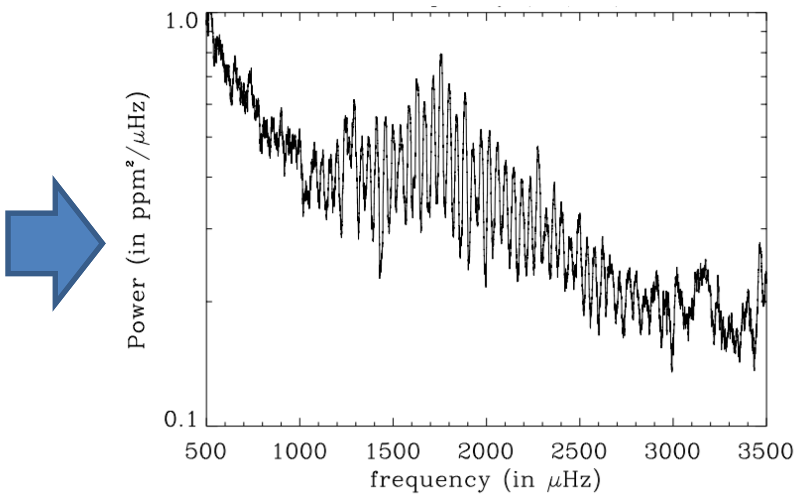


De Ridder et al. (2009) Nature, 459





Appourchaux et al. (2008) A&A, 488



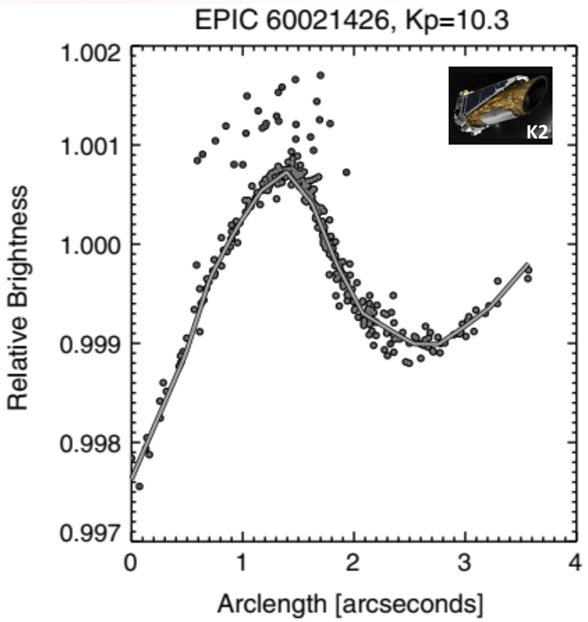
Stellar variability acts at very different time-scales. This can be seen in a power spectral density (PSD) as signal distributed across the Fourier domain.

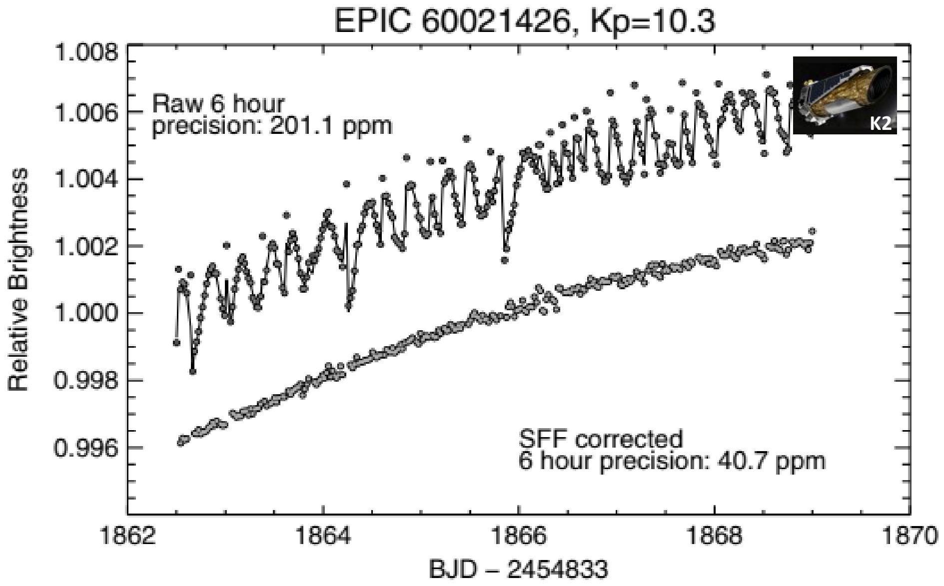
The relative amplitude of the different components and the frequency distribution depends on stellar type and evolutionary state of the star.

See the paper on the PLATO Solar-like Light-curve Simulator (SLS)

Samadi et al. (2019) A&A, 624, A117.

noise in the Fourier domain





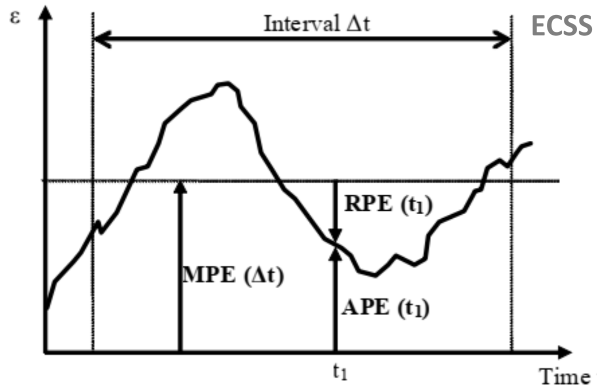
Vanderburg et al. (2014) PASP, 126

Stellar variability acts at very different time-scales. This can be seen in a power spectral density (PSD) as signal distributed across the Fourier domain.

Any pointing drift will produce a measurable signal on the photometry that can prevent the detection of stellar oscillations (in particular, if the drift is periodic).

In PLATO, there are requirements for:

- pointing drift error (PDE): long-term trends at time-scales larger than 3 days.
- mean pointing error (MPE): any pointing change between 25s and 3 days.
- high frequency jitter (RPE): for the very high frequencies (<25s/<2.5s).



ECSS

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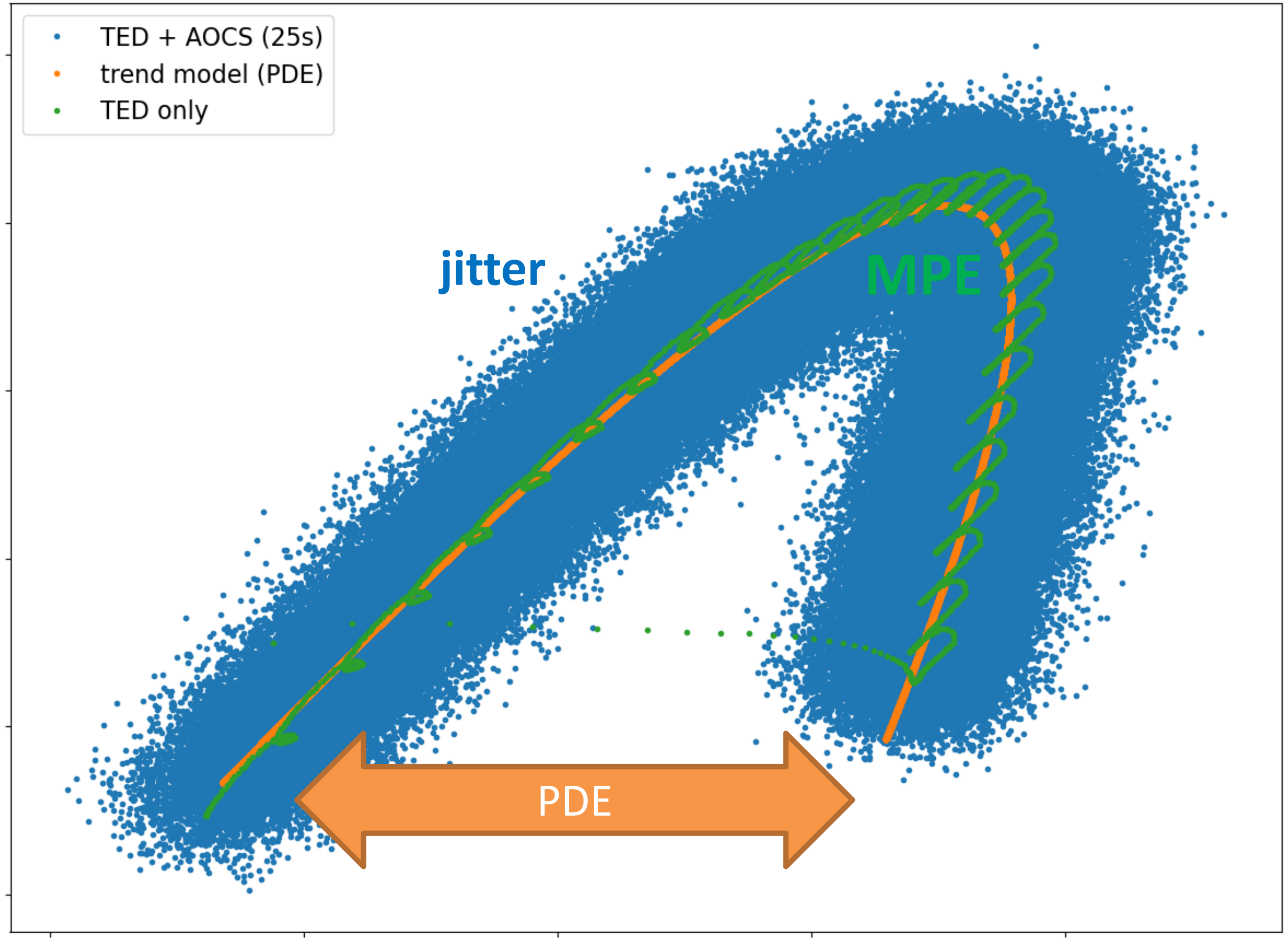
noise in the Fourier domain

axes erased deliberately (work in progress)



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Preliminary analyses show that the expected performance is compliant to the requirements.

Note that pointing drifts are unavoidable because of the large FOV of PLATO (consider kinematic differential aberration).

noise in the Fourier domain

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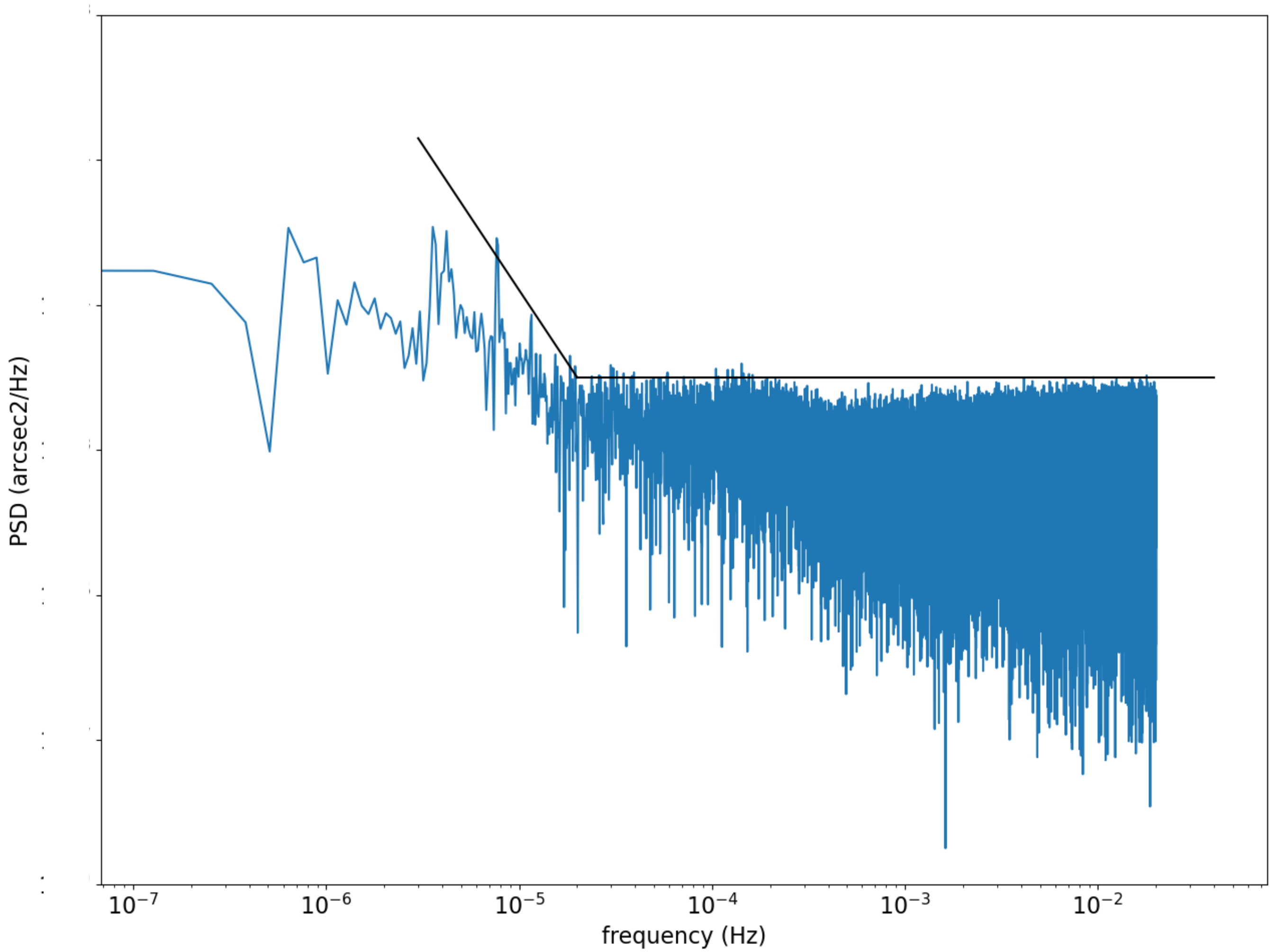

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take-home message

There is abundant information available to the PLATO Mission Consortium on PLATO Performance.

We want to make this information available to the community in a useful way -> papers in prep by Rauer; Börner; Cabrera...

There are already publications regarding PLATO Performance and simulators:

- Cunha et al. (2021) MNRAS, in press (in this conference, see the talk by M. Cunha).
- Nascimbeni et al (2021) submitted to A&A (in this conference, see the talk by G. Piotto).
- Montalto et al. (2021) A&A, 653, A98 (idem).
- Pertenais et al. (2021) SPIE 11852 (and references therein, including Ragazzoni et al. 2016; Magrin et al. 2016a, b; etc.).
- Grenfell et al. (2020) Exp. Ast. 50.
- Marchiori et al. (2019) A&A, 627, A71.
- Samadi et al. (2019) A&A, 624, A117 (PLATO Solar-like Light-curve Simulator)
- Verhoeve et al. (2016) SPIE 9915 (see also Prod'homme et al. 2016, 2018).
- Nascimbeni et al. (2016) MNRAS, 463, 4210.
- Marcos-Arenal et al. (2014) A&A, 566, A92 (on PLATOSim: there is a new paper in preparation by De Ridder et al.)
  - In this conference, see the poster by N. Jannsen & D. Seynaeve and `http://ivs-kuleuven.github.io/PlatoSim3/`
- Rauer et al. (2014) Exp. Ast. 38 (but see also Rauer et al. 2016, AN, 337).

For the first time since 2007, we have results from engineering models (EMs) from Telescope Optical Unit (TOU), front-end electronics (FFE), data processing units (DPU) -> **real hardware**. We are digesting and integrating this information as it comes.

We have huge challenges ahead, but we have a GREAT team that is doing excellent work

thank you!


Disney

Thanks to the PLATO Team for making this mission possible