PLATO GOP

The accompanying Ground-based Observation Programme of PLATO

- Management
- Design & implementation of subsystems
- Operational working teams
- Observers

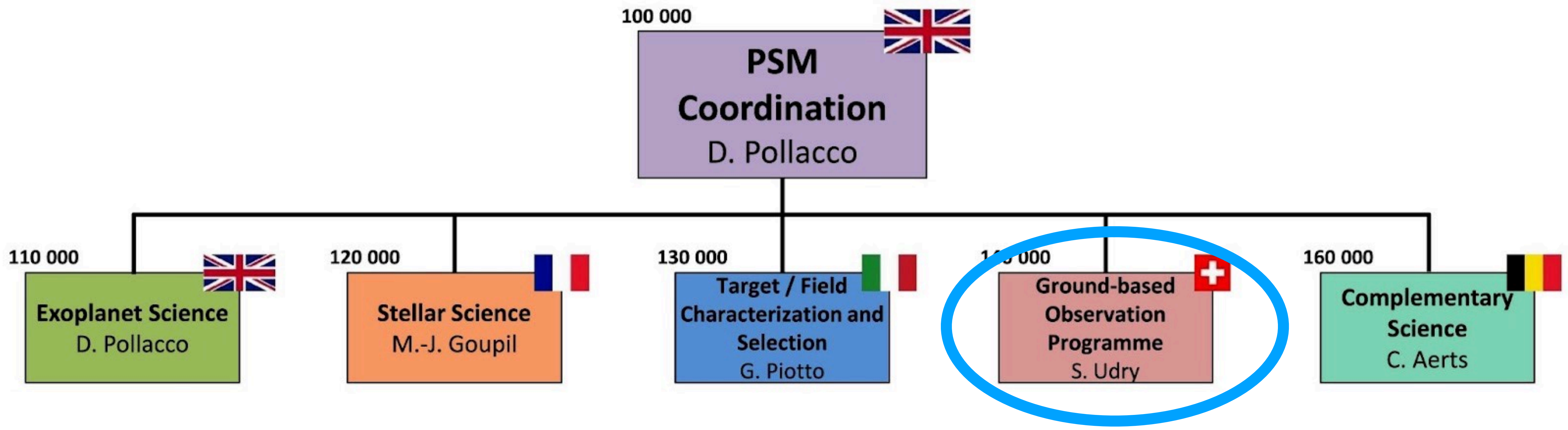
The GOP Team WP coordinators and active contributors: S. Udry, N. Mowlavi, D. Pollacco, F. Bouchy, R. Alonso, S. Desidera, A. Reiners, N. Santos, T. Wilson, Y. Alibert, I. Ribas, E. Masina, J. Portel, N. Billot, F. Alesina, J.C. Morales, A. Santerne, J. Poyatos, X. Dumusque, F. Pepe, E. Günther, T. Forveille, L. Malavolta, H. Deeg, G. Wüchterl, E. Palle, P. Chote, A. Vigan, M. Janson, D. Mesa, C. Lazzoni, P. Delorme, S. Sousa, P. Petit, D. Mourard, M. Bergemann, X. Bonfils, D. Ehrenreich, G. Hébrard, Pau Ballber, Néstor Campos Gestal, and many more…

Outline
- Motivation and role
- Estimated planet yield & telescope time
- Organisation (efficiency & optimisation)

Role of the PLATO Follow-up

Goals of the PLATO mission

- Detect planets and determine their radii and masses (respectively 3% and 10% precision at $m_V \leq 10$ mag);
- Demographics and architecture of planetary systems
- Determine accurate stellar masses, radii, and ages;
- Identify bright targets for atmospheric spectroscopy



Note: *the GOP is fully part of the PLATO consortium*

Main input for the science goals: **provide the missing complementary data to the PDC**

- Establish the nature of the transit events and identify/reject false positives — vetting, filtering: spectro, photom, imaging
- Characterise the planet properties (M, Rho, e) from Earth-type to giant planets as well as planetary system properties (statistics/architecture) — mass measurements
- Help correct for contamination effect (e.g. radius estimate) — new contaminants
- Help for the determination of stellar parameters — high-resolution spectroscopy

GOP: 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
   - binaries, 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

PDC

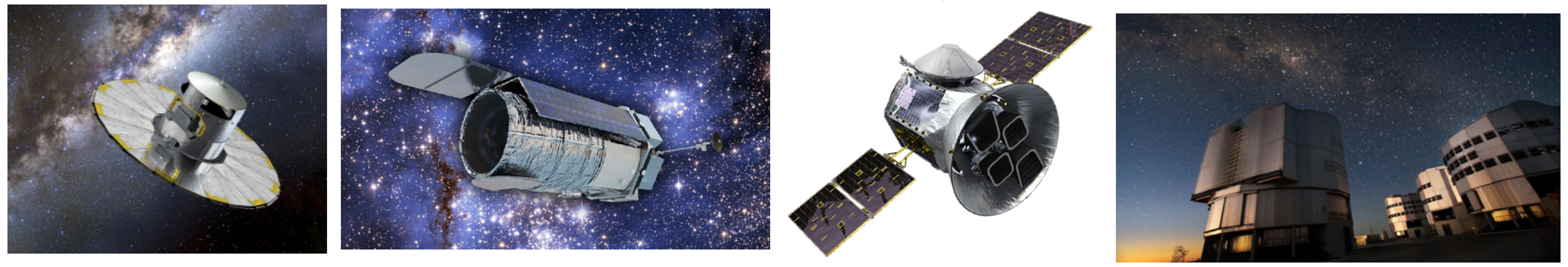
=> in PIC

Pipelines

PDC-DB

=> in PFU-DB database

=> + existing archive data



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

GOP will provide

- High resolution, high S/N spectra: v*sin*i, Fe/H, Teff, mean activity level (various indexes)
- Time series with BJD, RV, Sig_RV, CCF bisector, activity index, …
- Radii from interferometry
- High-angular resolution [high-contrast] images
- Ground-based photometry

Main PLATO Data Products

Level-0

Imagettes of selected targets

Validated light curves and centroids (generated on-board)

Level-1

Processed imagettes of selected targets

Light curves and centroids corrected for instrumental effects

Level-2

Planetary transit candidates

Results of asteroseismic analysis

Stellar rotation periods and activity

Stellar masses, radii, and ages

Planetary systems confirmed through TTV

Level-3

For Prime sample

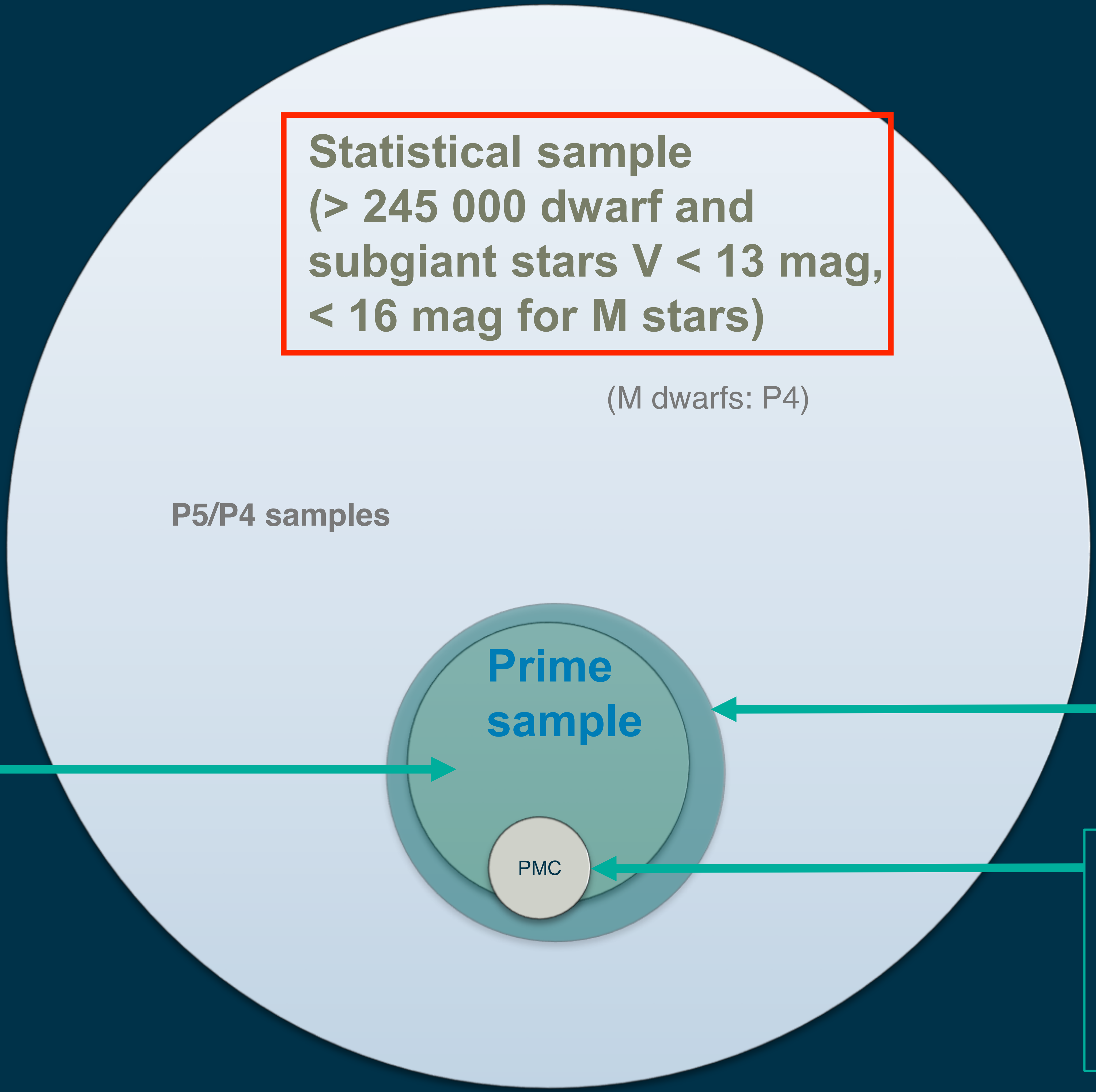
Catalogue of confirmed planetary systems combining transit and ground-based RV observations

Talk by H. Rauer

SAMPLES AND DATA ACCESS

Data access defined according to:

- Prime sample
- Non-prime sample (legacy part)
- PMC Proprietary targets
- Guest observers programme



Prime sample: ~20'000 stars

- Ground-based Observation Programme and delivery of L3 products
- List of stars will be published nine months before launch

P1/P2 samples:

~15 000 dwarf and subgiant stars (F5 to K7) with V <11 mag, < 50 ppm in one hour

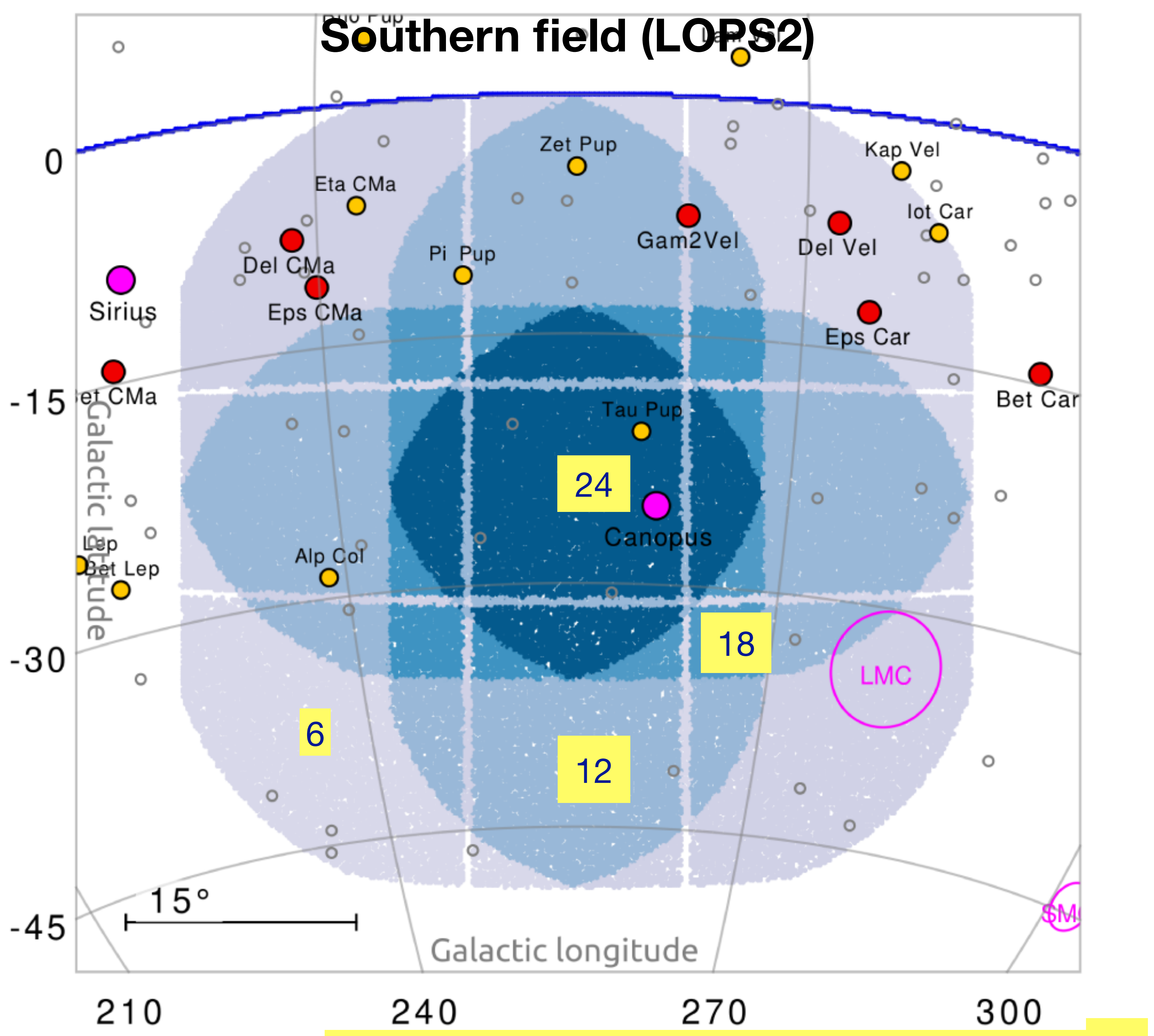
PMC Proprietary targets: 25% of the 25% prime sample targets of < 11 mag observed with best N/S

Talk by V. Nascimbeni

GOP Targets

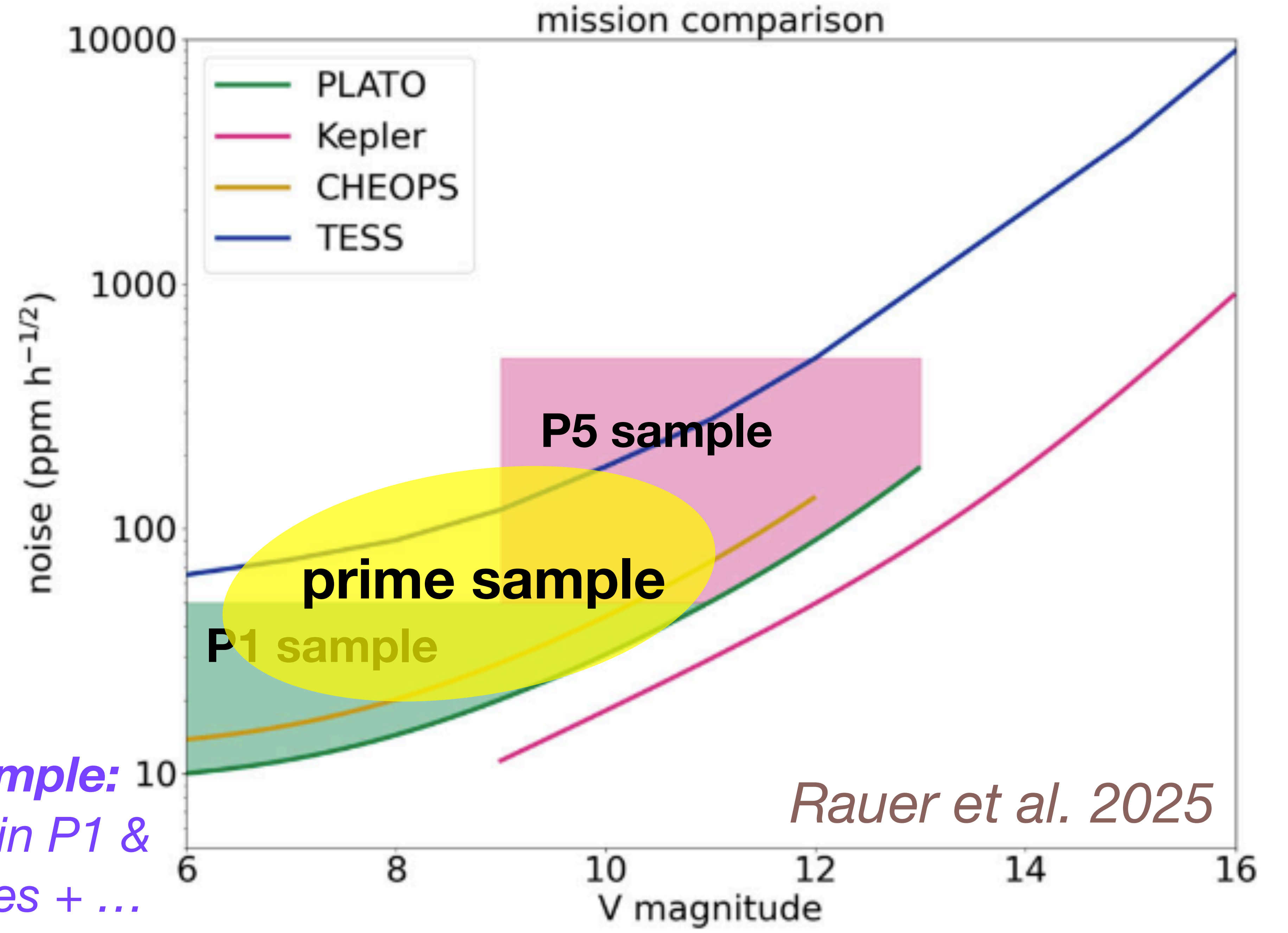
Talk by
V. Nascimbeni

- ***The prime sample*** (base for dimensioning)
  - Is the main priority of GOP targets (contractual)
  - Optimised to detect/characterise Earth-like candidates in habitable zone
  - ~20'000 targets (over the 4-year nominal mission)
  - Later release date than other targets



Number of cameras observing each region

- ***Additional observations of targets** devoted to science cases (PMC Science activities)*
  - To **enhance scientific return** of the mission
  - Benefiting from GOP machinery (infrastructure and organisation)
  - Requests from **Working Groups** of the PMC science community, prioritised by a dedicated *operational WG,* and monitored by the PLATO Science Core Team (PSCT).
  - Can be scheduled **on facilities upon availability**.



Rauer et al. 2025

Prime sample: *selection in P1 & P5 samples + …*

Expected planet yield

Samples	known transiting planets	Red Book	Heller	2+2 Cabrera
all planets, <13 mag in P1, P5 samples	1 151	≈4 600	n/a	6 800-7 100
all planets V<11 mag	330	≈1 200	n/a	1 200-1 350
planets <2 r_e in HZ <11 mag	0	6 - 280	11 - 34	0 - 120

Samples	known transiting planets	Red Book	Heller	3+1 Cabrera
all planets, <13 mag in P1, P5 samples	1 151	≈11 000	n/a	10 100-10 700
all planets V<11 mag	330	≈2 700	n/a	2 200-2 500
planets <2 r_e in HZ <11 mag	0	3-140	8-25	0 - 90

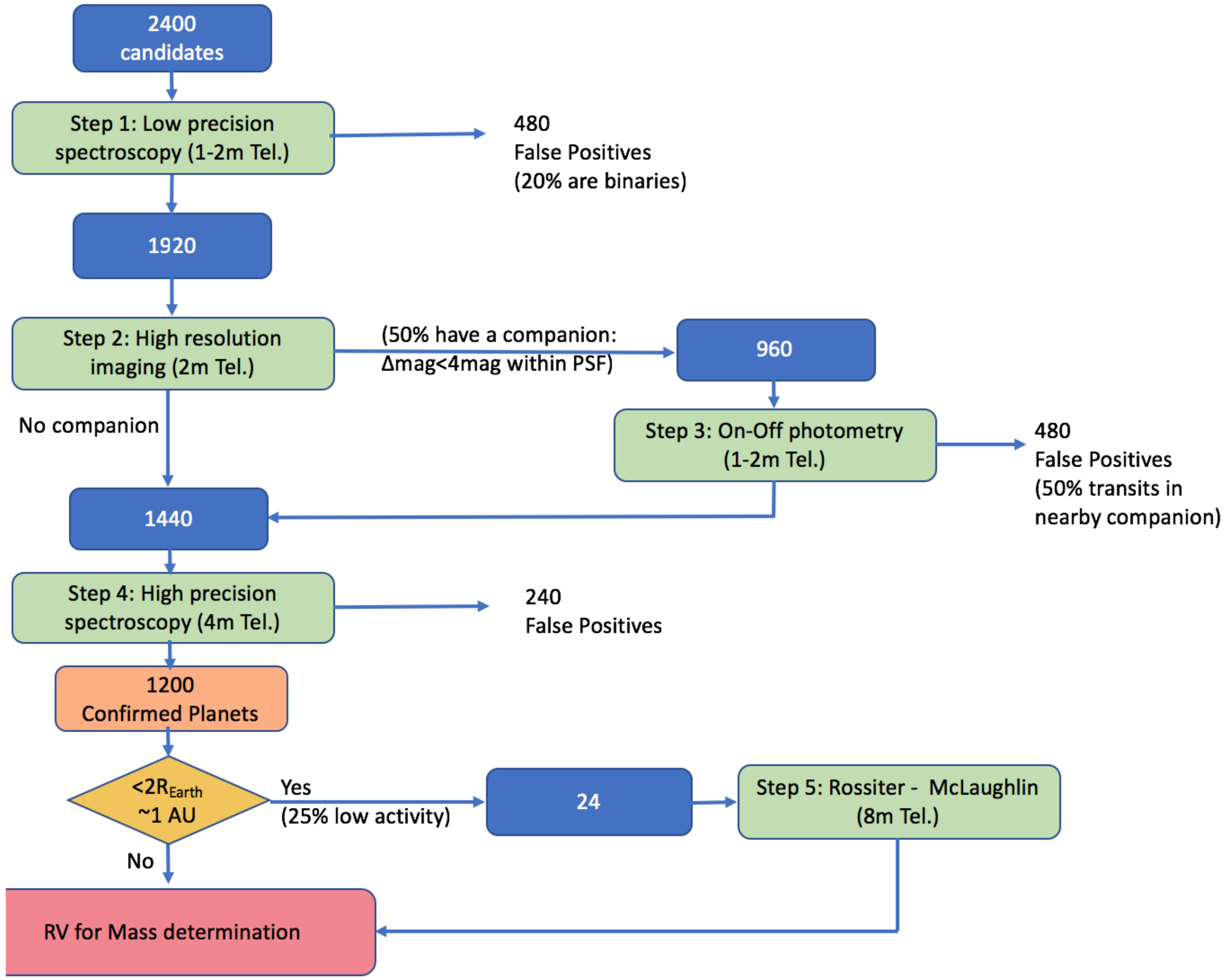
Table 1 Estimated PLATO planet yields. Red Book: ESA-SCI(2017)1; Heller: Heller et al. (2022); Cabrera: Cabrera et al. in prep. 2022. 2+2 means 2 long pointings of 2 years duration; 3+1 means one 3-year observation followed by one year with six target fields for 60 days each, as in the Red Book. Known transit planets are taken from the NASA exoplanet archive in Dec. 2022)

Largest uncertainty comes from unnown frequency of small planets
→ to be provided by PLATO

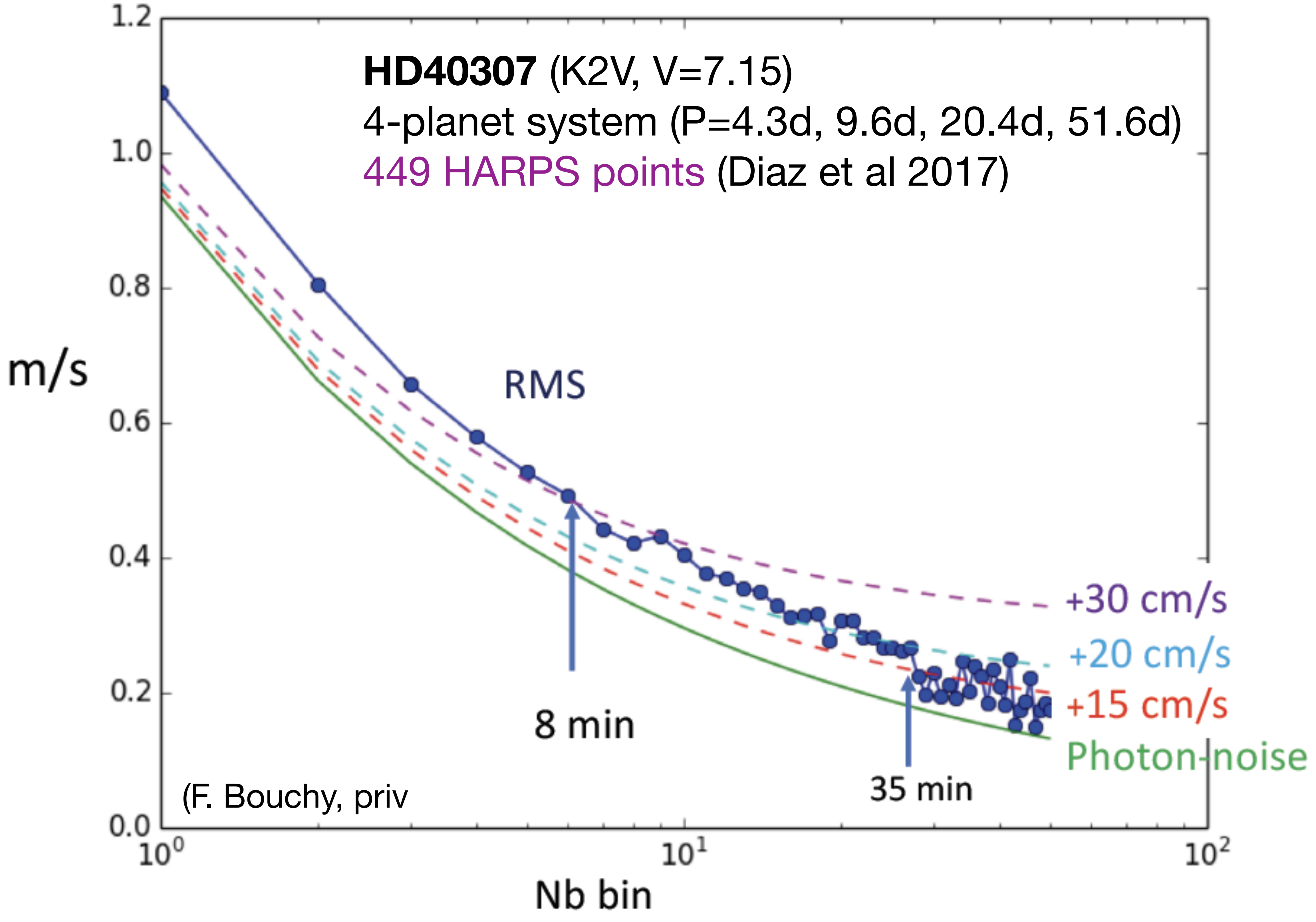
Rem: for the telescope time estimate we considered 10 Earth-type planet in the HZ

PLATO yield and need in telescope time?

1. ***Early estimate***
   - based on results from Kepler + ad hoc value of *eta Earth* = 40% (publications: 0 % — 90%)
   - vetting needs (from Kepler) and standard procedure (recon spectro, on-off photom, …) => educated guesses
   - challenge: precise mass estimate => only for the 25% of the most quietest candidates
   - binning of RVs to obtain equivalent precision per bin, taking activity into account (Dumusque et al. 2010, 2011)



ESPRESSO continuous observations over 5 nights:
1150 measurements



Telescope time estimate for the prime sample (2015)

Table 6.2: Estimates of ground-based telescope resources needed for follow up of planet candidates discovered during the PLATO Long-duration Observation Phase in both hemispheres.

Telescope Class	Filtering/Candidate Confirmation		Radial Velocity Measurements		Total Nights
	(nights/year)	(Total nights in 7 years)	(nights/year)	(Total nights in 9 years	
1- sp					
1- imaging					
1-					
1- sp					
4m high-resolution spectroscopy	~20	~140	~100	~900	~1040
8m high-resolution spectroscopy	~5	~35	~80	~720	~755

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

The largest part of the effort goes into the precise mass measurements

Note 1: The time spans of 7 years for the filtering observations and of 9 years for the radial velocity observations are assumptions based on estimates of available telescope resources.

Note 2: The numbers reported in the Table are global for northern and southern sky visibility.

PLATO yield and need in telescope time?

2. ***A statistical framework estimate (# of observations to obtain masses at 10%):*** (Hara & Udry in prep)

- based on Gaussian statistics

RV uncertainty of individual measurements
Instrument + photon noise + stellar signal

$$\sigma_K \approx \frac{1}{\sqrt{\frac{1}{\sigma^2_{K,\mathrm{prior}}} + \frac{1}{2\sigma^2_{RV}(P)}\left(N\left(1 - \sum_{j=1}^{r} \rho_j^2\right) - p\right)}}$$

desired precision

A priori precision:
at the beginning, very big
Term ⇢ 0

# of observations

Correlation effects between
close red noise time scale and P_{pl}
Term ⇢ 0 if no such correlation

# of free parameters
(# of planets)

When N large,
planets not important

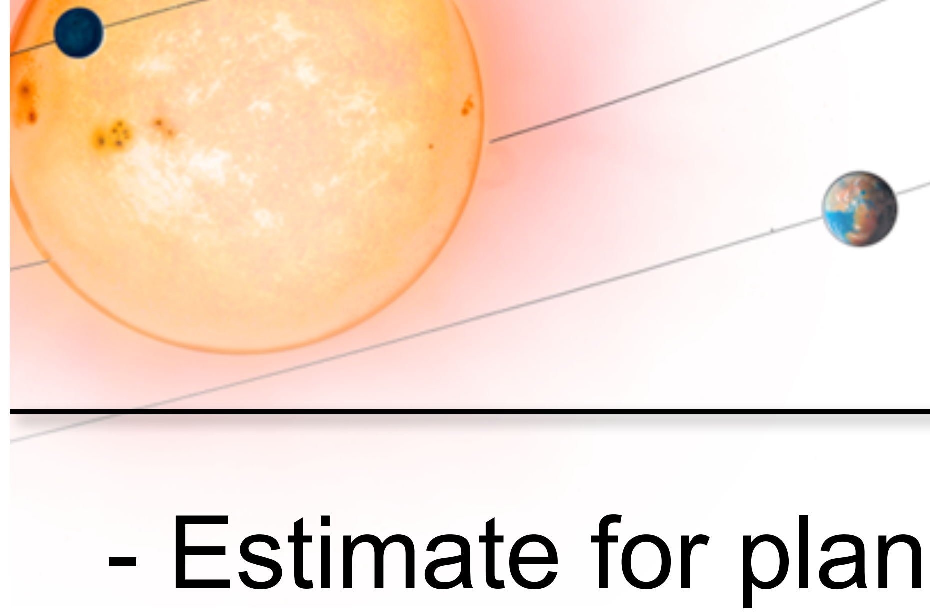
RV measurements: statistical framework

Final estimate: Number of observations for a given precision
by inverting the previous relation

$$N \approx \frac{1}{1 - \sum_{j=1}^{r} \rho_j^2} \left(p + 2\sigma_{RV}^2(P) \left(\frac{1}{\sigma_{K,\text{desired}}^2} - \frac{1}{\sigma_{K,\text{prior}}^2} \right) \right)$$

(Hara & Udry in prep)

- Formalism very flexible and quick to apply
- Needed parameters provided by
  - PLATO light curve: P_{pl}, phase, R_{pl} (via R_{star})
  - PIC: stellar mass & radius, and potential other knowledge about the star (e.g. Prot)
  - A priori:
    - instrumental stability (from facilities)
    - distribution of activity per spectral type (from existing spectro surveys) or modelling
    - R_{pl} - M_{pl} relation (from models, observations, etc)

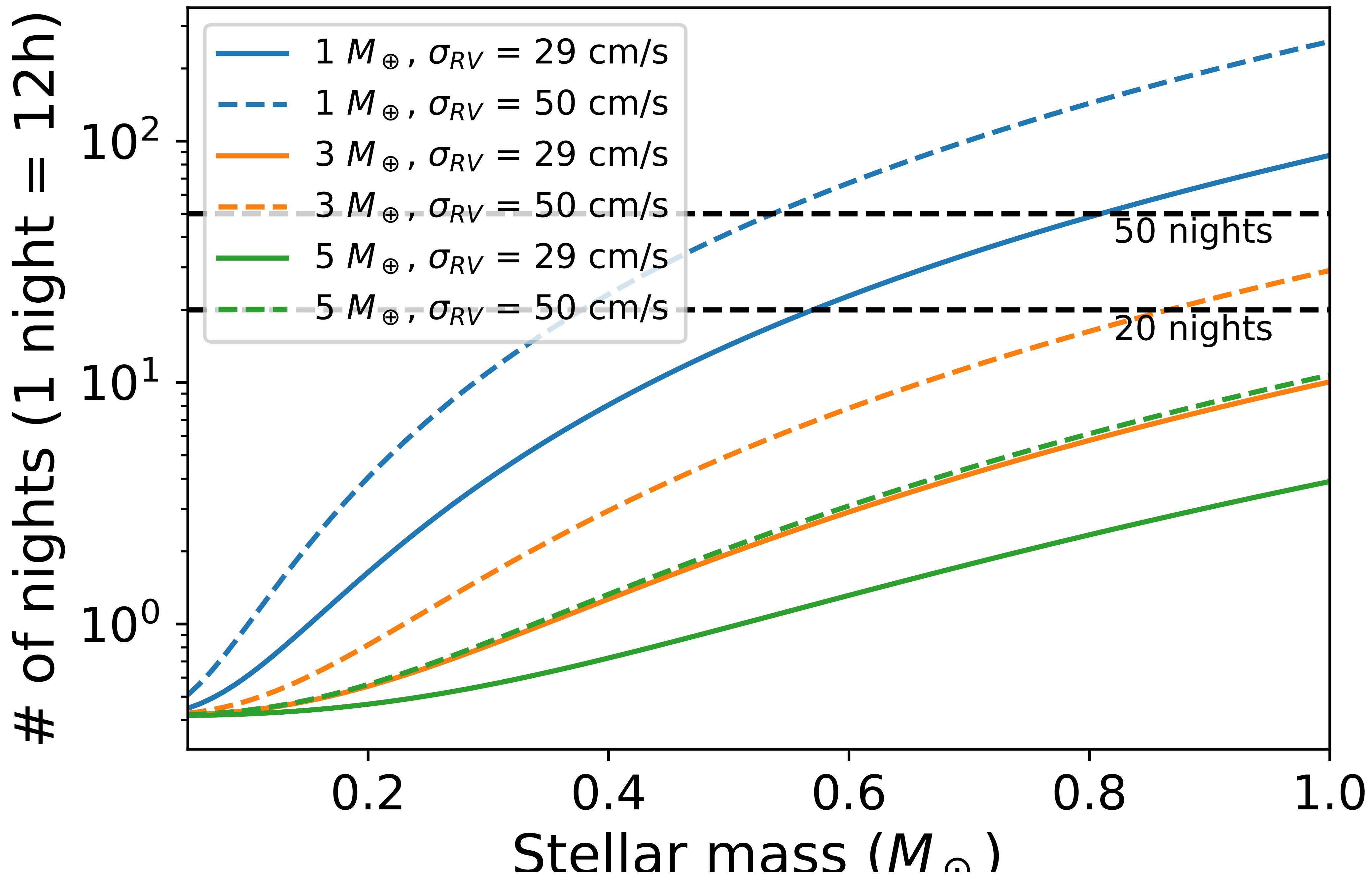


RV measurements: statistical framework

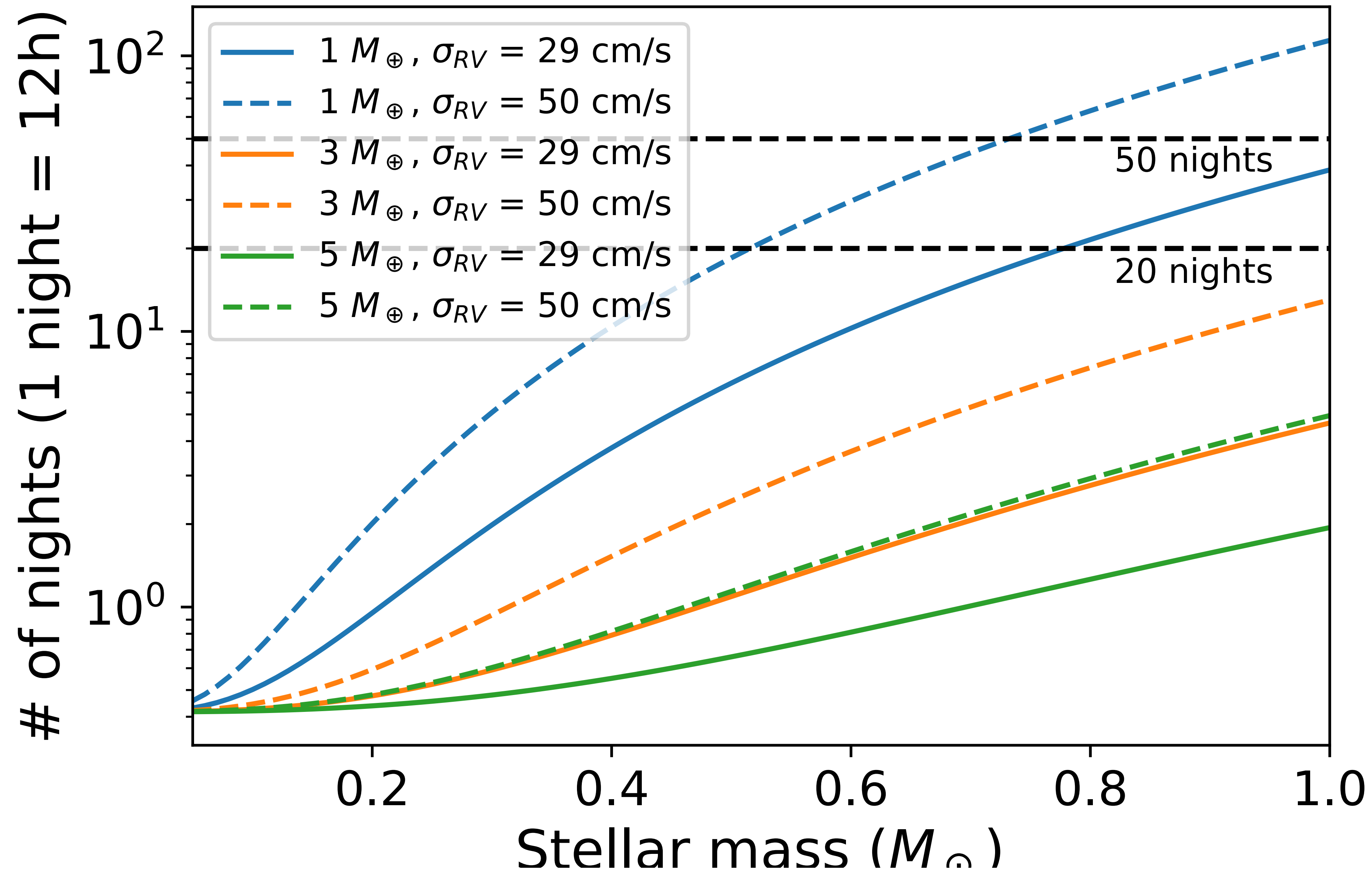
- Estimate for planets in the habitable zone

• Case of a 1 Earth mass planet in the habitable zone of stars of various masses (V=10)
• Keep in mind that the estimate is only valid for large N
• Results on individual cases in agreement with our basic estimates from 2015

10% precision on mass



15% precision on mass



=> confirmation of the numbers previously estimated with binning (within uncertainties)

PLATO yield and need in telescope time?

3. ***Status today***

- Vetting part is +/- under control
  - GAIA is helping tremendously (stellar parameters, identification of contaminants
  - large number of small size facilities and several moderate precision spectrographs (5-10 m/s on RVs)
  - some unknown about the need for high-angular resolution, high-contrast imaging (8m telescopes)
- Main difficulty is the mass estimate (10% level is incredibly difficult for an Earth around the Sun)
- Longer periods are also more difficult

Talks by S. Gouffal/L. Pietro

- In some cases (e.g. resonant systems) TTVs will help (but be careful of potential systematics, Leleu et al. 2022) => combining RVs and TTVs will be a wining approach

Talks by R. Mardling/A. Leleu

- Challenge of the RV precision (next slide):
  - photon noise => bright stars + large facilities
  - instrumental fidelity (stability and reproducibility)
  - stellar contribution

Talk by L. Malavolta

- A PLATO Stellar Variability Working Group (SVWG) is presently addressing the question

Talk by S. Aigrain

  - with specialists of stellar physics, precision photometry (transits detection) and precise RV measurements
  - photometric and RV data challenges are on-going

Talk by Crétignier/Hara

  - development of a best observing strategy for each type of stellar effect influencing RV measurements

- Important challenge we are facing: when do we start intensive RV follow-up of a candidate?

New smart approaches for disentangling stellar, instrumental, telluric and planetary contributions

1) RV extraction => 2) Analysis of time series => 3) Frequency analysis and robust statistics

Recent developments

Method	Metric	Mitigation	Separation	Reference
GP Framework		Multidimensional GP Modeling		Rajpaul+2015, Barragan+2022
GLOM		Multidimensional GP Modeling		Gilbertson+2022
FDPCA		Commonalities in Fourier Space		Ramirez Delgado+2022
GPRN		GP Neutral Net Modeling		Camacho +2022
SCALPELS	PCA Amplitudes (CCF)		Shape/Shift-driven RVs	Collier Cameron+2021
CCF Prime	GP Model Coefficients		Shape/Shift-driven RVs	Baptiste Klein tbs
FIESTA+GLOM	Fourier Model Coefficients			Zhao & Ford 2022
CCF Linear Regression			Shape/Shift-driven RVs	de Beurs+2020
CCF Masks			Variable/Stable Lines	Alex Wise, Lafarga+2020
LBL+PCA spectr			Variable/Stable Lines	Dumusque 2018, Cretignier+2022
LBL+PCA rv	PCA Amplitudes (LBL RVs)			Cretignier+2021, +2022
PWGP			Variable/Stable Lines	Rajpaul +2020
DCPCA	PCA Amplitude (Spectra)			Jones+2017
Generative RR		Regression w/ Spectral Residuals		Zhao+2022
Discriminative RR				Zhao+2022

=> Next week EPRV6 meeting in Porto

Gaussian Process Linear Ordinary Differential Equation (ODE) Maker (GLOM)
Fourier Domain Principal Component Analysis (FDPCA),
Gaussian Process Regression Network (GPRN)
Self-correlation Analysis of Line Profiles for Extraction of Low-amplitude Shifts (SCALPELS)

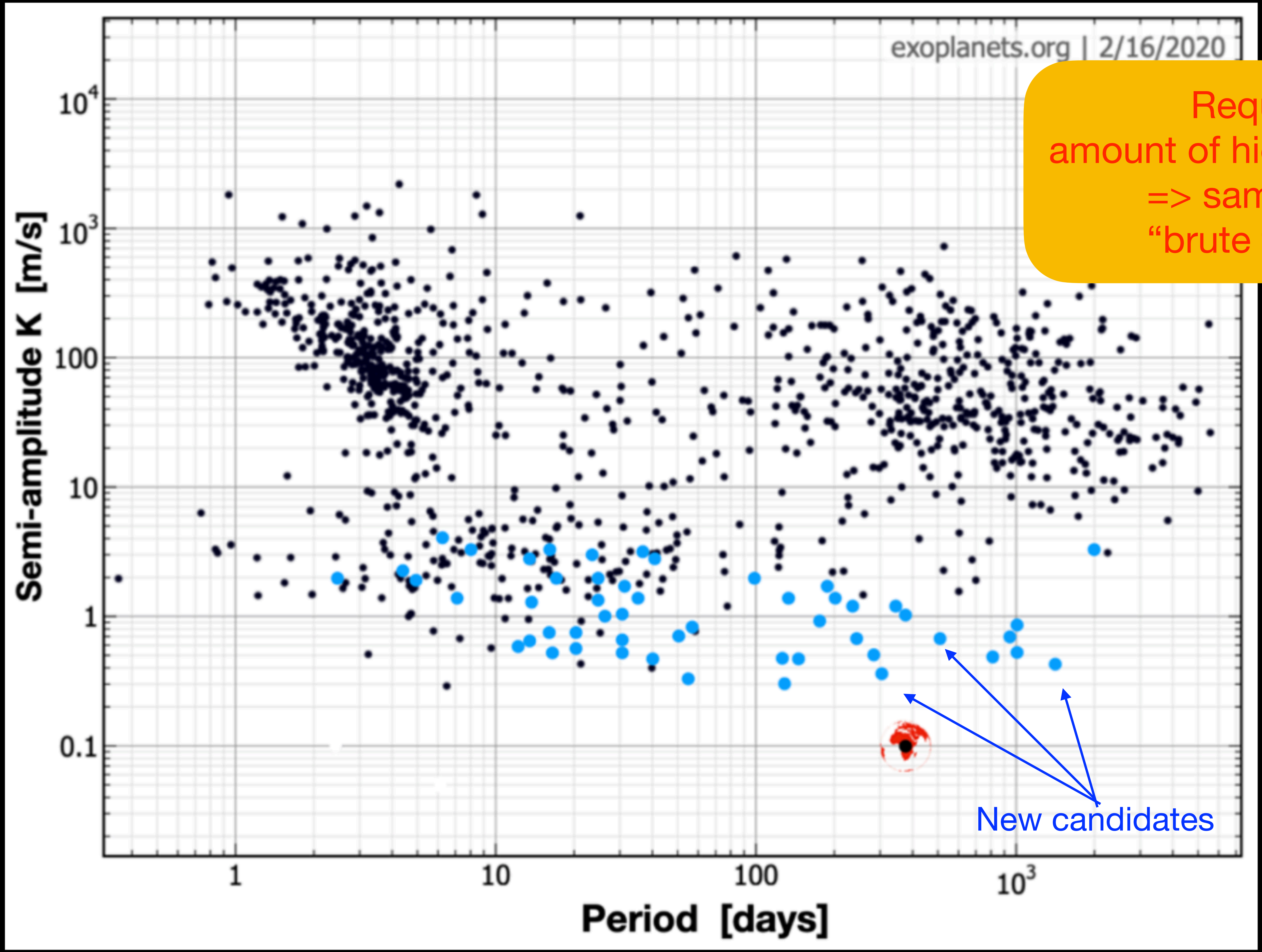
Fourier Phase Spectrum Analysis (FIESTA)
Line By Line (LBL)
Pairwise GP (PWGP) RV extraction
Doppler-constrained PCA (DCPCA)

Adapted from Zhao+2022

Luca Malavolta, GOP workshop, Geneva 2022

Reanalysis of HARPS archive data

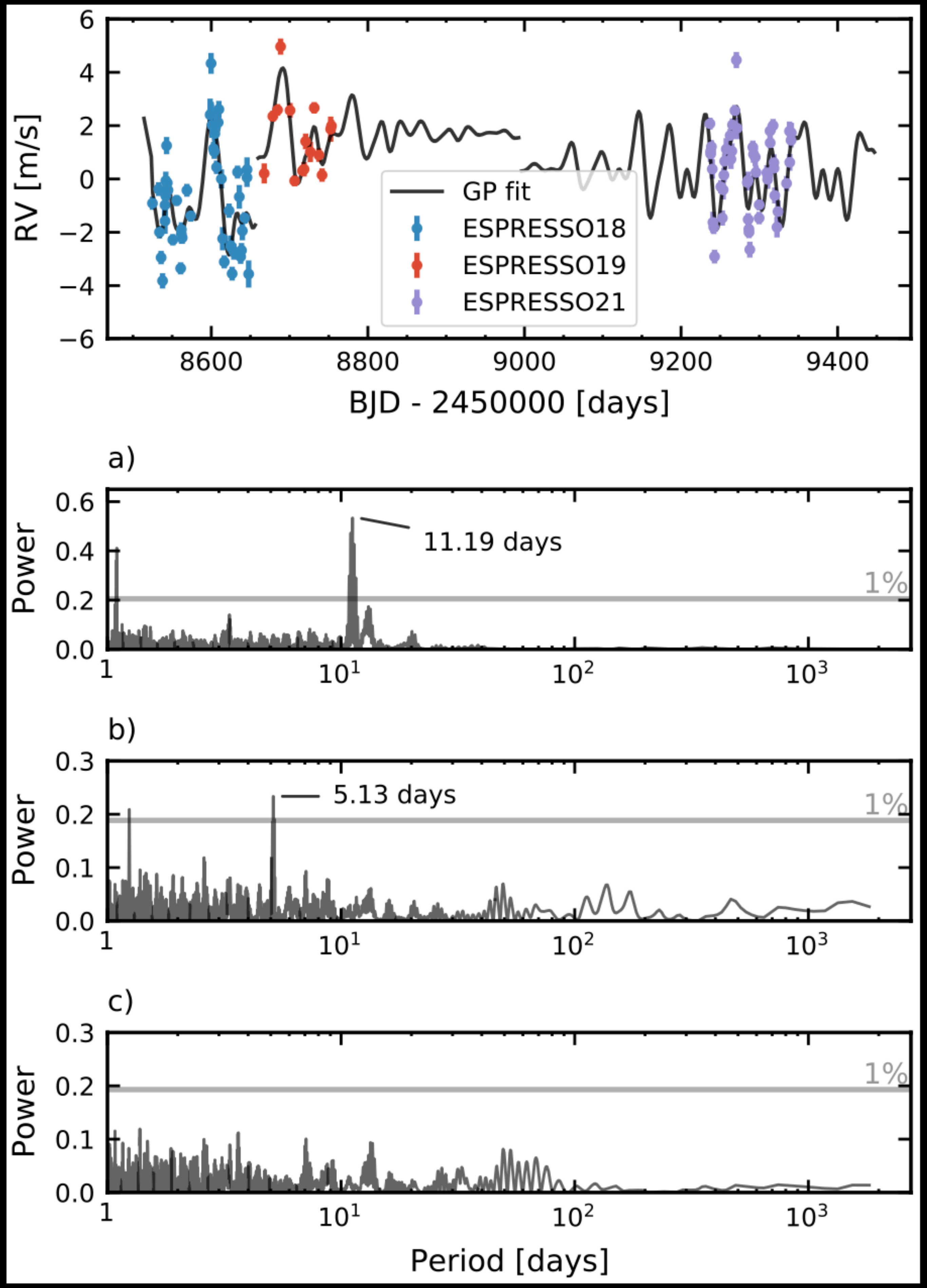
There is some hope !!!

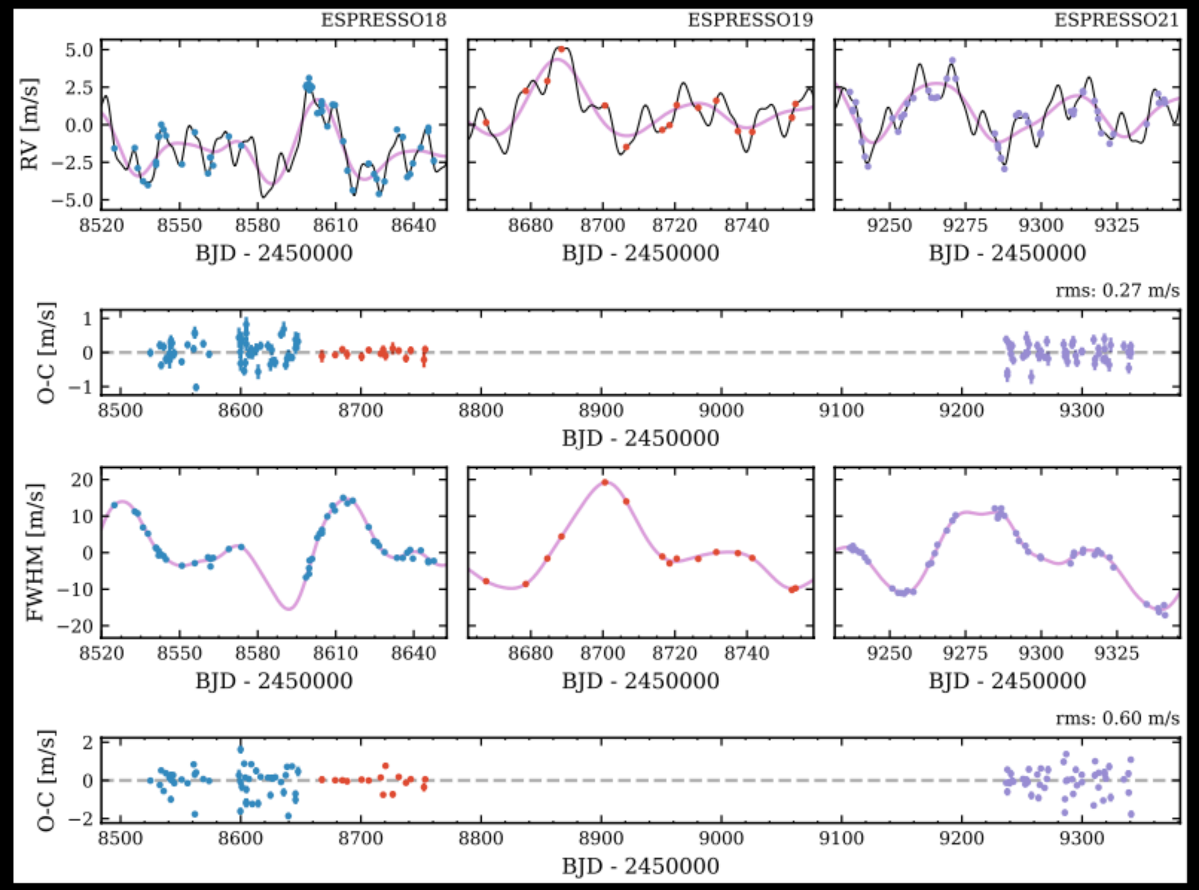


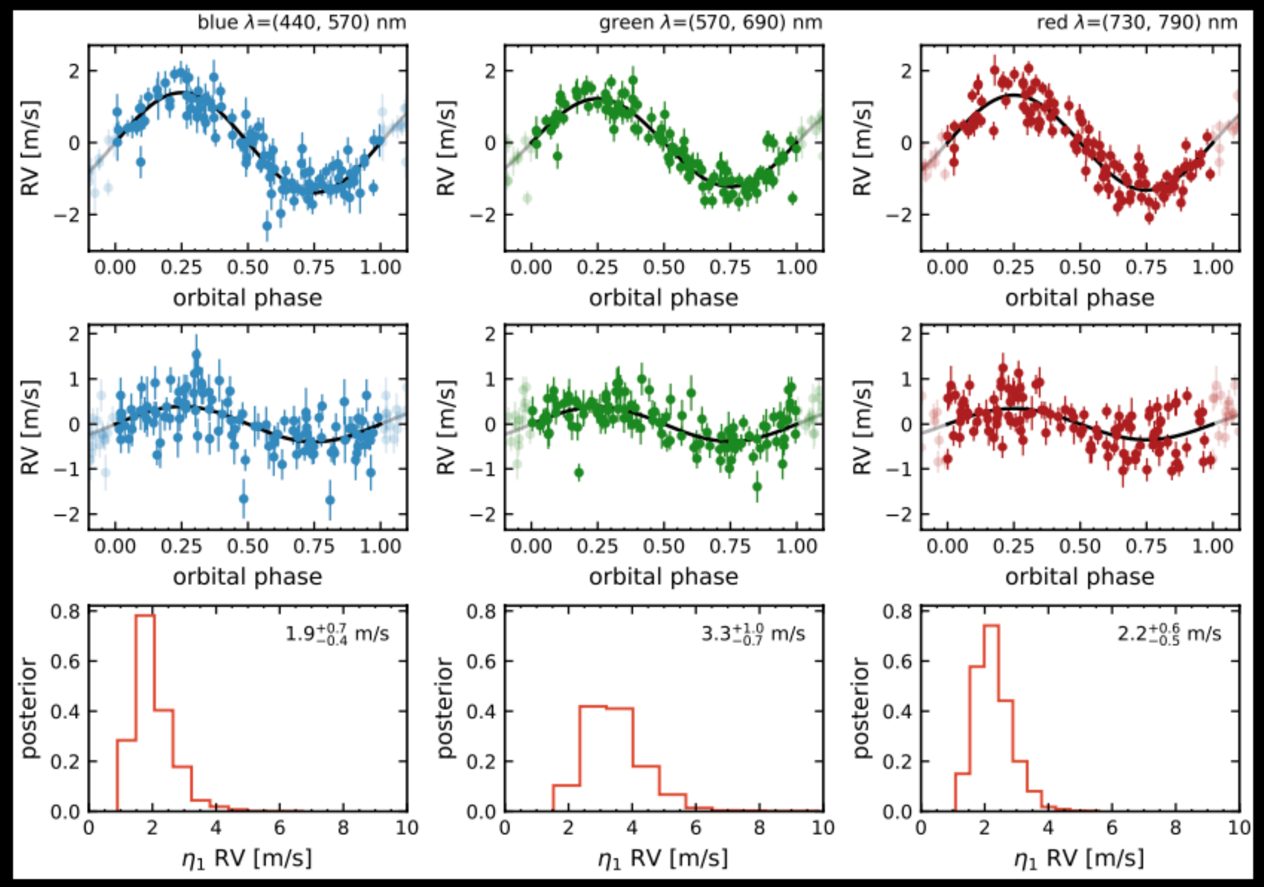
Requires a large amount of high S/N observations => same order as the “brute force” binning)

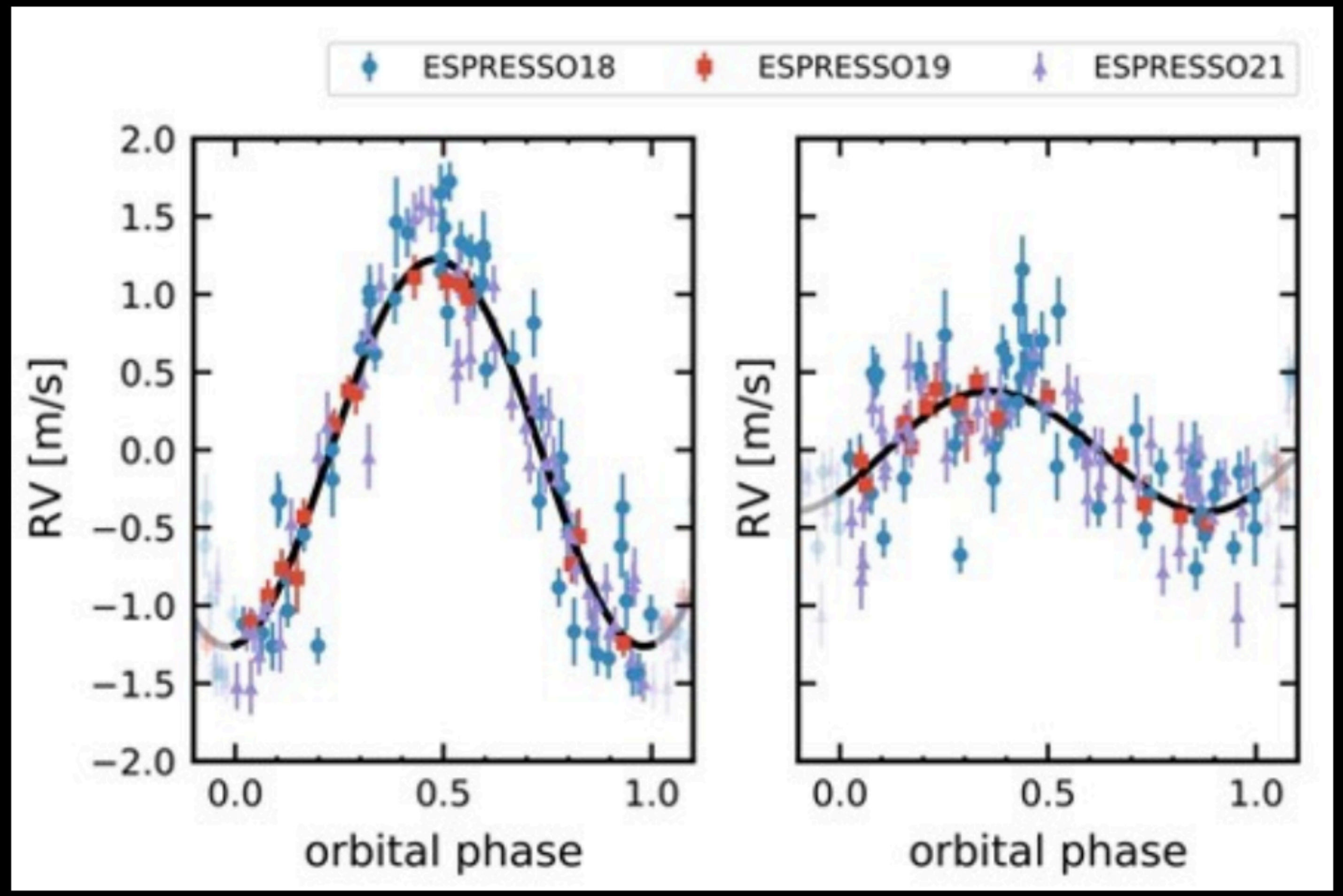
Cretignier+ 2021, 2022
Cretignier+ in prep.

The example of Proxima Cen (ESPRESSO)









Proxima Cen

rms to the orbit fit of 29 cm/s. Planet d of 0.26 M_E on a 5-day orbit!

Faria et al., A&A 2022

HD3651b with EXPRES

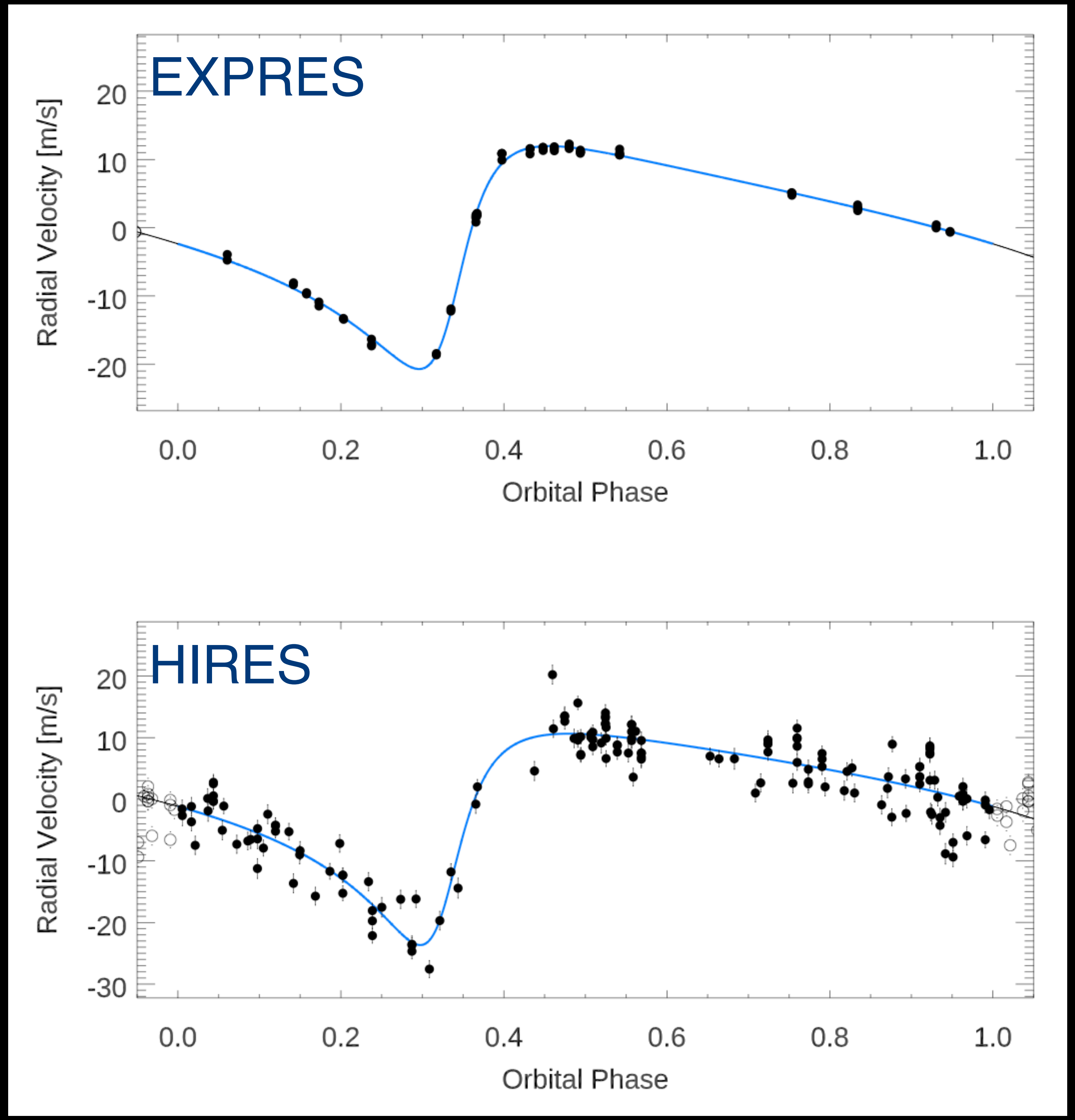


Table 4. Keplerian Model for HD 3651 b

Parameter (1)	EXPRES (2)	Keck HIRES (3)
P [d]	61.88 ± 0.55	62.26 ± 0.075
T_p [d]	58726.2 ± 1.2	58726.68 ± 0.5
e	0.606 ± 0.09	0.612 ± 0.12
ω	243.8 ± 23.4	231.9 ± 41
K [m s^{-1}]	16.93 ± 0.22	17.15 ± 0.9
$M \sin i$ [$M_\oplus$]	69.04 ± 4.1	66.88 ± 5.9
a_{rel} [AU]	0.284 ± 0.002	0.285 ± 0.001
RMS [m s^{-1}]	0.58	3.4

Brewer et al., Astron. J. (2020)

Good precision presented on specific cases
Not clear about the potential number of nights available
Telescope access for Europeans?

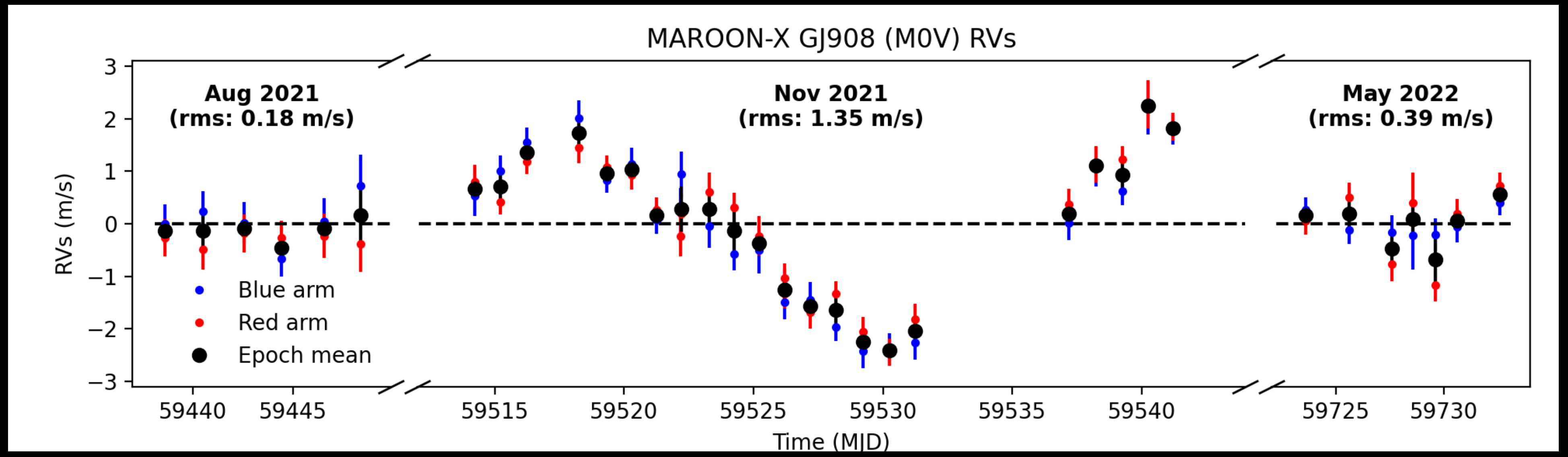
Maroon X (Courtesy of J. Bean)

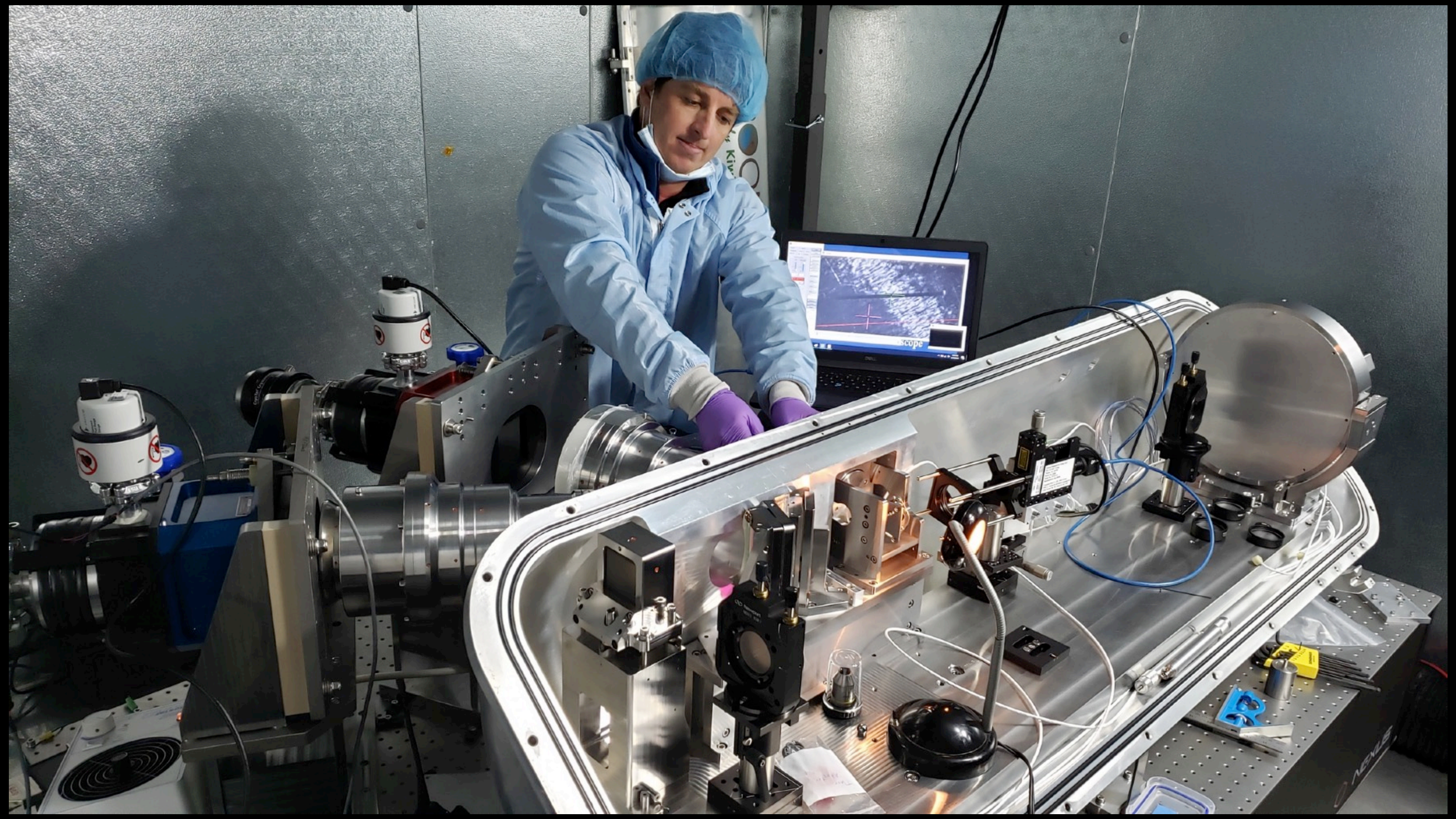
Primary science driver: Confirmation and mass measurement of transiting, temperate, and terrestrial planets that are feasible targets for atmospheric spectroscopy. I.e., *TESS* follow up.

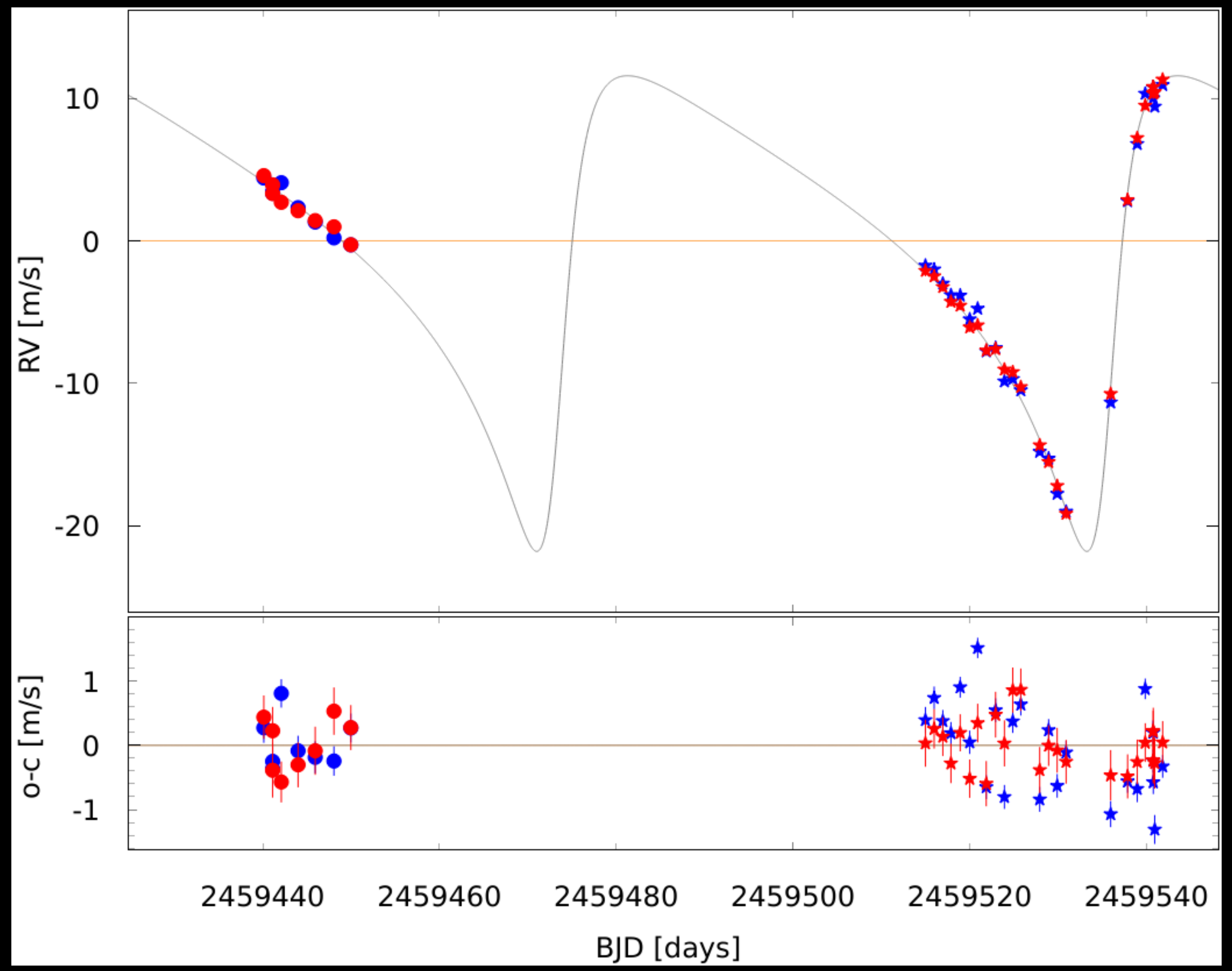
Goal: σ = 1 m s^{-1} in <30 min for late M dwarfs out to 20 pc (V=16.5).

Approach: A highly-stabilized, fiber-fed spectrograph covering 500 – 900 nm at R=85k with simultaneous calibration feed and pupil slicing.

Seifahrt et al. 2022







HD3651

rms to the orbit fit of 38 cm/s for the red arm and 63 cm/s for the blue arm

Good precision presented on specific cases

No long-term plans

Very limited number of nights (even for the development team)

Telescope accessibility?

Radial Velocity Facilities

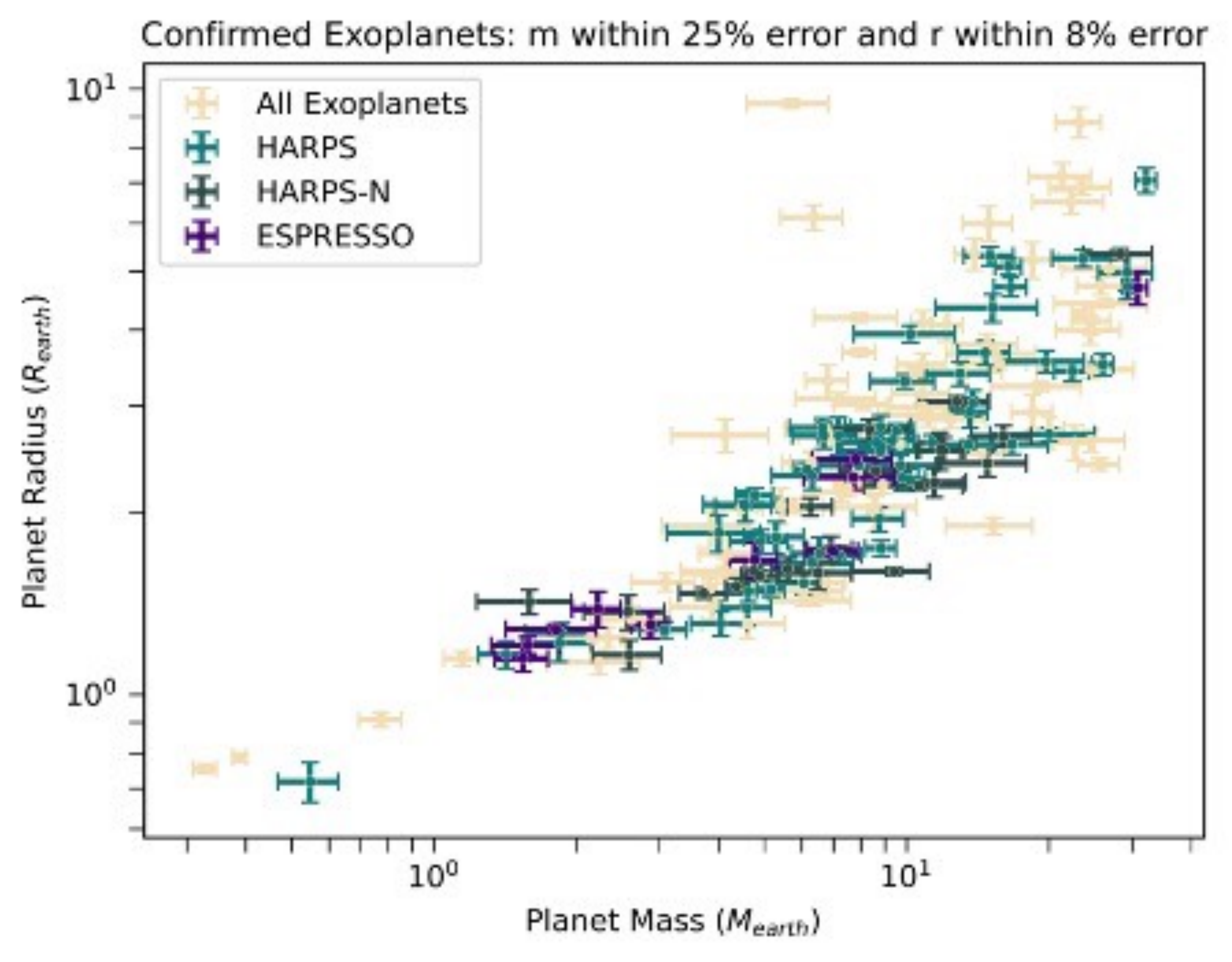
Facilities will be ranked not as function of the telescope diameter but as a function of the RV uncertainties effectively obtained for a solar-type star of magnitude mv=11 in a 1h exposure. The uncertainty should include photon-noise and instrumental systematic error.

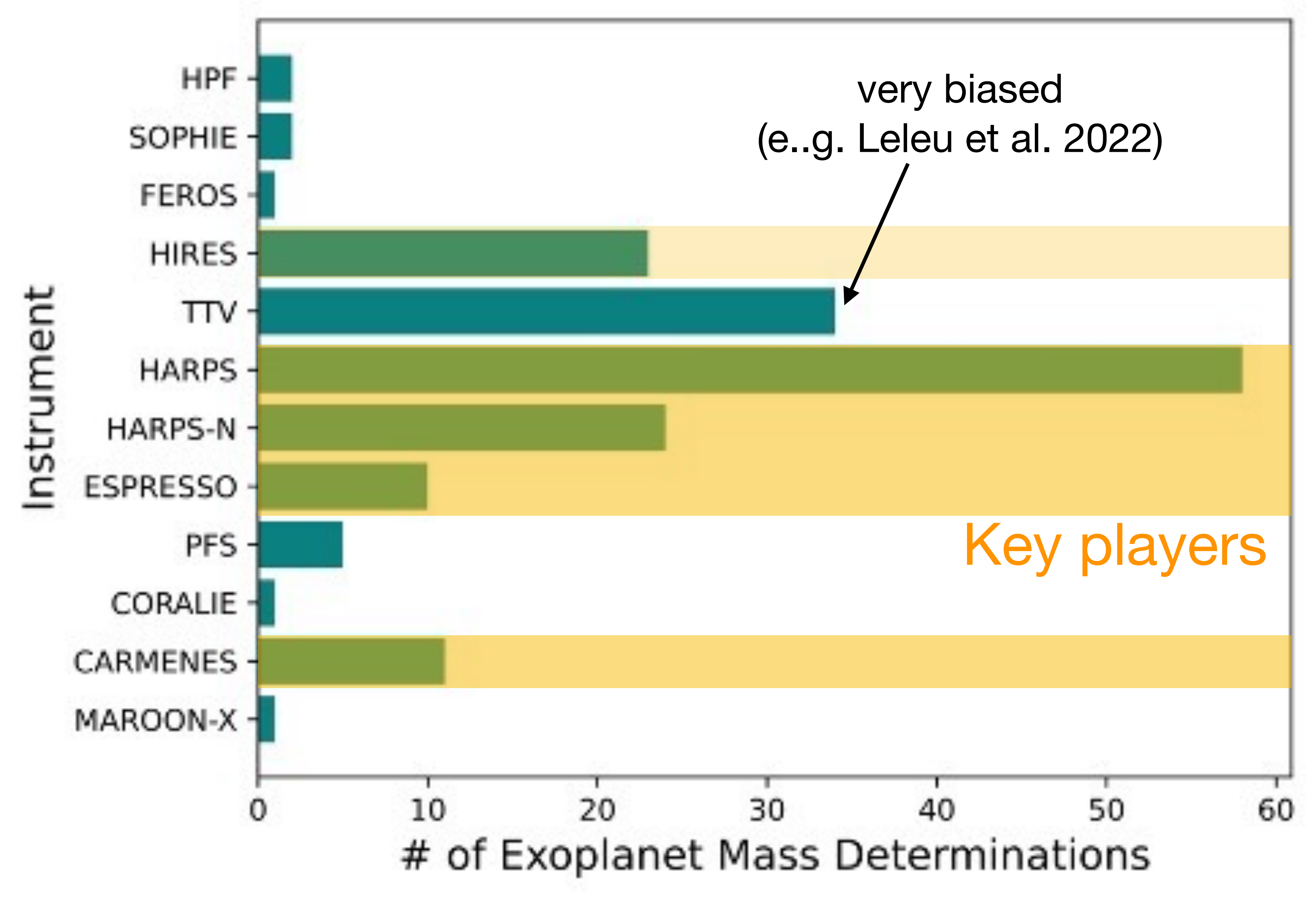
Precise mass measurements of small planets require at the same time "precision" and "availability"

=> not many facilities can provide both

Challenge - Precise radial velocities (GOP)

- Mass-radius diagram of small exoplanets as of August 2022. Only planets published in a refereed journal with a mass precision better than 25% and a radius precision better than 8% are shown





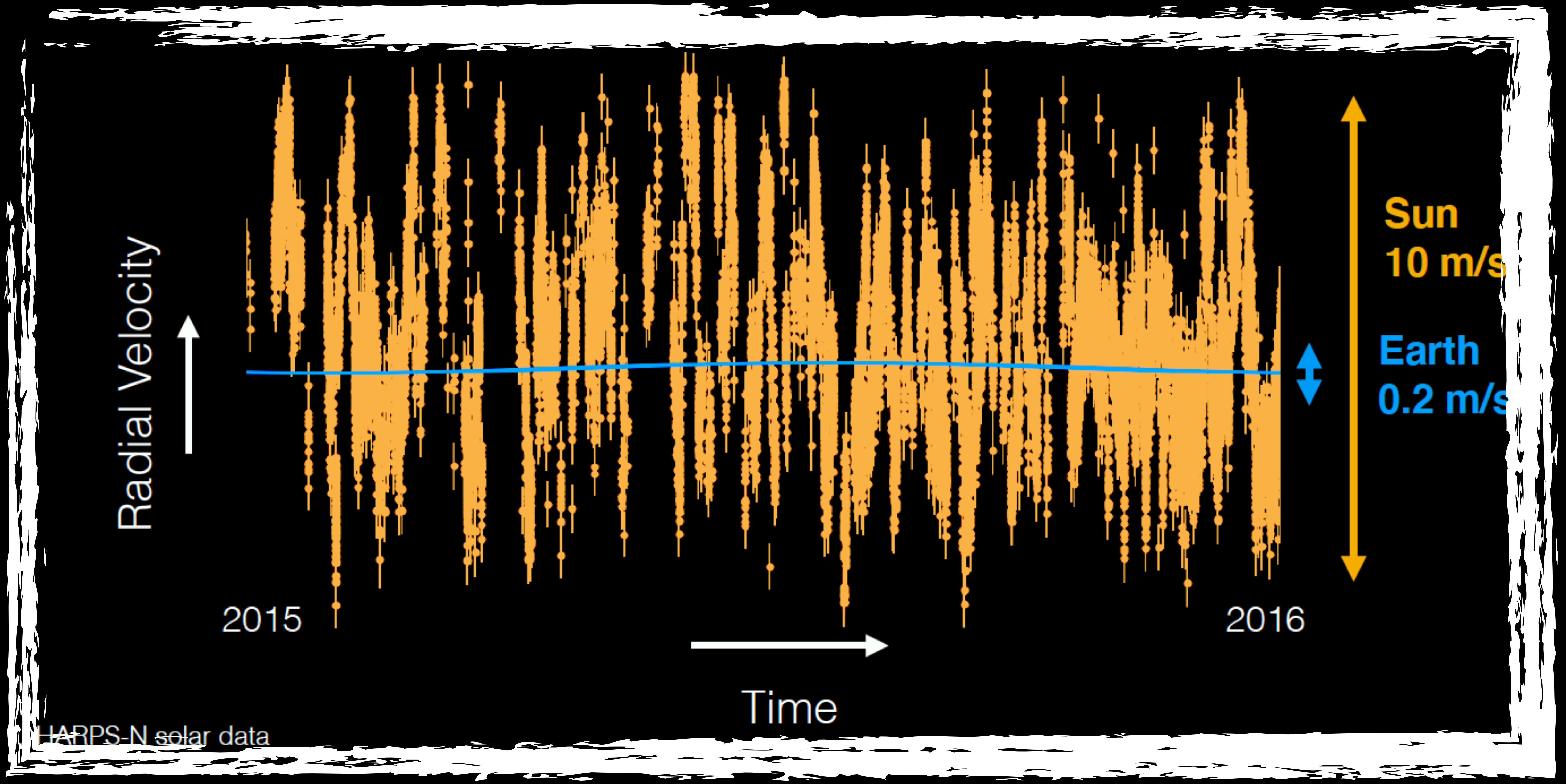
Naidar, private communication

- HARPS, HARPS-N, Carmenes (4-m tel): ~1m/s, many nights, photon-limited below 1 m/s
- HIRES: 1-2 m/s, substantial investment of telescope time
- ESPRESSO: ~0.3 m/s (stability ~10 cm/s)

Challenge - Precise radial velocities (GOP)

A feel of the challenge with solar data => use the Sun as a proxy (solar telescopes)

Talk by B. Lakeland



=> Not only RV precision (stability & repeatability) => New generation of spectrographs ✓
=> Also model of the stellar effect => huge effort of the community on-going ✓
=> And large amount of available nights => discussion with ESO ✓

Another challenge : GOP organisation & efficiency

- Large number of expected transit candidates (prime sample + interesting candidates in statistical sample)
  => systematic observation of all transits with large telescopes unfeasible
  => an optimised follow-up scheme has been 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 (avoid useless observations)
  => minimum number of used facilities per target (avoid inefficient duplications)

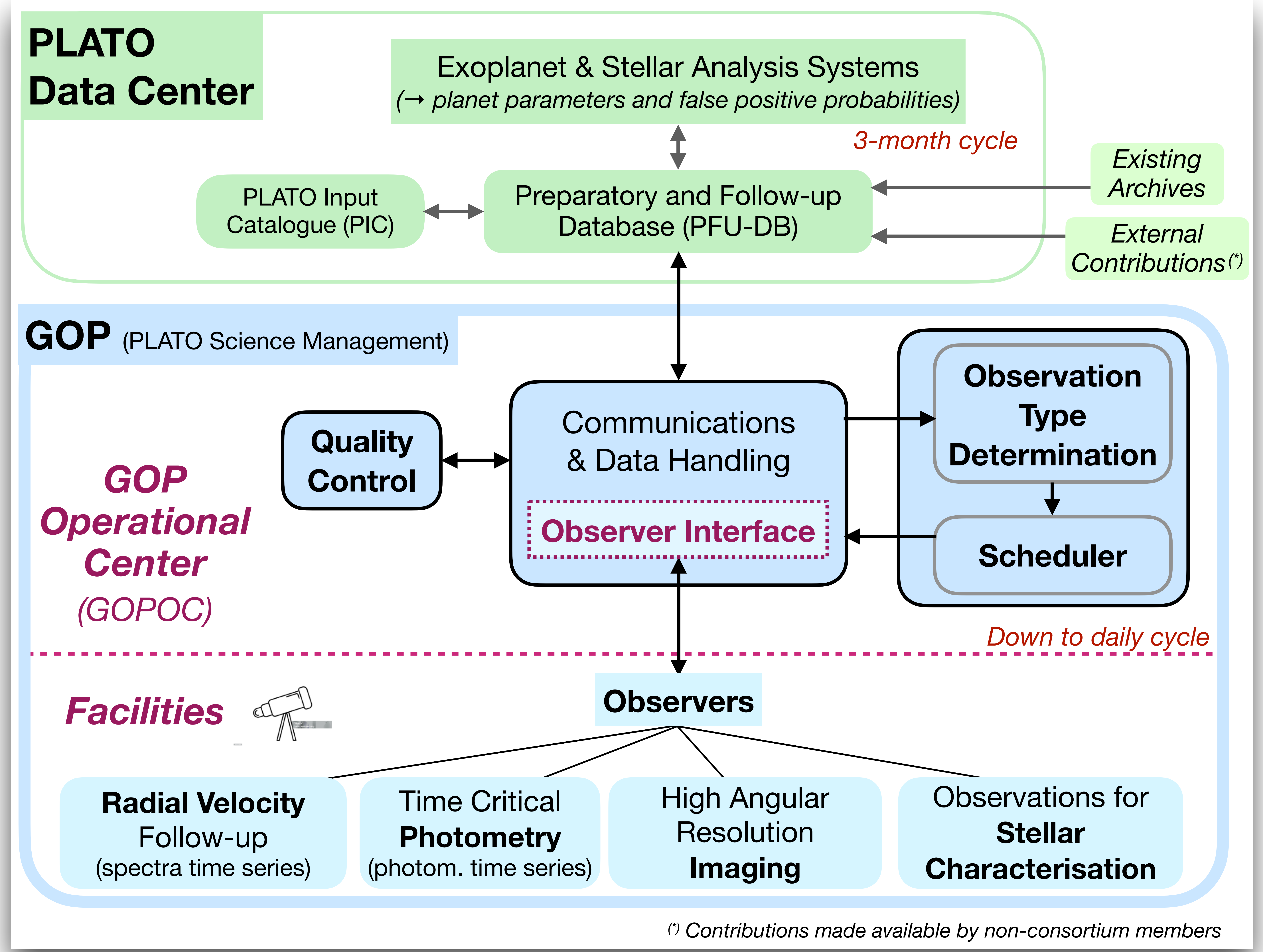
In practice => a “guided” multi-step approach from moderate to high-precision (screening)

=> Design and development of tools for:
- optimum automatic match between participating facilities and target needs
- efficient interface between observers and target information

+ optimisation of scheduling

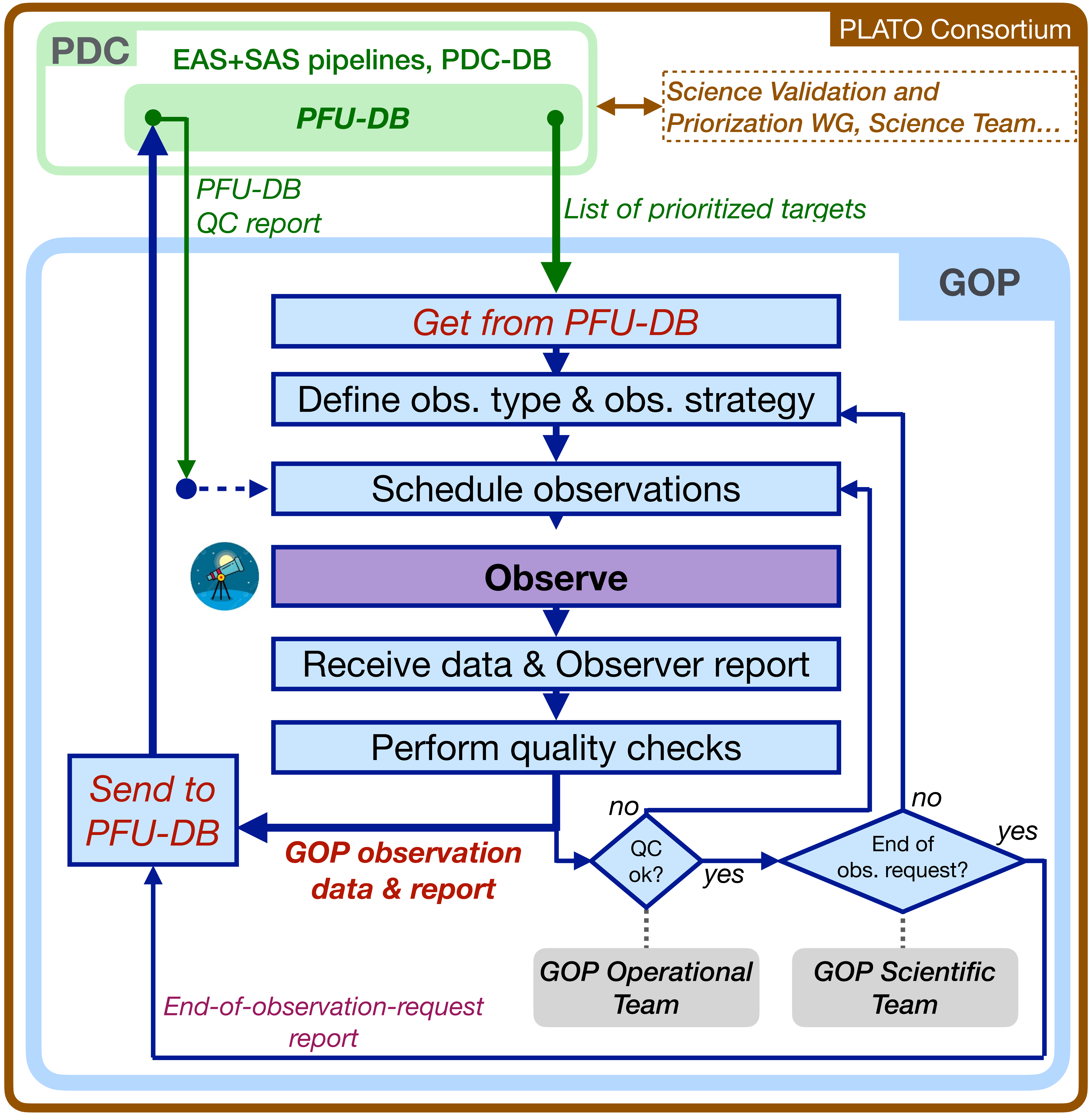
GOP Operations

Design and Implementation of needed subsystems in the GOP Operational Center



GOP Operations

Flow of information



PDC	: PLATO Data Center
EAS	: Exoplanet Analysis System
SAS	: Stellar Analysis System
PDC-DB	: PDC Data Base
PFU-DB	: Preparatory Follow-Up DataBase
WG	: Working Group
QC	: Quality Control

GOP Operations: *Observation Type Determination*

For vetting

Automatic determination of the observation type (Recon Spectro, Photometry, Imaging) depending on configuration probabilities determined in the Exoplanet Analysis System

For mass determination

Automatic determination of the observation strategy (long RV time series) depending on target properties and planet candidate parameters and stellar properties (origin/nature of "activity signal")

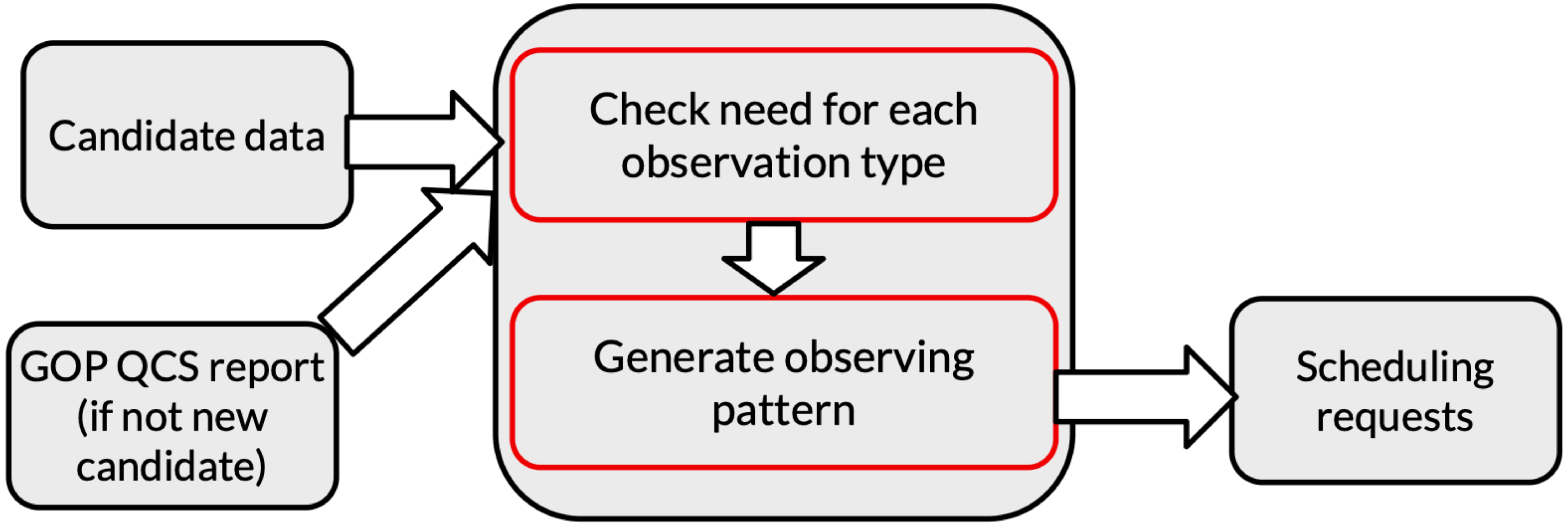


Figure courtesy David Armstrong

GOP Operations: *Scheduler*

Automatic matching between targets and facilities, based on the type of observation needed and the availability of corresponding registered facilities.

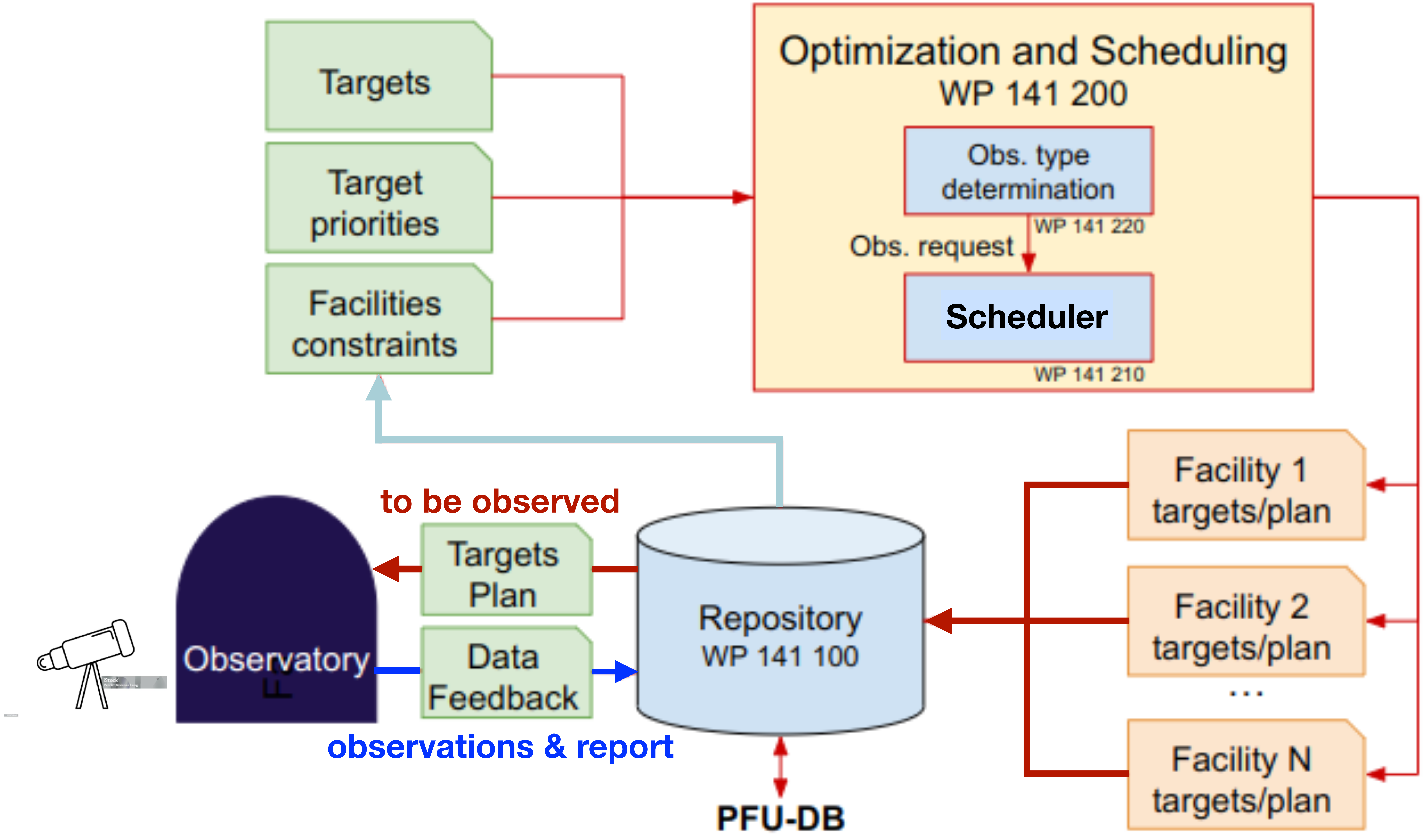
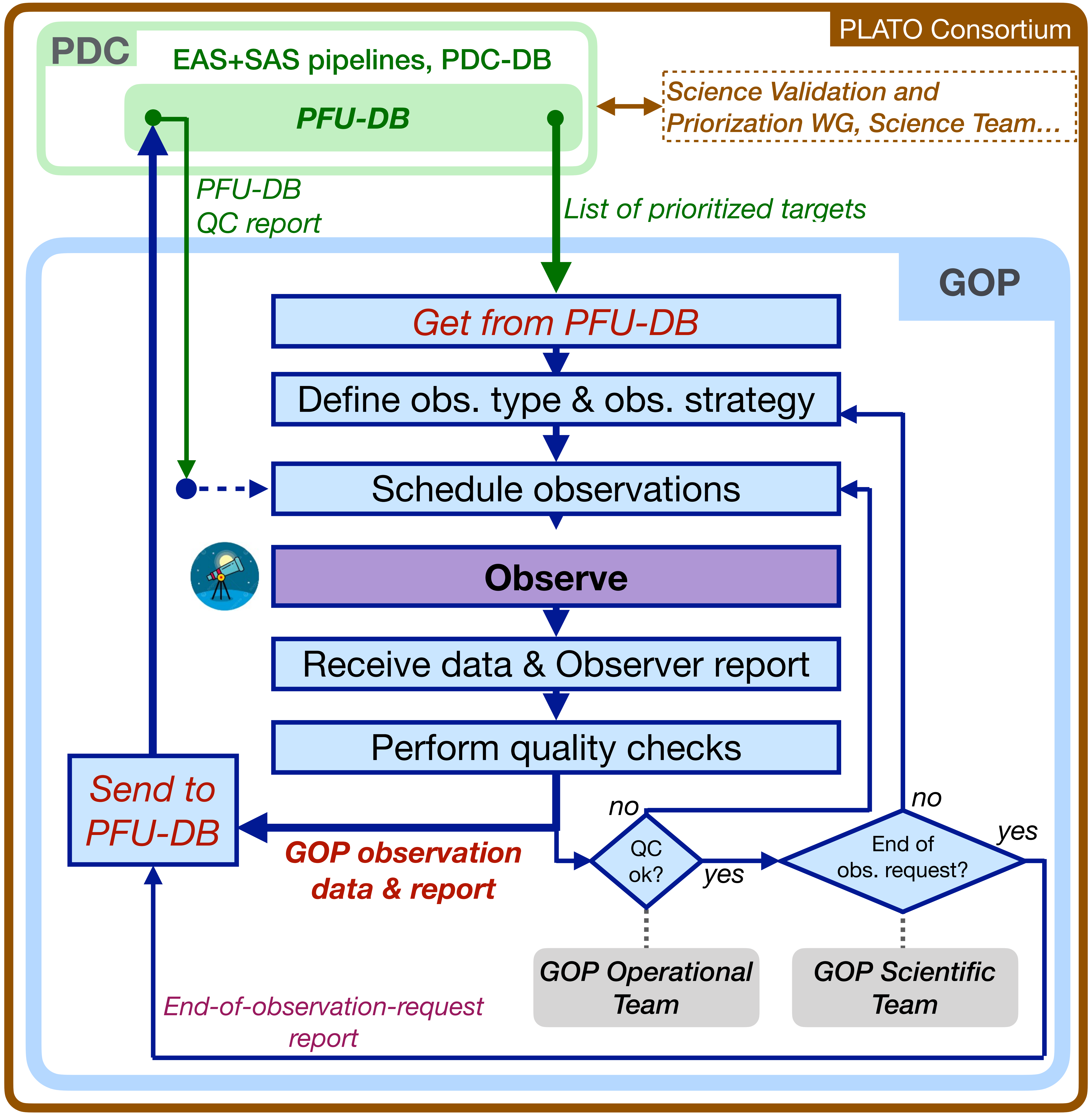


Figure courtesy Juan Carlos Morales

GOP Operations

Flow of information



PDC : PLATO Data Center
EAS : Exoplanet Analysis System
SAS : Stellar Analysis System
PDC-DB : PDC Data Base
PFU-DB : Preparatory Follow-Up DataBase
WG : Working Group
QC : Quality Control

GOP Operations: *Observer Interface*

Main interface between the observers and the GOP Operations Center

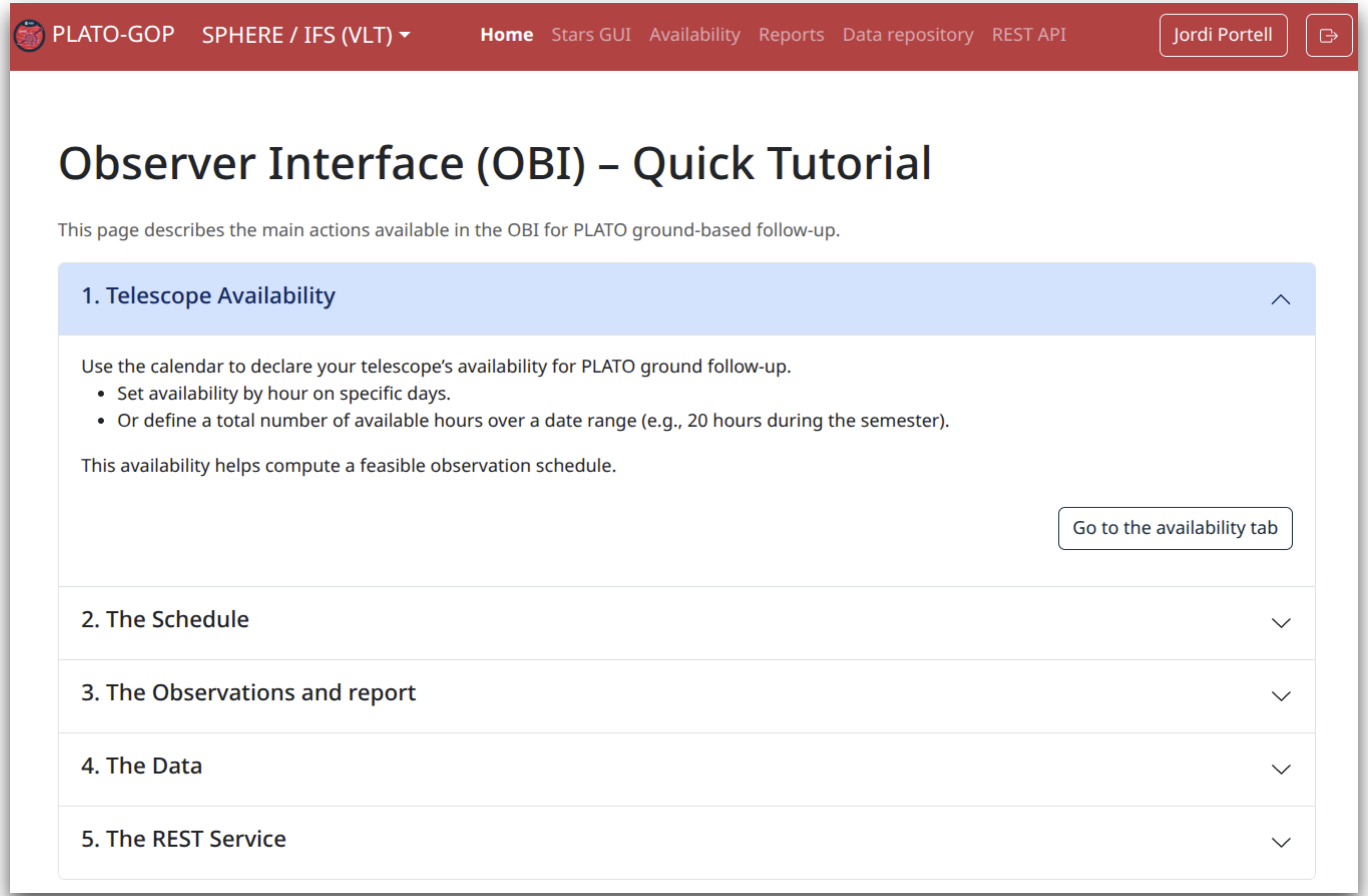


Figure courtesy Fabien Alesina & Nicolas Billot

GOP Operations: *Observer Interface*

See poster by J.C. Morales et al.:
« Optimization of ground-based observing plans for PLATO »

Main interface between the observers and the GOP Operations Center

Identify facility

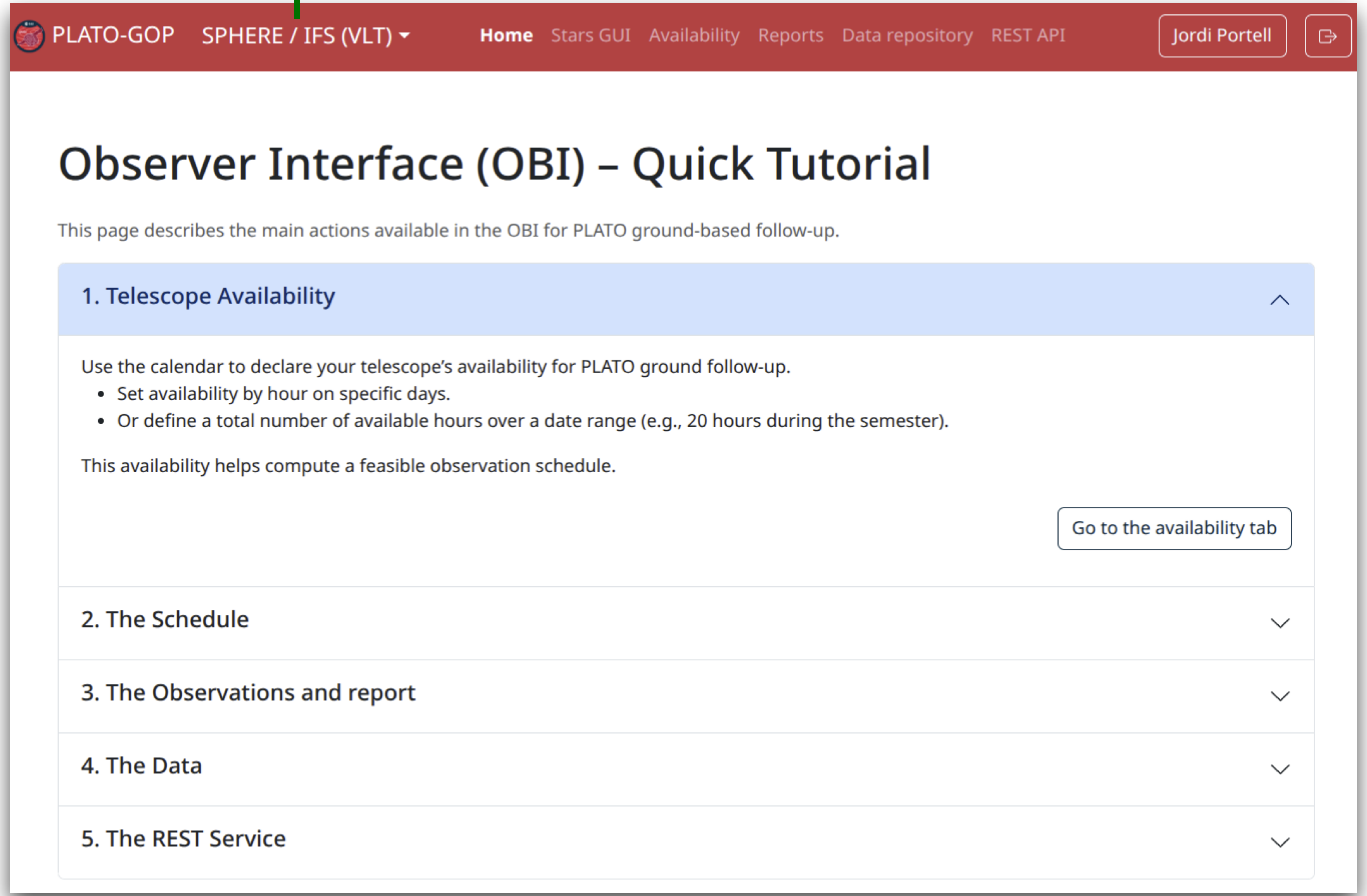


Figure courtesy Fabien Alesina & Nicolas Billot

GOP Operations: *Observer Interface*

See poster by J.C. Morales et al.:
« Optimization of ground-based observing plans for PLATO »

Main interface between the observers and the GOP Operations Center

Provide facility availabilities

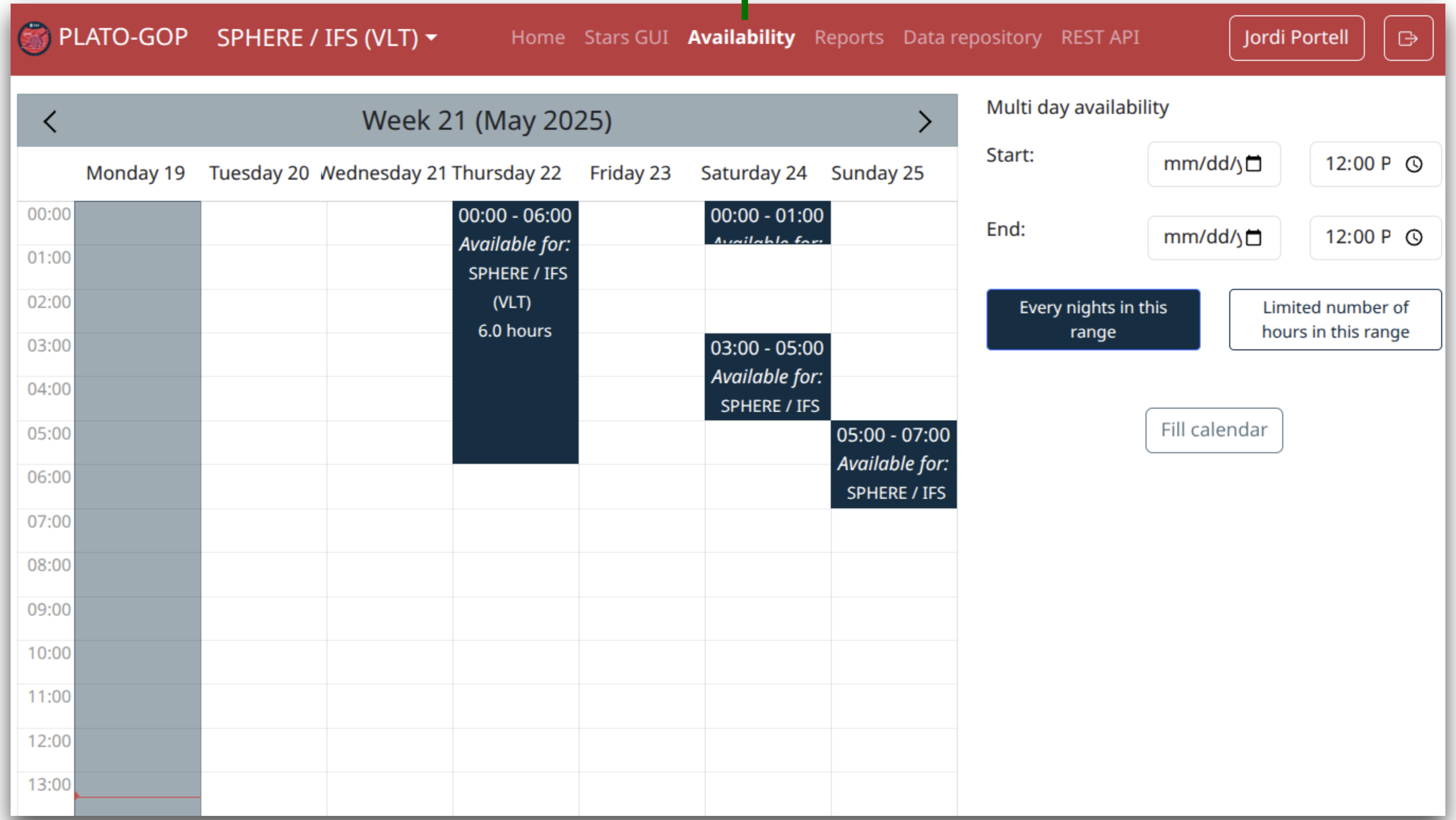


Figure courtesy Fabien Alesina & Nicolas Billot

GOP Operations: *Observer Interface*

See poster by J.C. Morales et al.:
« Optimization of ground-based observing plans for PLATO »

Main interface between the observers and the GOP Operations Center

Send obs. report at end of night

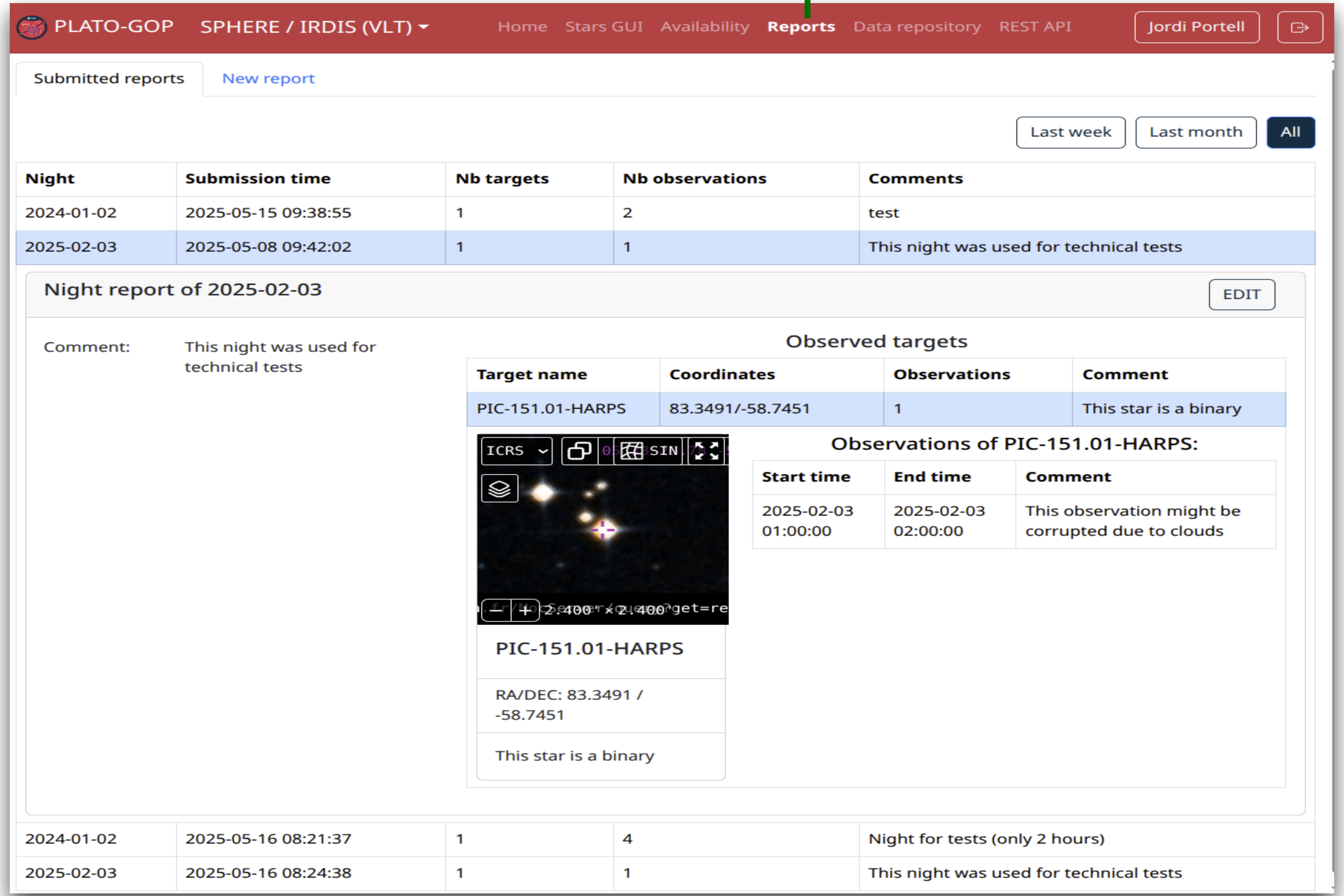
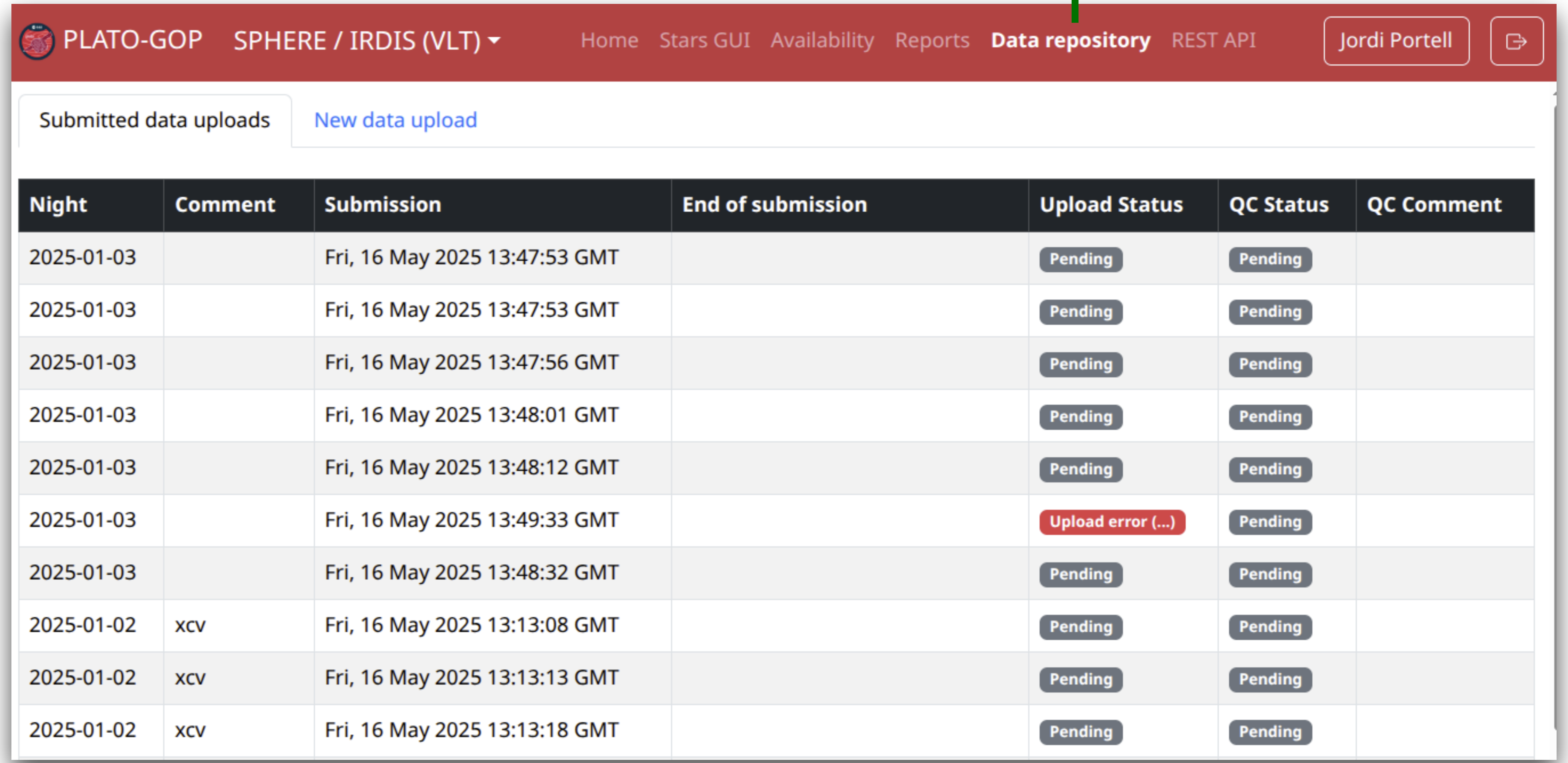


Figure courtesy Fabien Alesina & Nicolas Billot

See poster by J.C. Morales et al.:
« Optimization of ground-based observing plans for PLATO »

Main interface between the observers and the GOP Operations Center

Send obs. data



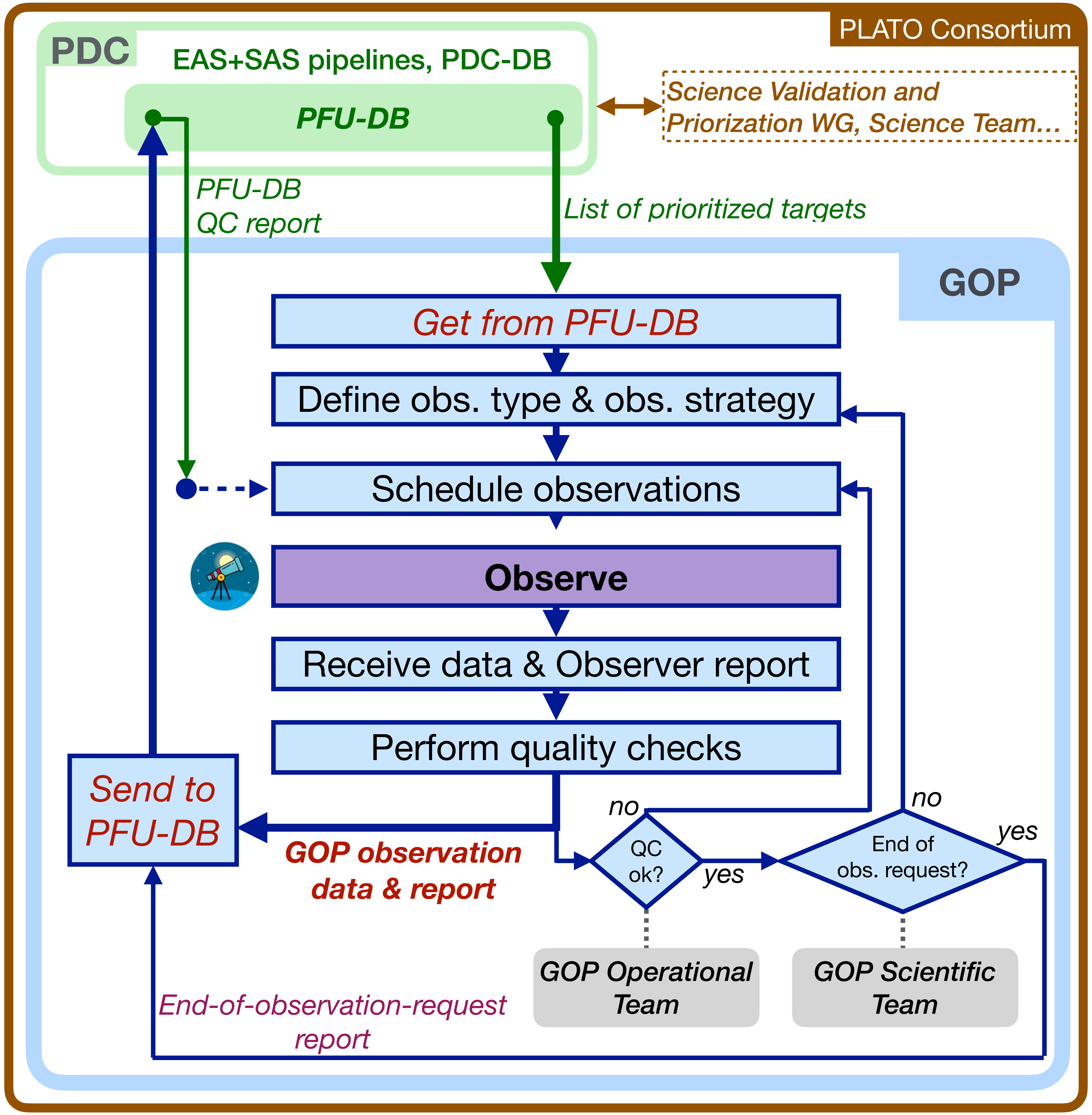
Night	Comment	Submission	End of submission	Upload Status	QC Status	QC Comment
2025-01-03		Fri, 16 May 2025 13:47:53 GMT		Pending	Pending	
2025-01-03		Fri, 16 May 2025 13:47:53 GMT		Pending	Pending	
2025-01-03		Fri, 16 May 2025 13:47:56 GMT		Pending	Pending	
2025-01-03		Fri, 16 May 2025 13:48:01 GMT		Pending	Pending	
2025-01-03		Fri, 16 May 2025 13:48:12 GMT		Pending	Pending	
2025-01-03		Fri, 16 May 2025 13:49:33 GMT		Upload error (...)	Pending	
2025-01-03		Fri, 16 May 2025 13:48:32 GMT		Pending	Pending	
2025-01-02	xcv	Fri, 16 May 2025 13:13:08 GMT		Pending	Pending	
2025-01-02	xcv	Fri, 16 May 2025 13:13:13 GMT		Pending	Pending	
2025-01-02	xcv	Fri, 16 May 2025 13:13:18 GMT		Pending	Pending	

+ possibility to send (by observer to GOP Ops Center) or retrieve (by GOP Ops Center from facility) data using API

Figure courtesy Fabien Alesina & Nicolas Billot

GOP Operations

Flow of information



PDC : PLATO Data Center
EAS : Exoplanet Analysis System
SAS : Stellar Analysis System
PDC-DB : PDC Data Base
PFU-DB : Preparatory Follow-Up DataBase
WG : Working Group
QC : Quality Control

GOP Operations: *Quality Control*

Automatic quality control:

- **quality-check** of the observations data (file formats, observations requirements, data quality)
- **flag the nature of the event** (='dispositions') for vetting (SB2, nearby EB, …)
- **generate report**

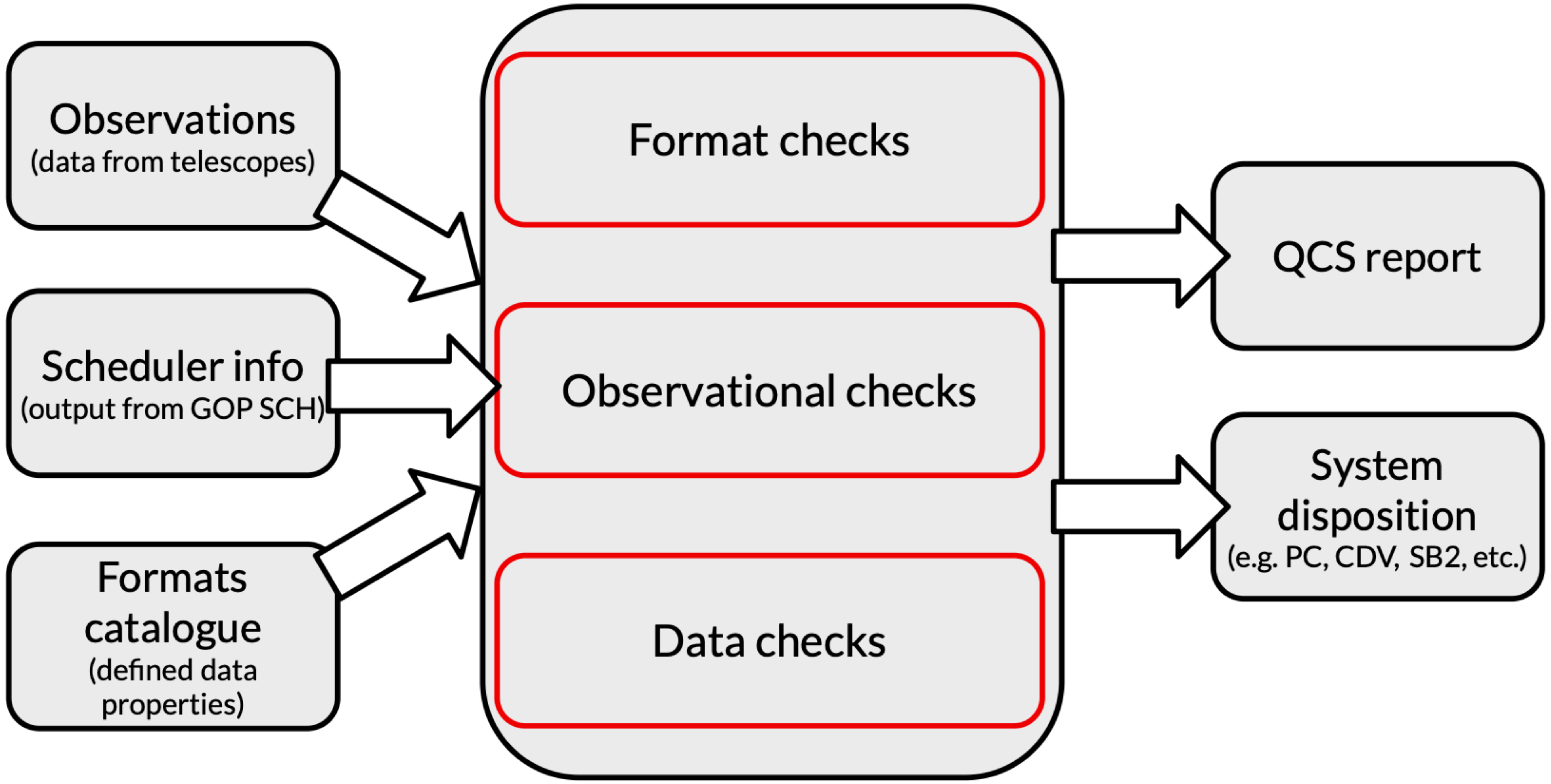
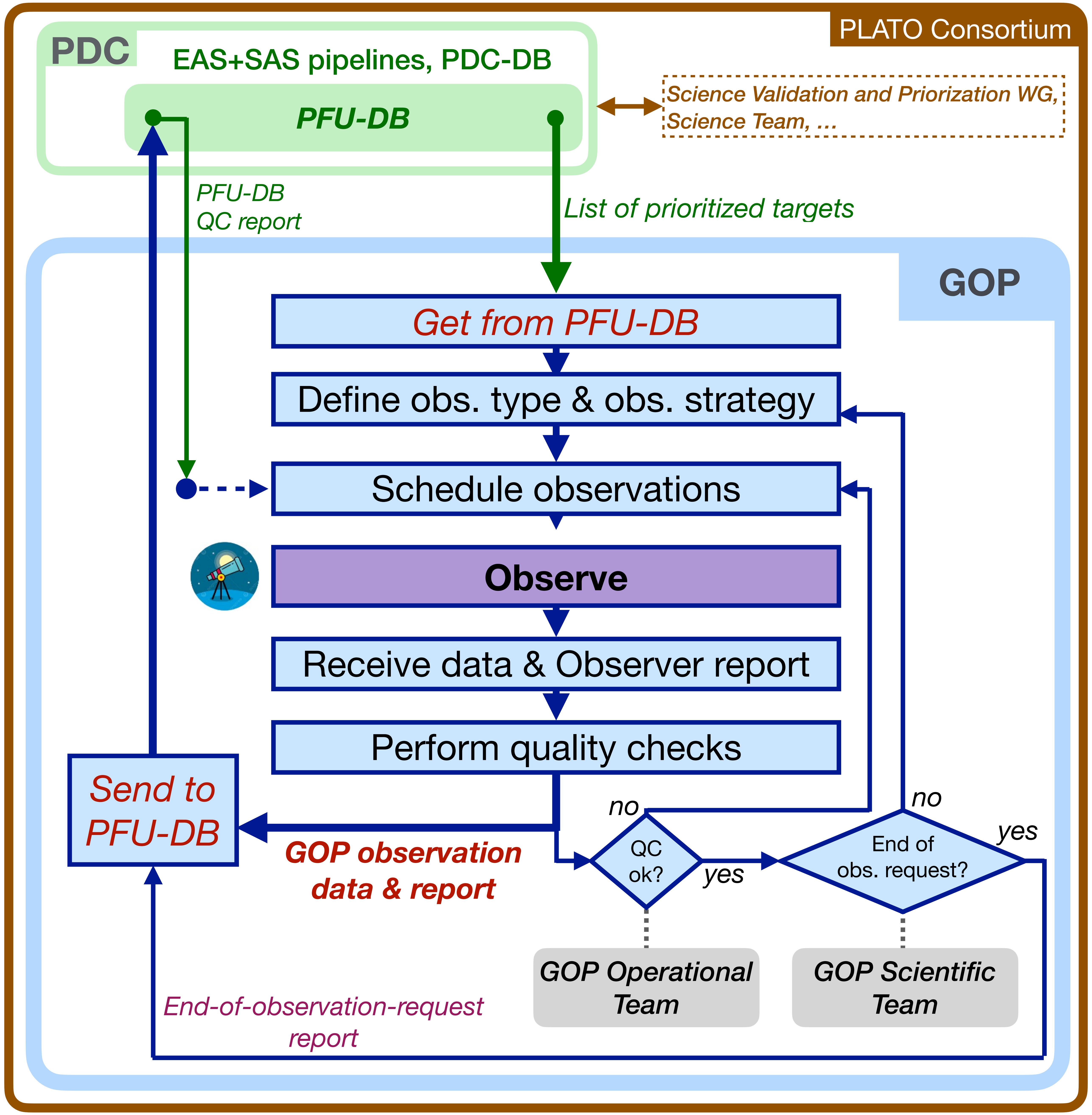


Figure courtesy Fabien Alesina & Nicolas Billot

GOP Operations



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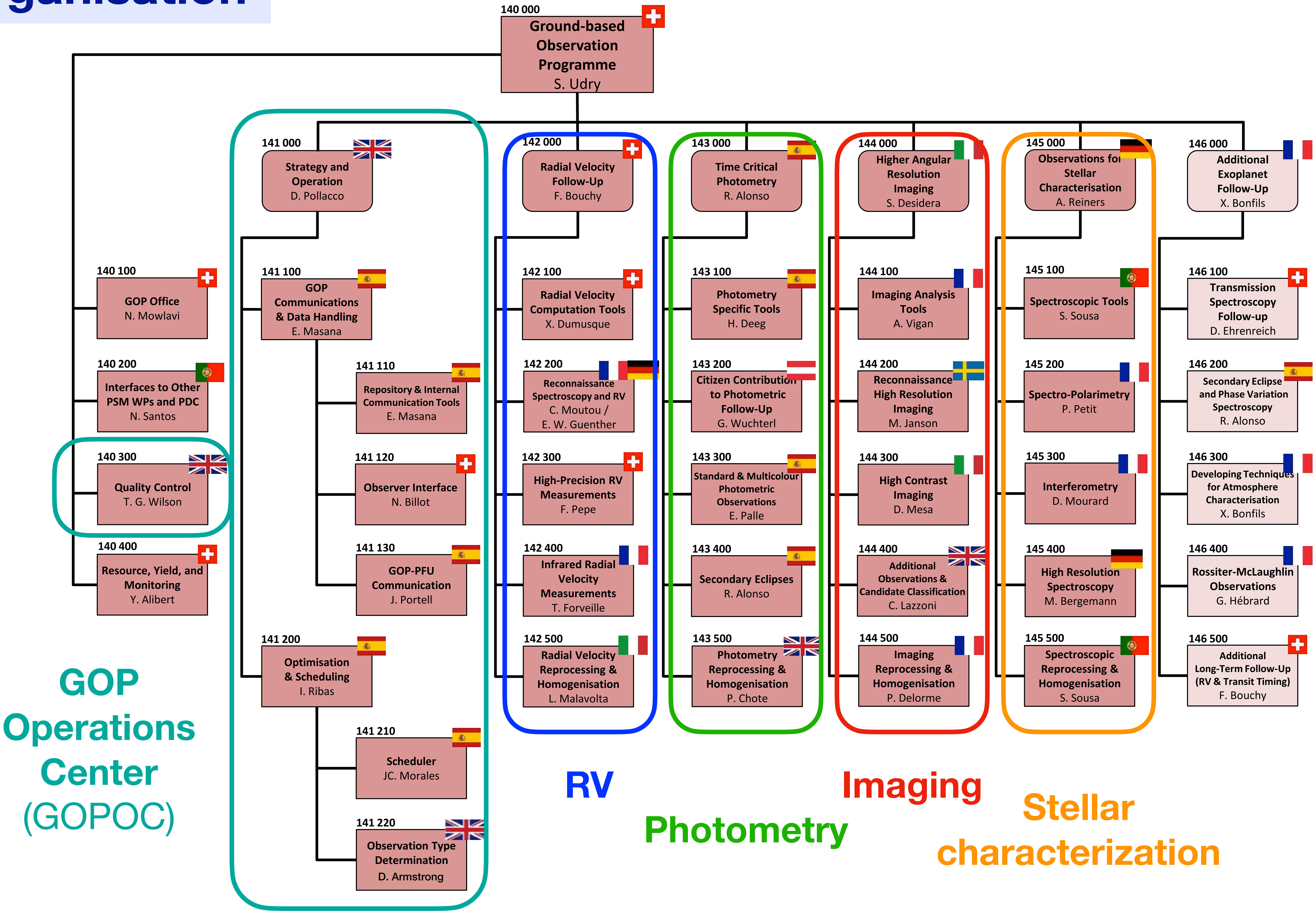
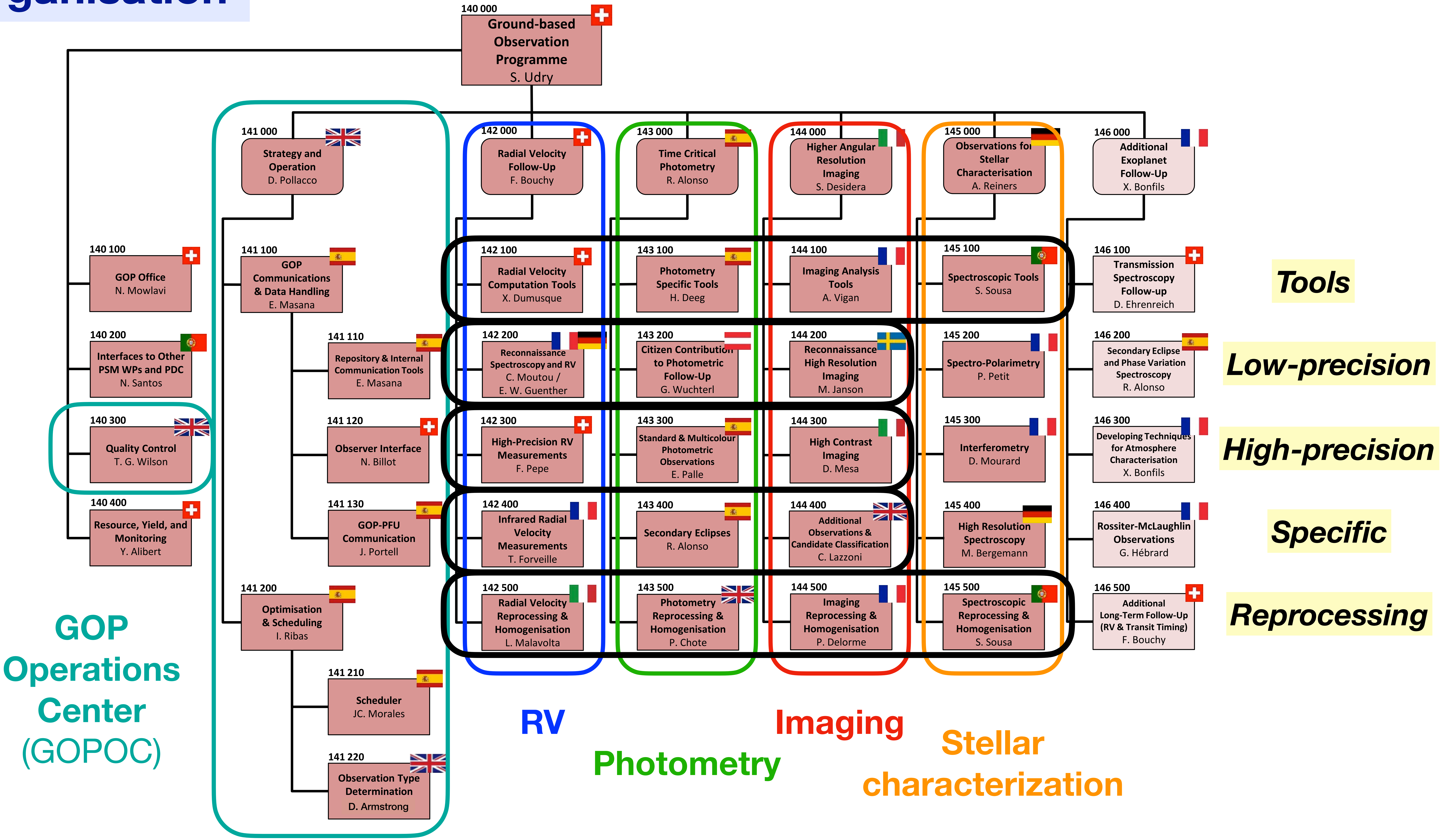
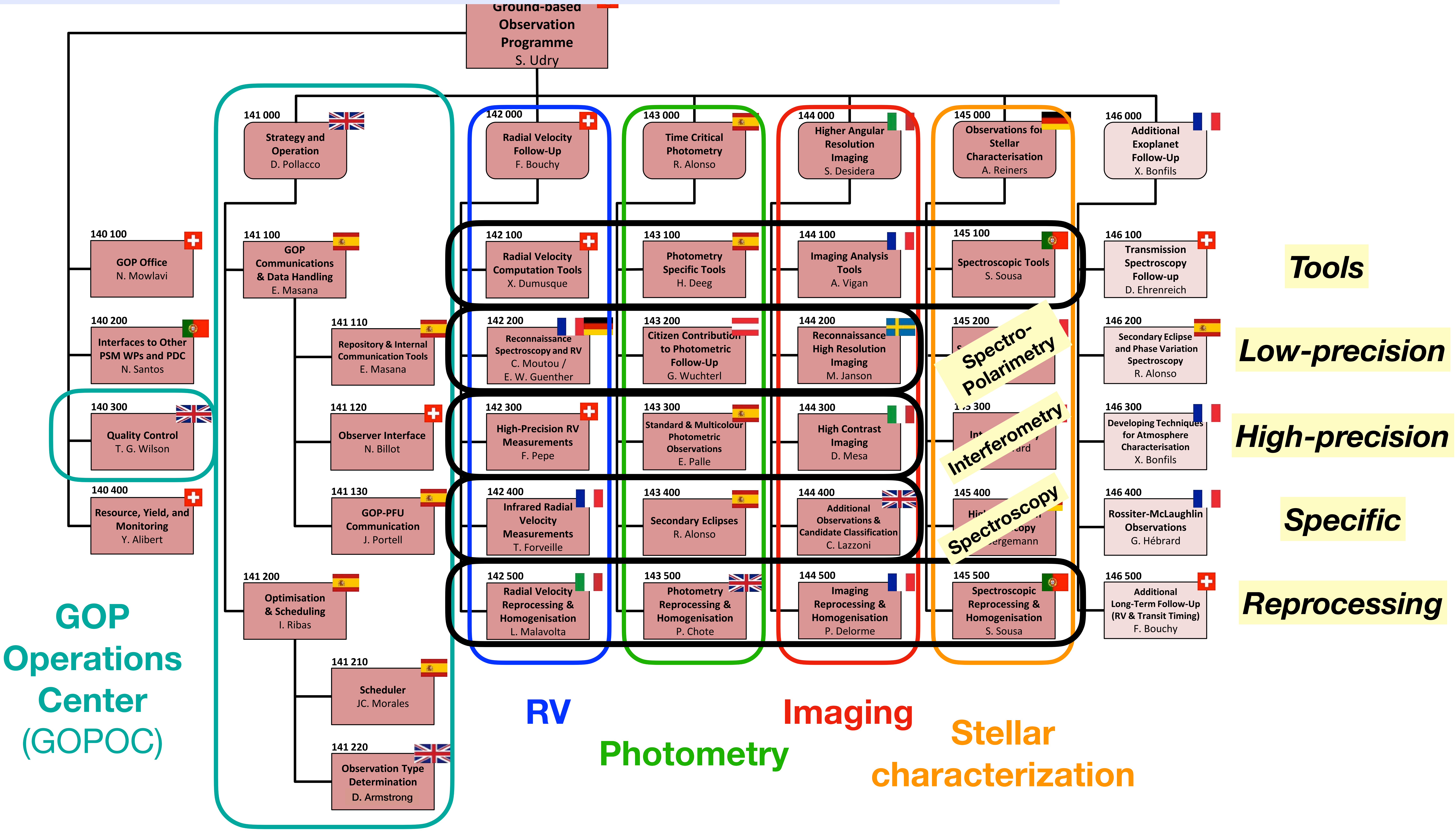
GOP Organisation



GOP Organisation



GOP Organization: *Work packages for the different observation types*



Observers & Participation to the GOP

Participants to the GOP must be **members of the consortium**. For this, they have to:

- choose a GOP work package (WP) they want to contribute to, and describe this contribution
- contact the responsible of the WP and the top-level WP leader of the given observation type who will then transmit the request to the head of the consortium with the WP recommendation. **The decision is made by the head of the consortium (office)**
- after confirmation, sign the Non-Disclosure Agreement (agreement to follow the data access and publication policies) if not yet a consortium member.

As a consortium member,

- they have access to the full PLATO data (according to the data access rule)
- they can participate to consortium publications (following the consortium publication policy)
- they have to abide by the member rules, which include:
  - the non-disclosure of PLATO data and information, and
  - the requirement to be fully in the consortium (i.e. either in *or* out of the consortium).

Particular cases (in discussion):

- Observers at the telescope might not need to be consortium member
  - they might be serving several programmes (PLATO, Prog2, Prog3, etc) in time sharing schemes
- Non ESA members in large collaborations with a substantial contribution to PLATO (several 10's of nights
  - Examples: HARPS-N consortium on TNG, including CfA partners, NIRPS consortium including Canadian partners, …
  - Discussion of a special status for them, with full participation to the GOP activities but restricted access to to the full PLATO data: GOPEC (GOP External Contributors)

You want to be involved

Persons of contact

Please, contact the responsible of the corresponding observation type with the GOP office and leader in copy

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GOP Office
N. Mowlavi

142 000
Radial Velocity Follow-Up
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143 000
Time Critical Photometry
R. Alonso
ras@iac.es

144 000
Higher Angular Resolution Imaging
S. Desidera
silvano.desidera@inaf.it

145 000
Observations for Stellar Characterisation
A. Reiners
ansgar.reiners@phys.uni-goettingen.de

Observers & Participation to the GOP

GOP work packages relevant to Observers

WP 142 - Radial Velocity Follow-up (François Bouchy)

- WP 142 200 : Reconnaissance Spectroscopy and RV (Claire Moutou / Eike Günther)
- WP 142 300 : High-Precision Measurements (Francesco Pepe)
- WP 142 400 : Infrared Radial Velocity Measurements (Thierry Forveille)

WP 143 - Time-Critical Photometry (Roi Alonso)

- WP 143 200 : Citizen Contribution to Photometric Follow-up (Günther Wuchterl)
- WP 143 300 : Standard & Multicolor Photometric Observations (Enric Pallé)
- WP 143 400 : Secondary Eclipses (Roi Alonso)

WP 144 - Higher Angular Resolution Imaging (Silvano Desidera)

- WP 144 200 : Reconnaissance High Resolution Imaging (Marcus Janson)
- WP 144 300 : High Contrast Imaging (Dino Mesa)
- WP 144 400 : Additional Observations & Candidate Classification (Cecilia Lazzoni)

WP 145 - Observations for Stellar Characterization (Ansgar Reiners)

- WP 145 200 : Spectro-Polarimetry (Pascal Petit)
- WP 145 300 : Interferometry (Denis Mourard)
- WP 145 400 : High-Resolution Spectroscopy (Maria Bergemann)