Time-critical photometry for PLATO

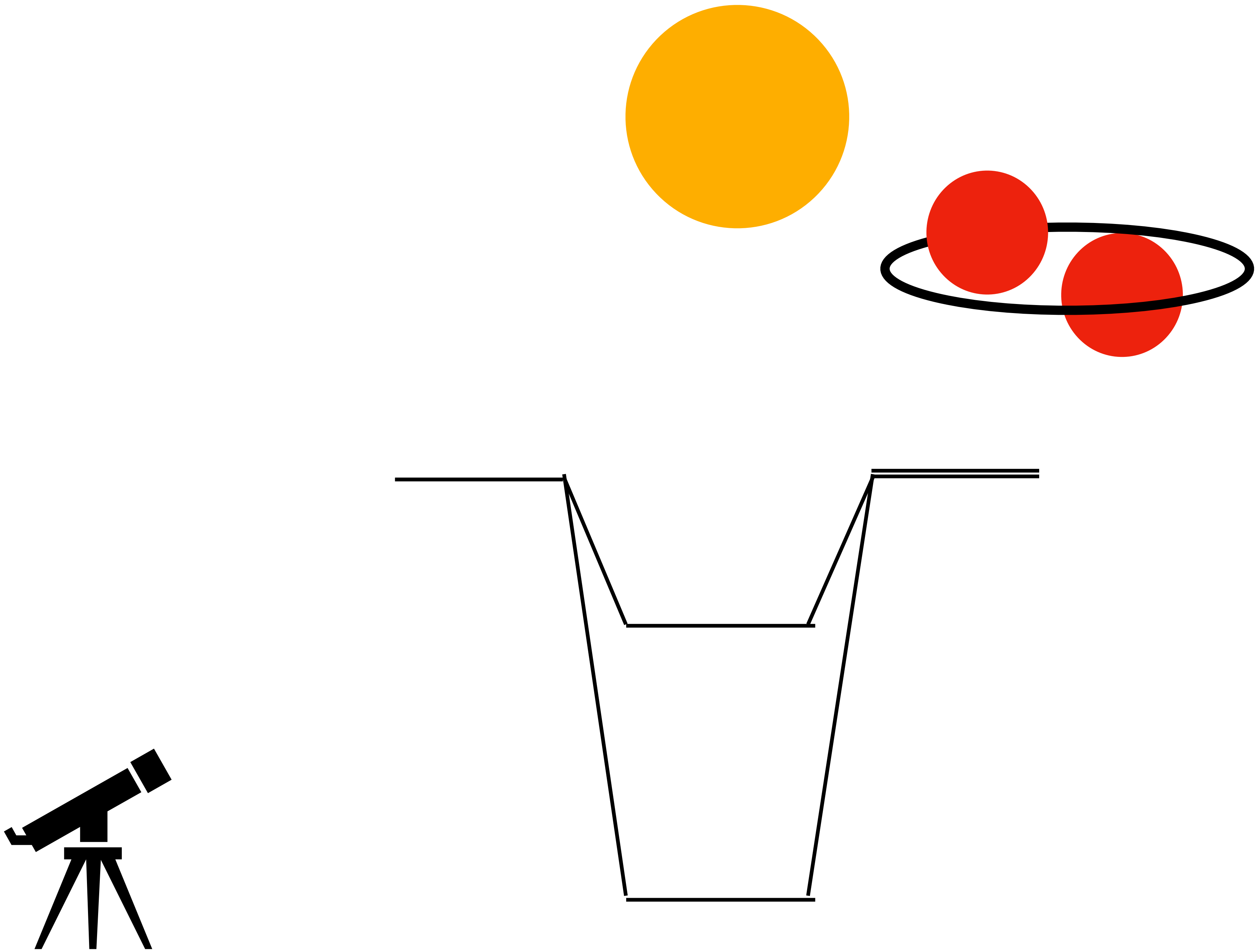
Strategy, needs, deliverables

Roi Alonso, PLATO GOP Workshop, Geneva, 2022 Oct 17-19

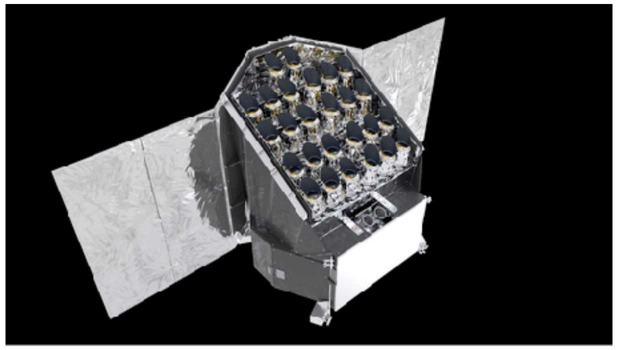
Outline

- Context: why is it needed.
- Previous experiences: CoRoT, Kepler, K2, TESS.
- Our strategy and our needs.
- Archival photometry.

Why do we need time-critical photometry?



Why do we need time-critical photometry?



PLATO plate scale 15”/px —> possible BEBs. (Background Eclipsing Binaries)

From other telescopes on ground / archival photometry, it is possible to detect the deeper eclipses of BEBs, down to distances ~1”.

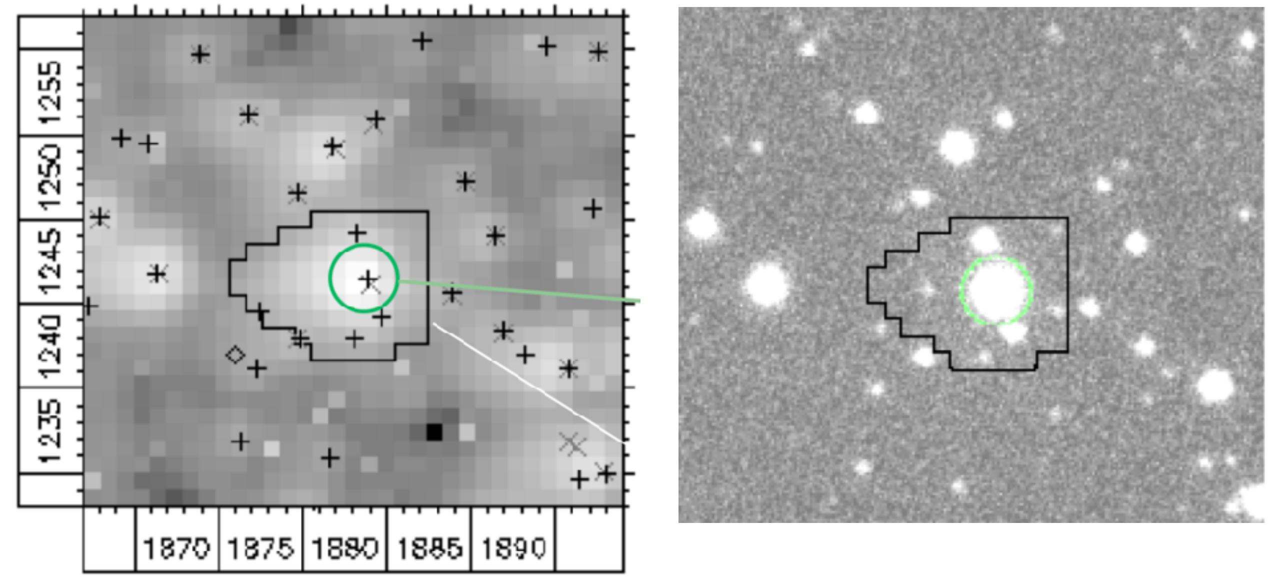
Goal: observe with **higher angular resolution** than PLATO at times of expected transit.

In some cases (deep transits), **chromatic information** to detect non-resolved EBs.

On longer time-scales, **extending** transit baselines for TTV (Transit Timing Variations) systems, or predicted long-period companions (—> **A. Leleu’s** talk).

Learning from previous experiences

CoRoT (2007-2013)



- 27-cm aperture space mission.

- λ-dispersed PSF ~**35x25”** (chromatic information).

- Spatial overlap of several stars in crowded fields, in many instances the chromatic information was used as a **spatial** discriminator.

- Photometric follow-up strategy:

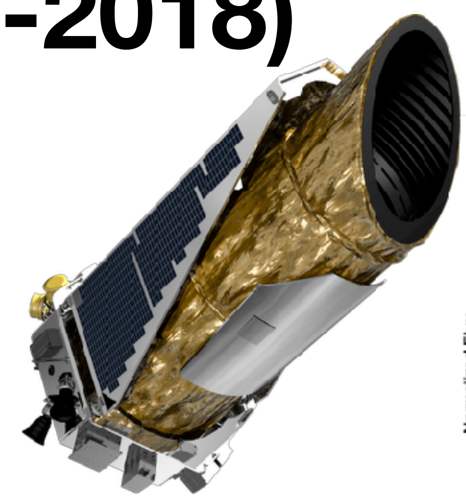
    - Scheduler (web). Observable targets for given night and observatory.

    - Wiki page for reports/updates. Mailing lists.

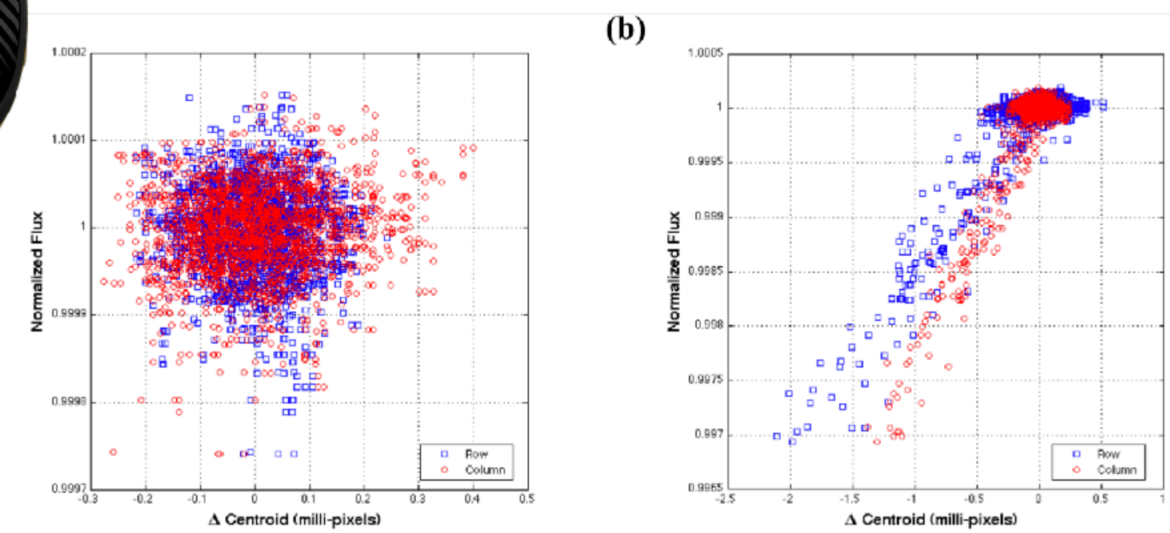
    - Each facility (~10) running own scripts and reporting results via e-mail & wiki. Re-analysis sometimes required.

Learning from previous experiences

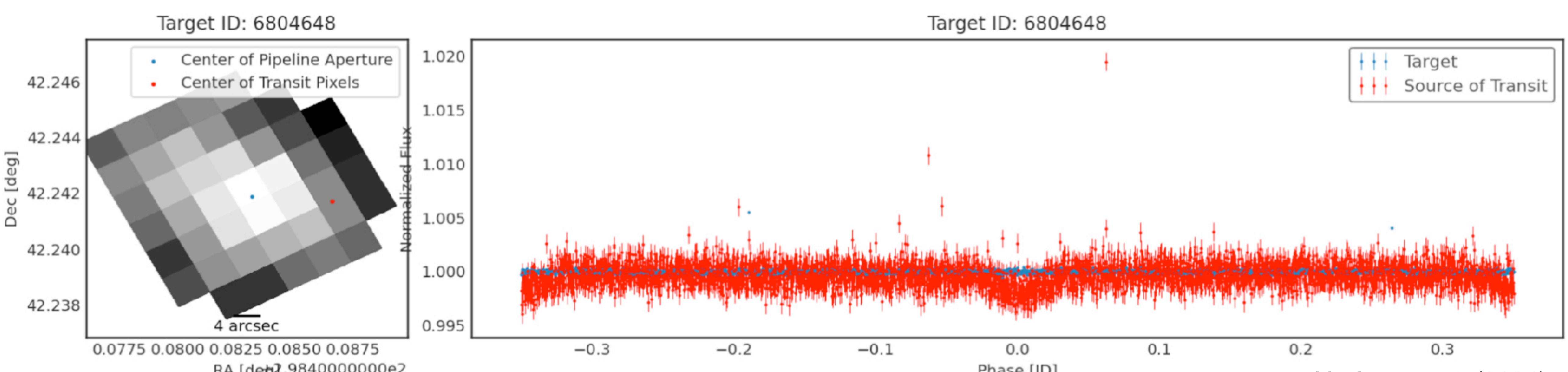
Kepler - K2 (2009-2018)



- 95-cm, trailing orbit
- ~**4**”/px
- Centroid information!
- Not much photFU was needed.
- Tools to provide light curves of the BEBs in Kepler data (*contaminante*, Hedges et al. 2021)



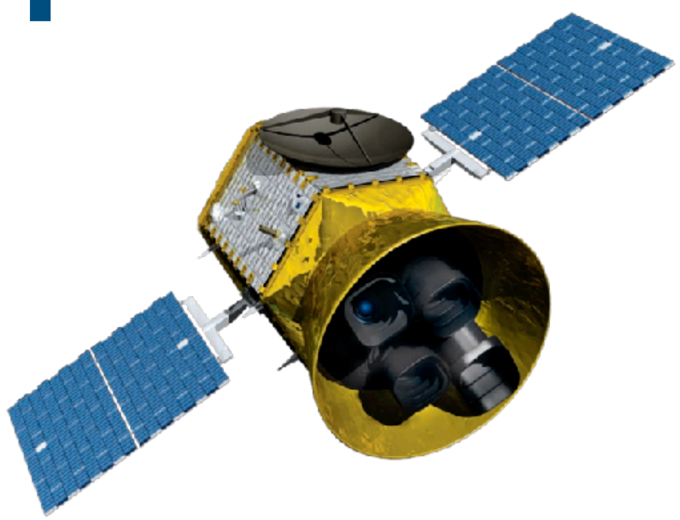
Wu et al. (2010)



Hedges et al. (2021)

Learning from previous experiences

TESS (2018 —)



4x10cm, all sky —> ~**21**”/px

TFOP **SG1**, an active part of TESS follow-up.

Nominal mission: 2018-2020, extended mission:

2020-09/2022, 2nd extended mission: 09/2022-2024

SG1 requirements similar as expected for PLATO: ”Applicants should ideally have access to a facility with the capability to maintain the position of the field on the detector to within a few pixels throughout a sequence of time-series observations. On-axis guiding is preferred over off-axis guiding, but both are preferred over no telescope guiding. Also, pixel scales of 1 arcsec or less are preferred. Applicants should also be capable of calibrating their own image sets, performing differential photometry, and submitting light curve plots, finder field images, and photometric data to ExoFOP-TESS.”

Sam Quinn’s presentation

From K. Collins@TESS Science conference I

Our structure

WP 143 000 - Time-Critical Photometry (R. Alonso)

Description

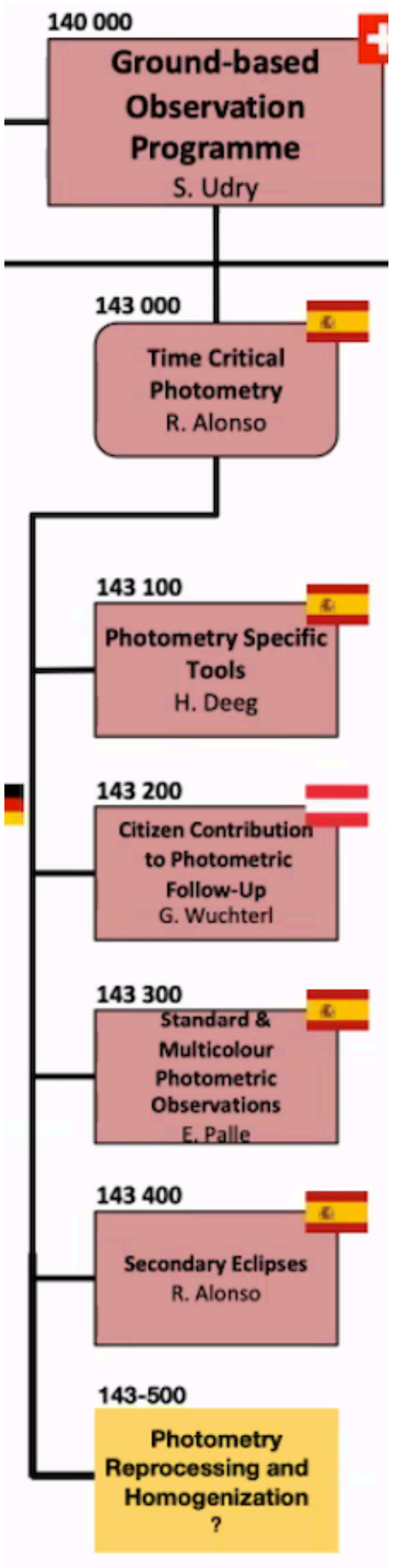
Identify and assess **false positive** transit detections in PLATO photometry caused by **stellar blends**. Define suitable optical and NIR photometric time critical follow-up strategies. Estimate required resources (development phase) and communicate with participants (operation phase).

Tasks (development):

1. Estimate expected demand of observational resources.
2. Assemble and organize group of observers.
3. Organize and execute benchmark observations to assess the performances of each facility.
4. Define efficient and effective strategies for time critical follow-up photometry.

Tasks (operations):

1. Coordinate collection, analysis and interpretation of time critical photometric data, and reports
2. Update status of candidates based on photometric results (PDC-DB)



WP 143 100 - Photometric Specific Tools (H. Deeg)

Description
Provide to observing facilities state-of-the-art data analysis and reporting tools for photometric follow up. These tools (or templates) shall enable a standardized reporting of observing results to the FUP data-base.

1. Define photometric methods / tools best suited for PLATO follow up
2. Implement, document, and distribute the tools to contributing observing facilities.

WP 143 200 - Citizen Contribution to Photometric Follow-Up (G. Wuchterl)

[alternative would be to call it "Swarm Photometry" or "Photometry with Telescope-Swarms"]

Provide a framework and tools for and to support follow-up with small telescopes and interfaces to the community ("the swarm" or "telescope swarm") and the PLATO data center.

Use the candidate validation (the PLATO Fast Planet Filter) on bright targets to communicate the mission to the public and enable low threshold participation in PLATO's discovery adventure.

Distribute priorised candidates and their contingent information as well as the observing strategy, as decided by the Science Team, to the community (the swarm) and collect the data and contingent information automatically for inclusion into the PDC.

A one design camera system (mass production of open hardware) that has a mission mode will be fed with observation tasks under full control of the PDC for operation at the focal plane of participating volunteer astronomers (citizen scientists, schools, small observatories).

Gamification of participation to encourage efficiency and fun by contributing.

A pilot is currently run as *PLATO PLANET TESST* with a call in general astronomy magazine(s) using existing equipment, selected TOIs and the ETD as hub and data collector, see http://info.plato-planets.at and http://info.planeto-planeten.at. In summer 2020 the pilot produced 1 ETD-TOI-transit-upload every three days. An estimated 60 per day are foreseen for the flight time.

WP 143 300 - Standard and Multicolor Photometric Observations (E. Palle)

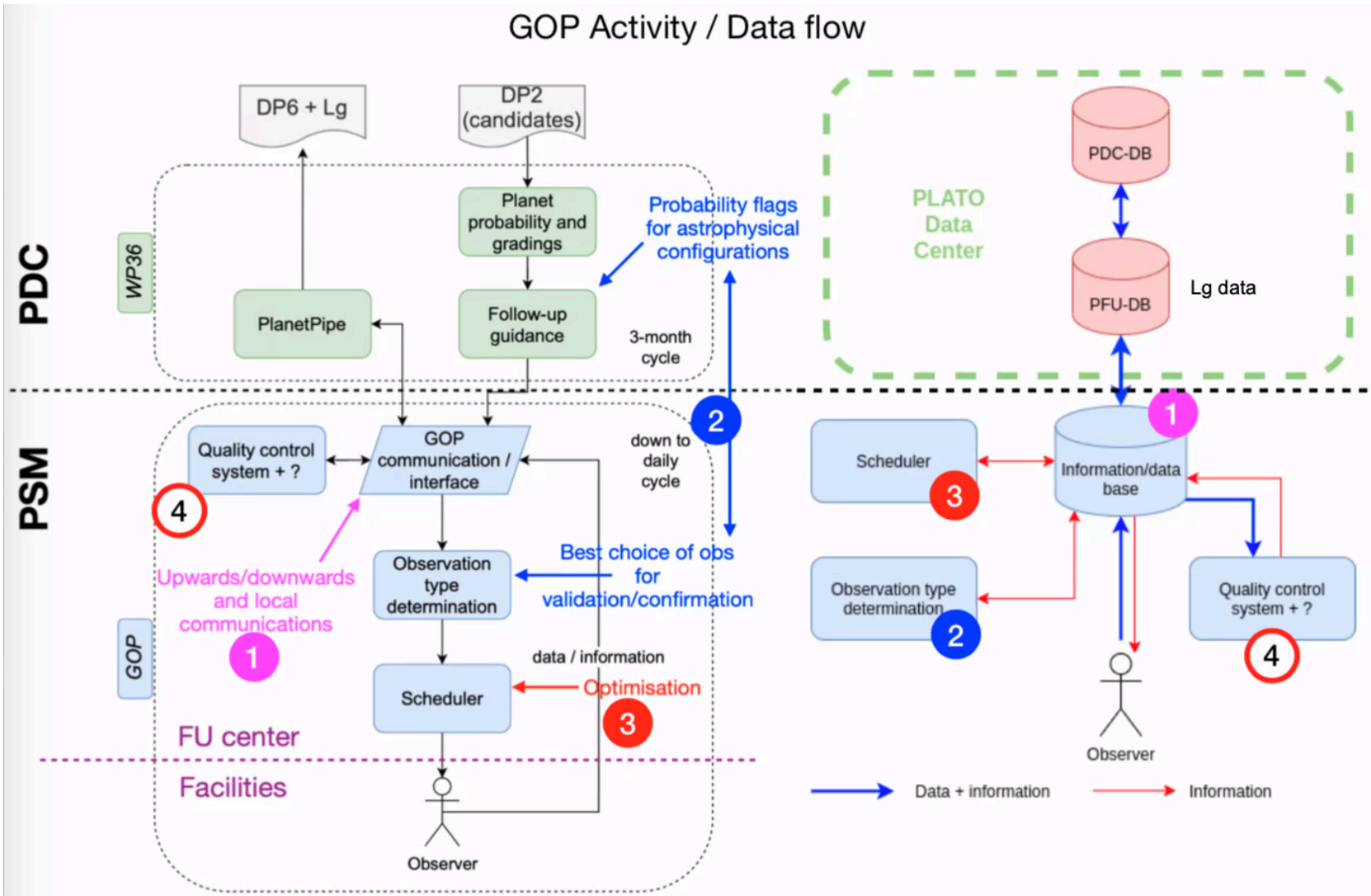
Description
The main objective is to perform time-critical observations, using the appropriate telescope aperture, field of view and observing wavelength(s) to confirm planet candidates and determine their properties

Tasks (operations):
1. Coordinate data analysis of benchmark observations requested and defined in WP 143 000.
2. Apply the most appropriate tools defined in WP 143 100 to each observation
3. Assure required precision for each observation is regularly met
4. Deliver standard results of benchmark observations, with standard documentation for interested participants.

WP 143 400 - Secondary eclipses (R. Alonso)

Description

Perform observations of secondary eclipses of PLATO candidates in case these can be used to validate/reject alternative scenarios. Provide constraints to the eccentricity for the orbital solution and mass estimation.



GOP Activity / Data flow
PDC
PSM
WP36
GOP
DP6 + Lg
DP2 (candidates)
Planet probability and gradings
PlanetPipe
Follow-up guidance
3-month cycle
Probability flags for astrophysical configurations
PLATO Data Center
PDC-DB
PFU-DB
Lg data
Quality control system + ?
GOP communication / interface
down to daily cycle
Observation type determination
Best choice of obs for validation/confirmation
Upwards/downwards and local communications
data / information
Scheduler
Optimisation
FU center
Facilities
Observer
Scheduler
Information/data base
Observation type determination
Quality control system + ?
Observer
Data + information
Information
1
2
3
4

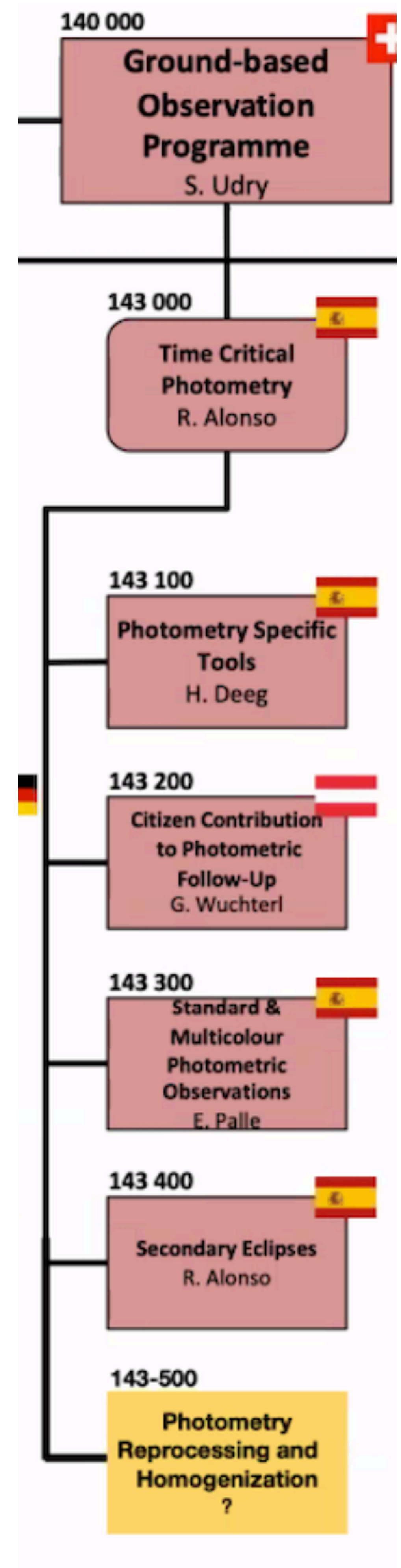
Our strategy and future steps

-**Tools** available to each observing facility:

* Photometric extraction (AstroimageJ, …)
* **Homogeneous** formatting/reporting, and interaction with PFU-DB.

- **Interaction** with PFU-DB:
    * Scheduler: *What should I observe tonight?*
        * Prioritised list, for my telescope coordinates.
        * Finding charts, coordinates, times with uncertainties.
        * Preferred color.
        * "**Difficulty**", "**uniqueness**" (WP 141200)
    * *How do I report my observations?* tools, templates, and quality control (GOP-level).

- Definition of **data formats/outputs.** (on-going)
- **List of facilities** (end 2022– .. evolutive).
- Benchmark observations and **end-to-end tests in 2025.**



Ground and space-based facilities

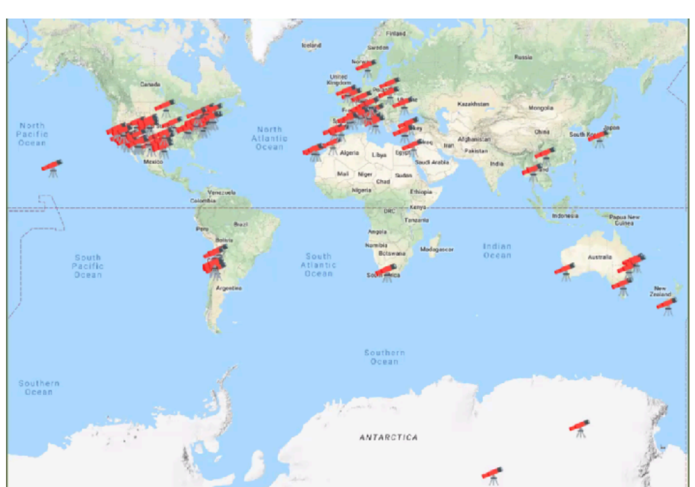
Shopping list (non-exhaustive, and not confirmed)!

Ground southern hemisphere:

* 0.2m NGTS (Paranal)
* 0.4m ASTEP Dome-C
* 0.6m SARA CT Chile
* 0.6m REM La Silla
* 0.6m Trappist-S
* 1.0m LCOGT (Australia, South Africa, Chile), 0.4-m LCOGT, 2.0m Australia
* 1.0m Speculoos (4x1m, Paranal)
* 1.2m Euler (Chile)
* 1.54m Danish
* 2.2m MPG/ESO
* 3.6m NTT - **Ultracam**
* VLT - SPHERE
* LSST

Space:

CHEOPS,
JWST?
Twinkle?
HST?
Ariel?



Sam Quinn's presentation

Ground northern hemisphere:

* 0.4m OU COAST
* 0.4m GOTO
* 0.6mTrappist-N
* 0.6m OU PIRATE
* 0.8m TJO
* 0.8m IAC80
* 0.8m OAJ
* 0.9m SARA-KP
* 1.0m JKT
* 1.0m OGS
* 1.0m WISE
* 1.0m Warwick SAFT
* 1.0m Speculoos-N (2x1m, Teide)
* 1.0m Saint-Ex (Mexico)
* 1.0m LCOGT (Texas, Teide, Israel, China?), 0.4-m LCOGT, 2.0m Hawaii
* 1.2m Stella (x2)
* 1.2m Mercator
* 1.23 Calar Alto
* 1.52m TCS-Muscat2
* 2.2m Calar Alto
* 2.5m NOT
* **4m NRT**
* **2m LT**
* Calar Alto: TBD
* 10.4m GTC - **HiPERCAM**
* Argus Array

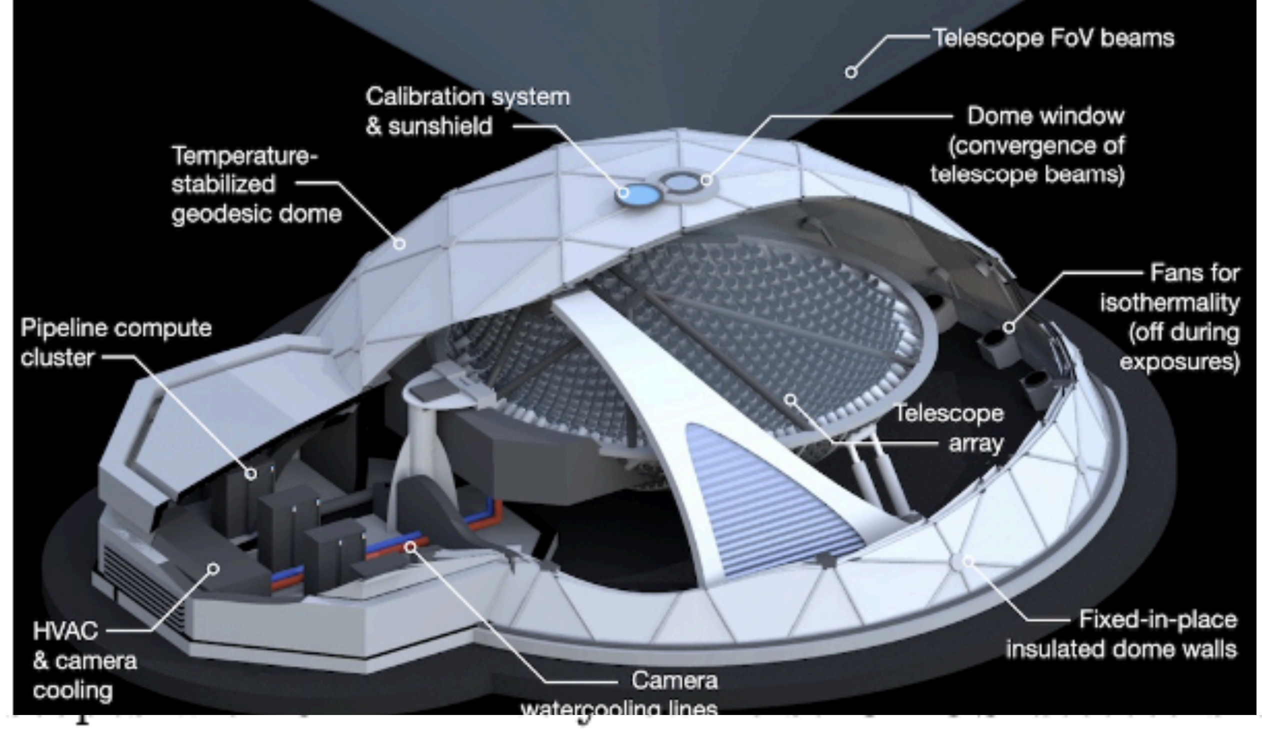
* **Citizen scientists** (several 1m class)

Archival photometry

	Telescope size	Location	Time sampling	Pixel scale	Mags	Accesible sky	Years of operation	Comments
PTF	1.2m	Palomar			> ~14	All north	2009-2012	
iPTF	1.2m	Palomar	60s to 5 days			All north	2012-2017	
ZTF	1.2m	Palomar	~2 days	1.01”	>12.5-13	All north	2018—	FWHM~2”
Pan-STARRS	2x1.8m	Hawaii	~every week	0.26”	>12-14	All north	2010—	FWHM~1.1”
ASAS-SN	0.14m Nikon lens	LCOGT sites	100-400 epochs in 2-5 years	8”	>10-11 < 17	All sky	2013—	
ATLAS	4x50cm	Hawaii, Chile, South Africa	~1h	1.9”	r >~12.5	All sky	2016—	
Vera Rubin-LSST	8.4 m (6.7)	Chile	~few days	0.2”	r >~16	All south	2024—	FWHM~0.7”
Tycho-2	Hipparcos	Space	~130 points per object		5<V<11.5	All sky	1989-1993	Høg et al. (2000)
Gaia		Space				All sky	2013—	Talk by T. Mazeh tomorrow!
TESS	4x0.1m	Space	27 days/ sector	21”	V<~16	All sky	2018 —	Also TFOP results!
NGTS	12x0.2m	Chile	minutes	5”	I > ~9	South fields	2015—	
WASP, Kelt, TrES, HAT, XO	0.1-0.2 m	Several	minutes	tens of “	V<12	~all sky	dark ages	Non-trivial data access
ExoFOP (S. Quinn’s talk)								> 10,000 LCs of TOIs available
Evryscope	24x6.1 cm	Chile and California	2 min	13”	V<16	All sky	2015—	
Argus	900x20 cm	North America	30s (1s possible)	1.4”	?	All north	2025	Pathfinder (38 telescopes) in 2022
…more to come								

Argus Array

Law et al. (2022)



sub-second cadences. Argus will observe every part of the northern sky for 6-12 hours per night, achieving a simultaneously high-cadence and deep-sky survey. The array will build a two-color, million-epoch movie, reaching dark-sky depths of m_g=19.6 each minute and m_g=23.6 each week over 47% of the entire sky, enabling the most-

	Argus Array Technology Demonstrator (2021)	Argus Array Pathfinder (2022)	Argus Optical Array
Telescopes	**9x** 203 mm Celestron Rowe-Ackermann Schmidt Astrograph or Planewave Argus-8	**38x** 203 mm aperture, F/2.8 Planewave Instruments Argus-8	**900x** 203 mm aperture, F/2.8 Planewave Instruments Argus-8
Detectors	61 MPix Sony IMX455 sCMOS 1.7e- noise at 80 µs readout >90% QE at 540 nm	61 MPix Sony IMX455 sCMOS 1.7e- noise at 80 µs readout >90% QE at 540 nm	61 MPix Sony IMX455 sCMOS 1.7e- noise at 80 µs readout >90% QE at 540 nm
Field of View	17.7 sq. deg. per telescope 155 sq. deg. instantaneous total	9 sq. deg. per telescope 344 sq. deg. instantaneous total (right ascension stripe for -20° < decl. < 72°)	9 sq. deg. per telescope 7,916 sq. deg. instantaneous total
Nightly Field of View	5000 sq. deg (15+ minutes per night depending on decl.)	19,000 sq. deg (15+ minutes per night depending on decl.)	19,000 sq. deg (2-10 hours per night depending on decl.)
Sampling	1.93" per pixel	1.38" per pixel	1.38" per pixel
Site	Lab resource, deployed on-site in Chapel Hill, NC	*Pisgah Astronomical Research Institute (Rosman, NC, USA)*	North America
Exposure Time	1-second high-speed mode 30-second standard cadence	1-second high-speed mode 30-second standard cadence	1-second high-speed mode 30-second standard cadence
Wavelengths	g-band or r-band	g-band or wideband g+r	Alternating 9-minute ratchets of g-band & wideband g+r
Total Detector Size	550 MPix	2.3 GPix	54.9 GPix
Nightly Raw Data	43 TB (1-second cadence) 710 GB (30-second cadence)	180 TB (1-second cadence) 6 TB (30-second cadence)	4.3 PB (1-second cadence) 145 TB (30-second cadence)
Peak Throughput (95% duty cycle)	110 Gbps (1-second cadence) 3.7 Gbps (30-second cadence)	464 Gbps (1-second cadence) 15.5 Gbps (30-second cadence)	11 Tbps (1-second cadence) 367 Gbps (30-second cadence)

Archival photometry use cases

A) Ground-based detectable transits, confirmed on target (~>1ppt) —> **query** archives to increase baseline (ephemeris, TTVs). Potential re-analysis.

B) Ground-based non-detectable transits (<~1ppt) —> higher spatial resolution surveys (e.g. ZTF, Gaia, Argus), that do not saturate nearby resolved stars, potential EBs —> **query archives.** Thresholds set by PLATO PSF and distances to known nearby sources.

C) Well-documented and archived space data from previous surveys (e.g. TESS) —> **query** + re-analyse (custom apertures, detrending, etc.)

A new WP is being set-up in the WP143,000 structure, to lead these efforts (143,500). Contact us if interested!

Summary

- PLATO photometric follow-up, needed mostly to discard BEBs, as in previous large-PSF surveys.
- Well-trained community (thank TESS!), trying in PLATO to improve efficiency: templates for reporting, use of data bases, flow of information (communication).
- Archival photometry (Gaia, Argus, etc.) will largely help to unload the needed telescope time.
- North-South significant differences in available facilities.
- Working on obtaining a list of facilities + information.
- **Work on estimation of needed facilities: Next talk (Hans Deeg)**
- **Operating a state-of-the-art photometric follow-up facility (Muscat2 — Enric Pallé)**
- **The input from citizen scientists (Günther Wuchterl)**
- **An use case of archival photometry: Gaia-TESS and Gaia-PLATO (Tsevi Mazeh)**