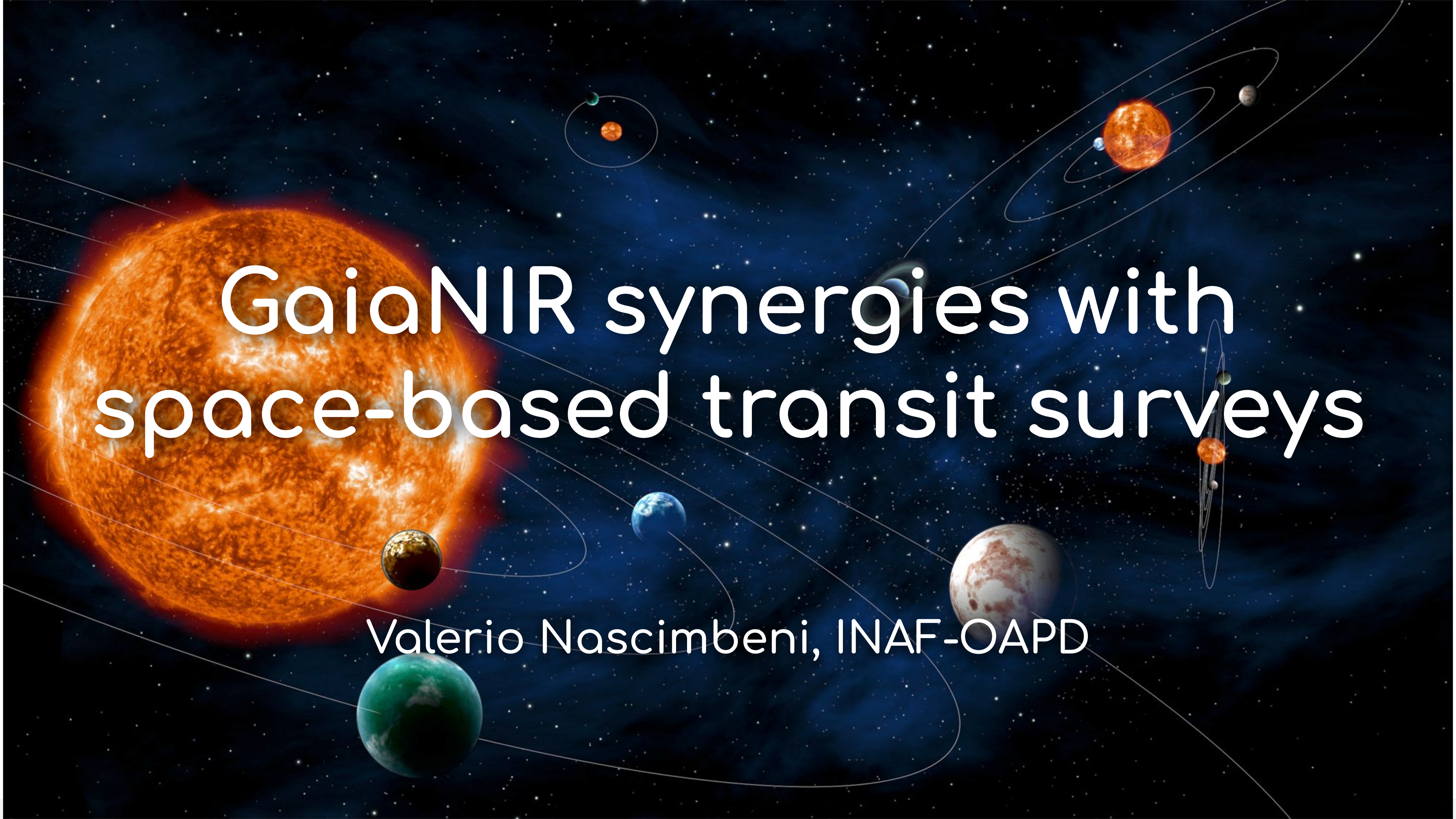


GaiaNIR synergies with space-based transit surveys

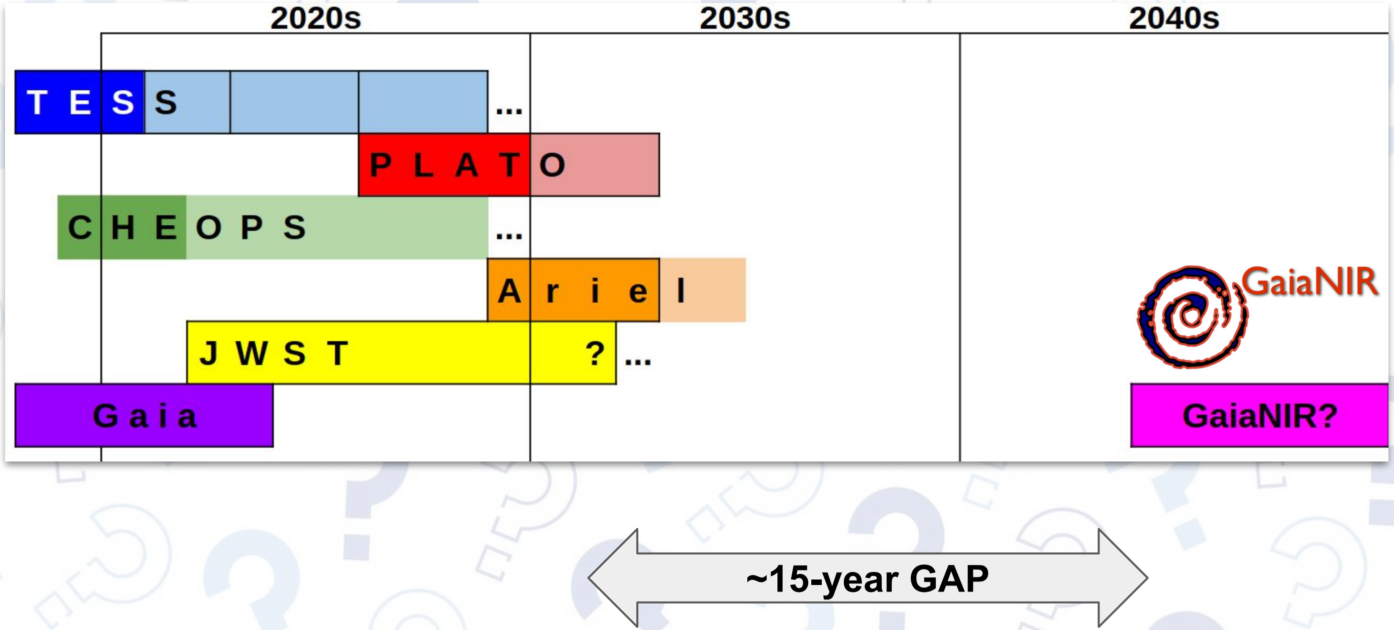
Valerio Nascimbeni, INAF-OAPD

Space-based telescopes for transits

(not just *transit surveys*, but more in general observatories doing science on transiting exoplanets):

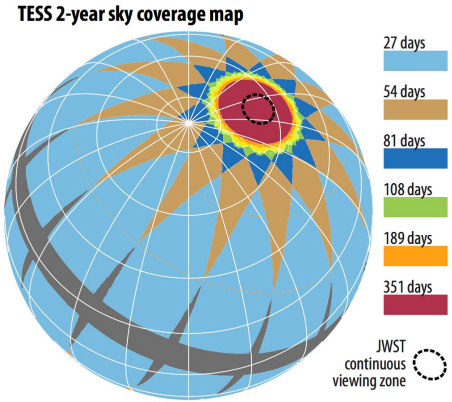
- **TESS**: launched in Apr 2018 (NASA), ME#1 (2020-2021), ME#2 (2022-2024), currently planning ME#3 (2025-2028). Orbit stable “over tens of years”, status of consumables unclear
- **CHEOPS**: launched in Dec 2019 (ESA S), currently ME#1 (2024-2026). A second extension, up to ~2029, has been presumed by ESA SPC. Not limited by consumables, rather by radiation damage
- **PLATO**: to be launched end 2026 (ESA M3), currently on schedule. Primary mission 2027-2030 (4 yr), extendable to 6.5 yr (2031.5). Consumables for 8 yr at most (≤2033)
- **Ariel**: to be launched in 2029 (ESA M4). Nominal mission 4 yr + consumables for a 2 yr extension. Ends before ~2035 if on schedule.
- **JWST**: launched in Dec 2021 (NASA/ESA/CSA). Nominal mission 5 yr (2022-2027), original goal 10 yr (2032), later revised to ~20 yr following a very efficient launch (2042? Probably not limited by consumables)

The timeline: no overlap

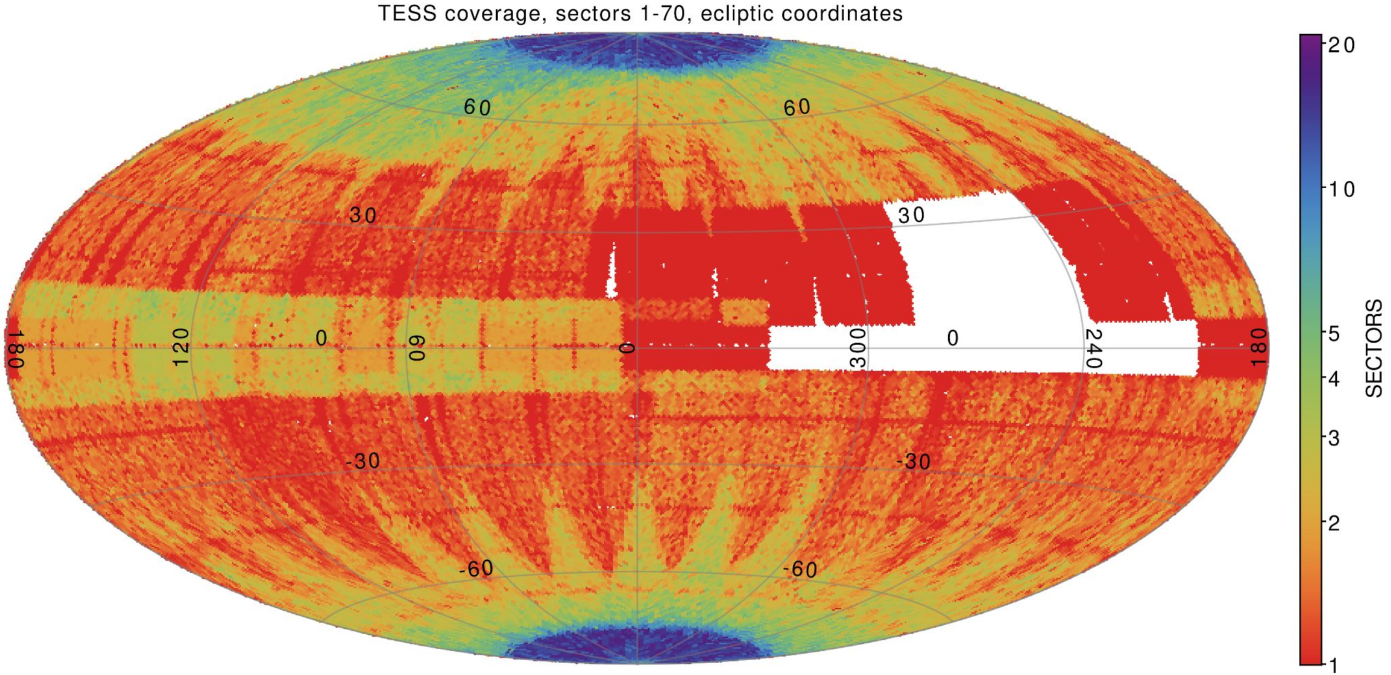


Space-based transit surveys: TESS

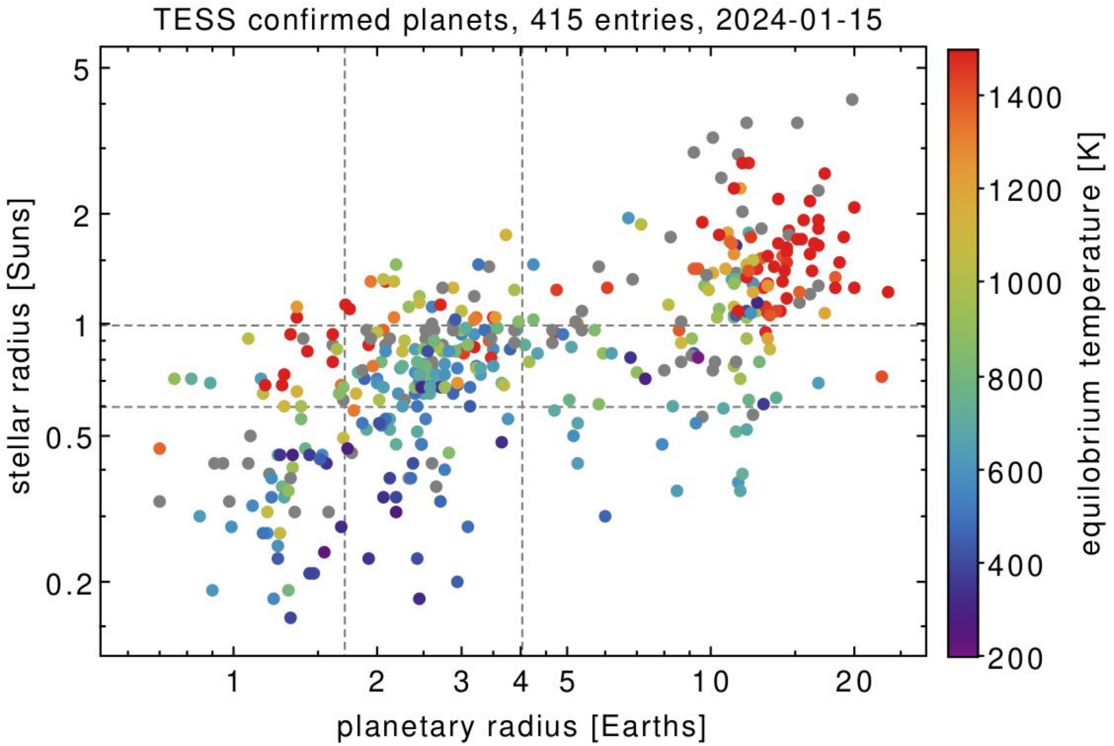
- **TESS**: launched in Apr 2018 (NASA), ME#1 (2020-2021), ME#2 (2022-2024), currently planning ME#3 (2025-2028). Injected on a Moon-synchronous 14-days orbit
- **Primary goal**: discovery of transiting planets hosted by bright and nearby stars over the whole sky, with a particular focus on late-type stars (K+M dwarfs)
- Four non-overlapping wide-field **cameras** arranged as a 4:1 rectangle, giving an instantaneous FOV of ~24°x96°. Single pass optical band (~600-1000 nm). Cadence is 120s (pre-selected targets from the candidate target list, CTL) to 30/20/15 min (full-frame images, FFI)
- **Nominal mission** (2 yr): 13+13 pointings called “sectors”. Each “sector” is four-week long, toward the anti-Sun and covers an Ecliptic latitude strip from |β|=6° to the Ecliptic pole. Coverage goes from 1 sector (~28 d) close to the Ecliptic to 13 sectors (~1 yr) at the poles (“continuous” viewing zone, CVZ).
- **Mission extensions (cycles 3-7)**: hybrid strategy combining the above scanning law with alternative pointings in order to cover the Ecliptic and fill the CCD gaps. So far about 92% of the sky has been mapped (Sectors 1-73)
- 7,027 candidates published so far (TOIs), **415 confirmed planets** (source: Nasa Exo Archive). Most of them are Neptunes and super-Earths around K+M stars



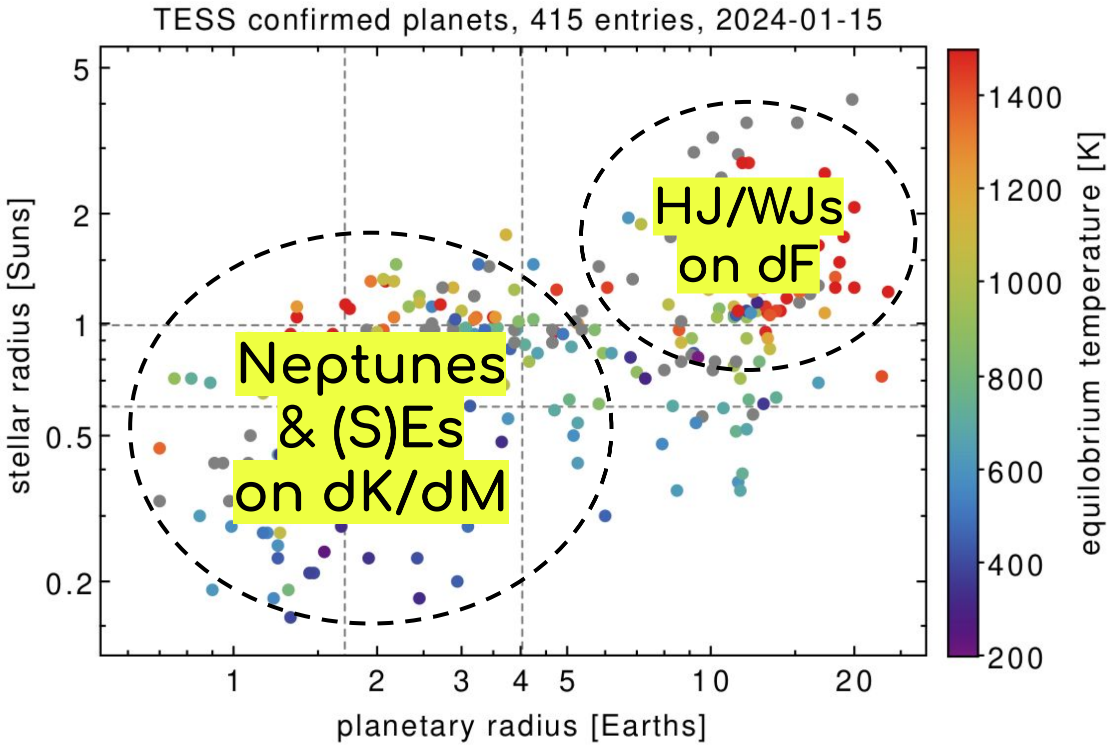
Space-based transit surveys: TESS



Space-based transit surveys: TESS

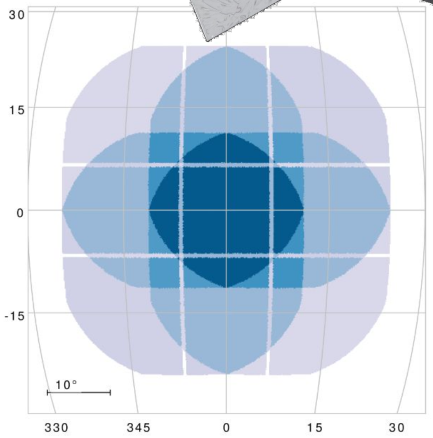


Space-based transit surveys: TESS

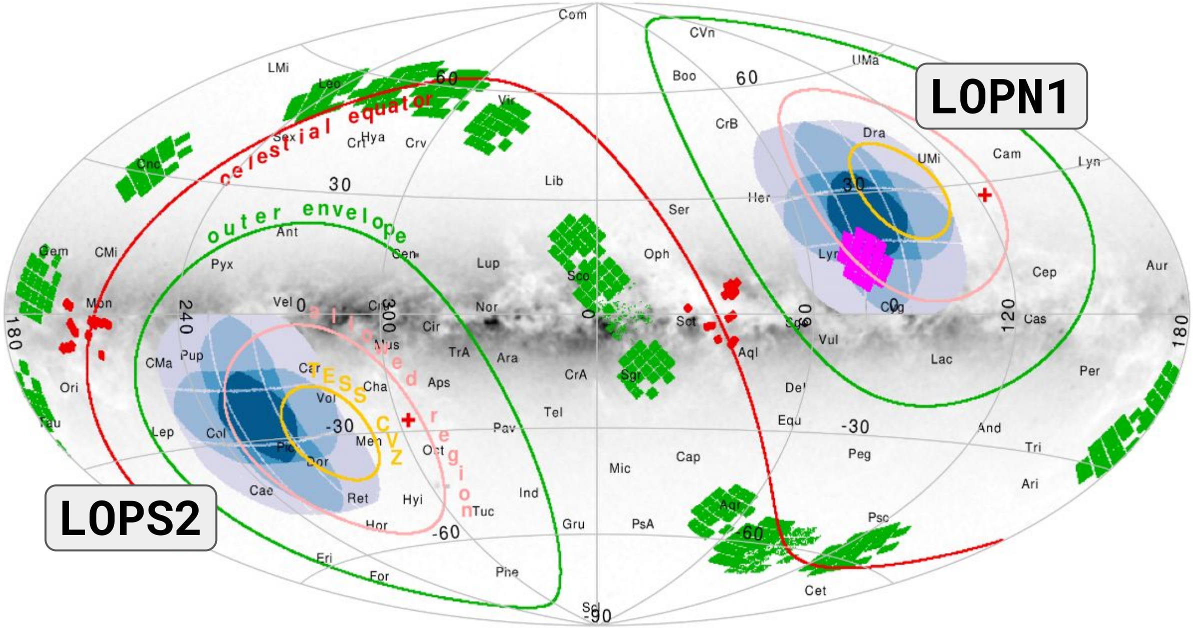


Space-based transit surveys: PLATO

- **PLATO**: to be launched end 2026 (ESA M3), currently on schedule. Primary mission 2027-2030 (4 yr), extendable to 6.5 yr (2031.5). Consumables for 8 yr at most (≤2033)
- **Primary goal**: discovery of transiting planets hosted by bright and nearby stars, with a particular focus on habitable Earth twins around G stars; accurate characterization of the stellar host including ages through asteroseismology
- 24 overlapping wide-field **cameras** (NCAMs) arranged in flower-like pattern, giving an instantaneous FOV of ~49°x49° (~2132 deg²) covered by 6, 12, 18, 24 telescopes + two "fast" cameras (FCAMs) with a smaller FOV. NCAMs: single pass optical band (~600-1000 nm), FCAMs (red and blue dichroic).
- **No FFI will be downloaded**; all the targets must be pre-selected and processed on-board. Nominal cadence for NCAMs is 25 s (imagettes) to 600 s (light curves). FCAMs cadence is 2.5s.
- **Nominal mission** (4 yr): combination of Long-duration Observing Phase (LOP), one or two fields for least 2 yr each + A Short-duration Observing Phase (SOP, aka "*step & stare*"), fields 2-3 months each.
- **Two LOP fields have been already selected by the PLATO Science Team (LOPN1, LOPS2); PLATO will begin with LOPS2 (Nascimbeni+ in prep.)**

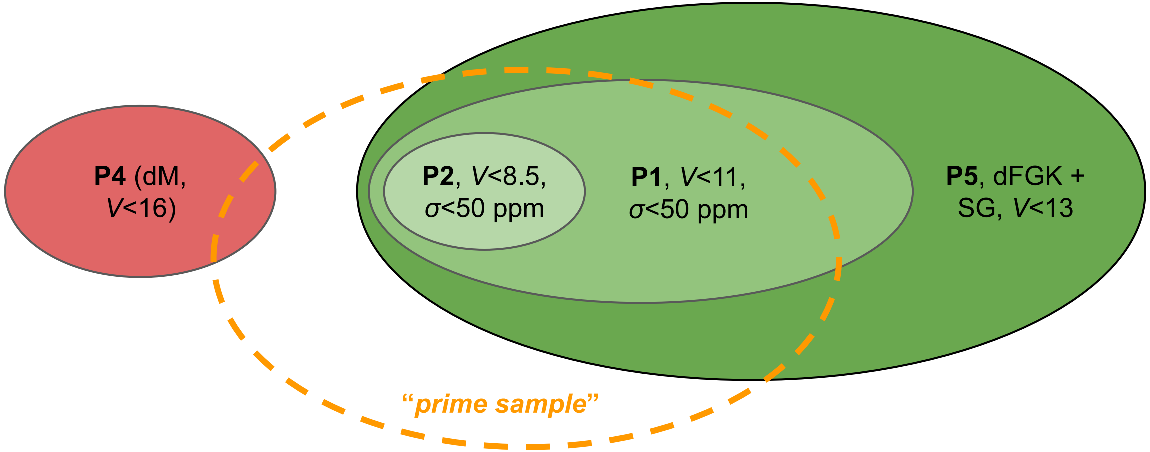


Space-based transit surveys: PLATO



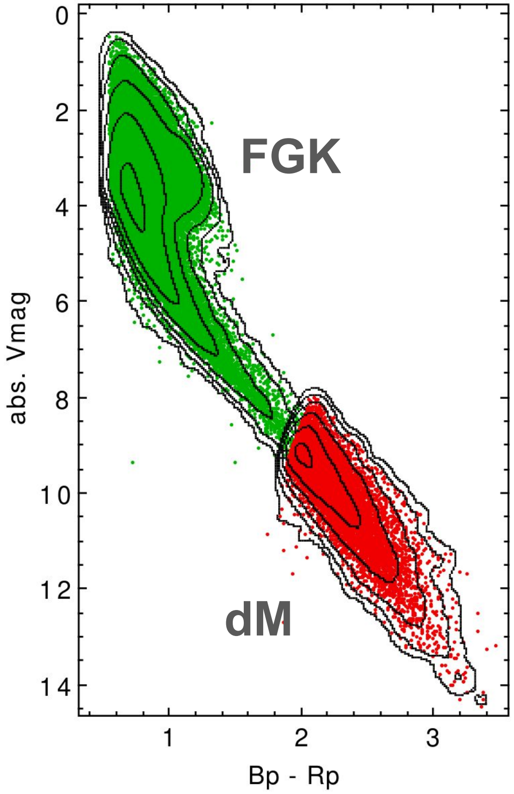
field	LOPS2	LOPN1	notes
HEALPix index	#2189	#0878	level $k = 4$, RING scheme
α [deg]	95.31043	277.18023	ICRS
α [hms]	06:21:14.5	18:28:43.2	ICRS
δ [deg]	−47.88693	52.85952	ICRS
δ [dms]	−47:53:13	52:51:34	ICRS
l [deg]	255.9375	81.56250	IAU 1958
b [deg]	−24.62432	24.62432	IAU 1958
λ [deg]	101.05940	287.98162	Ecliptic
β [deg]	−71.12242	75.85041	Ecliptic

PLATO samples



Montalto+ 2021

	P1	P2	P4	P5
Stars	≥15 000 (goal 20 000)	≥1000	≥5000	≥245 000
Spectral type	Dwarf and subgiants F5-K7	Dwarf and subgiants F5-K7	M Dwarfs	Dwarf and subgiants F5-late K
Limit *V*	11	8.5	16	13
Random noise (ppm in 1 h)	<50	<50	–	–
Wavelength (nm)	500–1000	500–1000	500–1000	500–1000



PLATO LOPS2

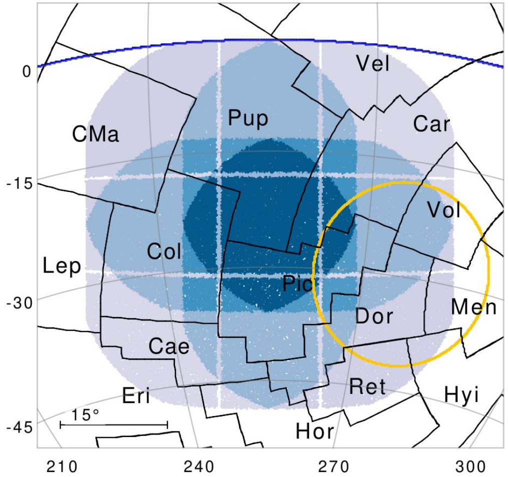
LOPS2 includes (Nascimbeni+ in prep.):

- 179,564 **tPIC stars** (P1+P2+P5+P4); most of them will be selected as targets
- Wide range of **stellar populations**: |*b*|=0°–50°, LMC
- Most the the TESS southern CVZ
- 92 **known transiting planets**, including 11 multiple systems + 608 **TESS candidates**
- 73 **non-transiting planets** + 5 Gaia DR3 astrometric candidates (ASOIs)
- 367 **OCs and associations**, including ~10 close enough to hunt for exoplanets
- ~30,000 known **variable stars** at *V*<15 (incl. EBs, pulsators, YSOs, CVs, etc.)

Very wide science available! Also, ~8% of telemetry will be available to the community as GO programs

Table 1. Properties of the LOPS2 field.

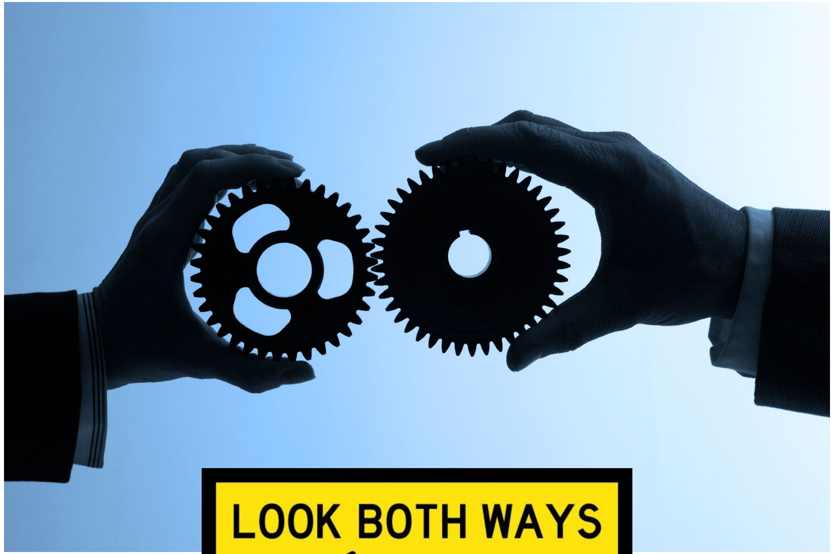
parameter	value	notes
α [deg]	95.31043	ICRS
α [hms]	06:21:14.5	ICRS
δ [deg]	−47.88693	ICRS
δ [dms]	−47:53:13	ICRS
l [deg]	255.9375	IAU 1958
b [deg]	−24.62432	IAU 1958
λ [deg]	101.05940	Ecliptic
β [deg]	−71.12242	Ecliptic
P1 targets	8 236	Req. 7 500
P2 targets	699	Req. 500
P4 targets	12 415	Req. 2 500
P5 targets	158 913	Req. 122 500

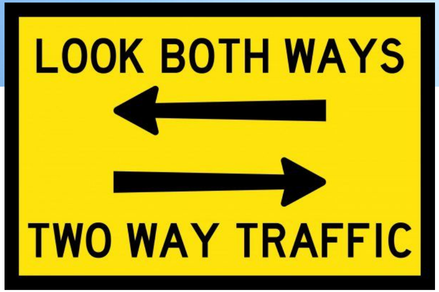


Synergies between TESS/PLATO and GaiaNIR

Synergies can go in **both ways**:

- GaiaNIR can be exploited to **follow-up** and/or confirm TESS/PLATO candidates, or to improve their stellar parameters (and hence the planetary parameters)
- TESS/PLATO can be seen as a **target provider** for GaiaNIR: systems with transiting planets can also host outer companions detectable through astrometry, expanding the parameter space. High-precision photometry also provides rotational periods, seismic parameters (including ages)

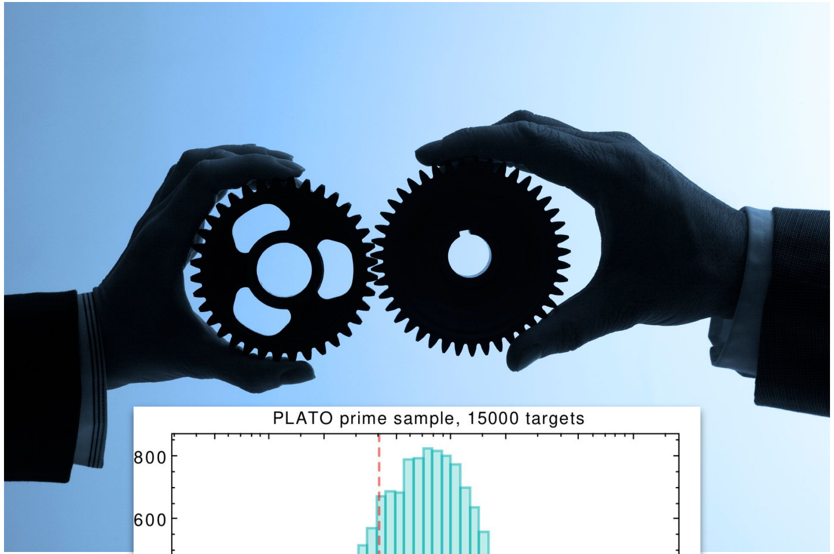


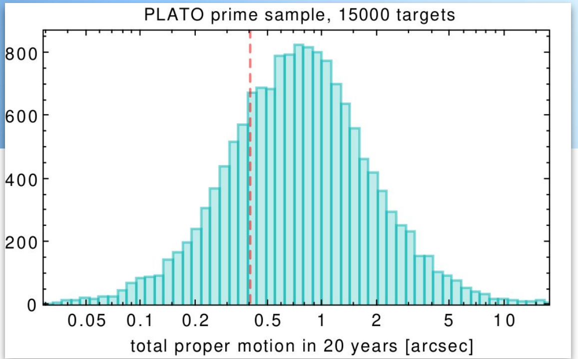


Synergies between TESS/PLATO and GaiaNIR

TESS/PLATO targets are usually nearby, main-sequence stars, for which Gaia DR3 already yields parallaxes at <1%. Let's focus in particular on what Gaia alone *cannot* do:

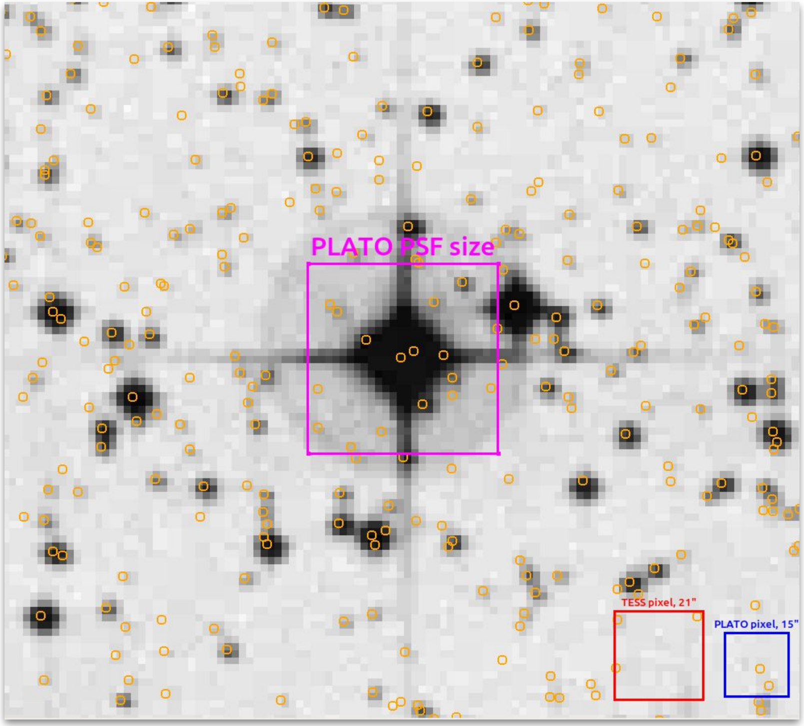
- Gaia+GaiaNIR with its much longer baseline could expand the detection parameter space of **astrometric planets** to much larger orbital periods (up to ~30 yr in principle) -> dynamical architecture. Gaia+GaiaNIR will also more easily identify **physical binaries** with the same technique (or PMAs).
- GaiaNIR, in the *filters* design, could provide a much better and more complete census of the **astrophysical and photometric contaminants**, also providing accurate colors (and hence dilution ratios in the TESS/PLATO passband, crucial to get unbiased parameters). Gaia is limited by the low resolution of Bp/Rp, and single-band (*G*) fluxes are not effective
- GaiaNIR will also benefit of ~20+ yr of **proper motion** to optically resolve very close contaminants: most PLATO targets will move by more than ~0.4”, under which Gaia is unable to directly detect contaminants even at ΔG~0





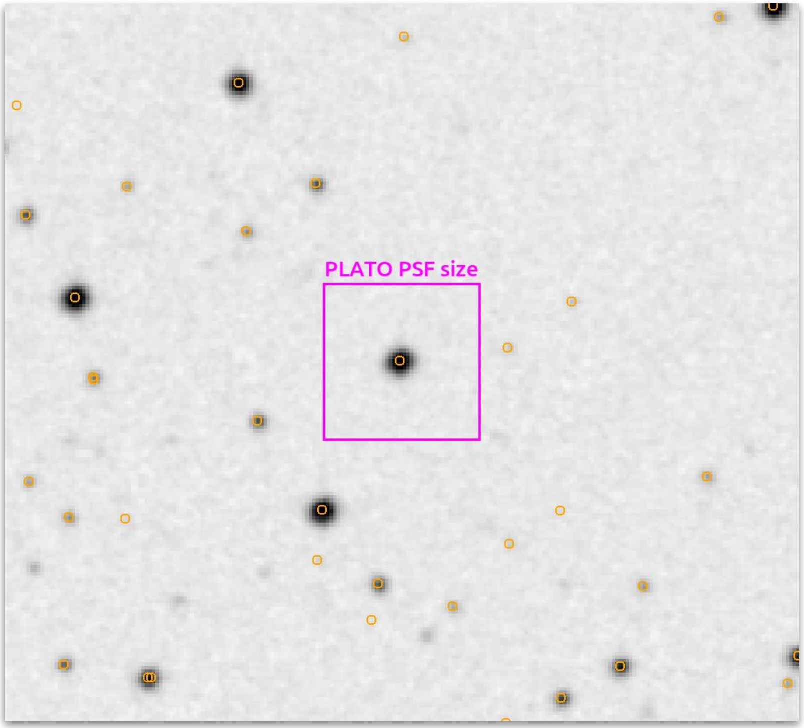
Example I: astrophysical contaminants

- Example: **TOI-622** (*b*=-5.5°, *V*=9, F5V), hosts a hot Saturn discovered by TESS (Psaridi+ 2023); also a PLATO P1 target
- Typical low-*b* target in LOPS2, observed by 12 NCAMs at σ~26 ppm in one hour
- PLATO PSF size (at 90% EE) ranges from 2.5x2.5 to 3x3 pixels. TESS PSF size is comparable
- 16 (!) contaminants within the PLATO PSF, from Gaia DR3 (orange points); closest one at 3.4”.
- Combined flux of contaminants: 0.4% of the target. BUT all these contaminants could be a potential source of FP in the case of an Earth-like transit (a dEB can mimic a 80-ppm eclipse when diluted up to Δmag~10)



Example II: photometric contaminants

- Example: **NGTS-3A** (*b*=-21.8°, *V*=14.6), hosts a hot Jupiter discovered from the ground (Gunther+ 2018); also a PLATO target on a special list
- Observed in LOPS2 by 12 NCAMs
- No contaminants resolved by Gaia DR3 within the PLATO PSF size. Not even in the NSS solution catalog
- BUT it is *d*<1" **binary** star (G6V+K1V); dilution factor is 0.43 in the *r* band. The two components cannot be disentangled by single-band photometry or RV alone. Planetary parameters are completely different if we neglect contamination (e.g., R_p = 1.48 vs. 0.84 R_{jup})

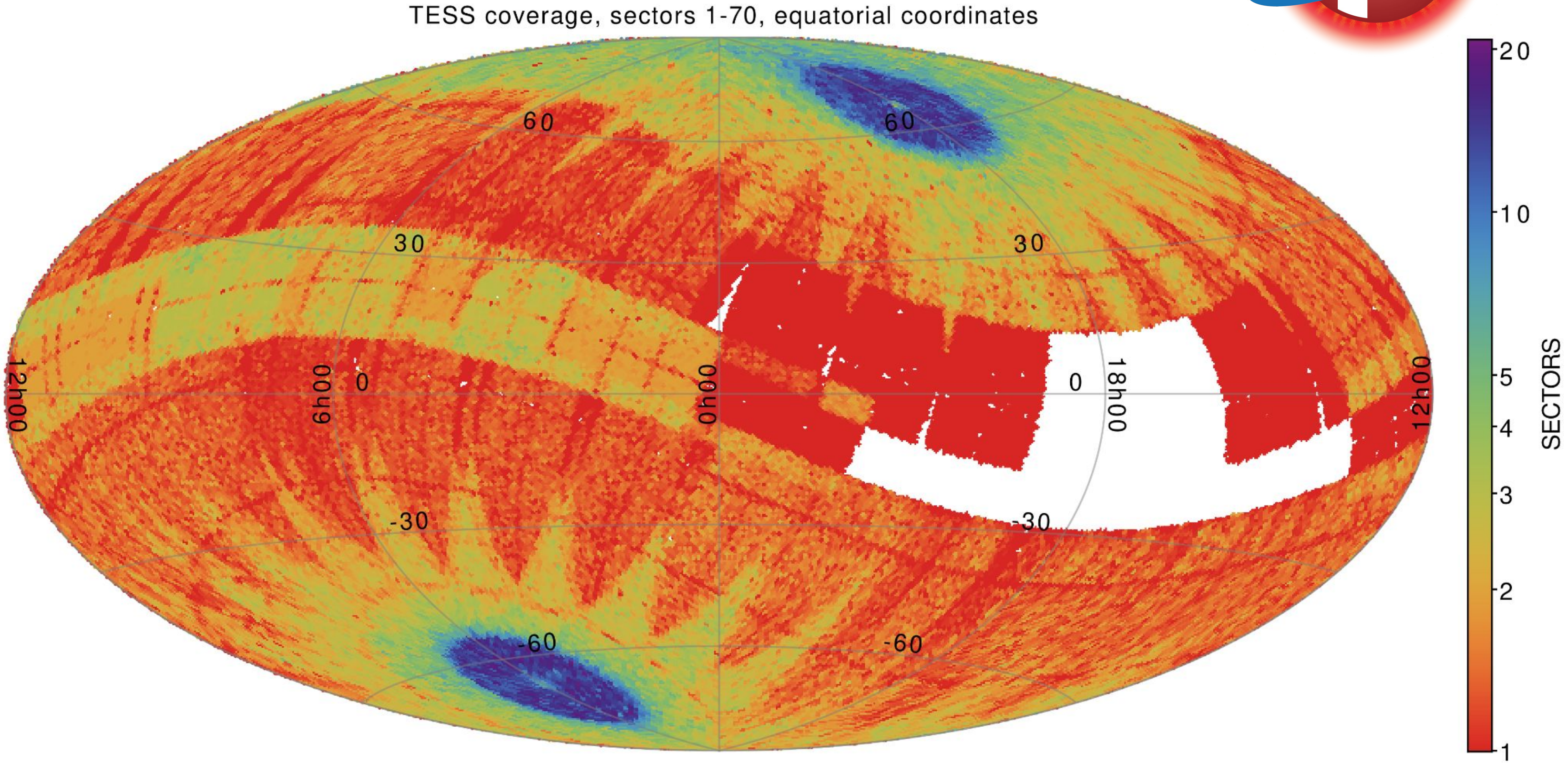


Take home messages

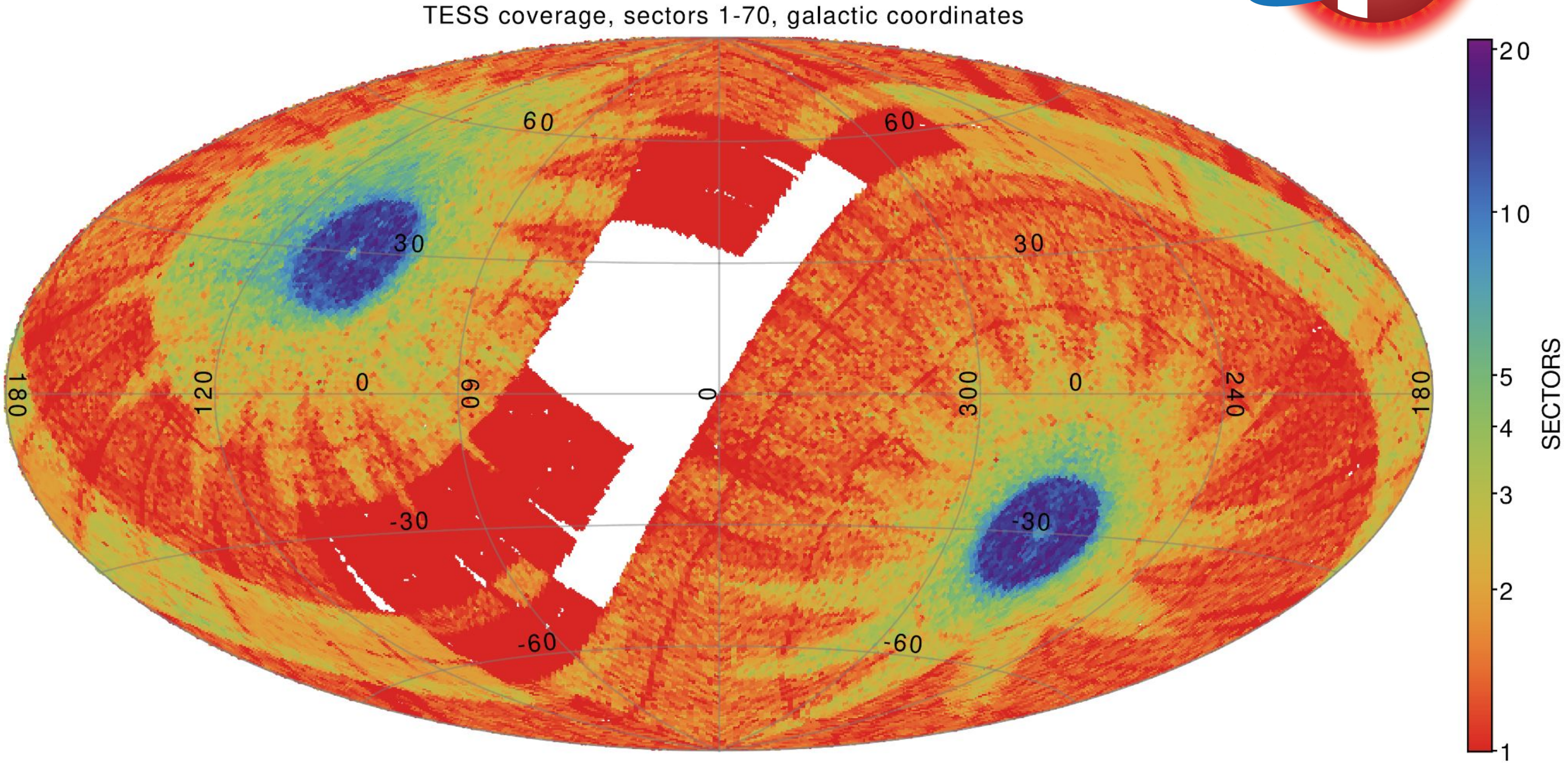
- GaiaNIR (+Gaia) could discover astrometric planets in systems where PLATO will detect transiting planets, expanding our parameters space and unveiling the dynamical architecture on a larger scale;
- GaiaNIR could be helpful in identifying some false-positive scenarios (through multi-filter photometry) and binary systems (through astrometry)
- Could the same be done with a combination of ground-based RV, imaging, on-off photometry? *Sometimes* yes, but this is an expensive and very slow process (only <6% of TESS candidates were confirmed so far, despite a global effort)

Backup slides

Space-based transit surveys: TESS



Space-based transit surveys: TESS



Space-based transit surveys: PLATO vs. TESS