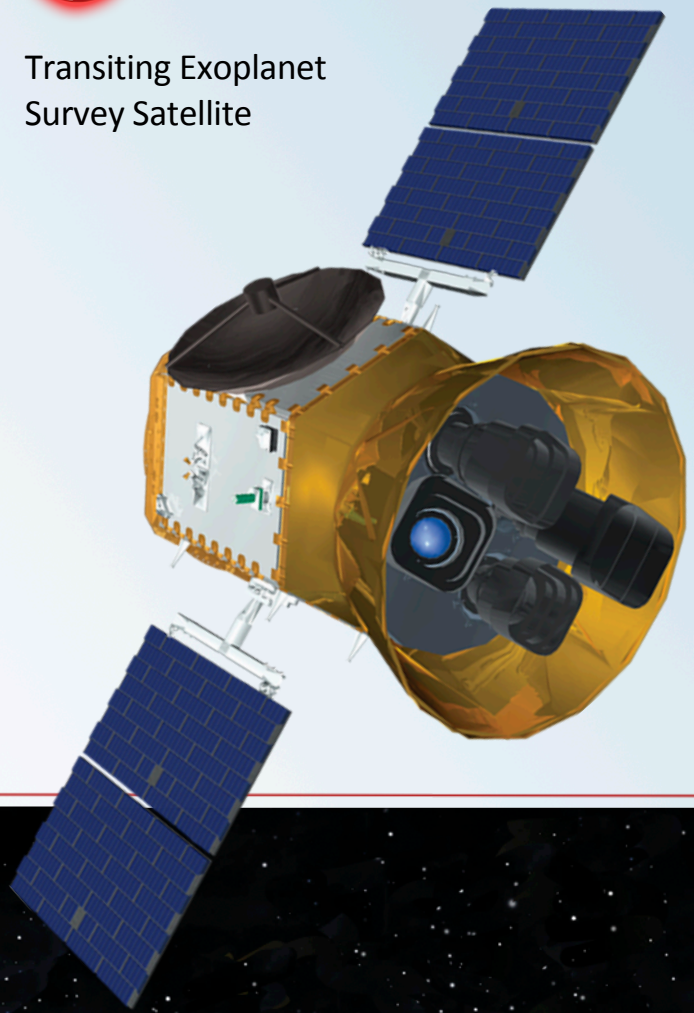
Transiting Exoplanet Survey Satellite



TESS Update: Discovering New Earths and Super-Earths in the Solar Neighborhood

Presented by: George Ricker

NASA Astrophysics Subcommittee

21 July 2015

TESS Institutional Partners

Massachusetts Institute of Technology

NASA Goddard

Orbital ATK

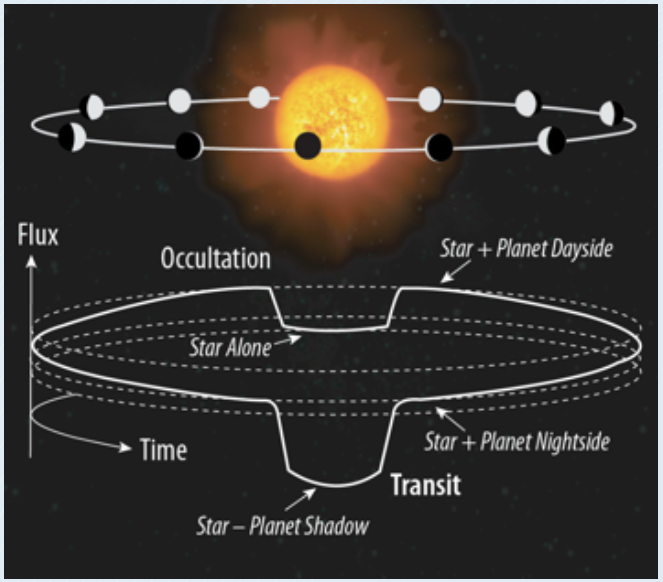
Harvard

NASA Ames

Space Telescope Science Institute

TESS Science Team

So Many Stars...So Little Time



Primary Goal: Discover Transiting Earths and Super-Earths Orbiting Bright, Nearby Stars

- *Rocky Planets & Water Worlds*
- *Habitable Planets*

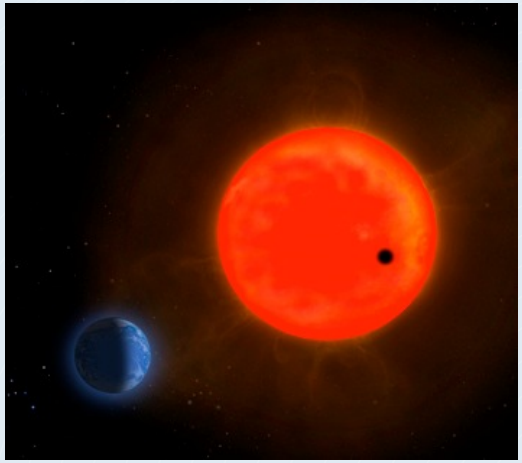
Discover the "Best" ~1000 **Small** Exoplanets

- *"Best" Means "Readily Characterizable"*
  - *Bright Host Stars*
  - *Measurable Mass & Atmospheric Properties*
- *Present: Only 3 small transiting exoplanets orbiting bright hosts are known*

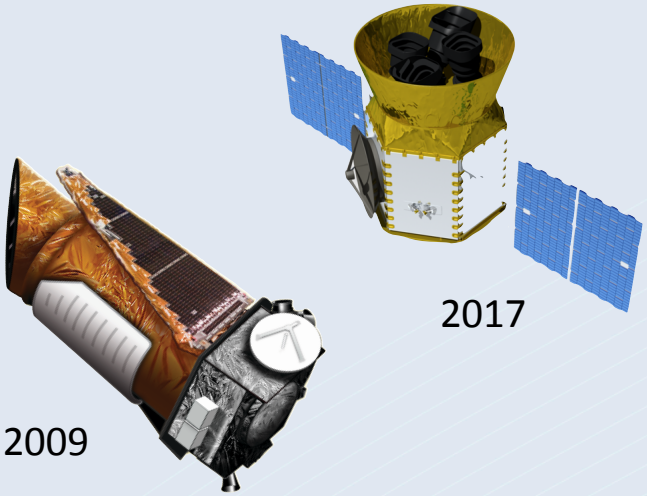
Large Area Survey of Bright Stars

- *Sun-like stars: $I_c \lessapprox 2$ to $I_c = 12$ magnitude*
- *M dwarfs known within ~60 parsecs ($I_c \lessapprox 14$)*
- *"All sky" observations in 2 years:*
  - *> 200,000 target stars at <2 min cadence*
  - *> 20,000,000 stars in full frames at 30 min cadence*

Launch in August 2017

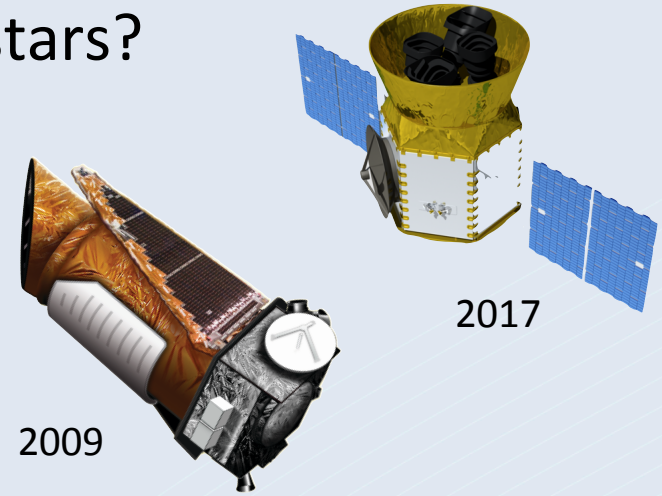


TESS Stars Are Brighter than Kepler Stars



TESS Stars Are Brighter than Kepler Stars

- How do we arrange for brighter stars?
  - *Two ways…*



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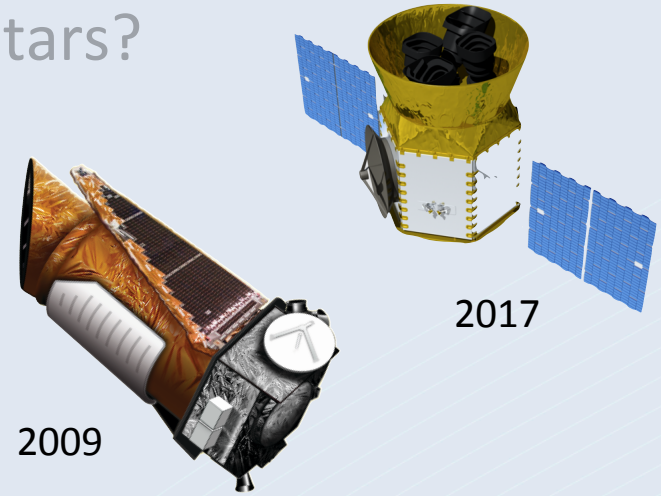

- Increase solid angle coverage
  - $\Omega_{TESS} \simeq 400\ \Omega_{Kepler}$
  - *Number of accessible bright stars increased by same factor*

TESS Stars Are Brighter than Kepler Stars

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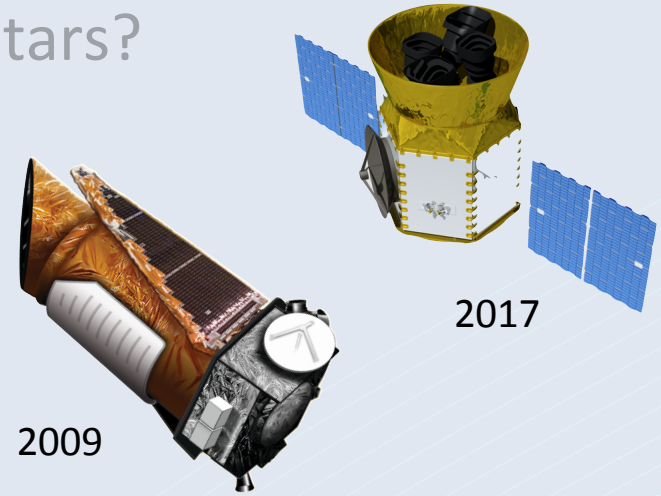

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- Select stars that are much closer
  - *TESS: ~10^2 light-yr*
  - *Kepler: ~10^3 light-yr*

TESS Stars Are Brighter than Kepler Stars

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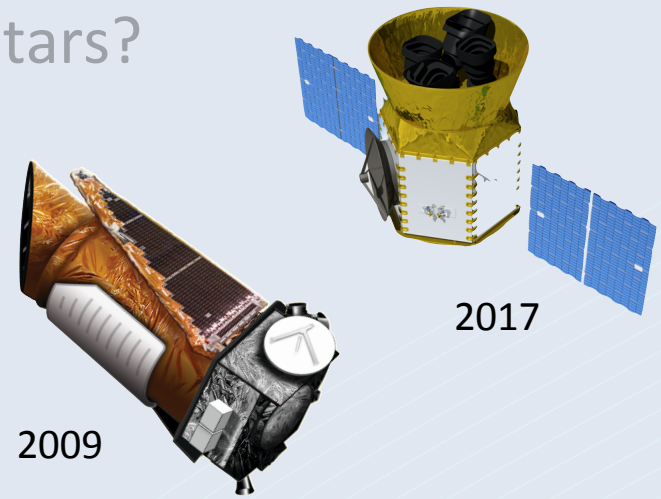

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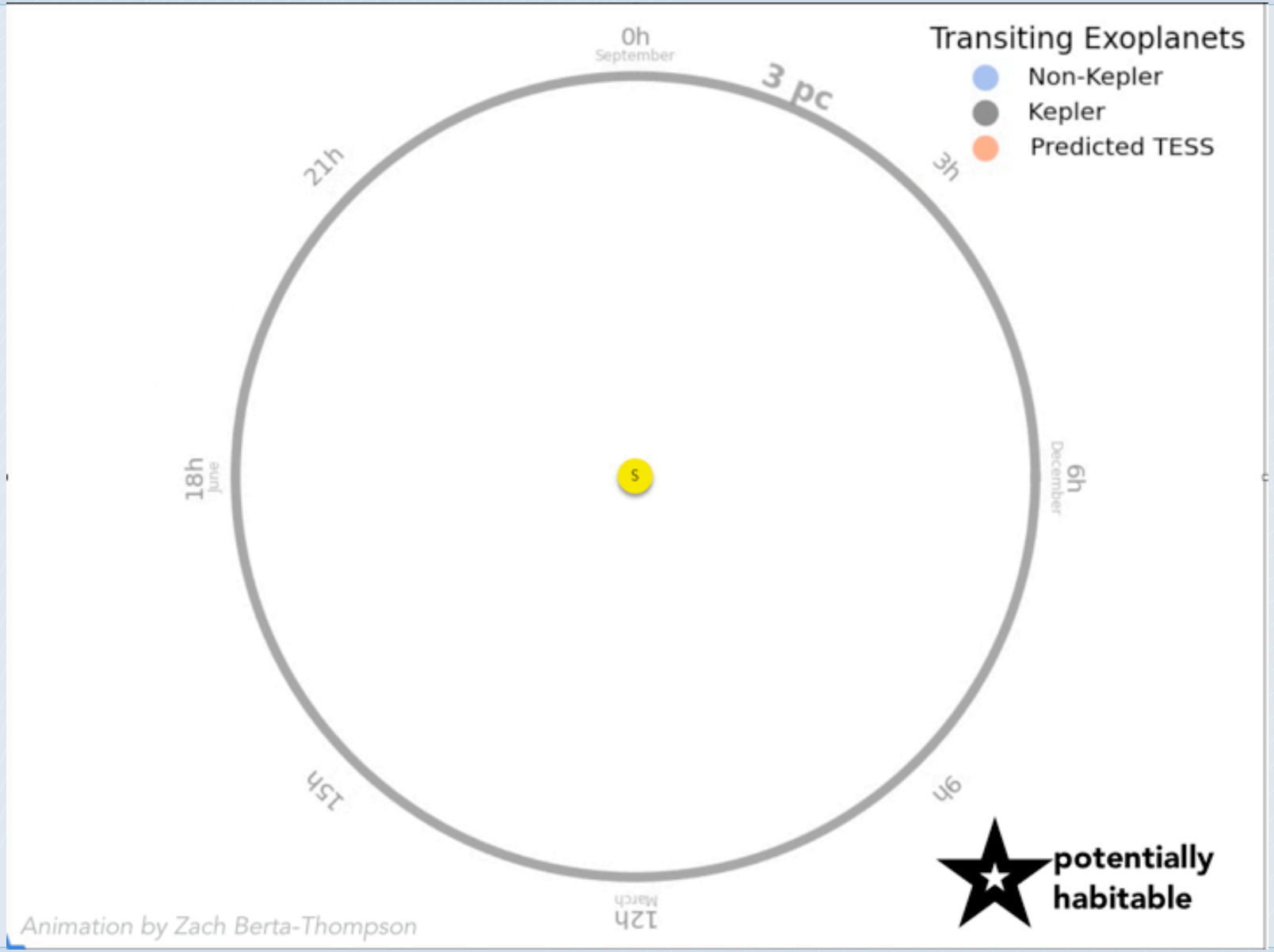
  - *Kepler: ~10^3 light-yr*

$1/R^2$ dependence means TESS stars are ~100 times brighter on average

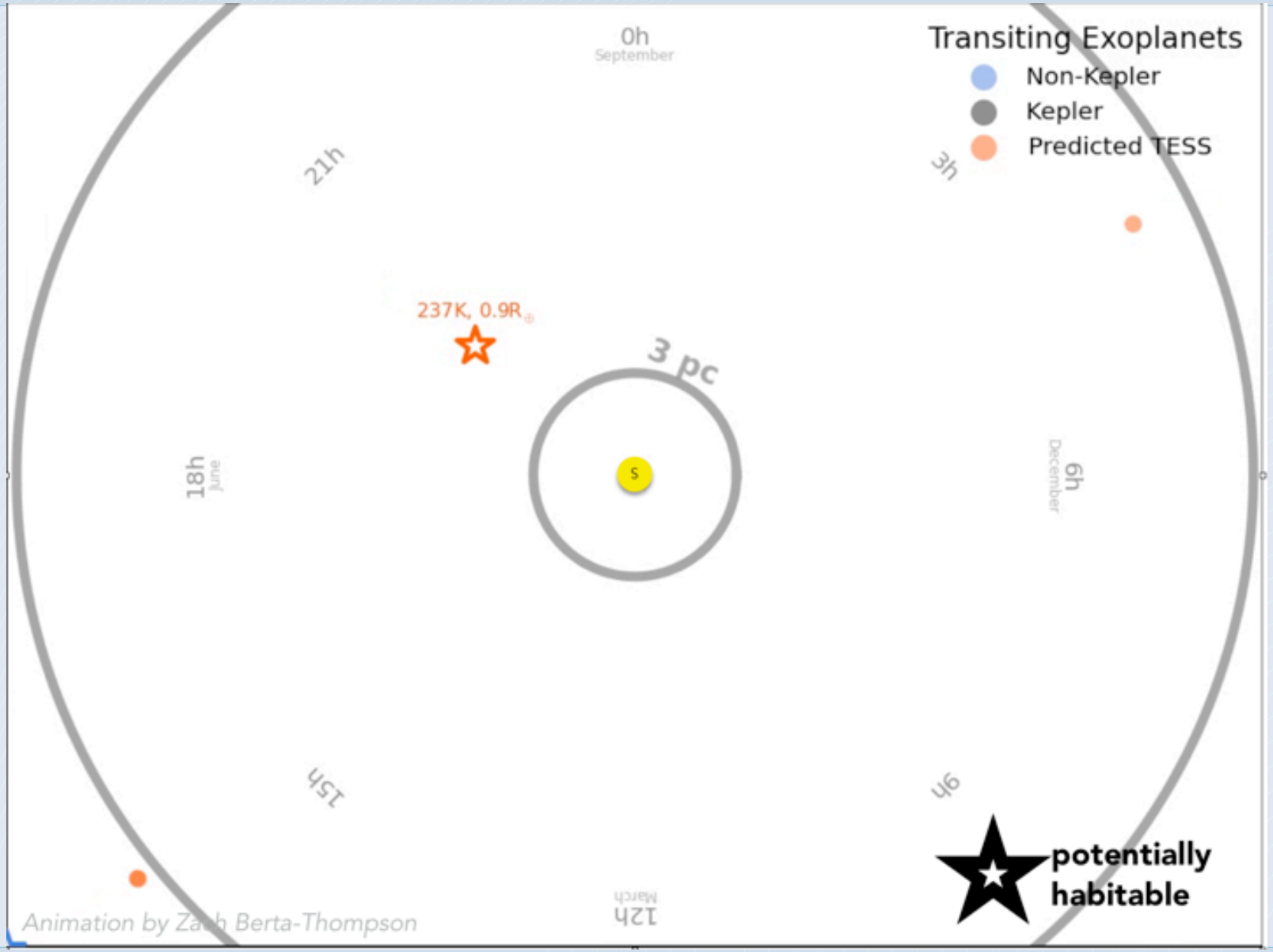
TRILEGAL Simulation of Expected TESS Detections

- TRIdimensional modeL of thE GALaxy (Girardi et al. 2005)
  - *Monte Carlo population synthesis code that models the Milky Way with four components*
    - *Thin Disk*
    - *Thick Disk*
    - *Halo*
    - *Bulge*
- Details are given in Sullivan et al. (arXiv:1506.08845)
- Animation follows showing transiting planets expected at increasing distances from Sun
  - *3 pc*
  - *10 pc*
  - *30 pc*
  - *100 pc*
  - *300 pc*

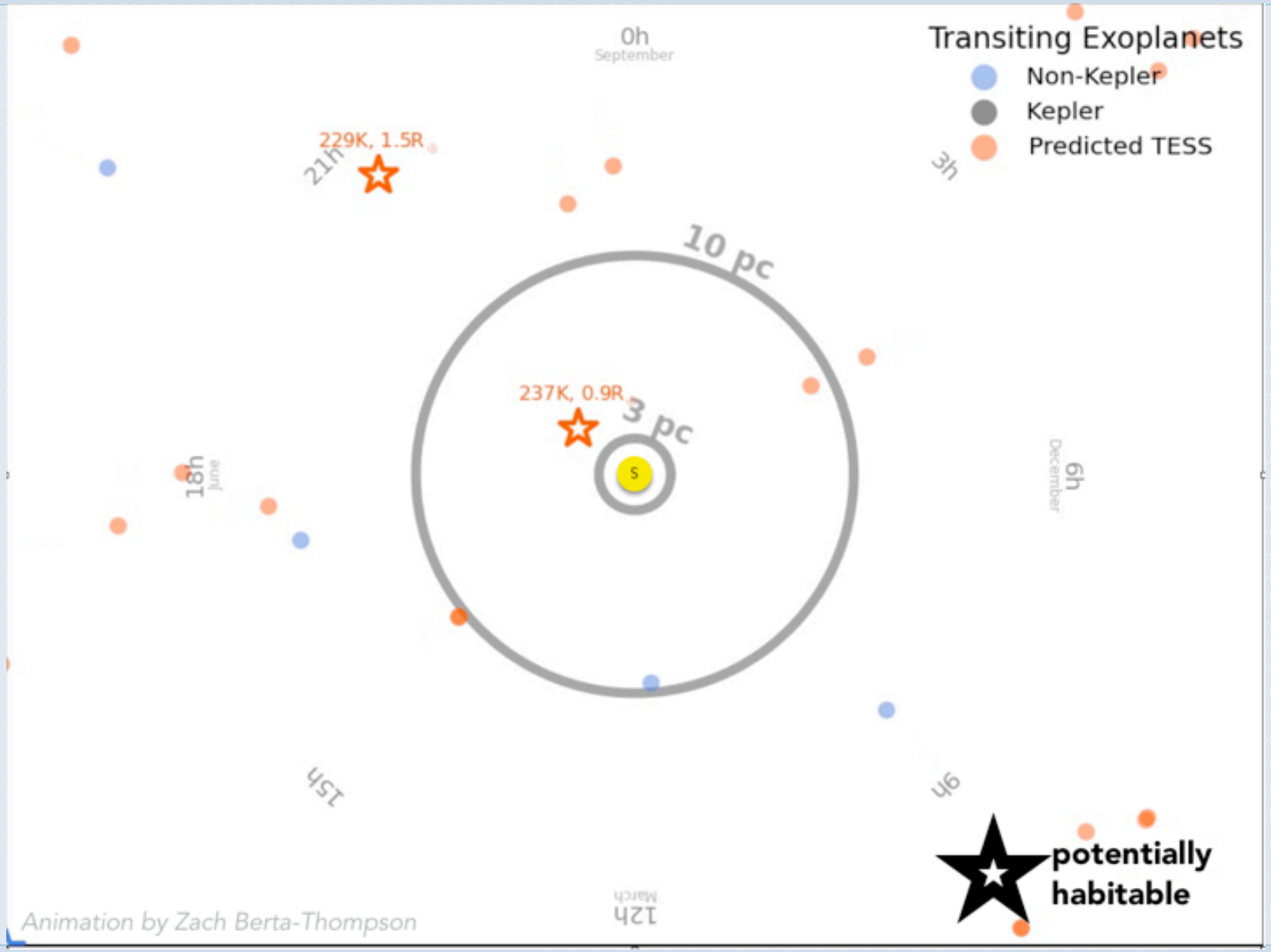
Transiting Planets in the Solar Neigborhood-2



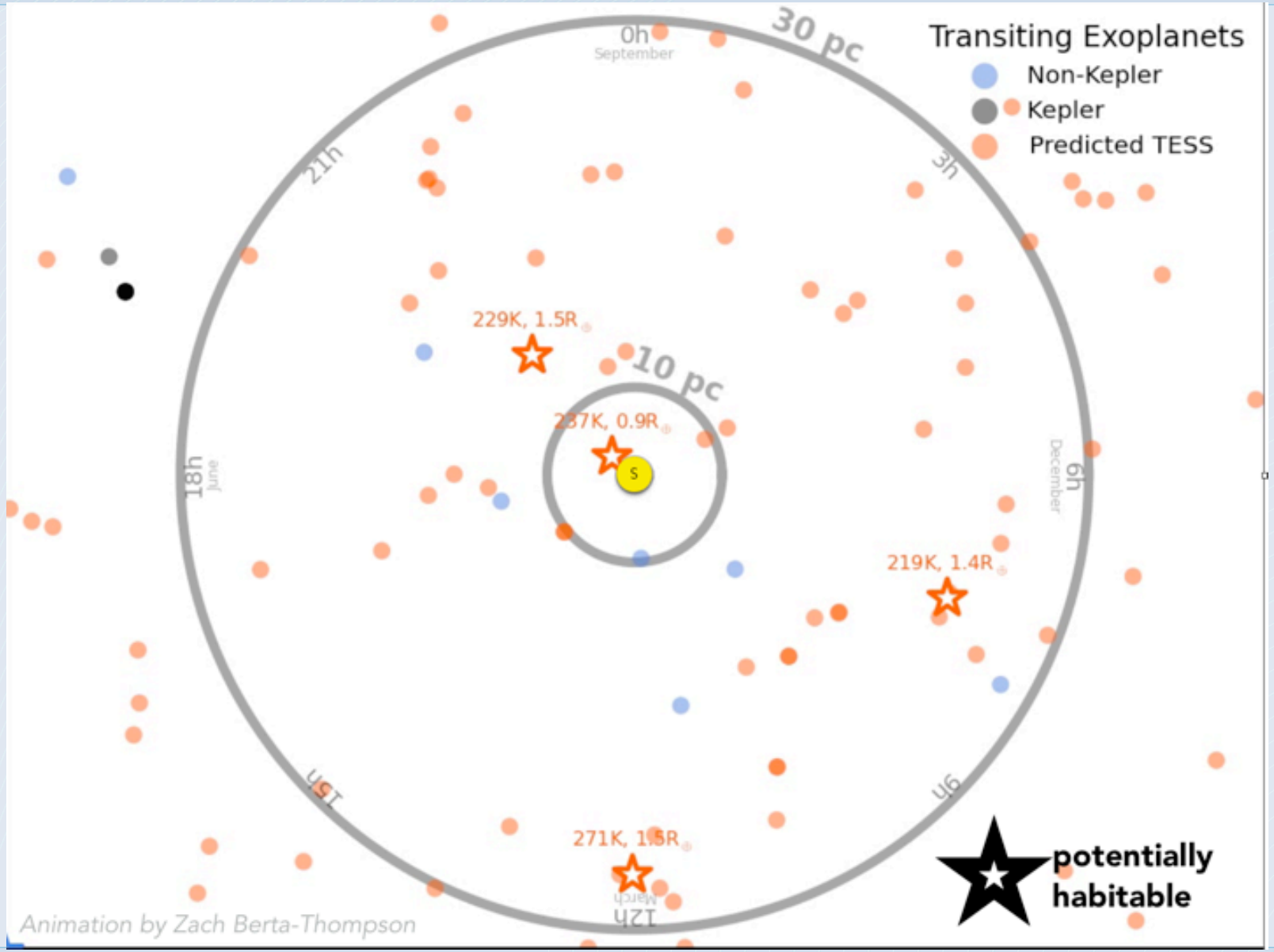
Transiting Planets in the Solar Neigborhood-3



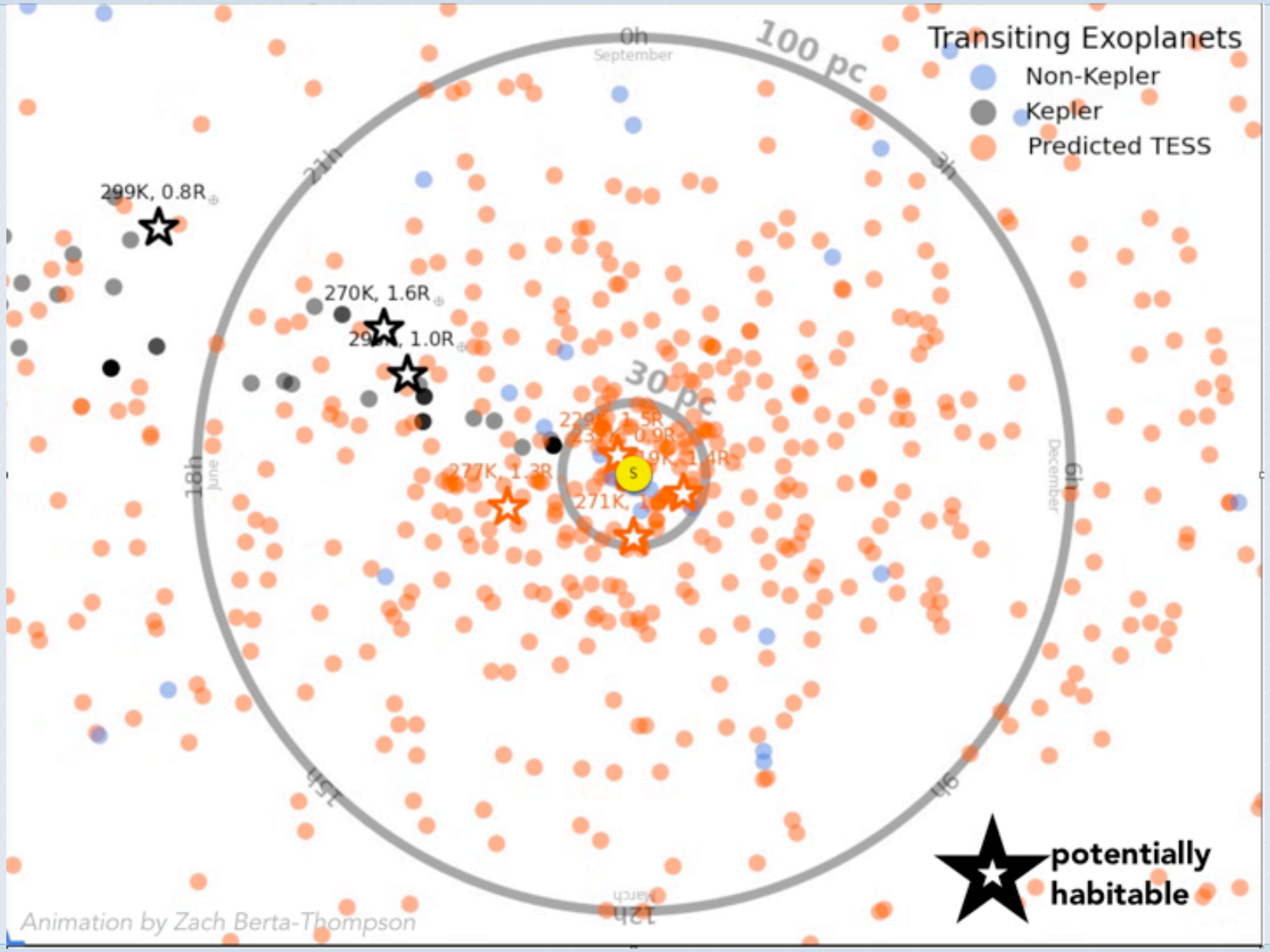
Transiting Planets in the Solar Neigborhood-4



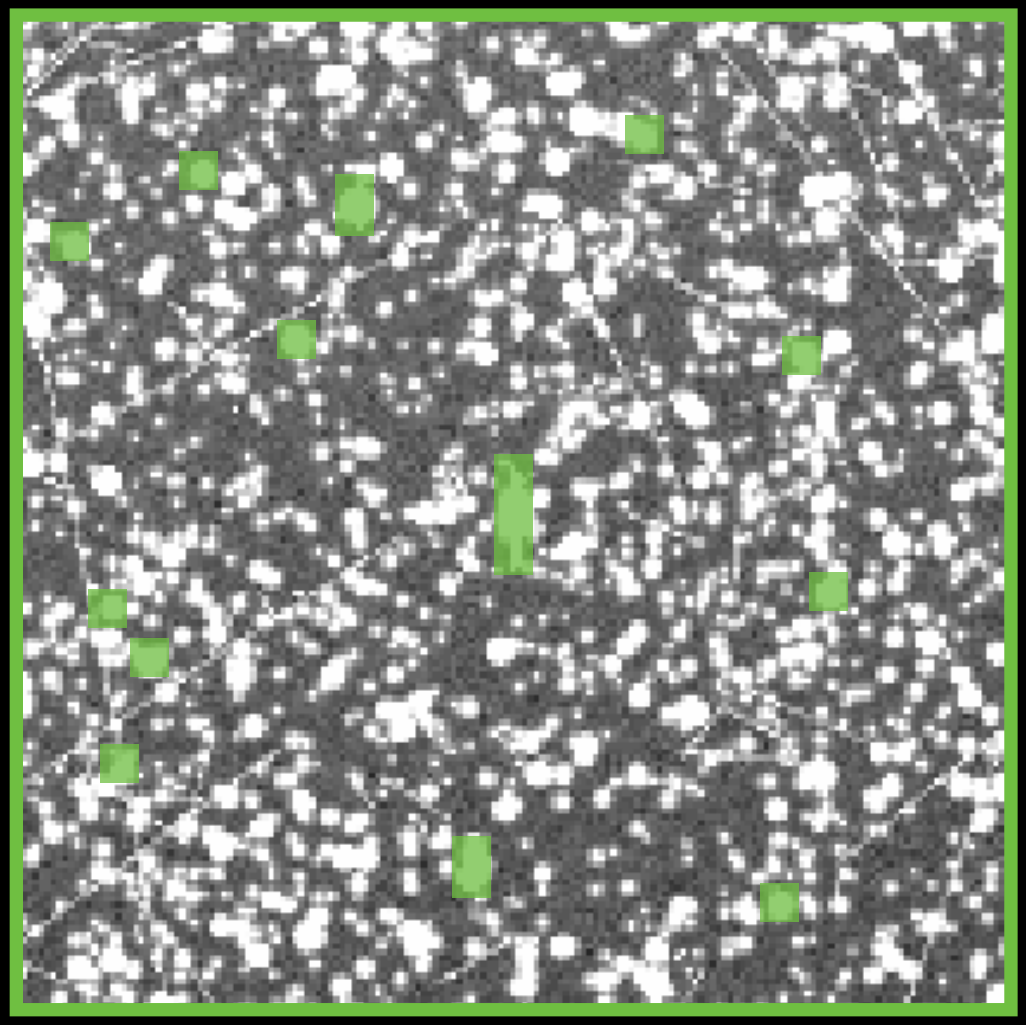
Transiting Planets in the Solar Neigborhood-5



Transiting Planets in the Solar Neigborhood-6



2-minute cadence
for >200,000 stars

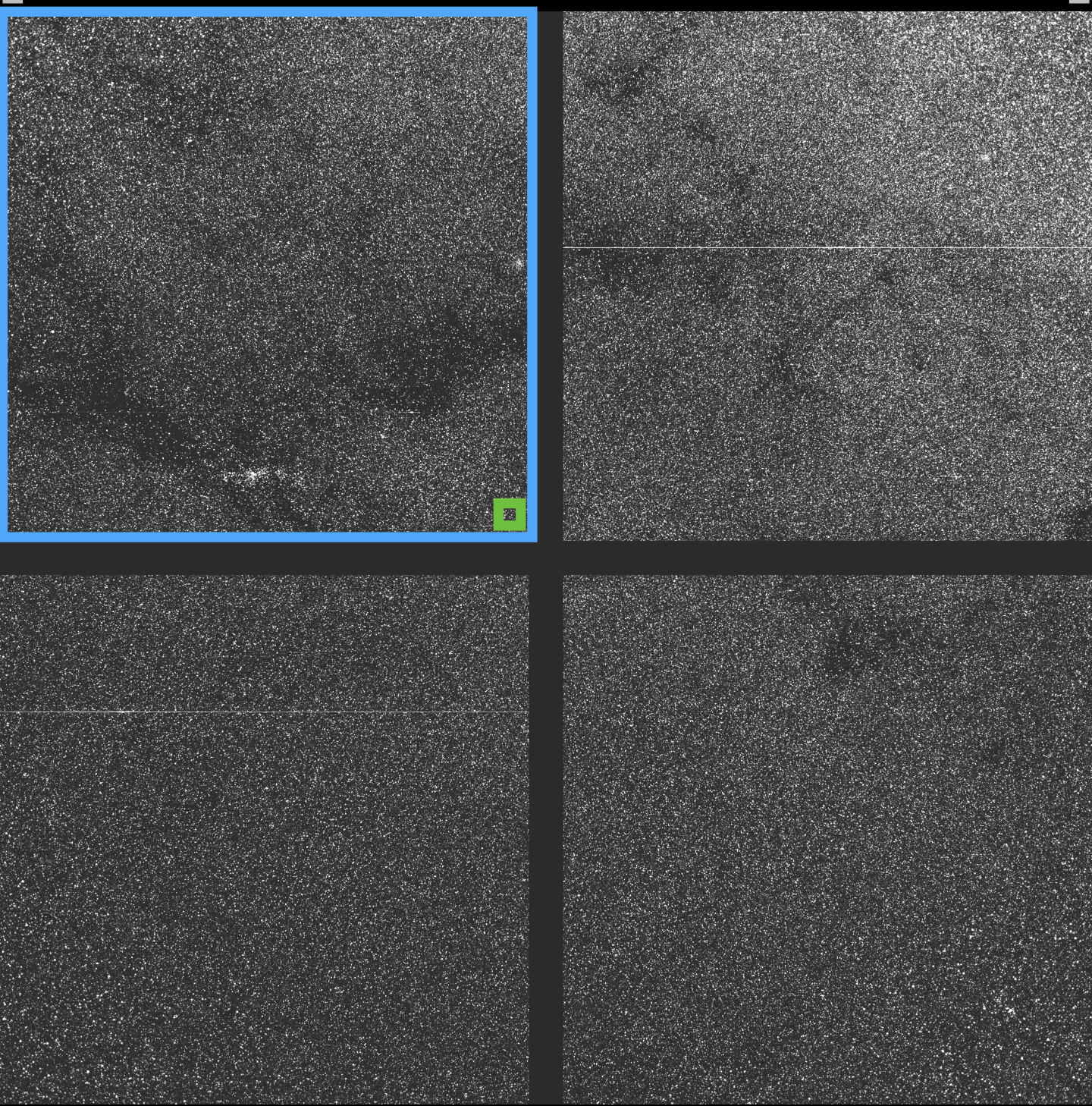


1 degree

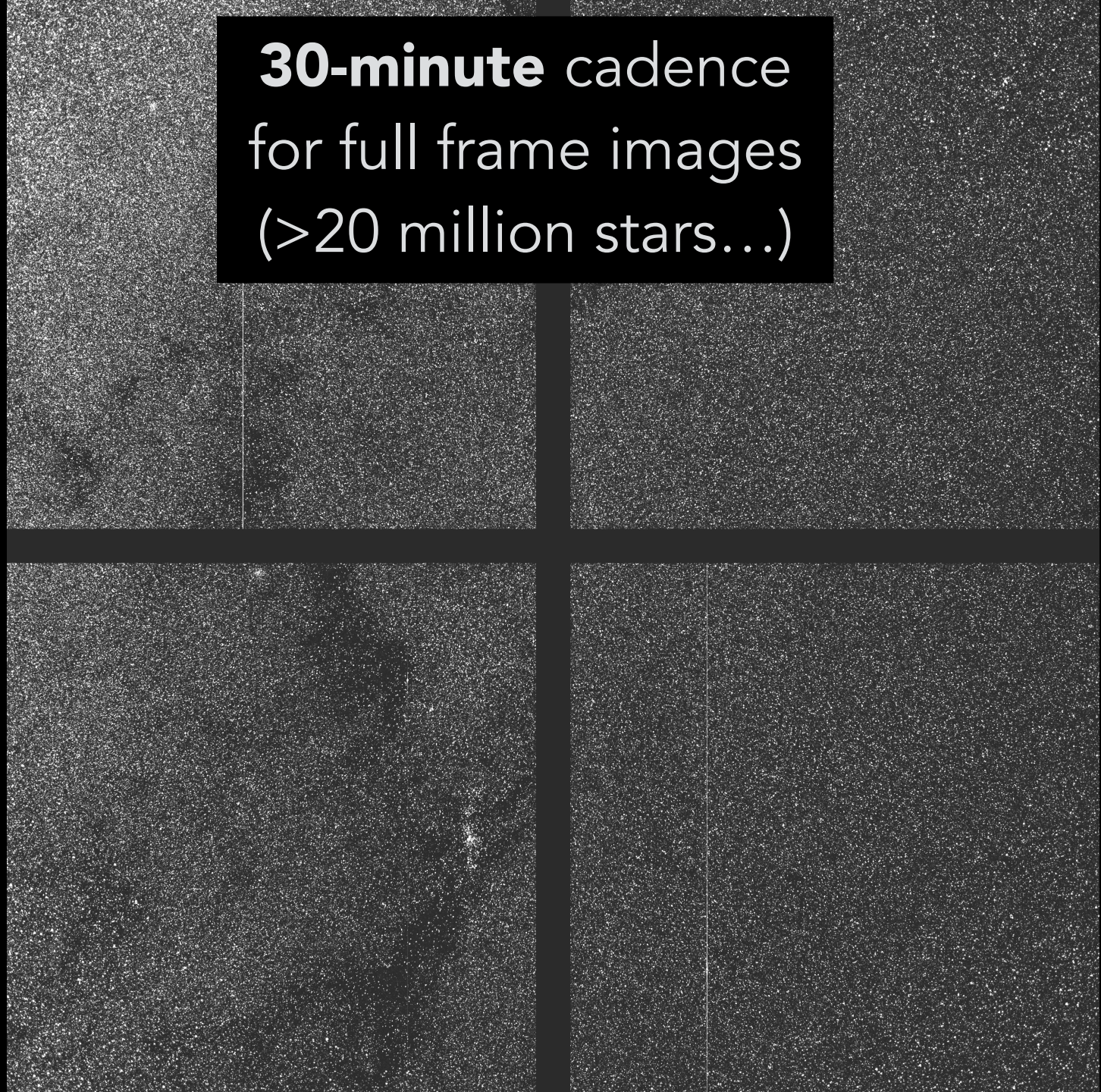
prioritizing detectability of small planets

simulated images by Zach Berta-Thompson

one camera:
24 degrees

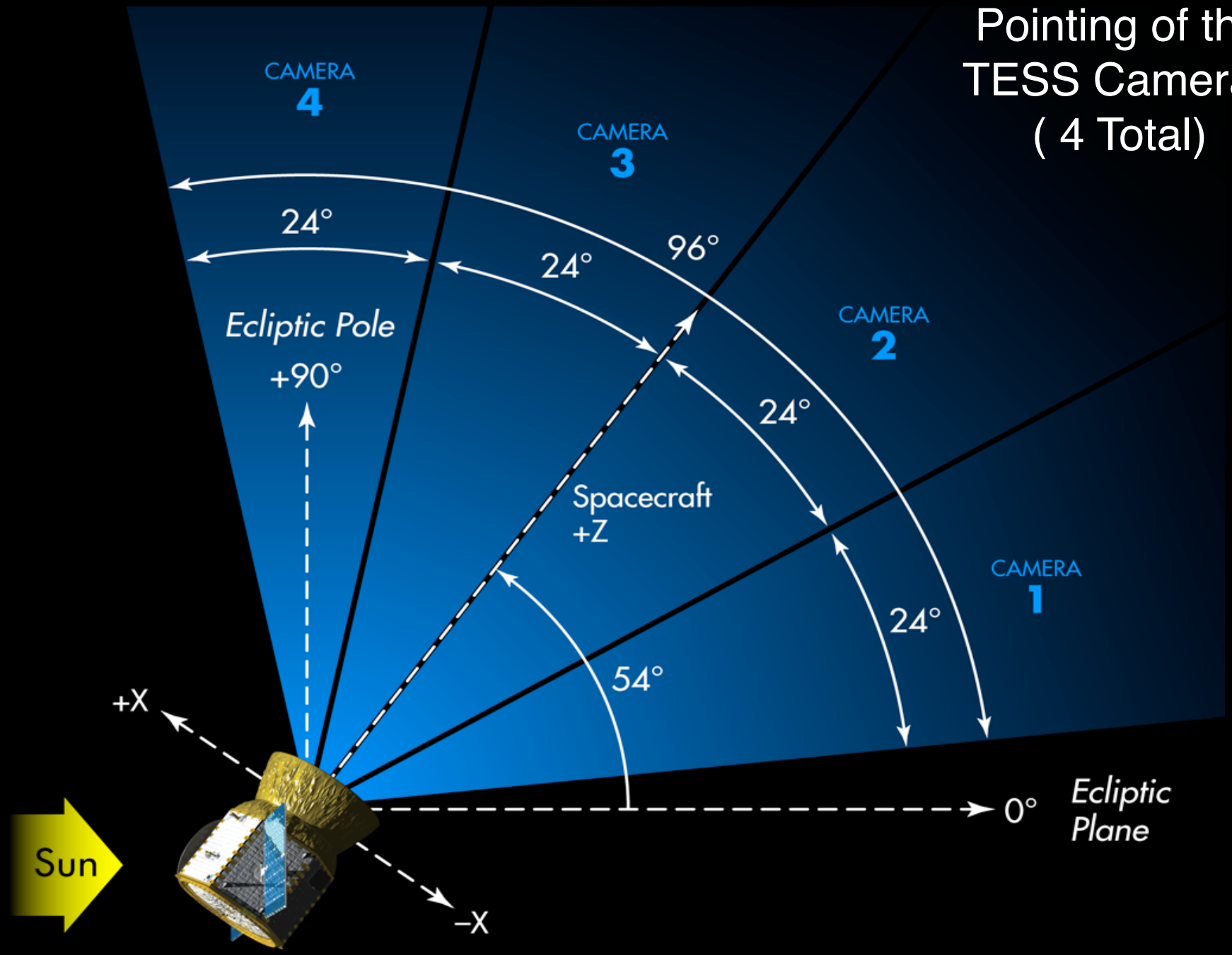


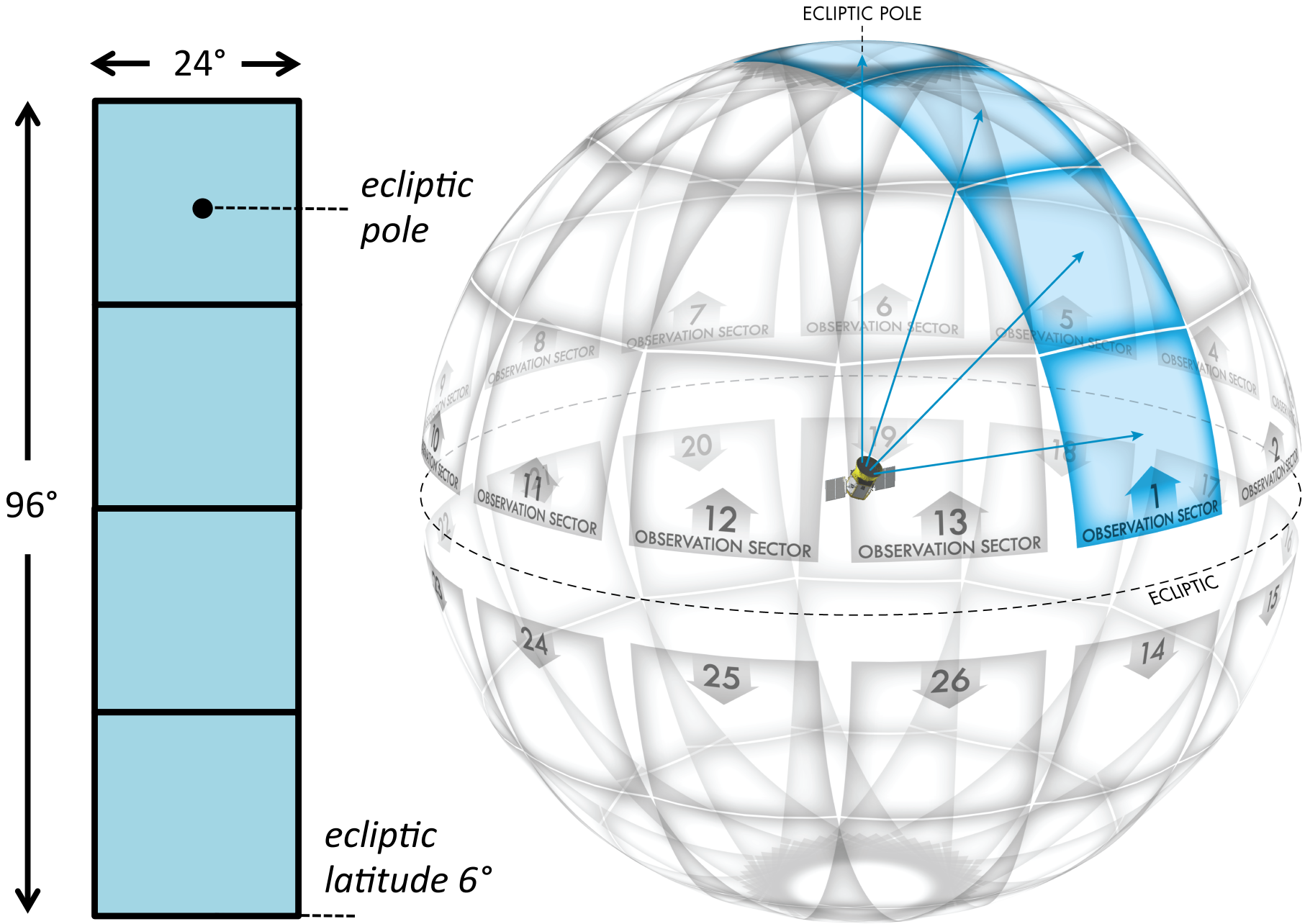
30-minute cadence for full frame images (>20 million stars…)



one camera: 24 degrees

Pointing of the TESS Cameras (4 Total)




24°
96°
ecliptic pole
ecliptic latitude 6°
ECLIPTIC POLE
ECLIPTIC
1 OBSERVATION SECTOR
2 OBSERVATION SECTOR
4 OBSERVATION SECTOR
5 OBSERVATION SECTOR
6 OBSERVATION SECTOR
7 OBSERVATION SECTOR
8 OBSERVATION SECTOR
11 OBSERVATION SECTOR
12 OBSERVATION SECTOR
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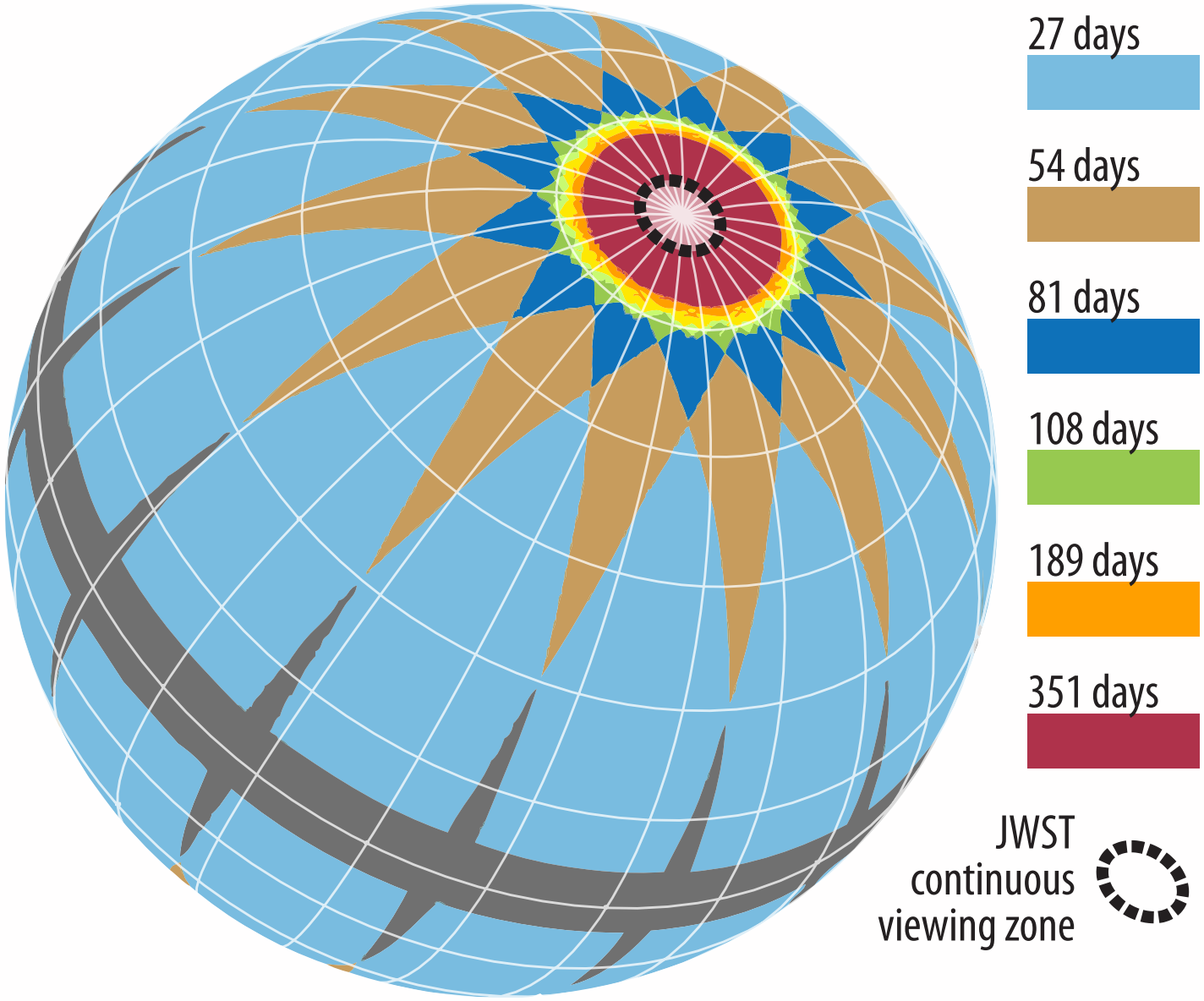
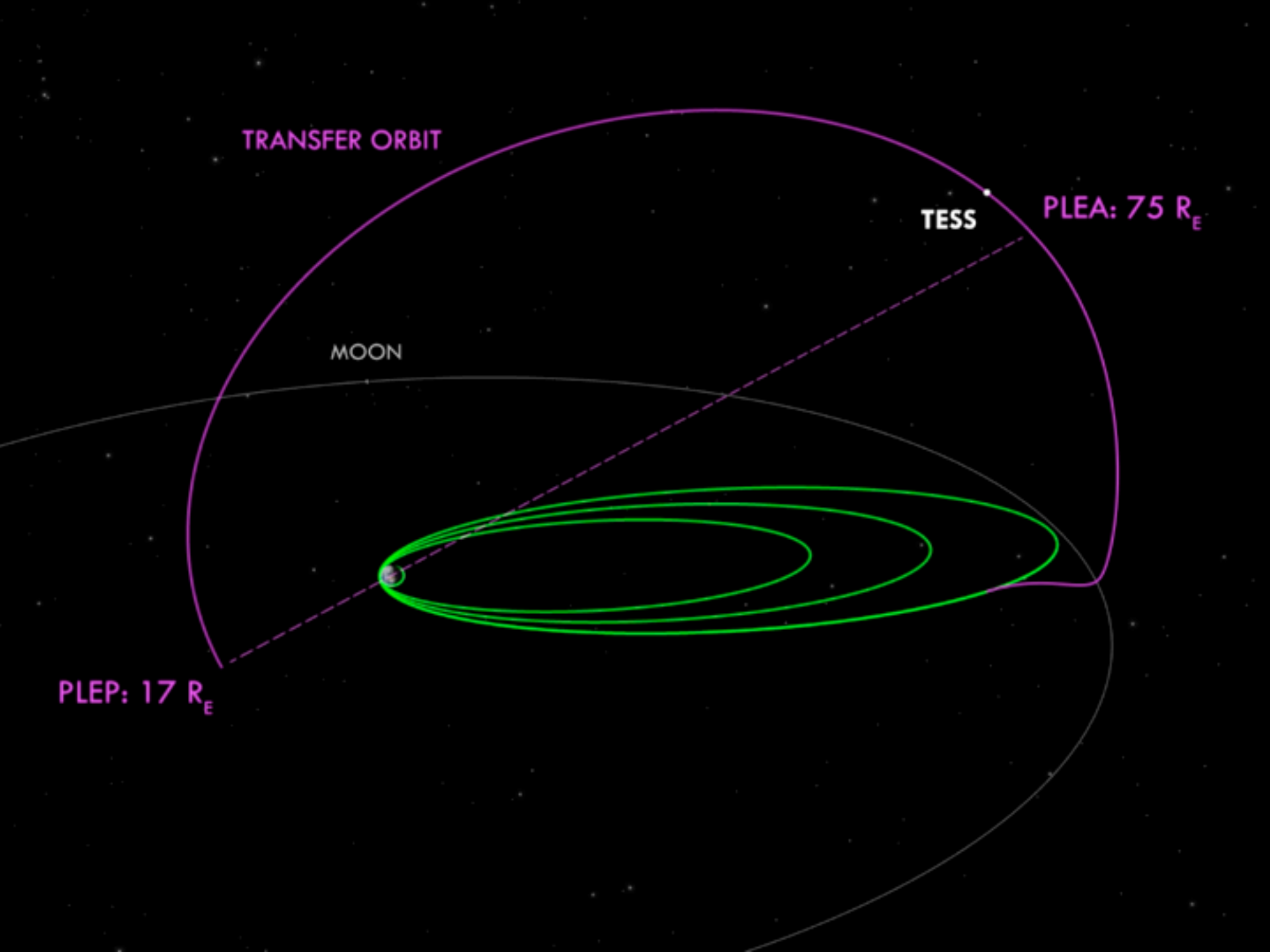


TESS — Discovering New Earths and Super-Earths in the Solar Neighborhood

TRANSITING EXOPLANET SURVEY SATELLITE

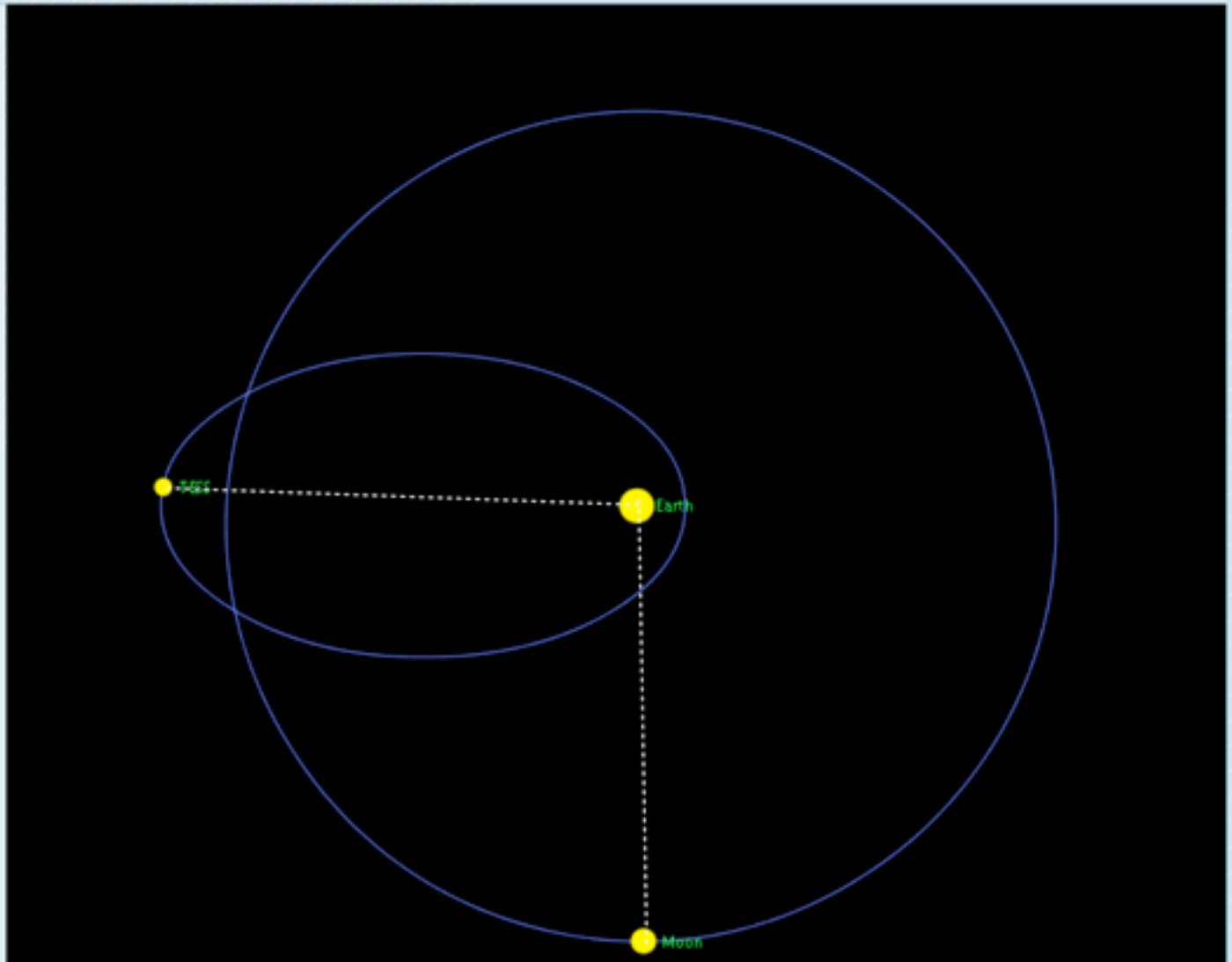
MISSION ORBIT INSERTION


TRANSFER ORBIT
TESS
PLEA: 75 R_E
MOON
PLEP: 17 R_E

TESS's Novel High Orbit

Uninterrupted viewing for >95% of time

Orbital Periods:
TESS = 13.7 days
Moon = 27.4 days
➡ 2:1 Resonance
➡ 90° Phasing



TESS Orbit is ***Stable*** for Decades *(no station keeping req'd)*

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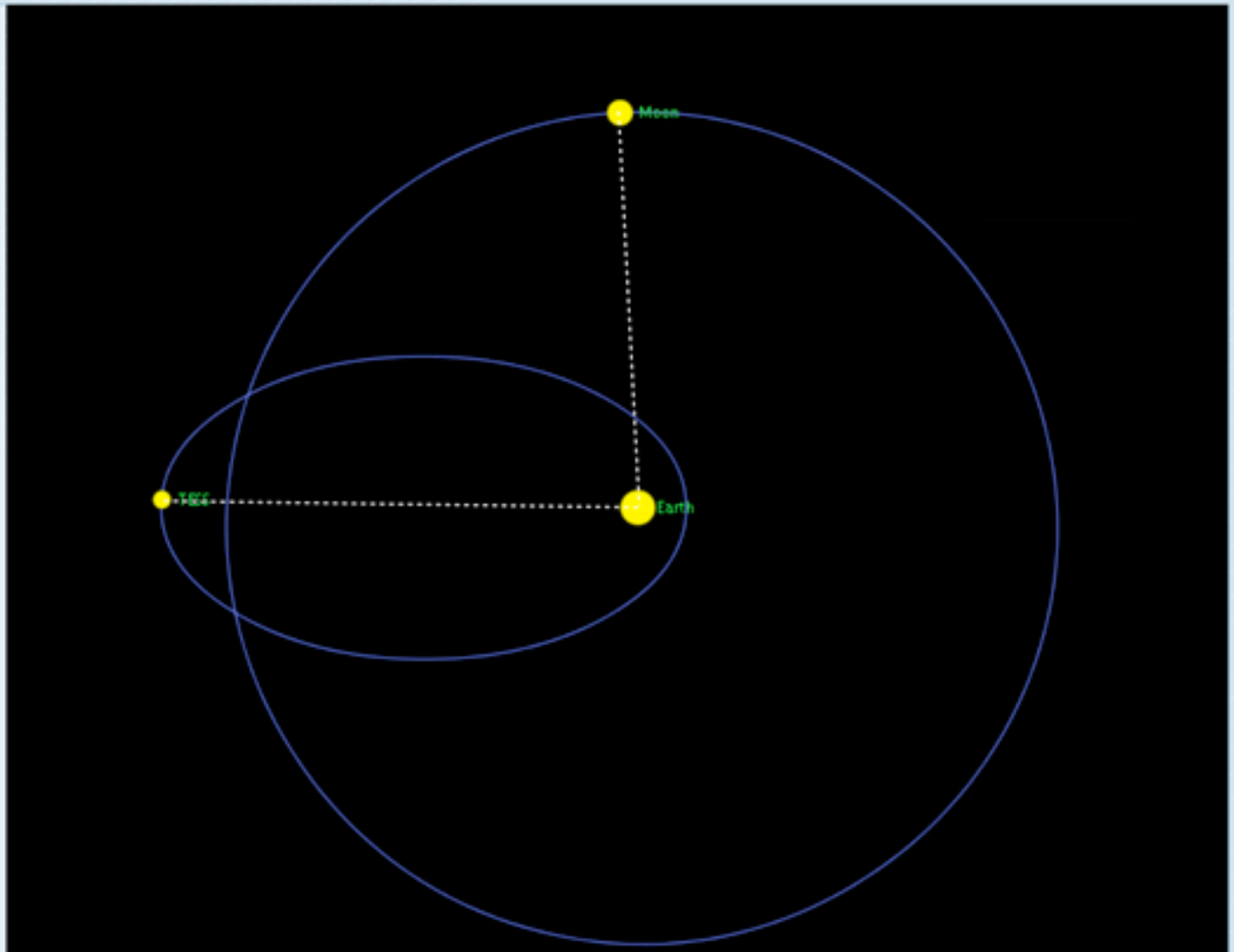


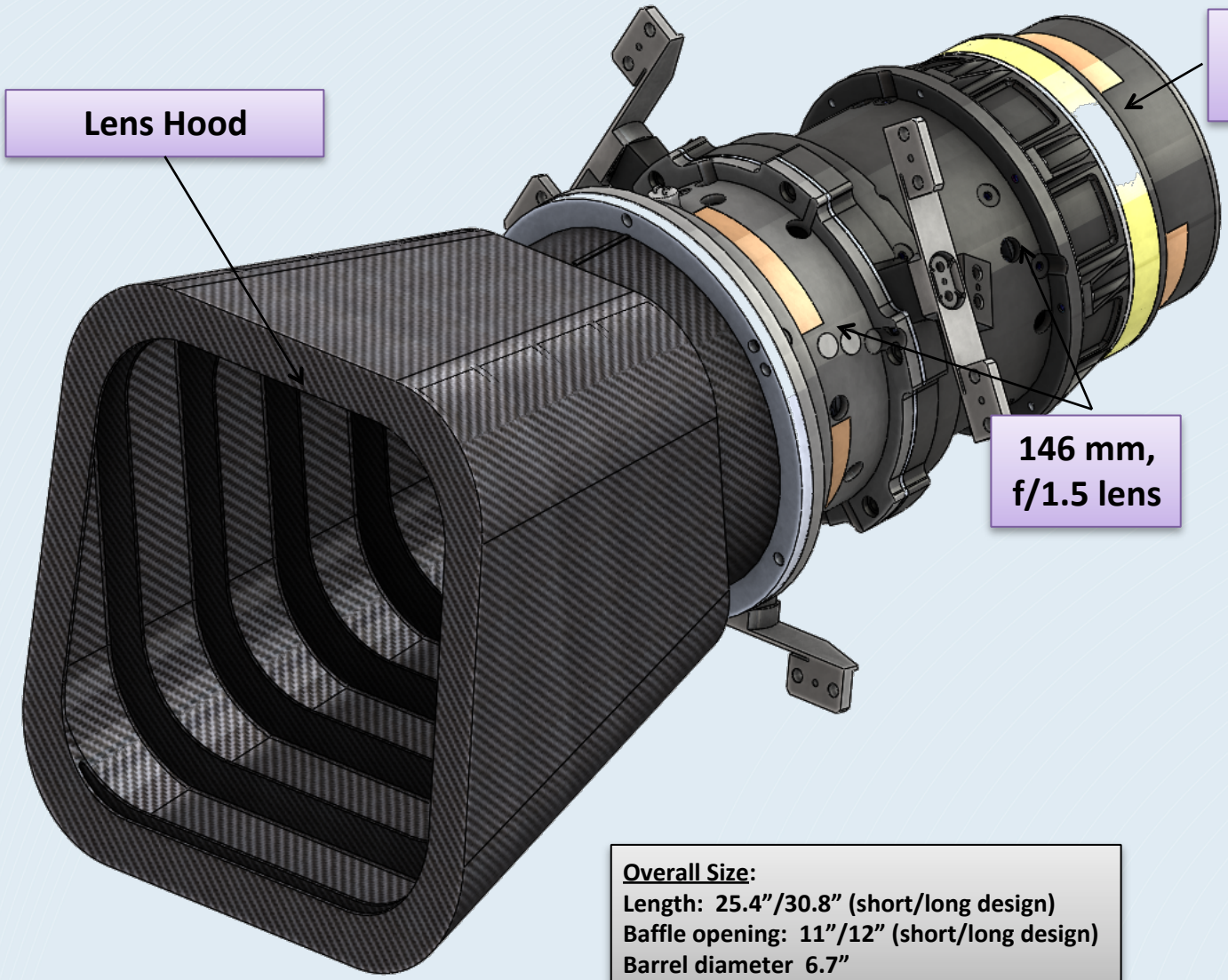
TESS Orbit is ***Stable*** for Decades *(no station keeping req'd)*

"Special" Orbit Enables and Simplifies TESS

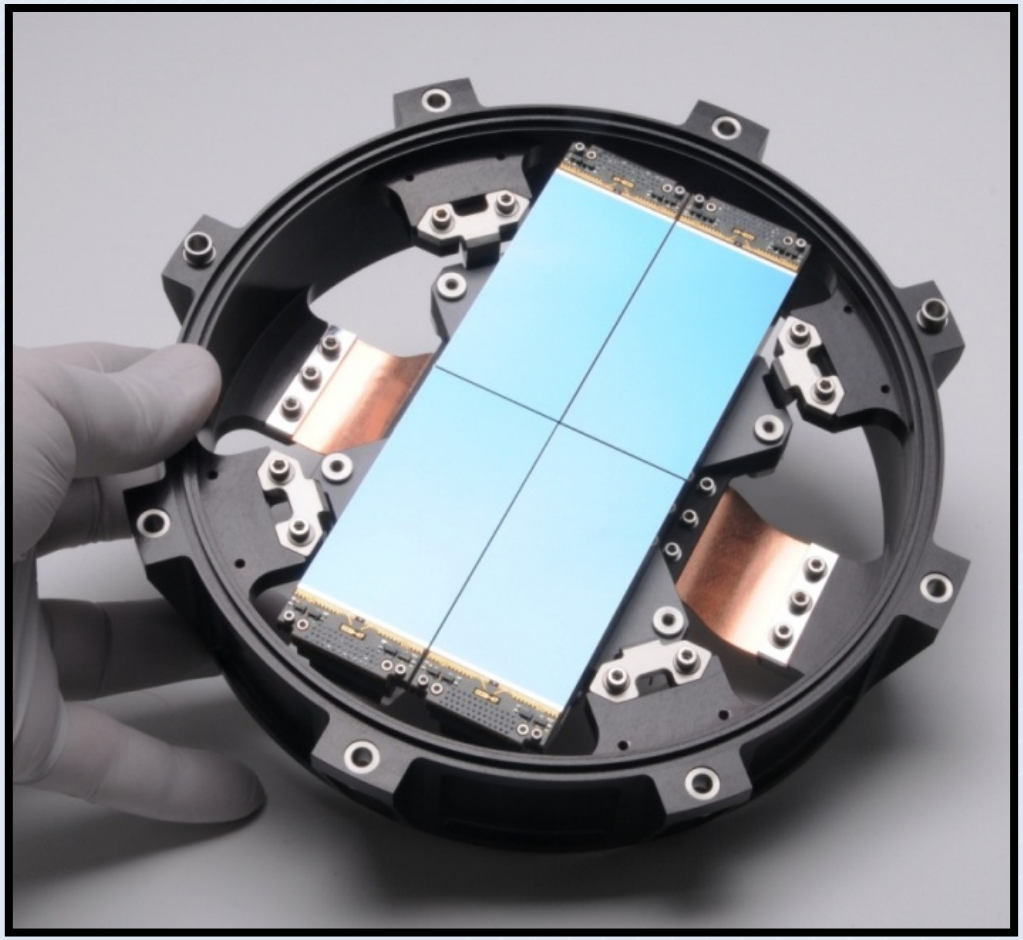
1) Extended & Unbroken Observations: *>300 hrs per orbit*
2) Thermal Stability: *<40 mK/hr (passive control only)*
3) Earth/Moon Stray Light Tolerance: *10^{-6} (vs 10^{-12} in LEO)*
4) Low Radiation Levels: *No SAA, No Outer Belt Electrons*
5) Frequent Launch Windows: *5 of 27 days per lunar month*
6) **High Data Rates:** *100 Mbit/s (200 GB in 3hr at Perigee)*
   [$1/R^2$ advantage: ~200x Earth-Sun L2; ~10,000x Kepler-type Orbit]
7) Excellent Pointing Stability: *No Drag, No Gravity Gradient*
8) Simple operations: *Single 5-7 hr Downlink & Repoint every ~2 wks*
9) Long Orbit Lifetime: *~Several Decades with Perigee > 6.6 R_E*

Gangestad et al. 2013 (astro-ph 1306.5333)

A TESS Camera (with short lens hood)



Overall Size:
Length: 25.4”/30.8” (short/long design)
Baffle opening: 11”/12” (short/long design)
Barrel diameter 6.7”

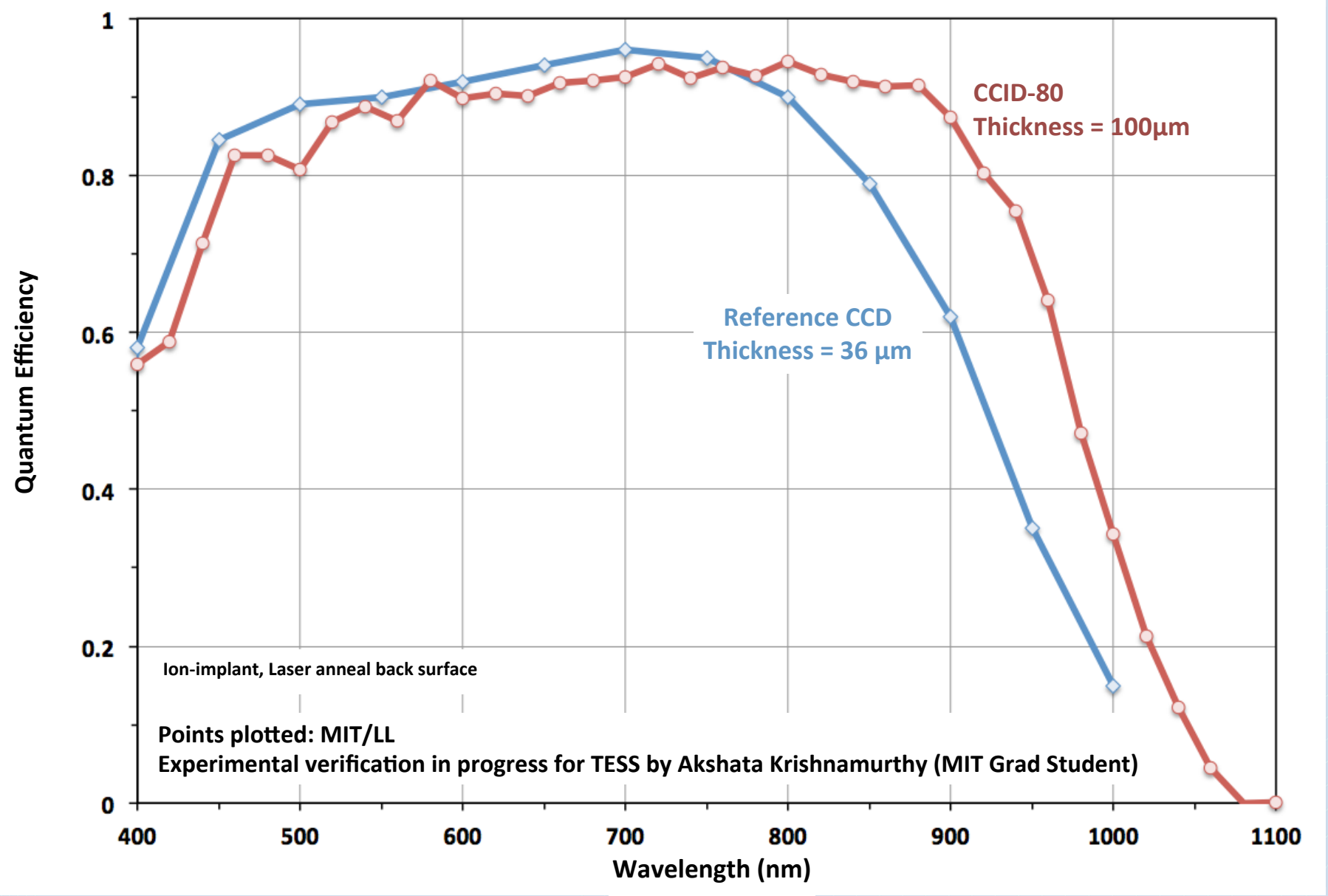


LL Deep Depletion CCDs

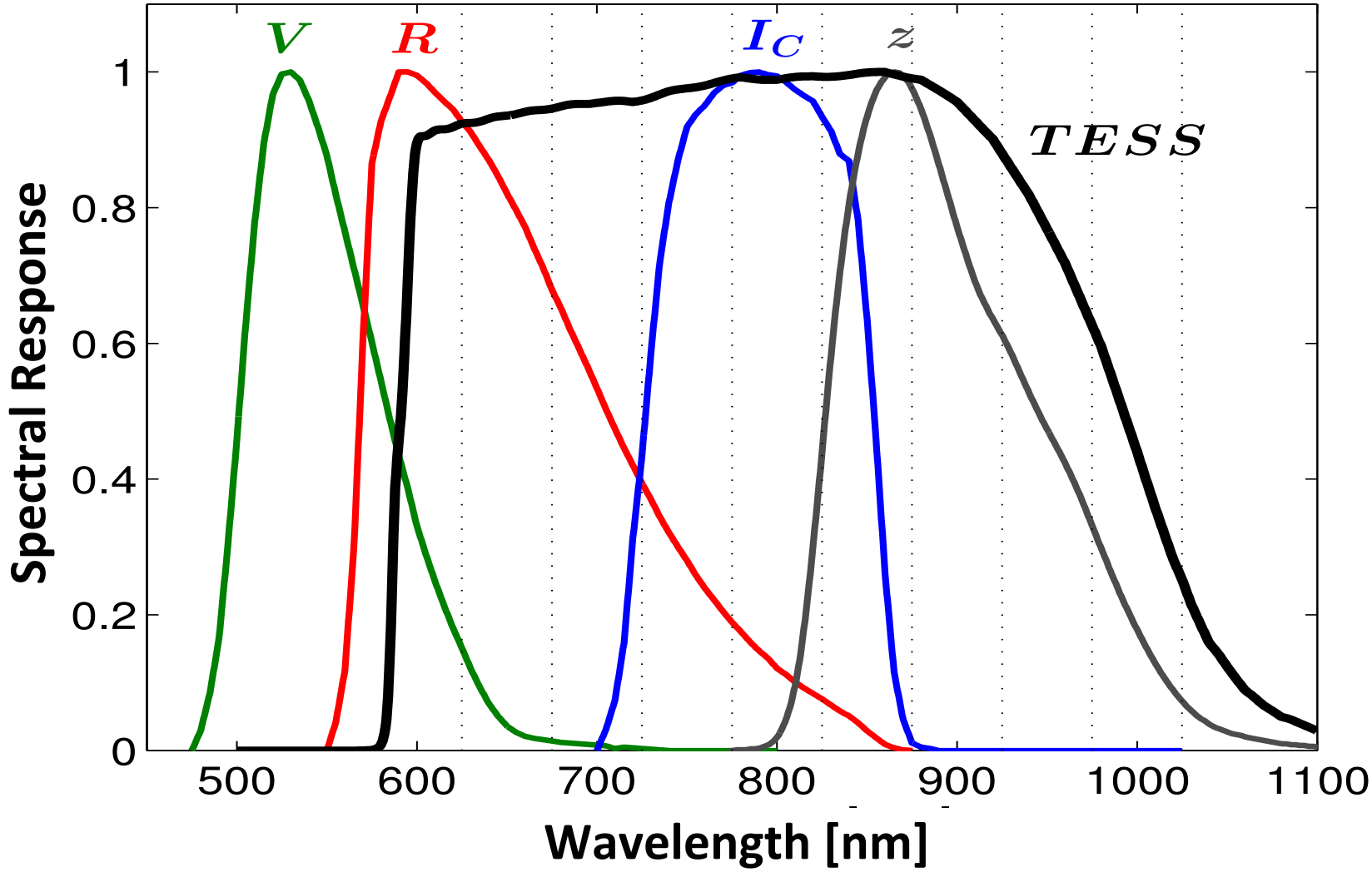
(Assembly by: GL Scientific)

Ricker et al. (2014)

Quantum Efficiency of BI CCID-80

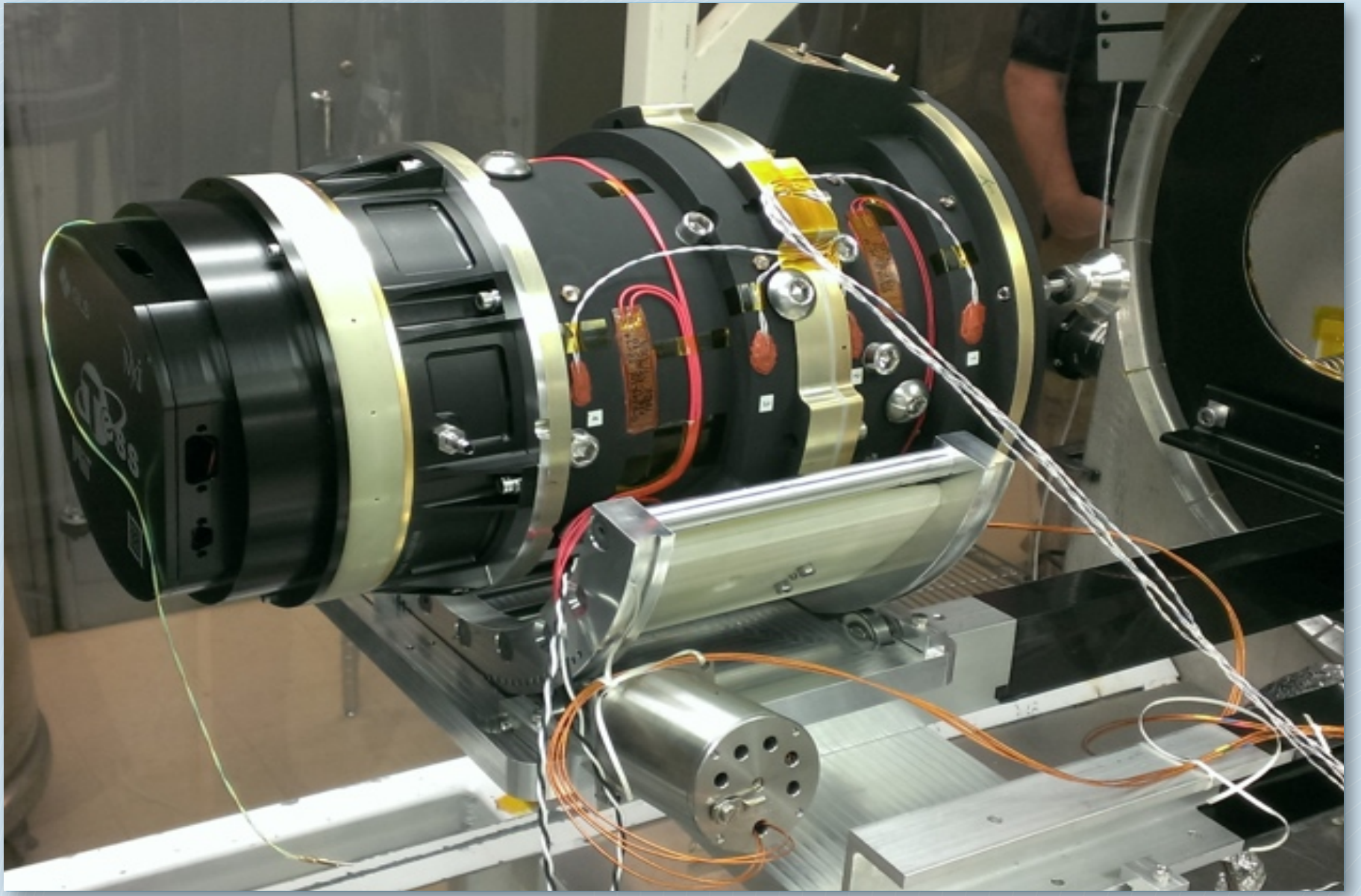


TESS Filter Passband



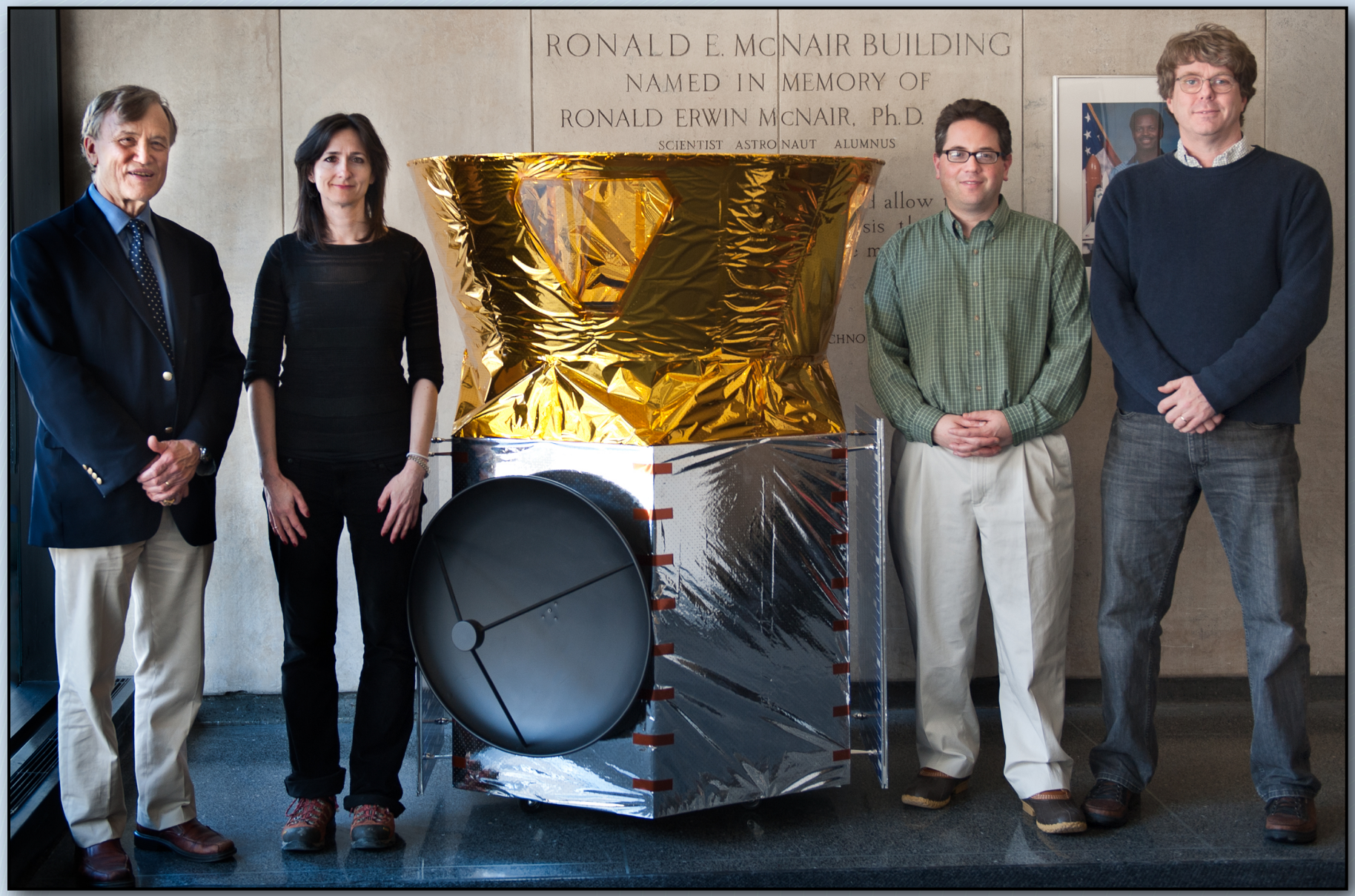
Passband of 600nm-1000nm: Tailored to enhance spectral performance for F to M dwarfs

TESS Engineering Model Camera at MKI



TESS Wide FOV CCD Camera Prototype

Full Size Replica of TESS



SpaceX's Falcon 9 is the TESS Launch Vehicle

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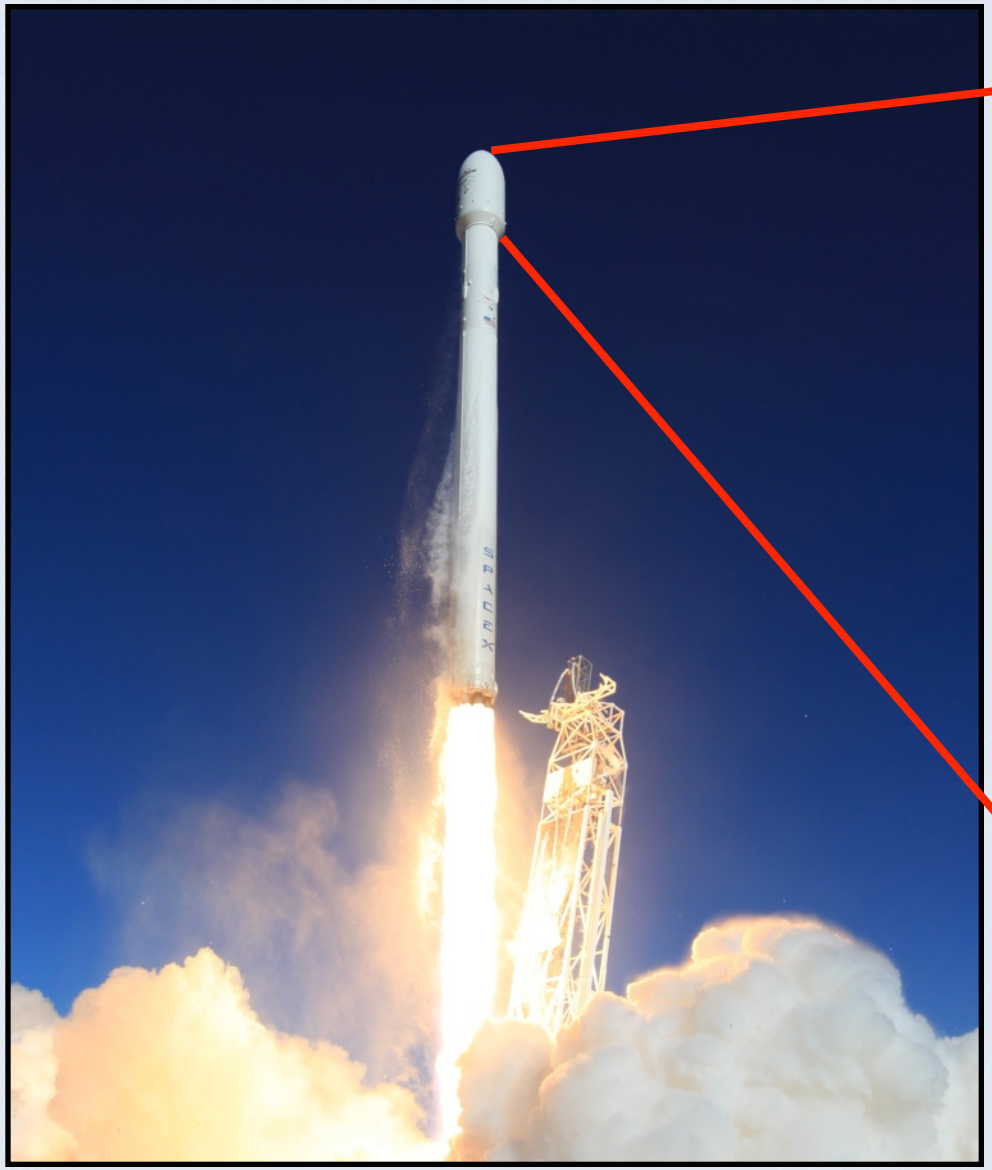
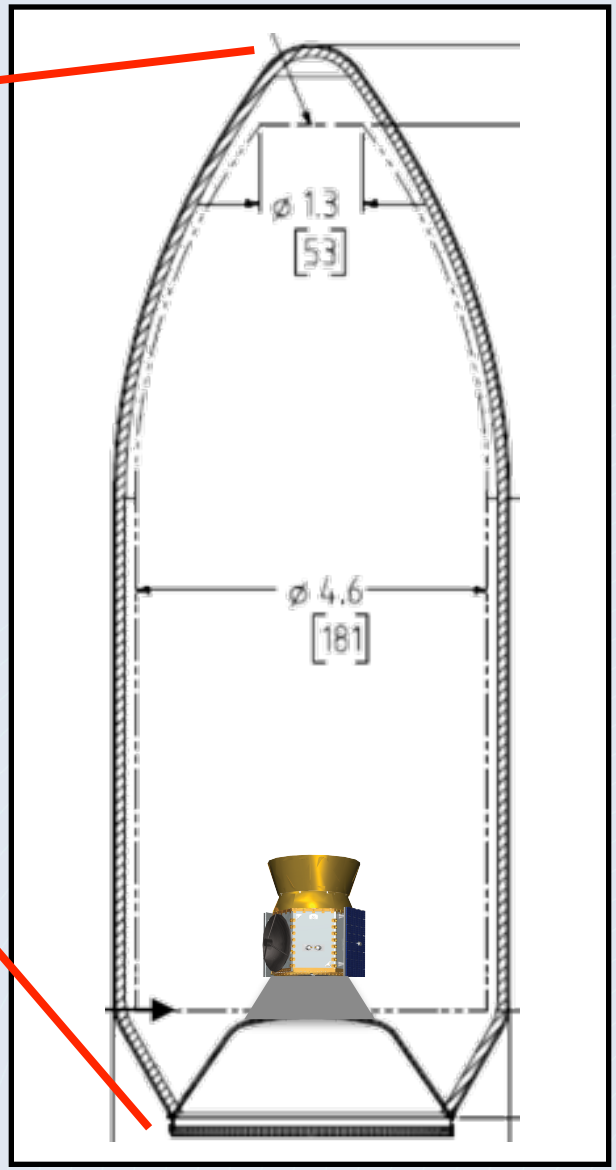
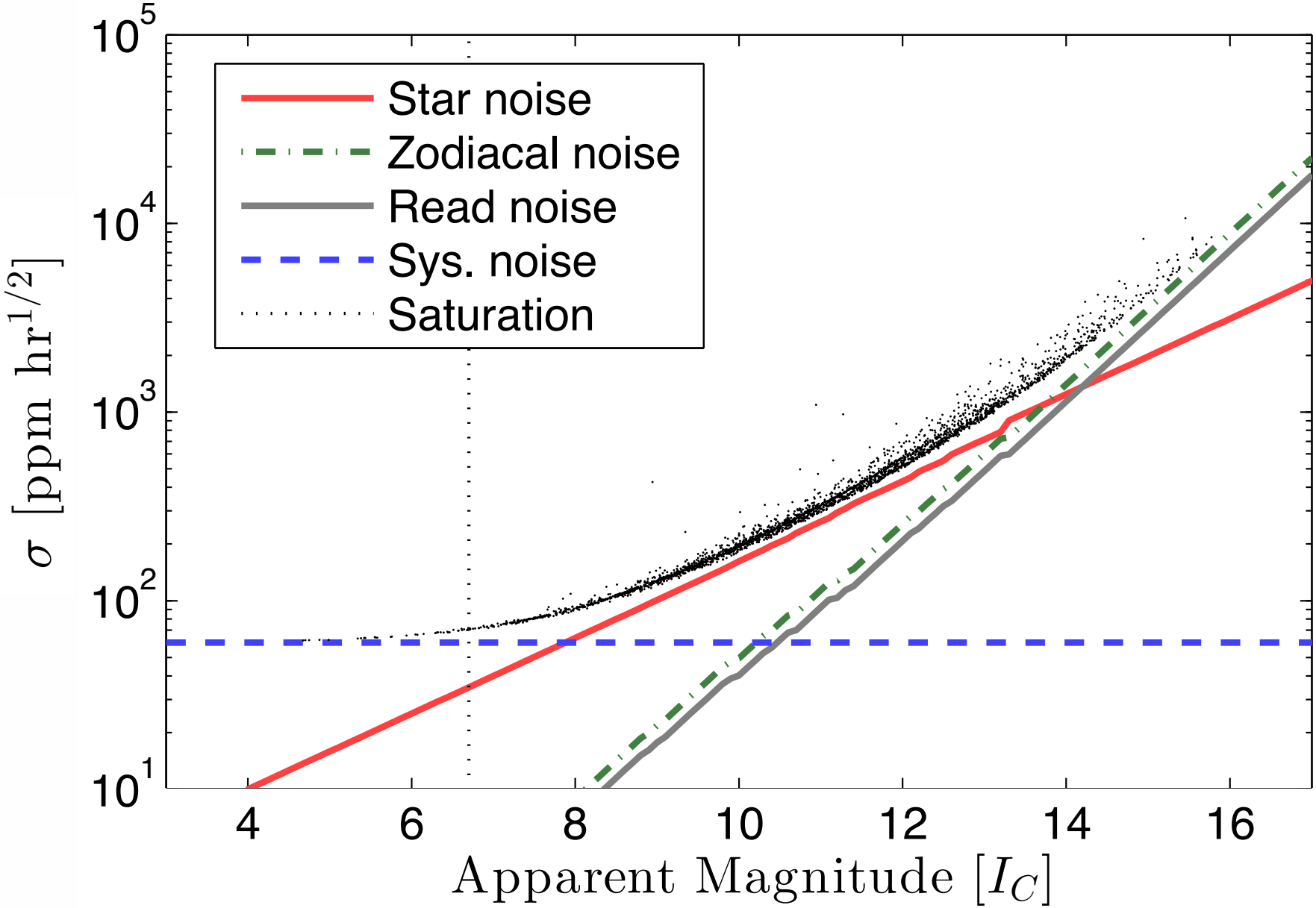




Photometric Noise in 1 Hour



Ricker et al. (2014)

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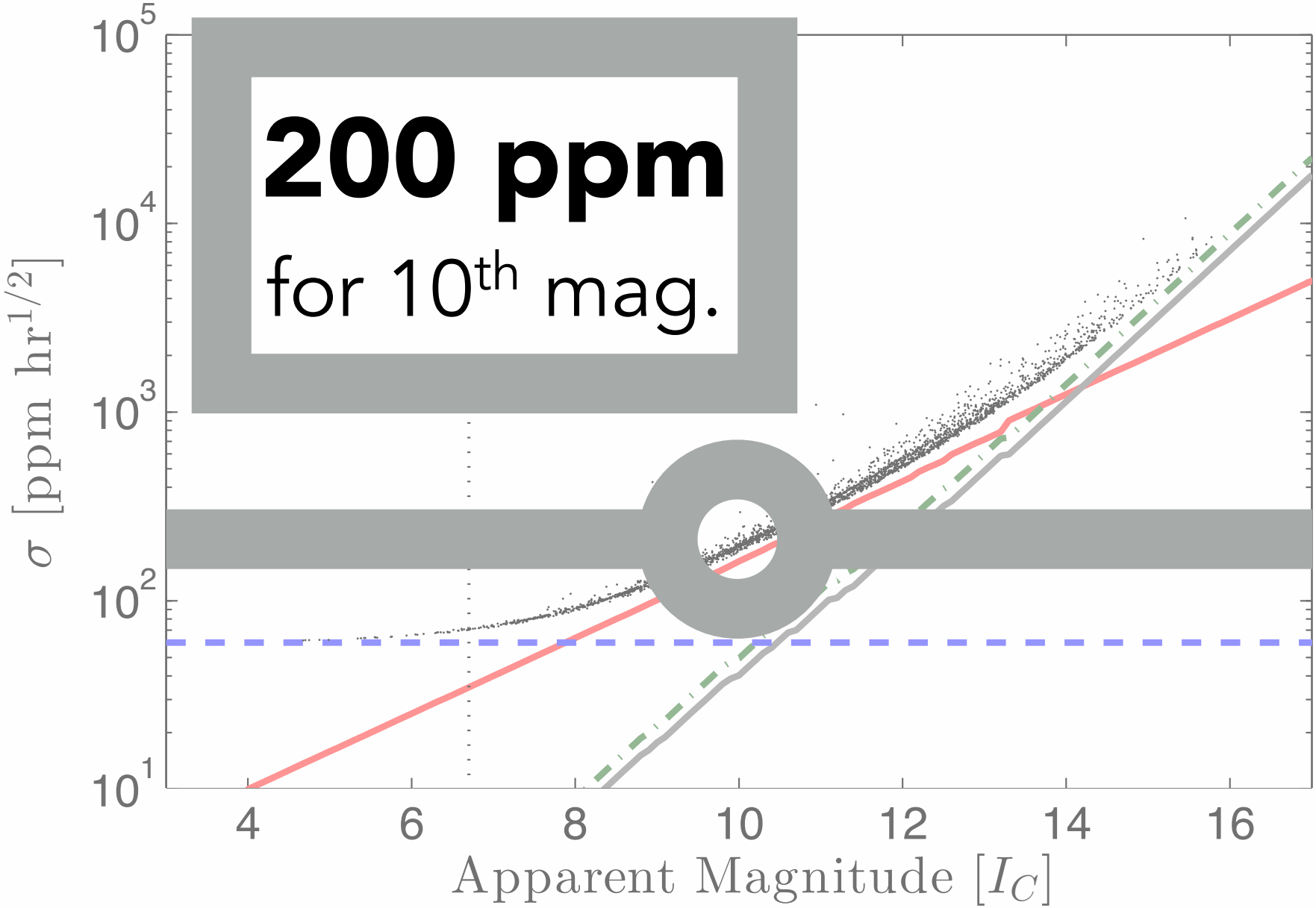

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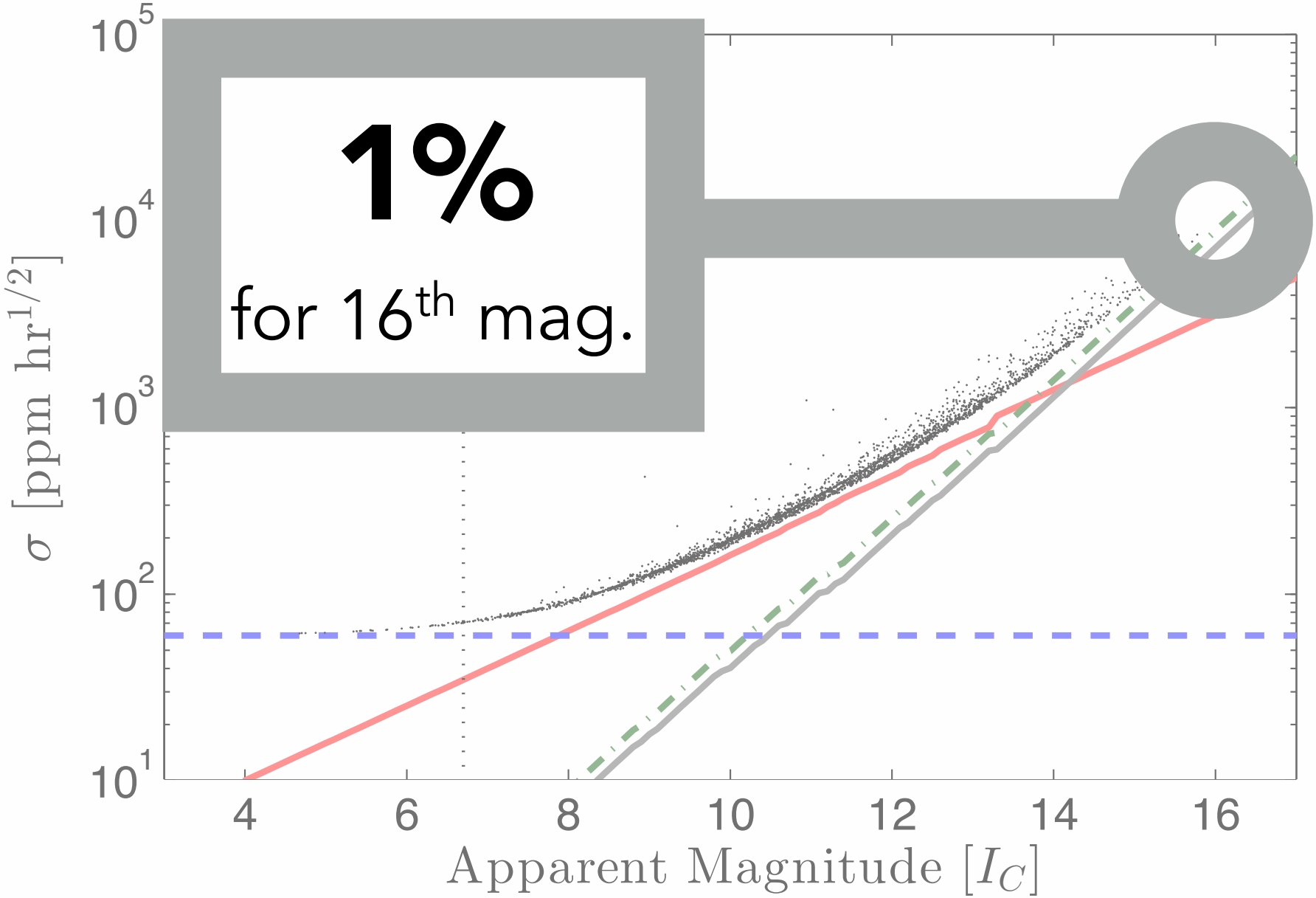
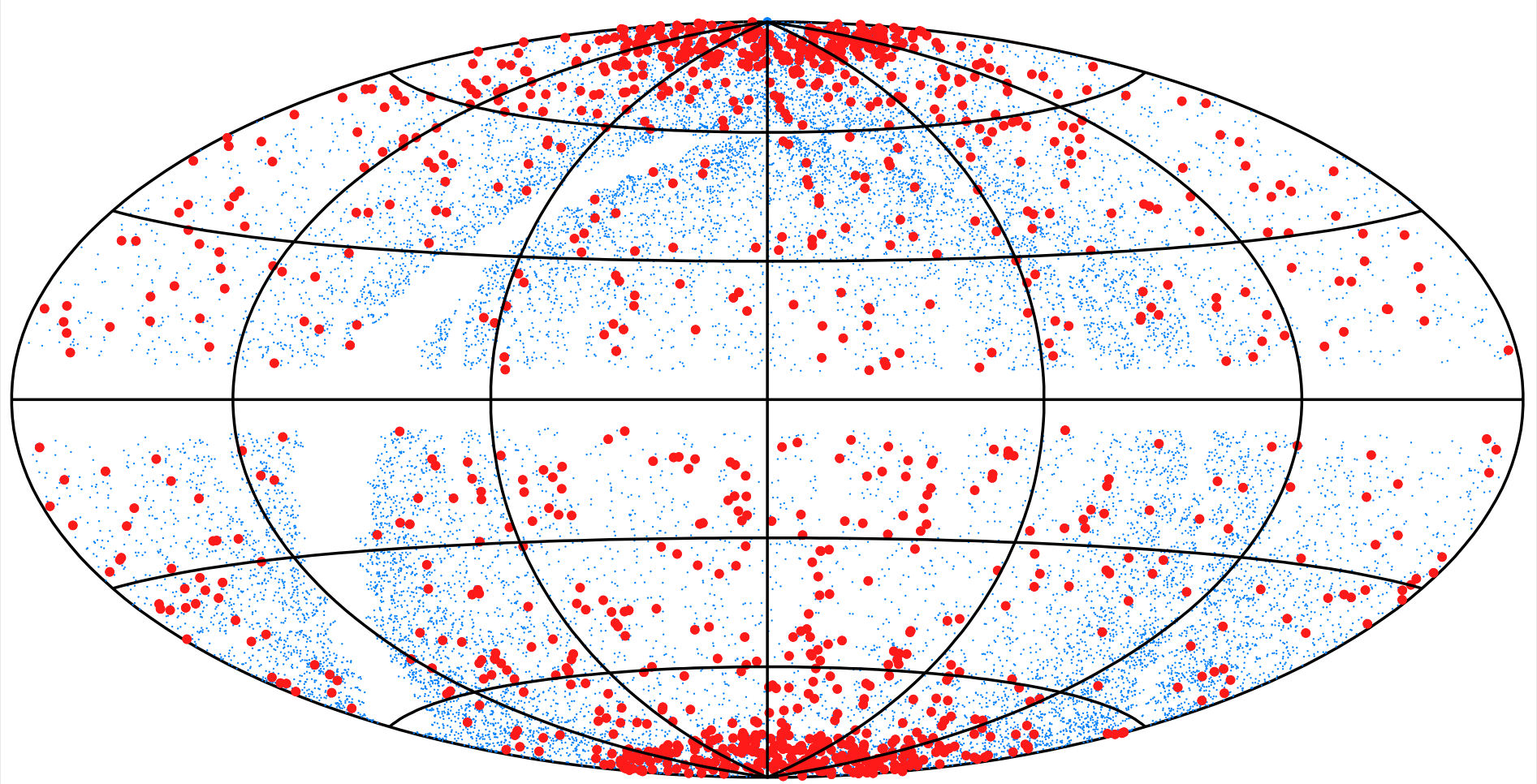


Ricker et al. (2014)

Simulated TESS detections



Ecliptic
Coordinates

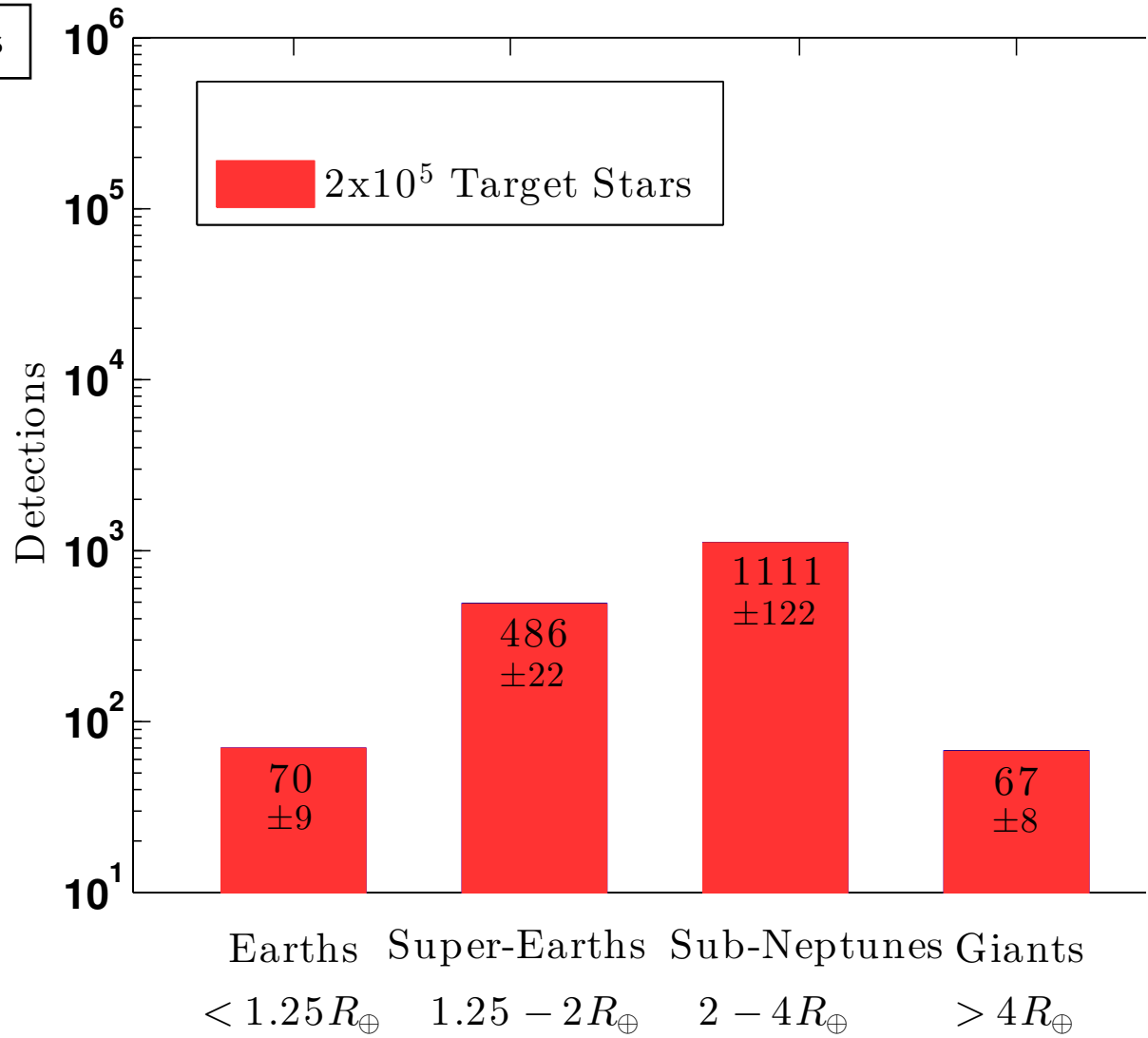
Sullivan et al. (arXiv:1506.08845)

Detectable planets around **200,000 pre-selected stars**

Detectable planets around **20,000,000 stars in full images**

The Predicted TESS Yield

NB: Log Scale on Y Axis



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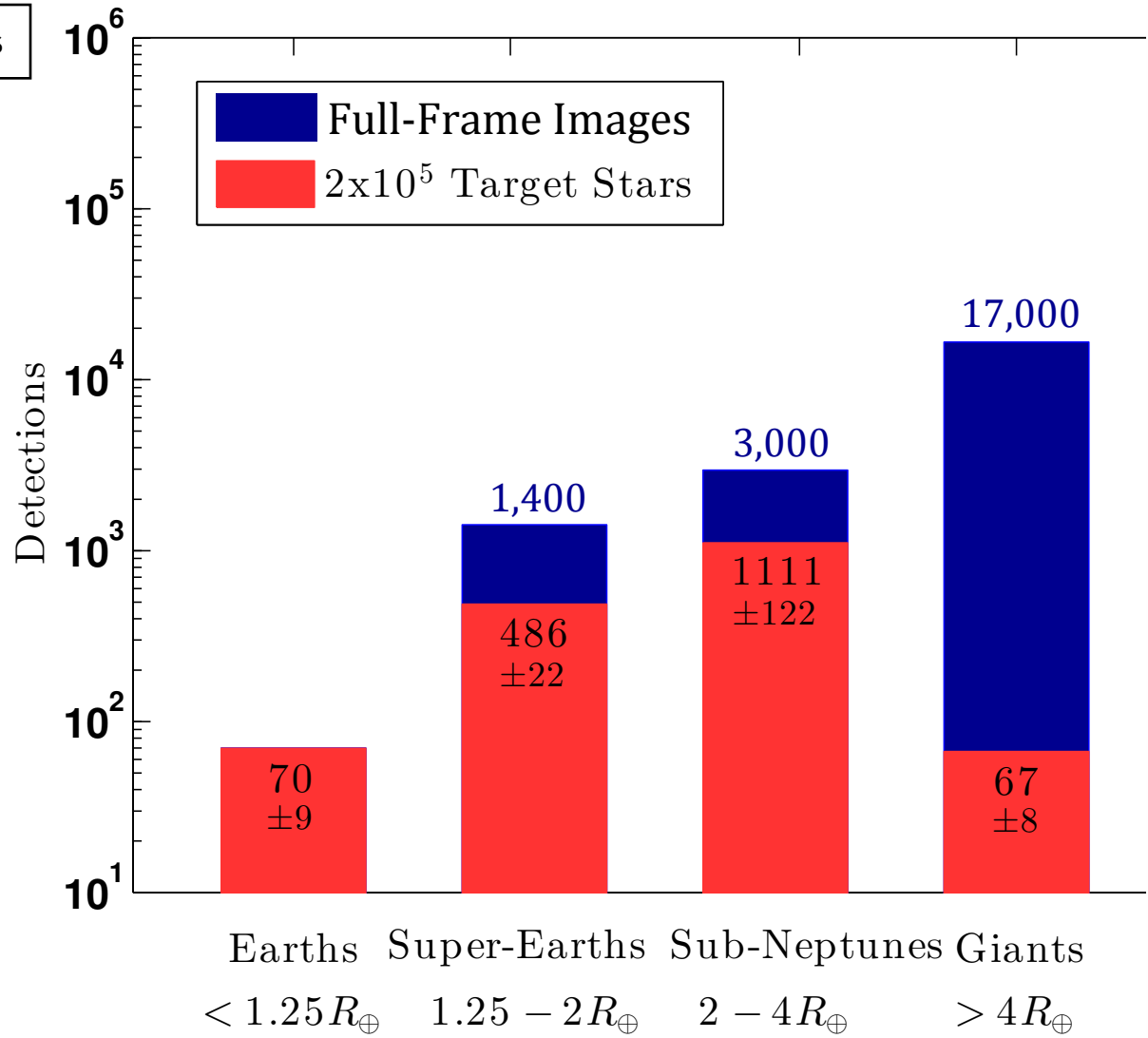

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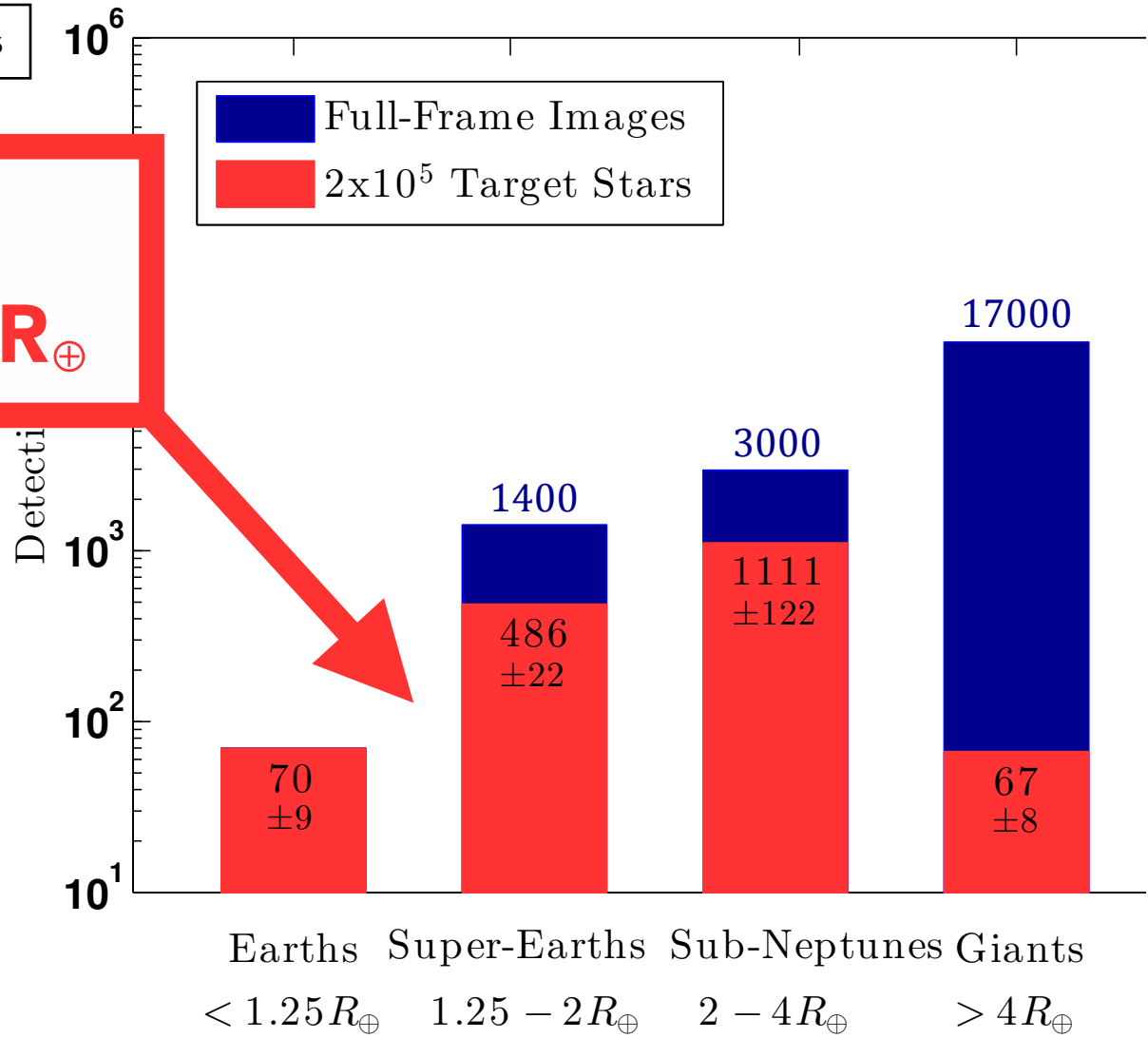
The Predicted TESS Yield

NB: Log Scale on Y Axis

500 planets smaller than $2R_\oplus$

mass measurements could resolve the rocky planet transition



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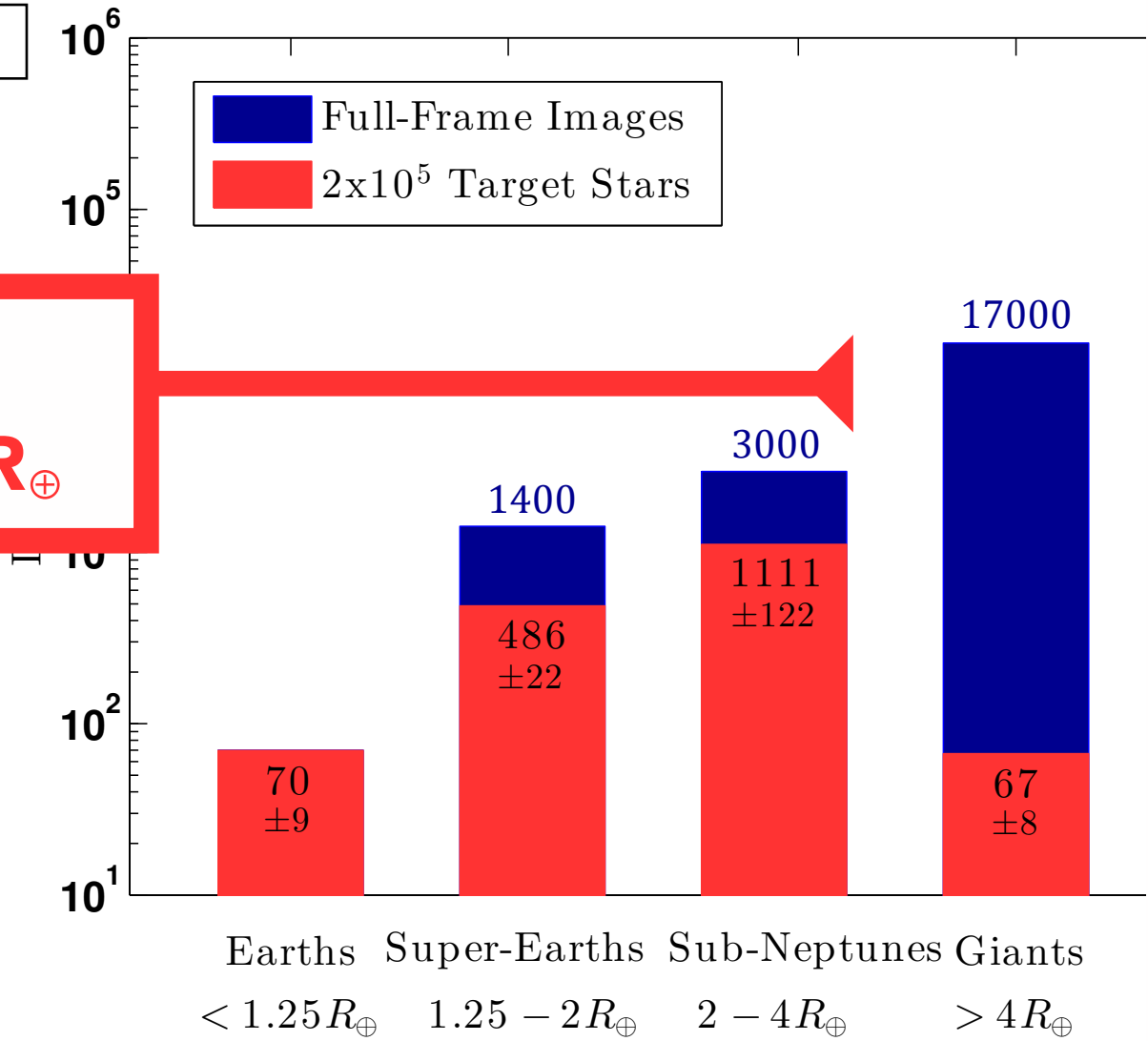


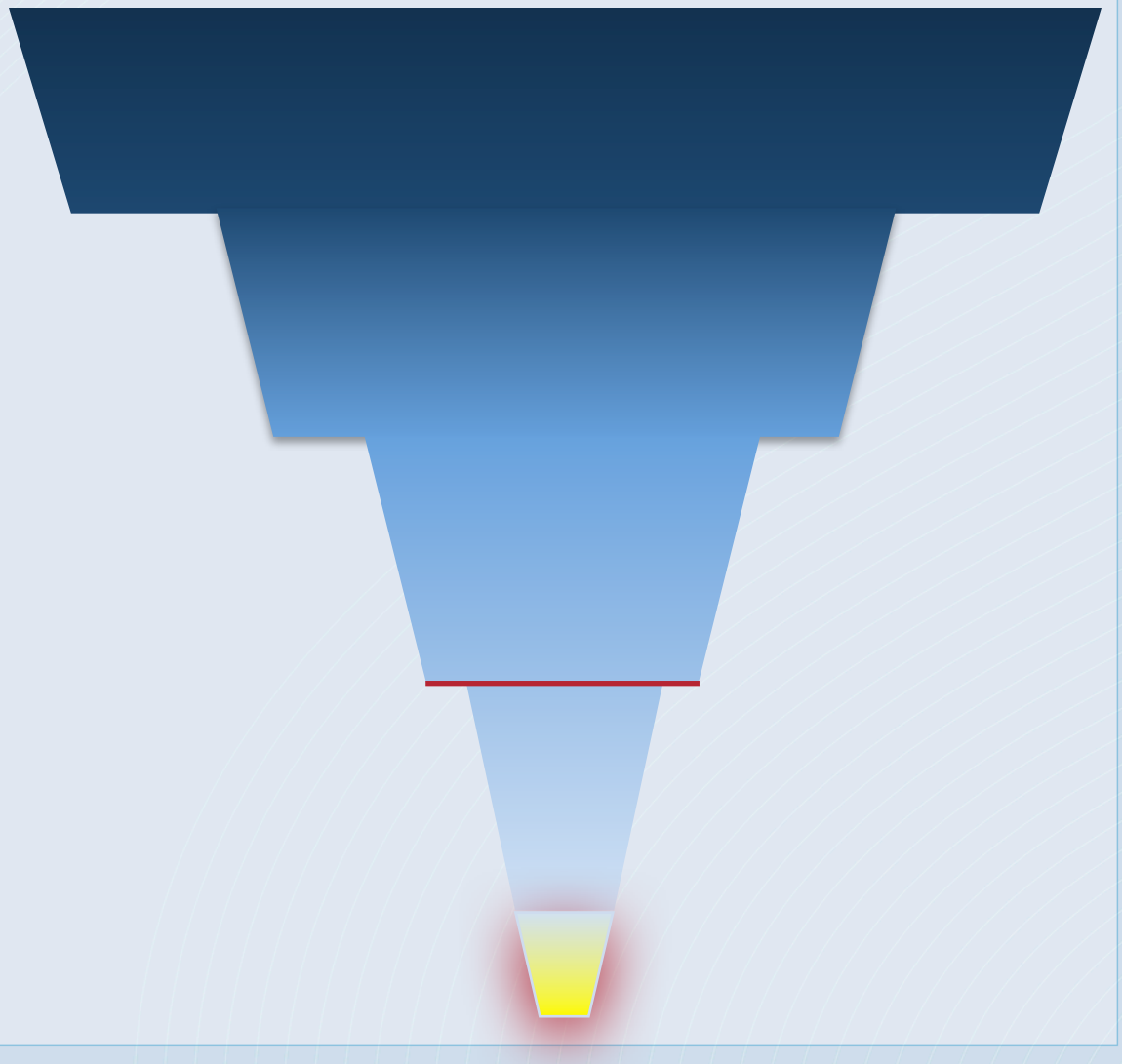
1500 planets smaller than $4R_\oplus$

atmospheric studies will be possible for many of these

Sullivan et al. (arXiv:1506.08845)

Small Planet Validation and Mass Measurements

Details in Sullivan et al. (arXiv:1506.08845)



Small Planet Validation and Mass Measurements

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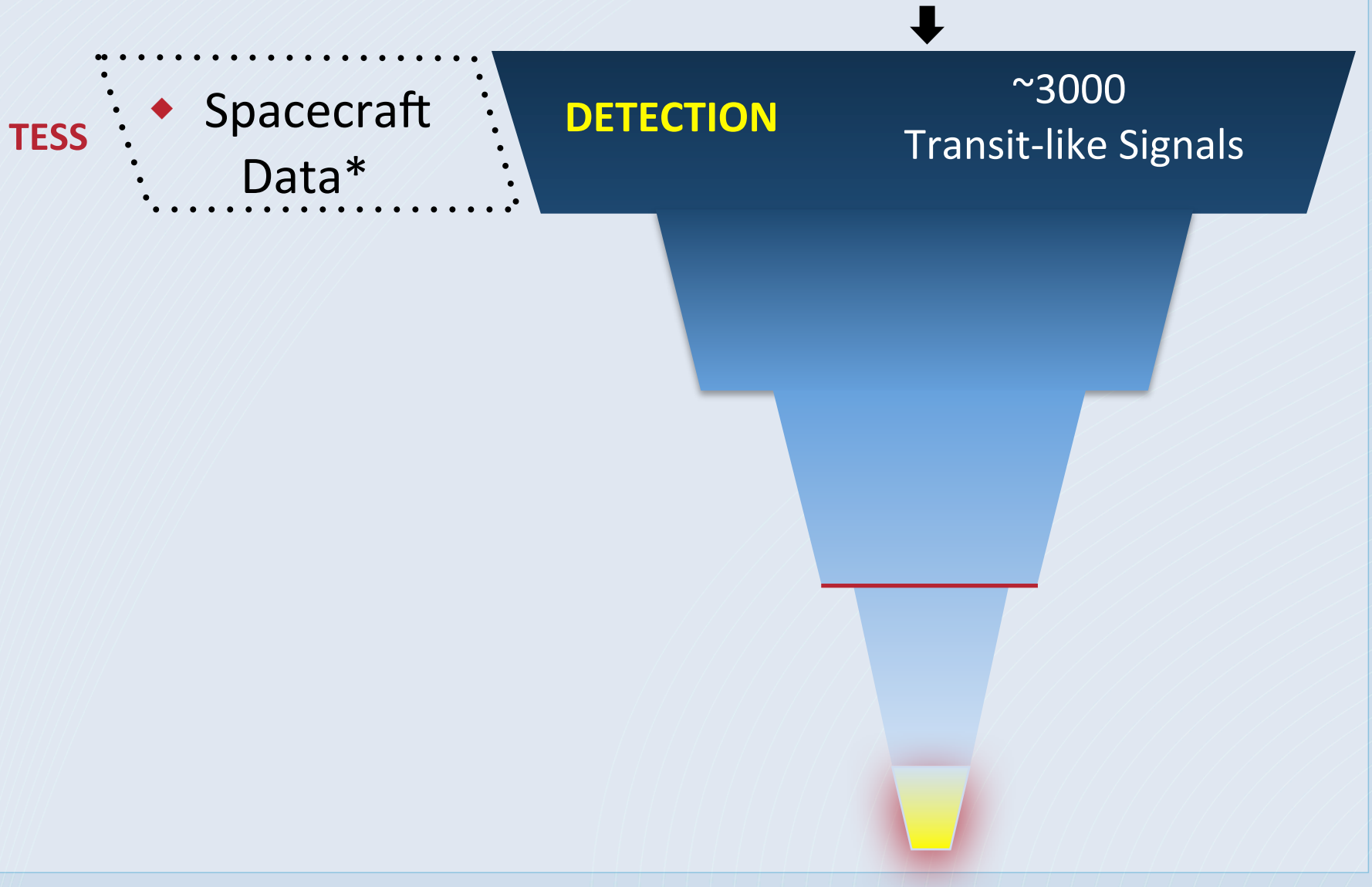
Light Curves from 200,000 Stars ("Postage Stamps")*



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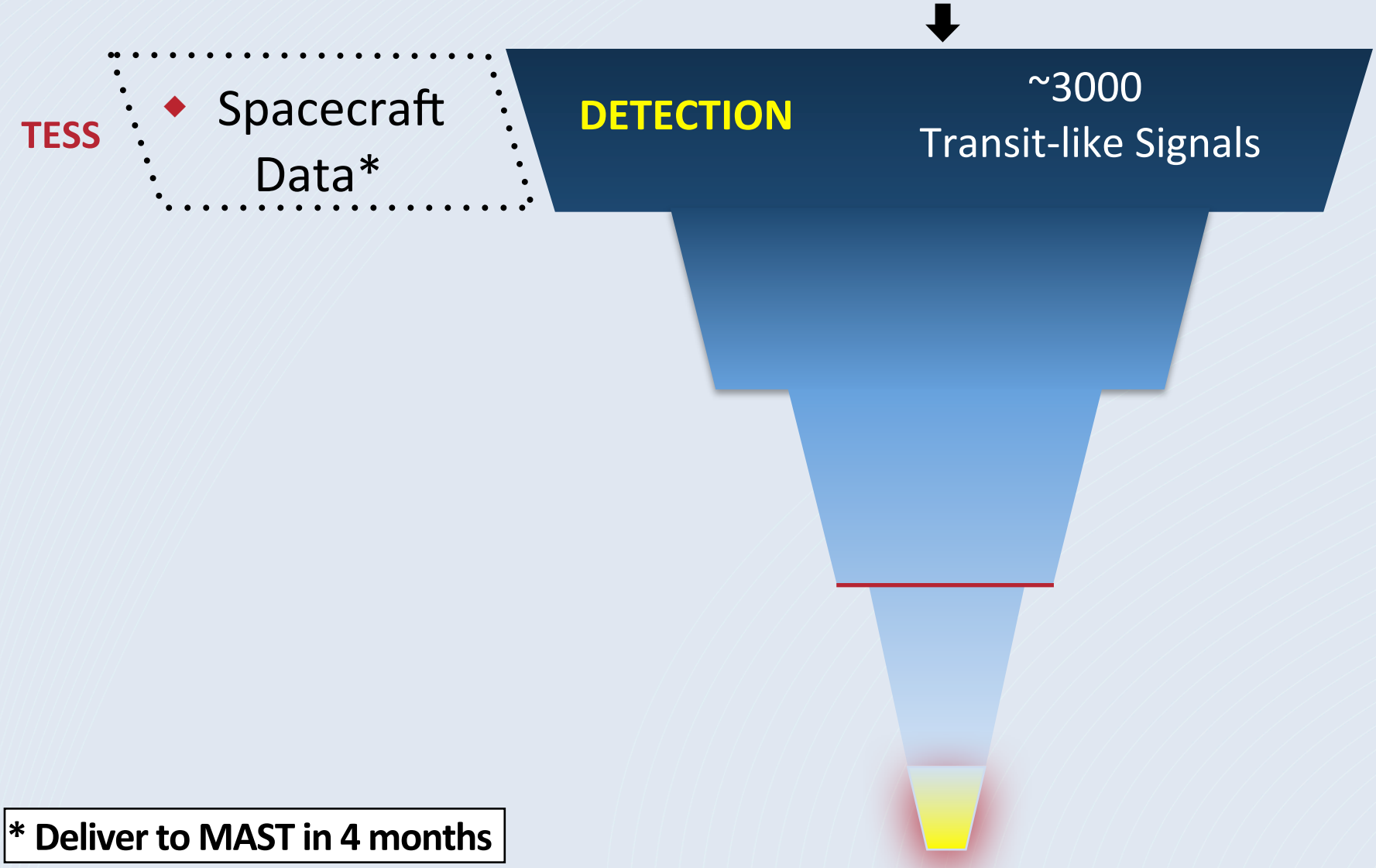

*** Deliver to MAST in 4 months**

Small Planet Validation and Mass Measurements

Details in Sullivan et al. (arXiv:1506.08845)

Light Curves from 200,000 Stars ("Postage Stamps")*

TESS

- Spacecraft Data*

Ground Telescopes

- LCOGT, MEarth, Euler
- LCOGT, Euler, OHP

DETECTION

~3000 Transit-like Signals

~2500 Survive Direct Imaging

~1700 Survive Reconnaissance Spectroscopy & Direct Imaging

*** Deliver to MAST in 4 months**

Small Planet Validation and Mass Measurements

Details in Sullivan et al. (arXiv:1506.08845)

Light Curves from 200,000 Stars ("Postage Stamps")*

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- LCOGT, Euler, OHP
- HARPS and HARPS-North

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100

FULL VALIDATION

~6% of Small Planet Candidates Selected by TESS Team for Precise Doppler Spectroscopy

*** Deliver to MAST in 4 months**

Small Planet Validation and Mass Measurements

Details in Sullivan et al. (arXiv:1506.08845)

Light Curves from 200,000 Stars ("Postage Stamps")*

TESS

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100

FULL VALIDATION

~6% of Small Planet Candidates Selected by TESS Team for Precise Doppler Spectroscopy

R < 4 R⊕ **50** **Measured Masses**

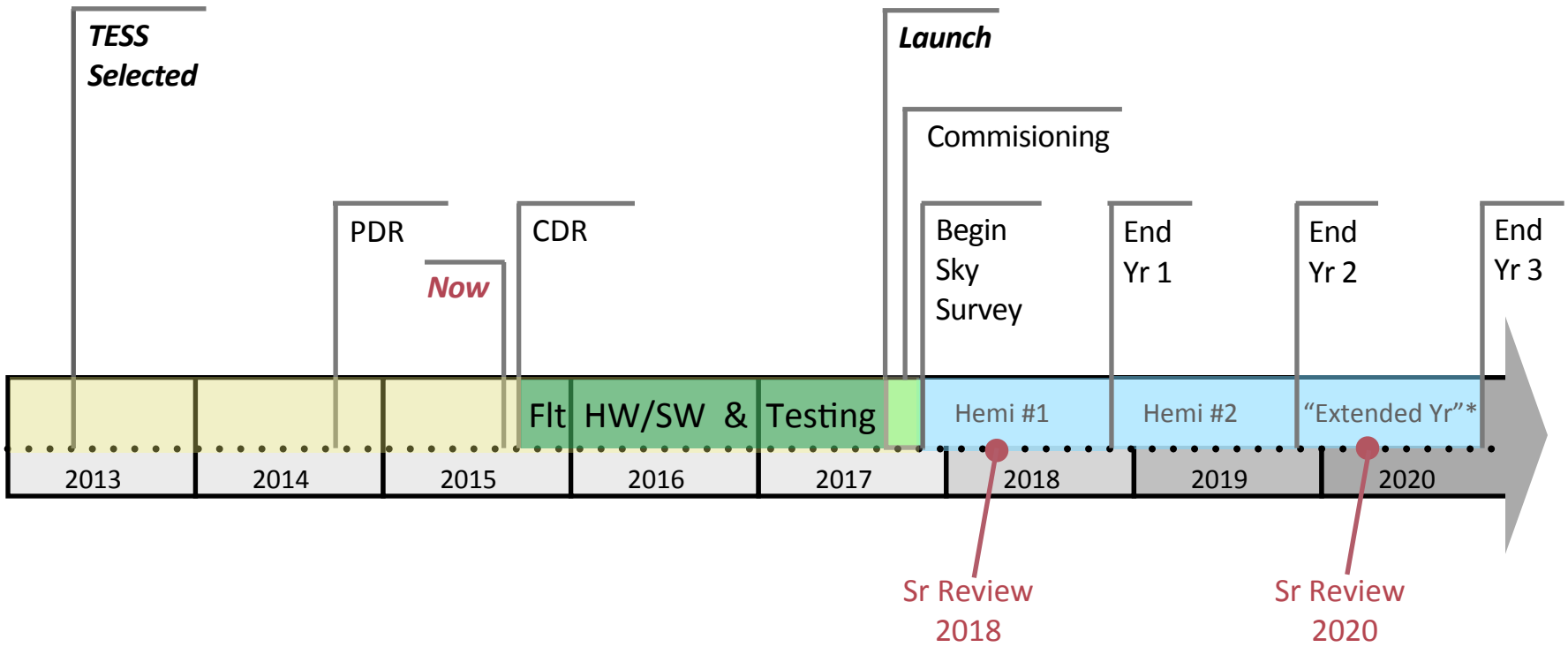
"NASA Level 1"

*** Deliver to MAST in 4 months**

Preliminary TESS Mission Schedule

Activity	Date	Status
Systems Requirement Review	12-13 Feb 2014	✓ Completed
Preliminary Design Review	8-11 Sep 2014	✓ Completed
Mission Confirmation	31 Oct 2014	✓ Completed
Launch Vehicle Selection	16 Dec 2015	✓ Completed
Critical Design Review	4-7 Aug 2015	Upcoming
Systems Integration Review	4 Oct 2016	Planned
Launch Readiness Review	2 Aug 2017	Planned
Science Mission Complete	8 Oct 2020	Planned

Timeline for TESS Mission



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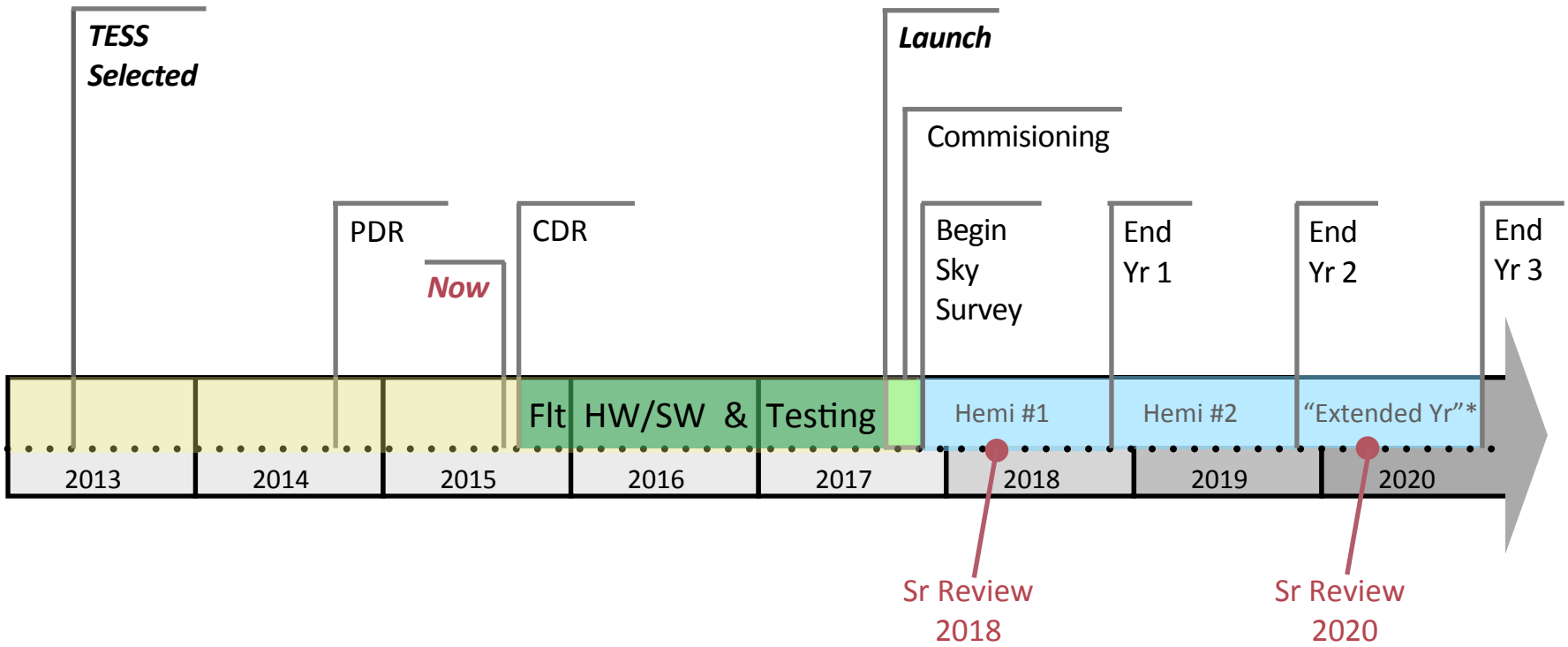

* 3rd "Extended Year" of Survey:
Contingent on residual funds remaining from TESS mission reserves

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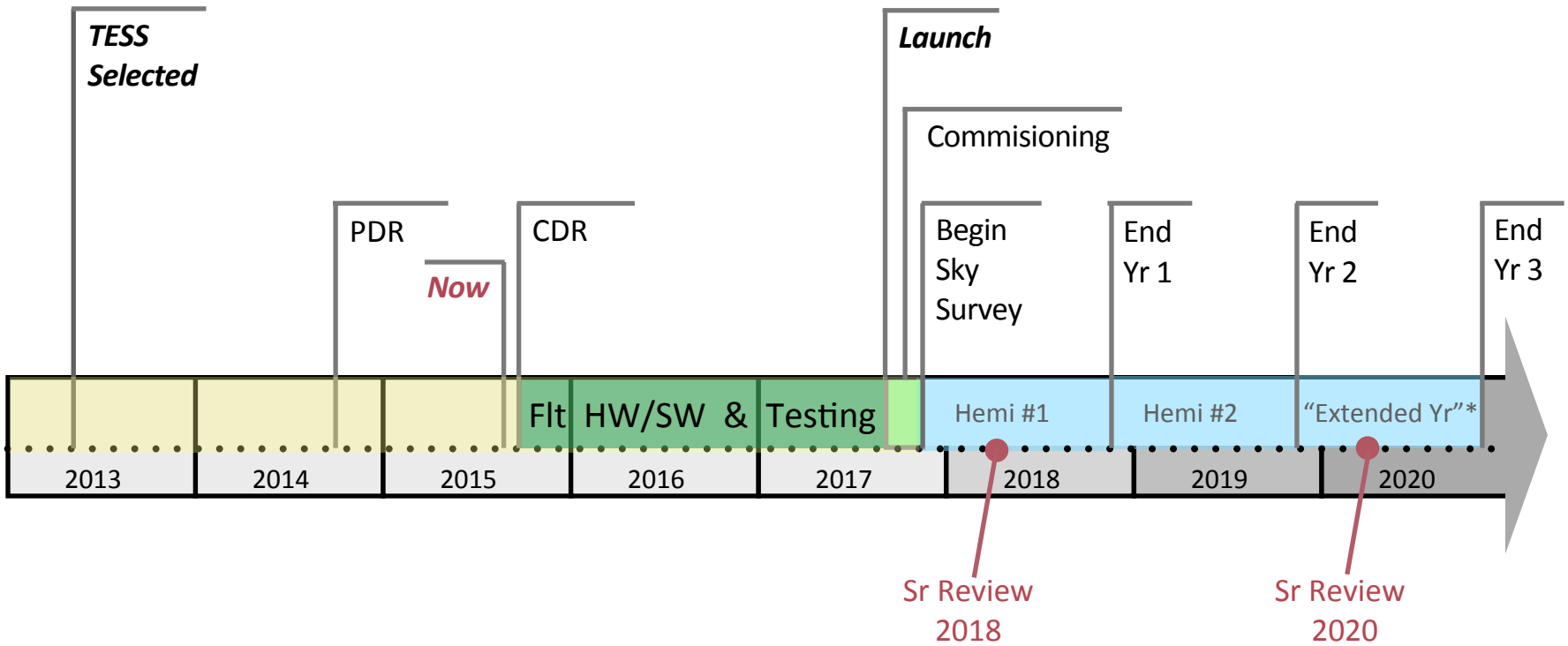

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** TESS itself (and the orbit) should be operable for more than a decade

Next Steps in TESS Science Planning-1

- Interacting with Other Initiatives and Missions:
  - *Providing for Non-Exoplanet Targets in TESS FFIs*
  - *Coordinating with Gnd Followup and TESS GO's*
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  - *~15,000 targets @ 2 min cadence*
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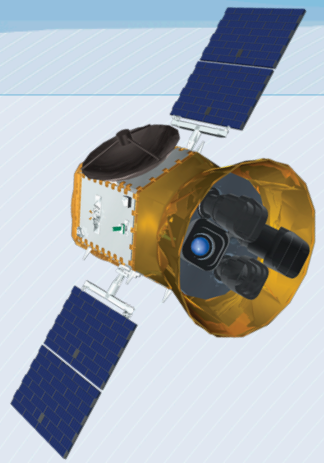
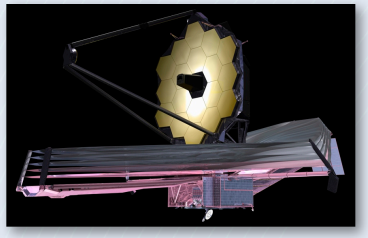
- Planning for Extended Year(s):
  - *Repeat survey in a single hemisphere?*
  - *Concentrate on an ecliptic pole?*
  - *Concentrate on the ecliptic plane?*
    - *~5 x 72 day durations; comparable to ~ 100 K2 pointings*

Next Steps in TESS Science Planning-2

- FFI Pipeline Tools in Development by TESS Science Team
  - *Three TESS Team Groups are Developing Pipelines*
    - *Princeton (Bakos, Huang)*
    - *Harvard + MIT (Vanderberg, Johnson, Rappaport)*
    - *UC Berkeley (Sanchis-Ojeda, Marcy)*
  - *Builds on Entrepreneurial Efforts from K2*
  - *Demonstrates Cost Effective Use of Collaborative, Open Source Tools*
  - *Coordination by TESS SOC*
- GI Program for TESS
  - *In Formulation*

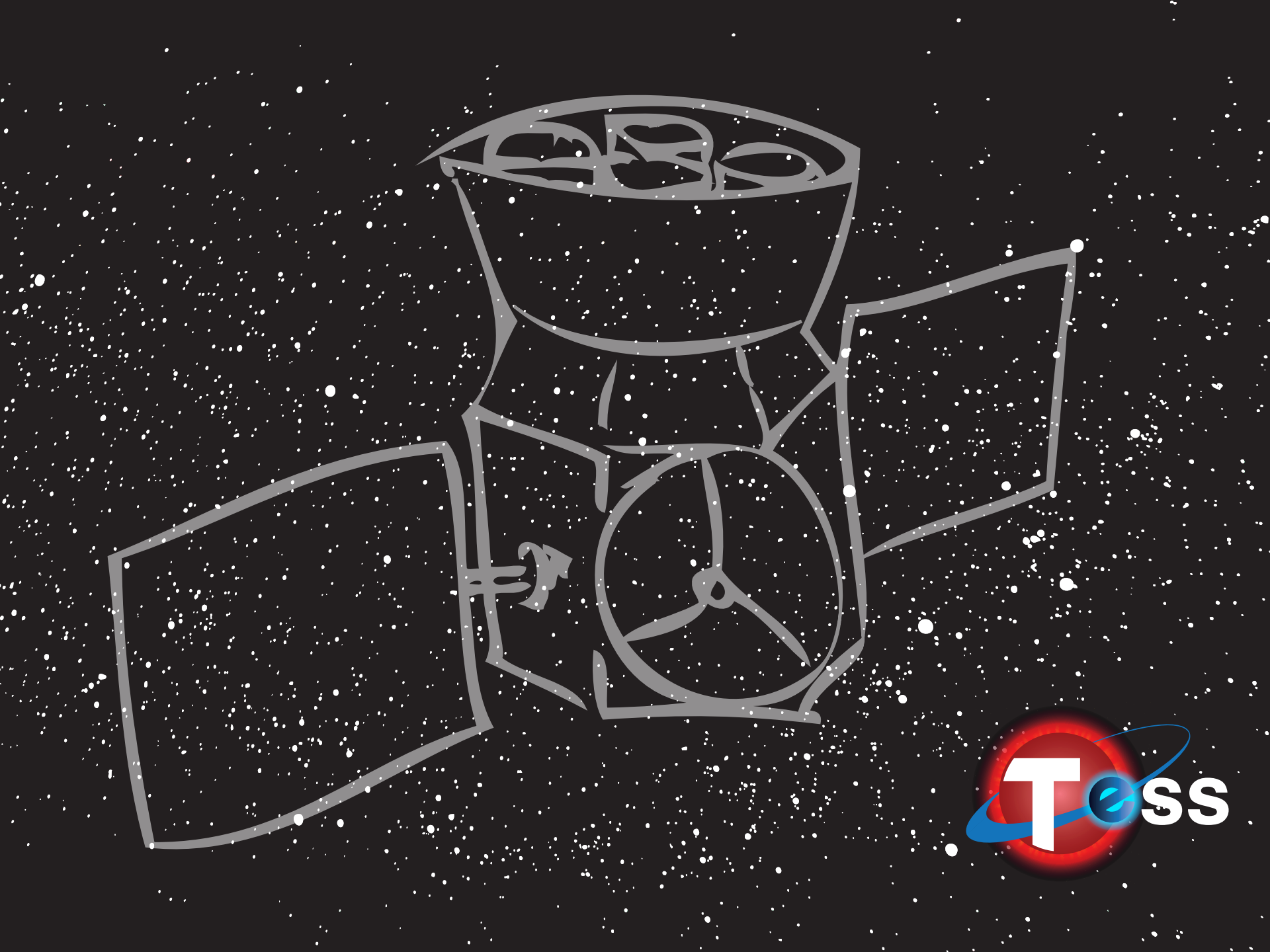
Legacy of TESS





- TESS's launch planned for 2017
- TESS will find 1000 planets smaller than Neptune transiting nearby stars
- TESS will provide a map to the easiest-to-observe exoplanet atmospheres
- TESS will identify several habitable zone planets orbiting stars sufficently bright for JWST and future ELT study of their atmospheres

Ricker et al. 2014
(astro-ph 1406.0151)


TESS