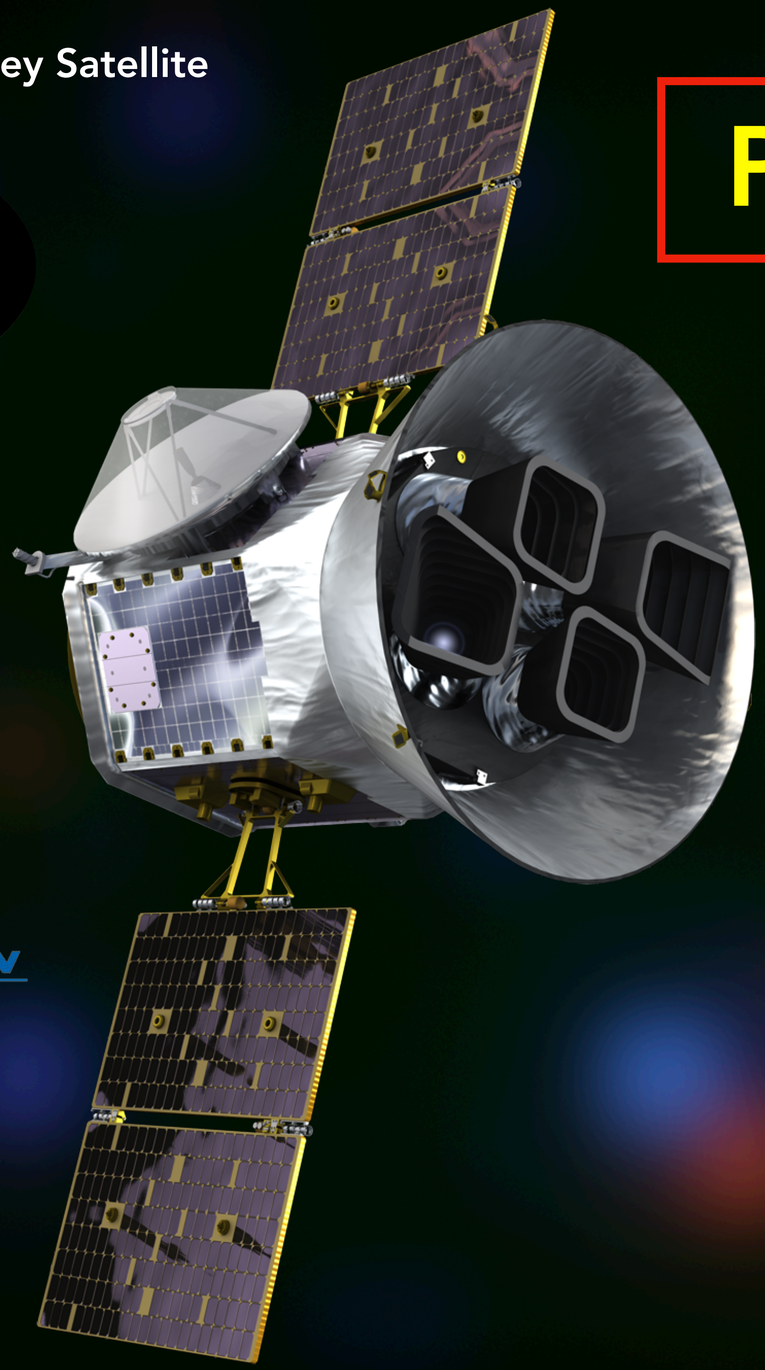
Transiting Exoplanet Survey Satellite



Paths to PI-ship — TESS

Dr. George R. Ricker
Senior Research Scientist
PI, Transiting Exoplanet Survey Satellite

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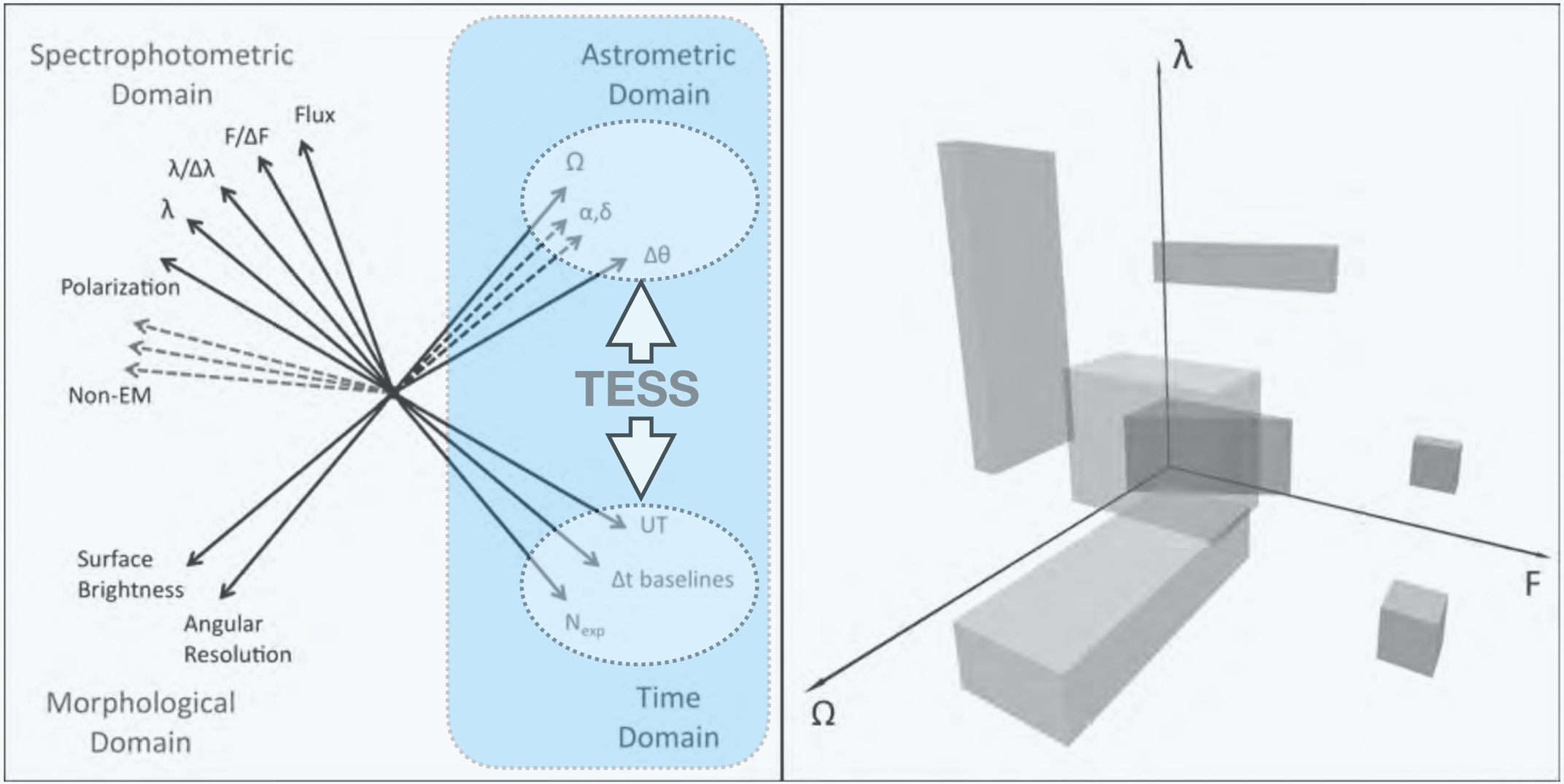
https://www.space.mit.edu/people/george-ricker-jr/

PhysPAG Early Career Workshop
20 November 2024

Chapters in my Career leading to my PI Role on the TESS Mission

- **Chapter 1: Scientific Ballooning and the SAS-3 Explorer (1970-1980)**
  - *Discovery of brightest hard X-ray source in Galactic Center Region (1971; it was not Sag A*); Lunar Occultation of Crab Nebula and Crab Pulsar (1975); X-ray Seyferts and QSOs (1978).*
- **Chapter 2: Silicon CCD Detectors for Optical and X-ray Astronomy (1980-1990)**
  - *Lots of Lab work in collaboration with MIT's Lincoln Laboratory; Deputy PI for the ACIS instrument for Chandra.*
- **Chapter 3 : PI-ships on 2 Explorer-class Missions: ASCA and HETE (1990-2005)**
  - *1993: SIS Instrument PI on Japan-US ASCA mission, which flew the first ever X-ray photon-counting, energy-resolving CCD image array*
  - *2000: Mission PI for the HETE-2 (Explorer 79) international mission, which detected more than 300 GRBs, X-ray flashes, and X-ray GRBs. Discoveries included the first confirmed detection of a GRB associated with a supernova (GRB030329) and the first short GRB with a confirmed*
- **Chapter 4 : PI-ships on 3 incarnations of TESS (2005-present)**
  - *Details and lessons-learned will follow over the next 20 minutes…*

Concept: Exploration of Observable Parameter Spaces (OPS) in Astronomy



Technology opens new domains of the OPS → New discoveries

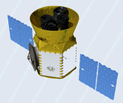
George Djorgovski, Caltech (2019)

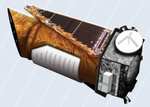
Etendue Comparison: Roman WFI, Kepler, and TESS

- Definition of Etendue [$m^2 * deg^2$] aka "GRASP":

$$\mathbf{G} = A_{optics} * \Omega_{net}$$

$$\text{where } \Omega_{net} = \Omega_{gross} * \left(\frac{\textit{\# pixels telemetered}}{\textit{\# pixels in focal plane}} \right)$$





	A_{optics} [m^2]	Ω_{gross} [deg^2]	$\frac{\textit{\# pixels telemetered}}{\textit{\# pixels in focal plane}}$	G [$m^2\ deg^2$]
TESS	0.0095	2304	1	21.9
Kepler	0.71	105	0.06	4.2
Roman WFI	**4.5**	**0.281**	**1**	**1.3**

TESS is the highest etendue optical space mission ever flown:

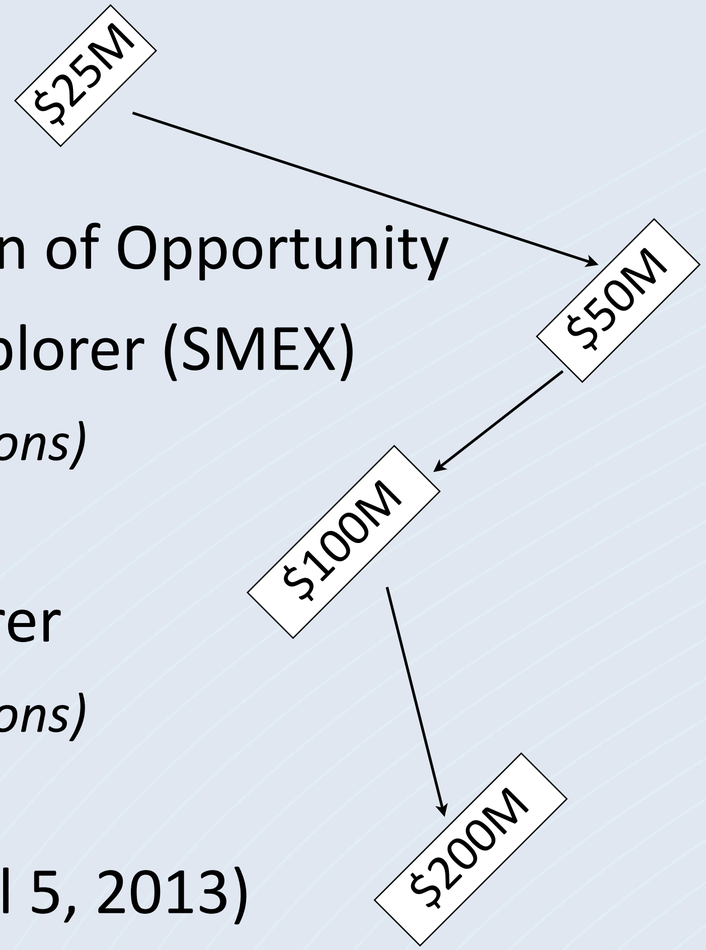
$$G_{TESS} \approx 5 \times G_{Kepler} \qquad G_{TESS} \approx 28 \times G_{Roman\ WFI}$$

Refs:

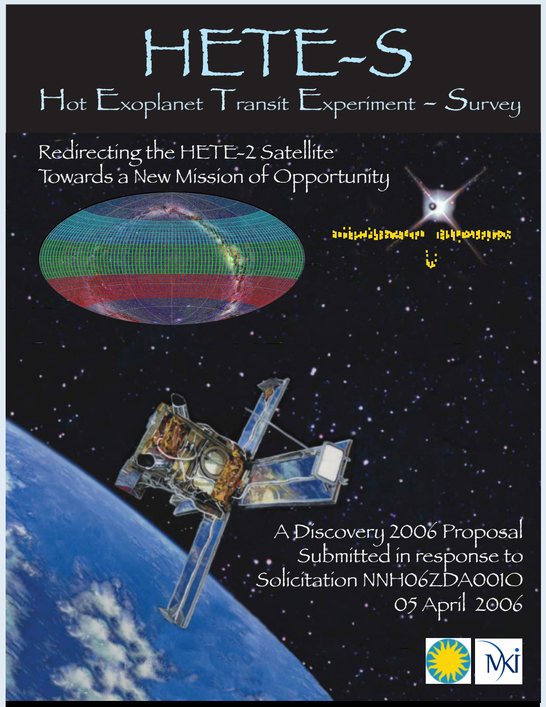
TESS: Ricker et al. 2016 Kepler: Bryson et al. 2010 Roman: https://roman.gsfc.nasa.gov/science/WFI_technical.html

TESS's First Decade: Conception to Launch Ready

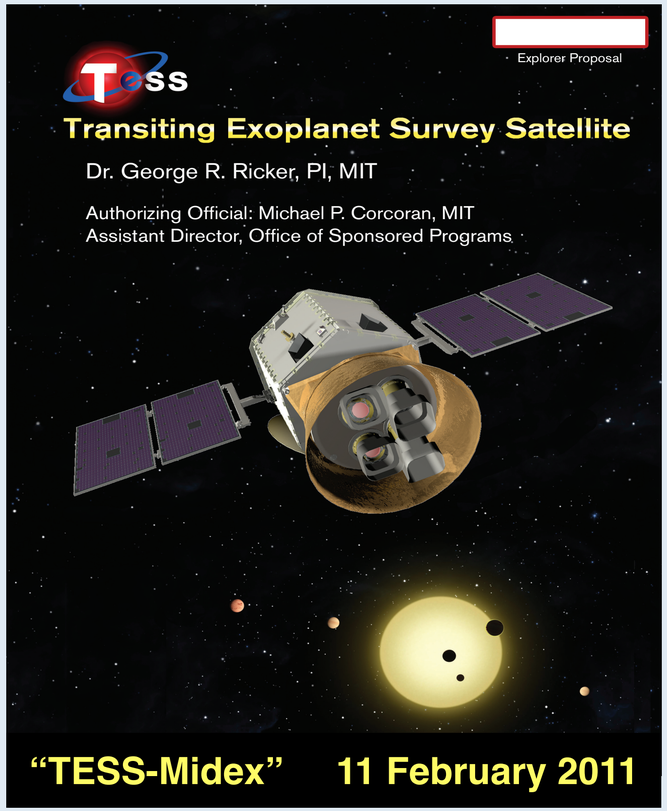
- **2006**: Conceived as a Privately-Funded Small Mission
  - *Kavli Foundation and MIT Support*
  - *Google Seed Funding*
  - *Private Donors Sought Through MIT*
- **2007**: Re-structured as a Possible Mission of Opportunity
- **2008**: Re-configured as a NASA Small Explorer (SMEX)
  - *Selected for Phase A (1 of 3 Astrophysics Missions)*
  - *Not Selected for Flight*
- **2010**: Re-proposed as a NASA Full Explorer
  - *Selected for Phase A (1 of 2 Astrophysics Missions)*
  - *Selected for flight*
- **2013**: Selected for Implementation (April 5, 2013)
- **2018:** Launch ready in March 2018



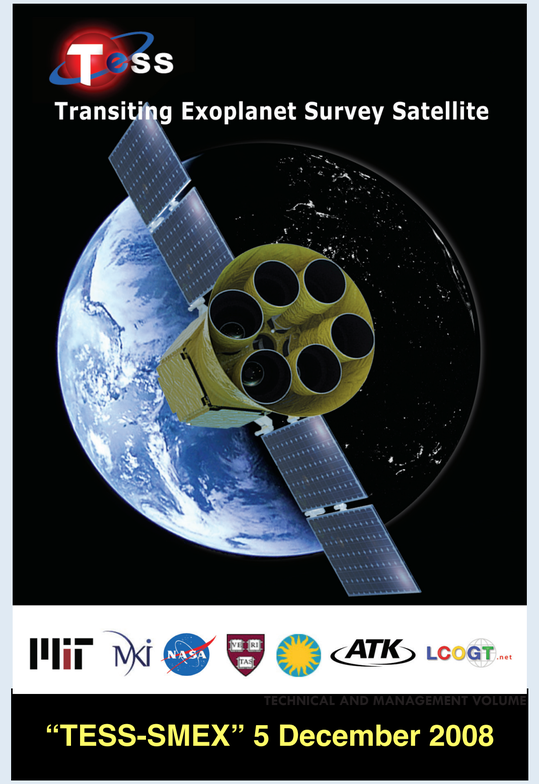
A Brief History of TESS in Proposals (~20,000 Pages of Proposal Documents)



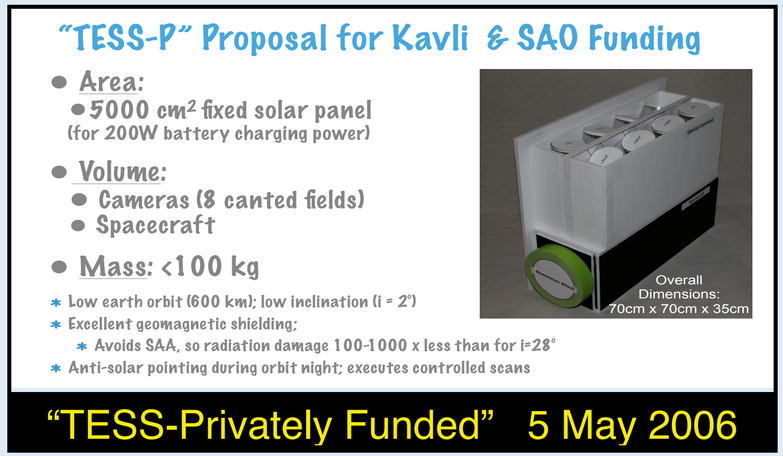
"HETE-S" 5 April 2006



"TESS-Midex" 11 February 2011

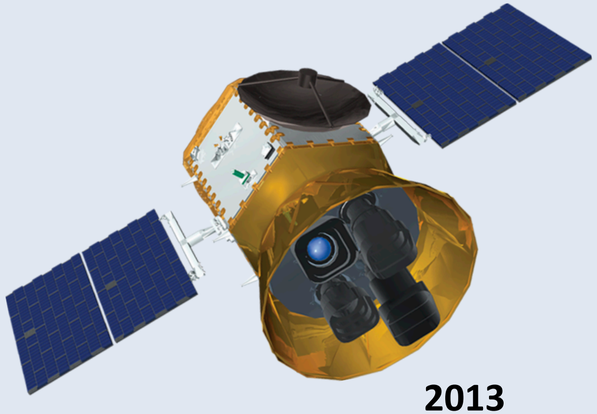


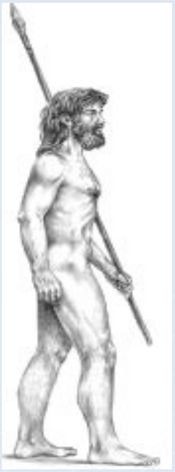
"TESS-SMEX" 5 December 2008



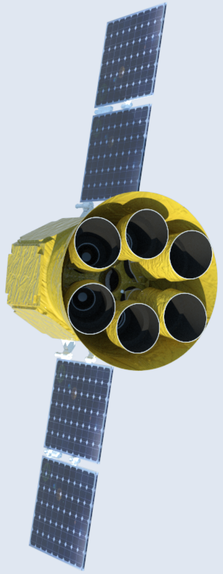
"TESS-Privately Funded" 5 May 2006

The Ascent of TESS

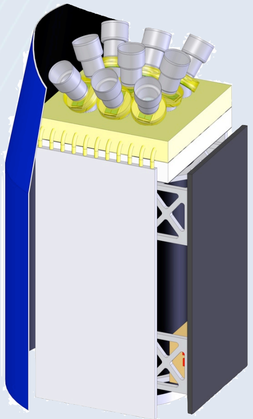




2013
***4* cameras**
(Selected)



2010
***6* cameras**
(Proposed)



2007
***9* cameras**
(Proposed)

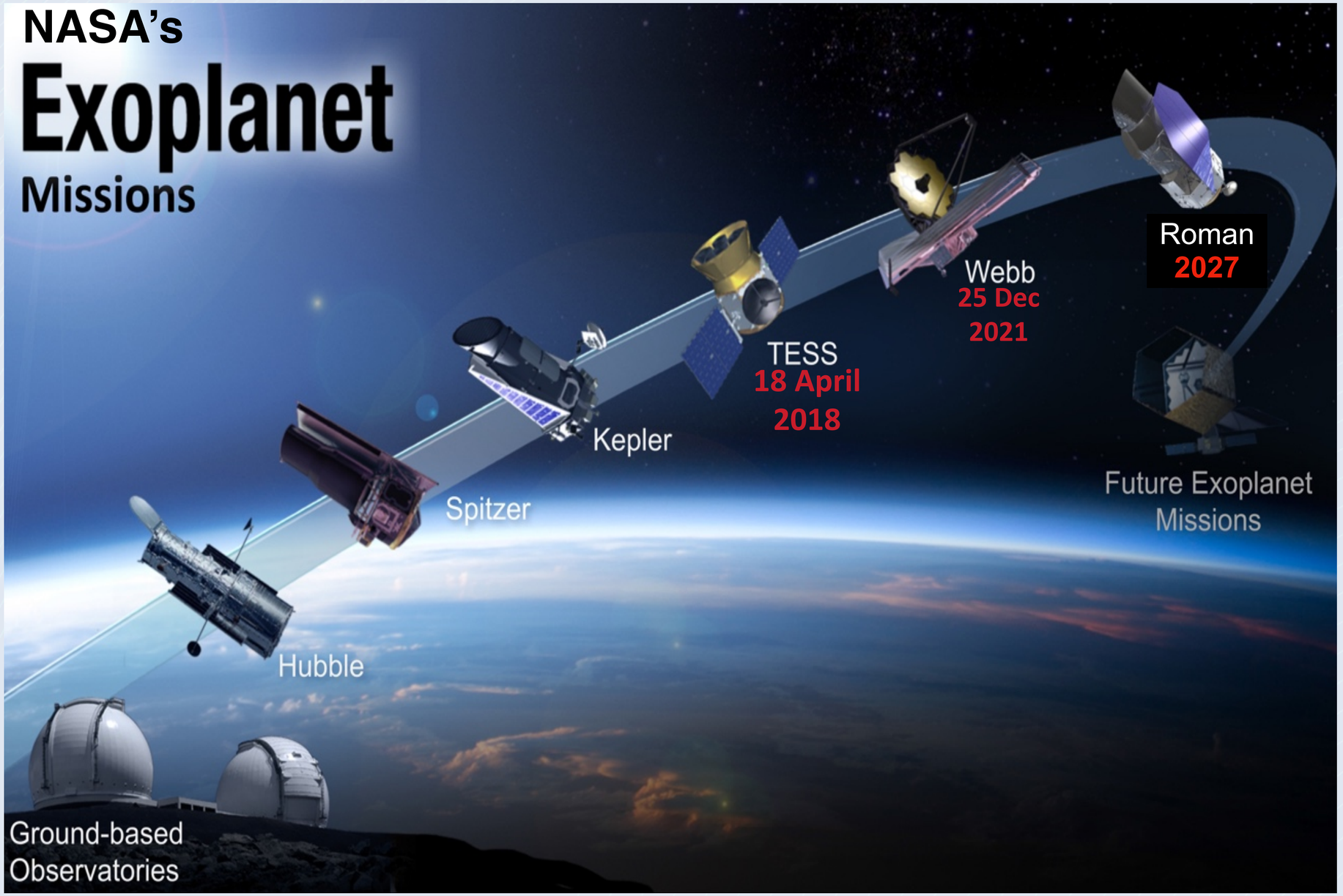
TESS Institutional Partners

Ames

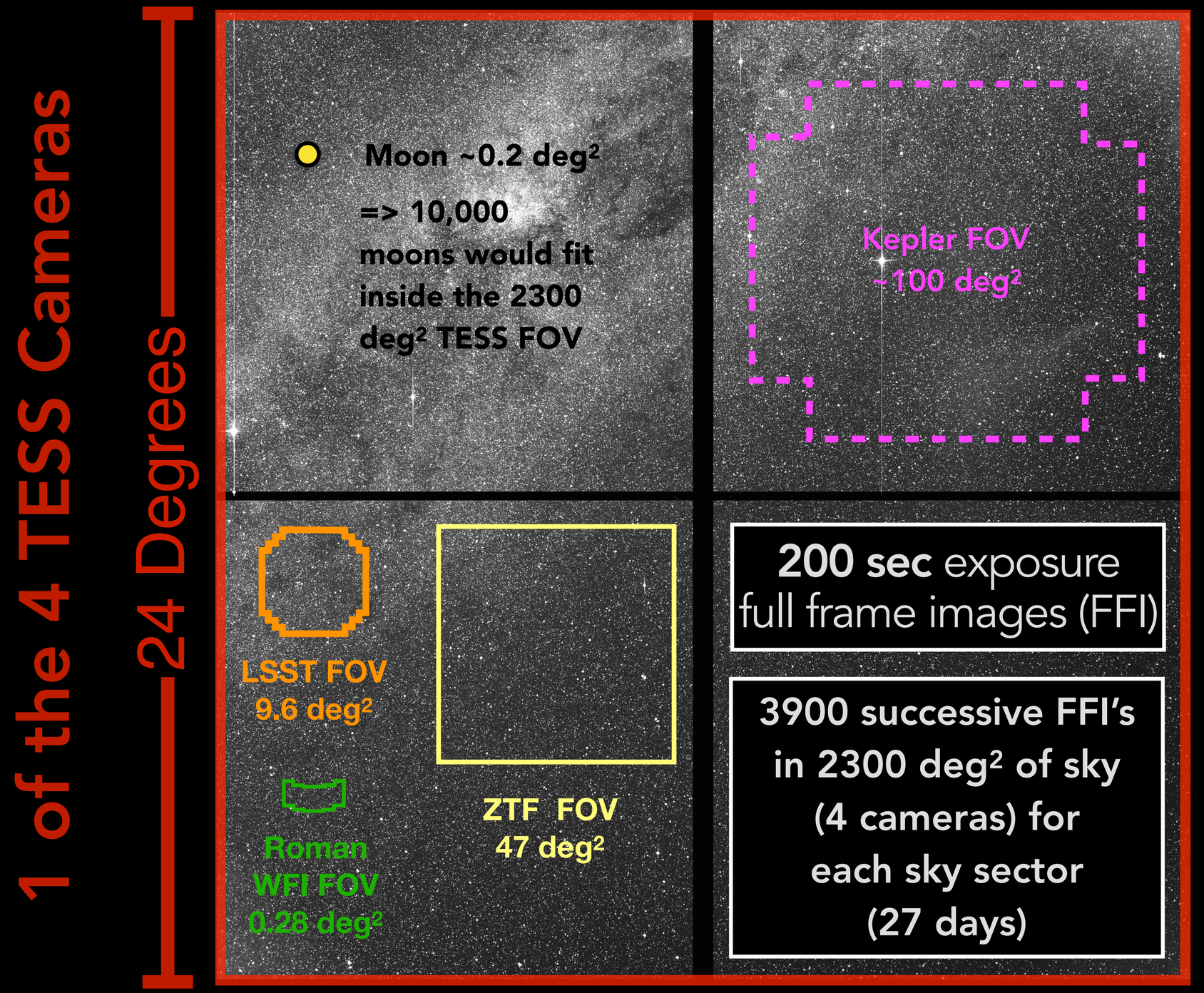
TESS Science Team

TESS Engineering and Management Team at Preliminary Design Review (16 September 2014)

TESS: A Bridge to the Future…



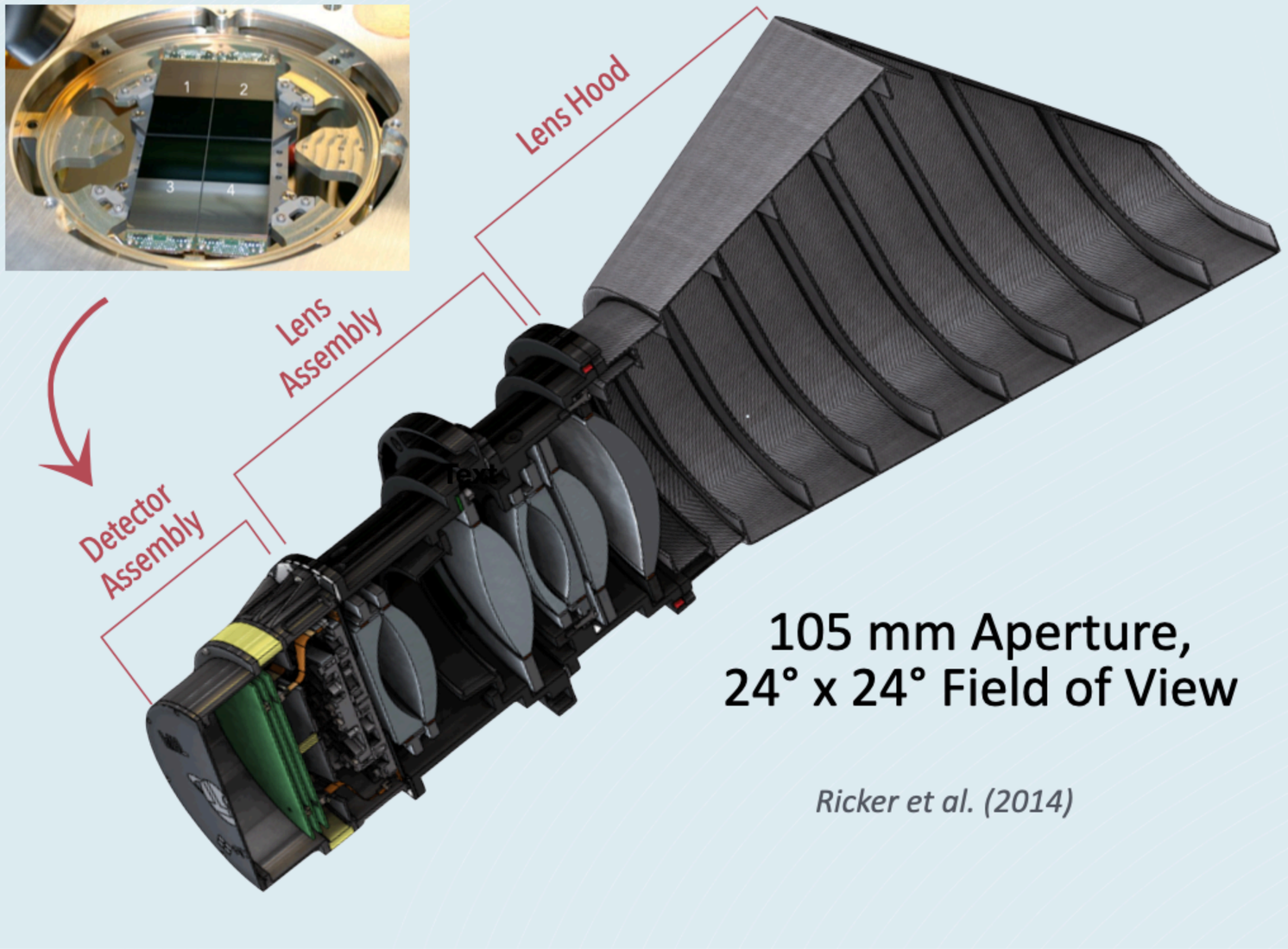
TESS has an enormous field-of-view:
~2300 square degrees FOV
(~ 6% of the entire sky at any given time)



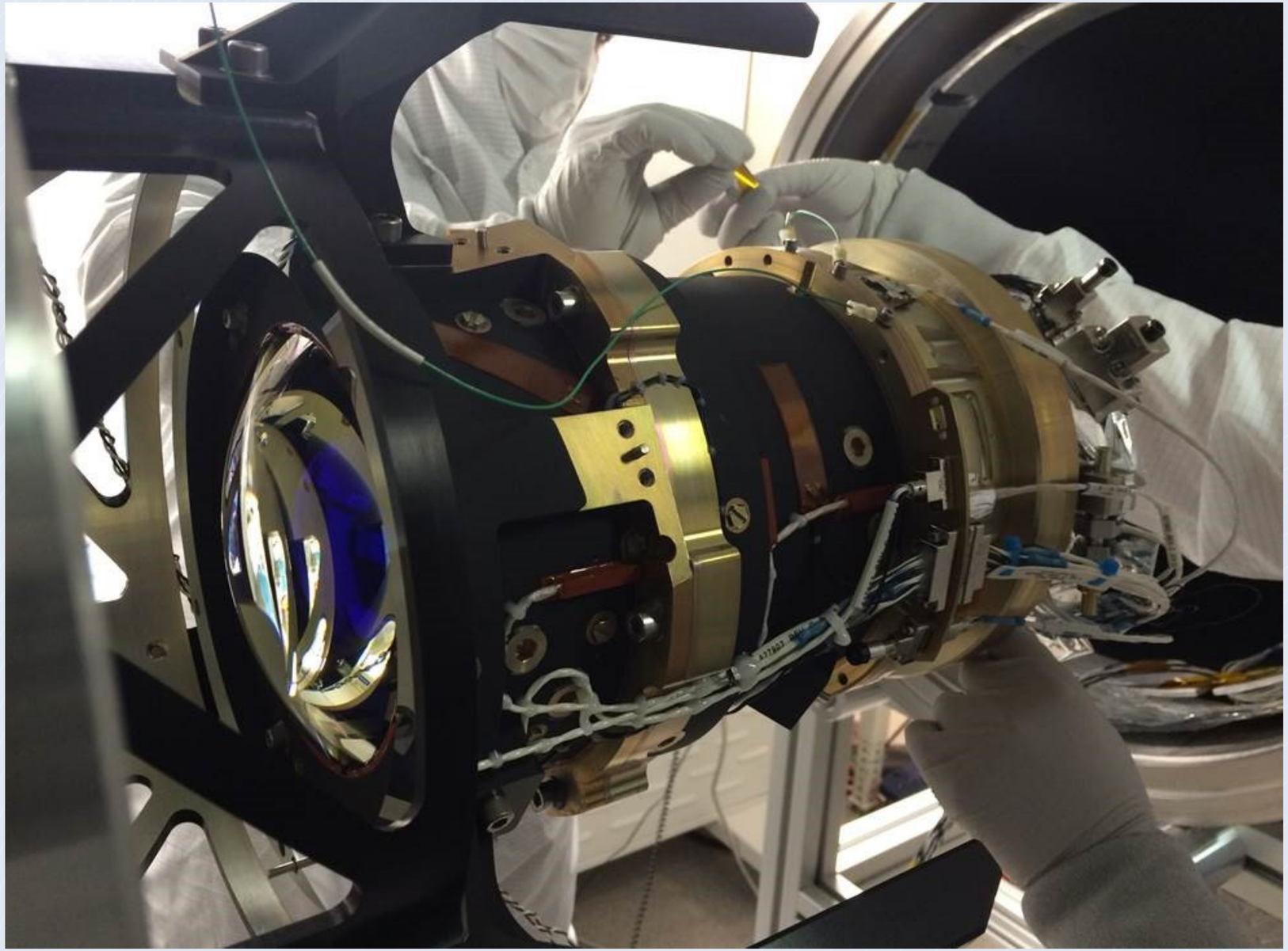
Total FOV of 4 TESS cameras is 4x that shown here!

TESS "Cameras" = Exquisite *Photometers*

- TESS cameras act as 64 million tiny "light meters"
- Precision of ~10 ppm (~100 x better than gnd-based photometers)
  - *Optical focus stability of < 1μm*
  - *Thermal stability of ~10 mK per hr*
  - *Electronic noise < 8 e- rms*
  - *Pointing stabilization ~20 milliarcsec (~30 silicon atomic spacings on the TESS CCDs)*
- Enormous grasp: ~300 million stars & galaxies in 2 yrs



Flight Camera #1 (of 4) in Thermal Vacuum Test at MIT



Important Lessons Learned:

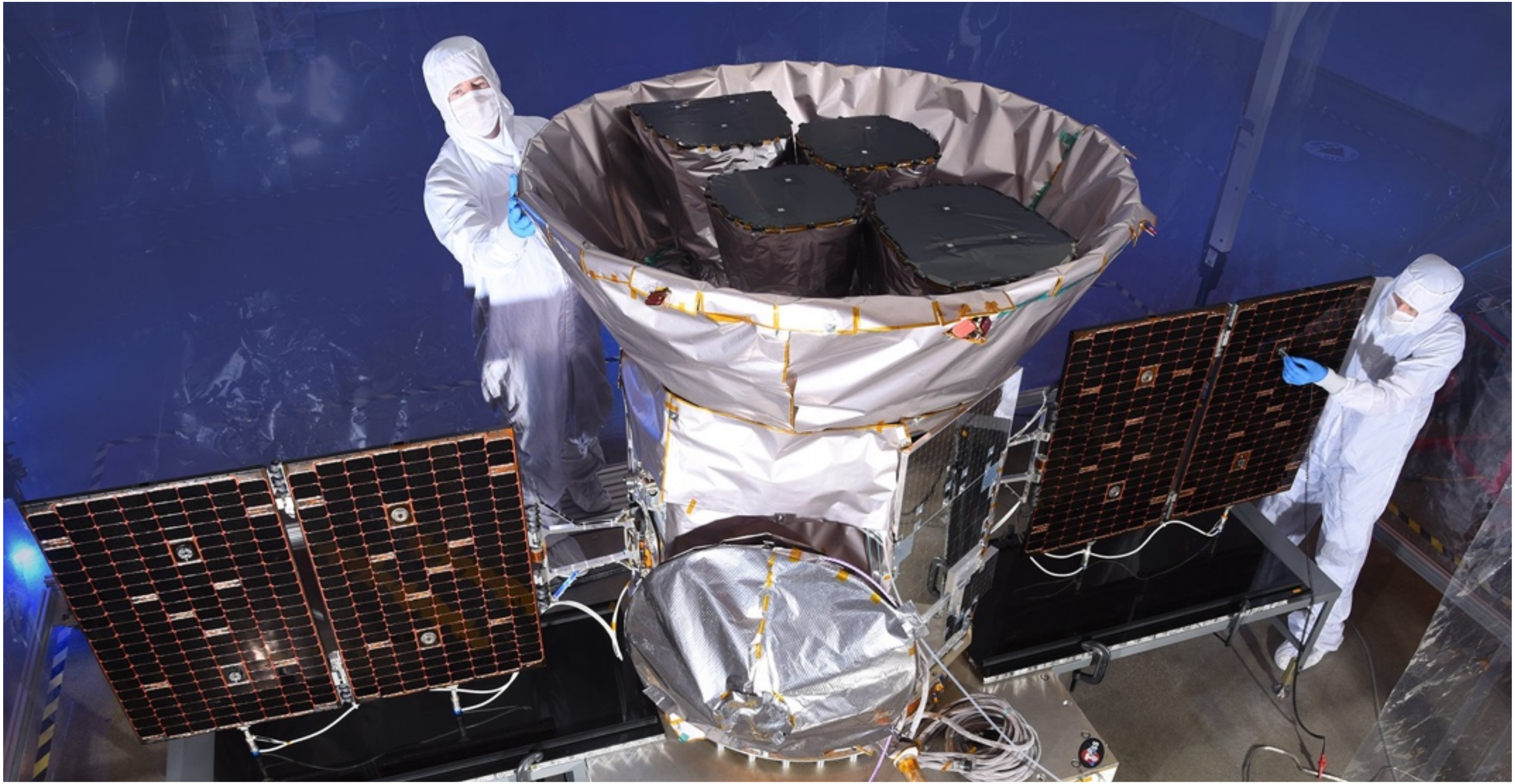
1) **Build & TESS Instrument Prototypes ASAP**
   > Find any surprises early

2) **Eliminate moving parts if at all possible (shutters, doors, covers, flip mirrors…)**
   > Improves reliability
   > "Best part is no part"

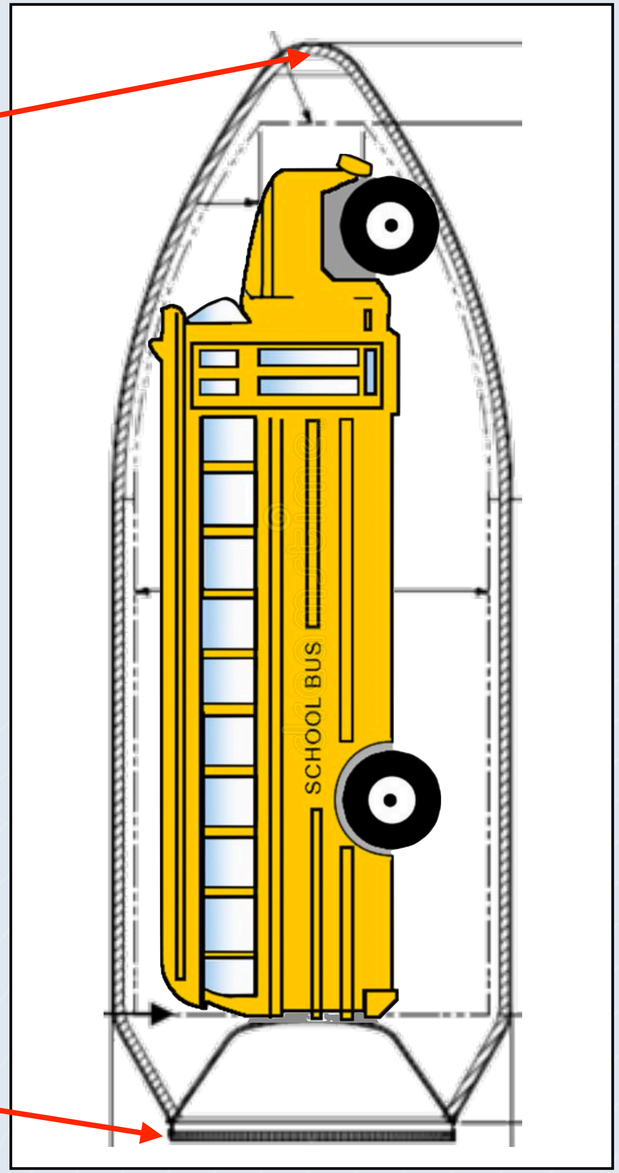
3) **Test multiple flight instruments in parallel**
   > Small TVAC Chambers are cheap to build
   > Saves cost & schedule

4) **Build a flight spare Instrument**
   > Diagnose problems post-integration and in early flight

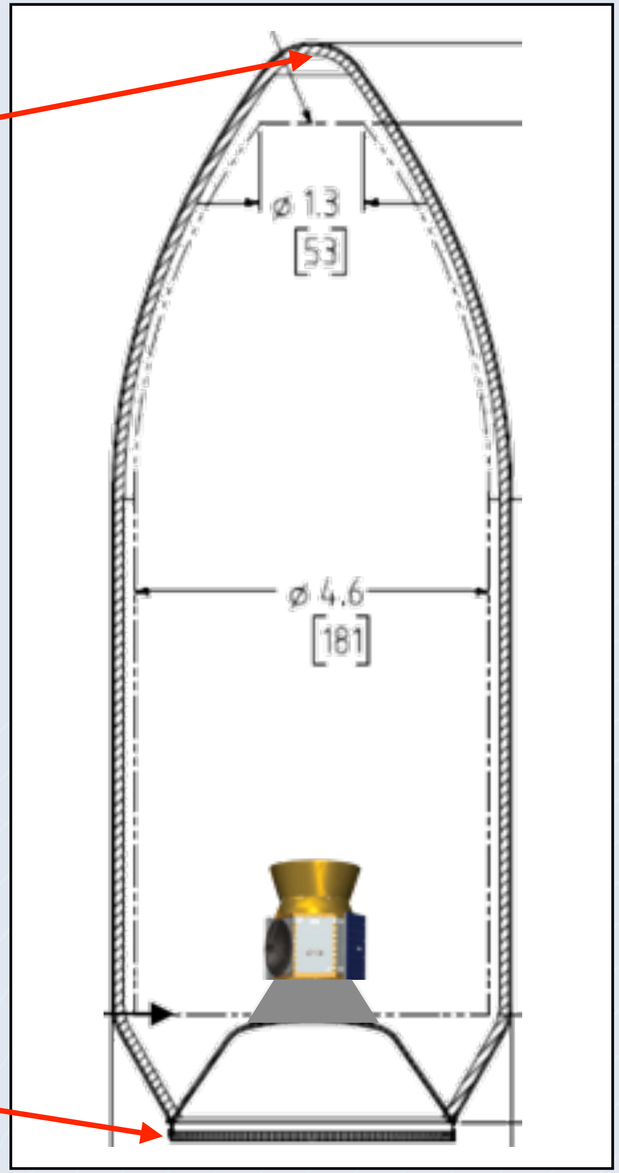
TESS ready for delivery to the launch pad at Cape Canaveral !



TESS's Fairing for Falcon 9



TESS's Fairing for Falcon 9



TESS Launch

SpaceX Falcon 9

April 18, 2018

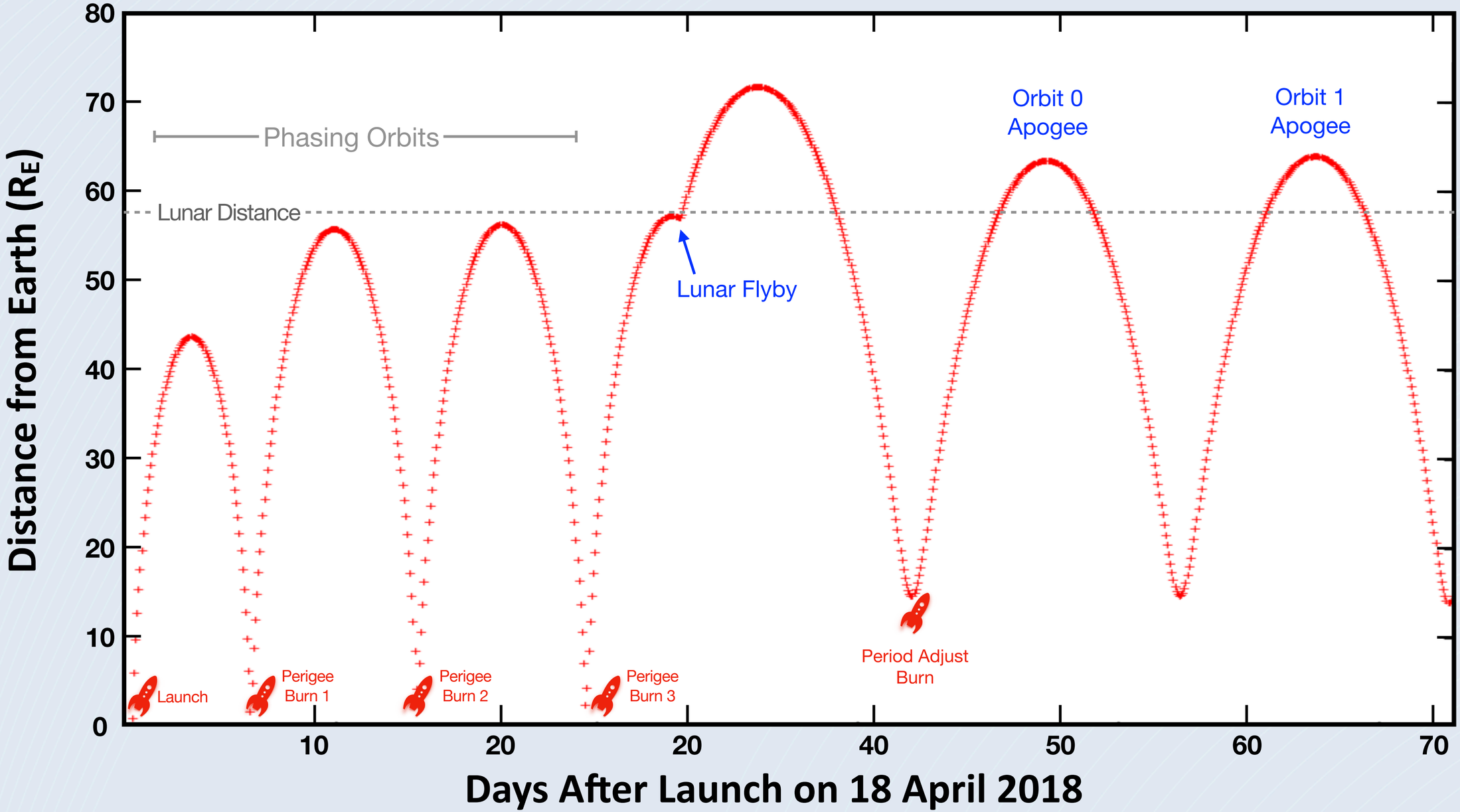
Commissioning:

Next 3 months

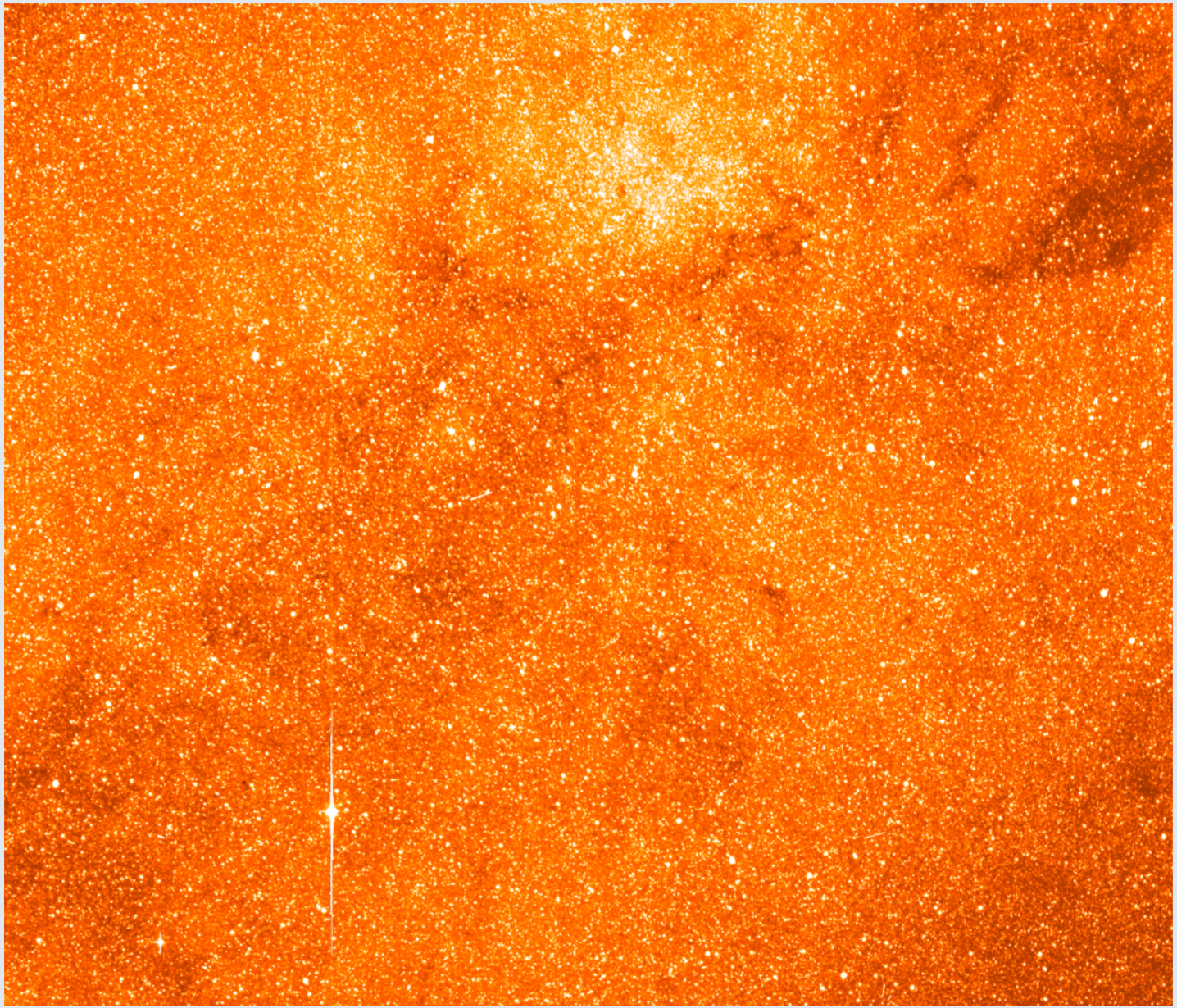
Survey Commenced:

25 July 2018

Key Propulsion Events for TESS's P/2 Lunar Resonant Orbit



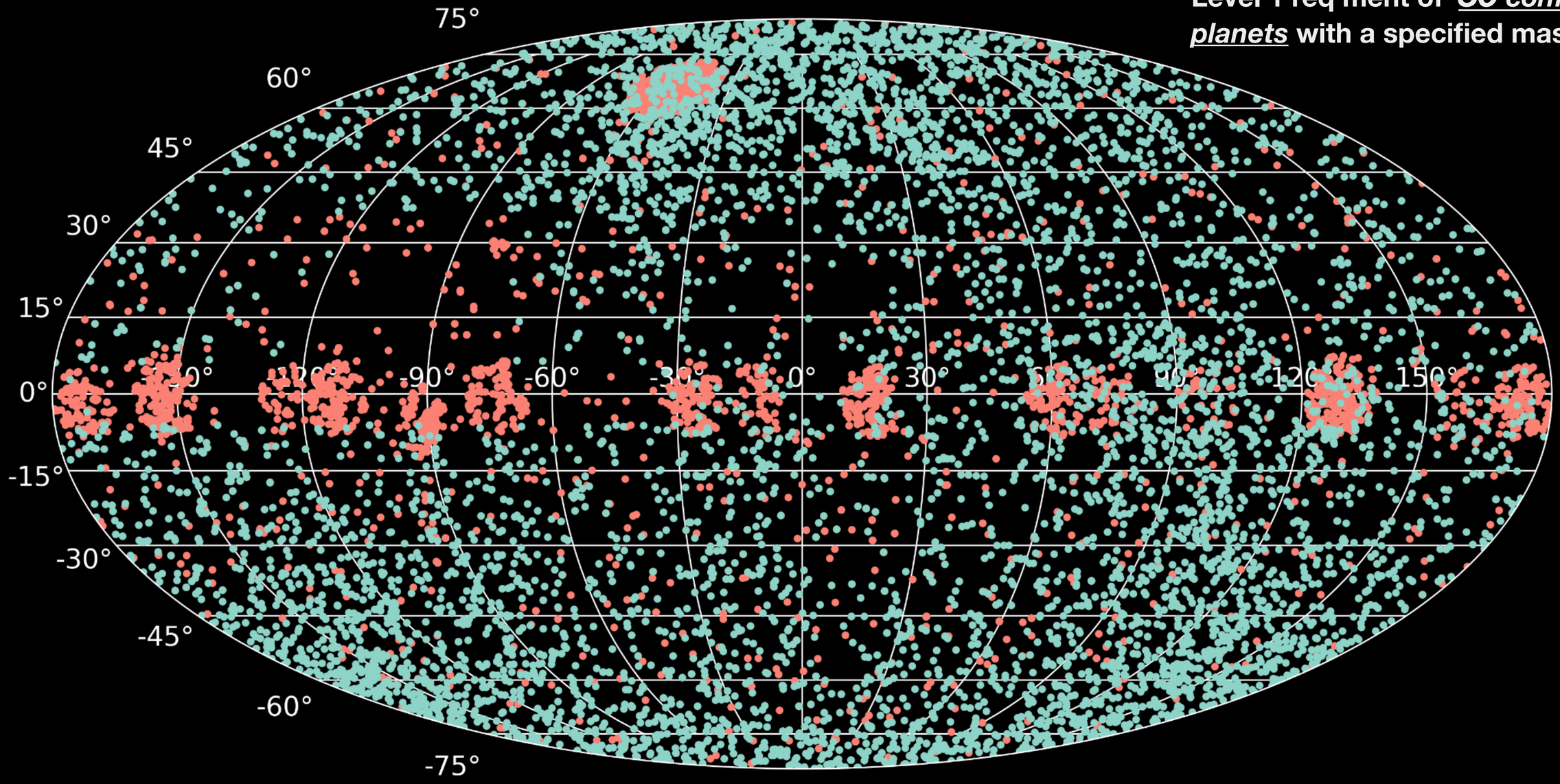
TESS "Test Image" Released on 18 May 2018 (1 month post-launch)



7341 TESS Objects of Interest (TOIs) in 6 Years

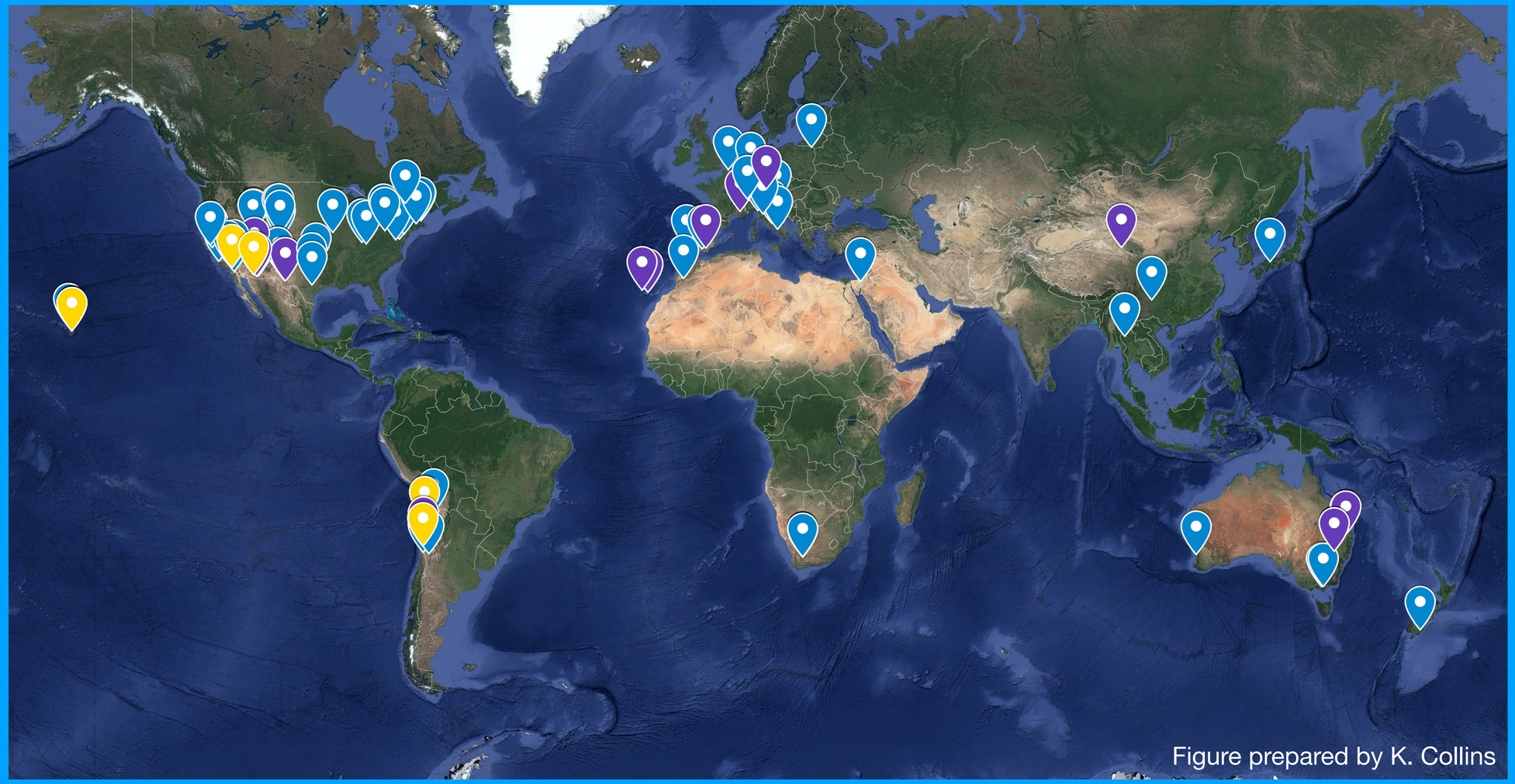
***570** Confirmed TESS Planets* as of 11/4/24

<= Handily beats the TESS Mission Level 1 req'ment of *50 confirmed planets* with a specified mass!!



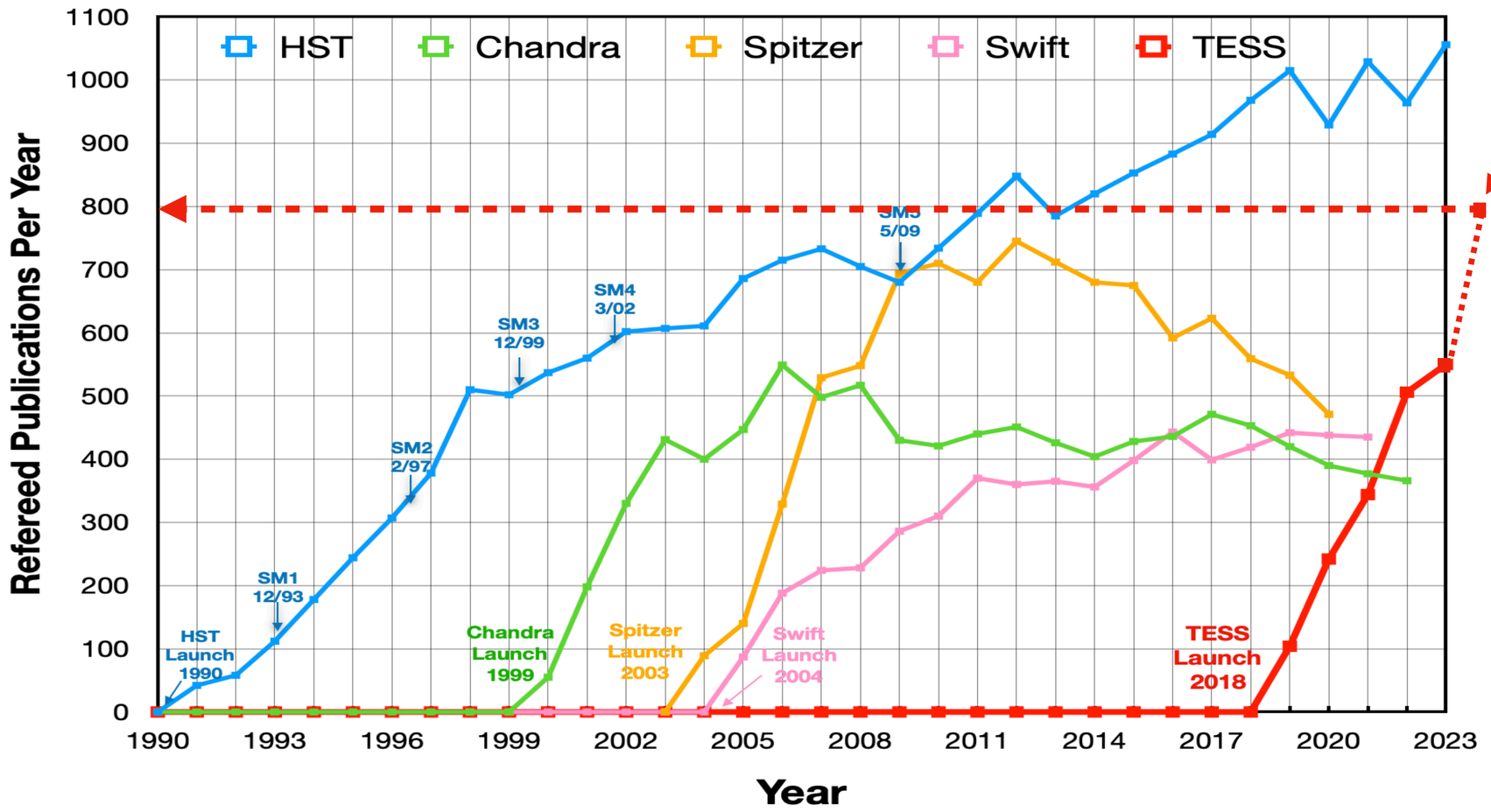
Planets and planet candidates from the NASA Exoplanet Archive; ecliptic coordinates

The *TESS* Follow-up Observing Program (TFOP)



700 astronomers…100 institutions on 6 continents…250 telescopes…**> 500 new planet masses**

Comparison: Refereed Publications Per Year For 5 NASA Astrophysics Mission



Plus 250 more publications in 2024 to date, or an estimated rate of ~800 publications/yr

Bottom Line:
TESS could be approaching HST's Publication Rate by beginning of EM3 in 2026

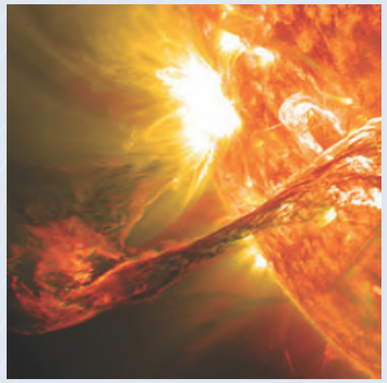
Notes:

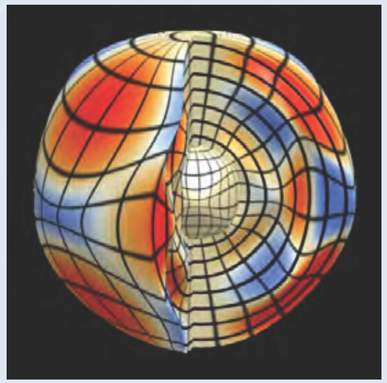
1) Publication rates are given for the first full year of mission operations following the launch year for each of the four missions, and for each year following the launch year, for which compiled data has been provided on the respective Mission Teams' websites. *Publications for the year of launch (and all previous years) are not included for any of the missions.*

2) Tabulated data used was from:
   - **HST**: https://archive.stsci.edu/hst/bibliography/pubstat.html
   - **Chandra**: https://cxc.harvard.edu/cda/bibstats/bibstats.html
   - **Spitzer**: https://iopscience.iop.org/article/10.1088/1538-3873/ac4959#paspac4959bib35
   - **Swift**: https://swift.gsfc.nasa.gov/results/refereed/all.html
   - **TESS**: https://heasarc.gsfc.nasa.gov/docs/tess/tpub.html

3) For HST and TESS, the latest year for which complete publication data is available is 2023. For Chandra, the latest year for which complete data is available is 2022. For Swift the latest year for which complete data is available is 2021. For Spitzer, the latest year is 2020.

TESS is Enabling a Broad Range of Astrophysical Discovery Areas





Solar System Objects:

Thousands in 4 years…

- ✓ Comets
- ✓ Asteroids
- ✓ Trans-Neptunian Objects
- ✓ SDOs/Centaurs

Explosive & Variable Extragalactic Sources:

Thousands in 4 years…

- ✓ Supernovae
- ✓ AGNs
- ✓ Blazars
- ✓ Quasars
- ✓ Tidal Disruption Events
- ✓ Gamma-ray Bursts
- ✦ Kilonovae (NS-NS Gravitational Wave Counterparts) [**anticipated in EM3]**
- ✦ **EBOT/FBOT [**searches underway…]

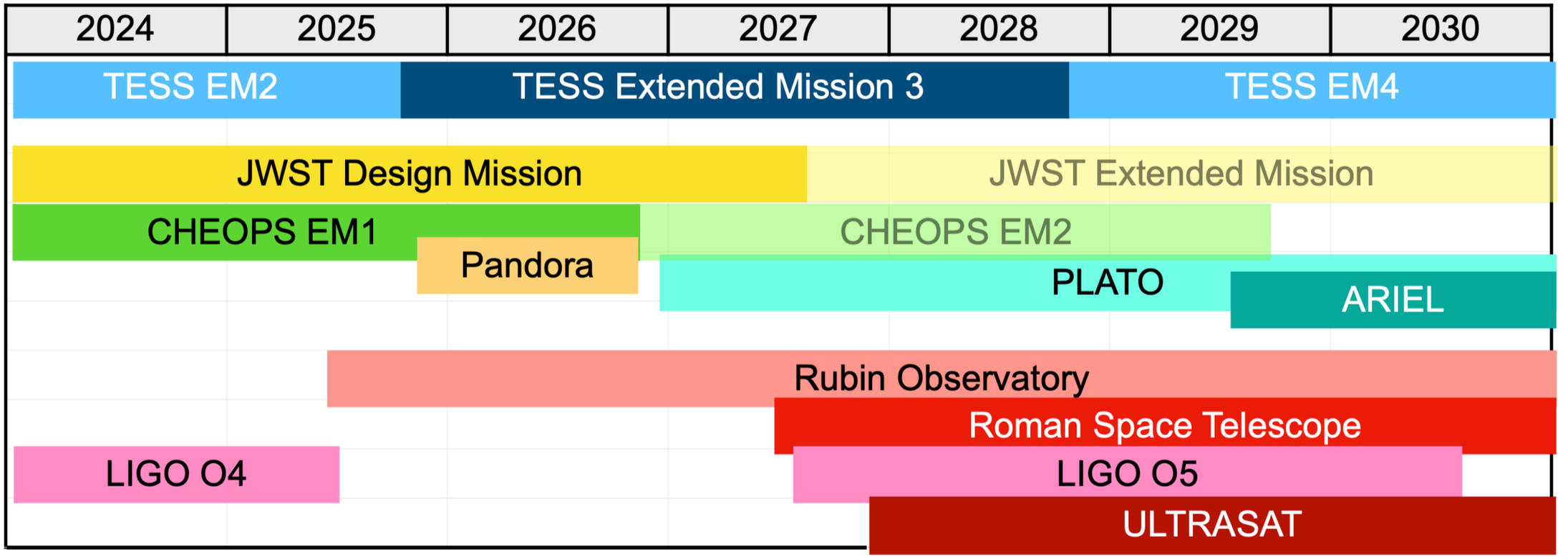
✓ TESS Results in Years 1-6

Variable Stars:

Millions in 4 years…

- ✓ Asterioseismology
- ✓ Brown Dwarfs
- ✓ Eclipsing Binaries
- ✓ Flare Stars
- ✓ Cepheids
- ✓ T Tauri Stars
- ✓ Cluster Gyrochronology
- ✓ White Dwarfs
- ✓ Neutron Stars
- ✓ Emission line stars (Be stars)
- ✓ RR Lyrae Stars
- ✓ WD Oscillations
- ✓ Novae
- ✓ Young Stellar Objects

TESS and Timeline of Synergistic Projects and Missions



HST-Chandra-NICER-Swift-Fermi-XMM