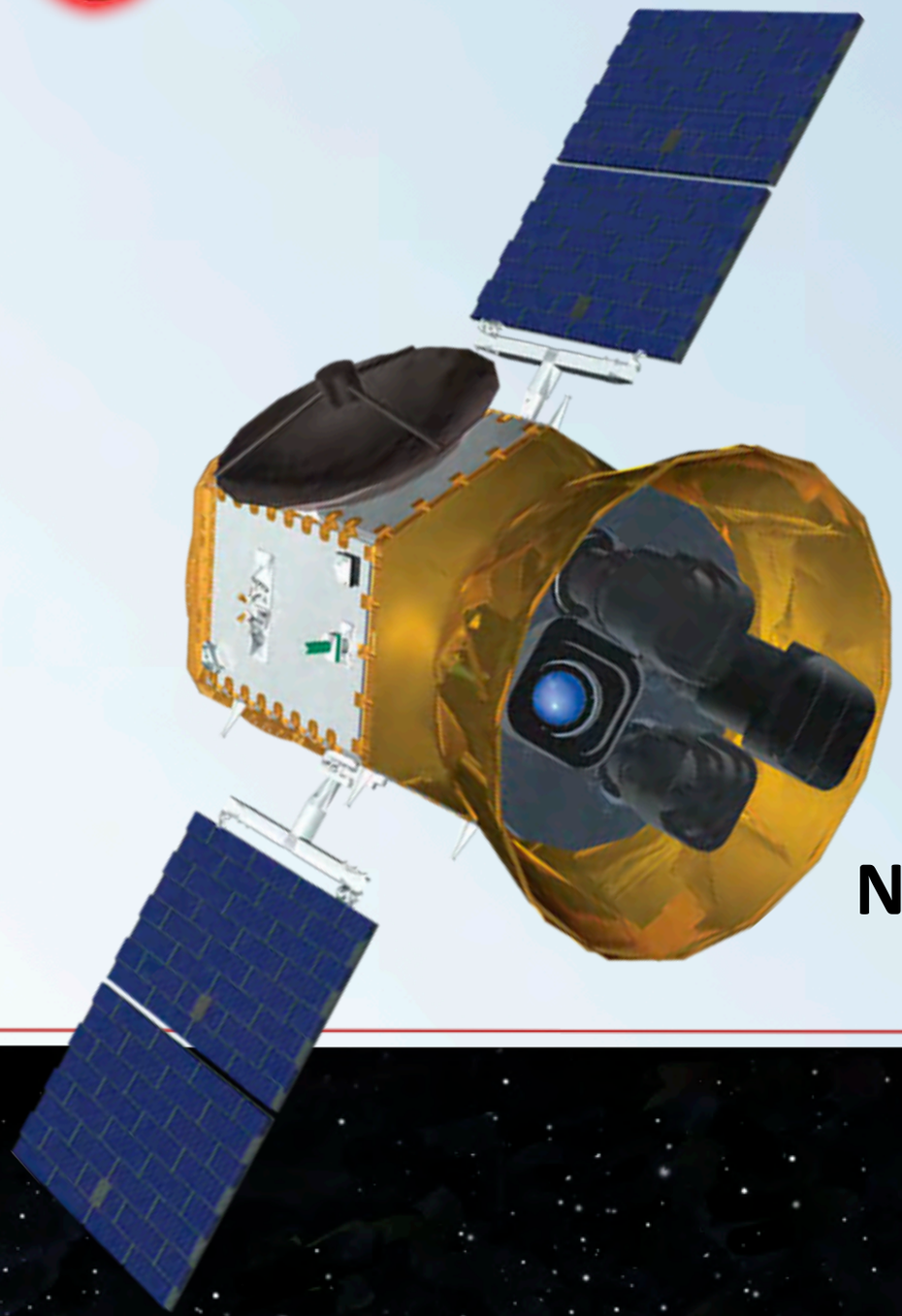
Transiting Exoplanet Survey Satellite



Discovering New Earths and Super-Earths in the Solar Neighborhood

George Ricker (MIT)

NRC Committee on Astronomy and Astrophysics

4 March 2014

TESS Partnerships

MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MKI + LL)

PI, Payload, Science Center

NASA'S GODDARD SPACE FLIGHT CENTER

Mission Management, Engineering, Safety & Mission Assurance, E/PO

ORBITAL SCIENCES CORPORATION

Spacecraft Bus, Observatory I&T, Mission Operations Center

NASA AMES

Data Pipeline

SAO

Follow-Up Program, Science Center

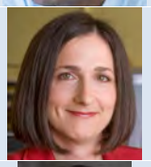
STScI

Archive, E/PO

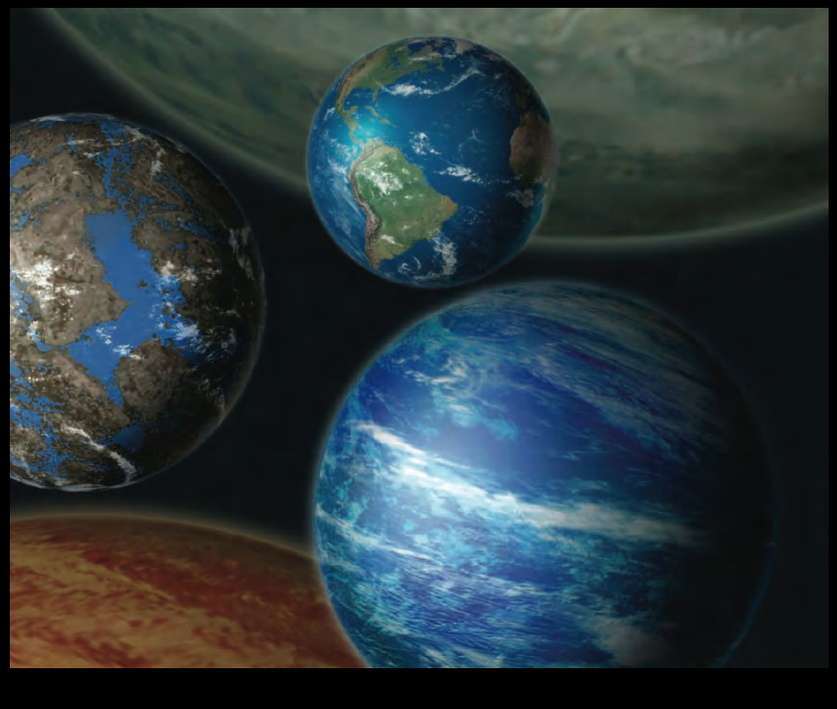
Contributors include: SAO, MPIA-Germany, Las Cumbres Observatory, Geneva Observatory, OHP-France, University of Florida, Aarhus University-Denmark, Harvard College Observatory, STScI, and Vanderbilt University. There are no mission hardware contributions.

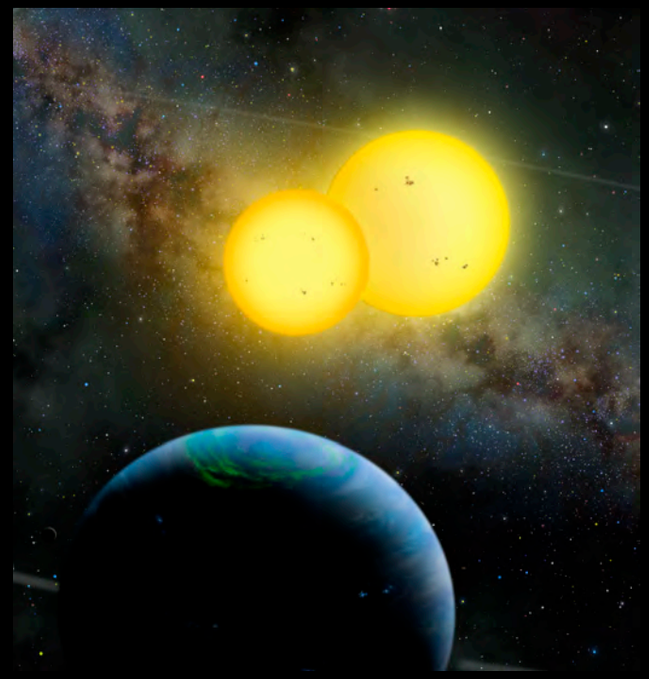
TESS Science Team Co-I's

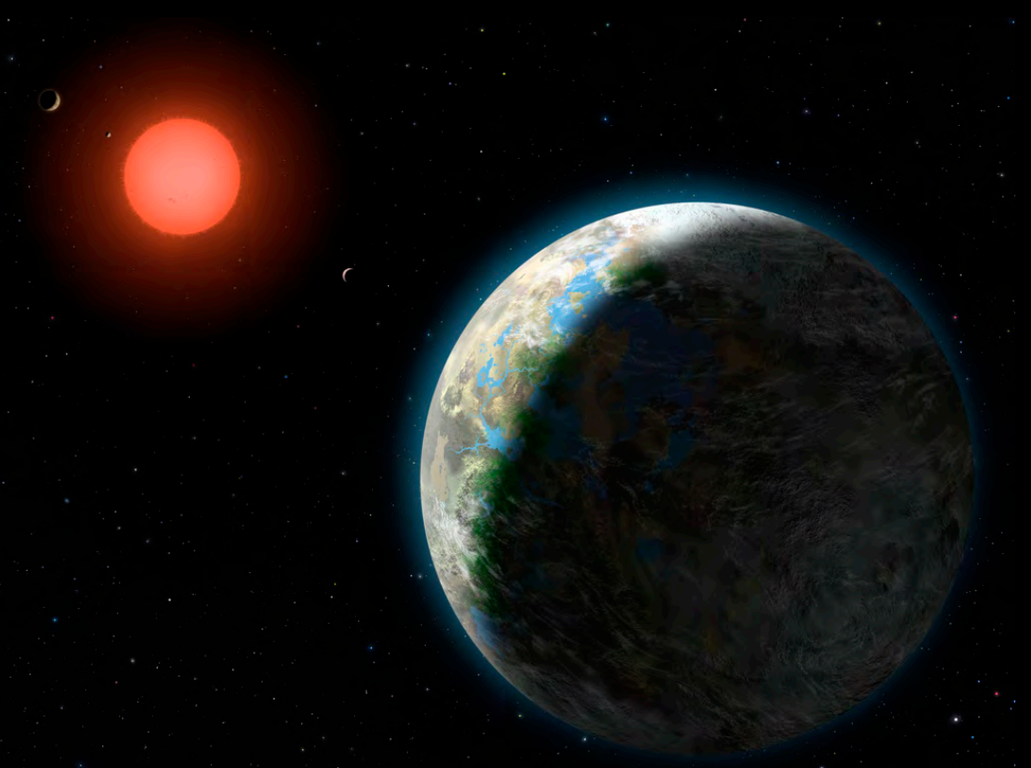
	G. Ricker (MIT-PI)		R. Vanderspek (MIT-DPI)

	D. Latham (CfA)		J. Doty (Noqsi/MIT)		J. Lissauer (ARC)
	J. Winn (MIT)		T. Dunham (Lowell Obs.)		P. McCullough (STScI)
	J. Villasenor (MIT)		M. Holman (CfA)		S. Rinehart (GSFC)
	G. Bakos (Princeton)		J. Jenkins (ARC/SETI)		D. Sasselov (CfA)
	T. Brown (LCOGT)		G. Jernigan (Espace/UCB)		S. Seager (MIT)
	D. Charbonneau (CfA)		L. Kaltenegger (MPIA)		K. Stassun (Vanderbilt)
	J. Christensen-Dalsgaard (DN)		G. Laughlin (UCSC)		A. Szentgyorgyi (CfA)
	M. Clampin (GSFC)		A. Levine (MIT)		G. Torres (CfA)
	D. Deming (UMd)		D. Lin (UCSC)		S. Udry (Geneva Obs.)

Imagine Finding a New Earth-sized Planet Every Month…

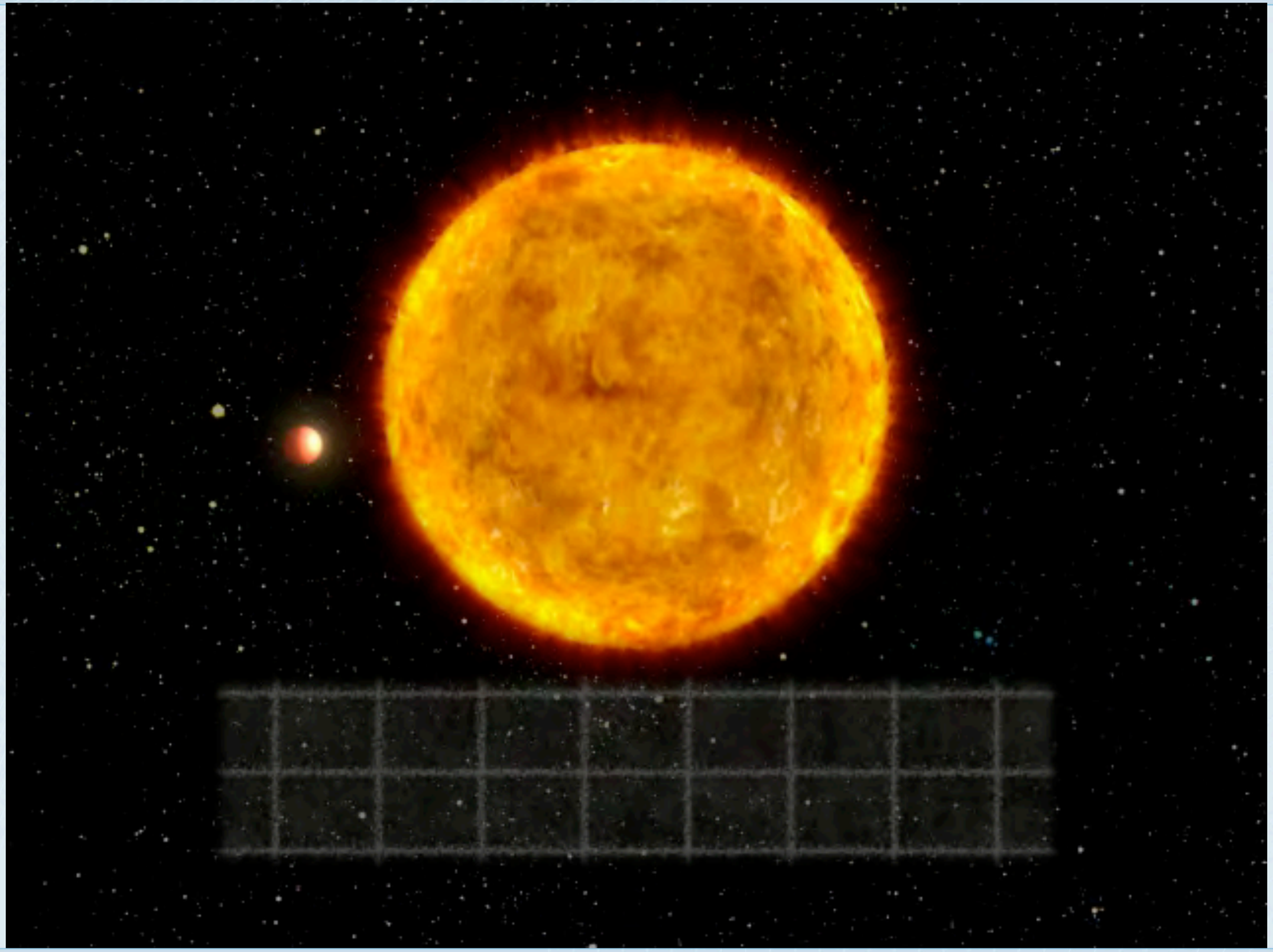






TESS:
The “People’s Telescope”

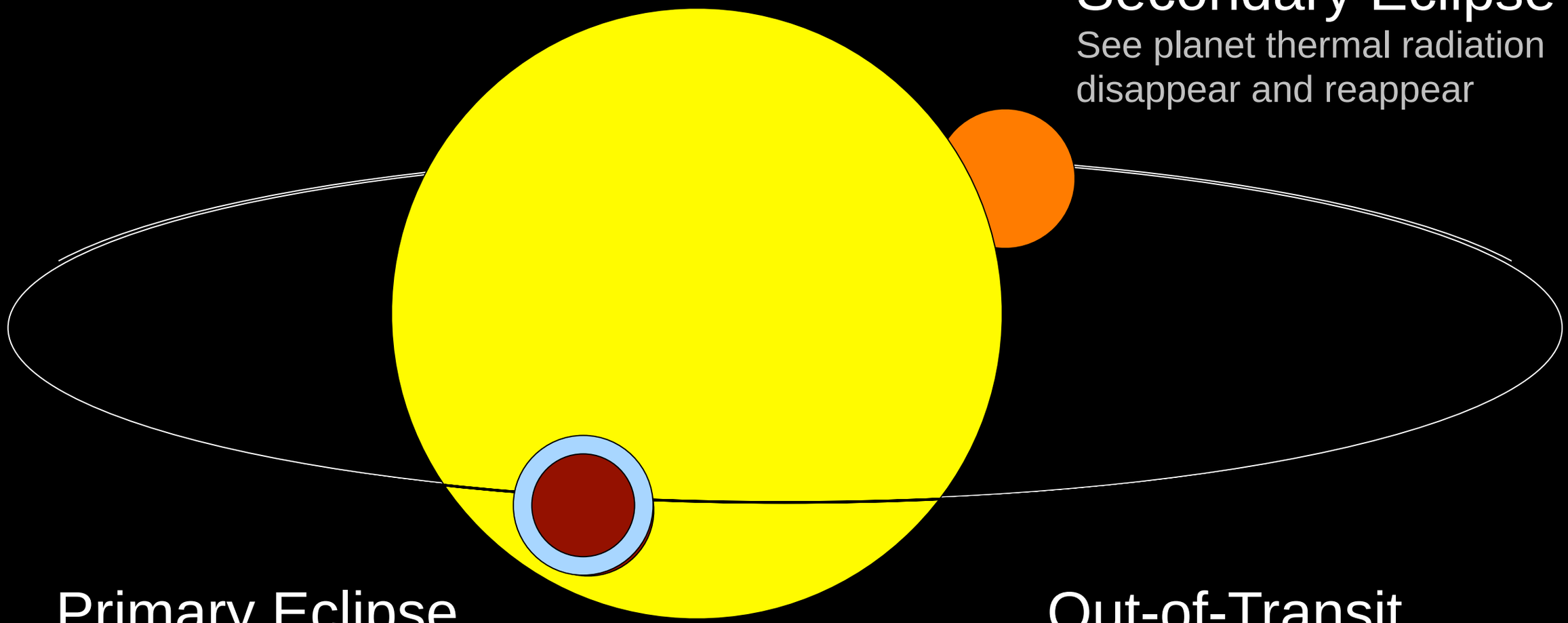
What is a Transit?



Transiting Planet Science

Secondary Eclipse

See planet thermal radiation disappear and reappear



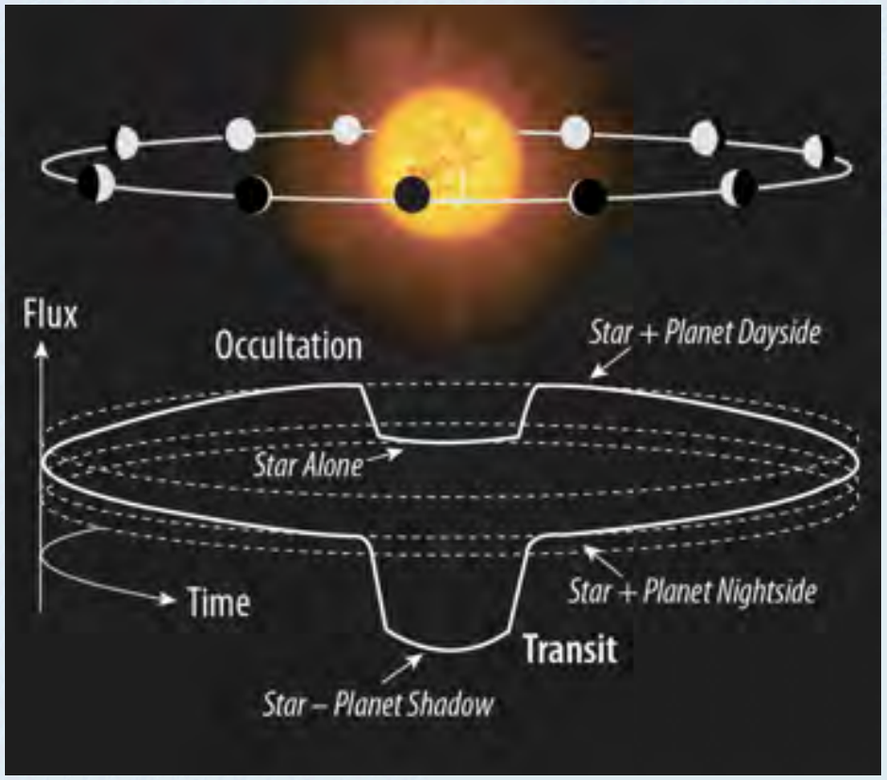
Primary Eclipse

Measure size of planet
See star’s radiation transmitted through the planet atmosphere

Out-of-Transit

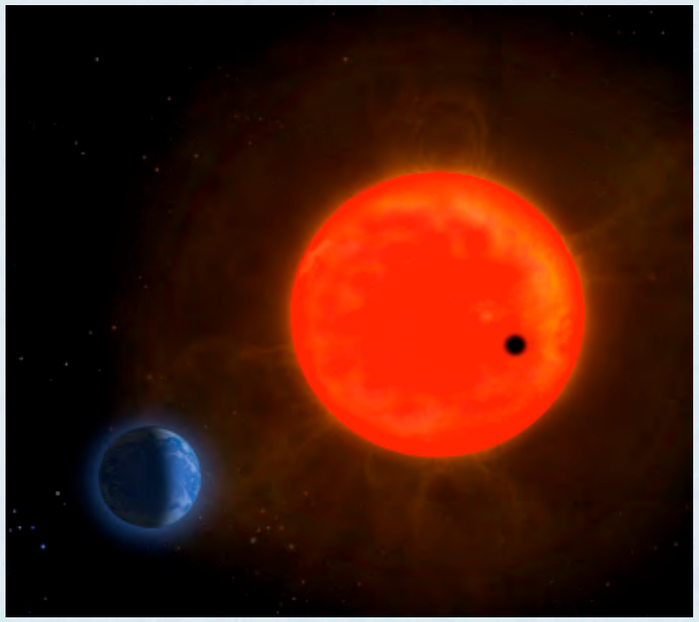
Learn about atmospheric circulation from thermal phase curves

TESS Science Goals and Drivers



- **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: <u>Only 2</u> small transiting exoplanets orbiting bright hosts are known*

- **Large Area Surveys of Bright Stars**
  - *F, G, K dwarfs: +4 to +12 magnitude*
  - *M dwarfs known within ~60 parsecs*
  - *>200,000 target stars in two years*



TESS Science Objectives

- OBJECTIVE 1: Locate a diverse sample of transiting small exoplanets orbiting the brightest stars in the solar neighborhood.

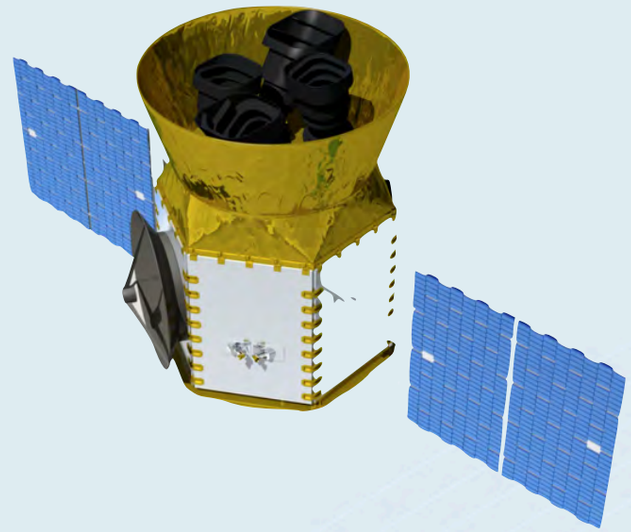
- OBJECTIVE 2: Locate a sample of transiting small exoplanets orbiting bright stars situated near the ecliptic poles, locations that are optimal for JWST followup.

- OBJECTIVE 3: Establish the masses of a sample of TESS-located small transiting planets by means of precise radial velocity measurements.

TESS and Kepler Address Different Questions

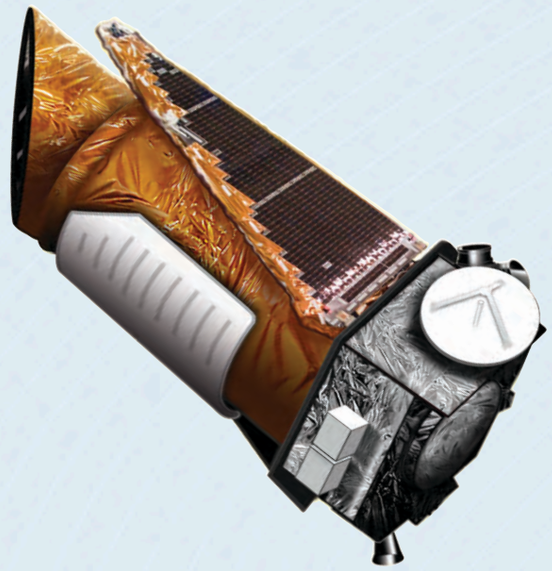
- **TESS:**

  Where are the nearest transiting rocky planets?



- **Kepler:**

  How common are true Earth analogs?



TESS Stars Are Brighter than Kepler Stars

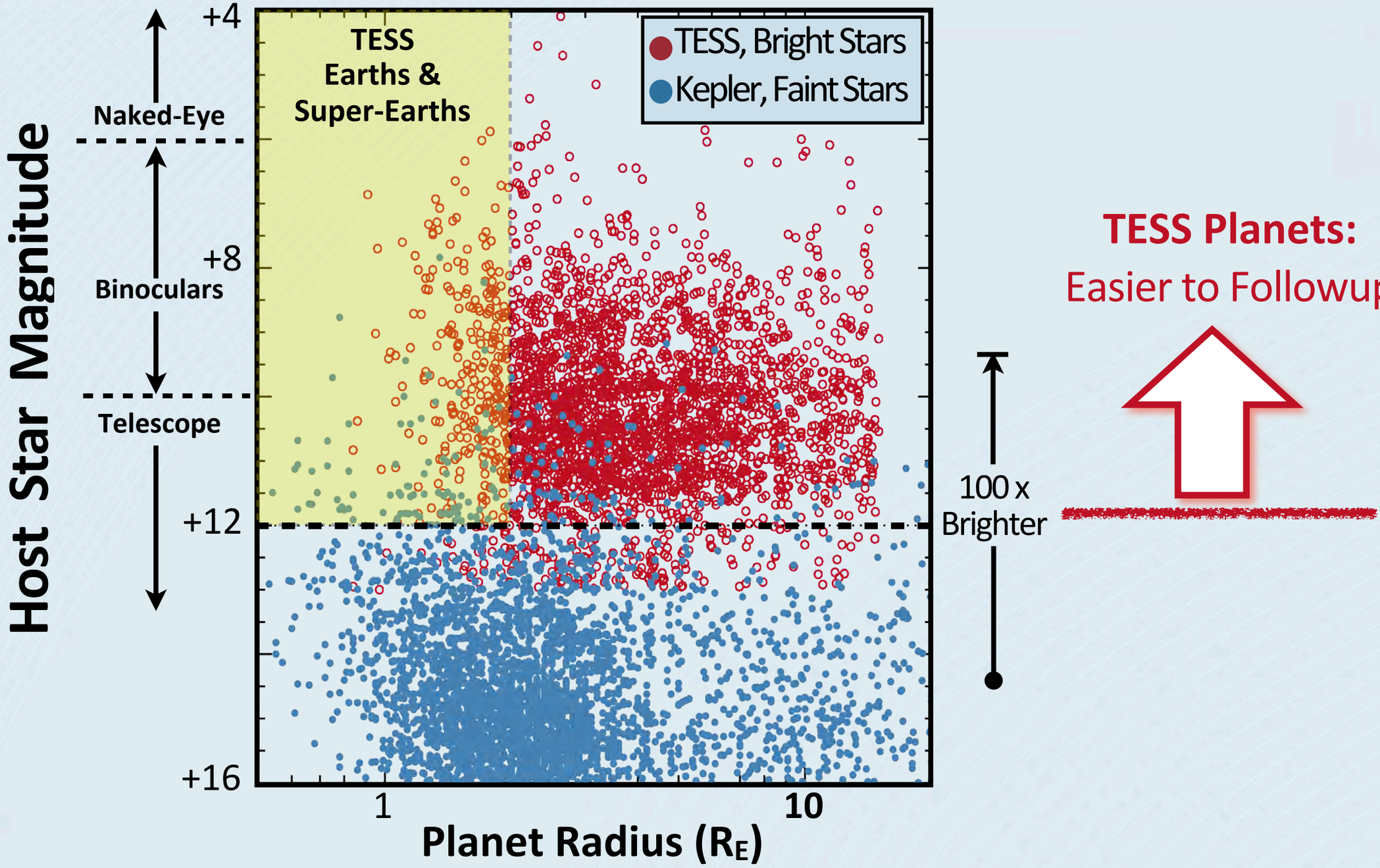
- Why?
  - *Two reasons…both arise from TESS's focus on Solar Neighborhood*

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

- Catalog star distances
  - *TESS: ~10^2 light-yr*
  - *Kepler: ~10^3 light-yr*

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

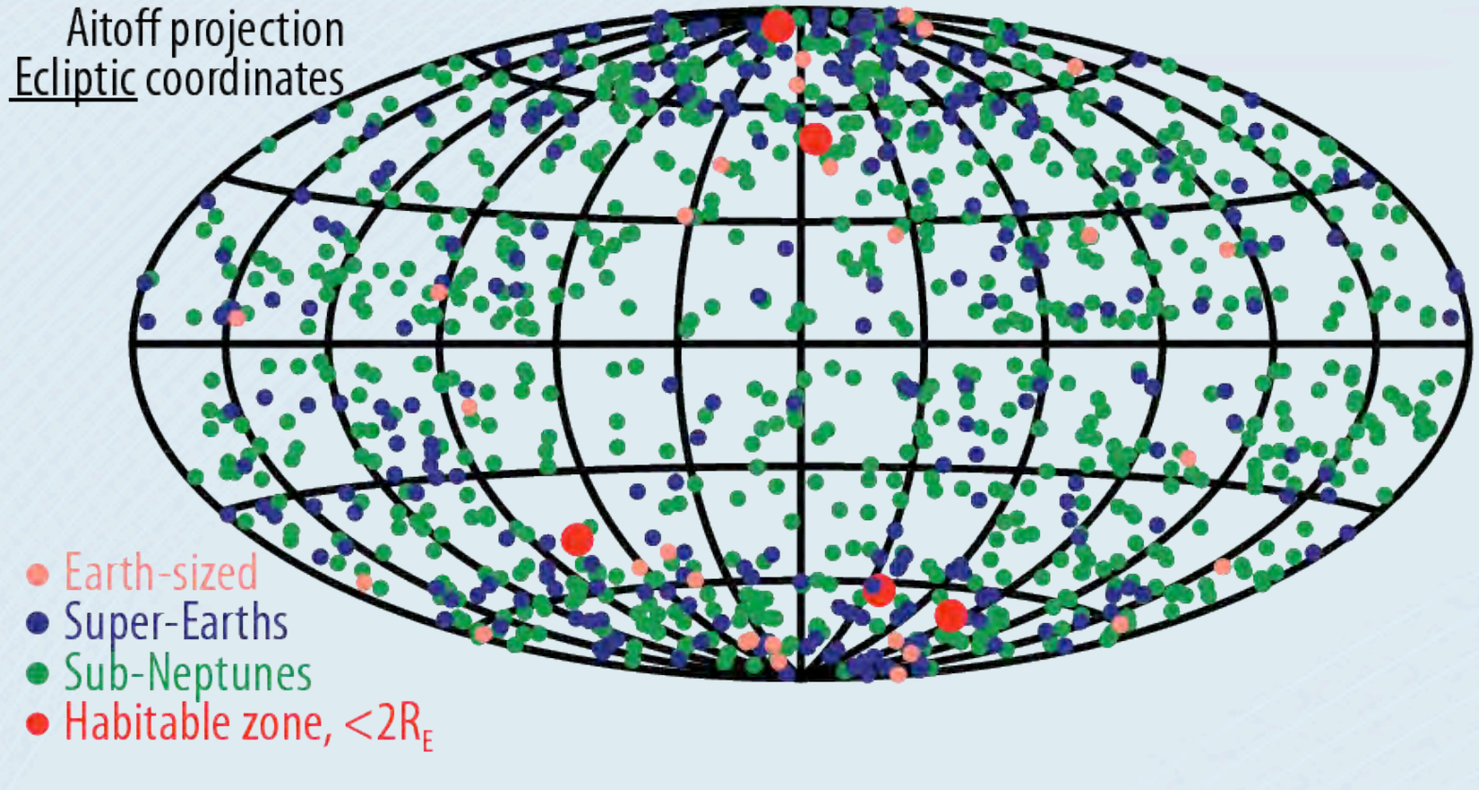
Comparison of Host Star Brightness

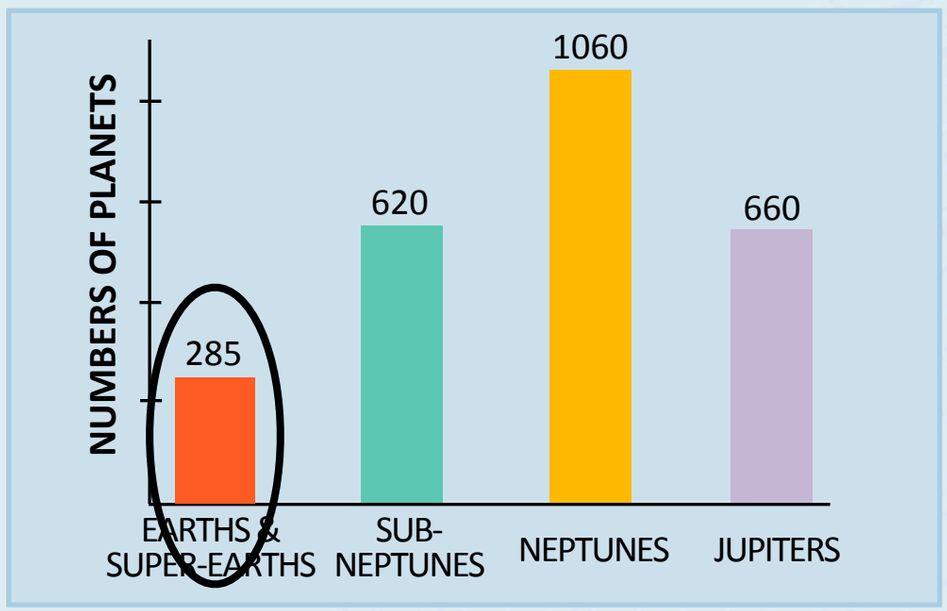


TESS Planets:
Easier to Followup

TESS Will Discover Earths & Super-Earths Orbiting Bright Stars

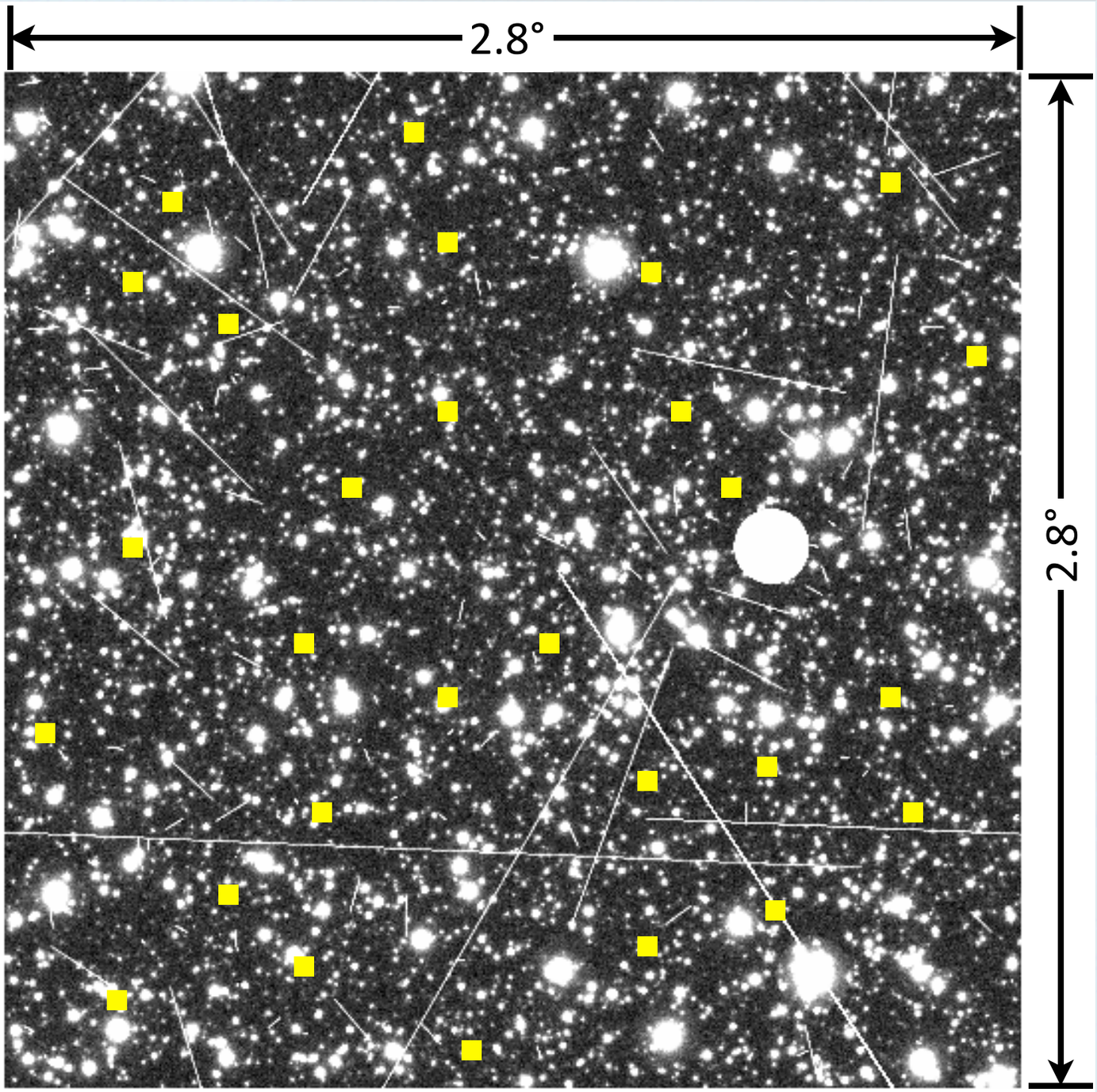
Predicted Science Yield from TESS Mission





TESS Will Discover ~300 Earths & Super-Earths

Simulated ½ Hour Stacked Full Frame TESS Image



Definition:
Full Frame Image = FFI = 100% of FOV
cf: 10x10 “postage stamps” = 2% of FOV

FFI Stack:
900 TESS images @ 2s/integration

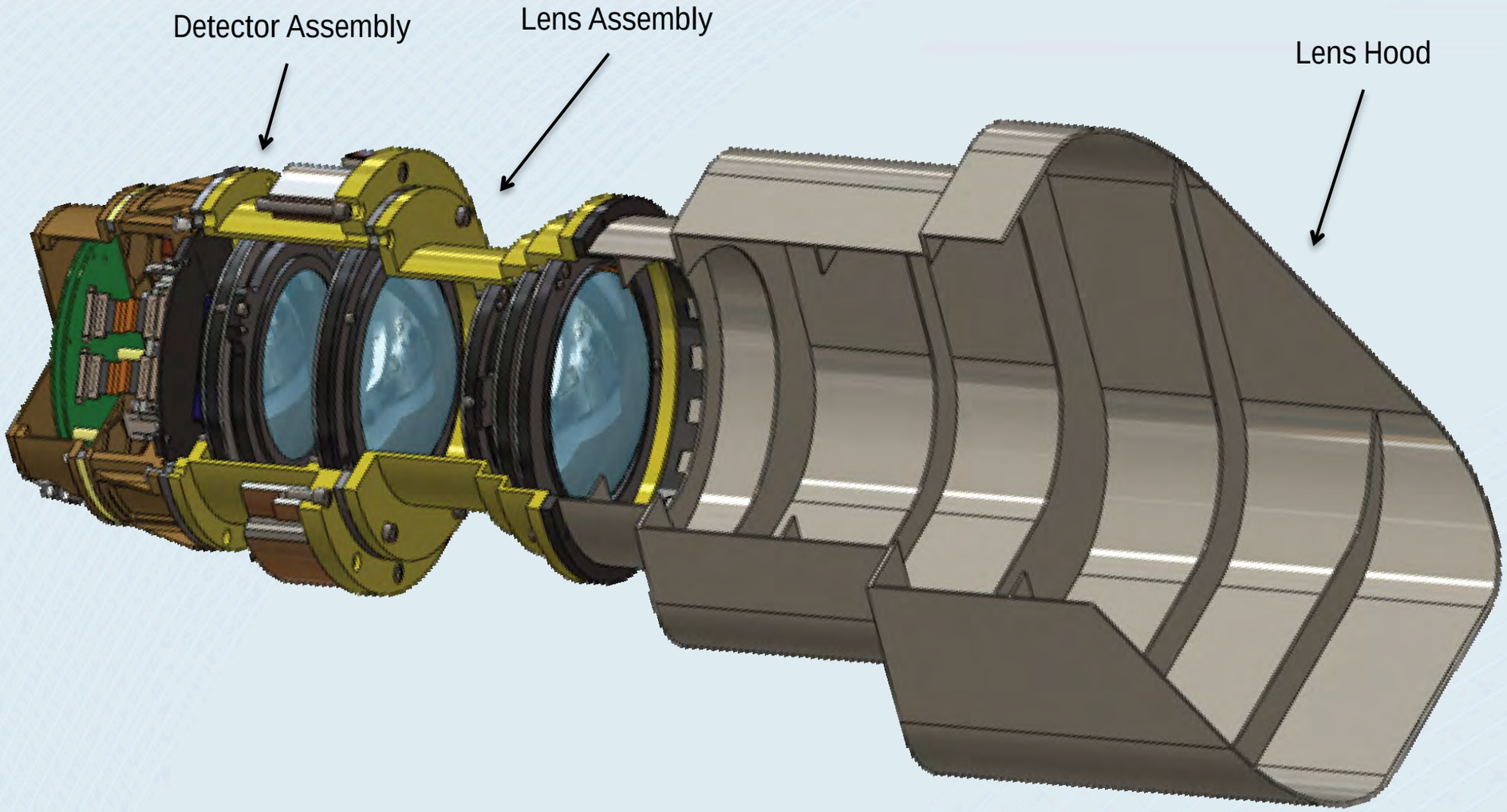
Portion of Image Stack Shown:
= 7.8 deg^2 out of 570 deg^2/camera
= 0.34% of instantaneous TESS FOV

Limiting Mag in I Band	S/N Ratio Achieved by TESS in 30 minutes	# Stars* in 40,000 deg^2
12.0	1350	≳6*10^6
13.0	600	≳12*10^6
14.0	250	≳24*10^6

*R band mean star counts from Bahcall & Soneira (1980) re-scaled to I band assuming R-I = +1.0 mag, appropriate for early M stars.

TESS Can Provide FFI’s at Kepler’s 30 Minute Cadence

TESS Wide FOV CCD Camera

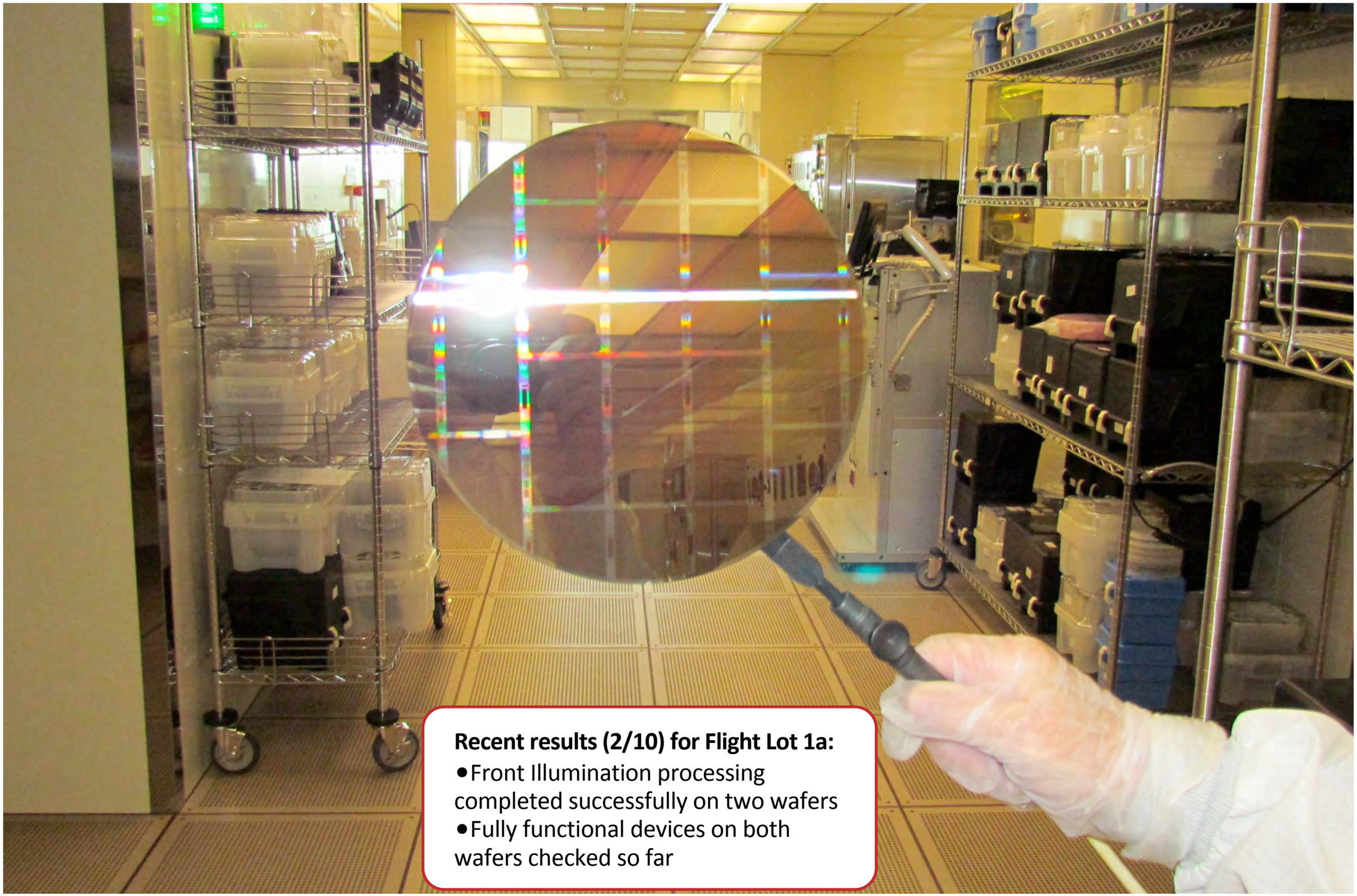


Important Parameters for Temporal Astronomy:

Timing Parameter	Value
Frame Time	2 sec
Transfer Time	0.004 sec
Baseline Cadence (>200,000 Stars)	1 min
Full Frames Cadence (>20,000,000 Stars)	30 min

Optical Parameter	Value
Entrance Pupil Diameter	105 mm
Passband	600—1000 nm
CCD Focal Plane Array (Frame Transfer Devices)	4 @ 2K x 2K pixels 15 µm/pixel
Camera FOV	24° x 24°
Number of Cameras	4 ⇒ 2304 deg^2 FOV

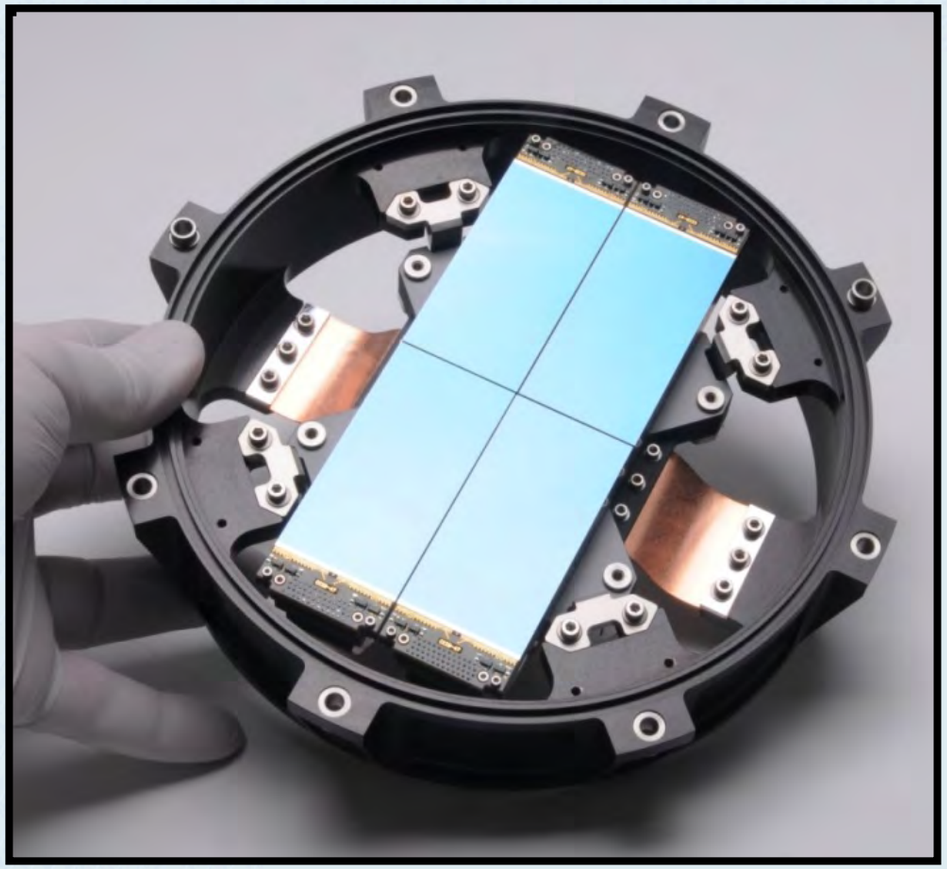
TESS Flight CCD Wafers (*in progress at MIT Lincoln Lab*)



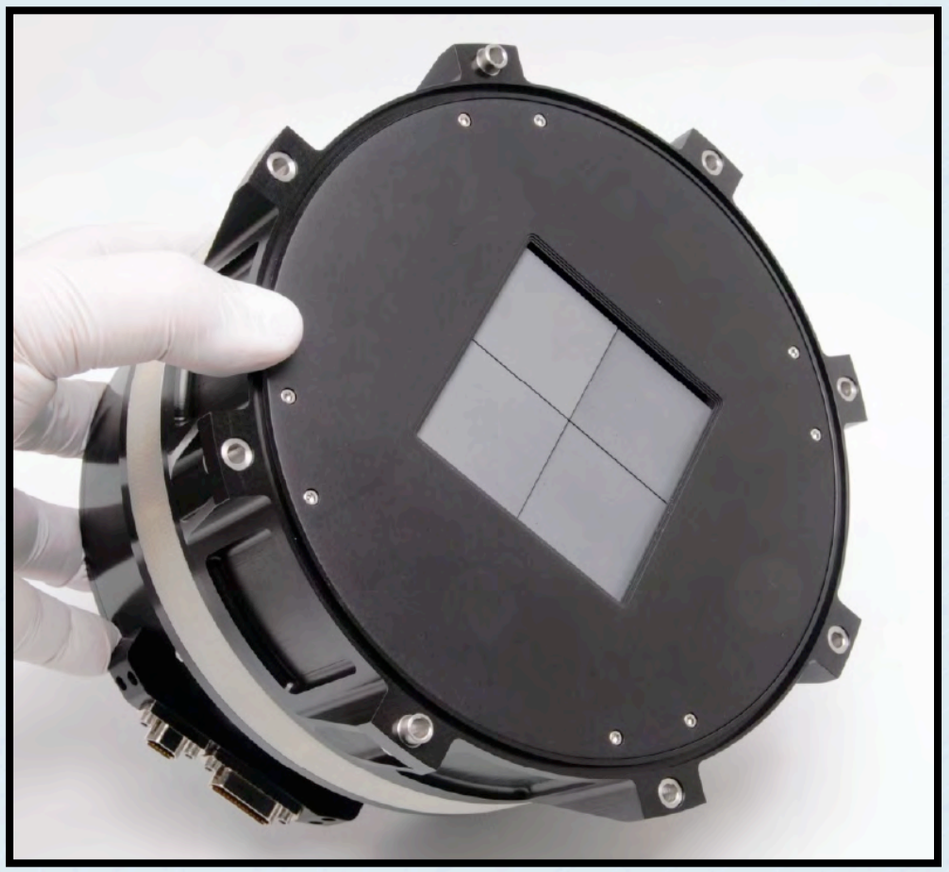
Recent results (2/10) for Flight Lot 1a:

- Front Illumination processing completed successfully on two wafers
- Fully functional devices on both wafers checked so far

TESS Prototype Focal Plane Assembly

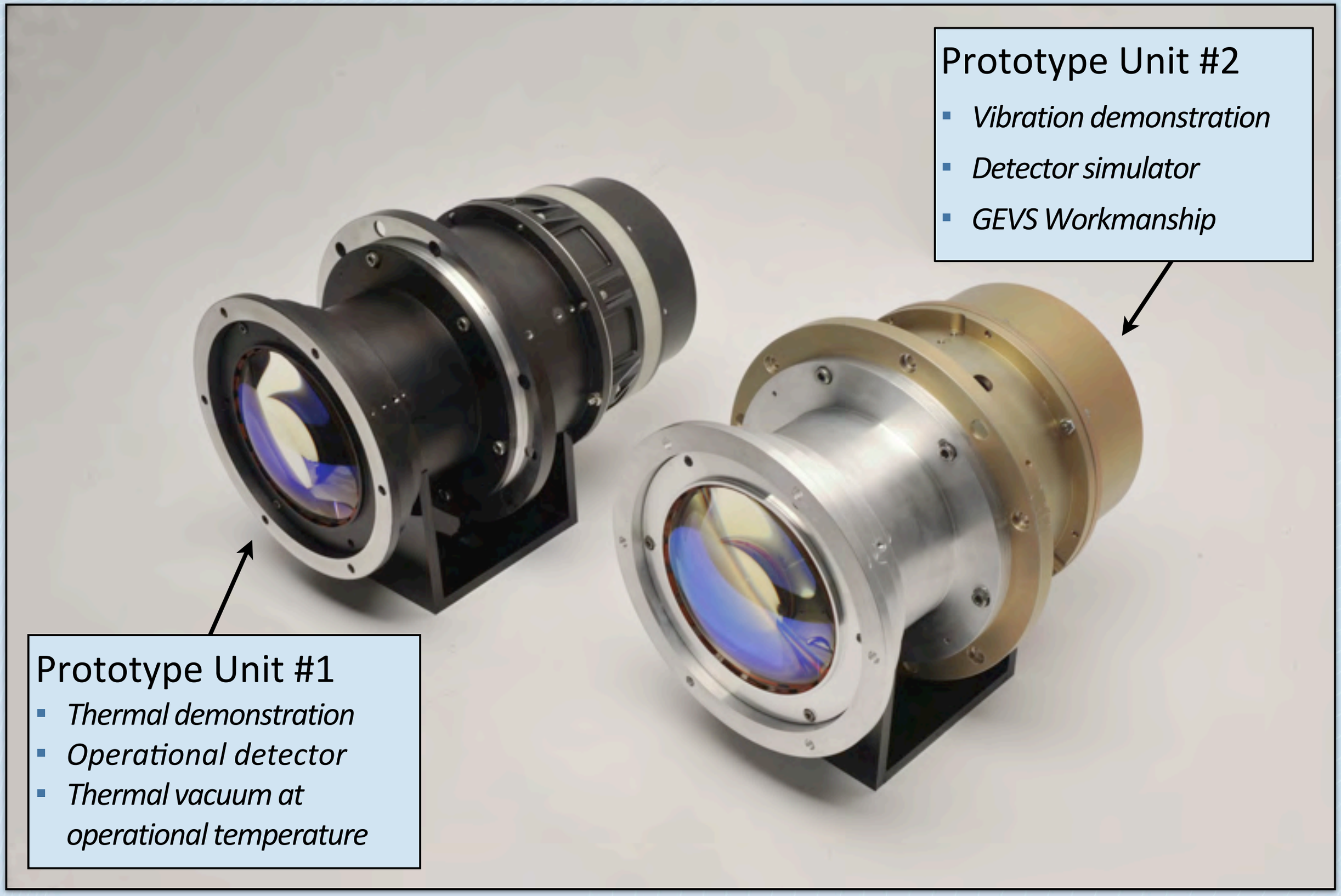


A) Array of 4 CCDs During Assembly



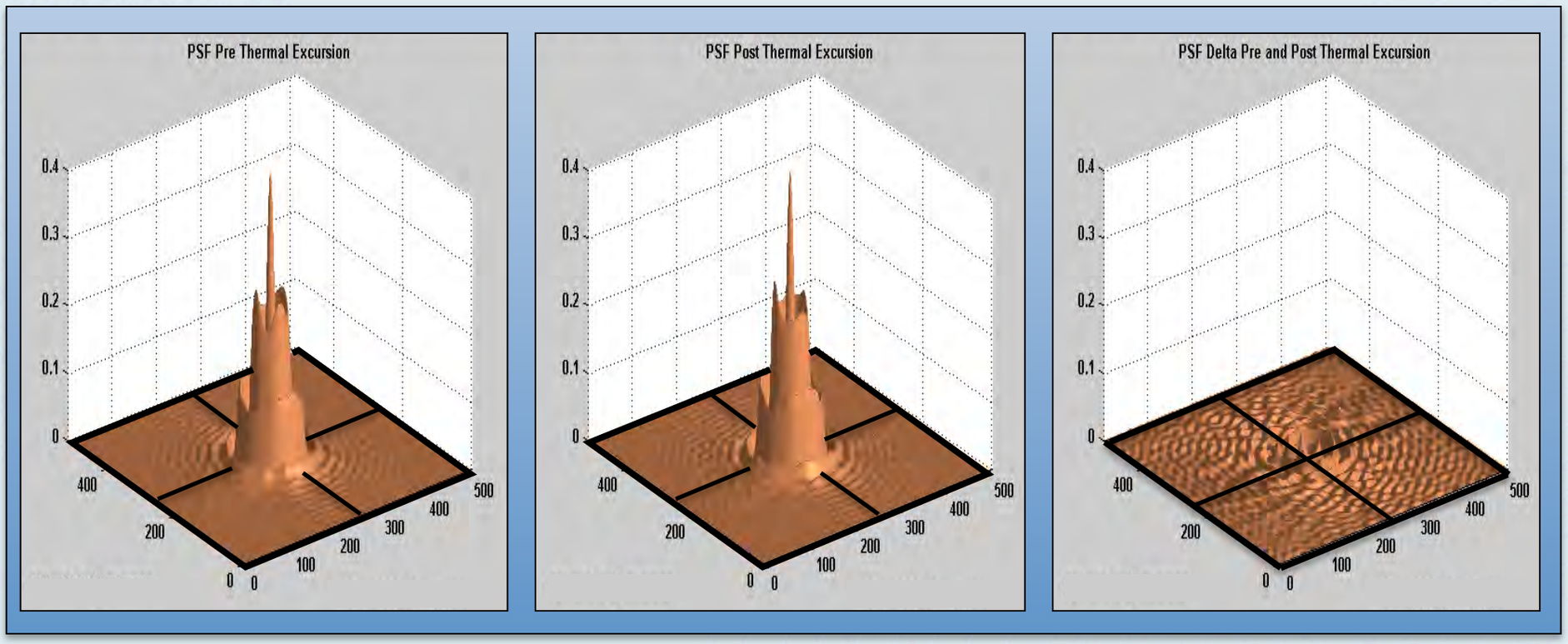
B) Completed CCD Focal Plane Array
(Frame Store Cover in Place)

TESS Prototype Cameras



Optical Alignment Stability of Prototype Cameras

- Optical properties measured interferometrically:
  - *Before and after >10 thermal cycles from ambient to -90°C*
  - *Before and after vibration at GEVS workmanship levels*
  - *No discernible difference identified after cycling*



Scales on X & Y Axes: 500 units = 30 microns

Optical Alignment is Stable Over Thermal and Vibration Cycling

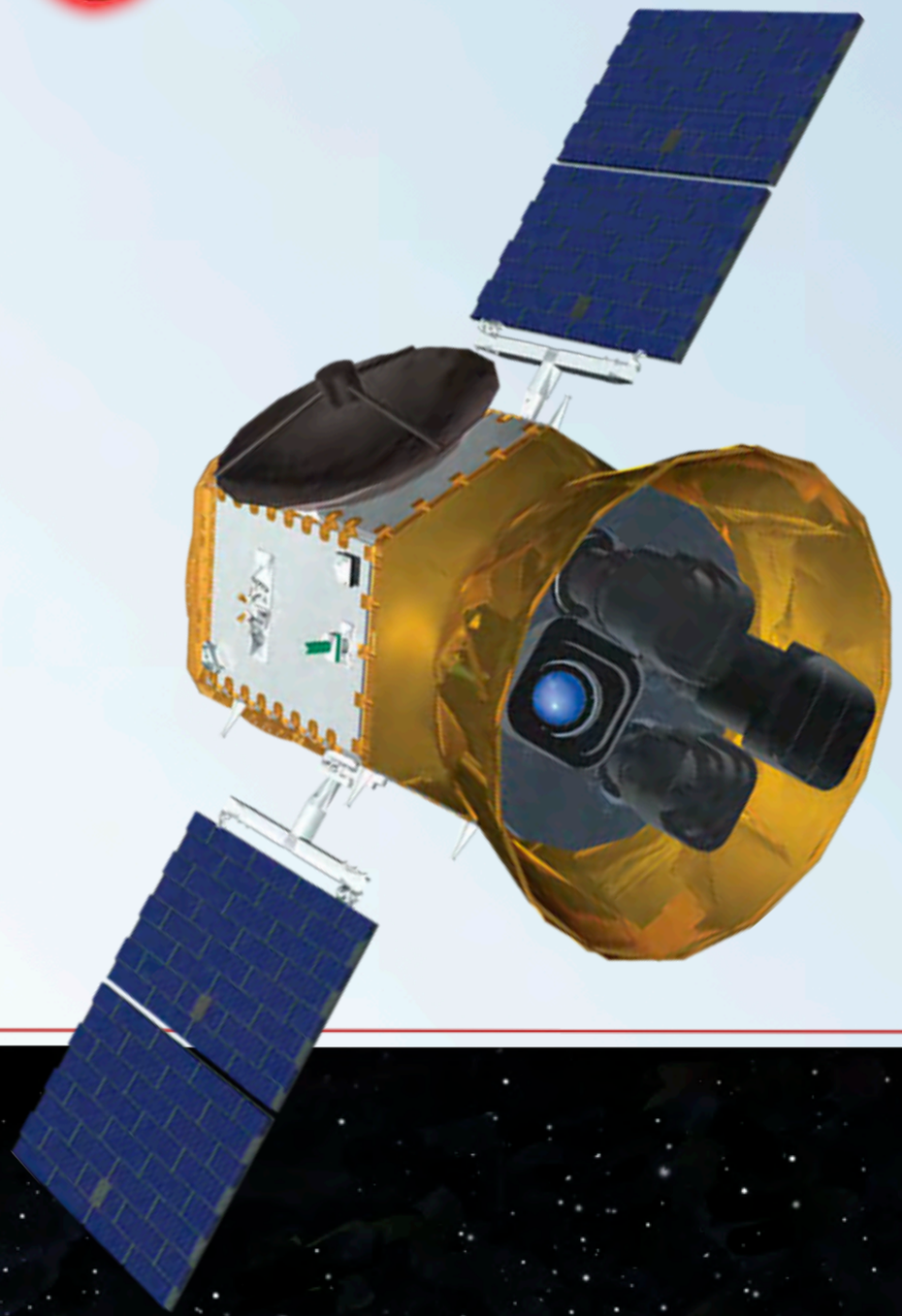
TESS Wide FOV CCD Camera Prototype

Full Size Replica of TESS

How TESS Gets Launch Ready By August 2017…

- Simple Mission Design
  - *HEO assures stable instrument operation*
    - *Anti-sun, fixed inertial pointing*
    - *Infrequent maneuvers*
  - *All cooling is passive*
  - *Solar panels are the only deployable*

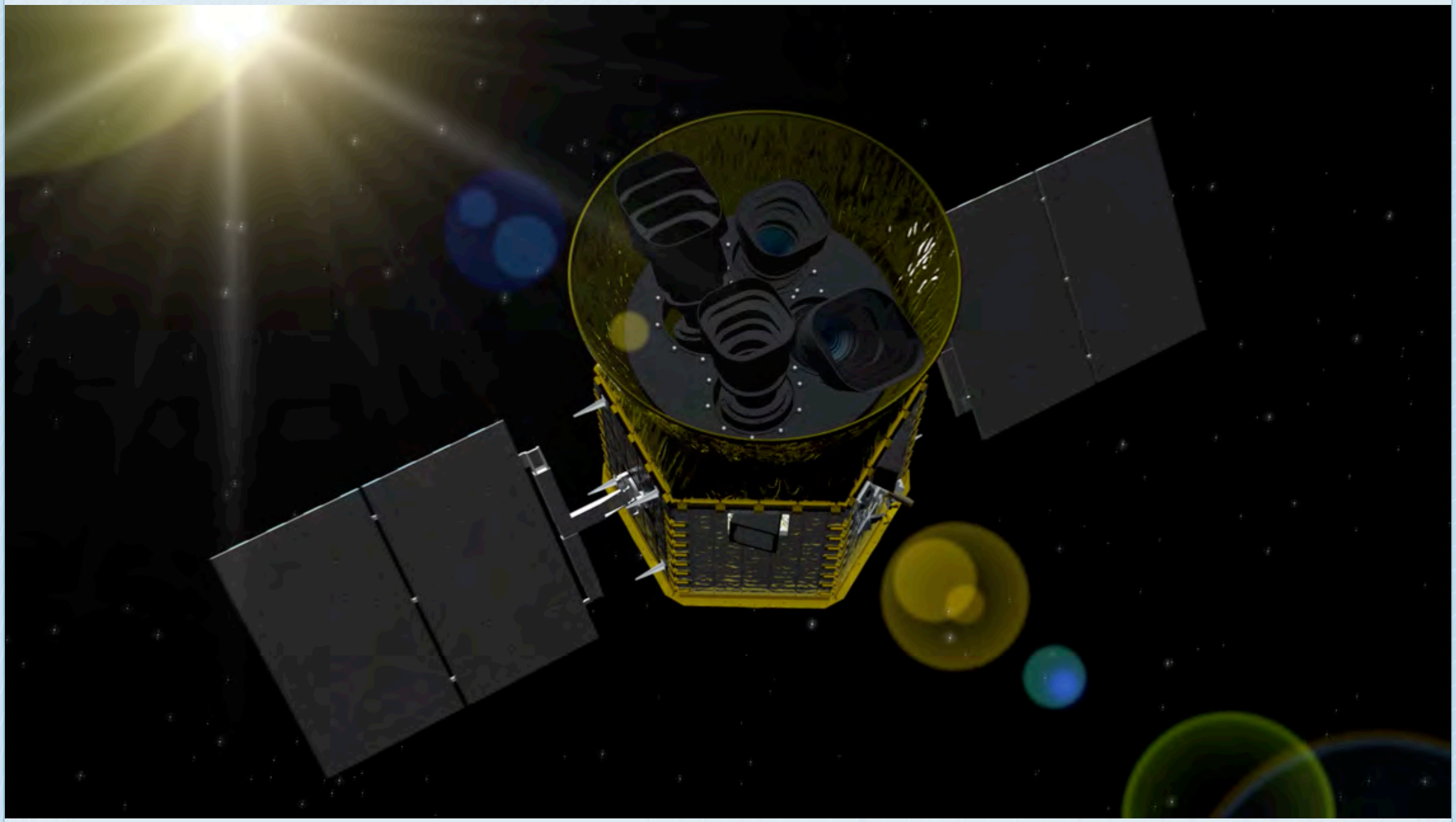
- Four Identical Cameras
  - *Modest aperture*
- Simple Payload Interface to Orbital's Heritage Bus
  - *Cameras bolt in place with no critical alignments*



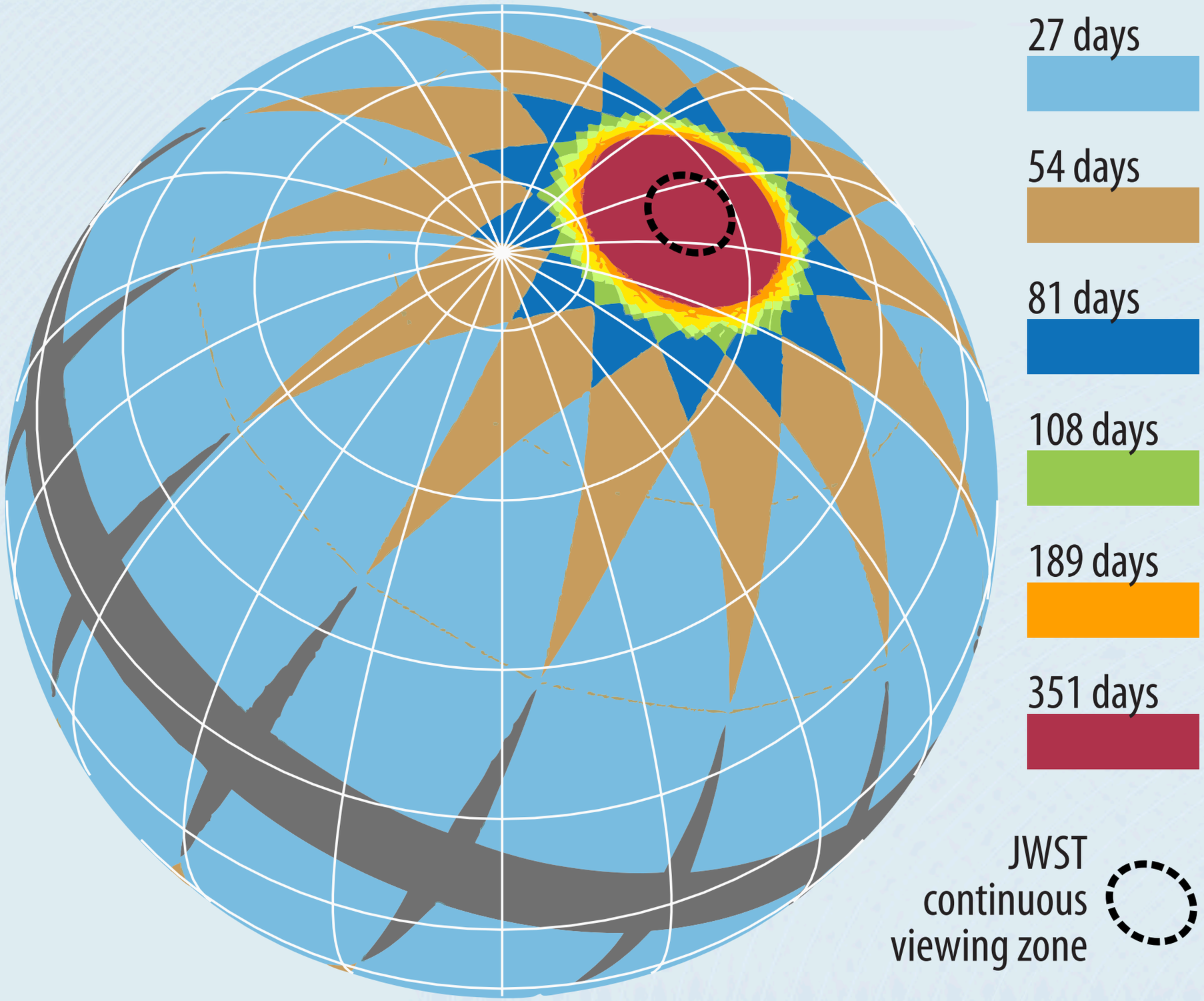
TESS Mission Videos

http://www.youtube.com/watch?v=mpViVEO-ymc

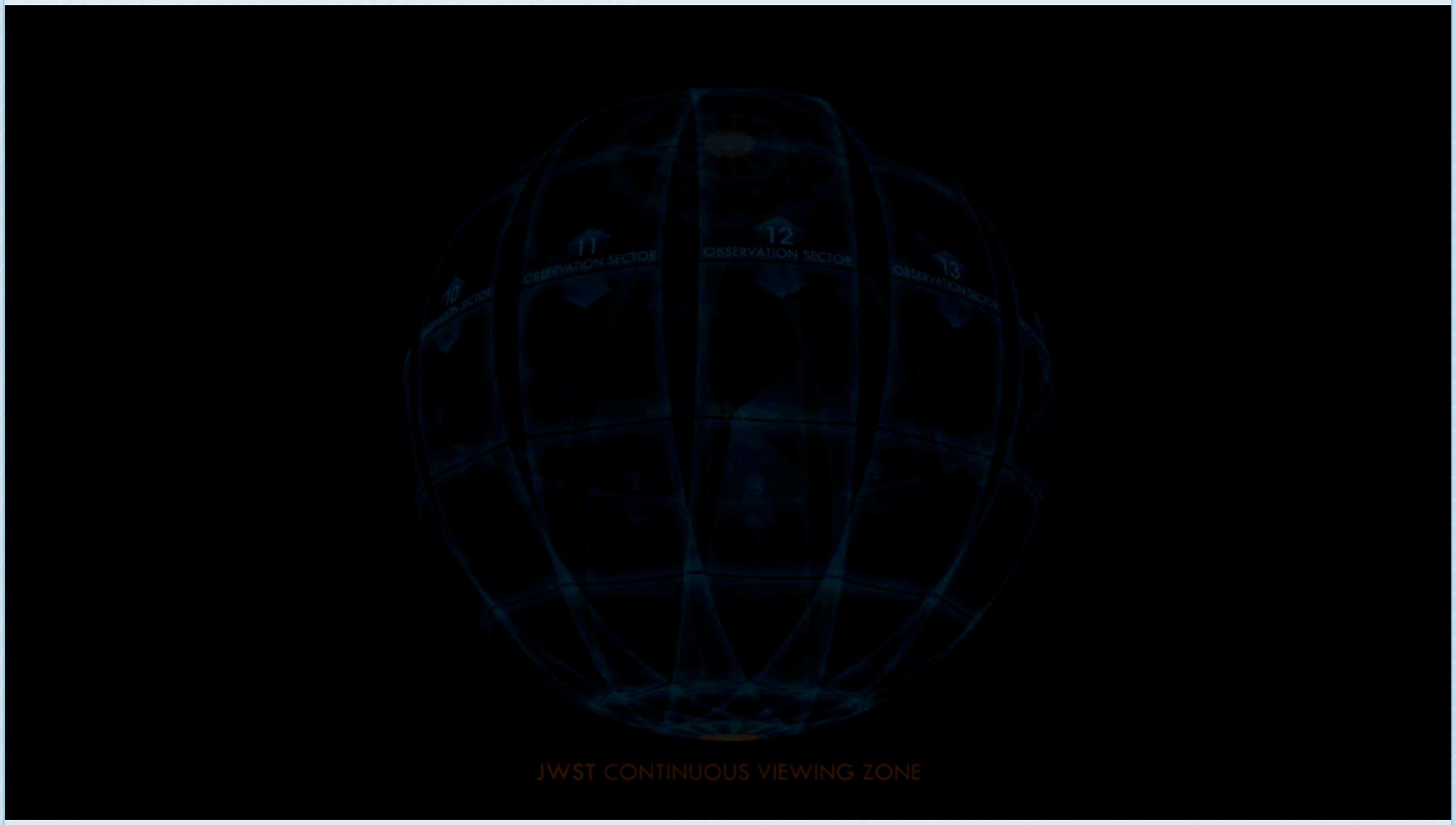
TESS Sky Mapping Strategy



TESS 2-year Sky Coverage Map



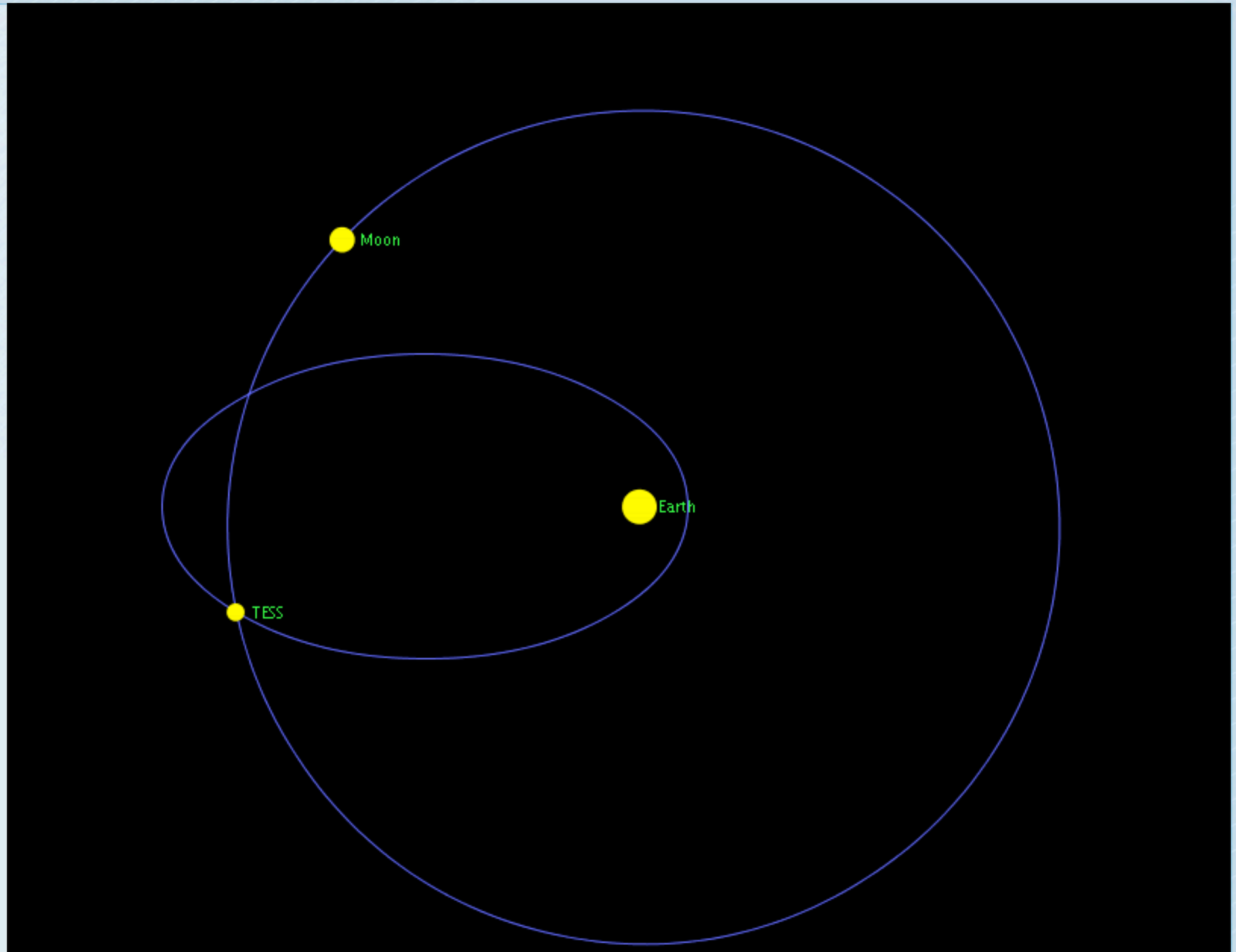
TESS Orbit Insertion



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)*

"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: *20 of 27 days per lunar month*

6) **High Data Rates:** *100 Mbit/s (200 GB in 3hr at Perigee)*

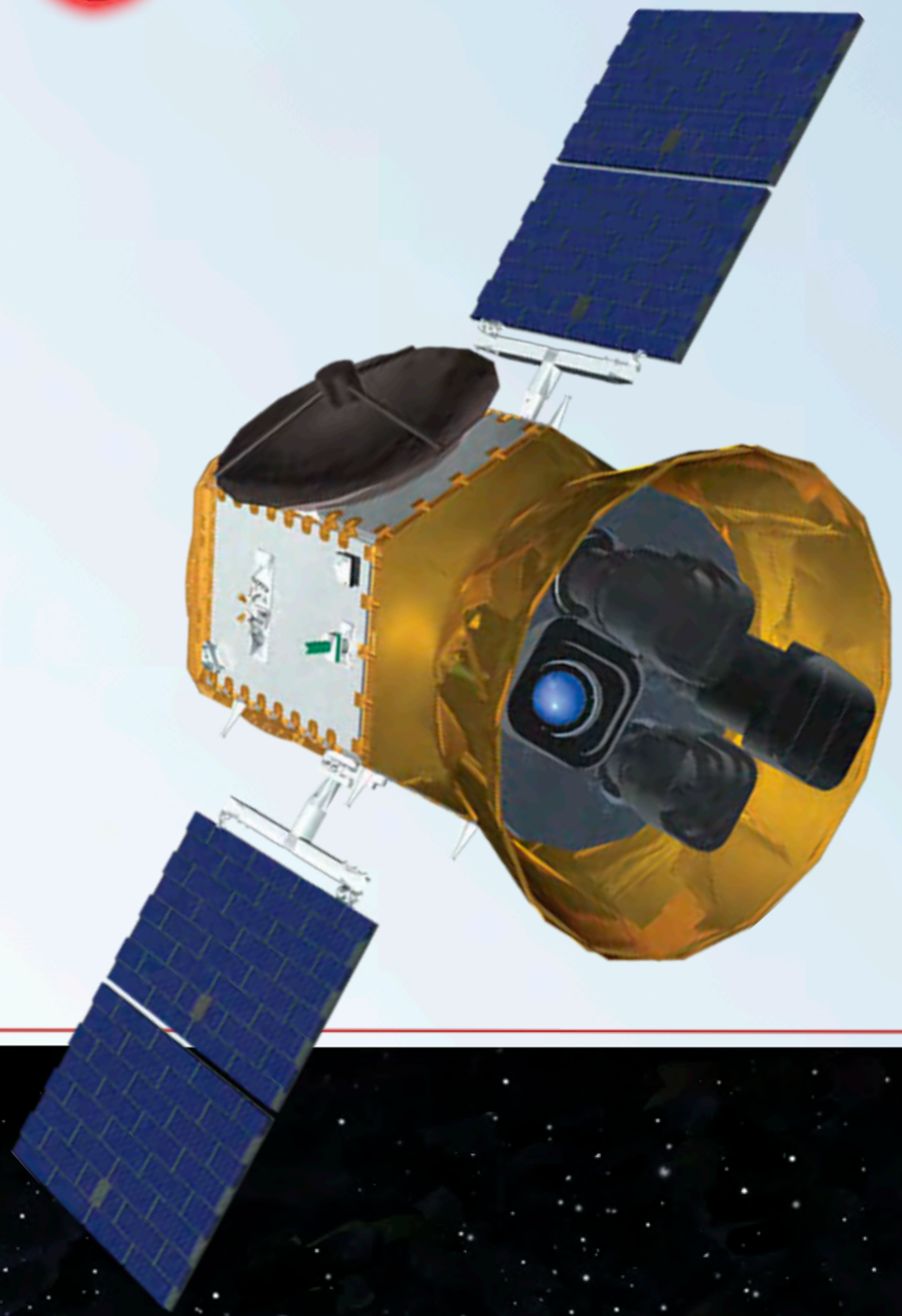
[$1/R^2$ advantage: ~200x Earth-Sun L2; ~10,000x Kepler-type Orbit]

7) Excellent Pointing Stability: *No Drag, No Gravity Gradient*

8) Simple operations: *Single 5 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)

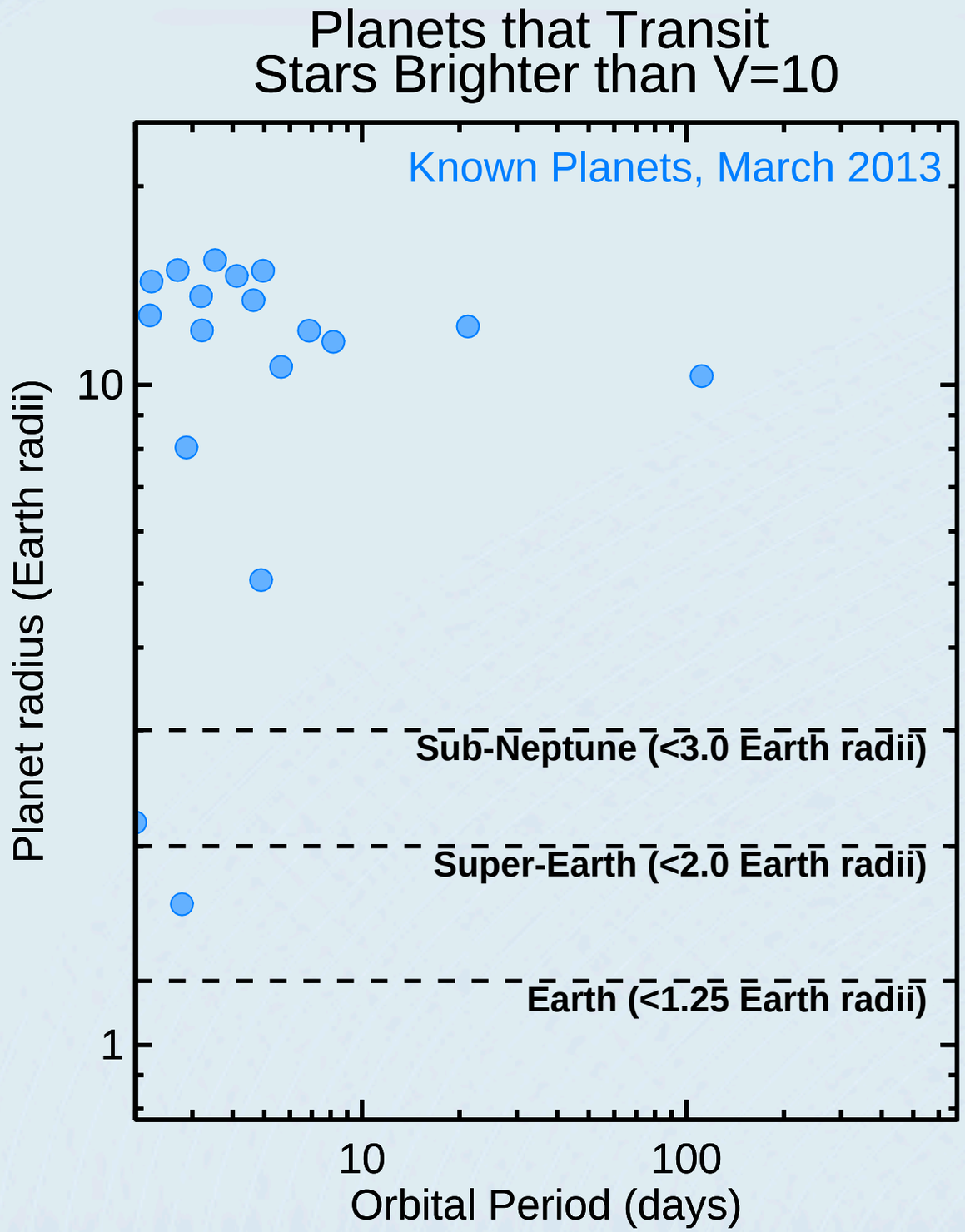


Why TESS?

Why Now?

Small Planets and Bright Stars

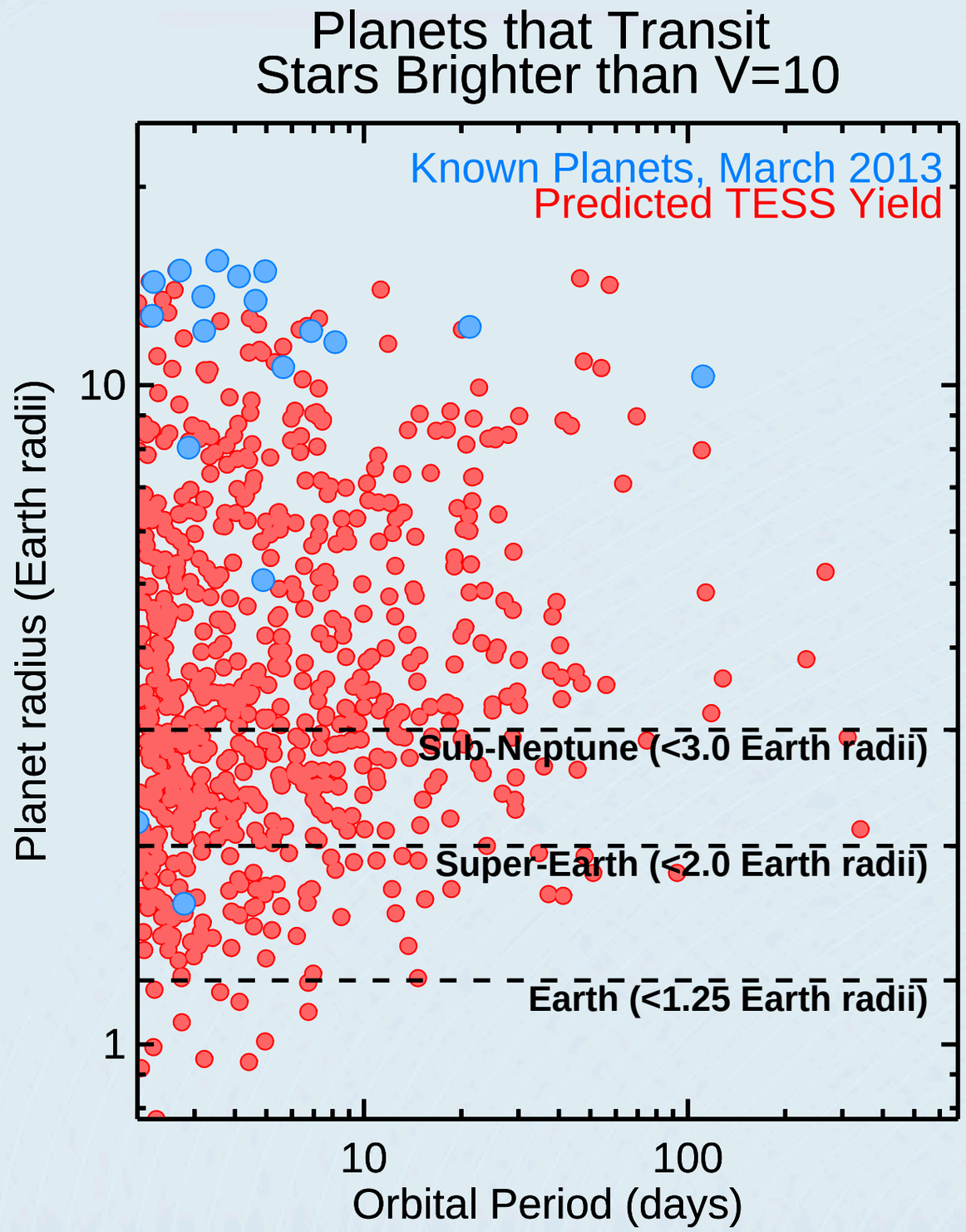
- ***Kepler:*** The most common members of the exoplanet family are Earths and Super-Earths
- Population of characterizable Earths and Super-Earths is extremely impoverished
- Two smallest transiting exoplanets with bright hosts were discovered from space:
  - *Kepler-21b: Kepler Team*
  - *55 Cnc e: MOST [Co-I Josh Winn]*



Small Planets and Bright Stars

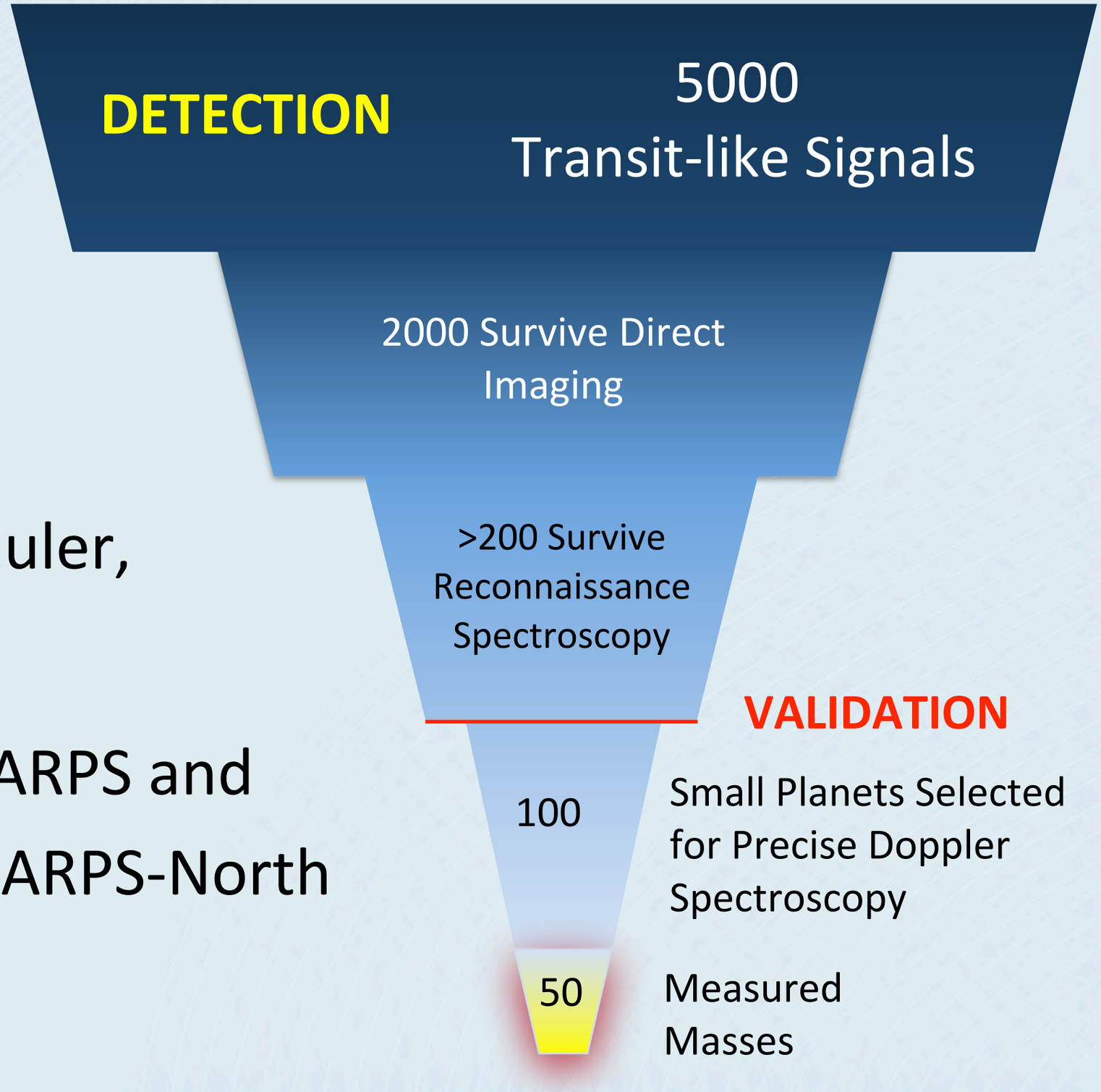
- ***Kepler:*** The most common members of the exoplanet family are Earths and Super-Earths
- Population of characterizable Earths and Super-Earths is extremely impoverished
- Two smallest transiting exoplanets with bright hosts were discovered from space:
  - *Kepler-21b: Kepler Team*
  - *55 Cnc e: MOST [Co-I Josh Winn]*

TESS Will Discover the Earths and Super-Earths Transiting the Brightest & Nearest Stars

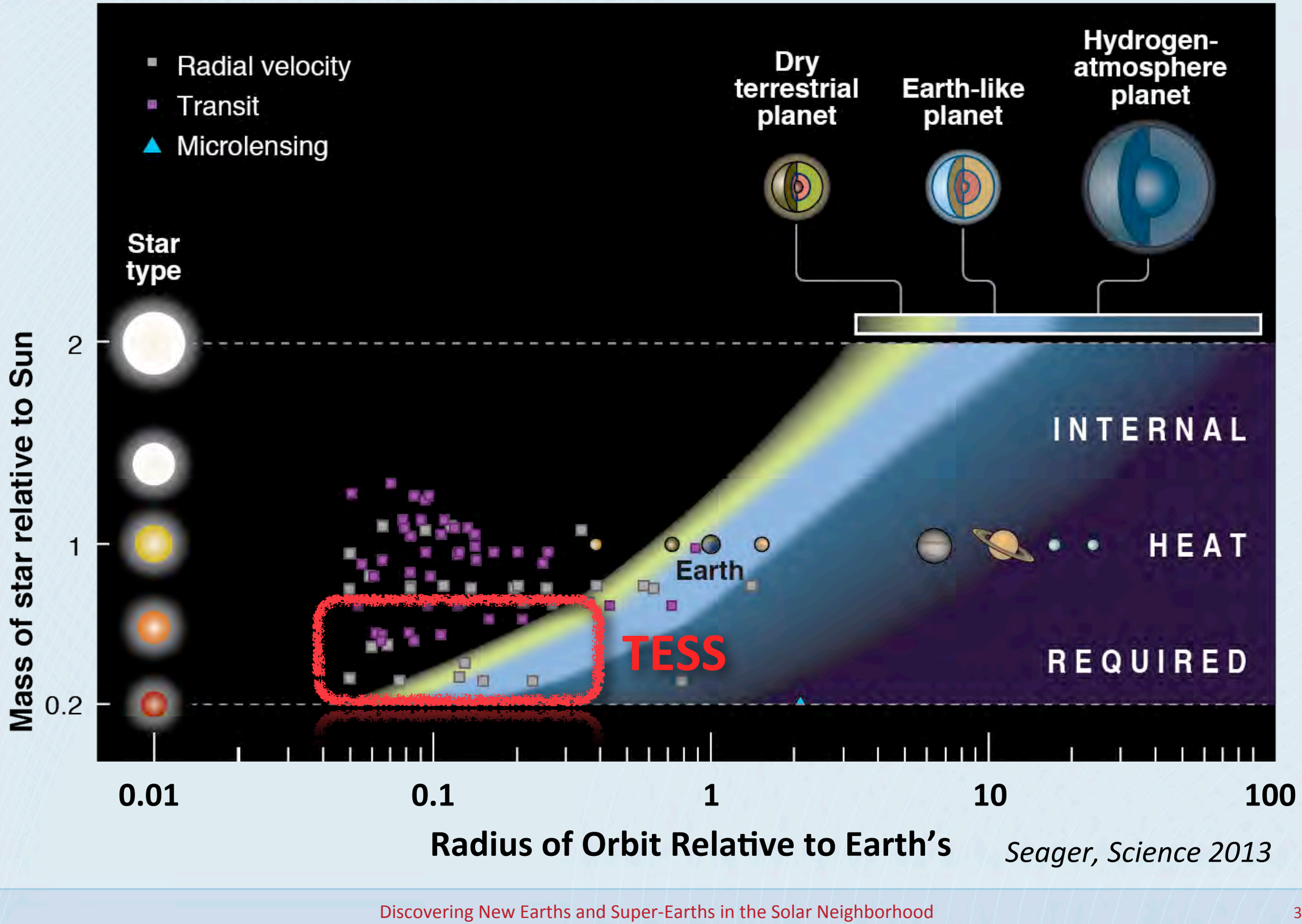


Small Planet Validation and Mass Measurements

- TESS spacecraft data
  - LCOGT, MEarth, Euler telescopes
    - LCOGT, Euler, OHP
      - HARPS and HARPS-North

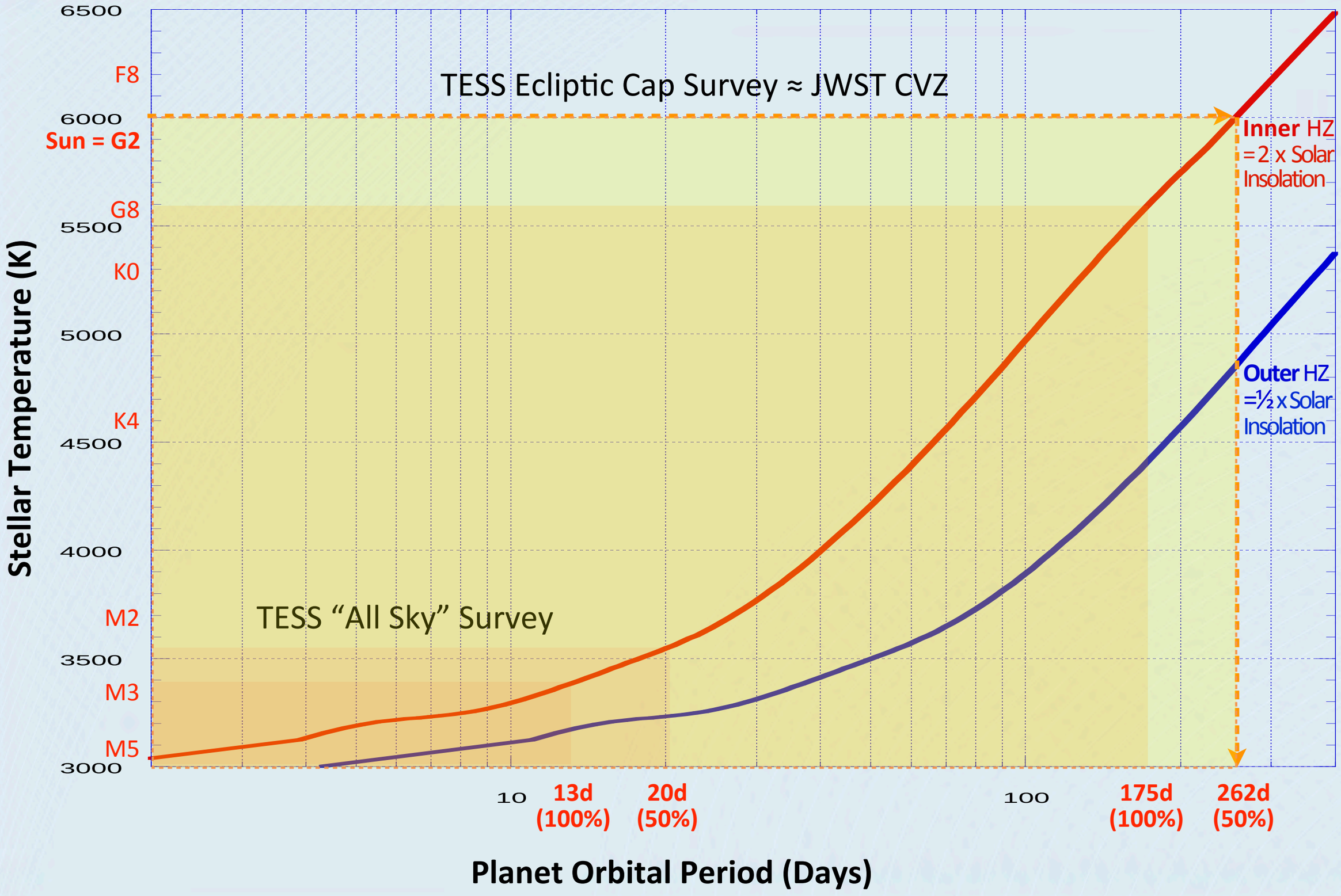


TESS and the Habitable Zone



Seager, Science 2013

Stellar Habitable Zones Accessible to TESS



TESS: A Bridge to the Future…