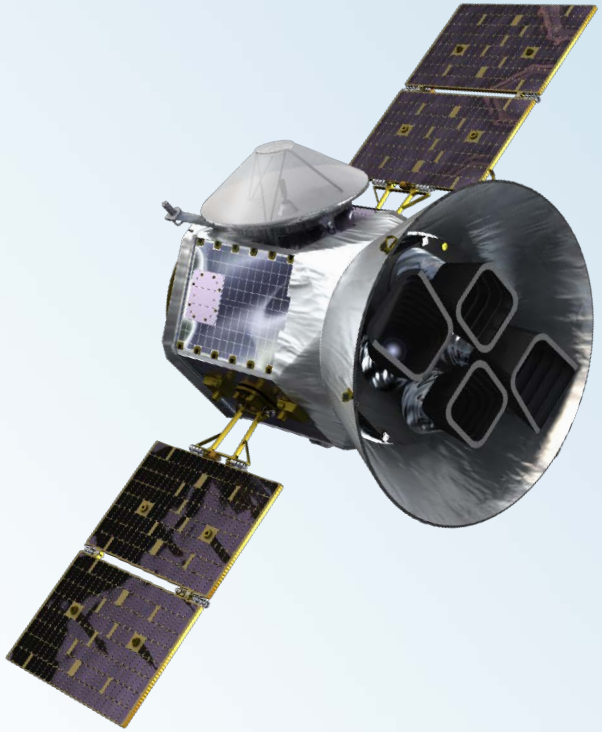
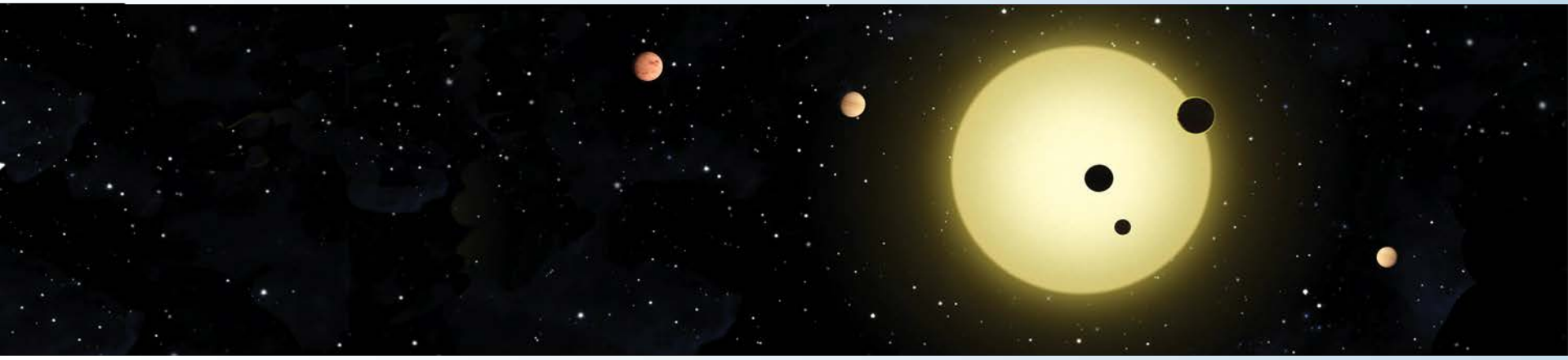
Transiting Exoplanet Survey Satellite

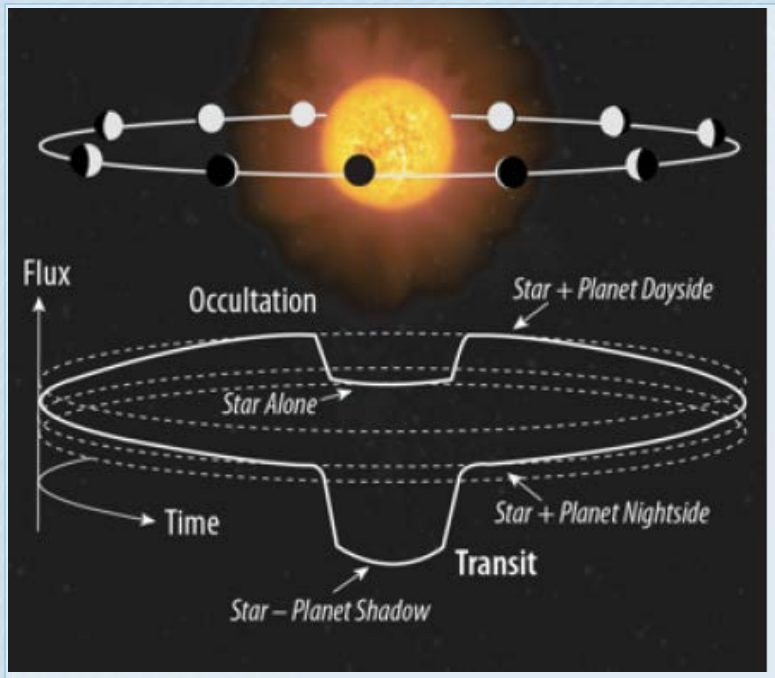


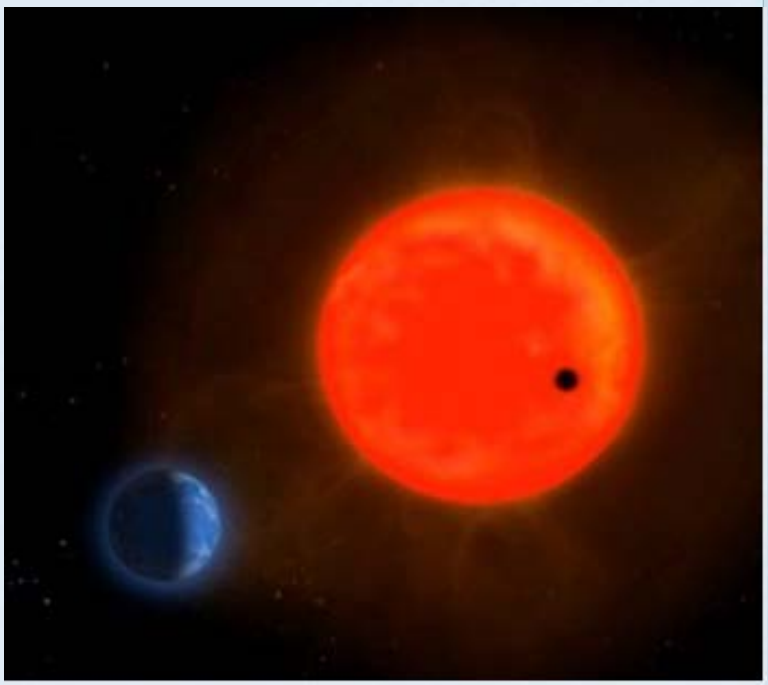
The TESS Mission

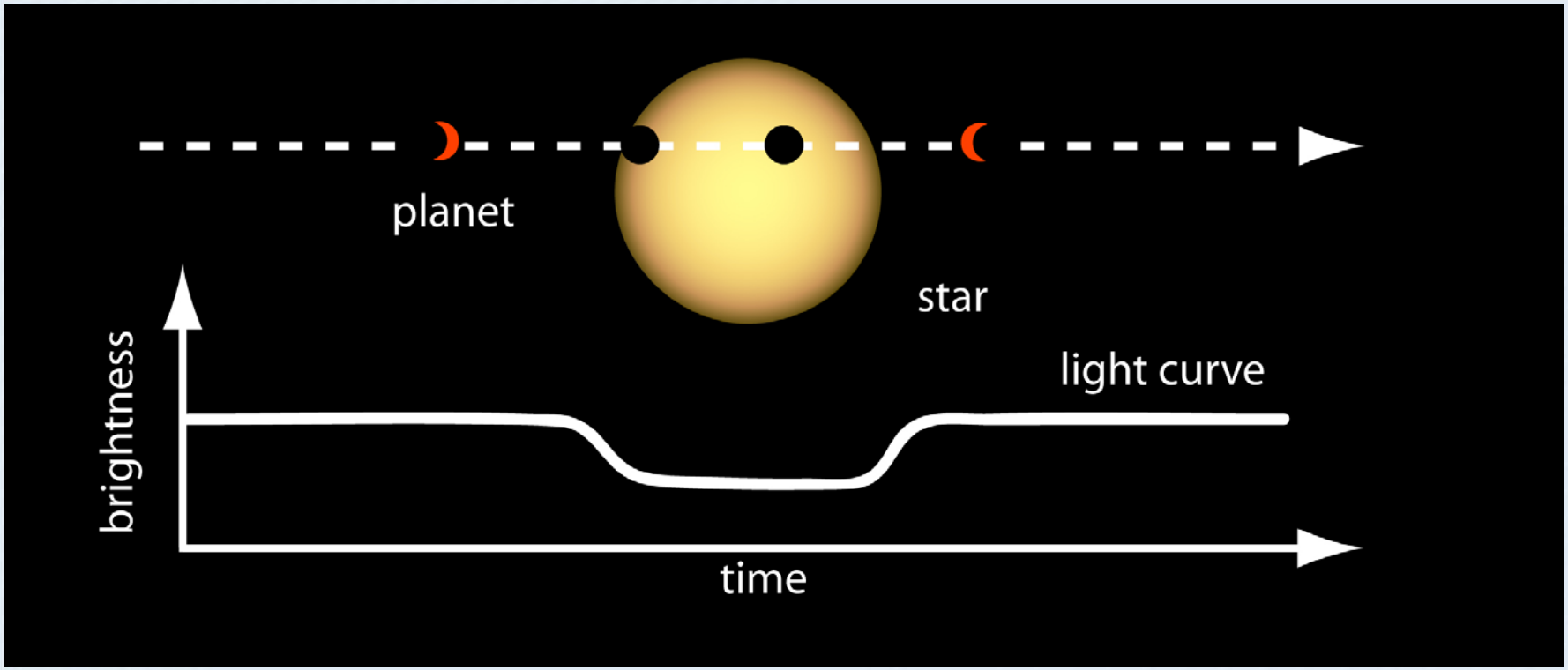
Shane Hynes
Mission Systems Engineer
9/14/2017
Shane.Hynes@nasa.gov 301-286-1016

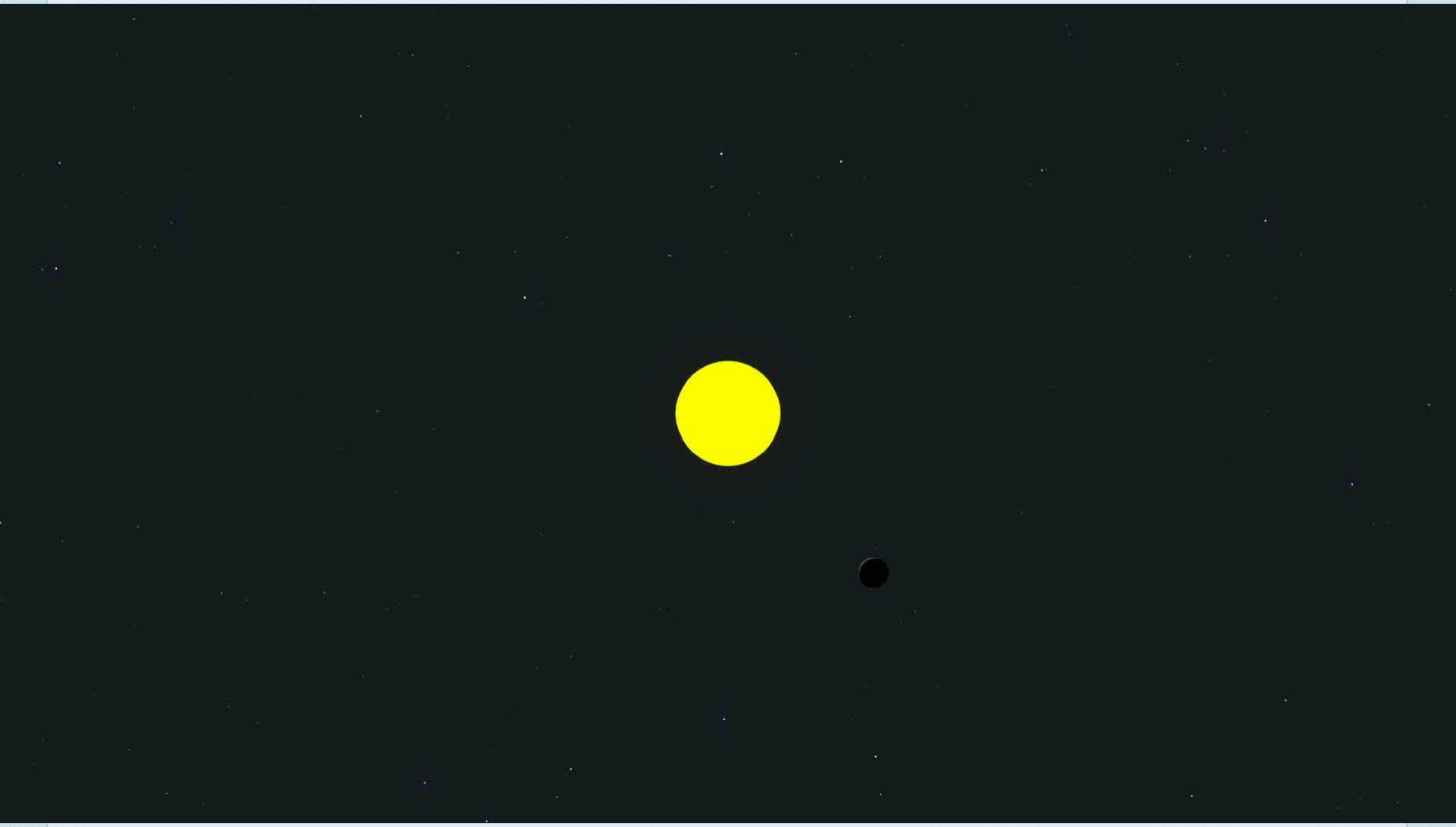


Massachusetts Institute of Technology	George Ricker Principal Investigator Camera calibration & Focal Plane Electronics
MIT Lincoln laboratory	Optics, CCDs, and Instrument mechanical design
NASA/Goddard	Project Management, Systems Engineering, Safety & Quality
Orbital ATK	Spacecraft, integration & Mission Operations
NASA/Ames	Science data processing
Space Telescope Science Institute	Data archiving & data interface to users
Harvard-Smithsonian Astrophysical Observatory	Target selection

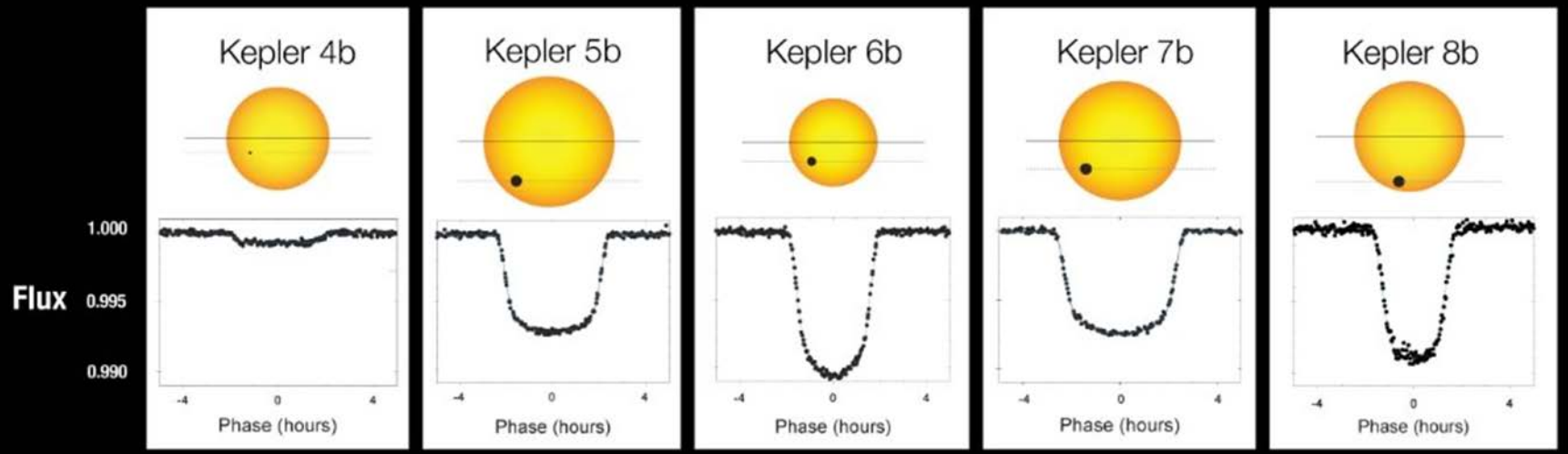

Flux
Occultation
Star + Planet Dayside
Star Alone
Time
Star + Planet Nightside
Transit
Star – Planet Shadow




planet
star
light curve
brightness
time

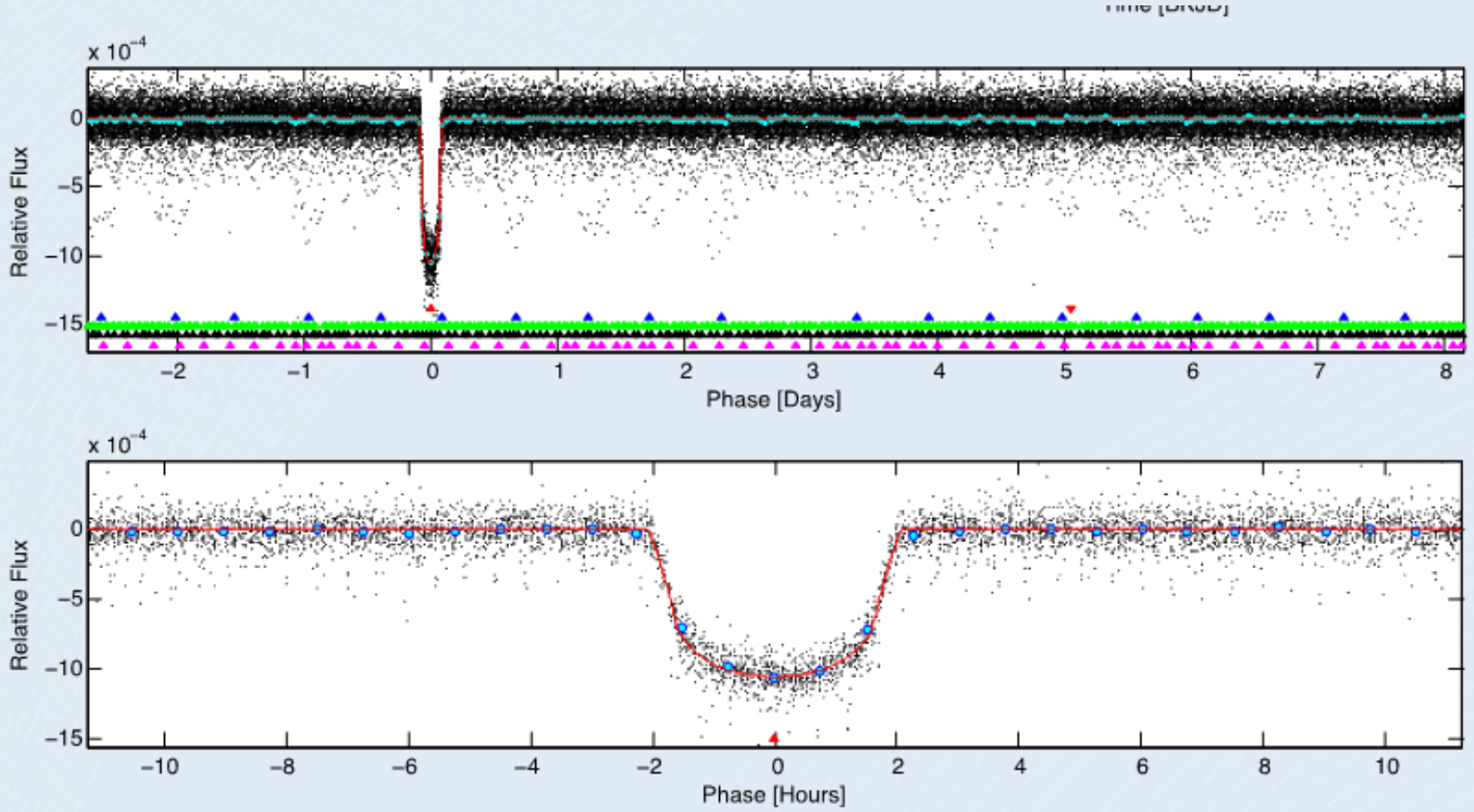


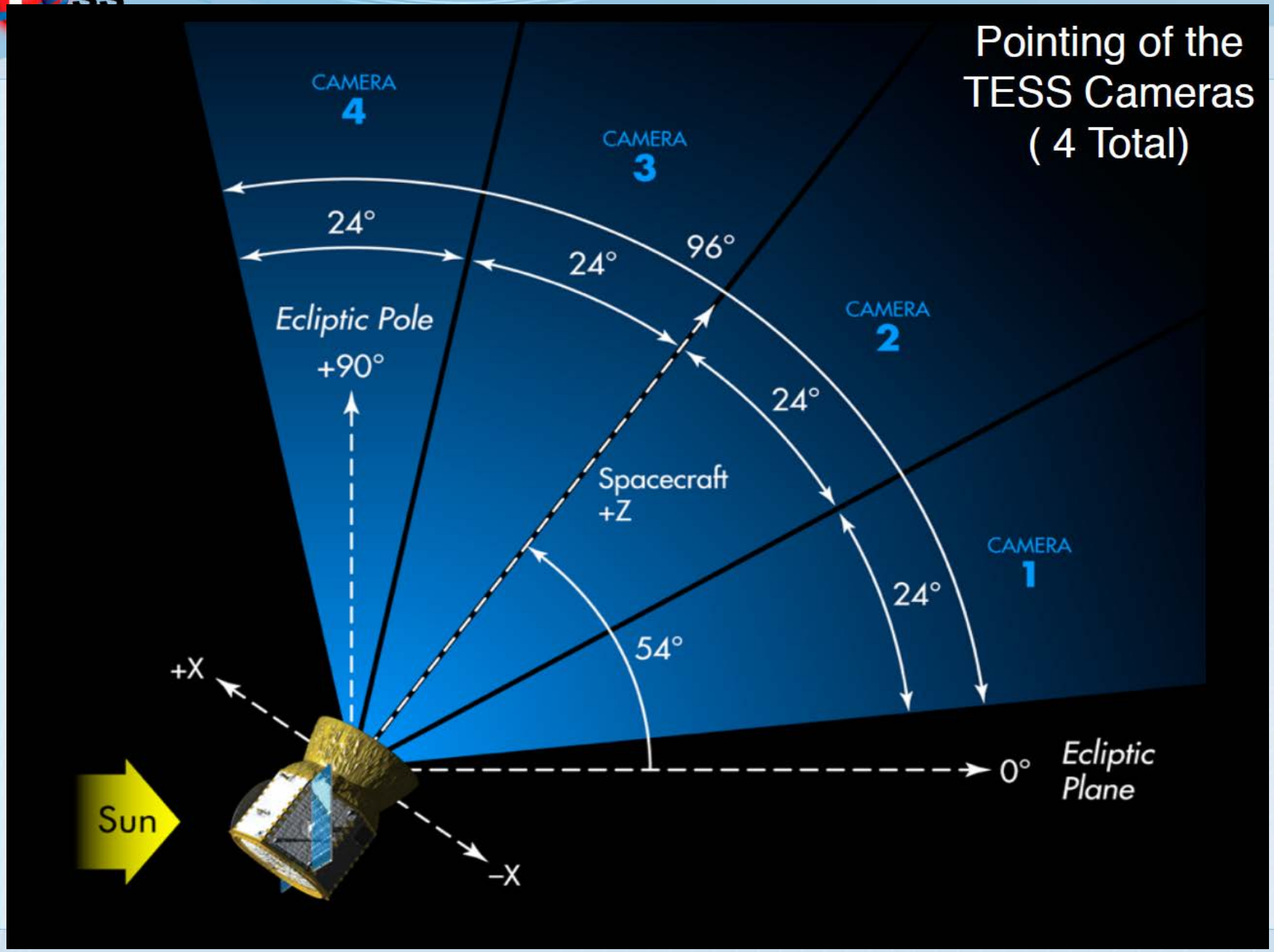
Transit Light Curves

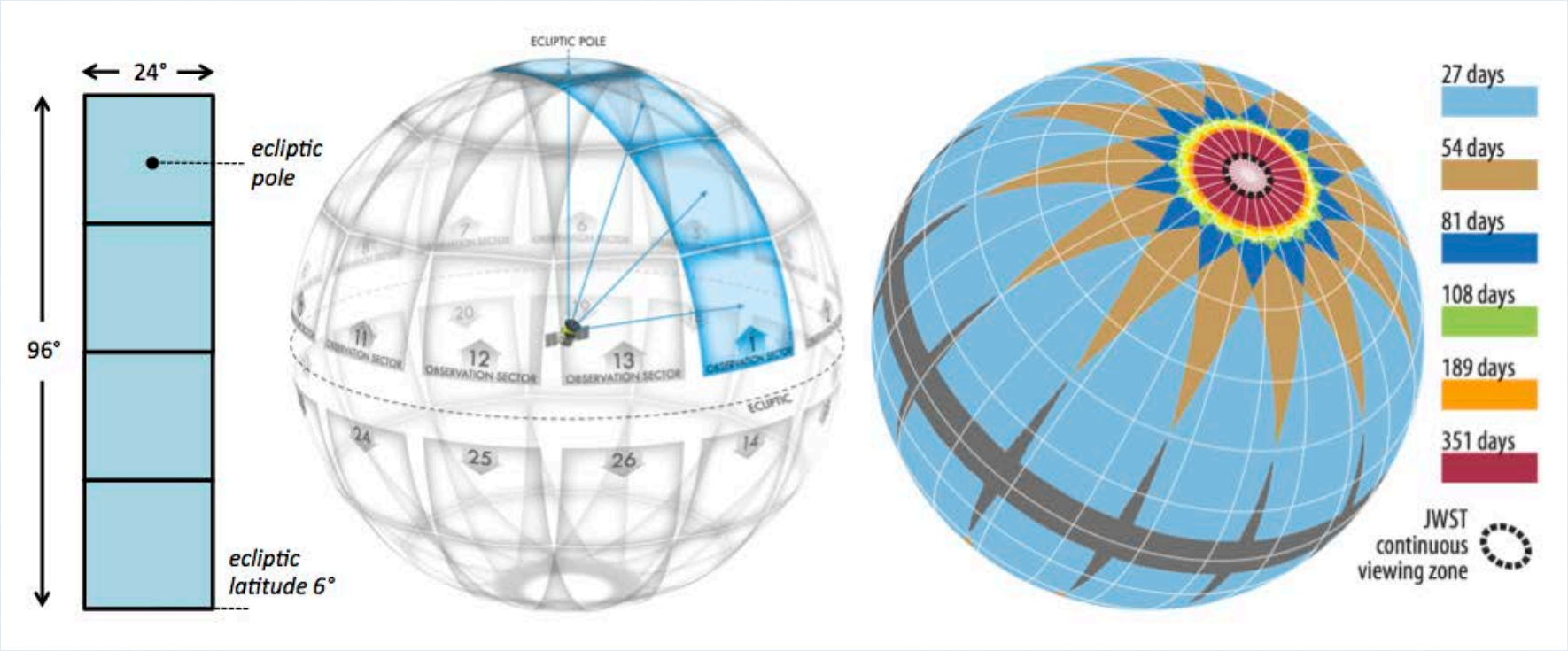


Orbital Period (days)	3.2 days	3.5 days	3.2 days	4.9 days	3.5 days

Light Curve from Kepler

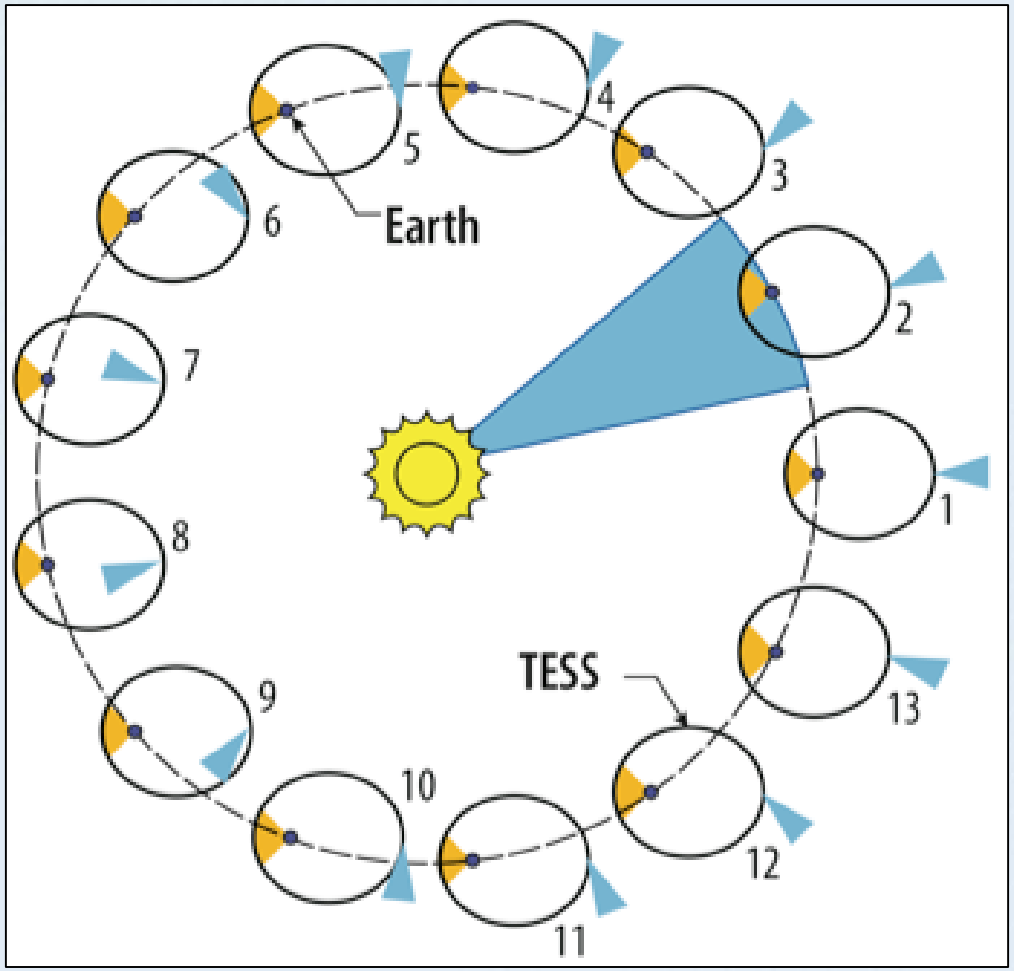



Pointing of the TESS Cameras (4 Total)
CAMERA 4
CAMERA 3
CAMERA 2
CAMERA 1
24°
24°
96°
24°
24°
24°
54°
Ecliptic Pole
+90°
Spacecraft +Z
+X
-X
Sun
0°
Ecliptic Plane



- Each sector lasts a lunar month (~28 days)
- Northern hemisphere in one year, Southern Hemisphere the next

Orbit Segments through the year

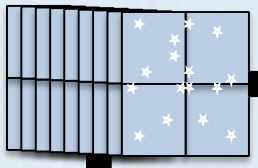


Blue segments are camera field of view
Yellow segments are downlink opportunities

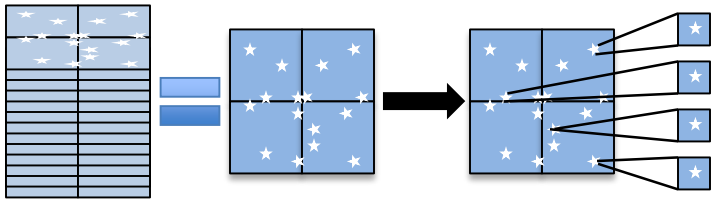
Not to scale!

Instrument Data Flow

Continuous stream of 2-second full-frame images



Postage Stamps



Images are summed in groups of 60 into 120-second stacks

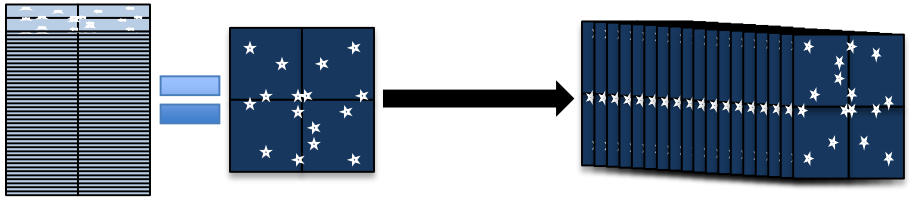
Postage Stamps are extracted near target stars

10,000 Postage Stamps around 15k stars per orbit

Compression

Recorder

Full-Frame Images (FFIs)



Images are summed in groups of 900 into 30-minute FFIs

One orbit produces >600 30-minute FFIs from each camera

Compression

Recorder

Fine-Attitude Quaternions

Photometric centroids are calculated for 200 guide stars from each integration from each camera

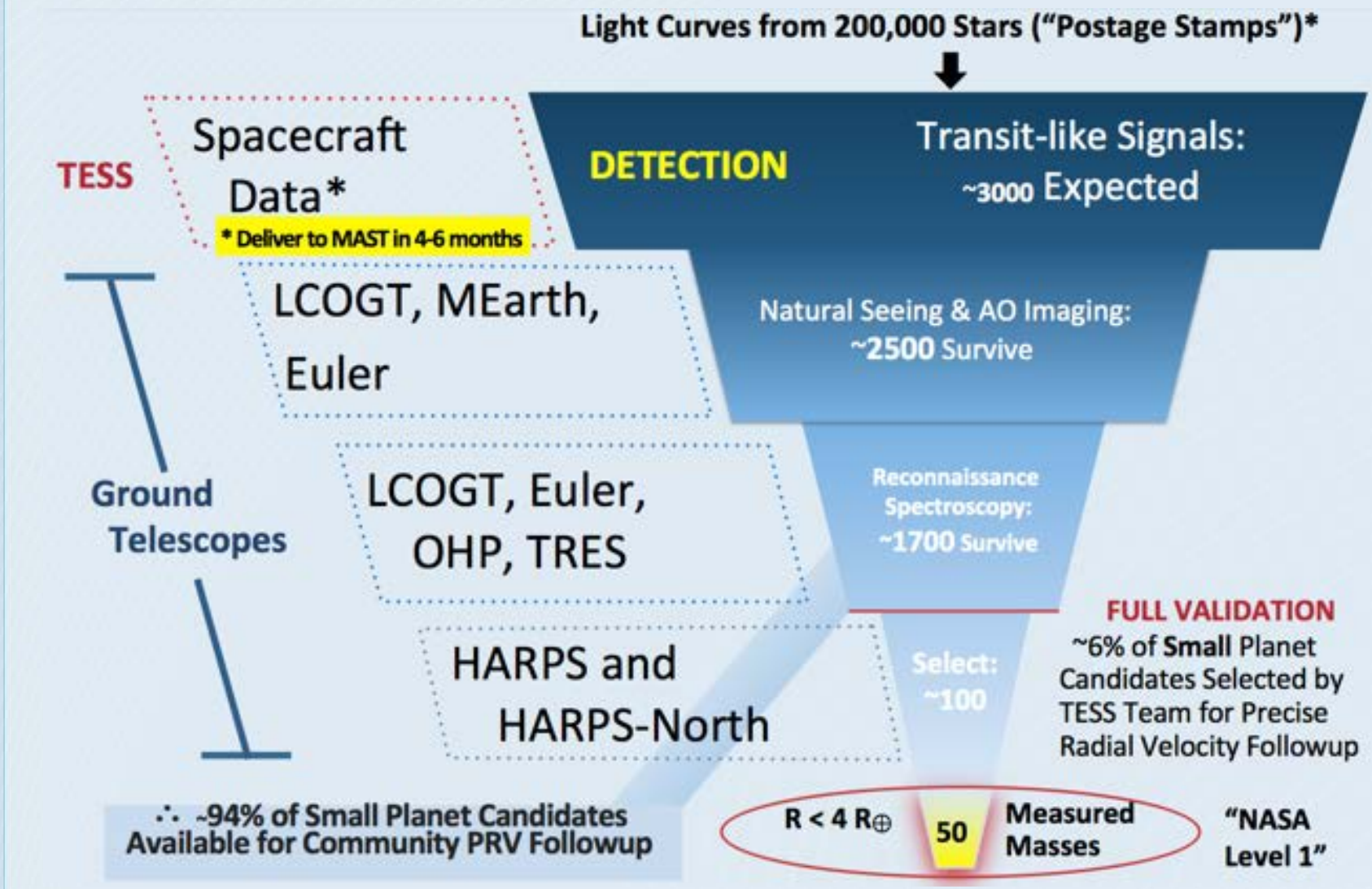
Offset quaternion is calculated

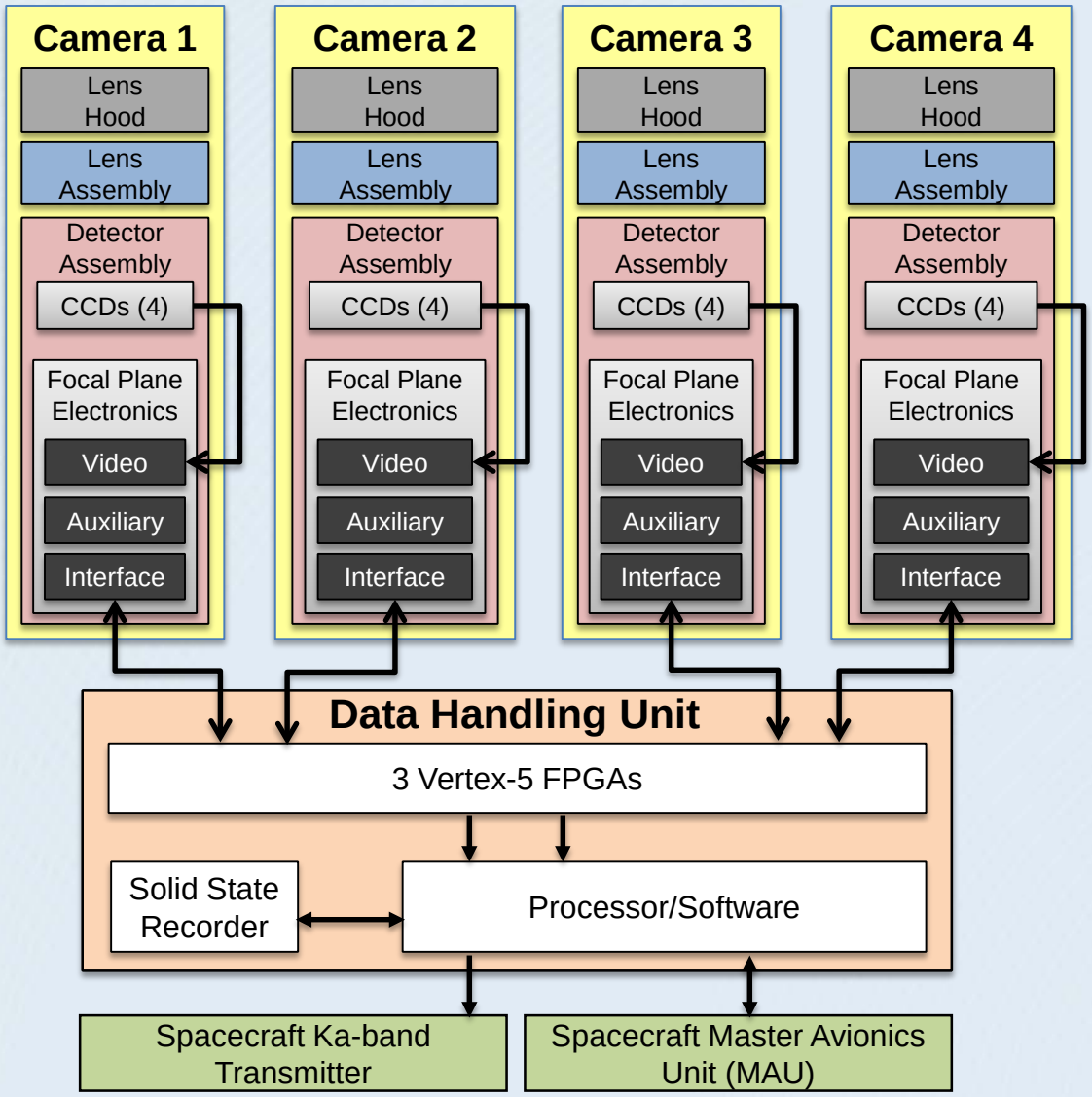
Quaternion sent to ACS

Spacecraft

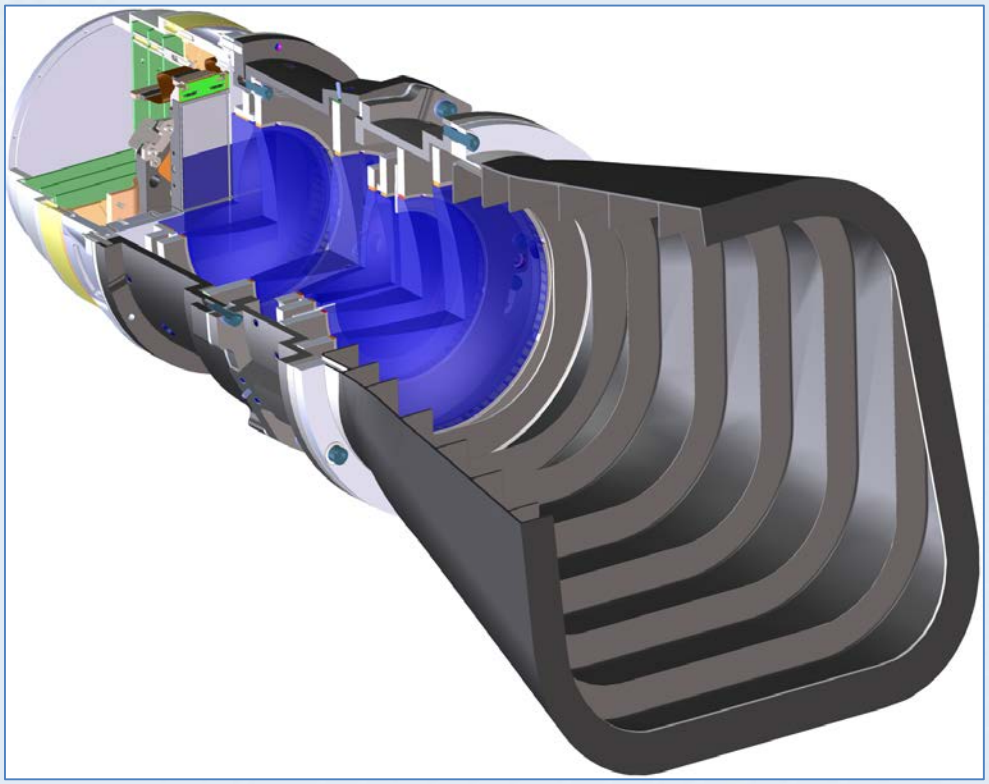
Level 1 requirements from HQ

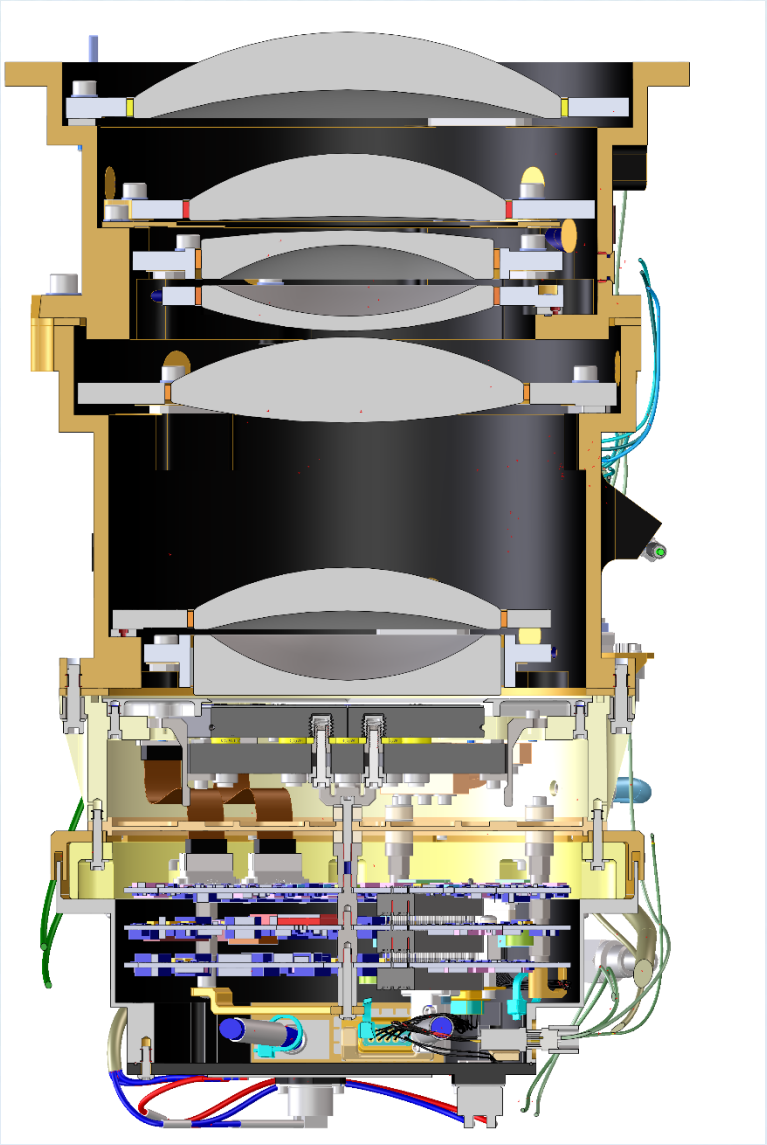
Objective	Baseline Science Requirement
Objective 1: *Identify a diverse sample of transiting exoplanets with radii less than 2.5 Earth radius and orbital periods of up to 10 days orbiting the brightest stars in the solar neighborhood*	**BSR1:** TESS shall perform a wide-field sky survey sensitive to transiting planets with orbital periods of less than 10 days. • TESS shall monitor >200,000 stars spread over the celestial sphere with radius > 2.5 Earth radius
Objective 2: *Identify a sample of transiting exoplanets with radii less than 2.5 Earth radius and orbital periods 120 days or more orbiting bright stars situated near the ecliptic poles, locations that are optimal for JWST followup*	**BSR2:** TESS shall perform a concurrent sky survey sensitive to transiting planets with periods of less than 120 days. • TESS shall monitor >10,000 stars in regions centered on the ecliptic poles with radius > 2.5 Earth radius
Objective 3: *Establish the masses of a sample of TESS-located transiting exoplanets with sizes less than 4 Earth radius by means of precise radial velocity measurements*	**BSR3:** The TESS team shall assure that the masses of 50 planet with radius less than 4 Earth radius are determined.


Light Curves from 200,000 Stars ("Postage Stamps")*
TESS
Spacecraft Data*
* Deliver to MAST in 4-6 months
DETECTION
Transit-like Signals:
~3000 Expected
LCOGT, MEarth, Euler
Natural Seeing & AO Imaging:
~2500 Survive
Ground Telescopes
LCOGT, Euler, OHP, TRES
Reconnaissance Spectroscopy:
~1700 Survive
HARPS and HARPS-North
Select:
~100
FULL VALIDATION
~6% of Small Planet Candidates Selected by TESS Team for Precise Radial Velocity Followup
∴ ~94% of Small Planet Candidates Available for Community PRV Followup
R < 4 R⊕
50
Measured Masses
"NASA Level 1"

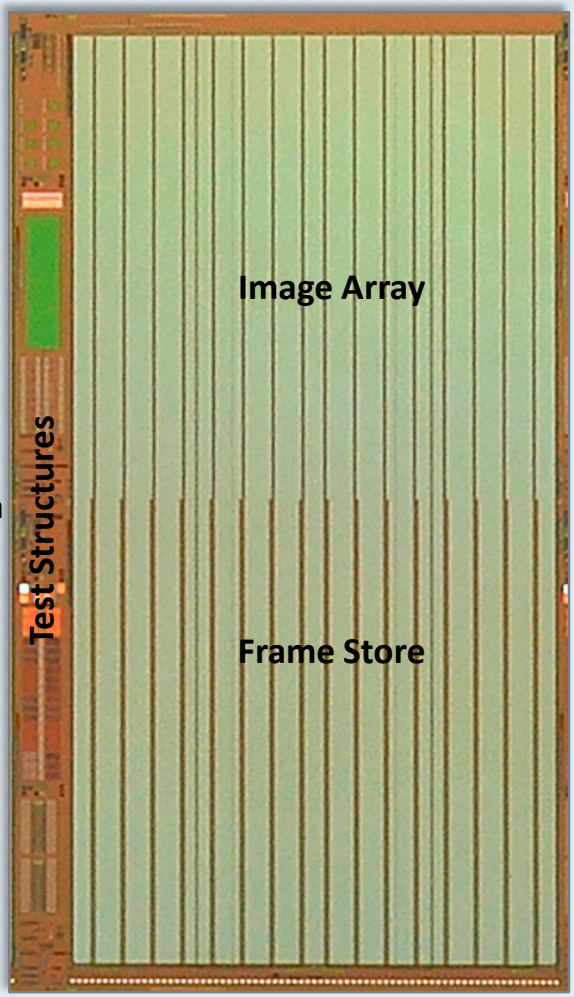

Camera 1
Lens Hood
Lens Assembly
Detector Assembly
CCDs (4)
Focal Plane Electronics
Video
Auxiliary
Interface
Camera 2
Lens Hood
Lens Assembly
Detector Assembly
CCDs (4)
Focal Plane Electronics
Video
Auxiliary
Interface
Camera 3
Lens Hood
Lens Assembly
Detector Assembly
CCDs (4)
Focal Plane Electronics
Video
Auxiliary
Interface
Camera 4
Lens Hood
Lens Assembly
Detector Assembly
CCDs (4)
Focal Plane Electronics
Video
Auxiliary
Interface
Data Handling Unit
3 Vertex-5 FPGAs
Solid State Recorder
Processor/Software
Spacecraft Ka-band Transmitter
Spacecraft Master Avionics Unit (MAU)

- 24° x 24° field of view
- 16.8 Megapixel CCD's per camera
- First lens ~ 105mm dia (~4 inch)
- For low noise the CCDs operate at ~-65°C
- CCDs cool through the lens hood
- So lenses run -75°C in orbit





- 7 elements
- 600 nm (red) to 1000 (near infrared)
- Focal length 146 mm
- F # 1.4

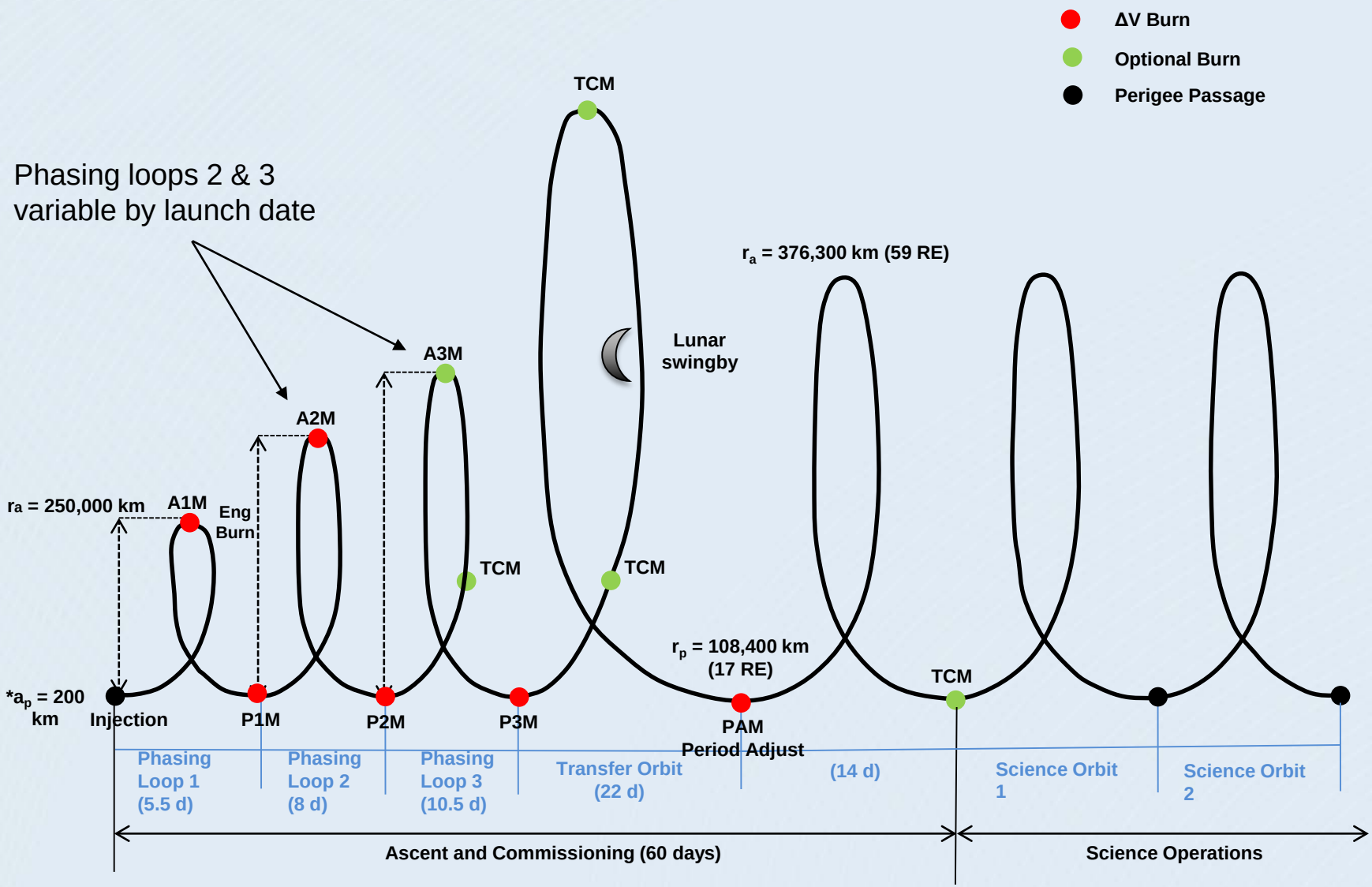


Front Illuminated Die Photo

Back Illuminated Die Photo

Packaged Part

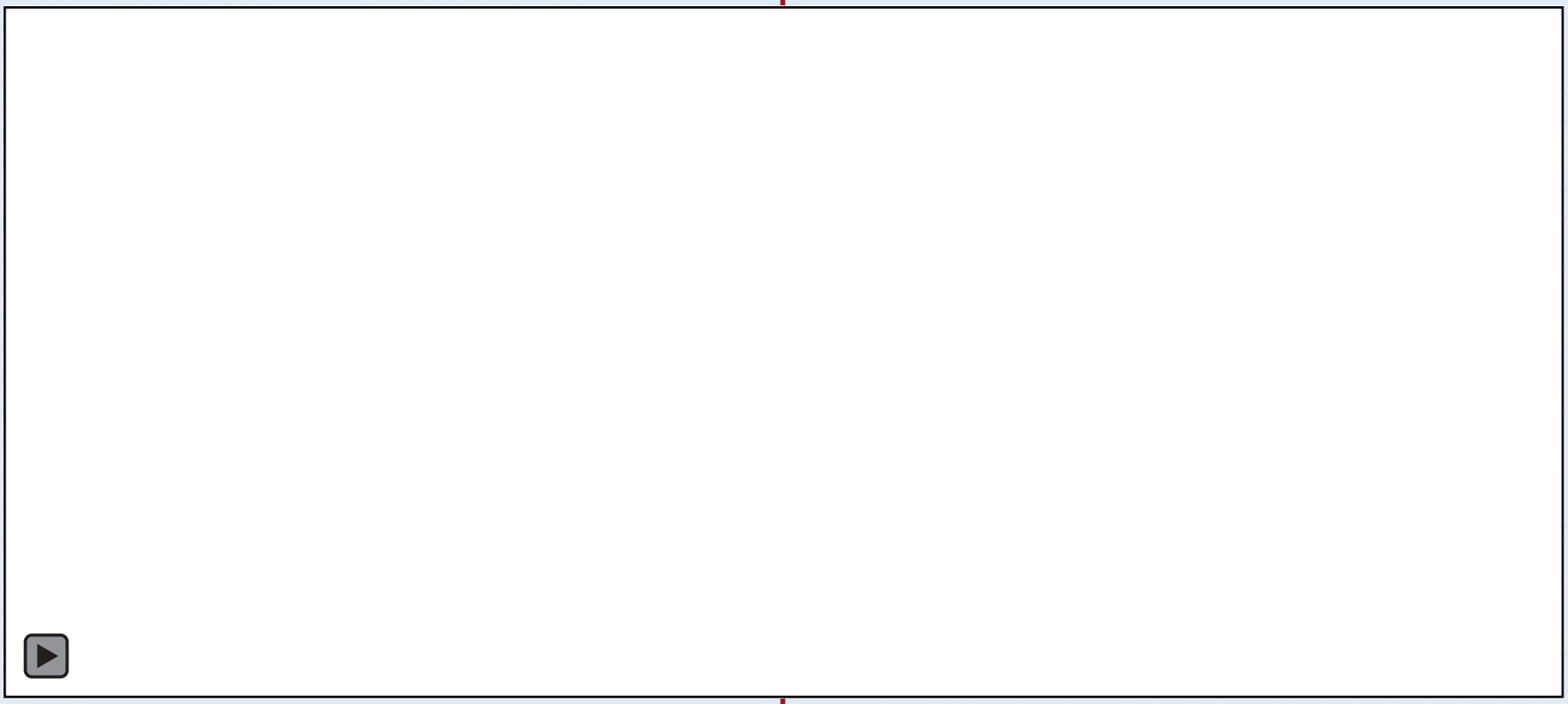
Phasing Orbits & Lunar flyby

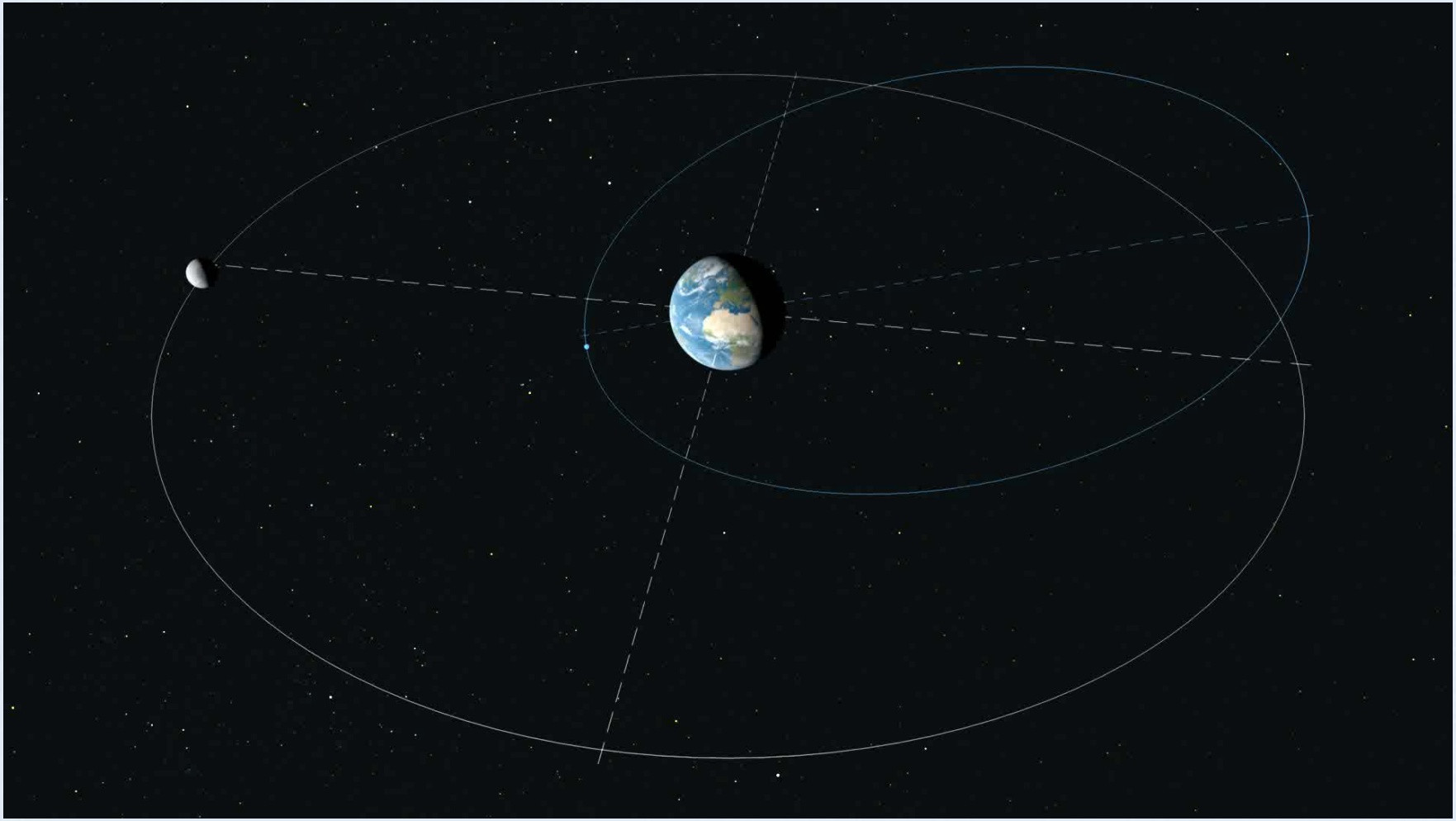


TESS Trajectory: Inertial & Rotating Frames

Inertial Frame

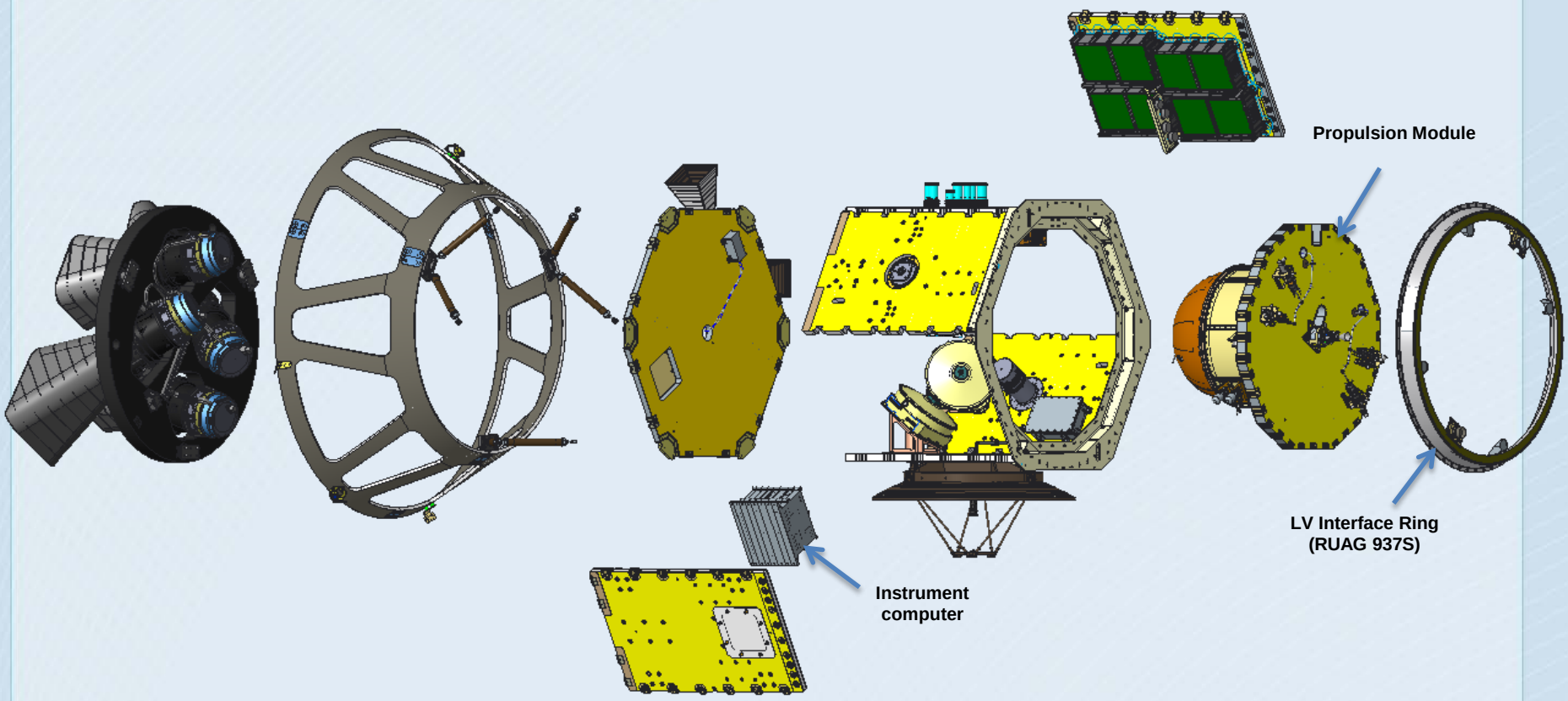
Rotating Frame





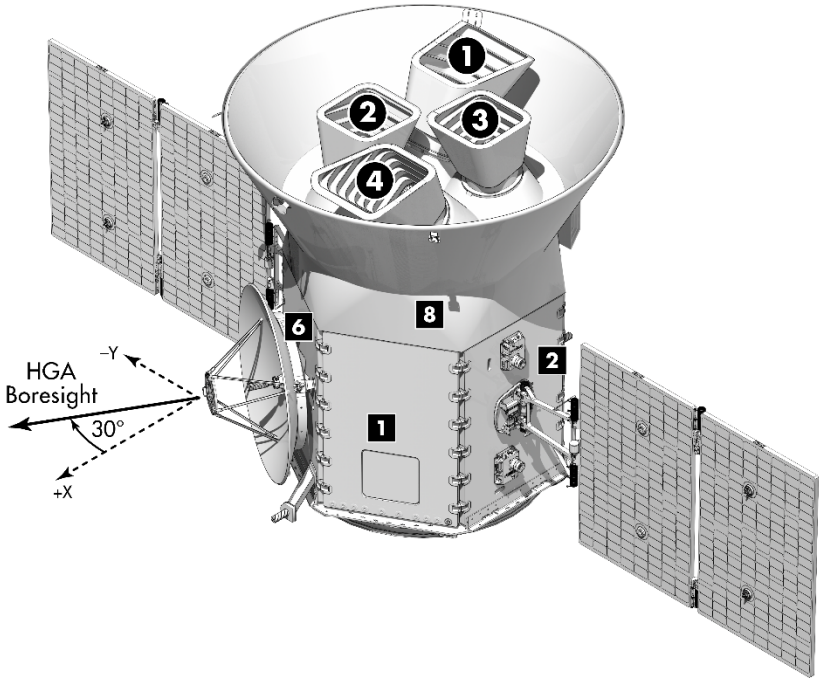
Why this Orbit?

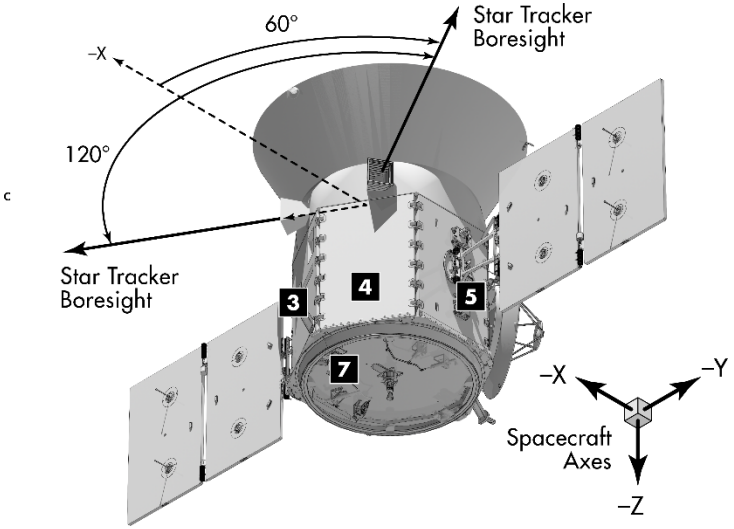
- Unobstructed visibility for long continuous viewing
  - *The Earth and Moon can get in the camera fields of view and will contaminate some of the celestial sphere*
- Very stable thermal environment
- Low Radiation environment
- Apogee is ~59 Re (Earth Radius), Perigee is ~17 Re
  - *Orbit period is exactly ½ of a lunar month*
  - *The moon pulls in one direction for one orbit and then the other direction for the second orbit --- so the average is much smaller purturbations*



Orbital ATK LEOStar-2 spacecraft modified for TESS

Spacecraft Axes





Observatory lift mass 430 kg

Hydrazine capacity = 45 kg

Solar Array capability = 500 W

Span from solar array to solar array = 4.0 m

Height from sep plane to sunshade tip = 1.57m

Pointing stability <0.06 arc-sec 3δ over 10 minutes

Launch Service Overview

- **Launch Service Contractor: SpaceX**
- **Launch Vehicle: Falcon 9 V1.1**
- **Launch Date: August 2017**
  - **Launch Site: Eastern Test Range**
  - **Spacecraft Mass: 430 kg**
  - **Orbit Requirements: Setup for Lunar Flyby**
    - » **Apogee Radius: 254,000 km +43,000 km / -31,000 km**
    - » **Perigee Radius: 6,578 +/- 15 km**
    - » **Inclination 28.5 deg +/- 0.10 deg**
- **Launch Service includes:**
  - **Enhanced fairing internal surface cleaning (level 400A)**
  - **RUAG 937S Separation System**
  - **Load isolation system**

Falcon 9 v1.1 System Overview

Falcon 9

With Fairing

Fairing
The world's largest, capable of carrying a satellite the size of a small school bus

Interstage
Composite

Connects first, second stages

All-pneumatic separations

Fins and Landing Legs
Designed for future reusability

9 Merlin 1D Engines
Engine-out reliability

1,323,000 lbf of thrust at sea level
1.5M lbf of thrust in vacuum

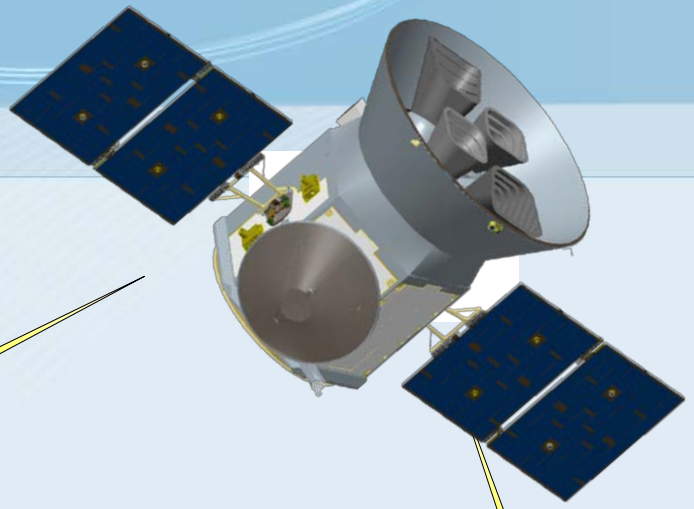
Second Stage
Liquid oxygen and kerosene propellants
Triple-redundant avionics

Multiple in-space start capability

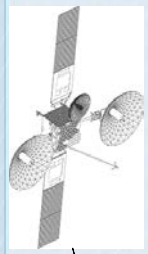
Powered by one MVacD engine
180,000 lbf of thrust in vacuum

First Stage
Liquid oxygen and kerosene propellants

High-strength aluminum-lithium alloy construction



S-Band SN



Ka-Band DSN

S-Band DSN

White Sands Complex (WSC)

S-Band
CSO

Mission Operations Center (MOC)
OA

S-Band
CSO

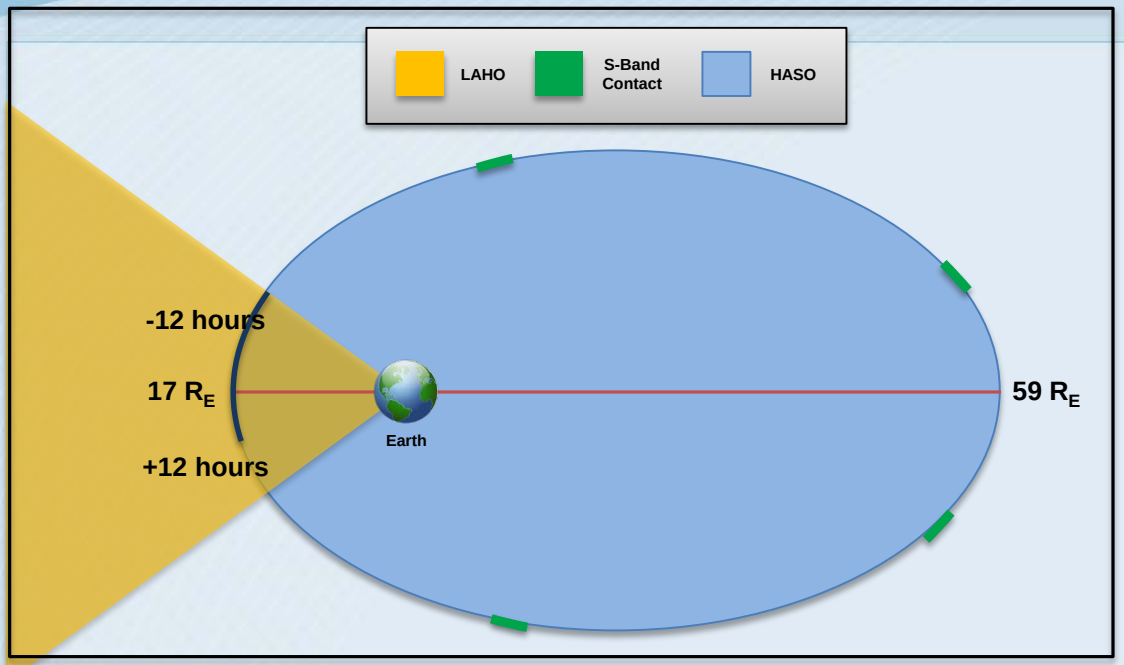
Science Operations Center (SOC)
MIT

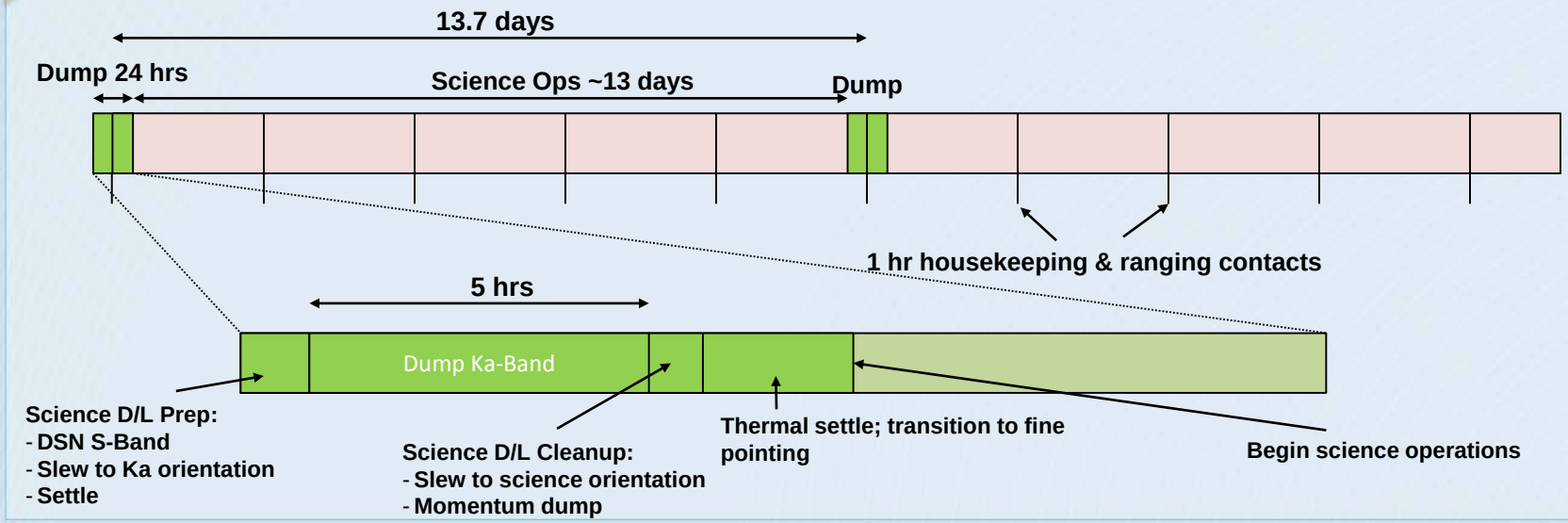
Ka-Band
VPN

S-Band
VPN

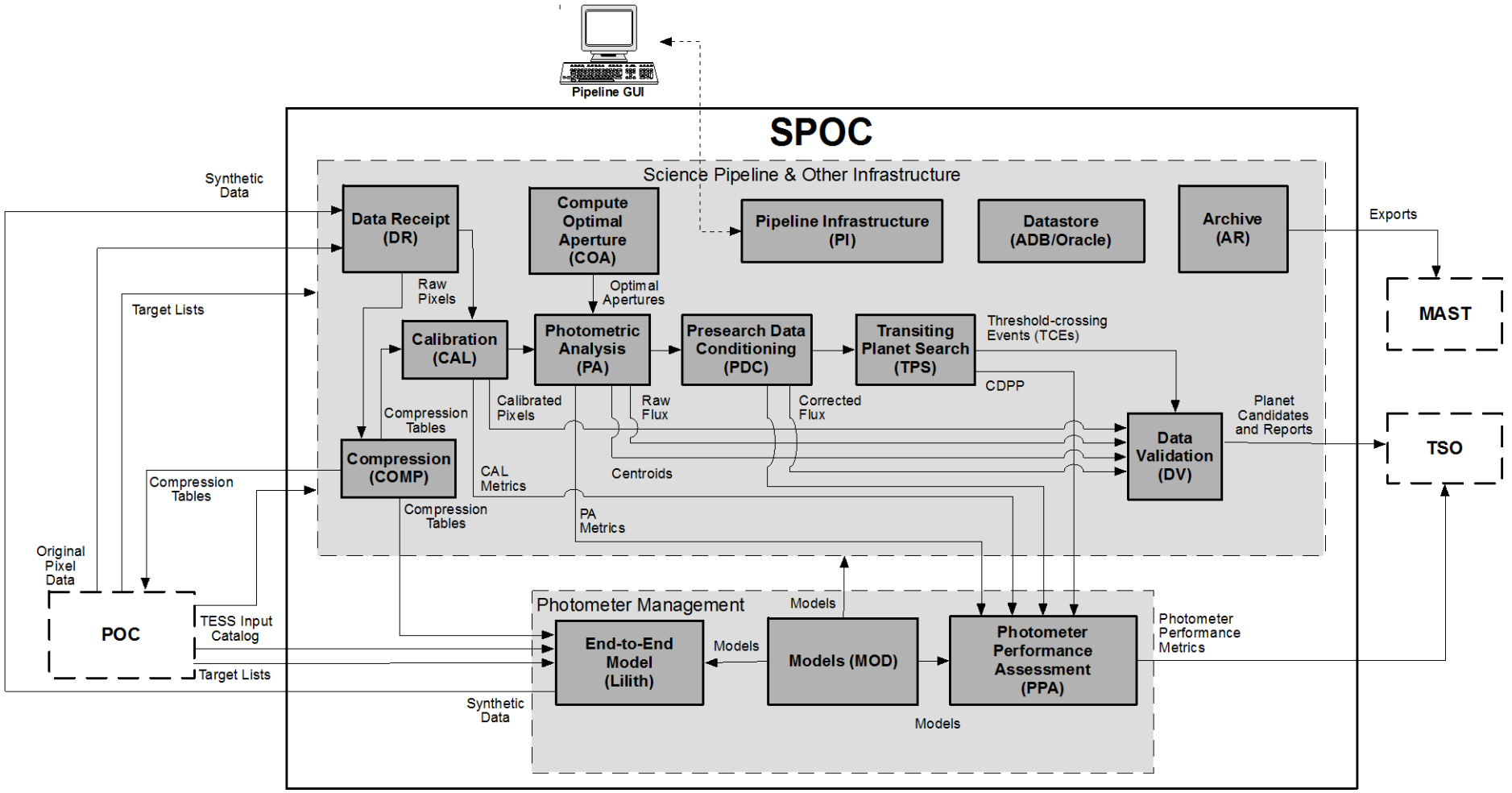
DSN Ground Stations:
34m BWG Goldstone, California
34m BWG Madrid, Spain
34m BWG Canberra, Australia

Orbit in the Life

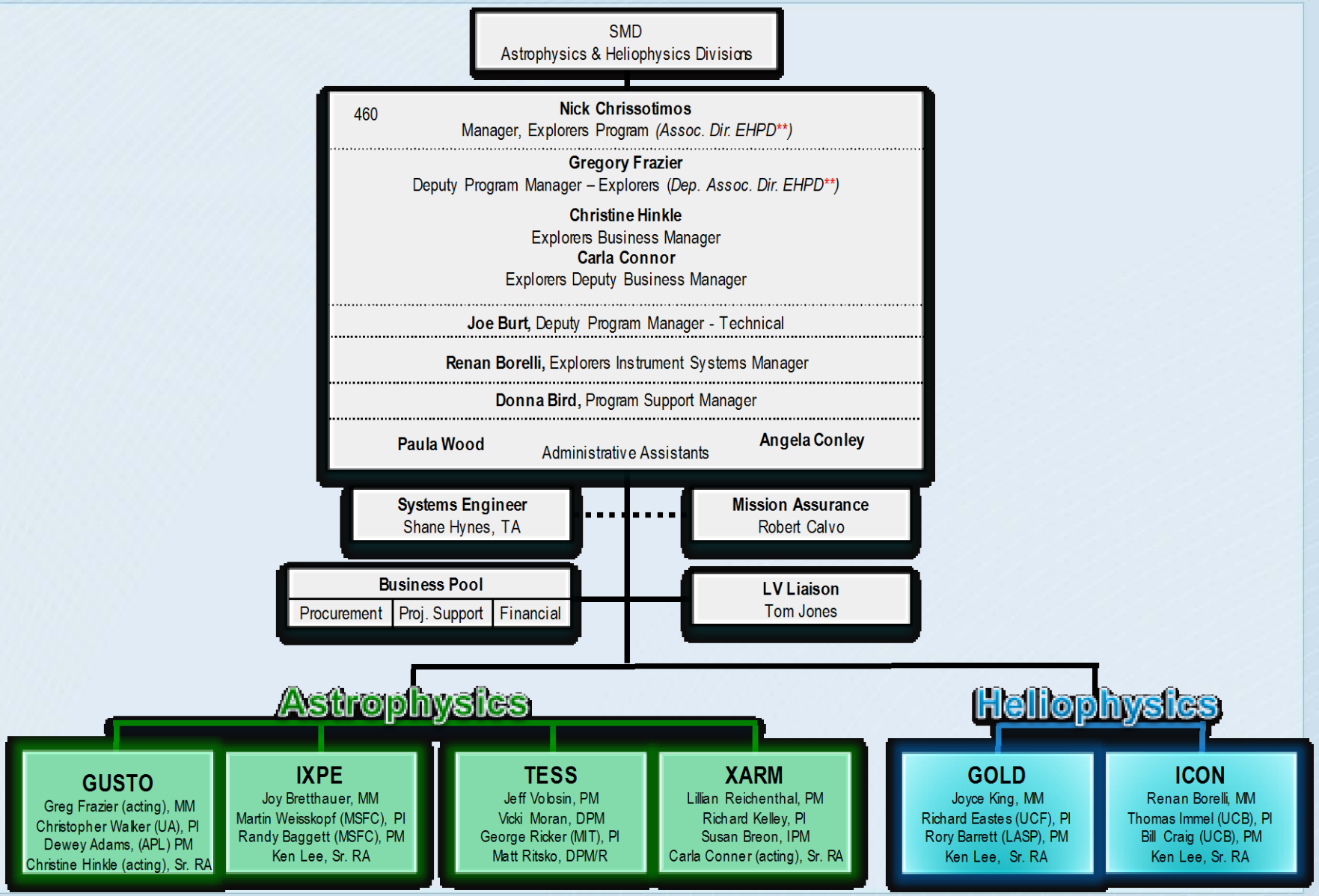




NASA/AMES Science Processing Operations



Explorers Program Organization Chart

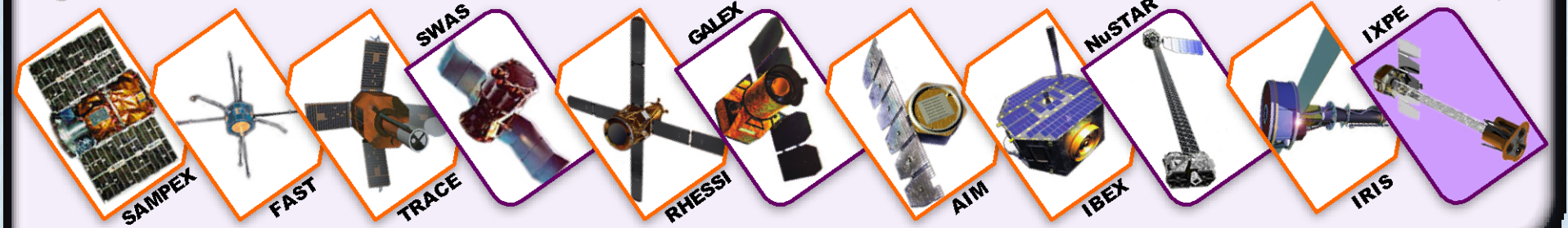


**Explorers & Heliophysics Projects Division (EHPD)

Astrophysics & Heliophysics Explorers Missions

MIDEX

SMEX



UNEX • MO • INTERNATIONALS

Astrophysics Missions

Current Astrophysics Missions

Heliophysics Missions

Current Heliophysics Missions

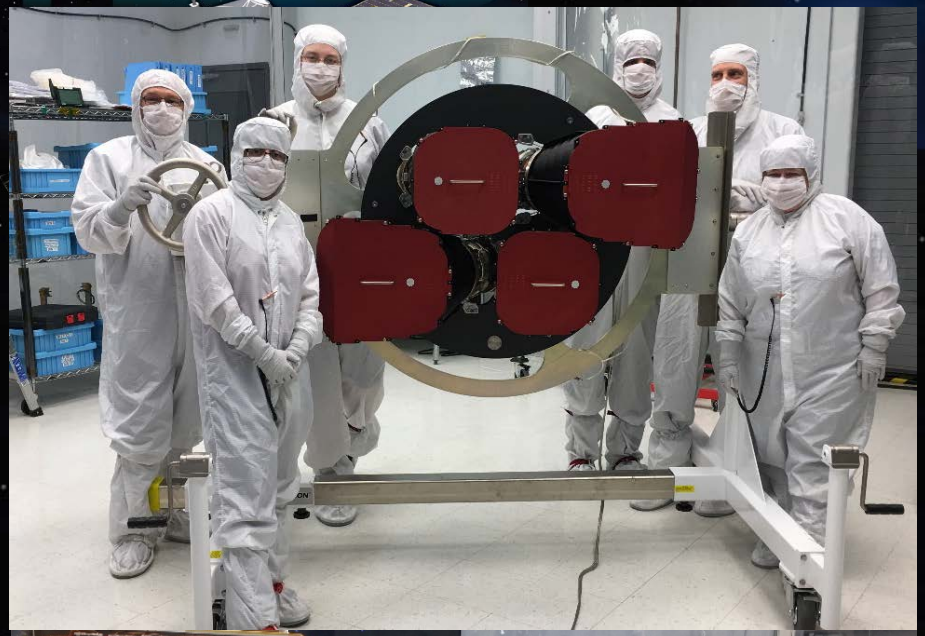
- The Explorers Program is the oldest continuous program in NASA. It is comprised of a long-standing series of space science missions that are independent, but share a common funding and NASA oversight/insight management structure.
- The Program is directed by the Heliophysics and Astrophysics Divisions within the NASA Science Mission Directorate (SMD).
- The Program resides at Goddard Space Flight Center (GSFC) and was initiated with the Explorer 1 launch in 1958.
- The Explorer Program has launched approximately 100 missions including the Nobel Prize winning Cosmic Background Explorer (COBE) Mission.
- Explorer missions are Principal Investigator (PI) led, focused single science investigations, selected via an Announcement of Opportunity (AO) process.

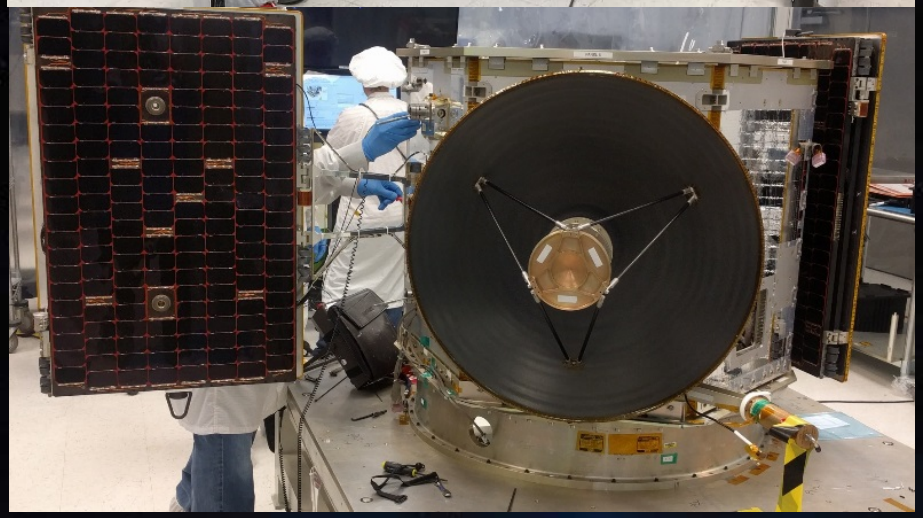
GSFC folks who have supported TESS

- **Brendan Feehan**
- Matt Ritsko
- Vickie Moran
- Chris Grau
- Pam Wood
- Chris Green
- Steve Graham
- Scott Gordon
- Erik Hagquist
- Chad Mendelsohn
- Joel Parker
- Don Dichman
- Glenn Roseclans
- Juan Cifuentes
- Ryan Lebois
- Kevin Ferrant
- David Jeyasunder
- Victor Sank
- Howard Johnson
- Travis Ross
- Michael Campola
- Will Conn
- Shirley Dion
- Terry James
- Michael Johnson
- Chris Derkacz
- Steve Scott
- Andy Carson
- Jeff Volosin
- Nettie Lindon
- Stephan Rinehart
- Therese Errigo
- Calinda Yew
- Joel Gallun
- Bhanu Sood
- Paula Pruessner
- Patti Boyd
- Augustine Pendus
- David Steinfeld
- Alan Copsey
- Mihn Phan

TRANSITING EXOPLANET SURVEY SATELLITE

TESS



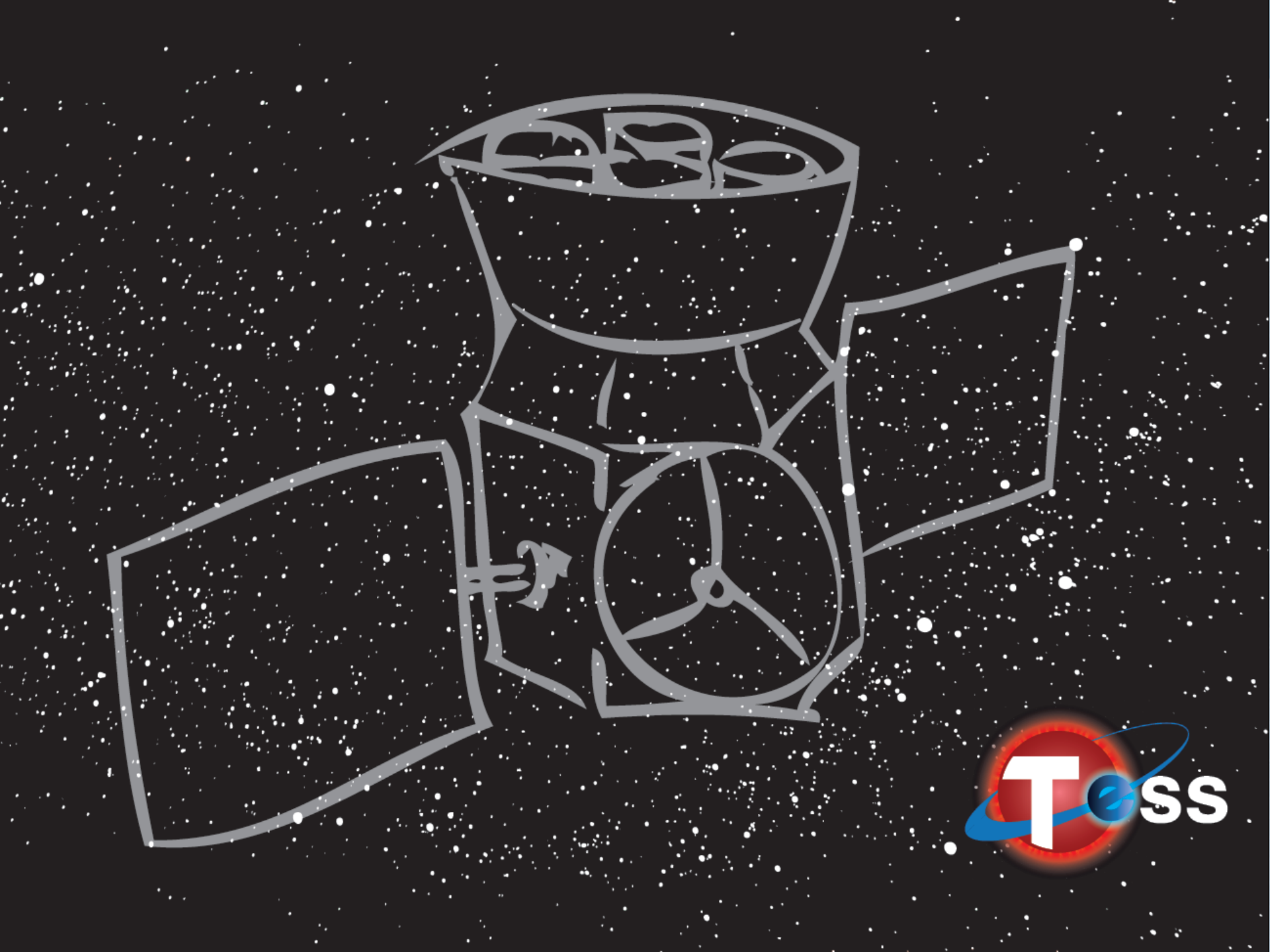


• MASSACHUSETTS INSTITUTE OF TECHNOLOGY • NASA GODDARD SPACE FLIGHT CENTER •
• ORBITAL ATK • NASA AMES RESEARCH CENTER •
• SPACE TELESCOPE SCIENCE INSTITUTE • SMITHSONIAN ASTROPHYSICAL OBSERVATORY •

Smiling faces of the instrument team at instrument delivery!

Where is TESS now?

- The instrument has been delivered and installed on the spacecraft
- The spacecraft is fully assembled with the exception of the Ka-band transmitter. The flight transmitter is have difficulties & still at the manufacturer. The engineering unit is currently on the spacecraft
- We have completed the first Comprehensive Performance Test and currently in EMC testing
- Vibration, Acoustics and Shock are scheduled for October
- Thermal Vacuum testing is scheduled for November
- Current ship date is 27th January 2018
- Current launch date is 30th March 2018


TESS