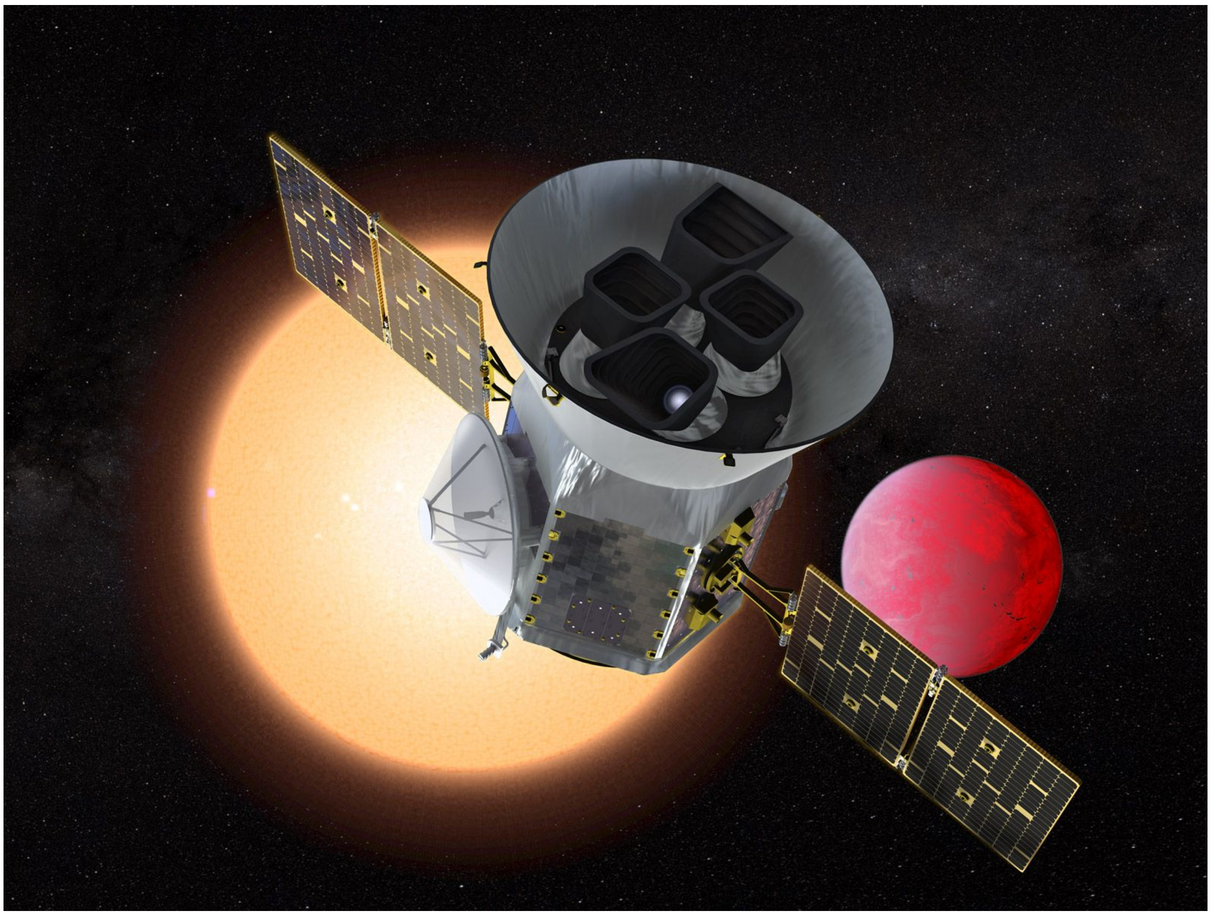
TESS Guest Investigator Program

TESS Observatory Guide



Version 1.1 (June 30, 2017)

TESS Science Support Center, NASA Goddard Space Flight Center, Greenbelt, MD

http://space.mit.edu/TESS **https://tess.gsfc.nasa.gov/** **https://heasarc.gsfc.nasa.gov/docs/tess/**

Revision History

Revision	Date	Editor	Comments
V0.1	2017-06-16	TSSC/ J. Schlieder	Initial draft
V0.2	2017-06-26	TSSC/ J. Schlieder	Revisions after comments from *TESS* collaborators on V0.1
V1.0	2017-06-28	TSSC/ J. Schlieder	First public distribution
V1.1	2017-06-30	TSSC/ J. Schlieder	Small updates to formatting and text in Sec. 6 to improve clarity

Table of Contents

List of Figures

List of tables

1. INTRODUCTION

The Transiting Exoplanet Survey Satellite (*TESS*) is a NASA Astrophysics Explorer mission designed to perform an all-sky survey to detect transiting planets around the closest brightest stars by monitoring their brightness with high precision and high time cadence. These observations allow detection of transiting planets via characteristic drops in brightness (Fig. 1). *TESS* is currently scheduled for launch via a SpaceX Falcon 9 no earlier than March 20, 2018 and will be placed in an inclined and highly elliptical 13.7 day orbit around the Earth. In its 2-year mission, *TESS* will monitor > 200,000 main-sequence dwarf stars with four wide-field optical CCD cameras to detect planetary transits. Photometry of these pre-selected targets will be recorded every 2 min. *TESS* will also obtain full-frame images (FFIs) of the entire, four camera field-of-view (24^o x 96^o) at a cadence of 30 min to facilitate additional science. The *TESS* mission also includes a Guest Investigator (GI) program to allow the astrophysics community to propose new 2 min cadence targets (~10,000 per yearly observing Cycle) and investigations using both 2 min and 30 min cadence data. *TESS* GI calls will occur once per year and be announced within the NASA ROSES solicitation.

This guide serves two purposes. The first is to provide a comprehensive description of the *TESS* observatory design, operations, and capabilities. The second is to provide potential proposers detailed information relevant to preparing proposals for the *TESS* GI program. This includes descriptions of *TESS* data processing and data products and GI program procedures, services, and tools. Additional information about the *TESS* mission, the GI program, and proposer resources can be found via the links in Table 1.

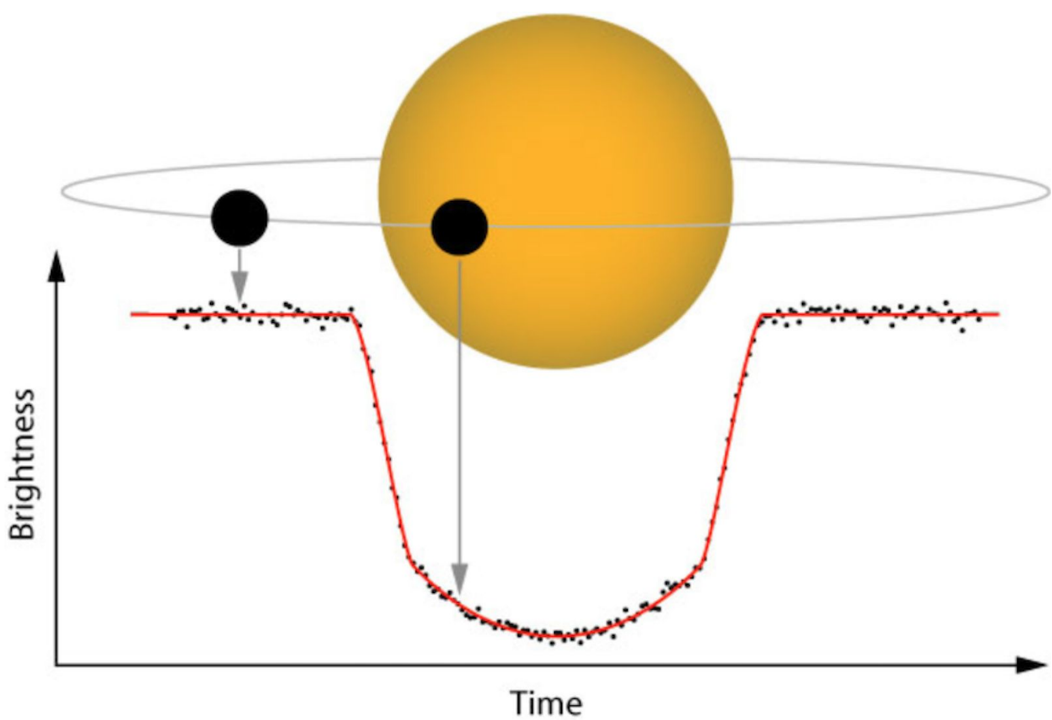


Figure 1 The transit method of detecting exoplanets involves monitoring the brightness of a star to identify periodic drops caused by planets crossing in front and blocking a fraction of its light as viewed by the spacecraft (Image credit: NASA).

Table 1 Additional *TESS* information links

NASA *TESS* homepage	https://tess.gsfc.nasa.gov/
MIT *TESS* website	http://space.mit.edu/TESS/TESS/TESS_Overview.html
TESS Science Support Center website	https://heasarc.gsfc.nasa.gov/docs/tess/
TESS GI program ROSES Solicitation	https://nspires.nasaprs.com/external/solicitations
TESS GI ARK/RPS page for proposal submission	https://heasarc.gsfc.nasa.gov/ark/rps/
MAST *TESS* website	https://archive.stsci.edu/tess/
TESS Input Catalog (TIC) and Candidate Target List (CTL) access at the MAST	https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html
TESS data access at the MAST	https://archive.stsci.edu/tess/all_products.html
TESS Candidate Target List Filtergraph data visualization portal	https://filtergraph.com/tess_ctl
NExScI Exo-FOP service	https://exofop.ipac.caltech.edu/
A description of the *TESS* observatory and science mission	Ricker et al., 2015, JATIS, 1, 014003 (ADS)
TESS science yield predictions	Sullivan et al., 2015, ApJ, 809, 77 (ADS)
TESS Input Catalog (TIC) and Candidate Target List (CTL) documentation	Stassun et al., 2017, eprint arXiv:1706.00495 (ADS)

Questions related to the *TESS* GI program, data, and analysis can be submitted through the HEASARC help desk:

http://heasarc.gsfc.nasa.gov/cgi-bin/Feedback

Select TESS under 'Choose a mailing list' or through the *TESS* GI program email address:

tessgi@bigbang.gsfc.nasa.gov

1.1 TESS Mission Organization

TESS is a NASA Astrophysics Explorer mission led by the Massachusetts Institute of Technology (MIT), which hosts the Principal Investigator Dr. George Ricker. MIT is responsible for the overall direction of the mission. The MIT Lincoln Laboratory leads the science camera development and construction. NASA's Goddard Space Flight Center provides project management, systems engineering, and safety and mission assurance. The spacecraft is led and operated by Orbital

ATK, Inc.. This includes mission operations at the Orbital ATK Mission Operation Center (MOC). The *TESS* Science Center is a partnership between MIT's Physics Department and Kavli Institute for Astrophysics and Space Research, the Smithsonian Astrophysical Observatory, and the NASA Ames Research Center. The Science Center analyzes the science data and organizes the co-investigators, collaborators, and working groups. The *TESS* Science Support Center (TSSC) operates the Guest Investigator program at NASA's Goddard Space Flight Center. All *TESS* raw and processed data are made publicly available through the Mikulski Archive for Space Telescopes (MAST, https://archive.stsci.edu/tess/), operated by the Space Telescope Science Institute (STScI). *TESS* will be launched on a Falcon 9 rocket through a contract with SpaceX.

2. THE *TESS* OBSERVATORY

The *TESS* observatory consists of a payload and spacecraft (Fig. 2). The payload is comprised of four identical wide field-of-view CCD cameras and their associated hoods, mount, and sun shield and a Data Handling Unit (DHU). The payload is coupled to the spacecraft, an Orbital LEOStar-2/750 satellite bus. The spacecraft provides power (via two deployable solar arrays), attitude control, data storage, and communications/transmission. Each of the observatory subsystems are described in detail in the following subsections along with the spacecraft launch and orbit.

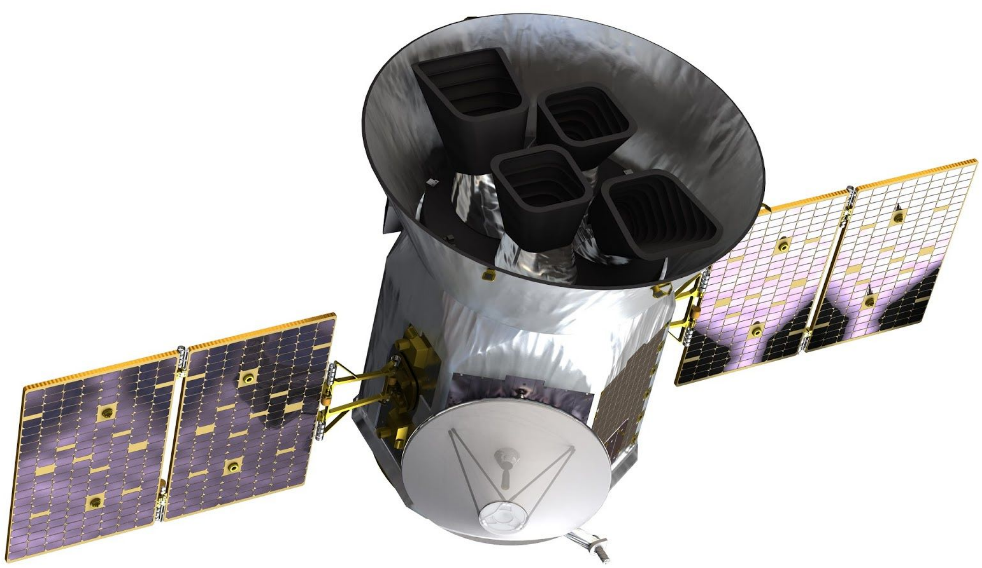


Figure 2 Artist's conception of the *TESS* spacecraft and payload on-orbit configuration.

2.1 Cameras

Each of the four *TESS* cameras consists of a lens and detector assembly. The lens assembly is a custom design comprising seven glass lens elements mounted into two separate aluminum barrels that are fastened together (Fig. 3). Each lens assembly has a 10.5 cm diameter entrance pupil and a focal ratio *f*/1.4. All optical elements have antireflection coatings and one element has a long-pass filter coating to enforce a short-wavelength cutoff at 600 nm in the *TESS* bandpass. Each camera forms a 24^o x 24^o un-vignetted image on the detector in its focal plane. The lens assemblies were designed for consistent image spot size across the field-of-view (FOV) and to produce undersampled images similar to *Kepler*. Operating at nominal focus and a flight temperature of -75° C, the anticipated 50% ensquared-energy half-width is 15 μm averaged over the FOV. This corresponds to 1 detector pixel or $\approx$21 arcseconds ($\approx$0.35 arcmin) on sky. Along with an internal stray light baffle, each lens assembly aperture is equipped with a hood to reduce scattered light from the Earth and Moon (Fig. 3).

The detector assembly in each camera consists of a focal plane CCD array and associated electronics. Each CCD array contains four back-illuminated MIT/Lincoln Laboratory CCID-80 devices. The deep-depletion, frame-transfer CCDs consist of a 2048 x 2048 imaging array and a 2048 x 2048 frame-store region (for rapid shutterless readout $\approx$ 20 ms) with 15 x 15 μm pixels (Fig. 4, *Left*). The four CCDs in each array are separated by approximately 2mm and create an effective 4096 x 4096 pixel detector that is operated at -75° C to reduce dark current (Fig. 4, *Right*). The

Table 2 Anticipated characteristics of the TESS cameras. Ensquared energy is the fraction of the total energy of the point-spread function (PSF) that is within a square of the given dimensions centered on the peak.

Single camera field-of-view	24° x 24°
Combined field-of-view	24° x 96° (3200 deg^2)
Entrance pupil diameter	10.5 cm
Focal ratio (*f*/#)	*f*/1.4
Wavelength range	600 to 1000 nm
Ensquared energy	50% within 15 x 15 μm (1 pix^2) 90% within 60 x 60 μm (4 pix^2)

detectors are read out at 625 kHz with < 10 e^- read noise. The detector electronics consist of two compact double-sided printed circuit boards seated beneath the CCD focal plane (Fig. 3). The electronics transmit digitized data over a serial LVDS link to the Data Handling Unit. The four *TESS* cameras are bolted to a common plate such that their FOV's are aligned to form a total simultaneous FOV of 24° x 96°.

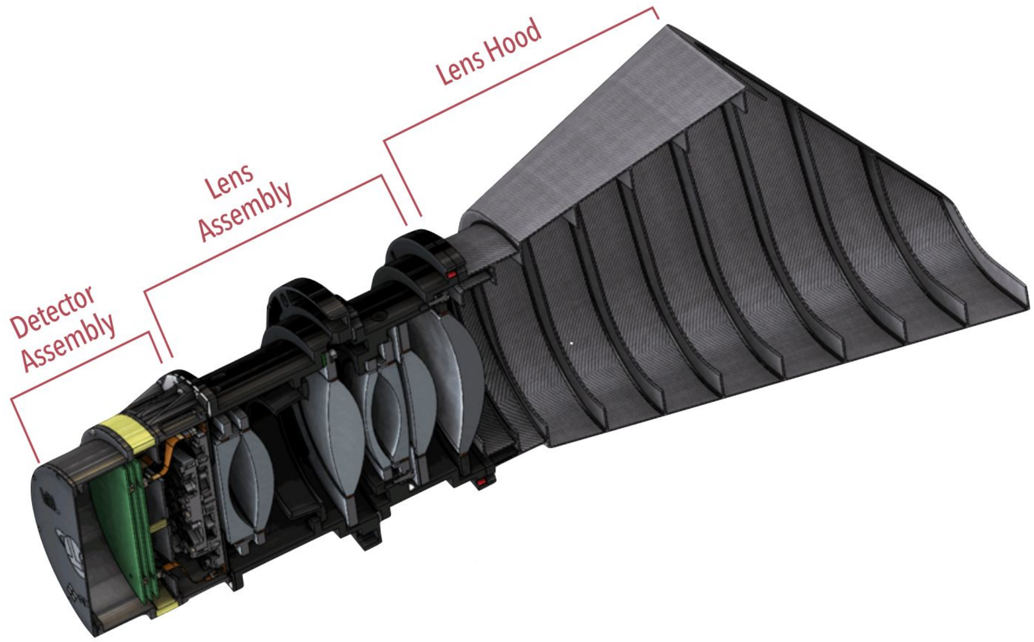


Figure 3 *Left* - *TESS* camera cutaway showing the lens hood, seven glass lens elements in the lens assembly, and the detector mosaic and electronics in the detector assembly. Each of the four cameras are identical. Key components are labeled (Ricker et al. 2015, image credit: MIT)

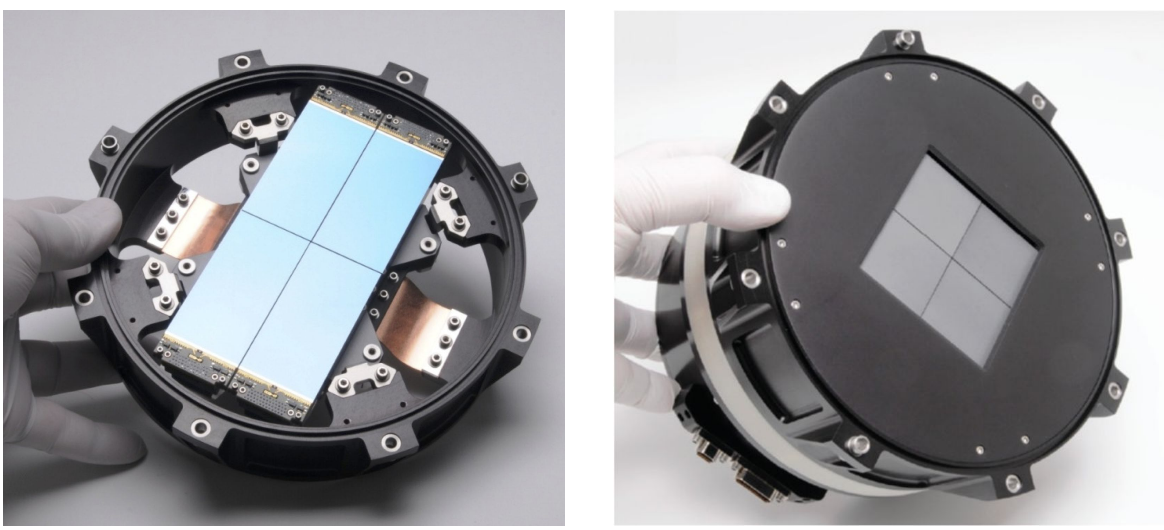


Figure 4 *Left* - *TESS* CCD mosaic in mounting bracket. *Right* - *TESS* CCD mosaic and focal plane electronics with frame store regions covered (Image credit: MIT).

2.2 Data Handling Unit

The *TESS* Data Handling Unit (DHU) provides the hardware, software, and firmware for camera control, on-board data processing, data storage, spacecraft avionics, and ground communications. The DHU is manufactured by SEAKR Engineering, Inc. and consists of an

Athena-3 Single Board Computer, an RCC5 module, an FMC-Gen3 192 gigabyte solid state recorder (SSR), a low voltage power supply, and other ancillary components. During science operations, the four *TESS* cameras produce a continuous stream of images with an exposure time of 2 s. The DHU performs real time processing on these data to convert raw CCD images into data products responsible for ground postprocessing. This includes cosmic ray mitigation and collecting pixel sub-arrays for 2 min cadence targets and image stacks for the 30 min FFIs (Fig. 5). The DHU also calculates photometric centroids from ~200 photometric guide stars from each 2 s image from each camera. These data are used to calculate offset quaternions for fine attitude pointing control by the Master Avionics Unit (MAU). Data downlink via the Ka-band antenna (see Sec. 2.3) is also controlled by the DHU. Data stored on the SSR are downlinked every 13.7 days at orbit perigee.

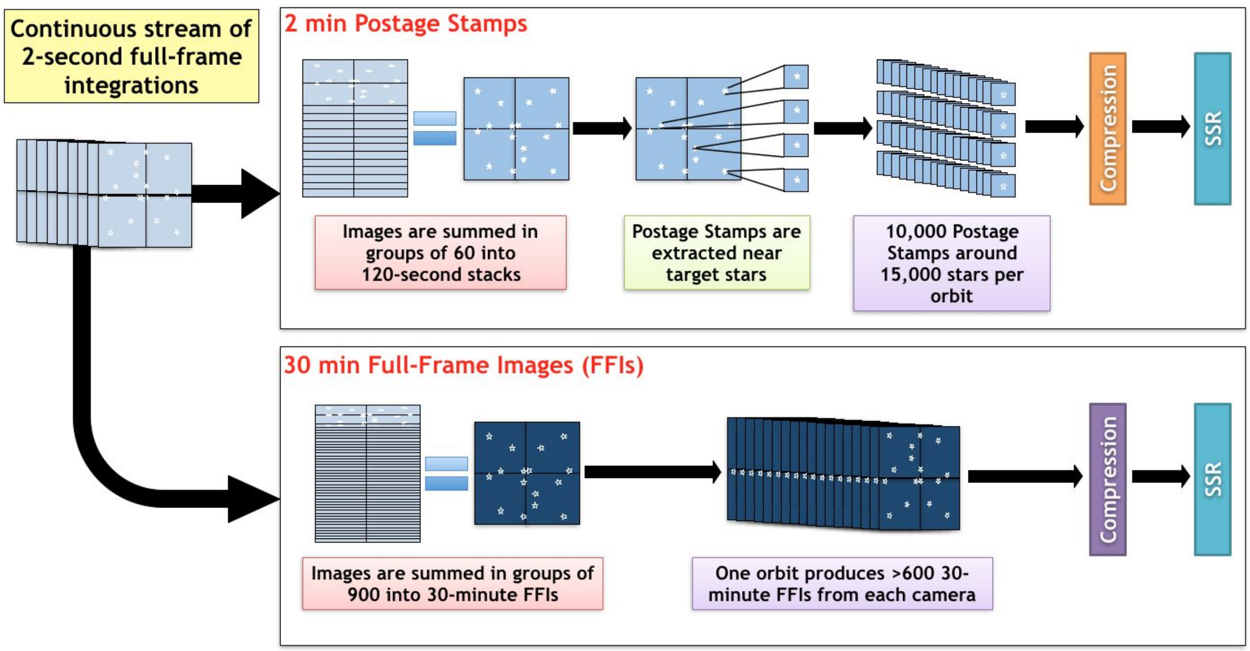


Figure 5 Schematic of *TESS* time sampling, data processing, and storage performed by the DHU. The *TESS* cameras have an exposure time of 2 s, and the images are stacked for 2 min cadence targets and 30 min FFIs onboard before they are compressed and stored in the solid state recorder. Each sector is observed for two orbits, each of which produces over 10,000 postage stamps and over 600 FFIs.

2.3 Spacecraft

The cameras are mounted to an Orbital LEOStar-2/750 bus (Fig. 6). *TESS* spacecraft power is supplied by two deployable solar array wings that are capable of providing 415 W of total power. The estimated requirement of the observatory is 290 W. The bus is equipped with a Ka-band transmitter coupled to an 0.7m body-fixed high-gain antenna. The transmitter operates on 2 W of power and transfers data at a rate of 100 Mb s^{-1}, sufficient to downlink science data during 4 h intervals at each orbit perigee. Spacecraft attitude is controlled through a zero-momentum attitude control system with a three-axis hydrazine monopropellent propulsion system and 2 star trackers. Observatory fine-pointing is achieved through four reaction wheels and high-precision quaternions produced by the science cameras.

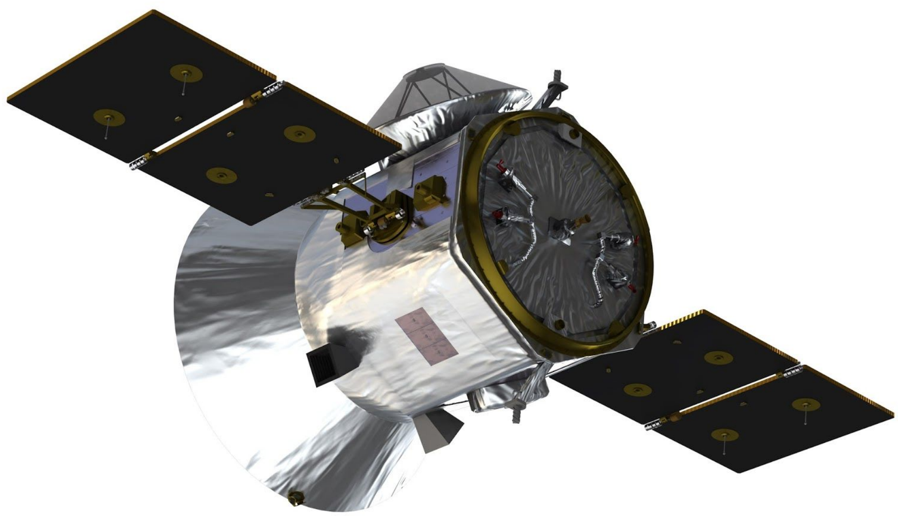


Figure 6 Alternate on-orbit view of the *TESS* observatory displaying the spacecraft bus with the Ka-band transmitter/antenna, monopropellant propulsion system, and star trackers visible.

2.4 Launch and Orbit

TESS will launch from the Cape Canaveral Air Force Station aboard a SpaceX Falcon 9. The Falcon 9 is a 2 stage, liquid oxygen and kerosene fueled rocket. The first stage is reusable and has 9 Merlin 1D engines, the second stage has a single Merlin engine. The system is designed for safe and efficient transport of satellites, cargo, and eventually crew, to low-earth orbit. *TESS* is the first NASA Astrophysics satellite mission to be launched under a contract with SpaceX. The launch is currently scheduled for no-earlier-than March 20, 2018 and not-later-than June 2018. Within this interval, the specific launch windows for *TESS* will be dictated by the lunar encounter necessary to reach its final orbit. Several launch windows are available each month. The time and date of launch determines several of the key parameters of the observatory's phasing orbits, final orbit inclination, and commissioning phase. Thus the orbit parameters and timescales provided below and in other sections of this guide are approximate and assume a nominal March 20, 2018 launch date.

TESS will observe from a unique high earth elliptical orbit (Fig. 7). The launch will carry the observatory to a parking orbit inclined by 28.5°. The high earth orbit is achieved through a series of propulsion system burns and a lunar flyby. Two burns raise the orbit apogee to 400,000 km, one at perigee of the first phasing orbit and another at perigee of the second phasing orbit. Another small adjustment is made at third perigee before a lunar gravitational assist raises the ecliptic inclination to ~40°. The final orbit inclination is dependent on the date and time of launch and may vary by a few degrees. The final apogee and 13.7 day orbital period are achieved through a final period-adjustment maneuver after the lunar flyby. Final orbit is achieved around 60 days after launch and science operations begin shortly afterward.

The final orbit is elliptical with a period of 13.7 days and nominal perigee and apogee of 17 R_{Earth} and 59 R_{Earth}, respectively. The orbit places the spacecraft in a 2:1 resonance with the Moon and is inclined with respect to the Ecliptic plane. This avoids lengthy eclipses of the Earth and Moon through the FOV. The large apogee and perigee keep the spacecraft above the Earth's radiation belts and provide a nearly constant thermal environment for the stable -75° C operation of the CCDs. The orbit is operationally stable due to the Moon leading or lagging the apogee by about 90°, effectively averaging out lunar perturbations. The period and semi-major axis are relatively stable, with long term inclination and eccentricity exchanges over periods of 8-12 years. There are additional short term perturbations caused by the Sun with a period of 6 months. The *TESS* high earth orbit is stable for decades or longer and requires no propulsion for station-keeping.

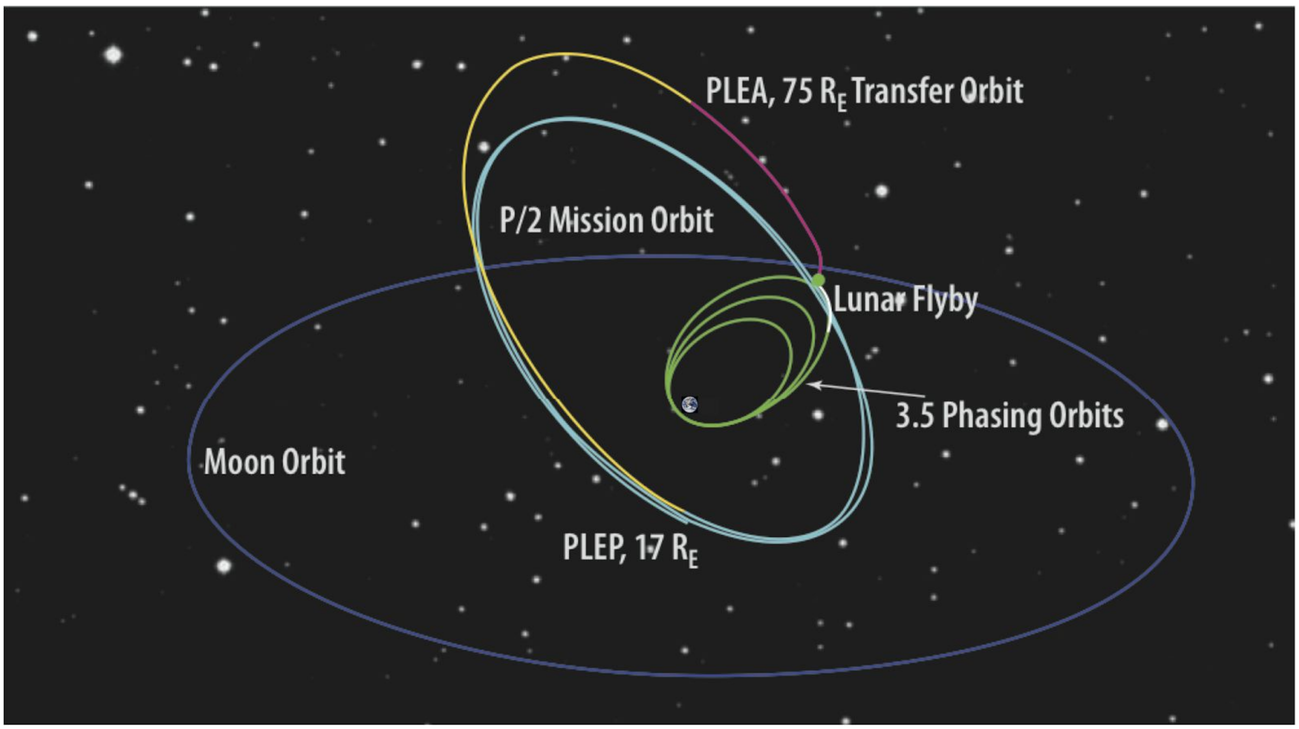


Figure 7 Schematic of maneuvers and encounters leading to the final *TESS* orbit (light blue). The observatory orbits with a period of 13.7 days in a 2:1 resonance with the Moon. PLEA and PLEP are the post-lunar-encounter-apogee and -perigee, respectively (Ricker et al. 2015).

3. Survey Operations

3.1 Science Objectives

TESS continues the legacy of *Kepler* and K2 by monitoring the brightness of hundreds-of-thousands of the closest brightest stars to discover transiting planets. This will be achieved by pursuing a 2-year survey covering an area of sky ~400 times larger than covered by *Kepler* and that targets stars 10-100 times brighter. Planets detected around these stars will therefore be far easier to characterize, resulting in refined measurements of planet masses, sizes, densities, and atmospheric properties. The primary goal of *TESS* is therefore to identify a large sample of planets where follow-up observations are feasible with current and planned instruments (e.g. the James Webb Space Telescope (*JWST*)). These goals will be achieved by monitoring > 200,000 pre-selected stars using 2 min cadence observations. The primary science requirements of the *TESS* mission are as follows:

1. Search over 200,000 stars to discover transiting exoplanets with periods < 10 days and radii < 2.5 R_{Earth} orbiting the brightest stars in the solar neighborhood and discover transiting exoplanets with radii at least 2.5 R_{Earth} distributed across the celestial sphere;

2. Search for transiting exoplanets with periods up to 120 days among the ~10,000 stars in regions surrounding the ecliptic poles;

3. Determine the masses for at least 50 transiting exoplanets with radii < 4 R_{Earth} using ground-based follow-up resources or other methods.

3.2 Target Selection

To meet the primary mission goals, an all-sky catalog was generated to act as a basis for target selection. The *TESS* Target Selection Working Group (TSWG) was tasked with the creation and maintenance of the catalog with the aim of compiling every optically luminous, persistent object in the sky down to the limits of available wide-field photometric catalogs including both point sources and extended sources. This enables the selection of optimal targets to search for small transiting planets and allows flux contamination to be calculated in an optimal aperture for each target (critical due to the ~21" *TESS* pixels). The resulting catalog is the source from which the > 200,000 primary mission targets will be selected and is known as the *TESS* Input Catalog (TIC).

The TIC was assembled by merging three base catalogs and many auxiliary catalogs to create a full list of point sources, extended sources, and other special objects of interest that could be observed by *TESS*. A series of algorithmic procedures are used to determine both observational and astrophysical parameters of all objects in the TIC for which adequate data are available. The brightness in the *TESS* bandpass (*T* mag) is calculated for all objects, both stars and galaxies. Stellar parameters, including mass, radius, and other parameters are calculated for a subset of the TIC stars. The final TIC contains data for ~596 million objects, including 470 million point sources, 125 million extended sources, and 1 million special objects. Figure 8 provides a visual overview of the input catalogs and methodology used to construct the TIC.

A subset of TIC objects was isolated to select the > 200,000 targets for *TESS* 2 min cadence observations in service of the mission's primary science requirements. This list is known as the Candidate Target List (CTL). The CTL was constructed by applying strict cuts to the ~470 million point sources in the TIC that included cuts in regard to magnitude, reduced proper motion, and lack of calculated parameters (T_{eff}, radius, and flux contamination). The resulting list is ranked by priority; a function of sky position, stellar radius, brightness, and contamination, to provide a list of the ~11 million top ranked stars. The CTL currently contains both dwarf and subgiant stars (giants have been effectively removed using reduced proper motion cuts). Once parallaxes from the second Gaia Data Release (DR2) are available (expected no earlier than April 2018), dwarfs and subgiants can be differentiated.

Complete documentation of the input and methods used to construct the TIC and CTL are provided in the TIC paper prepared by the TSWG team (Stassun et al. 2017, available here). The current full versions of the TIC and CTL are hosted publicly at the MAST (https://archive.stsci.edu/tess/) and a high priority subset of the CTL is available via the Filtergraph data visualization system (http://filtergraph.vanderbilt.edu/tess_ctl). Subsequent versions of the TIC and CTL containing additional data (e.g. Gaia, new GI targets) will be generated and made available leading up to the *TESS* launch.

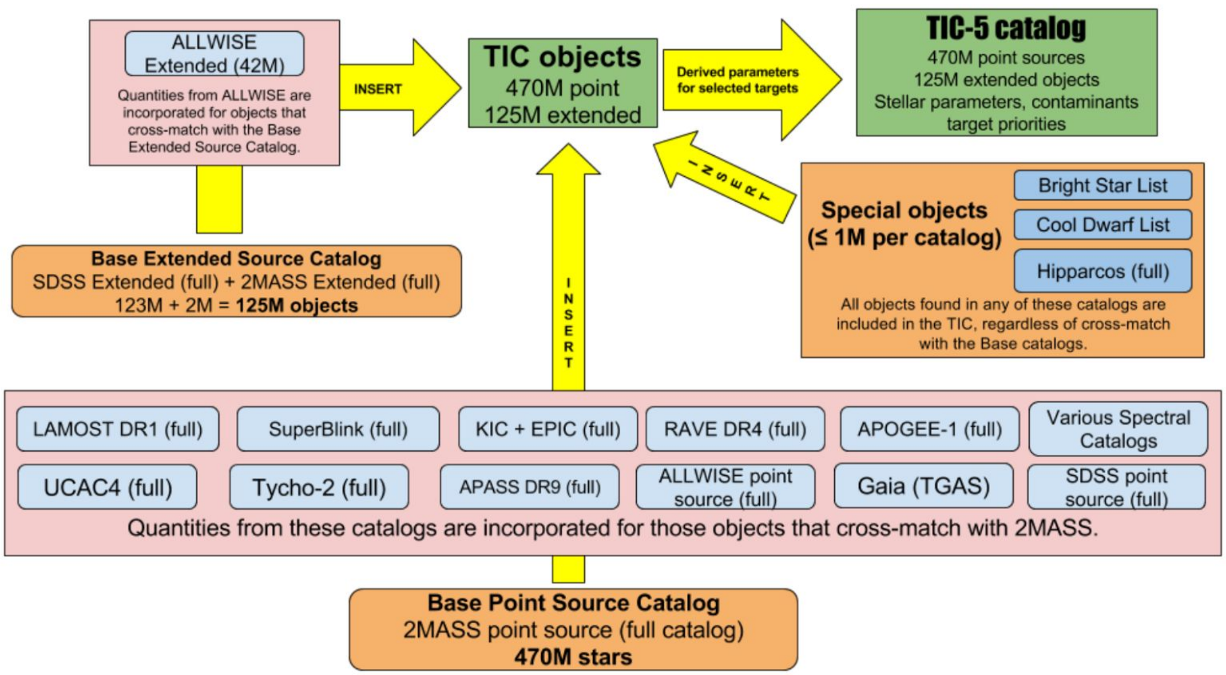


Figure 8 Overview of the photometric catalogs used to construct the *TESS* Input Catalog (TIC). Yellow arrows depict the order that catalogs are crossmatched and or merged. The final TIC (TIC-5 as of 2017-06-04) is represented by the green box at the upper right (Stassun et al. 2017).

3.3 Observing Strategy

The four *TESS* cameras act as a 1 x 4 array, covering a combined FOV of 24° x 96° or ~2300 deg^2 (Fig. 9). *TESS* will observe the southern and northern ecliptic hemispheres for 1 year each in its 2 year prime mission, beginning in the south. Each hemisphere will be observed with 13 partially overlapping sectors, each covering ecliptic latitudes from 6° to the ecliptic pole. Each sector will be observed for two orbits (2 X 13.7 days = 27.4 days), then the FOV will shift eastward in ecliptic longitude by about 28° to observe the next sector. This process continues until the hemisphere has been tiled by 13 sectors. The 26 observing sectors in the two year mission will cover over 90% of the sky. The sectors overlap at higher latitudes, with ~350 days of continuous coverage in the Continuous Viewing Zone (CVZ) at the ecliptic poles. The *TESS* CVZs also overlap the regions of continuous viewing accessible to the *JWST* (Fig. 10). Figure 10 also provides an approximate breakdown of the sector overlap and sky coverage. Individual *TESS* camera integrations last 2 s. For the > 200,000 preselected science targets, these frames are co-added to generate pixel postage stamps every 2 min. A full frame image (FFI) of the entire four camera FOV is also stored once every 30 min to produce data at a cadence comparable to *Kepler* for nearly the entire sky. The first *TESS* observing sector will be centered at a point in the southern ecliptic hemisphere that is anti-solar at the end of commissioning (Fig. 11). The position of the first and all subsequent observing sectors therefore depends on the launch date and commissioning timescale. Since *TESS* observing sectors are anti-solar, the relative time that a sector is affected by eclipses and scattered light contamination from the Earth and Moon will vary. Which sectors will be most affected is dependent on the launch date (Fig. 11). A video illustrating the *TESS* survey strategy, along with the pathway to the spacecraft orbit, can be seen at http://www.youtube.com/watch?v=mpViVEO-ymc.

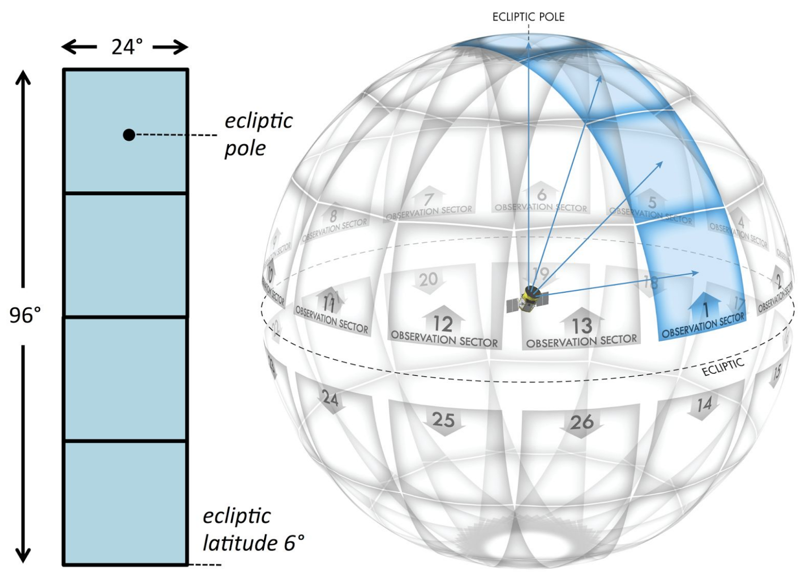


Figure 9 *Left***:** Instantaneous combined FOV of the four *TESS* cameras. *Right:* Division of the celestial sphere into 26 observation sectors, 13 per hemisphere. The *TESS* survey will begin in the southern Ecliptic hemisphere with the first observing sector in the anti-solar direction. The exact position of the first observing sector is dependent on the launch date and commissioning timescale (Ricker et al. 2015).

3.4 Data Downlink and Housekeeping

At the *TESS* orbit perigee (17 R_{Earth}), science operations are interrupted for no more than 16 h to point *TESS*'s antenna toward Earth, downlink data, and resume observing (Fig. 11). This timeframe includes the nominal 4-h period for Ka-band science data downlink using NASA's Deep Space Network (DSN). Occasionally during this period, *TESS* will also use its hydrazine thrusters to unload angular momentum built up from solar photon pressure.

3.5 Science Data Flow and Processing

Data from *TESS* will be downloaded through the NASA Deep Space Network (DSN) and delivered to the Payload Operations Center (POC) at MIT. The POC sends uncalibrated re-quantized pixel data, target lists, spacecraft configuration and engineering data, and focal plane characterization models (for calibration) to the Science Processing Operations Center (SPOC) at the NASA Ames Research Center. The SPOC calibrates the science data in two steps, first by orbit and then by observing sector. The SPOC uses instrument calibration models provided by the POC to calibrate all science data. Once a full sector is calibrated, pixel level data of the priority science targets and Guest Investigator program targets (see Section 6) will be processed by the SPOC with a data reduction pipeline based on software that was developed for the *Kepler* mission. This includes pixel-level calibration, background subtraction, aperture photometry, identification and removal of systematic errors, and the search for transit-like signatures, also known as threshold crossing events (TCEs), in 2 min cadence data. All TCEs will also be fitted with a limb-darkened transit model and subjected to a suite of diagnostic tests to evaluate confidence in their planetary nature.

Baseline (days)	**Sky Coverage (deg^2)**	**Sky Coverage (%)**
0	6023	14.6
27.4	25989	63.0
54.8	6270	15.2
82.2	1238	3.0
109.6	231	0.56
137.0 to 301.4	578	1.4 (total)
328.8	215	0.52
356.2	701	1.7

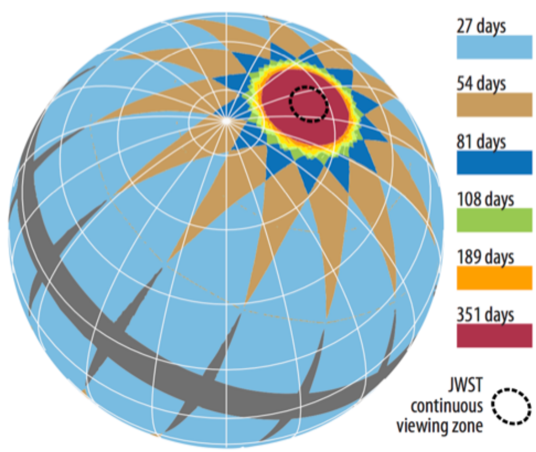


Figure 10 *Left*: *TESS* observing baselines and sky coverage (values are approximate). *Right*: Schematic showing observing baselines on the celestial sphere including sector overlap regions. The dashed black circle enclosing the Ecliptic pole shows the region where the *JWST* has continuous viewing capabilities.

Calibrated target pixels, light curves generated from 2 min cadence targets, and TCEs are sent to the *TESS* Science Office (TSO, which includes MIT and the Smithsonian Astrophysical Observatory, SAO). The TSO is responsible for detailed analysis of TCEs and the identification of *TESS* Objects of Interest (TOIs). FFIs will be processed by the SPOC using standard image calibration techniques that include flat fielding and bias subtraction. All processed data products and meta-data from the SPOC will be sent to the Science Operations Center (SOC) at MIT and then subsequently archived at the MAST at STScI. The first data release is planned for no more than 6 months after acquisition, but would include all data more than 2 months (observing sectors) old that have been processed at that time. After that, data releases are anticipated monthly and keep up with the data stream from the observatory. The TSO will also deliver lists of TOIs with dispositions and information documenting the vetting process for each TOI on a regular schedule, nominally keeping up with the data flow from the spacecraft. The MAST is the primary science data archive for *TESS* and will provide tools to search and retrieve data. The *TESS* Science Support Center (TSSC) operates the Guest Investigator program, which will supply a list of GI targets to the POC, and GI proposers will retrieve their data from the MAST. All data archived at MAST will have no proprietary period and will be publicly available, including data for the > 200,000 primary science targets and GI program targets. The partners involved and steps in the data flow are summarized in Fig. 12.

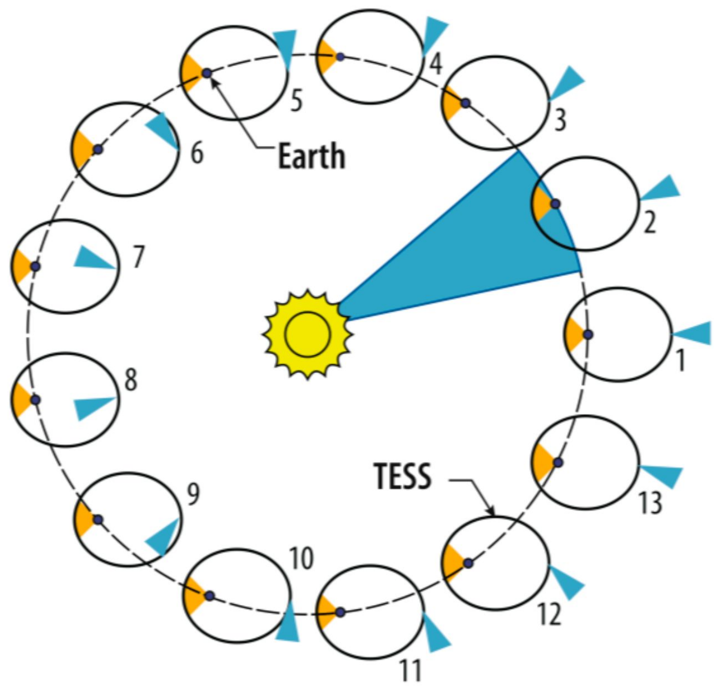


Figure 11 Schematic of *TESS* spacecraft orbit orientation and observing sectors with respect to Earth and Sun during 1 year (1 Cycle) of observations. In one year, *TESS* observes 13 sectors around an ecliptic hemisphere starting with sector 1. The direction of observation is denoted by the small blue triangles and is always anti-solar. This requirement leads to varying timescales of contamination due to the Earth and Moon in some sectors throughout the year. The orange triangle at each perigee denotes the portion of the orbit used for data downlink where no observations occur.

3.6 Follow-up Program

Once the 2 min cadence data are processed and transits are identified, stars hosting high priority planet candidates will be characterized with ground-based imaging and spectroscopy. These observations are used to establish reliable stellar parameters, confirm the existence of planets, refine their radii, and measure planet masses. The focus will be on stars hosting planet candidates $< 4\ R_{Earth}$ to measure their masses via radial velocity (RV) follow-up in support of the mission's primary science requirements. The *TESS* Follow-Up Observing Program (TFOP) organizes and carries out follow-up of TOIs. The TFOP is organized into five sub-groups: Seeing Limited Photometry, Recon Spectroscopy, High-Resolution Imaging, Precise Radial Velocities, and Space Photometry.

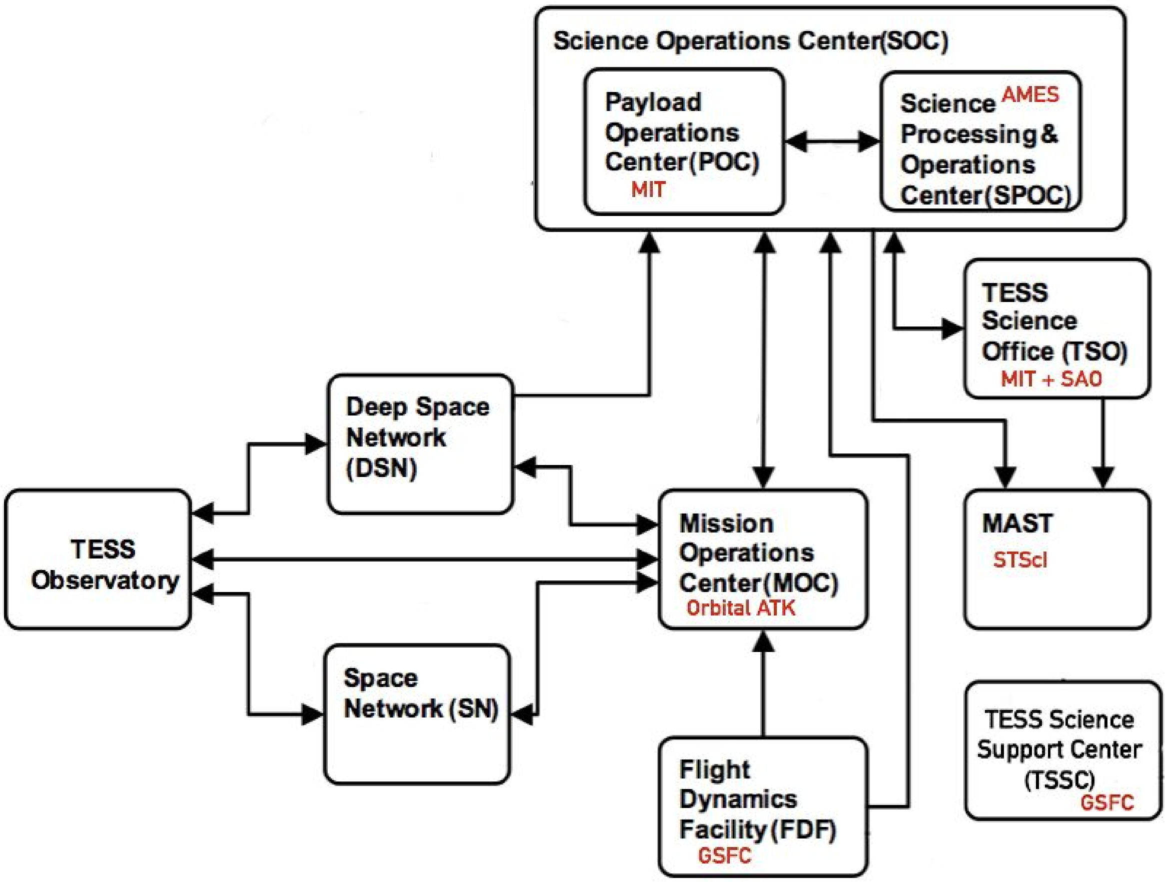


Figure 12 *TESS* data flow schematic showing the flow of data from the spacecraft to data products delivered at the MAST with all participating program partners and their roles defined.

TFOP observations will be performed with committed time on the Las Cumbres Observatory Global Telescope Network and the MEarth observatory and numerous other facilities through the usual telescope time allocation processes. The TFOP and *TESS* science team includes a large group of collaborators and welcomes additional participation and follow-up programs. TFOP organizational information will be publicly available at the ExoFOP-TESS, hosted and maintained by the NASA Exoplanet Science Institute (NExScI).

4. Performance, Commissioning, and Calibration

4.1 Detector Bandpass

The *TESS* detector bandpass spans from 600 - 1000 nm and is centered on the traditional Cousins *I*-band (I_C, λ_c = 786.5 nm; Fig. 13). This wide, red-optical bandpass is preferred to reduce photon-counting noise and increase sensitivity to small planets transiting cool, red stars. The long wavelength end represents the red-limit of the CCD detectors and is set by their quantum efficiency. The short wavelength end is set by a long-pass filter coating on one of the camera lenses (see Fig. 3). In contrast to *Kepler*, the *TESS* bandpass is comparably wide but covers redder wavelengths, reflecting the differing target priorities of the two missions (Sun-like stars for *Kepler*; small, cool stars for *TESS*).

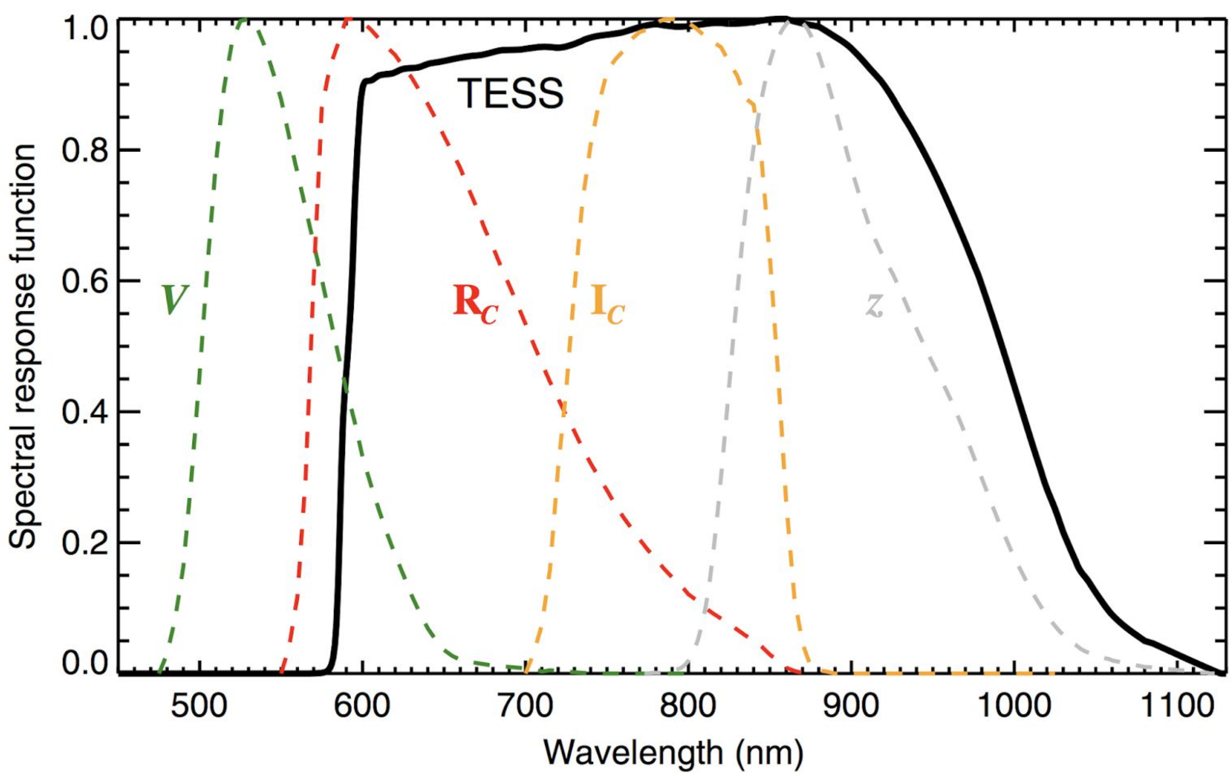


Figure 13 *TESS s*pectral response function compared to commonly used optical to red-optical bandpasses. The *TESS* bandpass is centered on the Cousins *I*-band (I_C) and is redder than *Kepler* to enhance sensitivity to small planets transiting cool, low-mass stars (Ricker et al. 2015).

4.2 Photometric Performance

TESS is anticipated to achieve ~200 ppm (0.02%) photometric sensitivity for an I_C = 10 star and ~10,000 ppm (1%) sensitivity for an I_C = 16 star (Fig. 14). These limits allow *TESS* to detect small transiting planets around bright nearby stars and service the mission's level one science requirements. Figure 14 shows the total estimated photometric performance of the TESS cameras and the contributions from modeled noise sources. The noise sources include photon counting noise from the star and background (zodiacal light, faint unresolved background stars), dark current, which is very small, read out noise, and additional systematic errors that cannot be corrected by cotrending. A key source of systematic noise is anticipated from random pointing variations - "*spacecraft jitter*" which causes changes in the measured brightness as stars move across CCD pixels. The floor for this intrinsic noise is assumed to be 60 ppm on hourly timescales.

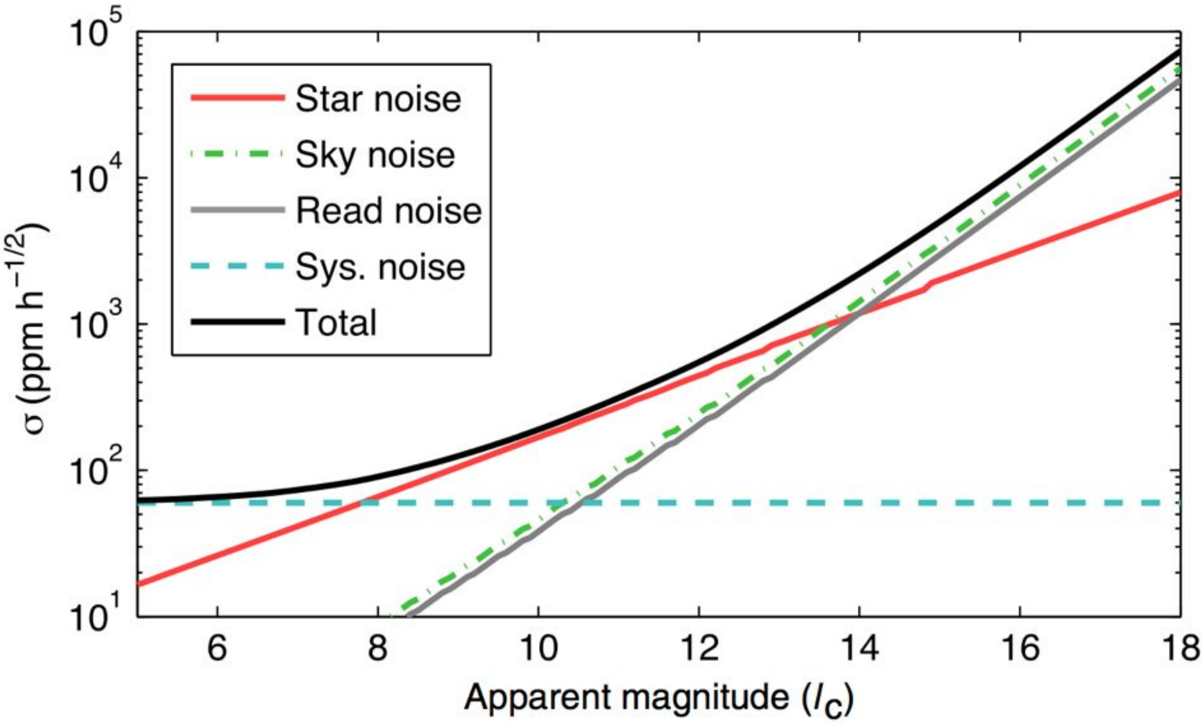


Figure 14 *Top:* Anticipated *TESS* photometric precision as a function of target star apparent I_C-band magnitude (black curve). The contributions from noise sources described in the text are shown (Ricker et al. 2015).

Saturation is anticipated in the central pixel at $I_C = 7.5$. This however does not represent the bright limit for precise photometry. Excess charge from saturated pixels is conserved and spread across adjacent pixels in a CCD column until the excess reaches a CCD boundary. This leads to "*bleed trails*" extending above and below a saturated pixel, similar to what is seen for bright stars in *Kepler*/K2 photometry. Precision photometry can still be achieved by creating a photometric aperture that is large enough to encompass all excess charge and the *TESS* bright limit is anticipated to be $I_C \cong 4$. Resources to estimate the optimal aperture size for targets of a given brightness will be made available in a future update to this document and on the TSSC website.

4.3 Commissioning and Calibration

TESS will undergo a ~60 day commissioning phase that begins shortly after launch. The commissioning period is separated into four phases that include spacecraft initialization, instrument initialization, fine pointing updates, and instrument calibration. During spacecraft initialization, *TESS* will undergo various checkouts and parameter updates of of key spacecraft systems involved in communication and attitude control. This includes the S-band receiver, star trackers, and propulsion system. This phase also includes the first spacecraft maneuvers to reach the final orbit and will last approximately 7 days.

In the second phase of commissioning, instrument initialization, the DHU and cameras are powered on and undergo initial tests to check their health. The powerup of the 4 cameras will be done one camera at a time and include first light. This phase also includes the initial alignment of each camera to transform the on-orbit boresights into the spacecraft reference frame. After this initial camera alignment, on day 10 of commissioning, the third phase begins. In phase 3, three fine pointing updates will be performed, the first checks of on board cosmic ray mitigation will be performed, and the first FFI's will be obtained. Two orbit maneuvers will also be performed in this phase. The fine pointing update phase ends on day 16 of commissioning.

During commissioning phase 4, instrument calibration, the first target pixel masks will be uploaded to the spacecraft, a guide star table will be uploaded, scattered light calibrations will be performed for each camera, and two calibration sequences will be uploaded and performed. These calibration sequences include taking data on bright stars to characterize the pixel response function and refine the focal plane geometry model (sky-to-pixel mapping). This phase also includes the lunar encounter and final period adjustment maneuver to inject *TESS* into its final high earth elliptical orbit (see Sec. 2.4, Fig. 7). The instrument calibration phase nominally ends on day 55 after launch. *TESS* will then begin science collection with an initial science test orbit and data downlink. Science operations and the collection of data in the first observing sector are expected to start day 68 of the mission.

If the *TESS* launch is delayed from the currently scheduled date of March 20, 2018, the commissioning timescale will change. This is to accommodate the revised timing of phasing orbit maneuvers needed to reach the key lunar encounter and attain the final orbit. The nominal commissioning plan as presented lasts 60 days, but this can extend by a few weeks depending on the exact launch date and time.

5. Data Products

Processing of *TESS* data is performed by the SPOC (Jenkins et al. 2016). *TESS* data products are then sent to the SOC for validation and disseminated for hosting at the MAST. Data products at the MAST will be updated during the mission at regular intervals (see Sec. 3.5). The primary data products from *TESS* are very similar to the deliverables from the *Kepler* mission, with some key differences where there is not an analogous *Kepler* data product. *TESS* data products are described in the below subsections. A more detailed description of their naming conventions, timestamps, coordinate systems, file and header formats, and detailed data structure can be found in supporting *TESS* data product documentation, available closer to launch, on the *TESS* MAST pages.

5.1 Full Frame Images

TESS FFI files are in FITS format and contain all pixels on a single CCD per 30 minute cadence observation. Thus, a full *TESS* observing sector (see Fig. 9) consists of many such FFIs, one for each CCD in each camera for each 30 min observation. FFI data will be provided in three types: uncalibrated, calibrated, and uncertainty. Uncalibrated FFI data will be provided in one file with two Header/Data Units (HDUs): a primary header and the CCD image header and data. The calibrated image and its uncertainty will be provided in a separate file with several HDUs: a primary header, the CCD calibrated image header and data, the CCD uncertainty image header and data, and the cosmic ray corrections binary table header and data.

5.2 Target Pixel Files

TESS Target Pixel Files (TPFs) are in FITS format and and contain all the pixels collected for a single 2 min cadence target in one observing sector. If a target is observed in more than one sector, multiple TPFs will be created for that target but they may be made available in separate deliveries to the MAST. The images in the TPF will have dimensions equal to the bounding box of the pixels that were collected for that target. Depending on the location of the target on a CCD, a TPF may therefore contain pixels that do not contain stored data. TPFs will have several HDUs: a primary header, a binary table of images header and data, the aperture mask image header and data, and the cosmic ray correction binary table header and data. The aperture mask image provided with each TPF file indicates the pixels that were collected for the target and which of those pixels were used for photometry.

5.3 Light Curves

TESS light curves are FITS format files that contain the output of the photometric extraction and subsequent systematics removal (cotrending) performed by the SPOC algorithms. A single light curve file contains the data for one target for one observing sector. Identical to the case for TPFs, if a target was observed in more than one *TESS* sector, multiple light curve files will be created but they may be made available on the MAST in separate deliveries. Light curve files will also consist of several HDUs: a primary header, the light curve photometry binary table header and data, the aperture mask image header and data. The aperture mask image provided with each light curve is the same as that provided with the corresponding target TPF file.

5.4 Complementary Data Products

Many data products complementary to the FFIs, TPFs, and light curves will also be provided with each release. These include:

- Collateral Target Pixel files which archive the pixel level calibration data collected per CCD per camera during science operations.

- Cotrending Basis Vectors (CBVs) which represent the set of systematic trends present in the light curve data for each CCD. CBVs can be implemented to remove common instrumental effects from uncorrected light curve data if standard cotrended data is insufficient for a given target.

- Data products related to the automated search for transit signals in *TESS* light curves:
  - Data Validation (DV) summary reports for a single TCE,
  - Full DV reports that detail all TCEs associated with a single target,
  - DV Results XML Schema definitions,
  - DV Time Series that contain light curves for the target as a whole and separate HDUs for each TCE.

A full list of the primary and complementary TESS data products is provided in Table 3.

Table 3 Summary of *TESS* data products

Data Type	Naming Convention	File Type
Uncalibrated full frame image	tess*yyyydddhhmmss-cam-ccd-scid-cr*_ffir.fits.gz	FITS+GZIP
Calibrated full frame image	tess*yyyydddhhmmss-cam-ccd-cr*_ffic.fits.gz	FITS+GZIP
Target pixels	tess*yyyydddhhmmss-tid-scid-cr*_tp.fits.gz	FITS+GZIP
Light curves	tess*yyyydddhhmmss-tid-scid-cr*_lc.fits.gz	FITS+GZIP
Collateral target pixel files	tess*yyyydddhhmmss-cam-ccd-scid-cr*_col.fits.gz	FITS+GZIP
Cotrending basis vectors	tess*yyyydddhhmmss-cam-ccd-scid-cr*_cbv.fits	FITS
Full data validation report	tess*yyyydddhhmmss-tid-pin*_dvr.pdf	PDF
TCE summary report	tess*yyyydddhhmmss-tid-pn-pin*_dvs.pdf	PDF
Data validation results	tess*yyyydddhhmmss-tid-pin*_dvr.xml.gz	XML
DV Results XML Schema Definition	tess*pin*_dvr.xsd	XML Schema
Data validation time series	tess*yyyydddhhmmss-tid-pin*_dvt.fits.gz	FITS+GZIP

6 Guest Investigator Program

6.1 Overview

The *TESS* mission has a robust Guest Investigator (GI) program that will be administered and managed by NASA's Goddard Space Flight Center through the TSSC. The goal of the *TESS* GI program is to enhance and maximize the science return of the *TESS* mission. Under the GI program, the astrophysics community may propose new 2 min cadence targets and investigations using both 2 min cadence data of preselected CTL targets and 30 min cadence FFI data. *TESS* GI proposal calls will occur once per year and be announced within the NASA ROSES solicitation. The GI program is intended to enable science investigations outside of the core science goals of the mission and provide associated funding to US institution based Principal Investigators to analyze 2 min cadence target pixel files and light curves and 30 min cadence FFI data. Funding will be allocated to proposals ranked highly during panel review on the basis of a budget request.

The *TESS* primary mission duration is two years. The first year will be spent observing the southern ecliptic hemisphere and corresponds to *TESS* GI Program Cycle 1. The Announcement of Opportunity for Cycle 1 will be released 9 months prior to the launch date as an amendment to the NASA ROSES solicitation. Cycle 1 proposals will be due 6 months prior to launch and selected programs will be announced 3 months prior to launch. In the second year, *TESS* will observe the northern ecliptic hemisphere and solicit GI Program Cycle 2. During the primary mission, the majority of the 2 min cadence targets observed will be taken from the *TESS* CTL. In each Cycle, around 10,000 2 min cadence target slots will be assigned to the GI Program, or about 700-800 unique GI targets per observing sector. Consistent with NASA Explorer Program policy, there will be no proprietary data rights to observations conducted with *TESS*. All data will be made freely available through the MAST archive (see Sec. 3.5).

The following subsections provide a summary of the *TESS* GI program requirements, procedures, and resources. Proposers should use the *TESS* GI program Cycle 1 call for proposals (available here) as their primary source for more detailed information regarding the program requirements. Questions regarding the *TESS* GI program requirements, proposal suitability and compliance, and any other questions related to the *TESS* mission can be addressed to the TSSC using the HEASARC help desk:

http://heasarc.gsfc.nasa.gov/cgi-bin/Feedback

Select TESS under 'Choose a mailing list', or through the *TESS* GI program email address:

tessgi@bigbang.gsfc.nasa.gov

6.2 Allowed Programs

The GI Program welcomes proposals addressing compelling scientific questions in almost any area of astrophysics and planetary science provided that the required observations are amenable to the operational characteristics and constraints of the *TESS* mission and do not reproduce the core science of the mission (see Sec. 3.1). The science motivation may include, but is not limited to, exoplanet characterization, stellar astrophysics, galactic and extragalactic astrophysics, transient observations, and solar system science. Proposals may request investigations with 2 min cadence target pixel files and light curves, including new 2 min cadence targets, investigations with 30 min cadence FFI data, or combinations of these options. Allowed investigations can include software development, for example to extract light curves from FFI data or perform transient searches. *TESS* GI program proposals are anticipated to fall into 5 broad categories:

Programs Solicited

1. Exoplanet investigations proposing new 2 min cadence targets beyond those already being observed in support of the *TESS* primary mission science;

2. Exoplanet investigations using 30 min cadence FFI data, including ground-based observing components and the development of analysis software;

3. Solar system, galactic, and extragalactic astrophysics investigations using 2 min cadence target pixel files and light curves, including new targets and those already being observed in support of the *TESS* primary mission science;

4. Solar system, galactic, and extragalactic astrophysics investigations using 30 min cadence FFI data, including the development of analysis software;

5. Development of novel planet confirmation techniques and/or algorithms using *TESS* data.

The *only* science topics that Guest Investigators are not permitted to propose are those that directly reproduce the primary science of the mission (see Sec. 3.1). Explicitly, this restriction is limited to investigations whose aims include:

Programs Not Solicited

1. Detection of transiting exoplanets with periods up to 10 days orbiting the ~100,000 high priority targets in each ecliptic hemisphere that are being observed in support of the *TESS* primary mission science;

2. Detection of transiting exoplanets with periods up to 120 days orbiting stars near the ecliptic poles that are being observed in support of the *TESS* primary mission science ;

3. Assuring the masses of 50 exoplanets $<4\ R_{Earth}$ are determined through ground-based follow-up and/or analytical techniques.

We emphasize that these restrictions *apply only* to the detection of exoplanets orbiting the subset of high priority mission target stars, using 2 min cadence data products, and *using the transit method*. Alternate planet detection techniques and all other astrophysics investigations that use *TESS* data are allowed for any of the high priority targets. There are no restrictions imposed on the use of FFI data for exoplanet detection and characterization and such proposals are encouraged.

All science proposals must be compelling and carefully justified scientifically and technically. The *TESS* GI program is reserved for science requiring new *TESS* data. The proposal may include limited theoretical components, unique ground-based follow-up, software development and/or data simulations that strengthen the proposal. However, at least 70% of the work effort should be focused on using *TESS* data products. Investigations where the primary emphasis is ground-based observing, theory/modeling, or archival data analysis will be considered non-compliant. The NASA ROSES Research Announcement provides several alternative opportunities to exploit or support the *TESS* mission in these areas:

- Investigations for which the primary emphasis is theory/modeling may propose to the Astrophysics Theory Program (ATP) or the Exoplanets Research Program (XRP);

- Investigations for which the primary emphasis is analysis of archival data may be proposed to the Astrophysics Data Analysis Program (ADAP). ADAP proposals require that all data being used for the investigation are publicly available at the time of the proposal deadline;

- Investigations for which the primary emphasis is the collection and/or analysis of ground-based data may be proposed to the Exoplanet Research Program (XRP) or the NSF Astronomy and Astrophysics Research Grants Program (AAG).

Proposers with questions regarding the compliance of their investigation are encouraged to contact the TSSC.

Any software developed with *TESS* GI funds must add value to the *TESS* science community, be free and open source, with the source code made publicly available. Any ground-based follow-up data collected through *TESS* GI funding support must be made publicly available in a timely fashion NASA Exoplanet Science Institute (NExScI) ExoFOP service (https://exofop.ipac.caltech.edu/). Any supporting exoplanet data should also be archived through the NExScI --- NASA's repository for exoplanet data. Supporting data for non-exoplanet related science should be archived through a public data archive service. Proposals must clearly describe plans to make any new software or supporting data publicly available.

The *TESS* GI program also accommodates Target of Opportunity Observations (ToOs). ToOs are rapidly evolving phenomena whose occurrence is not predictable. ToO's can only be uploaded to the spacecraft during uplinks that occur once every 13.7 days. Proposals requesting ToOs must describe the circumstances in which a ToO is "triggered" in the scientific justification and the description of the target. ToO proposals must also include an estimated duration of the event, as well as an estimated probability for triggering the observations; the latter will be used in the accounting of total allocated targets. ToOs remain active only for the observing Cycle in effect; ToOs not carried out during the Cycle 1 may be re-proposed for subsequent Cycles. In the case of ToOs, observations would commence at the next upload event following the trigger event. The timeline of such uploads can be as large as 2 months, particularly early in the mission. The impact to science of such a potential delay must be addressed in proposals requesting ToO observations.

A small part of the *TESS* GI pixel budget may be allocated by the project as Director's Discretionary Targets (DDT). The DDT program is intended to facilitate community proposed requests that are based on exceptional, time-critical observations that could not be accommodated during the regular proposal Cycle, and that address scientific topics missed in the proposal review process. Other possible avenues for DDT proposals include innovative observations that extend the scientific capabilities of *TESS*, and extraordinary events and opportunities that necessitate observations be obtained with *TESS* for the benefit of the astronomical community. More details of the DDT program will appear in revised versions of this guide and on the *TESS* GI website when the program is initiated. In the interim, please contact tessgi@bigbang.gsfc.nasa.gov with comments and concerns.

6.3 Proposal Preparation and Submission

The *TESS* GI program uses a two-phase proposal process. A Phase-1 proposal will include a science/technical justification, and in the case of requesting funds, a one paragraph budget narrative describing in sufficient detail how the proposed funds will be used to achieve the goals outlined in the proposal. Only proposers whose Phase-1 proposals are accepted will be invited to submit full budget proposals in Phase-2. It is not necessary for the PI of the Phase-2 proposal to be the Science PI. Proposal content, including the list of investigators, must remain consistent between Phase-1 and Phase-2 proposals. All proposal materials will be submitted electronically:

- All Proposers must submit their Phase-1 proposals electronically through the Astrophysics Research Knowledgebase/Remote Proposal System (ARK/RPS) website;
- Target tables for all observation proposals are to be submitted through ARK/RPS;
- The Scientific/Technical section of proposals is limited to four pages (including budget justification where appropriate), no table of contents is required in the body of the proposal, and no supporting material (e.g., curriculum vitae (CV), pending/current support) is required or permitted;
- Optional LaTeX and MS Word templates for the Scientific/Technical section are available on the TESS GI program website;
- The Scientific/Technical section must be uploaded to the RPS website as a PDF file.

All Phase-1 proposal materials must be submitted electronically by 4:30 p.m. Eastern time on the due date for the current program Cycle given in the *TESS* GI proposal call in order to be included in the proposal review. NASA uses a single, uniform set of instructions for the submission of ROSES proposals. These instructions are given in the NASA Guidebook for Proposers. *TESS* GI Proposers should follow these instructions, except where they are overridden by the instructions given in the ROSES Summary of Solicitation or the *TESS* GI proposal call.

Subject to the availability of funding, successful Phase-1 proposers will be contacted and invited to submit a Phase-2 budget proposal. The Phase-1 selection notification will provide instructions for submitting the Phase-2 proposals through the NASA NSPIRES electronic proposal website (https://nspires.nasaprs.com) by an Authorized Organizational Representative (AOR) of the proposing organization. The Phase-2 proposal will consist of a Budget Details sections with a maximum length of 2 pages and a Narrative section with a maximum length of 2 pages.

6.4 Proposal Evaluation

Phase-1 proposals submitted in response to the *TESS* GI program call will be evaluated via peer-review with respect to the criteria specified in the NASA Guidebook for Proposers, which are intrinsic merit, relevance to the GI solicitation, and the realism/reasonableness of the proposed work effort and resources. In addition to the factors for intrinsic merit given in the NASA Guidebook for Proposers, intrinsic merit includes the following factors:

- The suitability of using the *TESS* survey and data products for the proposed investigation;
- The extent to which the investigation complements and enhances the anticipated science

return from the *TESS* mission;

- The degree to which the proposed investigation places demands upon mission resources; and
- The degree to which the proposed investigation capitalizes on the unique capabilities of *TESS*.

The proposed *TESS* Guest Investigation must clearly enhance the science return of the *TESS* mission. Proposers must take into account the difference between science that can be achieved exclusively using 30 min cadence FFI data and science that requires new observations at 2 min cadence.

All Phase-1 proposals will be peer-reviewed and ranked by a panel of professional volunteers, followed by ratification from NASA Headquarters. The members of the peer-review panel will not be disclosed. The deliberations and decisions of the peer-review panel will only be disclosed to PIs after ratification by the NASA selecting official. NASA recognizes and supports the benefits of having diverse and inclusive scientific, engineering, and technology communities and fully expects that such values will be reflected in the composition of all panels and teams including peer review panels (science, engineering, and technology), proposal teams, science definition teams, and mission and instrument teams.

Phase-2 budget proposals will be evaluated by NASA program personnel against cost realism and reasonableness. Comparison of the proposed cost to available funds will be performed as specified in Section C.2 of the NASA Guidebook for Proposers.

6.5 Funding Availability and Eligibility

It is anticipated that up to $2.5M will be available in Cycle 1 for the support of approximately 30 Guest Investigations of two-years duration each. Additional 2 min cadence GI targets may be selected and observed from proposals not selected for a funding award if target resources permit. New *TESS* 2 min cadence observations are open to all scientists at U.S. or non-U.S. institutions. *TESS* GI funding is *only* open to individuals who are identified as Principal Investigators and employed at U.S. institutions, including *TESS* science team members. Scientists participating in the *TESS* mission, including members of the Follow-up Team who are not funded by the Project, are also eligible for funding support under the GI Program. *TESS* science team members who already receive support from the Project must provide a compelling justification for the award of additional funds under the GI Program.

There are typically two categories of *TESS* GI proposals. Guest Investigators are free to select the category that best reflects the scope of their proposed work.

- Small proposals - proposals of limited scope that will carry an average award of $50,000.
- Large proposals - proposal of wide-ranging scope and science yield. Large proposals will carry an average award of $200,000. Large proposals must deliver a clear benefit for the broader scientific community.

Funding will be allocated to successful programs following a budget justification provided by the proposer. Funding for selected programs typically starts upon availability of data to the public archive at the MAST. The performance period of each award will be 2 years.

6.6 Proposal Tools and Tips

The first stop for *TESS* GI proposers when preparing their proposals should be the STScI/MAST *TESS* pages (https://archive.stsci.edu/tess/). Here, proposers can follow tutorials to learn how to access the TIC and CTL, crossmatch their targets with these catalogs, and create output files with relevant target information required for the GI call. The *TESS* GI program office *requires* that if a target is in the TIC, GI proposers must provide ***only the following columns*** from the TIC in comma separated value (csv) format:

1. TIC ID (if available),
2. Right Ascension (decimal degrees),
3. Declination (decimal degrees),
4. Proper motion in Right Ascension (mas yr^{-1}),
5. Proper motion in Declination (mas yr^{-1}),
6. *T* mag.

Since adherence to this format is critical for target list uploads to the RPS system (see Sec. 6.3), the MAST has provided a custom tutorial to show GI proposers how to select and output these columns for their target lists. Please follow this tutorial to provide a compliant target list.

The TSWG has also provided a tool for GI proposers to view and manipulate a high-priority subset of the current CTL in the Filtergraph data visualization system (Burger et al. 2013). Filtergraph is an online tool to upload data files, visualize the data in various formats (i.e. scatter plots, histograms, heat maps, etc.), manipulate these visualizations by filtering the data, and save figures in standard image output formats. Figure 15 provides an example of a CTL visualization that can be made using Filtergraph. The figure displays all stars in CTL-5 in Dec vs. RA and color-coded by *T* mag. Features inherent to the CTL are immediately noticeable, such as the lower density of targets in the Galactic plane (due to high background contamination) and the higher density of targets in the ecliptic poles where *TESS* will have the longest continuous observation baseline and be more sensitive to transiting planets (see Fig. 10). Additional premade figures are available on the CTL Filtergraph page, including CTL *T* mag and effective temperature histograms. Users may also create their own Filtergraph account and upload their own target lists for visualization following the instructions and tutorials on the main Filtergraph webpage.

Software tools are also provided by the TSSC to aid GI proposers. The currently available tools and their capabilities are described below. Detailed descriptions of their use and installation of downloadable code are available on the TSSC website. As more tools are developed and made publicly available, this document will be updated along with the documentation on the TSSC website.

Tool for predicting *TESS* target observability:

TESS Viewing Guide (TVGuide)	
	● Estimate observability of a single target during Cycle 1 ● Estimate the observability of a list of targets during Cycle 1 ● Estimates number of times target will be observed ● Available as webtool or downloadable python tool
URL:	https://heasarc.gsfc.nasa.gov/docs/tess
Notes:	TVGuide is based on current best estimates of *TESS* sector positions assuming March 20, 2018 launch. Detailed information regarding CCD and camera gaps are not currently included.
RPS input:	None.

Tool for estimating *T* mag and other parameters for any target:

TICGen	
	● Used for targets not available in the TIC ● Estimate *TESS* mag and other TIC parameters for a single target ● Estimate *TESS* mag and other TIC parameters for a list of targets ● Available as webtool or downloadable python tool
URL:	https://heasarc.gsfc.nasa.gov/docs/tess
Notes:	TICGen uses algorithms developed by the TSWG to generate the TIC/CTL.
RPS input:	*T* mag is required input for targets in RPS

Due to the observing strategy of the *TESS* mission, the TSSC notes that GI proposers should be aware of several details when composing a science cases and target lists.

- The exact location of the first observing sector (and therefore all subsequent observing sectors) is a sensitive function of the *TESS* launch date. For GI program Cycle 1, the impact of the uncertainty in the exact sky locations of the *TESS* FOVs is that there is no guarantee that any given proposed target will not fall into a gap between sectors, camera CCDs, or camera FOVs. The mitigate this uncertainty, Cycle 1 proposers are encouraged to consider target lists that include a number of similar sources distributed across the sky.

- Adjacent *TESS* observing sectors have overlapping regions near the ecliptic poles (see Fig. 10), providing longer-term continuous coverage for stars falling in these regions which in turn provides sensitivity to smaller and longer-period planets. Objects within 12^{o} of the ecliptic poles may be observed for ~1 year.

- Camera 4 is always centered on the ecliptic pole and targets in this camera will be observed continuously for an entire Cycle. This leads to a limitation in the number of 2 min cadence targets that can be selected in the portion of sky covered by camera 4.

- Camera 1 is always closest to the ecliptic plane and will be contaminated by stray light from the Earth and Moon during some observing sectors (see Fig. 11). The level of contamination and which sectors will be most affected is dependent on the launch date and the final inclination of the *TESS* orbit. These parameters will not be known until after commissioning and calibration.

- Some cameras during some observing sectors will cover portions of the Galactic plane and suffer from increased background contamination (see Fig. 15). The exact cameras and sectors are dependent on the *TESS* launch date.

- A primary science target will nominally be observed nearly continuously for 27.4 days in a given *TESS* observing sector. However, mission requirements only require a minimum of 20 days of observations out of the 27.4 possible per sector. This requirement accounts for all sources of observing inefficiency, including repointing for data downlink and interruptions due to the Earth and/or Moon in a camera FOV.

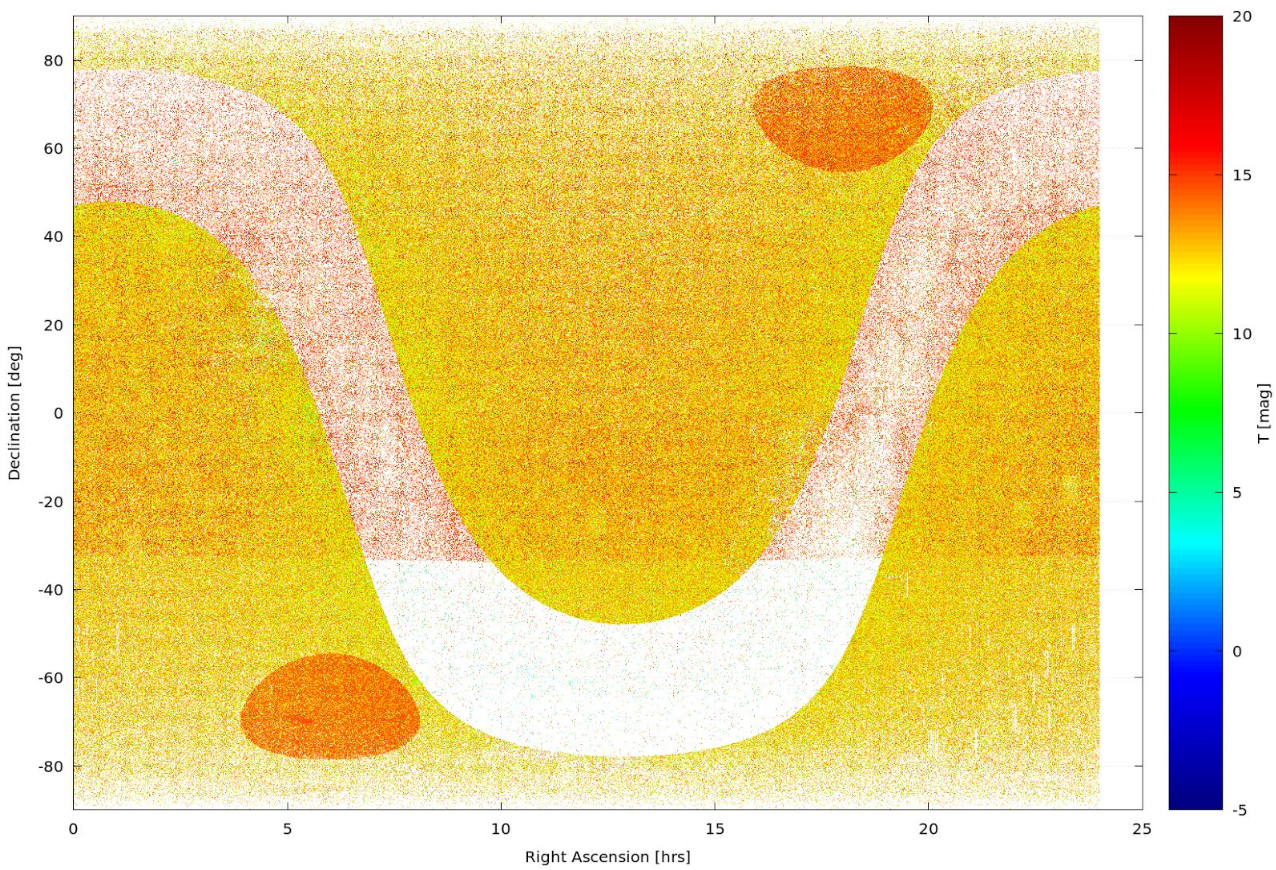


Figure 15 CTL-5 visualization generated using TIC/CTL Filtergraph portal. The figure shows the distribution of stars in the CTL-5 in equatorial coordinates. The color bar represents the targets' *T* magnitudes. There are fewer stars in the Galactic plane due to background contamination. The two elliptical regions of higher target density are the ecliptic poles, where *TESS* will observe continuously for nearly a year.

6.7 Simulated Data

During development of the *TESS* mission, the ground-segment goes through several tests known as Ground System Interface Tests (GSITs). These include data simulations to develop data formats and test SPOC processing algorithms. To aid potential *TESS* users in the development of tools and to assess the feasibility of investigations, the mission is planning to make available simulated data from the GSIT-2 test. This includes TPFs and light curves and is anticipated to be available on the *TESS* MAST pages in Summer 2017. Simulated FFIs and Data Validation products will be produced during GSIT-3 and are anticipated to be publicly available in Fall 2017.

7. Data Analysis

The TSSC is currently developing data analysis tools that are adapted from the PyKE package developed for Kepler/*K2* (Still & Barclay 2012). PyKE currently provides software for extracting light curves and tuning cotrending and detrending to suit a user's science needs. We anticipate the release of *TESS* oriented tools prior to the first public data release. The MAST is also developing tools to work with *TESS* FFIs which will be made available on the *TESS* MAST pages. The TSSC website and future versions of this guide will provide descriptions and access to these tools as they become available.

References

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