Guide for TESS Extended Mission Planning

This document accompanies the Call for Community Input into Extended Mission Planning for NASA's Transiting Exoplanet Survey Satellite (TESS). The intent of this document is to provide the community with information about the TESS mission and operational limitations that may be helpful during science pitch preparation. Note that substantial changes in operations may not be feasible in time for the start of Extended Mission 3 (EM3) in September 2025 but may be considered for future extended missions. Please direct questions to the TESS help desk at tesshelp@bigbang.gsfc.nasa.gov.

Background on TESS

TESS launched in 2018 to perform a near all-sky survey to search for planets transiting nearby stars. The below text summarizes TESS, and more information can be found at the TESS Science Support Center's website[1].

The TESS observatory consists of the spacecraft and the payload. The TESS payload has a single instrument, a camera suite composed of four identical refractive cameras with a combined field-of-view (FOV) of 24x96 degrees. The observing strategy for TESS since launch is to tile the sky, observing a 24x96 degree section of sky for two spacecraft orbits (each 13.7 days on average) over a ~27-day period of time known as a sector, before moving on to the next sector. During observations, the TESS cameras produce a continuous stream of images with an exposure time of 2 seconds. The onboard Data Handling Unit performs real-time processing on these data, including cosmic ray mitigation, collecting pixel sub-arrays for postage stamp targets (also referred to as Target Pixel Files or TPFs), and image stacking for the Full-Frame Images (FFIs).

TESS data are downlinked from the spacecraft weekly via the Deep Space Network (DSN) and processed by the SPOC mission pipeline at NASA Ames and the TICA pipeline at MIT. The TPFs routinely achieve 200 parts per million (ppm) photometric precision in 1 hour at T = 10 (TESS magnitude 10).

During its 2-year prime mission (2018-2020), over 200,000 pre-selected stars were monitored at 2-minute cadence as TPFs. FFIs of the entire 24 x 96 degrees FOV were obtained at a cadence of 30 minutes to facilitate additional science. Most of the northern and southern ecliptic hemispheres were surveyed during the prime mission. In its first extended mission (2020-2022), TESS introduced a new 20-second cadence mode for pre-selected targets, continued its 2-minute cadence mode for pre-selected targets, and shortened the FFI cadence to 10 minutes. In its second extended mission (2022-2025), TESS shortened the FFI cadence to 200 seconds and maintained the 20-second and 2-minute cadence mode for pre-selected targets. In both extended missions, the northern and southern ecliptic hemispheres were re-observed and parts of the ecliptic plane were surveyed for the first time. See Table 1 for a summary of the cadences and pointings to date.

TESS's third extended mission (EM3) is expected to occur September 2025-September 2028, with operations contingent upon the outcome of the 2025 Astrophysics Senior Review.

[1] https://heasarc.gsfc.nasa.gov/docs/tess/documentation.html

Table 1. Summary of TESS cadences and pointings.

	FFI Cadence	Target Pixel File (TPF) Cadence	Number of TPF Targets	Pointing	Cumulative coverage of the sky			
					≥1 sector	≥2 sectors	≥3 sectors	Baseline ≥ 1 yr
Prime Mission (2018-2020)	30 min	120 s	20,000	Southern Hemisphere, Northern Hemisphere	70%	22%	10%	1.6%
First Extended Mission (2020-2022)	10 min	120 s 20 s	20,000 1,500	Southern Hemisphere, Northern Hemisphere, Ecliptic Plane	89%	67%	33%	59%
Second Extended Mission (2022-2025)	200 s	120 s 20 s	13,000 2,500	Southern Hemisphere, Northern Hemisphere, Ecliptic Plane	97%	87%	68%	84%

Broad sky coverage, fast cadence, and exquisite photometric precision have enabled TESS to evolve from an exoplanet hunter in its prime mission to a general-purpose time-domain facility in its extended mission. There are currently >1700 peer-reviewed TESS publications, with 60% of these related to general astrophysics and 40% related to exoplanets.

Examples of TESS science include:

- Transiting exoplanets around nearby, bright stars
- Asteroseismology of solar-type and giant stars
- Stellar flares and rotation
- Optical counterparts of gamma-ray bursts
- Supernovae
- Asteroids

The TESS General Investigator (GI) program[2] solicits TPF targets and funds science investigations every year following a dual-anonymous peer-review process. As a survey mission, TESS's observing plan is fixed, but GI proposals may request TPF targets in TESS's planned FOV. Anyone may propose for TPF targets, but only those at U.S. institutions may receive funding.

[2] https://heasarc.gsfc.nasa.gov/docs/tess/proposing-investigations.html

The almost 1 PB of available TESS data are archived at the Mikulski Archive for Space Telescopes[3] (MAST). Official mission products include FFIs, TPFs, and high-quality light curves produced from the TPFs. The mission produces data release notes for every sector and several catalogs identifying transiting exoplanet candidates. Various tools exist to generate light curves directly from the FFIs for any target, including eleanor[4] and TESSCut[5]. There are millions of light curves generated by the TESS community hosted on MAST as high-level science products[6]. MAST's TIKE platform enables analysis of TESS data in the cloud.

The TESS mission maintains a help desk[7] dedicated to answering the community's questions about the TESS mission, proposing to observe with TESS, instrument characteristics, data and calibration issues, and data analysis software. Please email: tesshelp@bigbang.gsfc.nasa.gov.

Mission parameters and constraints to consider for extended mission science pitches

See Table 2 (below) for a summary of possible changes to the TESS mission that could enable new science investigations. The following text describes restrictions imposed on the mission by the spacecraft and ground systems.

Observatory pointing constraints

Sector Durations

The duration of each TESS sector is set by the need to keep the TESS payload pointed in the anti-solar direction to maintain thermal stability. This pointing requirement has historically been to keep the centerline of the camera array within ±15° of anti-solar, limiting the duration of a sector to two orbits, or ~27 days. The TESS team is exploring whether it may be possible to relax this anti-solar pointing requirement to ±30°, allowing the duration of a sector to be increased to four spacecraft orbits, or ~54 days. See Figure 1 for an example of how this would impact TESS's sky coverage.

Locations on the Sky

TESS observations have generally tiled an ecliptic hemisphere in one year by orienting the FOV North-South and centering camera 4 on the ecliptic pole, then alternating which hemisphere is observed every year (Figure 1). There is some flexibility that allows the fields to be shifted poleward along the centerline, as was done in Sectors 14-16[8]: this results in observations that are roughly centered on the

[3] https://archive.stsci.edu/missions-and-data/tess
[4] https://eleanor.readthedocs.io/en/latest/
[5] https://mast.stsci.edu/tesscut/
[6] https://mast.stsci.edu/hlsp
[7] https://heasarc.gsfc.nasa.gov/docs/tess/helpdesk.html
[8] https://heasarc.gsfc.nasa.gov/docs/tess/primary.html#sky-coverage

poles, at the cost of not observing fields at lower ecliptic latitudes. Shifting the fields toward the equator is also possible.

If the anti-solar requirement is relaxed from ±15° to ±30°, observations of a particular part of the sky in this orientation can be roughly doubled in duration.

The FOV can also be rotated 90° and the long axis centered close to the ecliptic, as was done in Sectors 42-46[9] and 70-72. The Earth and Moon live near the ecliptic, as seen from TESS, and both can be a very strong source of scattered light during ecliptic observations; however, these regions of high scattered light are typically ~120° in extent in ecliptic latitude and can be avoided by planning the observations for times of the year when the Earth and Moon are less of a problem. Ecliptic pointings to date were made to ensure coverage of 240° of ecliptic longitude over 2-3 sectors; however, there is some flexibility in ecliptic pointings that could allow longer observations of some parts of the ecliptic. Relaxation of the anti-solar requirement to ±30° will have no effect on ecliptic observations.

Image cadence and data downlink constraints

TESS has a solid state recorder (SSR) with a capacity of 192 GB for onboard storage. Science data stored on the SSR are currently downlinked twice every orbit (i.e., once a week) using TESS's Ka-band antenna and the DSN, once at perigee and once at apogee. TESS is currently observing ~13,000 2-minute TPFs, ~2,500 20-second TPFs, and is collecting FFIs every 200 seconds: this science plan fills the SSR roughly half-full each half-orbit, which allows for a data safety margin of ~100% (in case a DSN contact is missed). The vast majority of the data collected is in FFIs: currently, 20-second and 2-minute TPFs each contribute ~6% of the total collected data volume.

Other cadences for the TPFs and FFIs can be considered, in principle: their impact on data management will scale roughly as the exposure time and the number of targets. A 2-second TPF mode is being investigated, which would be available to a limited number of targets. These changes are subject to both on-board data processing and storage considerations and downlink capacities, as well as cost considerations for changes to ground operations.

The TESS team uplinks commands and downlinks housekeeping data from TESS four times per orbit (i.e., twice a week) using TESS's S-band antenna. The volume of information communicated is much smaller than the less frequent Ka-band downlinks. It may be possible to quickly downlink subarrays from a few TESS FFIs via this S-band interface for time-critical events that TESS may have observed (e.g., high energy transients such as kilonovae) in order to localize these events on the sky.

Table 2. Summary of possible changes to the TESS mission for EM3 and beyond.

Possible parameters to	**Current (EM2) value(s)**	**Notes**

[9] https://heasarc.gsfc.nasa.gov/docs/tess/extended.html

change		
FFI cadence	200 s	Available Ka-band downlink resources and on-board storage capacity limit the FFI cadence to ≥200 seconds. Shortening the cadence would require additional financial and downlink resources, which may not be available.
TPF cadence(s)	120 s and 20 s	Faster cadences will fill up on-board storage more quickly. A 2-second TPF cadence is being investigated.
Pointing locations (sectors)	Northern Hemisphere, Southern Hemisphere, Ecliptic Plane	Observations to date have been made a) with the camera array oriented N-S and centered at either ±54° or ±85° ecliptic latitude or b) with the camera array oriented along the ecliptic, with all observations lasting 2 orbits. Possible changes include centering at different ecliptic latitudes, introducing a small roll (≲20°, if the anti-solar restriction is loosened) in the camera orientation, and ecliptic observations with significant overlap between sectors.
Sector durations	~27 days	It may be possible to extend sector durations up to 54 days.
Science data availability	All collected science data downlinked 1x per week	For time-critical events, the TESS team is investigating the possibility that subarrays of a few FFIs could be downlinked 2x per week via existing S-band downlink resources. Data could be made available within a few days of downlink.

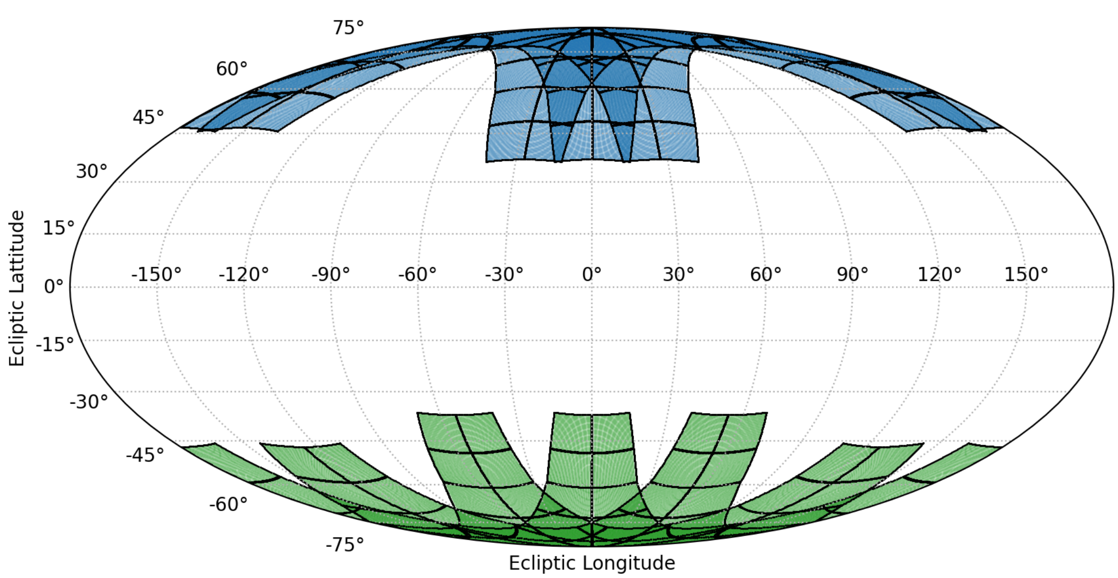

Figure 1. Example pointings where the camera array is oriented N-S centered at +85° (blue) and -85° (green) ecliptic latitude. The blue pointings show three consecutive 27-day sectors, and the green pointings show three consecutive 54-day sectors.