Transiting Exoplanet Survey Satellite

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- *The Transiting Exoplanet Survey Satellite (TESS) is a space telescope for NASA's Explorers program, designed to search for exoplanets using the transit method in an area 400 times larger than that covered by the Kepler mission.*
- *The first light image from TESS was taken on August 7, 2018, and released publicly on September 17, 2018.*

The Transiting Exoplanet Survey Satellite (TESS) is a space telescope for NASA's Explorers program, designed to search for exoplanets using the transit method in an area 400 times larger than that covered by the Kepler mission. It was launched on April 18, 2018 atop a Falcon 9 rocket. During its 2-year primary mission, it is expected to find more than 20,000 exoplanets, compared to about 3,800 exoplanets known when it launched. The first light image from TESS was taken on August 7, 2018, and released publicly on September 17, 2018.

The primary mission objective for TESS is to survey the brightest stars near the Earth for transiting exoplanets over a two-year period. The TESS satellite uses an array of wide-field cameras to perform a survey of 85% of the sky. With TESS, it is possible to study the mass, size, density and orbit of a large cohort of small planets, including a sample of rocky planets in the habitable zones of their host stars. TESS will provide prime targets for further characterization by the James Webb Space Telescope, as well as other large ground-based and space-based telescopes of the future. While previous sky surveys with ground-based telescopes have mainly detected giant exoplanets, TESS will find a large number of small planets around the nearest stars in the sky. TESS records the nearest and brightest main sequence stars hosting transiting exoplanets, which are the most favorable targets for detailed investigations.

TESS uses a novel highly-elliptical orbit around the Earth with an apogee approximately at the distance of the Moon and a perigee of 108,000 km. TESS orbits Earth twice during the time the Moon orbits once, a 2:1 resonance with the Moon. The orbit is expected to remain stable for a minimum of 10 years.

Led by the Massachusetts Institute of Technology with seed funding from Google, on April 5, 2013, it was announced that TESS, along with the Neutron Star Interior Composition Explorer (NICER), had been selected by NASA for launch.

History

- *TESS passed its critical design review (CDR) in 2015, allowing production of the satellite to begin.*
- *In 2008, MIT proposed that TESS become a full NASA mission and submitted it for the Small Explorer program at Goddard Space Flight Center, but it was not selected.*
- *While Kepler had cost US$640 million at launch, TESS cost only US$200 million (plus US$87 million for launch).*

The genesis of TESS was as early as 2006, when a design was developed from private funding by individuals, Google, and The Kavli Foundation. In 2008, MIT proposed that TESS become a full NASA mission and submitted it for the Small Explorer program at Goddard Space Flight Center, but it was not selected. It was resubmitted in 2010 as an Explorers program mission, and was approved in 2013 as a Medium Explorer mission. TESS passed its critical design review (CDR) in 2015, allowing production of the satellite to begin. While Kepler had cost US$640 million at launch, TESS cost only US$200 million (plus US$87 million for launch).

Mission overview

- *TESS will also utilize a Guest Investigator program, allowing scientists from other organizations to use TESS for their own research.*
- *TESS is designed to carry out the first spaceborne all-sky transiting exoplanet survey.*

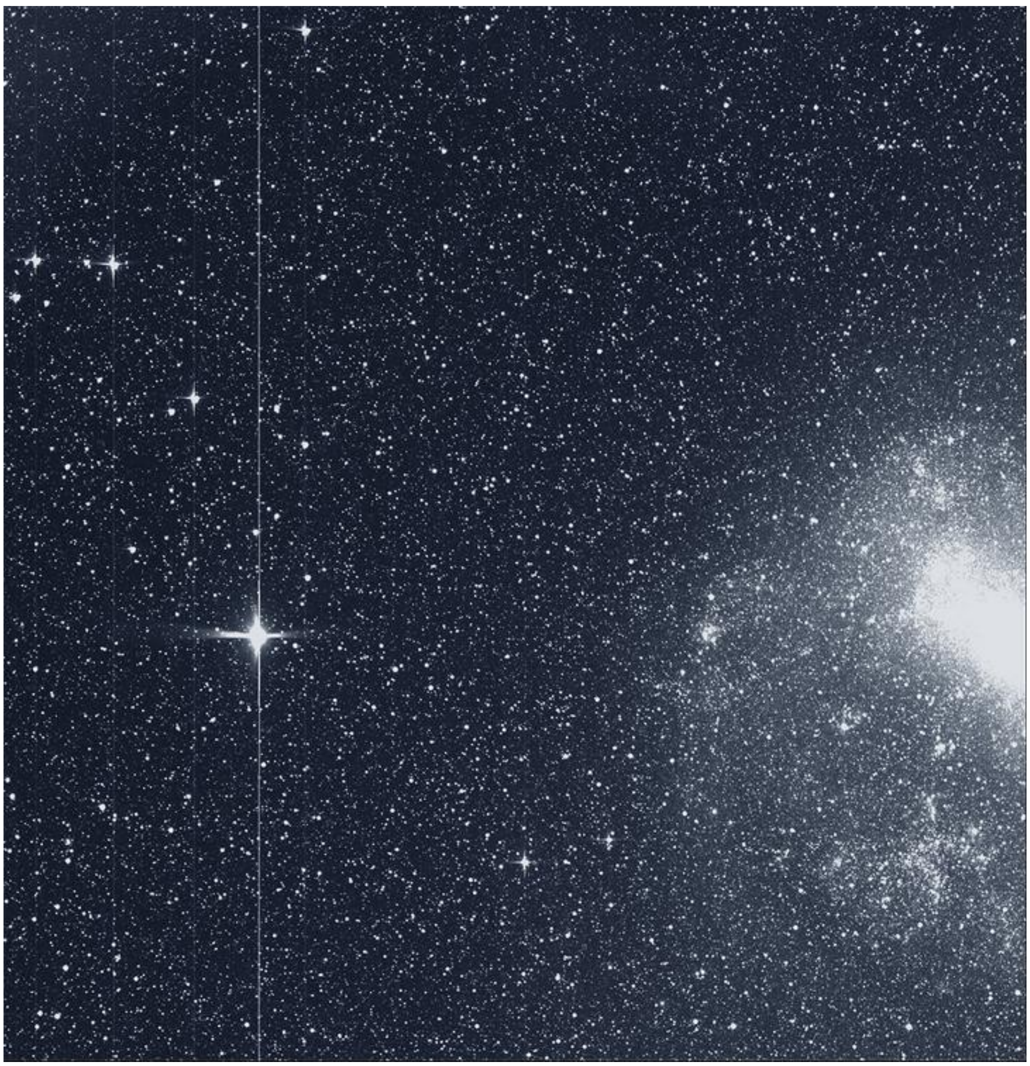
TESS is designed to carry out the first spaceborne all-sky transiting exoplanet survey. It is equipped with four wide-angle telescopes and associated charge-coupled device (CCD) detectors. Science data will be transmitted to Earth every two weeks. Full-frame images with an effective exposure time of two hours will be transmitted as well, enabling scientists to search for unexpected, transient phenomena, such as the optical counterparts to gamma-ray bursts. TESS will also utilize a Guest Investigator program, allowing scientists from other organizations to use TESS for their own research. This will allow an additional 20,000 celestial bodies to be observed.

Orbital dynamics

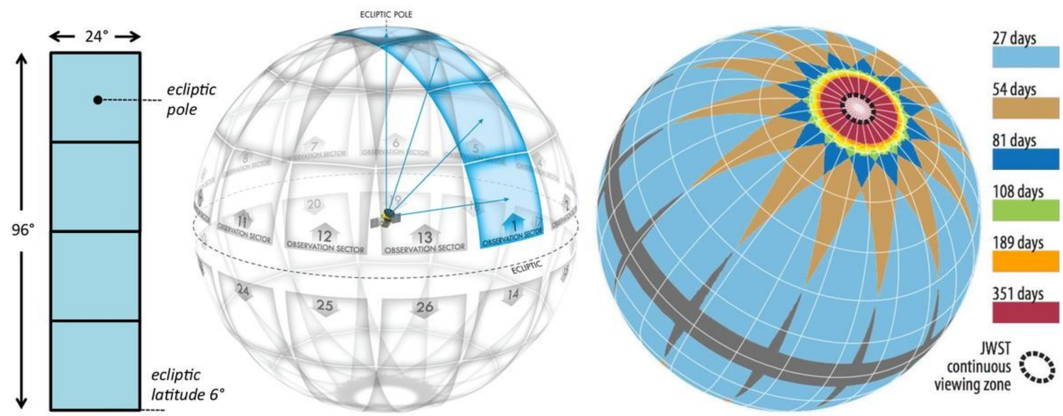
- *The orbit is entirely outside the Van Allen belts to avoid radiation damage to TESS, and most of the orbit is spent far outside the belts.*
- *This orbit should remain stable for decades and will keep TESS's cameras in a stable temperature range.*

- *In order to obtain unobstructed imagery of both the northern and southern hemispheres of the sky, TESS will utilize a 2:1 lunar resonant orbit called P/2, an orbit that has never been used before (although IBEX uses a similar P/3 orbit).*

In order to obtain unobstructed imagery of both the northern and southern hemispheres of the sky, TESS will utilize a 2:1 lunar resonant orbit called P/2, an orbit that has never been used before (although IBEX uses a similar P/3 orbit). The highly elliptical orbit has a 373,000 km (232,000 mi) apogee, timed to be positioned approximately 90° away from the position of the Moon to minimize its destabilizing effect. This orbit should remain stable for decades and will keep TESS's cameras in a stable temperature range. The orbit is entirely outside the Van Allen belts to avoid radiation damage to TESS, and most of the orbit is spent far outside the belts. Every 13.7 days at its perigee of 108,000 km (67,000 mi), TESS will downlink the data it has collected during the orbit to Earth over a period of approximately 3 hours.



TESS – first light(August 7, 2018)



The 26 observation sectors of the sky planned for TESS

Science objectives

- *TESS's two-year all-sky survey will focus on nearby G-, K-, and M-type stars with apparent magnitudes brighter than magnitude 12.*
- *This means that during the 2 years, TESS will continuously survey 85% of the sky for 27 days, with certain parts being surveyed across multiple runs.*
- *TESS is expected to discover more than 20,000 transiting exoplanets, including 500 to 1000 Earth-sized planets and super-Earths.*

TESS's two-year all-sky survey will focus on nearby G-, K-, and M-type stars with apparent magnitudes brighter than magnitude 12. Approximately 500,000 stars will be studied, including the 1,000 closest red dwarfs across the whole sky, an area 400 times larger than that covered by the Kepler mission. TESS is expected to discover more than 20,000 transiting exoplanets, including 500 to 1000 Earth-sized planets and super-Earths. Of those discoveries, an estimated 20 could be super-Earths located in the habitable zone around a star. Most exoplanets are expected to be between 30 and 300 light-years away.

The survey is broken up into 26 observation sectors, each sector being 24° × 96°, with an overlap of sectors at the ecliptic poles to allow additional sensitivity toward smaller and longer-period exoplanets in that region of the celestial sphere. The spacecraft will spend two 13.7-day orbits observing each sector, mapping the southern hemisphere of sky in its first year of operation and the northern hemisphere in its second year. The cameras actually take images every 2 seconds, but all the raw images would represent much more data volume than can be stored or downlinked. To deal with this, cutouts around 15,000 selected stars (per orbit) will be coadded over a 2-minute period and saved on board for downlink, while full-frame images will also be coadded over a 30-minute period and saved for downlink. The actual data downlinks will occur every 13.7 days near perigee. This means that during the 2 years, TESS will continuously survey 85% of the sky for 27 days, with certain parts being surveyed across multiple runs. The survey methodology was designed such that the area that will be surveyed, essentially continuously, over an entire year (351 observation days) and makes up about 5% of the entire sky, will encompass the regions of sky (near the ecliptic poles) which will be observable at any time of year with the JWST.

Asteroseismology

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The TESS team also plans to use a 30-minute observation cadence for full-frame images, which has been noted for imposing a hard Nyquist limit that can be problematic for asteroseismology of stars. Asteroseismology is the science that studies the internal structure of stars by the interpretation of their frequency spectra. Different oscillation modes penetrate to different depths inside the star. The Kepler and PLATO observatories are also intended for asteroseismology.

The Falcon 9 rocket carrying TESS, launching from Space Launch Complex 40 at Cape Canaveral in April 2018.

Launch

- *The launch was postponed again from April 16, 2018, and TESS was eventually launched on a SpaceX Falcon 9 rocket from the SLC-40 launch site at Cape Canaveral Air Force Station on April 18.*
- *The 362 kg spacecraft was originally scheduled to launch on March 20, 2018, but this was pushed back by SpaceX to allow additional time to prepare the launch vehicle and meet NASA launch service requirements.*

In December 2014, SpaceX was awarded the contract to launch TESS in August 2017, for a total contract value of US$87 million. The 362 kg spacecraft was originally scheduled to launch on March 20, 2018, but this was pushed back by SpaceX to allow additional time to prepare the launch vehicle and meet NASA launch service requirements. A static fire of the Falcon 9 rocket was completed on April 11, 2018, at approximately 18:30 UTC. The launch was postponed again from April 16, 2018, and TESS was eventually launched on a SpaceX Falcon 9 rocket from the SLC-40 launch site at Cape Canaveral Air Force Station on April 18.

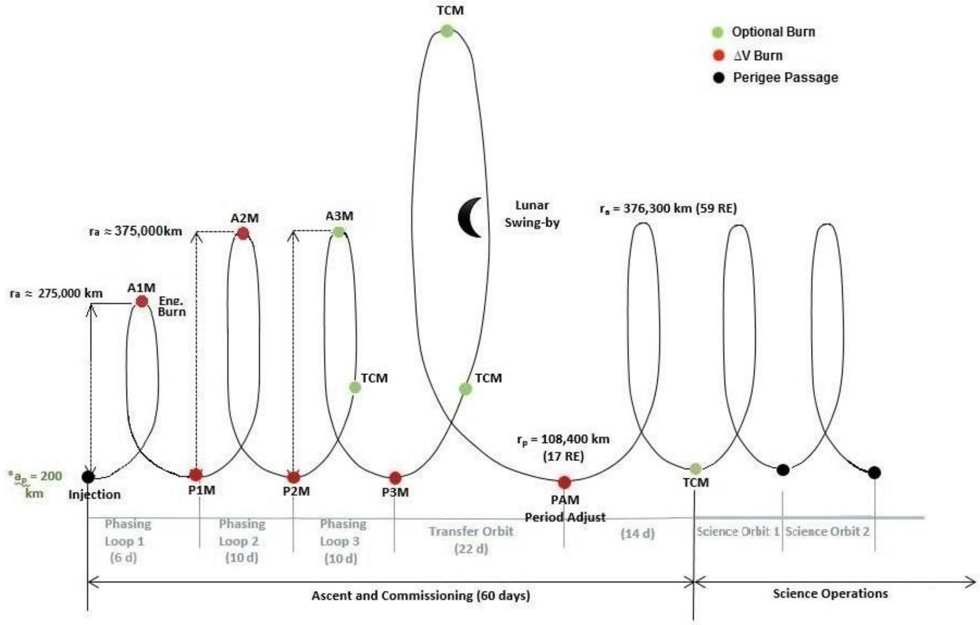
The Falcon 9 launch sequence included a 149-second burn by the first stage, followed by a 6-minute second stage burn. Meanwhile, the B1045 first-stage Block 4 booster performed controlled-reentry maneuvers and successfully landed on the autonomous drone ship Of Course I Still Love You. After coasting for 35 minutes, the second stage performed a final 54-second burn that placed the TESS spacecraft into a supersynchronous transfer orbit of 200 by 270,000 km at an inclination of 28.5 degrees. The second stage released the payload, after which the stage itself was placed in a heliocentric orbit. An experimental water landing was performed for the fairing, as part of SpaceX's attempt to develop fairing reusability.

TESS spacecraft before launch

Spacecraft

- *In 2013, Orbital Sciences received a four-year, US$75 million contract to build TESS for NASA.*
- *TESS uses an Orbital Sciences LEOStar-2 satellite bus, capable of three-axis stabilization using four hydrazine thrusters plus four reaction wheels providing better than three arc-second fine spacecraft pointing control.*

In 2013, Orbital Sciences received a four-year, US$75 million contract to build TESS for NASA. TESS uses an Orbital Sciences LEOStar-2 satellite bus, capable of three-axis stabilization using four hydrazine thrusters plus four reaction wheels providing better than three arc-second fine spacecraft pointing control. Power is provided by two single-axis solar arrays generating 400 watts. A Ka-band dish antenna provides a 100 Mbit/s science downlink.



Planned orbital maneuvers after release from Falcon 9's 2nd stage. Horizontal axis schematically represents longitude relative to the moon, vertical axis is altitude. A1M = Apogee 1 manoeuvre, P1M = Perigee 1 manoeuvre, etc., TCM = trajectory correction manoeuvre (optional), PAM = period adjustment manoeuvre.

Operational orbit

- *If TESS receives an on-target or slightly above nominal orbit insertion by the Falcon 9, a theoretical mission duration in excess of 15 years would be possible from a consumables standpoint.*
- *Once injected into the initial orbit by the Falcon 9 second stage, the spacecraft performed four additional independent burns that placed it into a lunar flyby orbit.*

Once injected into the initial orbit by the Falcon 9 second stage, the spacecraft performed four additional independent burns that placed it into a lunar flyby orbit. On May 17, the spacecraft underwent a gravity assist by the Moon at 8,253.5 km (5,128.5 mi) above the surface, and performed the final period adjustment burn on May 30. It achieved an orbital period of 13.65 days in the desired 2:1 resonance with the Moon, at 90 degrees phase offset to the Moon at apogee, which is expected to be a stable orbit for at least 20 years, thus requiring very little fuel to maintain. The entire maneuvering phase was expected to take a total of two months, and bring the craft in an eccentric orbit (17–75 R⊕) at a 37° inclination.

The total delta-v budget for orbit maneuvers was 215 m/s (710 ft/s), which is 80% of the mission's total available reserves. If TESS receives an on-target or slightly above nominal orbit insertion by the Falcon 9, a theoretical mission duration in excess of 15 years would be possible from a consumables standpoint.

Project timeline

- *Around 60 days after launch, TESS was expected to begin its primary science mission.*
- *The first light image was made on August 7, 2018, and released publicly on September 17, 2018.*
- *For the first two years of operation TESS will monitor both the southern (year 1) and northern (year 2) celestial hemispheres.*

Around 60 days after launch, TESS was expected to begin its primary science mission. The first light image was made on August 7, 2018, and released publicly on September 17, 2018.

TESS actually completed its commissioning phase at the end of July and the science phase officially started on July 25.

For the first two years of operation TESS will monitor both the southern (year 1) and northern (year 2) celestial hemispheres. During its mission TESS will tile the sky in 26 separate segments, with a 27.4-day observing period per segment (a bit over one sidereal month).

Scientific instrumentation

- *The sole instrument on TESS is a package of four wide-field-of-view CCD cameras.*
- *The TESS lenses have a combined field of view of 24° × 96° (2,300 deg2, around 5% of the entire sky) and a focal ratio of f/1.4.*

The sole instrument on TESS is a package of four wide-field-of-view CCD cameras. Each camera features four low-noise, low-power 4 megapixel CCDs created by MIT Lincoln Laboratory. The four CCDs are arranged in a 2x2 detector array for a total of 16 megapixels per camera and 16 CCDs for the entire instrument. Each camera has a 24° × 24° field of view, a 100 mm (4 in) effective pupil diameter, a lens assembly with seven optical elements, and a bandpass range of 600 to 1000 nm. The TESS lenses have a combined field of view of 24° × 96° (2,300 deg2, around 5% of the entire sky) and a focal ratio of f/1.4. The ensquared energy, the fraction of the total energy of the point-spread function that is within a square of the given dimensions centered on the peak, is 50% within 15 × 15 µm and 90% within 60 × 60 µm. For comparison, Kepler's primary mission only covered an area of the sky measuring 105 deg2, though the K2 extension has covered many such areas for shorter times.

Ground operations

- *The TESS ground system is divided between eight sites around the United States.*
- *These include NASA's Space Network and the Jet Propulsion Laboratory's Deep Space Network for command and telemetry, Orbital ATK's Mission Operations Center, MIT's Payload Operations Center, the Ames Research Center's Science Processing Operations Center, The Goddard Space Flight Center's Flight Dynamics Facility, the Smithsonian Astrophysical Observatory's TESS Science Office, and the Mikulski Archive for Space Telescopes (MAST).*

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Stable light source for tests

- *Although both plan to look at bright nearby stars using the transit method, CHEOPS is focused on collecting more data on known exoplanets, including those found by TESS and other survey missions.*
- *While this instrument was created to support ESA's CHEOPS exoplanet observatory, one was also ordered by the TESS program.*

One of the issues facing the development of this type of instrument is having an ultra-stable light source to test on. In 2015, a group at the University of Geneva made a breakthrough in the development of a stable light source. While this instrument was created to support ESA's CHEOPS exoplanet observatory, one was also ordered by the TESS program. Although both plan to look at bright nearby stars using the transit method, CHEOPS is focused on collecting more data on known exoplanets, including those found by TESS and other survey missions.

Test image taken before the start of science operations. The image is centered on the constellation Centaurus. In the top right corner the edge of the Coalsack Nebula can be seen, the bright star in the bottom left is Beta Centauri.

Results

- *HD 21749c represents the 10th confirmed planet discovery by TESS.*
- *TESS started science operations on July 25, 2018.*
- *The discovery was announced on October 5, 2018.*
- *Both known planets in the system, HD 21749b and HD 21749c, were discovered by TESS.*
- *On 15 April 2019 TESS' first discovery of an earth-sized planet was reported.*

TESS started science operations on July 25, 2018. The first announced finding from the mission was the observation of comet C/2018 N1. The first exoplanet detection announcement was on September 18, announcing the discovery of a super-Earth in the Pi Mensae system orbiting the star every 6 days, adding to a known super-Jupiter orbiting the same star every 5.9 years.

On September 20, 2018, the discovery of an ultra-short period planet was announced, slightly larger than Earth, orbiting the red dwarf LHS 3844. With an orbital period of 11 hours, LHS 3844 b is one of the planets with the shortest known period. It orbits its star at a distance of 932,000 kilometres (579,000 mi). LHS 3844 b is also one of the closest known exoplanets to Earth, at a distance of 14.9 parsec.

TESS's third discovered exoplanet is HD 202772Ab, a hot Jupiter orbiting the brighter component of the visual binary star HD 202772, located in the constellation Capricornus at a distance of about 480 light-years from Earth. The discovery was announced on October 5, 2018. HD 202772Ab orbits its host star once every 3.3 days. It is an inflated hot Jupiter, and a rare example of hot Jupiters around evolved stars. It is also one of the most strongly irradiated planets known, with an equilibrium temperature of 2,100 K (1,830 °C; 3,320 °F).

On 15 April 2019 TESS' first discovery of an earth-sized planet was reported. HD 21749c is a rocky planet with about 89% of Earth's diameter and orbits the K-type main sequence star HD 21749 in about 8 days. The planet's surface temperature is estimated to be as high as 427 °C. Both known planets in the system, HD 21749b and HD 21749c, were discovered by TESS. HD 21749c represents the 10th confirmed planet discovery by TESS.

Data on exoplanet candidates continue to be made available at MAST. As of 20 April 2019, the total number of candidates on the list was up to 335. Besides candidates identified as previously discovered exoplanets, this list also includes the ten newly discovered exoplanets mentioned above. Forty-four of the candidates from Sector 1 in this list were selected for follow-up observations by the TESS Follow-Up Program (TFOP), which aims to aid the discovery of 50 planets with a planetary radius of $R < 4R_\oplus$ through repeated observations. The list of candidate exoplanets continues to grow as additional results are being published on the same MAST page.

See also

- *TESS, NASA's Exoplanet hunter jointly developed and managed by MIT*

CHEOPS, 2019 exoplanet observatory

COROT, 2006–2012 exoplanet observatory

Kepler, 2009–2018 exoplanet observatory

MOST, 2003–present asteroseismology and exoplanet observatory

PLATO, 2026 exoplanet observatory

SWEEPS, 2006 Hubble exoplanet survey

List of transiting exoplanets

TESS, NASA's Exoplanet hunter jointly developed and managed by MIT

References

Further reading

- *"TESS and Galactic Science" (PDF).*
- *"Transiting Exoplanet Survey Satellite".*
- *1 (1): 914320. arXiv:1406.0151.*

Ricker, George R.; et al. (October 24, 2014). "Transiting Exoplanet Survey Satellite". Journal of Astronomical Telescopes, Instruments, and Systems. 1 (1): 914320. arXiv:1406.0151. Bibcode:2014SPIE.9143E..20R. doi:10.1117/1.JATIS.1.1.014003.

Stassun, Keivan (November 18, 2014). "TESS and Galactic Science" (PDF). California Institute of Technology.

External links

- *APOD, 2018 April 21*
- *Interactive 3D simulation of TESS's 2:1 lunar resonant orbit*
- *TESS website by Massachusetts Institute of Technology*
- *TESS website by the Kavli Foundation*
- *TESS website by NASA Goddard*
- *TESS launch closeup, atop Falcon 9 rocket.*
- *TESS twitter account by NASA*

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