# Transiting Exoplanet Survey Satellite (TESS)

## NASA's Next Mission to Find Strange, New Worlds


Matt Ritsko, TESS Deputy Project Manager for Resources

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Bob Calvo, Chief Safety Mission Assurance Officer

# Project Description

## NASA's next Exoplanet hunter

Launched April 2018

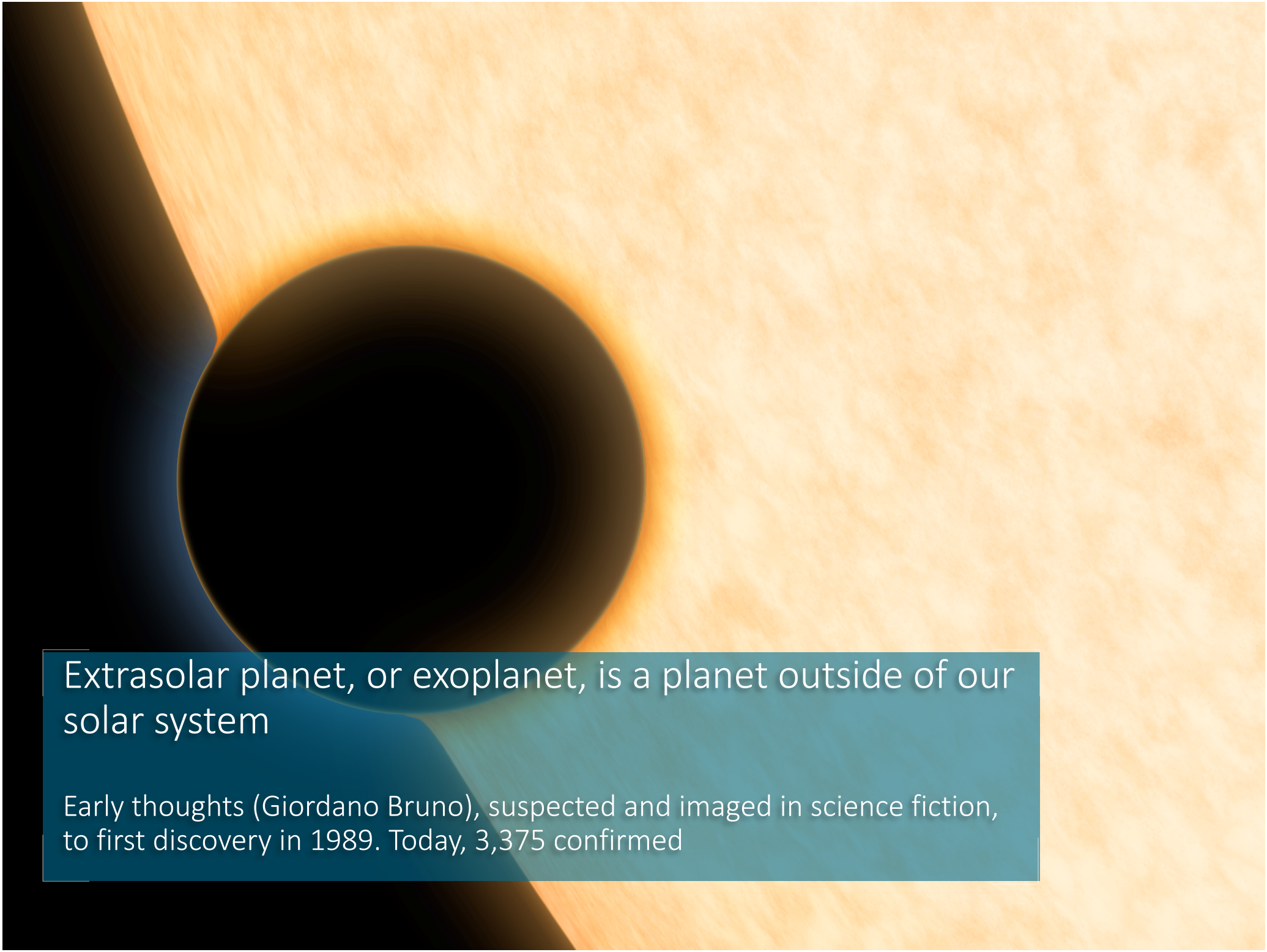
George Ricker (P.I.)

Massachusetts Institute of Technology

collaboration including:
NASA Goddard, NASA Ames, MIT Lincoln Lab, Orbital ATK, STScI, SAO, Harvard/Smithsonian, MPIA-Germany, Las Cumbres Observatory, Geneva Observatory, OHP-France, University of Florida, Aarhus University-Denmark, Harvard College Observatory, Vanderbilt University

# What is an Exoplanet?

Boldly going to turn science fiction into science fact

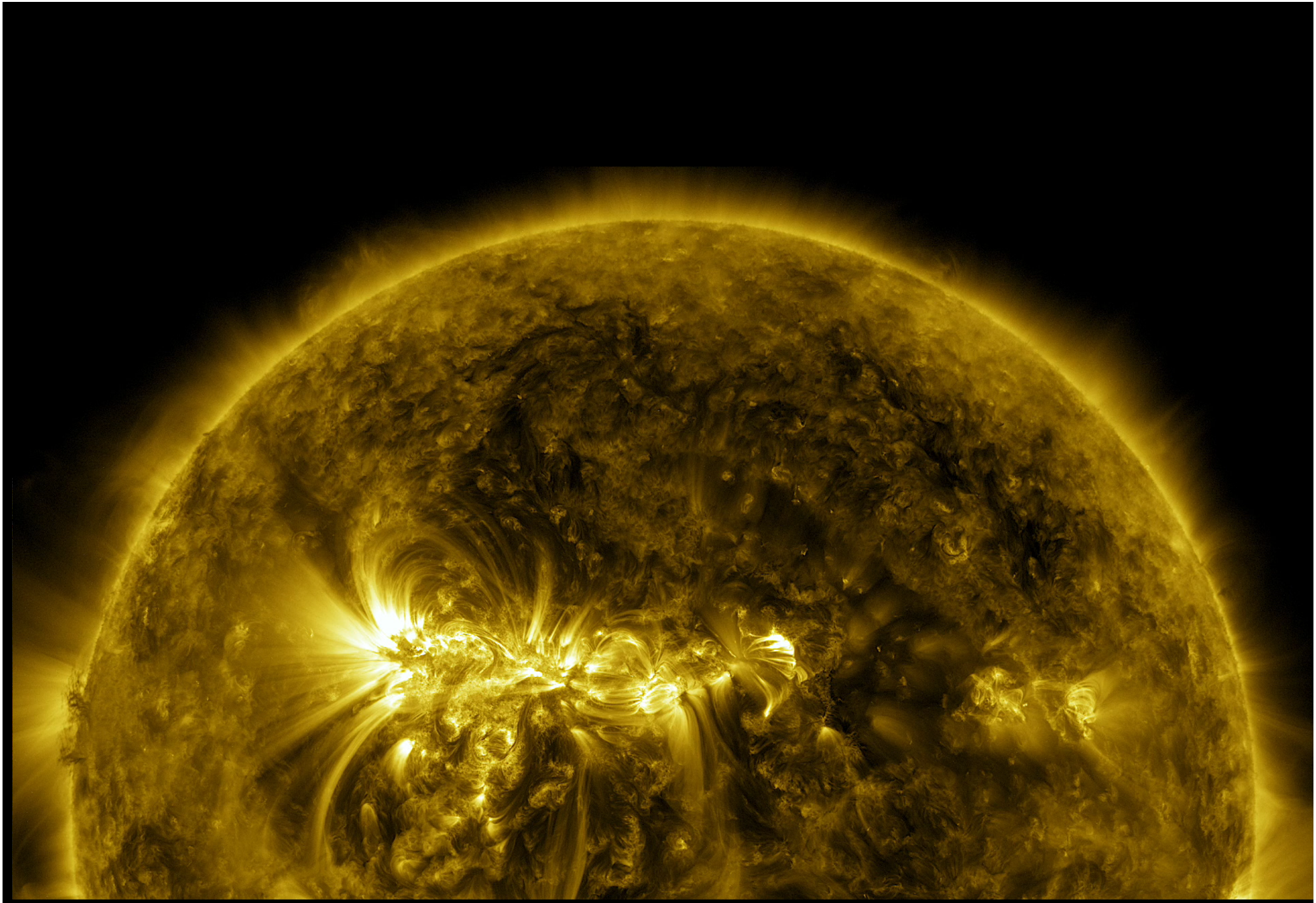


# Extrasolar planet, or exoplanet, is a planet outside of our solar system

Early thoughts (Giordano Bruno), suspected and imaged in science fiction, to first discovery in 1989. Today, 3,375 confirmed

# One Method of Discovery: Transits

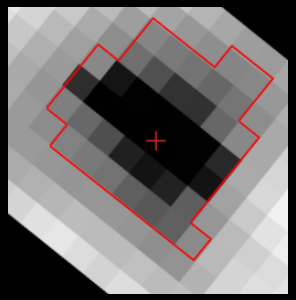

Shadows of strange new worlds

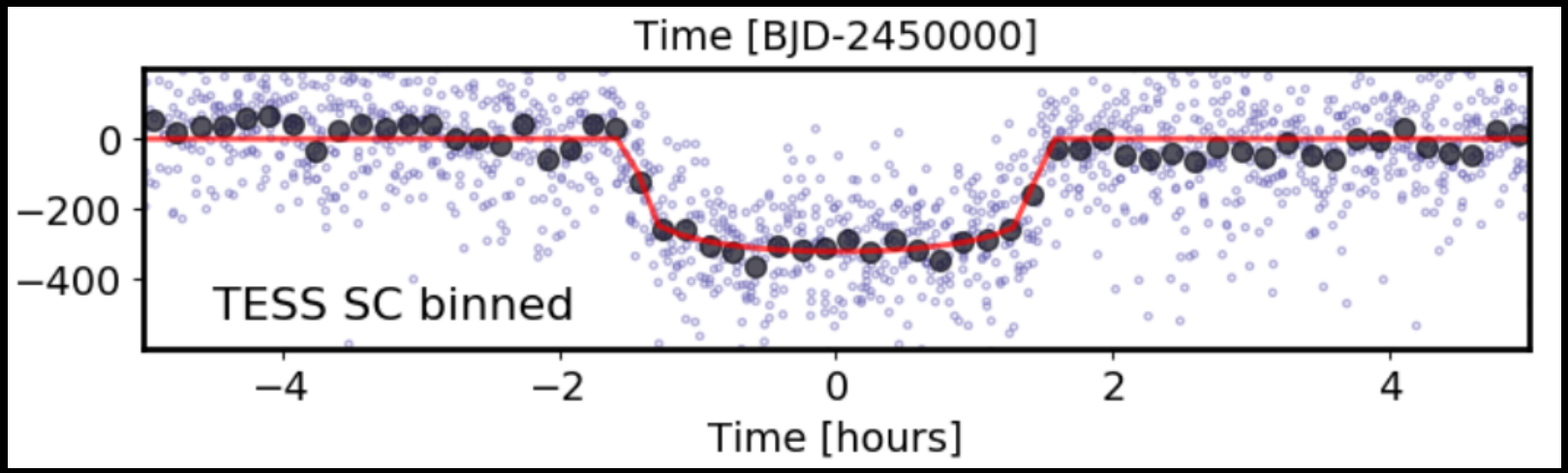


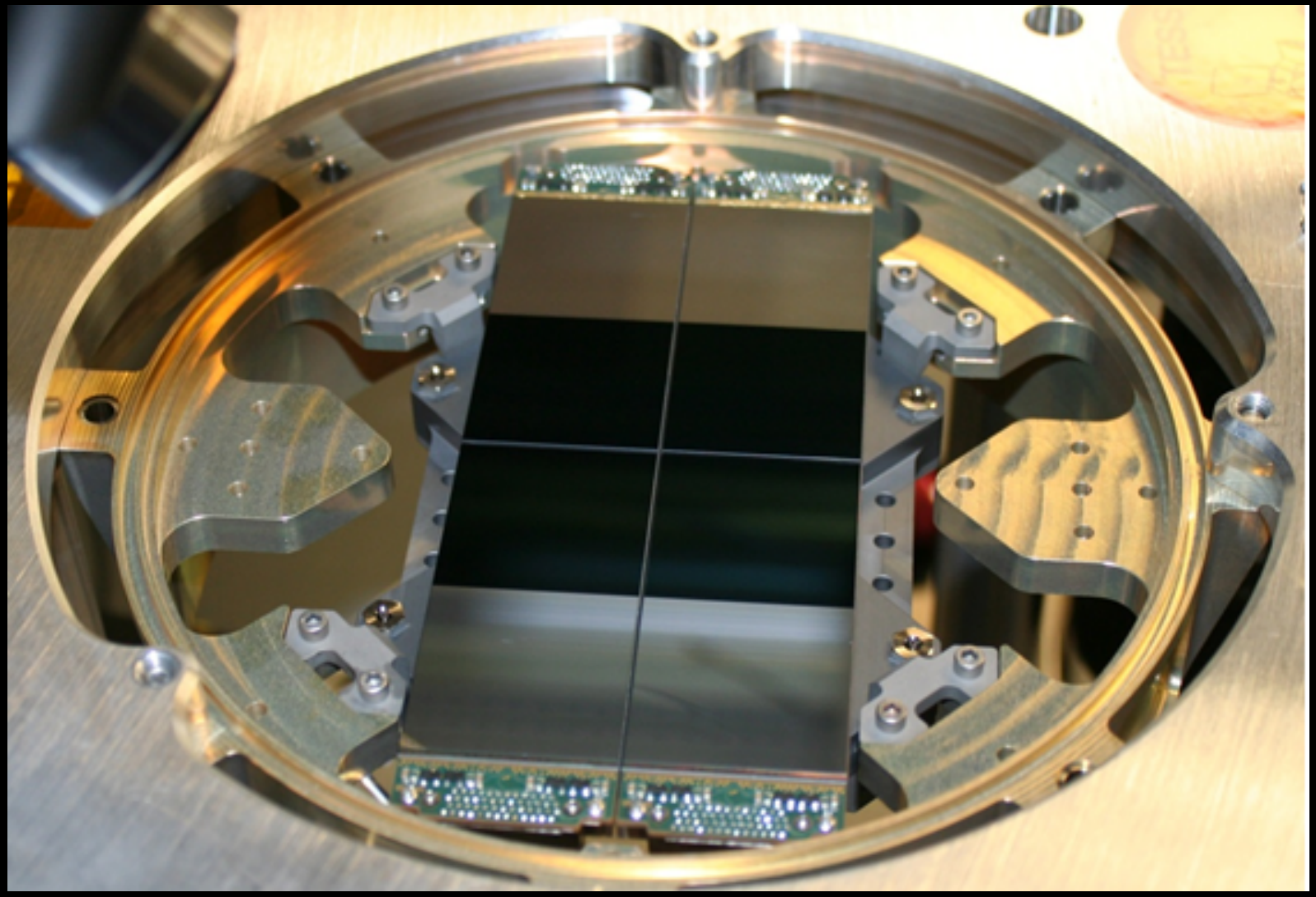
# Transit Method

PLANET QUEST
THE SEARCH FOR ANOTHER EARTH

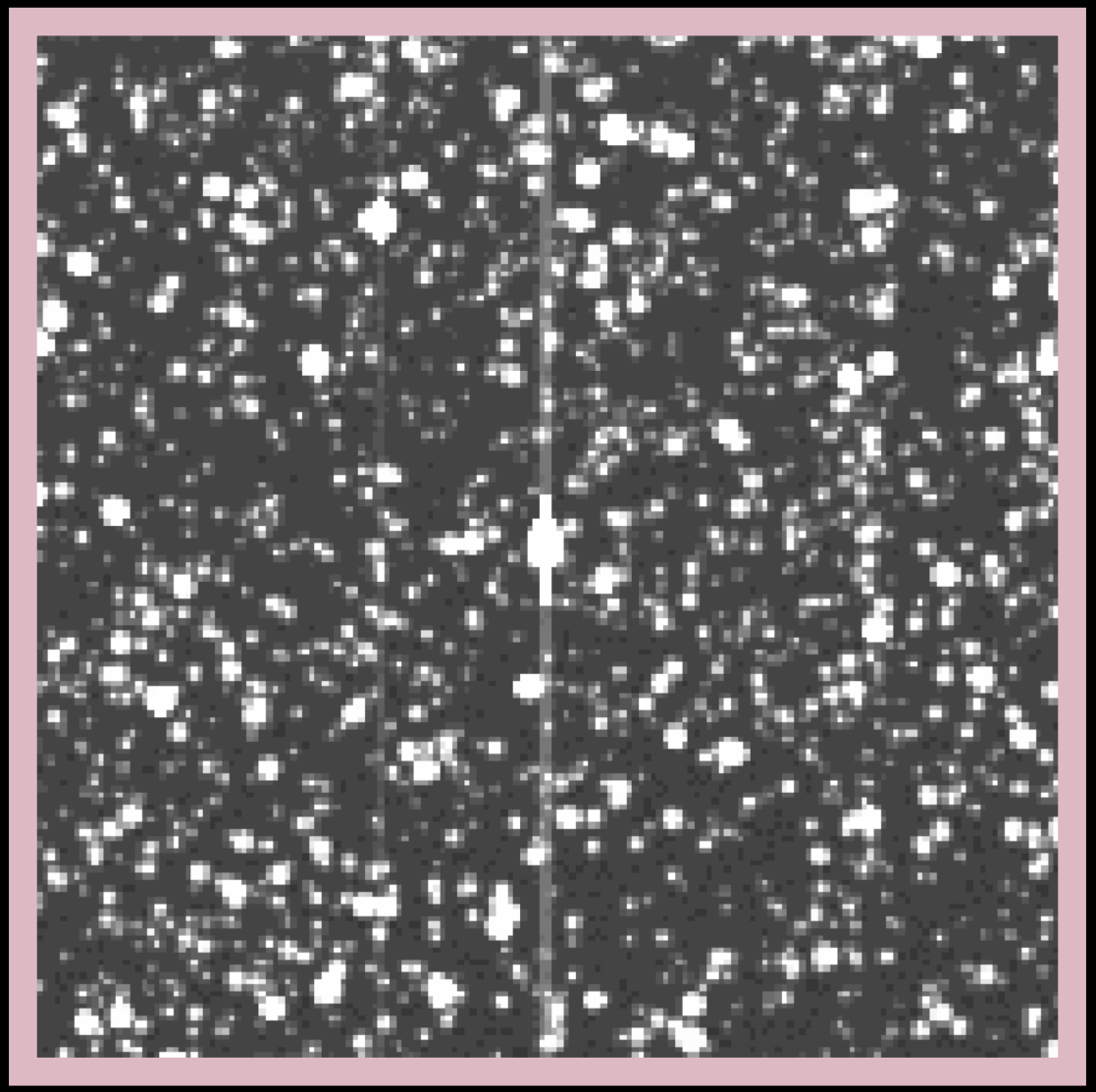

# Turning Pixels into Planets





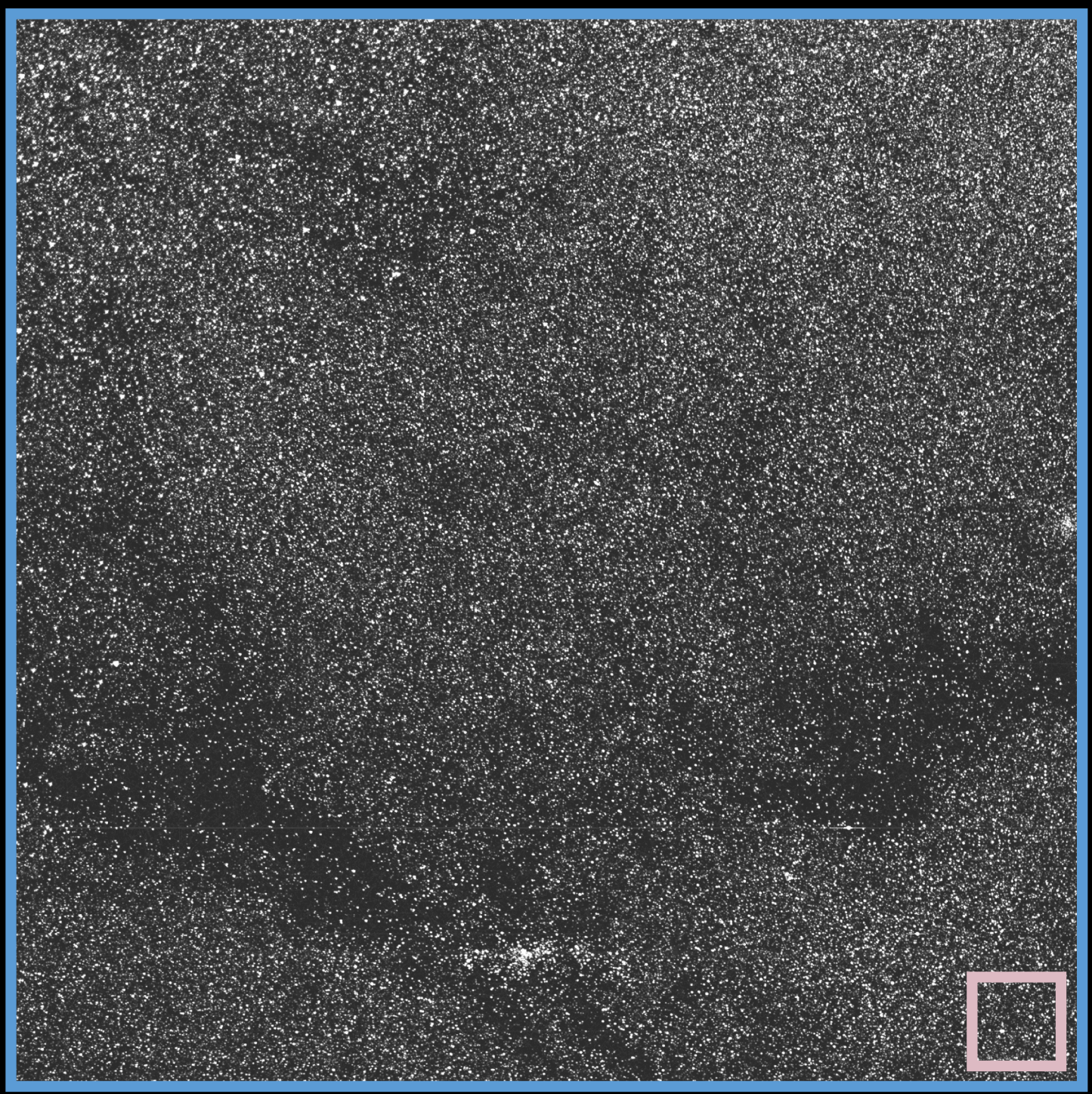
A photometer:
a device that can capture and measure the intensity of light
(we call it a detector on our spacecraft)



1°

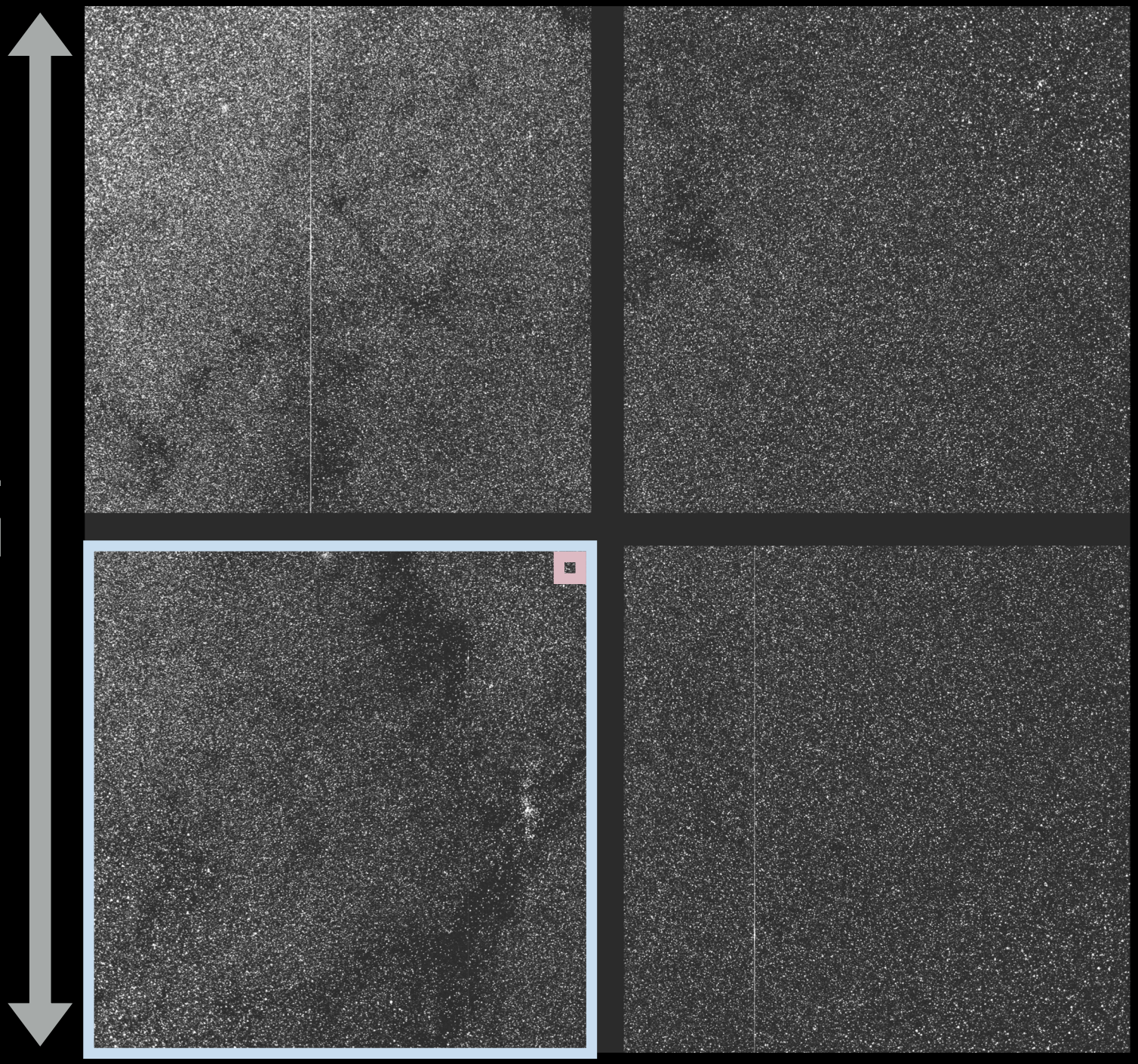
simulated images by Zach Berta-Thompson

# one CCD:
# 12°



simulated images by Zach Berta-Thompson

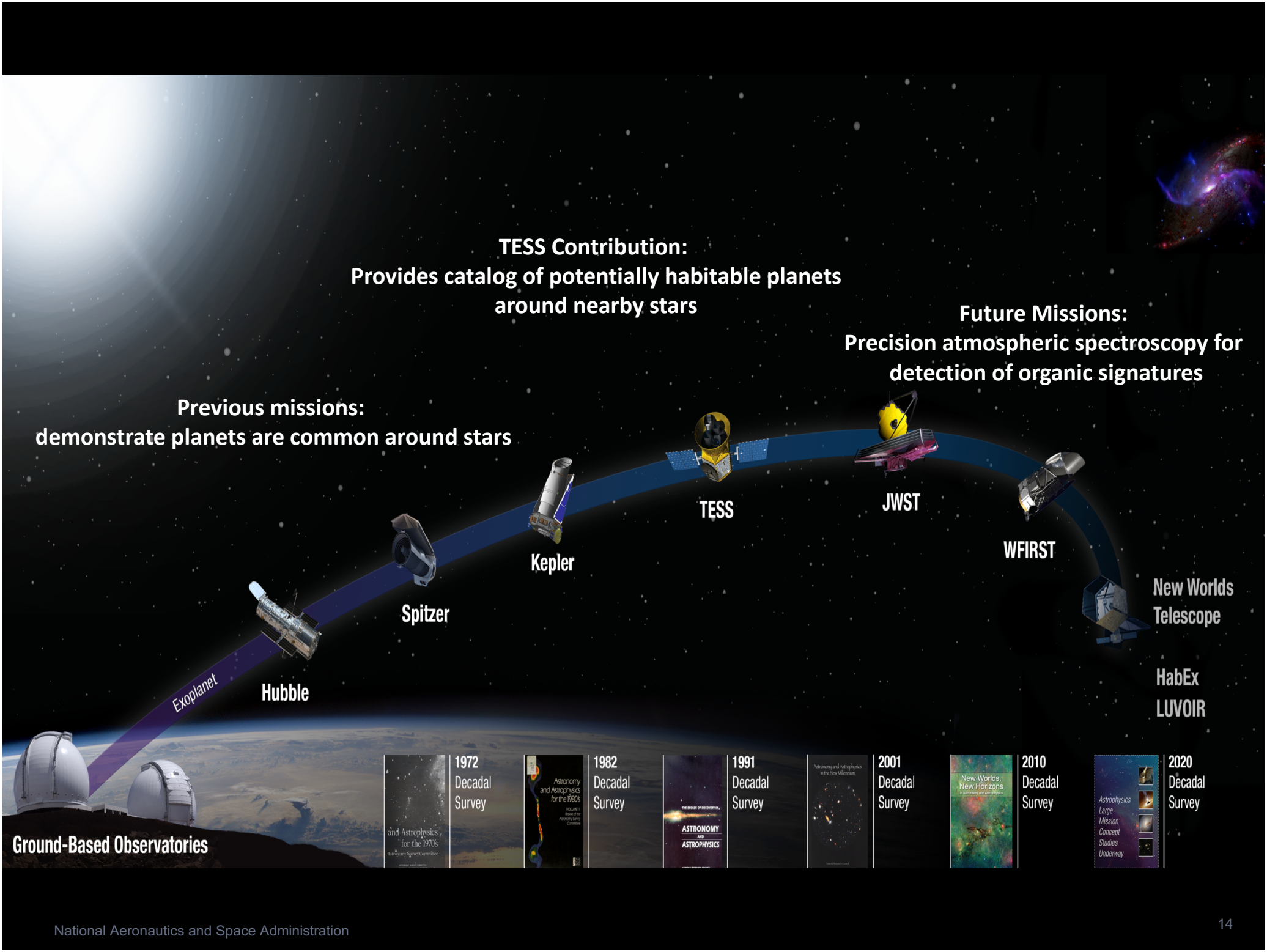
# View from one TESS camera:

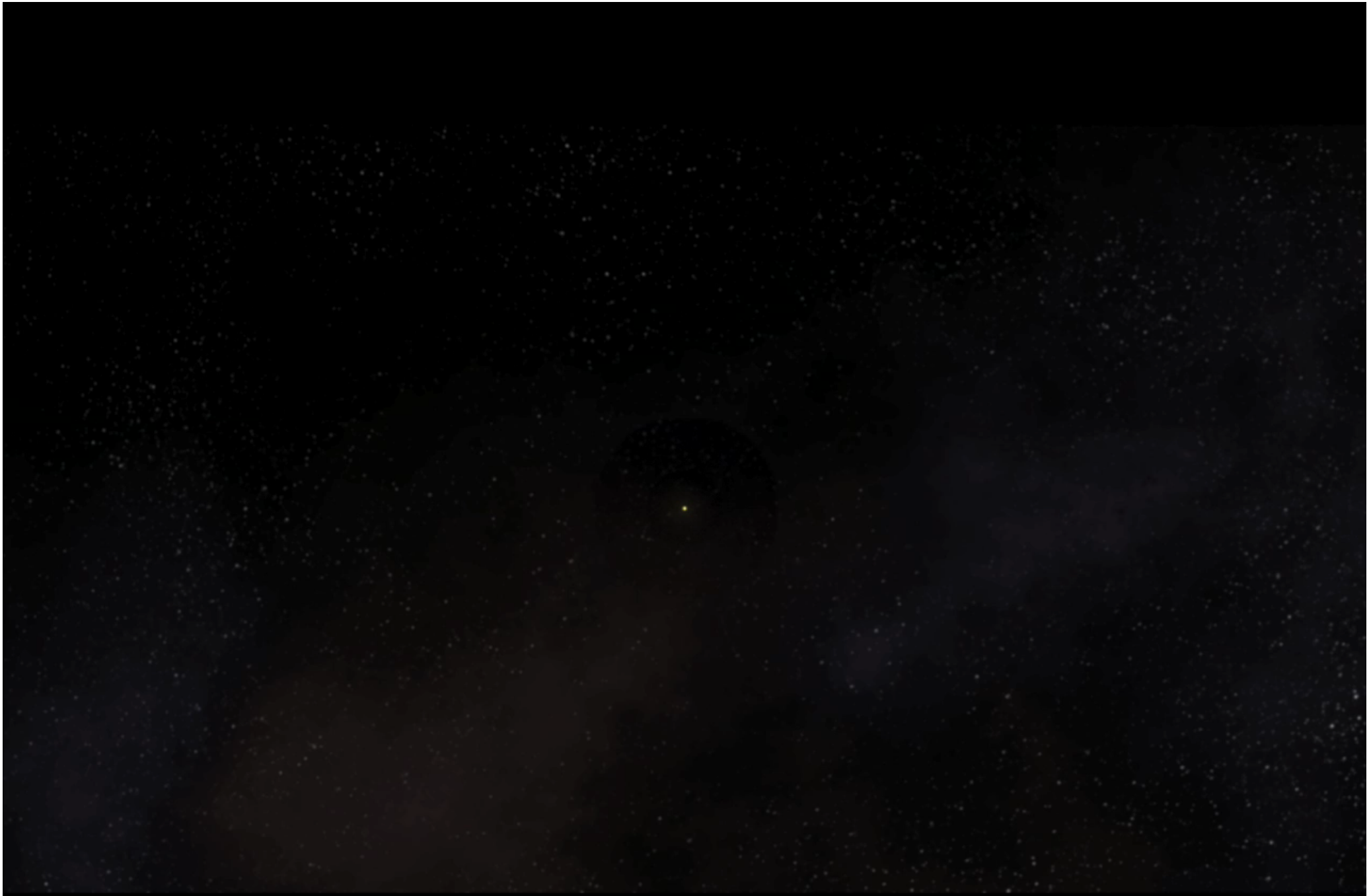


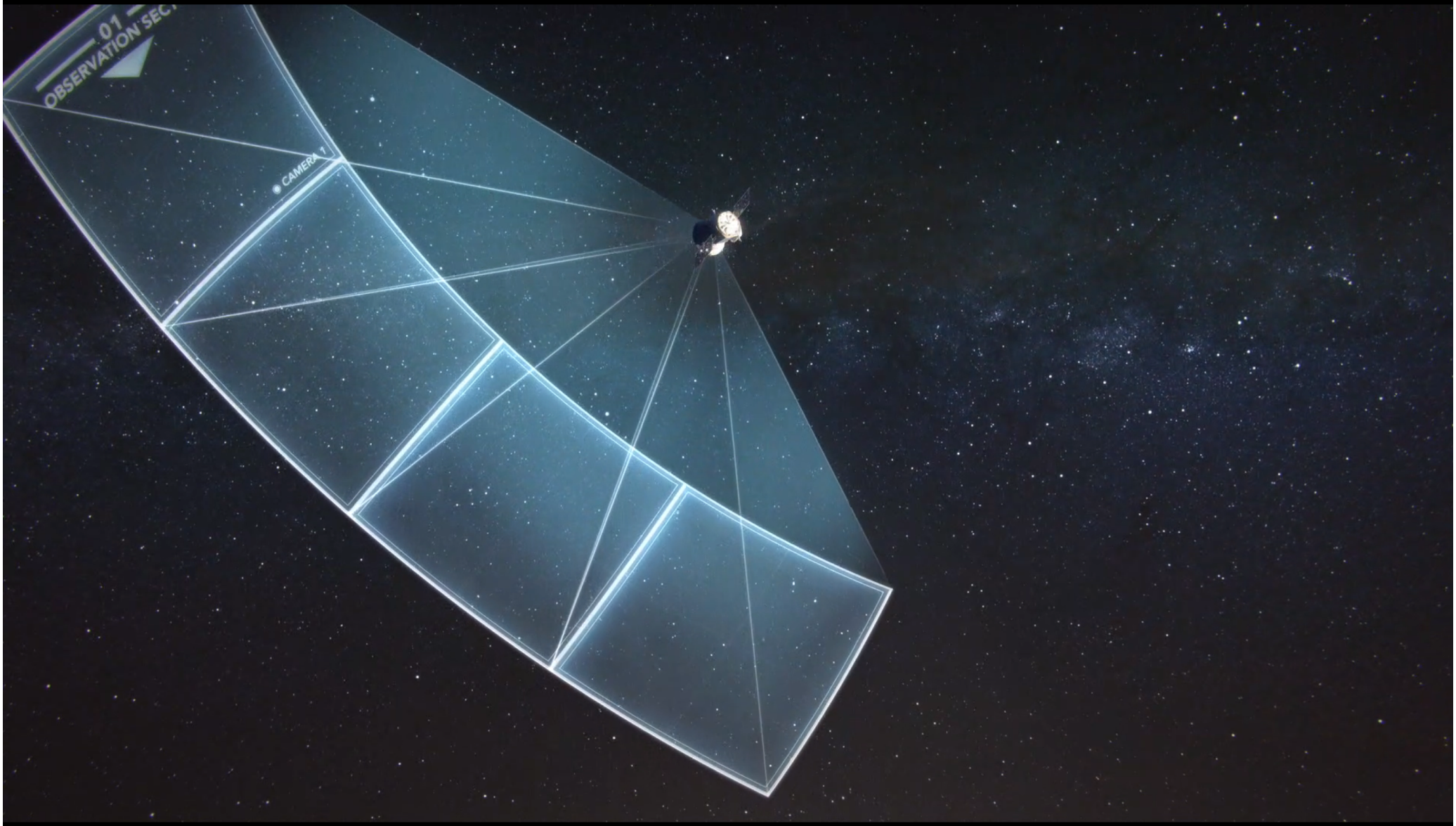

simulated images by Zach Berta-Thompson

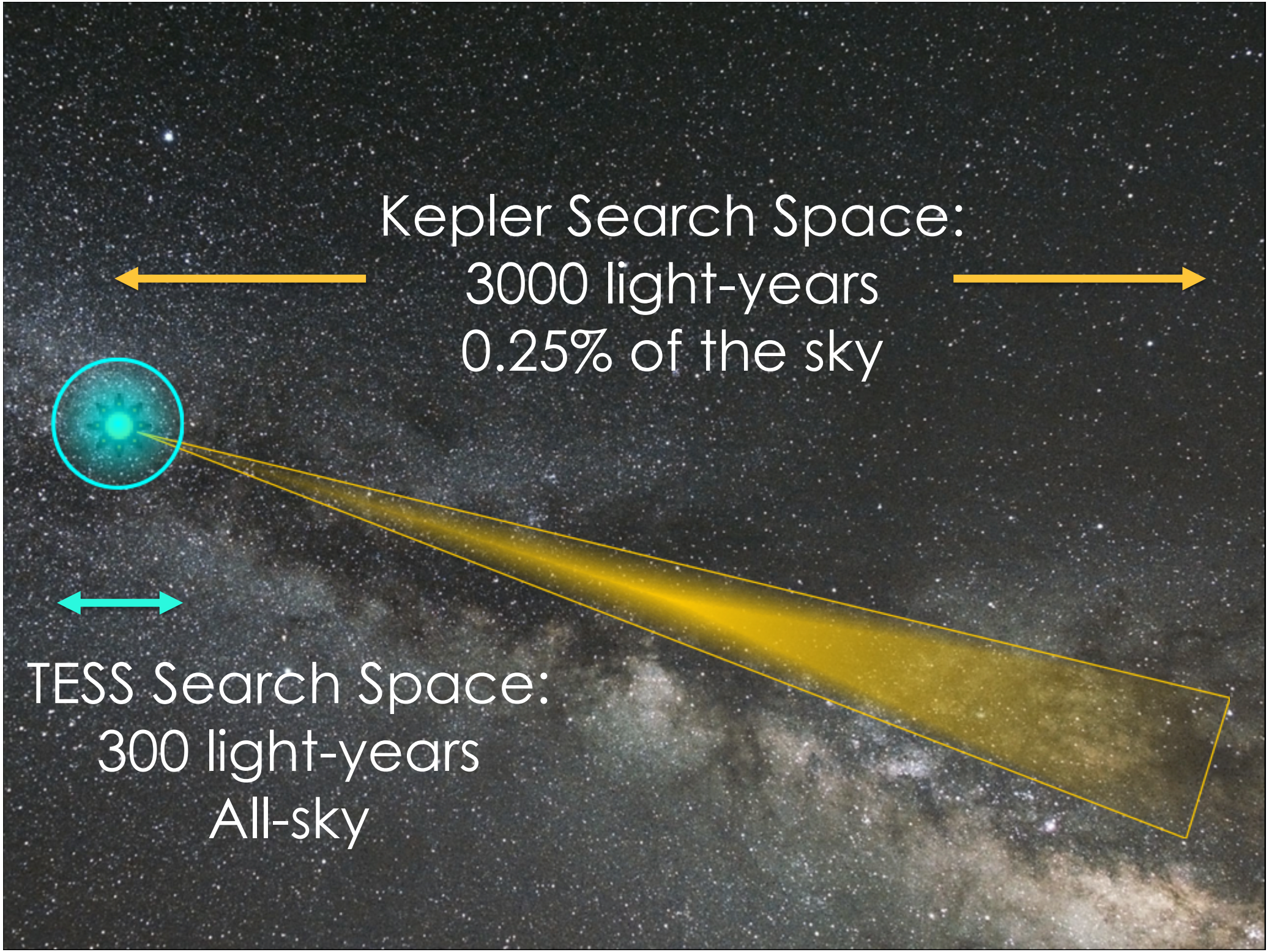
# Why TESS? Why Now?


The first “all-sky” survey of nearby, bright stars


TESS Contribution:
Provides catalog of potentially habitable planets around nearby stars
Future Missions:
Precision atmospheric spectroscopy for detection of organic signatures
Previous missions:
demonstrate planets are common around stars
Exoplanet
Hubble
Spitzer
Kepler
TESS
JWST
WFIRST
New Worlds Telescope
HabEx
LUVOIR
Ground-Based Observatories
1972 Decadal Survey
1982 Decadal Survey
1991 Decadal Survey
2001 Decadal Survey
2010 Decadal Survey
2020 Decadal Survey




01
OBSERVATION SEC
CAMERA 1


Kepler Search Space:
3000 light-years
0.25% of the sky
TESS Search Space:
300 light-years
All-sky

# Building TESS

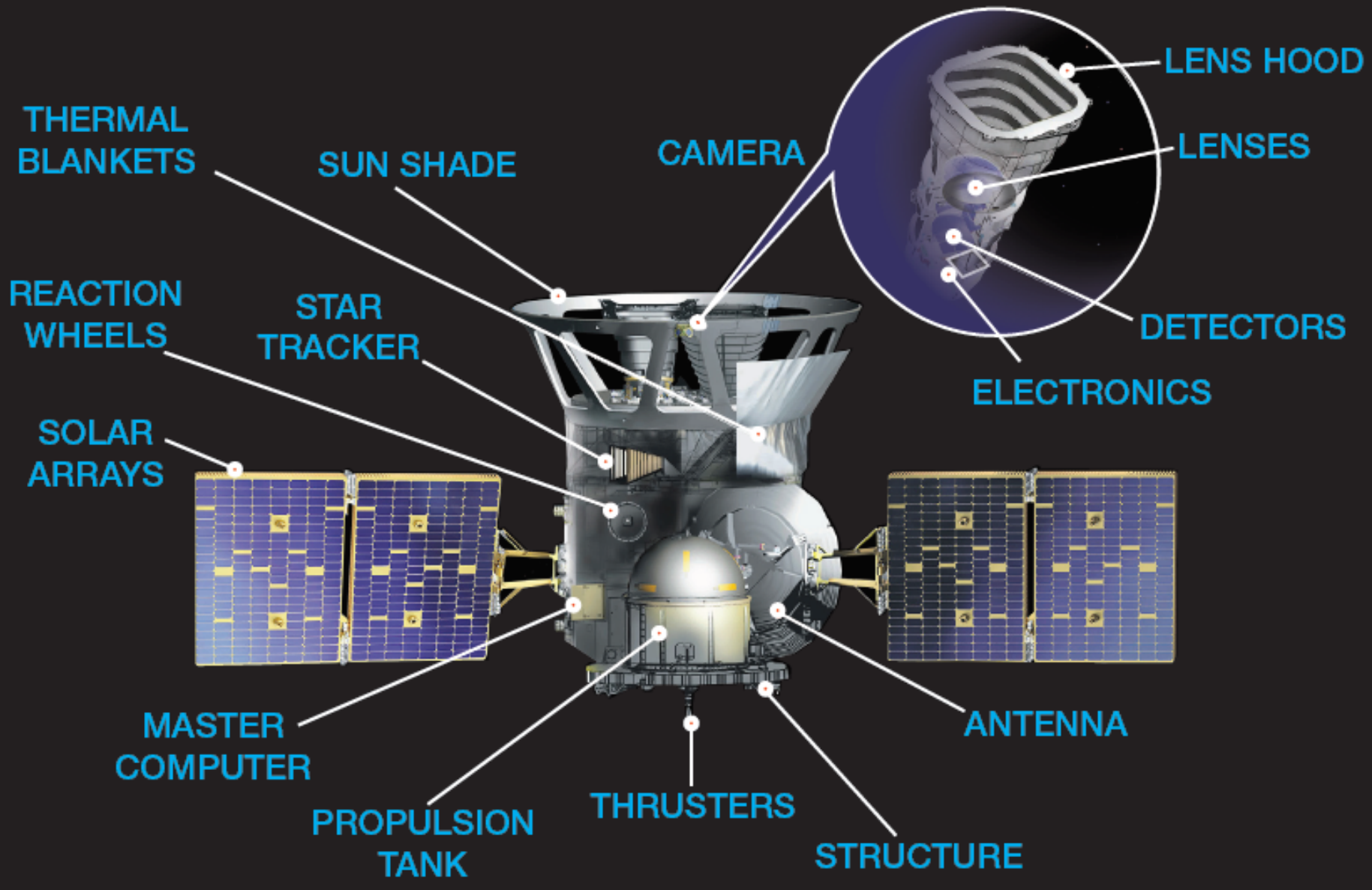
Risk is our business

# Many Firsts for an Explorer Mission…

- Teaming arrangement was new and unique
  - Prior Explorer missions with an external PI did not hold Project Management, Systems Engineering and SM&A leadership roles
- Requirements drove a Ka-Band transmitter
  - Way of the future for space missions, with a smaller industry base of experience to draw upon
- SpaceX: TESS was the first official NASA science observatory to fly on a Falcon 9
- Hardware with limited spaceflight experience
  - Examples: FGPAs, RTV

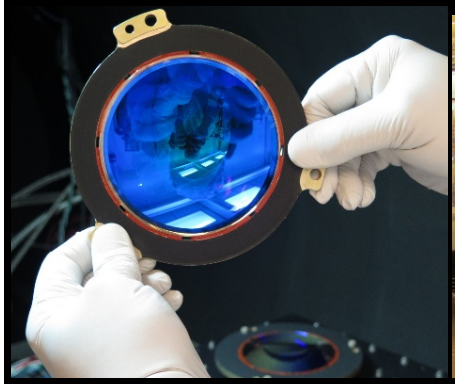
- With some of the same challenges seen on prior Explorer missions:
  - Small budget, relatively short schedule
  - Little/no redundancy within design

# TESS Observatory



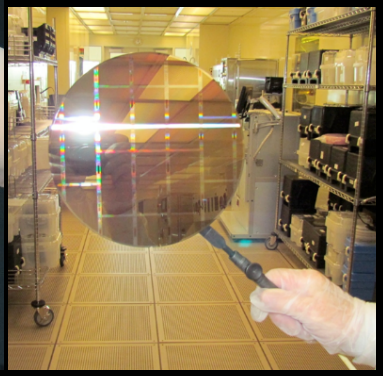
# TESS Observatory

## Lenses

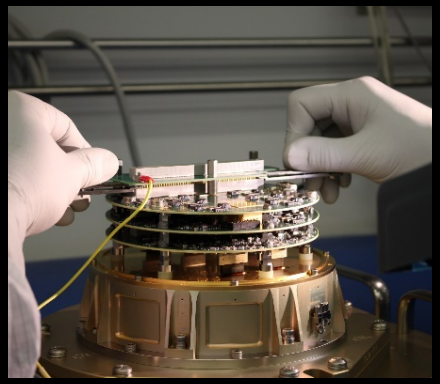


MIT's Lincoln Laboratory developed camera barrels with lenses (7 in each) to focus the photons from stars to Charged Coupled Devices (CCDs) to capture images of the sky

## CCDs

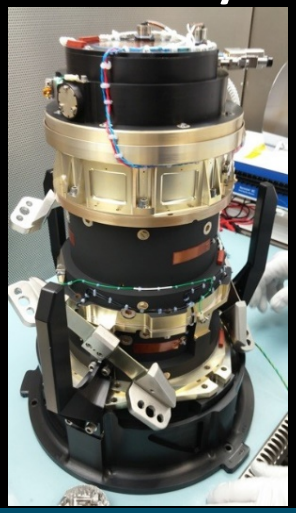


## Focal Plane Electronics



Low noise electronics translate photons from stars into data. Includes heaters to provide thermal control to cameras

## Camera Assembly



Assembled and tested at MIT's Kavli Institute for Astrophysics. Four cameras were designed to fly with TESS

MIT KAVLI INSTITUTE

## Spacecraft

LEO-Star 2 Spacecraft with history of flying on many prior Explorer missions

NORTHROP GRUMMAN

Overall project management authority, leadership and responsibility

NASA Goddard SPACE FLIGHT CENTER

Lead for Mission Systems Engineering and Safety and Mission Assurance

# Key Tools to Manage Mission Success

- Experienced GSFC Team – demonstrated GSFC commitment to the mission
- Rigorous Risk Management Boards
  - Closely linked to project reserves and threat process
- Utilization of resources to mitigate critical risks on the supply chain
- Baseline Change Request Management
  - Challenge: conducting in a timely/effective manner in multiple configuration management systems from partners
- Proven Requirements Verification and test program
  - Insight and oversight

# Risk Management Insights: Risks Over Time

| Risk ID | Summary | 15-Sep | 15-Oct | 15-Nov | 15-Dec | 16-Jan | 16-Feb | 16-Mar | 16-Apr | 16-May | 16-Jun | 16-Jul | 16-Aug | 16-Sep | 16-Oct | 16-Nov | 16-Dec | 17-Jan | 17-Feb | 17-Mar | 17-Apr | 17-May | 17-Jun | 17-Jul | 17-Aug | 17-Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0001 | Aggressive DHU development schedule | Y 4x2 | | | | | | | | | | | | | | | | | | | | | | | | |
| 0004 | Ka-Band transmitter late delivery | Y 4x3 | Y 4x3 | Y 3x3 | Y 3x3 | Y 3x3 | Y 4x3 | | Y 4x3 | Y 4x3 | | | | | | Y 2x4 | | Y 3x4 | R 4x4 | R 4x4 | R 4x4 | | | | | |
| 0007 | Ka high gain antenna development | | | G 3x2 | | | | | | | | | | | | | | | | | | | | | | |
| 0010 | CCD fabrication, packaging, and selection aggressive schedule | | | | | | | | | | Y 3x3 | | | | | | | | | | | | | | | |
| 0013 | DHU impacted by SCOPE Growth | Y 4x3 | Y 4x3 | Y 4x3 | Y 3x3 | Y 3x3 | Y 3x3 | | | | Y 3x3 | Y 3x3 | Y 3x3 | Y 3x3 | | Y 2x3 | | | Y 3x3 | Y 3x3 | Y 3x3 | | | | | |
| 0016 | DHU technical issues | Y 4x3 | Y 4x3 | | | | | | | | | | | | | | | | | | | | | | | |
| 0018 | Limited closed loop testing of fine pointing mode | | | | | | | | | | | | | | | | | | | | | | G 2x2 | | | |
| 0019 | Solar array late delivery | | | | | | | | Y 3x3 | Y 3x3 | | | | | | | | | | | | | | | | |
| 0021 | Two TVAC chambers not available for camera TVAC testing / MIT TVAC Chamber certification delays | Y 3x4 | Y 3x4 | Y 2x4 | Y 3x4 | Y 3x4 | Y 3x4 | | Y 3x4 | Y 3x4 | Y 3x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | | Y 3x3 | | | | | | | |
| 0021* | S-Band transponder possible solder cracks | | | | | | | | | | | | | | | Y 4x2 | | Y 4x3 | | Y 3x3 | | | | | | |
| 0025 | Late delivery of the DHU may impact FSW development | | | Y 3x3 | | | | | | | | | | | | | | | | | | | | | | |
| 0097 | Camera optics / CCD contammination | | | | | | | | | | Y 3x3 | | | | | | | | | | | Y 2x3 | | | | |
| 0102 | Contamination from launch vehicle | | | | | | | | | | | | | | | | | | | | | Y 2x3 | | | | |
| 0158 | Camera poser ground and EMI testing | Y 3x3 | Y 3x3 | Y 3x3 | | | | | | | | | | | | | | | | | | | | | | |
| 0163 | Inability to reach SIR maturity on schedule | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | | Y 4x3 | Y 4x3 | | | | | | | | | | | | | | | | |
| 0164 | Madrid 34 m BWG availibility | Y 2x4 | Y 2x4 | Y 2x4 | | | | | | | | | | | | | | | | | | | | | | |
| 0167 | FPE development and test schedule | Y 3x4 | Y 3x4 | Y 2x4 | Y3x4 | Y 3x4 | Y 3x4 | | Y 3x4 | Y 3x4 | | | Y 3x3 | Y 3x3 | Y 3x3 | Y 3x3 | Y 3x3 | Y 3x3 | | | | | | | | |
| 0187 | Falcon 9/CRS-7 Mishap will delay TESS Launch / Falcon 9 Delays impacting TESS launch / SpaceX LV manifest and certification schedule delays | Y 3x4 | Y 3x4 | Y 3x4 | Y 3x4 | Y 3x4 | Y 3x4 | | Y 3x4 | Y3x4 | Y 3x4 | Y 3x4 | Y 3x4 | Y 3x4 | R 4x4 | | | | | | R 4x4 | R 4x4 | R 4x4 | Y 3x4 | Y 3x4 | Y 2x4 |
| 0195 | Commissioning tools development delays | | | | | | | | | | | | | | | | | | | | | G 2x2 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 |
| 0201 | DHU power dissipation | | Y 4x2 | | | | | | | | | | | | | | | | | | | | | | | |
| 0209 | Limited time available for flight software/firmware/systems testing of flight-like EDHU DHU or ADHU prior to delivery to OA/Resource contention for Flight like EDU DHU | | | | Y 3x3 | Y 3x3 | Y 3x3 | | | | Y 4x3 | Y 3x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | R 4x4 | Y 3x4 | | | | |
| 0211 | No time between flight like DHU EDU and flight board fabrication | | | | Y 3x3 | Y 3x3 | Y 3x3 | | Y 3x3 | Y 3x3 | Y 3x3 | Y 3x4 | Y 3x4 | Y 3x4 | Y 3x4 | Y 3x4 | Y 3x4 | Y 3x4 | | | | | | | | |
| 0212 | Flight DHU and ADHU delivered late in observatory flow | | | | | | | | | | | | | | | | | | Y 2x3 | Y 2x3 | Y 2x3 | Y 2x3 | | | | |
| 0214 | ADHU resources for continuation to flight | | | | Y 5x2 | Y 5x2 | Y 5x2 | | Y 5x2 | Y 5x2 | | | | | | | | | | | | | | | | |
| 0216 | Flight camera performance issues | | | | | | | | | | | | | | Y 2x5 | Y 2x5 | Y 2x5 | Y 2x5 | | | | | | | | |
| 0223 | GL scientific detector assembly delivery concerns | | | | | | | | Y 4x3 | Y 4x3 | Y 3x4 | | | | | | | | | | | | | | | |
| 0231 | Flying ADHU impact on LRD/Limited software/firmware testing of flight ADHU prior to integration | | | | | | | | | | | Y 2X4 | Y 2x4 | | | | | | Y 2x3 | Y 2x3 | Y 3x4 | Y 3x4 | Y 2x4 | Y 3x4 | Y 2x3 | Y 2x3 |
| 0236 | Late camera thermal balance test | | | | | | | | | | Y 3x3 | Y 3x3 | Y 3x3 | Y 3x3 | Y 3x3 | Y 3x3 | Y 3x3 | | | | | | | | | |
| 0242 | Parallel Work | | | | | | | | | | Y 4x3 | Y 3x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 5 4x3 | Y 4x3 | | | | | | | | |
| 0246 | Resource contention at MKI Between DHU and ADHU | | | | | | | | | | | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | G 3x2 | | | | | |
| 0247 | Deformed brushes on SADA slip ring | | | | | | | | | | | | | | | | | | | | | | | | Y 3x5 | Y 3x4 |
| 0251 | SPOC development delays | | | | | | | | | | | | | | | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 3x3 | Y 2x3 | Y 2x3 | | |
| 0255 | SIR impacted by verification status | | | | | | | | | | | | | | | | | | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 3x3 | | |
| 0257 | POC readiness for ground system freeze | | | | | | | | | | | | | | | | | | | | | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | |
| 0259 | Further degradation of SADA insulation resistance | | | | | | | | | | | | | | | | | | | | | | G 2x2 | G 2x2 | | |
| 0260 | Flight camera focus issue after delivery to spacecraft | | | | | | | | | | | | | | | | | | | | | | Y 2x5 | Y 2x5 | Y 2x5 | Y 2x5 |
| 0261 | Flight camera focus issue in flight | | | | | | | | | | | | | | | | | | | | | | Y 2x5 | Y 2x5 | Y 2x5 | Y 2x5 |
| 0262 | Current HQ held UFE | | | | | | | | | | | | | | | | | | | | | | | | | Y 2x5 |
| 0264 | Low schedule margin during observatory I&T | | | | | | | | | | | | | | | | | | | | | | | | | Y 2x4 |
| 2010 | No thermal testing of flight-like EDU DHU | | | | Y 3x3 | Y 3x3 | Y 4x3 | | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x3 | Y 4x2 | | | | | |

# Risk Management Insights: Issues Over Time

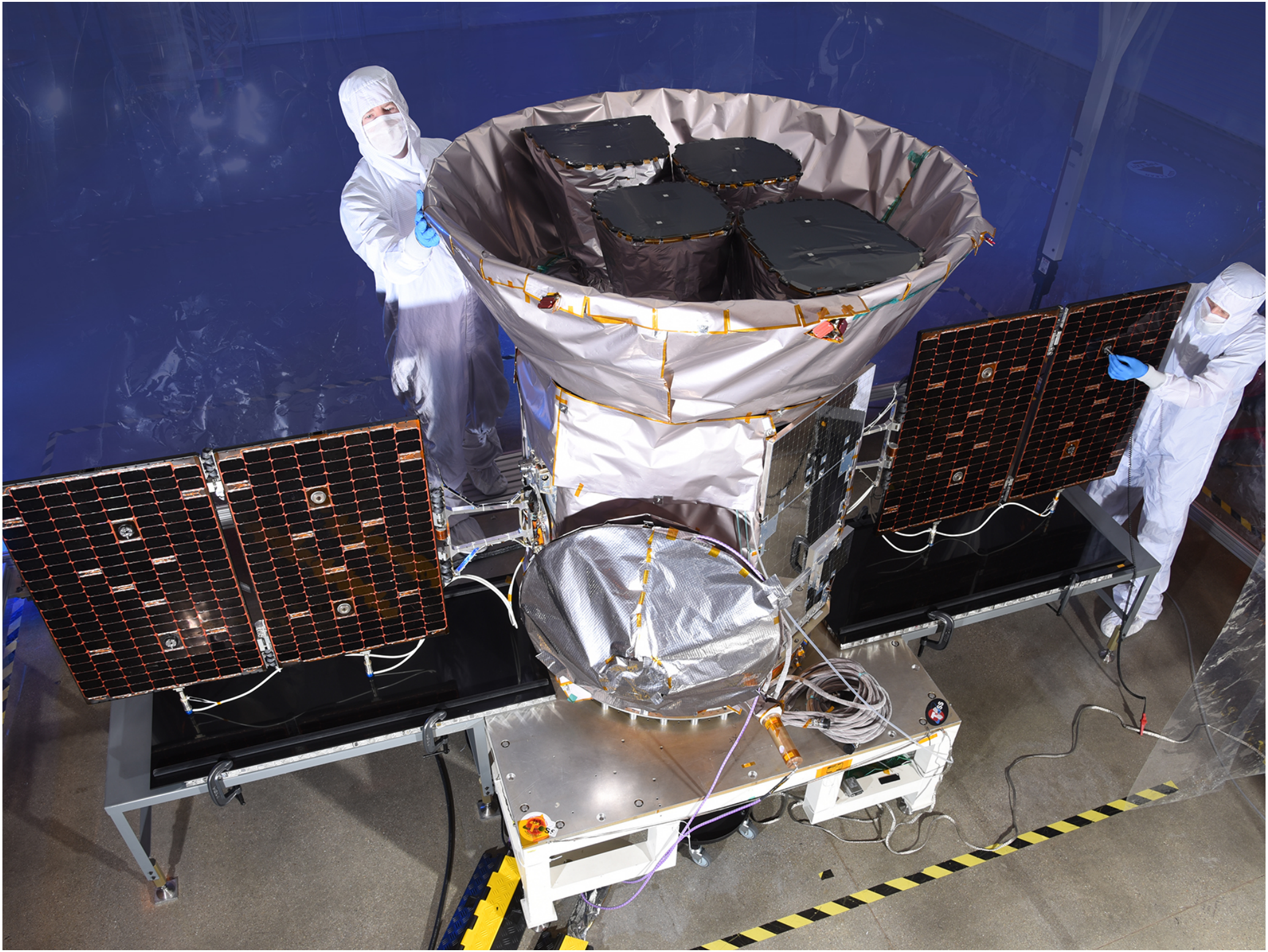
| Issue | 15-Sep | 15-Oct | 15-Nov | 15-Dec | 16-Jan | 16-Feb | 16-Mar | 16-Apr | 16-May | 16-Jun | 16-Jul | 16-Aug | 16-Sep | 16-Oct | 16-Nov | 16-Dec | 17-Jan | 17-Feb | 17-Mar | 17-Apr | 17-May | 17-Jun | 17-Jul | 17-Aug | 17-Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Open CDR technical liens require closure before CDR evaluation can be completed and flight design can be finalized | | | | G | G | | | | | | | | | | | | | | | | | | | | |
| Technical and programmatic challenges both on the observatory side and the launch vehicle side have significantly eroded the slack and funded schedule margin remaining against the August 2017 launch date. | | | | | | | | Y | Y | G | | | | | | | | | | | | | | | |
| Instrument Data Handling Unit (DHU) has faced technical design and development issues | | | | | Y | Y | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | G | | | | | |
| During acceptance testing of the TSS SADAs at RUAG, the slip ring insulation resistance values were lower than expected with some values out of spec. | | | | | | | | | | | | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | G | |
| The TESS planned FY16 budget was reduced by $11M below previous anticipated levels in Feb. 2016 | | | | | | | | Y | Y | Y | Y | Y | G | | | | | | | | | | | | |
| During commercial launch, SpaceX had a failure on 9/21/16 | | | | | | | | | | | | | | Y | Y | Y | R | R | R | G | | | | | |
| Flight S-Band transponder may have cracked solder | | | | | | | | | | | | | | | | Y | Y | Y | Y | Y | Y | G | | | |
| During TVAC testing of the firs tTESS flight camera, a focus drift of ~25 microns was identified. The level-5 requirement for allowable focus change from the selected fous is +/- 10 microns. | | | | | | | | | | | | | | | | | | | | | Y | G | | | |
| During box level testing of the Ka transmitter, new manufacturing issues were uncovered. | | | | | | | | | | | | | | | | | | | | | Y | Y | Y | Y | Y |
| Current Phase C/D cost reserves are below the 7120.7A requriement | | | | | | | | | | | | | | | | | | | | | | | | R | G |
| Reduction in HQ held UFE guideline increases programmatic risk posture | | | | | | | | | | | | | | | | | | | | | | | | R | G |

# Safety and Mission Assurance (S&MA)

- Mission Assurance Requirements (MAR) flowed to prime
  - Reviewed and Approved Contractor Implementation Plans
- Performed site visits of critical suppliers and implemented Surveillance Plan with emphasis on areas of concern.
  - Insight or oversight was adjusted as necessary.
- Material and Failure Review Boards are the cornerstone of a closed loop corrective action process.
  - Integrated with the Risk Management System as needed.
- SMA collaborated with Systems Engineering and Management throughout the development lifecycle.

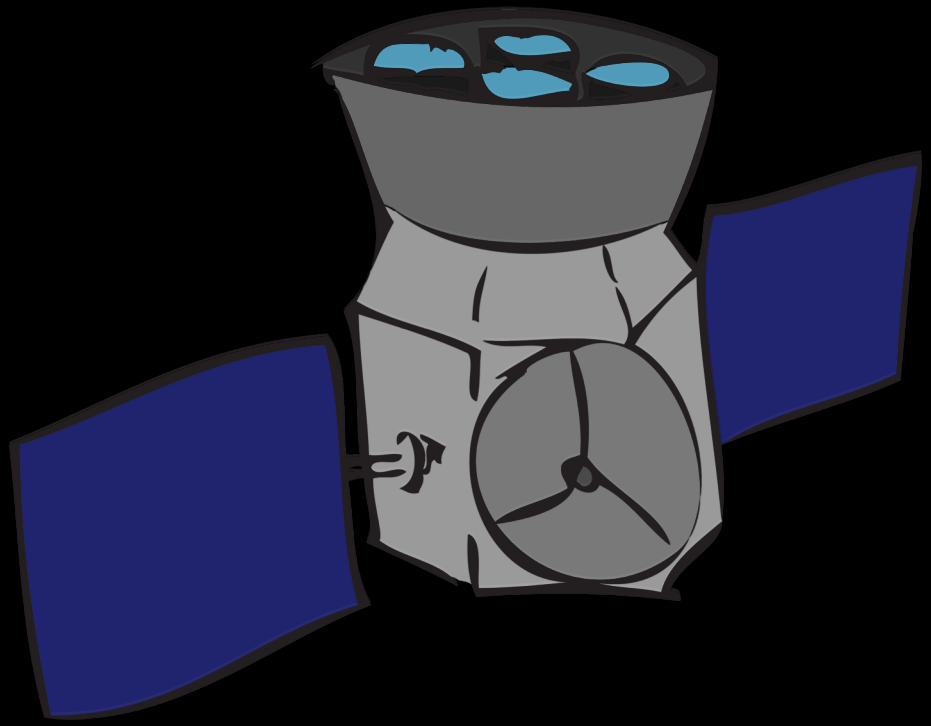
# Verification Process

| Element | SC | INST | Ground | Level 2 |
|---|---|---|---|---|
| Verified By Obs Integration | 78 | 39 | 77 | 35 |
| Verified, By EMI/EMC, Dynamics | 129 | 39 | 131 | 65 |
| Verified by TVAC | 129 | 61 | 131 | 65 |
| Verified, Pre-Ship Actual | 159 | 66 | 260 | 116 |
| Verified, Pre-Ship Target | 174 | 70 | 265 | 144 |
| Verified, @KSC | 175 | 70 | 266 | 146 |
| **TOTAL Level 3** | 175 | 70 | 266 | 146 |

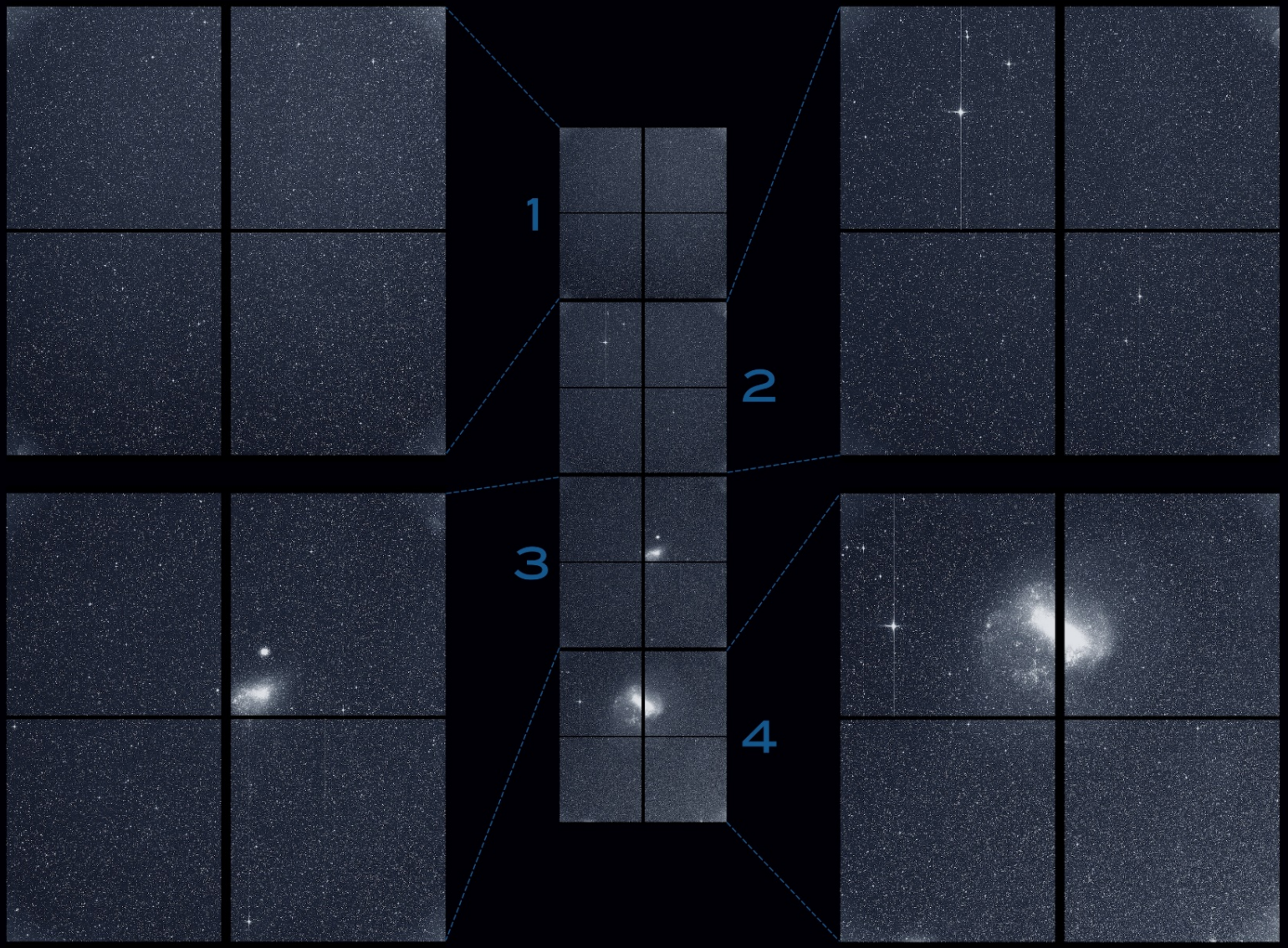



JUSTIN HARTNEY

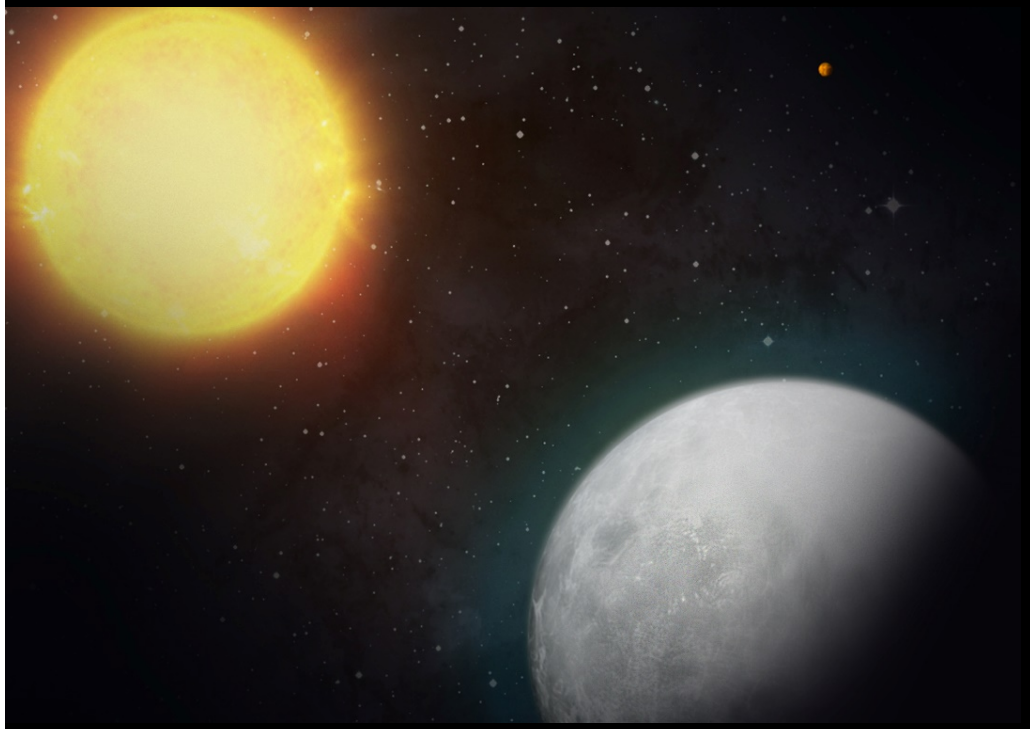
# TESS is bringing back science!



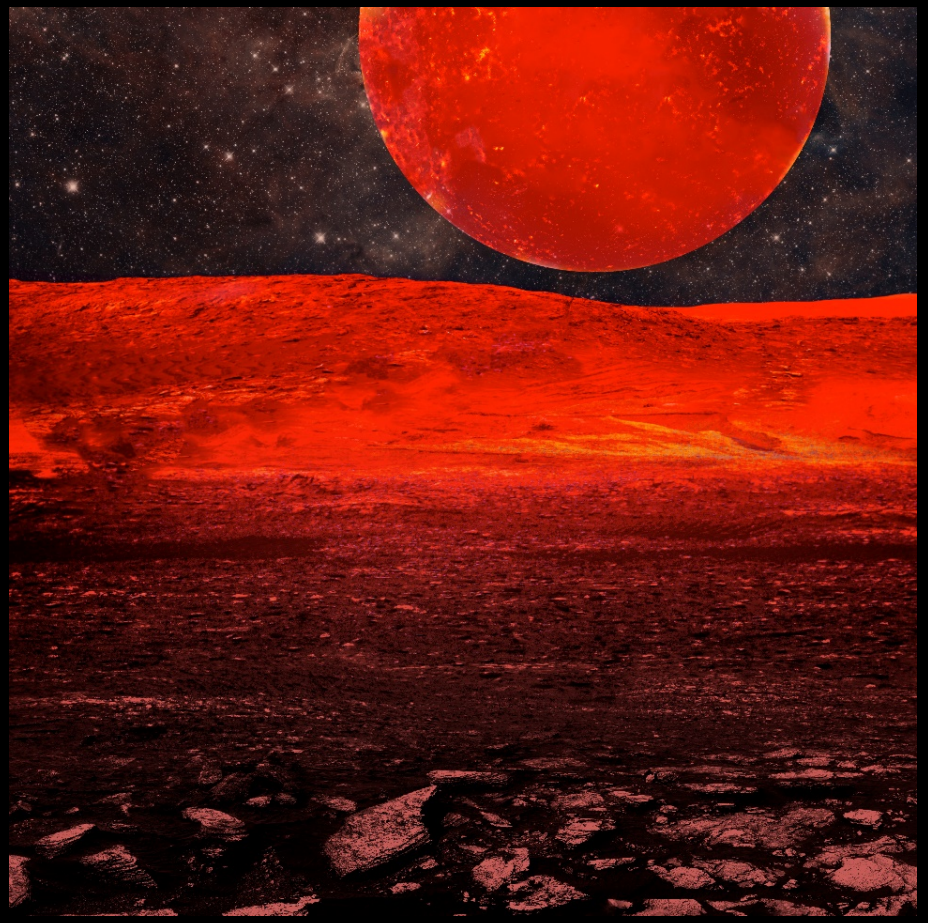
# TESS: First-Light Image



# First Exoplanet Discoveries



Star: Pi Mensae – an M Dwarf
Planet: ~2.1 Earth Radii, water-like density
Orbit: 6.3 days
Distance: 60 Light-Years Away



Star: LHS 3844 – an M Dwarf
Planet: ~1.2 Earth Radii
Orbit: 11 hours
Distance: 49 Light-Years Away

# Key Lessons Learned

- Building relationships in all partnerships are key
  - Face-to-Face time early was valuable to learn about organizational culture differences
  - Define what rules to bend, break, and know the ones that are unbreakable
- Risk Management is highly effective when closely tied to programmatic practices and technical judgement
- Teaming arrangement and cost-plus fixed contracts worked well
  - Selected procurement options that made sense
  - Investment in mission success by all parties was more important than
- Small vendors – can be very capable, however depth and experience will need mitigations, perhaps ones that cross boundaries to focus on success
- Don’t be afraid to pursue insurance policies

# CONNECT WITH US!

Websites:

NASA HQ: nasa.gov/tess

Project Office: tess.gsfc.nasa.gov

Science: tess.mit.edu

Social Media:

/NASATESS

@NASA_TESS

@TESSatMIT