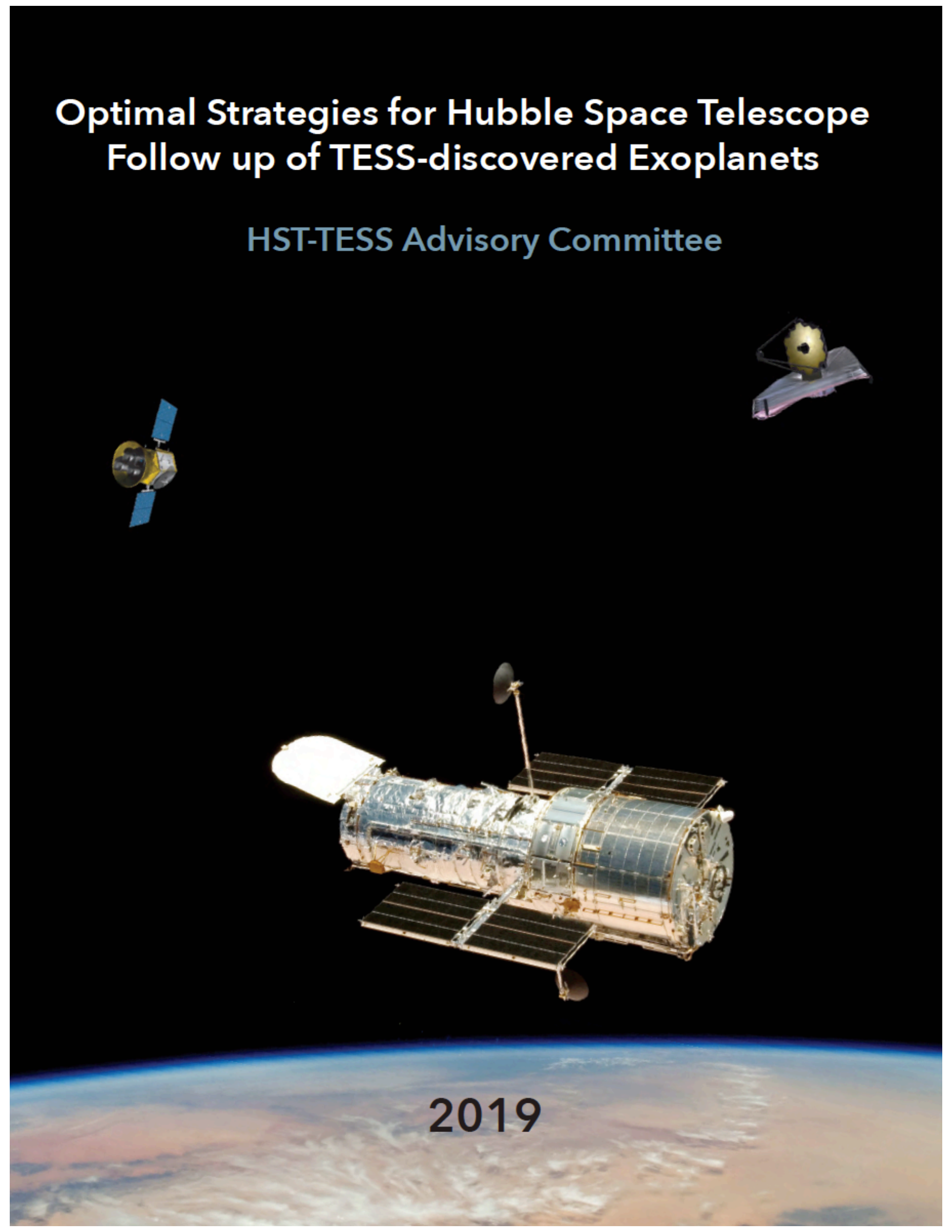
HST-TESS Advisory Committee

Dániel Apai (Chair, University of Arizona, USA)
Nicolas Cowan (McGill University, CA)
Kevin Heng (University of Bern, CH)
Laura Kreidberg (Center for Astrophysics | Harvard & Smithsonian, USA)
Mercedes López-Morales (Center for Astrophysics | Harvard & Smithsonian, USA)
Caroline Morley (University of Texas, Austin, USA)
John Mackenty (STScI, Ex Officio)
Iain Neill Reid (STScI, Ex Officio)



Charter of the Committee

Charter

The HST-TESS Advisory Committee is charged with providing guidance on optimal strategies for maximizing the scientific return from HST observations of TESS targets.
In particular, the Advisory Committee should address the following tasks:
1) Solicit input from the community on how HST can capitalize on the discoveries made by TESS;
2) Identify specific science themes and/or exoplanet types that should receive particular attention;
3) Provide advice on the optimal timing for substantive follow-up observations and suggest mechanisms for enabling those observations;
4) Comment on the appropriate scale of resources likely required to support those programs.
The committee will summarize their conclusions in a report to the Director and presentations to the STUC by the fall of 2019.

Constituted in: April 2019

Report submitted in November 2019

Workflow

Assessment

Review of TESS' expected ultimate yield of exoplanet discoveries

Review of HST transiting exoplanet science

Community and expert input

Programatic context for HST transiting exoplanet observations

Timeline for TESS, HST, JWST missions and supporting observations

Findings

Scientific Opportunities & Scientific and Programmatic Challenges

Key Findings

Recommendations

Process for Soliciting Community and Expert Input

Call for White Papers

Online survey (41 individuals responded, about 430 entries)

Informal input at meetings at major conferences and institutions

Invited expert input on key aspects

- Dr. Didier Queloz
- Dr. Drake Deming
- Dr. Kate Isaak
- Dr. Sam Quinn

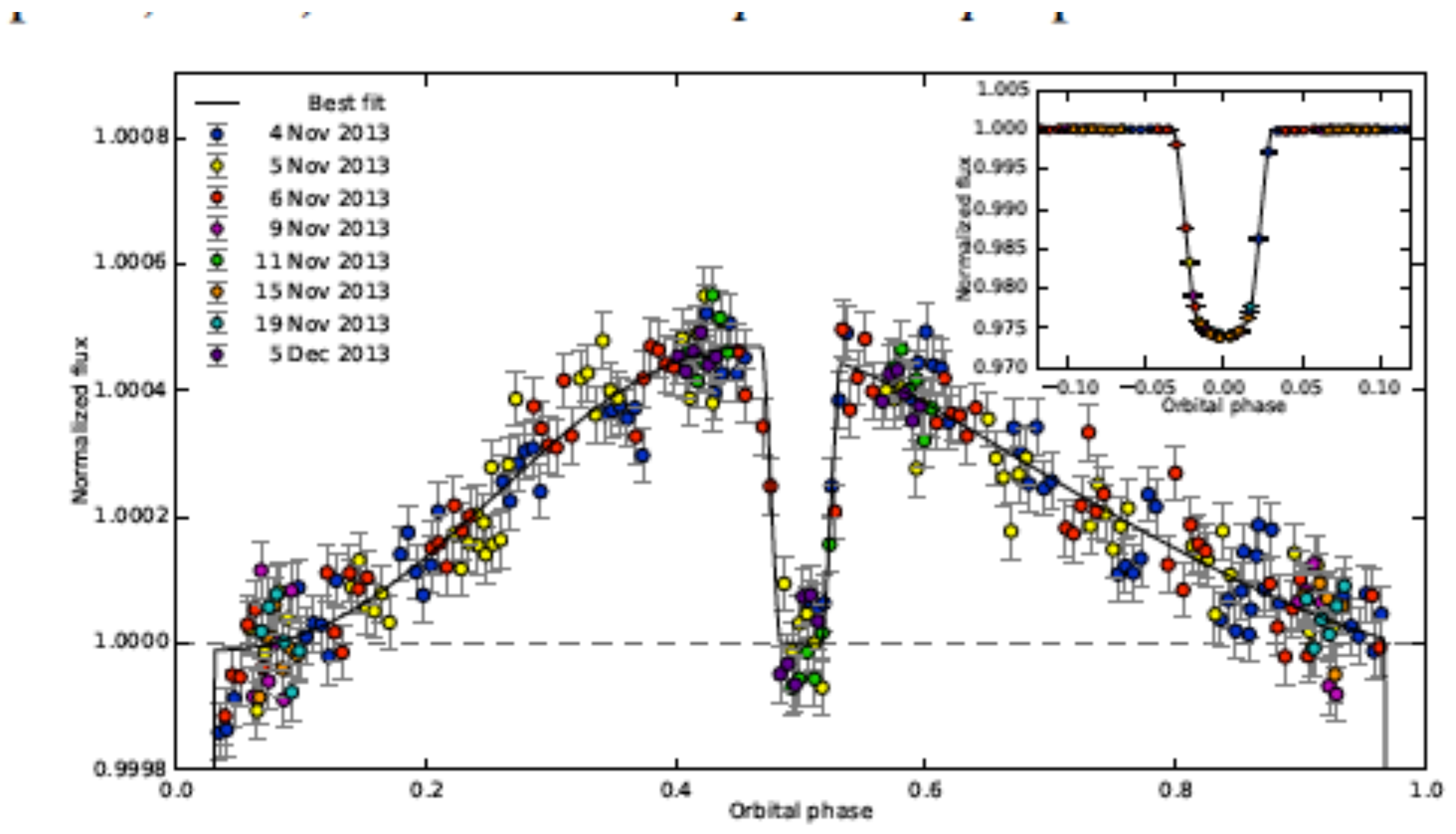
HST Transiting Exoplanet Science

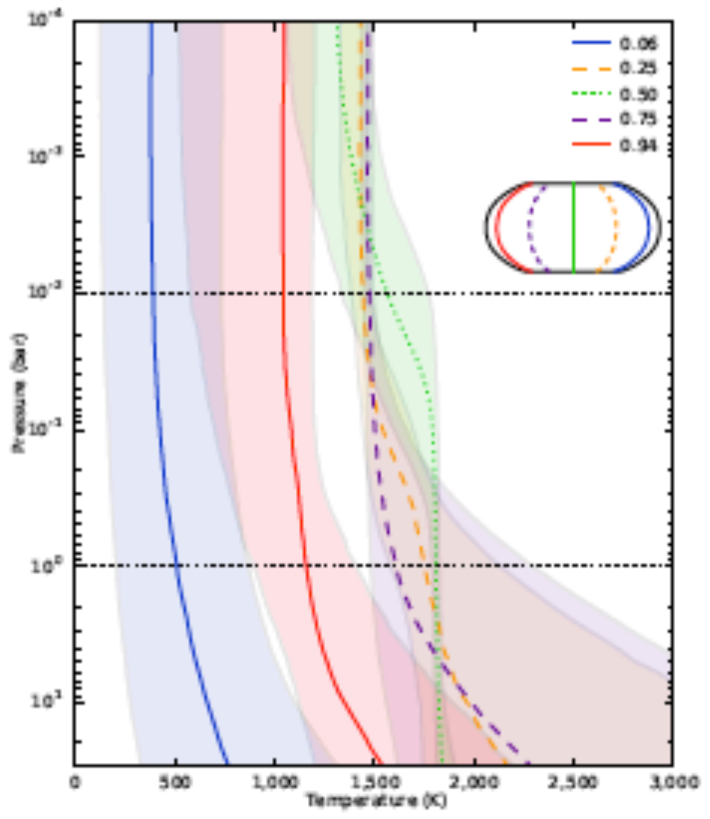
Atmospheric Abundances and Aerosols

Atmospheric Circulation

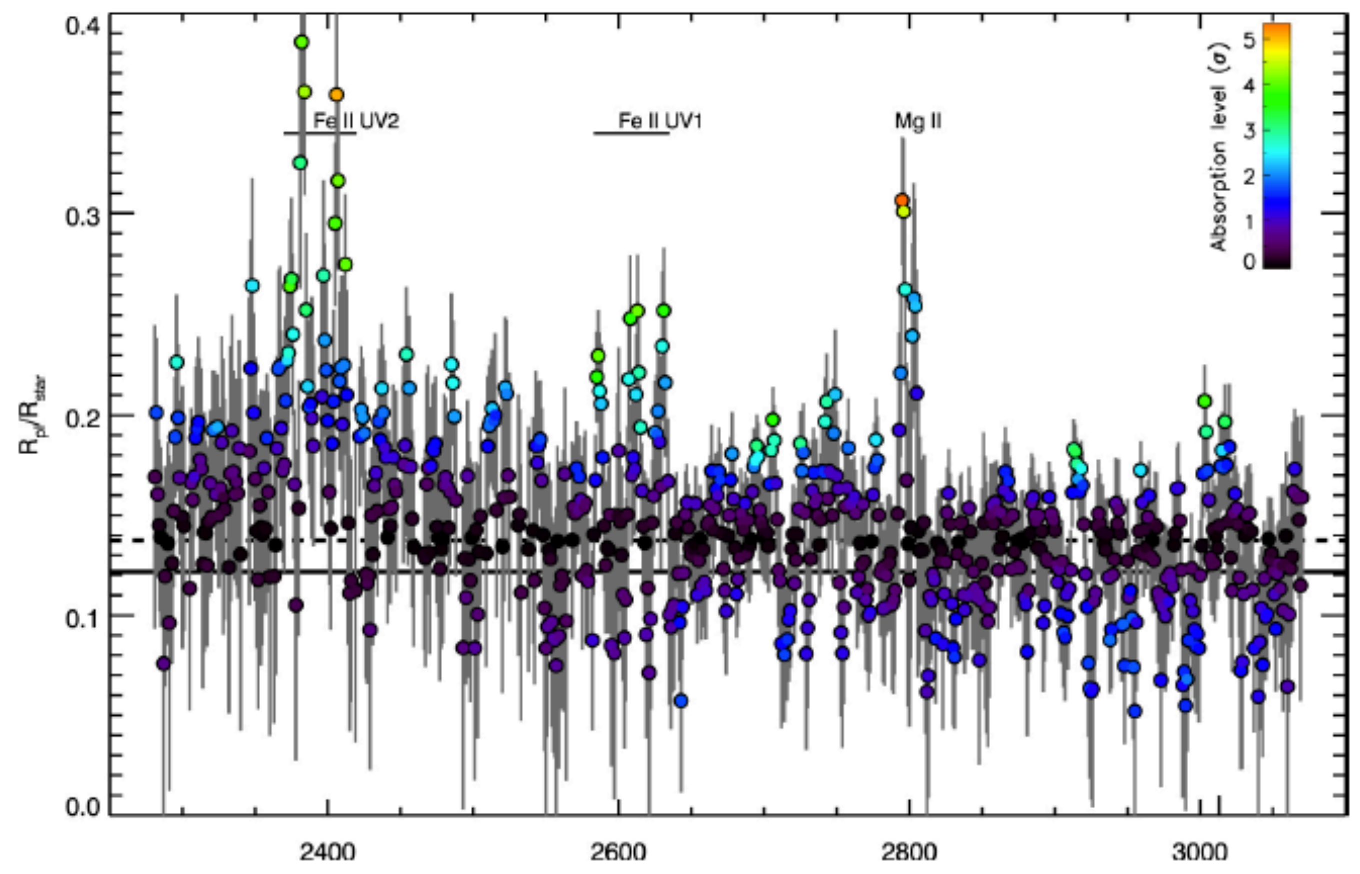
Atmospheric Escape

Host Star Characterization





Stevenson et al. 2017



Sing et al. 2019

TESS: Expected Yield

Prime mission:
Southern hemisphere completed
Northern hemisphere in progress

First extended mission approved:
Will re-observe most fields

Level 1 Science Requirement:
50 small (R_p<4 R_{Earth}) planets with mass measurements, bright host stars

Total number of planets: 12,000-17,000

BUT: TESS only finds candidates

Ground-based follow up is essential

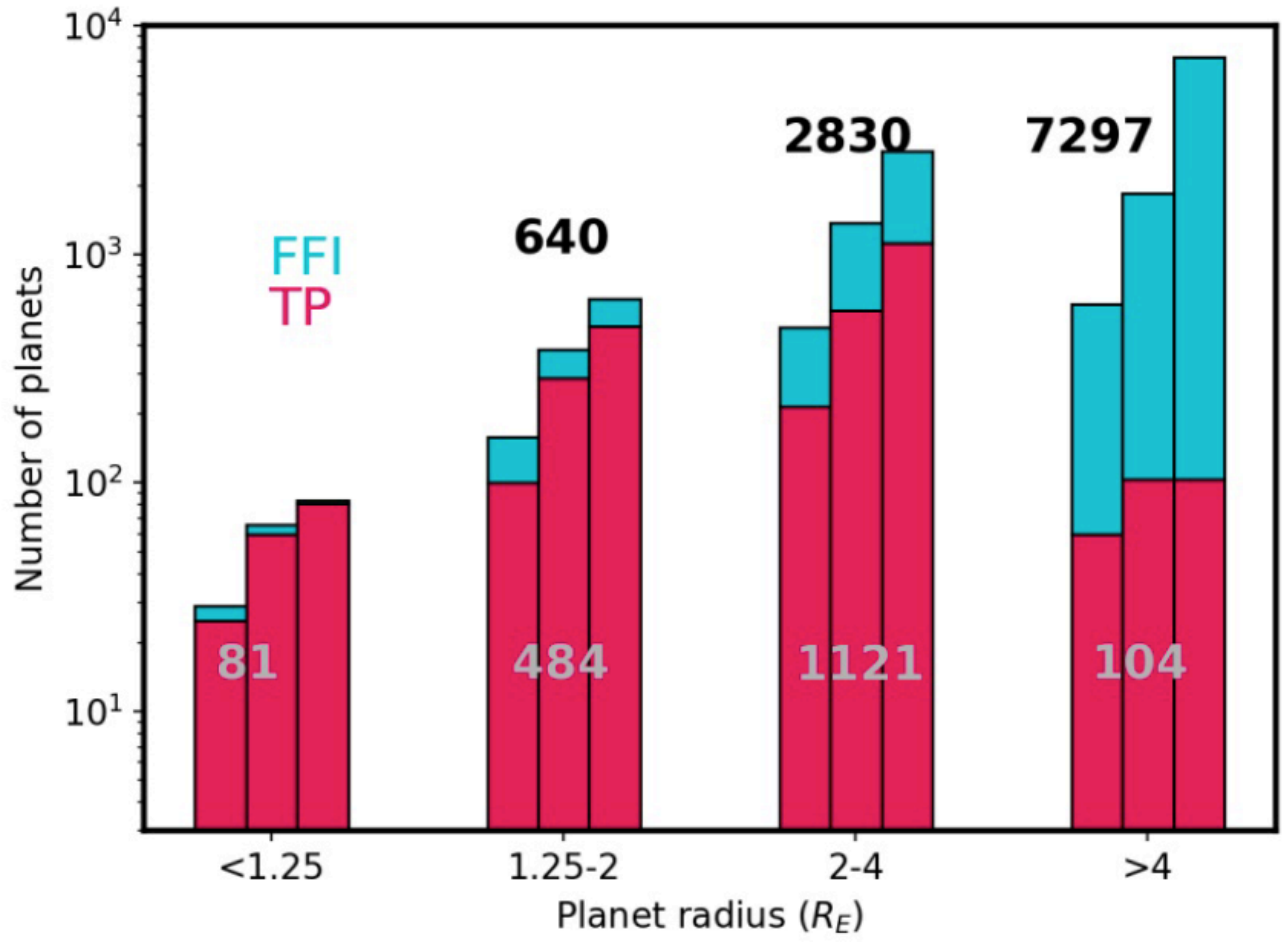


Figure 3: Expected yield of planets in the TESS 2-year primary mission. The three different bins represent stars brighter than TESS magnitude of 10, 12, and 15 mag. Red represents planets discovered in target pixels, and cyan represents planets discovered in full frame images (FFIs) only. The numbers labeled on top of each planet category shows the total number of planets expected around stars with $T < 15$ mag. Grey numbers represent the planets discovered in target pixels only. Figure reproduced from Huang et al. (2018).

Scientific Opportunities

1. High-quality, in-depth studies of archetype and extreme planets, comprehensive (multi-instrument)

study of planets and atmospheres.

2. Reconnaissance of Potentially Habitable Planets and their Environment
3. Scouting Targets for JWST and Preparatory Observations
4. Stellar characterization of exoplanet host stars
5. Large-scale, comparative studies
6. Other Discoveries: Exomoons, WD debris, disintegrating planets
7. Planet candidate verification in unusual circumstances, if impossible from ground

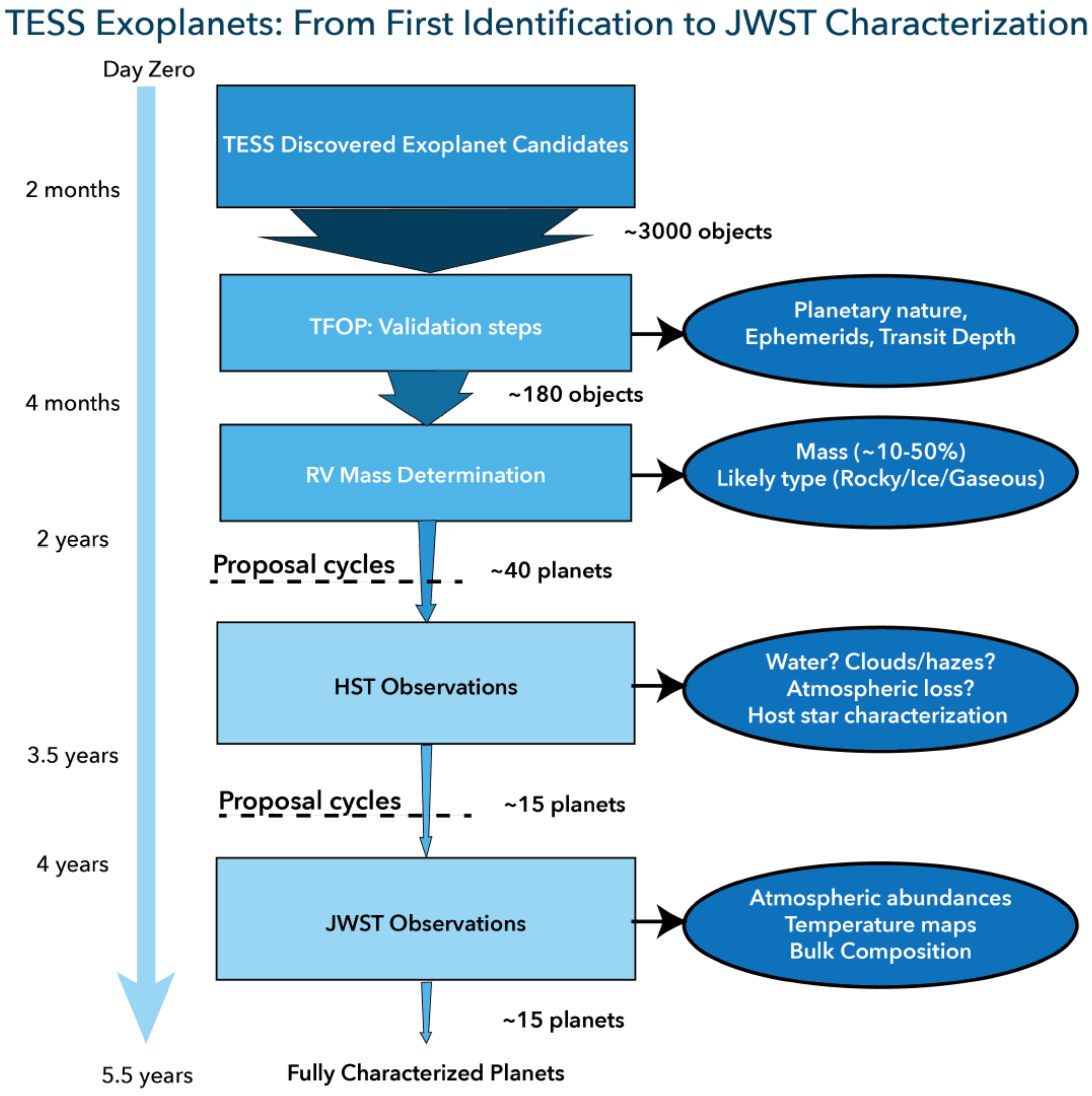
TESS: From Candidates to HST and JWST Targets

TESS can only find planet *candidates*

Verification requires complex and lengthy follow up process

TFOP

TESS ACWG



Scientific and Programmatic Challenges

1. A tension exists between timely follow-up observation of TESS discoveries and the need for proper vetting.

2. A systematic approach is necessary to address population-level questions.

3. Correct interpretation requires data from multiple instruments, often collected over many transits.

4. Clouds and hazes may complicate transmission studies of many small planets.

5. Stellar activity (primarily spectral changes due to time-evolving spot/faculae coverage) makes it difficult to combine data from multiple epochs.

6. Stellar contamination.

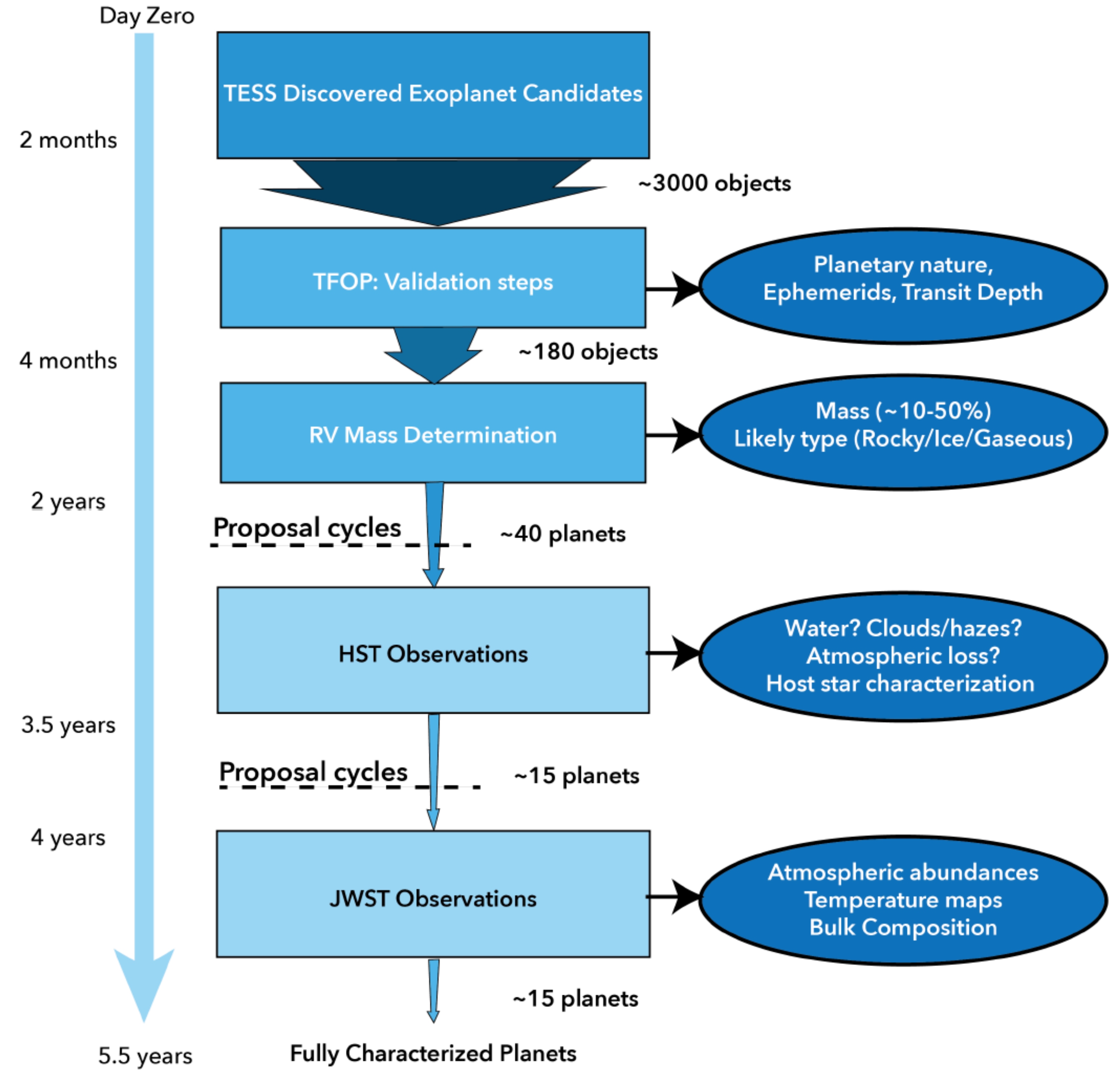
7. Slow decline in UV efficiency and overall scheduling efficiency.

8. With the imminent loss of the Spitzer Space Telescope we will lose the ability to carry out high-precision, continuous photometric monitoring.

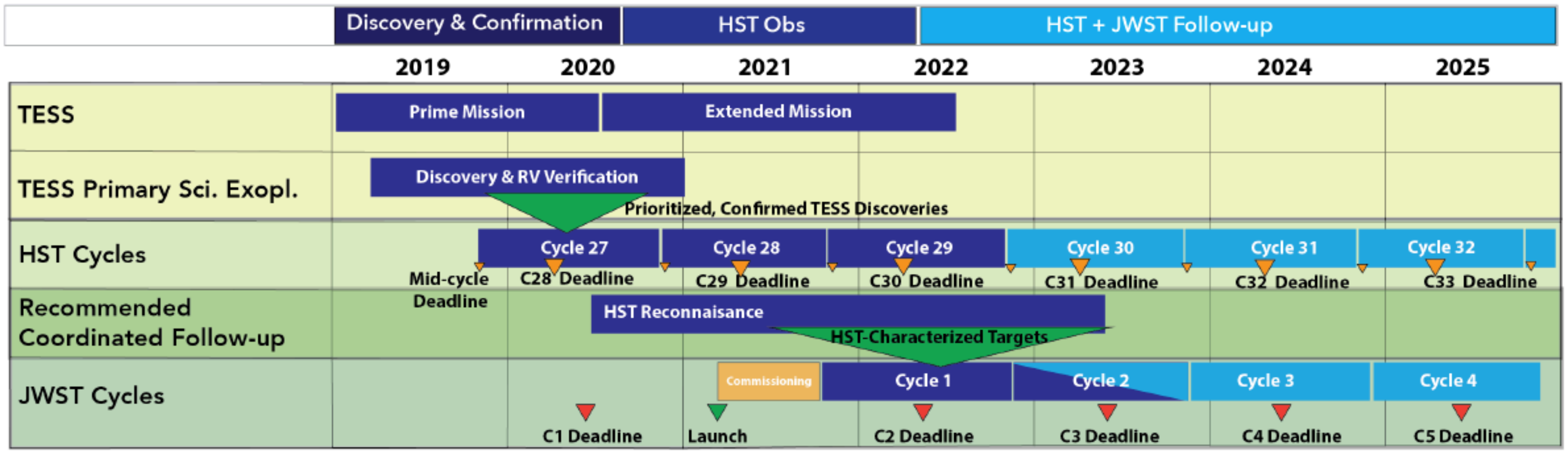
9. Healthy balance between small programs vs. large programs.

Greatest Challenge: Timeline

TESS Exoplanets: From First Identification to JWST Characterization



Timeline for HST and JWST Follow-up of TESS-discovered Exoplanets



Representative Scenarios

No Key Project

Table 1 Pessimistic, NO Key Project Scenario (Estimated Number of targets, Cumulative)

Year	TESS Candidate	Confirmed & Characterized	HST Prop. Accepted	HST Obs. Complete	JWST Prop. Accepted	JWST Obs. Complete
2019	1300	15	0	0	0	0
2020	1900	20	2	0	0	0
2021	2200	40	4	1	0	0
2022	2300	50	5	3	0	0
2023	2400	60	7	4	1	0
2024	2600	65	9	7	2	1
2025	2600	70	10	$\boxed{10}$	4	$\boxed{2}$

Pessimistic

Table 2 Optimistic, NO Key Project Scenario (Estimated Number of targets, Cumulative)

Year	TESS Candidate	Confirmed & Characterized	HST Prop. Accepted	HST Obs. Complete	JWST Prop. Accepted	JWST Obs. Complete
2019	1300	25	0	0	0	0
2020	1900	70	3	0	0	0
2021	2200	100	9	2	0	0
2022	2300	130	15	6	1	0
2023	2400	150	21	11	3	1
2024	2600	175	26	15	5	2
2025	2600	200	30	$\boxed{20}$	8	$\boxed{4}$

Optimistic

Select Key Findings

1. TESS's ultimate goal: identify small planets for atmospheric studies via transit spectroscopy. HST and JWST are the most powerful facilities for such studies. One of JWST's four science themes is "Life and Planetary Systems", prominently featuring the study of small exoplanet's atmospheres. In short, TESS, HST, and JWST were funded, fully or in part, to work in synergy, the only way to fulfill their potential for exoplanet studies.

2. TESS L1SR sample: ~50 small ($R < 4R_{Earth}$) exoplanets orbiting bright stars.

3. HST and JWST offer unique capabilities and transform our view of super-earth/sub-neptune planets.

5. HST's aperture is too small to meaningfully characterize the atmospheres of nearly all habitable zone earth-sized planets, but can provide powerful observations required to characterize the system and their host stars.

Select Key Findings

6. HST: powerful, unique roles in characterizing transiting exoplanets and their host stars.

7. Ultimately, the science gain from the TESS-HST-JWST synergy will be determined by (a) how efficiently the important planetary targets can be ushered through the validation–characterization–reconnaissance–proposal process;
(b) whether the combined sample of JWST-observed planets allows addressing population-level questions.

8. The most important unique HST capabilities (prior to JWST) include: (a) UV characterization of the host stars and atmospheric escape from the planets. (b) sensitive probe of water absorption present in the atmosphere. (c) comprehensive broad wavelength coverage (from UV to NIR).

9. The transmission spectra of an unknown fraction of small planets will be limited by the presence of particulates (clouds/hazes) and/or by stellar activity and stellar contamination. Therefore, many compelling JWST proposals will require HST scouting/reconnaissance observations.

Select Key Findings

10. **A major concern is the timeline** for validating and characterizing TESS targets, and for proposing these to HST reconnaissance observations, before they can be proposed for JWST.

12. The slowest part of verifying small planet candidates is the radial velocity follow up (typical timescale 1.5–2 years).

13. Without a larger, coordinated effort HST/JWST studies will focus on individual planets. A sample built from such observations will fail to address population-level questions.

15. If a community-driven large program is implemented, the program should be managed in a transparent and efficient manner.

Recommendations

1. **Opportunity for a Small Planets Key Project:** Large, multi-cycle, community-driven, treasury program to answer population-level questions. Fully transparent; aim to maximize joint impact of TESS-HST-JWST synergy.

2. **Key Project Timeliness:** Aim to complete project by JWST Cycle-3 deadline as much as possible.

3. **Sub-neptunes and super-Earths** should be prioritized.

4. Planets **thoroughly vetted** should be prioritized, but also **allow conditional acceptance** when well justified.

5. Well-organized **repository** for open-source data reduction, analysis, and modeling tools.

6. Support for **a group to interface** between TESS, TFOP, HST communities to aid target identification/characterization.

Expected Impact of Key Science Project

No Key Project

Table 1 Pessimistic, NO Key Project Scenario (Estimated Number of targets, Cumulative)

Year	TESS Candidate	Confirmed & Characterized	HST Prop. Accepted	HST Obs. Complete	JWST Prop. Accepted	JWST Obs. Complete
2019	1300	15	0	0	0	0
2020	1900	20	2	0	0	0
2021	2200	40	4	1	0	0
2022	2300	50	5	3	0	0
2023	2400	60	7	4	1	0
2024	2600	65	9	7	2	1
2025	2600	70	10	10	4	2

Table 2 Optimistic, NO Key Project Scenario (Estimated Number of targets, Cumulative)

Year	TESS Candidate	Confirmed & Characterized	HST Prop. Accepted	HST Obs. Complete	JWST Prop. Accepted	JWST Obs. Complete
2019	1300	25	0	0	0	0
2020	1900	70	3	0	0	0
2021	2200	100	9	2	0	0
2022	2300	130	15	6	1	0
2023	2400	150	21	11	3	1
2024	2600	175	26	15	5	2
2025	2600	200	30	20	8	4

Key Project

Table 3 Pessimistic Key Project Scenario (Estimated Number of targets, Cumulative)

Year	TESS Candidate	Confirmed & Characterized	HST Prop. Accepted	HST Obs. Complete	JWST Prop. Accepted	JWST Obs. Complete
2019	1300	15	0	0	0	0
2020	1900	20	9	2	0	0
2021	2200	40	19	9	4	0
2022	2300	50	23	21	7	3
2023	2400	60	25	23	9	5
2024	2600	65	27	25	17	7
2025	2600	70	29	27	18	11

Table 4 Optimistic Key Project Scenario (Estimated Number of targets, Cumulative)

Year	TESS Candidate	Confirmed & Characterized	HST Prop. Accepted	HST Obs. Complete	JWST Prop. Accepted	JWST Obs. Complete
2019	1300	25	0	0	0	0
2020	1900	70	11	3	0	0
2021	2200	100	24	10	4	0
2022	2300	130	28	19	7	4
2023	2400	150	32	24	13	10
2024	2600	175	36	28	20	13
2025	2600	200	39	32	24	20

Pessimistic **Optimistic**

Comments on Resources

1. Support for a group to interface between TFOP, HST, and JWST communities
2. Characterization and screening of targets
3. Transparency and Repeatability: Shared data reduction, analysis, and modeling libraries
4. Within the Key Science Project, redundant data reduction and analysis efforts needed to maximize reliability and minimize time required to inform JWST observations

HST-TESS Exoplanet Initiative in Cycle 28

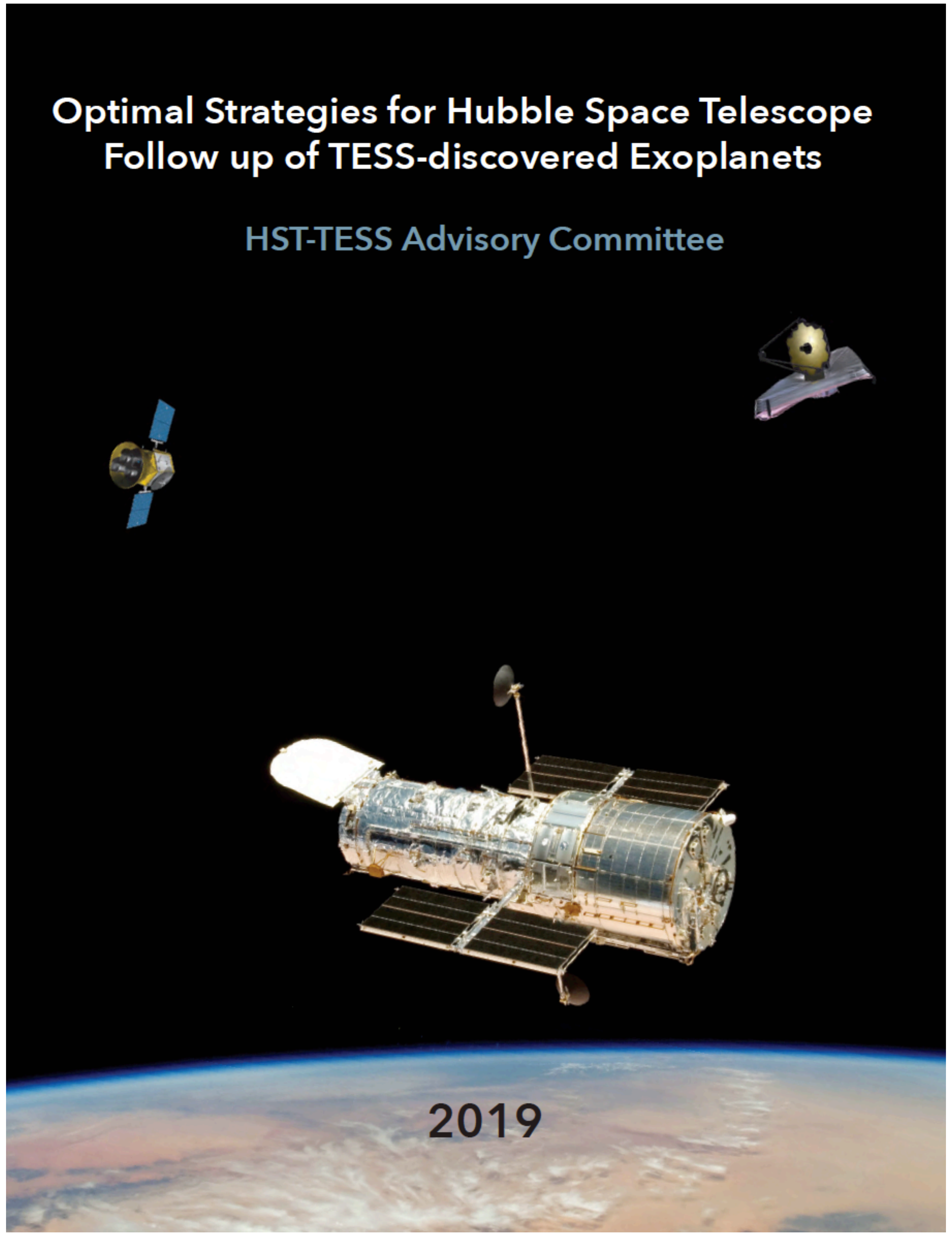
"[…] the HST-TESS Exoplanet Initiative (HTEI) to provide the community with an opportunity to propose for observations of a well-characterized, representative sample."

"Exoplanet Initiative proposals should
- Focus on mini-neptunes and super-earths
- Be sufficiently comprehensive in scope to address demographic questions
- Characterize the atmospheric properties as a function of size and equilibrium temperature
- Lay the foundations for subsequent observations with JWST"

- Treasury programs, JWST Preparatory programs, probably long period (multi-cycle) programs
- Capitalize quickly on the ongoing characterization of TESS exoplanet discoveries.
- Strong community participation
- Targets must have reliable mass determinations.
- Specific targets for Cycle 28 but may list generic targets for future cycles.
- Must specify the quantitative criteria (such as mass, density and separation) that will be used to define the full sample.
- Appropriate mechanisms for building community consensus on how new targets will be added in future cycles

Summary

Community and expert input
Scientific opportunities and challenges
Programmatic challenges
Realizing TESS's potential requires HST+JWST follow up
Realizing JWST's potential requires TESS planet discoveries
JWST observations will typically require HST observations
Bottleneck in candidates-to-HST/JWST-targets process
Current project yield is insufficient
Bottleneck can be alleviated by key science project
  if executed relatively quickly
Lead to HST-TESS Exoplanet Initiative



Supporting Slides

Small Planets Key Project

1. Comprehensive scope to answer population-level questions.
2. Scope and scientific focus determined by the community.
3. Comprehensive characterization of the most favorable small planets.
4. Characterize planetary atmospheres as a function of size and equilibrium temperature.
5. Focus on mini-neptunes and super-earths.
6. Treasury program: data and results shared w community, managed transparently.
7. All precursor HST observations for JWST should be completed in a timely manner.
8. Assess presence of aerosols and problematic stellar activity.
9. Consider the potential combined science yield from HST and JWST.
10. A balanced program portfolio (small/medium/large programs) should be maintained.

HST-TESS Exoplanet Initiative

NASA's Transiting Exoplanet Survey Satellite has discovered a wide range of planetary systems, notably small exoplanets (mini-neptunes and super-earths) around nearby stars. The HST-TESS Advisory Committee was constituted by the STScI Director to provide guidance on optimal strategies for maximizing the scientific return from HST observations of TESS exoplanet targets. Following extensive consultation with the community, the HST-TESS AC final report highlights the vital role that HST can play in characterizing small exoplanets and identifying high priority targets for subsequent JWST observations.

Specifically, the committee noted that in order to maximize the science return, it is crucial that TESS targets have well determined periods and masses. Proceeding in a linear fashion, however, will lead to significant delays in obtaining follow-up HST observations of sufficient systems. Moreover, working on a target-by-target, proposal-by-proposal basis is unlikely to optimally sample the exoplanet population. Based on those considerations, the Space Telescope Users Committee has recommended the HST-TESS Exoplanet Initiative (HTEI) to provide the community with an opportunity to propose for observations of a well-characterized, representative sample.

Exoplanet Initiative proposals should

- Focus on mini-neptunes and super-earths
- Be sufficiently comprehensive in scope to address demographic questions
- Characterize the atmospheric properties as a function of size and equilibrium temperature
- Lay the foundations for subsequent observations with JWST

HST-TESS Exoplanet Initiative programs are Treasury programs and must meet the requirements for those programs. They should be identified as JWST Preparatory programs using the APT check box. They are anticipated as long period (multi-cycle) programs that can capitalize quickly on the ongoing characterization of TESS exoplanet discoveries. The HST-TESS AC also recommended strong community participation in these programs, particularly with regard to target selection.

All HTEI exoplanet targets must have reliable mass determinations. Since an appropriately characterized sample of TESS targets is not available at the present time, HTEI proposals should identify specific targets that could be observed in Cycle 28 but may list generic targets for future cycles. The proposal must specify the quantitative criteria (such as mass, density and separation) that will be used to define the full sample. In addition, the proposals must describe appropriate mechanisms for building community consensus on how new targets will be added in future cycles.

HST Programmatic Context

Most successful programs focus on single targets

Single gyro operations
UV capabilities

As of now TESS follow-up observation proposals unsuccessful