Exoplanet WG Preliminary Recommendations

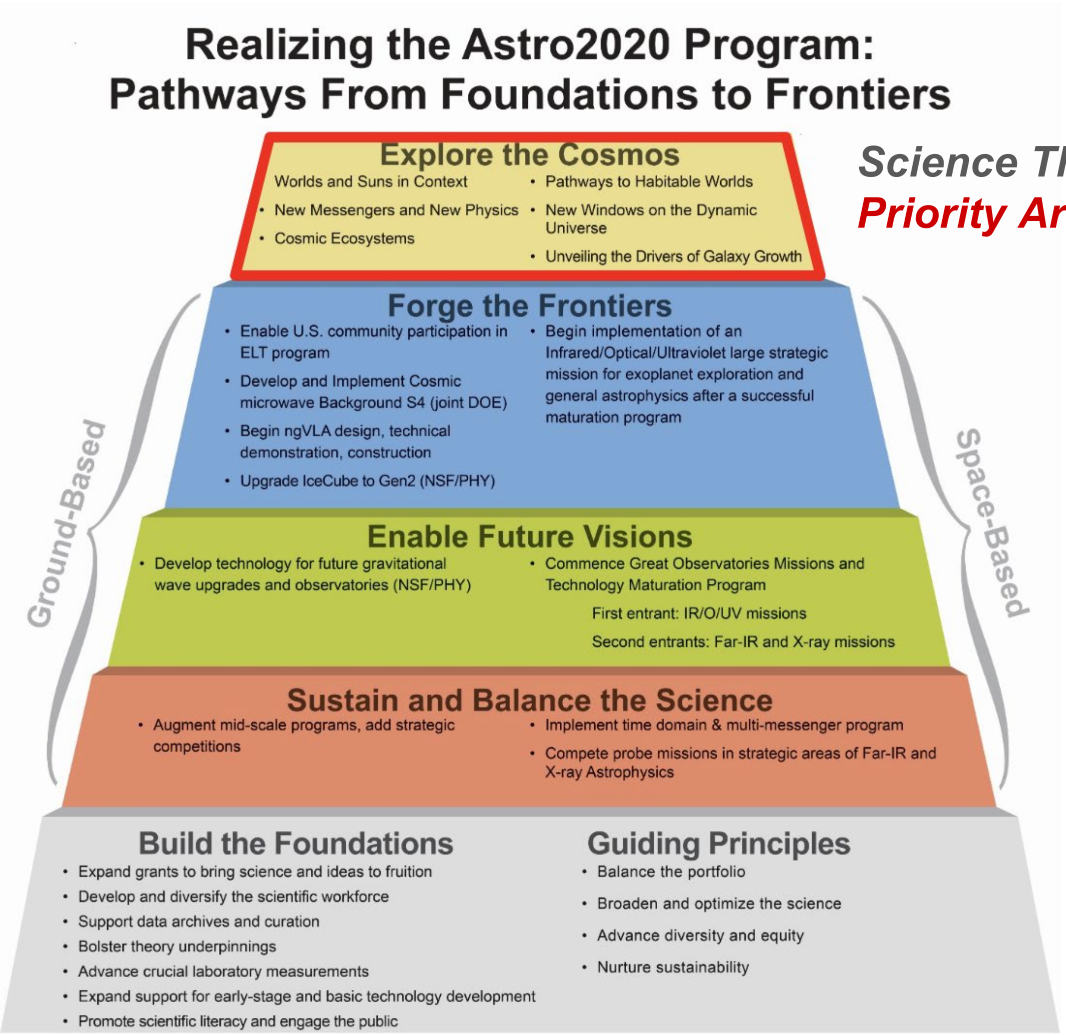
Natasha Batalha, Bjorn Benneke, Beth Biller (STUC Chair), Nestor Espinoza, Kevin France, Quinn Konopacky, Laura Kreidberg, Emily Rauscher, Seth Redfield (Chair), David Sing

Exoplanet Strategy WG was charged to:

1. Solicit input from the community on key science areas that should be prioritized for HST or JWST observations;
2. Identify science themes that should be prioritized for future HST and JWST General Observer programs and/or Archival analyses, including potential HST multi-cycle programs;
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
5. Develop a specific concept for a large-scale (~500 hours) Director’s Discretionary exoplanet program to start implementation by JWST Cycle 3.

This is the right time to inject new observations and do strategic planning around exoplanet science!

1. JWST observations are off the charts and stellar UV information critical
2. Exoplanet science questions are a high priority for our field
3. The field has been profoundly transformed over the developmental lifetime of JWST



Science Theme: Worlds and Suns in Context
Priority Area: Pathways to Habitable Worlds

We are on a path to exploring worlds resembling Earth and answering the question: “Are we alone?” The task for the next decades will be finding the easiest of such planets to characterize, and then studying them in detail, searching for signatures of life.

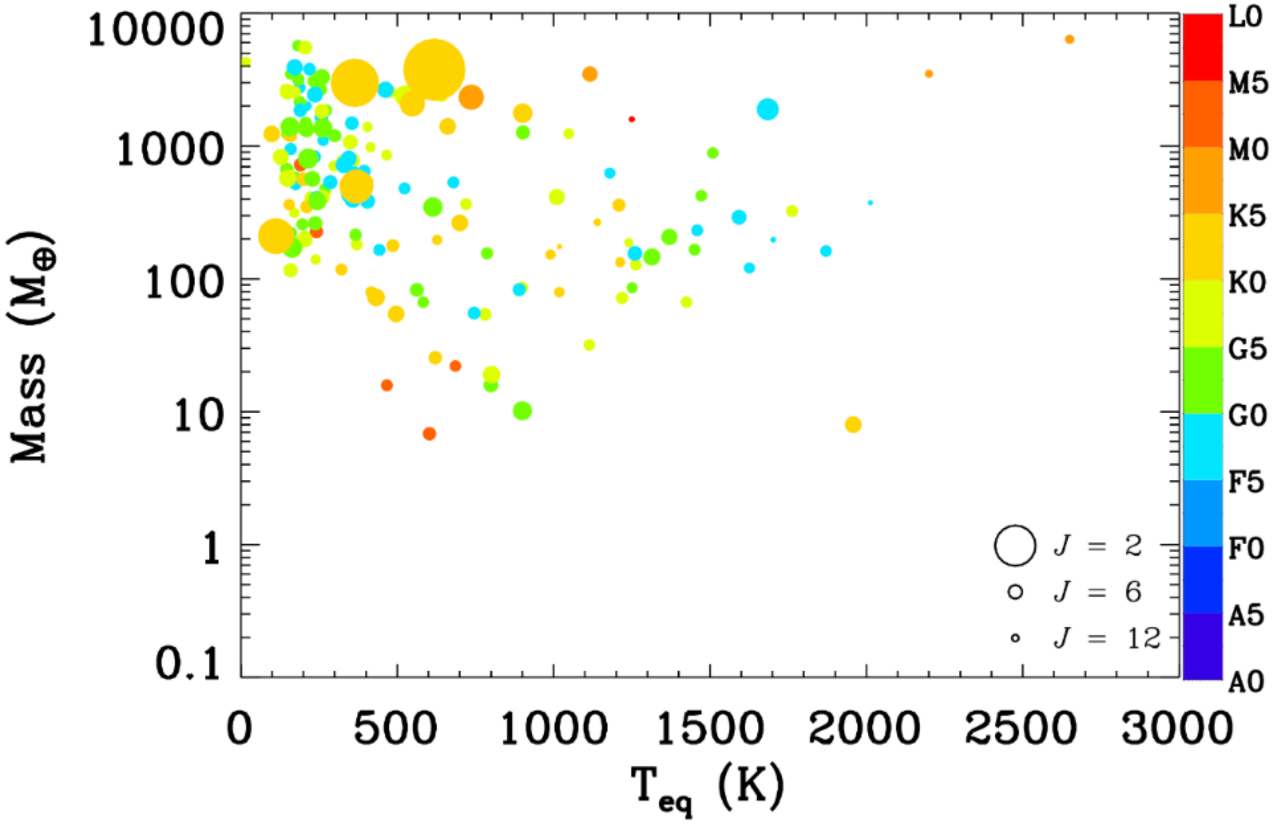
TABLE E.1 Science Questions and Discovery Area

Questions	Subquestions
E-Q1: What is the range of planetary system architectures, and is the configuration of the solar system common?	E-Q1a: What are the demographics of planets beyond the reach of current surveys? E-Q1b: What are the typical architectures of planetary systems? E-Q1c: How common is planetary migration, how does it affect the rest of the planetary system, and what are the observable signatures? E-Q1d: How does the distribution of dust and small bodies in mature systems connect to the current and past dynamical states within planetary systems? E-Q1e: Where are the nearby potentially habitable planets, and what are the characteristics of their planetary systems?
E-Q2: What are the properties of individual planets, and which processes lead to planetary diversity?	E-Q2a: Which physical processes govern a planet's interior structure? E-Q2b: How does a planet's interior structure and composition connect to its surface and atmosphere? E-Q2c: What fundamental planetary parameters and processes determine the complexity of planetary atmospheres? E-Q2d: How does a planet's interaction with its host star and planetary system influence its atmospheric properties over all time scales? E-Q2e: How do giant planets fit within a continuum of our understanding of all substellar objects?
E-Q3: How do habitable environments arise and evolve within the context of their planetary systems?	E-Q3a: How are potentially habitable environments formed? E-Q3b: What processes influence the habitability of environments? E-Q3c: What is the range of potentially habitable environments around different types of stars? E-Q3d: What are the key observable characteristics of habitable planets?
E-Q4: How can signs of life be identified and interpreted in the context of their planetary environments?	E-Q4a: What biosignatures should we look for? E-Q4b: How will we interpret the biosignatures that we see? E-Q4c: Do any nearby planets exhibit biosignatures?
E-DA Discovery Area: The search for life on exoplanets.	

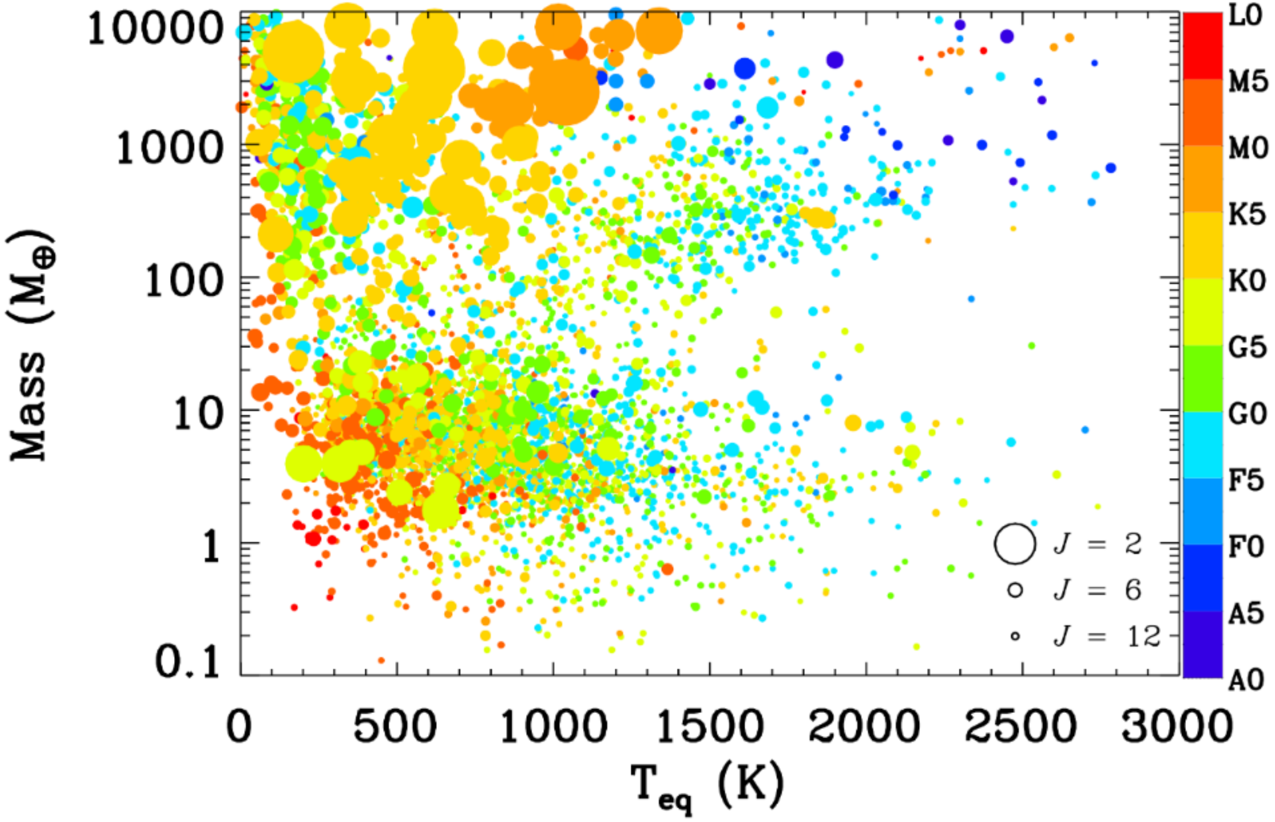
Comprehensive Population Survey (Key Science priority)

Survey of Rocky Worlds (DDT)

Landscape of Exoplanets during JWST's 2005 Science Assessment



Landscape of Exoplanets today



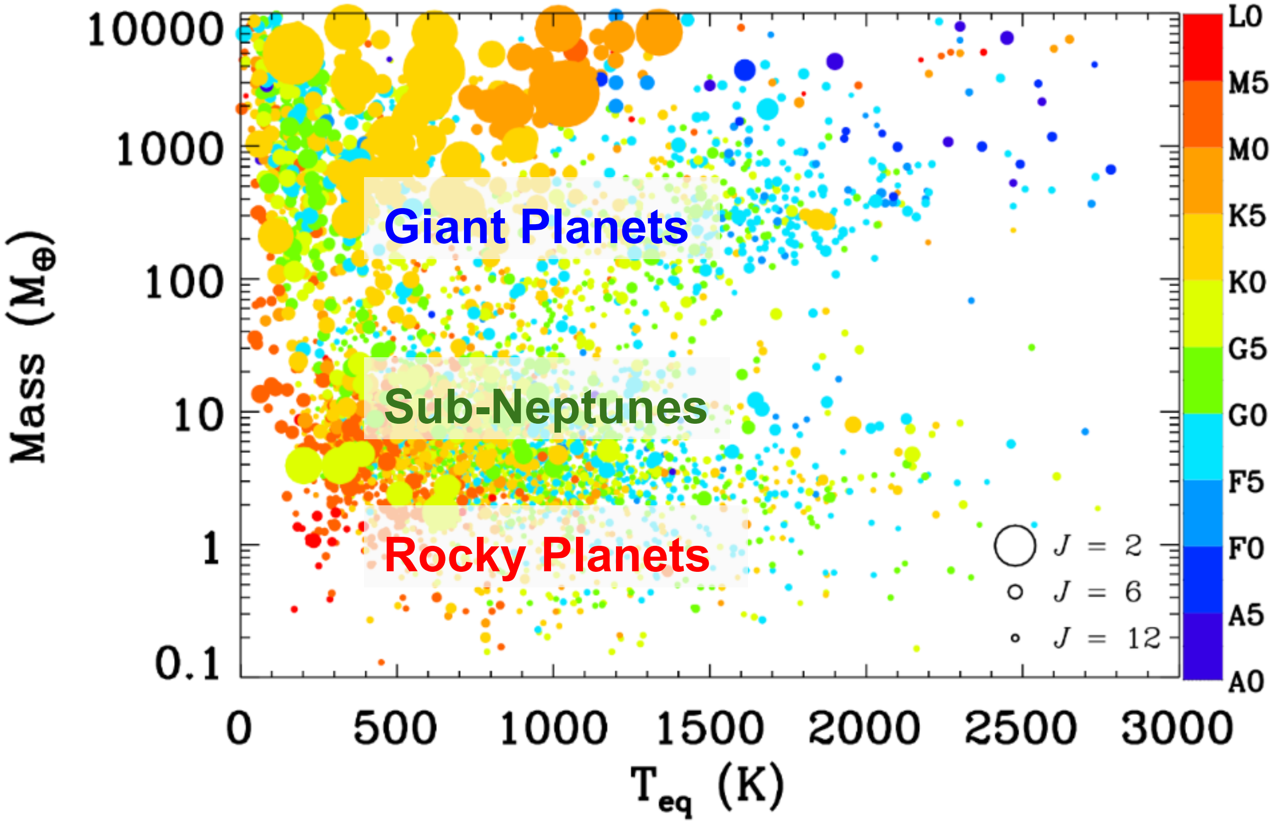
The community feedback forms the basis for our recommendations

1. Lots of communication with community prior to White papers + surveys
    a. WG webpage with active email/FAQ
    b. Three Town Hall meetings with ~100+ attendees at each (one devoted to Early Career Researchers)
2. Good response from community
    a. 46 white papers (WPs)
    b. 75 surveys
    c. We have demographic information, but are waiting until after recommendations are finalized
3. Lots to say on all the charges
    a. Key science themes (91% surveys; 76% WPs)
    b. Optimal timing (63% surveys; 24% WPs)
    c. Scale of resources (68% surveys; 22% WPs)
    d. DDT Concepts (52% surveys; 63% WPs)

The Connection of the Key Science Themes and DDT Concepts

1. Community feedback highlighted the profound connection between the Key Science Themes and DDT Concepts
2. **The 10^4 Hour Survey**: Extrapolated JWST exoplanet mission commitment
   a. 5000 hrs per cycle * ⅓ allocated to exoplanets * 20 cycles = 30,000 hours ~ 10^4 hours
3. Questions that guided our discussions
   a. How can a 500 hr DDT program unlock scientific questions that the community can pursue with the remaining JWST exoplanet observations? What observations would not be done in the GO paradigm?
   b. How can we scaffold and support GO programs in future cycles to optimize this 10^4 hours of exoplanet observations? What observations are we taking for granted now and will wish we had later?

Landscape of Exoplanets today



Key Science Themes

1. **Giant Planet** science aims to answer diversity questions in the population, as well as the link between planet formation and interior structure. Given their relative ease of observability, a large sample of deep spectra can be obtained to address a wide range of science questions.

2. **Sub-Neptune** science aims to understand a population not observed in our Solar System and at the intriguing transition between terrestrial and giant planets. This population is highly sensitive to stellar influence (e.g,. photochemistry), atmospheric loss and evolution, and a relatively easier sample to explore shared science questions with rocky planets.

3. **Rocky Planet** science aims to directly put our own planet into a cosmic context. Fundamental questions of the diversity, and even existence, of terrestrial atmospheres must be answered first in the pathway to habitable worlds. The significant challenges of observing this population must be understood to optimize the design of future observations and observatories (e.g., HWO).

Needs and Recommendations to Address Key Science Themes

1. Provide support for observations that will provide archival/legacy value in the context of a broad 10^4 hr exoplanet survey
    a. Scaffold a comprehensive atmospheric characterization and planet search survey across diversity of all planets/stars
    b. Gives a mechanism for diversity of great ideas from WP and ambitious (very large) GO proposals to be realized
    c. Provide incentive for larger sample, higher S/N, broader wavelength coverage, e.g., check box, time subsidy
    d. Need publicly accessible figure/database to identity where the holes are (perhaps an archival project)
    e. Need clear criteria
    f. Allows the GO community to decide how to fill out parameter space, allow it to evolve with field
    g. Provide synergy for transit and direct imaging communities as samples overlap
2. Clear need for HST UV stellar characterization and UV exoplanet atmospheric characterization
3. Emphasize unique parameter space of facilities
    a. JWST’s observations beyond 3 micron and planet searches around MS stars and WDs
    b. HST’s UV spectroscopy
4. Favor characterization programs with well constrained planetary masses

Optimal Timing Recommendations

1. Refine start of proprietary period to final transit/epoch observation
    a. Impacts both transit and DI, lots of community angst, advocate to change culture in our field
    b. Previous STUC recommendation.
2. Enable a stepwise / hierarchical progress through a program, evaluate as you go to make sure optimal use (including DDT)
    a. Important as programs require many epochs of observations
3. Support simultaneous JWST+HST (UV)
    a. Better communication or policy to prevent fear of double jeopardy if need both facilities
4. HST observations for DDT or Key Science support implemented immediately given its age
5. Support deep-dive, multi-cycle observations early in the JWST mission (e.g., very large proposals and temperate, rocky exoplanet spectroscopy)

Scale of Resources Recommendations

1. Dedicated and robust funding support for DDT
    a. JWST early cycle funding ~$10K/hr * 500 hr = $5M
    b. Holistic needs including computing, lab measurements, customized data reduction/modeling software
    c. Lessons from ULYSSES indicate timing and organization of archival proposal was challenging
    d. Worry of underfunding based on ERS experience
2. Provide inclusive, program management support
    a. Possibilities include setting up a Slack, first-look / data reduction / model comparison meetings, call for WGs
3. Holistic needs require supporting HST, ground-based, and X-ray observations
    a. HST data is a key resource for understanding the presence or absence of an atmosphere on rocky planets and photochemistry on all types of planets
    b. Expand, support 10% for JWST/HST simultaneous observations
    c. Push against NASA XRP limit on ground-based observations
4. High demand/need could support more than 500 hrs (key science theme 10^4 hr survey)
5. Provide most advanced data products as possible, a necessary resource for stepwise/hierarchical project implementation

DDT Concept Recommendations

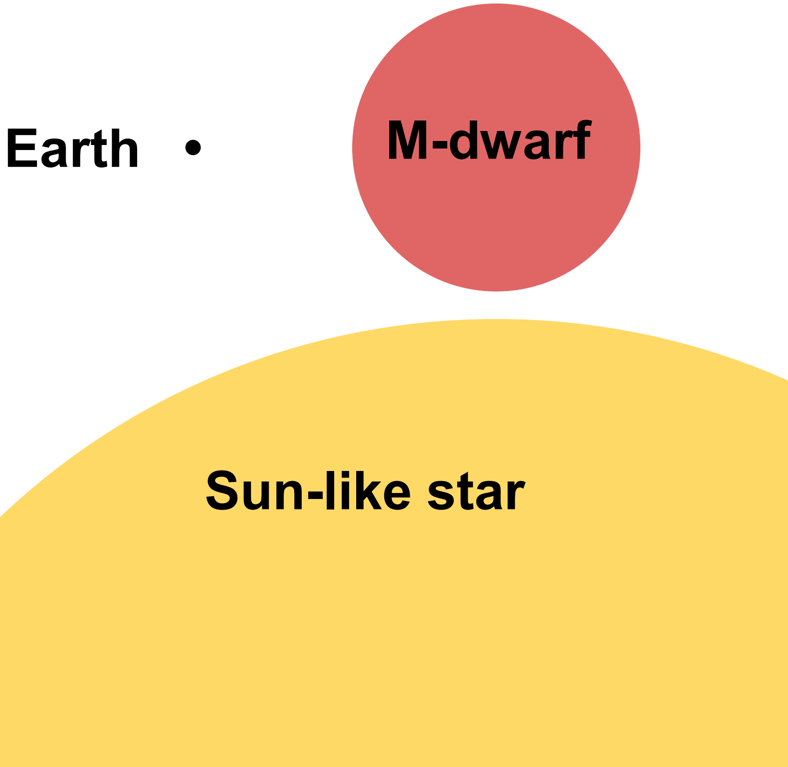
1. DDT Concept categories
   a. Sub-Neptune to Giant broad atmospheric characterization surveys (31%)
   b. Terrestrial/Sub-Neptune atmospheric characterization (29%)
   c. Planet Searches (22%)
   d. Stellar Characterization (10%)
   e. Other (6%)
2. Recommended DDT Concepts: Survey of Rocky Worlds
   a. Will answer key Astro2020 science questions on the Pathway to Habitability
   b. Will kickstart important community follow-up in future cycles
   c. Requires UV stellar characterization from HST
   d. Has focused observational design in order to enable transformative results in 500 hr
   e. Would not efficiently accumulate from GO efforts

Key questions for rocky planets: is there an atmosphere? What is it made of? Which planets might be habitable? Very hard to predict this!

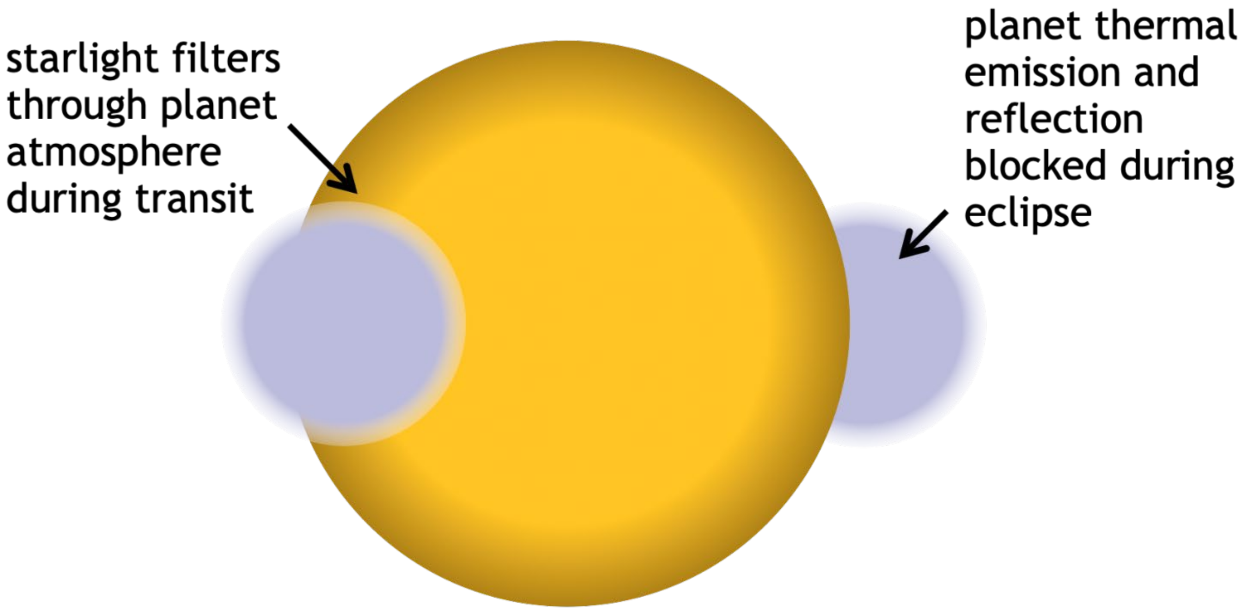
Inspiration from the Solar System:
Wide range of chemistry (carbon dioxide, nitrogen, oxygen, methane) and atmospheric pressure (0.00001 - 100x Earth)

The M-dwarf + JWST opportunity

- Most of the rocky planets in the galaxy orbit M-dwarfs
- Transits are more likely, more frequent, and deeper
- JWST IR observations of these planets are the only opportunity to characterize their atmospheres – ***not even HWO will do this!***

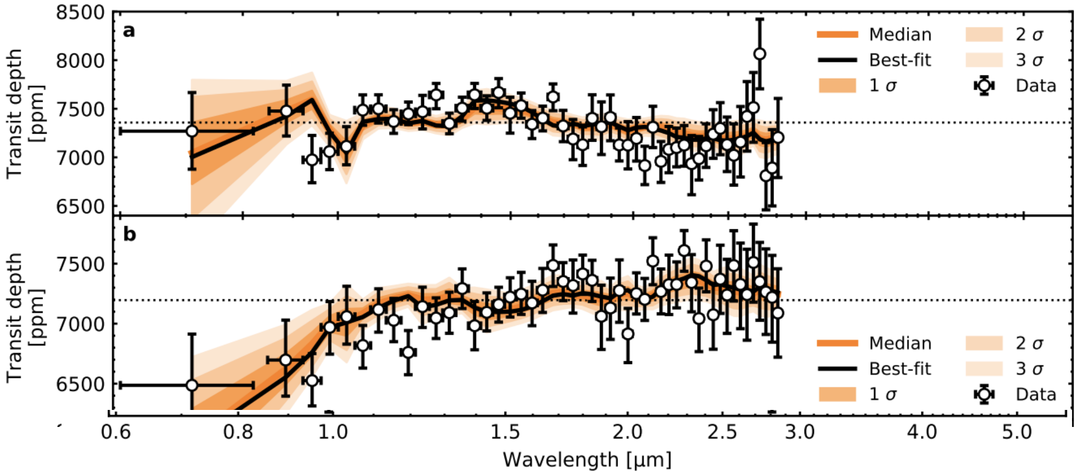


How do we characterize rocky planet atmospheres?

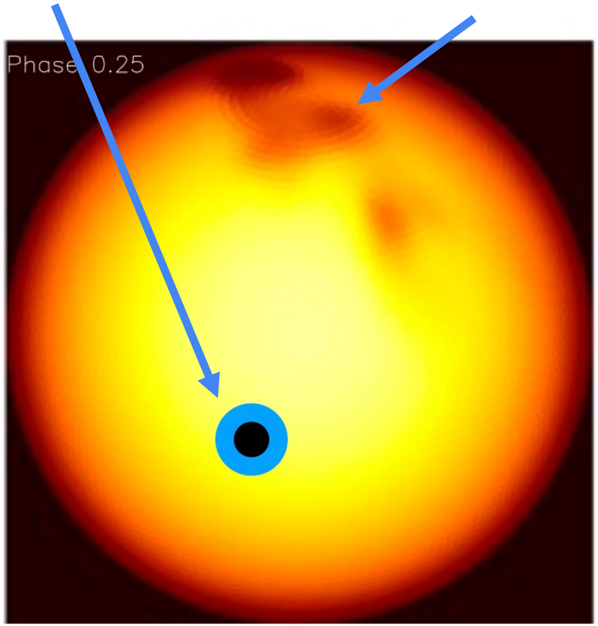


- At wavelengths where the atmosphere is opaque, more starlight is blocked
- Sensitive to chemical composition, temperature, clouds/haze

First JWST results for rocky planets:
Stellar contamination emerging as a challenge

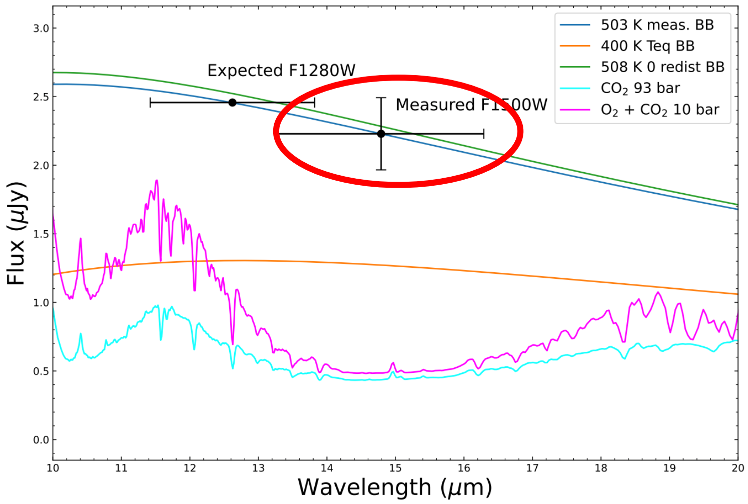


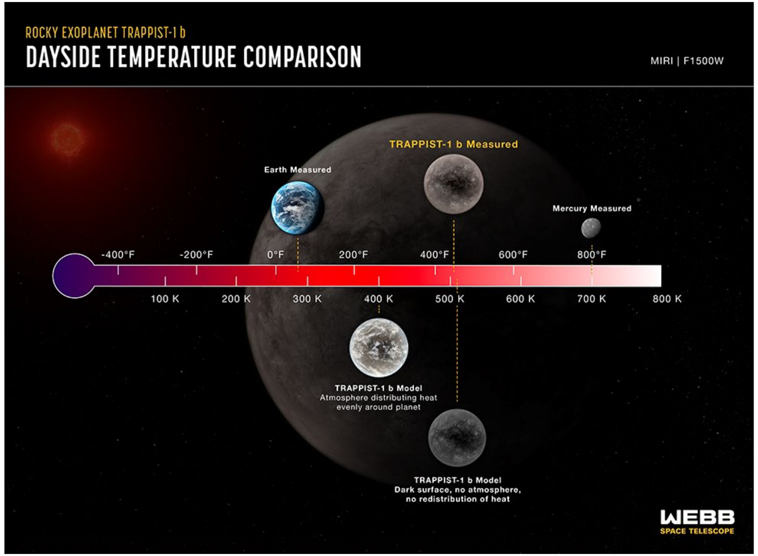
Water features from the planet, or the star spots?



Contamination 10x greater than the expected planet signal on TRAPPIST-1b – Lim et al. 2023

First JWST results for rocky planets:
Thermal emission measurements can determine presence (or absence) or an atmospheres

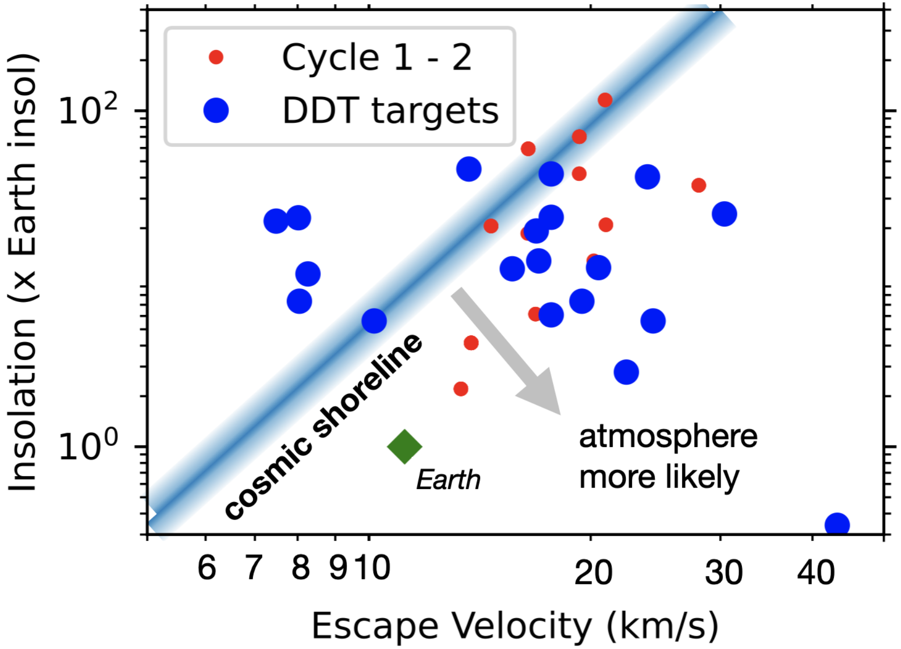




Hot dayside → bare rock with no heat redistribution (Greene et al. 2023)

DDT concept: Rocky Planet Survey

- Measure the dayside temperature of 15 -20 rocky planets orbiting M-dwarfs, to distinguish between a thick atmosphere and bare rock at 5σ
- Double the sample of rocky planets with thermal emission measurements
- Sample planets across the “cosmic shoreline” and push to cooler temperatures
- Combine with HST UV observations of the host star



DDT targets from White Paper 12

Observing strategy

- MIRI/15 micron eclipses for 15 - 20 targets across the cosmic shoreline, spanning temperatures from 200 - 700 Kelvin, planet masses from 0.5 - 7 Earth masses
- 15 micron band probes strong CO_2 absorption feature
- 2 - 15 eclipses per target, roughly 5 hours per visit
  - Coolest targets are expensive (50 - 75 hrs) → too large for GO proposals
- HST UV characterization of the host stars → essential input for calculations of atmospheric mass loss rate and photochemistry

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Time needed: 500 hours JWST; 220 orbits HST

Risks and Reward for rocky planet survey

Risks:

- Planets could all be bare rocks!
- Less risky than transit observations, which can have false positives and negatives
- Interpretation of one photometric point can be degenerate if an atmosphere is present
- Could miss eclipse, if eccentricity is higher than expected

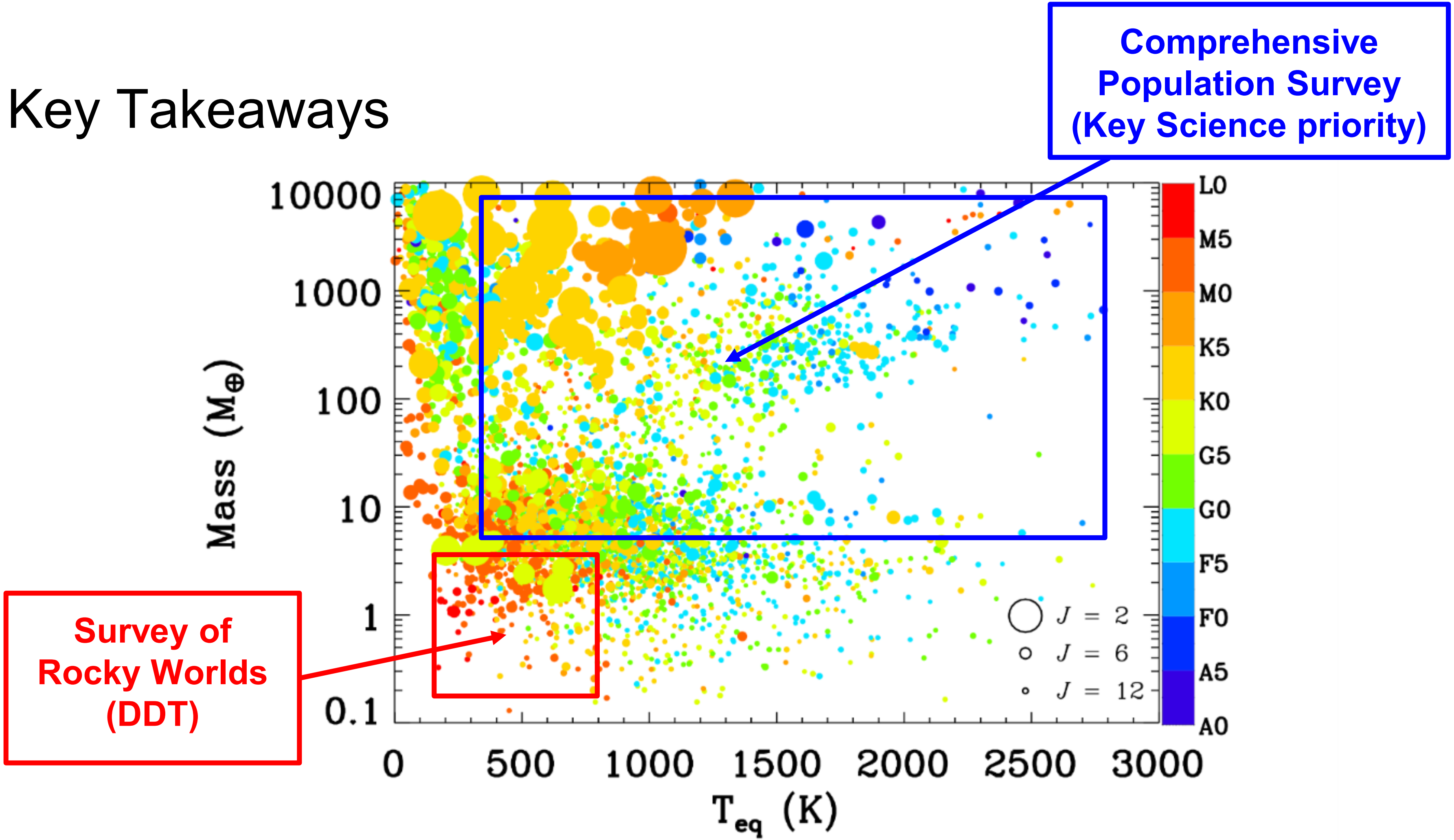
Legacy:

- Definitively answers the question which rocky planets orbiting M-dwarfs have atmospheres, which JWST alone can do
- Enables efficient follow-up of planets that do have atmospheres, to determine chemical composition and surface pressure
- Pathway to habitability - pushes the “existence test” for atmospheres down to the HZ
- Informs the design of future JWST observations and future facilities like HWO
- Strong benefit from HST/UV capabilities (atmospheric escape)

Community Involvement

1. Recommendations stem from community feedback from this WG and Astro2020
2. Key Science Priorities and the DDT program will engage and bring together a wide range of communities (exoplanet, stellar, planetary) across different axes (e.g., data reduction/analysis, modeling/theory, spectroscopic lab support, multi-wavelength ancillary observations)
3. Dedicated resources for GO-driven Archival proposals
4. Prioritized support for the 10^4 hour JWST Exoplanet Population Survey would build on the communities developed through ERS programs, move the transit and direct imaging samples closer together, and provide a dataset used by the community for years to come
5. DDT program on Rocky Worlds would encourage greater participation by the planetary science community and identify optimal targets early in the JWST mission for GO follow-up programs on the atmospheres of terrestrial planets

Key Takeaways



Key Takeaways

1. Scaffold the GO-driven 10^4 hour JWST Exoplanet Population Survey as a key science priority to produce a comprehensive, high-S/N, pan-chromatic legacy archive to address a broad range of Key Science Questions across various populations of planets.

1. Use the DDT time to Survey M-dwarf Rocky Worlds to answer the fundamental question: Do they have atmospheres? This will quickly identify the most exciting targets for follow-up, shape the design of future observations/missions, and be a major step forward along the Pathway to Habitable Worlds.