Exoplanet WG Recommendations

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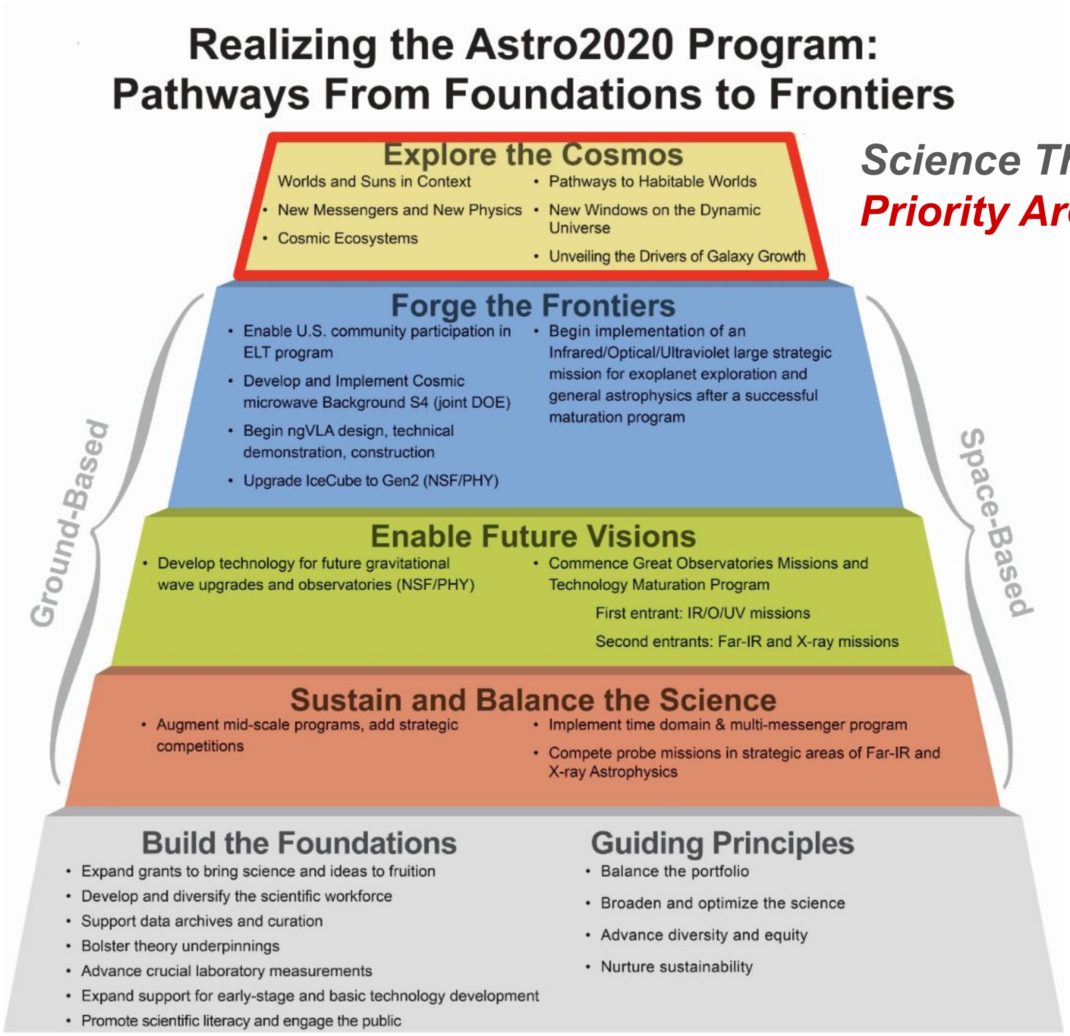
Exoplanet Strategy WG was charged to:

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.

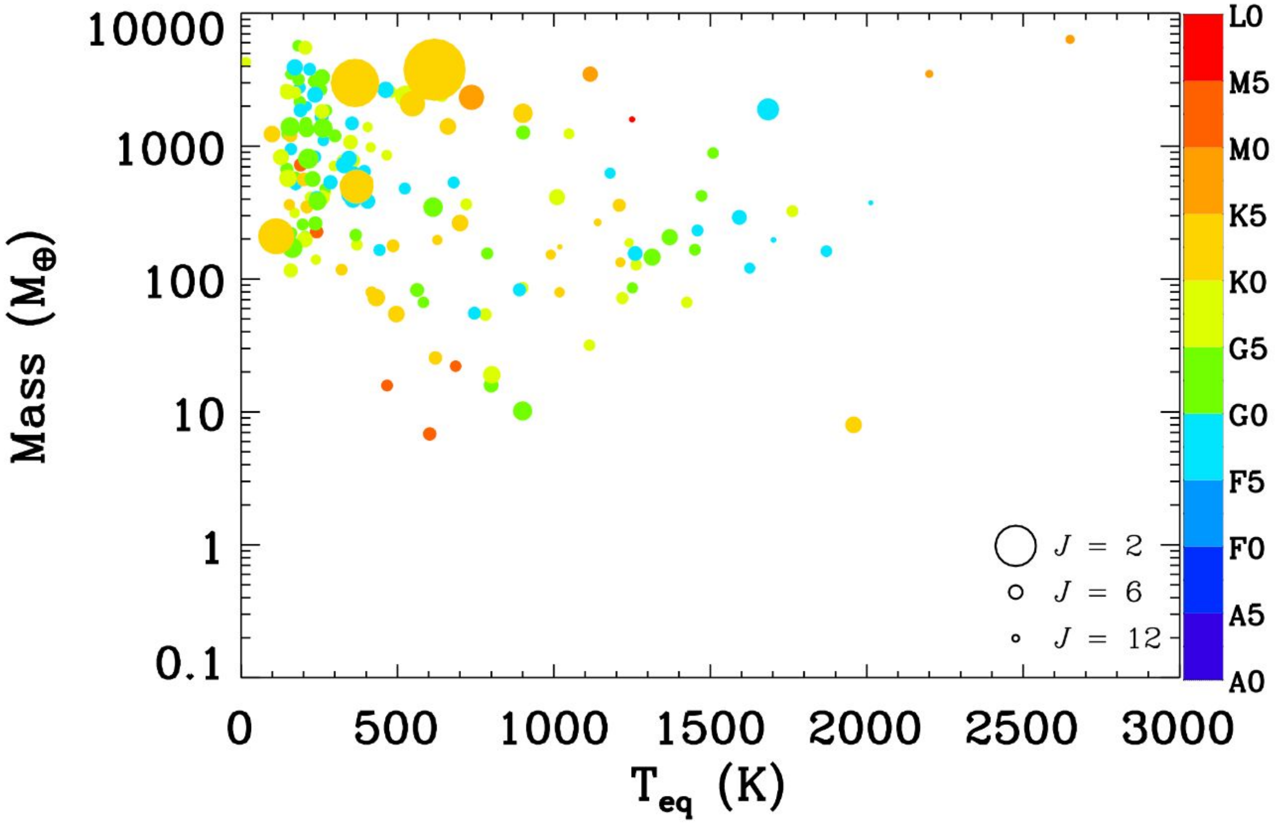
TABLE E.1 Science Questions and Discovery Area

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.	

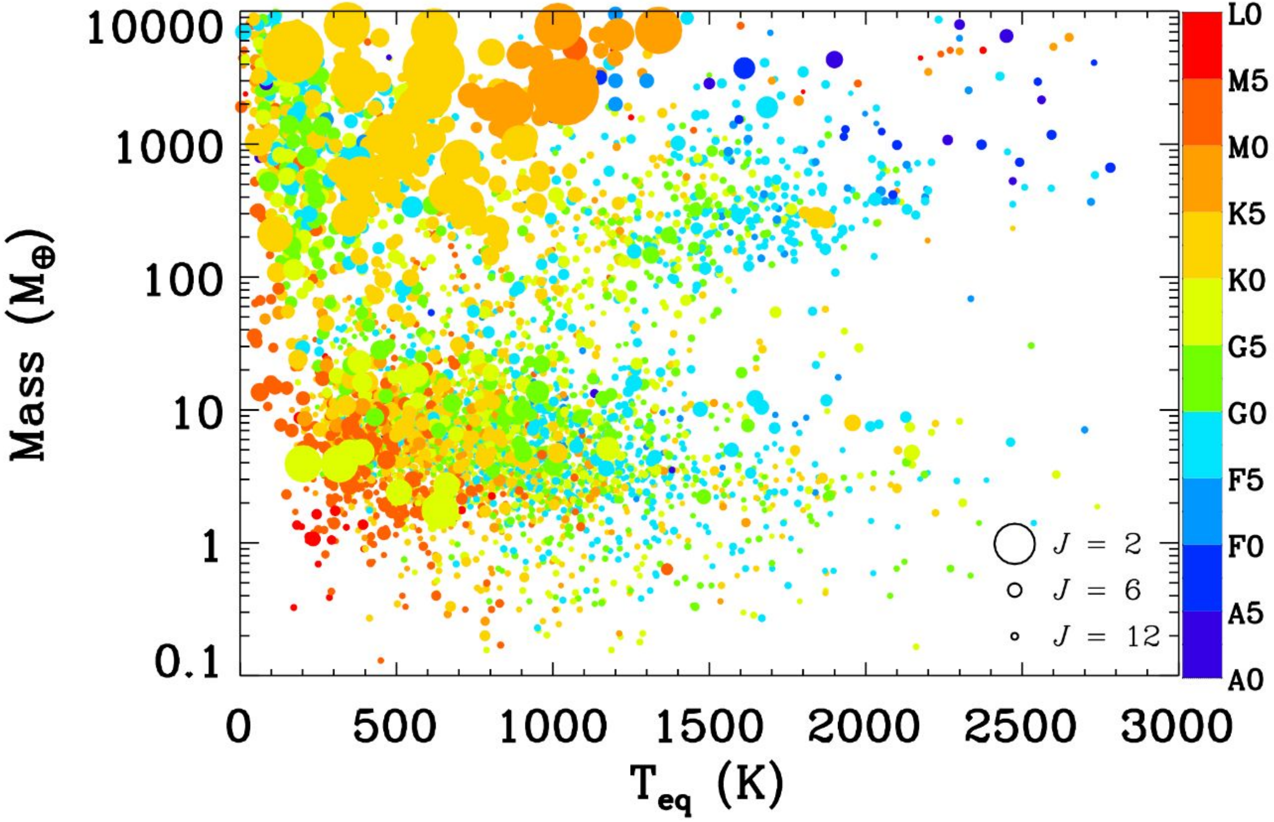
Giant Planet Survey (10^4 hour Exoplanet Survey)

Survey of Rocky Worlds (DDT Concept)

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. 42 white papers (WPs); 230+ unique authors
   b. 75 surveys
   c. Demographic information shows we got broad representation across career stage and prior HST+JWST involvement
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)

Anticipated JWST Mission Exoplanet Commitment

1. Over its mission lifetime, JWST will spend ~30,000 hours on exoplanet observations

   5000 hr/cycle * ⅓ allocated to exoplanets * 20 cycles = 30,000 hours

2. Given the early cycle usage and WPs we expect at least ⅓ of that time will be devoted to atmospheric characterization across various populations of planets, exploring diversity across various physical properties (e.g., temperature, host star, metallicity, age, etc)

3. **The 10^4 Hour Exoplanet Survey**: the inevitable, synergistic dataset that will be created from GO-driven programs which will enable a broad, comparative population study that will be a profound legacy of JWST exoplanet science

Key Science Themes

1. **Understand the prevalence and diversity of atmospheres on rocky-M dwarf worlds**
    a. Understanding the prevalence of detectable atmospheres on rocky-M-dwarf planets
    b. Probing the diversity of atmospheres on rocky-M-dwarf planets
    c. Searching for biosignatures and other signs of habitability on rocky-M-dwarf planets

2. **Understanding population-level trends of exoplanet atmospheres from sub-Neptune to gas giants**
    a. Understanding the physical and chemical processes that sculpt planetary atmospheres
    b. Using atmospheric tracers to understand planetary formation, migration, accretion, and evolution

3. **Understand exoplanets in the context of their stellar environments**
    a. Understanding how stellar heterogeneities affect observable planetary spectra
    b. Understanding how X-ray and ultraviolet emission sculpt planetary environments
    c. Understanding how the magnitude of stellar activity influences atmospheres
    d. Understanding planet occurrence as a function of stellar evolution

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10^4 hr Exoplanet Survey

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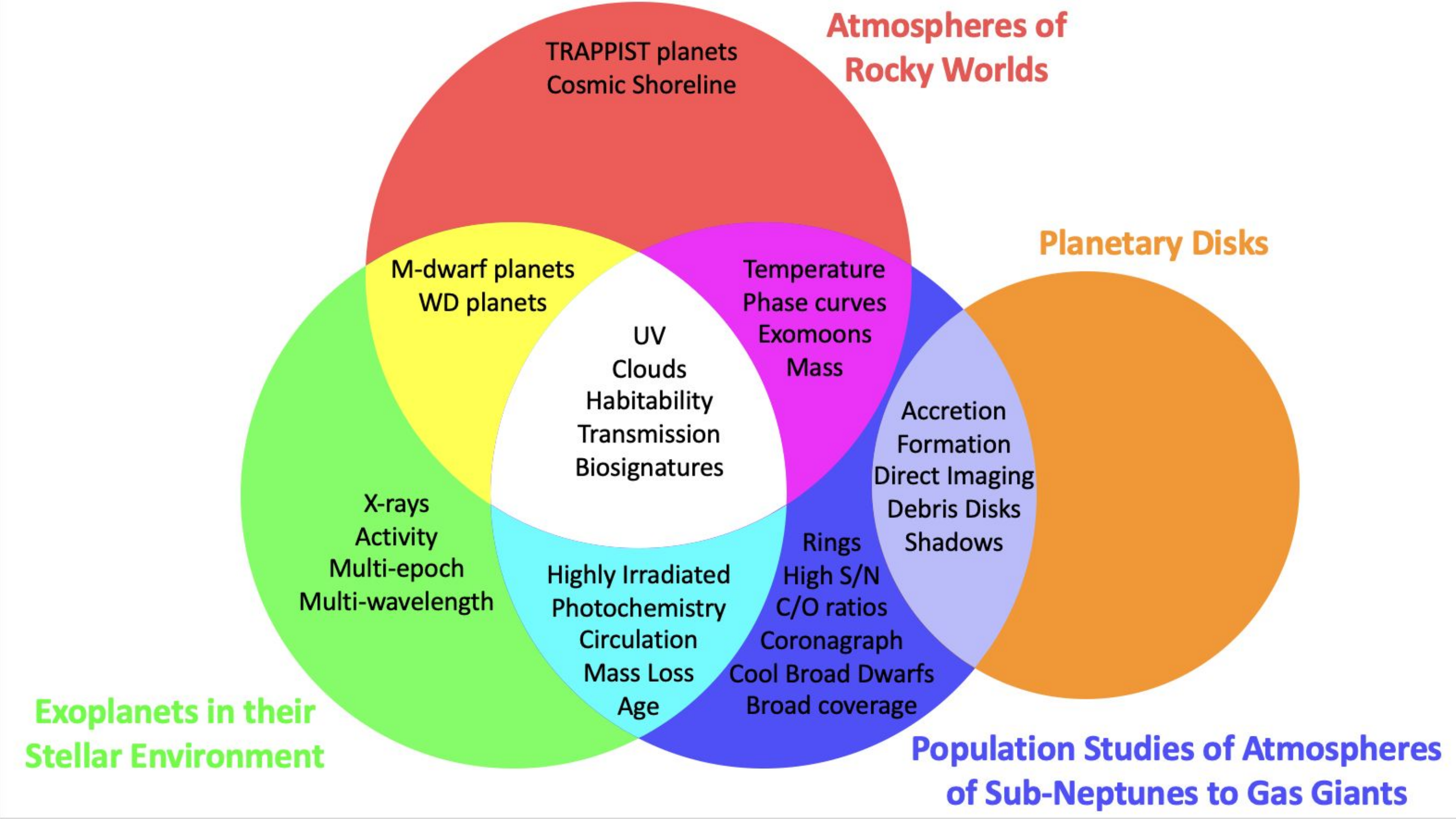
Need for HST

Interconnectedness of Key Science Themes



DDT Concept Recommendation: Survey of Rocky Worlds

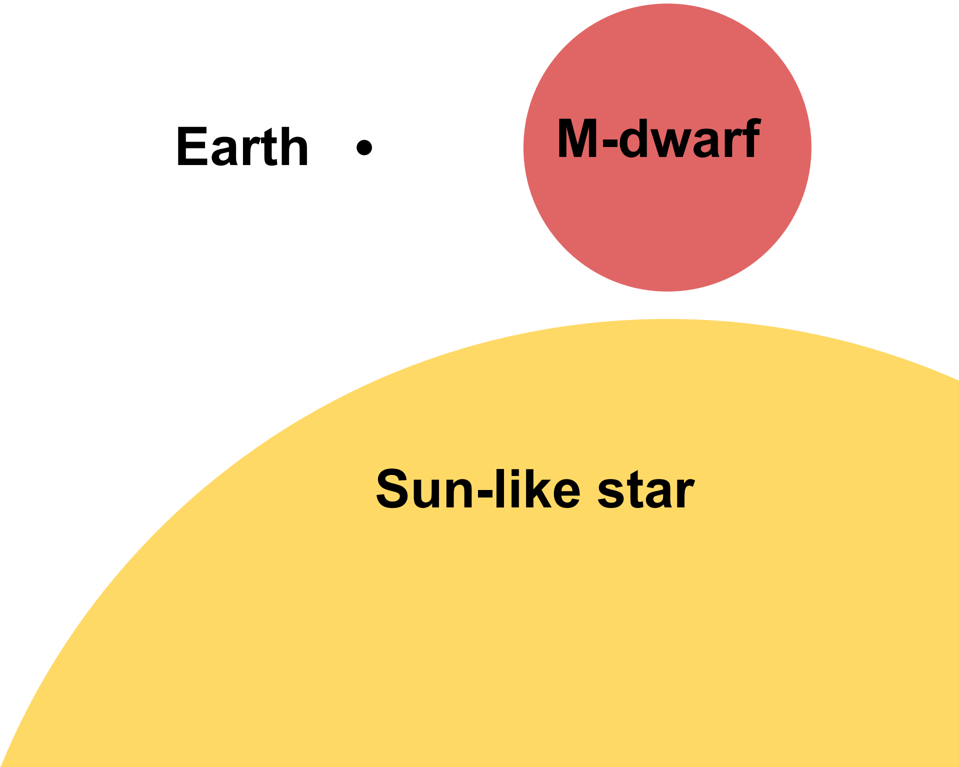
1. **Use 500 hours of *JWST* time and 240 orbits of *HST* to perform a survey of rocky worlds to measure the cosmic shoreline and identify exciting targets for follow-up observations.**
    a. Observe thermal emission at 15 microns for 15-20 targets with T_{eq} = 200-600 K to measure full vs. zero thermal redistribution (i.e., with or without an atmosphere)
    b. In other words: Measure the “cosmic shoreline”, a concept developed for evaluating atmospheres for solar system objects to M dwarf exoplanets
    c. Will answer key Astro2020 science questions on the Pathway to Habitability
    d. Will identify high value targets and kickstart important community follow-up in future cycles
    e. Requires UV stellar characterization from HST because it is the XUV that drives atmospheric loss and photochemistry, and the XUV is very different and variable for M dwarf stars
    f. Has focused observational design (e.g., simple measurement for almost entire known sample) in order to enable transformative results in 500 hr
    g. 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!

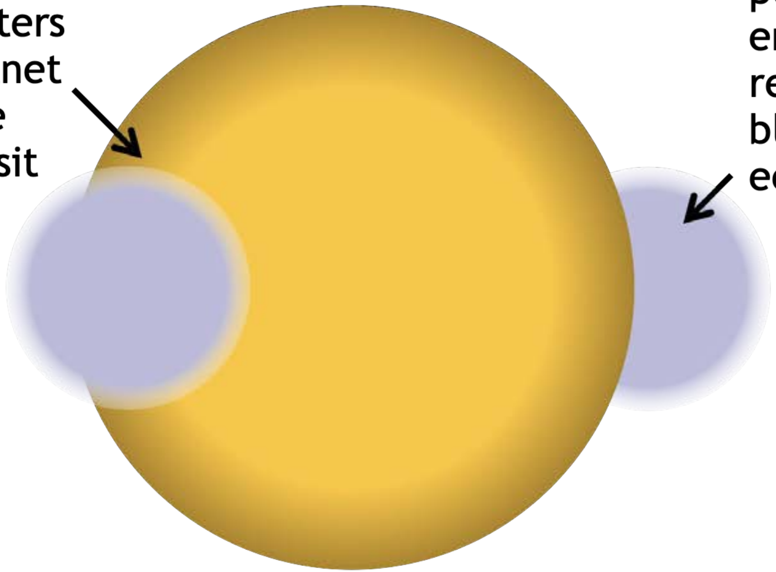
Inspiration from the Solar System:
Wide range of chemistry (carbon dioxide, nitrogen, oxygen, methane) and atmospheric pressure (0.00001 - 100x Earth)

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!***

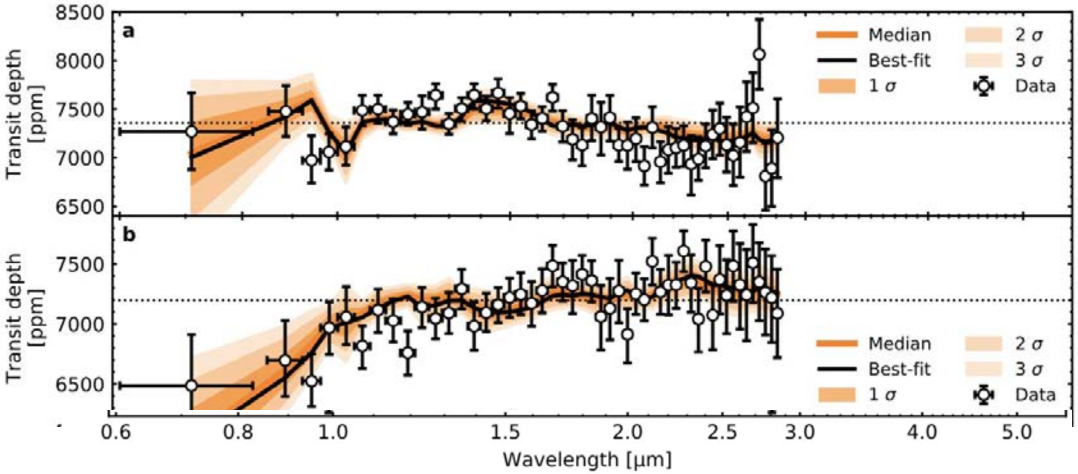


How do we characterize rocky planet atmospheres?

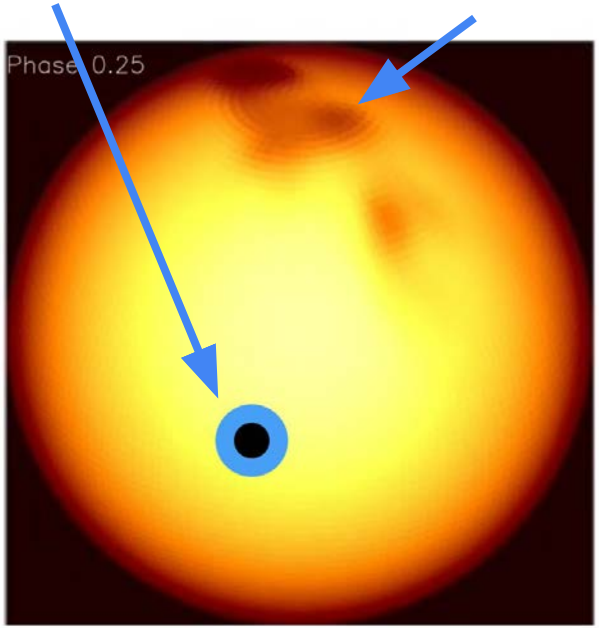


- At wavelengths where the atmosphere is opaque, more starlight is blocked
- Sensitive to chemical composition, temperature, clouds/haze

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

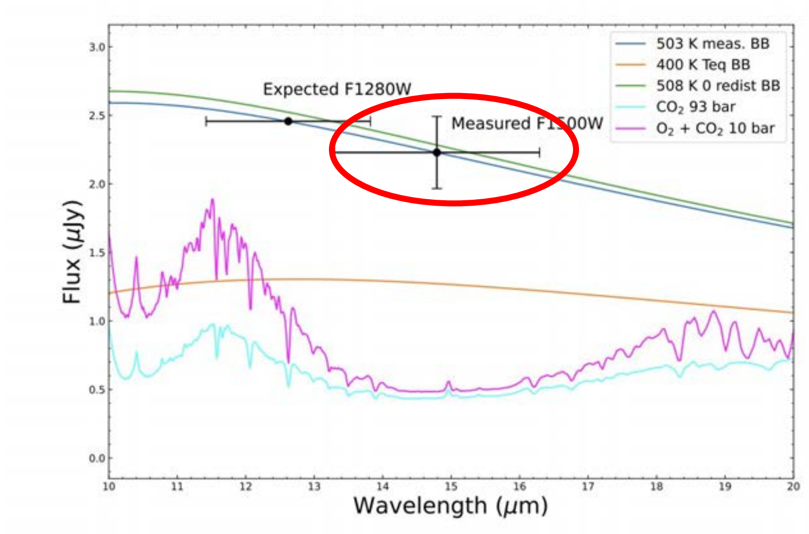


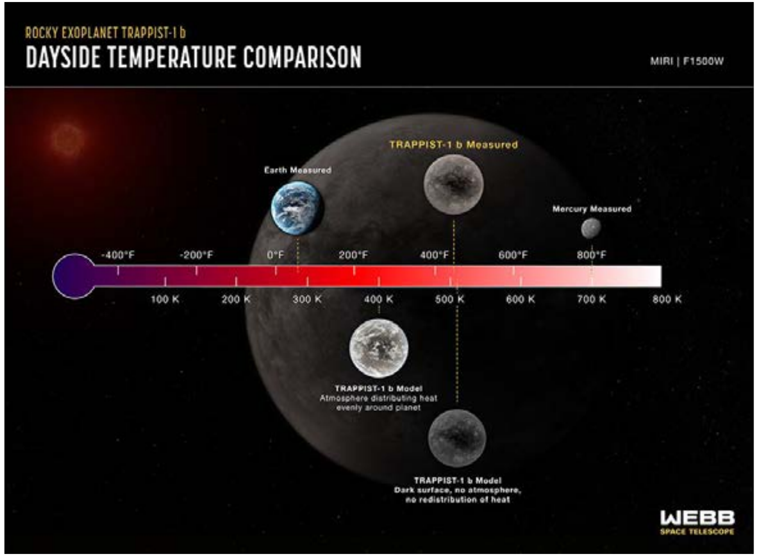
Water features from the planet, or the star spots?



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

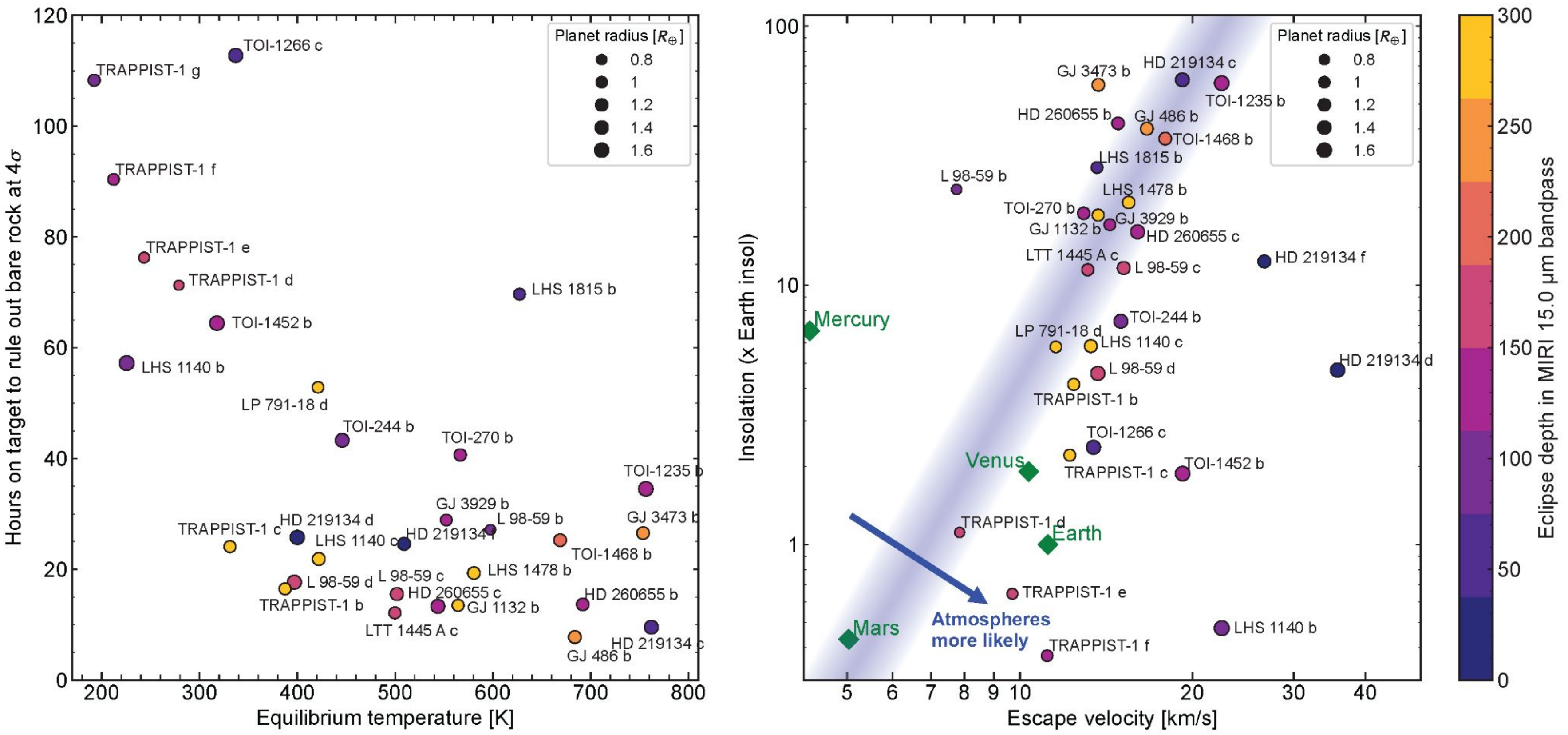
First JWST results for rocky planets:
Thermal emission measurements can determine presence (or absence) or an atmospheres





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

DDT Concept: Survey of Rocky Worlds



DDT Concept: Survey of Rocky Worlds

1. Provide an FAQs section
    a. Why not exclusively study TRAPPIST-1?
    b. Why not measure each target at multiple wavelengths?
    c. Why not transits?
2. A legacy dataset that will provide a definitive answer and if there are atmospheres, it will find which ones deserve follow-up
3. Provide a detailed Implementation Checklist
4. 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; 240 orbits HST

Optimal Timing Recommendations

1. **Tie proprietary period to final epoch for multi-epoch observations.**
    a. Impacts both transit and DI, lots of community angst, advocate to change culture in our field
    b. Previous STUC recommendation.
2. **Observing programs that may be impacted by programmatic timelines should be scheduled with high priority.**
    a. HST observations for DDT or Key Science support implemented immediately given its age
3. **Study Item 1: The feasibility of simultaneous *JWST* and *HST* (UV) observations.**
    a. Better communication or policy to prevent fear of double jeopardy if need both facilities
4. **Study Item 2: Forward funding of observing programs to support analysis and model preparation, and personnel acquisition necessary to carry out the proposed work.**

Scale of Resources Recommendations

1. **Provide 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. **Study Item 1: Explore providing inclusive, program management support.**
    a. Possibilities include setting up a Slack, first-look / data reduction / model comparison meetings, call for WGs
3. **Prioritize supporting *HST*, ground-based, and X-ray observations to enable holistic exoplanet studies.**
    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 and need could support more than 500 hrs**
    a. Provide strategic support for the 10^4 hr Exoplanet Survey
5. **Provide the most advanced data products possible, a necessary resource for projects with dynamical scheduling / hierarchical implementation.**

Support the eventual 10^4 hour Exoplanet Survey

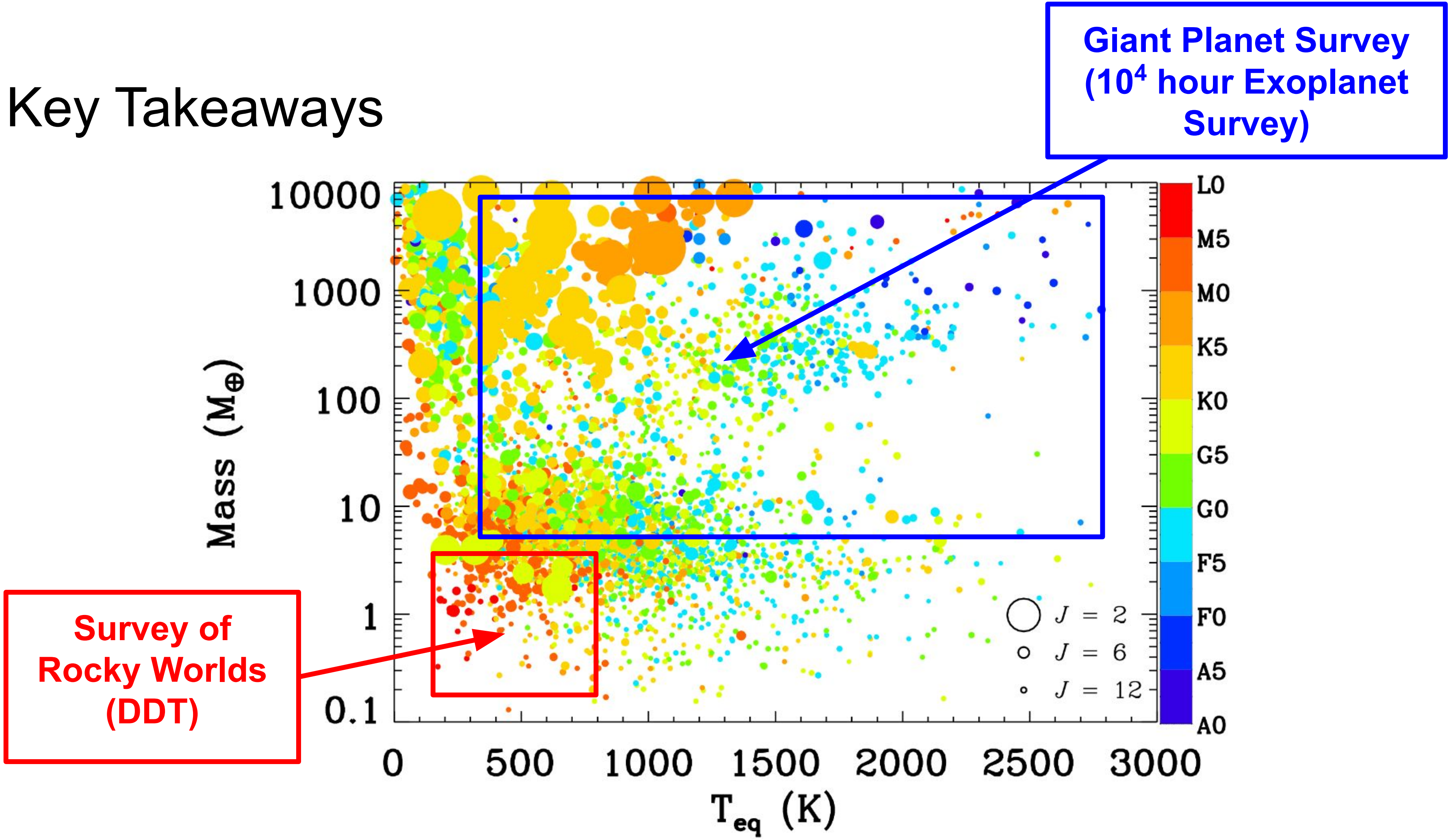
1. **Provide support for observations that will provide archival and legacy value in the context of a broad 10^4 hr exoplanet atmospheric survey in the form of an exoplanet demographic observation website and incentives for programs that qualify.**
    a. A resource that includes system parameters, integration with exo.MAST, and on-the-fly plots would be a powerful tool for the transit and direct imaging exoplanet communities.
    b. Incentives could include check boxes (e.g., UV Initiative) or time subsidies (e.g., medium proposals)

2. **Enable a mechanism for Multi-Cycle Treasury Programs which could support large-scale exoplanet surveys.**

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. Support the GO-driven 10^4 hour JWST Exoplanet 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.

2. Use the DDT time to Survey M-dwarf Rocky Worlds with JWST *and* HST 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.