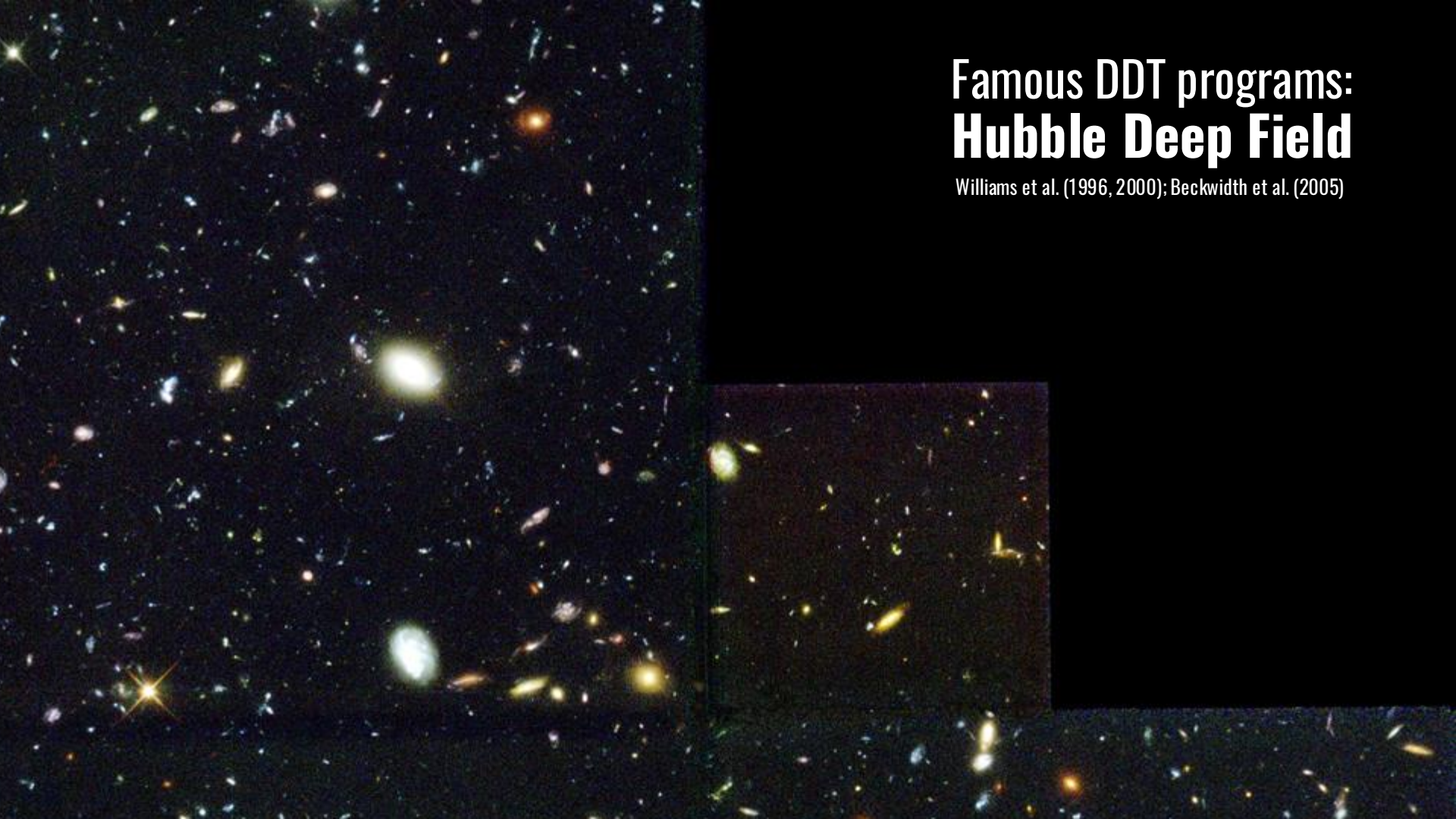
ROCKY WORLDS

Néstor Espinoza (STScI) | CIT Lead

On behalf of the Core Implementation Team at STScI

rockyworlds.stsci.edu

January 4th, 2026

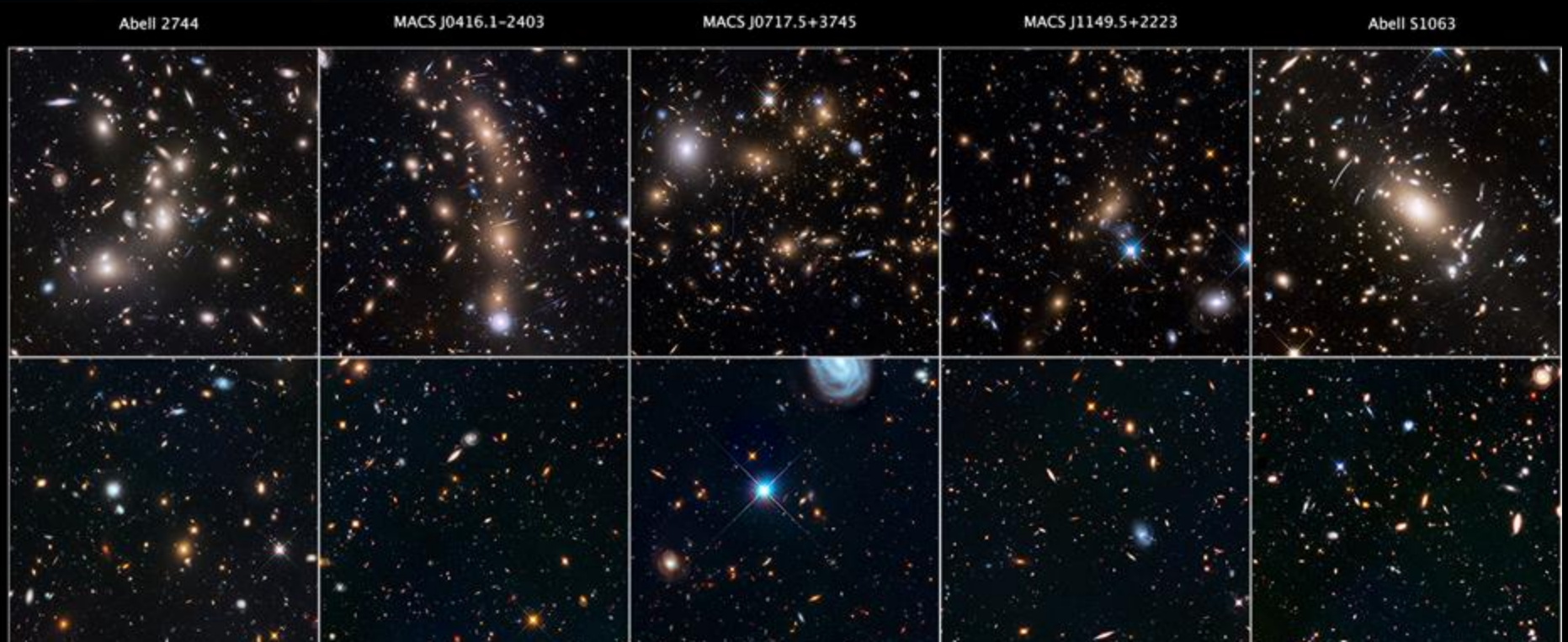


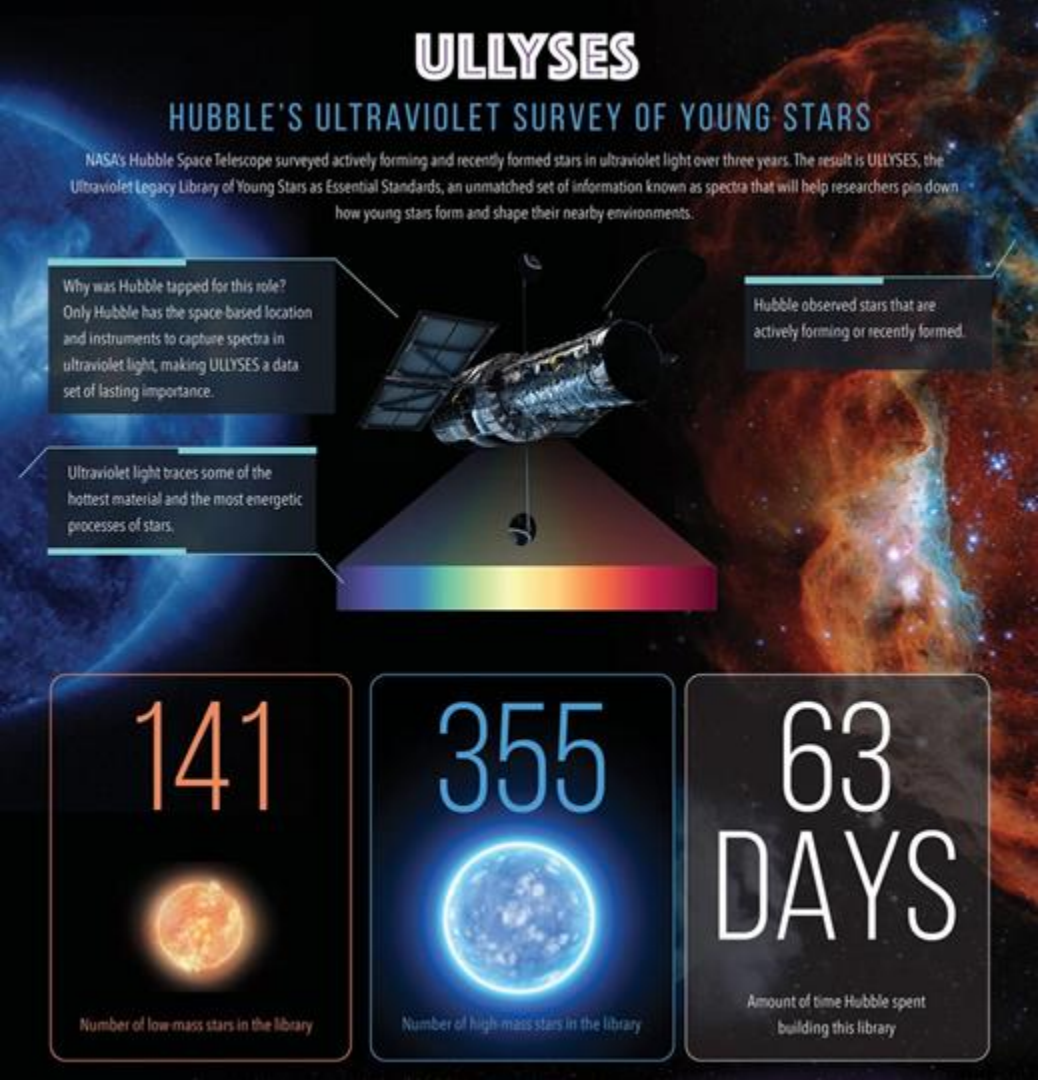
Famous DDT programs:
Hubble Deep Field

Williams et al. (1996, 2000); Beckwidth et al. (2005)

Famous DDT programs:
Hubble Frontier Fields

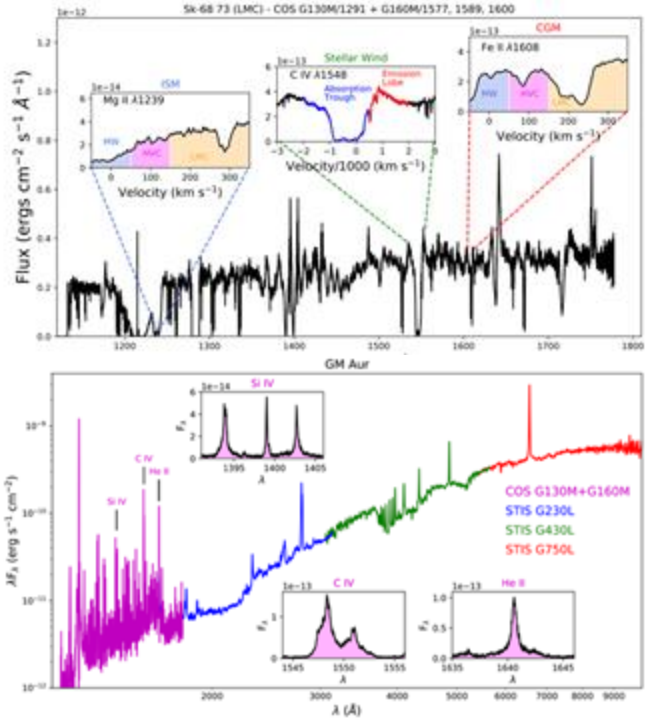
Lotz et al. (2016)





Famous DDT programs: **ULLYSES**

Roman-Duval et al. (2025)



The Rocky Worlds DDT Program

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Main aim: look for **evidence of atmospheres** in rocky exoplanets orbiting **M-dwarf stars**.

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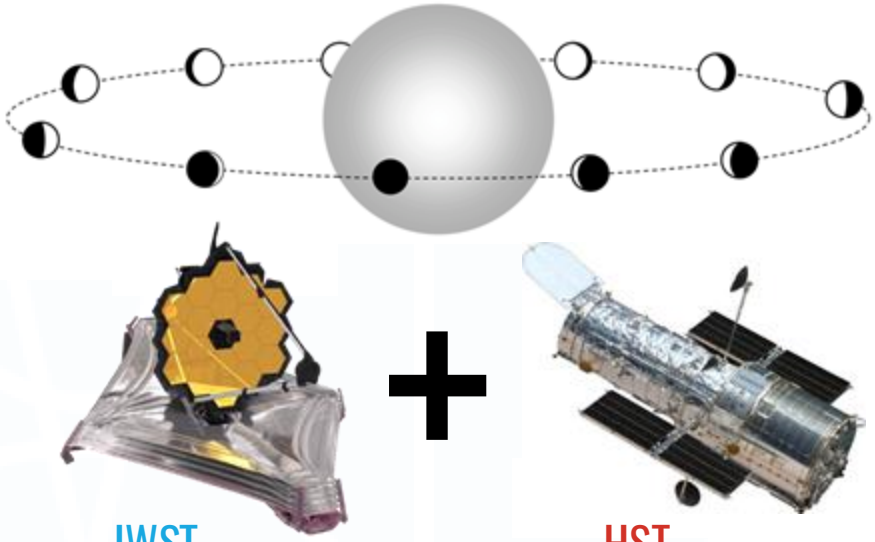

JWST
To characterize the exoplanets
500 hours

HST
To characterize the host stars
250 orbits

Image credit: Winn+2010

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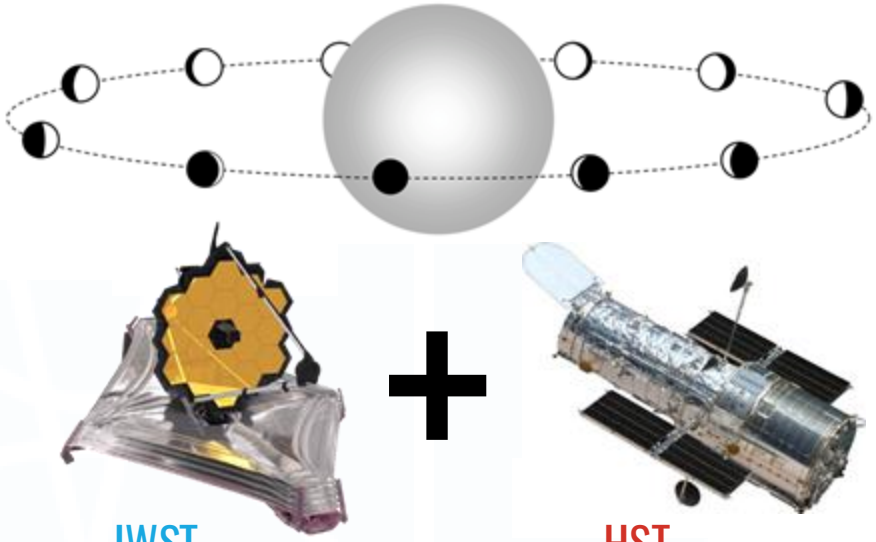

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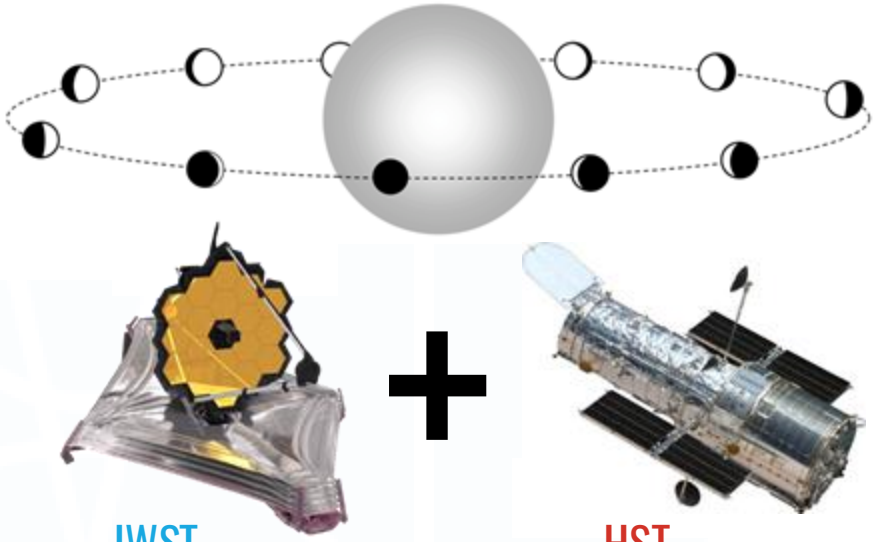

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12 community members, advise the CIT

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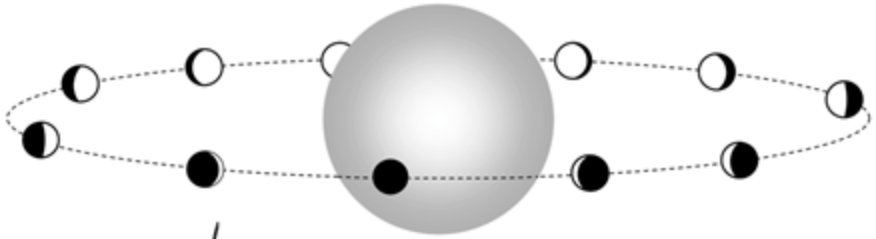
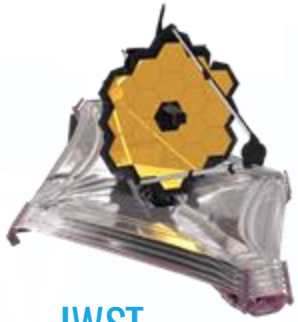




JWST

To characterize the exoplanets

500 hours

+

HST

To characterize the host stars

250 orbits

Core Implementation Team (CIT)

At STScI: scheduling, data, community

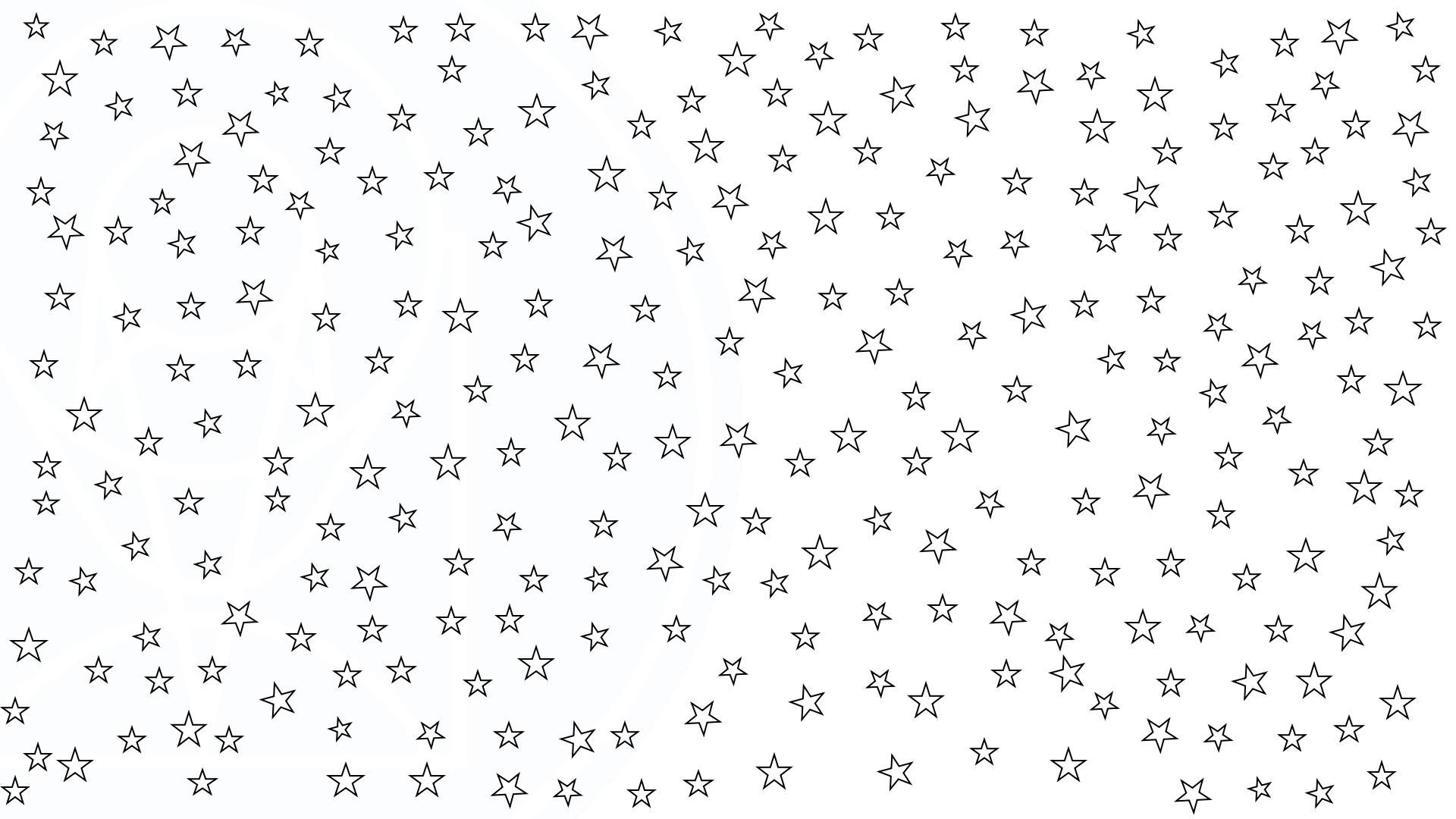
Science Advisory Council (SAC)

12 community members, advise the CIT

Community (i.e., you)

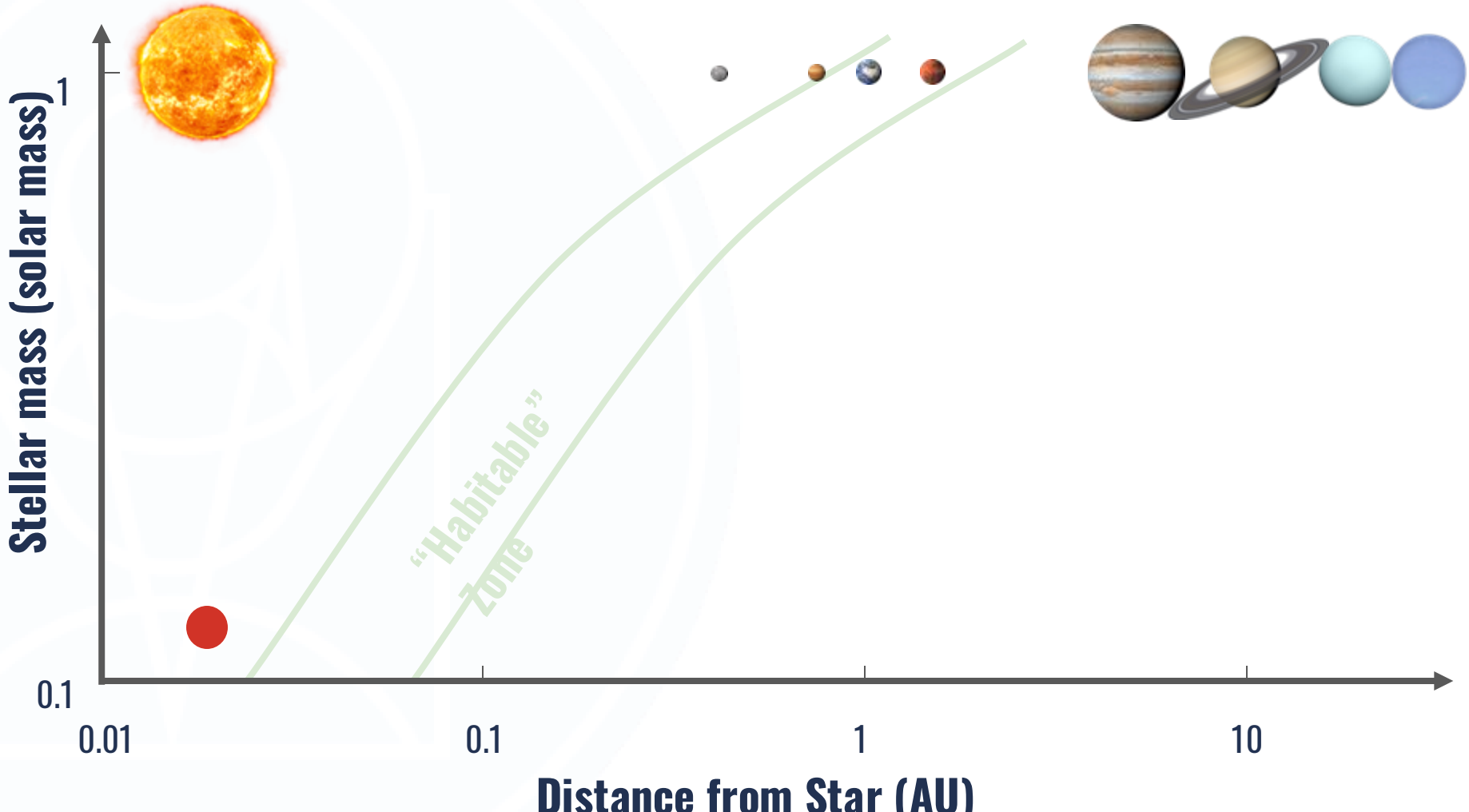
Provides feedback to CIT/SAC, squeezes science out of the data!

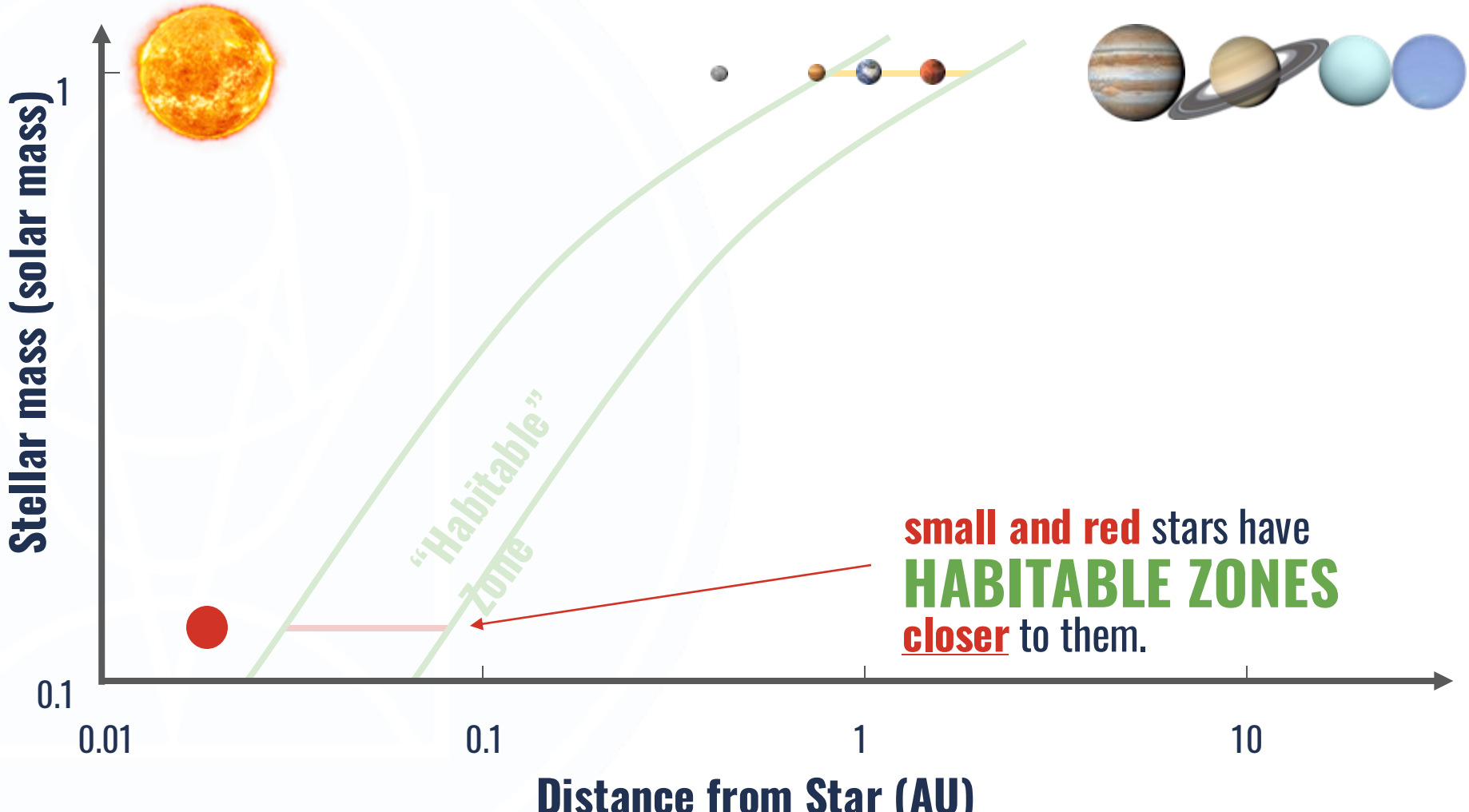
Why?

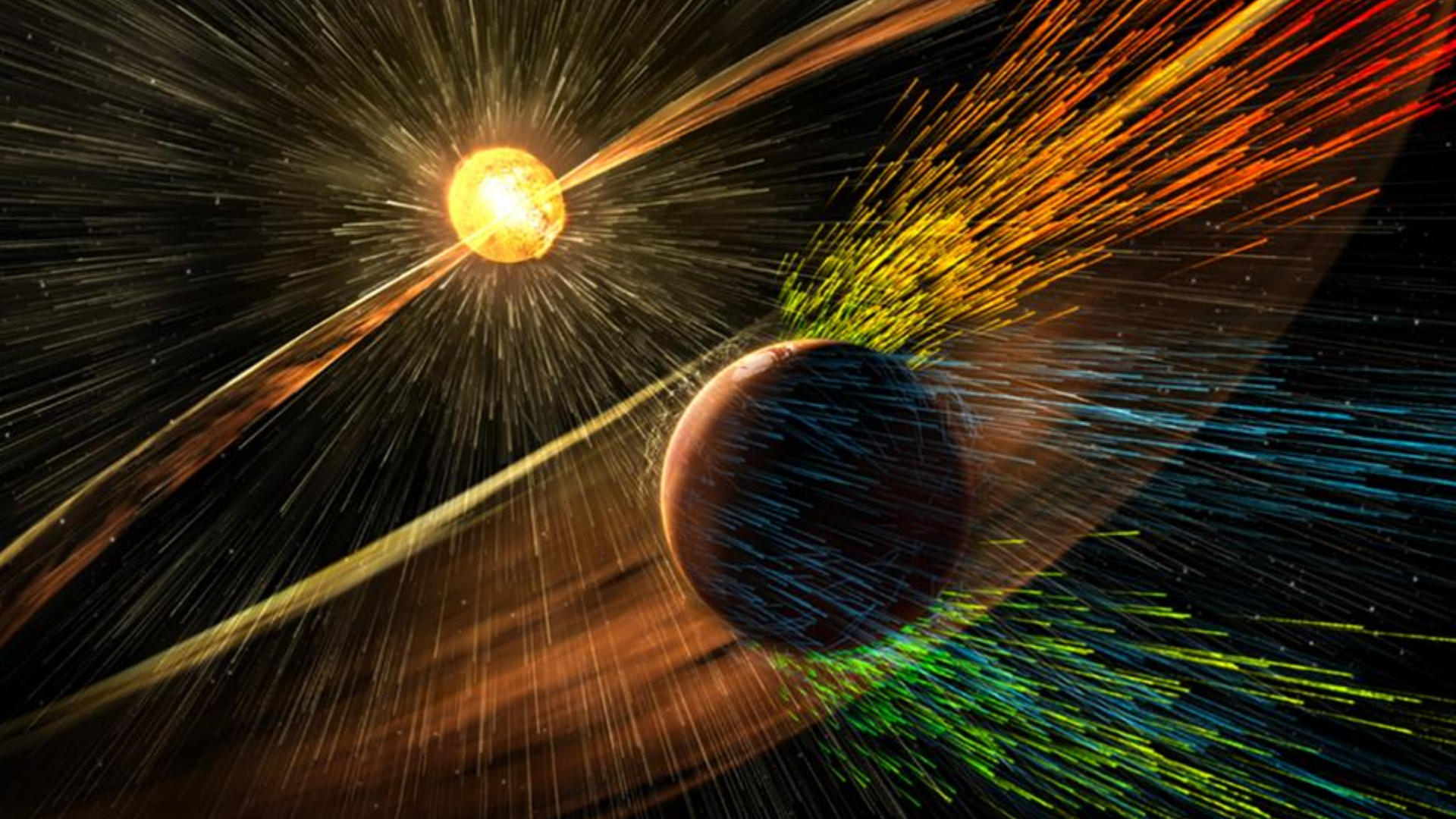


Most stars out there* are small and red.

*about 70% of stars within 10 pc are M-dwarfs a number that likely extends to the rest of our galaxy too!


Stellar mass (solar mass)
1
0.1
0.01
0.1
1
10
Distance from Star (AU)
"Habitable" Zone


Stellar mass (solar mass)
1
0.1
0.01
0.1
1
10
Distance from Star (AU)
"Habitable" Zone
small and red stars have
HABITABLE ZONES
closer to them.




Do rocky exoplanet atmospheres
survive around M-dwarf stars?

The Cosmic Shoreline Concept

Zahnle & Catling (2017)

The Cosmic Shoreline Concept

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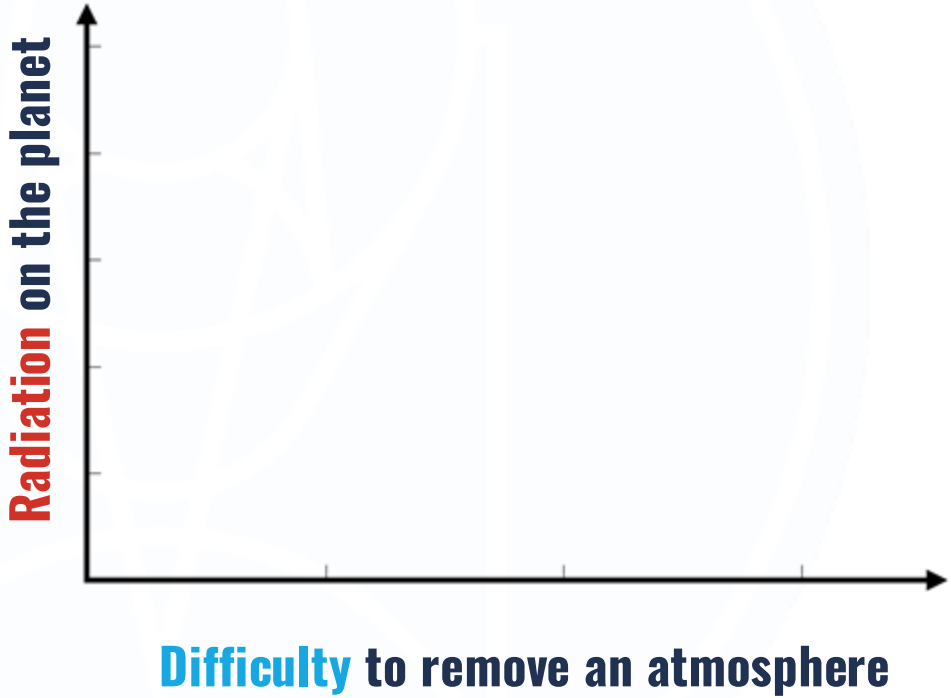

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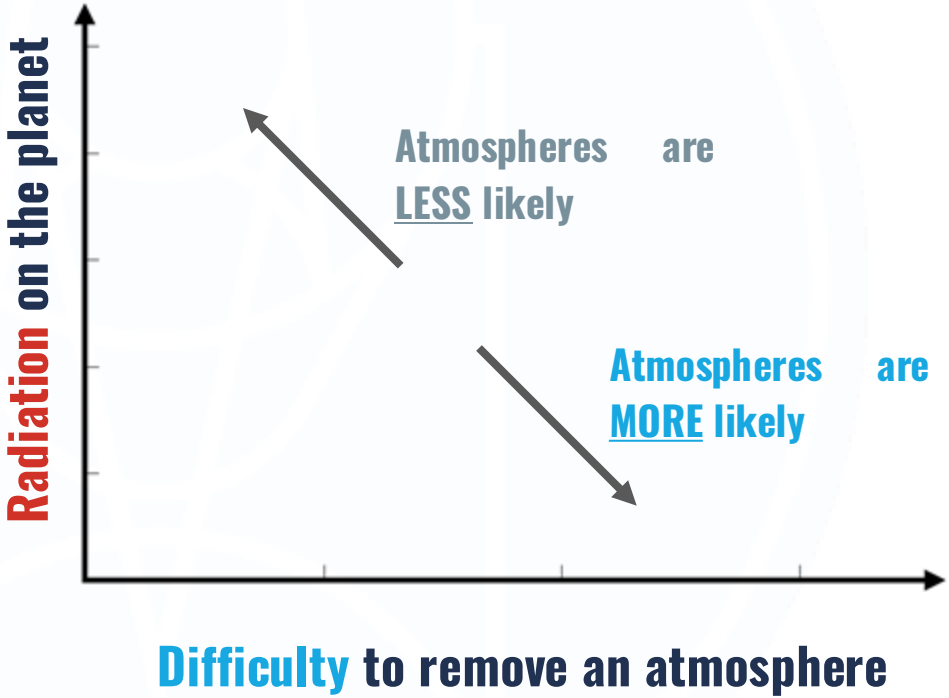

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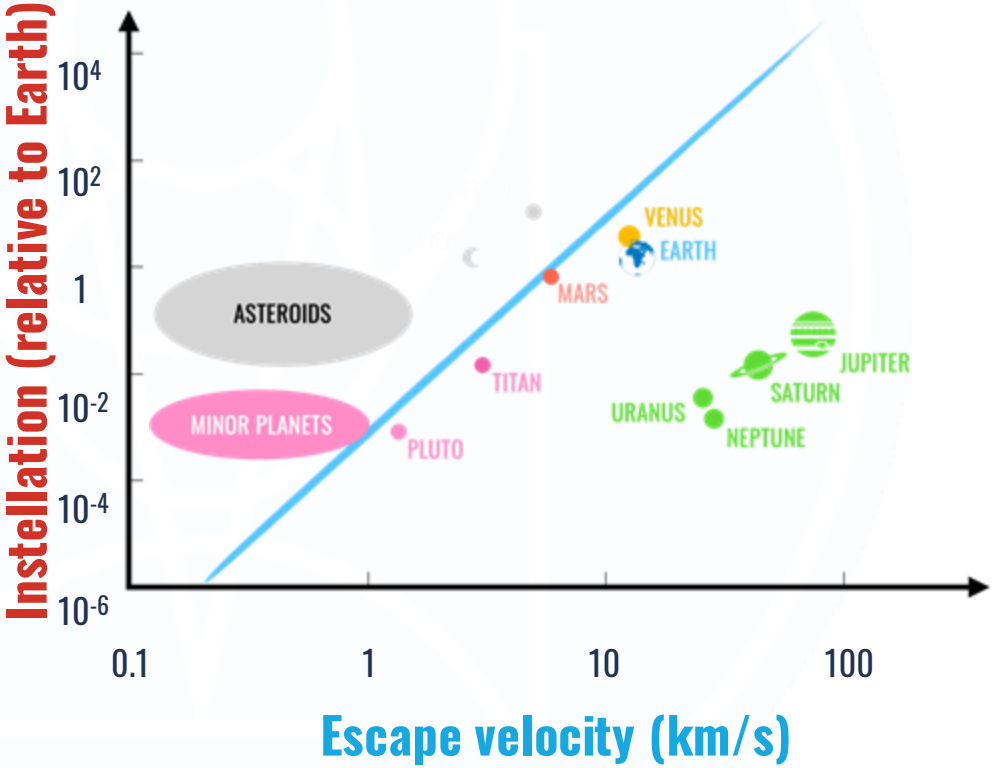

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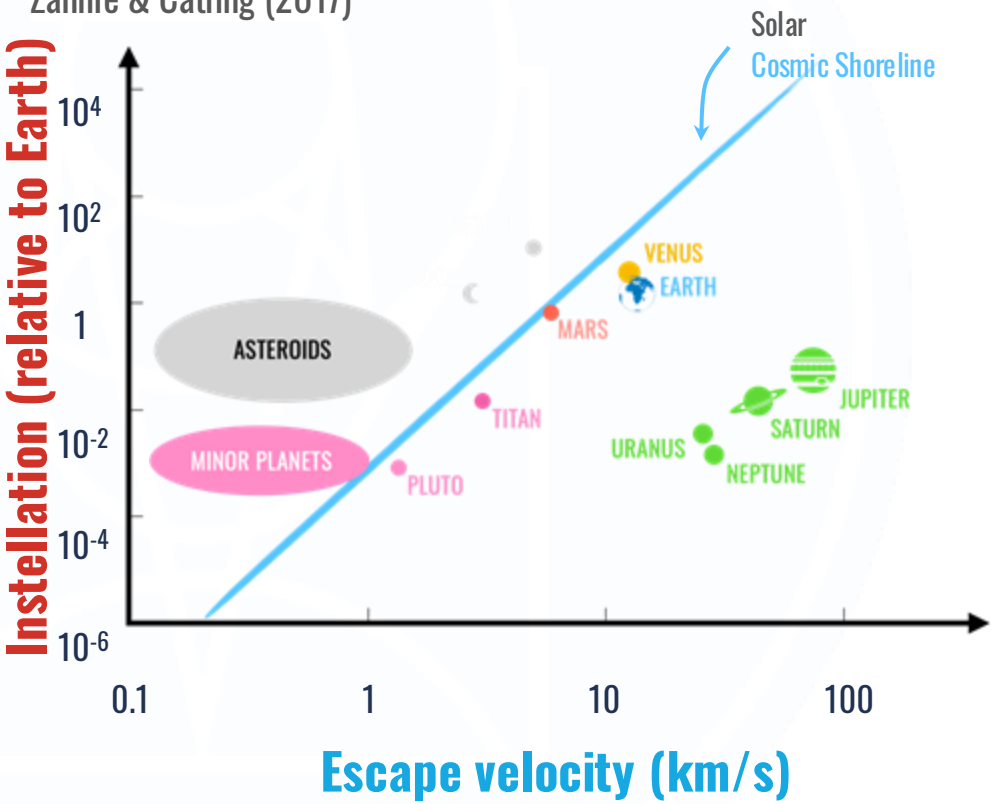

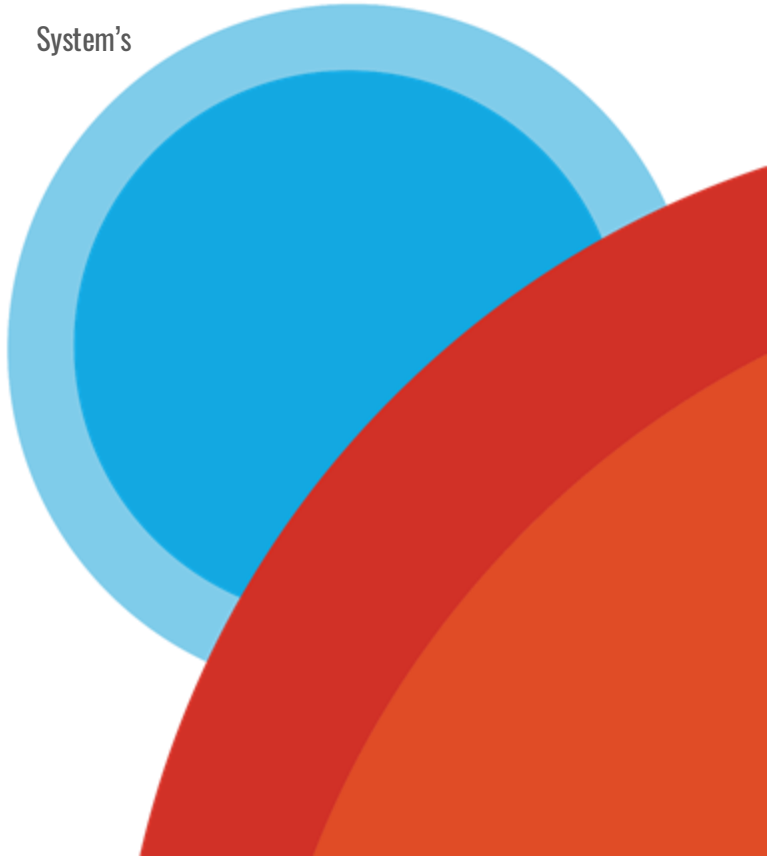

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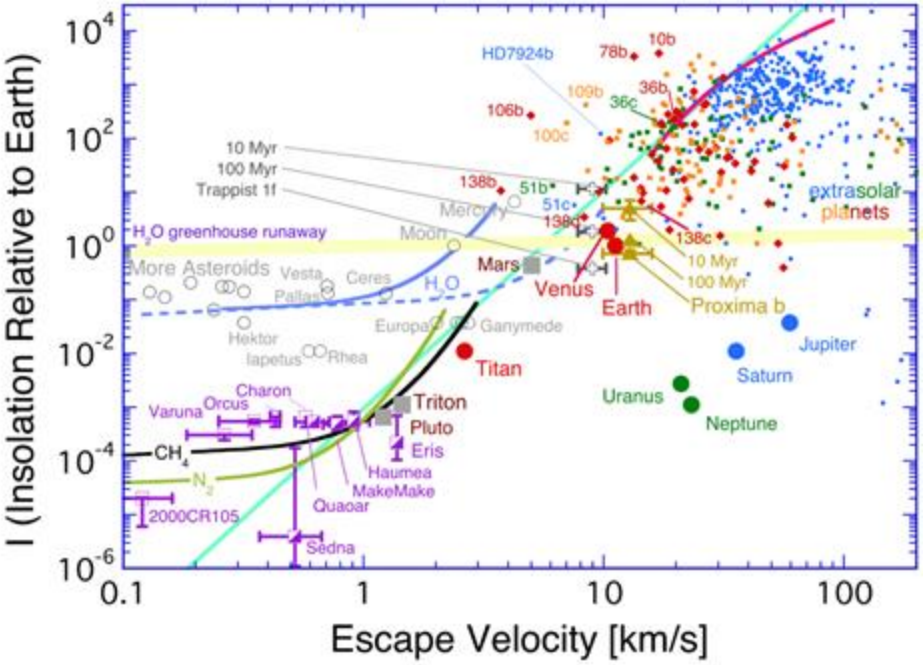

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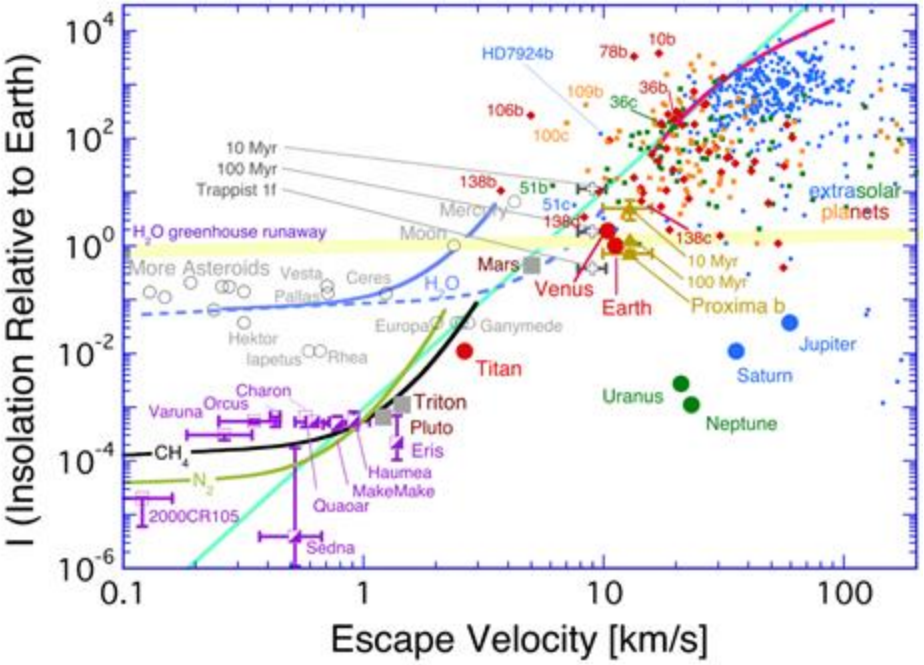

Does the Cosmic Shoreline apply for

EXOPLANETS?

Would the Cosmic Shoreline change for

OTHER STARS?

How?

How?

Rocky exoplanets orbiting M-dwarfs only doable with

transiting exoplanets

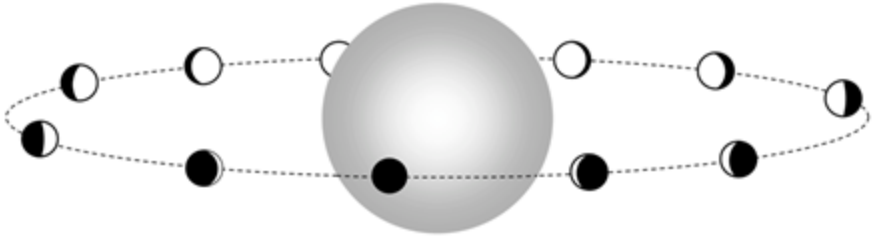

Image credit: Winn+2010

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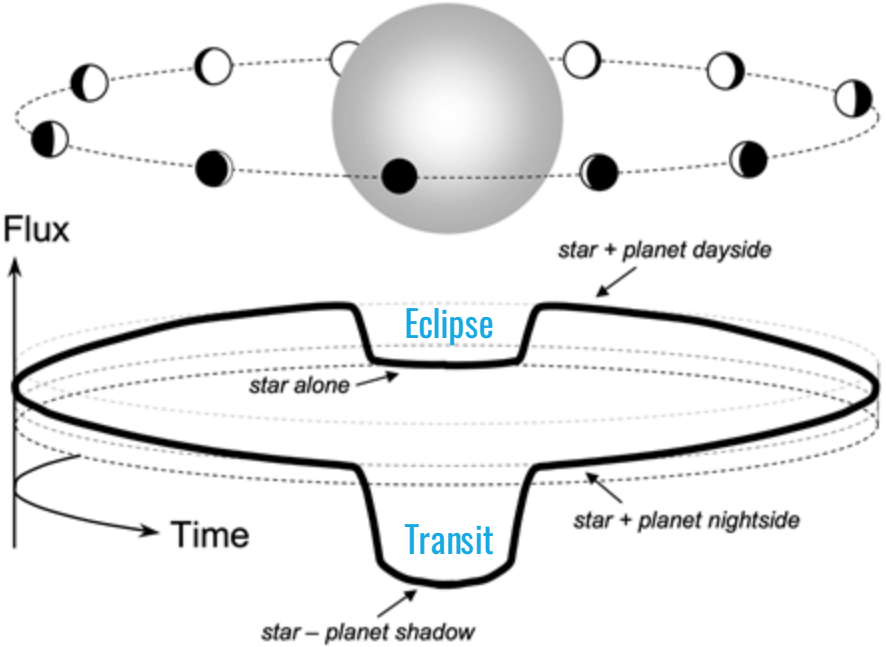

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Secondary eclipses

Rocky exoplanets orbiting M-dwarfs only doable with

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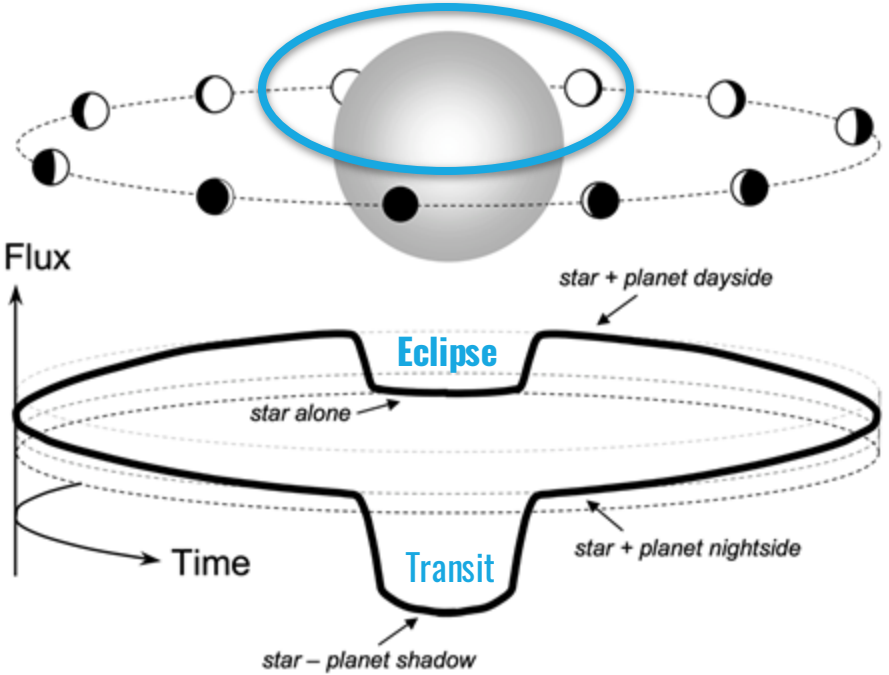

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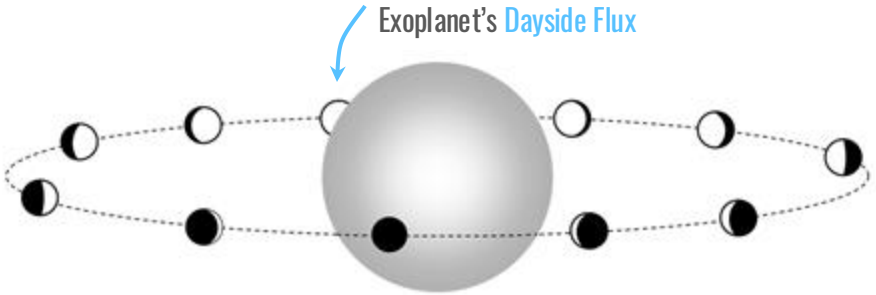

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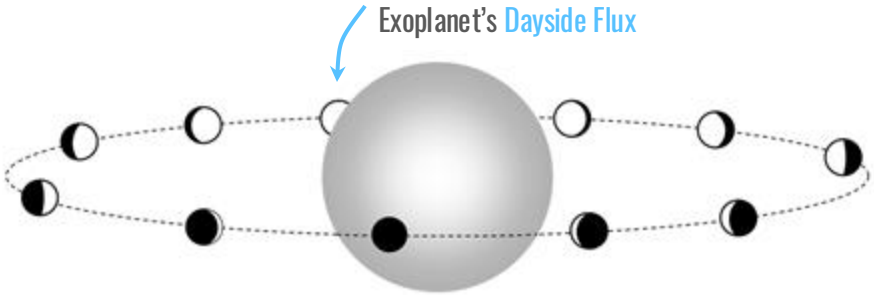
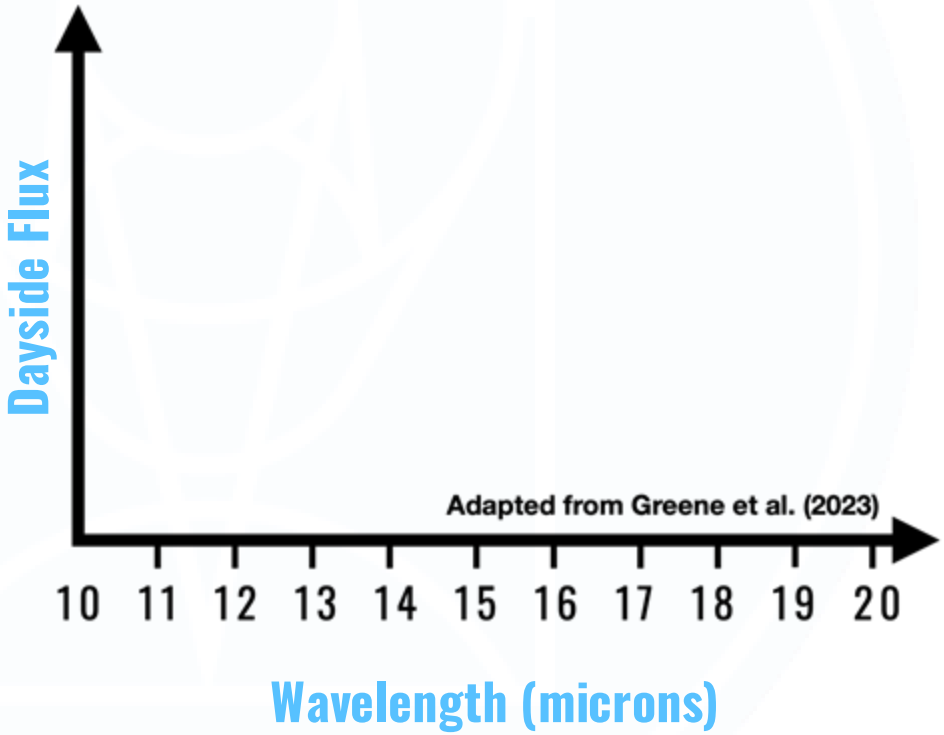
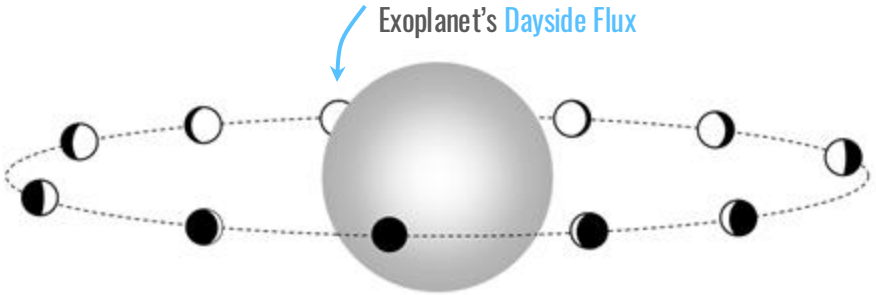


Moon & **Earth** at 10 μm (Robinson+2011)

Secondary eclipses





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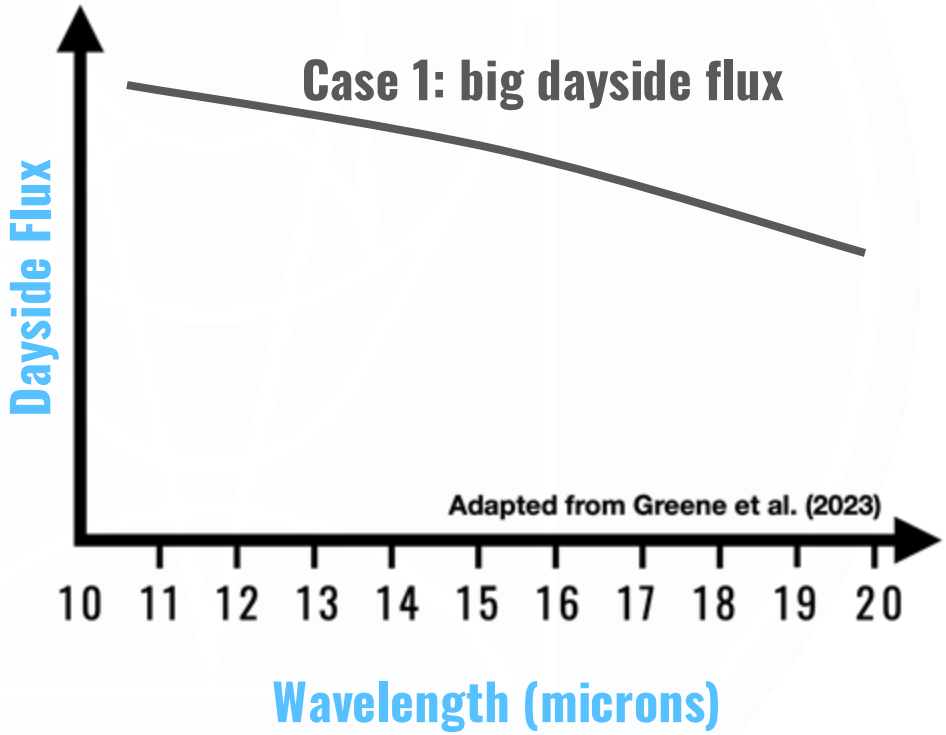

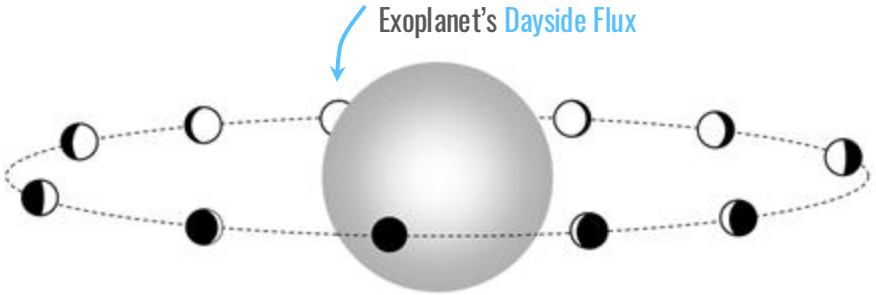

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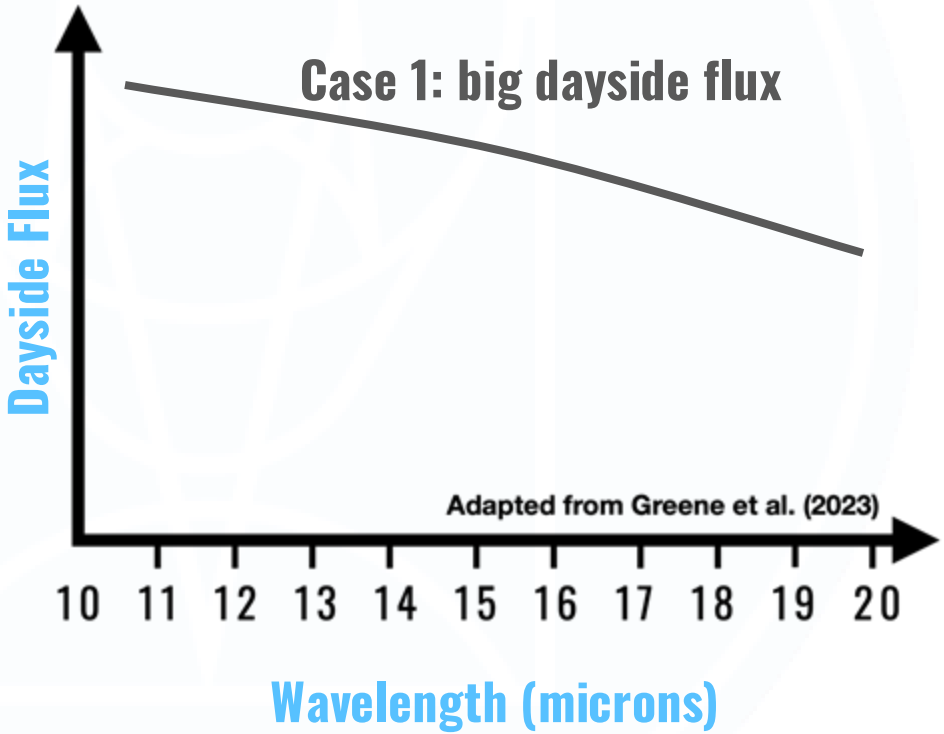

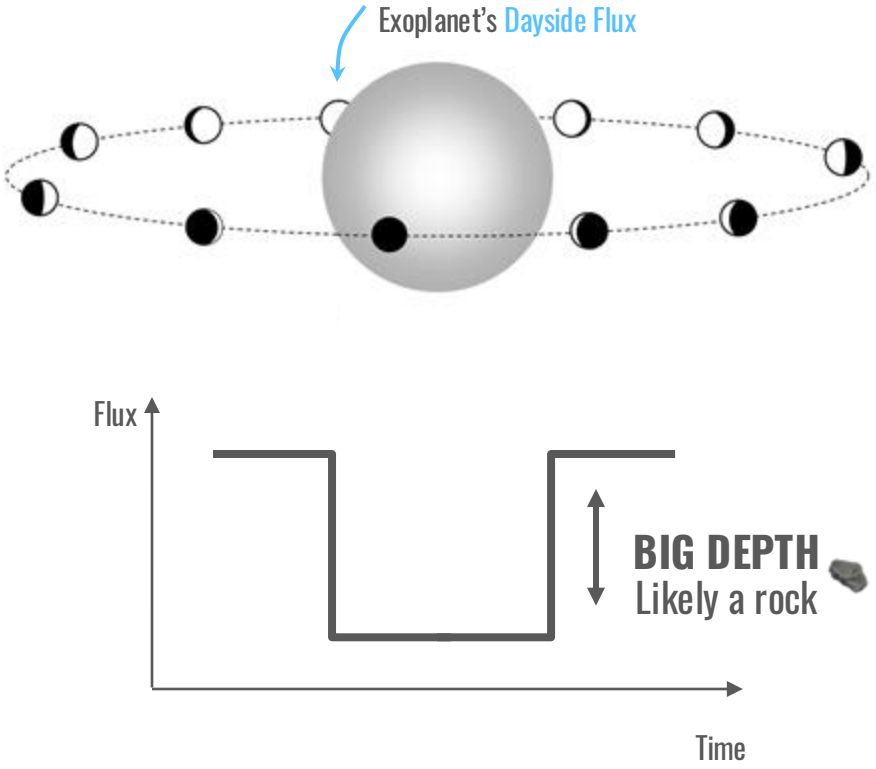

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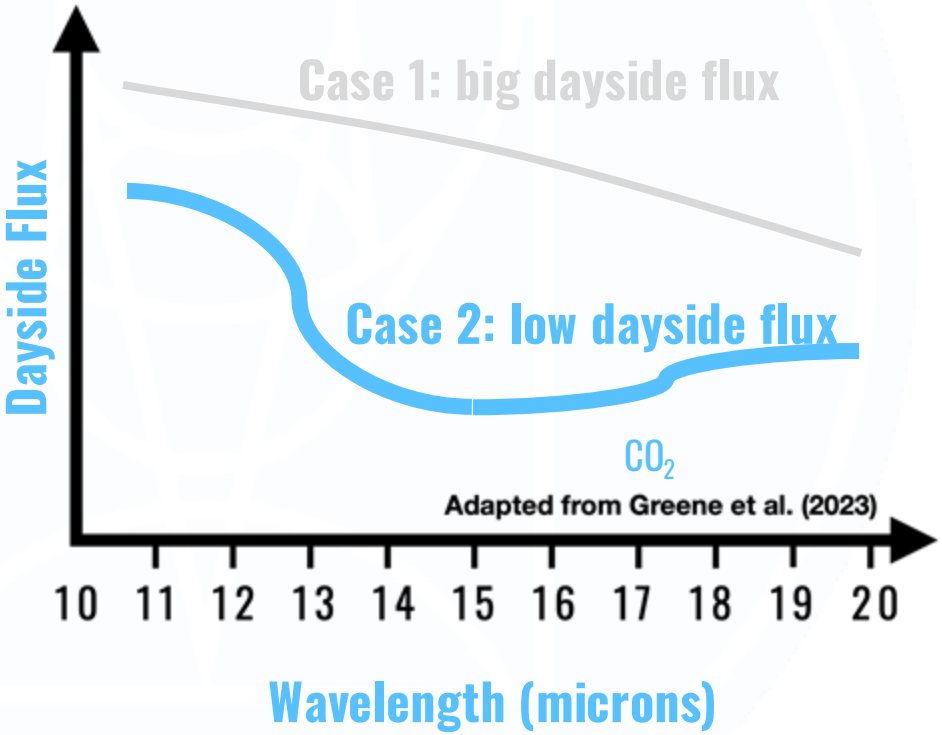

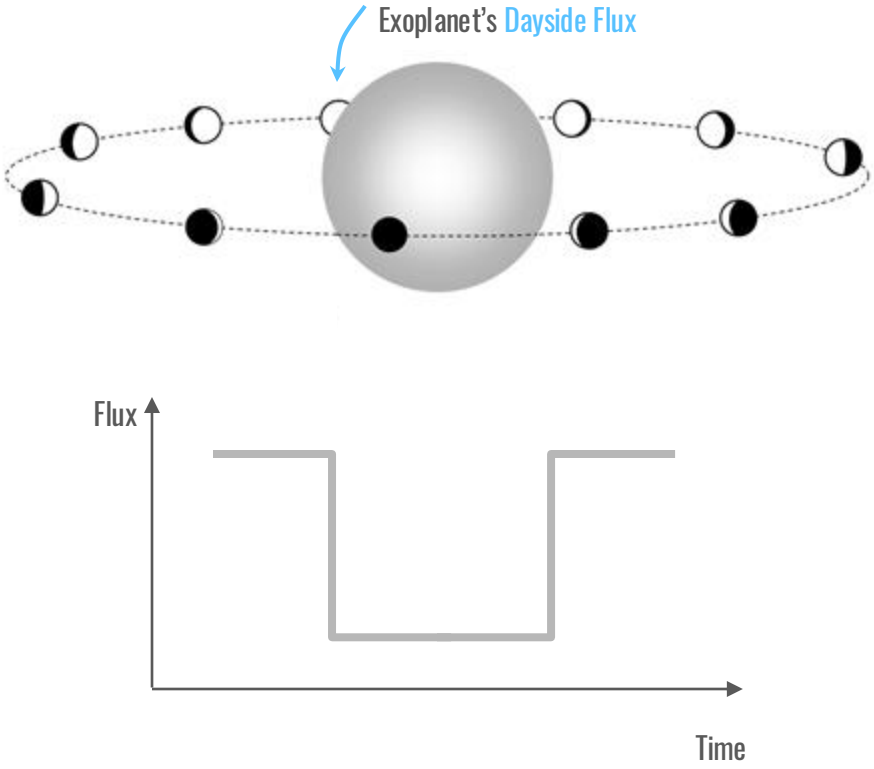

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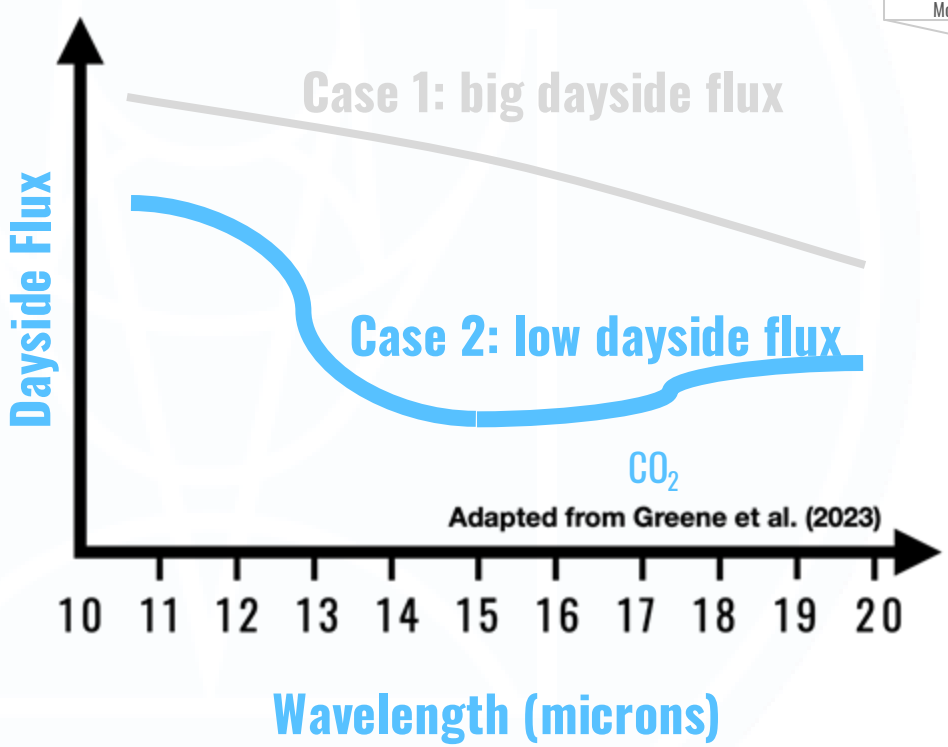

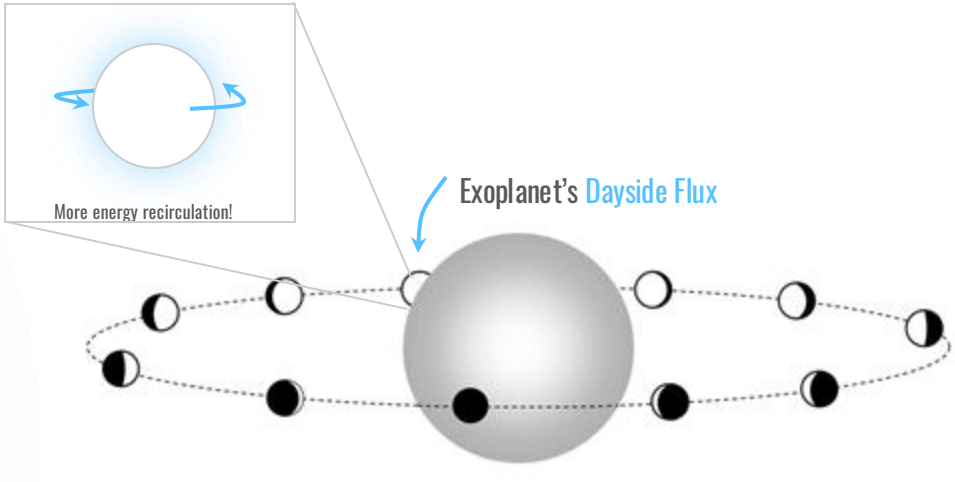

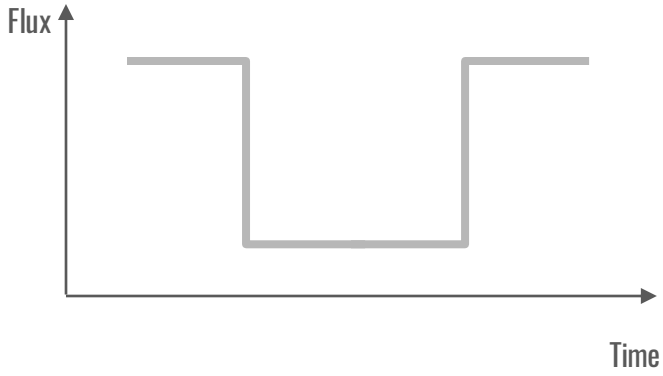

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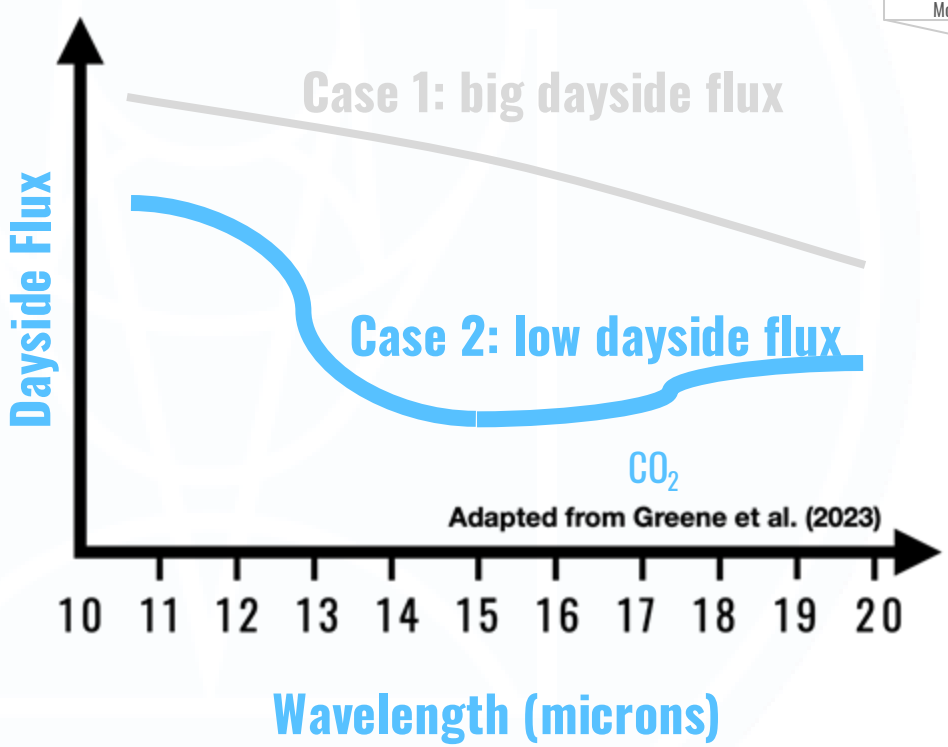

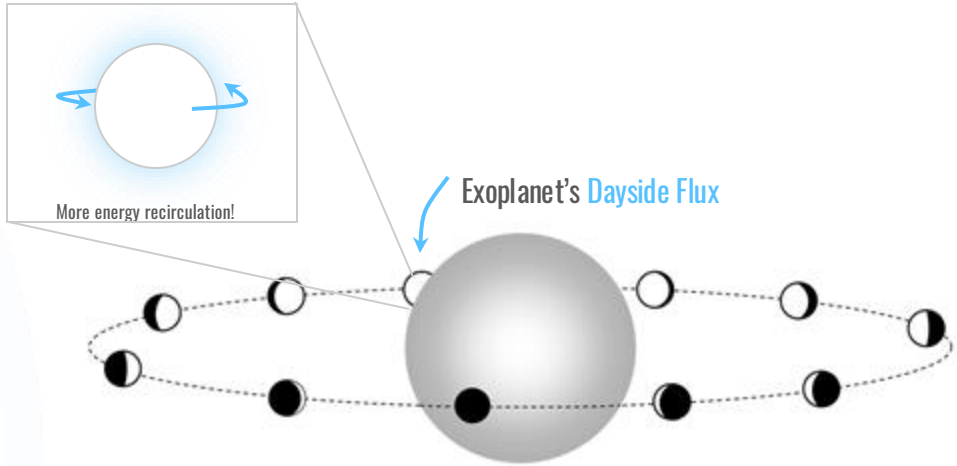

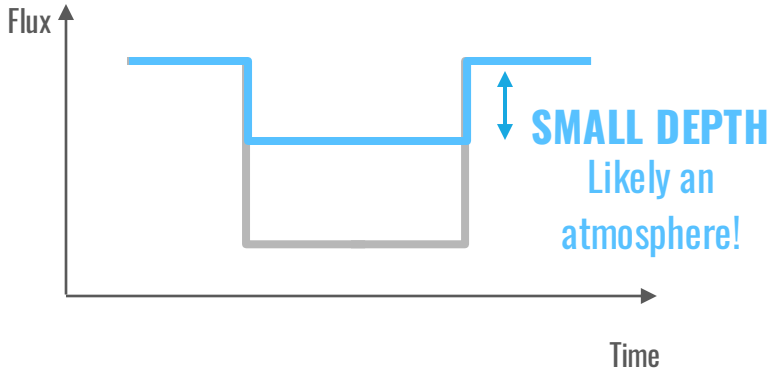

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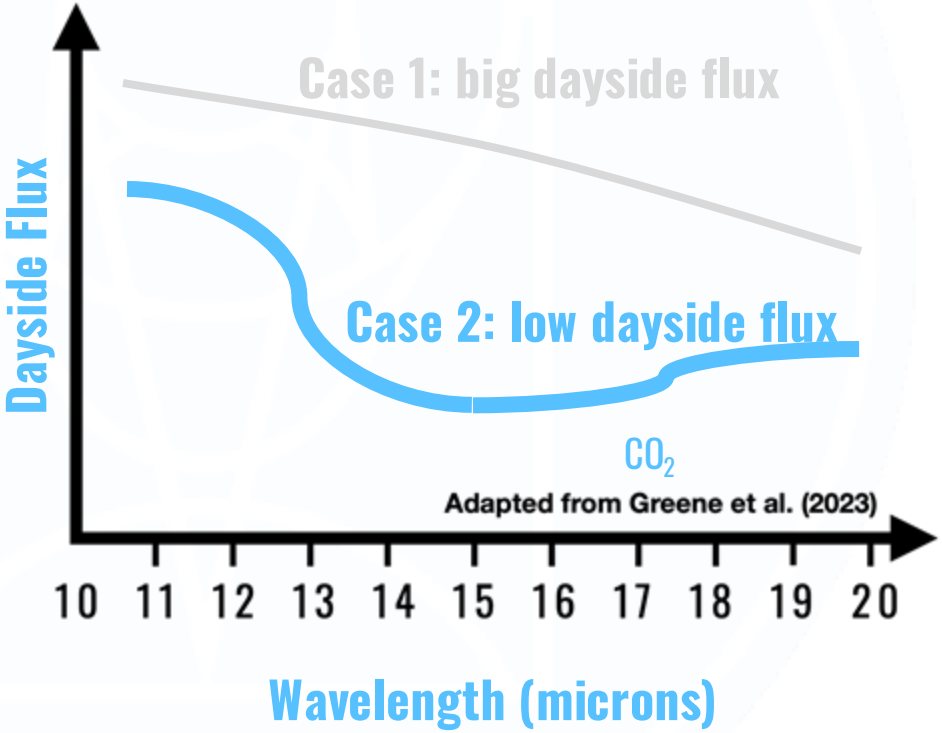
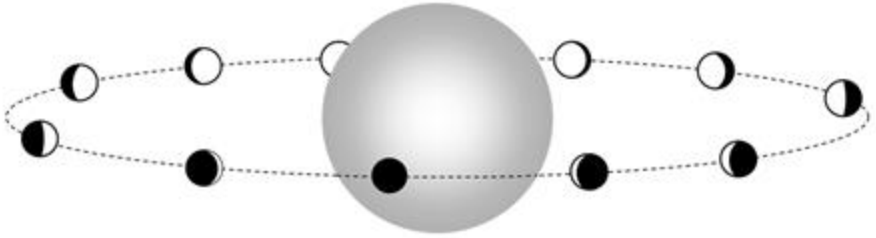
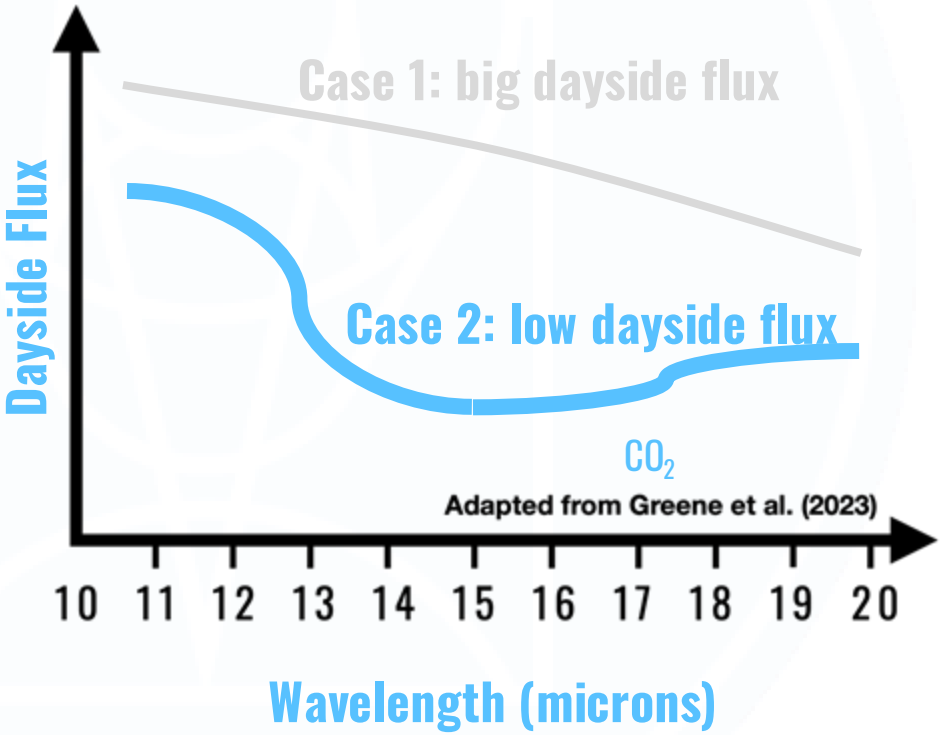




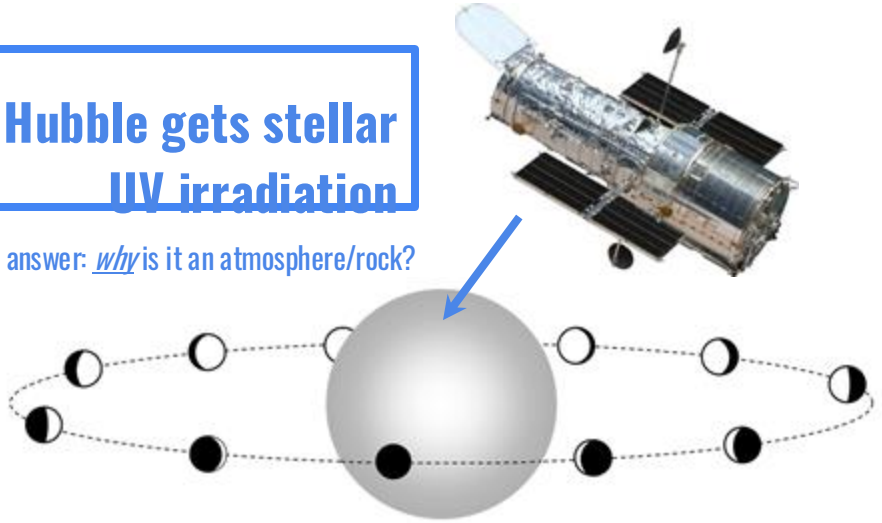
To answer: is it an atmosphere/rock?

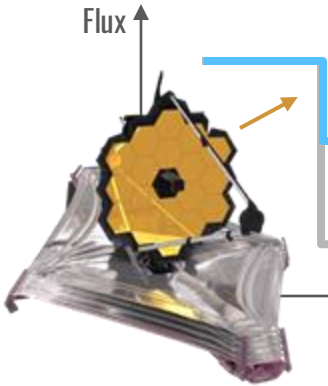
Secondary eclipses



Hubble gets stellar UV irradiation

To answer: *why* is it an atmosphere/rock?





Webb gets eclipses at 15 μm

To answer: is it an atmosphere/rock?

Target List

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A total of **9 targets** have been selected for the ROCKY WORLDS

Figure credits: NASA, ESA, CSA, Margaret Carruthers (STScI)

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Final sample announced ~a month before JWST Cycle 5 CfP deadline.

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- **Final sample announced ~a month before** JWST Cycle 5 CfP deadline.
- **Target selection process shared via** information session with the community (see here).

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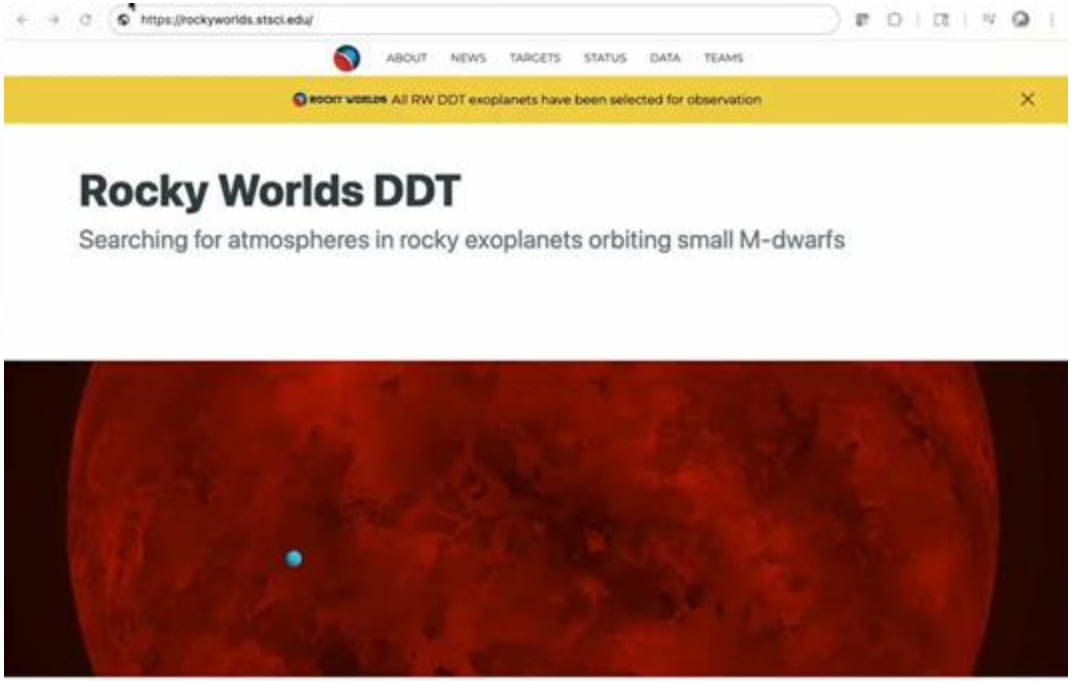
Figure credits: NASA, ESA, CSA, Margaret Carruthers (STScI)

- **Final sample announced ~a month before** JWST Cycle 5 CfP deadline.
- **Target selection process shared via** information session with the community (see here).
- Aiming to schedule observations for most targets before Cycle 6 CfP next year.

Website: rockyworlds.stsci.edu

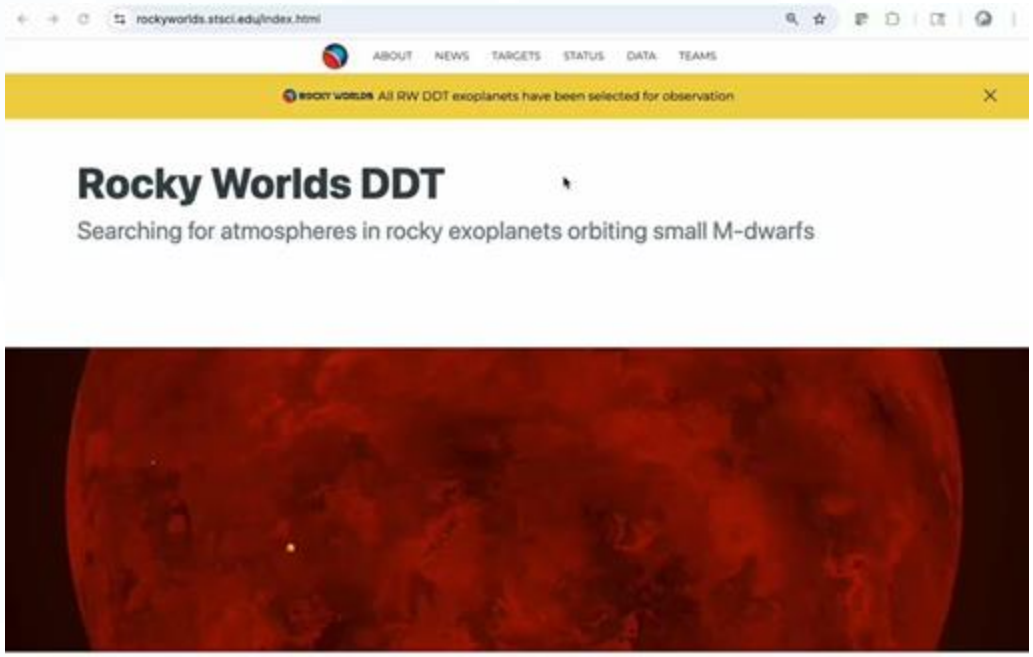


- **Frequent updates** (news, observation status).
- Makes **data accessible** — **“download-and-play”**.
- Access to quick-look-type data visualization, reports, and more!

Website: rockyworlds.stsci.edu — the “Status” page

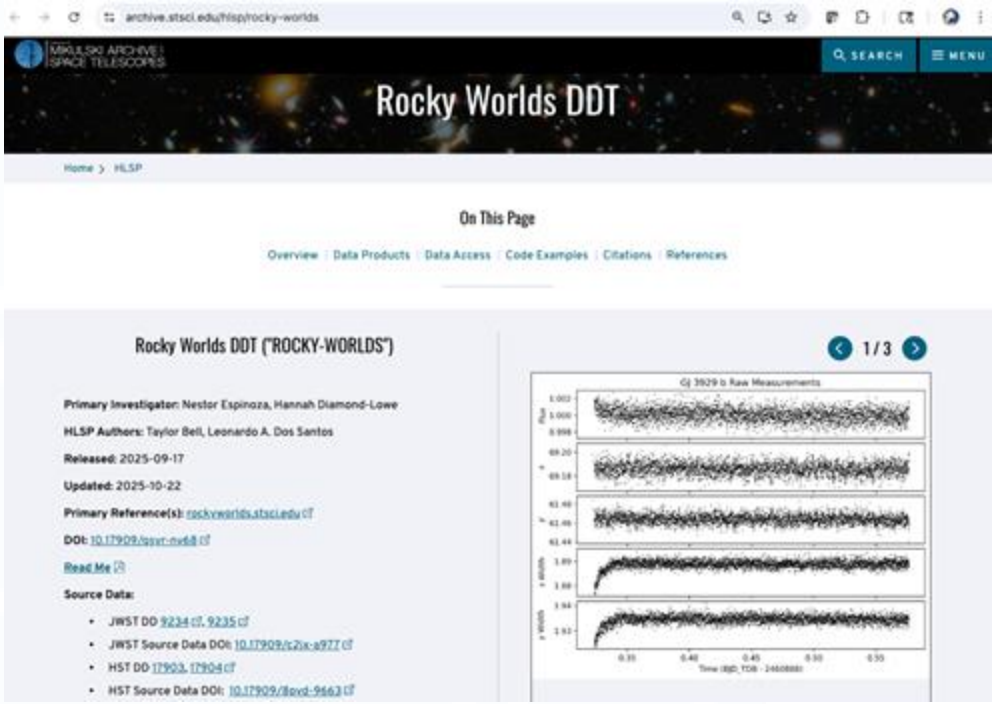
- **Detailed status** for every Rocky Worlds target.
- Individual program details, **scheduling timeline & reports**.
- Access to **quick-look information** & **deep-dive data reports**.

Website: rockyworlds.stsci.edu — data visualization



- **Provides a quick-look** for high-level science data products (HLSPs).
- Provides quick understanding of **data quality for individual visits**.
- Allows to bin, toggle between detrended data, zoom-in, etc.

Website: rockyworlds.stsci.edu — data access



All data lives in MAST — including high-level science data products (HLSPs).

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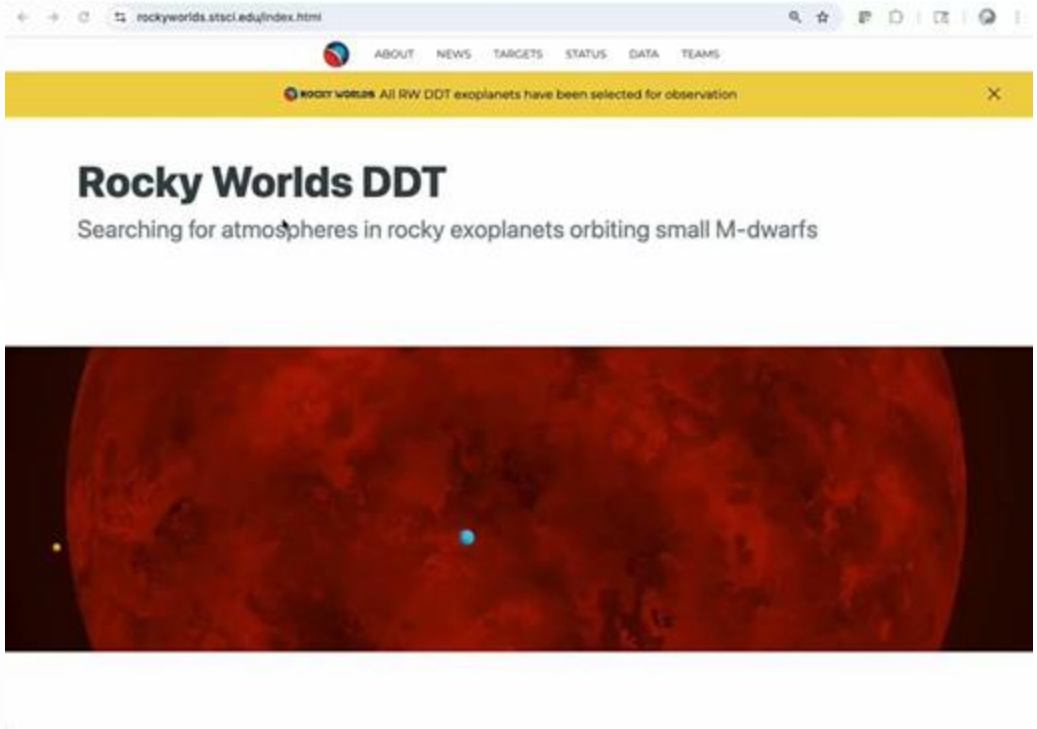

- **All data lives in MAST —** including high-level science data products (HLSPs).
- Website provides **code to download and plot HLSPs on your own machine.**

AAS 247 Rocky Worlds “Pin” Challenge

AAS 247 Rocky Worlds “Pin” Challenge

Do *you* want a ***Limited Edition*** **pin?**

AAS 247 Rocky Worlds “Pin” Challenge

Do *you* want a ***Limited Edition*** **pin?**

Download & plot all Rocky Worlds GJ 3929 b eclipses.

AAS 247 Rocky Worlds “Pin” Challenge

Do *you* want a ***Limited Edition*** **pin?**

- **Download & plot** all Rocky Worlds GJ 3929 b eclipses.
- **Find Néstor Espinoza** (CIT lead) and show him your plot.

AAS 247 Rocky Worlds “Pin” Challenge

Do *you* want a ***Limited Edition*** **pin?**

- **Download & plot** all Rocky Worlds GJ 3929 b eclipses.
- **Find Néstor Espinoza** (CIT lead) and show him your plot.

Do something interesting with the data (e.g., fit it), to get a **special *metal embedded* pin!**

Status of observations

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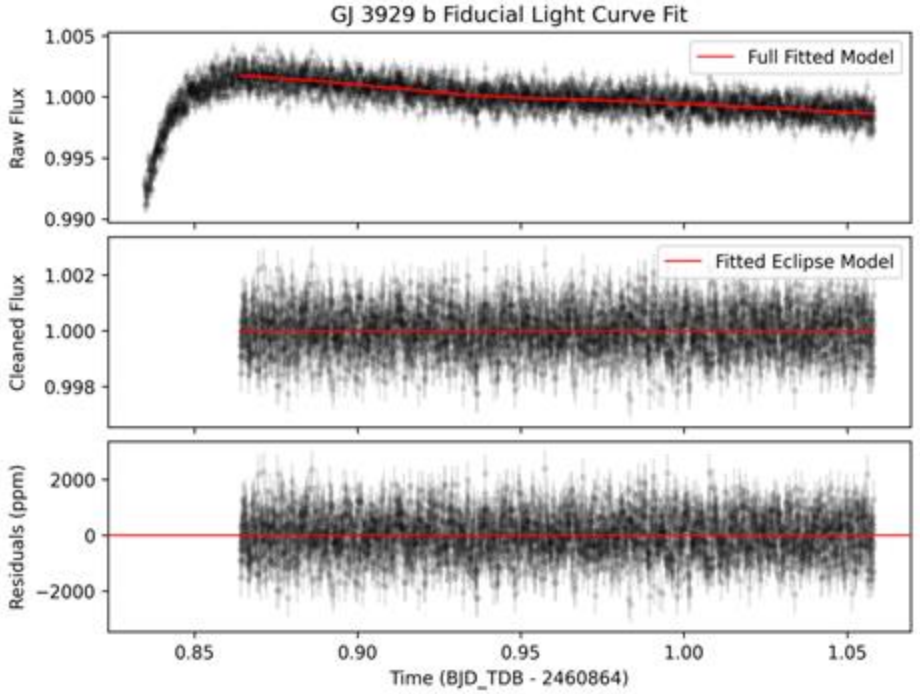

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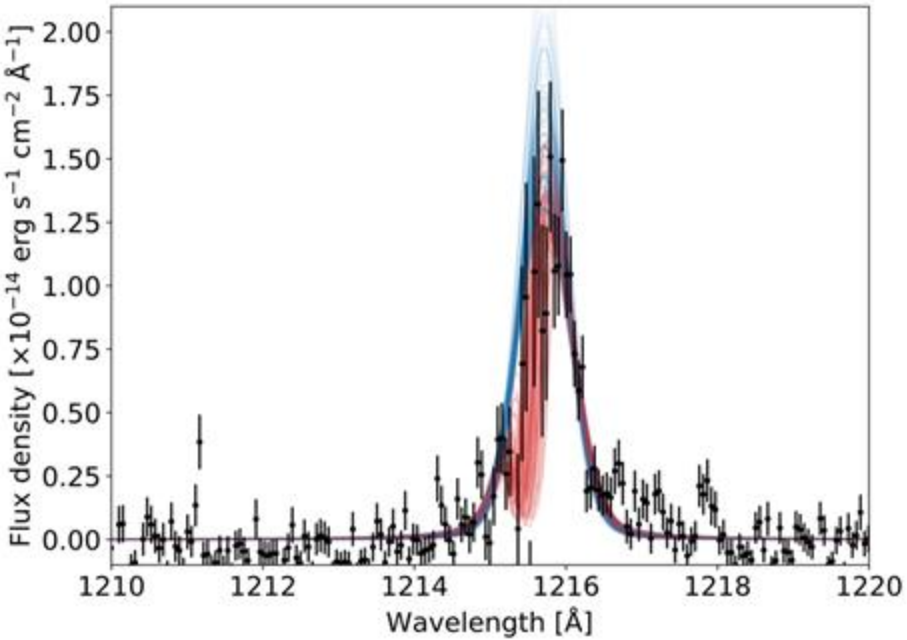

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- **One HST/STIS visit of GJ 3929** has been obtained, HLSP published. More STIS+COS in Jan-Mar 2026
- **Next to schedule:** LHS 1140 b, LTT 1445 A b/c — then rest of targets!

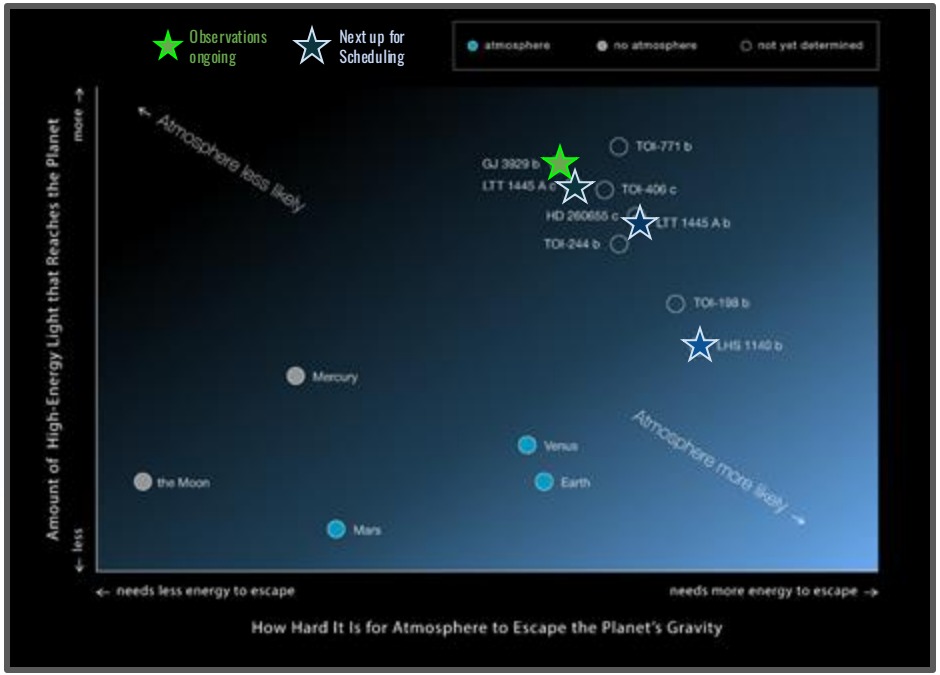

Figure credits: NASA, ESA, CSA, Margaret Carruthers (STScI)

Rocky Worlds Data Challenge & Workshop

Rocky Worlds Data Challenge & Workshop

Work on Data Challenge has begun

Will include a 3-day Workshop likely end of 2026:

- Day 1: ECR training on JWST/MIRI time series photometry.
- Day 2: Unveiling of results from data challenge in a full day of presentations.
- Day 3: Hackathon to compile results and methodologies.

Top performers will be invited talks to the Workshop.

Idea is for this to culminate in a (or set of) peer-review manuscripts.

Summary

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Summary

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- **The Rocky Worlds DDT has selected its final sample of 9 targets** — their equilibrium temperatures, sizes and position in the "Cosmic shoreline" plot encompasses a key part of the parameter space to provide evidence as to whether rocky exoplanets around M-dwarfs can host atmospheres.
- **2026 will be an exciting year for the Rocky Worlds DDT** — from scheduling observations of new targets, obtaining new data coming as early as January to the Data Challenge. Stay tuned!

ROCKY WORLDS

Néstor Espinoza (STScI) | CIT Lead

On behalf of the Core Implementation Team at STScI

rockyworlds.stsci.edu

January 4th, 2026

Primary Transit

Rocky exoplanets orbiting M-dwarfs only doable with

transiting exoplanets

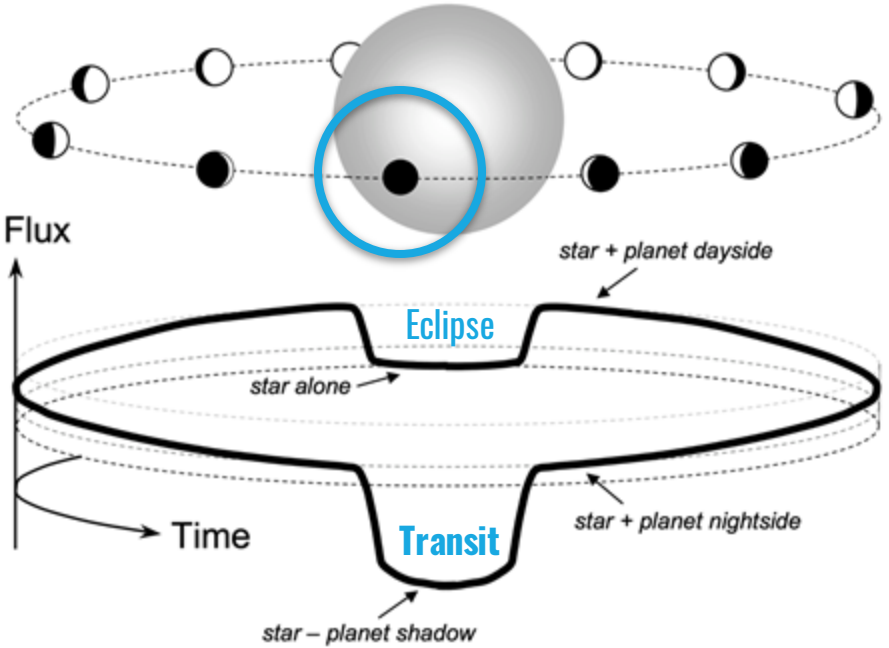
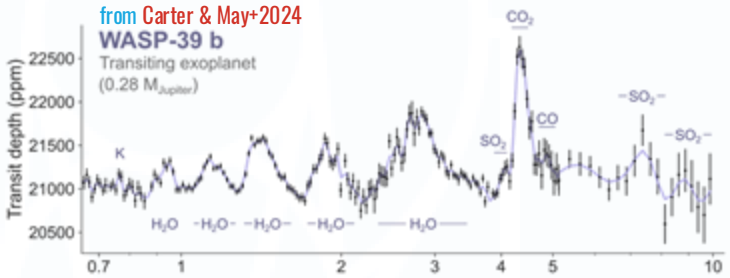


Image credit: Winn+2010

Primary Transit

Works beautifully for FGK stars:



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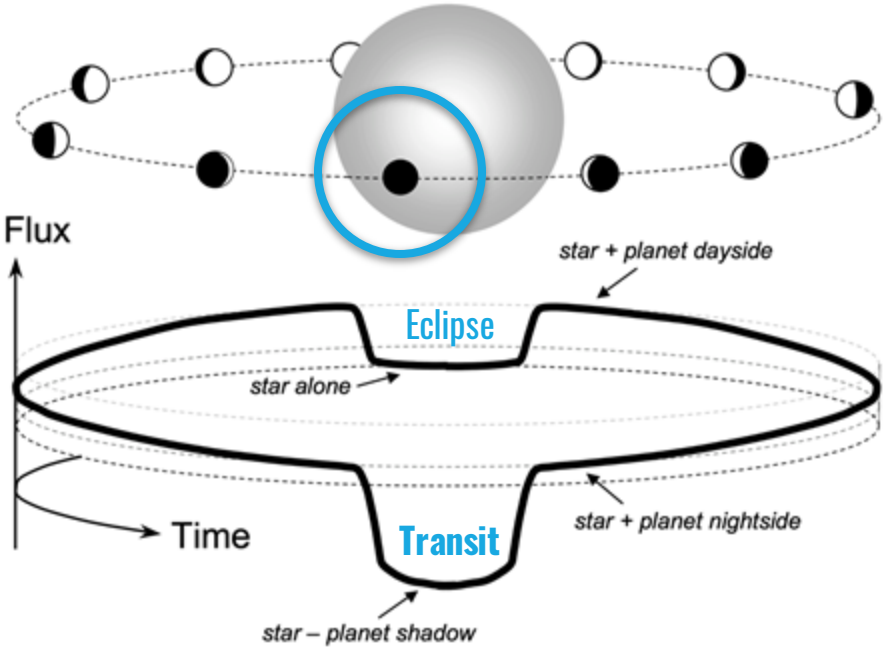

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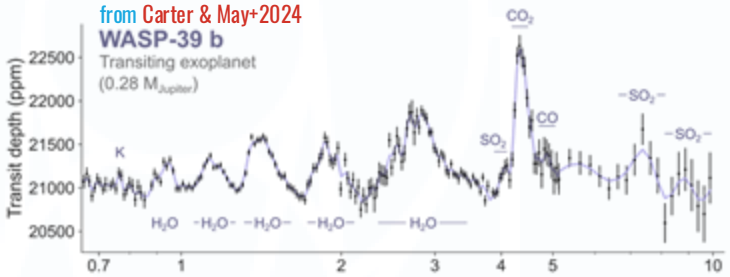
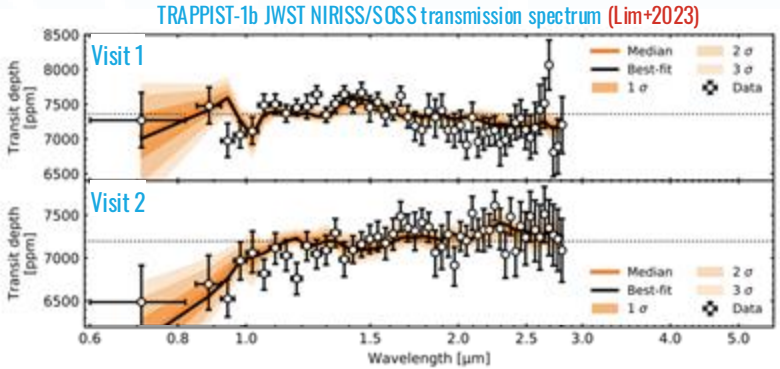


The M-dwarf challenge of stellar contamination:



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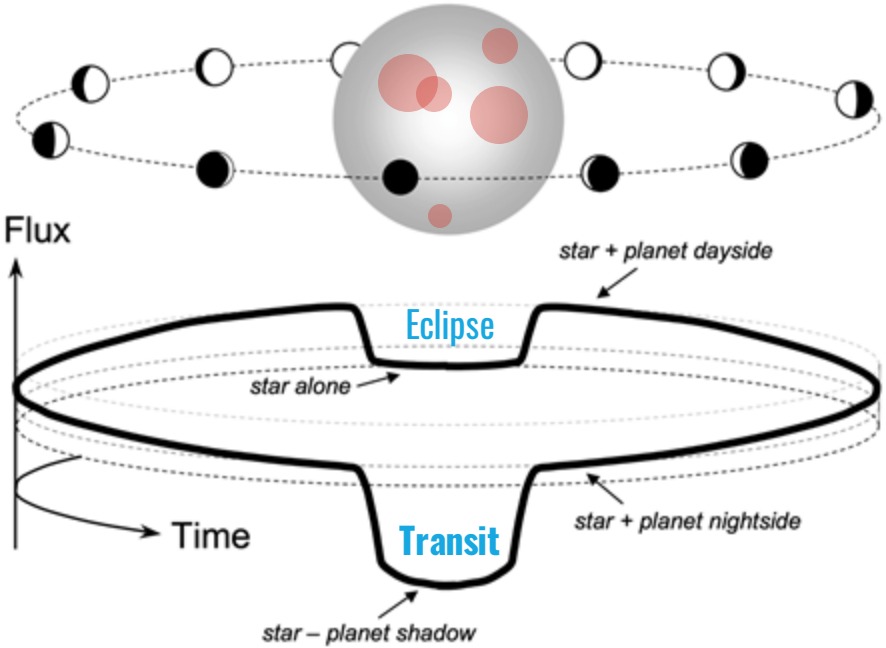

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Scheduling Rocky Worlds targets

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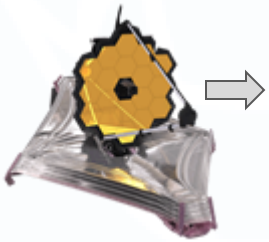

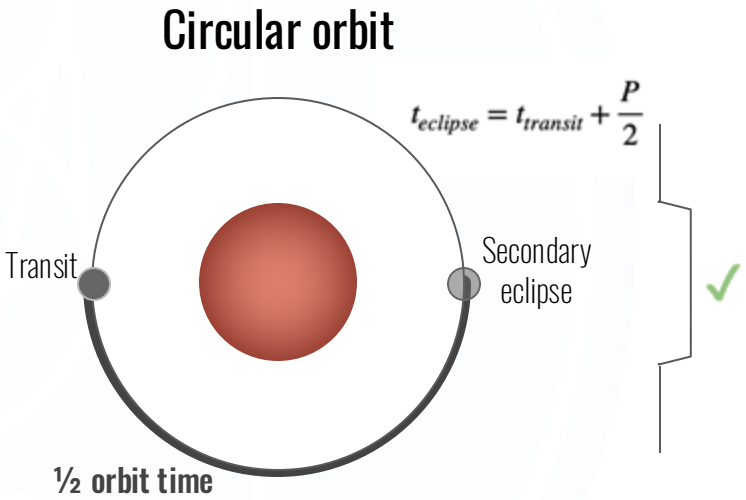

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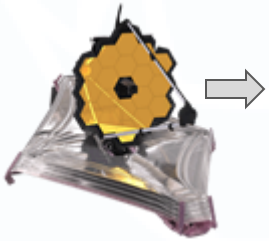
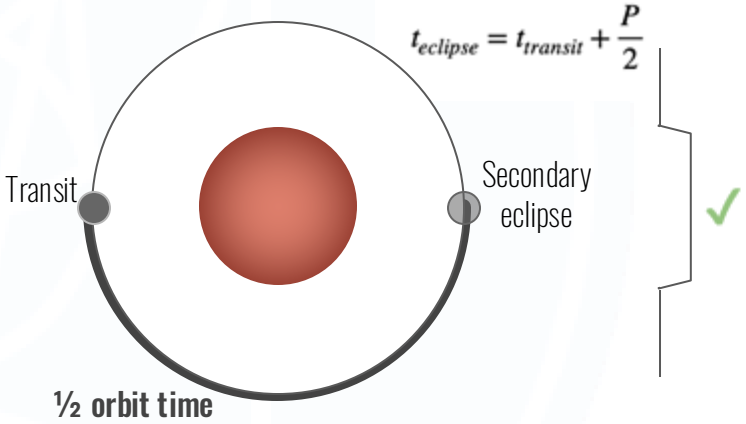
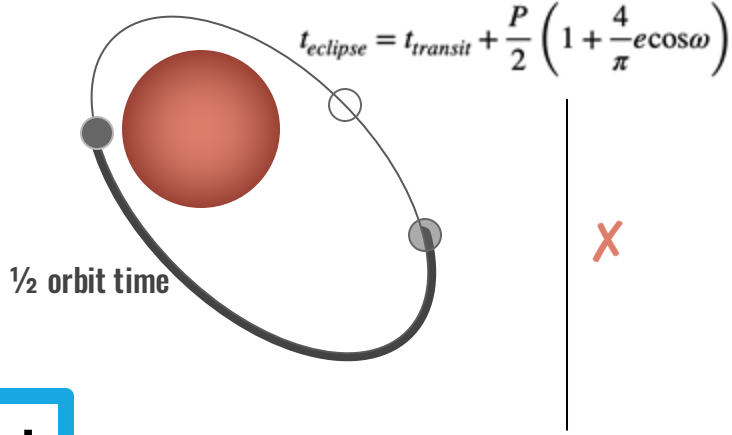


Circular orbit



✓

Eccentric orbit



✗

Need to calculate exact time for JWST to look

Scheduling Rocky Worlds targets

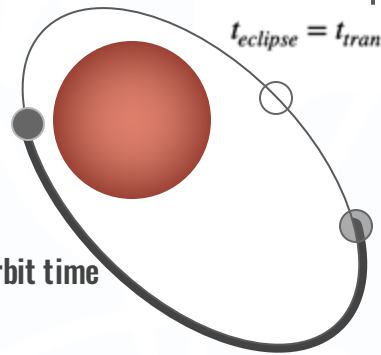
It's harder than it sounds!

Eccentric orbit

Well constrained from transit observations

$$t_{eclipse} = t_{transit} + \frac{P}{2}\left(1 + \frac{4}{\pi} e\cos\omega\right)$$

e and ω are somewhat constrained by RVs and highly correlated



½ orbit time

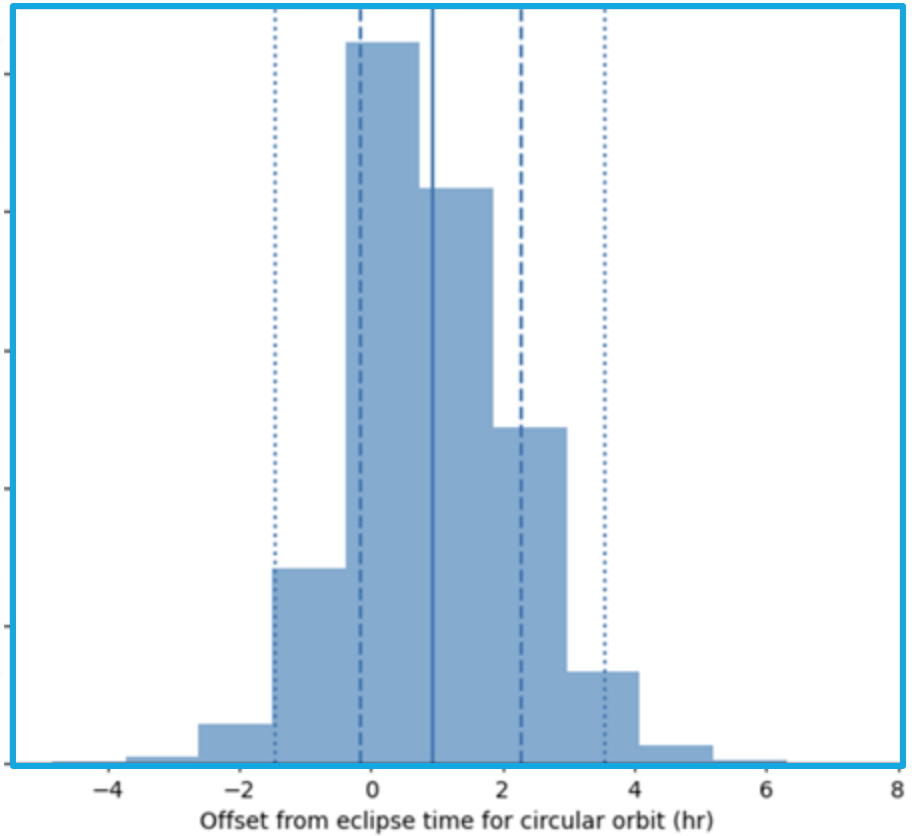
Scheduling Rocky Worlds targets

Target scheduling: GJ 3929 b

MAROON-X RVs constrain the eccentricity to be consistent with 0 at 2-sigma.

(Thank you to Madison Brady and Jacob Bean for sharing proprietary MAROON-X RVs and analyses; results now published in Xue et al., 2025, arXiv:2508.12516)

ExofastV2 global fits (that include MAROON-X RVs) favor a slightly eccentric orbit consistent with e=0 at 1-sigma.



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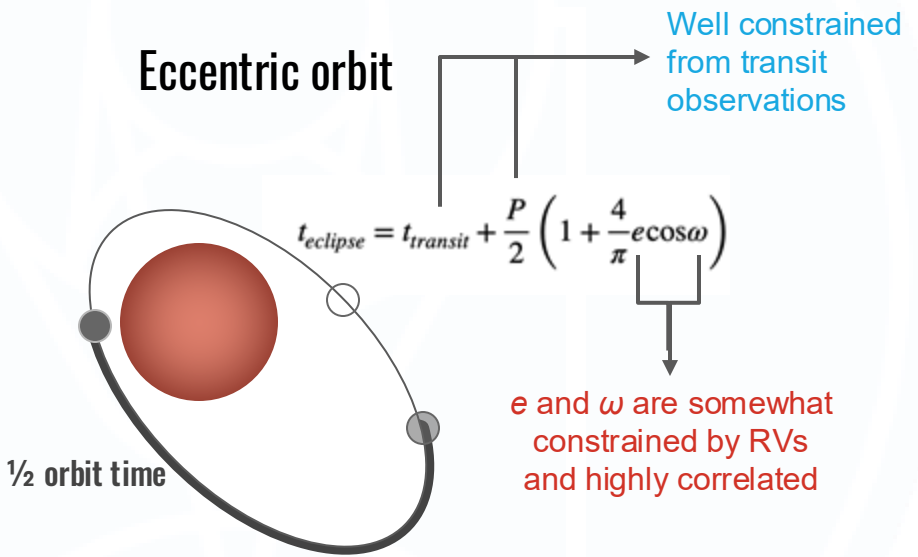


CIT Scheduling Team performs global fits using all available

- Radial velocities*
- Transit lightcurves*

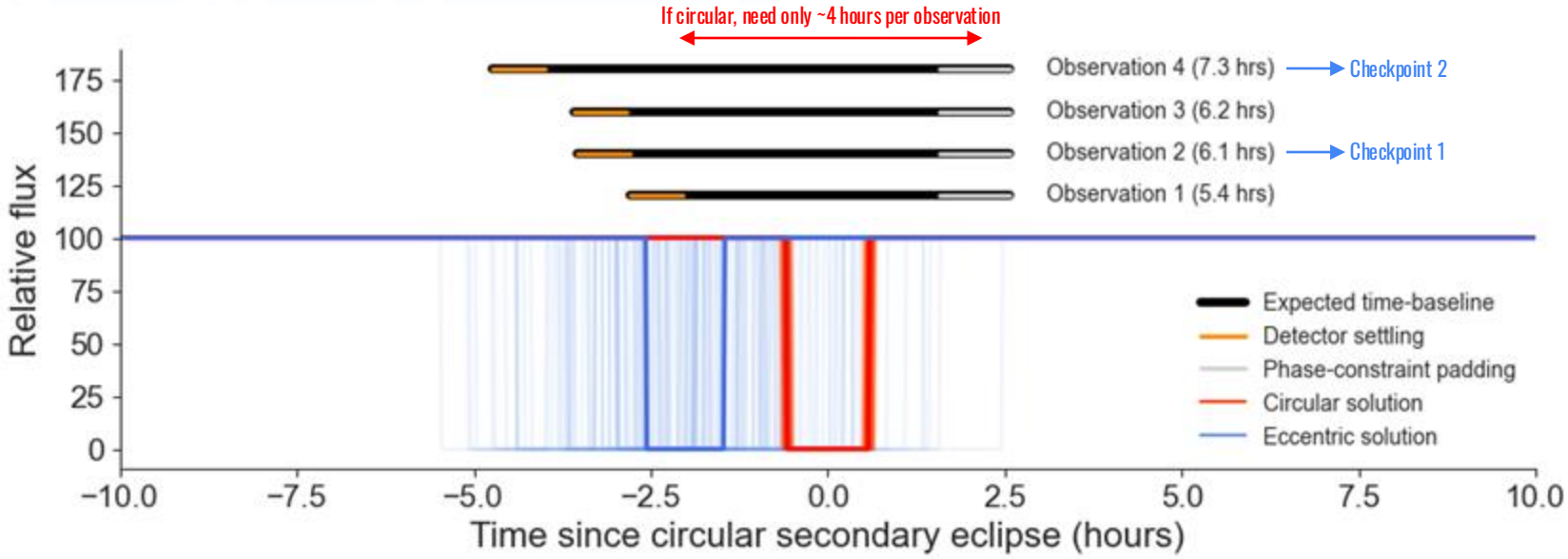
to constrain orbital parameters. ***High-precision data* is the most effective.**

(If you have any data like this for the Rocky Worlds targets and would like to share, we would be very grateful!)

Scheduling Rocky Worlds targets

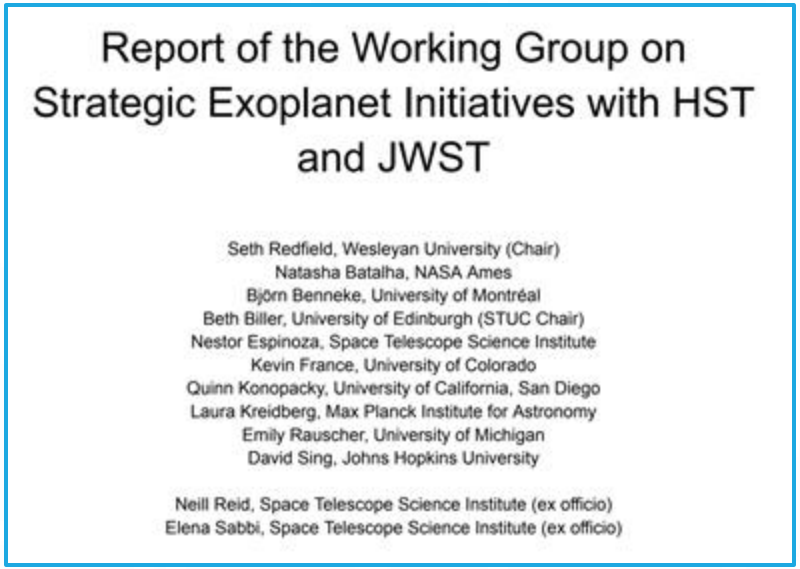
Mitigate uncertain eclipse times: tinker scheduling and checkpoints

Tinker Scheduling strategy: GJ 3929 b



The Rocky Worlds DDT Program

A direct recommendation from the...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Redfield+2024

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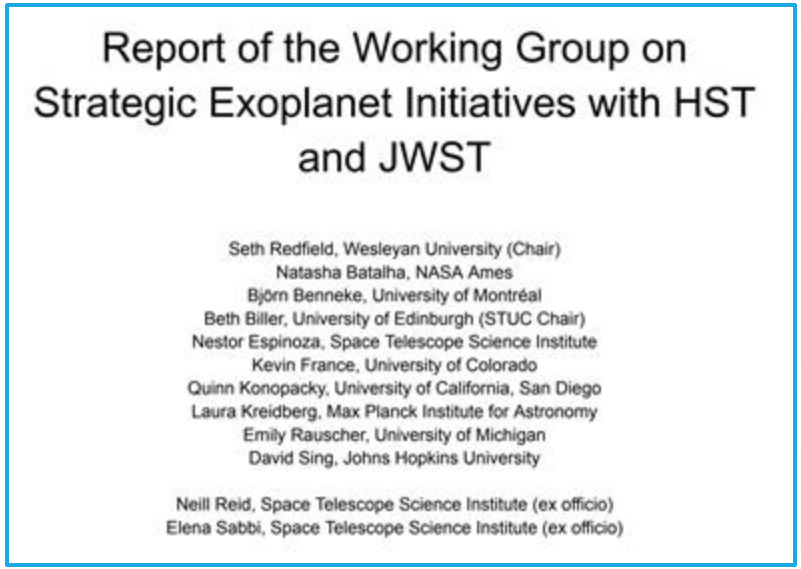
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x3 Town Halls
x42 White Papers
x75 Survey Responses

Redfield+2024

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- **Main aim:** look for **evidence of atmospheres** in rocky exoplanets orbiting **M-dwarf stars**.
- **With what? 500 hours** of JWST for planet/atmospheric characterization + **250 HST/UV** orbits for stellar characterization.
- **How? Core Implementation Team (CIT)** deals with data + community (at STSCI); **Science Advisory Council (SAC)** advises the CIT.

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INS: Instruments Division | PMO: Program Management Office | DMD: Data Management Division | OPO: Office of Public Outreach

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Hannah Diamond-Lowe (INS; CIT Deputy Lead)

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CIT Community Software, Analysis and Communications Team

Hannah Braun (OPO)
Kelly Lepo (OPO)
Kyle Conroy (DMD)
Leonardo Ubeda (INS)
Mees Fix (INS)
Julie Imig (DMD)
Jade Carter (design consultant)

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Science Advisory Council (SAC) meets monthly with CIT Leadership

Target Selection Process

General philosophy & starting points


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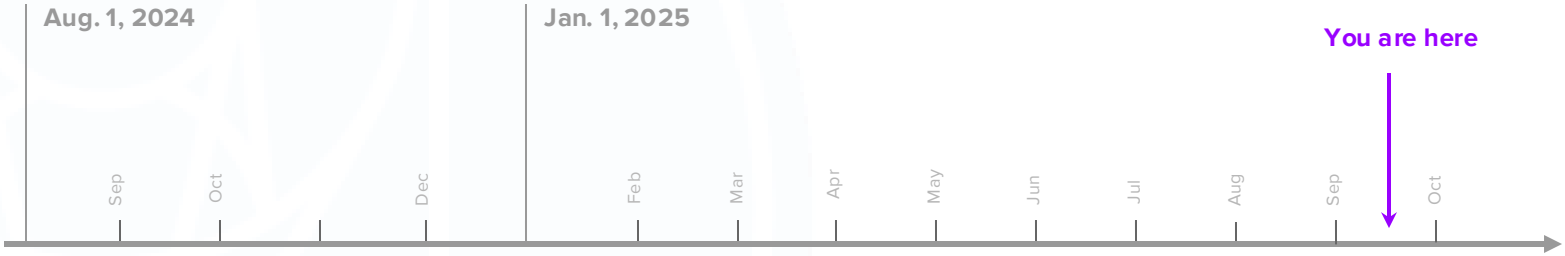
Redfield+2024

- Planets **up to 600 K equilibrium temperatures**.
- 40-70% of the time (**200-350 hours**) to "cool" planets; i.e, planets with **250-450 K equilibrium temperatures**.
- Project is **high risk, high reward** — hence the **DDT route**!

Target Selection Process



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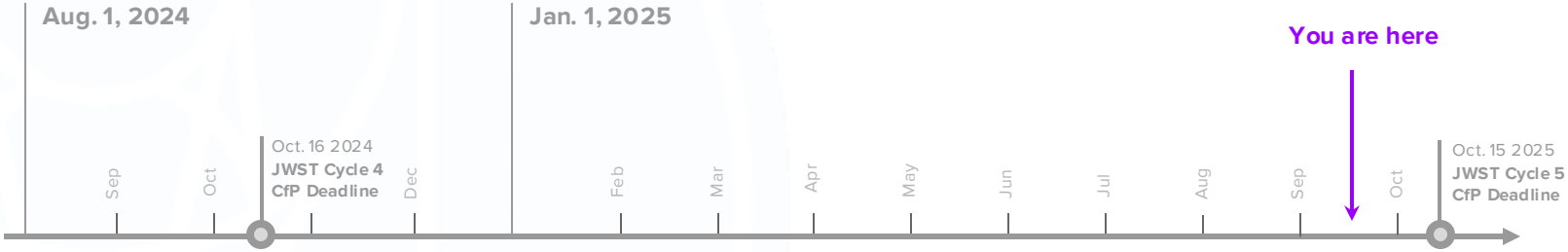

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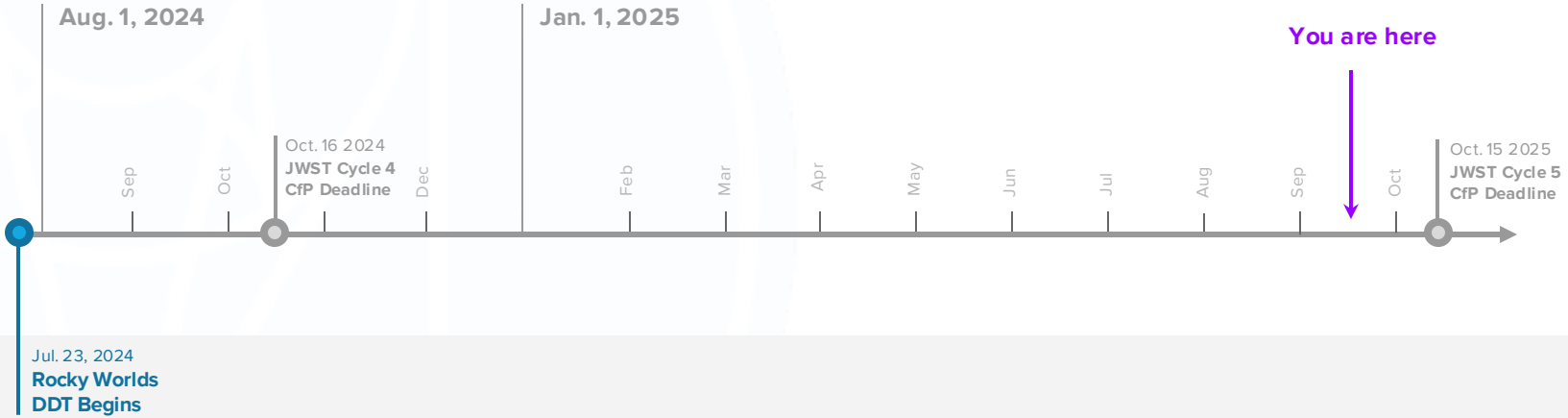

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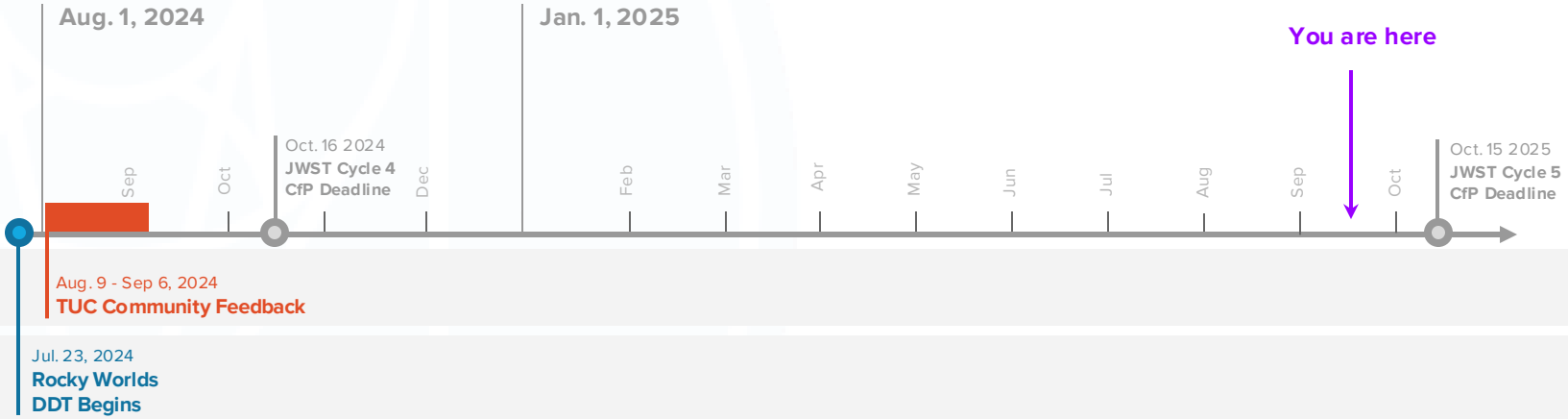

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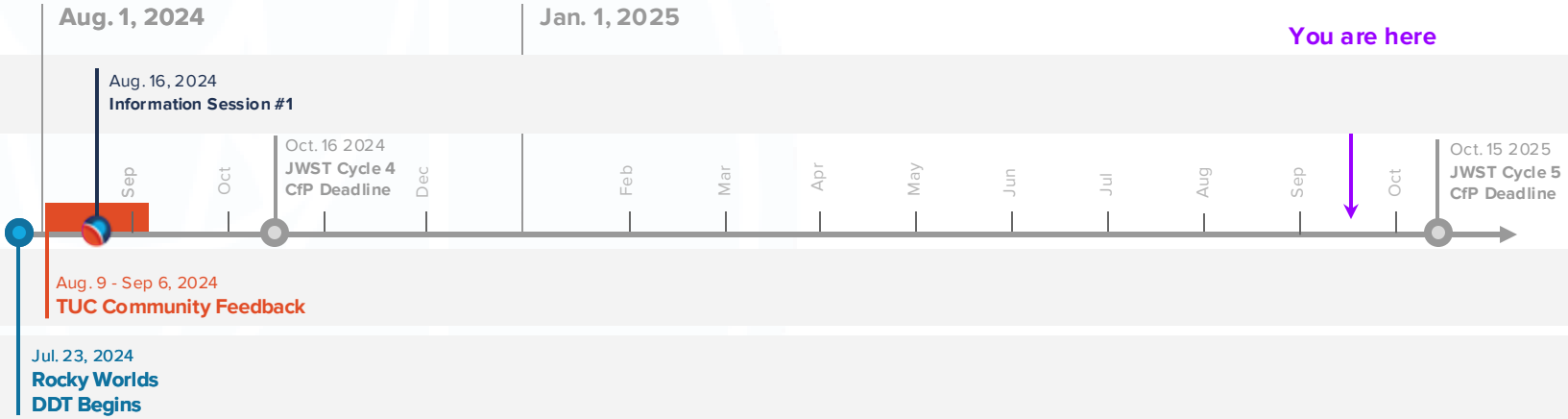

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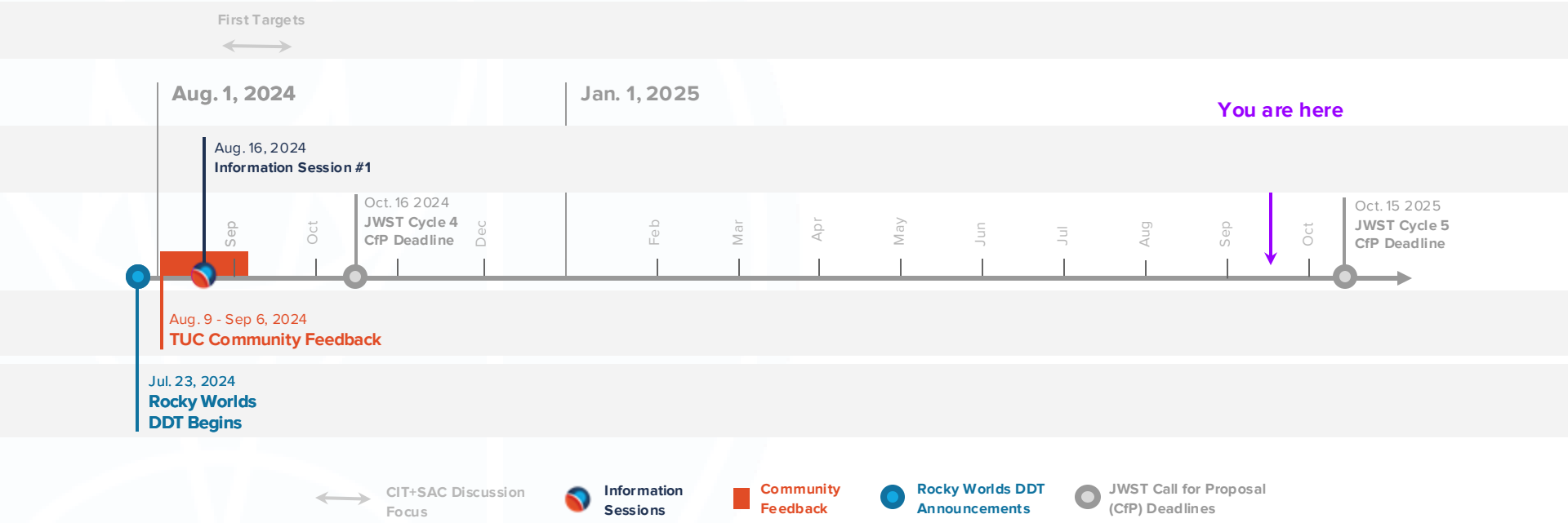

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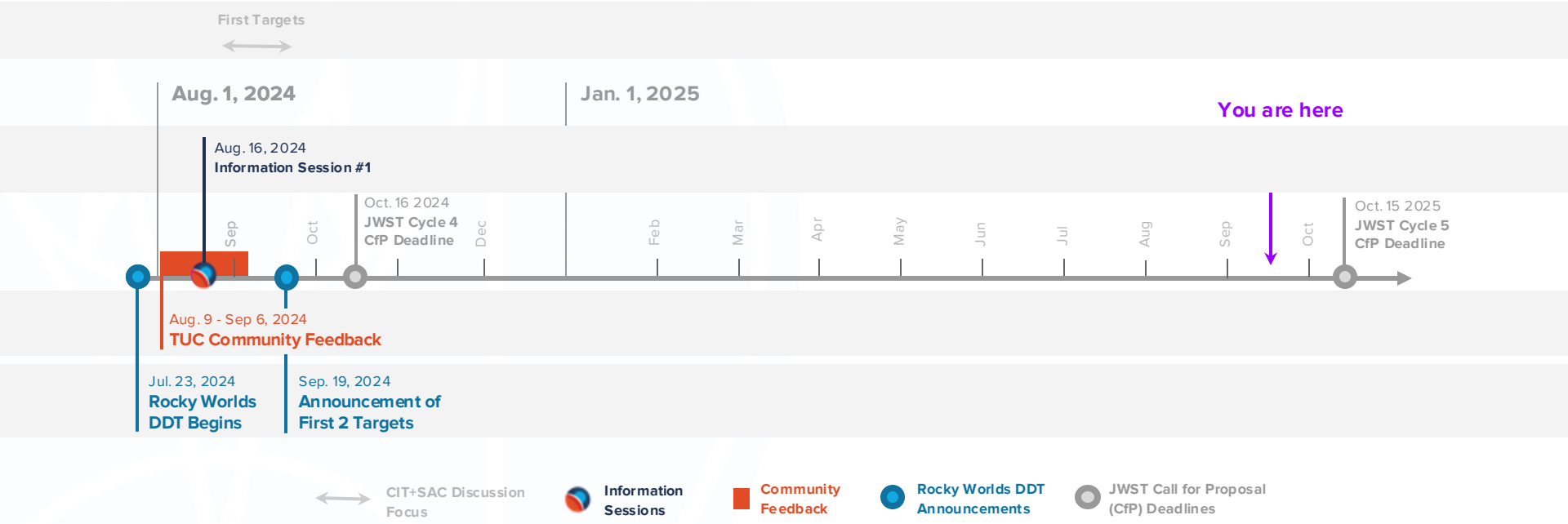

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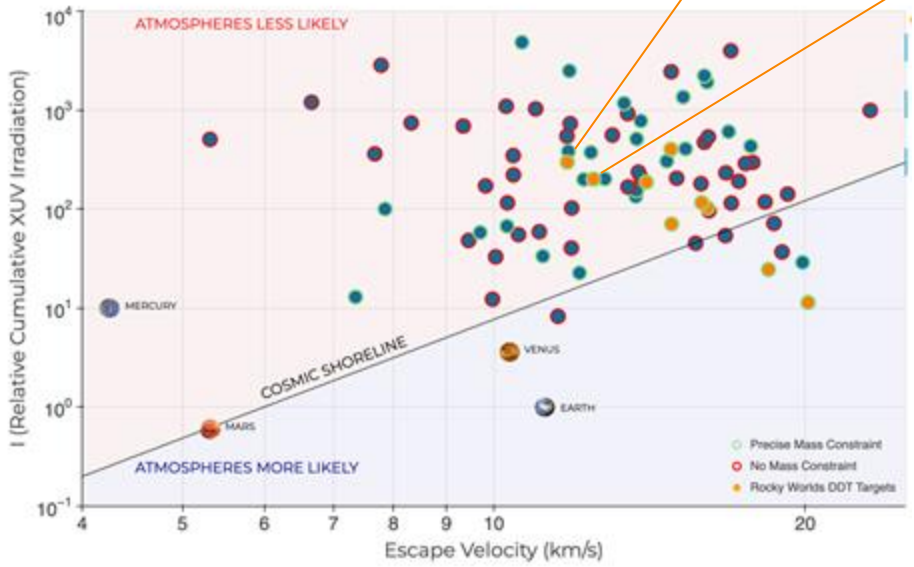

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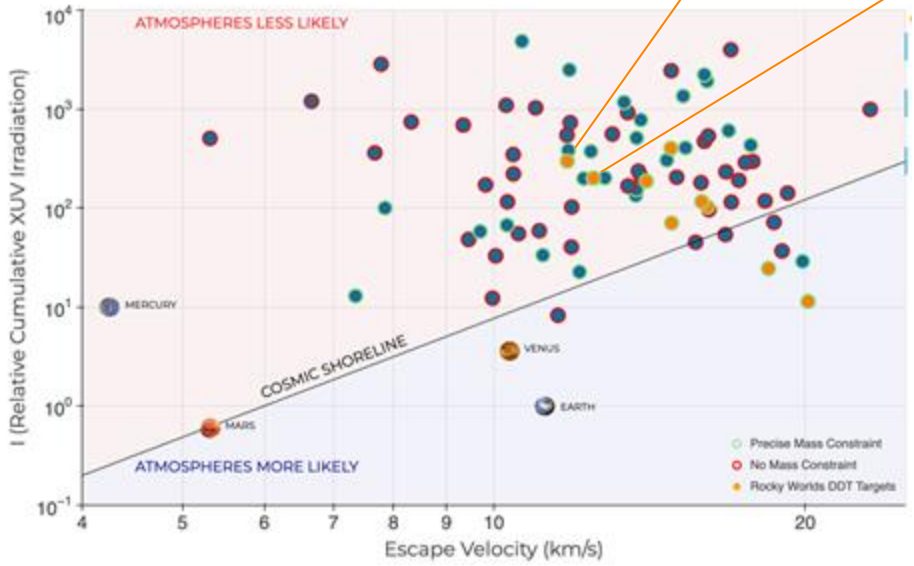
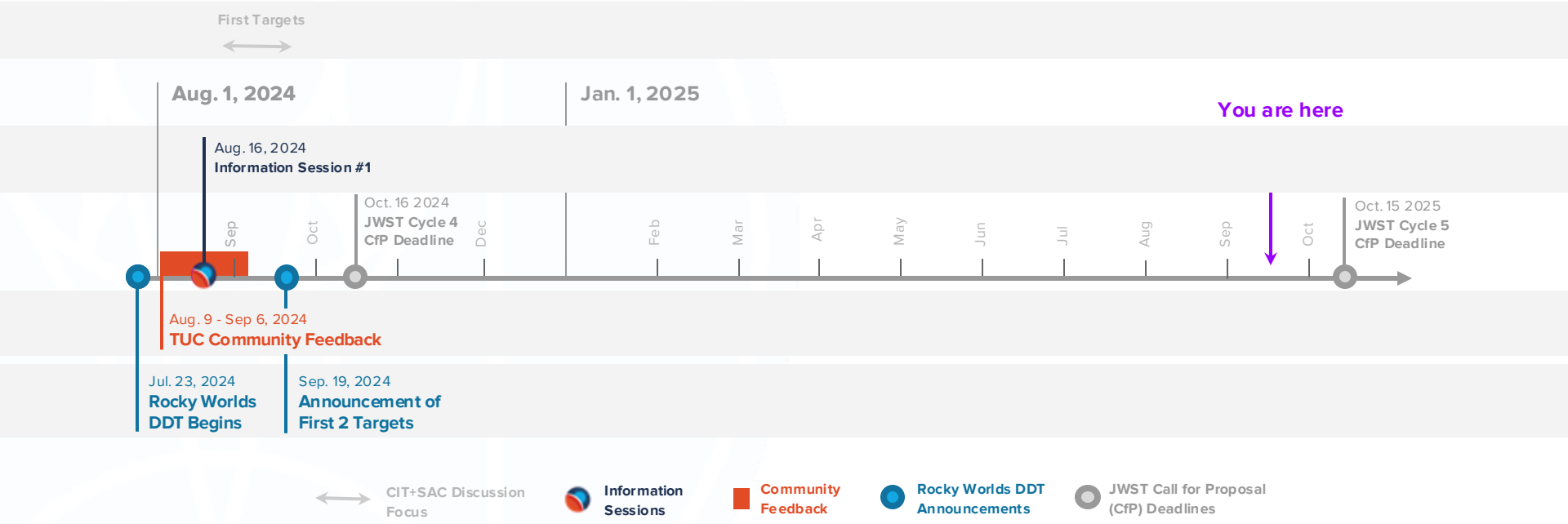


- Evident from the start selecting targets was going to be a **"beggars can't be choosers" regime**.

- Selected targets were the ones that had the **most consensus across the SAC** — easier to schedule, easier to start the DDT process.

Target Selection Process



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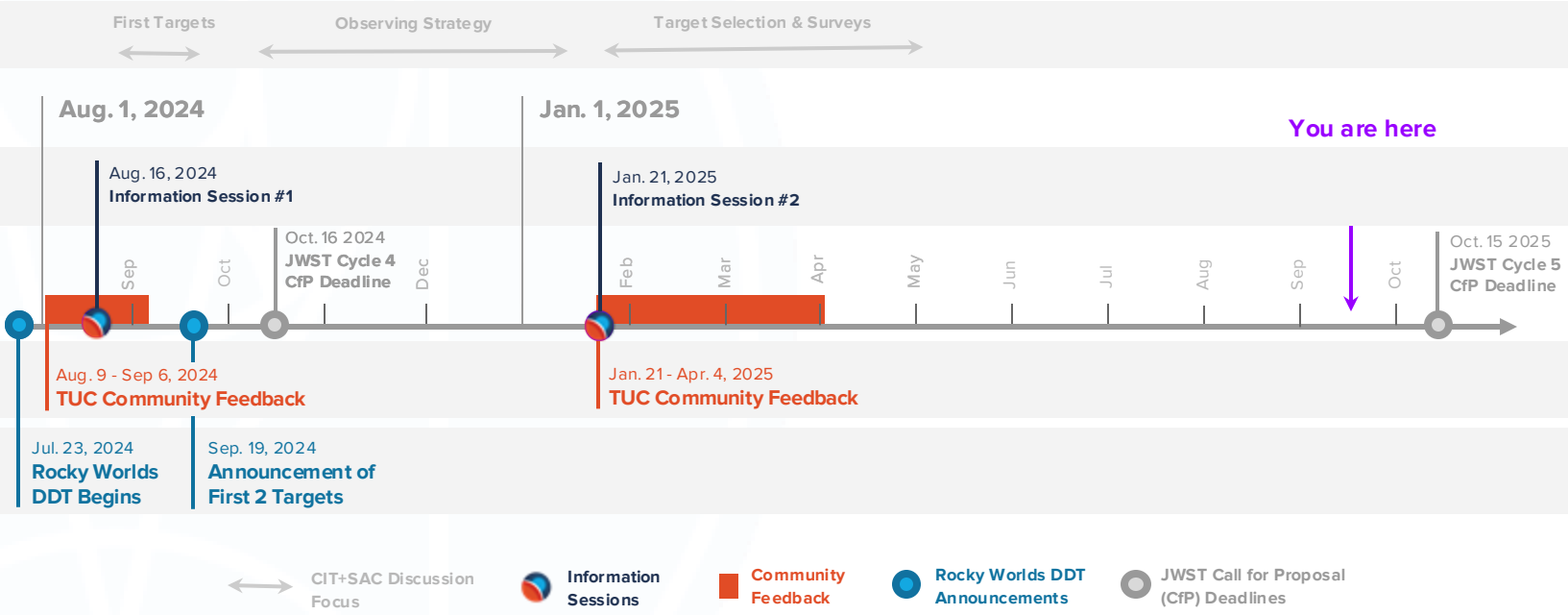

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Metrics for scheduling & target selection: summary of SAC+CIT discussions

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Challenge

Solution/Consensus

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Even "easy" targets (e.g., GJ 3929 b) require ~100 hours for x1.3-1.4 JWST ETC noise levels.

Solution/Consensus

Study/use empirical levels via existing 15 μm (x1.25; Diamond-Lowe, in prep.).

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Metrics for scheduling & target selection: summary of SAC+CIT discussions

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Metric should be bare rock scenario v/s full redistribution.		
Should do a narrow and deep (>4-sigma) survey instead of a shallow (~3-sigma) one.		

Target Selection Process

Metrics for scheduling & target selection: summary of SAC+CIT discussions

Initial thoughts	Challenge	Solution/Consensus
Should be ***very*** conservative on noise levels for 15 μm photometry.	Even "easy" targets (e.g., GJ 3929 b) require ~100 hours for x1.3-1.4 JWST ETC noise levels.	Study/use empirical levels via existing 15 μm (x1.25; Diamond-Lowe, in prep.).
Metric should be bare rock scenario v/s full redistribution.	"Easy" targets (e.g., GJ 3929 b) require ~50-70 hours.	
Should do a narrow and deep (>4-sigma) survey instead of a shallow (~3-sigma) one.	This would mean 3-4 targets. Also, might not be optimal for finding patterns like the CS (e.g., Ih+2025).	

Target Selection Process

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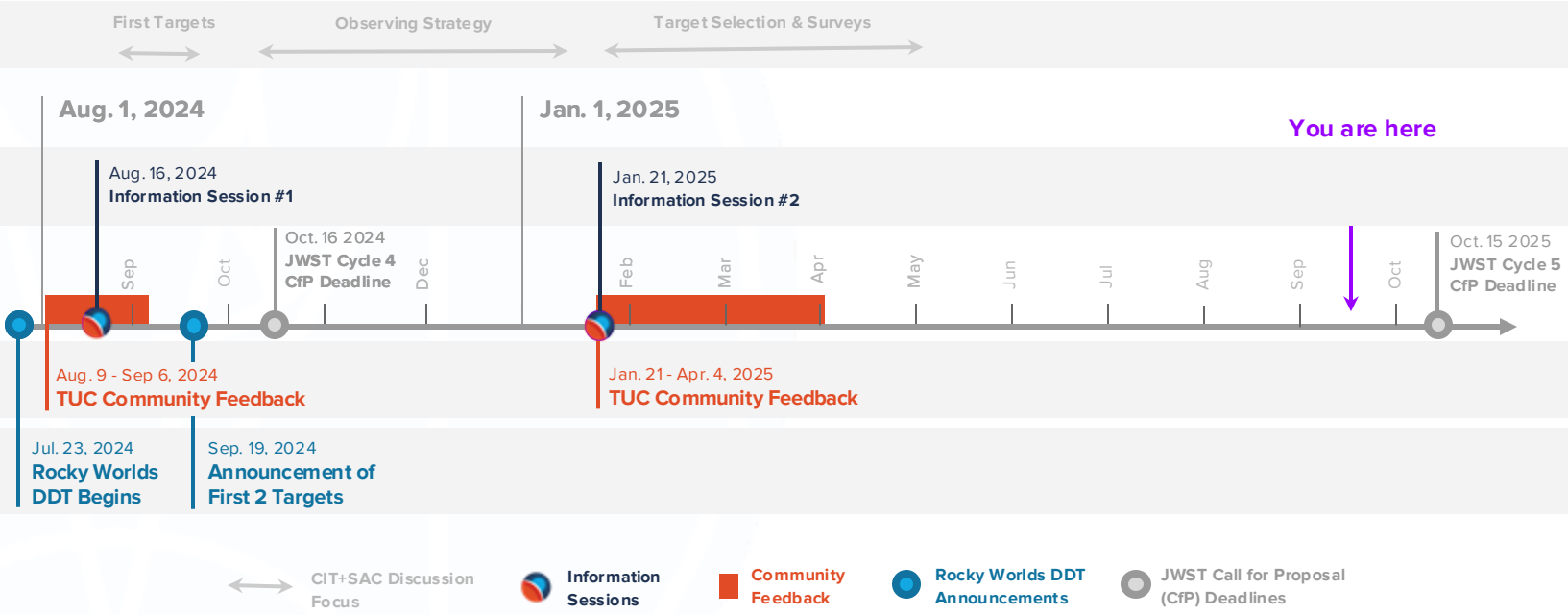
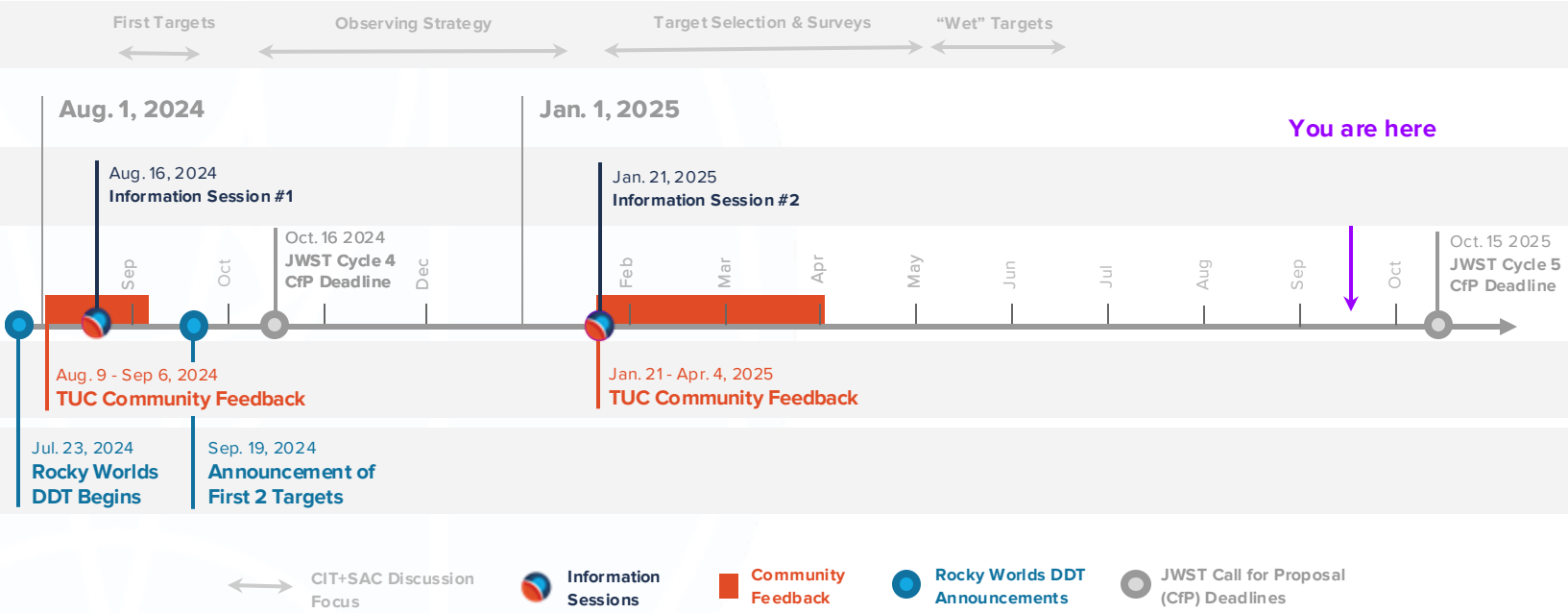
Metric should be bare rock scenario v/s full redistribution.	"Easy" targets (e.g., GJ 3929 b) require ~50-70 hours.	Metric should be bare scenario v/s CO_2-dominated.
Should do a narrow and deep (>4-sigma) survey instead of a shallow (~3-sigma) one.	This would mean 3-4 targets. Also, might not be optimal for finding patterns like the CS (e.g., Ih+2025).	Let Rocky Worlds DDT be a wide and shallow (3-sigma) survey. Community can push further!

Target Selection Process



Target Selection Process



Target Selection Process

“Wet” target selection process

Considered exoplanets on the “atmosphere” side of the Cosmic Shoreline (e.g., **LHS 1140 b**, **TOI-198 b**) ***and*** also planets with Teq < 450 K and radius less than 1.5 R_{earth} (following Redfield+2024; e.g., **LTT 1445 A b**):

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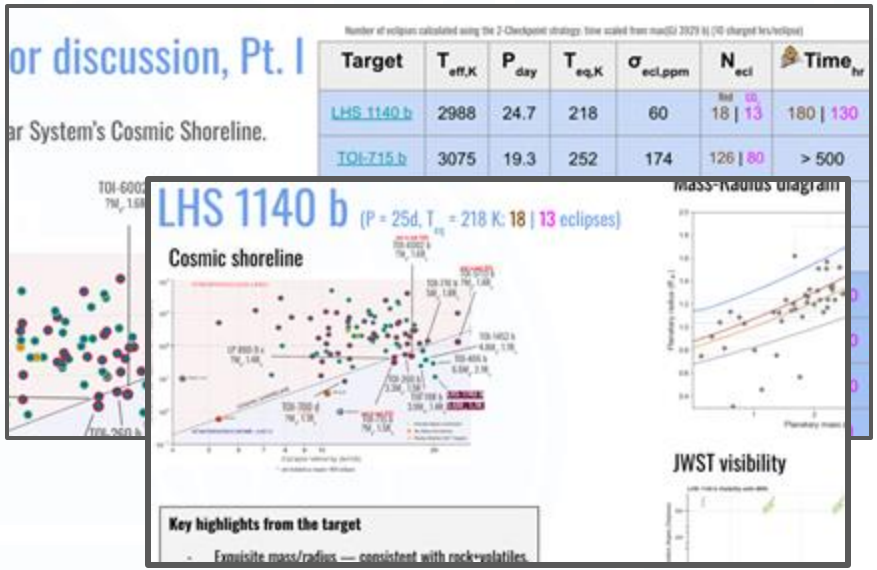
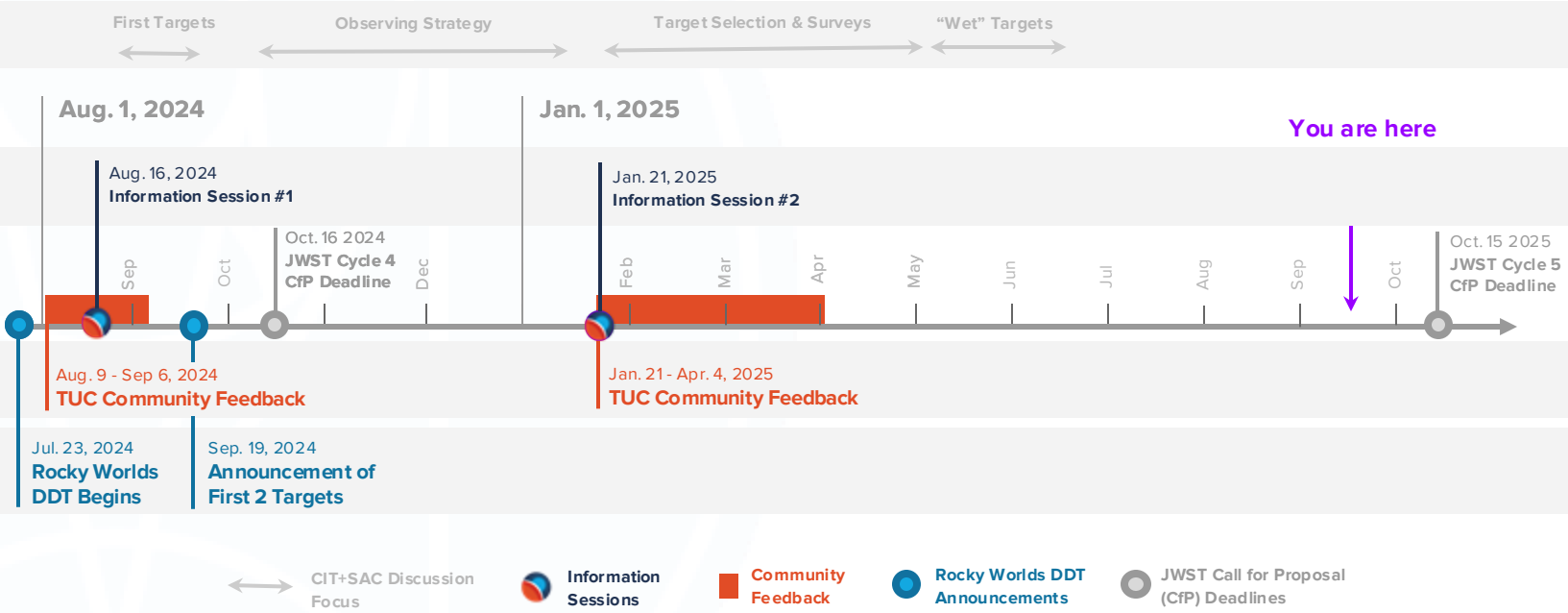


- CIT leads compiled dossier that was studied by the SAC.
- SAC met for a 2-hour bunker discussion session organized by the CIT leads. Clear in the discussions there was a keen interest on **LHS 1140 b** and **LTT 1445 A b**.
- Interest on Gliese 12 b and **TOI-198 b** too – latter selected after community shared data with CIT on both planets, and additional discussion with SAC.

Target Selection Process



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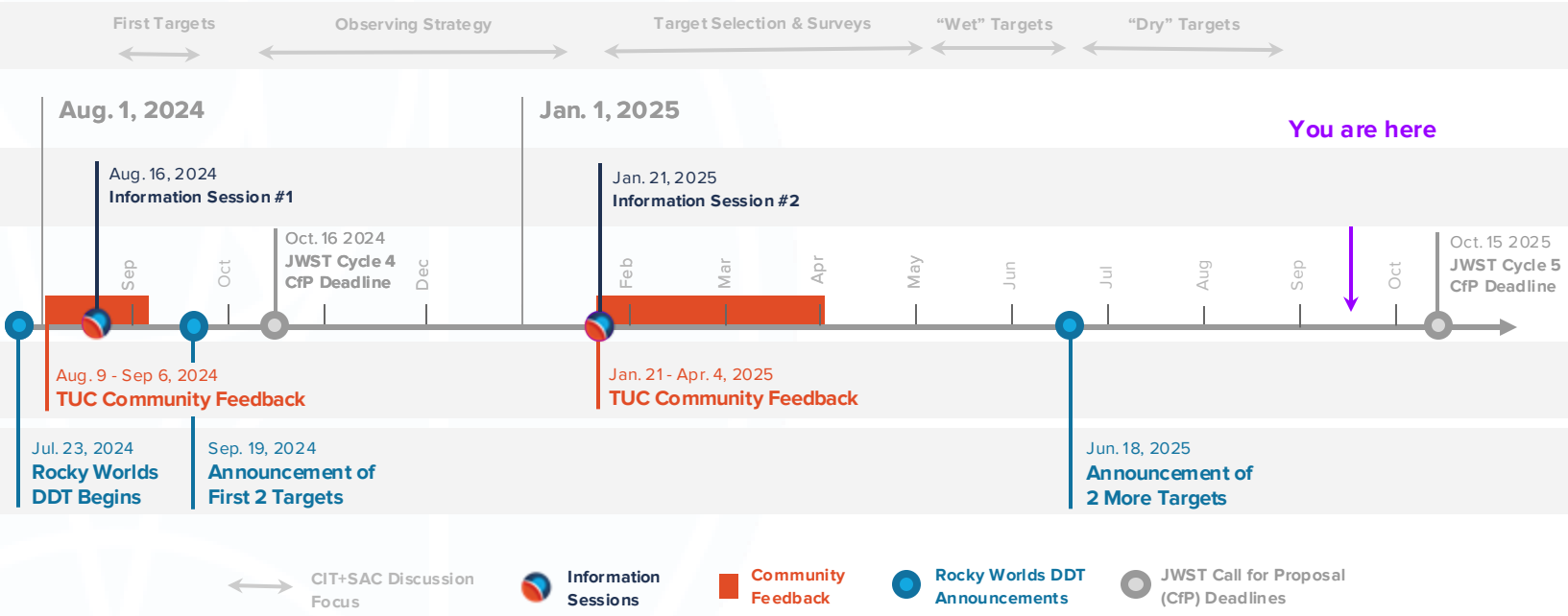
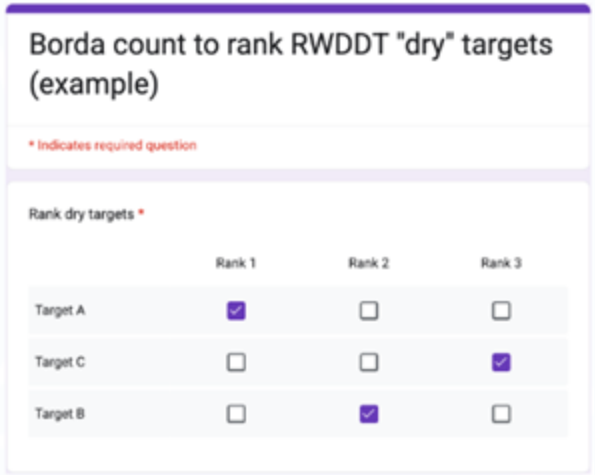


Target Selection Process

“Dry” target selection process

While material was similar (i.e., CIT leads compiled a dossier, etc.), process needed to be more involved due to the larger number of targets:


Borda count to rank RWDDT "dry" targets (example)

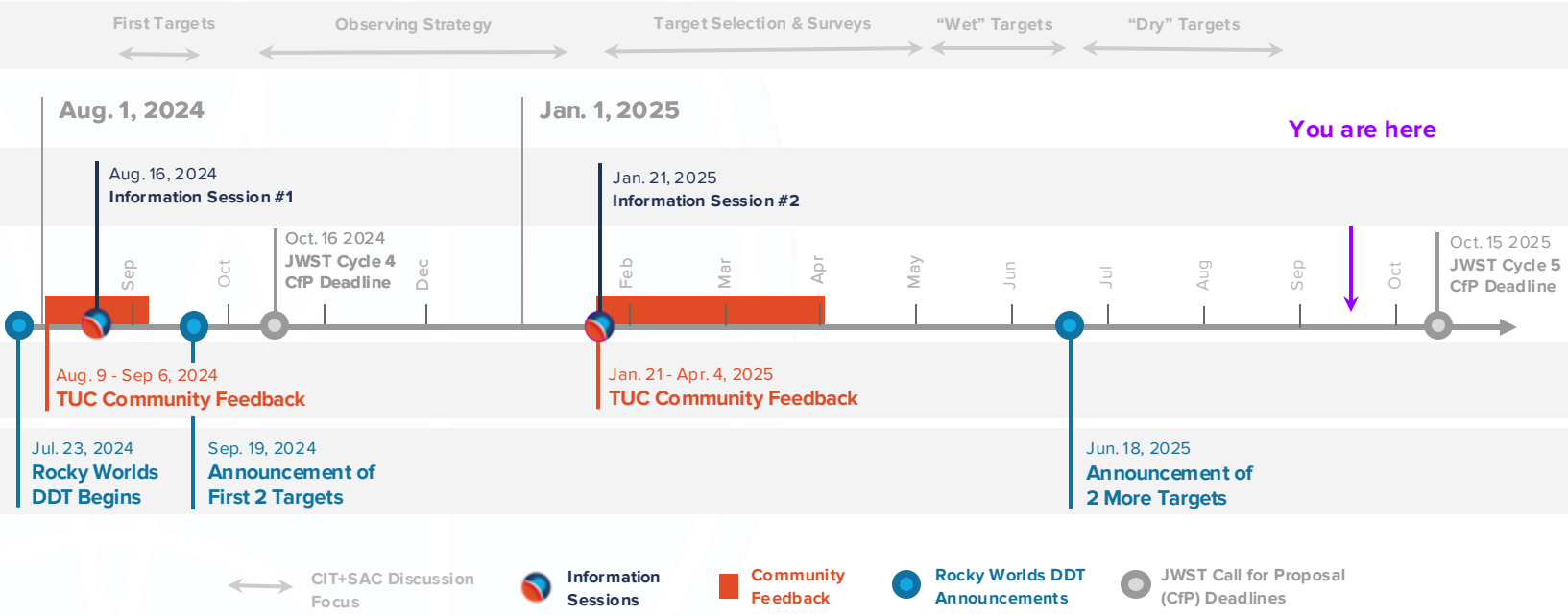
* Indicates required question

Rank dry targets *

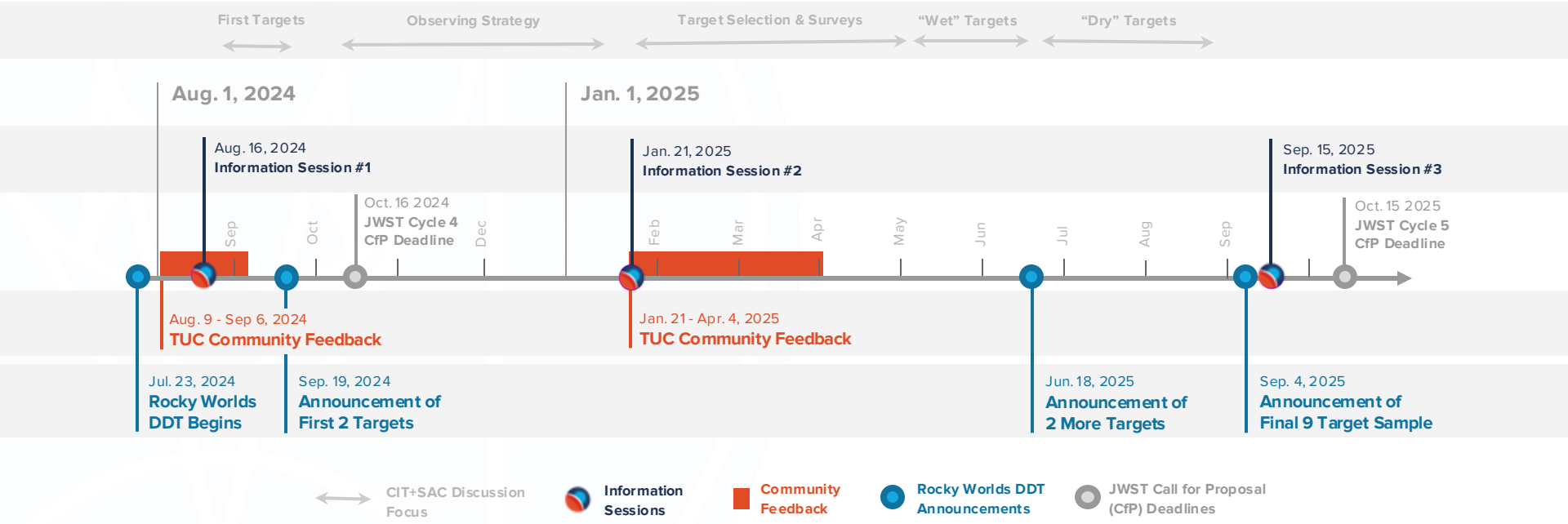
	Rank 1	Rank 2	Rank 3
Target A	☑	☐	☐
Target C	☐	☐	☑
Target B	☐	☑	☐

- CIT leads compiled dossier that was studied by the SAC.
- SAC met for a 1-hour bunker discussion session organized by the CIT leads. No clear targets identified, but clear “clusters” of targets identified by SAC members.
- Targets were decided via a Borda count based on SAC ranking of targets.

Target Selection Process



Target Selection Process



Target Selection Process

Target breakdown

Target	$T_{eff,K}$	P_{day}	$T_{eq,K}$	N_{ecl}
LHS 1140 b	2988	24.7	218	13
TOI-198 b	3650	10.2	368	22
LTT 1445 A b	3340	5.36	430	2
TOI-244 b	3433	7.4	458	8
LTT 1445 A c	3340	5.36	514	4
HD 260655 c	3803	5.7	557	2
TOI-771 b	3201	2.3	571	3
TOI-406 c	3392	3.3	572	7
GJ 3929 b	3384	2.62	584	4

- This is the **number of eclipses we've calculated** are needed to **differentiate bare rock from CO_2-dominated** atmospheres according to our calculations.
- **This is not the final number of eclipses** that will get observed per target. Was estimated with many caveats. Might change depending on work within the CIT.
- **We'll communicate changes to these numbers with the community as work begins at the CIT on new targets,** and we schedule observations.