# ROCKY WORLDS

Hannah Diamond-Lowe (STScI) | CIT Deputy Lead
On behalf of the Core Implementation Team at STScI

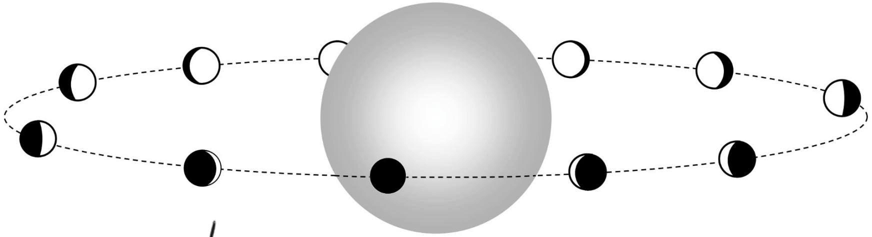
STScI | SPACE TELESCOPE SCIENCE INSTITUTE

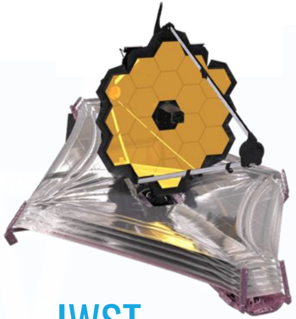
rockyworlds.stsci.edu
16 June 2026

# Director's Discretionary Time program:

ROCKY WORLDS

Main aim: look for **evidence of atmospheres** in rocky exoplanets orbiting nearby, "quiet" **M dwarfs**.





+

**JWST**
To characterize the rocky planets
**500 hours**

**HST**
To characterize the host stars
**240 orbits**

Image credit: Winn+2010

How this program was selected:
Redfield, et al., 2024, [arXiv:2404.02932](arXiv:2404.02932)

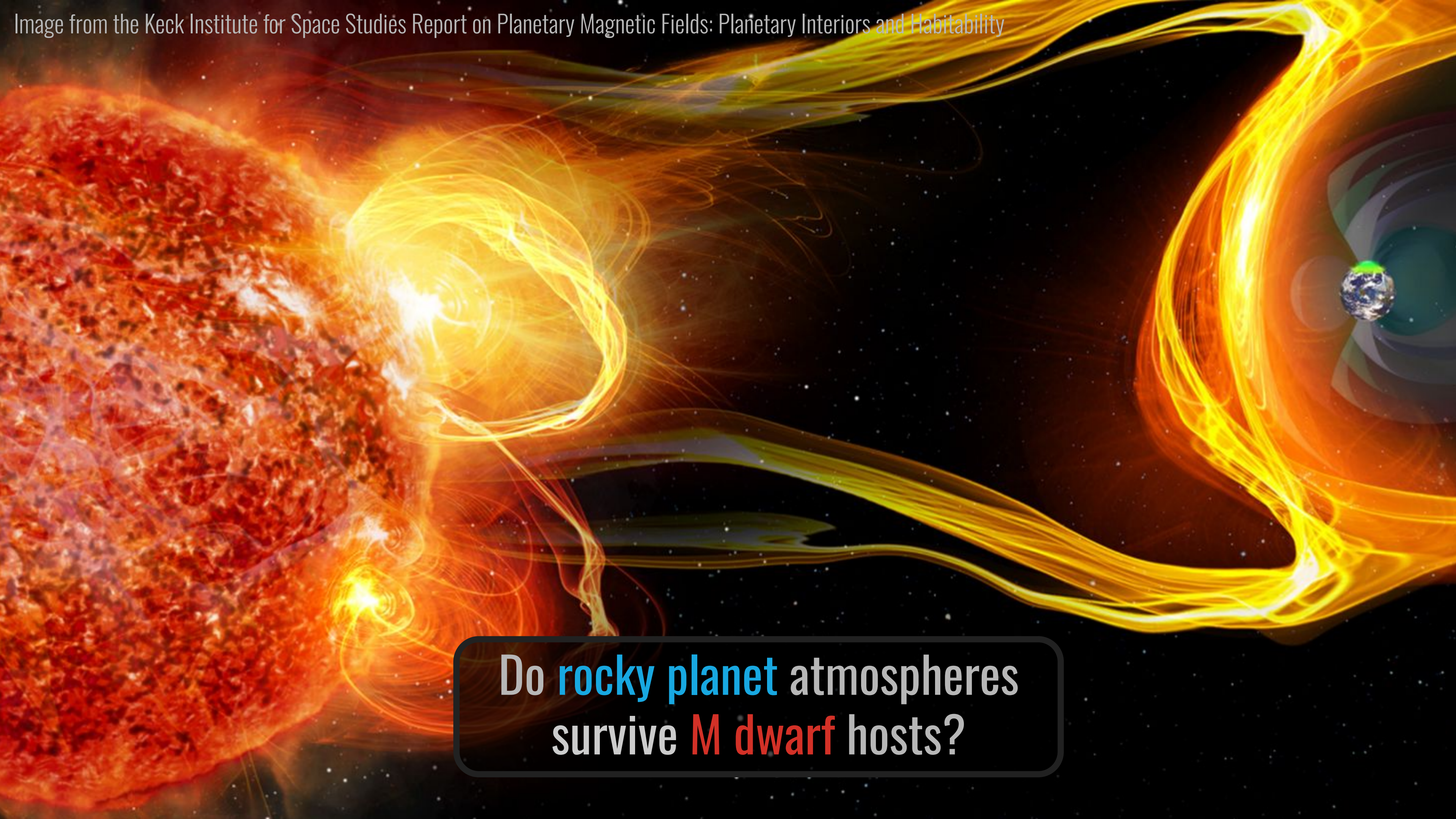
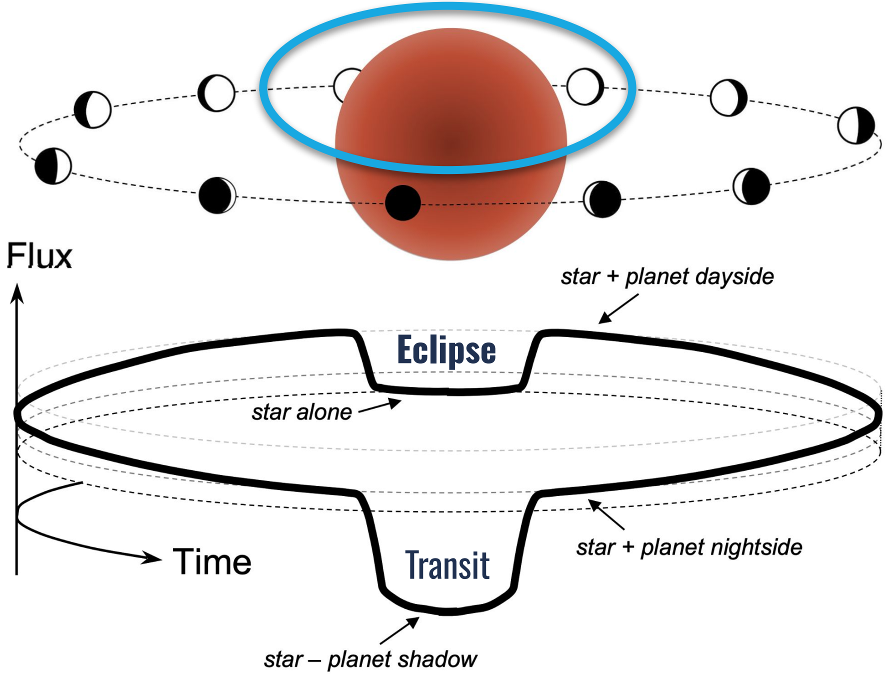


Image from the Keck Institute for Space Studies Report on Planetary Magnetic Fields: Planetary Interiors and Habitability
Do rocky planet atmospheres survive M dwarf hosts?

# Observing strategy: **Secondary eclipses**

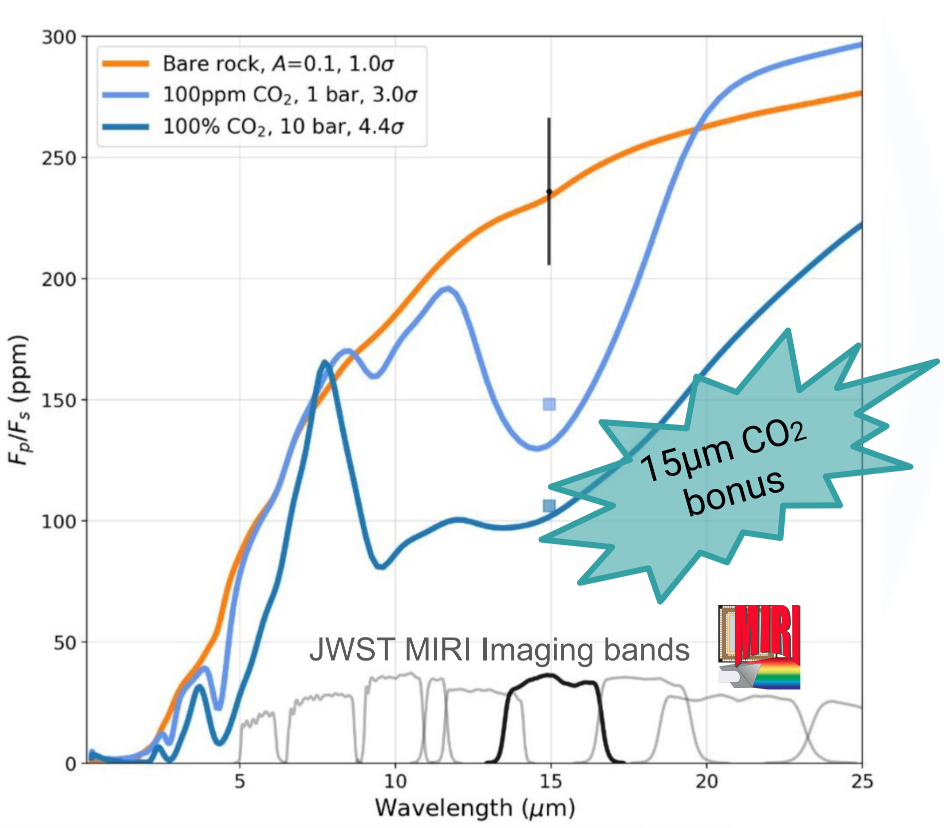
Look at rocky planets **transiting** nearby M dwarfs




* Assume the rocky planet is tidally locked in 1:1 synchronous rotation

Image credit: Winn+2010

# Observing strategy: **Secondary eclipses, thermal emission**

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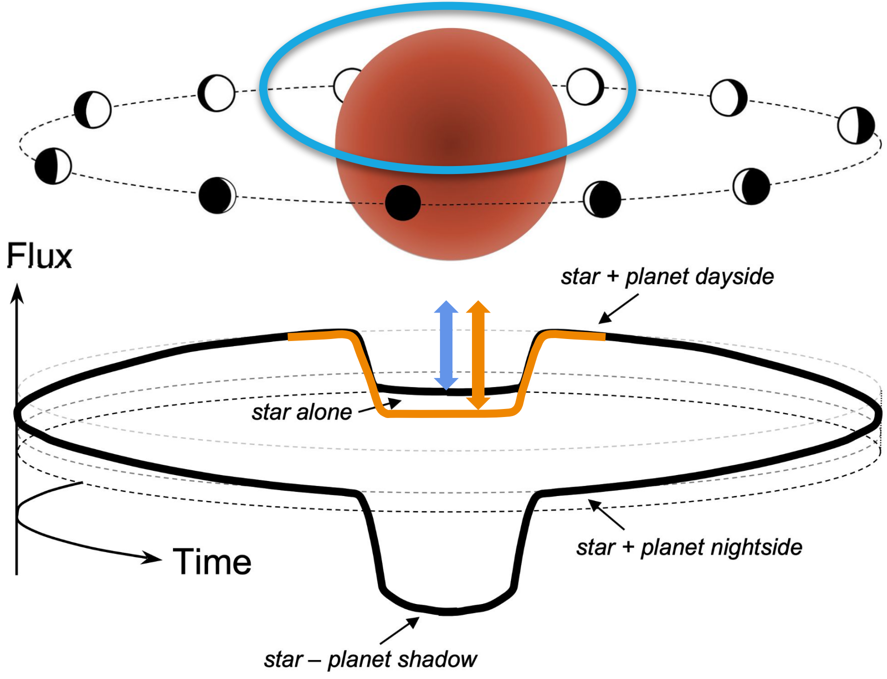
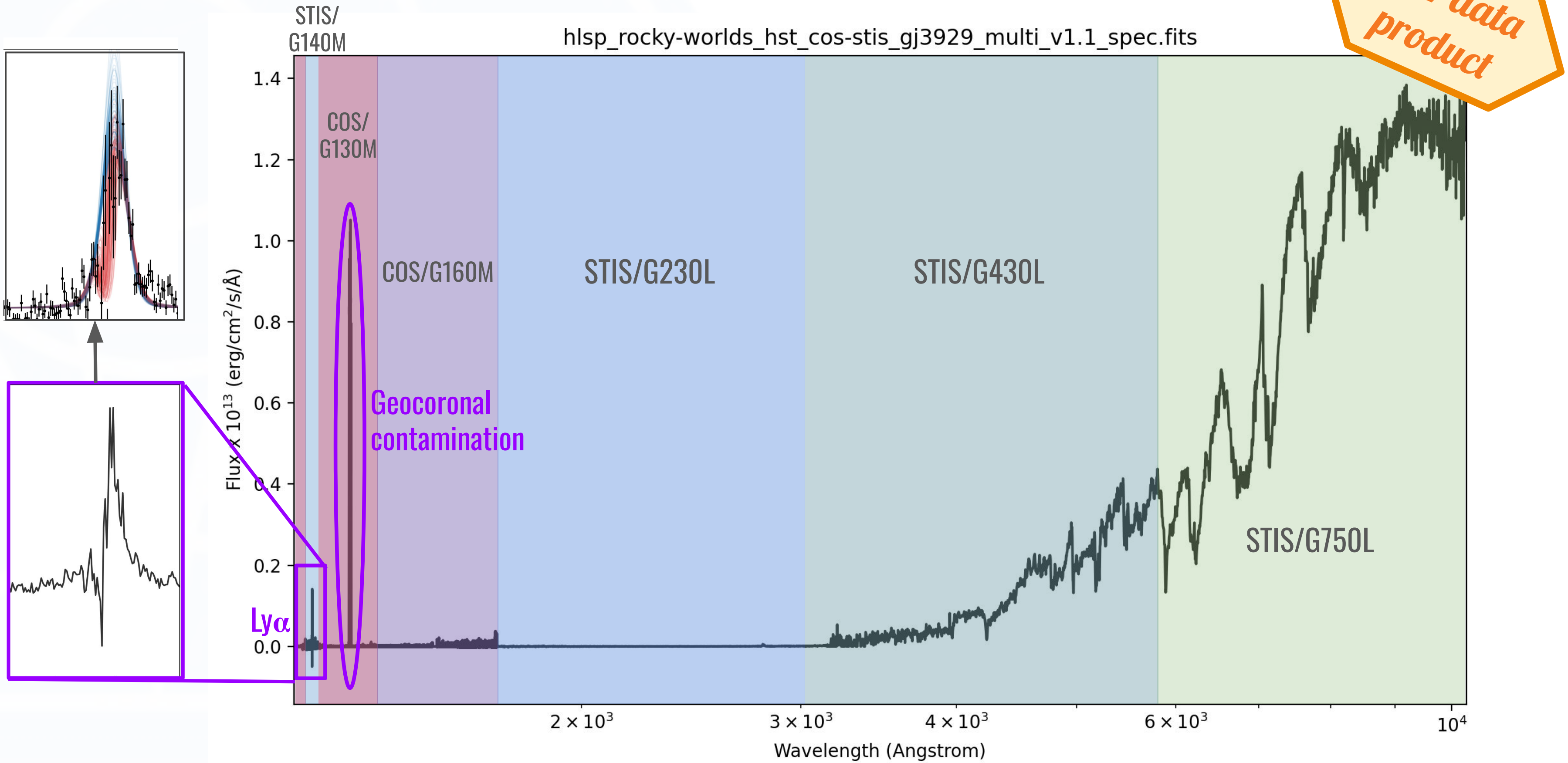
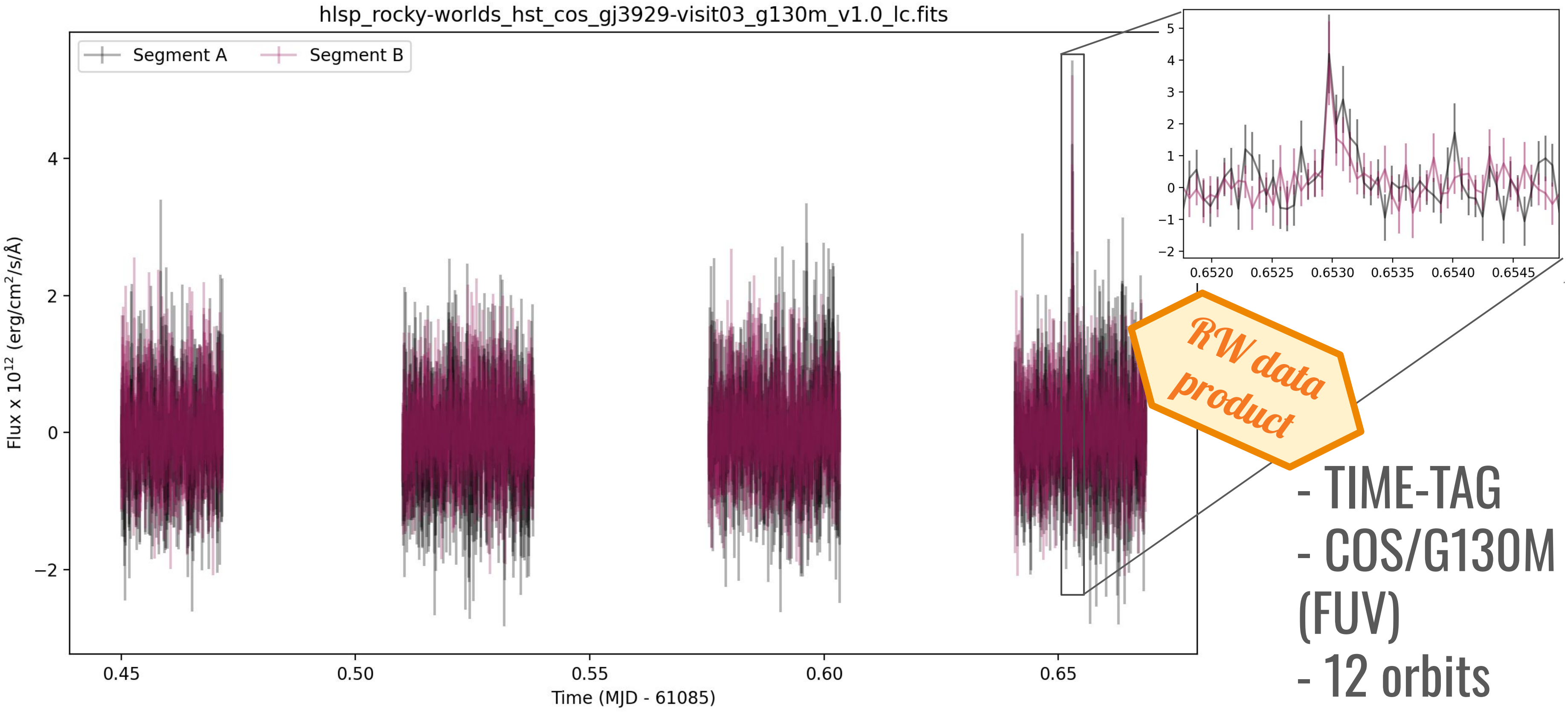



Image credit: Winn+2010

# Observing strategy: FUV–optical spectra



# Observing strategy: FUV–optical spectra, flare monitoring



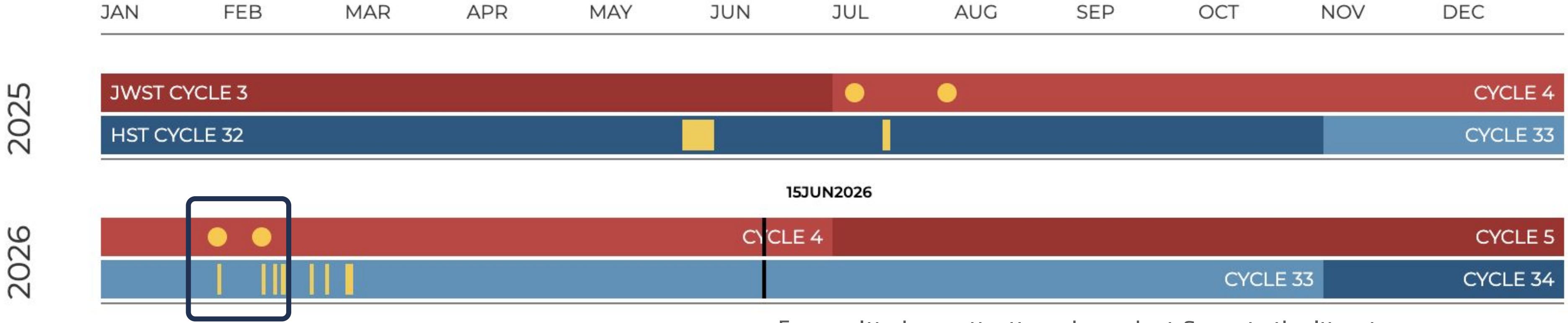

- TIME-TAG
- COS/G130M (FUV)
- 12 orbits

# Flares from the FUV to MIR

# Observing strategy: **simultaneous HST FUV + JWST MIR**

## Aim: catch a flare in FUV and at 15 μm — explore the chromatic and temporal nature of flares in “quiet” M dwarfs

Status graphic for GJ 3929 (b) — available on rockyworlds.stsci.edu

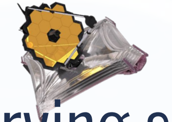



Few multi-chromatic, time-dependent flares in the literature

MacGregor, et al., (2018) — Proxima Cen, UV to millimeter

Kowalski, Osten, Notsu, et al., (2025) — CR Dra, NUV (A, B, Mg II)

Howard, et al., (2023, 2025) — TRAPPIST-1, NIR (spec bins)

 + 

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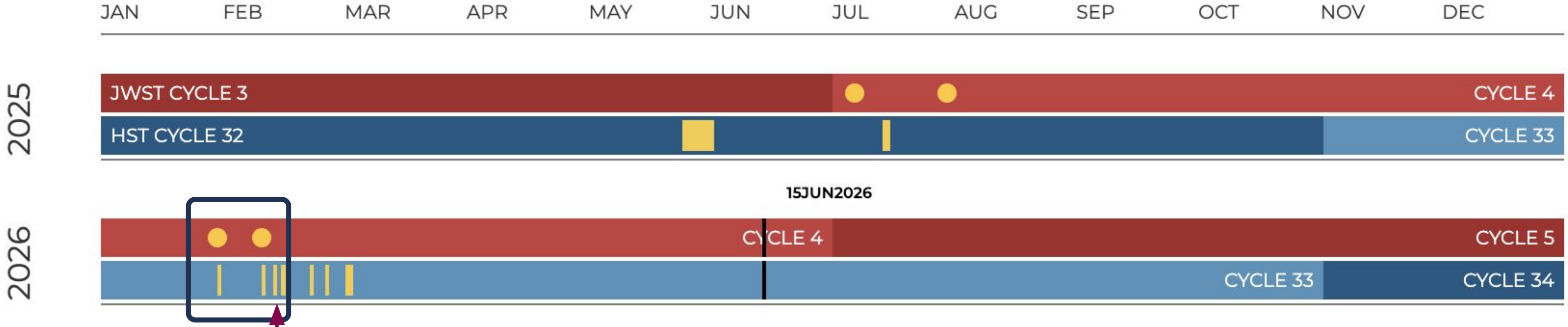


Visit with flare, shown a few slides ago

*So far, simultaneous observations have not had flares

# Looking for ($CO_2$) atmospheres

# Sample: M dwarf rocky planets and the Cosmic Shoreline

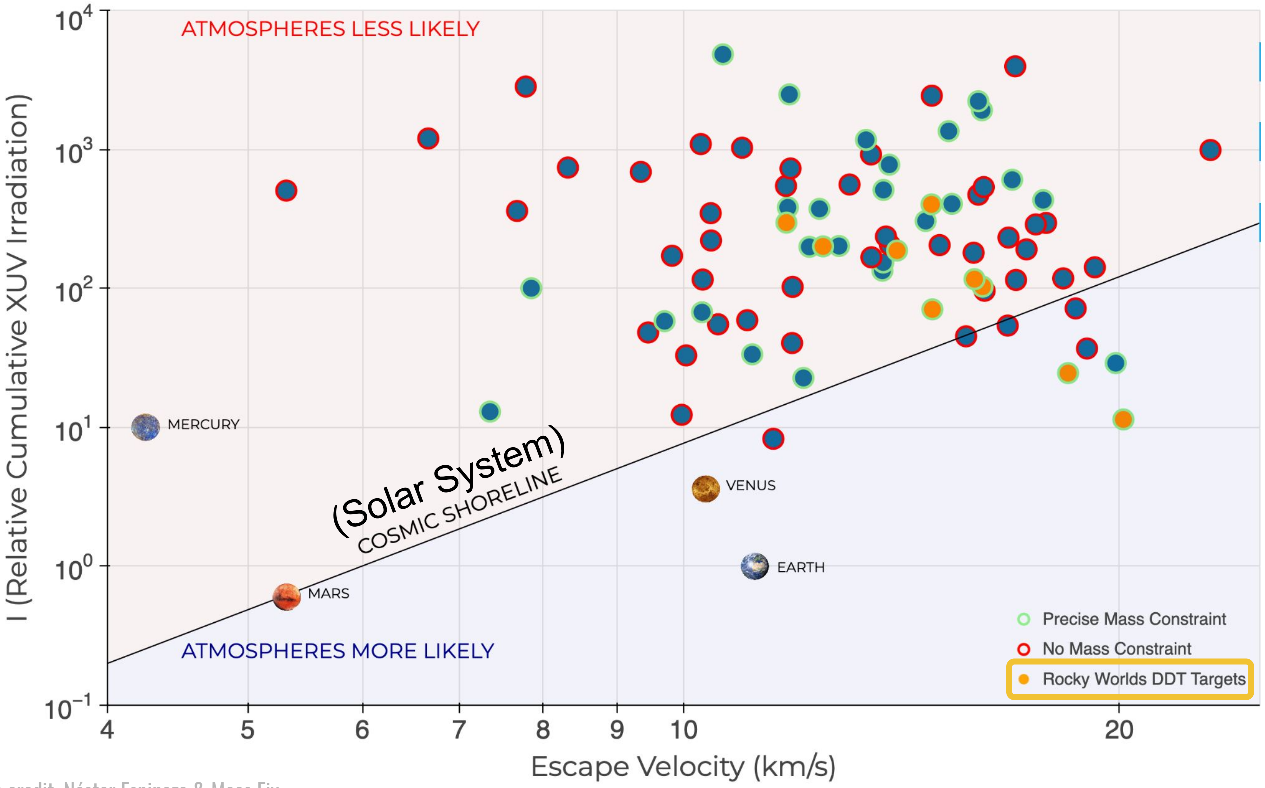


Image credit: Néstor Espinoza & Mees Fix

Zahnle & Catling (2017)
updates by:
**Pass**, et al., (2025)
**Ji**, et al., (2025)
**Berta-Thompson** (2025)

## Published results

**GJ 3929 b** (Xue, et al., 2025; Connors, et al., (2026)

**So far no** (definitive) **evidence for >1-10 bar $CO_2$-rich atmospheres**

# Sample: M dwarf rocky planets and the Cosmic Shoreline

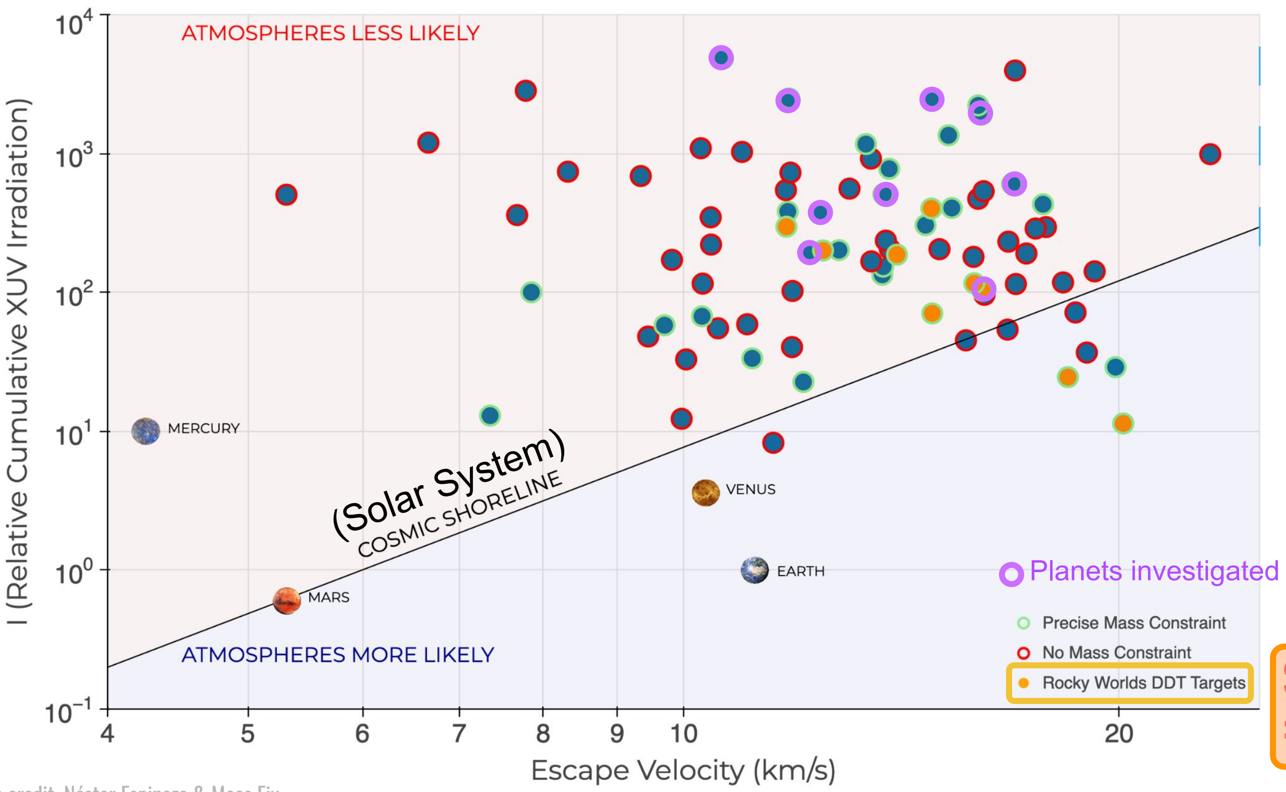


Image credit: Néstor Espinoza & Mees Fix

**LHS 3844 b** (Kreidberg, et al., 2019)
**GJ 1252 b** (Crossfield, et al., 2022)
**TRAPPIST-1 b** (Greene, et al., 2023, Ih, et al., 2023, Gillon, et al., 2025)
**TRAPPIST-1 c** (Zieba, et al., 2023, Ducrot, et al., 2024, Gillon et al., 2025, Maurel, et al., 2025)
**GJ 367 b** (Zhang, et al., 2024)
**GJ 1132 b** (Xue, et al., 2024)
**GJ 486 b** (Weiner Mansfield, et al., 2024)
**LTT 1445 A b** (Wachiraphan, et al., 2025)
**TOI-1685 b** (Luque, et al., 2025)

**So far no** (definitive) **evidence for >1-10 bar $CO_2$-rich atmospheres**

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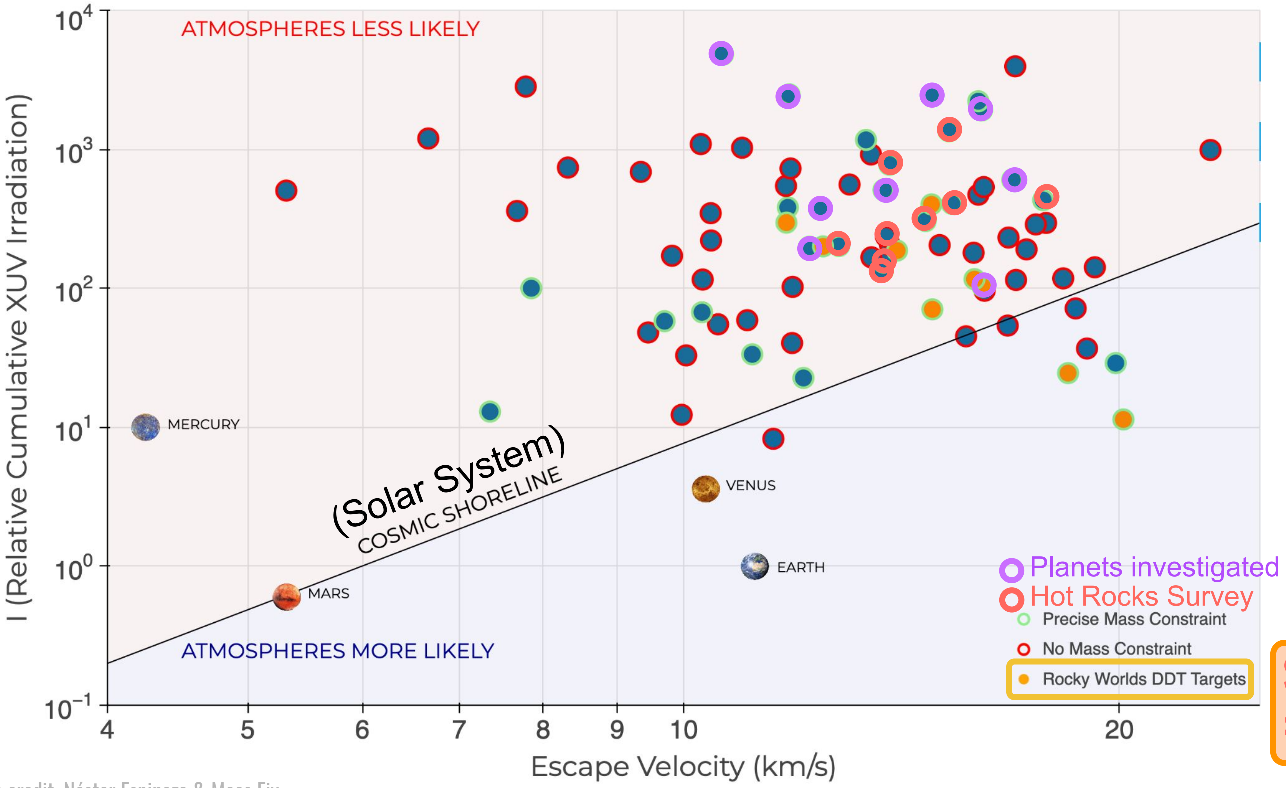



hot-rocks.vercel.app

**Hot Rocks Survey I: LHS 1478 b**
(August, et al. 2025)

**Hot Rocks Survey II: TOI-1468 b**
(Meier Valdés, et al., 2025)

**Hot Rocks Survey III: LHS 1140 c**
(Fortune, et al., 2025)

**Hot Rocks Survey IV: LTT 3780 b**
(Allen, et al., 2025)

**Hot Rocks Survey V: GJ 3473 b**
(Holmberg, et al., 2026)

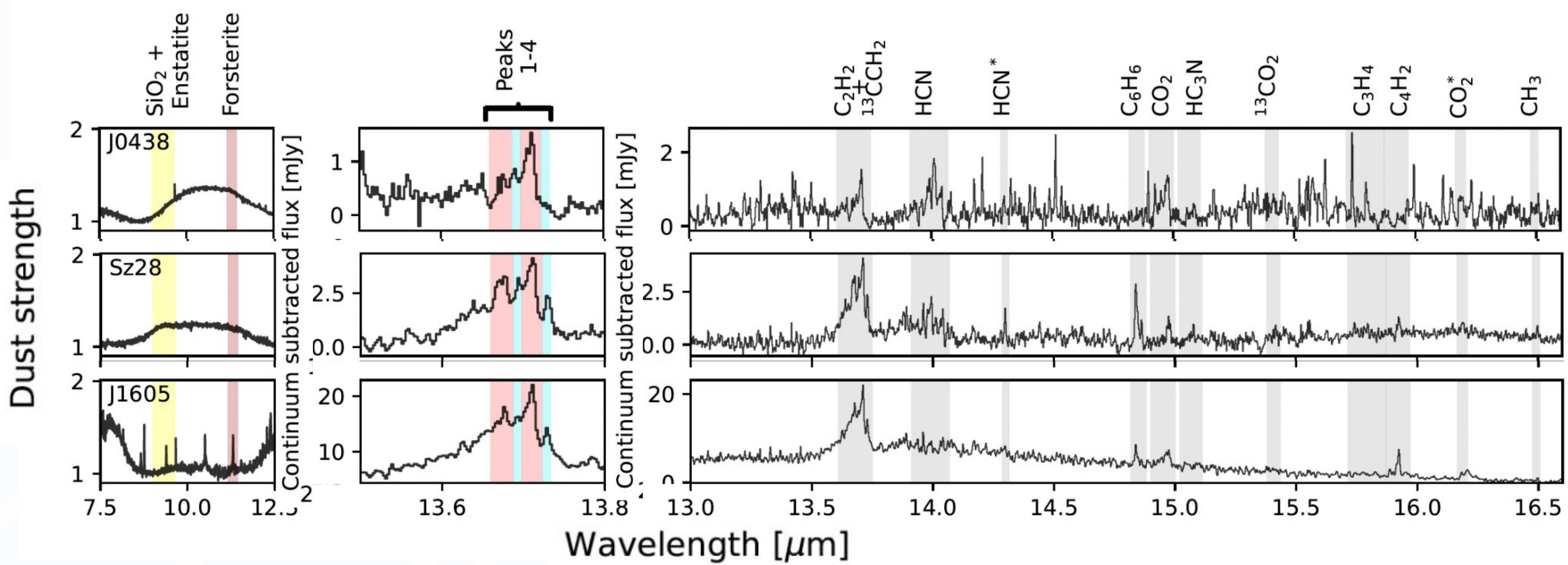
**Hot Rocks Survey VI, VII, VIII, IX, X**
(in prep)

**So far no (definitive) evidence for >1-10 bar $CO_2$-rich atmospheres**

Image credit: Néstor Espinoza & Mees Fix

# Why haven't we detected a $CO_2$ atmosphere?

## $CO_2$ detected in the inner disks of low-mass stars (e.g., MINDS program)




Arabhavi, MINDS Collaboration (2025)


Image from the Keck Institute for Space Studies Report on Planetary Magnetic Fields: Planetary Interiors and Habitability

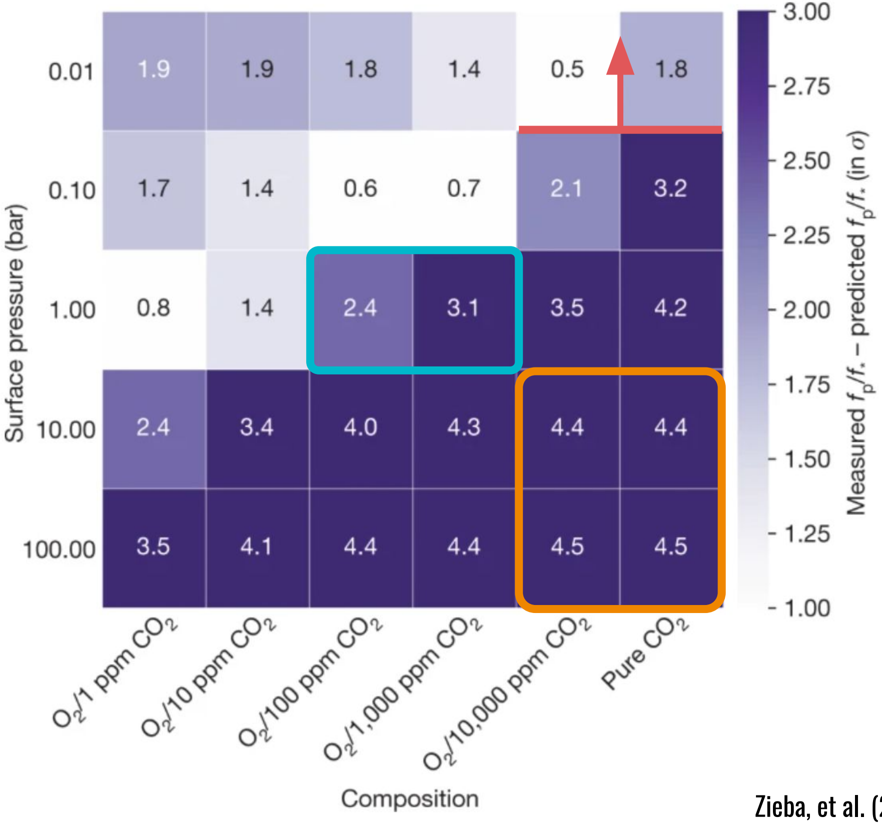
# What kinds of $CO_2$ atmospheres are we sensitive to?

Atmosphere: 96% $CO_2$, 3.5% $N_2$, 0.5% other
$T_{eq}$ = 328 K
$T_s$ = 740 K
$P_s$ = 92 bar

Atmosphere: 78% $N_2$, 21% $O_2$, 1% other
$T_{eq}$ = 255 K
$T_s$ = 289 K
$P_s$ = 1 bar

Atmosphere: 95% $CO_2$, 3% $N_2$, 2% Ar
$T_{eq}$ = 226 K
$T_{s,avg}$ = 218 K
$P_s$ = 0.006 bar

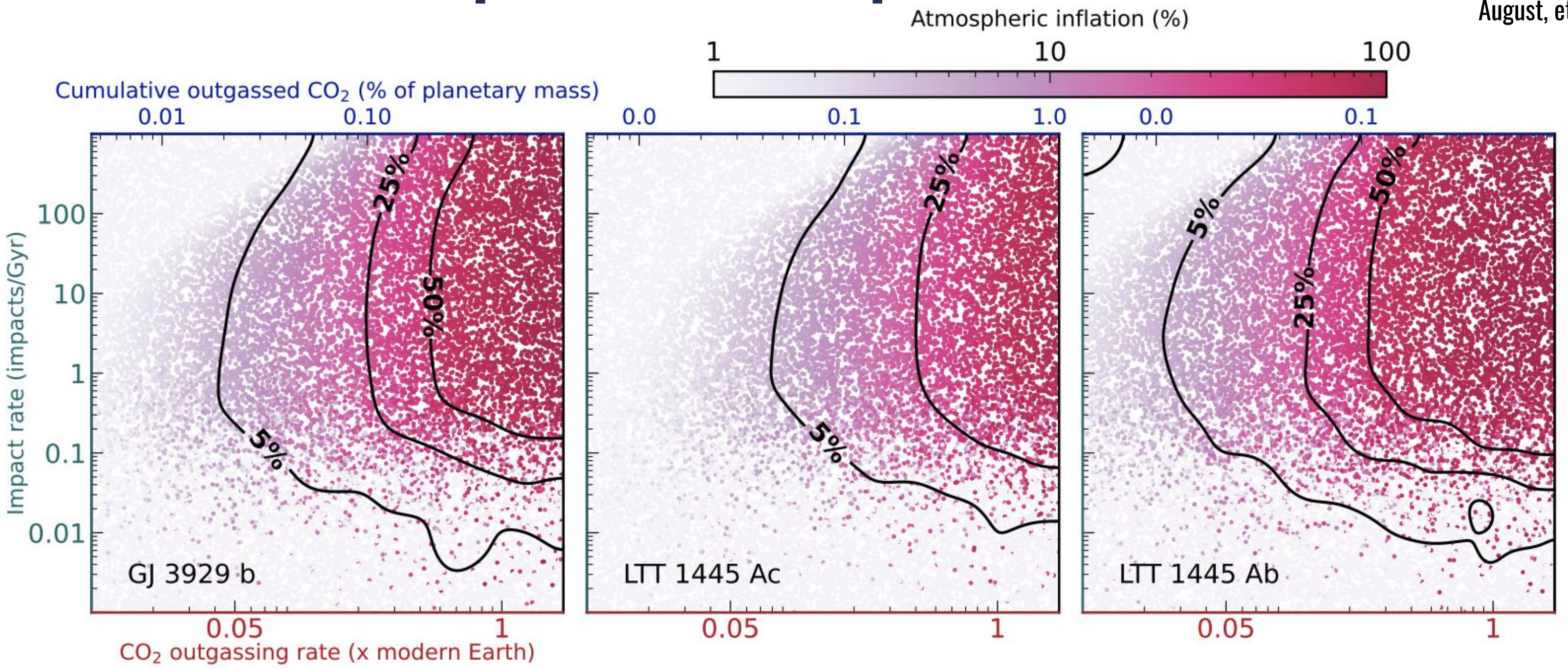
TRAPPIST-1 c model atmospheres compared to data




Zieba, et al. (2023)

# Maybe $CO_2$ atmospheres are episodic?

August, et al., (2026)




“Assuming current Earth outgassing and impact rates, GJ 3929 b, LTT 1445 Ac, and LTT 1445 Ab could spend around 65%, 45%, and 75% of their lifetime, respectively, with a transient CO2 atmosphere. For outgassing rates 10 times lower, these fractions are around 10%, 5%, and 20%, respectively.”

# ROCKY WORLDS

# and you

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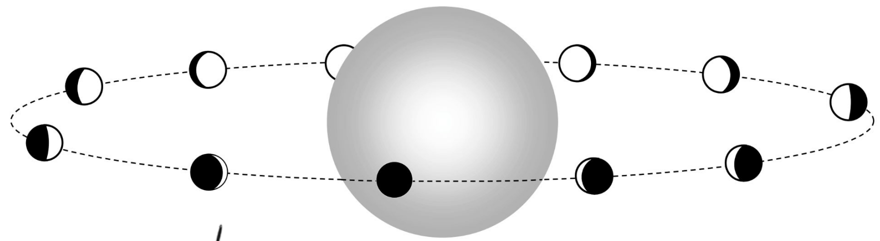
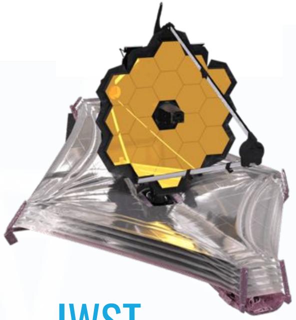




**JWST**

To characterize the rocky planets

**500 hours**

**HST**

To characterize the host stars

**240 orbits**

Image credit: Winn+2010

## Core Implementation Team (CIT)

**At STScI**: scheduling, data products

## Science Advisory Council (SAC)

12 community members, advise the CIT

## Community (you)

Uses the data for original research; provides feedback to CIT & SAC

# How to get involved in ROCKY WORLDS

**MAST** | data products

**Website** | information nexus

**Mailing list**

**Data Challenge** | JWST

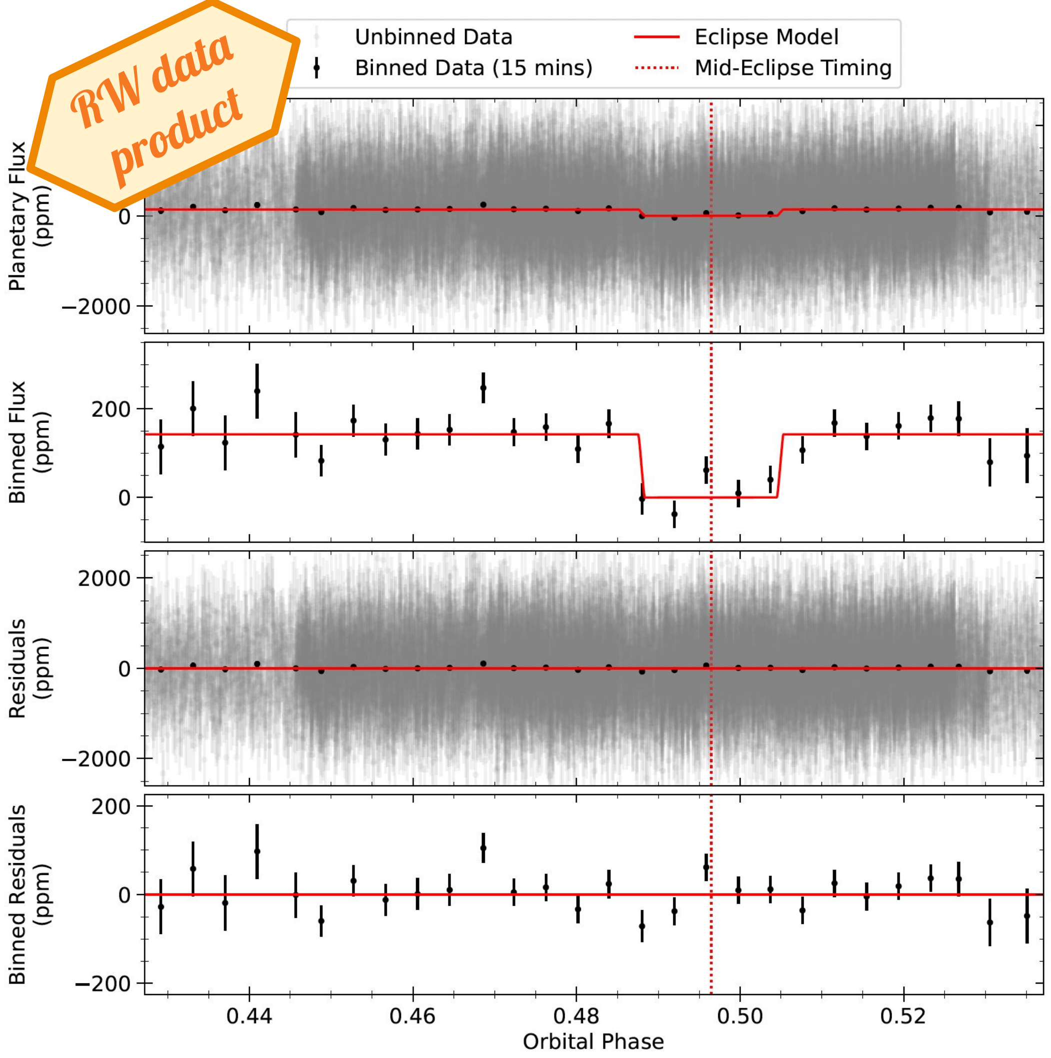
**Workshop**

16–18
NOV
2026

**Connect** | Community

# Bonus slides

# Products: Time series



# Observing strategy: **Secondary eclipses, thermal emission**


**Moon** & **Earth** at 0.6 μm (optical light)

* Assume the rocky planet is tidally locked in 1:1 synchronous rotation

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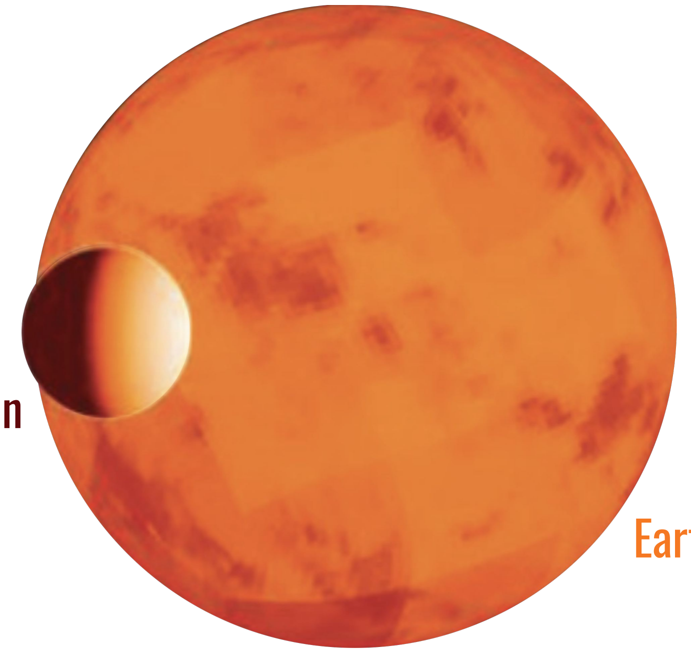
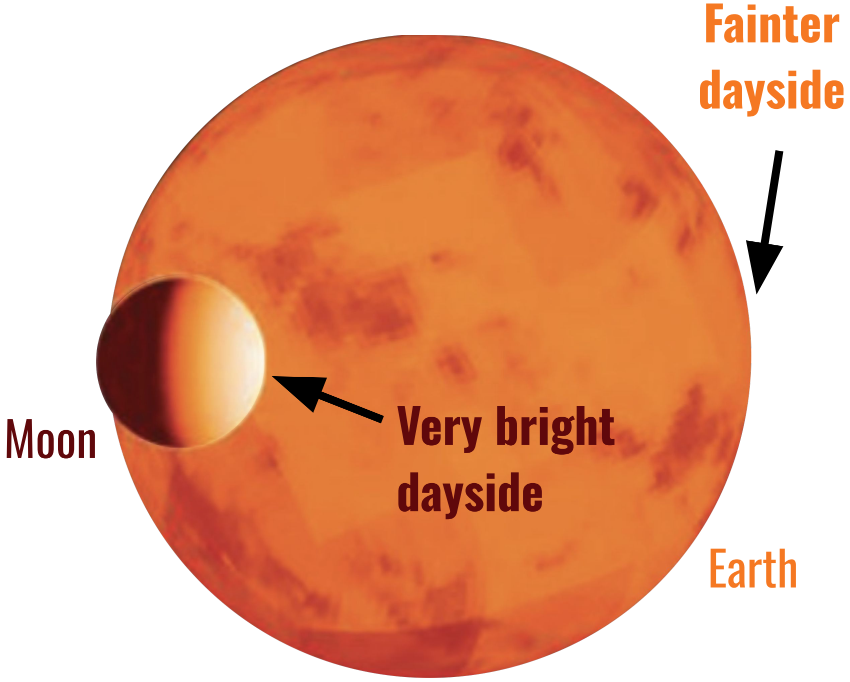



**Moon** & **Earth** at 10 μm (thermal emission)

(Robinson+2011)

* Assume the rocky planet is tidally locked in 1:1 synchronous rotation

# Observing strategy: Secondary eclipses, thermal emission




**Moon** & **Earth** at 10 μm (thermal emission)

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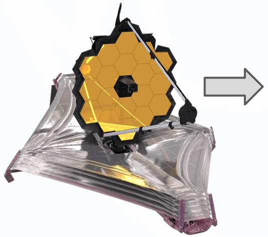
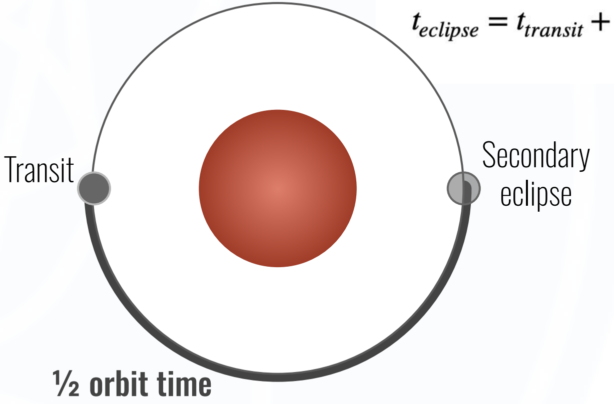
# Scheduling Rocky Worlds targets

## It's harder than it sounds!



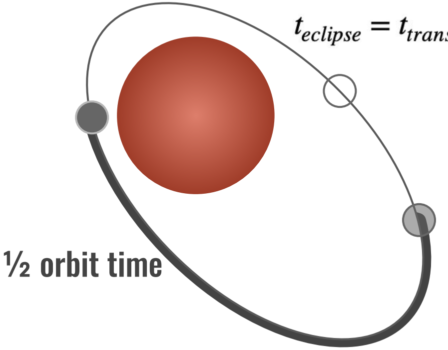
### Circular orbit




$$t_{eclipse} = t_{transit} + \frac{P}{2}$$

✔

### Eccentric orbit




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

✘

**Need to calculate exact time for JWST to look**

# Scheduling Rocky Worlds targets

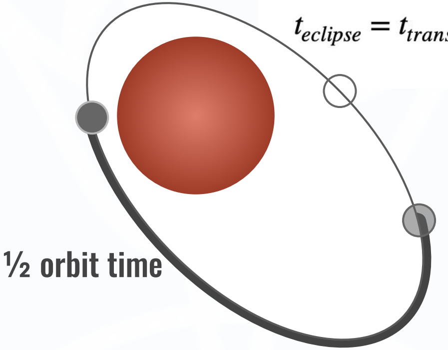
## It's harder than it says sounds!

Eccentric orbit

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

Well constrained from transit observations

$e$ and $\omega$ are somewhat constrained by RVs and highly correlated

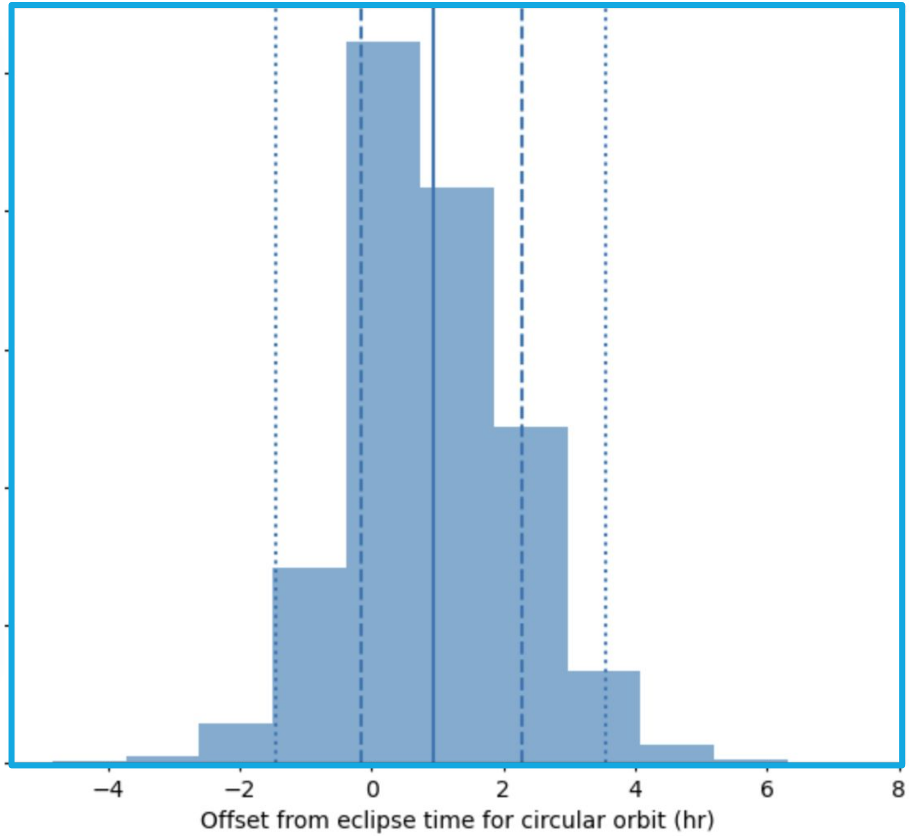


# Scheduling Rocky Worlds targets

## 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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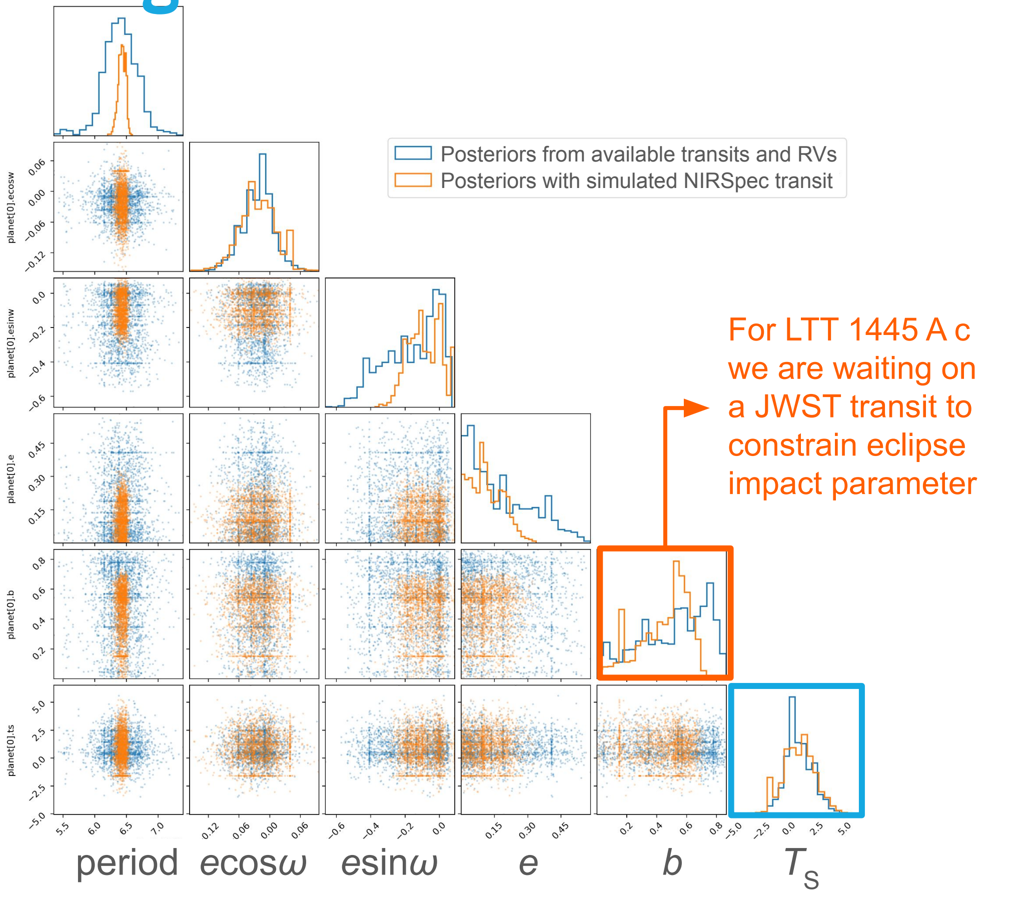
Adding a JWST/NIRSpec transit does not really help (orange posteriors).



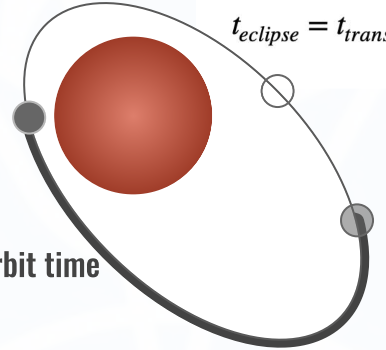
# Scheduling Rocky Worlds targets

## 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 $\omega$ are somewhat constrained by RVs and highly correlated

½ orbit time

CIT Scheduling Team performs global fits using all available

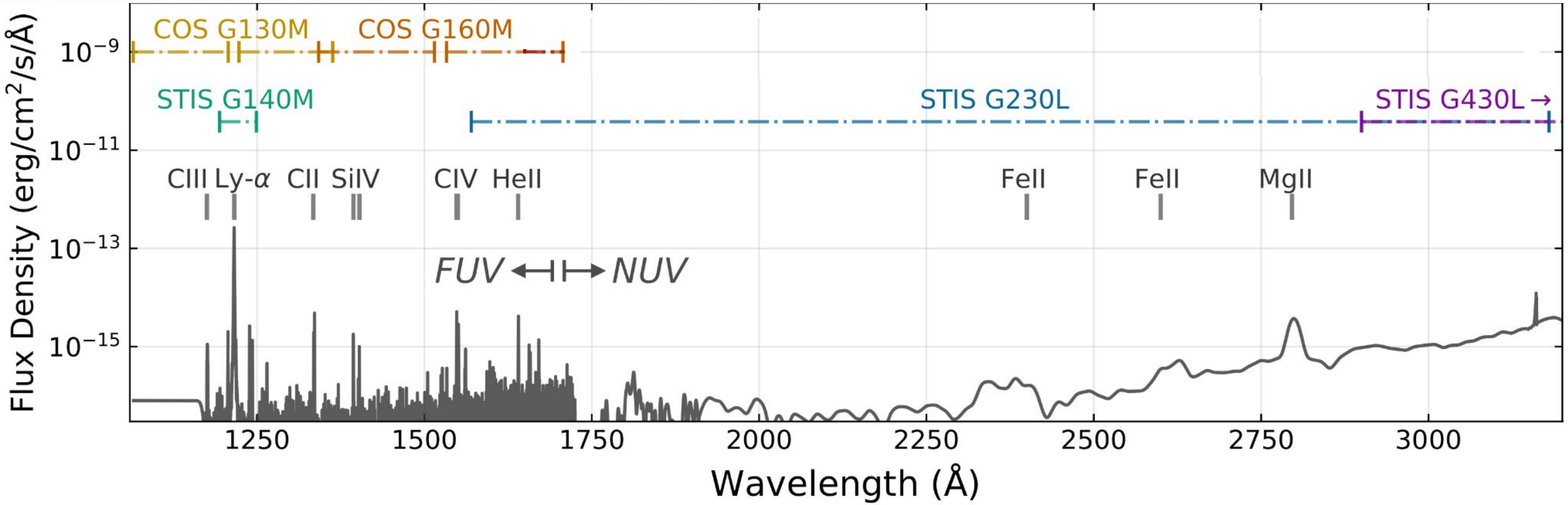
- Radial velocities*
- Transit lightcurves*

to constrain orbital parameters.

***High-precision data** is the most effective.*

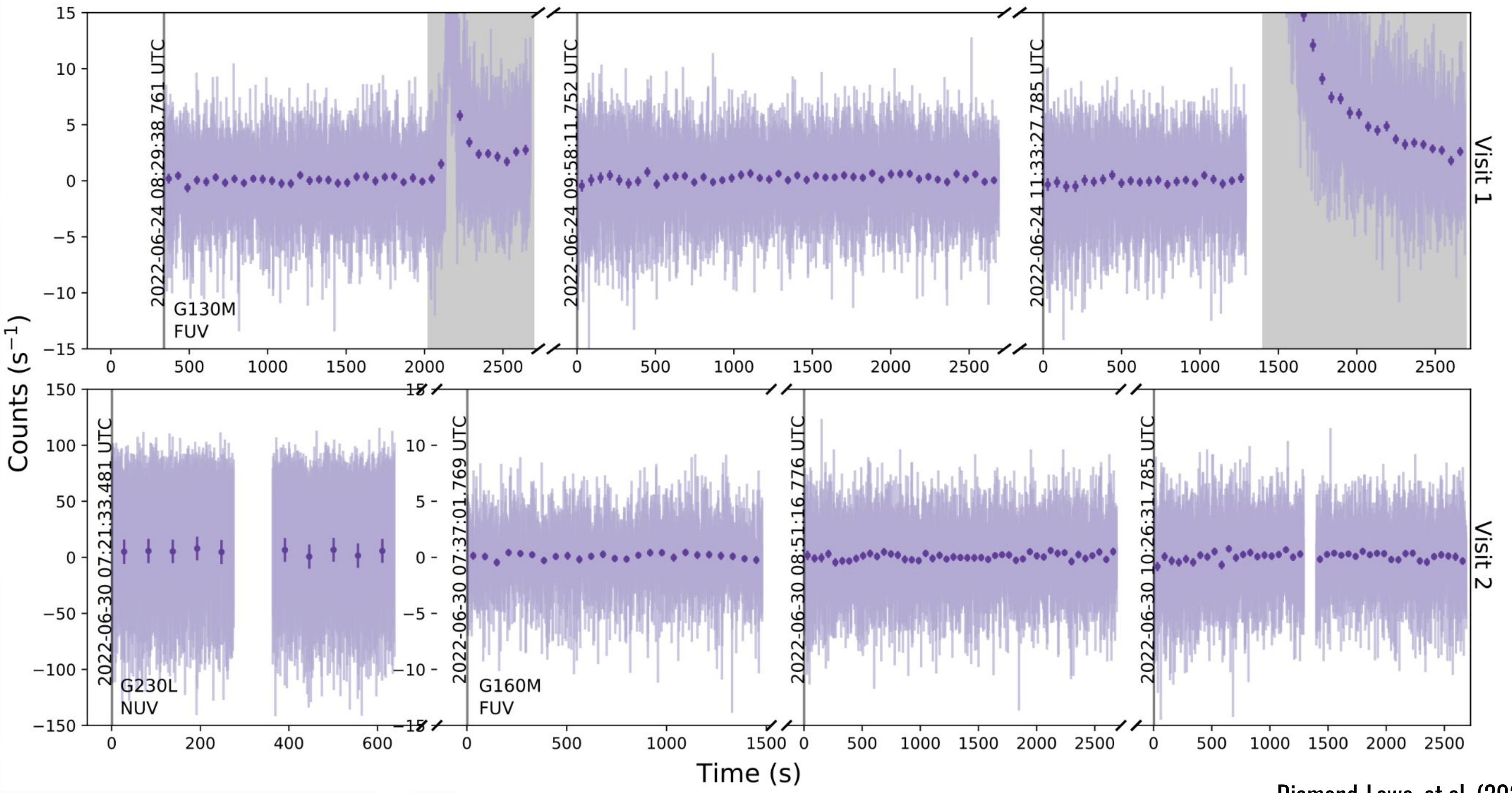
(If you have any data like this for the Rocky Worlds targets and would like to share, we would be very grateful!)

# Observing strategy: **UV-optical spectra**



# Observing strategy: **UV-optical spectra, flare monitoring**

- TIME-TAG
- G130M
- 12 orbits

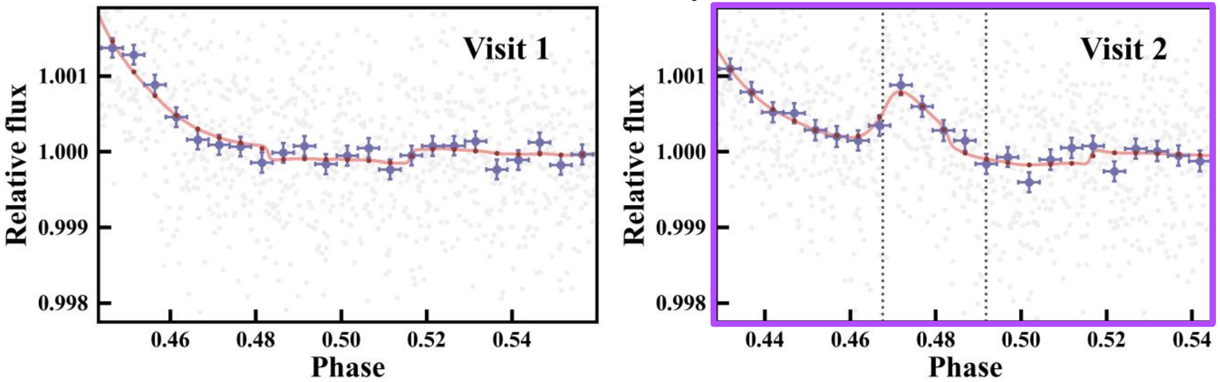



Diamond-Lowe, et al. (2024)

# What does a flare from a “quiet” M dwarf look like at 15 μm?

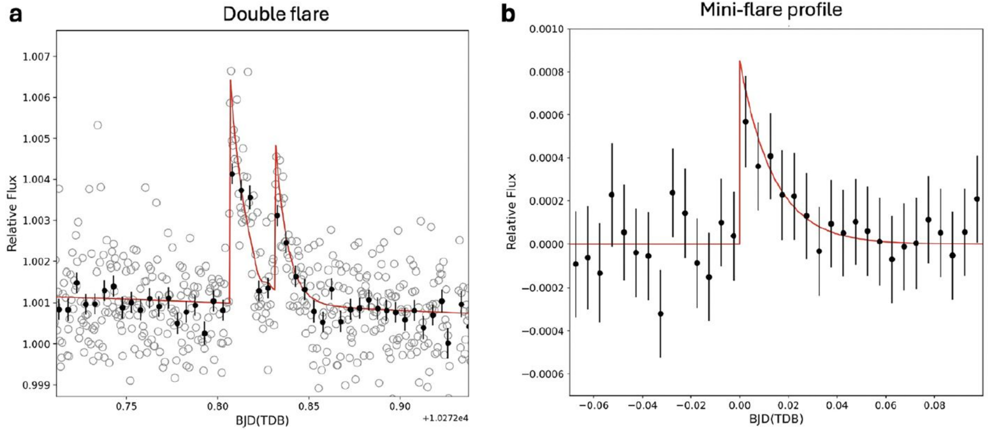
Possible 15μm flare in a “quiet” M dwarf →

**Hot Rocks Survey: GJ 3473 b**



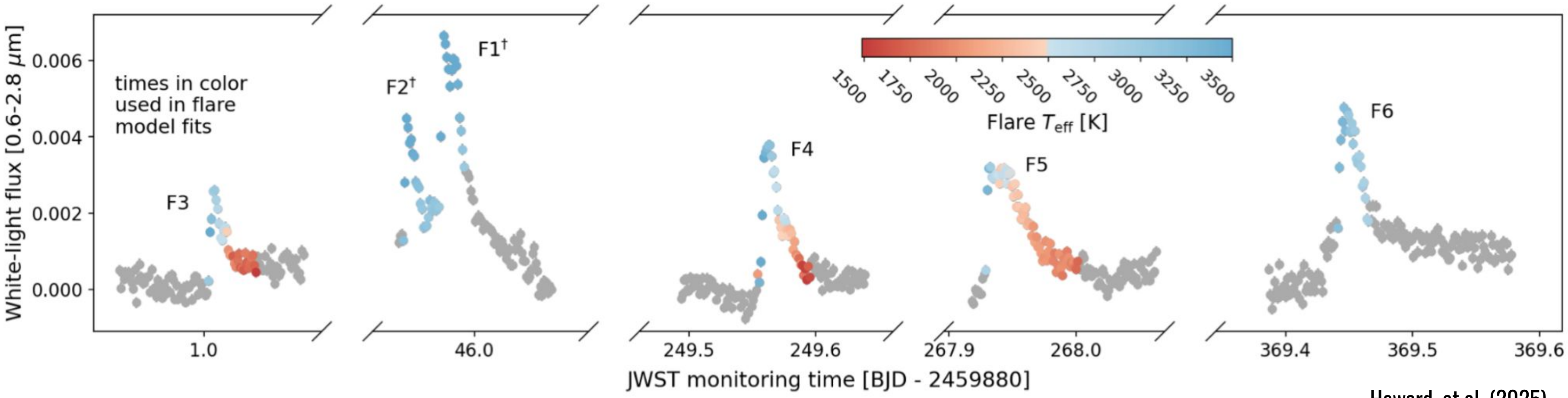

Holmberg, Diamond-Lowe, et al. (2026)

15μm flare in TRAPPIST-1 →




Gillon, et al. (2026)

# Flares: TRAPPIST-1 in the NUV

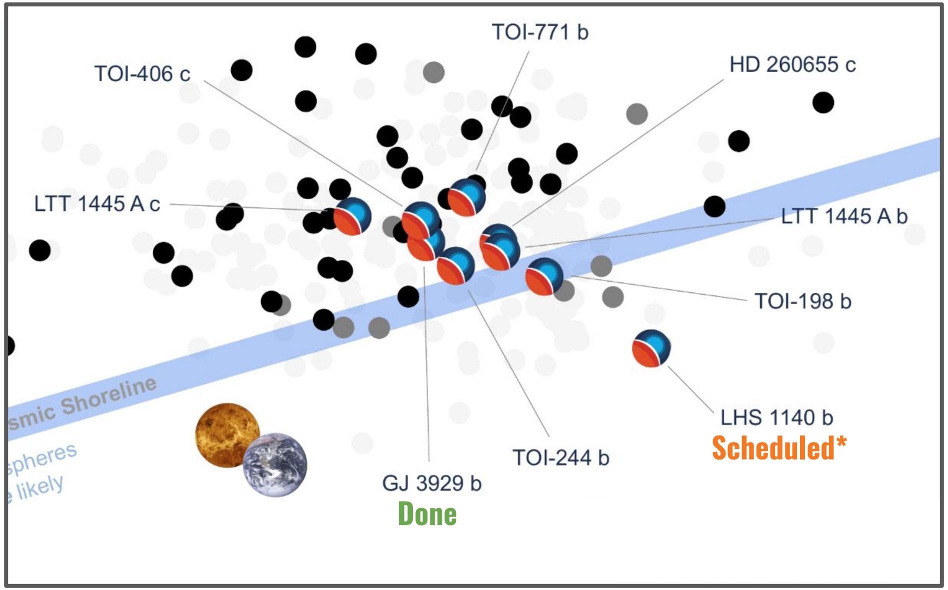



Howard, et al. (2025)

# Status of observations

- ***All*** **JWST eclipses of GJ 3929 b** already obtained, HLSPs published.
- ***All*** **HST/STIS+COS visits of GJ 3929** has been obtained, HLSPs hitting MAST as we speak!
- **Scheduling for** LHS 1140 b done; scheduling LTT 1445 A b/c, TOI-771 b — then rest of targets!

JWST Observations Summary




*first eclipse plan window on July 10th, 2026

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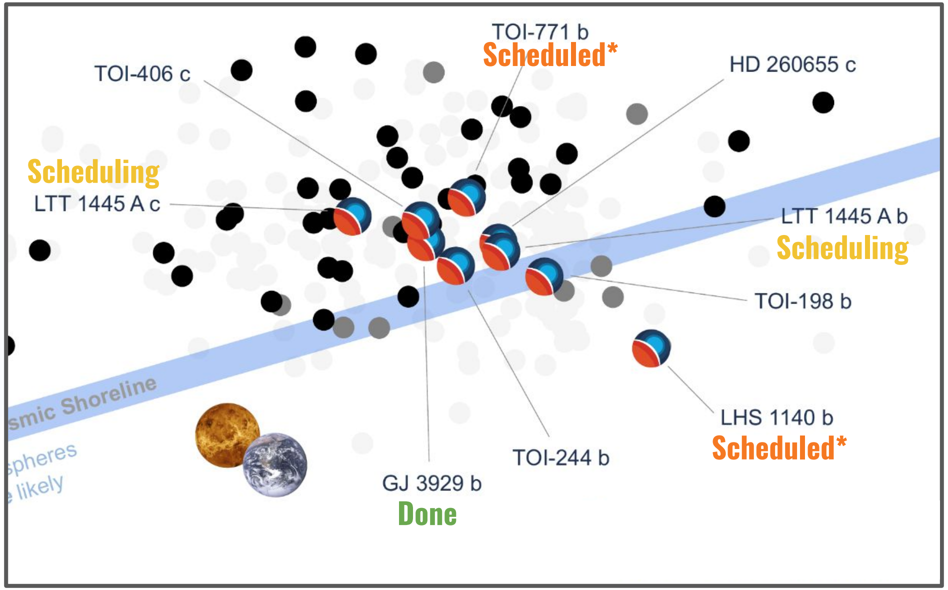


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# Rocky Worlds Data Challenge & Workshop

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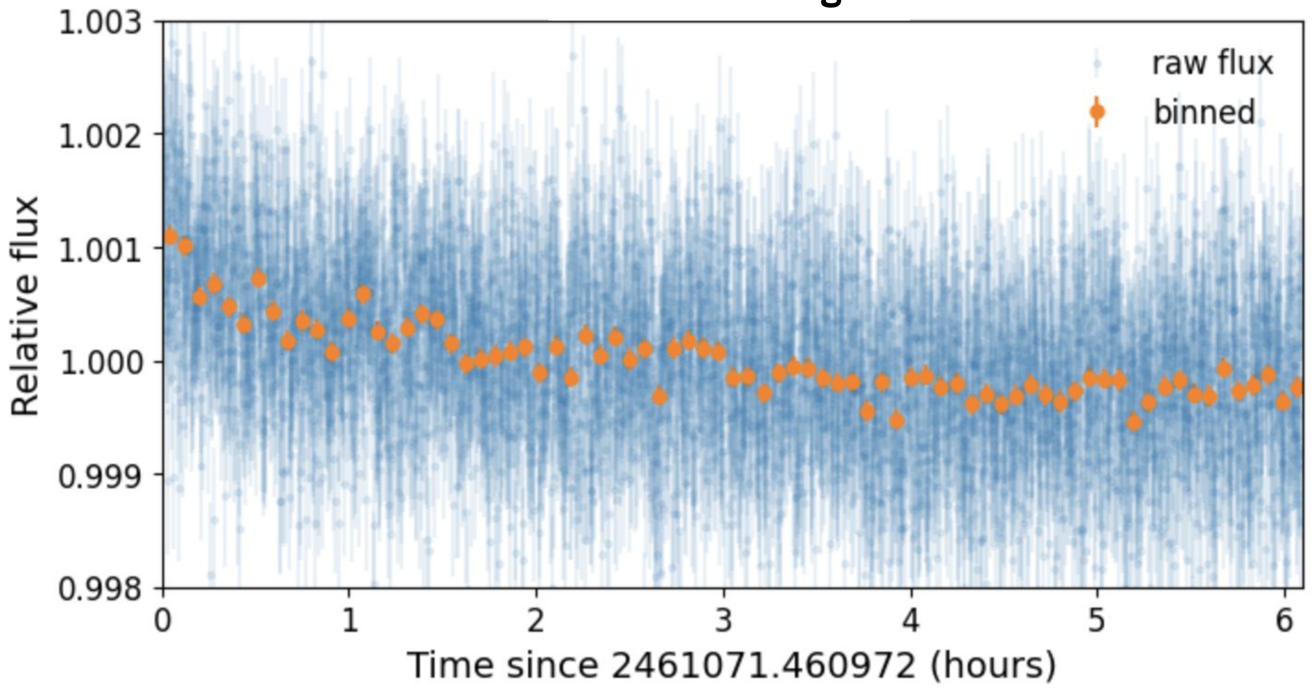
A real JWST/MIRI lightcurve



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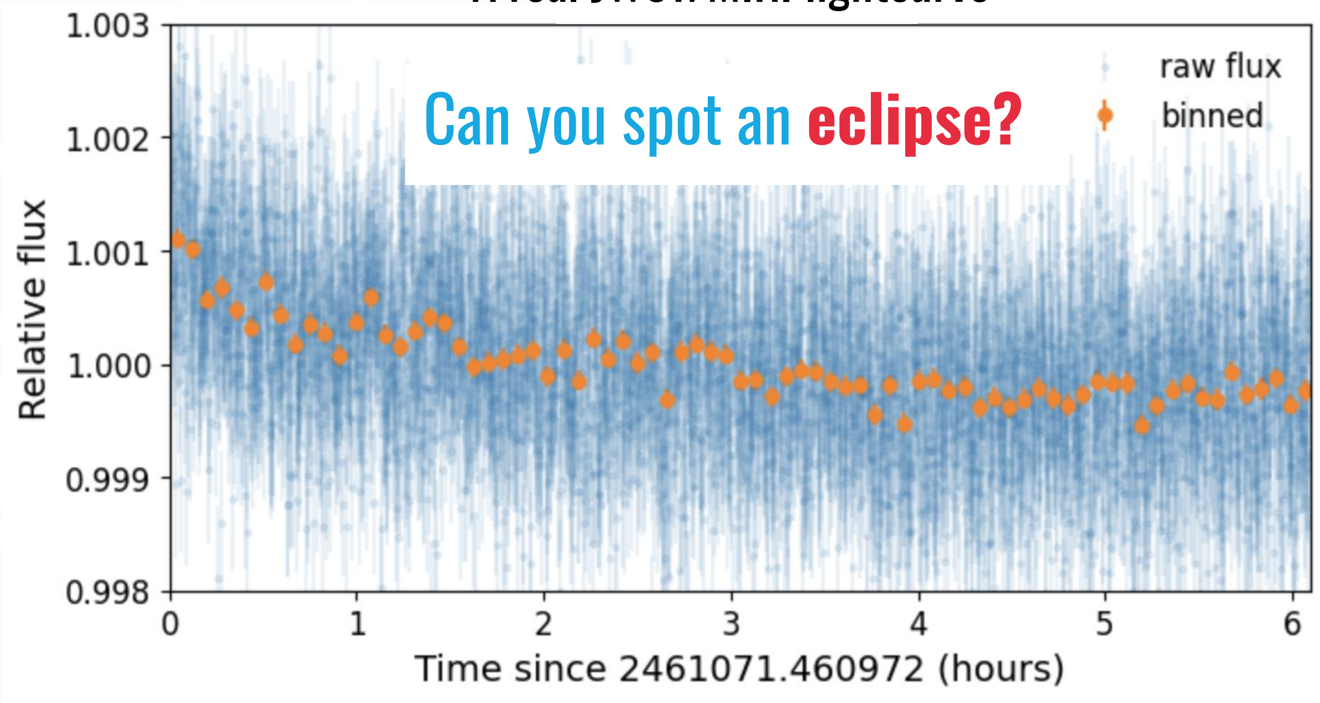

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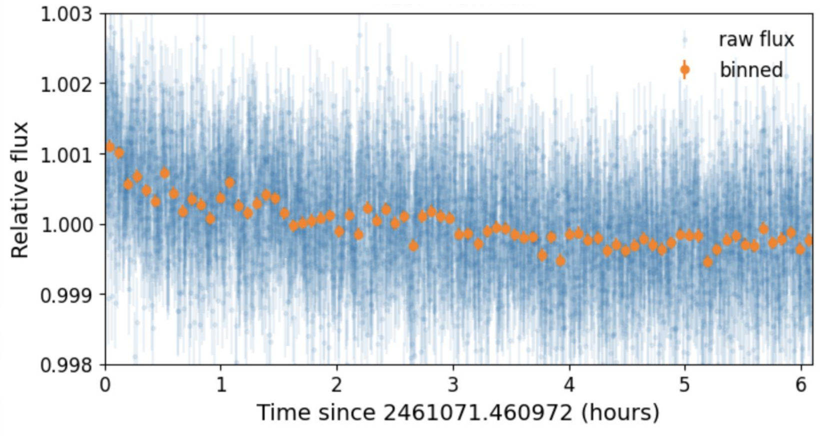

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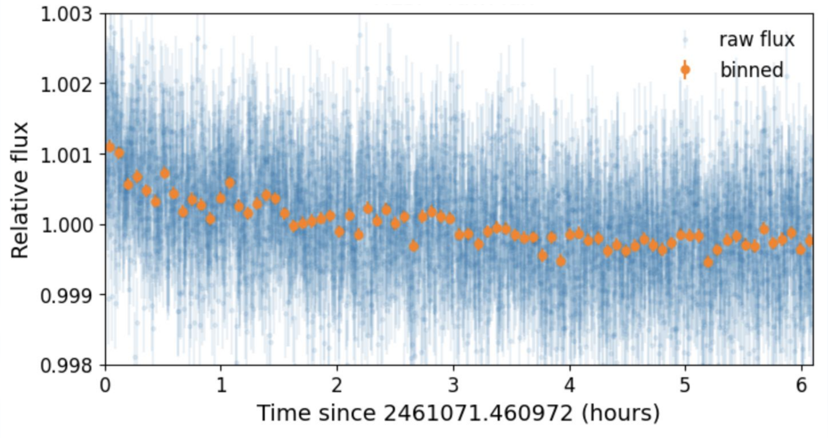
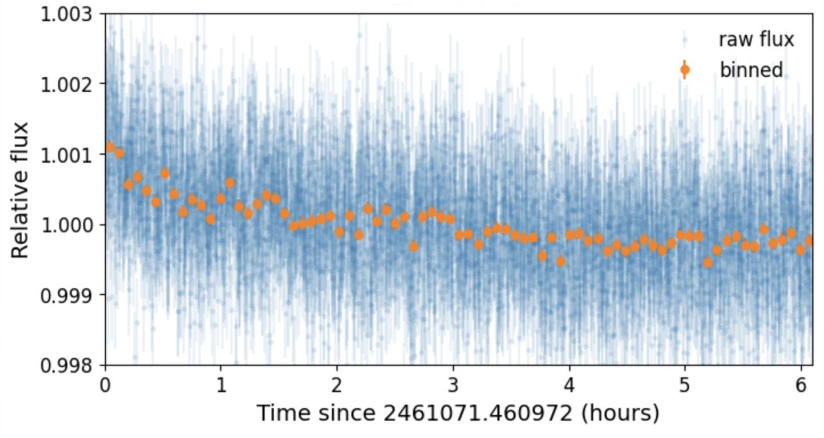



- What is **useful data**? What is **noise**?

# Rocky Worlds Data Challenge & Workshop




- What is **useful data**? What is **noise**?
- Best **practices and caveats**?

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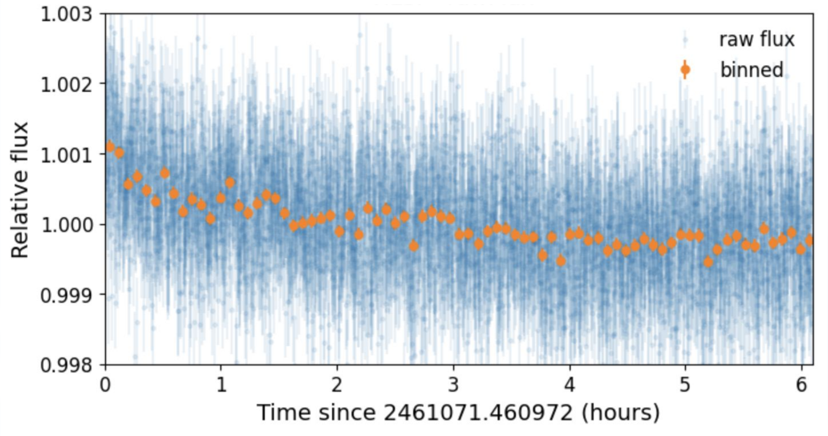


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- Best **practices and caveats**?
- How to **maximally squeeze science**?

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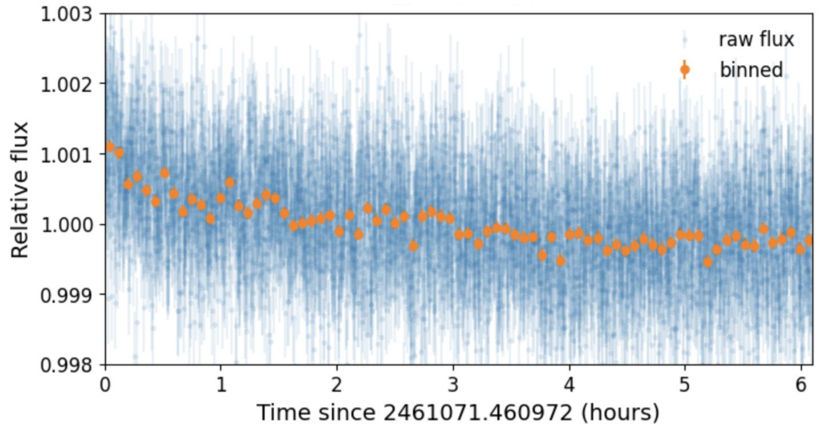


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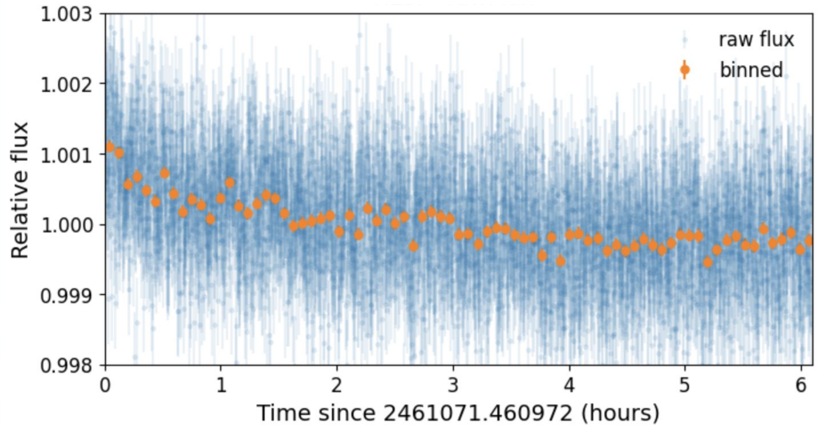
The Rocky Worlds
**Data Challenge**

# Rocky Worlds Data Challenge & Workshop

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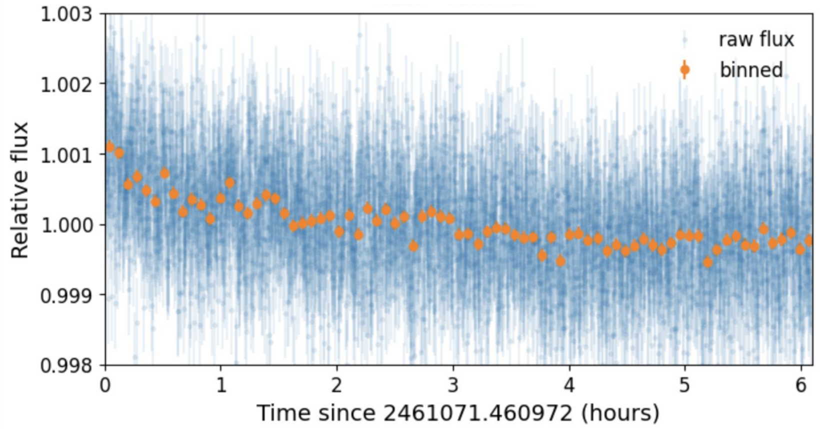
The Rocky Worlds **Data Challenge**

**Real data**: GJ 3929 b

**Simulated data**: LHS 1140 b

# Rocky Worlds Data Challenge & Workshop




- What is **useful data**? What is **noise**?
- Best **practices and caveats**?
- How to **maximally squeeze science**?

The Rocky Worlds

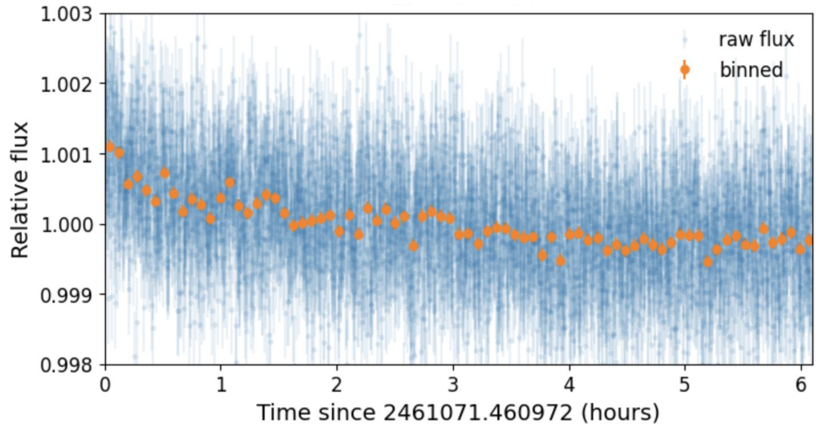
**Data Challenge**

Apr - Aug, 2026

**Real data**: GJ 3929 b

**Simulated data**: LHS 1140 b

# Rocky Worlds Data Challenge & Workshop

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**The Rocky Worlds**
**Data Challenge**
Apr - Aug, 2026

→

**Data Challenge**
**Workshop**
Nov 16-18, 2026 @ STScI

# Past DDT programs:
# **Hubble Deep Field**

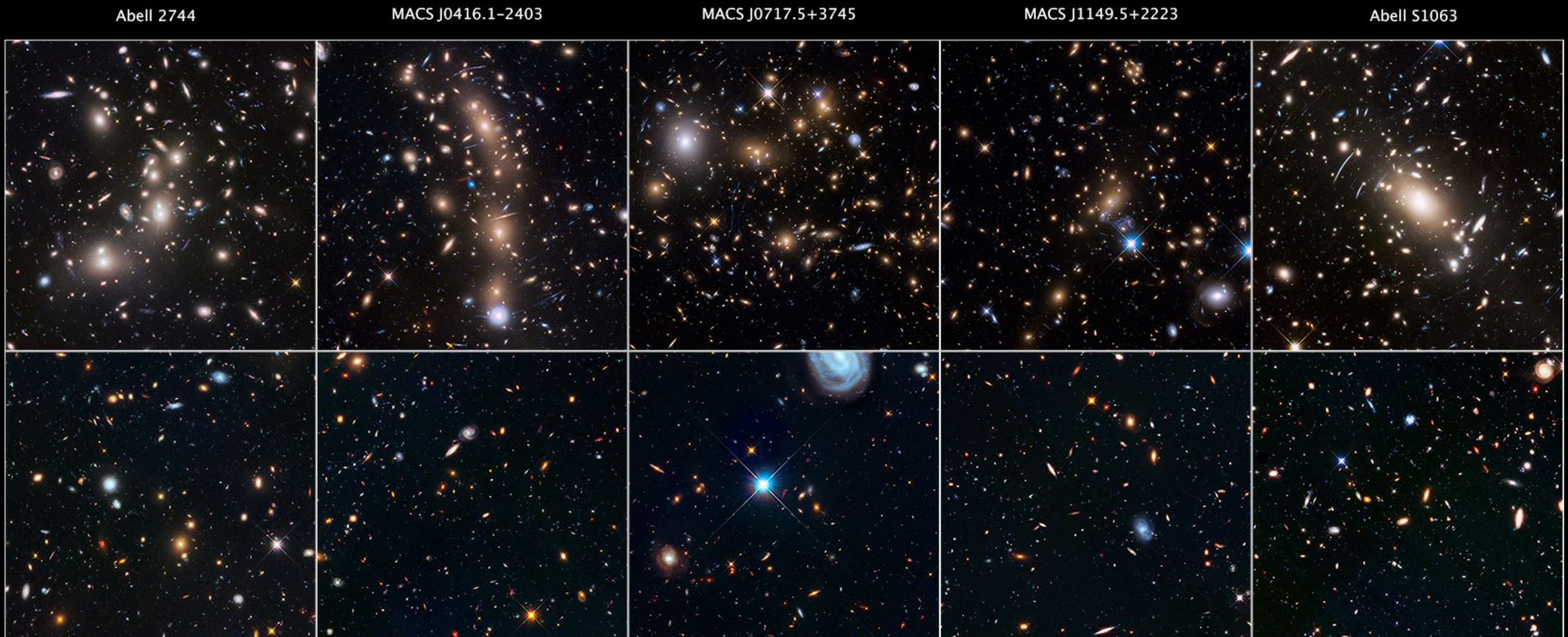
150 HST orbits

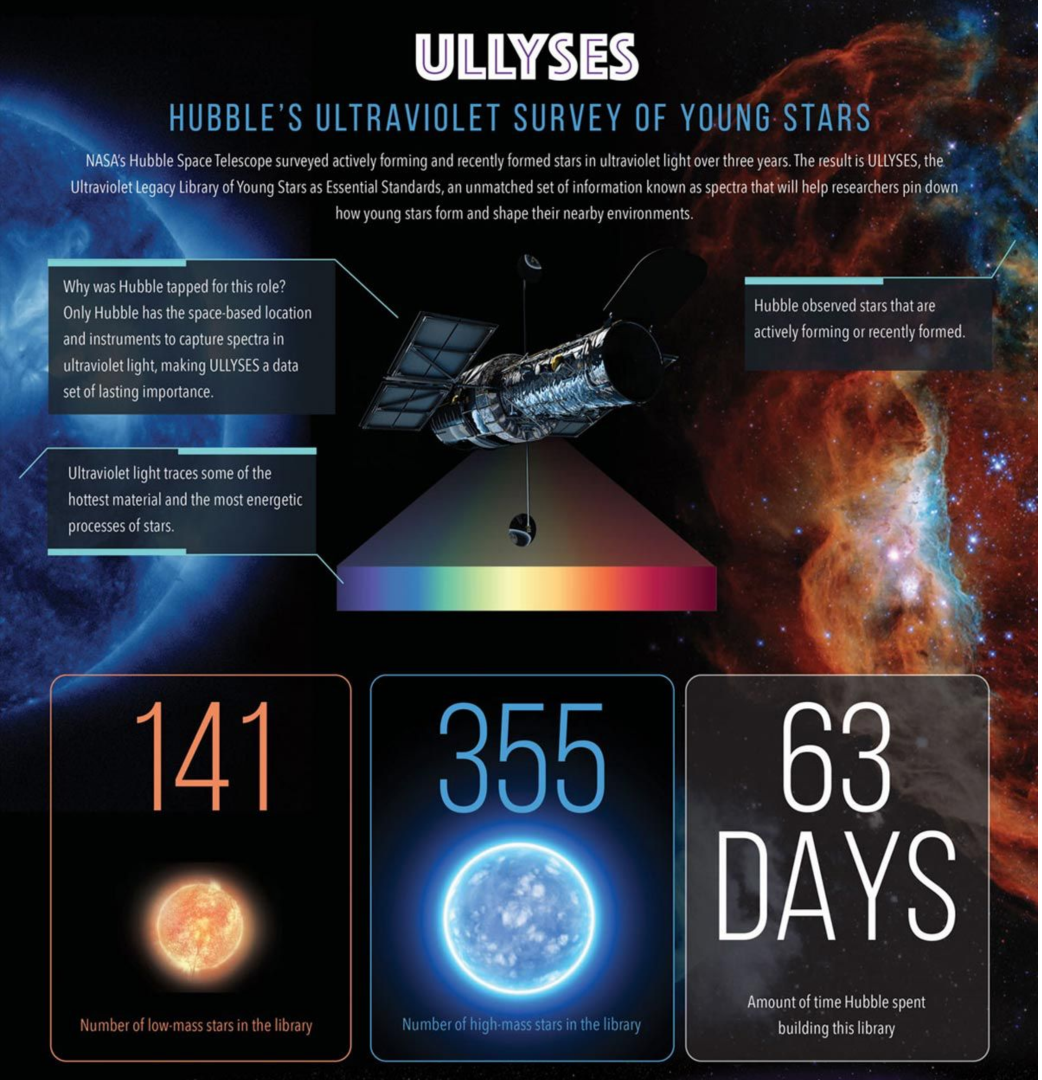
Williams et al. (1996, 2000); Beckwith et al. (2005)

# Past DDT programs:
# **Hubble Frontier Fields**

840 HST orbits + 1000 Spitzer hours

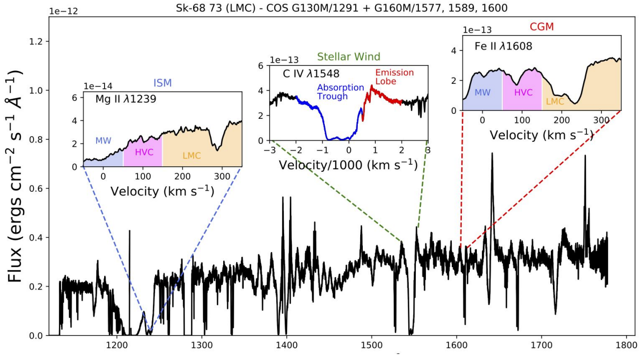
Lotz et al. (2017)

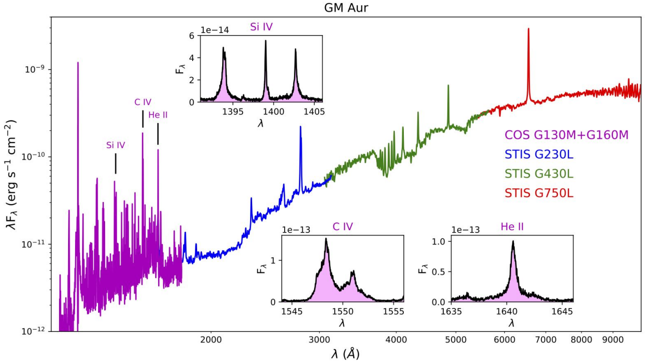





# Past DDT programs: **ULLYSES**

## 1000 HST orbits




Roman-Duval et al. (2025)