Rocky Worlds DDT: JWST/MIRI Checkpoint 1 Report for GJ 3929 b

Munazza K. Alam, Rachel A. Cooper, Tyler Baines | *JWST Target Scheduling Team*

Taylor J. Bell, Brett Morris, Tyler Baines, Ian Wong, Achrène Dyrek, Joseph Filippazzo | *JWST Data Analysis Team*

Néstor Espinoza, Hannah Diamond-Lowe | *RWDDT CIT Leads*

The Rocky Worlds Director's Discretionary Time (RWDDT) program observed four eclipses of the rocky exoplanet GJ 3929 b using MIRI Imaging photometry with the F1500W filter. Based on an analysis of the Checkpoint 1 observations (two eclipses) by the JWST Data Analysis Team (§1), the JWST Target Scheduling Team refined the orbital parameters for this planet (§2) to determine if updates should be made in APT to the length of the observing windows for the remaining two eclipse observations (§3). Observing windows were designed to initially follow a "tinker scheduling" strategy, but can be shortened if the eclipse is detected at the 3σ level at Checkpoint 1[1]. From our analysis of Eclipses 1 and 2, we find that the detection of the eclipse at the 3σ level strongly depends on the choice of systematic model used. We therefore decided not to change the scheduling properties of Eclipses 3 and 4.

1 DATA ANALYSIS

The JWST Data Analysis Team conducted a detailed analysis of the two Checkpoint 1 eclipses of GJ 3929 b individually as well as jointly. T. Baines and A. Dyrek independently analyzed Observation 1, and I. Wong and J. Filippazzo performed independent analyses of Observation 2. For both eclipses, the data analysts tested fits with different linear decorrelation methods (against PSF centroid positions and widths), with and without a Gaussian Process (GP) regression model, and circular vs. eccentric solutions.

1.1 Individual Visit Fits

We briefly summarize the results of the individual eclipse analyses here. For further details, see the Observation 1 Data Analysis and Observation 2 Data Analysis reports.

For both observations, we explored circular vs. eccentric orbits, as archival data was not able to tightly constrain the planet's orbital eccentricity. Unsurprisingly, we found that with only one observation we could not meaningfully constrain both the eclipse depth and the orbital eccentricity, so for each individual fit we chose to impose a mid-eclipse timing prior based on R. Cooper's circular-orbit global fitting results (performed prior to scheduling Observations 1 and 2).

The Observation 1 analyses recovered eclipse depths consistent with 0 ppm and relatively large errorbarrs, that spanned both bare rock and atmospheric scenarios for the

[1] rockyworlds.stsci.edu/rw-website-schedule.html#strategy

planet, although the eclipse depth and timing were found to be method and assumption dependent. Without a GP, the fitted eclipse depth was found to be ∼300 ppm, which is considerably higher than the maximum expected eclipse depth for GJ 3929 b of ∼134 ppm, assuming zero albedo and zero recirculation. Meanwhile, our fiducial fit that included a GP ended up with a suppressed eclipse depth and inflated eclipse depth uncertainties.

For Observation 2, our analyses also yielded eclipse depths consistent with 0 ppm with relatively large errorbars, while also not being meaningfully inconsistent with the maximum-expected eclipse depth. The amplitude of the best-fit GP term ranged from 50 to 100 ppm – comparable to the expected eclipse depth for GJ 3929 b. These results suggest the presence of time-correlated noise hindering our ability to constrain both the mid-eclipse time and the eclipse depth from only a single visit.

1.2 Checkpoint 1 Joint Fits

B. Morris performed a joint fit with `Eureka!` (Bell et al., 2022) to both Observations 1 and 2. The goal of the joint fit was to test whether we can obtain robust and minimally-biased constraints on the planet's eclipse depth and mid-eclipse time by combining the first two eclipse observations of GJ 3929 b. The astrophysical priors for the orbital parameters and planetary radius used in the joint fit were based on R. Cooper's eccentric global fitting results (performed prior to scheduling Observations 1 and 2).

In the joint fit, we directly fitted for the eclipse depth, and indirectly fit for the mid-eclipse time via $e \cos \omega$. B. Morris tested trimming different numbers of integrations at the start of the time-series observations (450–700 integrations; 42–67 minutes), different linear regression models, and including or excluding a GP as a function of time. We find that the fits including a GP do not significantly detect the eclipse, since the GP's mean predictive model ends up having features of a similar length-scale and amplitude as the expected eclipse signal. In the fits without a GP, Observation 1 is well-fit with no residual red noise, and Observation 2 has a small amount of residual red noise visible in the RMS vs. bin size plots. Our fiducial, no-GP Checkpoint 1 analysis yielded $F_\mathrm{p}/F_* = 143^{+28}_{-56}\,\mathrm{ppm}$ and $e \cos \omega = -0.0103^{+0.0015}_{-0.0009}$.

1.3 Results

The large uncertainty on the eclipse depth measurements for Observations 1 and 2, as well as the sensitivity to different reduction/analysis choices (e.g., aperture/annulus selection, initial trimming intervals, use of a GP) indicate that the inclusion of additional eclipses are required to robustly constrain the eclipse timing, depth, and potential orbital eccentricity, as is expected for such low-SNR eclipse signals.

2 UPDATED ORBITAL PARAMETER FITTING

Based on the results of the RWDDT Data Analysis Team (§1), R. Cooper performed updated eccentric global fits using `juliet` Espinoza et al. (2019) for GJ 3929 b. The full orbital fits included TESS and LCO transit photometry, CARMENES, NEID, MAROON-X blue, and MAROON-X red RVs, and the RWDDT Checkpoint 1 MIRI eclipse photometry. Across data sets, the flux dilution factors for the photometric instruments were fixed and all other parameters were fitted. We recovered the eclipse at $\sim$18.3 minutes ($\sim$20% eclipse duration) before the MIRI-only Checkpoint 1 joint fits (§1.2) and an eclipse depth of $F_{\rm p}/F_{*} = 155^{+27}_{-26}\,{\rm ppm}$.

3 APT UPDATES

After a detailed inspection of the posteriors from R. Cooper's updated global fits, N. Espinoza, M. Alam, and T. Bell agreed that we could not confidently narrow the observing windows for Observations 3 and 4 since it is difficult to detect the Checkpoint 1 eclipses of GJ 3929 b at the 3σ level or higher. We therefore removed holds on these visits, without modifying their durations or phase constraints. Eclipses 3 and 4 of GJ 3929 b were scheduled to coincide with RWDDT observations of the host star taken with HST.

References

Bell, T., Ahrer, E.-M., Brande, J., et al. 2022, The Journal of Open Source Software, 7, 4503, doi: 10.21105/joss.04503

Espinoza, N., Kossakowski, D., & Brahm, R. 2019, MNRAS, 490, 2262, doi: 10.1093/mnras/stz2688