JWST Observations of Potentially Hazardous Asteroid 2024 YR4

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Abstract: The destructive power of an impacting asteroid is primarily estimated by knowledge of its size. Asteroid 2024 YR4 reached a peak 2032 impact probability with Earth of 3%, motivating a desire to determine its size. Owing to its infrared capabilities, JWST is uniquely suited for such assessment, especially for decameter-scale objects [1]. We used JWST to observe 2024 YR4 and find a diameter of 60± 7 m. This size range corresponds to an albedo for 2024 YR4 of 8-18%, consistent with observation that it is an S-type asteroid [2], if at the low-albedo end of that asteroid taxon. Future observations through May 2025 will help further refine the asteroid's thermophysical model.

Observations and Data Reduction: JWST measured 2024 YR4's spectral energy distribution (SED) on 26 March 2025 using the Mid-Infrared Instrument (MIRI: [3,4]) via a multi-filter sequence with the F1280W, F1000W, and F1500W filters. For all three filters, MIRI exposures were taken in each of four dither positions, with each exposure composed of 27 groups, which are separately-accessible non-destructive reads. Each group represents roughly 3 seconds of integration, and each set of dithers required roughly 20.5 minutes including overhead. This three-filter sequence was then repeated. 2024 YR4's spin period is 19.46 minutes [5], and each set of 4 dithered exposures averages over roughly one rotation period.

Images were also taken with the Near-Infrared Camera (NIRCam: [6]) using the F322W2 and F150W2 filters on 8 March and 26 March 2025. The NIRCam images also are composed of multiple groups and dithers. In this case, a dichroic allows simultaneous images to be obtained through two filters, one with a bandpass > 2.5 µm and the other < 2.5 µm. The total length of integration for the NIRCam datasets was again set to be close to 2024 YR4's spin period. The NIRCam data will be used for lightcurve and astrometric purposes, and to support ongoing additional thermal modeling of 2024 YR4, but were not used in the analysis below other than to check consistency with YR4's H magnitude [5].

The raw data were retrieved from the Mikulski Archive for Space Telescopes (MAST) and processed using version 1.17.1 of the JWST calibration pipeline [7] and reference file context `jwst_1322.pmap`. Several "flavors" of products were produced to accommodate thermal modeling, astrometry, and rotational lightcurve construction. For thermal modeling, we used the latest pipeline and reference files and included the non-default `clean_flicker_noise` step to remove 1/f detector pattern noise. For the rotational light curve analysis, we performed the same processing described above on individual integrations; default processing combines the integrations, but by processing each integration separately we could extract additional time-dependent brightness information. Finally, we used the same process for the individual integrations but omitted cosmic ray detection to prevent flagging and removing the cores of the star streaks in the images. Unaltered star streaks were required for precise absolute astrometry of 2024 YR4.

Thermal Modeling and Results: We used the Near Earth Asteroid Thermal Model (NEATM: [8]) to determine the effective diameter of 2024 YR4. The "beaming parameter" (η), a free parameter abstractly representing the effects of spin, shape, thermal inertia, and surface roughness on the object's surface temperature distribution, is well constrained by observed MIRI flux ratios. Figure 1 shows the corresponding NEATM flux predictions at the MIRI reference wavelengths of 10.0, 12.8, and 15.0 µm for $\eta = 2.22$ and 3.14 and over a broad diameter range. These model predictions (solid lines) incorporate the constraint from the object's absolute magnitude in visible light, which was measured as $H_V=24.05 \pm 0.15$ mag [5].

For the size determination we quadratically added 5% to the measurement errors to account for MIRI's absolute flux calibration scheme [1]. The resulting minimum and maximum flux levels are shown as dashed horizontal lines in Figure 1, while dotted vertical lines indicate the diameter range for 2024 YR4 that is consistent with NEATM model solutions and the measured fluxes. The solutions from the F1000W band are shown in red, F1280W in green, and F1500W in blue. The resulting diameter of a sphere with equal volume as 2024 YR4 ranges from roughly 55—67 m. A second, independent Monte Carlo NEATM modeling effort provided a similar best-fit size of 62 ± 4 m. We combine these two models, preliminary results from other ongoing efforts, and possible unidentified sources of uncertainty, and conservatively adopt 60 ± 7 m as our estimated size for 2024 YR4. The corresponding geometric albedo values are between 0.08 (for a size of 67 m, H_V=24.2 mag) and 0.18 (for a size of 53 m, H_V=23.9 mag). For comparison, H = 24.05 ± 0.15 with the range of common asteroid albedos (0.04—0.4) suggested a size range of 30-110 m.

The object is rotating quickly (P_{sid} = 19.46 min). However, from a thermal point of view, its SED is better fit by the NEATM model than by a theoretical "fast rotating model" isothermal temperature distribution (see [9]). The best-fit NEATM η values are, however, exceedingly unusual if not unique for an object at ~30° phase angle.

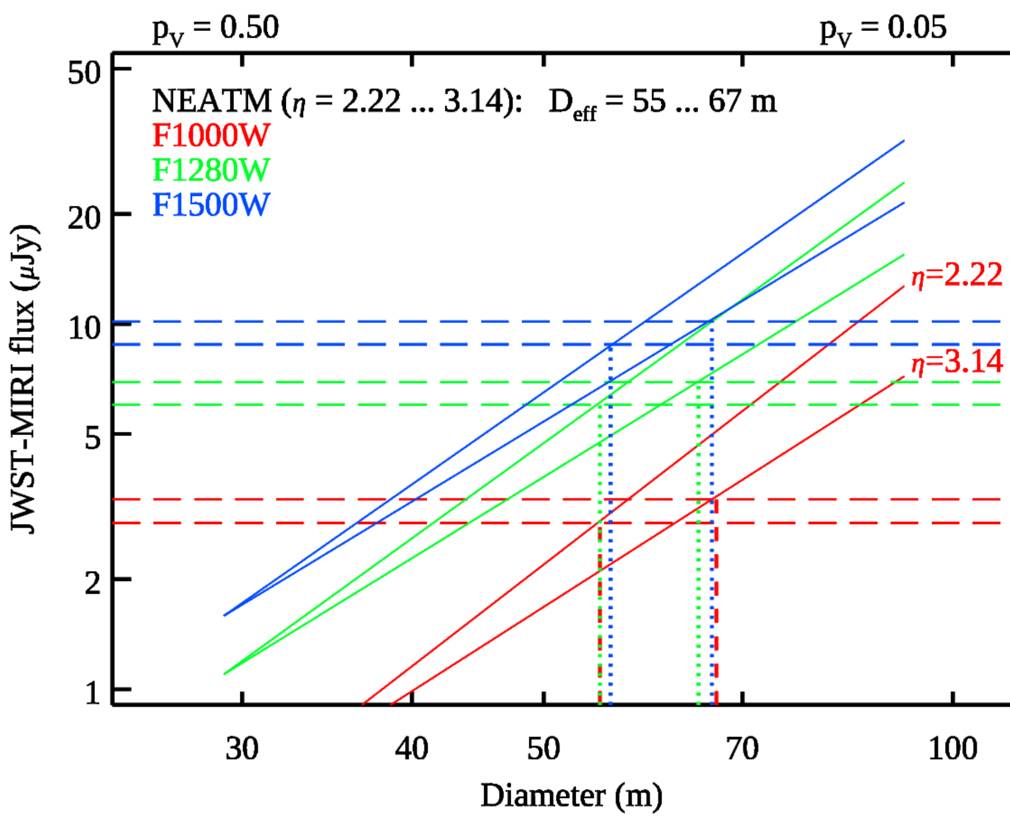

Figure 1: *NEATM size determination for 2024 YR4. The MIRI measurements are shown as horizontal dashed lines (±1-σ absolute flux uncertainty). The solid lines are NEATM model predictions at 10.0, 12.8, and 15.0 μm, considering the range of beaming parameters η compatible with the measured flux ratios for all 3 bands. The intersections of the vertical dotted lines with the x-axis indicate the corresponding size constraints for each band.*

Implications: The best-fit albedo of 13% is not diagnostic of any particular asteroid class, and can be found in a wide range of spectral classes. The range of indicated albedos (8-18%), while not common among S-complex asteroids at the low end, are compatible with S-like spectra of 2024 YR4 obtained by de Leon et al. and Moskovitz et al. [2].

Objects the size and mass of 2024 YR4 are expected to hit the Earth roughly every 5000 years [10]. To assess the potential effects of an Earth impact of object similar to 2024 YR4, we used the probabilistic asteroid impact risk model of Mathias 2017 and Wheeler 2024 [11-12]. Combining the physical properties reported in this paper and orbital parameters similar to 2024 YR4, the energy provided by an impact could range from 2 to 30 Mt. The blast damage radius (shattered windows, some structural damage) could range from 0 to 80km.

Future Work: While the simplicity of NEATM allows the size of 2024 YR4 to be determined in a timely manner to a precision useful for planetary defense applications, further work will be done in coming months to provide additional insights. Thermophysical models, which are more sophisticated than NEATM, can be used to better constrain 2024 YR4's thermal properties. The

NIRCam data will also be used as possible to make astrometric measurements to improve the orbit of 2024 YR4. At this writing a 2032 impact with the Moon has not been ruled out. After May 2025, 2024 YR4 will next enter JWST's observing window in the first part of 2026 as a challenging target, which may be worth pursuing to determine whether a lunar impact will occur.

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