Using the NEO Size-Frequency Distribution in Probablistic Assessments

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The NEO Size-Frequency Distribution

- It is well understood that there are many more small NEOs than large ones (Figure 1, from Nesvorny et al. 2024)
- For any H magnitude and an uncertainty, there are more NEOs between the nominal and 1-σ faint value of H than between the nominal and 1-σ bright value of H
- This is *also* true for estimated sizes and uncertainties
- The increase of objects at small sizes can in some cases outpace the decrease in likelihood for larger-σ outcomes
- ***If a measurement of H or size is being interpreted as a probability distribution, this effect should be included!***
- As the size uncertainty gets smaller relative to the SFD slope, the asymmetry shrinks

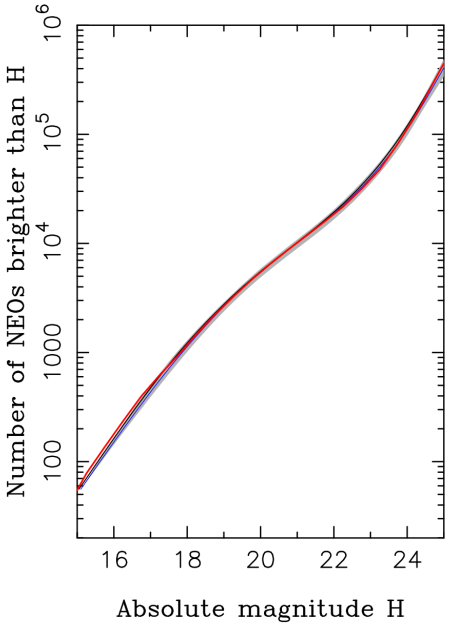

Fig 1. from Nesvorny et al. (2024). Debiased absolute magnitude distribution of NEOs. The black line is the median, the blue is the best fit, and the red line is the model of Harris and Chodas (2021). The gray area is the 3-sigma envelope including their posterior distribution.

2024 PDC25: Including the SFD

- 2024 PDC25 is reported as being "most likely 90-160 m diameter" with a median of 126 m, a 5% chance of being < 75 m and a 95% chance of being < 194 m diameter
- This is consistent with a diameter estimate of 126 ± 35 m (1 σ, Gaussian uncertainty)
- Also consistent with an expectation of a ~90-m object as often as a ~160-m object
- Considering Figure 1 and the SFD, however, there are 4x as many objects between 90-100 m as between 160-170 m.
- Convolving the SFD with the diameter estimate (Figure 2) yields the following estimates of impactor size likelihood:
  - Most likely 60-125 m diameter
  - Median diameter ~100 m
  - 5% chance of being < 50 m; 95% chance of being < 155 m.
- The mass difference between 100-m and 125-m objects of the same density is a factor of ~2.

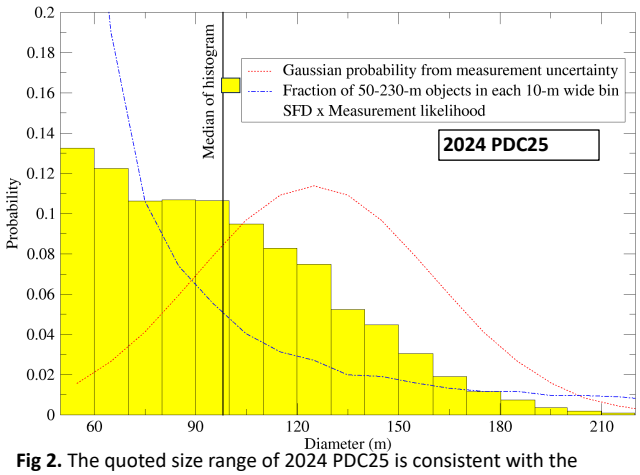

Fig 2. The quoted size range of 2024 PDC25 is consistent with the Gaussian probability shown. When convolved with the SFD, the resulting histogram shows the distribution of expected impactor sizes, along with the median value. The median is ~25% smaller than the mean of the size measurement.

2024 YR4: Real-life Case

- H = 23.92 for 2024 YR4
- The range of likely asteroid albedos (4-40%) results in a size range of 35-110 m
- Treat as "mean" of 72.5 m, equal probability for all albedos.
- SFD convolution using 5-m bins gives median diameter of 45 m
- JWST measurement: 60 ± 7 m
- SFD convolution too small by 25%; "mean" too big by 21%

Conclusions

- The Gaussian uncertainty around typical size measurements cannot be interpreted as a symmetrical uncertainty around the likeliest impactor size
- The steep increase in number of NEOs at smaller sizes increases the likelihood that an object will be smaller than a measurement mean compared to larger than it.
- This effect can lead to differing mass estimates by up to a factor of 2.
- The community should consider how to best include the characteristics of the NEO SFD when considering risk when little information is at hand.

References

Nesvorný, David, et al. "NEOMOD 3: The debiased size distribution of Near Earth Objects." Icarus 417 (2024): 116110.

Harris, Alan W., and Paul W. Chodas. "The population of near-earth asteroids revisited and updated." Icarus 365 (2021): 114452.

Coates et al. 2025, "Impact Risk Assessment Dashboard 2024 PDC25 Hypothetical Asteroid Impact Exercise, Epoch 1" https://cneos.jpl.nasa.gov/pd/cs/pdc25/PDC25_Epoch1_Dashboard-Final.html