CMB-Steroids: Exploring the Solar System in mm wavelengths

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Asteroids in mm wavelengths

- Millimeter observations of solar system objects are rare in comparison to optical and infrared.
- Fluxes in optical and IR ranges have a major contribution from reflected solar light.

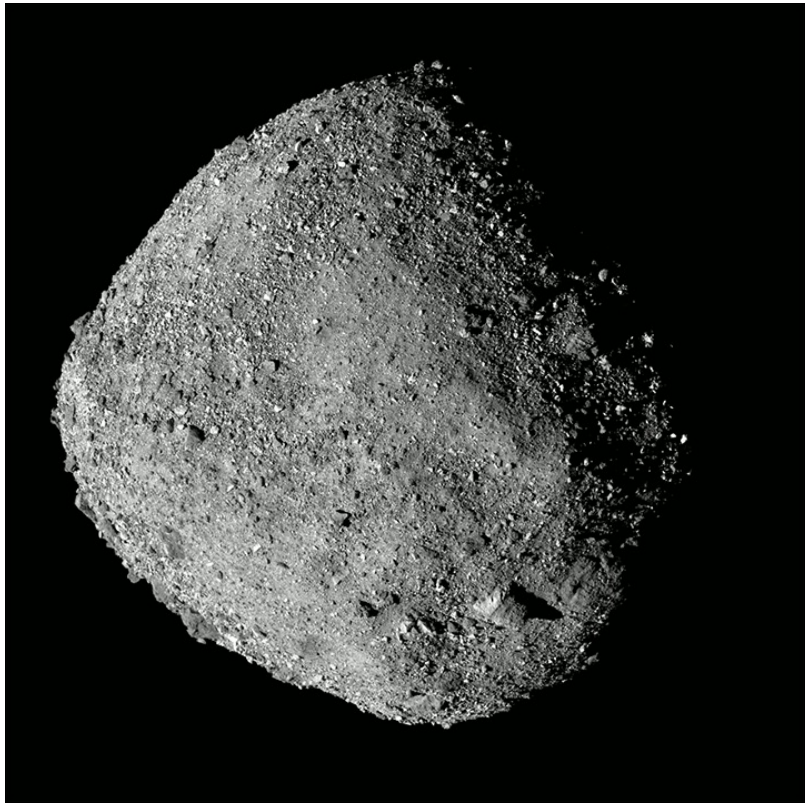


Fig. 1: Asteroid Bennu

Asteroids in mm wavelengths

- Fluxes in optical and IR ranges have a major contribution from reflected solar light.
- In mm waves, the observed radiation is mostly from emission.
- Millimeter observations constitute of radiation from below the surface.
- They carry important information about the surface and sub-surface layers.
- Can be potentially used for better classification and sorting of bodies than what currently exist.

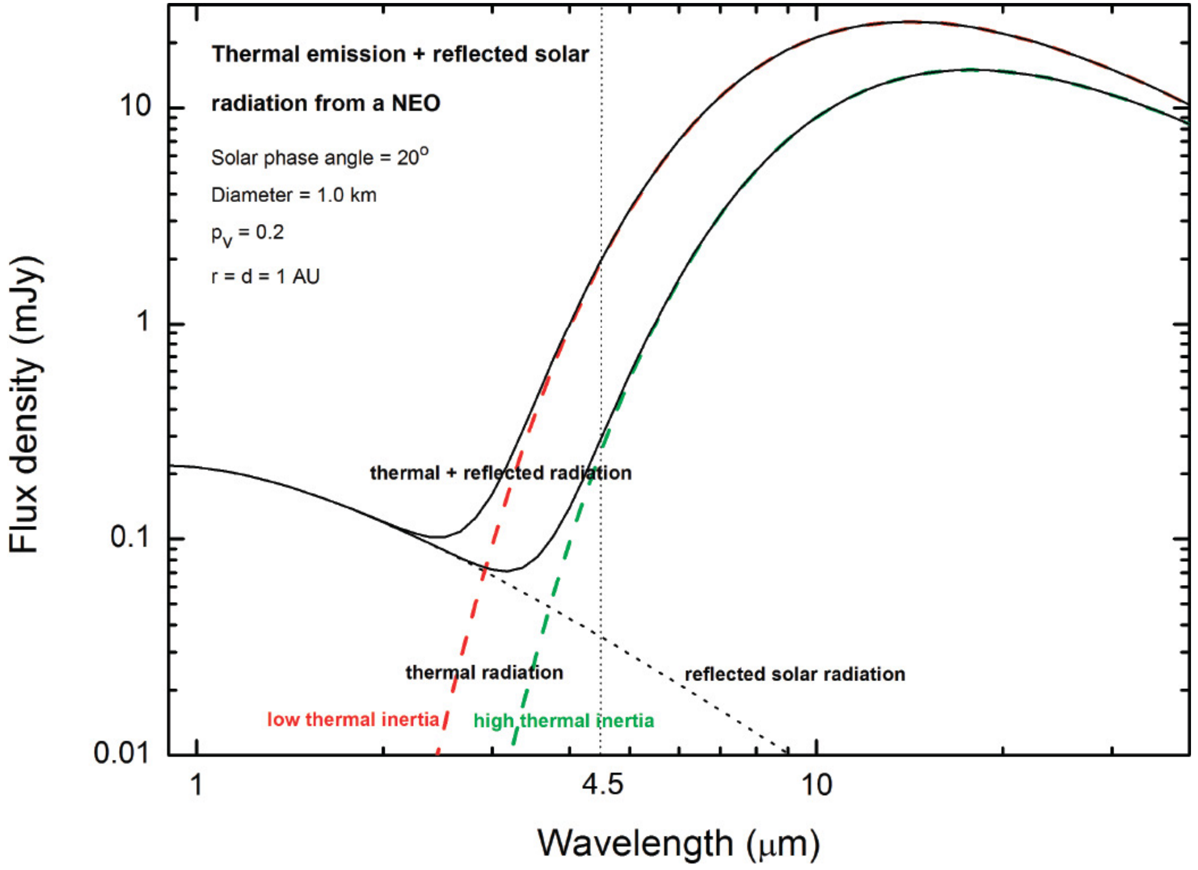


Fig. 2: Flux composition for an asteroid.
https://nap.nationalacademies.org/read/25476/chapter/7#39

Asteroids in mm wavelengths

- Asteroids observed at longer wavelengths have consistently shown lower than expected flux.
- Johnston et al. (1982) observed dwarf planet Ceres in microwave (2 and 6 cm) and the observed flux signaled a $T_B \sim 120$ K, in contrast to the expected $T_{eq} = 165$ K. Conclusion: diameter estimate might be incorrect, misalignment of rotational axis, unknown thermal properties.
- They also noted that such a drop is consistent with other contemporary mm wave observations.
- Works like Webster et al. (1988) and Redman et al. (1992) again confirmed the flux discrepancy.

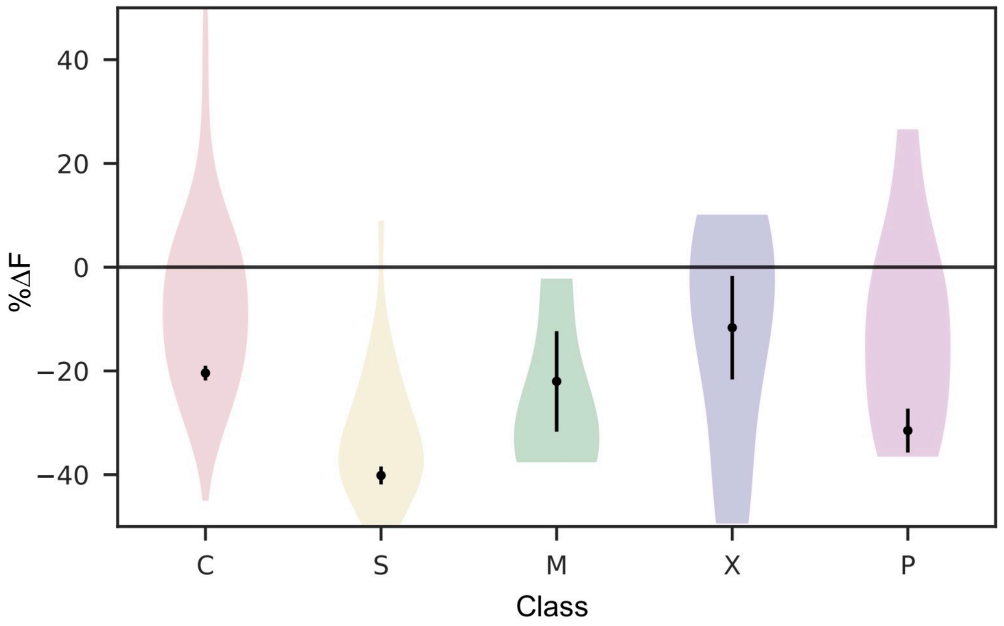


Fig. 3: Population distribution of difference in flux for various classes of asteroids compared to prediction based on WISE data as shown by Orlowski-Scherer et al. (2023).

Reason for the discrepancy?

- Historically, researchers have attributed the drop in flux to a reduced effective emissivity.
- Flux predictions are generally based on simple models like NEATM (Harris (1998)), which does not consider shape, rotation, or sub-surface temperatures of asteroids.
- Keihm et. al. (2013) proposed that this may be caused by the sharp temperature gradient below the surface, while emissivity remains near unity.

Our objective

- Understand the discrepancy between predicted and observed asteroid flux at mm wavelengths.
- Develop ability to accurately predict asteroid flux at mm wavelengths.
- Predict the prospect of CMB-S4 in terms of observability and discoverability of Solar System Objects(SSOs).
- Explore the possibility of new physics to be derived from the CMB-S4 data in the context of SSOs.

Thermophysical model

- Our thermophysical model can simulate asteroid temperatures throughout the body.
- We take the shape model of asteroid with triangulated surface and consider a strand from each triangular facet running deep towards the core, along which heat transfer is simulated.
- Neglecting lateral heat transfer, we solve an implicit formulation of the transient 1-D heat equation at every time step.
- With JPL Horizons data for exact ephemeris, proper spin axis and a date corresponding to its initial orientation of the shape model, we can simulate the exact orientation of the asteroid at the time of observation.
- This gives us a tool to investigate whether subsurface temperature drop can solve for the flux discrepancy.

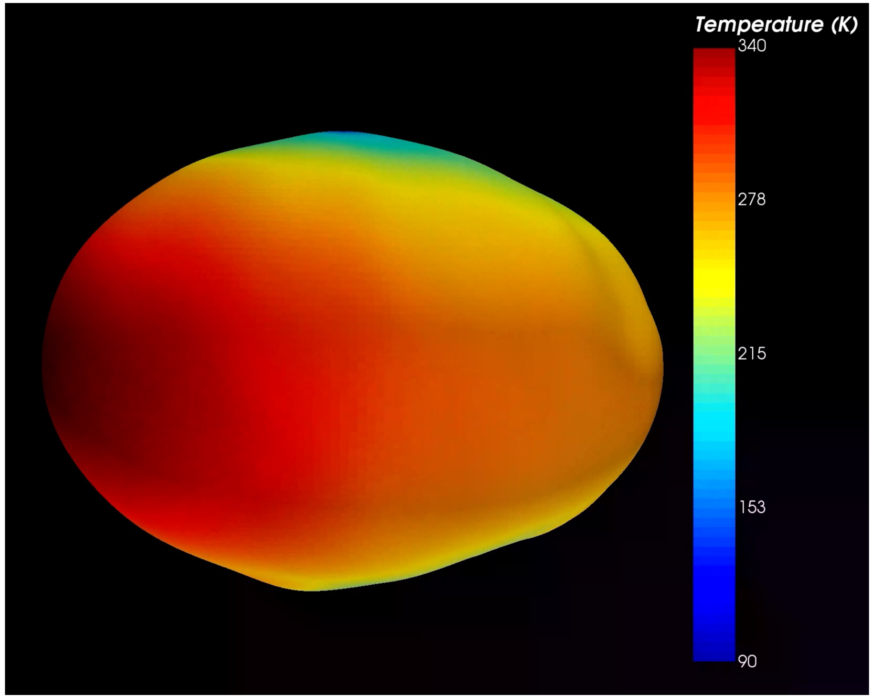
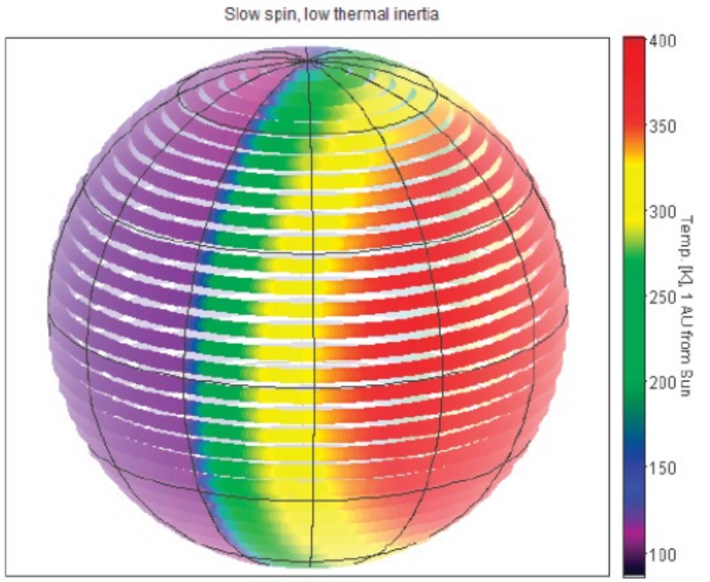
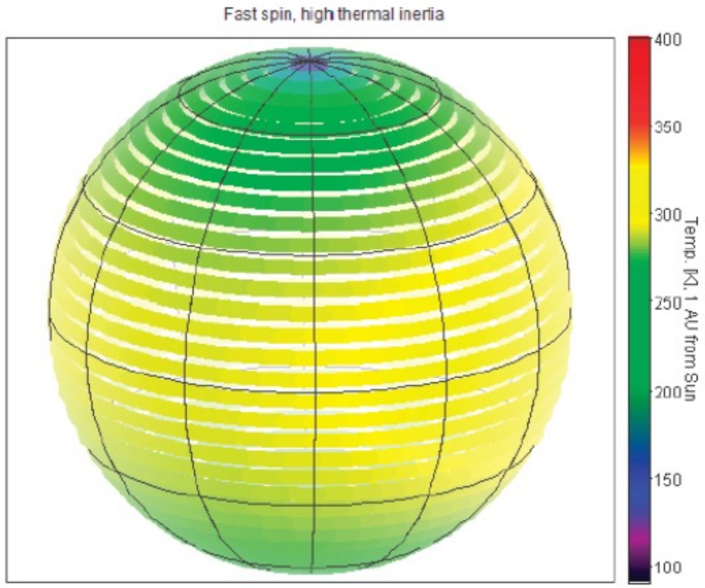


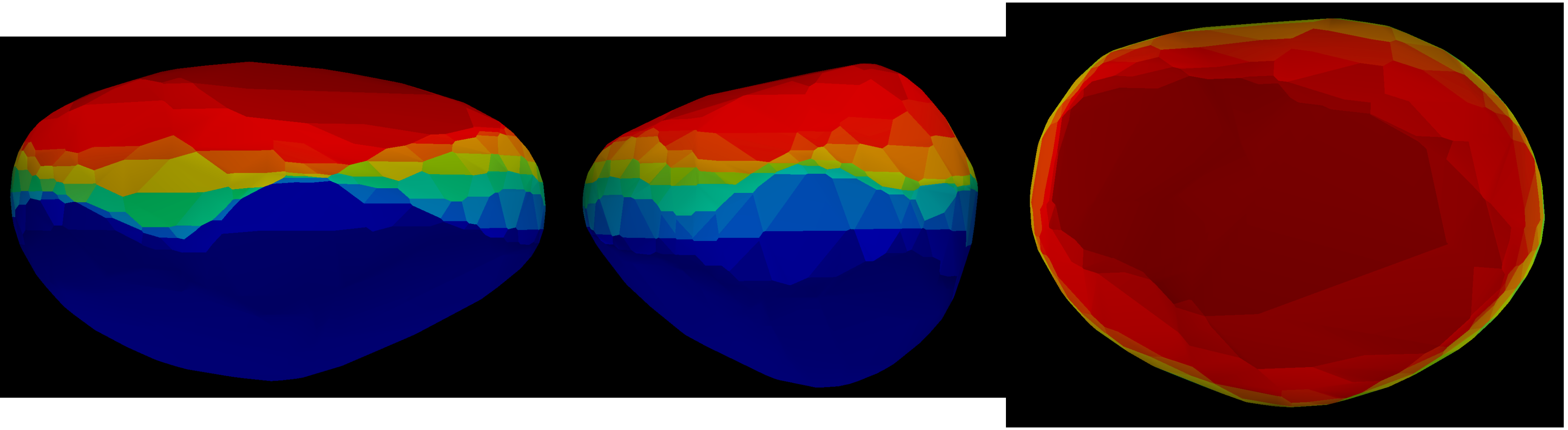
Fig. 4: A 360-degree thermal map of Didymos at a fixed time epoch, from one of our simulations. We placed Didymos at a distance of 1au from the Sun for these simulations.

Others vs our model

Other simpler models







Our thermophysical model

Asteroid 22 Kalliope

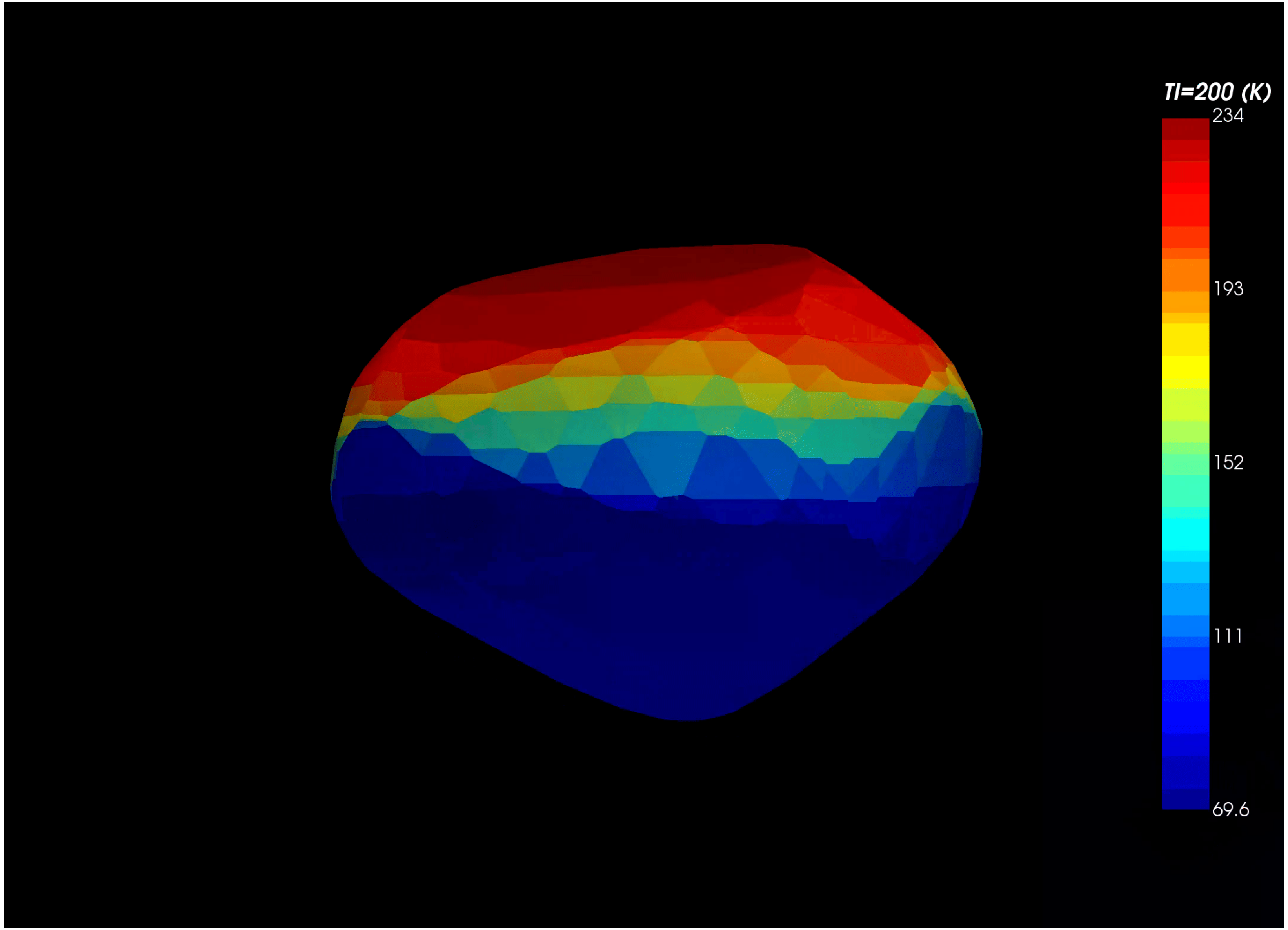


Fig. 5: Asteroid Kalliope temperature model obtained from our simulation. Thermal inertia of 200 TIU is considered for this case.

Asteroid 22 Kalliope flux simulated

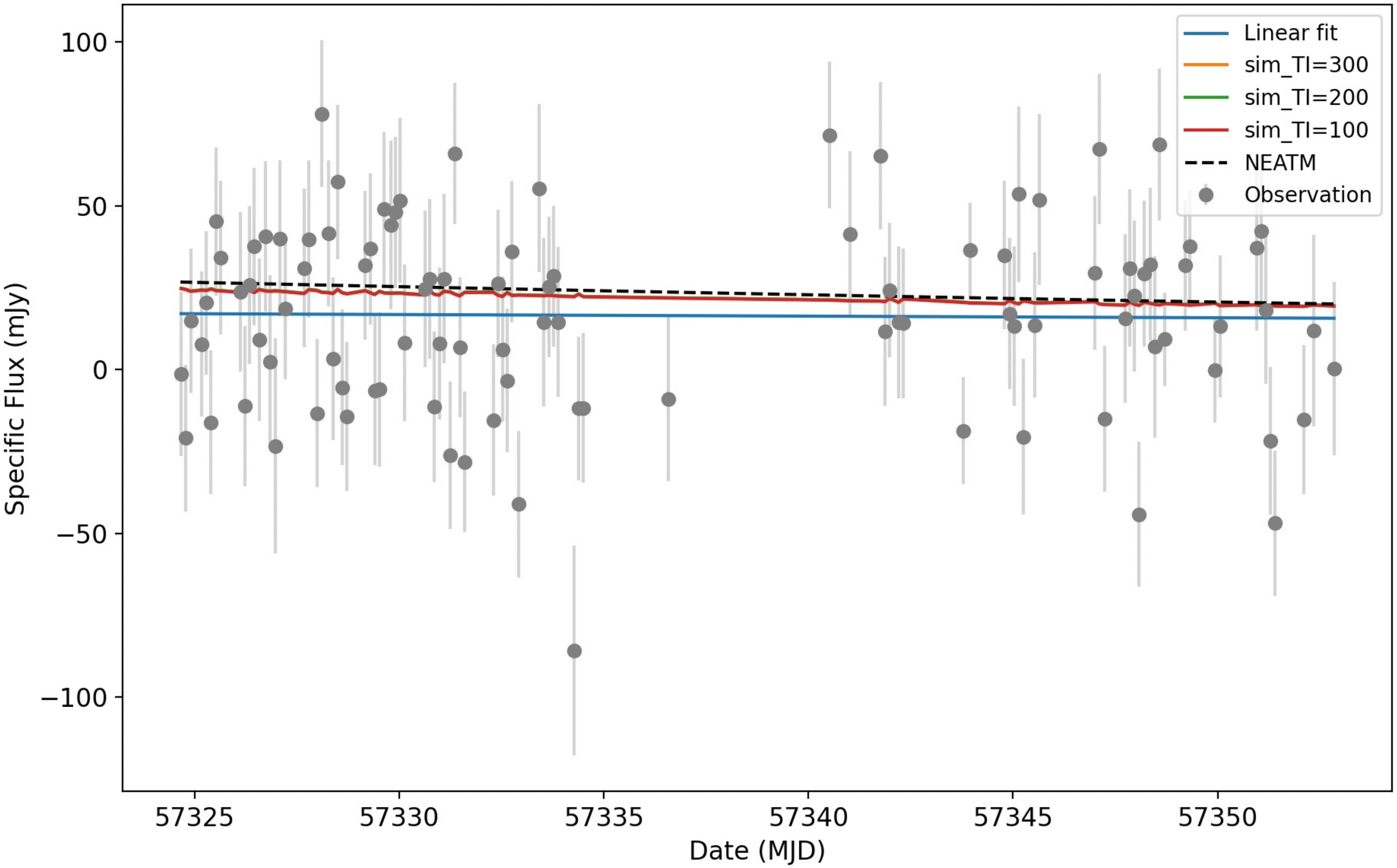
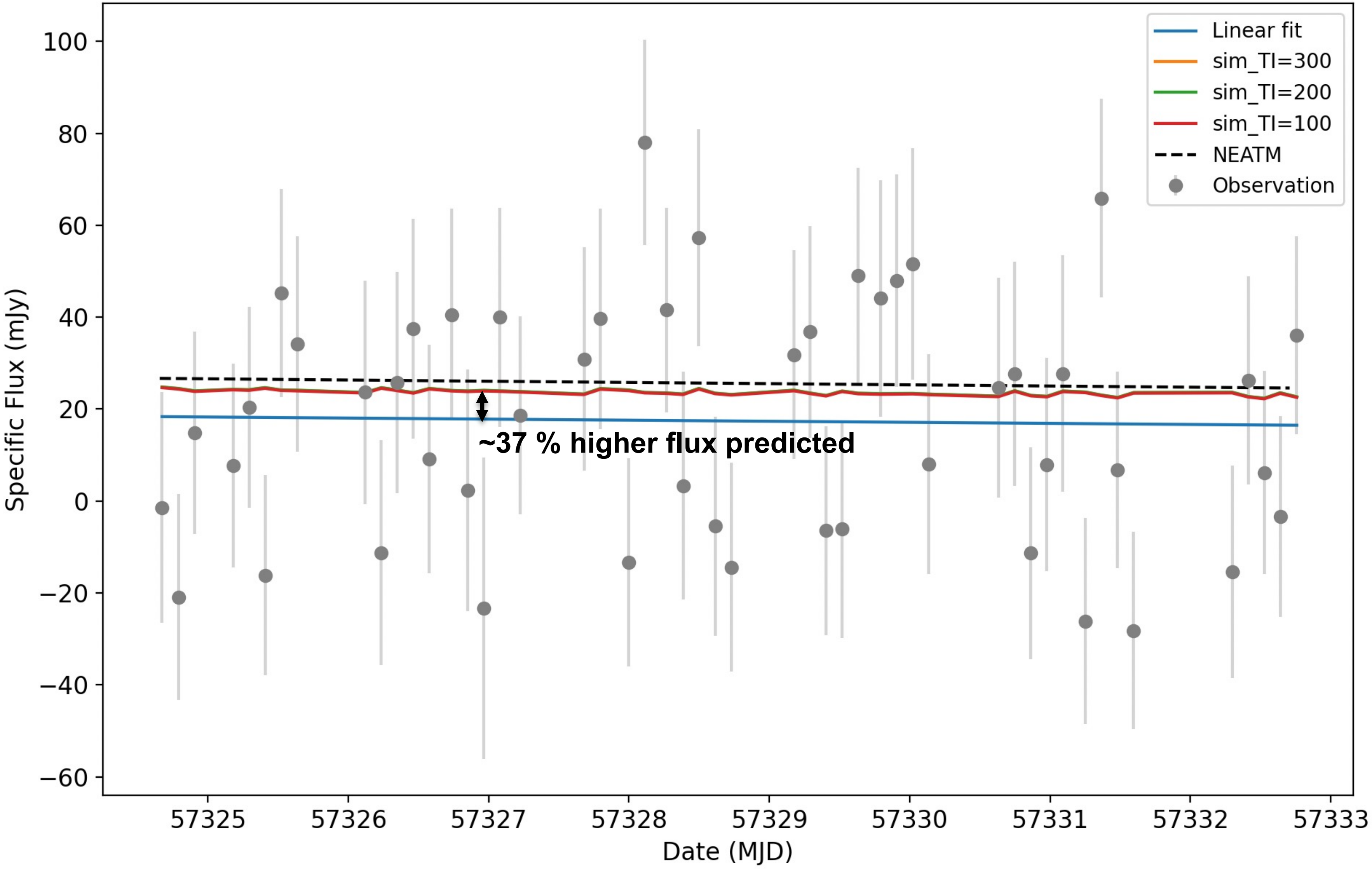


Fig. 6: Comparing the simulated flux of asteroid Kalliope for different thermal inertias and NEATM prediction with SPT data (150 GHz) (Chichura et al. (2022))

Asteroid 22 Kalliope flux simulated



Other possibilities

- M type asteroids have been assigned low thermal inertias, and de Kleer et. al. (2021) disputes that.
- In their analysis of Psyche, de Kleer et. al. (2021) notes that thermal emission from the asteroid is mostly unpolarized, and surface roughness alone cannot be the cause.
- They suspect that scattering might be the only plausible reason.
- More work to be done.

Plans with CMB-S4

- Once the gap in flux is understood and properly modeled, we can use our model to accurately predict asteroid flux in millimeter wavelengths.
- Sorcha Solar System survey simulator releases this summer.
- CMB-S4 survey simulation with Sorcha will allow us to get an idea of what we can see and how much we can discover with CMB-S4.
- With better sensitivity, CMB-S4 can provide asteroid fluxes with lower noise and scatter, giving us a good chance to peek below the surface of asteroids.
- Machine learning to speed up our model?
- Better post-processing of the observed raw data?

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Thank You

Asteroid types