



PHYSICAL CHARACTERIZATION OF POTENTIALLY HAZARDOUS ASTEROID (1566) ICARUS

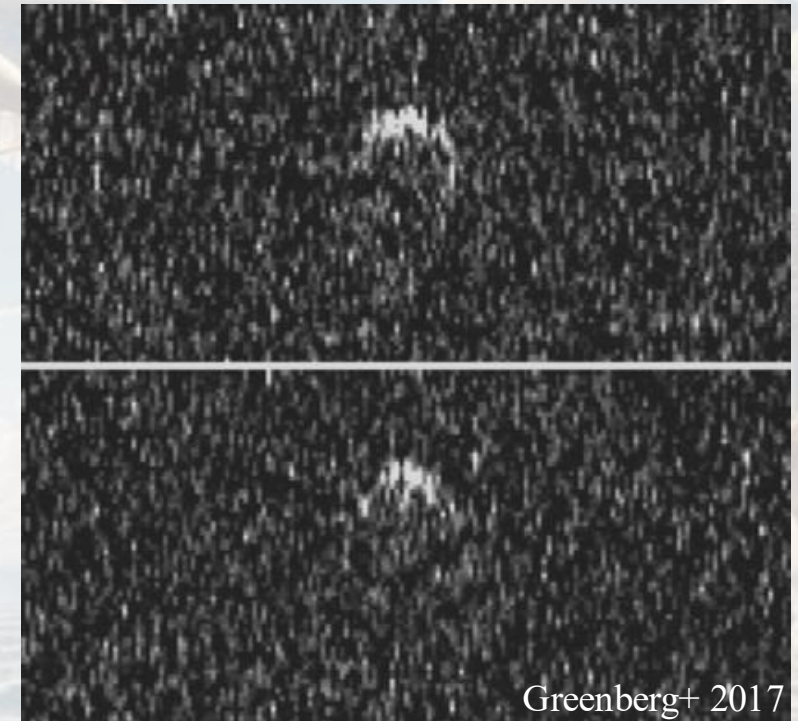
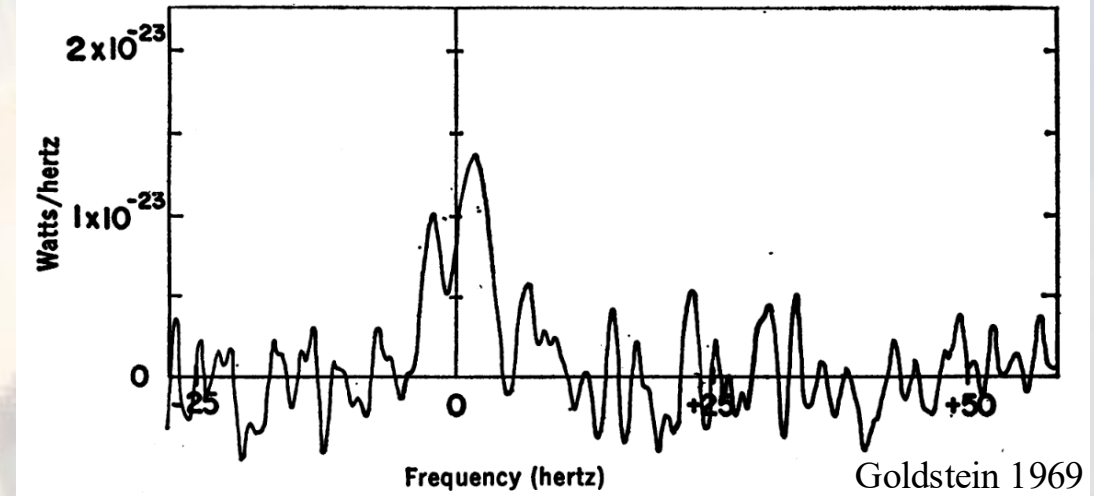
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Stellenbosch, Cape Town, S. Africa

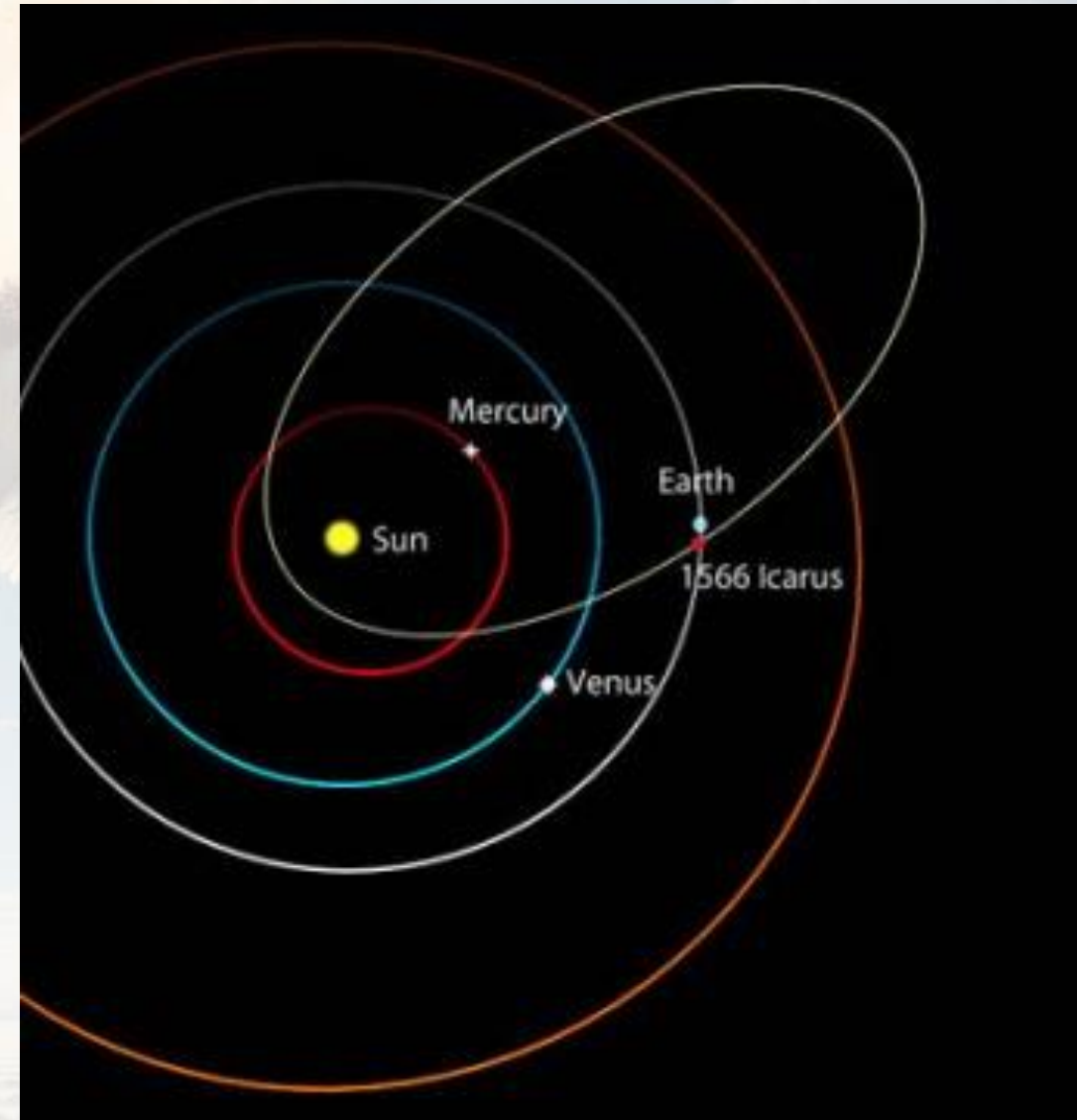
MOTIVATION

- potentially hazardous NEA
 - Earth MOID = 0.0352 AU or 13.7 LD
 - rare close passes to Earth (every 9, 17 yr)
- possibly linked to Taurid-Perseid meteors (Kasuga & Jewitt 2019): debris hazard?
 - rotational disruption? ($P_{rot} = 2.27$ hr)
 - near-Sun disruption? (Granvik+ 2016)
 - tidal disruption? (Granvik+Walsh 2024)
- first asteroid to be observed using radar → yet remains poorly characterized
 - very low radar albedo (Greenburg+ 2017) & no shape model is possible
 - $D_{eff} = 1.44 \pm 0.26$ km
 - uncertain spin orientation, **H** mag, albedo



TALK OUTLINE:

1. physical characterization from pre-existing observations
 - shape modeling
 - thermophysical analysis
2. new ground-based infrared observations
 - theoretical foundation
 - planning and reduction techniques
 - simultaneous visible photometry
3. prospects for planetary defense



credit: Sky & Telescope

SHAPE MODELING & TPM

Photometric Dataset:

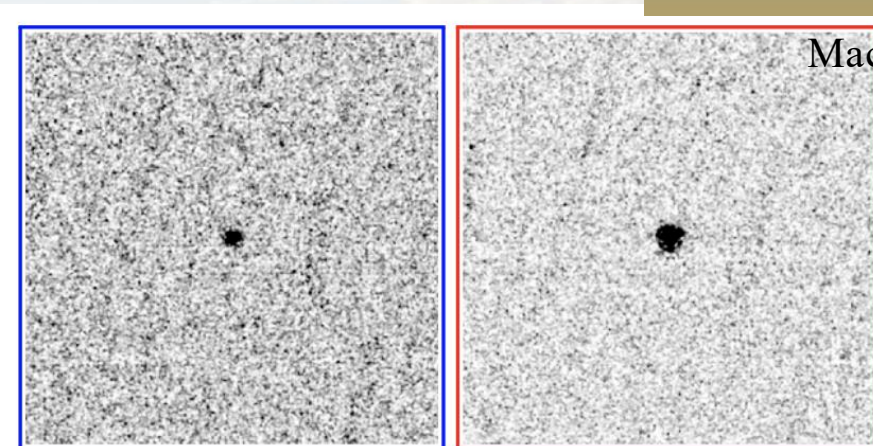
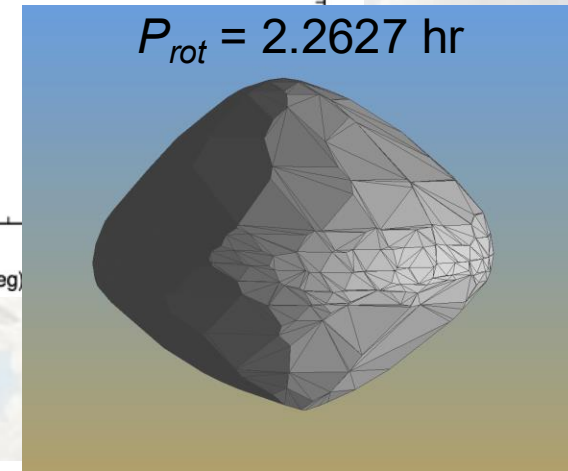
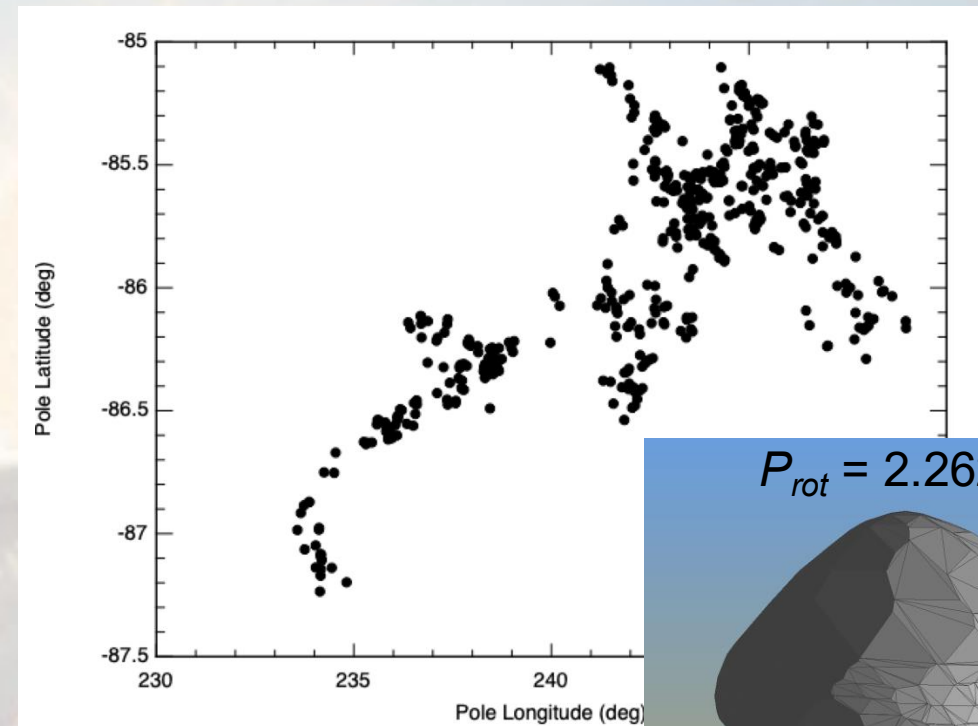
- 42 lightcurves from 1968, 2015 (LCDB)
 - 5 *Gaia* DR3 datapoints
- lightcurve inversion w. MCMC →
(Muinonen+ 2020)

IR Dataset:

- NEOWISE W1 & W2: 3.35 μm , 4.60 μm
2010, 2014, 2020
- Spitzer CH1 & CH2: 3.55 μm , 4.49 μm →
(IRAC) 2014, 2017

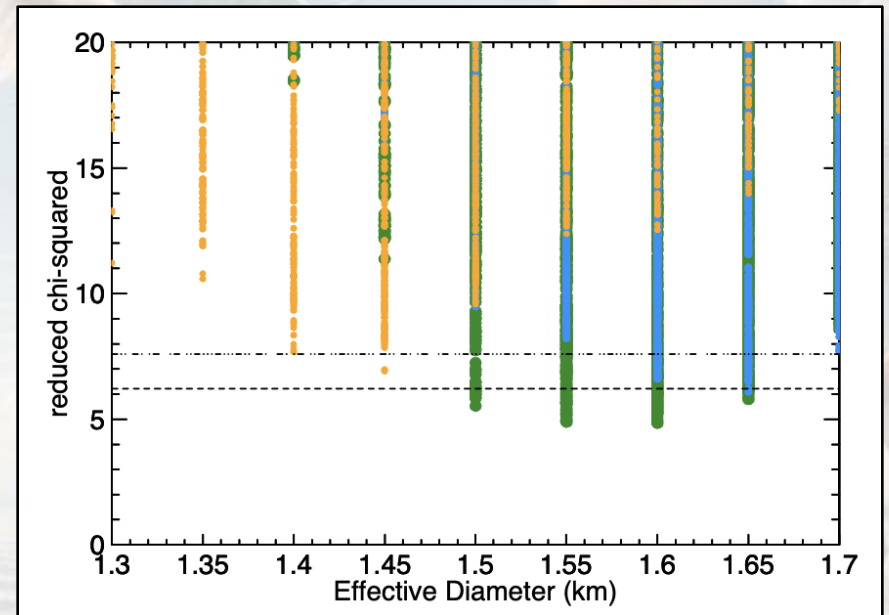
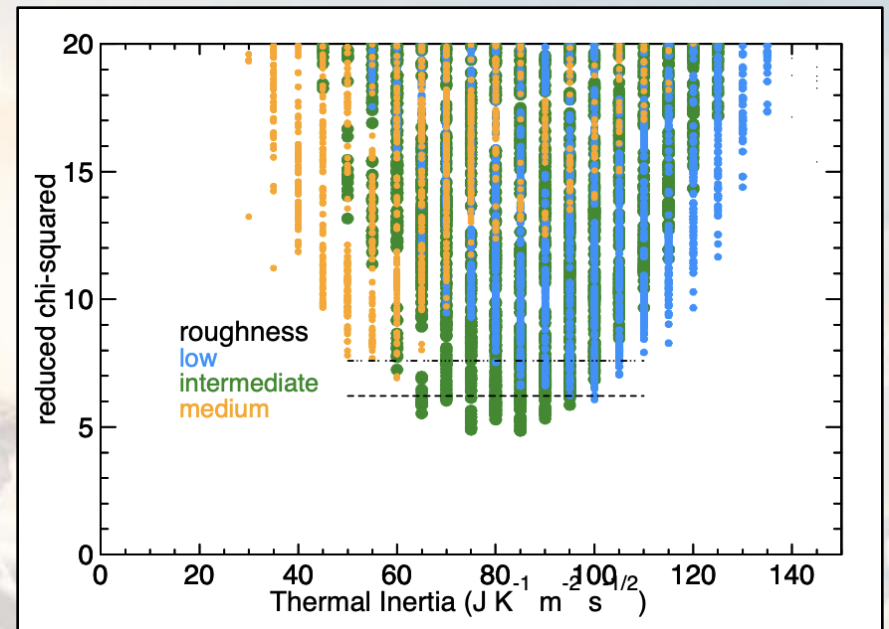
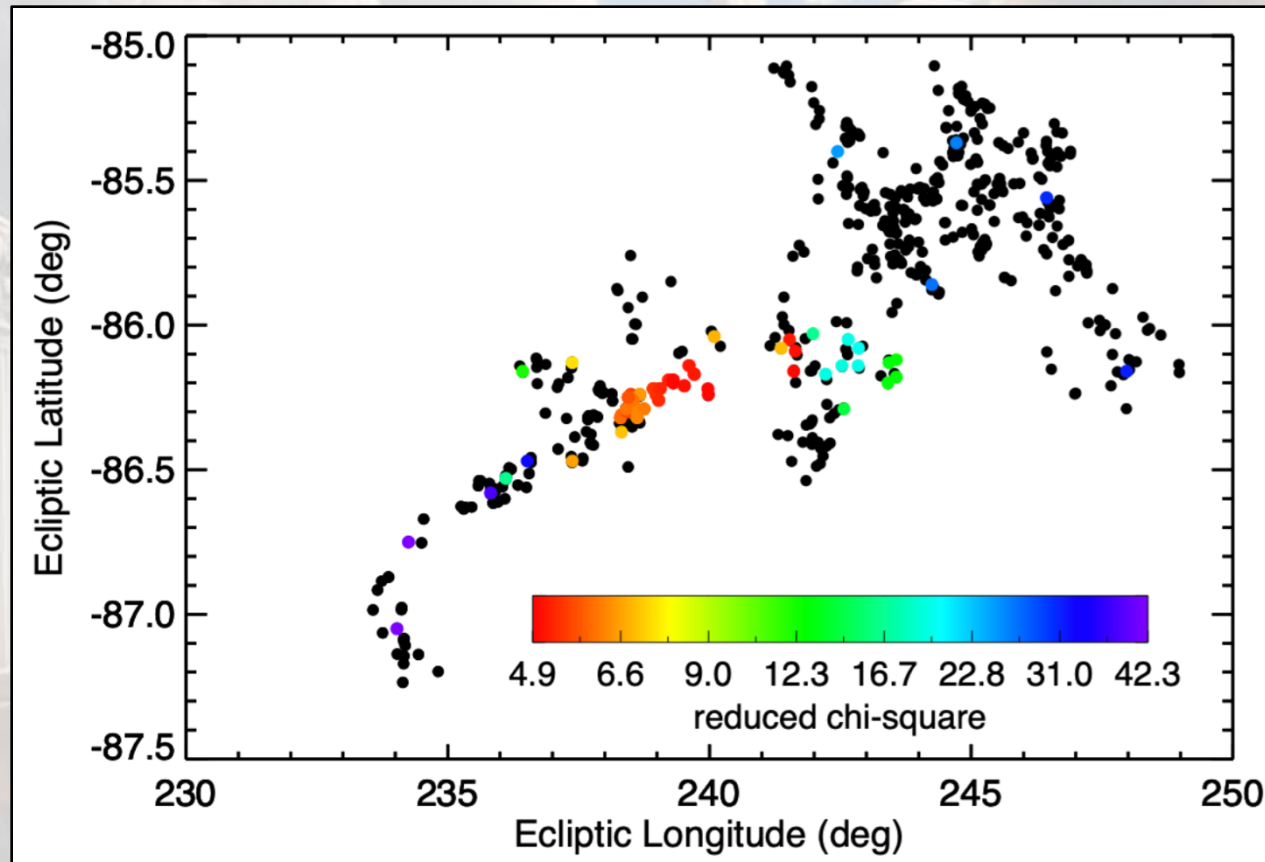
Thermophysical Model (TPM):

- MacLennan & Emery (2019, 2021)
- use the set of spins and shapes with TPM



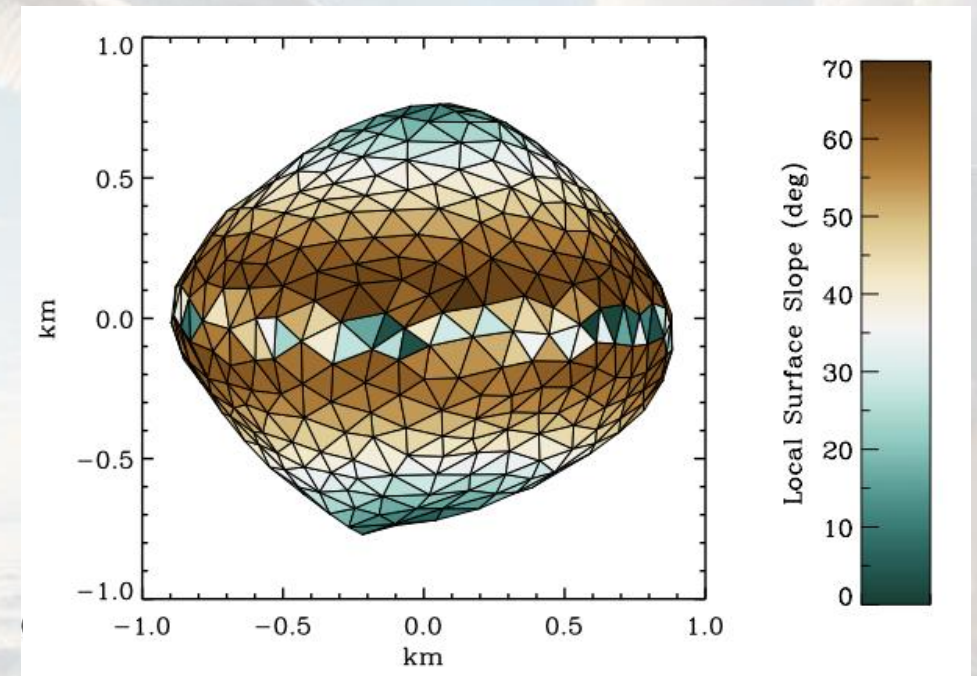
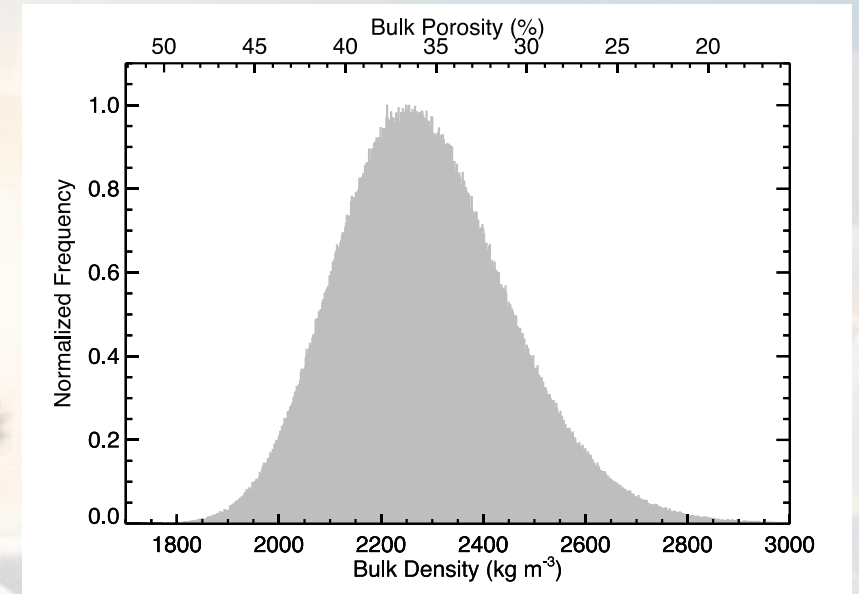
SHAPE MODELING & TPM

$D_{eff} = 1.57 \pm 0.1$ km
low thermal inertia (lunar-like)
moderate roughness
improved spin constraint



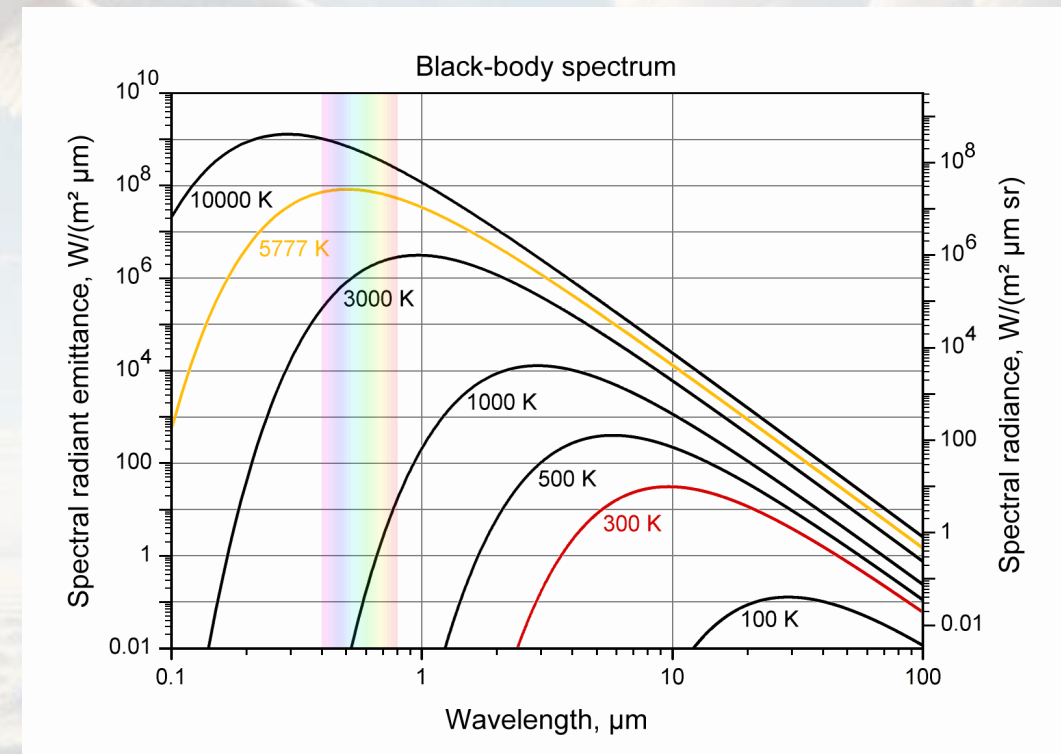
SHAPE MODELING & TPM

- bulk density & porosity via Yarkovsky model
 - Greenberg+ 2017 da/dt value
- gravitational slopes approach 70°
 - 0° = net force is downwards
 - 90° = perpendicular to local surface
- higher risk of landslides & dust ejection
 - possible meteor source
- in June 2024, Icarus made a close 0.21 AU flyby with Earth
 - opportunity to perform ground-based infrared observations for comparison to space-based



ASTERIODS IN THE INFRARED

- sunlight is incident at the surface
 - **albedo** determines how much energy is reflected and absorbed
- heat transfer into the subsurface
 - **thermal inertia** dictates how quickly the temperatures change
- peak surface blackbody emission at infrared wavelengths
- **size** is directly proportional to the total flux



NASA INFRARED TELESCOPE FACILITY

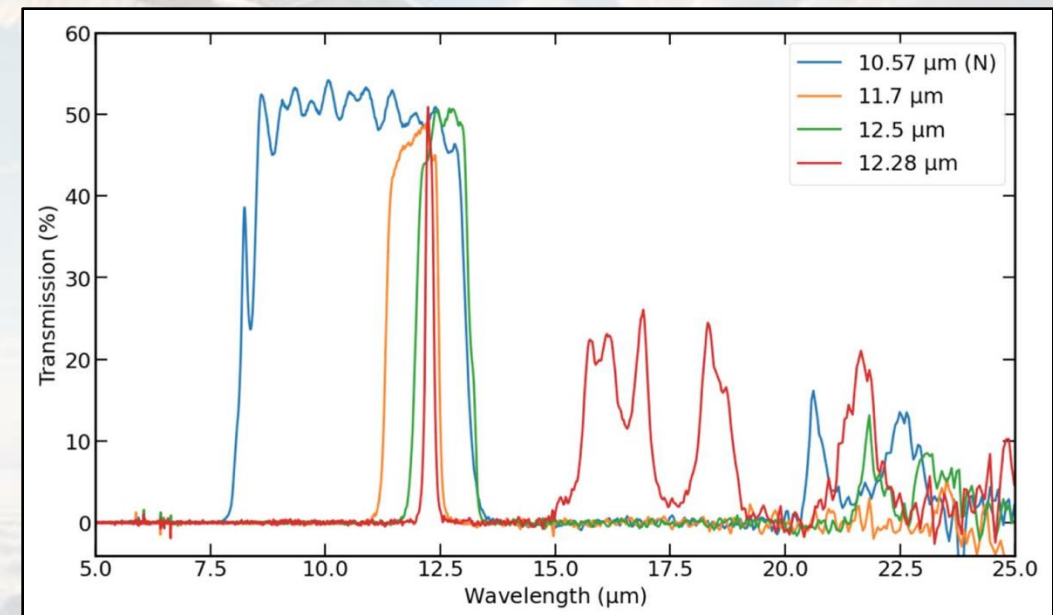
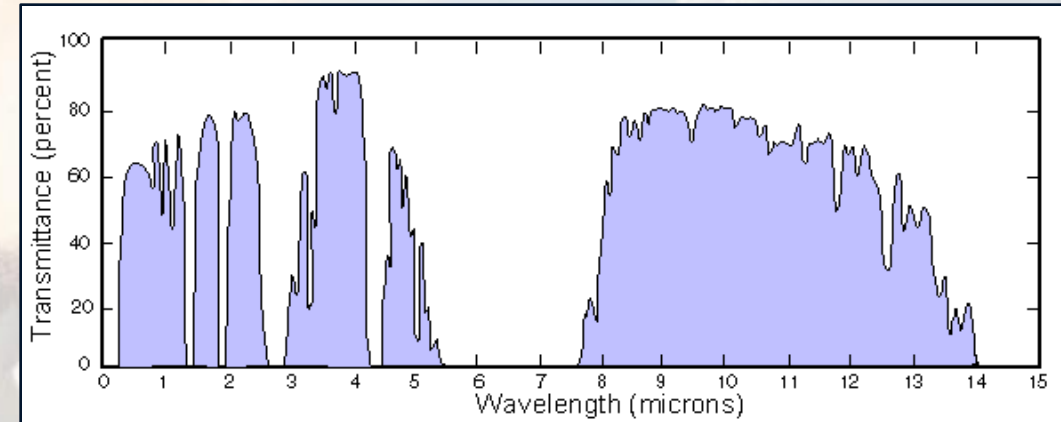
- **MIRSI:** Mid-Infrared Spectrometer and Imager
 - 2 – 20 micron observations
 - narrow and wide-band filters
 - N-band: 10 microns
- `Opihi: 17" finder scope
 - 0.5 x 0.5 field of view
 - standard visible filter set



Credit: NASA IRTF

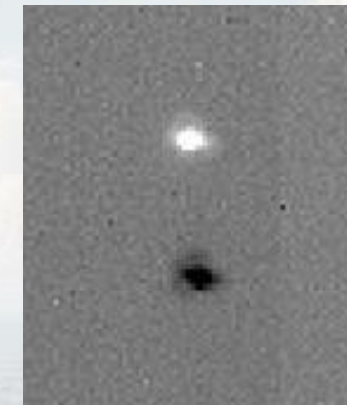
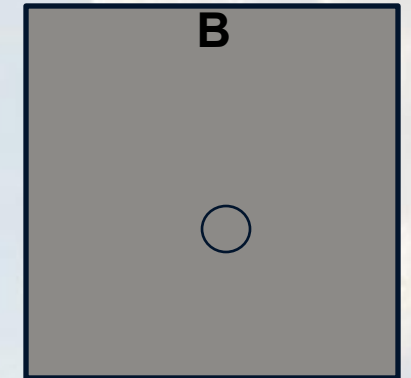
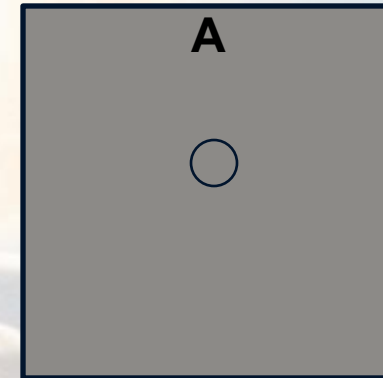
OBSERVING IN THE INFRARED

- best to be outside of Earth's atmosphere
 - high elevation sites are second best
- atmospheric transmission window centered around 10 microns
- the atmosphere is also warm and bright at infrared wavelengths
 - overcome via unique observing and data reduction techniques



INFRARED OBSERVATION TECHNIQUES

- reduce the sky emission:
 - take short (0.01 sec) exposures
 - co-adding hundreds of images gives uniform sky emission across the detector
 - nod telescope to acquire A-B pairs
 - position of the target changes
 - subtract the pairs to remove the sky emission
 - result: positive and negative source
- Hora+ 2024 describes the basic operation and data reduction steps for IRTF MIRSI
 - and thanks to A. López-Oquendo



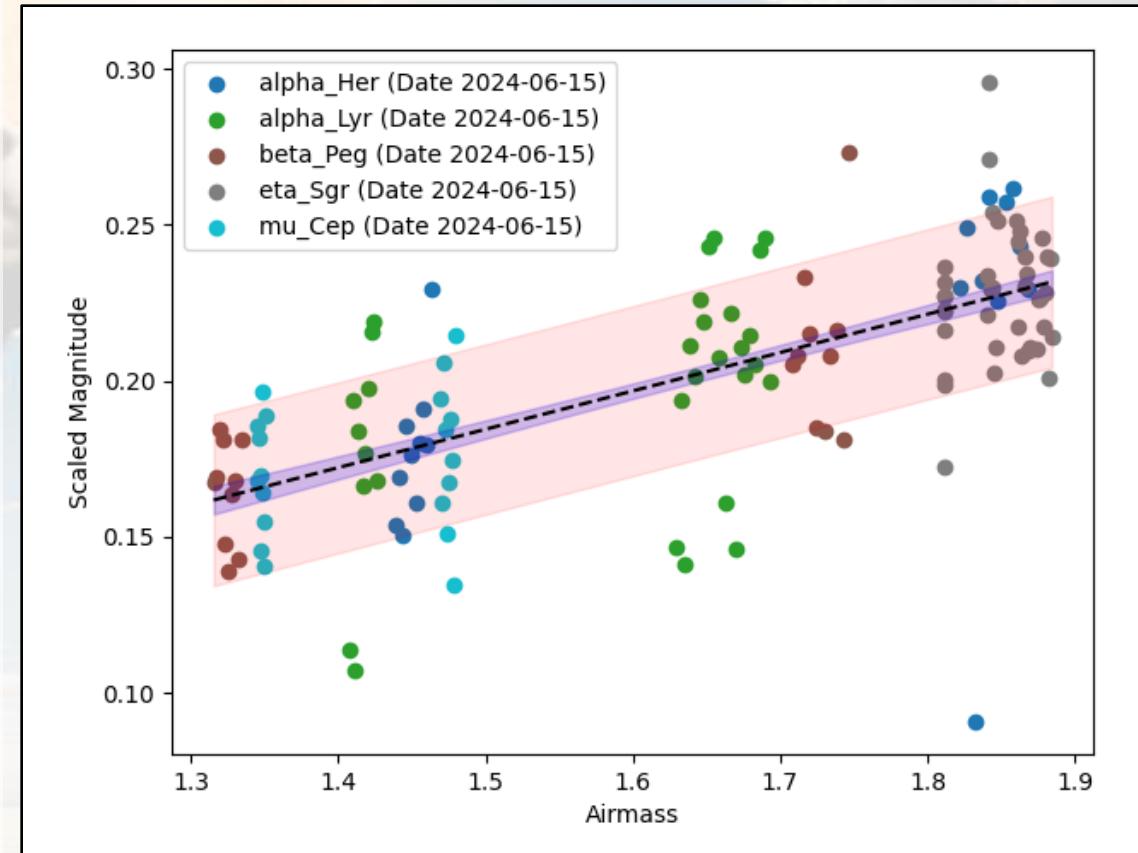
subtracted pair



stacked pair

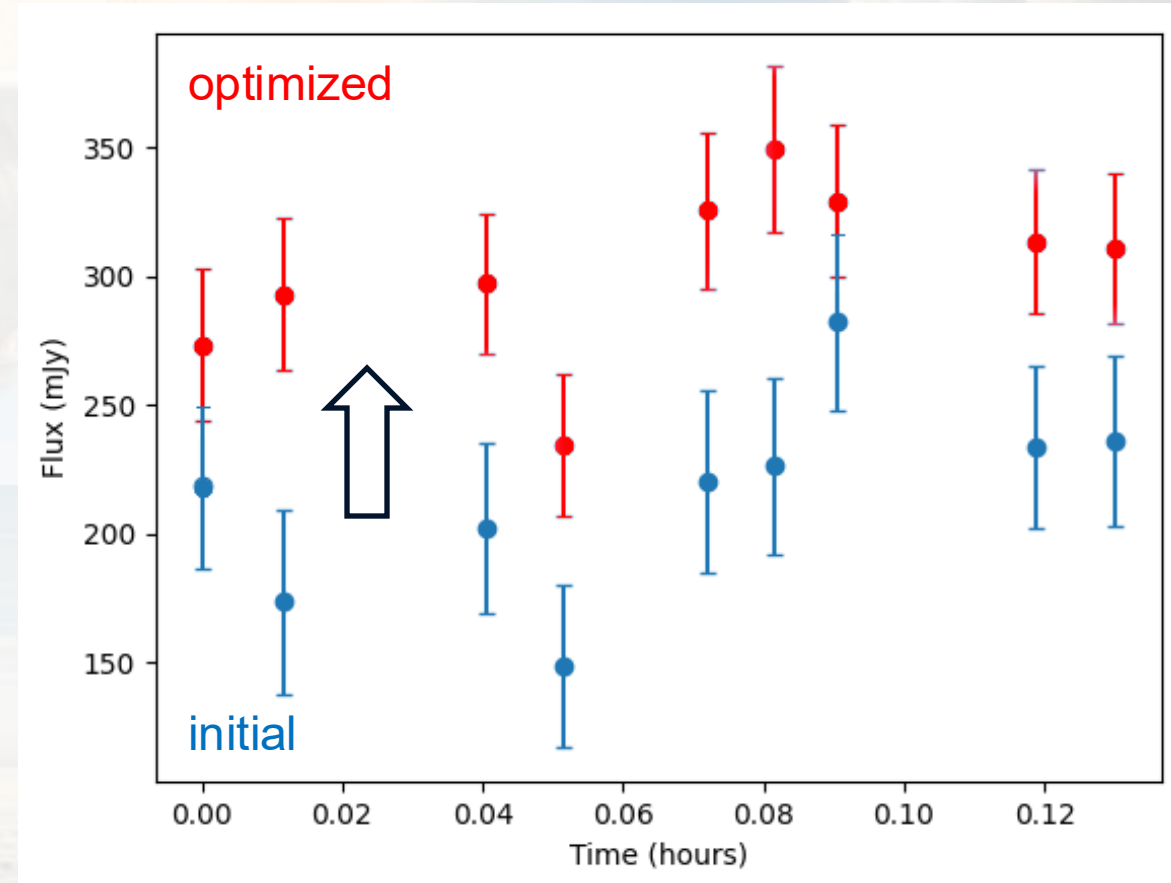
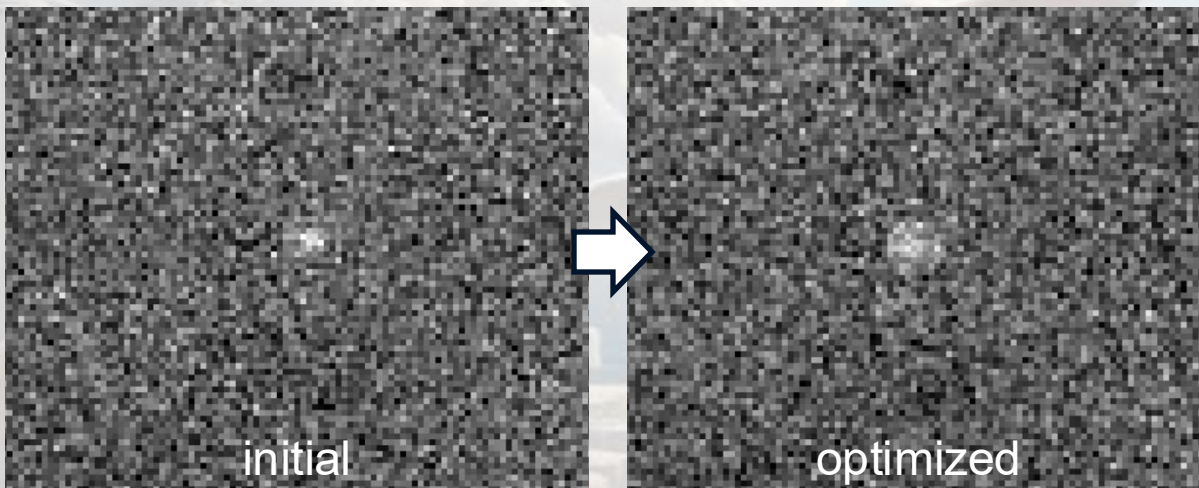
STAR REDUCTION & MAGNITUDE CALIBRATION

- stars are bright enough to be detected in sky subtracted A-B pairs
1. create image mosaics from A-B pairs and extract counts in circular aperture
 2. extinction factors for absolute calibration
 - fit a constant slope (e.g. 0.1 mag/airmass) for all stars (2 per night is enough)
 - critical for *high airmass* observations
 - can vary over 2x over different nights
 3. typical 1σ uncertainties are 0.02 to 0.04 mag



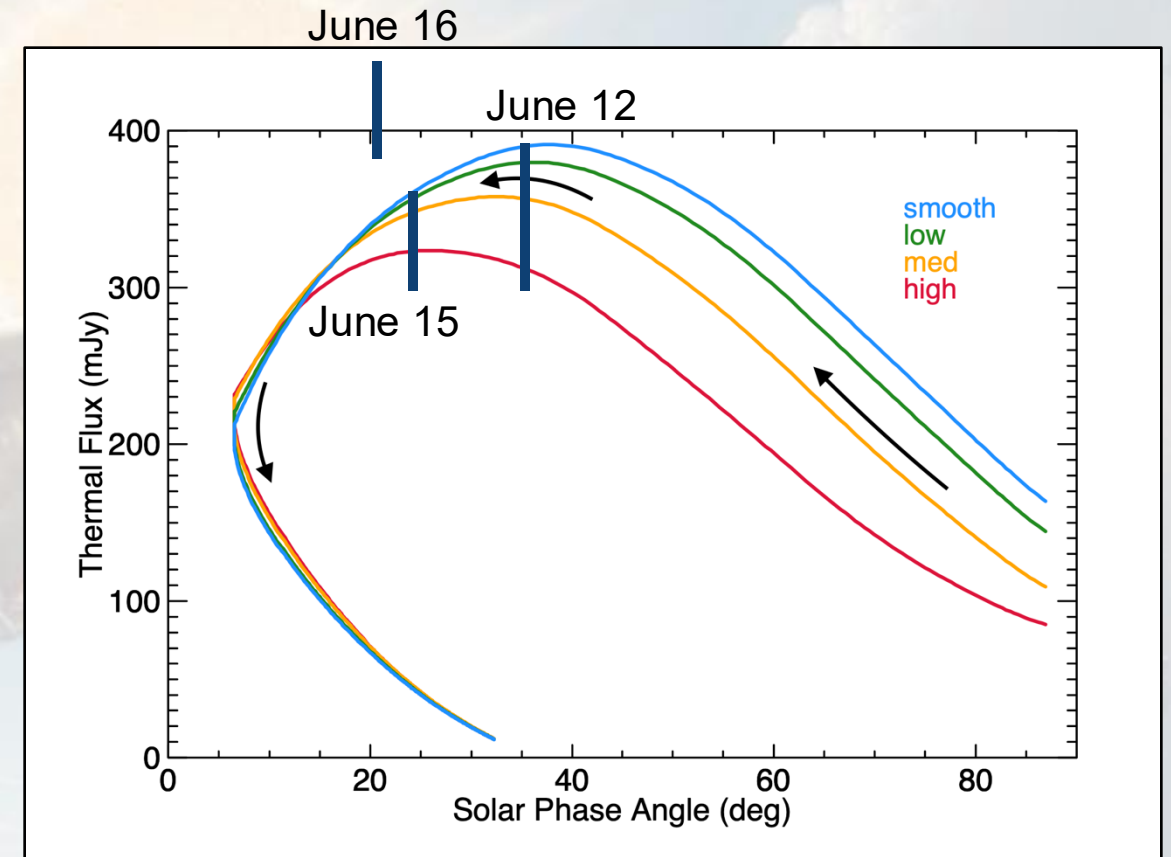
MIRSI ASTEROID REDUCTION

- Icarus is too faint to be seen in single A-B pairs
 - use telescope offsets for *initial* alignment and blind stacking
- search for optimal image shifts to *optimize* signal in a small aperture
 - requires lots of computation
 - significant increase in ADU counts!!
 - ~50-100 mJy difference



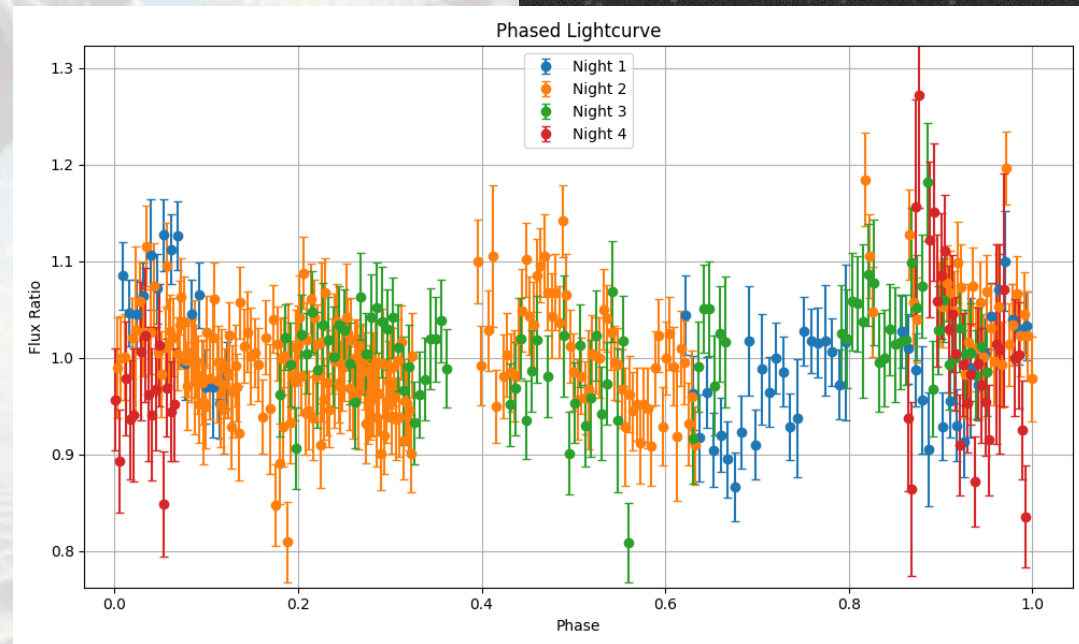
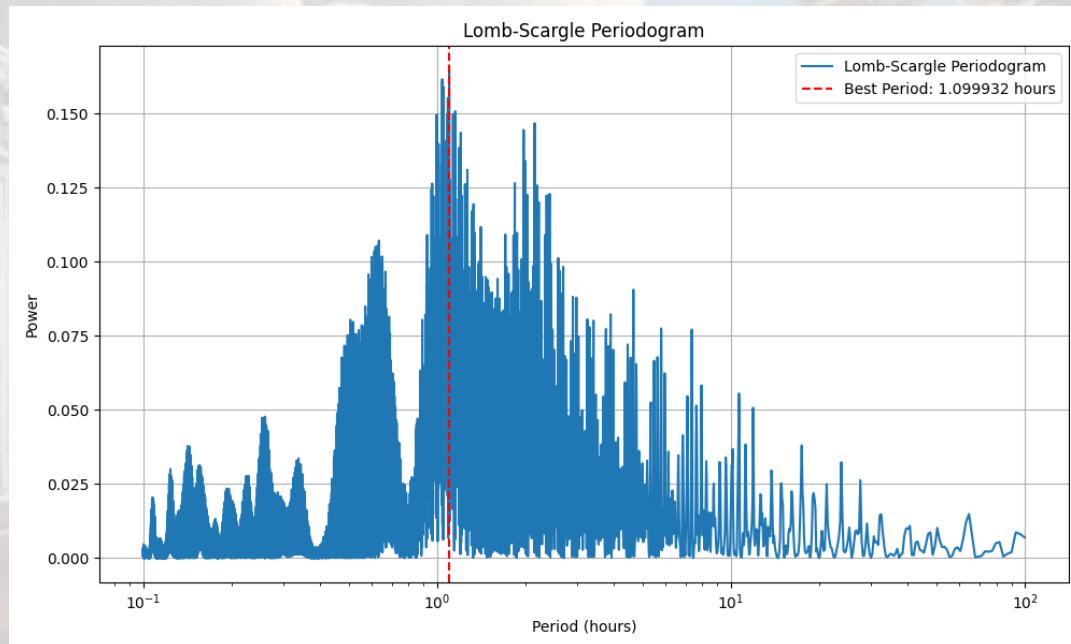
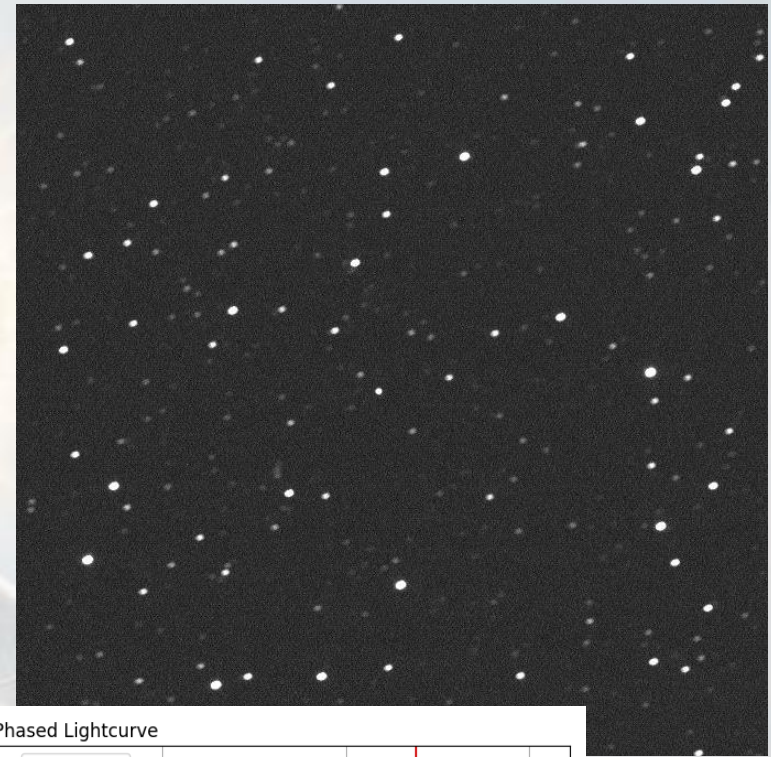
SIZE ESTIMATION

- fluxes are consistent with 1.4 km diameter, thermal inertia of $80 \text{ J K}^{-1}\text{m}^{-2}\text{s}^{-1/2}$
- 30 mJy for 300 mJy source uncertainty corresponds to $\sim 10\%$ size uncertainty
 - without proper stacking, the size estimate would be $\sim 25\%$ smaller
- MIRS I fluxes are consistent with predicted fluxes from space-based IR observations
 - except for June 16?



OPTICAL PHOTOMETRY

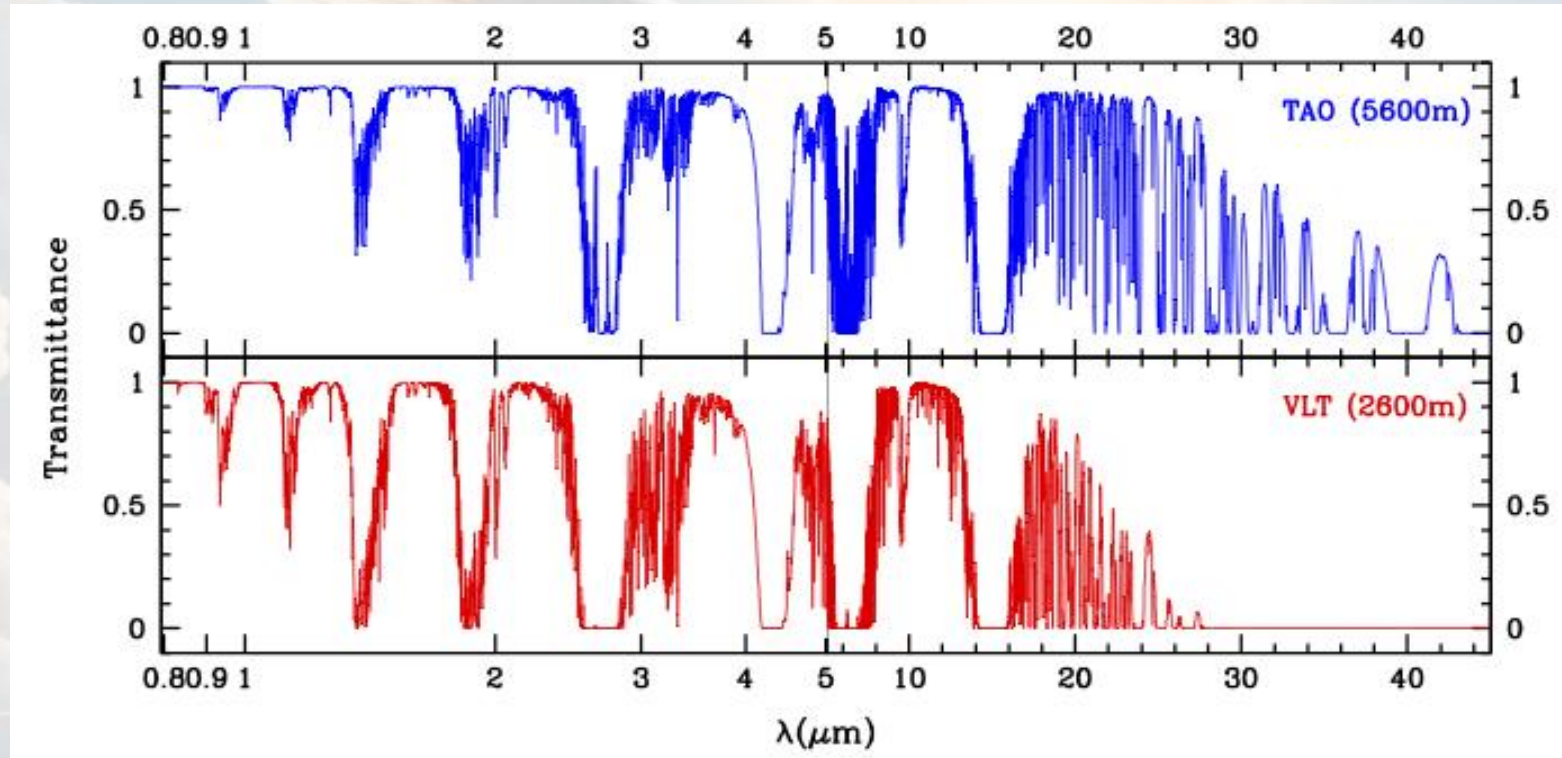
- simultaneous r' -band photometry using `Ophi
- time-series brightness variations over several nights
- PSF photometry to account for mid-exposure dithering
- known rotation period is 2.2726 hours, low amplitude
 - L-S analysis gives a best period at 1.099



IMPLICATIONS FOR PLANETARY DEFENSE

- ground-based thermal IR observations with IRTF/MIRSI are possible for ~km PHAs
 - detection of Icarus (~1.4 km) 0.21 – 0.23 AU from Earth
 - comparable flux accuracy to space-based observations
 - could have observed 2024 YR₄ within a few days after its discovery
- with the loss of Arecibo, direct asteroid size determination via *radar* is limited to relatively close approaches of larger-sized asteroids
- infrared observations are the best option for direct size determination
 - physical characterization (e.g., thermal inertia, albedo) is possible with a shape model via visible lightcurve photometry

IMPLICATIONS FOR PLANETARY DEFENSE



- currently, only JWST, VLT, IRTF, and TAO (U. Tokyo Atacama Observatory project) can be used for new IR observations
- looking forward to NASA's NEOSurveyor & ESA's NEOMIR missions



THANK YOU!