Reflectances at $\lambda > 2.5 \, \mu m$ of TNOs, Centaurs, and Pluto

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Motivation for $\lambda > 2.5 \, \mu m$

- Characterize dark material
  - Neutral and moderately red TNOs/Centaur
    - attributable to different materials (silicates, organics)
    - spectra diverge at longer wavelengths
  - Reddest TNOs/Centaur most likely organic
    - use longer wavelengths to constrain type
  - Pluto: uncertain cause of $\sim 4 \, \mu m$ spectral shape
    - perhaps tholins
- Possibly identify/characterize other ices (e.g., CH$_3$OH, CO, CO$_2$)
  - not primary goal, but must be kept in mind
IRAC observing program

- Infrared Array Camera (IRAC)
  - 3.6, 4.5, 5.8, 8.0 µm imaging
  - 5.2 arcmin FOV, 1.2 arcsec pixels

- TNO/Centaur/Trojan program
  - 30 objects (12 TNOs, 8 Cen., 10 Troj. ast.)
  - 3.6 and 4.5 µm for all, 5.8 µm for a few
  - 8 µm thermal for Trojans and two Centaurs
  - 2 observations of each object (9 to 16 dith. each)

- Pluto
  - all four IRAC bands in reflectance
  - 8 longitudes – evenly spaced
Pluto Images

pl = \frac{F_\lambda r_{AU}^2 \Delta^2}{F_{sun,\lambda} \Phi R^2}

bg subtraction of nearby stars and sky error – stdev of dithers & photon stats
5.8 and 8.0 μm have very similar light curves.

4.5 μm similar at ~70 – 200°, but distinct at ~240 - 30°.

3.6 μm somewhat similar to 5.8 and 8.0, but much lower amplitude (strong CH₄ absorption).
• 5.8 and 8.0 μm track with vis and strong CH$_4$ (but no min in 5.8)
• 4.5 μm does not follow any of the known compositional light curves

Grundy & Buie (2002)
Pluto Albedos (2)

- Overall increase in albedo to longer wavelengths
- Distinct spectral shape at ~240 - 30° due primarily to higher 4.5 µm albedo relative to 5.8 and 8.0 µm
- Tholins? Other hydrocarbons? Other ices?
Pluto Albedos (2)

![Graphs showing Geometric albedo vs Wavelength (µm) for different E. Longitudes: 200, 159, 116, 72, 26, 341, 297, 250.](image-url)
TNO / Centaur / Trojan images

Quaoar, 3.6 µm

Hektor, 3.6 µm

2.9'

Hektor, 8.0 µm
Asbolus (Centaur)

- Vis-NIR ($\lambda < 2.5 \, \mu m$):
  - low albedo (~4.5%)
  - moderately red, featureless spectrum
  - generally modeled in terms of tholins, but silicates can also adequately match
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- **IRAC data**
  - most closely matches Triton tholin mixture
  - not ice or Titan tholin or pure silicates (but IRS data)

IRAC albedos are nearly identical for the two different observations (separated by 2.5 rotations)
**Pholus (Centaur)**

- **Vis-NIR** ($\lambda < 2.5 \, \mu m$):
  - Low albedo (~7%)
  - Extremely red
    - Requires tholins
  - Features of $H_2O$ and $CH_3OH$
- **IRAC data**
  - Very low albedos at 3.6 and 4.5 $\mu m$ indicate strong absorber, probably $H_2O$ and $CH_3OH$, but requires further modeling
Hektor (Trojan asteroid)

- **Vis-NIR ($\lambda < 4.0 \ \mu m$):**
  - Low albedo (~3%)
  - Moderately red, featureless spectrum
  - No absorption in L-band from tholins or H$_2$O

- **IRAC data**
  - Consistent with silicate models
  - Simultaneous thermal measurement at 8$\mu$m gives $p_v$ of 3%
Summary

• Pluto
  – Rotational variation at 4.5 μm different from $p_v$ and $\lambda < 2.5$ μm features
  – 3.6, 5.8, and 8.0 similar to CH$_4$ light curve
  – 90° to 220° distinct spectrophotometrically from 270° to 40° (E. Long.)

• TNOs/Centaurs/Trojans
  – 30 objects in program
    • most only observable at 3.6 and 4.5 μm
  – Use to constrain dark component and surface ices
    • analysis ongoing, but initial results are promising (possibly imply organics for Asbolus, silicates for Hektor)
  – For Trojans and a few Centaurs, we detect thermal flux at 8 μm => size and albedo est.
IRS Data

- Measure emitted flux density as a function of wavelength
- Model thermal continuum and remove (divide) to produce emissivity spectrum
  - accentuates compositional features

\[ R_{\text{eff}} = 49.4 \pm 3.6 \text{ km} \]
\[ \rho_v = 0.040 \pm 0.013 \]
\[ \eta = 0.87 \pm 0.04 \]
IRS Data

Fine-grained silicates on Hektor and Asbolus.
Uncertain feature in 1999 TD10 and 1999 RG33