

**Thermophysical Characterization of Potential Spacecraft Target (101955) 1999 RQ<sub>36</sub>.** J.P. Emery<sup>1</sup>, Y.R. Fernández<sup>2</sup>, M.S. Kelley<sup>3</sup>, C. Hergenrother<sup>4</sup>, J. Ziffer<sup>5</sup>, D.S. Lauretta<sup>4</sup>, M.J. Drake<sup>4</sup>, H. Campins<sup>2</sup>. <sup>1</sup>Univ. Tennessee (jemery2@utk.edu), <sup>2</sup>Univ. Central Florida, <sup>3</sup>Univ. Maryland, <sup>4</sup>Univ. Arizona, <sup>5</sup>Univ. Southern Maine.

**Introduction:** The goal of visiting and returning samples from near-Earth asteroids (NEAs) is rising in priority for space agencies across the globe. This trend is evidenced by the recent NASA NEAR mission to Eros [1], the recent NRC recommendation for New Frontiers-class mission [2], the JAXA Hayabusa mission to Itokawa [3], the planned ESA/JAXA Marco Polo mission [4], discussion within NASA of NEAs as potential destinations for a rejuvenated human flight program [5], and the high ranking of NEA sample return missions in the planetary science decadal survey and recent Discovery mission calls. Characterization of potential targets is important in the context of both mission science goals and mission planning.

We present characterization of the composition, surface structure, and thermophysical properties of the near-Earth asteroid (101955) 1999 RQ<sub>36</sub> with the Spitzer space telescope. This asteroid was the target of the OSIRIS mission, which was selected for Phase A study in the last Discovery round. Although OSIRIS did not advance further in that round, 1999 RQ<sub>36</sub> remains a likely target for future missions.

**Background on 1999 RQ<sub>36</sub>:** 1999 RQ<sub>36</sub> is a B-class NEA. In the asteroid population, B-class objects are thought to be primitive, volatile-rich remnants from the early Solar System. Spectroscopy of B-class objects suggests surface constituents of anhydrous silicates, hydrated clays, organic polymers, magnetite, and sulfides [6,7]. The idea that B-class objects are volatile rich is also supported by observations of the Themis family, a cluster of asteroids produced by a large disruption in the Main Belt [8]. Two members of the Themis family, (7968) Elst-Pizarro and (118401) 1999 RE70, display intermittent comet-like activity [9,10]. These observations suggest that 1999 RQ<sub>36</sub>, which may have come from the Themis family through the 2:1 jovian mean motion resonance, represents volatile rich material from the early Solar System.

Spectrally, 1999 RQ<sub>36</sub> is a B-class object characterized by a linear, featureless spectrum from 0.5 to 2.5  $\mu\text{m}$  with a neutral to bluish spectral slope [11,12]. A thermal tail is observed longward of 2  $\mu\text{m}$ , confirming a very low albedo (0.03-0.06). Radar observations from Goldstone and Arecibo in 1999 and 2005 resolved the shape and size of 1999 RQ<sub>36</sub>, which will significantly aid the interpretation of the proposed thermal observations. 1999 RQ<sub>36</sub> has a diameter of  $\sim 775$  m and a nearly spherical shape. The surface of 1999 RQ<sub>36</sub> is featureless down to the radar resolution

limit of 7.5 m. It is plausible that resurfacing was a consequence of impacts or electrostatic dust levitation [13], though these mechanisms do not explain 1999 RQ<sub>36</sub>'s nearly spherical shape. This shape may be evidence that recent close approaches with Earth either exposed fresh material on its surface or possibly even turned the body "inside out". Based on these data, it is highly plausible that fresh material is readily available for sampling on the surface of 1999 RQ<sub>36</sub>.

**Observations:** Spitzer observed 1999 RQ<sub>36</sub> in three modes during the time period 3 to 9 May 2007. Since the rotation period was well constrained by radar observations and ground-based lightcurve data, we were able to phase our observations for uniform longitude coverage. Thermal spectra from 5.2 to 38  $\mu\text{m}$  were measured with the Infrared Spectrograph (IRS) of opposite hemispheres of the body. Photometry at 16 and 22  $\mu\text{m}$  was obtained with the IRS peak-up imaging (PUI) mode and at 3.6, 4.5, 5.8, and 8.0  $\mu\text{m}$  with the Infrared Array Camera (IRAC). Because of greater sensitivity of the imaging modes, we targeted 10 equally distributed longitudes in order to search for rotational heterogeneities. The heliocentric distance during observing period was 1.238 – 1.145 AU, the Spitzer-centric distance was 0.506 – 0.536 AU, and the phase angle was 63.5 – 61.5°.

**Table 1. Spitzer Observations**

Mode	Wavelengths ( $\mu\text{m}$ )	# Lons.	Date (2007)
IRS	5.2 – 38	2	4 May
PUI	16, 22	10	3-4 May
IRAC	3.6, 4.5, 5.8, 8.0	10	8-9 May

The thermal spectra were measured in four segments. The most mineralogically diagnostic spectral features for silicates occur near 10  $\mu\text{m}$ , so the observations were planned so as to obtain the highest S/N in the 7.5 to 14.2  $\mu\text{m}$  module. Much of the data reduction and calibration is carried out by pipeline processing. We performed background subtraction on the flat-fielded, flux calibrated spectral images, extracted the 1-D spectra, and scaled the modules relative to each other using regions of overlap. The imaging data are also delivered as flux-calibrated images. We performed aperture photometry, applying appropriate aperture and color corrections to derive fluxes.

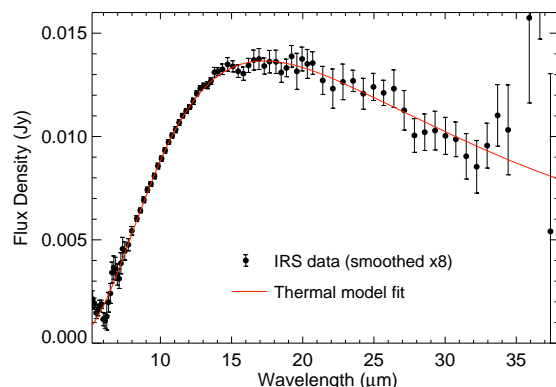
**Thermal Modeling:** Thermal flux spectra measured by Spitzer/IRS are well suited to constraining

physical properties of asteroids because of the broad and continuous wavelength coverage that includes the peak in thermal emission from most asteroids. Due to the status of 1999 RQ<sub>36</sub> as the target of a spacecraft mission proposal that made it to the final round of Discovery selection, this NEA has been well observed recently. Those ground-based characterizations provide strong constraints on e.g., rotation rate, spin pole, shape, size, phase curve, and visible brightness that significantly aid thermophysical modeling.

The thermophysical model (TPM) that we use balances solar insolation against thermal emission and heat conduction into the interior of the body. The technique is described in [14] and is very similar to that of [15]. In practice, we use a  $\chi^2$ -minimization routine to find the best-fit size and thermal inertia to the measured flux spectrum and/or photometry.

Along with constraining size, albedo, and thermal inertia of the surface, the thermal model results in a computed continuum. The thermal flux spectrum is divided by this continuum to reveal any spectral features in the data. Silicate spectra in the 5 – 38  $\mu\text{m}$  range are dominated by Si-O stretch and bend fundamentals [16,17]. Interplay between surface and volume scattering around these bands creates complex patterns of emissivity highs and lows that are diagnostic of mineralogy as well as grain size and texture.

**Results and Discussion:** Figure 1 shows the TPM fit to one of the IRS spectra. The thermal inertia derived from the model fit is  $\sim 600 \text{ J m}^{-2} \text{ s}^{-1/2} \text{ K}^{-1}$  (the lunar regolith is  $\sim 50$  in these units). This moderately high thermal inertia suggests a somewhat blocky surface, perhaps similar to that of the similarly sized NEA Itokawa. [18] found a similar thermal inertia for (162173) 1999 JU<sub>3</sub>, a potential target of the Hayabusa-2/Marco Polo sample return missions. The inferred size of RQ<sub>36</sub> as derived from this model ( $D \sim 610 \text{ m}$ ) is in excellent agreement with radar observations. The

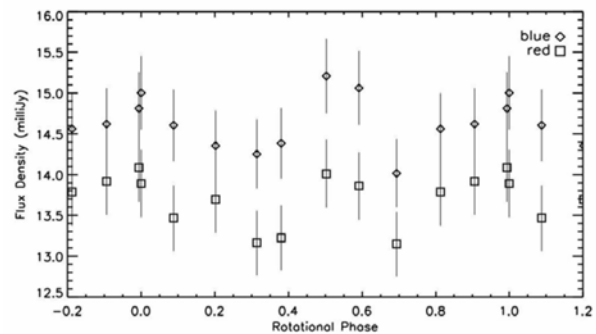


**Figure 1.** IRS spectrum of 1999 RQ<sub>36</sub> binned by a factor of 8 and fit with a thermophysical model. The model fit suggests thermal inertia  $\sim 600 \text{ J m}^{-2} \text{ s}^{-1/2} \text{ K}^{-1}$  and diameter of  $\sim 610 \text{ m}$  (giving  $p_V \sim 0.03$ ).

current model assumes a moderate surface roughness (RMS slopes  $\sim 20^\circ$ ). We will present additional models exploring a broad range of surface roughness to better constrain the range of possible thermal inertias.

The resulting emissivity spectrum has S/N  $\sim 40$  to 50 in the 7.5 to 14.2  $\mu\text{m}$  region. There is no evidence for spectral features larger than the noise in the final spectrum. The flat emissivity spectrum is consistent with an absence of very fine regolith particles.

Although we have not yet completed detailed thermal modeling of the photometric data, the fluxes themselves do not indicate any obvious temperature variations throughout one full rotation. Figure 2 shows PUI fluxes at 16 and 22  $\mu\text{m}$ . A temperature change would change the relative fluxes between these two bands, but there is no obvious evidence for such variation outside the flux uncertainties. We will present more detailed analysis of the PUI and IRAC data in terms of potential variability in surface properties.



**Figure 2.** PUI photometry of 1996 RQ<sub>36</sub>. The diamonds (labeled blue) are 16  $\mu\text{m}$  and the squares (labeled red) are 22  $\mu\text{m}$ .

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