**OBSERVATIONS OF 21 LUTETIA IN THE 2-4 μM REGION WITH THE NASA IRTF .** A. S. Rivkin[1], B. E. Clark[2], M. E. Ockert-Bell[2], M. K. Shepard[3], E. L. Volquardsen[4], E. S. Howell[5], and S. J. Bus[4], [1]JHU/APL, Laurel MD (andy.rivkin@jhuapl.edu), [2]Ithaca College, Ithaca NY, [3]Bloomberg College, Bloomberg PA, [4]Institute for Astronomy, Hilo HI, [5]Arecibo Observatory/NAIC, Arecibo PR.

**Background:** It has been difficult to reach a consensus on the composition of the asteroid 21 Lutetia. It was one of the original members of the M asteroid class, and thought likely to be either akin to iron meteorites or enstatite chondrites [1]. However, decades of more in-depth observations have interpretations that are difficult to reconcile with those analogs (particularly iron meteorites).

For instance, Lutetia's radar albedo is similar to that of the C and S asteroids rather than what is expected of a metal-rich surface [2]. Polarimetry of Lutetia also shows a surface unlike high-metal asteroids like 16 Psyche [3]. An extension of the Tholen taxonomy to 2.5 μm by Howell et al. [4] found Lutetia grouped with the C asteroids, with only its high albedo precluding a reassignment. Most pertinent to this presentation, observations in the 3-μm region in 1996 found Lutetia to have an absorption interpreted as due to hydrated minerals [5], though this has not been confirmed [6,7]. Visible-near IR (0.5-0.8 μm) spectral slope differences have been seen on Lutetia and attributed to compositional variation on its surface [8].

Interest in Lutetia increased when it was announced as a flyby target for the Rosetta spacecraft, and Belskaya et al. [9] compiled the current state of knowledge about Lutetia before Rosetta's July 2010 flyby. Here we present additional 3-μm spectra using SpeX on the NASA Infrared Telescope Facility (IRTF) and another look at the 1996 observations.

**Observations:** Table 1 shows the UT dates, and sub-solar and sub-Earth coordinates on Lutetia for the midtimes of the IRTF observations. The 1996 observations used NSFCam, as described in [5]. The new observations used SpeX in long wavelength cross-dispersed (LXD) mode, covering the 2-4 μm region. The data were reduced using Spextool and additional IDL routines, as in previous recent work [10].

| UT Date | SE Lon | SE Lat | SS Lon | SS Lat | Note |
|---|---|---|---|---|---|
| 9/29/96 | 227.6 | +3.3 | 223.4 | -17.8 | NSFCam |
| 9/30/96 | 316.0 | +3.3 | 311.8 | -18.1 | NSFCam |
| 3/2/03 | 124.9 | +85.5 | 160.5 | +65.9 | Spex |
| 3/31/07 | 358.5 | +67.3 | 71.5 | +85.2 | Spex |
| 12/23/08 | ~117 | -77.6 | ~105 | -67.3 | Spex |
| 7/10/10 | --- | --- | --- | +46.6 | Rosetta |

Table 1: Observational circumstances for IRTF Lutetia spectra and the Rosetta encounter.

Lutetia was warm enough to exhibit measurable thermal flux in the longer-wavelength portions of our spectra. This thermal flux was removed using a version of the standard thermal model (STM), modified so as to allow the "beaming parameter" (η) to vary. We found the best values for η to be 0.75-0.82 for the SpeX data, near the low end of the observed range for asteroids but not unprecedentedly so. Recorrecting the NSFCam data indicates higher values of η for those spectra, in the range of 0.9-1.0, will result in good matches between the 1996 and later data.

**Results:** The three Spex spectra and the 1996 NSFCam data are shown in Figure 1, thermally corrected and offset from one another. The NSFCam data were shown as an average when previously published [5]. Band depths in the 3-μm region vary from nearly 10% for 29 September 1996 (measured from an extrapolated continuum) to 1-2% (perhaps consistent with zero) for 2003 and 2007.

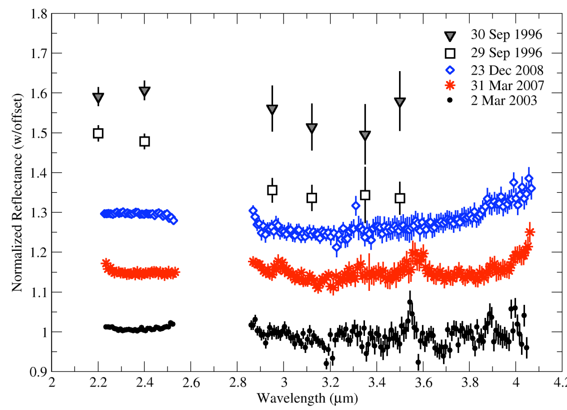


Figure 1: Lutetia's spectral shape in the 2-4 μm region is qualitatively similar in the 5 spectra shown here. The apparent band depth varies from ~15% on 29 September 1996 to < 2% in 2007. The high-frequency structure present in the 2003 and 2007 data is due to unremoved artifacts, and we interpret the overall band shape to be like the 2008 spectrum.

**Discussion:** Figure 2 from Carry et al. [11] shows the fraction of Lutetia's surface visble from Rosetta, with the sub-solar positions of the IRTF observations included. Interestingly, none of the three observations showing deeper 3-μm bands were visible from the high northern latitudes observed during the Rosetta flyby. Both SpeX and NSFCam data from the southern hemisphere show evidence of a 3-μm band, and the data are consistent with compositional variation on Lutetia's surface. The observations of Birlan et al. and Vernazza et al. [6,7] were also centered at high northern latitudes, consistent with their interpretations of little or no absorption in the 3 µm region.

The band shapes seen in the southern hemisphere are not typical of the 3-µm bands seen in C-class asteroids or carbonaceous chondrites: they do not have the triangular or "checkmark" shape seen in objects like Pallas (interpreted as CM-like phyllosilicates) [12], nor the well-defined minima seen in Ceres or Themis interpreted as brucite and ice, respectively [13,14]. Instead, the spectrum appears to step down into the 3-µm band, which is shallow but broad and has no identifiable substructure.

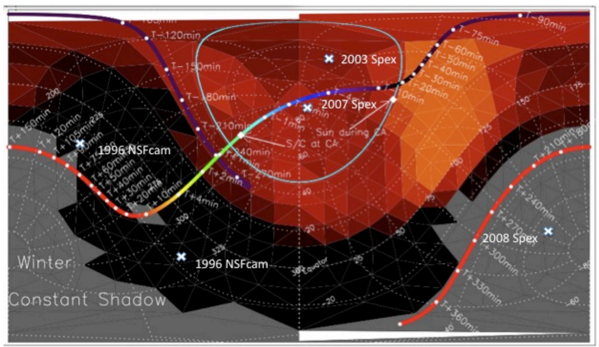


Figure 2: Adapted from Carry et al. (2010), this figure shows the portion of Lutetia visible from the Rosetta spacecraft (shades of red) and the sub-solar positions during the IRTF observations. The three observations with the deepest 3-µm bands are all largely comprised of areas unobservable by Rosetta.

Beck et al. recently proposed goethite (FeO(OH)) as a possible component of low-albedo asteroid surfaces. [15]. Interestingly, a simple mixing model (Figure 3) suggests that a two-component mixture of goethite and a neutral material can match the Lutetia spectra, with goethite's contribution to the spectra varying between~ 0% and ~20% depending on the spectrum. Goethite is a common mineral on Earth, forming through weathering of iron-bearing minerals and oxidation of reduced, iron-bearing waters [16].

While Lutetia's band shape in the 3-µm region is unlike C-complex asteroids, it is qualitatively similar to some other X-complex asteroids like 44 Nysa. Constraining the composition of Lutetia's surface will have implications and applications beyond Lutetia alone.

**References:** [1] Burbine T. H. et al. (2002) *Asteroids III.* [2] Magri C. et al. (1999) *Icarus 186,* 152. [3] Lupishko D. F. and Belskaya I. N. et al. (1989) *Icarus 78,* 395. [4] Howell E. S. et al. (1994) *JGR 99, 10847.* [5] Rivkin A. S. et al. (2000) *Icarus 145,* 351. [6] Birlan M. et al. (2006) *Astron Astroph. 454,* 677. [7] Birlan M. et al. (2010) *DPS 42,* Abst. # 46.04. [8] Lazzarin M. et al. (2010) *Mon. Notes Royal Ast. Soc. 408,* 1433. [9] Belskaya I. N. et al. (2010) *Astron Astroph. 515,* A29. [10] Volquardsen E. L. et al. (2007) *Icarus 187,* 464. [11] Carry B. et al. (2010) *Astron Astroph. 523,* 94. [12] Rivkin A. S. et al. (2002) *Asteroids III* [13] Milliken R. E. and Rivkin A. S. (2009) *Nature Geosc. 2,* 258. [14] Rivkin A. S. and Emery J. P. (2010) *Nature 464*, 1322. [15] Beck P. et al. (2011) *Astron Astroph. 526,* 85. [16] Mineral Society of America goethite fact sheet.

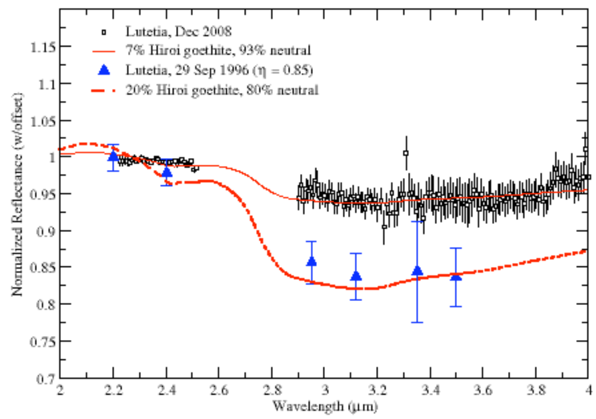


Figure 3: Beck et al. suggested goethite as a possible consituent of low-albedo asteroid surfaces. Lutetia's spectra can be fit by a simple two-component mix of goethite and a neutral material.

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