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Thermal and shape properties of asteroid (21) Lutetia from Herschel observations around the Rosetta flyby ☆, ☆☆

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ABSTRACT

Prior to and around the Rosetta flyby of (21) Lutetia, the Herschel Space Observatory performed a collaborative observation campaign with its two photometers observing the asteroid in the far infrared, at wavelengths not covered by Rosetta's instruments. The Herschel observations, fed into a thermophysical model (TPM) using as input a shape model based on in-situ images, were also further correlated with ~70 multi-wavelength observations of Lutetia. We confirm the geometric albedo measured by Rosetta, derive a H-mag value based upon the effective diameter of the asteroid and point to (21) Lutetia having an extremely low thermal inertia (5 J m^{-2} s$^{-0.5}$ K^{-1}). This thermal inertia is only possible through the existence of a significant amount of small scale roughness which is not directly observable by the OSIRIS (Optical, Spectroscopic, and Infrared Imaging System) instrument on-board Rosetta. In addition, our results point to the existence of a hill/crater surface feature located on the asteroids southern region not observed by Rosetta. From our results, we conclude that only through the merging of in situ and remote sensing observations can a true global picture be obtained of this asteroid.

1. Introduction

Remote sensing and in-situ measurements are considered highly complementary in nature: remote sensing shows the global picture, but conversion of measured fluxes in physical quantities depends upon model assumptions to describe surface properties. In-situ techniques measure physical quantities in a more direct way e.g., size, shape, geometric albedo or surface details. However, such techniques are often limited in spatial coverage (flybys) and results from disk-resolved observations are often not directly usable for the interpretation of global, disk-integrated properties e.g., local temperature versus thermal inertia.

Numerous studies have taken place of the peculiar (Barucci et al., 2008) asteroid (21) Lutetia based upon ground and space based observations. Once this asteroid was selected as a Rosetta flyby target, it became an important object to observe for two main reasons. First, it provided input to the Rosetta team as to the thermal and physical conditions existing on the asteroid. Secondly, it allowed the comparison of the pre-flyby measurements with those produced as output of the flyby with the associated benefits e.g., confirming the model accuracy that arises as a result. Such studies (see Table 1) have provided estimates of optical and thermal properties for this asteroid (geometric albedo, inertia)

☆ Herschel is an ESA space observatory with science instruments provided by European-led Principal Investigator consortia and with important participation from NASA.
☆☆ Analysis is also based on observations collected at the European Southern Observatory, Chile; ESO, No. 79.C-0006.
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Table 1
Summary of thermal and physical properties of (21) Lutetia.

Geometric Albedo (p_V)	Thermal inertia $\mathrm{J m^{-2} s^{-0.5} K^{-1}}$	Beaming factor (η)	Effective diameter (Deff – km)	G (mag)	H (mag)	Roughness (ρ, f)	Reference
				0.11	7.35		Tedesco, 1992
0.2212 ± 0.020		0.756	95.76 ± 4.1				Tedesco et al., 2001
0.208 ± 0.025	<50	0.93/0.94	98.3 ± 5.9	0.11	7.35		Mueller et al., 2006
0.1							Zellner and Gradie, 1976
$0.129 + 0.003 - 0.03$	5.2						Carvano et al., 2008
			~ 110				Drummond et al., 2009
0.18^{a} –0.22^{b}				0.125	7.25		Belskaya et al., 2010
0.13 and 0.26^{c}	≤ 30	~ 0.70–0.83					Lamy et al., 2010
0.19			98 ± 2				Sierks et al., 2011
0.20 ± 0.01	<10 Best fit 5		95.97	0.12		$\rho = 0.6$ $f = 0.7$	Present Study

[a] p_V based on Deff from Drummond et al., 2009.
[b] p_V based on Deff from Mueller et al., 2006.
[c] p_V from Mueller et al., 2006, where p_V=geometric albedo, Deff=effective diameter.

which served as important inputs when preparing for in-situ based observations.

These inputs could be verified by in-situ/flyby observations which provide the "ground truth" for the asteroid, however such a comparison is limited in nature and it is only through the execution of a combined observation campaign with both remote and in-situ/flyby data at similar epochs that the final calculated properties can be obtained. The output of such an observation campaign can be maximised if the observations are taken with similar viewing conditions and if the flyby geometry visible to the in-situ spacecraft is matched to that from the remote spacecraft observations thus comparing, from an observation perspective, like with like. Additionally, having instruments on both spacecraft complementing one another through looking at the object at similar wavelengths serves to reinforce the science results generated from both. With such approaches being applied, one can obtain highly accurate values for surface composition, reflectance, thermal inertia and temperatures, thus greatly improving the scientific understanding of the object in question.

Indeed, these are the properties which provide confidence not only in the accuracy of the pre-flyby results but also in the techniques used as input in deriving those results, especially where it is clear that not all asteroids can have the benefit of an in-situ observation campaign. As a minimum, by confirming the validity of such remote based measurement techniques, one can apply them to objects of a similar size and makeup.

The above approaches were followed with the Herschel Space Observatory SPIRE (Spectral and Photometric Imaging Receiver, Griffin et al., 2010) instrument observing (21) Lutetia less than 1 day after the Rosetta flyby in a similar viewing epoch as seen by Rosetta instruments. Measurements taken at the end of 2009 and approximately 24 day before the flyby by the PACS (Photodetector Array Camera and Spectrometer, Poglitsch et al., 2010) instrument helped to reinforce those results and indeed contribute to the extraction of the thermal inertia, surface roughness, shape model discrepancies and measured surface temperature. We compare our results not only with the Rosetta MIRO and VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) instrument flyby measurements (whose wavelength ranges are highly complementary to those of Herschel PACS and SPIRE) but also utilise data from other observatories (Spitzer, ESO-VISIR, Akari) in our analysis to complete the quite significant data set of 92 observations in use in this current study.

In this paper, we firstly present the PACS and SPIRE observations taken of (21) Lutetia, the data reduction, and the results obtained. We follow this with the measurements derived from other observatories to feed into our thermal model. We proceed to introduce the shape model and the thermal model we have used to analyze the above results, followed by a description of the H–G values and the albedo calculated by us and confirmed through direct measurements by Rosetta at the asteroid. We then derive the thermal inertia for a range of different surface roughness levels. At this point we present the impact of our results on the shape model in use and identify shortcomings and necessary modifications in this shape model (beyond the Rosetta results). We finally conclude the paper with the implications of our results on current and future asteroid research.

2. Observations with the Herschel space observatory

2.1. Observations of (21) Lutetia with the PACS & SPIRE instruments

The European Space Agency's (ESA) Herschel Space Observatory (Pilbratt et al., 2010), launched in 2009, performs observations from the 2nd Lagrangian point ($L2$) at 1.5×10^{6} km from Earth. It has three science instruments on board covering the far-infrared part of the spectrum, two of which, PACS and SPIRE, have been used to observe (21) Lutetia.

Although covering different wavelengths from those of the Rosetta instruments, the wavelengths ranges of the PACS and SPIRE photometer instruments were found to match extremely well however with the Rosetta MIRO and VIRTIS instruments i.e., PACS 60–210 μm versus VIRTIS ending at 5 μm, SPIRE 250–500 μm versus MIRO starting at 530 μm.

In advance of the flyby, two observation data sets for PACS (2009-Dec-21 and 2010-June-17, See Table 2 and Fig. 1 PACS Image) already existed for this asteroid, however no SPIRE data had yet been taken. In this respect, a dedicated campaign was organized around the flyby to further obtain SPIRE measurements and as a result complete the full data set from Herschel of this asteroid.

The SPIRE photometer imaged the asteroid on the 2010-July-11 at a time exactly 2 rotation periods (16.34 h) after the flyby. The SPIRE observation (Table 2, Fig. 1 SPIRE image) was timed to be as close as possible to the asteroid visibility conditions observed by Rosetta instruments in its flyby.

2.2. Data reduction and results from the SPIRE observations

The SPIRE observations were processed with the SPIRE Photometer pipeline version 5.0 in the Herschel Interactive Processing