

ROSETTA NAVIGATION FOR THE FLY-BY OF ASTEROID 21 LUTETIA

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ABSTRACT

Rosetta was launched on 2nd March 2004 and during its 10 years voyage to rendezvous with comet 67P Churyumov-Gerasimenko has made three swing-bys of Earth and one of Mars. It is presently in hibernation and will be reactivated on 20th January 2014.

During its first outward passage through the main asteroid belt, the spacecraft was navigated to make a fly-by of the ~5 km diameter asteroid 2867 Steins, on 5th September 2008, with a targeted miss-distance of 800 km and relative speed of 8.6 kms⁻¹. On its second and last passage it was navigated to make a fast fly-by (15.0 kms⁻¹) on 10th July 2010 of asteroid 21 Lutetia whose longest axis is greater than 100 km and was then the largest asteroid at which *in situ* scientific measurements had been made.

In a similar manner to the Steins navigation (presented at ISSFD21), the operations for the Lutetia fly-by relied on conventional ground-based astrometric measurements of the asteroid, two-way Doppler and range data of the spacecraft, acquired mainly by the ESA 35 m antenna at New Norcia in Western Australia, and most importantly on optical data extracted on ground from images obtained by both navigation cameras (NAVCAMs) and by the OSIRIS Narrow-Angle Camera (NAC), whose resolution is five times better. In the following, emphasis is given to how the Lutetia navigation differed from that for Steins.

The targeted miss distance was much larger at 3160 km. This was necessary to avoid any possibility around closest approach of Lutetia extending outside the field of view of the NAVCAM used in closed-loop attitude control to ensure continuous pointing of the instruments towards the asteroid. Like Steins, on the near approach it was desired to pass through zero solar phase angle. At far approach this angle was 10^o, so that the fully illuminated asteroid was seen 18 minutes before closest approach when the separation distance was still more than 16000 km.

For the Steins orbit determination the acceptable, modern astrometric data were all equally weighted. For Lutetia they were differentially weighted according to observatory, based on the root mean square values of the residuals. The excellent quality data from the USNO at Flagstaff were reduced using the Tycho-2 catalogue and were exceptionally well weighted. Most of the other reductions were made using catalogues that are now known to suffer from significant zonal

biases. Before optical data were acquired, the predicted position of Lutetia at the fly-by time differed by 180 km from that based on an equal weighting solution. Analysis after the fly-by confirmed the better accuracy of the solution based on differential weighting.

Due to favourable geometry, after processing the first few optical data acquired of Steins, the predicted time of closest approach changed significantly, by +11 s, and its 3σ uncertainty diminished by 5.4 s to 13.1 s. This was not the case for Lutetia. Including the first optical data obtained on 31st May and 7th June 2010 changed the predicted time by only 0.3 s and the 3σ uncertainty only marginally from 8.1 to 7.6 s. As expected, all the following optical data led to hardly any change in the uncertainty that was still 7.1 s after processing the final optical data before the fly-by.

With the accumulation of optical data, the size of the uncertainty ellipse in the B-plane progressively reduced. After two weeks of such data, the predicted miss distance was 2640 km with a 3σ uncertainty of 50 km. A manoeuvre of 27.5 cms^{-1} magnitude was executed on 18th June to re-aim to the target point. The good performance combined with the accuracy of the prediction meant that no further trajectory correction was needed.

After the fly-by, to determine accurately the Rosetta orbit an estimate of the GM value for Lutetia had to be included. Since the angle between the relative velocity and the line-of-sight from Earth was only 9° , there was comparatively little difference between the pre- and post fly-by Doppler signature. But Doppler data were also acquired up to 5 minutes before closest approach when the maximum rotation rate of the High-Gain Antenna (HGA) was reached and were re-acquired 50 minutes later. For processing these data, the relative motion of the HGA phase centre with respect to the spacecraft centre of gravity had to be accurately modelled because the effect on the Doppler signal was of the same order of magnitude as Lutetia's gravity.

In order to improve the final estimates of the fly-by parameters, 272 direction measurements deduced from images obtained during an interval of 44 minutes ending 15 minutes before closest approach, were additionally processed. During this time the pointing direction was continuously close to the photometric centre of the asteroid and the solar phase angle changed by 10° . For one solution, a simple correction to the raw data was made for the offset from the asteroid's centre of gravity, assuming Lambertian light reflection from a sphere of 50 km radius. The estimates with and without this correction were very similar. From the latter solution, the miss distance at closest approach was 3168.2 km, reached 2.5 s earlier than the last pre-fly-by prediction. The minimum solar phase angle during the approach was 0.15° . The estimate for the GM value of Lutetia was $0.1081 \pm 0.0019 \text{ km}^3\text{s}^{-2} \ 1\sigma$ ($\pm 1.7\%$).

The same type of navigation data, software and processing technique will be used during the first half of 2014 while Rosetta approaches its final target, until the time when the comet appears as an extended object and landmarks on the surface become the primary source of navigation data.