ESOC

Rosetta Navigation for the Fly-by of Asteroid (21) Lutetia

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Purpose: In situ scientific observations of 67P/Churyumov-Gerasimenko (Comet C-G is easier to pronounce)

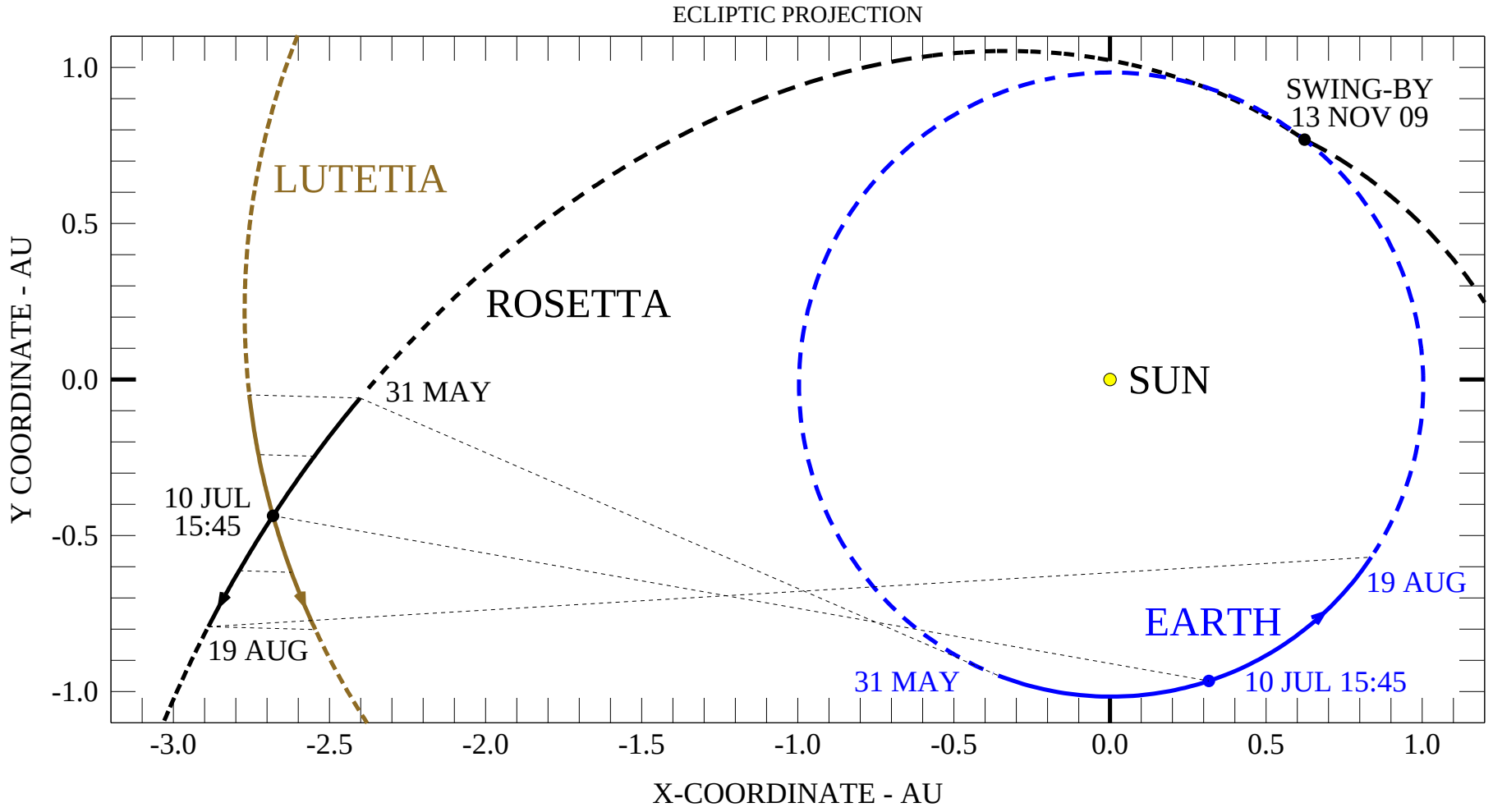
Event	Date
Launch	2nd March 2004
1st Earth Swing-by	4th March 2005
Mars Swing-by	25th February 2007
2nd Earth Swing-by	13th November 2007
(2867) Šteins Fly-by#	5th September 2008
3rd Earth Swing-by	13th November 2009
(21) Lutetia Fly-by	10th July 2010
Hibernation	8th June 2011
Reactivation	20th January 2014
Arrival at Comet	4th August 2014

Navigation for (2867) Šteins Fly-by was presented at the 21st ISSFD

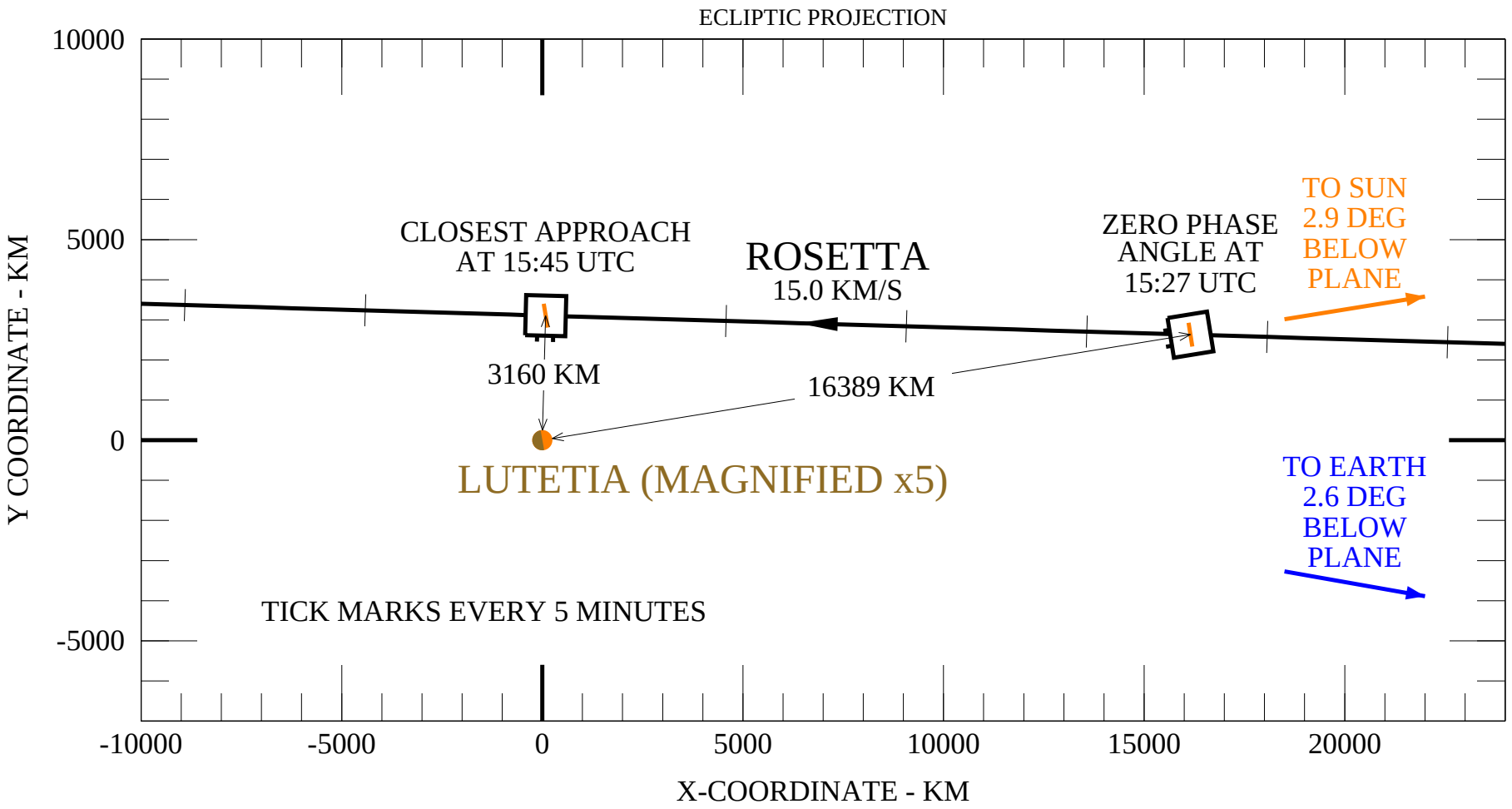
Asteroid Fly-by Parameters

Parameter	(2867) Šteins	(21) Lutetia
Size	~6 km diameter	124 x 101 x 93 km
Fly-by Speed	8.6 km/s	15.0 km/s
Planned Miss-distance	800 km	3160 km
Solar Phase Angle (SPA) at Far Approach	38°	11°
Planned Minimum SPA	0°	0°
Time of Minimum SPA before Fly-by	2 minutes	18 minutes

Orbits of Rosetta, (21) Lutetia and the Earth



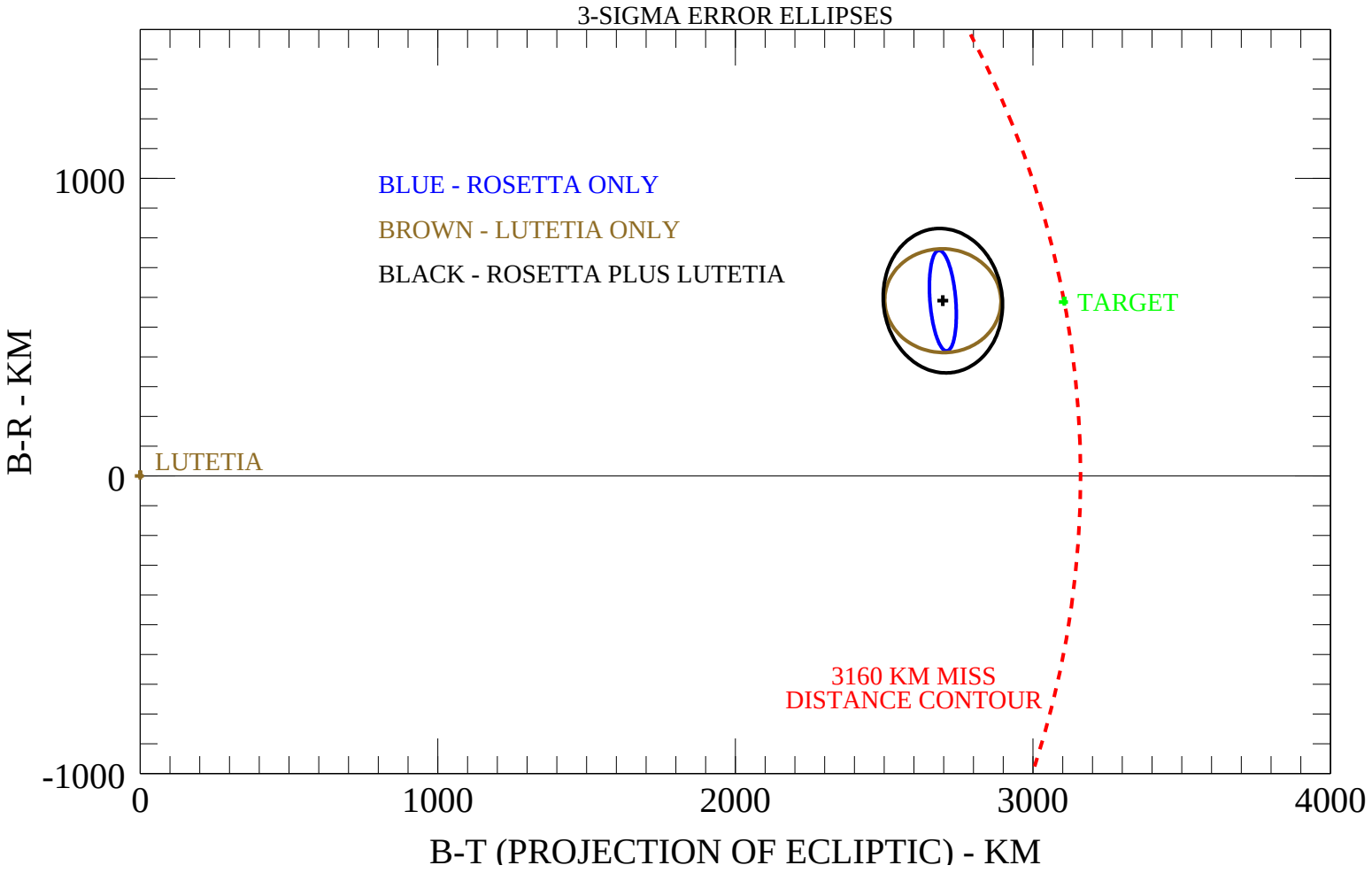
Planned Trajectory past Lutetia on 10th July 2010



Rosetta and Lutetia Orbit Determinations

- Until end May 2010 separate orbit determinations (OD).
- Rosetta OD used coherent 2-way Doppler and range data:
  - ESA New Norcia (NNO) 35 m antenna was primary station;
  - Tracking data arc started on 4th February 2010;
  - From 25th May up to fly-by, 35 passes from NASA/DSN stations.
- Lutetia OD used astrometric data from 31 observatories:
  - 1630 R.A. and declination measurements, 1866-2010;
  - Post 1990 rms of 1 arcsec, pre 1990 rms of 2-5 arcsec;
  - Initially, no differential weighting between observatories;
  - Prediction at fly-by time, 77 km different from JPL Horizons.

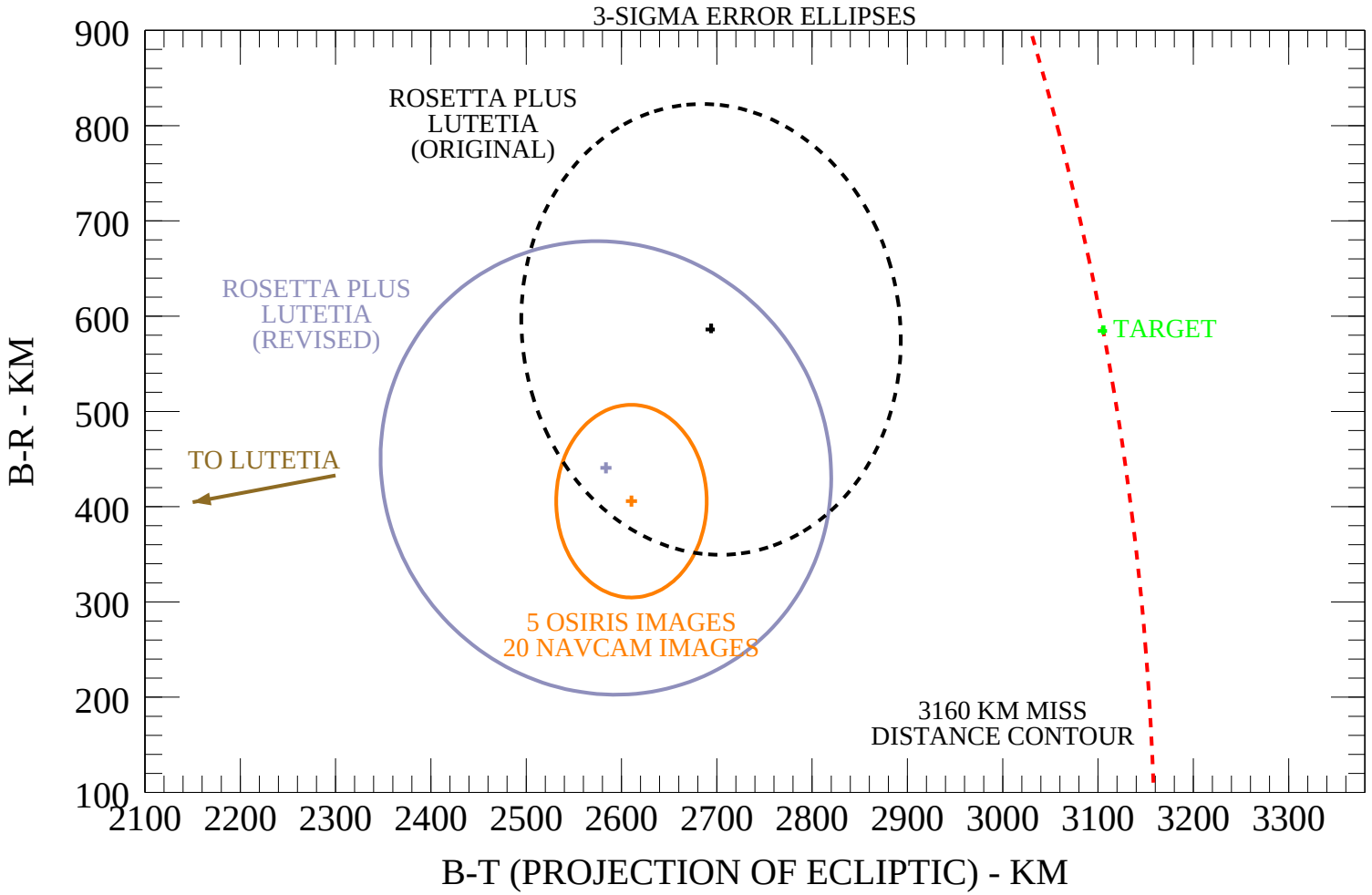
B-plane Estimate using Data up to 27th May 2010



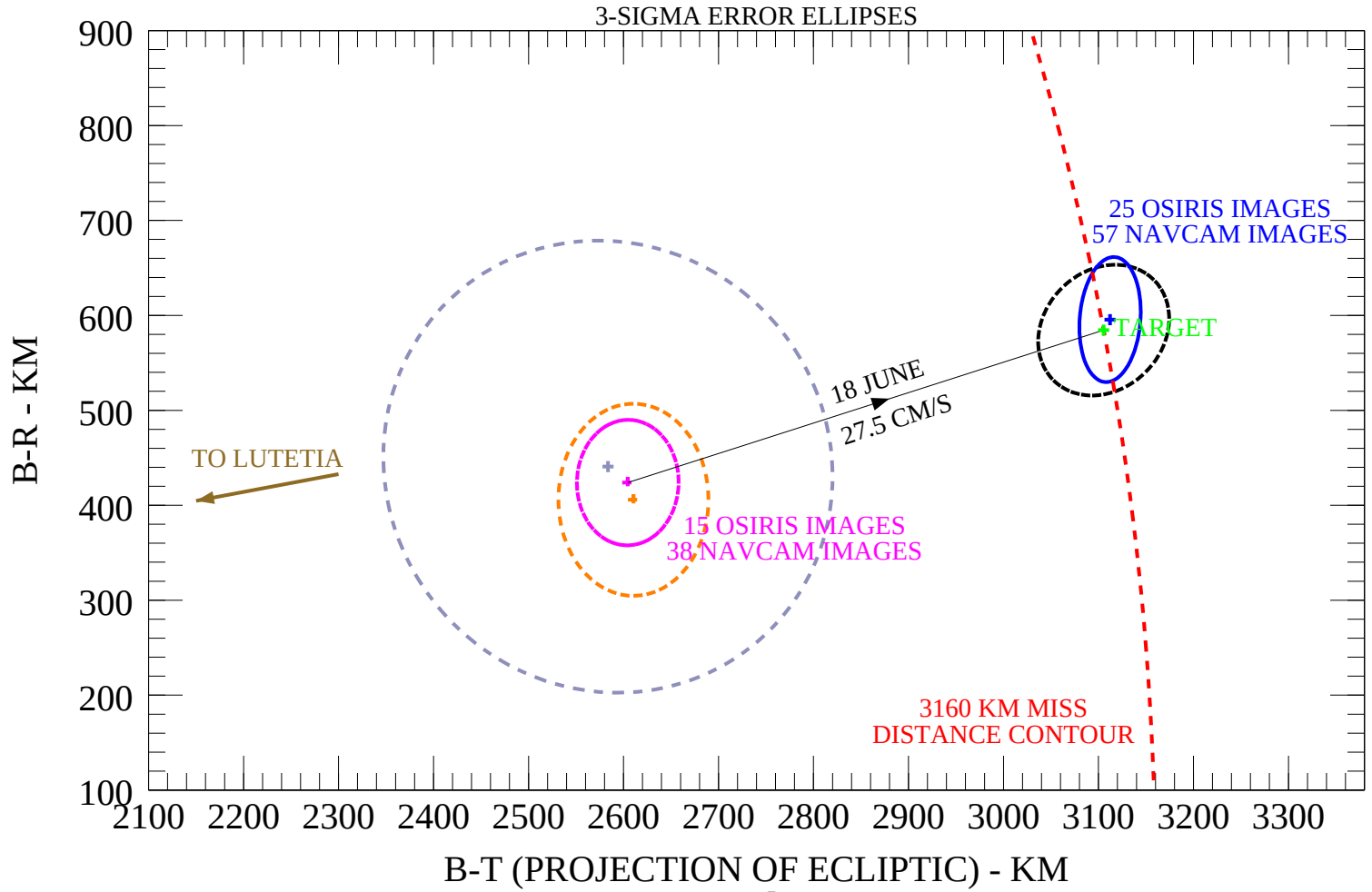
Relative Orbit Determination

- Starting 31st May acquired optical data from 3 on-board cameras:
  - 2 identical navigation cameras (NAVCAMs) - 1 pixel = 5 mdeg;
  - OSIRIS Narrow Angle Camera (NAC) - 1 pixel = 1.1 mdeg.
- Imaging sessions twice per week, then daily from 28th June 2010.
- Images processed on ground to give Rosetta-to-Lutetia directions.
- Rosetta and Lutetia states then determined simultaneously:
  - state and error estimates from separate ODs used as *a priori* info.
- First relative OD results were inconsistent with previous ones:
  - unreliable asteroid OD result suspected
    - known biases in popularly used star catalogues (Chesley *et al*. 2010);
  - revised Lutetia OD, differential weighting data between observatories
    - highest weighting given to data reduced with UCAC-2 and Tycho-2.

B-plane Estimates using Data up to 7th June 2010

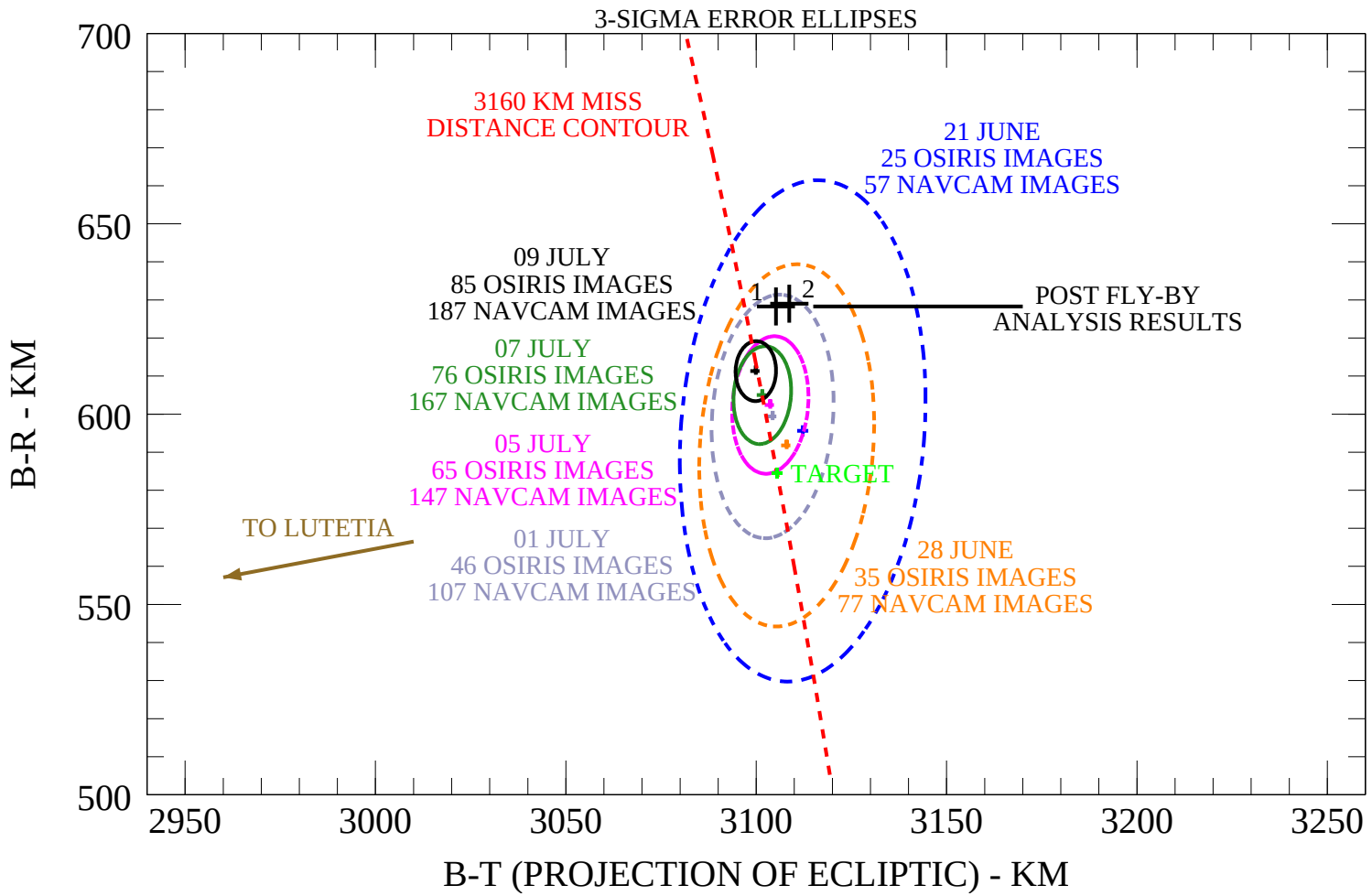


B-plane Estimates using Data up to 21st June 2010



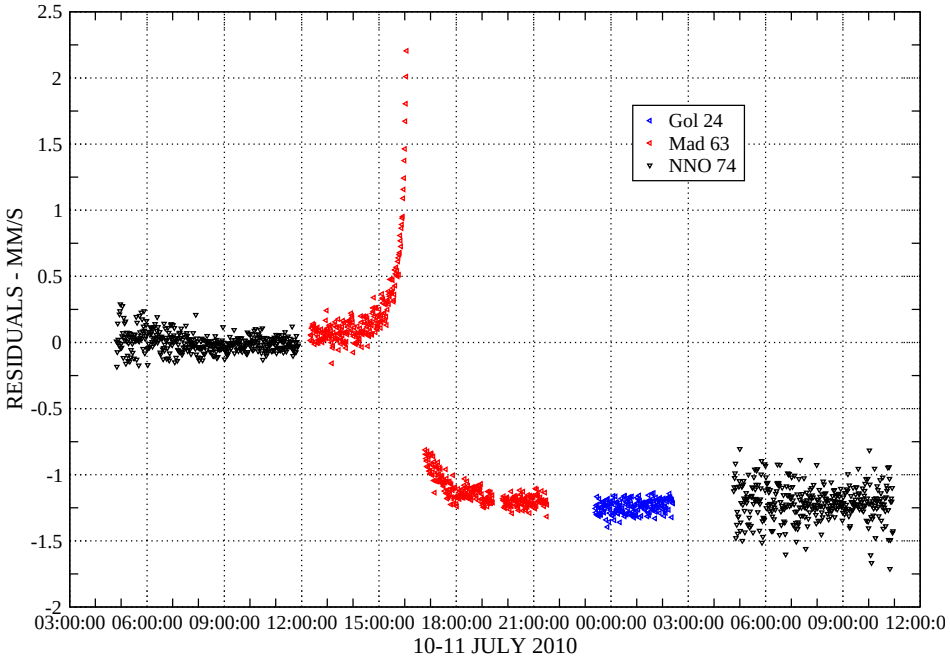
Predicted time of closest approach was 10th July at 15:44:55.51 UTC ±7.43 s (3σ)

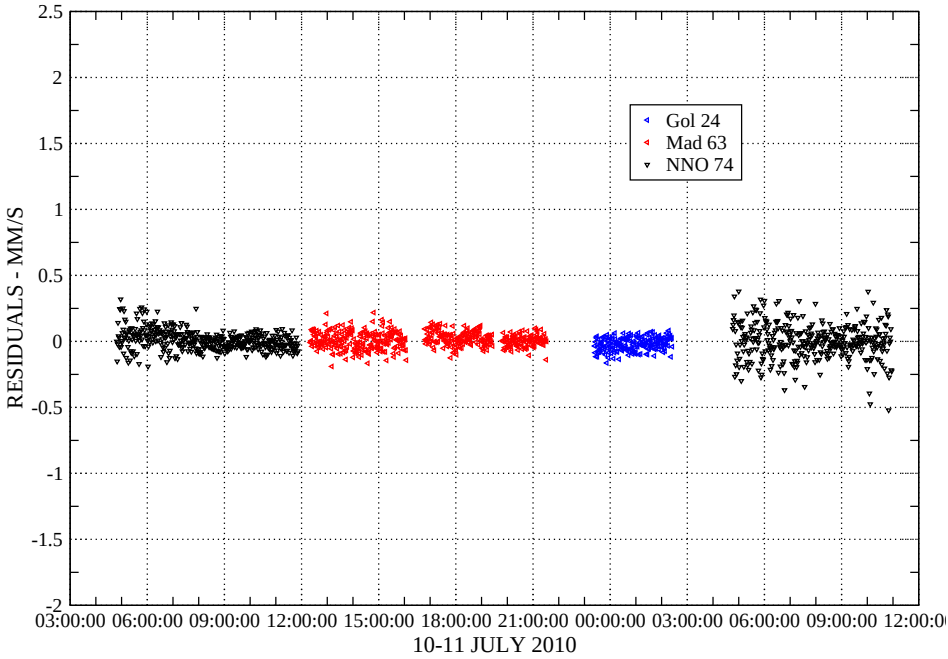
B-plane Estimates using Data up to 9th July 2010



(21) Lutetia's Gravity Signature

Black - New Norcia, Red - DSS-63 Madrid. Blue - DSS-24 Goldstone





Pre-fit (Lutetia massless) **Post-fit (Lutetia GM estimated)**

Rosetta 2-way range-rate residuals, 10th July 03:00 to 11th July 12:00

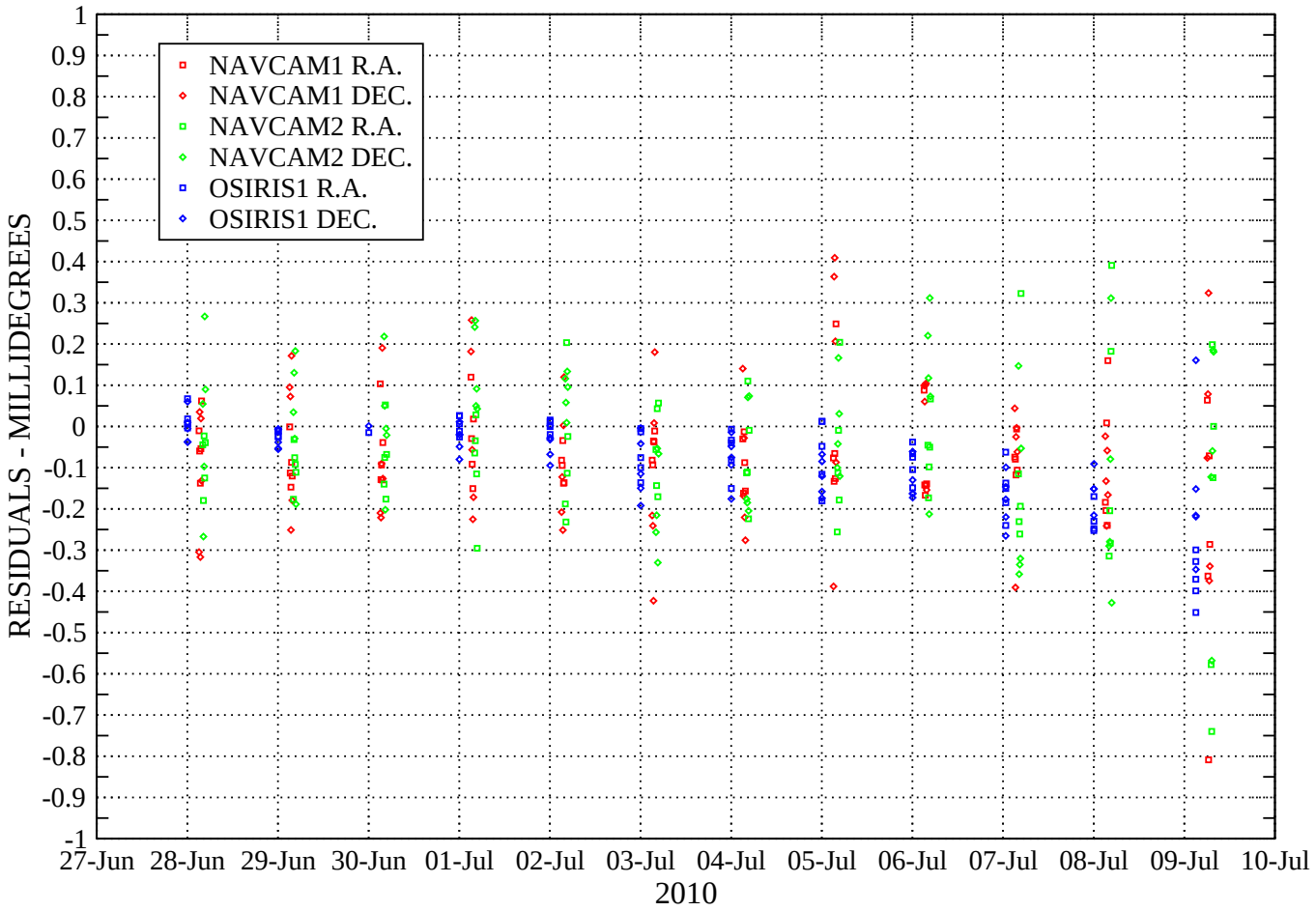
Preliminary Lutetia GM estimate: 0.1087 km^3s^{-2}

- Processed additionally radiometric data up to 16th July plus pointing directions during early part of the fly-by:
  - pointing was close to photometric centre not centre of gravity;
  - used 44 minutes of data up to 15 min before closest approach;
  - Solar phase angle reduced from 7.7° to ~0° then rose to 2°;
  - Two schemes - (1) raw data,
  - (2) Correction using Lambertian reflection from 50 km radius sphere.

Final Fly-by Estimates

Parameter	1	2
UTC of closest approach (on 10th July)	15:44:54.75	15:44:55.93
Miss-distance (km)	3168.2	3171.7
Minimum solar phase angle (degrees)	0.15	0.15
UTC of minimum solar phase angle	15:26:59.53	15:26:59.52

Optical Data Residuals



NAC data biases up to -0.3 mdeg when asteroid size was 3 mdeg

(21) Lutetia GM and Bulk Density Estimates

- **Final GM estimate = 0.1081 km^3s^{-2} ± 1.7% (1σ)**
- **Radio Science Team estimate was 4.9% higher* -**
  - their analysis was simpler and based on fewer data.
- **More scientifically interesting result is the density -**
  - its uncertainty is predominantly due to the volume uncertainty.
- **From ground-based observations using adaptive optics plus OSIRIS images from the asteroid fly-by:**
  volume estimate# = (5.0 ± 0.4) x 10^5 km^3.
- **Bulk density estimate = 3.2 ± 0.3 gcm^{-3}.**

* Pätzold, M. *et al.*, Science, Vol. 334, 491-492, 2011.
# Sierks, H. *et al.*, Science, Vol. 334, 487-490, 2011.

(21) Lutetia 40 Min. before Closest Approach

Rosetta Separation distance:
From Lutetia: 36000 km
From Saturn: 6.5 AU