Virtis / Rosetta: temperatures analysis during Lutetia Dynamic Rehearsal as an input in Lutetia Fly-By planning

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EGU General Assembly 2011 - EGU2011-1945

1 The Mission

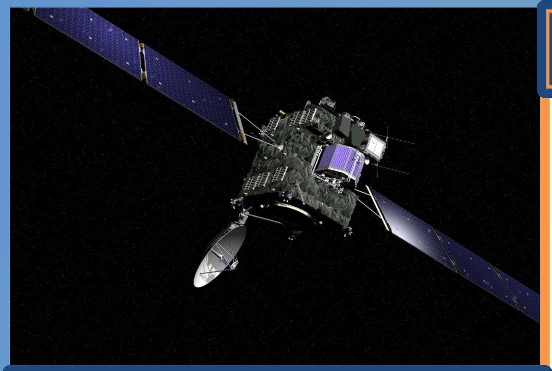

Fig.1 Rosetta

The International Rosetta Mission (Fig.1) is one of ESA's Planetary Cornerstone Missions. It is one of the most challenging missions ever attempted. Rosetta will be the first mission ever to land on a comet. On cruise to the main target (comet 67P/Churyumov-Gerasimenko) the spacecraft has been scheduled for close fly-bys at two main belt asteroids (Steins and Lutetia). The Steins fly-by took place on 5 September 2008 while the Lutetia fly-by took place on 10 July 2010.

2 The Instrument

VIRTIS (Visible Infrared Thermal Imaging Spectrometer) (Fig.2) carried by the ESA's Rosetta spacecraft is a spectrometer wich uses two optical heads (-M,-H), respectively dedicated to the VIS-NIR imaging spectroscopy (250-5000 nm) and infrared spectroscopy (2500-5000 nm) with high spectral resolution. VIRTIS-M is the first imaging spectrometer dedicated to planetary exploration that shares the same optical system to analyze the visible (250-1050 nm) and the infrared (1000-5000 nm) spectral range. The high spatial (IFOV = 250 μrad/pixel, FOV = 64 × 64 mrad) and spectral (Δλ = 1.8 nm/band in the VIS and 9.8 nm/band in the IR) performance allow the observation of the basic compositional unit of planetary surfaces with high resolution. [1][2][3]

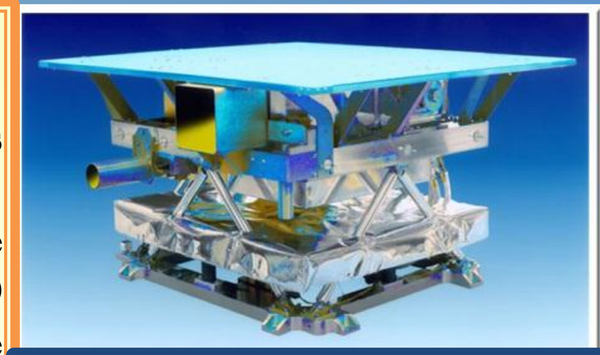

Fig.2 VIRTIS

[1]A.Coradini et al., 1996. VIRTIS Visible Infrared Thermal Imaging Spectrometer for Rosetta Mission. Lunar and Planetary Institute Conference Abstracts XXVII, 253-254

[2]A.Coradini et al., 1998. Virtis : an imaging spectrometer for the Rosetta mission. Planet. Space Sci., 46, 1291-1304

[3]A.Coradini et al., 1999. VIRTIS: the imaging spectrometer of the Rosetta mission. Adv. Space Res. 24, No. 9, 1095-1104

This research was conducted at INAF/IFSI and IASF institutes (Rome, Italy), supported by the Italian Space Agency, ASI-INAF Grant I/062/08/0, and under ASI/INAF Contract I/026/05/0.

3 Lutetia Dynamic Rehearsal and Lutetia Fly-By

Since the Lutetia fly-by geometry would have required a flip (Fig.3) in the spacecraft attitude before closest approach which would have implied the illumination of the –X and ±Y panels of the spacecraft including the radiators of some instruments, four months before the actual Lutetia fly-by it has been scheduled a Lutetia Dynamic Rehearsal with the purpose of testing the flight dynamics aspects of the Lutetia fly-by. In addition payload operations have been allowed to monitor the background (temperatures, pressure, etc.) as a calibration for the asteroid flyby. The attitude of Rosetta during the Lutetia Dynamic Rehearsal was chosen so that the position of the sun as seen from Rosetta was the same as during the Lutetia flyby, the only parameter different being the spacecraft/sun distance.

The geometrical parameters during the Rehearsal are given below. For reference, the parameters for the actual flyby are also provided:

- Rosetta-Sun distance: 1.74 AU (Lutetia flyby: 2.71 AU)
- Rosetta-Earth distance: 0.84 AU (Lutetia flyby: 3.03 AU)
- Sun-Spacecraft-Earth Angle: 19.4 deg (Lutetia flyby: 19.3 deg)

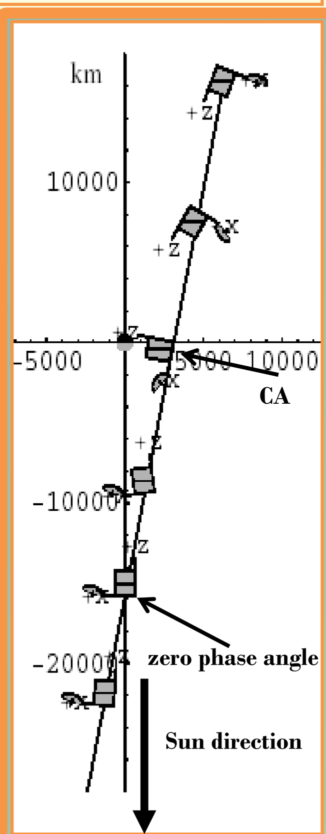

Fig.3 S/C Flip

4 Operating Procedures during Lutetia Dynamic Rehearsal

During Lutetia Dynamic Rehearsal the following operating procedures have been adopted:

- The ME[1] and the two PEM[2] have been powered on, to be able to get internal H/K temperatures during the illumination phase.
- The ME[1] has been powered on from 19:00 of 14th March 2010 until 01:40 of 15th March 2010.
- The cooler have not been switched on as the goal was the monitoring of the VIRTIS temperatures due to the Sun exposure of the radiators.

[1] Main Electronics

[2] Proximity Electronics Module

5 Radiance Equation

The sun can be considered a black body (Fig.4). The global emittance of the black body as a function of the temperature in the vacuum is :

$J_0 = \sigma_0 \cdot T^4$ (Stefan-Boltzmann Law).

$\sigma_0 = \frac{\pi^2 \cdot k^4}{60 \cdot c^2 \cdot \hbar^3} = 5{,}6696 \cdot 10^{-8}\,[W \cdot m^{-2} \cdot K^{-4}]$ (Stefan-Boltzmann Constant).

k = the Boltzmann Constant

c = the speed of light in the vacuum

h = the Planck Constant

$\hbar = \frac{h}{2\pi}$ = the reduced Planck Constant

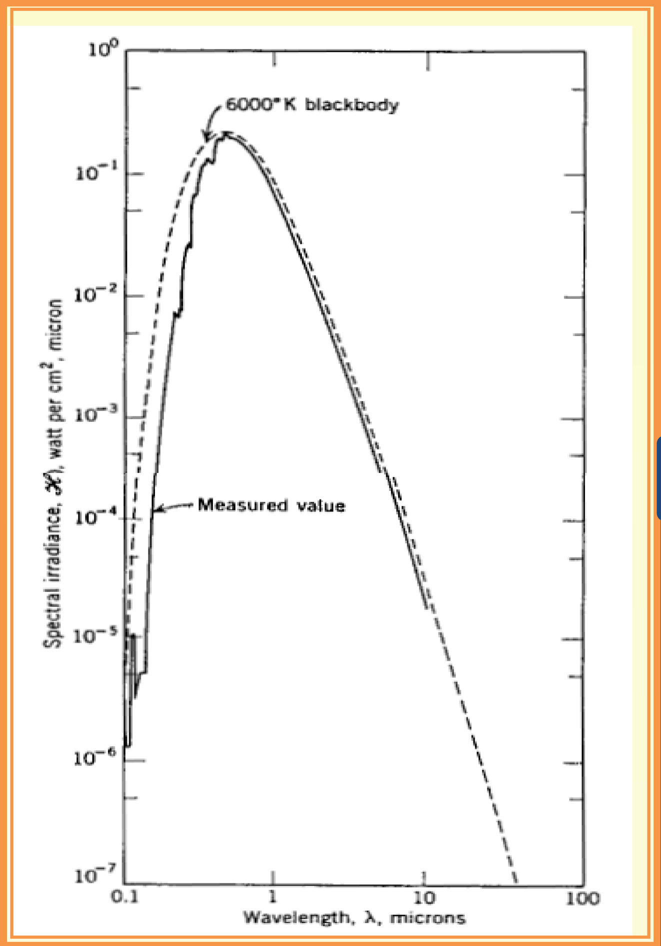

Fig.4 Sun Irradiance

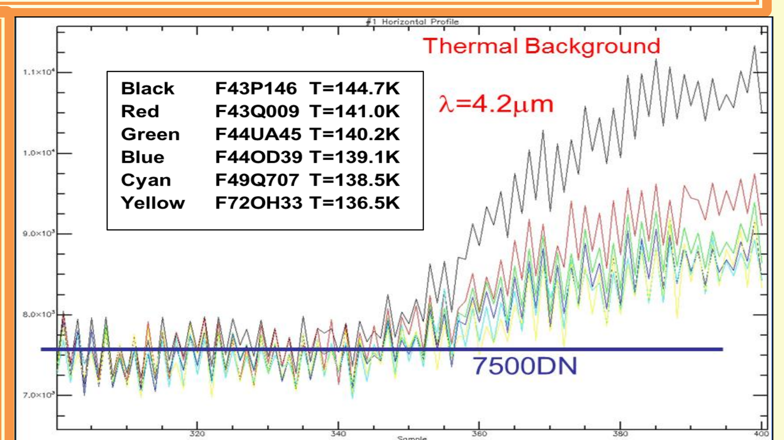

Fig.8 Termal Background

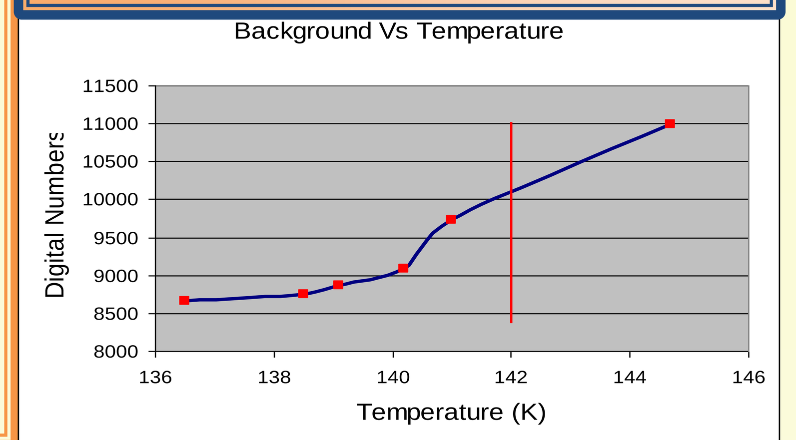

Fig.9 Background Signal Vs Temperature

6 Lutetia Dynamic Rehearsal Telemetries

The sun can be considered a point source. If dW is the part of the power radiated by the sun incident on an infinitesimal area dA of the S/C, the surface density of energy flow received by dA is:

$$E = \frac{dW}{dA}$$

Since $dA \cdot \cos\alpha = dA_n = R^2 \cdot d\Omega \longrightarrow dA = \frac{R^2 \cdot d\Omega}{\cos\alpha}$

$\longrightarrow E = \frac{I \cdot \cos\alpha}{R^2}$ with $I = \frac{dW}{d\Omega}$ = intensity of the power emitted by the sun in the considered direction (Fig.5).

The only parameter useful to compare the effects on Virtis components temperatures during the Lutetia Dynamic Rehearsal versus the Lutetia Fly-by is the Rosetta-Sun distance, since I and α can be considered the same in the two cases.

And since the energy flow is inversely proportional to the square of the Sun-S/C distance, the radiance power ratio at the two times is $\frac{1{,}74^2}{2{,}71^2} = 0{,}41$.

Assuming that the temperature trend is similar in both cases, by measuring Virtis components temperatures during the Lutetia Dynamic Rehearsal it is possible to calculate the expected temperatures during the Lutetia Fly-by (Fig.6) (Fig.7).

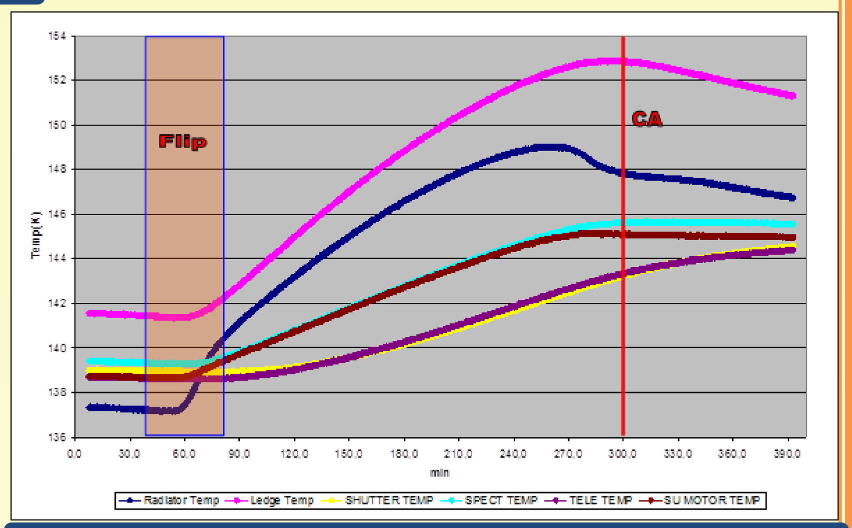

Fig.6 Temperatures measured during Lutetia Rehearsal – Virtis M

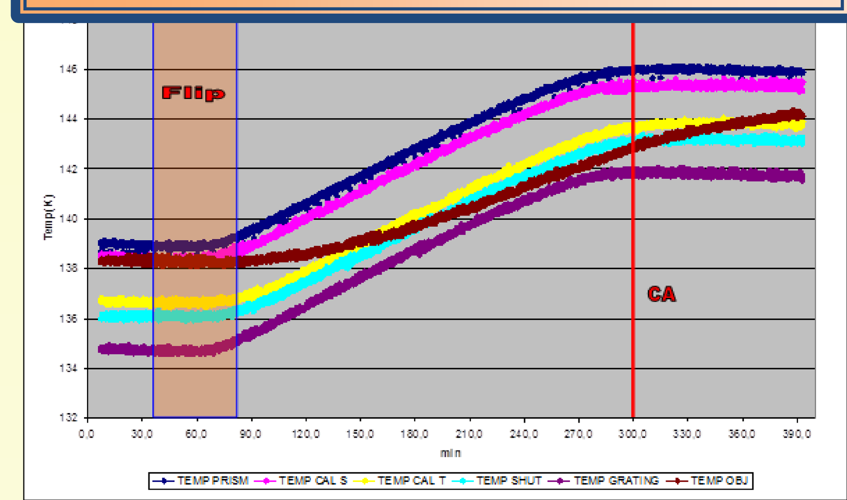

Fig.7 Temperatures measured during Lutetia Rehearsal – Virtis H

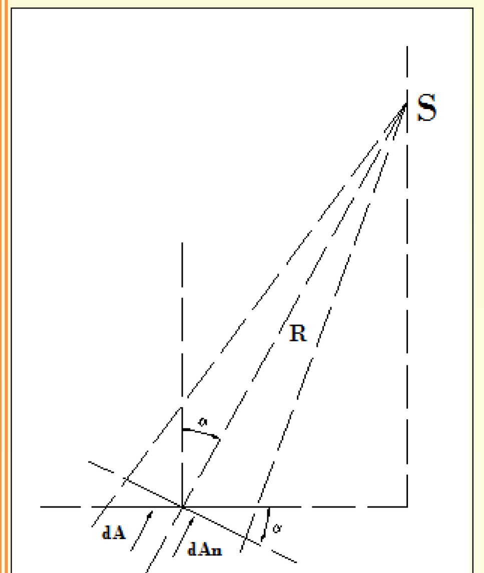

Fig.5 Radiance Geometry

For the purpose of preparing the Lutetia Flyby the temperatures taken into account were those at the beginning of the flip, at the maximum temperature of the radiator (3 hours and 38 minutes after the beginning of the flip), at the CA and at 30 minutes after CA (end of Lutetia observations) (Tab.1).

The radiator temperature and the ledge temperature, which is connected by thermally insulated cylindrical rods to the baseplate, are the most affected by the Sun exposure .

	Lutetia Dynamic Rehearsal				Lutetia Flyby			
	Flip	Max(263')	CA	CA +30'	Flip	Max(263')	CA	CA +30'
Radiator Temp (M)	137,2	149,2	147,9	147,7	137,2	142,1	141,6	141,6
Ledge Temp (M)	141,7	152,4	152,8	152,4	141,7	146,1	146,3	146,1
Shutter Temp (M)	139,0	142,2	143,2	143,9	139,0	140,3	140,7	141,0
Spect Temp (M)	139,4	145,2	145,7	145,7	139,4	141,8	142,0	142,0
Tele Temp (M)	138,7	142,4	143,3	143,9	138,7	140,2	140,6	140,8
SU Motor Temp (M)	138,7	145,0	145,2	145,2	138,7	141,3	141,4	141,4
Temp Prism (H)	138,8	145,6	146,0	146,0	138,8	141,6	141,8	141,8
Temp Cal S (H)	138,4	144,8	145,3	145,3	138,4	141,0	141,2	141,2
Temp Cal T (H)	136,8	142,8	143,7	143,9	136,8	139,3	139,6	139,7
Temp Shut (H)	136,0	142,3	143,2	143,2	136,0	138,6	139,0	139,0
Temp Grating (H)	134,7	141,3	141,9	141,9	134,7	137,4	137,7	137,7
Temp Obj (H)	138,3	141,9	143,0	143,5	138,3	139,8	140,2	140,4

Tab.1 Lutetia Rehearsal and Lutetia Flyby thermal comparison

7 Lutetia Fly-By

Virtis uses a radiator to keep the spectrometers temperature within the operating range. Usually Virtis radiator has an operative temperature of 135K when facing the deep space. Due to the flip in the spacecraft attitude, the radiator would have been illuminated by the sun (with an angle of about 5 degrees from the normal to the radiator) for about four hours during Lutetia fly-by and would not been able to maintain the nominal temperature. Under these conditions it was expected an increase in the background signal in the thermal IR range (4000-5000 nm).

In order to avoid a signal saturation, it was necessary to evaluate with sufficient precision the temperature increases and their effects on the background signal.

The radiator temperature, which leads the temperatures of every Virtis component, increased by 12K during Lutetia Dynamic Rehearsal.

With the assumptions made, it was expected a radiator temperature increase of about 5K and smaller increases for the other Virtis components during Lutetia Flyby.

After the analysis of several observations taken throughout the cruise phase for various external conditions and consequently for various background temperatures and, in particular, a collection of several calibration sessions with the integration time of 0.5s (Fig.8), it was possible to make a plot showing the history of the background signal variation (at band 389, corresponding to about 4900nm) as a function of the temperature (Fig.9).

The present spectrometer operative temperature is around 135-136K while the 145K case corresponds to the initial commissioning phase.

The spectrometer temperature was expected to reach 142K due to the Sun exposure during Lutetia Fly-by.

Using an integration time of 0,7 sec it was calculated an increase of 3500 DN in the background signal. In addition the CCD thermal contribution needed to be added.

Virtis telemetries collected during Lutetia Fly-by shown that the instrument components temperature trends were predicted within 1K precision (Fig.10) (Fig.11).

The integration time chosen proved to be correct since Virtis obtained a good signal in the IR range without saturation (Fig.12).

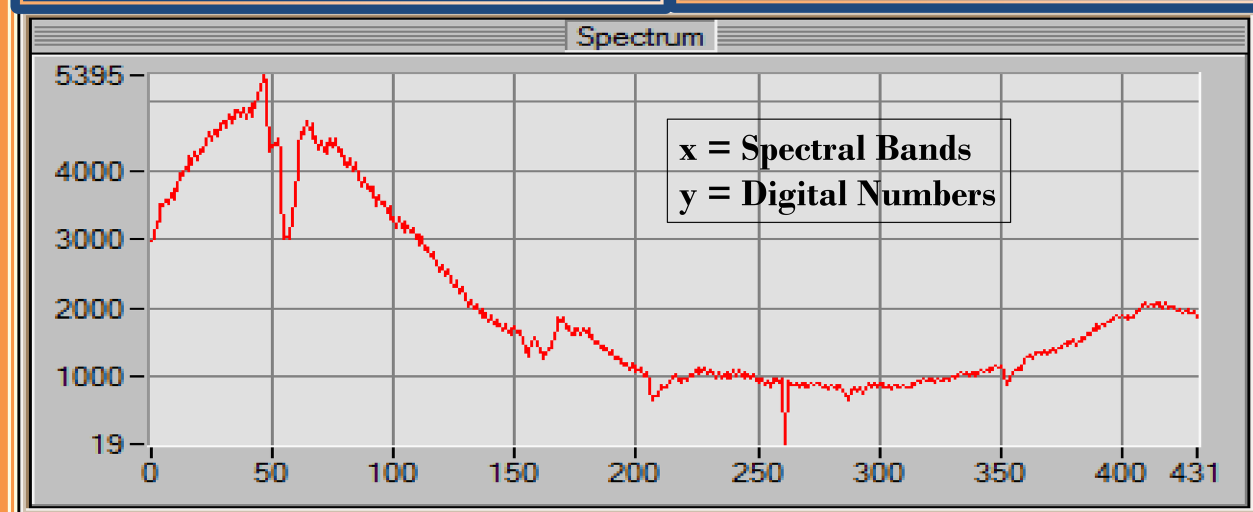

Fig.12 Spectrum obtained during Lutetia Fly-by – Virtis M – IR uncalibrated data

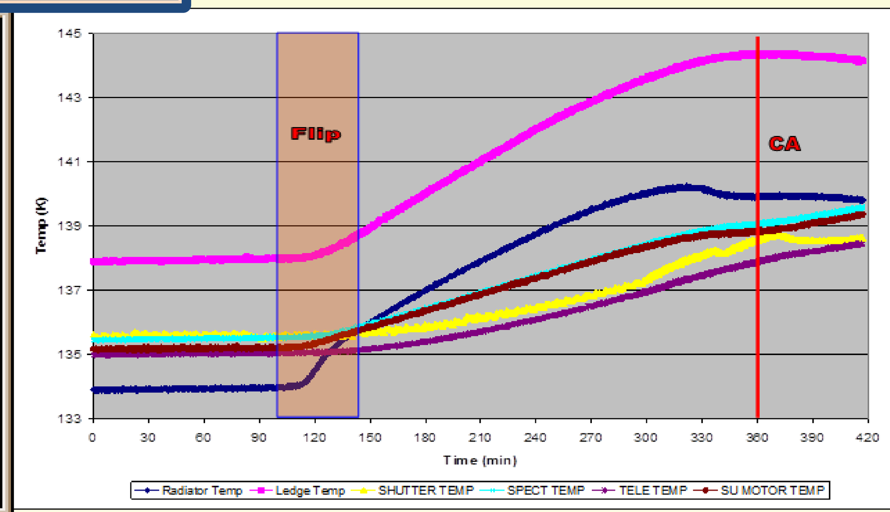

Fig.10 Temperatures measured during Lutetia Fly-by – Virtis M

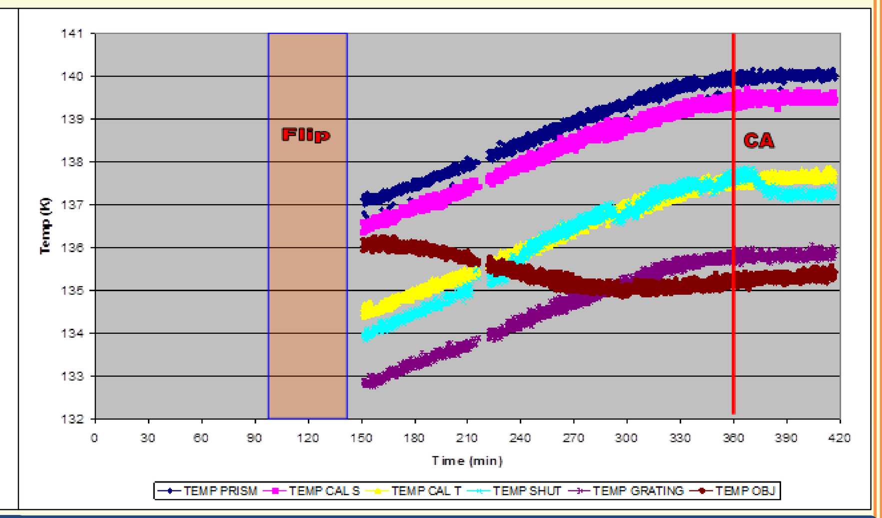

Fig.11 Temperatures measured during Lutetia Fly-by – Virtis H