TEMPERATURE OF THE NUCLEUS OF COMET TEMPEL 1. O. Groussin[1], M. F. A'Hearn[1], J-Y. Li[1], P. C. Thomas[2], J. M. Sunshine[3], C. M. Lisse[1,4], A Delamere[5] and the Deep Impact Science Team, [1]University of Maryland, College Park, MD, USA, groussin@astro.umd.edu, [2]Cornell University, Ithaca, NY, USA, [3]Science Applications International Corporation (SAIC), Chantilly, VA, USA, [4]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA, [5]Delamere Support Services, Boulder, CO, USA

Introduction: The Deep Impact spacecraft (DI) encountered comet 9P/Tempel 1 on July 4th, 2005 and observed it with several instruments. In particular, we obtained infrared spectra of the nucleus with the HRI-IR spectrometer in the wavelength range of 1-5μm. From these spectra, we derived the first temperature map of a comet nucleus. The data were taken before impact, with a maximum resolution of ~120m per pixel at the time of observation. A temperature map of a comet nucleus is of paramount importance to address several problems related to the thermal properties of the surface, including its roughness, the link between temperature and surface topography and/or patterns, and to check and improve current thermal models, *e.g.*, the Standard Thermal Model [1].

Observations: The observations were performed during the approach phase, before impact. It consists of three IR scans of the nucleus performed 19 min, 12 min and 6 min before impact, with pixel resolution of 200m, 160m and 120m respectively. The data were corrected for non-linearities, compression, dark subtraction, absolute calibration and scattered light. The overall uncertainty of the calibration process is less than 20%. We also carefully checked that the contribution of the coma to the nucleus signal can be neglected to derive the temperature.

Temperature maps: In order to derive the temperature of each spectrum, we fit the data with a model that includes the reflected light from the Sun (normalized at 2μm and reddened by 3% per 1000Å to account for the color of the nucleus) and the thermal component of the nucleus (Planck function with an infrared emissivity of 0.90). The resulting temperature maps are illustrated on Figure 1. The maps are consistent with each other, which is expected since the phase angle did not change significantly over the period of observations. It also gives us confidence in our methods. Resolution is important since isothermal areas become non-isothermal and show temperature variations when they are resolved. This is particularly true for the upper left part of the nucleus. To first order, the temperature matches the topography, indicating a low thermal inertia. The temperature ranges from ~260K to ~334K on the sunlit hemisphere visible from the spacecraft. With our spatial resolution, we do not see areas colder than 200 K, which would be related to free sublimation of volatiles on the surface, *e.g.*, H_2O, CO_2 and/or CO. Since water ice has been detected on the surface based on the presence of water ice absorptions, our temperature data indicate that water ice and dust are thermally and thus physically decoupled [2].

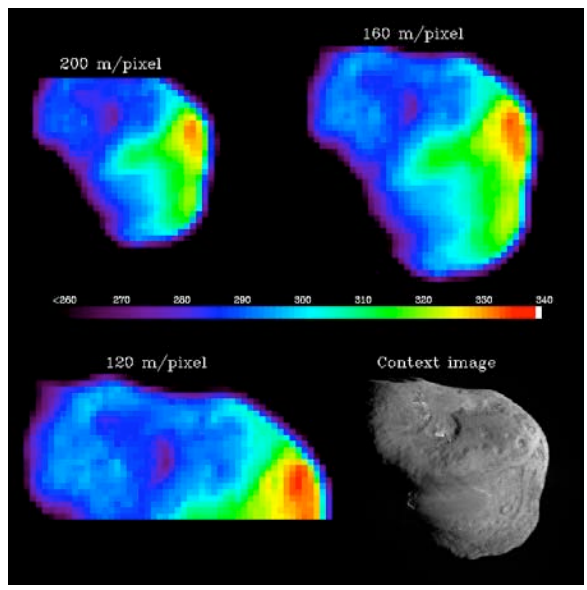

Figure 1: Temperature maps of the nucleus derived from the DI data, with a resolution of 200, 160 and 120m/pixel. A deconvolved HRI-VIS image is shown on the lower left corner to give the context.

Thermal modeling: In order to derive the thermal properties of the nucleus, a thermal model is required. We used the thermal model presented in [3] and [4], combined with the shape model of the nucleus of comet 9P/Tempel 1 [5].

Thermal inertia. Figure 2 illustrates the results of our model (shape model + thermal model) for different values of thermal inertias. While there is no obvious solution that fits the data perfectly, it is clear that the lower the thermal inertia, the better the fit. In particular, a critical constraint is the sub-solar point temperature. We measured the temperature of the sub-solar point as 334±8K from DI, while the model results are 329K, 329K, 327K, 324K and 226K for I=0, 10, 50, 100, and 1000 MKS, respectively. So, within one sigma, we can reject thermal inertias

higher than 100 MKS. We also note that the model fits the data better near to the sub-solar point than far from it (*e.g.*, the upper left part of the nucleus). This means that other physical processes must be taken into account.

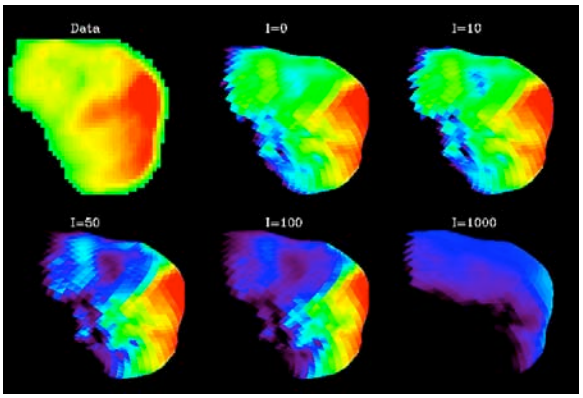

Figure 2: Computed temperature maps of the nucleus derived from the shape model with different thermal inertia of 0, 10, 50, 100 and 1000 MKS.

Roughness. Roughness is an important process to take into account since the surface of a cometary nucleus is not flat. Moreover, roughness has some implications on the temperature of the nucleus since it changes the incident angle to the Sun, which is the critical parameter for computing the temperature. In order to study the first order effect of roughness, we added another step in our model. Each plate of the shape model is now a combination of two plates that have a slope of +X and –X degree respectively, compared to the original slope. X is a free parameter and X=0 means no roughness. The results are illustrated on Figure 3 with different values of X from 10 to 30 degrees. The higher the roughness, the higher the temperature is far from the sub-solar point. This results from the fact that the temperature varies as $\cos^{1/4}$ of the incident angle (or slope), so that the effect of changing the slope is more pronounced at higher incidence angles. Even if it is difficult to estimate the roughness from this simple model, a value of 20 degrees gives the best fit to the data. This value is also in agreement with the results of Emery et al. [6] who derived a Hapke parameter θ of 20 degrees for Mercury using a more realistic roughness model.

Perspectives: In future work, we will develop a more realistic thermal model that will take into account roughness with random surfaces at very small scales, multiple scattered light for self-heating of the different facets of the shape model, and shadowing effects.

Conclusions: We derived the first temperature map of a comet nucleus, which allows us for the first time to derive important properties of the nucleus surface *in-situ*. In particular, the thermal inertia of the nucleus is lower than 100 MKS and its roughness is on the order of 20 degrees. The Standard Thermal Model is probably a good model to the first order. However, we expect to propose in the near future a more realistic model based on DI data that will support interpretations of ground-based IR observations of comet nucleus.

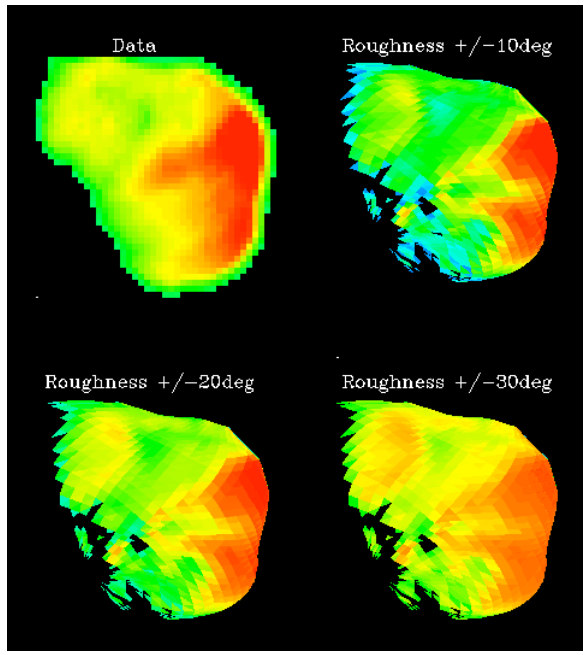

Figure 3: Computed temperature maps of the nucleus derived from the shape model with no thermal inertia but with roughness of 10, 20 and 30 degrees.

References: [1] Lebofsky L. A. and Spencer J. R. (1989) *Asterdoids II, Tucson, AZ, University of Arizona Press*, 128-147. [2] Sunshine J. M. et al. (2006) *Science*, in press. [3] Groussin O. and Lamy P. (2003) *A&A 412*, 879-891. [4] Groussin O. et al. (2004) *A&A 413*, 1163-1175. [5] Thomas P. et al. (2005) *DPS conference 37*, Abstract #43.16. [6] Emery J. P. et al. (1998) *Icarus 136*, 104-123.