Chapter 7

The Nucleus of Comet Tempel-Tuttle

7.1 Background

Comet 55P/Tempel-Tuttle currently is the third-longest known periodic comet. Chinese records indicate it was observed in October 1366; only P/Swift-Tuttle and P/Halley have been observed longer than that. The more tactile claim to fame, however, is the comet's parentage of the Leonid meteor stream. The November meteor shower associated with it becomes a veritable storm for a few lucky locations on Earth roughly every 33 years, that is, around the time of perihelion of this 33-year period comet. In addition to all the other reasons for studying nuclei, models of the meteor stream grain population depend on the parameters of the nucleus and the dust production rate.

I have described much of this work elsewhere (Fernández *et al.* 1999a) and will reproduce some of the text here.

7.2 Thermal Measurements

We observed this comet on 21 Jan 1998 at NASA/IRTF with the MIRLIN mid-IR imager, and on 22 to 24 Jan 1998 with a CCD on the UH 2.2-m telescope on Mauna Kea. The comet's heliocentric distance (r) was 1.15 to 1.13 AU, the geocentric distance (Δ) was 0.39 to 0.43 AU, and the phase angle was between 55.0° and 59.3°.

Our mid-IR dataset is shown in Fig. 7.1 (in logarithmic intensity scale); each frame shows a separate filter, and the filter's wavelength and bandpass of the are written in white (in μm). There are two images of the comet (and two negatives) in each frame because our chop and nod throws were smaller than the field of view of the instrument. An M band (4.7 μm) observation is not shown since only upper limits could be had from that wavelength. There is some coma visible in the images, and we performed the coma-fitting method to extract the nucleus. At each wavelength, about 50 to 60% of the flux is due to coma. We performed photometry on the residuals and the result is shown as a broad-band spectrum in Fig. 7.2. The S/N is low but we find a consistent flux of about 1 Jy in the 10-micron range. This is one of the few mid-IR broadband spectra of a cometary nucleus in existence (cf. e.g. Hanner *et al.* 1985).

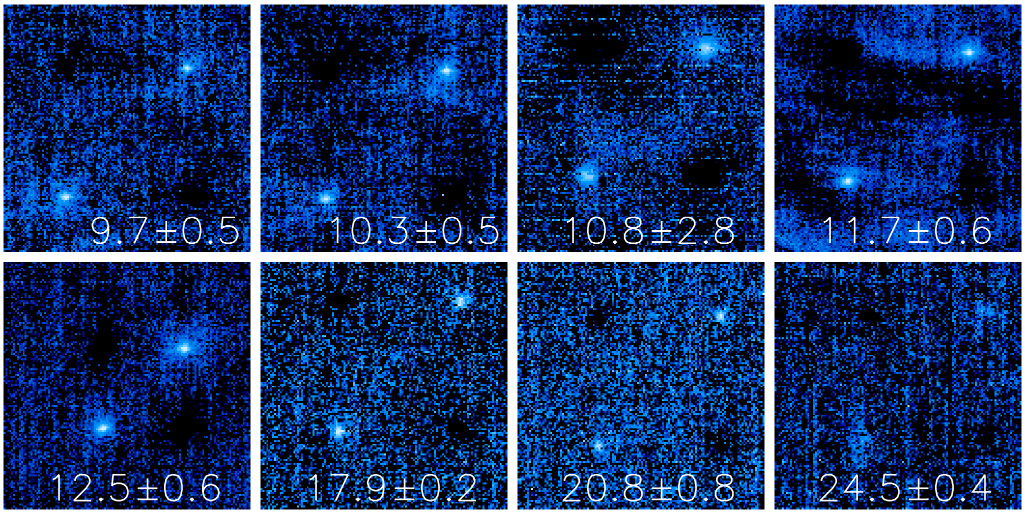


Figure 7.1: Mid-infrared images of comet Tempel-Tuttle. The two positive and two negative comets in each image are caused by the chop and nod throws being smaller than the field of view of the detector. The wavelength and bandpass are written in each frame.

The current best estimate of the rotation period is about 15 hr (Jorda *et al.*, reported by Green 1998). For a lunar-like thermal inertia, the nucleus of Tempel-Tuttle is reasonably modeled with the STM, and plotted on the spectrum in Fig. 7.2 are model spectra based on the STM. The usual plausible input parameters – mentioned in previous chapters – yield an effective radius of 1.75 $\pm$ 0.4 km, a subsolar temperature (T_{SS}) of 380 to 410 K, and a brightness temperature (T_B) of about 280 to 350 K.

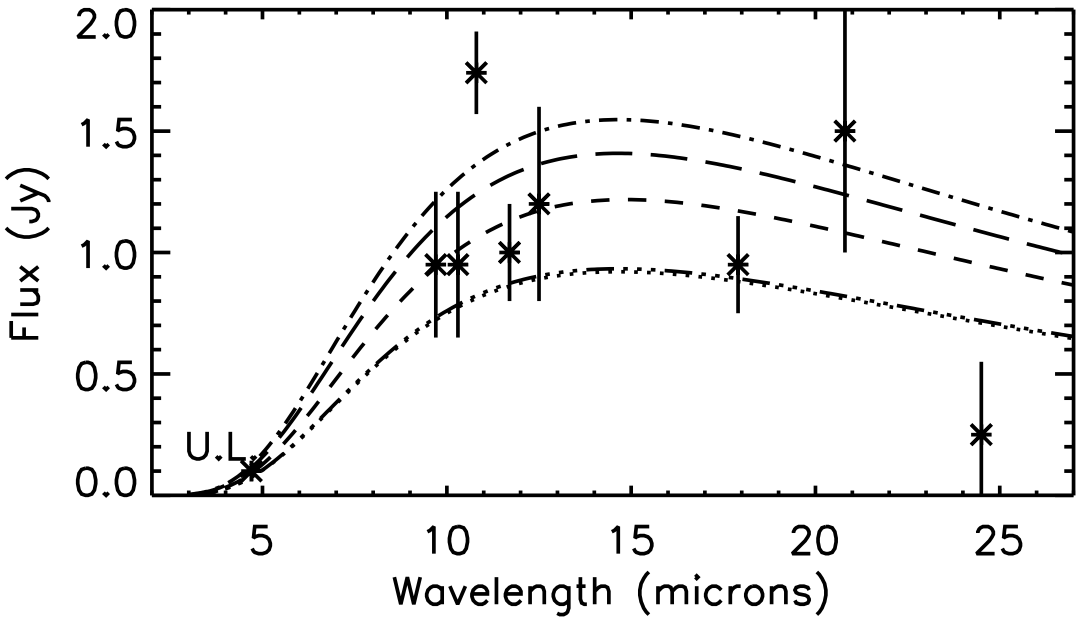


Figure 7.2: Mid-infrared spectrophotometry of comet Tempel-Tuttle's nucleus. The model spectra drawn through the data are based on the STM and varying all of the STM's parameters indicate that the effective nuclear radius is 1.75 ± 0.4 km. The plotted example models assume a beaming parameter of 0.8, an emissivity of 0.9, an infrared phase coefficient ranging between 0.005 and 0.015 mag/degree, and an effective radius ranging between 1.35 and 2.15 km. "U.L." indicates the 3-σ upper limit to the flux at that wavelength.

7.3 Optical Measurements

A typical R-band optical image and its analysis products are shown in Fig. 7.3 (in logarithmic intensity scale). The left panel is an original (reduced) image, the middle panel is the model of the coma from the coma-fitting method, and the right panel is the residual from the subtraction of the two. Clearly good removal of the coma was apparently achieved, as can be seen from a comparison of the PSF, the residual's profile, and the original comet profile (plot in Fig. 7.3). The residual is a point-source, and we ascribe its flux as reflected light from the nucleus. The photometry of the residual has magnitude $R_C = 16.8 \pm 0.2$. This magnitude does not have rotational context but the uncertainty from removing the coma ameliorates this somewhat. An independent analysis of this optical dataset has not revealed any clear rotational signature in the comet's photocenter (J. M. Bauer, private communication), so the nucleus may happen to be not very elongated.

We now characterize the optical phase effect, ϕ, of the nucleus by combining our data with the magnitudes reported by Lamy (1998) and Hainaut *et al.* (1998) in Fig. 7.4. The asterisk is from this work, the triangle is from Lamy, the rhombuses are photometric points from Hainaut *et al.*, and the crosses are possibly photometric points from Hainaut *et al.* A straight line gives a satisfactory fit with $\beta = 0.041$ mag/deg, a not atypical value for nuclei (Jewitt and Meech 1988). We have also fit the data according to the pan-asteroidal phase law of Lumme and Bowell (1981), as we did in Chapter 5 with comet Encke. Though the two models yield equally good fits, we prefer the latter since it has a physical basis. The parameter Q, which attempts to account for multiple scattering of light on the surface, is around -0.037, implying that here, just as with comet Encke, the surface of the cometary nucleus is rougher than for the typical asteroid. The zero-phase absolute magnitude is 15.6$\pm$0.2; note the 0.4-mag difference in absolute magnitudes between the two models.

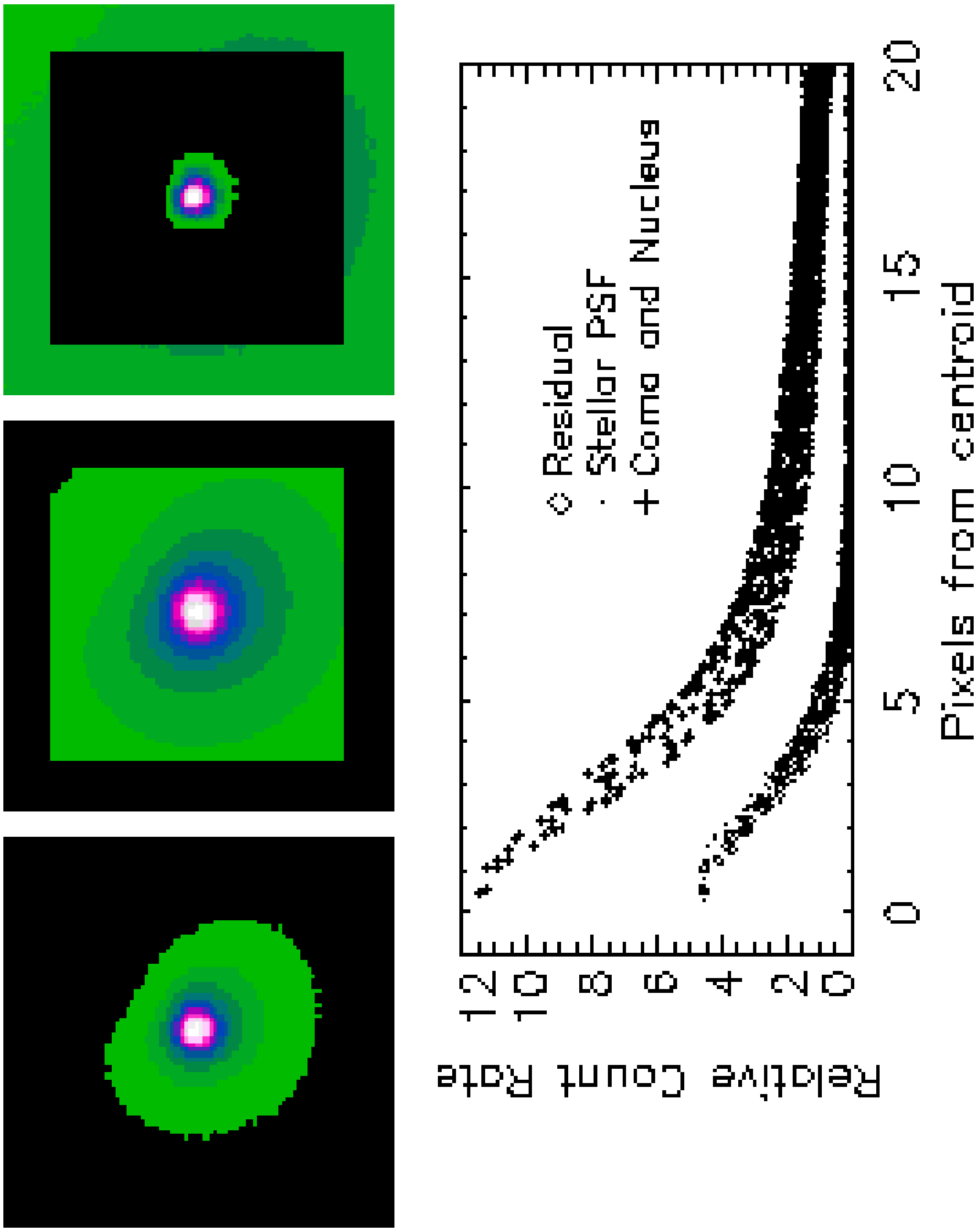
Using this phase-law and the absolute magnitude, our derived radius implies that the geometric albedo p is 0.06 ± 0.025, higher than the canonical value but not out of the range. (Assuming the β-formalism for ϕ would have yielded $p = 0.04 \pm 0.01$.)

7.4 Summary of Tempel-Tuttle Results

Our observations of Tempel-Tuttle resulted in several unique data products. First we have one of the few mid-IR spectra of a cometary nucleus in existence. This allowed us to derive the radius (1.75 ± 0.4 km) based on the STM, although the low S/N does not allow us to derive beaming parameters (Harris *et al.* 1998).

Second we have constrained the optical phase law, although the rotational context of all the optical data is unknown. With that caveat, the phase law is equivalent to a linear coefficient of 0.04 mag/degree, or, in the Lumme and Bowell (1981) formalism, $Q = -0.04$, implying a surface rougher than the typical asteroid. The albedo of the nucleus based on our determination of the absolute magnitude is $6 \pm 2.5\%$.

Figure 7.3: Coma-fitting method applied to optical image of Tempel-Tuttle. On the left is an R band image of comet Tempel-Tuttle, in the middle is a model of the coma from the coma-fitting method, and on the right is the difference between the two. The plot compares the residual's profile with the PSF and the original comet profile; it is clear that we have found a point source nucleus after subtracting the coma.



◇ Residual
· Stellar PSF
+ Coma and Nucleus
Pixels from centroid
Relative Count Rate
0
5
10
15
20
0
2
4
6
8
10
12

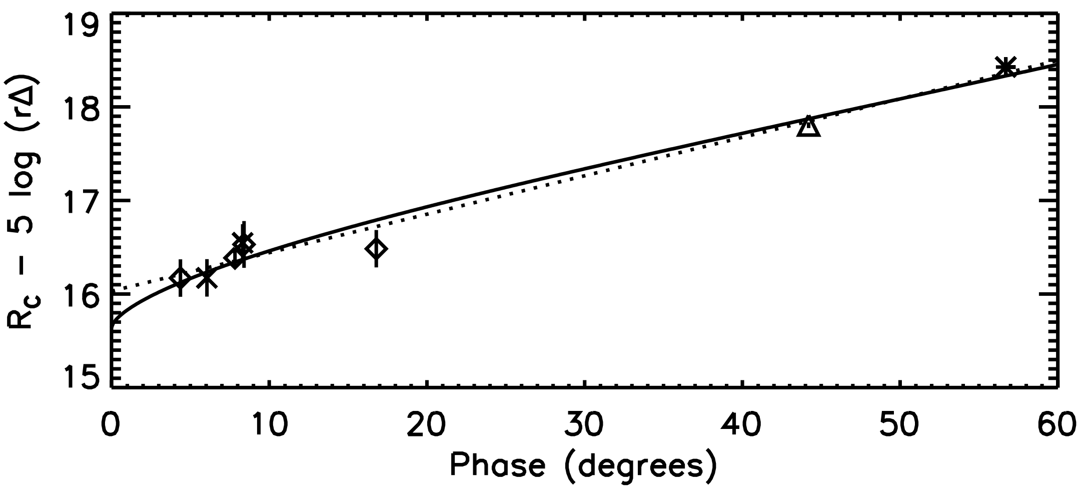


Figure 7.4: Optical phase behavior of comet Tempel-Tuttle's nucleus. The data include the measurement in this Chapter and other magnitudes culled from the literature. The straight line fits well, but since a physically-based phase law (Lumme and Bowell 1981) does also, we use the latter to derive the absolute magnitude.