# Infrared observation of meteoroid production by comet Encke

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**Comets lose mass primarily in the form of large particles[1,2] that form meteoroid streams in the comets' orbits[3]. At visible wavelengths, comets often have long dust tails directed away from the Sun, consisting of small dust particles being blown away by solar radiation pressure. Infrared observations reveal debris trails that stretch along large fractions of comets' orbits[2,4,5]. A syndyne analysis of our new observation of comet Encke, made with the *Infrared Space Observatory*[6], indicates that large particles dominate the comet's infrared surface brightness. Such particles give rise to meteor storms if their parent comet intersects Earth's[7,8]. These abundant large particles pose a significant hazard to spacecraft that might approach the comet.**

Our new image (Figure 1) was obtained with the mid-infrared camera ISOCAM[10] as part of a program to image cometary dust trails[11]. At the time of observation Encke was at a distance of 0.25 AU from the Earth and 1.15 AU from the Sun. The image was created by making a number of pointed observations coordinated with the comet's motion which resulted in a roughly square image in the comet's rest frame.[12]

The new image looks very different from previous groundbased comet images in the visible, because it has a prominent long, straight debris trail that runs diagonally across the image, in addition to a structured, peanut-shaped emission region nearer the nucleus. The debris trail follows the orbit of the comet; which is to say that the orbits of the debris trail particles are very similar to that of the nucleus, differing primarily in mean anomaly. Most visual-wavelength comet images, on the other hand, display dust tails that are produced by small particles that are blown away from the comet, in the anti-solar direction, by solar radiation pressure.

To determine the size of particles that produce the emission in our image, we calculated trajectories of particles emitted from the comet nucleus and overlaid them on the image (Figure 2). These trajectories are zero-velocity syndynes which show the path of a particle as a consequence of its sensitivity to solar radiation pressure. This sensitivy is expressed by the ratio of the forces due to radiation pressure and the Sun's gravity, $\beta = F_{\text{rad}}/F_{\text{grav}}$. For spheres,[13] $\beta = K/\rho a$ where $\rho$ is the particle's mass density (g $\text{cm}^{-3}$), $a$ is the particle's radius (cm), and $K = 6 \times 10^{-5}$. Over time, particles of a given $\beta$, ejected with zero velocity, trace out the paths (referred to as syndynes) shown in Fig. 2 It is immediately obvious that particles with $\beta > 10^{-3}$ cannot be responsible for the emission, because they would occupy a portion of the image which has very little infrared emission. When the ejection velocity is added, these syndynes fan out, which means that the observed emission would require even larger particles. Thus, the zero-velocity syndyne analysis errs on the side of higher $\beta$, or smaller particles. While it may appear that high $\beta$ particles are required to explain the trail component forward of the comet's orbital position (East), this is not the case. The dust trail is due to even larger particles, with $\beta < 10^{-4}$. The portion of the trail behind the comet's orbital position requires the low $\beta$ particles, and it is the inclusion of velocity which results in the extension of the trail ahead of the comet[14].

Large particles are well known to carry most of the mass of cometary debris, as was shown by the Giotto spaceprobe flybys of comets Halley[1] and Grigg-Skjellerup[15], the wide 'skirt' of radar reflections from comets IRAS-Araki-Alcock[16] and Hyakutake[17], and the infrared photometry of comets by *IRAS*[2] and *COBE*[18]. Preminary results from a more detailed analysis[12] of this image indicate that all of the particles observed in Figure 1 end up in the debris trail, of which the narrow trail structure is the core. Therefore, for the first time, we are able to trace the path of large cometary particles from the nucleus to the debris trail. Such particles also would give rise to a meteor storm, were the comet's debris trail to cross the Earth's path[8]. Indeed, comet Encke is throught to be the parent of the Taurid meteor streams, which produce annual shows in October through November[9]. The width of the debris trail core in our image is 20,000 km, so that, if traversed by Earth, the meteor storm would only last $\sim 20$ minutes. Howevere, Encke's orbit approaches only to within $25 \times 10^6$ km of Earth's, so the meteoroids we observed will not produce a storm of Taurid meteors. Over time, gravitational perturbations by the planets scatter the meteoroids' orbits, so that they evolve away from their parent comet's orbit.

In November 2003, the CONTOUR spacecraft is scheduled to fly within 200 km of Encke[19]. At this time the comet will be at heliocentric and geocentric distances similar to those when our ISOCAM observations were made[20]. Using a color temperature of 260 K, as measured measured by ISOPHOT (C. M. Lisse, personal communication), the optical depth at an impact parameter 200 km is $\tau \simeq 7 \times 10^{-6}$. For spherical particles, the mass of particles encountered by a spacecraft (with area $A$) is

$$M = \frac{4KA\tau}{3\beta}. \tag{1}$$

The encountered mass is relatively insensitive to assumptions about the particle properties; in particular, it is independent of the mass density (hence, fluffiness) of the particles. The number of particles encountered by the spacecraft is

$$N = \frac{A\tau\rho^2\beta^2}{\pi K^2}, \tag{2}$$

which is sensitive to particle density as well as $\beta$. Using the upper limit $\beta < 10^{-3}$ for coma particles, we find that a 10 m$^2$ spacecraft will encounter $> 1$ g of cometary particles during its traverse. The expected number of particles encountered with $\beta < 10^{-3}$ is $N \sim 10^3$. For comparison, the dust detectors on the Giotto spaceprobe passing through the coma of comet Halley in 1986 detected only 0.01 g, though an estimated total mass of $\sim 0.15$ g penetrated the dust shields,[21] at a distance of 2,200 km. In the dust trail core, there are relatively fewer particles than in the coma, but they are larger. Using the trail optical depth of $\tau \sim 1.4 \times 10^{-8}$ and an upper-limit to $\beta < 10^{-4}$, the mass of trail particles encountered is $M > 10^{-3}$ g, but there is $< 1\%$ chance of hitting a trail particle. At high flyby velocities of tens of kilometers per second, the large particles near the comet represent a significant hazard to spacecraft.

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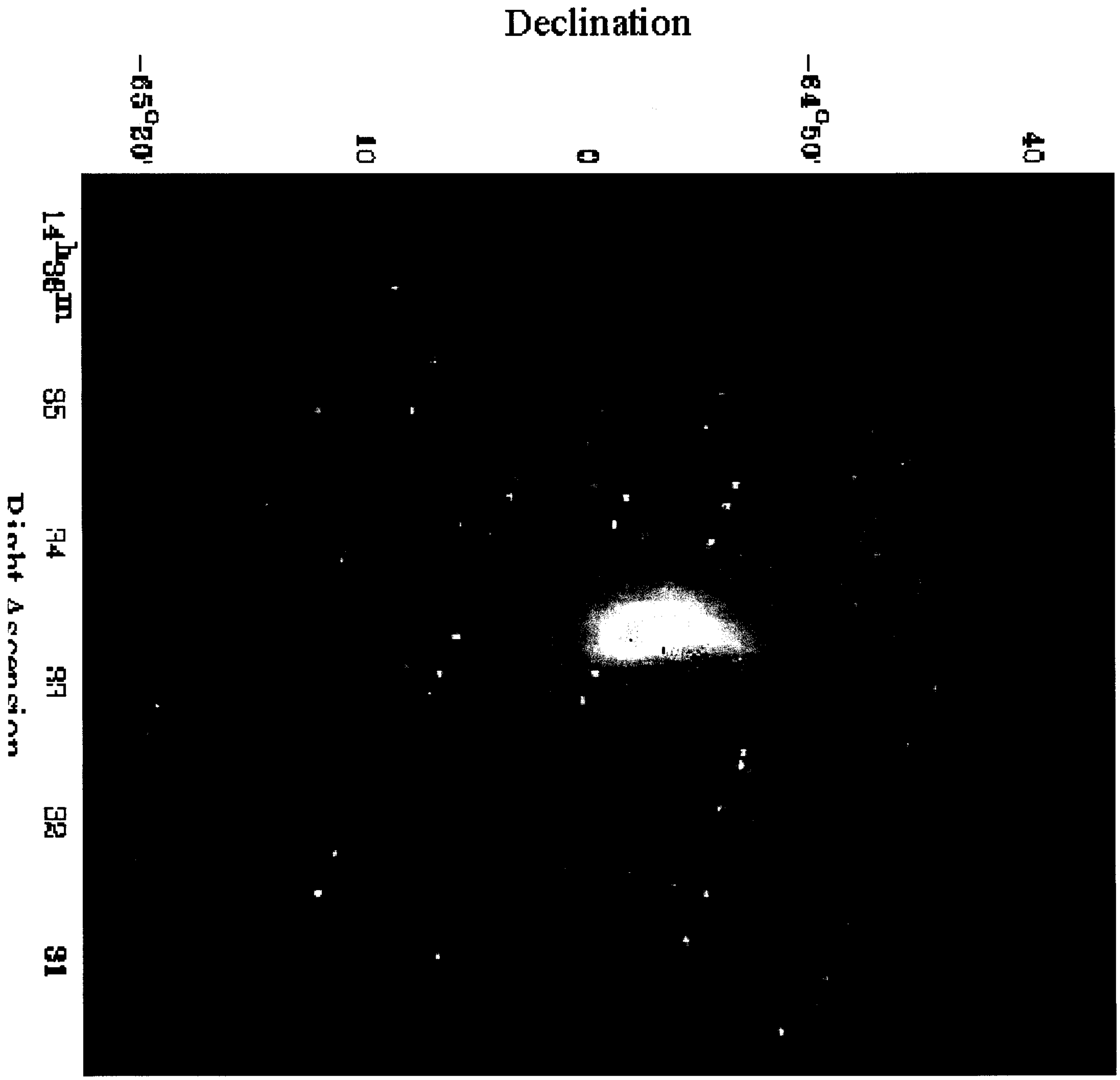
Figure 1: Image of comet Encke in the comet rest frame made from observations by the *Infrared Space Observatory* in 1997. This image is a mosaic of 231 individual pointings with an instantaneous field of view of $3' \times 3'$. each of the individual pointings was shifted (before coaddition into the final mosaic) in reflex with the comet's motion. The pixel size is $6''$ and the final image size is $40' \times 40'$ in the comet's rest frame. Stars appear as multiple point sources, one for each raster leg that crosses the star's position, spread out along a straight line in the direction of the comet's motion. The dust trail is clearly visible in this image, stretching diagonally from the lower left to upper right.

Figure 2: Trajectories (syndynes) of particles with several different values of $\beta$ (as labeled), ejected from the comet over the 260 days prior to our ISOCAM observation. The syndynes are overlaid on the same image as Figure 1. The dotted line shows the projected direction of Encke's orbit.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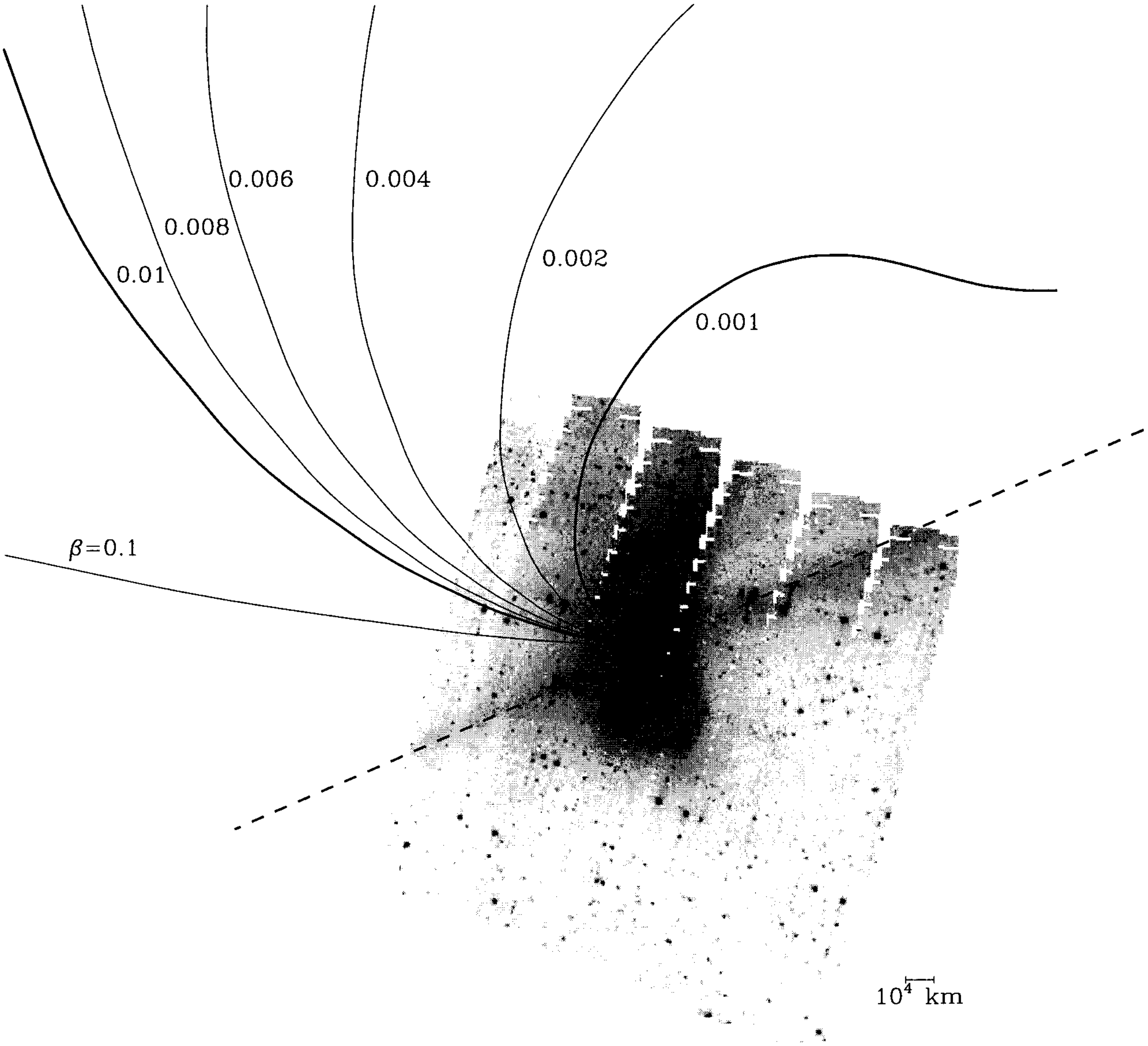
35
34
33
32
31
Right Ascension



0.006
0.004
0.008
0.01
0.002
0.001
$\beta$=0.1
$10^4$ km