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# PHOTOMETRIC OBSERVATIONS OF RECENT COMETS

E. P. Ney

The first infrared observations of a comet were made by Becklin and Westphal (1966) who studied Comet Ikeya Seki (1965f). Their data at wavelengths of 1.6 to 10 microns revealed that this comet was a bright infrared object because of thermal radiation by dust grains in the coma. This is just another example of the importance of dust in infrared astronomy. The success of infrared is largely due to the extreme visibility of dust which reveals itself by reradiation in the infrared and by scattering or extinction in the visible. Optical opacities are $\chi = 10^4 \mathrm{cm}^2/\mathrm{gm}$ for one micron dust particle, $\chi = 1 \frac{\mathrm{cm}^2}{\mathrm{gm}}$ for plasma free electrons, $\chi = 10^{-4}\ \mathrm{cm}^2/\mathrm{gm}$ for neutral molecules. By the time Bennett came along (1969i) infrared techniques were well developed, and the presence of an emission feature at 10 and 20 microns had been discovered in the infrared energy distributions of late type luminous supergiant stars (Woolf and Ney, 1969, for a summary see Ney (1972)). This feature is now widely believed to be due to the presence of Fe and Mg silicates condensed in the outer atmospheres of these stars and blown into the interstellar medium by their stellar winds. We believe that carbon and SiC condense in the atmospheres of carbon stars and silicates in the atmospheres of oxygen rich supergiants and giants. From the cosmological point of view, comets differ from the interstellar material because they represent a sample of the solid material without the "contamination" of all that hydrogen and helium.

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Because of the thermal emission by the atmosphere, infrared observations are made by beam switching on the sky to cancel this emission. Liquid helium cooled bolometers at 1°K can be used at all wavelengths in the atmospheric windows from visual wavelengths (.5μ to 18 microns). The limiting noise is the statistical noise due to radiation within the bandpass of the filters. These techniques work equally well day or night except that at wavelengths shorter than 1 micron the scattered sunlight degrades the performance in daytime.

A comet can be acquired on the meridian by pointing the telescope to the ephemeris position and scanning for it.

The principal results that I will review come from the Arizona group, the Cal Tech group, and the Minnesota group. Comet Bennett was the first comet in which the silicate emission feature was seen (Maas, Ney and Woolf, 1970) and this comet taught us that we needed observations at all wavelengths preferably made with the same diaphragm geometry to untangle the scattered light and separate it from the thermal emission.

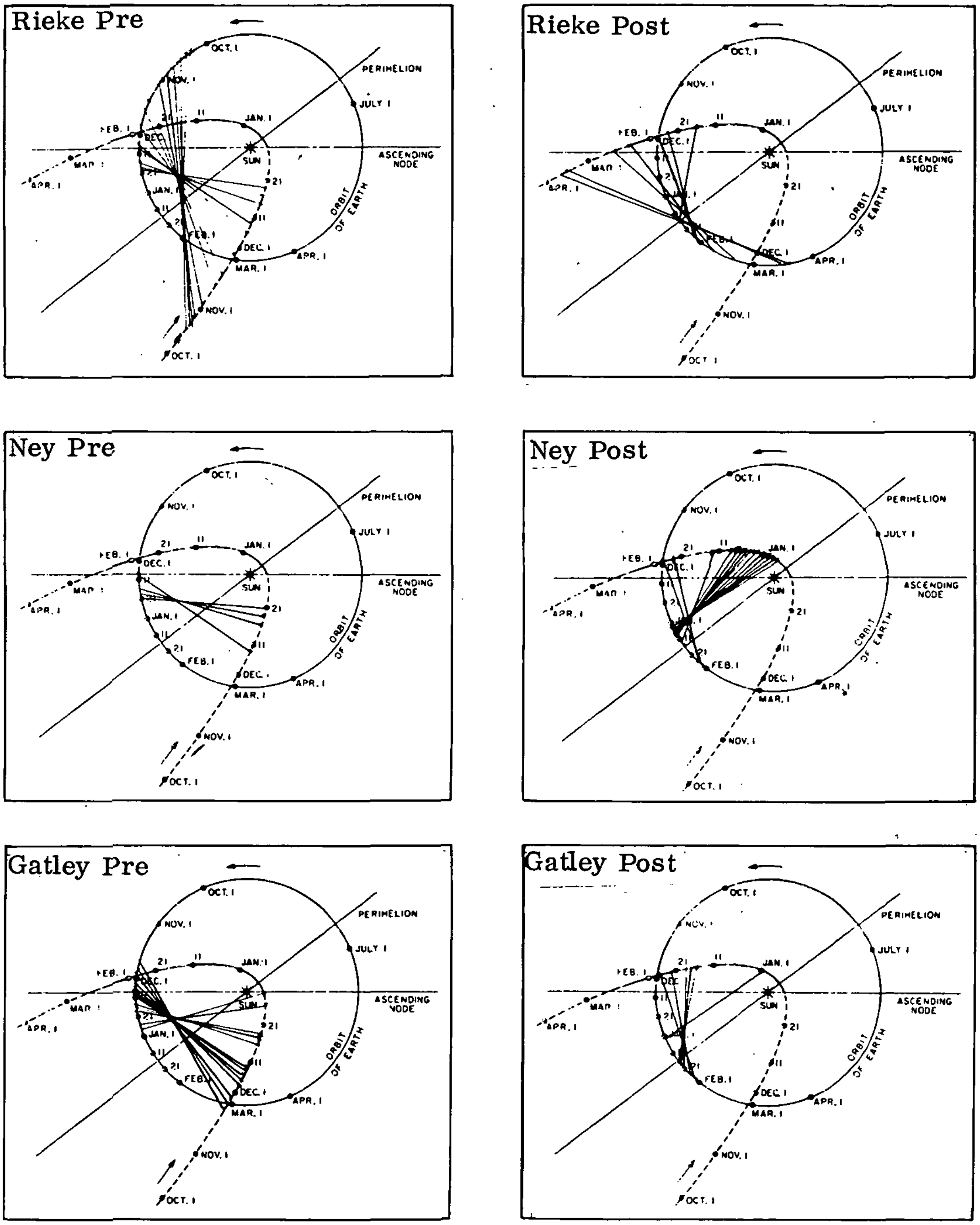
In these broadband $\frac{\lambda}{\Delta\lambda} = 10$ observations, the cometary observations are dominated by the scattered sunlight from the dust at short wavelengths and the thermal emission by the dust at long wavelengths. The interesting lines that we have heard so much about are only a minor contaminant. Also dust is its own parent molecule, being evaporated from the nucleus and flowing out into the coma and tail.

Figure 1 shows the observing record for Comet Kohoutek. Figure 2 shows what some solid objects in the solar system look like. I show this because cometary dust has a similar energy distribution.

Figure 3 shows a comparison of Comet Bennett and Kohoutek at the same distance from the sun. The principal features are scattered sunlight at short wavelengths and thermal emission at long wavelengths with a superimposed silicate dust bump at 10 and 18 microns.

Because different observers use different beam sizes, it is important to know how comet brightness depends on beam size. All three groups have studied this and shown that the flux is proportional to beam diameter at least between about 10 seconds of arc and 100 seconds. This fact of course also makes it possible to correct observations to the same geocentric distance. Figures 4 and 5 show the intercomparison of the three groups, and also indicate the excellent absolute agreement among the three groups.

Figure 4 shows the comparison between Cal Tech (Gatley et al. 1974) and Minnesota (Ney 1974). The former used a 35 arc second diaphragm and the latter a 27 arc second diaphragm. The 40% increase in diaphragm size is reflected in a 40% increase in observed brightness. Figure 5 shows the comparison between Arizona (Rieke and Lee 1974) and Minnesota. The factor of five in diaphragm diameter produces about a factor of five in observed brightness. Flux proportional to beam diameter observed at all wavelengths is to be expected in a simple model of the coma which is optically thin in dust, which has surface brightness proportional to $\frac{1}{r}$; r is distance from the



Rieke Pre

Rieke Post

Ney Pre

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Gatley Pre

Gatley Post

Figure 1. Graphical representation of those days on which the comet was observed at some wavelengths by each of the three groups. The observations are divided into pre and post perihelion.

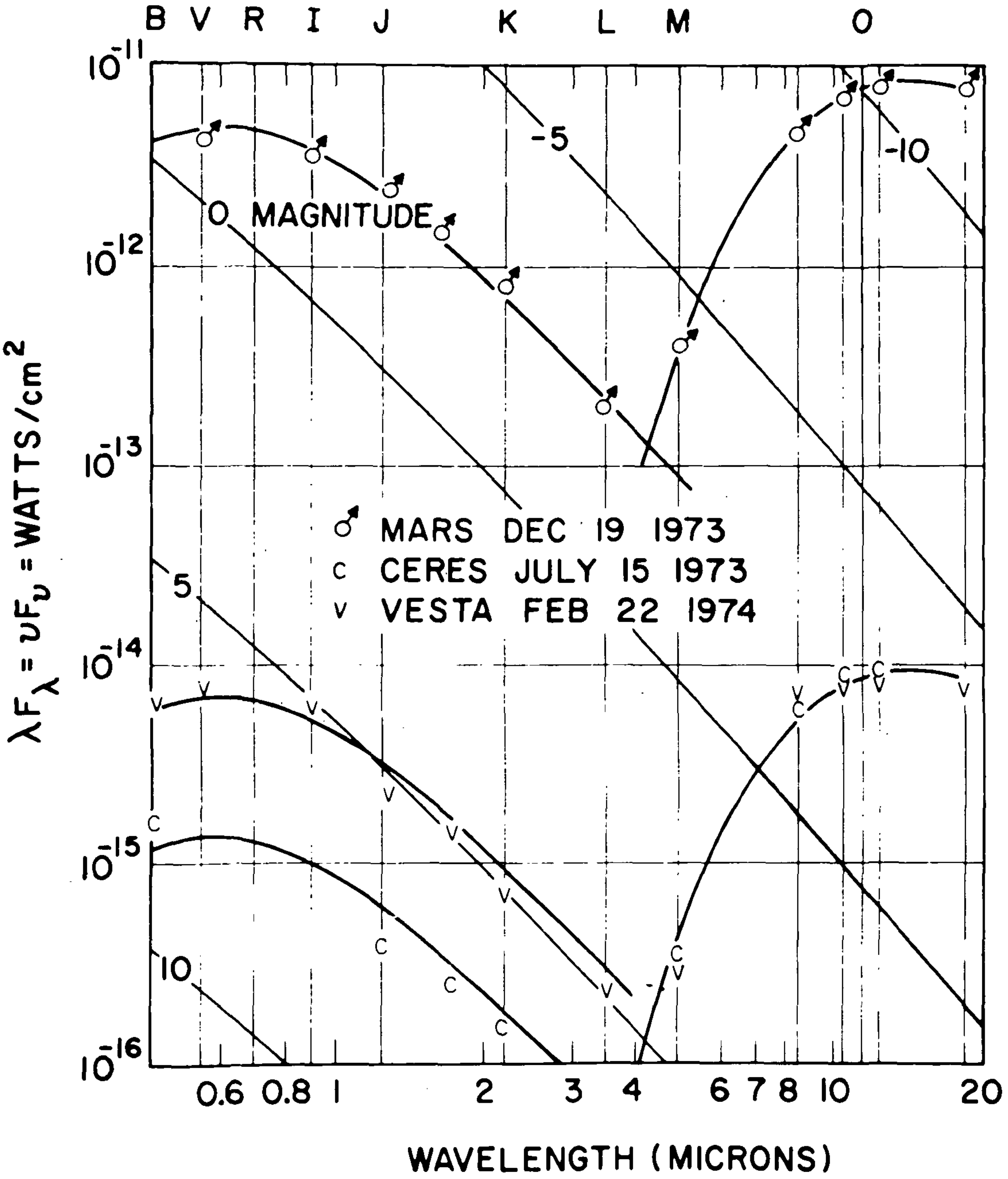

Figure 2. The infrared energy spectra of Mars and the asteroids Vesta and Ceres. The quantity plotted is $\lambda F_\lambda$ which is proportional to energy/area octave against the wavelength.

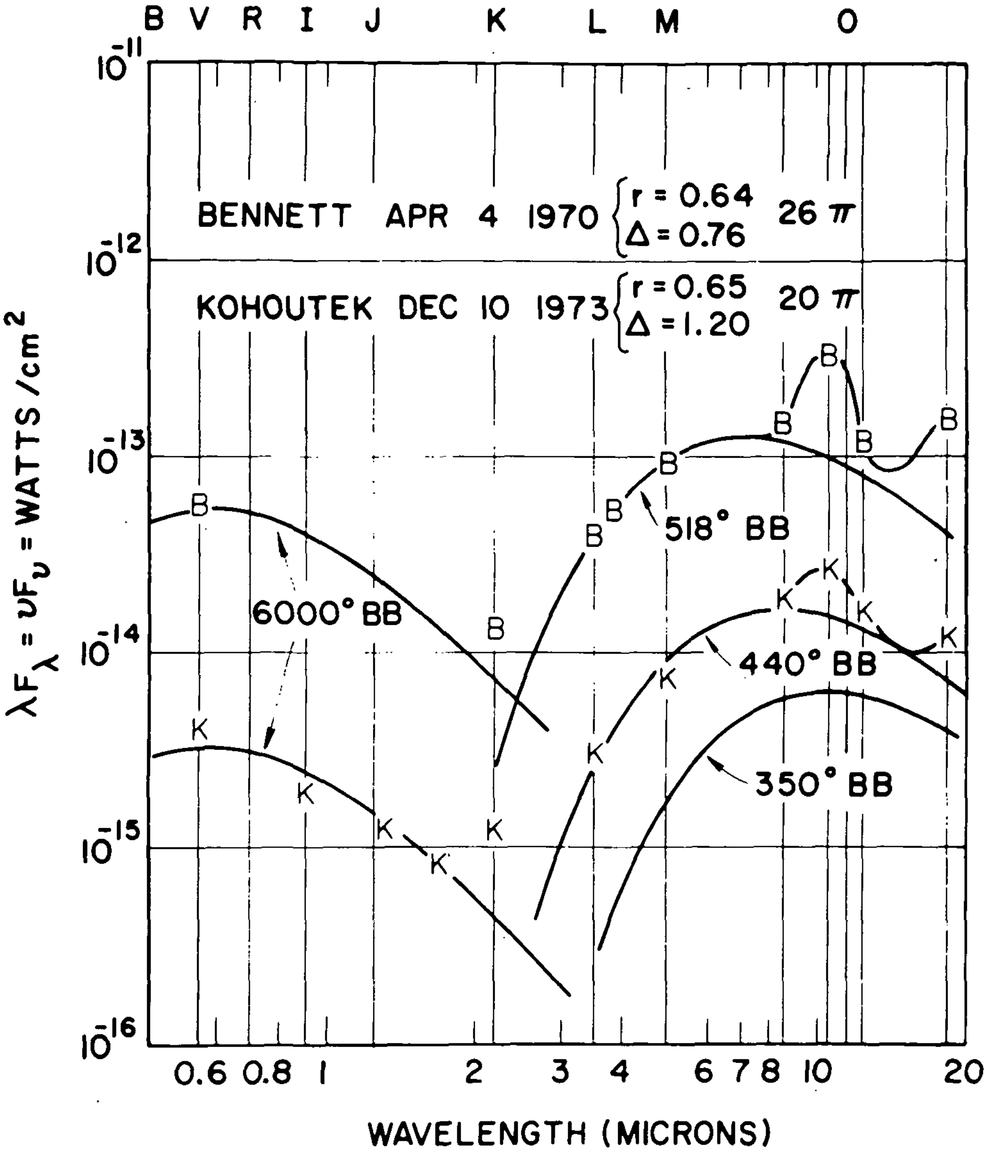

Figure 3. Comparison of the energy spectra of Comet Bennett and Comet Kohoutek, both at the same distance from the sun. Comet Bennett has a more pronounced silicate signature and also has a larger temperature excess above the grey body temperature at the appropriate distance.

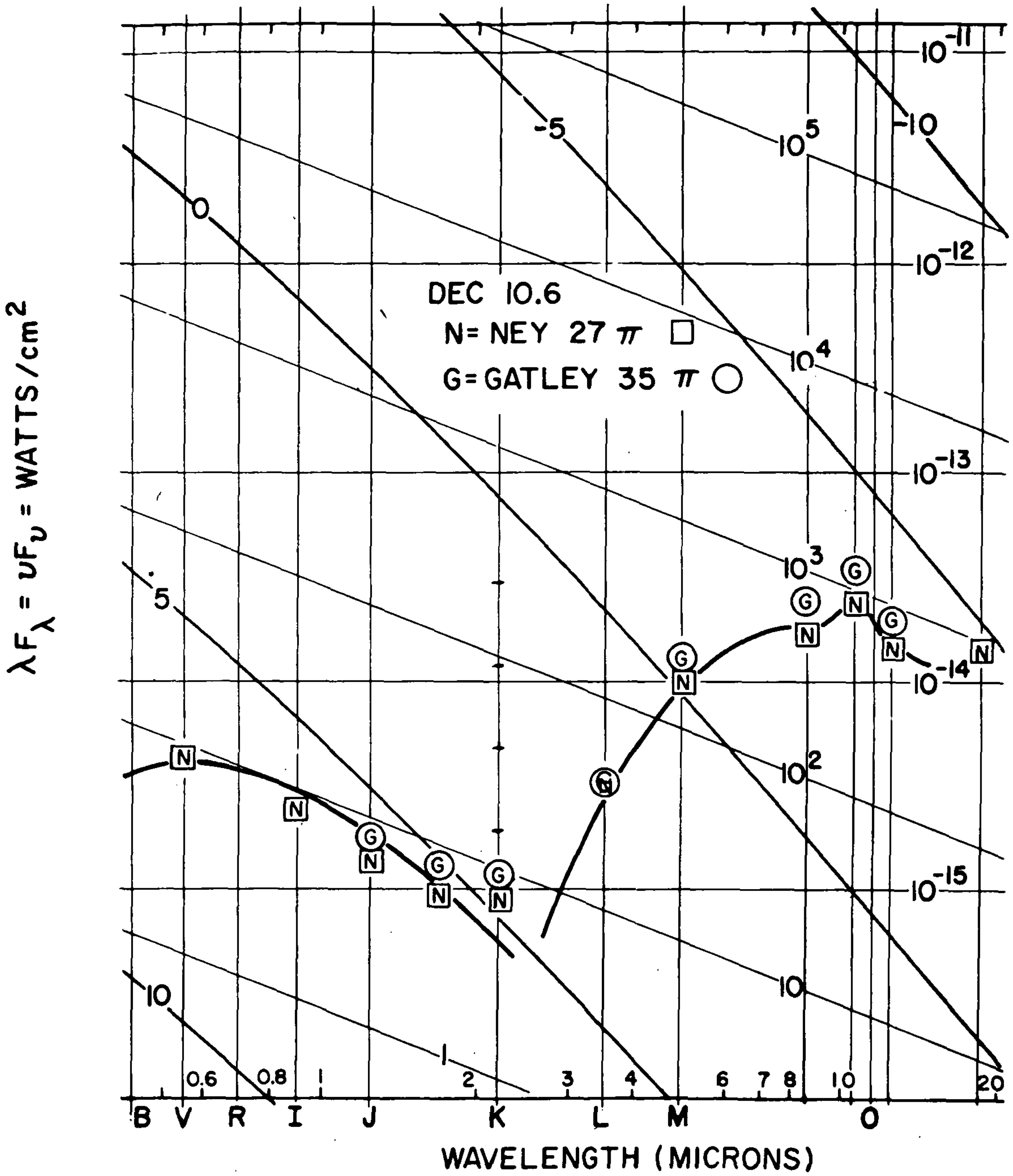

Figure 4. Comparison of the Cal Tech data and the Minnesota data on December 10.6. The larger diaphragm of Gatley et al. produces a proportionally larger signal.

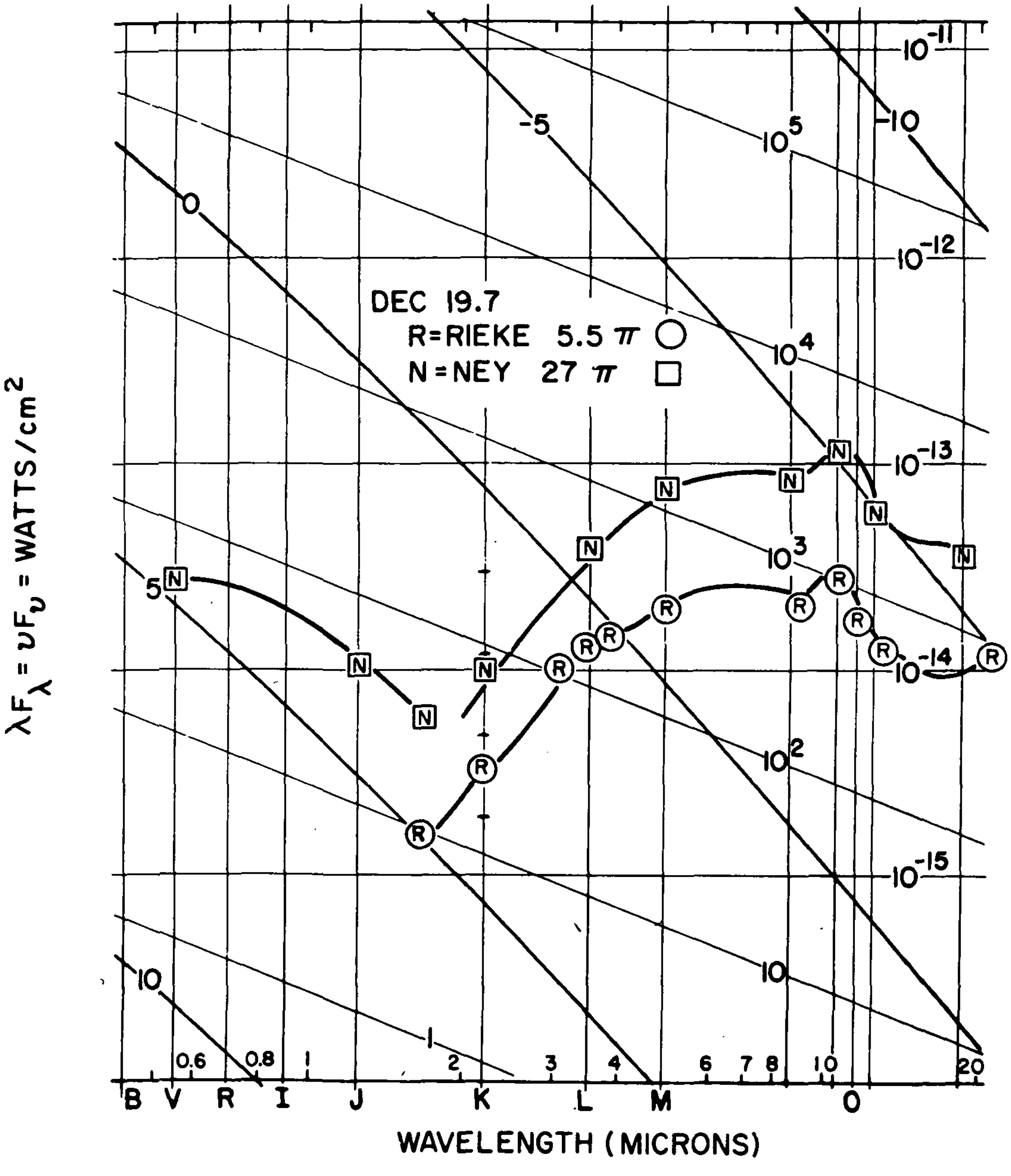

Figure 5. Comparison of results from the Arizona group with the Minnesota data. The diaphragm used by Rieke and Lee. is 5.5 sec of arc in diameter. Ney used a square diaphragm 27 arc seconds on a side. The measured fluxes are proportional to the diaphragm diameters.

nucleus and in which the particle number densities are proportional to $\frac{1}{r^2}$.

Figure 6 shows Comet Kohoutek and the planet Mercury at the same distance from the sun and earth and on the same day. The absence of any 10 micron feature in Mercury proves its real existence in the comet. Both the comet grains and the mercurian surface are hotter than a fast rotating black body at this distance from the sun. In the case of the comet it is because the grains are small and in the case of Mercury it is because the back side is cold and the thermal reradiation is principally from the heated surface.

Shortly after perihelion passage of Kohoutek an anti tail was discovered on the comet. Figure 7 shows the coma tail and anti tail observed at 3.5 microns. The remarkable thing about the anti tail is that its infrared energy distribution shows that it is cooler than the coma and tail and it does not have the silicate signature. This tells us a lot about the particles and connects these observations with the elegant analysis of Zdenek Sekanina (1974) who shows that the particles in the anti tail must be large and old (i.e. ejected at a much earlier time). There are three separate physical effects.

1) For the silicate feature to appear the grains must be small enough so that at 8 to 12 microns a single grain is optically thin. This means thatthe grain diameter must be less than about 1 micron.

2) The presence of the temperature excess means that the grains are small compared to the plankian maximum of the thermal radiation they must emit.

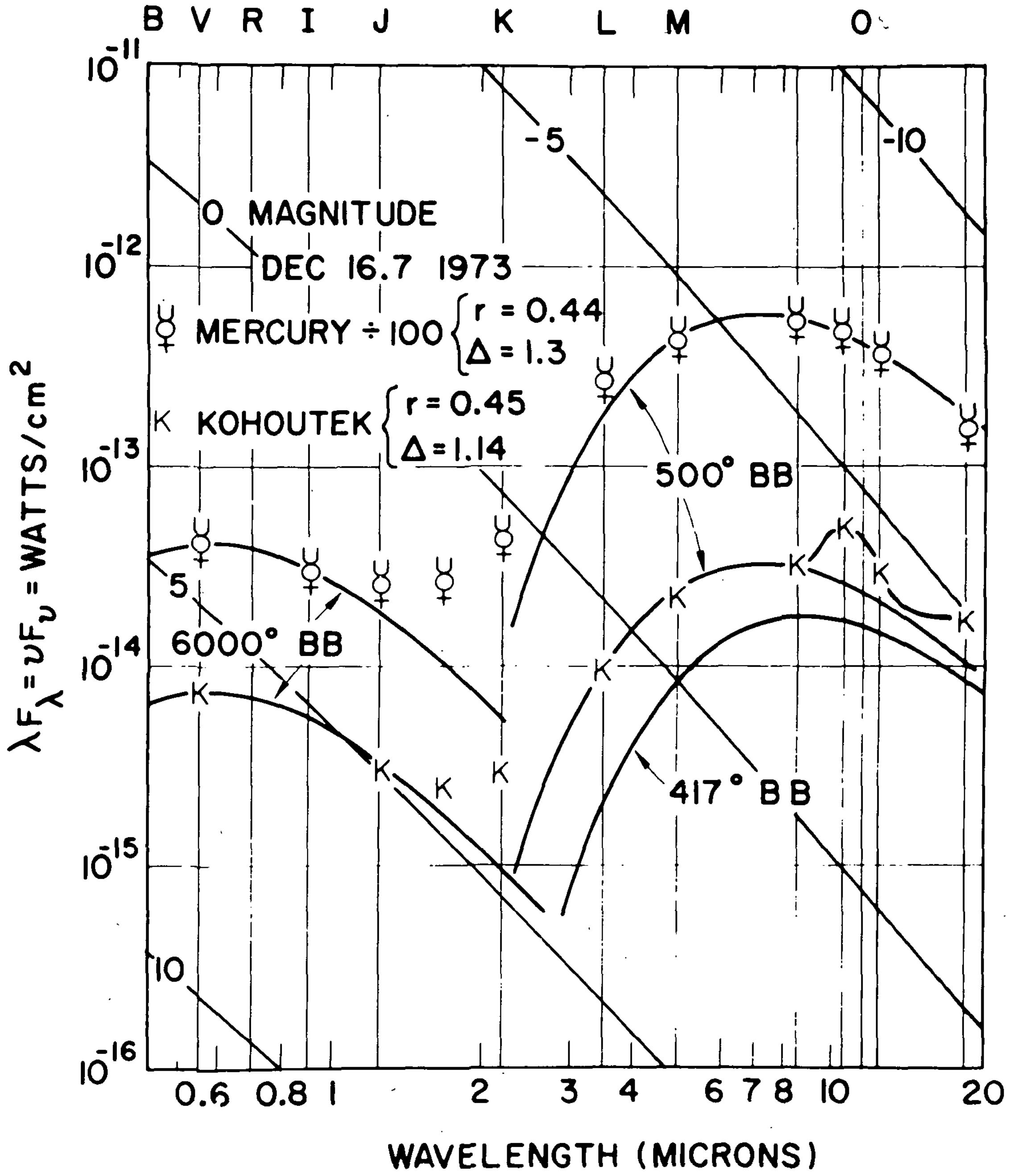

Figure 6. Comet Kohoutek and the planet Mercury at the same distance from the sun and on the same day. Note that the reflected energy by the planet is a smaller fraction of the energy in thermal emission than is the case for the comet.

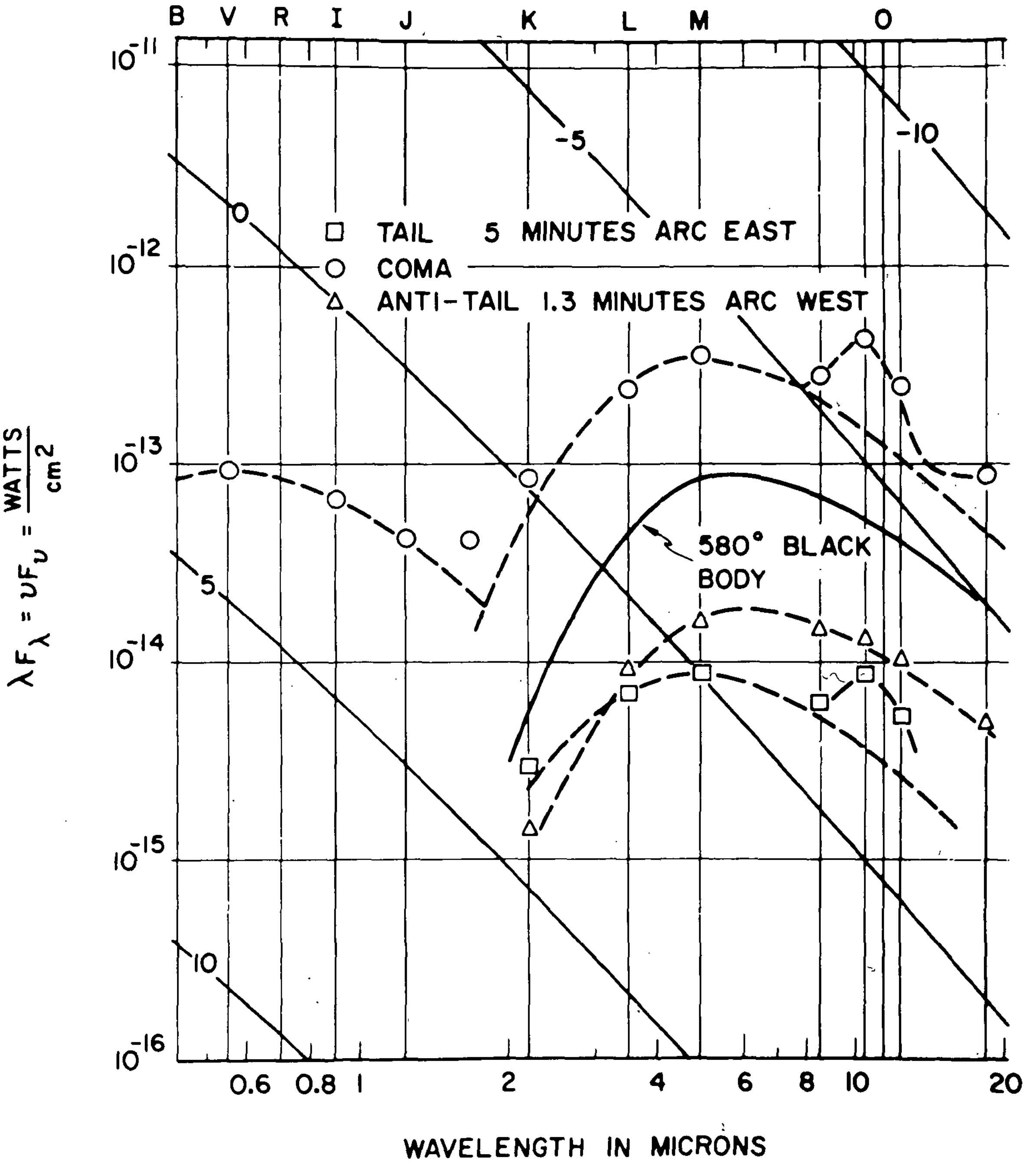

Figure 7. The coma, tail and anti tail of Comet Kohoutek on New Year's day. The coma and tail have very similar energy distributions. The anti tail is very different and is a good match for a grey body at the given distance from the sun.

3) The grains in the coma and tail cannot be too small or they would Rayleigh scatter the short wave radiation which is seen to have the solar colors. Finally,

4) the particle albedo is rather high $\gamma=0.2$. O'Dell (1971) was the first to point out for Comet Bennett that the grain albedo is determined by the ratio of the infrared thermal emission to the scattered sunlight.

For the anti tail particles, the same arguments show that unless they are of a different material they must have diameters greater than about 20 microns, although they could be as large as baseballs. Sekanina will discuss his analysis of the anti tail ballistics, but it is exciting to see his predictions confirmed by the infrared observations. There is of course a tantalizing connection between Sekanina's large particles and the shower meteors.

In the connection of particle size in the coma, the Japanese observers at Kyoto and Nagoya (Noguchi, 1974) have measured the polarization at visual and near infrared wavelengths and find that the polarization is 15 to 20% at wavelengths from visual to 1.6 microns. The direction of the polarization is correct for scattered sunlight and the wavelength independence of the polarization argues for a mixture containing small particles.

Figure 8 shows the way the comet changed after perihelion passage. The data are corrected to $\Delta=1$.

Figure 9 shows Comet Bradfield at the end of March and in early April.

Table 1 gives the Minnesota data on Comets Bennett, Kohoutek, Bradfield and Encke.

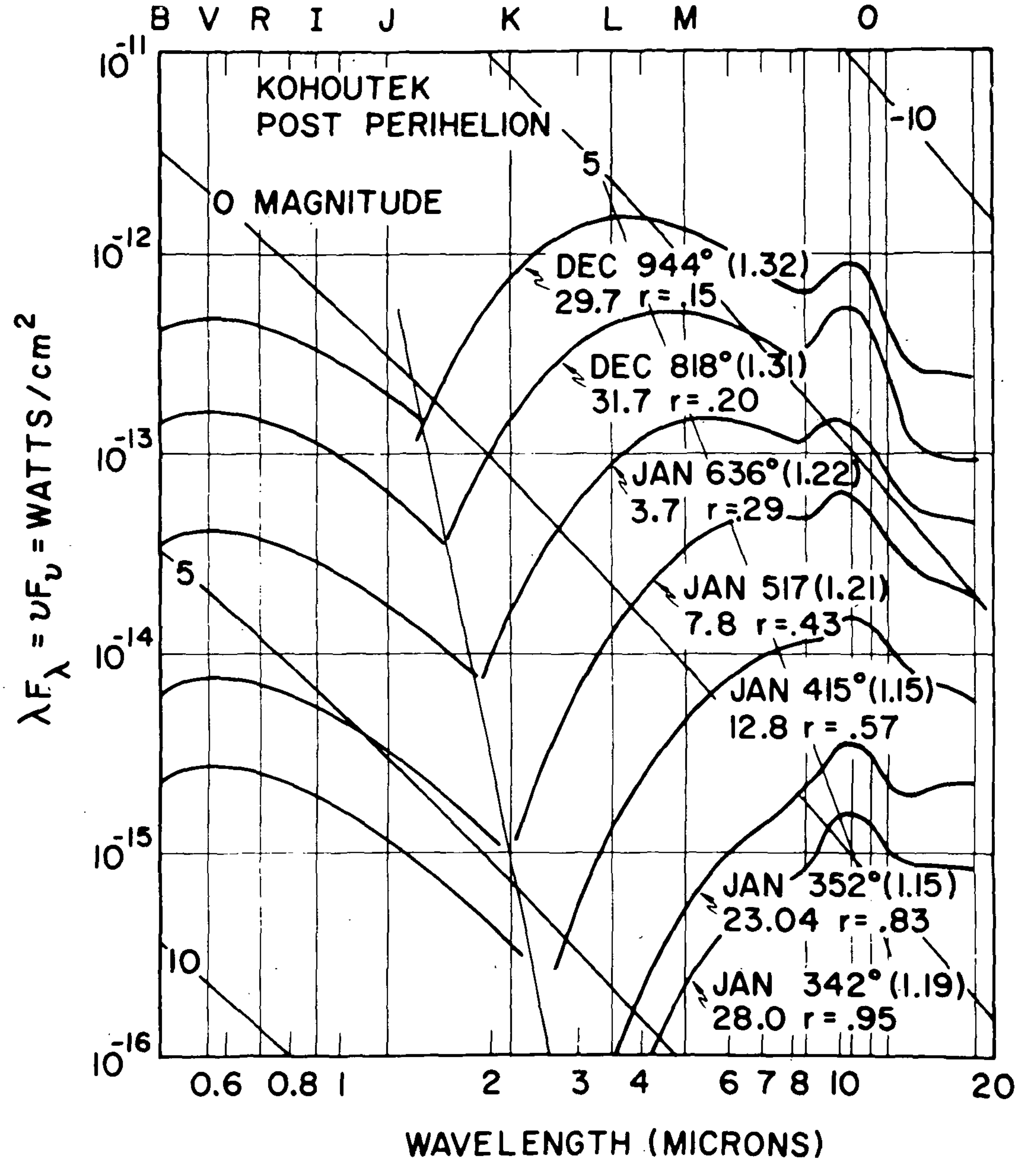

Figure 8. Some examples of the spectra of Kohoutek after perihelion passage. The temperatures of the fitted black bodies are indicated along with the factor by which the temperature exceeds the black body temperature. The relative strength of the silicate feature varies.

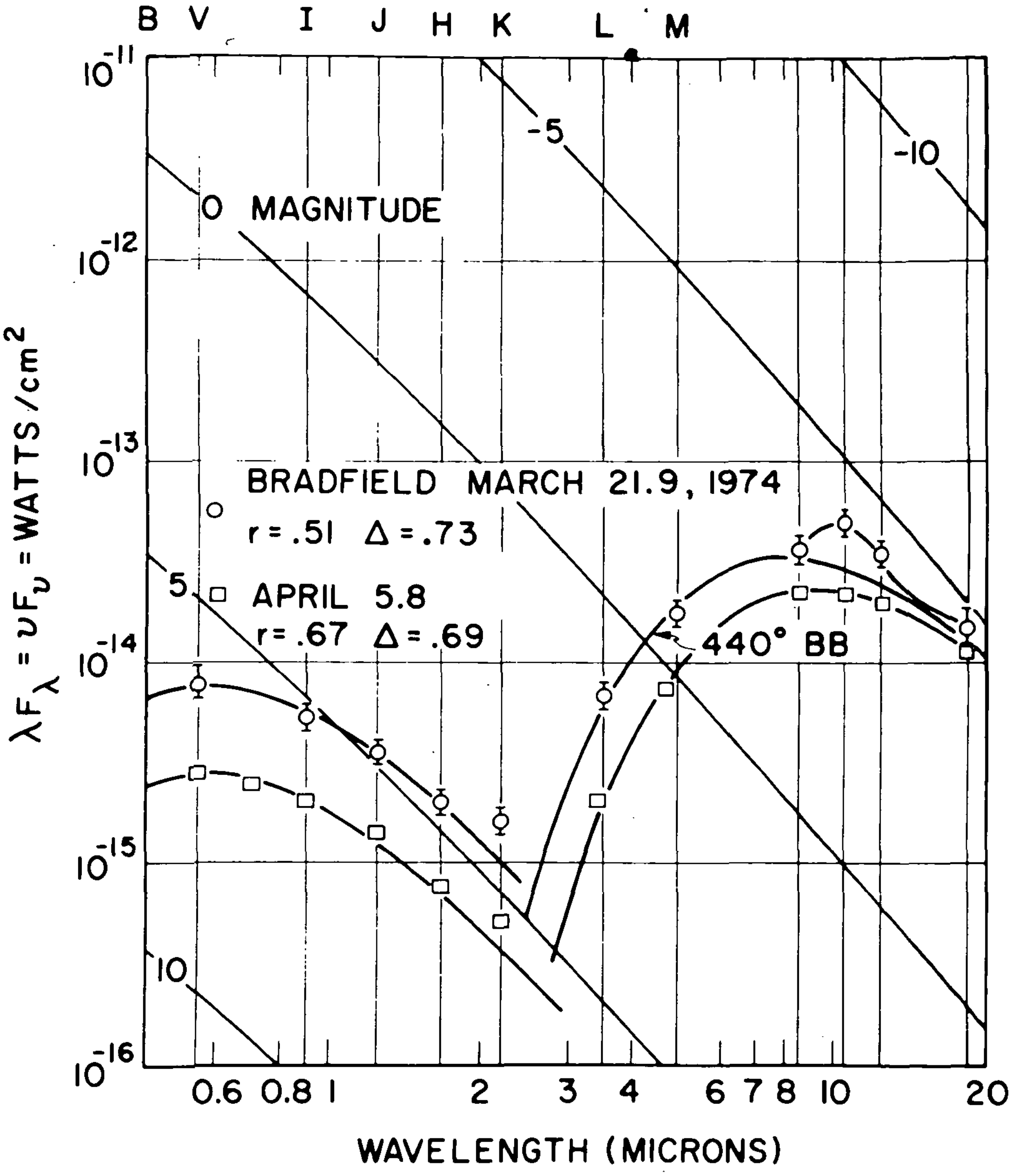

Figure 9. Comet Bradfield between r=.51 and r=.67. On the earlier date this comet had an energy distribution much like Comet Kohoutek. However, between the two dates the albedo decreased and the dust bomb disappeared.

## TABLE 1

## MINNESOTA OBSERVATIONS OF COMETS

| Date | Diaphragm | r | Δ | V | R | I | 1.2μm | 1.6μm | 2.2μm | 3.5μm | 4.8μm | 8.5μm | 10.6μm | 12.5μm | 18μm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Magnitudes | | | | | | | | | | | |
| Comet Bennett (1969i) | | | | | | | | | | | | | | | |
| April 4, 1970 | 26π | 0.64 | 0.8 | | | | | | 1.8 | -0.9 | -2.6 | -4.9 | -6.2 | -5.8 | -7.2 |
| April 24, 1970 | 26π | 0.94 | 1.1 | | | | | | 5.2 | 2.8 | 0.9 | -1.6 | -3.5 | -3.3 | -5.1 |
| May 5, 1970 | 26π | 1.1 | 1.4 | | | | | | 6.1 | 5.9 | 3.1 | -0.9 | -2.5 | -1.9 | |
| Comet Kohoutek (1973f) | | | | | | | | | | | | | | | |
| Dec. 10.7, 1973 | 27π | 0.65 | 1.2 | 6.6 | | 6.4 | 5.8 | 5.5 | 4.4 | 2.0 | 0.0 | -2.6 | -3.4 | -3.6 | -4.4 |
| Dec. 16.7, 1973 | 27π | 0.48 | 1.1 | 6.3 | | 6.0 | 4.8 | 4.5 | 3.6 | 0.8 | -1.0 | -3.2 | -4.1 | -4.1 | -4.8 |
| Dec. 19.7, 1973 | 27π | 0.37 | 1.1 | 4.6 | | 4.4 | 3.9 | 3.4 | 2.2 | -0.6 | -2.1 | -4.1 | -5.0 | -5.0 | -5.7 |
| Dec. 20.7, 1973 | 27π | 0.34 | 1.1 | 4.8 | | 4.1 | 3.6 | 3.0 | 1.8 | -1.0 | -2.6 | -4.4 | -5.4 | -5.4 | -5.9 |
| Dec. 29.7, 1973 | 27π | 0.15 | 1.1 | | | | | | -2.5 | -4.5 | -5.5 | -6.3 | -7.2 | -7.1 | -7.9 |
| Dec. 29.7, 1973 | 60π | 0.15 | 1.1 | | | | | | | -5.9 | -6.9 | -7.8 | -8.6 | -8.4 | |
| Dec. 30.7, 1973 | 27π | 0.19 | 1.1 | 2.0 | | 1.8 | 1.4 | 0.1 | -1.7 | -4.0 | -5.1 | -6.2 | -7.1 | -7.0 | -7.3 |
| Dec. 30.7, 1973 | 60π | 0.19 | 1.1 | | | | | | | -5.0 | -6.3 | -7.3 | -8.1 | -8.1 | |
| Dec. 31.7, 1973 | 27π | 0.20 | 1.0 | 2.6 | | 2.2 | 1.8 | 0.8 | -0.8 | -3.3 | -4.5 | -5.7 | -6.6 | -6.5 | -7.2 |
| Jan. 1.7, 1974 | 27π | 0.23 | 1.0 | 3.3 | | 2.6 | 2.1 | 1.2 | -0.2 | -2.7 | -4.0 | -5.5 | -6.6 | -6.6 | -6.7 |
| Jan. 2.7, 1974 | 27π | 0.26 | 1.0 | 4.3 | | 3.4 | 2.6 | 2.4 | 0.8 | -2.1 | -3.6 | -5.0 | -5.9 | -5.9 | -6.8 |
| Jan. 3.7, 1974 | 27π | 0.29 | 0.9 | 4.4 | | 3.5 | 2.9 | 2.4 | 1.3 | -1.6 | -3.0 | -4.6 | -5.5 | -5.6 | -6.7 |
| Jan. 3.7, 1974 | 60π | 0.29 | 0.9 | | | | | | 0.1 | -2.8 | -4.3 | -5.9 | -6.7 | -6.8 | |
| Jan. 4.8, 1974 | 27π | 0.33 | 0.9 | 4.7 | | 4.2 | 3.3 | 2.9 | 1.9 | -1.1 | -2.7 | -4.6 | -5.6 | -5.5 | |
| Jan. 5.8, 1974 | 27π | 0.36 | 0.9 | | | 5.0 | 3.8 | 3.5 | 2.5 | -0.3 | -2.1 | -4.1 | -4.9 | -4.8 | -5.8 |
| Jan. 6.8, 1974 | 27π | 0.39 | 0.9 | 5.6 | | 5.0 | 4.5 | 4.1 | 3.0 | 0 | -1.9 | -3.9 | -4.8 | -4.8 | -5.7 |
| Jan. 7.8, 1974 | 27π | 0.43 | 0.9 | 6.0 | | 5.2 | 4.9 | 4.4 | 3.6 | 0.5 | -1.4 | -3.6 | -4.4 | -4.5 | -5.0 |
| Jan. 9.8, 1974 | 27π | 0.48 | 0.8 | | | | | | 4.4 | 1.4 | -0.6 | -2.8 | -3.9 | -3.9 | -4.8 |
| Jan. 12.8, 1974 | 27π | 0.57 | 0.8 | | | | | | 5.2 | 2.7 | 0.7 | -2.3 | -3.0 | -3.2 | -3.8 |
| Jan. 23.0, 1974 | 27π | 0.85 | 0.8 | | | | | | | 5.1 | 3.9 | -0.3 | -1.2 | -1.2 | |
| Jan. 28.1, 1974 | 27π | 0.92 | 0.9 | | | | | | | 6.7 | 4.2 | 0.7 | -0.6 | -0.5 | -1.6 |
| Comet Bradfield (1974b) | | | | | | | | | | | | | | | |
| March 21.9, 1974 | 27π | 0.51 | 0.73 | 5.6 | | 5.2 | 4.8 | 4.7 | 4.1 | 1.2 | -0.7 | -3.2 | -4.2 | -4.4 | -4.8 |
| March 24.9, 1974 | 27π | 0.52 | 0.70 | | | | | | | 1.5 | -0.3 | -2.8 | -3.9 | -4.0 | |

TABLE 1 (Continued)

| Date | Diaphragm | r | Δ | Magnitudes |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | V | R | I | 1.2µm | 1.6µm | 2.2µm | 3.5µm | 4.8µm | 8.5µm | 10.6µm | 12.5µm | 18µm |
| Comet Bradfield (1974b) (Continued) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| April 5.8, 1974 | 27π | 0.66 | 0.69 | 7.1 | 6.8 | 6.2 | 5.7 | 5.6 | 5.3 | 2.5 | 0.3 | -2.9 | -3.5 | -3.8 | -4.7 |
| April 7.8, 1974 | 27π | 0.69 | 0.70 |  |  |  | 6.7 | 6.7 | 6.5 | 3.9 | 1.3 | -2.0 | -2.8 | -3.0 | -4.0 |
| April 9.8, 1974 | 27π | 0.72 | 0.73 |  |  |  |  |  |  |  |  | 1.4 |  | -0.4 |  |
| April 16.8, 1974 | 27π | 0.83 | 0.82 |  |  |  |  |  |  |  | 4.8 | 1.0 | 0.1 | -0.4 |  |
| P/ENCKE |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| April 16.7, 1974 | 27π | 0.46 | 1.2 |  |  |  |  |  |  | 5.9 |  |  |  |  |  |
| April 23.8, 1974 | 27π | 0.35 | 1.0 |  |  |  |  |  |  | 5.8 |  |  |  |  |  |
| April 25.8, 1974 | 27π | 0.35 | 1.0 |  |  |  |  |  | 8.6 | 5.3 | 3.0 | 1.2 |  |  |  |
| Calibration Stars |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| α Sco |  |  |  | 1 |  | -1.7 | -3.1 | -3.8 | -3.8 | -4.1 | -3.9 | -4.3 | -4.8 | -4.8 | -4.8 |
| α Lyra |  |  |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NML Cyg (Cygnus) |  |  |  |  |  |  | 4.8 | 2.5 | 0.4 | -1.9 | -3.2 | -5.0 | -5.5 | -6.0 | -6.8 |
| α Boo (Bootes) |  |  |  | 0 | -1.05 | -1.7 | -2.3 | -3.0 | -3.1 | -3.15 | -3.05 | -3.05 | -3.2 | -3.2 | -3.2 |

In contrast to the smooth decrease in brightness of Comet Kohoutek something drastically different happened to Comet Bradfield as its heliocentric distance increased.

Between March 21 and April 5 the dust bump disappeared and the albedo decreased. I interpret this to mean that the size or the chemical nature of the grains changed, as if the comet were layered like an onion.

Then between April 7 and April 9 the brightness of Comet Bradfield decreased abruptly. This decrease in the infrared was paralleled by a decrease in the visible light shown in the photometry of Minton (1974) at LPL and reported in the I.A.U. Circular 2674. In a matter of two days the 8 and 12 micron fluxes dropped 3 magnitudes and the V magnitudes decreased 2 magnitudes. The dust just went away.

Figure 10 shows the behavior of $(\lambda F_\lambda)_{max}$, the total energy radiated as a function of distance from the sun for Bennett, Kohoutek and Bradfield.

To summarize:

1) many comets contain silicates.

2) the particles in the coma and tail of Comet Kohoutek were small $.2\mu < d < 1\mu$ and the temperatures exceed the black body temperature.

3) the particles in the anti tail were large and the temperature is close to the black body temperature.

4) the strength of the silicate feature varies from comet to comet and can change even in the same comet.

5) the albedo of the cometary dust is relatively high $\gamma=0.2$.

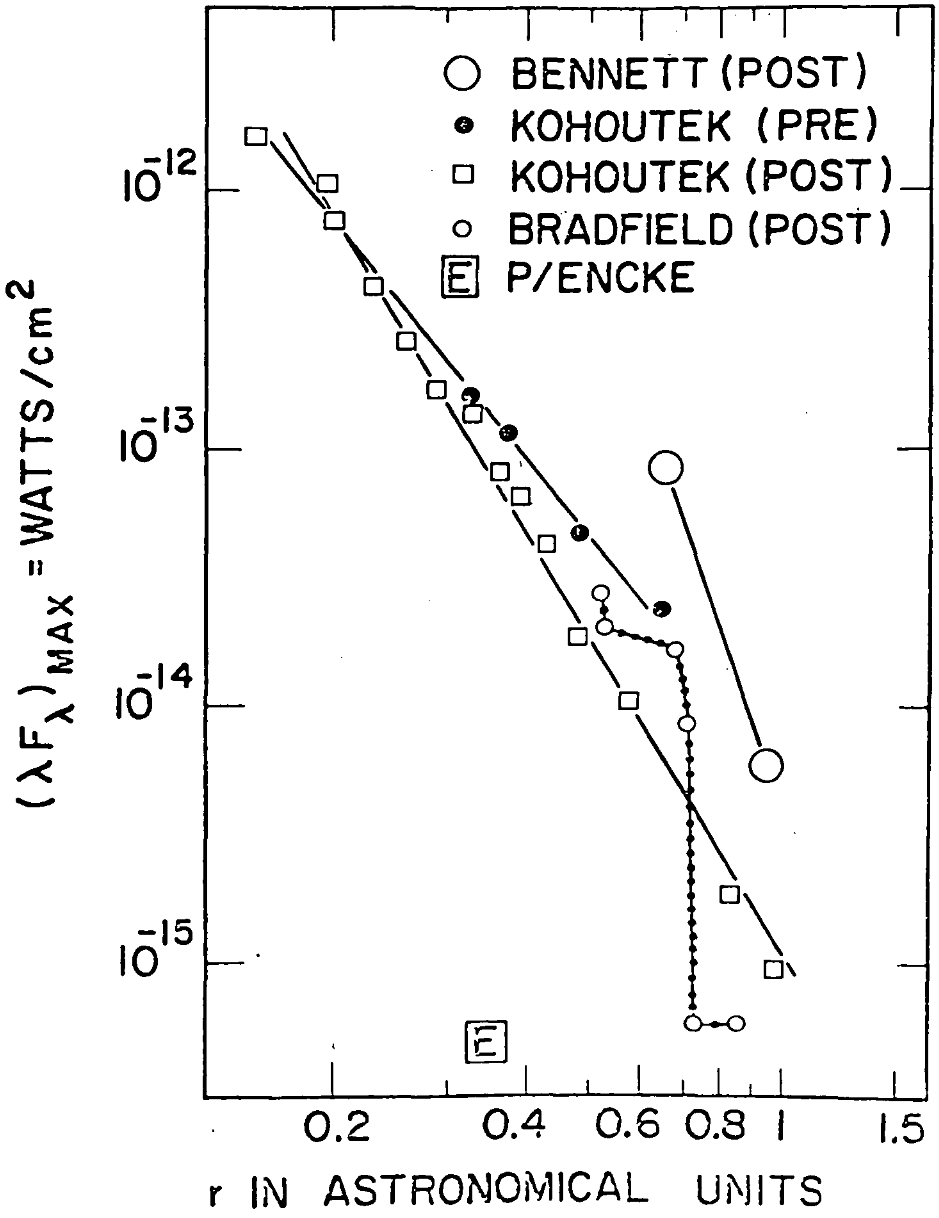

Figure 10. A plot of the value of $(\lambda F_\lambda)_{max}$ as a function of distance from the sun. The data are all corrected to the same heliocentric distance. Note that Comet Encke radiates 100 times less energy than Comets Kohoutek and Bradfield. Also shown is the abrupt drop in brightness of Comet Bradfield at a heliocentric distance of about 0.7 astronomical units.

6) the composition and/or sizes of particles can change from comet to comet and in the same comet.

Several observations on future comets are suggested.

1) The changes in brightness, strength of the silicate feature and albedo should be well documented.

2) The polarization at ten microns should be measured. It would be expected to be small, because this radiation is thermal radiation, but any effect of aligned grains could produce polarization.

3) Most important to measure is the albedo of the anti tail particles. The data at the short wavelengths were not obtained on Kohoutek, but could be acquired on a comet as bright as Kohoutek just after perihelion passage.

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# DISCUSSION

Z. Sekanina: In regard to our yesterday's discussion of the investigation of comets at large heliocentric distances, I believe that application of the methods of the type professor Ney was describing should be strongly encouraged. Since, however, the distant comets are considerably fainter than the ones that have so-far been studied in the infrared, I wonder what magnitude could be reached by the currently used techniques.

E. Ney: If you look at the data on these comets, you will find that we are getting into trouble between 1.5 and 2 A.U. on Comets Bradfield and Kohoutek, and the 100 times down on Encke was misery at the distance it was. There are, however, prospects for improved detectors. I suspect the time will come when we may be able to do infrared observations on comets that are this dirty at perhaps 3 A.U., but not tomorrow. Two, one-and-a-half to two A.U. tomorrow.

F. L. Whipple: Doesn't the relative efficiency correlation with particle dimension produce a distortion in the flux/wavelength curve to change the $\lambda_{max}$ and hence the calculated temperature?

E. Ney: What you say is entirely correct, and I think if the effect were to move it very much you would in fact have to change it, because the physics is that instead of radiating like black bodies, small particles have an additional factor that multiplies the Planck function which depends on the ratio of the particle size to wavelength. In addition to shifting the maximum, it should in fact change the shape.

W. F. Huebner: Making a reasonable assumption about the size distribution of the particles, can you make some estimate about the relative abundance of silicates to other materials?

E. Ney: No. I can only say that there is kind of a black body component of the comet which could be carbon or it could be big silicate particles. We just can't make any estimates of the relative abundance because it depends so much on particle size. It was different in Bennett and Kohoutek, but it is an appreciable amount of the material. It is not a negligible fraction of the dust in the coma that are silicates.

K. S. Krishna Swamy: I have tried to get the variation of grain temperture as a function of heliocentric distance from the observations of Rieke and Lee for Comet Kohoutek. I used the measured refractive index of some Lunar samples to get the absorption coefficient. The emission curves for the grain sizes of 0.2 and 1.0 microns were calculated. The general shapes of the two curves are the same. From a comparison of the observed energy distribution with those of the calculated ones, the temperature of the grains was obtained. The process was repeated for different heliocentric distances. I get a grain temperature variation of 225°K to 550°K for distances between 1.34 and 0.37 A.U. The temperature of 580°K at 0.23 A.U., as given by Ney, fits well the relation I get. As a typical case, calculations were done for two Lunar core samples. The results are the same.

Next thing is to calculate the absorption property of the dust in the UV and visible region which gives the above observed grain temperature variation. Unfortunately, detailed refractive index measurements are not available covering the whole wavelength region, so I did calculations for different silicate materials for which refractive index measurements are available. I did so for olivine, enstatite, and magnetite. I also did calculations assuming for the refractive index a value of 1.3-0.05i and of 1.6-0.05i. The expected grain temperatures for olivine and enstatite are very low compared to the observed one, which means they do not absorb much in the UV and visible regions. Magnitite could give the observed variation, but the temperature is larger than the observed one. This may be because it is a pure iron type material, which is very unlikely in comets. The temperatures obtained with 1.3-0.05i and 1.6-0.05i can give the observed temperature distribution. This shows that we require the complex part to be of the order of 0.05 in the UV and visible regions.

C. R. O'Dell: The solar-direction distance at which the IR emission ceases is a measure of the distance the particles travel before being reversed by radiation pressure. This is $v^2/2a$ (v is velocity of ejection, a is acceleration) and is a function of the mass loss rate and the particle size. Have any sunward scans been made in the coma?

E. Ney: I agree with what you say. These data are representative of what we had, and I realized afterwards that we should have done more to use the anti-tail as a kind of mass spectrometer for particle sizes, based on the kind of analysis that you and Sekanina have done. The anti-tail got pretty hard for us after three days.

M. Mumma: Your observation of an IR flux for Encke of $10^{-2}$ of that for bright comets, together with the production of H-atoms which is also down by a factor of 100, suggests that the gas/dust production ratios are similar for this very old comet and for some newer ones. We know that the visual continuum emission is very weak for Encke, suggesting that any dust production is primarily in the form of large particles. Since the total mass of particles required to produce a given scattered brightness goes as $\sim R^3/R^2 = R$ (R is the particle radius), we can conclude that the proportion of total mass flow in the form of dust is much greater for Encke than for new comets.

B. Donn: The fact that you see in the visible almost no continuum of Encke means that the small particles that are very efficient in scattering are not there. We could have larger particles that could contribute in the infrared but would not scatter efficiently, as the cross-section to mass ratio would be low. If that is the case, the silicate signature should be very low, so the determination of whether Encke really shows a silicate bump would be a very important measure of the particle size.

Z. Sekanina: If Comet Encke produced a significant amount of rather large particles in recent times, it should have displayed anti-tails on a number of occasions. A tentative comparison of favorable visibility conditions with available reports suggests that no such anti-tail has been observed. This conclusion is not in any apparent conflict with the existence of the extensive stream of Taurids, whose origin is put back at a time several thousand years ago.

M. Mumma: The dependence of visual magnitude on heliocentric distance follows an $R^{-2}$ law from ~0.8 A.U. to perihelion, based on the observations of Bayer and Bortle. Hence the measured H-atom rate at 0.7 A.U. should scale as $R^{-2}$, so that one can compare dust brightness measurements at 0.34 A.U. with the H-atom production rate scaled to 0.34 A.U.

B. Jambor: I would like to point out the importance of Comet Encke in connection with such infrared measurements. It has to do with the contribution that periodic comets can make to the "permanent" interplanetary dust—the zodiacal cloud. Only particles larger than 10 microns can stay in the inner portion of the solar system if ejected from Comet Encke, for example. How many such particles are ejected by Encke strongly influences the total contribution to the Zodiacal light. As pointed out by Dr. Sekanina, a large quantity of such particles would create an anti-tail at certain times.

F. L. Whipple: The comments by Mumma regarding the substantial quantity of observed particles in Comet Encke brings me to the "gospel" that I have been preaching for more than two decades, viz., the predominance of gas spectra in periodic comets does not disprove large solid particle contribution by those comets. Comet Encke is responsible for the largest known meteor stream—the Taurid meteors, dating back for thousands of years. Simply stated, the periodic comets expel larger particles than the newer comets, such as Bennett, etc. The optical ratio of band to continuum spectrum is no measure of the gas/particle ratio. We very much need IR measures of Encke in order to plan space missions more efficiently.