THE NUCLEUS: PANEL DISCUSSION

B. Donn

My remarks will present some views of the behavior of the nucleus and problems with their explanation.

One thing we definitely know about comets is that there has to be a permanent structure which revolves around the sun in the comets orbit. Permanent means carrying over from apparition to apparition during the lifetime of the comet. I adopt some form of the "icy nucleus" model as proposed by Whipple. This structure reasonably fits most of the known cometary features although no completely consistent model accounting for all known phenomena in a satisfactory manner has yet been described. The icy nucleus does not appear to have any major flaws. It has a real advantageous feature in that detailed models can be constructed and their behavior more or less accurately predicted, e.g. (Donn 1963; Delsemme and Miller, 1971; Sekanina 1972, 1973; Huebner, 1975).

The attempts to analyze various models in greater detail emphasize one of the great needs in cometary research, namely, more laboratory studies of simulated icy nucleus material. Only very limited work has been published in this area (Delsemme and Wenger, 1970, and Kajmakov, et al. 1972a, b).

Another important area of research concerns physical observations; luminosity, spectra and colors of comets over large intervals of

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heliocentric distance extending beyond 2 A.U. Only occasional observations of this type are available. Several papers and much of the discussion at this colloquium have shown the need for such data.

The main points I wish to discuss here are rather closely related to the last item, observations at large distances, and show in more detail why such observations are so important.

For a long time it has been my belief that the presence and behavior of the C_3(4050) bands are important clues to nuclear and probably coma processes. C_3 is one of the first molecular emissions to become detectable as a comet approaches the sun. This is well shown in Plates I and II of the Atlas of Cometary Spectra (Swings and Haser, 1957). The high relative intensity of C_3 at large heliocentric distances is brought out in the Atlas. In every instance of spectra taken beyond 1.5 A.U. the C_3 emission is the second most prominent after CN(0,0). Qualitative evidence is given by Hogg (1929) (CH_x has been identified as C_3) based on all spectra taken prior to 1929. This was true for Halley's Comet in 1909 (Bobrovnikov, 1931) and also for Comet Encke (Swings, 1948 ; Swings and Haser, 1957).

The behavior of C_3 is essentially the same in comets making their first approach to the Sun and in very old Comets. The general similarity of the behavior of all molecular emissions among all categories of comets, as far as it is now known, is a strong argument for similar processes occurring throughout the life of a comet after its initial close perihelion passage.

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Although several sources for C_3 have been proposed, none are generally acceptable at the present time. The formation of C_3 either requires (i) photodissociation of a complex organic molecule containing a three carbon chain, methylacetylene H_3 C - C   C - H is the only laboratory source yielding C_3 in an apparently primary photochemical process (Stief, 1972),(ii) formation by collision (iii) release of C_3 radicals from the nucleus. There are difficulties with making any of these mechanisms consistent with the reduced activity and lower coma densities at large distances and the absence or relatively lower intensities of all other cometary emissions as r increases. Only the scattered solar continuum shows the same general intensity behavior. In fact, at distances greater than 3 A.U., with the exception of Comet Humason, 1962 VIII, only a solar continuum has been detected.

Spectroscopic observations of the behavior of cometary emissions at 3 A.U. and beyond using image intensifiers or large aperture interference spectrometers are essential. There is great danger in developing a theoretical explanation or model on insufficient data. Although many of the details of comet activity at large distances are uncertain, there is no doubt of the common occurrence of such activity beyond 5 A.U. as Sekanina has shown. The first problem is to account for it in a way consistent with other cometary features.

A second problem is closely related to the point just raised. Not only do comets show significant ejection of material beyond 3 A.U., but there are several indications that this ejection rate decreases after and even during its first approach to the sun. There are direct observations such as for the recent apparition of Comet Kohoutek 1973, which showed a luminosity drop of perhaps 1 1/2 to 2 magnitudes (Jacchia, 1974) after perihelion. A very suggestive evidence for rapid fading is the sharp peak in the 1/a distribution for $1/a < 50 \times 10^{-6}$ (Oort, 1951, Whipple, 1962).

Comets in an Oort cloud have existed in interstellar space for the lifetime of the solar system, about 4×10^9 years. During this time they have been exposed to all the radiation found there. The possible chemical effect of an intense early solar wind was pointed out by Donn (1968). More recently Shul'man (1972) has called attention to the chemical effects of cosmic rays over the lifetime of a comet in producing similar results. The results of a more detailed analysis of this phenomena is given here.

For the region of the Oort cloud the extrapolated cosmic ray flux near the Earth may be represented by

$$\frac{dN}{dE} = k(E_T)^{-\gamma} \text{ particles/m}^2\text{-s-ster-MeV/nucleon} \qquad (1)$$

where E_T is the total energy = $E_{kin} + m_o c^2$ (938 MeV) γ is very near 2.5 and $k = 2.5 \times 10^8$ (Goldstein et al., 1970; Gleason and Urch 1972). Intensities of cosmic rays below about 100 MeV are not determined by these measurements because such particles are degraded from higher energy cosmic rays. It is reasonable to extrapolate over some interval and it is assumed here that the distribution law in

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Equation 1 is valid to 10 MeV. As the proton flux is a factor of ten higher than the alpha particle flux, only protons are considered in the following analysis.

Radiation incident on the comet surface penetrates to a distance R(E) where E is the particle kinetic energy. Energy is lost along the path primarily by ionization (Dalgarno, 1962) which produces electrons of several tens of electron volt energy. These in turn dissociate molecules, producing chemical effects. Range and energy loss as a function of energy up to 5000 MeV for protons in water are given in Table III of Barkas and Bergen (1964). From that table the energy deposited in successive layers of thickness 20 gm/cm^2 was obtained for protons in water. Proton ranges in a wide variety of materials from quartz to propane lie within 20% of the range in water. Energy calculations for a water-ice nucleus will apply closely for the uncertain actual composition of the nulceus. Above 1400 MeV an average loss of 43 MeV per layer was used.

From the energy loss vs energy data a matrix $\Delta E_{j,n}$ was determined. This represents the energy deposited in a layer ΔD_j between mass load limits 20 (j-1) and 20j gm/cm^2 for a particle of initial energy E_n with range 20n g/cm^2. The total energy deposition for normal incidence cosmic rays was found by suitably combining this matrix with the energy distribution of equation 1. The results for an isotropic cosmic ray flux was obtained by integrating the above slant range distribution over a hemisphere. Figure 1 shows the relative energy deposition as a function of depth for protons. As the nucleus density

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is about 1 g/cm^3 and probably nearly constant in the outer portion, the abscissa also represents depth in meters.

In addition to cosmic rays protons the comet nucleus in the Oort cloud will be irradiated by cosmic ray electrons, gamma rays and ultraviolet photons. Ultraviolet photons will only interact with a very thin surface layers but will subject that region to an intense irradiation. The electron flux is one tenth of the protron flux (Goldstein et al, 1970). Although the energy loss of electrons is similar to that of protons with 2000 times greater energy, the large scattering of electrons will cause the electron energy deposition to also have a high gradient. The gamma ray photon flux is about a factor of ten less than the extrapolated proton flux at 10 MeV and has a steeper slope (Peterson et al, 1974). For 10 MeV photons, 90% of the energy is absorbed within 1.5 m. The net effect of all energetic radiation is to make the curve of Figure 1 even steeper.

In order to determined the effect of the radiation during the comets stay in the Oort cloud, we need the absolute energy deposition. The unit of the ordinate corresponds to 240 MeV/cm^2 sec. There is little experimental data to cover the irradiation of a cosmic mixture. Oro (1963) irradiated a condensed mixture of methane,ammonia and water with 5 MeV electrons. An irradiation of 6×10^{16} MeV/gm over a two hour period converted 6% of the carbon to other species including 4% to non-volatile products. Berger (1961) exposed a condensed methane-ammonia-water mixture to 12 MeV protons and obtained a yield of 1.4

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molecules formed per 100 ev. This presumably refers to energy incident rather than absorbed and an equivalence of about 100 molecule formed per 100 ev absorbed may not be unreasonable.

The energy absorbed per 20 cm layer of the nucleus in the Oort cloud can be obtained by setting unit ordinate in Figure 1 at 2.4 x 10^{19} MeV/cm^2. A comparison of this dosage with the experimental yields indicates that approximately complete conversion of the first few layers of an icy nucleus will occur during its time in the cloud. Only some percent of the nucleus below a few meters will be affected. The irradiation will tend to polymerize the simple, volatile original ices. The results would be a less volatile outer zone compared to the inner protected region.

This conclusion is in contradiction with the apparent greater activity of new comets coming from the Oort cloud. Hence, the importance of studying the spectra, especially of new comets at large distances.

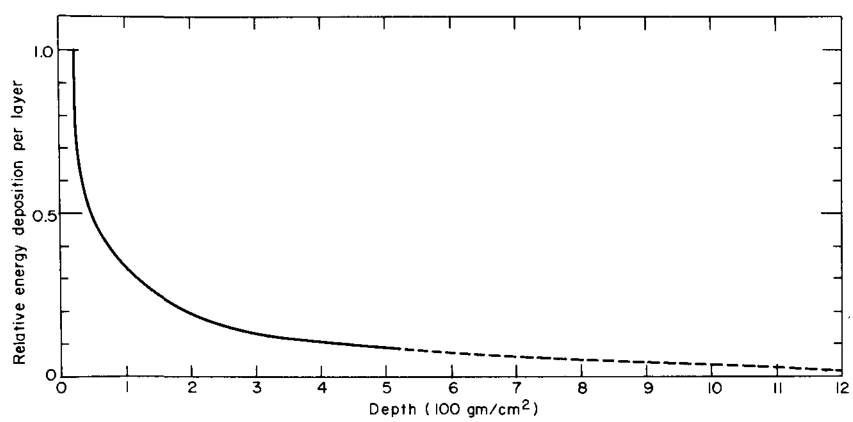

Figure 1. Relative energy deposition as a function of depth. The dashed line is based on an extropolation.

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REFERENCES

Barkas, W.H. and Bergen, M.J., 1964, NBS SP 6421.

Berger, R. 1961, P.N.A.S. 47, 1434.

Bobrovnikov, N.T. 1931, Lirk Obs. Bull 17, 309.

Dalgarno, A. 1962, In Atomic and Molecular Processes, ed. D.R. Bates (N.Y. Academic) p. 623.

Delsemme, A. H. and Miller, D. C. 1971, Planet. Space Sci. 19, 1229.

Delsemme, A. M. and Wenger, P. 1970, Planetary Space Sci. 18, 717.

Donn, B. 1963, Icarus 2, 396.

Donn, B. 1968, Introduction to Space Science, ed. W. N. Hess and G. N. Mead (Gordon and Breach, N.Y.) p 501

Gleason, L.J. and Urch, I., 1971, Ast. and Space Sci. 11, 288.

Goldstein, M.L., Ramaty, R., Fisk, L.A., 1970, Phys. Rev. Let. 24, 1193.

Hogg, F.S. 1929, J.R.A.S. Can. 23, 55.

Huebner, W.F., 1975, Their Proceedings

Jacchia, L.J., 1974, Sky and Telescope 47, 216.

Kajmakov, E.A. and Sharkov, V.I., 1972a, In I.A.U. Symposium 45, The Motion Evolution of Orbits and Origin of Comets, ed. G.A. Chebotarev, E. I. Kazimirchak-Polonskaya and B.G. Marsden (Dordrecht: Reidel) p. 308

Kajmakov, E.A., Sharkov, V.I. and Zhuralev, S.S. 1972b, In I.A.U. Symposium 45, The Motion, Evolution of Orbits and Origin of Comets, ed. G.A. Chebotarev, E.I. Kazimirchak-Polonskaga and B.G. Marsden (Dordrecht, Reidel) p. 316.

https://doi.org/10.1017/S0252921100034126 Published online by Cambridge University Press

Oort, J.M. 1951, B.A.N. 11, 91.

Oro, J. 1963, Nature 197, 971.

Peterson, L.E., Trombka, J.I., Metzger, A.E., Arnold, J.R., Matteson, J.I., and Reedy, R.C., 1974 in NASA SP 339 ed. F.W. Streaker and J.I. Trombka (Washington, NASA) p. 41.

Sekanina, Z. 1972, In AGU Symposium No. 45, The Motion, Evolution of Orbits and Origin of Comets, ed. G.A. Chebotareo, E.I. Kazimirchak-Polonskaya and B.G. Marsden p. 301.

Shul'man, L.M. , 1972, In IAU Symposium No. 45, The Motion, Evolution of Orbits and Origin of Comets, ed. G.A. Chebatarev, E.I. Kazimirchak-Polonskaya and B.G. Marsden (Dordrecht; Reidel) p. 265.

Stief, L.J. 1972, Nature 237, 29.

Swings, P. 1948, Ann. d'Astrophys. 11, 124.

Swings, P. and Haser, L. 1957, Atlas of Representative Cometary Spectra Liege.

Whipple, F.L. 1962, In the Moon, Meteorites and Comets, ed. B.M. Middlehurst and G.P. Kuiper (Chicago, Univ. of Chicago Press) p. 639.

DISCUSSION

A. H. Delsemme: The volatile material diffuse has ample time to diffuse away from the center into the upper layers of the model you have just described.

D. J. Malaise: I thought that the general behavior of comets is that they are more active before perhilion than after?

F. L. Whipple: That's part of Donn's paradox.

D. A. Mendis: I'd like to make one comment, and that's about the charging of the grains. The grains are charged by electrostatic charging in a stream. The charging does not necessarily disrupt the stream. One has to take into account the effect of the polarization image charge which can cause the grains to stick. The same point has to do with the more general comment on the classifications of nuclear models on loose to very loose to compact. It might also be classified as a time sequence: very young, middle-aged, and older.

G. H. Herbig: This doesn't have implications for cosmic ray irradiation, but one way of dating material, of cosmic composition, as you know, is determining a lithium to the calcium ratio in the material. This dates stars. The question is whether the material that's in comets has an older or new lithium to calcium ratio.

In the passage of Ikeya-Seki near the Sun in 1965, there was a major attempt to find out what the lithium-calcium ratio was when this Comet was very near the Sun. And, as you know, the resonance lines of potassium, calcium, sodium, nickel, copper, and iron came up in the spectrum of the coma when it was near the Sun. But lithium never appeared.

Now, this isn't as simple a thing as it is in stellar atmosphere; the fact that lithium didn't come up may be that it was bound chemically in some very tight fashion.

All I was going to say is that if you are interested in answers to questions of this sort, there's another kind of chemistry that ought to be talked about. That is the chemistry of the volatile compounds these metallic elements. If lithium is locked up preferentially, that may account for the observations. But it's a rather puzzling thing.

If things like copper appeared in the coma, why can't we see the lithium lines in resonance emission at that time?

W. Jackson: It would seem that lithium would have more volatile compounds than any of the other things that we see. If I remember correctly, I think that lithium compounds tend to be more volatile than the others.

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