THE NUCLEUS: PANEL DISCUSSION

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My approach to the nature and origin of the nucleus is strongly influenced by the quantitative data on amounts of dust and gas being released near perihelion. Calibrated spectra and photoelectric photometry (Gebel 1970, O'Dell 1971, Stokes 1972) have shown that the morphological division of Oort and Schmidt into dust-rich and dust-poor seems to be correct. More accurately, I can say that we have observed a wide variation in the ratio of scattered light continuum to molecular emission. This may or may not reflect a large variation of the dust to gas ratio in the nucleus. In fact, the apparently dustiest comets may have smallest dust to gas ratio at the nucleus! This is because the process of accelerating the particles out from the nucleus by means of viscous gas flow depends sensitively on the amount of gas leaving (Finson and Probstein 1968). The comet with weak scattered light is probably one that is unable to lift the particles from the nucleus, leaving a residual surface of particles. Since small particles can be lifted more easily, the remaining surface would selectively become one of large particles, forming an insulating layer of low albedo with internal degasification occuring at an even slow

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rate. This in turn would diminish the particle loss rate, with a rapid convergence to a particle cover and nucleus. This model would explain the variation from continuum strong to continuum poor in the Oort-Schmidt new and old comets, in addition to the intrinsically low luminosity and photometric radius of old comet nuclei.

In a young strong continuum comet, if one assumes that a cosmic abundance of gases applies and proceeds from observations of reasonably well understood molecules such as C_2 (O'Dell 1973), one can calculate that the total mass of particles and gas leaving the coma is nearly unity. Since the gas escapes much more easily than the dust, this means that particulate matter probably dominates the nuclear composition, even in the initial state as a comet enters the inner solar system. In the old comets, the preferential loss of gas would leave an even greater particle dominance. For this reason, I believe that we must look on the nucleus as a gasey dustball rather than as a dusty snowball.

Of course, what we are discussing is the particles that succeed in leaving the nucleus, for only they are observable. Under appropriate conditions, one can eject particles nearly a millimeter in size (Gary and O'Dell 1974, Sekanina 1974); but, most of the ejected mass is in the small particles. We do not directly measure these small particles' parameters, but only the combination $\rho d/Q_{rp}$, where ρ is the particle density, d the diameter and Q_{rp} the radiation pressure scattering efficiency. This value cuts-off at $\rho d/Q_{rp} \simeq 5 \times 10^{-5}$ (O'Dell 1974), which may indicate a true minimum size but is more likely due to the result of Q_{rp} becoming small for particles much smaller than the wavelength of sunlight.

Starting from the position that comet nuclei must be very dusty, I have examined the three types of models that can be constructed by particles. These are listed in Table 1:

Table 1
Models of Comet Nuclei

Name	Gravitational Binding	Proponent
Very Loose	Not Bound	Lyttleton (1953)
Loose	Bound	Richter (1954)
Solid	Very Strong	Whipple (1950

Each model has its advocate and the models differ primarily in the amount of gravitational binding that is assumed. The Lyttleton (1953) model of a comet being a host of particles, not gravitationally bound to one another, but sharing a common orbit has been most successfully

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criticized by Whipple (1963), who argues convincingly that this model does not apply to observed comets. The second model involves a swarm of particles gravitationally bound together, and bears many resemblances to a globular cluster. The strongest arguments against this model are theoretical. Both Shatzman (1952) and O'Dell (1973) have calculated the effects of perturbations on and collisions within the swarm of hypothesized particles. It is shown that those clouds of particles that are sufficiently dense to survive solar tidal torques have physical collision rates so high as to cause them to collapse down to solid bodies during infall from large heliocentric distances. This means that the three models can also be referred to as the inconsistent, the impossible, and the unavoidable. The unavoidable model that I envision is not the classical Whipple nucleus of dominant ices near the surface, but one composed mostly of very small particles, together with large particles built up of them, and initially a comparable amount of frozen gases. Such a model is quite consistent with the low tensile strength of the nucleus as inferred from the phenomenon of splitting, the low density and fragility of comet related meteors and the evolutionary change of the coma that characterizes long and short period comets.

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It is interesting to consider the possible origin of such a solid nucleus, composed of many small particles (O'Dell 1973). Due to the volatile nature of the trapped gases, I argue for formation at large heliocentric distances, which raises the possibility that the frozen gases are not from the original pre-solar nebula but may be a frost acquired by the small particles prior to collapse into a gravitationally bound system. The one known source of small particles in the present solar system is in the zodiacal light cloud. Through the effects of radiation pressure (Harwit 1963), selectively the small particle component can be forced into highly eccentric orbits, with aphelion distances in the hypothesized Oort Cloud. Since the zodiacal cloud must continuously be replenished, this means that there must be a continuous flow of particles to very large heliocentric distances. If this is the source of particles eventually forming comet nuclei, it requires trapping into these outer orbits and forces to initiate collapse into single, gravitionally bound clouds, neither of which are now understood.

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M. Dubin: On the Schatzman arguments of compacting, does Schatzman take into account either or both, the charge on the bodies as they approach the Sun, either comparable to gravity or the angle momentum of the ensemble as they approach the sun?

C. R. O'Dell: Neither.

M. Dubin: In other words, there are two contra-forces that may make the impossible less impossible, more likely to happen?

C. R. O'Dell: No. The time scale is so strong in the sense of saying they must compact that the force, the angular momentum, would have to be very high or the electrostatic repulsion by the neutral particles would have to be quite high.

Actually, I've done the calculations too, you know, the language barrier strikes again. You do a calculation and then you find out that it's been done but published in French, and you finally face up and you make the translation you did the same thing.

Most of the compaction occurs at such large distances that charges on particles should be small. The angular momentum effect still would remain, though.

J. C. Brandt: Is there an inconsistency with your picture by presupposing the dust to make comets whereas Whipple's model says that comets make dust, for example the zodiacal light?

F. L. Whipple: I don't think we're inconsistent on that.

B. Donn: The compaction was early in the history, and this is now. Fred has them releasing dust now.

C. R. O'Dell: They didn't hear the question in the back.

F. L. Whipple: The question was whether comets make dust or dust makes comets, and I think the point is that in the zodiacal light you meant that the comets now break up into dust, didn't you? I hope.

C. R. O'Dell: That certainly fit by the calculation. On the other hand, I'm not convinced that by the numbers that you've proven the zodiacal light particles all come on as debris from comets.

J. C. Brandt: Where does it come from, then?

C. R. O'Dell: I don't know. All I know is it exists.

G. Wetherill: As I understand from the things McCrosky has told me, the large Taurids, Perseids, and Leoniels seen by the Praire network have finite strength and densities of about 2. While they ablate more readily than the Lost City chondrite their densities indicate considerable compaction.

F. L. Whipple: It's still a moot question, how dense they are whether it's four-tenths or two?

G. Wetherill: The conclusion that there is evidence for their being very weak, dusty aggregates, I don't understand.

F. L. Whipple: They're extremely fragile. That is proven by the way they break up. They break up much faster than they should.

G. Wetherill: There are things that break up more easily as well.

D. J. Malaise: Monte Carlo computations by Dr. Everhart shed in my mind some doubts about the Oort's model for the origin of comets; that is we are observing the tail of a continuous diffusion of a huge number of comets formed at the origin of the solar system in the inner part of the primitive nebula.

The process you just described is a nice way to solve the problem because it is based on things which we know that exist (the dust in the vicinity of the sun) and on process we know that are working (radiation pressure). This gives us a cloud of dust in the position of Oort's original cloud of comets. The question now is how do you build comets from this dust cloud. Did you put any figure on the expected density and in homogeneity? Anyhow I don't think this question should stop you developing further this model by simply assuming that comets are formed in the cloud. After all we see stars forming in interstellar clouds without knowing exactly how to explain the beginning of the contraction process.

C. R. O'Dell: This key issue is what produces the cloud of these particles. It demands somehow you could form such a cloud, either through interaction with the interstellar gas remember, these conditions are interstellar rather than solar system or by perturbations of other objects, such as large objects gravitationally perturbed or passing stars. However, in any event it does take the formation of an initial cloud, and the collapse time of that cloud one can calculate.

A cloud sufficiently dense to survive tidal distortion does have sufficiently short freefall time to collapse within the in-fall time into inner solar system.

So what's needed is an intitial formation into a cloud.

D. J. Malaise: This makes me very happy, because it solved the biggest problem I had in Oort's Theory, that is, you had to bring them out and then to bring them in.

F. L. Whipple: That's what worried us all these years.

D. J. Malaise: Because when it is collapsed the radiation force is much less, of course. And, as far as the cloud formation goes, we don't have to worry about this because clouds are formed, anyhow.

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