COMETS AND SCIENTIFIC METHOD

(Letter to the Editor)

P. B. FELLGETT

Department of Cybernetics, University of Reading, England

(Received 13 June, 1985)

With spacecraft on the way to Comet Halley likely to yield a flood of new knowledge, the present seems an appropriate time for those who advocate hypotheses about comets to stand up and be counted. This is especially so of those who, like the writer, are unable to accept aspects of the so-called received view.

The main questions concern the origin and ages of comets, their physical form and composition, and their orbits. It must be said that the author does not know the scientific answers to these questions, for the simple reason that science does not concern itself with absolute truth, but only with ascertaining which hypotheses have the greatest likelihood in the light of available evidence. Science regards a statement as meaningful only if it is capable of being tested operationally. Since a test would be nugatory unless it could fail, it follows that all scientific knowledge is in principle capable of refutation, and is therefore held only provisionally.

Scientific method consists essentially in abstracting, by observation or experiment, a description of an aspect of natural phenomena. Consequences of this description are then made explicit by theoretical development, and the result tested by confrontation with new observations. Two guiding principles are crucial. First, an hypothesis can be strengthened only by agreement with observations independent of those which originally suggested the hypothesis. In other words, only successful prediction counts; mere circular 'confirmation' is valueless. Secondly, an hypothesis is to be preferred in proportion as it accounts for the most facts with the least assumptions. In particular, a theory is worthless if a new assumption is needed to 'explain' each fact. This principle of parsimony of hypotheses is often known as the razor of William Occam (*c.* 1280–1349) and rendered alternatively as 'Entia non sunt multiplicanda praeter necessitatem' or 'Pluralitas non est ponenda sine necessitate'. It is also referred to by quoting Isaac Newton (1642–1727) 'hypotheses non fingo'. Neither verbal assertions nor established authority has scientific standing; 'Nullius in verba'.

Of the main cometary questions, that of composition is, in one sense, the easiest and, in another sense, the least soluble. The observable part of a comet will consist mainly of cosmically abundant volatiles on almost any hypothesis whatsoever. Composition is therefore the least diagnostic characteristic of comets, and it is strange that it is sometimes quoted as if it were a clinching argument in favour of the 'icy snowball' hypothesis.

Earth, Moon, and Planets **33** (1985), 223–227. 0167–9295/85.15

Much of the 'received' view of comets is attached to the hypothesis of a reservoir of comets at great distances from the Sun. Indeed it is curious that many aspects that are really quite distinct are treated as if they were part and parcel of this hypothesis. Despite later denials, the record of the Halley Lecture at Oxford in 1951 shows that it was originally proposed as a 'shell' which, as was soon pointed out, was evidenced by no more than an artefact of the chosen coordinate system. A false reason for adducing an hypothesis does not of course exclude the possibility of it being a fruitful intuition that might later receive independent support. However, the writer is not aware of any direct published theoretical or observational evidence for the existence of the supposed cloud, which remains a matter of conjecture only.

The suppositions relating to this hypothetical cloud include the notion that comets arose as part of the early formation of the solar system, that they were ejected to large distances, and that they are now being returned to the neighbourhood of the Sun through random gravitational perturbations by stars or interstellar clouds.

This picture thus involves postulating a cloud, then postulating both the formation of comets and their ejection in order to account for the cloud, and finally supposing that the observed comets come from the cloud. In other words four, *ad hoc* assumptions are needed to account for the existence of the observed entities we call comets, and this conflicts with the principle of economy of hypotheses. So far as the writer is aware, no properly developed physical and dynamical theory has been published, within this framework of ideas, for the original formation of comets (which therefore remains as unexplained as ever) or for their ejection into the hypothetical cloud. Return from semi-stellar distances by gravitational perturbations has been extensively studied by a number of authors, although with inconclusive results; this therefore is the one aspect for which at least some plausible physical mechanism is suggested. However the probability of producing a sun-grazing comet by this mechanism is very small indeed. Yet sun-grazing comets are observed, indeed not uncommon, and we are not entitled just to ignore their existence. One suspects that current views on comets would have been very different had one or more really spectacular Sun-grazers been experienced within living memory; although Ikeya-Seki 1965 VIII, for example, was a daylight comet and a Sun-grazer it was unfavourably placed at relevant times and never attracted the attention bestowed on 1882 II.

The cloud-reservoir hypothesis, in its usual form, necessarily implies that the comets are primordial. This creates a further problem which needs quantitative treatment. Whether the total mass of comets, or the total number, or the mass of an individual comet, is considered, if the known or estimated rate of loss is carried backwards through the age of the solar system (or for less time), an exponential catastrophe ensues on most, and perhaps all, reasonable assumptions.

Concerning the physical form of comets, the usual assumption, on which indeed the spacecraft missions seem to be conceived, is that there is a single solid body which contains most of the mass of the comet. The best that can be said is that the observations neither support nor exclude this hypothesis. Photometric considerations preclude the star-like 'nucleus', sometimes observed (but by no means always) being identified with such a solid body, and it appears to be an optical illusion. There is however nothing to say that the coma might not conceal such a body which, if of plausible size and mass, would not be directly observable from the Earth's distance. The most cogent evidence for a solid central body is said to come from the fact that the observable part of a comet does not follow the orbit to be expected of a gravitating particle. The discrepancy is supposed to be caused by reaction forces generated by outgassing or evaporation from the solid body, for example an icy snowball, under the influence of solar heating. It is asserted that these reaction forces can be calculated and used to predict the deviation from particle-dynamics, and further that these predictions are confirmed by observation.

This is a remarkable line of reasoning. It endeavours to support the existence of a compact body by admitting that its orbital behaviour is not that of such a body and it then tries to resolve the apparent contradiction by postulating non-gravitational forces. The crucial question must then be whether the existence, magnitude and direction of these forces can be predicted independently of the observed orbital deviations and in such a way as to explain these perturbations. It is said that this is so, but the writer is unaware of any publication demonstrating that it has actually been done. The possibility remains that the argument is circular in the sense that the forces calculated from the observed perturbations are found to 'predict' the perturbations from which they were derived in the first place.

From these and other considerations it may reasonably be concluded that some confusion prevails as to how proper scientific procedures should be applied to the major problems that the existence of comets present to the astronomer. In an attempt to resolve this confusion it seem appropriate to make a clean start by attempting to identify what is often called the null hypothesis; that which makes no postulate at all. More precisely, we should speak of the minimal hypothesis, since in practice some assumptions are always needed, but which we seek to keep to an absolute minimum.

It has already been mentioned above that it would be hard to devise any hypothesis at all that would contradict the actual observations of cosmically abundant volatiles. Seeking hypotheses that are minimal with respect to composition is not therefore very fruitful.

In seeking a minimal hypothesis on the origin of comets we need to ask if there is some mechanism which, if our understanding of the physics and mathematics is sound, would *predict* objects that resemble the observed entities we call comets. This requires us to ask precisely which observed properties characterize this identification. It then emerges immediately that the orbital elements are highly characteristic. Of course a comet making a passage through the inner solar system suffers gravitational perturbations, the physics of which is well understood, and these may by chance give it an orbit resembling any other object one cares to name, but what are taken as original orbits occupy such a restricted part of the parameter space that a minimal hypothesis for this fact would rank as powerful indeed. Specifically, the binding energy to the solar system is extremely small, yet comets pass close to the Sun at perihelion. This latter fact cannot be ascribed to observational selection; obviously we see only comets which come fairly close to the Earth and Sun, but the reference is to comets passing within a few solar diameters, sometimes even passing through the observable corona. Such Sun-grazers exist, and the *a priori* probability of such highly specified orbits is very low, as small or smaller than that of the near-circular orbits of the major planets. Such comets are consistent with having been launched with small scatter about zero binding-energy (those with negative binding-energy are of course lost to observation) and in paths aimed at the barycentre of the solar system.

We ask therefore if there is a mechanism that is *predicted* to occur which would have launched putative comets in such unlikely orbits; and indeed just such a mechanism is predicted to occur. This is the mechanism of line-accretion extensively studied theoretically by the Cambridge astrophysics school in the 1940's.

The starting point is that when the Sun encounters an interstellar grain or parcel of gas, the initial relative orbit is a hyperbola which always intersects the line from the Sun towards the antapex of the relative motion (except for the few where the encounter is so nearly head-on that actual collision with the photosphere intervenes). There is thus a tendency for interstellar material to collide close to this line. Accumulation of material then further increases the likelihood of further collisions, and if the density of interstellar material is sufficient in relation to its internal motions and other conditions the process becomes run-away; virtually all the material passing within a calculable distance of the Sun then undergoes collision. The material thus concentrated at points greater than a critical distance flows away, while that at less than the critical distance falls towards the Sun. Such materials will have small binding energy and be aimed nearly at the barycentre of the solar system, in complete accord with the observed orbits of comets. The volume-density of the incident material may be sufficiently high for self-gravitation to concentrate it into separate knots, identifiable with individual comets or giving rise to comet groups.

If comets are supposed to originate in this way, two further advantages follow. First, the supply of comets may be renewed at any time an interstellar cloud is encountered. Comets need not then be primordial, and the exponential catastrophe previously mentioned no longer applies.

The second advantage is that this mechanism enables comets to be more or less extended structures. This eases the requirements for material not to be 'lost' from the comet, thus further mitigating the exponential problem. Moreover all *direct* observations of comets seem to show them as extended objects. These include:

(a) The appearance at larger observable distances from the Sun is of a fuzzy object; comet-discoverers have traditionally relied on comparison with catalogues of nebulae, not stars. The coma is said to contract as the comet approaches the Sun. Care is of course needed in defining the size of such a variable object, but contraction would be inconsistent with a solid 'nucleus' from which the material of the coma is ejected by solar action.

(b) The streak appearance of a sun-grazer near perihelion passage: this is a phenomenon which unfortunately seems not to have been well recorded photographically; the spectacular sun-grazers observed by Victorian astronomers came just a little to soon, but the visual appearance was unquestioned at the time.

(c) Meteor-showers. These are often ascribed to the 'debris' of comets following the same orbit, but this involves two unnecessary hypotheses; first that the 'comet' is a highly concentrated object, and second that the material has somehow become dispersed along the orbit. It is also pertinent that no shower meteor has been observed to reach the ground, indicating that they are small, light friable particles and quite distinct from the meteorite-asteroid population. Attempts to identify comets with asteroids on the basis of rare resemblances in orbit seem ill-founded; as already mentioned, such coincidences are bound to occur by chance in comets of short period that have been much deflected by close approaches to planets. (Equally, it is unsafe to identify meteoritic material with samples of the surface of Moon or Mars on the basis of similarity of chemical composition and thermal history; it offends against the principle of parsimony of hypotheses to seek mechanisms for the material to *escape* the gravitational field of the parent body, and then to be deflected to cross the orbit of the Earth, when infall onto all three bodies of material from a common interplanetary pool will more simply account for the observed common features.)

Indeed there is no need to go to extremes in either direction in estimating the degree of concentration of the objects we identify as comets. A cloud of particles can hold together by mutual gravitation when at great distances from the Sun but they would follow essentially independent orbits around perihelion. Inelastic collisions tend to annul relative motions. On the other hand, dispersing mechanisms include differential radiation effects and gravitational perturbations. A comet may well be in dynamic equilibrium betweeen these opposed tendencies.

The intention of the foregoing discussion has been to emphasise scientific methodology rather than particular details. Reliance has therefore been placed on observational data that are, or are believed to be, 'well known', and contrary to normal scholarly practice no references have been quoted; a further motive for this policy has been to avoid personal views so far as possible. Some readers may feel that the discussion has been inadequate or biassed either in its premises or in its development, or has failed to take account of some crucial published observation. The writer asks any such reader to accept that what has been presented has been an attempt in good faith to look at the problems of comets without preconceptions, following rigorously the dictates of Occam's razor, not seeking to assert what is true but only what is most probable in the light of present evidence. If what has been presented is good science, it is for that very reason refutable in principle. It is therefore to be hoped that this publication will induce those who disagree to attempt that refutation by accurate argument and specific quotation of published observations, thus supplying what has deliberately, and for the reasons stated, been omitted from the present account.