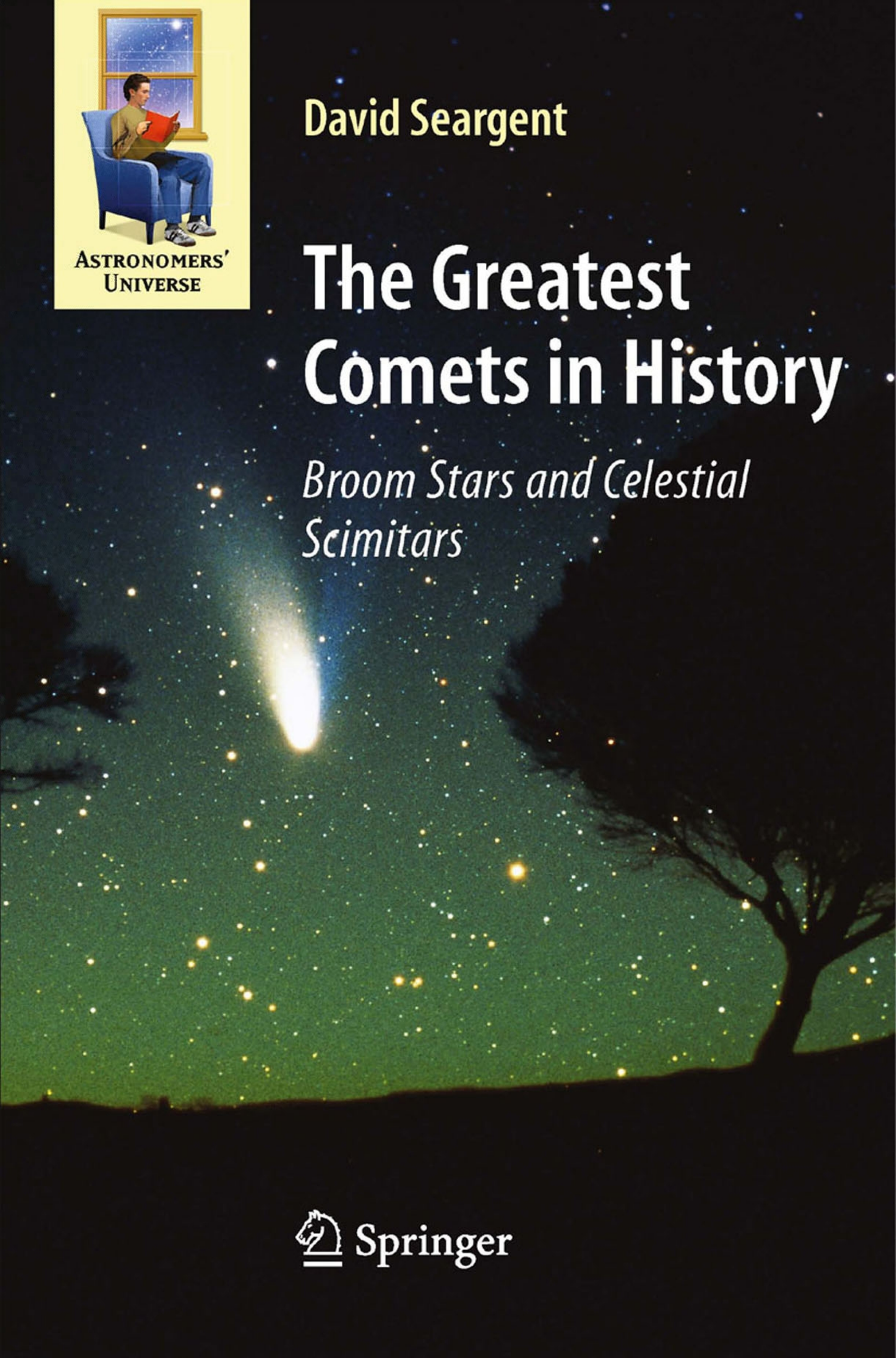
Astronomers' Universe

David Seargent

The Greatest Comets in History

Broom Stars and Celestial Scimitars



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Comet 2006 P1 (McNaught), as photographed by its discoverer, Rob McNaught, January 20, 2007. © 2007 Robert H. McNaught.

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For my wife Meg, and David Austen

Preface

Naked-eye comets are far from uncommon. As a rough average, one appears every 18 months or thereabouts, and it is not *very* unusual to see more than two in a single year. The record so far seems to have been 2004, with a total of five comets visible without optical aid. But 2006, 1970, and 1911 were not far behind with a total of four apiece.

Yet, the majority of these pass unnoticed by the general public. Most simply look like fuzzy stars with tails that are either faint or below the naked-eye threshold. The ‘classical’ comet – a bright star-like object with a long flowing tail – is a sight that graces our skies about once per decade, on average. These ‘great comets’ are surely among the most beautiful objects that we can see in the heavens, and it is no wonder that they created such fear in earlier times.

Just what makes a comet “great” is not easy to define. It is neither just about brightness nor only a matter of size. Some comets can sport prodigiously long tails and yet not be regarded as great. Others can become very bright, but hardly anyone other than a handful of enthusiastic astronomers will ever see them. Much depends on their separation from the Sun, the intensity of the tail, and so forth.

Probably the best definition of a great comet is simply one that would draw the attention of non-astronomers if viewed from somewhere well away from city lights and industrial haze. Typically, they are at least as bright as a reasonably bright star and sport easily visible tails, at least 5–10 degrees long. Most of the traditionally great comets of history were as bright as or brighter than a star of first- or second-magnitude with tails that could be traced to 10–20 degrees or more in a dark sky.

But these comets are not the subject of this book! What we are searching for are not simply “great” comets but the greatest of the great, the cream of the comet world. We are looking for nothing less than cometary royalty!

Picking out the best of the best is not as easy as it may sound. Ancient peoples were frequently awed by the sight of a comet in their skies, and this reaction tended to color the way they recorded it. In fact, comets were objects of such fear and dread that anything seen in the sky looking vaguely like a star with a tail was enough to trigger rumors of a comet! This can make it very difficult for a modern reader of these centuries-old records to sort out what was a real comet and what was something else.

A prime example of this is the famous (infamous?) description of a "comet" in 1528 by the French surgeon Ambroise Pare. In Pare's own words

> *So horrible was it, so terrible, so great a fright did it engender in the populace, that some died of fear, others fell sick.... This comet was the color of blood; at the summit of it was seen the shape of a bent arm holding a great sword as if about to strike. At the end of the blade there were three stars. On both sides of the rays of this comet were seen a great number of axes, knives, bloody swords, among which were a great number of hideous human faces, with beards and bristling hair.*

Very picturesque and graphic indeed! The trouble is that there are no other records of a bright comet in 1528. Whatever Pare saw in the sky, it was not a comet. Most likely, he witnessed a spectacular display of the aurora borealis. The faces, swords, and axes are probably not hard to imagine in the moving lights and curtains of a great aurora. (By the way, lest we be tempted to scoff at the naivety of our "superstitious" ancestors seeing these sorts of images in an aurora, we might recall the number of times Venus is reported today as an alien spaceship complete with landing gear and windows!).

But it is not always the original observer who causes confusion about the object recorded. A case in point is the occasional reference in modern works to a "comet" recorded by St. Augustine, probably for the year 396, that is said to have given off "a smell of sulfur." At least one book of elementary astronomy saw evidence here of the old belief in comets having an effect on the air and dismissed the reported odor accordingly.

However, what St. Augustine actually wrote was "a fiery cloud was seen in the east, small at first, then gradually as it came over the city it grew until the fire hung over the city in a terrible manner; a horrendous flame seemed to hang down, and there was a smell of sulfur." Whatever this was, it was not a comet. Augustine did not even *claim* that it was a comet. It *may* have been a meteorite fall, but an even better guess might be a lightning filled tornado funnel. The luminous effects associated with these can be very spectacular, and they are often accompanied by "a smell of sulfur"!

Incidentally, Chinese chronicles *do* record an astronomical object that year, although the description matches a nova or supernova rather than a comet. In any case, the Chinese object is almost certainly unrelated to the phenomenon noted by Augustine.

We should also be aware that, as well as dubious cases like these, some comet records are completely fictitious. A chronicler will sometimes invent a portentous comet to mark the birth and/or death of some great political personality. For example, an alleged comet appearing at the death of Charlemagne in A.D. 814 seems to have been pure embellishment.

For the most part, comets that were only mentioned on one or two nights or which appeared in a single record were eliminated straightaway as contenders for the greatest comets on record, even if their description implied something unusually spectacular. Although a minor comet might be seen on a single occasion only (and there are bona fide instances of this), anything truly spectacular is likely to have been widely observed over a considerable period of time and to have been immortalized in abundant records.

However, even after minor and dubious objects had been pruned from the list, a daunting number of entries remained. Many of these had clearly been spectacular objects that left great impressions on those who saw them. But how many could truly be listed among the *greatest* of the great comets?

For the next step in the selection, I referred to a "scale of importance" devised by D. Justin Schove in his 1984 book *Chronology of Eclipses and Comets AD 1∼1000*. Although this work covered only part of the period of interest, it could be extended to earlier and later comets without too much difficulty.

Schove's scale is as follows:

1. Minor comet, noted only by experienced sky-watchers.
2. Not noted by the general public.
3. Noted by at least one contemporary chronicler.
4. Noted by some chroniclers.
5. Noted by most chroniclers.
6. Noted as remarkable in most chronicles.
7. Noted as remarkable even in short annals.
8. Created consternation. Long remembered.
9. Created terror. Remembered for generations.

After reading through Schove's list of comets and comparing them with the descriptions given in Kronk's *Cometography*, I decided as a rough rule of thumb that a scale reading of 7 or higher would qualify a comet as one of history's greatest. My aim, therefore, was to use Kronk's descriptions of Scove's 7+ comets as the standard by which to measure comets of earlier and later centuries.

In essence, this remained the method followed, although I did not always stick rigidly to Schove's evaluations and found myself disagreeing with a couple of the values he assigned.

In those cases where an orbit for the comet had been computed, and even the absolute brightness known at least approximately, it was also a helpful check to compare the comet's performance with a recent object of similar true brightness and observed under comparable circumstances. This counted as something of a reality check, especially when we are dealing with records of "frightening, prodigious signs in the sky" and so forth. Expressions like this occur mostly in early European chronicles, and they tend to conjure up images of some utterly fantastic object unlike anything seen in recent times. Yet, where an orbit allows us to form some idea of the comet's true appearance in the sky, we more often than not find it to have been something that would have fitted in very well with the brighter comets of the past few decades. Where European and Chinese records of the same object exist, the latter tend to be more sober in their descriptions and can act as another good reality check.

The end product of this pruning and sifting forms the subject of this book. What emerges is a list of over 30 individual comets, which (as far as I could ascertain from their often varied descriptions) met the criterion for being history's greatest. In addition to these comets, I have also included, separately, the historical appearances of Halley's Comet and the members of the Kreutz group of sungrazers. Among these latter are found the brightest and some of the most spectacular of all comets as well as, paradoxically, most of the smallest and faintest ever recorded.

Essentially, the comets included here were ones of exceptional brightness and/or those having long and intense tails. Yet, brightness alone or tail length alone did not automatically mean inclusion in the list. A comet might have been recorded as having a tail (say) 70 degrees long, but if there were reasons for thinking that this tail was so faint as to be missed by most casual observers, it would have been left off this list. Likewise, even comets bright enough to be seen in broad daylight were omitted if they did not also become spectacular nocturnal objects (a list of daylight comets and possible daylight comets has been added as a final chapter to compensate for what some may feel to be an unfair omission).

There will probably be objections to some of my specific omissions.

For instance, I did not include the comet of 147 B.C. The very impressive-sounding account sometimes given of this comet is, in reality, most probably a combination of three separate objects. The Chinese comet of August (for which an orbit has been computed) is not consistent with the Chinese comet of May, or with that of October and November, the latter suspected by H. H. Kritzinger as being the previous appearance of C/1858 L1 Donati. None of these objects can clearly be identified with the one recorded by Seneca sometime between the years 151 and 147 B.C. This was said to have been as large as the Sun and "so bright that it dispelled the night" – a description reading more like that of a great meteor than a great comet.

I have also omitted the comet observed by Peter Apian in 1532, despite its inclusion in most catalogs of great and remarkable comets and Apian's historically important observations showing the tail as pointing away from the Sun. This seems to have been the first European recognition of this fact, although the Chinese had already noticed it as early as the ninth century.

The comet was unquestionably bright, but the tail seems to have been no longer than around 10 degrees, more in the nature of a 'typical' great comet than one of the greatest of the greats. Moreover, judging by Apian's drawings and the general descriptions of this object, its tail appears to have been predominantly a plasma type. These are not as intense as the strong dust tails of very large and active comets. If Apian's Comet was rather low on dust, it is unlikely to have rated as one of history's finest, despite its obvious brightness and historical importance.

Of course, it is quite possible that I have missed some comets that should have been included, and I may have included one or two that should not be here. Moreover, there must surely have been splendid comets in ancient times that were only at their best from far southern latitudes. These would either have passed unseen and unrecorded by the chroniclers of the time or else entered into the records as relatively minor objects unworthy of being included in the present list. To these comets I offer my apologies. If recent times are any indication, some of them may even have been the greatest of them all!

In the course of the following pages, we look first and foremost at the historical returns of Halley's Comet. This is *not* because it is the biggest, brightest, and the best (it is not!) but simply because it is the most famous and the only comet that has achieved 'great' status at more than one known return. On several appearances, it has entered the ranks of the other objects in this book, having been rated variously as 7, 8 and even 9 by Schove during the first millennium of our era. Because this is a book about the greatest of the greats, the more spectacular apparitions of Halley will be the ones of chief interest to us.

Succeeding chapters will take us initially from ancient times until the end of the tenth century, then from the beginning of the eleventh until the end of the eighteenth, before moving into the more detailed modern period from the beginning of the nineteenth century to the present day.

The sixth chapter deals with that fascinating family of comets known as the Kreutz sungrazers, some of which became the most brilliant ever recorded by humankind, and the seventh with those relatively rare objects seen in daylight.

Before launching into history, however, let us take a closer look at the characters of our story – the comets themselves, what they are and from where they come.

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Contents

About the Author

David Seargent is a former lecturer in Philosophy with the Department of Community Programs at the University of Newcastle in Australia and is now a full-time writer. He is the author of the very popular *Comets: Vagabonds of Space* (Doubleday), formerly a contributing editor on comets to *Sky & Space* magazine, and currently author of the regular comet column for *Australian Sky & Telescope* (the southern hemisphere edition). He was co-author with Joseph Marcus, of a paper published in 1986 entitled "*Dust forward scatter brightness enhancement in previous apparitions of Halley's comet*" (Proceedings, 20th, ESLAB Symposium on the Exploration of Halley's Comet, Vol. 3, B. Battrick, E. J. Rolfe and R. Reinhard, eds. ESA SP-250. European Space Agency Publications). He was also the Australian co-ordinator for visual observations during the International Halley Watch, 1985–1986.

Chapter 1
The Nature of Comets

Introduction

At one time astronomers believed that the Solar System was comprised of two radically different classes of objects (actually three, if we count the single star at the center of it all). On the one hand, there were the planets and asteroids – also conveniently called minor planets, to place them in their proper planetary perspective. Although there were clear differences between the massive Jupiter and the rocky "terrestrial" planets, such as our own Earth, the similarities were great enough to ensure their inclusion in the one cosmic family. All these objects were solid and stable. The orbits they followed around the Sun were sedate, almost circular, and widely separated from one another. Asteroids, with a few errant exceptions such as Earth-crossing Apollos, shared this clockwork regularity and did not, therefore, present any great danger of rocking the astronomical boat of the Sun's planetary family.

By contrast with this well-behaved planetary family, the second component of the Solar System seemed like the proverbial prodigal son. Unlike planets and even asteroids, this second population – the comets – happily disregarded any semblance of cosmic decorum. Whereas the planetary population followed the same nearly circular orbits for eons, comets darted hither and thither in between planets and asteroids like a swarm of agitated gnats. Their orbits were anything but circular. Most of them were cigar-shaped ellipses extending from the region of the inner planets to far beyond the orbit of Pluto. Some were calculated to stretch out at least a third of the way to the nearest star. Comets in these orbits return to the planetary region only after great lapses of time.

The "periods" of many comets are calculated to reach hundreds of thousands and, in some cases, even millions of years. Orbits of others are so elongated that their period cannot even be determined with the limited data available. For these comets, the "official" orbit is simply given as a parabola, even though a perfectly parabolic orbit cannot be sustained in the real universe. In certain instances, a comet even seems to achieve the escape velocity of the Solar System, and its orbit is transformed from a very elongated ellipse into the spreading open curve of a hyperbola. These comets go off into the void of interstellar space, never to return. Or, rather, some of them do. The

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hyperbolic orbits of others will revert to ellipses when they recede to great distances, thanks to the gravitational attraction of the Solar System as a whole. Needless to say, the final "period" of comets such as these is stupendous when compared to a human lifetime or even to the whole of recorded human history.

Not content to move in orbits as far removed as possible from those of the planets (in eccentricity if not in distance), comets are also found to pay no greater respect to the plane of the planetary system. Thus, while the Sun's planetary population orbits in pretty much the same plane – known as the ecliptic – comets have their orbits tilted each way and everywhere. A few stay close to the ecliptic plane, but most zoom in from all directions, approaching at all possible angles. There are comets that come in from below the plane at right angles and others that approach perpendicularly from above. Others approach at obtuse angles, which effectively have them moving in a direction opposite to that of the planets. These latter are known as *retrograde* orbits.

Equally un-planet-like is the appearance of comets. Instead of being stable, solid discs, comets assume nebulous, almost ghost-like, forms. Their appearance can radically change from one night to the next in a way that no planet ever would. Worse, they may even split into two or more pieces and in the most extreme cases, disintegrate altogether. That is certainly not the expected behavior of a planet!

Fig. 1.1 This view of Comet Bennett, March 27, 1970, gives a good idea of a "typical" great comet (courtesy, David Nicholls)

With these thoughts in mind, some astronomers of half a century ago felt it prudent to speak about two Solar Systems: the planetary and the cometary. Theorists such as R. A. Lyttleton even went so far as to deny a common origin for the two "systems." The planets, in the view of Lyttleton and colleagues, formed together with the Sun "in the beginning," but comets were far later acquisitions – nothing more substantial than clouds of cosmic dust clumped together and collected by the Solar System during its sporadic passages through the dark nebula that inhabit certain regions of our galaxy.

Today, the picture is at once more unified and more confusing. As astronomical discoveries began to fill in the increasingly fine details of the Solar System, the two populations became less and less distinct. Apollo asteroids went from being a handful of freaks to a populous asteroidal subsystem. Even worse, long-period asteroids in highly eccentric and steeply inclined orbits started turning up. These looked like typical asteroids but moved like typical comets! At the other end of the scale, astronomers also uncovered a population of comets moving in orbits that are more typical of asteroids!

If all of that was not enough, "transitional" objects started turning up in the lists of discoveries; apparent asteroids that sporadically sprouted comet-like tails or Earth-approaching asteroids that were found, in long-exposure images, to be enveloped in very faint veils of nebulosity.

What, then, does all this mean? What actually are comets and how do they really fit into the Solar System?

At the risk of oversimplification, we can say that a comet is actually an asteroid largely made of ice – nothing more, nothing less. Think of the minor, sub-planetary members of the Solar System as being arranged on a sort of spectrum with hard, dry, and rocky or rocky–metallic bodies at one extreme and fluffy conglomerations of ice and dust mixed together (as it turns out) with organic tar on the other. Those on the "dry" end are asteroids and those on the volatile end are fully active comets. In between lies a variety of ice-rock bodies that either spend most of their days as inert asteroids, with occasional bouts of cometary activity, or as weakly active comets amounting to little more than asteroids occasionally surrounded by thin and extremely extended "atmospheres."

Although we will look a little more closely at the differences between comets and the broad types of orbits these objects follow, let us just note at the moment that comets on the more or less "asteroidal" end of the spectrum are usually of short period (although there are exceptions), whereas those having very long periods and nearly parabolic orbits appear to be quite fragile, icy bodies.

So, in the end it may be best think of a comet as an icy asteroid. Please do not, however, form the mental picture of a white and pristine snowball! The ice is far from pure. For one thing, comets contain not only water ice but also a mixture of various frozen gases. In addition, there is a meteoric dust component as well as a rich variety of quite complex organic compounds. Perhaps a better description of a comet would be a mass of frozen mud – or even a mass of frozen muddy froth, considering the low density of much cometary material. One thing is for sure: you would not be adding lumps of cometary ice to your cocktails!

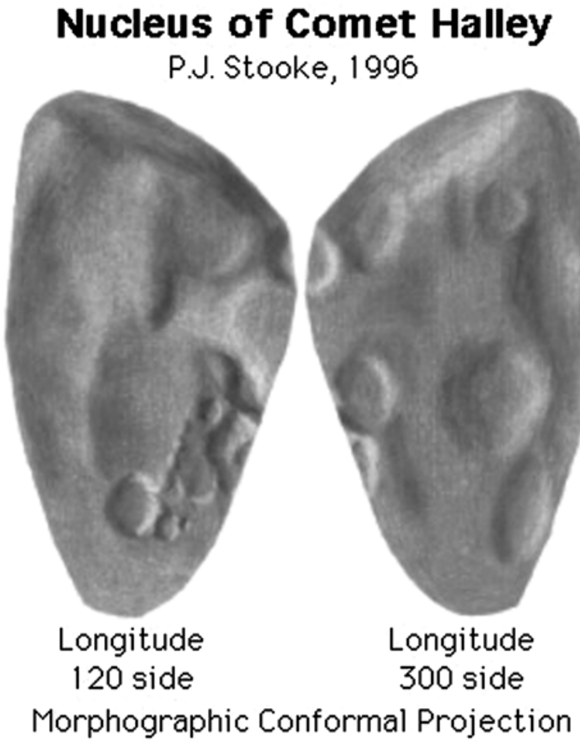

Fig. 1.2 A map of the solid nucleus of Halley's Comet drawn by Phil Stooke, Department of Geography, University of Western Ontario, from data obtained by spacecraft during the 1986 return (courtesy, NASA)

As this mass of low-density icy mud approaches the Sun, the latter's warmth causes the surface ices to boil off into surrounding space. In the vacuum of space, the melting point and the boiling point of water are one and the same, and water ice behaves in the same way as the "dry ices" or the frozen gases with which it is mixed. Water vapor and other gases boil out of the frozen body and into the surrounding void. As they do, particles of the "mud" are also released and carried away from the solid body to join the ever-expanding cloud that has begun to surround it. Solar radiation excites atoms of gas and causes them to glow by fluorescence, rather like Earth's polar lights or the gaseous contents of a neon sign. The particles of mud (which we will more correctly call as "dust" from now on) reflect and scatter incident sunlight. Both the ice and dust contribute to making the cloud visible in our telescopes.

It is this hazy cloud that we see as the coma of a comet. The word "coma," by the way, means *hair* in this context and is so named because of its typical fuzzy appearance. It has no association with a prolonged period of unconsciousness!

The coma of a comet is an immense object, in dimension if not in mass. Some very large comets have sported comas having diameters greater than the Sun itself, although quarter to half a million kilometers is more typical.

By comparison, the central icy asteroid – technically known as the "nucleus" of the comet – is a tiny thing. There are some giant ones measuring tens of kilometers or even larger, and there are also Lilliputian ones less than 10 m (approximately 33 feet) across, but the majority of nuclei are found within the 1–10 km (roughly, 0.6–6.3 mile) range. These smaller ones, however, are most often far from spherical in shape, and their length is often considerably greater than their width. Some of those observed close up from space probes have been likened to sweet potatoes. But whatever their shape, it is remarkable that from objects such as these – bodies that would sit comfortably within the perimeter of a moderately sized city – the great nebulous comas are formed, clouds that dwarf the biggest planets and that occasionally swell to sizes larger than the Sun itself!

It is one of the paradoxes of comets that these small and fragile objects can not only generate such huge comas but that they are capable of doing it again and again, even after repeated close encounters with the Sun. Halley's Comet, to use a famous example, possessed a coma over a million kilometers (625,000 miles) across during its 1986 return. Yet, it has been generating comas of this dimension for thousands of years, each time sweeping past the Sun within the orbit of the planet Venus! We might think that something so fragile and icy would have broken up and vanished long ago.

The reason why a comet such as Halley's can go on producing comas return after return is the very tenuous nature of the coma. Although enormous, comet comas contain relatively little matter. By the standards of Earth's atmosphere at sea level, the coma is a hard vacuum. Halley's, and similar comets, lose the equivalent of a couple of meters girth each time they pass through the inner Solar System. For a body 10 km in diameter, this is not a very great shrinkage!

Nevertheless, although one return (or even 100 returns) may make little difference to a comet, eventually the nucleus will be exhausted and the comet will disappear. The only alternative to eventual disintegration is a close approach to Jupiter, resulting in the comet being kicked into a different orbit that keeps it well clear of the Sun, or the development of an insulating crust of dusty material on the nucleus' surface blanketing underlying ices from the Sun's heat. A third alternative, collision with one of the planets, offers a more violent (and rare) means of disintegration!

Actually, all of these alternatives from disintegration to planetary collision have been observed or inferred. The famous Shoemaker-Levy 9 hit on Jupiter was a spectacular example of the latter, but the demise of comets through breakup and disintegration has also been observed, and there is good evidence that some comets have been damped down into asteroids, presumably through the growth of an insulating crust. Asteroids in comet-like orbits may truly be old comets that can no longer produce comas, and there is evidence that some comets go through long periods of dormancy, periods that may eventually stretch out into permanent extinction. A prime suspect is the short-period comet Denning–Fujikawa. This comet was discovered in 1881 by Denning and, despite a period of just 9 years, was not seen again until its rediscovery by Fujikawa in 1978. Both times it was a relatively bright and active object visible in small telescopes. Except for rather fast-fading and a probable sharp rise and fall in brightness, it appeared pretty normal for a short-period comet. But why had it not been seen between the two discoveries? What is more to the point, why has it not been seen since, even though the 1987 return should have been very favorable and potential observers had the advantage over its discoverers of knowing where to look for it?

It seems that this comet spends most of its time as a very faint and dormant asteroid, presumably crusted over with an insulating layer that keeps its ices from direct exposure to sunlight. Once in a while, we may imagine a piece of the insulation breaks loose for some reason or other (perhaps meteorite impact or thermal or tidal cracking) and Denning–Fujikawa bursts briefly into full-blown cometary activity. We might call this the "Brigadoon comet," only coming to life, like the fabled Irish village, once every 100 years!

Earlier, we mentioned that the light by which we see the coma is a combination of fluorescing gases and sunlight reflecting and scattering off particles of dust. The contribution from these two light sources is not always the same but varies from one comet to the next a nd may even vary for the same comet at different times in the same apparition.

When the light of some comets is passed through a spectroscope, it is found to consist almost entirely of the emission lines of various molecular species. In most instances, the visual region of the spectrum is dominated by the three so-called Swan bands of diatomic carbon. In these comets, the solar continuum of light reflected from the dust component is very weak and confined to the brighter central regions of the coma, very close to the central nucleus.

By contrast, other comets are so rich in dust that the solar continuum dominates, effectively swamping the gas emission lines in the visual spectrum. In these comets, not only is there a bright continuum in the nucleus region, but the coma itself and even the tail can, in the most extreme cases, be devoid of gaseous emissions.

It would really be more accurate to speak about two comas, the gas coma and the dust coma, and for the study of the dynamics within a comet, this is a distinction that must be made. However, as the two occupy (more or less) the same region of space, there is no need for us to be so pedantic here.

There is, however, a third component of the coma that we should distinguish, namely, the neutral hydrogen coma. If we think that the visual coma is big, this third component becomes almost unbelievable. But because it radiates only at ultraviolet wavelengths, it remained completely unknown until the advent of space-based observatories. It was discovered in early 1970 by the first orbiting UV observatory (OAO – Orbiting Astronomical Observatory) in UV images of the comet Tago-Sato-Kasaka. This comet – not an especially large one – was found to be surrounded by a tenuous cloud of hydrogen one million kilometers in diameter. A couple of months later, the great comet Bennett was shown to have an even larger hydrogen coma, and in more recent years, Comet Hale-Bopp of 1997 was found to possess a hydrogen cloud some 150 million kilometers (93 million miles) across. The diameter of this hydrogen coma was equal to Earth's distance from the Sun!

The hydrogen for these vast clouds is supplied by photo-disassociation of water vapor molecules within the visible coma. Once again, we marvel at the paradox of a small object such as a comet nucleus giving rise to something that even on a cosmic scale is large, exceeded only by the largest supergiant stars, galactic nebula, and entire stellar systems.

When the coma of a typical comet is viewed through a small telescope, its appearance is much like an unresolved globular star cluster or, as an unidentified friend of the famous practical astronomer Sir Patrick Moore is reputed to have said, "like a small lump of cotton wool." Unless the comet is only weakly active, there is normally a marked brightening toward the center. When this is present, the comet is said to be "centrally condensed." There is actually a 0–9 point scale of degrees of condensation that comet observers use in their visual descriptions. A degree of condensation (DC) of zero means that the coma is totally diffuse, with no perceptible central brightening, whereas a DC of nine means that the comet appears either as a stellar point of light or a small planetary disc with little or no trace of diffuse coma.

However, as if to make matters a little more confusing, the term "central condensation" can also refer to a discrete feature within the central regions of the coma. Certain comets are not only centrally condensed in the sense of brightening steeply toward the center of their comas, but also display a central "core" that may appear either as a small fuzzy disc or else as an almost star-like point. Either way, it stands out as being more or less differentiated from the general concentration of brightness at the coma's center.

A comet may, however, be described as being centrally condensed without having a true central condensation in this sense. When the central condensation (in the sense of a discrete core) is very intense and bright, it is very often referred to as a "false nucleus," "photometric nucleus," or (simply and unfortunately) "nucleus." This last is technically incorrect and very confusing. Very rarely is the true physical nucleus – the solid, icy, asteroidal body from which issues the phenomena that make comets what they are – discernible. In some comets, a discrete central condensation and a definite photometric nucleus are both discernible. In these comets, the central condensation typically appears as a small central disc in low-power eyepieces and appears to be the core of the comet. However, when carefully examined through a powerful eyepiece, an even smaller "core within the core" is visible, normally as nothing more than a faint star-like point of light. Technically speaking, this, not the larger and more conspicuous central condensation, should then be termed the photometric nucleus.

When a comet is active, the feeble light of the nucleus – that is, the true, physical nucleus – is swamped by the far brighter glow of the inner coma and photometric nucleus. Unless a comet passing close to Earth shows only the weakest activity and sports a coma that is nothing more than a gossamer thin veil, the best chance of observing a true comet nucleus is after the comet has receded far from the Sun and its activity has all but shut down. Large telescopes armed with CCDs may then detect it as a very faint speck of reflected sunlight. What is sometimes referred to as the nucleus of an active comet in older literature is simply the central condensation, or maybe the photometric nucleus within the *central region* of the central condensation. Either way, the term applies to a region far more voluminous than the solid body itself. Early estimates of the nuclei of comets that gave values of hundreds or even thousands of kilometers certainly did not refer to the true nucleus. Clearly, they were measures of the far larger central condensation.

Comet observers like to see comets displaying a sharp central condensation. Other things being equal, these comets tend to be active objects and, if they are moving along orbits that will bring them close to the Sun, can become visually impressive. Although not an iron-clad guarantee, a bright and sharply defined central condensation is welcomed as a positive sign. A comet showing a sharp condensation early in its apparition (i.e., while still relatively far from the Sun) and which is also destined to venture within Earth's orbit, holds a good chance of developing an impressive pseudo-parabolic coma with the central condensation brightening into an intense false nucleus at its focus. The outer comas of comets such as these form relatively distinct envelopes rather than the indistinct boundary of the more typical globular coma. Sometimes, there is even a series of concentric envelopes and jet-like structures emanating from the photometric nucleus. Most impressive of all, though, these are the comets that traditionally develop the best examples of the phenomenon that has come to characterize comets in the popular mind, namely, the "tail." We will now turn to this spectacular feature.

The Tails of Comets

Ask the average non-astronomer what word comes to mind when comet is mentioned, and the answer will most likely be either "Halley" or tail! Yet, the majority of comets observed nowadays actually display very little tail when observed visually. Photography and CCD imaging do far better at detecting tails, but the typical appearance of a faint comet in the eyepiece of a modest telescope is that of a fuzzy coma with, at best, a minor extension in a direction away from the Sun. The grand appendages that have struck such wonder and terror in the collective psyche of humanity since time immemorial are not typical of comet tails in general.

Another popular misconception by the person in the street is that comet tails relate to the speed of the object. The spectacular tails of great comets do indeed mimic trails left in the wake of a speeding body, but in reality that appearance is nothing more than an illusion. In the near perfect vacuum of outer space, there is insufficient resistance to sweep material back into a train of this type.

Although it might superficially resemble a wake left by something speeding by, a comet tail actually has a very different genesis.

As the Chinese have known for over a 1000 years and the Europeans since Peter Apian's observations of the Great Comet of 1532, comet tails basically point away from the Sun, irrespective of the direction of motion of the comet itself. This implies that when a comet is moving inward toward the Sun, it is moving coma first (we can now safely say "head first," as the coma/central condensation/nucleus is termed the "head" when a tail is visible). However, when a comet is moving outward from the Sun, it goes away tail first!

Clearly, something emanating from the Sun pushes material away from a comet and into the tail. For a long while this repulsive force was thought to be sunlight but, although partially correct, the real situation is more complex than this. A better understanding of the process requires us to distinguish two basically different types of tails.

Recall that earlier we mentioned two types of coma – gas and dust – but passed it by as a needless complication for our purposes. Well, the same distinction carries over to comet tails where, however, it assumes too great an importance to be casually set aside!

The broadest division of comet tails is, therefore, into gas (or more accurately "ion" or "plasma," as the gas is ionized in these features) and dust. Tails of the first variety are known as Type I and the second (predictably) as Type II and Type III. The difference between Types II and III is minor and can be overlooked for the present. (There are also rare and only recently detected sodium and iron tails, but as these are not visually discernible they need not concern us here.)

Type I tails are traditionally straight, tend to be long, and when well-developed consist of a bundle of narrow thread-like rays diverging from the central region of the coma. Small and weak tails of this type are much less impressive, most often appearing as nothing more than a single faint ray emerging from the center of a coma. Comets whose tails are predominantly of this type also tend to have globular comas.

Well-developed and active Type I tails make for very spectacular images, but are unfortunately a lot less impressive when viewed by eye. Being streams of ionized gases, they radiate principally in the blue region of the spectrum, to which the human eye is not particularly sensitive. Unless they are especially intense, we tend to see Type I tails as being rather dim and disappointing.

Type I tails are directed almost precisely away from the Sun. As the comet swings around the Sun, tails of this type show little distortion but sweep around like a searchlight beam as they maintain their relatively strict anti-solar orientation.

On the other hand, Type I tails may (apparently without warning) experience the most fantastic contortions. They have been seen on occasion to develop warps and kinks of up to 90 degrees. At other times, comets have shed their tails altogether, only to immediately sprout new ones in their place. The old tail, or the portion of it that was set adrift, takes the form of an elongated cloud, unconnected with the comet as it drifts away. These peculiar happenings are known as disconnection events or DE's.

Following an idea originally proposed by S. Arrhenius and developed in the first decade of the twentieth century by K. Schwarzchild and P. Debye, it was thought that the pressure of sunlight alone, acting upon the ions in the gaseous coma, was responsible for the occurrence of Type I tails. Certainly, light does exercise pressure, as we will see shortly, but astronomers came to doubt its ability to explain the motion of discrete tail features such as fast-moving knots and kinks. Once the velocities attained by some of these were measured with tolerable accuracy, it became clear that something else was involved. Although Debye had shown that radiation pressure from sunlight could account for forces of repulsion that exceeded solar gravitational attraction by a factor of 20 or 30, studies of the motions within the plasma tails of very active comets such as Morehouse of 1908 and Whipple-Fedtke-Tevzadze of 1943 indicated repulsive forces exceeding solar attraction by as much as 100–200 times, quite beyond the capabilities of sunlight. Even worse, to account for the very narrow thread-like streamers so often photographed in Type I tails, repulsive forces as great or greater than 1,000 times that of solar attraction were required! Clearly, something else was being emitted by the Sun; something that exercised a far greater repulsive force on particles of ionized gas than sunlight alone could accomplish.

As long ago as 1893, J. M. Schaeberle proposed that material particles ejected from the Sun were the cause of comet tails. Writing in the *Astronomical Journal* he proposed that, "The tail of a comet is produced by the visible particles of matter originally forming the comet's atmosphere, and by the previously invisible particles of a coronal stream that, moving with great velocity, finally produce by repeated impact of the successive particles almost the same motions in the visible atmosphere of the comet as would be communicated by a continuously accelerating force directed away from the sun."

Although Schaeberle's idea did not catch on at that time, it was remarkably close to the truth. Type I tails, we now know, are formed by the so-called solar wind, which (as Schaeberle opined) boils outward from the solar corona. Essentially, it forms an extension of the corona itself. It is this "wind" of protons and free electrons, streaming outward at velocities of 1,000–2,000 km (625–1,250 miles) per second, that carries away cometary ions into those long streaming tails of plasma. Turbulence within this wind reflects in turbulent motions within the tails, and even such dramatic and seemingly unpredictable events as tail disconnection events can be explained in terms of magnetic polarity reversals within the solar wind. For this reason, Type I tails have been graphically described as "solar windsocks," and prior to the advent of artificial satellites capable of directly measuring the wind, they were the only way of monitoring this phenomenon.

By contrast, light pressure alone appears quite adequate to account for the more sedate motions within dust tails.

Tails of this variety, though usually not very detailed photographically, tend to be more visually apparent than those of plasma. This is because we see them by means of sunlight reflected off, and scattered by, myriads of fine dust particles. Our eyes are more sensitive to this continuum spectrum of sunlight than to the blue glow of Type I tails, even if photography and other imaging techniques are not!

The more leisurely pace of dust tail particles is betrayed by the morphology of these appendages. For one thing, although they also extend away from the general direction of the Sun, they do not stay as close to the strictly anti-solar vector as Type I tails do. As the dust particles travel further from the comet's head, they depart more and more from this strictly anti-solar direction. Moreover, not all the particles of dust in a Type II tail have identical masses. Less massive particles experience a greater degree of acceleration, by light pressure, than that experienced by larger ones, and they will therefore be accelerated away from the comet at greater velocities than their larger companions.

The trajectories of small dust particles will, therefore, lie closer to the strictly anti-solar direction than those of the more massive ones. Consequently, the paths of the latter are more strongly curved as they increasingly lag behind the anti-solar vector.

The overall result of this divergence of dust-particle trajectories is a delicately curving tail, widening away from the head as the differing degrees of curvature become more apparent. These curving features do not reach full development, however, until after the comet has passed the Sun. On the inward leg of its orbit, a comet (if displaying a dust tail at all) will normally possess a relatively straight and fairly short appendage, even though this may at times be spectacularly bright.

Fully developed Type II tails, despite their sometimes considerable length and breadth, are quite thin. Dust particles swept back from a comet's head have very little tendency to drift either above or below the plane of the comet's orbit, causing the tail to be remarkably flat within the orbital plane. If Earth is located such that we see the comet from a perspective more or less perpendicular to its orbital plane, we will view the dust tail face on. If the tail is an intense one containing plenty of dust, it will be spectacular and assume the famous scimitar shape of a classical bright and dusty comet. On the other hand, if the comet has not been shedding a great deal of fine dust – if it is either a gassy comet or one whose dust is too coarse to feed strong Type II tail development – this feature may be so faint and transparent as to pass unnoticed.

Nevertheless, if or when Earth moves through the comet's orbital plane and we are in a position to see the tail edge-on, the dust tail will quite suddenly emerge from obscurity, though not as a classical curving scimitar. From a perspective within the plane of the comet's orbit, we view the tail edge-on, peering through its entire width. Needless to say, its curvature is not apparent, and the tail will appear to us as a long beam of light having approximately the same width as the coma. Because line-of-sight curvature is not apparent, we could gain the mistaken impression that the Type I tail had inexplicably intensified ... except that the characteristic tail rays found in these appendages remain absent.

An excellent example of this effect was exhibited by Comet Austin in 1990.