What Happened to Hyakutake?

On the Trail of a Comet

B S Shylaja

B S Shylaja is with the Bangalore Association for Science Education, which administers the Jawaharlal Nehru Planetarium as well as a Science Centre. After obtaining her Ph.D. on Wolf-Rayet stars from the Indian Institute of Astrophysics, she continued her research on novae, peculiar stars and comets. She is also actively engaged in teaching and writing essays on scientific topics to reach students.

The comet Hyakutake was discovered on January 30th of this year. In this article the author describes many special features associated with it.

The beauty of a particular celestial object attracted a lot of attention in March 96. The hero was not the brilliant (eclipsed!) sun, but a tiny object called comet *Hyakutake*.

This comet, discovered on the 30th of January by the Japanese astronomer Yuji Hyakutake, has many special features. When it was first spotted with binoculars, it was a fuzzy blub of magnitude [1] 11. However a quick follow up on the position details revealed information on the orbit and an extraordinary situation arising as a consequence.

[1] Magnitude six is about the faintest that the naked eye can see. Each additional magnitude makes the object about a factor of 2.5 dimmer, so magnitude 11 is a hundred times too dim to be seen unaided!

Generally, all the comets are discovered, i.e. detected for the first time in their orbit, at distances of about 2-3 AU (one astronomical unit is the mean distance from the earth to the sun, about 150,000,000 km.) as very faint hazy blobs. Most of them go unheard of (by the layperson) since they do not reach the visibility limit of even small telescopes. They become brightest when they are very close to the sun, that is at the *perihelion*. This obviously indicates that they are available above the horizon in the absence of sunlight for a very limited period. We did experience this 10 years ago, when comet *Halley* was back to salute the sun. Twilight and the larger air mass through which the object had to be viewed, diminished observations for any scientific purpose. The same is true with any other comet, be it *Giocobinni-Zinner* or *Austin* or *Levy*. Therefore for astronomers to be able to see a comet at a very comfortable elevation (i.e. high above the horizon) is a luxury and *Hyakutake* offered this very generously. How did it do that?

It wandered slowly in the constellation of Libra for almost the whole of February and most of March. Rising just about midnight, it crossed the meridian by the early hours of the day making life very easy for telescope users. This guaranteed 3-4 hours of astronomical observation in the clear winter months. By the second week of February, the spectroscopic details started pouring in, in the IAU circulars. (These are quick messages that are despatched for the benefit of the astronomical community.)

It is a luxury for astronomers to be able to see a comet at a very comfortable elevation (i.e. high above the horizon) and *Hyakutake* offered this luxury very generously.

The comet then headed towards the sun in its usual course. Surprisingly one the way to its perihelion point, it crossed us via the north pole and as a consequence was available above the horizon all through the night for about 4 days in the last week of March. The distance was a mere 0.1 AU on March 25th and it showed up quite brightly letting millions enjoy this rare sight of a comet at a pole. (In 1983, the comet *IRAS-Araki-Alcock* provided a similar opportunity, but it enacted this at very short notice depriving many of the rare sight.) The tail, which was faintly recognizable till March 20th, grew and then changed its orientation by the end of the month.

Astronomers noticed one more peculiarity of the comet on March 26th just after its closest approach to the earth. The nucleus of the comet which appeared very sharp to the naked eye, had split into two fragments. The two drifted slowly apart and their velocities were also measured. We are now immediately reminded of the "string of pearls" which created exciting news a couple of years ago. The comet *Shoemaker-Levy 9* which plunged into Jupiter had broken into 21 pieces. Why do comets break into pieces? Before answering this question we should know what comets are.

What are Comets?

Comets are very tiny (average size 4 km) fragile, irregularly

The Rocket Effect

Imagine that there is a snowman on the surface of a rotating comet. The snowman experiences a sunrise, sun at zenith and a sunset, akin to his counterpart on earth. Therefore the rate of melting of the snow increases gradually from morning, reaches a maximum by about mid day and reduces by evening. The chillness in the night however is sufficient to freeze him back again. After several days we would notice the evaporated material accumulate over the head of the snowman, because of the maximum rate of melting at midday. Some of this material will escape from the comet, because of the low escape velocity and this will generate a recoil effect. The direction of the recoil that is whether it is clockwise or anticlockwise will be decided by the spin of the comet. This effectively reduces or increases the orbital velocity and is called the *rocket effect.* This rocket effect was suggested as early as 1835, when Bessel observed the apparition of *Halley* that year. Comet *Halley* was spinning the 'right' way and got delayed in reaching the perihelion point at successive apparitions. Comet *Encke* was spinning the 'wrong' way and reached perihelion ahead of the scheduled time. The rocket effect successfully explained these anomalies.

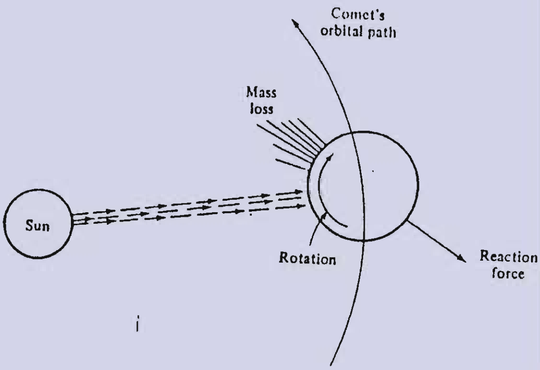


***Figure 1** As a comet approaches the sun, the gas molecules evaporate from the surface of the nucleus. The ejected gases have a preferential direction with reference to the sun-comet line. The recoil of the nucleus due to this gets the name 'rocket effect'.*

shaped bodies generally referred to as dirty 'snowballs', by virtue of their various ingredients. Most of them are visible because the volatile gases vaporise due to the sun's heat energy. This increases the density of the surrounding gaseous material as they move closer. The gases envelope the central body called the nucleus and at the perihelion point they block the view of the nucleus.

The eccentricity, *e*, is a measure of the departure of an ellipse from a circle. A circle has eccentricity zero, while the parabola has 1.

Comets obey the same universal laws of motion as the planets, but unlike planets they have elongated orbits. Mathematically, we can say their eccentricities are close to unity. The eccentricity, e, is a measure of the departure of an ellipse from a circle. A circle has eccentricity zero, while the parabola has 1. All the planets have eccentricity e close to 0, with only Mercury and Pluto deviating to about 0.1. That explains why the orbits of periodic comets resemble a parabola, even though they are really ellipses.

Many comets get perturbed very easily by a planet on their way to the perihelion. The comet *Halley*, known for its periodic visits, thus has a period ranging from 74.4 years to 79.2 years. In the original paper in 1709 by Edmund Halley, which predicted the return of the comet, he mentions that Jupiter undoubtedly had serious effects on the comet's motion.

It must be remembered that comets are fragile bodies. Their tensile strength is very low — of the order of 1000 dynes/cm^2 (Compare this with the strength of, say aluminium, which is of the order of 10^9 dynes/cm^2.) That is similar to a snowball which can be pulled apart with bare hands. The gravitational pull, by virtue of a comet's low mass, is also very small. Remember that it requires a velocity of 11 kms/sec for an object to leave the earth, whereas a similar escape velocity for a typical comet is about 1metre/sec. What is the consequence of this low surface gravity?

Comets obey the same universal laws of motion as planets, but have elongated orbits. Mathematically, we can say their eccentricities are close to unity.

We learned that the material which was frozen in the nucleus, evaporates during the period of perihelion approach. The evaporated dust and molecules are dragged along for a while and ultimately become independent of the nucleus. Moreover, they are pushed into the shadow region of the nucleus which is away from the sun. The solar wind pushes and aligns them neatly as the tail of the comet.

As the comet approaches the perihelion point, the molecules are exposed to the intense ultraviolet radiation, which breaks them apart and they become identifiable by their spectra. Very close to the sun, they are deprived of their electrons as well and the ions thus formed are electrically charged and are exposed to the magnetic lines of force of the solar wind. They align themselves into a different tail identified as the ion tail of the comet.

Models in Cometary Astronomy

1950 was the most important year in cometary astronomy. Oort proposed the 'cloud' or a store house of comets in the remote reaches of the solar system, a hundred times further than Pluto. Kuiper suggested a 'belt' beyond the orbit of Neptune for short period comets; Whipple offered the 'dirty snowball' model for the cometary nucleus.

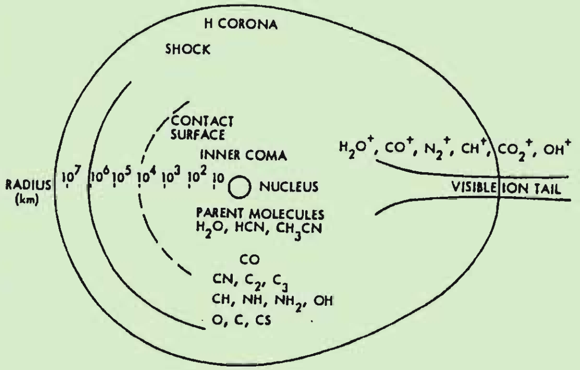


***Figure 2** The general distribution of the ions and molecules in a cometary coma shows the parent molecules like H_2O, HCN and CH_2CN in the inner coma. As the comet nears the sun, other molecules and ions are created.*

The model predicts the rate of production of molecules at different heliocentric distances. The gaseous activity becomes recognizable at about 3 AU. Beyond this distance the spectrum shows only continuum. At 3 AU the CN emissions appear, at about 2 AU C_3 and SH_2 appear. As the comet proceeds towards the sun, at about 1.5 AU the spectral lines of C_2, CH, OH and NH appear. By now the continuum is very weak or in other words, the emissions dominate the spectrum. These strong colourful lines look beautiful through a spectrograph. At still closer distances, ionised species like CO^+, OH, N^+_2 and CH^+ appear. The study of the spectrum and its variation through the perihelion passage is important, because differences in the spectra reveal the nature of the nucleus itself.

Thus comets are endowed with the special privilege of developing tails millions of kilometres long, that can be shaped, or stretched to 25 to 30 degrees of the sky, or can be colourful, with sodium providing a yellow tint. All this beauty is achieved at the cost of particles in the tail that are lost forever!

Comets are endowed with the special privilege of developing tails millions of kilometres long, that can be shaped, or stretched to 25 to 30 degrees of the sky.

The Breakup of the Nucleus

Although the fragmentation of the nucleus was best publicized in the *Shoemaker-Levy* episode, more than 25 such cases are known. One recent event was *McHoltz* which split in 1995. The splitting of *West* in 1977 was also well studied. Sometimes two or more comets share the same orbit indicating that they were once a single piece. Calculations point to Jupiter as responsible for this type of splitting in many cases.

When comets split, the pieces do not fly apart.

There is a family of about 16 comets, generally referred to as the *Kreutz* family (after Heinrich Kreutz, who investigated the comets and identified this group), which passes very close to the sun—within 3 million kms or less. Marsden of the International Bureau of Telegrams suggests, based on orbit computations, that all these may have resulted from the fragmentation of a comet which appeared in AD 1100, which in turn may have been part of a great comet of BC 372. Half of these could not survive the perihelion passage and splashed onto the sun. The other members of the family survived, but broke into pieces.

When comets split, the pieces do not fly apart. Calculations assuming the mean density to be about 0.5 gm/cc, (half of that of water), and a rotation period of 12 hours for a comet of size 12 km show that a particle at its equator (if it has any defined), would depart with only a velocity of 0.72 meters/sec relative to the centre of the comet. Many comets rotate much more slowly. This means that the drifting of pieces is not observable. Even when a piece is freed of the gravitation of the nucleus, it drifts slowly with continued weak interactions, which can cause further splitting of the fragments.

The pieces of *Hyakutake* which now have a relative velocity of about 0.8 km/s are being monitored closely. The two fragments have separated. This could have given us the spectacle of two independent tails, as developed by comet *Biela* 150 years ago. It appears, however, that this has not happened.

Address for correspondence
B S Shylaja
Jawaharlal Nehru
Planetarium
High Grounds
T Chowdaiah Road
Bangalore 560 001, India.

Suggested Reading

R A Lyttleton. The Comets and their Origin. Cambridge University Press. 1953.

Nigel Calder. The Comet is Coming. BBC. 1980.

J C Brandt and R D Chapman. Introduction to Comets. Cambridge University Press. 1981.

Various circulars from the IAU.

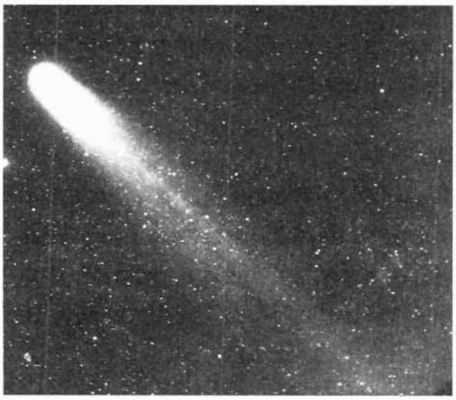
The Changing Forms of Comet Hyakutake (1996-B2)

Pictures of comet given below courtesy T Chandrasekhar, N M Ashok and J N Desai (PRL)

27 March 1996
3.15 a.m.

A spectacular photograph of *Comet Hyakutake* taken during its close approach to the earth of approximately 15 million km. A telephoto (focal length = 105mm, f/2.8) camera mounted on the drive of the large 1.2m telescope was used. The exposure time was 30 minutes. During the exposure the cometary motion was frozen by tracking it using a guiding telescope. The motion of stars in the field relative to the comet show up as star trails (smaller linear structures). The exposure was made when the comet was at a distance of 0.10 AU from the earth and 1.03 AU from the sun (1 AU = 150 million km). The photograph covers a field of view 6 degrees x 4 degrees. The tail is seen to extend at least 5 degrees.

5 April 1996
8.15 p.m.



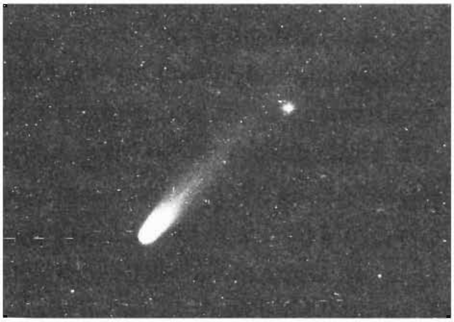
Schmidt photograph with an exposure time of 14 minutes, 30 seconds. A central ray extends to the edge of the field and beyond (>3 degrees). The star seen near the cometary head is *K Persei* (visual magnitude ~ 3.8). The comet was at a distance of 0.37 AU from the earth and 0.81 AU from the sun. The field of view of the photograph is 2.8 degrees x 2.4 degrees.

All photographs have been taken from Gurushikhar Observatory, Mt.Abu which is a field station of Physical Research Laboratory (PRL), Ahmedabad. The observatory is at an altitude of 1680m above sea level.

9 April 1996
8.30 p.m.

Another spectacular view of Comet *Hyakutake* showing the intricate structures in the tail of the comet. The exposure time was 10 minutes. The bright star to the right is the famous eclipsing binary star *Algol* (visual magnitude ~ 2.1). The angular separation between the cometary nucleus and the star is about a degree. The prominent ray structure and kinks along the tail are clearly seen. The tail extends at least 2.5 degrees. At the time of this exposure, the comet was at a distance of 0.49 AU from the earth and 0.71 AU from the sun. The field of view of the photograph is 3.4 degrees x 2.4 degrees.

10 April 1996
8.30 p.m.



Schmidt photograph with an exposure time of 10 minutes. The bright star seen in the tail region is the famous eclipsing binary star *Algol* (visual magnitude ~ 3). The angular separation between *Algol* and the cometary nucleus is 1.43 degrees. The fainter portions of the tail extend beyond the scale of the photograph (>2.5 degrees). At the time of this exposure, the comet was at a distance of 0.53 AU from the earth and 0.69 AU from the sun. The field of view of the photograph is 3.4 degrees x 2.4 degrees.