Structure of Comets

1. The cometary nucleus

The heart of a comet is a solid body, with a diameter in the order of tens of kilometers, which is called the nucleus. This nucleus is very cold, since the comet's orbit usually is such that it spends much time far from the Sun. Its material therefore is frozen. The currently held view is that of the ``dirty snowball': the nucleus is an irregularly shaped loosely packed mixture of ice (carbon dioxide and monoxide ices, frozen ammonia, and a little bit of water ice) and rock boulders and dust grains (silicates).

When this frozen nucleus journeys into the inner regions of the Solar System, it heats up because of the increasing solar radiation. The ices on its surface begin to evaporate. This seems to happen typically at a few isolated spots on the surface. This can be seen in the only close-up view of a cometary nucleus that we ever obtained, when the European Space Agency's Giotto probe made a flyby of Halley's comet: the picture (courtesy of Dr H.U. Keller, MPAE, Halley Multicolor Camera/ESA Giotto mission) clearly shows a few bright jets of gas emanating from a potato-shaped nucleus.

In fact, the existence of such jets was already inferred before: since the nucleus typically rotates, the jets give rise to periodic brightness variations in the tail, which have been used in the past to estimate the nucleus' rotation period. The release of gas is accompanied by the escape of dust grains that were mixed with the evaporating ice.

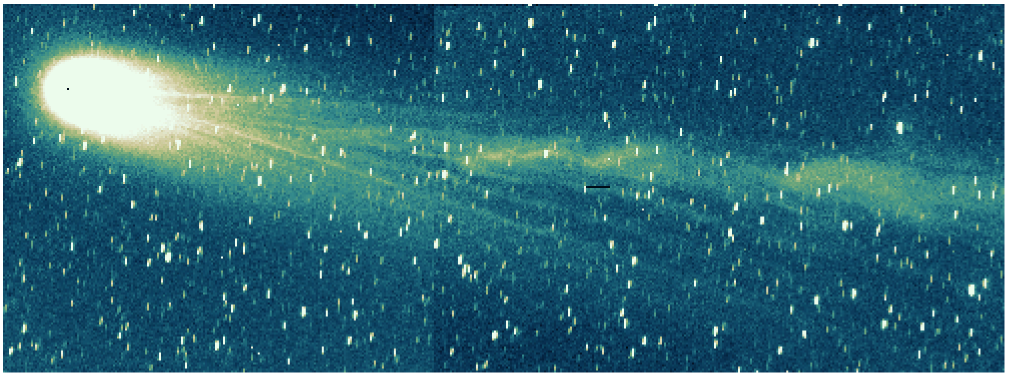
2. The gas

The escaping gas creates a sort of atmosphere around the nucleus, which is called the coma. The nucleus' gravity is very weak, so that the thermal motion of the gas atoms is already sufficient for them to break away from the nucleus' gravitational grip. While the density of neutral gas atoms is high enough to make collisions between them frequent close to the nucleus, the gas gets more tenuous farther away so that collisions become very rare events, and it is like each atom moves along its own path without interference from the other atoms.

At the same time, however, this neutral gas becomes ionized by solar UV radiation, like in the Earth's ionosphere. On their motion outward, these ionized particles meet the solar wind plasma, thus forming the cometopause, the interface between solar wind and cometary material. The motion of the ionized cometary gas then becomes determined by the interplanetary magnetic field, and the cometary ions and electrons are gradually ``picked up'' by the fast anti-sunward flow of the solar wind (remember that the plasma is so tenuous that there are no collisions between solar wind particles and the cometary particles, so the solar wind does not force the cometary plasma to move along by friction; the two types of material interact only through the magnetic field).

This gives rise to the comet's plasma tail, which points radially outward along the Sun-comet line. It was, in fact, the existence of such tails that led Bierman to infer the existence of the solar wind. The structure of the plasma tail is clearly determined by the interplanetary magnetic field. One manifestation of the role of the interplanetary magnetic field are disconnection events: when the comet passes through the heliospheric current sheet (that is, informally speaking, the magnetic equatorial surface in the solar wind; the interplanetary magnetic field points sunward on one side of it, and anti-sunward on the other side), the reversal of the magnetic field direction leads to a polarity reversal in the plasma tail. What happens is that the original tail is ``cut off'', while a new plasma tail with the new polarity starts to form.

An example is shown in the accompanying figure, where the old plasma tail is disconnected from the coma (it begins in the middle of the picture, there is no plasma tail between the coma and this point); the ray-structures (straight lines) immediately behind the coma are typical for the early stages in the formation of a new tail.



Comet Hyakutake (1996 B2), photographed by Herman Mikuz, Crni Vrh Observatory, Slovenia/JPL Hyakutake site, false colors were used to highlight the structures in the tail

3. The dust

The dust that is released from the nucleus typically has only a small velocity relative to the nucleus.

It will therefore follow more or less the orbit of the cometary nucleus, that is, a curved elliptical or parabolic trajectory. A large fraction of this dust is very small, with typical dust grain diameters of 0.001 mm. Because of their large surface to mass ratio these grains are very sensitive to the solar radiation pressure, that is, the pressure exerted by the light of the Sun on these particles.

They will therefore be pushed behind the comet, so that the dust grains form a diffuse dust tail trailing behind the comet, more or less along the curved orbit. The degree to which the dust deviates from the comet orbit depends on the size of the dust grains.

This dust tail has a yellow-white appearance, as the dust particles simply reflect the incident sunlight. The straight bluish and highly structured plasma tail and the curved diffuse white dust tail are clearly visible in the accompanying Hale-Bopp photograph (courtesy of the National Astronomical Observatory of Japan) .

Author: J. De Keyser