Space probes:
- **Halley** (March, 1986): USSR-Vega1, Japan-Suisei, USSR-Vega 2, Japan-Sakigake, ESA-Giotto

Other missions: NASA Stardust (launched in 1999) flew through the coma of comet 81P/Wild-2 in 2004 and returned a sample of comet dust to Earth. The recent Deep Impact mission successfully launched a probe into comet 9P/Tempel1 to see what it was made of. For additional information on all of NASA’s missions – past, present and future go to [http://sse.jpl.nasa.gov/planets/index.cfm](http://sse.jpl.nasa.gov/planets/index.cfm) and click on comets.

I. Origin and Evolution -- Comets, in some sense, are the true debris of the Solar System. The relatively low density of the solar nebula in its outermost parts limits the development and growth of planetesimals such that the size of comets are typically ~1-50 kilometers in diameter. The material of which comets are made is relatively unprocessed, due to the fact that the temperature is so low at these great distances from the Sun that relatively little has happened to change the nature and composition of the comet material since the initial stage in the collapse and formation of the solar system. The small size of the comet also limits the effects of gravitational contraction and subsequent re-heating that takes place inside the differentiated interiors of the larger planets. Only when comets are somehow perturbed into orbits that will bring them into the inner solar system, will they come close enough to the Sun to heat up and expel some of their material, or possibly collide with planets, moons, or even the Sun itself. Comets can be grouped into the following families:

- **Short Period Comets**
  - **location** -- The Kuiper Belt at 30-50 AU
  - **number / size** -- Up to ~70,000 with diameters larger than ~100 km, most in the 100-300 km range
  - **orbit** -- highly tilted from galactic plane and eccentric (like Pluto). Periods typically 100-200 yrs

- **The Centaurs**
  - **location** -- originally part of the Kuiper Belt, but now on orbits which take them 5-30 AU from Sun
  - **number / size** -- Extrapolating from the 6 that are now known, the total number of Centaurs is ~100. The largest object is **Chiron** (diameter ~200 km). Others are probably similar in size.
  - **orbit** -- elliptical orbits (ε = 0.2–0.6) which have typical perihelia of 5 AU and aphelia of 30 AU meaning that they cross the orbits of the 4 giant planets. Periods range from 10 to 150 yrs

- **Long period comets**
  - **location** -- Oort Comet Cloud at ~50,000 AU; this defines the outer limit of our solar system.
  - **number / size** -- anywhere from 10⁸ to 10⁹ objects in the Oort cloud, with diameters typically 1-50 km
  - **orbit** -- individual orbits can be at all tilt angles such that the ensemble of comets forms a spherical shell around the solar system. Orbital periods are typically between 10⁵ and 10⁶ years.

II. Composition -- Comets are now often described as being “dirty snowballs” because they seem to be composed of loose rock particles and dust intermixed with ices, primarily methane (CH₄), ammonia (NH₃), water (H₂O), carbon dioxide (CO₂) and carbon monoxide (CO).

III. Activity -- Comets become active only when they get close enough to the Sun to heat up to the point that their surface ices turn to gas. An active comet typically has the following appearance:
  - **coma** -- a relatively large cloud of glowing gas surrounding the nucleus
  - **nucleus** -- parent body of rock, dust, and ices a few km up to 300 km in diameter
  - **dust tail** -- dust particles in a slightly curved line behind the nucleus for a distance up to 1AU (!)
  - **gas (or ion) tail** -- gas particles blown straight out behind the comet by the solar wind

IV. Famous/Recent Comets -- Most if not all famous comets are periodic comets that have been perturbed into near Earth-crossing orbits from their original location in the Kuiper Belt, most likely through interactions with the outermost planets.
  - **Halley** -- 76 year period comet first cataloged in ~250 BC, and last seen near Earth in 1986.
  - **Shoemaker-Levy 9** -- ripped apart just before crashing into Jupiter in July, 1994