Missions to Comets

The following is the text portion of the overheads which were used for a talk to the American Association of Physics Teachers meeting (August 1999) entitled "Missions to Comets". The overheads are exclusively in black and white. There are sheets which have the word "note" in their titles which are place keepers for figures. Most of the figures can be found on web sites for the missions or there are pointers to the web site.

The general level of the overheads is suitable for adults with some science background such as amateur astronomers or general physicists and can be extended lower with suitable explanations. It will need to be embellished for professionals.

Anita Cochran
9 November 1999

Outline

- Background
  - Formation of the Solar System
  - Why study comets?
  - Structure of the outer Solar System
  - Composition of comets
- Missions to comets
  - Past missions
  - Current missions

Note: Include the following

Show a diagram of the current theory for how a solar system forms from a molecular cloud to a disk with the sun in the center. A good example is the Shu et al figure or something from the COMPLEX strategy

Why Study Comets?

- Comets are the least altered objects left over from the formation of the solar system and thus offer the best constraints on conditions in the early solar nebular.
- Comets contain volatiles, including water, which may have been important for life.
- There may be as much as 1 Earth mass of material currently in comets.
- Comets are some of the impactors which may have been responsible for the frustration of life.
- Studies of the comets in the outer part of the solar system are important for our understanding of the dynamics of the planets and planetesimals in the early times of formation.

Comet Taxonomy

Comet taxonomy has been based largely upon orbital period:

- **Long-Period Comet** (and non-periodic): Orbital periods greater than 200 years
- **Short Period Comet:** Orbital periods less than 200 years.

  The short period comets are broken into two subgroups:

  – Hally-Type comets (HTCs): Periods from 20-200 years

    These are sometimes referred to as "Intermediate-Period" comets.

  – Jupiter-Family comets (JFCs): Periods less than 20 years.

This taxonomy is <u>arbitrary</u>.

For short period comets, dynamical studies show that comets can move between Jupiter-family and Hally-type orbits.

Structure of the Outer Solar System

From dynamical considerations, we now understand the structure of the outer solar system to consist of two parts:

1. There is a primordial disk of objects, known as the Kuiper belt, with objects with orbits with semimajor axes as near the Sun as Neptune's orbit. This disk has a thickness of order $\pm 15°$. There are zones of the Kuiper belt which are stable for the lifetime of the solar system.

   $>$100 Kuiper belt objects have already been discovered.

2. There exists a "halo" of comets surrounding our planetary system called the Oort cloud. These objects were formed in the Uranus-Neptune zone (primarily) and planetary perturbations increased their orbital perihelia, semimajor axes and inclinations. There is no preferred inclination for objects which enter the inner solar system from this cloud. There is an inner cloud which is relatively unperturbed but will occasionally replenish the outer cloud. The outer cloud is stable for only 60% the lifetime of the solar system. The Oort cloud is *not a primordial* reservoir.

How do comets get from the outer solar system to the inner solar system?

- Giant molecular clouds in the galaxy perturb them.

  This is relatively rare. The mean occurrence interval is 3×10^8 years.

- Perturbations by nearby passing stars or stars burrowing through the Oort cloud perturb them.

  Over the life of the solar system, about 5500 stars have passed within 10^5 au of the Sun. These passages have ejected 10% of the Oort cloud population. A $1\,M_\odot$ star passing through the cloud with a velocity of 20 km sec^{-1} will eject all comets within about 450 au.

- The galactic gravitational field (tidal field of the disk) can perturb them.

  This is the **dominant force** acting on the Oort cloud. The cloud should be a prolate spheroid with its long axis pointing towards the center of the galaxy. Maximum semimajor axes are about 10^5 au for direct orbits (relative to galactic rotation) and 1.2×10^5 au for retrograde orbits.

Note: Include 2 figures

1. Show The HMC image of approaching the nucleus of Halley; explain about targeting problems. (A copy can be found on the Rosetta web page under science)

2. Show the SOHO Swan H Ly α map for Hale-Bopp of 1 April 1997 with the embedded ground-based image of Hale-Bopp; explain the scale of comets. The yellow dot on the right is the Sun to scale!! (Gotten from M. Combi)

Cometary Composition

Since we have not yet retrieved samples of comets for study in our labs, we use remote sensing techniques to study comets. In particular, we use the technique of *spectroscopy*. Comets are, roughly speaking, dirty snowballs, with water ice making up about 80% of the ice. About 50% of the mass of the nucleus is "dirt".

As the comet approaches the Sun, it is heated. In the low pressures of space, the ice does not get converted to liquid, but instead is transformed directly into its gas state. This process is know as *sublimation*.

The spectrum of a comet is characterized by predominantly molecular emission coupled with an underlying continuum resulting from sunlight reflected off dust.

NOTE: Include the Dr. Fun Cartoon

Now that you have stressed the audience, it is time for a cartoon. I use the "Doctor Fun" cartoon on building your own comet. Dr. Fun cartoons can be found at

http://sunsite.unc.edu/Dave/drfun.html

For the comet one I use, go to the archive, to 18 Sep 1996. Enjoy browsing the rest of the archive!

Missions to Comets

- Past Missions:
  - **ICE** (US): Giacobini-Zinner
  - **Giotto** (ESA), **Vega 1 and 2** (USSR), **Sakigake and Suisei** (Japan): Halley
  - **Giotto** (ESA): Grigg-Skjellerup
- Current Missions:
  - **Deep Space 1** (US): Wilson-Harrington, Borrelly
  - **Stardust** (US - Discovery Program): Wild 2
  - **Rossetta** (ESA): Wirtanen
  - **CONTOUR** (US - Discovery program): Encke, Schwassmann-Wachmann 3, d'Arrest
  - **Deep Impact** (US - Discovery program): Tempel 1

NOTE:

For each mission, you might want to select images from the mission web site (see addresses at end) for inclusion. There are no very good images for DS1 (at least the last I looked).

Deep Space 1

The first of the New Millennium Program missions, a series of missions to test cutting-edge technologies never before flown.

- Launched 24 October 1998
- Tests 12 new technologies, the most important being ion propulsion
- Primarily an *engineering* mission, with science possible
- Carries a UV, visible, IR camera/spectrometer and a plasma instrument

- Nominal mission includes a flyby of asteroid Braille on 29 July 1999 (had various problems)

- Extended mission includes flybys of two comets:

  - Wilson-Harrington: January 2001

  - Borrelly: September 2001

Stardust

The fourth Discovery mission to be chosen, Stardust is the *first robotic return of extraterrestrial material from outside the orbit of the Moon*. Its primary goal is to collect comet dust and return it to the Earth.

- Launched 7 February 1999.
- Principal investigator is Dr. Don Brownlee, U. Washington
- Will encounter comet **Wild 2** in June 2004 at 1.86 au from the Sun.
- Encounter distance as close as 150km and relative speed of 6.1 km/sec.
- Samples will be collected with a substance known as *aerogel*
- Sample returned to Earth in 2006 – landed at the Utah Test and Training Range

Rosetta Mission

- The third Cornerstone mission of the European Space Agency
- To be launched January 2003 from Kourou, French Guiana, aboard an Ariane 5
- Target comet is Wirtanen
- Encounter is November 2011 with end of mission July 2013.
- Rosetta has 12 instruments on the spacecraft and also carries the Rosetta lander (RoLand). RoLand will land on the comet, anchor, and perform a series of experiments.
- Rosetta will not return any samples but analyze samples *in situ*.

Comet Nucleus Tour – CONTOUR

- CONTOUR is a Discovery-class investigation of the **diversity of comet nuclei**. PI is Joe Veverka at Cornell. The spacecraft will be built at the Johns Hopkins Advanced Physics Lab.

- The aim is to improve dramatically the knowledge of key nucleus properties.

- CONTOUR includes the detailed investigation of three diverse short-period comets: Encke, Schwassmann-Wachmann 3 (SW3) and d'Arrest.

- The CONTOUR mission profile is extremely flexible and could be modified to include a first-ever study of a "new" comet (such as Hale-Bopp) or even a flyby of Wirtanen one apparition before the planned Rosetta investigation.

- A unique feature of CONTOUR is that it is put into a "hibernation" mode between encounters with the comets and Earth swing-bys. It will hibernate 76% of its time, saving costs of personnel to monitor the spacecraft.

Deep Impact

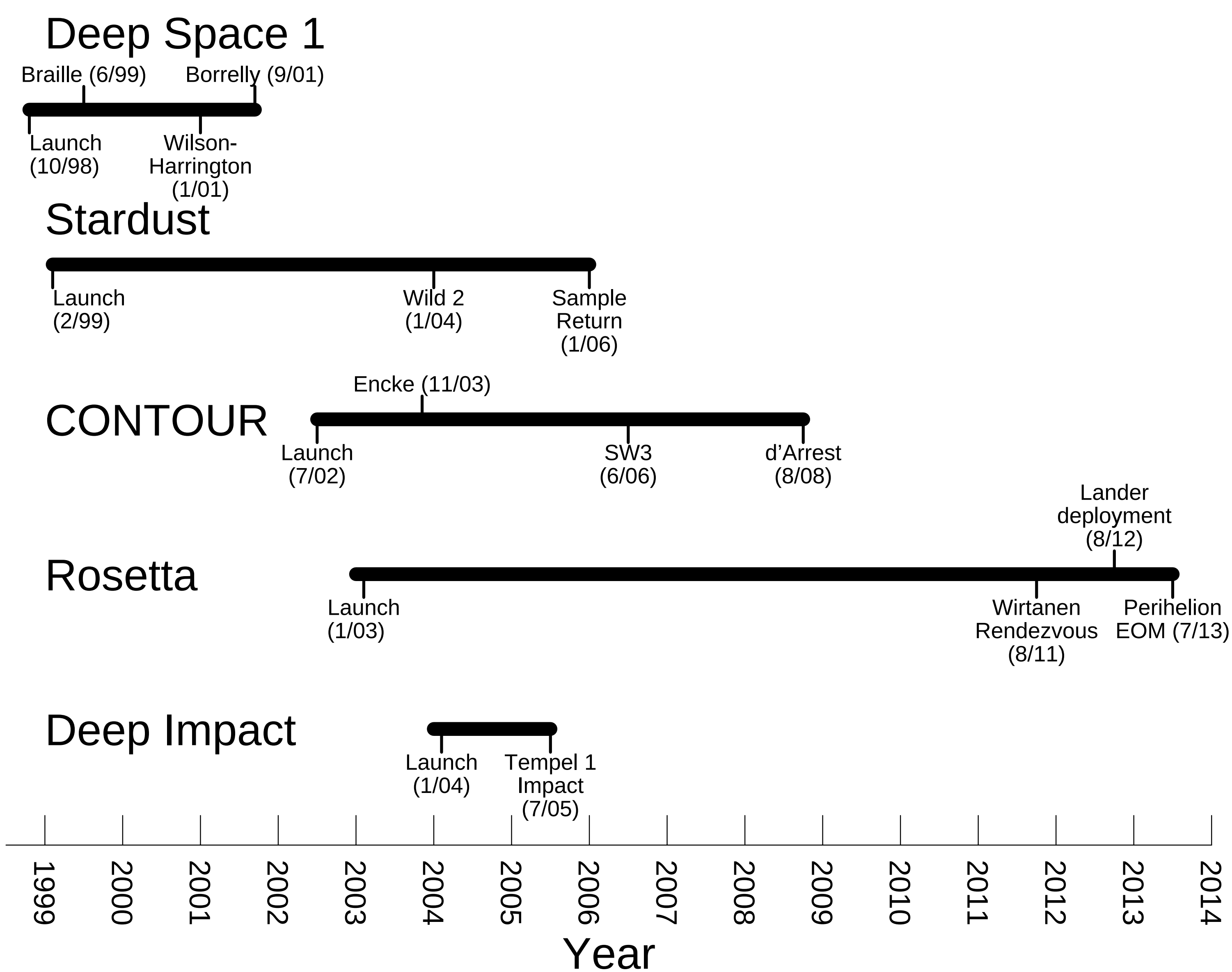
- The newest Discovery-class mission. PI is Mike A'Hearn at U. Maryland and the spacecraft will be built by Ball Aerospace and the Jet Propulsion Lab.

- The goal of the mission is to directly study the interior of a cometary nucleus by excavating a region the size of a football field and seven stories deep.

- The mission consists of a dual spacecraft which is separated 1 day before impact. One spacecraft will consist of a 1/2-ton, mostly copper impactor which will strike the comet. The other spacecraft will be retarded slightly so that it will fly past the comet and passes below the nucleus for the impact.

- Instruments on-board the flyby spacecraft will record the nucleus before the impact, during the impact and will study the final crater.

Timelines for Comet Missions



Web sites for the missions

- **Deep Space 1**: nmp.jpl.nasa.gov/ds1/
- **Stardust**: stardust.jpl.nasa.gov
- **CONTOUR**: www.contour2002.org/
- **Rosetta**: sci.esa.int/rosetta/
- **Deep Impact**:
  www.ss.astro.umd.edu/deepimpact/