Small Bodies and Dust and SolSys Form. Working Group

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After Ranking by a Systems Approach

‘Ordered’ Science Cases

Last November 2005 (Northeim). Results from systems analysis: (most broad coverage of targets and most involved methods of study)

ISSI

↗

HOW → 1. How can we best optimise from observations, numerical experiments, laboratory simulations, further analysis of past mission data the science return of Rosetta?

WHAT → 3. What are the relative contributions of asteroidal dust, cometary dust, meteor streams, interstellar dust and circumplanetary dust to the structure of the zodiacal dust cloud as a function of heliocentric distance, latitude (and time)?

OLD, relevance to extrasolar planets

WHAT → 6. What are the connections between TNOs, centaurs, trojans, comets and icy satellites and **what is the dynamical and morphological structure of the Kuiper belt**?

WHAT → 9. What are the values and ranges of key properties of a significant number of small bodies to constrain the formation environment and evolution, e.g. density, bulk composition, mineral composition, isotopic, elemental, molecular composition, chemical and physical properties, dynamical evolution, etc.?

Multi-working group questions:

- What drives the volcanism on Enceledus?
- How did Earth get its water?

Caveats:

- Haven't specified particular institutes
- Haven't drawn cross-links with other WGs yet

For Our Science Cases

1. What are the relative contributions of asteroidal dust, cometary dust, meteor streams, interstellar dust and circumplanetary dust to the structure of the zodiacal dust cloud as a function of heliocentric distance, latitude (and time)?

2. What is the dynamical and morphological structure of the Kuiper belt?

Contribution to Zodiacal Cloud?

1. What are the relative contributions of asteroidal dust, cometary dust, meteor streams, interstellar dust and circumplanetary dust to the structure of the zodiacal dust cloud as a function of heliocentric distance, latitude (and time)?

We had panel discussion at the "Dust in the Solar System and Other Planetary Systems" September 2005 Meeting, so today, the 30-year question still continues...

Marco Fulle from Stromboli 1997 Hale Bopp & Wedge of Cosmic Dust

"Découverte de la lumiere celeste qui paroist dan le zodiaque" (Cassini 1693)

Zodiacal Cloud

The interplanetary dust particles (IDPs), not only scatter solar light, the IDPs also produce thermal emission, which is the most prominent feature of the night sky light in the 5-50 micron wavelength domain (Levasseur-Regourd, A.C. 1996).

The total mass of the interplanetary dust cloud is about the mass of an asteroid of radius 15 km (with density of rho=2.5).

The interplanetary dust cloud has a complex structure. It has:

* at least 8 dust trails -- source is thought to be short-period comets, in particular the three asteroid families: Koronis, Eos, Themis, ...

* at least 2 resonant dust rings (the Earth resonant dust ring for example, but every planet in our solar system is

Zodiacal Cloud

Lifetime:
Very short compared to the lifetime of the Sun.

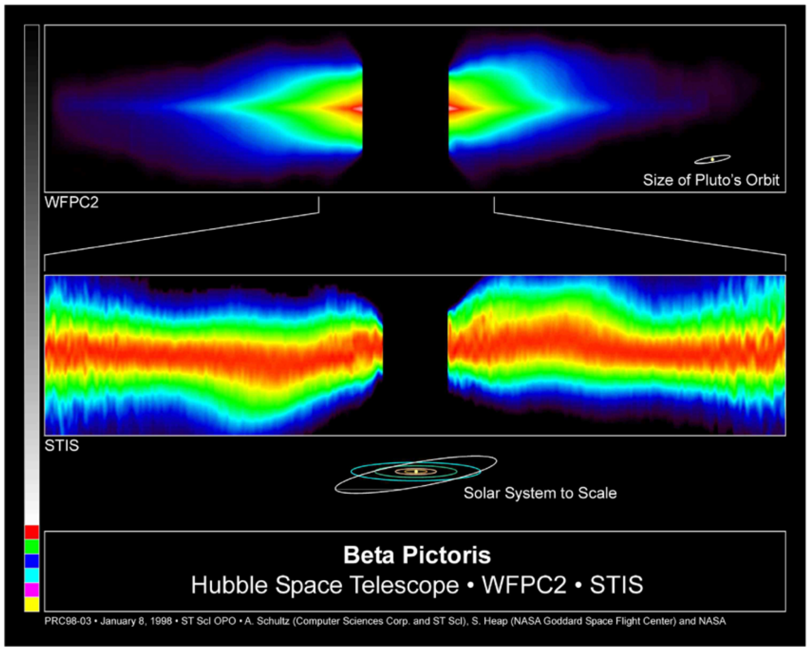
The main physical processes "affecting" (destruction or expulsion mechanisms) IDPs are: expulsion by radiation pressure, inward Poynting-Robertson (PR) radiation drag, solar wind pressure (with significant electromagnetic effects), sublimation, mutual collisions, and the dynamical effects of planets.

If one finds grains around a star > ~10^8 years, then the grains must have been from recently released fragments of larger objects.

The zodiacal dust in our solar sytem is 99.9% later-generation dust, 0.1% intruding ISM dust, and 0% primodial grains from the Solar Sytem's formation (which is, instead locked up in comets, meteorites, asteroids, planets ...).

Beta Pic

This Wide Field Planetary Camera 2 image shows 1500 astronomical units, edge-to-edge of the disk. The flaring at the top of the right side of the disk shows that dust has been pulled above the dense plane of the disk beyond what is observed. June 22, 1995.



A detailed close-up view of the inner region shows a warp in the disk. These new details support the presence of one or more planets orbiting the star. The image was taken in September 1997.

Why is knowing our dust cloud important?

-To Look "in": to understand what extra-solar systems might have beneath their dusty exterior.

-To Look "out" : peering through the haze; what is in our solar system, and what is the rest.

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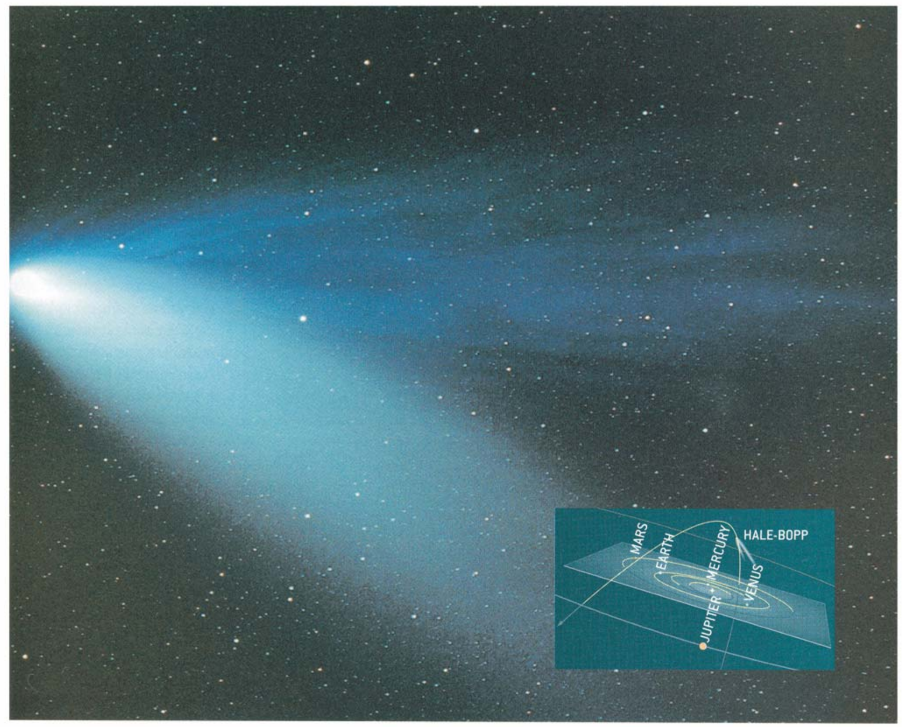
Contributions to Zodiacal Cloud?

The largest sources of dust in our solar system are from the activities of asteroids and comets.

Eros

Comet Hale-Bopp



Contributions to Zodiacal Cloud?

One difficulty: We keep finding more dust sources

Other Lesser Contributors

Interstellar dust (outer solar system).

Kuiper belt dust

Circumplanetary dust

Beta-meteoroids

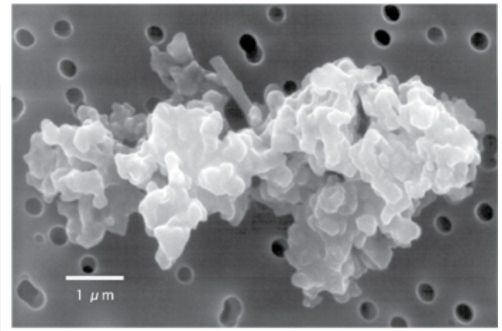
Jovian dust streams

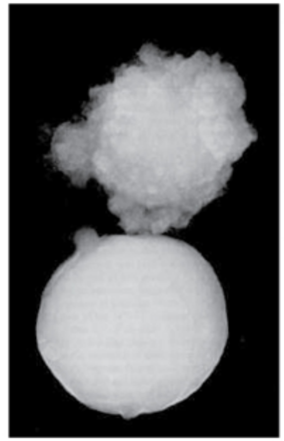
Saturn dust streams

Debris (man-made)

Examples of Dust (and Debris)

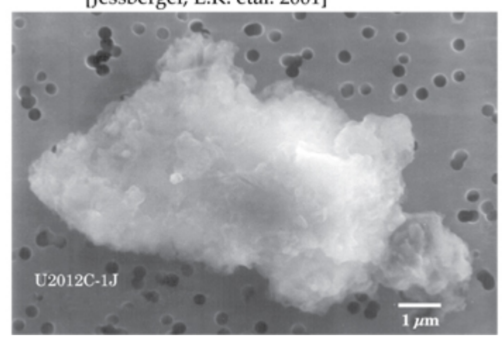
SEM image of a porous chondritic IDP. [Jessberger, E.K. etal. 2001]





Chondritic IDP rigidly attached to a smooth, aluminum-oxide sphere created by a solid-fuel rocket motor. Each particle measures 6 microns in diameter. [NASA JSC Photo S-84-41340 From Flynn, 1994]

SEM image of a smooth chondritic IDP. [Jessberger, E.K. etal. 2001]



Contribution to Zodiacal Cloud?

2) Needed Data Sets (for spatial distribution, number density, size, shape, structure, and material)

- Mission: In-situ Dust and Comet Flybys and Future Mission (Cosmic DUNE)
- Ground: Meteor surveys, Arctic/Antarctic Ice, and Stratospheric, photometry
- Laboratory: Dust (comet: Stardust), IDP Database (Houston), Polarization Studies (Levasseur-Regourd, Gustafson)

And Needed Models (for the temporal evolution and location in space):

- Empirical: Update of the Grün interplanetary complex (Dikarev), Kelsall
- Theoretical: Dynamical Evolution (Krivov, Landgraf, Liou, ...)
- Presently, the ESA Darwin mission is producing an open-source toolkit for exo-system modeling, where the zodiacal

3) How do scientists select the needed data?

In-situ: some from the Web
Heidelberg: Galileo, Cassini
ESA (Earth vicinity): GORID, Proba

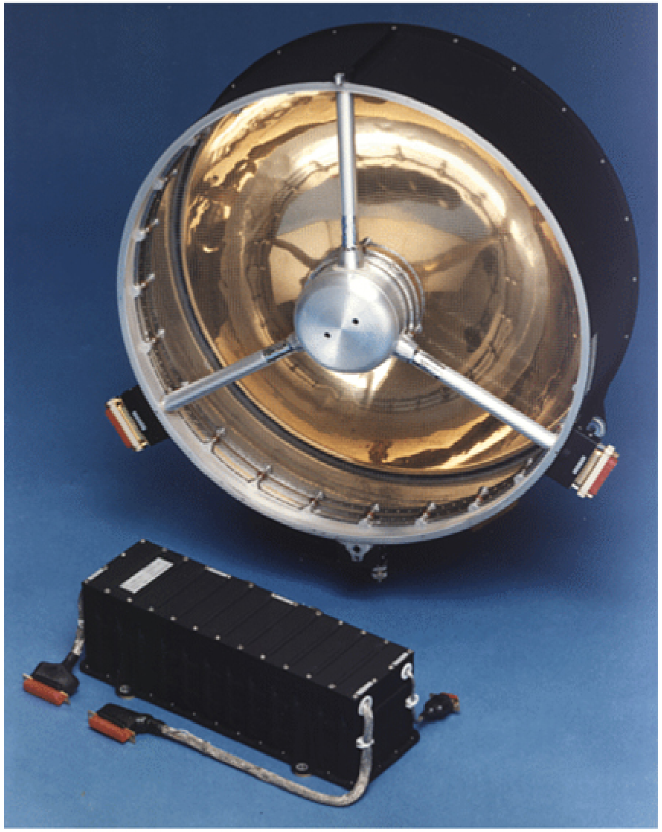
Meteor Surveys: from the Individual Scientists

Antarctic/Arctic Ice, Stratospheric: Houston

Laboratory data: from the Individual Scientists

Databases: In-situ Dust Data

Galileo Dust Detector System

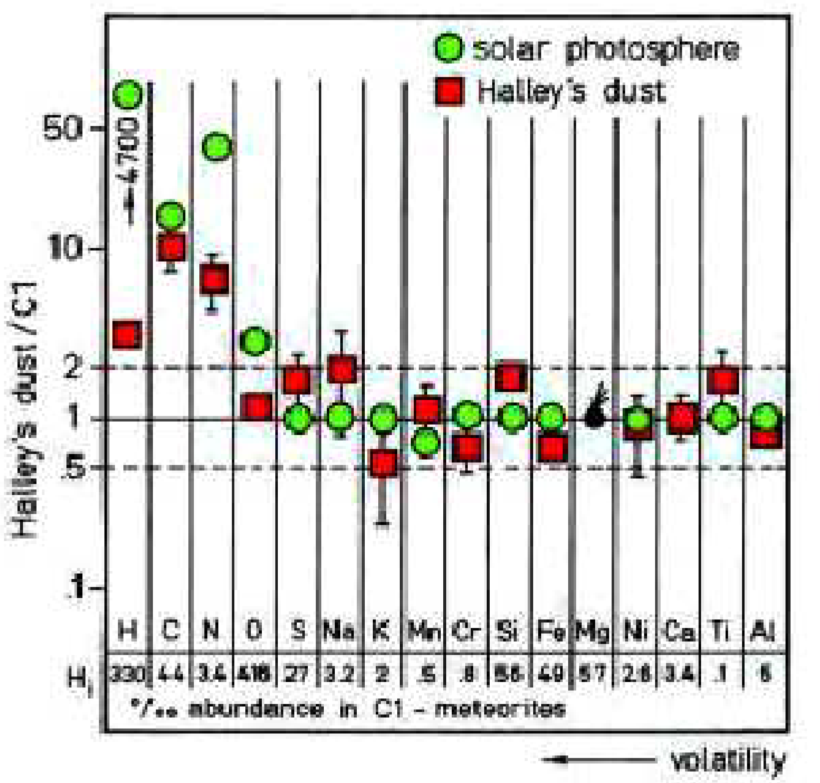


(r.i.p. 21.9.03)

Databases: Galileo (*), GORID (*), Pioneer 10/11 (*), HEOS-2 (?), Helios (?), Ulysses, Cassini, , Rosetta, ...

(*) Mission ended. Data archived.

Comet Halley Dust Elemental Abundance Compared to Solar



(Kissel, J. and Krueger, F.R. (1987). The organic component in dust from comet Halley as measured by the PUMA mass spectrometer onboard Vega 1. Nature 326, 755-760.)

Databases: Giotto, VeGa, Stardust, Deep Impact, ...

The average abundance of elements (with increasing refractivity from left to right in dust from comet Halley (squares) compared to element abundances in the solar photosphere (circles). All abundances are normalised to the elementary abundances of C1 chondrites. The error bars indicate the variability of the measured dust grains.

For Our Science Cases (cont.)

2. What is the dynamical and morphological structure of the Kuiper belt?

1. How can we best optimise from observations, numerical experiments, laboratory simulations, further analysis of past mission data the science return of Rosetta?

Rosetta: Europe's highest profile small bodies and dust space mission

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Rosetta Orbiter

1. How can we best optimise from observations, numerical experiments, laboratory simulations, further analysis of past mission data the science return of Rosetta?

OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System): A wide-angle camera and a narrow-angle camera to obtain high-resolution images of the comet's nucleus and asteroids.

ALICE (Ultraviolet Imaging Spectrometer): Analyses gases in the coma and tail and measures the comet's production rates of water and carbon monoxide/dioxide. Also provides information on the surface composition of the nucleus.

VIRTIS (Visible and Infrared Thermal Imaging Spectrometer): Maps and studies the nature of the solids and the temperature on the surface of the nucleus. Also identifies comet gases, characterises the physical conditions of the coma and helps to identify the best landing sites.

MIRO (Microwave Instrument for the Rosetta Orbiter): Used to determine the abundances of major gases, the surface outgassing rate and the nucleus subsurface temperature. It will also measure the subsurface temperatures of the asteroids that it approaches and will search for gas around them.

ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis): Two sensors will determine the composition of the comet's atmosphere and ionosphere, the velocities of electrified gas particles, and reactions in which they take part. It will also investigate possible asteroid outgassing.

COSIMA (Cometary Secondary Ion Mass Analyser): Will analyse the characteristics of dust grains emitted by the comet, including their composition and whether they are organic or inorganic.

MIDAS (Micro-Imaging Dust Analysis System): Studies the dust environment around the asteroids and comet. It provides information on particle population, size, volume and shape.

CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission): Probes the comet's interior by studying radio waves that are reflected and scattered by the nucleus.

GIADA (Grain Impact Analyser and Dust Accumulator): Measures the number, mass, momentum and velocity distribution of dust grains coming from the nucleus and from other directions (reflected by solar radiation pressure).

RPC (Rosetta Plasma Consortium): Five sensors measure the physical properties of the nucleus, examine the structure of the inner coma, monitor cometary activity and study the comet's interaction with the solar wind.

RSI (Radio Science Investigation): Shifts in the spacecraft's radio signals are used to measur the mass, density and gravity of the nucleus, define the comet's orbit and study the inner coma. Also used to study the solar corona during the periods when the spacecraft, as seen from Earth, is passing behind the Sun.

11 Orbiter Instruments

INAF

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Rosetta Lander

10 Lander Instruments

MUPUS (Multi-Purpose Sensors for Surface and Subsurface Science): Uses sensors on the lander's anchor, probe and exterior to measure the density, thermal and mechanical properties of the surface.

ROMAP (Rosetta Lander Magnetometer and Plasma Monitor): A magnetometer and plasma monitor to study the local magnetic field and the comet/solar wind interaction.

COSAC (Cometary Sampling and Composition experiment): One of two evolved gas analysers. It detects and identifies complex organic molecules from their elemental and molecular composition.

MODULUS PTOLEMY: Another evolved gas analyser which obtains accurate measurements of isotopic ratios of light elements.

SD2 (Sample and Distribution Device): Drills more than 20 centimetres into the surface, collects samples and delivers them to different ovens or for microscope inspection.

ROLIS (Rosetta Lander Imaging System): A CCD camera to obtain high-resolution images during descent and stereo-panoramic images of areas sampled by other instruments.

SESAME (Surface Electrical, Seismic and Acoustic Monitoring Experiments): Three instruments to measure properties of the comet's outer layers. The Cometary Acoustic Sounding Surface Experiment measures the way sound travels through the surface. The Permittivity Probe investigates its electrical characteristics and the Dust Impact Monitor measures dust falling back to the surface.

APXS (Alpha X-ray Spectrometer): Lowered to within 4 centimetres of the ground, it detects alpha particles and X-rays which provide information on the elemental composition of the comet's surface.

CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission): Probes the internal structure of the nucleus. Radio waves from the CONSERT experiment on the orbiter travel through the nucleus and are returned by atransponder on the lander.

ÇIVA: Six identical micro-cameras take panoramic pictures of the surface. A spectrometer studies the composition, texture and albedo (reflectivity) of samples collected from the surface.

Rosetta for ISSI

1. How can we best optimise from observations, numerical experiments, laboratory simulations, further analysis of past mission data the science return of Rosetta?

Rosetta represents an enormous investment of European resources.

The question to optimize is a “how” question, much better suited for an ISSI workshop.

The last full workshop on Rosetta science (not counting the Rosetta Science Meetings) was in 2003 in Capri, to discuss the new baseline/targets. Therefore, another workshop soon should be considered.

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Rosetta Science

1. How can we best optimise from observations, numerical experiments, laboratory simulations, further analysis of past mission data the science return of Rosetta?

ESA and European Southern Observator

Comet 67P/Churyumov-Gerasimenko

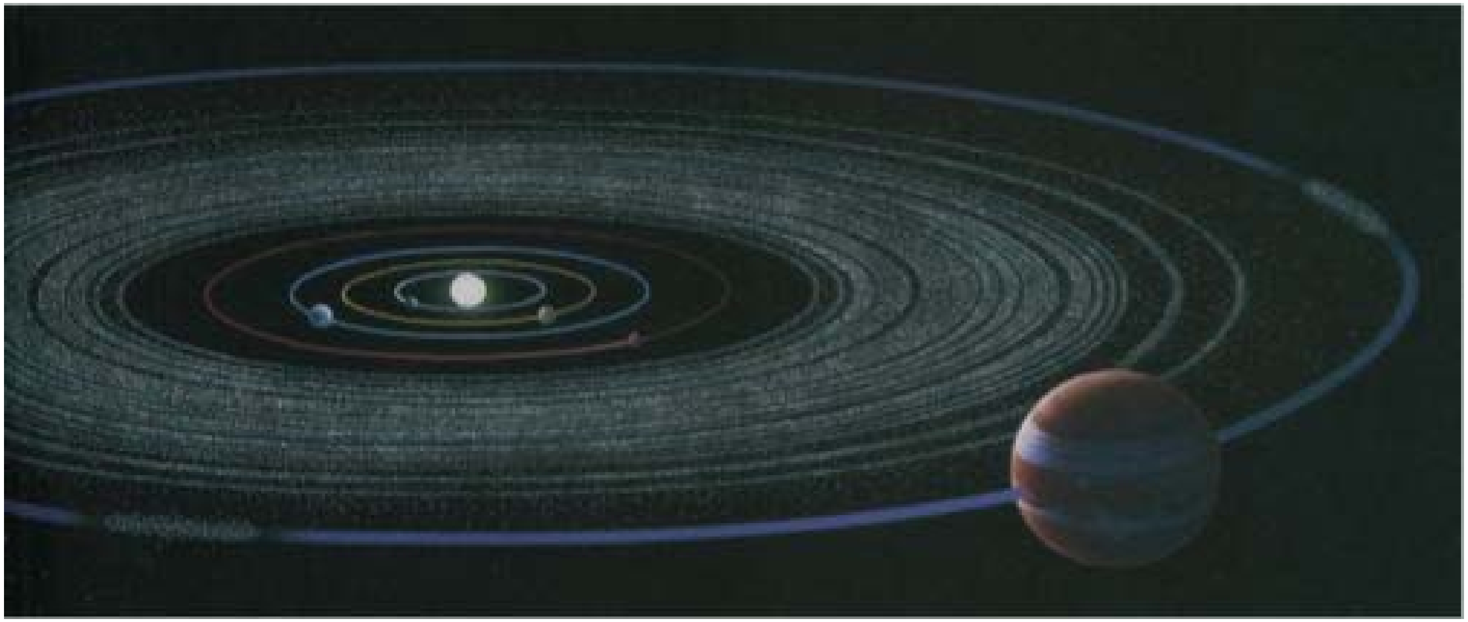
Diameter of nucleus – estimated (km)	4
Orbital period (years)	6.6
Minimum distance from Sun (million km)	186
Maximum distance from Sun (million km)	857
Orbital eccentricity	0.6
Orbital inclination (degrees)	7.1
Year of discovery	1969

Comet approach (January–May 2014)

Comet mapping/characterisation (August-October 2014)

Landing on the comet (November 2014)

Escorting the comet around the Sun (November 2014 – December 2015



Asteroid fly-bys.

On the outward leg of its ten-year trek to Comet 67P/Churyumov-Gerasimenko, Rosetta will make two excursions into the main asteroid belt. The two asteroid targets are: 21 Lutetia and 2867 Steins.

21 Lutetia belongs to the newly discovered sub-class of hydrated M-asteroids (see reflectance spectra).

21 Lutetia is supposed to be a parent body of iron meteorites, but IR spectrum shows similarity with carbonaceous chondrites (CV). At some rotational phases in the reflectance spectra, high-temperature silicates can be seen, indicative of a hydrated or oxidized state (uneven layer?)

Rosetta Science (including...)

Monitoring Comet 67P/churyumov-Gerasimenko
astrometric position
activity as a function of heliocentric distance
short-term variability
long-term variability (perihelion+aphelion)
rotational properties of the nucleus
coma morphology and colour
production rates coma gas species (CN, C2, C3, NH2, CO, HCN)
production rates of dust coma
dust-to-gas mass ratio
dust flux

Monitoring Asteroids 21 Lutetia and 2867 Steins
Composition / diameter/ rotation

Observatories
ESO (European Southern Observatory)
IRAM (Institut de radioastronomie millimetrique) (gas)
MPI-Radioastronomie bolometer array (dust)
Galileo Telescope (TNG)
1.8m Asiago Telescope
SOHO/SWAN

Databases
osculating orbital elements (JPL)
species line profiles
old observations of comet 67P (e.g. IUE, Nancay)
old observations of asteroids (e.g. IRAS)

standard stars (reference spectra)
extinction coefficients

Models
Radiative transfer --> line intensities --> gas production rate
Gas dynamical 3D model (Crifo et al, 2004)
Dust velocities --particles in gas flow (Weiler et al 2003)
--> dust mass production rate
coma model --> water production rate

Laboratory
IR emission lines from molecules
laboratory-condensed dust analogues
--> Table of Physical Properties of dusts (Rietmeijer)

Extra Slides

Tasks for the First Meeting of the EUROPLANET Small bodies and Dust Working Group

2) define science cases. We defined these:

1. How can we best optimise from observations, numerical experiments, laboratory simulations, further analysis of past mission data the science return of Rosetta? (Networking within EUROPLANET)

2. Which specific parameters of major interest to understand the history of the solar system should be addressed through a detailed space mission to a Near Earth object, and which instruments are required? (Networking within EUROPLANET)

3. What are the relative contributions of asteroidal dust, cometary dust, meteor streams, interstellar dust and circumplanetary dust to the structure of the zodiacal dust cloud as a function of heliocentric distance, latitude (and time)? (Ongoing activity, networking within EUROPLANET)

4. How representative are the comets that were intensively studied or that will be intensively studied, of the whole population of comets in space and time (i.e. everywhere in the solar system, now and in the past)? (Ongoing activity, networking within EUROPLANET)

5. How to better understand the physical processes taking place in dusty rings? How to extend the current physics of dusty rings of giant planets to the hypothetical martian dust rings? (Ongoing activity, networking within EUROPLANET)

Tasks for the First Meeting of the EUROPLANET Small bodies and Dust Working Group
2) define science cases continued.

6. What are the connections between TNOs, centaurs, trojans, comets and icy satellites and what is the dynamical and morphological structure of the Kuiper belt?

7. What are the physical/chemical processes leading to distant activity, outbursts, splitting and disruption of cometary nuclei?

8. To which extent have the interstellar grains preserved their pristine properties and to which extent have they been processed in the cometary nucleus?

9. What are the values and ranges of key properties of a significant number of small bodies to constrain the formation environment and evolution of these bodies, e.g. density, bulk composition, mineral composition, isotopic, elemental, molecular composition, chemical and physical properties, dynamical evolution, etc.?

Ordering Science Cases

Targets/ Cases	1 Rosetta	2 NEO mission	3 Zody cloud	4 comets	5 dusty rings	6 connexns	7 comet phenom	8 IS in comets	9 form environ	SUM
Small Moons			X		X	X			X	4
KBO/TNO	X		X	X		X	X		X	5
Comets	X		X	X		X	X	X	X	7
Asteroids	X		X			X			X	4
NEOs		X				X			X	3
Rings	X				X					2
Dust	X		X		X	X	X	X		6
Sum	5	1	5	2	3	6	3	2	5	

Ordering Science Cases

Method	1 Rosetta	2 NEO mission	3 Zody cloud	4 comets	5 dusty rings	6 connexns	7 comet phenom	8 IS in comets	9 form environ	SUM
Ground-based	X		X	X	X	X	X		X	7
Space-based	X		X	X	X	X	X		X	7
In-situ	X	X	X	X	X		X	X	X	8
Database	X	X	X	X	X	X	X		X	8
Modeling	X	X	X		X	X	X	X		7
Lab	X		X		X	X		X	X	6
Sum	6	3	6	4	6	5	6	3	5	

Expertise in Building Instruments in Europe (for small bodies and dust)

SOME INSTITUTES WITH EXPERTISE IN BUILDING INSTRUMENTS WHICH ARE OF INTEREST FOR SMALL BODIES AND DUST IN EUROPE:

Near-UV, Visible, NIR imagers: Lindau; Marseilles; Orsay (IAS); DLR/Berlin
UV spectrometers: Aeronomie/France(IPSL-UPMC)
Visible spectrometry: IASF/Rome; IFSI/Rome; Observatoire de Paris-Meudon
Microwave spectrometry: Observatoire de Paris-Meudon
Dust spectrometry: Lindau
Gas spectrometry: CETP/France(IPSL); Lindau
Radar type instruments: Aeronomie/France(IPSL-UPMC); Grenoble; Lindau; Rome
Atomic force microscopy: Graz/Austria; ESTEC
Dust impact instruments: Univ. Naples; Capodimonte Obs. Naples; Heidelberg; TU Muenchen; Open Univ./UK
Plasma instruments: LPCE/Orléans
Gas chromatography: Open Univ./UK; Aeronomie/France(IPSL-UPMC); LISA/France; Lindau
Magnetometer: IC/London; Braunschweig; Orléans
Energetic particle instruments: Toulouse; Mainz; IRF/Kiruna; IFSI/Rome; CETP/France(IPSL); Lindau
Radio science: DLR/Germany; Univ. Rome

Laboratory Experiments Expertise in Europe (for small bodies and dust)

SOME INSTITUTES WITH LABORATORY EQUIPMENT:

Capodimonte Obs. Naples/Univ. of Parthenope: dust production, processing and analysis

MPIK Heidelberg, Open Univ./UK; Univ. of Kent/UK; TU Munich: Dust impact simulation

TU Braunschweig; TU Munich; Univ. Jena: Dust coagulation experiments

Aeronomie/France(IPSL-UPMC), LPCE/Orléans: light scattering exp. for dust and regoliths; dusty plasma exp.

MPE Garching: dusty plasma exp.

Leiden: interstellar dust analogues