Dust Astronomy

Eberhard Grün
Mihaly Horanyi, Sascha Kempf, Frank Postberg, Ralf Srama, and Zoltan Sternovsky

Laboratory for Atmospheric and Space Physics, Boulde, USA
Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany
Dust Astronomy

Dust particles, like photons, are born at remote sites in space and time. From knowledge of the dust particles' birthplace and their bulk properties, we can learn about the remote environment out of which the particles were formed.
Outline

I. Motivation: Where does dust come from?
II. What do we know about planetary, interplanetary, interstellar dust
III. New Venues for Dust Research

HST: Reflection Nebula in the Pleiades
Stardust sources are low-mass carbon-rich AGB stars, Wolf-Rayet stars, novae, supernovae

Retina Nebula
HST-WFPC2
What is Known About Galactic Dust?

- Extinction and reddening of star light
- Composition: silicates, PAHs, graphite
- Grains grow in molecular clouds and are destroyed in the diffuse medium by supernova shocks
- ISD is recycled in the galactic evolutionary process
Protoplanetary Nebula

- Material is homogenised by evaporation and re-condensation
- Dust agglomerates in proto-planetary disk
- Planets, asteroids, and comets are formed from dust

W. Hartmann
What is known from meteorites?

- Some of the meteorites come from differentiated objects (asteroids, Mars, and the Moon)
- Undifferentiated meteorites (chondrites) maintain the "cosmic" elemental abundance
- Meteoritic material is homogenised in the protoplanetary nebula and lost its interstellar identity
- Presolar grains - identified by their isotopic signature - constitute a minor fraction (~ $10^{-5}$) of all meteoritic material.
Peekskill Fireball October 9th, 1992
Meteorites With Known Orbits

Peekskill

Neuschwanstein

Diagram showing orbits of various meteorites.
Comet Hale-Bopp

Zodiacal Cloud

M. Fulle
Dust Collection in the Stratosphere

[Image of an aircraft with inset image of dust particles]
Dust Analysis

Elements
Isotopes
Minerals
Leonid Meteors
from Comet P/Tempel-Tuttle
Examples of Dust Parent Body Connection

By going to the parent body:
• Giotto, VEGA: Halley
• Stardust: Wild 2
• Cassini: Enceladus geysers
Halley Dust Composition Measurements

- Abundance of light elements CHON
- Silicate minerals, FeS, metals
- Organic molecules
- Isotopic anomalies: $^{12}$C/$^{13}$C up to 5000
- $v \sim 70$ km/s
Stardust Dust Collector
Large crystalline CAI particles that formed at temperatures $> 1300^\circ C$ close to the Sun prove that large scale mixing occurred in the protoplanetary disk.
Cassini CDA Spectrum of Ice Grains from Enceladus

- Pronounced signatures of sodium and potassium salts in a water matrix.
- NaCl and NaHCO3 could be identified
- Important implications for subsurface water reservoir

(Postberg et al., 2009)
Sodium salts in E-ring ice grains from an ocean below the surface of Enceladus

Postberg et al., Nature, 2009

http://photojournal.jpl.nasa.gov/catalog/PIA08500
New Capabilities

Using any dust that comes to our instrument:

- Dust charge measurements of sub-micron-sized grains
- Accurate trajectory determination
- High resolution chemical analysis with a Large Area Mass Analyzer
- Dust Telescope
- Active Dust Collectors
- Electrostatic Dust Analyzers
Cosmic Dust Analyzer on Cassini

10 kB data from a single dust impact
Dust Charge Detection by CDA

- Dust charged by solar UV & ambient plasma
- $Q_{dust} \sim R_{dust} \cdot \Phi$
- Potential $\Phi$ is size-independent $\rightarrow$ get mass
- First in-situ measurement of dust charge

Kempf et al., 2004
Dust Telescope

Trajectory-Sensor
(accuracy 1% speed, 1 deg directions)

Compositional Analyzer
(mass resolution 200)

~ 1MB data from a single dust impact
<table>
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<tr>
<th>Mission</th>
<th>Instrument</th>
<th>Sensitive area (cm²)</th>
<th>Mass resolution</th>
<th>Object</th>
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<tr>
<td>Giotto</td>
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<td>&gt;100</td>
<td>Comet Halley 1986</td>
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<tr>
<td>VeGa</td>
<td>PIUMA</td>
<td>10</td>
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<td>Stardust</td>
<td>CIDA</td>
<td>90</td>
<td>~200</td>
<td>Comet Wild2 2004</td>
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<tr>
<td>Cassini</td>
<td>CDA</td>
<td>160</td>
<td>~30</td>
<td>E Ring, Jupiter dust streams, Enceladus dust 2002-present</td>
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<tr>
<td>Dust Telescope</td>
<td></td>
<td>1000</td>
<td>~200</td>
<td>Interplanetary dust, Interstellar dust, Dust rings, Dust around large satellites</td>
</tr>
</tbody>
</table>
Interplanetary and Interstellar Dust

- Distinguish and analyze interplanetary from interstellar dust
- Distinguish and analyze asteroidal from cometary dust
- Characterize beta-meteoroids and nano-dust
In-situ Identification of Interstellar Grains in the Planetary System

- Ulysses observed a retrograde flow of dust at 5 AU from the sun
- Flow direction coincided with interstellar gas flow
- Flux was independent of heliocentric latitude
- Grains had hyperbolic speeds ($\leq 26$ km/s)
- Grains of 0.2 to 3 $\mu$m have been identified
- Flux displays time variations
- Galileo, Cassini, and Helios identified interstellar dust grains between 0.3 and 5 AU
Orbital Evolution of Cometary Particles

T = 2.96
U = 0.2 U_J

Dikarev, 2005
Nano-Dust
Observed by Stereo WAVES

Signals are interpreted as charge bursts generated by impacts of intense streams of nano-dust onto the spacecraft skin (Meyer-Vernet et al., 2009).
Compositional Analysis of Satellite Surfaces

- From an orbiter spacecraft obtain compositional maps of surfaces of large airless planetary bodies: Mercury Moon, Io, Europa, Ganymede, Callisto, Triton
Galileo Flyby of Ganymede
Dust Clouds around Galilean Satellites and the Moon

- Io, Europa, Ganymede, and Callisto are surrounded by impact-generated dust clouds
- Dust spatial density increases towards satellite
- 100 to 1000 kg/s ejected from surface
- $10^3$ to $10^5$ kg contained in dust cloud
- Projectiles: interplanetary meteoroids
- Other airless bodies should have similar or more dense ejecta clouds

Krüger et al., 2003; Krivov et al., 2003
Ejecta particles lifted by meteoroid impacts from the satellites' surface

- Individual Dust trajectories determined by a dust sensor

- The composition of the same grain is analyzed by a high-resolution dust mass spectrometer.

- Compositional maps of the surface are generated.
Dust Ring Sources

• Characterize source bodies of dust rings
Mars Hypothetical Dust Ring

Optical depth $\tau \sim 5 \times 10^{-8}$

Krivov et al., 2006
Levitated Lunar Dust

• Analyze slow moving dust
Lunar Horizon Glow
Apollo 17 LEAM

Surveyor 7: 1968-023T06:21:37

LEAM Film Grid Events per 3-Hour Interval for 22 Lunations

Berg et al., 1976
Conclusions

Dust Exploration is needed!

- Measure trajectories and composition of individual sub-micron sized particles in interplanetary space and in planetary environments
- Interstellar dust is accessible to in-situ analysis and sample return at 1 AU
- Characterize nano-dust
- Map satellite surface composition
- Analyze slow-moving dust on the moon and other airless bodies
The End