Dust Astronomy

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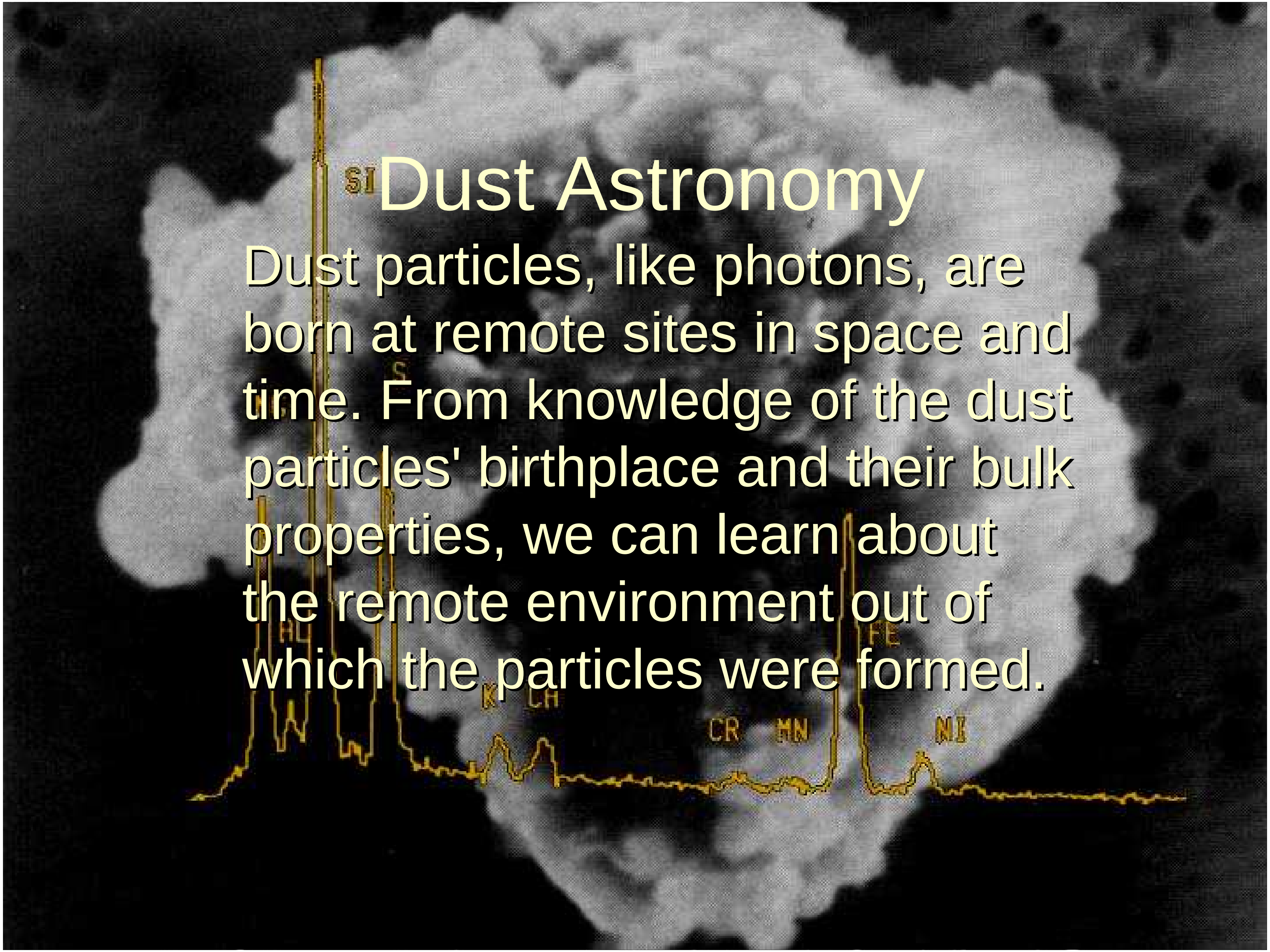
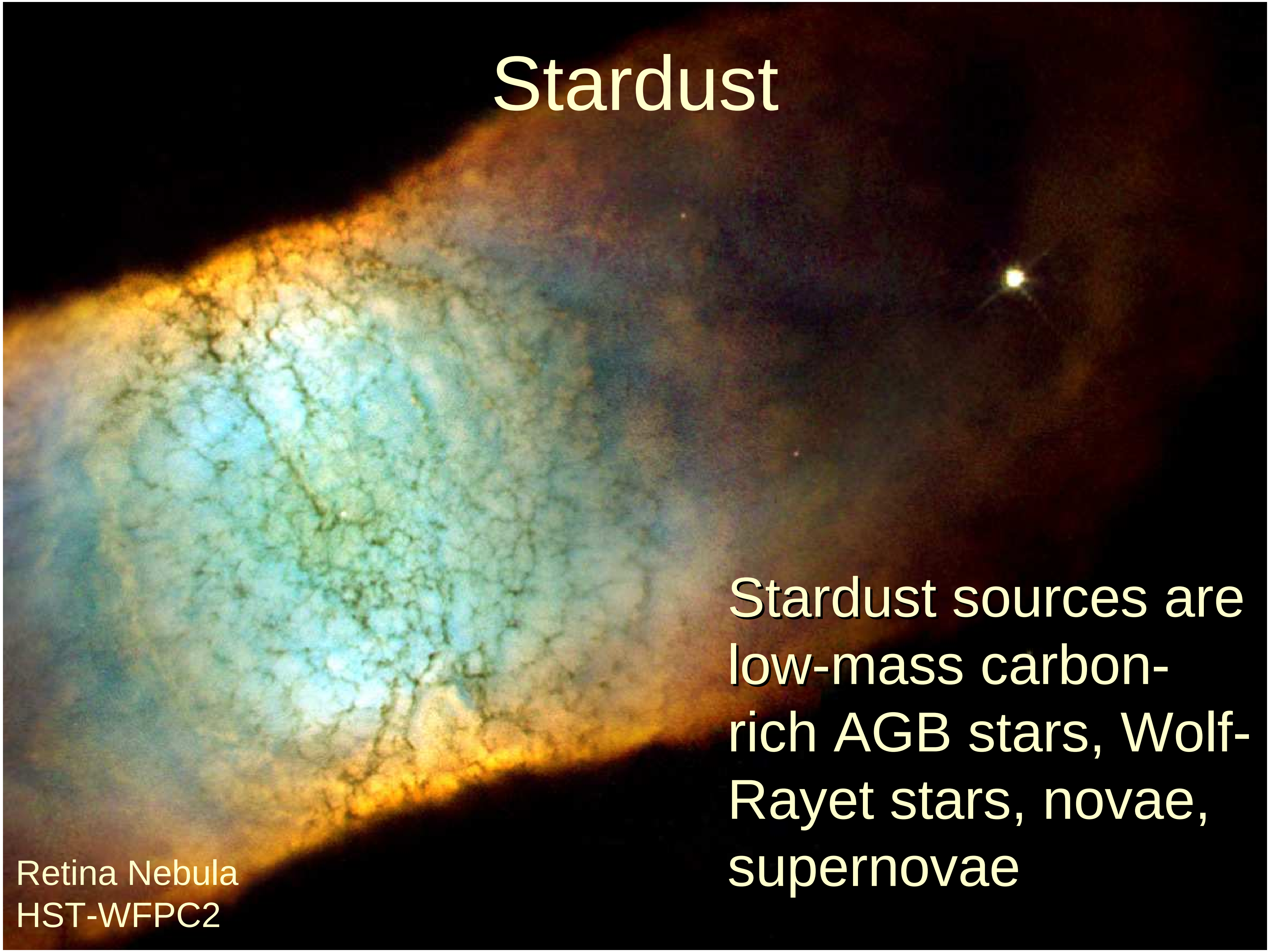
Dust Astronomy

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.



HST: Reflection Nebula in the Pleiades

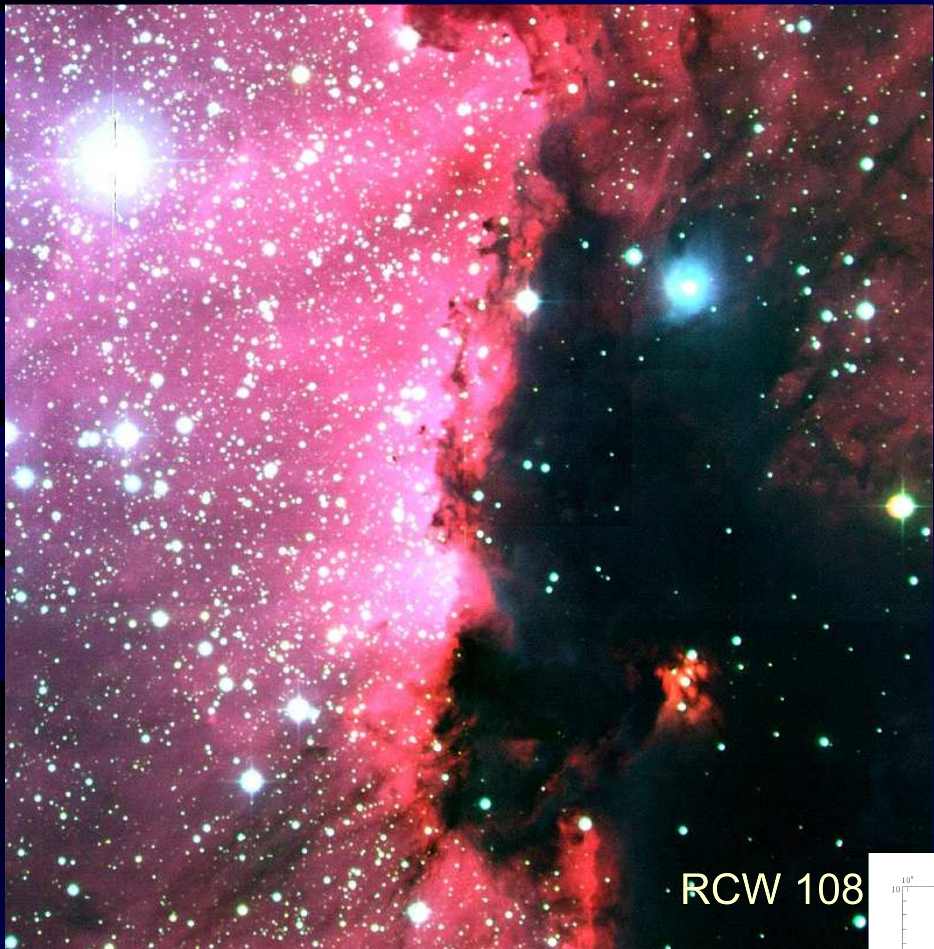
Stardust



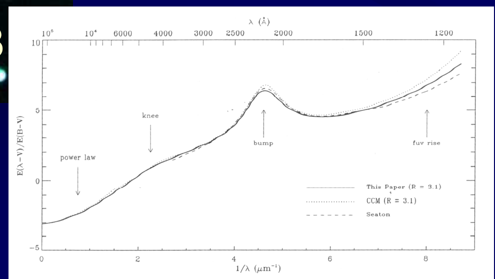
Retina Nebula
HST-WFPC2

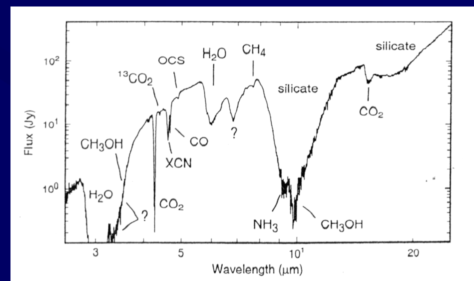
Stardust sources are low-mass carbon-rich AGB stars, Wolf-Rayet stars, novae, supernovae

What is Known About Galactic Dust?


RCW 108

- 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





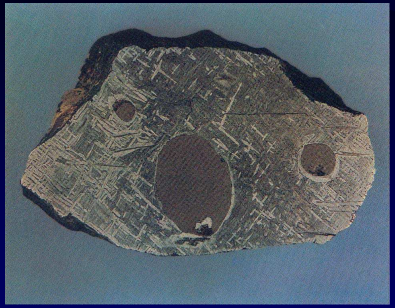
Protoplanetary Nebula

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

W. Hartmann

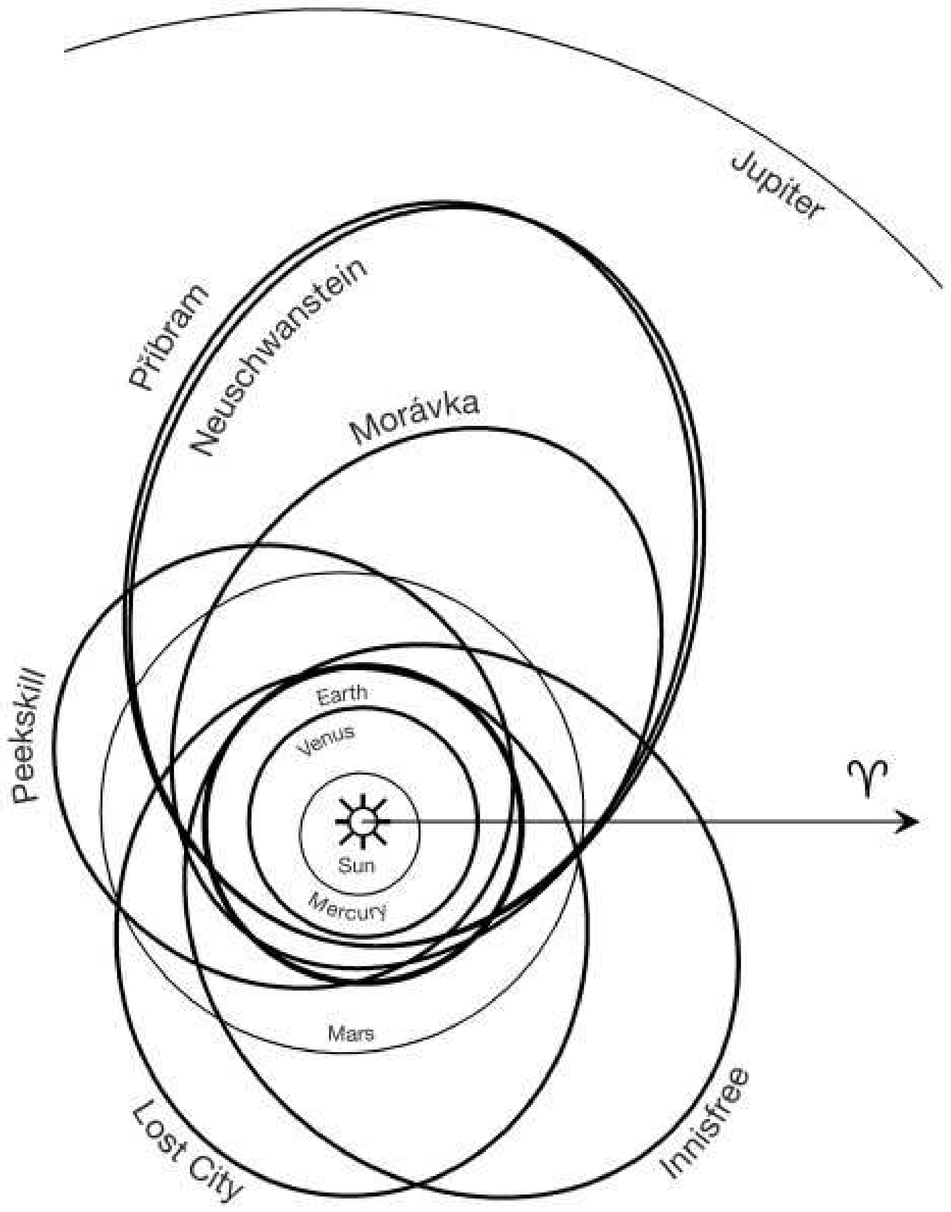
What is known from meteorites?

- 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

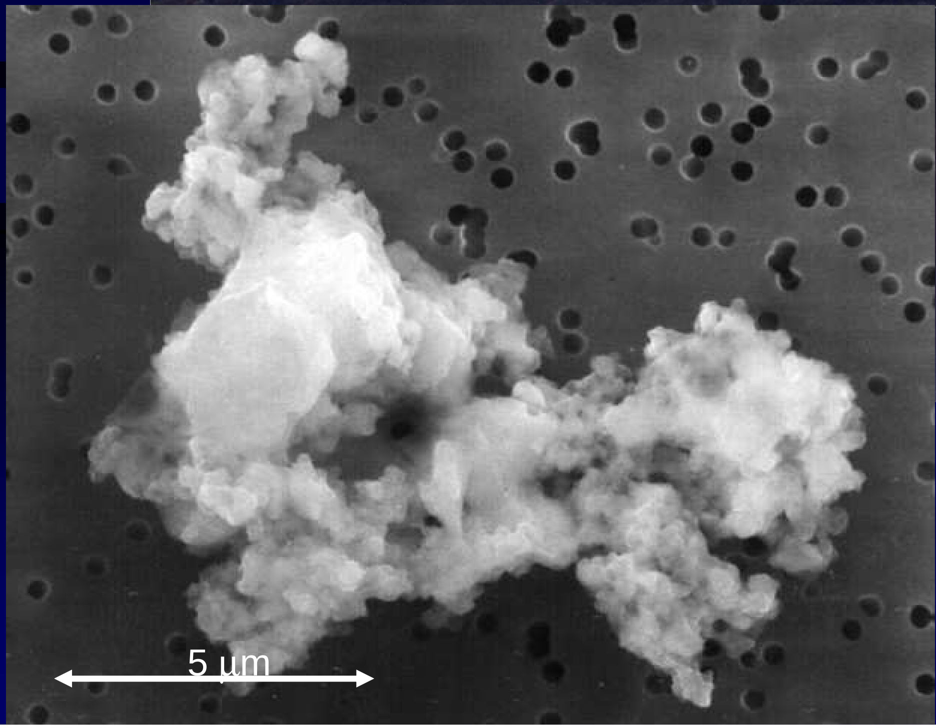
Meteorites With Known Orbits



Comet Hale-Bopp

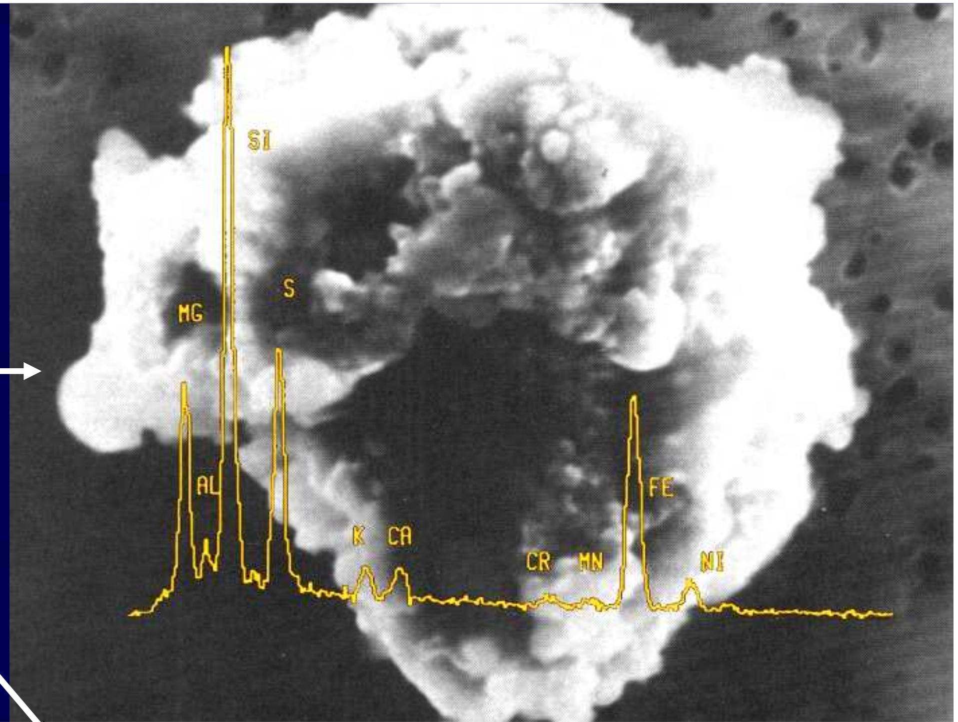
Zodiacal Cloud

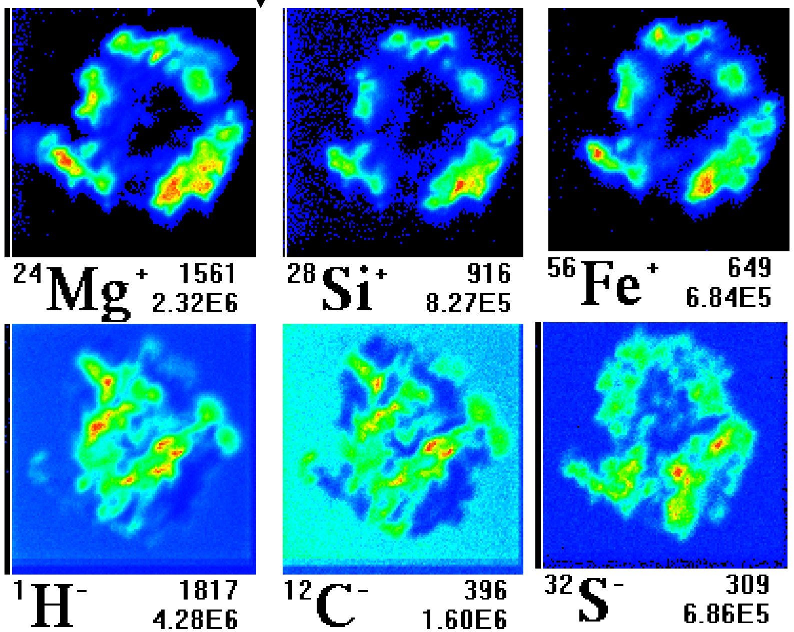
Dust Collection in the Stratosphere

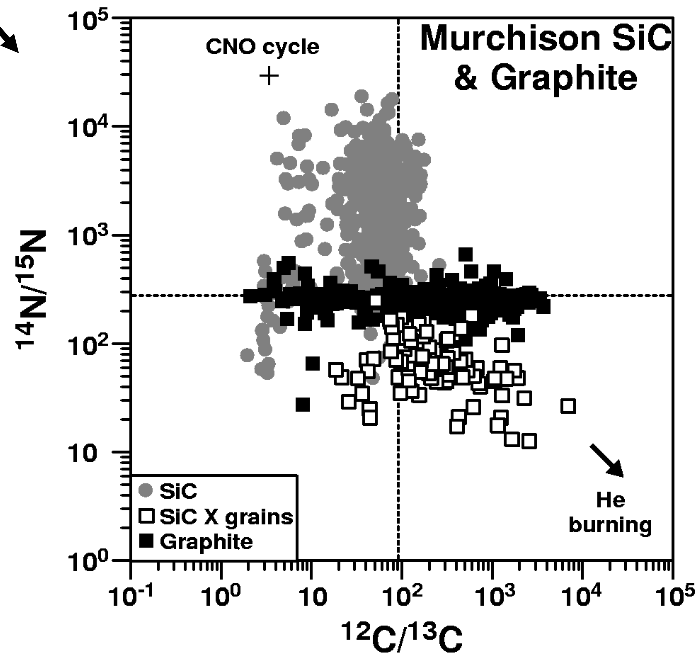


Dust Analysis

- Elements
- Isotopes
- Minerals







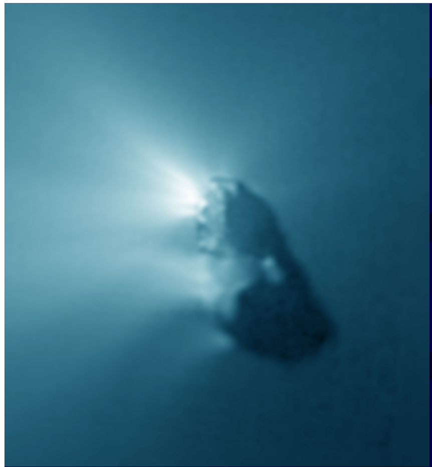
Leonid Meteors

from Comet P/Tempel-Tuttle

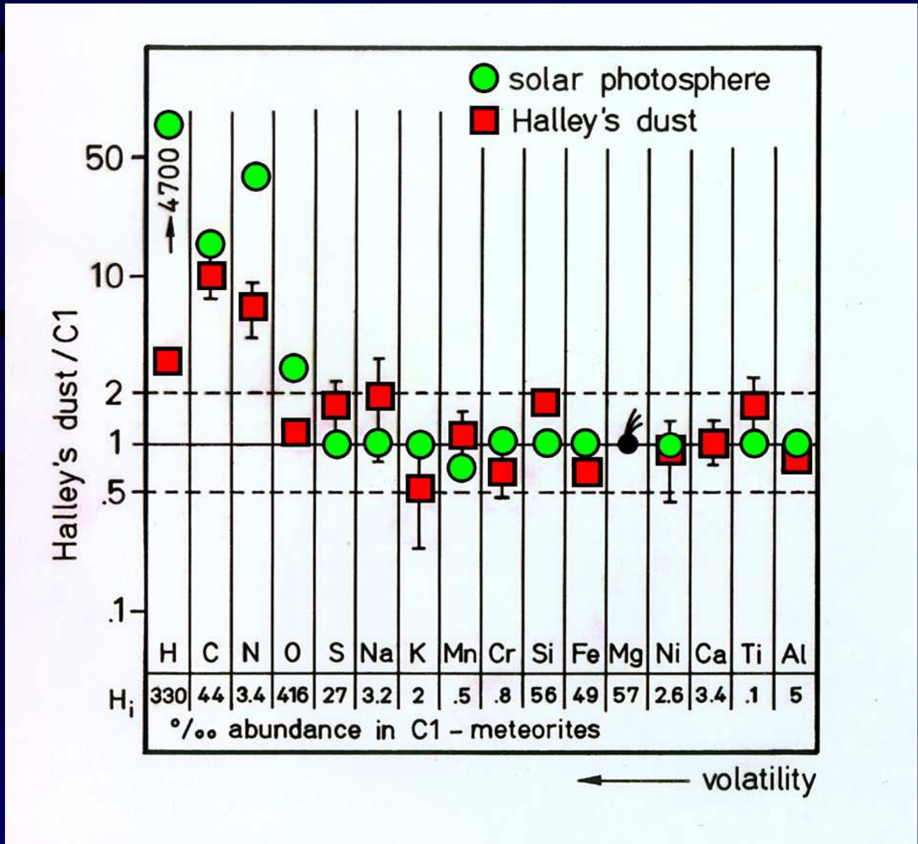
Examples of Dust Parent Body Connection

By going to the parent body:

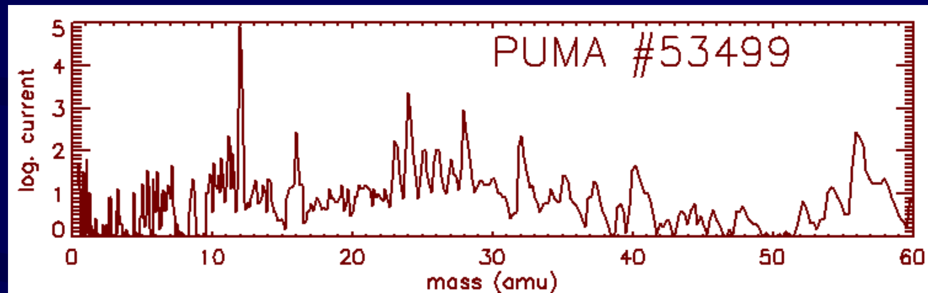
- Giotto, VEGA: Halley
- Stardust: Wild 2
- Cassini: Enceladus geysers



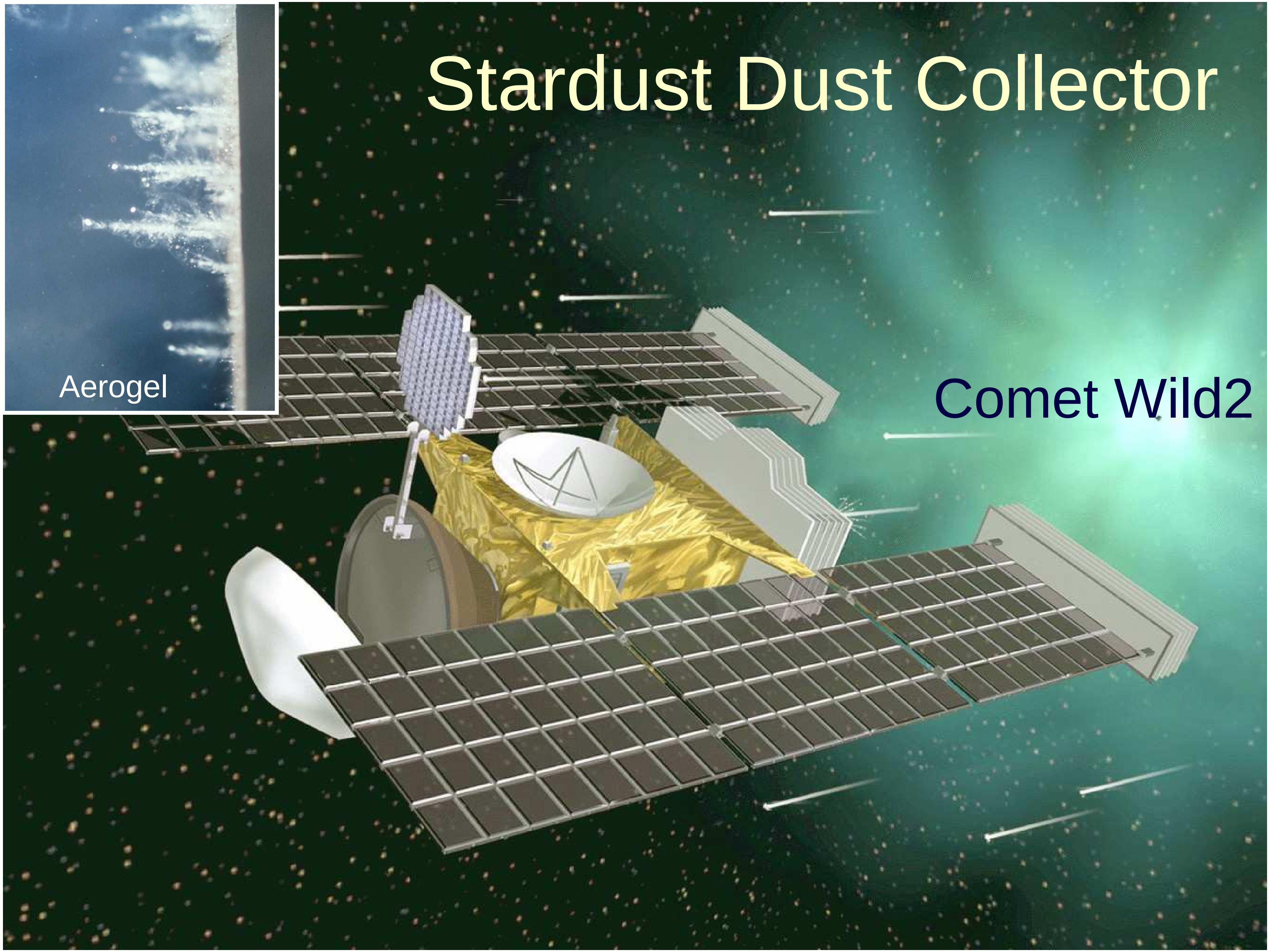
Halley Dust Composition Measurements



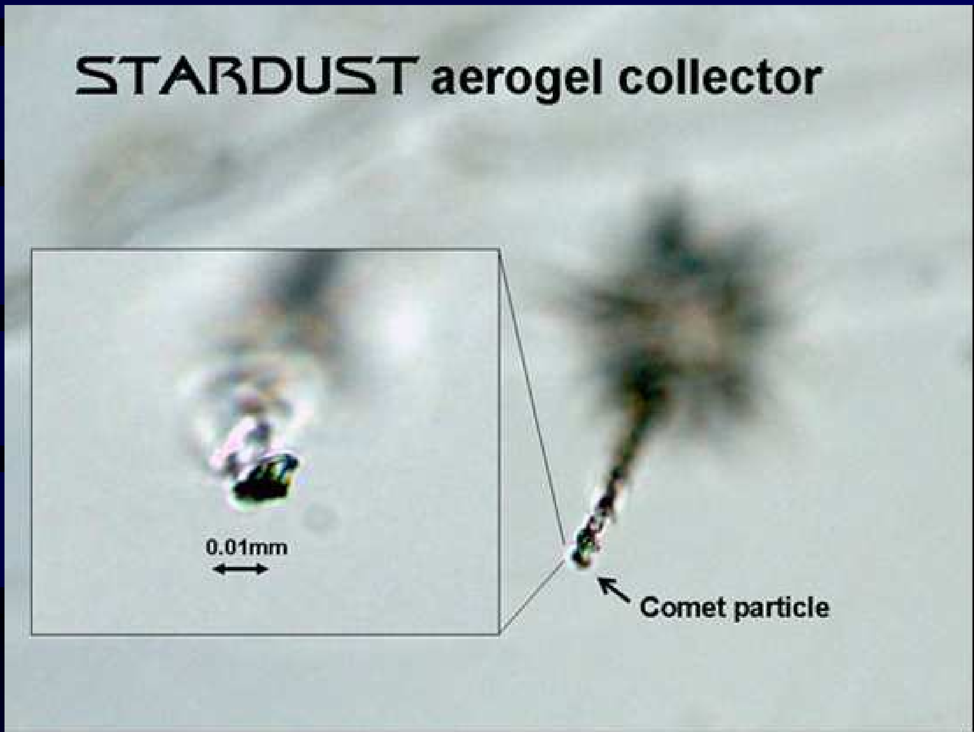
Jessberger and Kissel, 1988

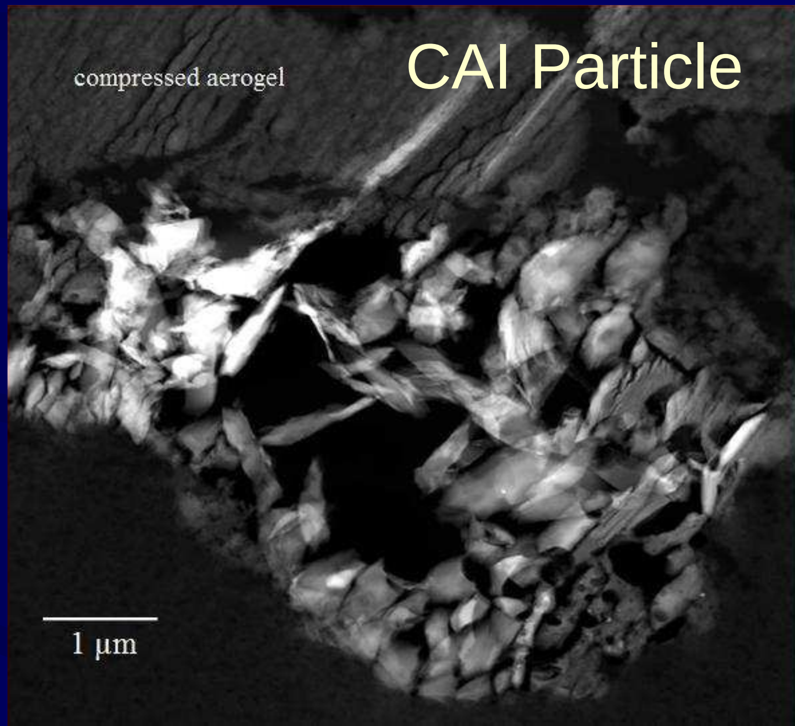


- Abundance of light elements CHON
- Silicate minerals, FeS, metals
- Organic molecules
- Isotopic anomalies: $^{12}C/^{13}C$ up to 5000
- v ~ 70 km/s

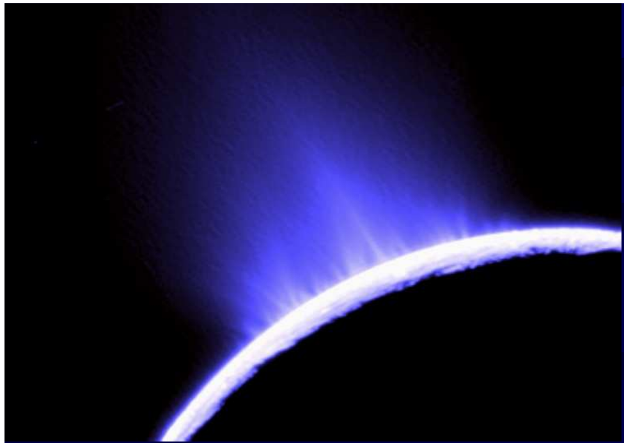

Stardust Dust Collector
Aerogel
Comet Wild2

Comet Wild 2 Particles

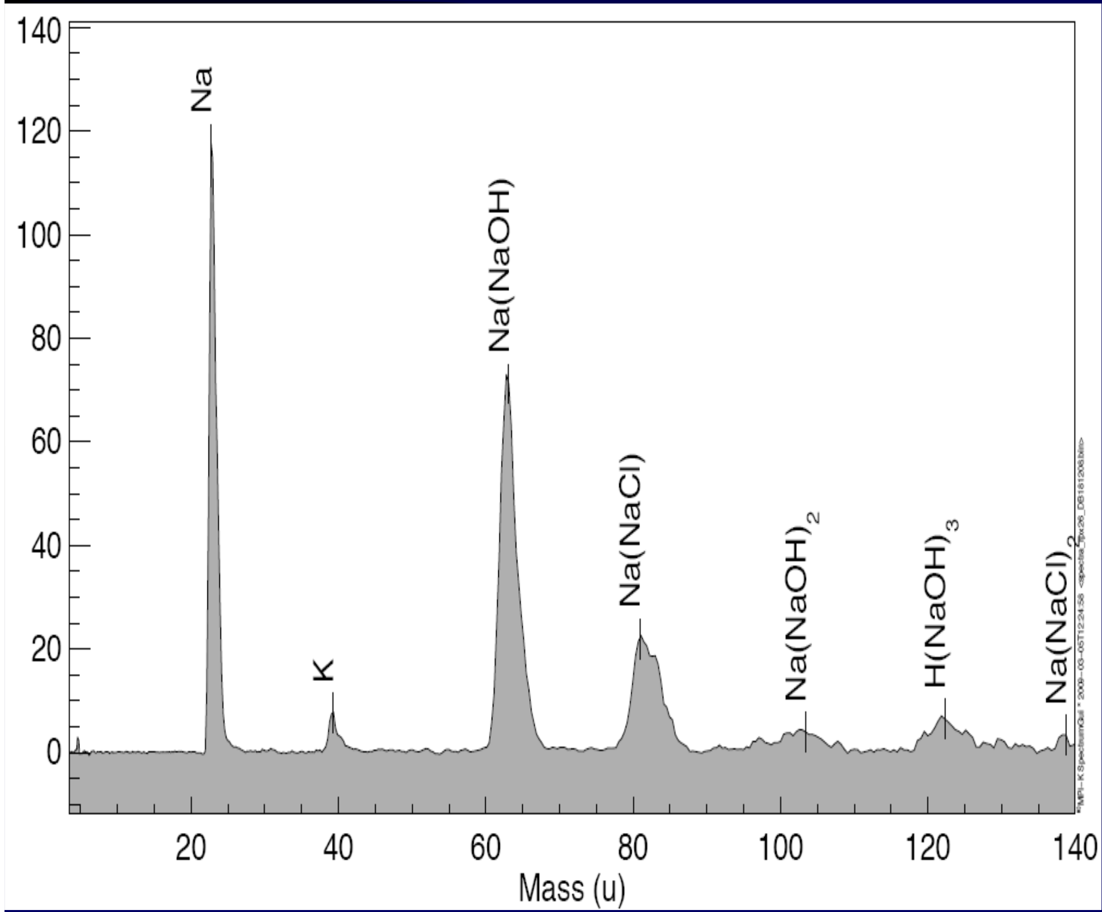




Large crystalline CAI particles that formed at temperatures > 1300º C close to the Sun proof that large scale mixing occurred in the protoplanetary disk.



Cassini CDA Spectrum of Ice Grains from Enceladus

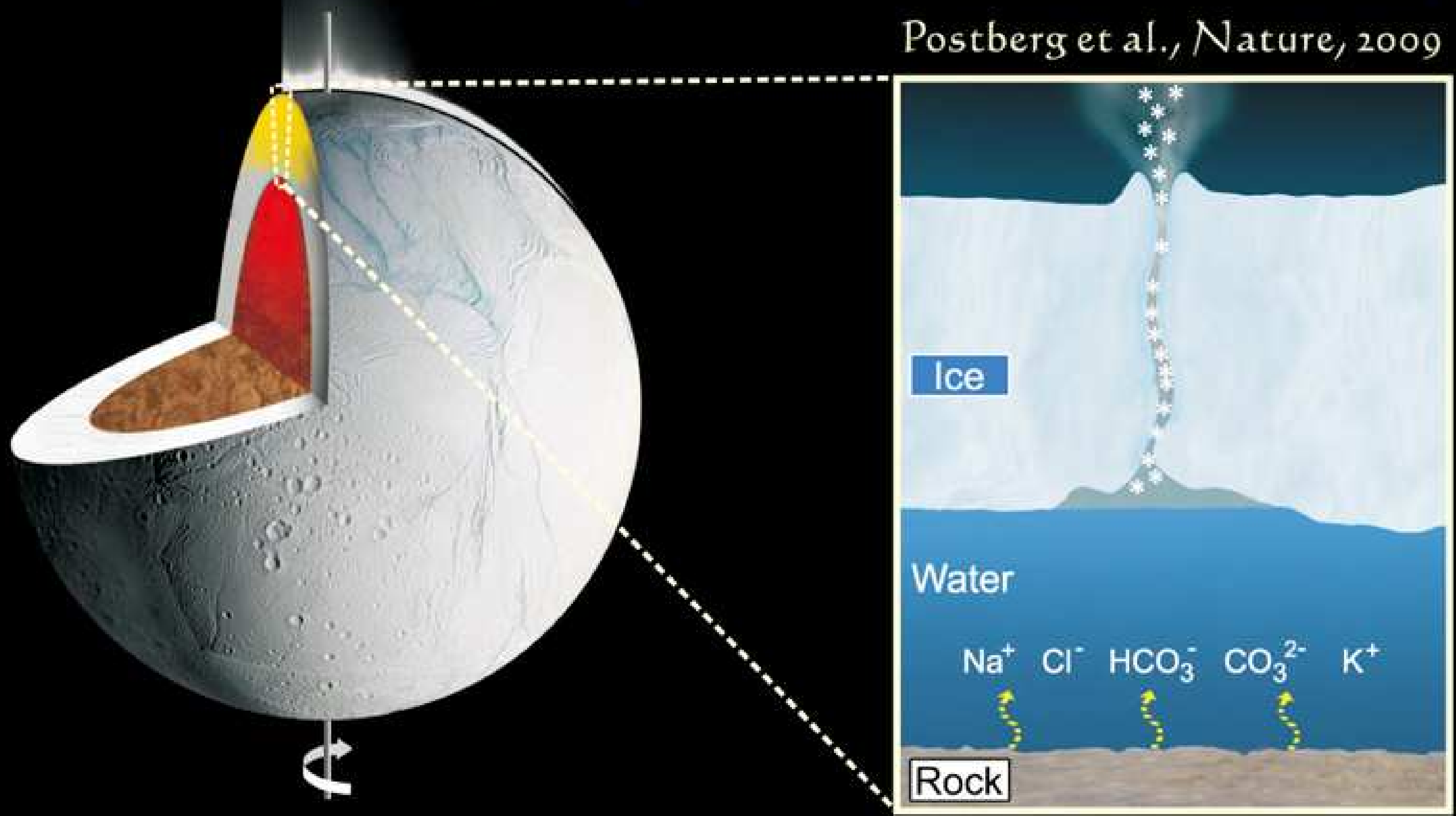


- Pronounced signatures of sodium and potassium salts in a water matrix.
- NaCl and NaHCO3 could be identified
- Important implications for subsurface water reservoir

(Postberg et al., 2009)

Sodium salts in E-ring ice grains from an ocean below the surface of Enceladus

Postberg et al., Nature, 2009



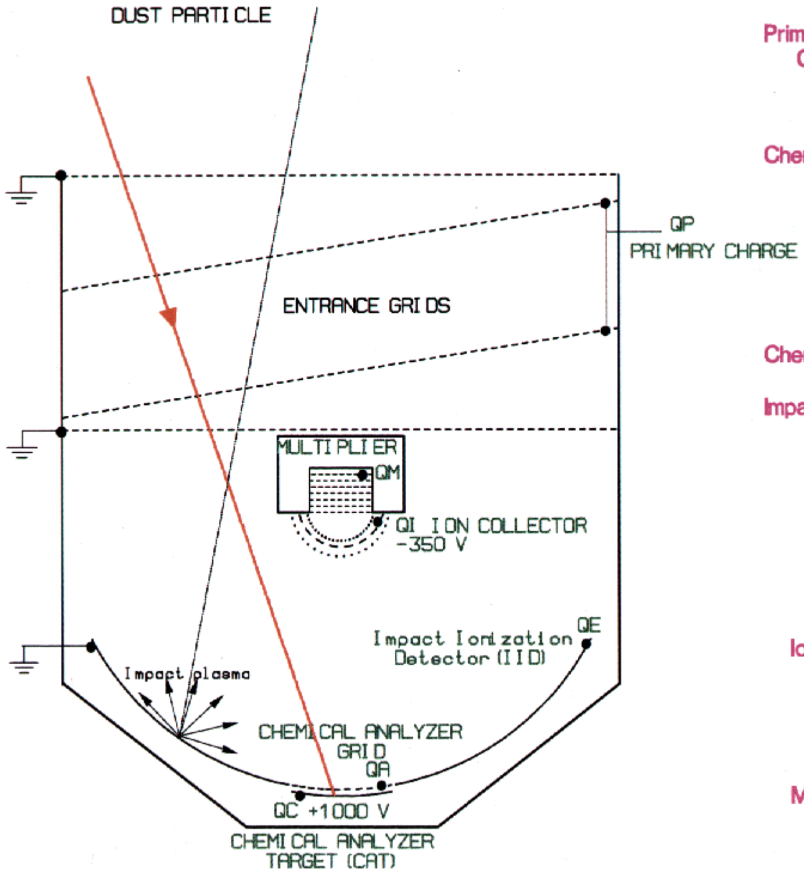
http://photojournal.jpl.nasa.gov/catalog/PIA08500

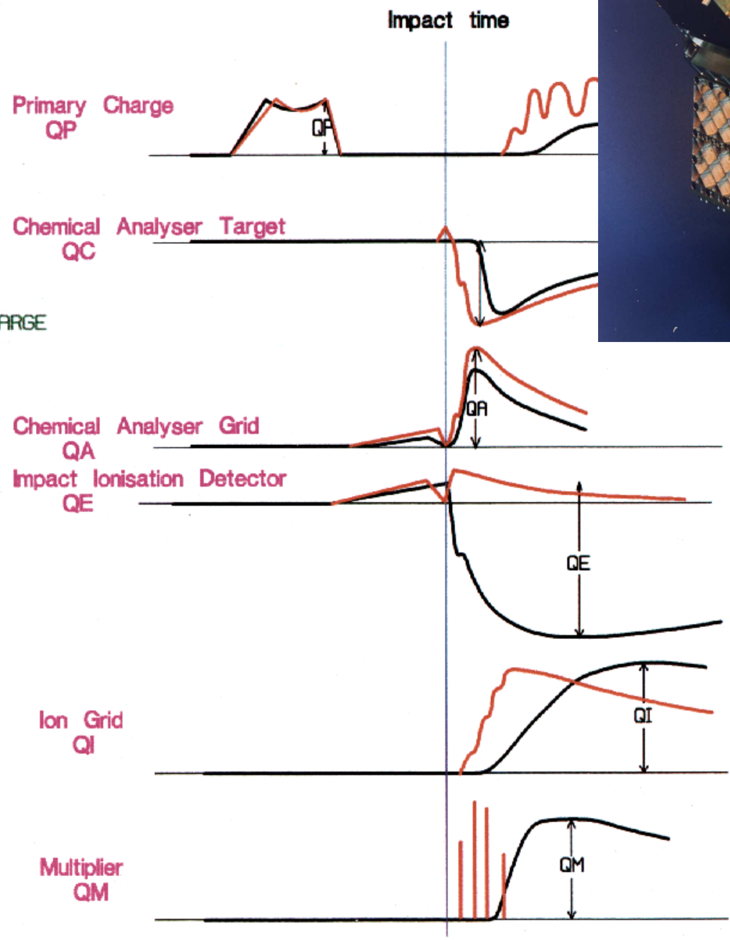
New Capabilities

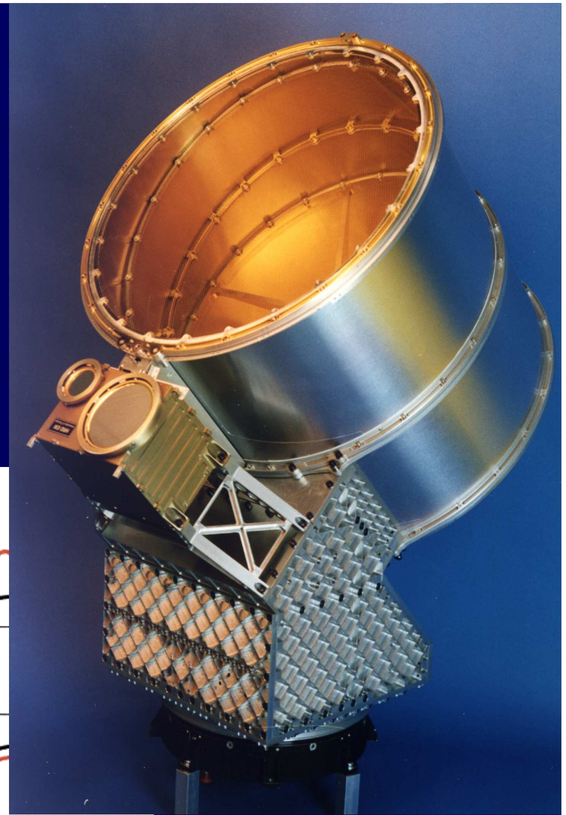
Using any dust that comes to our instrument:

- 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

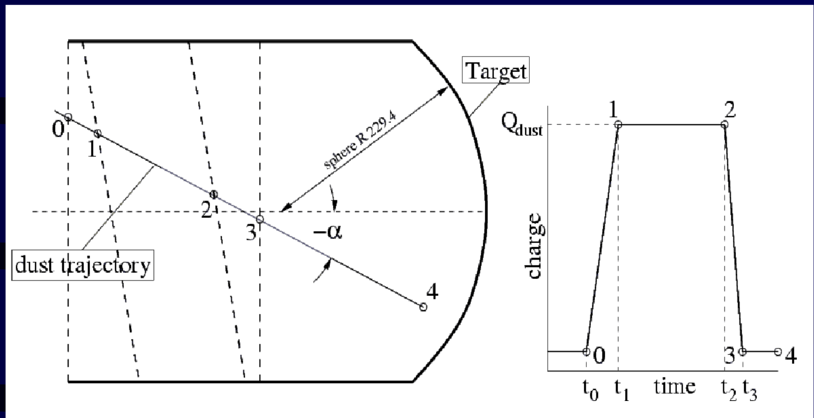






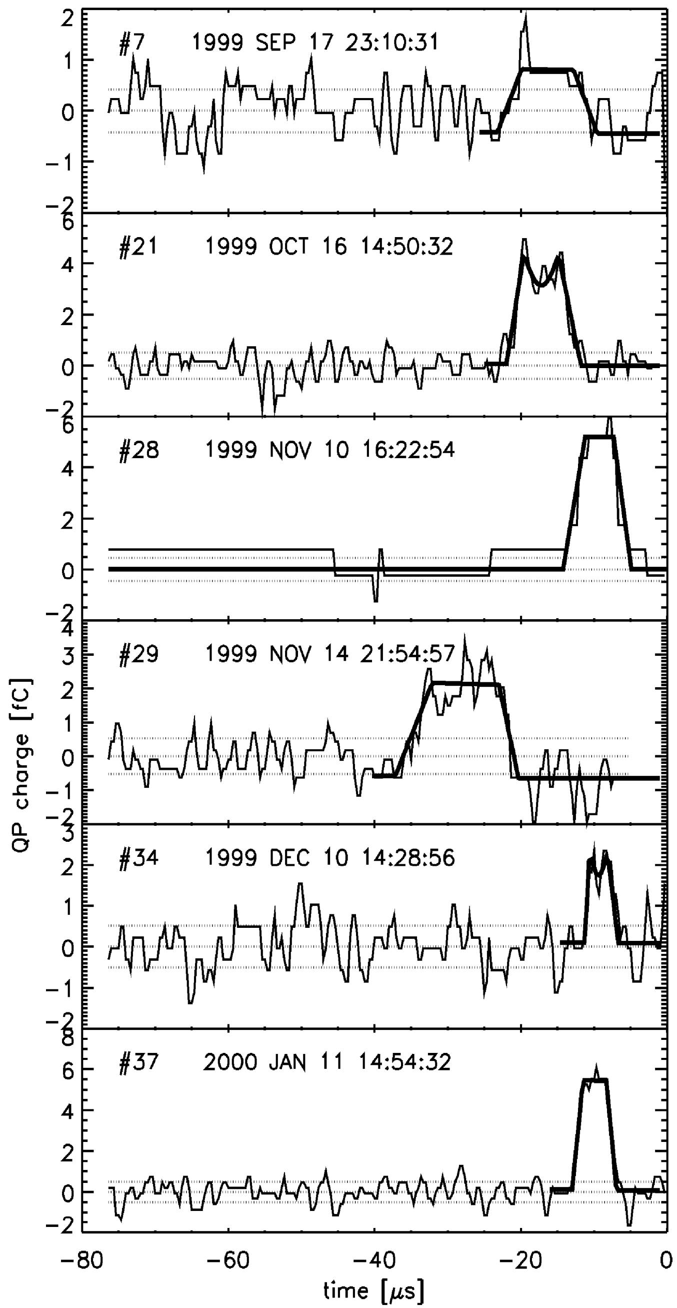
10 kB data from a single dust impact

Dust Charge Detection by CDA



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

Kempf et al., 2004

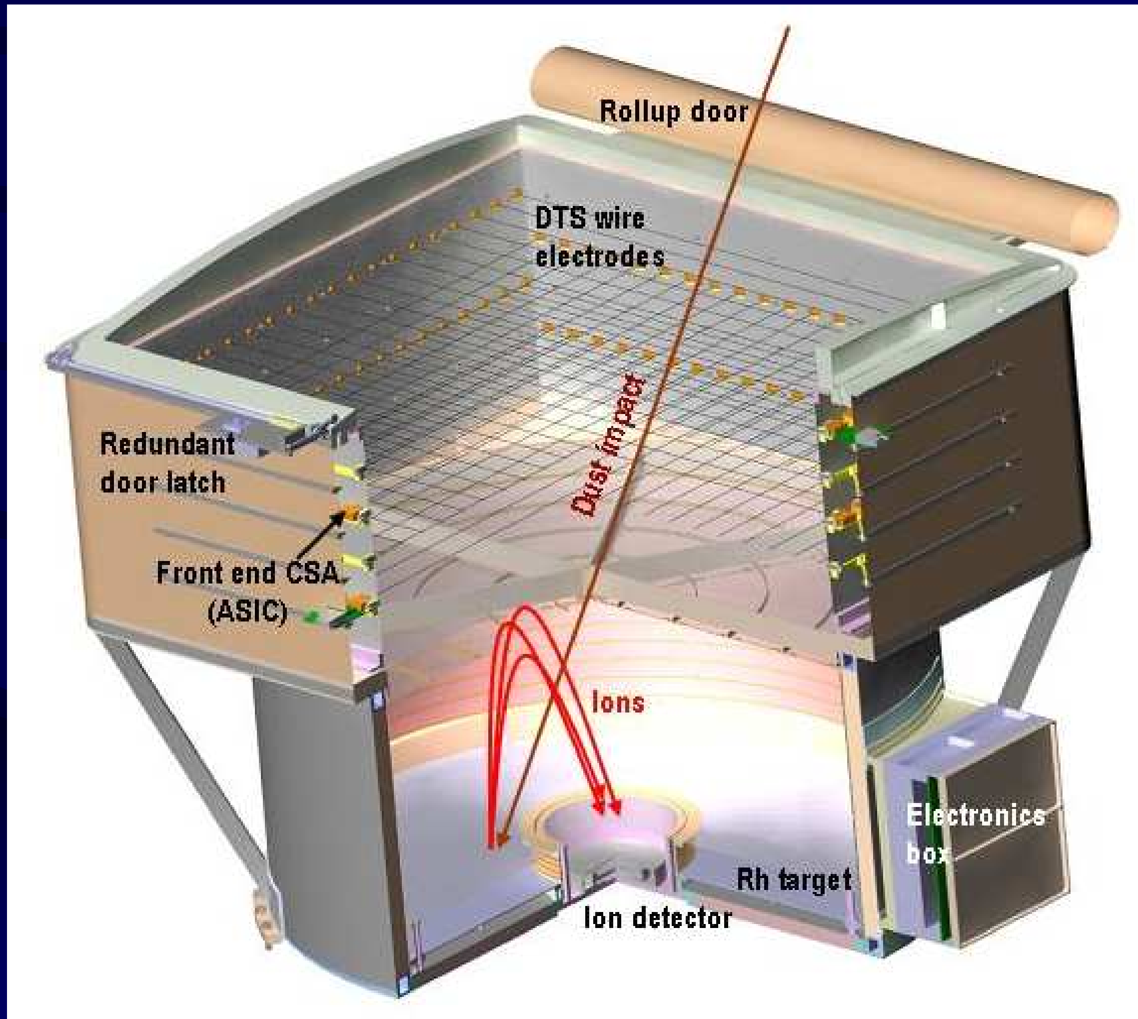


Dust Telescope

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

Compositional Analyzer (mass resolution 200)

~ 1MB data from a single dust impact



Dust Mass Spectrometers

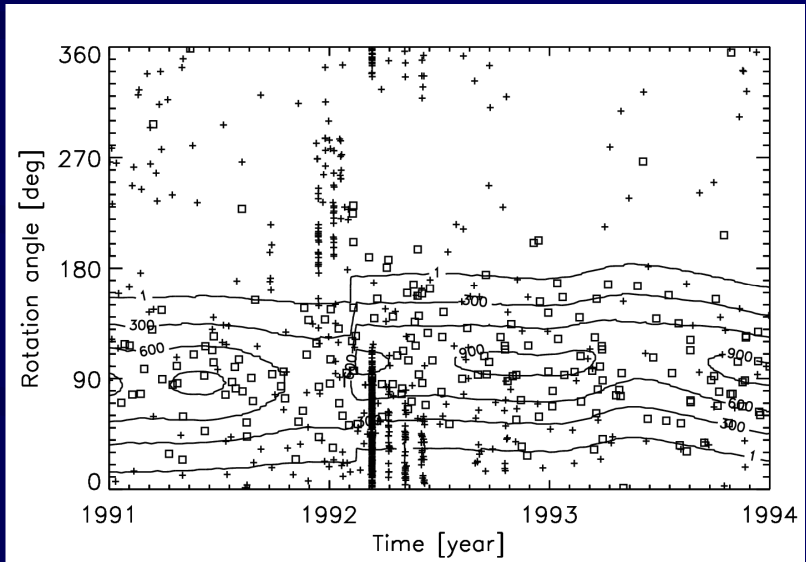
Mission	Instrument	Sensitive area (cm^2)	Mass resolution	Object
Giotto	**PIA**	10	>100	Comet Halley 1986
VeGa	**PIUMA**	10	>100	Comet Halley 1986
Stardust	**CIDA**	90	~200	Comet Wild2 2004
Cassini	**CDA**	160	~30	E Ring, Jupiter dust streams, Enceladus dust 2002-present
Dust Telescope		1000	~200	Interplanetary dust, Interstellar dust, Dust rings, Dust around large satellites

Interplanetary and Interstellar Dust

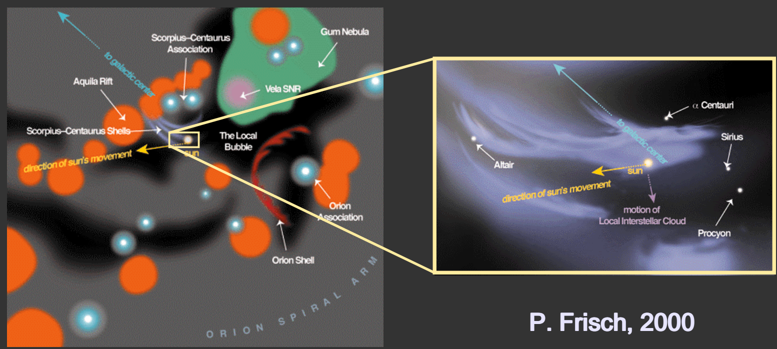
- Distinguish and analyze interplanetary from interstellar dust
- Distinguish and analyze asteroidal from cometary dust
- Characterize beta-meteoroids and nano-dust

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 (≤ 26 km/s)
- Grains of 0.2 to 3 μm have been identified
- Flux displays time variations
- Galileo, Cassini, and Helios identified interstellar dust grains between 0.3 and 5 AU

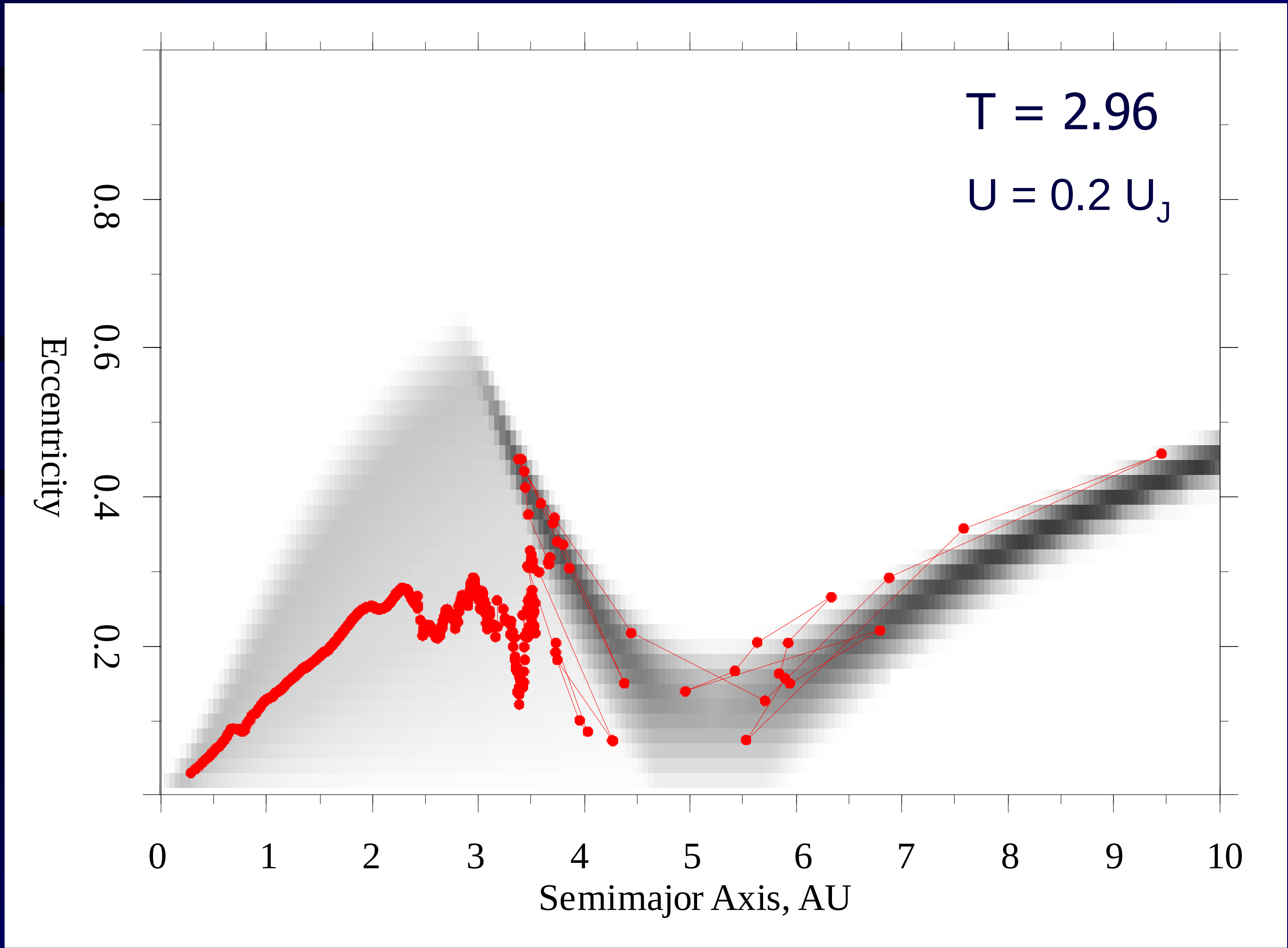


Our Galactic Environment



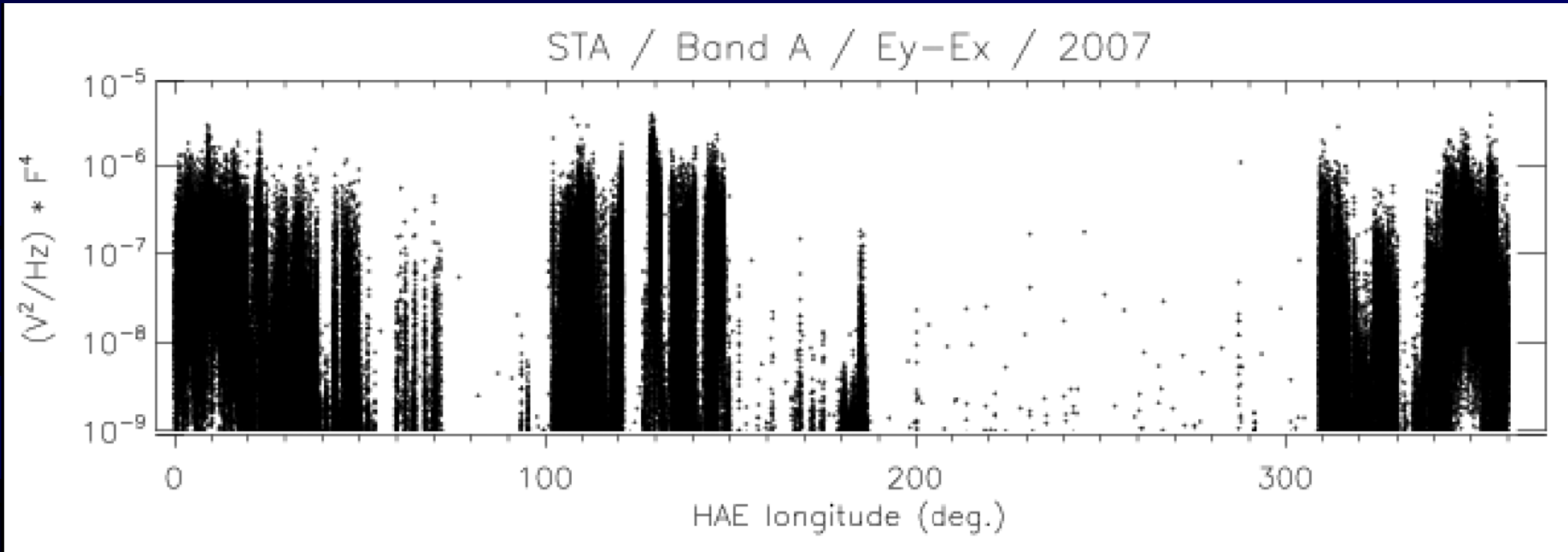
P. Frisch, 2000

Orbital Evolution of Cometary Particles



Dikarev, 2005

Nano-Dust
Observed by Stereo WAVES

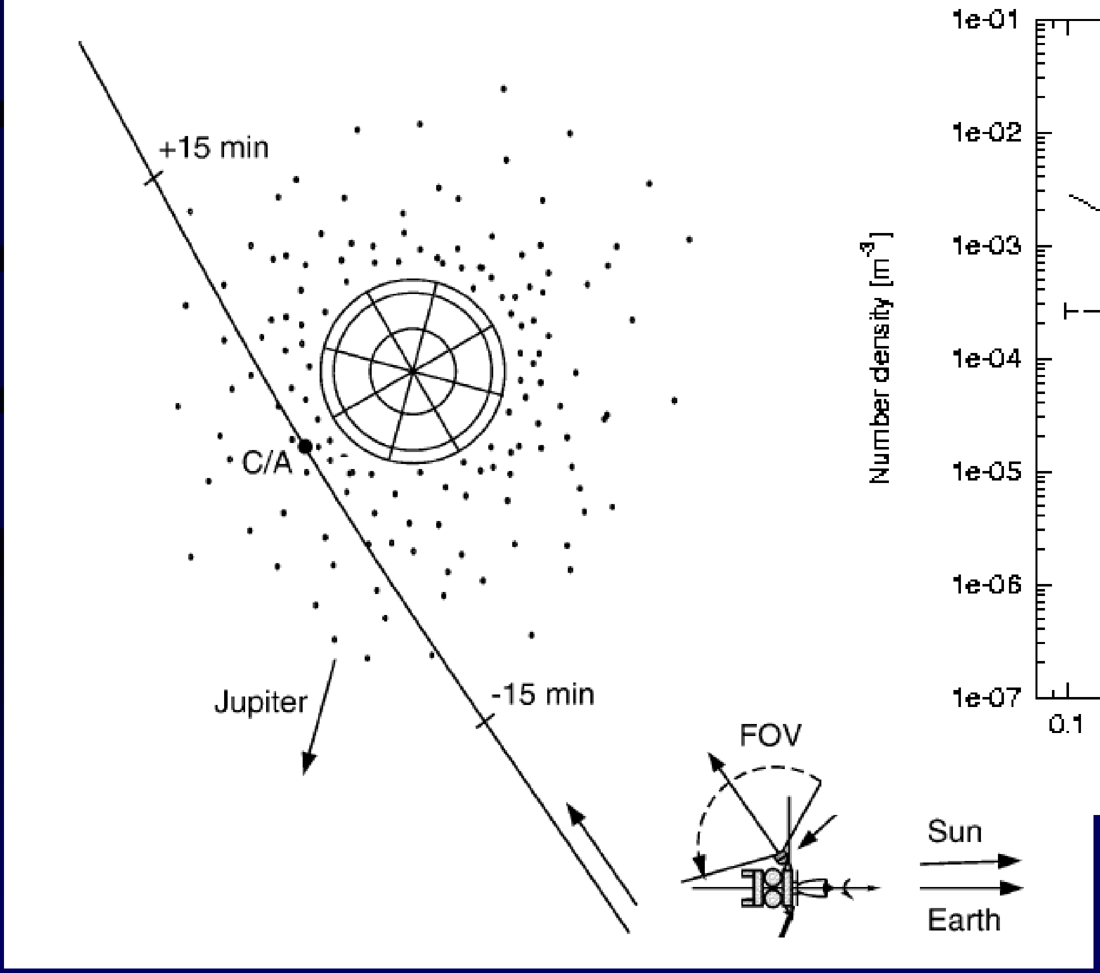


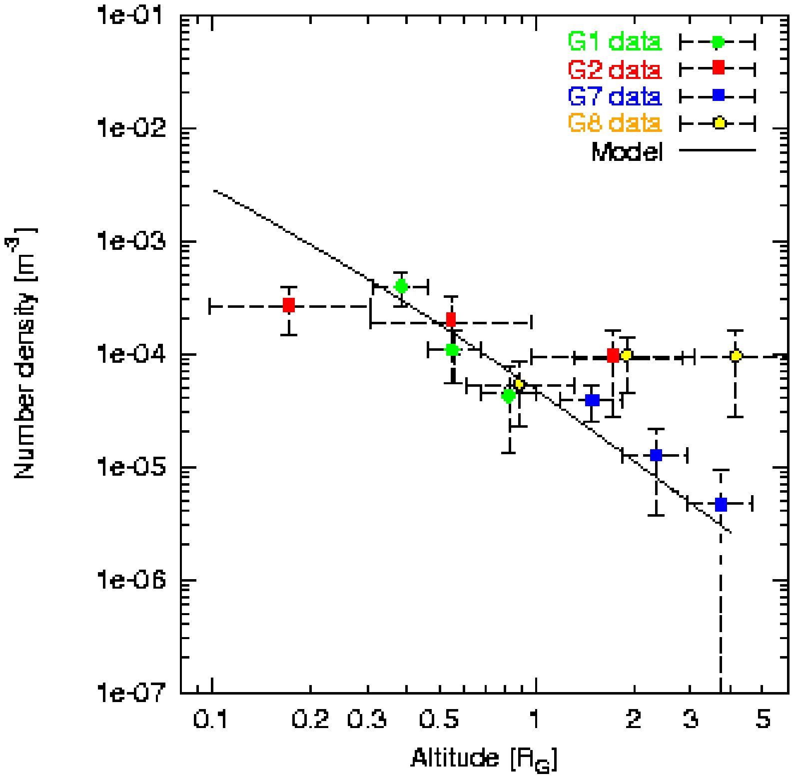
Signals are interpreted as charge bursts generated by impacts of intense streams of nano-dust onto the spacecraft skin (Meyer-Vernet et al., 2009).

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



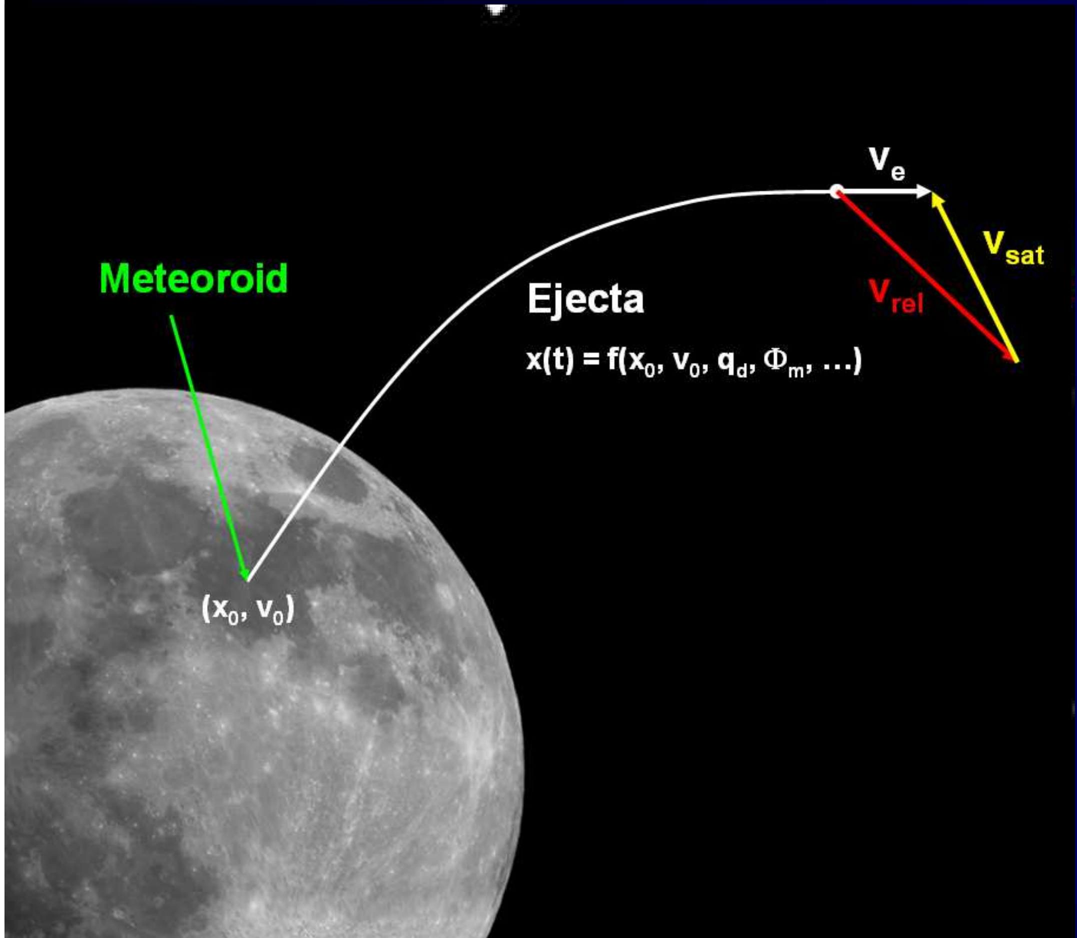


Dust Clouds around Galilean Satellites and the Moon

- 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

Compositional Surface Mapping of Big Planetary Objects



- Ejecta particles lifted by meteoroid impacts from the satellites' surface

- Individual Dust trajectories determined by a dust sensor

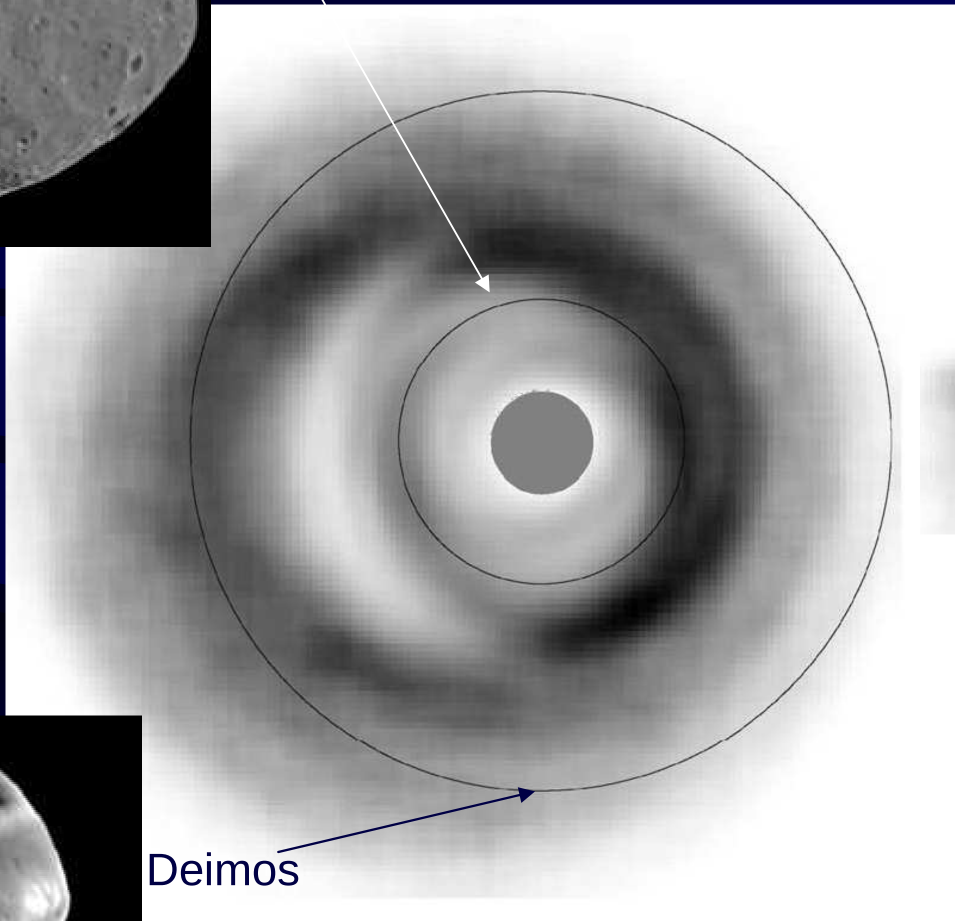
- The composition of the same grain is analyzed by a high-resolution dust mass spectrometer.

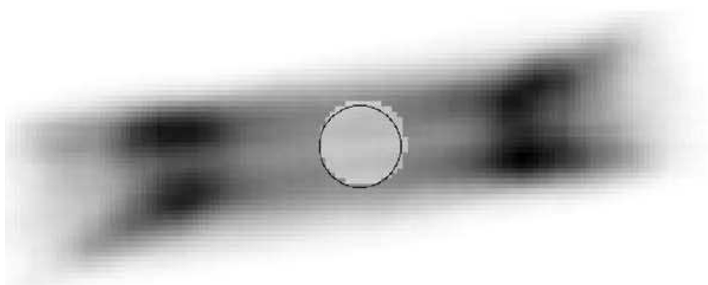
- Compositional maps of the surface are generated.

Dust Ring Sources

- Characterize source bodies of dust rings

Mars Hypothetical Dust Ring





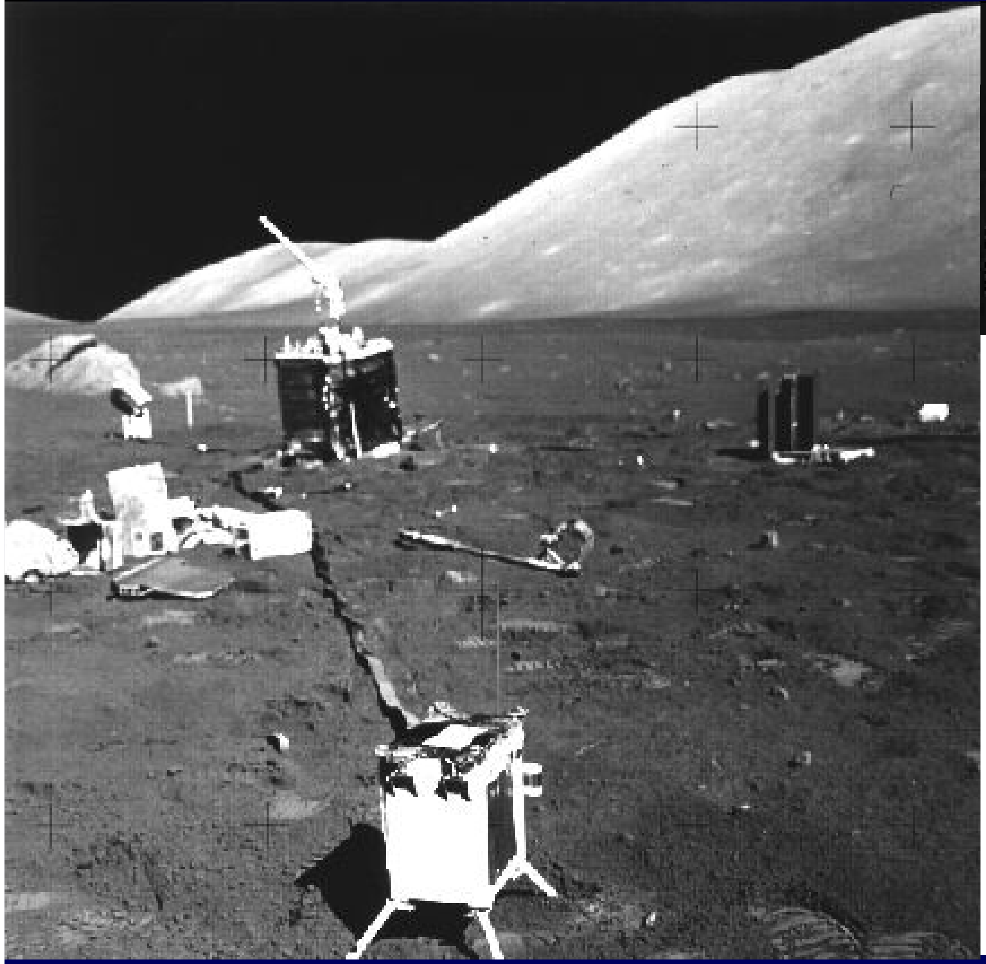
Optical depth $\tau \sim 5\ 10^{-8}$

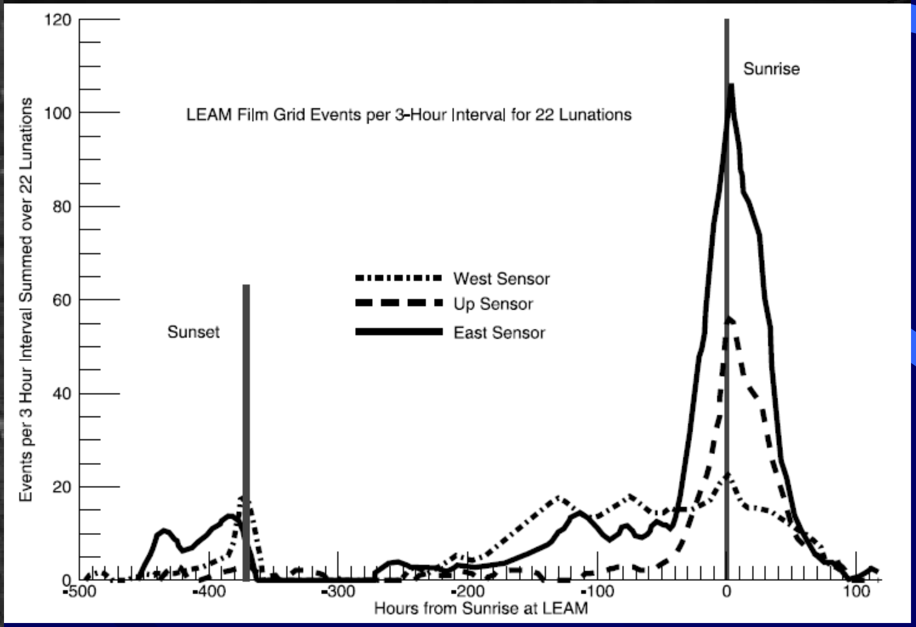
Krivov et al., 2006

Levitated Lunar Dust

- Analyze slow moving dust

Lunar Horizon Glow
Apollo 17 LEAM





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