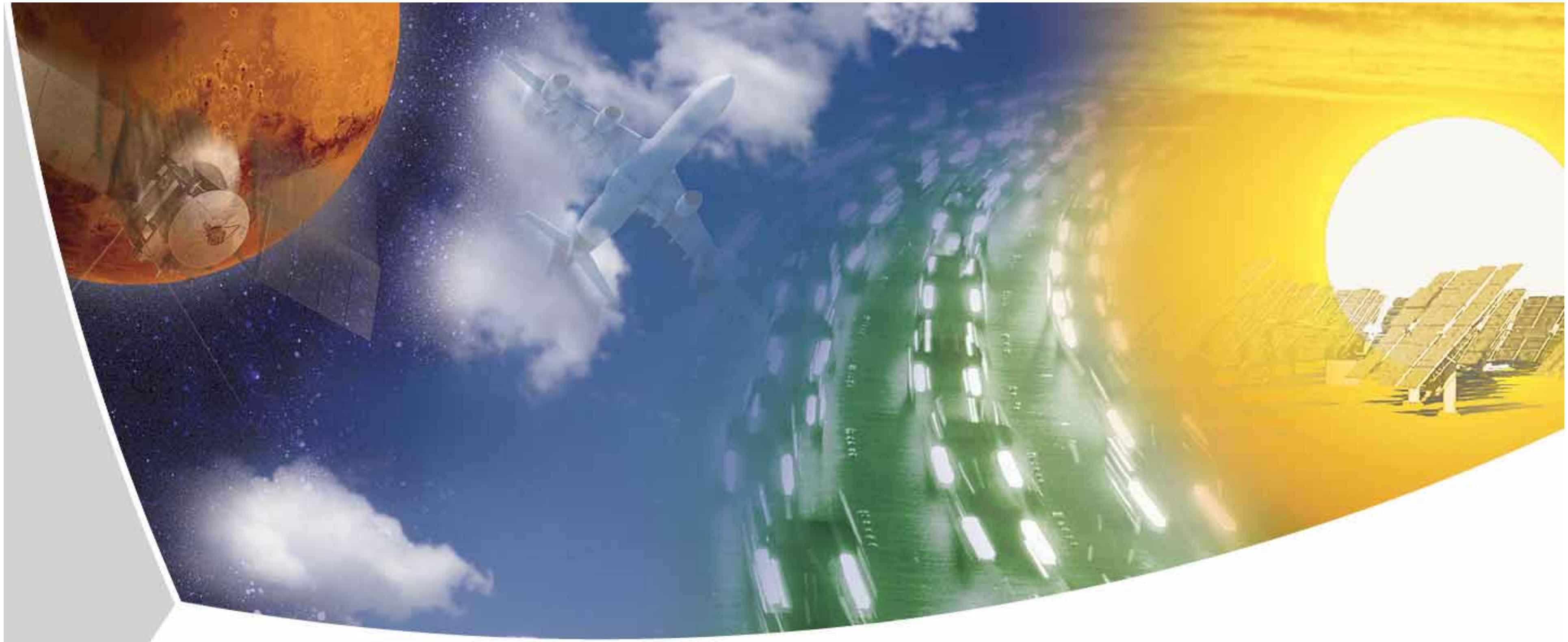

The enigma of comet nuclei

- or: Keep the frontiers open ! -

(D. Möhlmann, DLR Institut für Planetenforschung, Berlin)

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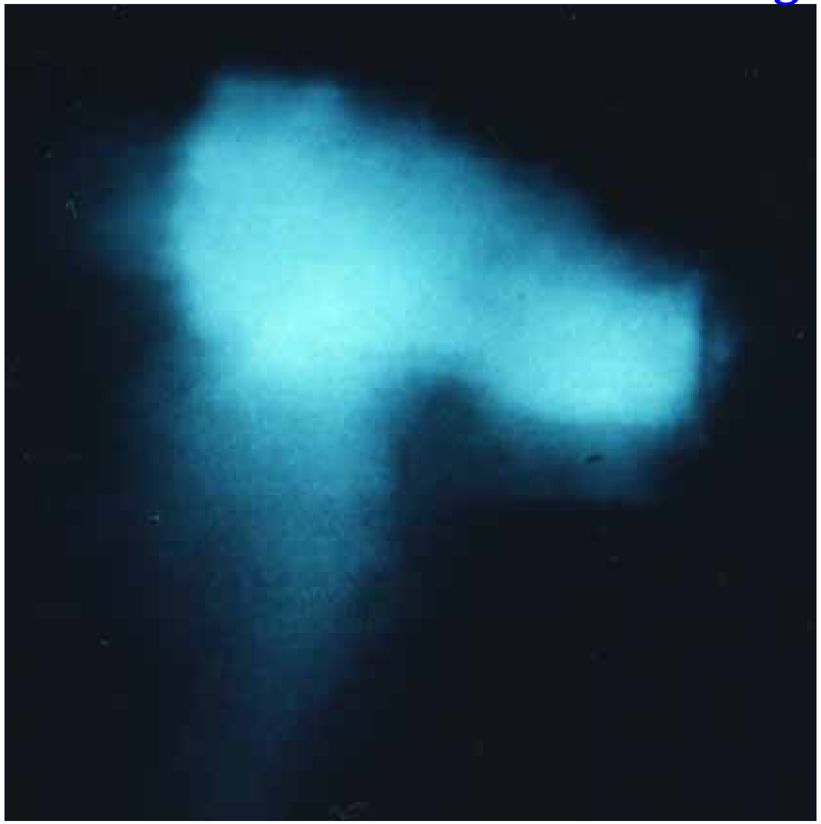
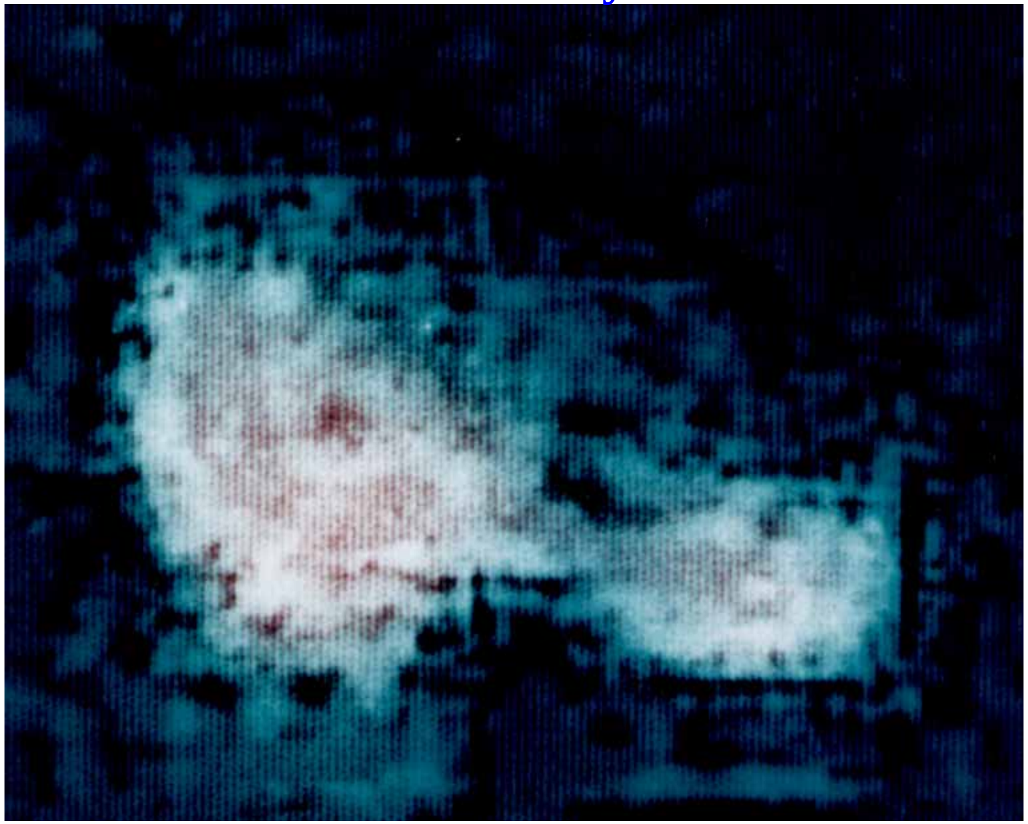
Modern comet research has begun with:
The VEGA-2 image of the nucleus of 1P/Halley



Original image

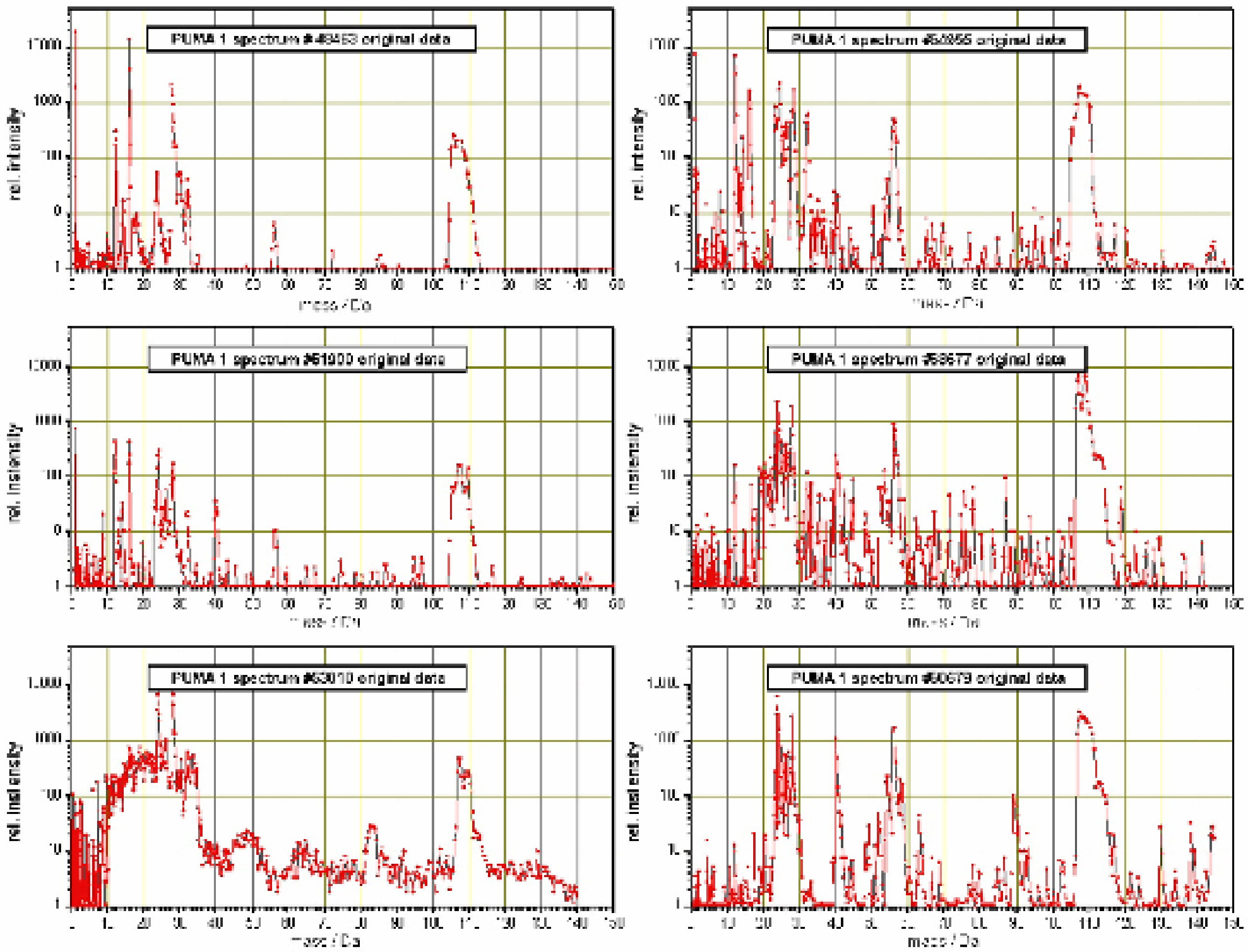


Contrast enhanced

Historically, this is the first image of contours and structures of a comet nucleus **(made here at IKI)**

at March 9, 1986; distance - 8030 km

1st proof: Comet nuclei are single solid bodies



PUMA 1 spectra for comparison left: short spectra, right: long spectra

PUMA-1
dust mass spectrometer onboard VEGA 1
(Cooperation MPI Heidelberg/IKI)

Results of
*** PUMA/PIA: CHONs - indicate complex organic constituents**
*** „pristine“ chemical composition**

P1/Halley, March 13, 1986

Image credit: Giotto team

Giotto has confirmed that comet nuclei are very dark solid bodies with a specific surface structure. About 10% of the surface are „active“ (i.e. outgassing)

Comet
19/P Borrelly

(Deep
Space
Mission
der NASA)

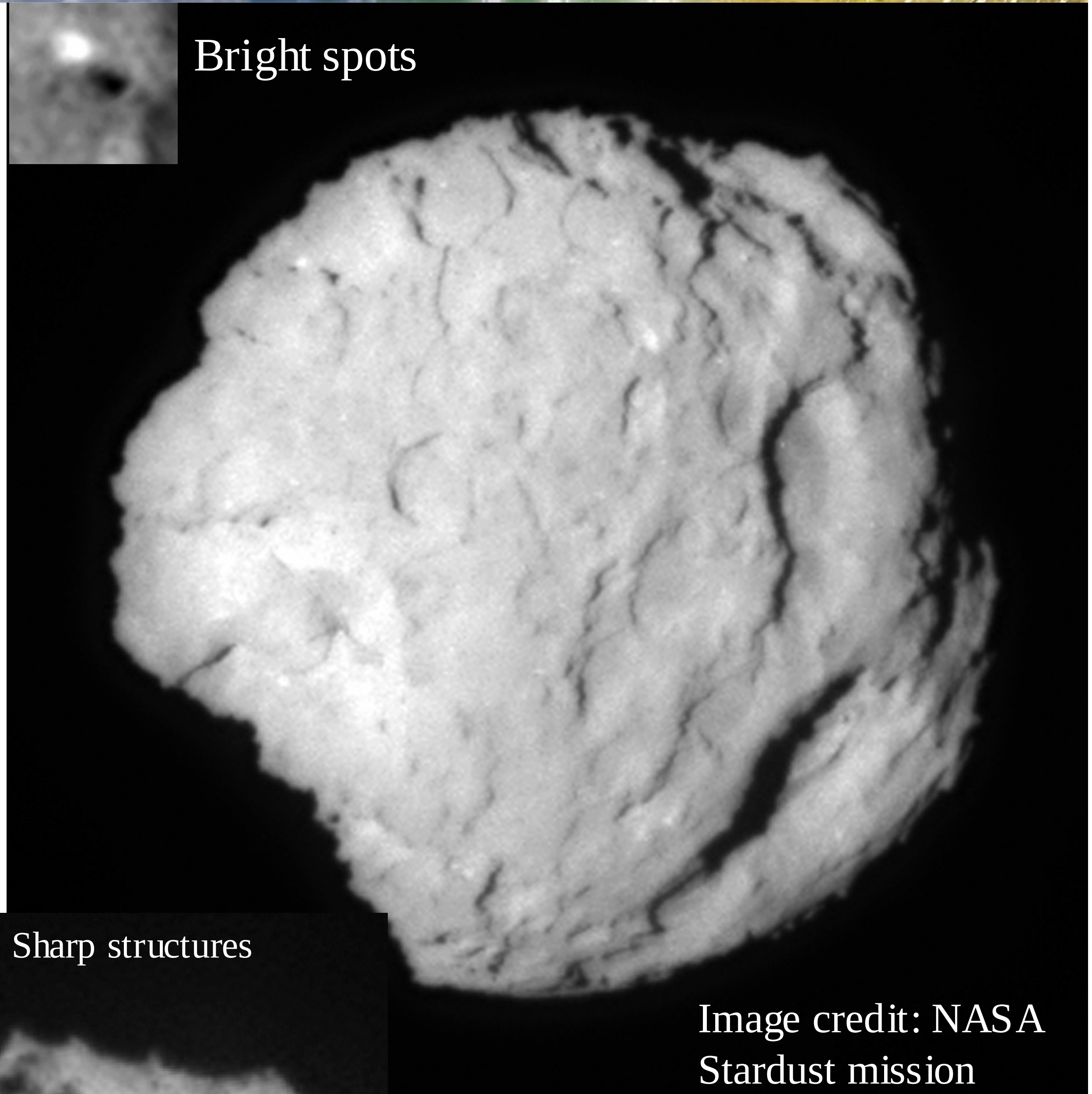
Only 6% of the surface are „active“

Large scale surface features, smooth terrains

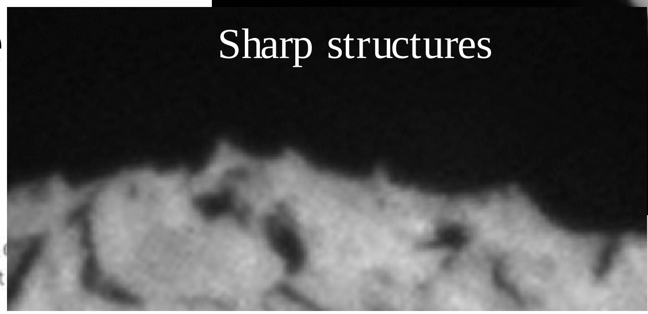
Image credit: NASA

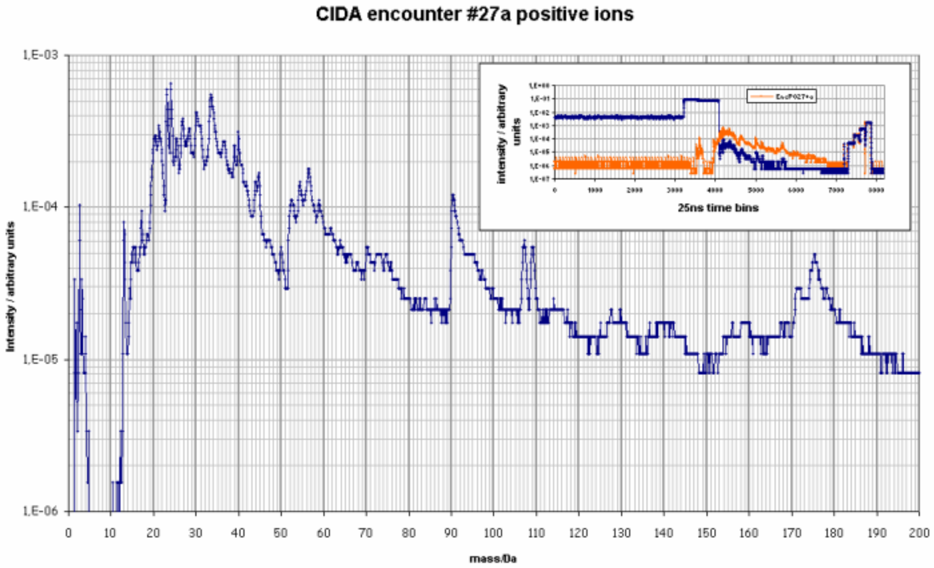
Comet 81 P/Wild 2

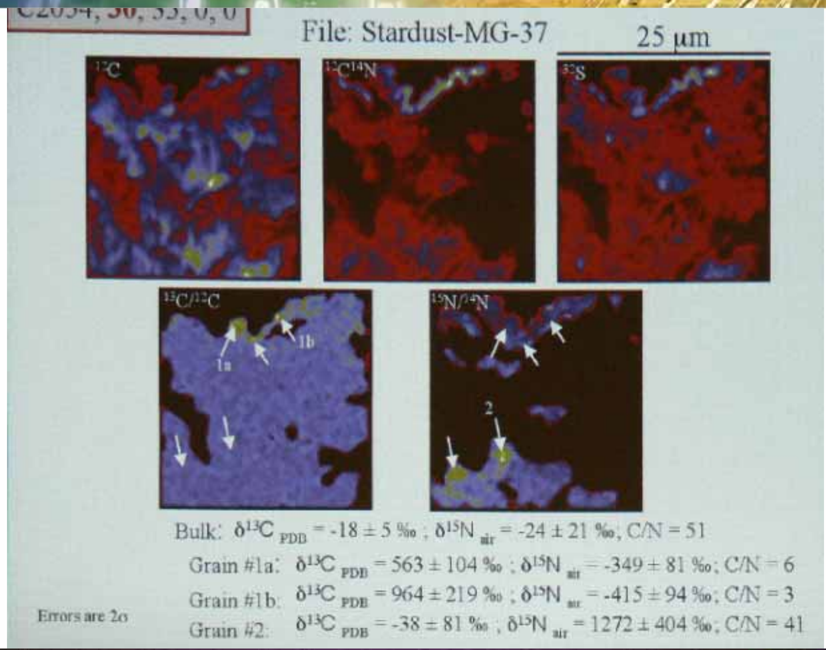
Cratered surface ?



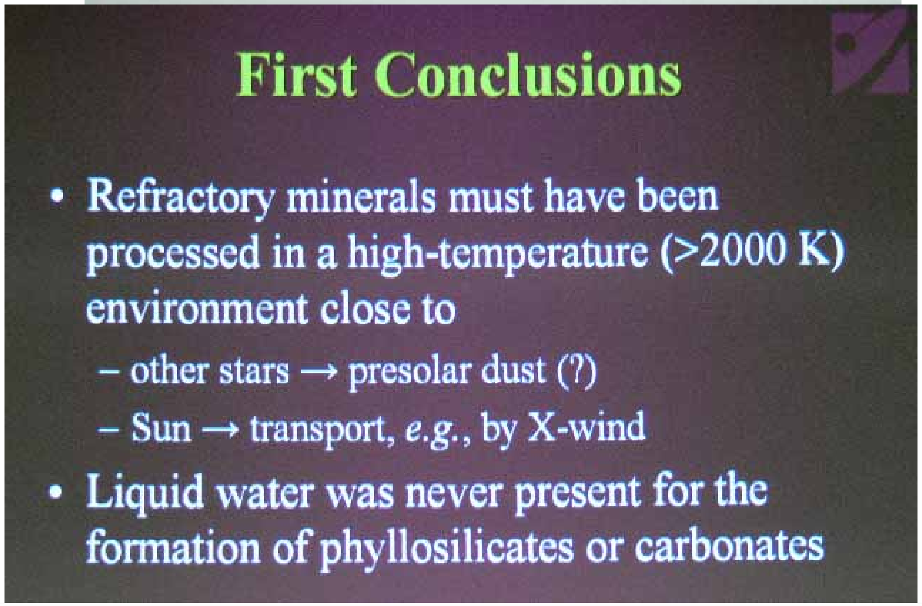
No relation between jets and surface features

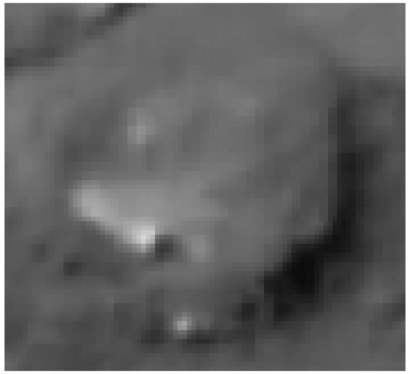


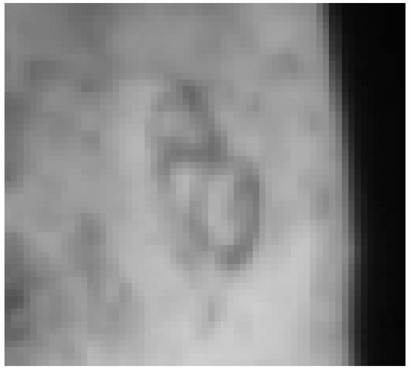

CIDA encounter #27a positive ions
Intensity / arbitrary units
mass/Da
1,E-03
1,E-04
1,E-05
1,E-06
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
intensity / arbitrary units
25ns time bins

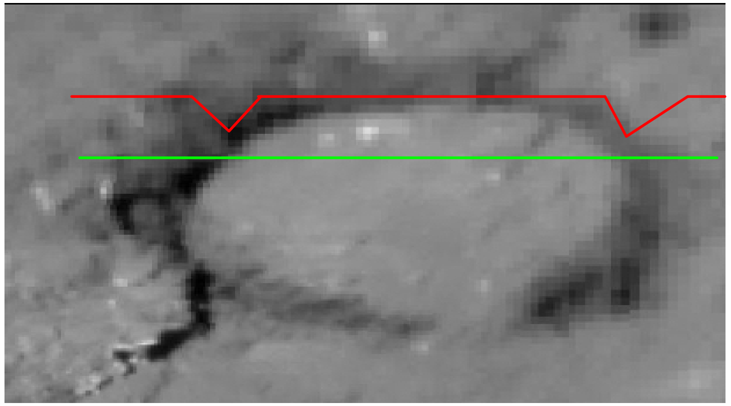

File: Stardust-MG-37
25 µm
Bulk: δ13C PDB = -18 ± 5 ‰ ; δ15N air = -24 ± 21 ‰; C/N = 51
Grain #1a: δ13C PDB = 563 ± 104 ‰ ; δ15N air = -349 ± 81 ‰; C/N = 6
Grain #1b: δ13C PDB = 964 ± 219 ‰ ; δ15N air = -415 ± 94 ‰; C/N = 3
Grain #2: δ13C PDB = -38 ± 81 ‰ ; δ15N air = 1272 ± 404 ‰; C/N = 41
Errors are 2σ

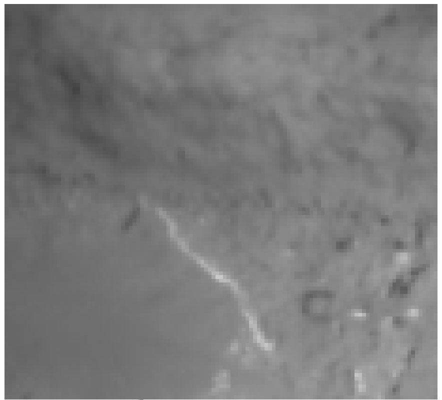

First Results (Mineralogy)
• Silicates
– Olivine, Pyroxene, Feldspar
• Glass
• Fe-Ni-Sulfides
• Huge variations in composition
• No phyllosilicates, no carbonates
• Refractory minerals
– anorthite, diopside, spinel, osbornite
– correspond to Ca,Al-rich inclusions in

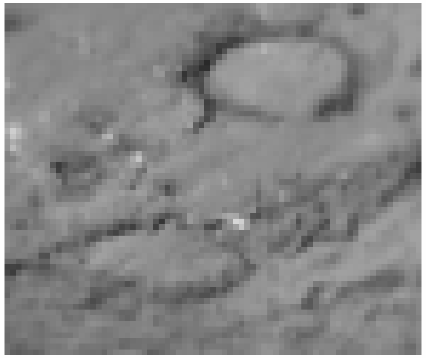

First Conclusions
• Refractory minerals must have been processed in a high-temperature (>2000 K) environment close to
– other stars → presolar dust (?)
– Sun → transport, e.g., by X-wind
• Liquid water was never present for the formation of phyllosilicates or carbonates

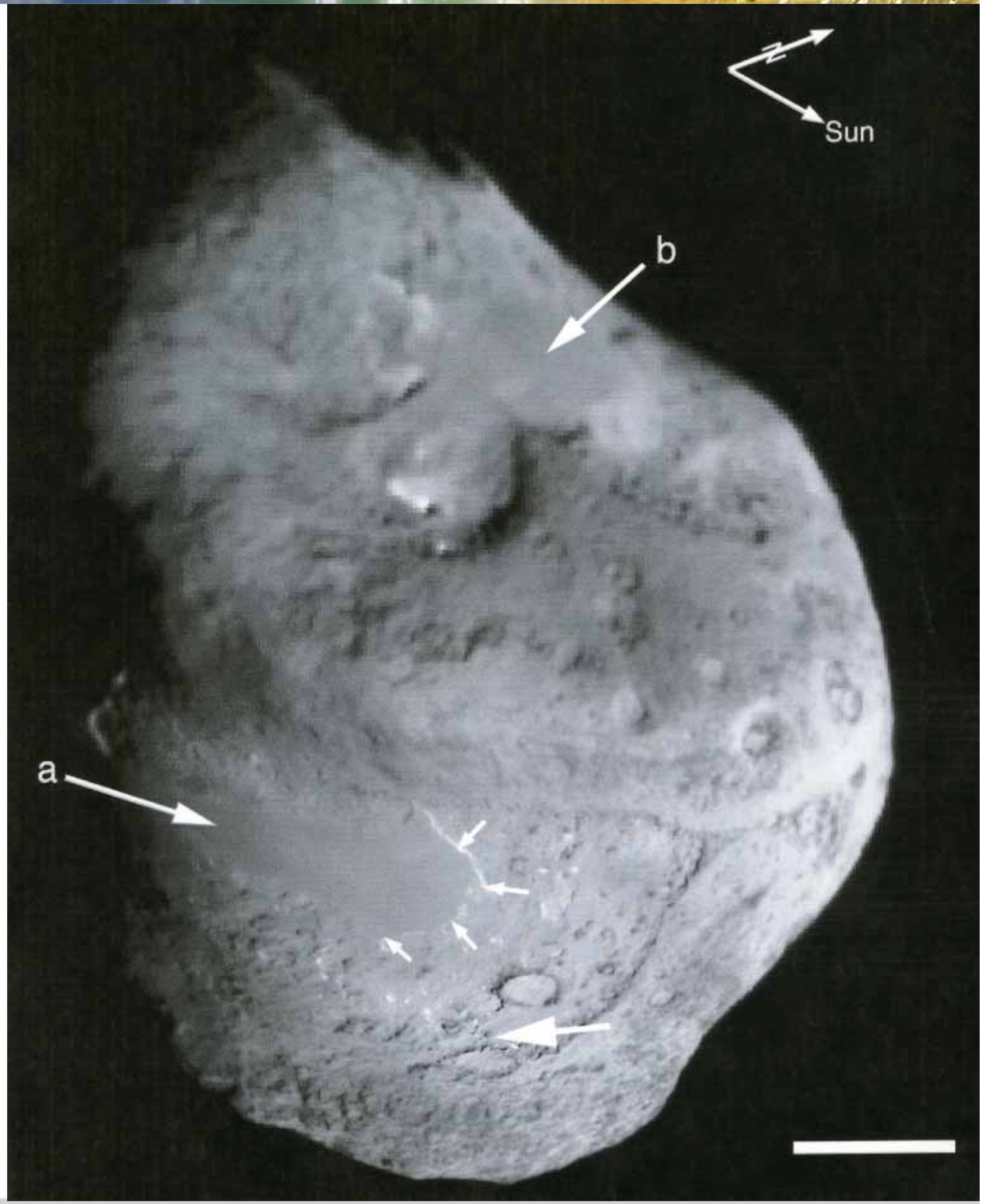












Images credit: NASA

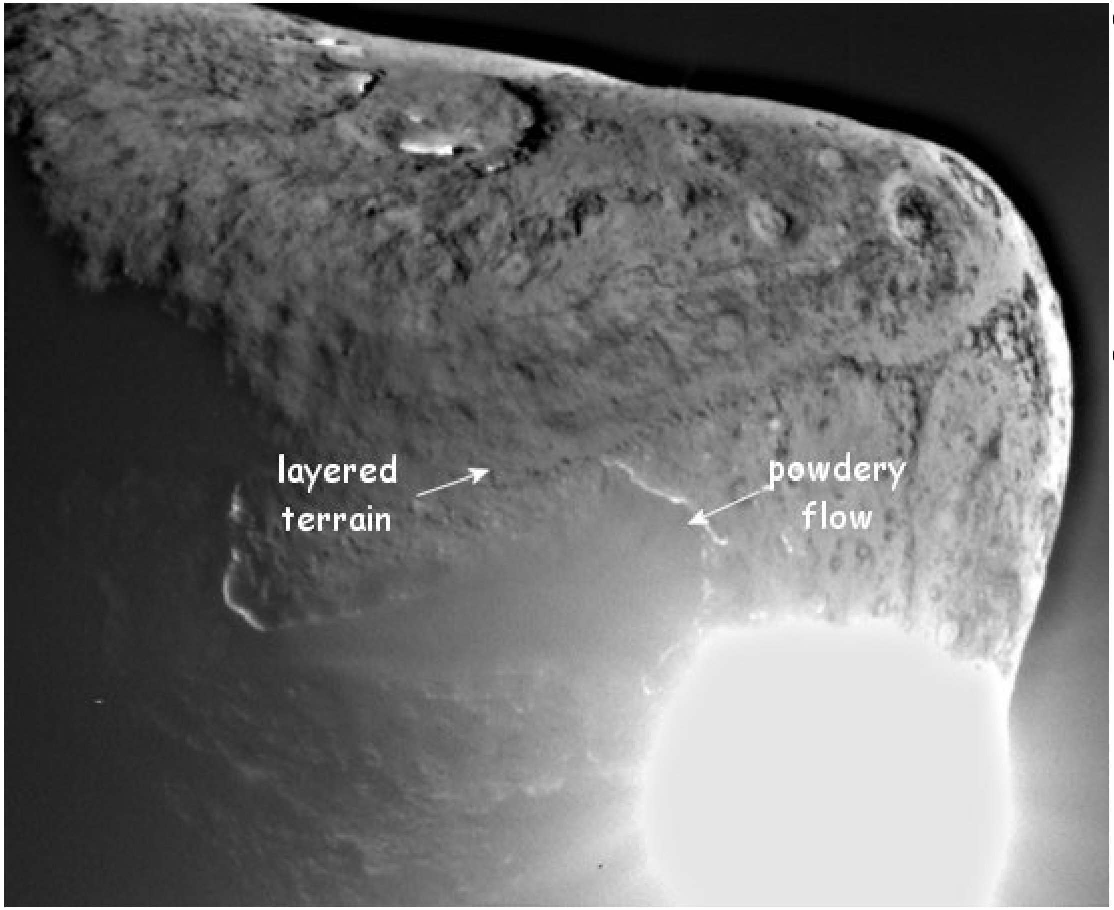


Image credit: NASA,DeepImpact

Geological features

- * Large, smooth surfaces
- * Round features (= craters?)
- * Stripped terrain (old)
- * Scarps
- * Evidence of layers

Overall Shape

- * Effective radius 3.0±0.3 km
- * Max-min diameters 7.6 and 4.8 km but very uncertain
- * Well-mapped surface is mostly in 3 large more-or-less flat areas

Tempel 1 Parameters

Mean radius: 3.0 ± 0.1 km
Diameter range: 5.0 - 7.5 km
Gravity: 0.024 - 0.030 cm /s^2
Area: 119 km^2
Range of gravitational heights: 0.73 km
Mean Density: 0.3 ± 0 .2 gm /cm^3

Tempel 1 (Veverka, DPS, 2006):

Layering

- Very pronounced in at least top 0.5 km
- Some possibly global in extent
- At least two types of layers identified: “thick” and “thin”
- Morphology suggests that layers probably differ in physical characteristic
- Origin of layering problematic:
  - primordial accretion ?
  - subsequent (thermal) processing ?
  - ejecta deposits on much larger precursor object ?
- Some (but much more subtle) evidence of “layering” exists in Wild 2 and Borrelly images

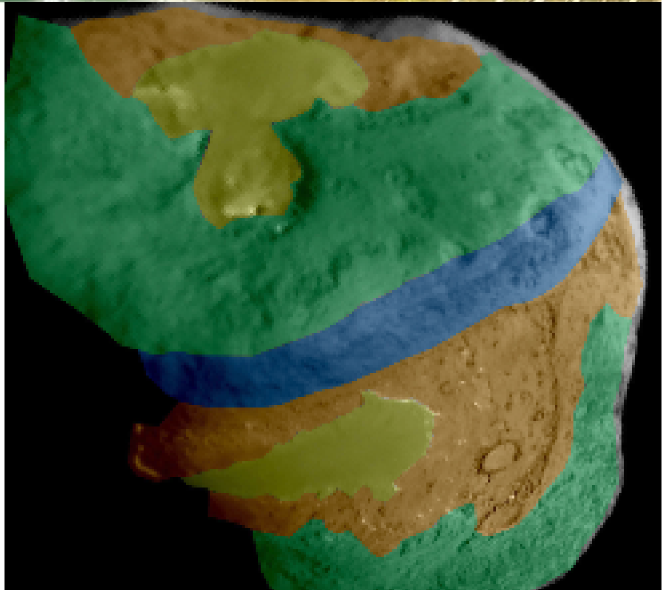


Image credit: DI Science team

Smooth terrains

- Two separate areas of extensive smooth terrain
- Appear uncratered ⇒ relatively recent!
- Very smooth ⇒ uniform in texture
- Outlines are elongated and flow-like
- Occur in topographically low areas
- Better imaged feature shows suggestions of flow features (i.e. sub-parallel, darker markings?)
- This feature is about 3 km long, 1 km wide and at least 0.02 km thick
- Ends in abrupt scarp (about 10-20 m high)

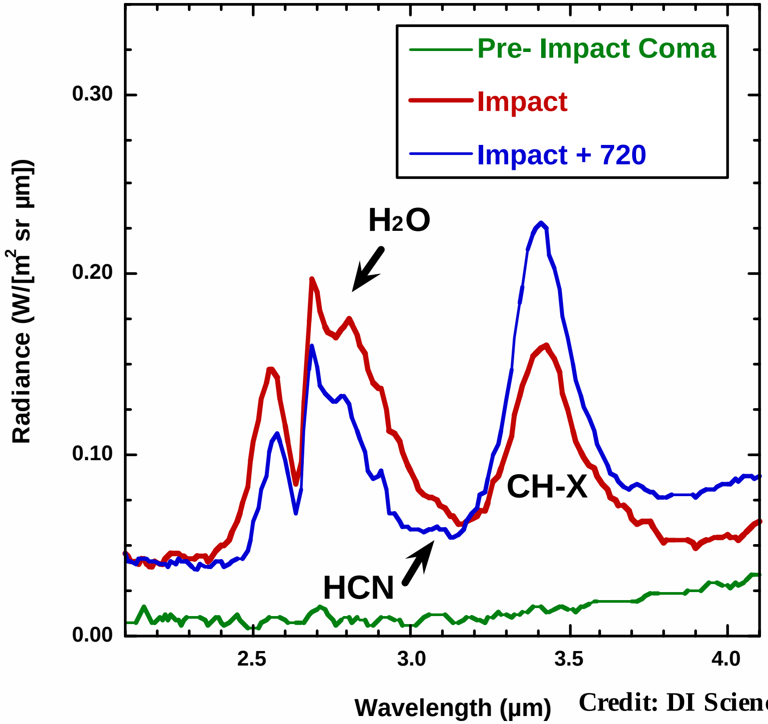
Comet dust :

Mg, Si, O:
Mg-rich SiO_3 and SiO_4
(Fosterite, Smectite, Enstatite)

Al, O, Ca:
Al_2O_3 (hibonite, spinel)

C,H, O, Ca, Mg
Carbonates (CO_3)
PAHs, HAC?
CO_2 (ice and gas)

Where are Fe and S?
S – probably in S_x, SO_x, OCS, CS_2
Fe – sequestered in FeO_x,? FeS_x?
(20 - 24 um features)



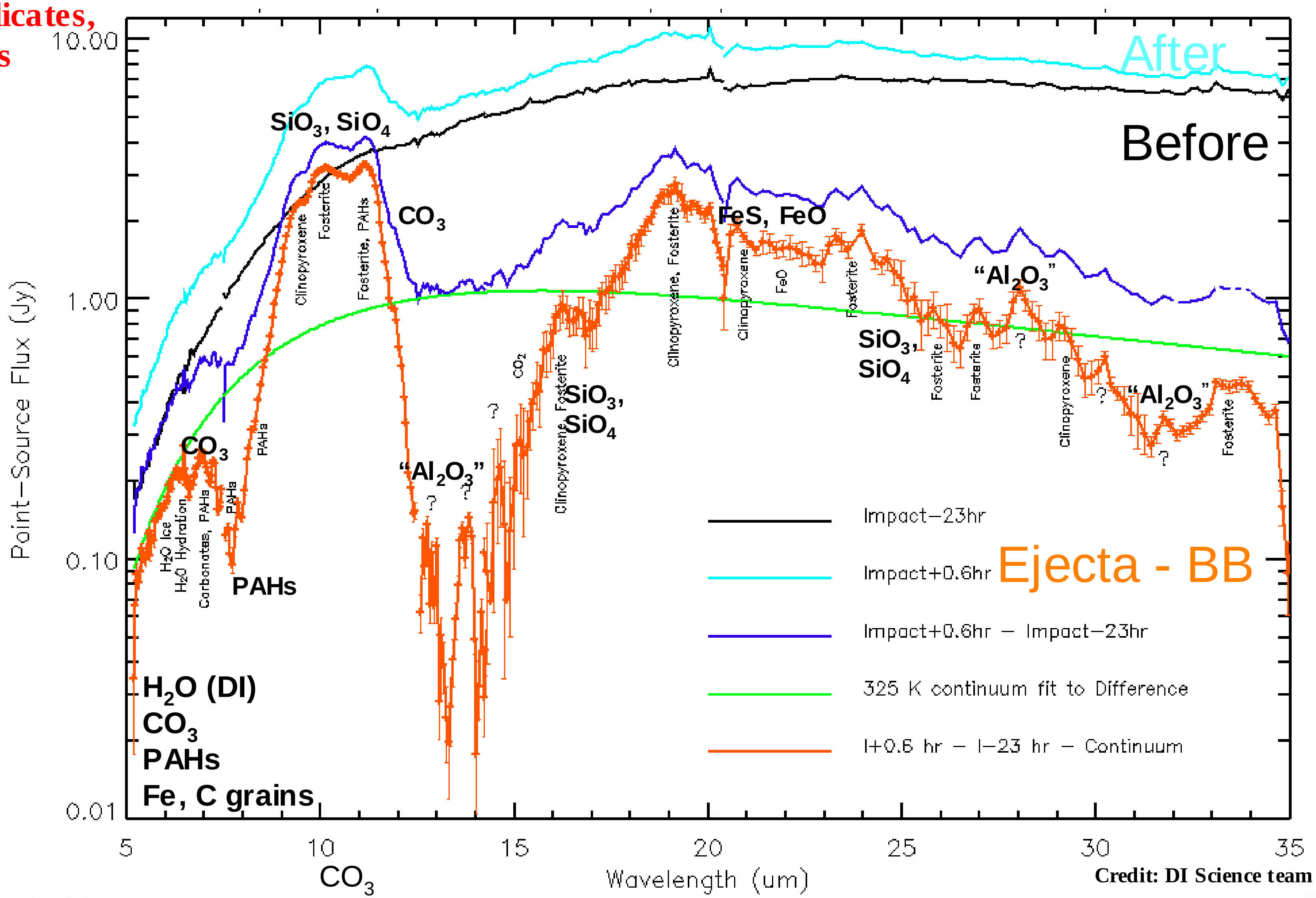
Credit: DI Science team

Achievements:

* very fine dust ~ 2-5 µm
* weak tensile strength (< 100 Pa ?) - under discussion
* mass density ~0,4 g/cm^3
* CO_2 ~ 7%wrt H_2O before and up to 10% wrt H_2O immediately after impact
* dramatic increase of organic material promptly after impact
* organic materials decay slower than H_2O or CO_2
* HCN and CH_3CN found, many more expected to follow (H-C bonds)
* for the first time: water-ice!

5 - 35 um Spitzer Spectra : (L+0.6 hrs) - (L-23hrs)

There are carbonates, carbon-containing polycyclic aromatic hydrocarbons, smectite (clay), crystalline silicates, metal sulfides



Credit: DI Science team

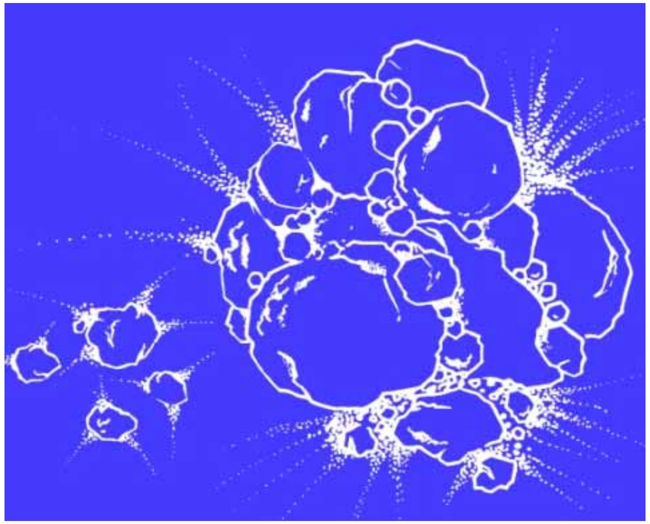
Relations to the early Solar system

O.Yu. Schmidt, V.S. Safronov (both Moscow, in the 1940s - 1980s):

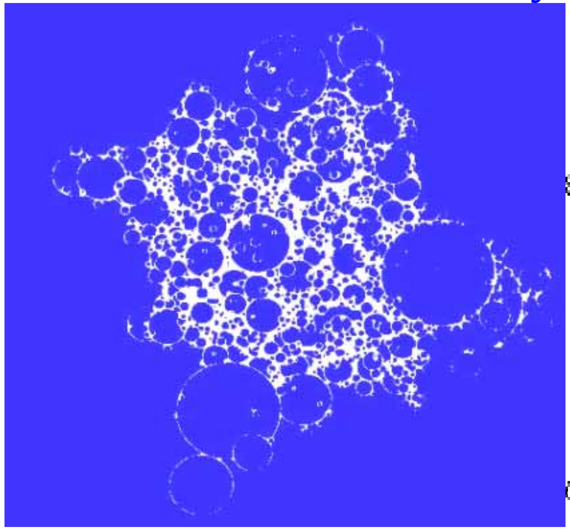
Collisional growth („accretion“) of solid preplanetary bodies incl. comet nuclei:

„Soft accretion“ in the outer parts of the early solar system:
-> low density, „fluffy“ bodies, impact formed surface and internal structure, „pristine“ composition!

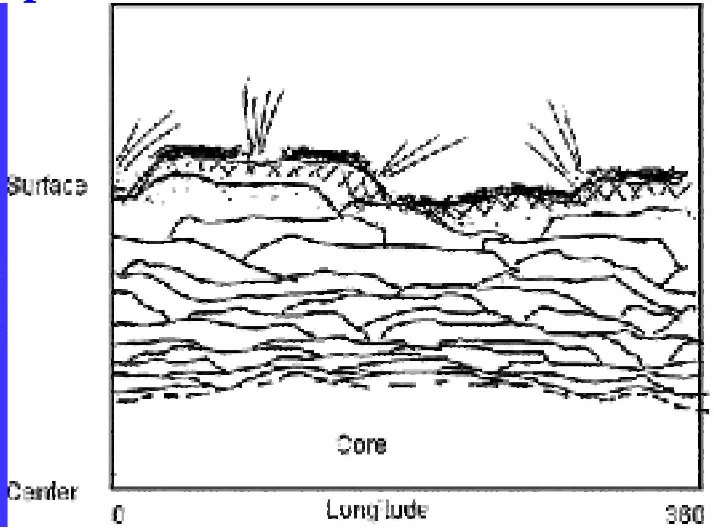
VEGA/Giotto+ ... : Comet nuclei are of low density, pristine materials,...



Primordial Rubble Pile Model
Weissman (1986)



Fluffy Aggregate Model
Donn et al. (1985)



Layered Piles Model
Belton et al., 2006

All seems to fit together „in principle“

But, comet nuclei show indications for a much more complicated origin and evolution:

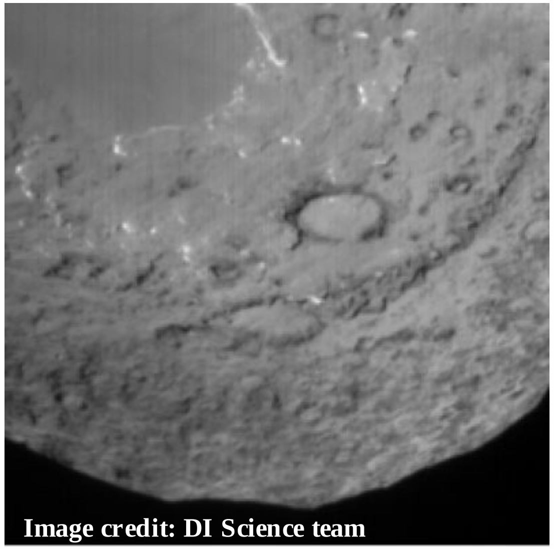


Image credit: DI Science team

Surface features:

Layering and flow features may indicate much larger precursor objects

Mineralogy/chemistry:

Clay and carbonates require liquid water to make.
Crystalline silicates require hot temperatures to form.

Orbits:

Comets have reservoirs (formation sites) in the outer solar system, but there are comet groups more inside: The „clandestine“ comets in the asteroid belt e.g. (Jewitt, Hsieh, 2006).

Challenges:

Have comets formed by accretion only, or may collisional destructions of larger and water/volatile-rich parent bodies have contributed too (as in the asteroid belt)?
Can outgassing of water/ice debris-bodies finally have led to porous or low density comets?
Has a high- and low-temperature materials mixing over great distances happened in the primordial solar system ?
Did comet formation in the early solar system take place at different sites, are there related different classes of comet nuclei?

Be open minded for new aspects/frontiers !
The planet forming processes in the outer solar system, incl. comets, are a yet open issue !