Jupiter’s Dust Disc
An Astrophysical Laboratory

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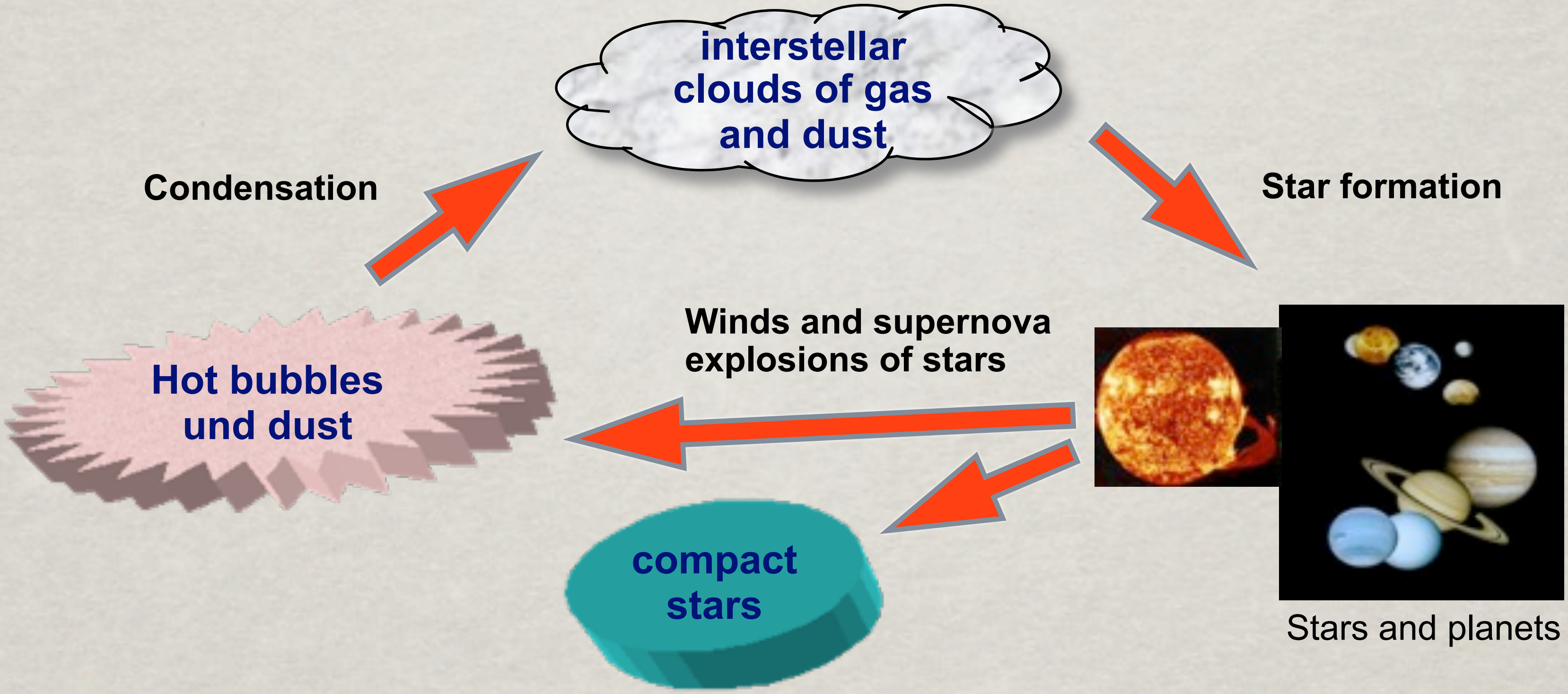
Images: NASA/JPL

Outline

- Introduction: Why dust?
- How do we study space dust?
- Galileo/Ulysses in situ dust measurements at Jupiter:
    - Electromagnetically interacting dust streams
    - Dust clouds at the Galilean moons, tenuous ‘Galilean’ dust ring
    - Galileo passages through Jupiter’s Gossamer rings

The Cosmic Cycle of Matter



interstellar clouds of gas and dust

Condensation

Star formation

Winds and supernova explosions of stars

Hot bubbles und dust

compact stars

Stars and planets

<u>The cosmic cycle of matter:</u>

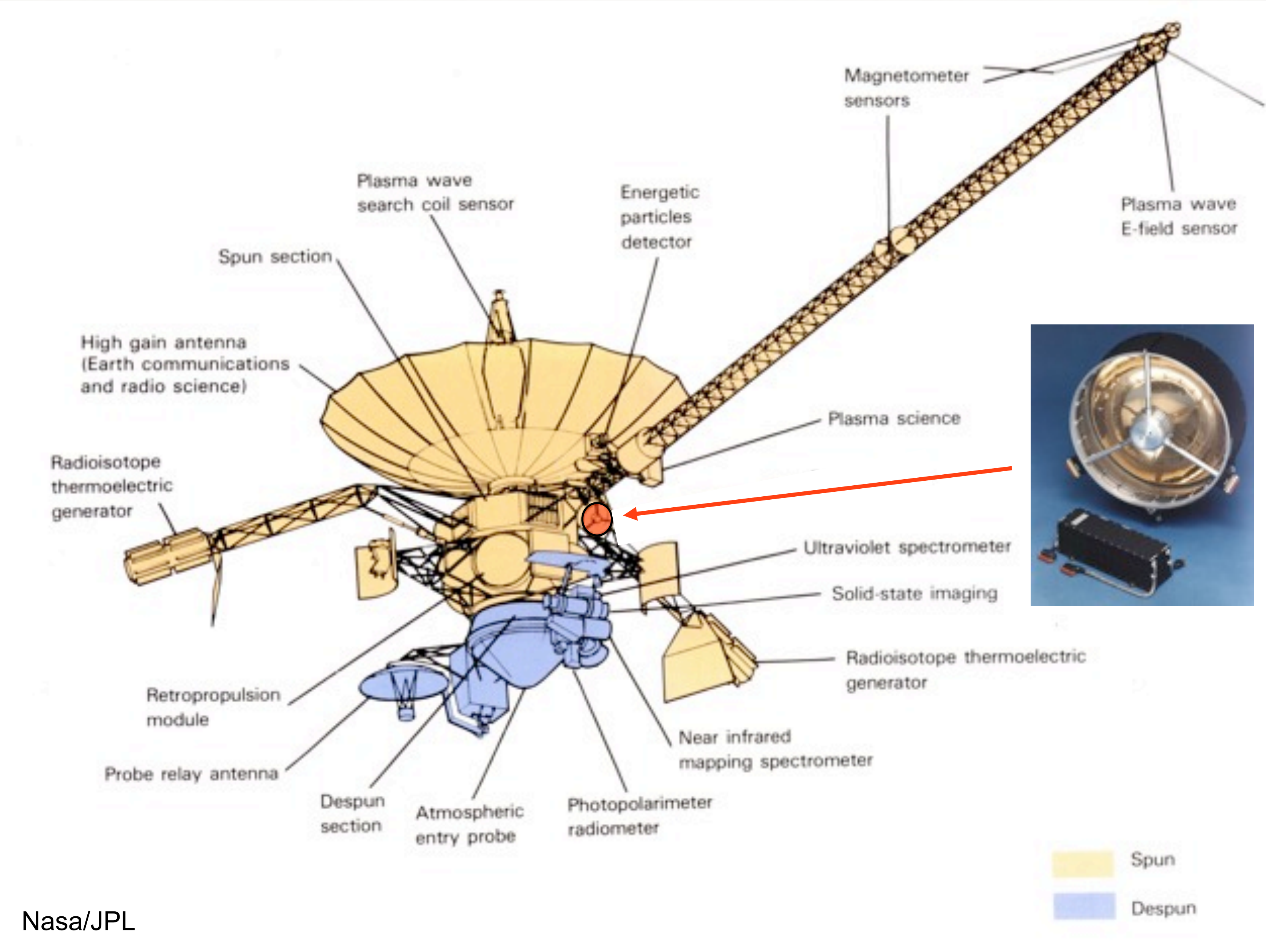
- Heavy elements are produced in stars and supernova explosions and ejected into interstellar space
- They form building blocks for the next generation of stars and planets.
- Also our solar system including the Earth was formed from such primitive matter.

Why Dust?

- **Dust particles are messengers and intimate players in cosmic processes, e.g. proto-planetary accretion disks and formation of planetesimals**
- **Like photons, dust carries information about its formation and history ('Dust Astronomy')**
- **Study of dust in space can provide important information on fundamental processes governing the formation of planetary systems**
- **Dust in a planetary system is the most processed of the different populations of cosmic dust**
- **Dust displays its presence impressively as cometary dust tails, the zodiacal light and 'dusty' planetary rings**
- **Dust is produced by endogenic and exogenic processes: collisions, condensation, sublimation, etc.**
- **In a dusty plasma dust traces plasma and magnetospheric conditions (charged dust behaves like ions in a magnetosphere).**
- **Solar system and planetary dust discs at Jupiter and Saturn are ideal places to study many of these processes**

⇒ ***Dust: A Tool to Study Astrophysical Processes***

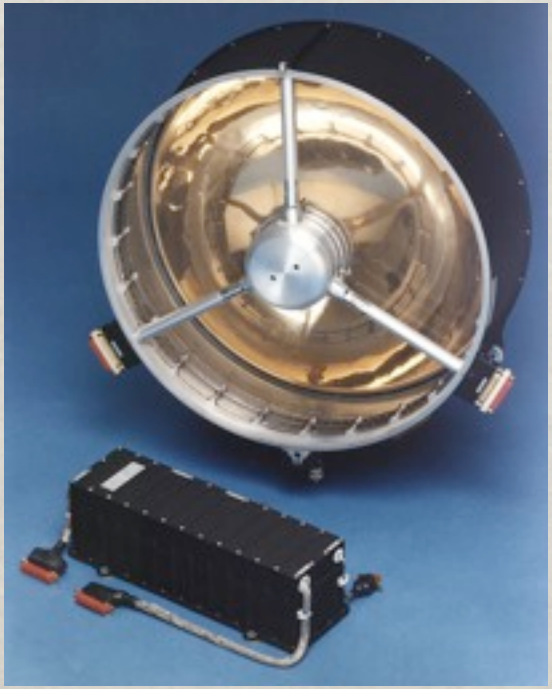
Galileo Spacecraft

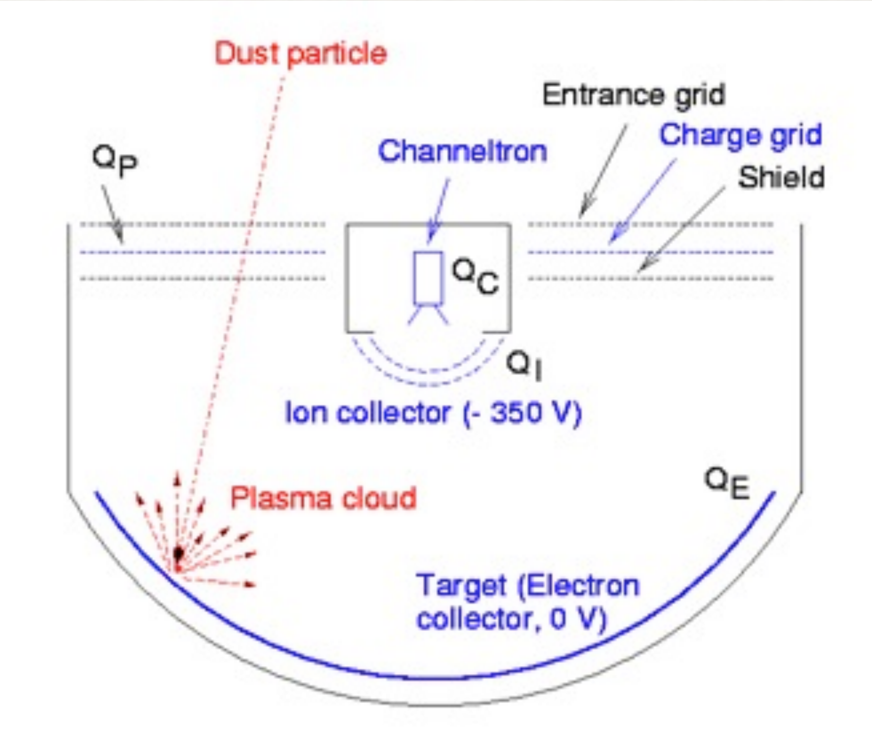


Nasa/JPL

Galileo/Ulysses In-Situ Dust Detectors

- Multi-coincidence impact ionization detector
- 0.1 m^2 sensitive area
- 140° field of view
- Measurement of mass, speed and impact direction
- Mass range: 10^{-19} - 10^{-9} kg (~ 0.1 - 10 µm radii)
- Speed range: 2 - 70 km s^{-1}

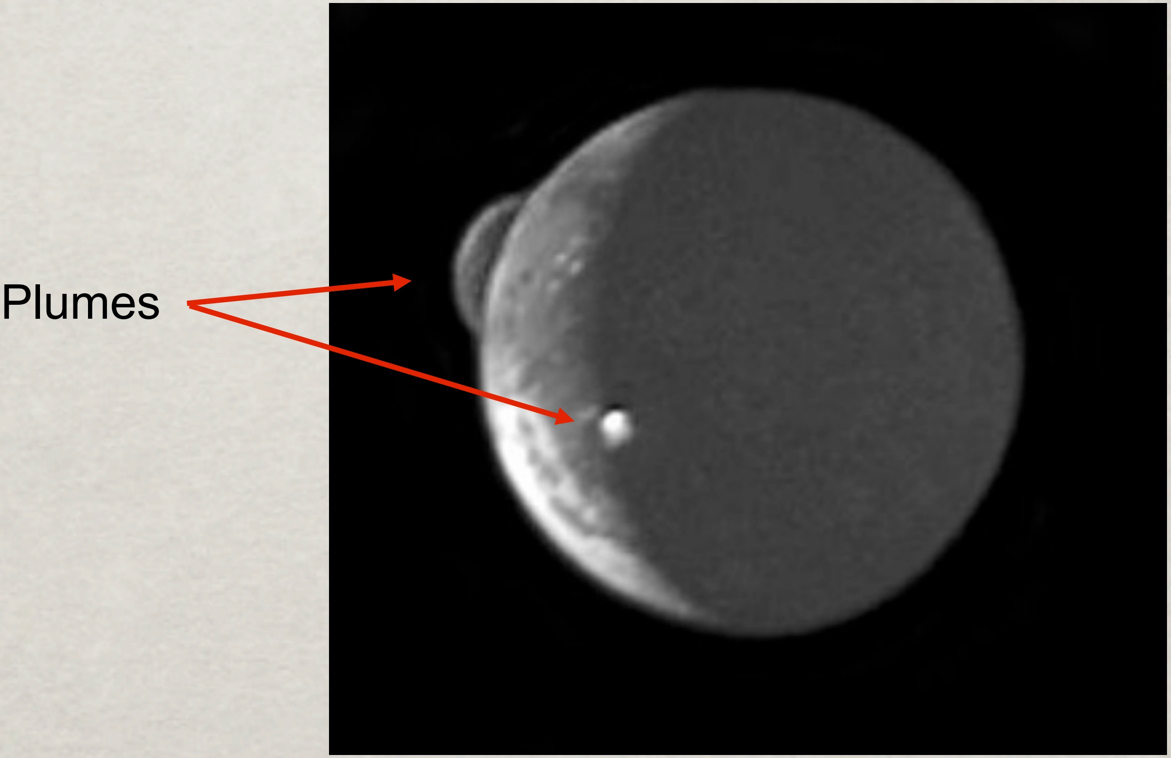




Dust at Jupiter

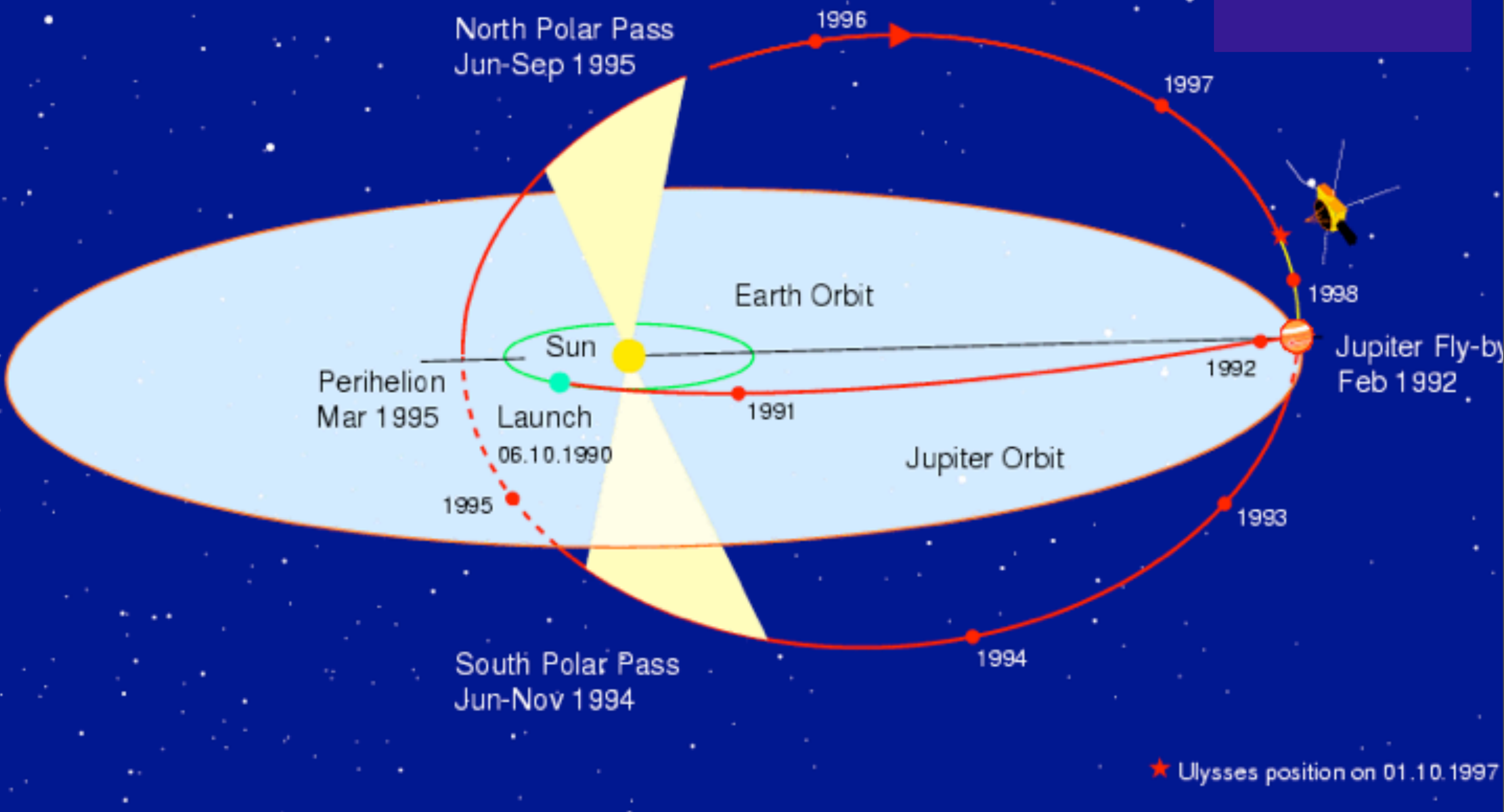
Voyager 1/2

- **Discovery of active volcanism on Io**
- **Can dust condensing in Io's plumes escape from Io?**
  (Johnson, Morfill and Grün, 1980)



Nasa/JPL

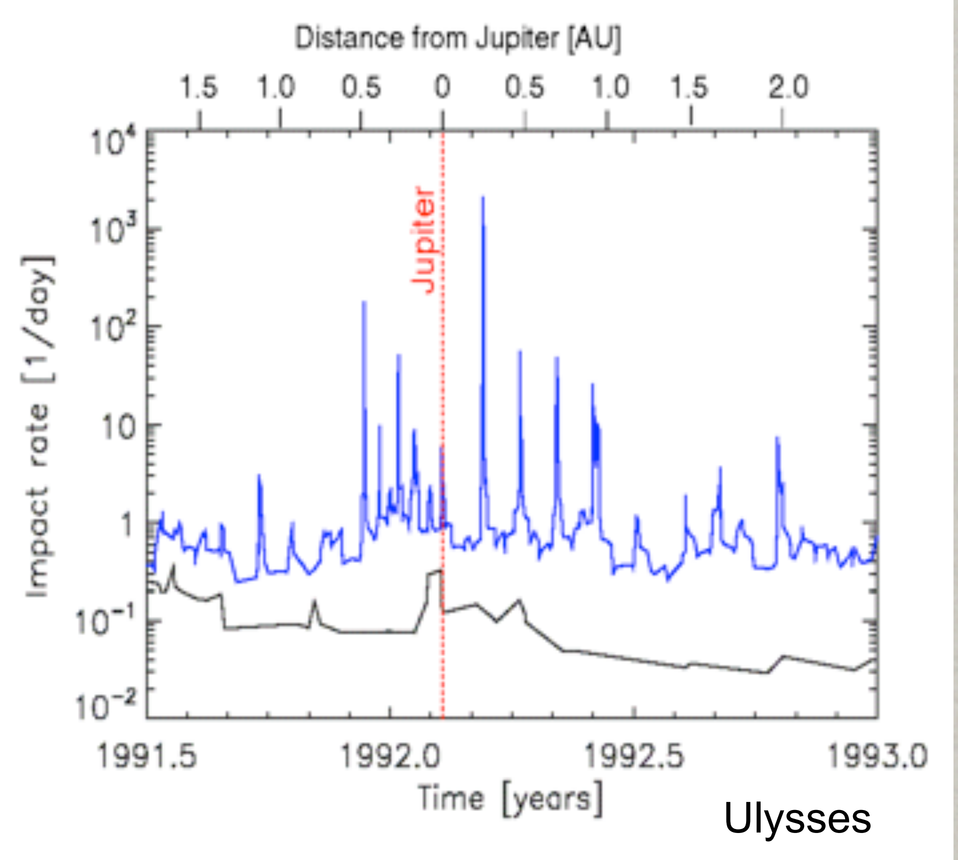
Ulysses First Solar Orbit



ESA

The Jovian System as a Source of Dust

- Streams of electrically charged dust grains emanating from the jovian system (Grün et al., 1993)
- 26 day periodicity
- Interaction with interplanetary magnetic field (Hamilton & Burns, 1993)
- Grain radii ~ 10 nm, speeds > 300 km/sec (Zook et al., 1996)
- Jupiter’s magnetosphere: giant dust accelerator
- Confirmed during 2nd Jupiter flyby of Ulysses in 2004 (Krüger et al., 2006)
- Stream formation connected with interaction with CIRs and CMEs (Flandes et al., 2011)



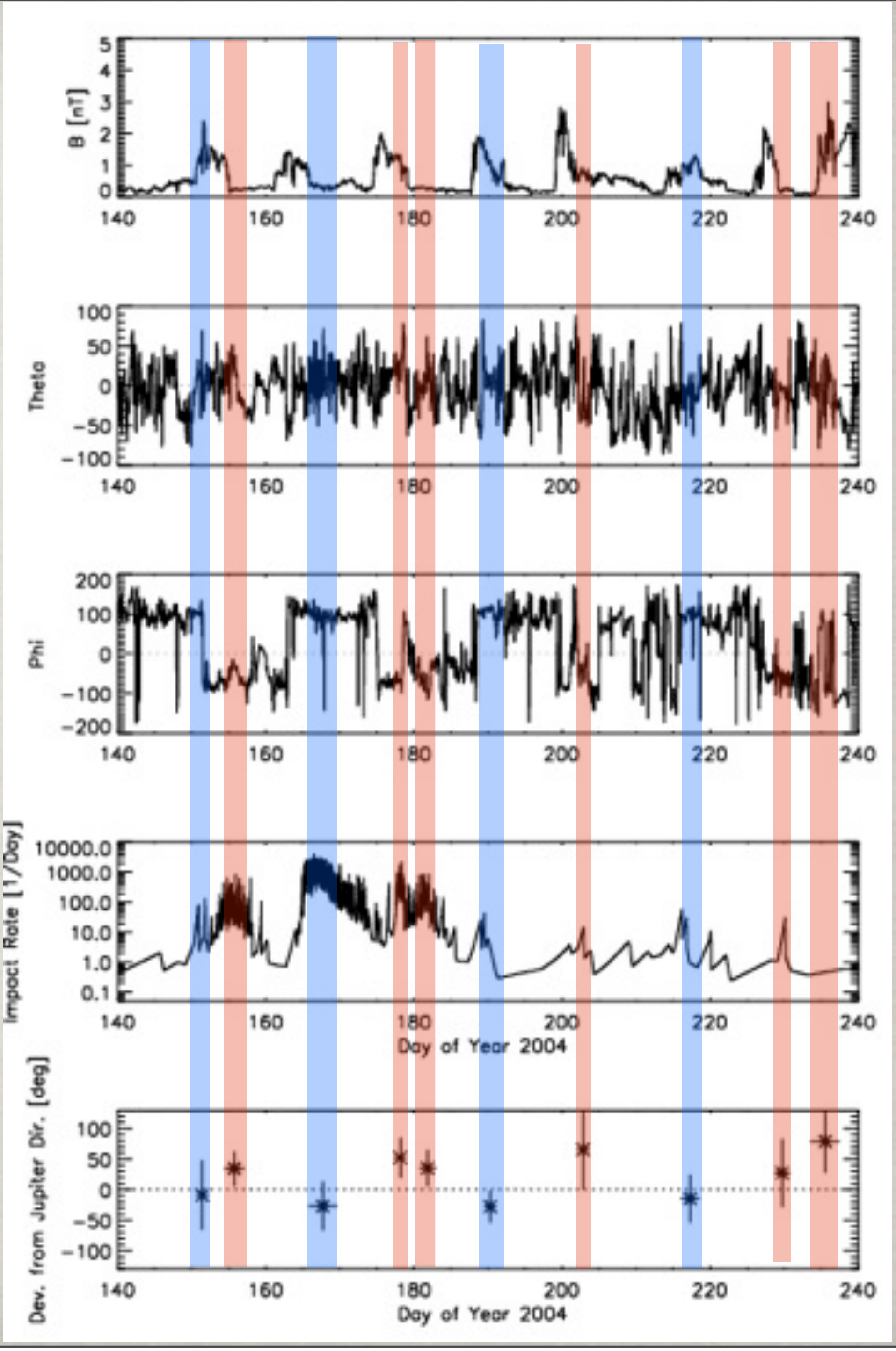
(Grün et al. 1994)

Correlations with IMF

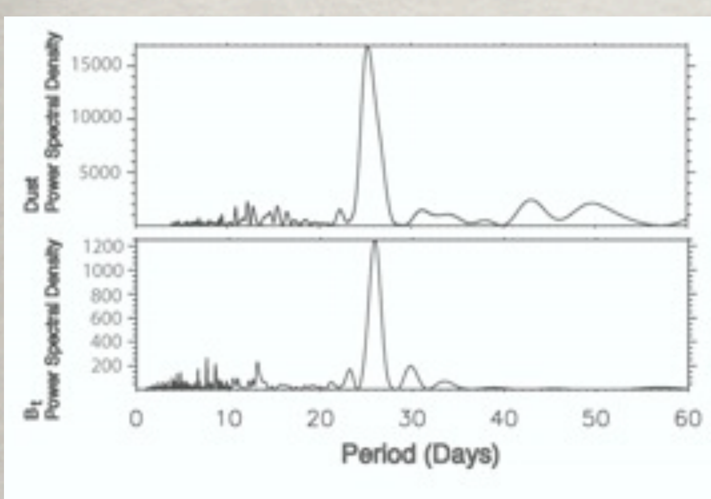
Magnetic Field:

Red: B_r points sunward

Blue: B_r points anti-sunward



Dust:

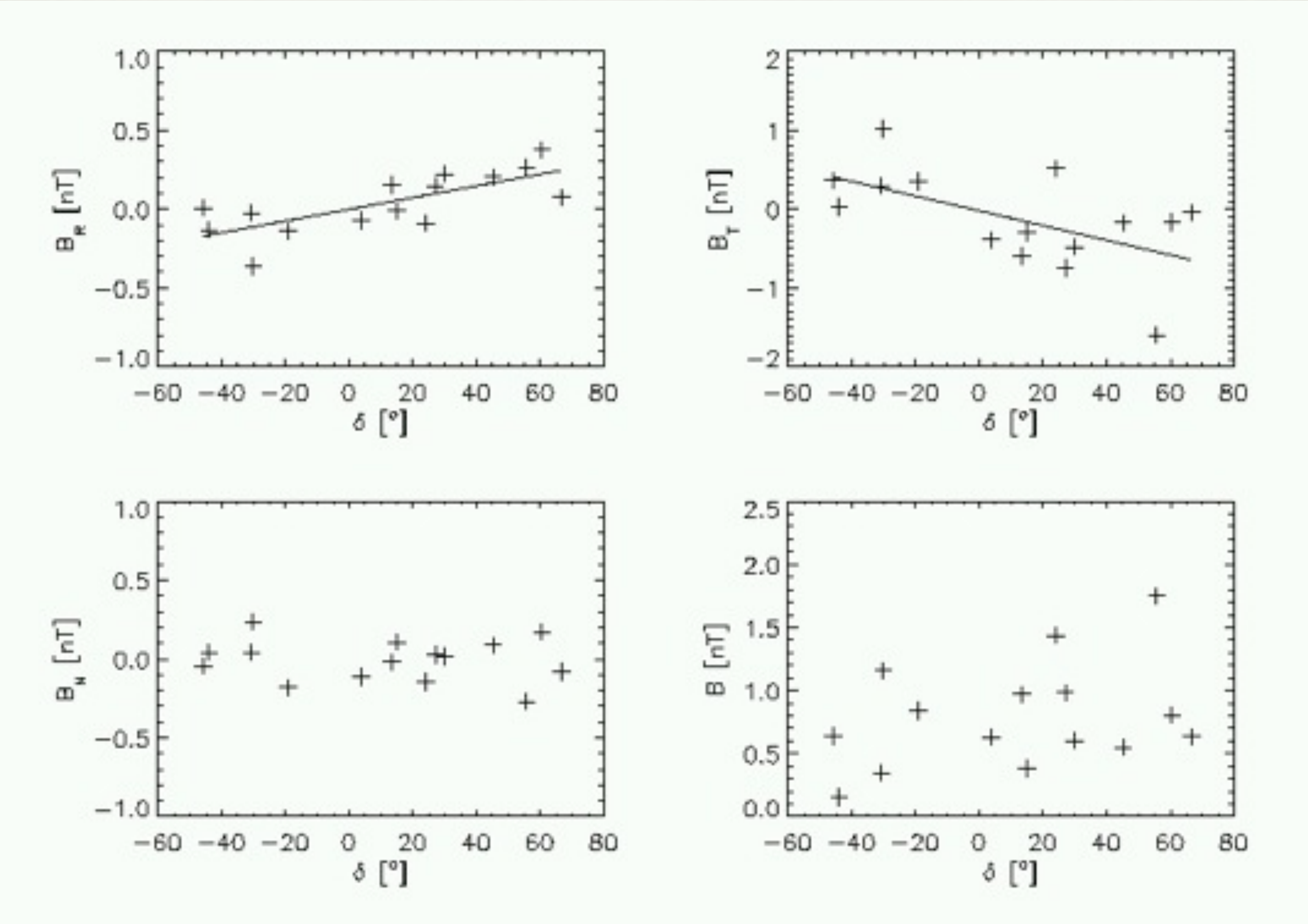


(Krüger et al. 2006)

Vertical bars: 1σ standard deviation

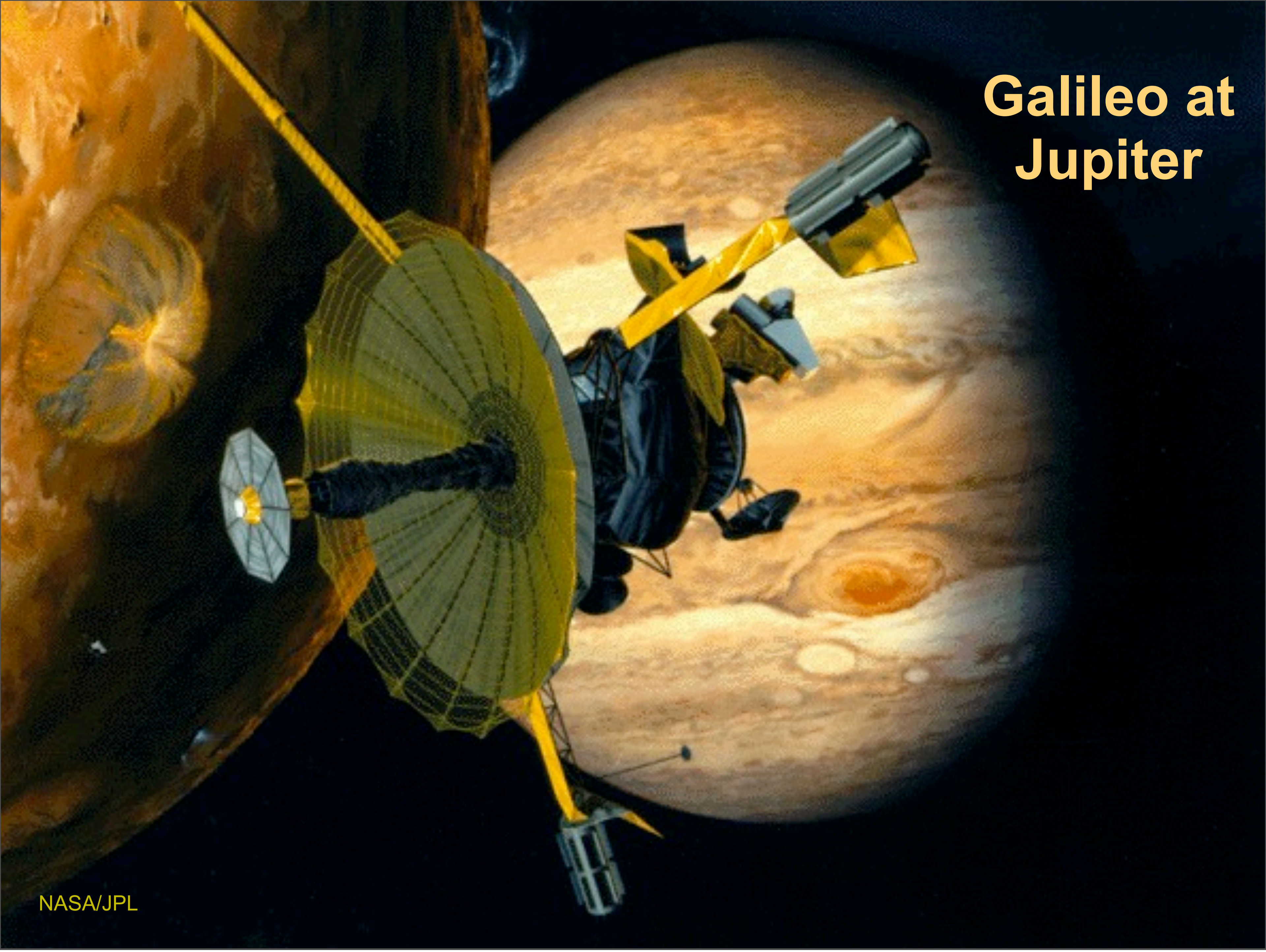
Correlations with IMF

Dust streams detected in 2004 ($-9^\circ < \beta_{ecl} < +10^\circ$; $-20^\circ < \beta_{jup} < +70^\circ$)
Deviation of streams from Jupiter line-of sight direction correlates with B field!



(Krüger et al. 2006)

Galileo at Jupiter

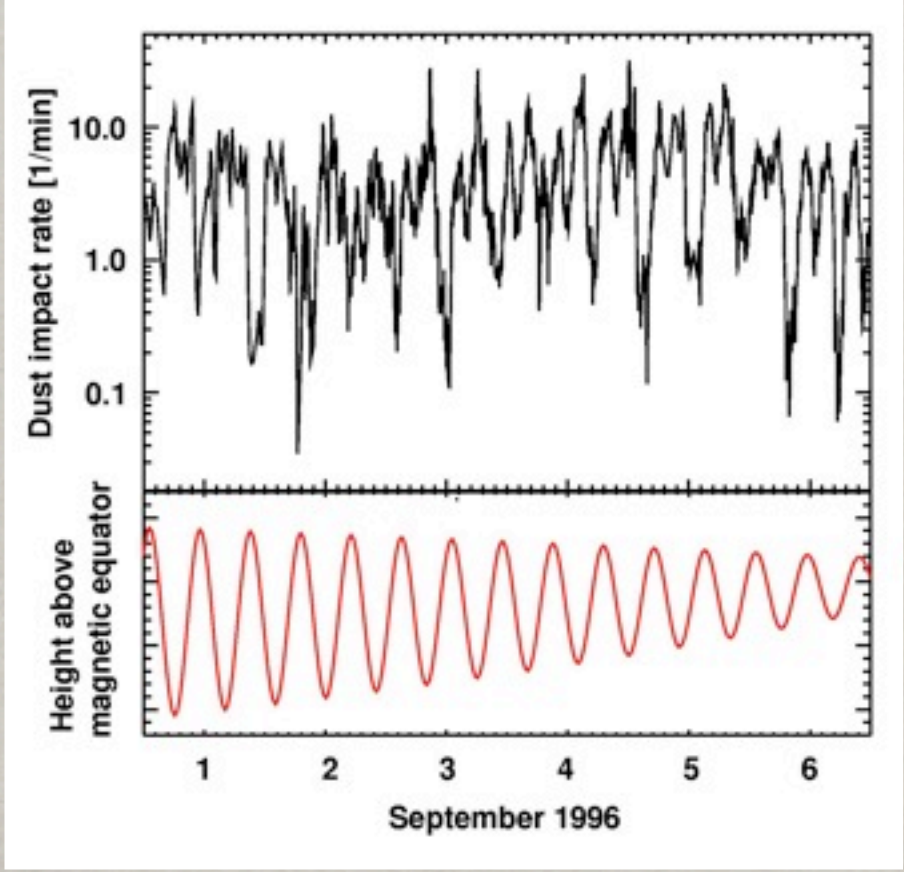


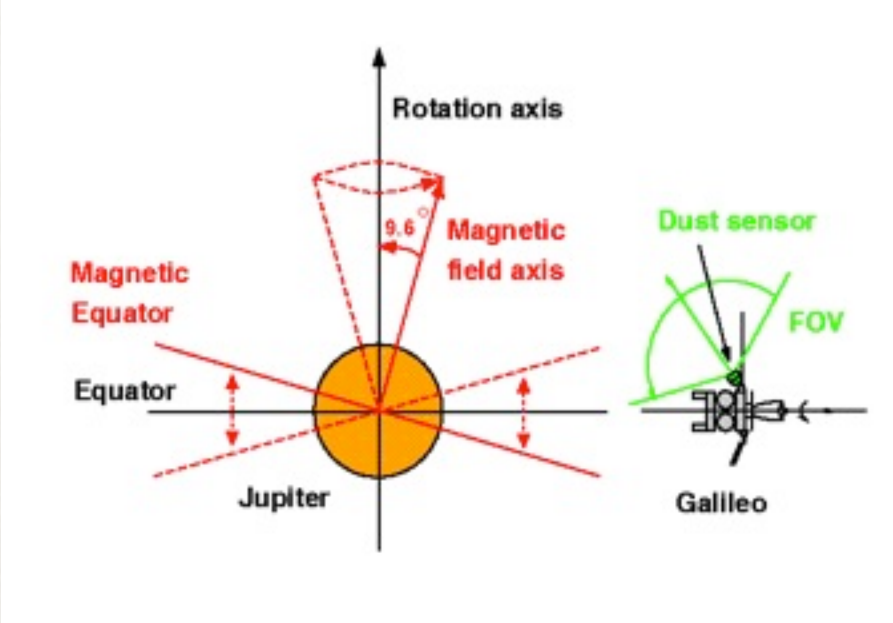
NASA/JPL

Electromagnetically Interacting Dust at Jupiter

5 and 10 hour periodicities: dust impact rate correlated with Jupiter’s 10 hour rotation period

⇒ grains strongly coupled to Jupiter’s magnetic field.





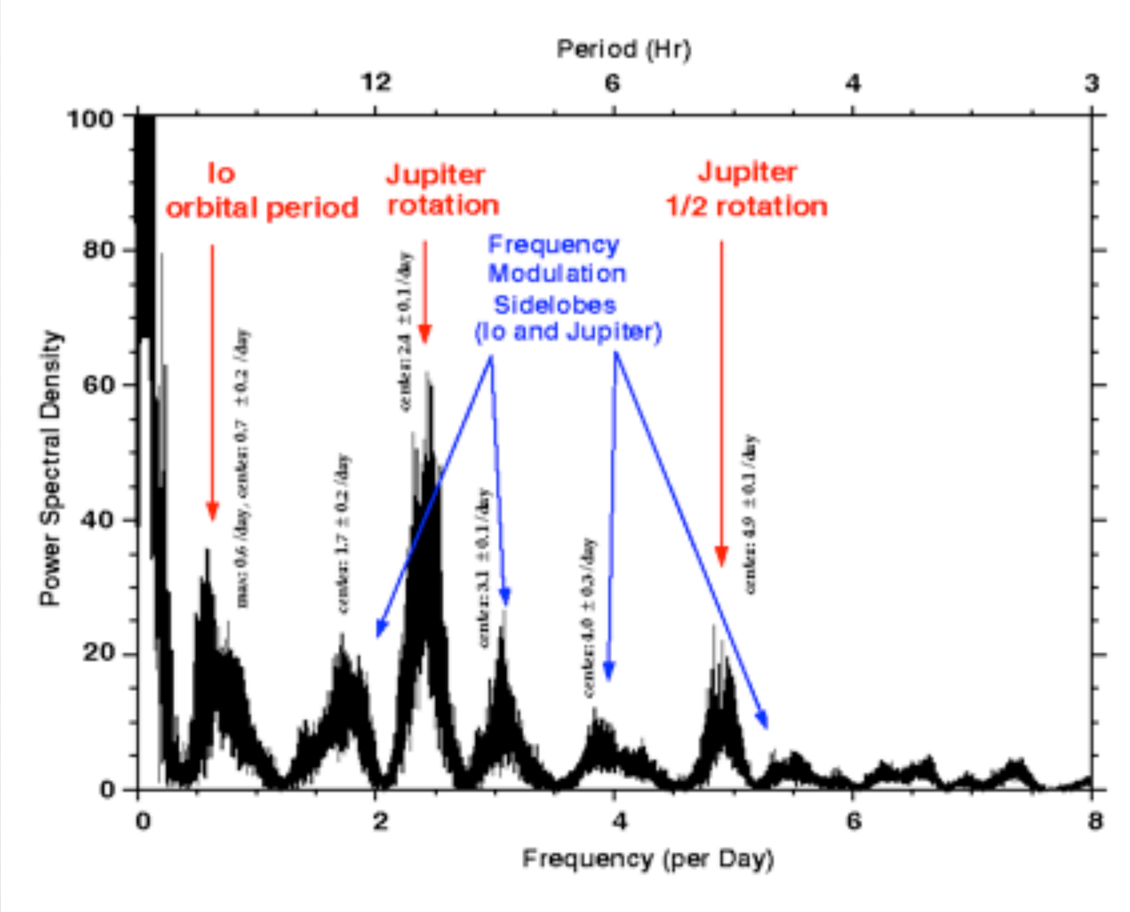
(Grün et al. 1998)

Jupiter Dust Streams: Electromagnetically Interacting Dust

5 and 10 h periodicities: dust particles couple with jovian magnetic field

~ 42 h periodicity imposed by Io's orbital period (Io signature)

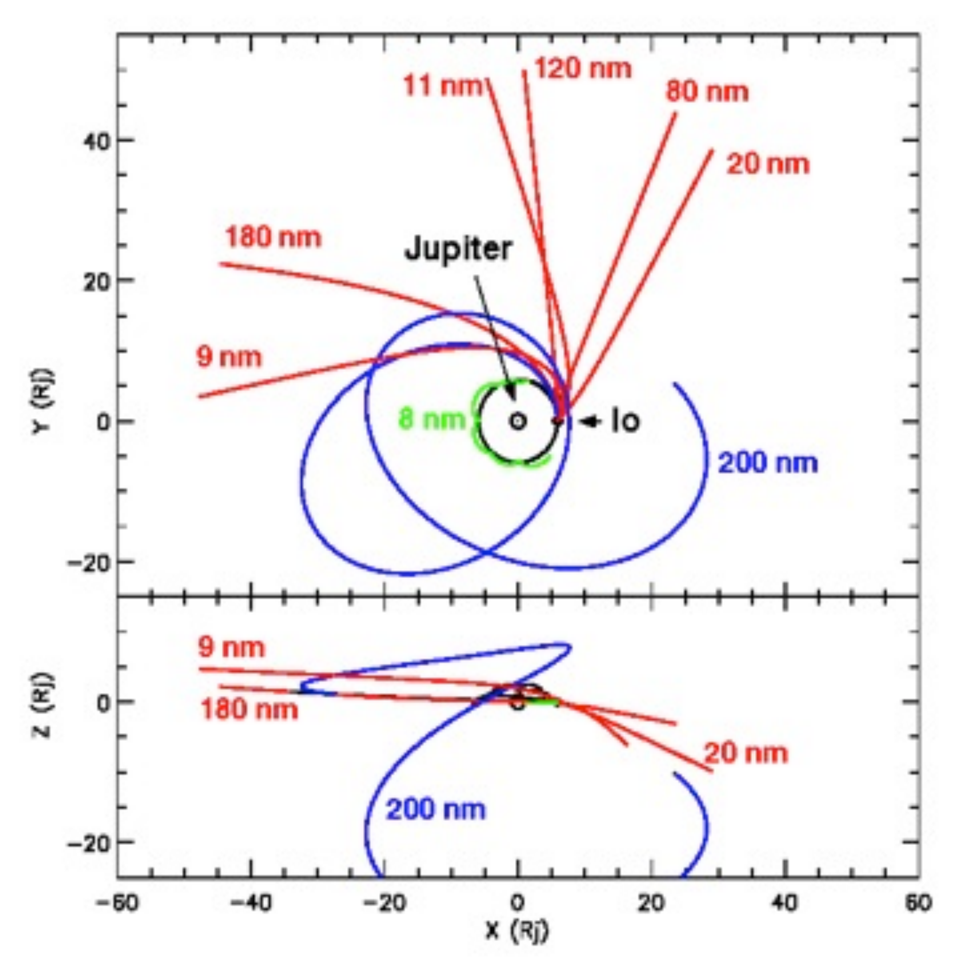
⇒ Io acts as point source for dust particles



(Graps et al. 2000)

Jupiter's Magnetosphere: A Giant Mass Spectrometer

- **Grains released from Io source**
- **Charged to +5 V in plasma torus (secondary electron emission)**
- **Accelerated by co-rotational electric field**
- **Size- dependent dynamics:**
  - **s > 200 nm: captured by Jupiter's grav. field**
  - **9 < s < 200 nm: escape from Jovian system**
  - **s < 9 nm: captured by Jupiter's magn. field**
- **Main acceleration within ~ 10 R_J from Jupiter**

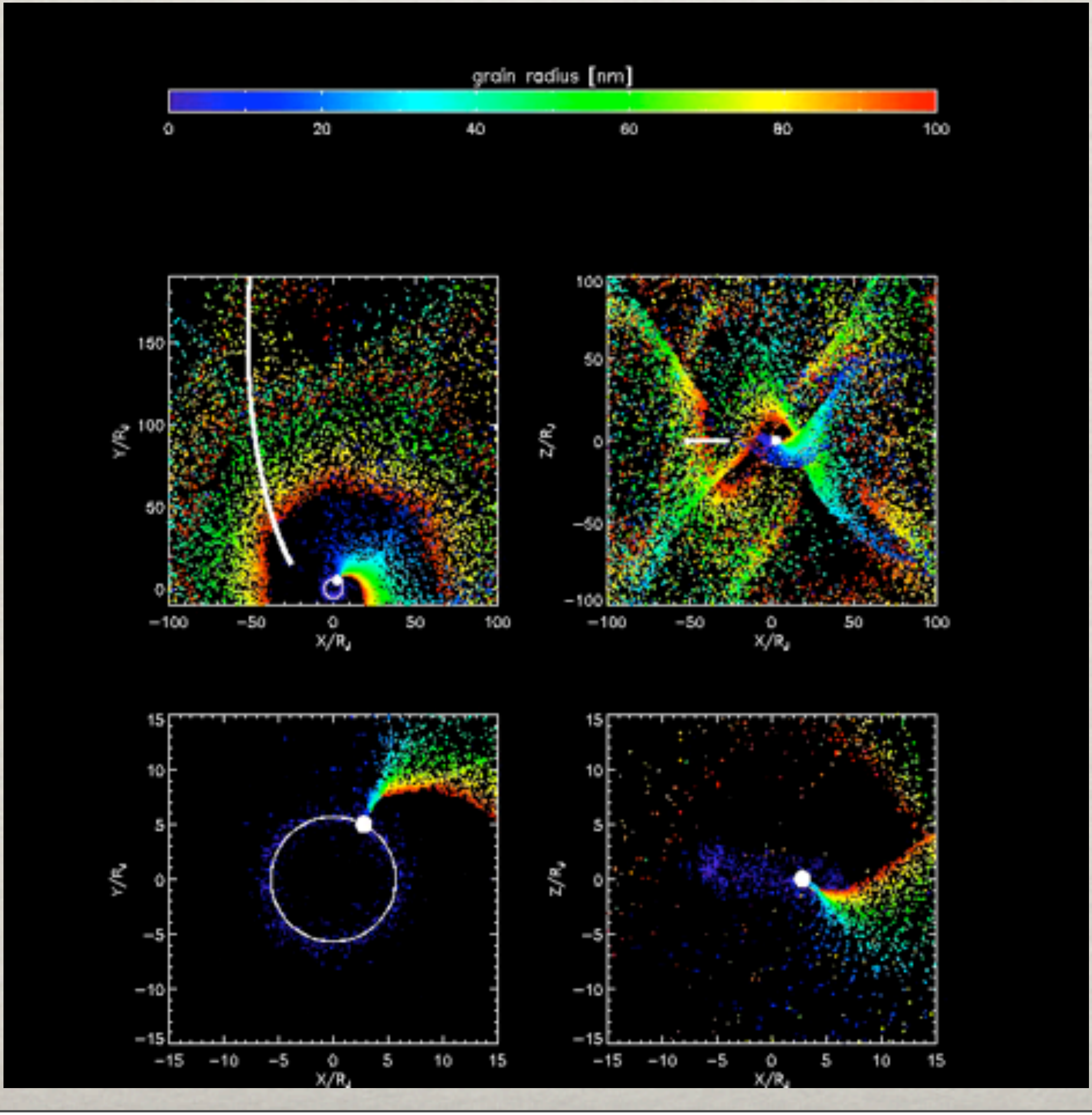


(Horanyi et al. 1993,1997, Hamilton & Burns, 1993; Grün et al. 1998)

Jupiter’s Dusty Ballerina Skirt

Horanyi 2000

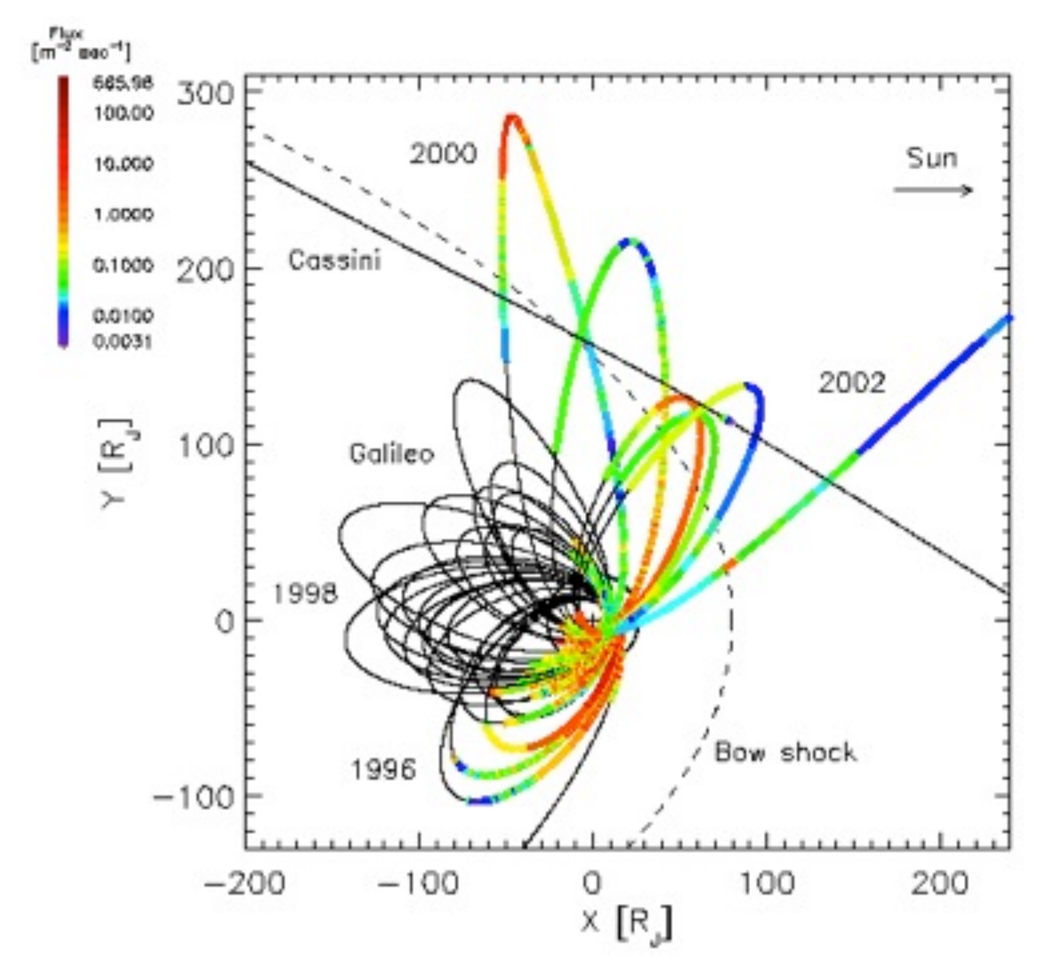
Jupiter’s Dusty Ballerina Skirt



Horanyi 2000

Dust Streams: A Monitor of Io's Volcanic Activity

NASA/JPL **Io, Galileo**

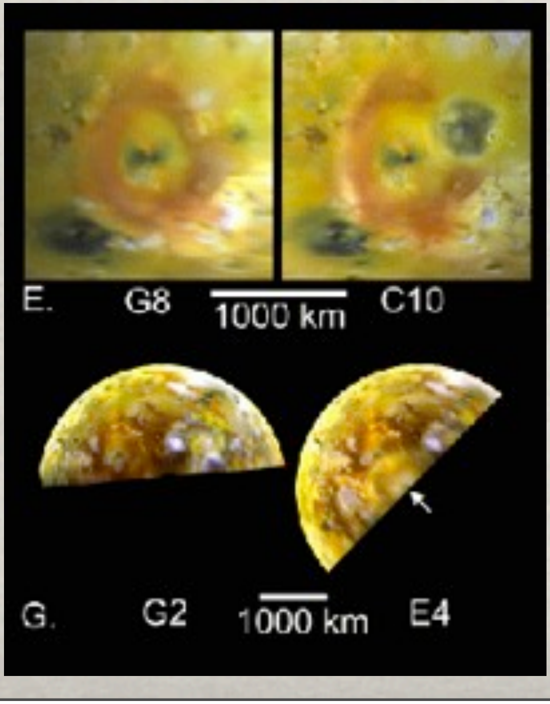


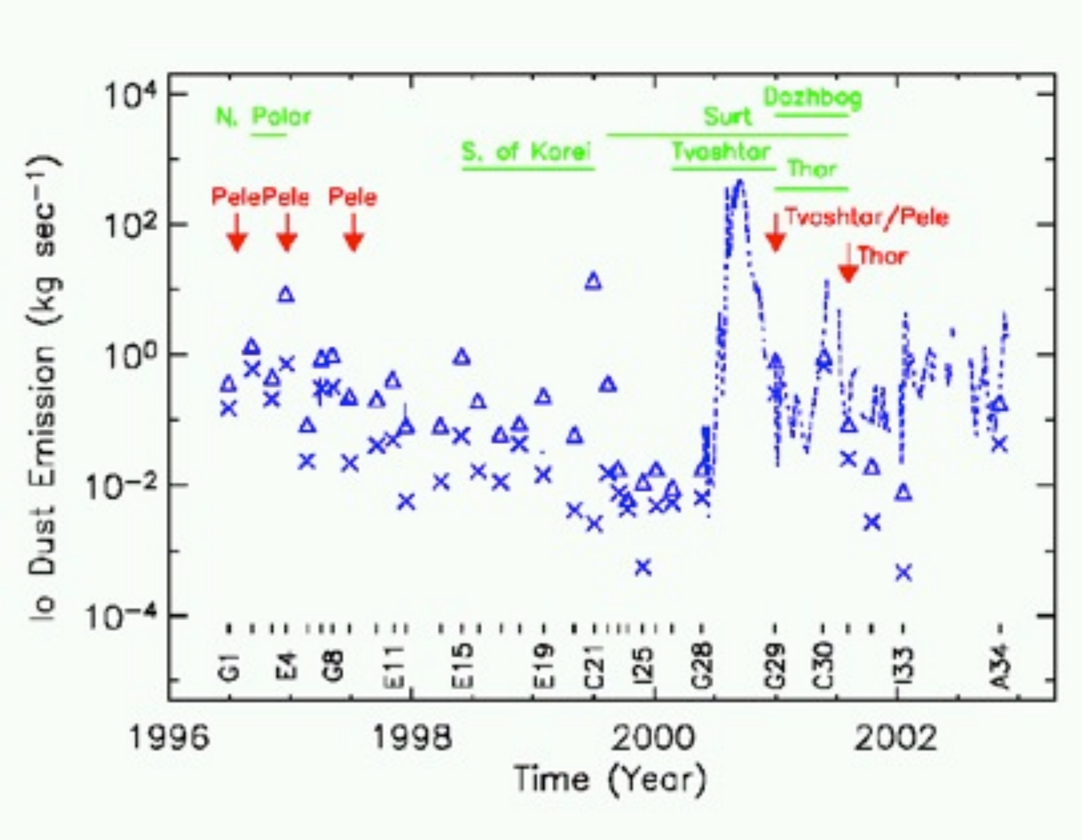
Galileo trajectory with dust flux superimposed (Krüger et al. 2005)

Dust Streams: A Monitor of Io's Volcanism

Io, Galileo NASA/JPL

- **Average Io dust emission ~ 0.1 - 1 kg s^{-1}**
- **Small compared to ~ 1 ton s^{-1} of plasma ejected**
- **Strong peaks in dust emission coincide with largest surface changes**
- **Dust condenses in Io’s plumes**

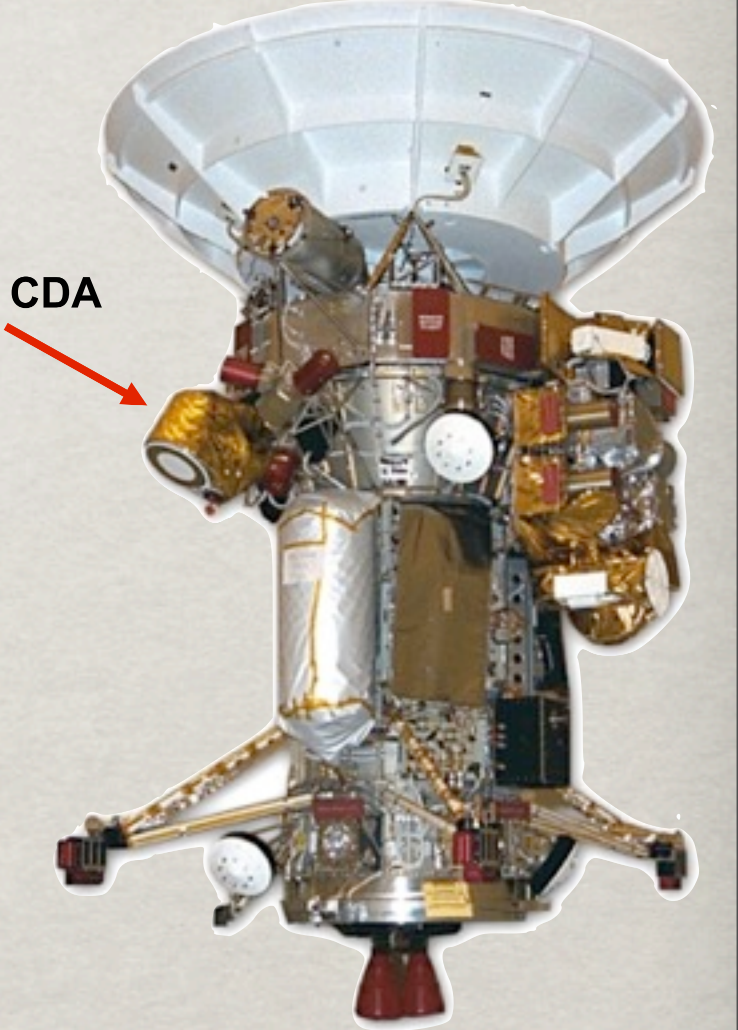




Krüger et al., 2003

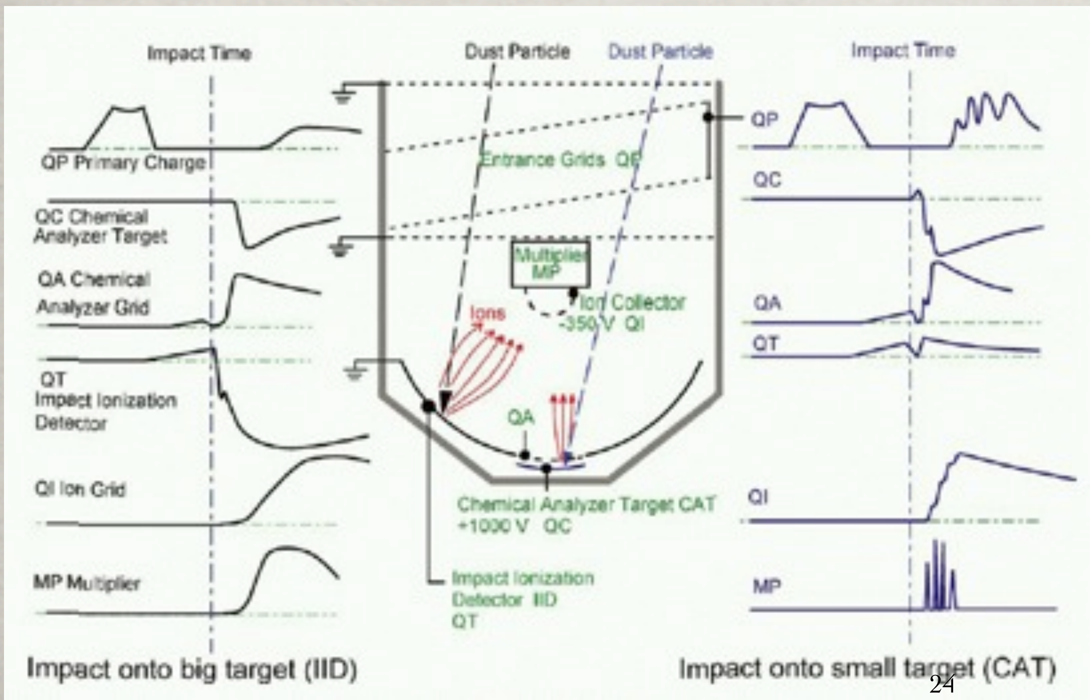
Cassini Cosmic Dust Analyser

- Impact Ionisation Detector
- Sensor area 0.1 m^2
- Mass, speed, impact direction, charge, composition
- Calibrated: 2 – 100 km s^{-1}
- Grain sizes: ~ 0.1 – 10 µm



Cassini

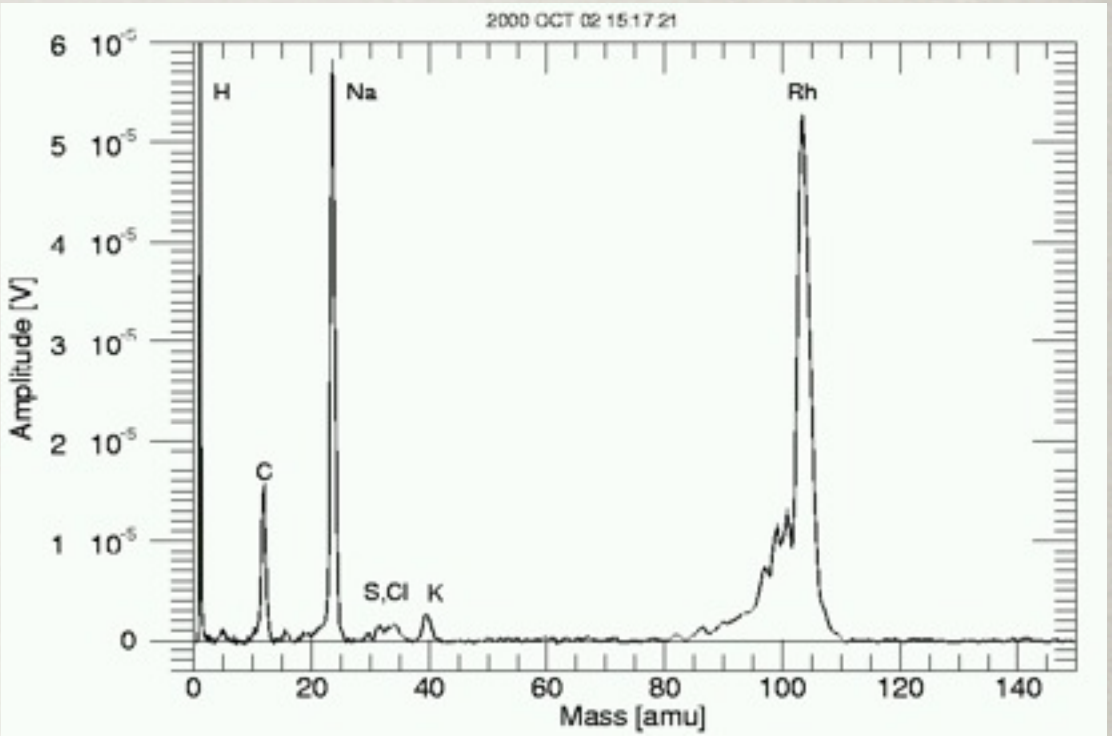
NASA/JPL



Srama et al. 2004

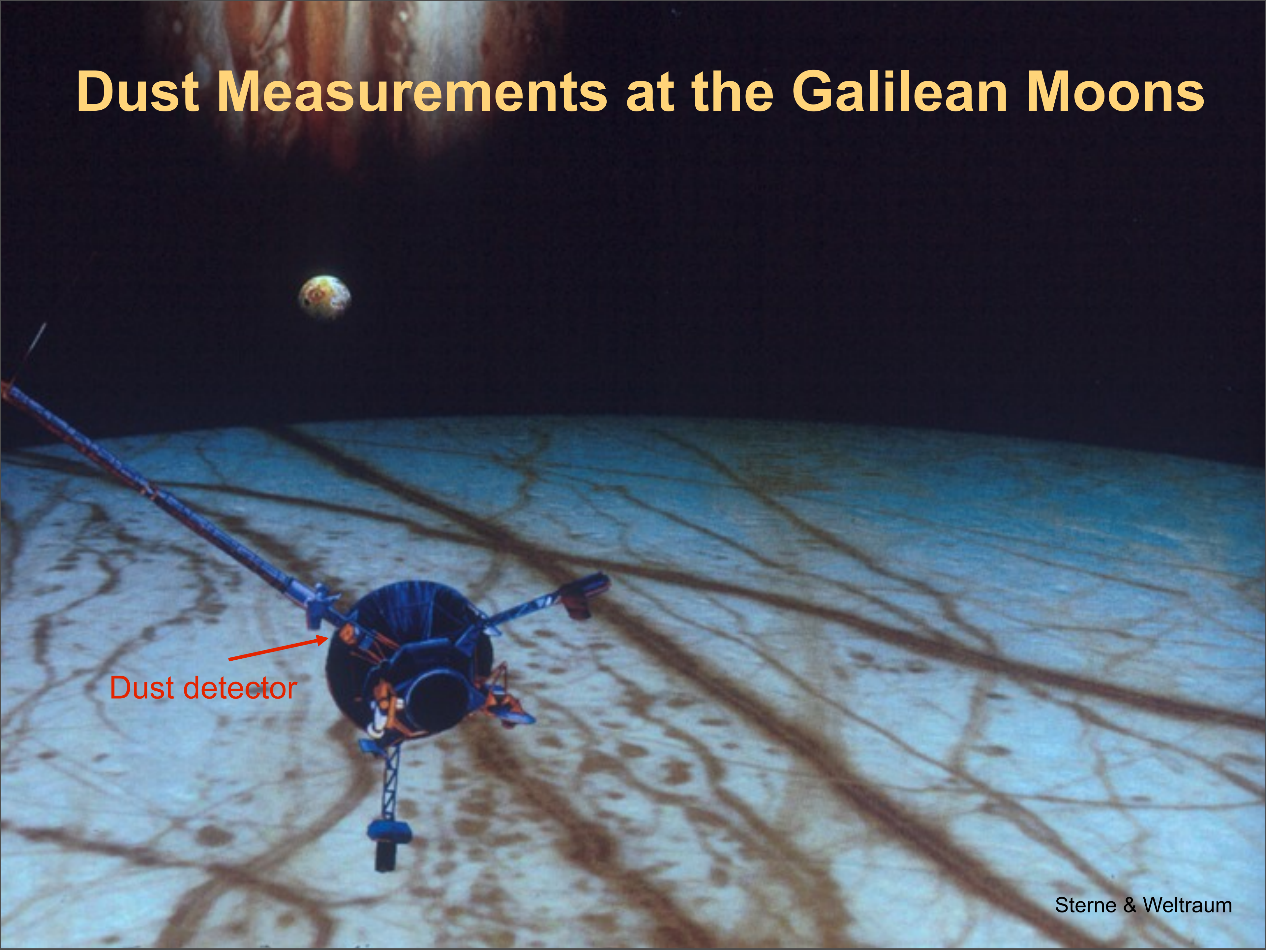
Composition of Io Dust Grains

- **287 Cassini mass spectra measured within 1 AU of Jupiter**
- **NaCl main constituent of grains (consistent with thermochemical condensation models,** Schaefer & Fegley 2005**)**
- **S other important component (also observed in volcanic plumes,** Spencer et al. 1996**)**
- **K minor component**
- **Low silicate component**



Postberg et al., 2006

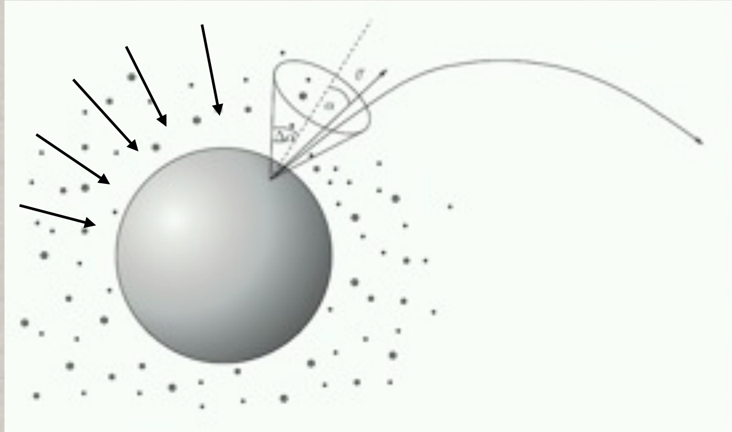
Dust Measurements at the Galilean Moons



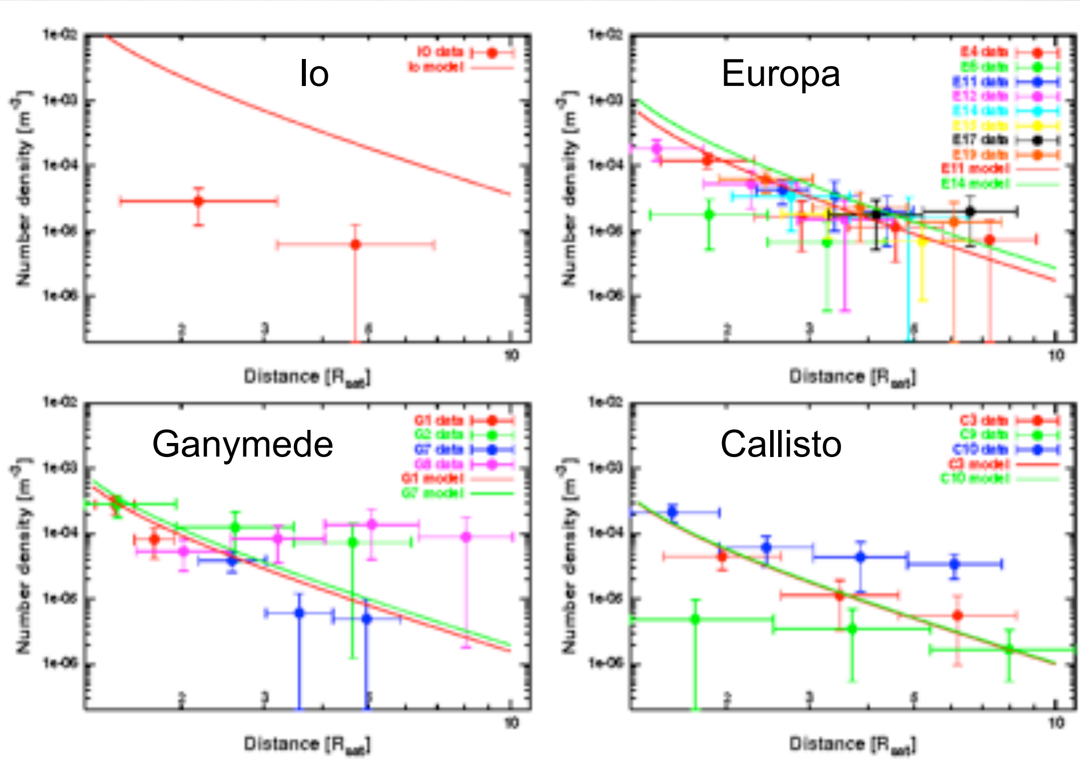
Sterne & Weltraum

Dust Clouds Surrounding Galilean Moons

- Dust concentrations detected within the Hill spheres of the Galilean moons.
- Grains ejected from surfaces by impacts of interplanetary micrometeoroids.
- Most grains follow ballistic trajectories forming dust clouds around the moons.
- Europa, Ganymede, Callisto consistent with solid ice-silicate surface (Io fluffier?)
- All celestial bodies without an atmosphere surrounded by a dust cloud.
- Analysis of grains can provide compositional information of the moons.



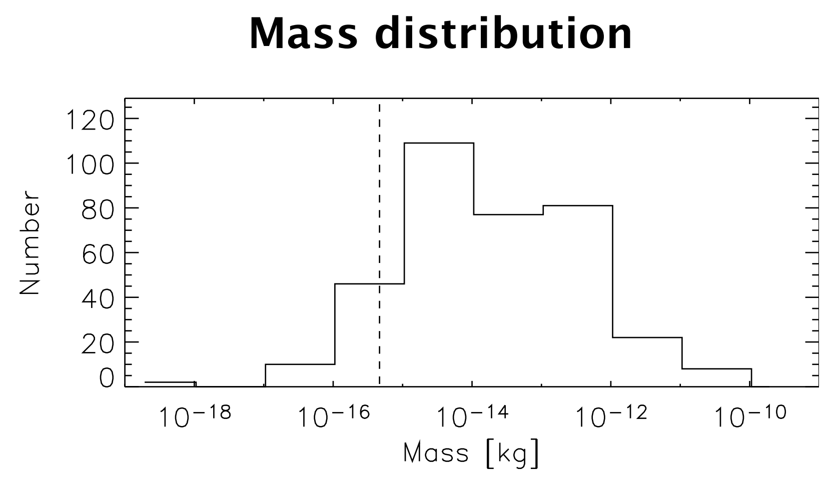
Krüger et al. 1999, 2003; Krivov et al., 2002; Sremcevic et al., 2003



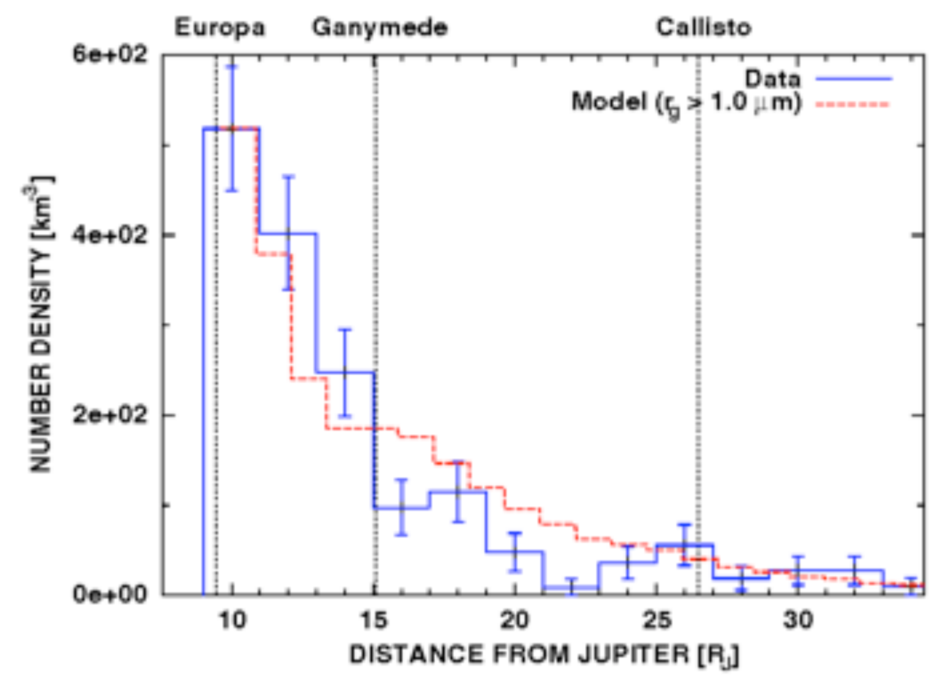
Tenuous ‘Galilean’ Dust Ring

At least two dust populations identified between Galilean moons (~ 6 - 30 R_J):

- **Prograde grains ejected from Galilean moons (Krivov et al. 2002)**
- **Retrograde grains captured by Jupiter's magnetosphere (Colwell et al. 1998)**
- **Sizes: ~ 0.6 - 2 µm**
- **Ring normal optical depth: $\tau < 10^{-9}$ (i.e. not optically detectable)**



Krüger et al. 2006



Krivov et al., 2002

3 | 2009

STERNE UND WELTRAUM

astronomie-heute.de

Im Schatten des Jupiter

Monde, Staub und Ringsystem

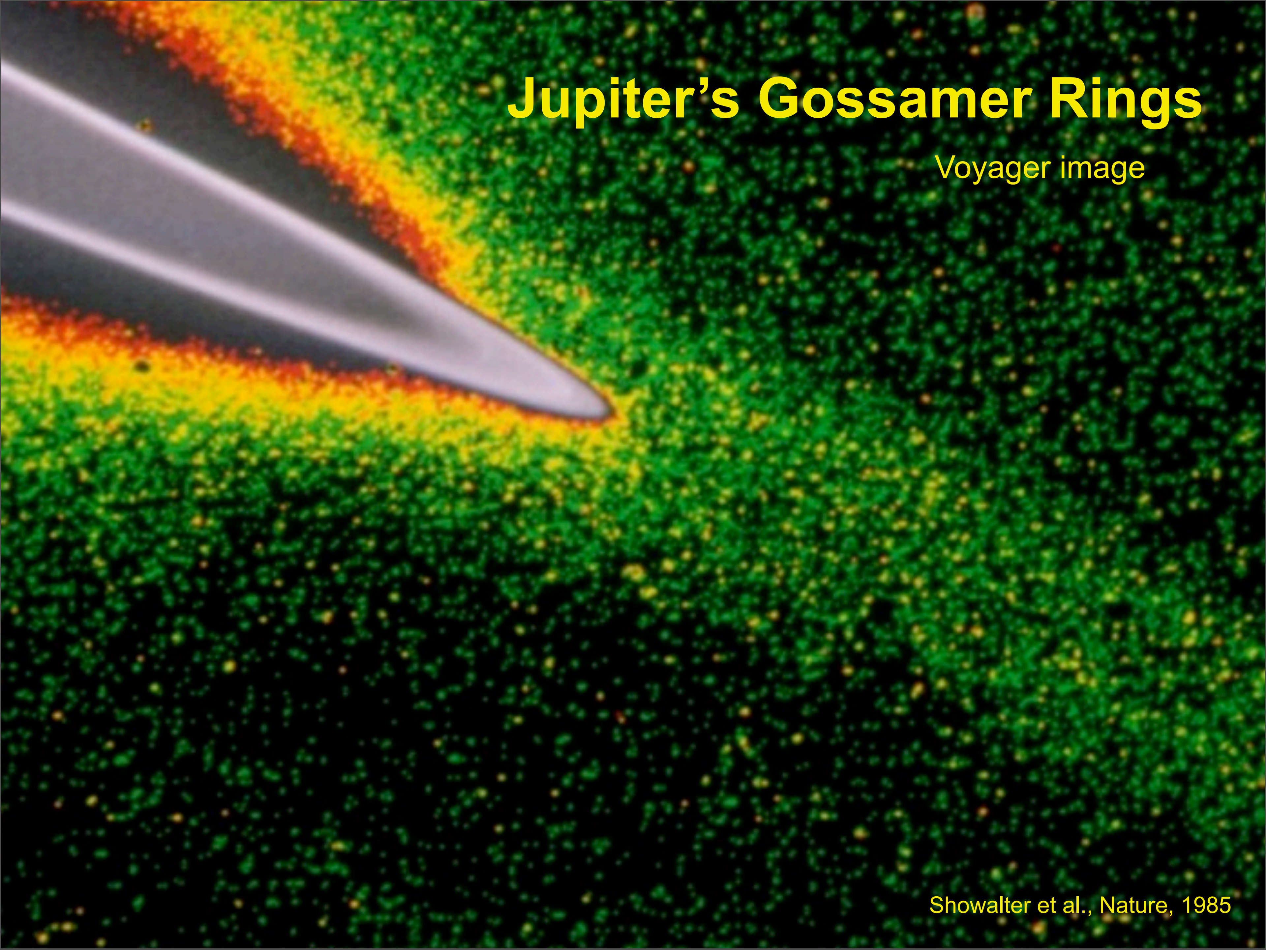
GAMMA-ASTRONOMIE
Das Rätsel der kosmischen Energieschleudern

PREIS DER ERKENNTNIS
Die Augenschmerzen der frühen Sonnenforscher

PRAXISTIPP
Ein Radioteleskop für die Schule

SKY QUALITY METER
Die Aufhellung des Himmels messen

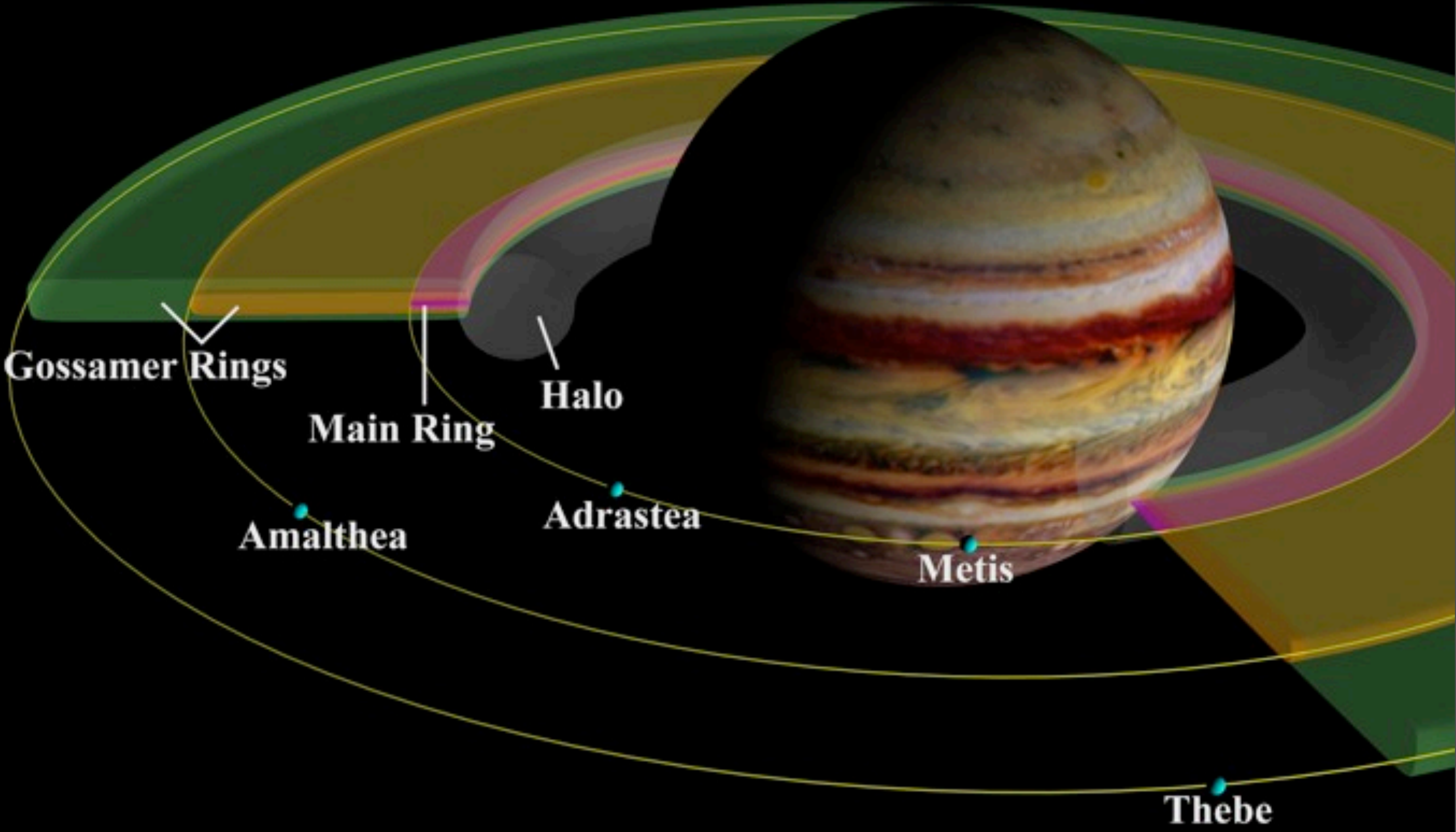
Jupiter’s Gossamer Rings



Voyager image

Showalter et al., Nature, 1985

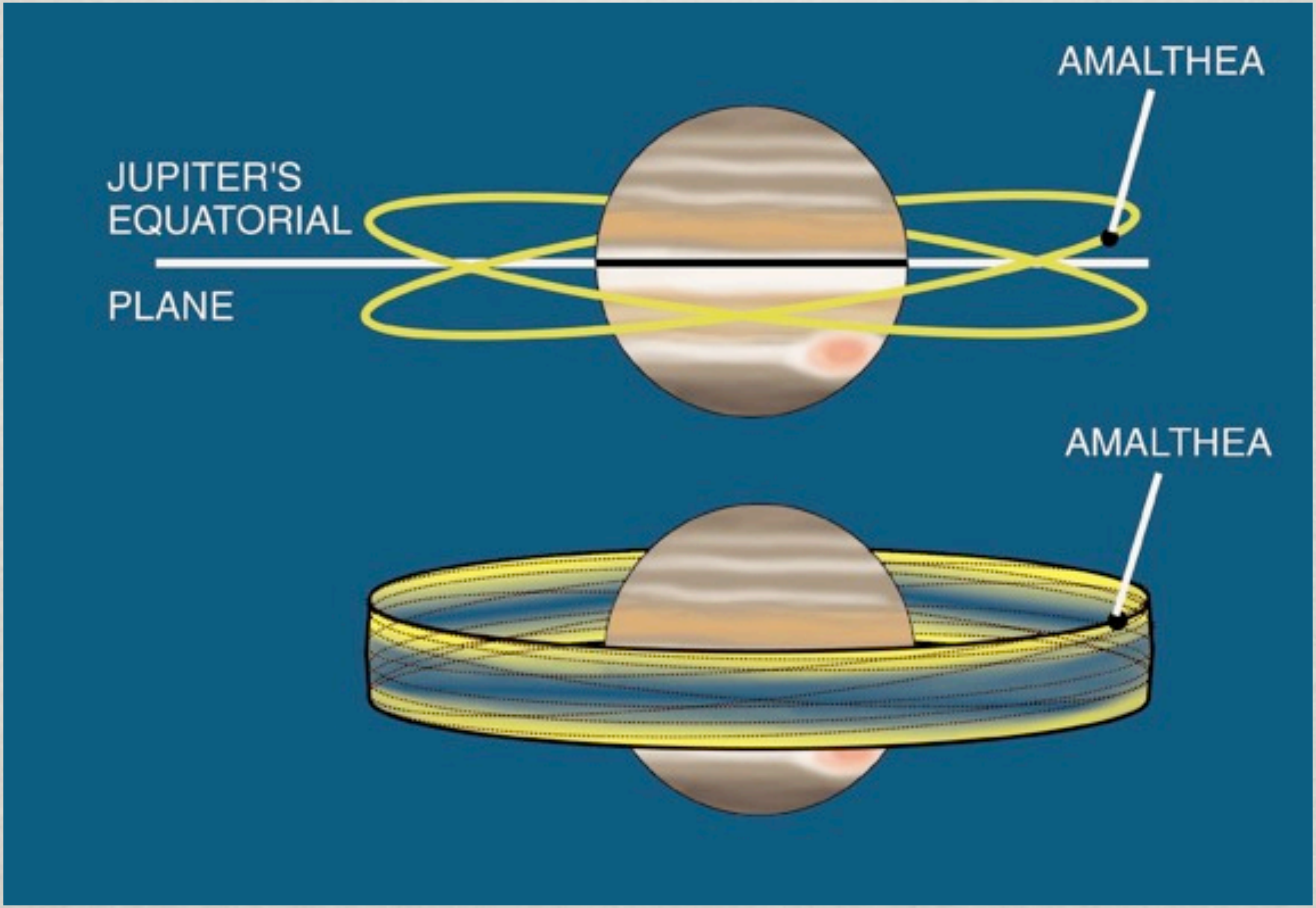
Jupiter’s Gossamer Rings



From Ockert- Bell et al., 1999

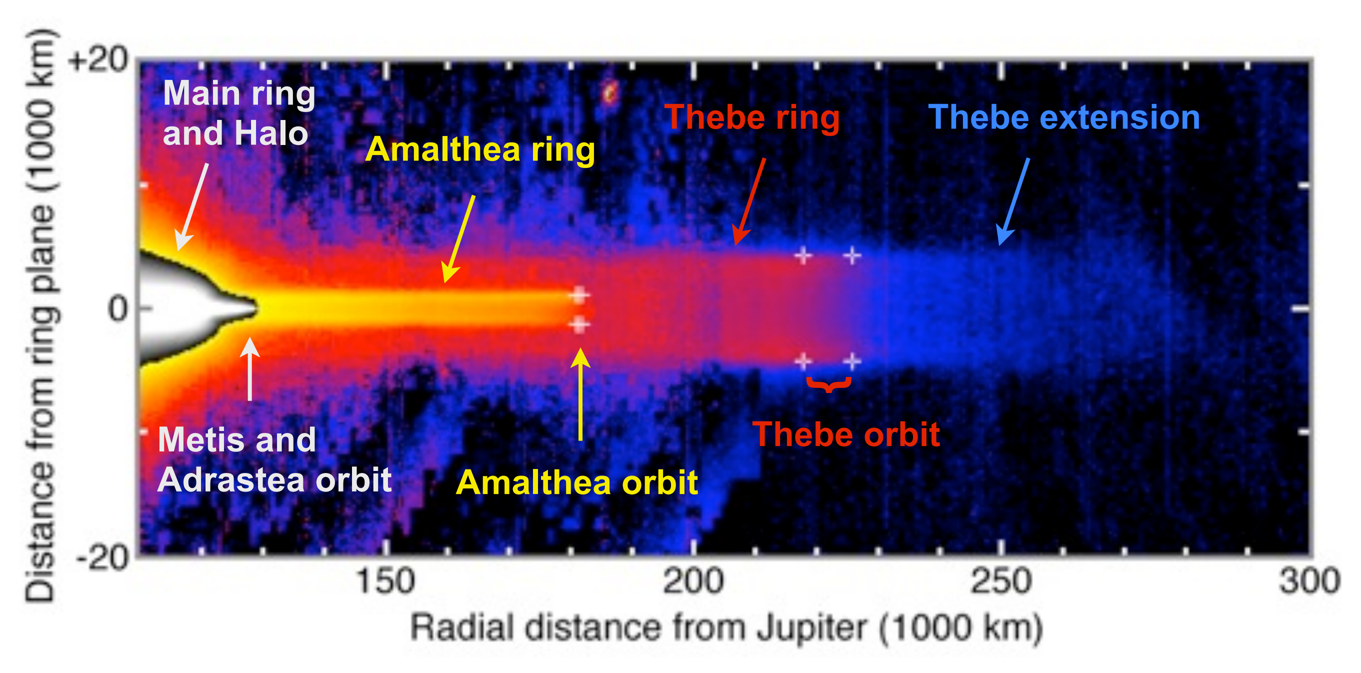
Vertical Extension of Gossamer Rings

Particles released from Amalthea are distributed along Amalthea’s orbit



Burns et al., 1999

Jupiter’s Gossamer Rings



Burns et al., 1999

Main ring structures: main ring and halo, Amalthea and Thebe rings (Burns et al., 1999; dePater et al., 1999, Ockert-Bell et al., 1999)

Most structures constrained by orbits of small moons Adrastea, Metis, Amalthea and Thebe

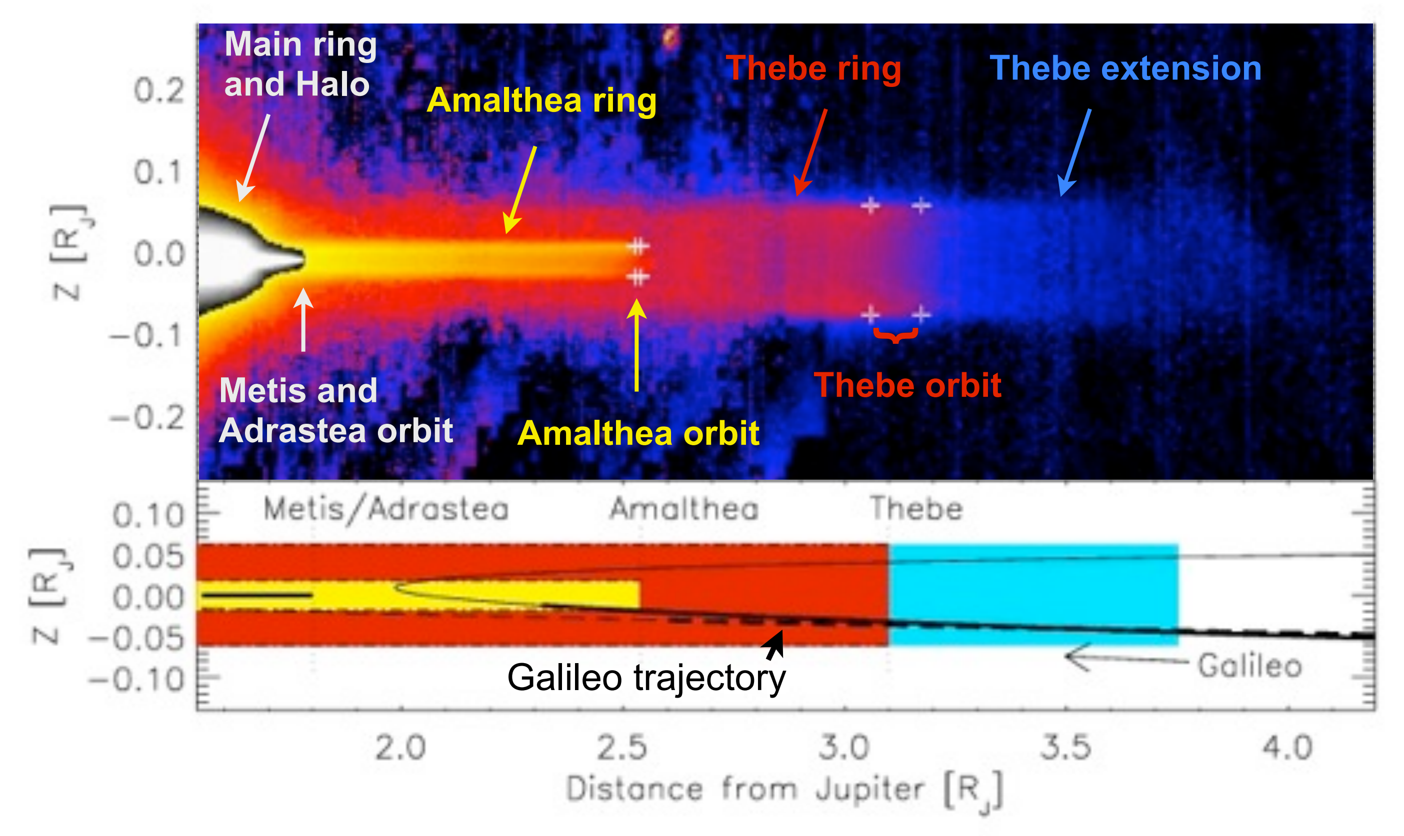
Ring particles are ejecta from small inner regular moons.

Grain sizes 5 - 10 µm, normal optical depth 10^{-7} - 10^{-8} (Showalter et al., 2008)

Ejecta particles move inward under Poynting-Robertson drag (Burns et al., 1999)

Unexplained outward protrusion called Thebe extension.

Galileo Gossamer Ring Passages



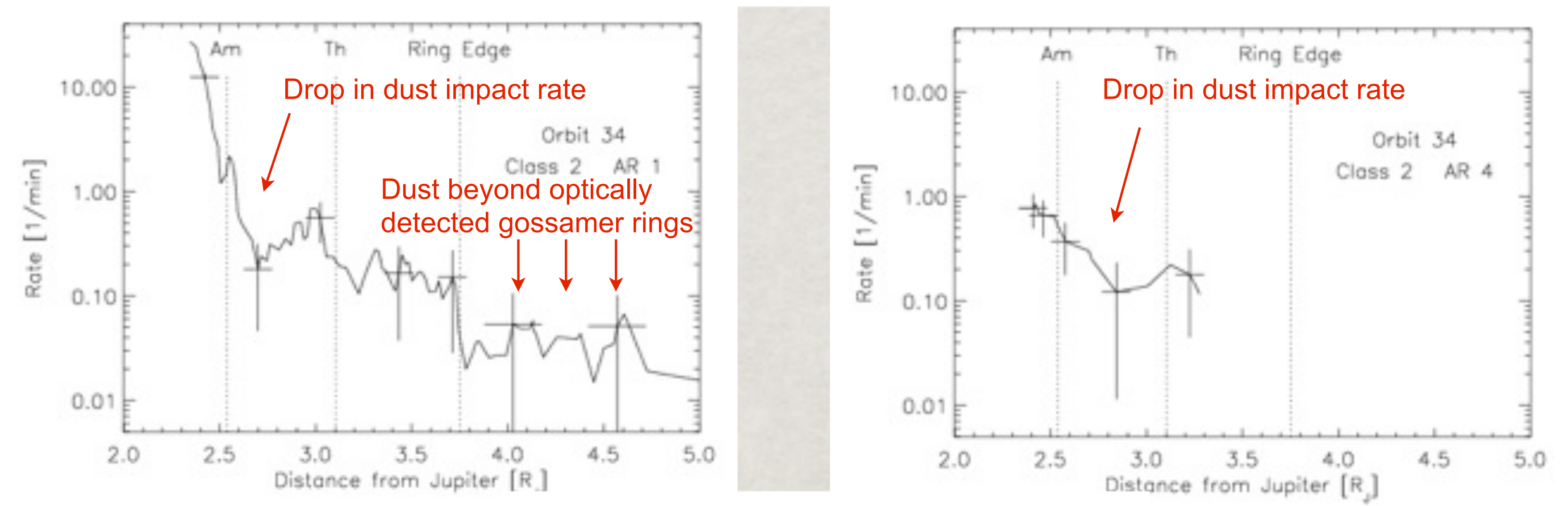
Two Galileo ring passages in 2002 and 2003

Gossamer Ring: Dust Impact Rate

Submicron

First gossamer ring passage

Micron-sized

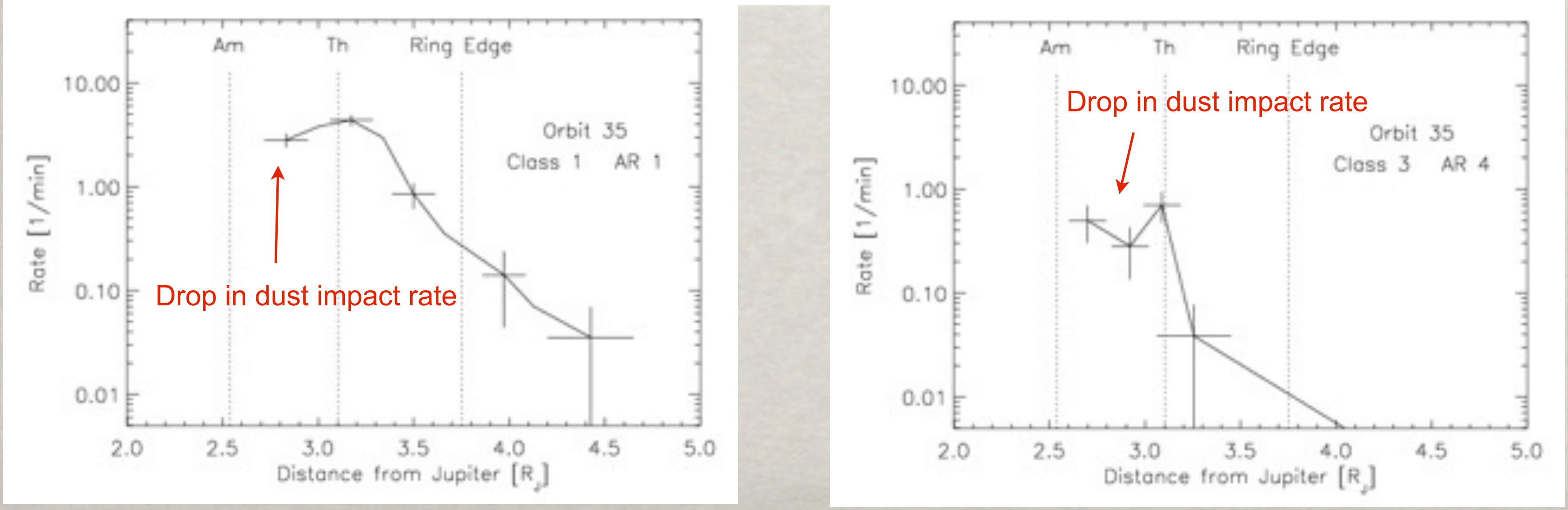


Drop in dust impact rate

Dust beyond optically detected gossamer rings

Drop in dust impact rate

Second gossamer ring passage

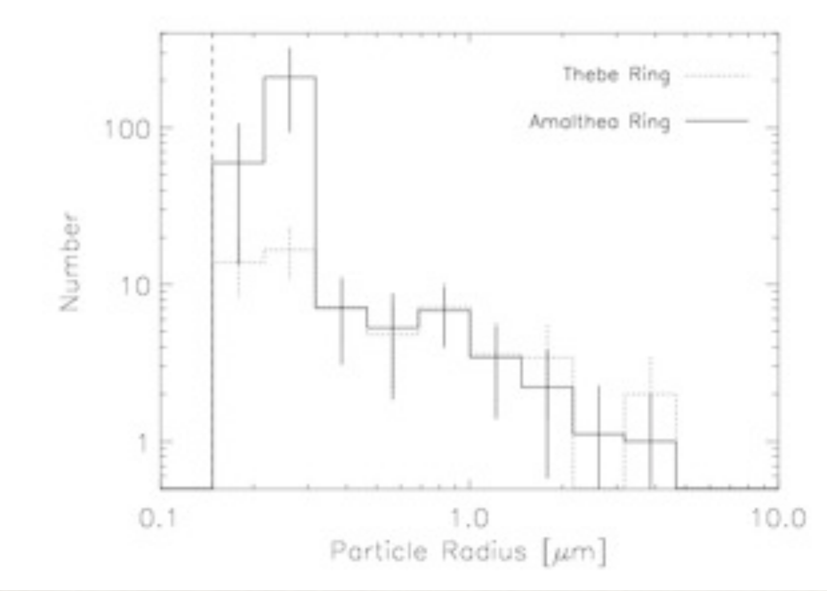


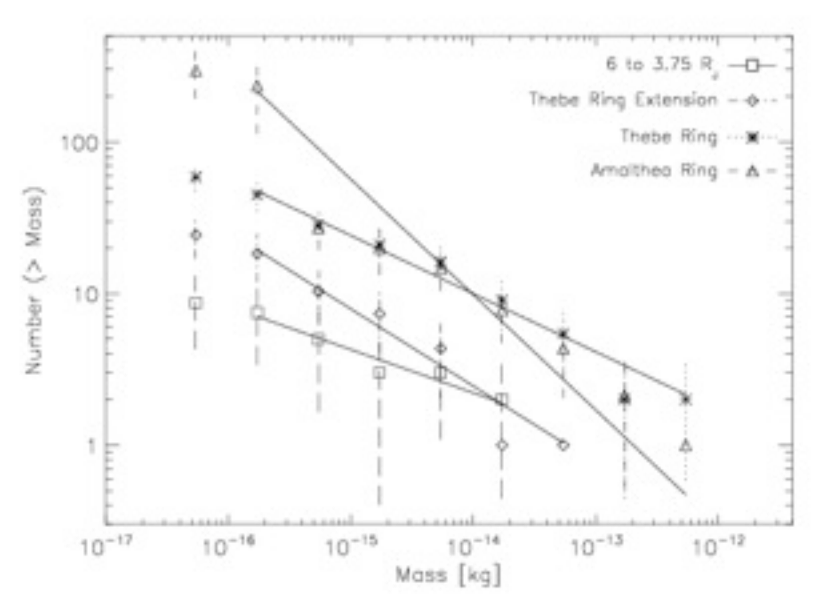
Drop in dust impact rate

Drop in dust impact rate

Krüger et al., 2009

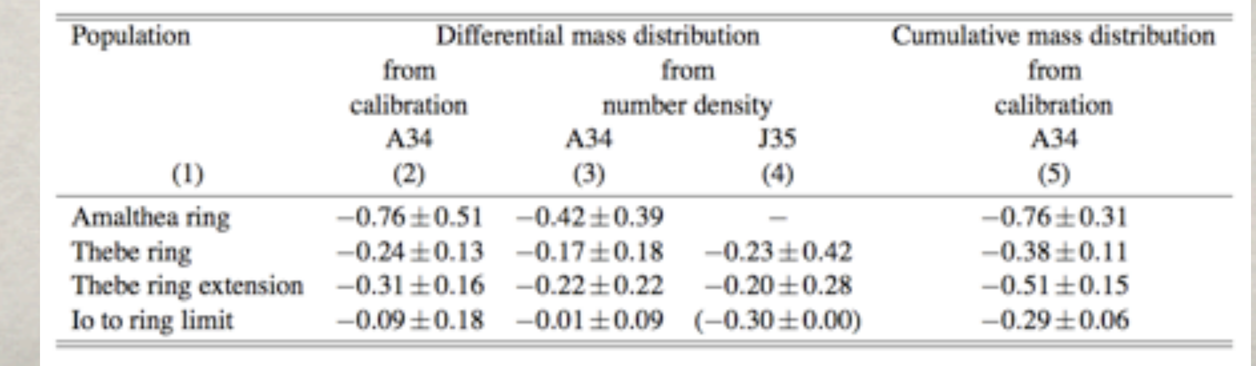
Gossamer Ring Size Distribution





Krüger et al., 2009

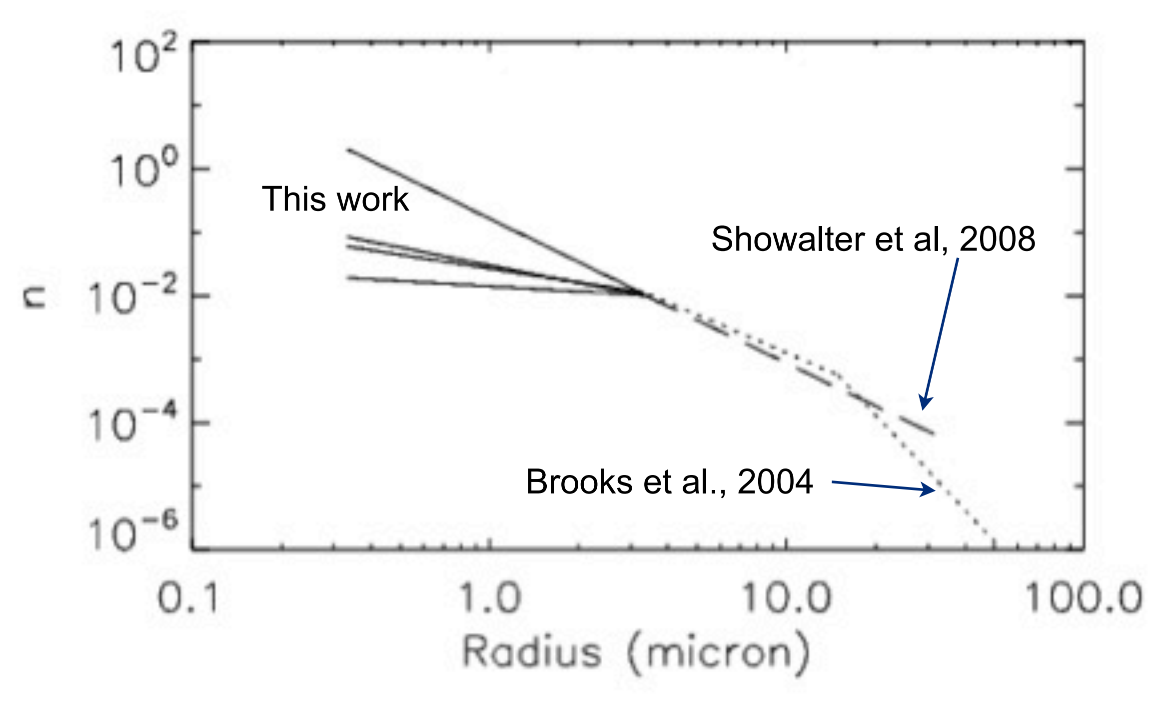
- **Size distributions similar in Thebe ring and Thebe extension (slope -0.3)**
- **Steepest slope in Amalthea ring (slope -0.6)**
- **Grain sizes 0.2 – 4 µm (factor 10 smaller than seen on images)**
- **No particles bigger than ~ 4 µm detected because of dust instrument degradation**



Population	Differential mass distribution from calibration A34	Differential mass distribution from number density A34	Differential mass distribution from number density J35	Cumulative mass distribution from calibration A34
(1)	(2)	(3)	(4)	(5)
Amalthea ring	−0.76 ± 0.51	−0.42 ± 0.39	–	−0.76 ± 0.31
Thebe ring	−0.24 ± 0.13	−0.17 ± 0.18	−0.23 ± 0.42	−0.38 ± 0.11
Thebe ring extension	−0.31 ± 0.16	−0.22 ± 0.22	−0.20 ± 0.28	−0.51 ± 0.15
Io to ring limit	−0.09 ± 0.18	−0.01 ± 0.09	(−0.30 ± 0.00)	−0.29 ± 0.06

Gossamer Ring Size Distribution

Relative number density

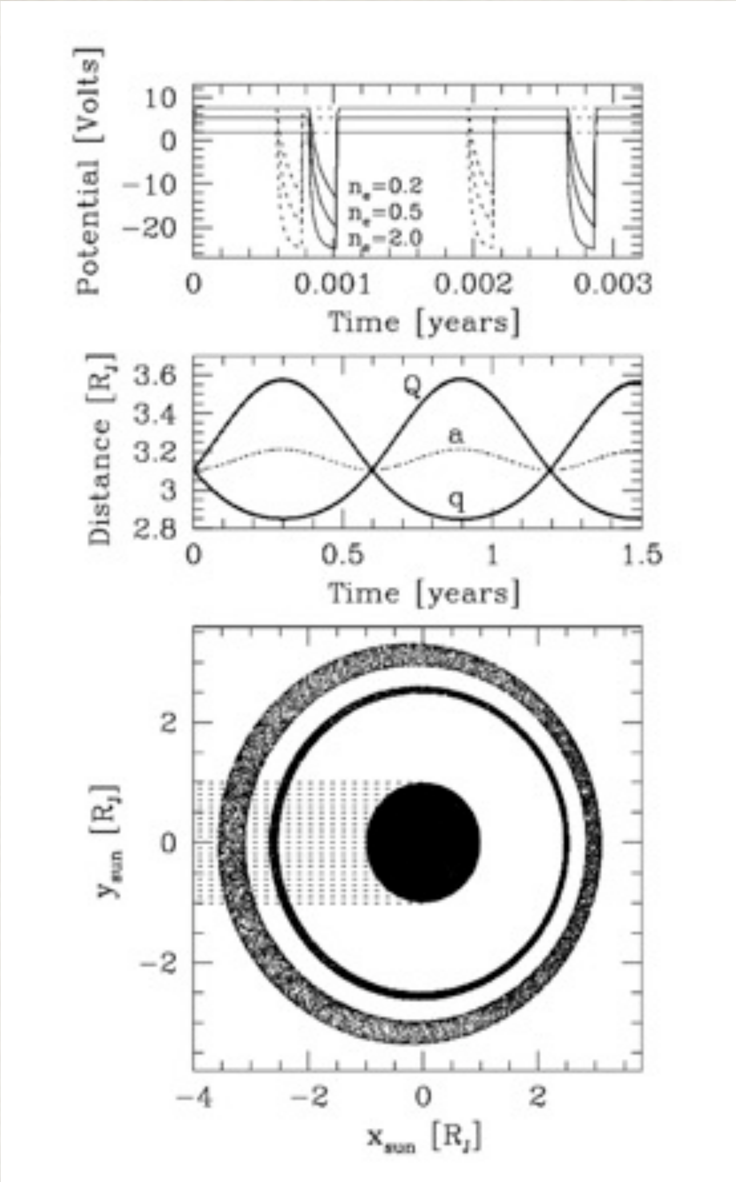


Krüger et al., 2009

Results of Brooks et al. (2004) are for the main jovian ring!

Vertical axis in arbitrary units! Curves are shifted so that they fit at 3 µm.

Gossamer Ring: Grain Dynamics



Hamilton & Krüger, Nature, 2008

Simulation for 3.2 μm dust grains.

Variable particle charging on day and night side of Jupiter (shadow resonance; two-compoent plasma model).

Semimajor axis and eccentricity increase (plasma density 2.0 cm^{-3}). Inner boundary at ~ 2.7 R_J. Q = a(1+e); q = a(1-e); a = semimajor axis.

Plasma density critical parameter: n_e>0.5 cm^{-3}.

Explains Thebe Extension.

No Amalthea extension because e/m force weaker at Amalthea, particles recollide more efficiently with Amalthea than with Thebe and Amalthea ring brighter than Thebe ring.

Shadow resonance is a pure electromagnetic effect!

Gossamer Ring Results (1)

- Ring structure measured outside 2.37 R_J from Jupiter (dust number density, grain sizes, impact direction, etc.).
- Grain size distribution: 0.2 – 4 µm, extends known size distribution by an order of magnitude towards smaller particles than previously derived from imaging.
- Small particles (< 1 µm) dominate dust number density.
- Large particles (~ 5 µm) dominate optical cross-section.

- ⇒ In-situ measurements are sensitive to small particles (with inclinations up to 20°) while images 'see' only large grains which are concentrated along the ring plane.

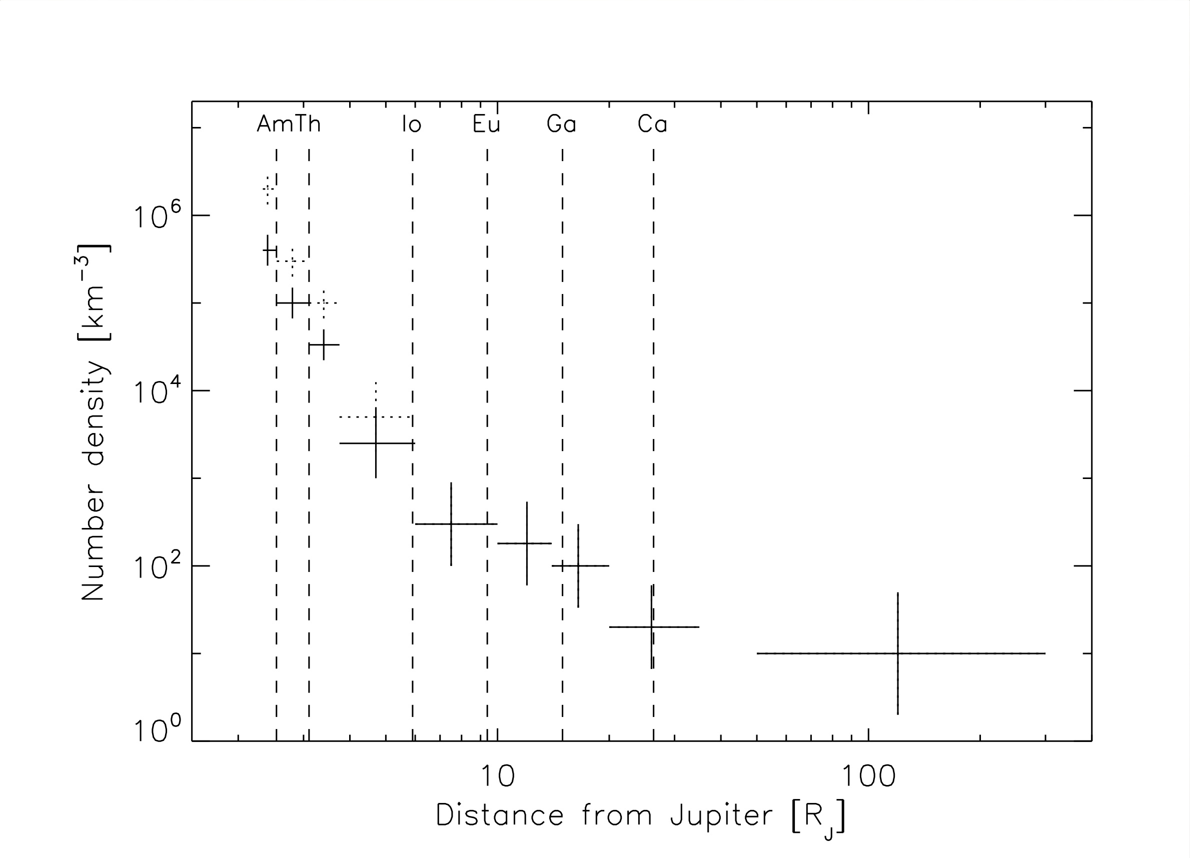
Gossamer Ring Results (2)

- Large drop in particle flux interior to Thebe's orbit.
- Steeper grain size distribution in Amalthea ring than further out.
- Variable positive and negative dust charge at day and night side of Jupiter (shadow resonance) accounts for these observations. Model accounts for all major observed stuctures.

- We now have a consistent picture for the gossamer ring particle dynamics!
- ⇒ Electromagnetic forces important in shaping Jupiter's gossamer ring!

Jupiter’s Dust Disc

We have learnt a lot about the distribution, dynamics and transport of dust in the jovian system from Galileo.



But we know almost nothing about grain composition!

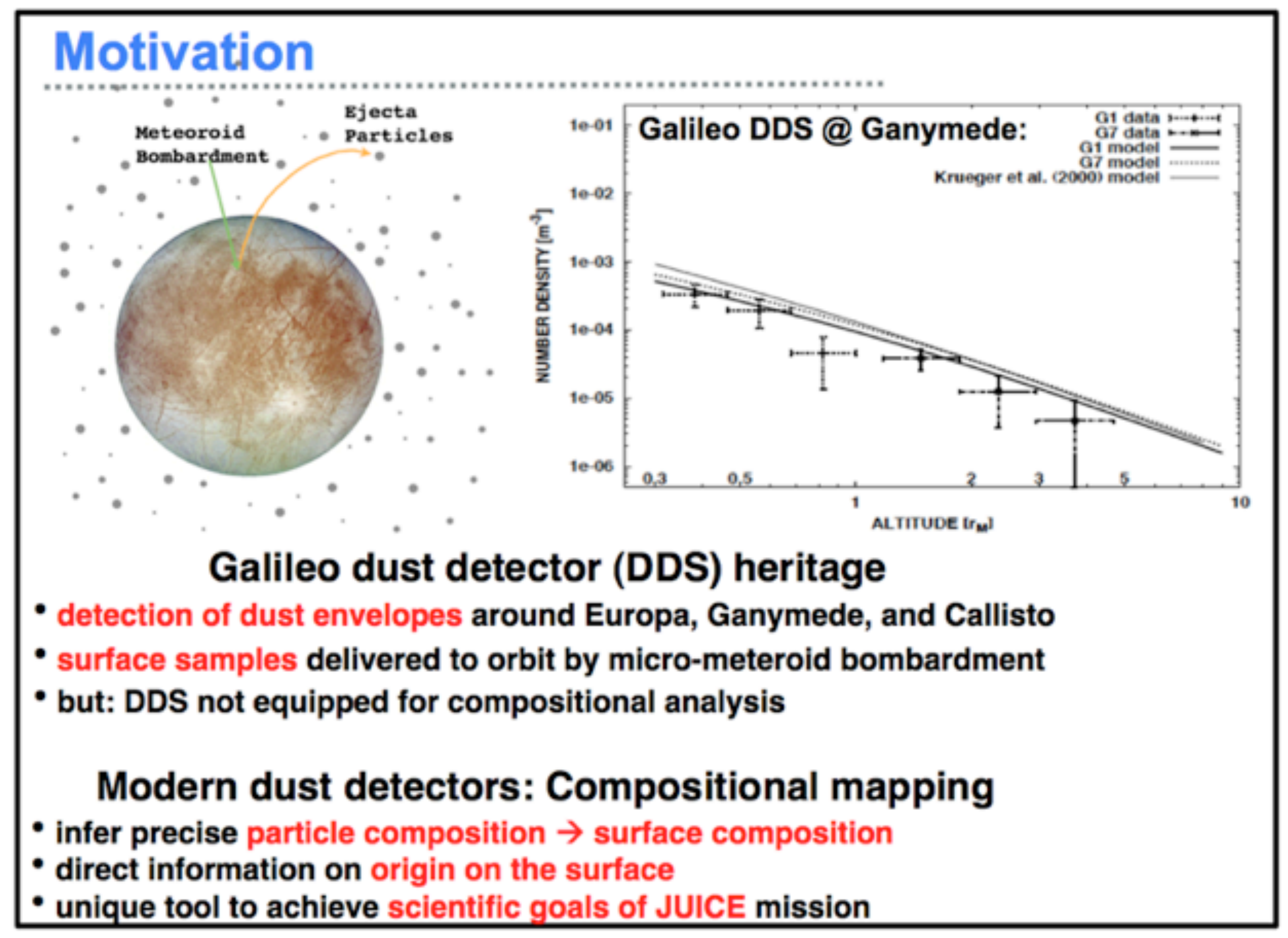
Summary

- Dust Astronomy: dust grains provide information about their origin and evolution, e.g. formation of planetary systems.
- Grain trajectories, mass, speed, (composition, charge) can be measured in situ.
- Electromagnetic interaction of charged grains with the jovian and the interplanetary magnetic fields (dust streams).
- Jupiter’s moon Io is a source for 10 nm dust stream particles.
- Dust streams: monitor of Io’s volcanic activity.
- Collisional ejection of dust grains from the Galilean moons.
- Electromagnetic interaction important in shaping Jupiter’s gossamer rings.

Outlook

Outlook

JUICE/JGO Dust Telescope



Motivation

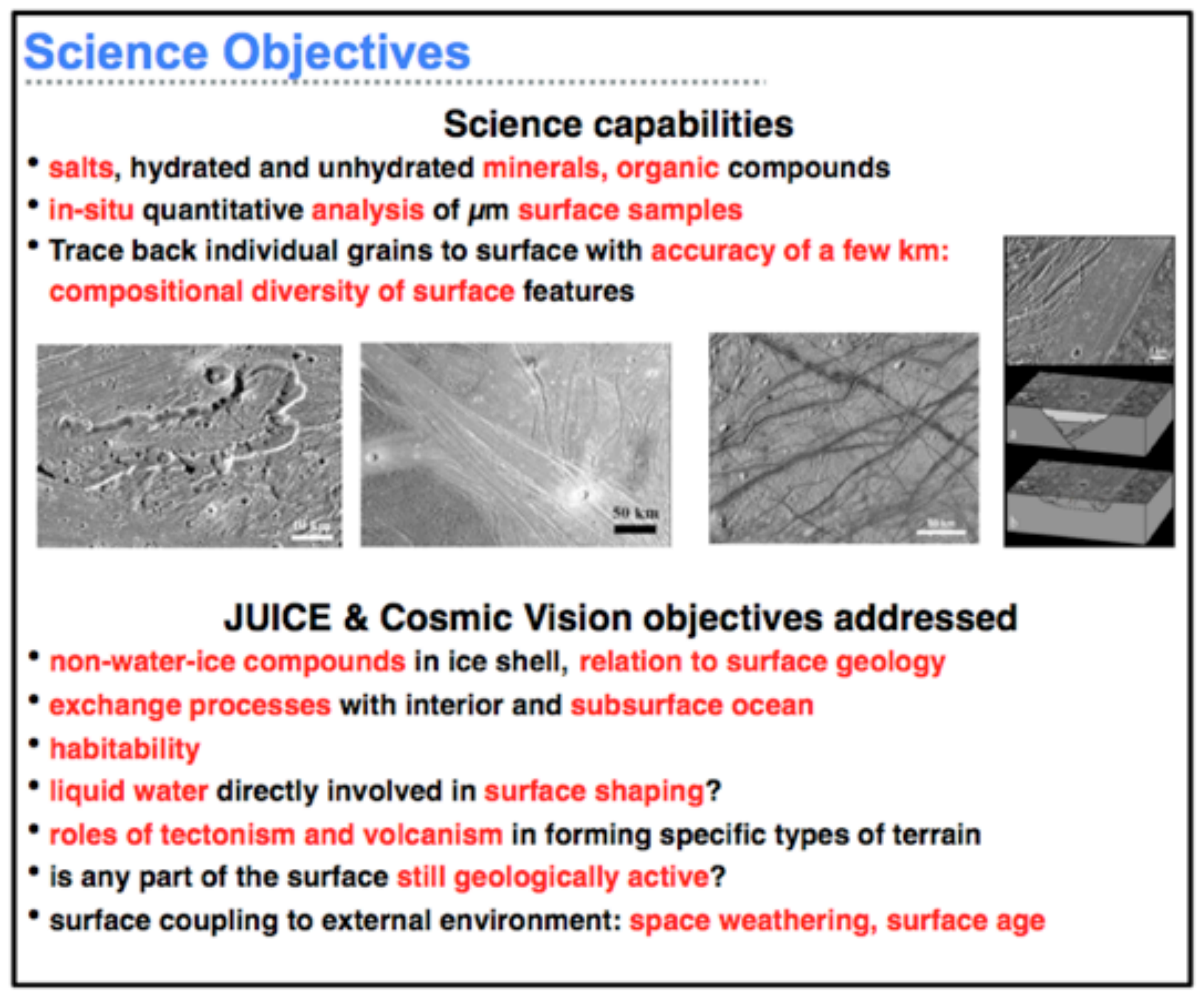
Galileo dust detector (DDS) heritage

- detection of dust envelopes around Europa, Ganymede, and Callisto
- surface samples delivered to orbit by micro-meteroid bombardment
- but: DDS not equipped for compositional analysis

Modern dust detectors: Compositional mapping

- infer precise particle composition → surface composition
- direct information on origin on the surface
- unique tool to achieve scientific goals of JUICE mission

JUICE/JGO Dust Telescope



Science Objectives

Science capabilities

- salts, hydrated and unhydrated minerals, organic compounds
- in-situ quantitative analysis of µm surface samples
- Trace back individual grains to surface with accuracy of a few km: compositional diversity of surface features

JUICE & Cosmic Vision objectives addressed

- non-water-ice compounds in ice shell, relation to surface geology
- exchange processes with interior and subsurface ocean
- habitability
- liquid water directly involved in surface shaping?
- roles of tectonism and volcanism in forming specific types of terrain
- is any part of the surface still geologically active?
- surface coupling to external environment: space weathering, surface age

JUICE/JGO Dust Telescope

Trajectory Sensor:
Charge induction
Down to 0.1 fC

Mass Analyser:
Impact Ionisation
ToF spectrometer
Reflectron
Mass resolution ~ 100

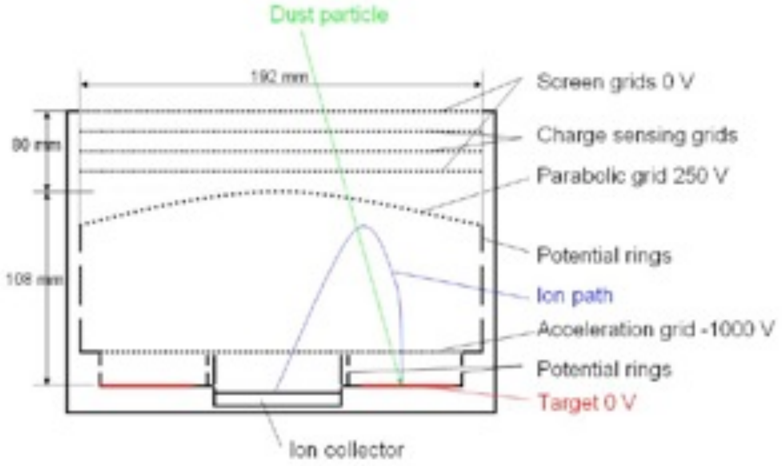
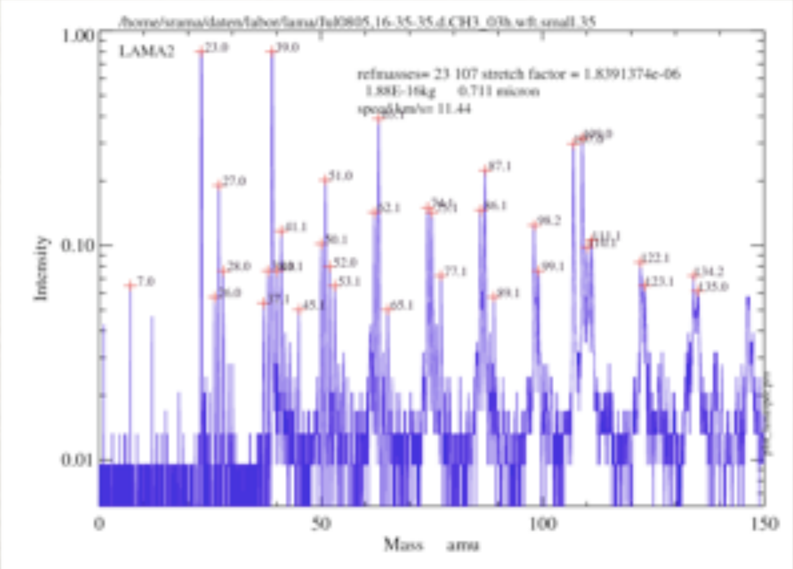


Fig. 1: Schematics of the SolO Dust Telescope. The top part (four grids and the segmented target) constitute the trajectory sensor. The target, acceleration and reflection grids and the ion collector are the chemical analyser. The path of the ions is shown in blue.

LEOPARD-Spektrometer



Thank you!