

Une nouvelle population de particules dans le vent solaire

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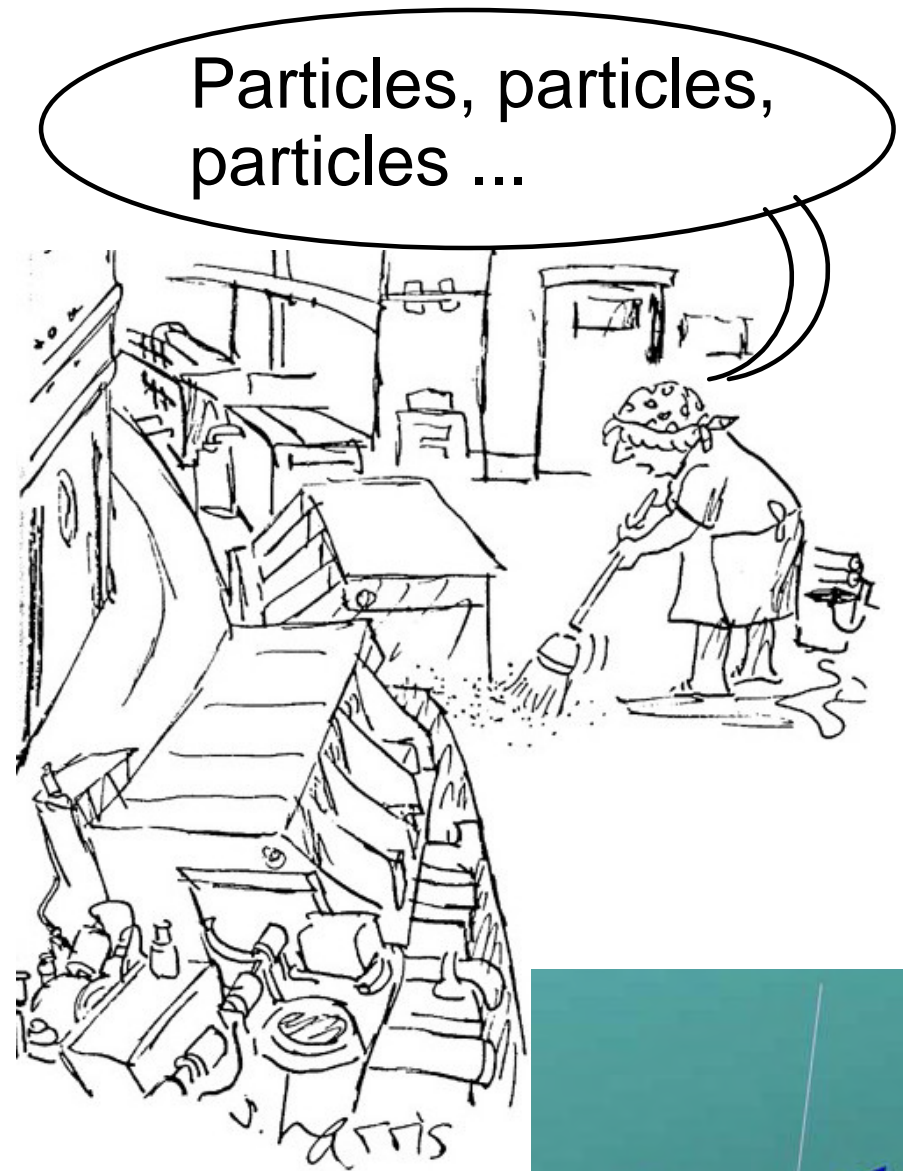
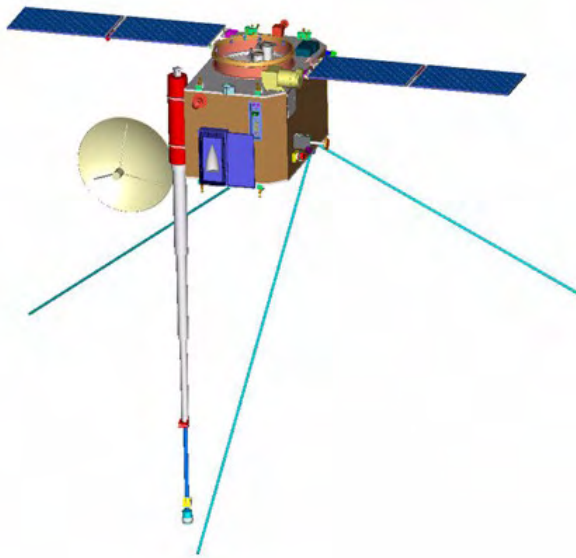
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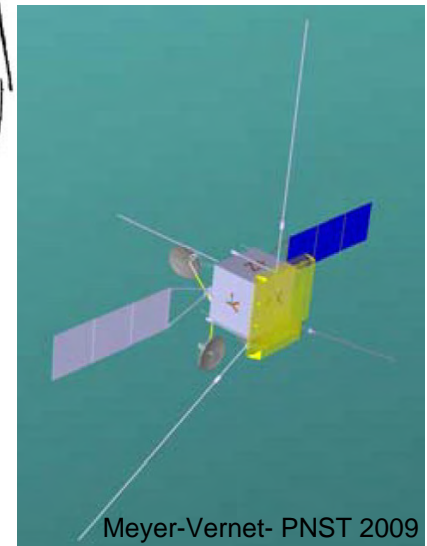
➤ Nanoparticules

➤ Nanoparticules dans l'héliosphère

➤ Principe de détection avec un instrument "ondes"



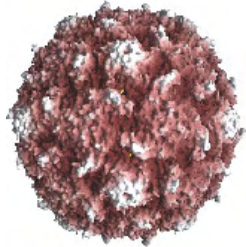
➤ Perspectives pour les missions futures



Nanoparticles



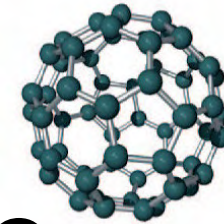
Red blood cells: 7 μ



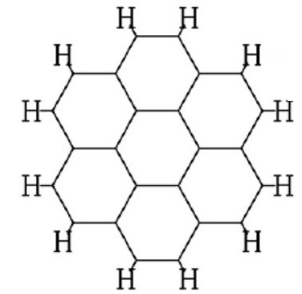
Flu virus
100nm



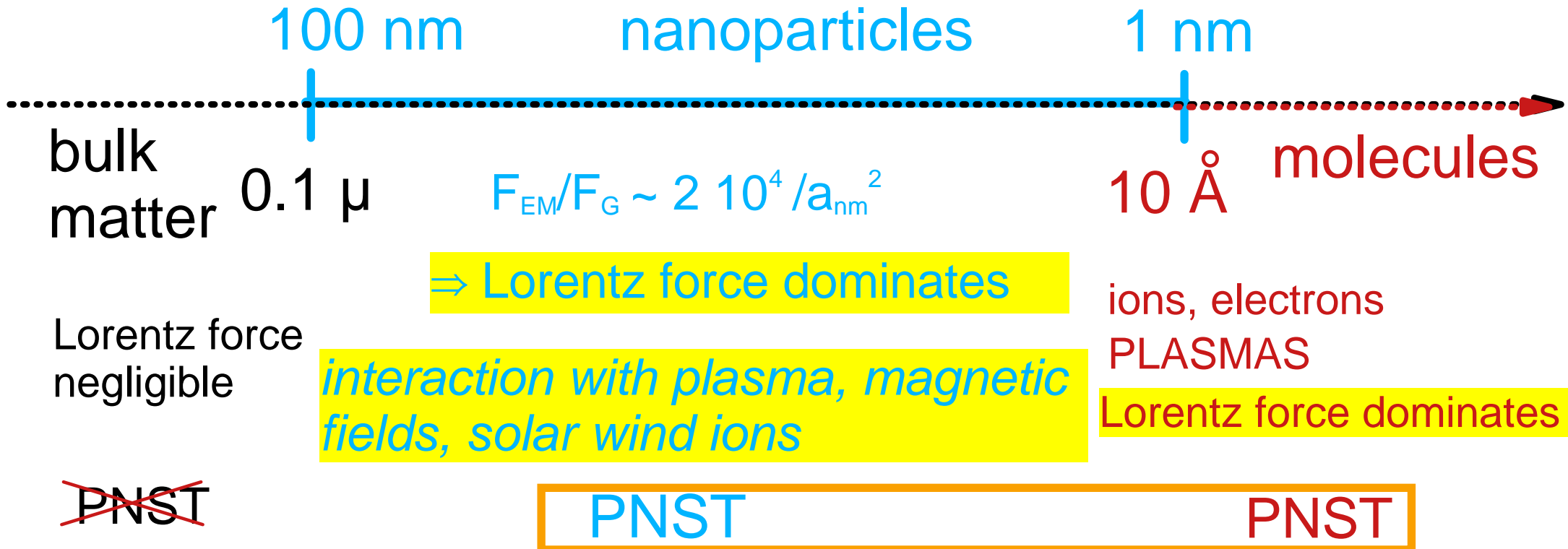
DNA
~ 2 nm wide



C₆₀ - 0.7nm



PAH:
C₂₄H₁₂



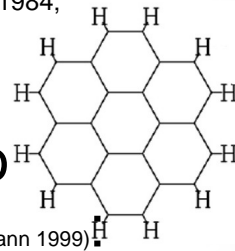
Astrophysics

- Interstellar nanoparticles inferred long ago
- far UV extinction

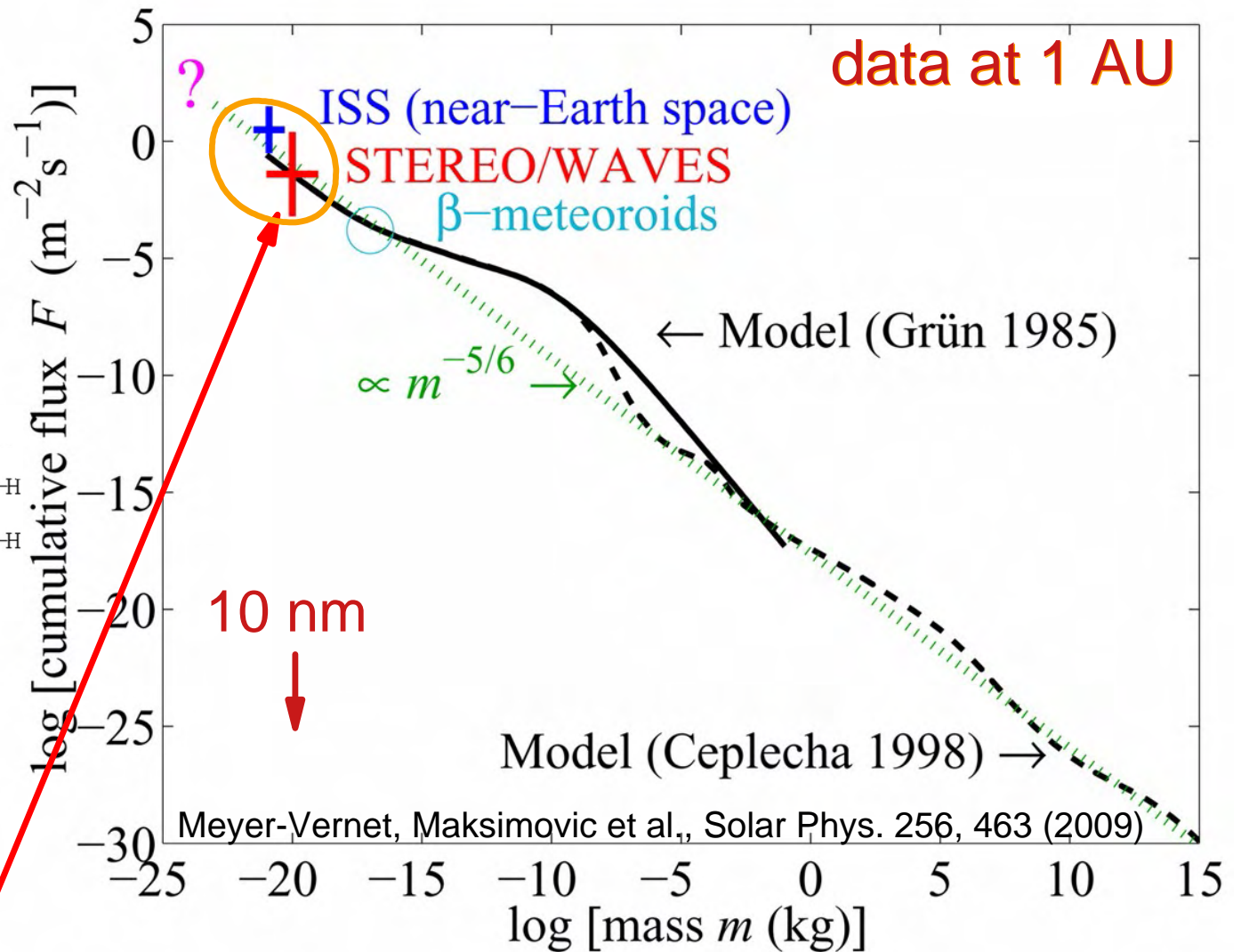
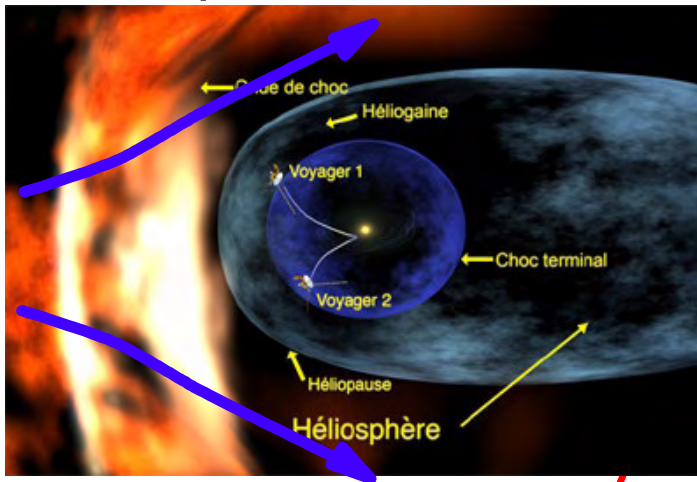
(Weingartner & Draine 2001)

- IR emission (Sellgren 1984;

Leger & Puget 1982, Draine & Li 2001)



- Cannot enter into heliosphere (Kimura & Mann 1999)



BUT within heliosphere:

- Nanoparticles ejected from planets detected a few years ago
- Recently detected serendipitously with STEREO/WAVES

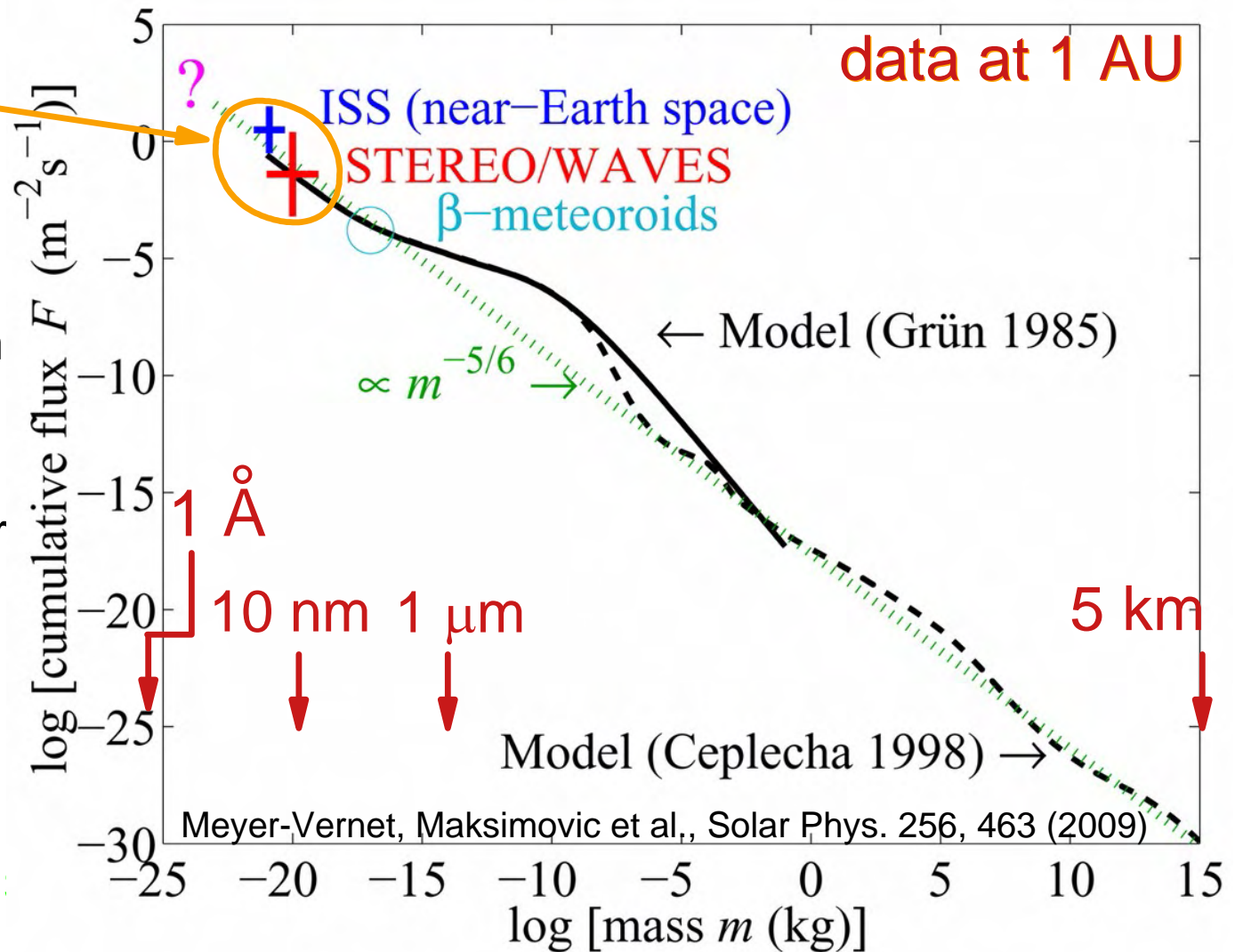
Nano dust in heliosphere

Produced by:

- ★ collisional fragmentation in dust cloud (Mann et al. 2007)
- ★ comets (Utterback & Kissel 1990)
- ★ asteroids & planets: Jupiter (Zook et al. 1996, Krüger et al. 2006) & Saturn (Kempf et al. 2005)

Transition between dust and molecular ions

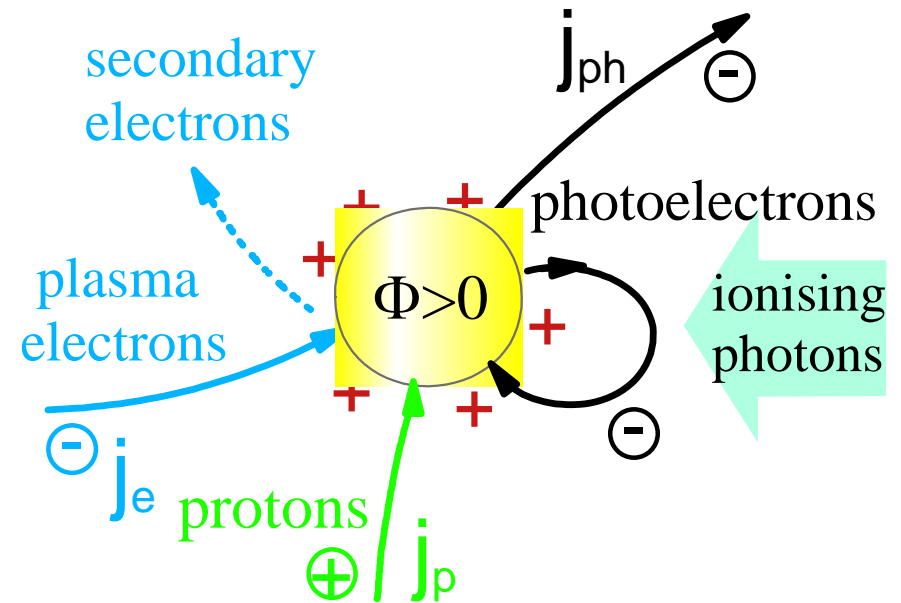
- ★ large surface-to-mass ratio (surface/mass $\propto 1/\text{size}$)
 - ☞ large charge-to-mass ratio \Rightarrow interaction with magnetic fields
 - ☞ chemical reactivity \Rightarrow interaction with solar wind ions
- ★ quantum effects \Rightarrow change optical, magnetic or electrical properties



Interplanetary nano dust: large charge-to-mass ratio

- Dust grain potential Φ determined by balance of currents

on uncharged grain: $j_{ph} \gg j_e \gg j_p$



\Rightarrow charges until Φ binds photoelectrons sufficiently to yield $j_{ph} \sim j_e$

photoelectron energy \sim a few eV $\Rightarrow \Phi \sim +5-10$ V

- Dust grain carry electric charge $q \sim 4\pi\epsilon_0 r\Phi$

\Rightarrow For $r \sim 10$ nm, charge-to-mass ratio $q/m \sim 10^{-5} e/m_p$
 $\propto r^{-2} \propto m^{-2/3}$

Interplanetary nano dust: move fast (Mann et al. 2007)

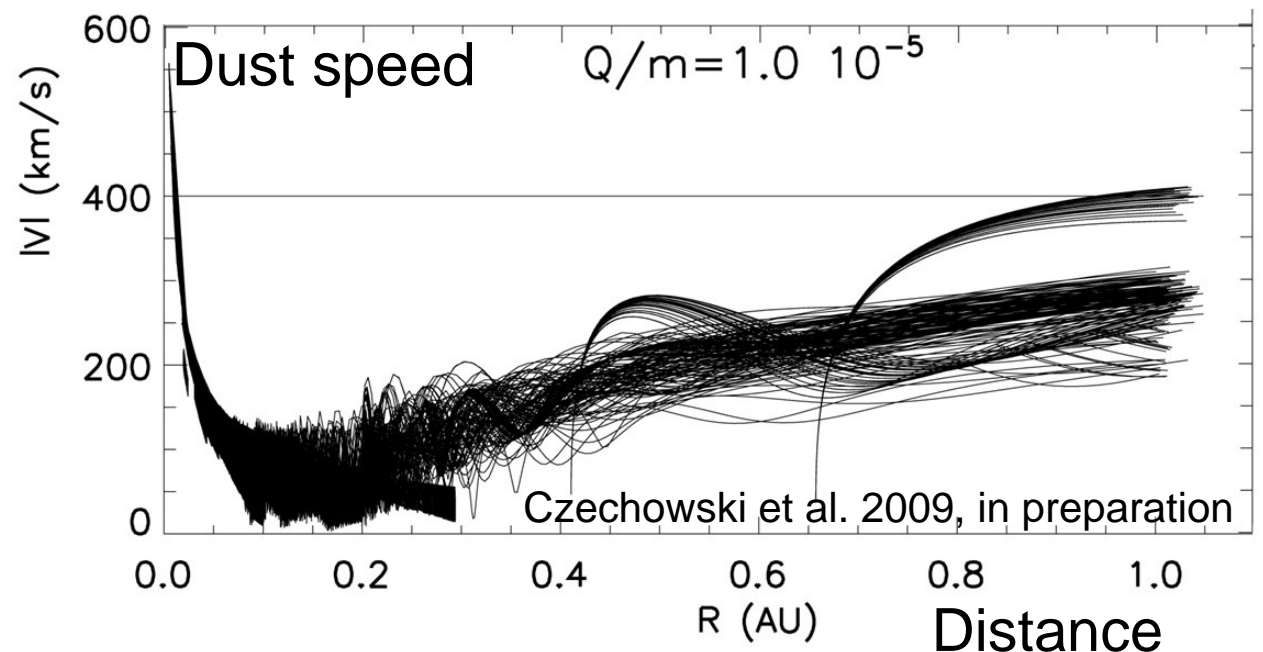
➔ Lorentz force: $F_L = q(V_{SW} - v_{dust}) \times B_{SW} \gg$ gravitational force F_G

Larmor frequency: $\Omega_L = qB_{SW}/m \gg$ Kepler frequency: $\Omega_G = (M_\odot G/d^3)^{1/2}$

For $r \sim 10$ nm: $F_L/F_G \sim 200 d_{AU}$

$\Omega_L/\Omega_G \sim 20$ at 1 AU

➔ Nano dust grains
accelerated to
 $\sim V_{SW}$ if released
farther than ~ 0.15 AU

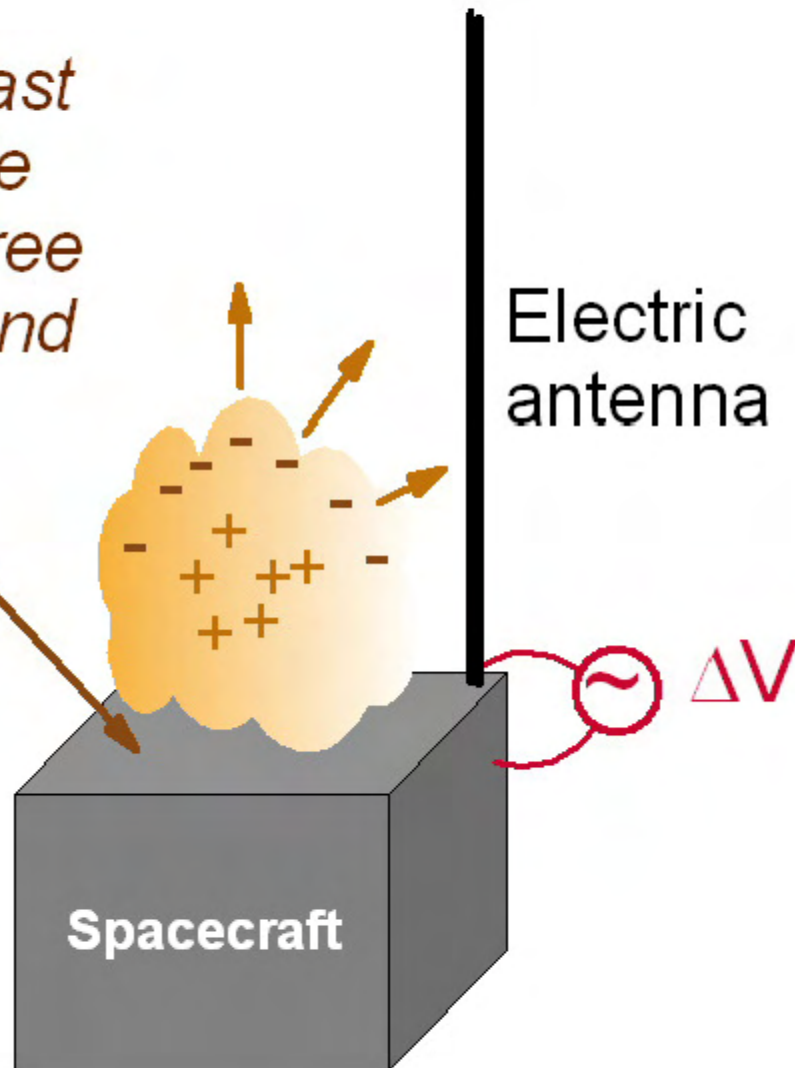


Measuring fast dust grains with a wave instrument

BASICS

Impact of fast dust particle produces free electrons and ions

Fast dust particle



- impact speed $V \sim 10$ km/s
kinetic energy/molecule
($A=20$): ~ 10 eV
- impact speed $V \sim 300$ km/s
kinetic energy/molecule
($A=20$): ~ 10 keV

Charge separation and/or recollection produces an electric field detected by the electric antenna

Measuring fast dust grains with a wave instrument

BASICS

Impact ionisation

Time scales:

radius of cloud: $R \sim v_{\text{exp}} t \Rightarrow$ density $n \propto t^{-3}$

- Charge separation:

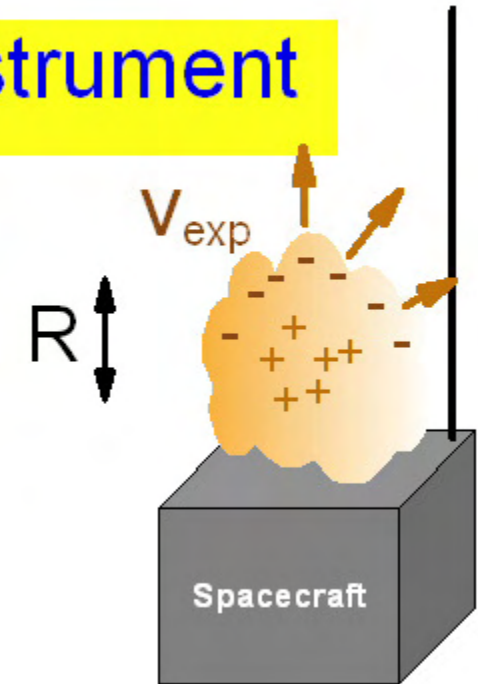
Debye length $L_D \propto t^{3/2} \Rightarrow$ charges decouple for $L_D > R \Rightarrow R > R_1 \sim Qe/\pi\epsilon_0 kT$

- Density in cloud $>$ ambient value n_a for $R < R_{\text{MAX}} \sim [Q/(\pi e n_a)]^{1/3}$

detection requires $R_1 < R < R_{\text{MAX}}$

$$t < \tau \sim [Q/(\pi e n_a)]^{1/3} / v_{\text{exp}} \sim 30 \mu\text{s at 1 AU}$$

↑
Pulse rise time



Measuring fast dust grains with a wave instrument

BASICS

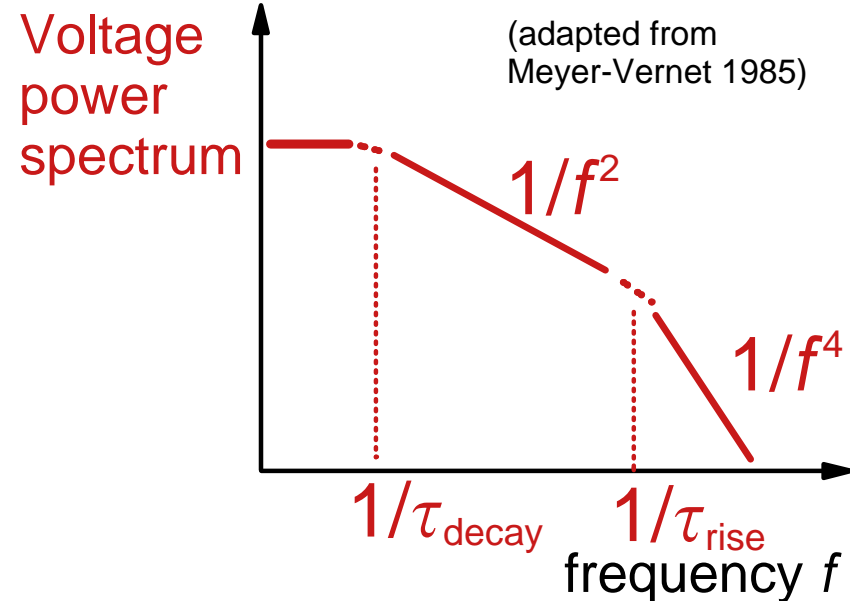
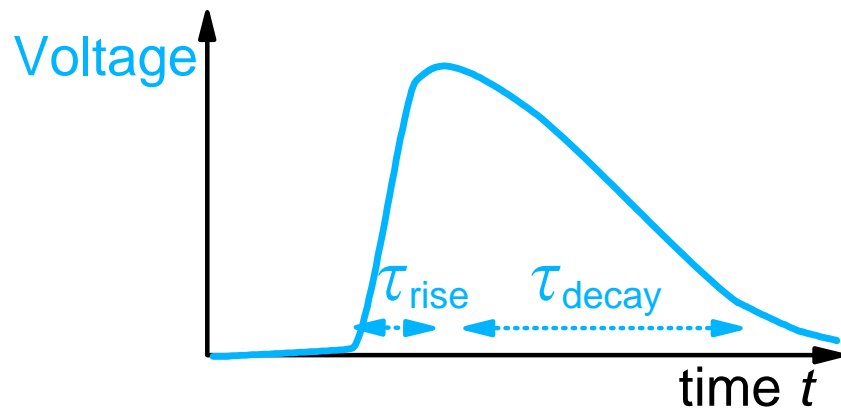
Impact ionisation

Time scales:

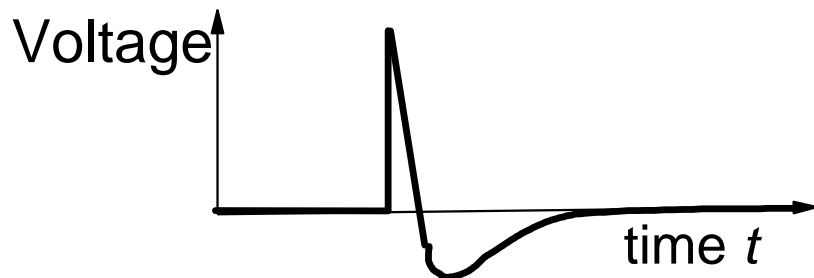
Waveform (time domain sampler)

Measurement: and/or

Power spectral density (frequency receiver)



Instrumental filtering



Frequency of observation $\sim 1/(2\pi\tau) \sim 5 \text{ kHz} \propto d_{\text{AU}}^{-2/3}$

Measuring fast dust grains with a wave instrument

BASICS

Impact ionisation Amplitude:

Extrapolation of laboratory measurements:

Detected electric charge upon impact:

⇒ increases fast with speed

$$Q \propto m v^{3.5}$$

grain mass grain speed

Nanoparticle:

radius $r \sim 10$ nm, mass $m \sim 10^{-20}$ kg, speed $v \sim 400$ km/s

yields same Q as:

submicron particle:

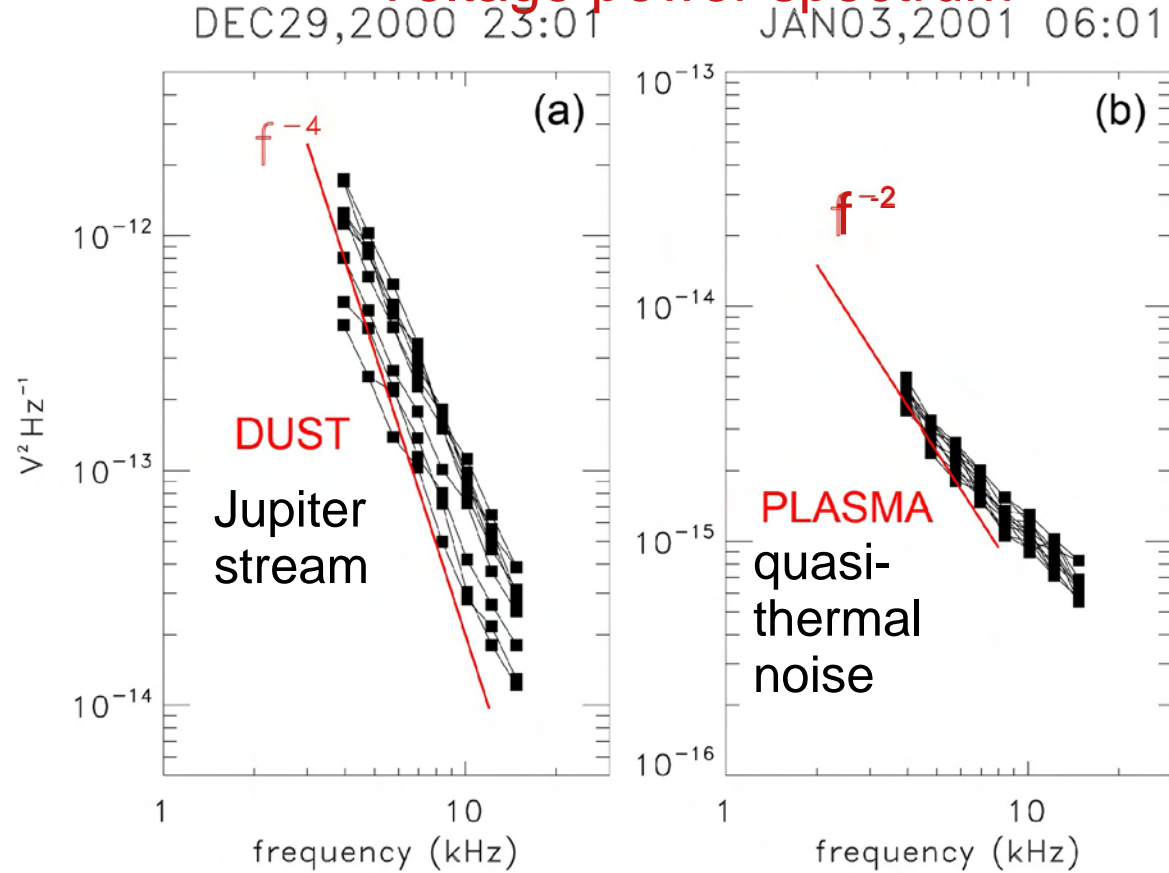
radius $r \sim 0.3$ μm , mass $m \sim 10^{-15}$ kg, speed $v \sim 20$ km/s



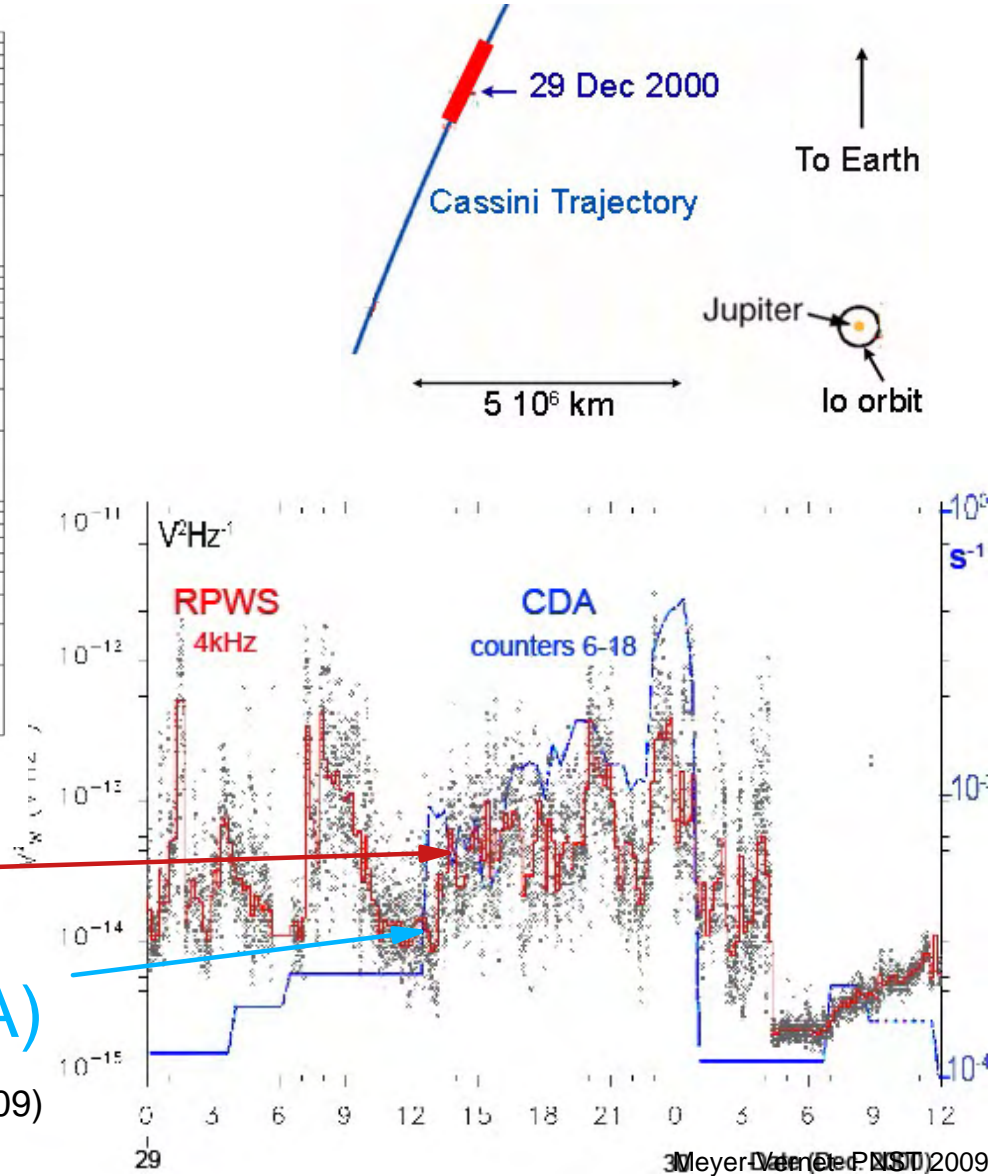
Nanoparticles produce large electric signals

Cassini in solar wind at 5 AU detects nano dust simultaneous with conventional detector

Voltage power spectrum



Cassini/RPWS near Jupiter

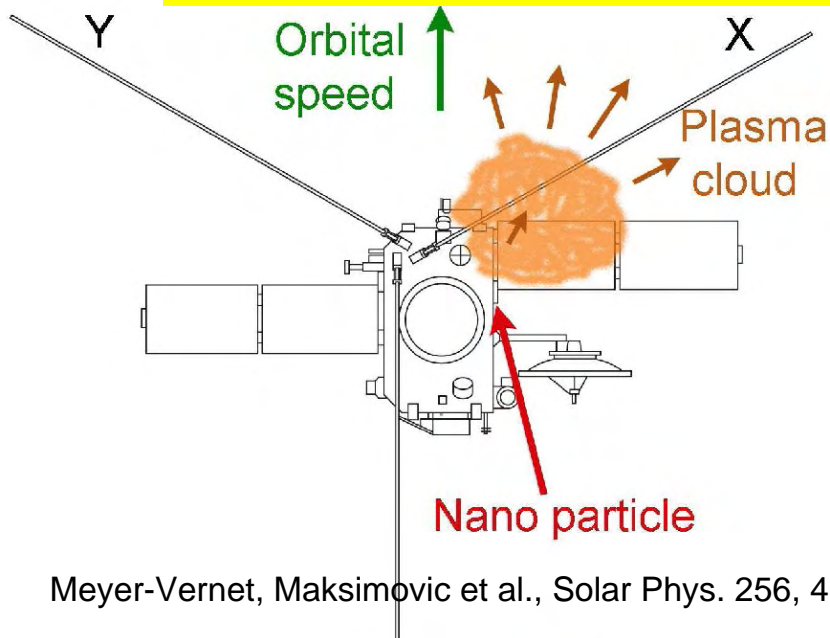


Diagnostic from waves (RPWS)

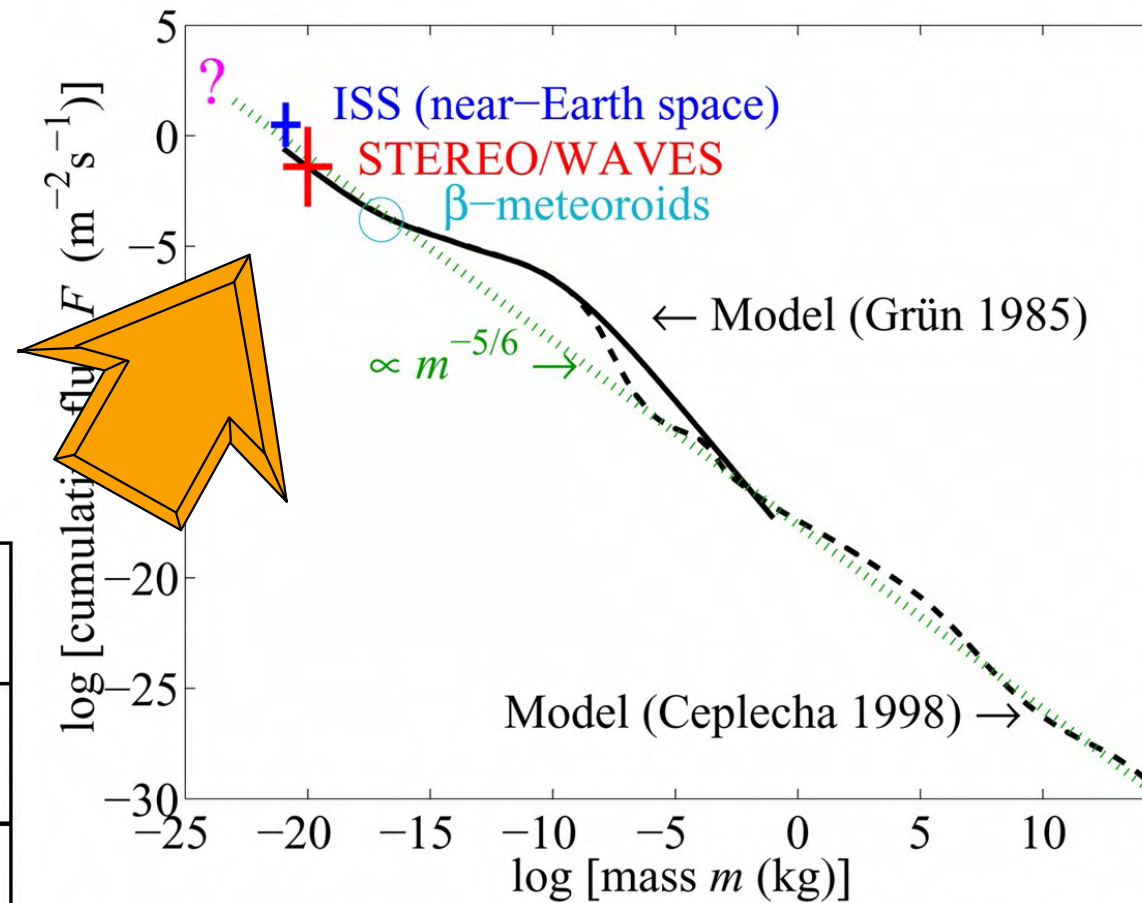
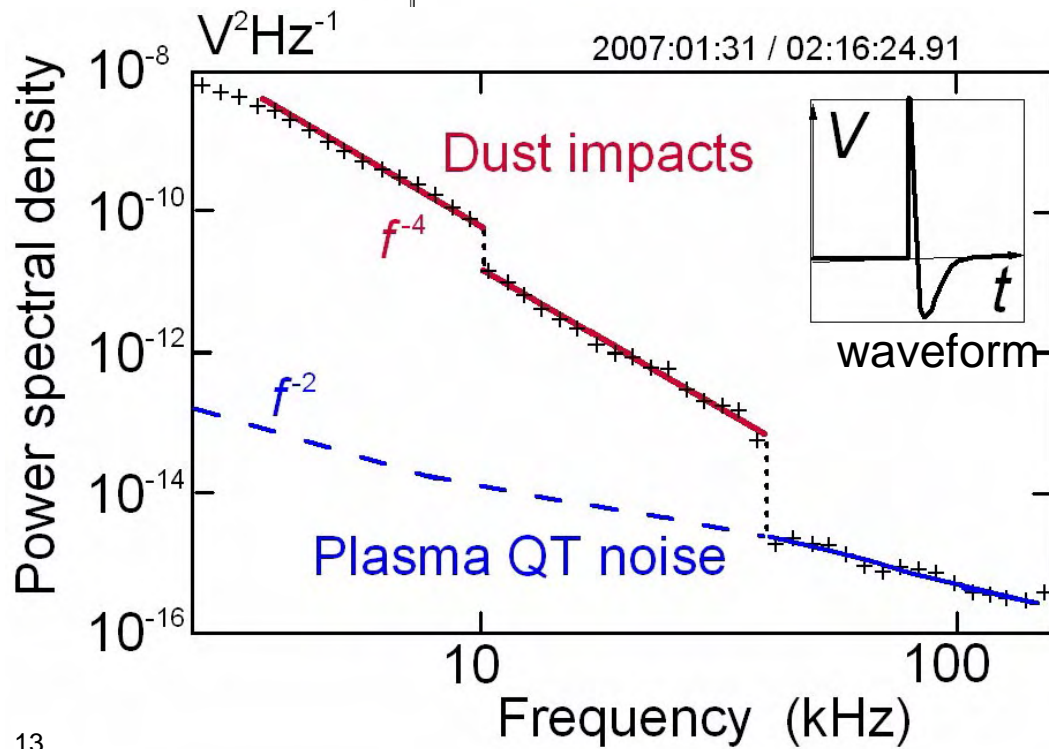
Diagnostic from dust detector (CDA)

Meyer-Vernet, Lecacheux & al., Geophys. Res. Lett. 36, L03103 (2009)

STEREO in solar wind at 1 AU detects nano dust



Meyer-Vernet, Maksimovic et al., Solar Phys. 256, 463 (2009)



Implementation on future missions in inner heliosphere

➤ Antennas used as dipoles:

measure quasi-thermal electric fluctuations near plasma frequency

⇒ electron density & temperature (talks by Issautier & by Le Chat)

➤ Antennas used as monopoles:

measure voltage pulses produced by ionisation of fast dust grains impacting spacecraft

Complementary to conventional dust detectors

- large collecting area (can be the whole spacecraft)
- not reliant on specific spacecraft attitude for dust detection
- requires few additional resources (by-product of plasma wave instrument)
- requires calibration

Scientific goals

- detect fast nanoparticles ($\sim 10^{-20}$ kg) inward of 1 AU
- investigate origin and dynamics
- investigate interaction with solar wind plasma particles
- investigate possible contribution to inner source pick-up ions

Implementation on BEPI-COLOMBO/MMO (SORBET)

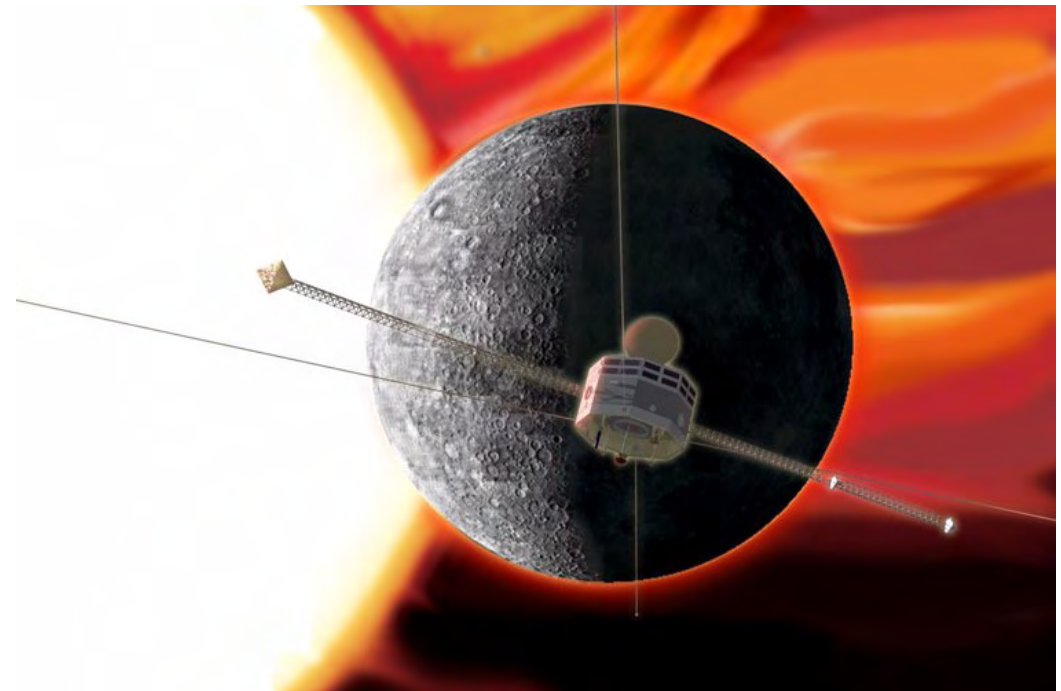
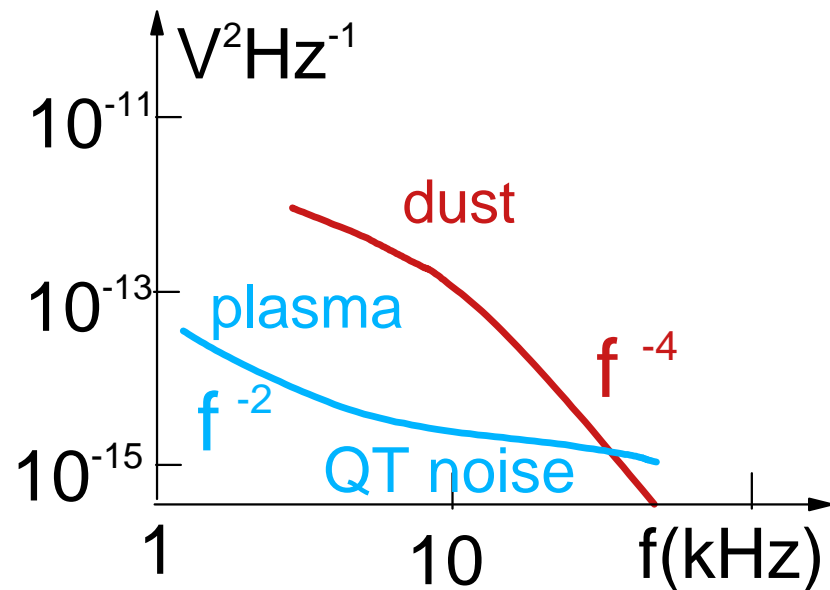
Flux of nanoparticles ($r \sim 10$ nm): extrapolation of STEREO flux

$\Rightarrow 0.3$ AU: $\langle F \rangle \sim 4 \text{ m}^{-2}\text{s}^{-1}$

Speed ~ 100 km/s



Spectral density:



Monopole antenna (wire 15 m)
In Mercury magnetospheric cavity

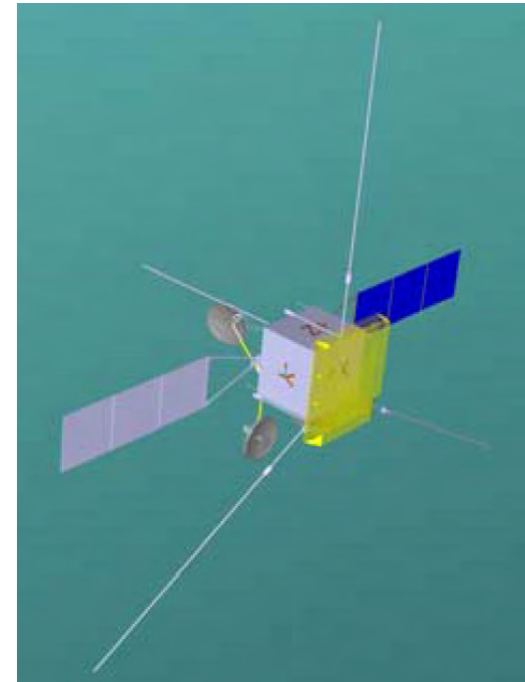
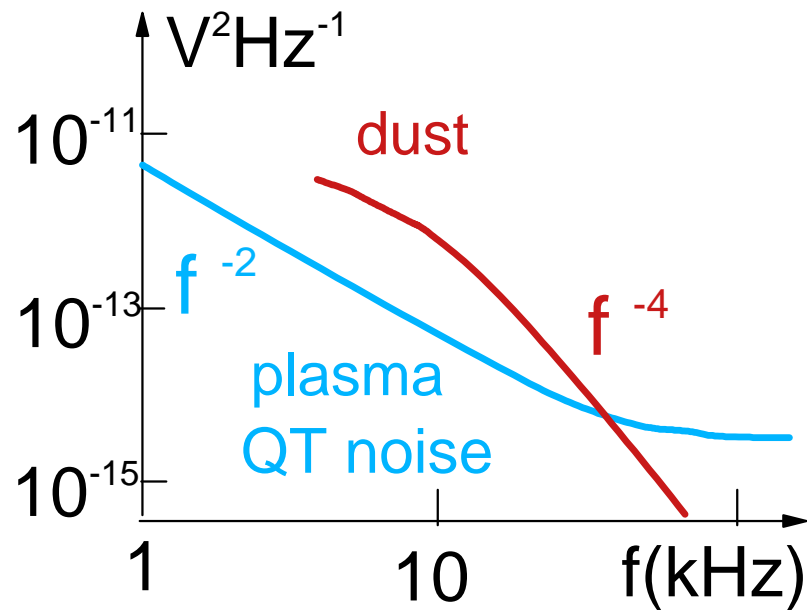
Implementation on Solar Orbiter /RPW

Flux of nanoparticles ($r \sim 10$ nm): extrapolation of STEREO flux

$\Rightarrow 0.3$ AU: $\langle F \rangle \sim 4 \text{ m}^{-2}\text{s}^{-1}$

Speed ~ 100 km/s

Spectral density:



Example: 1 m boom near S/C

..... and on Solar Probe