Séminaire Pôle Plasmas

Temporal and Spatial Evolution of the Interplanetary Medium

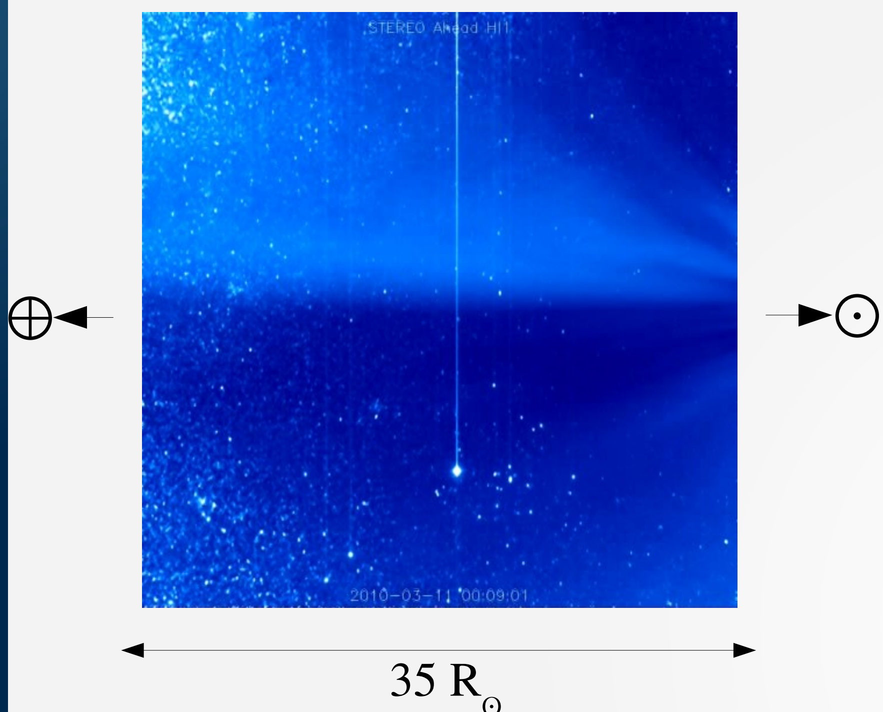
Gaétan Le Chat

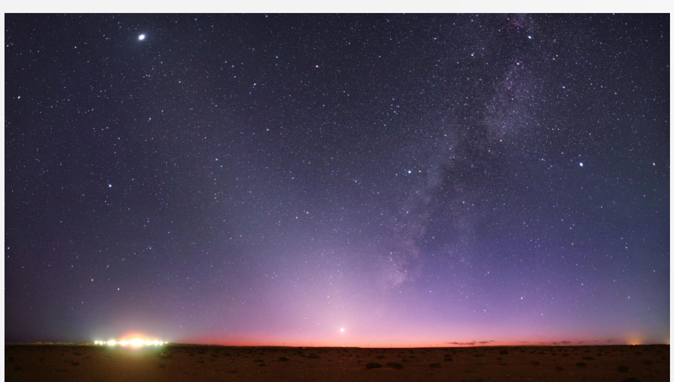
Curriculum Vitae

- **Octobre 2007 – 13 spetembre 2010 : Thèse, Université Paris 7, LESIA**
- Octobre 2010 – Septembre 2011 : A.T.E.R. de l'Observatoire de Paris
- Octobre 2011 – Décembre 2011 : CDD CNRS-INSU au LESIA
- **Janvier 2012 – Décembre 2013 : Postdoctorat au Harvard-Smithsonian Center for Astrophysics (USA)**
- **Janvier 2014 : Postdoctorat CNES**

The Interplanetary Medium

STEREO SECCHI/HI 1





Solar wind:

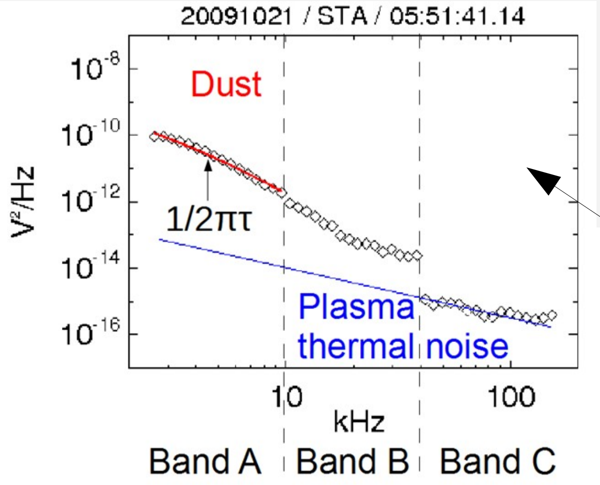
- evolution of thermal and non thermal properties of the solar wind
- transport of particles and energy in non equilibrium plasmas
- origins, acceleration and links to the solar corona

Interplanetary dust:

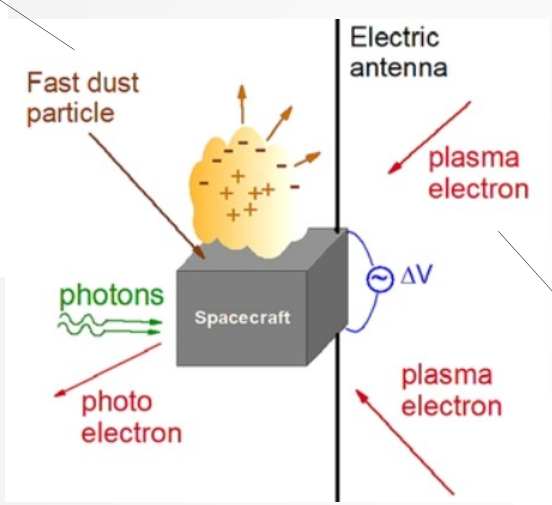
- second half of the mass flux in the solar system
- interactions with the solar wind
- Proxy for other phenomena: interstellar dust, origin of the solar system, collisions, motion of the solar system...

Radio Instrument in Space plasma

Dust

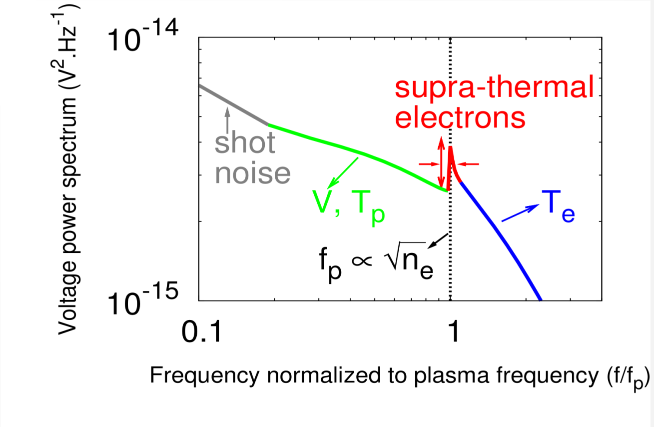


Le Chat et al., 2013



Meyer-Vernet et al, 2010

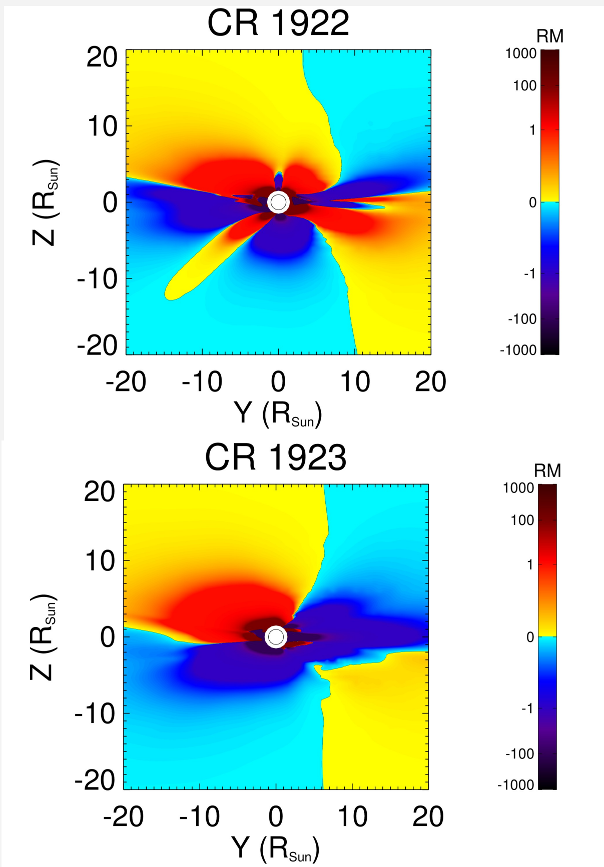
Plasma



Le Chat et al., PoP, 2009

Large Scale Properties of the Solar Wind

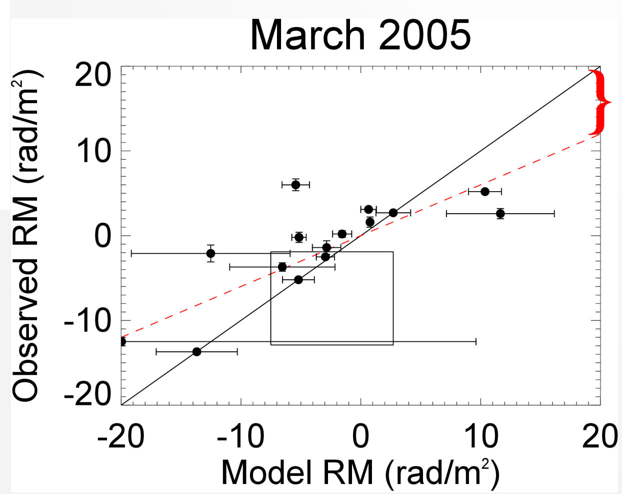
corona RF maps

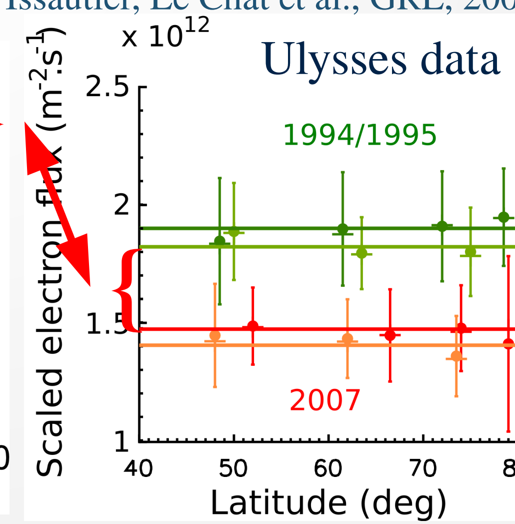


Le Chat et al., ApJ, 2014

- BATS-R-US : MHD-3D model of solar corona and wind plasma and magnetic field
- Rotation Faraday (RF) : a magnetized plasma rotates the plane of polarization of radio waves $\Delta\chi \propto \int_L n_e \vec{B}.\vec{ds}$
- **1st comparisons** between MHD model and RF
- **Fast (1 Carrington rotation) evolution of corona RF map even in solar minimum**
- **Provides unique test of the model**
- **Measures the same decrease in the solar wind parameters than Ulysses**

Issautier, Le Chat et al., GRL, 2008



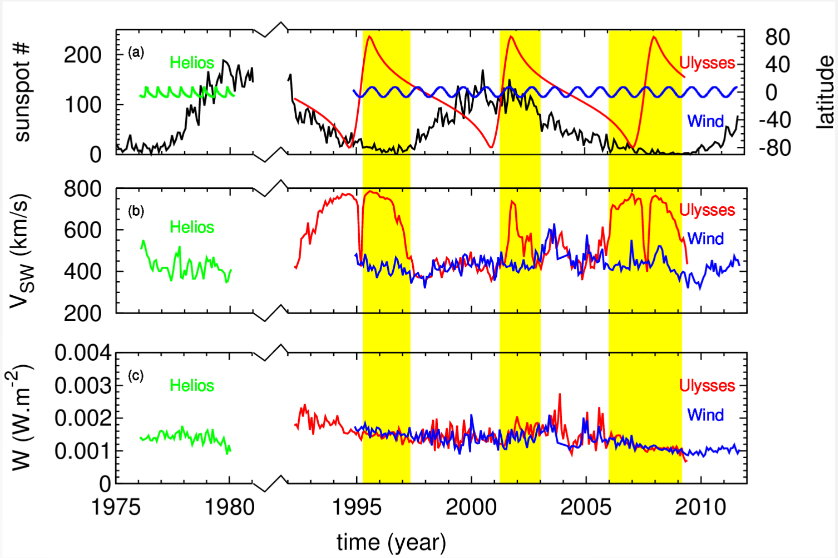


The Solar Wind Energy Flux

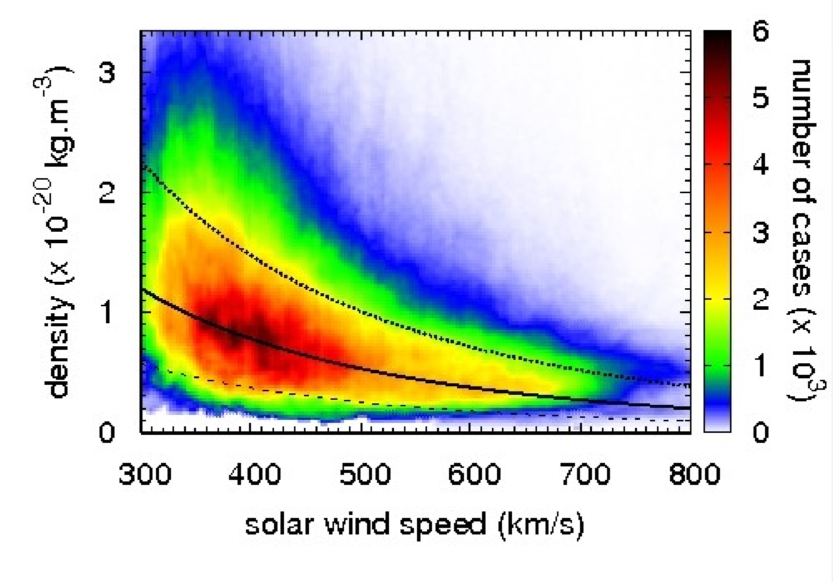
$$W[W\,m^{-2}] = \rho V \left(\underbrace{\frac{1}{2} V^2}_{} + \underbrace{\frac{M_o G}{R_o}}_{} \right)$$

kinetic energy

leave the Sun's gravitational potential



- Slow and fast wind: **different sources, different expansion factors of their flux tubes, different interaction… but same energy flux**
- Same energy flux => **Semi-empirical Relation between Speed and Density.**
- Stellar wind of cool giants and solar-type star: **same order of magnitude for the energy flux.**



Le Chat et al., CSSS15, 2009 ; Le Chat et al., Solar Physics, 2012

Context

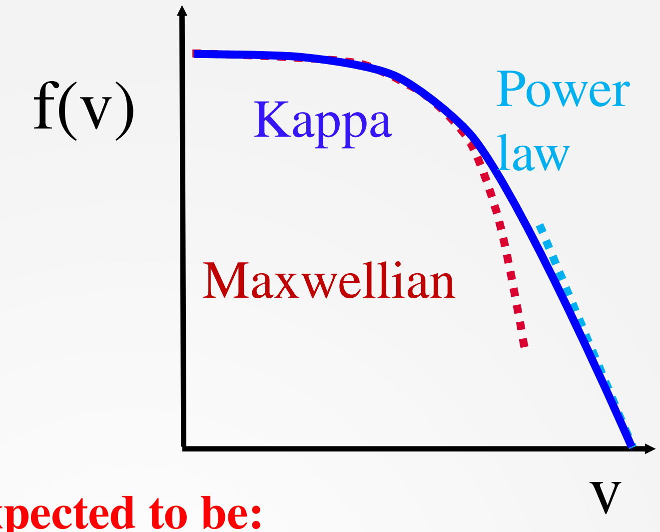
Solar Wind

Nanoparticles

Conclusions

Supra-Thermal Electrons

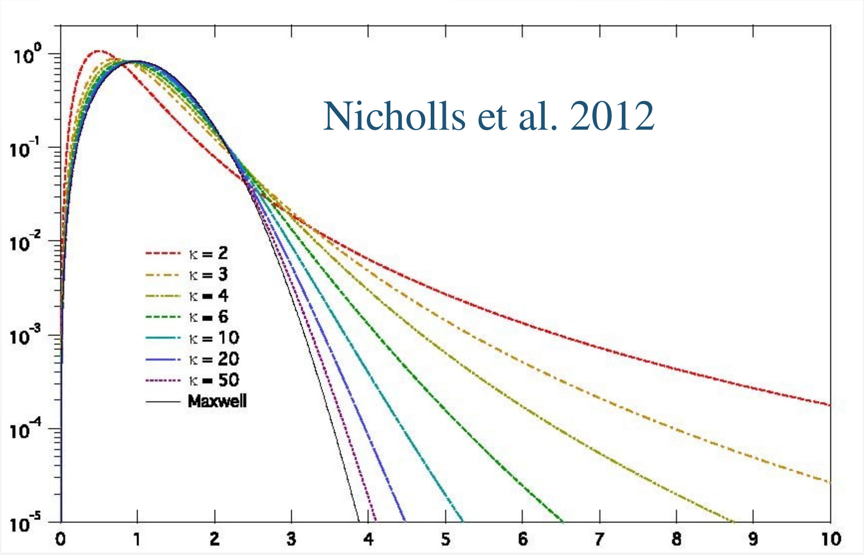
- Coulomb collisions => **lpm ∝ v^4**
  - Fast particles not in equilibrium, even if core of the distribution is in equilibrium
  - Acceleration processes often produce power law distributions



⇒Velocity distributions in space plasmas are expected to be:

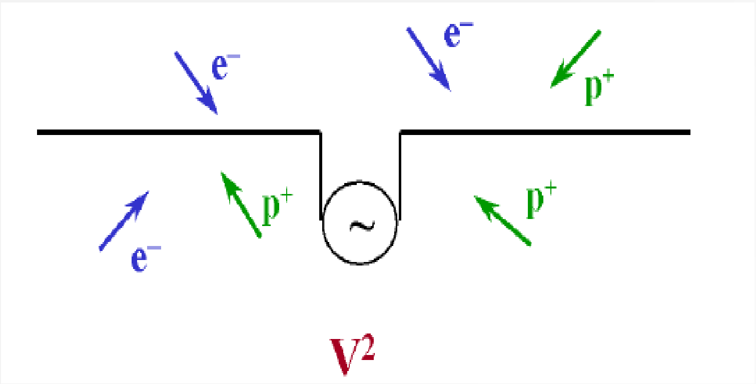
- **Close to Maxwellian at low energies**
- **Close to power-law at high energies**

- Kappa functions:
  - **Simple mathematical functions**
  - Good approximations of the **expected and observed** velocity distributions in space plasmas



Quasi-thermal noise spectroscopy

- Few collisions ⇒ supra-thermal electron in power law distributions ⇒ accurate measurements of their kinetic properties needed = **quasi-thermal noise spectroscopy with kappa functions**

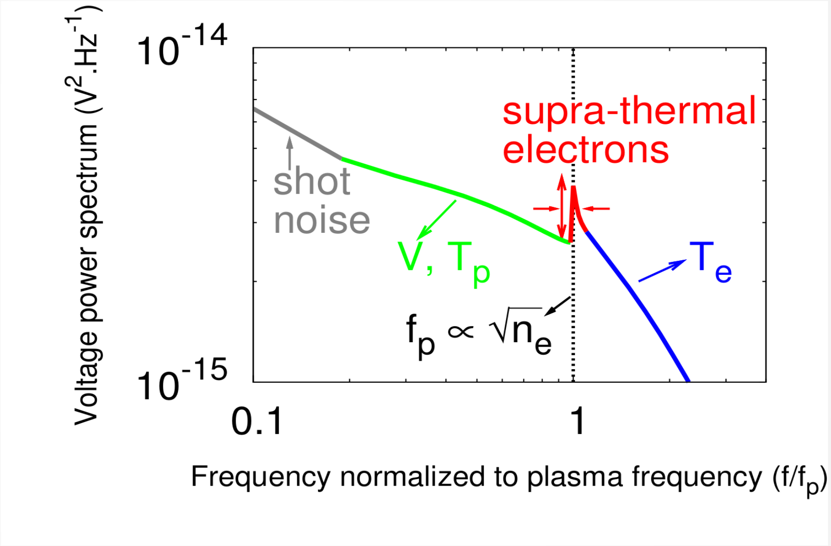


$$V_{\omega}^{2}=\frac{2}{(2\pi)^{3}}\int\left|\frac{\vec{k}\cdot\vec{J}}{k}\right|E^{2}(\vec{k},\omega-\vec{k}\cdot\vec{V})\,d^{3}k$$

Antenna response to electrostatic waves

Auto-correlation function of the electrostatic field fluctuations in the antenna frame

Thermal noise spectrum



Electrons quasi-thermal noise +
Doppler-shifted proton thermal noise
+ shot noise

Le Chat et al., PoP, 2009

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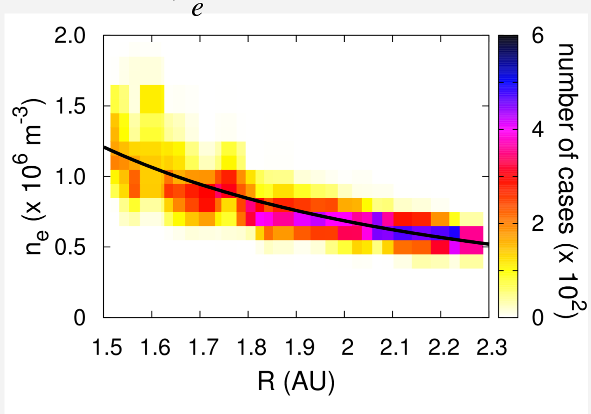
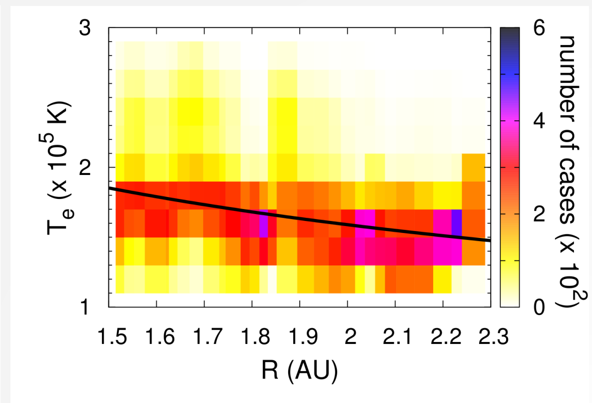
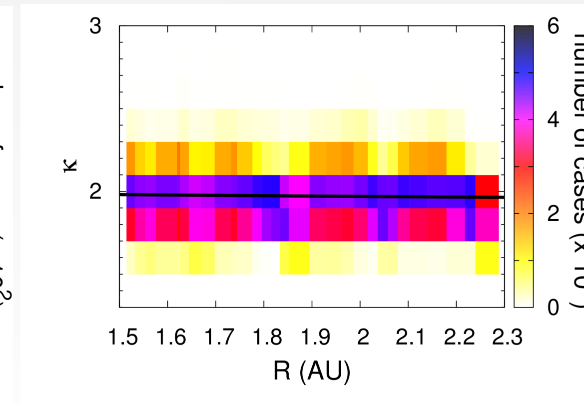
Large-Scale Variation of Solar Wind Electron Properties

$N_e \propto R^{-1,96 \pm 0.08}$ $T_e \propto R^{-0.53 \pm 0.15}$ $\kappa = cste$







Ulysses/URAP in high latitude fast solar wind:

- **Very good accuracy for the electrons density and total temperature.**
- **Temperature variation between adiabatic** ($\gamma = 5/3$) and **isothermal** ($\gamma = 1$). $T_e \propto n_e\ \gamma-1$, $\gamma = 1.27 \pm 0.07$.
- Highly supra-thermal distribution with constant kappa index.
- **These observations agree with the predictions of the exospheric theory.**
- **Solar Orbiter and Solar Probe Plus radio instruments will provide a larger distance range.**

Le Chat et al., 2009 ; 2010 ; 2011

Quasi-thermal noise in anisotropic plasmas

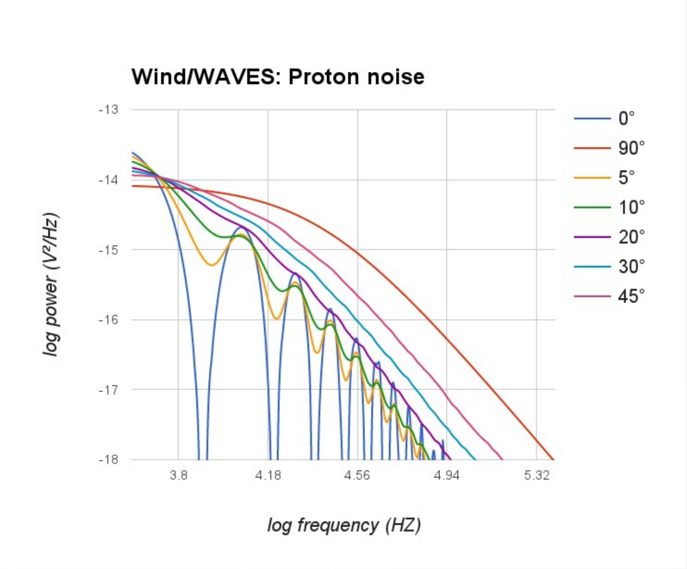
- **Anisotropy important in the solar wind** (competition between conservation of the adiabatic invariant and Coulomb collisions, driver of instability…)
- **Strahl measurements** on Solar Probe Plus might rely upon **quasi-thermal noise spectroscopy**

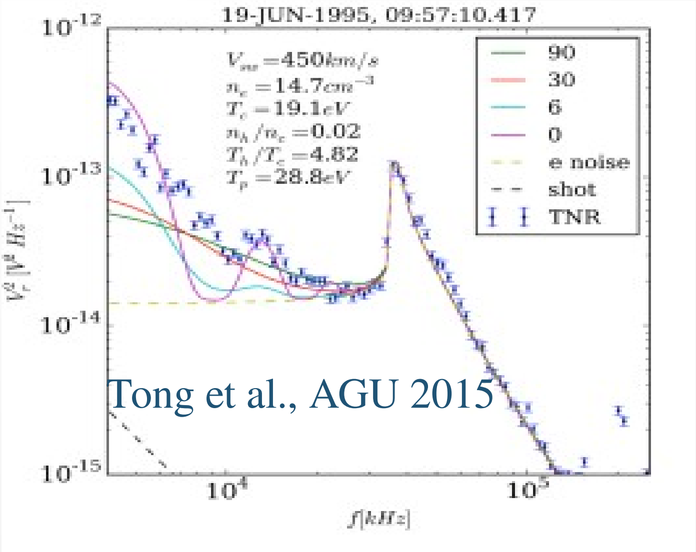
To do so

- need to describe all the effects due to the change direction between the antenna and solar wind
- and the effect of the spacecraft spin

Wind/WAVES is ideal to test this before SO and SPP launches

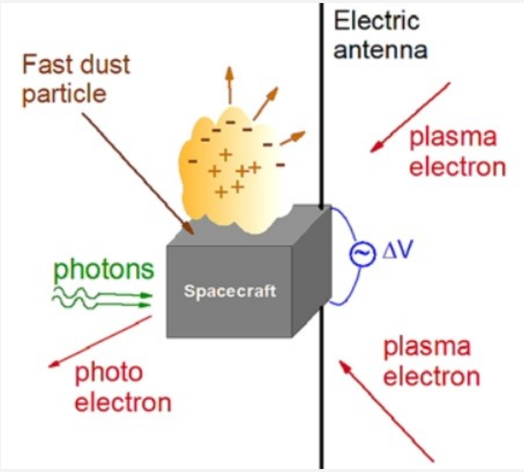
Work in progress!



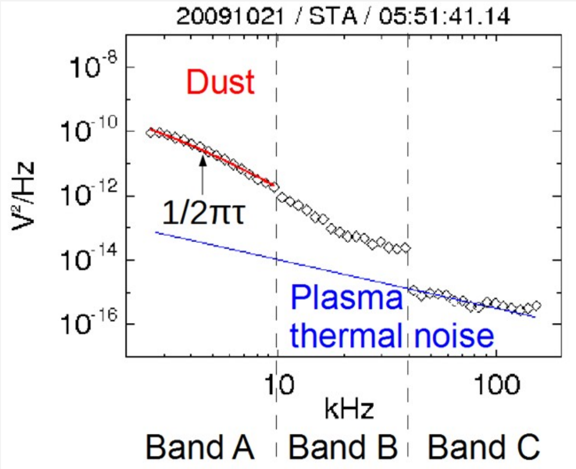


Tong et al., AGU 2015

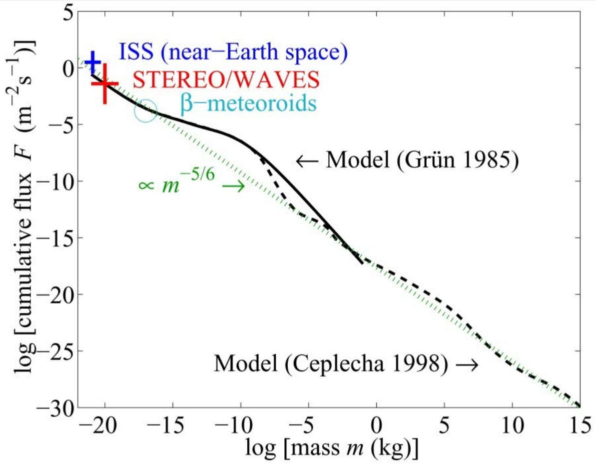
Interplanetary nanoparticles



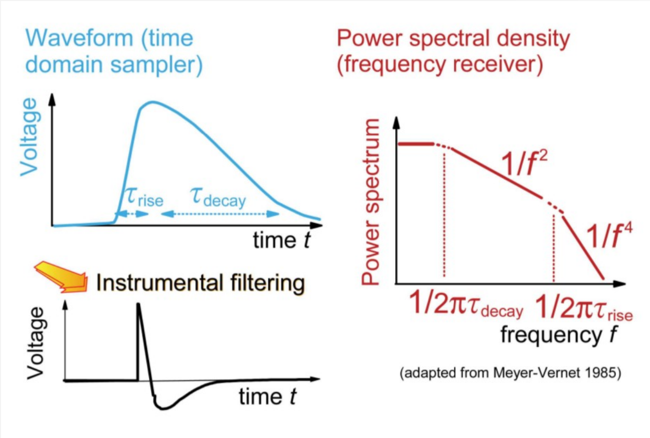
Meyer-Vernet et al, 2010



Le Chat et al., 2013



Meyer-Vernet et al, 2015



- Nanoparticles accelerated by the solar wind:

  in situ measurements feasible with radio instrument
- Detection mechanism by STEREO/WAVES (Pantellini et al., 2013) + analysis algorithm of the spectral density (Le Chat et al., 2013):
  - Analysis of 10 millions of radio spectra: **statistical study of nanodust properties and their evolution**

Discovery of nanodust at 1 AU:

fundamental result in the study of interplanetary dust

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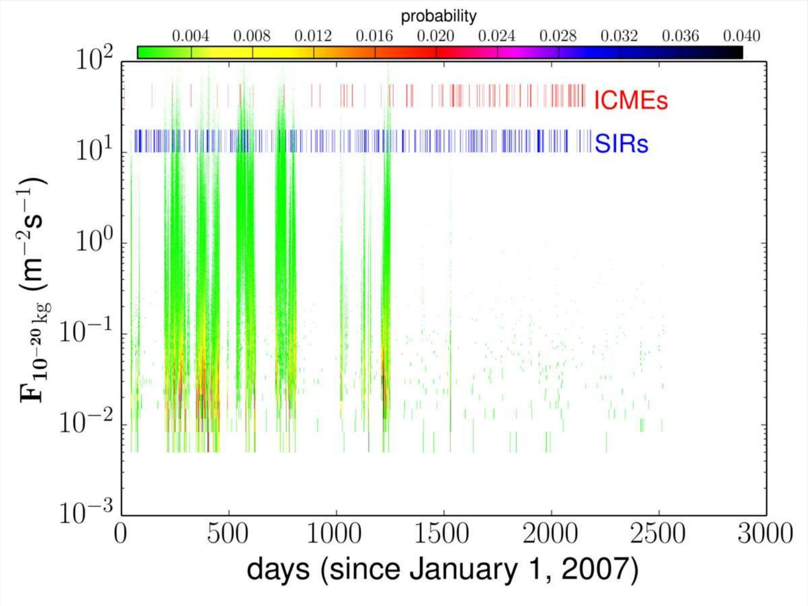
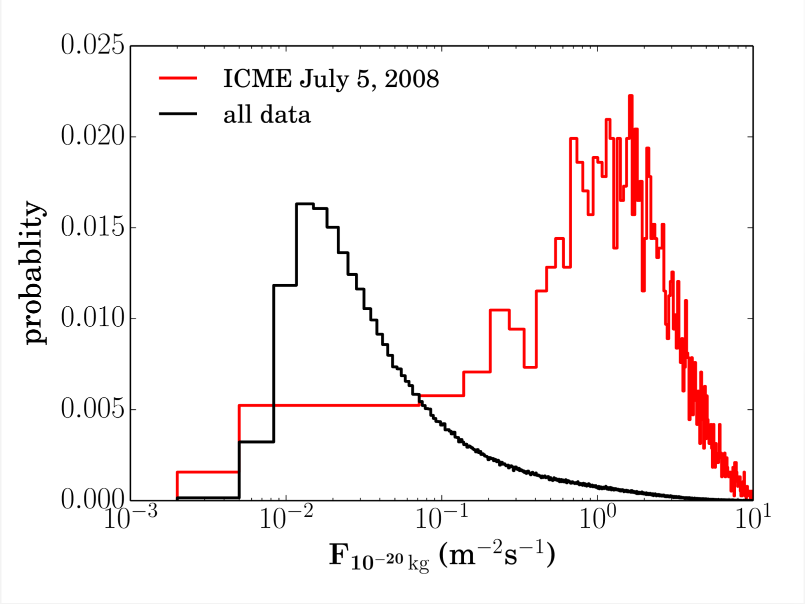


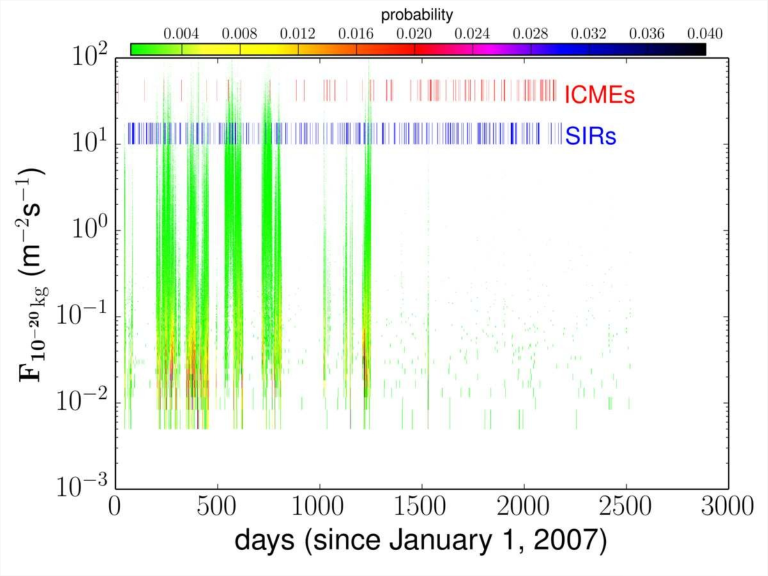


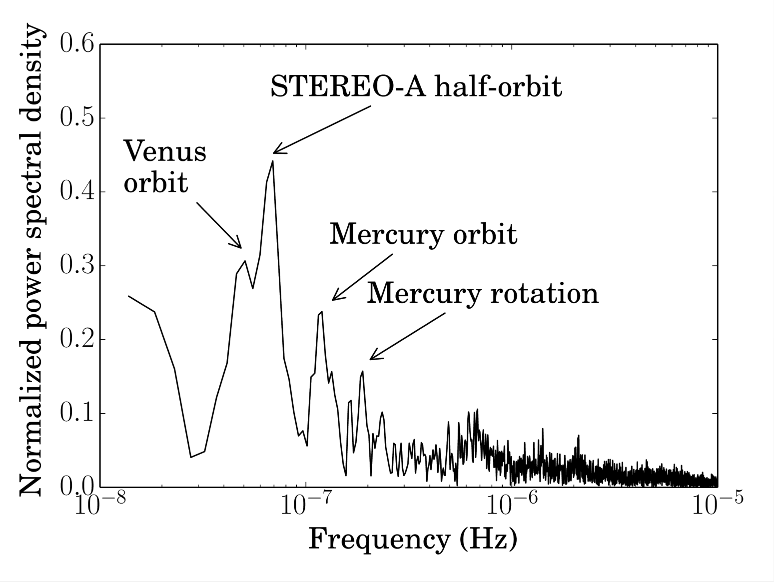
Effect of transient events on nanodust:

- Transient events (**ICMEs** and SIRs) **change the dynamic behavior of already released nanodust**
- Nanodust accelerated by the a focusing interplanetary magnetic field (IMF) with a speed close to the ICMEs' one allowed **the dust to interact with the plasma and magnetic field of the ICME**, leading to the observed higher nanodust fluxes
- Also explains the absence of nanodust observed within ICMEs outside focusing IMF configuration

Le Chat et al., 2015

Interplanetary nanoparticles





Effect of Mercury and Venus on the dust flux:

- **Nanodust flux** observed by STEREO-A at 1 AU may be **influenced by Venus and Mercury**
- Both planets increase the number of nanoparticles in the interplanetary medium. Might be cause by the encounter with regions of higher interplanetary dust density, such as cometary trails.
- Hot spots on the surface of Mercury might be releasing dust into the interplanetary medium when illuminated by the Sun
- Similar behavior observed for nanodust in the Saturn magnetosphere

Le Chat et al., 2015

Future Works

Solar Wind Measurements:

- Wind/WAVES/TNR L3 database
- Electron temperature anisotropy and strahl measurements
- Paving the road to Solar orbiter and Solar Probe Plus

Nanodust:

- Simulation of nanodust dynamic within ICMEs
- Planetary effects on nanodust: comparative study with Saturn magnetosphere
- Mass and angular momentum losses of stellar system from nanoparticles pickup by stellar winds (i.e. accretion disks)