

REVISITING THE "PERFECT DETECTOR" CONCEPT: electron moments from thermal noise spectroscopy and other techniques

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Space plasma measurements by classical particle spectrometers and Langmuir probes are intrinsically limited by the spacecraft potential. This limitation does not affect passive wave measurements at long wavelengths, since they perform an average over a large plasma volume. Thermal noise spectroscopy is based on a passive measurement of the plasma wave spectrum with a long electric antenna, and yields directly the density and the kinetic temperature of a stable electron velocity distribution. This technique does not suffer of the difficulties in plasma resonance identification that impede some other wave techniques as the resonance sounder and the quadripolar probe, and, contrary to them, does not perturb the other in-board instruments. We summarize the limitations and achievements of different plasma detectors in a variety of planetary and plasma environments, and examine how they might be combined on future missions. Finally, we examine how thermal noise spectroscopy might be implemented on a Solar Probe.

Space plasma detectors are basically of two types:

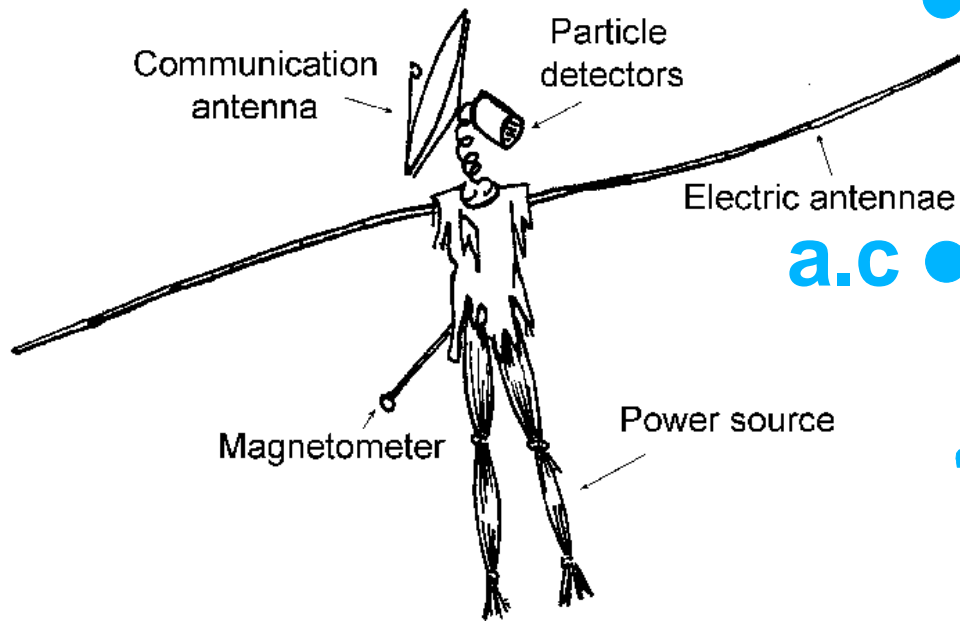
d.c ● **Particle spectrometer** \Rightarrow velocity distribution of particles $f(v)$

● **Langmuir probe/double probe:** measure plasma current \Rightarrow some moments of $f(v)$

a.c ● **Electric antenna** \Rightarrow electrostatic waves \Rightarrow some moments of $f(v)$

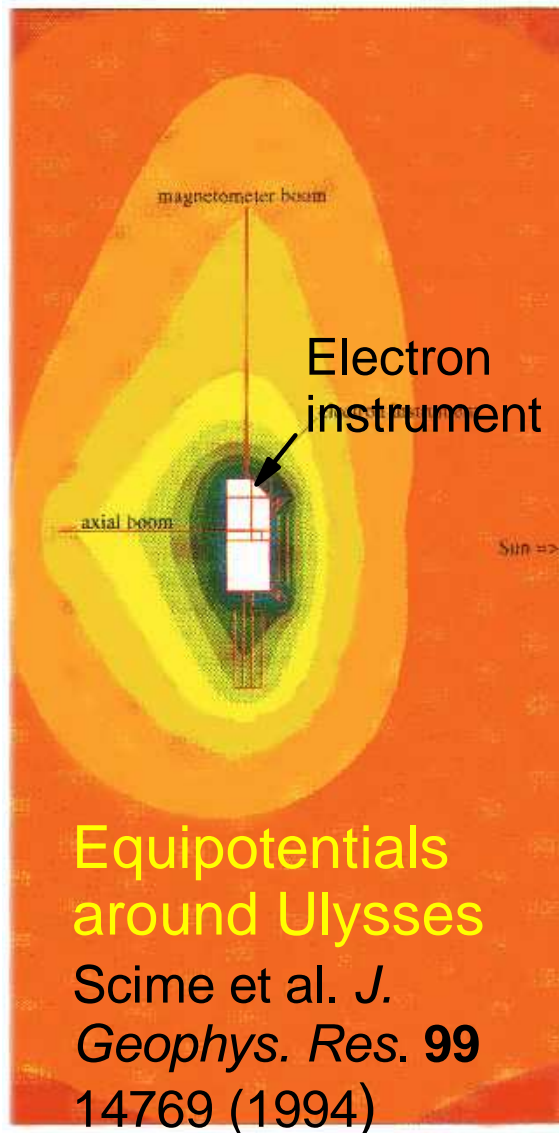
➤ **Passive: Thermal noise spectroscopy** has worked in: solar wind, various planetary ionospheres, magnetospheres, comets

➤ **Active: Resonance sounder, Quadrupolar probe** have worked in Earth magnetosphere



Simplified strawman payload
(copyright Meyer 2004, Meyer-Vernet, Basics of the Solar Wind, Cambridge U. P., 2005)

Inherent limitation of dc methods: measurement close to S/C



- Spacecraft charging/modif. of environment
- Photoelectrons
- Non ideal geometry and cleanliness

Some items discussed by:

- Song et al., *PSS* **45** 255 (1997)
 - Genot and Schwartz, *Ann. Geophys.* **22** 2073 (2004)
- for particle spectrometers in connection with the concept of "perfect plasma detector"

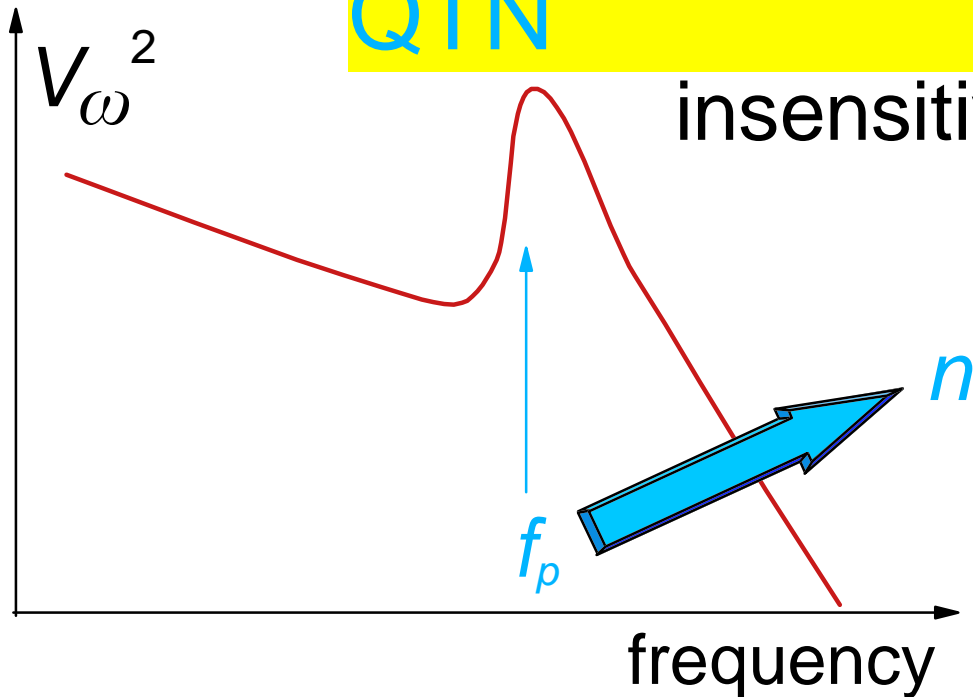
ac measurements: thermal noise spectroscopy

- Simplest of ac methods
- Has been proven in routine in numerous media



- Principle:** spectroscopy of plasma quasi-thermal noise measured at the ports of an electric antenna
 - around f_p if non magnetised: \Rightarrow *electron measurements*
 - around f_{UH}, f_Q, nf_H if magnetised *measurements*
- detector is large (long antenna)
- detects medium on a large scale because
Langmuir wavelength $\sim v_{th} (1 - \omega_p^2 / \omega^2)^{-1/2} / \omega \rightarrow \infty$
for $\omega \rightarrow \omega_p$

Density measurement with QTN



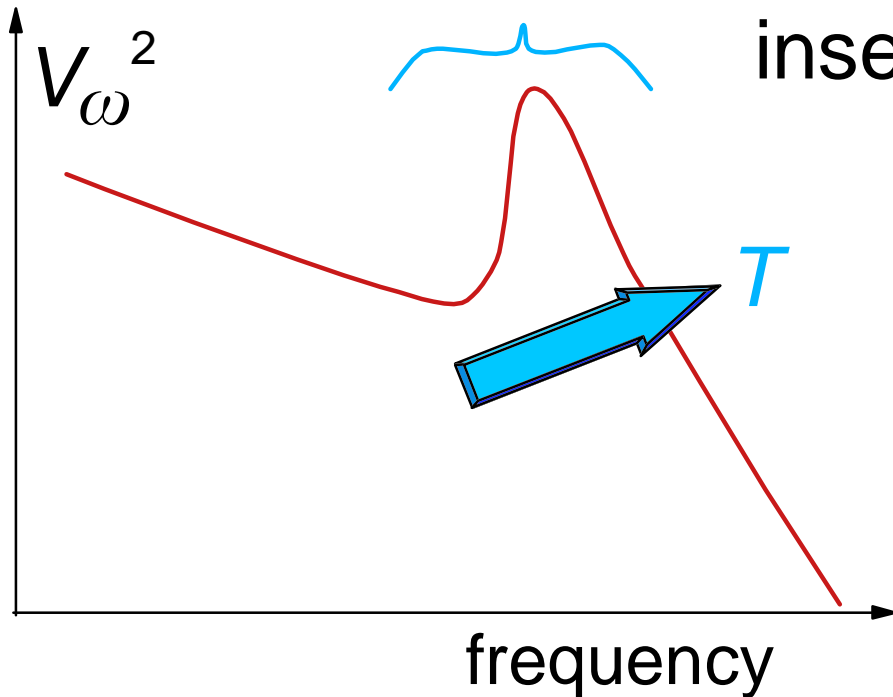
insensitive to:

- Spacecraft charging
- Photoelectrons
- Non ideal geometry and cleanliness

- Measurement of frequency
- Limitation: frequency resolution of receiver
- Requires antenna length $L > L_D$ (since Langmuir wavelength $> L_D$)

Meyer-Vernet and Perche (1989) *J. Geophys. Res.* **94** 2405

Temperature measurement with QTN



insensitive to:

- Spacecraft charging
- Photoelectrons

Requires:

- Constrained geometry
- Antenna length $L > L_D$
- Sensitive and well calibrated receiver

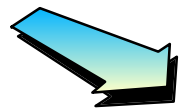
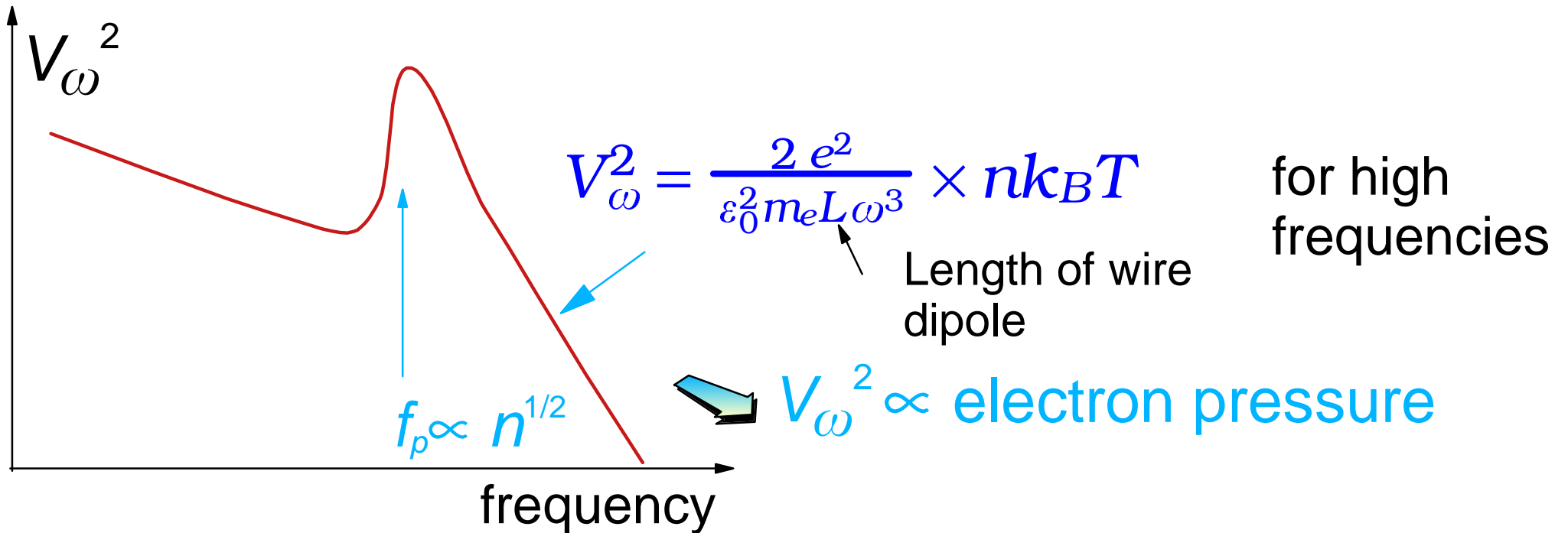
$$V_{\omega}^2 = \frac{e^2}{2\pi^2 \varepsilon_0^2} \int d^3 k F(\mathbf{k}) \frac{\int d^3 v f(\mathbf{v}) \delta(\omega - \mathbf{k} \cdot \mathbf{v})}{k^2 |\varepsilon_L(\mathbf{k}, \omega)|^2}$$

Meyer-Vernet et al. (1998)
AGU Monograph **103** 205

$F(k)$ depends on antenna geometry

for example if wire dipole antenna $\parallel \mathbf{x}$: $F(\mathbf{k}) = \left(4 \frac{\sin^2(k_x L/2)}{k k_x L}\right)^2$

Generic property: (holds for any stable $f(v)$)

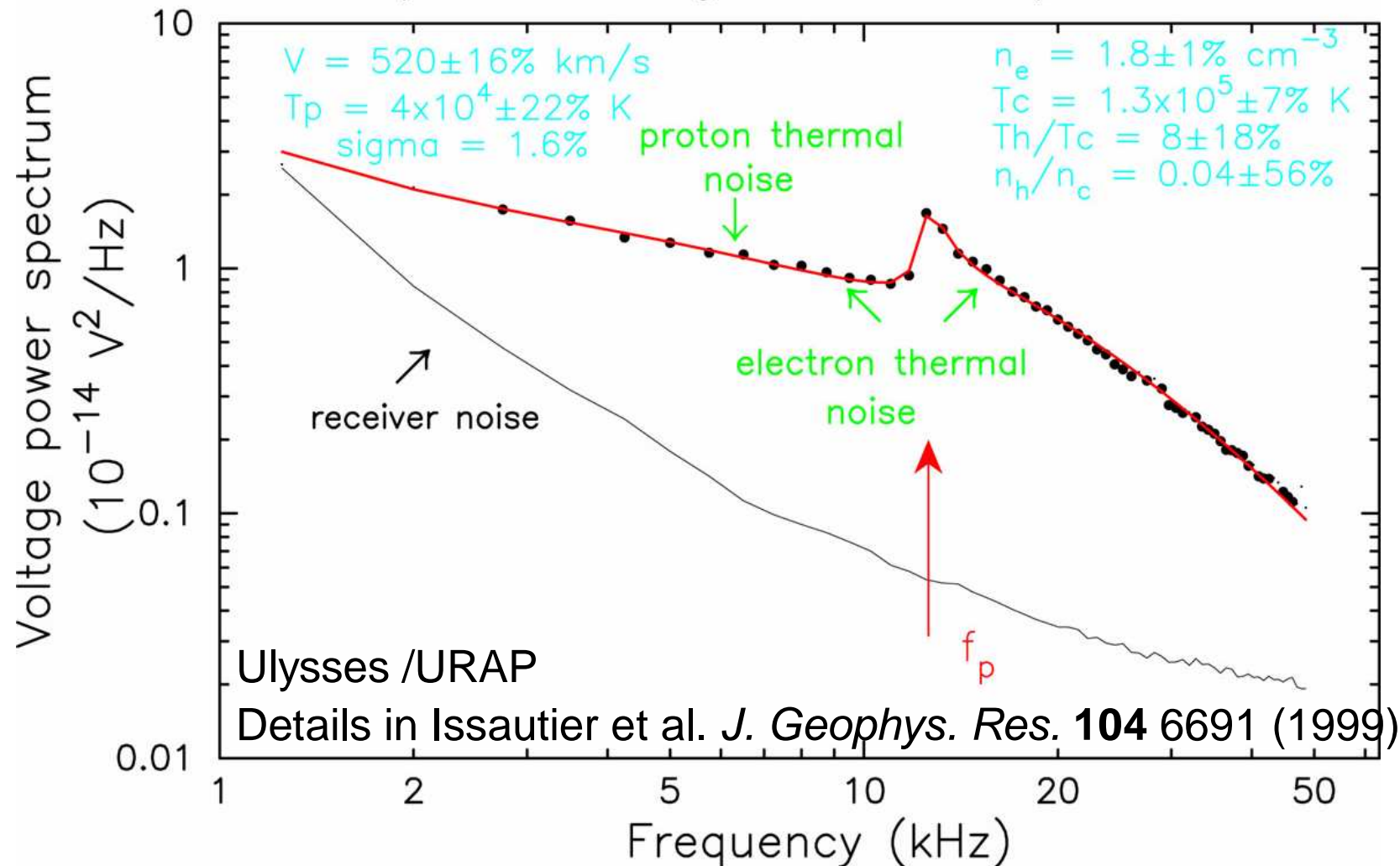


QTN spectroscopy = "Perfect detector" for moments of order 0 and 2

Chateau & Meyer-Vernet (1991) *J. Geophys. Res.* **96** 5825

Example of QT noise spectrum and diagnostics

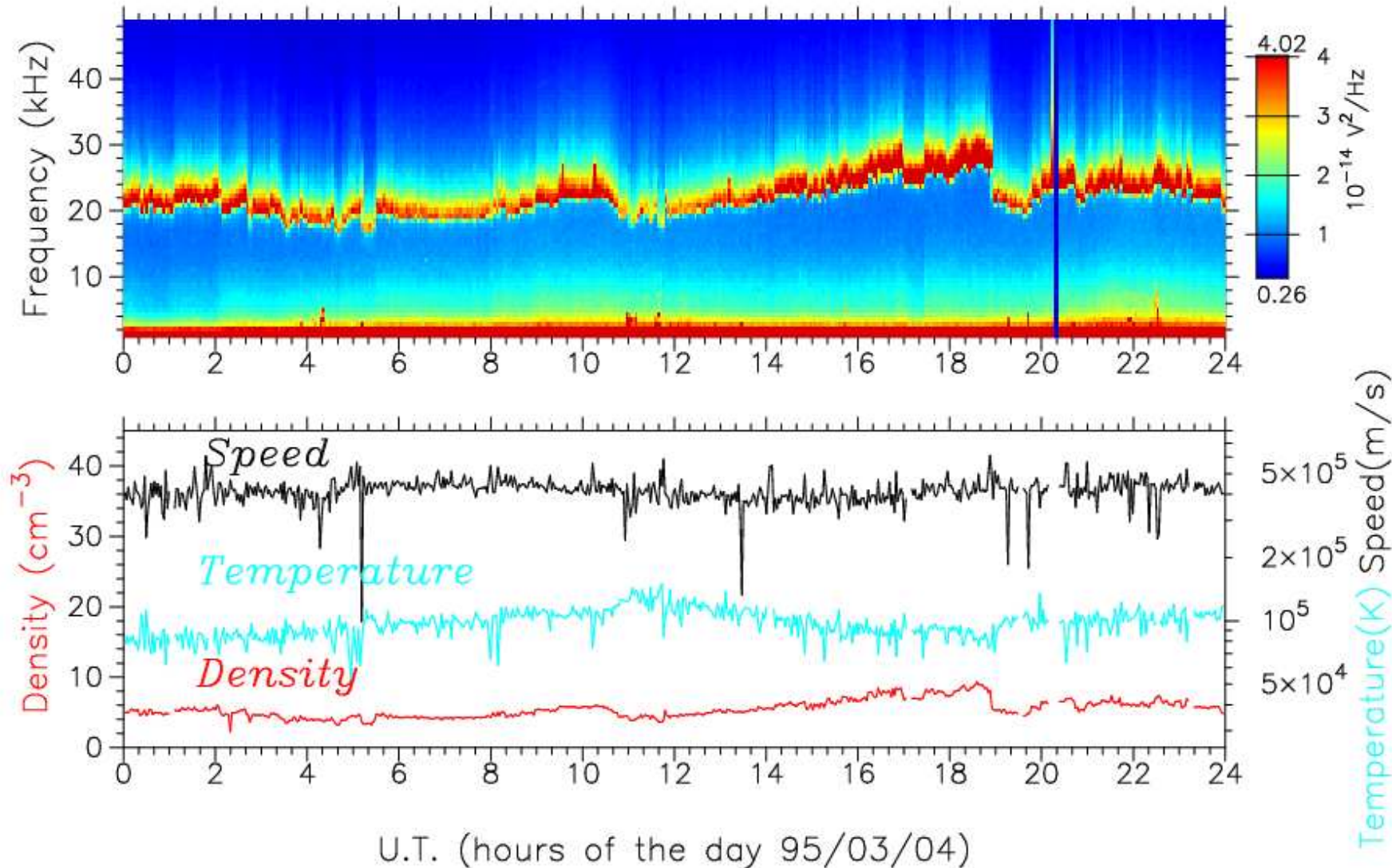
(Latitude: 11.1 deg, Distance: 1.34 AU)



Data points and **best fit** with 6 plasma parameters (electron density and core temperature, wind speed, suprathermal electron density and temperature)

Solar wind electron measurements in routine on Ulysses

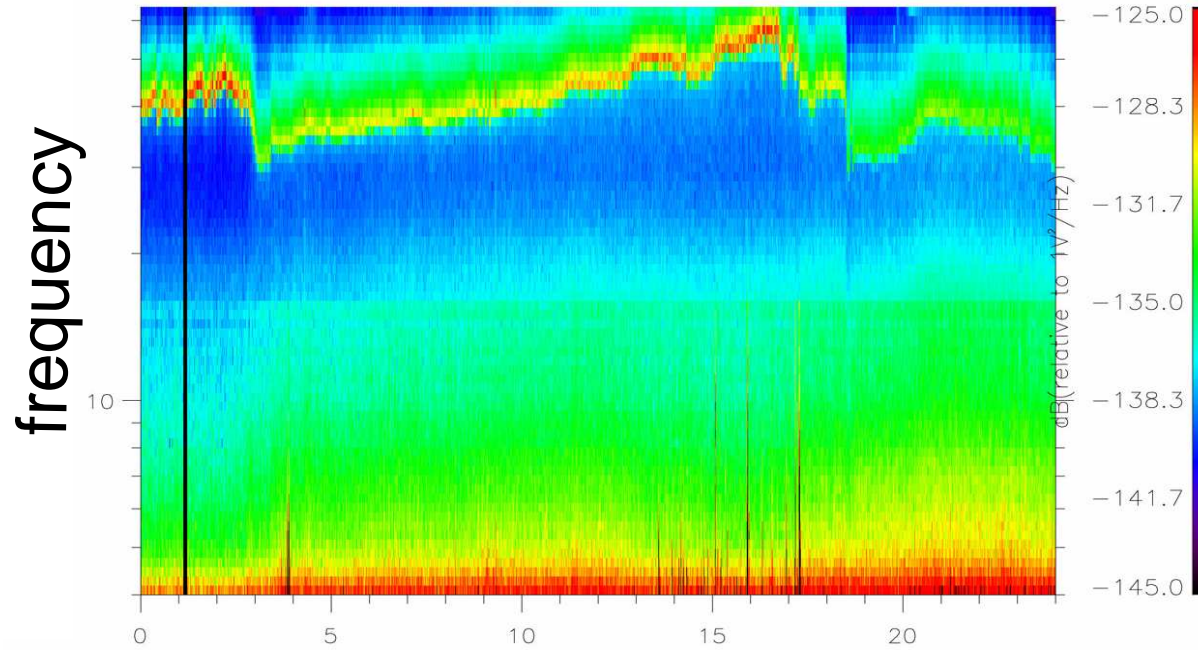
URAP



Details in Issautier et al. (1998) *J. Geophys. Res.* **104** 6691

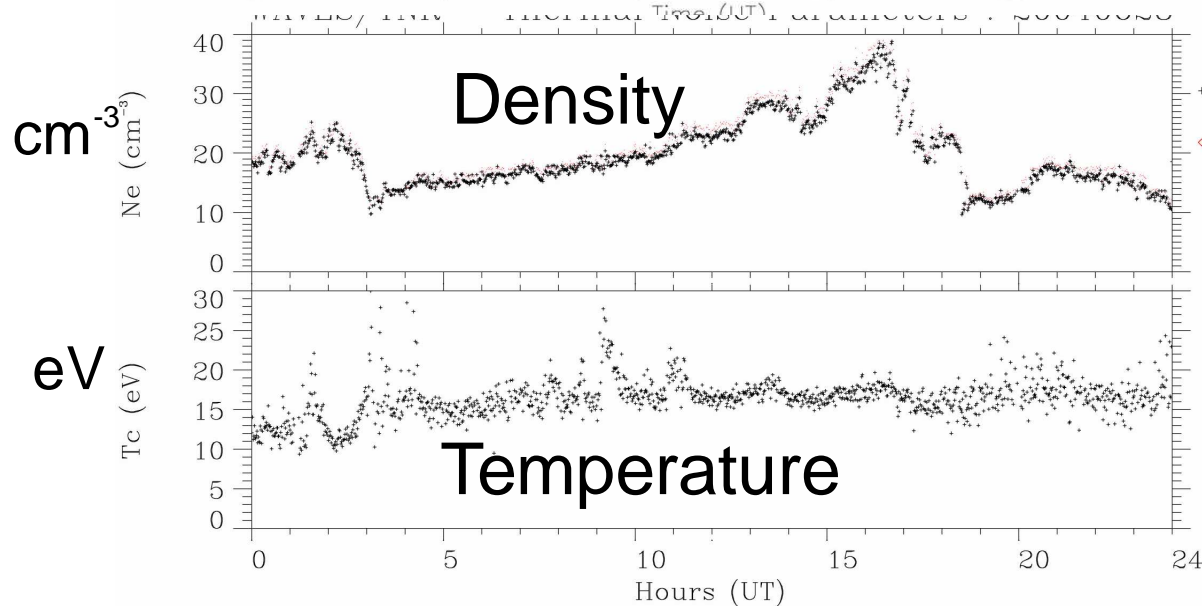
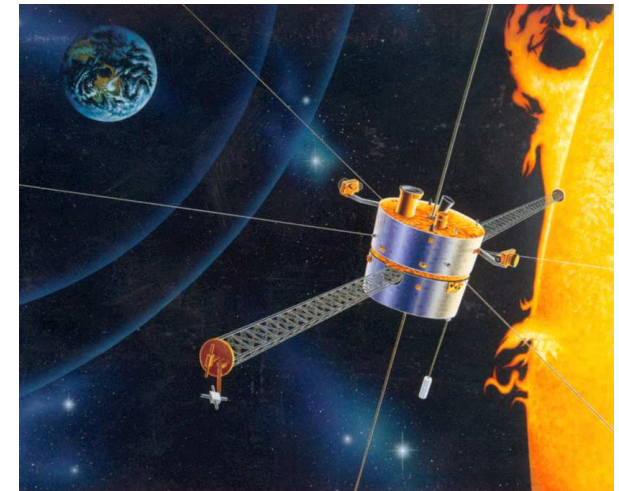
Solar wind electron measurements in routine on Wind

28-JUN-2004, 00:00:00.000 Ex TNR_A



$$V_{\omega}^2$$

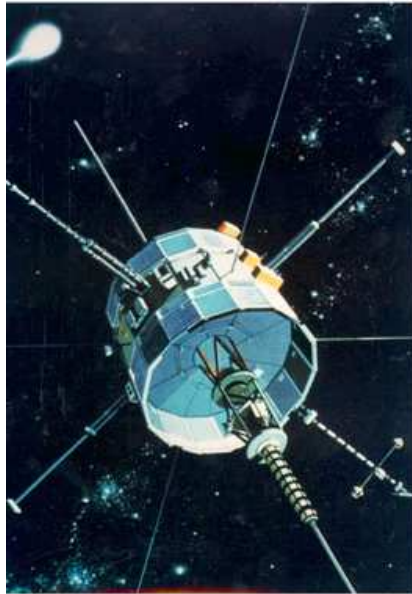
Waves



data available at
<http://cdpp.cesr.fr>

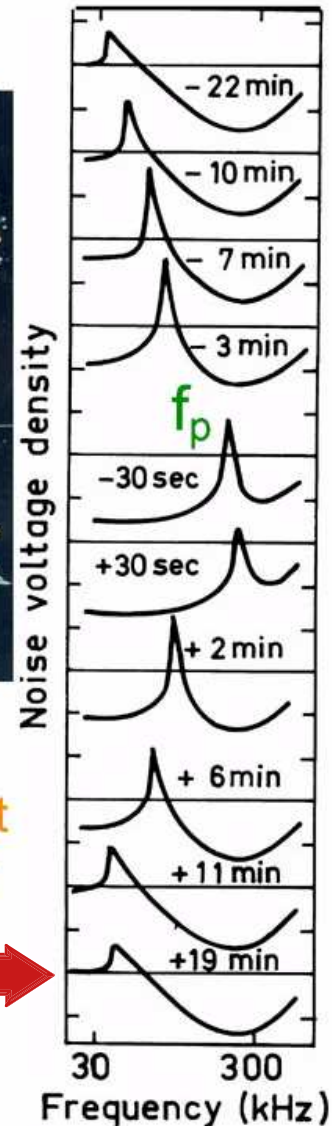
First (and only) encounter of a spacecraft with a comet's plasma tail

Measuring electrons with Thermal Noise Spectroscopy



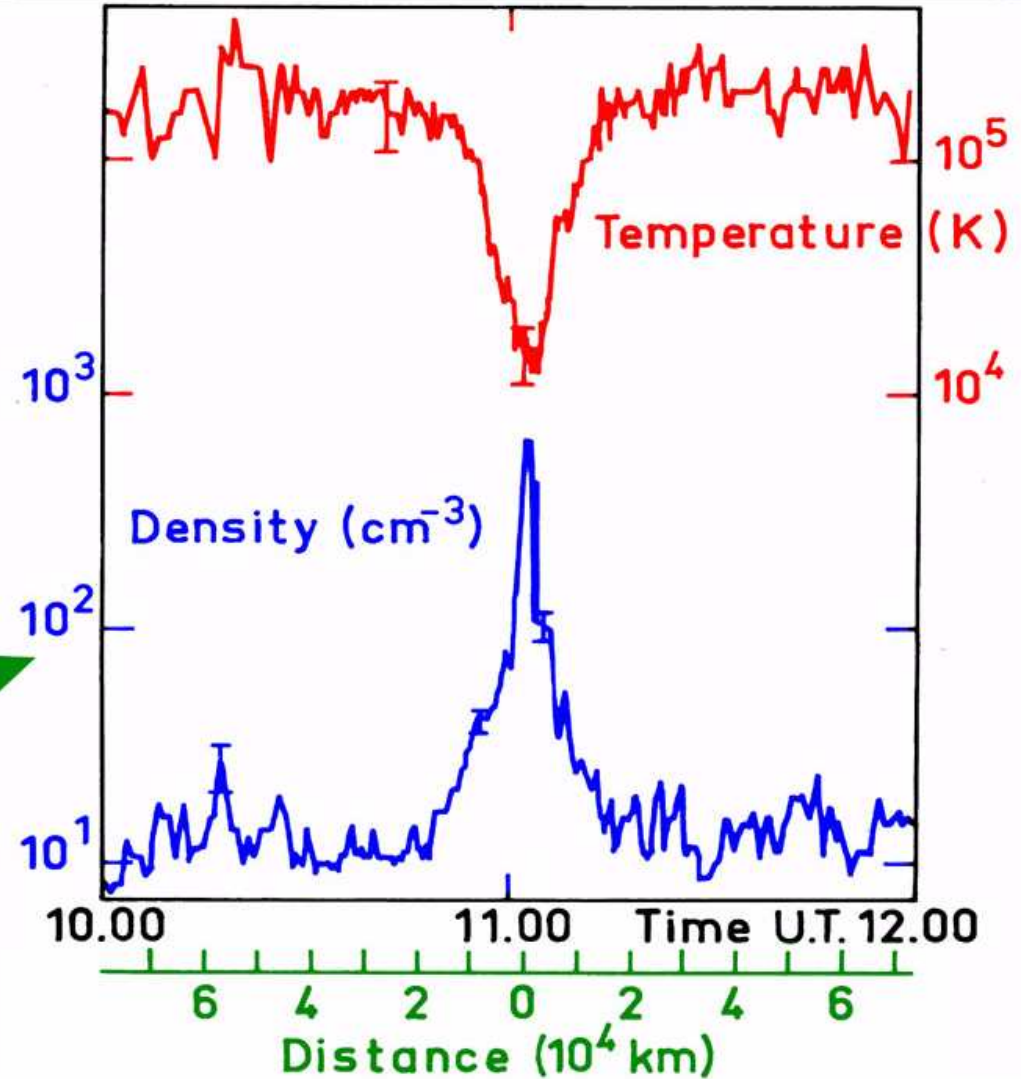
ISEE3/ICE encounters comet Giacobini-Zinner

Radio instrument



Plasma line

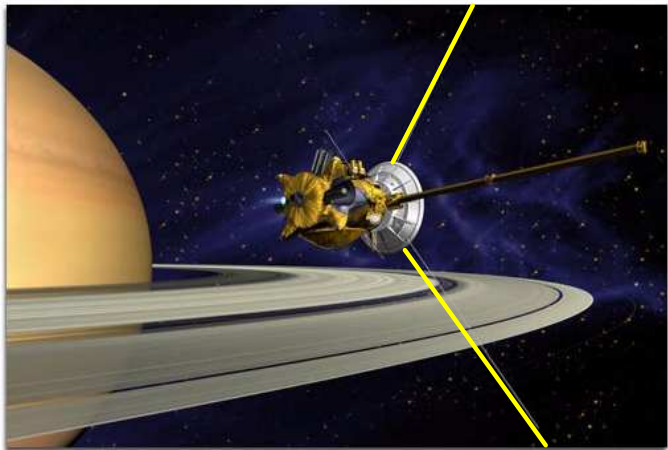
Observatoire de Paris/NASA GSFC - ICE Radio experiment



Meyer-Vernet et al. (1986) Science, 232, 370

Temperature $\sim 1\text{eV}$ particle spectrometers inadequate

Cassini/PWS/1 July 2004 : Encounter with Saturn



electric antenna

Diagnostic of electron density and temperature, dusty rings, and magnetic field from QTN spectroscopy



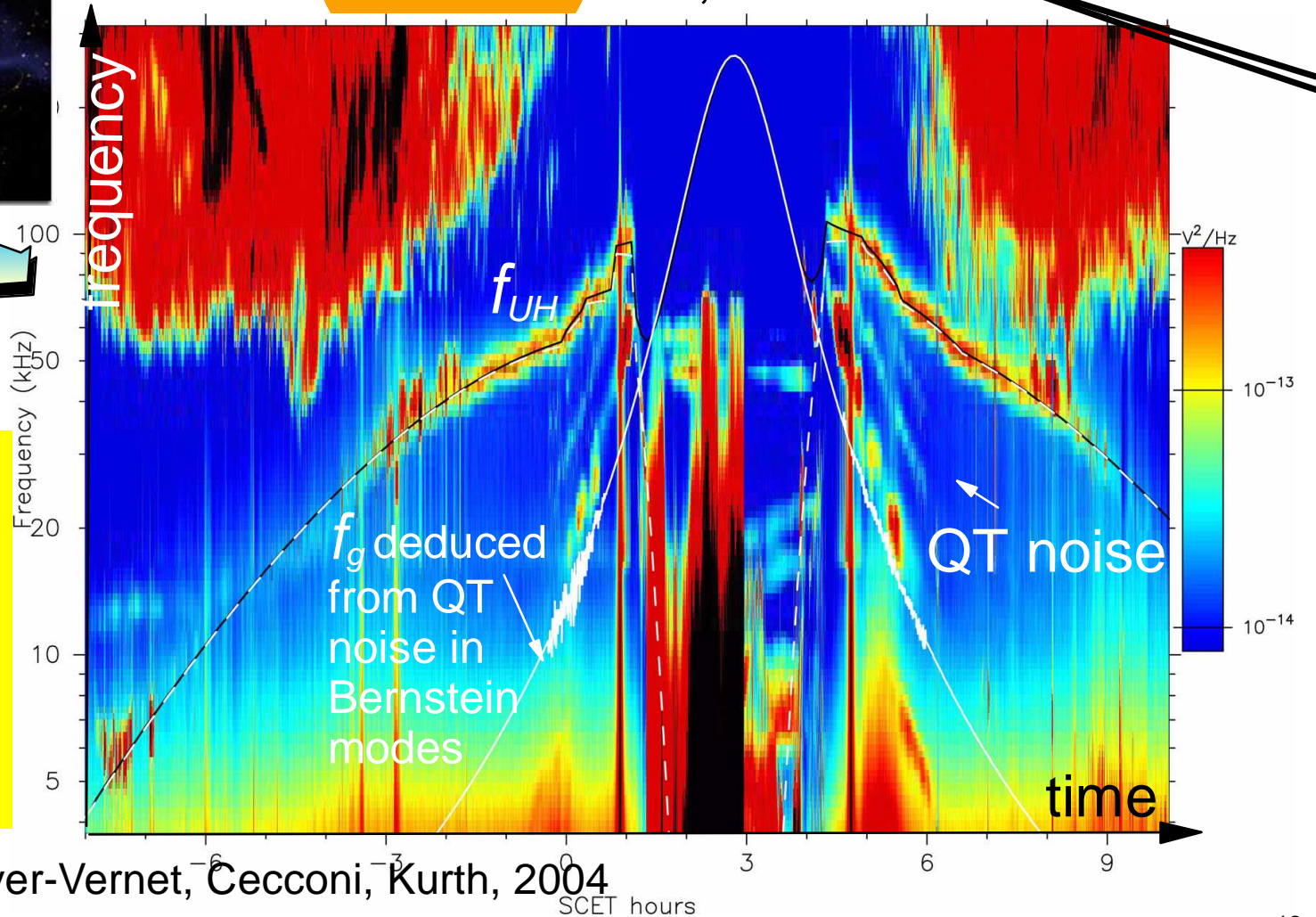
Trajectory of Cassini



Saturn

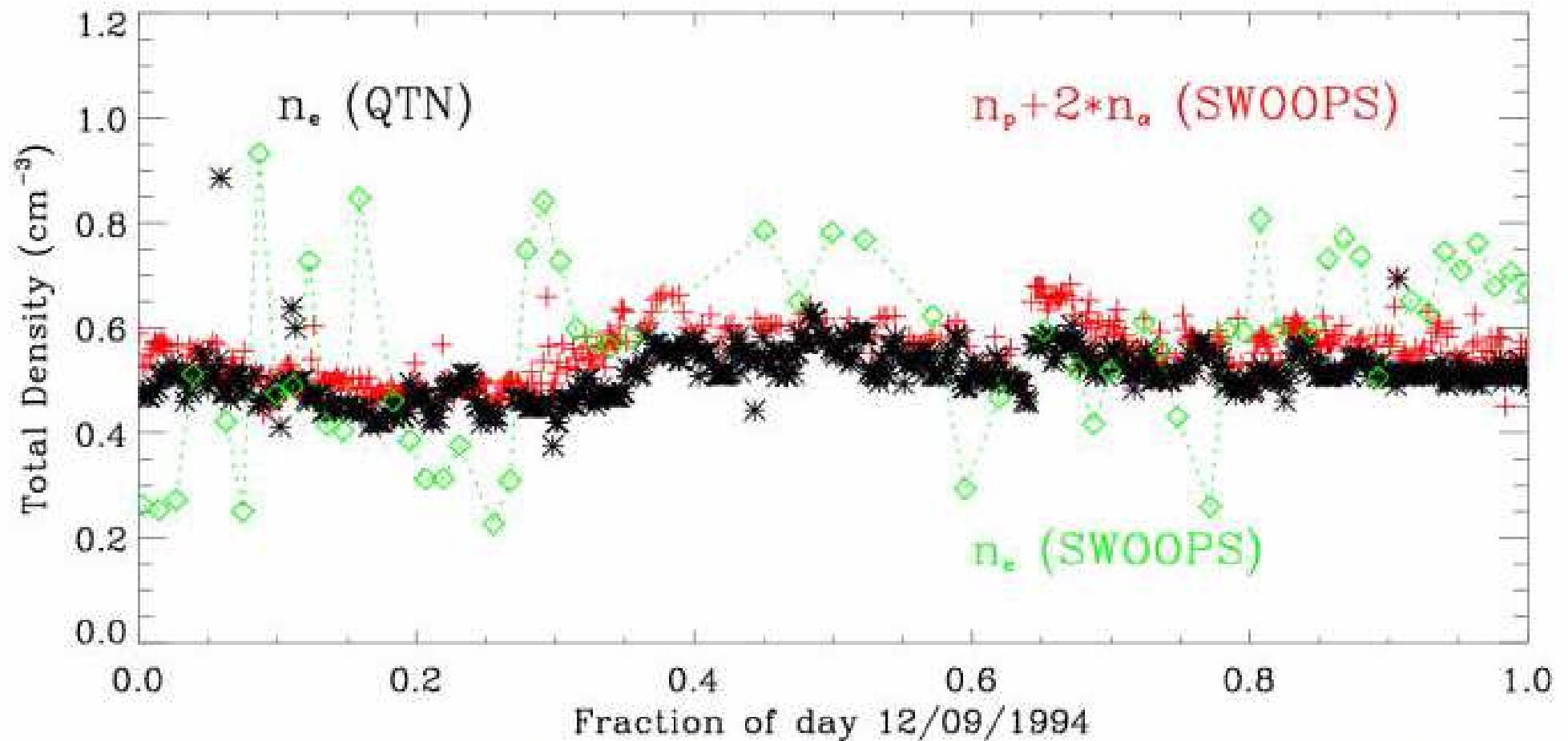


Rings



Moncuquet, Lecacheux, Meyer-Vernet, Cecconi, Kurth, 2004

Comparison of solar wind density measurements on Ulysses

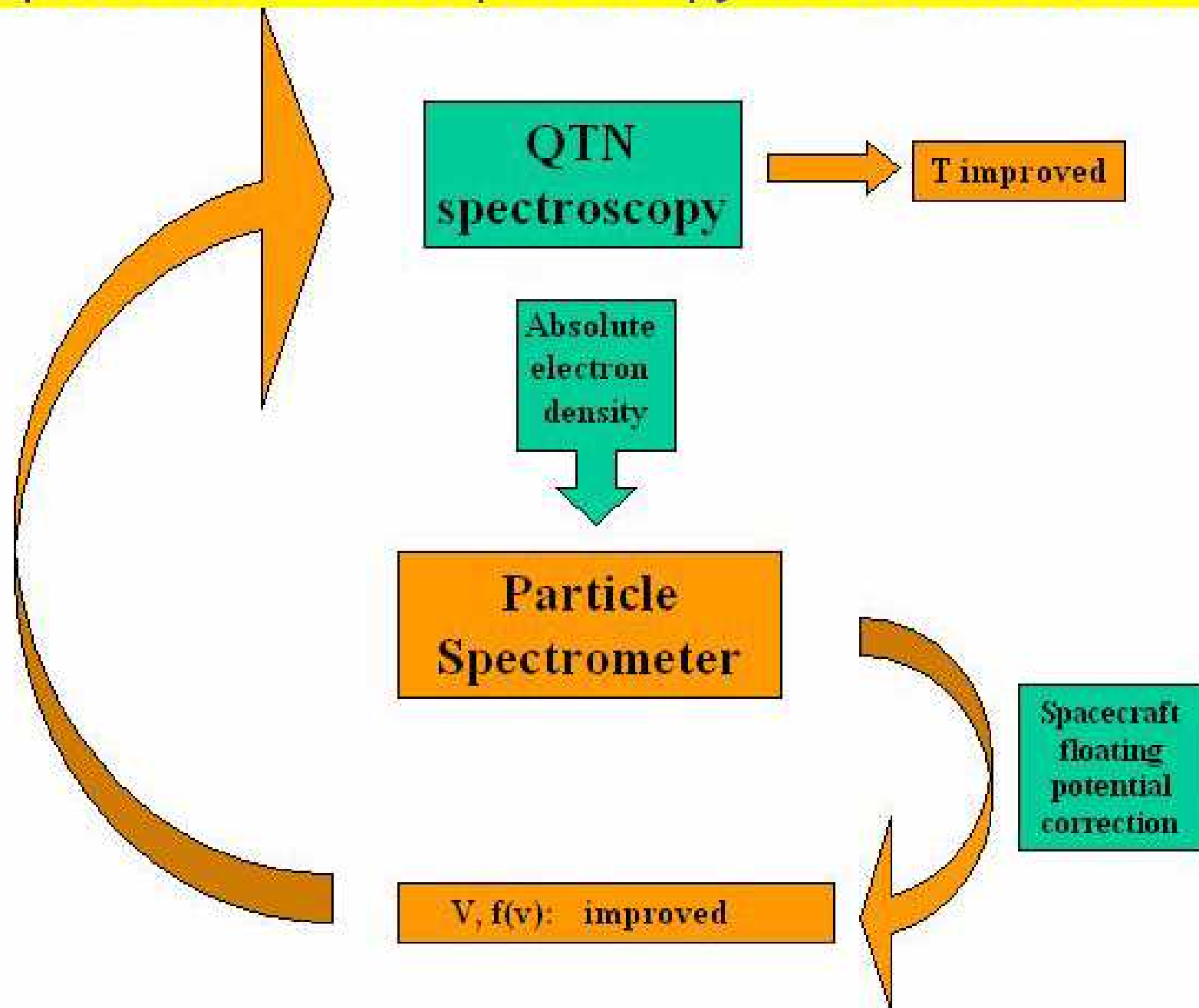


- ion spectrometer and QTN spectroscopy in agreement
- electron spectrometer polluted by spacecraft effects



electron spectrometers need calibration
by QTN spectroscopy

Perfect detector for moments of order 0, 1, 2, etc.: Particle spectrometer + QTN spectroscopy with electric antenna

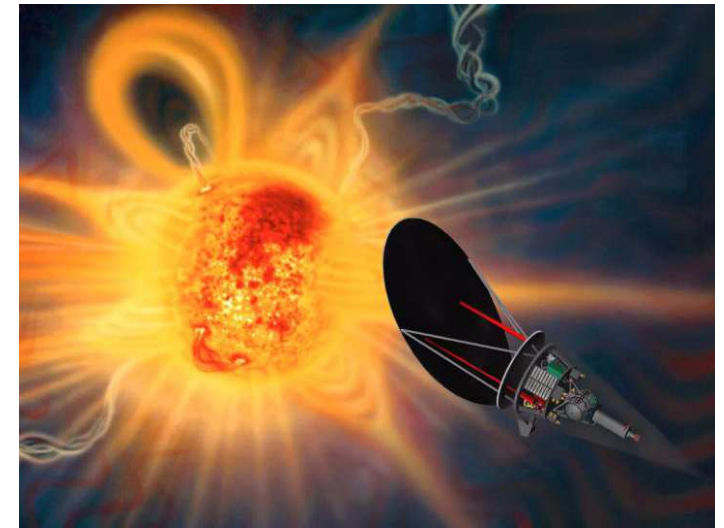


The future: Solar Probe



Electron density and temperature can be measured in the corona with WAVE instrument (1 m electric antenna)

Solar Orbiter ($L > 5$ m), ...



Debye length in the corona

