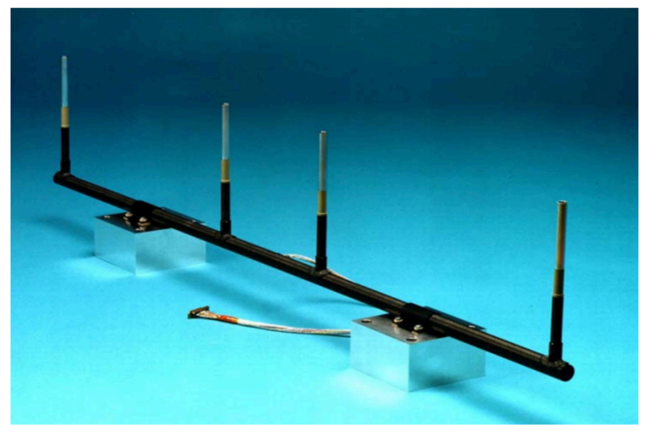
Modelling and calibration of the mutual impedance experiments
Application to ESA's Rosetta Mission and preparation of BepiColombo and JUICE

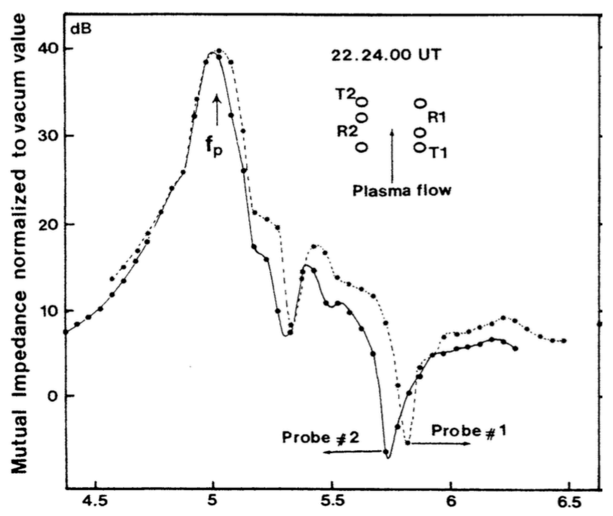
N. Gilet[1], P. Henri[1], G. Wattieaux[2], O. Randriamboarison[1], J.-L. Rauch[1]

[1] Laboratoire de Physique et Chimie de l'Environnement et de l'Espace, CNRS, Université d'Orléans, Orléans, France
[2] Laboratoire Plasma et Conversion d'Energie, Université Paul Sabatier, Toulouse, France

Mutual Impedance Probe : RPC-MIP on Rosetta, PWI/AM2P on BepiColombo and RPWI/MIME on JUICE



Mutual Impedance Probe (RPC-MIP) on-board Rosetta



Example of MI response [Beghin et al., 1982]

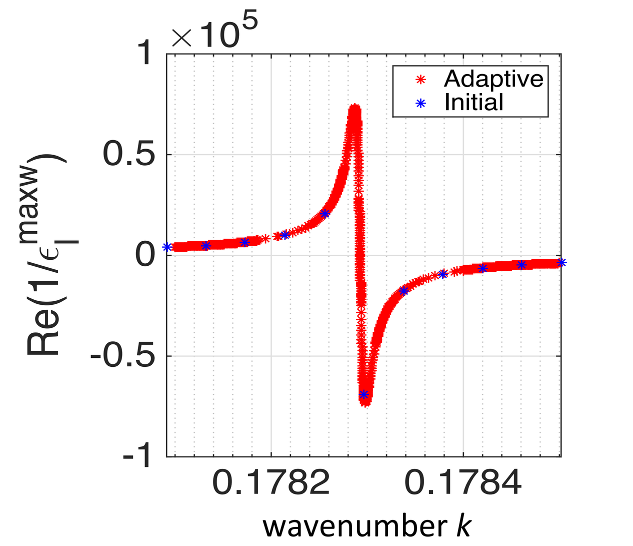
Mutual impedance (MI) probe experiments are used in various ionised environments, from ionospheric to space plasmas, to constrain plasma parameters such as the electron density from the identification of the plasma frequency f_p. To finalize the calibration of about 2 years of RPC-MIP mutual impedance spectra in the ionised environment of 67P/Churyumov-Gerasimenko and to prepare the calibration of mutual impedance experiments onboard future exploratory planetary missions (PWI/AM2P onboard BepiColombo and RPWI/MIME onboard JUICE), a modelisation of the electric potential generated by a pulsating charge is realized, taking into the fact that space plasmas are out of local thermodynamic equilibrium (non-Maxwellian).

The potential ϕ induced for each emitter in an isotropic, homegenous plasma by a pulsating point charge *Q.exp(iωt)*, at frequency *ω*, a distance *r* from the charge, with ε_l the longitudinal dielectric function, is :

$$\phi(\omega, r) = \frac{Q}{4\pi\varepsilon_0} \frac{2}{\pi} \lim_{Im(\omega)\to 0} \int_0^{\infty} \frac{\sin(kr)}{kr} \frac{dk}{\varepsilon_l(k,\omega)}$$

The potential, as a solution of the linearized Vlasov-Poisson equation, is computed using a numerical integration. The mutual impedance response is the difference of potential between the receivers.

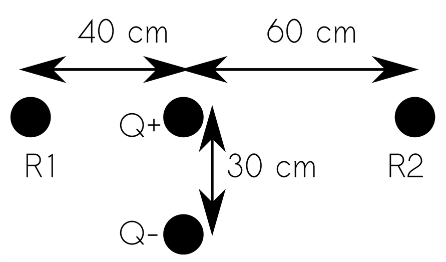
To properly account for the weakly damped pole of the dielectric function located close to the path of integration, a method of grid refinement is used as shown on the right figure for ω = 1.05 centering on the pole for a Maxwellian electron velocity distribution function (evdf).



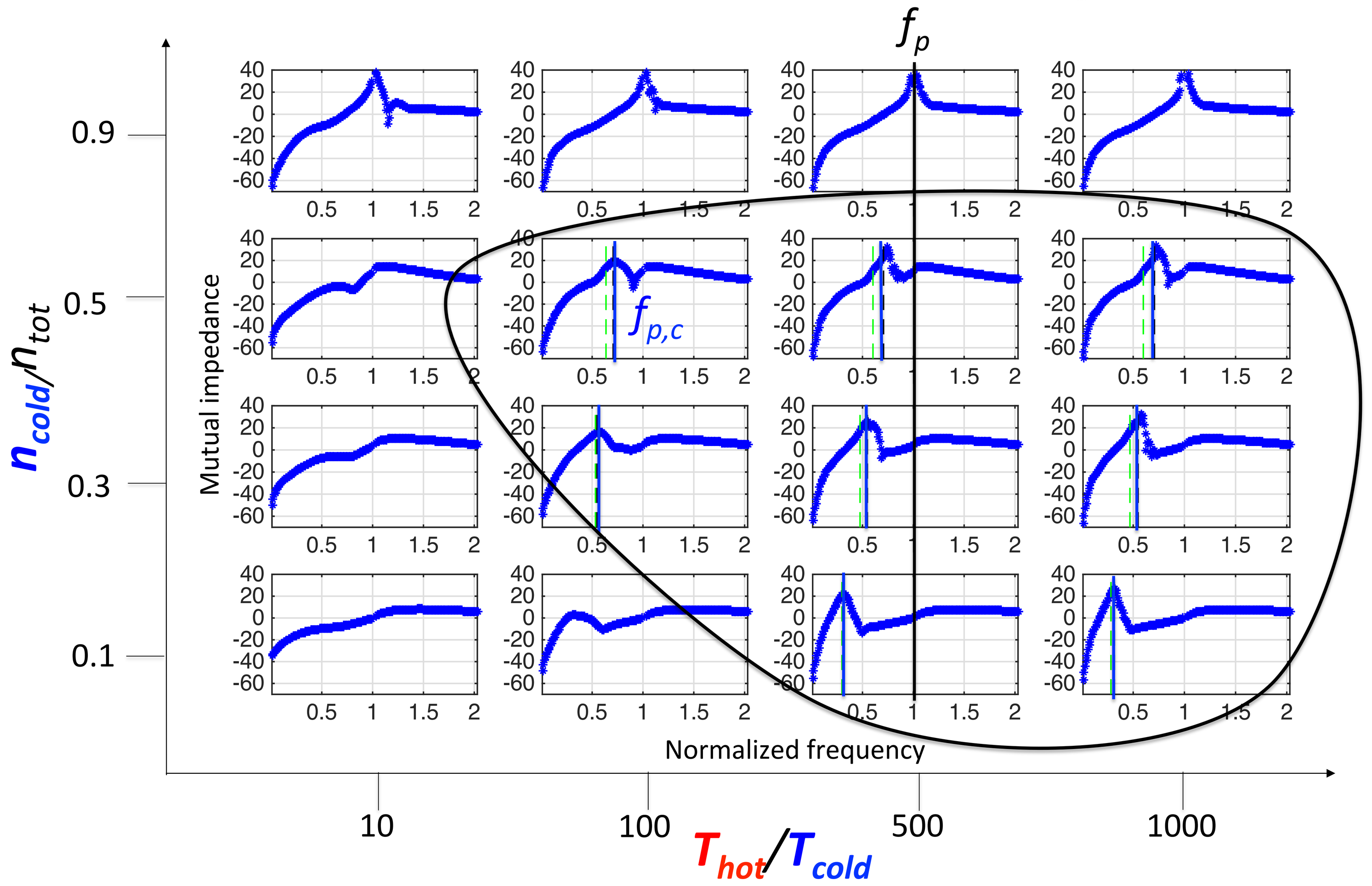
Dielectric function around the weakly damped pole before and after the grid refinement.

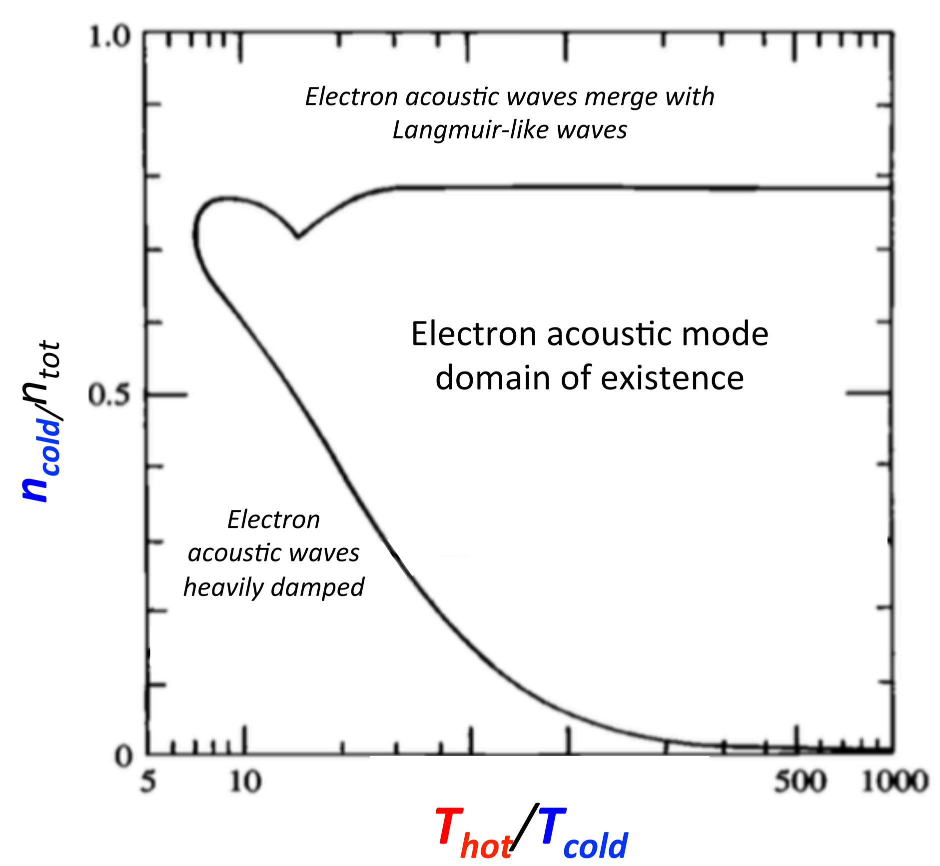
Mutual impedance spectra in a two-electron temperature plasma

We consider a bi-Maxwellian evdf (superposition of 2 Maxwellian electron populations), characterized by 4 parameters: n_{hot}, n_{cold}, T_{hot} and T_{cold} (electron density and temperature of the hottest and coldest electron populations). Two characteristic resonances can be observed in the MI spectra: at the plasma frequency f_p and close to the cold plasma frequency $f_{p,c} < f_p$. This second resonance is shown to be associated to the excitation of electron acoustic waves and is observed only in a restricted domain of hot-to-cold temperature and density ratio [*Gilet et al., submitted to Radio Science*].



Quadrupolar mutual impedance probe made from 2 conducting spheres and 2 potential sensors, for which the MI spectra are computed.



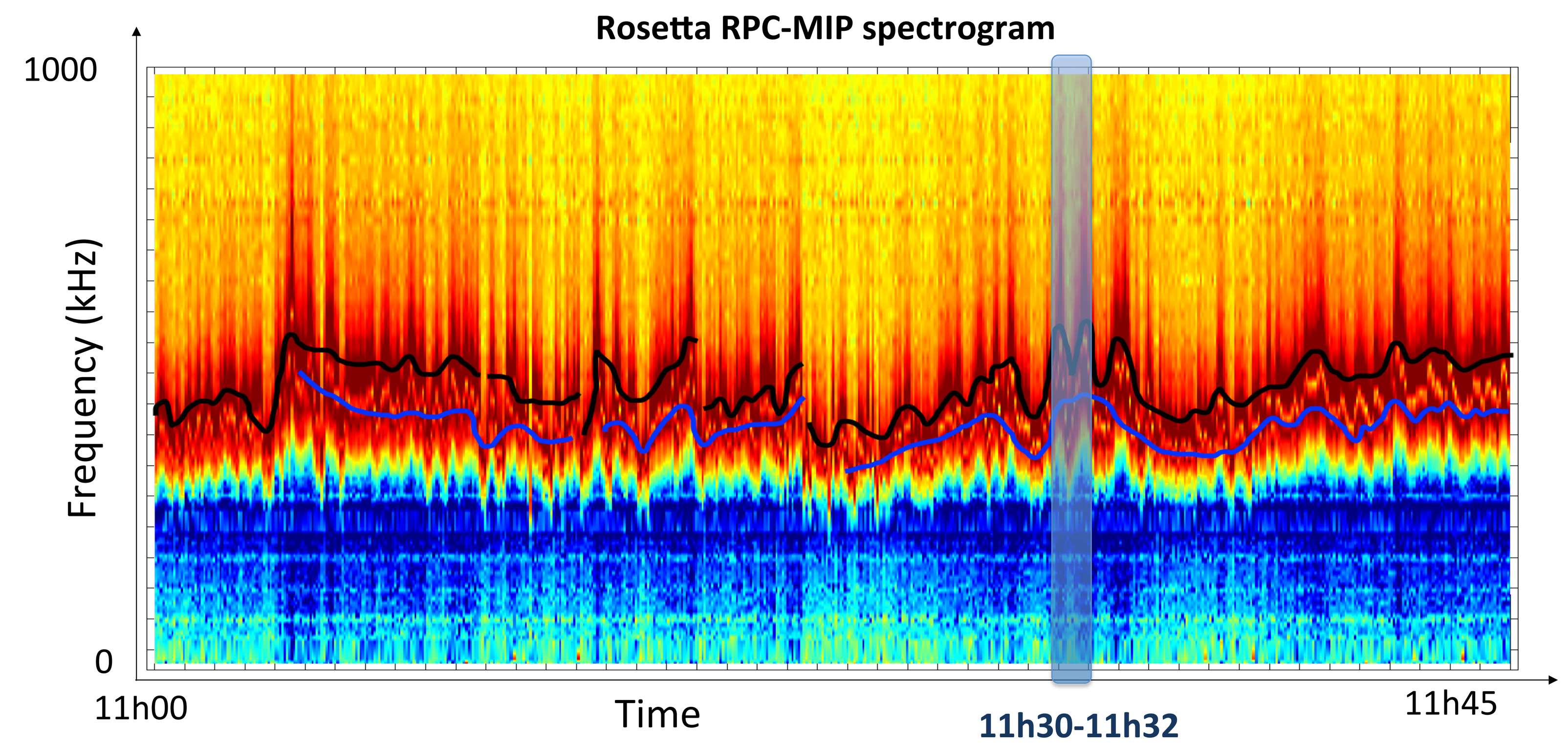


[from Gary & Tokar, 1965; Gary, Theory of Space Plasma Microinstabilities, 1993]

Amplitude (in blue) of the normalized mutual impedance spectra for different temperature and density ratios. The **hot Debye length** is fixed to 10cm. The green vertical dotted lines show the position of the electron acoustic pole, computed with the analytical dispersion relation. The blue vertical lines show the **cold plasma frequency**.

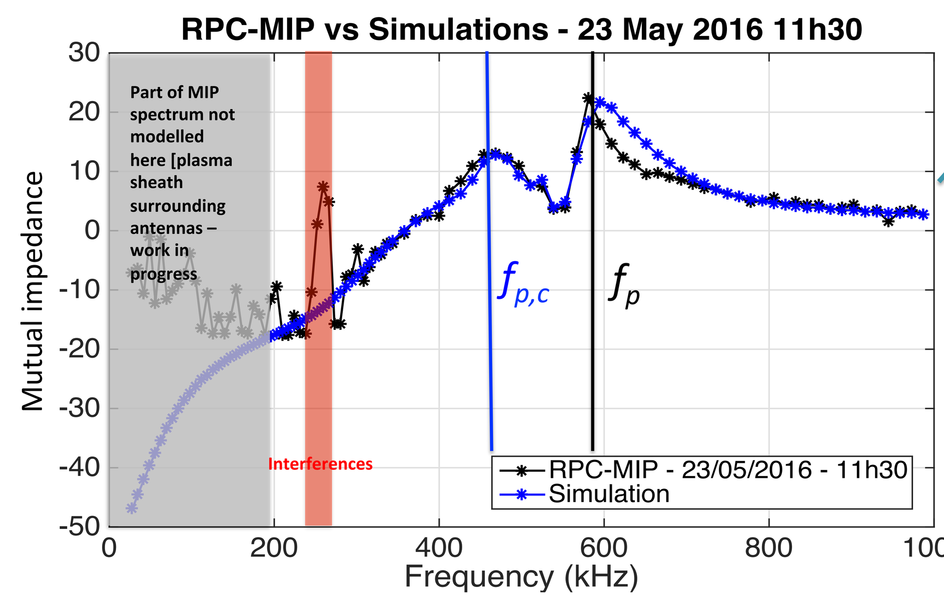
Observations of mixed warm and cold electrons with RPC-MIP at comet 67P/Churyumov-Gerasimenko

A comparison between MIP data and simulation of the mutual impedance response on a two electron temperature plasma has shown a presence of mixed **warm** and **cold** electrons at 67P [*Gilet et al, in preparation*]. For small frequencies (< 150-200 kHz) the modelisation of the plasma sheath is necessary to reproduce experimental spectra (*work in progress*).



Observations of a double peak at plasma frequency f_p in black line and at **cold** plasma frequency $f_{p,c}$ in blue line on MIP spectra between 11h and 12h (UTC Time) the 23th May 2016.

On one spectra at 11h30



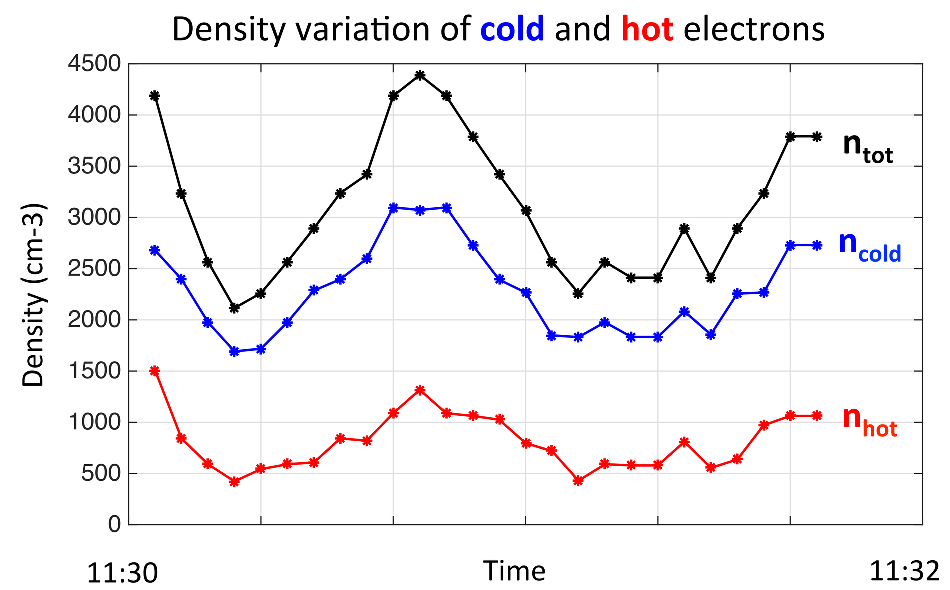
Best fit on simulations	
n_{hot}/n_{tot}	0.36
T_{hot}/T_{cold}	103
$\lambda_{D,hot}$	0.46 m

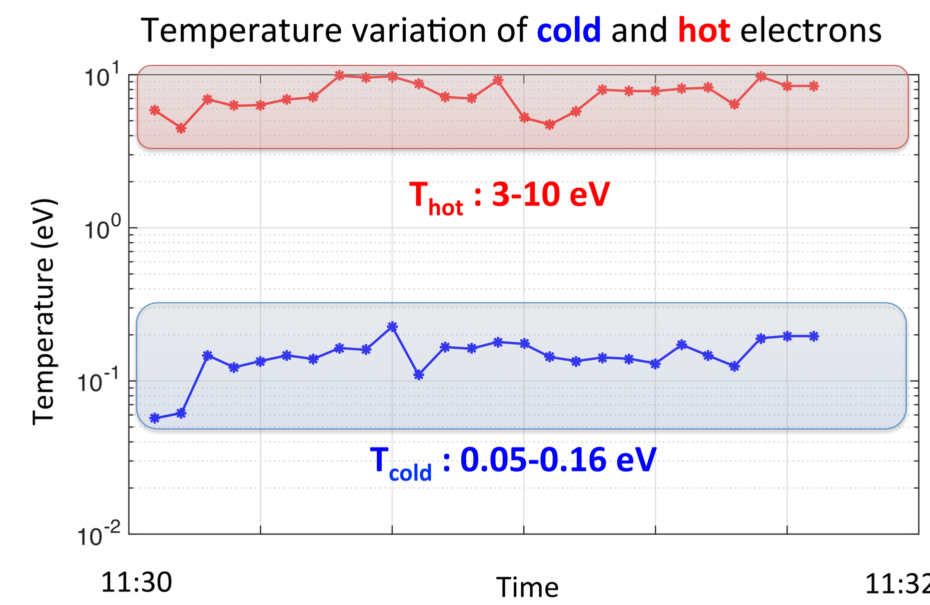
Derived physical parameters	
n_{tot}	4186 cm^{-3}
n_{hot}	1507 cm^{-3}
n_{cold}	2727 cm^{-3} (0.65)
T_{hot}	5.8 eV
T_{cold}	0.05 eV

In this example, simulations show a **mix** of a **hot** (**5.8 eV**) and **cold** (**0.05 eV**) electron populations, consistent with the **warm**, photoionised cometary electrons and the **cold** electrons, thermalised by collisions on cometary neutrals, observed separately by RPC-LAP at **3-10 eV** and about **0.1 eV** respectively [*Eriksson et al, 2017*].

On the MIP spectrogram between 11h30 and 11h32

The comparison with MIP data is also realized on a part on the MIP spectrogram between 11h30 and 11h32. It is possible to follow the density and the temperature of a **cold** and a **hot** electrons.





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For more details : nicolas.gilet@cnrs-orleans.fr