

# Automatic detection of the electron density from the WHISPER instrument onboard CLUSTER

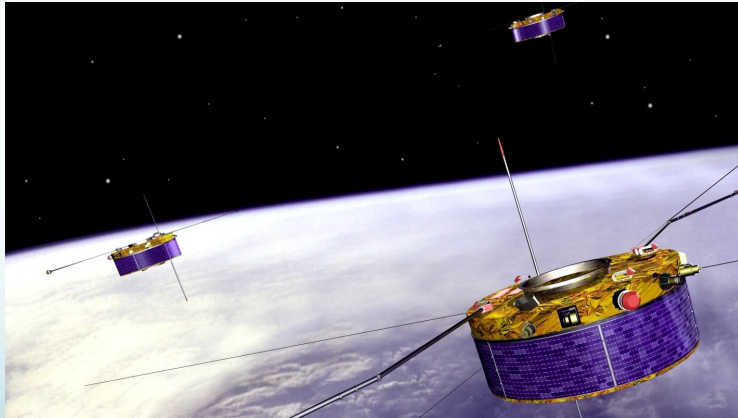
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# Cluster mission

## Earth magnetospheric mission

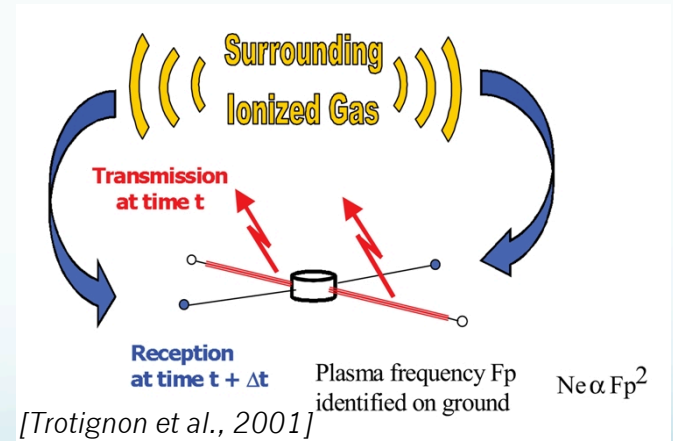
Launched in 2000  
Still in operations (until 2025 ?)



Credits: ESA

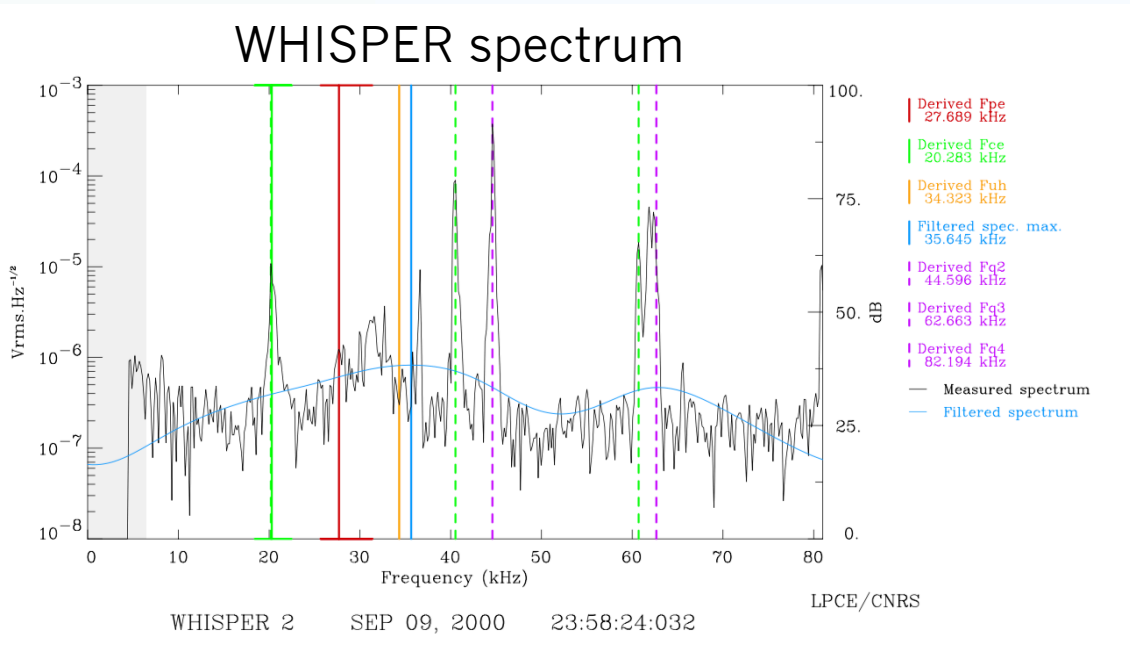
Four identical spacecraft  
in tetrahedral configuration

## WHISPER (Waves of High frequency and Sounder for Probing of Electron density by Relaxation)



Measurement of key plasma parameters:  
Electron density, magnetic field amplitude

# Extraction of the plasma resonances



[Trotignon et al., 2001]

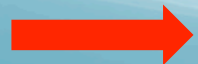
**Electron plasma frequency:**

$$f_{pe} \text{ [kHz]} = 9 \sqrt{n_e \text{ [cm}^{-3}\text{]}}$$

**Electron cyclotron frequency:**

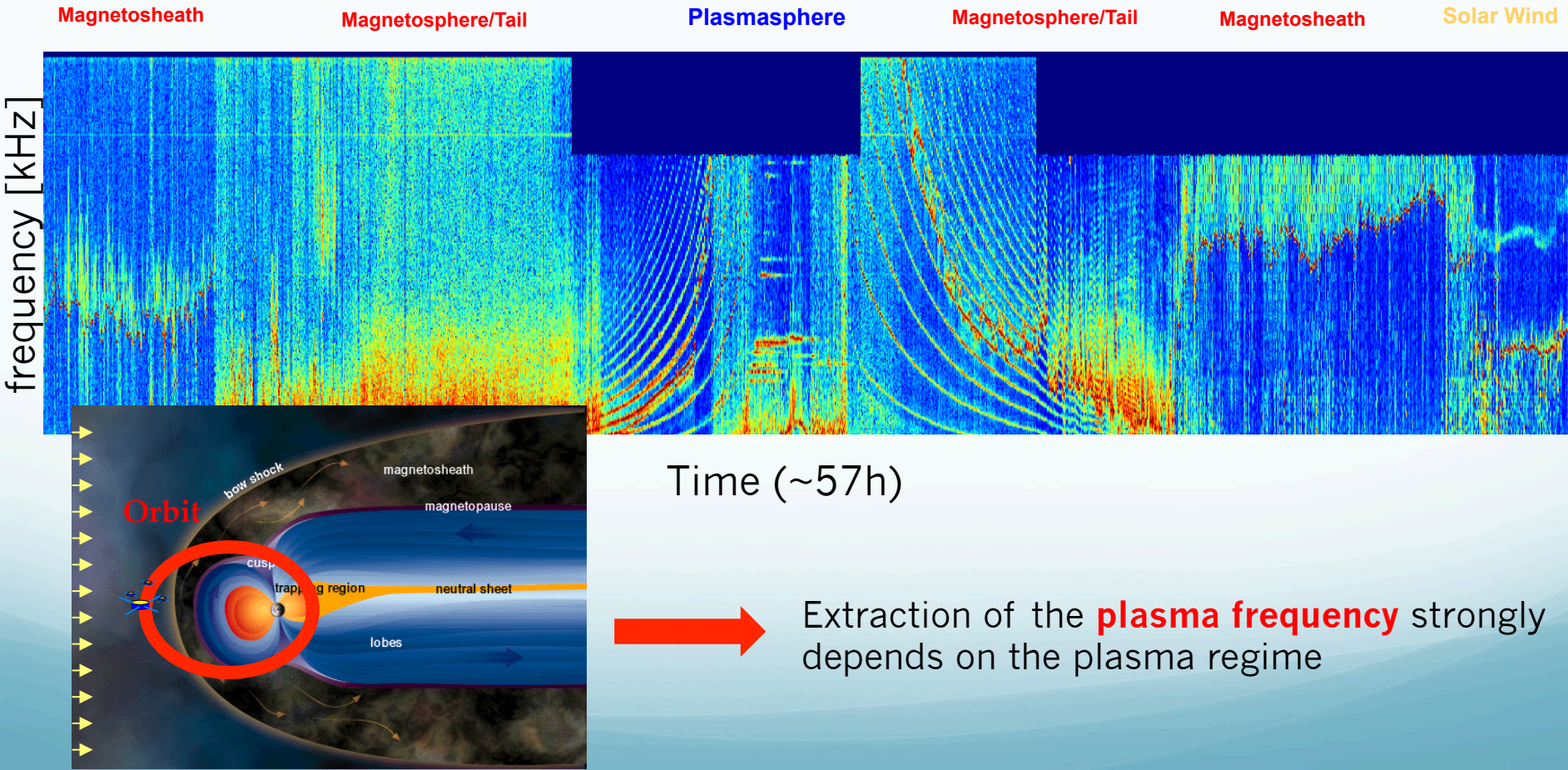
$$f_{ce} \text{ [kHz]} = 0.028 \cdot B \text{ [nT]} \text{ and its harmonics}$$

**Bernstein's resonances  $f_{qn}$**



**Electron density  $n_e$**  by extraction of the **plasma frequency  $f_{pe}$**

# Dependance of the plasma regime

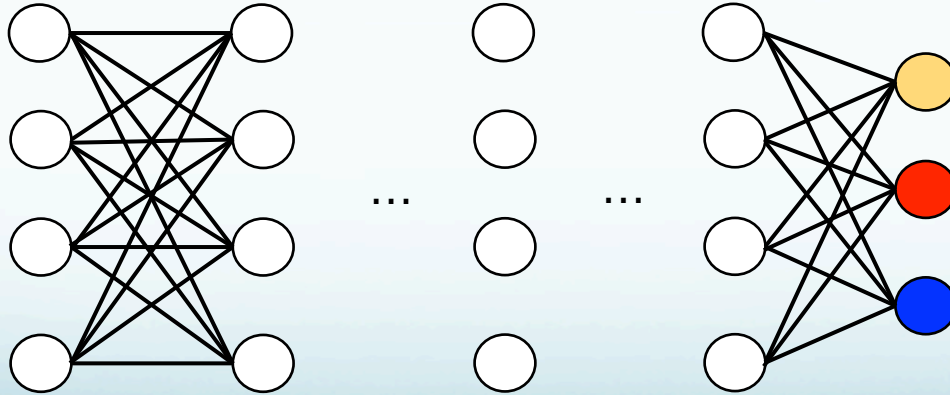


# Dependance of the plasma regime

**Main goal:** Automatic detection of the electron density by the extraction of the plasma frequency ( $n_e \propto f_{pe}^2$ )

- **1<sup>st</sup> step:** Detection of the plasma regime

**Input:**  
WHISPER  
spectrum  
(480 bins)



**Output:**

- **Solar Wind**
- **Magnetosheath**
- **Plasmasphere**  
+ Others

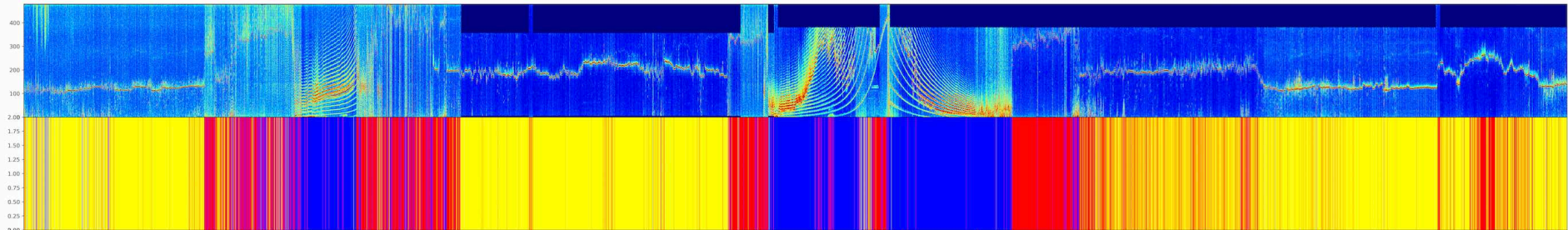


# Dependence of the plasma regime

**Main goal:** Automatic detection of the electron density by the extraction of the plasma frequency ( $n_e \propto f_{pe}^2$ )

- **1<sup>st</sup> step:** Detection of the plasma regime

## Example of classification by Neural Networks (RNN-GRU)



- Solar Wind
- Magnetosheath
- Plasmasphere + Others

# Dependance of the plasma regime

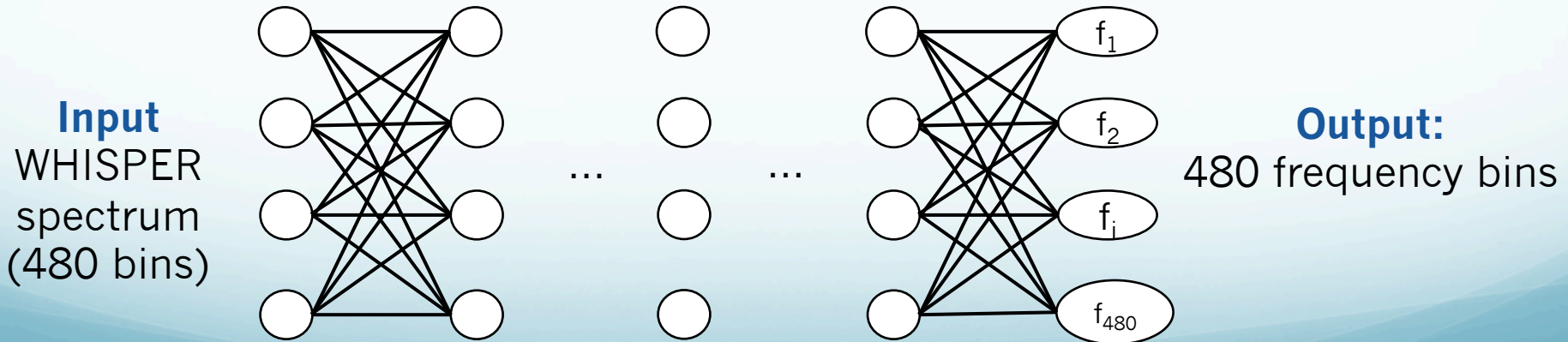
**Main goal:** Automatic detection of the electron density by the extraction of the plasma frequency ( $n_e \propto f_{pe}^2$ )

- **1<sup>st</sup> step:** Detection of the plasma regime
  - Neural networks (Recurrent): **97% of accuracy** but **poor explanations of what he learnt**
  - Classification (Decision Tree/Random Forest) or Clustering method (DBSCAN/OPTICS): **80% of accuracy** with only descriptors (no spectrum in input)

# Dependance of the plasma regime

**Main goal:** Automatic detection of the electron density by the extraction of the plasma frequency ( $n_e \propto f_{pe}^2$ )

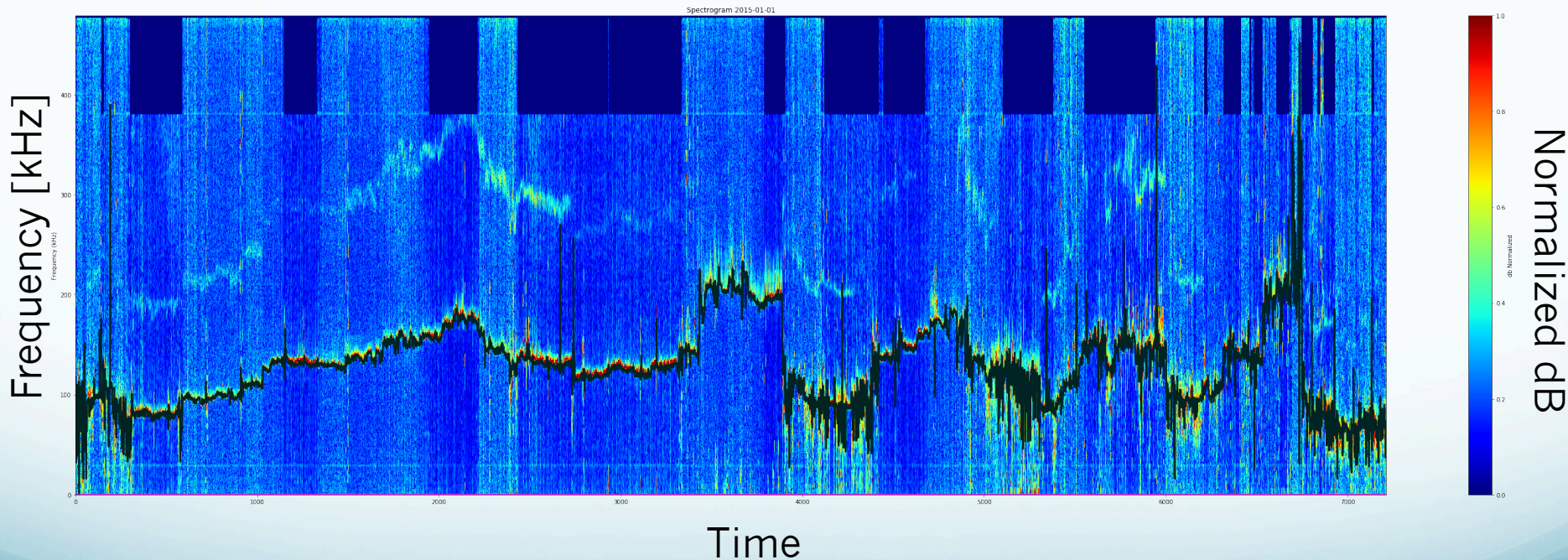
- **1<sup>st</sup> step:** Detection of the plasma regime
- **2<sup>nd</sup> step:** Extraction of the plasma frequency





# Extraction of the plasma frequency

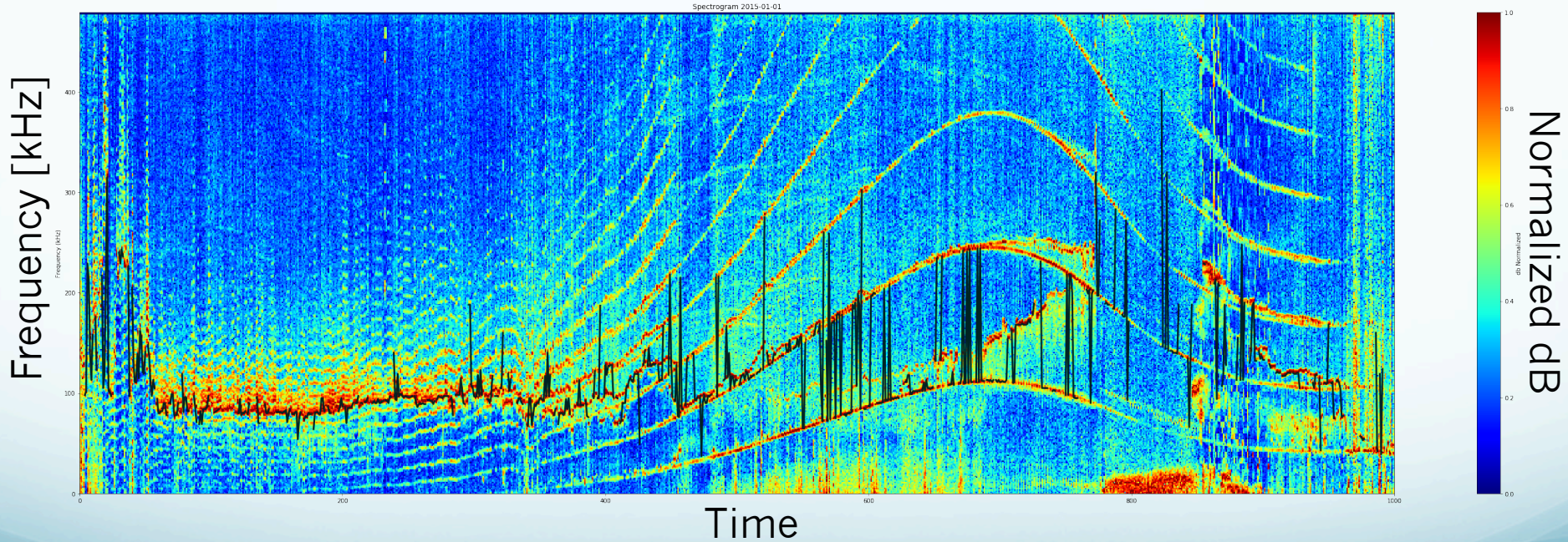
Solar Wind/Magnetosheath:



**Accuracy: 96% with  $\pm 1$  frequency bin**

# Extraction of the plasma frequency

Plasmasphère:

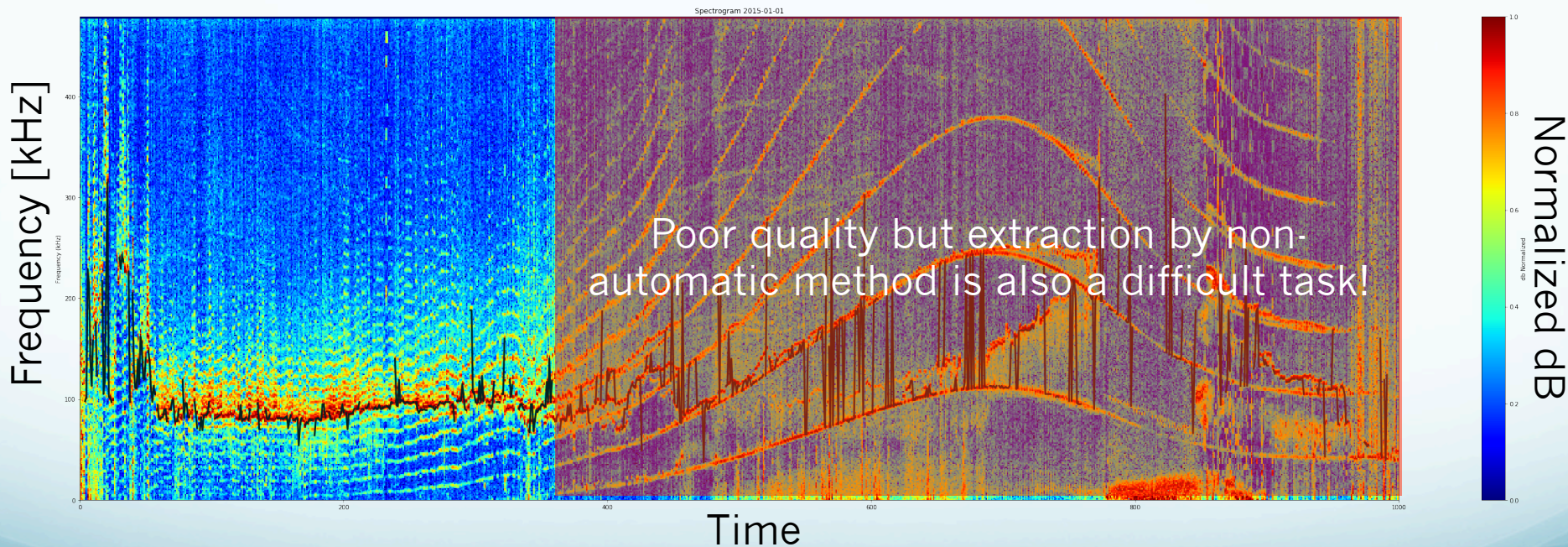


**Accuracy: 20% with +/- 1 frequency bin**



# Extraction of the plasma frequency

Plasmasphère:



**Accuracy: 20% with +/- 1 frequency bin**

# Conclusion

**Main goal:** Automatic detection of the electron density by the extraction of the plasma frequency ( $n_e \propto f_{pe}^2$ )

- **1<sup>st</sup> step:** Detection of the plasma regime
  - **Neural networks (97%)**
  - **Classification/Clustering (80%)**
- **2<sup>nd</sup> step:** Extraction of the plasma frequency
  - **Neural networks :**
    - **Solar Wind/Magnetosheath (96%)**
    - **Plasmasphere and Tail (20%)**

# Conclusion

**Main goal:** Automatic detection of the electron density by the extraction of the plasma frequency ( $n_e \propto f_{pe}^2$ )

- **1<sup>st</sup> step:** Detection of the plasma regime
  - **Neural networks (97%)**
  - **Classification/Clustering (80%)** ← **Improve the descriptors**
- **2<sup>nd</sup> step:** Extraction of the plasma frequency
  - **Neural networks :**
    - **Solar Wind/Magnetosheath (96%)**
    - **Plasmasphere and Tail (20%)** ← **Improve the training dataset**