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 ?)

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

[Trotignon et al., 2001]
Extraction of the plasma resonances

Electron plasma frequency:
\[ f_{pe} [\text{kHz}] = 9 \sqrt{n_e [\text{cm}^{-3}]} \]

Electron cyclotron frequency:
\[ f_{ce} [\text{kHz}] = 0.028. B [\text{nT}] \text{ and its harmonics} \]

Bernstein’s resonances \( f_{qn} \)

Electron density \( n_e \) by extraction of the plasma frequency \( f_{pe} \)

[Trotignon et al., 2001]
Dependance of the plasma regime

Orbit

Extraction of the plasma frequency strongly depends on the plasma regime
Dependance of the plasma regime

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

- 1st step: Detection of the plasma regime

Input: WHISPER spectrum (480 bins)

Output:
- 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 \( n_e \alpha f_{pe}^2 \)

- **1st step**: Detection of the plasma regime

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

- Solar Wind
- Magnetosheath
- Plasmasphere + Others
Main goal: Automatic detection of the electron density by the extraction of the plasma frequency \( n_e \alpha f_{pe}^2 \)

- **1st 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 \( n_e \alpha f_{pe}^2 \)

- **1\textsuperscript{st} step:** Detection of the plasma regime
- **2\textsuperscript{nd} step:** Extraction of the plasma frequency

Input
WHISPER spectrum (480 bins)

Output:
480 frequency bins
Extraction of the plasma frequency

Solar Wind/Magnetosheath:

Accuracy: 96% with +/- 1 frequency bin
Extraction of the plasma frequency

Plasmasphère:

Accuracy: 20% with +/- 1 frequency bin
Extraction of the plasma frequency

Plasmasphère:

Poor quality but extraction by non-automatic method is also a difficult task!

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

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

• **1\(^{st}\) step**: Detection of the plasma regime
  • Neural networks (97%)
  • Classification/Clustering (80%)

• **2\(^{nd}\) 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 ($n_e \alpha \Omega_{pe}^2$)

• **1st step**: Detection of the plasma regime
  - Neural networks (97%)
  - Classification/Clustering (80%)  
  [Improve the descriptors]

• **2nd step**: Extraction of the plasma frequency
  - Neural networks:
    - Solar Wind/Magnetosheath (96%)
    - Plasmasphere and Tail (20%)  
  [Improve the training dataset]