Quasi-Thermal Noise Spectroscopy, a powerful tool for understanding the plasma in the Heliosphere

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1) Powerful Tool to yield the Electron Density

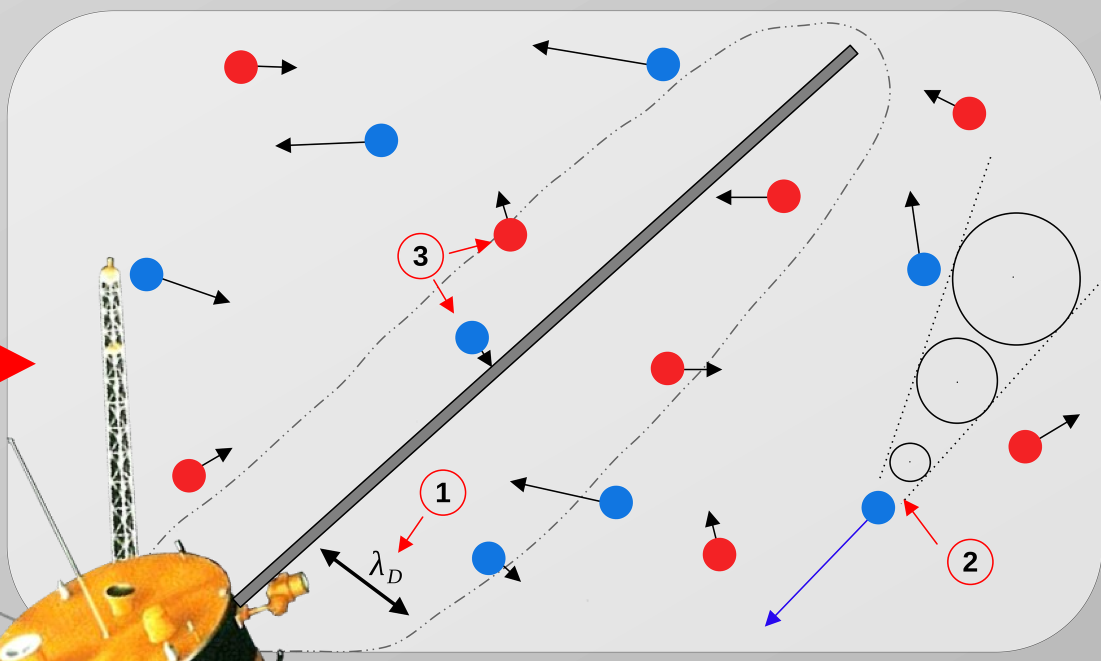
Applying a Fourier Transform to the autocorrelation of the potential difference of two passive antennas in space, one can see an ubiquitous signal due to the plasma surrounding them.

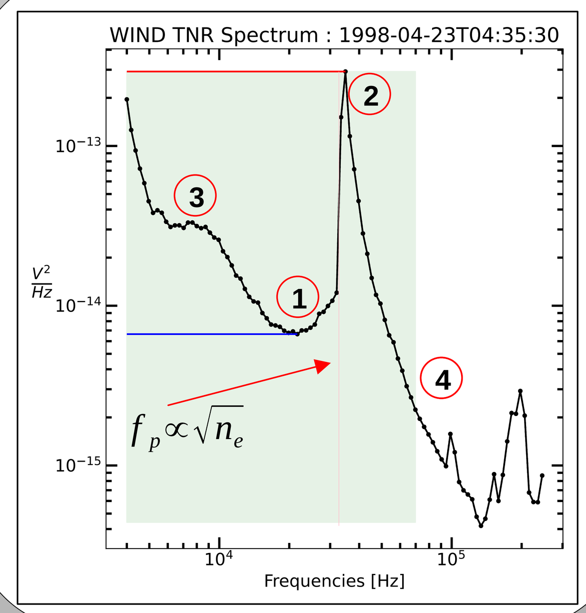
This is the **Quasi-Thermal Noise (QTN) Spectroscopy**.

It can be identified by :

- 1) A Thermal Plateau → Charged Particules passing closer than λ_D.
  → Linked to T_c, the **Core Temperature of the electrons**.
- 2) A Peak → **Langmuir waves** generated by **suprathermal electrons**. ($V_e > V_{The} = \sqrt{3k_b T_e / m_e}$)
  → **Cut off at** f_p .
  → Independent of the calibration, increases with $\frac{L_{Antenna}}{\lambda_D}$.
- 3) Low Frequency → **Doppler shifted proton Quasi-Thermal Noise**
  → **Shot noise** (particles impacting the antenna)
- 4) High Frequency → No Dielectric Response, decreases as $T_e \times f^{-3}$.

Finding the Peak <=> Finding the local density of the electrons



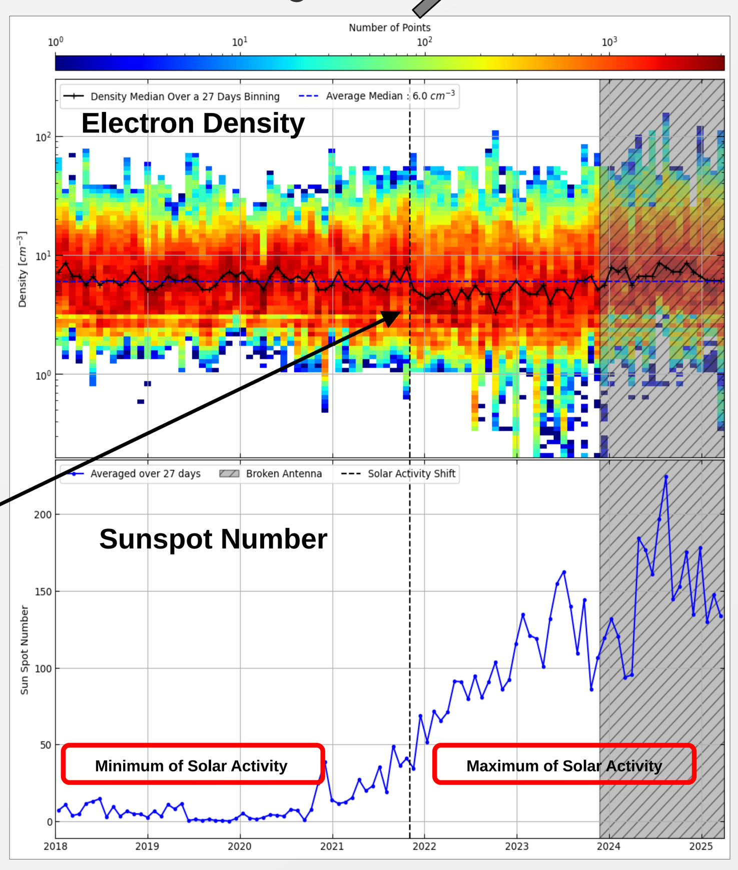


2) WIND saw a change in the Solar Wind Density

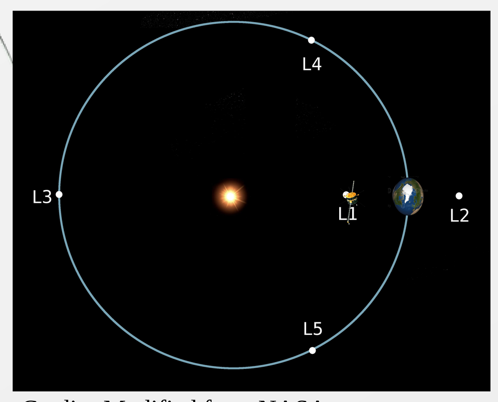
From Wind Data

- Between **early 2018** and **early 2025**, **3.7e6 points** (~97%) were obtained with the QTN Peak Finding Alogrithm.
- Upper panel → Histogram of **electron density versus time**
  → **Black crosses (+) <=> Median density** for each bin of time
  → **Data binned over 27 days** (= 1 Solar Rotation at L1)
- Lower panel → Averaged Sunspots number
- The observed density is 20% lower from November 2021 to November 2023
- **The break** of the antenna is **slightly increasing** the observed median density.

However, this **increase after the antenna break is physical** and also observed by the 3DP particules analyseurs suite.



THE WIND MISSION



Credit : Modified from NASA

The **Wind Spacecraft** was launched in 1994 to better understand the interactions between the Solar Wind and the Earth Magnetosphere.

- At the **First Lagrange Point (L1)** situated at 1 AU ($\sim 215 \times R_\odot$) in the Ecliptic plane.
- The **Wind / WAVES TNR** → Radio receiver, built **by the LIRA** for the QTN diagnostic.
- Voltage Measurement of 2 x 50* m long Antennas.
  → **Strong QTN Peak on the Dynamical Spectrum**, since $\frac{L_{Antenna}}{\lambda_D} \gg 1$.

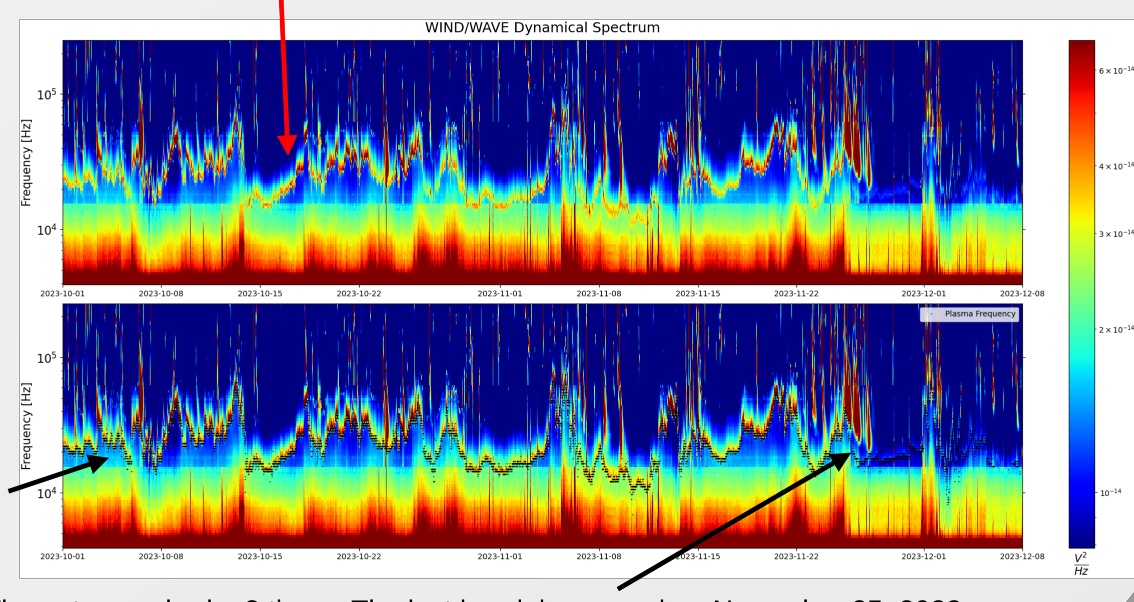
The Solar Wind parameters :
$n_e,\ T_e,\ n_p,\ T_p,\ \vec{V}, ...$

Change with the source :

- Coronal Holes
- Coronal Mass Ejection
- Streamers
- ...

They modify the shape, the amplitude and the frequency of the Peak.

I developped a semi-automatic **algorithm to get the density** from the highest slope of the QTN Peak.



* The antennas broke 3 times. The last break happened on November 25, 2023. They are now 24±4m and 12±2m long. [Verkampt et al. 2026] (in prep)

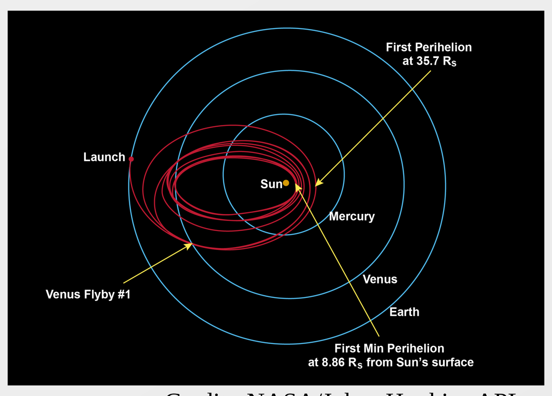
3) And Parker Solar Probe Saw it too !

THE PARKER SOLAR PROBE (PSP) MISSION

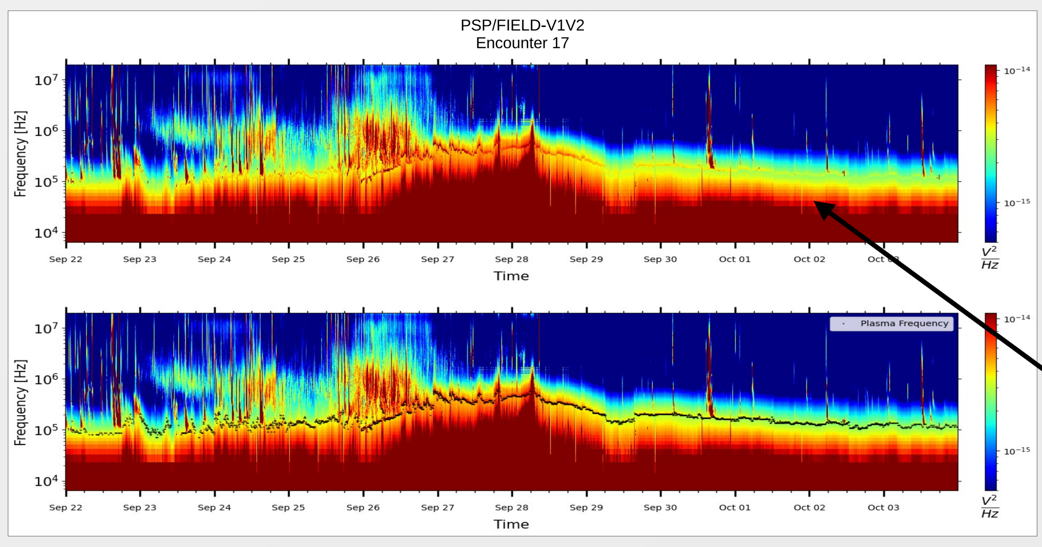
- The PSP Mission was launched in 2018 to **measure in situ** the plasma parameters of the **inner Heliosphere**.
- The trajectory is elliptical, with a fixed perihelion at $9.8\,R_\odot$ since the 23th encounter.

On board :

- **FIELDS** → Radio receiver with 4 x 2m long antennas used for the **QTN spectroscopy**.
- **SPAN** → ParticLE AnalysErs, get the Velocity Distribution Function & the local **average Solar Wind velocity**.

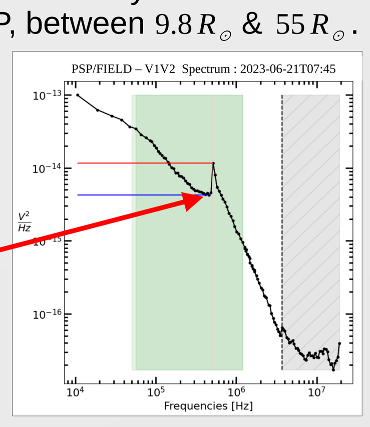


Credit : NASA/Johns Hopkins APL



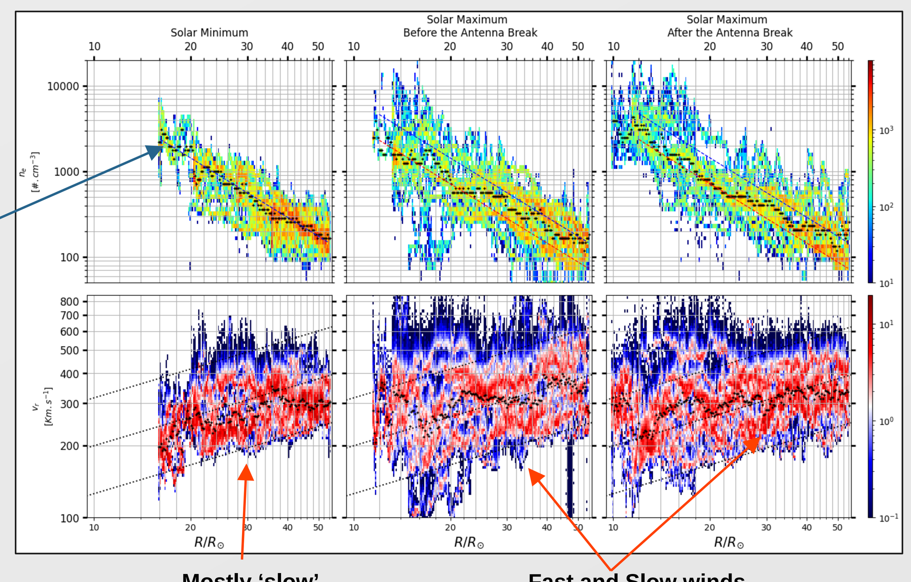
- QTN Peak **not visible** above $\sim 60\,R_\odot$.
  → Too short antennas
  → Not passives (Bias current always applied)
  → Frequency Resolution too low below 80 kHz
- Algorithm to find the density for the first 24 encounter of PSP, between $9.8\,R_\odot$ & $55\,R_\odot$.

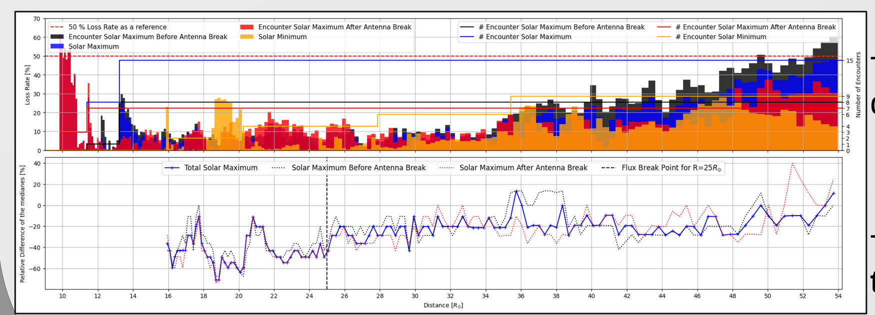
$f_p \propto \sqrt{n_e}$



PSP data obtained during solar minimum & maximum (based on the Wind periods) respectively separated 2D Histograms of the electron density (above) and the radial wind velocity (below). The black crosses represent the median bin value for each bin of distance.

- **Minimum of solar activity** :
  - Mostly **'slow' wind** at every distance.
  - Electron density compatible with the density law of [Kontar et al. 2019]
    $n_e \sim 0.6 \times 10^{6.2} \times \left(\frac{R}{R_\odot}\right)^{-2.3}\ [cm^{-3}]$
- **Maximum of solar activity** :
  - Mix of Slow and Fast winds.
  - A **new population of density** is observed. **Less dense** by a factor of ~2.



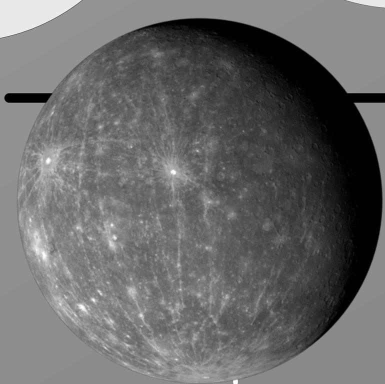


The lower resolution of the instrument increases the detection loss at high distances during the Maximum.

=> Consequence of the lower density population

The total **density at solar maximum is 20% lower than during the solar minimum**.

For both parts of the maximum.



4) Conclusion

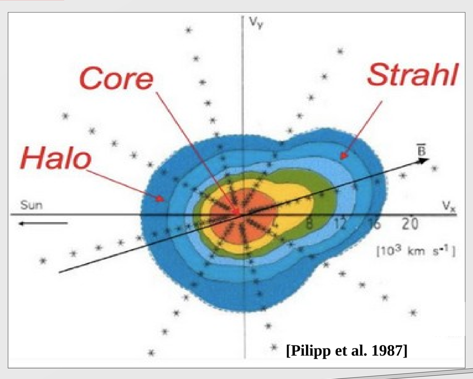
- Both the **Wind** and the **PSP** spacecraft **observed a lower density population of electrons during the solar mawimum**.
  It represents a common **drop of 20% for the total density during** the first pole inversion of **the solar maximum activity**.
- During the second part of the maximum, Wind observes an increase of density, but not PSP. This could be explained by a difference in the average source connectivity.

5) What's Next ?

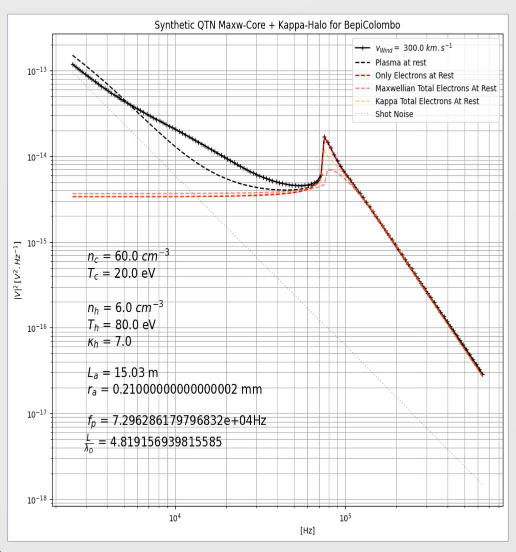
ON PSP DATA

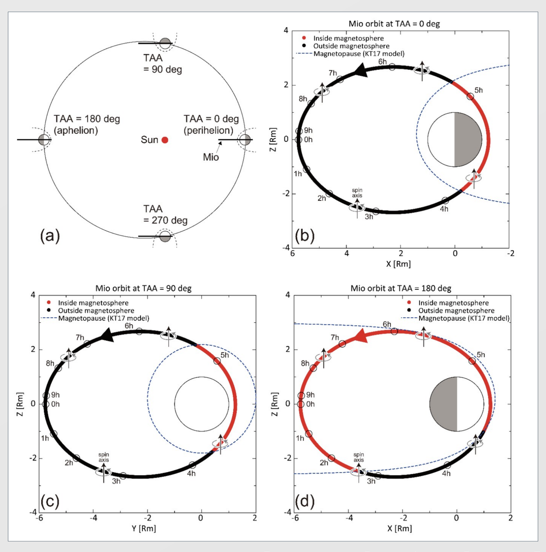
- Fit the whole QTN spectrum to **diagnose the Suprathermal Population** in the Solar Wind.
- Caracterise **the effects** of the **Strahl population.**

Using isotropic and doppler shifted populations for the Quasi-Thermal Noise.



[Pilipp et al. 1987]





[G. Murakami et al. 2020]

THE BEPICOLOMBO MISSION

- Launched in 2018, BepiColombo consists of 2 Spacecraft which should arrive at Mercury in late 2026.
- The **MIO** Spacecraft will probe both **the Solar Wind** and the Mercury Magnetosphere.
- The **SORBET** radio reciever, built **by the LIRA** and connected to the **WPT** antennas **on MIO**, should allow accurate **measurement** of the **QTN in both environments.**

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