Modeling of **mutual impedance** experiments and **quasi-thermal noise** spectroscopy in **magnetized** plasma

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PNST
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Introduction: electron in situ measurements

	Passive:	Active:
Collection of **particles**:	Electrostatic analyzer, Faraday cup	Langmuir probe
Collective behaviors, coupling with **fields**:	**Quasi-thermal noise spectroscopy**	**Mutual impedance**, relaxation sounders

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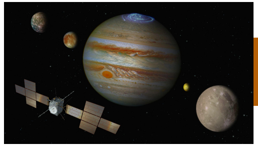

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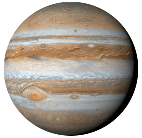

Jupiter

Ganymede

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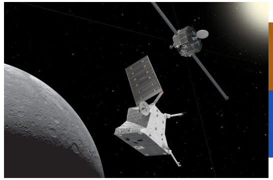

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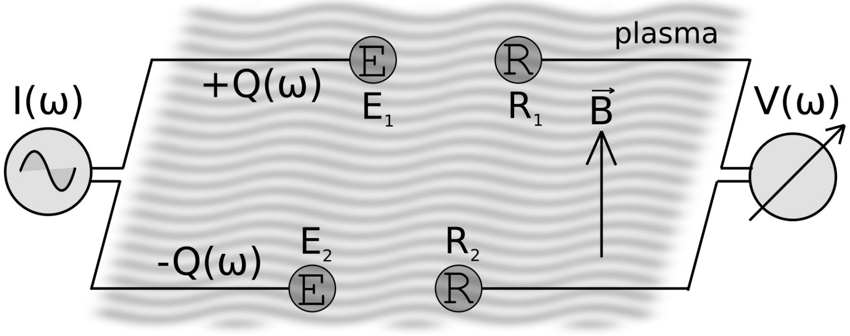
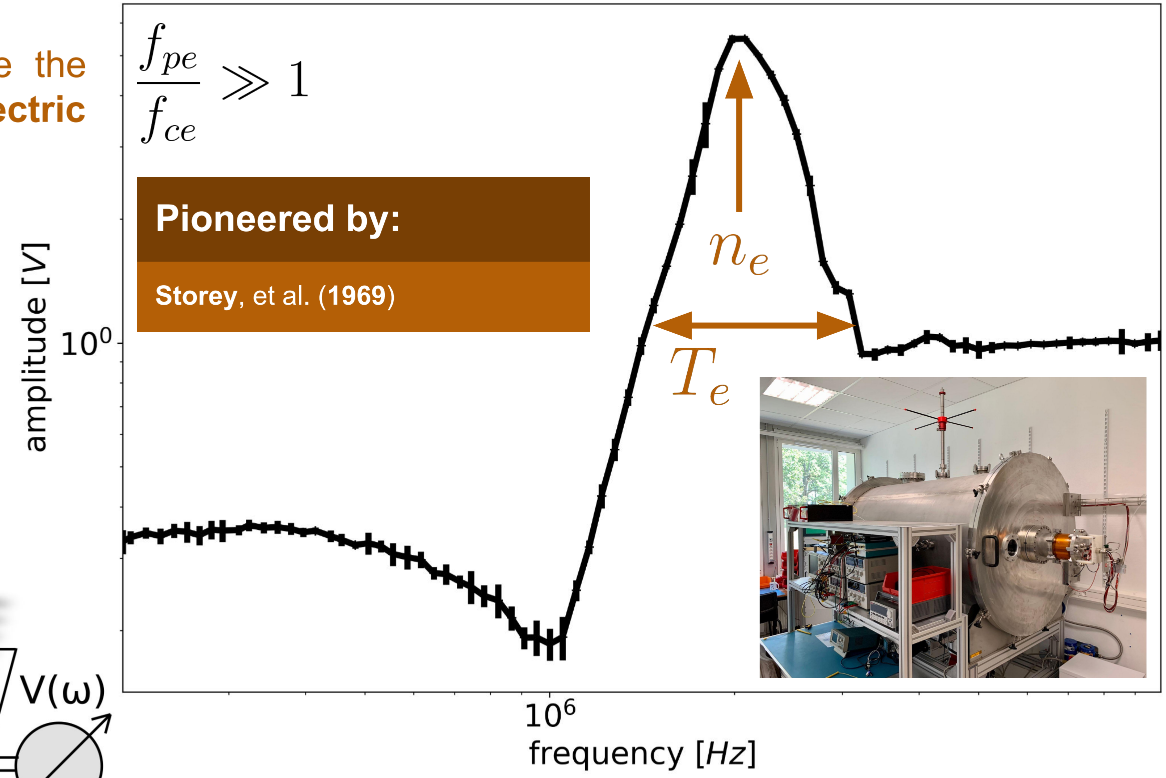
Mutual impedance - definition

Mutual impedance experiments measure the **mutual impedance** between a **pair of electric antennas** embedded in the plasma.

$$Z(\omega) = \frac{V(\omega)}{I(\omega)}$$

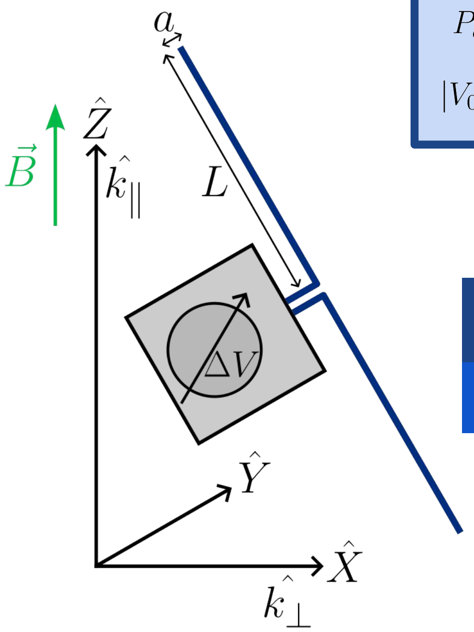




Typical mutual impedance spectrum, measured in the PEPSO plasma chamber at LPC2E (Orleans, FR), obtained by compensating for the Earth magnetic field.

Quasi-thermal noise - definition

Quasi-thermal noise spectroscopy measures the **power spectrum of the potential difference** between the terminals of an electric antenna embedded in the plasma.

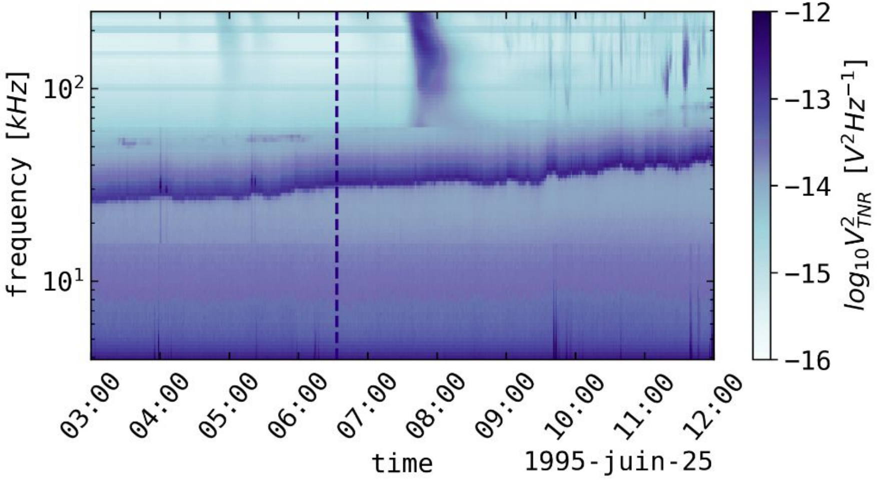


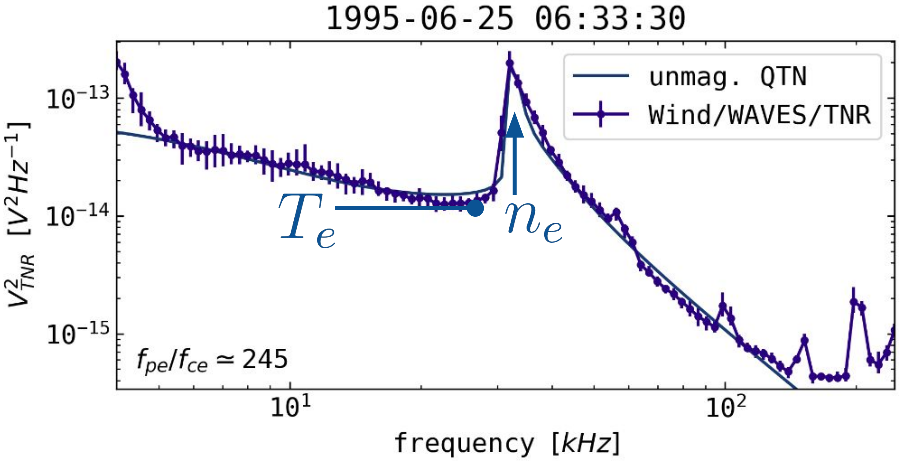
$$P_a = \int \boldsymbol{E}(\boldsymbol{r},t) \cdot \boldsymbol{J_a}(\boldsymbol{r}) d^3r = V_0(t) I_a$$

$$|V_0(\omega)|^2 = \int \langle V_0(t_1) V_0(t_1+t) \rangle \, e^{i\omega t} dt$$

Pioneered by:

Meyer-Vernet, et al. (**1979**)

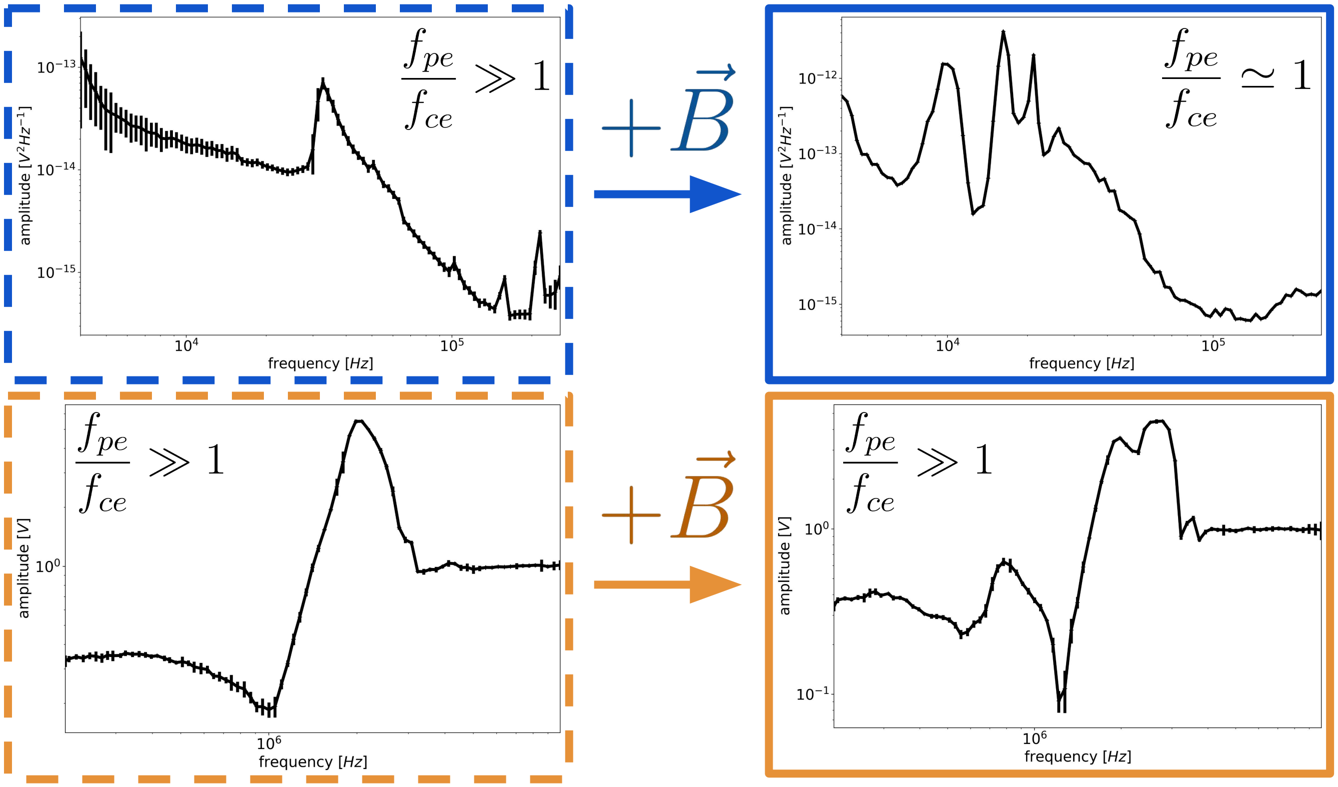




Representative example of quasi-thermal noise spectrum for a wire dipole antenna, measured by the WIND/TNR receiver on 25/06/1995 at 06:33 and averaged over one minute.

Limits and scope

The **mutual impedance** and **quasi-thermal noise** spectra **differ in the unmagnetized and magnetized case**, crucially in the presence of additional local maxima.



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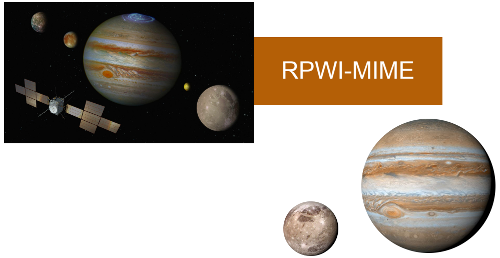

Ganymede Jupiter

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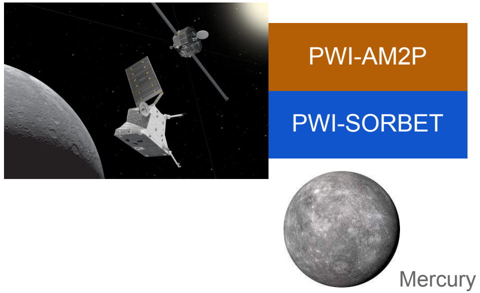

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Magnetized mutual impedance model

The model is based on the computation of the **electric potential** generated by the electric point charge deposited on the emitter antenna.

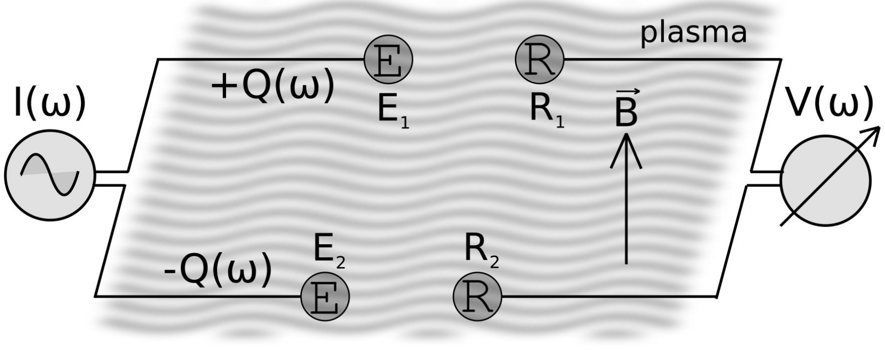
Hypothesis:

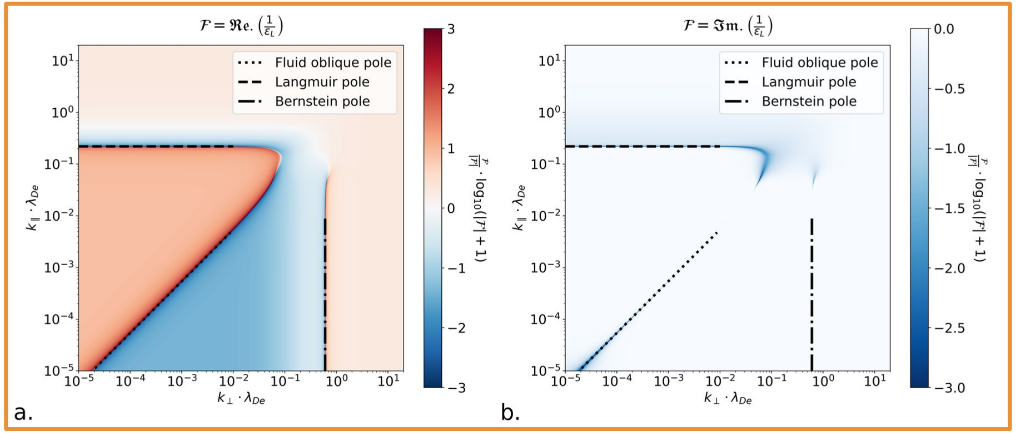
- Kinetic (Vlasov) model,
- electrostatic approximation,
- linear dielectric.

$$\frac{f_{pe}}{f_{ce}} \simeq 1$$

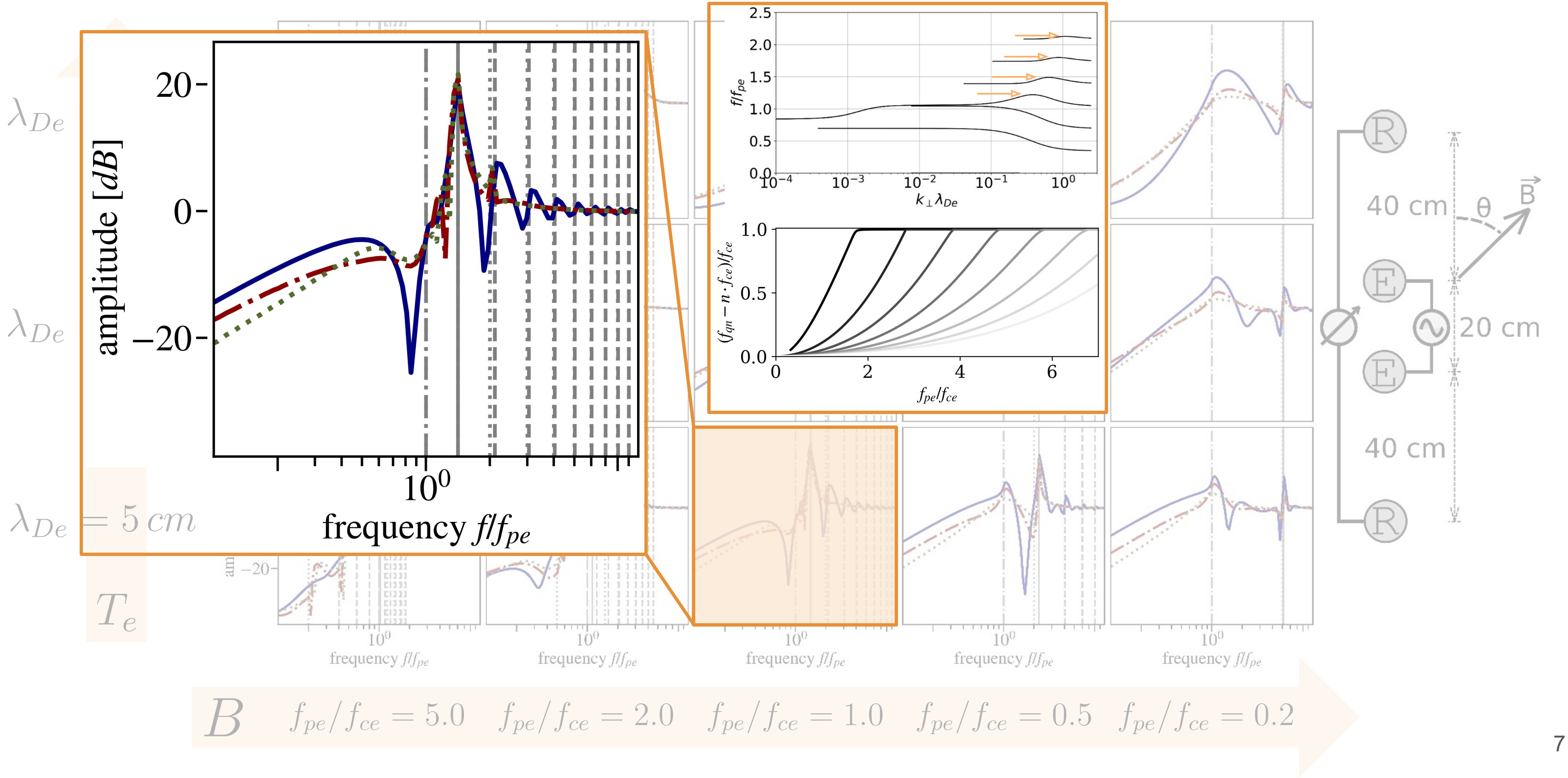
$$\frac{V}{V_0} = \frac{\sqrt{r^2+z^2}}{\pi}\int_0^{+\infty} dk_r \int_0^{+\infty} dk_z \frac{k_r J_o(k_r r)\cos(k_z z)}{k^2 \varepsilon_L(k_r, k_z, \omega)}$$

Expression valid for: isotropic Maxwellian, anisotropic Maxwellian, Maxwellian with weak electron-neutral scattering.





Magnetized mutual impedance results



Magnetized mutual impedance results

T_e electron temperature

n_e plasma density

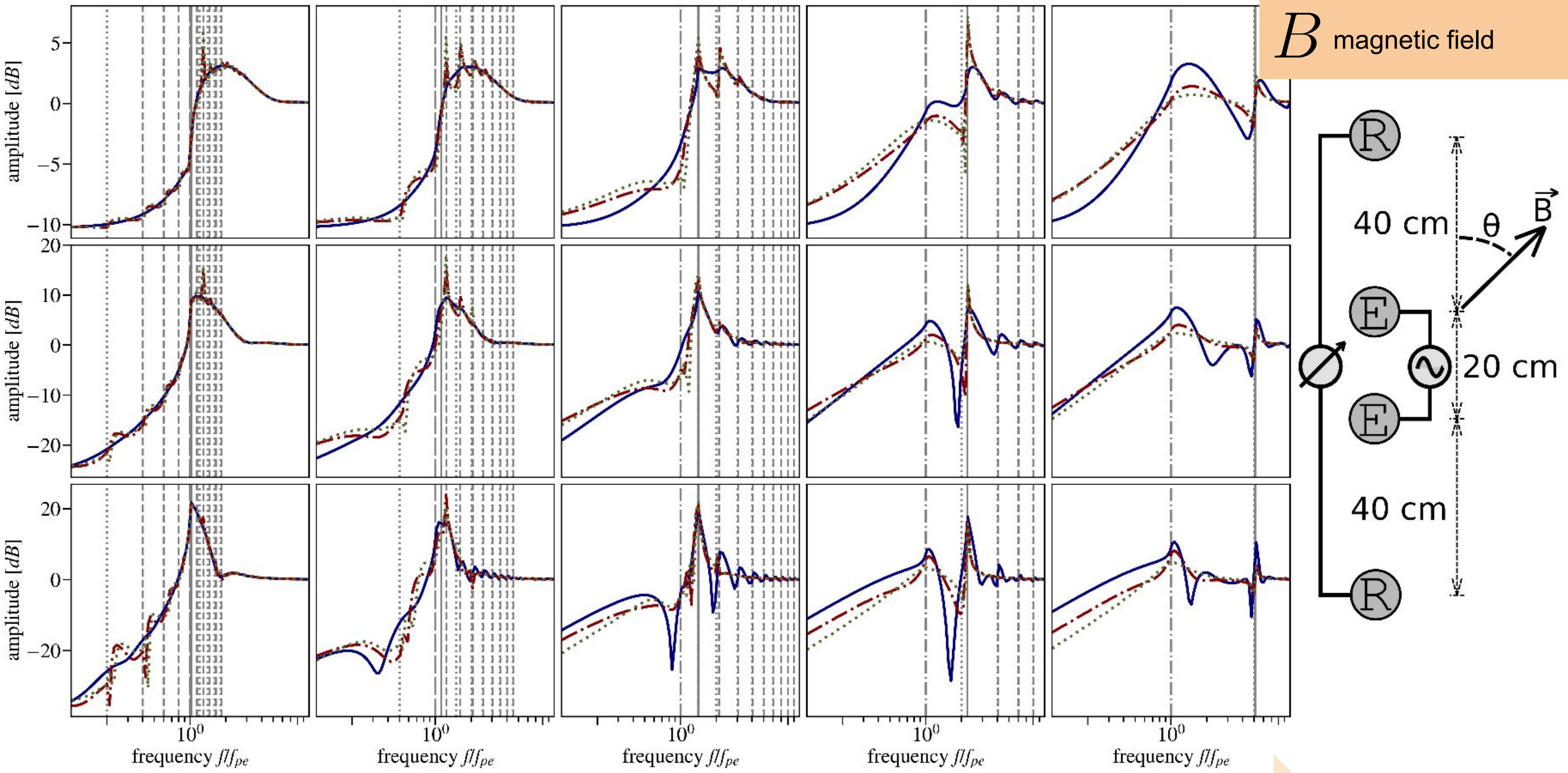
B magnetic field

$\lambda_{De} = 20\,cm$

$\lambda_{De} = 10\,cm$

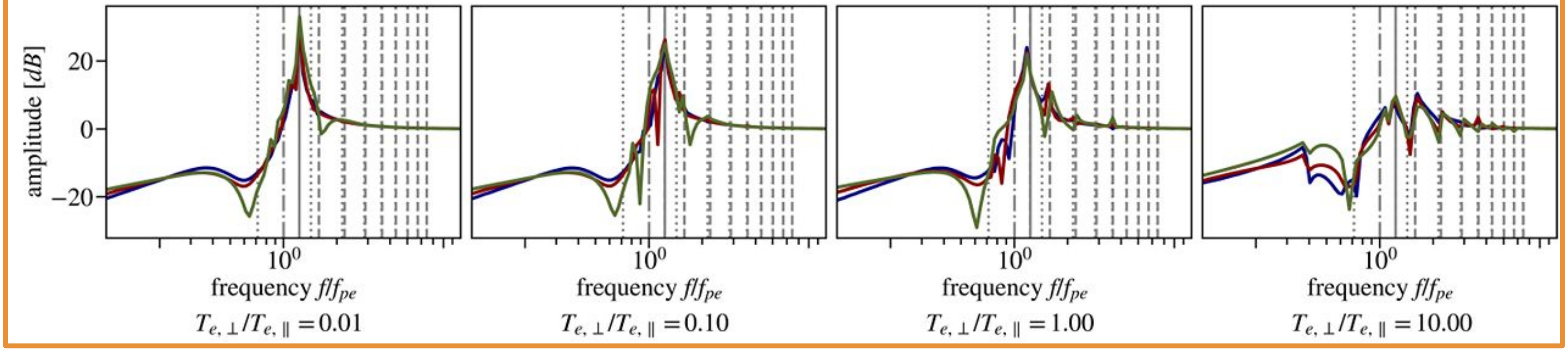
$\lambda_{De} = 5\,cm$

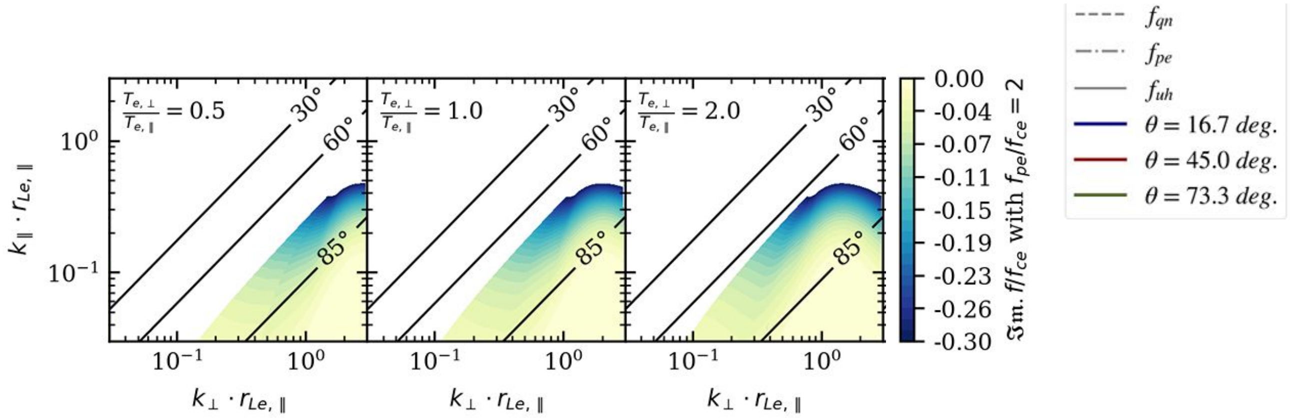
T_e



B $f_{pe}/f_{ce} = 5.0$ $f_{pe}/f_{ce} = 2.0$ $f_{pe}/f_{ce} = 1.0$ $f_{pe}/f_{ce} = 0.5$ $f_{pe}/f_{ce} = 0.2$

Magnetized mutual impedance results





$T_{e,\perp}/T_{e,\parallel}$ electron temperature anisotropy

Magnetized quasi-thermal noise model

The model is based on the computation of the **fluctuations of the electric field** inside a plasma, as measured by quasi-thermal noise spectroscopy.

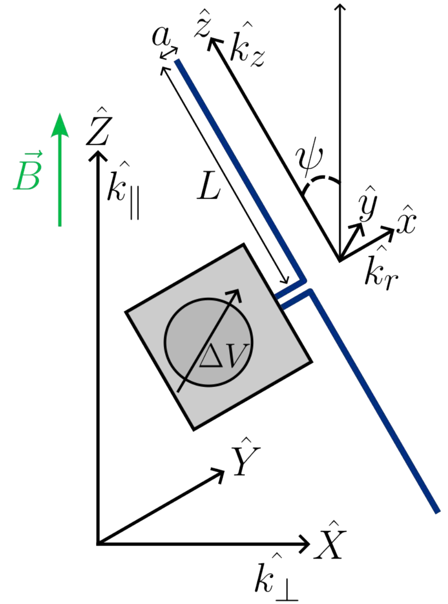
Hypothesis:

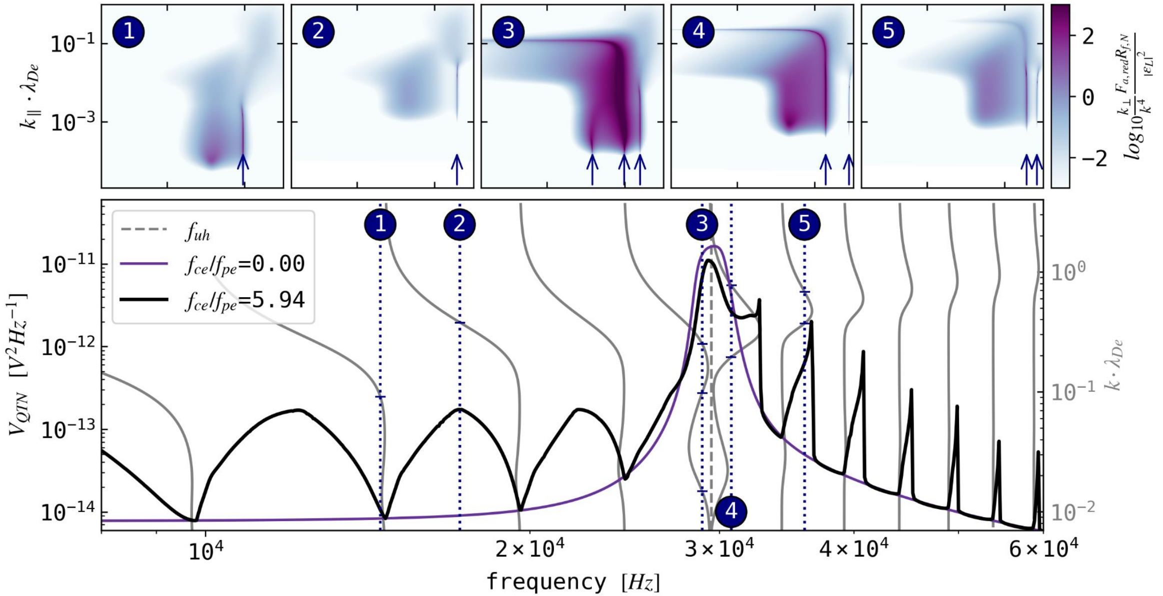
- Kinetic (Vlasov) model,
- electrostatic approximation,
- linear dielectric.

$$\frac{f_{pe}}{f_{ce}} \simeq 1$$

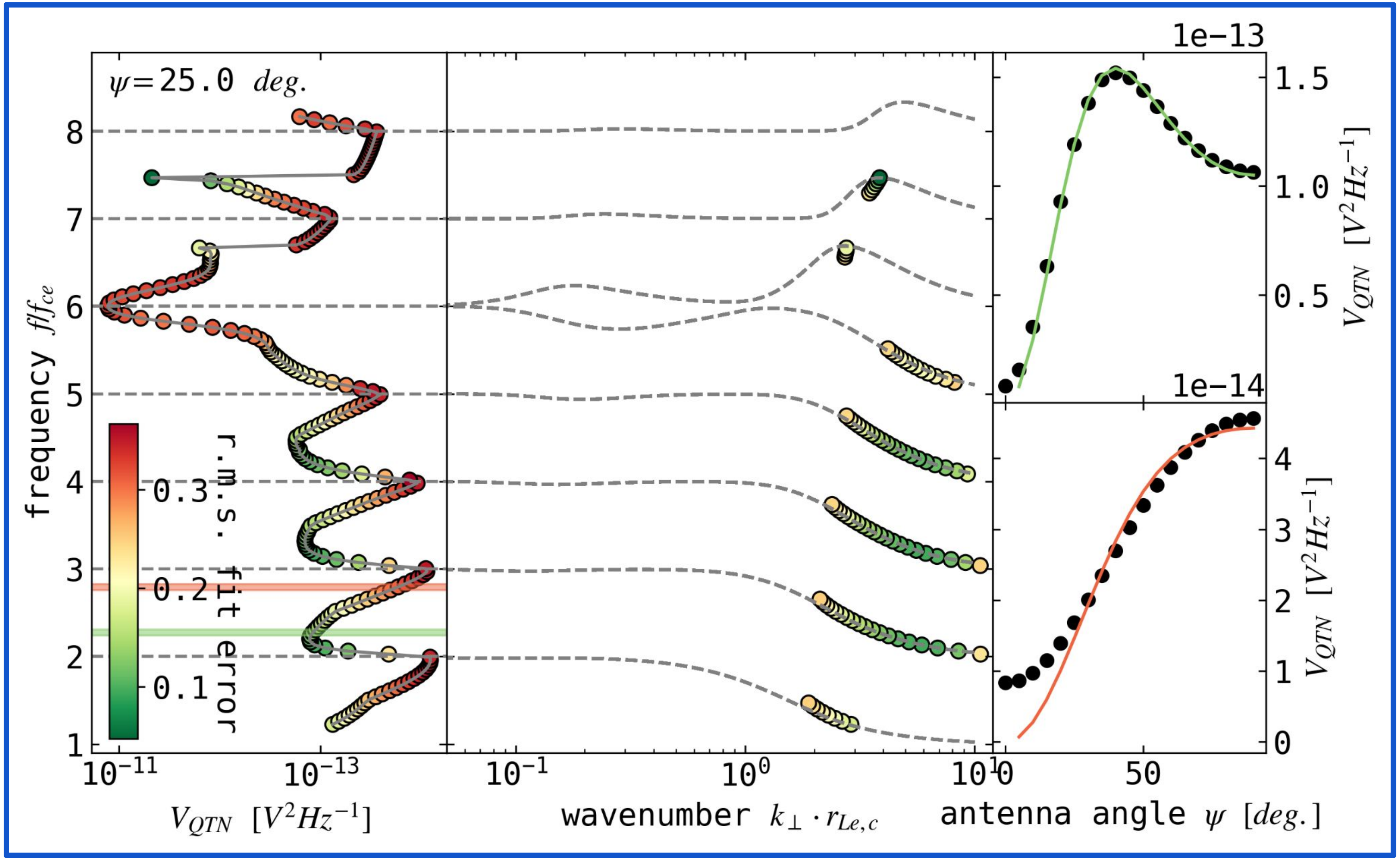
$$|V_{QTN}(\omega)|^2 = C_i \int_0^{+\infty} \int_0^{+\infty} \frac{k_\perp}{k^4} \frac{F_{a,red.} R_{f,N}}{|\varepsilon_L|^2} dk_\parallel dk_\perp$$

Expression valid for: isotropic Maxwellian, anisotropic Maxwellian, Maxwellian with weak electron-neutral scattering.



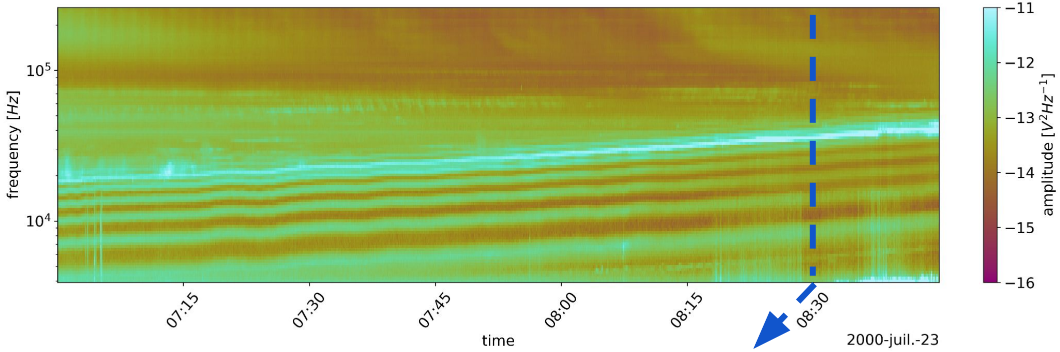


Magnetized quasi-thermal noise results



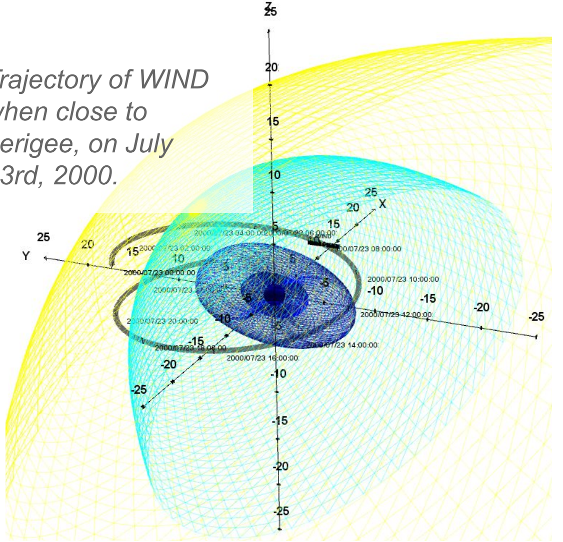
The magnetized quasi-thermal noise depends upon the angle between the antenna and the magnetic field. This dependency was investigated in (Moncuquet et al., 1995) by using measurements of the Ulysses/URAP receiver. We use the same approach to validate our numerical calculation.

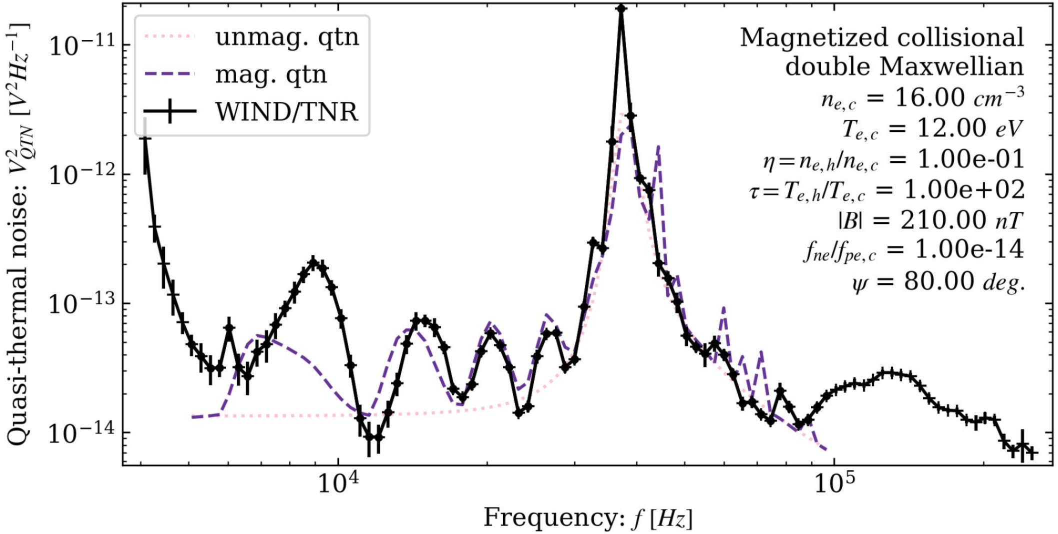
Magnetized quasi-thermal noise results



Dynamical spectrum measured by the WIND/TNR sensor during the Earth perigee or July 23rd, 2000.

Trajectory of WIND when close to perigee, on July 23rd, 2000.





Comparison between the spectrum measured by the WIND/TNR sensor and the magnetized quasi-thermal noise model.

The fitted plasma parameters obtained from our model are in agreement with the ones measured by the WIND/3DP instrument

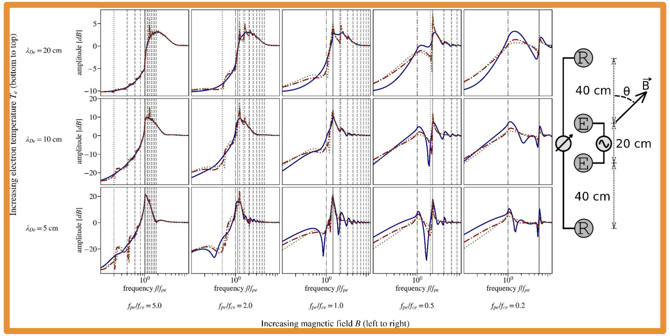
$T_{e,c}$	cold electron temperature
$n_{e,c}$	cold plasma density
$T_{e,h}$	hot electron temperature
$n_{e,h}$	hot plasma density
B	magnetic field

“Diagnostic of **density(s)** and **electron temperature(s)** in **magnetized plasma** using **mutual impedance** and **quasi-thermal noise** experiments.”

Mutual impedance in magnetized plasma

$$\frac{V}{V_0} = \frac{\sqrt{r^2+z^2}}{\pi} \int_0^{+\infty} dk_r \int_0^{+\infty} dk_z \frac{k_r J_o(k_r r)\cos(k_z z)}{k^2 \varepsilon_L(k_r, k_z, \omega)}$$

*



T_e electron temperature

n_e plasma density

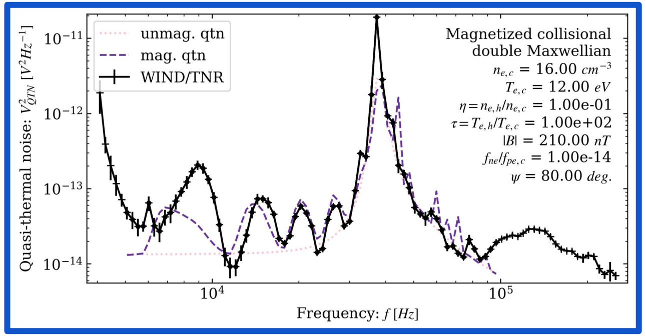
B magnetic field

$T_{e,\perp}/T_{e,\parallel}$ electron temperature anisotropy

Quasi-thermal noise in magnetized plasma

$$|V_{QTN}(\omega)|^2 = C_i \int_0^{+\infty} \int_0^{+\infty} \frac{k_\perp}{k^4} \frac{F_{a,red.} R_{f,N}}{|\varepsilon_L|^2} dk_\parallel dk_\perp$$

*



$T_{e,c}$ cold electron temperature

$n_{e,c}$ cold plasma density

$T_{e,h}$ hot electron temperature

$n_{e,h}$ hot plasma density

B magnetic field

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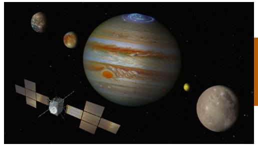

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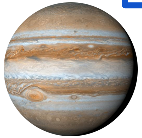

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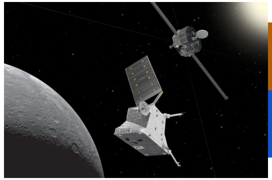

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