

Plasma Observatory

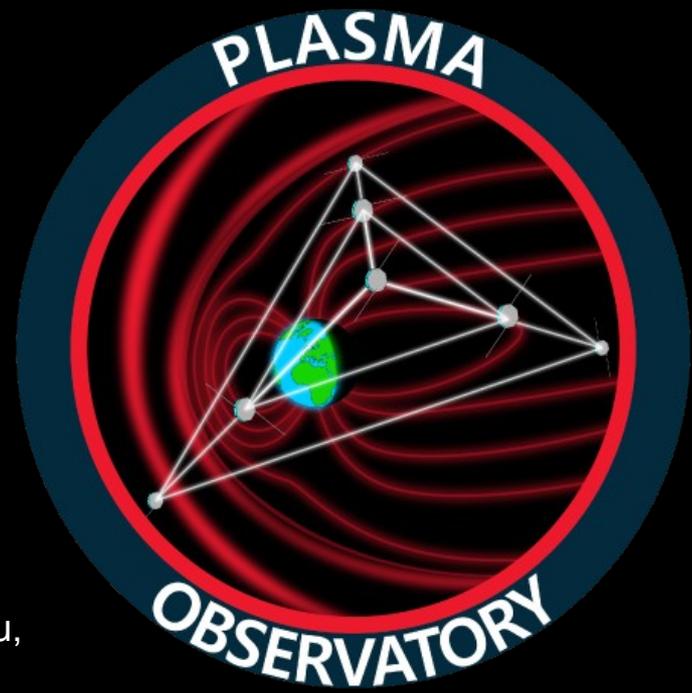
What it brings to plasma physics

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and

Maria Federica Marcucci, Cecilia Norgen, Julia Stawarz, Aurora Simionescu, Alessandro Retinò, Jan Soucek, Yuri Khotyaintsev, Takanobu Amano, Rumi Nakamura, Andris Vaivads, Jonny Rae, Heli Hietala, Hanna Rothkaehl, Malcolm Dunlop, Markus Fraenz, Matthieu Kretschmar, Matthieu Berthomier, Minna Palmroth, Matt Taylor and PO Team

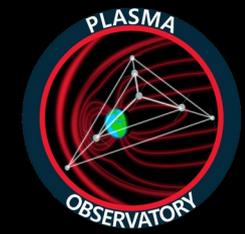




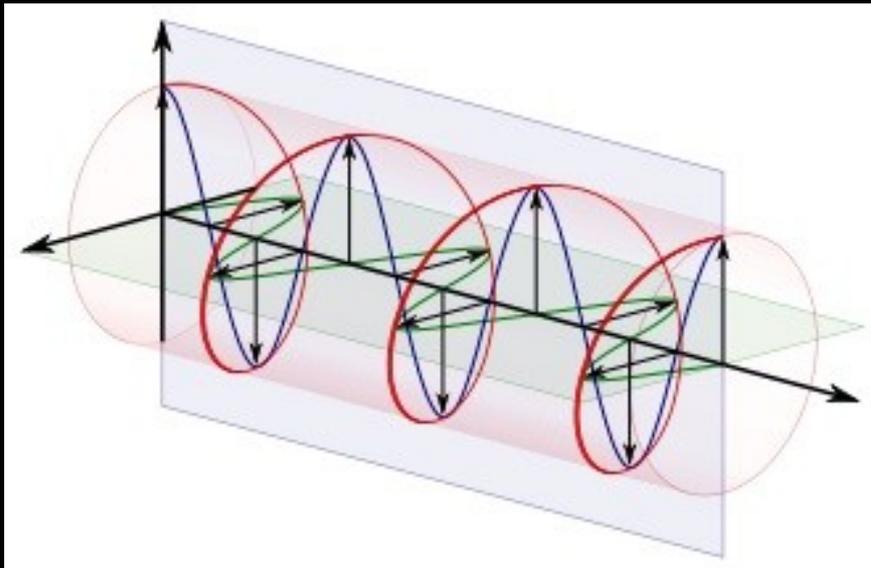
Science Objective 4: How are particles energized by waves and turbulent fluctuations?

Science Objective 8: Which are the key plasma instabilities involved in energy transport?

Ion-cyclotron resonance



Ion-cyclotron fluctuations (super ion/fluid scales)



Resonant interaction of ions with fluctuations

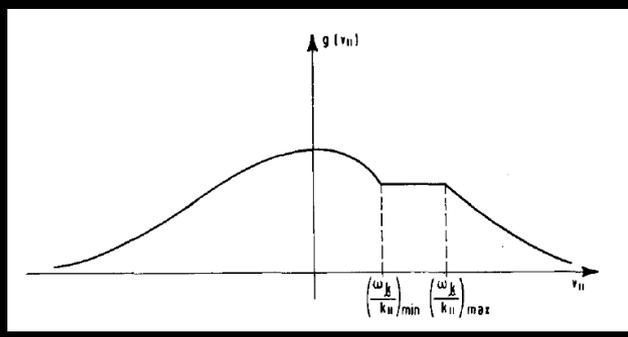
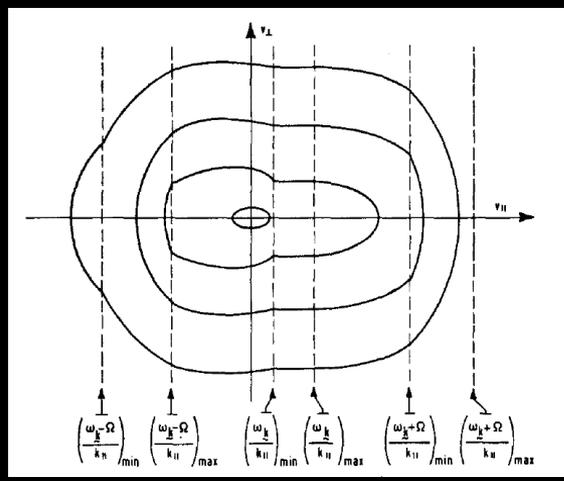
THE PHYSICS OF FLUIDS VOLUME 9, NUMBER 12 DECEMBER 1966

Velocity Space Diffusion from Weak Plasma Turbulence in a Magnetic Field

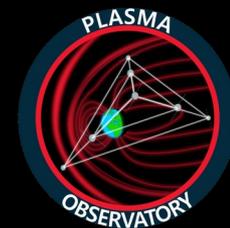
C. F. KENNEL* AND F. ENGELMANN†

International Atomic Energy Agency, International Centre for Theoretical Physics, Trieste, Italy
 (Received 14 March 1966; final manuscript received 8 August 1966)

$$\omega - k_{\parallel} v_{\parallel} = n\Omega_i$$



Kinetic effects in quasi-linear theory



Hybrid Vlasov-Maxwell (scaled units)

$$\frac{\partial f}{\partial t} + \mathbf{v} \cdot \nabla f + (\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot \frac{\partial f}{\partial \mathbf{v}} = 0$$

$$\left(\mathbf{E} + \mathbf{u} \times \mathbf{B} - \frac{\mathbf{j} \times \mathbf{B}}{n} \right) + \frac{1}{n} \nabla P_e = 0$$



In the electrostatic approximation (in 1D-1V phase space configuration) and for massless electrons

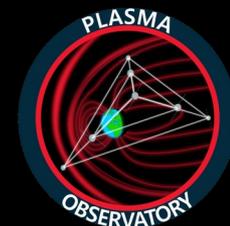
$$\frac{\partial f}{\partial t} + v \frac{\partial f}{\partial x} + E \frac{\partial f}{\partial v} = 0; \quad E = -\frac{1}{n} \frac{\partial P_e}{\partial x}$$

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}, \quad \nabla \times \mathbf{B} = \mathbf{j}$$

Dielectric function (Valentini+, PRL 2008, PRL 2011)

$$\mathcal{D}_R = -\frac{c_s^2}{n_0} P \int \frac{(\partial f_0 / \partial v) dv}{v - v_\phi} + 1; \quad \mathcal{D}_I = -\frac{\pi c_s^2}{n_0} \left. \frac{\partial f_0}{\partial v} \right|_{v_\phi}$$

Energy conversion to electrostatic fluctuations



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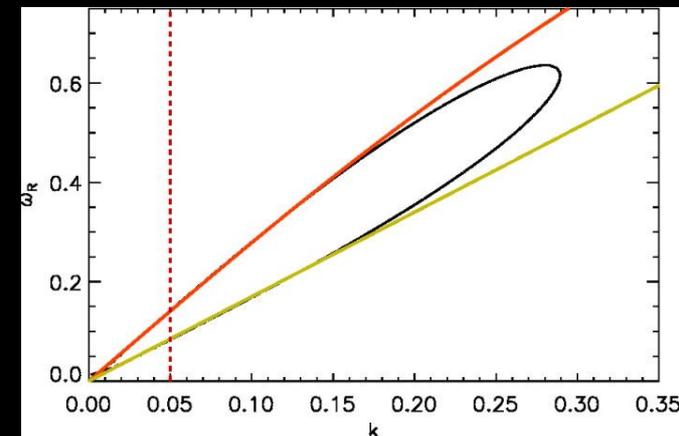
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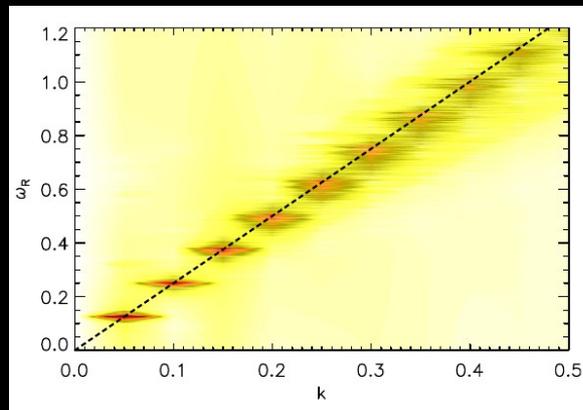
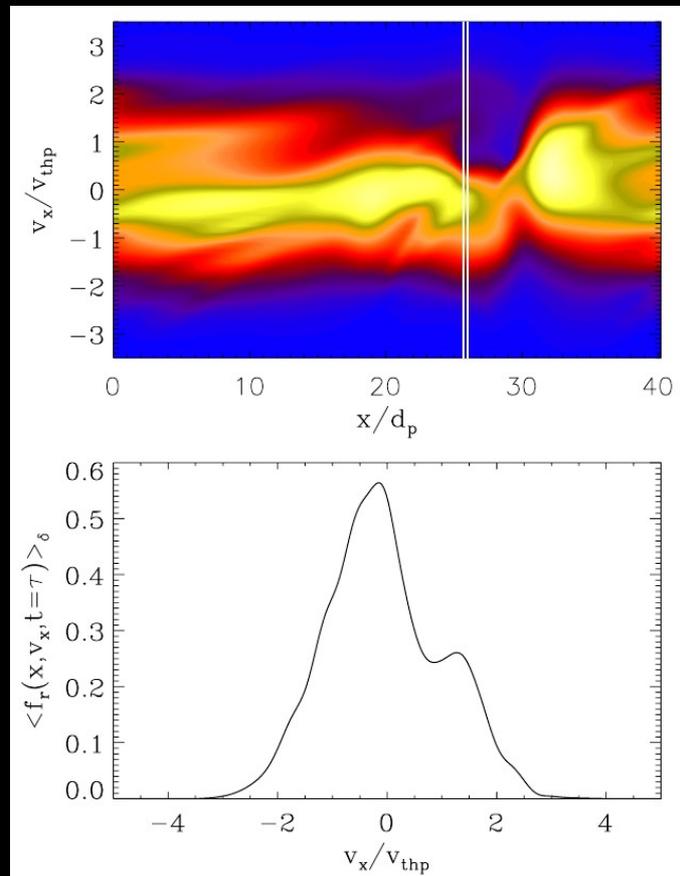
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Kinetic numerical simulations

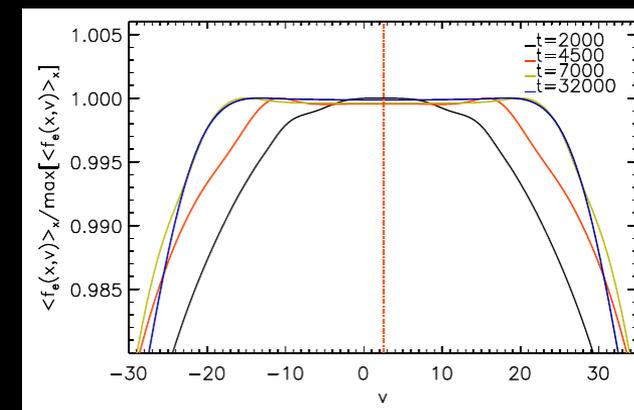
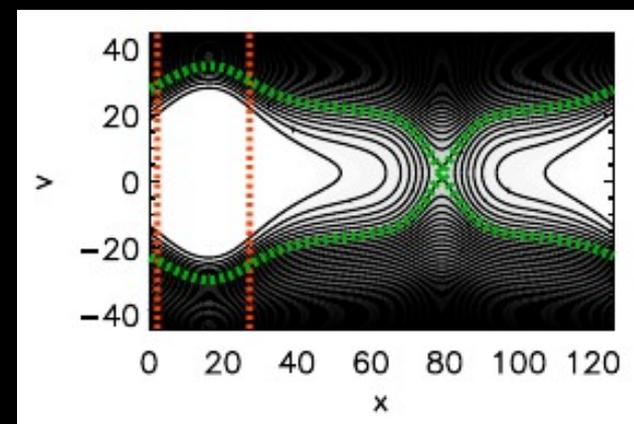


Protons, Valentini+, APJL 2014

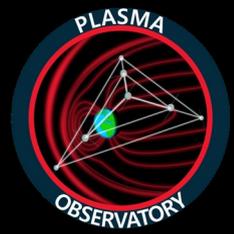


Hybrid simulations show the excitation of this branch of undamped nonlinear fluctuations, an efficient channel to bring energy to sub-ion scales

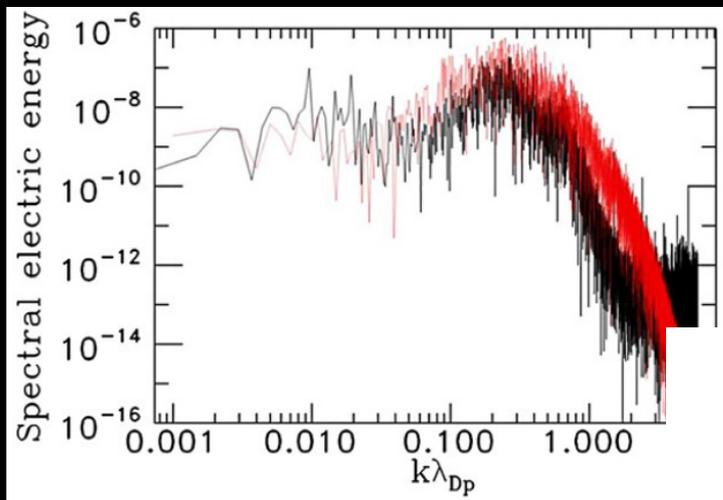
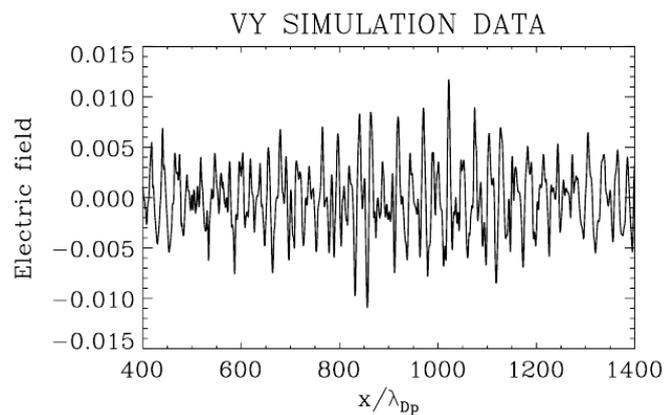
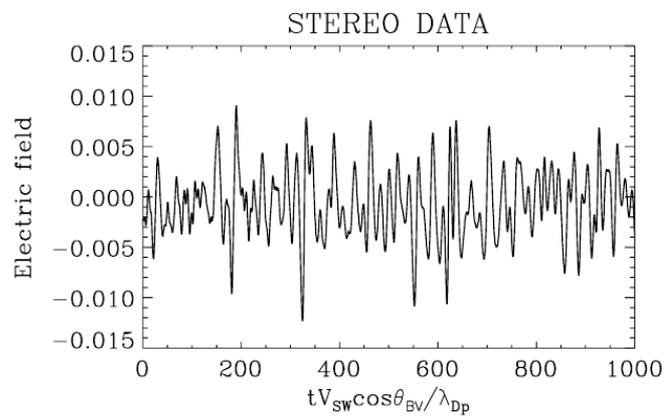
Electrons, Zanelli+, PoP 2025



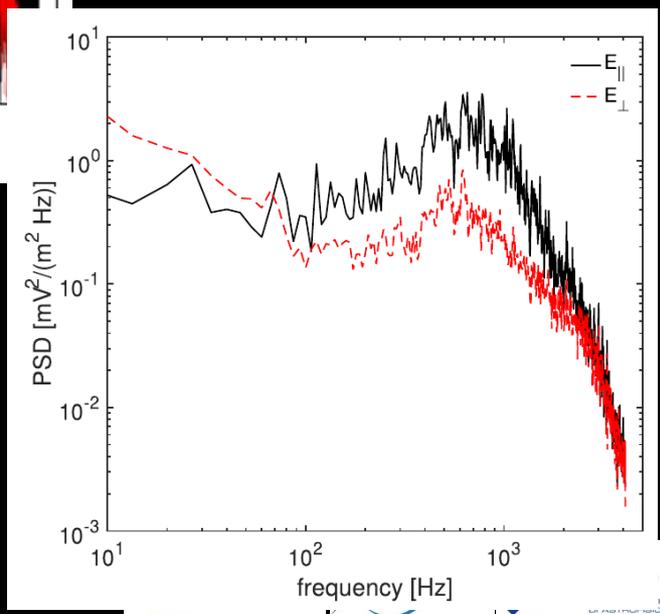
Comparison with data – electric signals



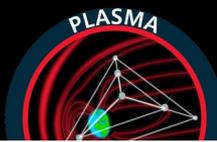
Spacecraft measurements in the solar wind,
Valentini+, APJL 2014



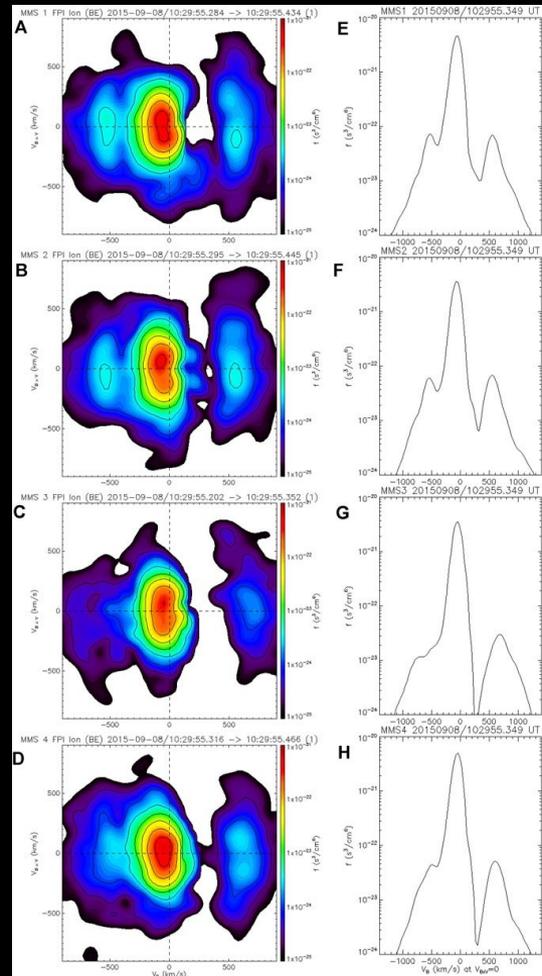
MMS measurements in the magnetosheath,
Perri+, APJ 2021



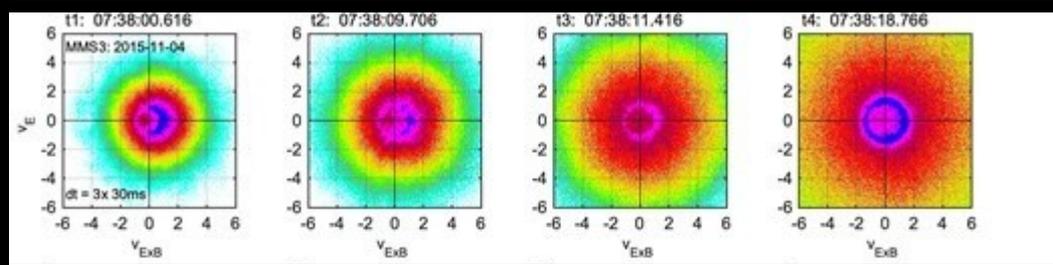
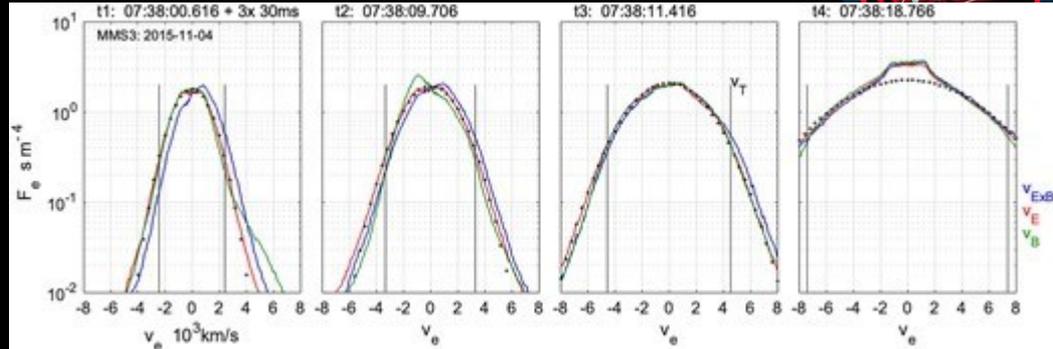
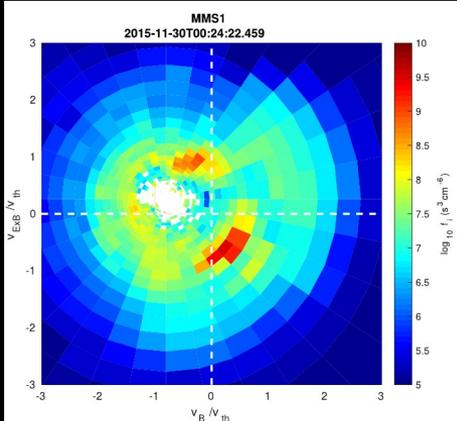
Comparison with data - velocity distributions



Eriksson+, 2021
 Ion-beam velocity distributions in the magnetosheath



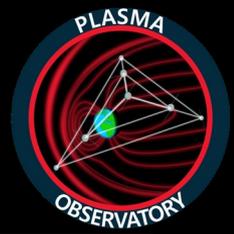
Perri+, APJ 2021



Stasiewicz, 2024 - Flat-top electron velocity distributions at the bow-shock

In regimes of low collisionality, the interaction between particles and fluctuations results in the deformation of ion and electron velocity distributions

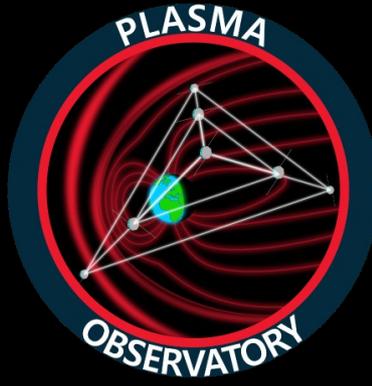
PO vs start-of-the-art multi-point missions



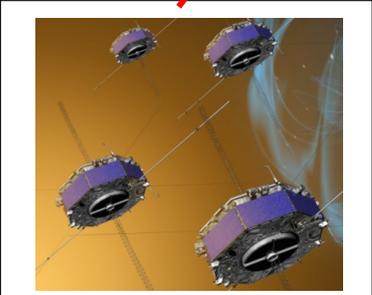
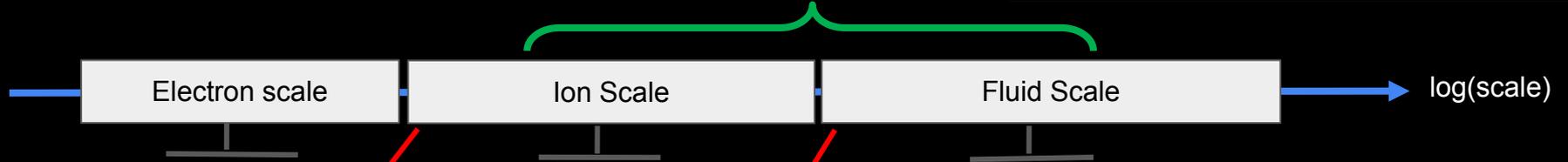
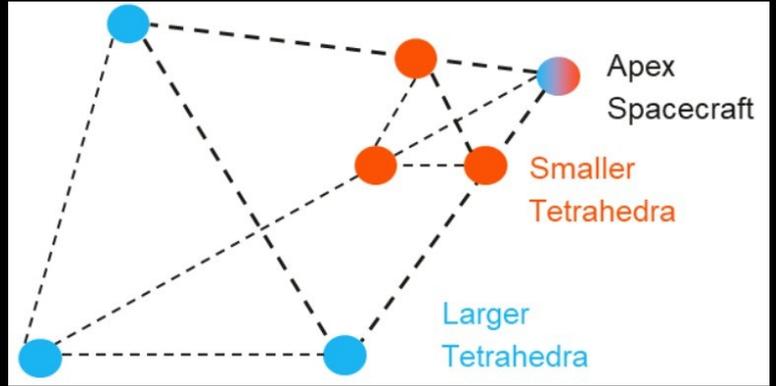
Plasma Observatory: 7 observations points

Next logical step following Cluster, THEMIS and MMS

Leverage Cross-Scale and SCOPE heritage studies



7 SC enable to study the coupling between ion and fluid scale in 3D



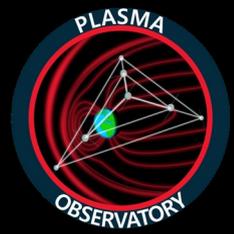
4 MMS
Electron or Ion scale



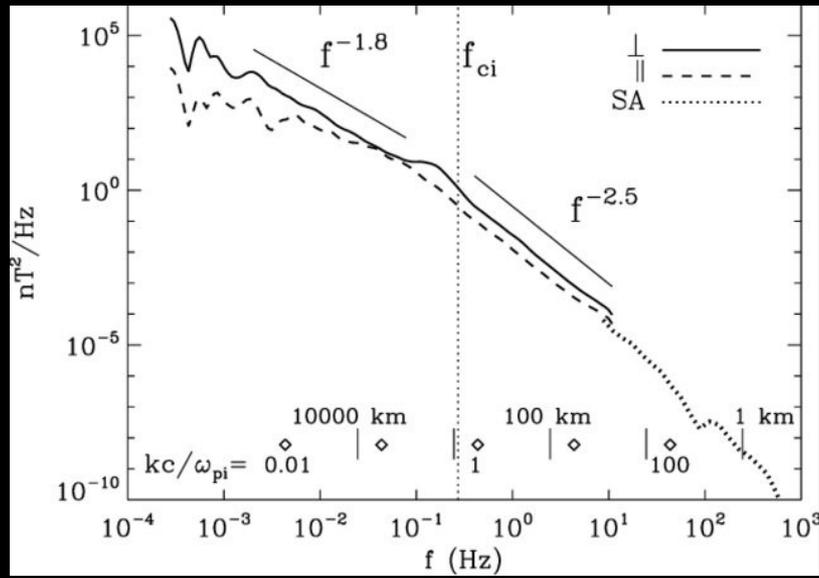
4 Cluster
Ion or Fluid

4 SC allows to study structures in 3D but only one scale at time

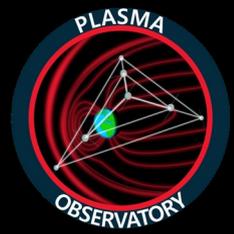
How scales couple



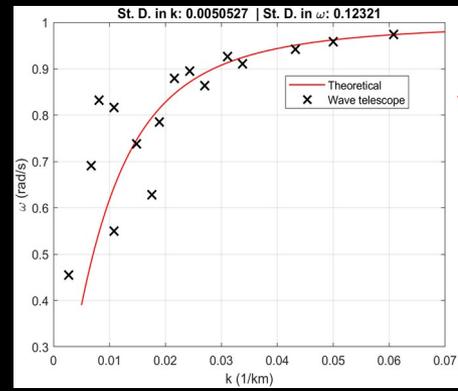
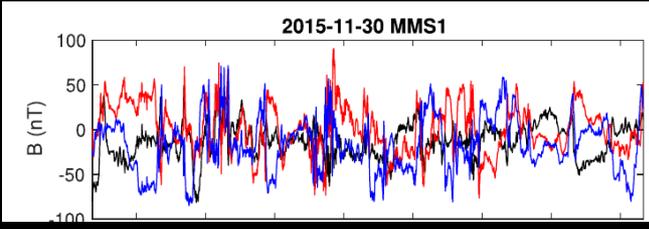
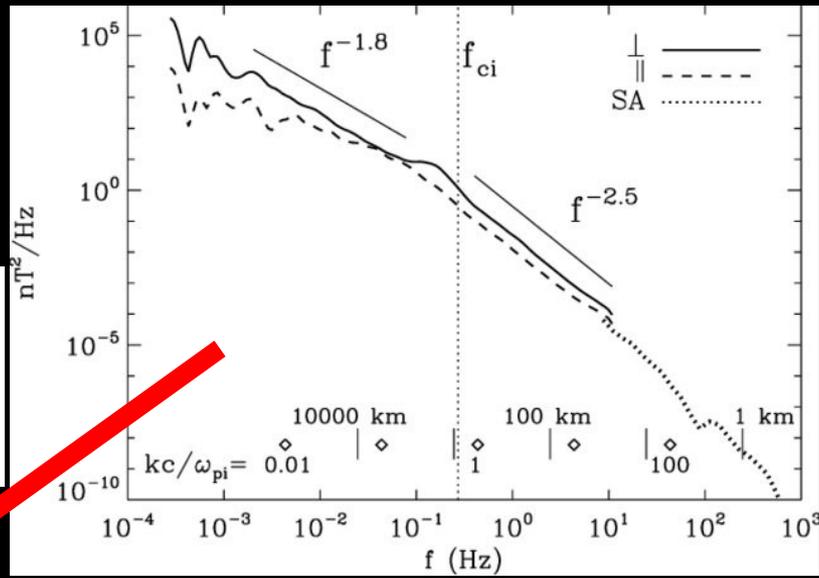
Establishing cause and effect in plasmas



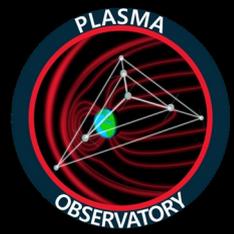
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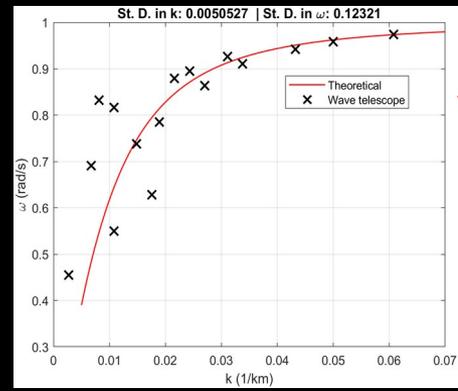
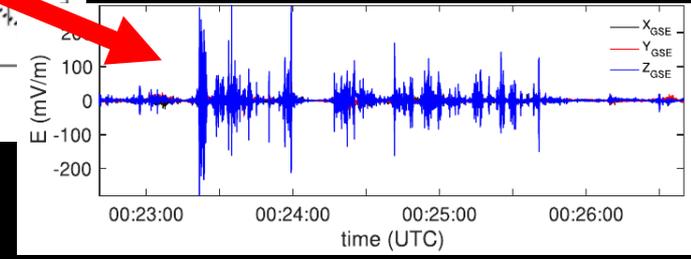
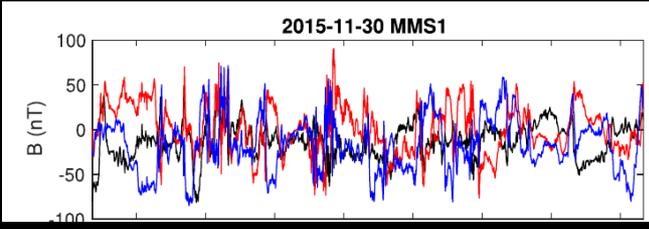
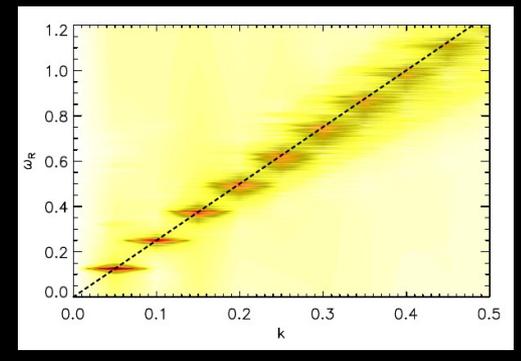
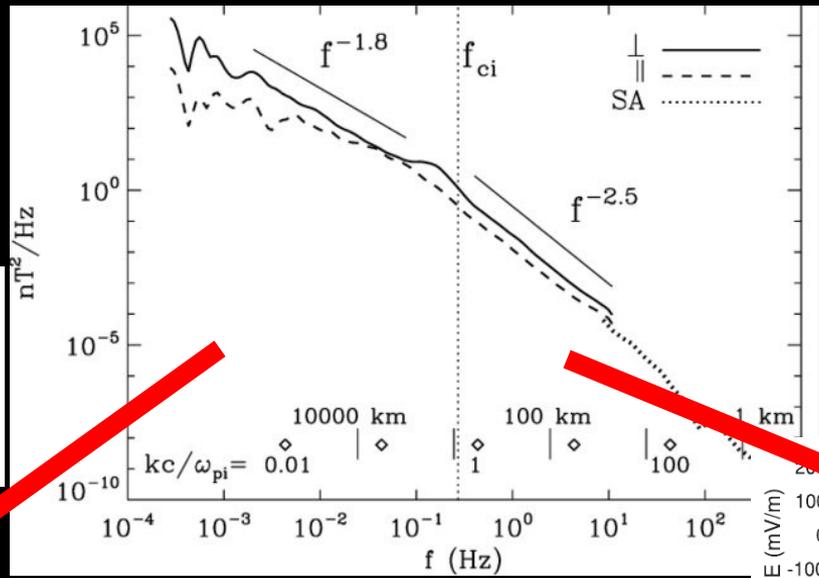
Establishing cause and effect in plasmas



How scales couple

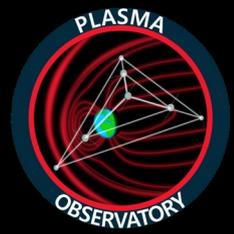


Establishing cause and effect in plasmas

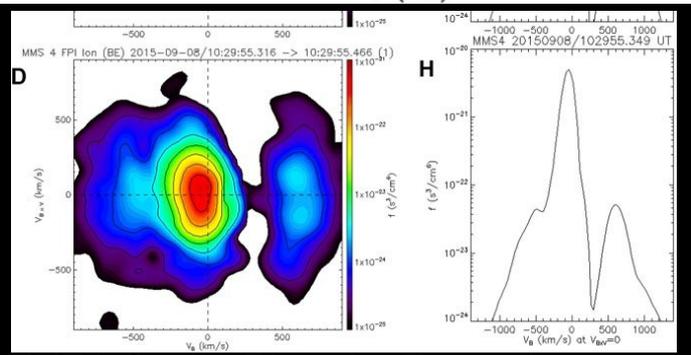
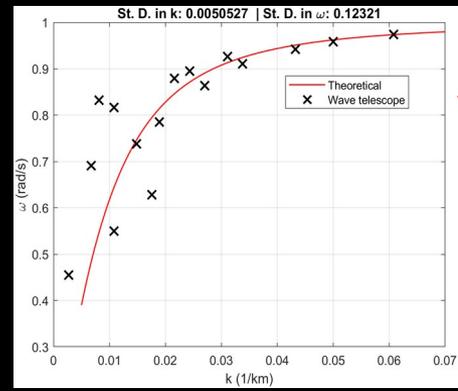
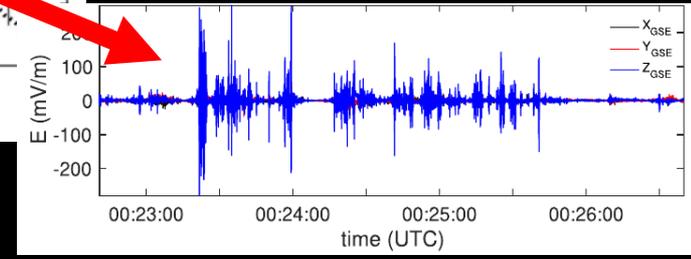
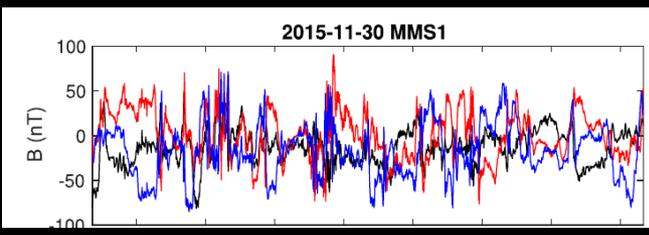
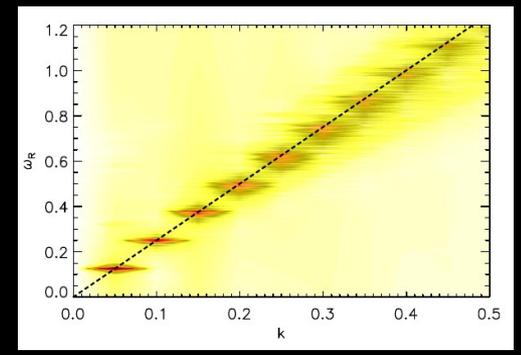
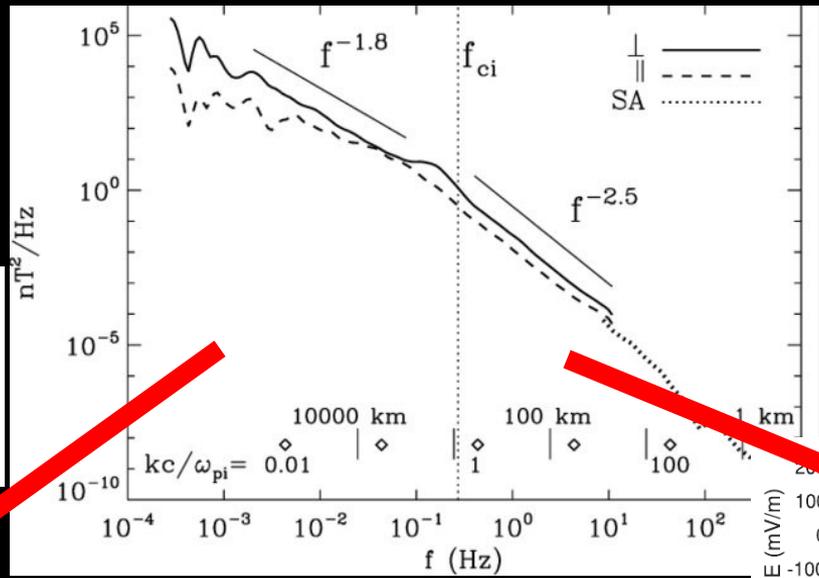


Curlometer \rightarrow $curl(E)$, electrostatic

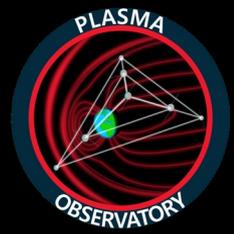
How scales couple



Establishing cause and effect in plasmas



Curlmeter \rightarrow $curl(E)$, electrostatic



Plasma Observatory is a plasma physics mission in a privileged natural laboratory

PO allows for the first time to investigate a fundamental and intrinsic property of a complex system, such as a turbulent plasma, that is cross-scale coupling

Many different plasma process can be get closure through PO measurements

Scientists interested in the physics of PO are encouraged to start thinking about possible lines of research where PO data could be game changer

Stay tuned for the final selection, GO PO!

