Electron Landau Damping and Wave Energy Flux in the Magnetosheath

MMS Telecon
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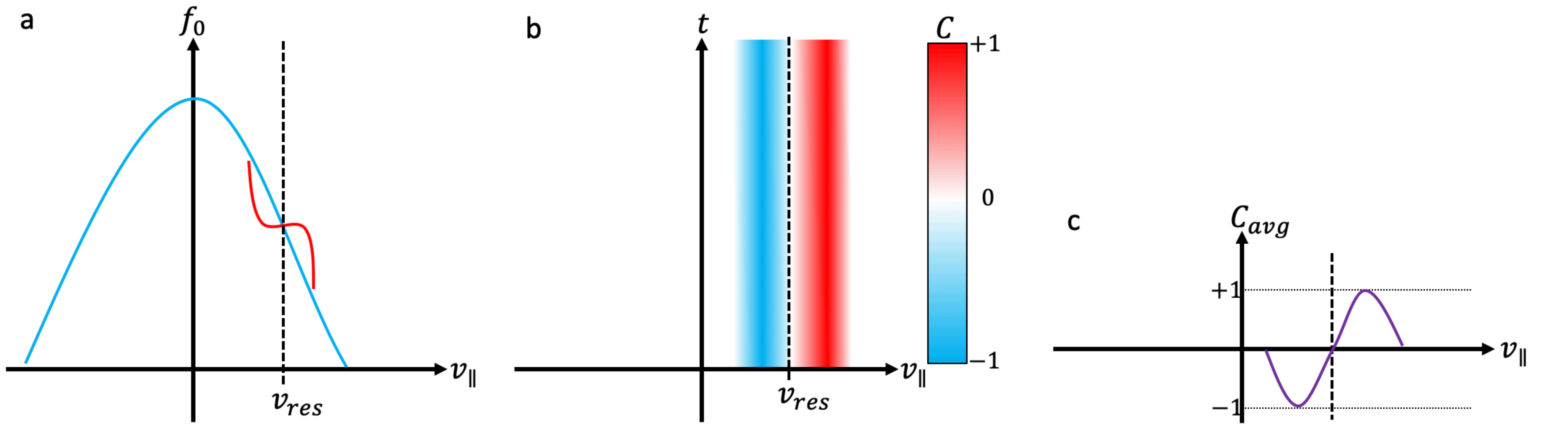
Field-Particle Correlation Technique

A technique for characterizing the net energy transfer from turbulent field fluctuations to particles

Klein and Howes, 2016; Howes et al., 2017; Klein et al., 2017; Klein et al., 2020

Collisionless Vlasov equation: $\frac{\partial f_s}{\partial t} + \vec{v} \cdot \nabla f + \frac{q_s}{m_s}\left(\vec{E} + \vec{v}x\vec{B}\right) \cdot \nabla_{\vec{v}} f_s = 0$

Considering Landau damping, energy transferred is in the parallel direction: $\frac{\partial w_{s,||}}{\partial t} = -\frac{q_s v_{||}^2}{2} E_{||} \frac{\partial f_s}{\partial v_{||}}$



$f_s(v,t) = f_{s0}(v) + \delta f_s(v,t)$

$\mathrm{C}(v_{||}) = \left\langle -\frac{q_s v_{||}^2}{2} E_{||} \frac{\partial f_s}{\partial v_{||}} \right\rangle$

$C_{avg}(v_{||}) = \left\langle -\frac{q_s v_{||}^2}{2} E_{||} \frac{\partial f_s}{\partial v_{||}} \right\rangle_{\tau}$

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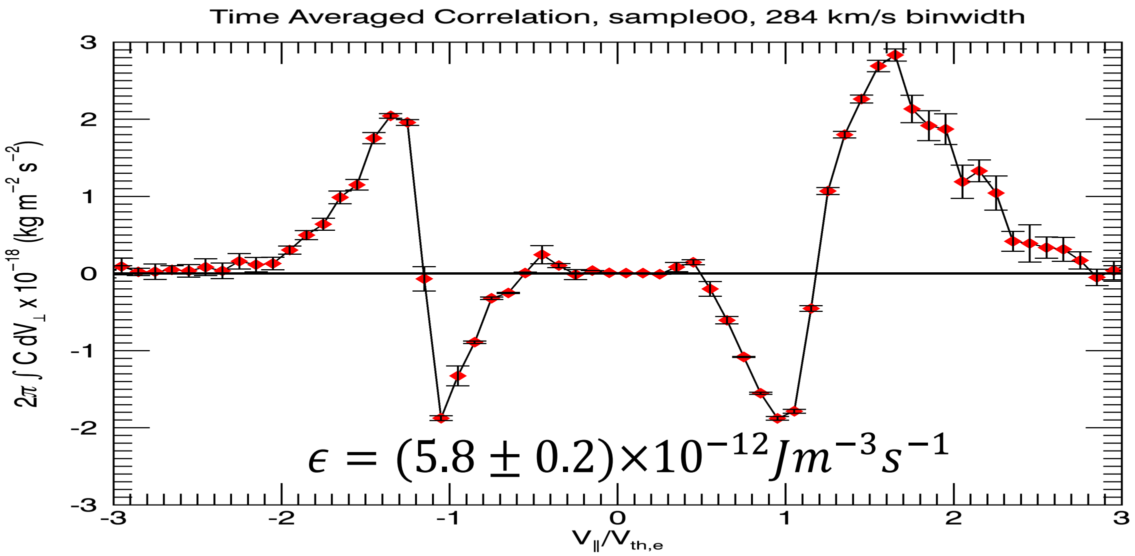
Observations

Alternative FPC:

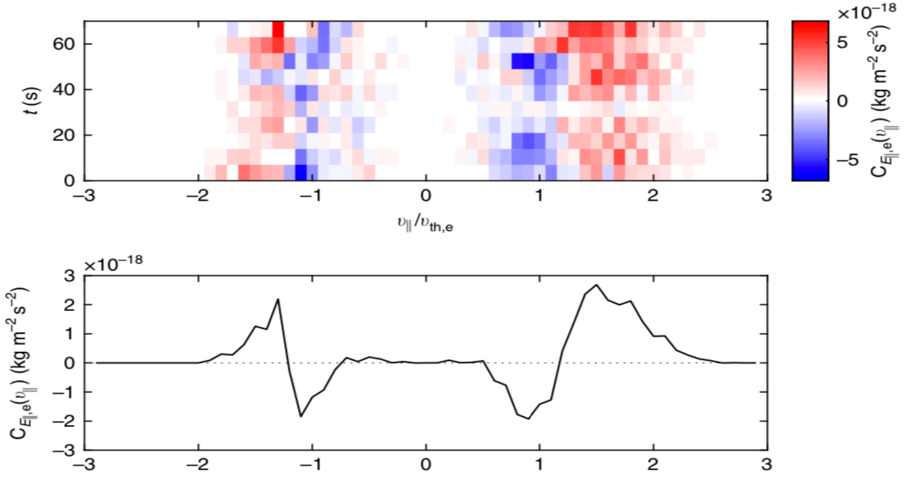
- $E_{\|}$ filtered at 1 Hz
- Fluctuations of the distribution at each time step: $\delta f_e = f - f_0$
- Correlated over an interval of time, τ

$$C'_{E_{||},s}(\mathbf{v}) = \left\langle q_s v_{||} E_{||} f_s \right\rangle$$

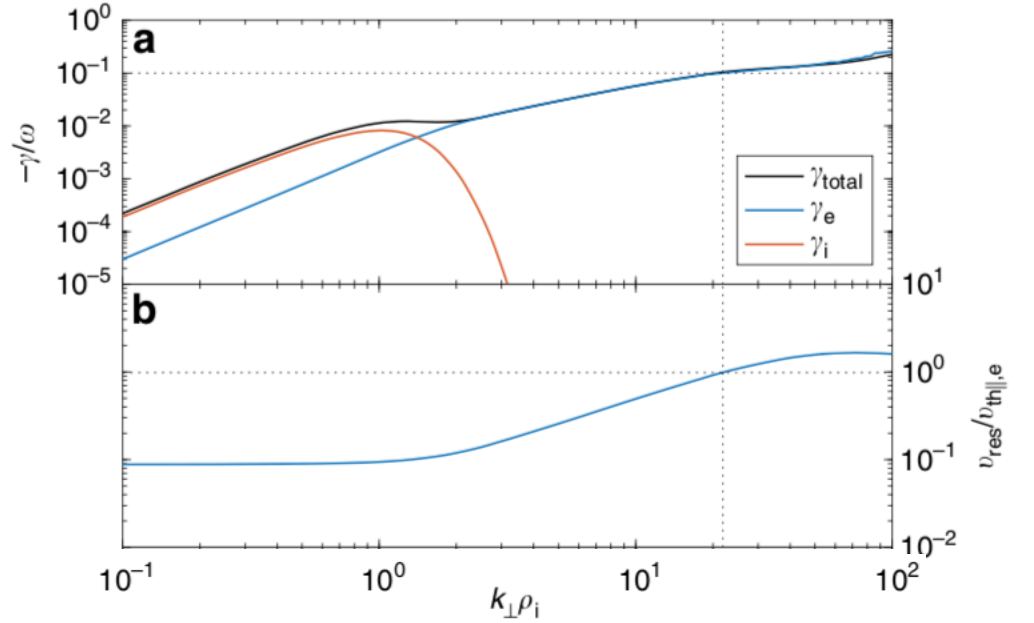
$$C_{E_{||,e}}(v_{||}) = -\frac{v_{||}}{2}\frac{\partial C'_{E_{||},e}(v_{||})}{\partial v_{||}} + \frac{C'_{E_{||},e}(v_{||})}{2}$$



$\epsilon = (5.8 \pm 0.2)\times 10^{-12} J m^{-3} s^{-1}$



$\epsilon = \int C(v_{\|}) dv_{\|} = 3.4\times 10^{-12} J m^{-3} s^{-1}$



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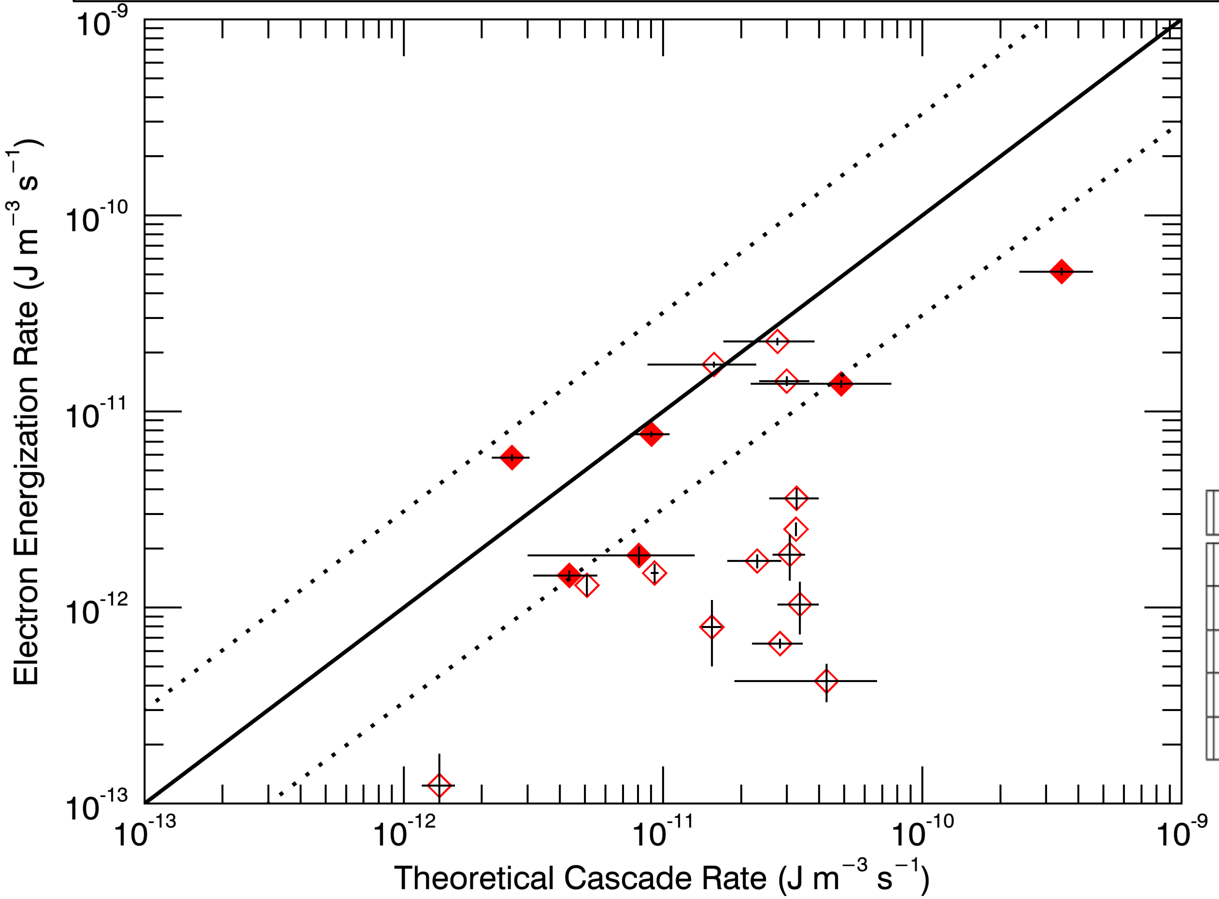
Chen et al., 2019

Electron Energization Rate vs Cascade Rate

20 intervals analyzed:
6 symmetric
13 asymmetric
1 inconclusive



Afshari et al., 2020, submitted

Electron Energization Rate:

$$\epsilon = \int C(v_\parallel)dv_\parallel$$

Theoretical Cascade Rate:

$$\epsilon \sim \frac{\text{Energy Density}}{\text{Cascade Time}} = \frac{n_0 m_p U_\perp^2}{1/(k_\perp U_\perp)} = n_0 m_p \left(\frac{2\pi f}{v_{\perp,sc}}\right) \frac{[\delta \hat{B}_\perp(f)]^3}{(\mu_0 n_0 m_p)^{3/2}}$$

Study	cascade rate (J m^{-3} s^{-1})	# of samples	spacecraft
Hadid et al. (2018)	10^{-16}– 10^{-12}	47	Cluster
Bandyopadhyay et al. (2018)	10^{-12}	1	MMS
Andrés et al. (2019)	10^{-13}– 10^{-12}	2	MMS
Bandyopadhyay et al. (2020)	10^{-13}	1	MMS
Afshari et al., (2020), submitted	10^{-12}– 10^{-10}	20	MMS

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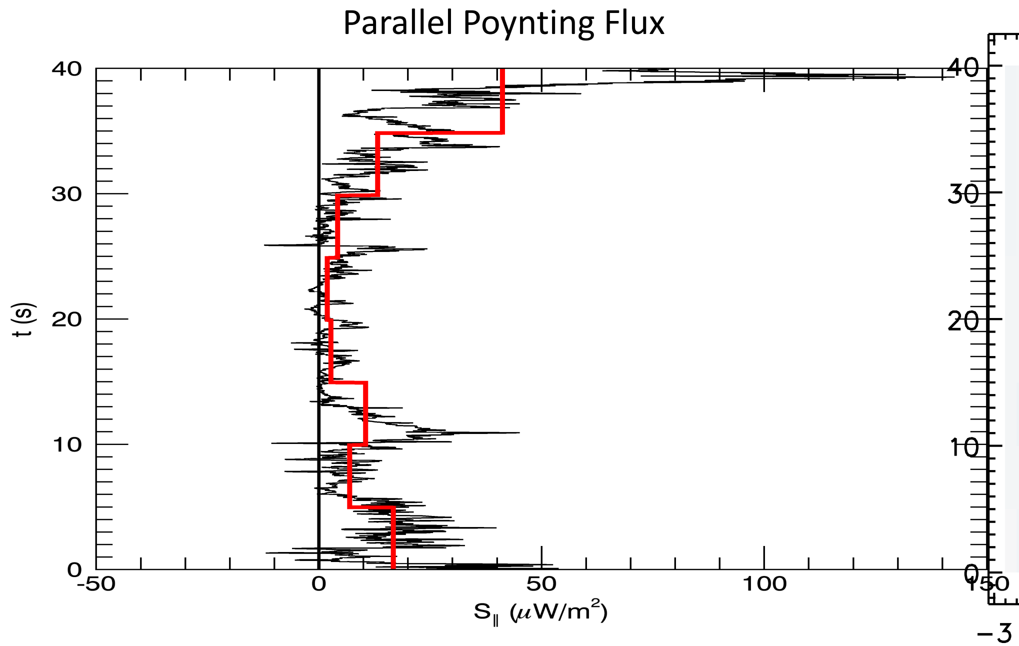
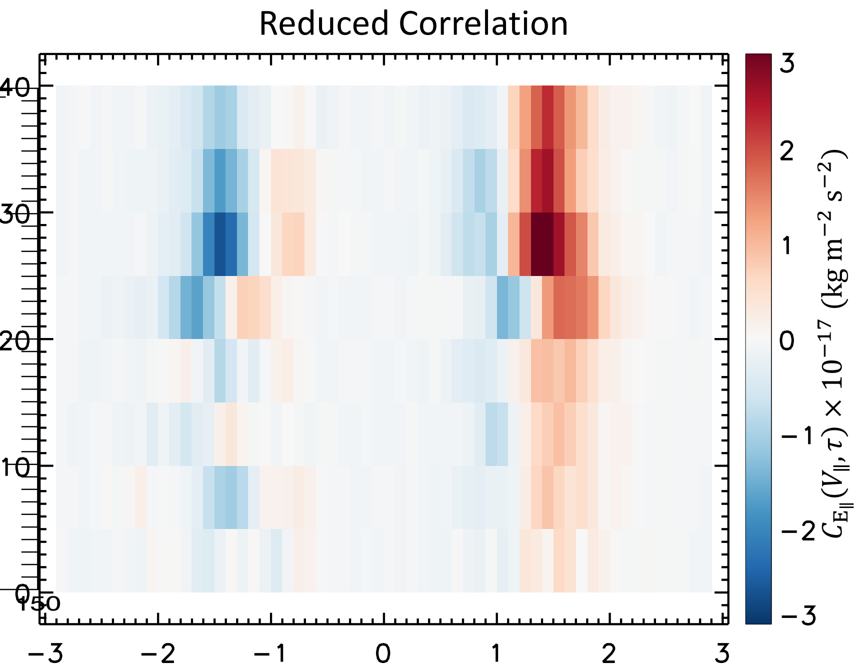
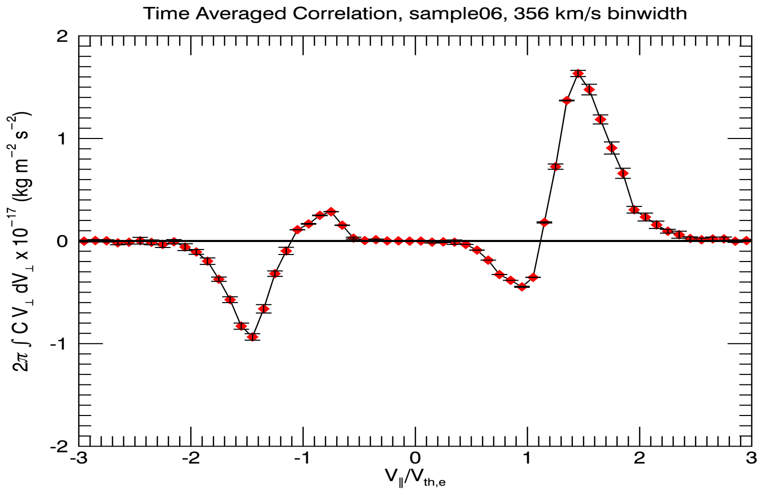
Wave Energy Flux







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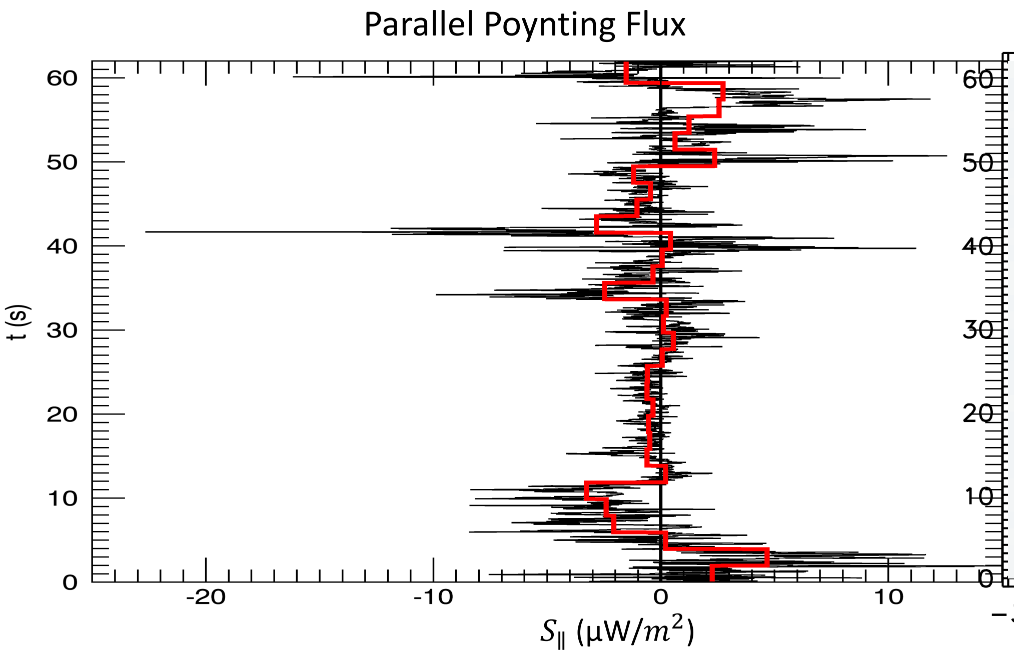
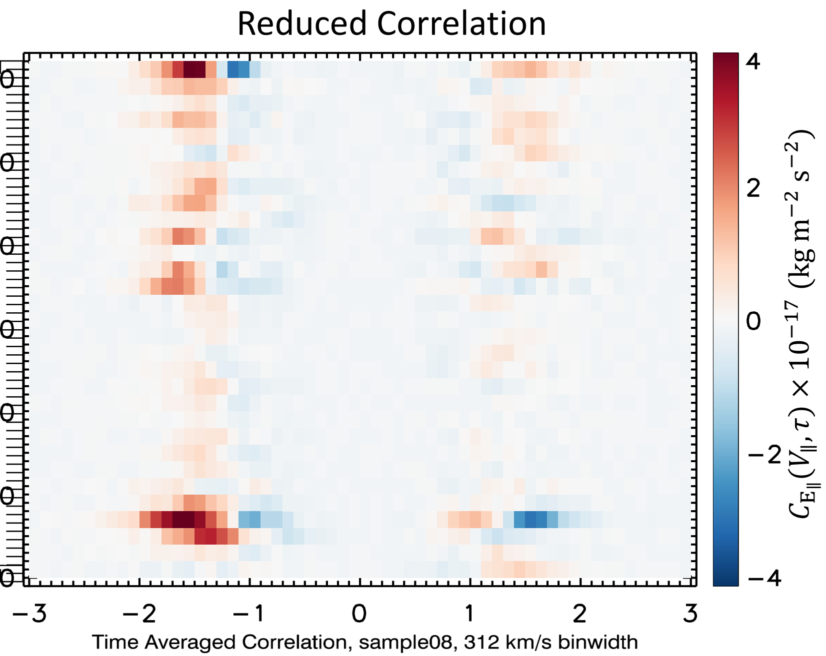
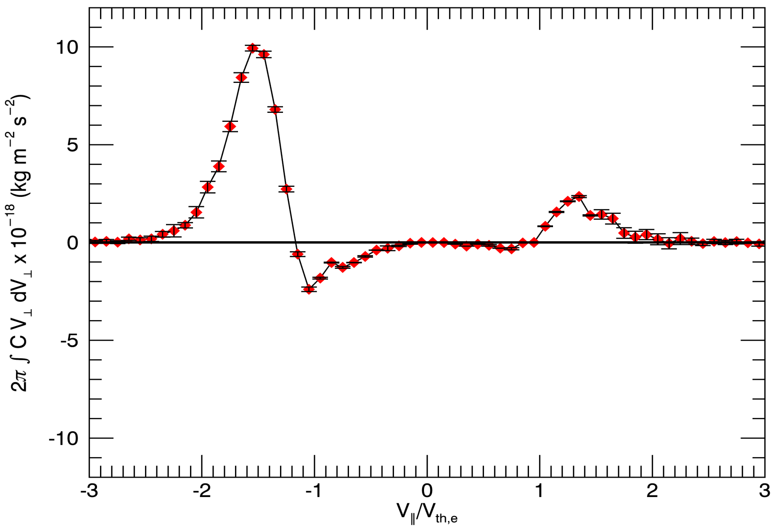
Wave Energy Flux







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THANK YOU!

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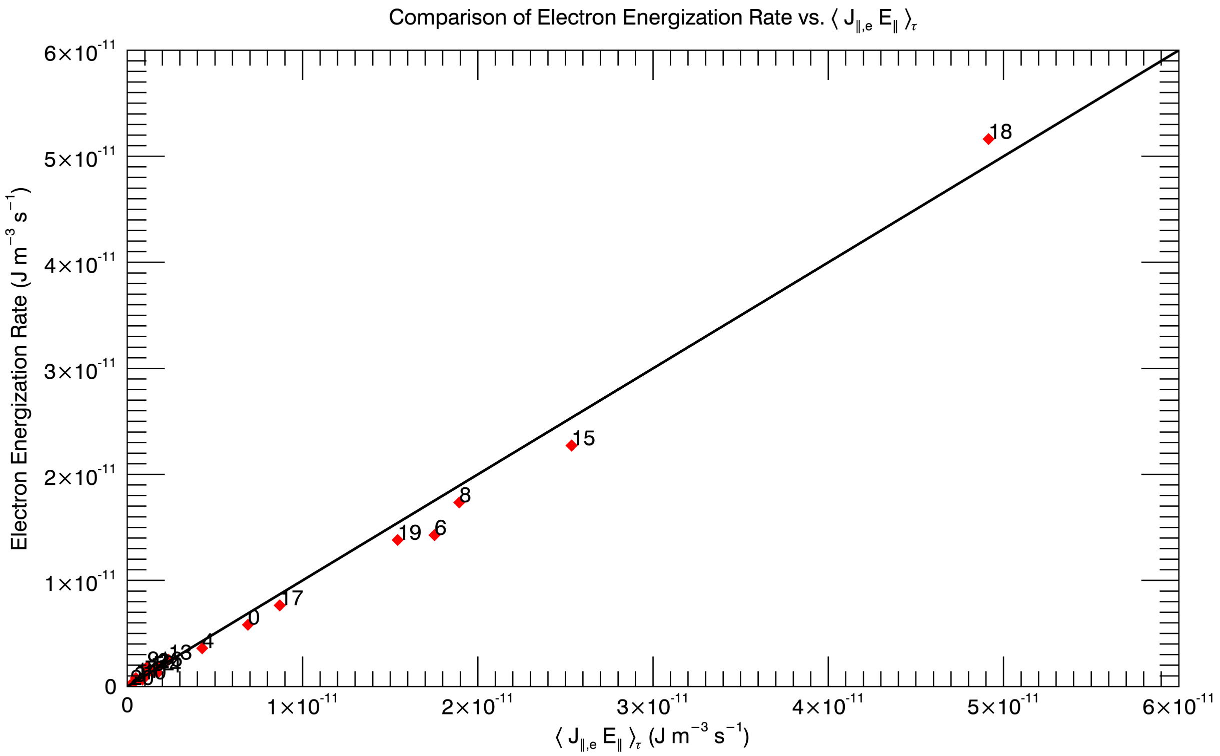
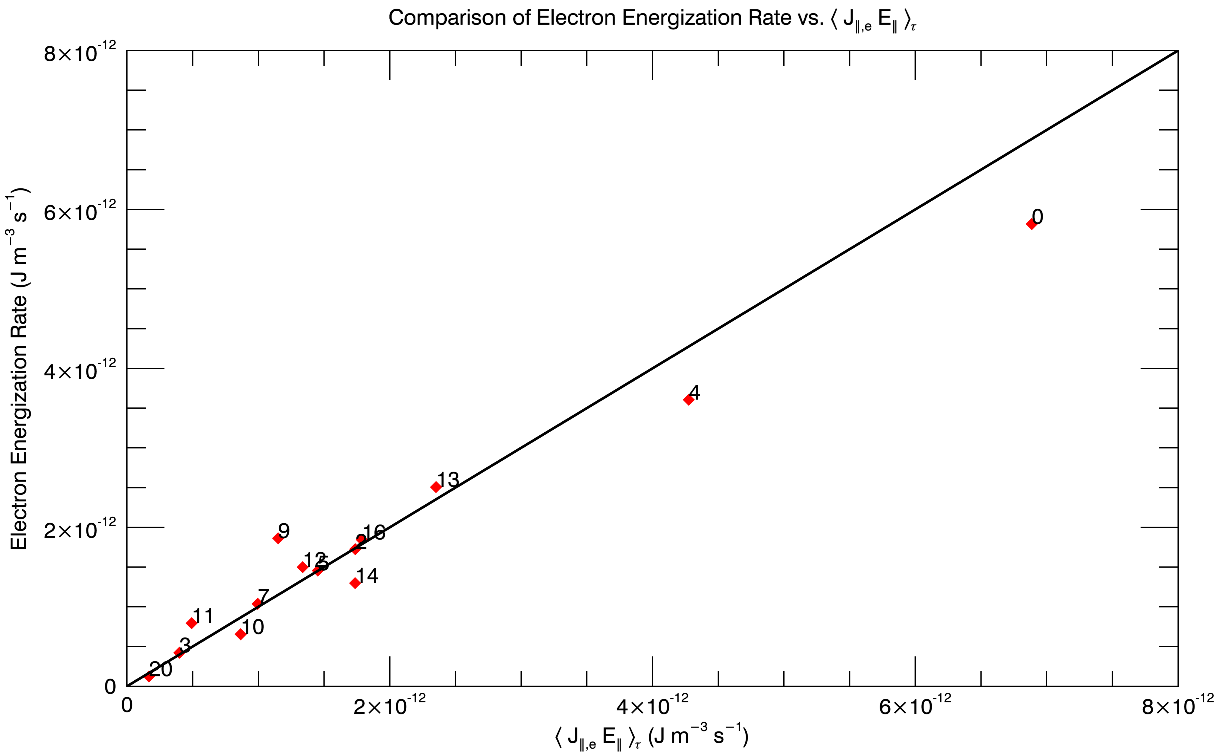
Quality Check





Electron Energization Rates:

$$\epsilon \sim [10^{-13}, 10^{-11}] \, Jm^{-3}s^{-1}$$

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