DISSIPATION MODEL FOR SOLAR WIND TURBULENCE AT ELECTRON SCALES

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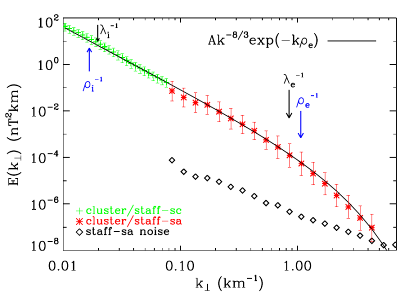
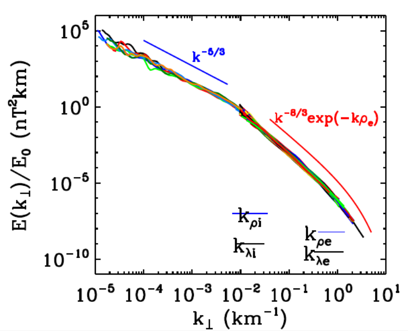
Alexandrova et al. 2012:



- Exponential decay
- Universal dissipation range

Solar Wind Observations

Alexandrova et al. 2012:



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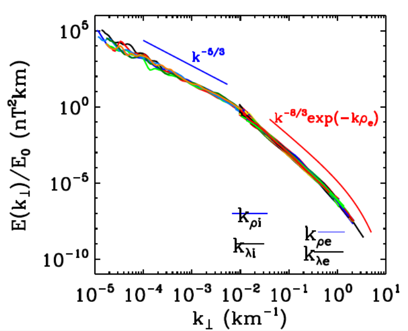

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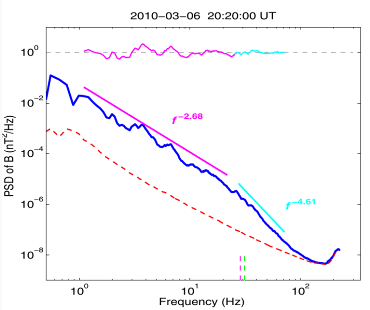
Sahraoui et al. 2013:



- Power law
- Varying spectral index (-5.5 to -3.5)

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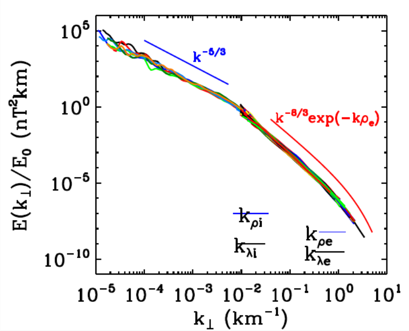

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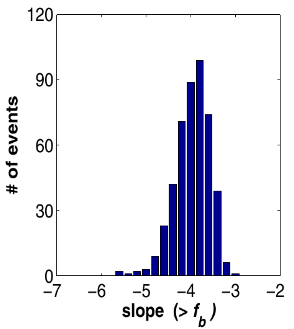


- Exponential decay
- Universal dissipation range

- Power law
- Varying spectral index (-5.5 to -3.5)

- High correlation between dissipation length and ρ_e

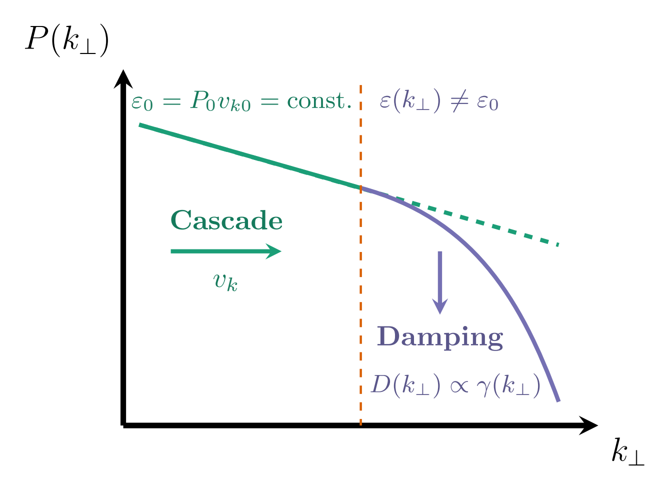
Dissipation Model

- Can damping of KAW explain observations quantitatively?
- Exponential or power law dissipation range for KAW damping?
- Why does the dissipation length seem to be independent of turbulent energy flux?

$\rightarrow$ Derivation of simple, 'quasi'-analytical dissipation model for electron scales under assumption of:

- Critically balanced turbulence,
- KAW damping from linear Vlasov theory

Dissipation Model



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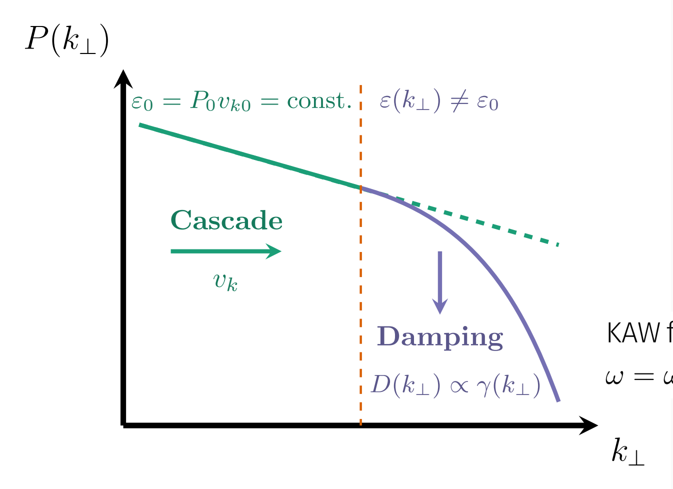


KAW frequency:

$\omega = \omega_r + i\gamma$

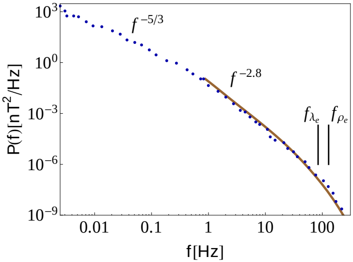
Dissipation Model

Magnetic energy spectrum:

$$\Rightarrow P(k_\perp) = P_0 \left(\frac{k_\perp}{k_0}\right)^{-\kappa} \exp\left(-2\, C_K^{3/2} \int_{k_0}^{k_\perp} dk'_\perp \frac{\overline{\gamma}(k_\perp, k_\parallel)}{\overline{\omega}_r(k_\perp, k_\parallel)} k_\perp^{-1}\right)$$

Energy flux:

$$\Rightarrow \varepsilon(k_\perp) = \varepsilon_0 \exp\left(-2\, C_K^{3/2} \int_{k_0}^{k_\perp} dk'_\perp \frac{\overline{\gamma}(k_\perp, k_\parallel)}{\overline{\omega}_r(k_\perp, k_\parallel)} k_\perp^{-1}\right)$$



Blue dots: Alexandrova et al. (2009)

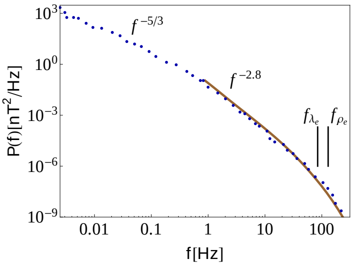
Observations:

$B = 15.5\,\mathrm{nT}$
$n = 20\,\mathrm{cm}^{-3}$
$T_i/T_e = 2.34$
$\beta_i = 2.04$

Model:

$C_K = 1.4$
$\kappa = 2.5$

Application to the Solar Wind



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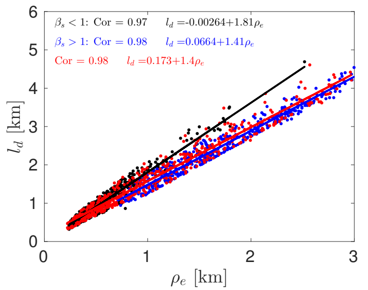
Model:

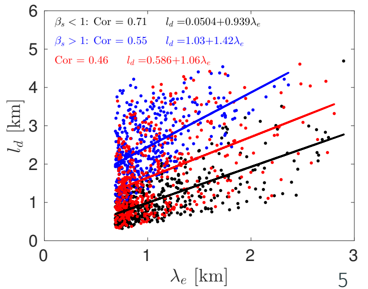
$C_K = 1.4$

$\kappa = 2.5$

Fit $P_A(k_\perp) = A k_\perp^{-\alpha} \exp(-k_\perp l_d)$

$\longrightarrow$

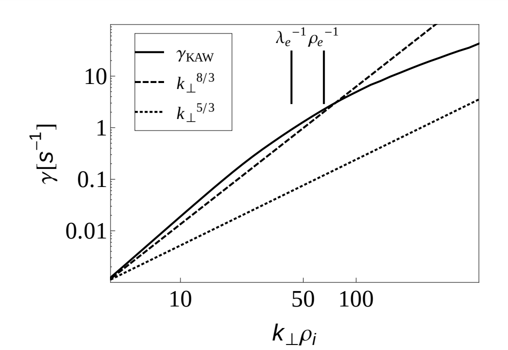




Implications for Solar Wind Dissipation

$$\varepsilon(k_\perp) = \varepsilon_0 \exp\left(-2C_K\left(\frac{\rho}{\varepsilon_0}\right)^{1/3} k_0^{\kappa-5/3}\int_{k_0}^{k_\perp} dk'_\perp \gamma(k'_\perp)k'^{-\kappa}_\perp\right)$$

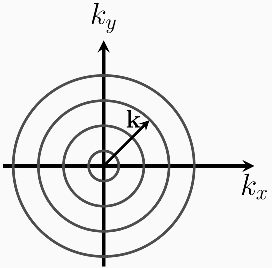
$$\gamma(k_\perp) \propto \begin{cases} k_\perp^{\kappa-1} & \Rightarrow \text{power law} \\ k_\perp^{\kappa} & \Rightarrow \text{exp} \\ f(k_\perp) & \Rightarrow \text{'quasi' exp} \end{cases}$$

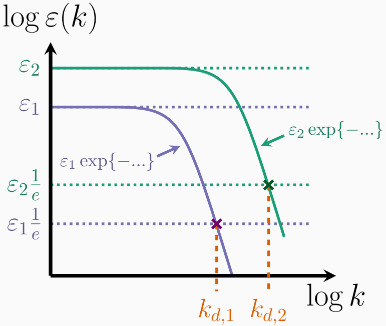


Implications for Solar Wind Dissipation

$$\varepsilon(k) = \varepsilon_0 \exp\left(-2\,C_K\left(\frac{\rho}{\varepsilon_0}\right)^{1/3} k_0^{\kappa-5/3}\int_{k_0}^{k} dk'\,\gamma(k')\,k'^{-\kappa}\right)$$

Hydrodynamic turbulence: $\gamma(k) = \nu k^2$





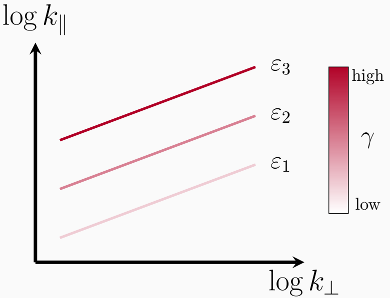
$\Rightarrow l_d = (\nu^3/\varepsilon_0)^{1/4}$

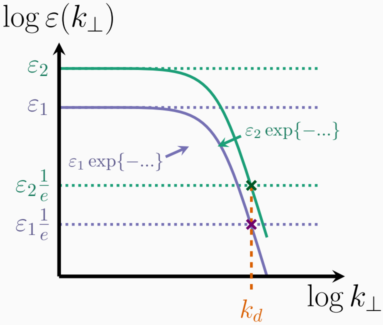
Implications for Solar Wind Dissipation

$$\varepsilon(k_\perp) = \varepsilon_0 \exp\left(-2C_K\left(\frac{\rho}{\varepsilon_0}\right)^{1/3} k_0^{\kappa-5/3}\int_{k_0}^{k_\perp} dk'_\perp \gamma(k'_\perp) k'^{-\kappa}_\perp\right)$$

Solar wind turbulence: $k_\parallel = C_K^{1/2}\left(\frac{\varepsilon_0}{\rho}\right)^{1/3} k_0^{5/3-\kappa}\left(v_A\overline{\omega}_r\right)^{-1} k_\perp^{\kappa-1}$

$$\gamma(k_\perp) \approx k_\parallel v_A \overline{\gamma}(k_\perp)$$





Conclusions

Under the assumption of critically balanced turbulence and KAW damping:

- Good agreement of model and observations at electron scales,
- KAW damping leads to 'quasi' exponentially shaped dissipation range,
- Dissipation length is related to the electron gyroradius,
- Dissipation length is independent of the energy cascade rate.

Dissipation Model

- Kolmogorov energy cascade rate:
  $\varepsilon_0 \sim P_0 v_{k0} = P(k_\perp) v_k(k_\perp) =$ const. in inertial range

- Eddy decay velocity:
  $v_k(k_\perp) = v_{k0} \left(\frac{k_\perp}{k_0}\right)^\kappa \;\;\&\;\; v_k(k_\perp) = \frac{k_\perp^2}{\alpha} v(k_\perp)$

- Ratio of velocity to magnetic fluctuations α:
  $v(k_\perp) = \alpha \sqrt{\frac{P(k_\perp) k_\perp}{\rho}} \quad \text{with} \quad \alpha = \omega_r / k_\| v_A$

- Dissipation: $P(k_\perp) v_k(k_\perp) = P(k'_\perp) v_k(k'_\perp) + D(k_\perp)$

- Heating rate: $D(k_\perp) = 2P(k_\perp)\gamma(k_\perp) dk_\perp$

- Damping rate: $\omega = \omega_r + \mathrm{i}\gamma \;\;\&\;\; \omega_r = k_\| v_A \overline{\omega}_r \;\;\&\;\; \gamma = k_\| v_A \overline{\gamma}$

- Critical Balance: $v_\perp k_\perp = k_\| v_A \overline{\omega}_r$