A kinetic Alfven wave cascade cannot reach the electron gyro-scale in the solar wind at 1 AU

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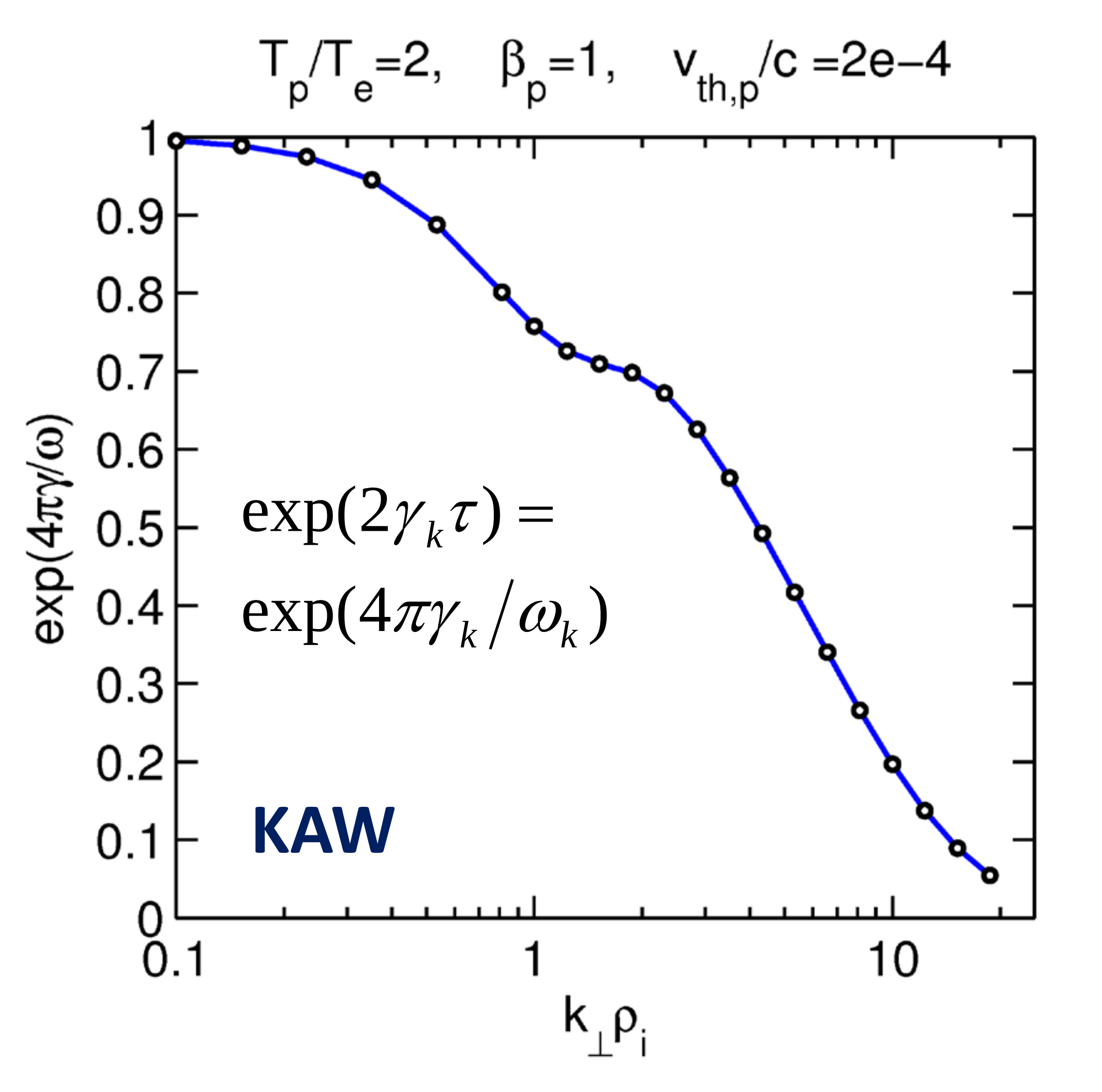
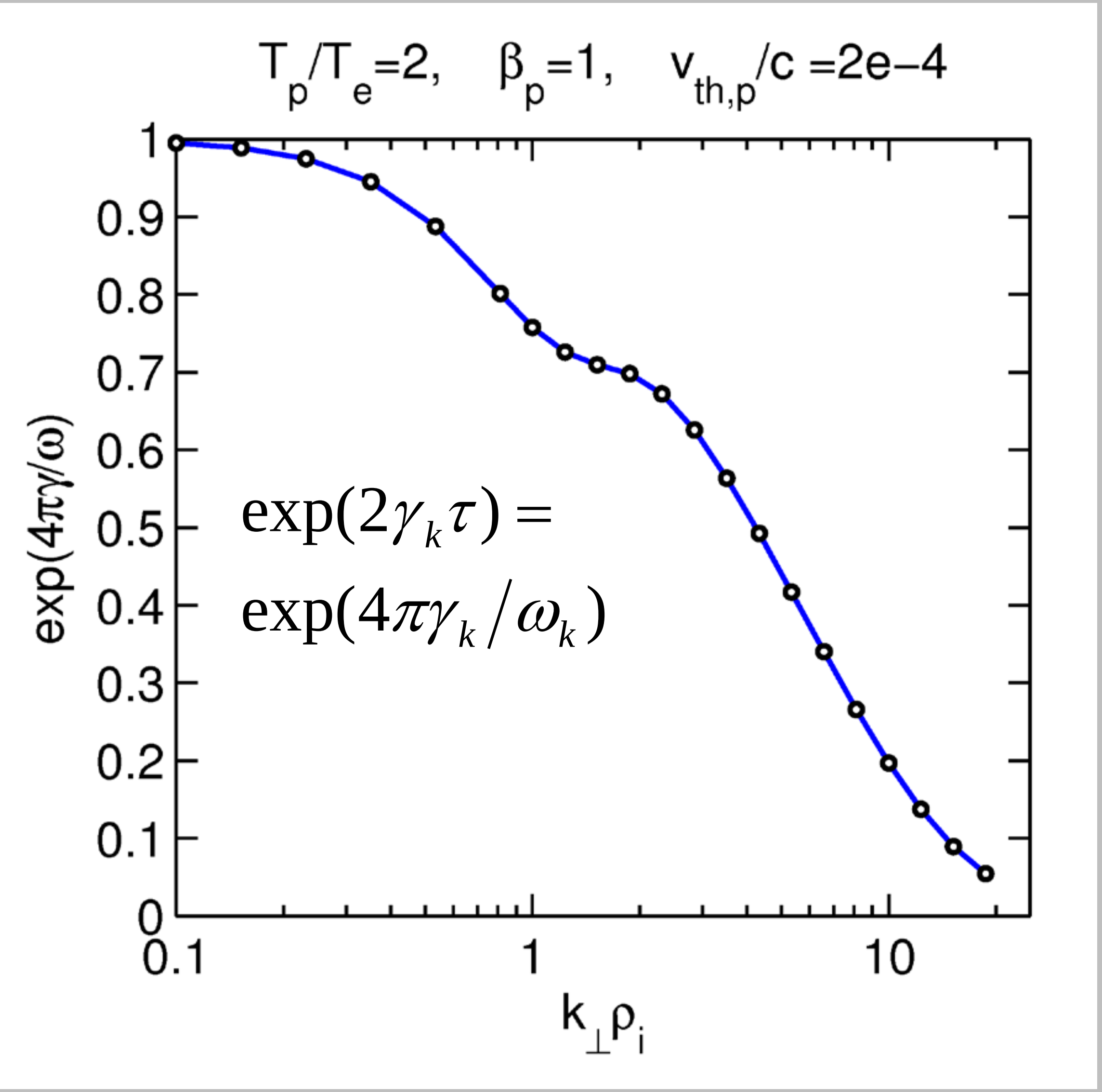
Energy attenuation in one wave period



The electron gyro-radius scale is **$k_\perp \rho_e$=1**, or, **$k_\perp \rho_i$=60**.

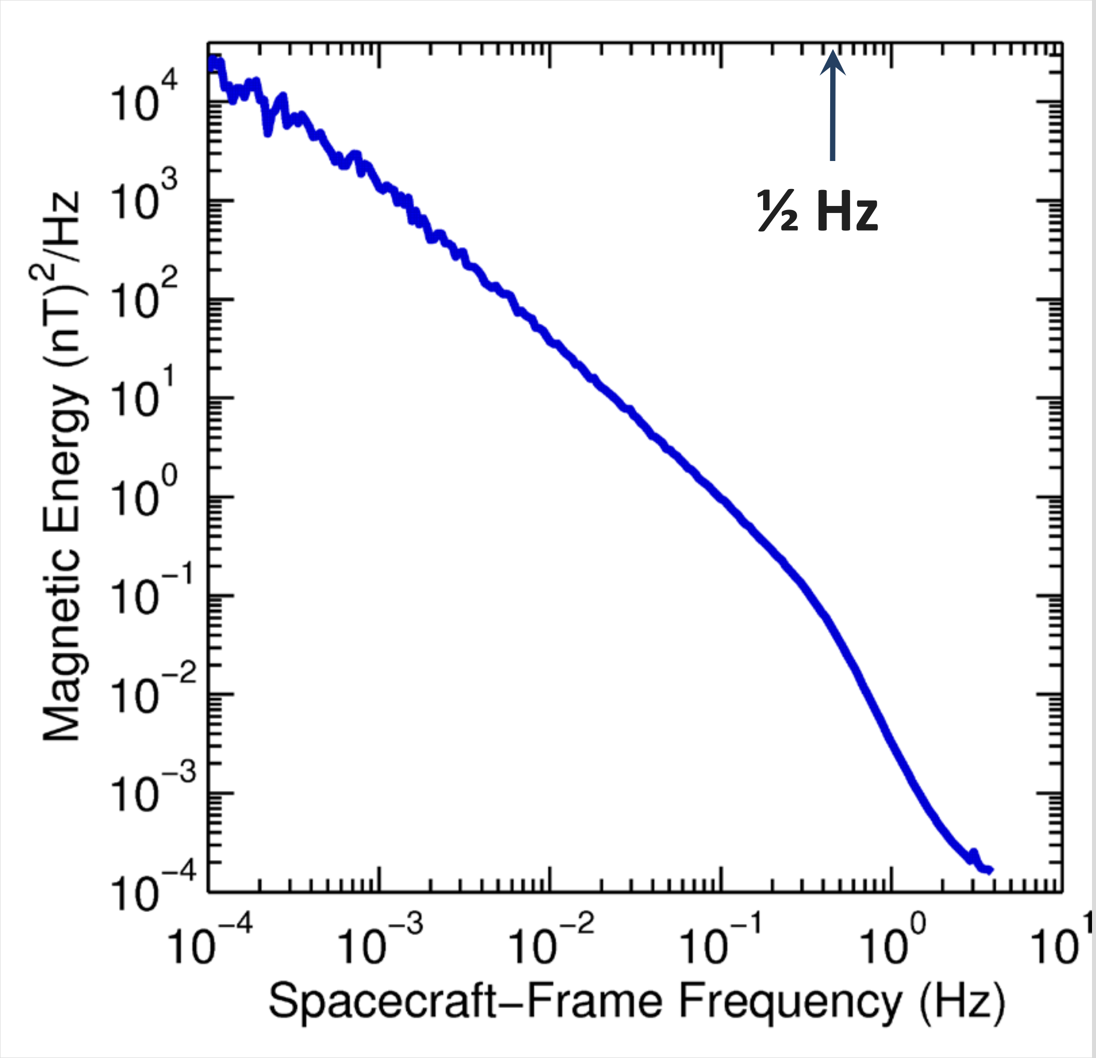
Energy attenuation in one wave period



Why is this important ?

High-Speed Stream: Stereo A

13-18 Feb 2008 (5 days)



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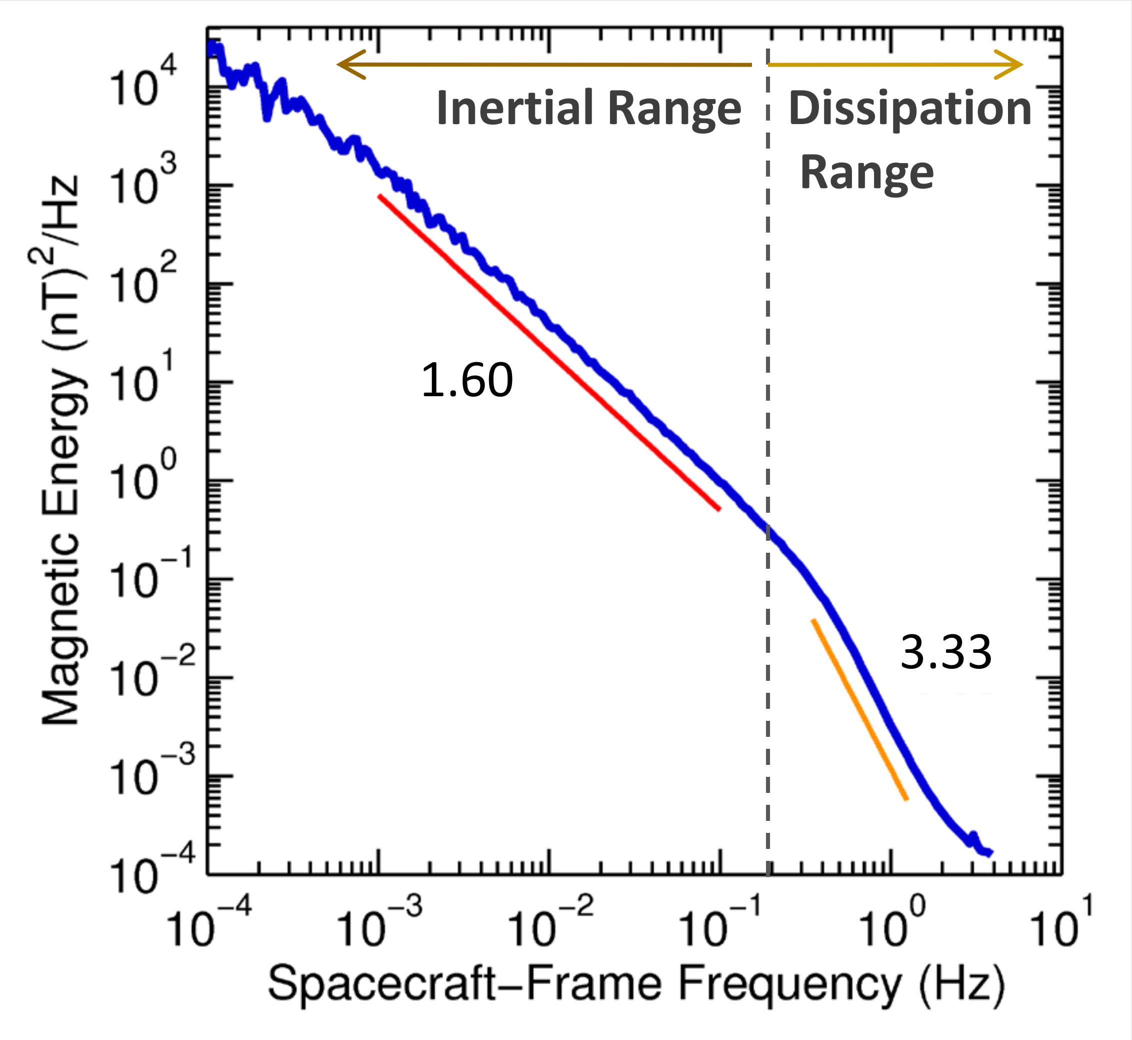
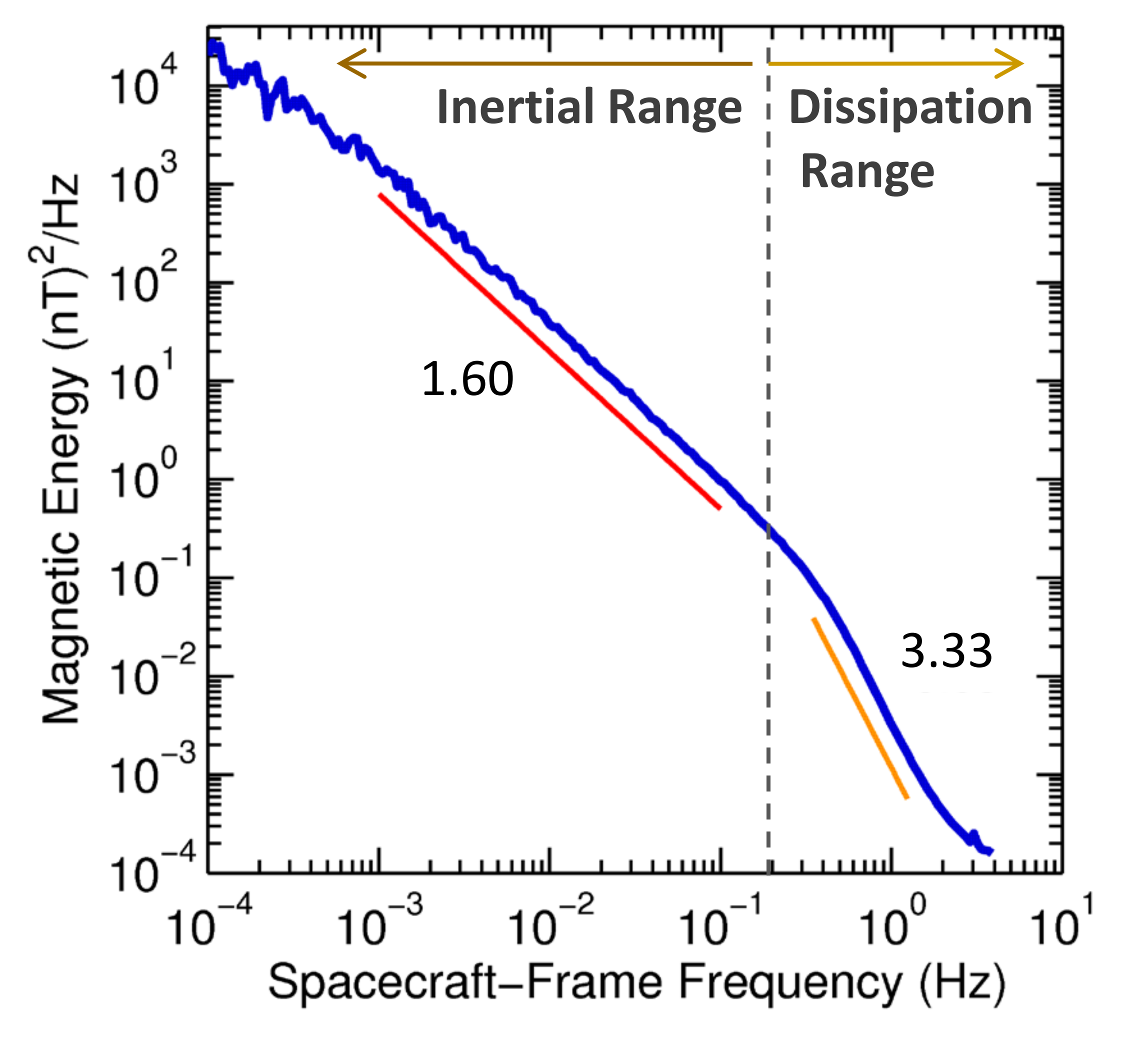


What does the spectrum look like from 1 Hz to 100 Hz?



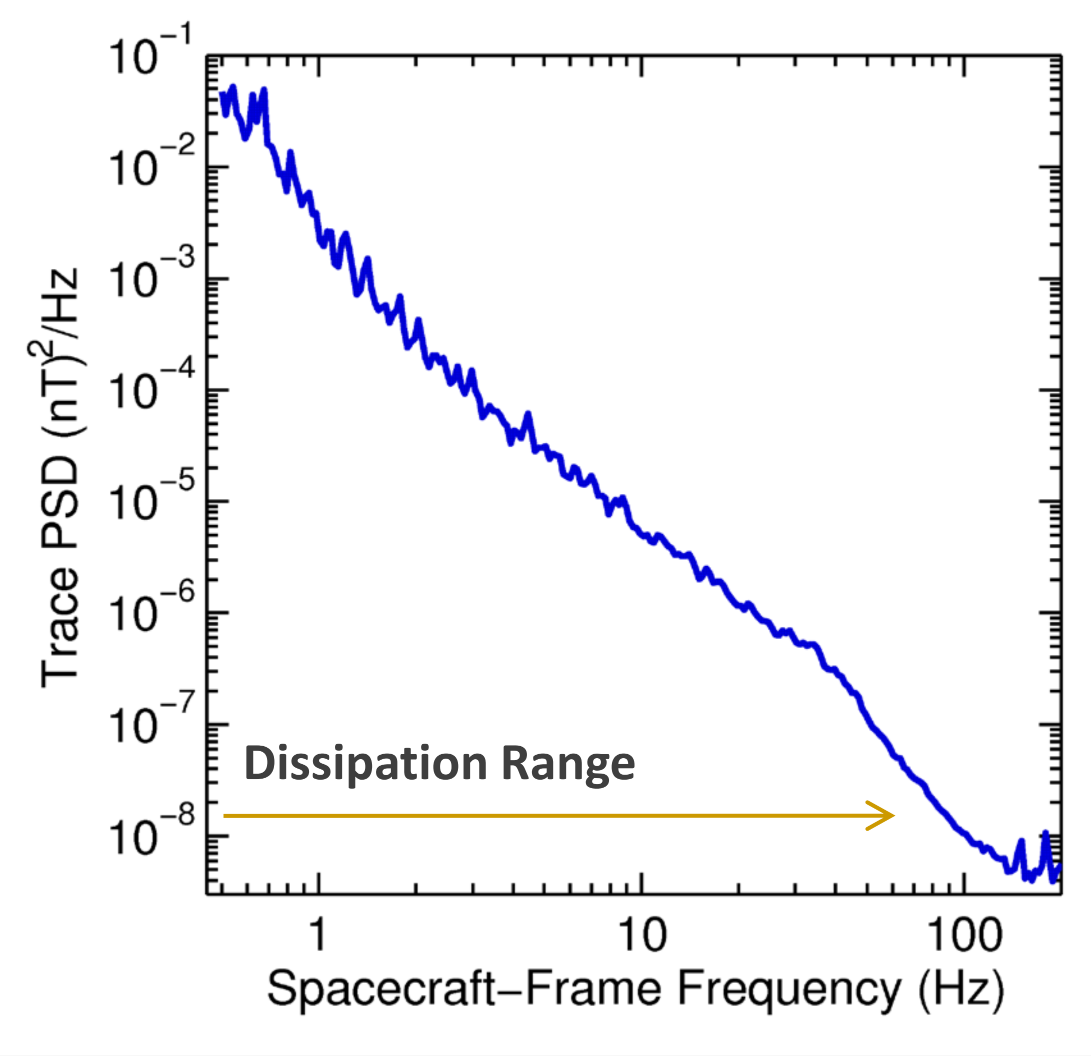
Helios search coil (1970s)

ISEE 3 (1970s)

Ulysses (1990s)

Cluster search coil (2000s)

Cluster search coil: 450 Hz burst mode data



19 Mar 2006

145.6 seconds

#17 of 70

near apogee

(In electron foreshock)

1st reported by Sahraoui et al. PRL 2009.

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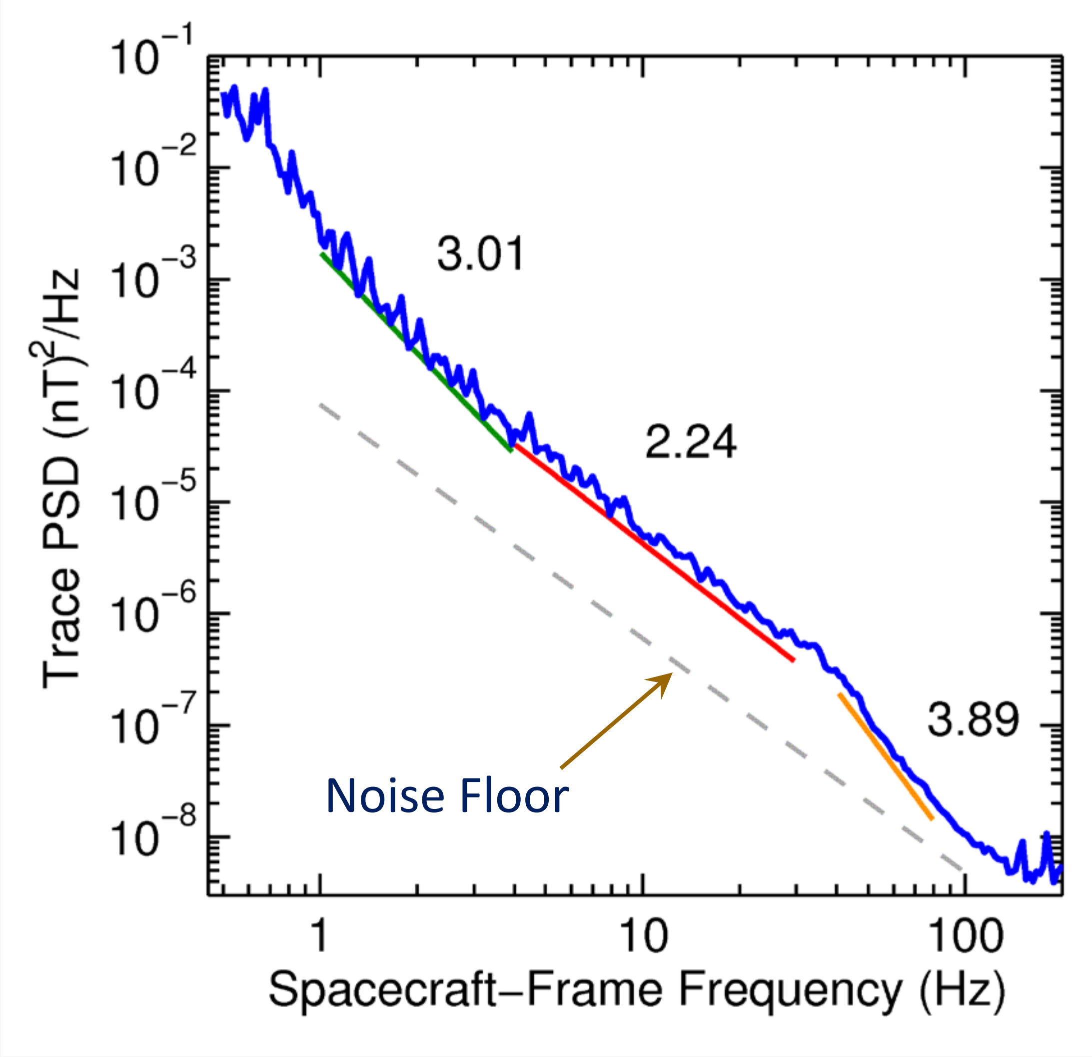

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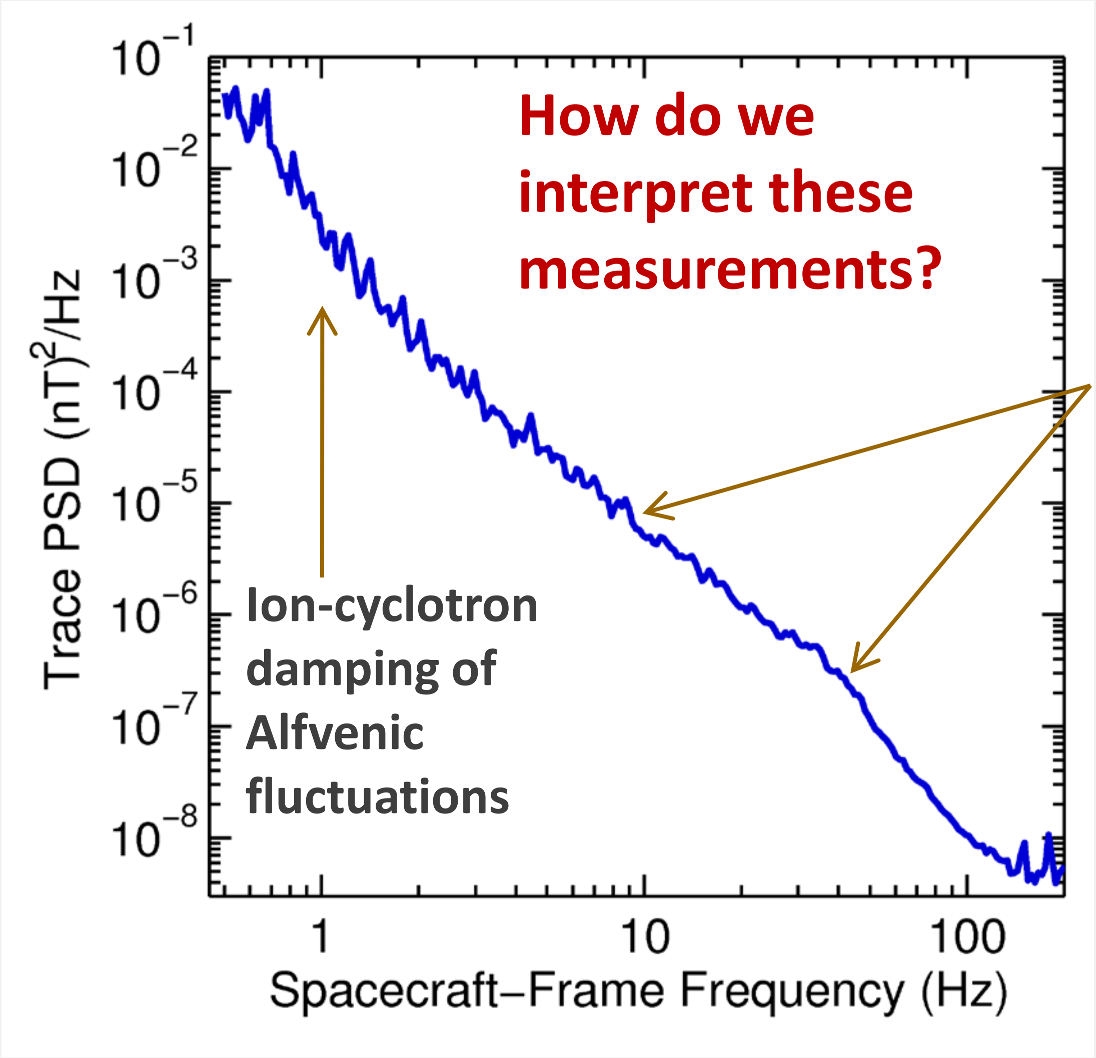


Denskat, Beinroth, & Neubauer (1983)

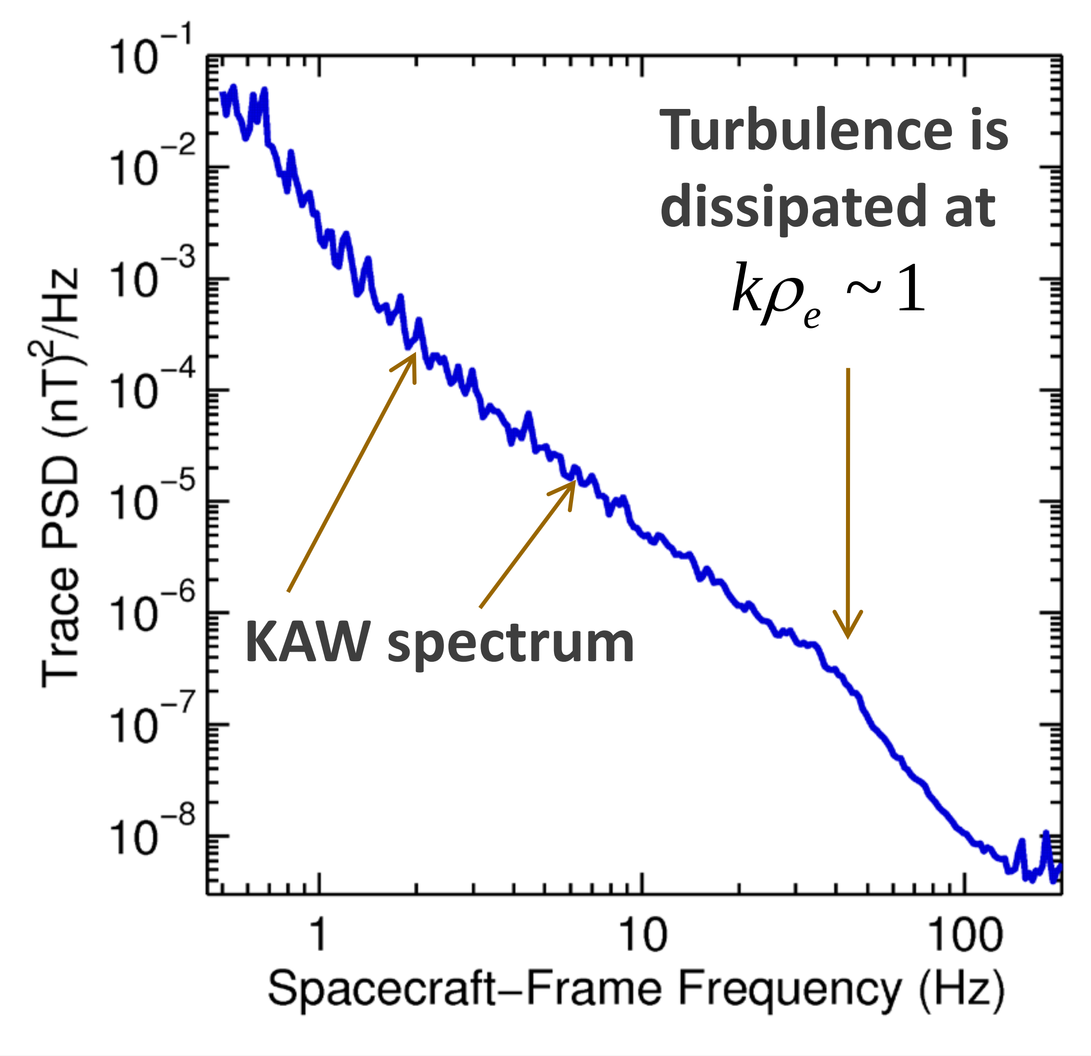
–IC damping

–Whistler spectrum

Leamon, Smith, Ness, & Wong (1998)

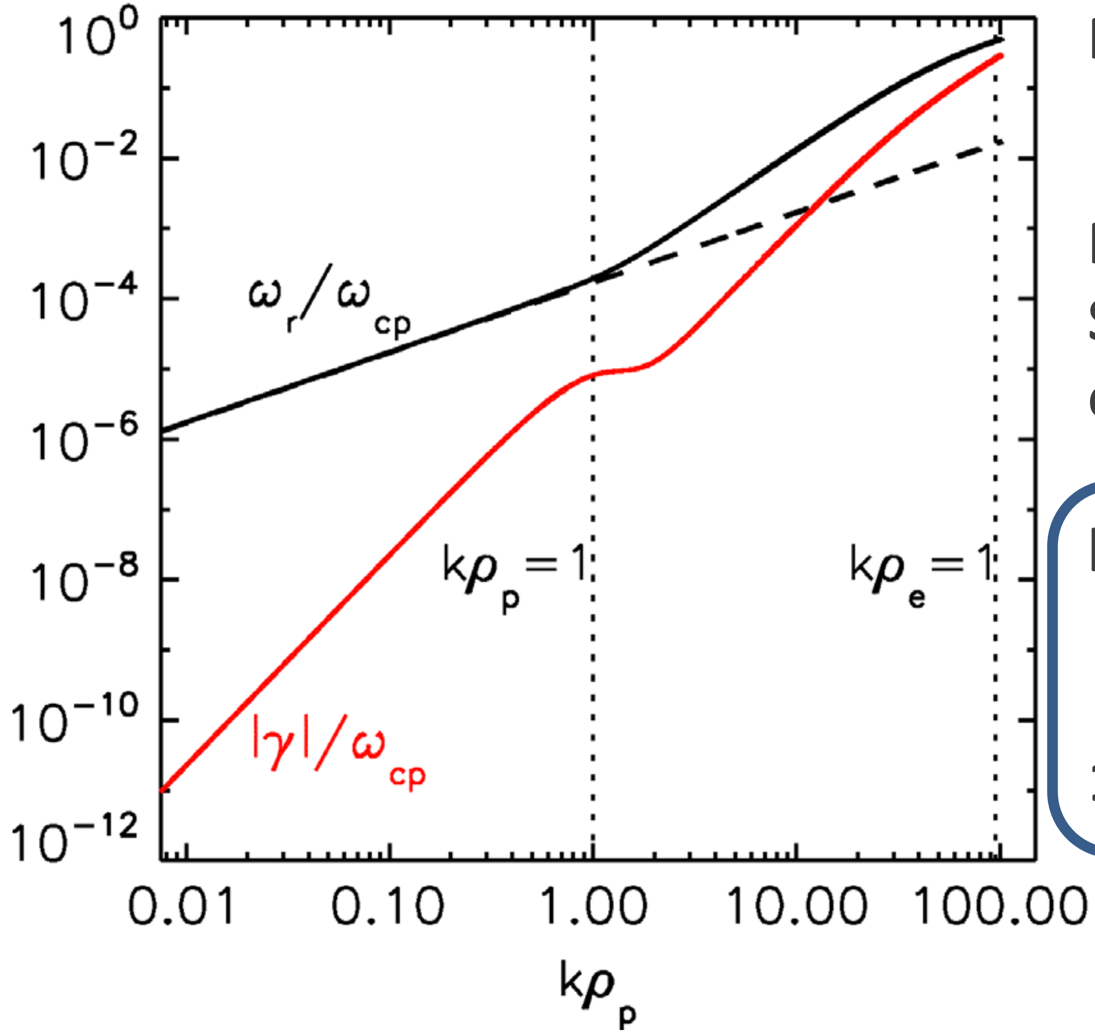
–Kinetic Alfven Waves (KAWs)

Entire spectrum is caused by KAW cascade



Damping of KAWs must be small in the range from $k_\perp \rho_i = 1$ to $k_\perp \rho_e = 1$ (Sahraoui et al. 2009)

KAW wave frequency and damping rate



Propagation angle 89.99°

From Sahraoui et al. (2009)

$k_\perp \rho_i$	$\lvert\gamma/\omega\rvert$
1	0.05
10	0.10
100	0.50

How do we compute the effect of wave damping on the KAW cascade?

1. Assume critical balance holds in KAW regime so that the **cascade time equals wave period**
2. Assume turbulent fluctuations in the KAW cascade obey the **linear damping rates** of Vlasov-Maxwell theory

- Energy cascades from one k-shell to the next in time $2\pi/\omega_k$
- In this time the energy is damped by the factor

$$\exp(4\pi\gamma_k/\omega_k) < 1$$

- The damping of the KAW cascade is compounded at each stage of the cascade process, like the way compound interest works.

The effect of wave damping on the KAW cascade

- Conservation of energy in wavenumber space

$$\frac{d\varepsilon}{dk} = 2\gamma_k E(k)$$

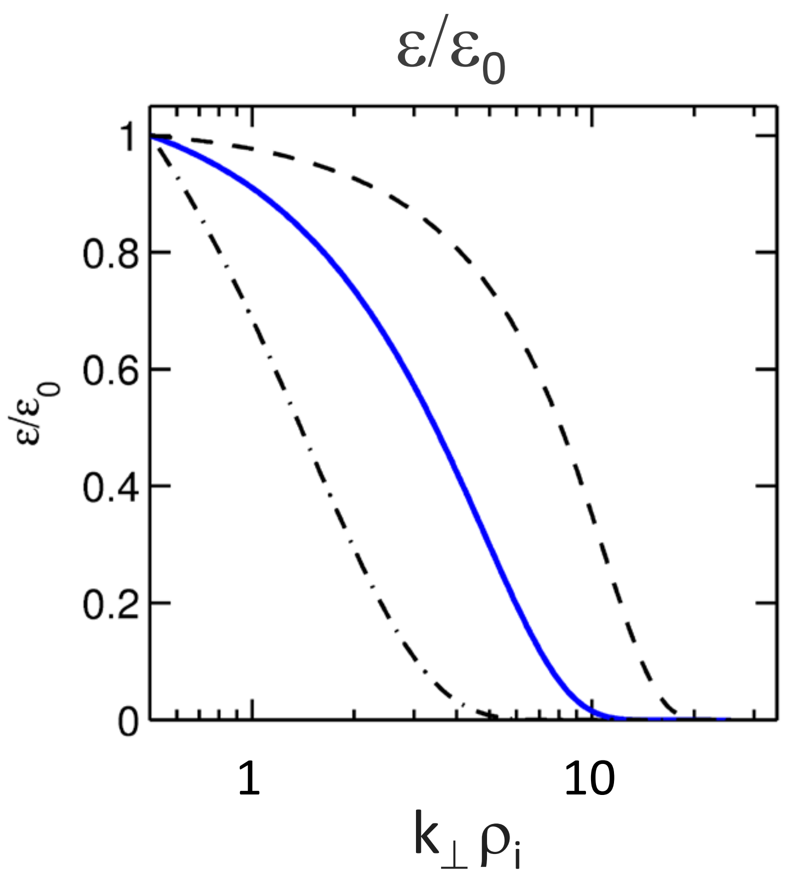
- ODE for the **energy cascade rate**

$$\frac{d(\log \varepsilon)}{d(\log k)} = \frac{1}{A} \cdot \frac{4\pi\gamma}{\omega} \exp\left(-\frac{4\pi\gamma}{\omega} \right).$$

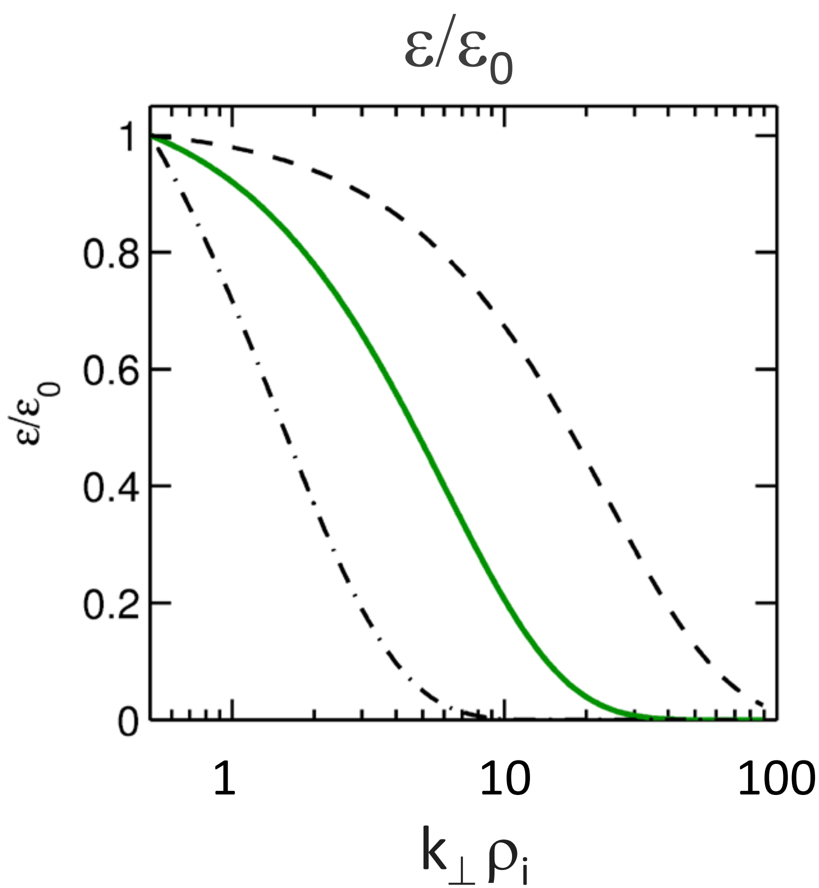
- The approximation $\frac{\gamma}{\omega} \approx -const \times k_\perp \rho_i, \quad k_\perp >> k_\parallel$

- yields analytic (closed form) solutions for the energy cascade rate as a function of wavenumber.

Change in energy cascade rate versus wavenumber



With exponential factor on RHS



Without exponential factor on RHS

Conclusions

For typical solar wind parameters at 1 AU, the KAW cascade is almost completely dissipated before reaching the wavenumber $k_\perp \rho_i$=25.

Therefore, it cannot by itself account for the observed spectrum of magnetic field fluctuations between 1 Hz and 100 Hz. Whistler waves likely play a role at these high frequencies.