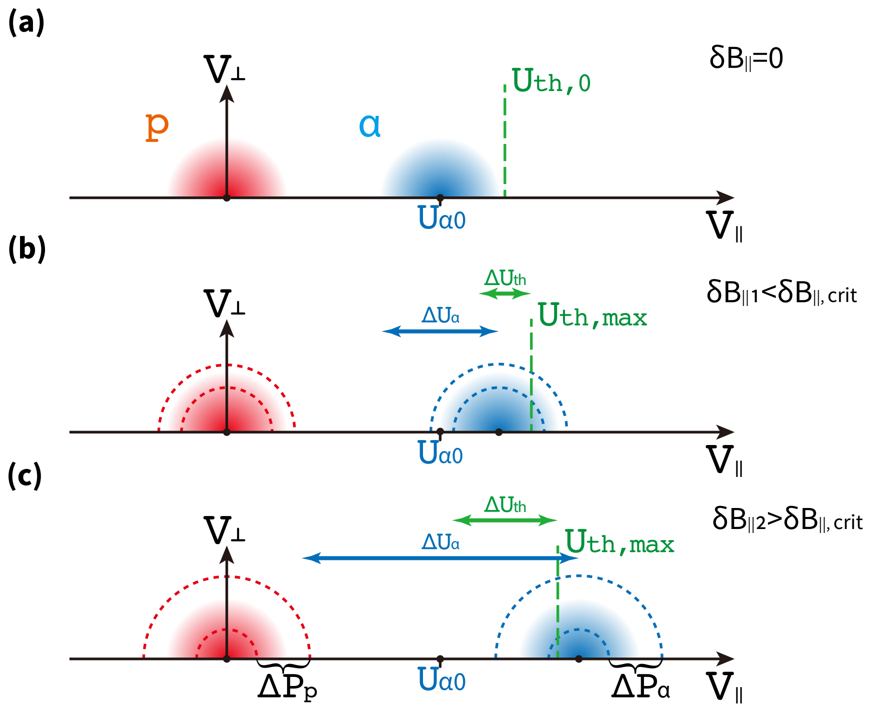
MULLARD SPACE SCIENCE LABORATORY
DEPARTMENT OF SPACE AND CLIMATE PHYSICS

Regulation of Proton-Alpha Differential Flow by Compressive Fluctuations and Ion-scale Instabilities in the Solar Wind



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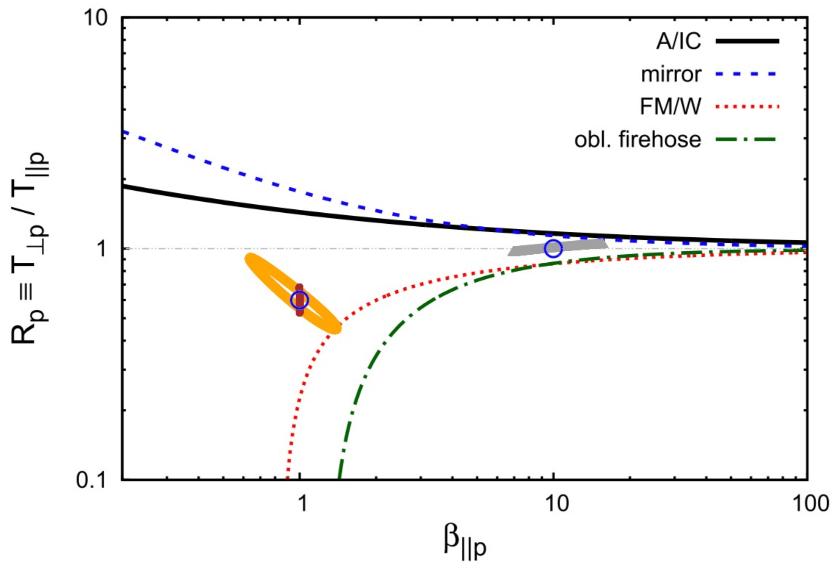
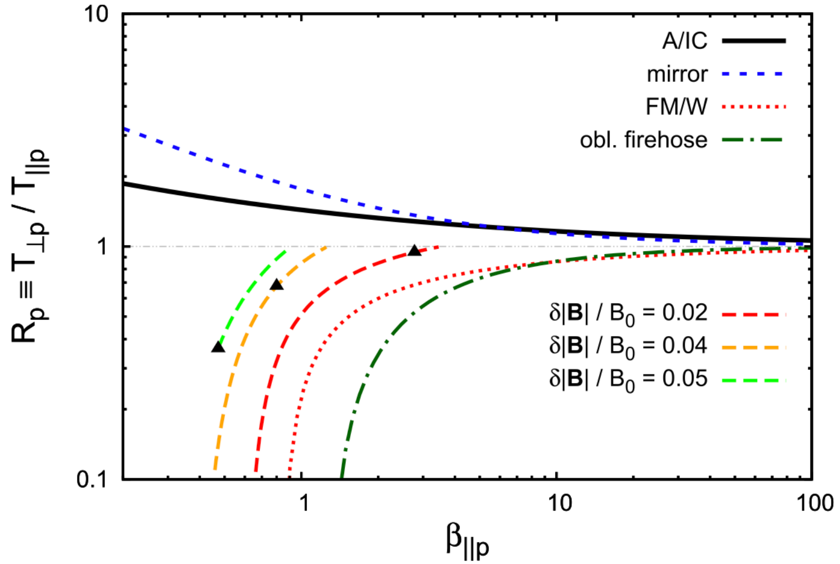
Fluctuating-anisotropy effect

- The slow-mode-like fluctuations can significantly modify n, T and $\boldsymbol{B}$, when the amplitude is large. Therefore, it can transport the plasma in the $\frac{T_{\perp p}}{T_{\parallel p}}-\beta_{p\parallel}$ plane around the background plasma parameter.

- Once the plasmas “touch” the instability threshold, The excited waves can scatter the protons and thereby raise up the average value of $\frac{T_{\perp p}}{T_{\parallel p}}$.

- This effect maintain the average value of $\frac{T_{\perp p}}{T_{\parallel p}}$ away from the instability thresholds at a location in the parameter space depending on the wave-amplitude.





Verscharen et al. (2017)

Motivation

- We extend the framework of the "fluctuating-anisotropy effect" to a broader "fluctuating-moment theory", incorporating the differential flow between different species (like protons and α-particles , U_α), which we also call "fluctuating-beam effect".

- We aim to study the dependence of the effective threshold (maximum permitted value) of $U_{\alpha 0}$ on $\beta_{p\parallel}$ and $\delta B_\parallel / B_0$ for Alfven/ion-cyclotron (A/IC) and Fast-magnetosonic/whistler (FM/W) instabilities.
- We consider large-scale quasi-perpendicular slow waves using multi-fluid model considering isotropic temperature.

(Due to time limitation, we wouldn't present the results for FM/W instability, the thresholds of which is greater than A/IC instability.)

Illustration of the Fluctuating-beam Effect

(a). No slow mode ($\delta B_{\parallel} = 0$):

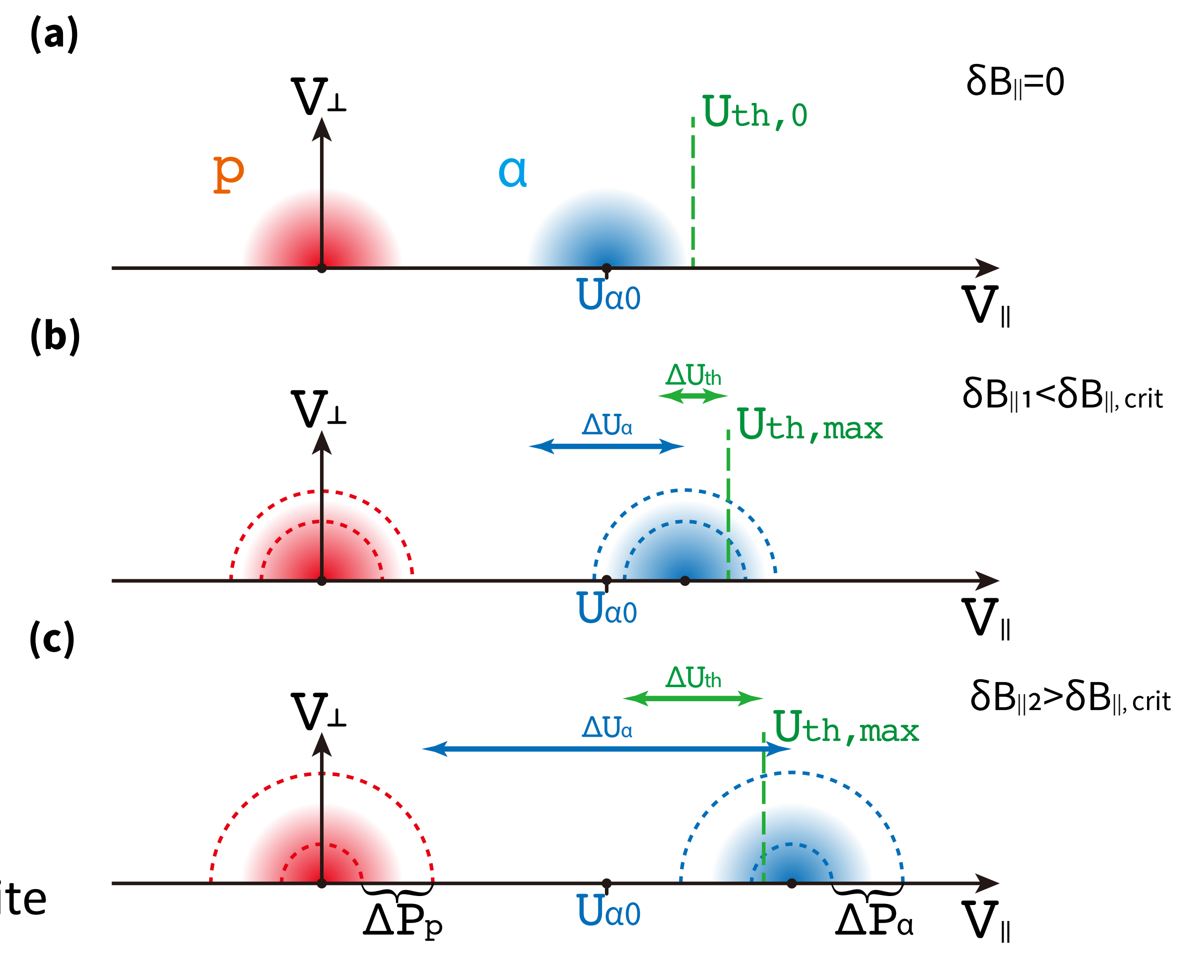
the α-particle drift velocity ($U_{\alpha 0}$) is below the instability threshold ($U_{th,0}$) (stable configuration)

(b). A small-amplitude slow wave ($\delta B_{\parallel 1} < \delta B_{\parallel,\mathrm{crit}}$):

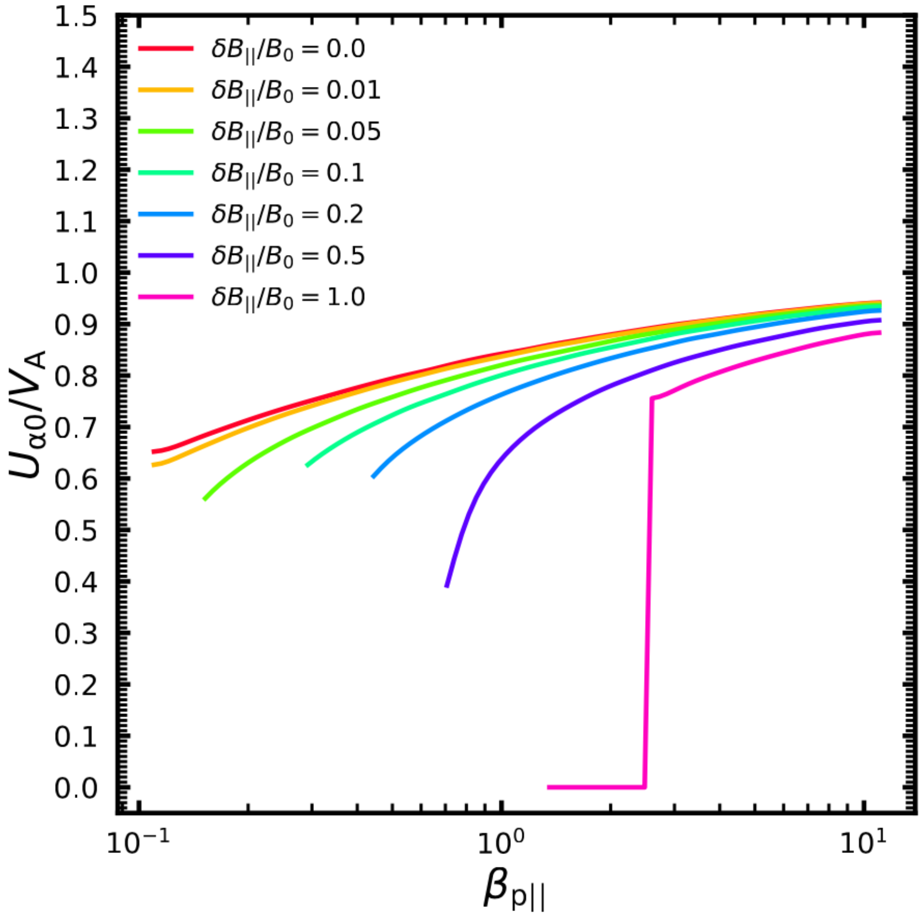
Plasma parameters and fields start to fluctuate. However, the amplitude is so small that $U_\alpha(t) < U_{th}(t)$ throughout the evolution of slow-mode fluctuations. (stable configuration)

(c). A large-amplitude slow wave ($\delta B_{\parallel 2} > \delta B_{\parallel,\mathrm{crit}}$):

As wave amplitude grows, the amplitude of beam velocity grows faster, it will exceed the instability threshold at a finite time interval during slow-mode wave evolution.



Effective thresholds for A/IC Instability



- Expression for A/IC instability threshold (Verscharen et al. 2013):

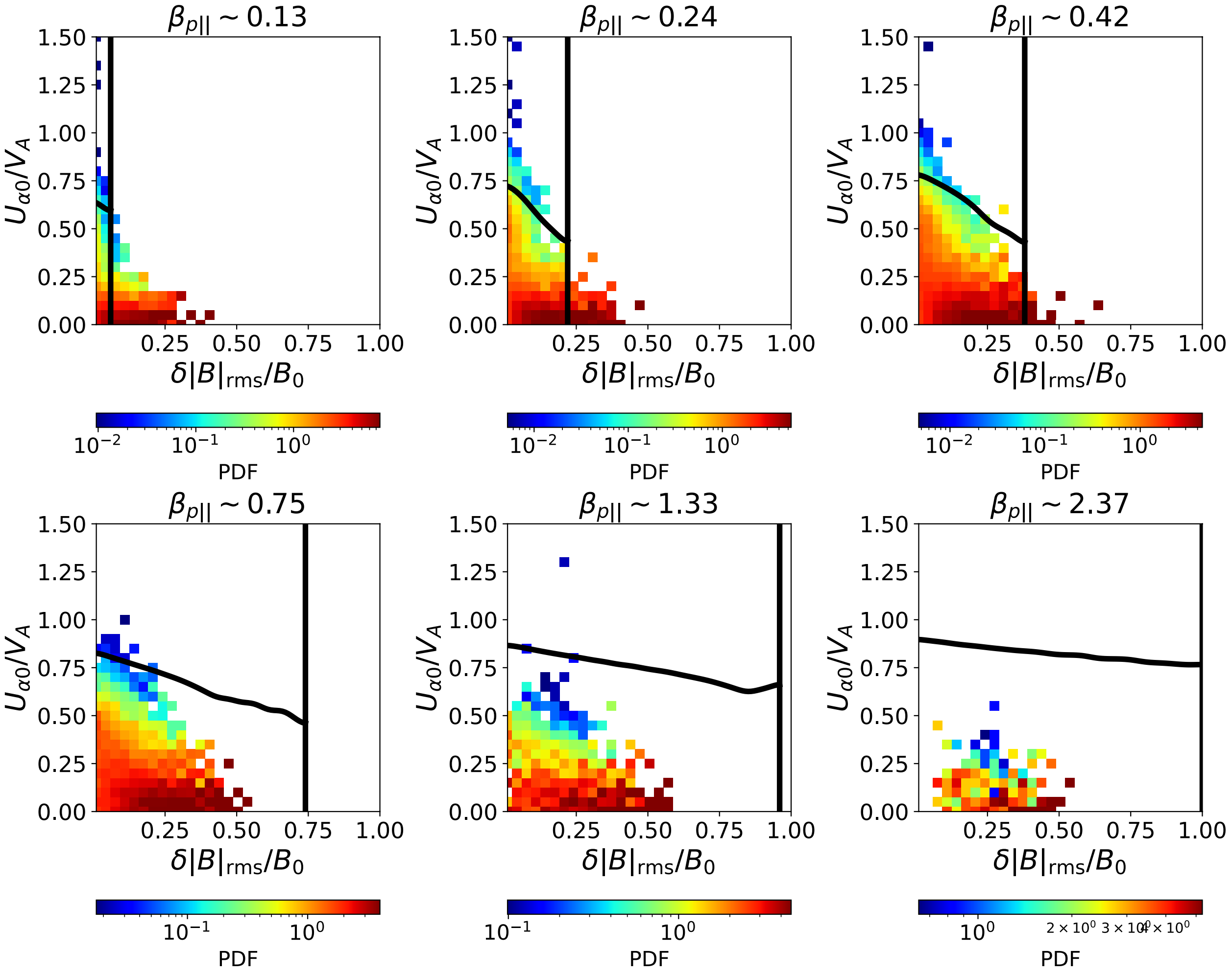
$$U_\alpha > \frac{T_{\perp\alpha} + T_{\parallel\alpha}}{4T_{\perp\alpha}}\left[\sigma_1 w_{\parallel \mathrm{p}} + V_{\mathrm{A}} + \sqrt{\left(V_{\mathrm{A}} + \sigma_1 w_{\parallel \mathrm{p}}\right)^2 - 2V_{\mathrm{A}}^2}\right] - \sigma_1 w_{\parallel \mathrm{p}},$$

- As $\delta B_{\parallel}/B_0$ becomes larger, the effective instability threshold $U_{\alpha 0,\mathrm{crit}}$ (maximum permitted $U_{\alpha 0}$) is reduced (more significant when β<1)

- Slow-mode-like fluctuations make it easier for plasmas to become unstable to the A/IC instability and thereby regulate U_α through wave-particle interaction.

Comparison with WIND Observations

- 1-D probability distribution function of $U_{\alpha 0}/V_A$ at different $\delta|B|_{rms}/B_0$ at six $\beta_{p\parallel}$:



- The effective A/IC instability thresholds (oblique black curves) decrease with the compression amplitude
- The linear assumption break-down amplitude increases with plasma beta (black vertical line).
- The effective instability thresholds restrict the data to the stable space.
- This finding is broadly consistent with our “fluctuating-beam effect” that the large-scale slow-mode-like fluctuations regulates the alpha drift velocity by kinetic instability in the solar wind .

Conclusion

- We propose a new concept of **fluctuating-beam effect**:

The large-scale slow-mode-like fluctuations can reduce the effective instability thresholds depending on the compression amplitude and regulate α-particle drift velocity through kinetic instability.

- The distributions of the measured α-particle drift velocity have an inverse dependence on the compressive wave amplitude and are restricted by the effective A/IC instability thresholds.