Multiscale Solar Wind Turbulence Properties inside and near Switchbacks measured by Parker Solar Probe

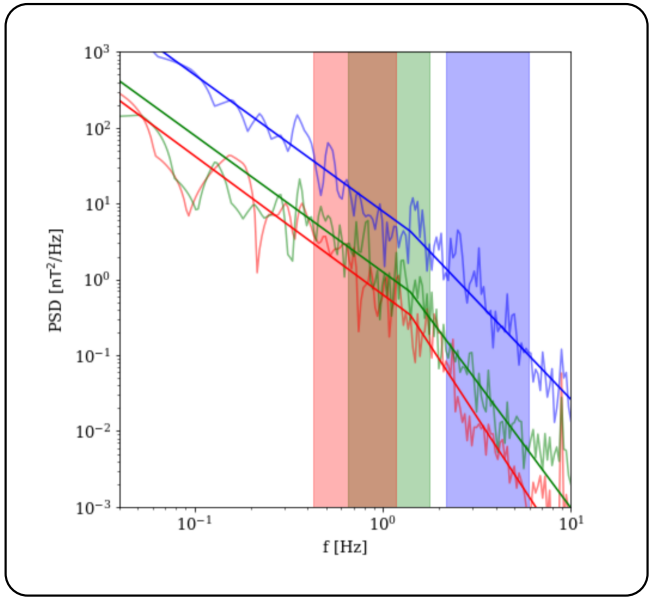
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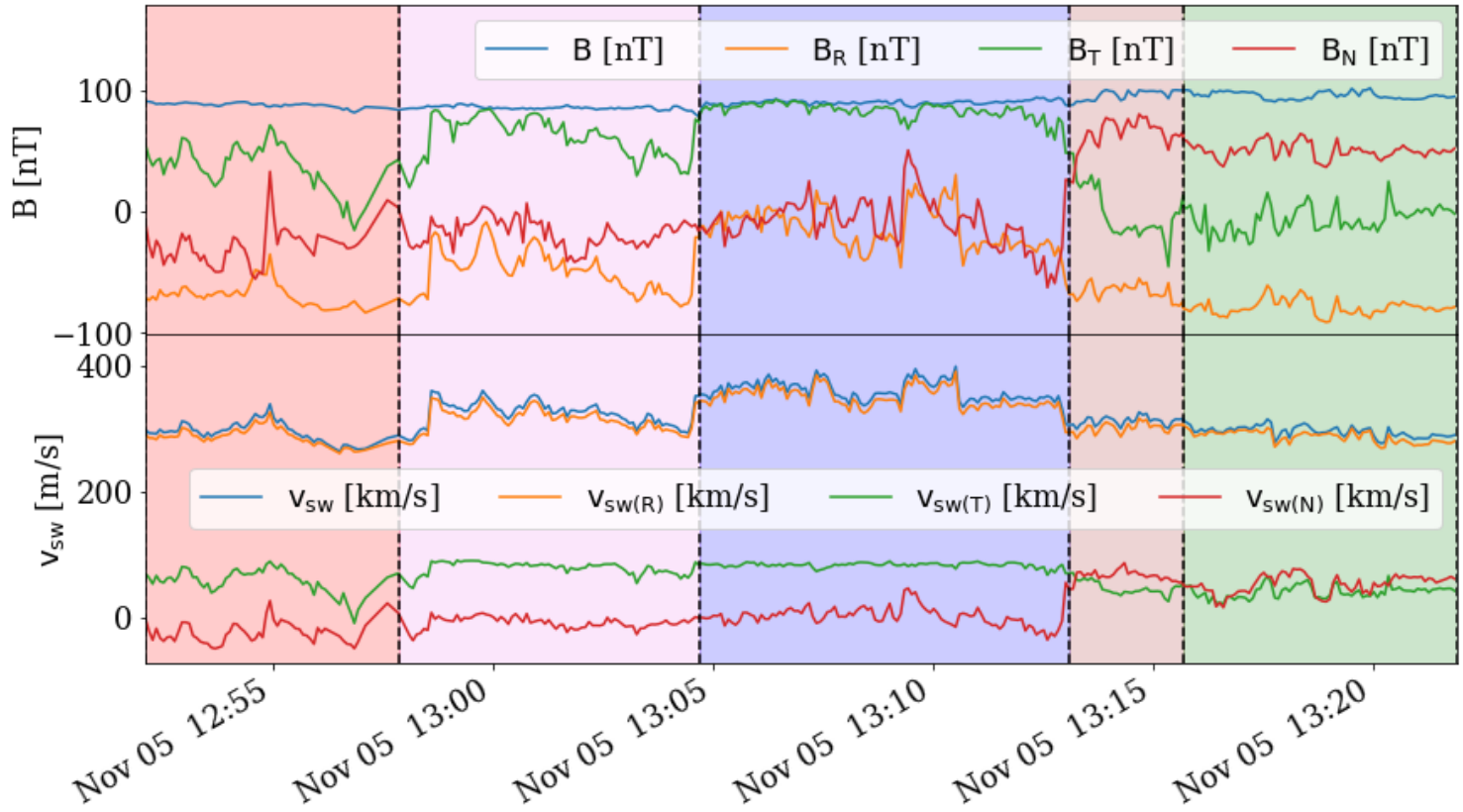
Lunar and Planetary Laboratory

Outline

- Intent - Observe characteristics of turbulence inside and outside of Switchback (SB) events
  - Directly compare plasma parameters
  - Observe turbulent spectra from large to small scales
  - Estimate intermittency effects for various parts of the event to read traces of the kinetic scale phenomena
  - Estimate effects of the small scale turbulence through estimates of Stochastic Heating (SH)
- Why? Provide constraints for models of origin and evolution of SBs

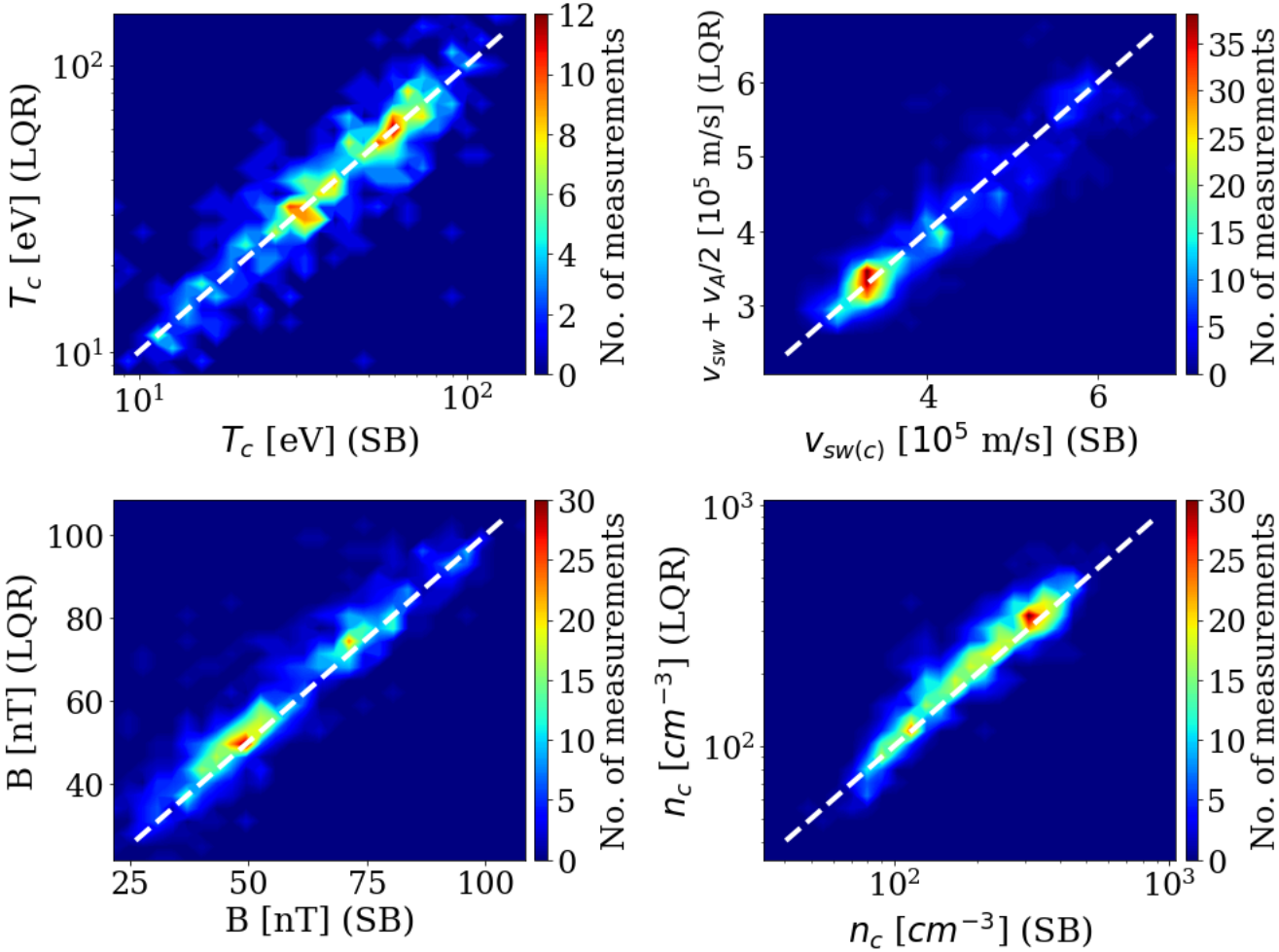
Switchbacks measured by PSP - classification

- Each event has: Switchback (SB), Leading and Trailing Quiet (LQR, TQR) and Transition Regions (LTR, TTR)
  - 912 clearly separated events in *PSP* E1 and E2



Large Scales - MHD parameters

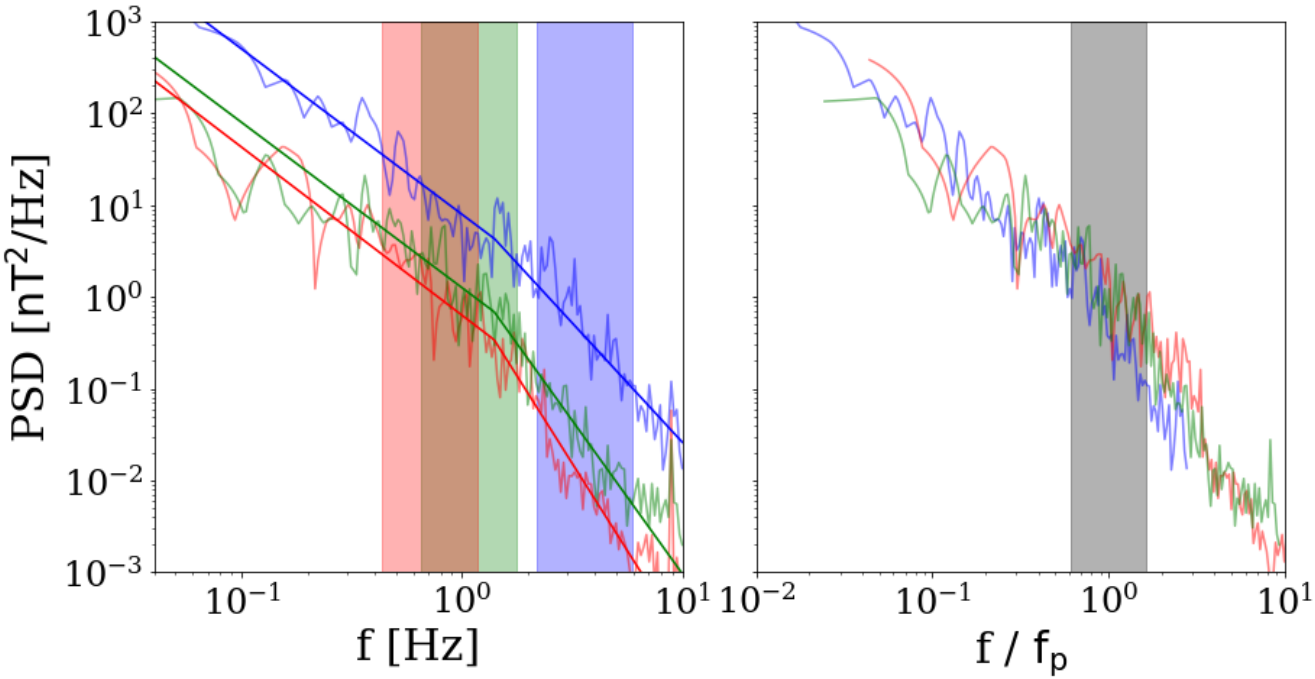
- For quiet regions (LQR, TQR) and SBs, we compare proton core parameters n_c, T_c, and field B
- Values don't systematically change
  - very few exceptions
- Solar wind bulk speed increased for 0.5 - 0.8 v_A (geometry of Alfvénic fluctuations)



Turbulence - Inertial Range and Spectral Break

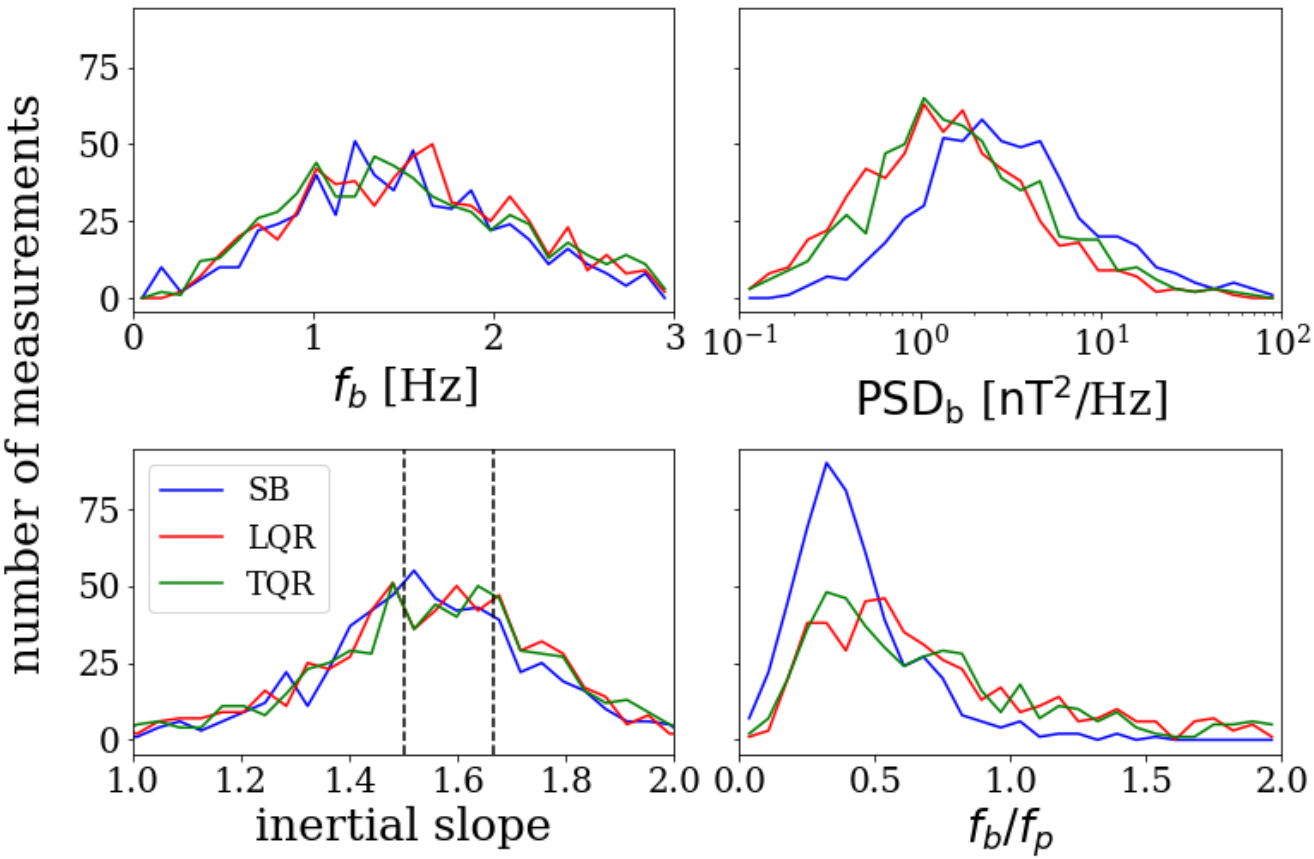
- Turbulent spectra (in SC frame) feature stronger Doppler shift for SBs
- When normalized to the convective gyrofrequency $f_p = \frac{v_{sw} \sin\theta}{2\pi\rho_p}$

- spectra tend to be similar
- however: spectral break point f_b does not shift



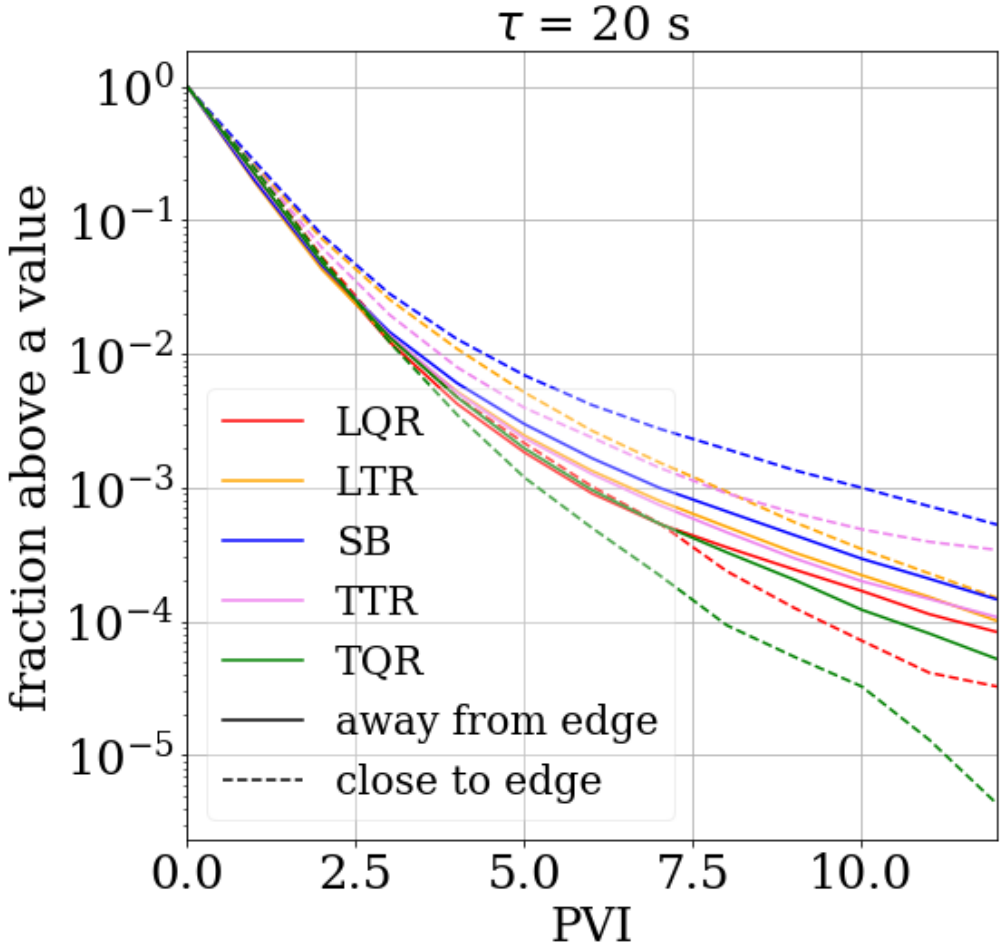
Turbulence - Inertial Range and Spectral Break

- Manual fitting of over 3000 turbulent spectra
- very similar inertial range + similar location of f_b = more intense fluctuations at f_b for SBs
- Behavior of f_b is open for interpretation



Turbulence - Kinetic Range and Intermittency

- Observe Partial Variance of Increments (PVI) close and far from the event border separately
- SB $>$ TRs $>$ QRs trend
- PVI is increased close to the edge
- Consistent with observed waves and current sheets at the edges
  [Krasnoselskikh et al., 2020 Farrell et al., 2020]



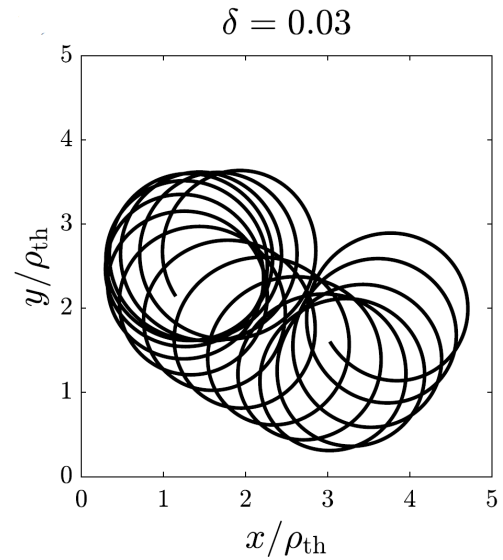
Non-Linear Stochastic Heating - Phenomenology

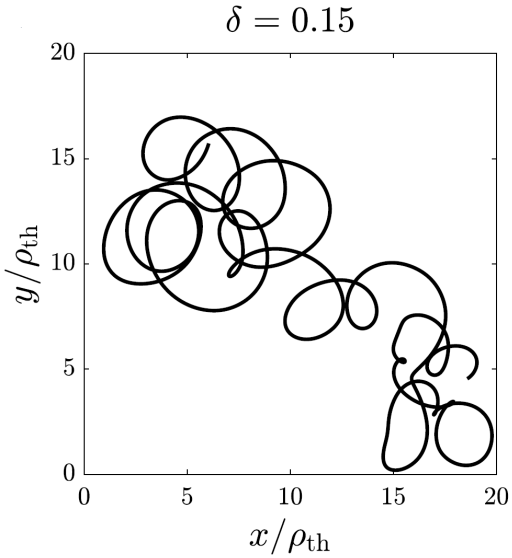
- Ion motion at gyroscale (tens of km) becomes stochastic due to fluctuations
- Magnetic moment invariance is violated
  - Energy diffusion in perpendicular direction [Chandran et al., 2010, Hoppock et al., 2018]
- SH rate can be quantified through fluctuations intensity

$$Q_\perp \sim \sigma_1 \delta^3 exp\left[-\frac{\sigma_2}{\delta} \right]$$

$$\delta = \delta B / B$$

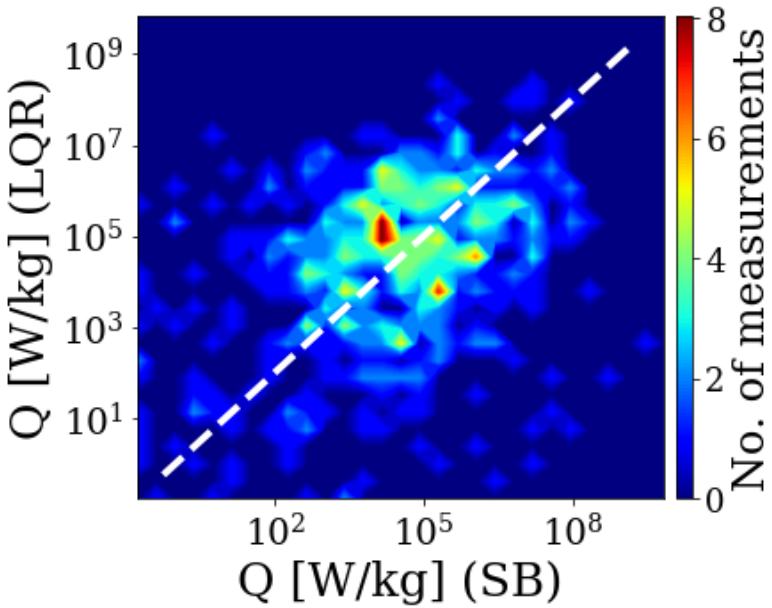
- Heating intensity reflects turbulence properties at ion scales

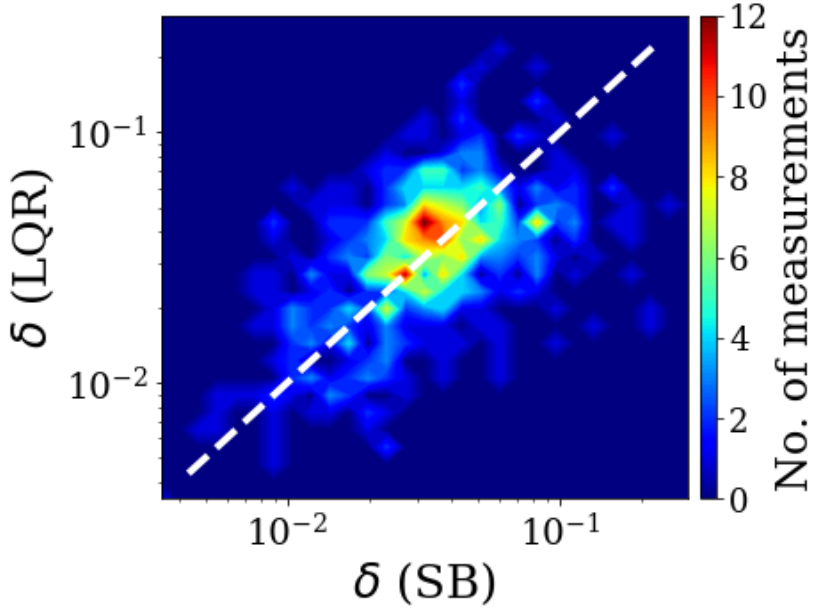




Non-Linear Stochastic Heating - QRs vs SBs

- Both fluctuation rate δ and heating rate Q are fairly similar
- Similar behavior of plasma at both at MHD (VDF properties) and kinetic scales





Conclusions - Modeling Constraints

Measured quantity	Underlying Physics	Conclusion
VDF Moments	MHD	very similar
Inertial range slopes	Turbulence - LS	very similar
Spectal break	Turbulence - SS	not shifted for SBs
PVI	Kinetic	SB $>$ TRs $>$ QRs
Stochastic Heating	Kinetic	very similar

Table: Different aspects of comparison between SBs and QRs/TRs

- Plasma is very similar inside and outside of SBs, with differences at:
  - intermittency
  - edge effects
- Intermittency is increased for SBs and TRs, but SH is practically unaffected
- General models of SB origin and evolution are required to fit within these observational limits

THANK YOU



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