The Evolution of Fast Solar Wind Turbulence Between 17.4 and 45.7 Solar Radii

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Parker Solar Probe Encounter 10

Data from Nov. 17-20, 2021 from PSP Encounter 10 is analyzed.

- Heliographic location varied by < 10° in Carrington longitude.
- Field line mapping places the source region of solar wind near the center of the same coronal hole for the entire period.
- Time interval excludes both coronal mass ejection and any crossings of the heliospheric current sheet.
- This time interval provides a nearly radial scan of the same fast solar stream from17.4 to 45.7 R_s.

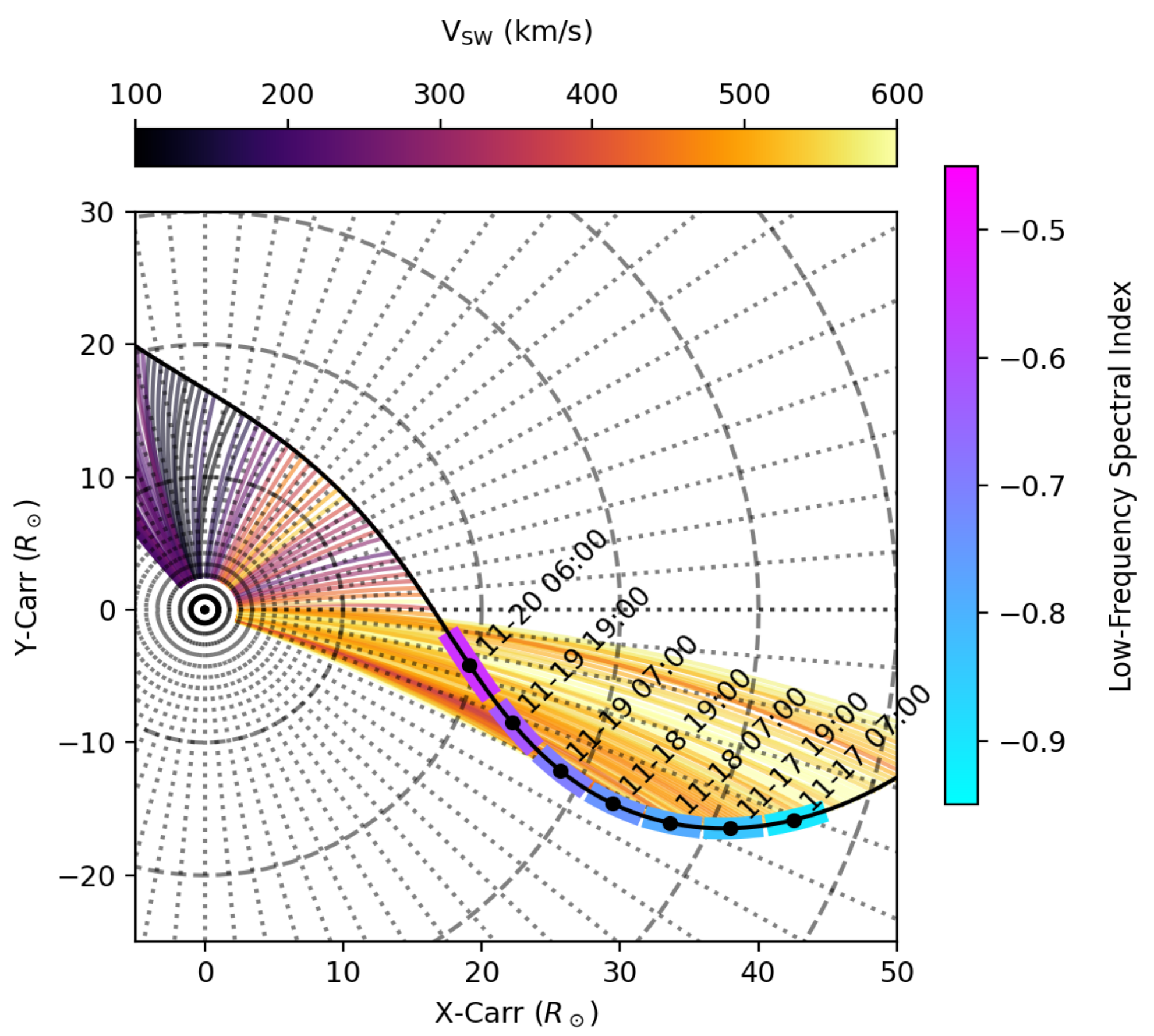

Figure 1: Orbit of PSP Encounter 10 and encountered solar wind.

Fast Solar Wind Stream

- Fast solar wind stream, with V_{SW} > 500 km/s most of the time.
- PSP orbit decreases from ~46 to ~17 R_s.

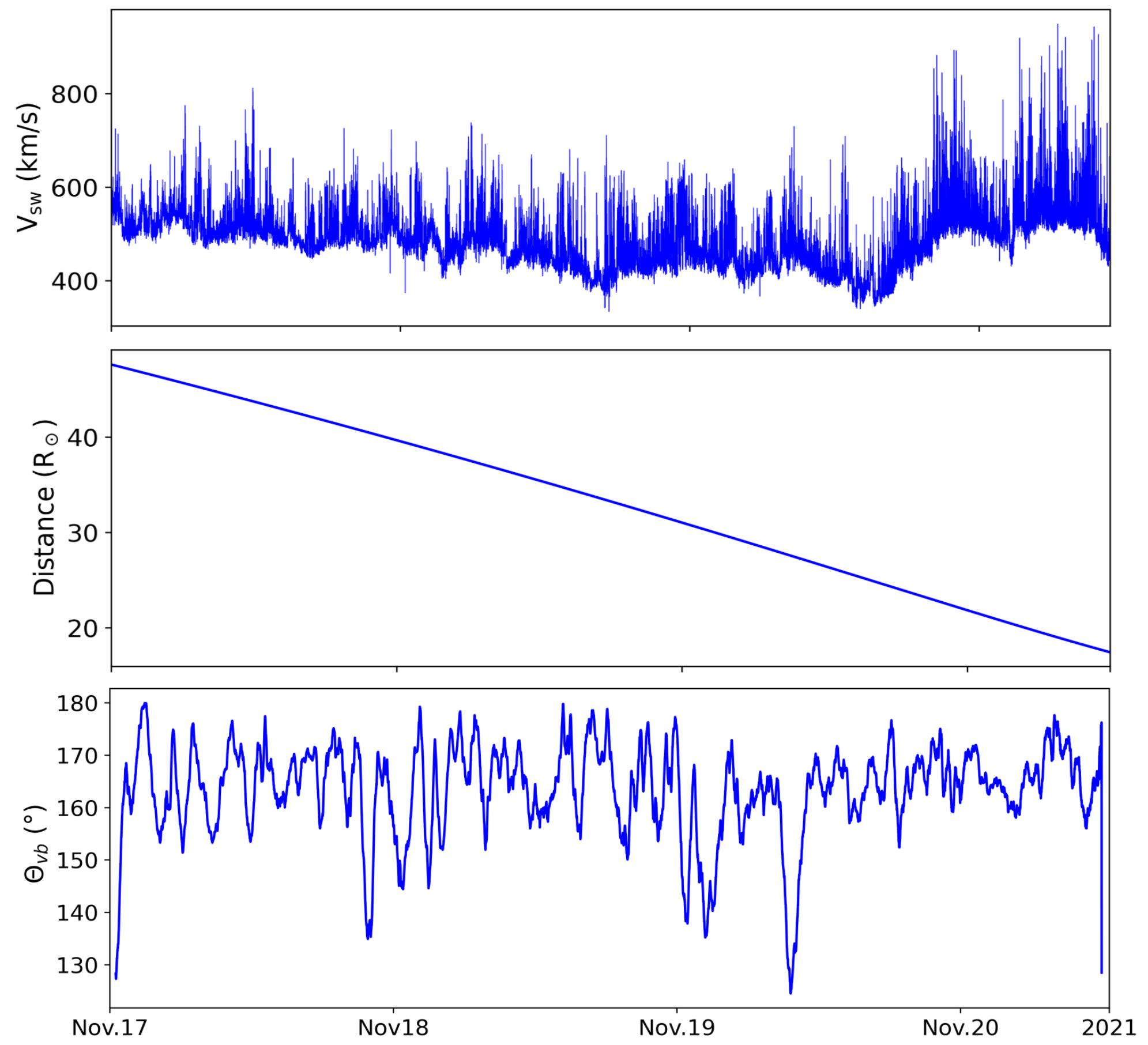

Figure 2: (top) Radial solar wind velocity, (middle) Heliocentric distance from the Sun, (bottom) Variations of the angle between the mean magnetic field and mean velocity field in spacecraft frame.

- Sin θ_{V_B} is small.
- The frequency spectra at $f < f_b$ corresponds approximately to the $k_\parallel$ spectra of the low-frequency fluctuations.

In Situ Development of the f^{-1} Spectrum

Magnetic power spectrum calculated by applying FFT and MODWT on each 12-hour intervals.

- As heliocentric distance increases, power levels decreases.
- Total power decrease exceeds an order of magnitude over the range of distance considered.
- This behavior is due to the expansion of the solar wind and the turbulent cascade.
- The power spectrum in the low frequency range, gradually steepens towards a f^{-1} *in situ* as heliocentric distance increases.
- This fast solar wind stream's evolution towards a f^{-1} spectrum is similar to the nonlinear evolution of the PDI that takes place when slow waves are significantly dampened.

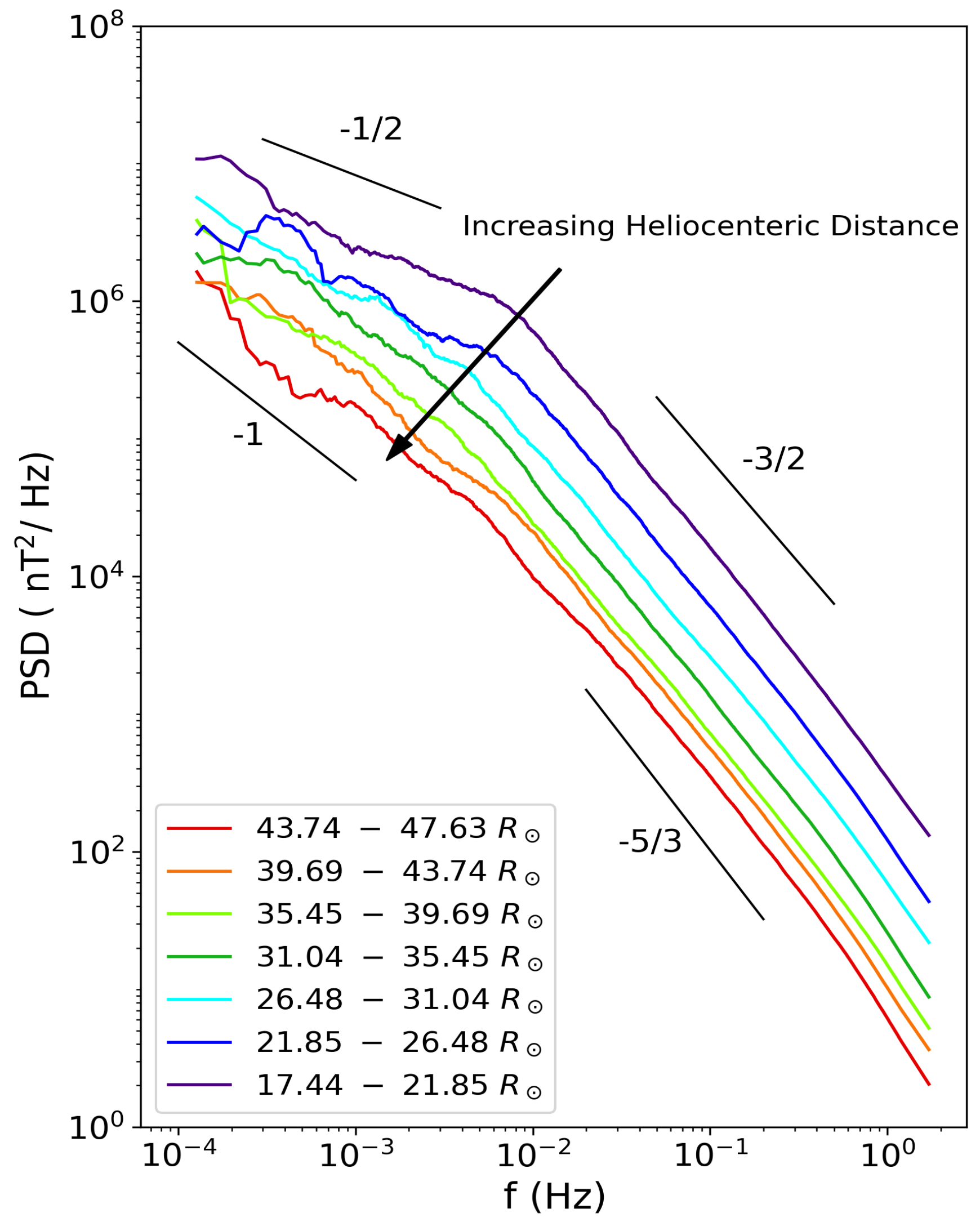

Figure 4: Magnetic field power spectrum for differential heliocentric distances, with several power-law slopes marked for reference.

- As heliocentric distance r increases from17.4 to 45.7 R_s, the spectrum steepens, α_B decreases from –0.61 to –0.94.
- The break point frequency f_b decreases as r increases.

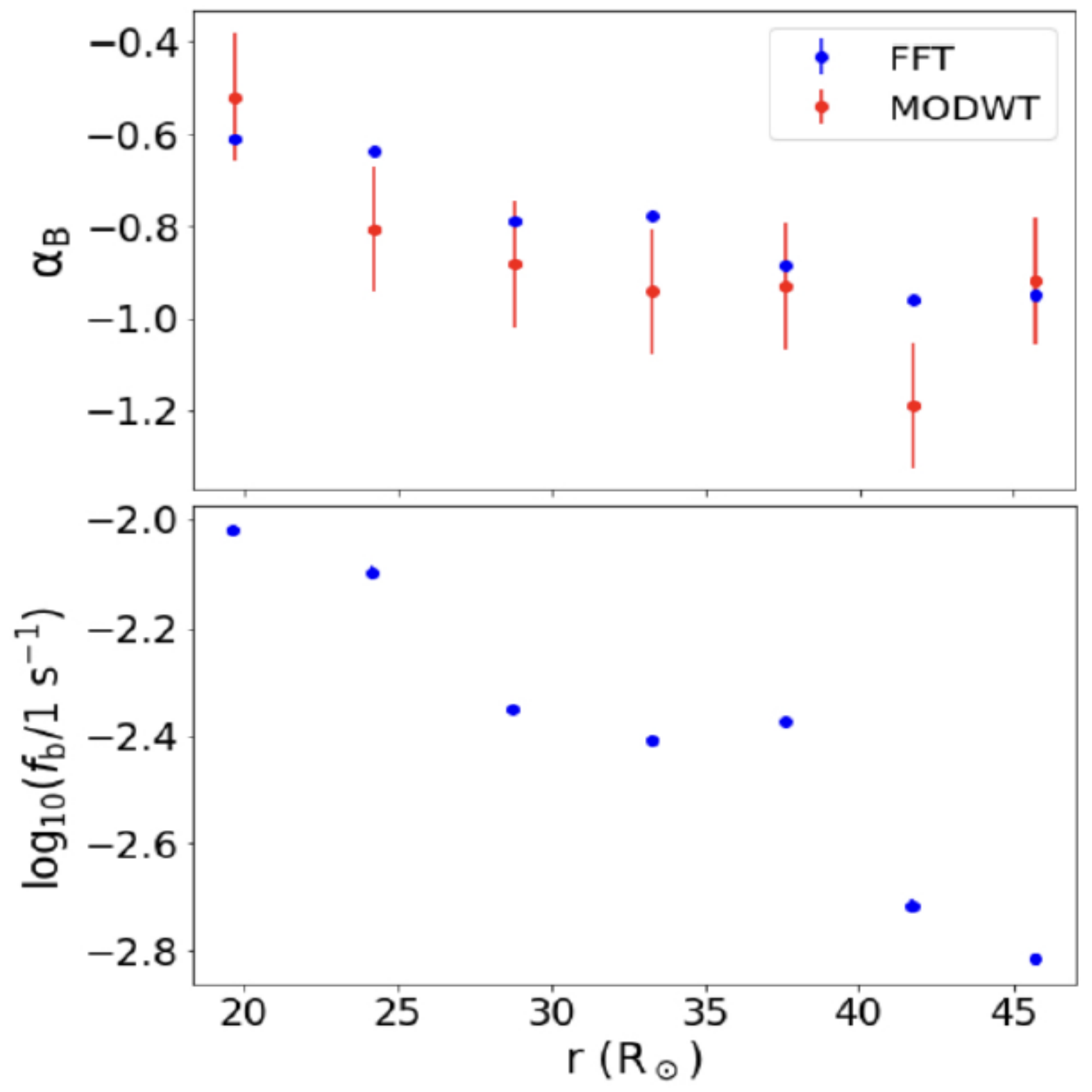

Figure 5: (top) Variation of α_B and (bottom) f_b with r.

Turbulence Spectrum

Elsasser variables, $z^\pm = v \pm b$ (b is magnetic field in Alfvén units), describe the inward- and outward- propagating Alfvenic fluctuations.

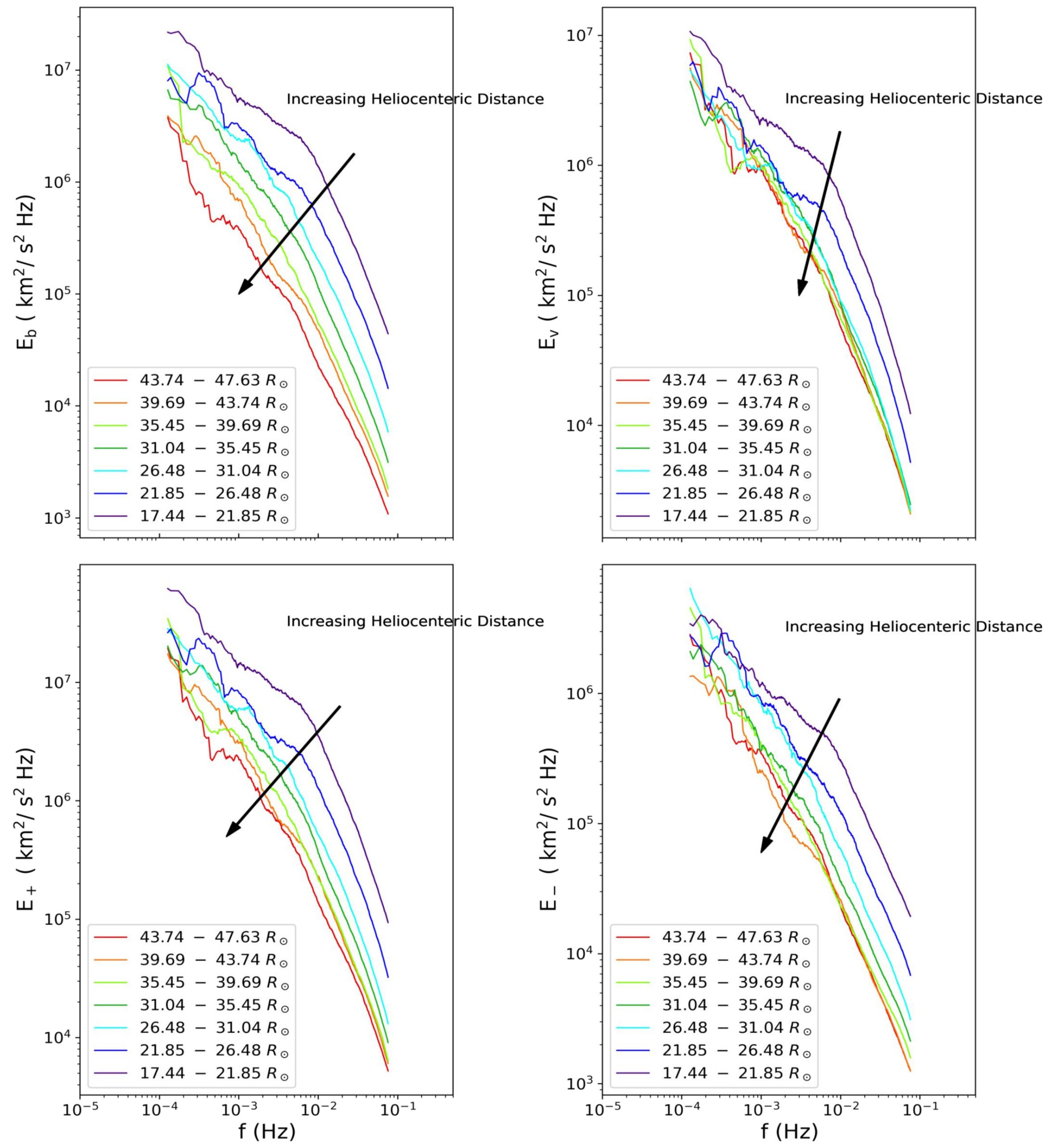

Figure 6: Spectra of Alfvenic turbulence variables for different heliocentric distances

- E_b, E_V and E^+ spectra exhibit similar behavior, while E^- spectrum is shallower for $f > f_b$.
- At $f > f_b$, E^+ follows a Kolmogorov (−5/3) spectrum, while E^- preserves a power-law spectral index of ~ −1.
- Approximately constant r_A and r_E.

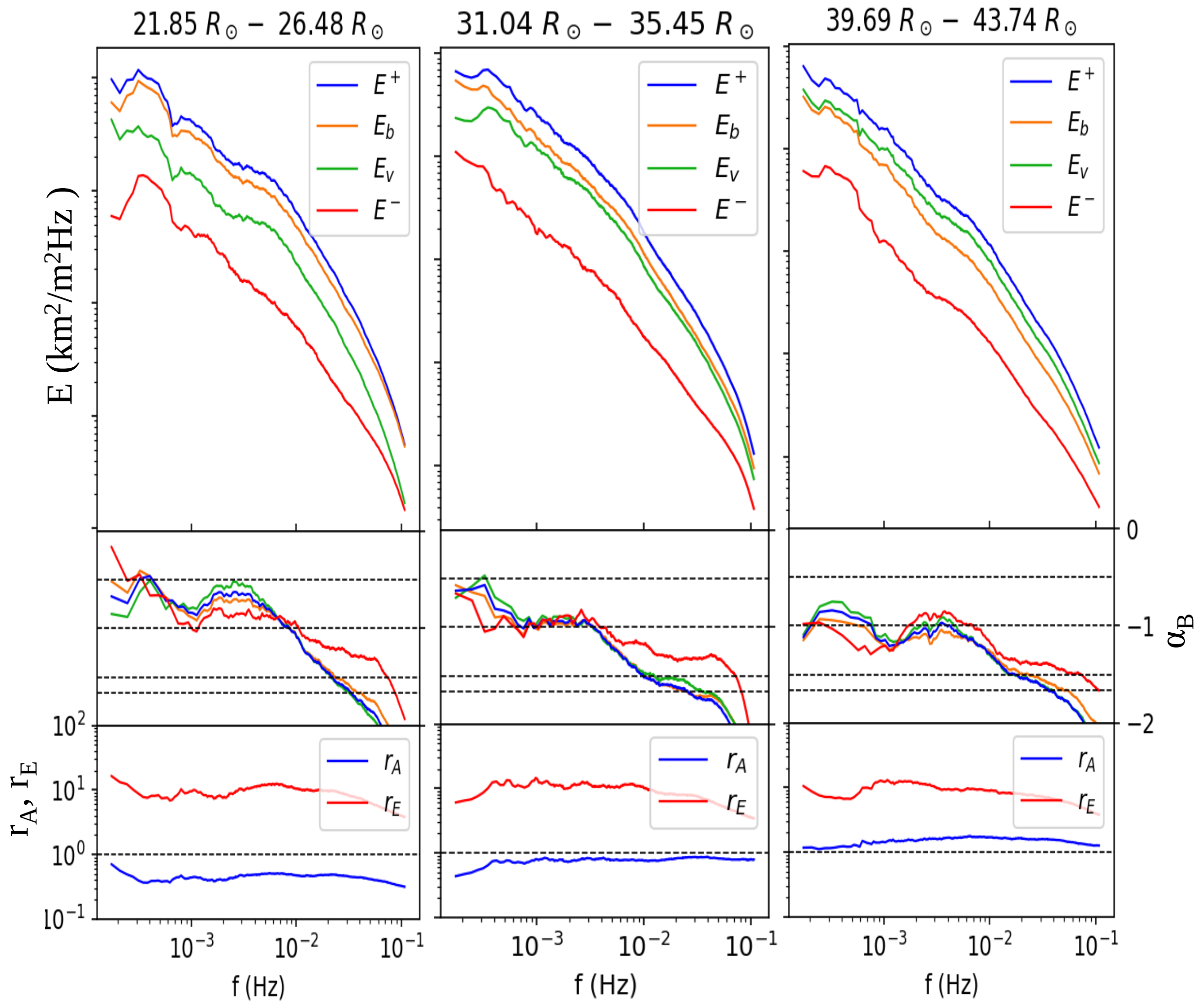

Figure 7: (top) Spectra of Alfvenic turbulence variables (middle) Local spectral index with lines for α_B= -1/2, -1, -3/2, and -5/3 (bottom) Alfven ratio, r_A,=E_V/E_B, and Elsasser ratio, $r_E=E_+/E_-$.

Radial Evolution of Spectral Index

α_B and f_b for the power spectrum of z+ exhibit a similar trends as the magnetic power spectrum.

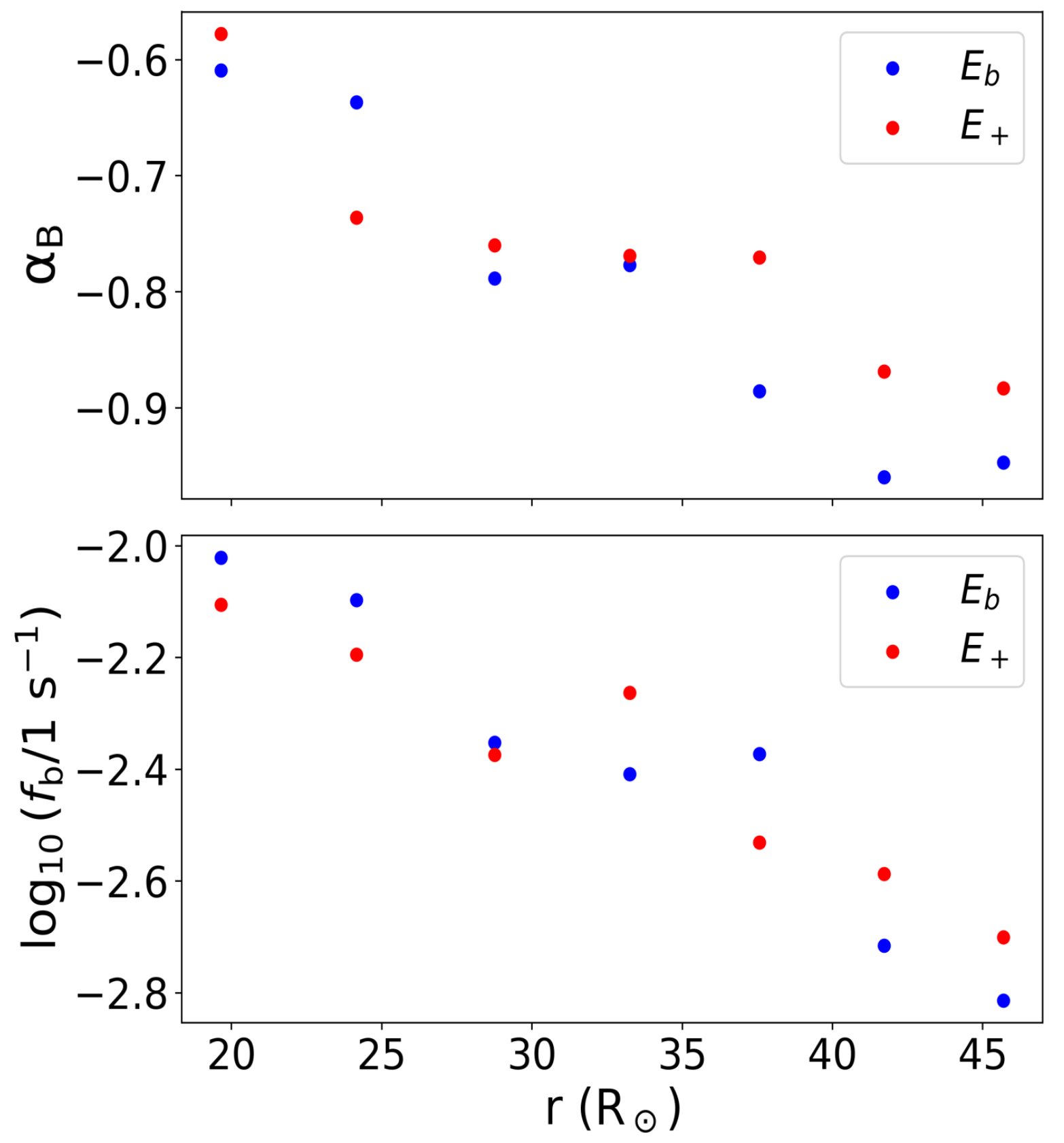

Figure 8: (top) Variation of α_B and (bottom) f_B with r.

Possible physical mechanisms: (1) nonlinear interaction in reflection-driven Alfven wave turbulence, (2) nonlinear evolution of the parametric decay instability

Summary and Future Work

Key Points:

- α_B in the low-frequency range $f < 10^{-3}$ Hz decreases as r increases from 17.4 to 45.7 R_s.
- Observations suggest that the $1/f$ spectrum is not produced at the sun, but develops *in situ*, at least within fast wind.
- Closer to the Sun, all fields exhibit similar behavior, with the spectra gradually steepening at higher frequencies.

Future Work:

- Revisit this behavior with further analysis of more solar-wind streams
- Investigate the physical mechanism(s) behind this behavior

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