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In situ observations of interstellar electron and magnetic turbulence spectra by Voyager 1

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In 1976, Lee and Jokipii first suggested that the interstellar turbulence at the length scale λ of 10^8m to 10^{18}m (100 light-years) has a Kolmogorov-like spectrum based on observations of radio wave scintillations and interstellar clouds. Many later ground observations confirmed this speculation. Armstrong et al. (1995) constructed the composite spectrum extending from $10^{6.4}$m to 10^{18}m, a.k.a. the Big Power Law in the sky, based on several observational results. In the present study, the interstellar turbulence spectrum of electron density was obtained for the first time from in situ observations of Voyager 1 and also for the first time being extended to the electron and ion kinetic scales. The in situ observed spectrum extends from $\lambda=q^{-1}$=15AU≈2.25×10^{12}m ($q=4.4\times10^{-13}$m^{-1}) to λ=50m ($q=2\times10^{-2}$m^{-1}), close to the Debye length. The spectrum covers part ($q=4.4\times10^{-13}$m^{-1} - 1×10^{-6}m^{-1}) of the Kolmogorov inertial range as well as ion and electron kinetic scales ($q=1\times10^{-6}$m^{-1} - 2×10^{-2}m^{-1}). The observed Kolmogorov inertial range shows a good agreement with earlier studies. Around the kinetic scales, a bulge of spectral intensity higher than the Kolmogorov spectrum is found. By combining the present result with the earlier studies from ground remote sensing, we now have the turbulence spectrum extending from 50m to 10^{18}m, over 16 orders of magnitude.

On the other hand, several theoretical models have been proposed to explain the turbulence spectrum associated with MHD wave modes/discontinuities. This study presents a preliminary report on the power relation between magnetic and density fluctuations and the connection to MHD wave modes/discontinuities based on theoretical models and observations in the interstellar medium.

References

K. H. Lee and L. C. Lee, Interstellar turbulence spectrum from in situ observations of Voyager 1, *Nature Astronomy* **3**, 154-159 (2019).