14TH ANNUAL INTERNATIONAL ASTROPHISICS CONFERENCE, TAMPA BAY, APRIL 20-24 2015

Spectral Analysis In The Solar Wind And Heliosheath

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This work gives the first spectral analysis of heliosheath solar wind, characterizing the plasma turbulence by estimating the spectral slopes. In order to compute spectra, signal reconstruction techniques are mandatory: at distances greater than 80 AU, available data are very spotty: for the plasma velocity, over 75% of the data is missing due to tracking gaps, noise, and other problems. The reconstruction methods used are tested on 1979 data and on synthetic fluid turbulent fields. These methods give results in good agreement with the literature, and allow us to compute the complete spectra of solar wind at 5 AU, with frequency ranging from 1.e-7 to 1.e-2 Hz. **RESULTS: The 1979 spectra evidence a different structure between the velocity and the magnetic field. The large scale of the magnetic field looses energy at a lower rate than the small scale, the opposite is true for the velocity field. The 2007-2010 heliosheath velocity spectra demonstrate clearly, on the decay slopes, the difference between the high and low electron intensity regions. This difference in the magnetic case is not associted to the slopes but to the energy density.**

Datasets

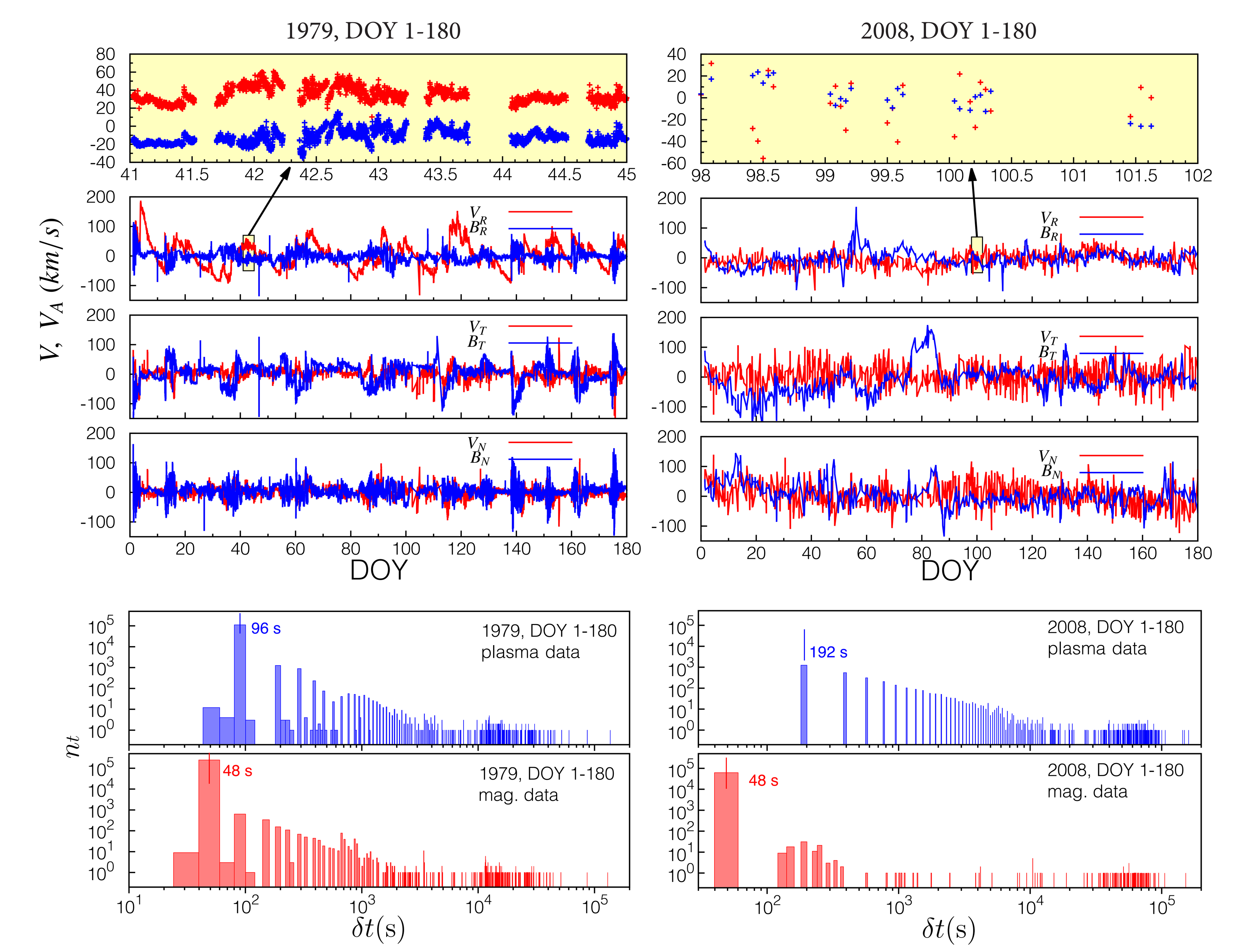


FIG. 1. **Datasets**. Upper panels: instantaneous values of plasma velocity (red lines) and magnetic fields (blue lines) recorded by Voyager 2 in the first 180 days of 1979 (left) and 2008 (right). The RTN Heliographic reference frame is used. The magnetic field is represented using the Alfvén units to make uniform the physical dimensions. In the two top panels, the magnification of 4 days periods make the data gaps apparent. Datasets from Voyager 2 are lacunous and irregularly distributed. In order to perform spectral analysis, methods for signal reconstruction of missing data should be implemented, see the poster bottom. Lower panels: gap distributions are shown. MIssing data are about 30% in 1979 and 75% in the Heliosheath (2007.7-2010.5).

	⟨V⟩	⟨B⟩	V_A	E_V	E_B	f_{ci}
1979	454 km/s	0.98 nT	49.4 km/s	1225 km^2/s^2	2420 km^2/s^2	0.02 Hz
2007.7-2010.5	153 km/s	0.12 nT	65.7 km/s	1678 km^2/s^2	2268 km^2/s^2	$1.46 \cdot 10^{-3}$ Hz

5 AU Solar Wind velocity and magnetic energy spectra

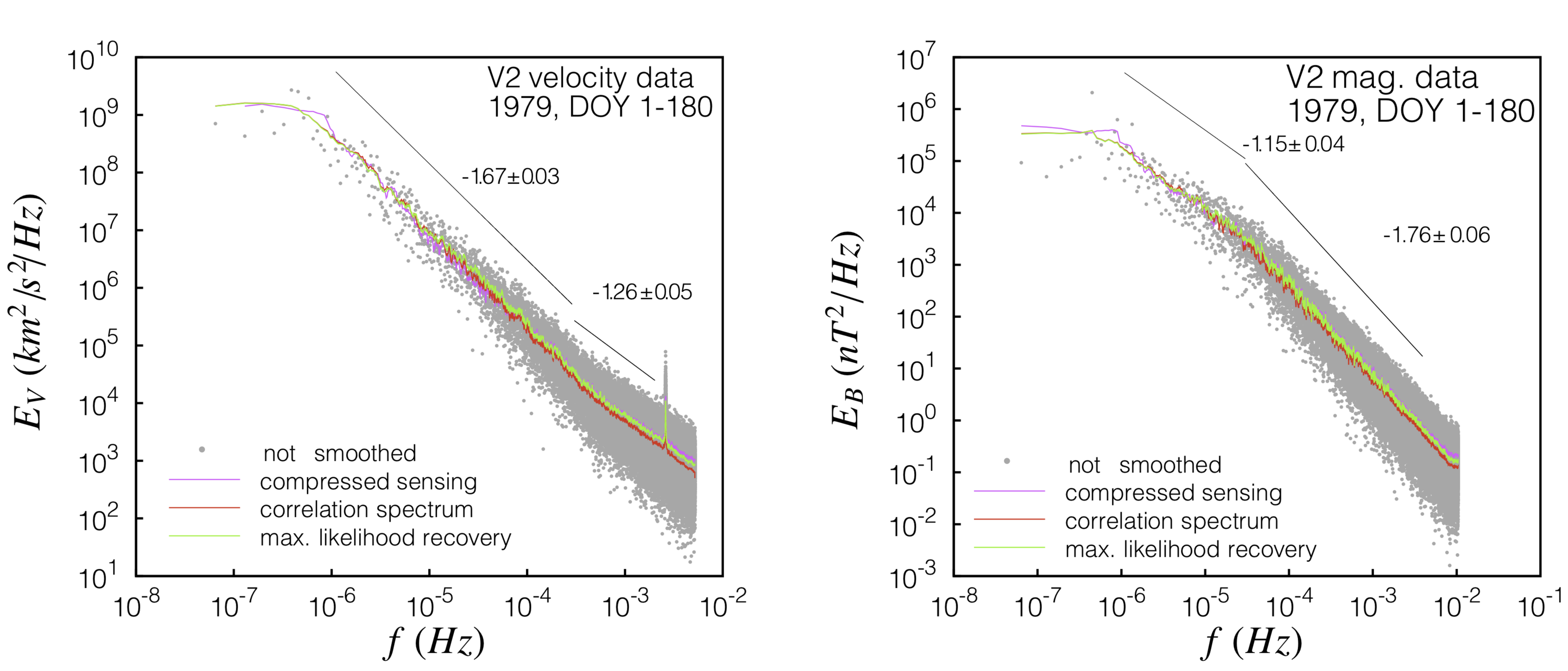


FIG. 2. **Spectral analysis of V2 plasma velocity and magnetic field data at 5 AU (1979 DOY 1-180) by using different spectral techniques**. Left: kinetic energy spectra. A slope change is observed at about f=$3{\cdot}10^{-4}$ Hz. For lower frequencies we observe a slolpe which is typical of developed turbulence. It is remarkable that for higher frequencies, instead, the slope is milder, a fact that is associated to the prevalence of Alfvén waves.
The peak visible at f=$2.6{\cdot}10^{-3}$ Hz is instrumental-related, since that frequency corresponds to four time the sampling period. Right: magnetic energy spectra. We see that the structure of the spectra is opposite to that of the velocity. The large-scale range loses energy at a lower rate with respect to the small-scale range. It should be noted that for the highest frequencies observed the effect of Alfvén waves is not discernable as it is for the velocity field. Good agreement with results by [1,2,3,4].

Preliminary Heliosheath spectral analysis

A little way down the road...

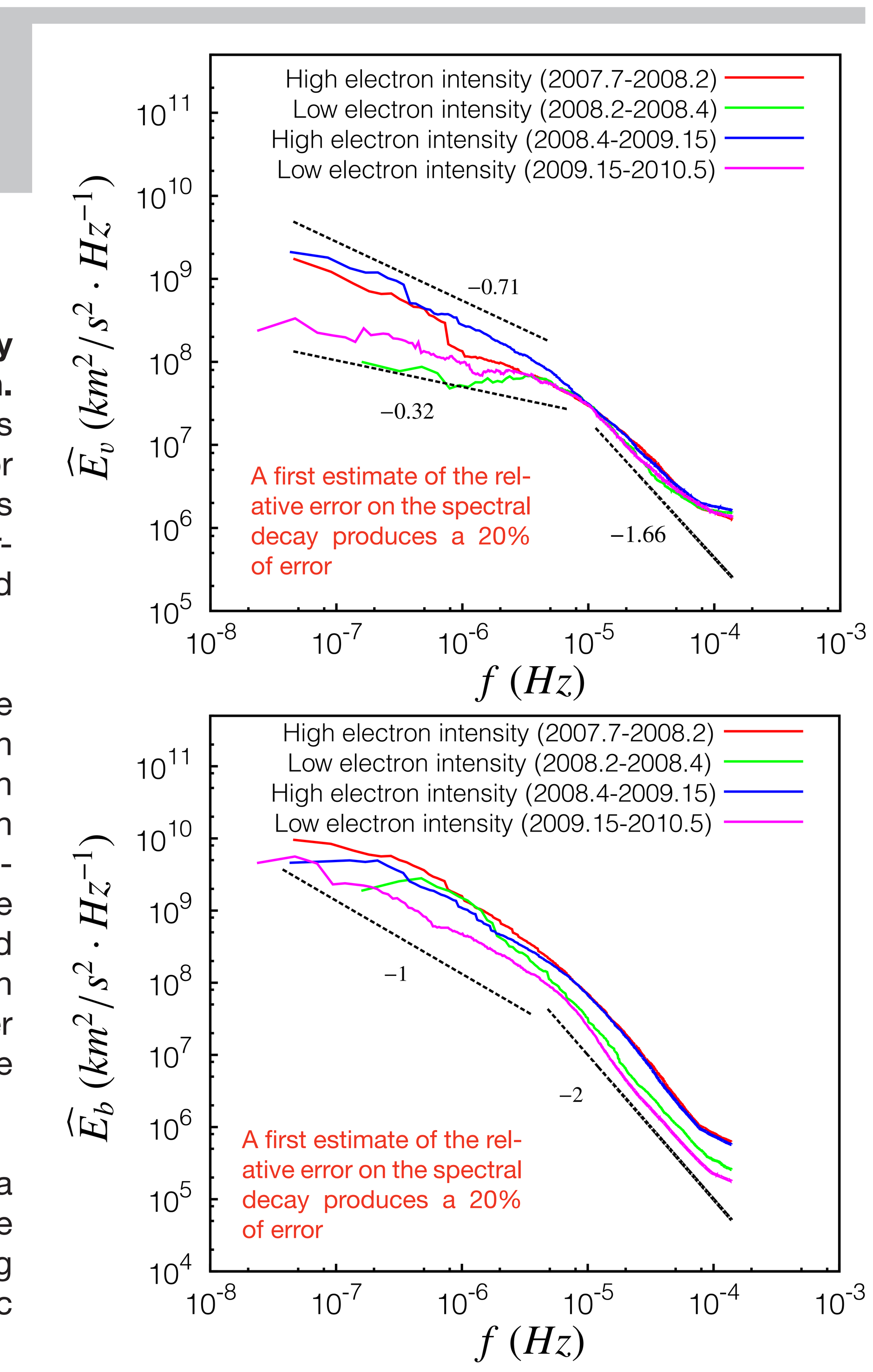
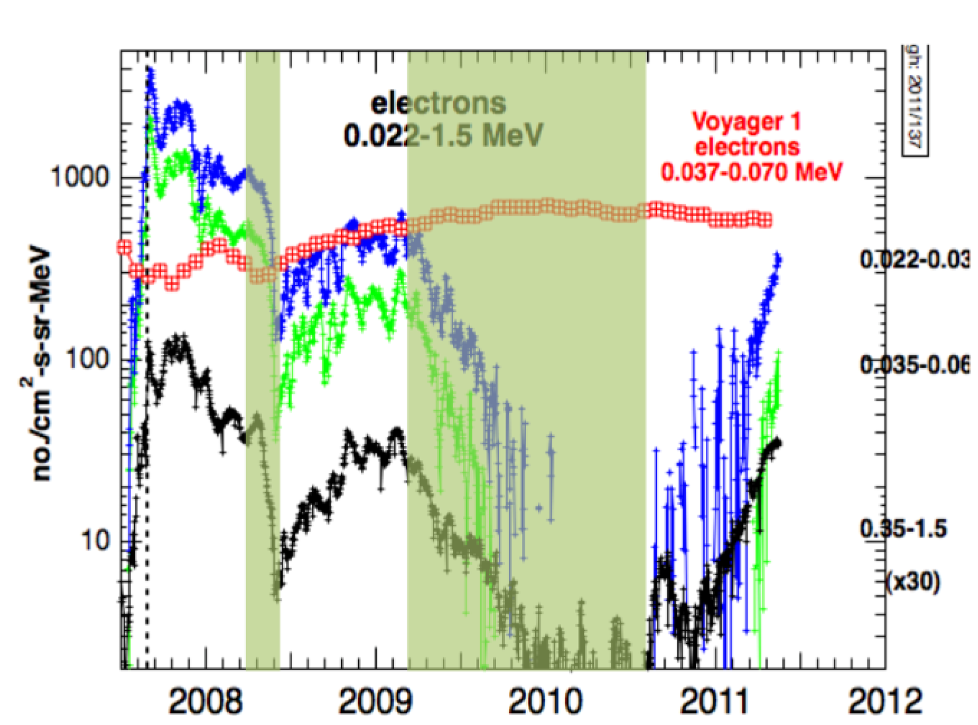


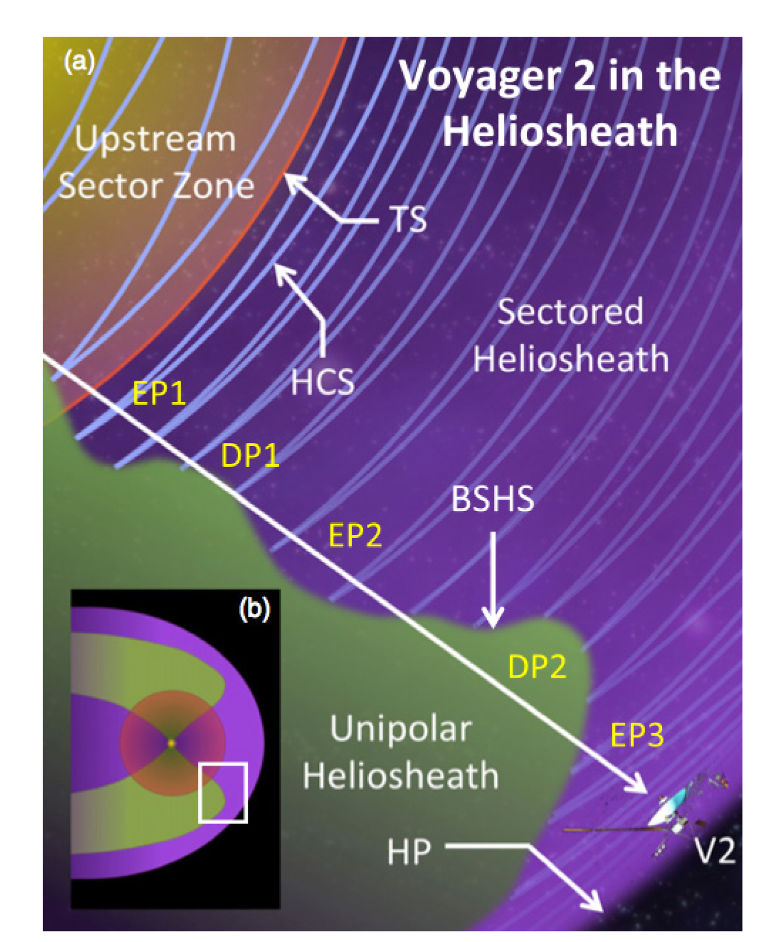
FIG. 4. **Preliminary power spectra of plasma velocity (top) and magnetic field (bottom) in the heliosheath.** Four subranges are selected by considering the periods when V2 was in the sectored (high electron intensity) or in the unipolar (low electron intensity) regions (see figures below and [7, 8]). Spectra are computed by using the correlation method described in the bottom of the poster and by considering hourly averaged data.

In the velocity field it is evident the presence of a change in the spectral slope at about f=10^{-5} Hz, particularly when V2 was in the low electron intensity regions. In that case, in fact, the spectra at the large scales become very flat, with values of decay exponents near -0.32. For high frequencies a Kolmogorov-like scaling is observed with a slope of about -1.48. For the magnetic field, both in sectored and in the unipolar sections, the large scale decays with a slope near -1. We used a smoothing technique in order to improve the readability of the spectra since the noise intensity at high frequencies is about 150%.

Notice that the frequency range in the 2007-2010 spectra ends at the frequency corresponding to 1 hour. For the 1979 spectra we were able to use the highest sampling rate available (96 s for velocity and 48 s for the magnetic field).



Unipolar regions (low electron intensity) are highlighted in green. Figures from [7, 8]



Spectral analysis procedures

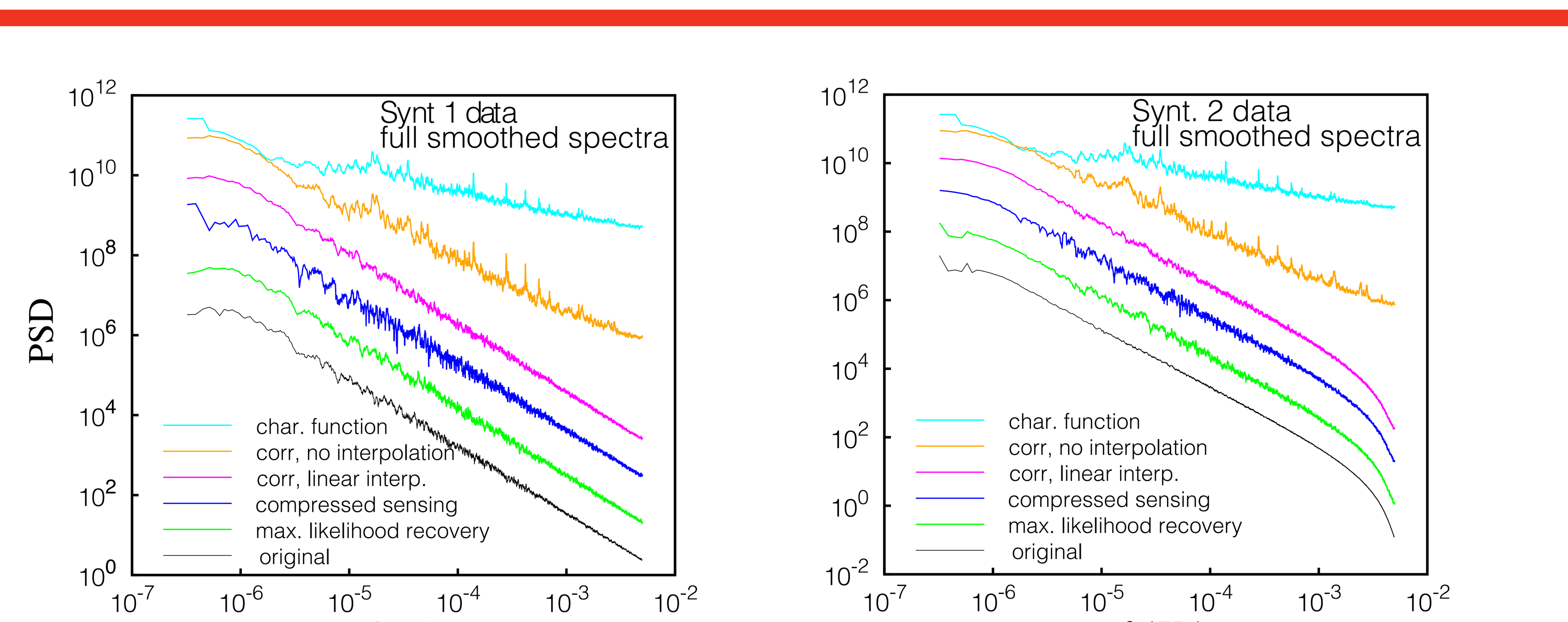


FIG. 3. **Validation of spectral analysis techniques for synthetic turbulence data** (with same gap of V2 1979 data, 30% of missing data) which mimic the behavior of the well-known homogeneous and isotropic turbulence system [9,10]. The sequences have been made lacunous by projecting the same gap distribution as in the V2 plasma data. A comparison with the original complete sequences (black curves) allows us to estimate the error in the spectral slopes. Cyan: spectrum of the characteristic function . Orange: spectrum of the two-point correlation function, computed from the gapped sequence. The influence of gaps is evident, non-physical spikes and wrong slope are observed. Correlations of linearly interpolated data, in the whole range, show a much better convergence, see the pink curve. Blue: spectral estimation via compressed sensing [5] (BPDN formulation). Green: spectrum from maximum likelihood data reconstruction [6] . Black: Fourier transform of the original compete sequences. The discrepancy of the power law exponent is below 2.5% for all methods. To all these spectra a smoothing is applied by averaging neighboring frequencies in bins of varying width. The energy is preserved for all spectra, but they have been shifted for clarity.

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