A Solar Wind Turbulence Event During the Voyager 1978 Solar Conjunction Profiled via a New DSN Radio Science Data Capability

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The Deep Space Network (DSN) has implemented a new radio science data capability within the DSN Tracking System – routine provision of phase fluctuation data concurrently computed over several different time scales. This new capability has been used to observe phase fluctuation spectral characteristics during a rapid increase in solar wind turbulence that occurred during a July 23, 1978, track of the Voyager 1 spacecraft by Deep Space Station (DSS) 11. This article suggests that the new capability will prove quite useful in future studies of variations in Solar Wind phase fluctuation spectral characteristics with, for instance, parameters such as the solar (sunspot) cycle and radial distance.

I. Introduction

During 1977, the Deep Space Network (DSN) implemented a new radio science data capability within the DSN Tracking System. This new capability was described in detail in Berman, Ref. 1. Essentially, the Tracking System routinely (i.e., automatically whenever a spacecraft is being tracked) computes rms phase fluctuation (ϕ) over the fluctuation frequency (ν) range (where ν is related to the Doppler averaging time (τ_a) by the approximate relationship $\nu \approx (36\tau_a)^{-1}$):

$$2.8 \times 10^{-4} \text{ Hz} < \nu < 2.8 \times 10^{-1} \text{ Hz}$$

The method of computation is briefly summarized as follows. Doppler samples (accumulated phase in cycles) are provided concurrently at four sample intervals: 0.1 s, 1.0 s, 10.0 s, and 100.0 s. In each case, 18 Doppler *frequency* samples (differenced Doppler accumulated phase divided by averaging time) are differenced with the equivalent *predicted* Doppler frequency. These 18 differenced (actual minus predicted) frequency samples are then fit with a least squares linear curve fit to remove low-frequency trajectory errors (and in the process, low-frequency solar wind induced phase fluctuations). The (scaled) rms phase fluctuation $\tau_a \cdot \sigma_f(\tau_a)$, where σ_f = rms *frequency* fluctuation, is then computed relative to the least squares linear curve fit. Subsequent to the fit, 100 contiguous rms phase fluctuation computations for the 0.1-s Doppler sample interval data, and 10 contiguous rms phase fluctuation computations for the 1.0-s Doppler sample interval data are averaged. The final provision of data is summarized in Table 1.

This article presents and briefly describes phase fluctuation data generated during a solar wind turbulence "event" so as to illustrate the potentiality of this new DSN capability.

II. The Data

On July 23, 1978, at about 21:00 Greenwich Mean Time (GMT), the Voyager 1 (ground) observed two-way Doppler data generated by Deep Space Station (DSS) 11 began to indicate that a solar wind flow of (relatively) high turbulence was interdicting the Voyager 1 signal path. At the time, Voyager 1 was at a Sun-Earth-probe angle (SEP) of approximately 6.4 deg. Figure 1 presents the phase fluctuation data for this period. The data presented in Fig. 1 were computed from two-way Doppler data generated by DSS 11. The vertical scale in Fig. 1 is Doppler rms phase fluctuation (ϕ, deg), which is related to rms frequency fluctuation (σ_f) by the approximate relationship (Ref. 1):

$$\phi(\tau_a) \approx \frac{5}{3} \cdot \tau_a \cdot \sigma_f(\tau_a)$$

For the 0.1-, 1.0-, and 10.0-s Doppler sample interval calculations in Fig. 1, ten 3-min phase fluctuation computations (as described in Section I) have been averaged to produce each 30-min (interval) data point. This explains the considerable "smoothness" of the 0.1-, 1.0-, and 10.0-s Doppler sample interval data as compared to the 100.0-s Doppler sample interval data. As can readily be seen, the behaviour of the phase fluctuation data in all Doppler sample interval regimes is quite similar. The increase in the 0.1-s Doppler sample interval phase fluctuation data is relatively less than the longer Doppler sample interval data because the 0.1-s Doppler sample interval data contain phase fluctuation components of both the solar wind and the ground tracking system. For the 1.0-, 10.0-, and 100.0-s Doppler sample intervals, the phase fluctuation data are essentially all a result of Solar Wind turbulence.

III. Columnar Solar Wind Phase Fluctuation Spectral Index

The relationship between the columnar (two-dimensional) spectral index is simply (from Berman, Ref. 1, or Douglass, Ref. 2):

$$\phi^2 \propto \nu^{-K_0+1}$$

where

ϕ = RMS phase fluctuation

ν = fluctuation frequency

K_0 = spectral index

Figure 1 additionally provides spectral index data computed from the phase fluctuation data. Inherent to these data is the assumption that the fluctuation spectrum is power-law with frequency. Spectral index data at 30-min intervals were computed for the following frequency ranges:

$$2.8 \times 10^{-3} \text{ Hz} < \nu < 2.8 \times 10^{-2} \text{ Hz}$$

$$2.8 \times 10^{-4} \text{ Hz} < \nu < 2.8 \times 10^{-2} \text{ Hz}$$

IV. Discussion and Summary

The DSN has implemented a new radio science data capability within the DSN Tracking System – routine provision of phase fluctuation data concurrently over several different time scales. The columnar solar wind phase fluctuation spectral index can be easily extracted from such data, and hence this new capability should prove quite valuable in studies such as the radial and solar cycle variations of the spectral index.

References

1. Berman, A. L., "Phase Fluctuation Spectra: New Radio Science Information To Become Available in the DSN Tracking System Mark III-77", in *The Deep Space Network Progress Report 42-40*, Jet Propulsion Laboratory, Pasadena, California, August 15, 1977.

2. Douglass, D. H., "Detection of Gravitational Radiation and Oscillations of the Sun via Doppler Tracking of Spacecraft", in *A Close-up of the Sun*, edited by Neugebauer, M., and Davies, R. W., JPL Publication 78-70, Jet Propulsion Laboratory Pasadena, California, September 1, 1978.

Table 1. Provision of phase fluctuation data

Doppler sample interval, s	Number of Doppler samples	Number of estimates averaged	Print-out interval, min
0.1	18	100	3
1.0	18	10	3
10.0	18	1	3
100.0	18	1	30

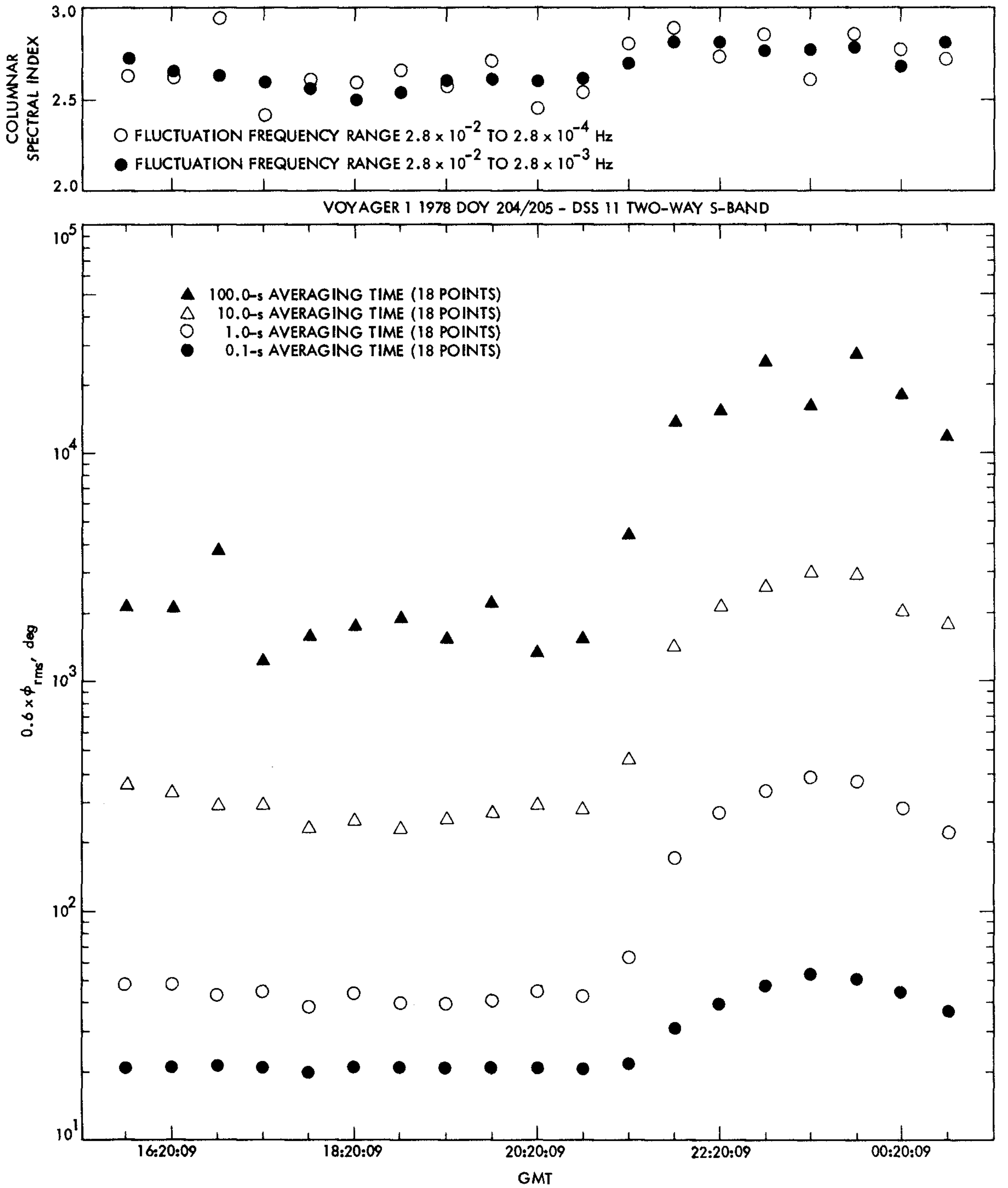

Fig. 1. RMS phase fluctuation and columnar spectral index vs GMT, July 23/24, 1978