Comparison between Single- and Multi-Station IPS Measurements

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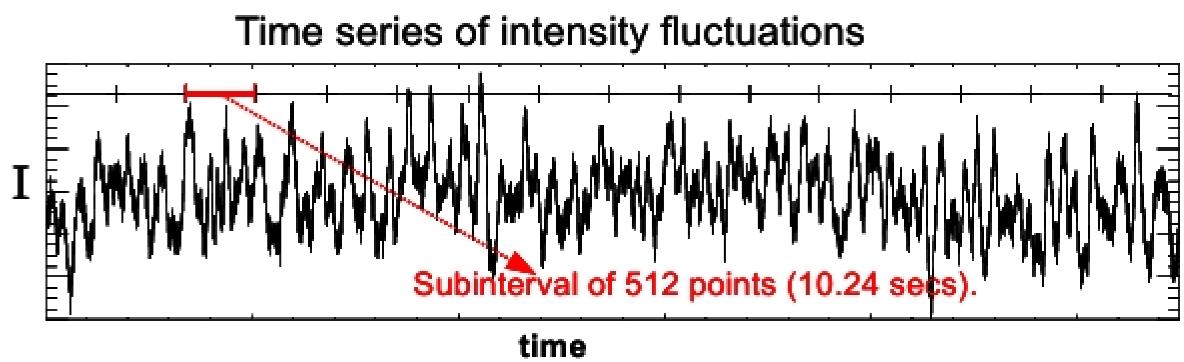
Two ways to determinate solar wind velocity by IPS observations

● **Multi-station:** The solar wind speed is derived by measuring the radiation pattern delay between separated stations (~ 100 km).

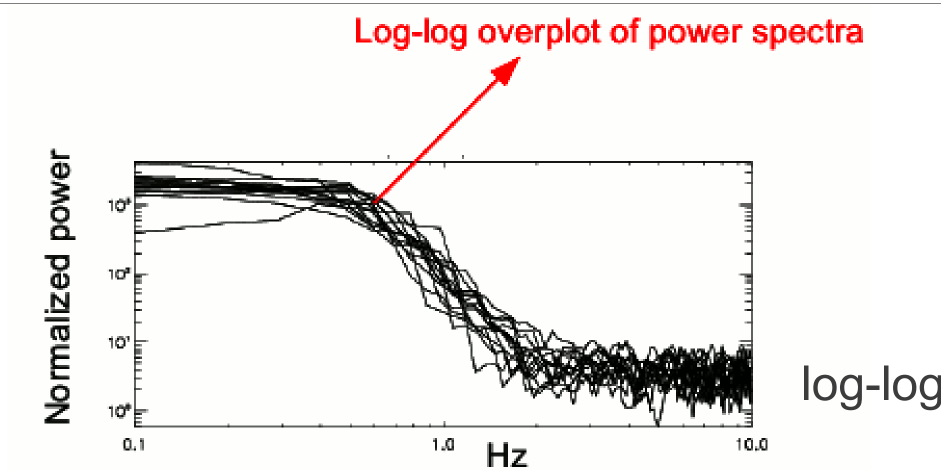
● **Single-station:** Determination of solar wind speeds by fitting a solar wind velocity model to the observed power spectrum of IPS.

General methodology to get the IPS observed power spectra

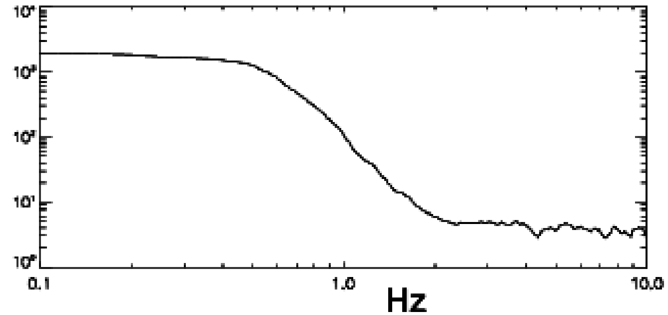
(1) Divide the time series into subintervals of 512 points each



(2) Take the FFT to get the power spectra of each subinterval. Spectra having high noise at high frequencies are discarded



(3) Take the sum of these power spectra to yield the total observed power spectrum



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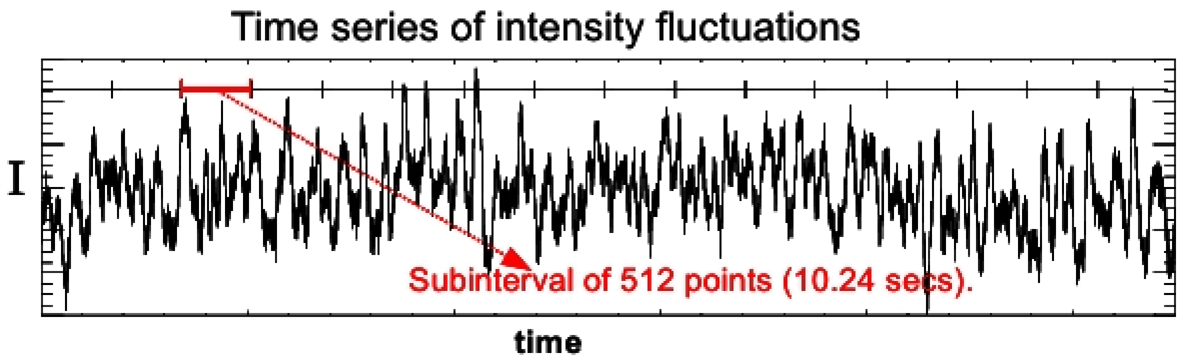

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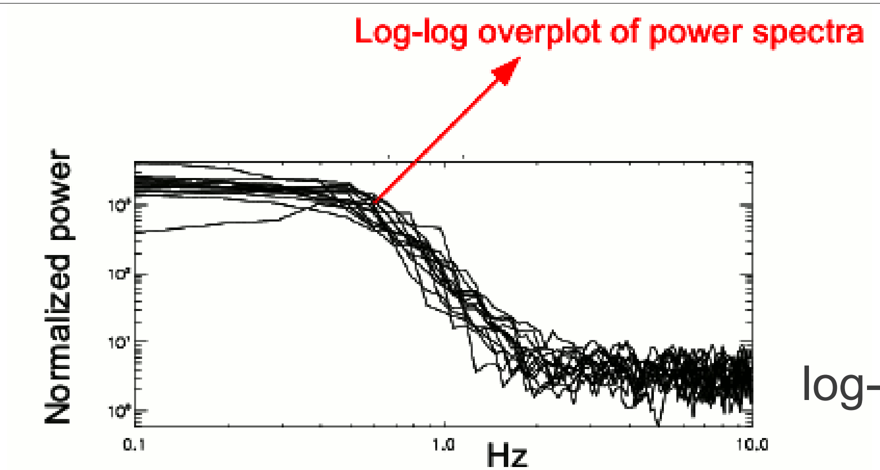

log-log

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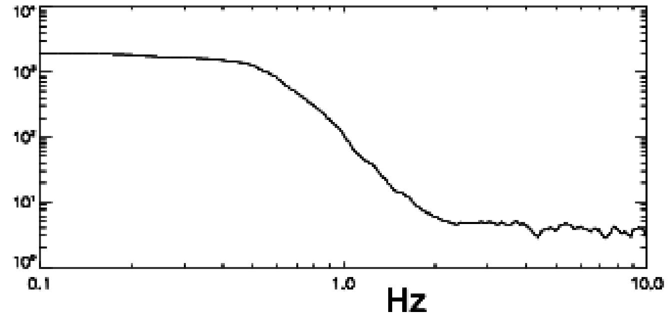


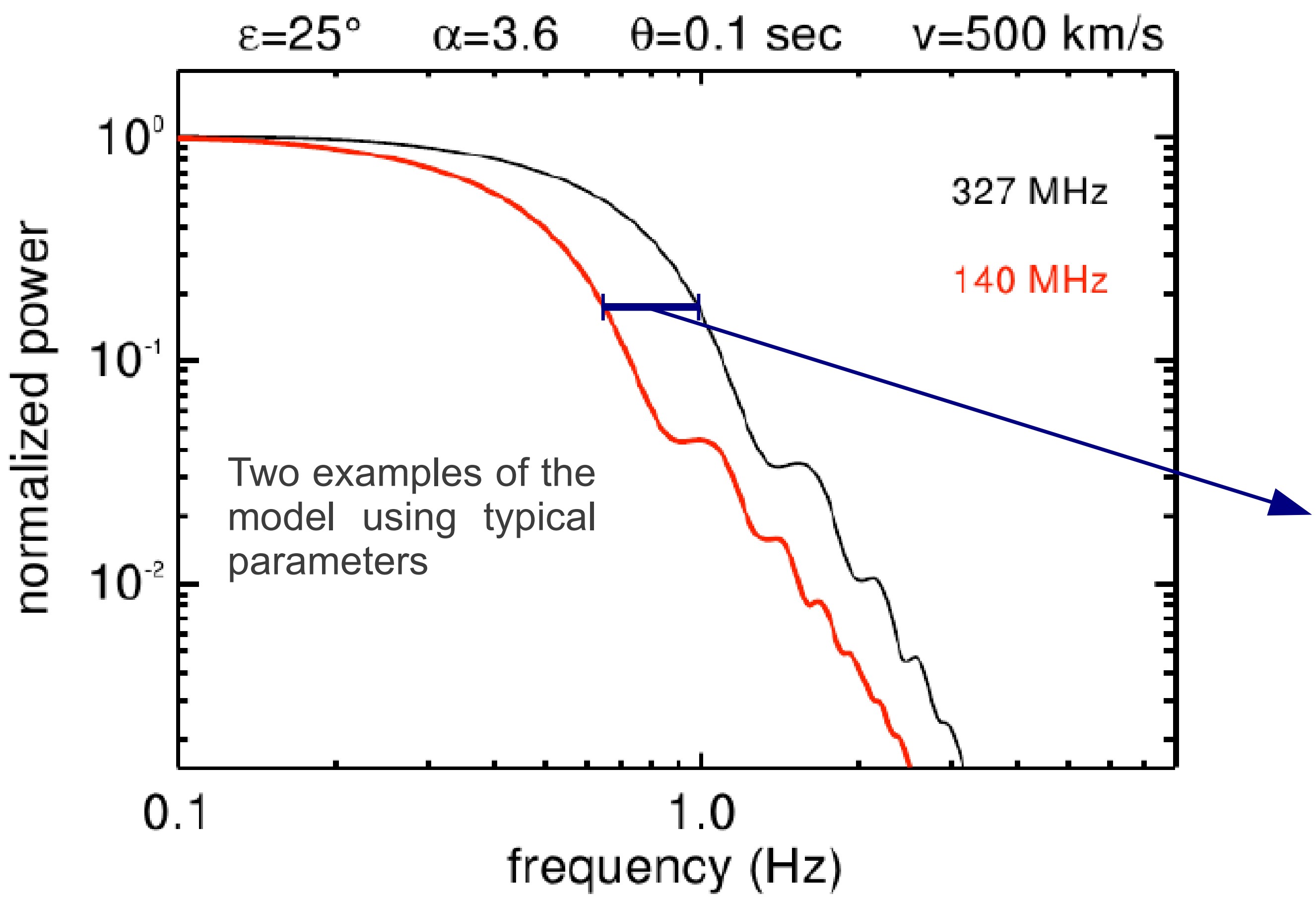
General methodology to obtain solar wind velocities: Single-station IPS technique

$$P(f) = c\int_{-T}^{\infty} \frac{dz}{V_x(z)} \int_{-\infty}^{\infty} dq_y \sin^2\left(\frac{q^2 z_0 \lambda}{4\pi}\right) e^{-\left(\frac{q z_0 \Theta}{2.35}\right)^2} R^{-4} q^{-\alpha}$$

- $P(f)$: Frequency of intensity fluctuations
- $\sin^2(\ldots)$: Diffractive function (Fresnel function)
- $e^{-(\ldots)^2}$: Visibility function of the source
- $q^{-\alpha}$: Wave number of solar wind irregularities

The model

Version: Isotropic solar wind and no contribution of the inner scale

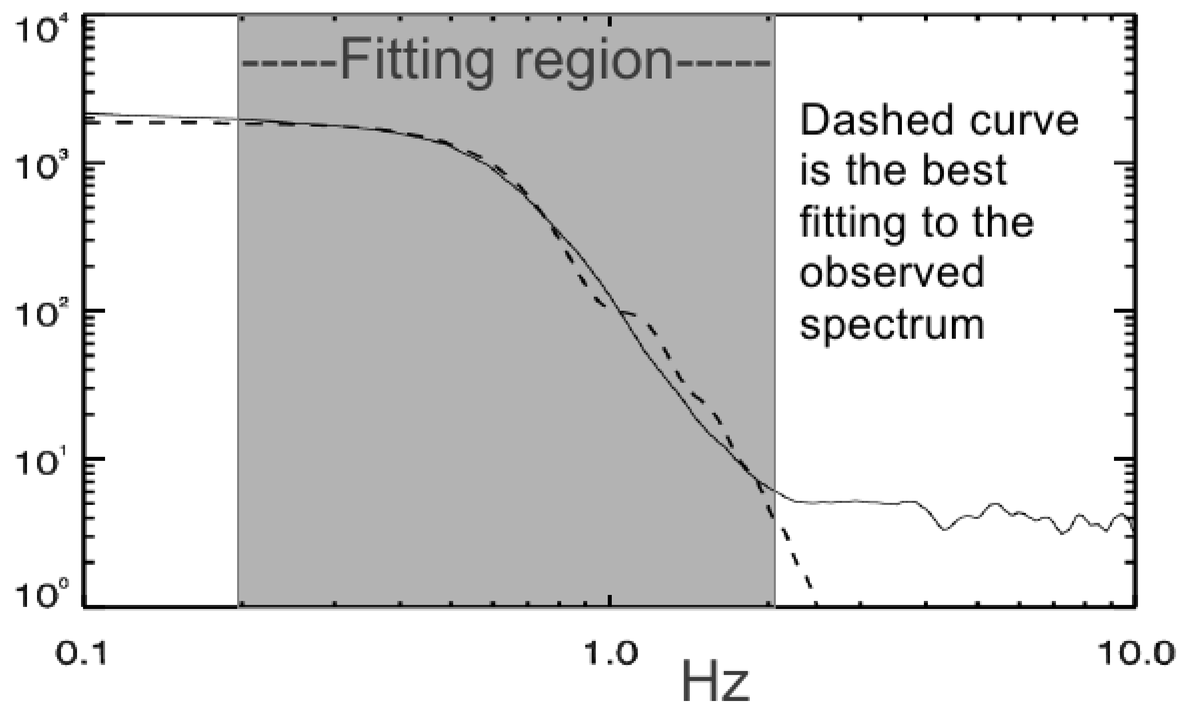


Spectra at 327 MHz are around 1.5X wider than those observed at 140 MHz.

General methodology to obtain solar wind velocities: Single-station IPS technique

Fit a model of the power spectra in the region of IPS contribution (~0.2 to ~2 Hz). Best fitting is obtained by minimizing the chi-square distribution:

$$\chi^2 = \sum_i \frac{[PO(fi) - PT(fi)]^2}{PO(fi)PT(fi)} \frac{1}{\exp\left[-(\alpha - \alpha_c)^2/0.08\right]}$$



To associate an error to the velocities, we fix all the other parameters and find where its chi-squared distribution becomes quadruple from the minimum value as v is varied.

Case of single-station study: MEXART and SWIFT (Toyokawa array) of STEL

MEXART

17 observations of 3C48 at 140 MHz to obtain solar wind speeds by applying the single-station technique. The observations were carried out during the minimum and maximum for solar cycle 24, at elongation angles 21° – 63° (0.37-0.89 AU).

(i) The **α** parameter is fixed assuming solar cycle dependence. **α=3.8** for the minimum and **α=3.3** for the maximum (Manoharan, Kojima, and Misawa, *JGR*, 1994; Glubokova, Chashei, and Tyul'bashev, *Adv Astron Space Phys,* 2012).

(ii) We fit the model to the observed power spectra using 2 free parameters: **V** and **Θ**.

(iii) We use the average of **Θ** from the previous fittings (**‹Θ›**=170 mas).

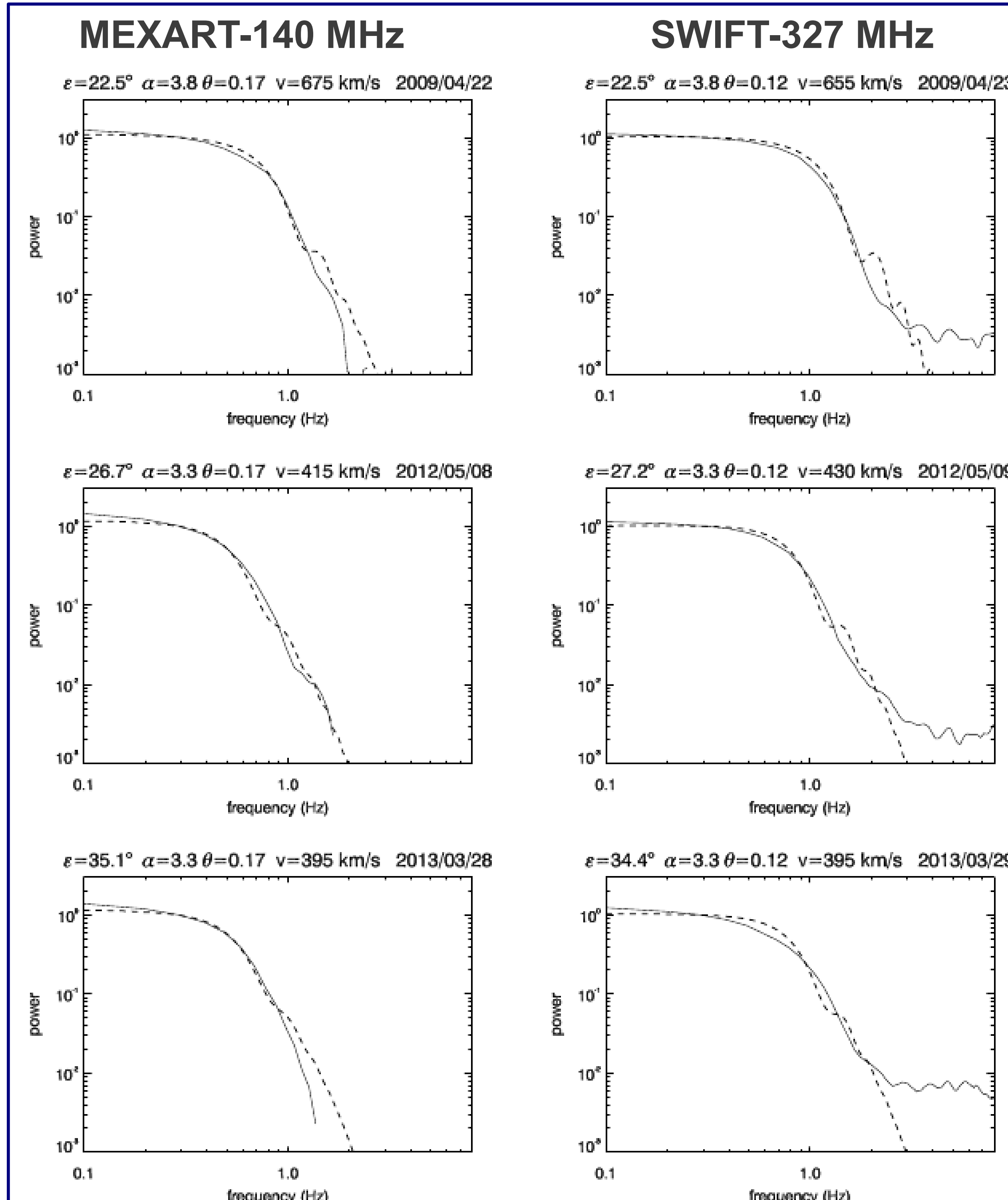
(iv) We fix all the parameters and find **V**.

SWIFT

We take 20 available observations of 3C48 obtained at 327 MHz at dates near to the selected observations of MEXART, and we apply the same steps above (**‹Θ›**=120 mas).

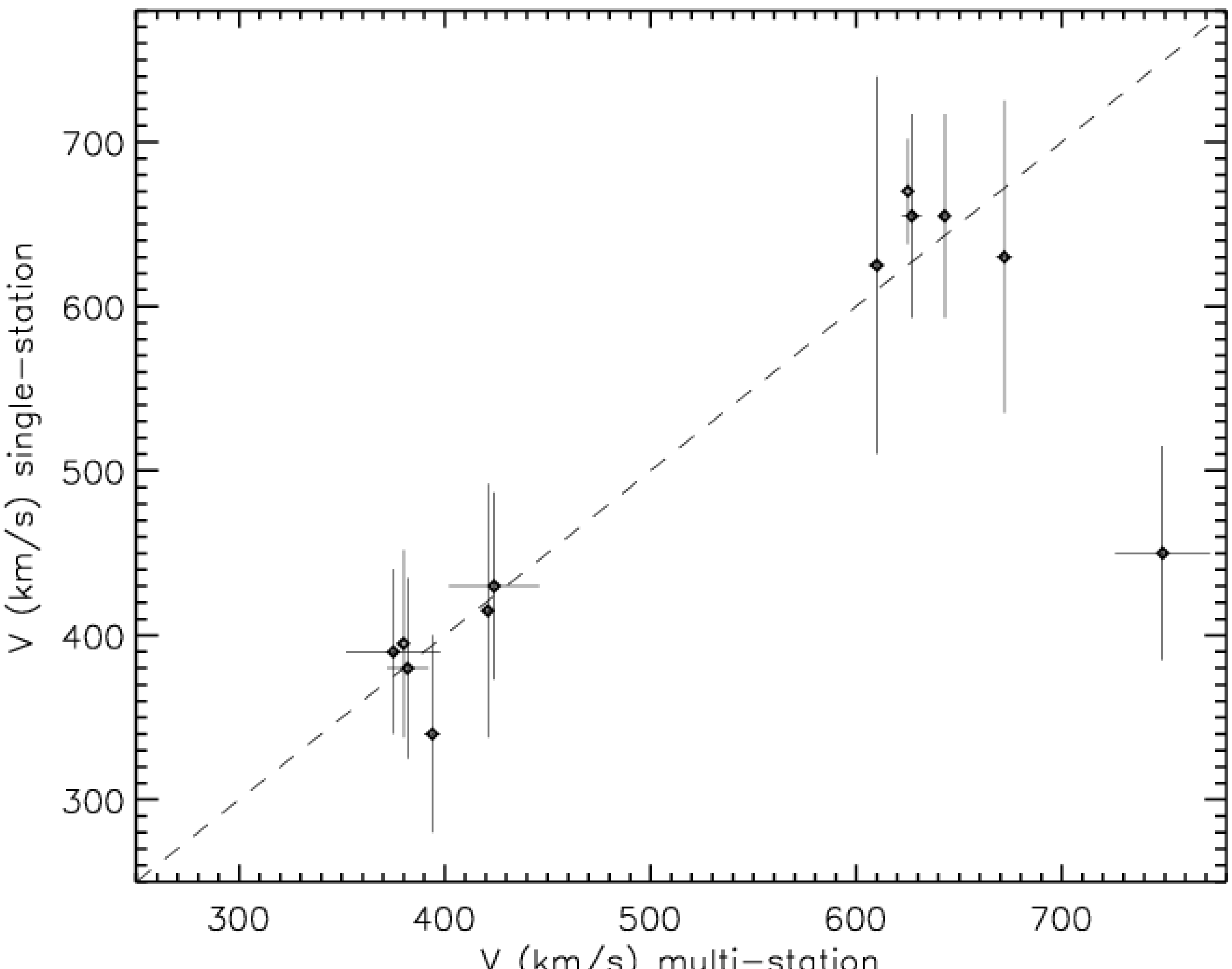
MEXART and SWIFT (Toyokawa array) of STEL

Comparison of IPS power spectra. Quasi-simultaneous observations (8 hours of difference). As expected the spectra observed with SWIFT (327 MHz) are around 1.5X wider than those observed with MEXART (140 MHz).

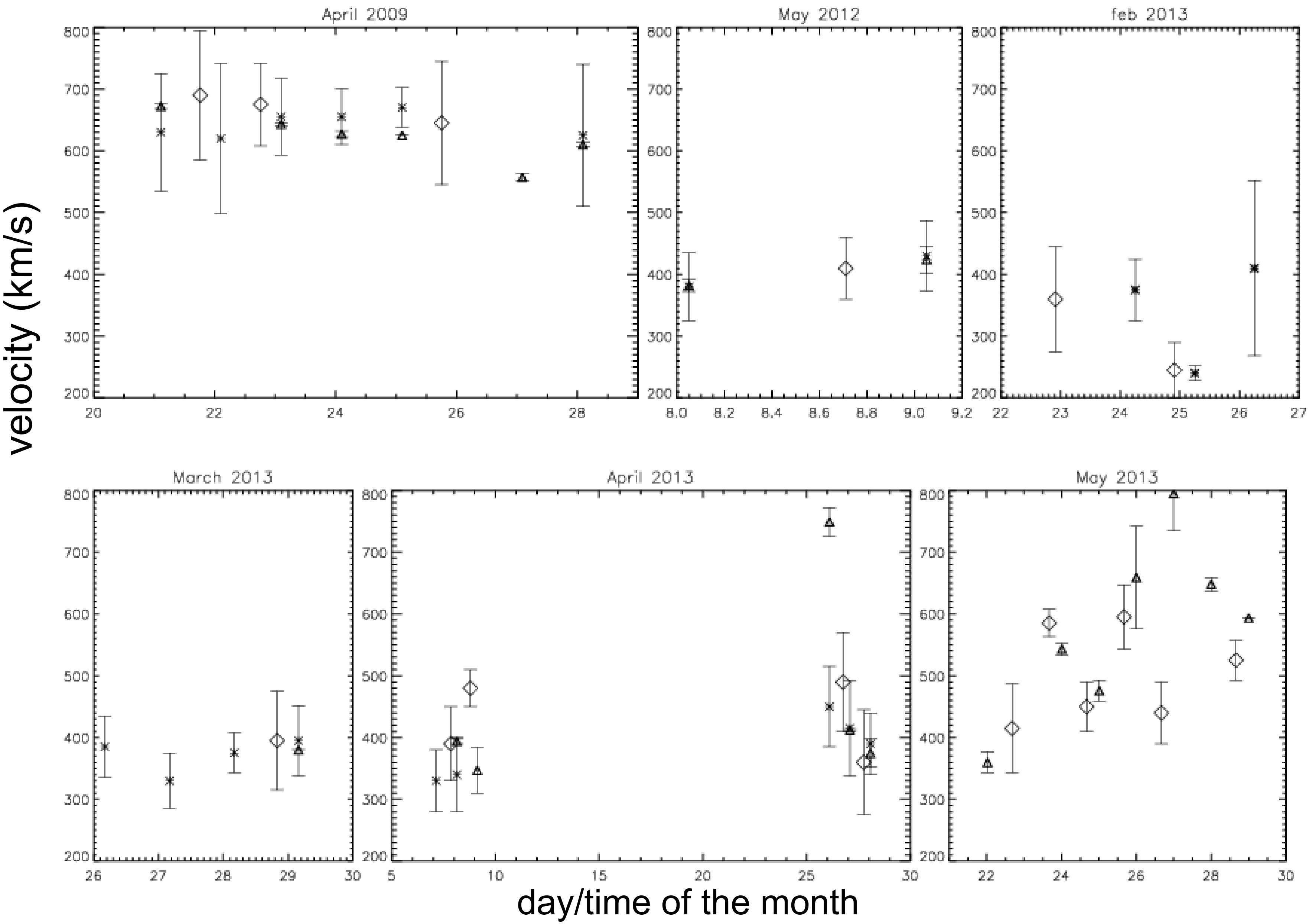


Comparison of simultaneous observations: STEL (multi-station) vs SWIFT-STEL (single-station)

12 observations. Velocities match very well, except for one observation in April 2013 which may be related to a combination of fast and slow solar wind at different positions on the line of sight (Moran et al., *Ann Geophysicae*, 2000).

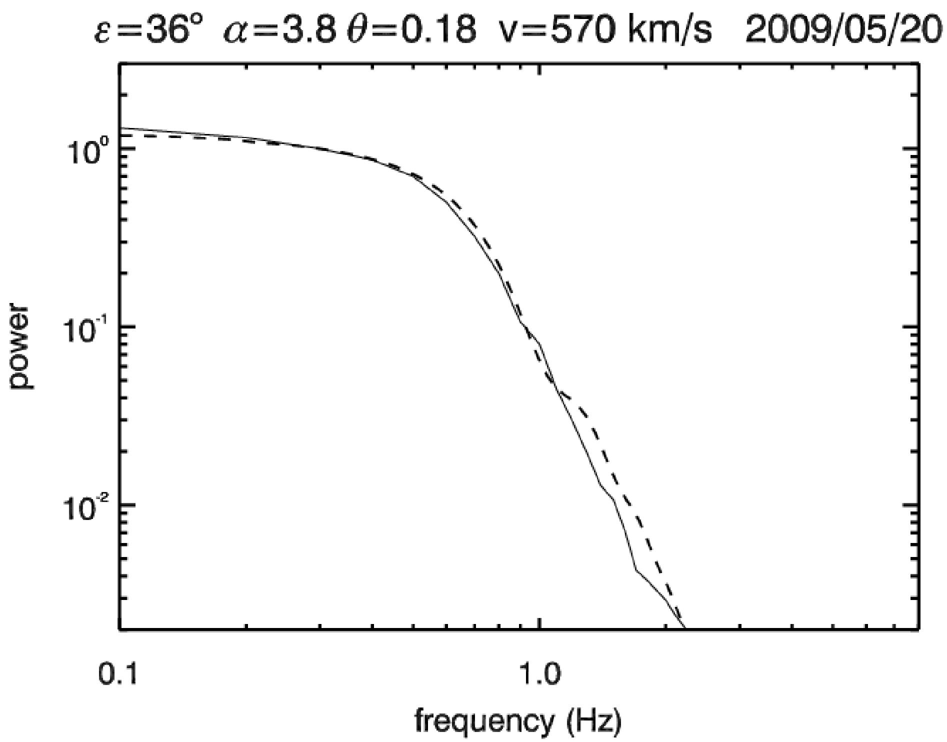


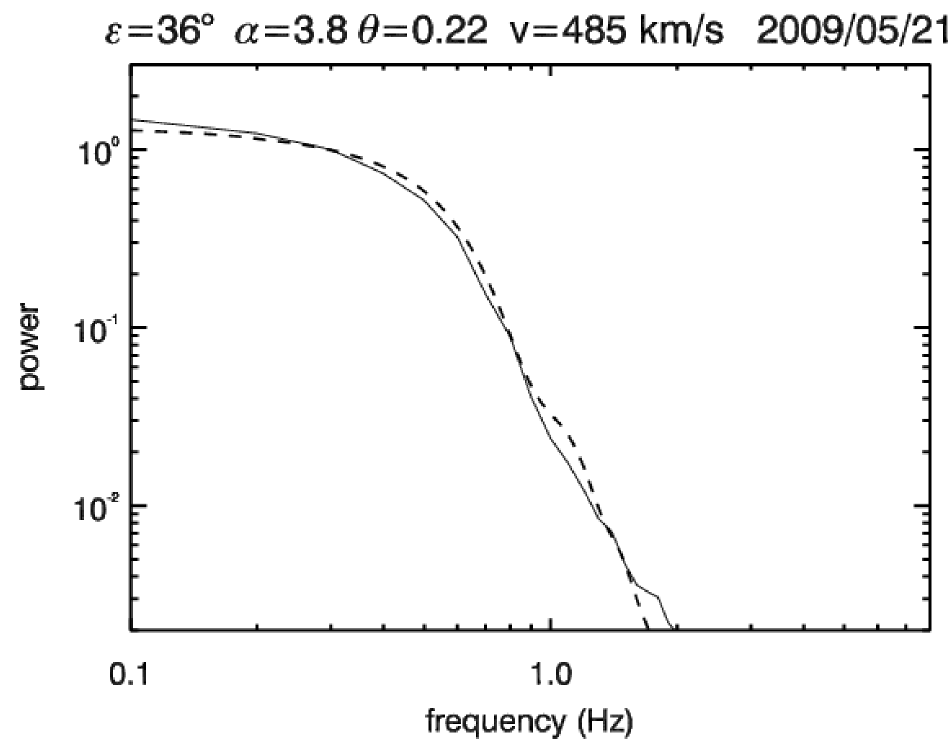
Observations carried out for 6 months:
Single-station 327 MHz, SWIFT-STEL (*)
Single-station 140 MHz, MEXART (◊)
Multi-station 327 MHz, STEL (Δ)



Case of single-station study: Big Scanning Array (BSA). Puschino Radioastronomy Observatory

3C48 111MHz 3C147





STEL, multi-station (~ 17 hours later)
v = 569 ± 3.

STEL, multi-station (~ 7 hours before)
V = 461 ± 1.

Data provided courtesy of S. Tyul'bashev

General results and comments

• We focus on the single-station technique to obtain solar wind speeds with IPS remote sensing observations.

• The reported solar wind velocities at 140 MHz are the first remote sensing results determined with MEXART.

• Measurements using the single-station technique with SWIFT and those from multi-site (STEL) agree very well.

• Taking the speeds measured by STEL (multi-site) as the actual values, the relative error of measurements with SWIFT (single-station) have an average of ∼ 8%. The fitting error using the chi-square distribution is ∼13%.

• Taking the average speed measured by STEL and SWIFT (8 hours of difference) as the actual value, the resulting average relative difference error for MEXART is ∼ 11%. The fitting chi-square distribution error is ∼13%.