Characterizing Turbulent Flow in Quiescent Prominences

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Abstract

Understanding the motion of plasma in quiescent prominences is important in determining how the magnetic field structure can become entangled to trigger eruptions. Hinode/Solar Optical Telescope (SOT) observations have already demonstrated the existence of convective flows and Kelvin-Helmholtz instabilities around the plume component inside these prominences. Our research uses the same observations to make quantitative measurements of the turbulent diffusive flows in these coronal structures. Fourier local correlation tracking (FLCT) is used to derive velocity fields from SOT observations of prominence plasma sheets. Analysis of these velocity fields in turn provides a measurement of the temporal and/or spatial length scales associated with the energy dissipation and diffusivity.

Background

Quiescent Prominences (QPs) form far from active regions and also go by the name "polar crown" prominence due to their appearance at higher latitudes. Observations from Hinode/SOT show a cavity or "bubble" forming next to the chromosphere and a columnar "plume" structure rising from this bubble as shown in Fig. 1. The plume is seen becoming turbulent and shedding Kelvin-Helmholtz vortex formations from its boundary as it ascends [1]. The initial perturbation that generates plumes from the prominence bubble is hypothesized to be a Rayleigh-Taylor instability. A magneto-thermal convection system is created and driven by the prominence bubble which has plasma that is 25-120 times hotter than the overlaying prominence [2]. Most of the modeling done on prominences is at a height of 20-100 Mm above the photosphere which is well above the plume formations. Modeling by Low & Hundhausen has shown the region directly below the twisted magnetic fields associated with QPs to have a very weak field strength [8]. This means these plumes can be moving in a region where the buoyant force is dominating over the Lorentz, i.e., a high β. *The primary objective of this investigation is to quantify the turbulent behavior associated with this high beta plasma found surrounding QPs.*

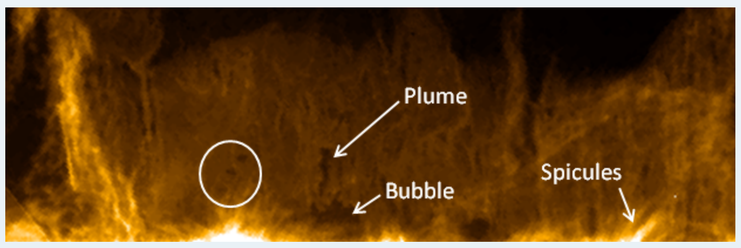

Fig. 1 – A large quiescent prominence observed with Hinode/SOT in the Ca II H-line 396.8 nm spectral line on 2006 November 30 (04:24:22 UT). A large plume can be seen ascending from an underlying prominence bubble. Circle emphasizes three smaller dark voids that are also moving upwards.

Methodology and Analysis Overview

A summary of the SOT data used for this study is shown in Table 1. The velocities were obtained from the contrast enhanced images with the use of Fisher & Welsch's Fourier Local Correlation Tracking (FLCT) program [5], which was done previously by McKenzie for supra-arcade downflows [3]. FLCT has the advantage of running quicker then other "optical flow" codes available. Results are then verified by placing test particles (corks) into the derived velocity field, with the original image in the background, and advecting the corks by the FLCT velocities. This allows for a quick determination on the fidelity between derived and observed flows. See Fig. 2 for more information on deriving the QP velocity maps.

Date	Time	Disk (X,Y) (arcseconds)	Cadence	SOT Filters
2006 Nov 30	01:00-07:00	(600,767)	17 sec	CaH
2007 Apr 25	13:00-18:00	(770, -556)	15 sec	Hα

Table 1: Summary of SOT Data Used

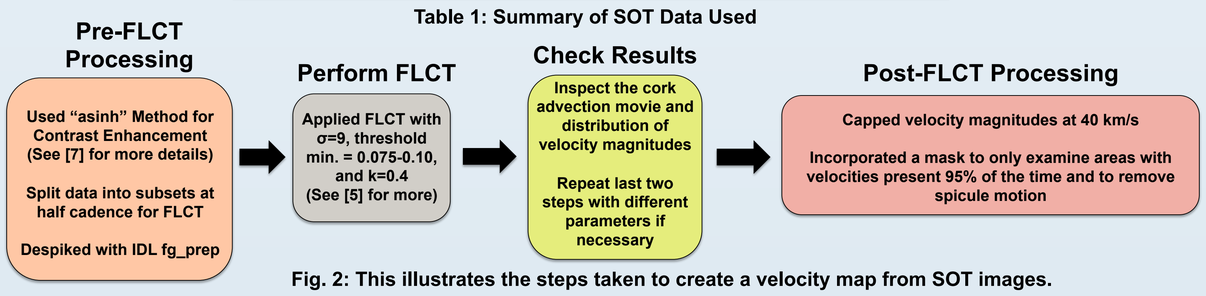

Fig. 2: This illustrates the steps taken to create a velocity map from SOT images.

The quantities that we are interested in for this study are displacement spectrum and kinetic energy power spectrum density (PSD) for the derived velocity maps.

$$E(k) = \frac{1}{2}k\int_0^{2\pi}\phi_{ii}(\vec{k})d\theta_k \qquad \phi_{ii}(\vec{k}) = \frac{|\hat{v}^2|}{\delta(\vec{k})}$$

E(k) **is the 2D kinetic energy PSD and** ***Φ*** **is the Fourier transform of the auto-correlation function for the velocities** ***v*****. δ is the Dirac distribution. See [6] for more details.**

$$\left\langle (\Delta l)^2 \right\rangle = 4K\tau \sim \tau^{\gamma}$$

$\gamma > 1$ means $K\uparrow$ and $\Delta l\uparrow$ (super-diffusion)
$\gamma < 1$ means $K\downarrow$ and $\Delta l\uparrow$ (sub-diffusion)

The displacement spectrum can be found from the above relationship, where ***Δl*** **represents the mean-square displacement,** ***K*** **is the diffusion coefficient,** ***tau*** **is the total time between initial configuration & present time step, and** ***γ*** **is the spectral index. A** ***γ≠1*** **indicates anomalous diffusion. See [4] for more details.**

References

[1] T. E. Berger, et al. Quiescent Prominence Dynamics Observed with Hinode Solar Optical Telescope. I. Turbulent Upflow Plumes. *APJ*, 716: 1288-1307, June 2010.
[2] T. E. Berger, et al., Magneto-thermal Convection in Solar Prominences. *Nature*, 472:197-200, April 2011.
[3] D. E. McKenzie. Turbulent Dynamics in Solar Flare Sheet Structures Measured with Local Correlation Tracking. *APJ*, 766:39, March 2013.
[4] V. I. Abramenko, et al. Turbulent Diffusion in the Photosphere as Derived from Photospheric Bright Point Motion. *APJ*, 743:133, December 2011.
[5] G. H. Fisher and B. T. Welsch FLCT: A Fast, Efficient Method for Performing Local Correlation Tracking. *Subsurface and Atmosphere Influences on Solar Activity*, Vol. 3 of APS Conference Series, page 73, 2008.
[6] M. Rieutord, et al. On the Power Spectrum of Solar Surface Flows. *A & A*, 512:A4, January 2010
[7] R.H. Lupton, et. al, in *The Astronomical Journal*, 118:1406-1410, 1999 September.
[8] B. C. Low and J.R. Hundhausen. Magentostatic structures of the solar corona. 2: The magnetic topology of quiescent prominences. *Astrophys. J.* 443:818-836, April 1995.

Results

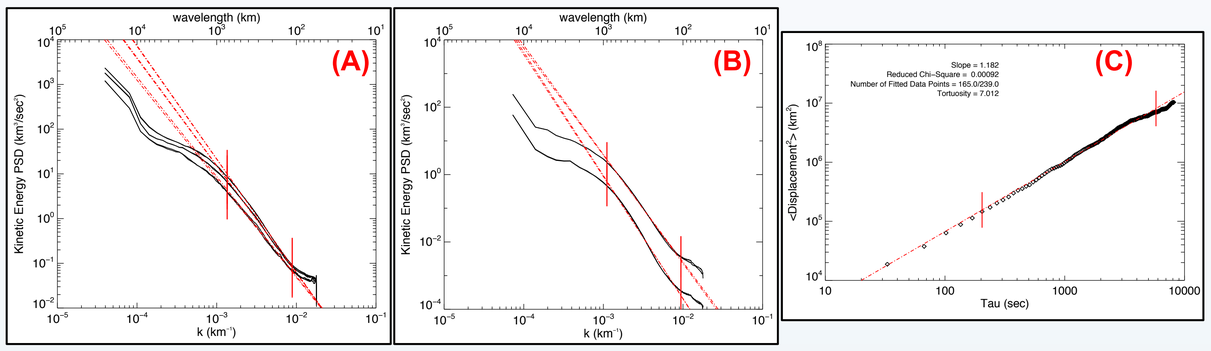

Fig 3: The temporally averaged kinetic energy PSD plots for all the subsets associated with Nov 30th (A) and Apr 25th (B). An example of the typical displacement spectrum is shown for Nov 30th (subset 1-even) in (C) without any filtering to remove bulk motion. The fitting range is indicated by the red vertical bars with fit lines shown as red dash lines.

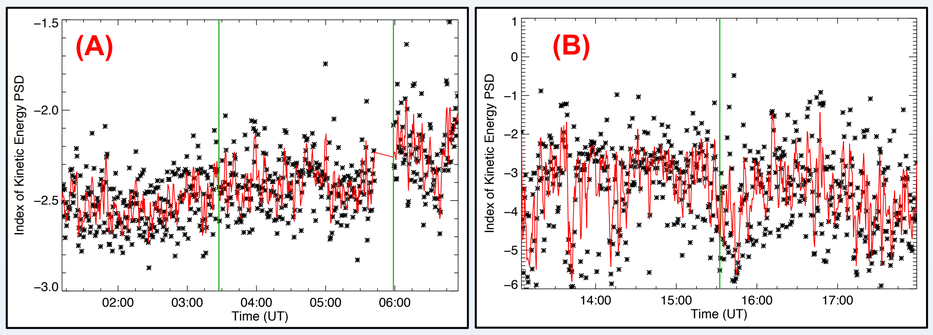

Fig.4: The temporal evolution of the kinetic energy PSD index for all the odd subsets associated with the Nov 30th (A) and Apr 25th (B) QP. The red line indicates the running or moving average of the data points and the vertical green line indicates the start of the next data subset. Results from Nov 30th (A) show a slight decrease in the PSD index with respect to time. Further investigation is necessary to explain this behavior. (B) illustrates the increase in noise found in the Hα data for Apr 25th.

Set Number	Even Set		Odd Set	
	Index ϒ (Unfiltered Data)	Index ϒ (Diffusive Motion)	Index ϒ (Unfiltered Data)	Index ϒ (Diffusive Motion)
Displacement Spectrum Information for Prominence on 2006 Nov 30				
1	1.182	0.921	1.198	0.908
2	1.309	0.900	1.381	0.942
3	1.326	0.966	1.300	0.924
Displacement Spectrum Information for Prominence on 2007 Apr 25				
1a/1b	1.616/1.556	1.010/1.231	1.528/1.568	1.070/1.231
2a/2b	1.548/1.350	1.111/0.769	1.541/1.372	1.129/0.814

Table 2: The displacement spectrum results with and without filtering to remove bulk motion.

Set Number	Even Set		Odd Set		Duration of Data (minutes)
	Index	Reduced Chi-Square	Index	Reduced Chi-Square	
Kinetic Energy Power Spectrum Information for Prominence on 2006 Nov 30					
1	-2.535 ± 0.003	3.309	-2.521 ± 0.003	2.689	135.5
2	-2.399 ± 0.003	2.264	-2.409 ± 0.003	2.482	135.4
3	-2.205 ± 0.006	0.543	-2.226 ± 0.006	1.291	56.7
Kinetic Energy Power Spectrum Information for Prominence on 2007 Apr 25					
1	-3.174 ± 0.015	0.483	-3.236 ± 0.015	0.741	177
2	-3.664 ± 0.013	2.431	-3.622 ± 0.012	2.537	177

Table 3: Kinetic Energy Power Spectrum Results

Conclusions

- **The resulting kinetic energy PSDs produced indices greater than those found from either Kolmogorov or Iroshnikov-Kraichnan turbulence theory.**
- **Both QPs show a consistent inertial range between a wavelength of 10-100km for PSDs.**
- **The displacement spectrum for the less noisy data on Nov 30th, showed super-diffusion behavior for the unfiltered results and then dropped to sub-diffusion after applying a filter to remove bulk motions.**

For More Information

Contact Info:

I will be at my poster between 2:00 to 3:45 on November 3rd.

Please feel free to text or email me if you have any questions or comments.

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