Edge zonal flows and blob propagation in Alcator C-Mod

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1. Introduction

Here we describe recent measurements of the 2-D motion of turbulence in the edge and scrape-off layer (SOL) of the Alcator C-Mod tokamak. These data were taken using the gas puff imaging (GPI) camera, which views a 6 cm radial by 6 cm poloidal region near the separatrix just below the outer midplane [1]. The data were taken in Ohmic or RF-heated L-mode plasmas at 391,000 frames/sec for ~100 msec/shot using a Phantom 710 camera in a 64x64 pixel format. The resulting 2-D vs. time movies [2] can resolve the structure and motion of the turbulence on a spatial scale covering 0.3-6 cm. The images were analyzed using either a 2-D cross-correlation code (Sec. 2) or a 2-D blob tracking code (Sec. 3).

2. Evidence for edge zonal flows

The time-resolved 2-D turbulence velocity was evaluated for these experiments using a cross-correlation analysis code similar to that used for NSTX [3]. The camera images for each frame were first normalized to a 20 msec-averaged frame to eliminate systematic pixel-to-pixel spatial variations due to the fiber bundle and optics. For each pixel for each frame, a short time series is created consisting of the normalized intensities at this pixel for ±5 frames, i.e. for ~25 μs. Then a cross-correlation of this time series is done with similar time series from all neighboring pixels within a 2-D box centered on the *following* frame; the size of this box is 8 pixels in each direction radially and poloidaly. The location of the maximum value of this 2-D cross-correlation within this box used to evaluate the radial and poloidal velocity for each pixel for each frame, up to a limit of 8 pixels/frame, i.e. ~2.6 km/sec. These velocities are then averaged over a poloidal range of 4 cm to obtain a 'zonal' average of these velocities within the GPI field of view. The frequency response of this analysis of velocity is ≤ 30 kHz, set by the 25 μs duration of the correlation time interval.

Figure 1 shows frequency spectra vs. time of the resulting poloidally-averaged V_{pol} for two different shots. For the RF-heated, 1.0 MA, 5.3 T shot at the left (#1110114026) there is a near-coherent oscillation in the V_{pol} (amplitude) spectrum at ~ 6-7 kHz, while for the 0.8 MA, 3.6 T Ohmic shot at the right (#110110025) the spectrum of V_{pol} is broadband with intermittent bursts at many frequencies. The frequency of the coherent mode corresponds to a peak in the spectrum of a B_{pol} magnetic coil, and the slight increase in frequency at 0.911-0.912 sec is coincident with a sawtooth crash; however, other peaks in the B_{pol} spectrum do not correspond to coherent V_{pol} peaks. The shot at the right had a similarly large coherent magnetic mode but did not have a corresponding V_{pol} peak, and the broadband spectrum in V_{pol} did not correspond to the B_{pol} spectrum. Thus there is only a partial correlation between magnetic modes and peaks in the V_{pol} spectrum of GPI.

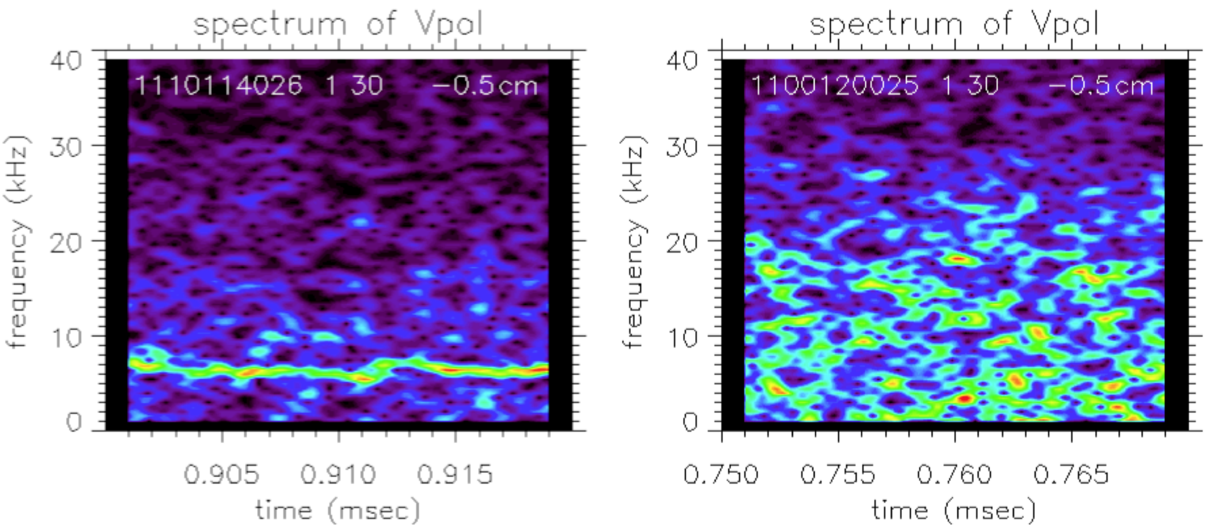

Fig. 1 - Frequency spectra of V_{pol} vs. time from the poloidally-averaged GPI data at ρ = - 0.5 cm.

Figure 2 shows the radial profiles of these frequency spectra for these same shots at a fixed time. The coherent mode at 6-7 kHz in the shot at the left extends over the radial range ρ ~ -1.5 cm to 0 cm at this time, and at other times extends out to ρ ~ 1.0 cm. However, in the shot at the right the structures in V_{pol} are localized within the ρ ~ ± 0.5 cm. The detailed structure of the frequency spectrum in the latter case varies with time, as can be seen in movies of these radially-resolved spectra in [2].

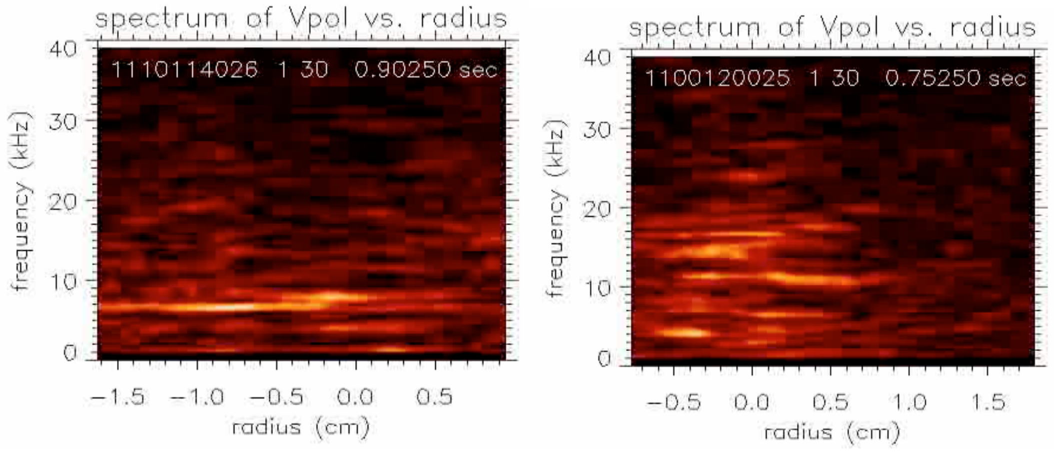

Fig. 2 - Frequency spectra of V_{pol} vs. radius from the poloidally-averaged GPI data at one time.

3. Blob tracking vs. cross-correlation

A separate code was used to track the 2-D motion of blob structures, which are defined here as space-time regions in which the normalized GPI signal is above some threshold level (e.g. 1.2 time the normalized level). The blob centers (i.e. local maxima) are calculated for each frame, and the blob velocities are calculated for each pair of frames in which the blob is tracked. This algorithm typically identifies ~1 blob/frame, so there are ~5000 blob velocities calculated for each 20 msec analysis time for each shot. Figure 3 shows a comparison of the time-averaged poloidal velocity determined by blob tracking with the time-averaged V_{pol} determined from the cross-correlation analysis for the same two shots as in Figs. 1 and 2. Even though the algorithms for velocity are completely different, the average poloidal velocities agree well in these (and all other) shots. The "error bars" in the V_{pol} from cross-correlation show the RMS values of the fluctuating components of the poloidally-averaged V_{pol} for each radius, which are comparable to the mean (i.e. time-averaged) V_{pol} at each radius.
Fig. 3 - Radial profiles of the time-averaged V_{pol} from cross-correlation (red) blob tracking (blue). The "error-bars" give the RMS fluctuations about the poloidally-averaged mean V_{pol}.

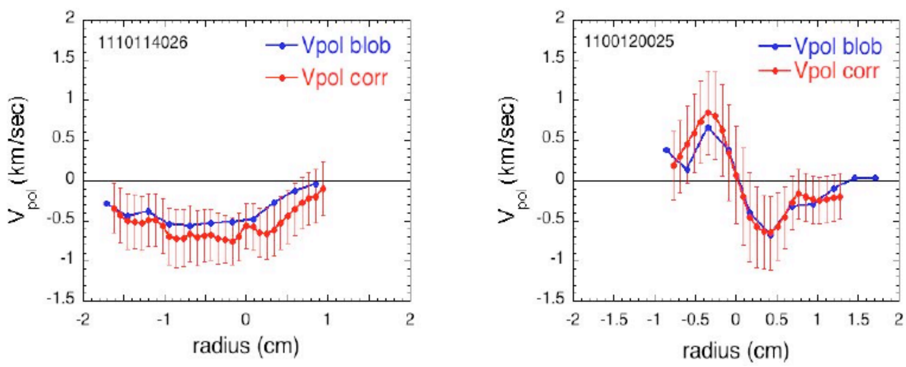

Fig. 3 - Radial profiles of the time-averaged V_{pol} from cross-correlation (red) blob tracking (blue). The "error-bars" give the RMS fluctuations about the poloidally-averaged mean V_{pol}.

4. Summary and Discussion

In this paper the time-dependent poloidal velocity of turbulence flows in the outer midplane GPI field of view of C-Mod was evaluated for Ohmic and RF-heated L-mode plasmas using a simple cross-correlation technique. The V_{pol} frequency spectra in some shots had a nearly coherent peak at ~6-7 kHz (e.g. left side of Fig. 1), but in most shots had a broadband, intermittent spectrum over ~2-20 kHz (e.g. right side of Fig. 1). The radial structure of the coherent peak can extended over the whole range of the GPI view, while the broadband structures are localized within ±0.5 cm of the separatrix, as shown in Fig. 2. The coherent mode at 6-7 kHz was nearly the same frequency as a peak in the B_{pol} spectrum, but not all magnetic modes in the B_{pol} spectrum had corresponding V_{pol} peaks. The mean poloidal velocities determined from this cross-correlation process agreed well with the mean poloidal velocity of the blob structures, as illustrated in Fig. 3 for the same two shots.

It is not quite clear whether these fluctuating poloidal flows are true zonal flows (i.e. m=0) since they are only observed over the GPI viewing area. The coherent oscillation in V_{pol} might be caused by the MHD mode at the same frequency, or it may be a GAM-like mode with a magnetic component. The estimated frequency of the electrostatic GAM for this type of Alcator C-Mod plasma for T_i=T_e=50 eV is f~20 kHz; however, this is uncertain to at least a factor of two. Since the coherent mode in V_{pol} has so far only been observed in discharges with RF minority heating, it is possible that the coherent mode in V_{pol} is related to an energetic particle driven EGAM [4]. The broadband and intermittent V_{pol} spectra seen in other cases may also be associated with a spatially-localized edge zonal flows with an autocorrelation times of ~ 1 msec.

References

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