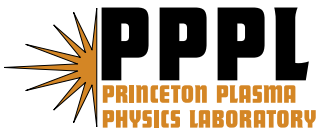

Princeton Plasma Physics Laboratory

PPPL-

PPPL-



Prepared for the U.S. Department of Energy under Contract DE-AC02-09CH11466.

Princeton Plasma Physics Laboratory

Report Disclaimers

Full Legal Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Trademark Disclaimer

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

PPPL Report Availability

Princeton Plasma Physics Laboratory:

<http://www.pppl.gov/techreports.cfm>

Office of Scientific and Technical Information (OSTI):

<http://www.osti.gov/bridge>

Related Links:

[U.S. Department of Energy](#)

[Office of Scientific and Technical Information](#)

[Fusion Links](#)

Edge zonal flows and blob propagation in Alcator C-Mod

S.J. Zweben¹, J.L. Terry², M. Agostini³, B. Davis¹, O. Grulke⁴, R. Hager⁵,
J. Hughes², B. LaBombard², D.A. D'Ippolito⁵, J.R. Myra⁵, D.A. Russell⁵

¹*Princeton Plasma Physics Laboratory, Princeton NJ 08540*

²*Massachusetts Institute of Technology, Cambridge MA 02139*

³*Consorzio RFX, Associazione EURATOM, I-35127, Padova Italy*

⁴*Max Planck Institute for Plasma Physics, D-17489, Greifswald, Germany*

⁵*Max Planck Institute for Plasma Physics, D-85748 Garching, Germany*

⁵*Lodestar Research Corporation, 2400 Central Ave., Boulder CO 80301*

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. This data was taken using the outer midplane 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 400,000 frames/sec for ~50 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 μ s. Then a cross-correlation of this time series is done with similar time series from each of ± 8 neighboring pixels in a 2-D box centered on the *following* frame. The location of the maximum value of this 2-D cross-correlation is 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 $25 \mu\text{s}$ correlation time.

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.

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 $\rho \sim -1.5$ cm to 0 cm at this time, and at other times extends out to $\rho \sim 1.0$ cm. However, in the shot at the right the structures in V_{pol} are localized within the $\rho \sim \pm 0.5$ cm. The detailed structure of the frequency spectrum in the latter case varies with time, as can be seen in [2].

3. Blob tracking

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. The blob statistics are insufficient to calculate a frequency spectrum for the poloidal blob velocity.

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 $\sim 6\text{-}7$ kHz (e.g. left side of Fig. 1), but in most shots had a broadband, intermittent spectrum over $\sim 2\text{-}20$ kHz (e.g. right side of Fig. 1). The radial structure of the coherent peak at the left extended over the whole range of the GPI view, while the broadband structures at the right were 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 $f\sim 20$ 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 most other cases may also be associated with a zonal flow with an autocorrelation time of ~ 1 msec.

References

- [1] J.L. Terry et al, Phys. Plasmas 10, 1739 (2003)
- [2] see <http://www.pppl.gov/~szweben/CMod2010/CMod2010.html>
- [3] S.J. Zweben, R.J. Maqueda et al, Phys. Plasmas 17, 102502 (2010)
- [4] R. Nazikian et al, Phys. Rev. Lett. 101, 185001 (2008); G.Y. Fu, Phys. Rev. Lett. 101, 185002 (2008)

Acknowledgments: This work was supported in part by US DOE Contracts DE-AC02-09CH11466 and DE-FC02-99ER5412. We thank D. Pace and T. Golfinopoulos of MIT for their help with the MHD analysis.

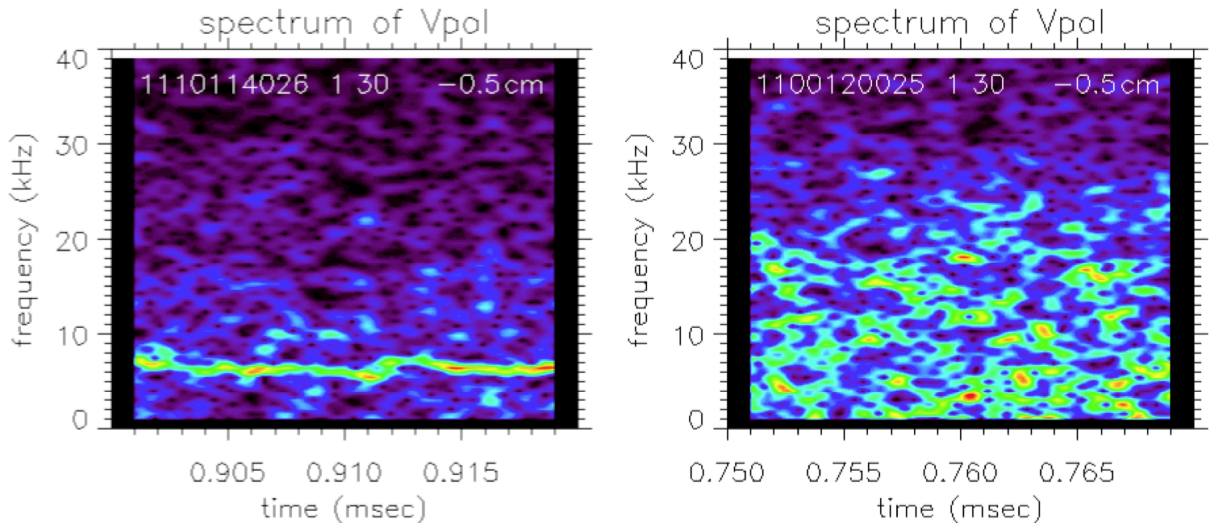


Fig. 1 - Frequency spectra of V_{pol} vs. time from the poloidally-averaged GPI data at $\rho = -0.5$ cm.

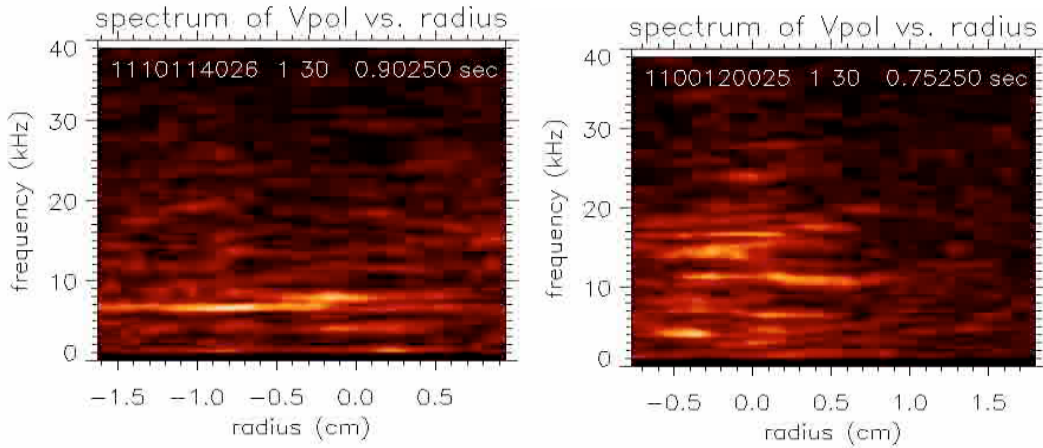


Fig. 2 - Frequency spectra of V_{pol} vs. radius from the poloidally-averaged GPI data at one time.

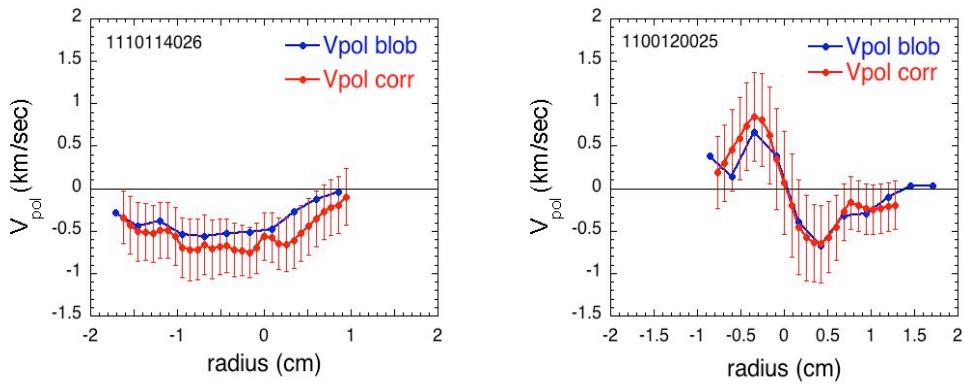


Fig. 3 - Radial profiles of the time-averaged V_{pol} from cross-correlation vs. blob tracking.

The Princeton Plasma Physics Laboratory is operated
by Princeton University under contract
with the U.S. Department of Energy.

Information Services
Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, NJ 08543

Phone: 609-243-2245
Fax: 609-243-2751
e-mail: pppl_info@pppl.gov
Internet Address: <http://www.pppl.gov>