

2-D Analysis of Edge Turbulence Velocity and Blobs in C-Mod

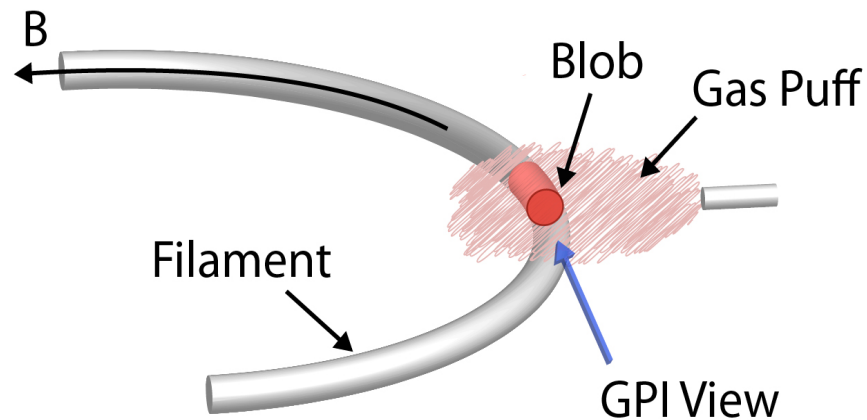
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¹ PPPL -- ² MIT -- ³ RFX -- ⁴ IPP -- ⁵ Lodestar

- Correlation analysis showing multi-frequency zonal flow
- Blob analysis vs. correlation analysis of 2-D velocity
- Correlation of poloidal and radial velocities

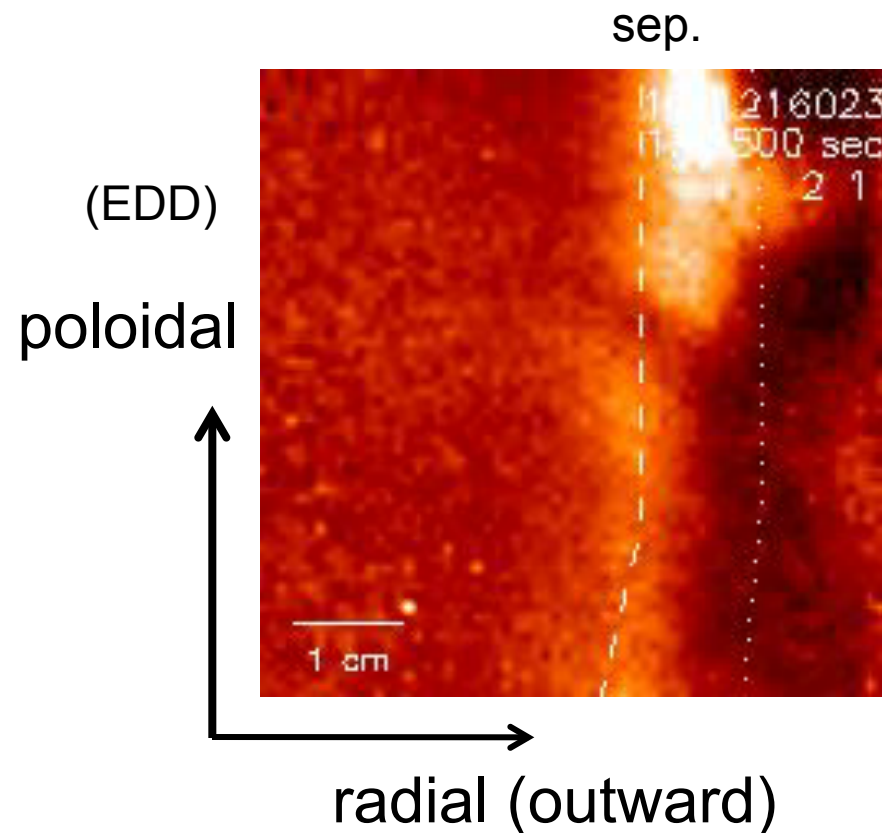
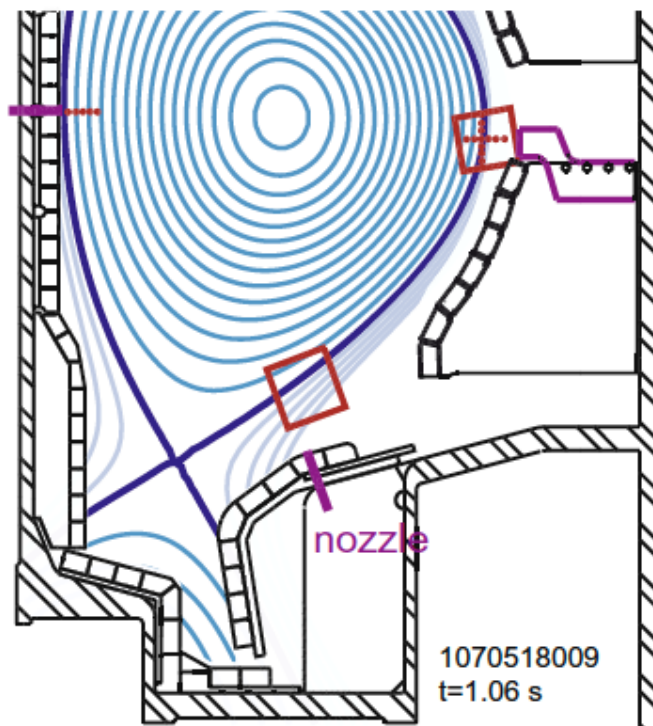
Gas Puff Imaging (GPI) Diagnostic

- Optics view along B toward D_α emission from D_2 gas puff
- Oriented to view 2-D radial vs. poloidal plane at gas cloud



Alcator C-Mod Gas Puff Imaging

- This movie 400,000 frames/sec (normalized to average)
- Viewing area ~ 6 cm radially x 6 cm poloidally



What Are We Seeing in GPI ?

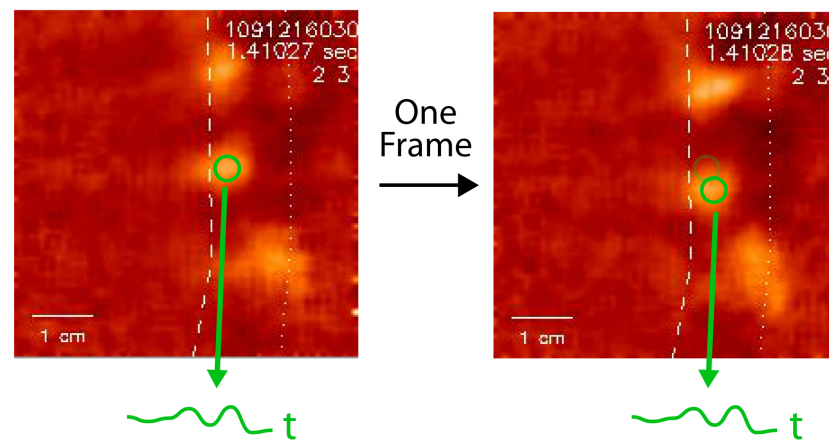
- Seeing local emission of $D_\alpha \sim n_o f(n_e, T_e)$ within window where D_α is emitted in plasma edge, where $T_e \sim 10 - 100$ eV
- Can measure 2-D **turbulence structure and motion** even if response of D_α is nonlinear (like contrast knob on a TV)
- Can **not directly measure fluid (ion) flow** or ExB flow, but measures turbulence flow velocity, as done previously*

* McKee et al, PoP '03 using BES on DIII-D

Conway et al, PPCF '05 using Doppler reflectometry on AUG

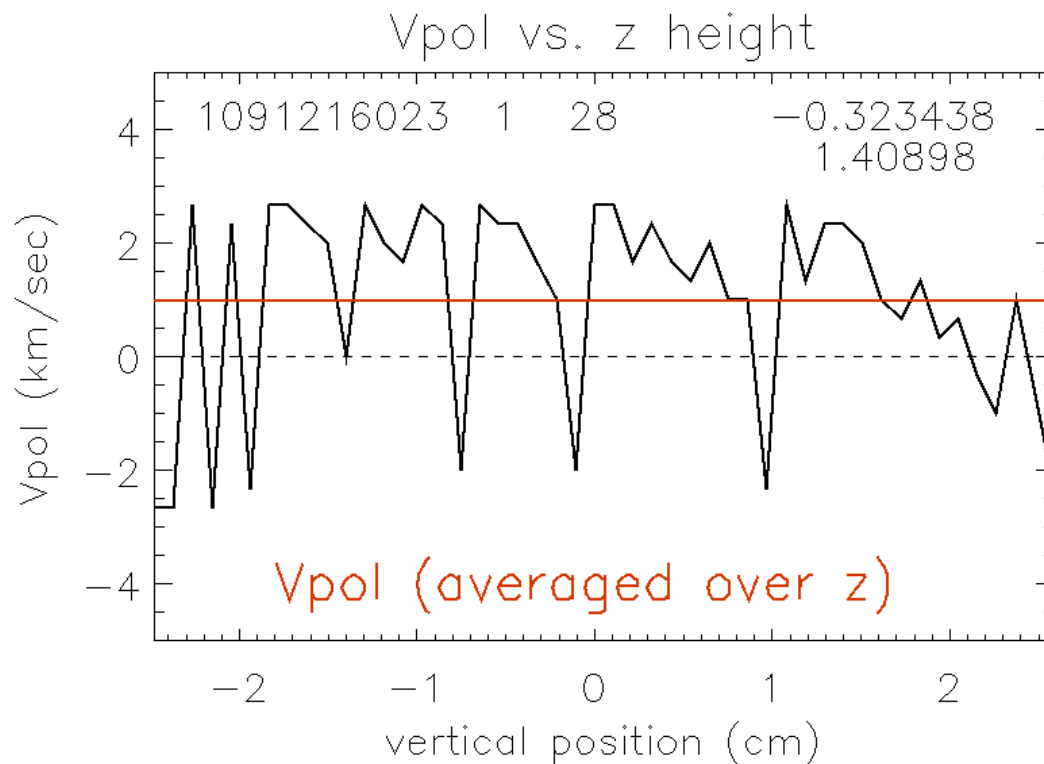
Method to Evaluate Turbulence Velocity

- for each pixel in each frame, make a short time series of the GPI signal at that pixel over ± 3 frames or $18 \mu\text{s}$ total
- find best match to this time series in pixels of the next frame
- find V_{rad} and V_{pol} from relative displacement of best match
- produces 2-D velocity field with time resolution $\sim 40 \text{ kHz}$



Poloidal Velocity vs. Poloidal Position

- Estimate 'zonal flows' by averaging V_{pol} over $z \sim 5$ cm
- Typical result has significant poloidal variations of V_{pol}
- Average over these variations to get $V_{\text{pol}}(\text{radius}, \text{time})$



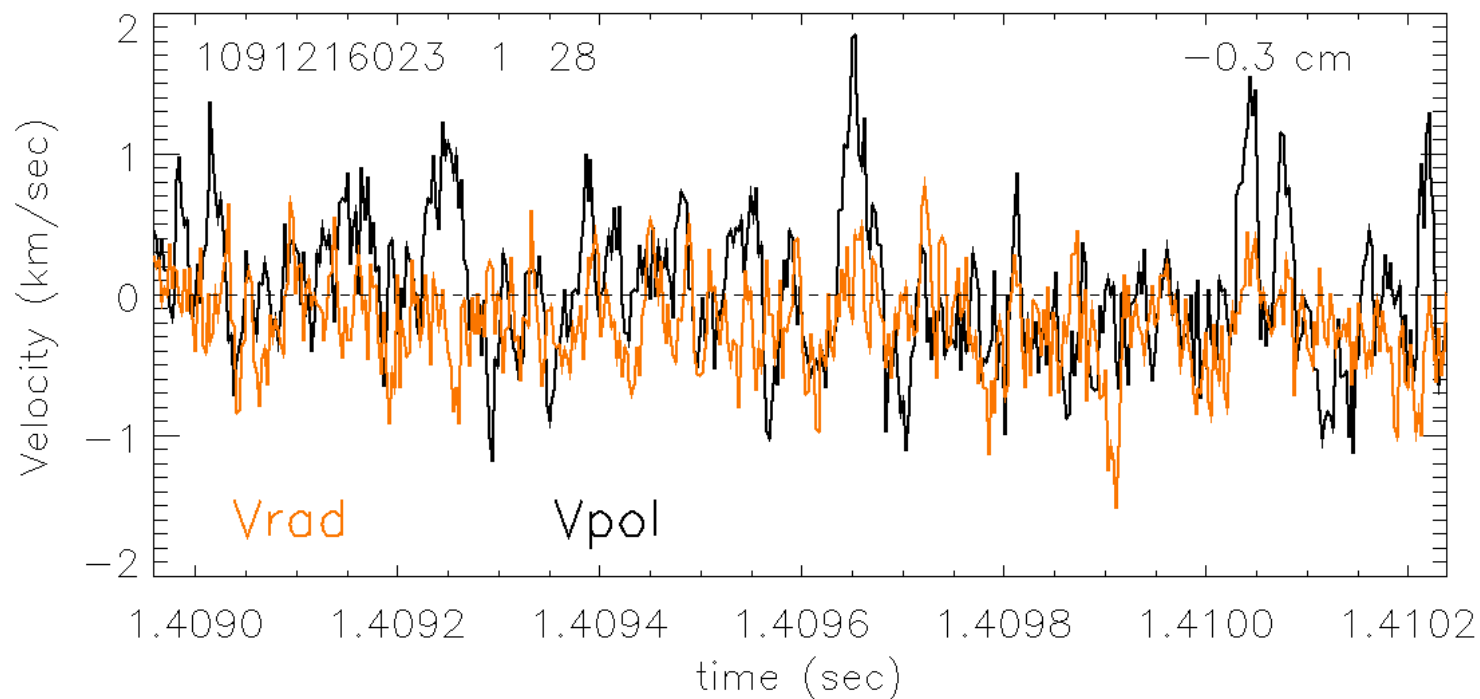
one time frame:

V_{pol} vs. z (black)

V_{pol} (ave) red

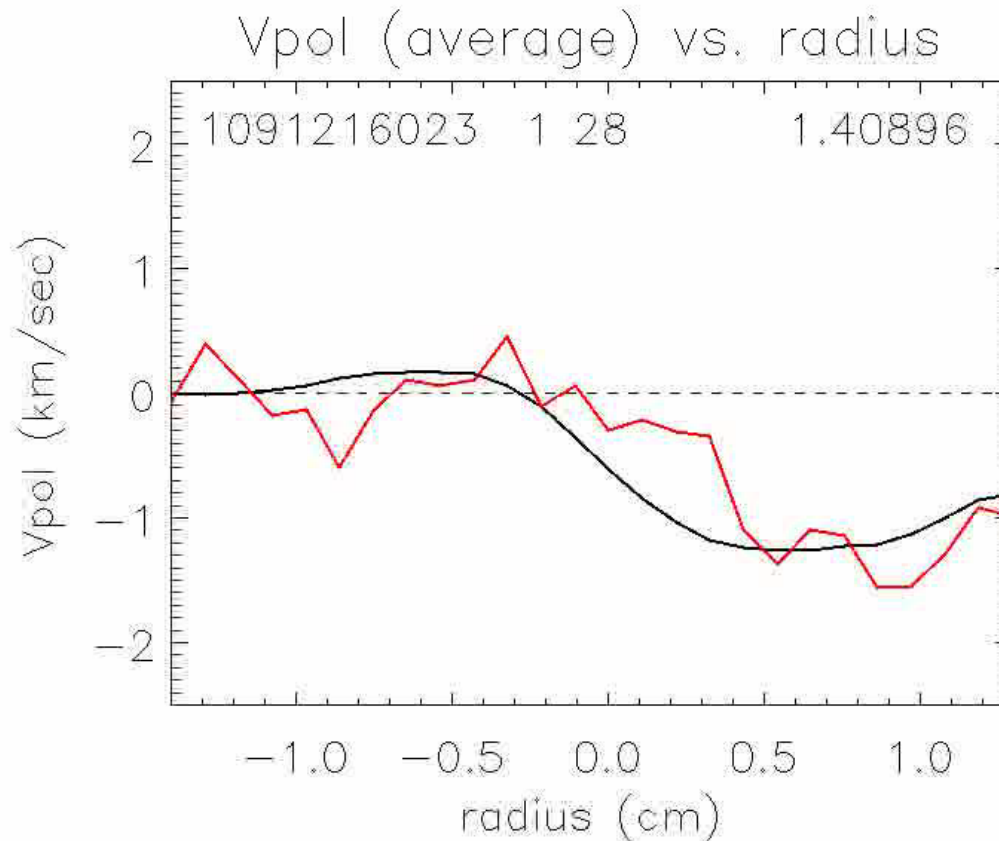
Poloidally Averaged Velocity vs. Time

- V_{pol} (black) and V_{rad} (orange) and for $\rho \sim 0$ cm
- Some cross-correlation between V_{pol} and V_{rad}



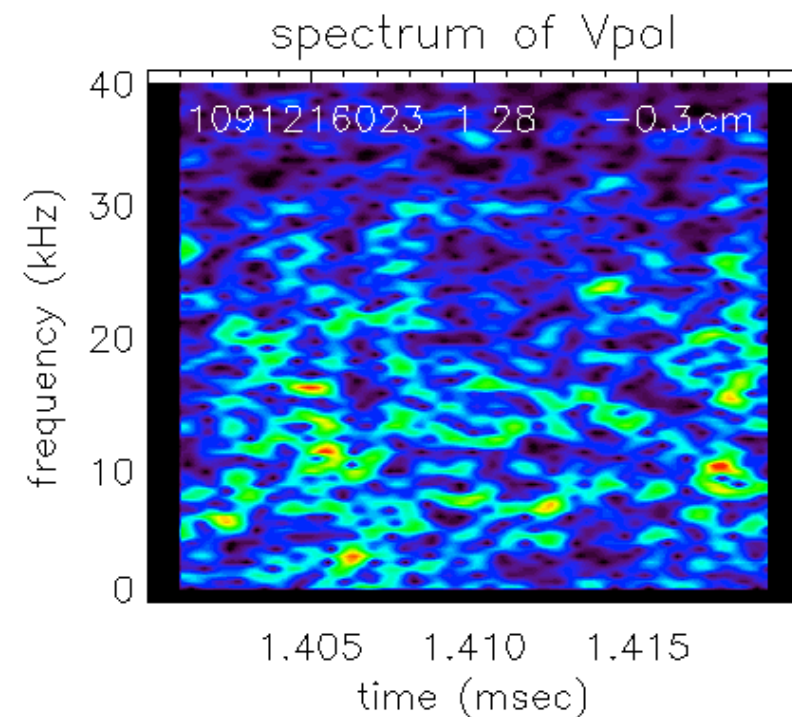
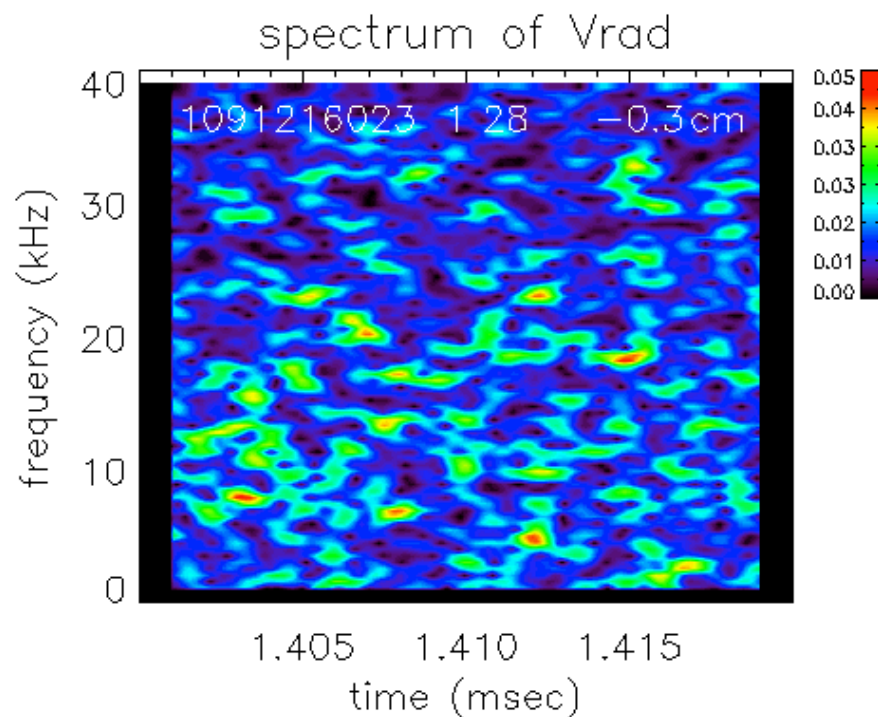
Radial Profiles of Poloidal Velocities

- Poloidal velocity fluctuations \sim time-averaged velocities
- Implies fluctuating “zonal flow” \sim time-averaged velocity



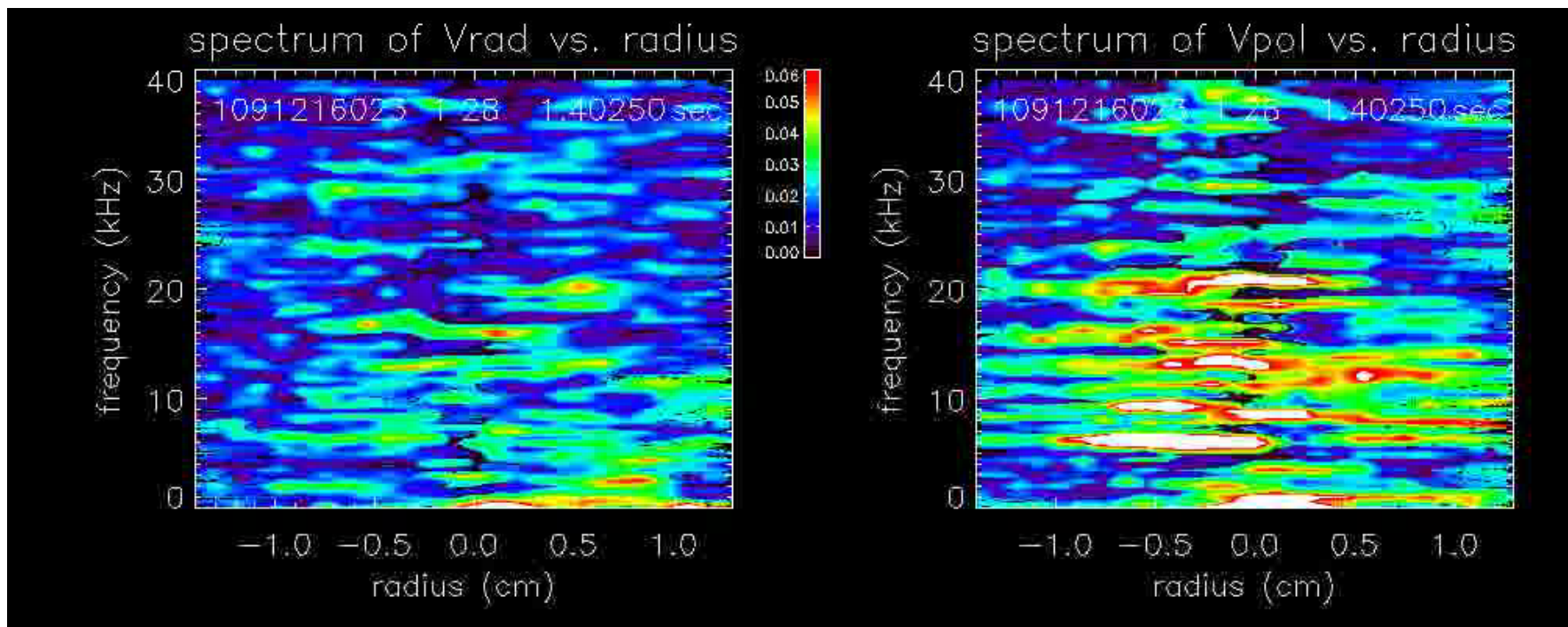
Time Dependence of Velocity Spectra

- No clear spectral features lasting more than ~ 1 msec
- Looks similar at other radii and for other similar shots



Radial Profile of Velocity Spectra

- Spectra of V_{pol} seems to have intermittent harmonic structure
- This structure seems localized within ± 1 cm of separatrix



Theoretical GAM Frequency for C-Mod

- GAM frequency $f = G c_s / (\pi R)$ with G =geometric factor,
 $R = R_o + r$, and $c_s = [\gamma(T_i + T_e) / m_i]^{1/2}$

where $G \sim (2^{-1/2}) (2 / (1 + \kappa)) (1 + 1 / (2A^{2/3})) (1 + 1 / (4q^2))$

for C-Mod with $A=3$, $\kappa=1.6$, $q=3$, $T_e=T_i=50$ eV, $\gamma=4/3$ and $m_i=2$

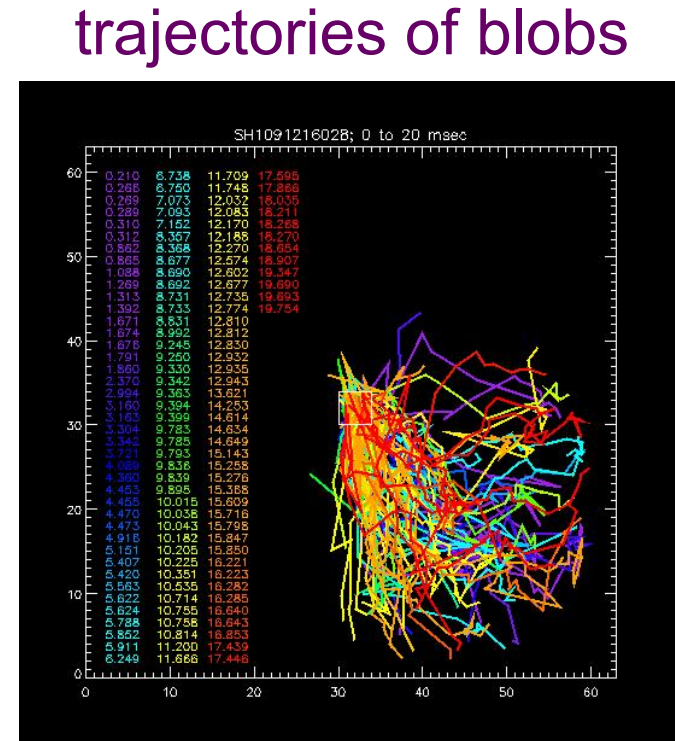
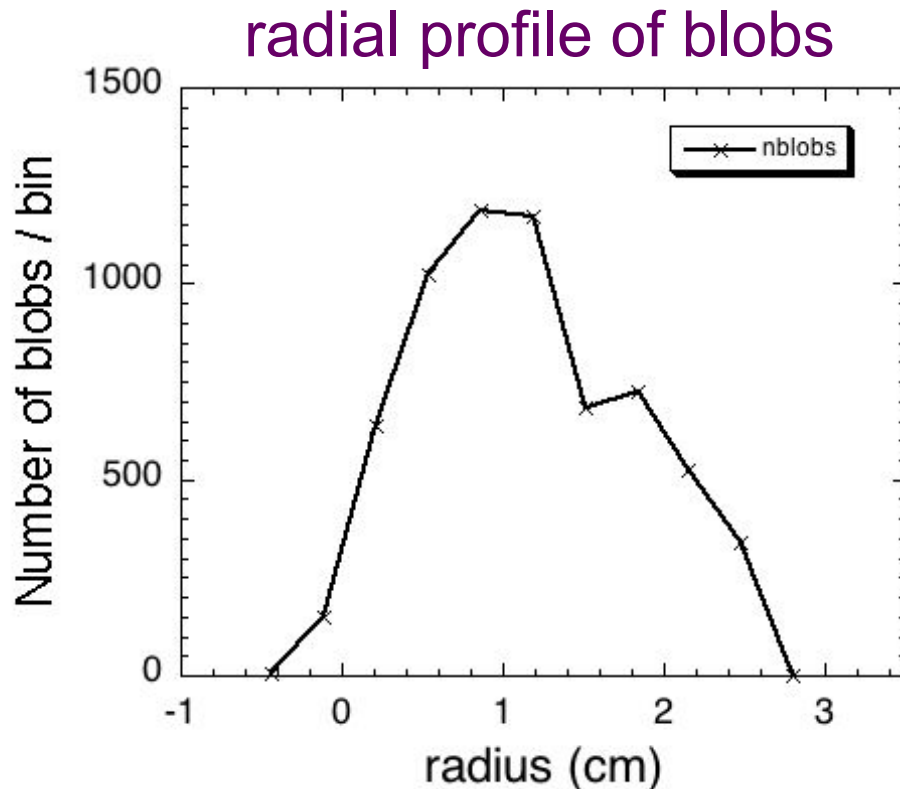


$$f_{\text{GAM}} \sim 20 \text{ kHz}$$

- These analytic values (from R. Hager) can still deviate a factor-of-two from experiment (Hallatschek PPCF 2007)¹¹

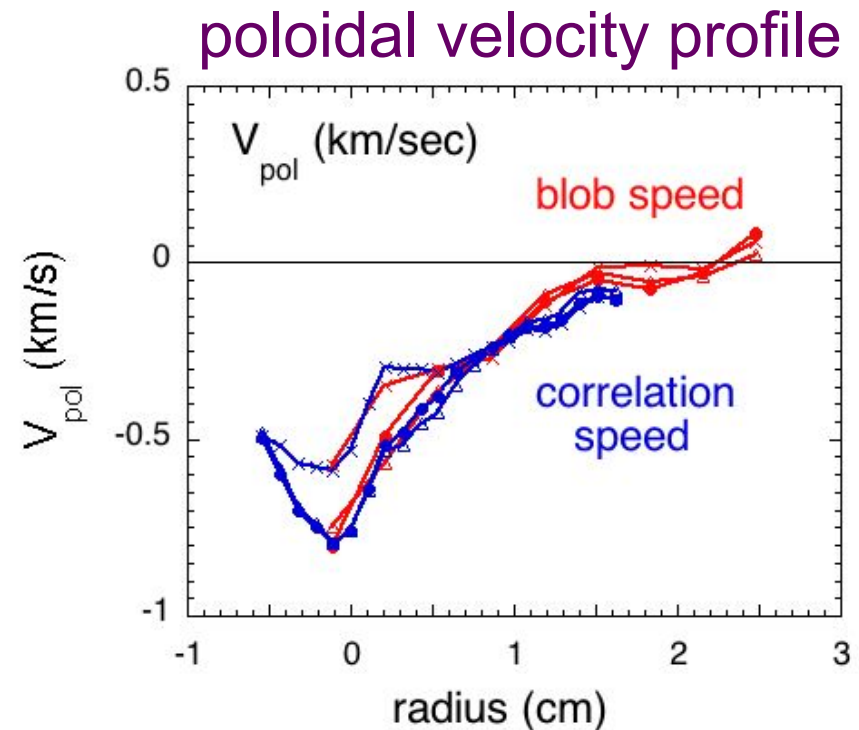
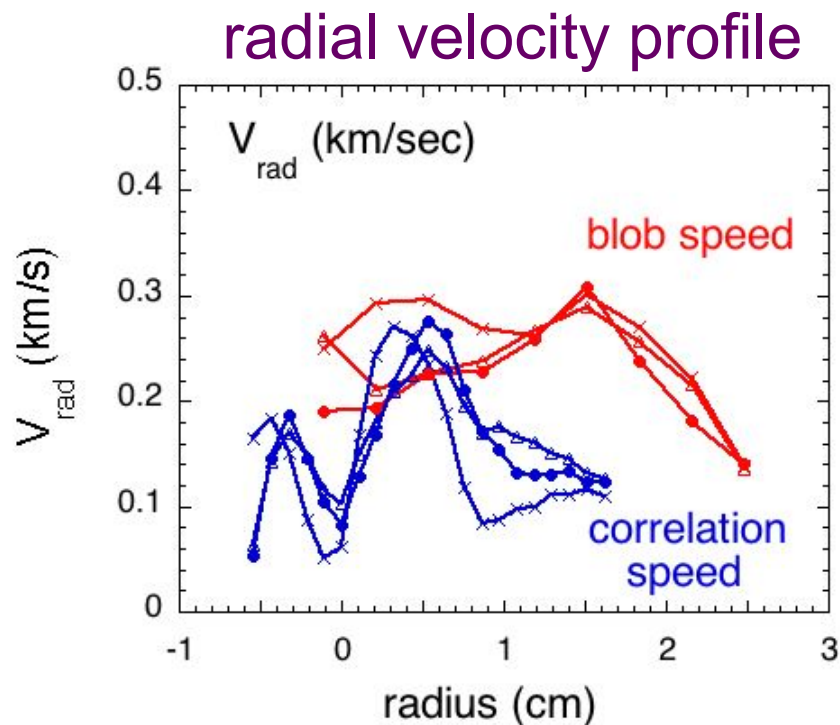
Blob Analysis of C-Mod GPI Data

- Choose threshold for blob detection (e.g. 1.2 x average)
- Calculate 2-D velocities from blob trajectories (~ 3 / frame)



Blob Analysis vs. Correlation Analysis

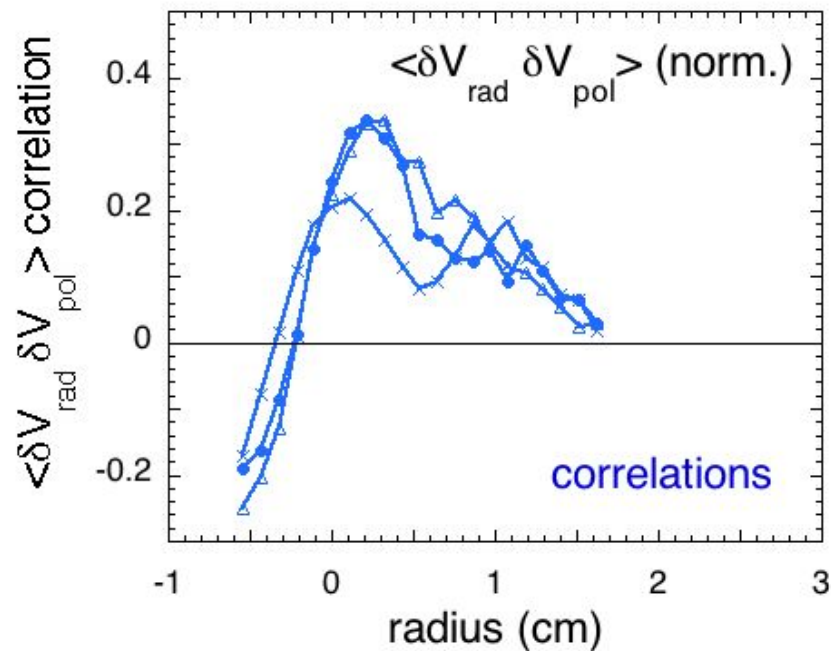
- Choose threshold for blob detection (e.g. 1.2 x average)
- Calculate 2-D velocities from blob trajectories ($\sim 3/\text{frame}$)
- See also Agostini et al (Friday am) for more comparisons



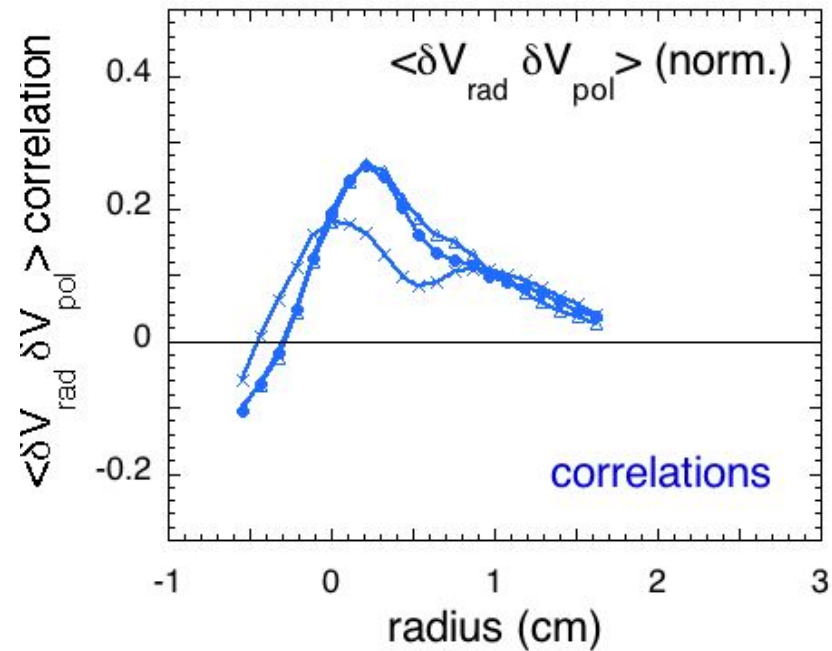
Correlation of Radial and Poloidal Velocity

- Can calculate $\langle \delta V_{\text{rad}} \delta V_{\text{pol}} \rangle$ either zonal-averaged or locally
- If RS $d/dr \langle \delta V_{\text{rad}} \delta V_{\text{pol}} \rangle = \nu V_{\text{pol}}$, then $\nu \sim 10^3 \text{ sec}^{-1}$ in SOL

zonal correlations



local correlations



Summary of 2-D Velocity Analysis

- Possible intermittent, multiple-frequency zonal-like flows seen near separatrix in at least some (not all) cases
- Velocities from blob-tracking similar to correlation method (both radially outward and in IDD in SOL, as expected)
- Correlation between V_{rad} and V_{pol} in SOL consistent with Reynolds stress-driven flows assuming $\nu \sim 10^3 \text{ sec}^{-1}$

Still very much to learn !