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

S.J. Zweben[1], J.L. Terry[2], M. Agostini[3], B. Davis[1], O. Grulke[4], B. LaBombard[2], D.A. D'Ippolito[5], J.R. Myra[5], D.A. Russell[5]

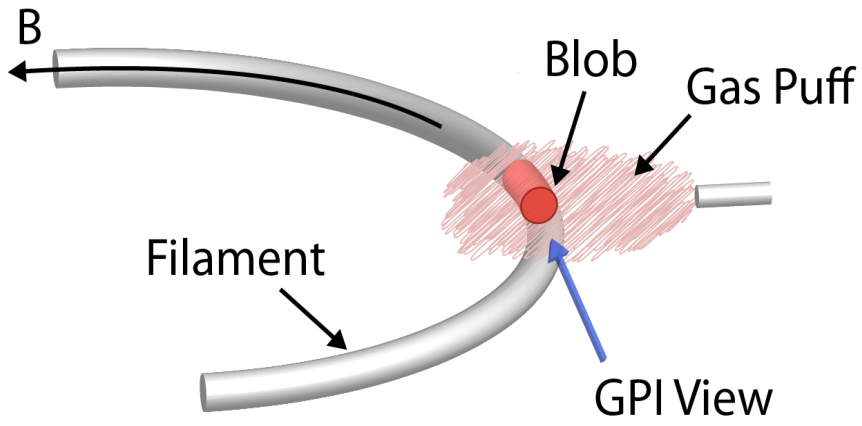
[1] PPPL -- [2] MIT -- [3] RFX -- [4] IPP -- [5] Lodestar

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

TTF Apr. 9, 2011

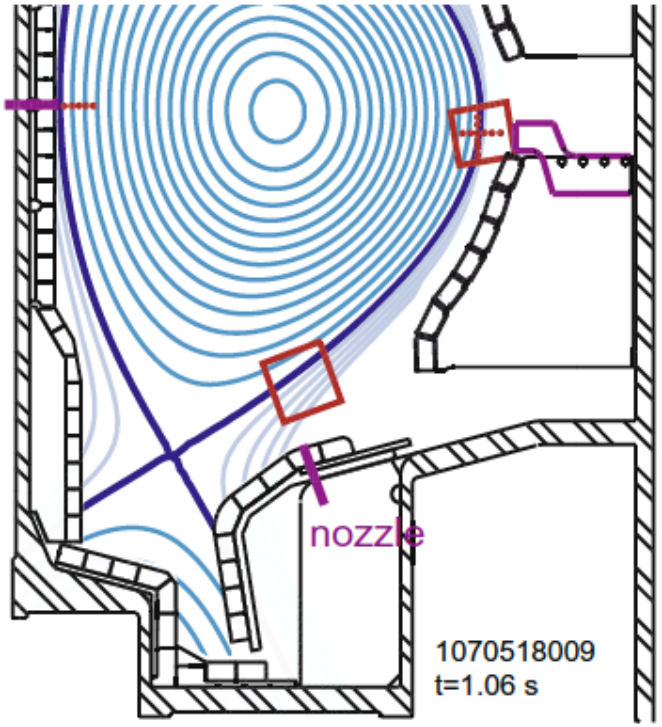
Gas Puff Imaging (GPI) Diagnostic

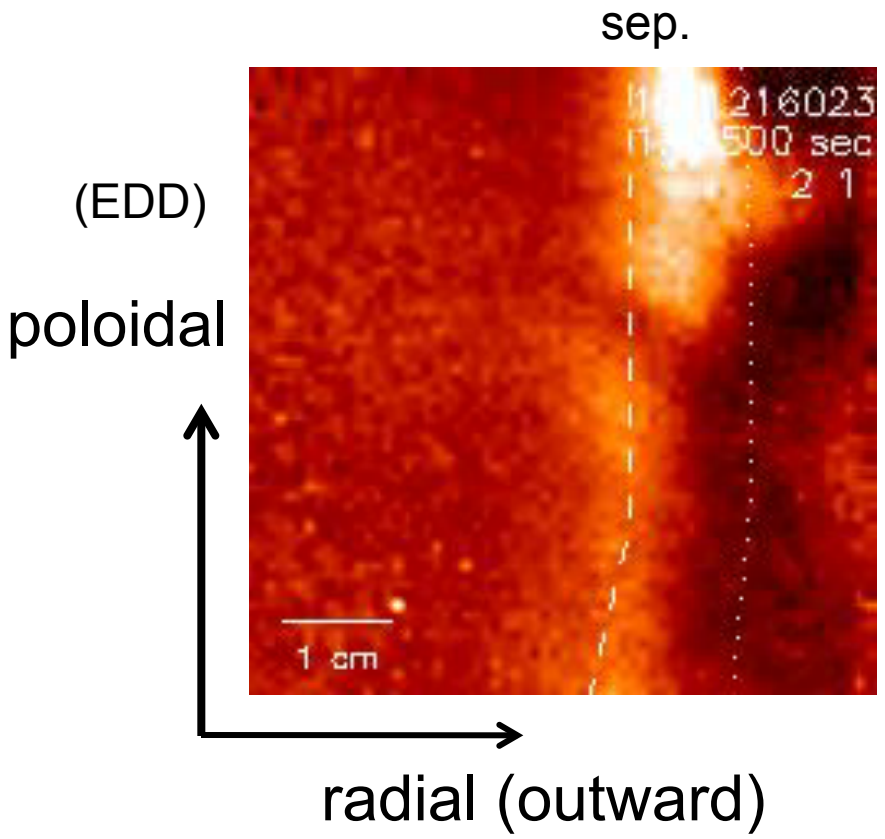
- Optics view along B toward D_α emission from D_2 gas puff
- Oriented to view 2-D radial vs. poloidal plane at gas cloud



Alcator C-Mod Gas Puff Imaging

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





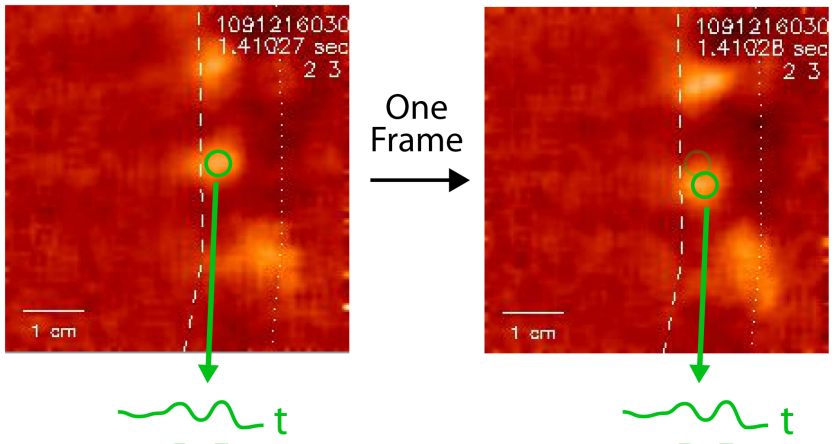
What Are We Seeing in GPI ?

- 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

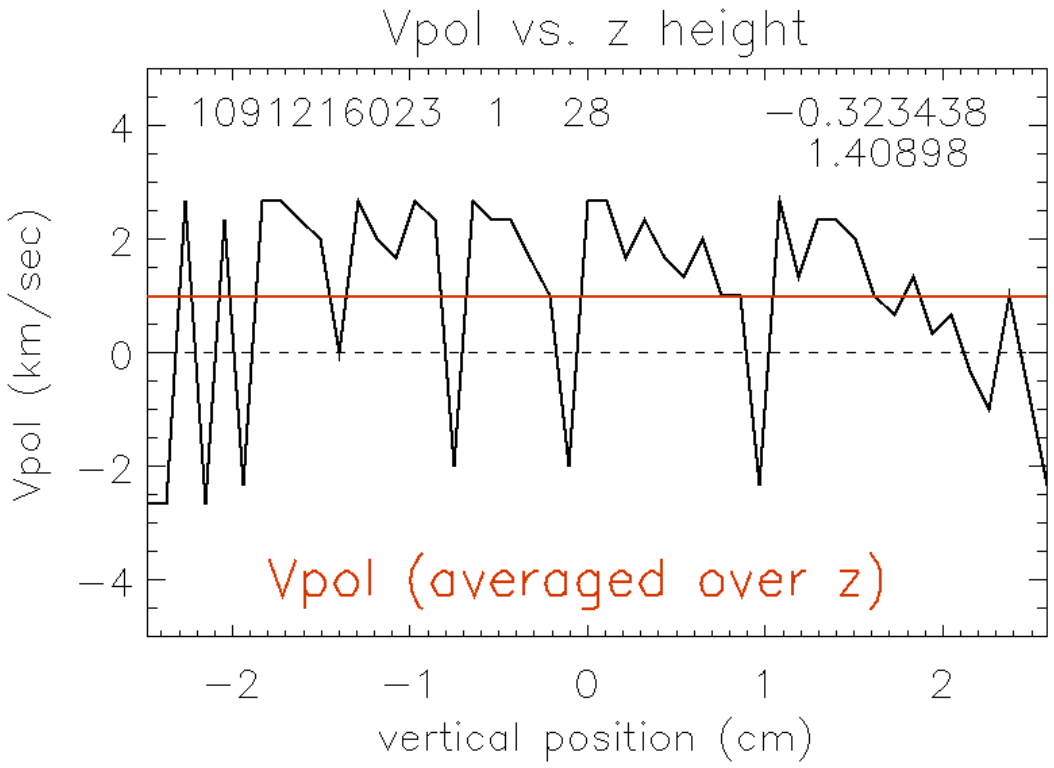
Method to Evaluate Turbulence Velocity

- for each pixel in each frame, make a short time series of the GPI signal at that pixel over ± 3 frames or 18 μs 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 ~ 40 kHz



Poloidal Velocity vs. Poloidal Position

- Estimate ‘zonal flows’ by averaging V_{pol} over z ~ 5 cm
- Typical result has significant poloidal variations of V_{pol}
- Average over these variations to get V_{pol}(radius, time)



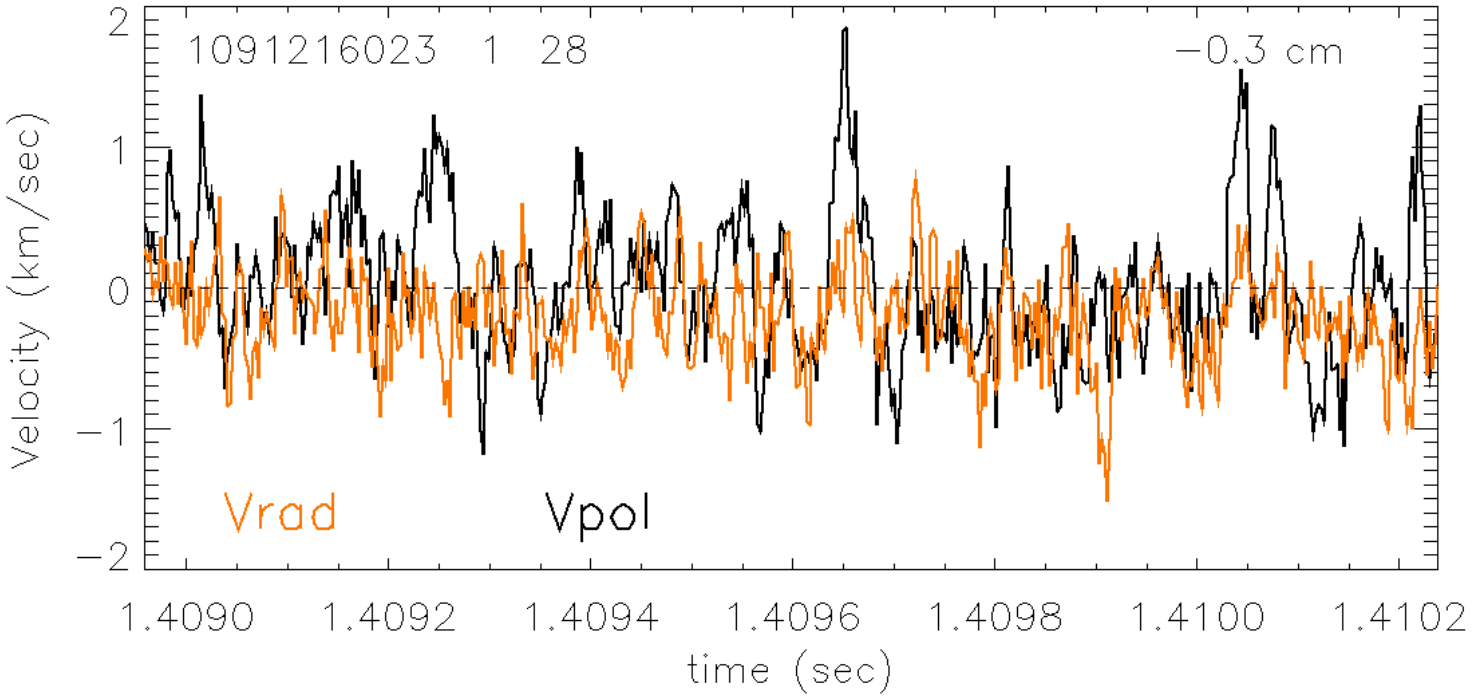
one time frame:

V_{pol} vs. z (black)

V_{pol} (ave) red

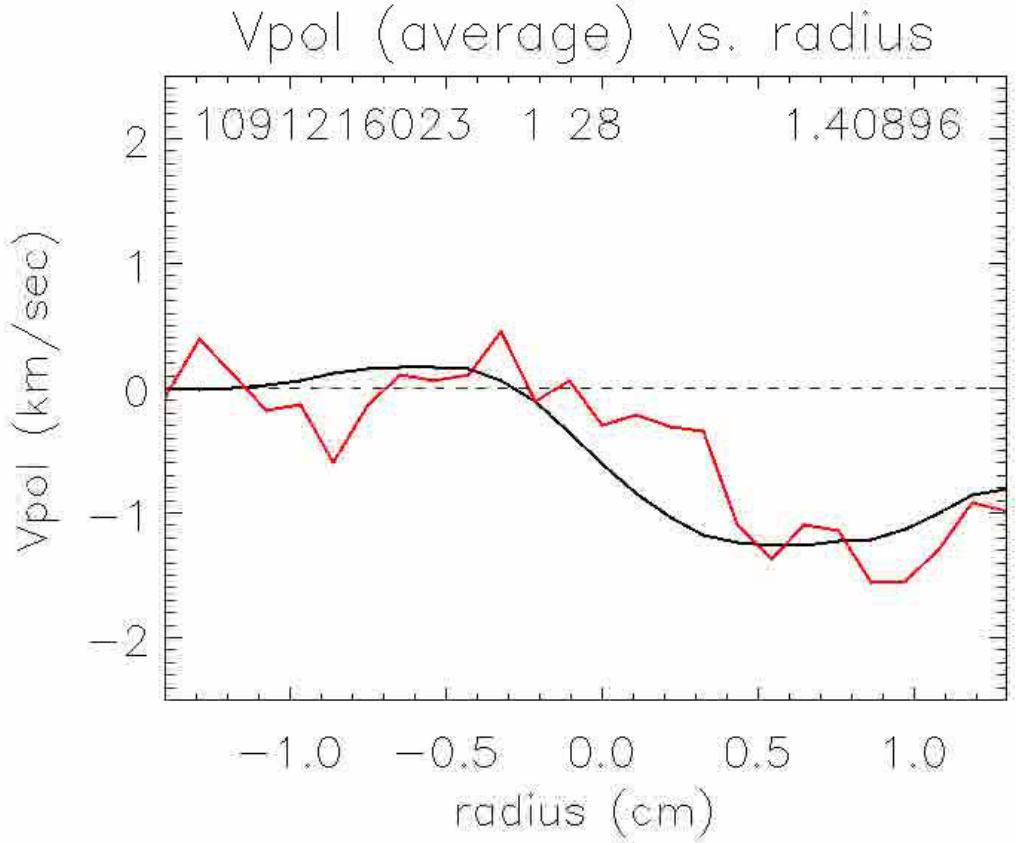
Poloidally Averaged Velocity vs. Time

- V_{pol} (black) and V_{rad} (orange) and for ρ ~ 0 cm
- Some cross-correlation between V_{pol} and V_{rad}



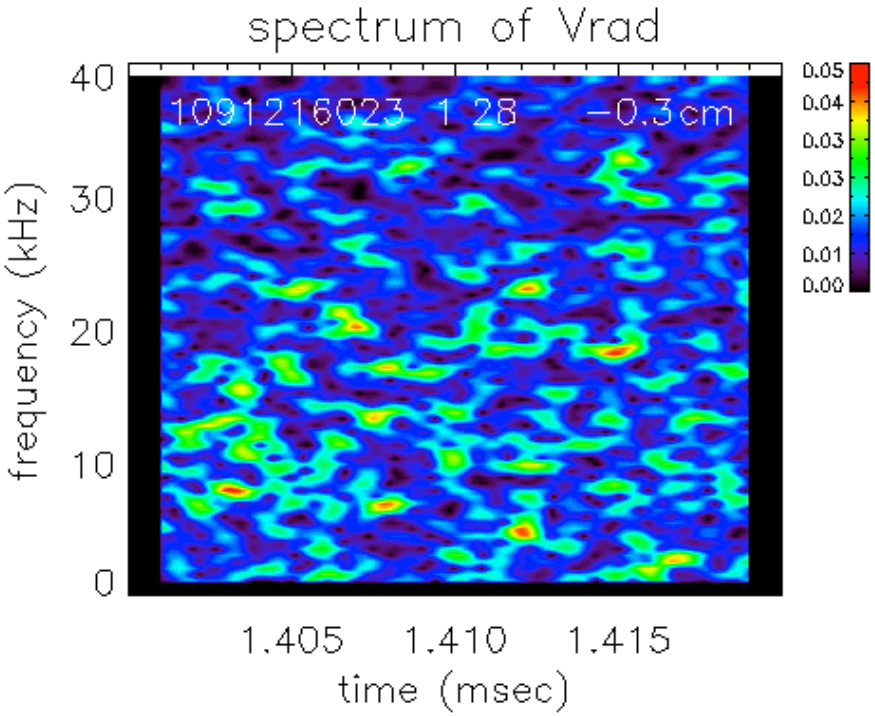
Radial Profiles of Poloidal Velocities

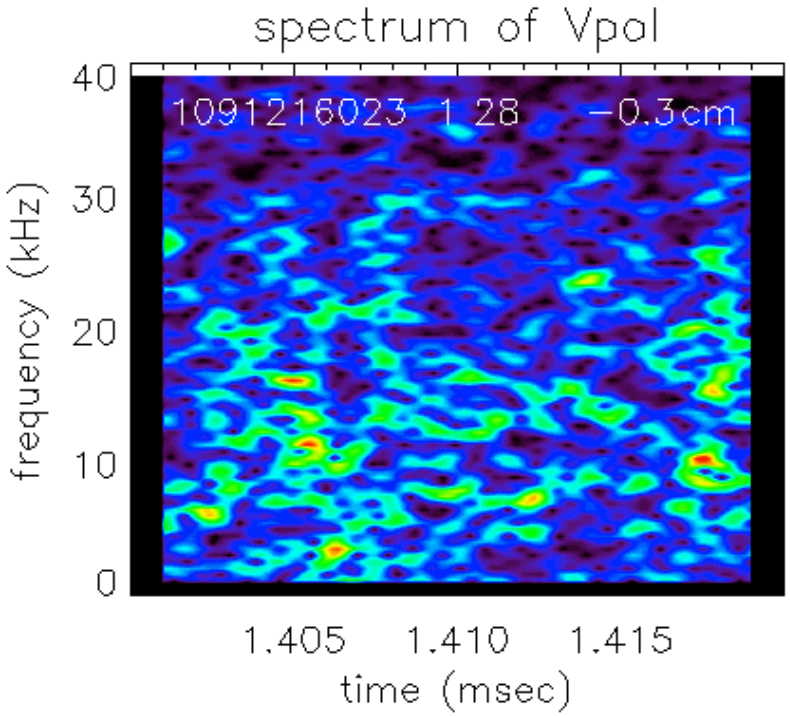
- Poloidal velocity fluctuations ~ time-averaged velocities
- Implies fluctuating “zonal flow” ~ time-averaged velocity



Time Dependence of Velocity Spectra

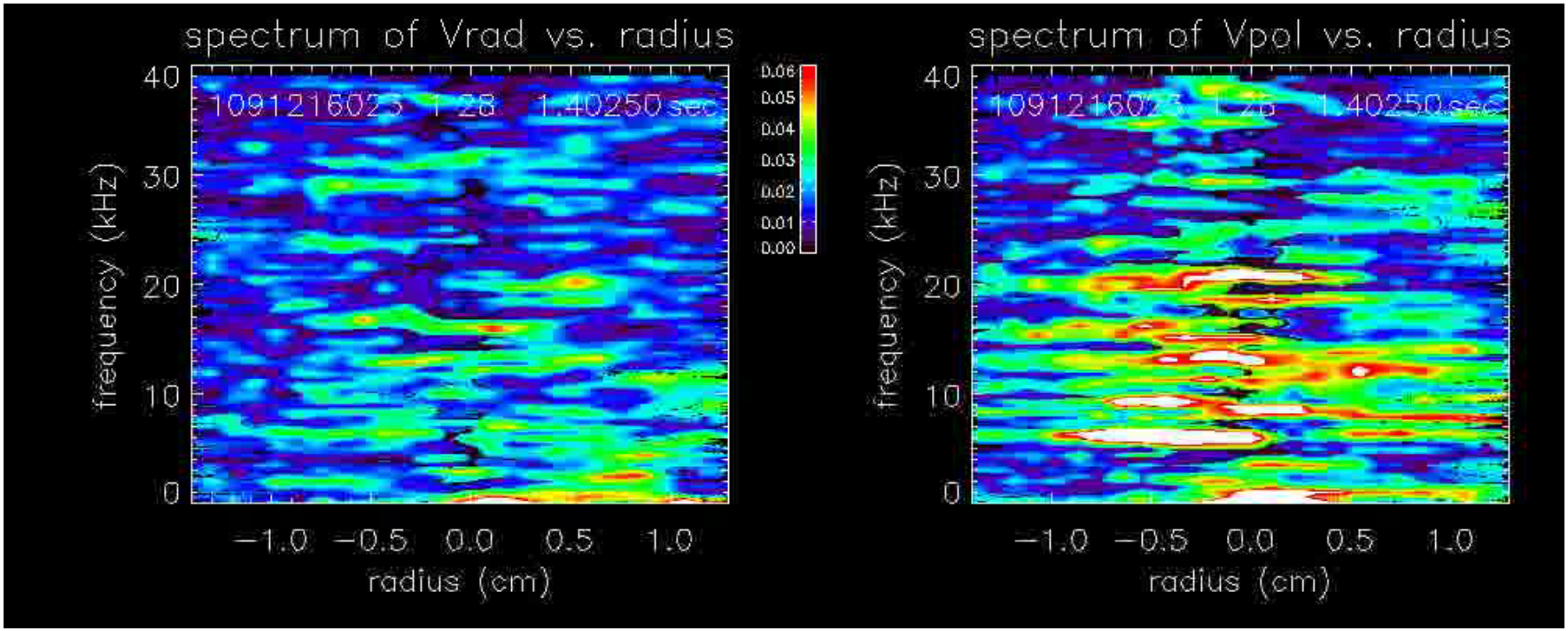
- No clear spectral features lasting more than ~ 1 msec
- Looks similar at other radii and for other similar shots





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, κ=1.6, q=3, $T_e=T_i$=50 eV, γ=4/3 and m_i=2

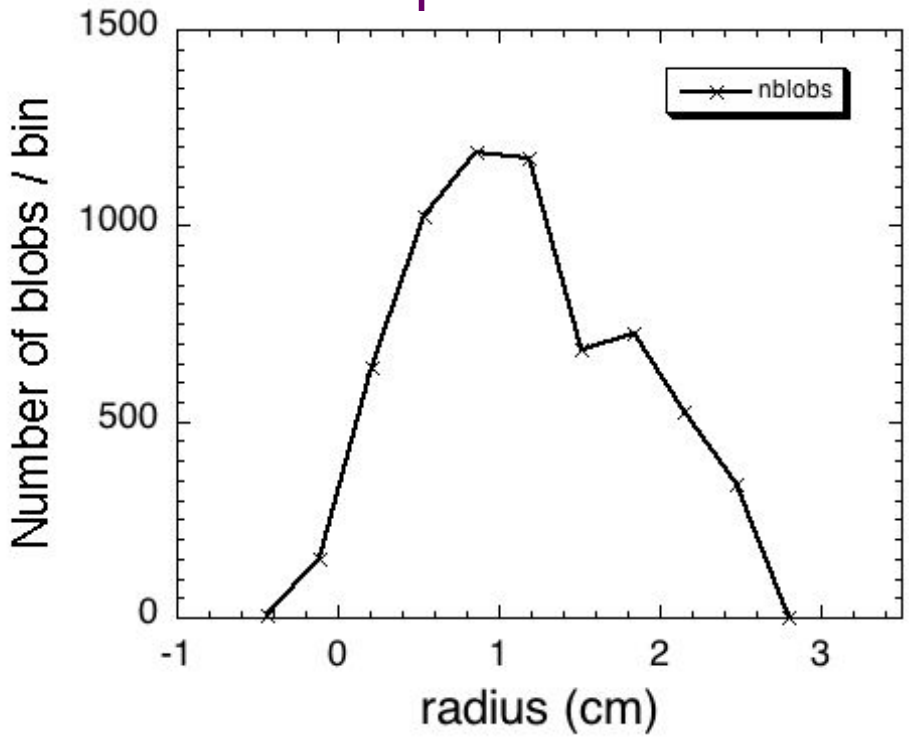
$f_{GAM} \sim 20$ kHz

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

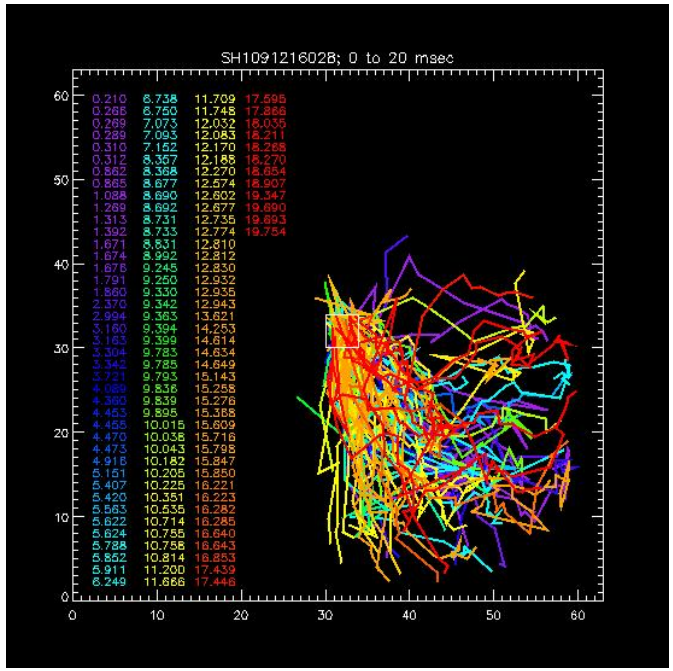
Blob Analysis of C-Mod GPI Data

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

radial profile of blobs



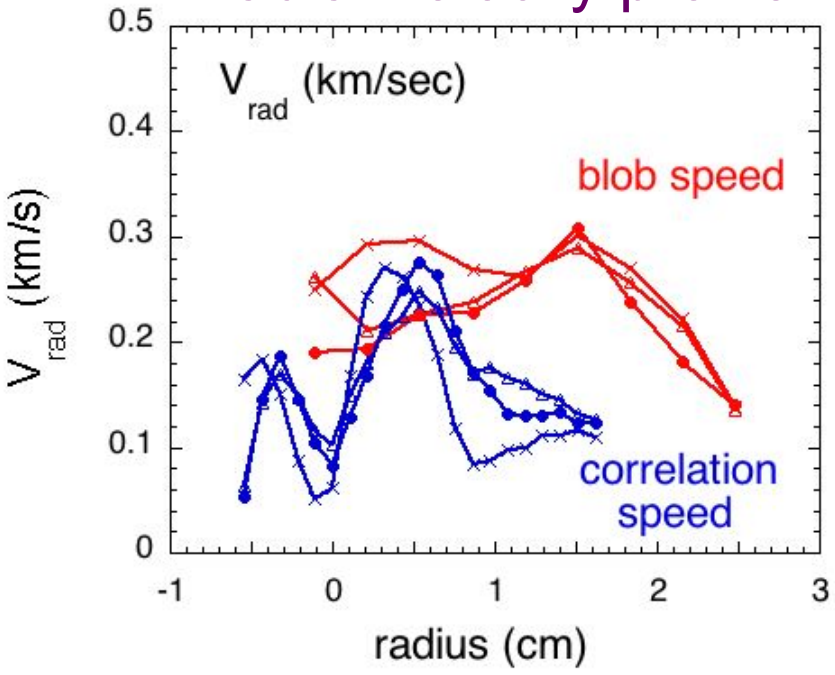
trajectories of blobs



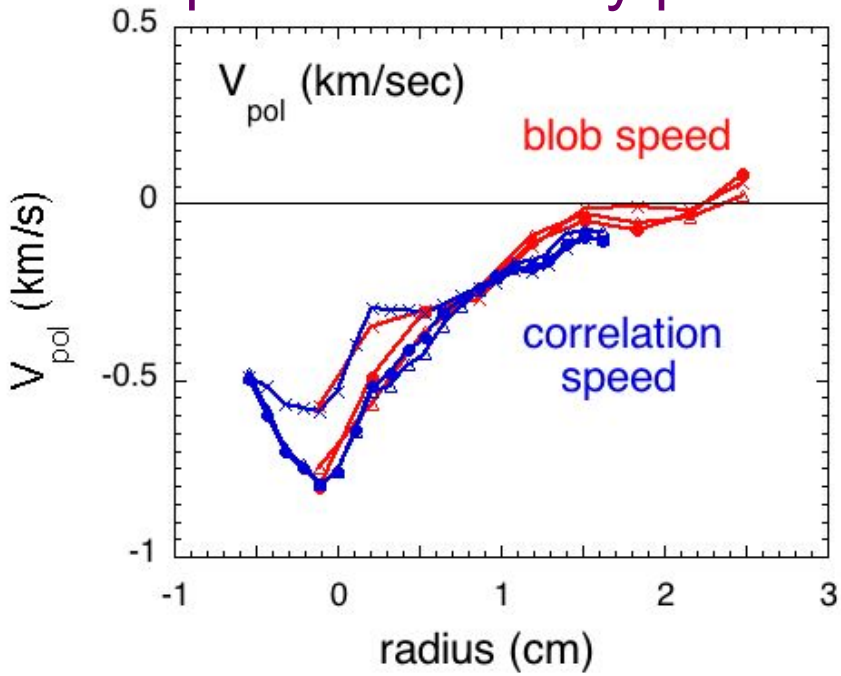
Blob Analysis vs. Correlation Analysis

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

radial velocity profile



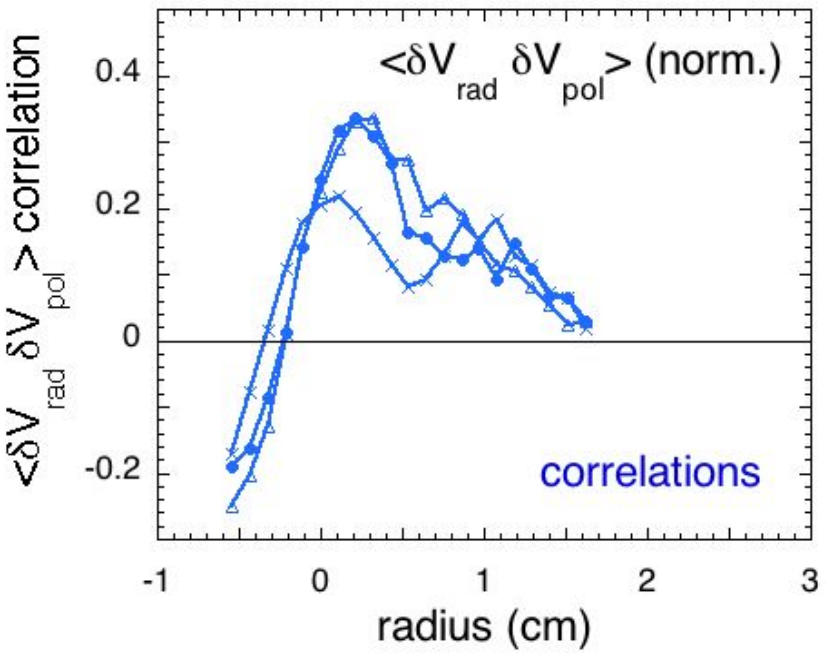
poloidal velocity profile



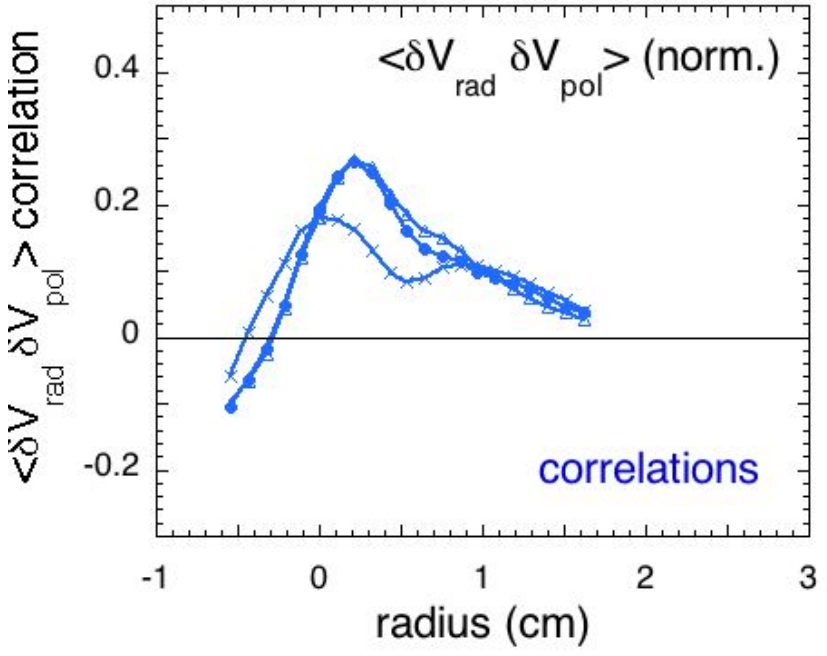
Correlation of Radial and Poloidal Velocity

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

Still very much to learn !