P3-20

Estimate of Convective Radial Transport due to SOL Turbulence as Measured by GPI in Alcator C-Mod

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Abstract

The convective radial transport effects of SOL turbulence have been estimated using recent turbulence data taken at 250,000 frames/sec using the gas puff imaging (GPI) camera diagnostic on Alcator C-Mod. Initial results were obtained for a series of Ohmic discharges covering I=0.4-1.1 MA at constant q(a) and moderate density. The average radial turbulence speed within the radial range ρ=1-2 cm near the outer midplane was v_r~200-300 m/sec, which can be (tentatively) identified with the convective radial flow speed in this region. With this assumption, the density SOL width λ_n was evaluated using the convective model $\lambda_n \sim v_r\ \tau_{II,n}$, with $\tau_{II,n} = L_{II}/v_{II,n}$, to be $\lambda_n \sim$ 4-7 cm, which is ~3 times higher than the SOL width measured by Langmuir probes for his region. A possible correction factor to this convection model due to the intemittency associated with blobs will be discussed [1].

The radial turbulence velocities from analytic blob model estimates [2] were ~3 times higher than these measured turbulence velocities, and the interpretation of this result will be discussed. The simplest model for the relationship between the density SOL width and the electron temperature SOL width, assuming the same convective radial transport velocity for both, and classical parallel transport in the collisional regime, is $\lambda_n/\lambda_{Te} \sim 60/\nu_{*e}$ [3]; however, this model appears to overestimate this ratio for the C-Mod cases discussed above. Possible explanations for this discrepency will also be discussed. These experimental results will be extended to include discharges near the density limit, discharges with RF heating, and data from an upgraded GPI camera system at ~380,000 frames/sec.

[1] S.I Krasheninnikov, A. Yu. Pigarov et al Phys. Plasmas 16, 014501 (2009)
[1] S.I Krasheninnikov, D.A. D'Ippolito, J.R. Myra, J. Plasma Phys. 74, 679 (2008)
[2] W. Fundamenski, Fusion Science and Technology 53, 1052 (2008)

Outline

- Motivation and goals
- GPI diagnostic in C-Mod
- Evaluation of convective velocity
- Estimate of SOL width from velocity
- Comparison with blob models
- Evaluation of radial blob velocity

Motivation and Goals

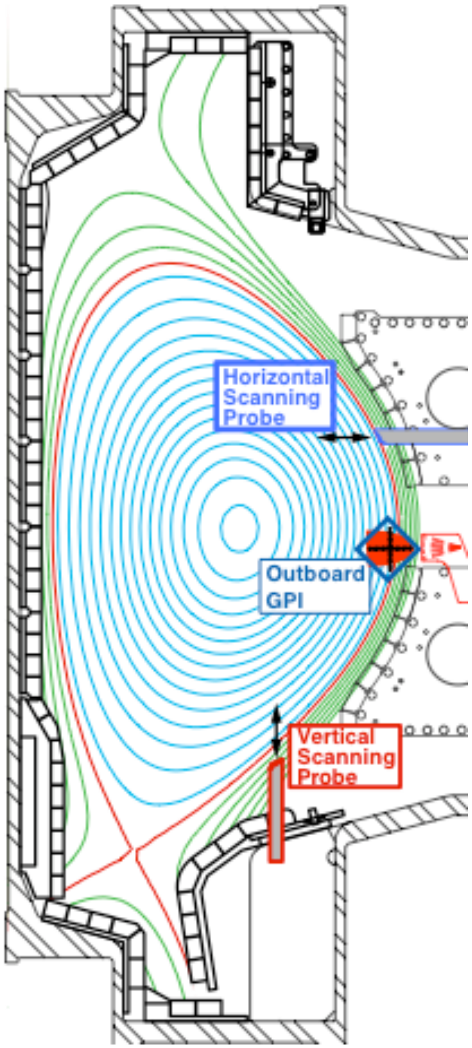
- Use GPI data to evaluate radial convective flow in SOL
- Use simple model to estimate density SOL width from measured radial convective flow
- Compare convective velocity with analytic blob models

=> understand better cause of SOL width in Alcator C-Mod

Caveats:

- only consider middle-to-near SOL width, not near-SOL
- only density SOL, not temperature or heat SOL width

GPI Diagnostic in Alcator C-Mod



- Views near outboard midplane SOL
- Views 6 cm x 6 cm radial/poloidal
- Phantom 7.3 camera ≤250,000 frames sec at 64x64 pixels
- 30,000 frames/shot (~0.1 sec)
- Density SOL width measured by horizontal scanning probe

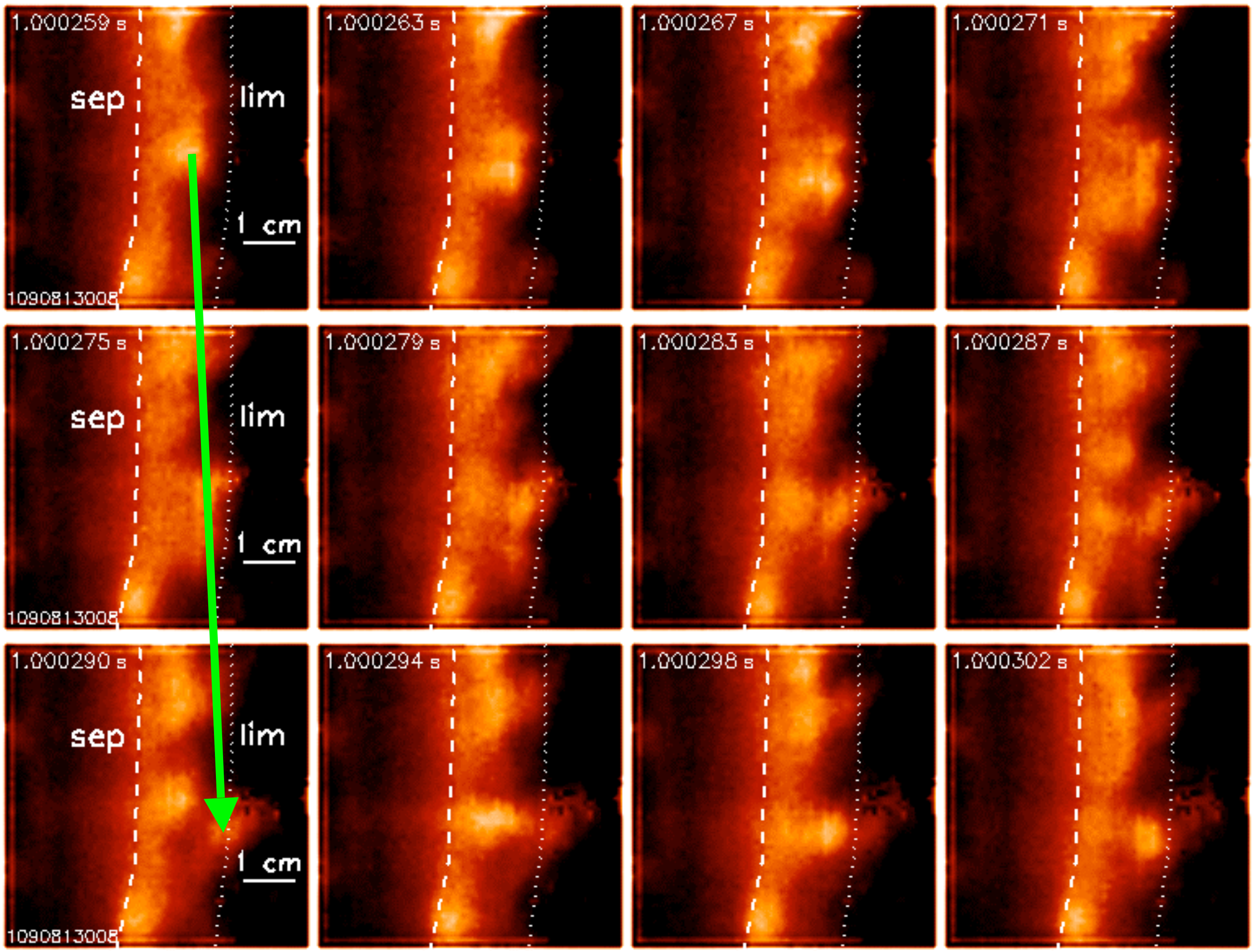
Convective Flow in GPI Data

250,000 frames/sec @ 4 μs/frame, I=1.0 MA

typical radial motion

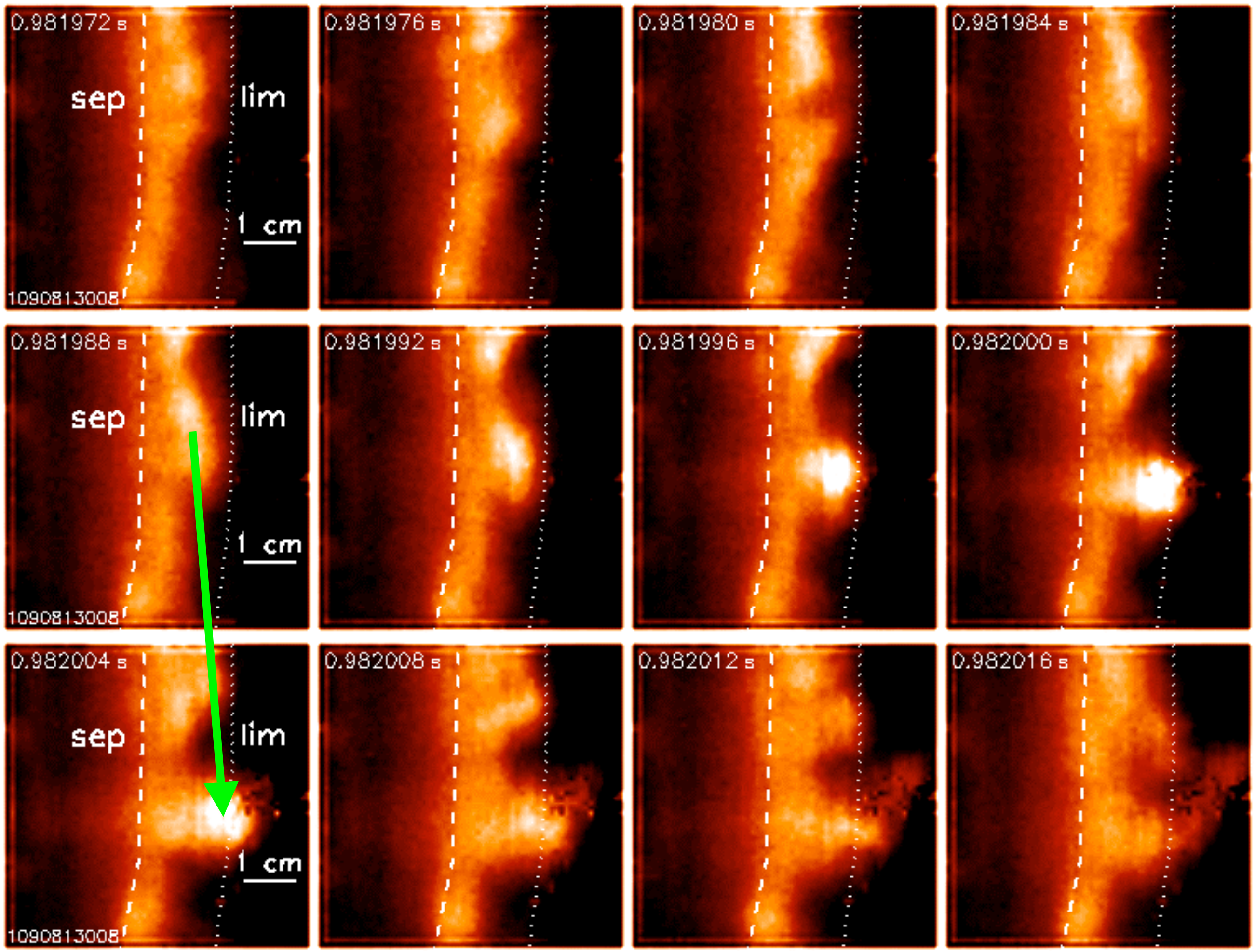
~ 0.7 cm in 30 μs

~ 0.2 km/sec



Blob Propagation in GPI Data

250,000 frames/sec @ 4 µs/frame, I=1.0 MA



blob motion

~ 0.8 cm in 16 µs

~ 0.6 km/sec

Convective Model of SOL Width

- Plasma convective speed is $V_r = \langle \delta n \, \delta V_r \rangle / n$, where V_r is the local radial plasma speed (i.e. ExB drift speed)
- If the GPI light emission fluctuations are proportional to δn, as expected, then the local V_r can be evaluated from the local GPI radial fluctuation speed
- This assumes that GPI fluctuations due to parallel flows are negligible, which is likely since $\tau_{auto} \ll L_{||}/c_s$
- If local velocity distribution is in/out symmetrical, the SOL width is determined by diffusion, not convection

Evaluation of Convective Velocity

(a) for each point in each image, the delayed-time cross-correlation coefficient was calculated for all nearby points using a fixed delay time (typically ~4 µs, i.e. much less than τ_{auto}), and the results were then averaged over 10 msec,

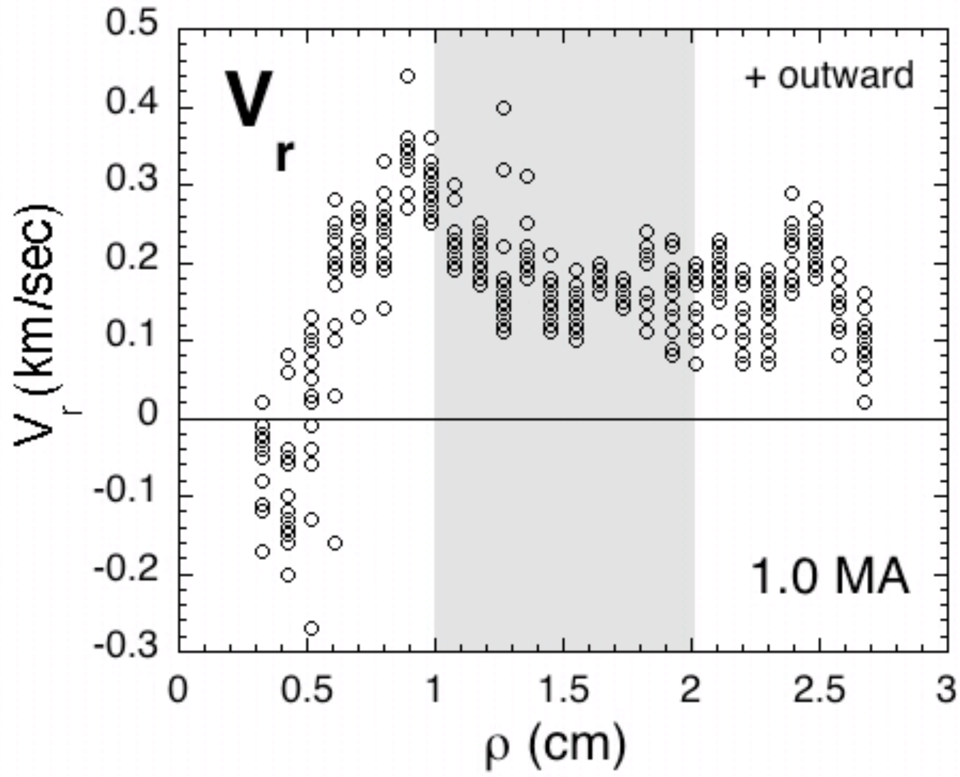
(b) the location of the peak of the cross-correlation coefficient was located in 2-D, and then the radial velocity of the turbulence was calculated from the radial displacement of this peak from the initial pixel divided by the chosen delay time,

(c) these results were averaged over a poloidal range of ~48 pixels covering the central 4.5 cm of the images for each radial column of pixels.

- These results were independent of the cross-correlation delay time over 4-20 µsec.
- A similar result is obtained by fitting the peak correlation location vs. delay time
- This process averages over *all* the turbulence, including blobs and turbulence.

Convective Velocity vs. Radius

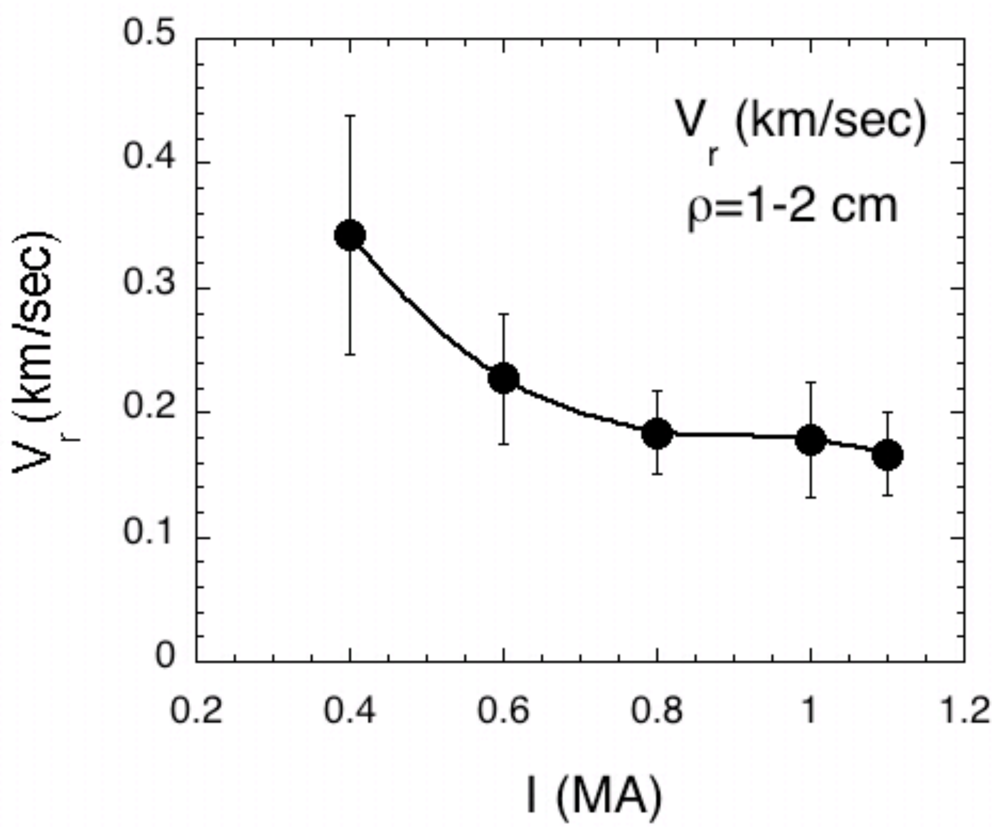
- Each point is one 10 msec time period in one shot
- V_r is outward within ρ=1-2 cm, but goes to zero for $\rho \sim 0$, where transport may be diffusive



$V_r \sim 0.2$ km/sec
in ρ=1-2 cm

Convective Velocity vs. Plasma Current

- Convective speed increases with lower plasma current in a Ohmic plasma scan at constant q(a)



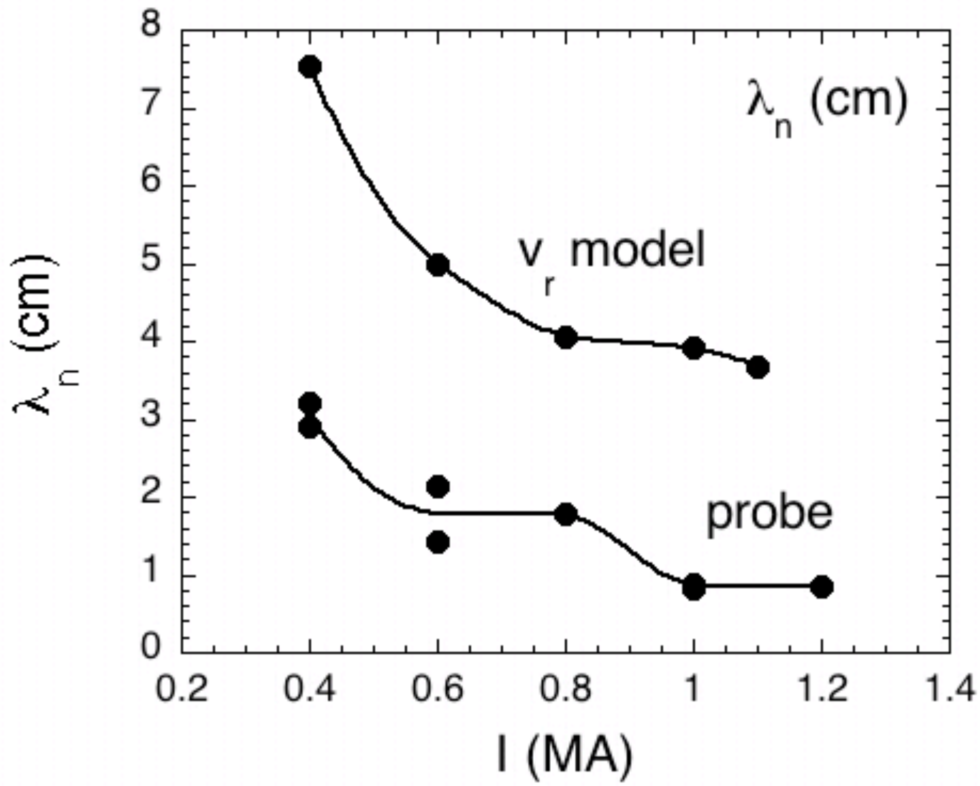
Ohmic current scan
(#1090813005-020)
I=0.4 - 1.1 MA
B= 2.3 - 6.0 T
q(95) = 3.7
$\langle n \rangle$=0.8 - 1.6 x10^{14} cm^{-3}
n (ρ=1.5 cm) ~ 1x10^{13} cm^{-3}
T_e (ρ=1.5 cm) ~ 20 eV

Estimate of SOL Width from Vr

$\lambda_n \sim V_r \, \tau_{\|,n} \sim V_r \, (L_{\|}/v_{\|,n})$, where $L_{\|}$ is the parallel length

$V_{\|,n} \sim 0.5 c_s$, where c_s is warm ion sound speed (Fundamenski)

[$L_{\|} \sim 5$ m, $T_e \sim 20$ eV, $T_i = T_e$]



SOL widths from simple convective model are 2-3 x larger than probe density SOL width

Uncertainties in SOL Width From Vr

- Parallel connection length uncertain (and varying) by x2
- Parallel flow speed not measured and uncertain by x2
- Assumes single SOL width, which is not really true
- Assumes poloidal uniformity of flow and SOL width
- Assumes no ionization source in SOL, not really true
- Ignores contribution from diffusion

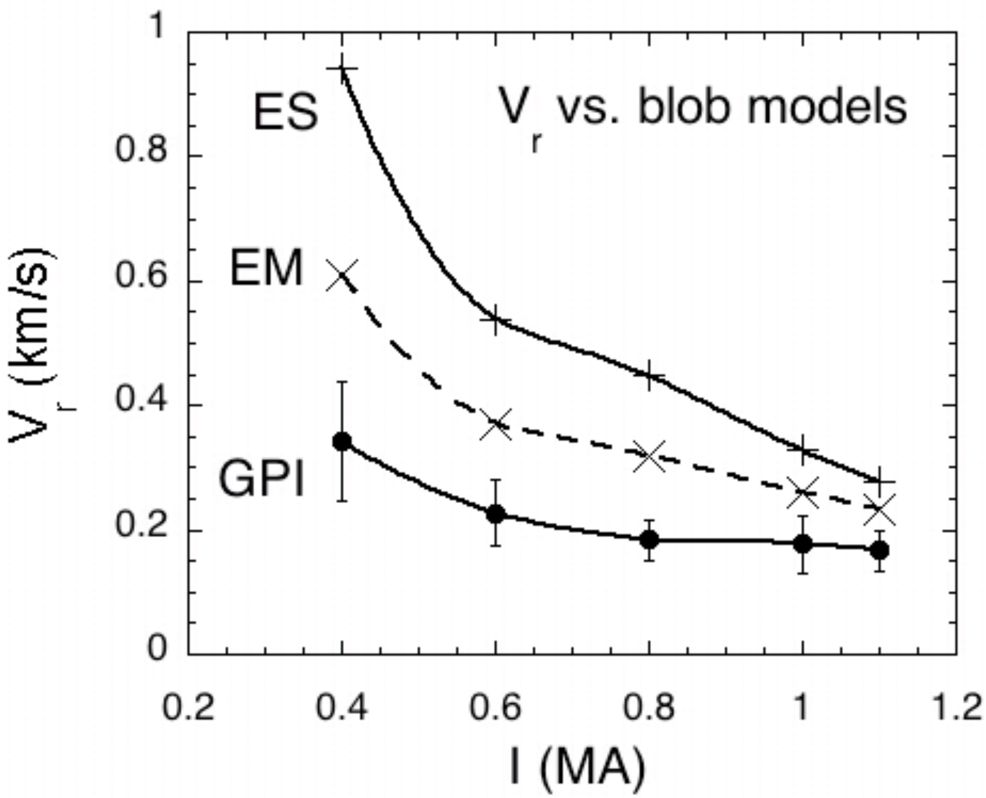
=> factor of x2-3 disagreement with probe not surprising

Comparison of Vr with Blob Models

$V_{r,ES} = 2\ c_s\ (\rho_s/\delta_b)^2\ (L_{||}/R)$ for $\nu_{*e} \sim 2$ (sheath connected)

$V_{r,EM} = qc_s^{\ 2}/V_{alf}$ where $q \sim (L_{||}/R)$ [from KDM, JPP '08]

[T_e=20 eV, n ~ 10^{19} cm^{-3} $c_s \sim 3x10^6$ cm/sec, $\rho_s \sim 10^{-2}$ cm, $\delta_b \sim 0.5$ cm, and $L_{||}/R \sim 7.5$]



simple blob model velocities are 2-3 x larger than GPI convective speed

Uncertainties in Blob Model

- Density in a blob may be greater near divertor plate, which would slow the blob down radially
- Temperature inside a blob may be greater than background, causing blob rotation and slowdown (Myra et al, PoP '04)
- High speed blobs may contribute to far-SOL density shoulder and so could be faster than average convective speed
- Non-zero background density will reduce blob radial speed (D'Ippolito and Myra, PoP '03)

=> factor of x2-3 disagreement with Vr results not surprising

Summary of Blob Model Comparison

- Simple analytic blob models overestimate convective speed by a factor of x2-3, and so would overestimate the SOL width by x4-9 (using the simple convective SOL model)

- But there are several approximations and uncertainties in the model which can explain this discrepancy

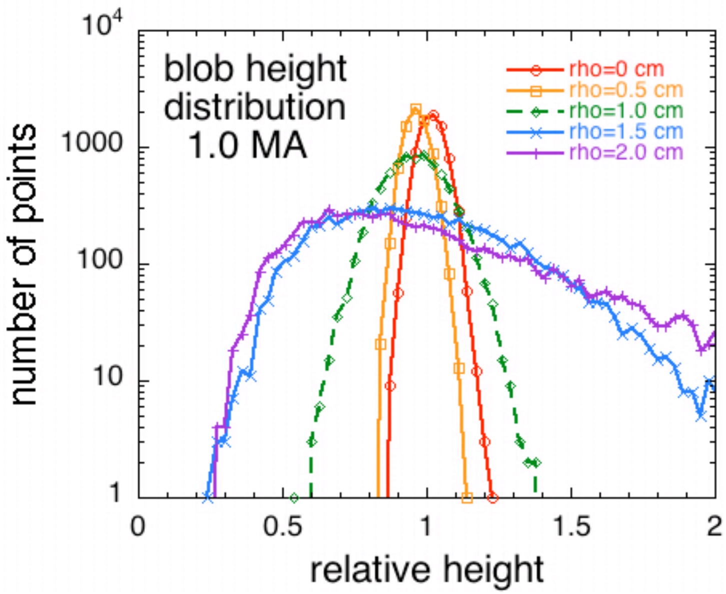
=> Analytic blob models are not reliable for quantitative explanation of the density SOL width in C-Mod

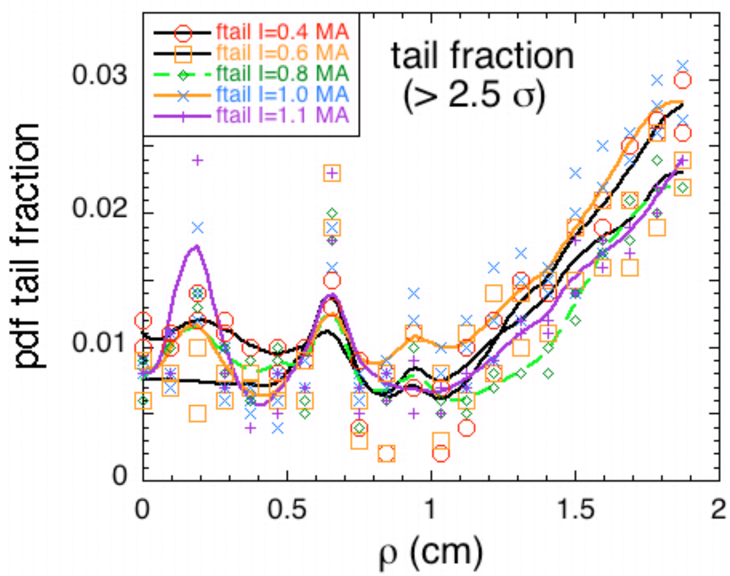
=> Probably need simulations like SOLT, ESEL, or BOUT

Measurement of Blobs in GPI Data

- GPI light emission has blob-like non-Gaussian tails with a larger skewness farther out in SOL (ρ > 1 cm)

- Fraction of tail ≥ 2.5σ is independent of plasma current





A Blob Tracking Algorithm

(a) the images for each 10 msec time period for each shot were first normalized to their time-average, and then smoothed over 3x3 pixels, such that a large blob had a relative magnitude of ~2 on this scale.

(b) then the region between the separatrix and the limiter shadow was searched for the largest blob, i.e. maximum pixel in each frame. If the maxima in two successive frames were within ±5 pixels (±0.5 cm) of each other, then the radial velocity for this blob was evaluated.

(c) the same procedure was then applied to the next-highest and third-highest maximum in each frame, with the constraint that all these maxima were outside ±0.5 cm of each other.

- Adding an additional constraint that three successive maxima needed to be within ±5 pixels of each other did not significantly change the results.

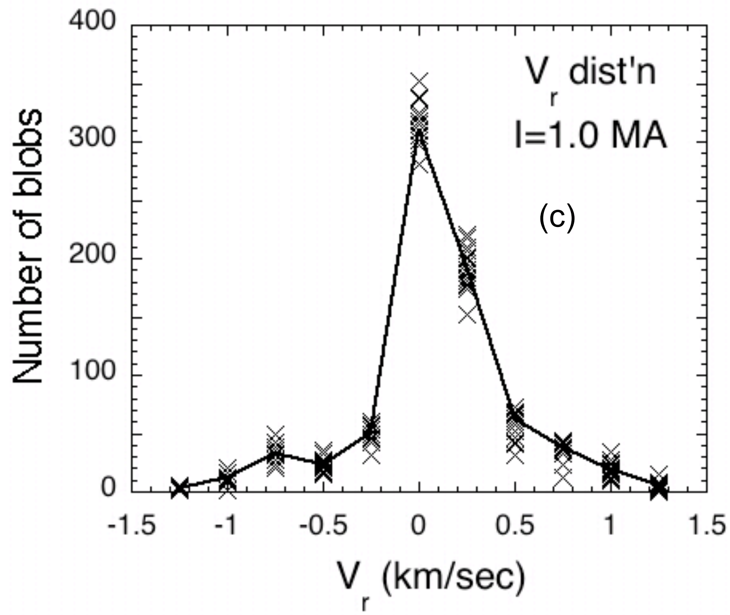
- This procedure resulted in about one blob track per frame, i.e. ~ 2500 blobs per 10 msec or about 15,000 blobs per shot.

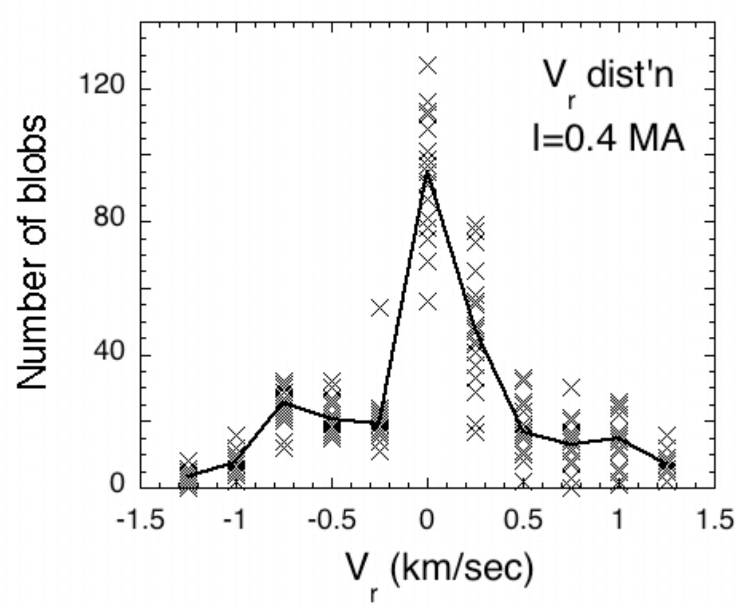
Blob Velocity Distributions

- First maximum had broad V_r distribution over ± 1 km/sec
- Distributions at I ≥ 0.8 MA were preferentially outward

(b)

- Distributions at I ≤ 0.6 MA were almost in/out symmetric

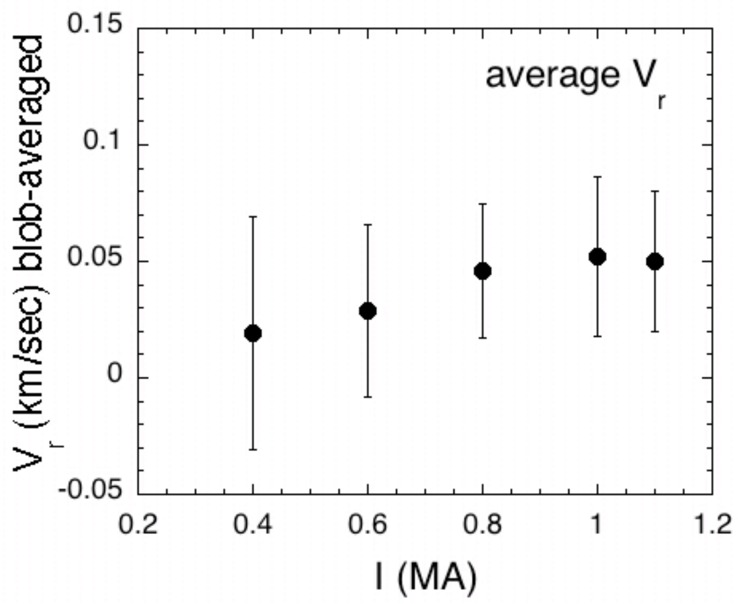


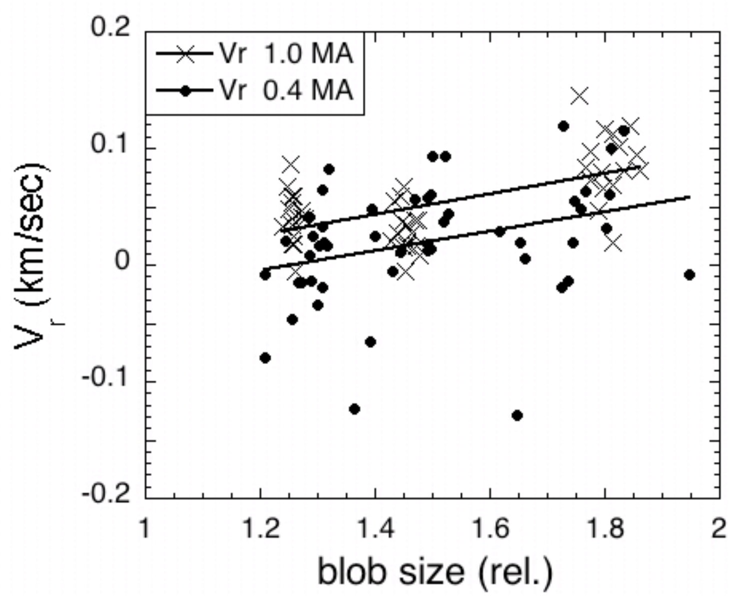


Average Blob Velocity and Scaling

- Average blob velocity significantly less than convective velocity from cross-correlation analysis

- Some evidence for increase in velocity with blob size



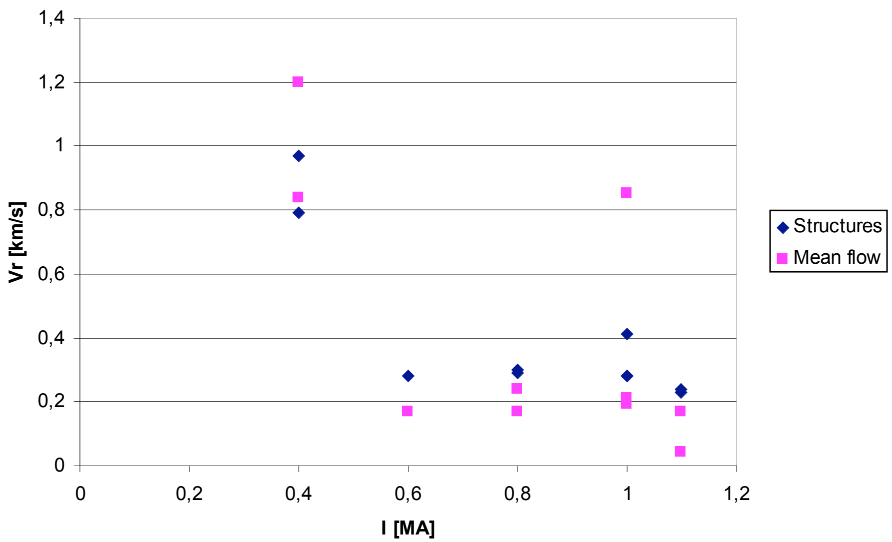


Alternative Blob Tracking Algorithm

(a) after detecting the time instant of an intermittent event in a camera pixel, take 6x6 pixels around it, and 100 sampling point around it, in this way extracting a small time-space image of the intermittent structure.

(b) apply the same cross-correlation algorithm as used to measure the radial and poloidal velocity.

- These results much closer to the mean flow from cross-correlations



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Summary of Blob Tracking

- Results using initial algorithm were surprisingly different from cross-correlation results and from blob theory
- For example, there were a significant number of inward-moving blobs which are not consistent with blob theory
- A different algorithm produced very different results

=> blob-tracking results can not be compared with theory without using a theory-based definition of a blob

=> blob-tracking results can be compared with simulations if experiment and simulation use same tracking method

Future Plans

- Extend C-Mod data base to look for scalings of V_r with collisionality (i.e. density) and beta (i.e. power)
- Use Phantom 710 data at 390,000 frames/sec to get better tracking information on blobs
- Improve blob-tracking algorithm, e.g. to evaluate radial velocity distributions (convection or diffusion ?)
- Compare midplane to X-region and divertor plate SOL
- Compare results with SOLT code SOL predictions

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