U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U

Blob Structure and Motion in the Edge of NSTX

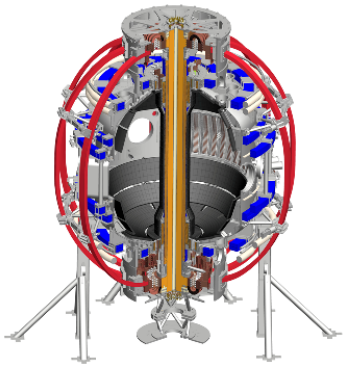
S.J. Zweben[1], J.R. Myra[2], W.M. Davis[1], D.A. D'Ippolito[2], D.A. Russell[2]

[1] Princeton Plasma Physics Laboratory, Princeton NJ 08540 USA
[2] Lodestar Research Corporation, Boulder, CO 80301, USA

APS DPP meeting
Savannah GA
Nov. 2015

Lodestar

PPPL



Abstract

The structure and motion of discrete plasma blobs (a.k.a. filaments) in the edge and scrape-off layer (SOL) of NSTX is studied for representative Ohmic and H-mode discharges. Individual blobs were tracked in the radial vs. poloidal plane using data from the gas puff imaging (GPI) diagnostic at 400,000 frames/sec. A database of blob amplitude, size, ellipticity, tilt, and velocity was obtained for about 45,000 blobs. The blob velocities are compared with theoretical estimates and analytic blob models, and the blob shapes are compared with edge flow shear. Empirical relationships between various blob properties will be described, e.g. radial speed vs. amplitude, tilt vs. ellipticity.

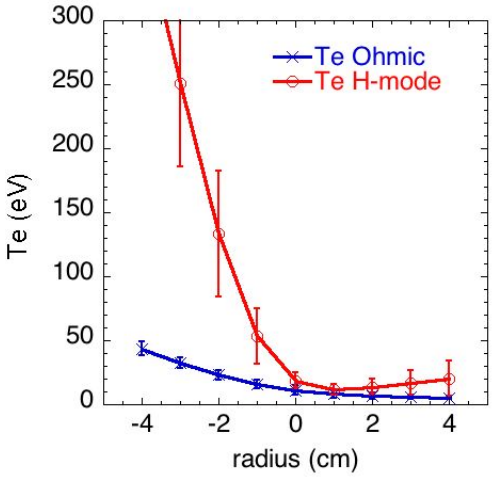
Motivation and Goals

- Characterize blob properties in typical NSTX Ohmic and H-mode plasmas
- Look for empirical trends in large blob database
- Compare blob data to analytic blob theory models

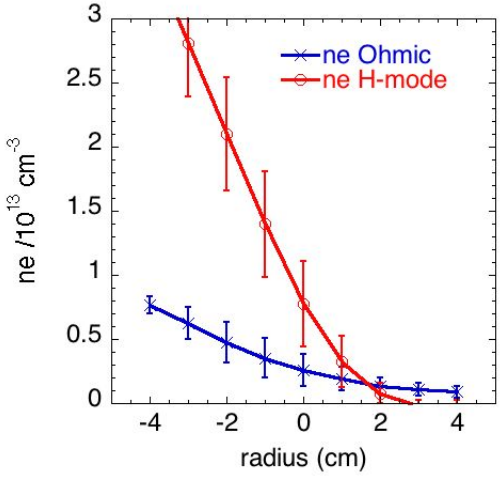
Plasma Parameters

- Focus on 7 similar Ohmic and 7 similar H-mode shots

edge T_e



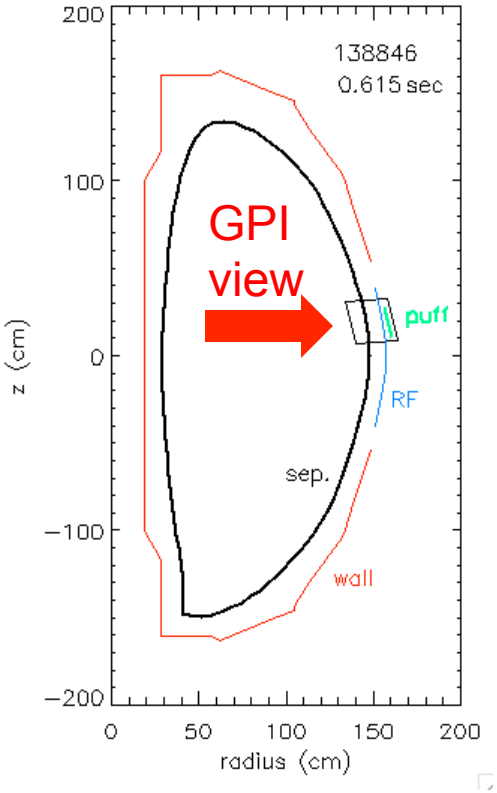
edge n_e

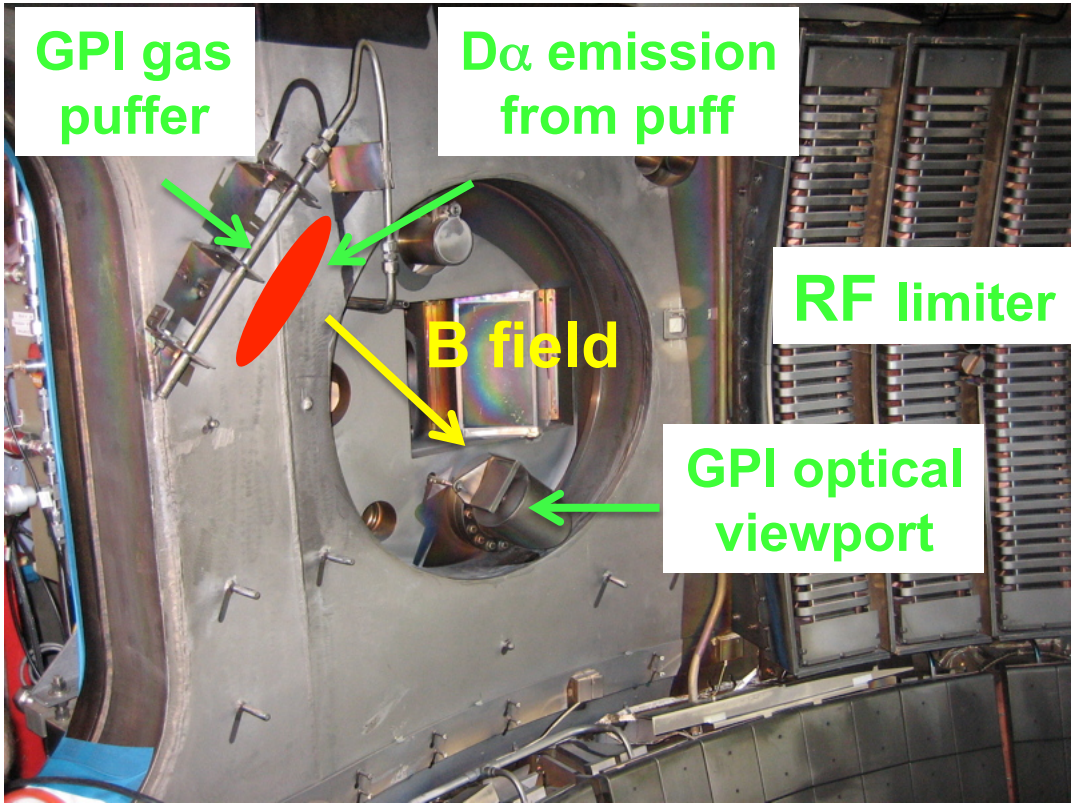


	Ohmic	H-mode
shot range	141746-756	140389-395
time range (sec)	0.213-0.214	0.535-0.550
I_p (kA)	830	830
B_t (kG)	3.6	4.9
kappa (elongation)	1.9	2.4
W_{mhd} (kJ)	32	220
n_e average (10^{13} cm^{-3})	1.6	5.2
P_{nb} (MW)	0	4.0
$T_e(0)$ (eV)	530	920
$n_e(0)$ (10^{13} cm^{-3})	2.3	5.6
$T_e(a)$ (eV)	13±6	29±17
$n_e(a)$ (10^{13} cm^{-3})	0.37±0.23	0.92±0.54
T_e @ -2 cm (eV)	23±4	134±53
n_e @ -2 cm (10^{13} cm^{-3})	0.47±0.17	2.1±0.47
ρ_s (cm) @ -2 cm	0.2	0.3
τ_{ei} (μsec) @ -2 cm	0.5	1.5
β_e @ -2 cm	0.0003	0.005
# of blobs identified	28,800	18,800
# of blob trails	2600	820
blob trail lifetime (μs)	23	36

Gas Puff Imaging (GPI) Diagnostic

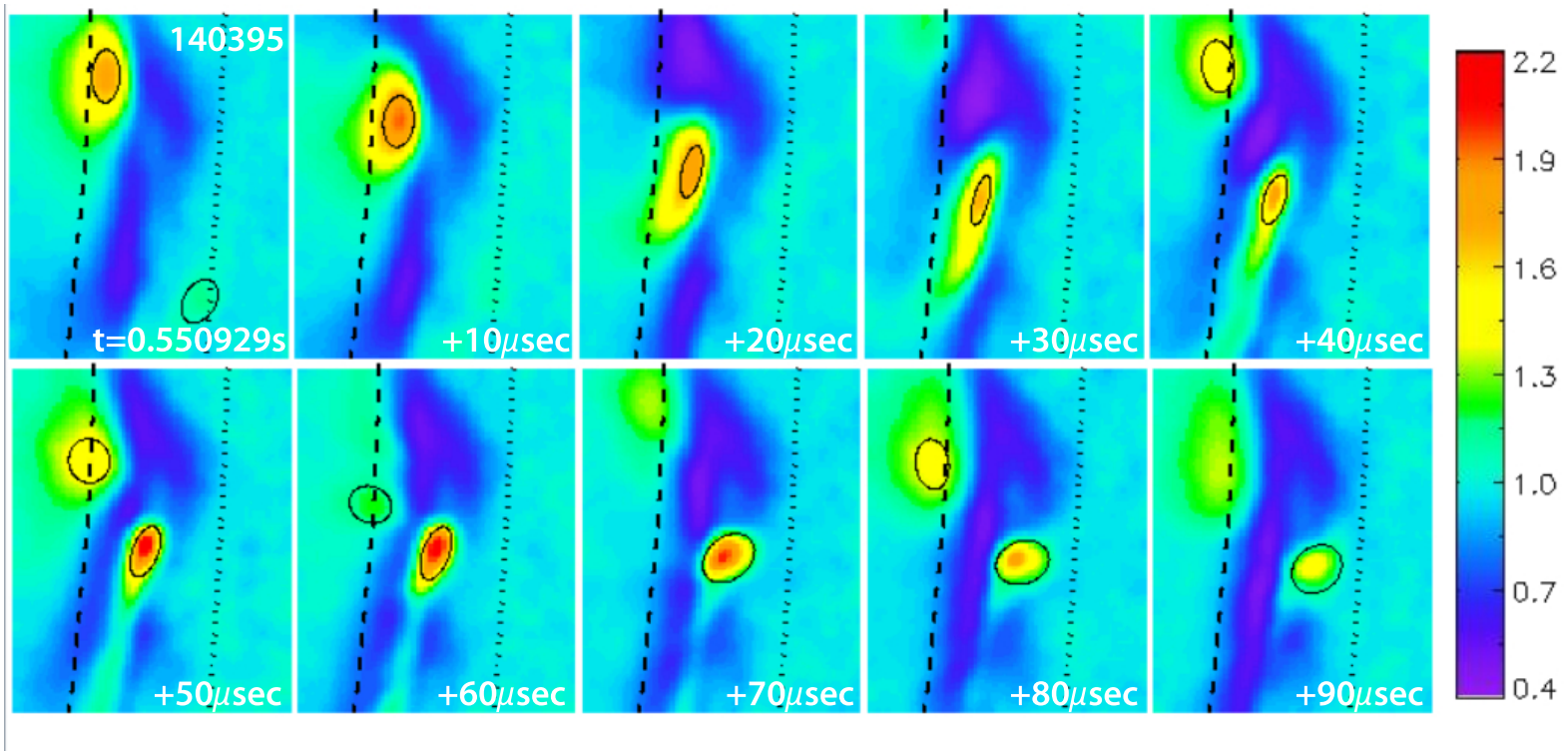
- Neutral deuterium puffed into edge (~6×10^{20} atoms)
- Excitation by electrons produce Dα light (656.2 nm)
- View Dα with fast camera aligned with local B field





Example of GPI Images vs.Time

- Images @ 2.5 μsec separation (400,000 frames/sec)
- Each image is normalized by time-averaged image
- Blobs with normalized amplitude ≥1.5 fit with ellipses



Interpretation of GPI Images

- Collisional radiative approximation for Dα emission:

  $S(\text{photons/sec-cm}^3) \sim n_0\, f(ne; T_e) \sim n_0\, n_e^{\alpha}\, T_e^{\beta}$

  n_0 = local neutral density, given by GPI gas puff

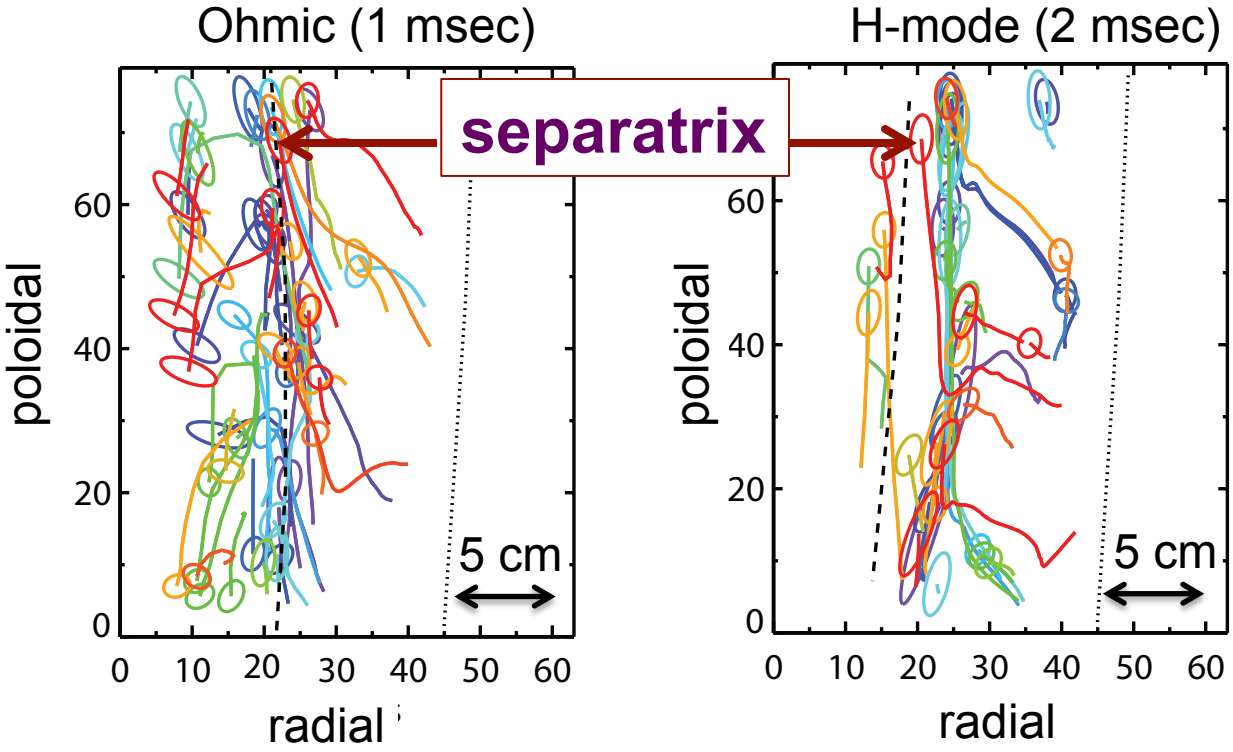
  $f(n_e; T_e)$ = density ratio between n=3 to n=2 state

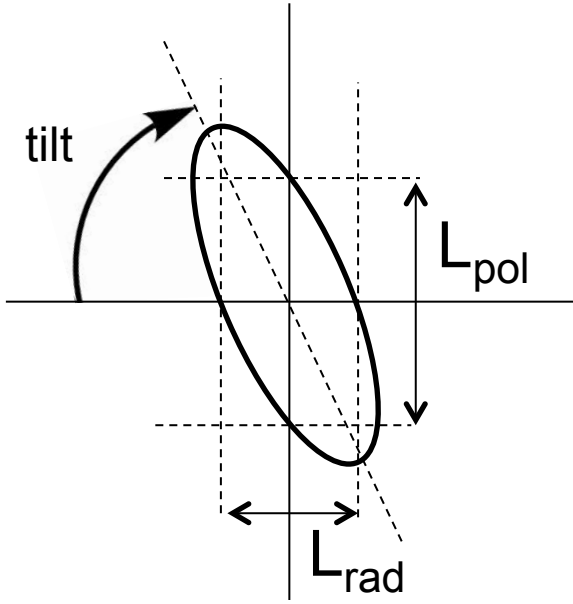
- Typically density exponent α~0.6-0.9 at $n_e \leq 2\times10^{13}$ cm^{-3}, and $\beta \sim 0$ near ~100 eV, but $\beta \sim 1$ near 10 eV

- We assume $\delta S/S \sim \delta n/n$ and fluctuations in T_e are small (see S.J. Zweben et al Nucl. Fusion 55 (2015) 093035)

Definition of a Blob in GPI Data

- Region where normalized peak amplitude $A_{blob} \geq 1.5$
- Closed contour at half-maximum level fit by an ellipse
- Blob trails (colored lines) typically last ~23-36 μsec





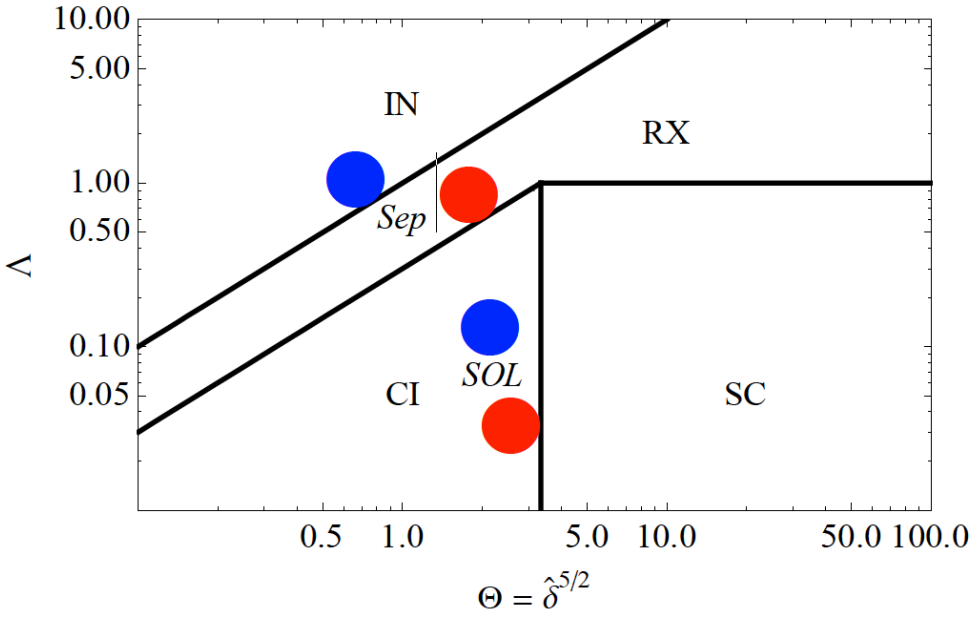
Theory of Blob Radial Velocity

- Radial blob velocity depends on regime diagram*

$$V_{SC} = c_s\,(L_{II}/R)(\rho_s/\delta_b)^2\,\tilde{n}/n$$

$$V_{IR} = c_s(\delta_b/R)^{0.5}\,(\tilde{n}/n)^{0.5}$$

blue=Ohmic red = H-mode



Λ = normalized blob size
Θ = collisionality
δ_b = blob radius in cm (= $L_{pol}/2$)
$\tilde{n}/n$ = blob amplitude (=1-1/A_{blob})

Regimes are:
inertial (IN),
resistive X-point (RX),
sheath connected (SC)
sheath interchange (CI)

* D.A. D'Ippolito et al, Phys. Plasmas 18, 060501 (2011)

Blob Database

- Every blob in every frame of every shot is included
- Total of 28,800 blobs in seven similar Ohmic shots, 18,800 blobs in seven similar in H-mode shots
- Quantities evaluated for each blob in database:

N_{blob} - number of blobs per 2 cm wide radial zone

A_{blob} - average blob amplitude within FWHM region

L_{pol} - poloidal blob size scale (cm FWHM)

L_{rad} - radial blob size scale (cm FWHM)

ellip - blob ellipticity (major/minor axis ratio)

tilt - blob tilt angle (clockwise from radially inward direction)

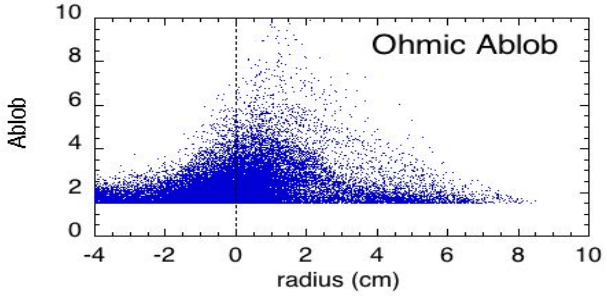
V_{pol} - poloidal blob velocity (km/sec)

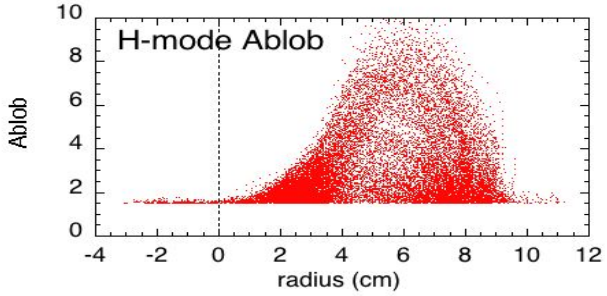
V_{rad} - radial blob velocity (km/sec)

Examples of Full Blob Database

- Each blob within a single frame is one small point

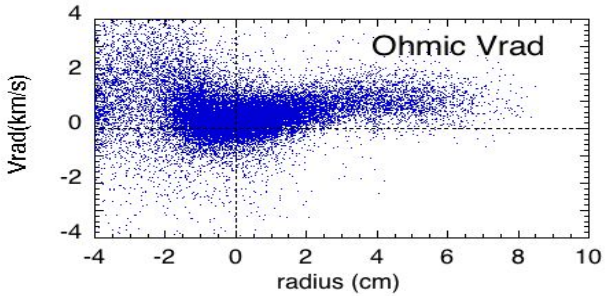
Ohmic A_{blob}

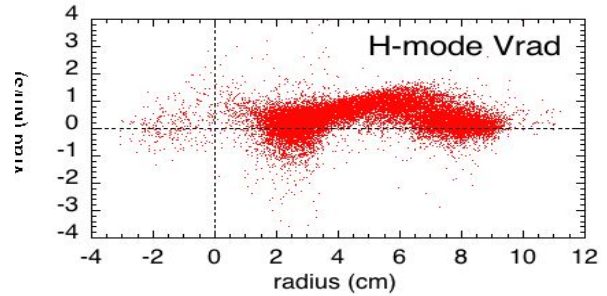




H-mode A_{blob}

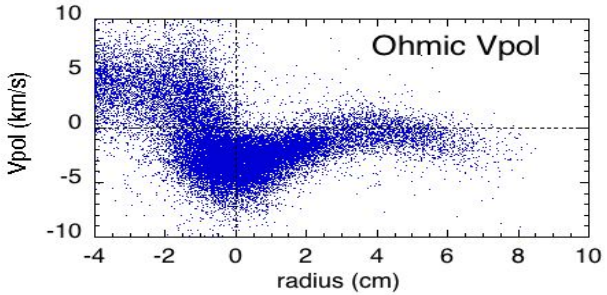
Ohmic V_{rad}

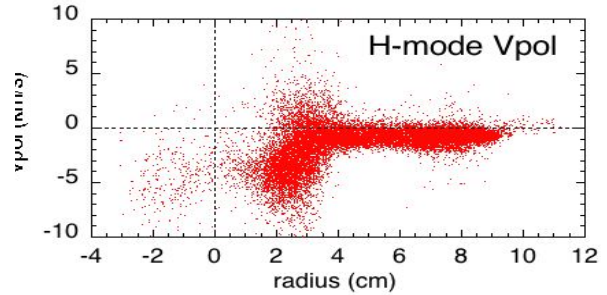




H-mode V_{rad}

Ohmic V_{pol}

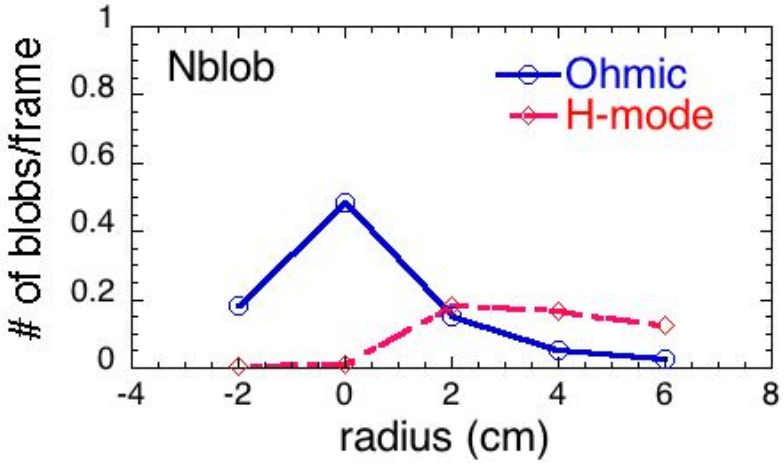


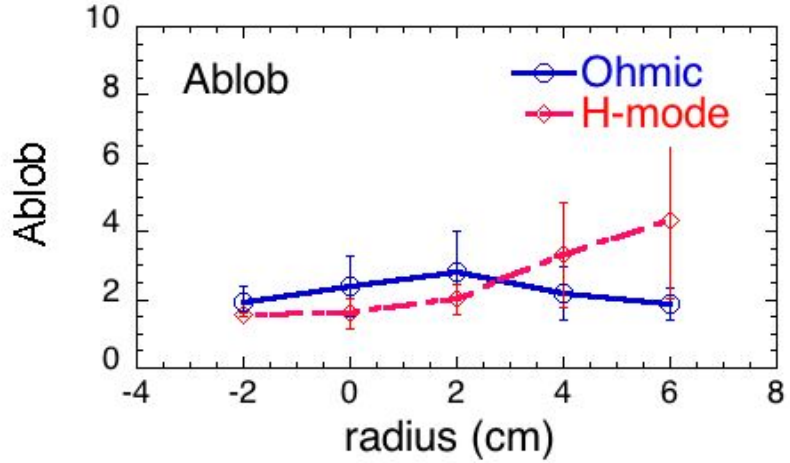


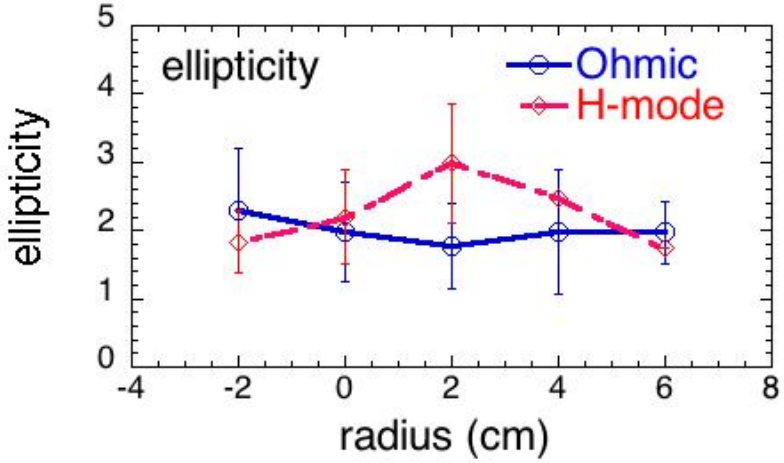
H-mode V_{pol}

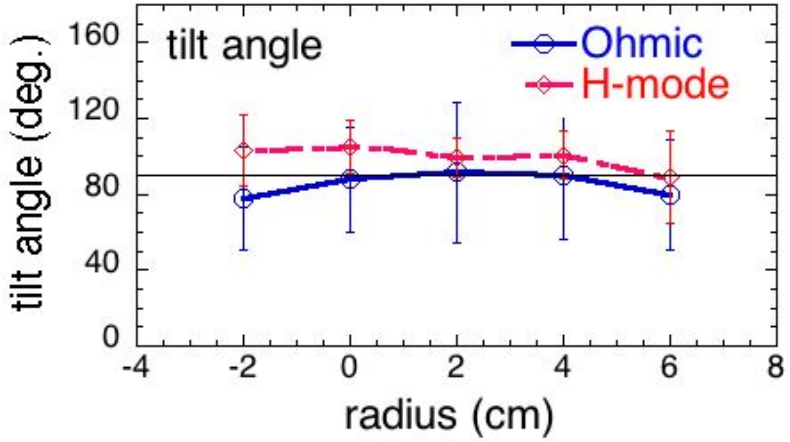
Summary of Blob Radial Profiles #1

- More blobs near separatrix in Ohmic than in H-mode
- Average blob tilt angles ~90º, i.e. elongated poloidally



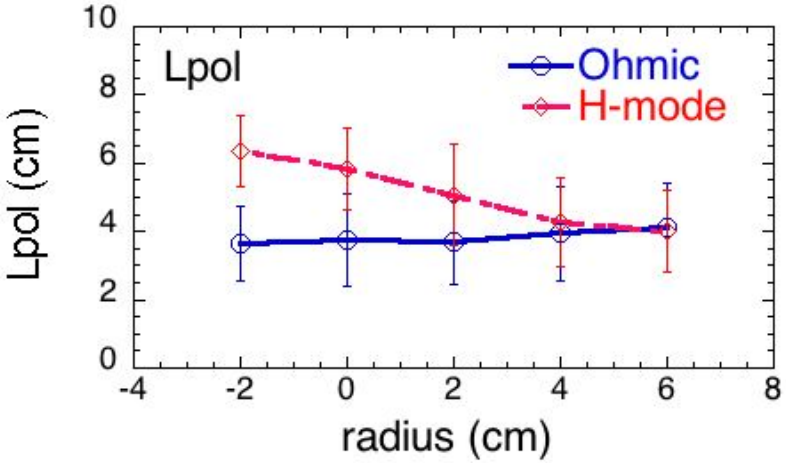


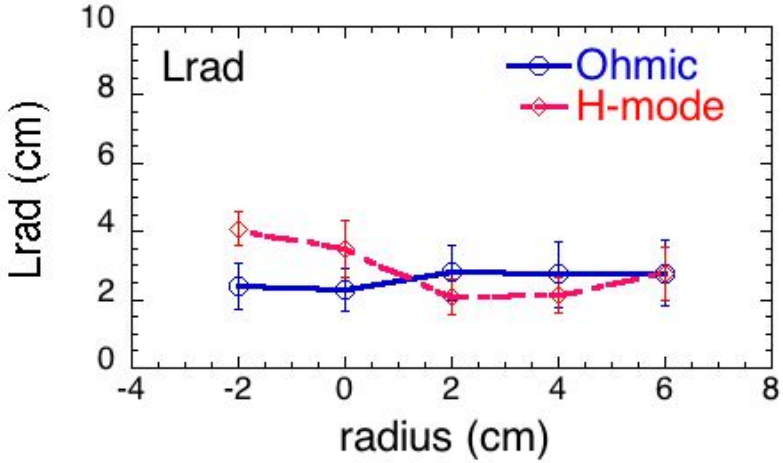


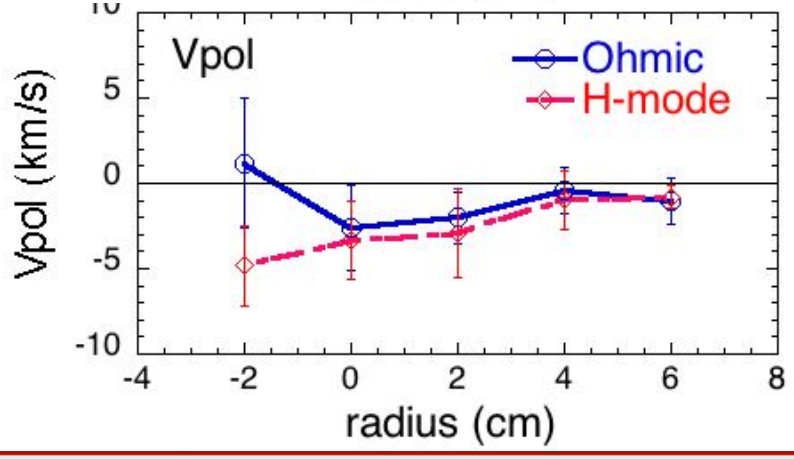


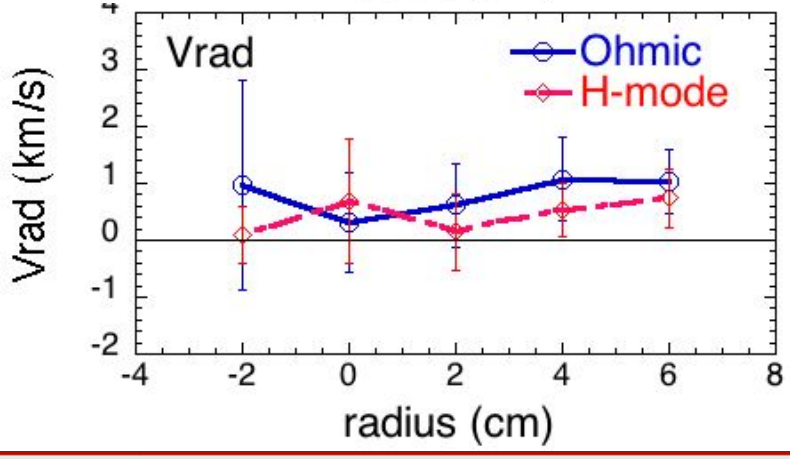
Summary of Blob Radial Profiles #2

- Poloidal size of blobs ~ 2x radial size of blobs
- Radial blob velocities V_{rad}~0.5-1 km/sec *outward*



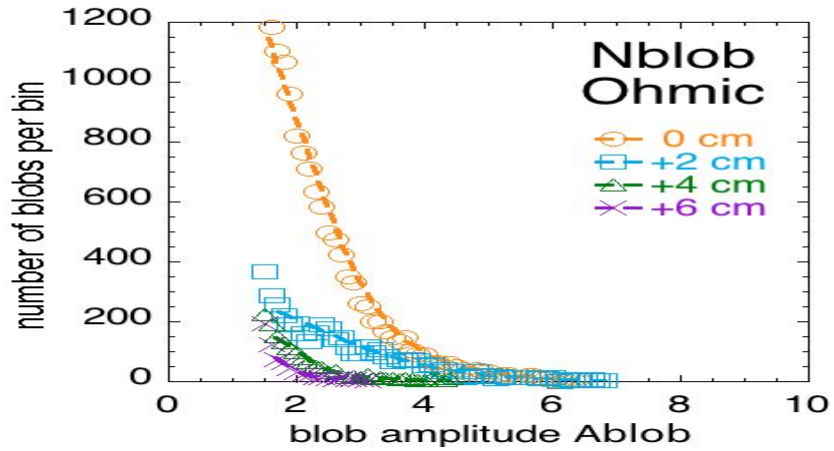


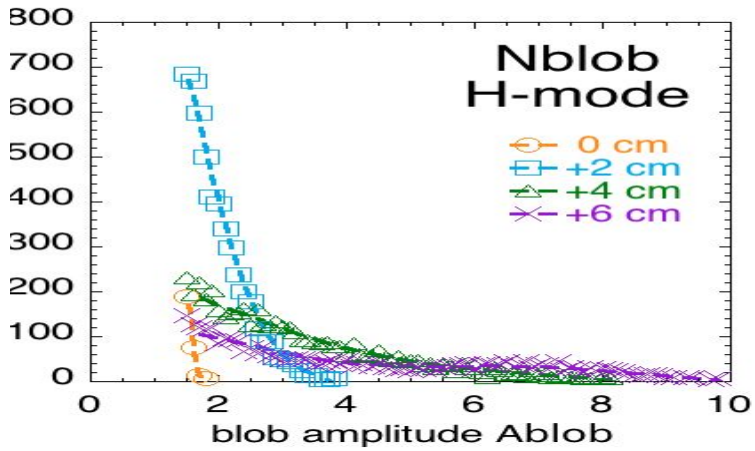


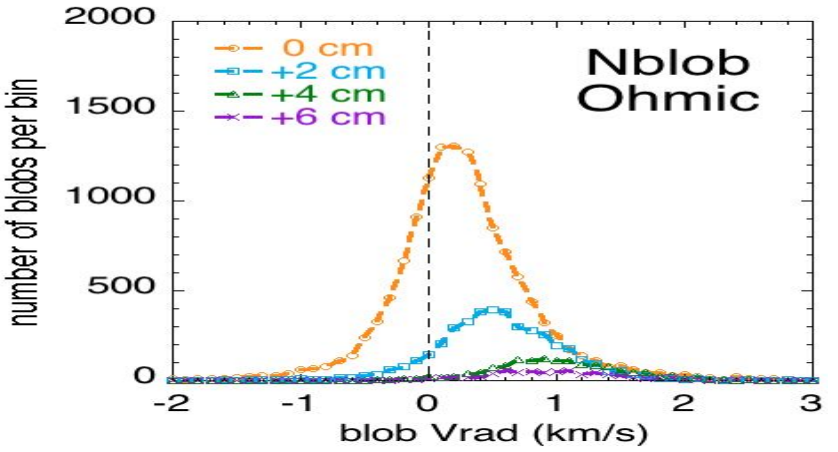


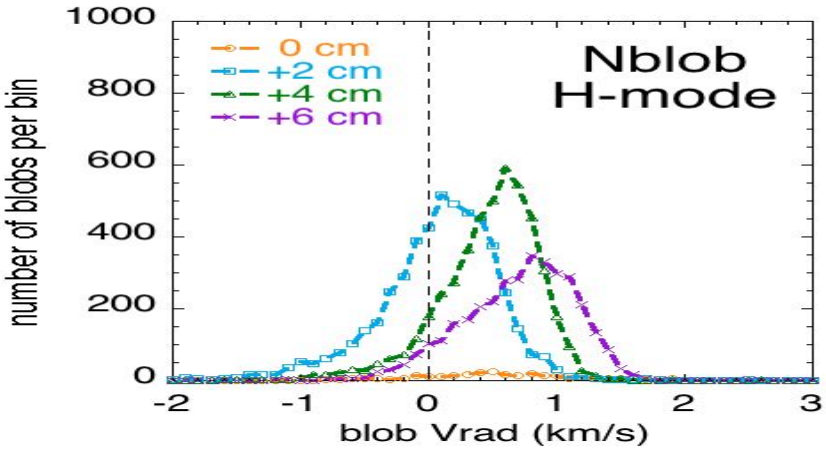
Blob distribution Functions of A_{blob} and V_{rad}

- Blob distributions are broad, but with fewer blobs at high A_{blob},and more outward V_{rad} in far SOL





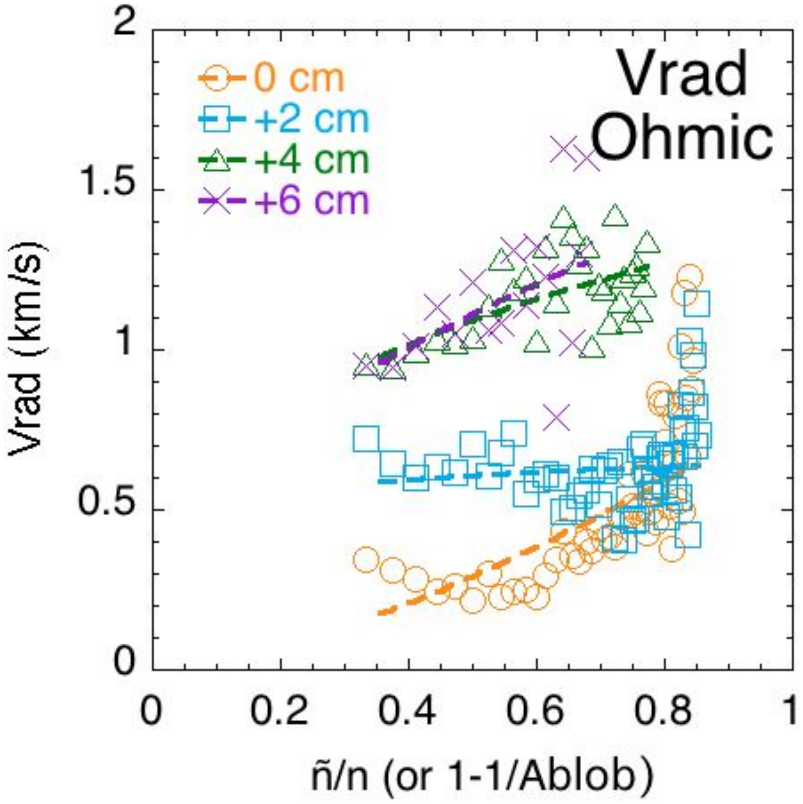


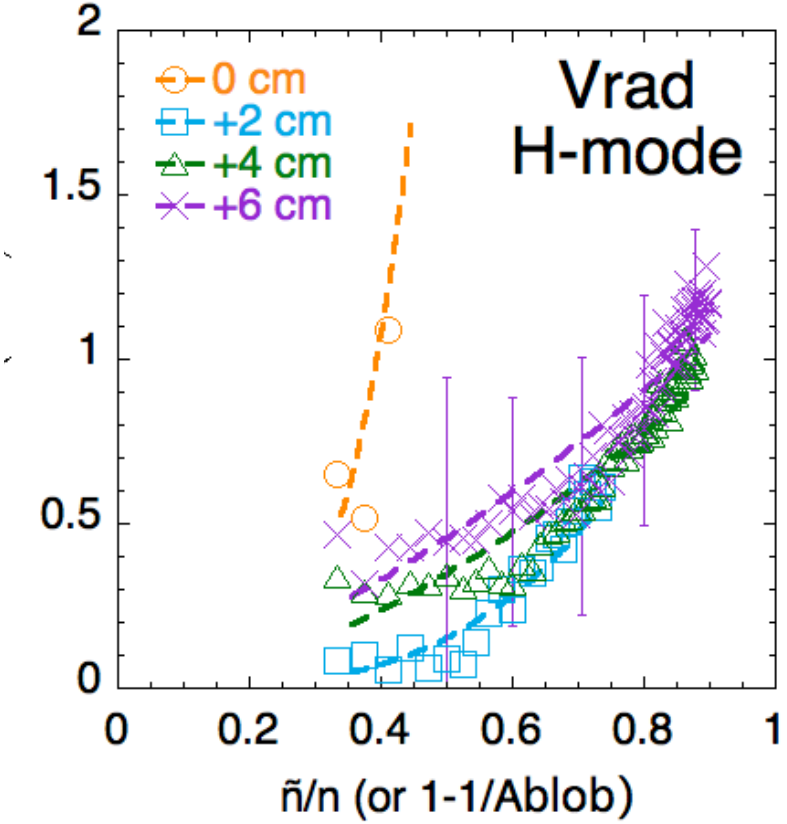


Scaling of V_{rad} with Blob Amplitude

- Blob amplitude can be converted to ñ/n = $(1-1/A_{blob})$
- Blob V_{rad} increases with ñ/n, especially in H-mode,

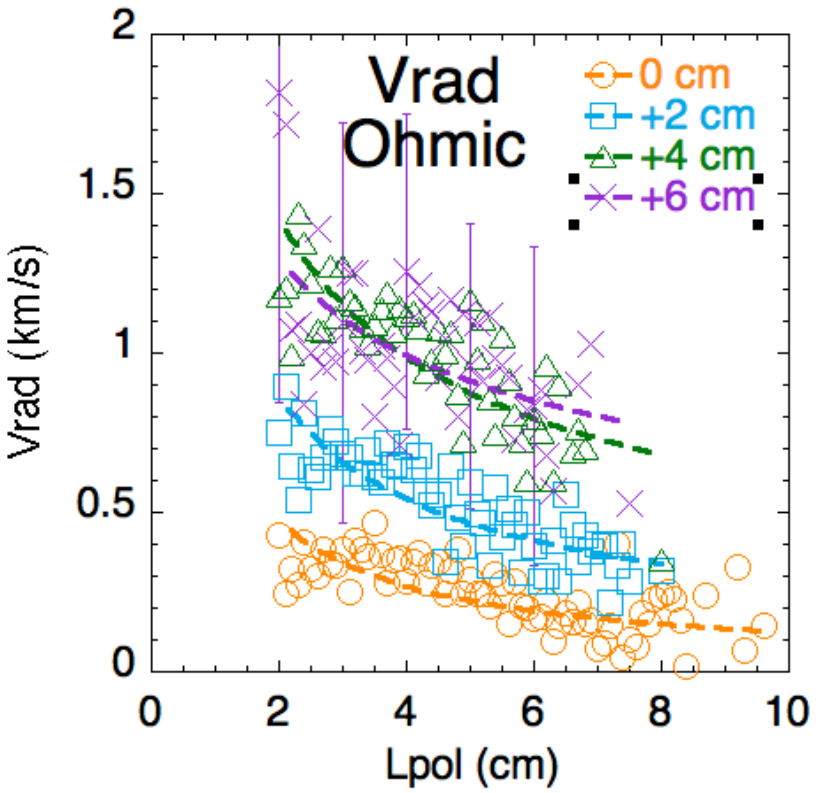
which is qualitatively consistent with SC blob model

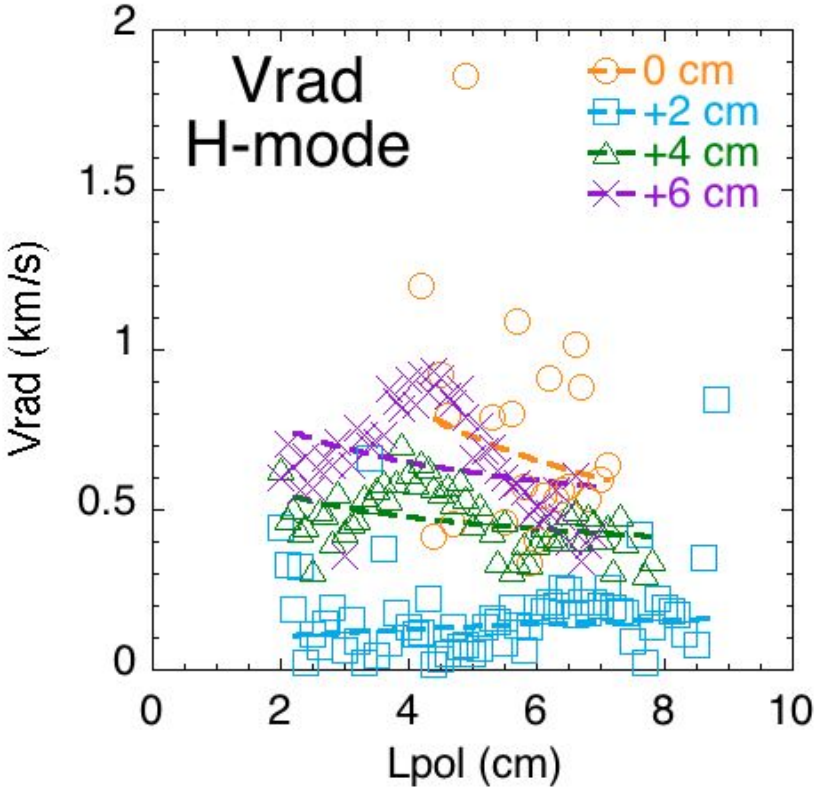




Scaling of V_{rad} with Blob L_{pol}

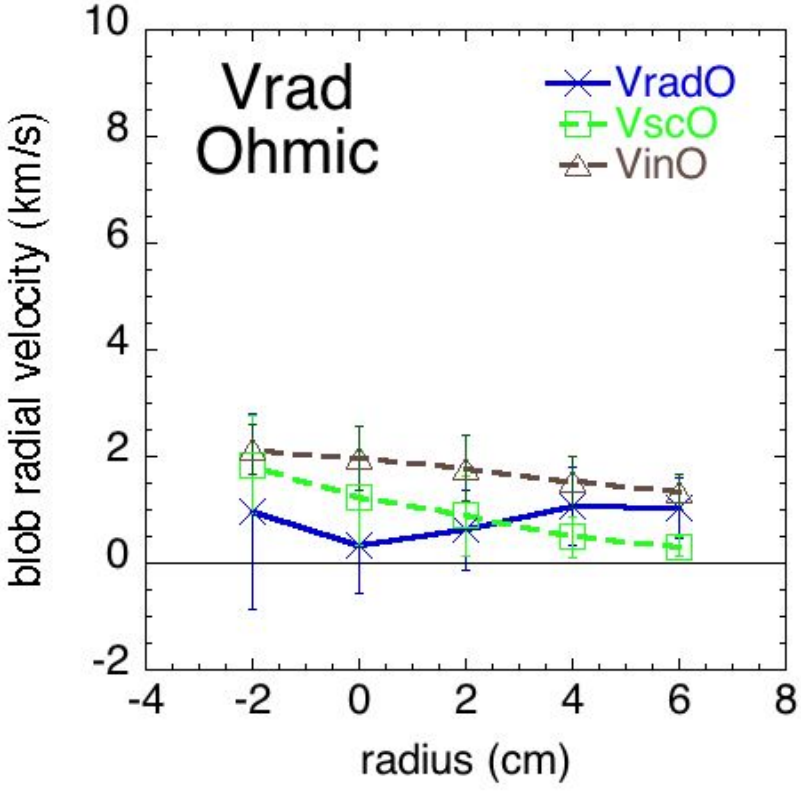
- Blob V_{rad} decreases with L_{pol} in Ohmic plasmas, at *which is qualitatively consistent with SC blob model*
- Blob V_{rad} ~independent of L_{pol} in H-mode plasmas

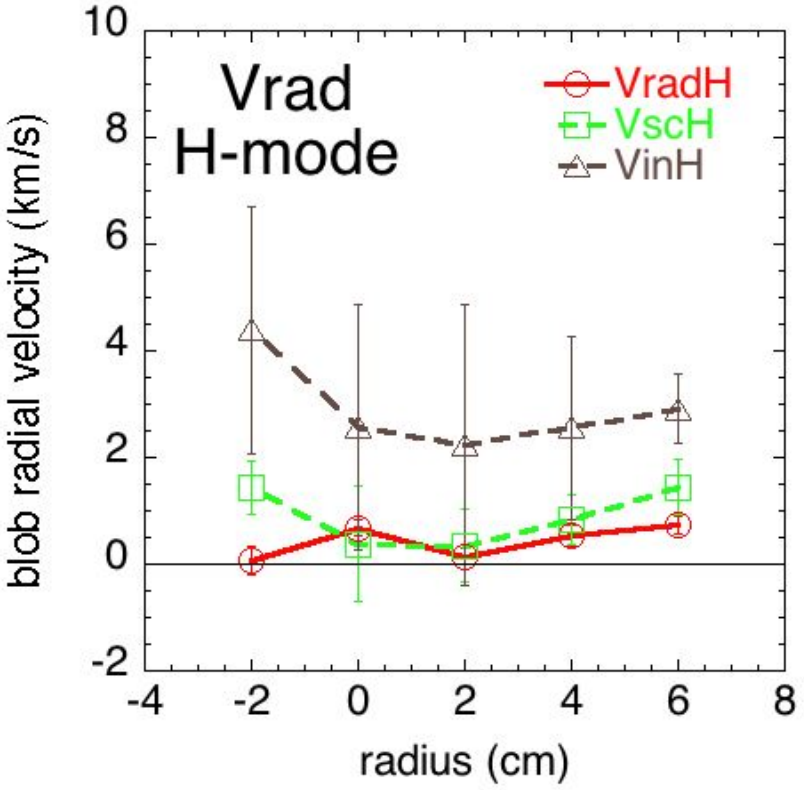




Average Blob V_{rad} vs. Blob Theory

- *Average V_{rad} in Ohmic ~ consistent with SC and IN*
- *Average V_{rad} in H-mode more consistent with SC*
- But large uncertainties in both data and theory





Theory of Poloidal Blob Motion

- All blobs should all move along with V_{pol} =E_{rad}xB drift
- Small blobs should also move with diamagnetic drift
- Large blobs should be "self-propelled" by blob tilting*

$V_{ExB} = 10^8 E_{rad}/B$, where $E_{rad} \sim 3*\text{grad}(T_e)$

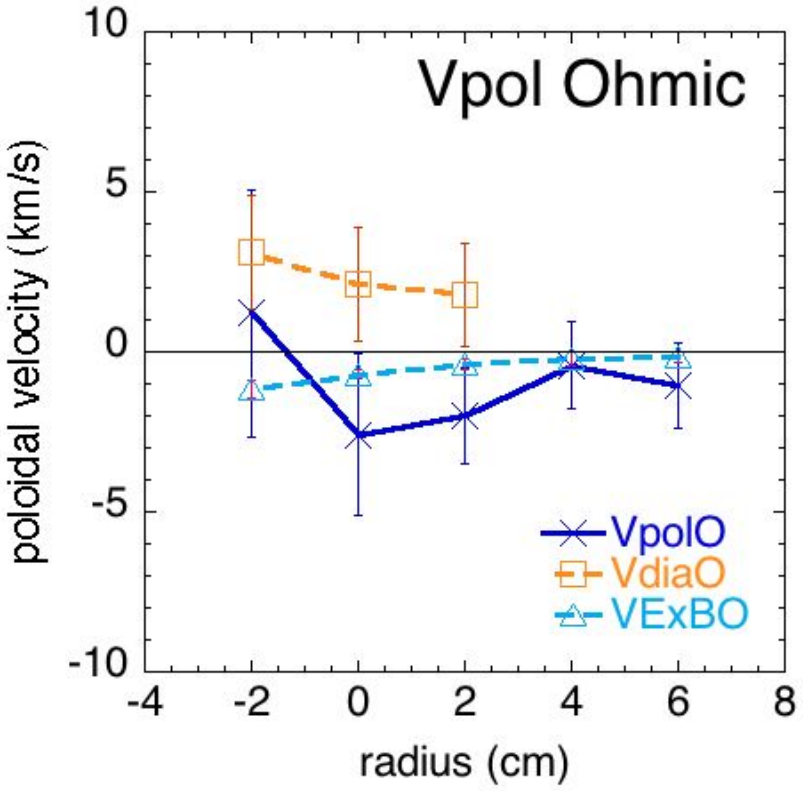
$V_{dia}=c_s\rho_s/L_n$ in electron diamagnetic direction

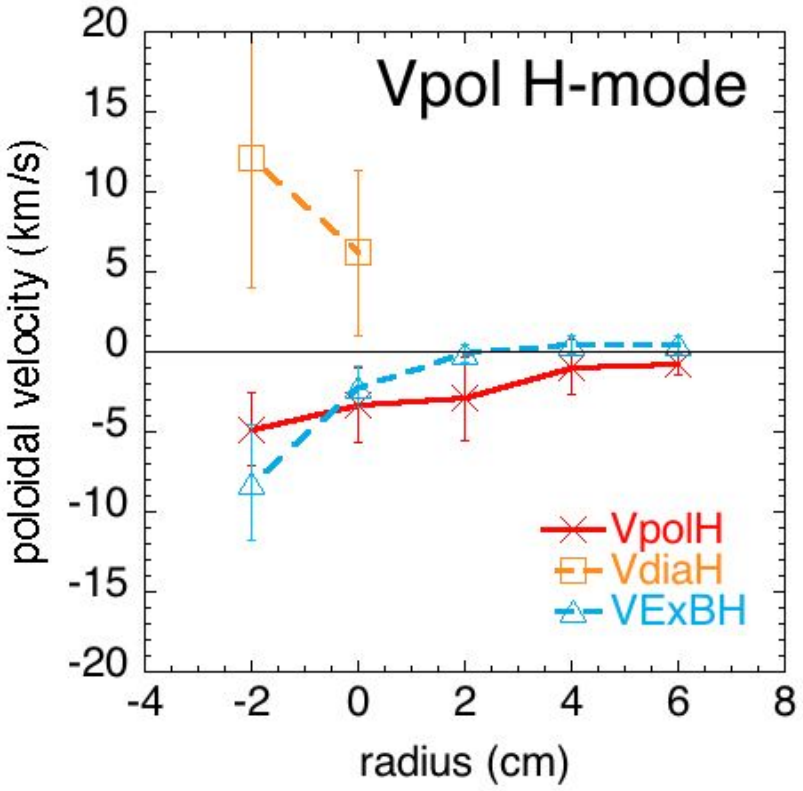
$V_{self} \sim \text{grad}\,[(-\sin 2*\text{tilt})(1-\text{ellip})^2]$

* J.R. Myra et al, Nucl. Fusion 53 (2013) 073013

Average Blob V_{pol} vs. Theory

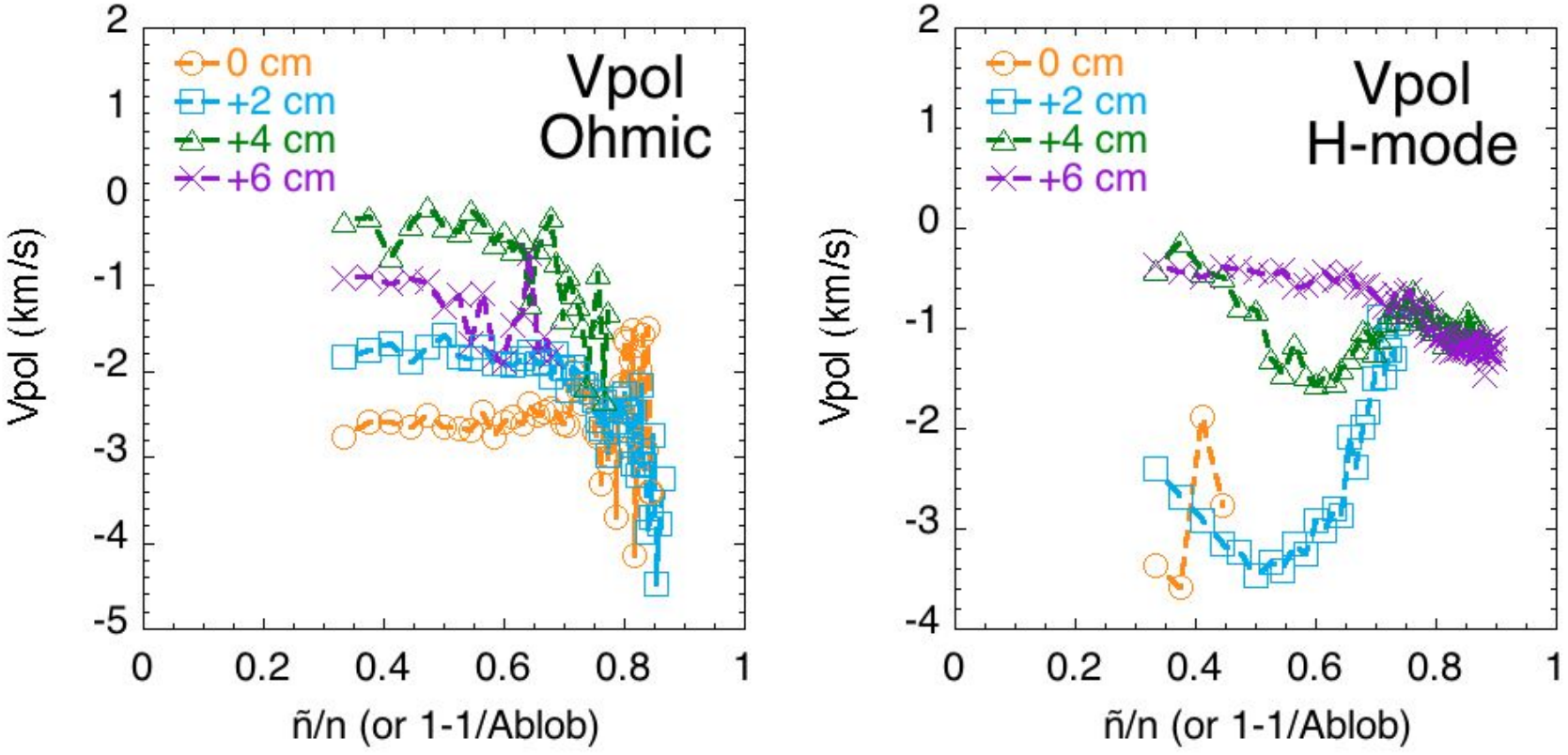
- *Average V_{pol} similar to estimated E_{rad}xB drift speeds*
- Average V_{pol} not similar to estimated V_{dia} speeds
- Ohmic blob V_{pol} reverses direction inside separatrix





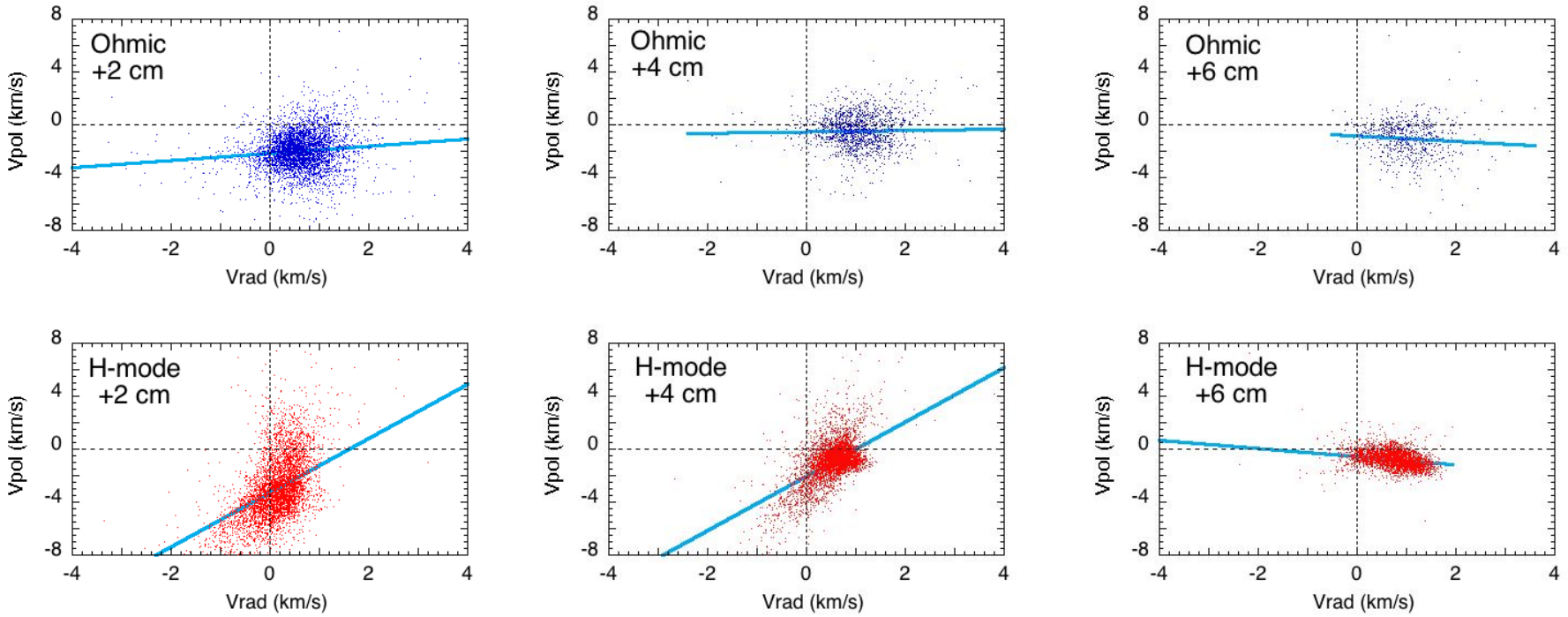
Scaling of V_{pol} with Blob Amplitude

- V_{pol} increases (in IDD) at large ñ/n in Ohmic plasmas, *qualitatively consistent with blob "self-propulsion"*
- V_{pol} tends to become lower at large ñ/n in H-mode



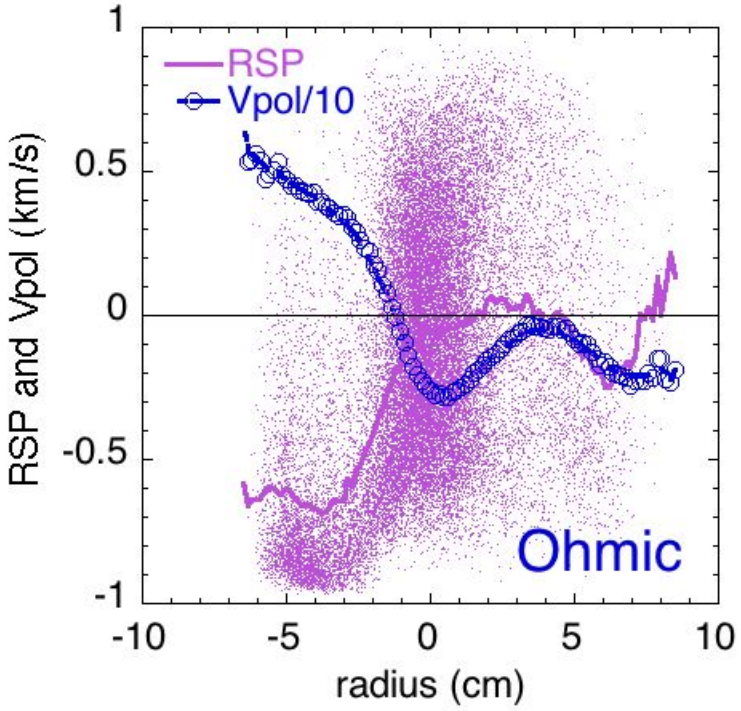
Empirical Scaling of V_{pol} with V_{rad}

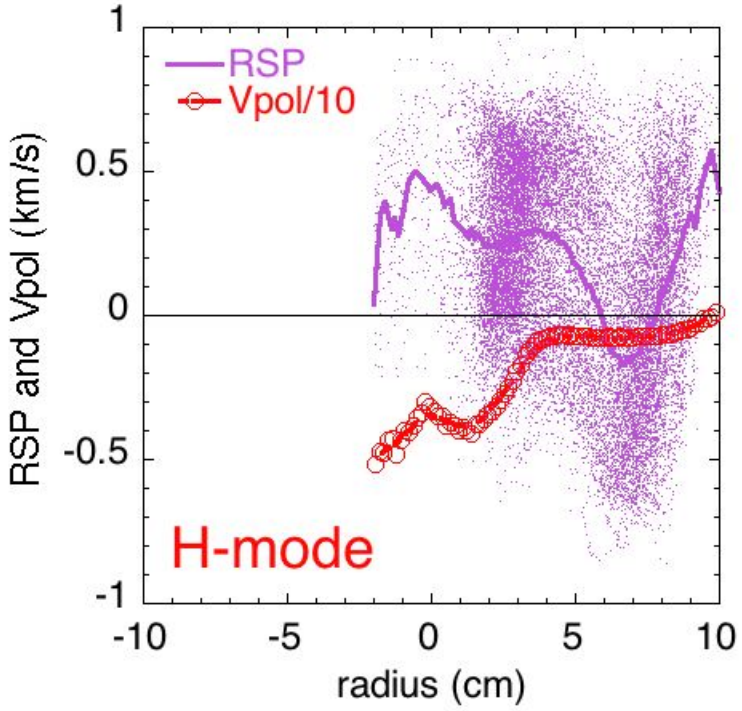
- No clear scaling of V_{pol} with V_{rad} in Ohmic plasmas
- Some correlation of V_{pol} with V_{rad} in H-mode plasmas
- Fairly wide scatter of blob velocities in all cases



V_{pol} vs. Reynolds Stress Proxy (RSP)

- RSP estimates blob V_{pol} from blob tilt and ellipticity*
- Ohmic data suggests blobs and V_{pol} affect each other
- H-mode data suggests that V_{pol} affects blob tilting





* J.R. Myra et al, Nucl. Fusion 53 (2013) 073013

Summary and Conclusion

- *Blob V_{rad} in H-mode increases with ñ/n like SC model*
- *Blob V_{rad} in Ohmic decreases with L_{pol} like SC model*
- *Average blob V_{rad} agreed fairly well with SC model*
- *Average blob V_{pol} consistent with estimated E_{rad}xB*

Conclusion: blob data is roughly consistent with blob models, but with large (unexplained) scatter

Possible Future Directions

- Measure n_e and T_e inside each blob, e.g. with THB[1]
- Measure blob electric and magnetic fluctuations[2,3]
- Measure 3-D blob structure with cameras & probes[4]
- Improve analysis techniques for blob dynamics[5]
- 'Seed' blobs in edge with ECH or injected pellets

1 Agostini M et al, Plasma Phys. Cont. Fusion 51105003 (2009)
2 Boedo J et al, Phys. Plasmas 21, 042309 (2014)
3 Spolaore, M et al, Phys. Plasmas 22, 012310 (2015)
4 Grulke O et al, Nucl. Fusion 54 (2014) 043012
5 Ogata, D et al, PP12.00050 poster Wednesday PM this meeting