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**Lodestar** NSTX

# Blob birth and transport in NSTX: GPI data analysis and theory

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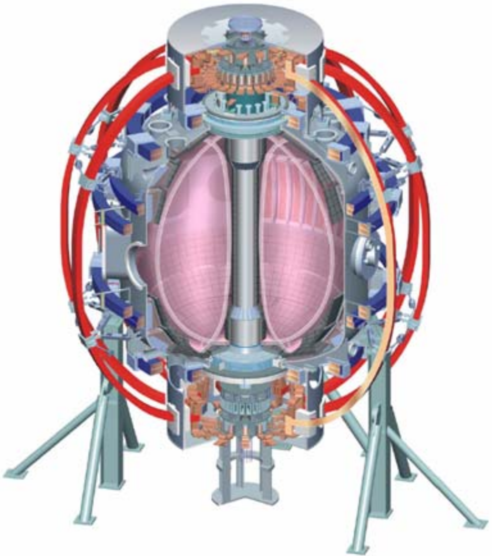

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# Background & Motivation

- Programmatic: ITER
  - **Pedestal/edge parameters** critical for performance, Q ⇒ understand edge T&T
  - **Power handling**: PFC damage by impact from blobs, ELMs, short-circuit divertor?
  - **Wall content** (tritium inventory)
  - **SOL environment** for RF antennnas
- Science: edge and blobs physics
  - **Convective** (vs. diffusive) transport
  - **Strong nonlinearity** ( ~ 1 fluctuations, no space scale separation)
  - Emergence of **coherent** structures, **intermittency** from turbulence

- Competition: parallel transport (well-known) vs. ⊥ convective blob transport
  - Need **radial blob velocity $v_x$**
  - Need **blob parameters** (n, T)
  - Need **rate of blob generation** (for <Γ>)

} this poster

# Preview

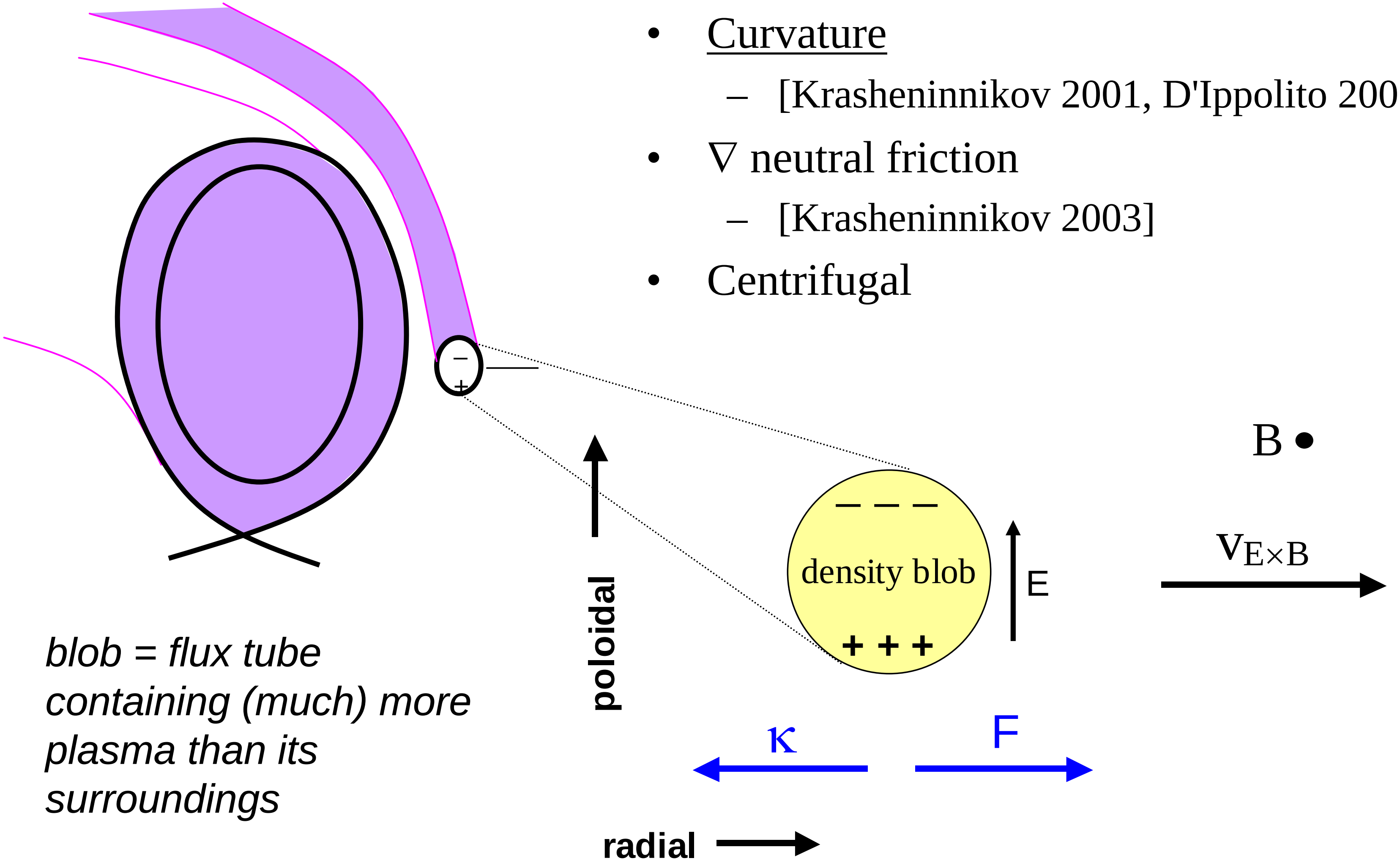
- Use gas-puff-imaging (GPI) diagnostic to extract blob parameters:
  - birth zone
  - scale size
  - radial velocity $v_x$
  - density and temperature (atomic physics model using He 5876 emission)
- Birth zone and blob parameters are related to the local maximum of the edge $\nabla ln <p> \Rightarrow$ blob generation by underlying edge instability.
- Categorize NSTX blobs by theory regime
- Observed $v_x$ bounded by theoretically predicted min and max

## Outline

- **Theory background**
- **Data analysis**
- **Future work; Conclusions**

# Blob filaments break off from edge plasma, charge polarize and convect outwards

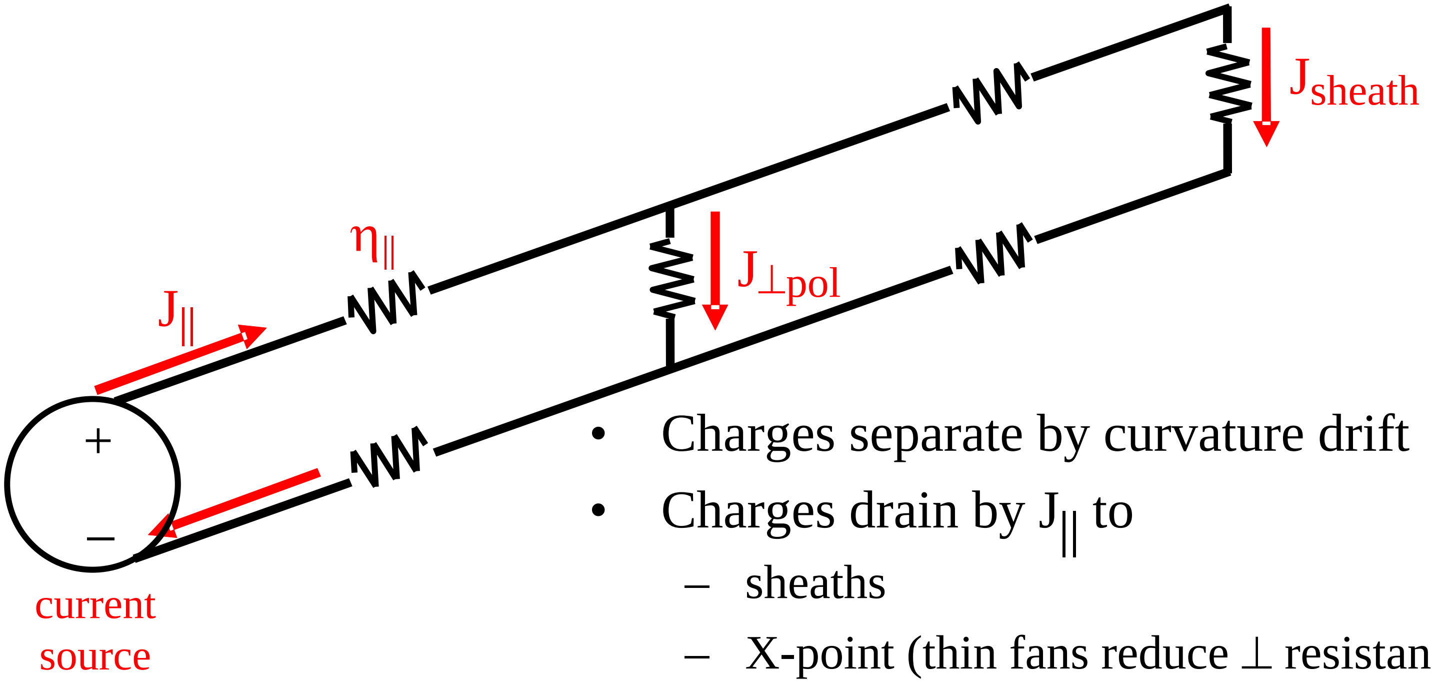
- Curvature
  - [Krasheninnikov 2001, D'Ippolito 2002]
- ∇ neutral friction
  - [Krasheninnikov 2003]
- Centrifugal



*blob = flux tube containing (much) more plasma than its surroundings*

*Lodestar/Myra/NSTX/2005*

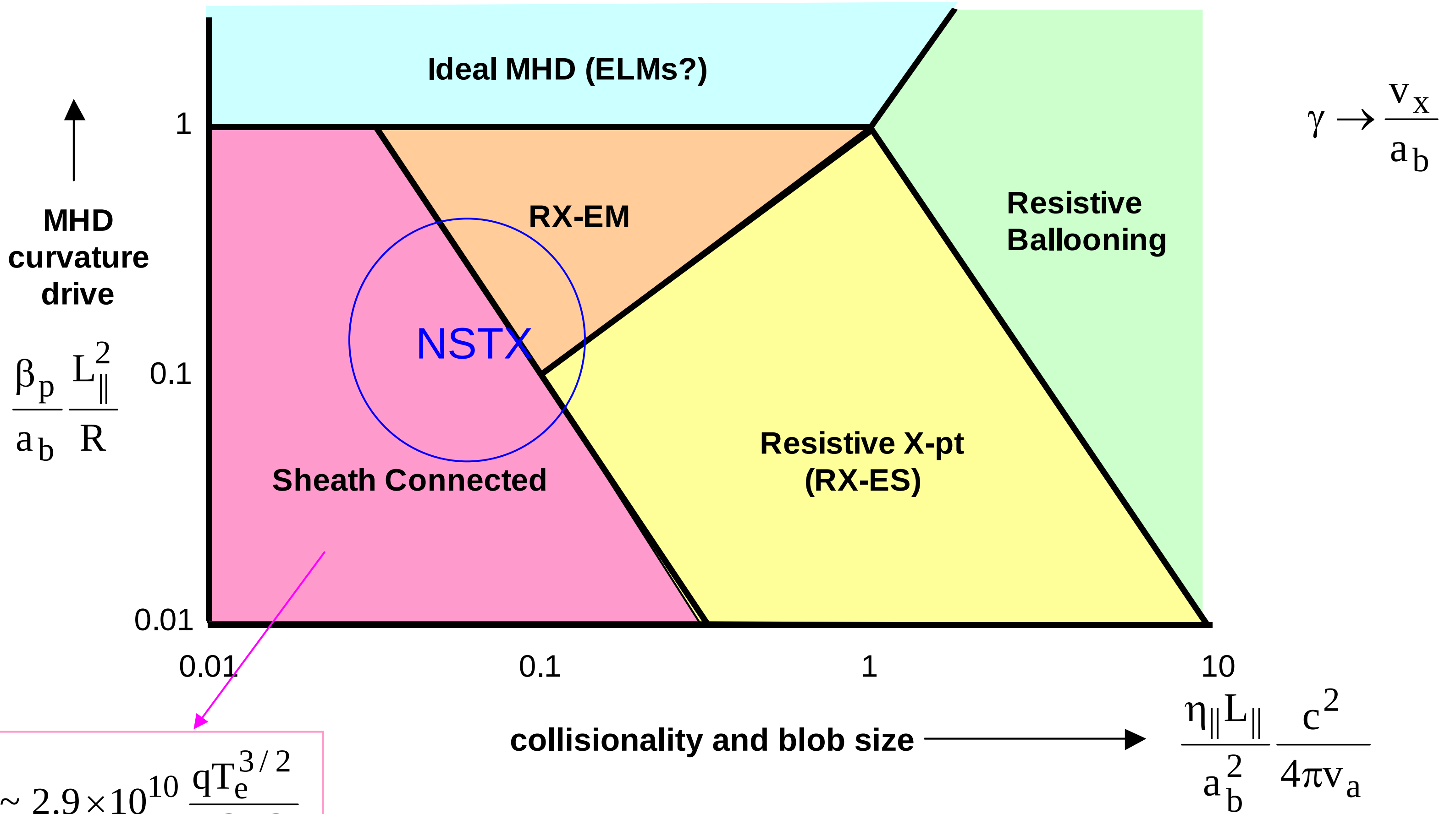
# Currents drain charges



- Charges separate by curvature drift
- Charges drain by $J_{||}$ to
  - sheaths
  - X-point (thin fans reduce ⊥ resistance)
  - outgoing Alfvén waves
- Charges mix by spin
- Effective circuit resistance ⇒ potential $\Phi$, speed $v_x$

# Current path determines blob regime

Resistive fluid analysis

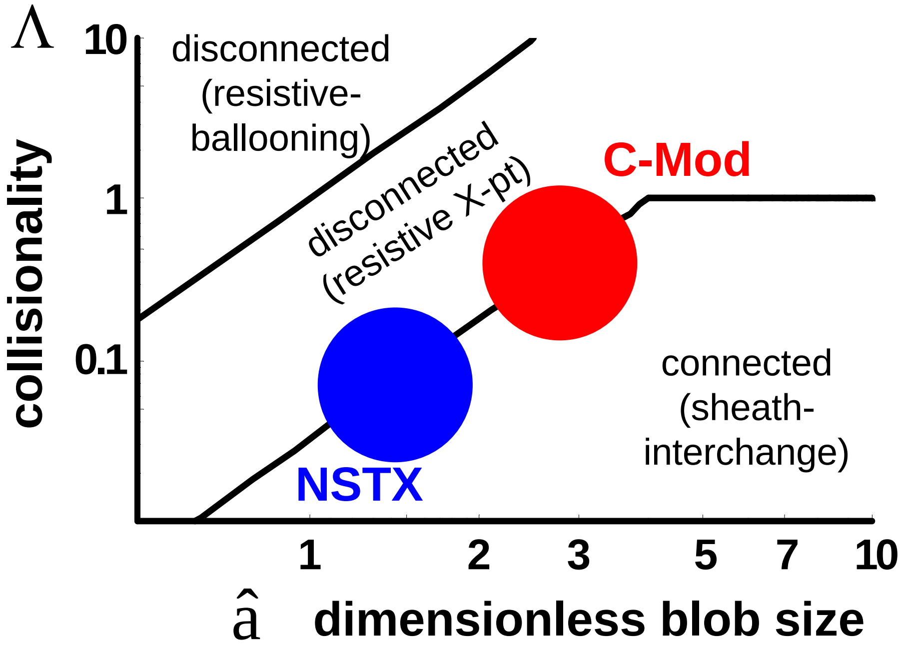


$$v_x \sim 2.9\times10^{10}\,\frac{qT_e^{3/2}}{a_b^2B^2}$$

Each regime has a characteristic magnitude and scaling of blob radial velocity

$v_x(n_e, T_e, a_b; B, q, R)$

# Electrostatic limit: characteristic regimes ⇒ blob velocities, & bounds



- NSTX and C-Mod explore different regions of parameter space
- Characteristic $v_*$ in NSTX and C-Mod is similar $v_* \sim 2$ km/s

$$\Lambda = \frac{\nu_{ei} L_\|}{\Omega_e \rho_s} = 1.7 \times 10^{14} \frac{n_e L_\|}{T_e^2} \qquad \hat{a} \equiv \frac{a_b}{a_*} = \frac{a_b R^{1/5}}{L_\|^{2/5} \rho_s^{4/5}} = 0.018 \frac{a_b B^{4/5} R^{1/5}}{L_\|^{2/5} T_e^{2/5}}$$

$$v_* = c_s \left( \frac{a_*}{R} \right)^{1/2} = 5.1 \times 10^6 \frac{L_\|^{1/5} T_e^{7/10}}{B^{2/5} R^{3/5}}$$

Theoretical bounds on blob radial velocity

$$\frac{1}{\hat{a}^2} < \frac{v_x}{v_*} < \hat{a}^{1/2}$$

sheath

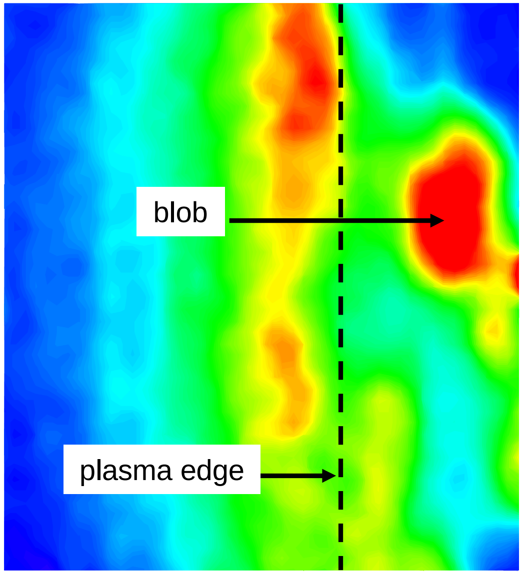
resistive bal.

# Important parameters affecting blob speed

- scale size $a_b$
- $T_e$
- collisionality $\nu_{ei}(n_e, T_e)$
- field line geometry ⇒ position wrt. separatrix
  - $L_{||}$, (weighted connection length) or $q_{eff} = L_{||}/R$
  - X-pt shear ⇒ $\varepsilon_x \sim 1/$(X-pt “fanning”)
- amplitude of blob above background plasma, $\delta n/n_{bkgd}$

# Background – GPI experiment

- Gas Puff Imaging (GPI)
  - Zweben 2004; Maqueda 2003; Terry 2003
  - 2D movies of blob motion
- Test theory of blob $v_x$
- Difficult to do with probe data alone
  - 1D time-slice through blob
  - Unknown impact parameter (no y info)
- NSTX GPI diagnostic well matched to blob dynamics
  - Spatially and temporally
- GPI measures light intensity, not $n_e$, $T_e$
  - Use atomic/radiation physics models



sample GPI frame

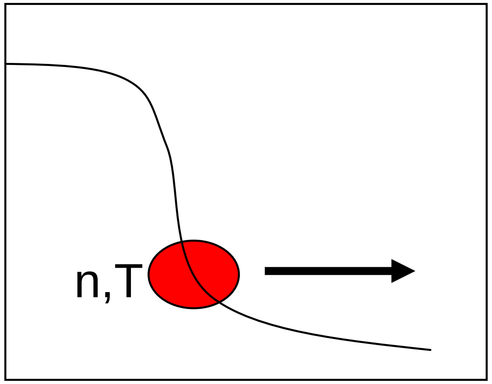
shot 112825
L mode 4.5 kG, 800 kA
0.8 MW NBI
He puff (HeI filter)

# GPI atomic physics, and modeling

- HeI 5876 line intensity is **$I = n_0 F(n_e, T_e)$**

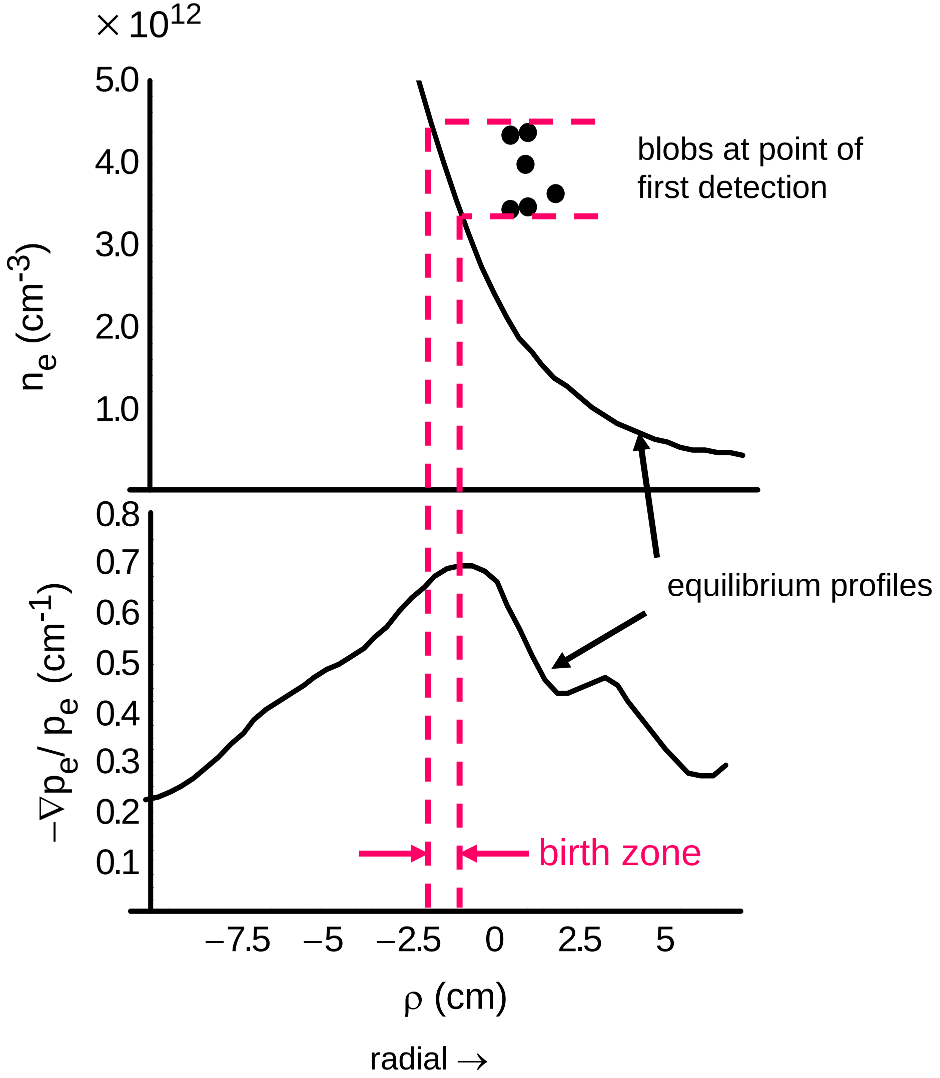
  $n_0$ = neutral He density

  $F(n_e, T_e)$ = atomic physics
- 2 basic ideas
  - Nonlinear interchange modes **passively convect $n_e$, $T_e$** together $\Rightarrow$ **$T_e$** = **$T_e(n_e)$** from equilibrium
  - $n_0$ is not measured so: "**calibrate**" I **to** median ("**equilibrium**") $n_e$, $T_e$ using Thompson Scattering, probe data [Boedo] and atomic physics modeling [Stotler]
- Apply inverse mapping of $I \rightarrow n_e, T_e$ derived from equilibrium profiles to turbulent (bloby) camera frames *near blob birth zone*
  - $n_0$ unaffected by blobs (assume)



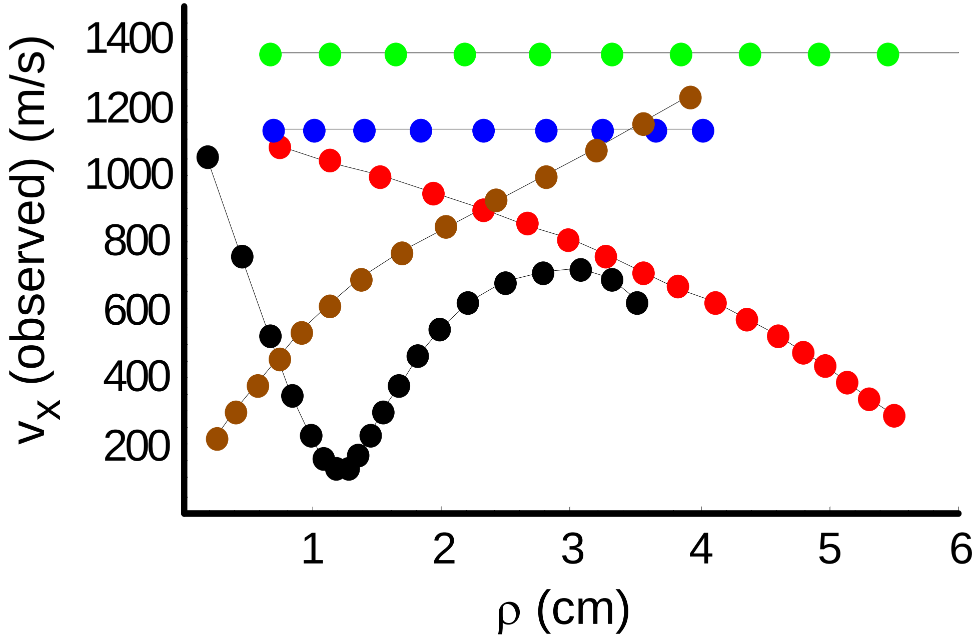
Assume blob convects birth $n_e$, $T_e$ radially outward

# Blob birth zone confirms edge instability drive



- Blobs are born with a density (and temperature) characteristic of where the underlying linear instability peaks
- Not e.g.
    - condensation of turbulent structure from deeper in core
    - core SOC avalanche

# Observed radial velocity $v_x$ of blob tracks show large scatter



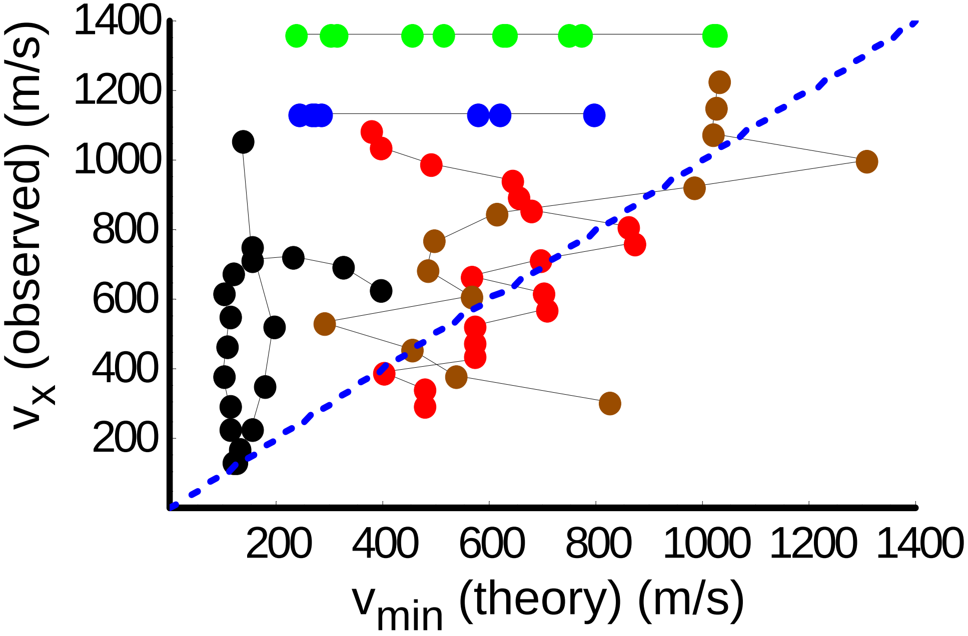
- Colors identify individual blob tracks
- Observed velocities seem “random”
- *What order, if any, is present in this dataset?*
- Needs a theoretical framework

# Observed blob velocity is bounded by theoretical minimum

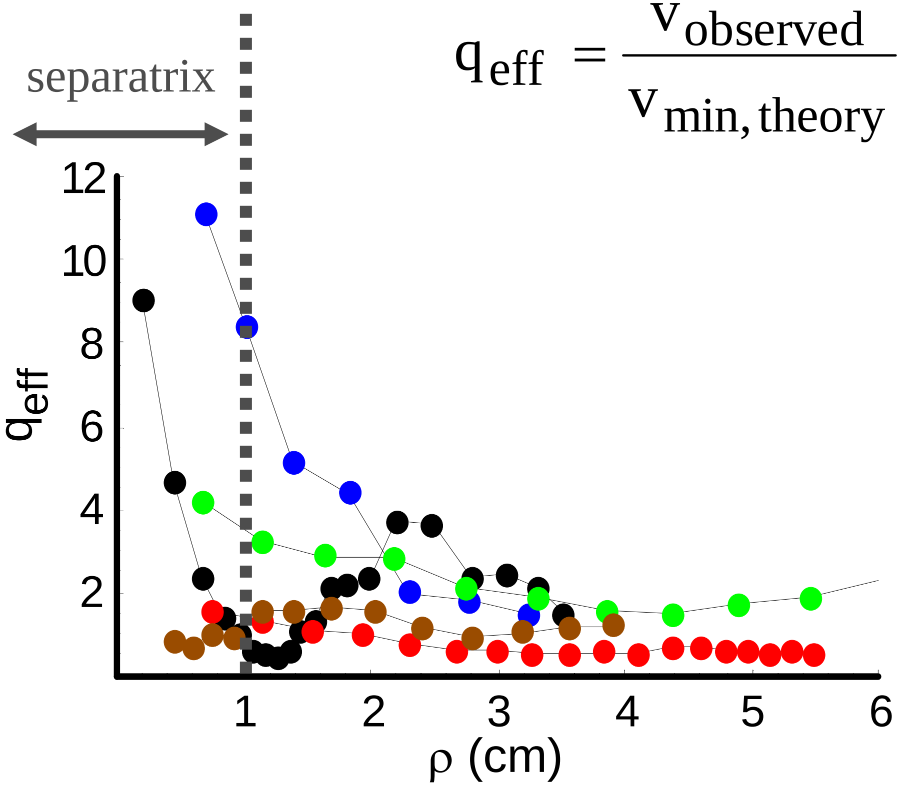
- Sheath-connected blobs have minimum $v_x$ of all the regimes

$$v_x \sim 2.9\times10^{10}\,\frac{qT_e^{3/2}}{a_b^2B^2}\,f \qquad f \sim \delta p/p \sim \text{blob amp above background}$$

- For spatial min set $q = L_{||}/R = 1 \Rightarrow v_{min}$



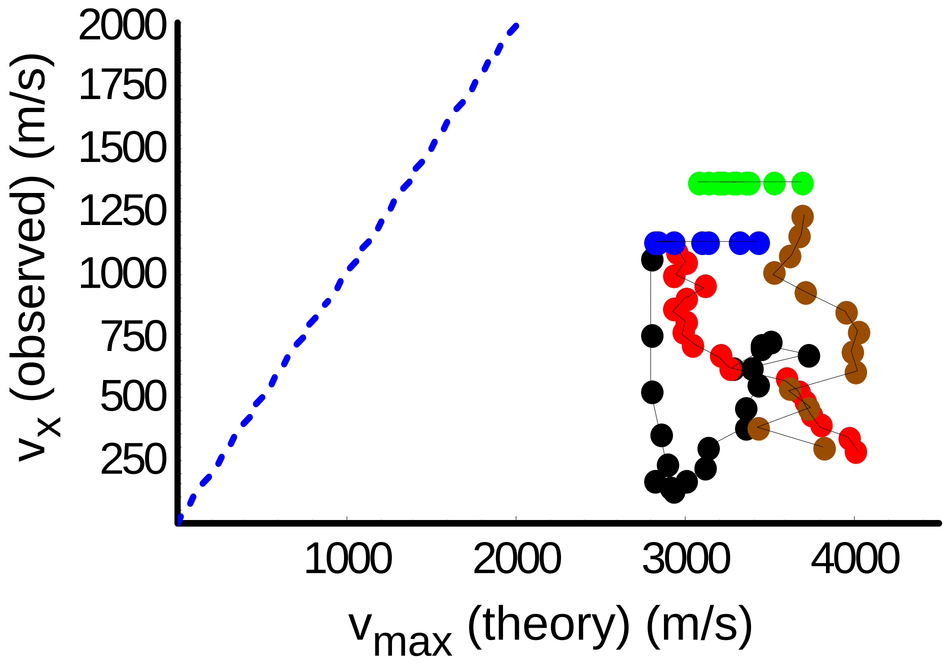
# Radial dependence of $q_{eff}$



$$q_{eff} = \frac{v_{observed}}{v_{min,theory}}$$

- Trend consistent with q profile expected from geometry
  - $q = L_{||}/R$ where $L_{||}$ = weighted connection length
- Significant variations of blob velocity remain and are not explained by present model
  - Analysis errors?
  - Parallel blob structure?
  - Blob spin?

# Observed blob velocity is bounded by theoretical maximum



- Blob scaling in the resistive ballooning regime gives maximum $v_x$
- Expect and confirm that observed $v_x << v_{max}$
- Simple theoretical estimates bound the observed blob velocity $v_{min} < v < v_{max}$

$$v_{max}(\text{theory}) \sim 6.9\times10^5 \frac{a_b^{1/2}T_e^{1/2}}{R^{1/2}} f$$

# Summary

- Edge turbulence produces coherent propagating structures - blobs
- Blobs are born with a density and temperature characteristic of where the underlying linear instability peaks
- Dynamics of blobs is consistent with simple theoretical models
  - Radial blob velocity arises from blob curvature-induced charge polarization and E×B convection
  - Identified the dependence on key blob parameters
  - Theoretical estimates bound the observed blob velocity
- Blob velocity is also influenced by effects not in the model used here:
  - Parallel blob structure?
  - Internal net vorticity (blob spin)?

# Challenge questions

- **Can we understand the dynamics of an individual blob with known properties?**
  - Given $n_e$, $T_e$, $a_b$ compare observed $v_x$ and evolution with theory and simulation

**well in hand**

- **What properties are blobs created with and why?**
  - Rate & statistics of blob generation, scale size $a_b$, $n_e$, $T_e$
  - Linear $\gamma$, $k \rightarrow a_b$, parallel mode/blob structure vs. circuit path
  - $v_y$ shear, nonlinear coupling effects on blob generation
  - Electromagnetic blobs and ELMs
  - Will try numerical simulation with 2D turbulence code (D. Russell's SOLT code, e.g. Poster CP1.00045)

**future work**