

Challenges in the Determination of the Interstellar Flow Longitude from the Pickup Ion Cutoff

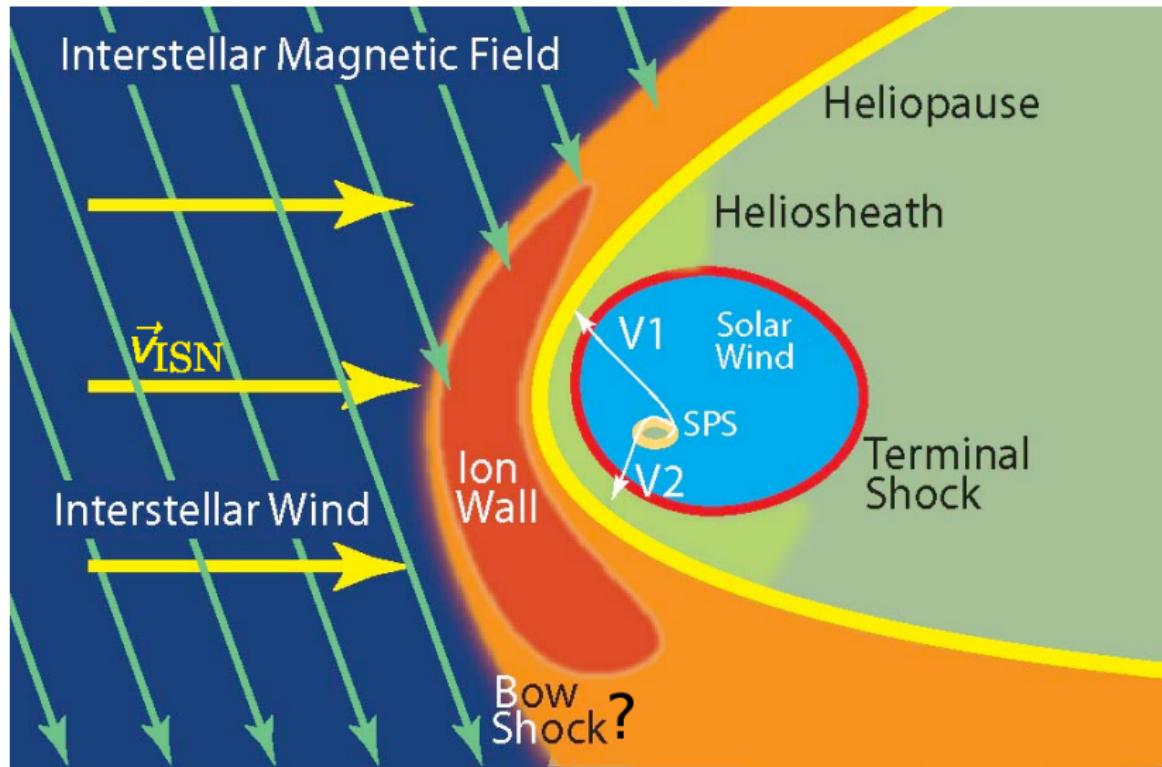
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UNH Space Science Seminar, Dec. 6th 2017

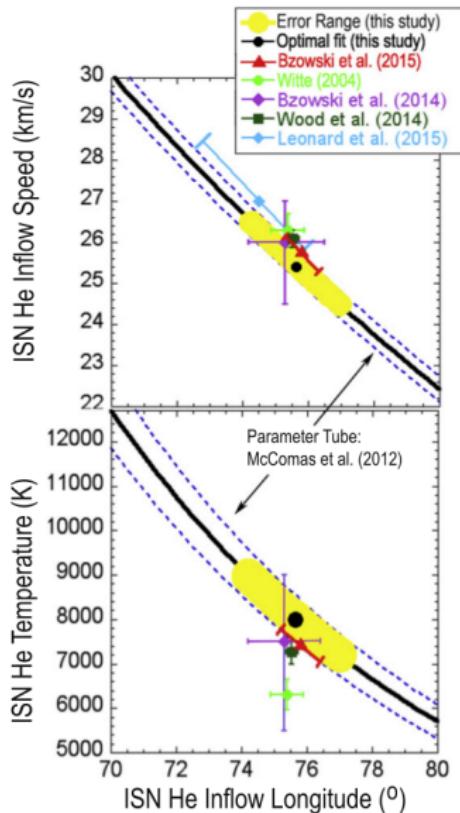
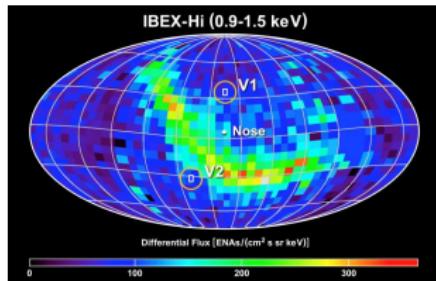
The Boundaries of the Heliosphere



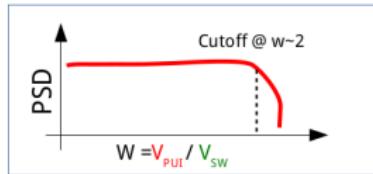
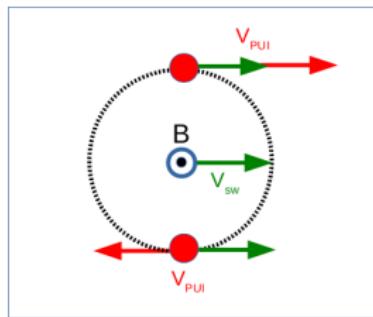
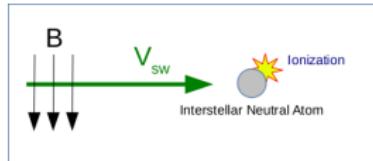
adapted from Treumann & Jaroschek, 2008

The Boundaries of the Heliosphere - Motivation

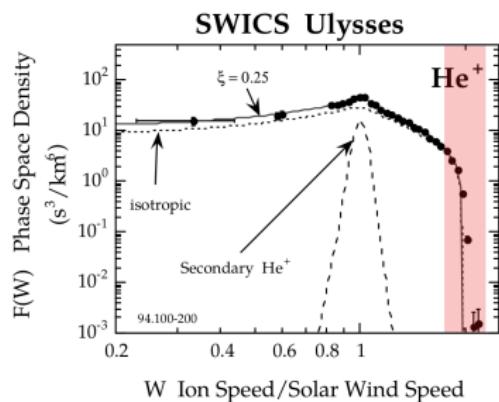
- ▶ Heliosphere - LISM interaction is determined by \vec{v}_{flow} , T_{LISM} , and \vec{B}_{LISM}
- ▶ IBEX results for \vec{v}_{flow} (v_{flow} , λ_{flow} , β_{flow}) and T_{LISM} are coupled and leave a 4D parameter tube.
- ▶ Independent measurement of λ_{flow} through PUIs!



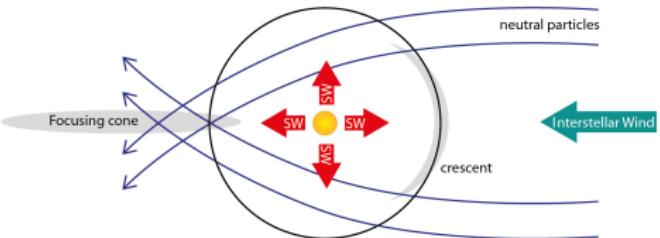
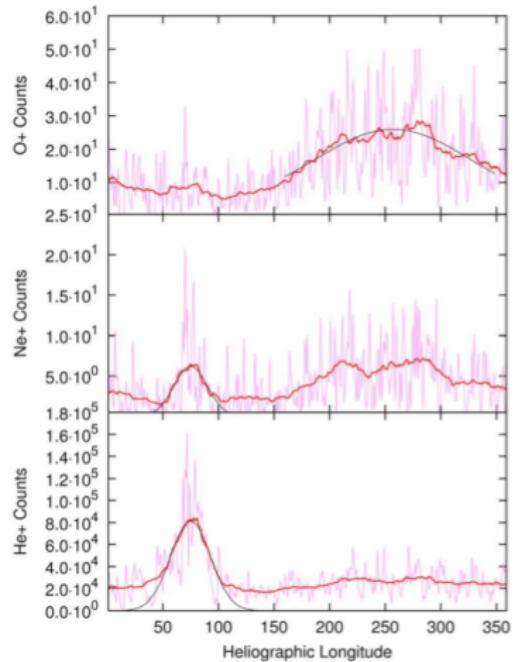
Pickup Ions - Basics



- ▶ Former neutrals that get ionized and "picked-up" by the solar wind.
- ▶ Typically $v_{neutral} \ll v_{sw}$
→ cutoff at $\sim 2v_{sw}$.
- ▶ Interstellar PUIs
→ created from interstellar neutrals.
Inner-source PUIs
→ neutral source in the inner heliosphere.



Pickup Ions - Flux



Helium: $\lambda_{fc} = 77.4^\circ \pm 1.9^\circ$

$\lambda_{\text{crescent}} = 80.4^\circ \pm 5.4^\circ$

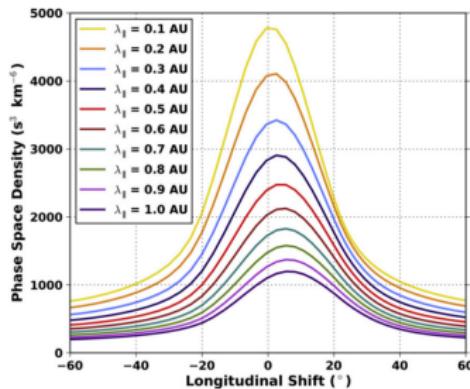
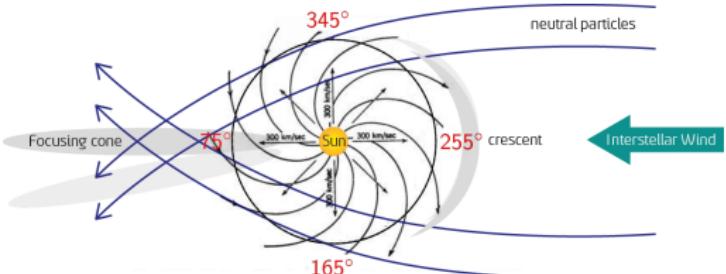
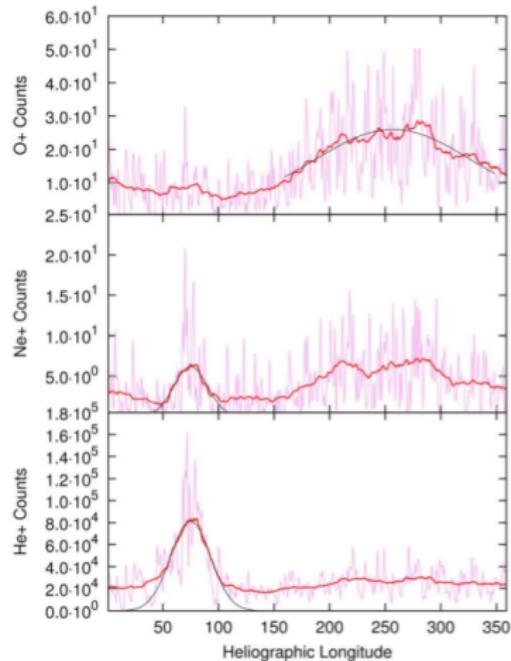
Oxygen: $\lambda_{\text{crescent}} = 78.9^\circ \pm 3.1^\circ$

Neon: $\lambda_{fc} = 77.4^\circ \pm 5.0^\circ$

$\lambda_{\text{crescent}} = 79.7^\circ \pm 2.6^\circ$

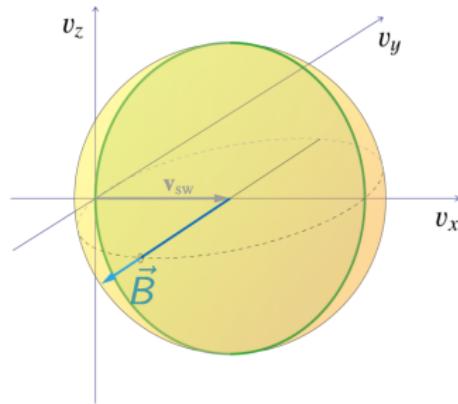
Drews et al., 2012, JGR

Pickup Ions - Flux

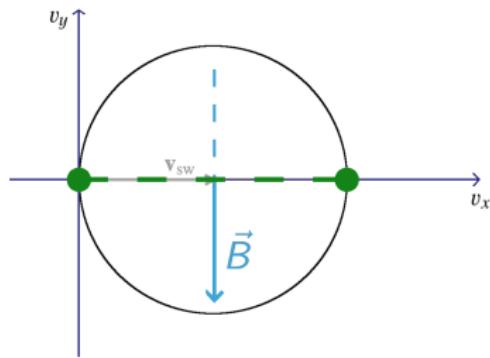


Quinn et al., 2016, ApJ

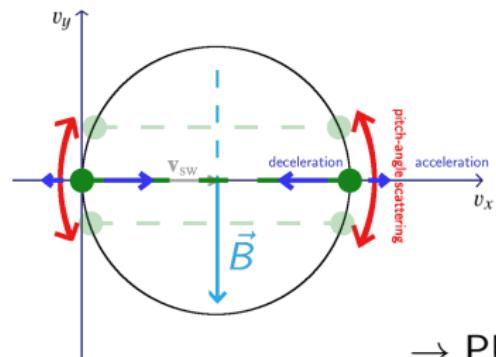
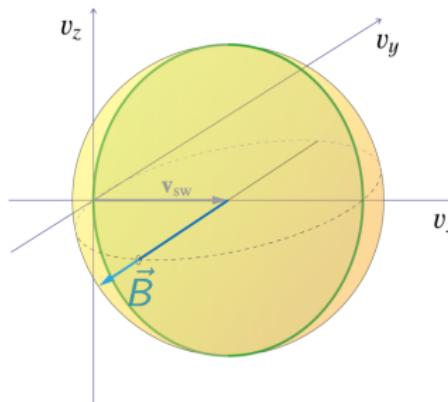
Pickup Ions - VDF



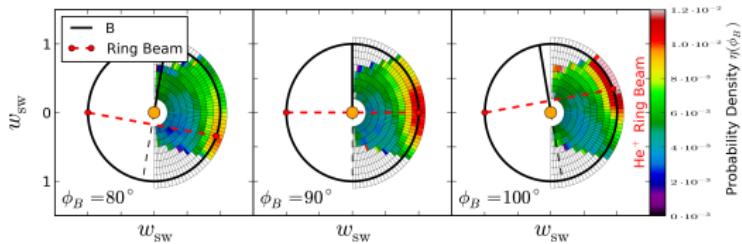
- ▶ PUIs are injected into solar wind with anisotropic torus VDF.



Pickup Ions - VDF



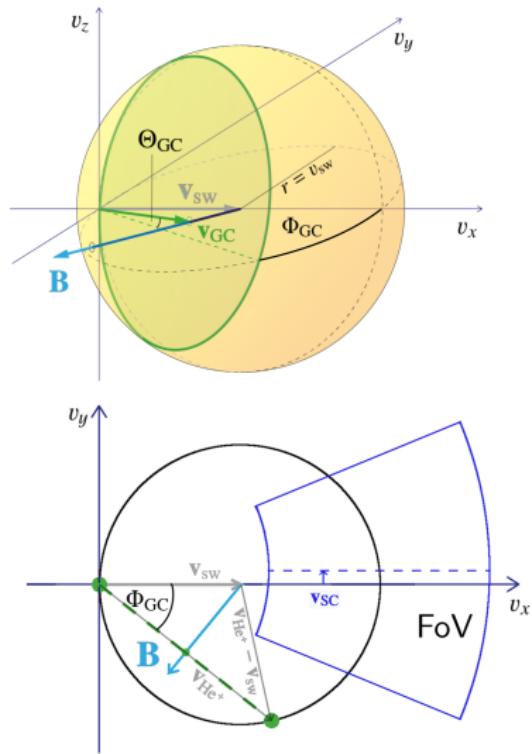
- ▶ PUIs are injected into solar wind with anisotropic torus VDF.
- ▶ Torus VDF is modulated by:
 - ▶ pitch-angle scattering
→ increases isotropy.
 - ▶ Deceleration/acceleration processes.



Drews et al., 2015, A&A

→ PUI VDF closely connected to \vec{B} orientation.

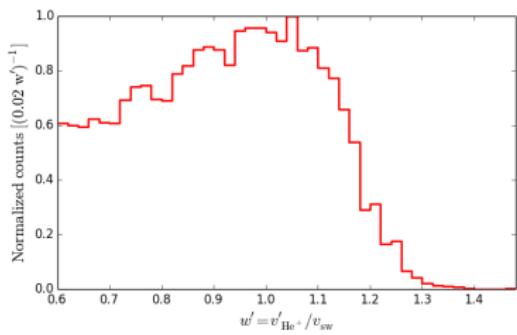
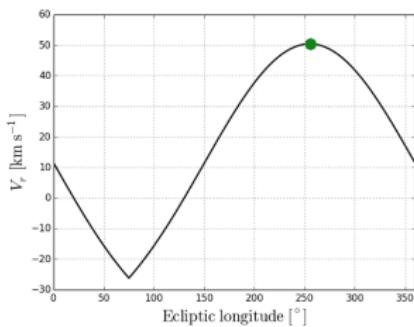
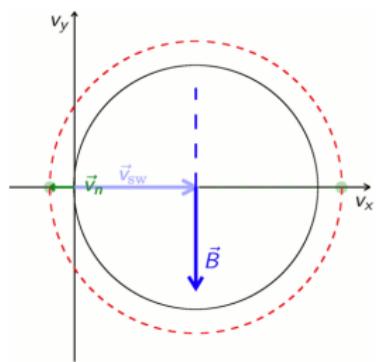
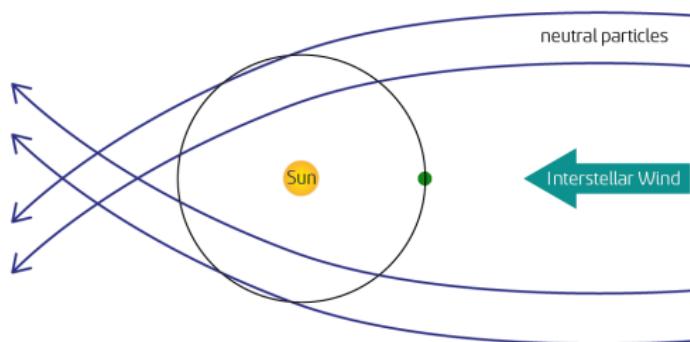
Pickup Ion Injection - Frame of Reference



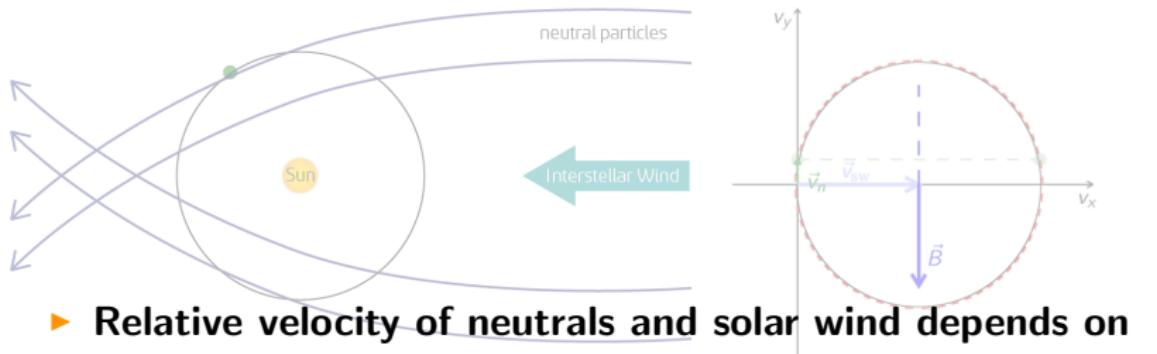
- ▶ Initial PUI torus lies on spherical shell centered around solar wind velocity.
- ▶ The solar wind frame is the natural frame for the PUI motion.
→ transformation from spacecraft into solar wind frame possible with STA/PLASTIC.
- ▶ Initial speed independent from \vec{B} orientation.

$$w = \frac{v_{He^+}}{v_{SW}} / w' = \frac{|\vec{v}_{He^+} - \vec{v}_{SW}|}{v_{SW}}$$

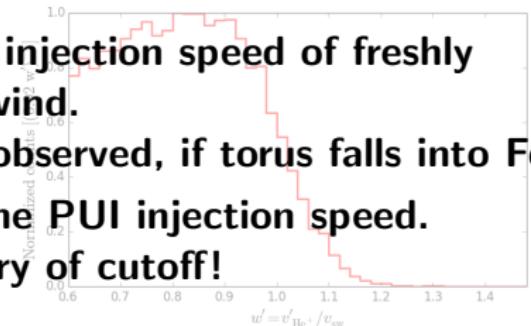
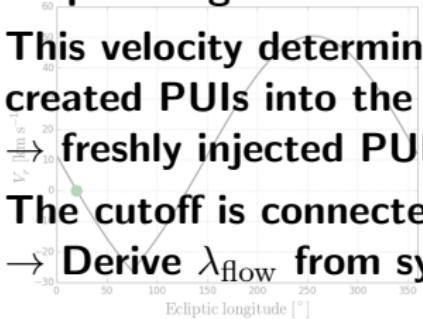
Utilizing the Cutoff to Determine λ_{flow}



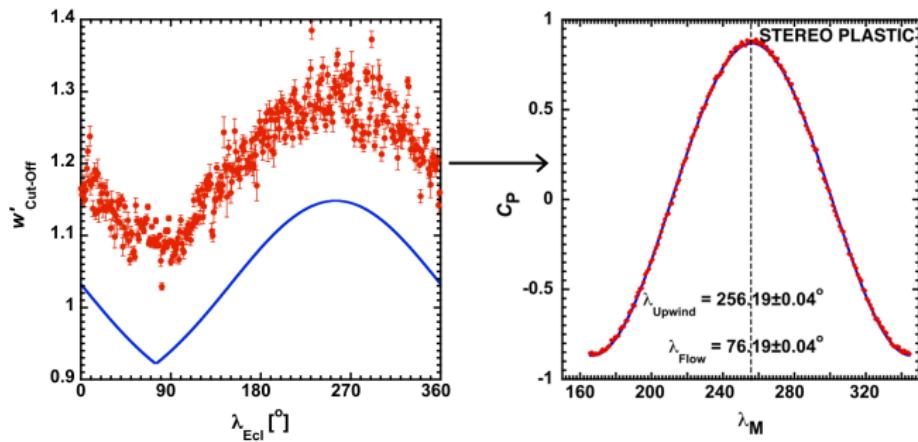
Utilizing the Cutoff to Determine λ_{flow}



- ▶ Relative velocity of neutrals and solar wind depends on ecliptic longitude.
- ▶ This velocity determines the injection speed of freshly created PUIs into the solar wind.
→ freshly injected PUIs are observed, if torus falls into FoV
- ▶ The cutoff is connected to the PUI injection speed.
→ Derive λ_{flow} from symmetry of cutoff!



Proof-of-Concept

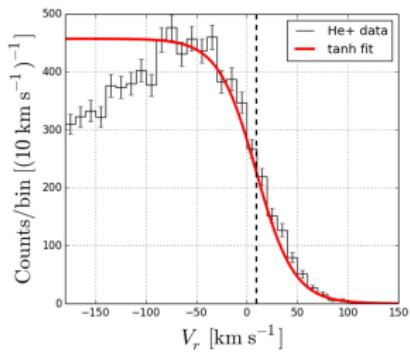
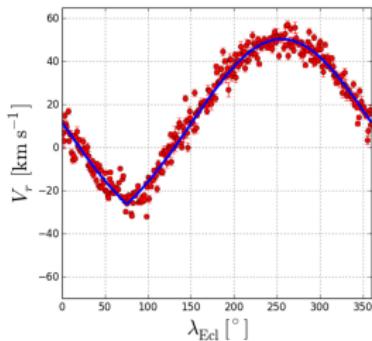
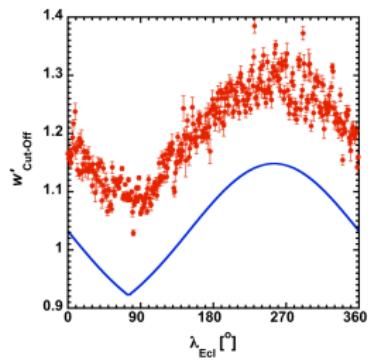
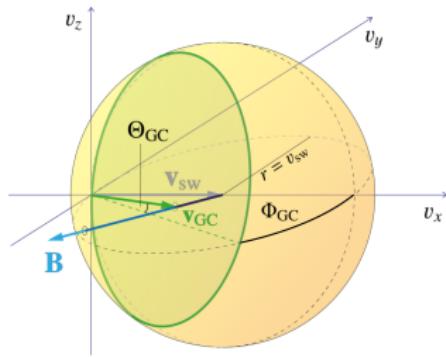


- ▶ Fit of STA/PLASTIC He⁺ histograms with tanh-function.
- ▶ Calculation and cos-fit of mirror-correlation coefficients.

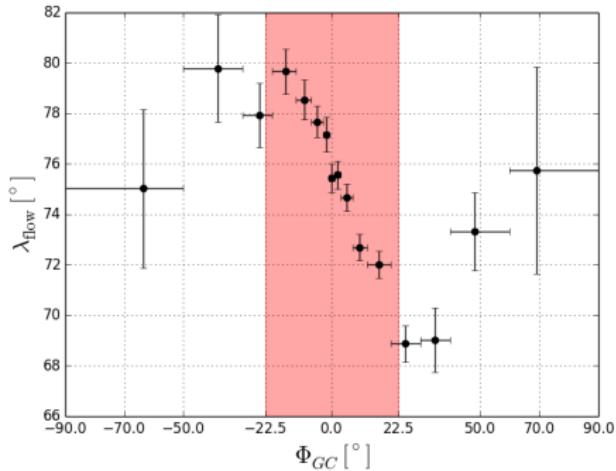
Möbius et al., 2015, ApJ

Improvements

- ▶ Reduce influence of v_{sw} .
- ▶ Test different cutoff determination techniques.
- ▶ Exclude acceleration sites.
- ▶ Estimate reasonable errors.
- ▶ Study IMF restriction.

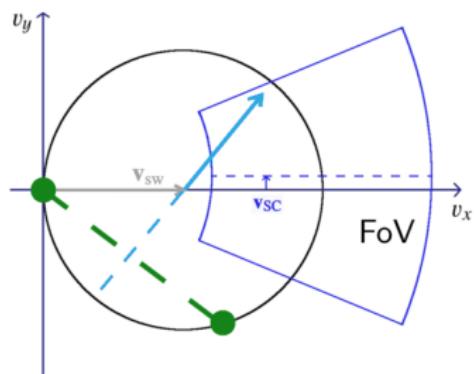
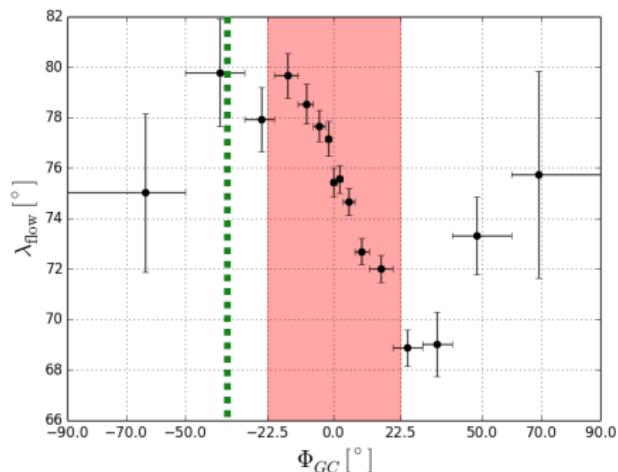


IMF Orientation Dependence



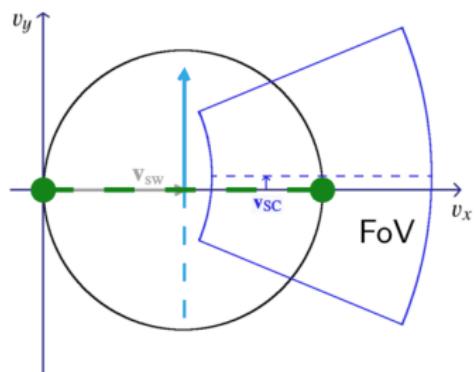
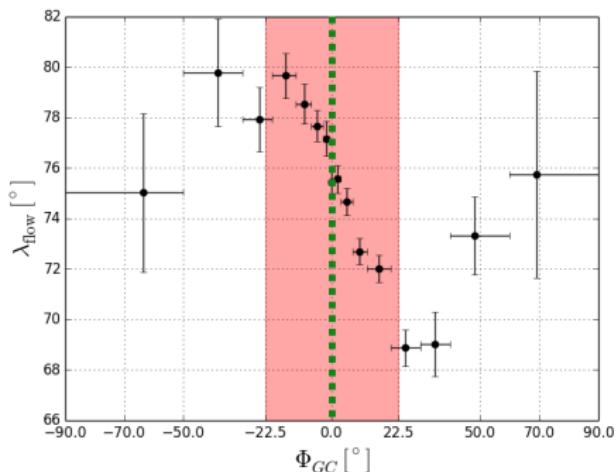
Taut et al., 2017, A&A, accepted

IMF Orientation Dependence



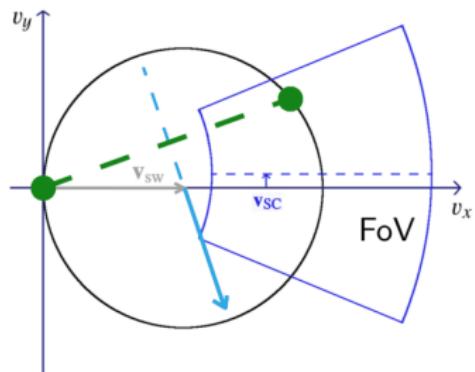
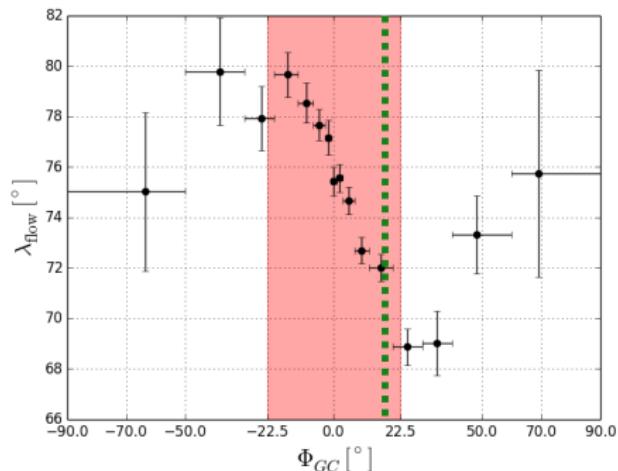
Taut et al., 2017, A&A, accepted

IMF Orientation Dependence



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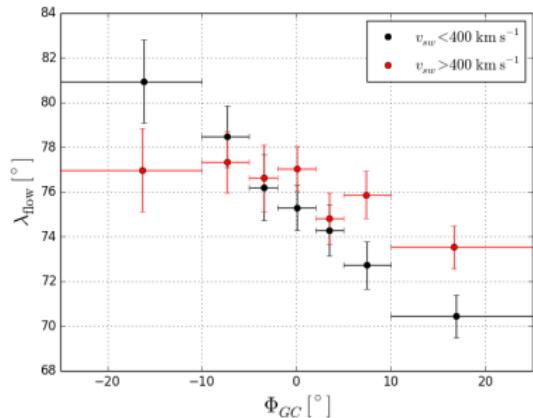
IMF Orientation Dependence



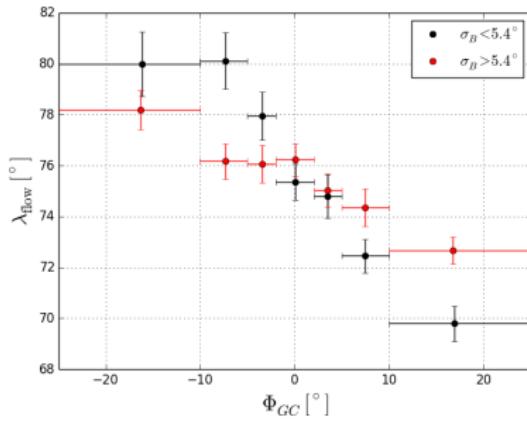
Taut et al., 2017, A&A, accepted

Observational Constraints

black: $v_{sw} < 400 \text{ km s}^{-1}$
red: $v_{sw} > 400 \text{ km s}^{-1}$

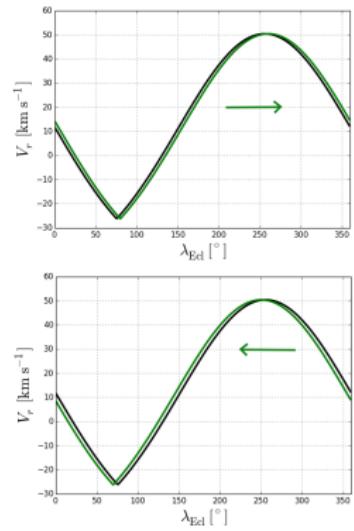
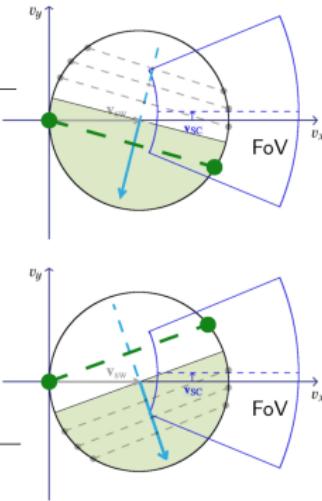
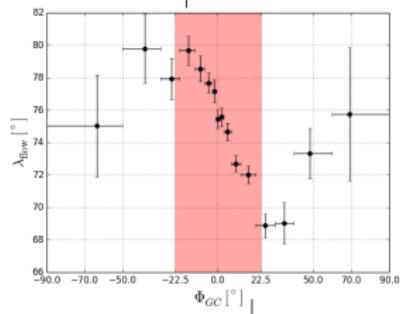


black: stable IMF
red: variable IMF

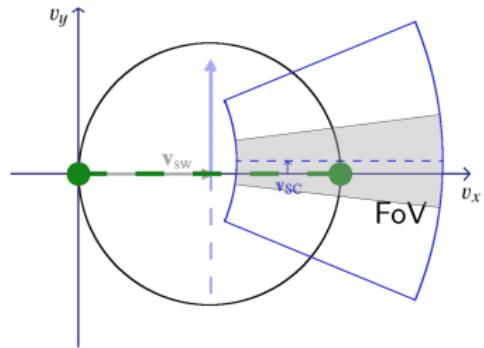


→ effect related to anisotropy!

Longitudinal Transport?



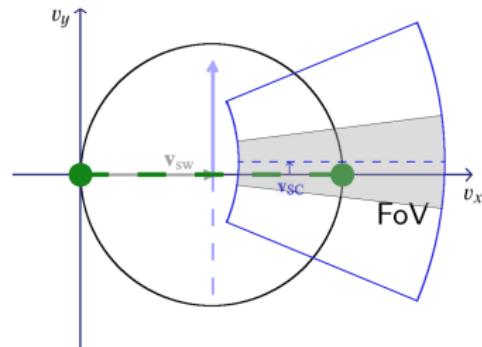
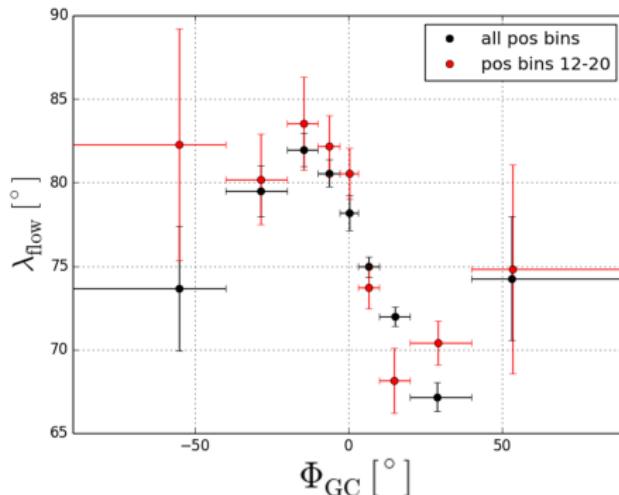
Variable FoV



Expectation:

- ▶ smaller tangential guiding center velocity at small angles.
- ▶ less affected by transport.

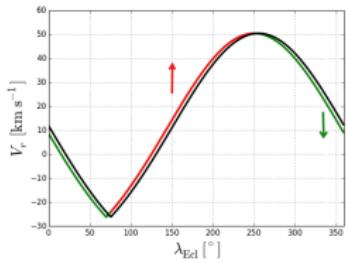
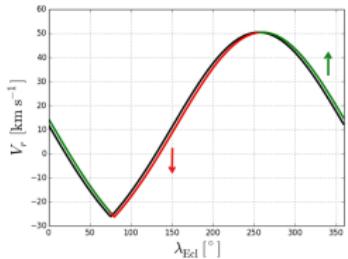
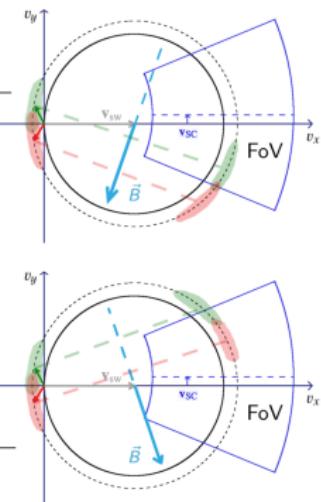
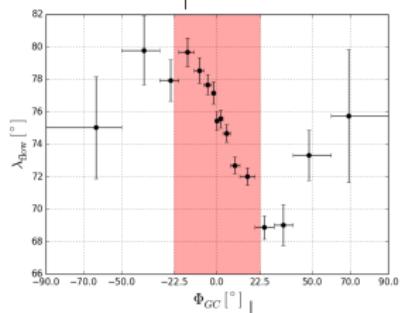
Variable FoV



Expectation:

- ▶ smaller tangential guiding center velocity at small angles.
 - ▶ less affected by transport.
- does not match expectations from transport assumption!

FoV Torus Coverage?

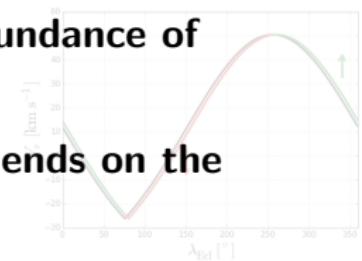
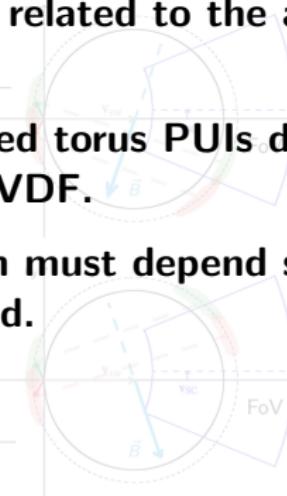
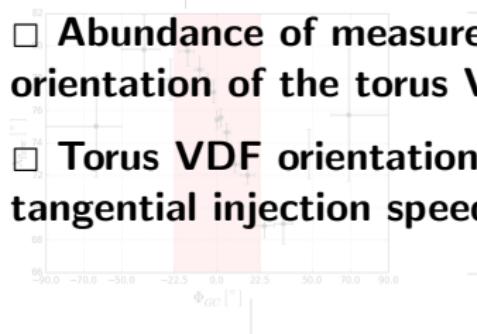


FoV Torus Coverage? - Conditions

Cutoff speed must be related to the abundance of measured torus PUIs.

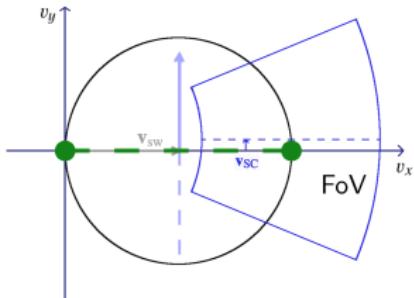
Abundance of measured torus PUIs depends on the orientation of the torus VDF.

Torus VDF orientation must depend significantly on tangential injection speed.

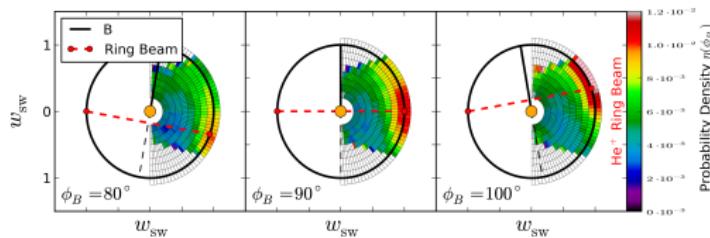


...need to be checked!

2D Δ VDFs

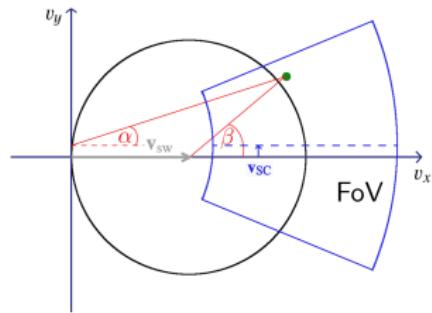
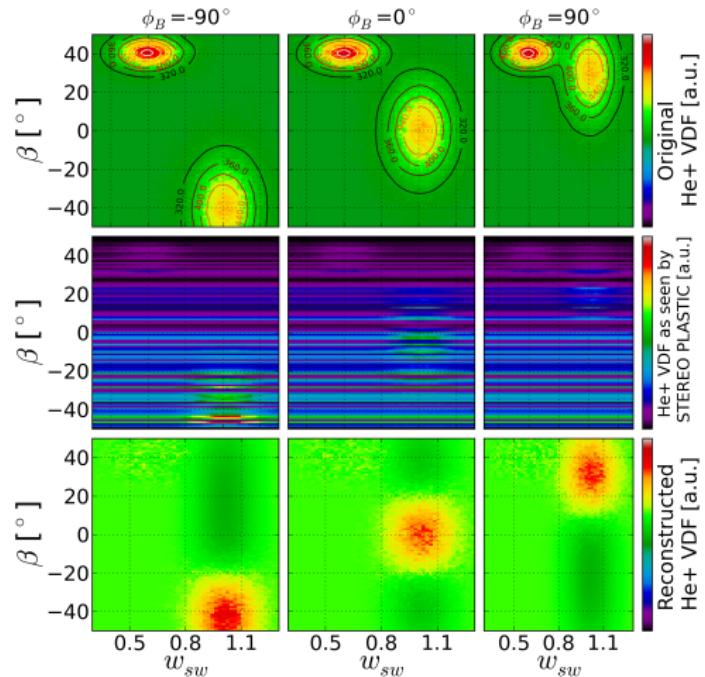


- ▶ PLASTIC measures incident angle of ions
→ enables reconstruction of 2D/3D VDFs.
- ▶ Requires efficiency correction of azimuthal position bins, which is poorly known.
- ▶ Anyhow, we are able to resolve changes in the VDF.



→ Drews et al., 2015, A&A

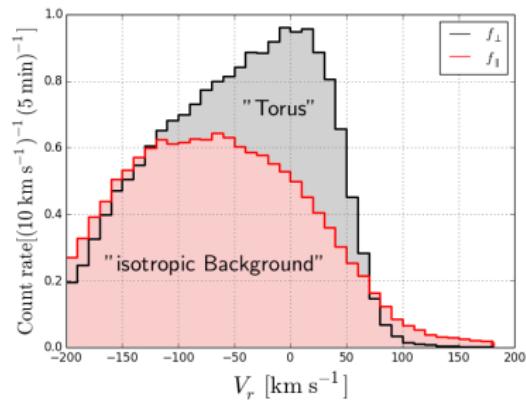
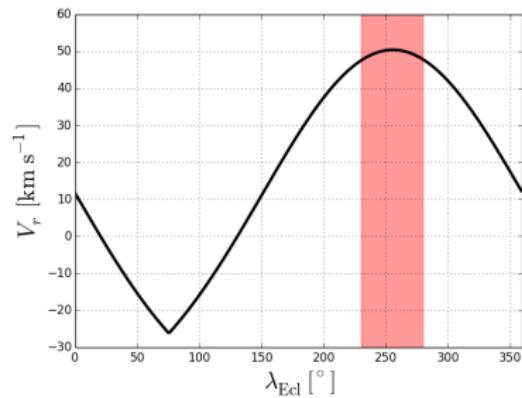
2D Δ VDFs - Proof-of-Concept



signatures dependent on IMF
→ visible

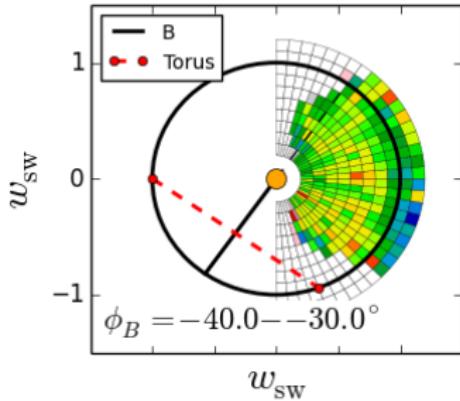
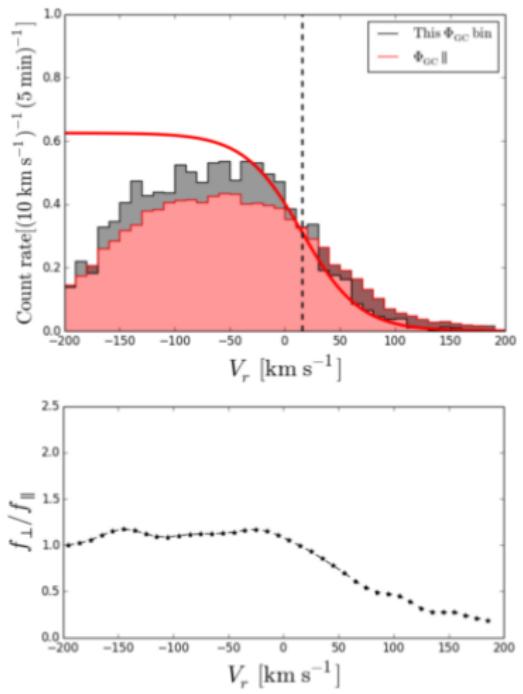
signatures independent on IMF
→ invisible

Cutoff - Torus Relation



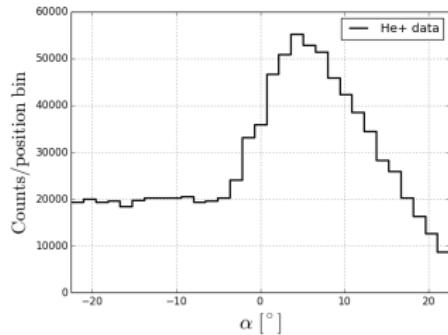
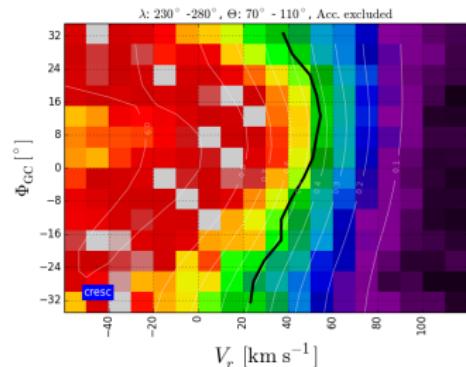
- ▶ Cutoff speed variation in crescent: $\lesssim 5$ km s $^{-1}$
- ▶ Consider PUI VDF as two populations.

Cutoff - Torus Relation



Cutoff - Torus Relation

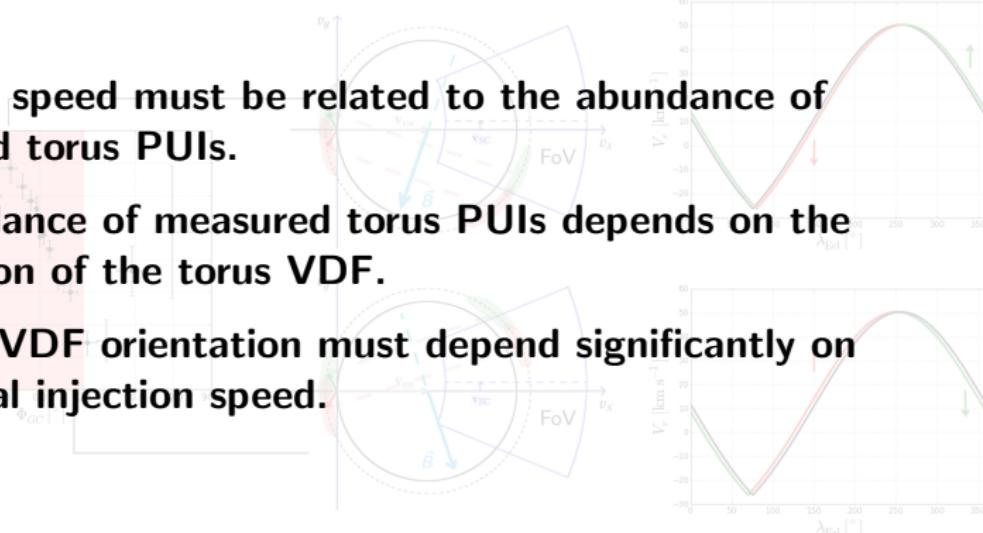
Cutoff - Torus Relation



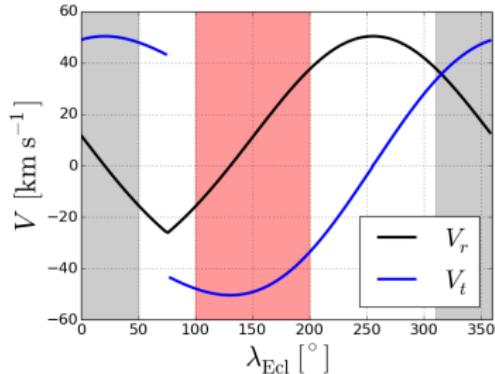
- ▶ Clear dependence of cutoff speed on IMF angle!
- ▶ Assymmetry due to:
 - ▶ SC eigen-velocity, $v_{STA} \approx 30$ km s⁻¹
 - ▶ position bin efficiency

FoV Torus Coverage? - Conditions

- Cutoff speed must be related to the abundance of measured torus PUIs.
- Abundance of measured torus PUIs depends on the orientation of the torus VDF.
- Torus VDF orientation must depend significantly on tangential injection speed.

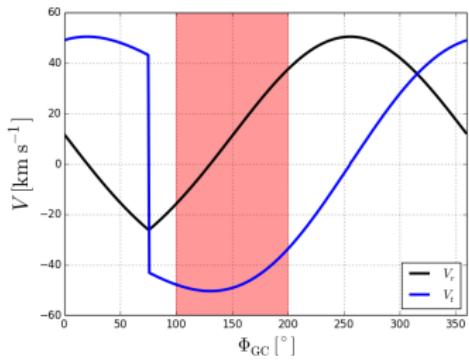
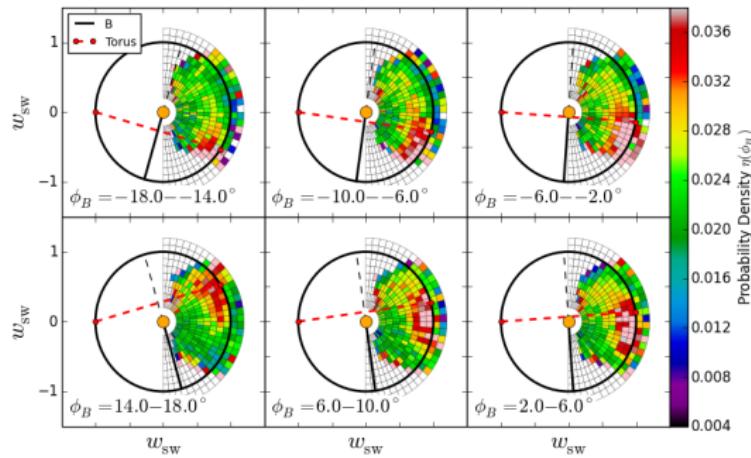


2D Δ VDF

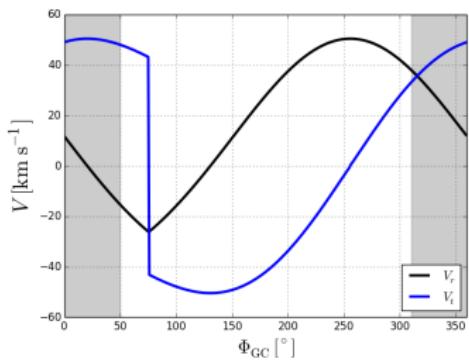
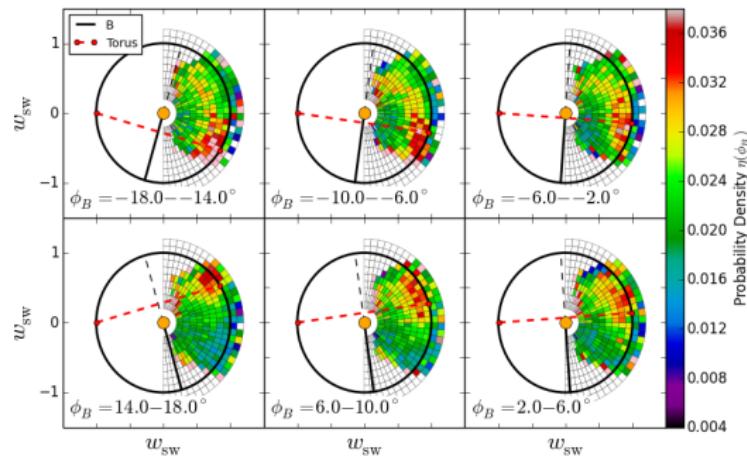


- ▶ Select longitudes, where a high tangential speed is expected.
- ▶ Check, where in the FoV the torus-related increase in PUI counts lies!

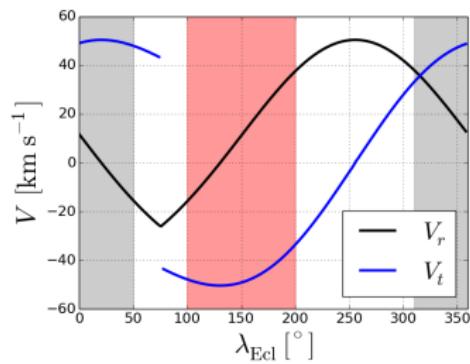
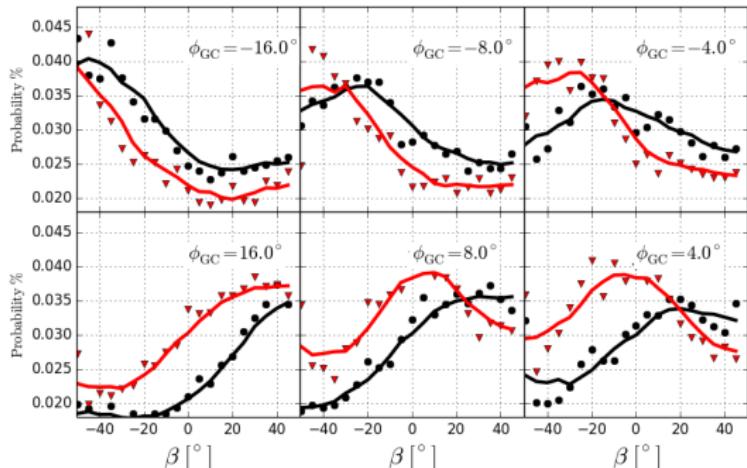
2D Δ VDF



2D Δ VDF

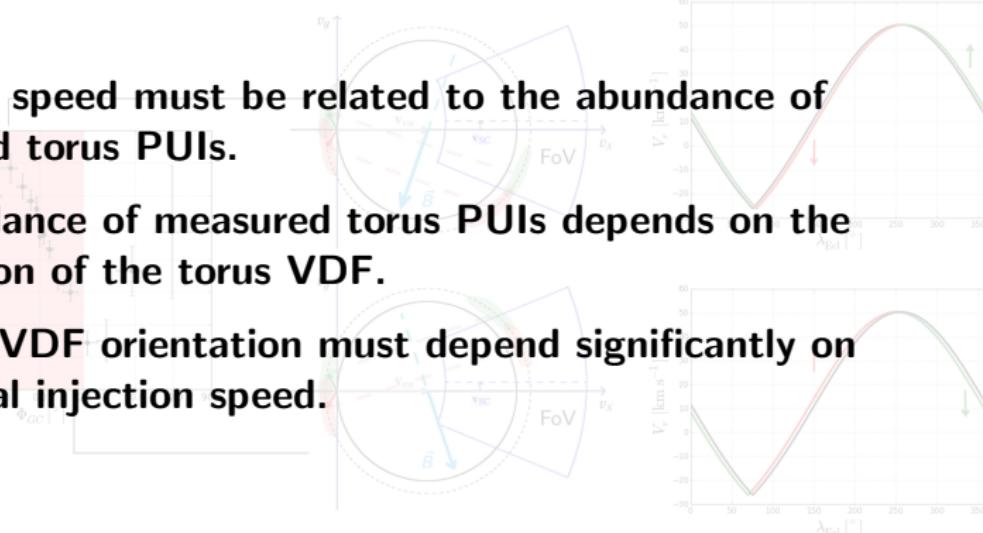


2D Δ VDF



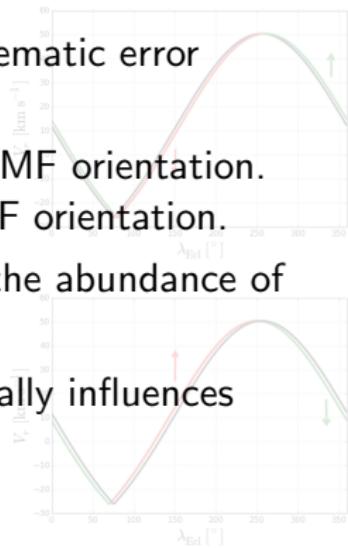
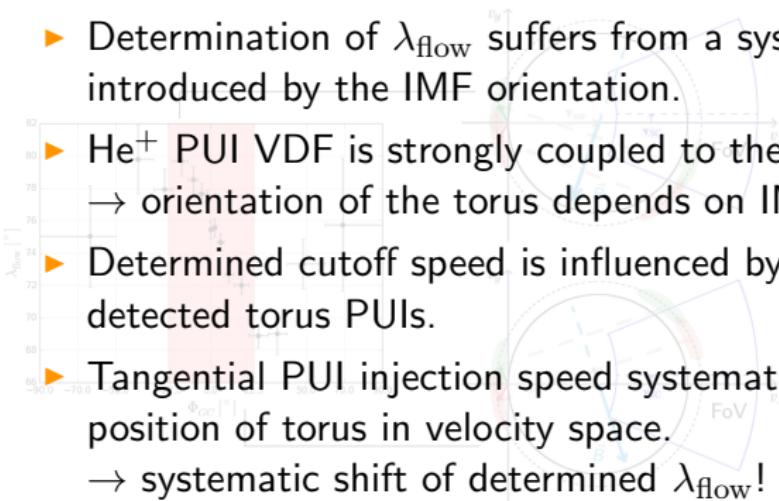
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- ☒ Cutoff speed must be related to the abundance of measured torus PUIs.
- ☒ Abundance of measured torus PUIs depends on the orientation of the torus VDF.
- ☒ Torus VDF orientation must depend significantly on tangential injection speed.



Conclusions & Outlook

- ▶ Determination of λ_{flow} suffers from a systematic error introduced by the IMF orientation.
- ▶ He⁺ PUI VDF is strongly coupled to the IMF orientation.
→ orientation of the torus depends on IMF orientation.
- ▶ Determined cutoff speed is influenced by the abundance of detected torus PUIs.
- ▶ Tangential PUI injection speed systematically influences position of torus in velocity space.
→ systematic shift of determined λ_{flow} !



Cutoff Determination Methods

