Pickup Ions in the Solar Wind
- Update -

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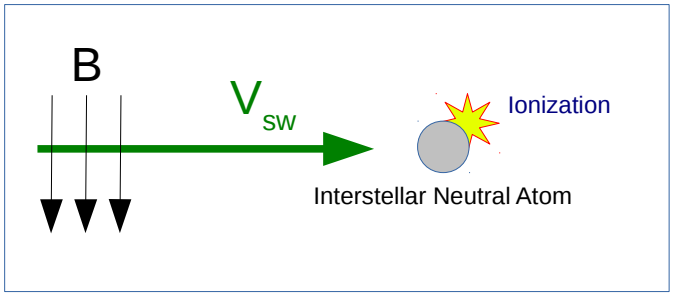
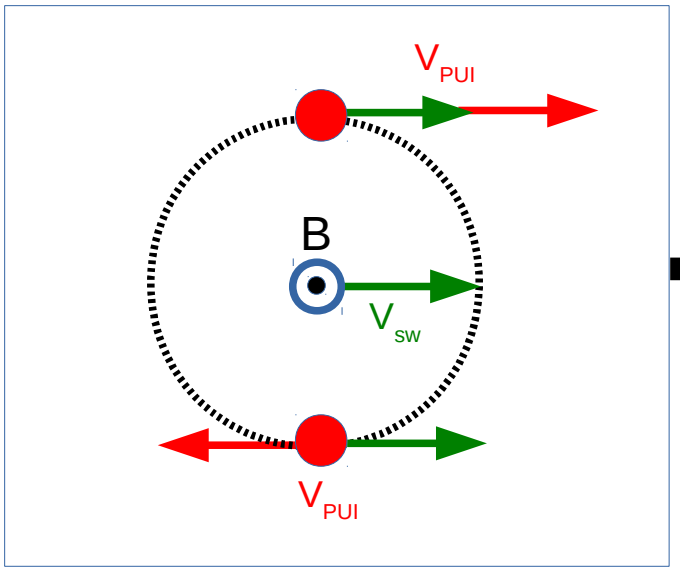
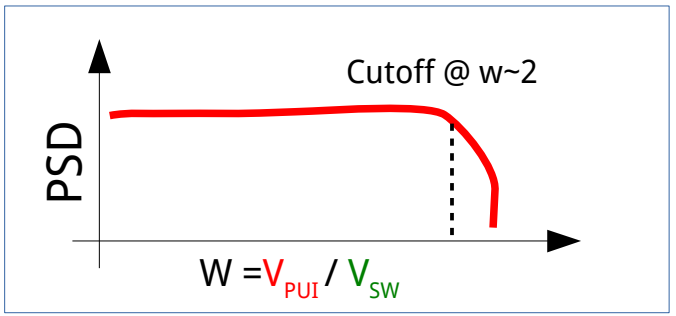
Outline:

- **Introduction**
  - **VDF of PUIs**
- **Determining the interstellar flow longitude**
  - **General concept**
  - **Exclusion of acceleration sites**
  - **Improved results**
- **Anisotropy of the He^+ VDF**

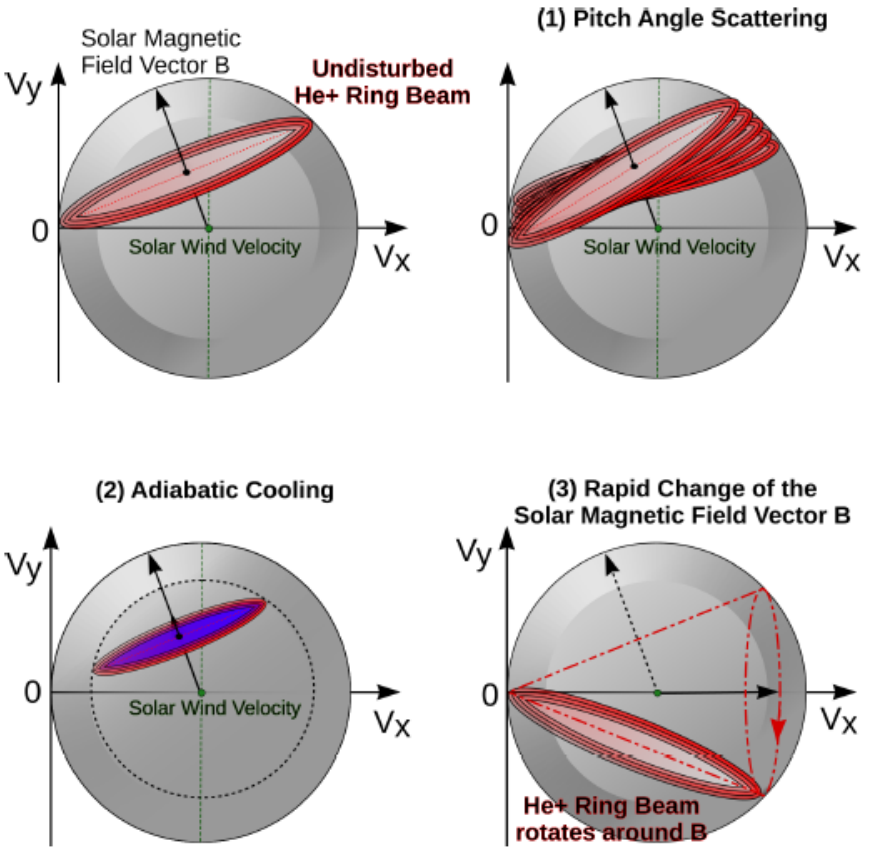
A simplified Illustration of the Pickup Process:







The Pickup Ion Torus Distribution
(„strong anisotropies“)

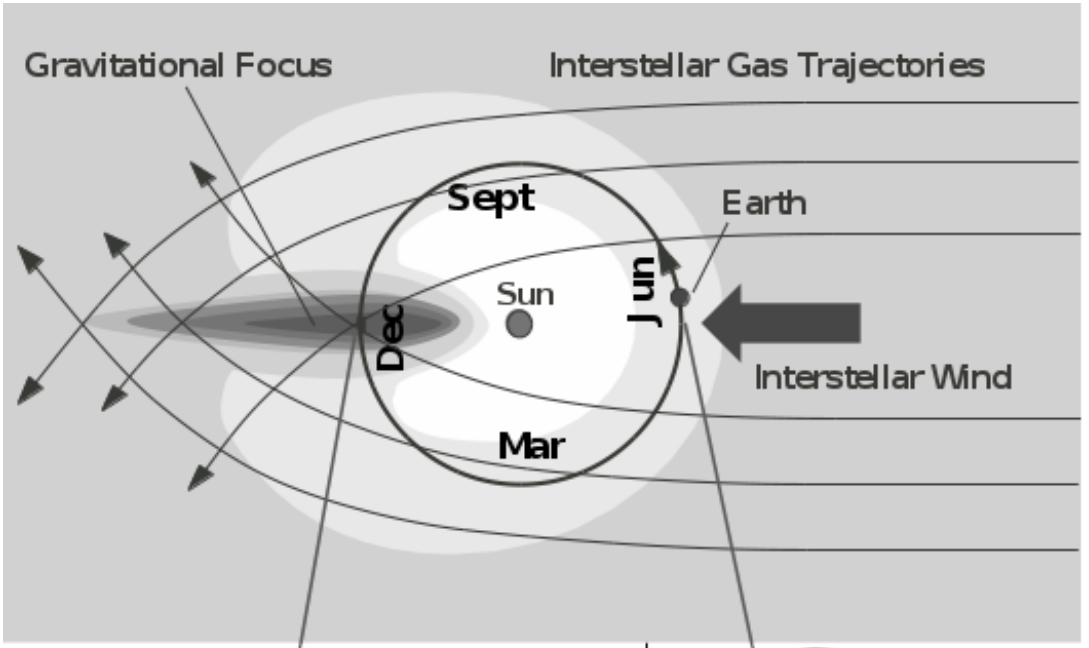


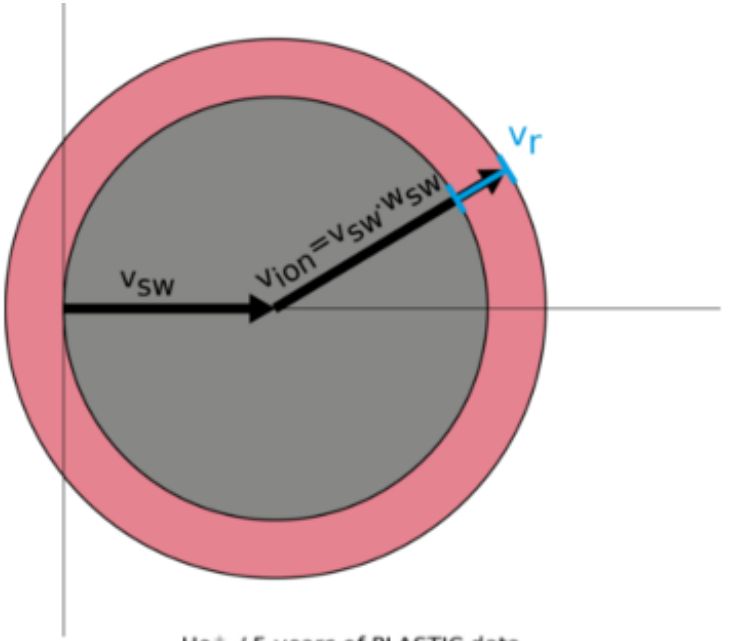
=> Flux increase during perpendicular IMF configurations [e.g., Möbius et al., 1998]

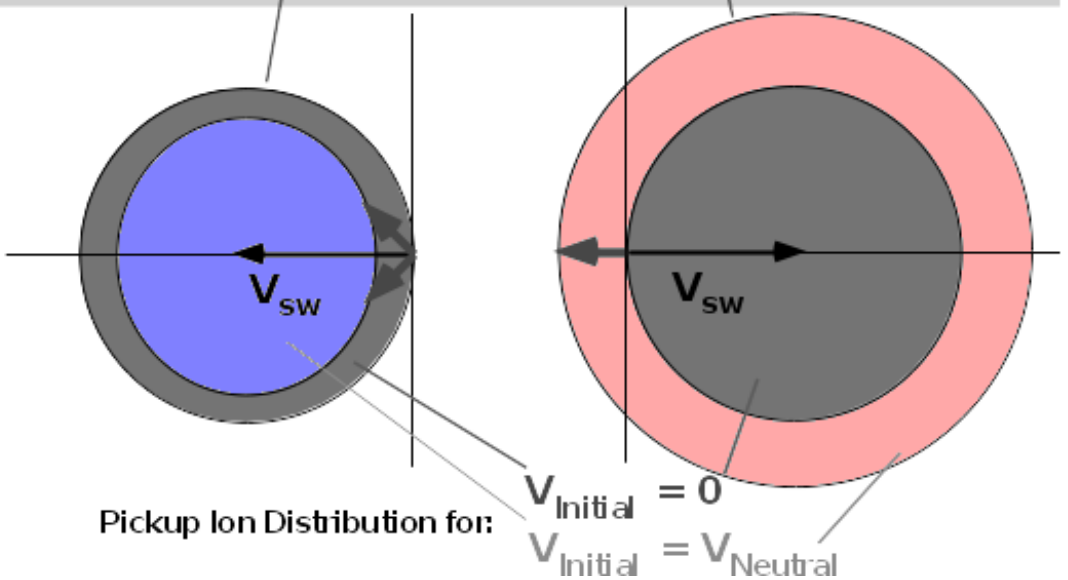
=> Distinct anisoptropies coupled to to the orientation of the local IMF

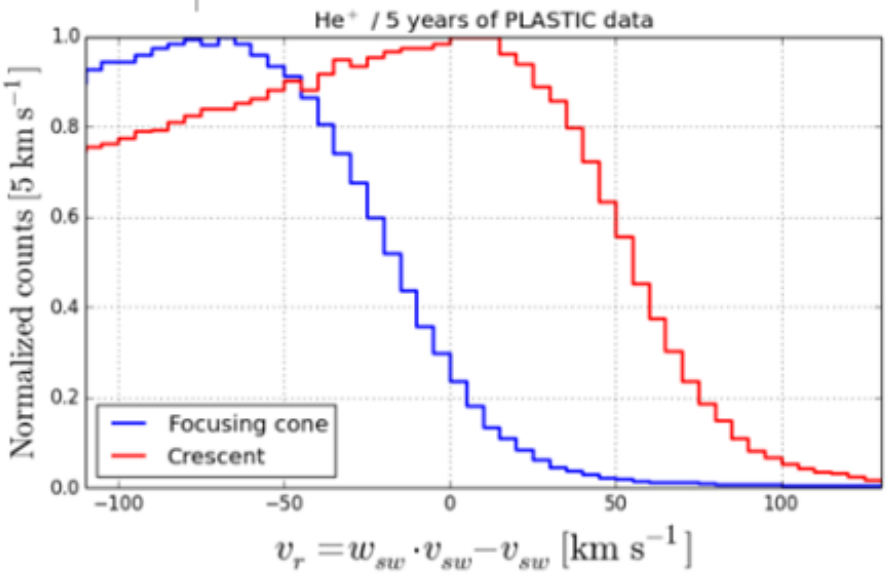
[Oka et al., 2012; Drews et al., 2013]

General concept

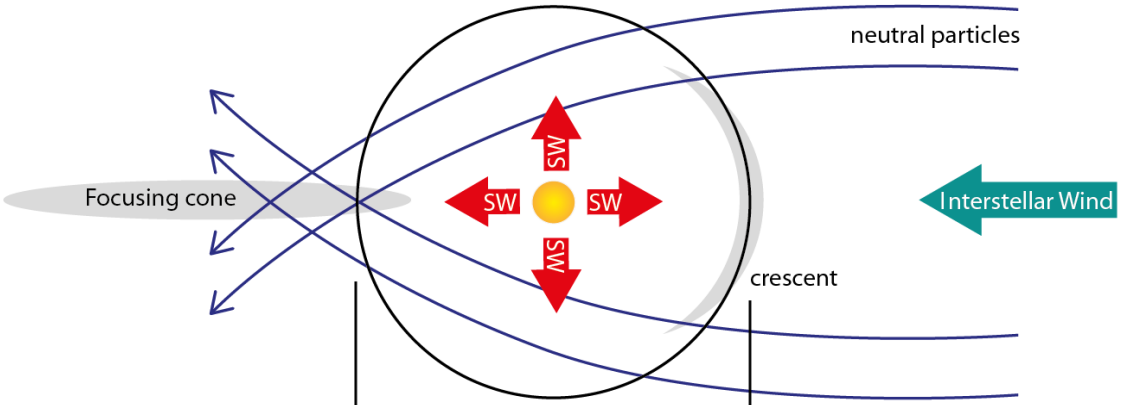






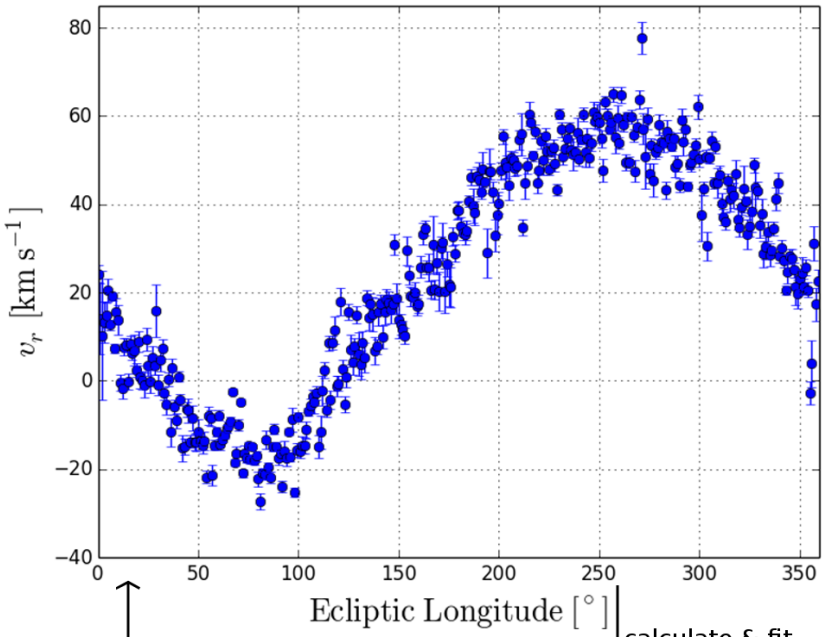


General concept



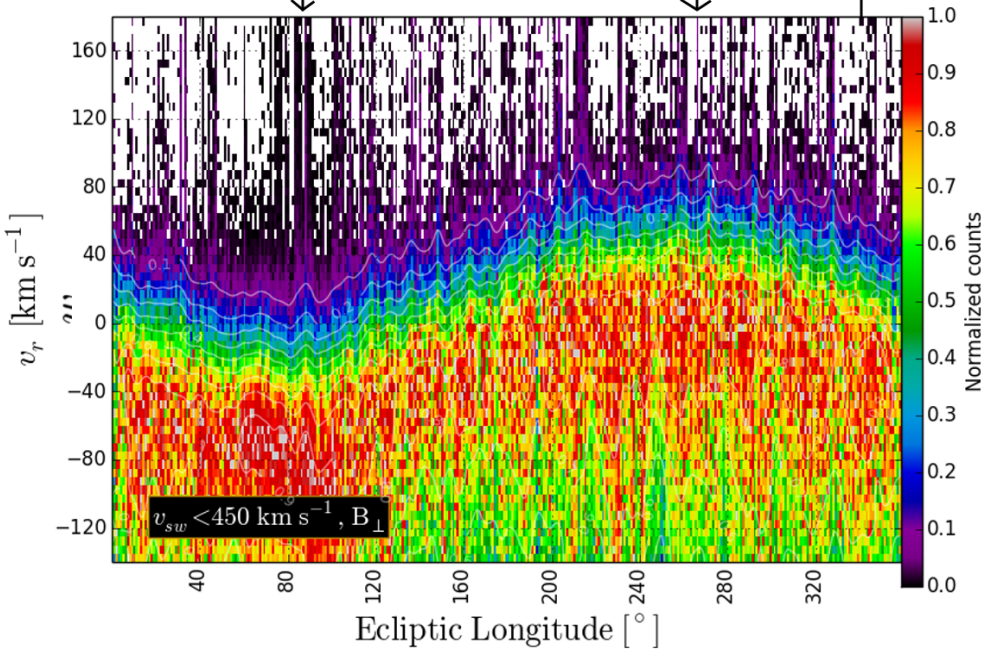
decreased injection speed

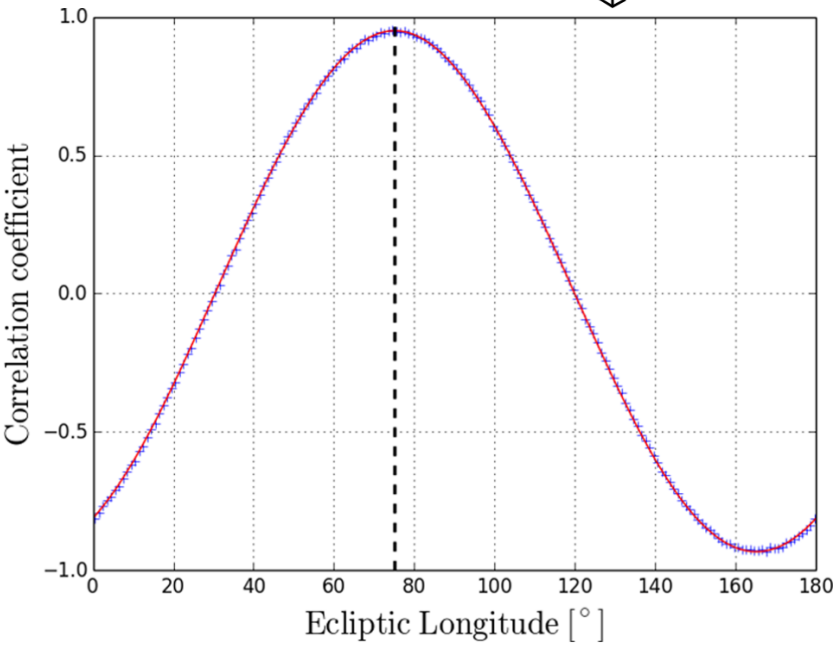
increased injection speed



determine cutoff speed

calculate & fit mirror correlation





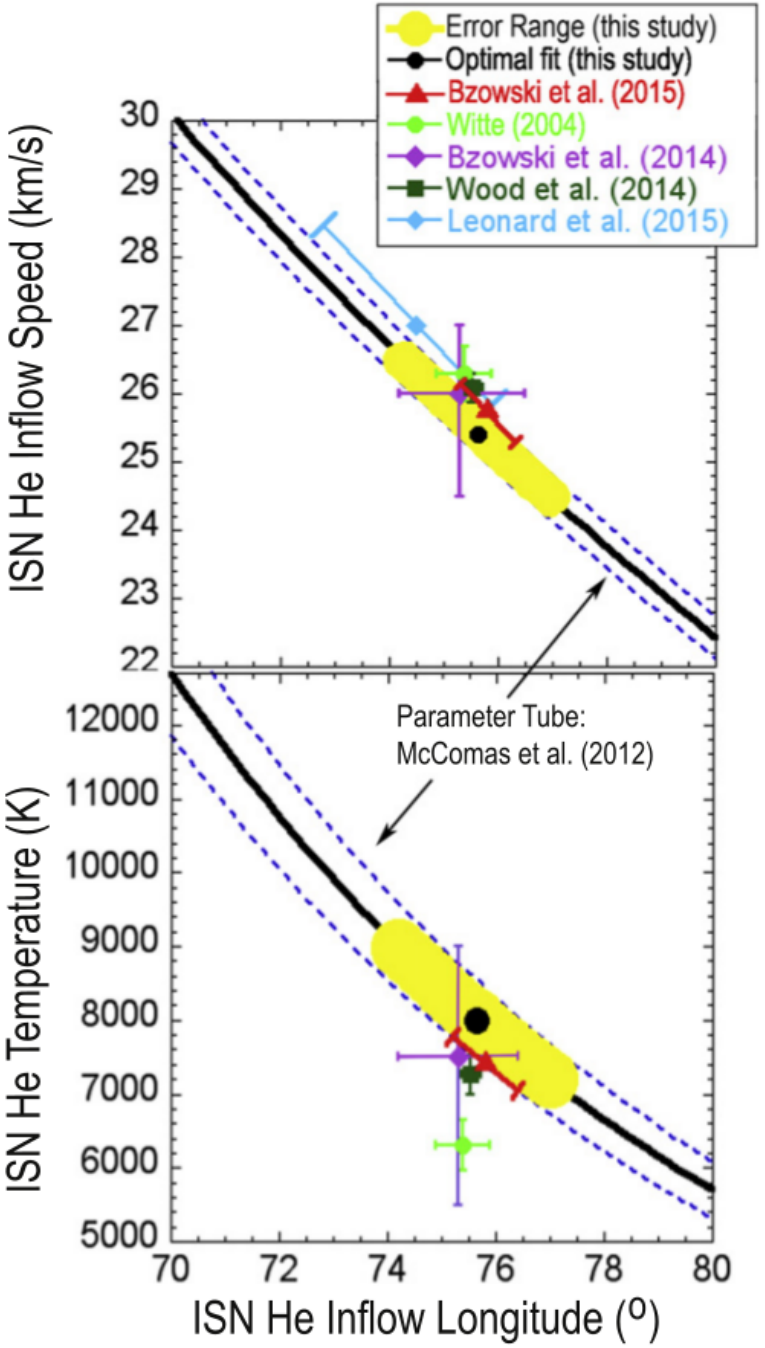
Why all this?

- Neutral particle measurements by IBEX yield a 4-dimensional parameter tube for LISM:

  Flow longitude, latitude, and speed + temperature

- LISM parameters are crucial to understand the heliospheric structure.

- An independent measurement of the flow longitude tightens the parameter tube, thus defining LISM parameters more precisely.



From Schwadron et al., 2015, ApJ 220:15

What have we done?

- Developed new methods to determine the cutoff.
- Showed that calculating and fitting mirror-correlation coefficients is redundant.
- Created an improved way to filter for magnetic field configurations where the torus lies inside PLASTIC's aperture.
- Exclude acceleration sites by considering the simultaneously measured VDF of He^{2+}.
- Calculated statistical and total errors of the interstellar flow longitude via Monte-Carlo based approaches.

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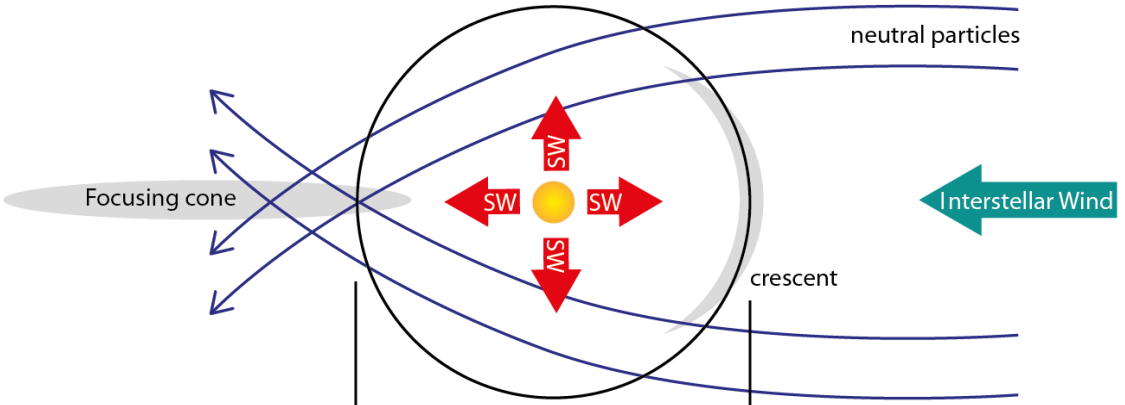
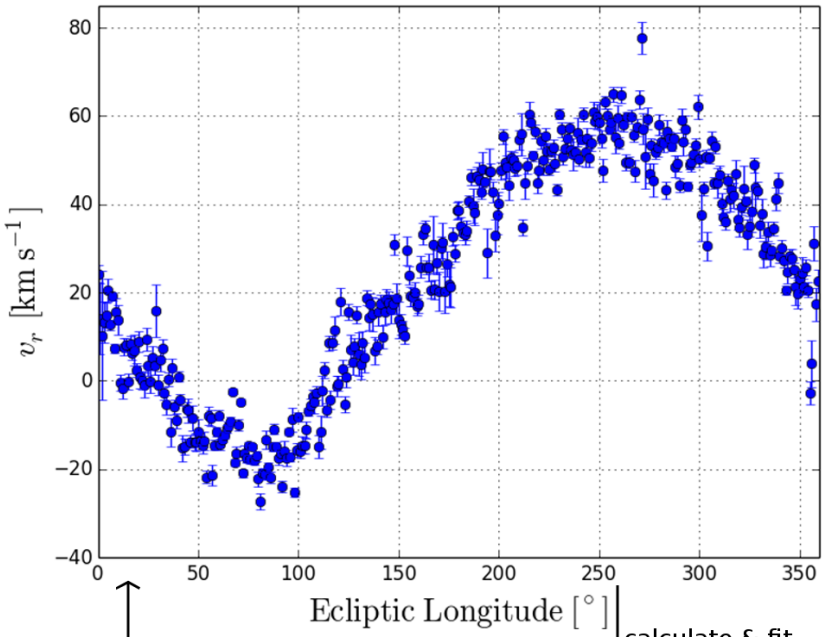
General concept



decreased injection speed

increased injection speed



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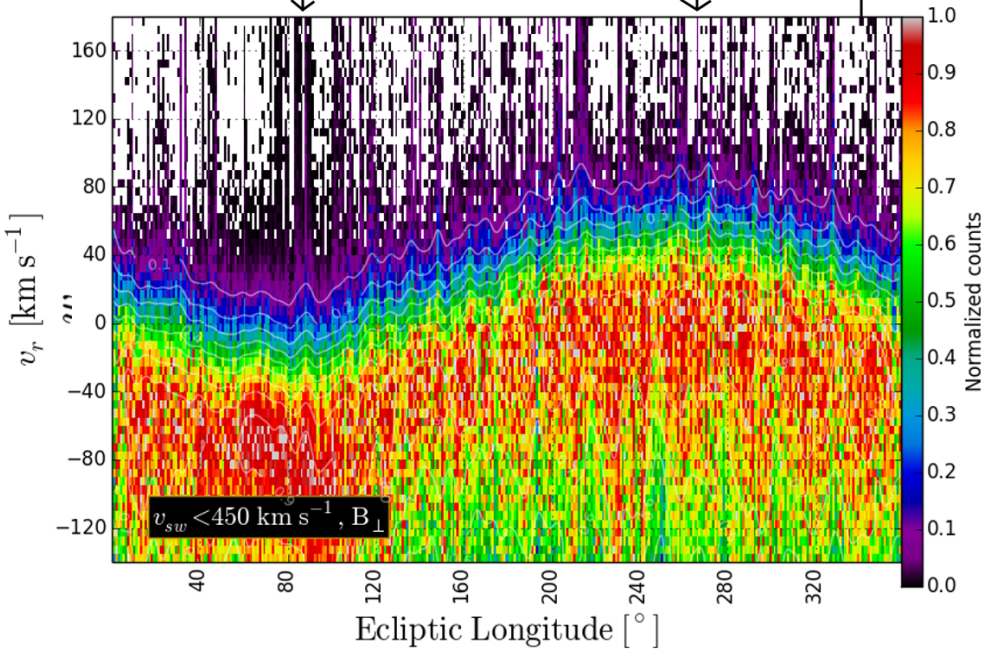
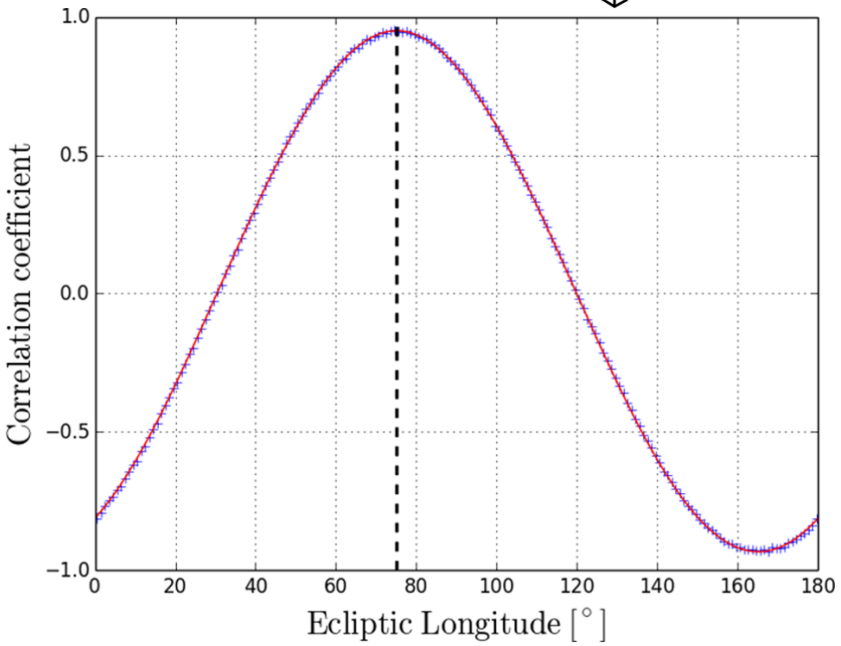
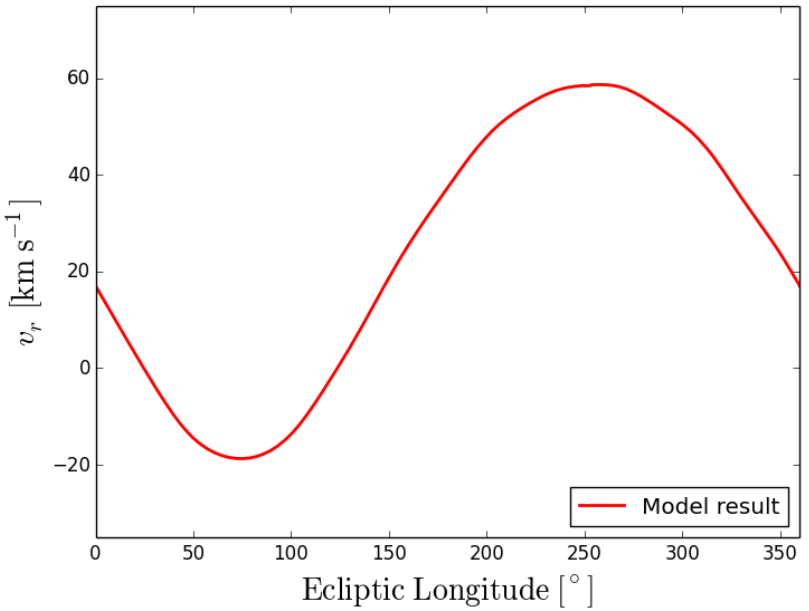




Do we really need the mirror-correlation?



Approach:

Use Duncan's results from a kinetic simulation for the radial seed particle speed. Add gaussian noise to his results and apply analysis.

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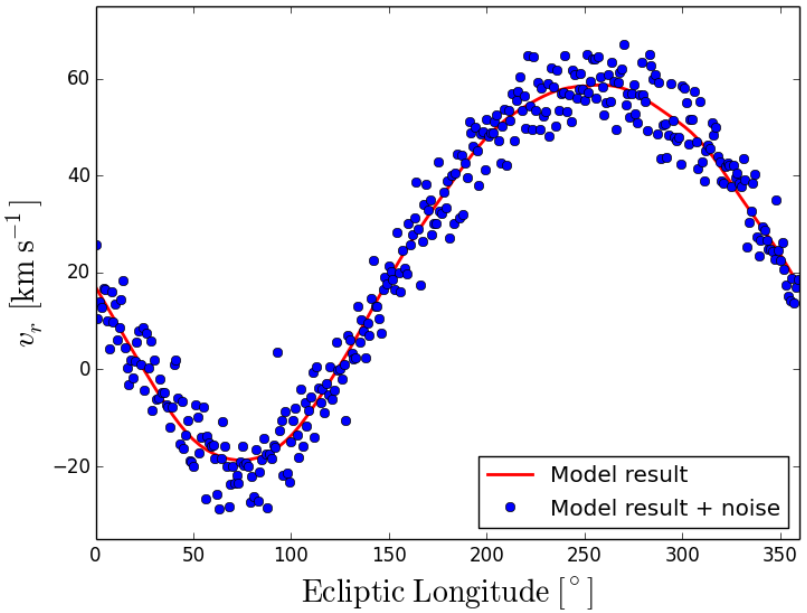
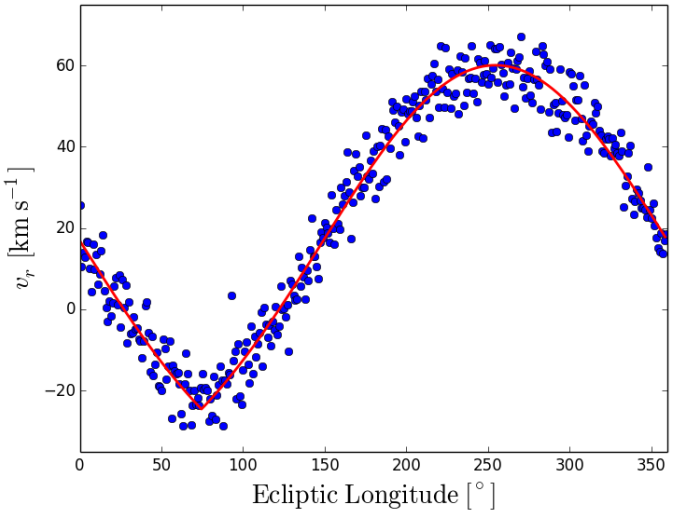
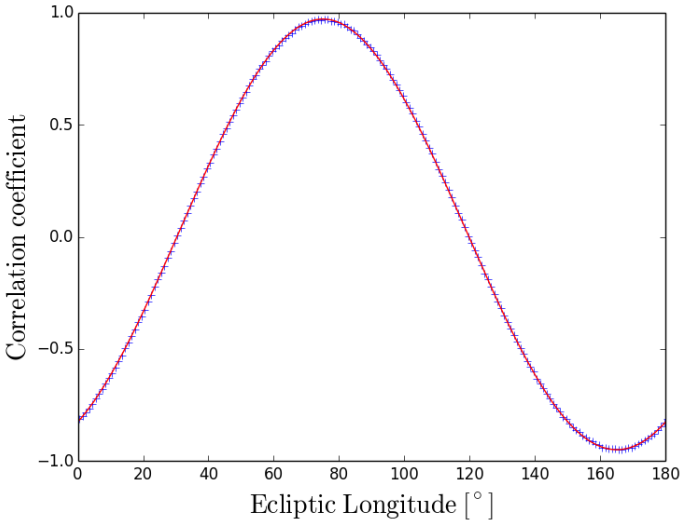




$$v_r^2 = v_{ISN\infty}^2 - (1 - \cos\lambda) - (v_{ISN\infty}^2 \sin^2\lambda + v_{ISN\infty} \sin|\lambda| \sqrt{v_{ISN\infty}^2 \sin^2\lambda + 4(1 - \cos\lambda)})/2$$

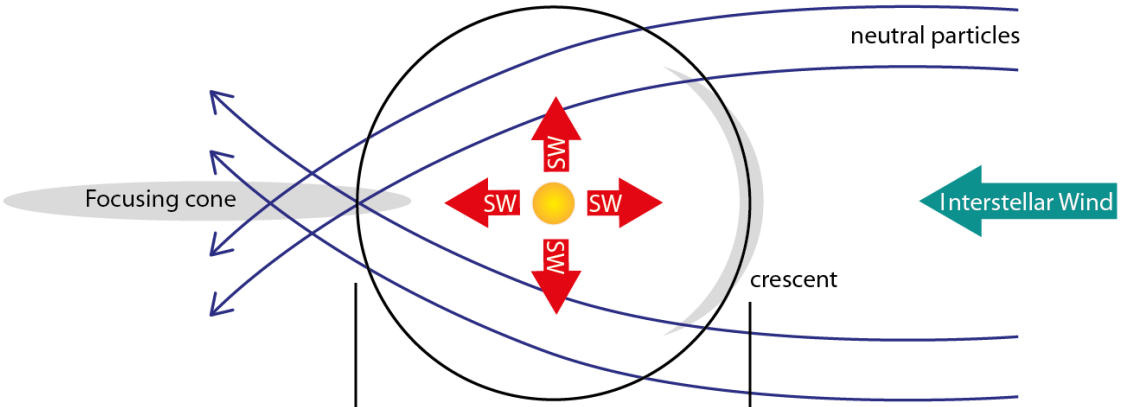
, where $\lambda = \lambda_{Obs} - \lambda_{ISN\infty} - \pi$



Results (N = 1000):

$$\sigma_{Fit} = 0.537° \qquad \sigma_{cc} = 0.543°$$

General concept



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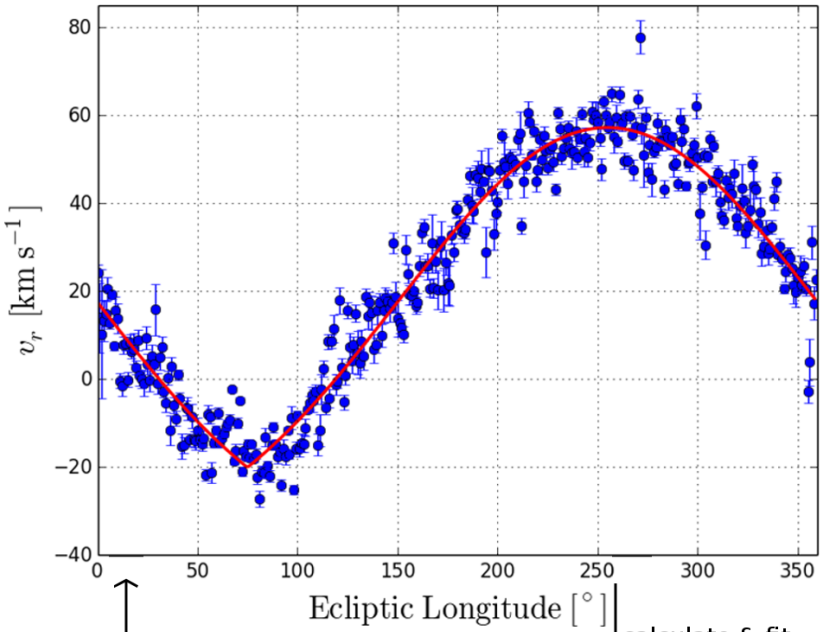

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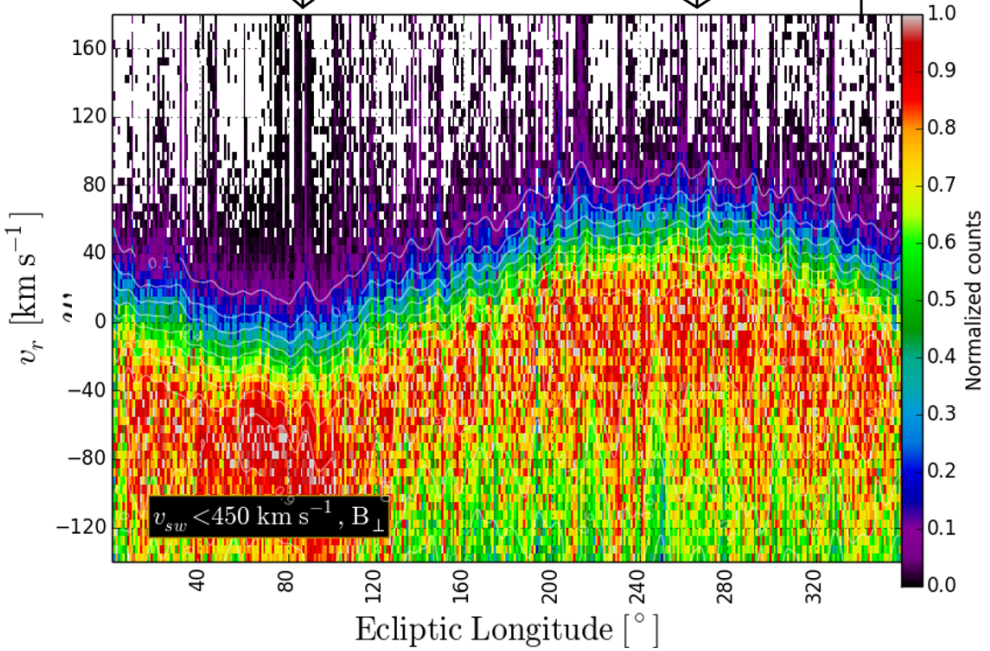
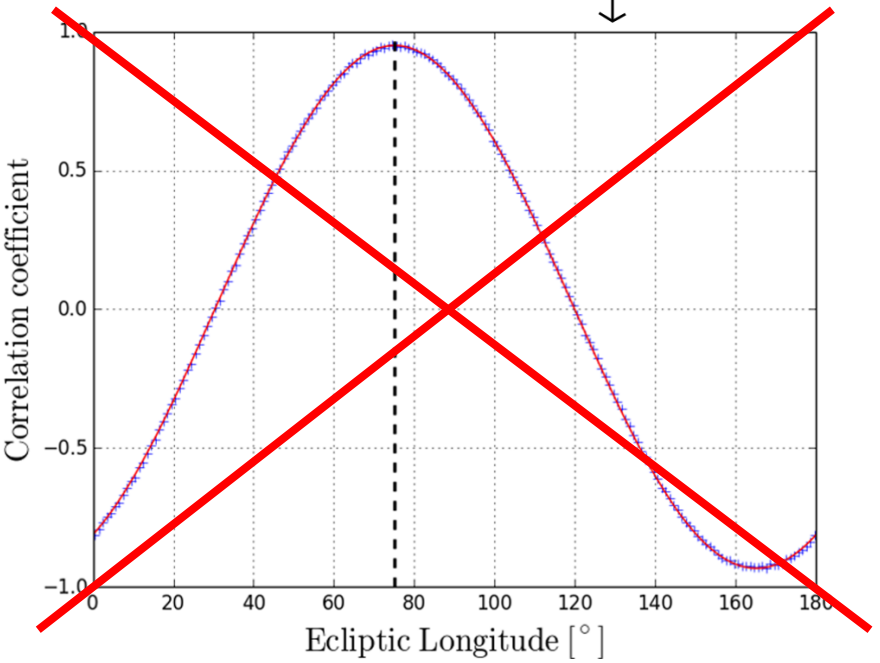
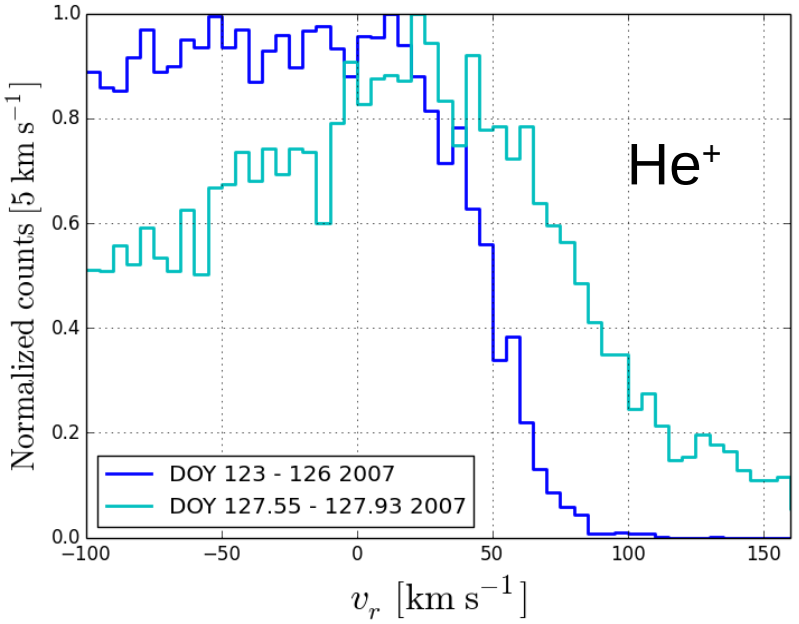
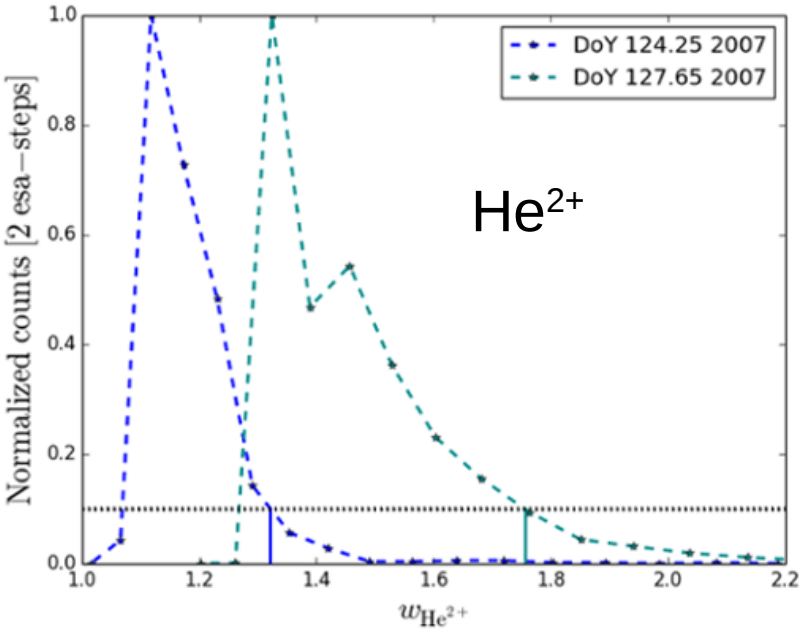
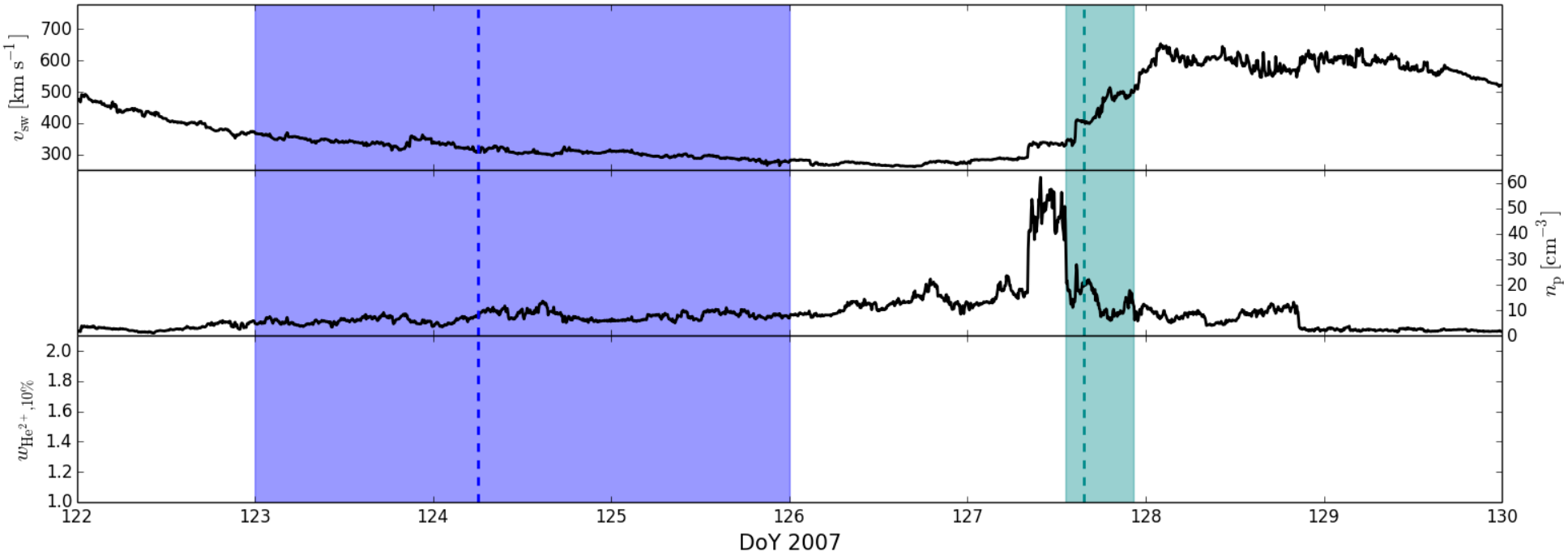




Handling of acceleration sites







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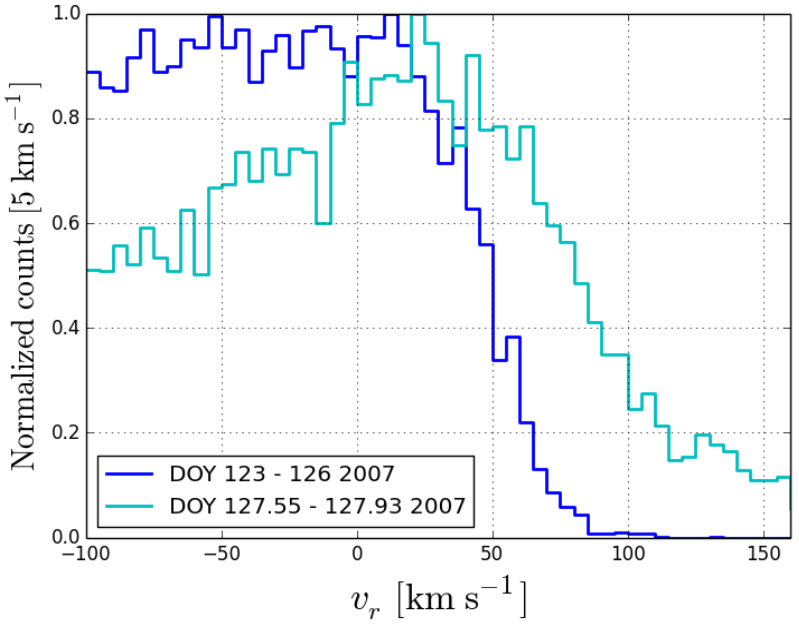
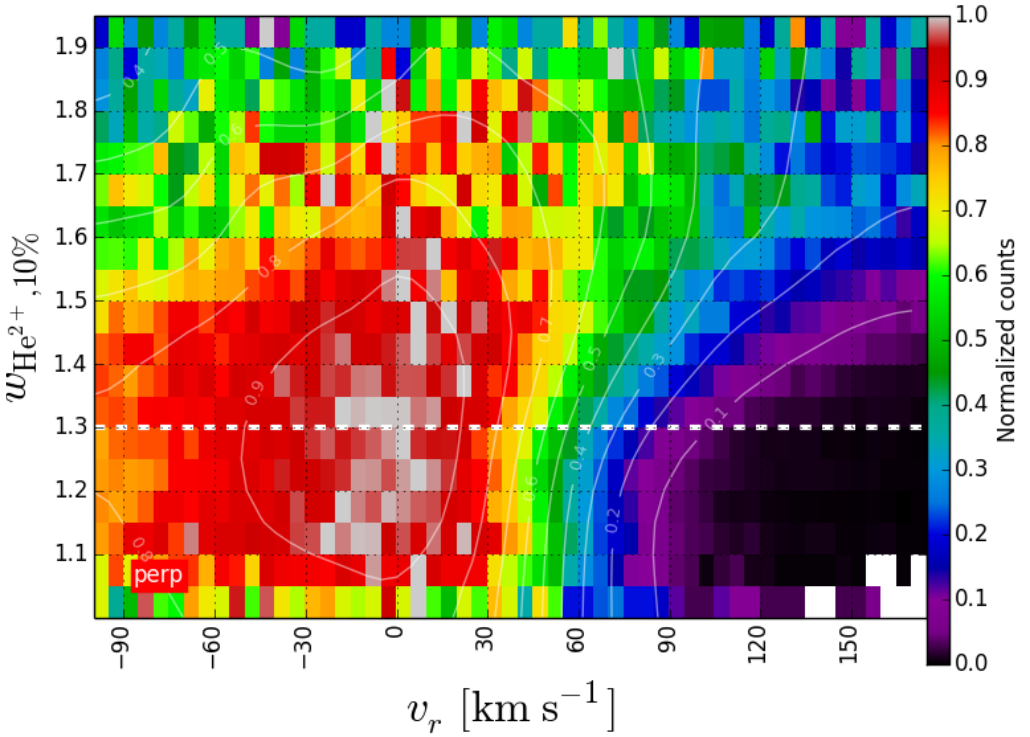
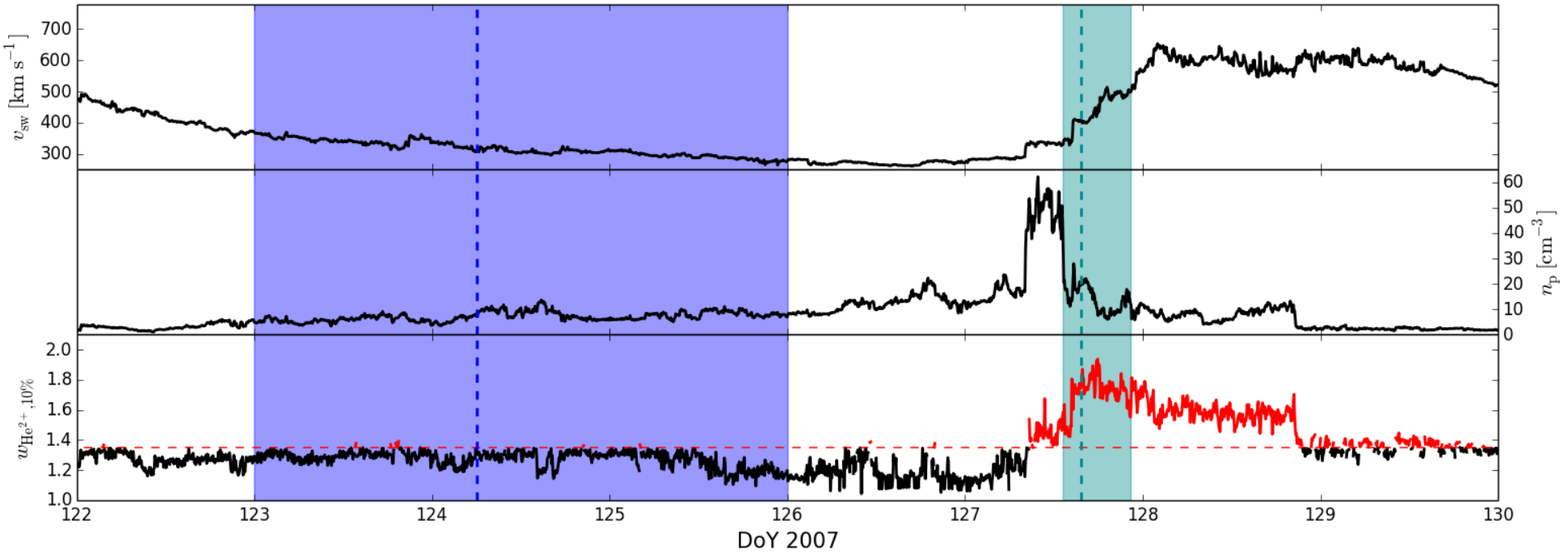






Error estimation

Statistical errors:

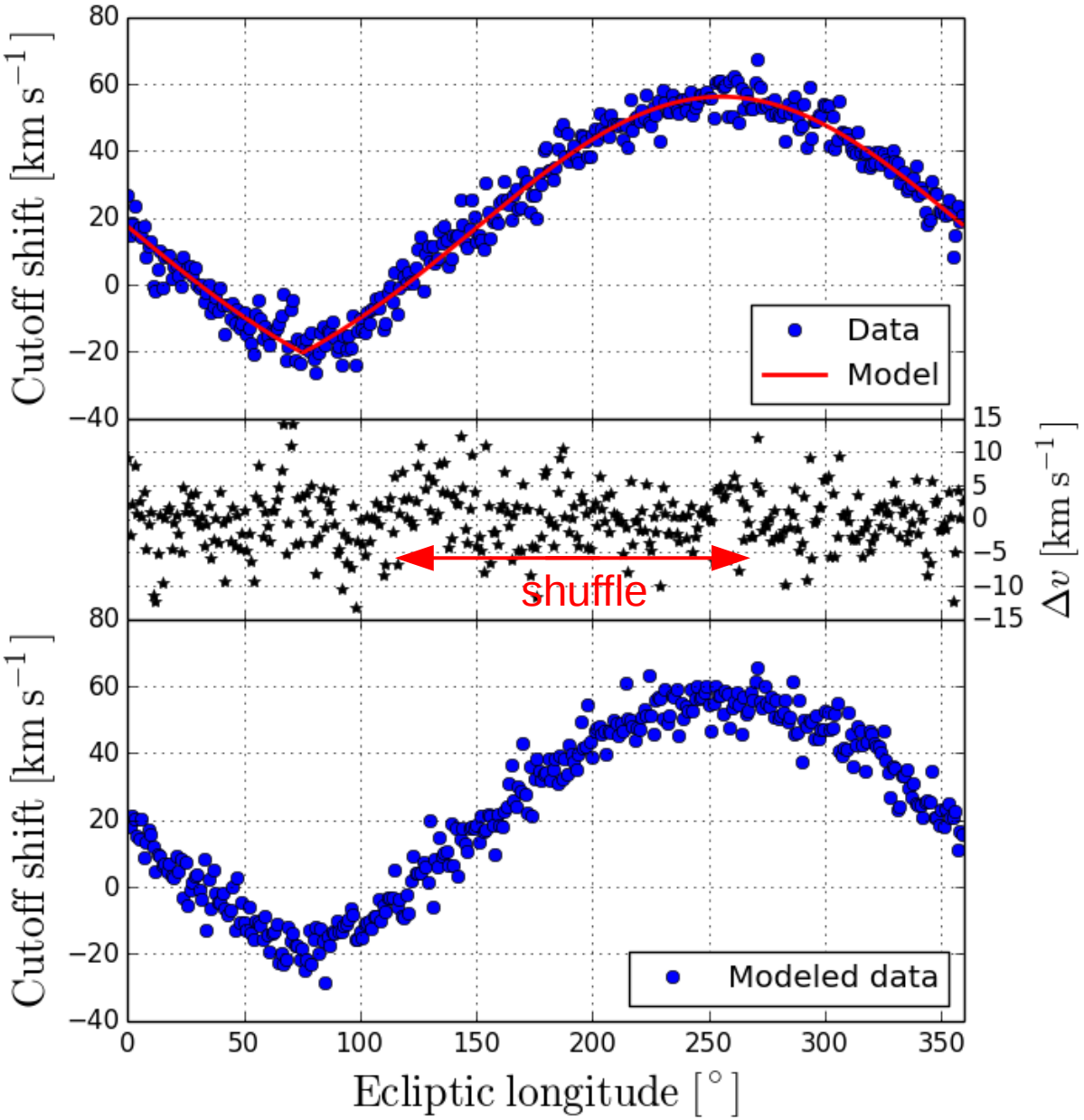
Bootstrap Monte-Carlo approach with Poisson noise added to every bin of ecliptic longitude.

$\sigma_{1^\circ,\mathrm{stat}} = 0.21^\circ \qquad \sigma_{0.5^\circ,\mathrm{stat}} = 0.32^\circ$

Total error:

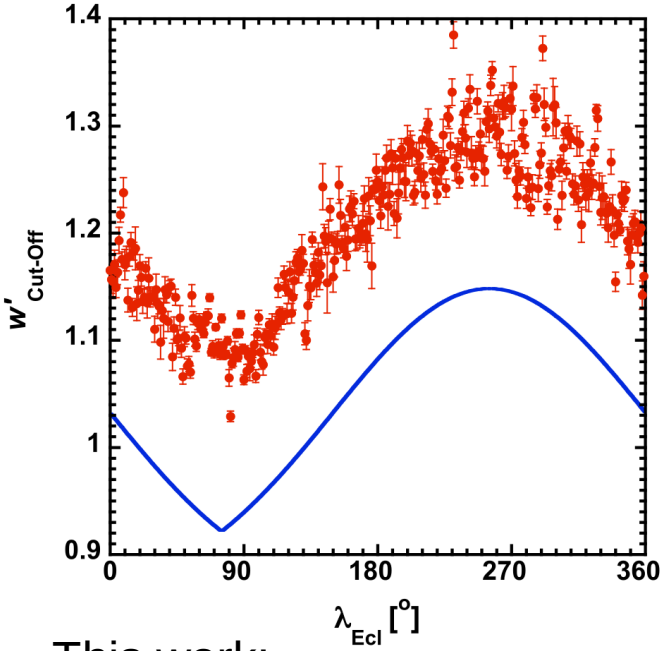
Shuffle deviations data to model function and repeat fit.

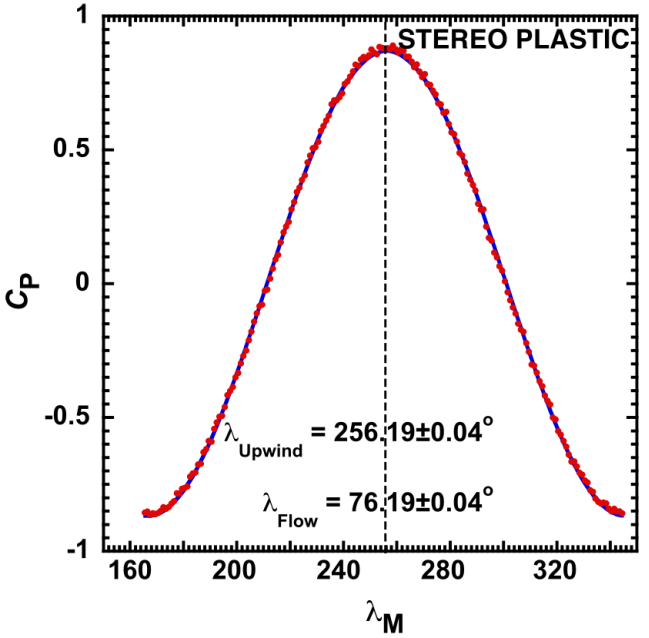
$\sigma_{1^\circ} = 0.53^\circ \qquad \sigma_{0.5^\circ} = 0.49^\circ$



Results

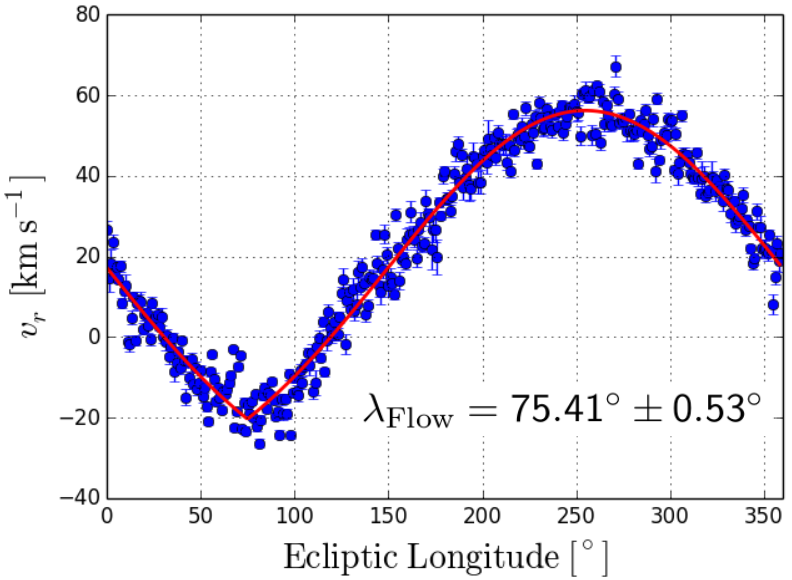
from Möbius et al., 2015, ApJ 815:20

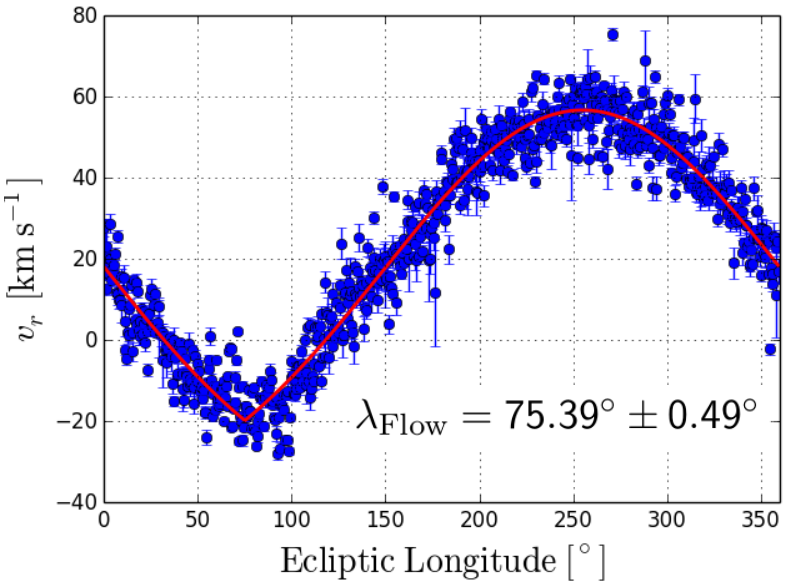




Work	Result
Schwadron 2015 IBEX	$75.6° \pm 1.4°$
Bzowski 2015 IBEX	$75.8° \pm 0.5°$
Wood 2015 Ulysses-GAS	$75.54° \pm 0.19°$
Möbius 2015 STA/PLASTIC	$76.19° \pm 0.04°$
This work STA/PLASTIC	$75.39° \pm 0.49°$

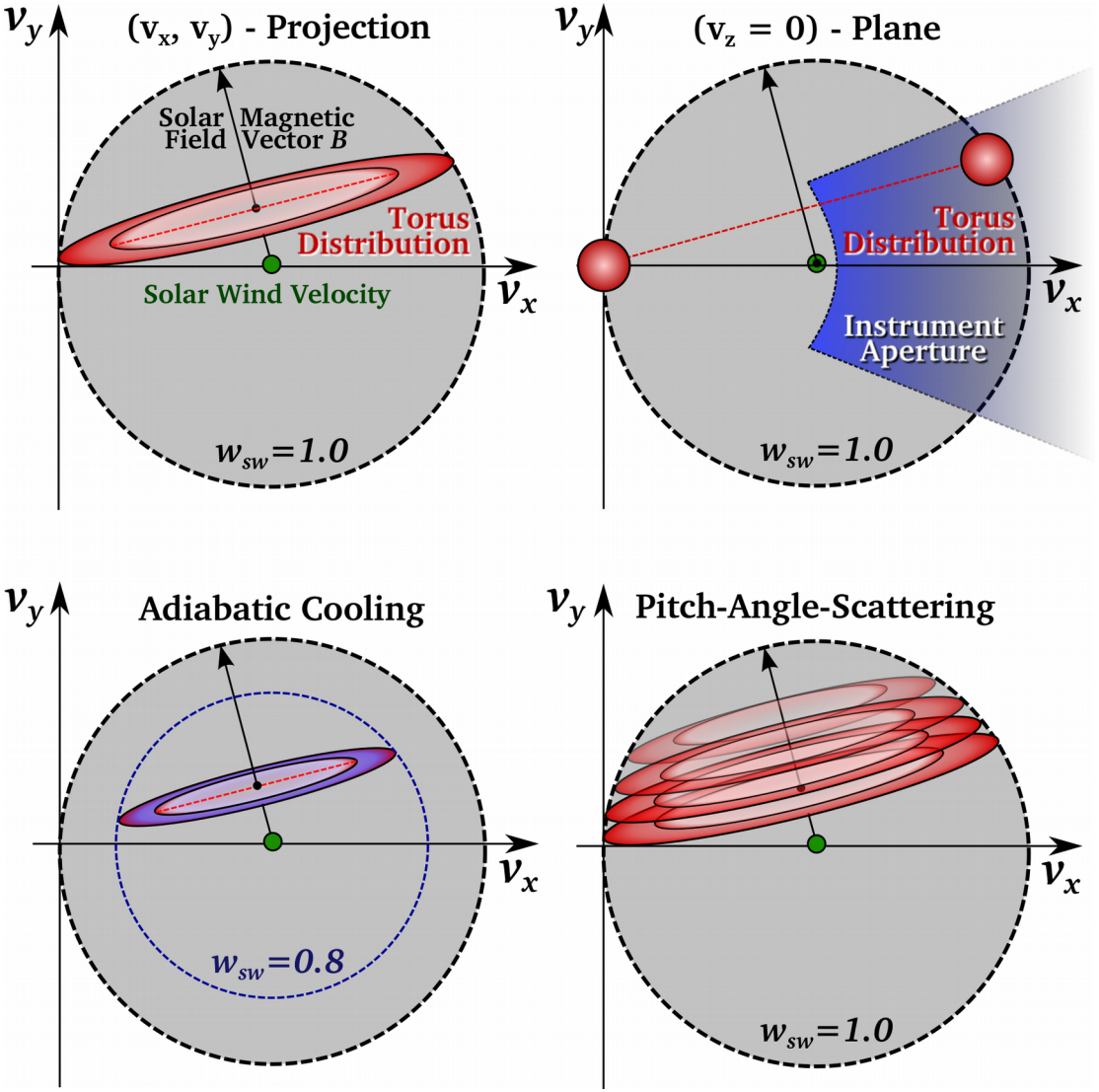
This work:





The Pickup Ion Torus Distribution

(„strong anisotropies“)



How does the phase space transport of pickup ions work?

=> impact of resonant wave-particle Interactions on the PUI VDF?

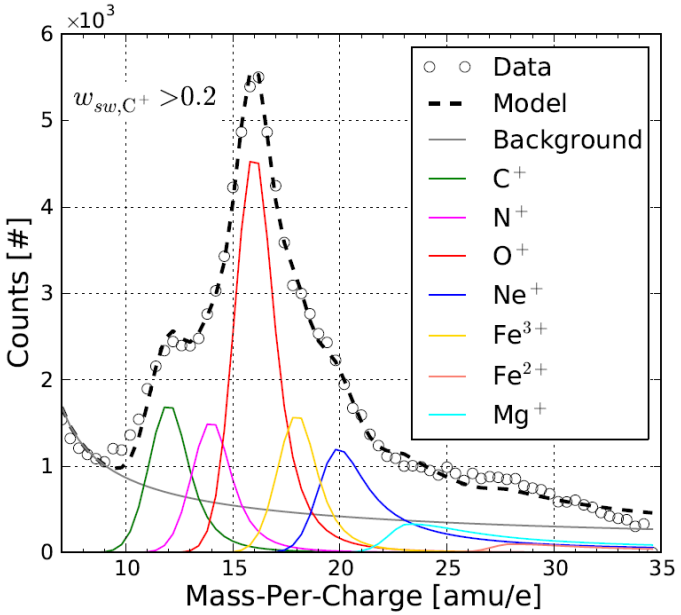
=> influence of the spatial injection pattern on the PUI VDF?

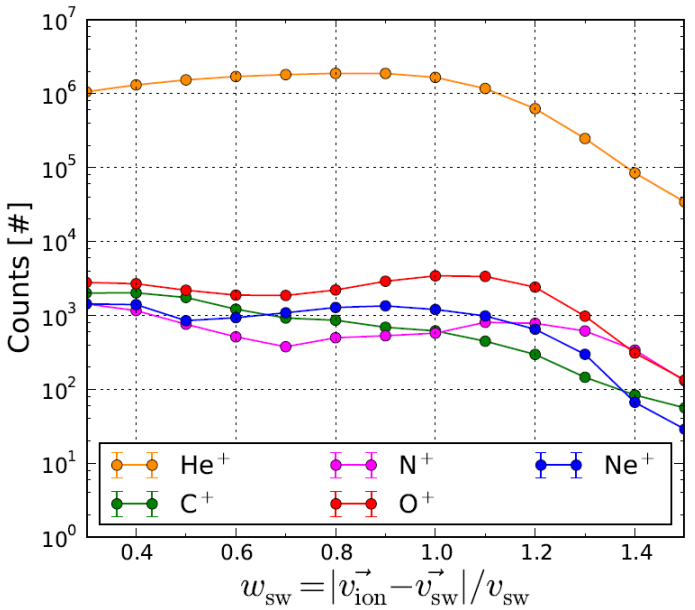
=> Influence of the source population on the PUI VDF?

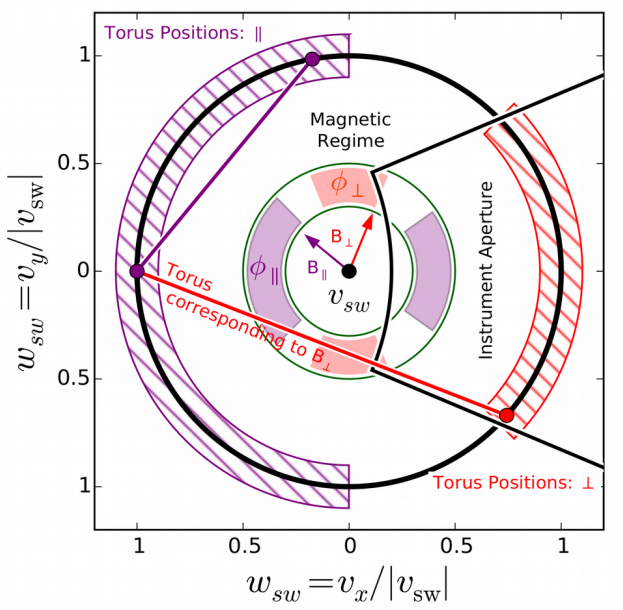
=> **Influence of solar wind structures on the PUI VDF?**

The Pickup Ion Torus Distribution:
How to determine the Anisotropy of the Pickup Ion VDF

[Drews et al., A&A 2016]



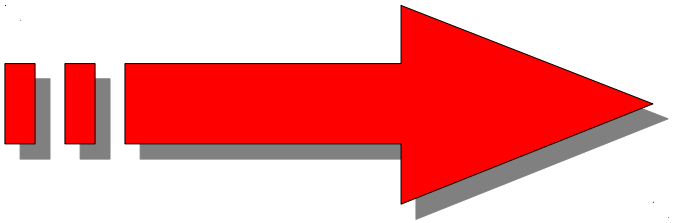




Mass-Per-Charge Model

w – spectra, $f(w)$, of
He+, C+ N+, O+, Ne+

Ratio $f(w)_{\mathrm{perp}} / f(w)_{\mathrm{parallel}}$
He+, C+ N+, O+, Ne+



„Fraction of torus- to isotropically distributed pickup ions“

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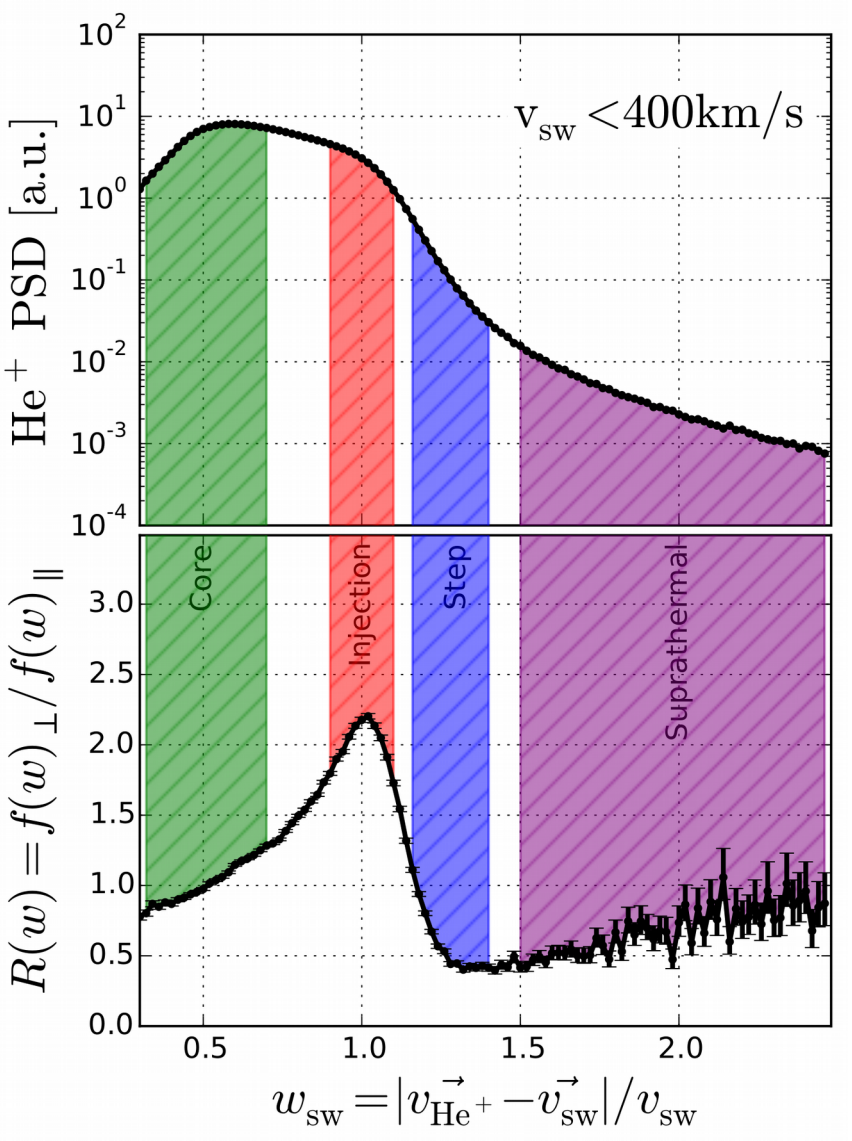
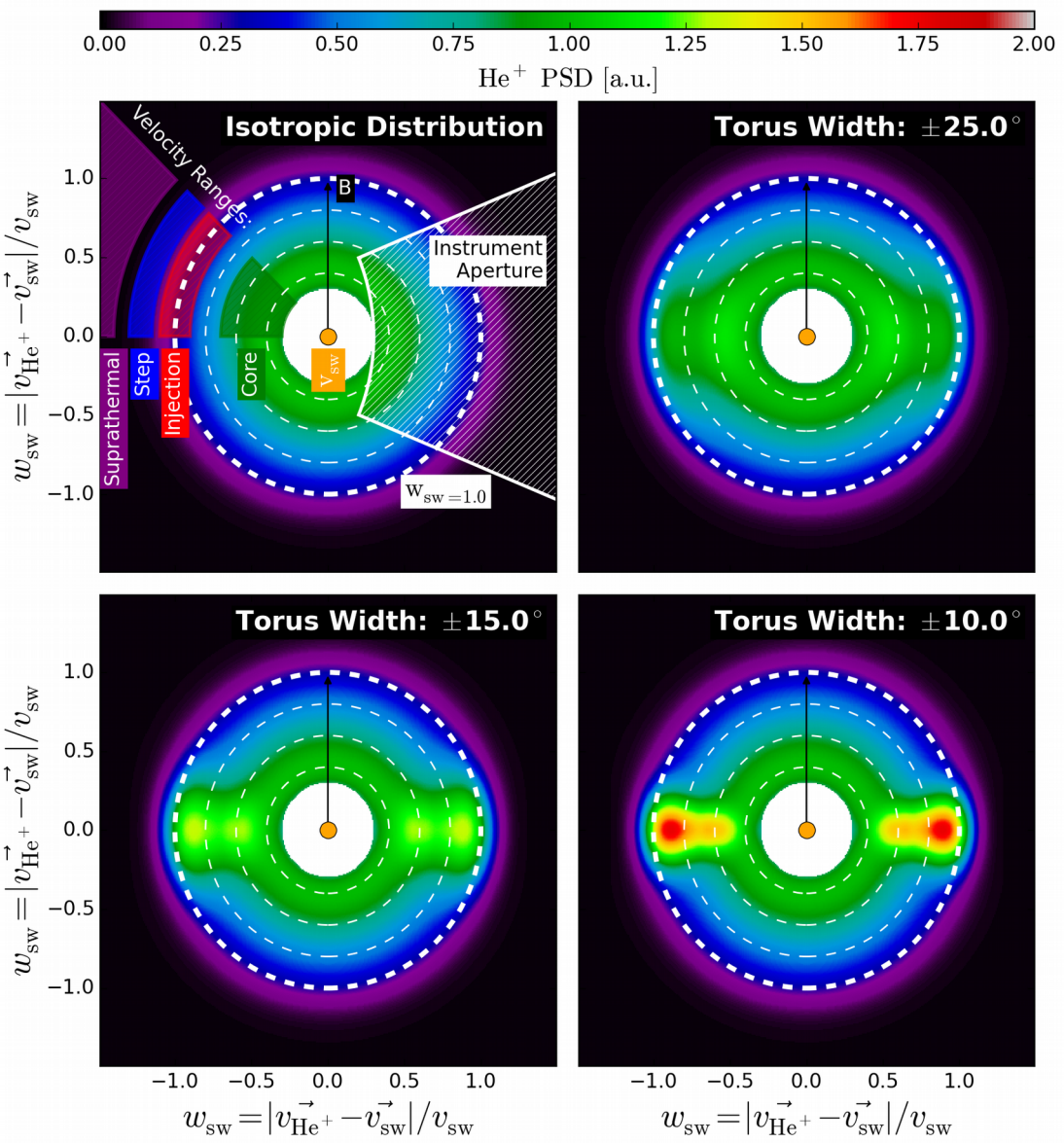
The Pickup Ion Torus Distribution: Analysis Method I

[Drews et al., A&A, in prep.]





He+ Observations → basic math & some assumptions → Implications for the He+ 2D VDF

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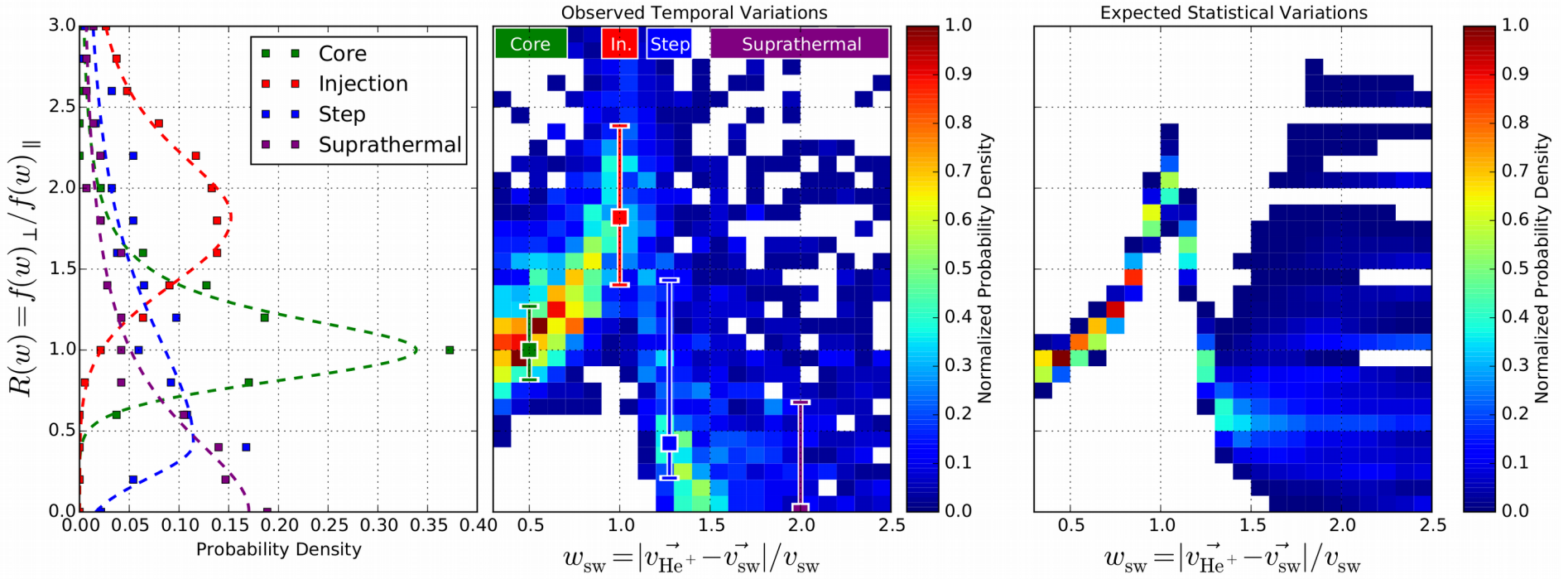
The Pickup Ion Torus Analysis: Sanity Check

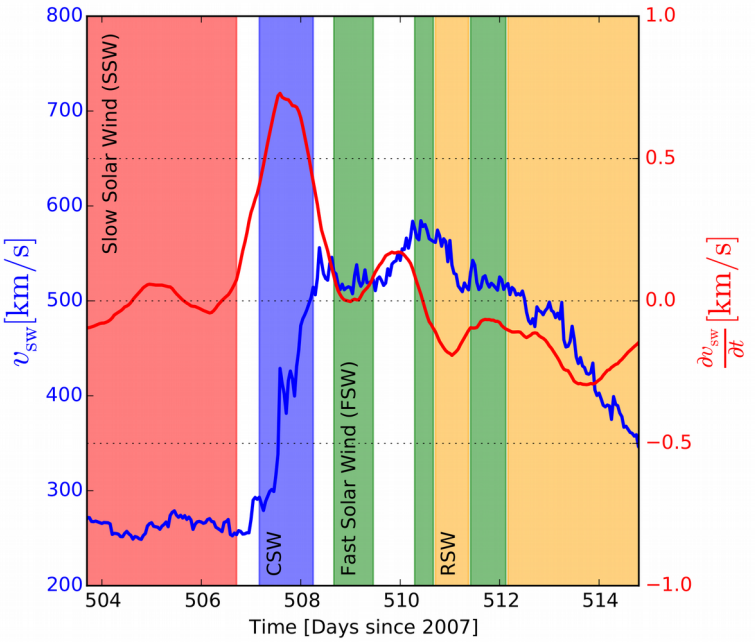


Analysis Method II

Table 1. Classification of solar wind types.

Solar Wind Type	Velocity v_{sw} [km/s]	Gradient $\partial v_{sw}/\partial t$ [km/s^2]
Slow Solar Wind	$200 < v_{sw} < 400$	$\lvert\partial v_{sw}/\partial t\rvert < 0.1$
Fast Solar Wind	$500 < v_{sw} < 700$	$\lvert\partial v_{sw}/\partial t\rvert < 0.1$
Compression	-	> 0.4
Rarefaction	-	< -0.1
Magnetic Cloud[a]	-	-

Notes. [(a)] Magnetic clouds were pre-selected using an ICME list (Jian et al. 2006) and manually classified via their magnetic properties, i.e. a smoothly rotating field.



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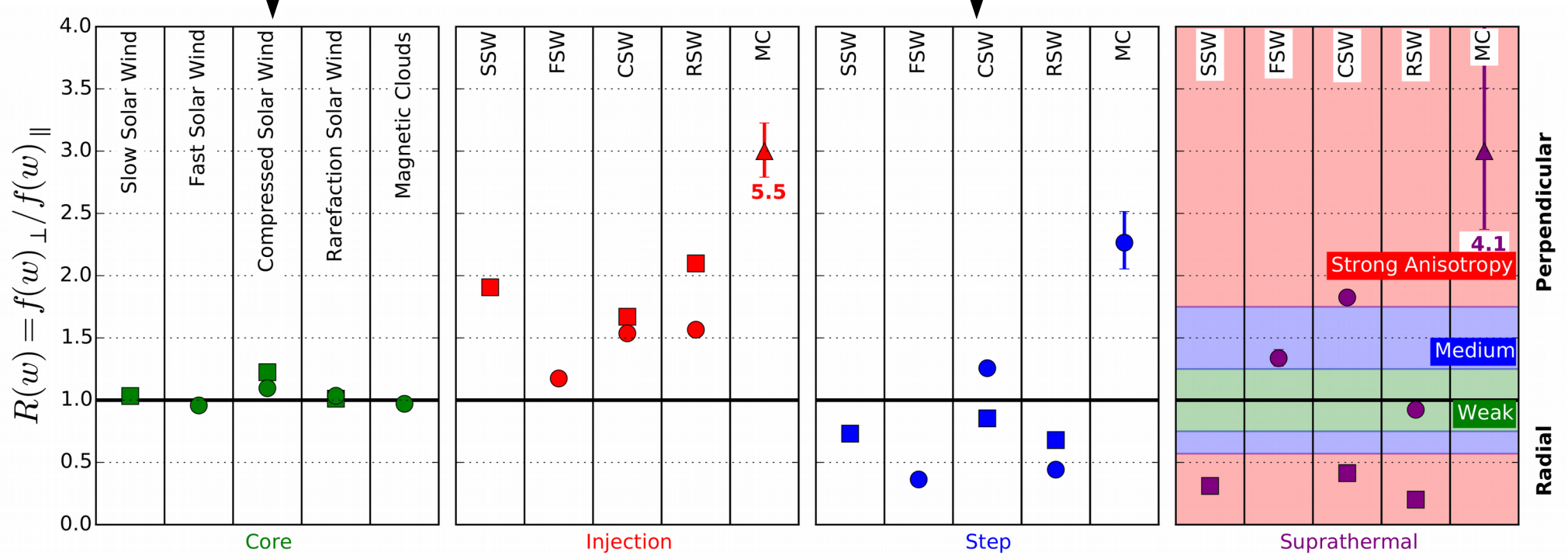
The Pickup Ion Torus Distribution: Results

[Drews et al., A&A, in prep.]

Core regime: 0.2 < wsw < 0.5:
(„old“ He+ PUIs)

Step regime: 1.2 < wsw < 1.4:
(„recently“ accelerated He+ PUIs)



Injection regime: 0.9 < wsw < 1.1:
(recently produced He+)

ST regime: 1.5 < wsw:
(accelerated He+)

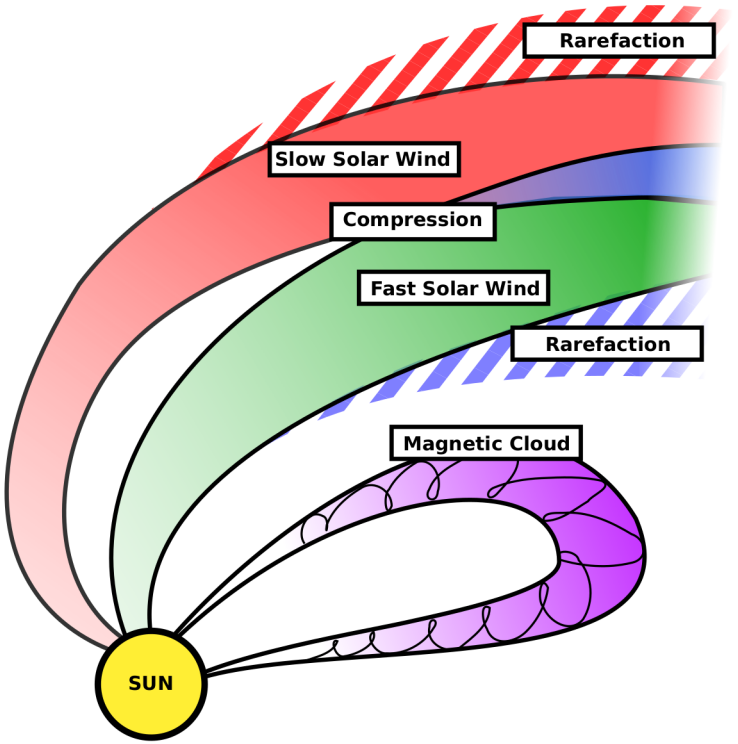
Conclusions:

- He+ VDF is significantly more anisotropic during slow SW conditions
  Likely related to SW magnetic turbulence levels
- High variability of the He+ anisotropy for $w_{sw} > 1.3$
  Acceleration conditions seem to be very important for the isotropization of the He+ VDF
- Pristine isotropic distribution for $w_{sw} < 0.5$
  True for all SW regimes
- Pristine torus distribution inside MCs
  Potential to study the in-situ He+ torus evolution without much influence of prior phase space transport processes

Next Steps:

TBD

Injection regime: $0.9 < w_{sw} < 1.1$:
(recently produced He+)

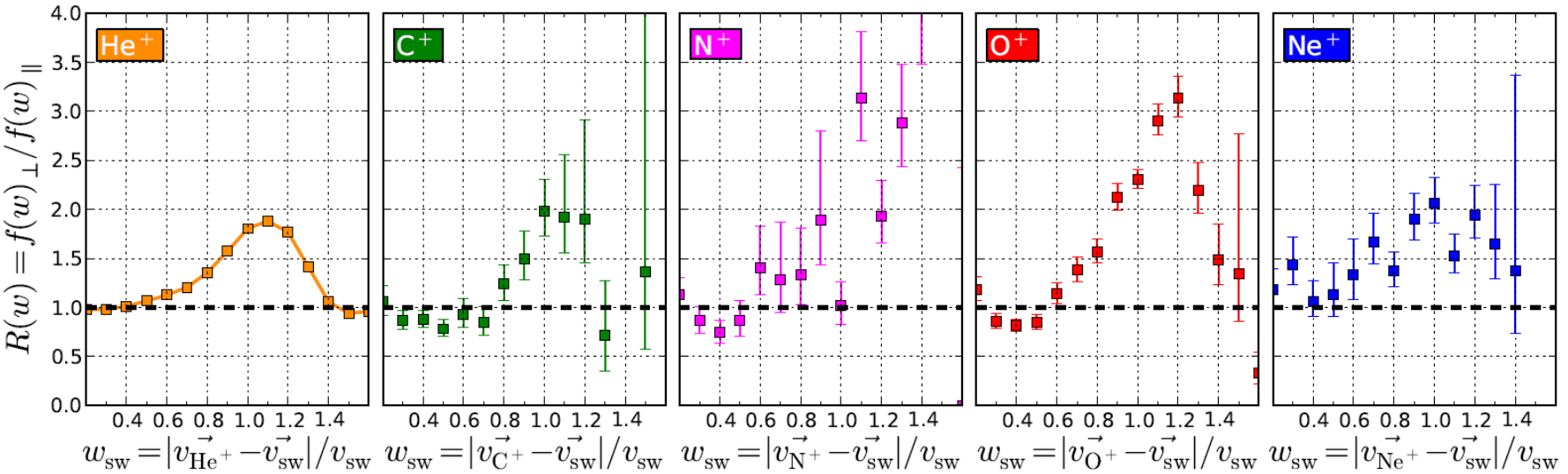


Anisotropy of He^+ VDF (Injection Range)
weak | medium | strong | very strong

Backup:

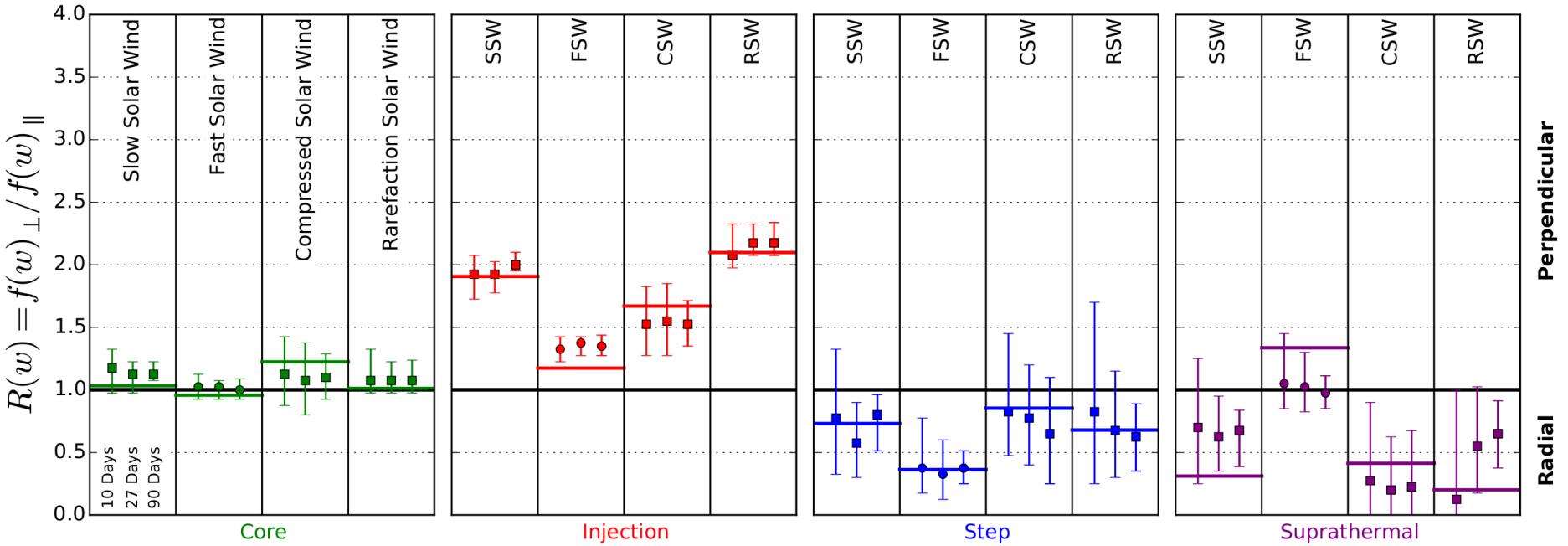
no clear mass-per-charge dependence?

weaker pitch-angle scattering of O+ / N+ compared to He+ / Ne+?

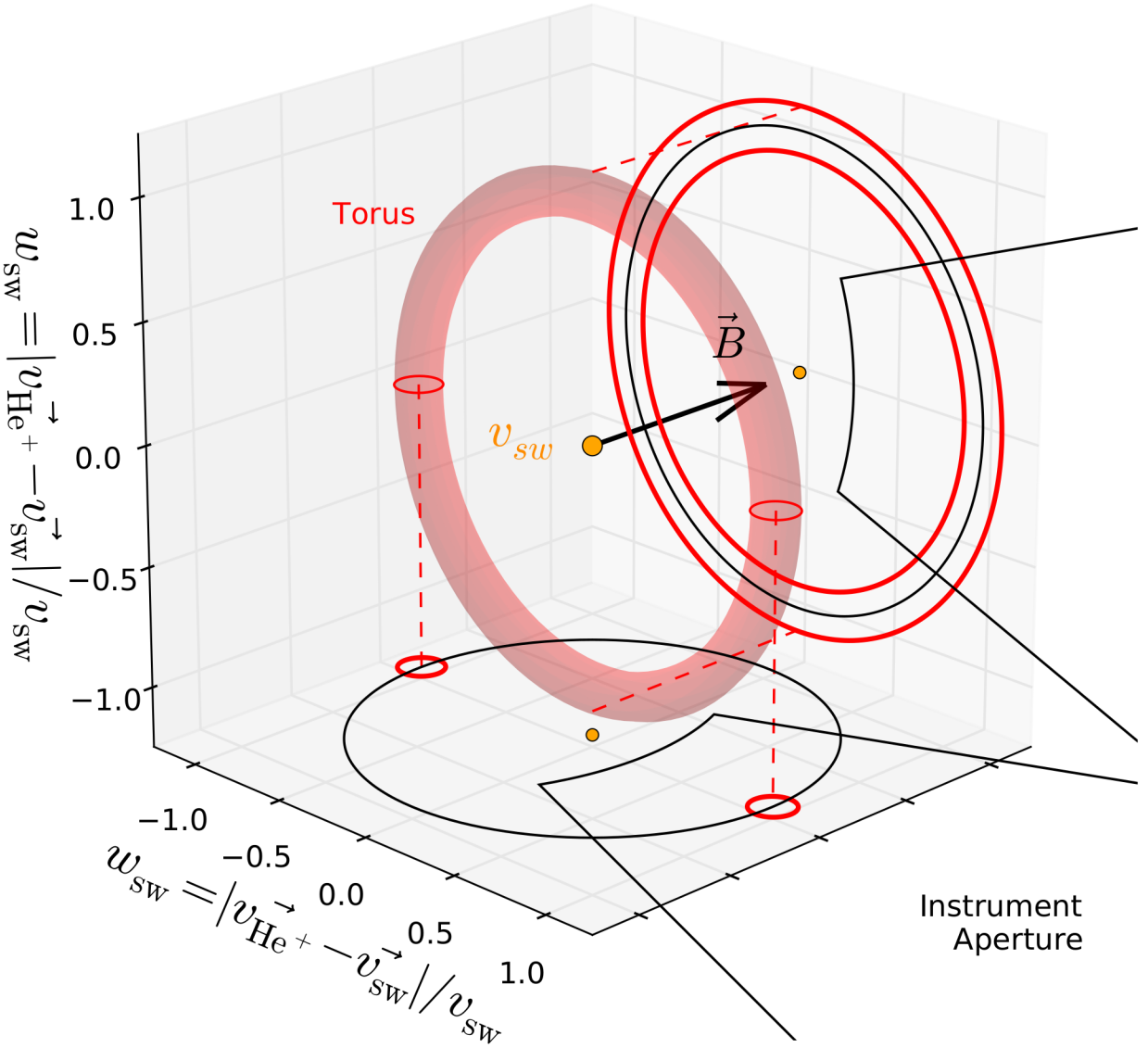


torus of inner-source C+?

Backup:


$R(w) = f(w)_\perp / f(w)_\parallel$
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Slow Solar Wind
Fast Solar Wind
Compressed Solar Wind
Rarefaction Solar Wind
10 Days
27 Days
90 Days
SSW
FSW
CSW
RSW
Core
Injection
Step
Suprathermal
Perpendicular
Radial

Backup:


Torus
$\vec{B}$
v_{sw}
Instrument
Aperture
$w_{sw} = |\vec{v}_{He^+} - \vec{v}_{sw}| / v_{sw}$
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
$w_{sw} = |\vec{v}_{He^+} - \vec{v}_{sw}| / v_{sw}$

The Pickup Ion Torus Distribution: STEREO PLASTIC 2D Observations

[Drews et al., 2015, Astronomy & Astrophysics., 575, A97]