Velocity Distribution Functions of Pickup Ions with Ulysses/SWICS

Master Thesis

Anne Fischer

November 19, 2019

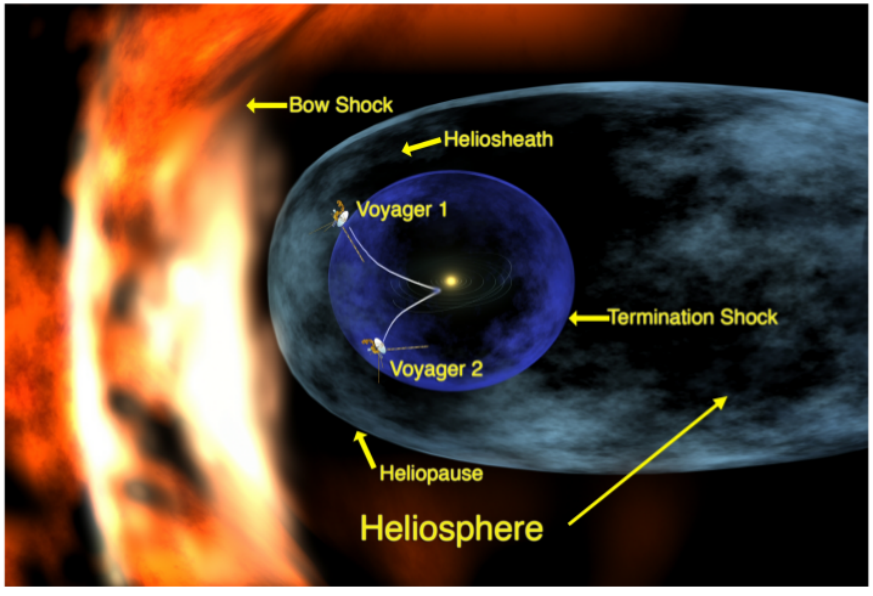
Outline

Pickup Ions Basics

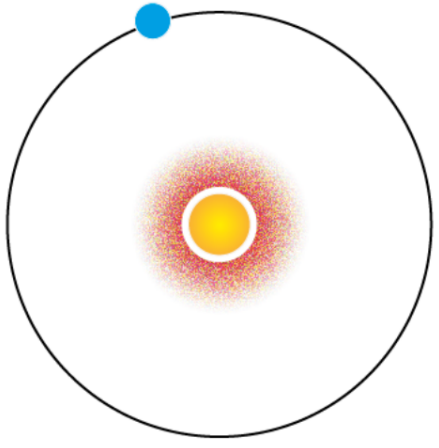
Pickup Ions:
Former neutrals that get ionised within the heliosphere

Origin of the neutrals:

- LISM
- Inner Source

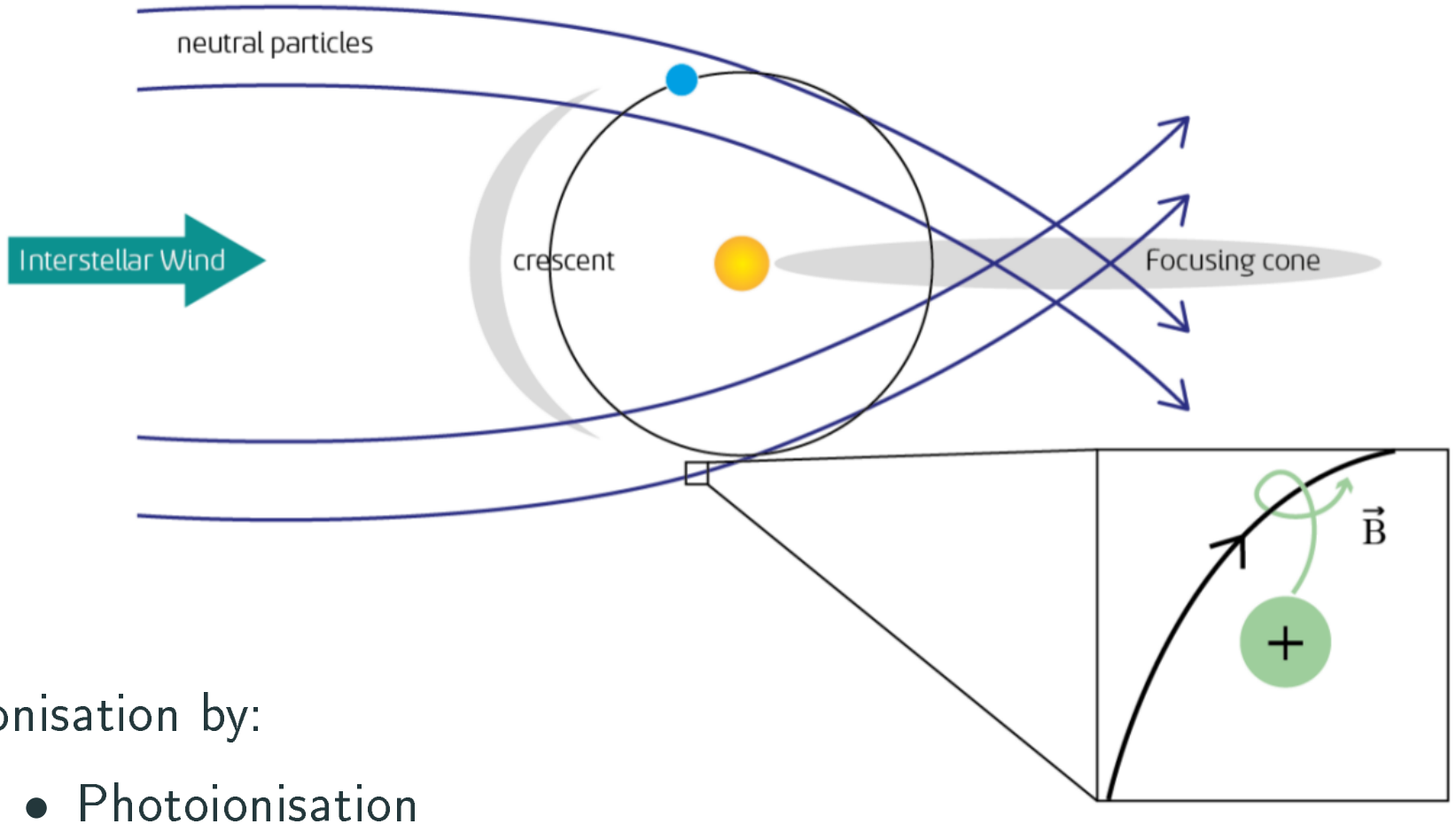


from http://science.nasa.gov



Taut 2018

The Pickup Process



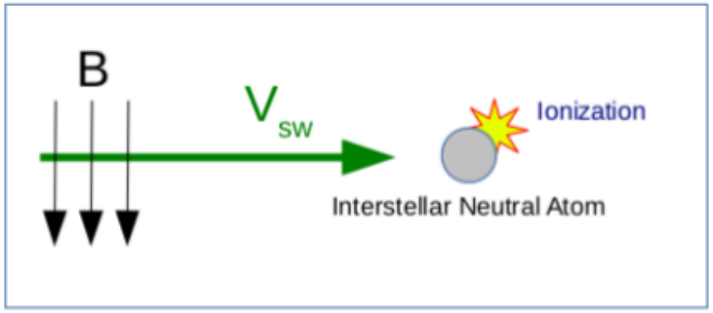
Taut, Drews et al., AGU fall meeting 2014

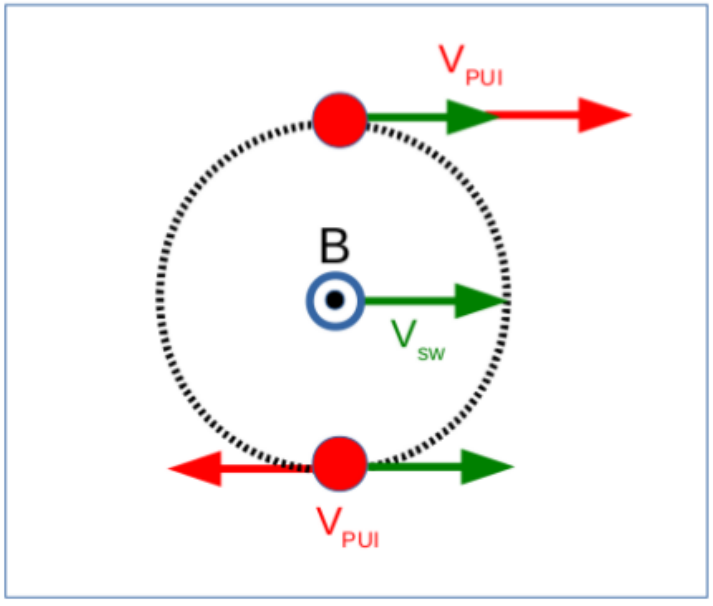
Ionisation by:

- Photoionisation
- Charge exchange
- Electron impact

→ **Newborn ion is subjected to electromagnetic forces**

The Pickup Process





Taut, Drews et al., AGU Fall Meeting 2014

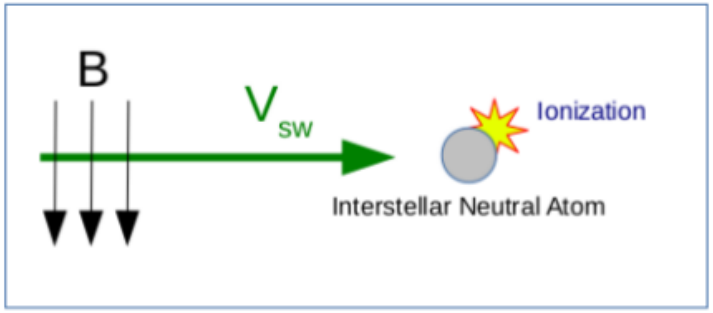
Assumptions:

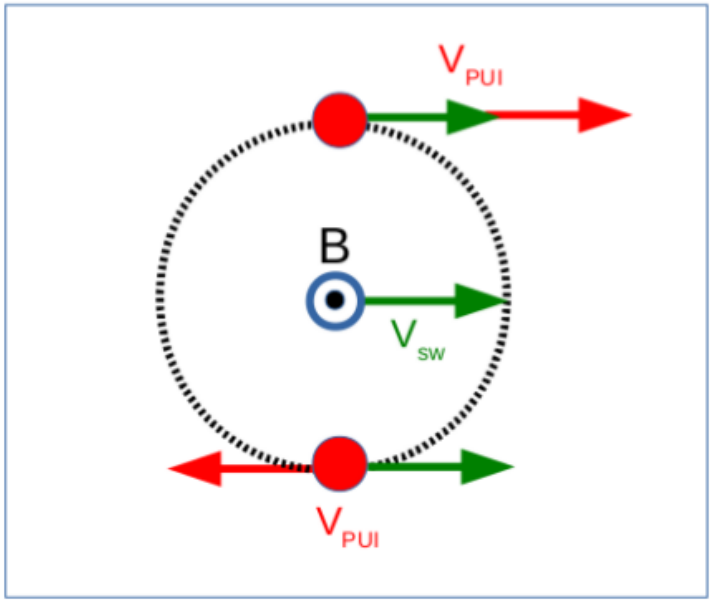
- particle at rest
- $\vec{B} \perp \vec{v}_{SW}$

Relative motion

$\rightarrow$ **Gyro-motion**

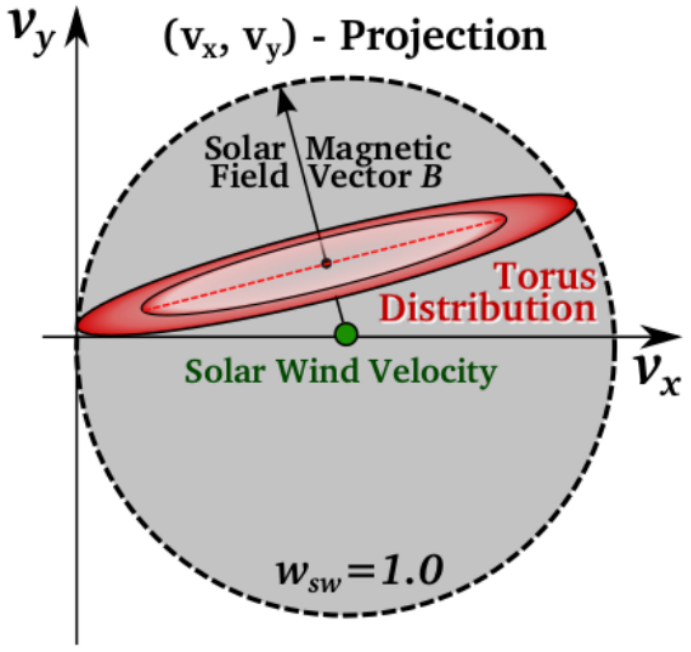
The Pickup Process





Taut, Drews et al., AGU Fall Meeting 2014

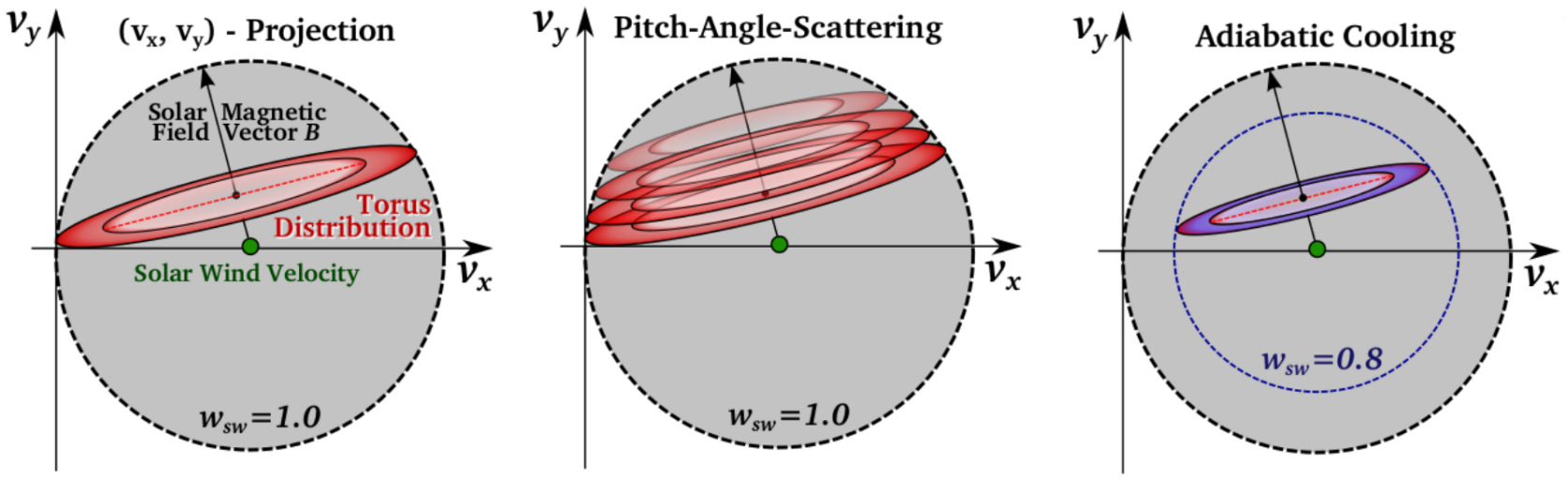
Velocity Space:



Drews et al., 2016

$\longrightarrow$ **Anisotropic torus VDF**

Evolution of the VDF



Drews, Berger et al., 2016

Modification of the initial torus-shaped VDF by:

- Pitch-angle scattering
  $\rightarrow$ isotropisation
- acceleration & decelaration

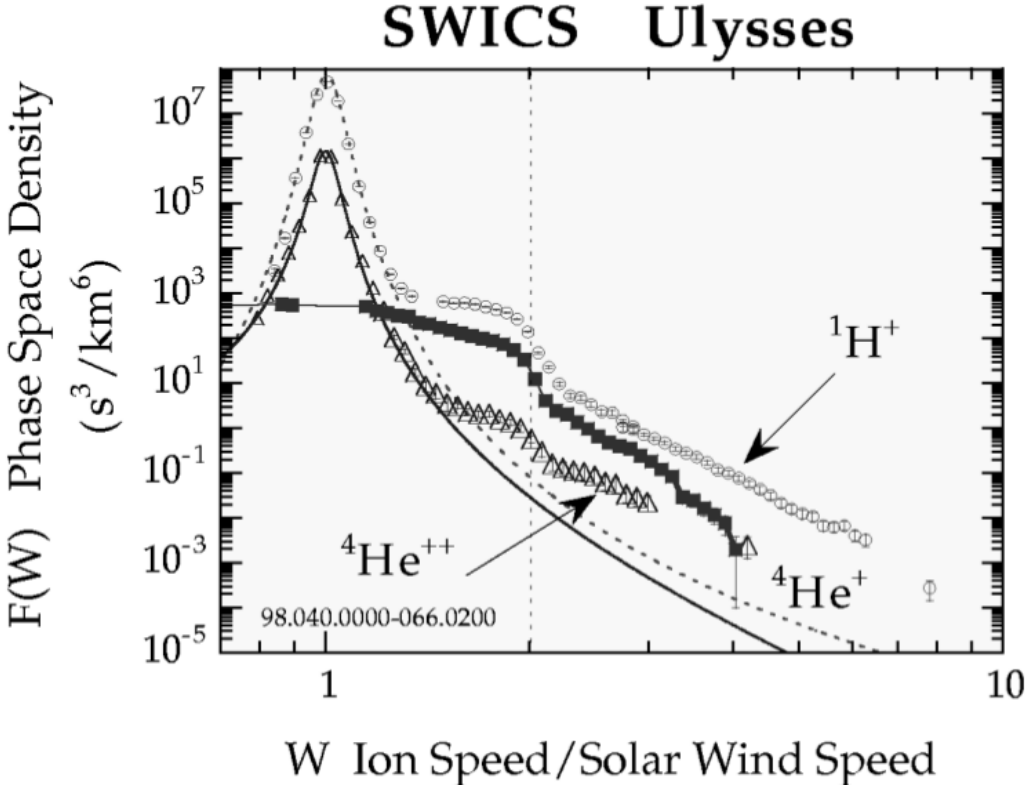
PUI – Measurement

Observed PUIs:

H^{1+}, $^3He^{1+}$, He^{1+},
He^{2+}, C^{1+}, N^{1+}, O^{1+},
Ne^{1+}, Mg^{1+}, Si^{1+}, Fe^{1+}

PUI or Solar Wind?

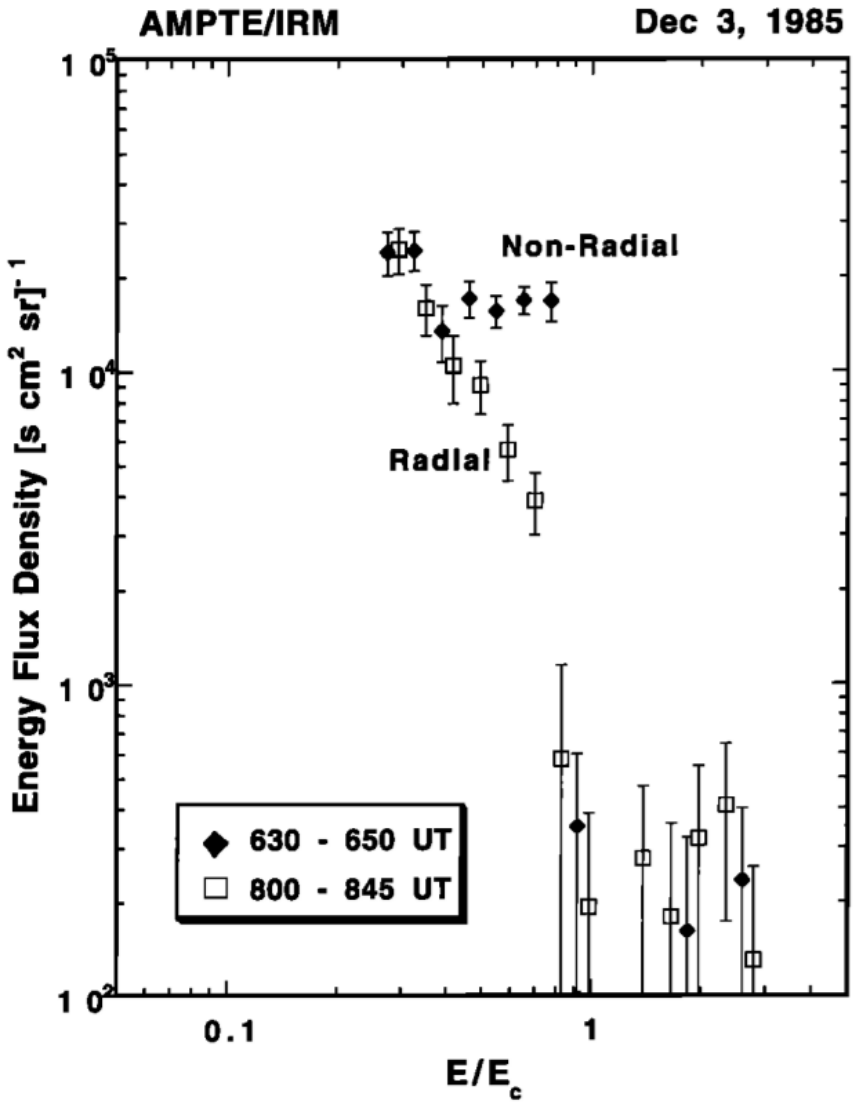
- Charge state
- Velocity distribution function (VDF)



Gloeckler et al., 1999

Anisotropic features of the VDF

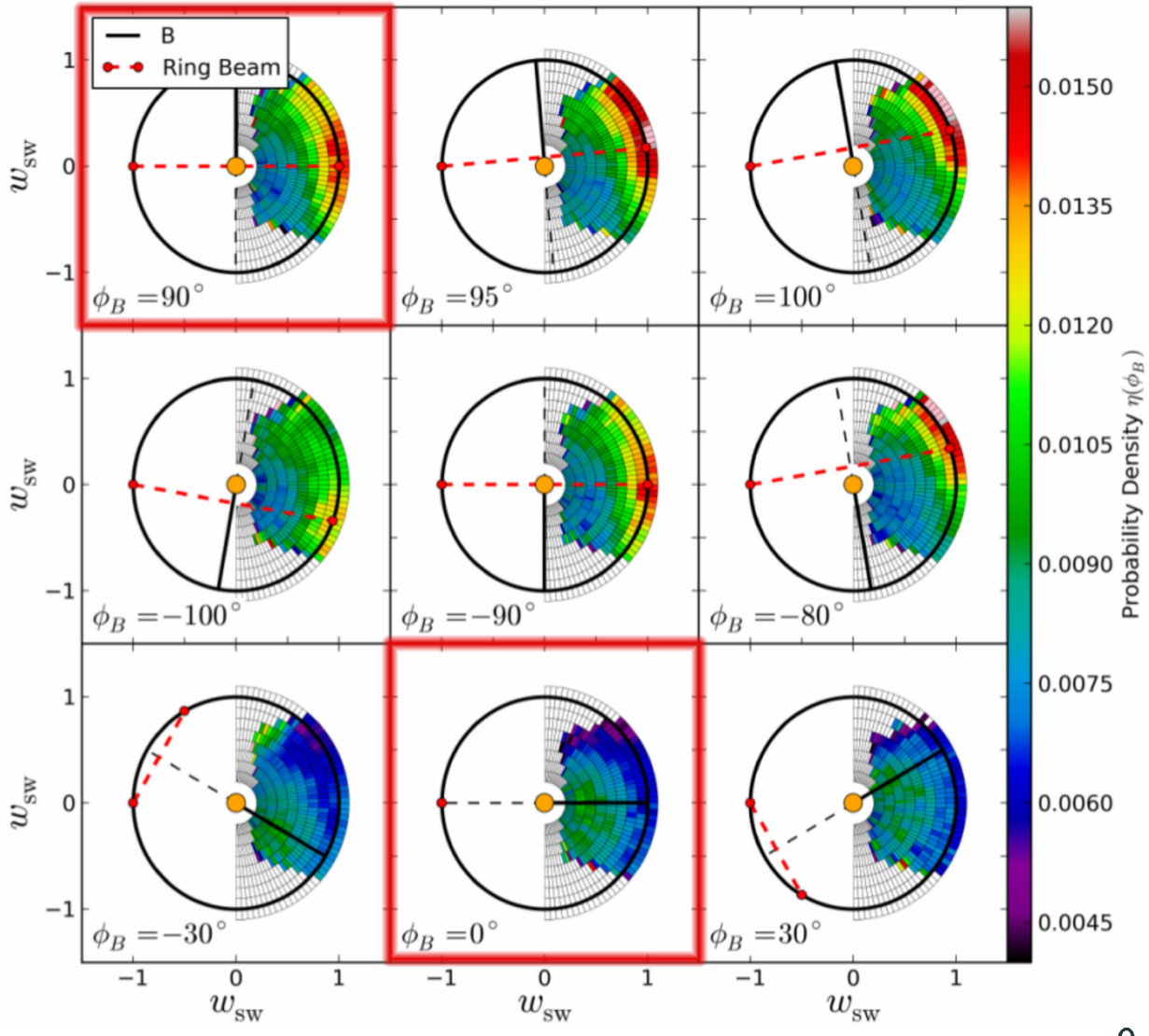
1D measurements discover **anisotropic features** of the VDF



Moebius et al., 1998

Anisotropic features of the VDF

- STEREO / PLASTIC:
  angular resolution
  $\rightarrow$
  2D measurement
  - anisotropic feature
  - $\vec{B}$-dependency

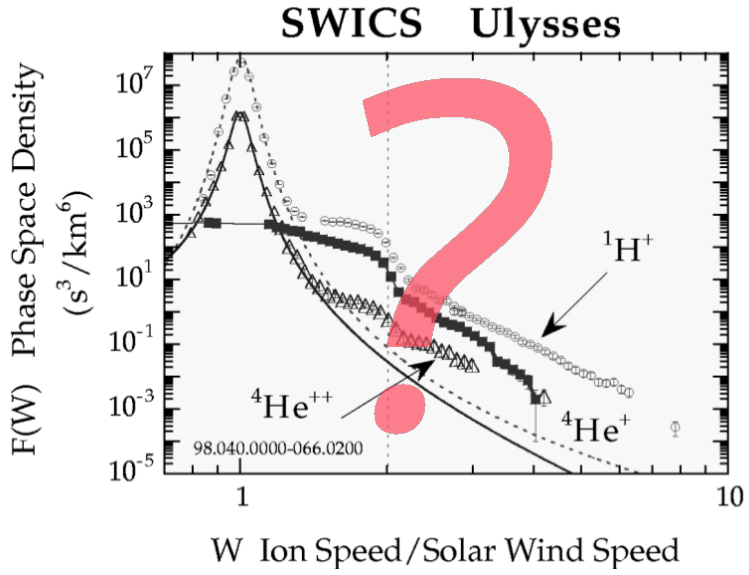


Drews, Berger et al., 2015

Motivation

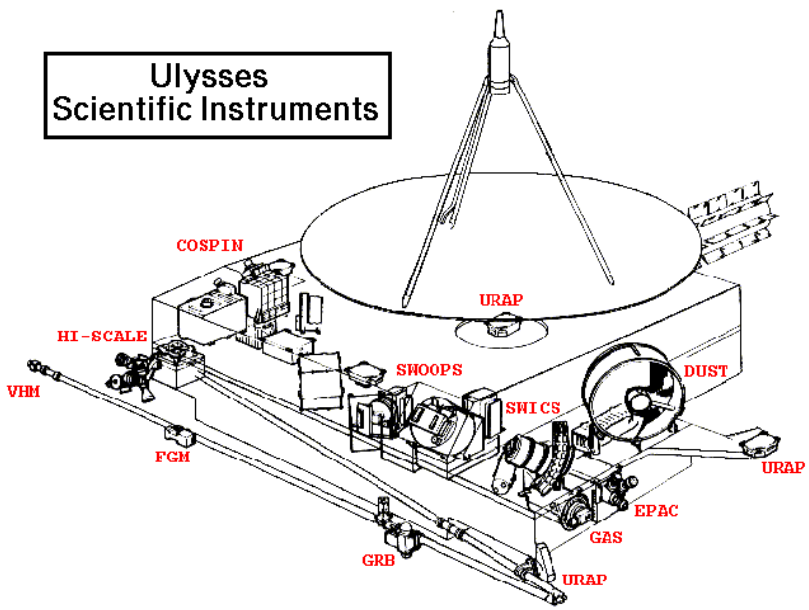
Problem:
Ambiguity of 1D reduced data

For fully understanding the PUI transport in phase space we need to analyse the **3D velocity distribution** function

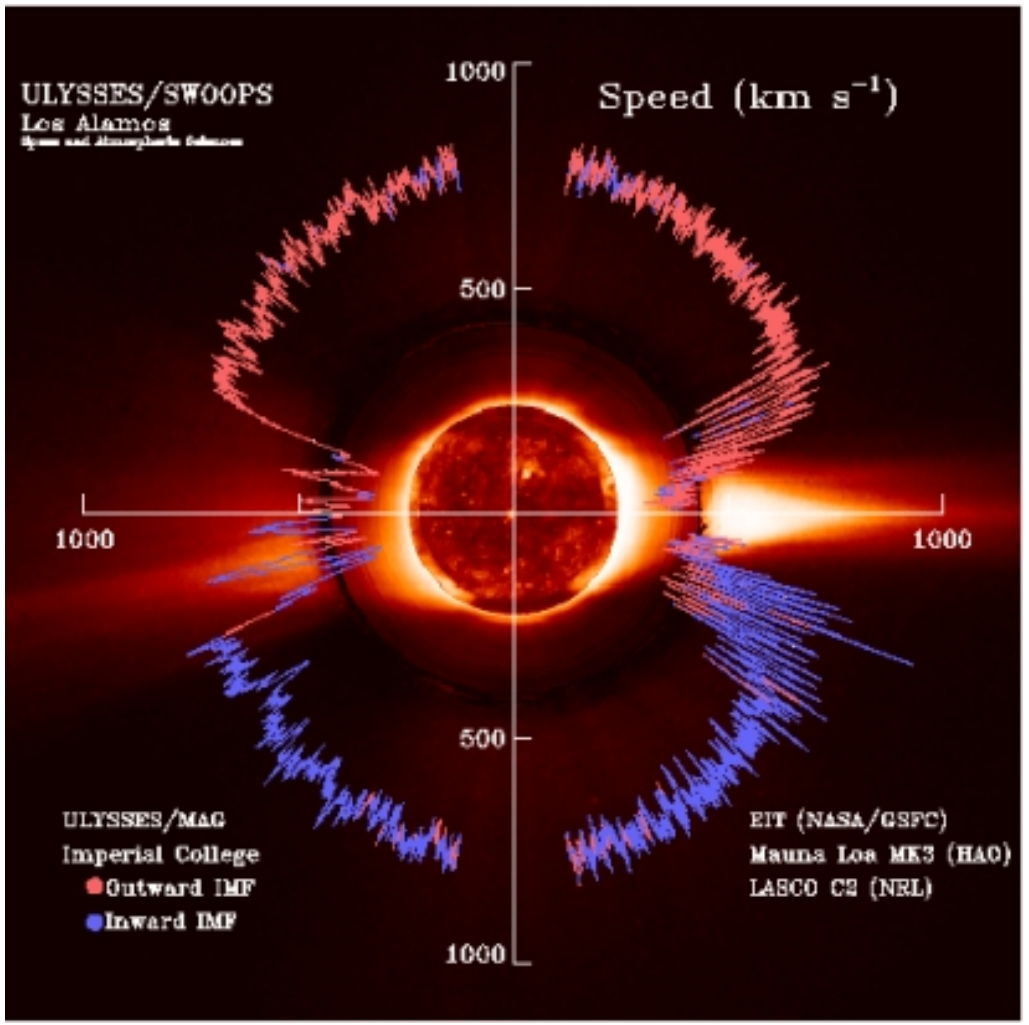


Ulysses Spacecraft

- Launched 1990 (– 2009)
- Highly inclined orbits above the solar poles
  $\rightarrow$ unique data!

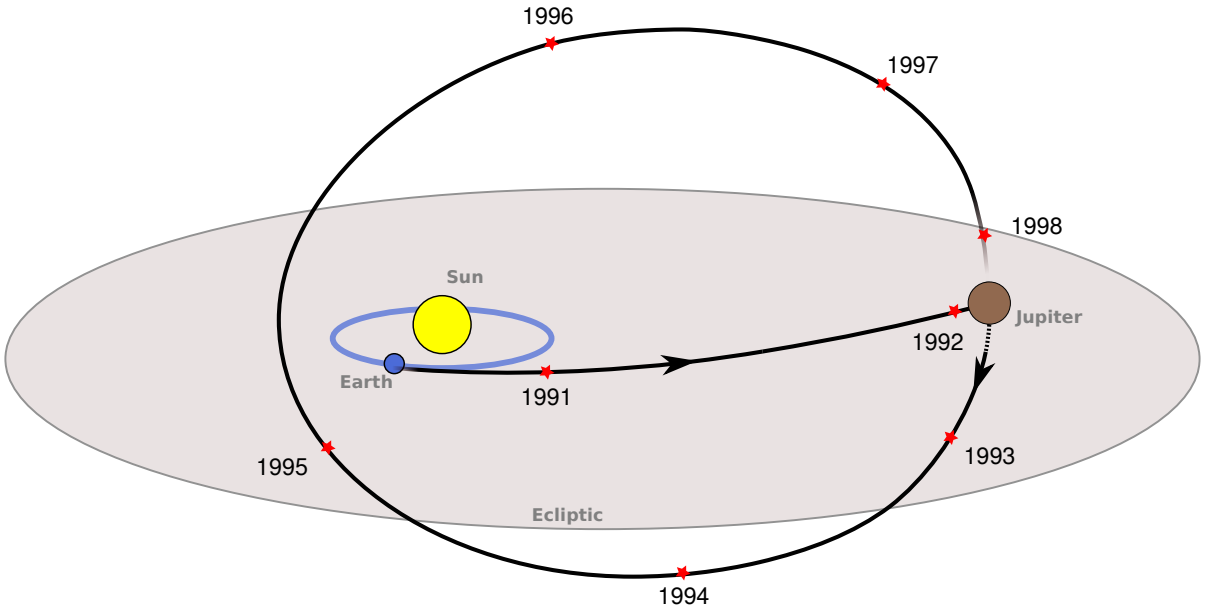


www.cosmos.esa.int, 2019



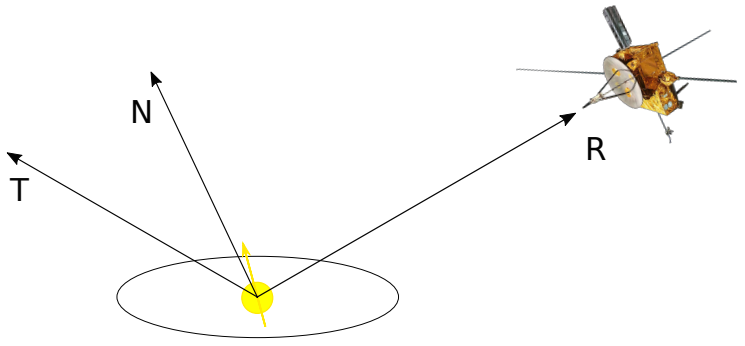
McComas et al., 2000

Ulysses Orbit



adapted from www.cosmos.esa.int, 2019

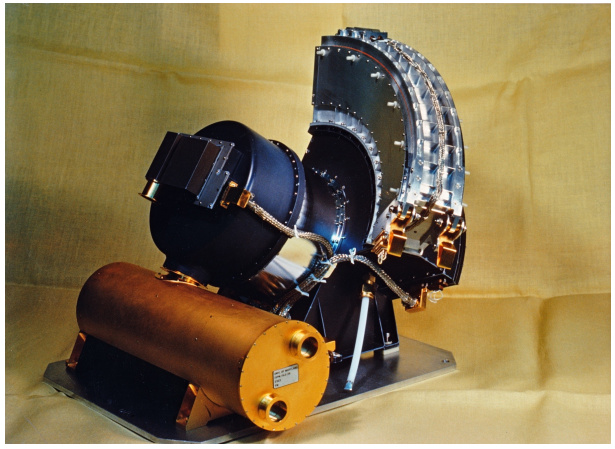
Orbital period: 6.2 years

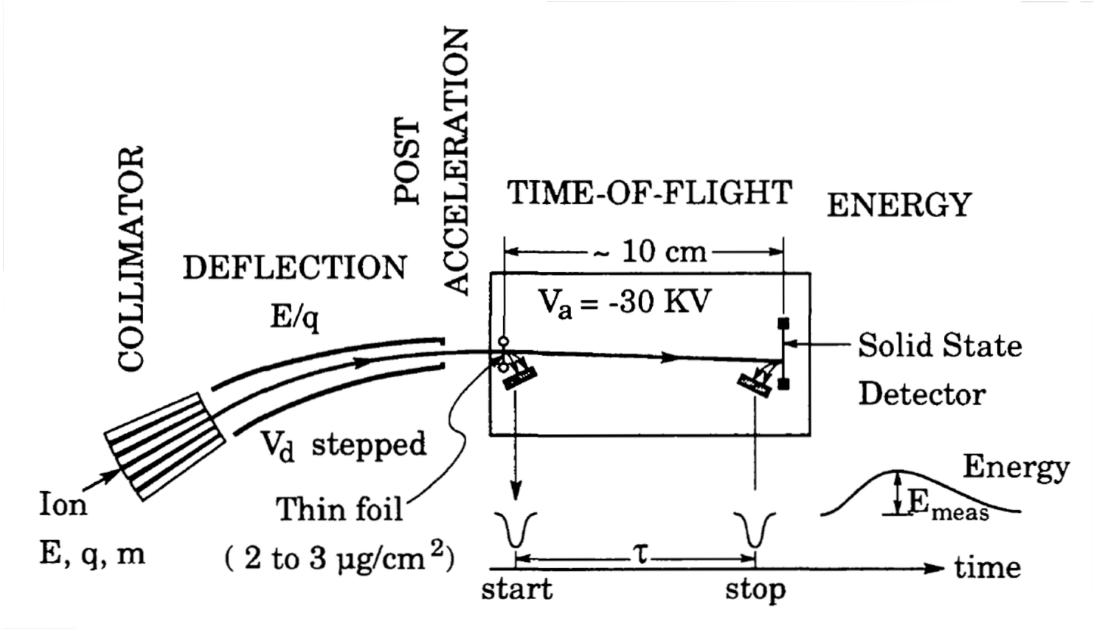


SWICS

The **S**olar **W**ind **I**on **C**omposition **S**pectrometer

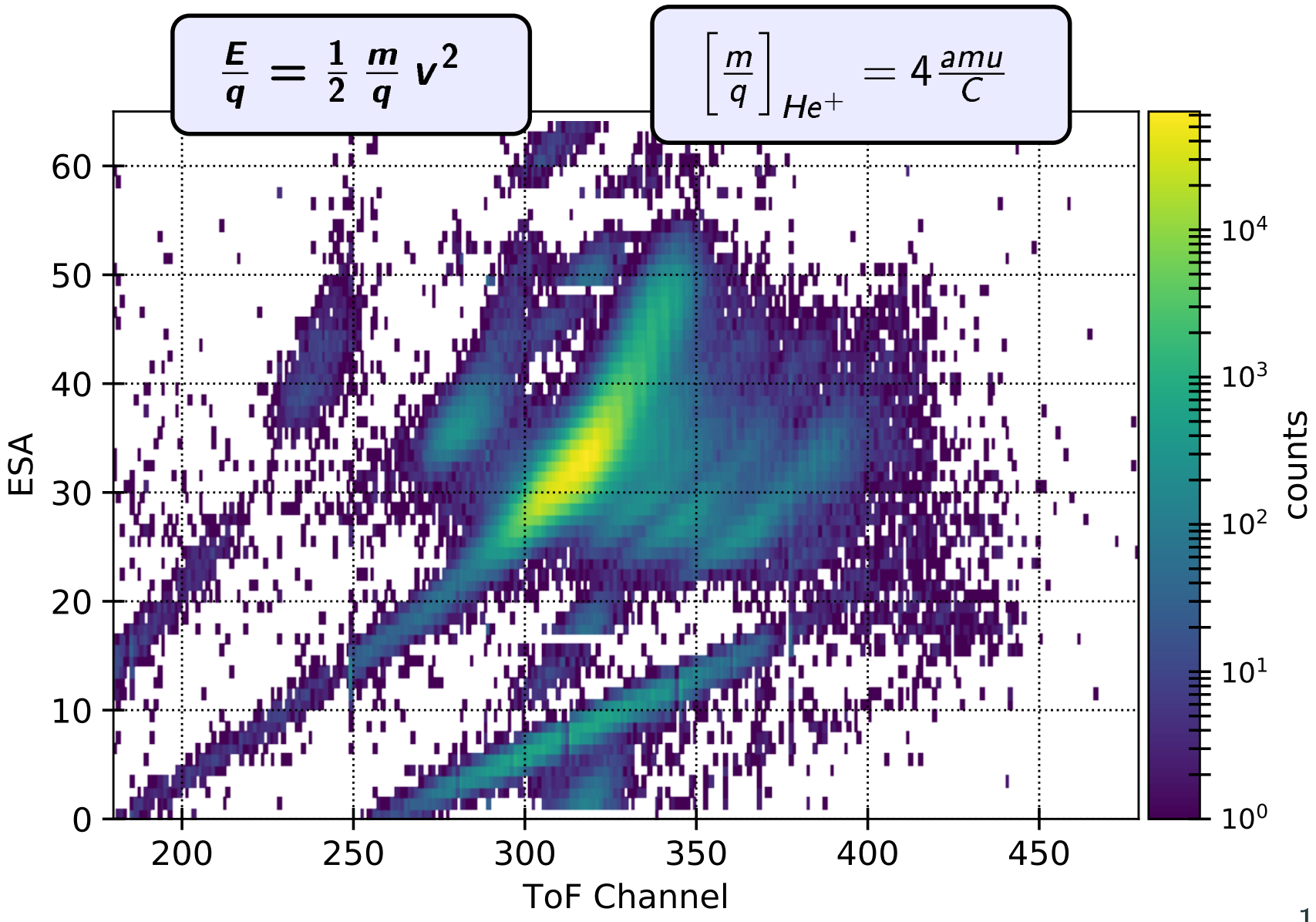
- Time-of-flight mass spectrometer
- $\left\{\frac{E}{q}, ToF, E_{SSD}\right\}$ $\Rightarrow \left\{\frac{M}{q}, M, |v|\right\}$
- identification & energy of the ion



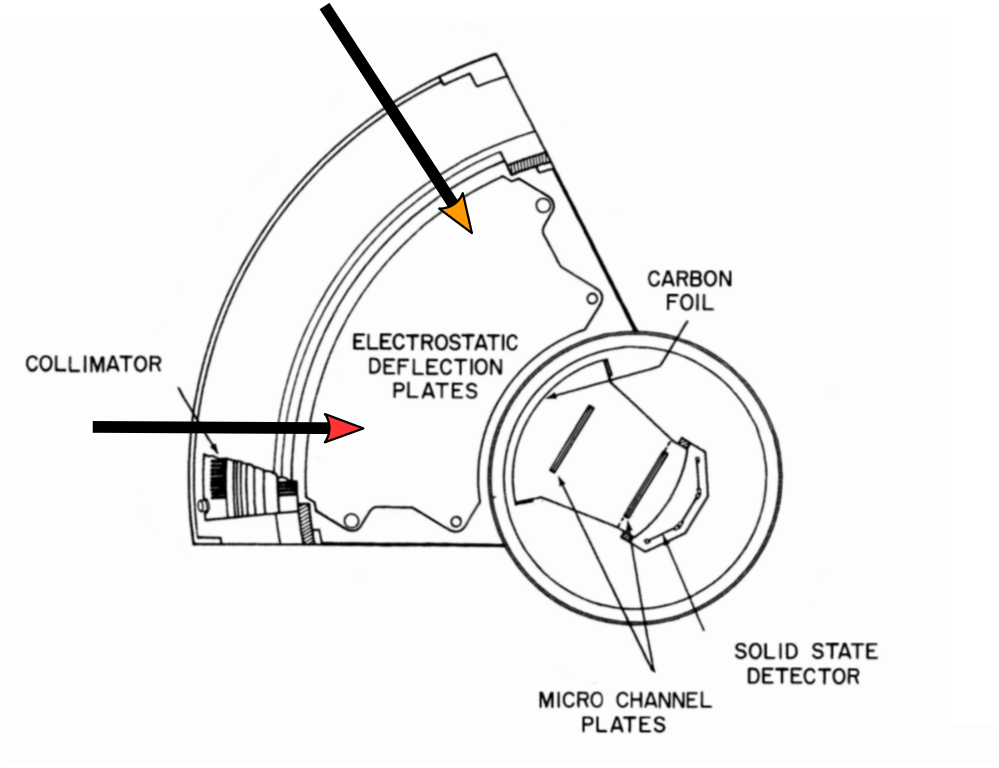


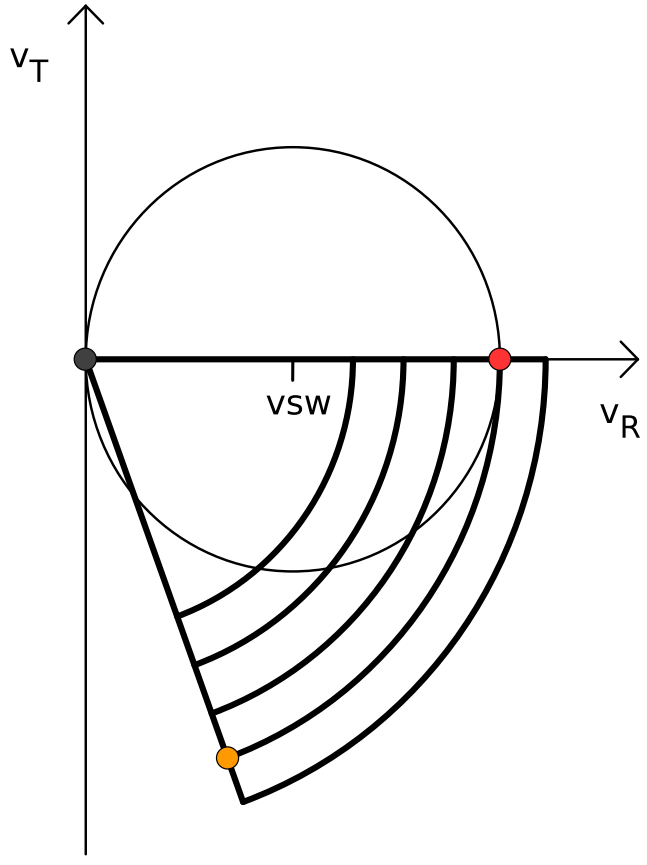
Gloeckler, Geiss et al., 1992

PHA data


$\frac{E}{q} = \frac{1}{2}\frac{m}{q}v^2$
$\left[\frac{m}{q}\right]_{He^+} = 4\frac{amu}{C}$
ESA
ToF Channel
counts
0
10
20
30
40
50
60
200
250
300
350
400
450
10^0
10^1
10^2
10^3
10^4

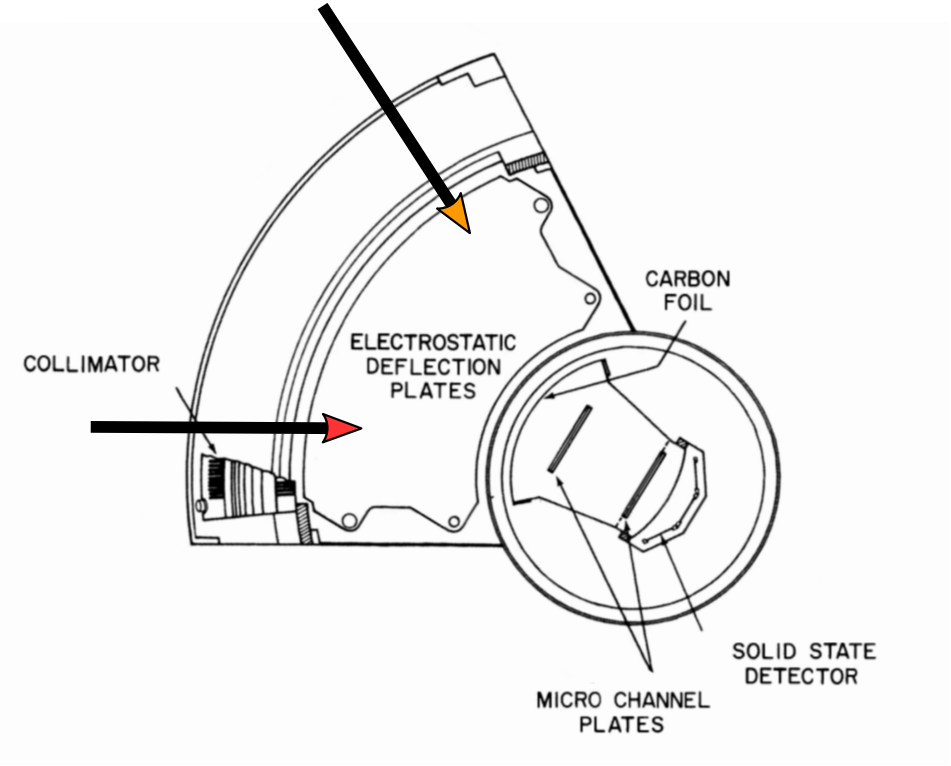
EpQ measurement

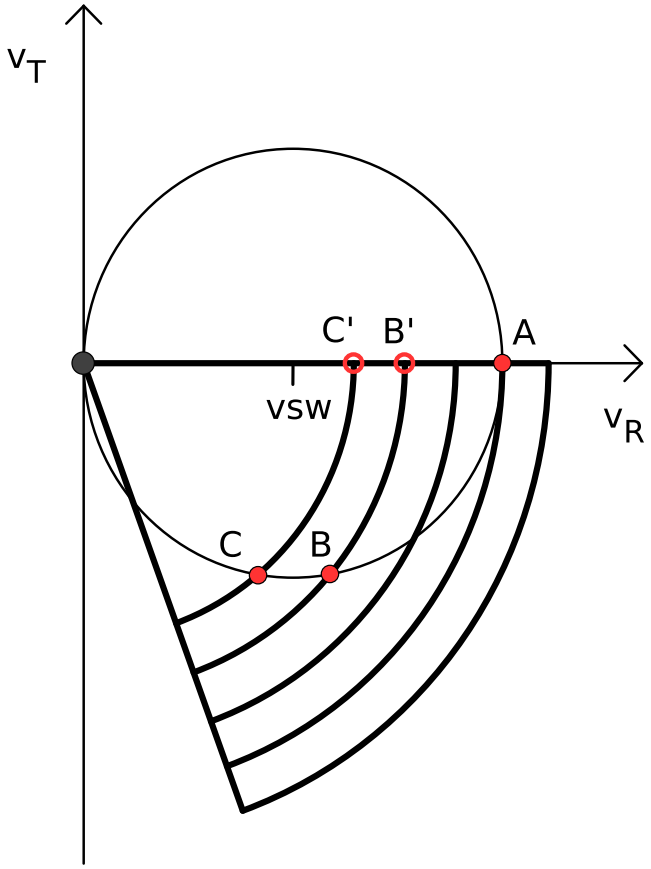




- For constant $\frac{m}{q}$: $\frac{E}{q}$-step $\widehat{=}$ absolute value of velocity

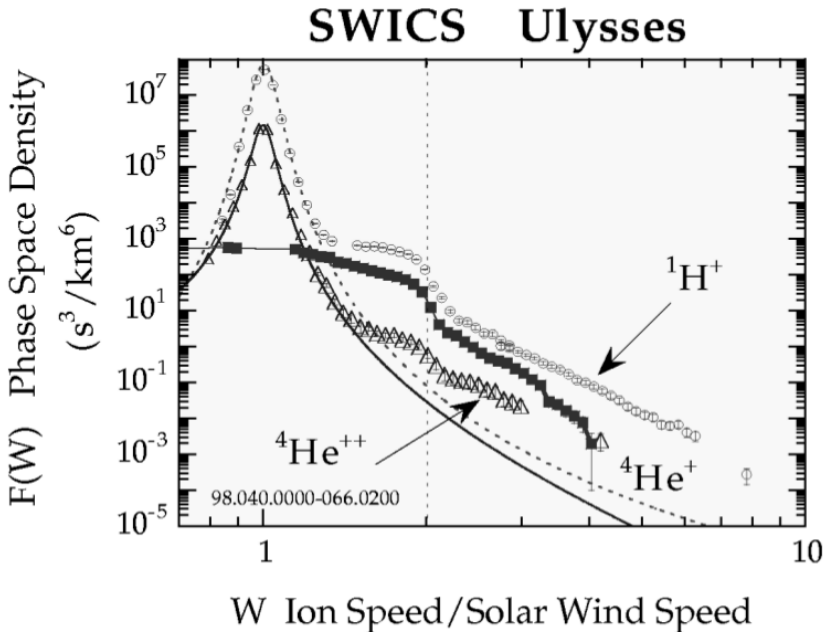
EpQ measurement



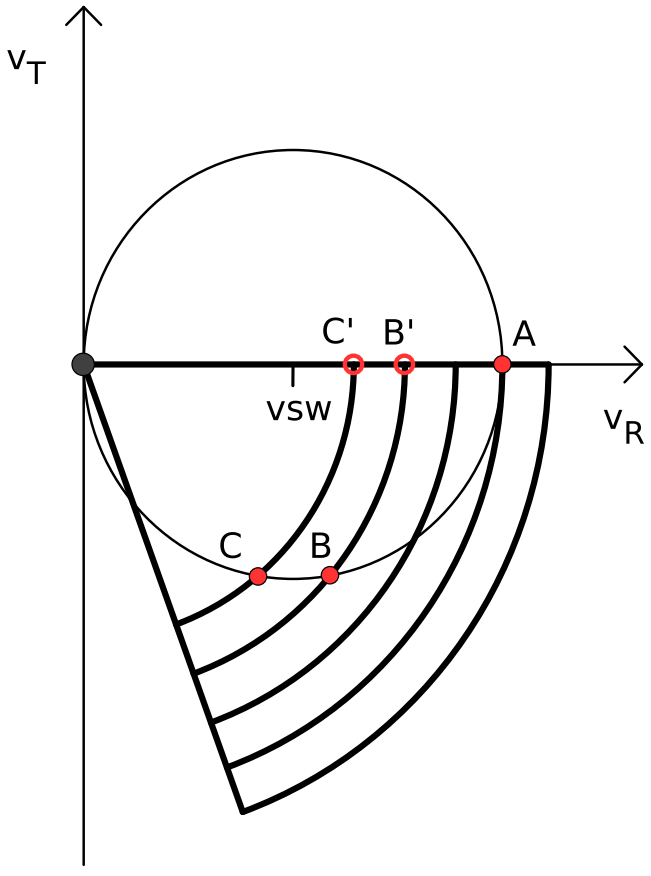


- For constant $\frac{m}{q}$: $\frac{E}{q}$-step $\widehat{=}$ absolute value of velocity

EpQ measurement

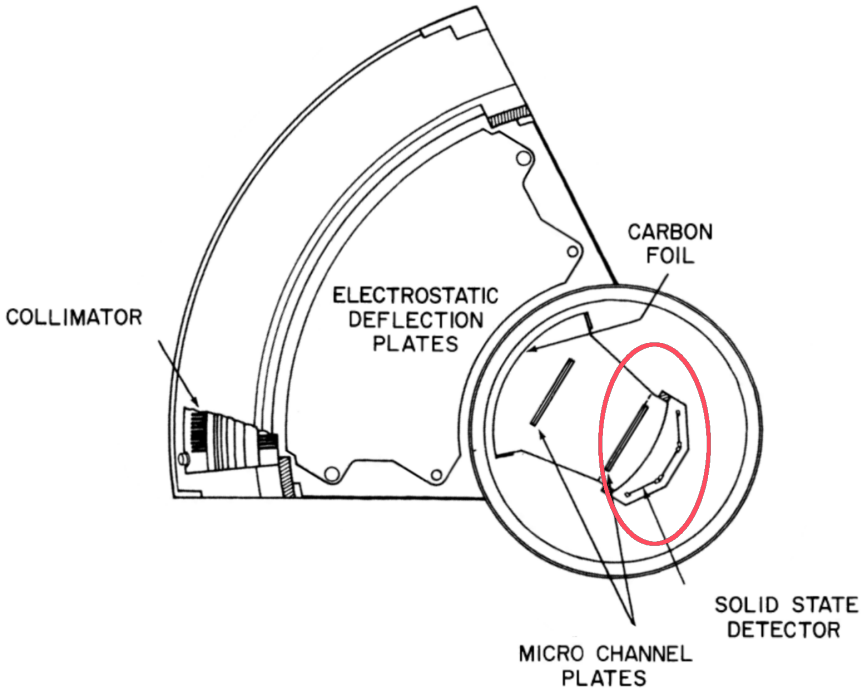


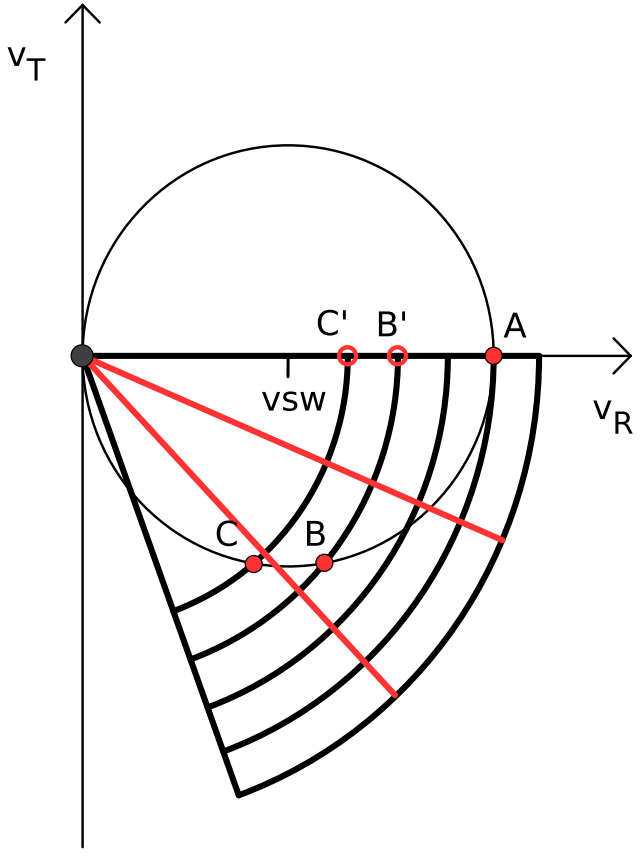
Gloeckler, Geiss et al., 1992



- For constant $\frac{m}{q}$: $\frac{E}{q}$-step $\widehat{=}$ absolute value of velocity
- Integration over EpQ shells $\rightarrow$ loss of information!

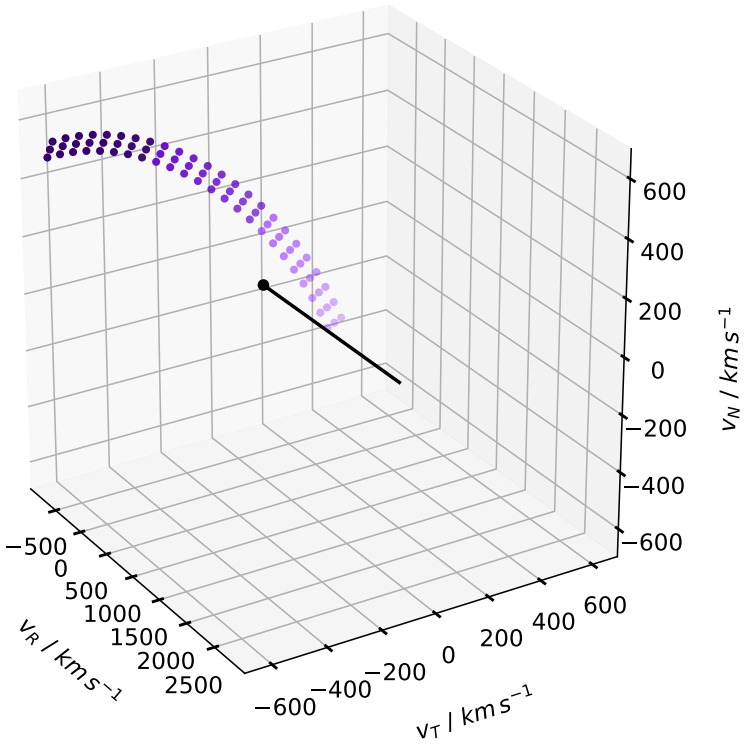
Angular resolution

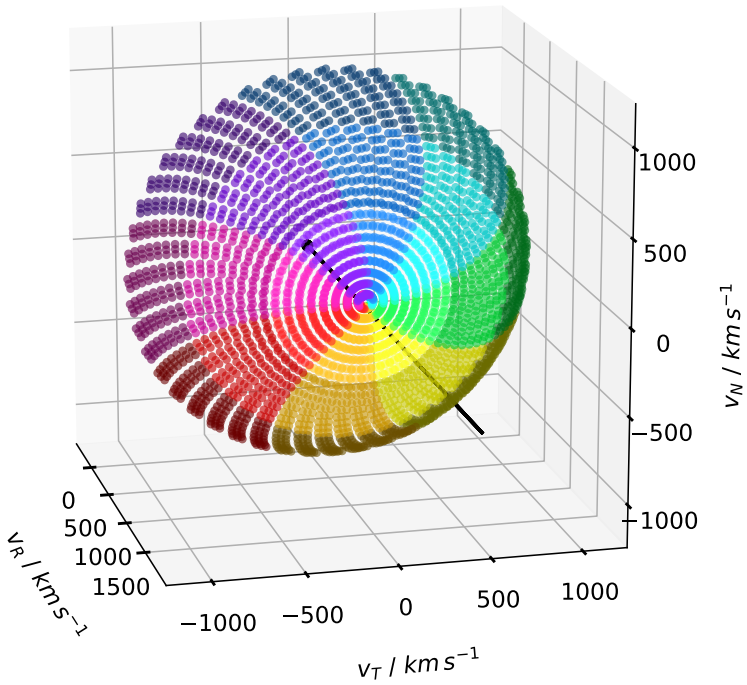


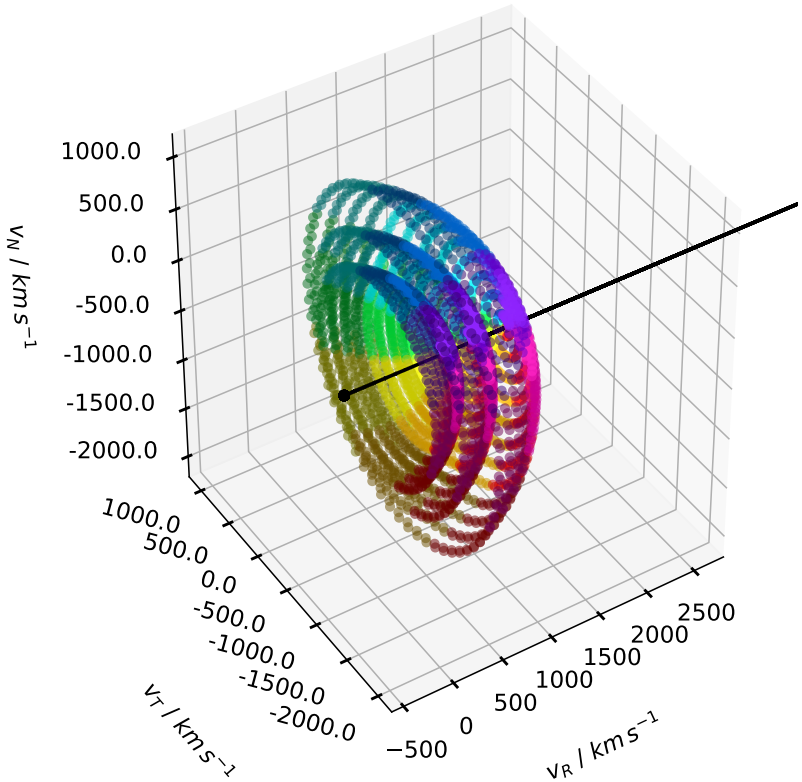


- SWICS: **3 detectors**
  Rough distinction between angles of incidence
- 3rd dimension: spin of the SC
  Divided into **8 sectors**

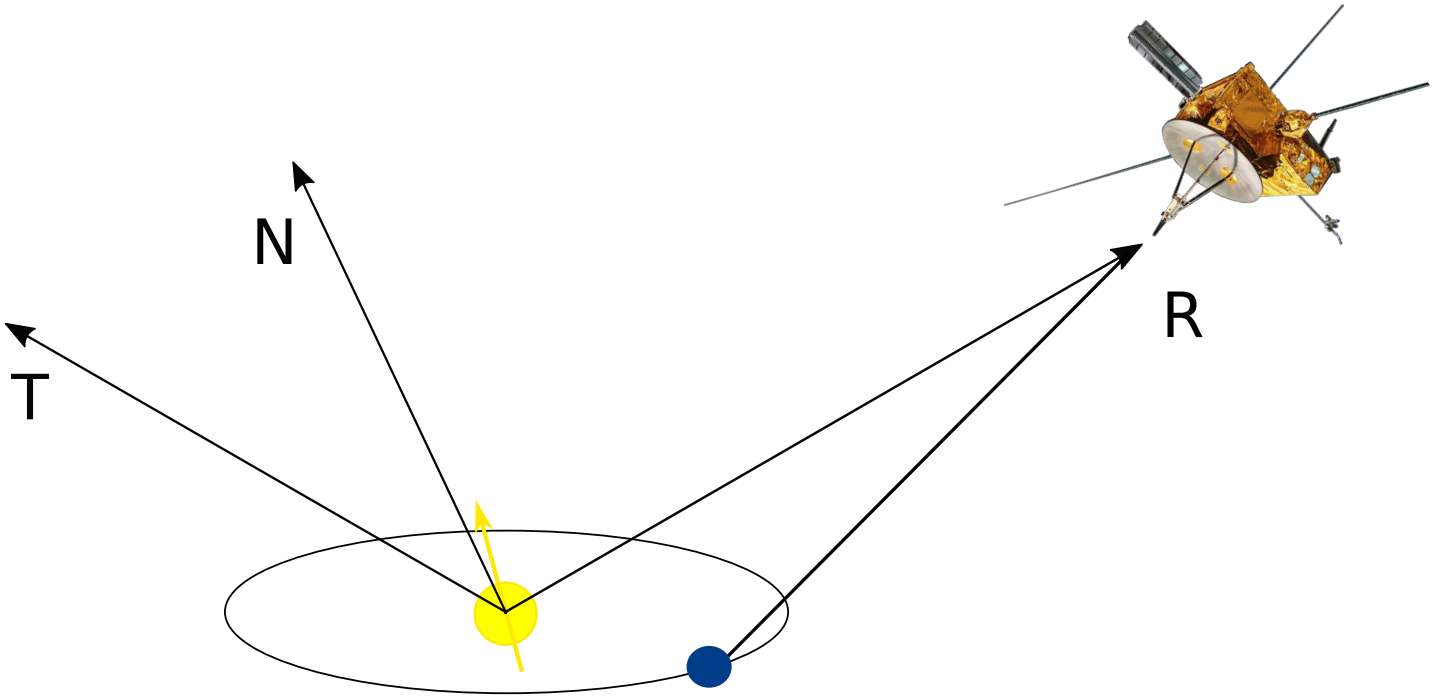
Virtual Collimator



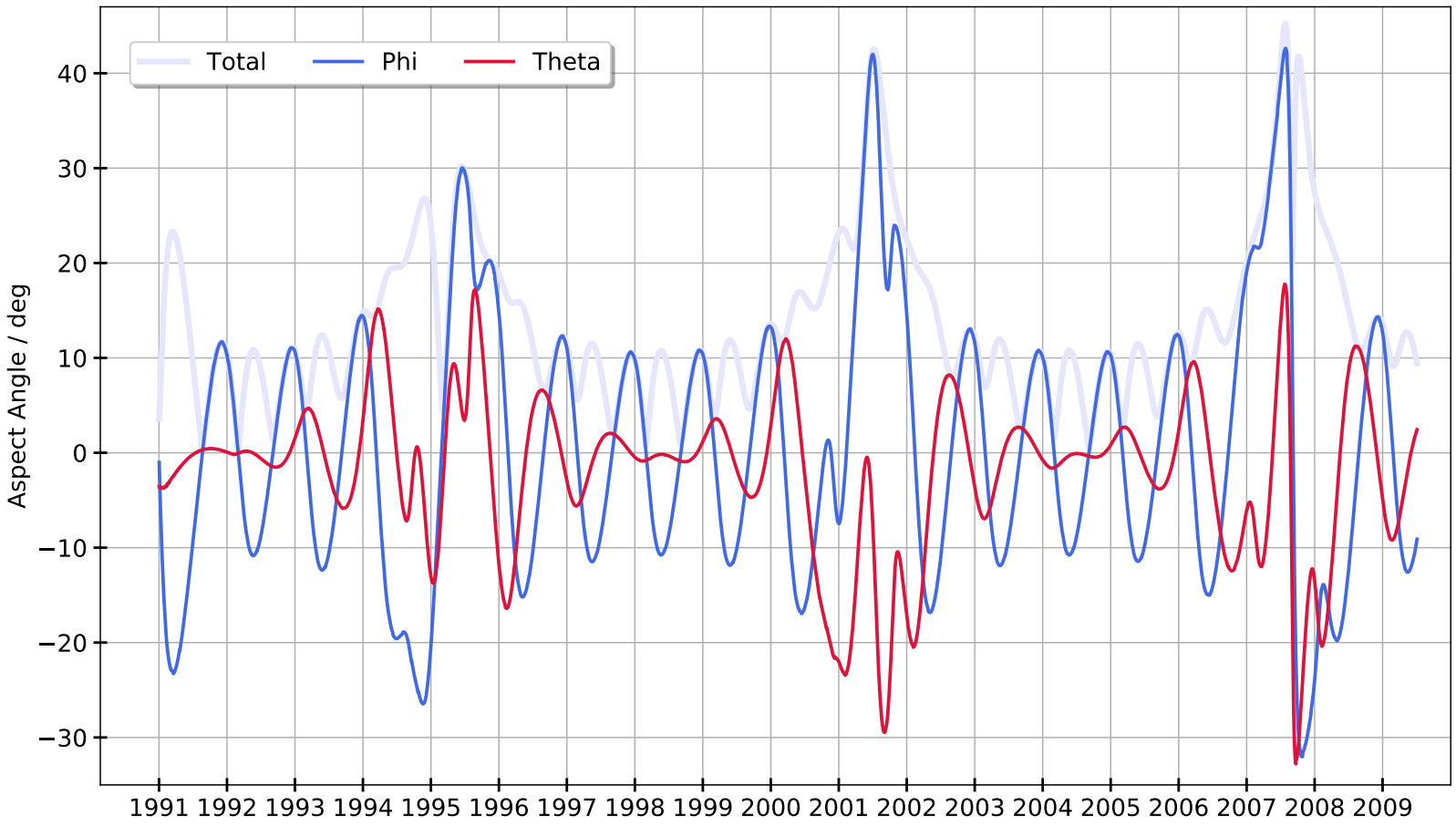



1000.0
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
v_N / km s^{-1}
1000.0
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
v_T / km s^{-1}
−500
0
500
1000
1500
2000
2500
v_R / km s^{-1}

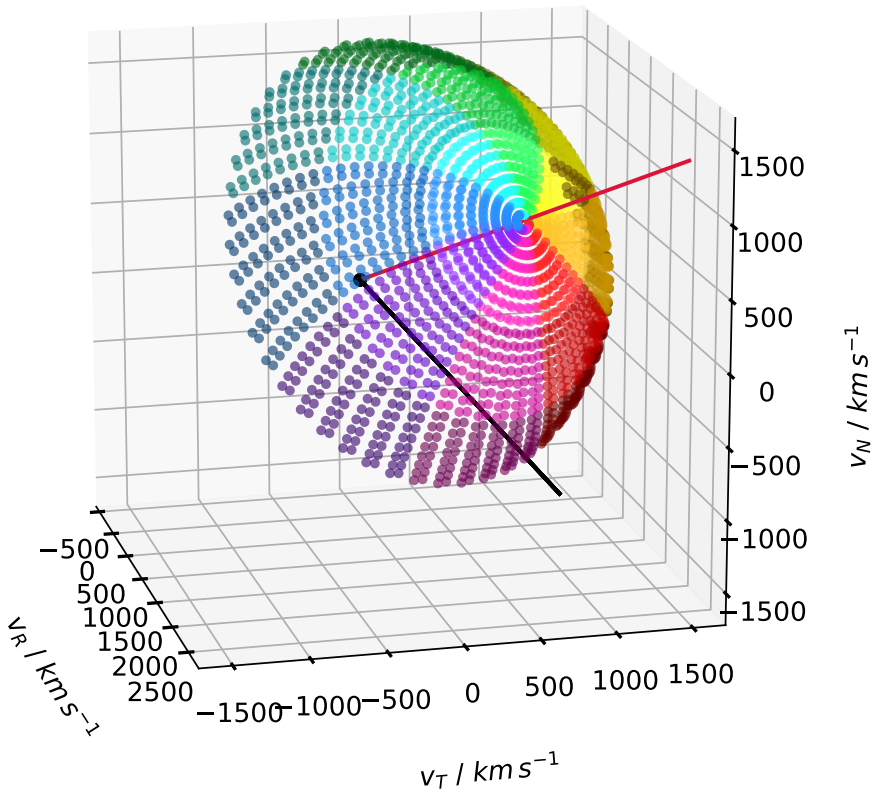
Aspect Angle

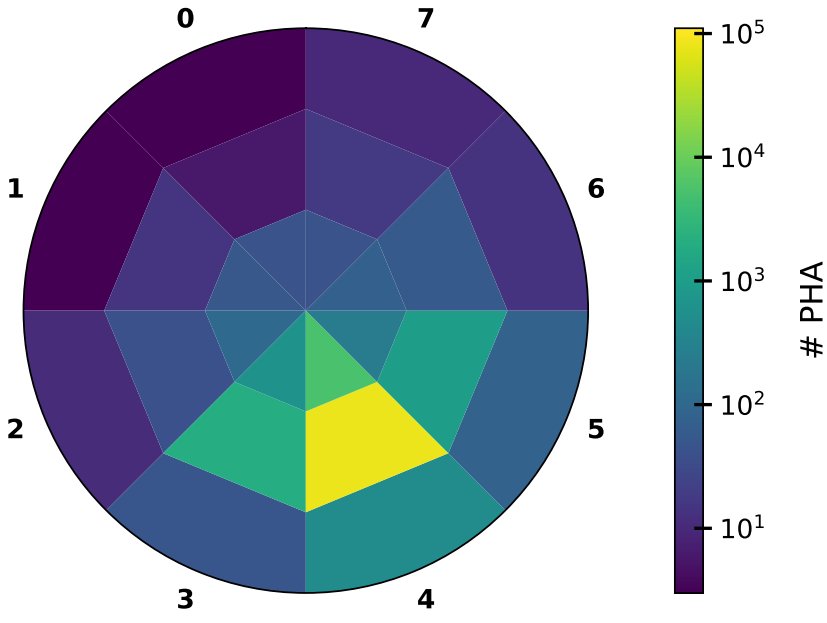


Aspect Angle



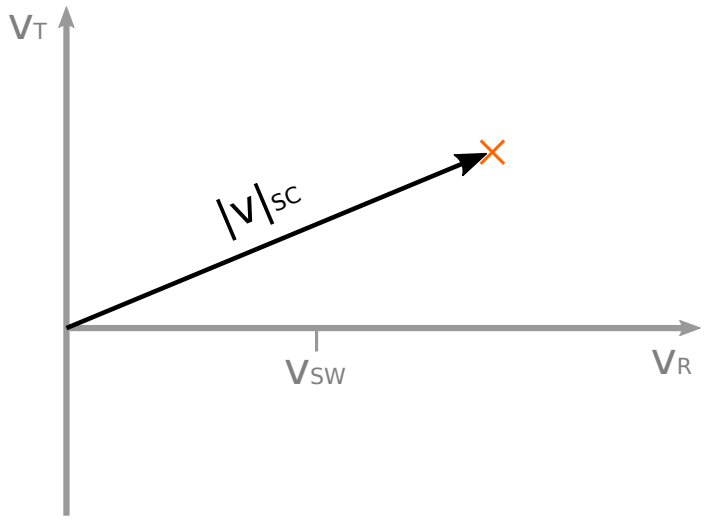
Aspect Angle

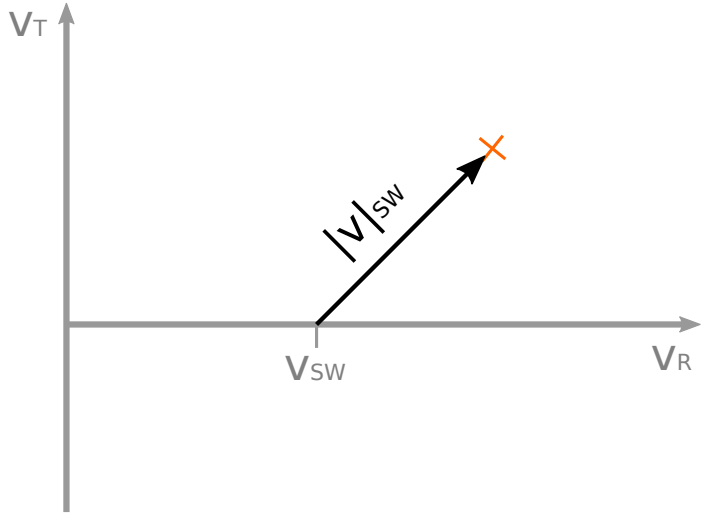


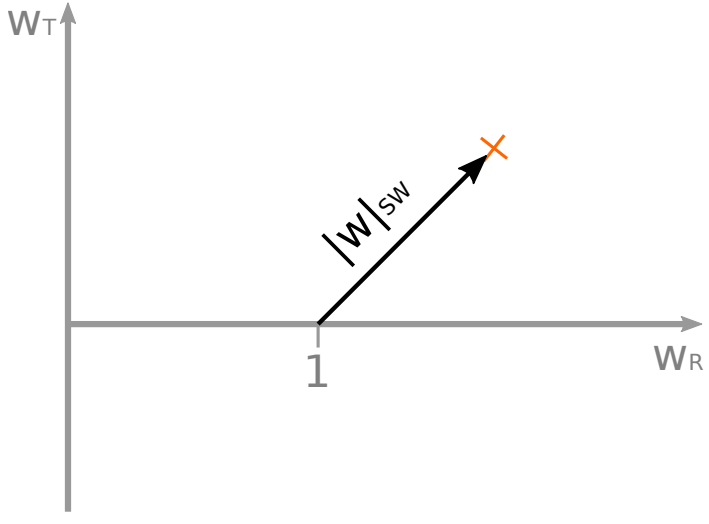


$\Rightarrow$ Plausibility check with solar wind He^{2+}

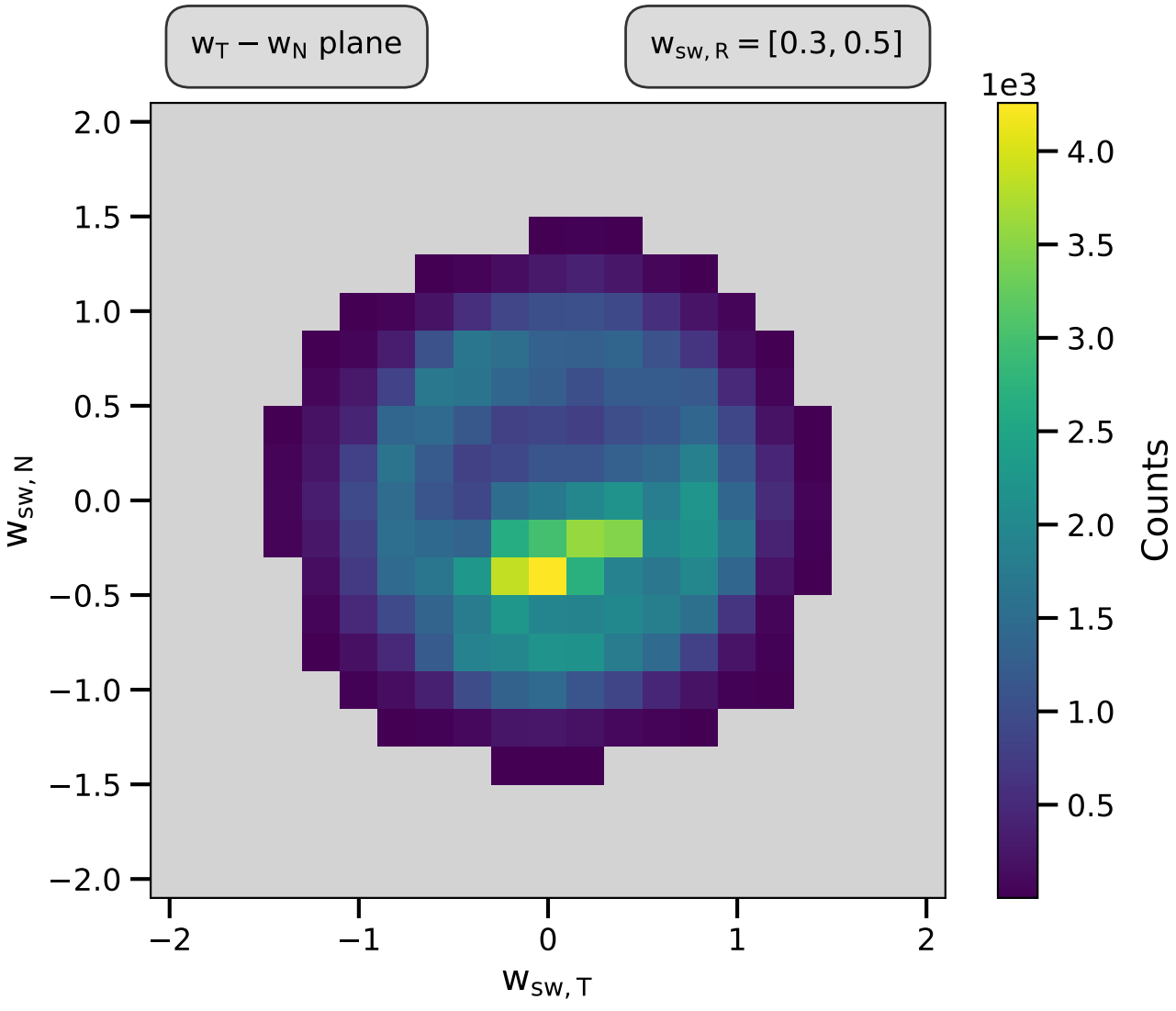
Transition



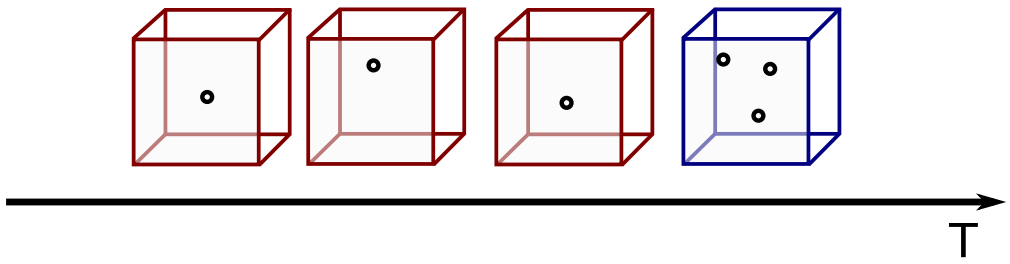




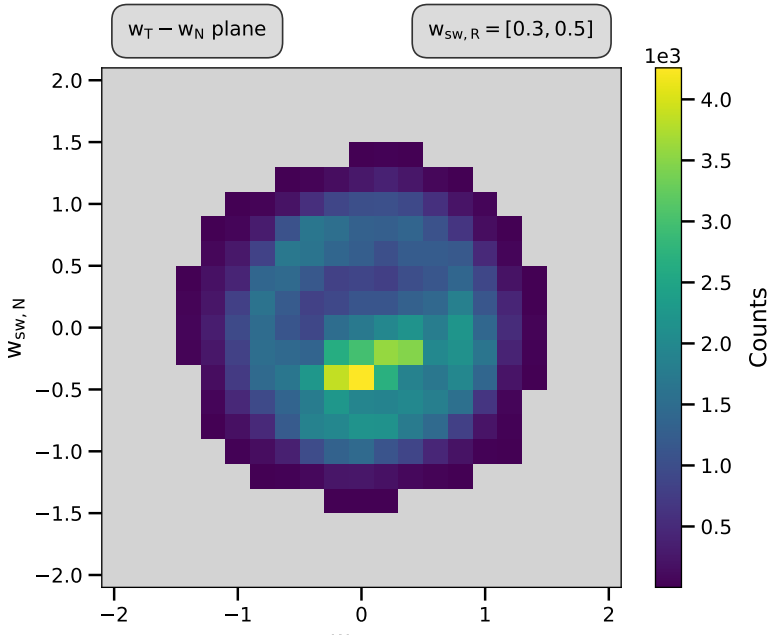
Slice Counts

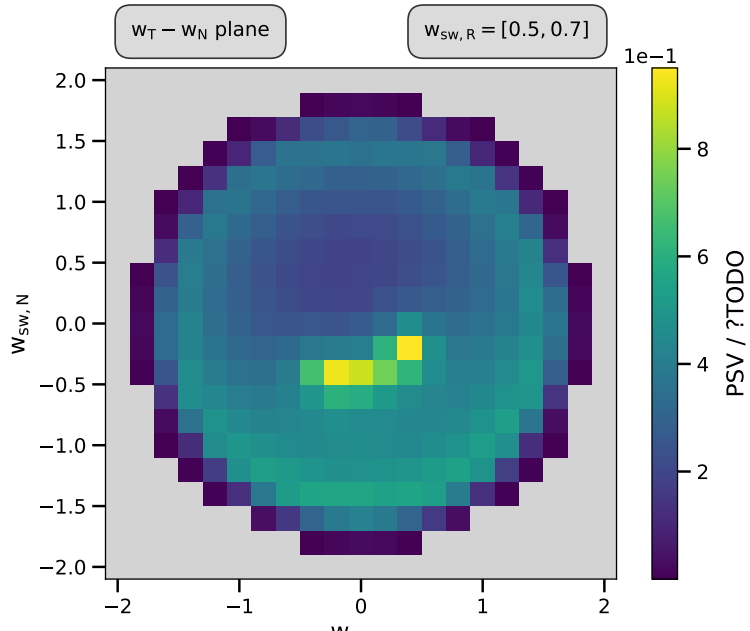


Einschub: Counts zu PSD

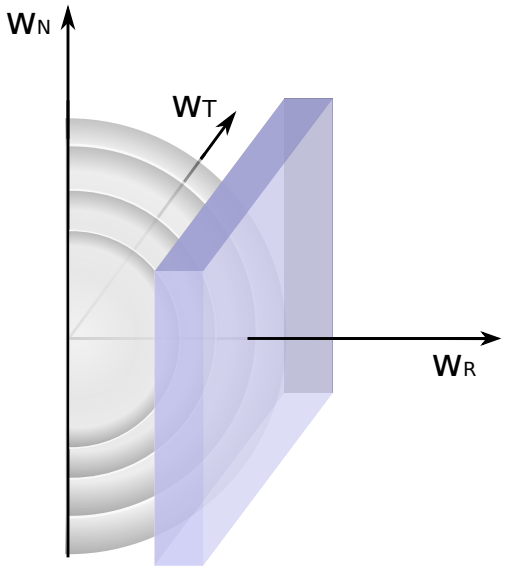


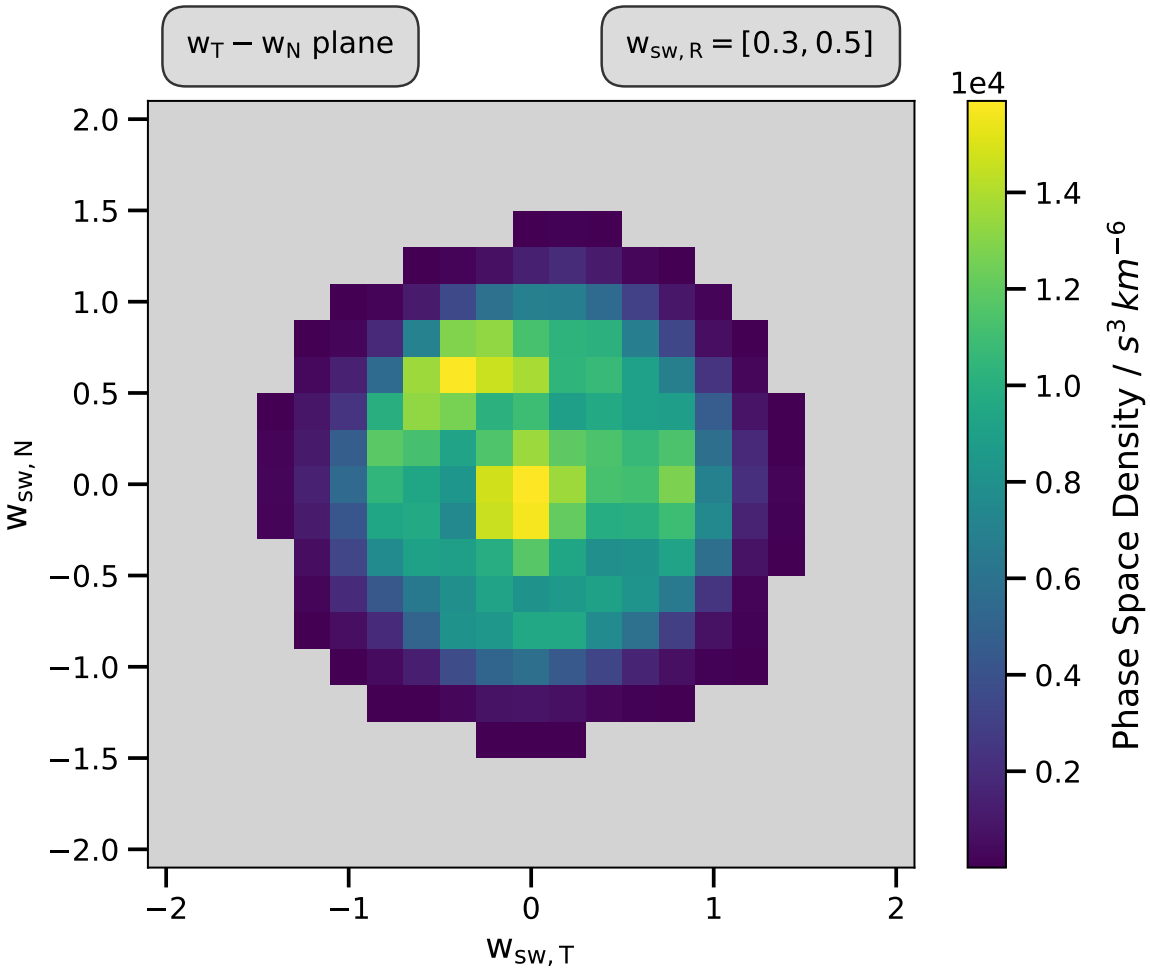
Formel PSD...



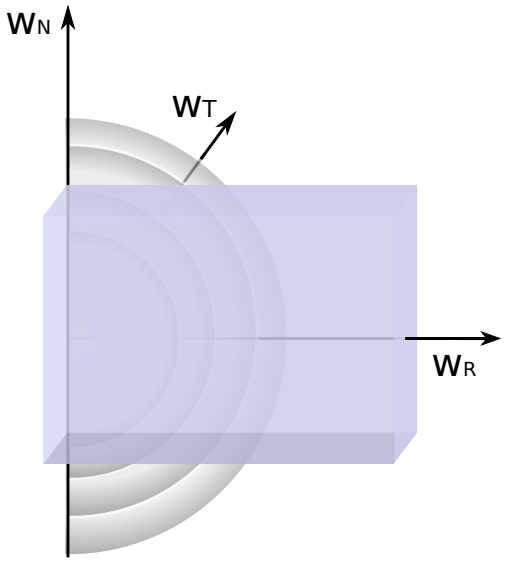


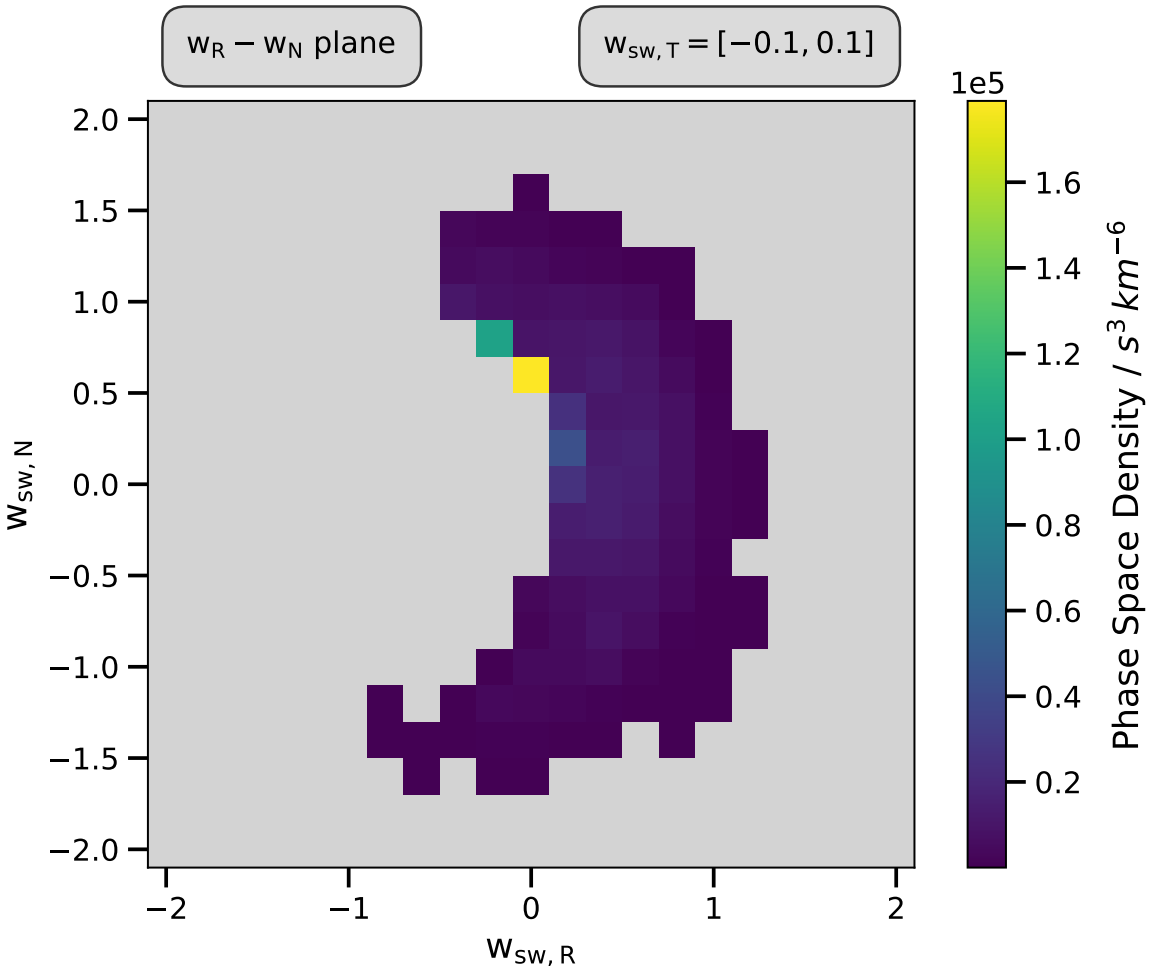
Slice PSD


w_N
w_T
w_R

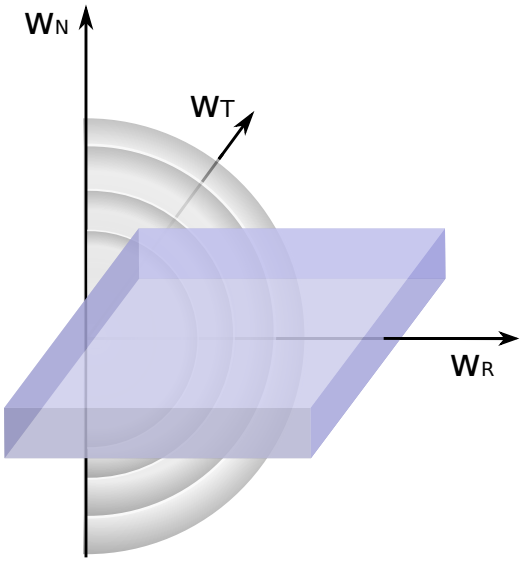

$w_T - w_N$ plane
$w_{sw,R} = [0.3, 0.5]$
1e4
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
$w_{sw,N}$
−2
−1
0
1
2
$w_{sw,T}$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Phase Space Density / $s^3\,km^{-6}$

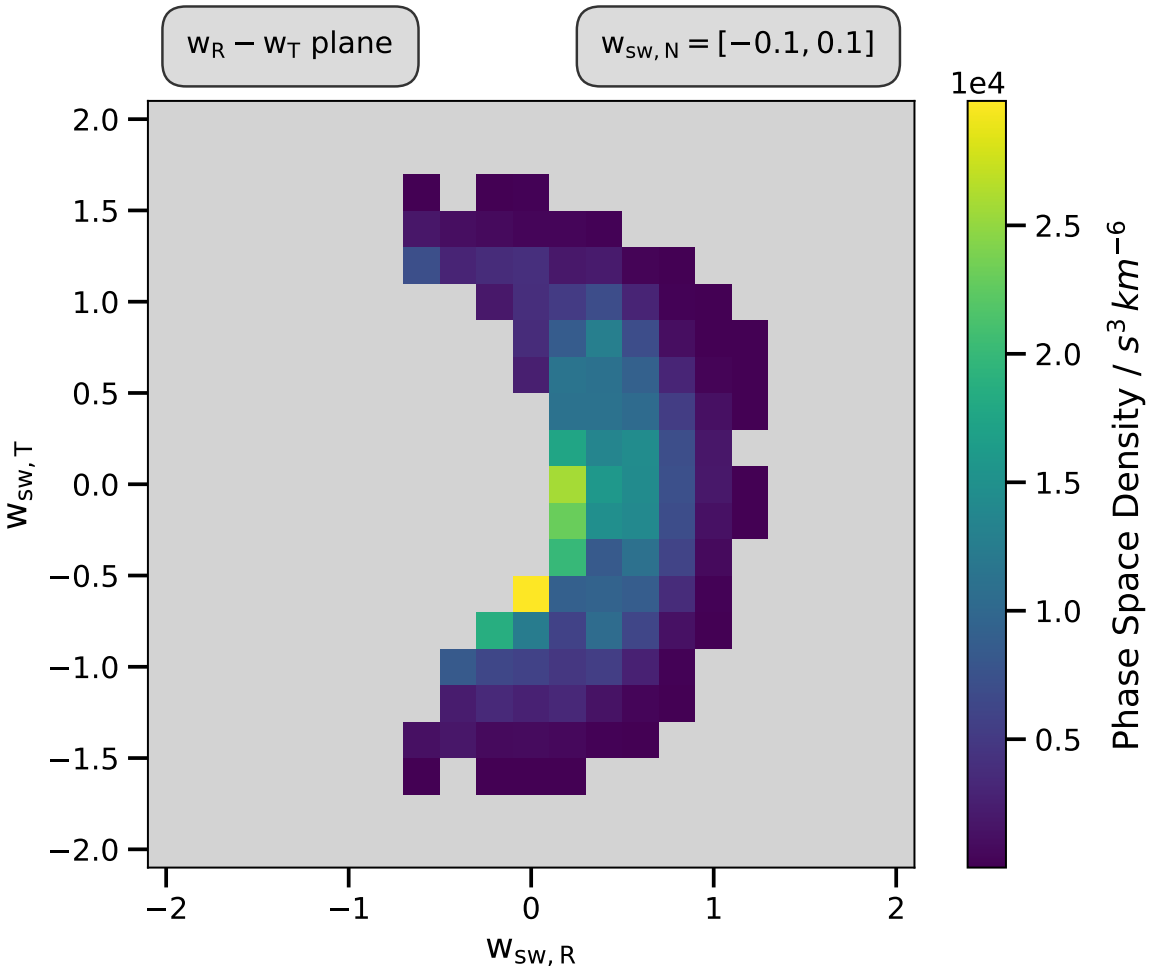
Slice PSD


w_N
w_T
w_R

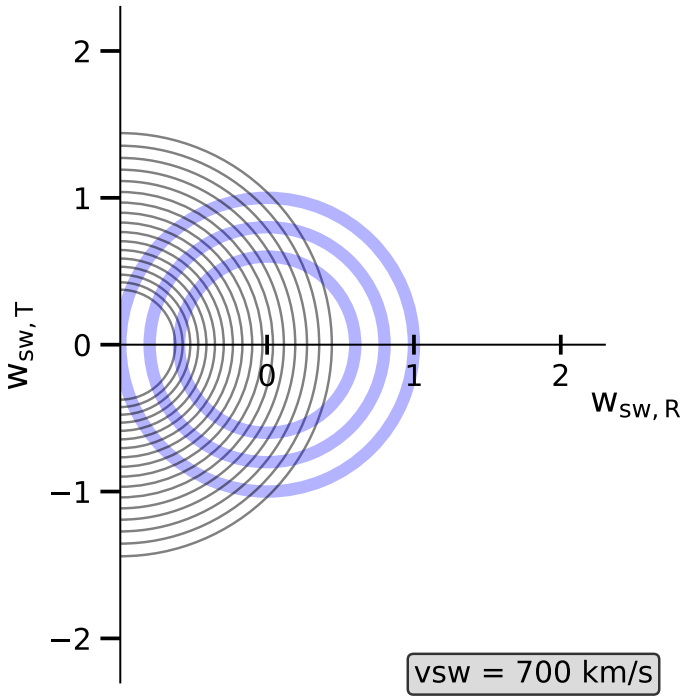

$w_R - w_N$ plane
$w_{sw,T} = [-0.1, 0.1]$
1e5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
$w_{sw,N}$
−2
−1
0
1
2
$w_{sw,R}$
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Phase Space Density / $s^3\,km^{-6}$

Slice PSD

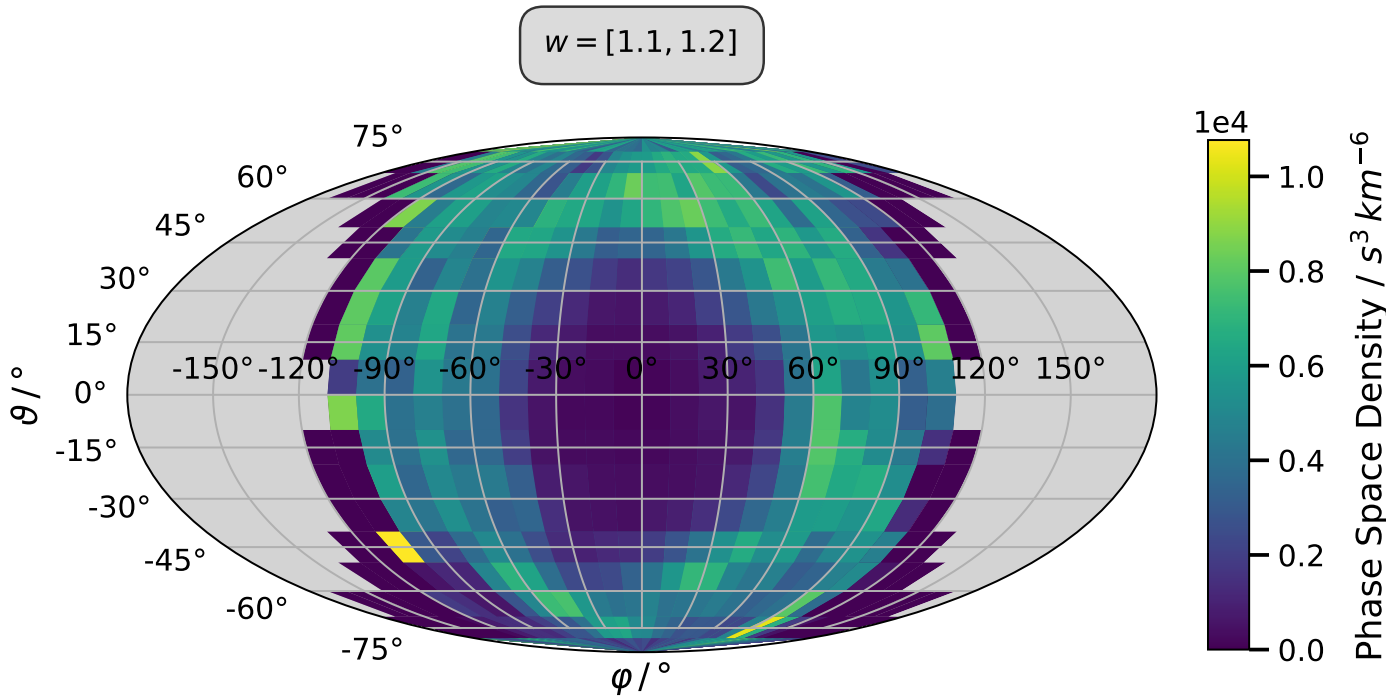

w_N
w_T
w_R


$w_R - w_T$ plane
$w_{sw,N} = [-0.1, 0.1]$
1e4
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
$w_{sw,T}$
−2
−1
0
1
2
$w_{sw,R}$
2.5
2.0
1.5
1.0
0.5
Phase Space Density / $s^3\,km^{-6}$

Coverage



Skymap


$w = [1.1, 1.2]$
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
ϑ / °
-150° -120° -90° -60° -30° 0° 30° 60° 90° 120° 150°
φ / °
1e4
1.0
0.8
0.6
0.4
0.2
0.0
Phase Space Density / $s^3\,km^{-6}$

Skymap

1D

Conclusion

BACKUP