Velocity Distribution Functions of Pickup Ions with Ulysses/SWICS

Master Thesis Results

Anne Fischer

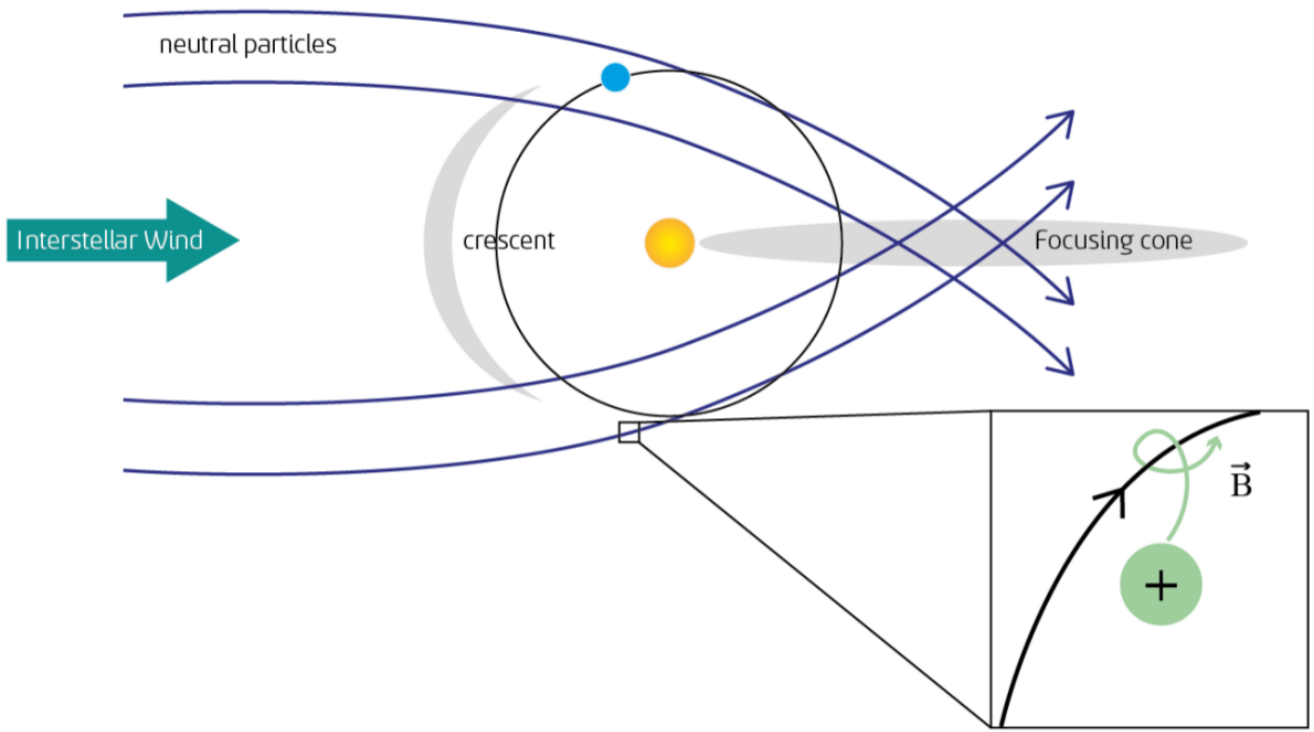
November 21, 2019

Outline

The Pickup Process

Pickup Ions:

Former neutrals that get ionised within the heliosphere



Taut, Drews et al., AGU fall meeting 2014

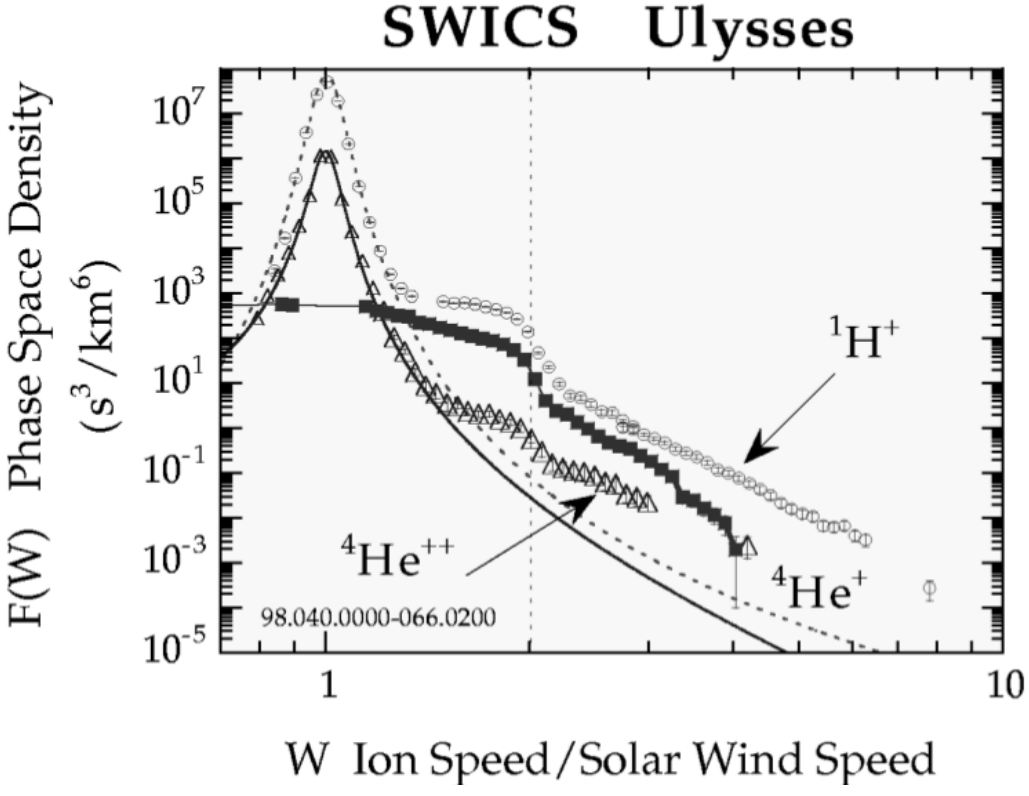
PUI – Measurement

Observed PUIs:

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

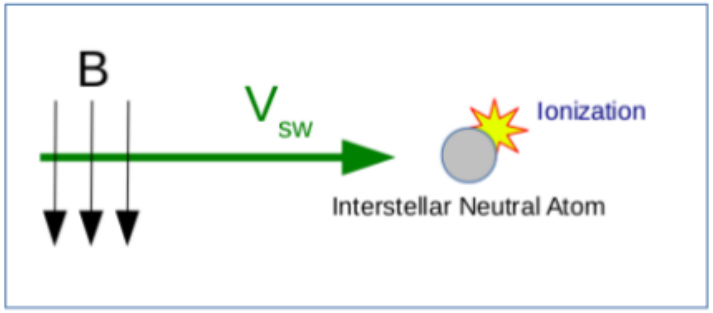
PUI or Solar Wind?

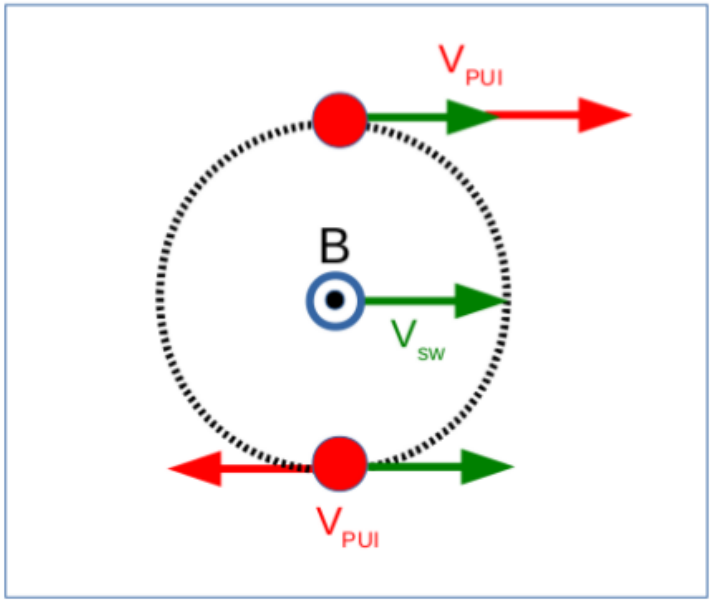
- Charge state
- Velocity distribution function (VDF)



Gloeckler et al., 1999

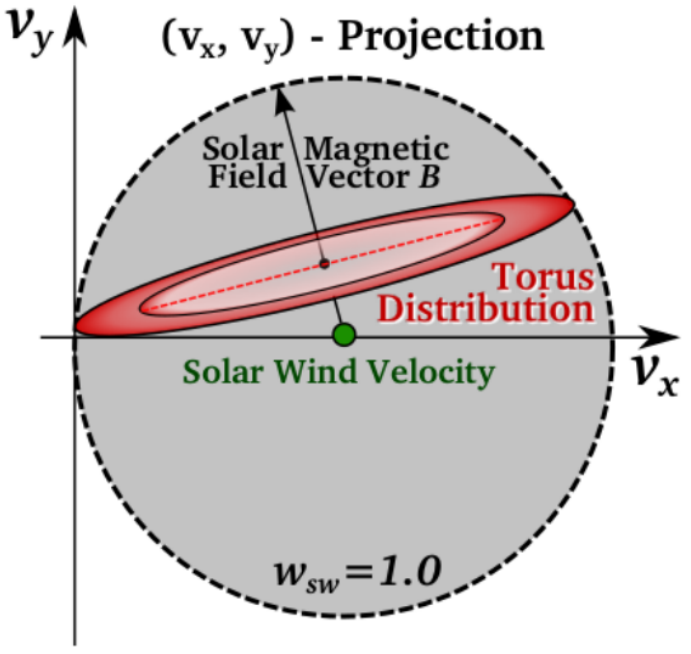
The Pickup Process





Taut, Drews et al., AGU Fall Meeting 2014

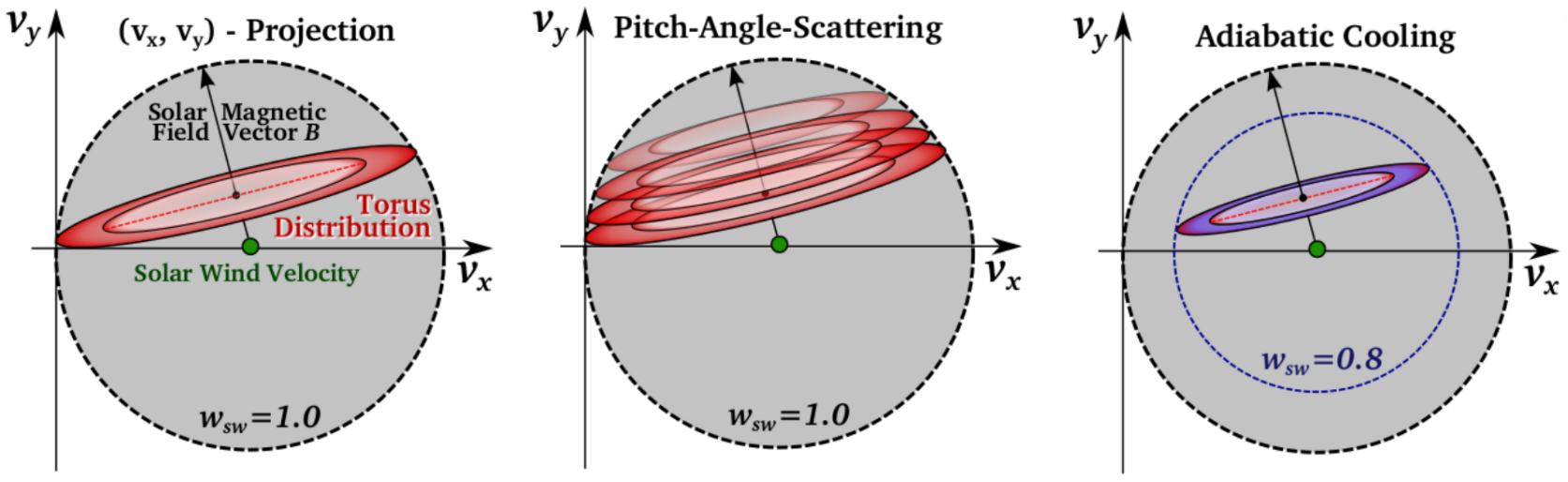
Velocity Space:



Drews et al., 2016

→ **Anisotropic torus VDF**

Evolution of the VDF

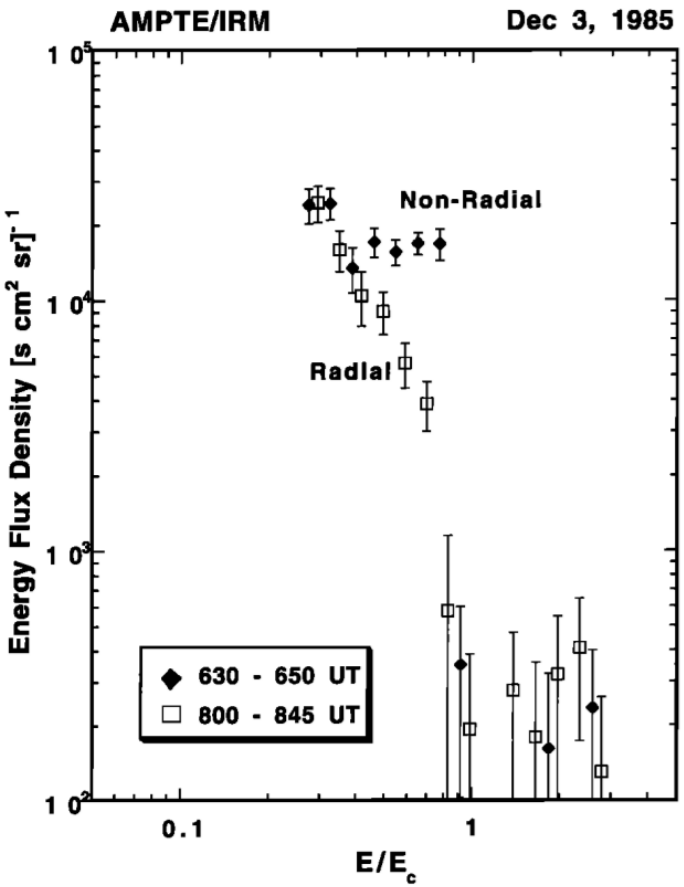


Drews, Berger et al., 2016

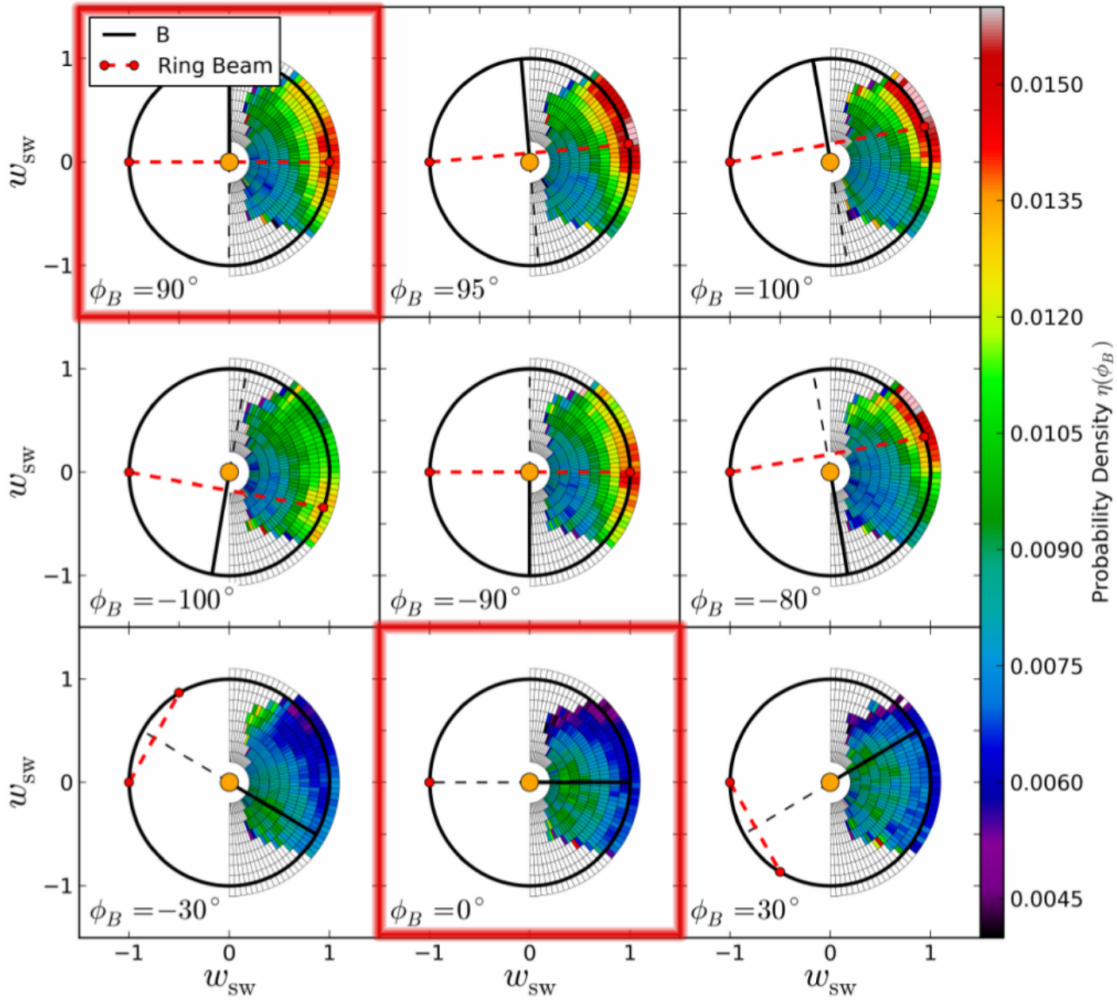
Modification of the initial torus-shaped VDF by:

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

Anisotropic features of the VDF



Moebius et al., 1998

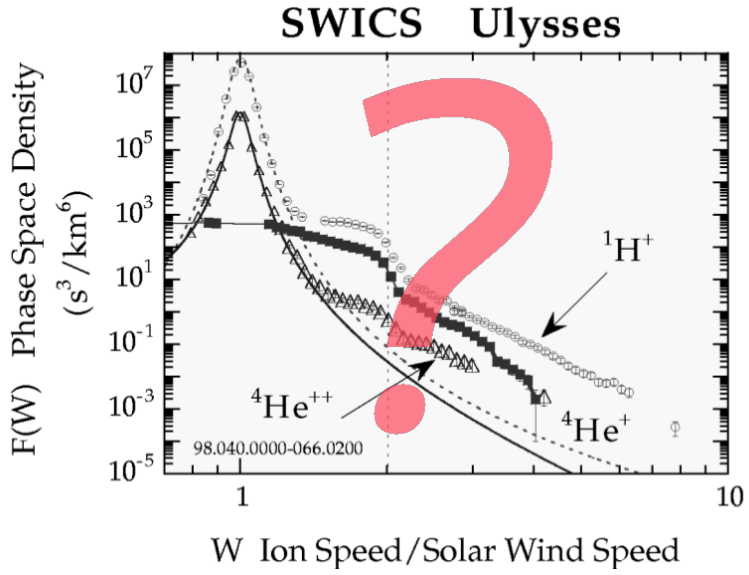


Drews, Berger et al., 2015

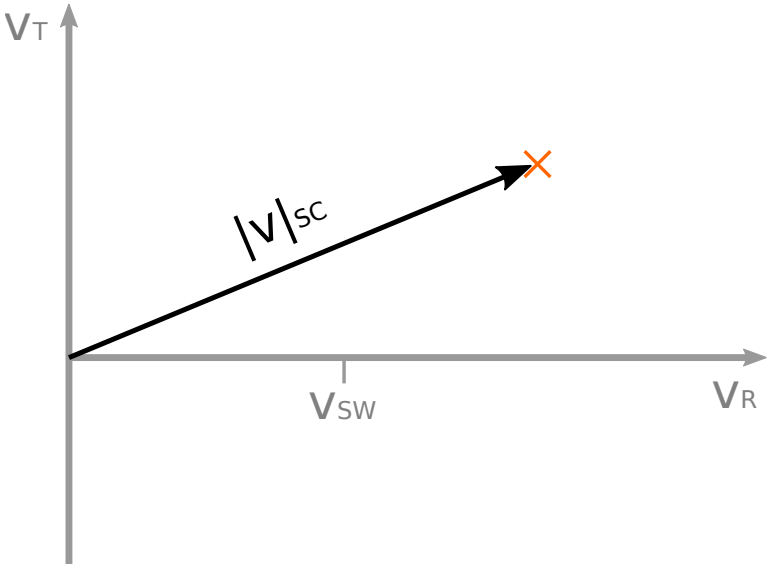
Motivation

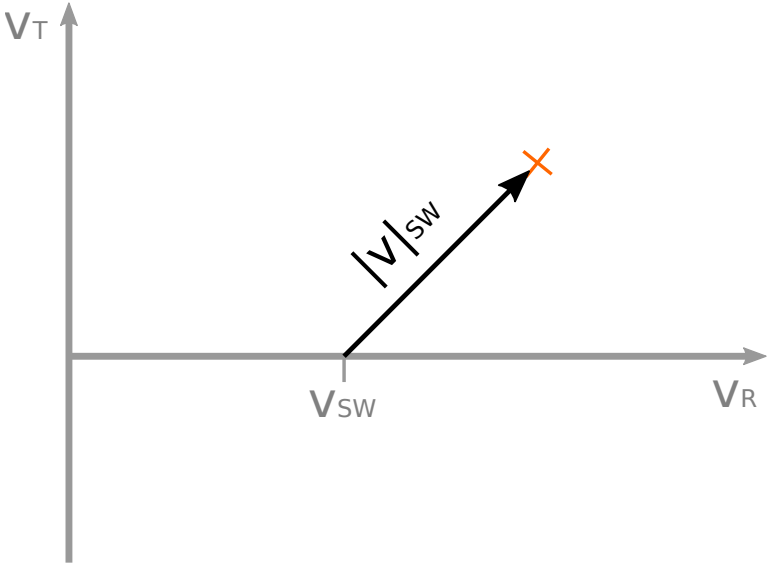
Problem:
Ambiguity of 1D reduced data

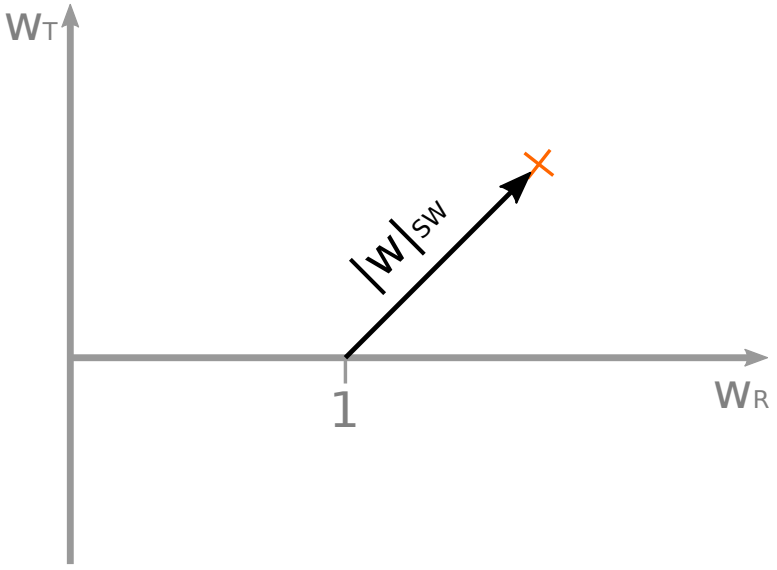
For fully understanding the PUI transport in phase space we need to analyse the **3D velocity distribution** function



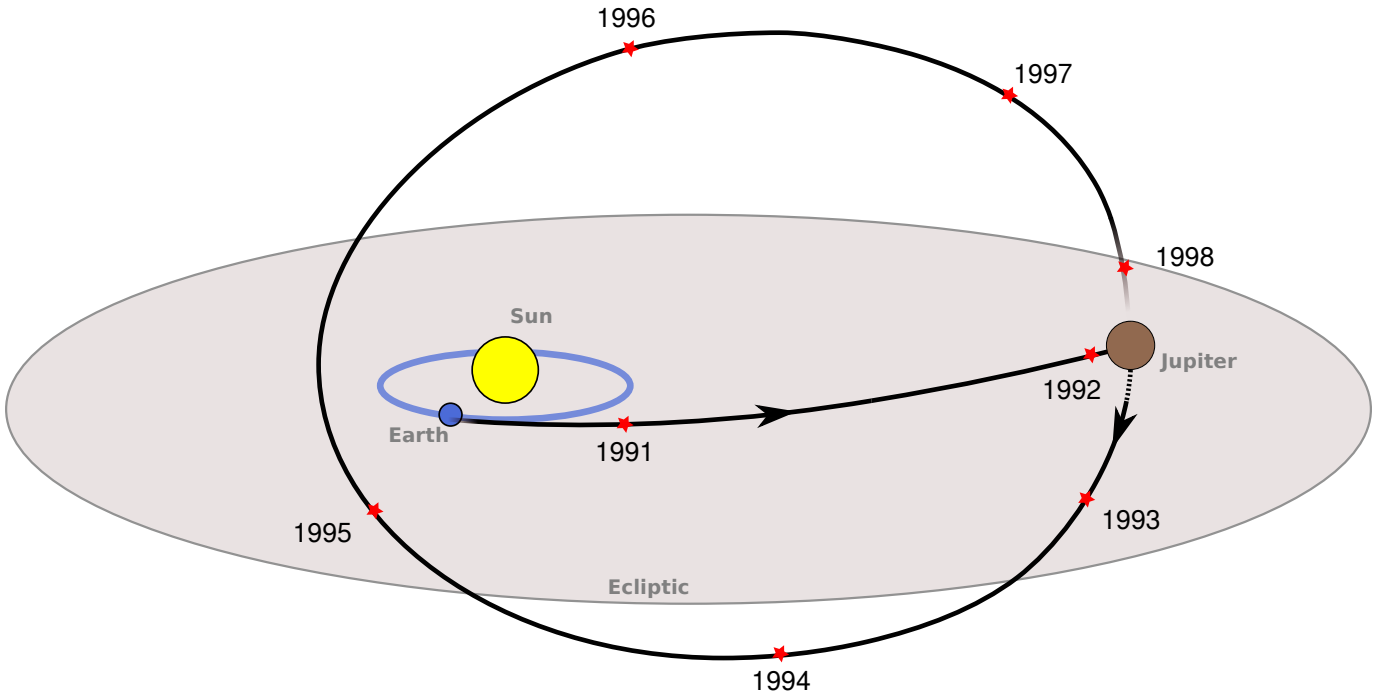
Frame of Reference





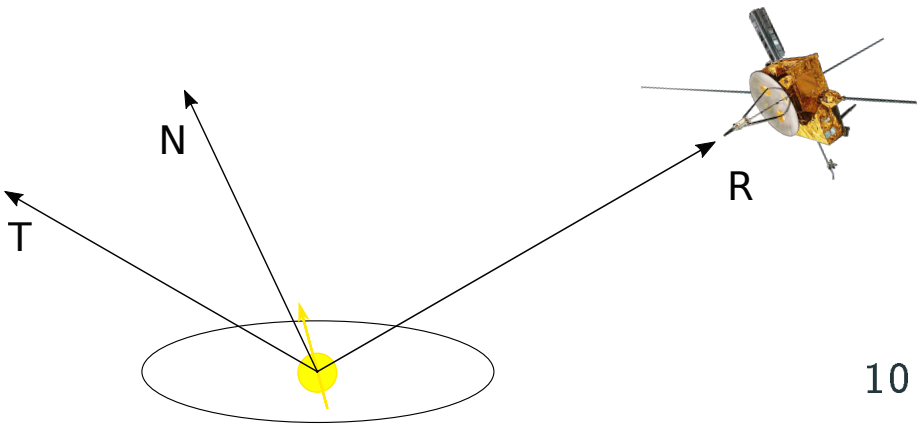


Ulysses Spacecraft (1990 – 2009)



adapted from www.cosmos.esa.int, 2019

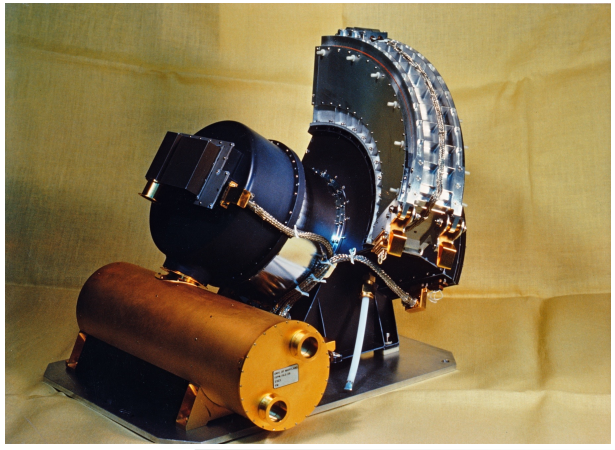
- Highly inclined orbit;
  orbital period: 6.2 years
- spin-stabilized

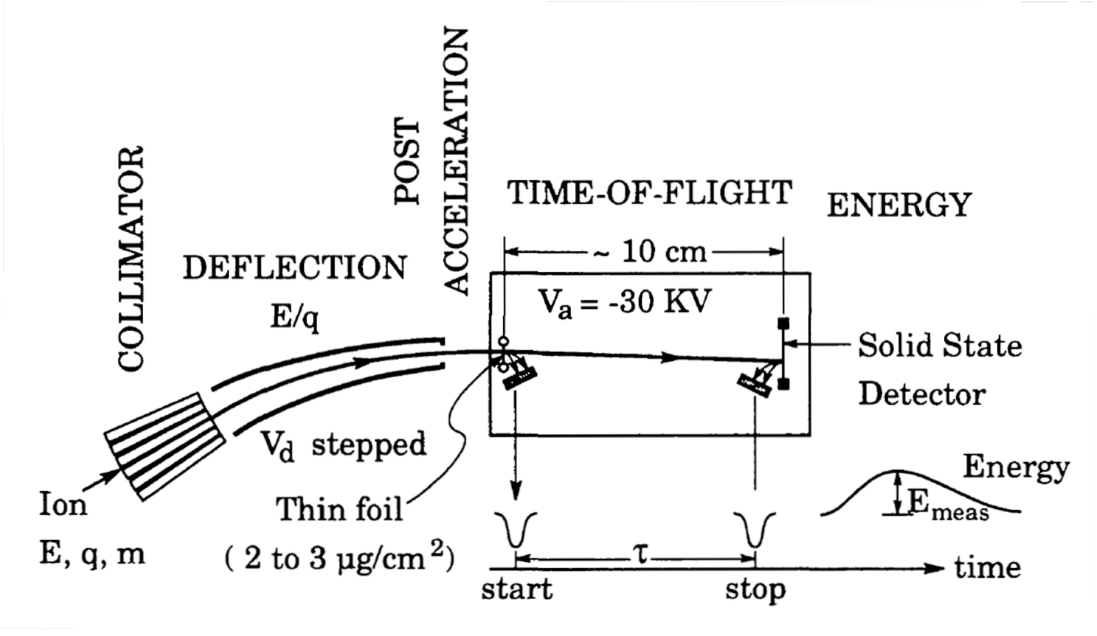


SWICS

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

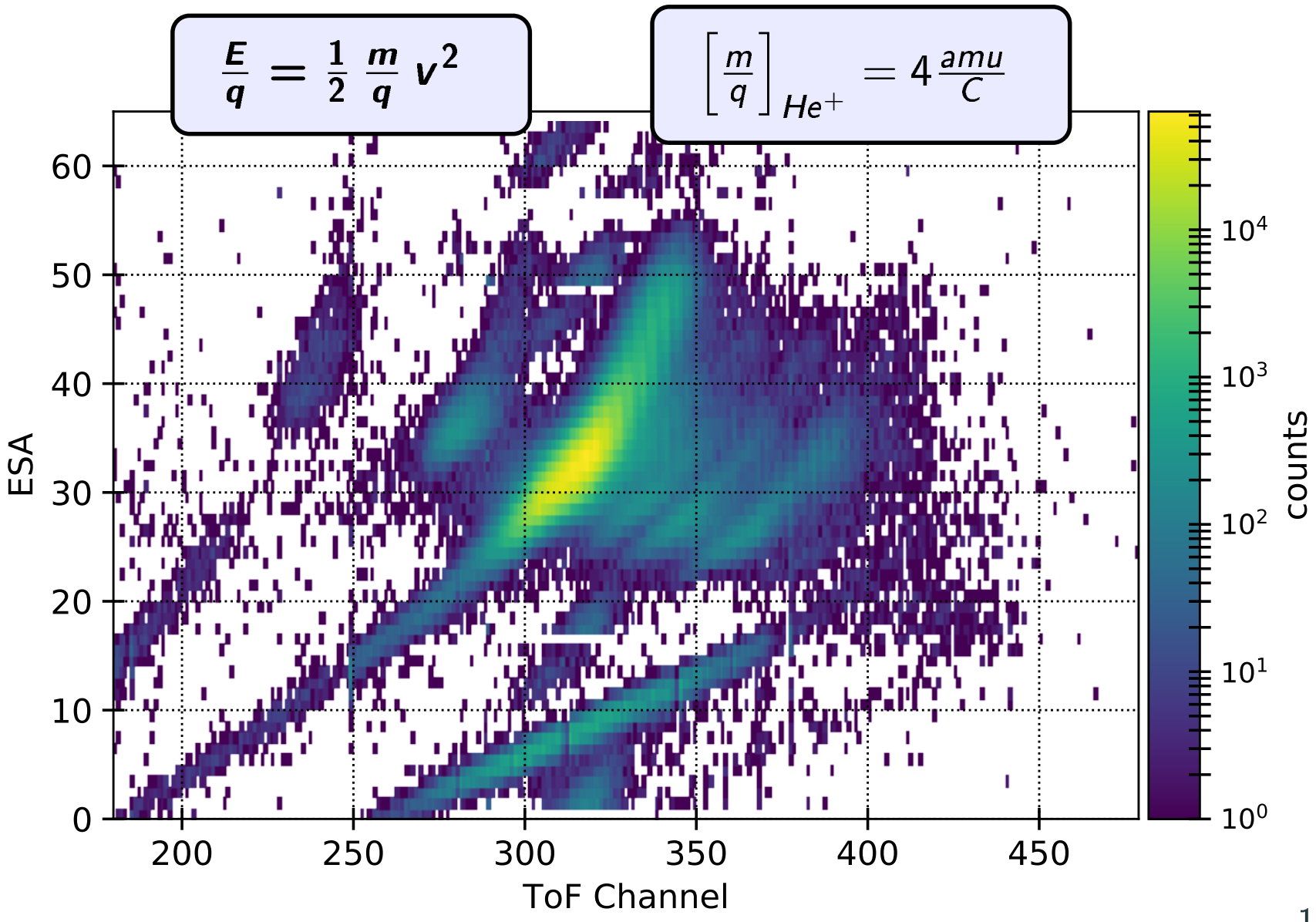
- Time-of-flight mass spectrometer
- $\left\{\frac{E}{q}, ToF, E_{SSD}\right\}$ $\Rightarrow \left\{\frac{M}{q}, M, |v|\right\}$
- identification & energy of the ion



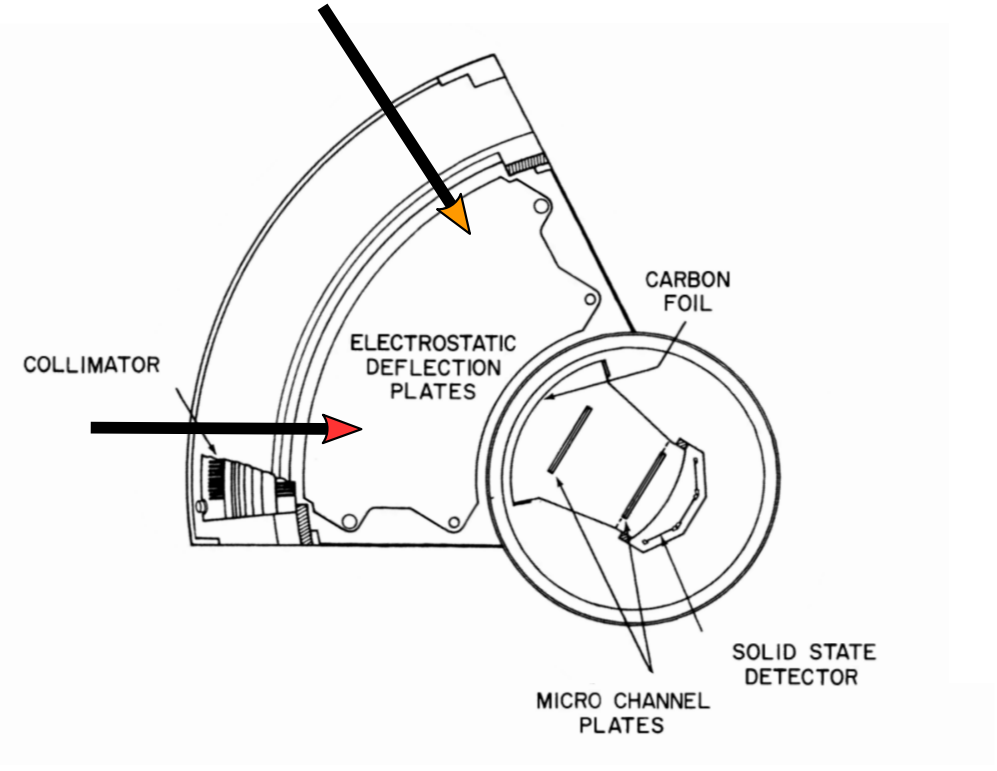


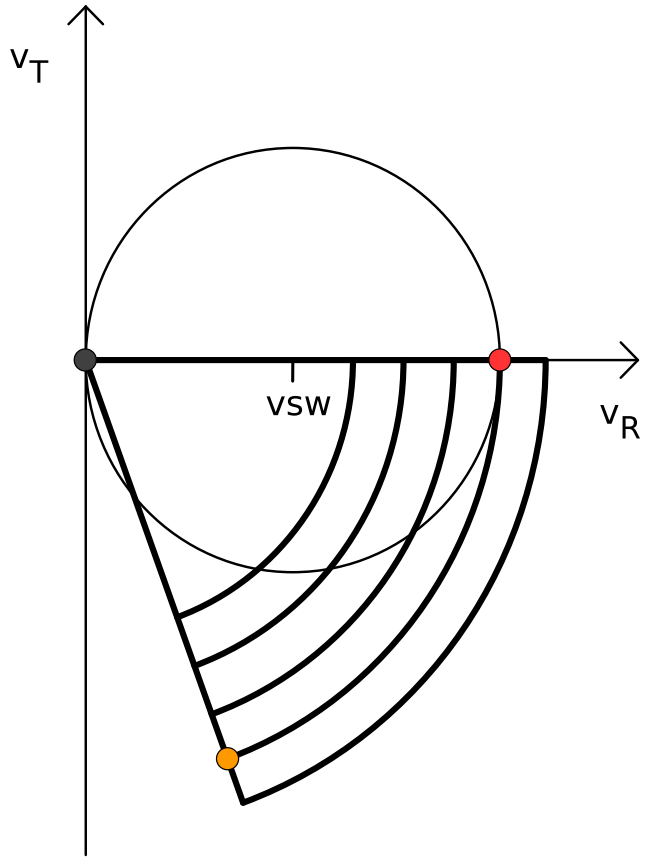
Gloeckler, Geiss et al., 1992

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

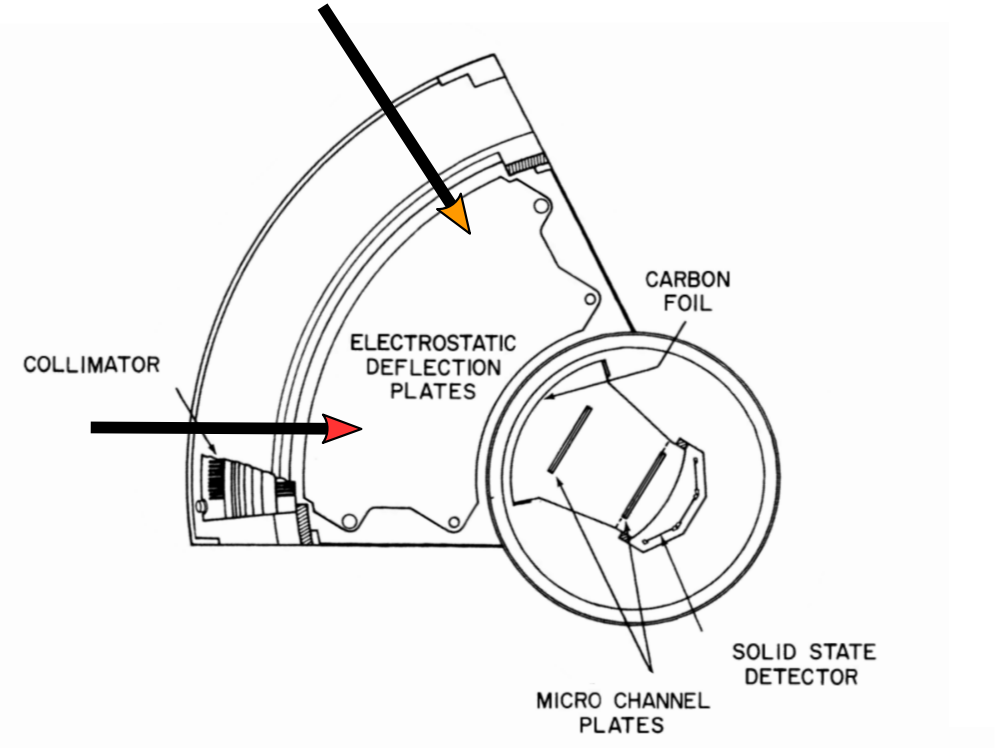
EpQ measurement

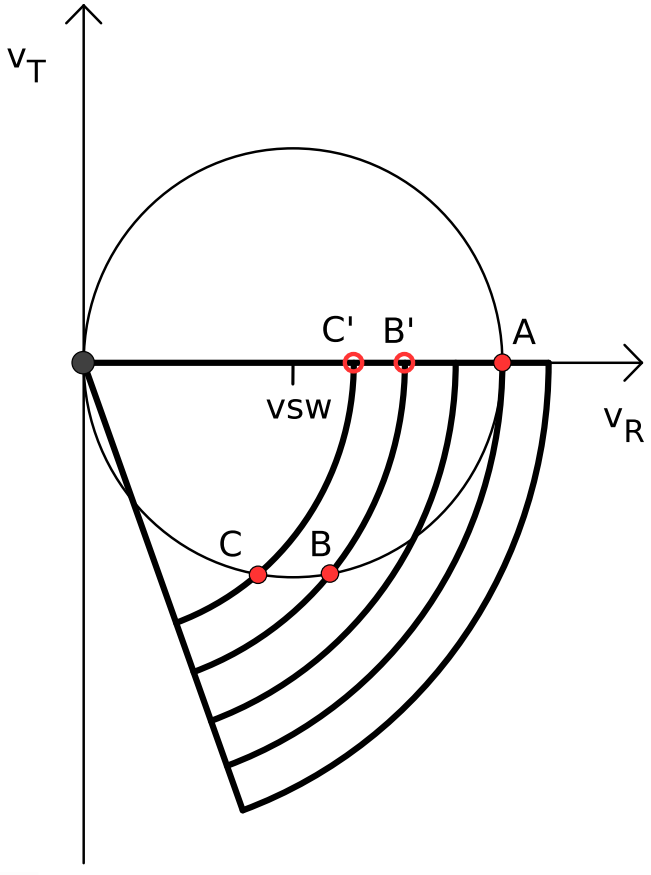




- For constant $\frac{m}{q}$: $\frac{E}{q}$-step $\widehat{=}$ absolute value of velocity
- Integration over EpQ shells $\rightarrow$ loss of information!

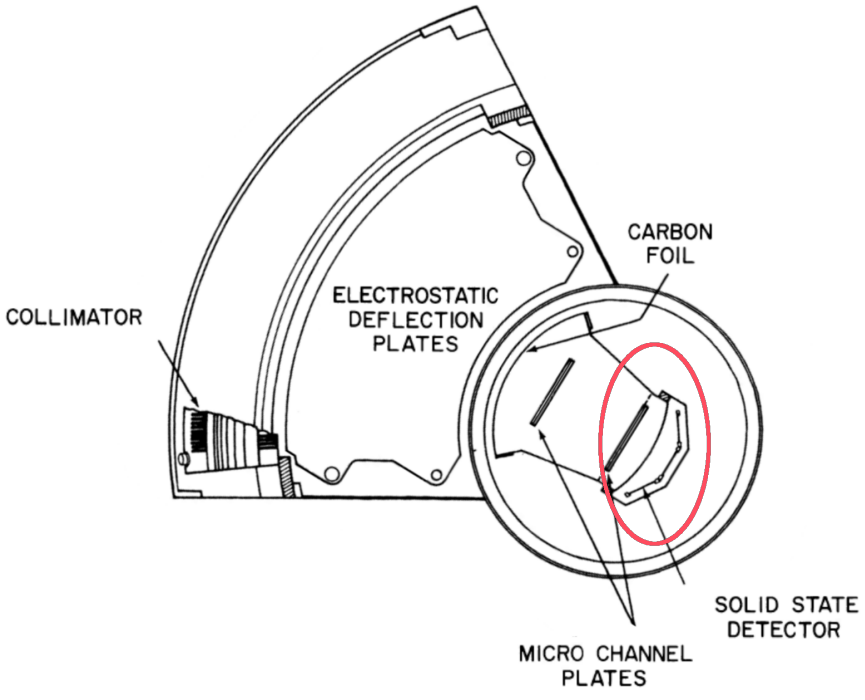
EpQ measurement

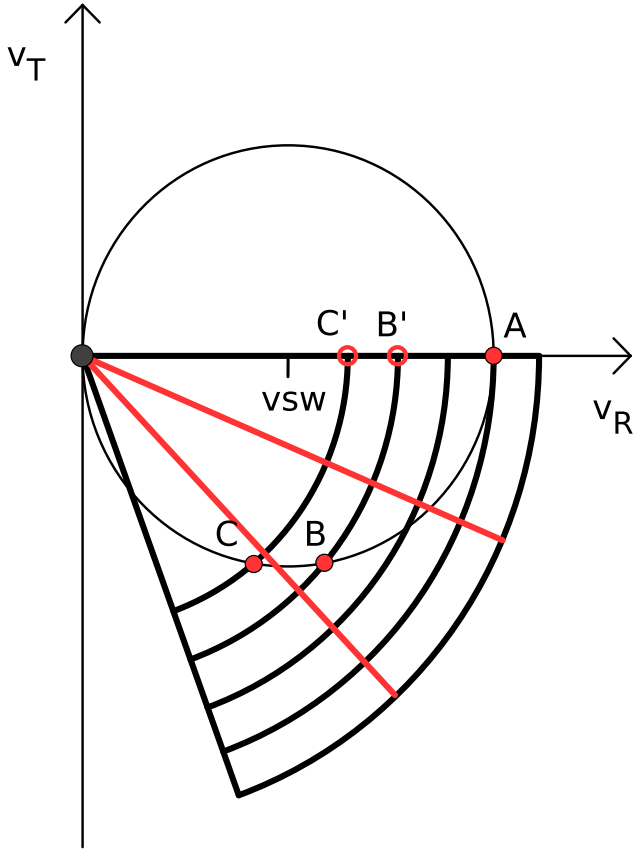




- For constant $\frac{m}{q}$: $\frac{E}{q}$-step $\widehat{=}$ absolute value of velocity
- Integration over EpQ shells $\rightarrow$ loss of information!

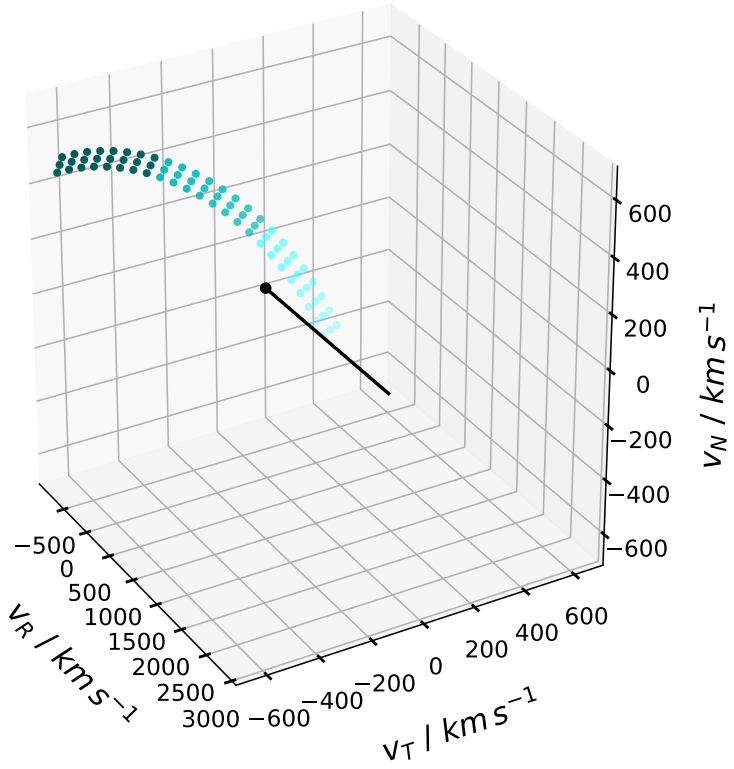
Angular resolution



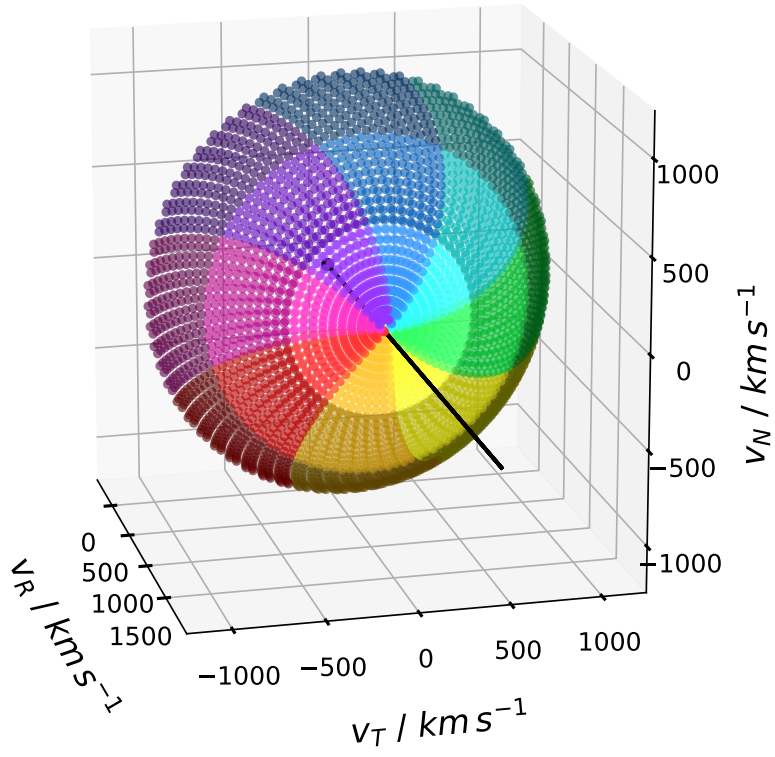


- SWICS: **3 detectors**
  Rough distinction between angles of incidence
- 3rd dimension: spin of the SC
  Divided into **8 sectors**

The Virtual Detector

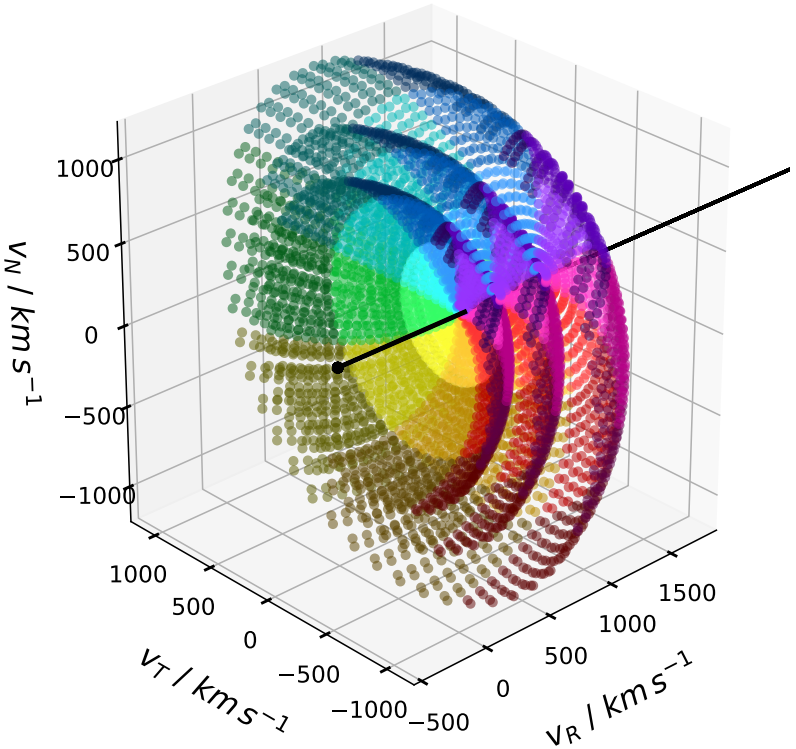


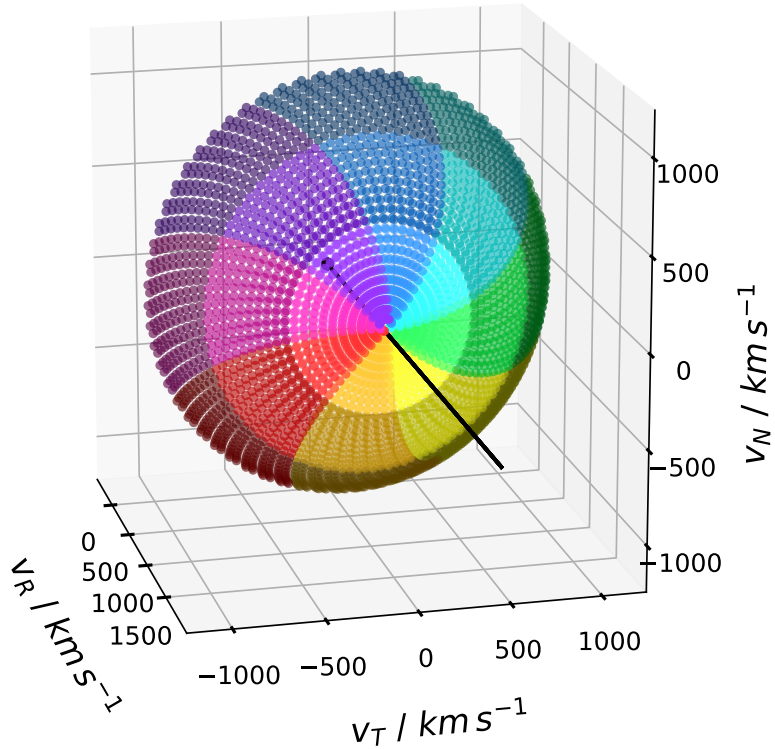
Unrotated collimator acceptance for one EpQ step



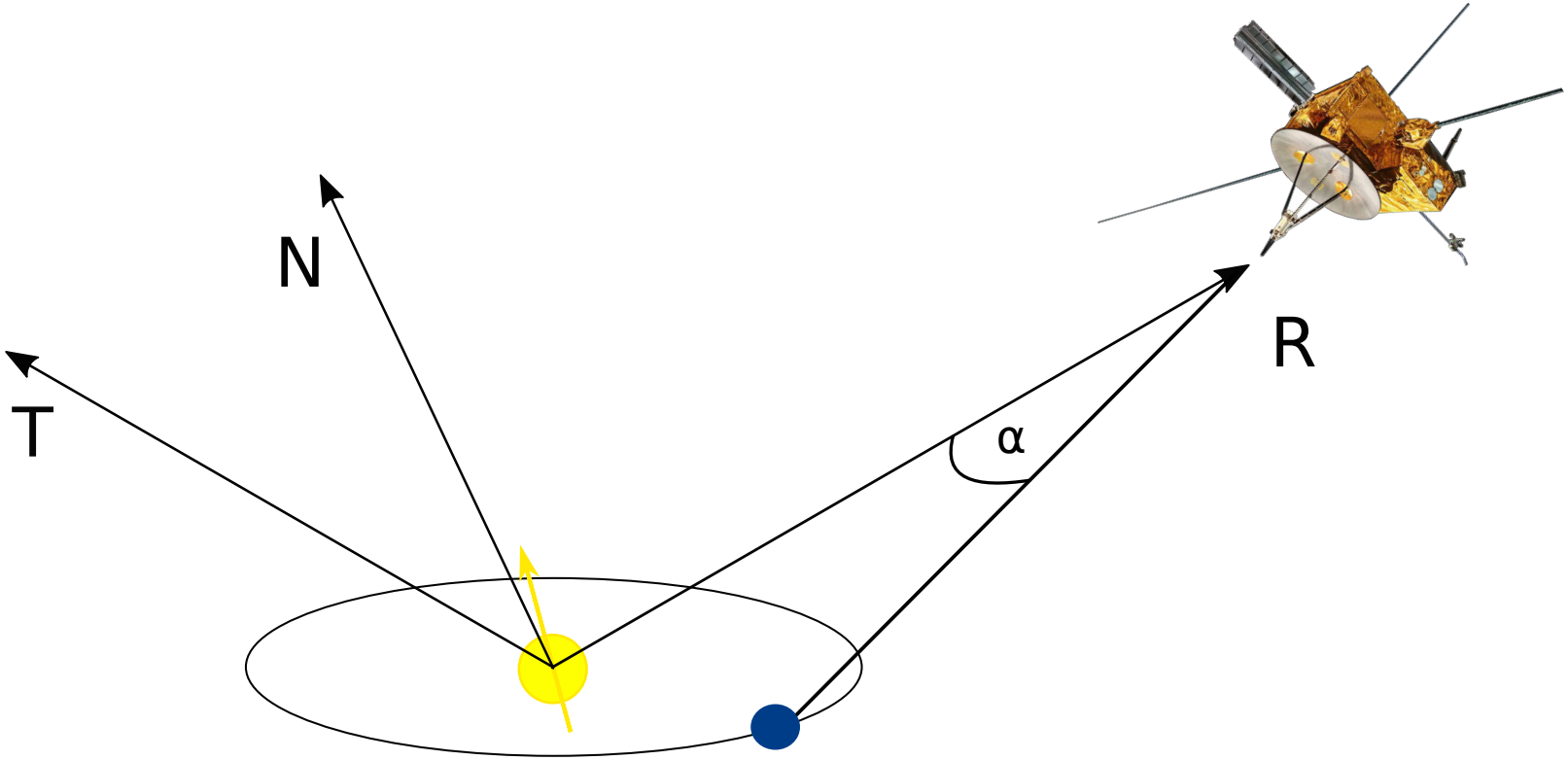
Collimator Acceptance for one spacecraft spin and one EpQ step

The Virtual Detector

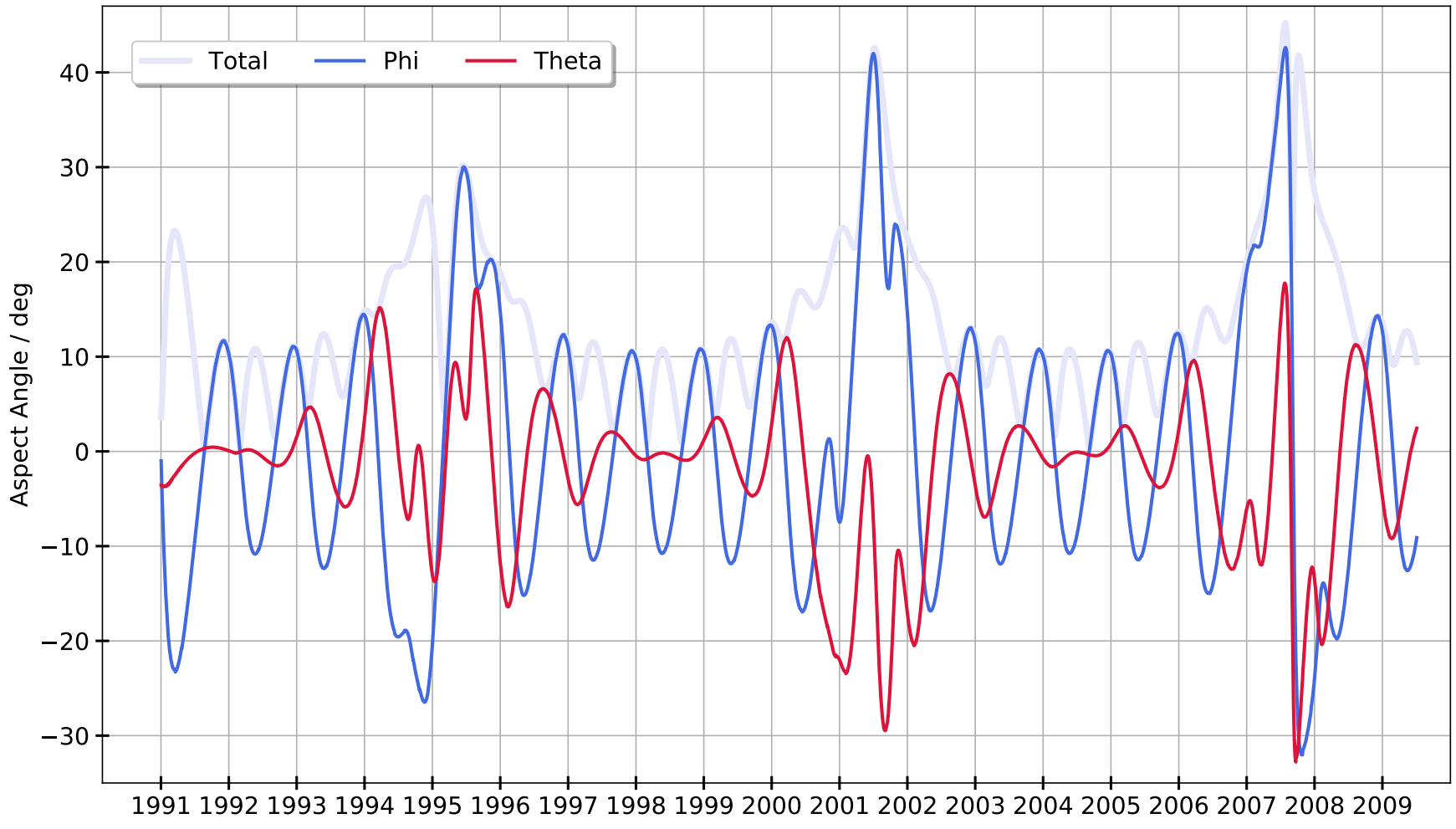




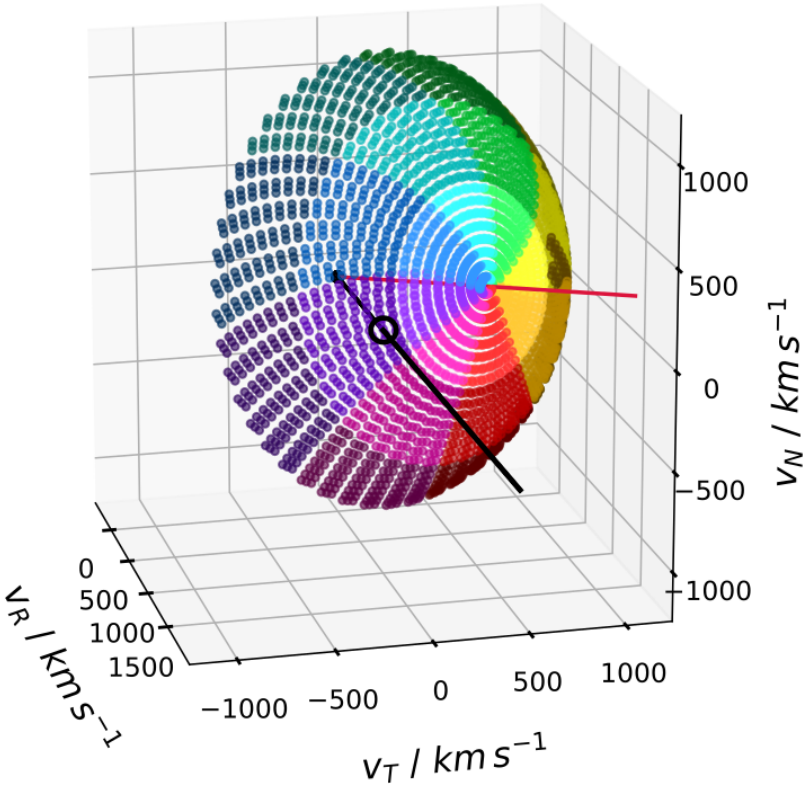
Aspect Angle



Aspect Angle

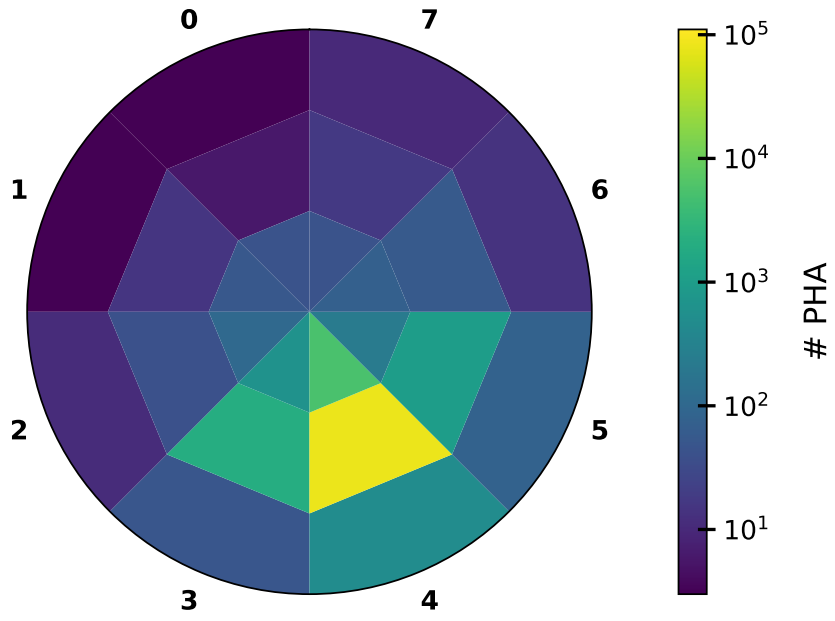


Aspect Angle



Aspect angle:

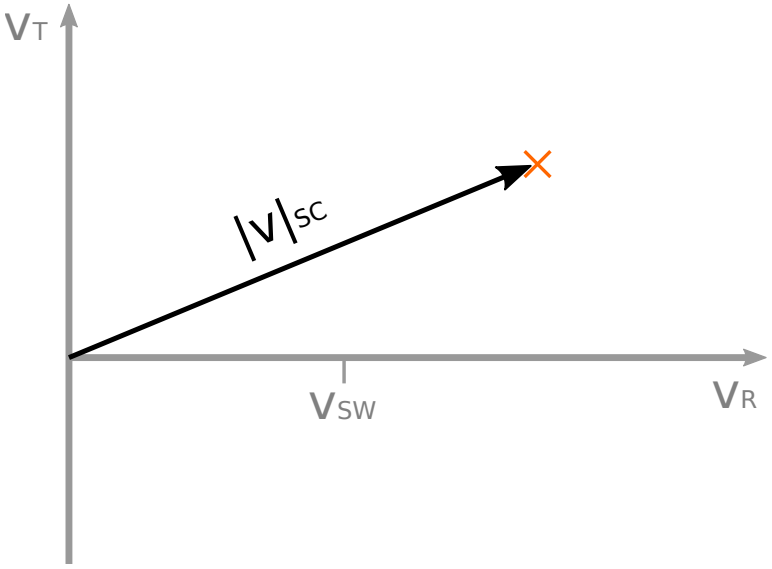
$\varphi = 25°, \vartheta = -10°$

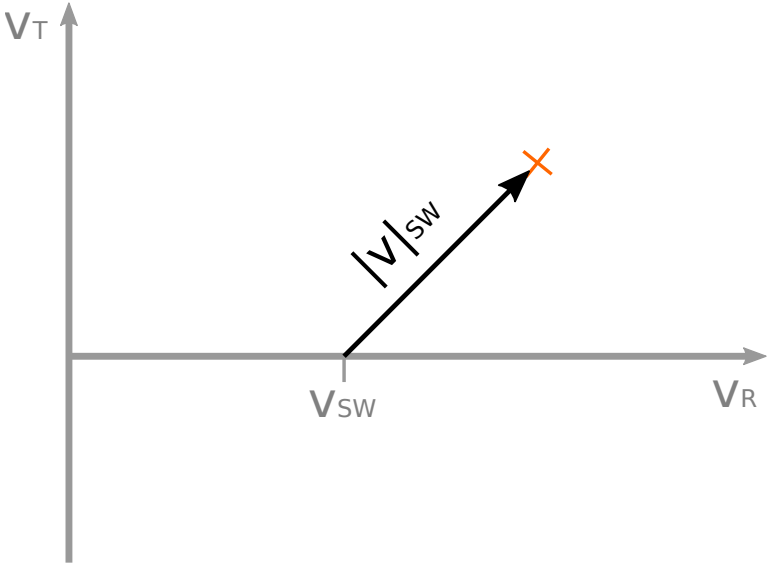


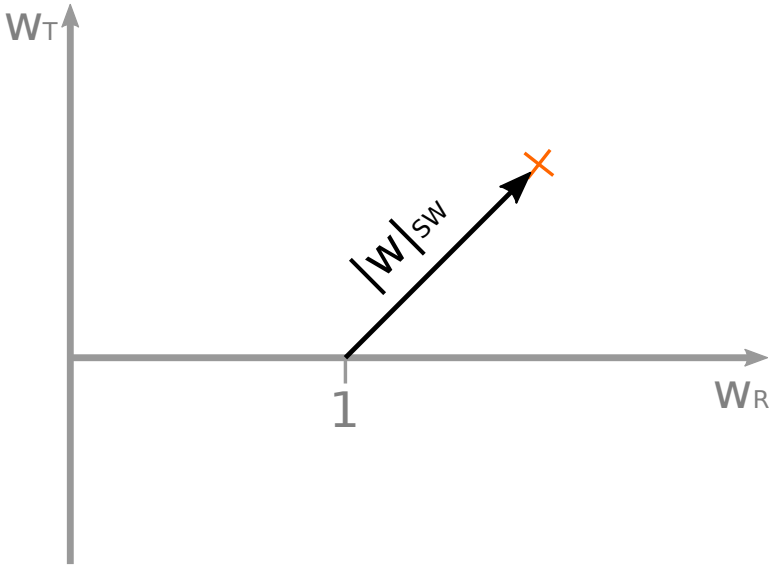
$\Rightarrow$ Plausibility check with solar wind He^{2+} PHA data

(120 days in 2001)

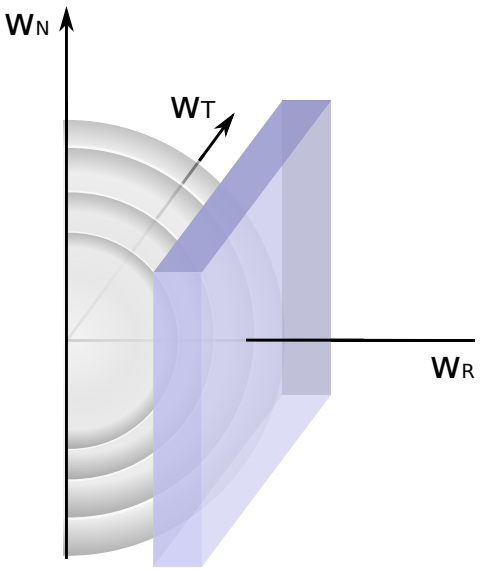
Frame of Reference







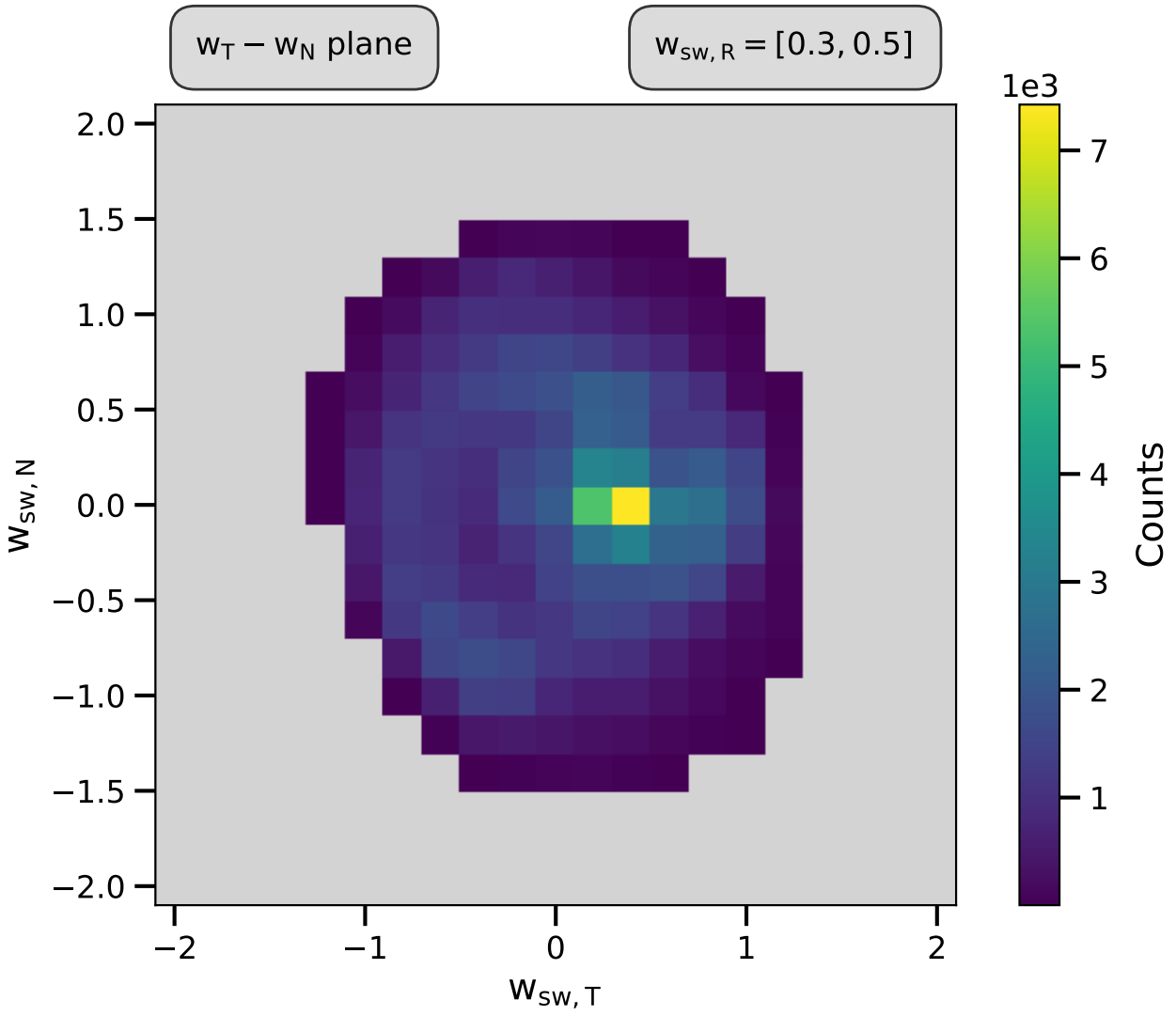
Spherical Cut through VDF



50 days in 1994

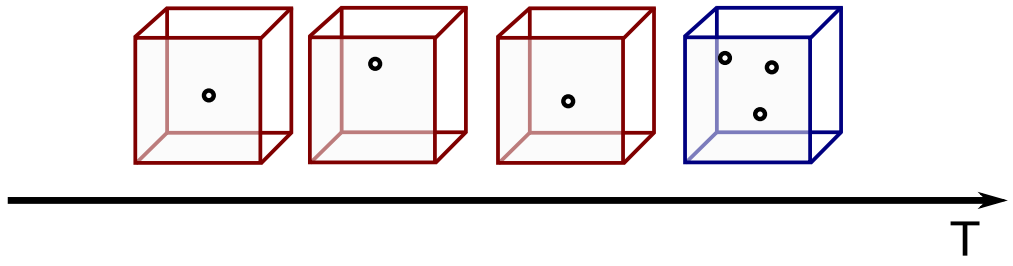
vsw :

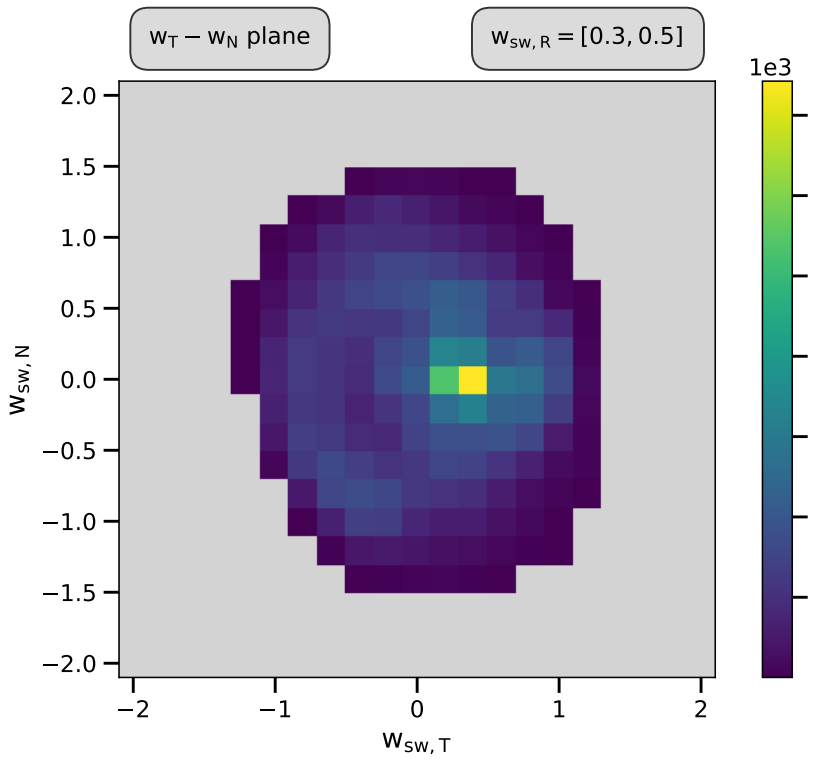
$760 - 780\,\mathrm{km\,s^{-1}}$

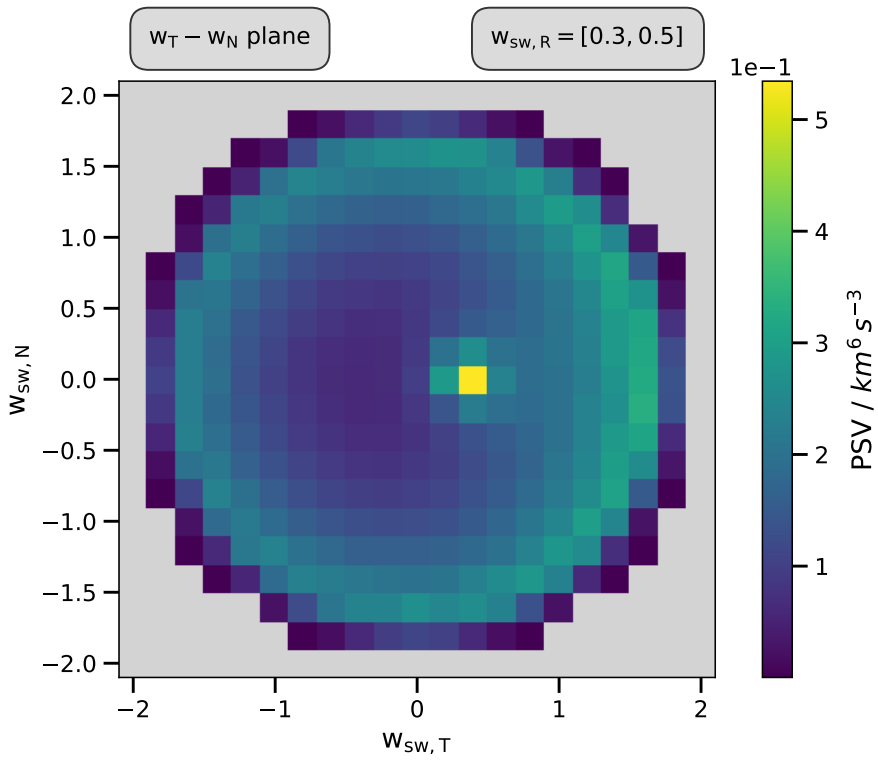


From Counts to Phase Space Density

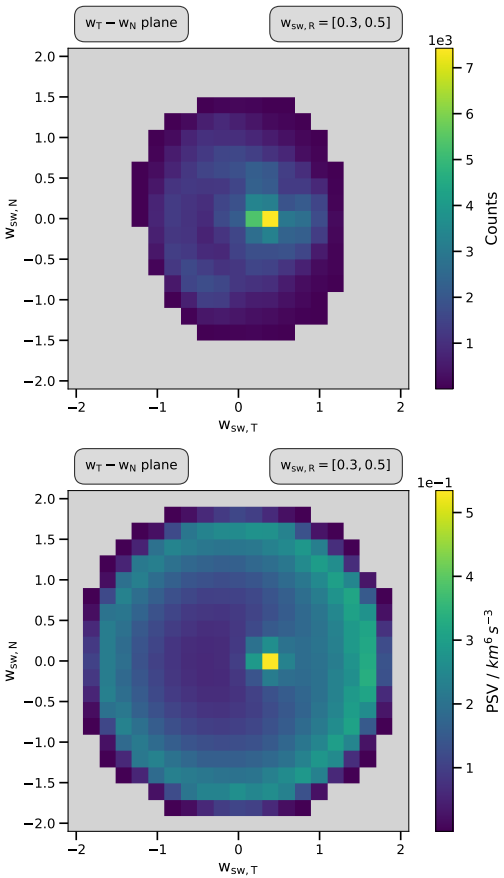
$$PSD = \frac{N}{PSV}$$

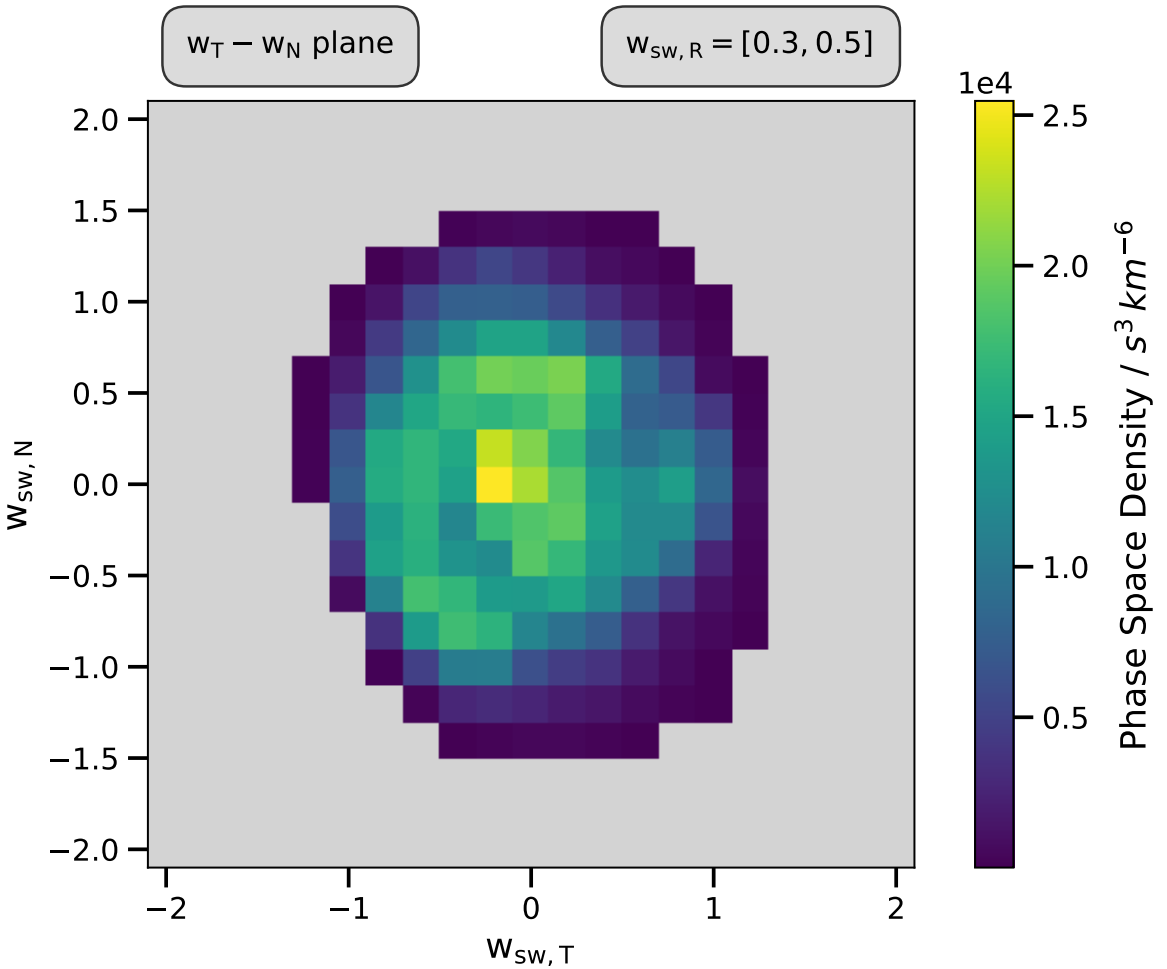




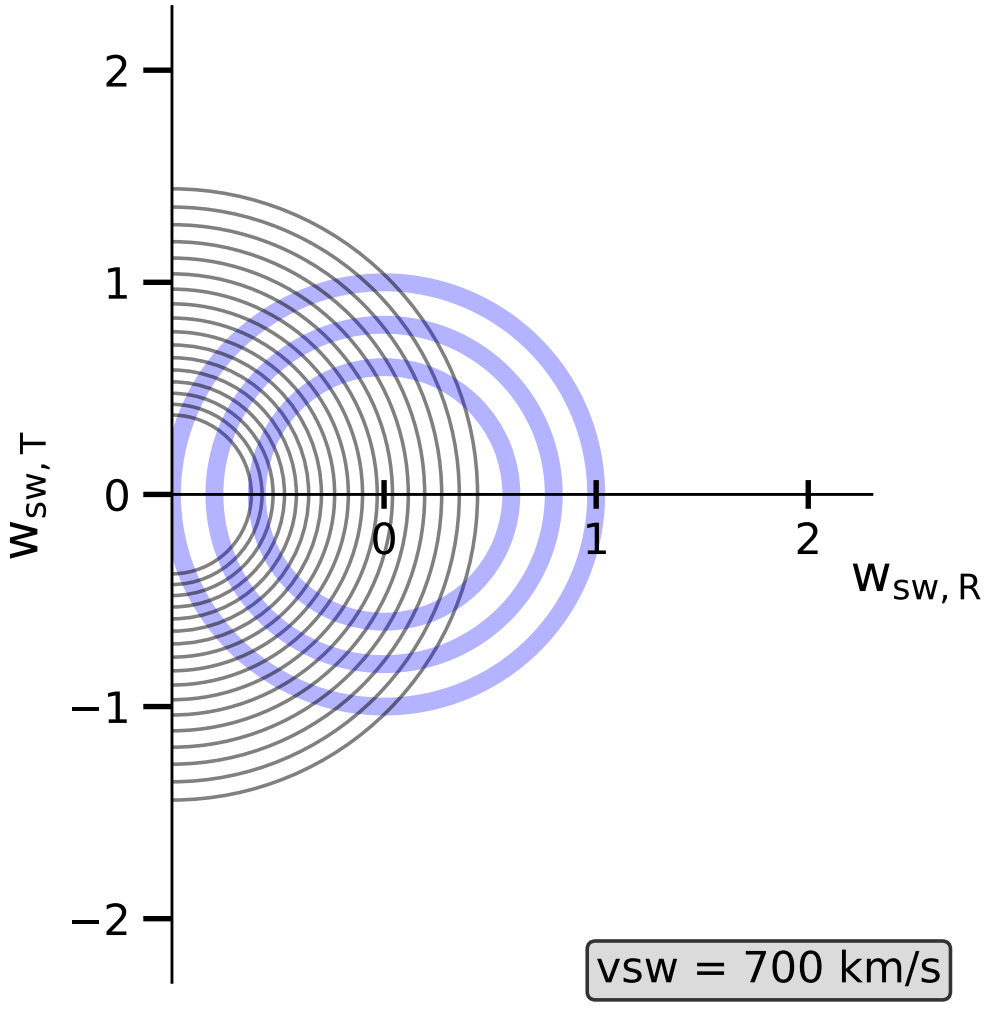


Spherical Cut through VDF

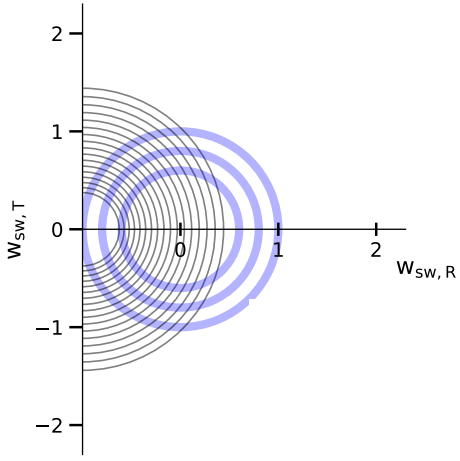


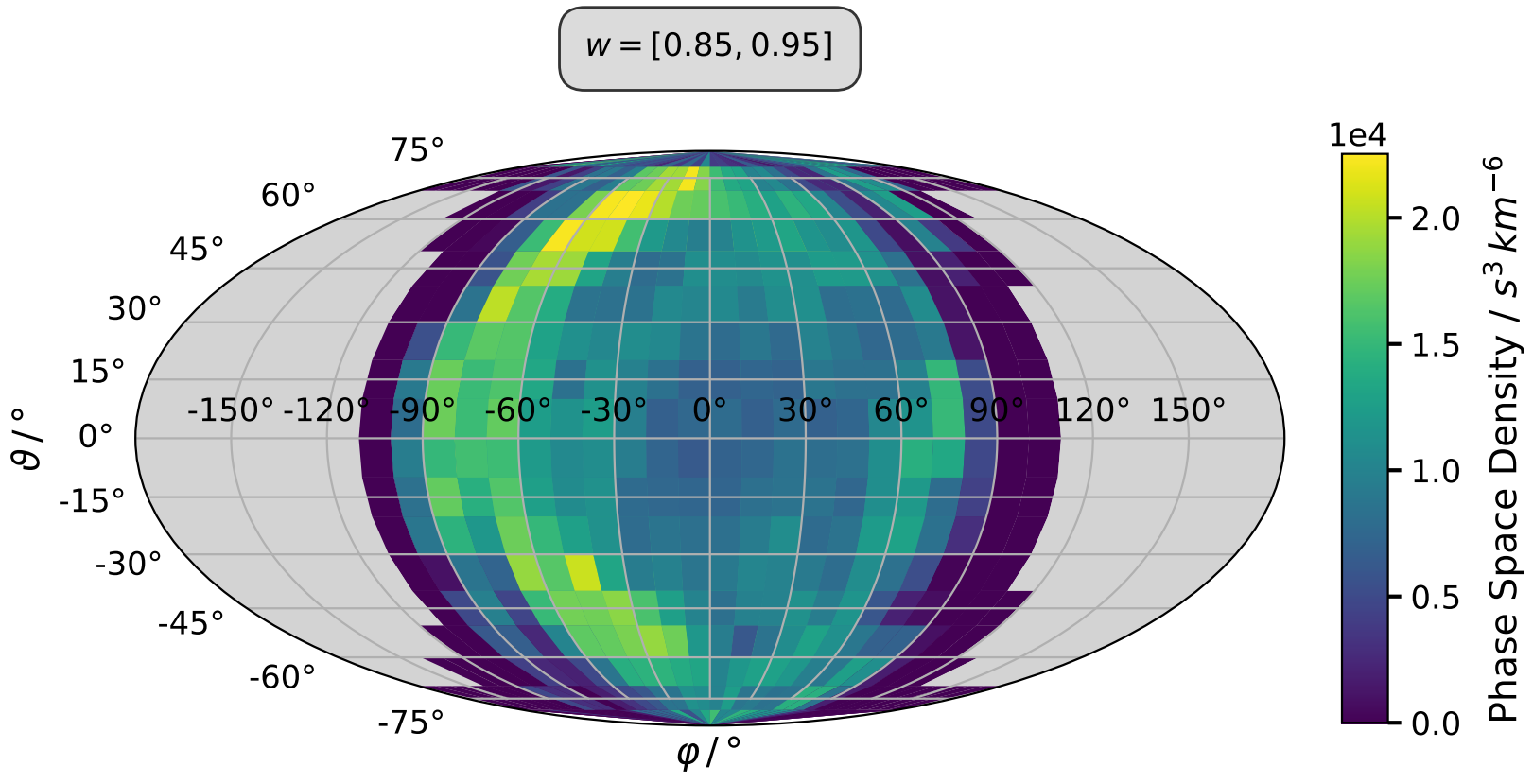


Spherical Surface



Spherical Surface





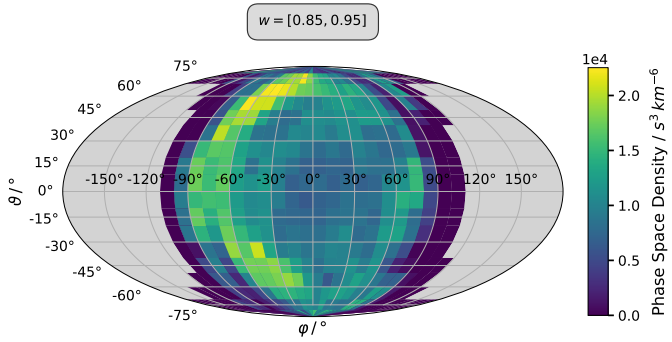
vsw : 760 — 780 $\mathrm{km\,s^{-1}}$ – 50 days in 1993

1D

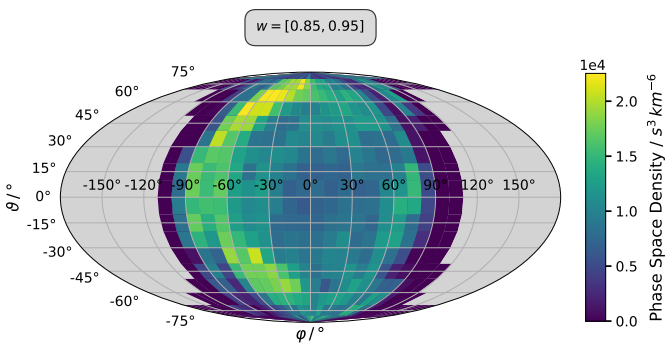
TODO

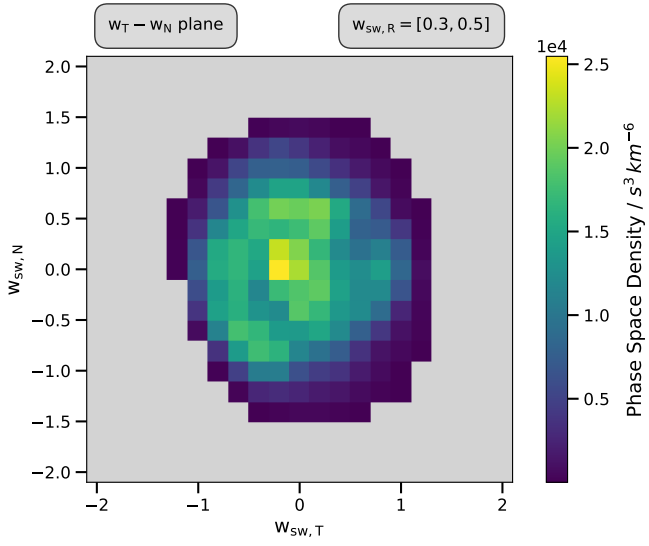
Outlook

- 1D radiale Abhängigkeit untersuchen
- B-Feld abhängige Torusverteilung

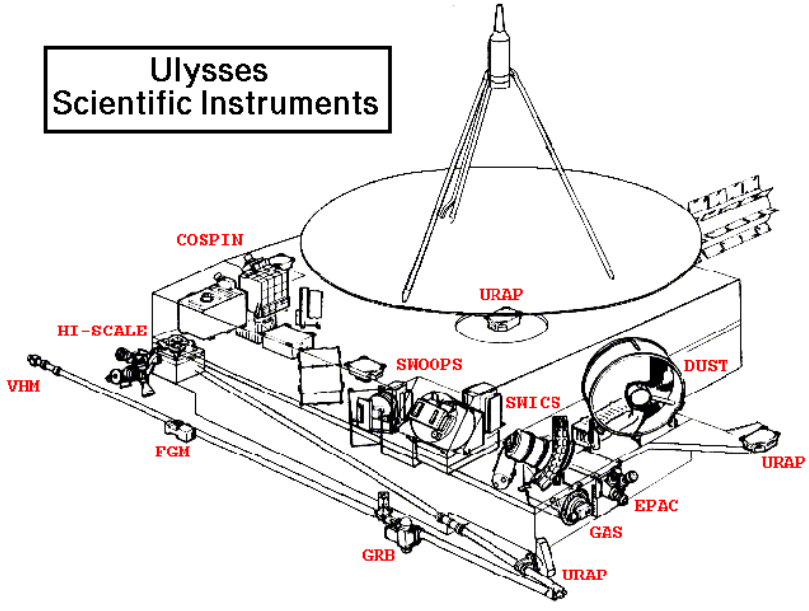


Summary

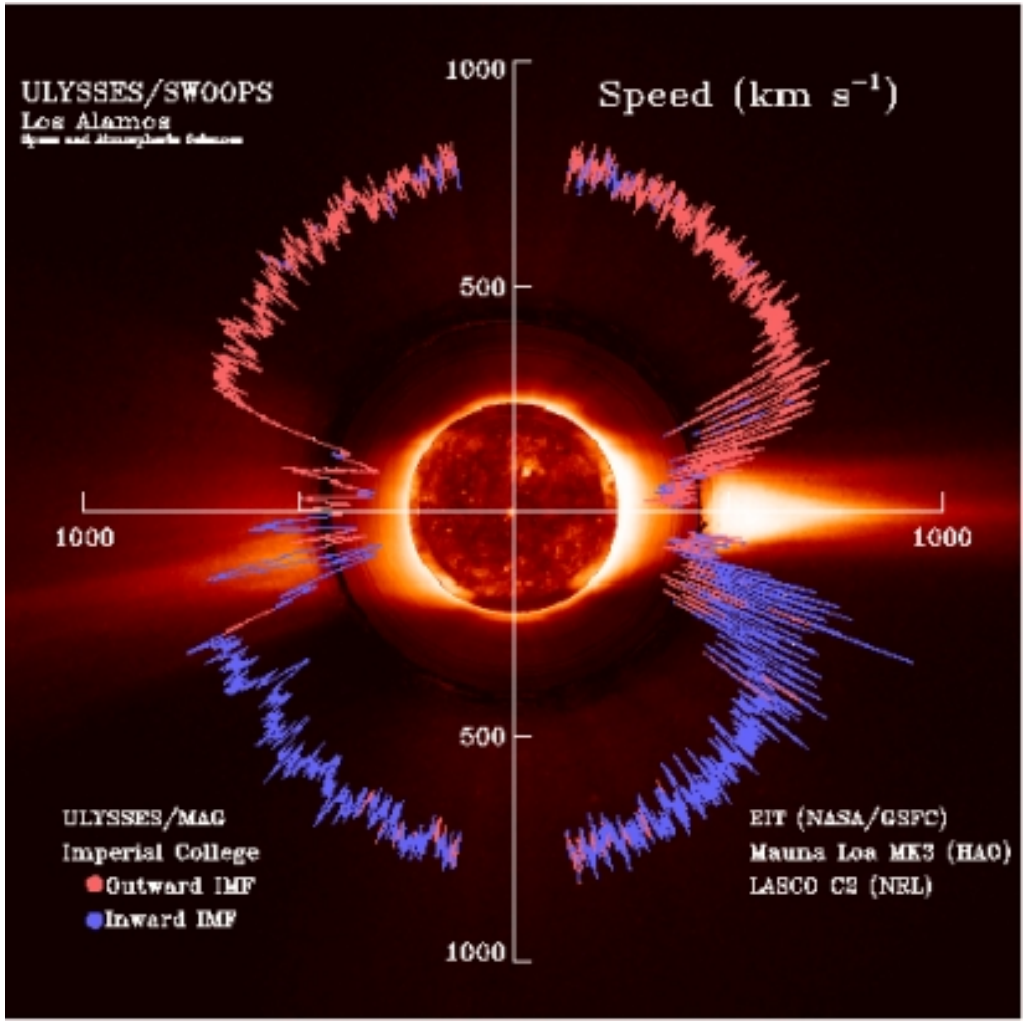

$w = [0.85, 0.95]$
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
-150° -120° -90° -60° -30° 0° 30° 60° 90° 120° 150°
ϑ / °
φ / °
1e4
2.0
1.5
1.0
0.5
0.0
Phase Space Density / $s^3\,km^{-6}$


$w_T - w_N$ plane
$w_{sw,R} = [0.3, 0.5]$
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
$w_{sw,T}$
1e4
2.5
2.0
1.5
1.0
0.5
Phase Space Density / $s^3\,km^{-6}$

BACKUP

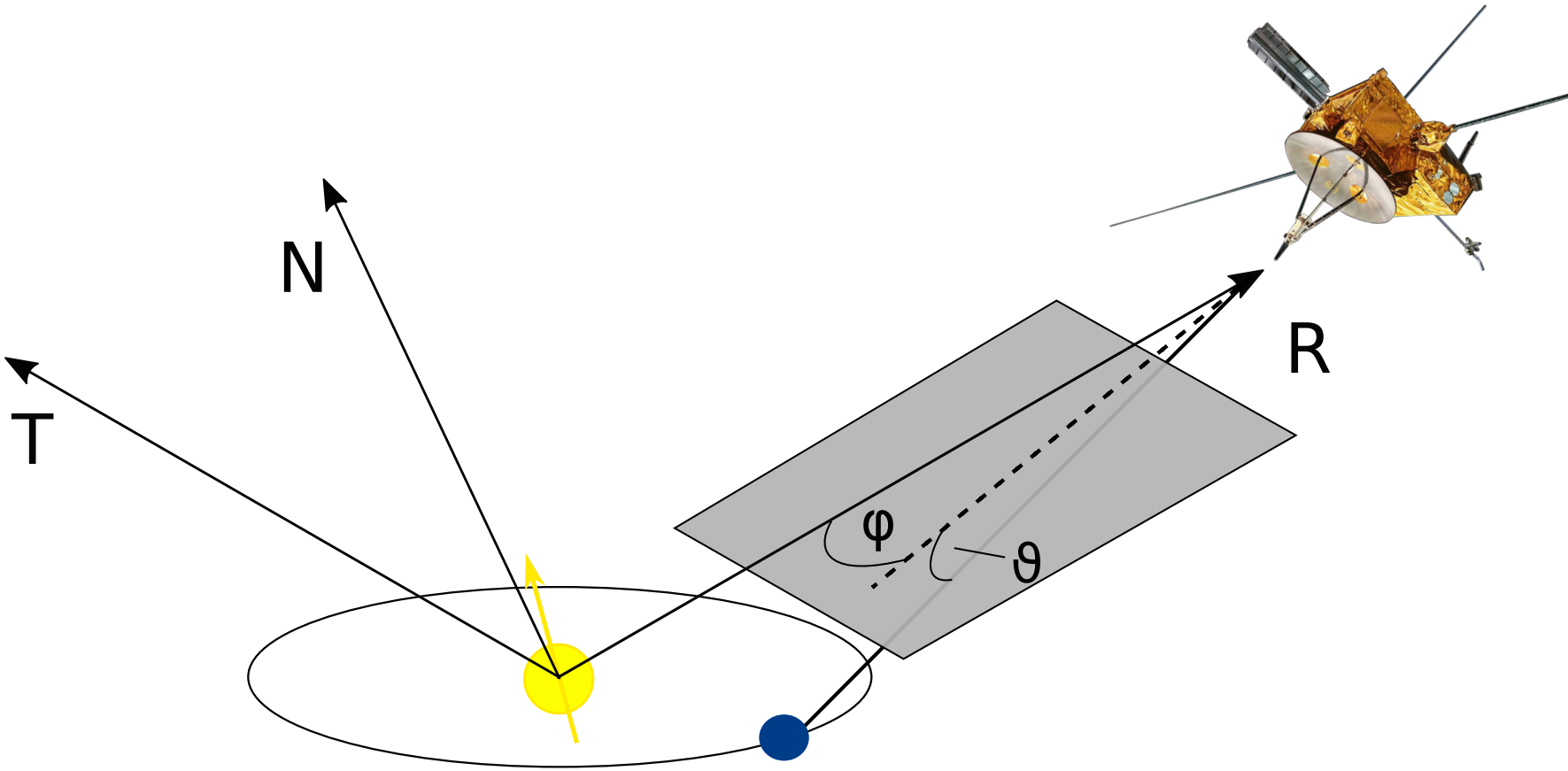


www.cosmos.esa.int, 2019

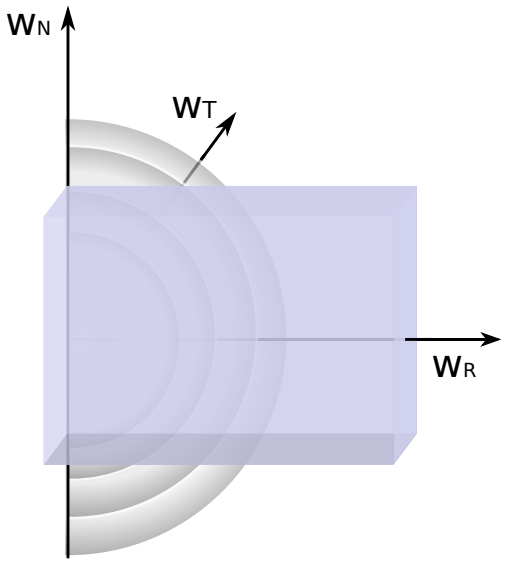


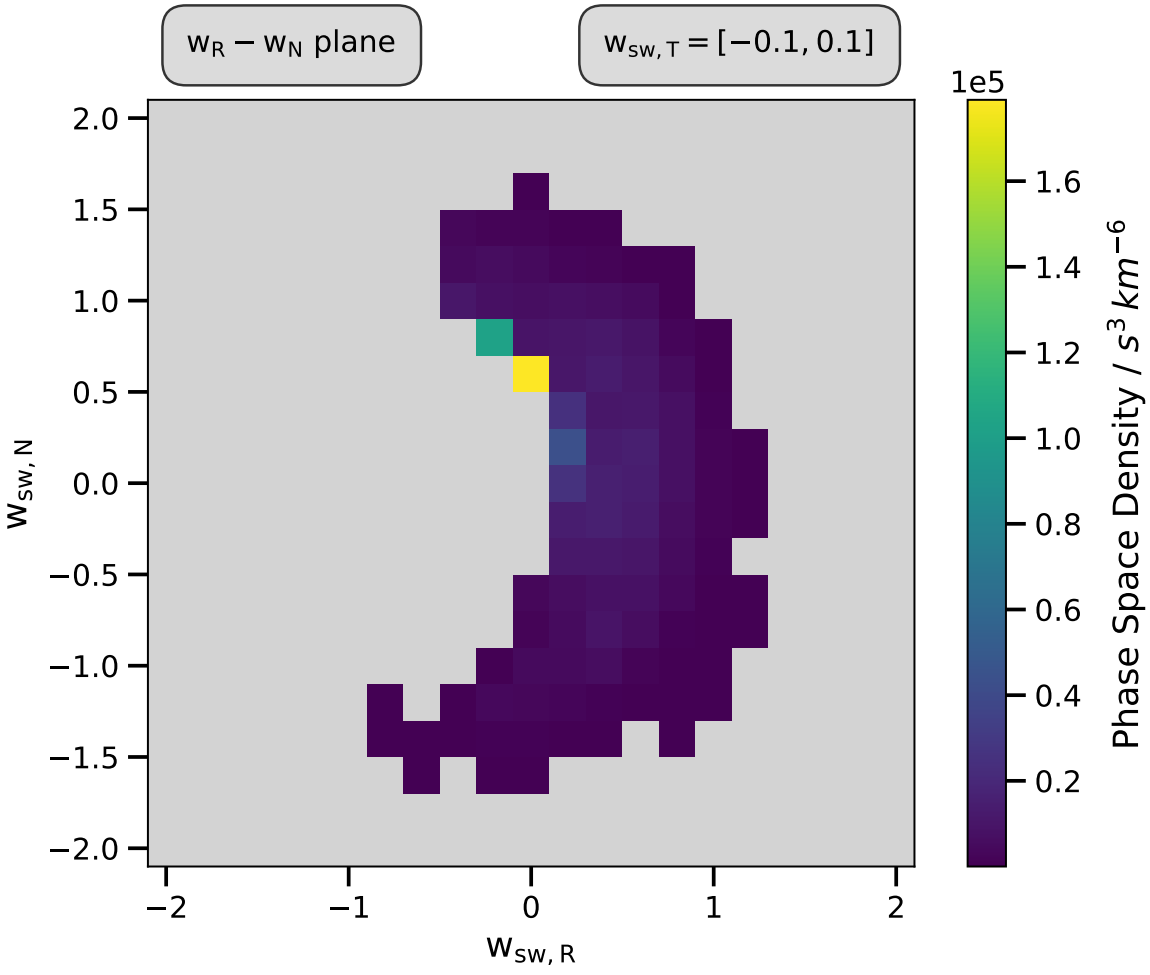
McComas et al., 2000

Aspect Angle

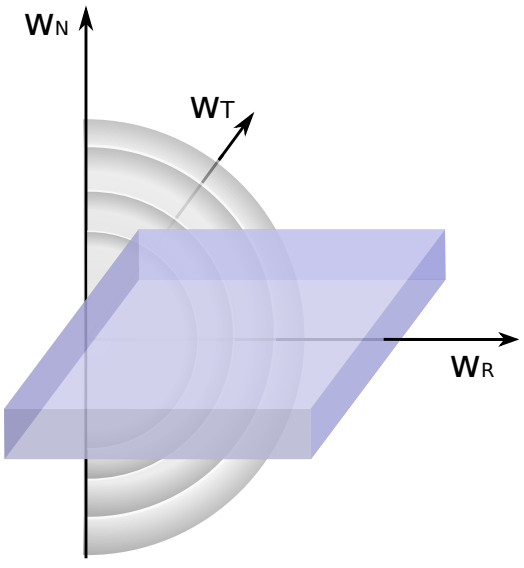


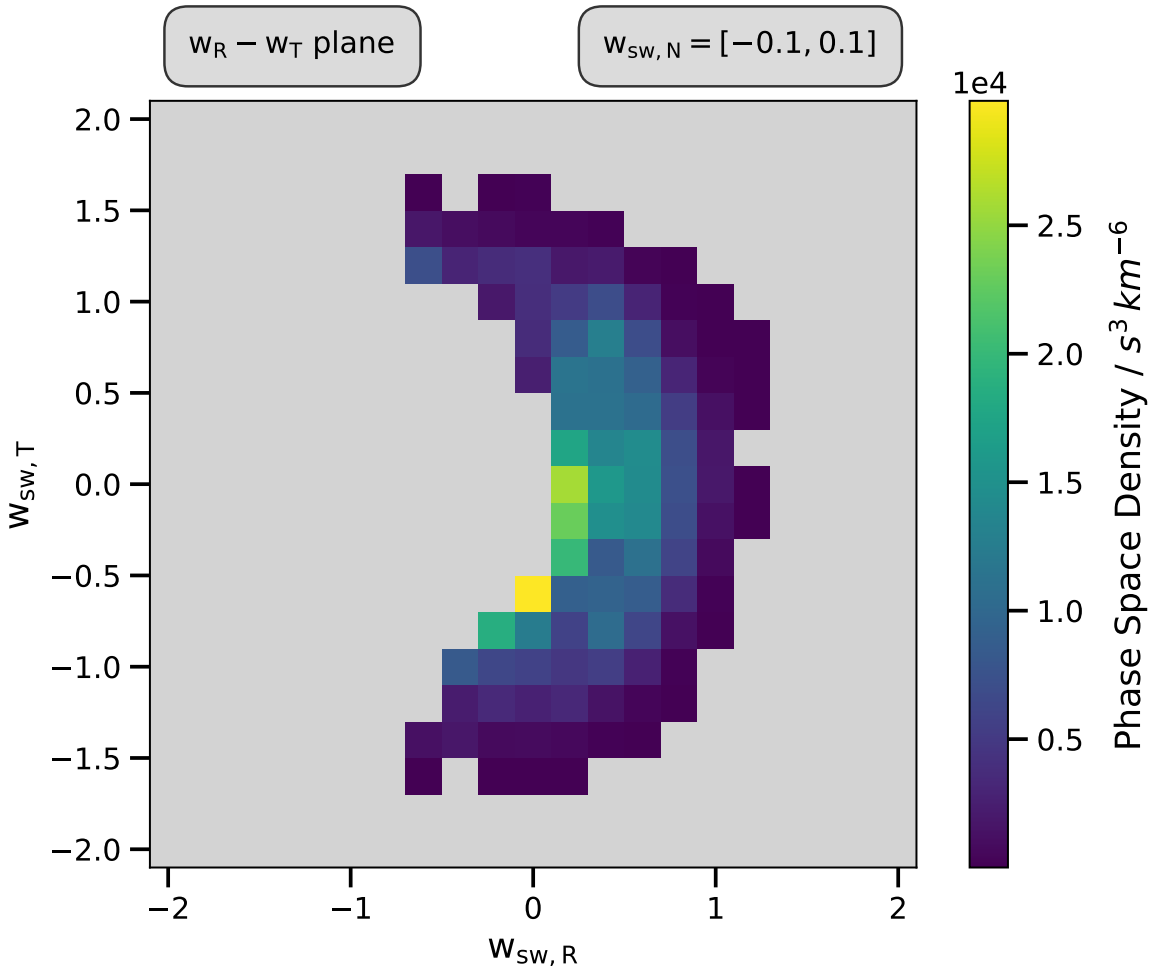
Cartesian Cut: T



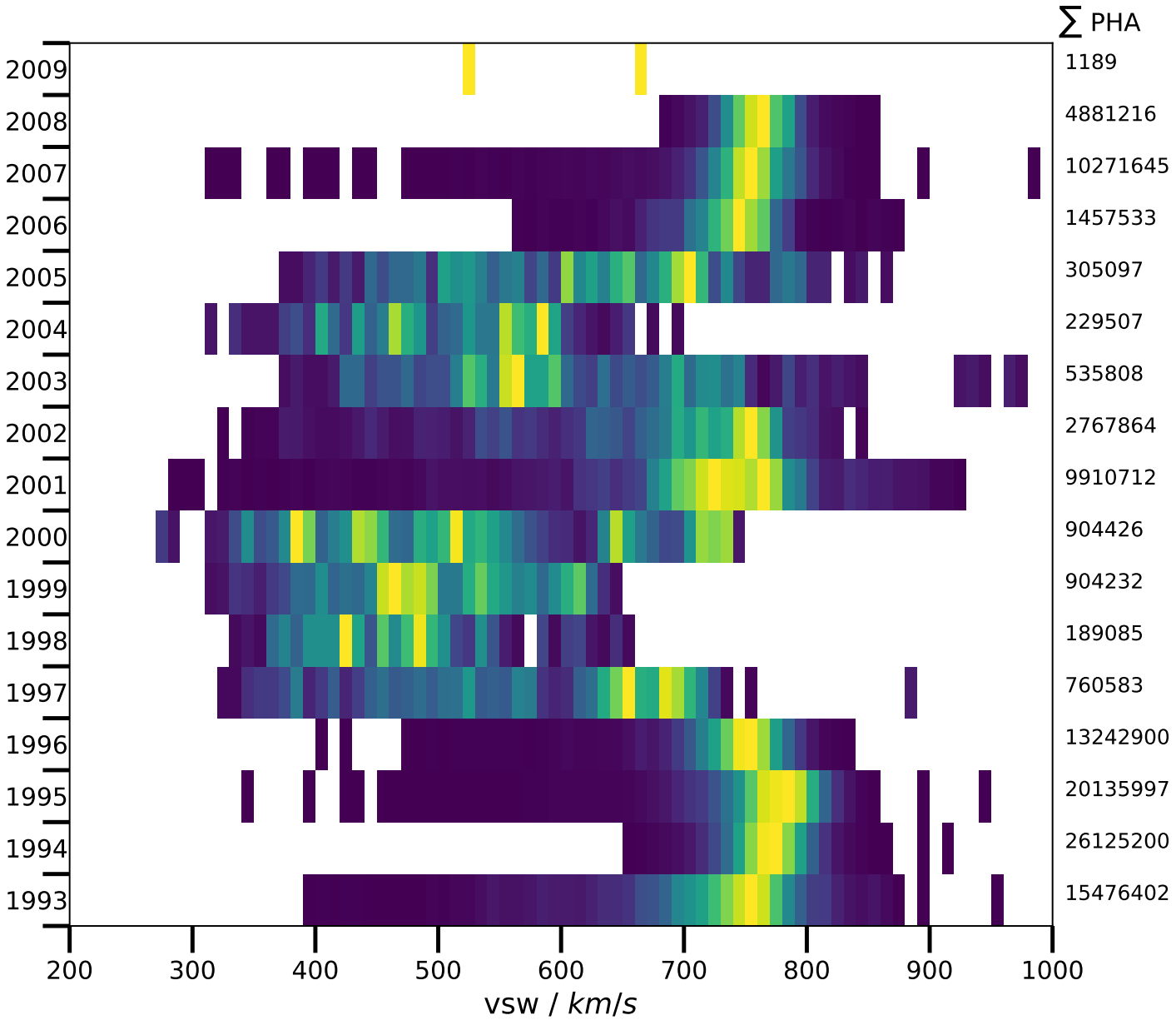


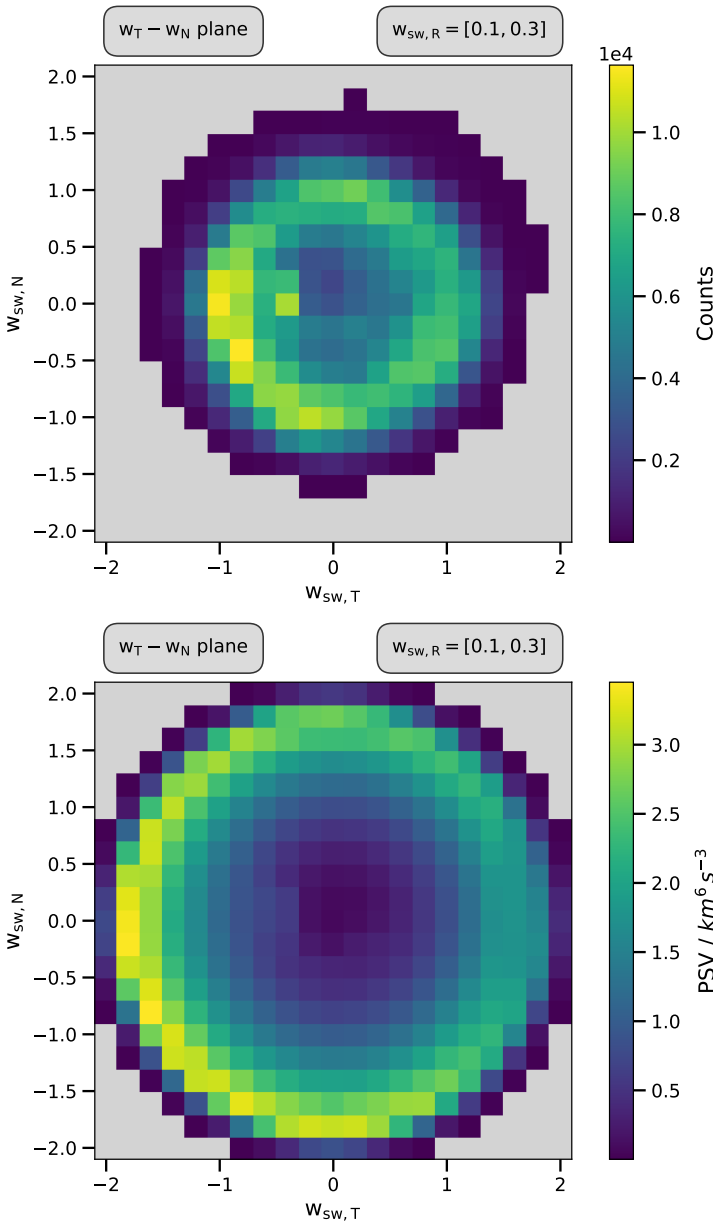
Cartesian Cut: N

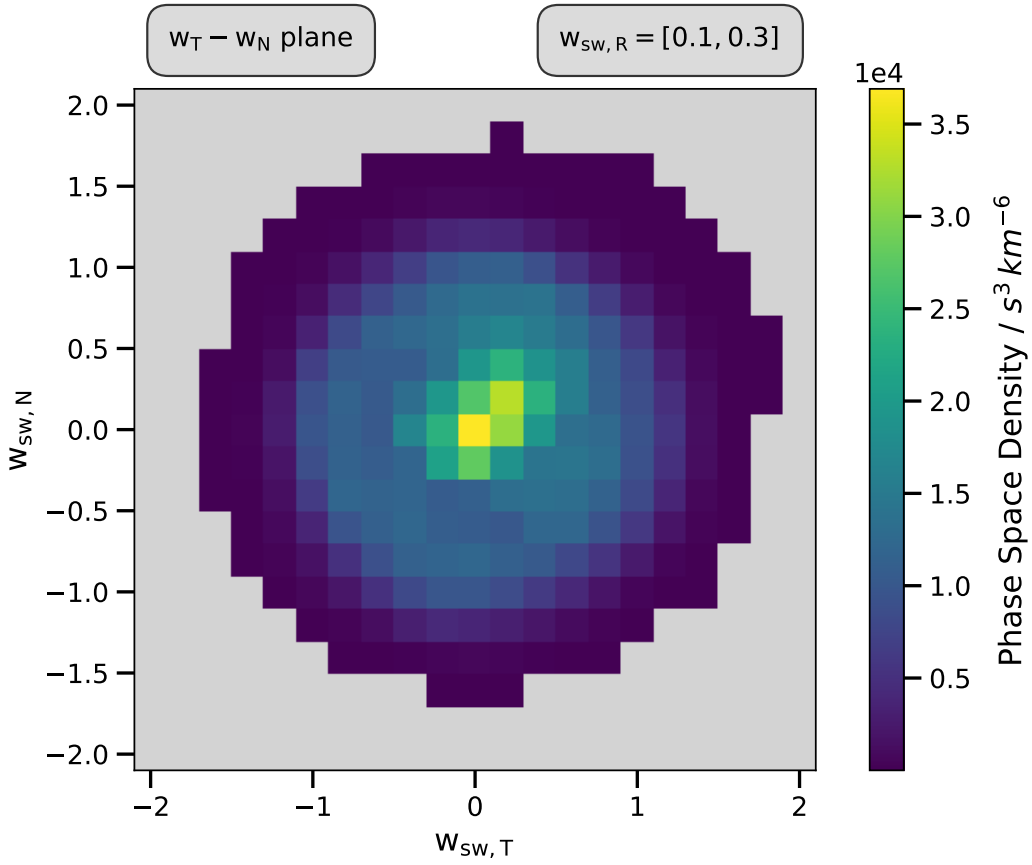




He^+ Data: vsw

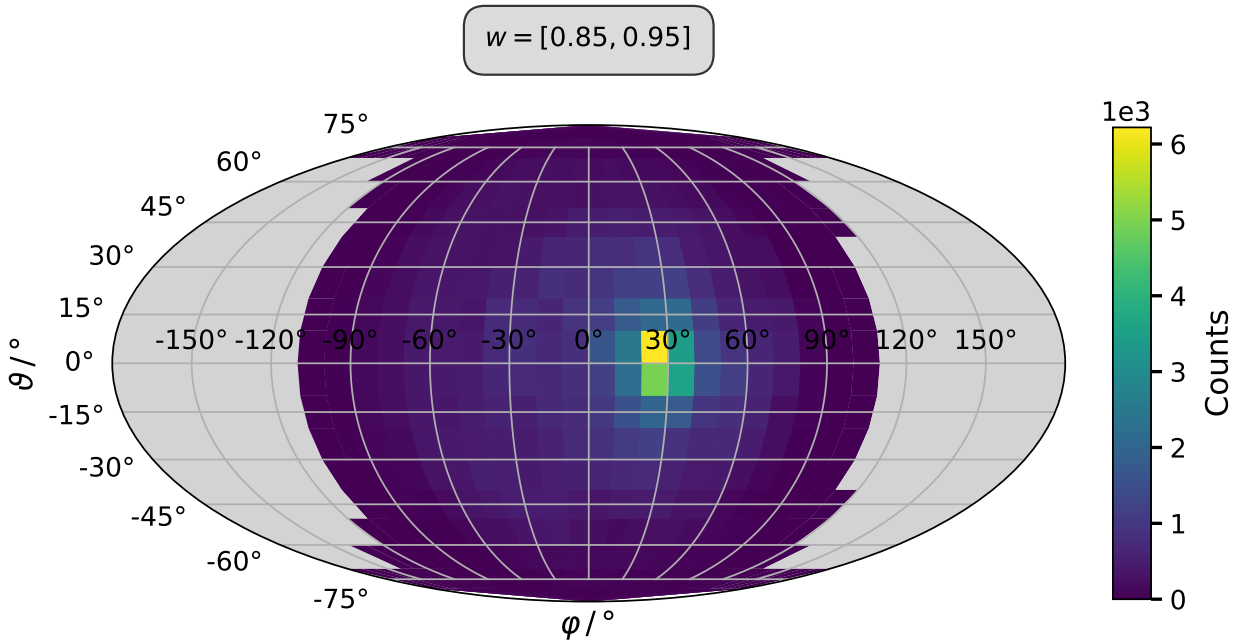

∑ PHA
2009
2008
2007
2006
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994
1993
1189
4881216
10271645
1457533
305097
229507
535808
2767864
9910712
904426
904232
189085
760583
13242900
20135997
26125200
15476402
200
300
400
500
600
700
800
900
1000
vsw / km/s

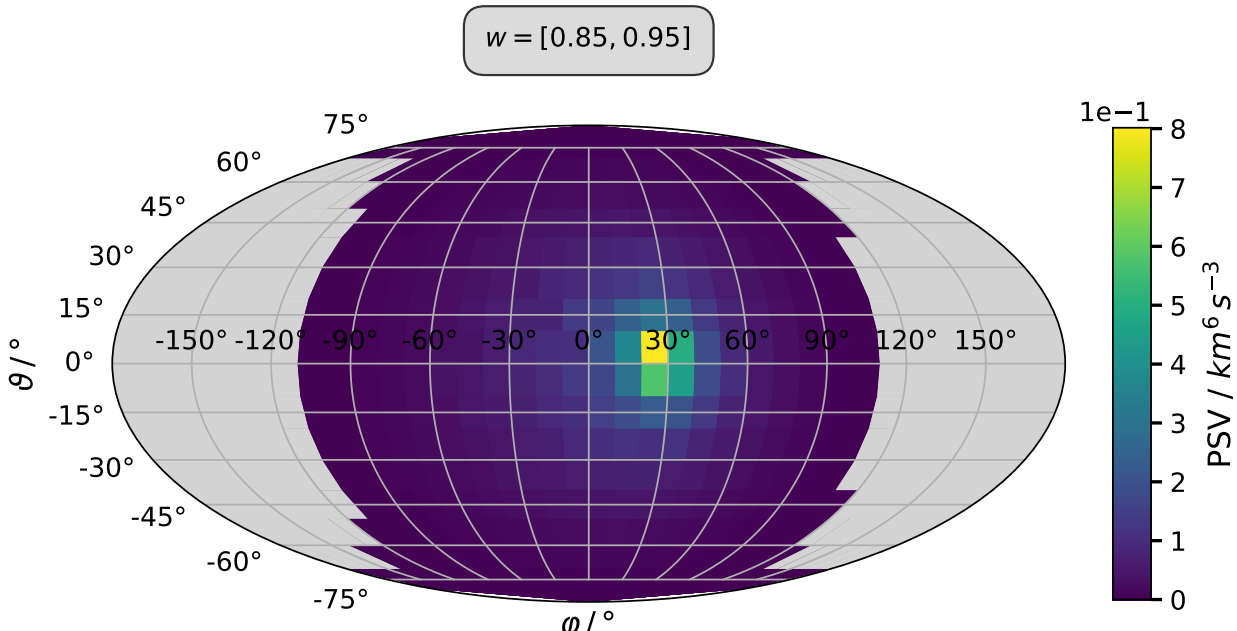




vsw : 740 – 780 $\mathrm{km\,s^{-1}}$

250 days in 1994





vsw : **760 — 780** $\mathrm{km\,s^{-1}}$

50 days in 1993