Pickup Ions

MNF-phys-1311 – Fachliche Spezialisierung

Anne Fischer

May 10, 2019

Outline

Introduction – History

- predicted 1971
  Fahr et al.
- measured 1985
  Moebius et al.
  AMPTE/SULEICA

Planet. Space Sci. 1971, Vol. 19, pp. 1121 to 1129. Pergamon Press. Printed in Northern Ireland

INTERSTELLAR MATTER AND THE LOCATION OF THE SHOCK FRONT

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(*Received in final form* 15 *March* 1971)

Abstract—The initially supersonic flow of the solar wind passes through a magnetic shock front where its velocity is supposed to be reduced to subsonic values. The location of this shock front is primarily determined by the energy density of the external interstellar magnetic field and the momentum density of the solar wind plasma. **Interstellar hydrogen penetrating into the heliosphere undergoes charge exchange processes with the solar wind protons and ionization processes by the solar EUV radiation.** This results in an extraction of momentum from the solar wind plasma. Changes of the geometry and the location of the shock front due to this interaction are studied in detail and it is shown that the distance of the magnetic shock front from the Sun decreases from 200 to 80 AU for an increase of the interstellar hydrogen density from 0·1 to 1·0 cm^{-3}. The geometry of the shock front is essentially spherical with a pronounced embayment in the direction opposite to the approach of interstellar matter which depends very much on the temperature of the interstellar gas. Due to the energy loss by the interaction with neutral matter the solar wind plasma reduces its velocity with increasing distance from the Sun. This modifies Parker's solution of a constant solar wind velocity.

1. INTRODUCTION

The solar wind is presumed to drop to subsonic velocities at a specific distance $r = r_s$ from the Sun. This distance is reached, if the energy density of the solar wind plasma has decreased to the value of the energy density $B_i^2/8\pi$ of the external interstellar field. In

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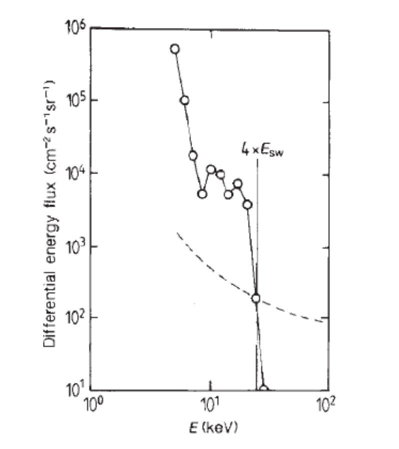
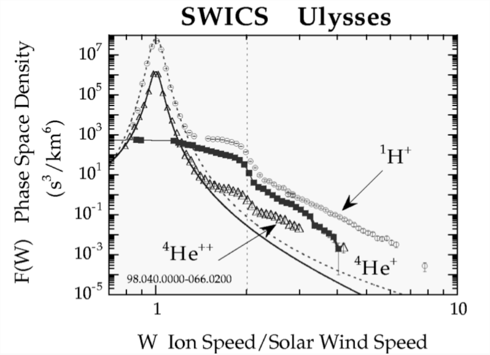


$MpQ = 4$, *Moebius et al. 1985*

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

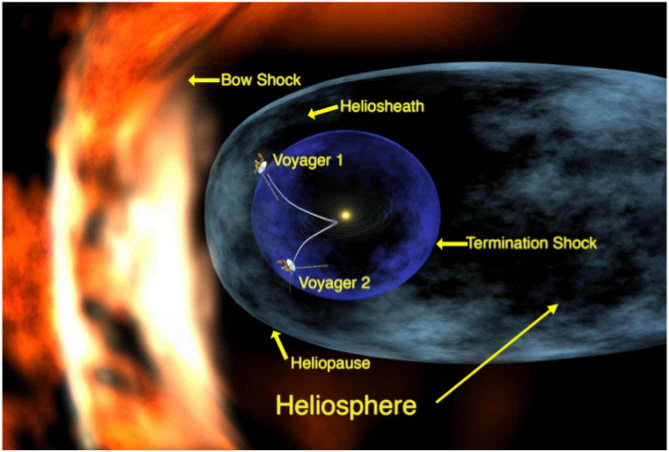
PUI or Solar Wind?

- Charge state
- Velocity distribution function (VDF)



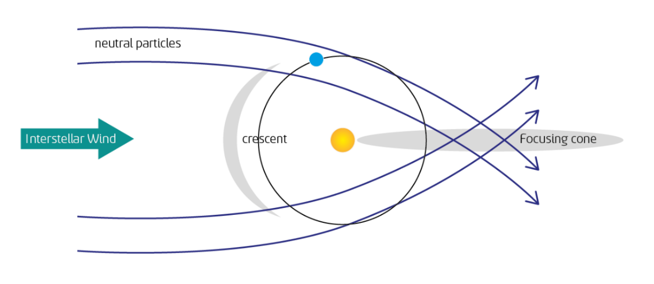
Gloeckler et al. 1999

Neutrals from the LISM – Interstellar PUIs



from *http://science.nasa.gov*

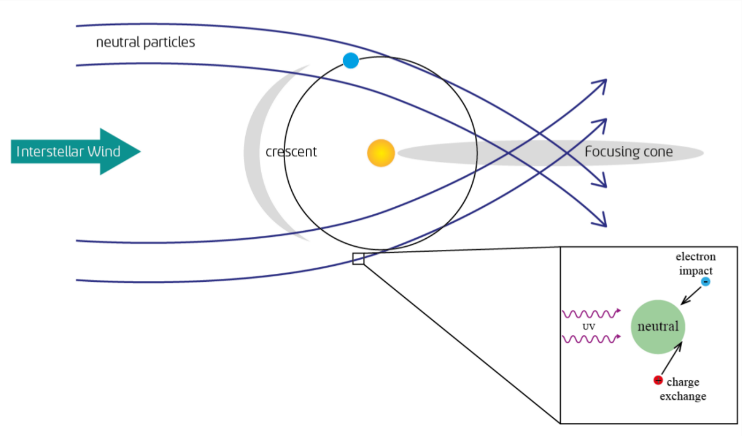
Neutrals in the heliosphere



Drews et al., AGU Fall Meeting 2014

- Neutrals from LISM enter the heliosphere – $v_n \approx 25 - 50\mathrm{km\,s^{-1}}$
- subjected to:
  gravitational force, radiation pressure, solar wind particles

Ionisation



Drews et al., AGU Fall Meeting 2014

Inner-source PUIs

- *Geiss et al. 1995*:
  observation of C^+ PUIs

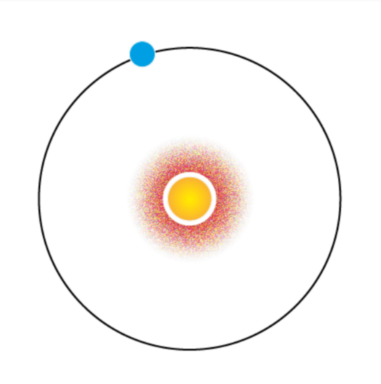
Element	PPM	I	II	III
H	10^6	0.776	0.224	-
He	10^5	0.611	0.385	$4.36 \cdot 10^{-3}$
C	661	$2.68 \cdot 10^{-4}$	0.975	0.0244
N	46.8	0.720	0.280	$8.52 \cdot 10^{-5}$
O	331	0.814	0.186	$4.71 \cdot 10^{-5}$
Ne	123	0.196	0.652	0.152
Na	2.04	$1.47 \cdot 10^{-3}$	0.843	0.155
Mg	6.61	$1.98 \cdot 10^{-3}$	0.850	0.148
Si	8.13	$4.21 \cdot 10^{-5}$	0.999	$8.02 \cdot 10^{-4}$

Elemental and charge state composition
in the LISM
Frisch et al. 2011 / Taut 2018

- *Geiss et al. 1995*: observation of C^+ PUIs

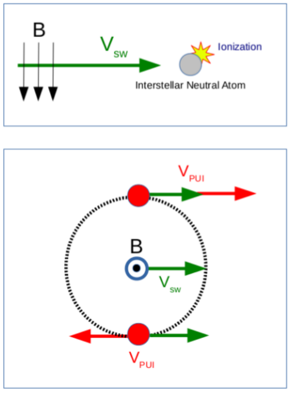
Solution:
Inner source of neutrals
$\rightarrow$ Inner-source PUIs

- production mechanism: unclear (solar wind $\leftrightarrow$ dust ?)
- nearly thermalised VDF (peak @ w $\approx$ 1)



2011 Taut 2018

The pickup-process



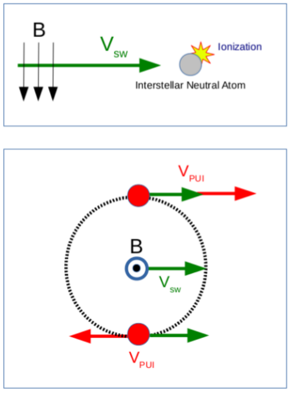
Drews et al., AGU Fall Meeting 2014

Assumptions:

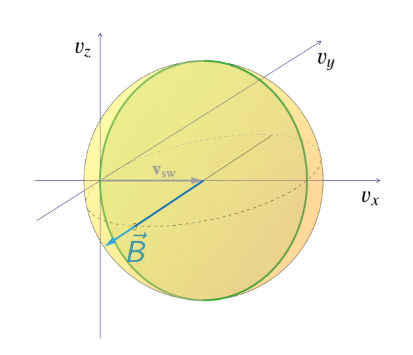
- particle at rest
- $\vec{B} \perp \vec{v}_{SW}$

Relative motion
$\rightarrow$ **Gyro-motion**

Velocity Distribution Function



velocity space



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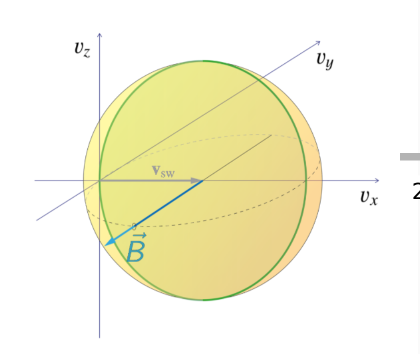
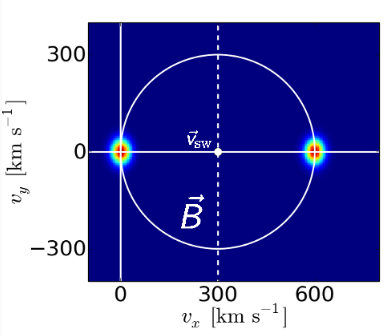
Velocity Distribution Function



2D cut



Drews et al., AGU Fall Meeting 2014

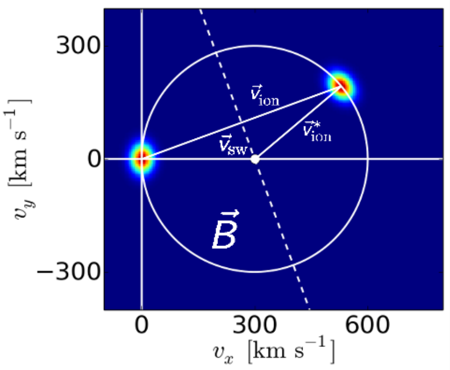
Taut 2018, disputation

Velocity Distribution Function

Non-perpendicular $\vec{B}$-field:

- gyro-motion perpendicular to $\vec{B}$
- inclination of the torus

$\Rightarrow$ **in SW-frame:**
every possible torus is part of a shell with $\mathrm{r} = \mathrm{v_{sw}}$



Taut 2018, disputation

$\longrightarrow$ Injection of PUIs into solar wind:
anisotropic torus-shaped VDF

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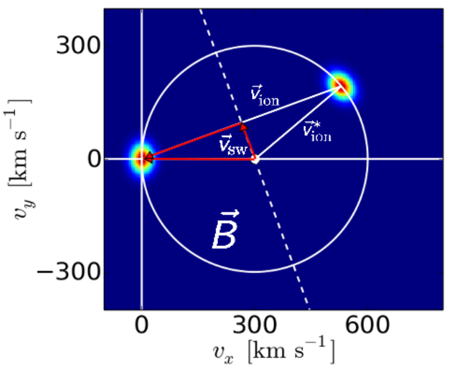
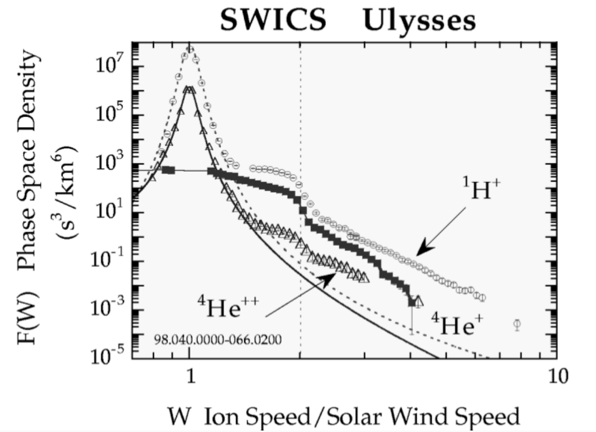


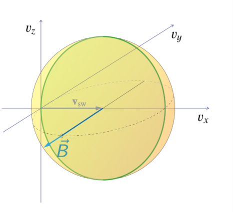
Taut 2018, with modifications

$\longrightarrow$ Injection of PUIs into solar wind:
anisotropic torus-shaped VDF

Velocity Distribution Function – measurement



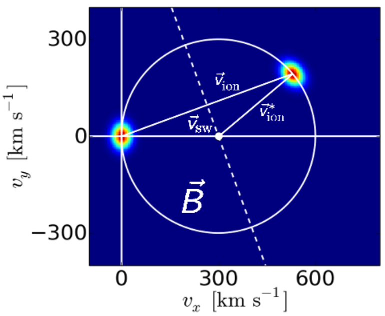
Reminder:



Gloeckler et al. 1999

Velocity Distribution Function – Diffusion

- Pitch-angle scattering
- Deceleration processes (*"cooling"*)
- Acceleration processes



Taut 2018, disputation

Vasyliunas & Siscoe 1978:
$\rightarrow$ fast isotropisation

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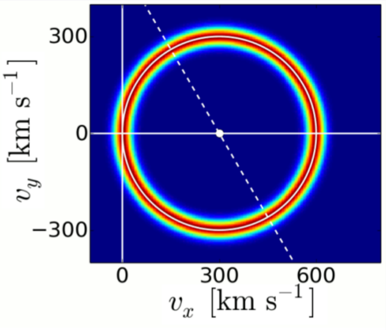

Taut 2018, disputation

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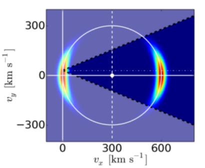
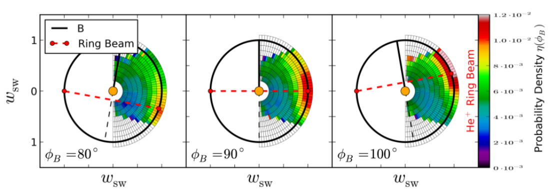
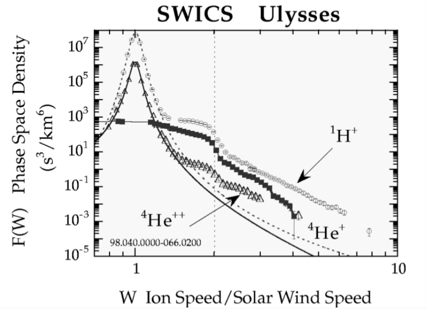




Drews et al. 2015

- anisotropic feature
- $\vec{B}$-dependency

Velocity Distribution Function – Diffusion



Gloeckler et al. 1999

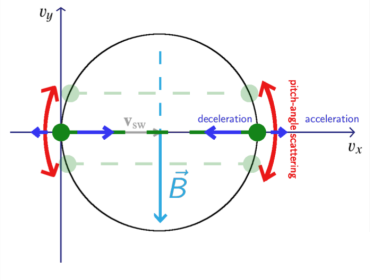
- Pitch-angle scattering
- Deceleration processes (*"cooling"*)
- Acceleration processes

$$E^{\frac{3}{4}} r = const.$$

$$r_0 = \left(\frac{E}{E_0}\right)^{\frac{3}{4}} r$$

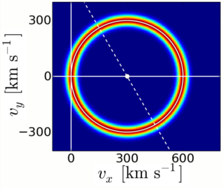
Velocity Distribution Function – Diffusion

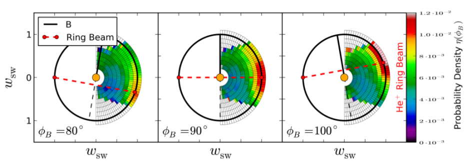
- Pitch-angle scattering
- Deceleration processes (*"cooling"*)
- Acceleration processes

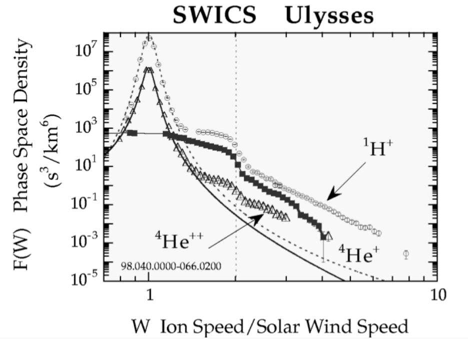


Taut et al., UNH Space Science Seminar 2017

Outlook

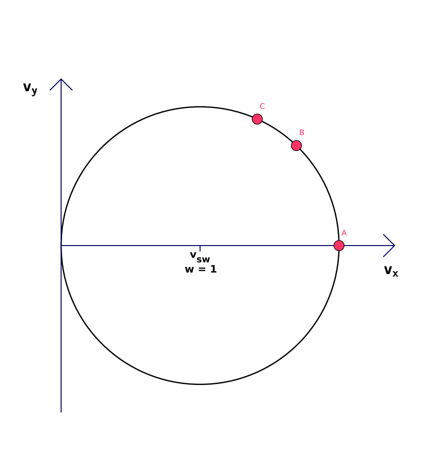


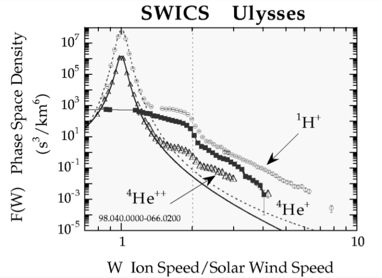




How does the VDF evolve after injection?

Outlook





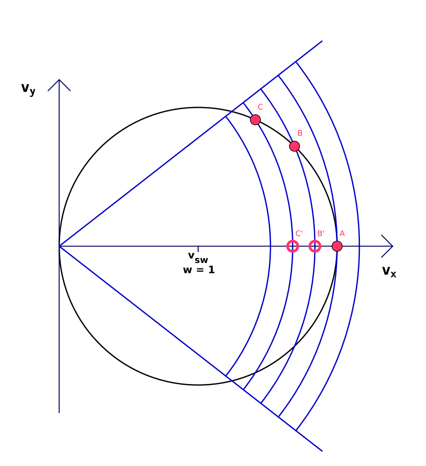
Gloeckler et al. 1999

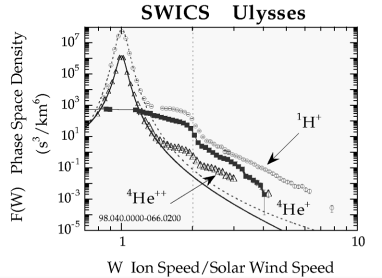
Assumption:

Particles on the shell

with $r = v_{sw}$

Outlook



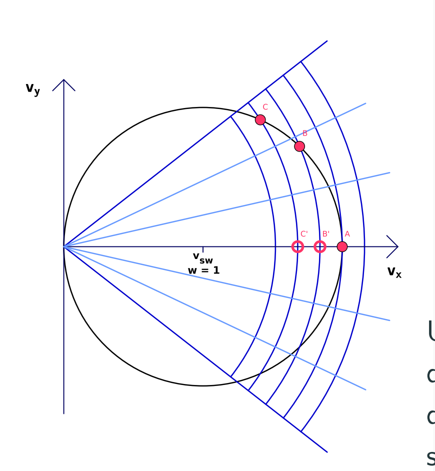


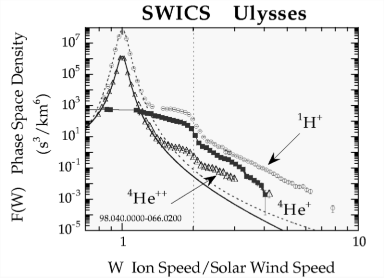
Gloeckler et al. 1999

Detector integrates over every shell:

$$w = \frac{v_x}{v_{sw}}$$

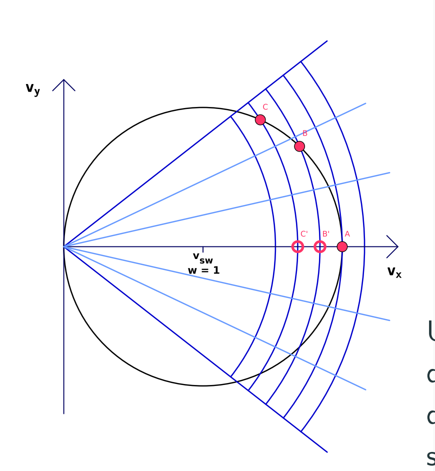
Outlook

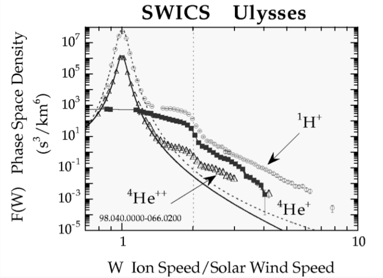




Ulysses/SWICS:
detector can
distinguish between
segments on one shell

Outlook





Ulysses/SWICS:

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- Introduction to Pickup ions and their basic concepts: sources, pickup-process
- Velocity distribution: models and measurements
- How 2D-measurements can help to understand processes better