

CHRISTIAN-ALBRECHTS-UNIVERSITÄT ZU KIEL

MASTER THESIS

Thesis Title

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Abstract

The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too...

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Chapter 1

Motivation

Chapter 2

Pickup Ions

Pickup ions are created when neutral atoms inside the heliosphere become ionised and are subsequently swept away with the heliospheric magnetic field that is embedded within the solar wind.

2.1 The Heliosphere

Oder Überkapitel Solar Physics?

Heliosphere: Grenze zu LISM

Solar Wind: Zusammensetzung, schneller und langsamer

B-Feldgleichung

2.2 Pickup Ions

A neutral atom inside the heliosphere is only subjected to the gravitational force and radiation pressure of the sun. It is not sensitive to any electromagnetic forces until it becomes ionised by solar ultra-violet radiation, charge exchange with solar wind protons or electron impact (Q?). After ionisation the particle starts interacting with the solar wind plasma. In particular it is forced onto a gyro orbit about the heliospheric magnetic field that is embedded within the solar wind. As the freshly created ion is swept away with the magnetic field line it is “picked up” from its location of ionisation – a new pickup ion (PUI) has been created.

PUIs were first observed by Möbius et al. (1985) with the SULEICA Instrument on the AMPTE spacecraft. The particles measured at 1 AU were He⁺ ions of interstellar origin.

Once the particle is ionised, its probability to become ionised another time decreases (Quelle). This characteristic of being only singly charged can help to discriminate PUIs from solar wind ions, that are mostly more often charged (Q?).

PUIs are mostly only single charged. This characteristic can help to distinguish them from solar wind ions of coronal origin which often have been ionized multiple times, if not completely. (Q?)

VDF non-maxwellian, spatial density pattern

There have been observed several species of PUIs:

2.3 Interstellar Pickup Ions

Heliosheath, relative motion

The neutral part of the LISM can enter the heliosphere as it is not affected by the heliosheath (Todo). Inside the heliosphere the neutrals are guided only by the gravitational force and radiation pressure of the sun. The neutral particle's species determines how deep it can travel into the heliosphere before it becomes ionized. Species with a higher First Ionization Potential will be able to approach the sun much closer without being ionized. This results in He⁺ being the dominant PUI species at a solar distance of 1 AU even if in the LISM the abundance of hydrogen is about 10 times the one of helium.

- ionisation process is also dependent on the species
- radiation pressure only important for H (and He?). Kepler orbit...
- Spatial distribution:
gravitational force and radiation pressure lead to two regions of enhanced density of neutrals (in the ecliptic): Focusing cone and crescent. Focusing cone: For species with high FIP (as the others are ionized before and do not reach the downwind side of the sun)
- variation of He⁺ with the solar cycle: Rucinski 2003
- H, O and N are depleted in the filtration region (Baranov Malama 1995), Wimmer Skript: even before ionization: density is determined by ratio of gravitational force and photon pressure
- neutral density determines PUI production rate

2.4 Inner-source Pickup Ions

The idea of an additional source for the PUI's neutral seed population was born when Geiss, Gloeckler, Fisk, et al. (1995) measured a global distribution of C⁺ PUIs with the SWICS instrument on Ulysses. Interstellar carbon exists almost exclusively in a single charged state (Frisch et al., 2011) in the LISM. As only neutral atoms can enter the heliosphere it was not expected to find a distinct signature of C⁺ pickup ions. However, pickup carbon was observed with about the same ratio as oxygen, of which, in contrast, 80% is in a neutral charge state in the interstellar medium. These findings suggested that there must be another source for neutrals that has its origin somewhere inside the heliosphere.

In following studies (e.g. Geiss, Gloeckler, and Steiger, 1995) there were found also other species like O⁺ and Ne⁺ of these, so called, inner-source PUIs.

Inner-source PUIs show a composition that is similar to the one of the solar wind (Gloeckler et al., 2000; Allegrini et al., 2005) as well as a velocity distribution function that is centered around $w_{SC} \approx 1$ (Schwadron et al., 2000) and seems to have thermalized with the solar wind.

Beneath those two characteristics there are other aspects concerning inner-source PUIs, that are still under debate. In particular that is the production mechanism of their neutral seed population. Allegrini et al. (2005) has summarized current candidates for possible scenarios. Two of those give an explanation for the ion's composition as they directly incorporate solar wind ions in the process:

- Solar wind recycling (Gloeckler et al., 2000; Schwadron et al., 2000): Absorption of solar wind ions by heliospheric grains and subsequent reemission of neutral atoms
- Solar wind neutralization (Wimmer-Schweingruber and Bochsler, 2002): Solar wind ions penetrate sub-micron-sized dust grains and undergo (partial) neutralization by charge exchange

(As this work does not focus on inner-source PUIs in particular...)

2.5 VDF

After the particle has been ionised it is forced onto a gyro motion about the local field line of the heliospheric magnetic field due to the Lorentz force.

To examine the velocity distribution of PUIs after they have been ionized we need to consider the initial speed v_{ini} of the neutral particle. For neutrals from the LISM this is mainly given by the inflow speed v_{ISM} of the local interstellar medium with which they enter the heliosphere. As we don't exactly know about the production mechanism of inner-source PUIs, the following considerations mainly relate to interstellar PUIs. Schwadron et al. (2015) obtained $v_{ISM} \approx 25 \text{ km s}^{-1}$ with the IBEX satellite for helium. Considering the acceleration by the sun's gravitational force we have a maximum initial speed of $v_{ini} \approx 50 \text{ km s}^{-1}$ at 1 AU. Compared to an average solar wind speed of $v_{sw} \approx 400 \text{ km s}^{-1}$ one can neglect this initial speed in a first step.

For simplicity we thus consider a neutral particle at rest that becomes ionized by one of the aforementioned processes. The freshly created ion now is subjected to the electromagnetic forces of the solar wind plasma. In particular, it finds itself at a velocity v_{sw} relative to the magnetic field which is convected outwards by the solar wind that is assumed to flow radially outwards. Due to the Lorentz force the PUI starts to gyrate about the magnetic field line on a orbit that is perpendicular to it. When we further consider a magnetic field's orientation that is perpendicular to the solar wind flow, $\vec{B} \perp \vec{v}_{sw}$, the ion's gyration speed is v_{sw} while its guiding center moves together with the field line at a speed of v_{sw} as well. Thus, the total speed of the PUI ranges between $0 v_{sw}$ and $2 v_{sw}$ in a sun frame of reference.

As the heliospheric magnetic field lines are shaped like an Archimedean spiral, the so called *Parker spiral*, the assumption of a perpendicular magnetic field only applies to cases in which the solar wind speed v_{sw} and the solar distance r_{\odot} follow the relation

$$90^{\circ} \approx \arctan \left(\frac{2\pi}{T_{\odot} \cdot v_{sw}} r_{\odot} \right)$$

with sun's sidereal period $T_{\odot} \approx 25 \text{ d}$ (Prölss, 2004). When this is not the case, e.g. for solar distances about 1 AU at which the angle between solar wind and magnet field direction is $\approx 45^{\circ}$,

Figure: Velocity Space. Torus shape around solar wind In a SW frame: velocity is always v_{sw}

When IMF is not perpendicular: The relative velocity is decreased. Particle is still

forced onto a gyro orbit around the HMF but with a smaller Bahngeschwindigkeit that is FORMEL.

Total velocity consists of the movement of the guiding center and the Bahngeschwindigkeit.

As one can see from figure... in a SC frame of reference the guiding center velocity is now smaller than v_{sw} . Interpretation: PUI departs from the sw bulk as it falls behind from the bulk. In this situation of a non-perpendicular IMF the PUI guiding center moves away from its originating field line

Consider more than one PUI (ensemble) injected at the same time: Different width of torus (because of different initial velocities?)

One needs to be aware of that the velocity in a SW frame is still v_{sw} , independent on the angle of the HMF.

Form of the torus depends on several factors: velocity of the particle before the PU process, orientation of the magnetic field

How the PUI distribution evolves further...

Vaslić and Siscoe: Fast PA scattering, isotropization

Adiabatic cooling and acceleration processes

However: early findings of anisotropy (Moebius), following explanations

Observations Drews etc.: anisotropy perpendicular to IMF! Torus distribution persists in parts

Instrument that is capable of measuring this distribution: large acceptance in absolute velocity, large variation and resolution in angles

2.5.1 1D reduced VDF, aim of this work...?

Chapter 3

Instrumentation

3.1 ULYSSES

sfsf

3.2 SWICS

sffsf

Appendix A

Frequently Asked Questions

A.1 How do I change the colors of links?

The color of links can be changed to your liking using:

```
\hypersetup{urlcolor=red}, or  
\hypersetup{citecolor=green}, or  
\hypersetup{allcolor=blue}.
```

If you want to completely hide the links, you can use:

```
\hypersetup{allcolors=.}, or even better:  
\hypersetup{hidelinks}.
```

If you want to have obvious links in the PDF but not the printed text, use:

```
\hypersetup{colorlinks=false}.
```


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Declaration of Authorship

I, Anne Fischer, declare that this thesis titled, and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

Date:

Acknowledgements

The acknowledgments and the people to thank go here, don't forget to include your project advisor...