Pickup-Ions in the Heliosphere: Theory and Measurements

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Outline

General processes

Seed population: Neutral atoms in the heliosphere

Get ionized by:

- Photoionization
- Charge exchange with solar wind protons
- Electron impact

Observed PUI:

H^{1+}, $^{3}\mathrm{He}^{1+}$, $^{4}\mathrm{He}^{1+}$, He^{2+}, C^{1+}, N^{1+}, O^{1+}, Ne^{1+}, Mg^{1+}, Si^{1+}, Fe^{1+}

General processes

After ionization:

- Acceleration by SW convection $\vec{E}$-field: $\vec{E} = \vec{v}_{sw} \times \vec{B}$
- Gyration around SW $\vec{B}$-field.
  $\rightarrow$ Maximum PUI speed: $v_{max} = 2 \cdot v_{sw}$, if $\vec{B} = \vec{B}_{\perp}$
- Further processes under debate:
  - Isotropization by pitch-angle scattering?
  - Adiabatic cooling/deceleration by expanding SW and decreasing $\vec{B}$-field?

Characteristics

- Charge state
- Velocity distribution
- Spatial distribution

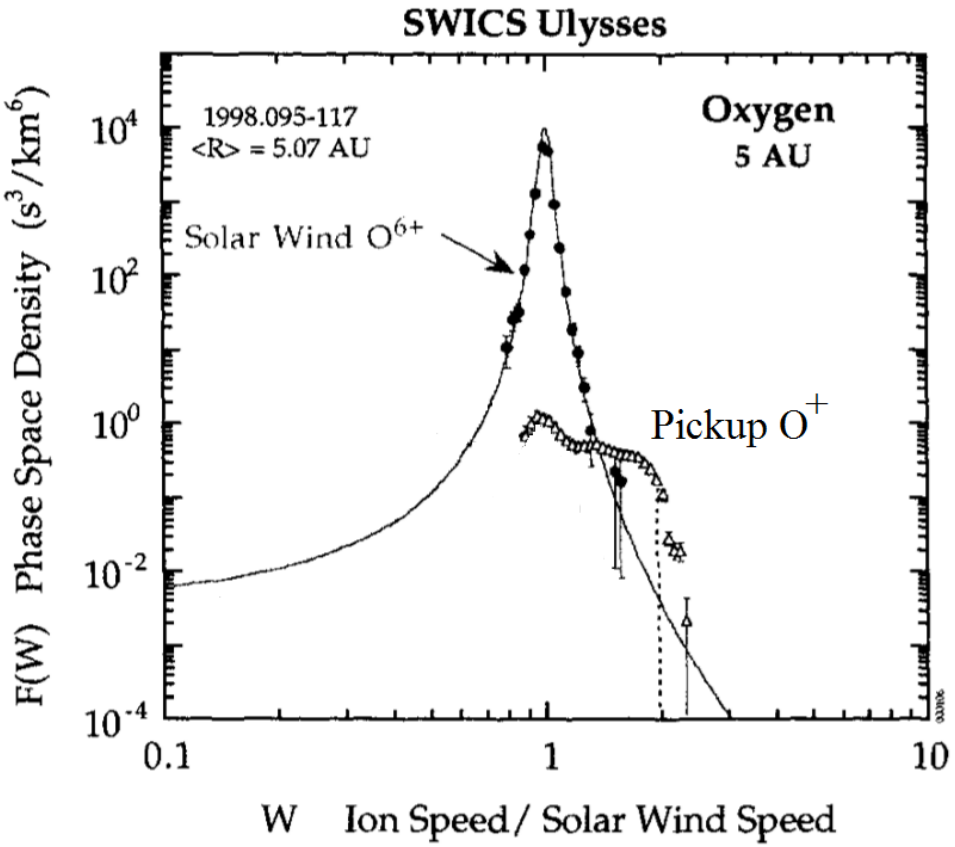
Characteristics

- Charge state
  - SW ions have high charge states ($T_{\mathrm{Corona}} \sim 10^6\mathrm{K}$).
  - Pickup ions are mostly single charged.
- Velocity distribution
- Spatial distribution

Characteristics

- Charge state
- Velocity distribution
  - Highly suprathermal VDF due to pickup process.
  - Sharp cutoff at $w \approx 2$.
- Spatial distribution

Characteristics

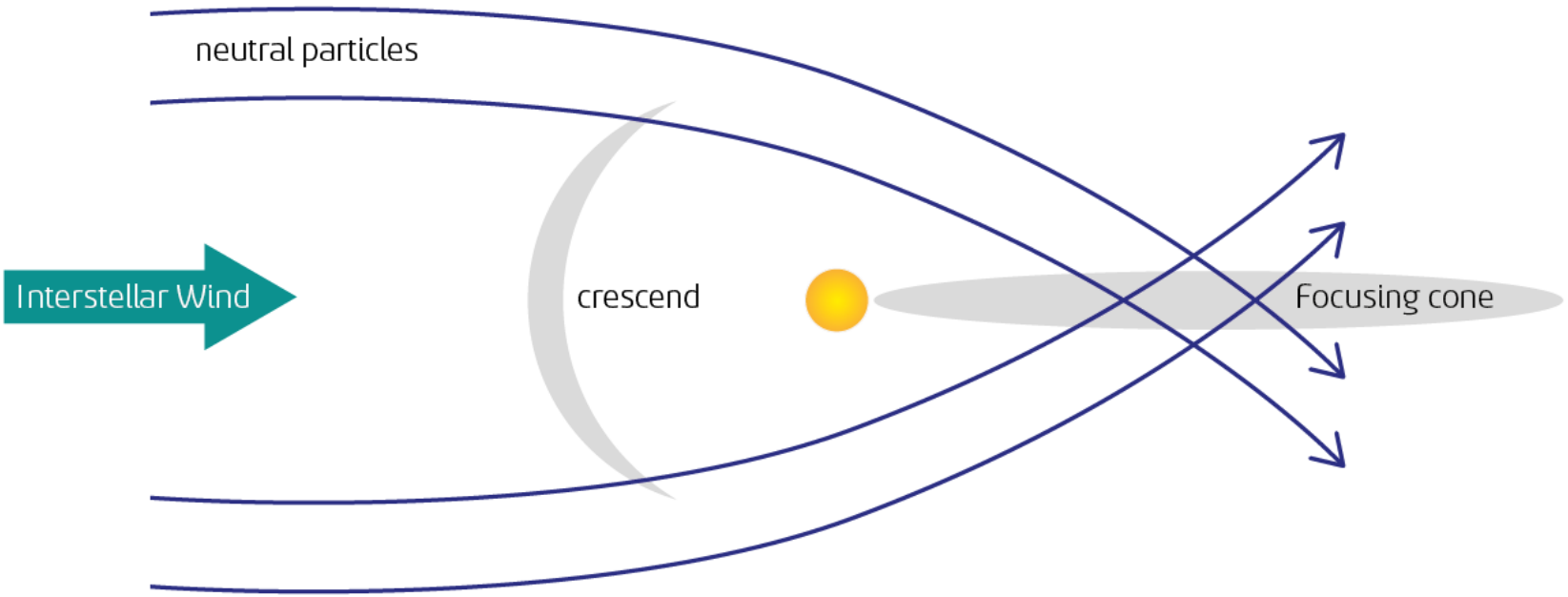


Taken from: Gloeckler et al. 2000, *Sources, Injection and Acceleration of Heliospheric Ion Populations*

Characteristics

- Charge state
- Velocity distribution
- Spatial distribution
  - Interstellar PUIs: Focussing cone and crescent.
  - Local point sources (for example: Venus tail rays (Grünwaldt et al. 1997)).

Interstellar PUI



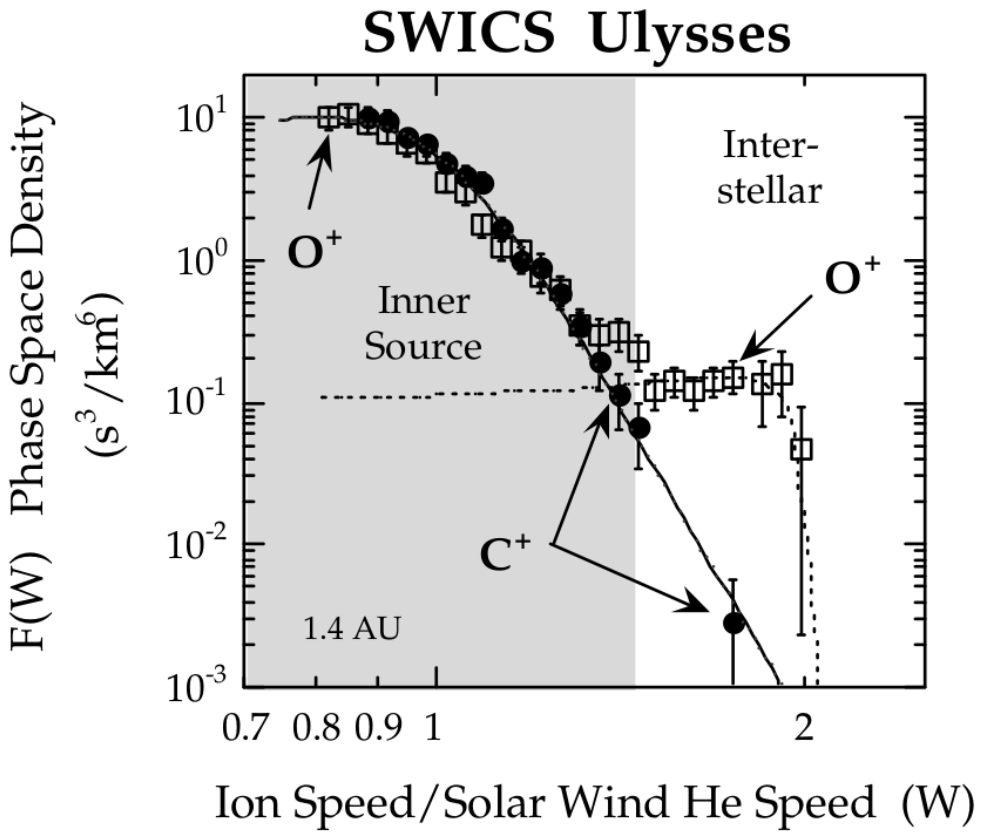
Atom	H	He	C	N	O	Ne	Mg	Si
FIP/eV	13.60	24.59	11.26	14.53	13.62	21.56	7.65	8.15

Data taken from `www.nist.gov/pml/data/ion_energy.cfm`

Inner source PUI

- C^{1+} PUI of the same amount of O^{1+} are measured.
- But: only $\sim 0.03\%$ of Carbon and $\sim 81\%$ of Oxygen is neutral in the interstellar medium.
- Also differences in VDF
  $\rightarrow$ almost thermalized with SW.

Inner source PUI



Taken from: Gloeckler & Geiss 1998, *Interstellar and inner source pickup ions observed with SWICS on ULYSSES*

Inner source PUI - Characteristics

→ Allegrini et al. 2005, *Stability of the inner source pickup ions over the solar cycle*

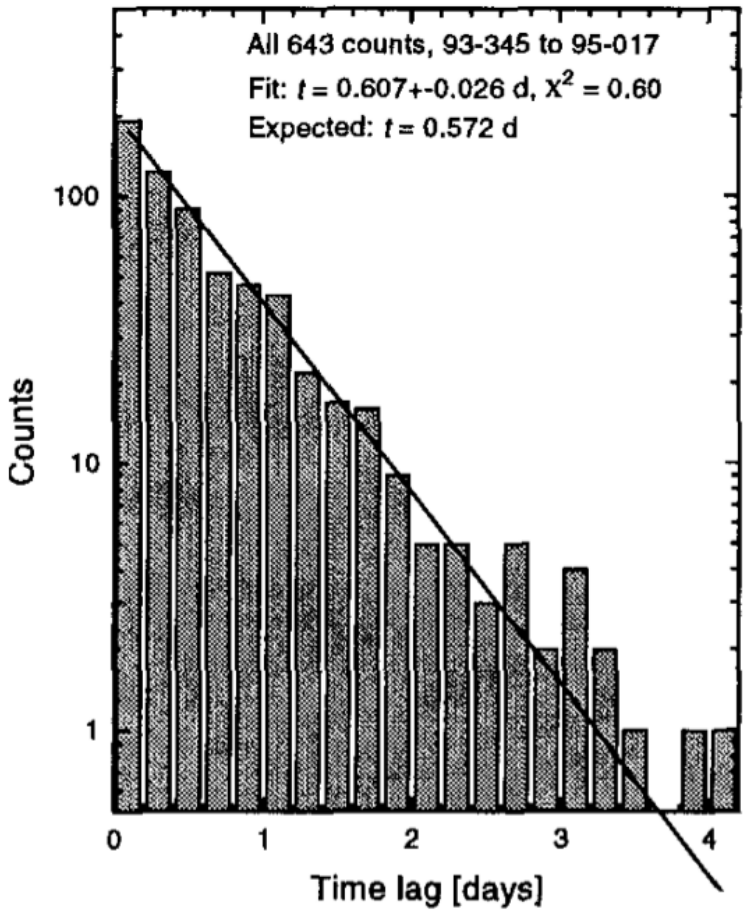
- SW composition
- Peak near the sun ($\sim 10 - 30 R_\odot$)
- Large pickup ion flux (Production rate: $\sim 2 \cdot 10^6 \frac{\mathrm{g}}{\mathrm{s}}$)
- Randomly distributed source
- Stability over solar cycle

Solar wind and inner source composition

Element	Inner source	Solar wind
C	1.46 ± 0.12	0.683 ± 0.040
N	0.40 ± 0.05	0.111 ± 0.022
O	1 ± 0.06	1
Ne	0.32 ± 0.05	0.082 ± 0.013
Mg	0.49 ± 0.15	0.105 ± 0.025
Si	0.32 ± 0.12	0.115 ± 0.023

Source: Gloeckler et al. 2000, *Elemental composition of the inner source pickup ions*

Randomly distributed source



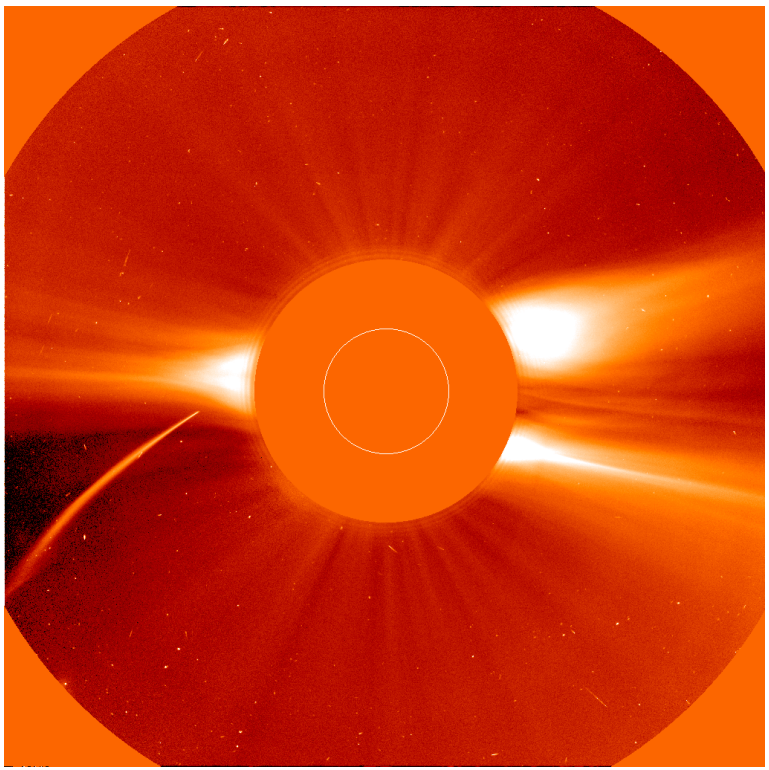
Taken from: Geiss et al. 1996, *Origin of* C^+ *ions in the heliosphere*

Possible Sources

- Sungrazing comets
- Dust-dust collisions
- Solar wind recycling
- Solar wind neutralization

Sungrazing Comets

→ Bzowski & Królikowska 2004, *Are the sungrazing comets the inner source of pickup ions and energetic neutral atoms?*



Picture taken from: `http://sohowww.nascom.nasa.gov/gallery/images/large/xmascomet_prev.jpg`

Sungrazing comets

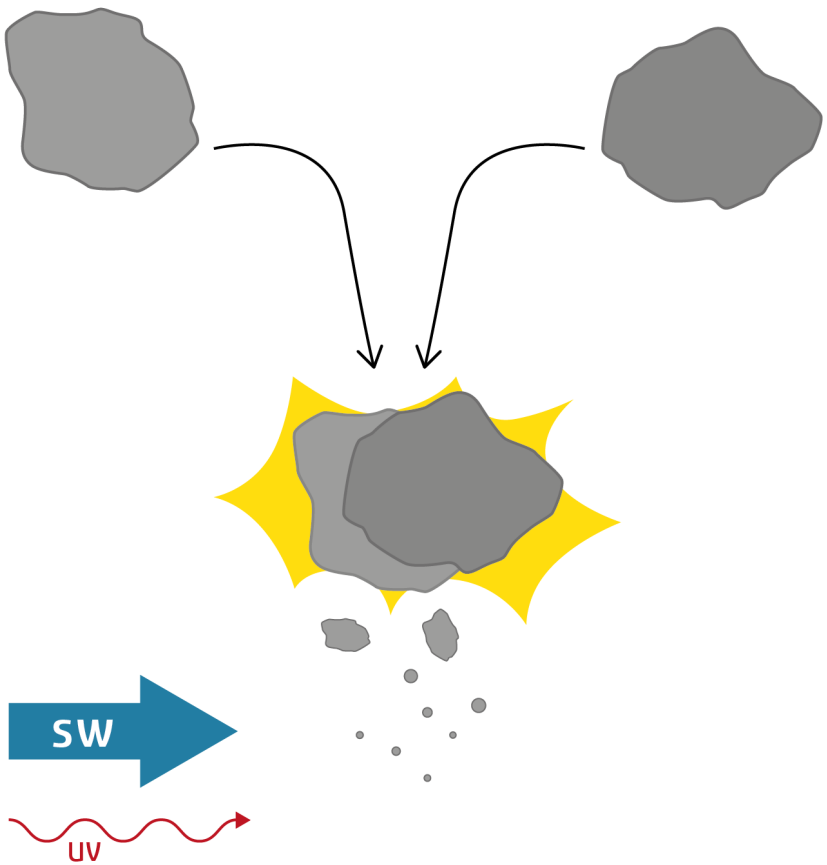
- Stream of comets approaching to few $R_\odot$ (60-120 comets per year).
- Comets disintegrate between $4R_\odot$ and $40R_\odot$.
- Mass is transferred into SW as PUI.

Characteristics:

- Almost permanent, but highly fluctuating production of PUI
- Composition estimation: 43%H, 27% O, 25% C, 5% Mg, Si, Fe and others.
  $\rightarrow$ almost no He and Ne!
- Change of PUI composition in certain time periods.

Dust-dust collisions

→ Mann & Czechowski 2005, *Dust destruction and ion formation in the inner solar system*



Dust-dust collisions

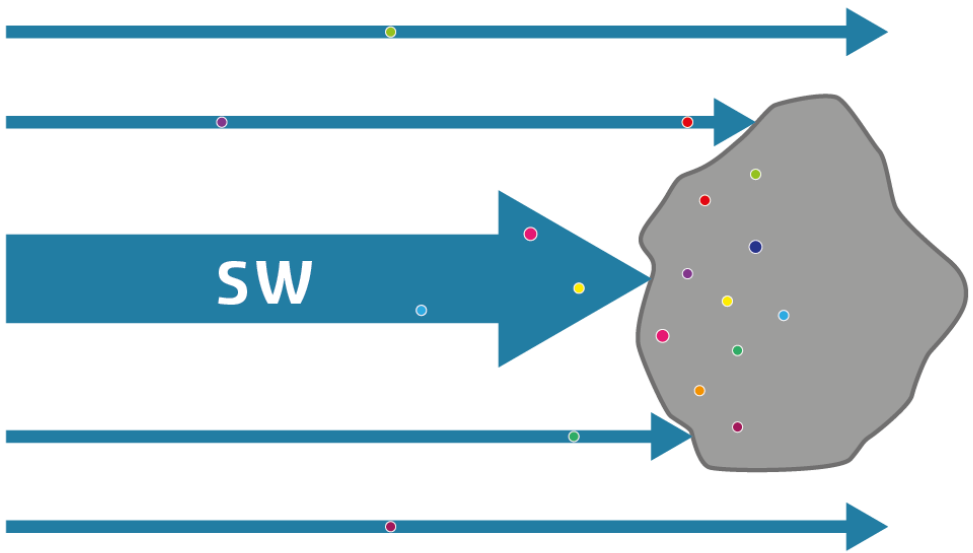
- Dust orbital motion and Poynting-Robertson effect increase dust density towards sun.
- Vaporizing dust-dust collisions create neutral atoms

Problem: SW composition!

- Dust grains are not supposed to contain He or Ne.
- Even if SW ions might be implanted into dust grains, their flux would be below solar wind ratios.

Solar wind recycling

→ Schwadron et al. 2000, *Inner source distributions: Theoretical interpretation, implications, and evidence for inner source protons*



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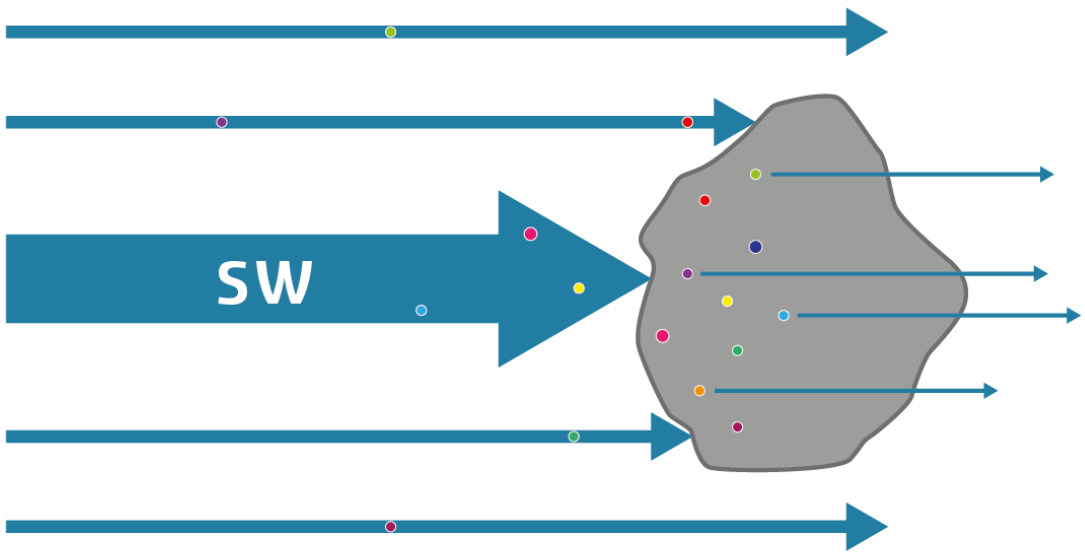


Solar wind recycling

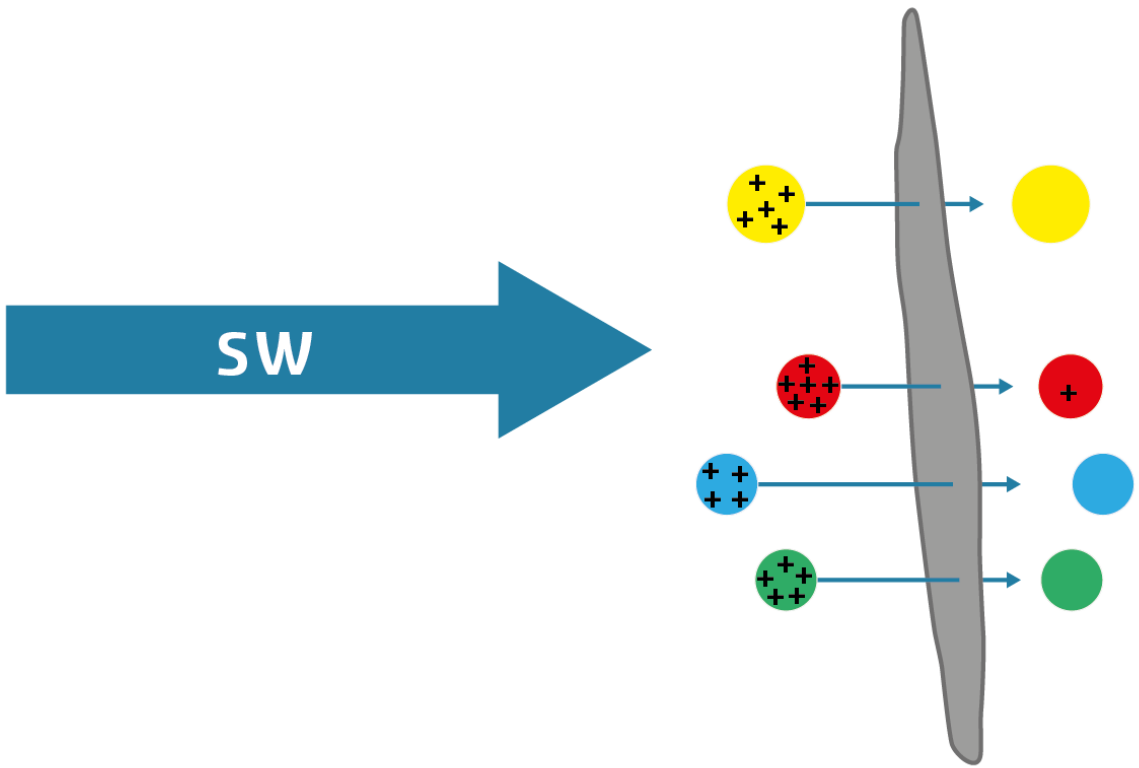
- SW ions are implanted into μm-sized dust particles near the sun.
- Dust becomes saturated with SW particles.
- Neutral molecules/atoms are reemitted or sputtered from the dust.

Characteristics:

- Complicated storage-release process.
- Also grain material must be released.
- Requires much more dust than observed to reach PUI fluxes.

Solar wind neutralization

→ Wimmer-Schweingruber & Bochsler 2003, *On the origin of inner-source pickup ions*



Solar wind neutralization

- Assume dust particles near sun with a diameter in the order of the penetration length ($\sim$ nm) of SW ions.
- SW particle pass through dust and exit as neutrals or lower charged ions.

Problem: Stability over solar cycle!

- in solar maximum number of CME increase
- CME might trap nm-dust particles

Comparison

	Sungrazing comets	Dust-dust collisions	SW recycling	SW neutralization
SW composition	No	No	Possibly	Yes
Peak near the sun	Possibly	Possibly	Yes	Yes
Observed PUI flux	Possibly	Possibly	Unlikely	Possibly
Randomly distributed	Unlikely	Yes	Yes	Yes
Stability	Yes	Possibly	Yes	Unlikely

After: Allegrini et al. 2005, *Stability of the inner source pickup ions over the solar cycle*

Summary

- Pickup ions are former neutral atoms ionized and picked up by the SW. They are mostly singly charged and show specific velocity and spatial distributions.
- Two sources: Interstellar and inner.
- Currently no proposed inner source production scenario can explain all observations.
- SoLO measurements might help understanding the inner source and pickup ions in general.

References

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