Ulysses/SWICS Investigations

Backmapping of in situ composition data

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Overview

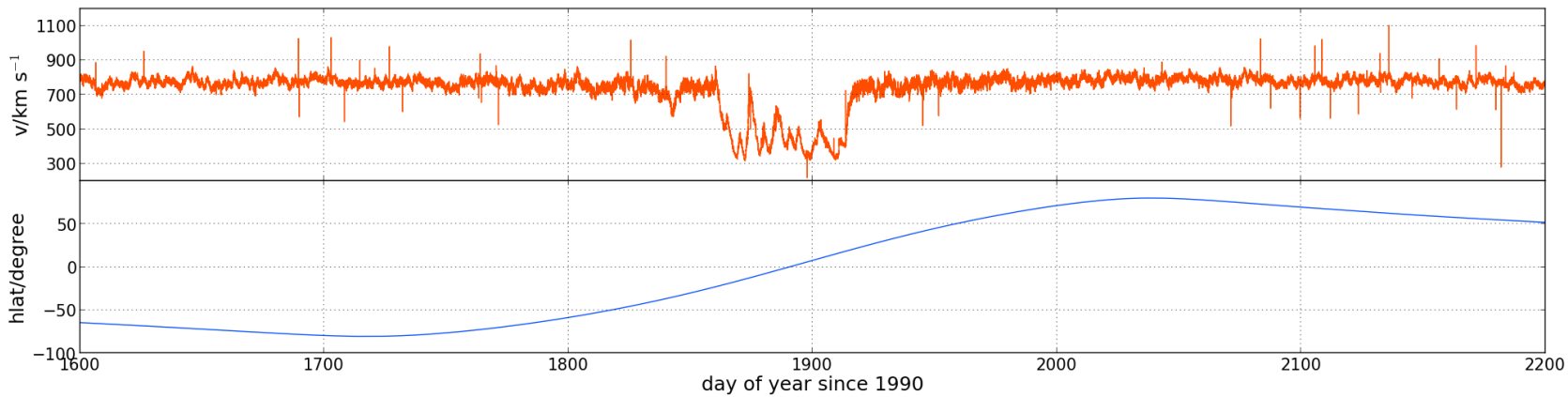
Just some bullet points to give you an overview...

- introduction and goal of this work
- The Ulysses mission and the instruments used for this study
- Ballistic backmapping of in situ measurements
- Combining backmapped solar wind footpoints with the PFSS model
- First implications for solar wind origins

Introduction: The Solar Wind

The fast solar wind

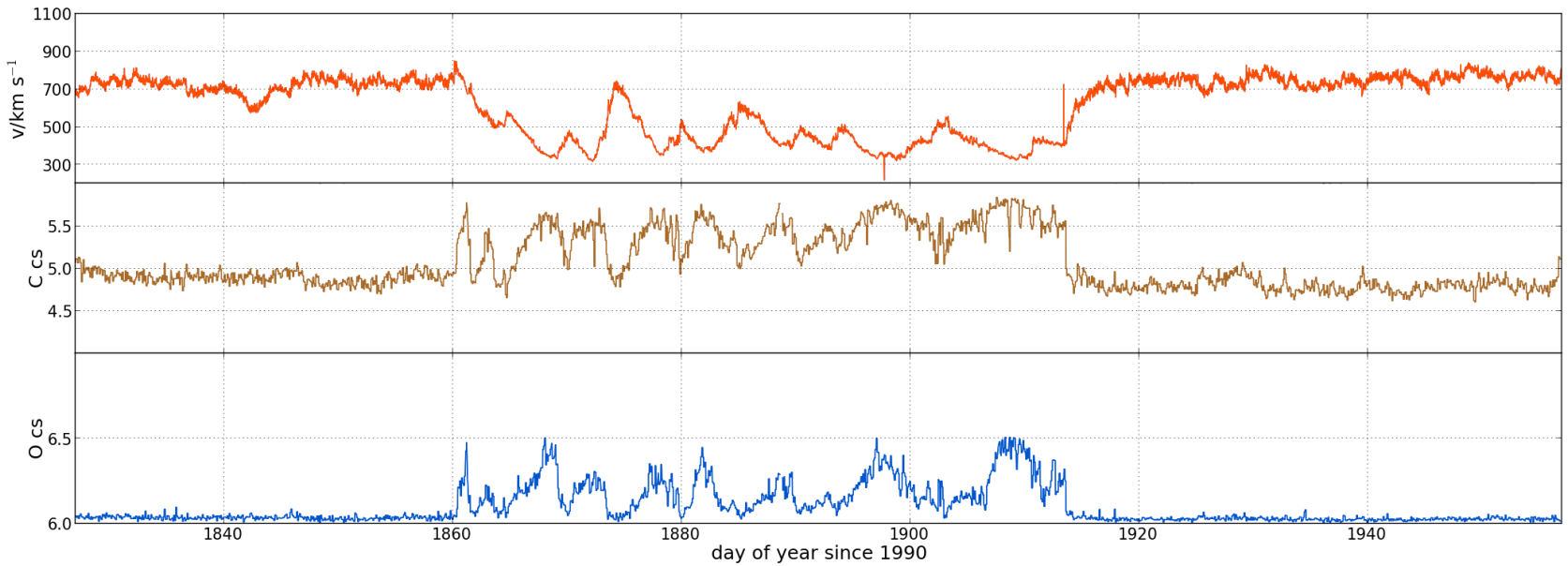
A steady nearly constant high speed solar wind, predominantly found on high heliographic latitudes.



Introduction: The Solar Wind

The slow solar wind

A variable low speed solar wind, predominantly found on ecliptic heliographic latitudes.



Introduction: The Sources of the Solar Wind

The fast solar wind: The ulysses mission unambiguously revealed the coronal holes to be the source of the fast solar wind.

The slow solar wind: The source for the slow solar wind remains elusive. Charge-state composition and FIP effect hint at a source location different from the coronal holes.

Introduction: Possible Source Locations

One source for the slow solar wind could be found in magnetic reconnection processes between open and closed magnetic field lines, see for example *L.A. Fisk*, 2003.
These reconnection events could take place...

- near the borders of coronal holes, where open and closed field line regimes adjoin each other
- deeper inside closed field line regimes due to foot-point motion of "stray" open field lines
- deeper inside closed field line regimes along the so called s-web, see S.K. Antiochos

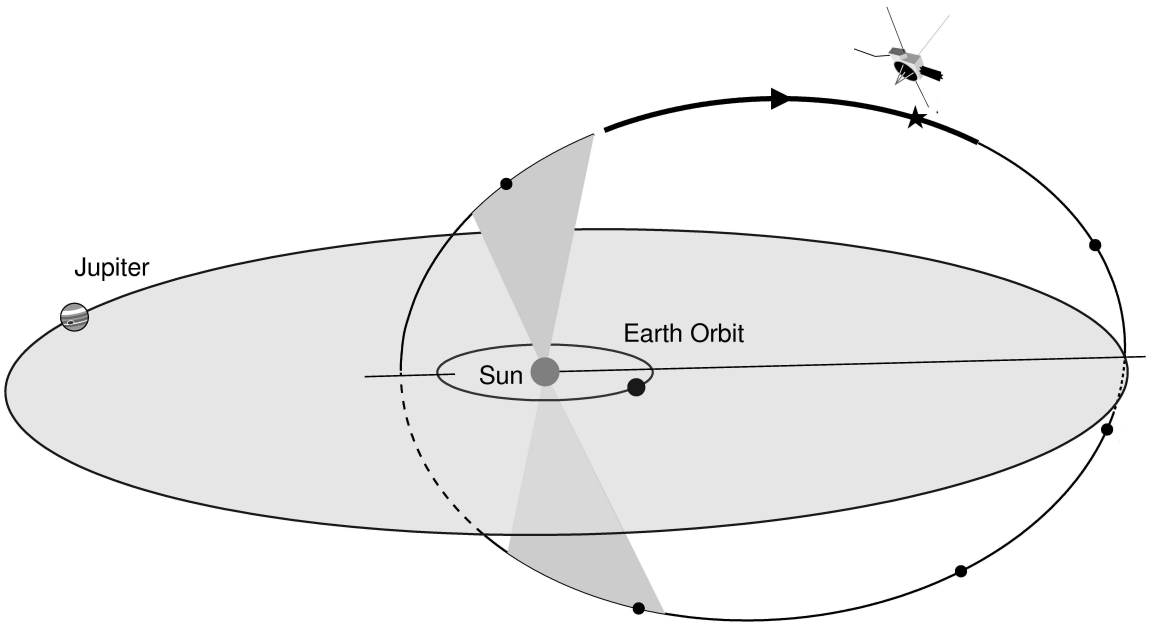
Introduction: Goal of this Work

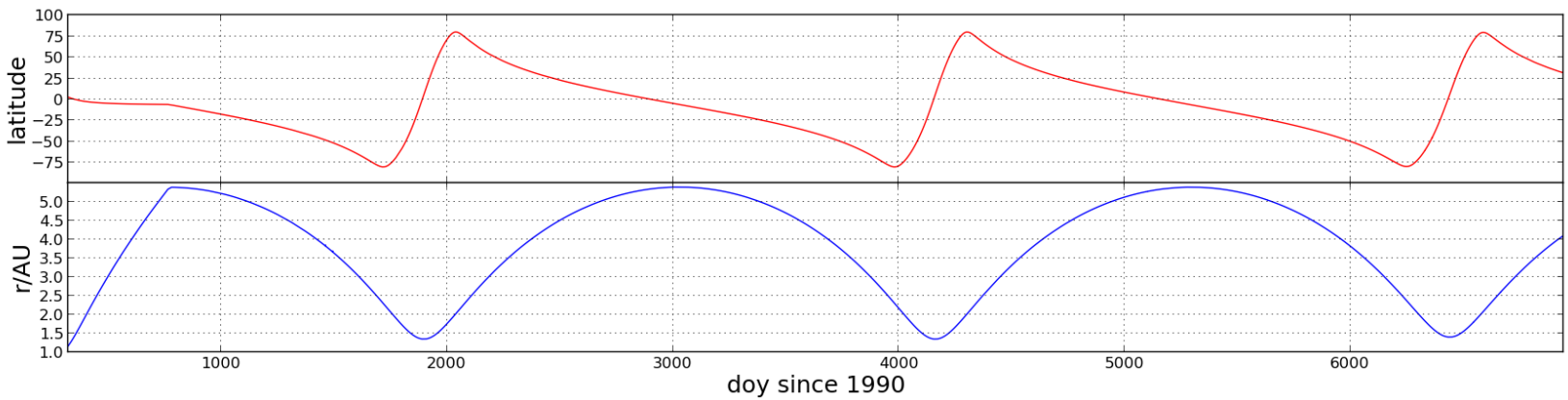
- Transitions between solar wind regimes are accompanied not only by changes in the solar wind velocity but also by changes in the charge state composition, electron temperature and low FIP elements abundance.
- we want to take these in situ measured transitions and map them back to there source location
- since the slow solar wind might originate from the coronal holes borders, we will focus on the position of the determined source location relative to the coronal hole borders

The Ulysses Mission

The Orbit of Ulysses

- orbit period: ca 6 years
- distance to the sun: from 1.33 to 6 AU
- max latitude: 80°

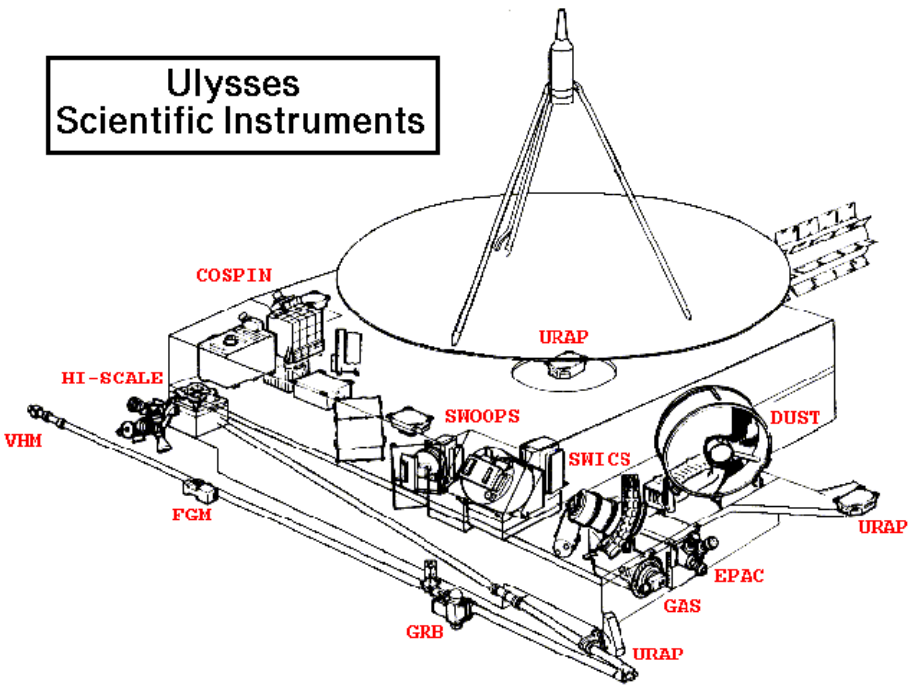




The Ulysses Mission

The Ulysses Probe

Ulysses operated from 1990 until 2009. During this time, roughly 6600 days of data have been accumulated.

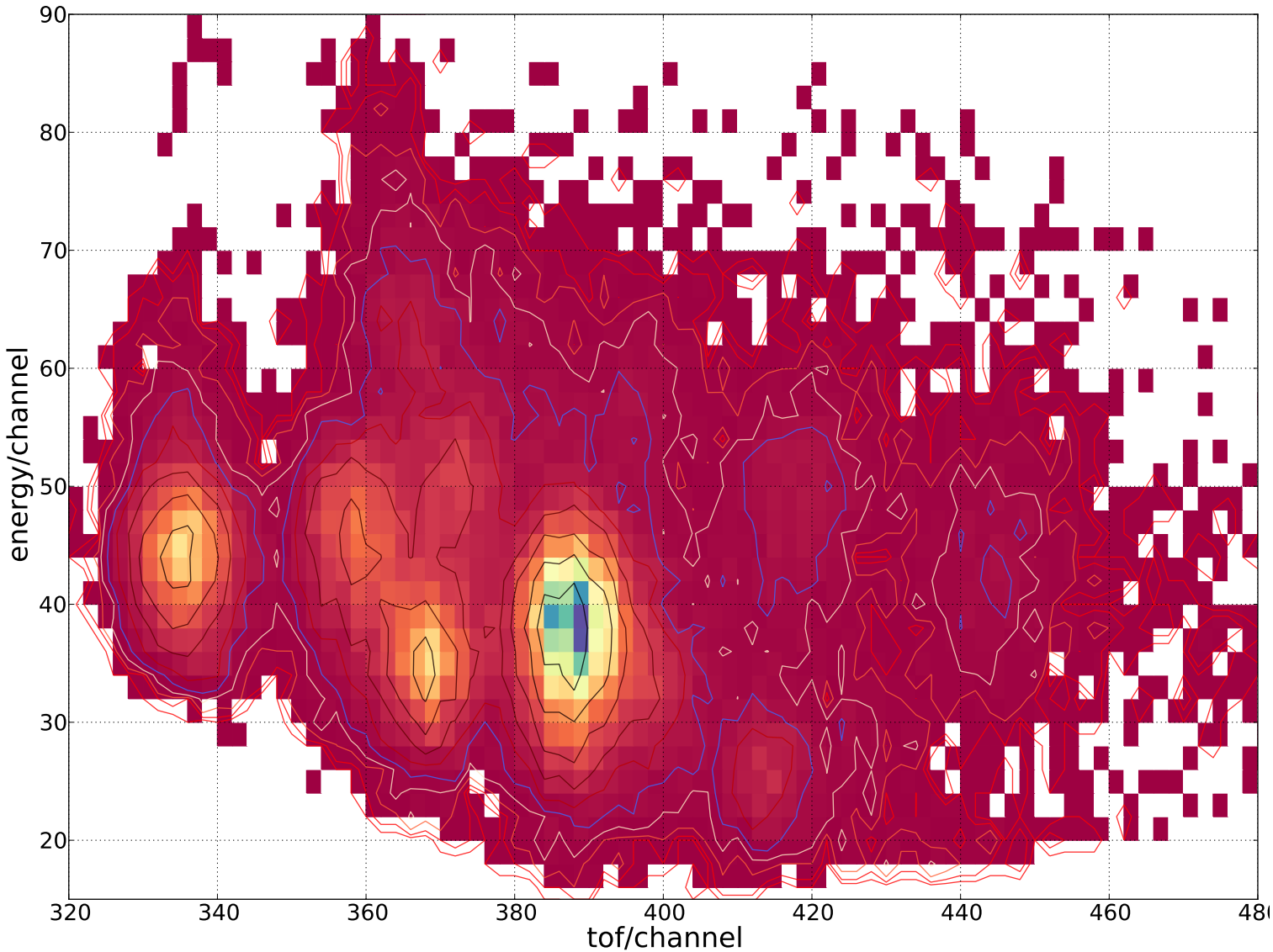


Instruments used for this study are:

- SWICS
- SWOOPS
- VHM

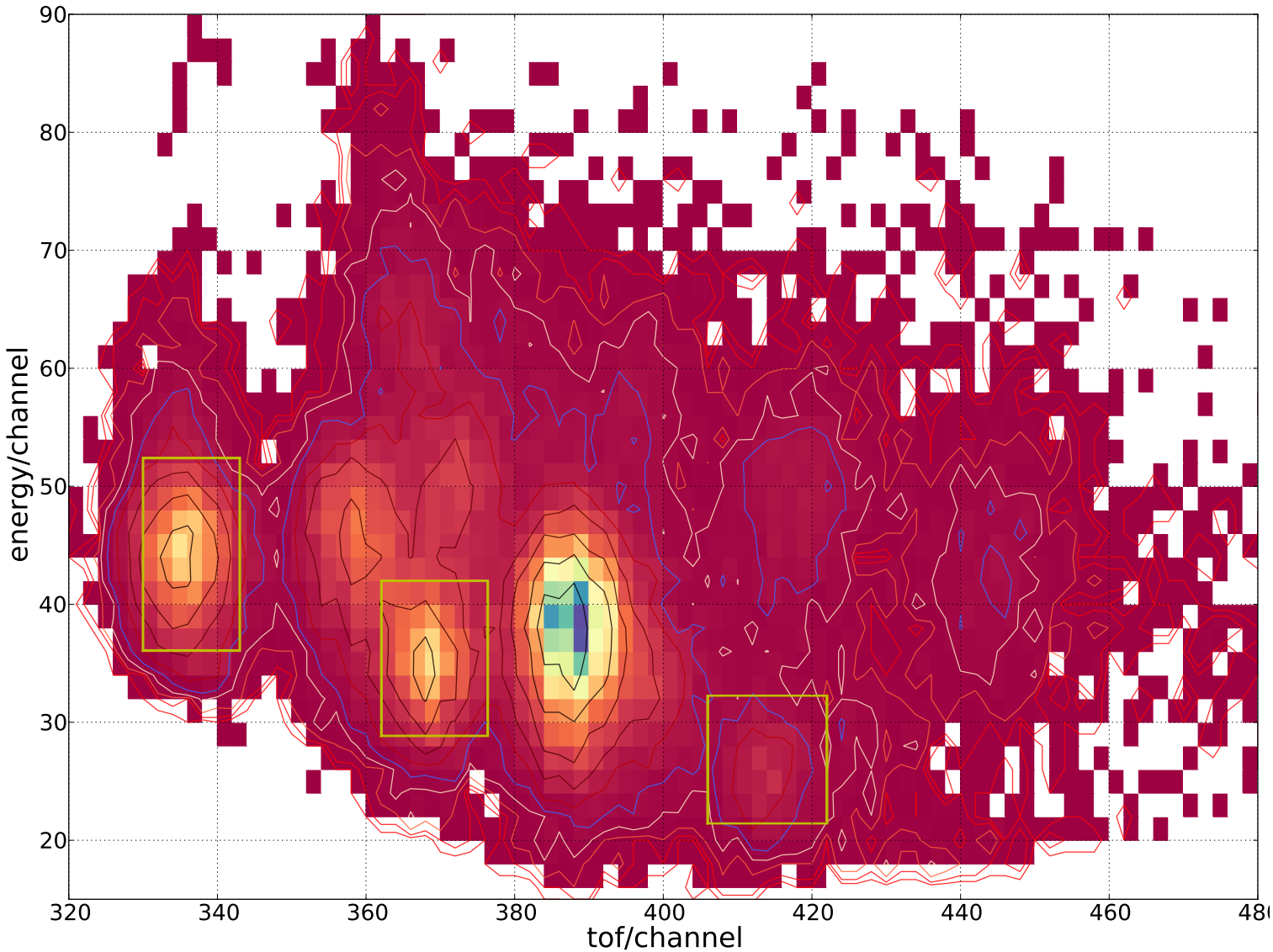
Swics Data

A SWICS data sample, shown is the energy-tof matrix



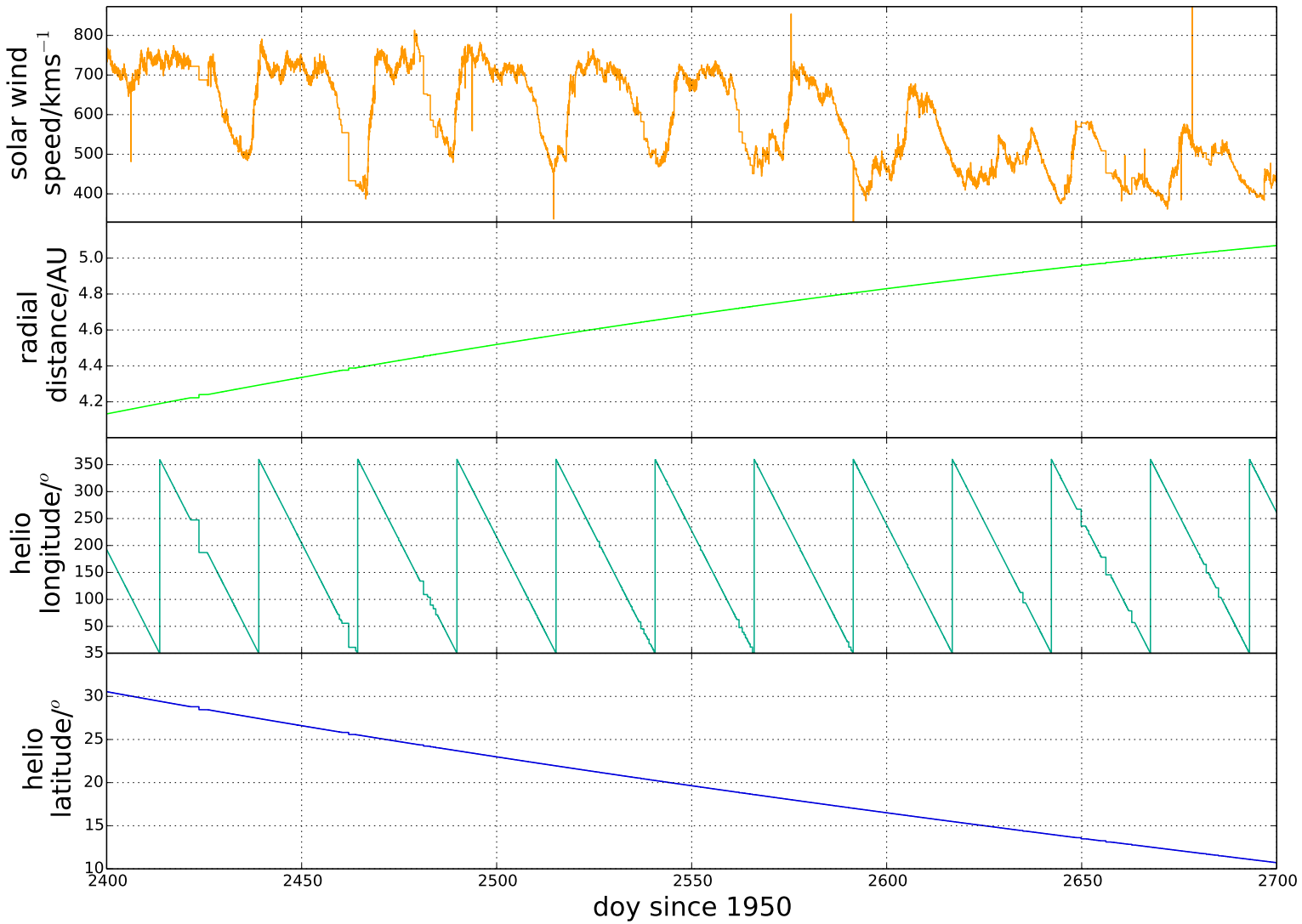
Swics Data: Extraction

Box rates are applied to C^{4+}, C^{5+} and C^{6+}



Ballistic Back Mapping

The in situ measured solar-wind speed and the Ulysses heliographic orbit data are used for the back mapping.



Ballistic Back Mapping

Now to use these parameters for back mapping. By using ballistic back mapping one can determine the origin of a measured ion under the assumption that the solar wind expands radially away from the sun.

$h_s = h + \frac{\omega}{v_{sw}}$

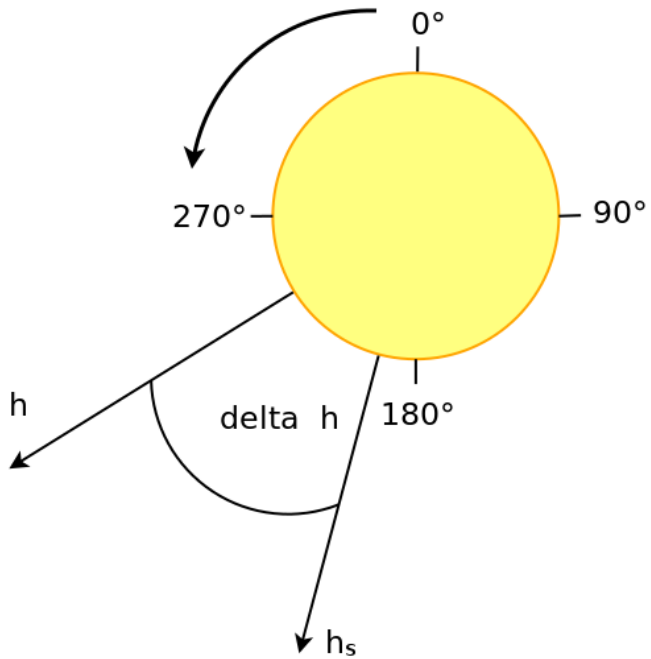
h_s: source longitude

h: spacecraft longitude

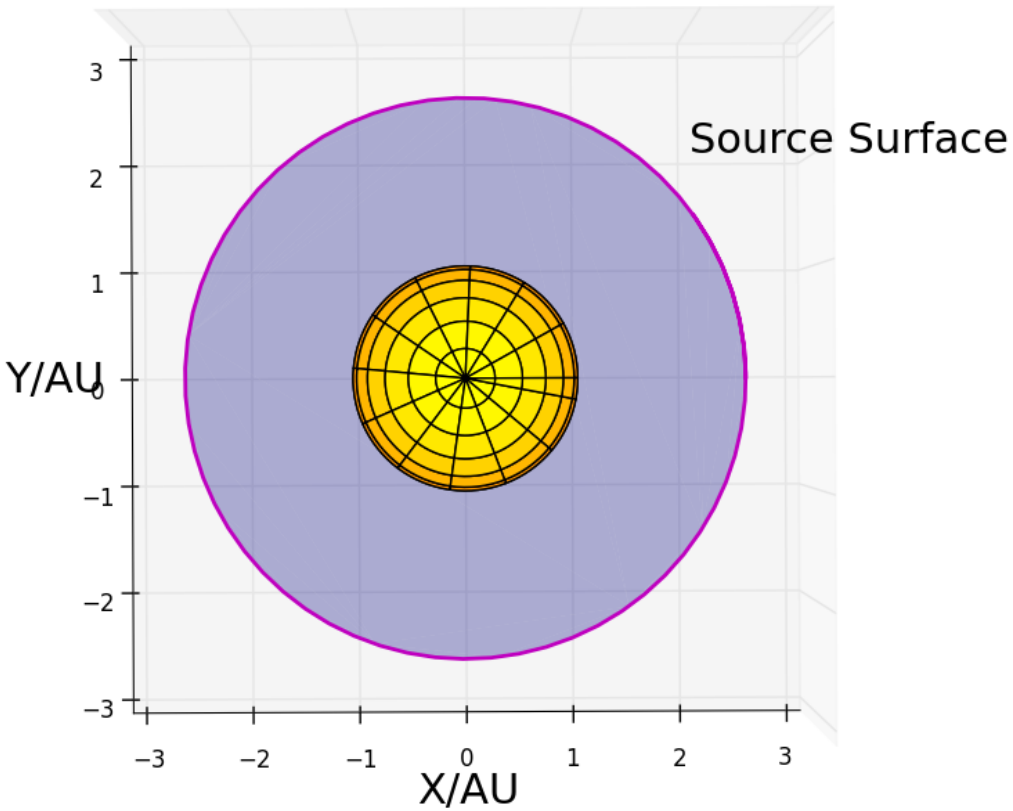
r: radial distance sun-spacecraft

ω: sun's angular velocity

v_{sw}: solar wind speed



Ballistic Back Mapping

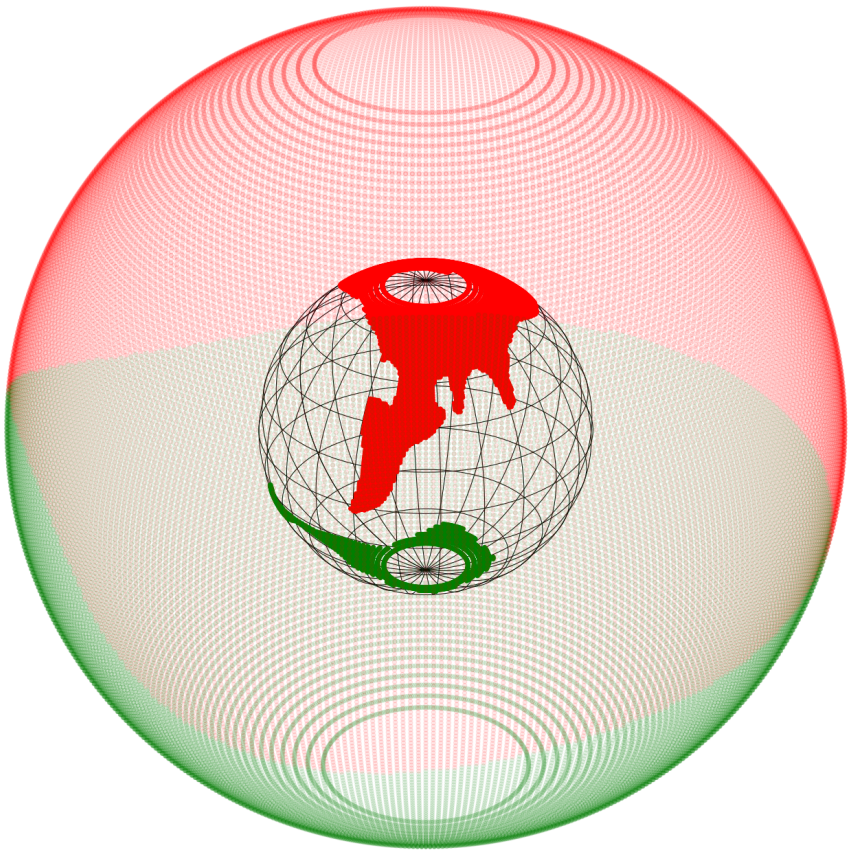


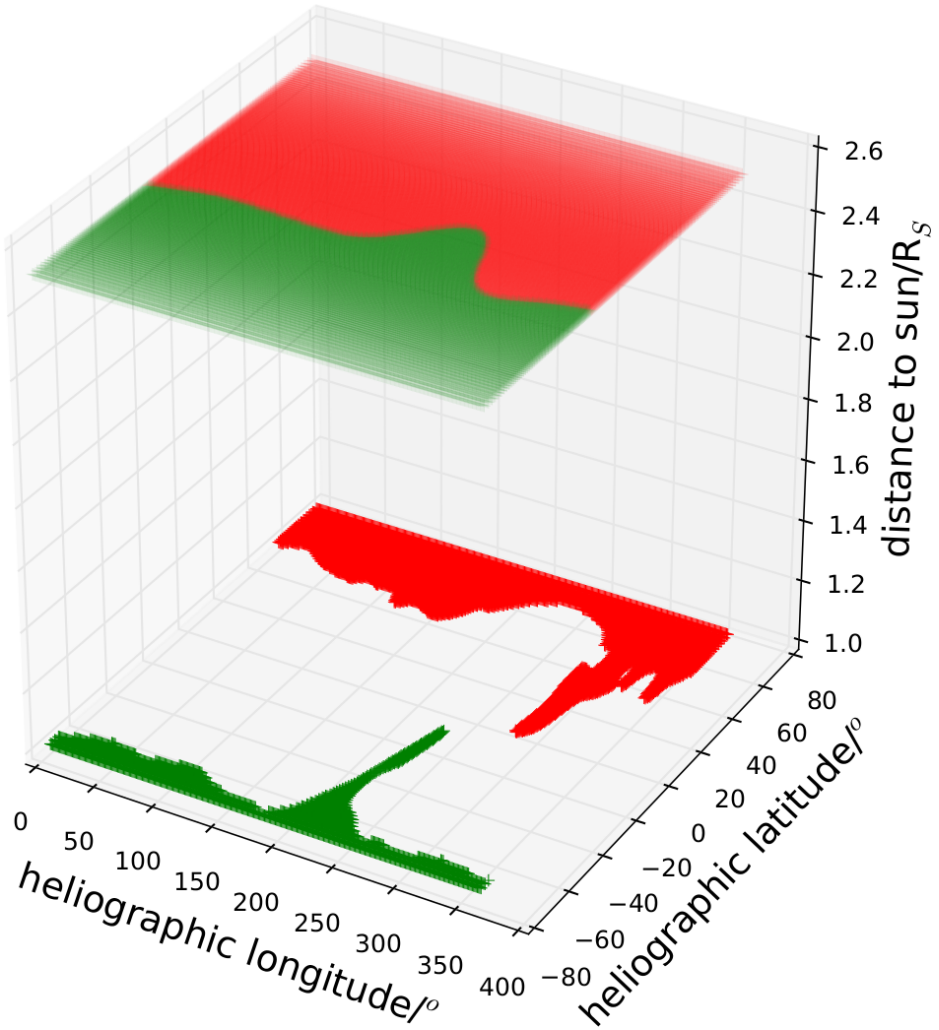
The assumption of radially outward flowing solar wind is not valid for the whole range from the photosphere to the spacecraft.

Beneath a more or less arbitrarily placed surface, called source surface, the solar-wind plasma flow is governed by the sun's magnetic field.

The source surface is assumed to be a sphere with a radius of 2.5 solar Radii.

Back Mapping: Adding the PFFS Model





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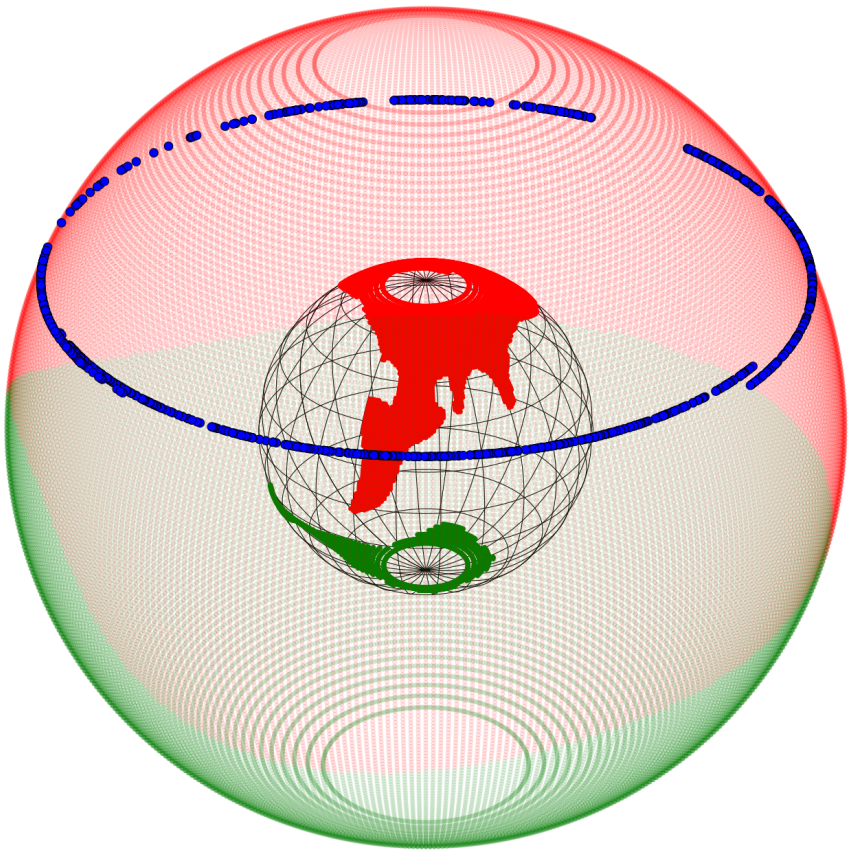

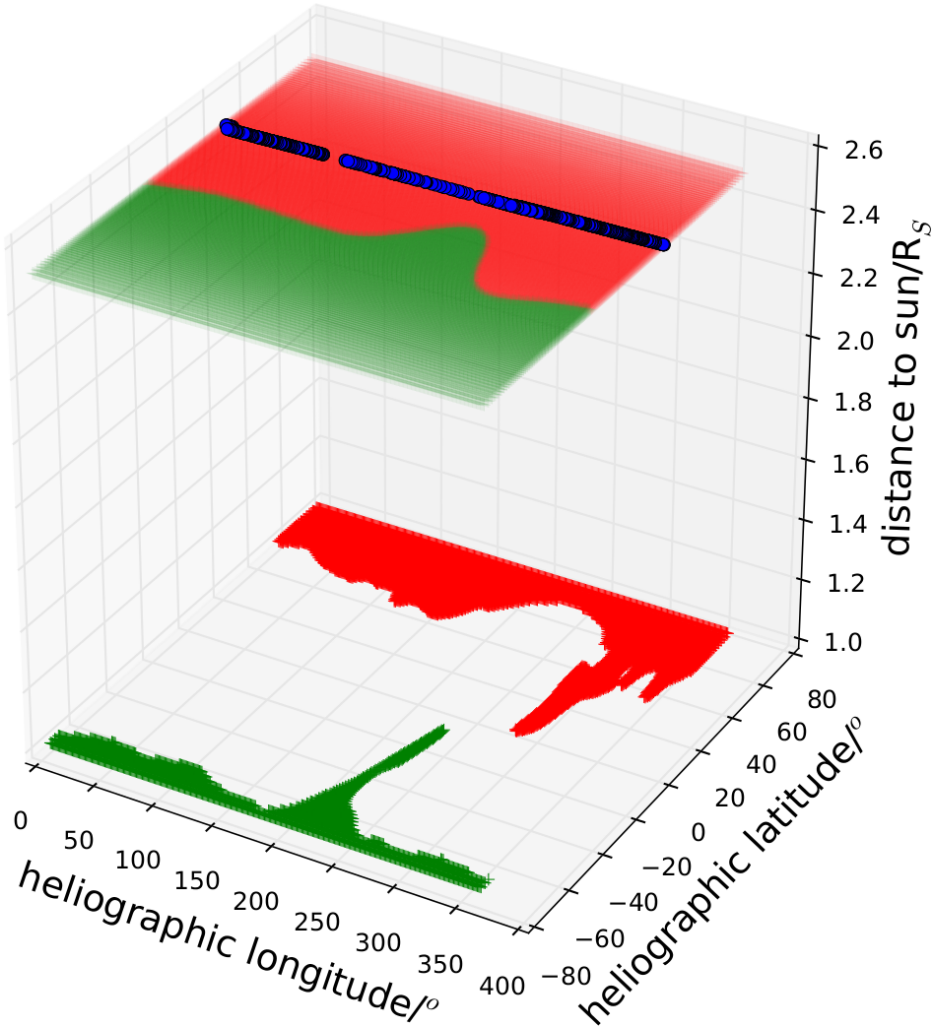

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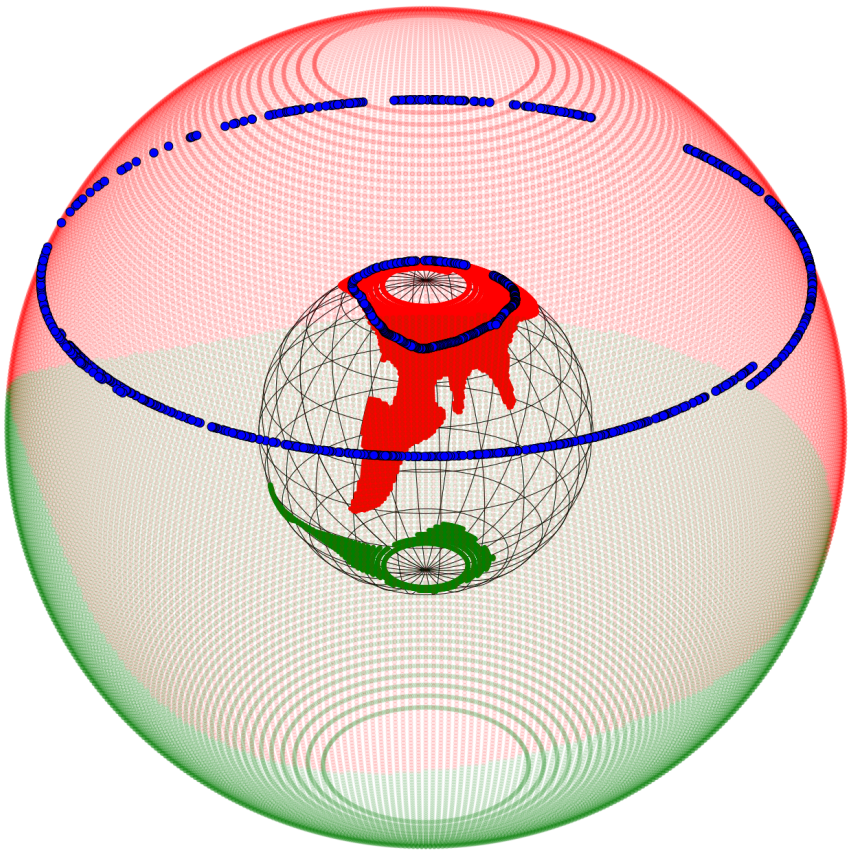
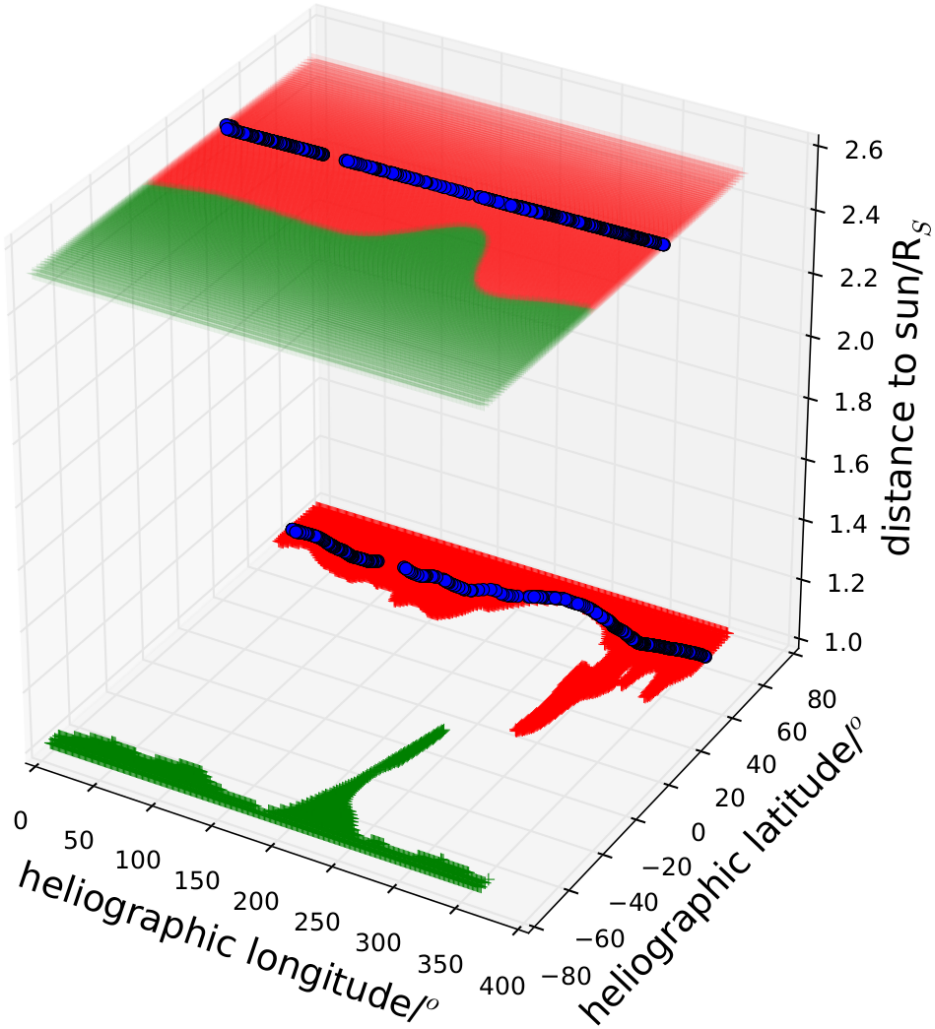
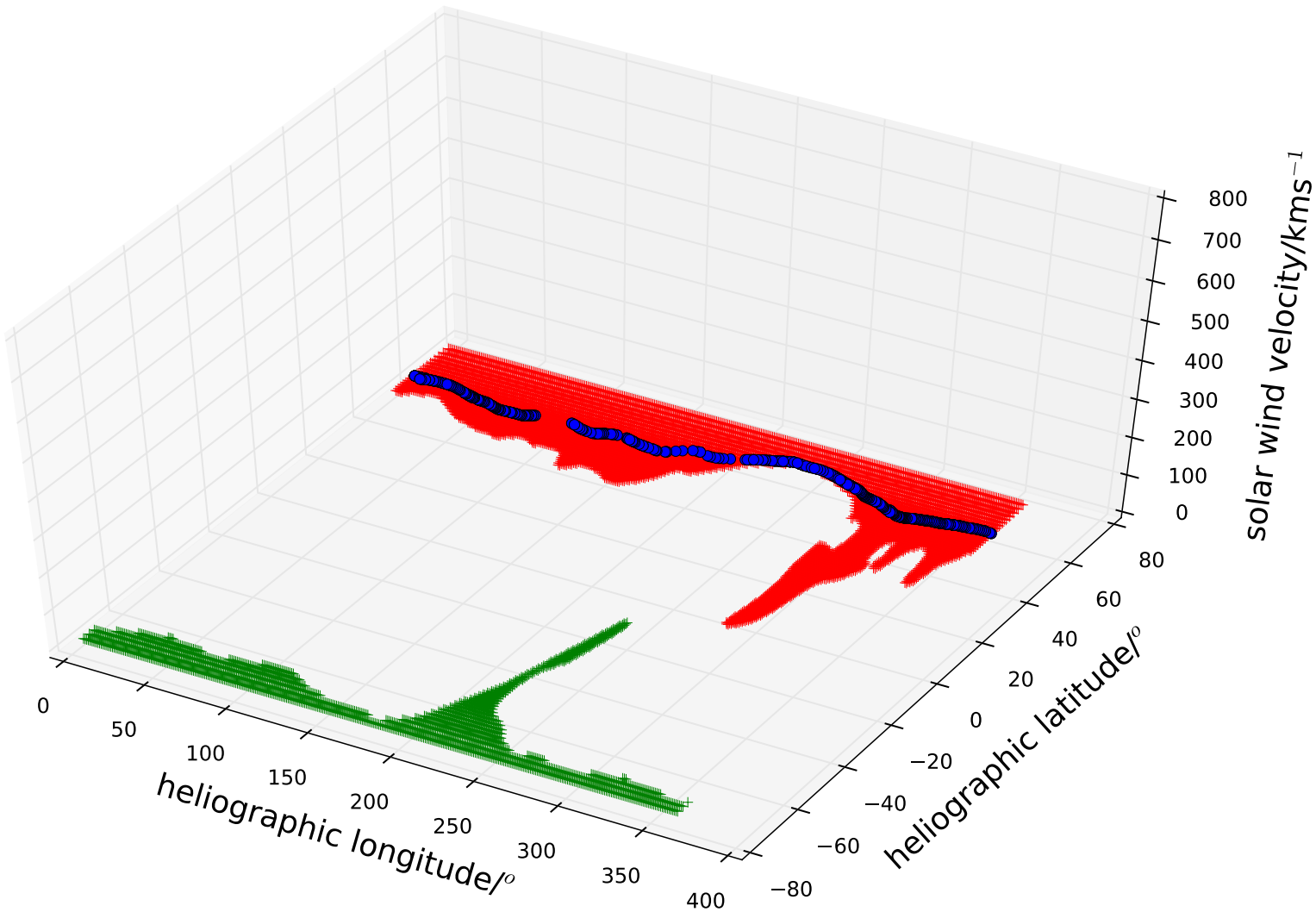




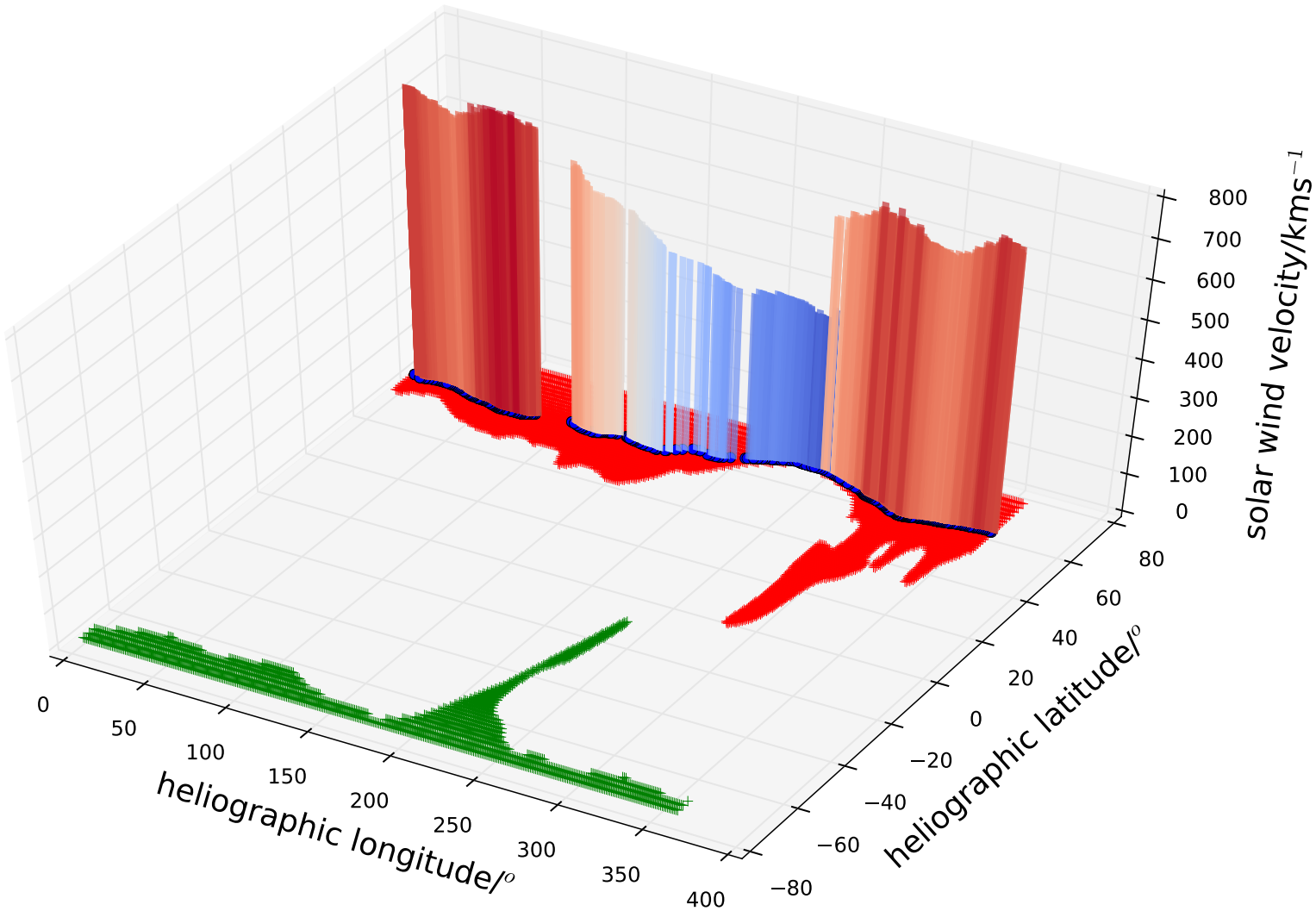
Combining in situ Data and Source Locations

Estimated source locations...



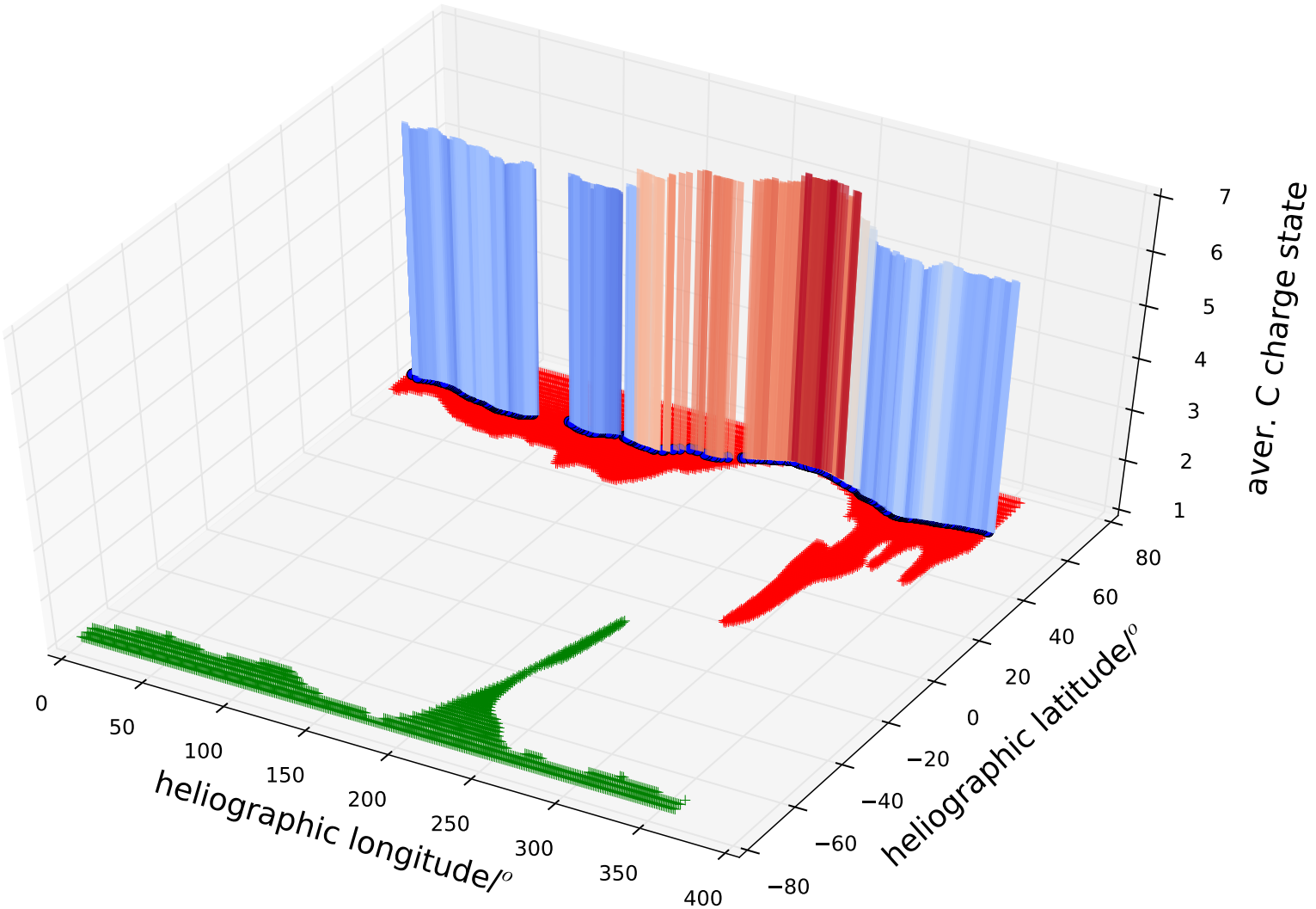
Combining in situ Data and Source Locations

...combined with in situ measured velocity



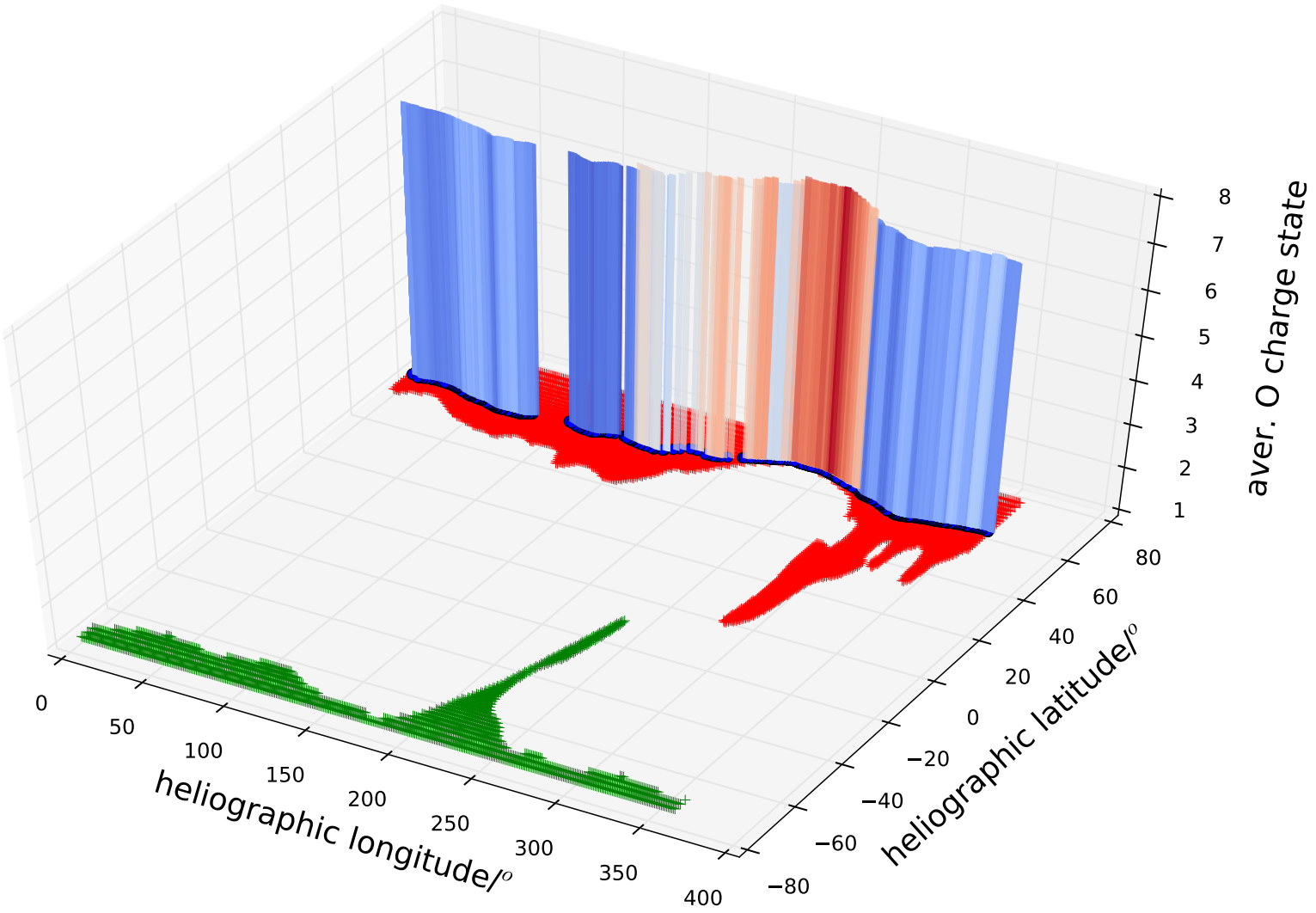
Combining in situ Data and Source Locations

...combined with in situ measured average carbon charge state

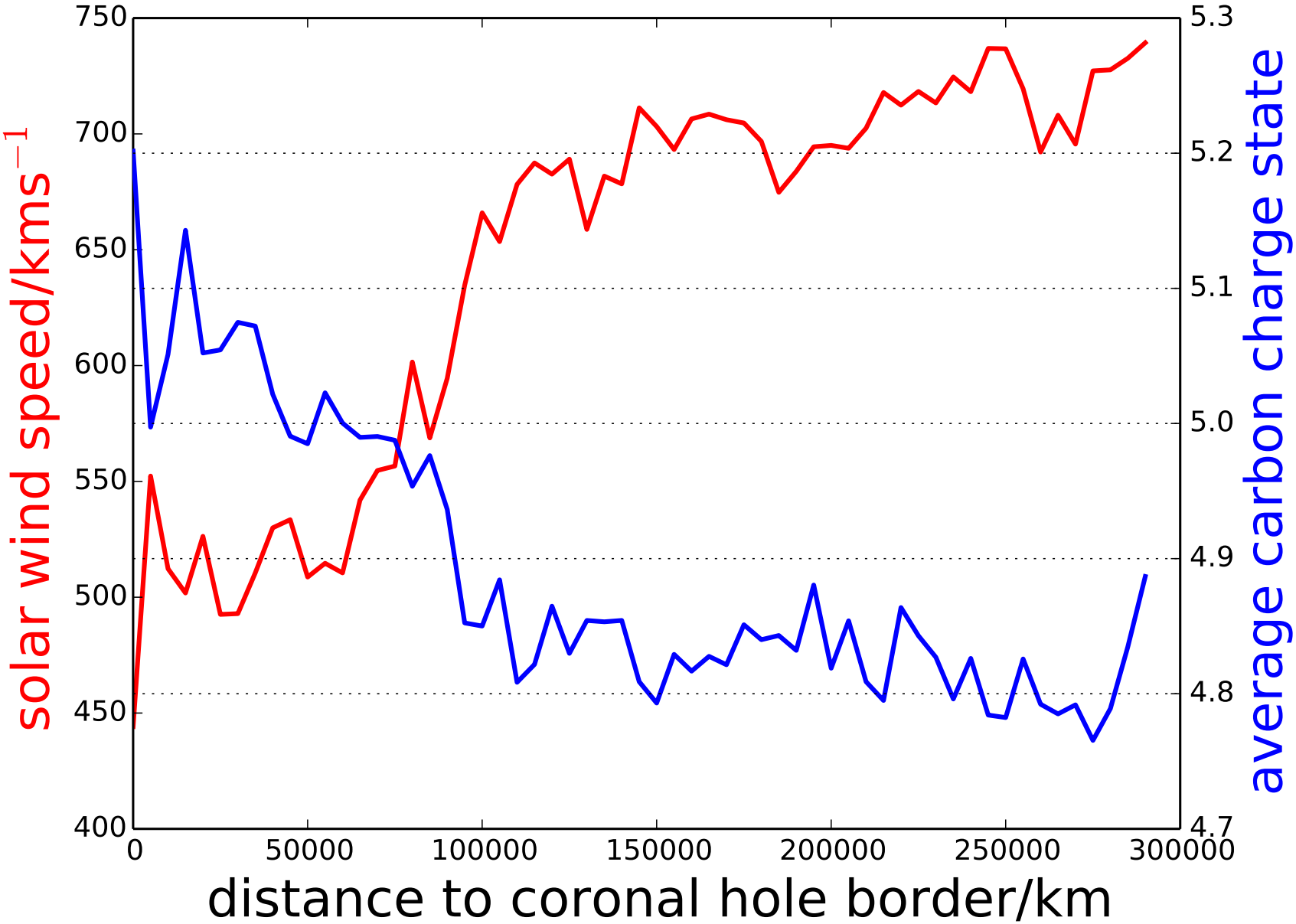


Combining in situ Data and Source Locations

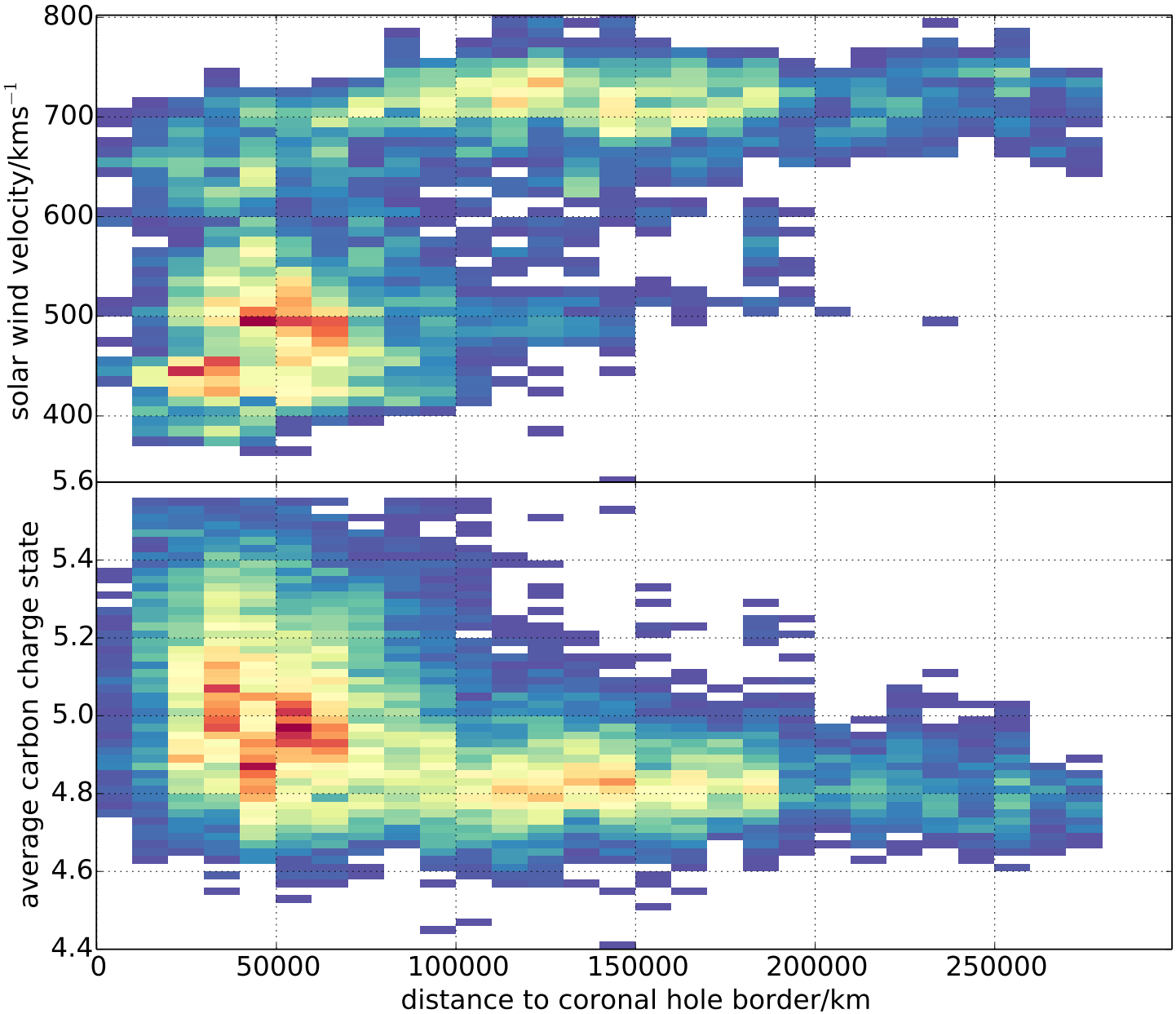
...combined with in situ measured average oxygen charge state



General Relations: Overview



General Relations: a Closer Look



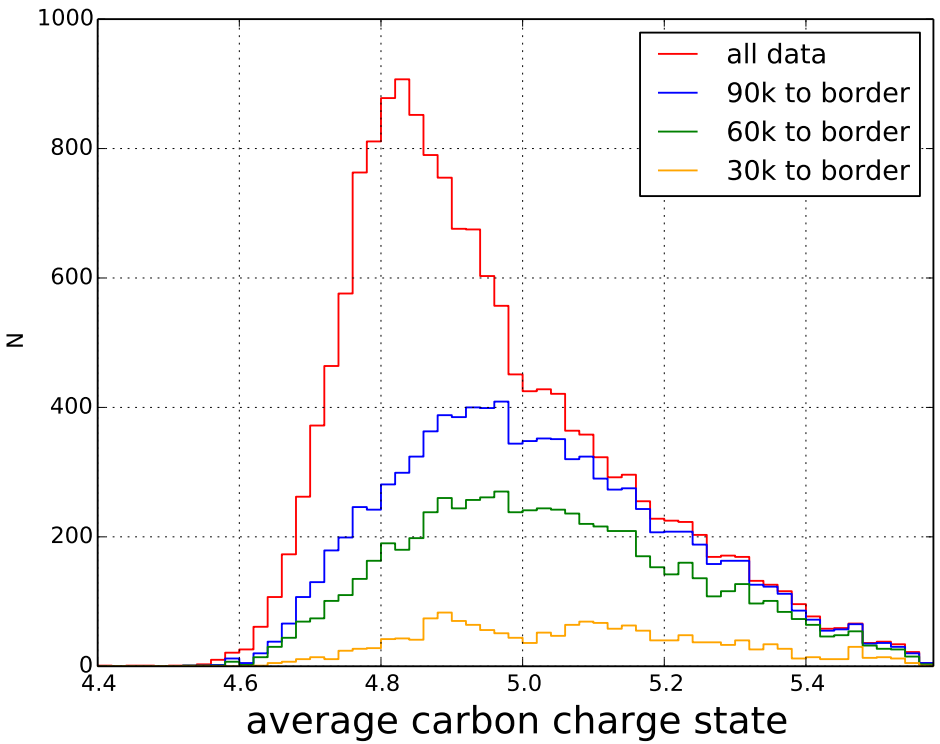
A Closer Look at the Coronal Hole Border

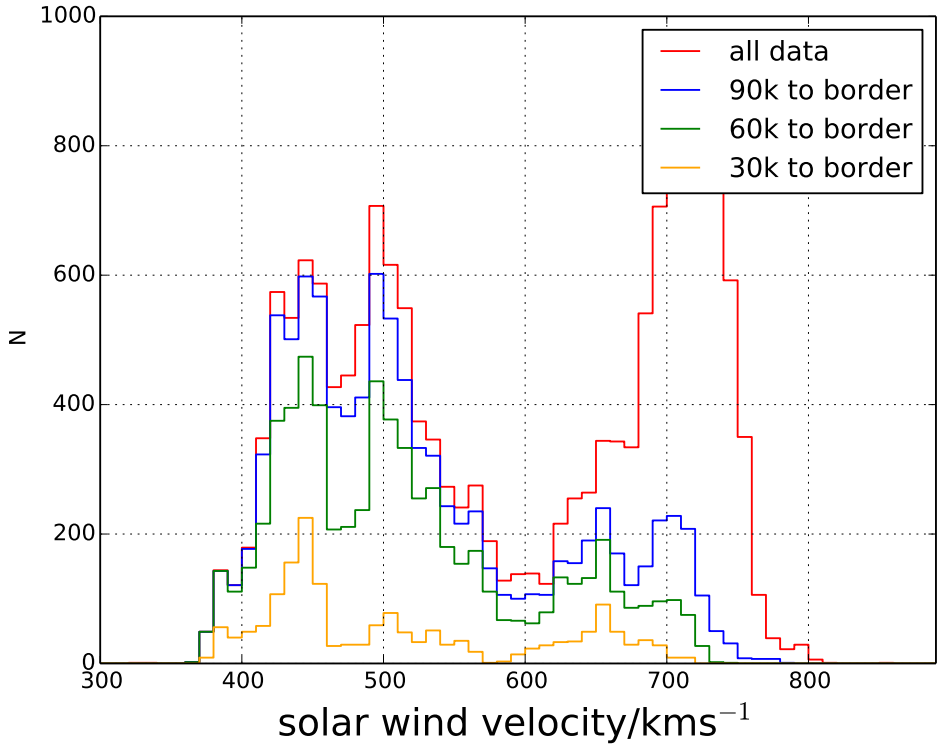
Define some masks to further investigate:

- '90k away from border': all datapoints which are $9 \cdot 10^4$ km and further away from the border
- '90k to border': all datapoints which are $9 \cdot 10^4$ km and closer to the border
- '60k to border': all datapoints which are $6 \cdot 10^4$ km and closer to the border
- '30k to border': all datapoints which are $3 \cdot 10^4$ km and closer to the border

A Closer Look at the Coronal Hole Border

Looking at the alteration of the velocity and charge-state distribution with decreasing distance to the coronal hole border





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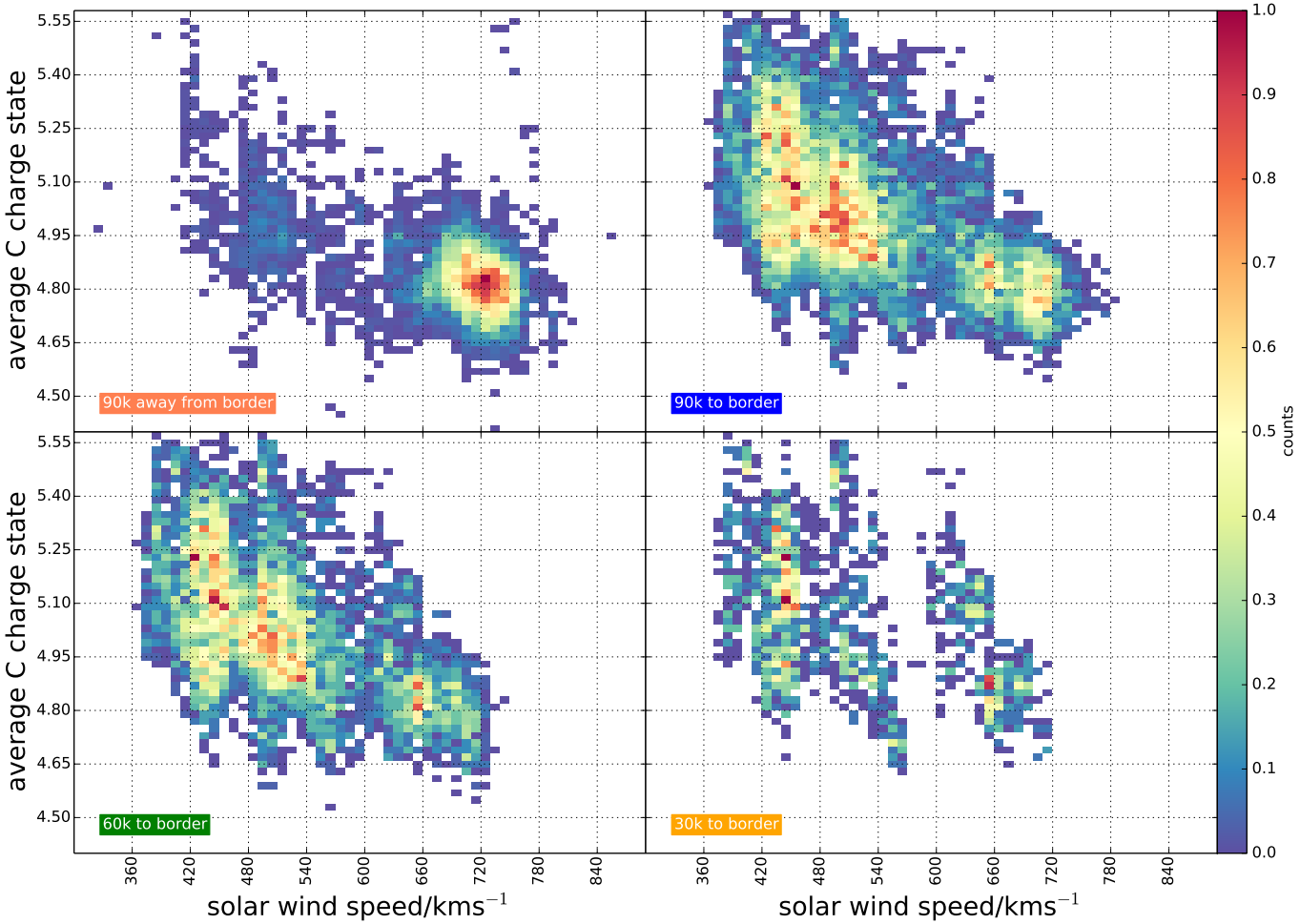

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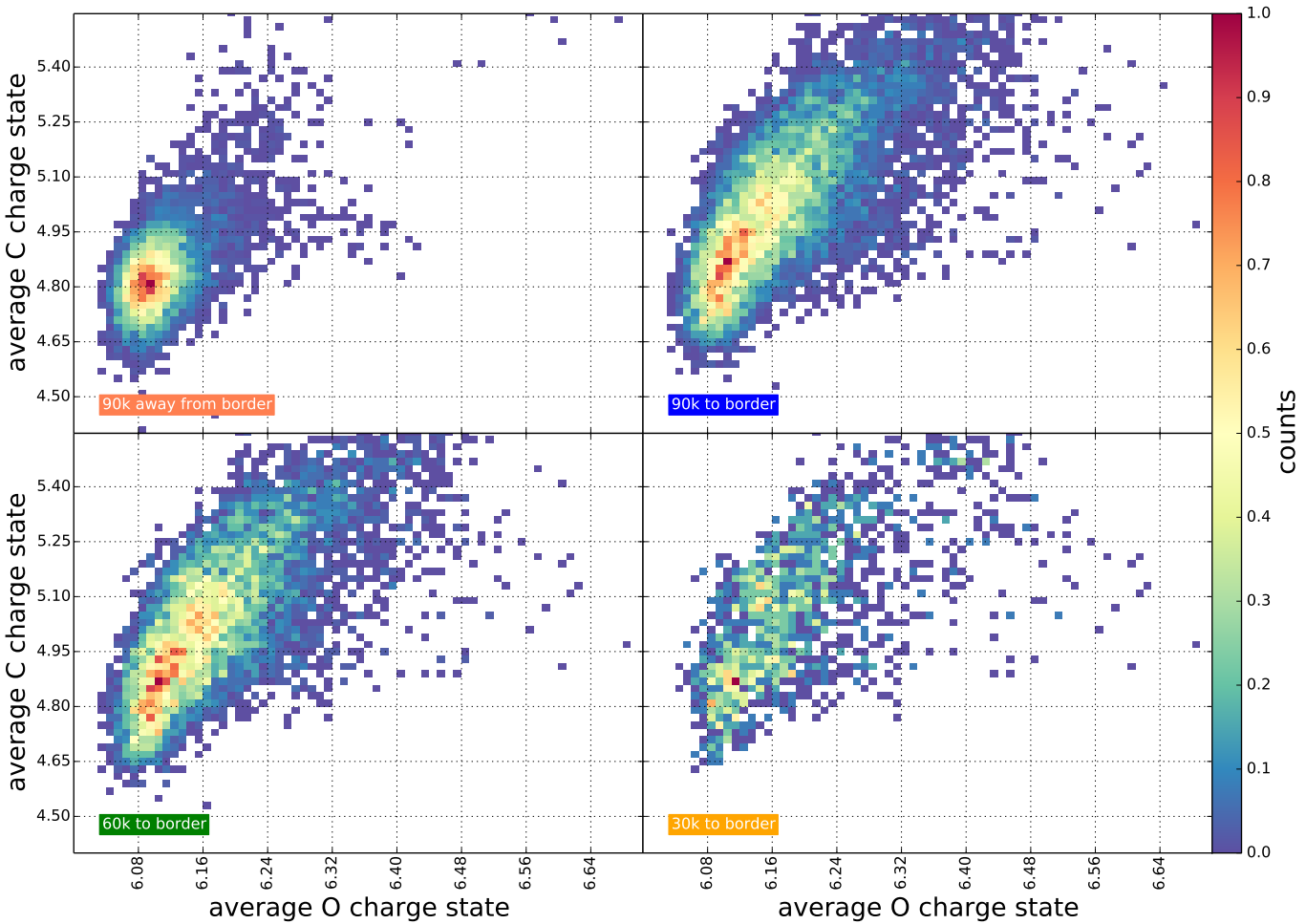
Looking at the alteration of the charge-state distribution with decreasing distance to the coronal hole border



Summary

- in general our work reproduces the common idea that the border regions of coronal holes produce the slow solar wind
- fast solar wind on the other hand originates from deeper within the coronal hole
- but closer examination reveals that the border regions of the coronal hole produce slow solar wind as well as fast solar wind
- everything under the assumption that the PFSS model correctly reproduces the solar magnetic field