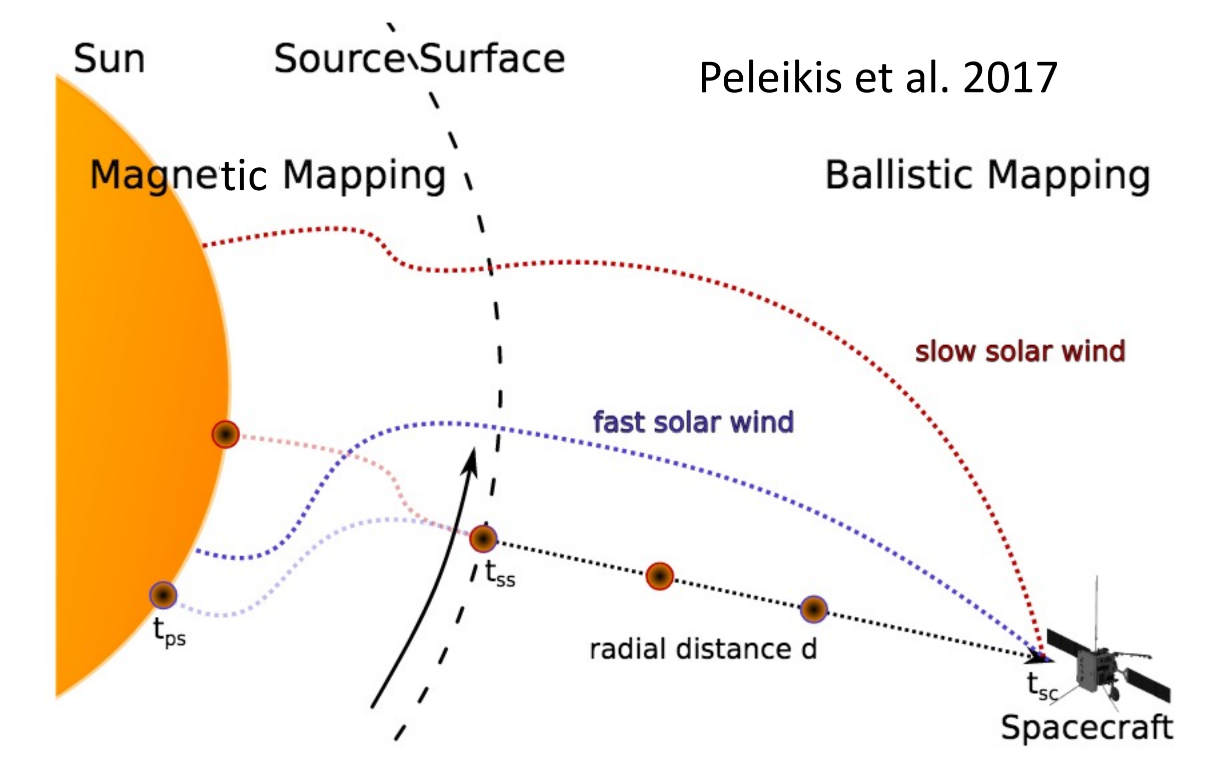
Updates and Early Results from the Heavy Ion Sensor on Solar Orbiter

Susan T. Lepri, Stefano A. Livi, Jim M. Raines, Antoinette B. Galvin, Lynn M. Kistler, Ryan M. Dewey, Benjamin L. Alterman, Frederic Allegrini, Michael R. Collier, and Christopher J. Owen

Linking the Solar Wind and the Corona

- Solar Orbiter (SO) will be key in linking remote measurements of the the Sun out into the solar wind
- Solar wind composition measurements with the SO Heavy Ion Sensor (HIS) will enable us to identify distinct structures in the solar wind and link them to their origin in the corona.
- Linkages will require leveraging remote observations and solar and solar wind models.

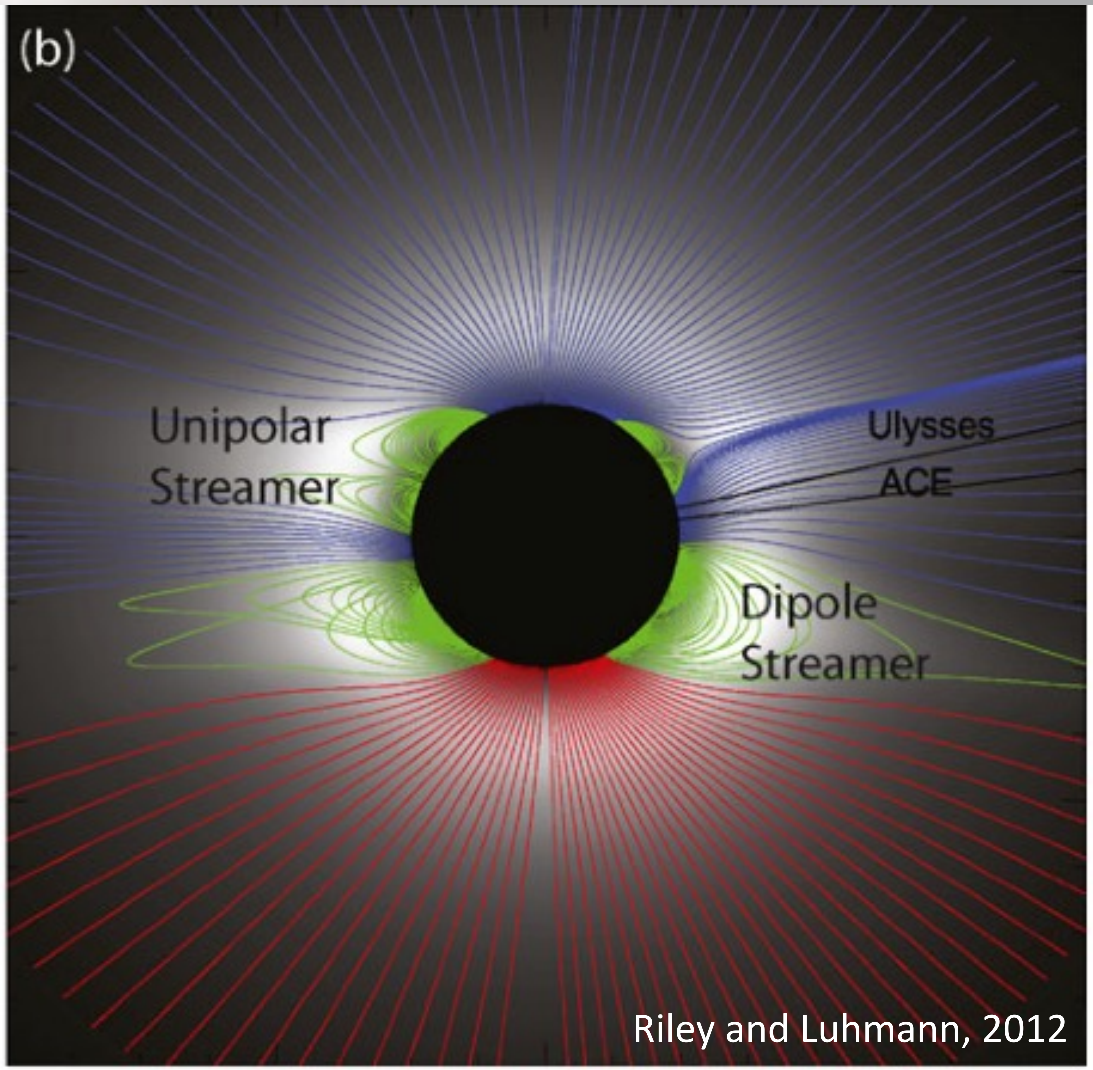


Sources of Solar Wind

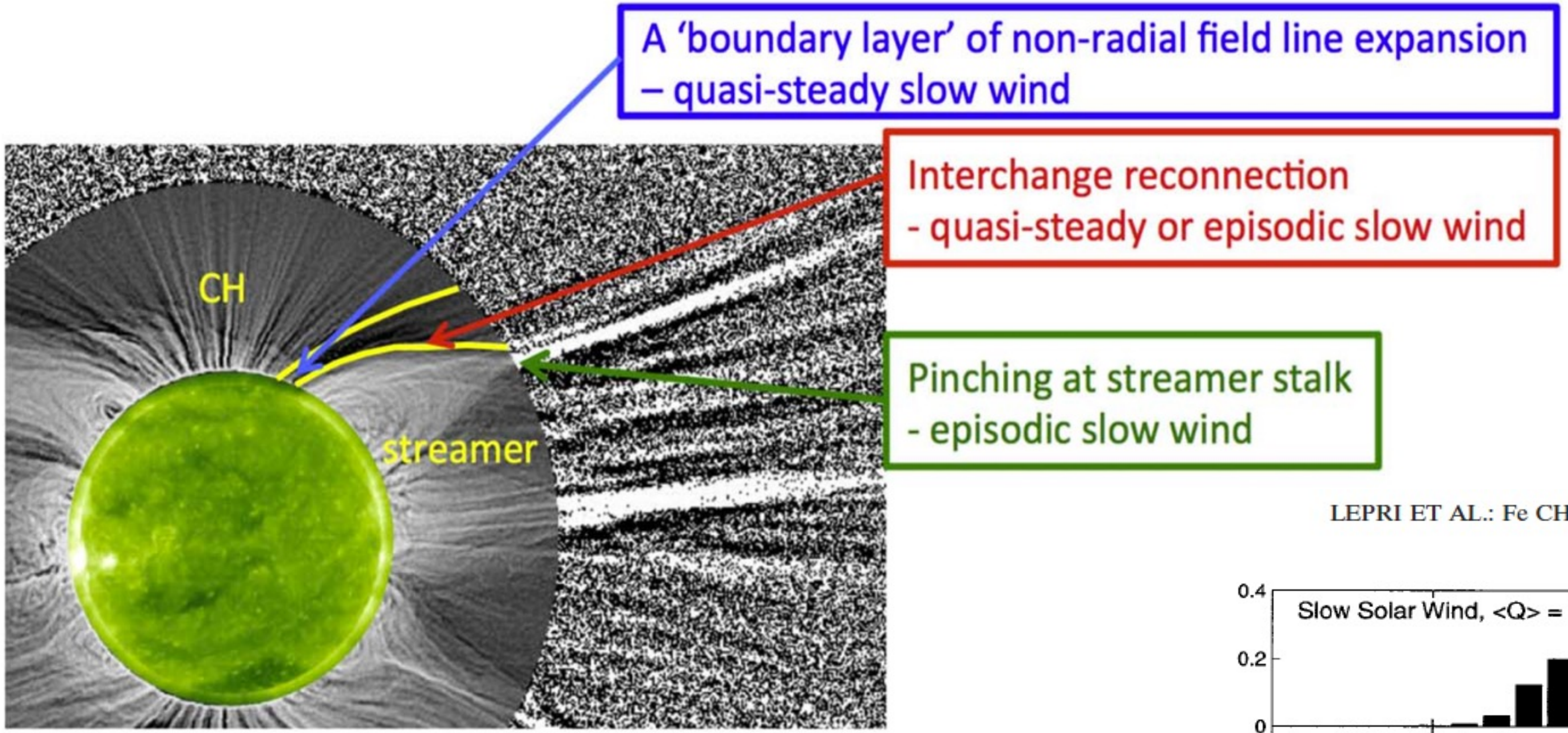
- <u>Open fields</u> in coronal holes create **fast wind**
- <u>Dipolar Streamers</u> centered at the heliospheric current sheet which separate coronal holes of opposite polarity and contribute to **slow wind**
- <u>Pseudostreamers</u>- originates in coronal holes and separates coronal holes of the same polarity. Observed in-situ, these have no embedded current sheet, and are associated with **slow wind**
- <u>Transients</u>-originate in **coronal mass ejections**, or other bursty releases of plasma and contribute to the **fastest wind**

Elemental and ion composition are some of the best indicators of different solar wind source regions

(Owens et al., 2014, Antiochos et al. 2011, Riley and Luhmann 2012, Crooker et al. 2012)



Riley and Luhmann, 2012



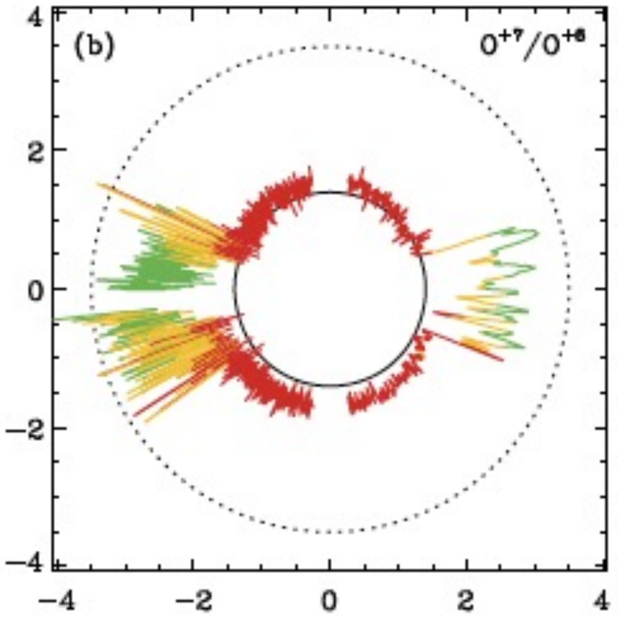
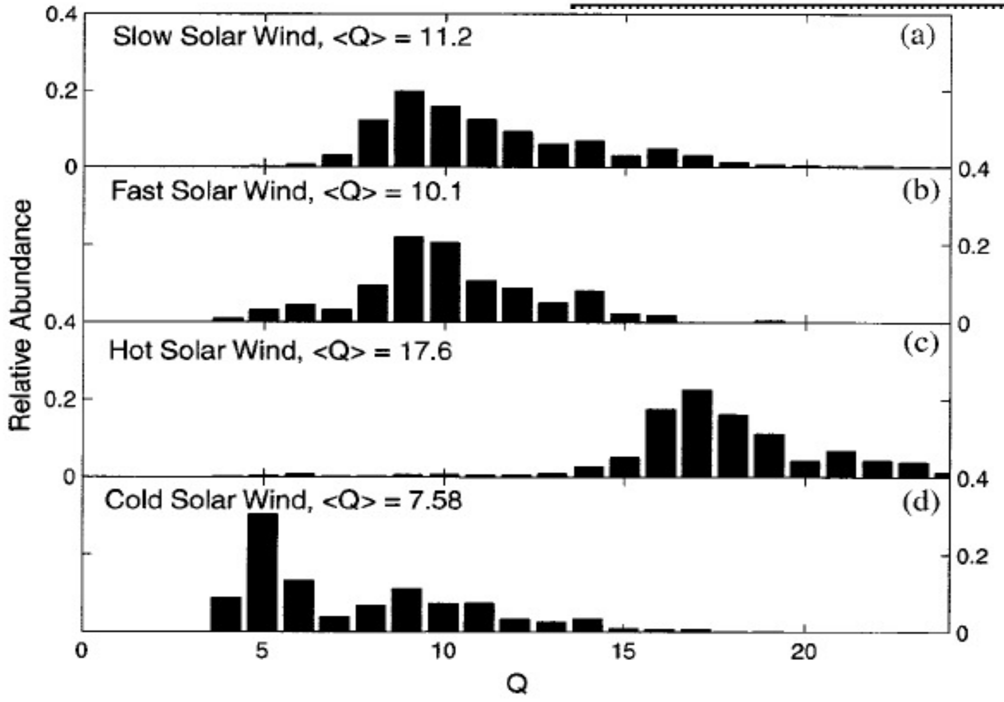
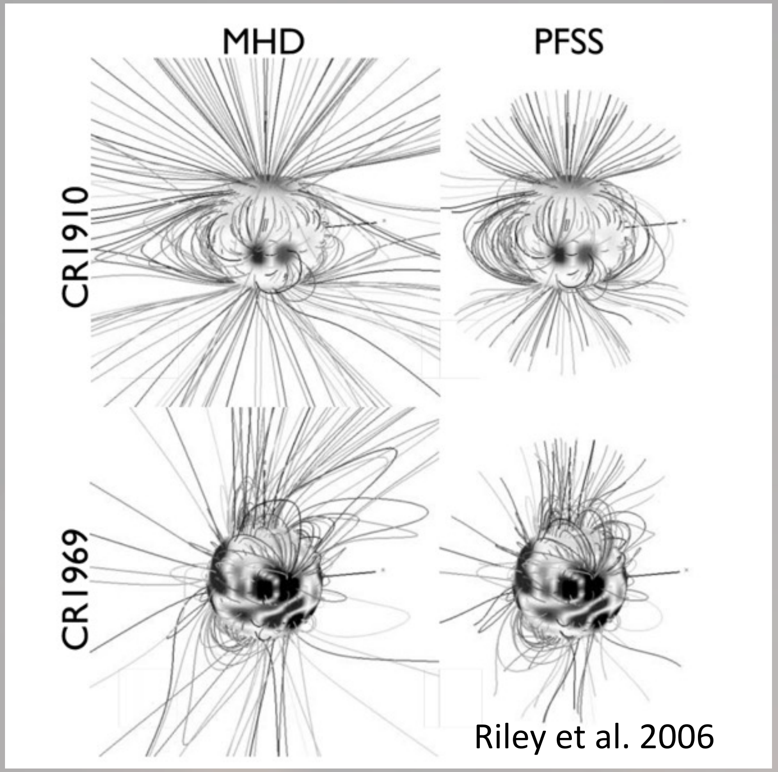


Figure 10. Illustration for three scenarios of the SSW origin. This work implies that the majority of the SSW stream as indic
in a "boundary layer" (in between the yellow lines) on the Sun around the coronal hole boundary. The composite image



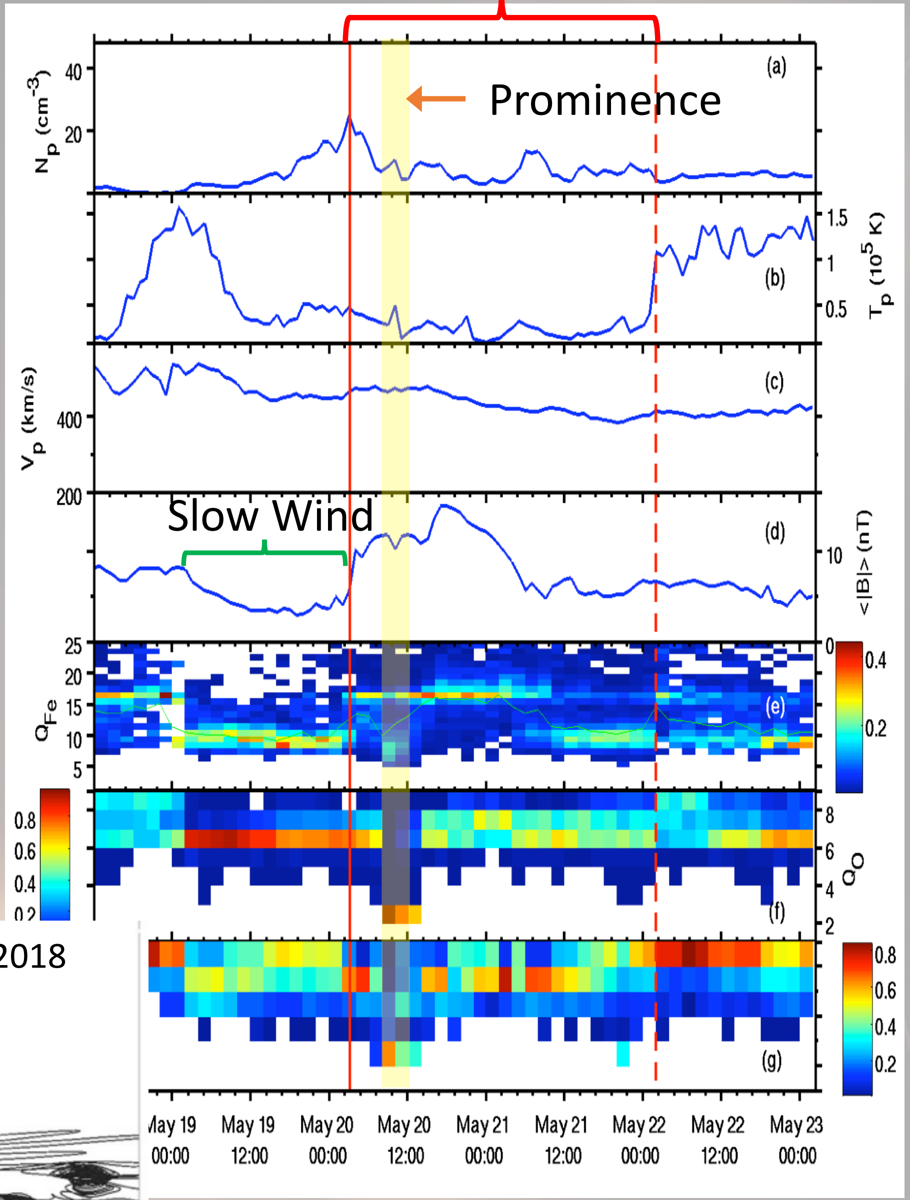
Solar wind sources are compositionally distinct and can be used to study solar wind origin and release

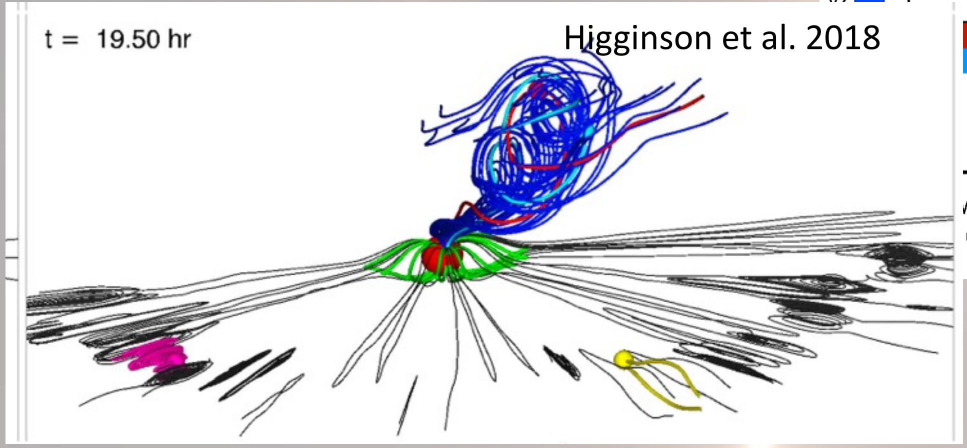
Linking the Corona to the Solar Wind will require remote and in-situ observations along with models and simulations of the corona and solar wind.



Riley et al. 2006

Models are used to link SW structures back to the Sun





Higginson et al. 2018

Fractionation varies across solar wind sources

Brooks et al. 2015

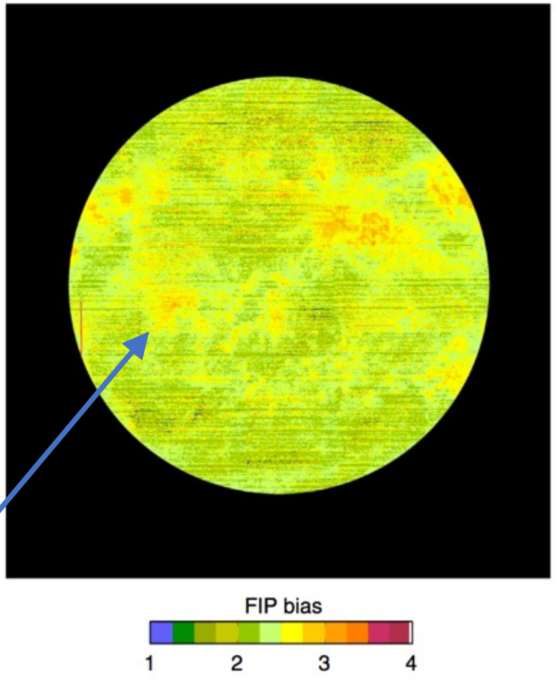
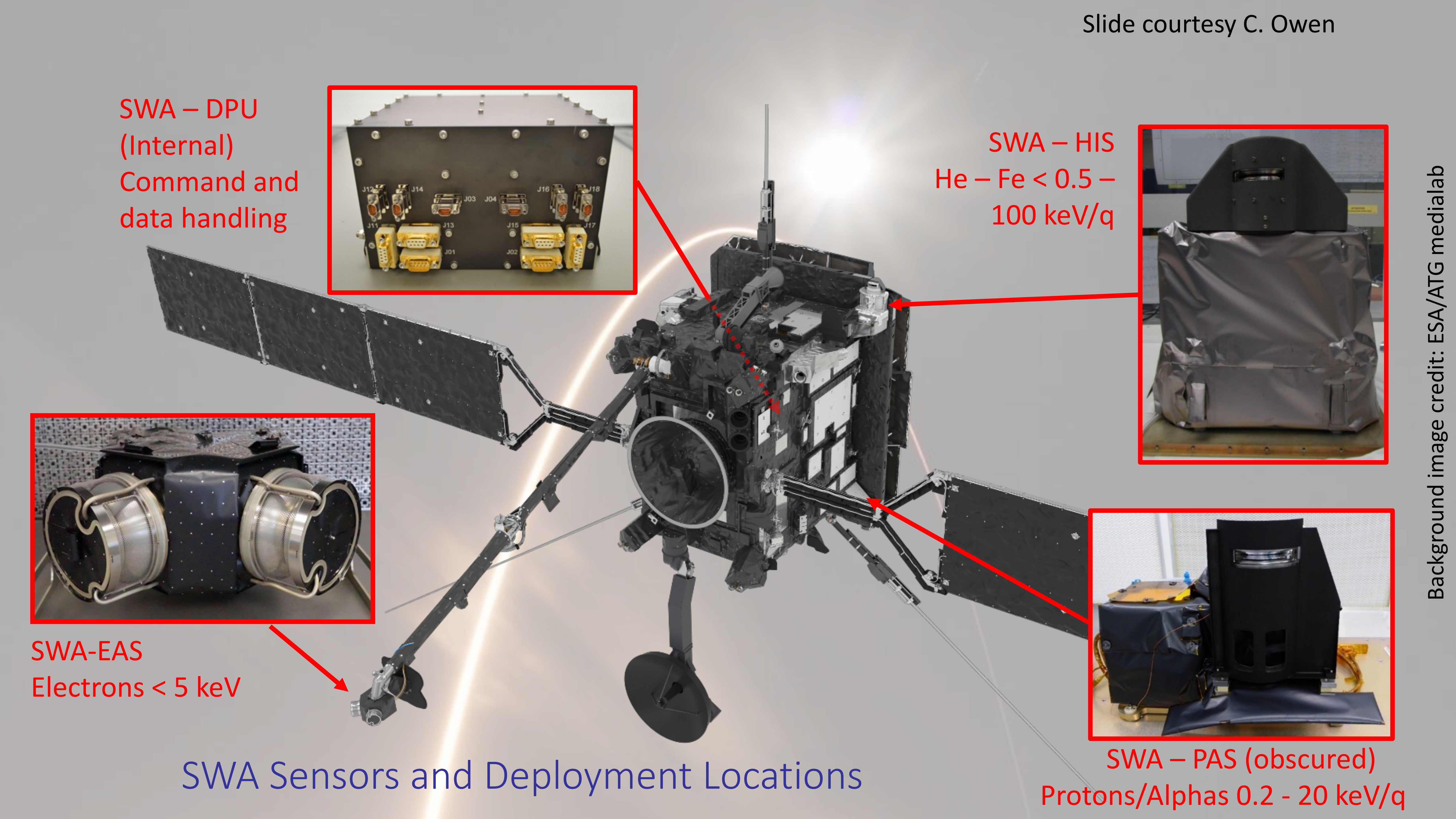


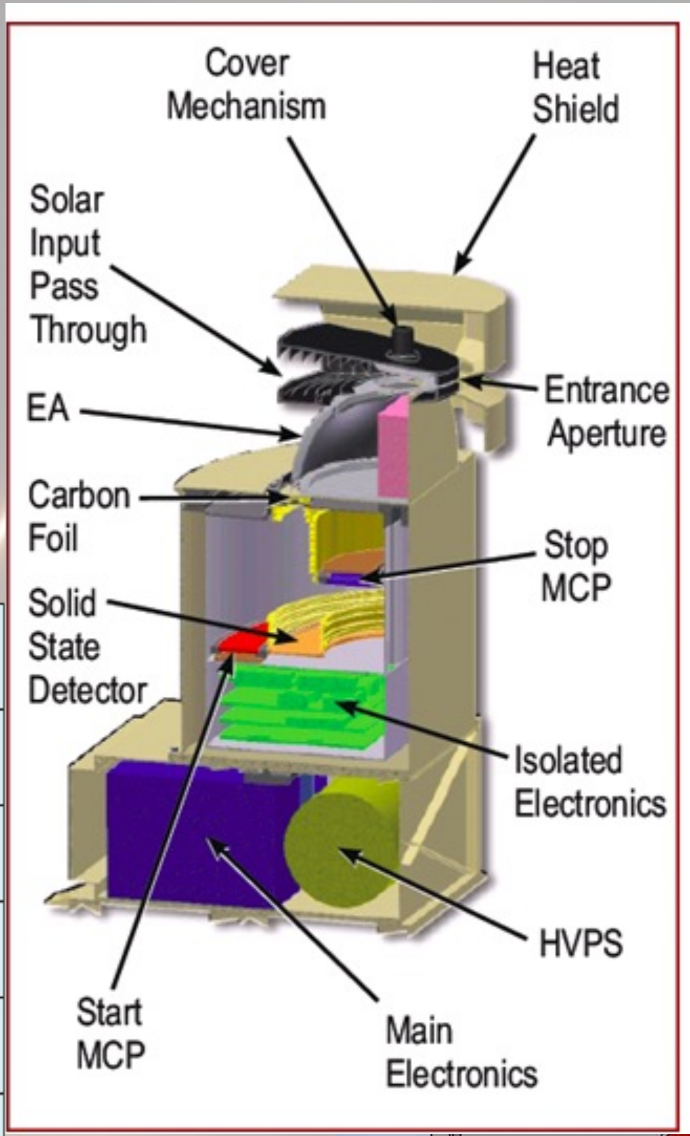
Figure 3 | EIS plasma composition map. Display version of the full-sun

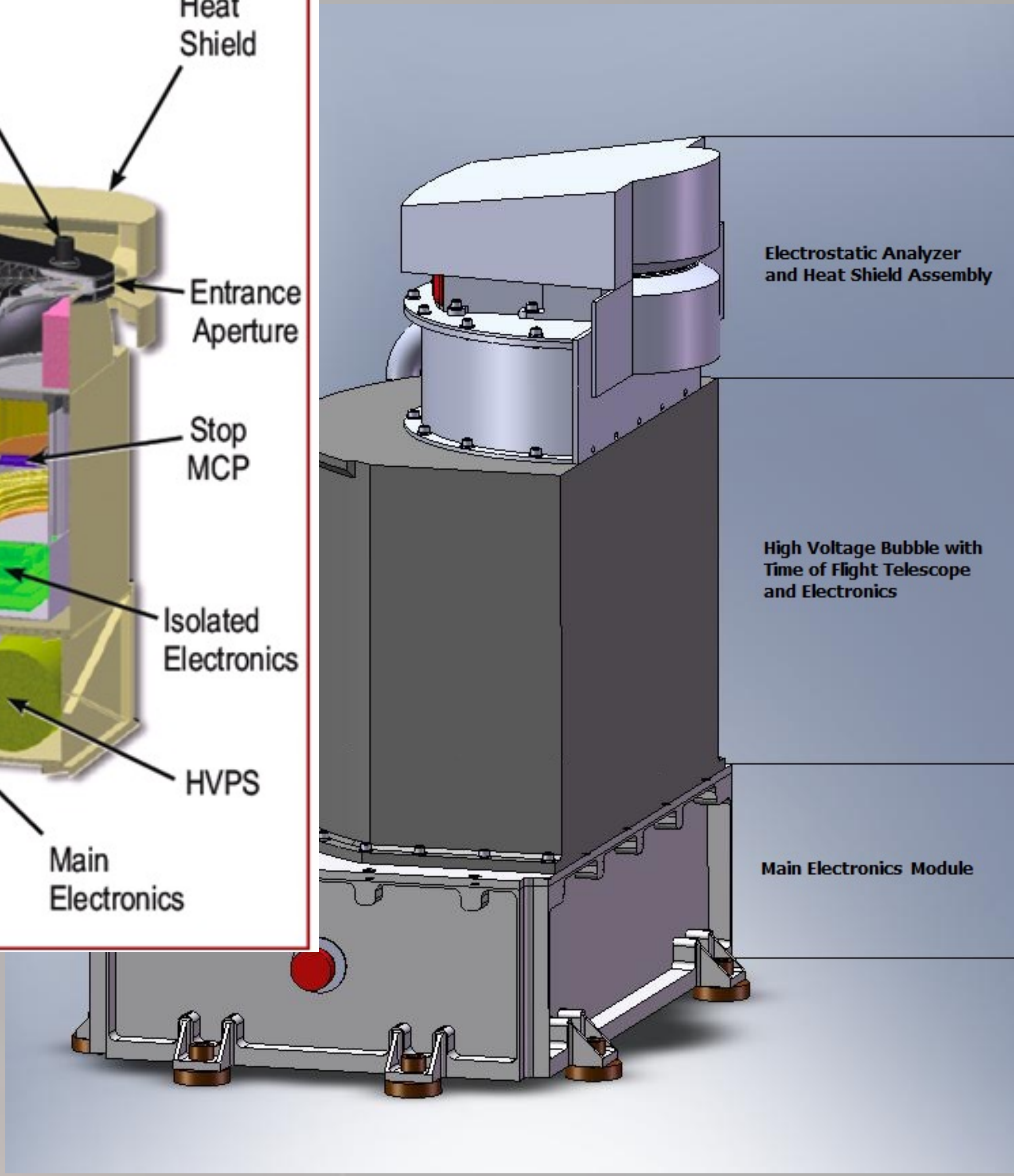

Slide courtesy C. Owen
SWA – DPU
(Internal)
Command and
data handling
J12
J14
J03
J04
J16
J18
J11
J13
J15
J17
J01
J02
SWA – HIS
He – Fe < 0.5 –
100 keV/q
Background image credit: ESA/ATG medialab
SWA-EAS
Electrons < 5 keV
SWA Sensors and Deployment Locations
SWA – PAS (obscured)
Protons/Alphas 0.2 - 20 keV/q

Heavy Ion Sensor

- Measures the composition, velocity distribution functions, and dynamic properties of solar wind heavy ions
- Measurement of 3D velocity distribution functions requires: Mass, Charge, Energy, and Direction

Ion Group	Species
0	He^{2+}
1	C^{4+} to C^{6+}, O^{5+} to O^{8+}
2	Fe^{6+} to Fe^{20+}
3	Mg^{6+} to Mg^{12+}, Ne^{6+} to Ne^{9+}, Si^{6+} to Si^{12+}, etc.
4	Pick up He^{+}, $3He^{+}$
5	Single charged ions (C^{+}, O^{+}, etc.)
6	Suprathermal H^{+}, $3He^{+}$, He^{2+} and heavies





Heavy Ion Sensor

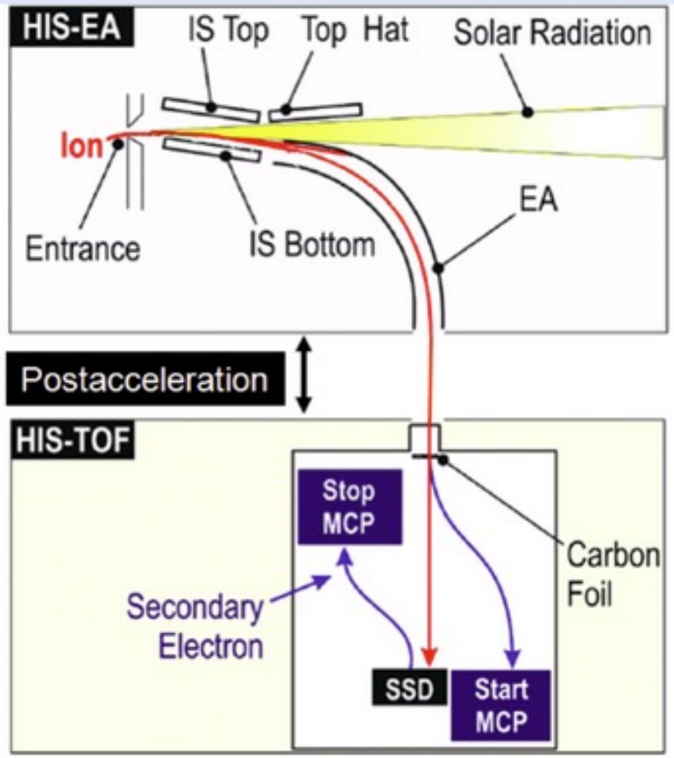


Figure 2. Principle of Operation of HIS. Ions enter are steered into the aperture from above and below the ecliptic into the electrostatic analyzer with ion steering (EA-IS) where they are selected based on an ion's E/Q. Once they pass through the ESA, ions are post accelerated by up to -25kV before they enter the time-of-flight (TOF) telescope. Once in the TOF telescope their total energy and velocity is measured and an ions identification is completed.

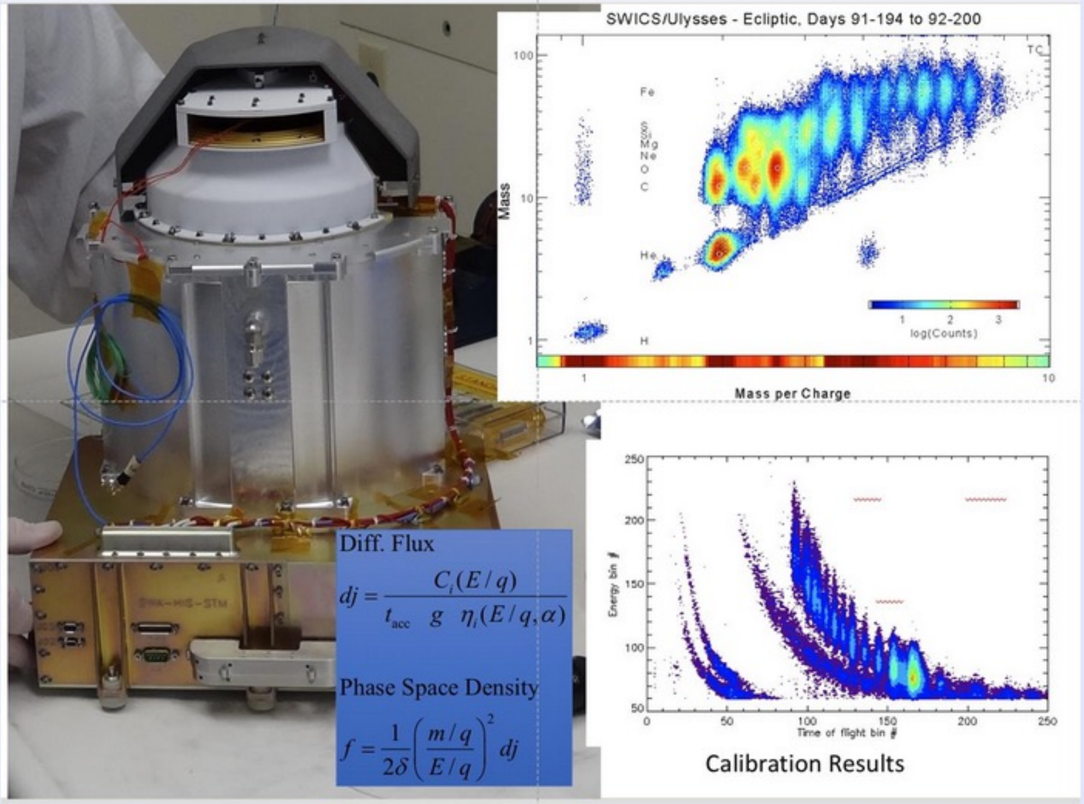


Figure 1. The fully assembled flight model of HIS is is pictured above at UCL MSSL. The rear exit aperture is shown where UV light from the Sun will exit out the back of the sensor to avoid containimation of ion measurements inside the sensor. ACE/SWICS measurements in the upper right hand plot show expectations for observations of ions present in the solar wind that will be observed by HIS, while calibration curves from HIS are shown in the lower right.

First Measurements

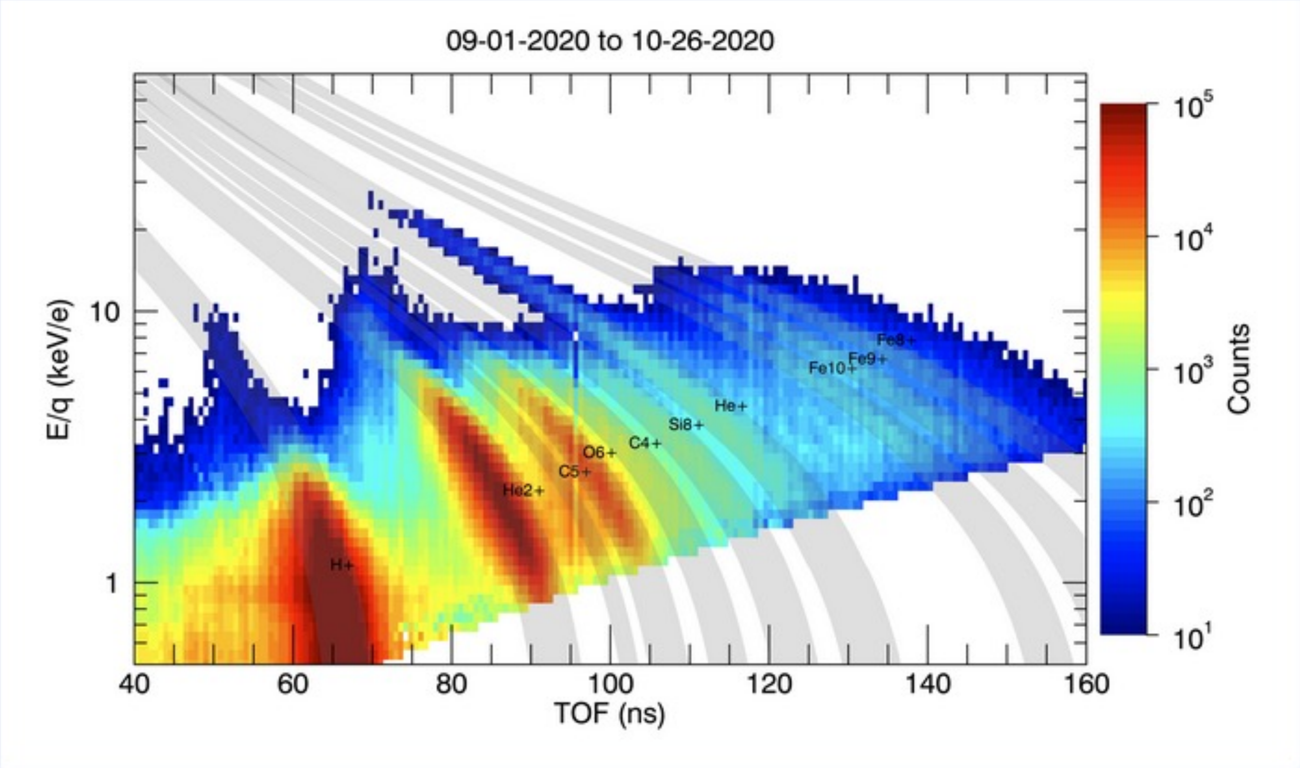
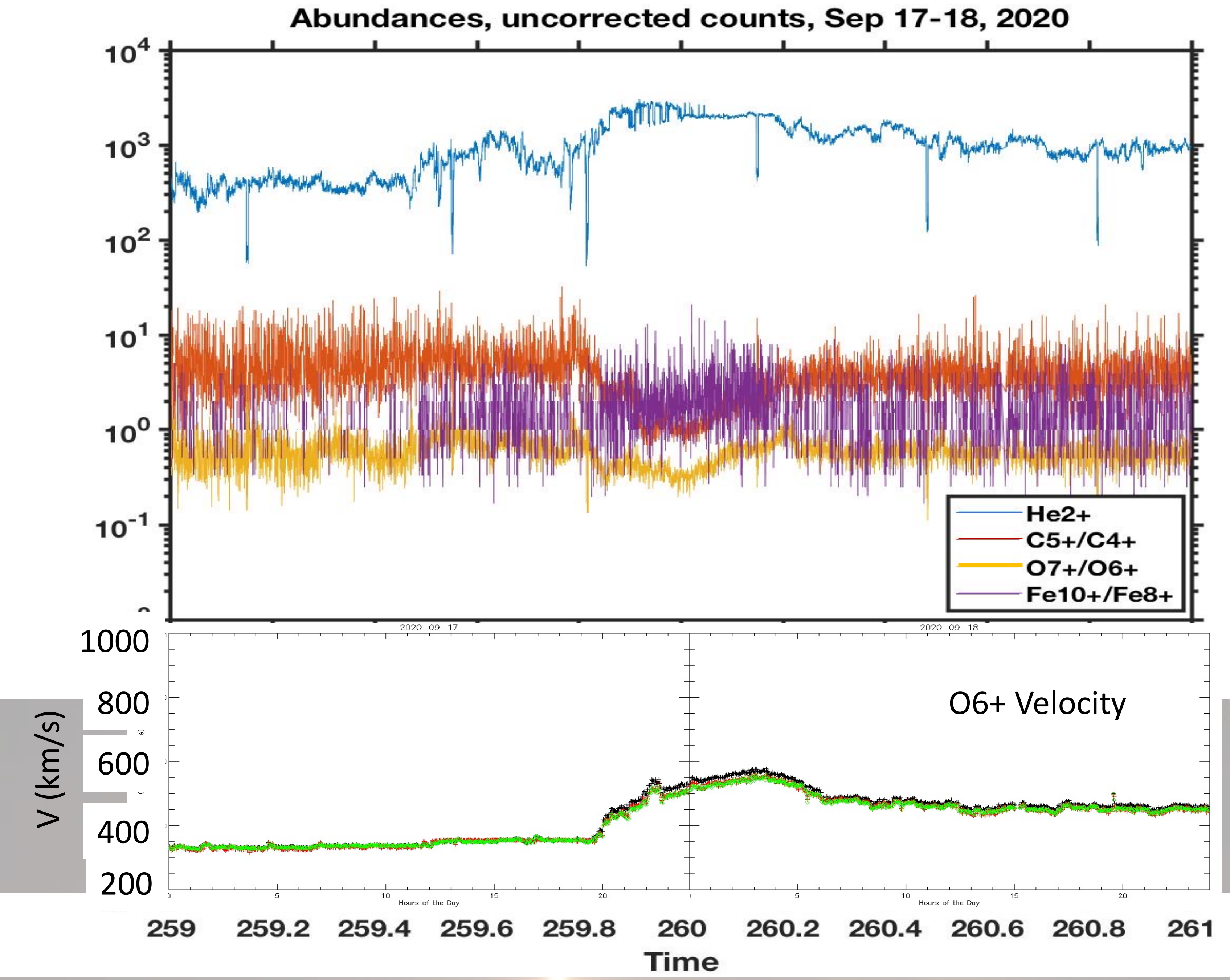


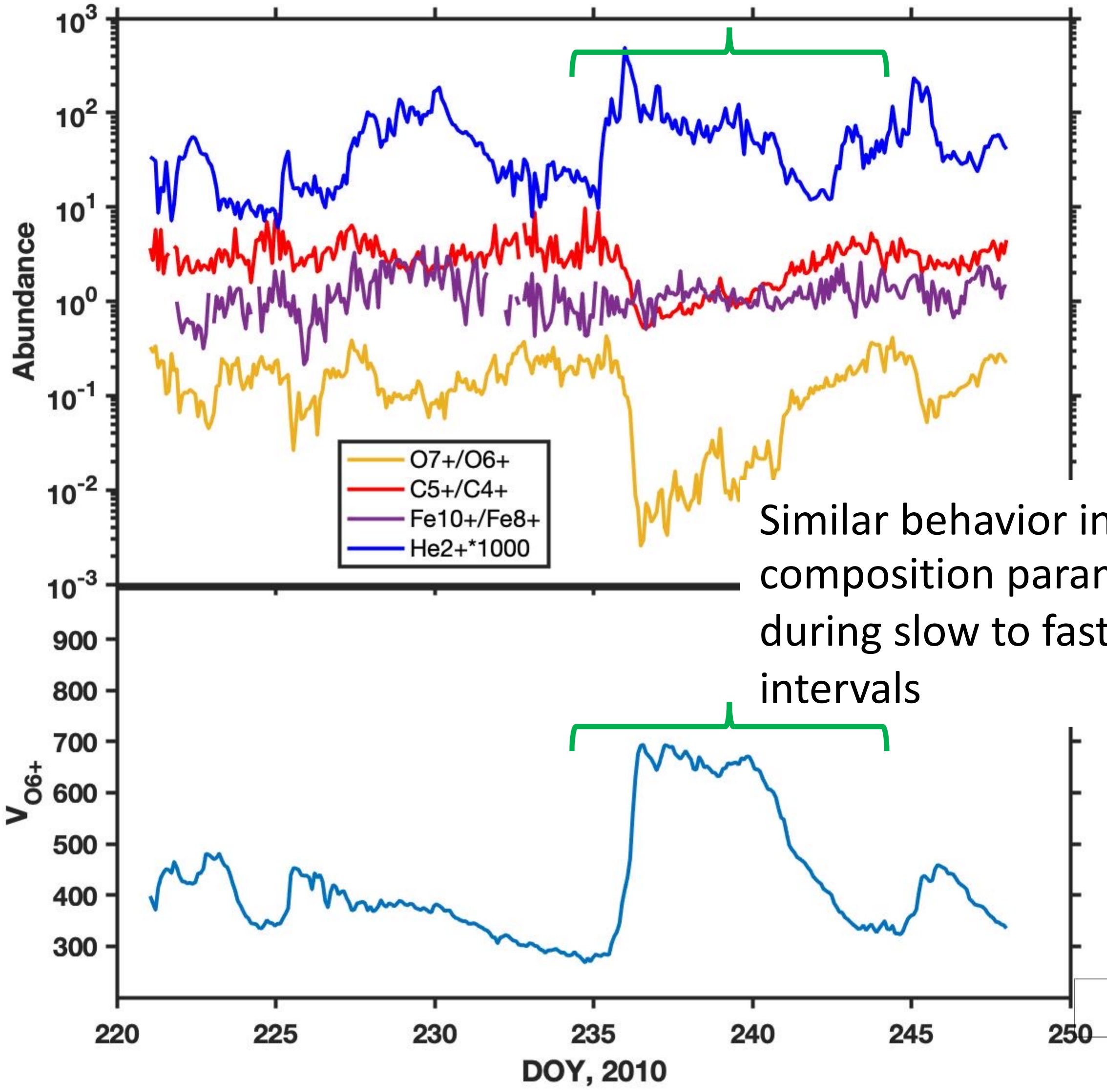
Figure 3. An accumulation of ion measurements observed in September and October 2020. While not all ions have been identified, the major ions of Fe are prominent along curves to the right side of the Figure. The diagonal swath of ions falls along a curve that is defined by the speed of the solar wind during this time interval. Pickup ions tails can be seen extending above this curve for He+.



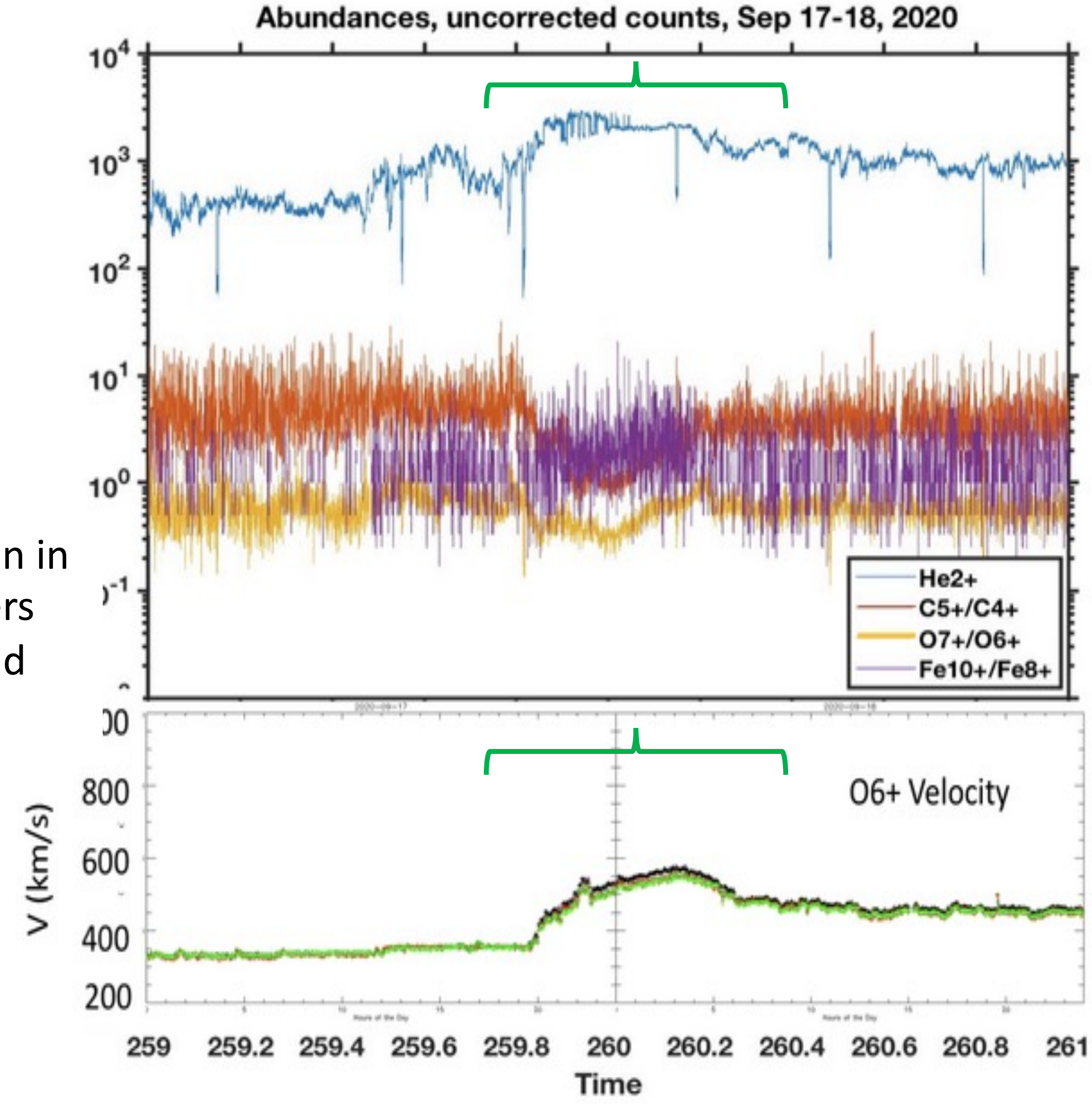
- Two days of observations on September 17th(DOY 259) and 18th (DOY 260), 2020.
- HIS operated at -10kV Post Acceleration.
- He2+ counts increase with jump in solar wind speed around DOY 260.
- Fe charge states shift towards higher charge states
- C5+/C4+ and O7+/O6+ both shift lower during the speed change.
- While these values show changing composition during this faster solar wind structure, further analysis is needed of full ion composition to understand the source of solar wind variations.
- Counts have not been corrected for telemetry prioritization or for instrument efficiencies

Example High Speed Streams observed by (ACE) and (SO)

Abundances, density ratios (and density), Aug 8 – Sept 7, 2010



Similar behavior in seen in composition parameters during slow to fast wind intervals



Solar Orbiter SWA-HIS Data CDFs

- Level 1 data publicly available at:
  - http://soar.esac.esa.int/soar/#home
  - https://spdf.gsfc.nasa.gov/pub/data/solar-orbiter/swa/science/l1/

PHA Available Dates (2020):

- March 10, 13
- April 22
- May 5, 8, 11, 30, 31
- June 1, 3, 6, 22-30
- July 16

Sensor Rates Available Dates (2020)

- March 10-13
- April 22, 24, 29
- May 5, 8, 11, 30, 31
- June 1, 3, 6, 15, 22-30
- July 16
- August 3-5

PHA Variables

- Epoch
- ACCUM_SECONDS
- MODE
- HIS_PHA_EOQ_STEP
- HIS_PHA_AZIMUTH_BIN
- HIS_PHA_ELEVATION_BIN
- HIS_PHA_TOF_BIN
- HIS_PHA_SSD_ENERGY_BIN
- HIS_PHA_DETECTOR_ID
- HIS_PHA_DECIMATION_CLASSIFICATION
- HIS_PHA_PRIORITIZATION_RANGE
- HIS_PHA_MULTI_SSD

Sensor Rate Variables

Each _RATE variable has a corresponding _DIMENSIONS variable:

- HIS_START_RATE
- HIS_STOP_RATE
- HIS_DC_RATE
- HIS_TC_RATE
- HIS_LOW_TOF_RATE
- HIS_PROTON_DEC_RATE
- HIS_ALPHA_DEC_RATE
- HIS_SSD_RATE
- HIS_PRIORITY_RATE

Other Variables

- Epoch
- ACCUM_SECONDS
- MODE
- HIS_STEP_TABLE
- HIS_MAIN_ENABLES
- HIS_SSD_ENABLES
- HIS_PRIORITY_ENABLES

HIS Science Operating Periods Summary

Date Range	PA HV	Note
2,3 June 2020	Full (-25 kV)	Variable TOF calibration.
22-30 June 2020	Full (-25 kV)	Variable TOF calibration.
28 Aug – 28 Oct 2020	Reduced (-10 kV)	Reduced capabilities.
2-4 Mar 2021	Reduced (-10 kV)	variable TOF calibration and reduced capabilities.
May 2021	Reduced (-10 kV)	Reduced capabilities.
June 2021 (expected)	Full (-25 kV)	Planned return to full capability, continuous operations.

Summary

- The successful launch of Solar Orbiter and commissioning of HIS set the stay for many years of heavy ion measurements in the inner heliosphere.
- Early measurements show clear contributions from heavy ions in the data.
- The instrument is able to resolve heavy ions both at -10kV post acceleration and -25kV post acceleration.
- We look forward to future investigations into the sources of solar wind, structures in the solar wind and their links to the solar corona, and studies of solar wind and pick up ion composition and kinetics.

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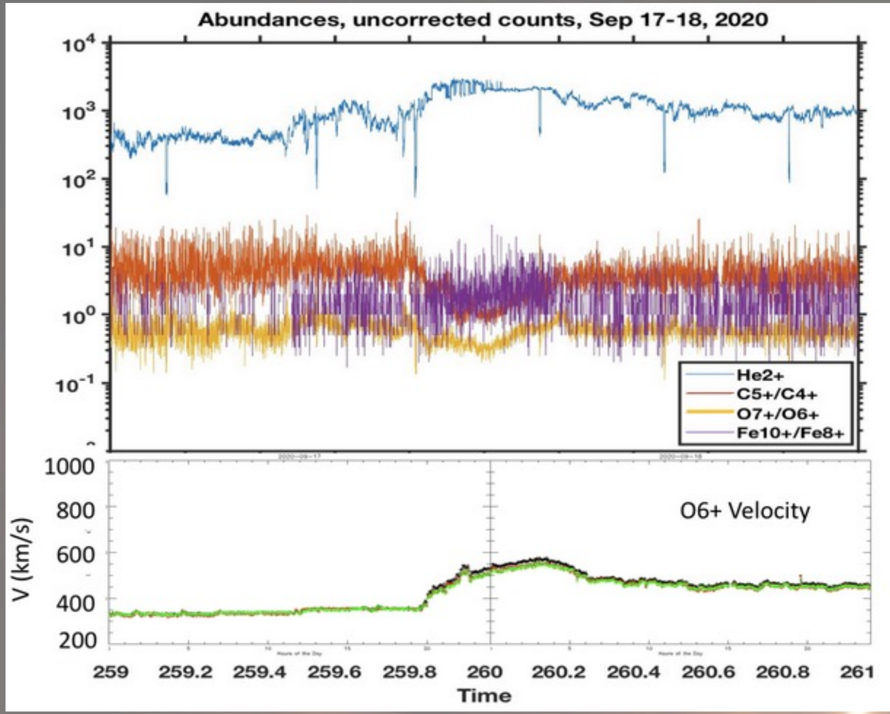

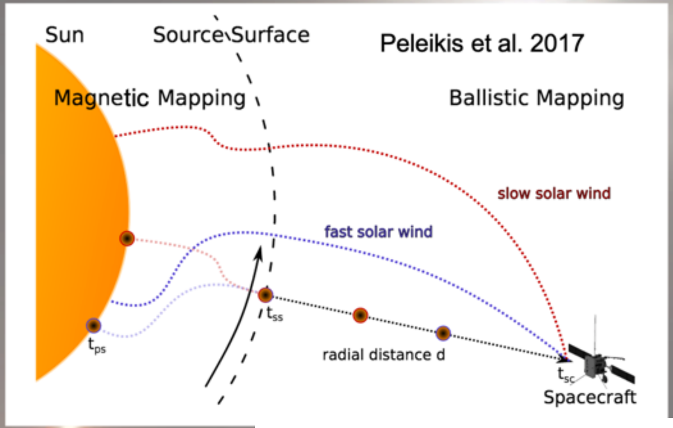

Heavy Ion E/q vs time-of-flight maps capture (L to R) SWA-HIS measurements of H^{+}, He^{2+}, C^{5+} O^{6+}, C^{4+}, Si^{8+}, He^{+}, Fe^{10+}, Fe^{9+}, Fe^{8+}. The diagonal swath of ions falls along a curve that is defined by V_{SW}. Pickup ions tails can be seen extending above this curve for He^{+}.

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