

Variations in the He+ Pickup Ion Distributions inside 1 AU

SH33E-2788

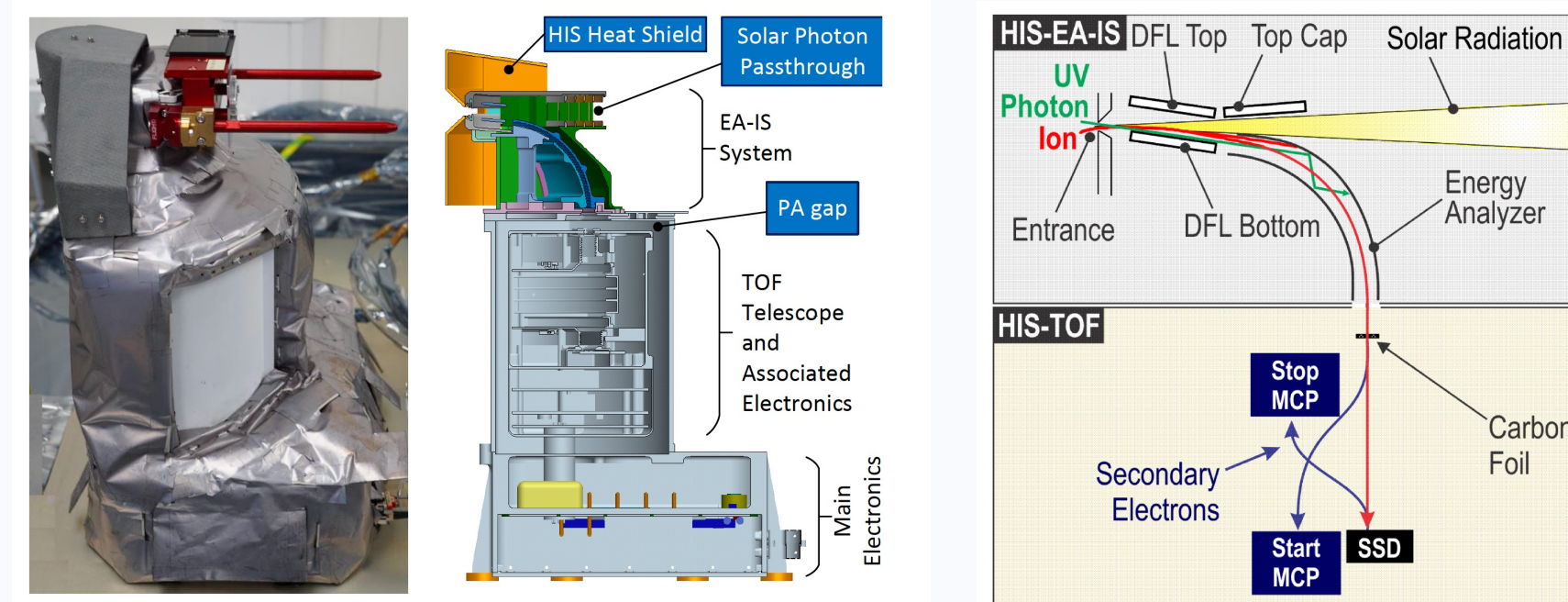
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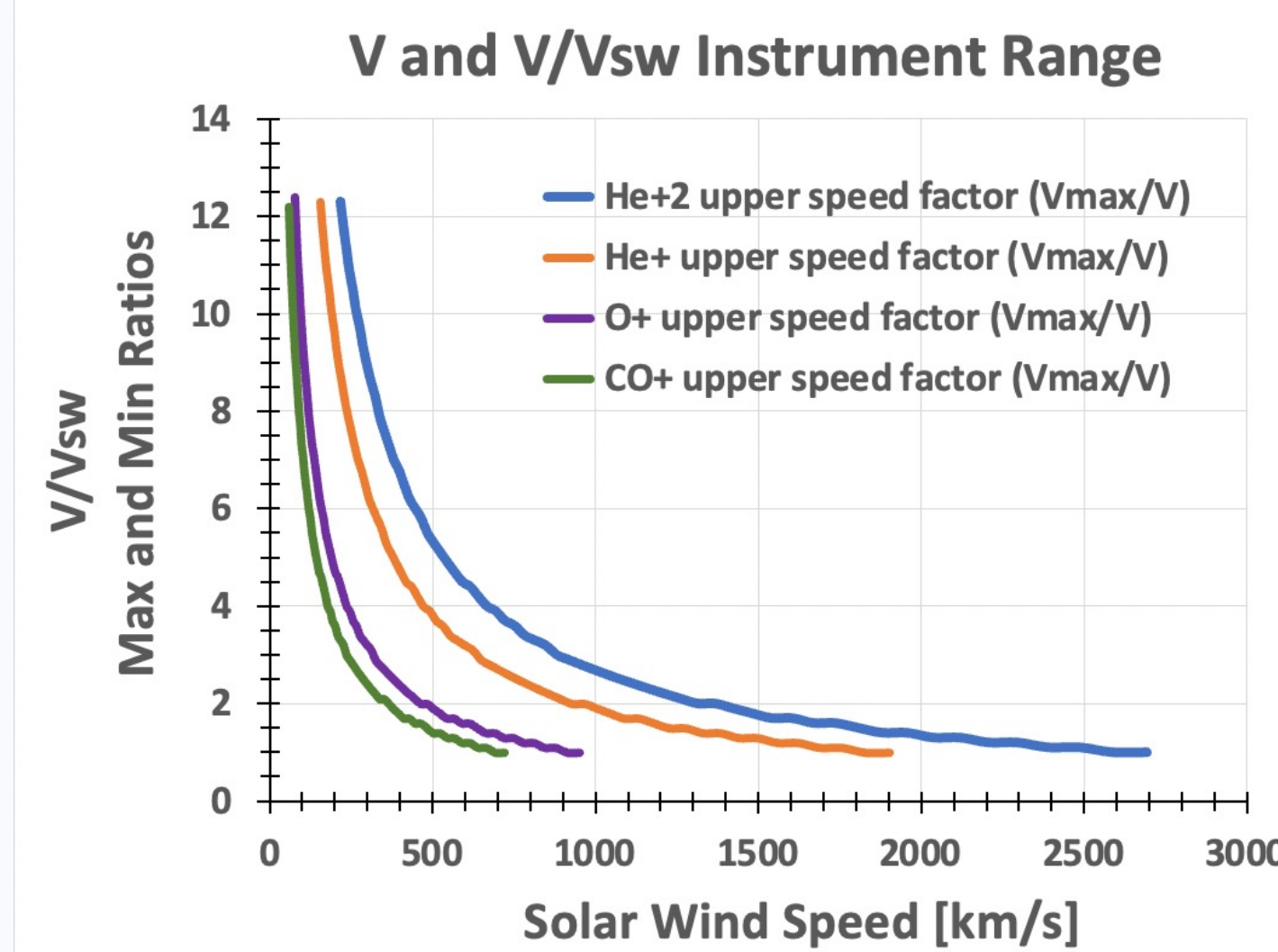
Abstract. Pickup ions (PUI) are generated when a neutral in the heliosphere is ionized and then is 'picked up' by the local magnetic field. The single charge state of PUI species (e.g., He+, C+, O+, Ne+) make them distinct from their highly ionized solar wind counterparts (e.g., He+2 C+5, O+6, Ne+8). PUIs can be further distinguished as they have a distinctive velocity distribution function depending on their source and evolution. Interstellar He+ pick-up ions initially form with a ring distribution about the solar wind, which becomes isotropized resulting in a flat speed distribution extending to twice the solar wind speed (in the spacecraft frame of reference). Previous studies have identified a second component to the He+ pickup ions energy distribution that peaks at the solar wind energy. Its similarity to an inner source pick-up ion distribution suggests that it is formed by charge exchange of solar wind ions, likely with dust close to the sun. Both the inner source and interstellar contributions to the He+ distribution are expected to increase closer to the sun. The interstellar contribution to the He+ distribution in addition has a distinctive longitudinal distribution due to the gravitational focusing cone. The Heavy Ion Sensor (HIS), part of the Solar Wind Analyser (SWA) suite on Solar Orbiter, provides an ideal opportunity to better characterize the spatial variations in the He+ distribution function. HIS measures the composition and 3D velocity distribution function of ions from 0.5-80 keV/e, covering the solar wind ions as well as suprathermal and pick-up ions. We will present how the He+ distribution varies with both longitude and radial distance from 0.3 to 1 AU, to better understand the interplay of the two pickup ion sources.

I. Mission and Instrumentation. The European Space Agency (ESA)'s Solar Orbiter Mission SO was launched in February 2020 into an inner heliospheric orbit. The data used in this presentation is from the **Solar Wind Analyser (SWA)** suite (Suite PI C. Owen) which includes a solar wind proton and alpha particle sensor (PAS, P. Louarn), solar wind electron analyser system (EAS, C. Owen), solar wind composition heavy ion sensor (HIS, S. Livi), and a central data processing unit (DPU, R. Bruno). The pickup ion data is generated from the **Heavy Ion Sensor (HIS)**, which is a collaborative effort between SwRI, UM, UNH, NASA/ GSFC, and IRAP; led by Southwest Research Institution under HIS PI S. Livi. The HIS sensor is the primary sensor on Solar Orbiter for studying the composition of the solar wind ions Z>2 and suprathermal ions (including pickup ions). We also utilize public domain magnetic field data, courtesy MAG (PI, T. Horbury).

II. HIS He+ Data



SWA/HIS principle of operation, taken from Owen et al. (2020). The HIS parameters include Energy/Charge E/Q from the Energy Analyzer (EA); Time-of-Flight TOF from the Start, Stop MCPs; Energy Emeas from the Solid-State Detectors (SSD); N/S flow angle from the polar deflectors (DFL), and E/W flow angle from a position sensing anode (not shown).



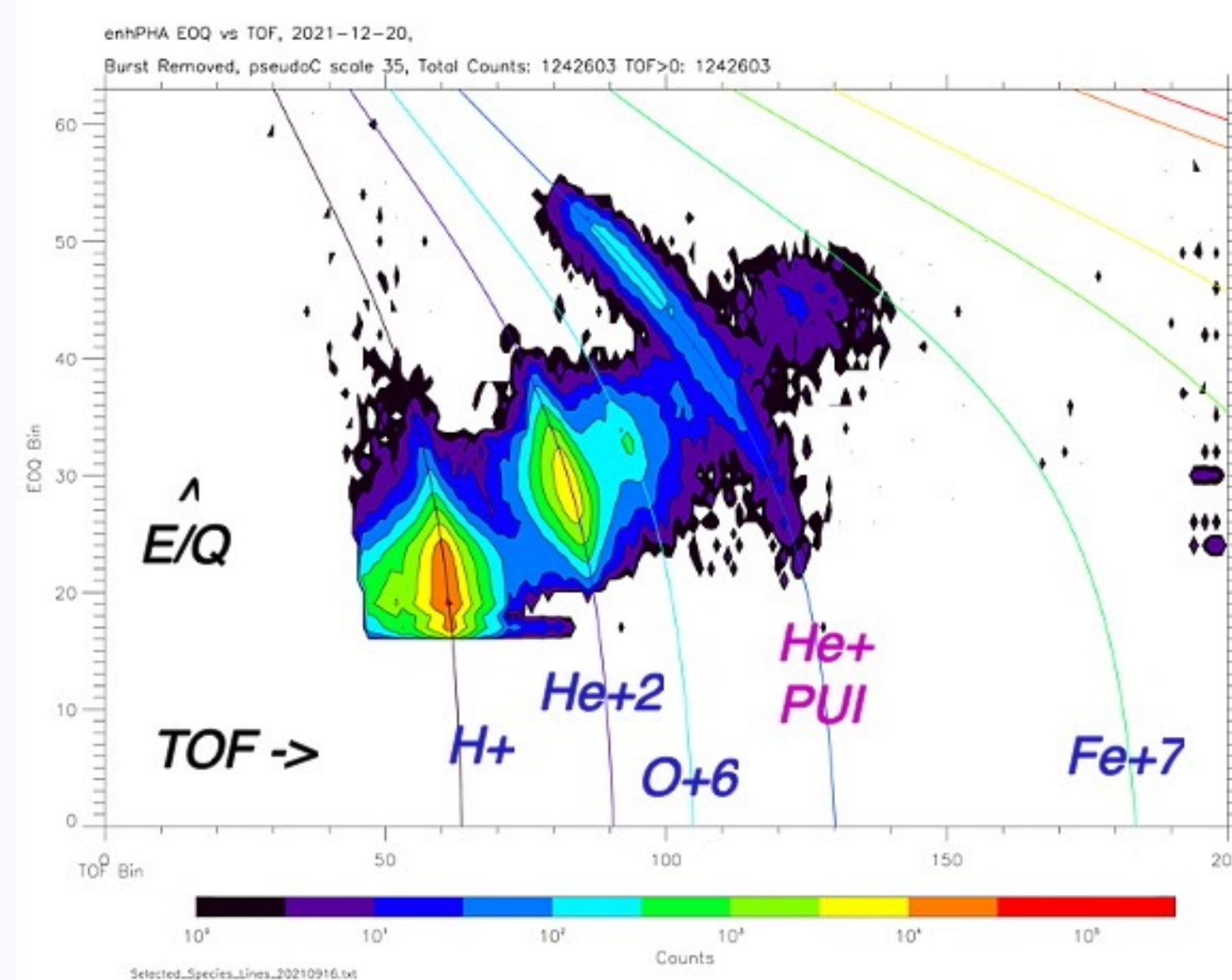
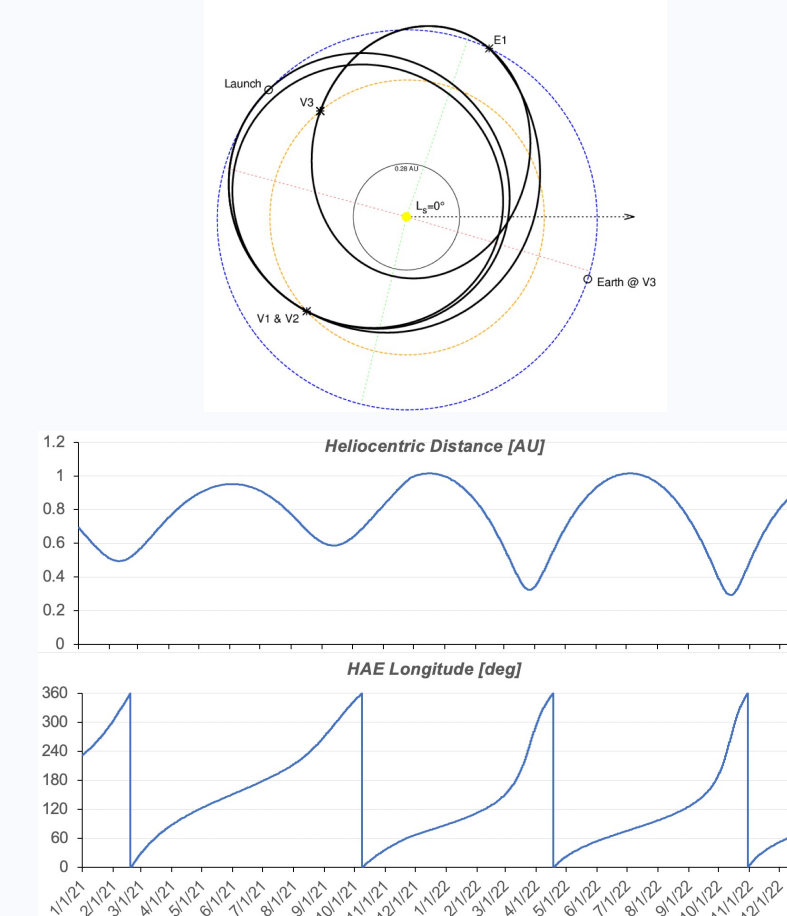
PUI Speed Limits. The energy-per-charge upper limit for HIS is 76 keV/e, creating limits in the V_{sw} range of a given ion and a limit on the V/V_{sw} ratios that can be observed. For pickup ions, it is desired to achieve ratios up to at least 2^*V_{sw} . This is in practice not an issue for He+ but affects solar wind speed selections for other species such as O+.

Acknowledgement: Solar Orbiter Contract at UNH: A99200MO Southwest Research Institute (SwRI). MAG data is courtesy the Solar Orbiter mission team, MAG team (PI Horbury), and is made available through NASA Space Physics Data Facility.

Solar Orbiter early mission trajectory

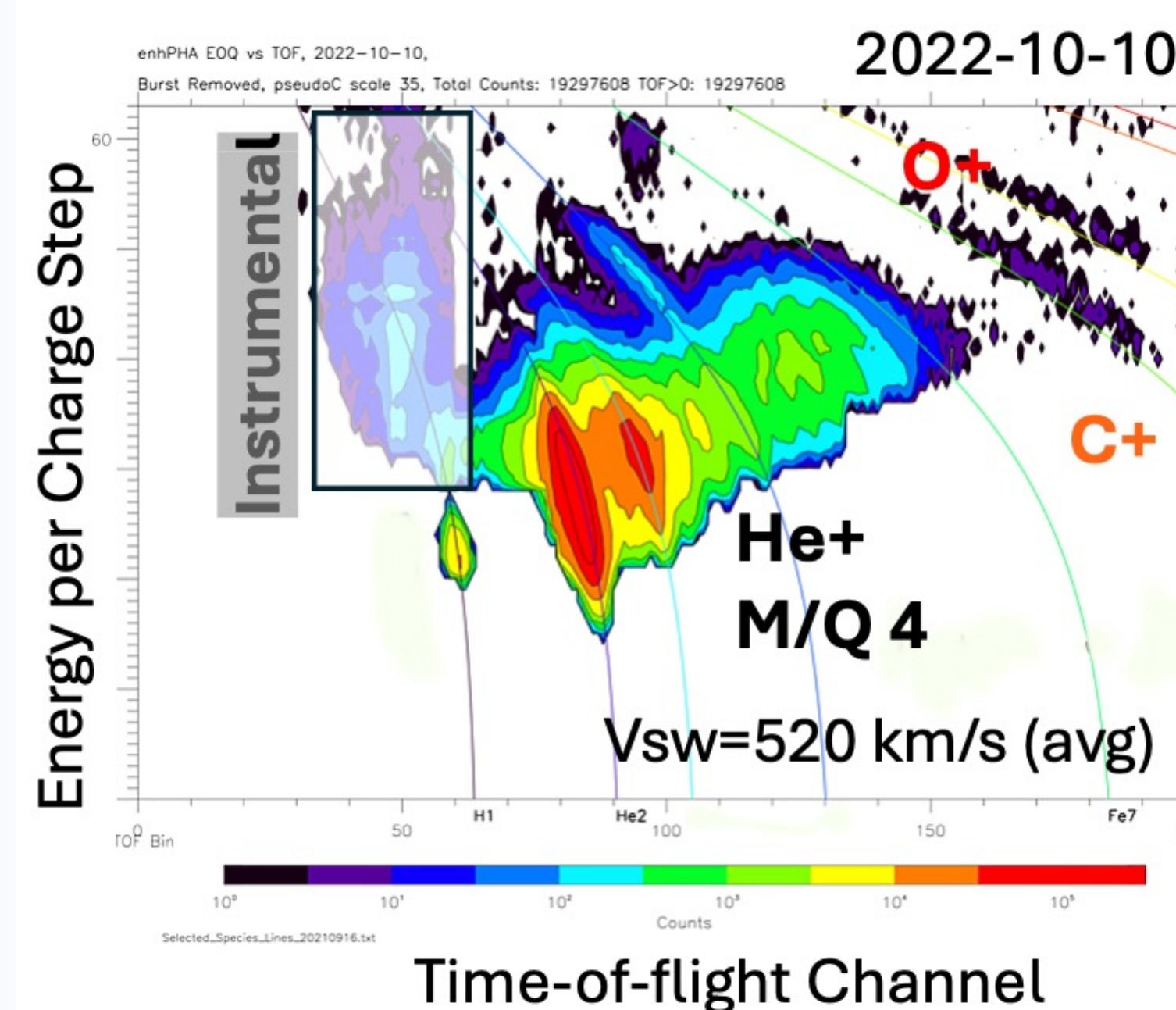
Looking down onto the ecliptic (Müller et al., 2020).

Heliocentric distance in [AU] and Heliocentric Aries Ecliptic Longitude [degrees] for 2021-2022.



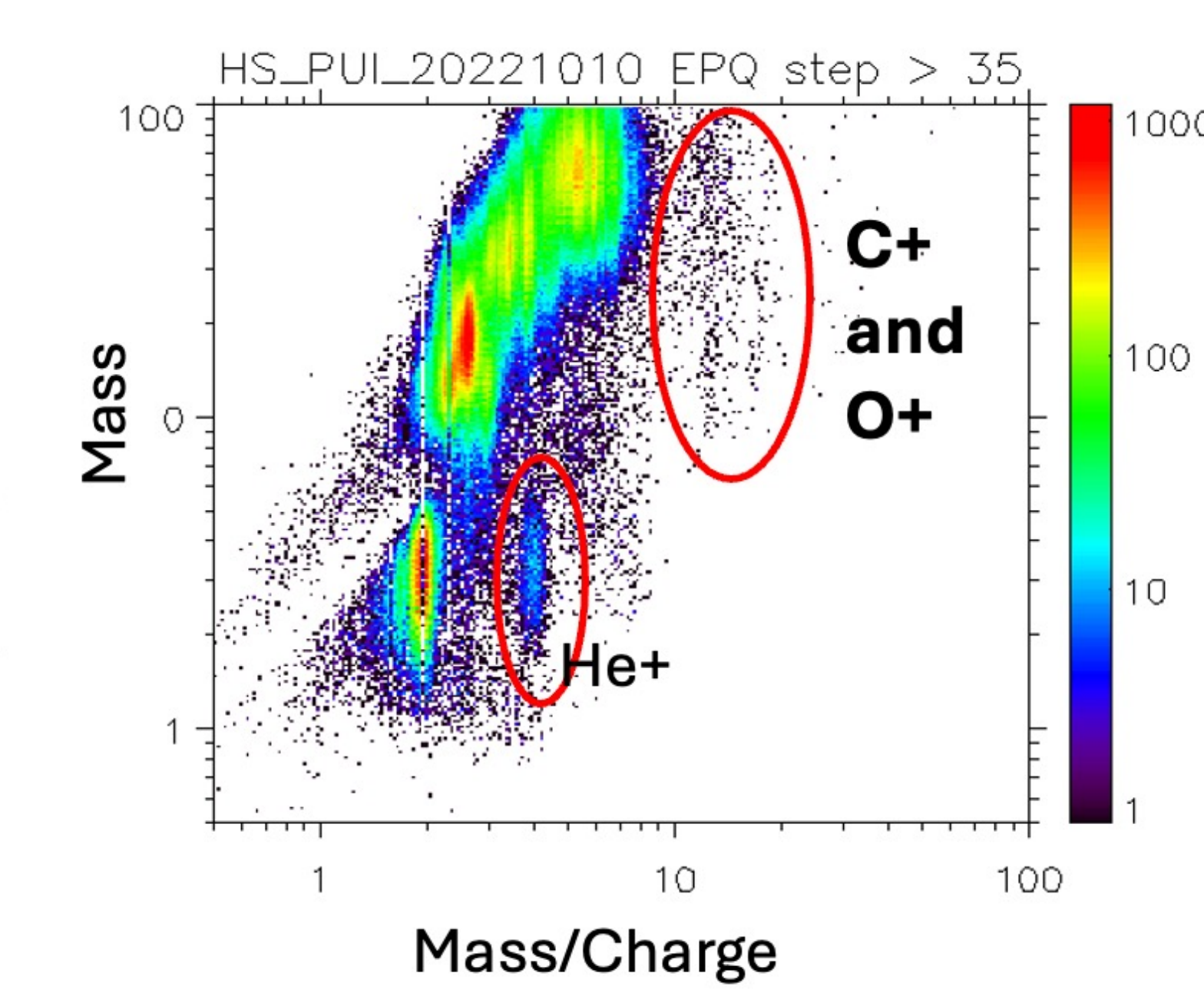
He+ in TOF-E/Q Space. Mass per Charge (M/Q) is obtained from E/Q and TOF measurements. In the E/Q vs ToF plot shown here, the He+ pickup ions stand out from the solar wind species (e.g., H+, He+2, O+6) by the He+ extended E/Q range above the V_{sw} to twice the V_{sw} .

Inner Source Species. In addition to interstellar species, there are at times signatures of inner source PUIs, such as C+ and O+.

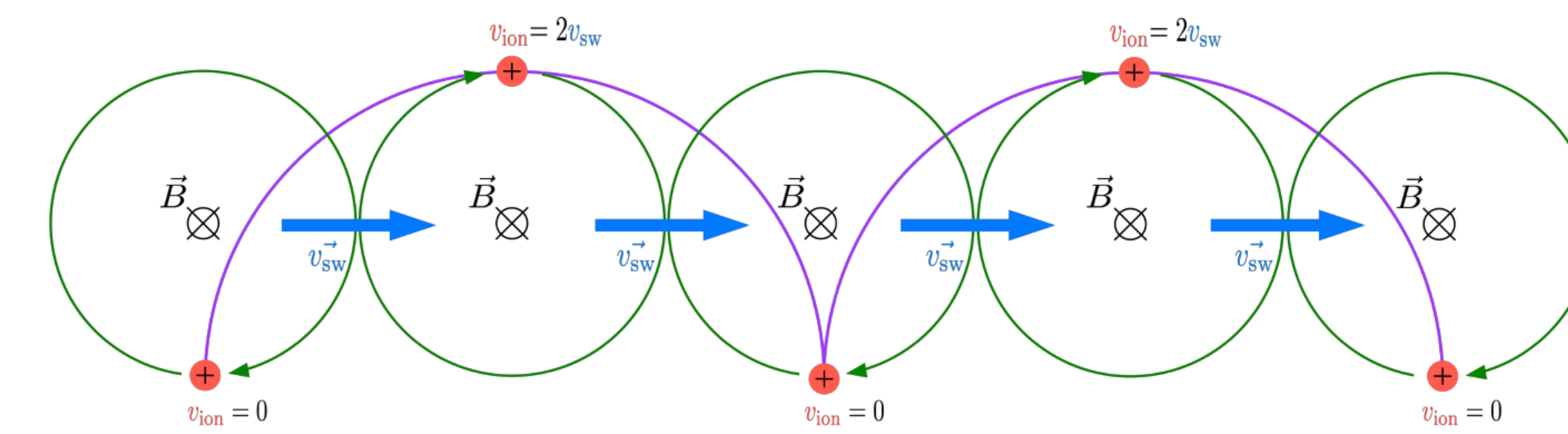


Accelerated He+. He+ spectra may extend beyond the $2^* V_{sw}$ in cases where acceleration has occurred (seen here for H+, He+2, and He+).

Mass Species Determination. By including Emeas information, M as well as M/Q may be calculated in cases where Emeas > Threshold. With Mass information, He+ can be separated from solar wind species at the same M/Q. To separate PUI He+ from solar wind S+8, Si+7, we select for M<8 for M/Q near 4.

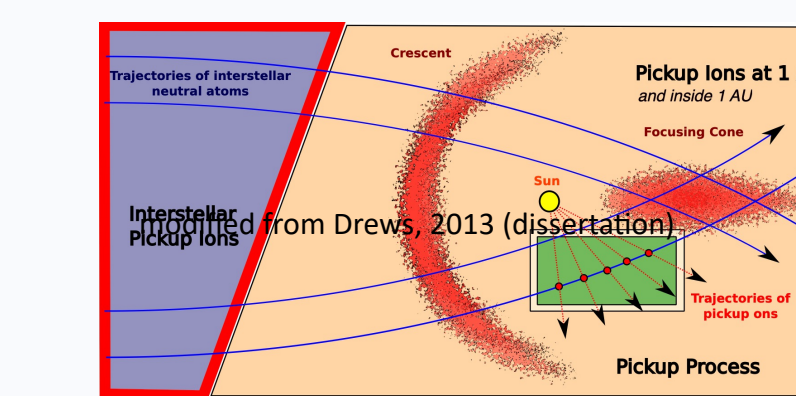


III. Pickup Ion VDF Signature. PUI are produced when neutral atoms are ionized and subsequently interact with the local magnetic field. Different ionization processes (or combos thereof) are involved. For example: pickup He+ and Ne+ are generated primarily through photo-ionization from solar EUV, while pickup H+ is generated primarily by charge exchange. Ionization rates depend on species (FIP), solar cycle, heliodistance, and heliolatitude (e.g., Justyna M. Sokół et al., 2019).

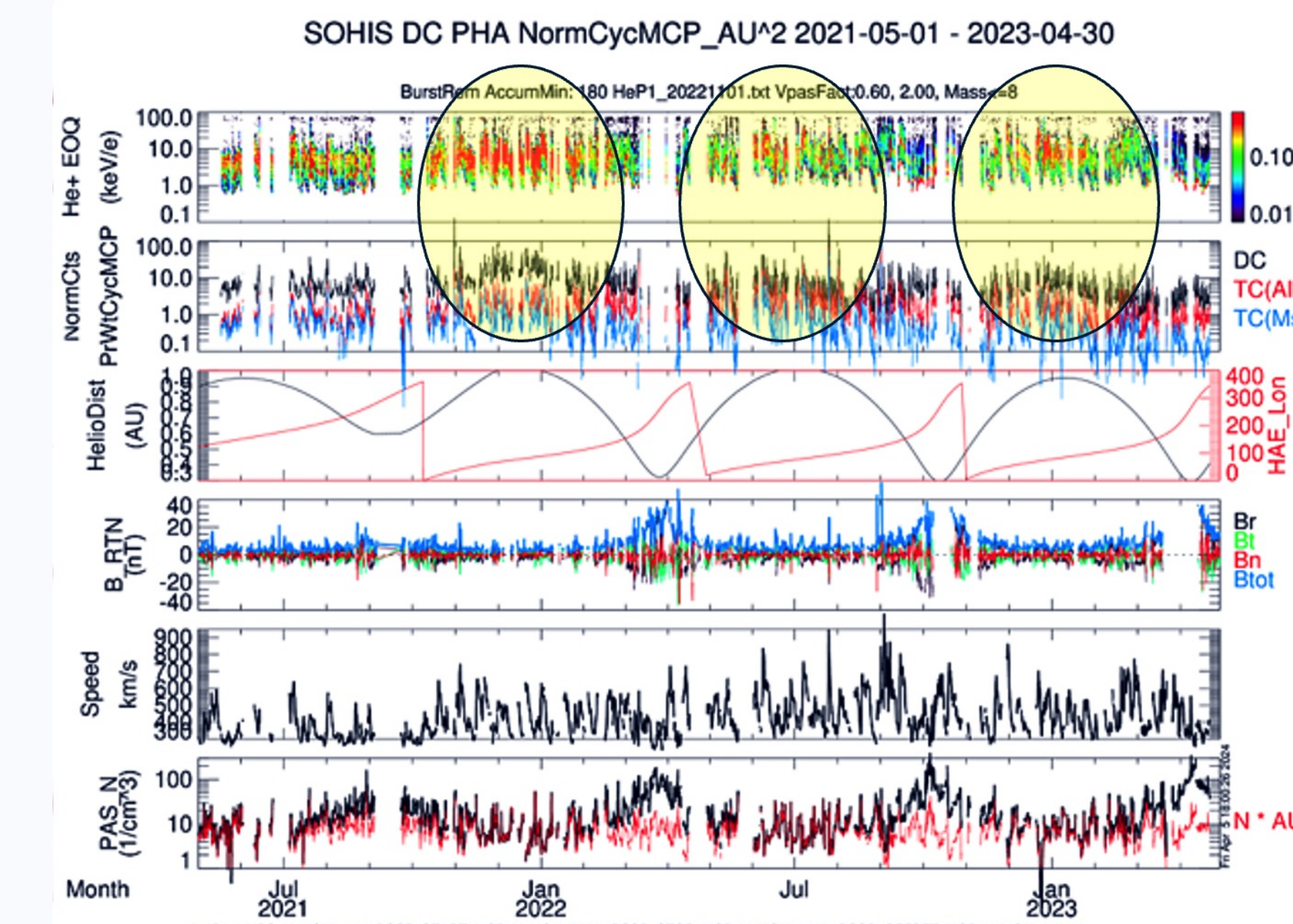


S/C Frame of Reference: 2*Vsw cutoff. Once ionized, the new ions are "picked up" by the convecting IMF and begin gyrating around the magnetic field. The resultant PUI is often recognized by its velocity distribution function (taken from Quinn, 2018).

IV. Longitudinal Observations: HIS Interstellar He+ Focusing Cone. We find the presence of helium plus (He+) ubiquitous throughout the mission period covered by HIS and seen at all sampled heliocentric distances.

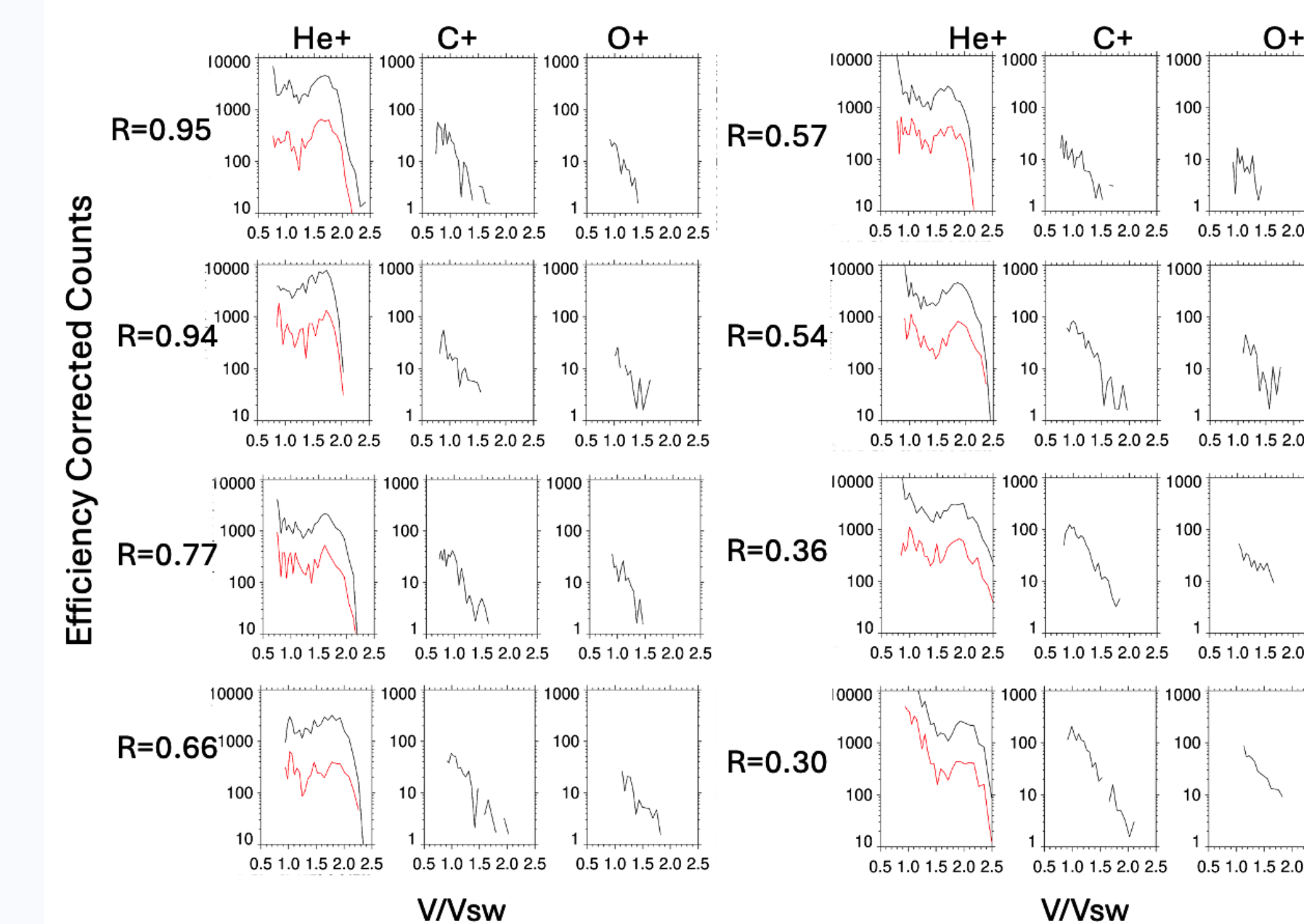


Gravitational attraction by the Sun of interstellar neutrals generates a longitudinal dependency in PUI intensities for some species. The focusing cone has been observed primarily for He+, but also Ne+ (Drews et al, 2012).



Survey M/Q=4 ions with $w = V_{He+}/V_{sw} > 0.6$ and Mass < 8. Three focusing cone passages are highlighted in yellow.

V. Radial and Angular Observations: Distinguishing He+ interstellar and Inner Sources. PUI He+ has two sources: interstellar origin or from solar wind charge exchange with dust (Rivera et al., 2020; Drews et al. 2015), which may be distinguished by their velocity distribution functions.

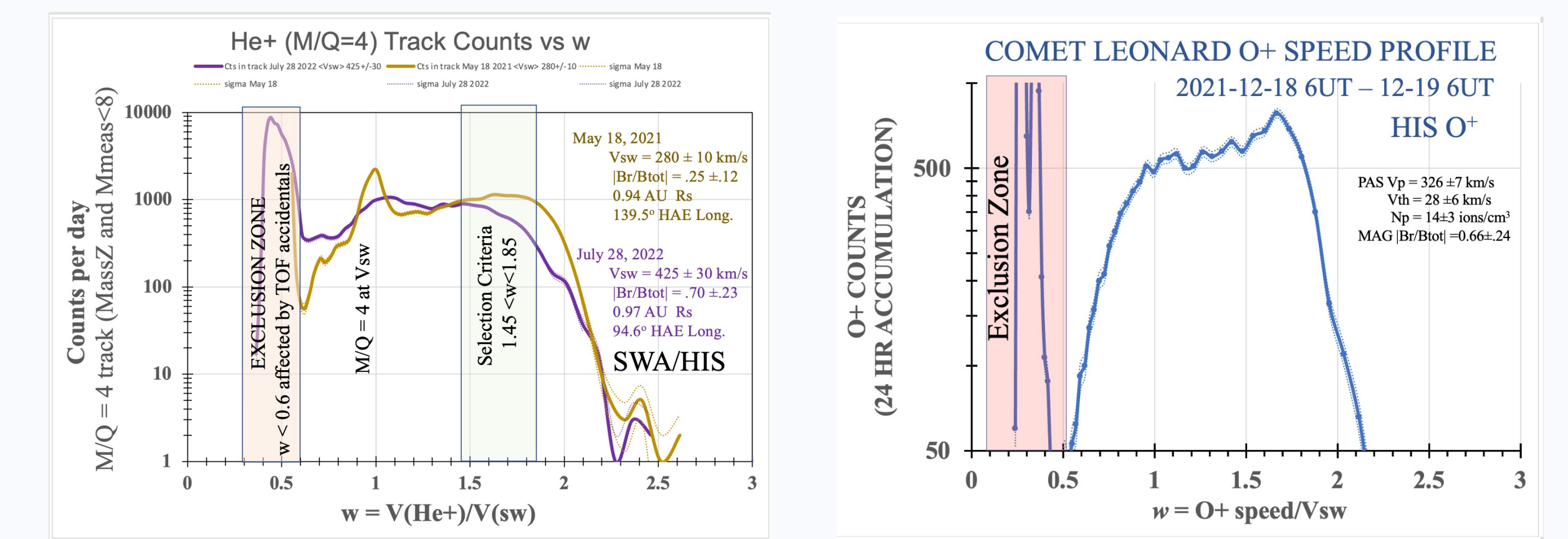


Radial. Time periods were selected at different heliocentric distances where inner source O+ and C+ were observed. The inner source O+, C+ distributions drop off steeply from V_{sw} . There is no indication of the classic "pick-up" spectrum, even at the lowest R. The C+ and O+ spectra do not change significantly between 1 and 0.3 AU.

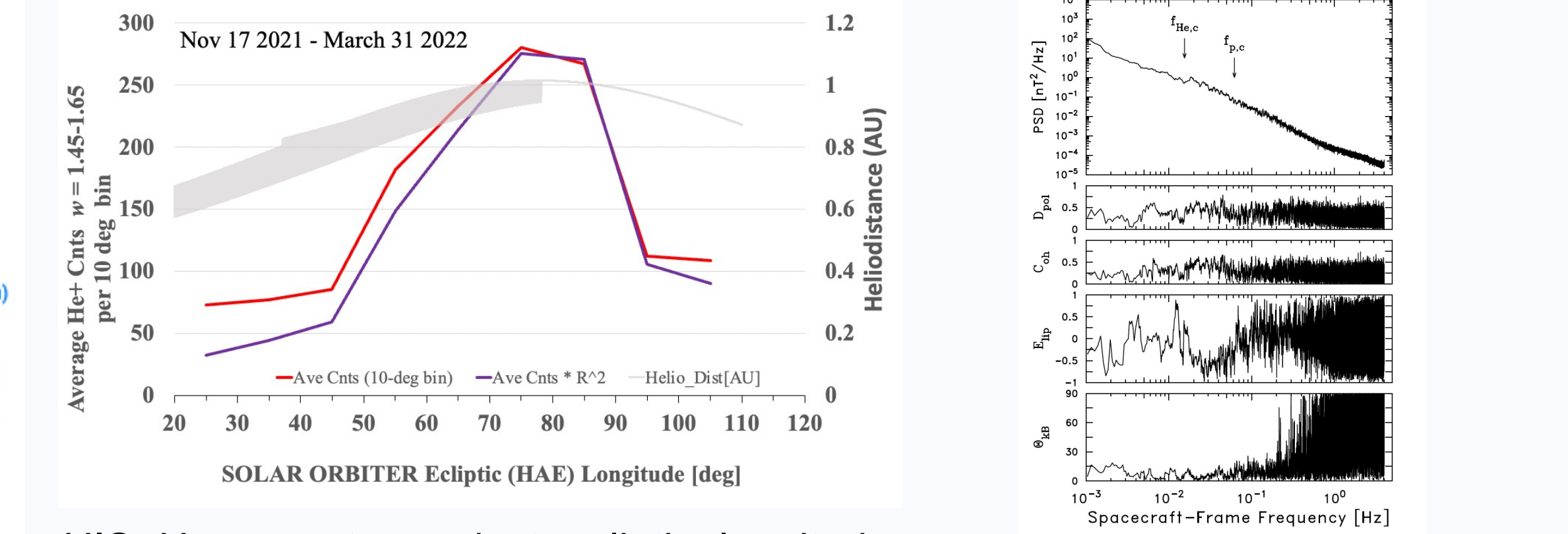
The He+ continues to show the classic interstellar speed distribution out to 2^*V_{sw} , peaked between 1.5- 2^*V_{sw} . But, in some cases He+ shows a second distribution at lower V/V_{sw} , dropping off from V_{sw} , not unlike the C+ and O+ distributions. This second peak increases in strength as the solar distance decreases and is a candidate for inner source He+.

Angular. The distinction between He+ sources is also seen in the angular distribution. Shown to the right are solar wind He+2 and the two distinct populations of He+ at 0.77 AU (where the ring distribution dominates) and at 0.3 AU (where the solar wind like distribution becomes more distinct).

This and additional information available in Kistler et al., this AGU, SH22B-07.



Pickup Ions vs Speed Ratio. The cutoff at $\sim 2^*V_{sw}$ (s/c frame) provides a tell-tale signature for pickup ions of interstellar, cometary, and planetary origins. Counts versus w , where w is the species speed over the solar wind, are typically seen in pickup ion studies. Shown are He+ for two different days with SO at similar heliocentric distances (near 1 AU), but different HAE longitudes and different magnetic field configurations (B_z/B_{tot}). Adjacent, a similar plot for O+ pickup ions originating from Comet Leonard. (Note: "MassZ" indicates mass was not measurable as the Emeas fell below the SSD threshold.)



HIS He+ counts against ecliptic longitude (red) and normalized to heliocentric distance-squared (blue). for the first HIS passage through the He+ focusing cone. The He+ FC expected location is at ecliptic longitudes $\sim 75-78^\circ$, with a width of $\sim 30-40^\circ$ (Drews et al., 2012). The He+ intensity is consistent with passage through the focusing cone.

Preliminary magnetic field spectral analysis indicates a small rise in power at the cyclotron He+ frequency with a left-handed elliptical signature. Data 12/16/2021 near central FC passage (B. Vasquez.)

