A Type III Radio Burst Event Observed Jointly by the Expanded Owens Valley Solar Array and the Parker Solar Probe

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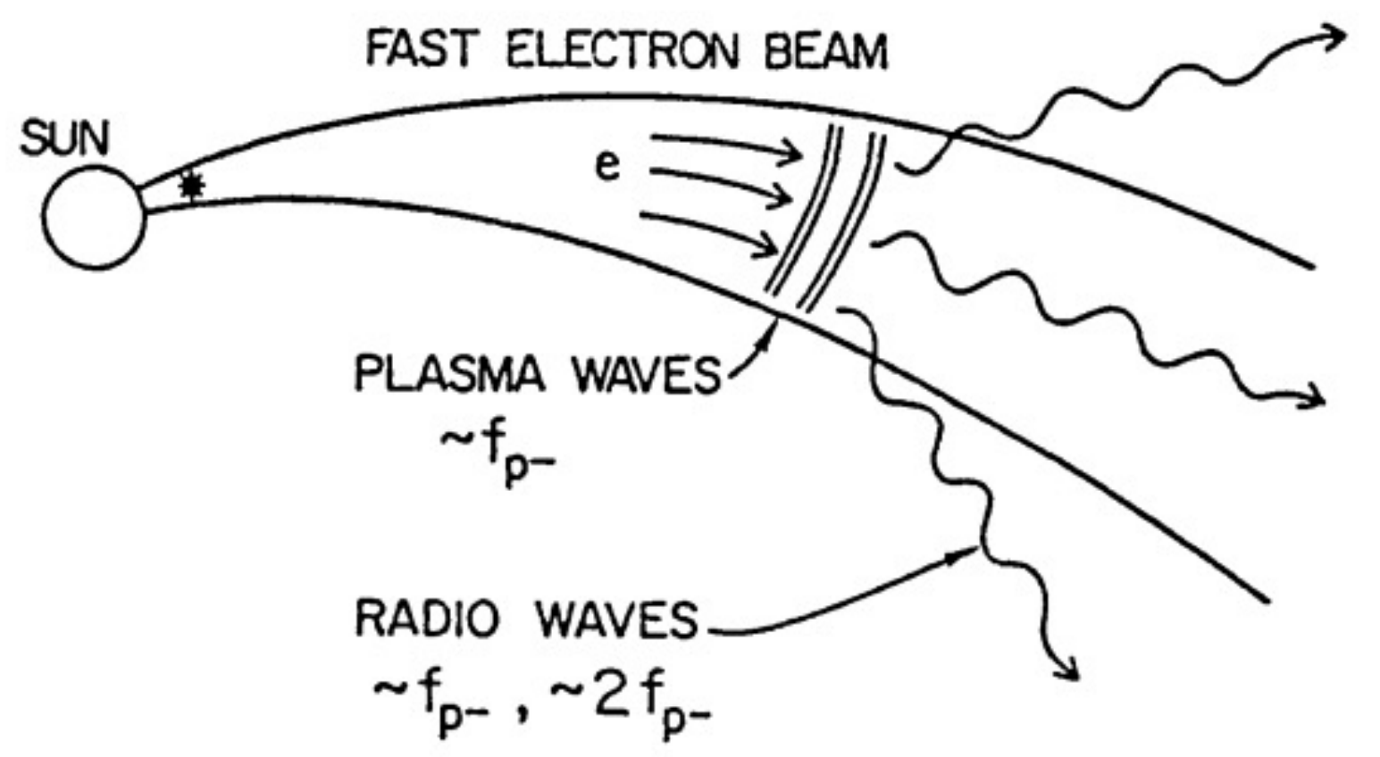
ABSTRACT

Solar type III radio bursts are generated by beams of energetic electrons that travel outward along open magnetic field lines through the corona and the interplanetary space. Here we report a type III burst event observed jointly by the Expanded Owens Valley Solar Array (EOVSA) and the Parker Solar Probe (PSP) near its second perihelion in April 2019. This type III burst event is associated with a solar jet near the boundary of a solar active region, which manifests in EOVSA 1–18 GHz dynamic spectrum as a group of impulsive microwave bursts. The type III burst event continues to the interplanetary space in the decameter–kilometer wavelength range (300kHz–30MHz) observed by multiple spacecraft including PSP/FIELDS, and appears to reach the local plasma frequency at the spacecraft. The widely separated spacecrafts make remote multipoint measurements of interplanetary radio sources of solar origin giving us the chance to discuss the type III burst's source location and directivity of the radio emssion. In addition, the type III burst event coincides with an enhanced suprathermal electron population with an anti-sunward beam-like component as measured by PSP/SWEAP. We also discuss the source region of the type-III-burst-emitting energetic electrons and their transport from near the solar surface to the interplanetary space.



Lin, R.P. (1990)

OBSERVATIONS

EOVSA's observation at ~19:30 UT on 04/15/2019 and compared with AIA 171 image. The type III radio burst event locates at the edge of the active region. From the SDO/AIA 171 image, this event is associated with a small jet.

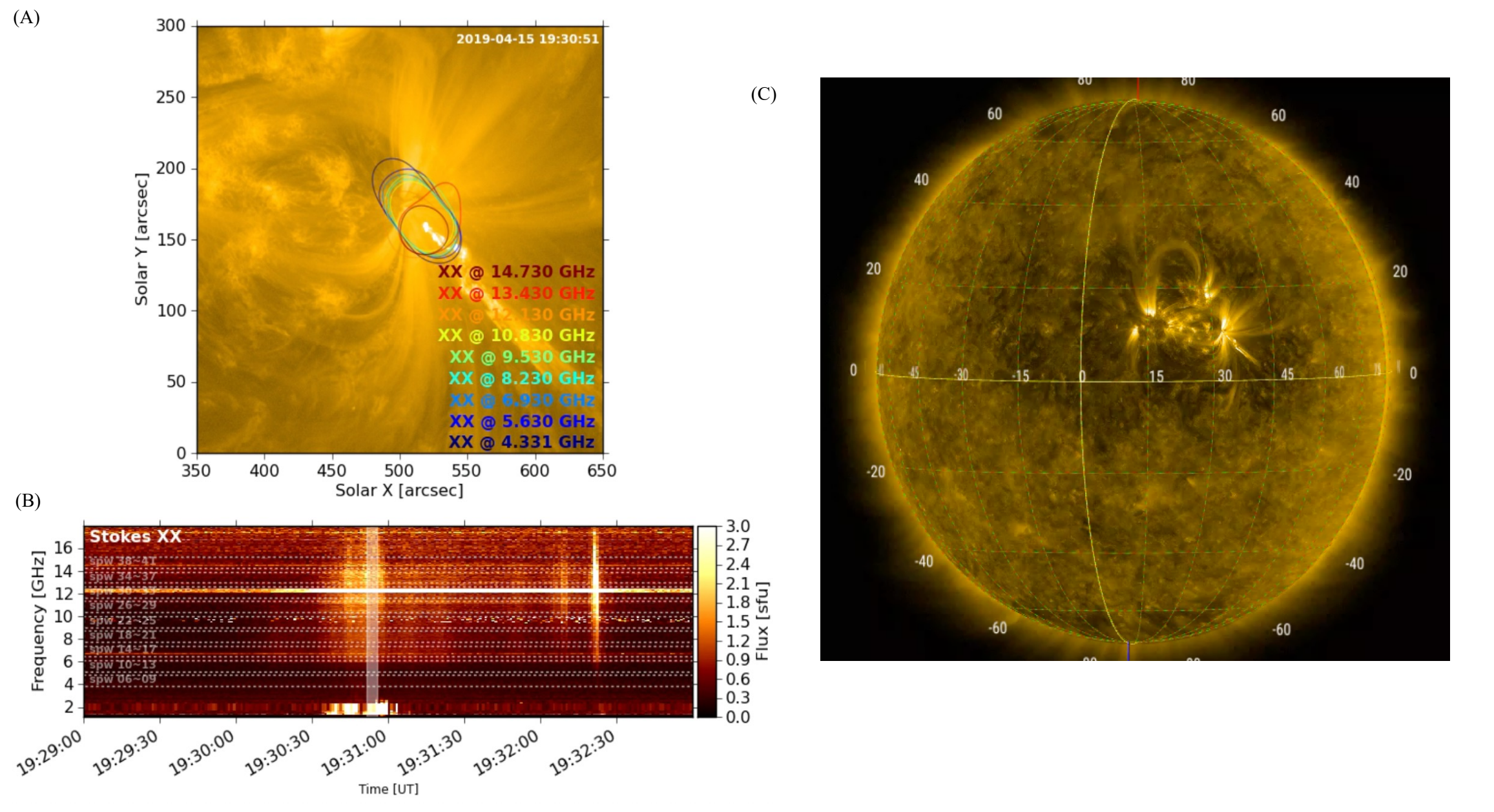
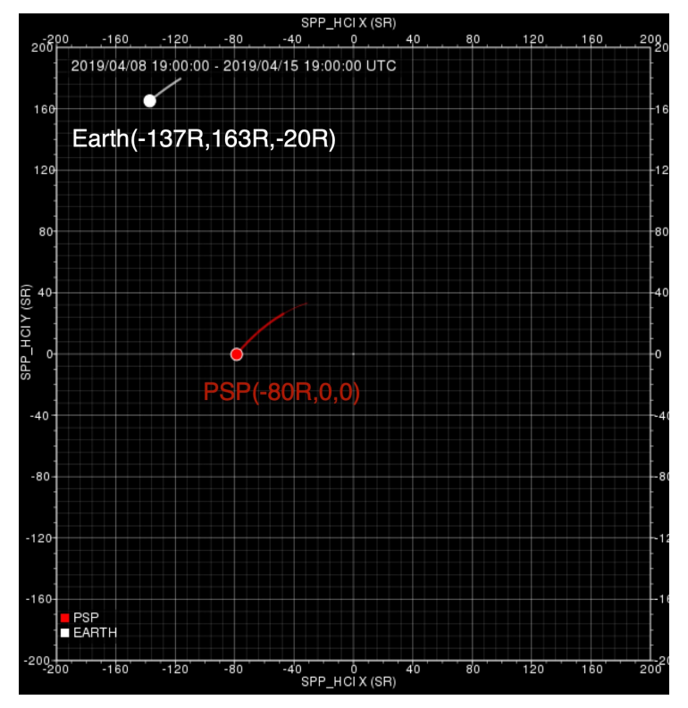


Fig 1(A): 50% contours of EOVSA's image at different frequencies is over-plotted on SDO/AIA 171 image on 2019 April 15 at 19:30:51 UT. (B): EOVSA microwave cross-power dynamic spectrum from 19:28 UT to 19:38 UT. (C): SDO/AIA 171 full sun image at 19:30 UT.

The time delay between the PSP and EOVSA



PSP Orbit and Position
(https://sppgway.jhuapl.edu/orbitplot)

This type III radio burst:
The onset time observed by EOVSA ~19:30 UT
The onset time observed by PSP ~19:25 UT
The travel time from sun to PSP:

$$\Delta t_1 = \frac{80R_{sun}}{3*10^8} \sim 3.1min$$

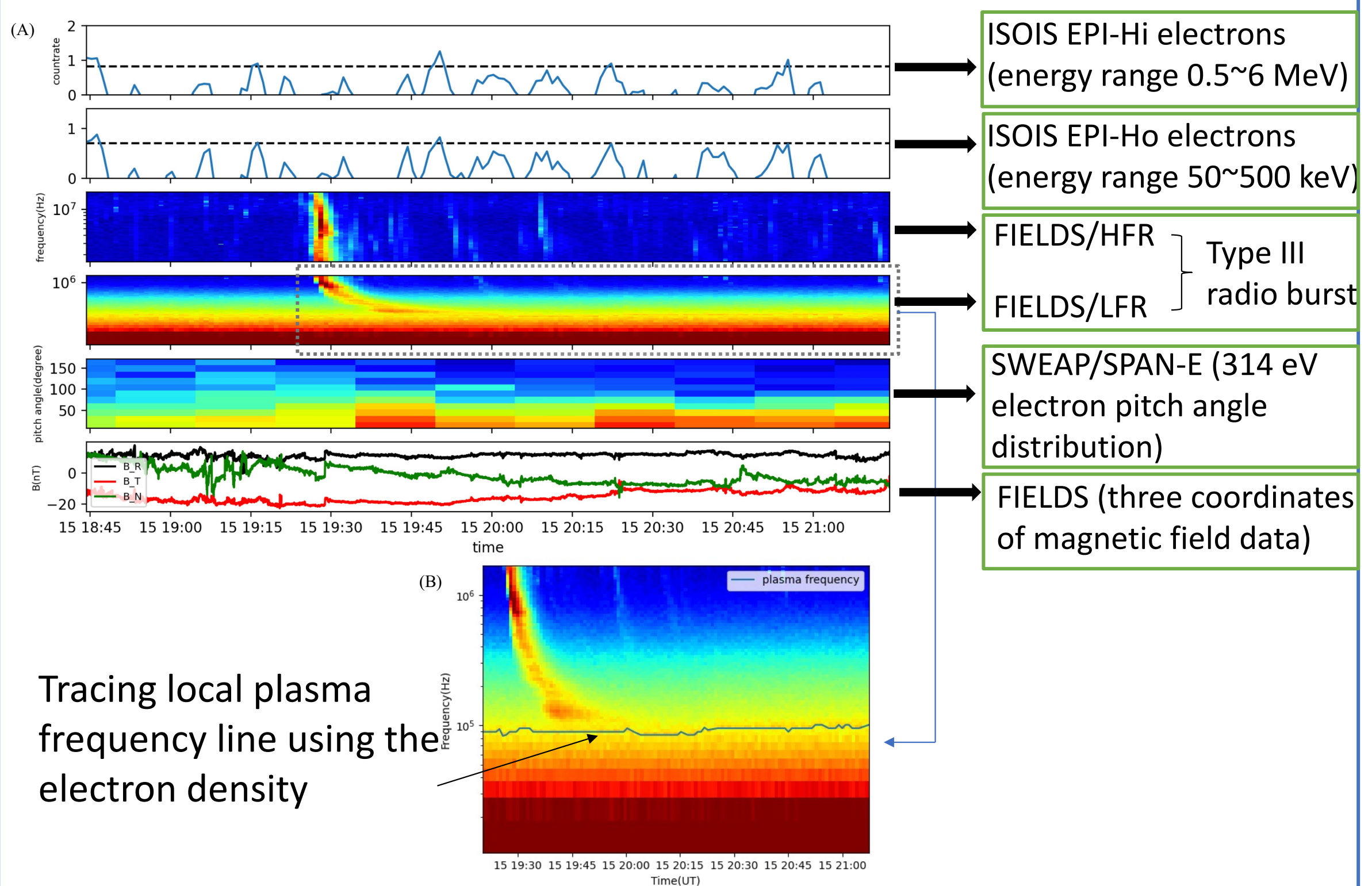
The travel time from sun to EOVSA:

$$\Delta t_2 = \frac{213.86R_{sun}}{3*10^8} \sim 8.3min$$

Delay time: $\Delta t = \Delta t_2 - \Delta t_1 \sim 5.2min$
This result agrees with the onset time difference between PSP and EOVSA

OBSERVATIONS

PSPs observation summary plot showed in Fig 2. Using the local electron density to trace the plasma frequency line (see Fig 2 (C)). The Type III radio burst appears to reach the local plasma frequency at the spacecraft.



ISOIS EPI-Hi electrons (energy range 0.5~6 MeV)

ISOIS EPI-Ho electrons (energy range 50~500 keV)

FIELDS/HFR
FIELDS/LFR
Type III radio burst

SWEAP/SPAN-E (314 eV electron pitch angle distribution)

FIELDS (three coordinates of magnetic field data)

Tracing local plasma frequency line using the electron density

Fig 2(A): Top two panels: First panel is PSP/ISOIS EPI-HI data. The data is background subtracted and then used the second degree Savitzky-Golay smoothing filter over 7 minutes. The black dash line is one sigma of the data. The second panel is PSP/ISOIS EPI-Lo data proceed the same as the first panel. Middle two panels: top panel is PSP/FIELD HFR data, below panel is PSP/FIELD LFR data. Bottom two panels: top panel is the pitch angle distribution of 314eV getting from PSP/SWEAP. Bottom panel is the magnetic field from PSP/FIELD. 2(B) Enlarge the green dash line box, tracing the plasma frequency line in the PSP radio dynamic spectrum.

RESULTS

1.1 Source Location

The type III radio source is observed by **STEREO, WIND, PSP and EOVSA**.

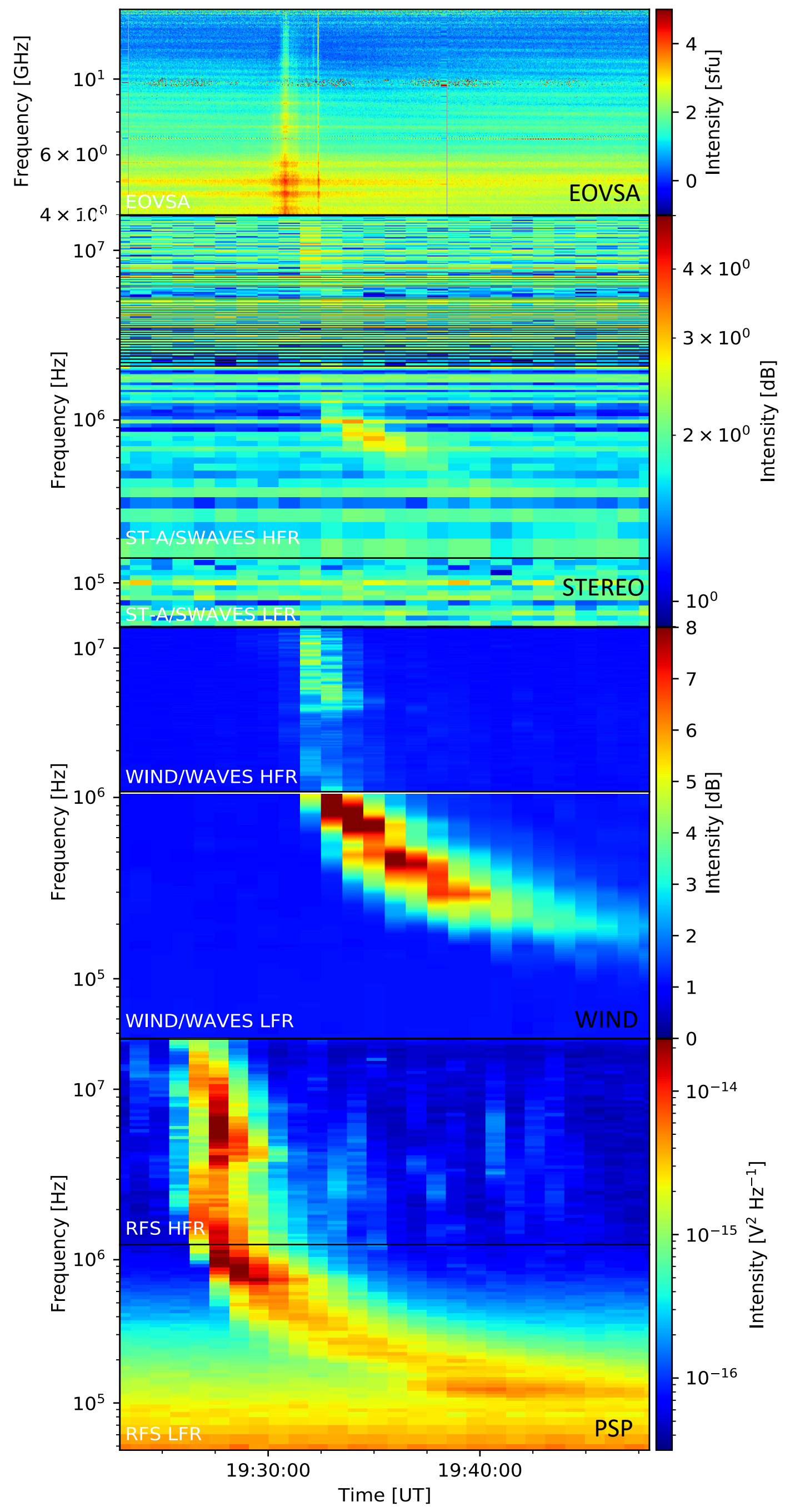
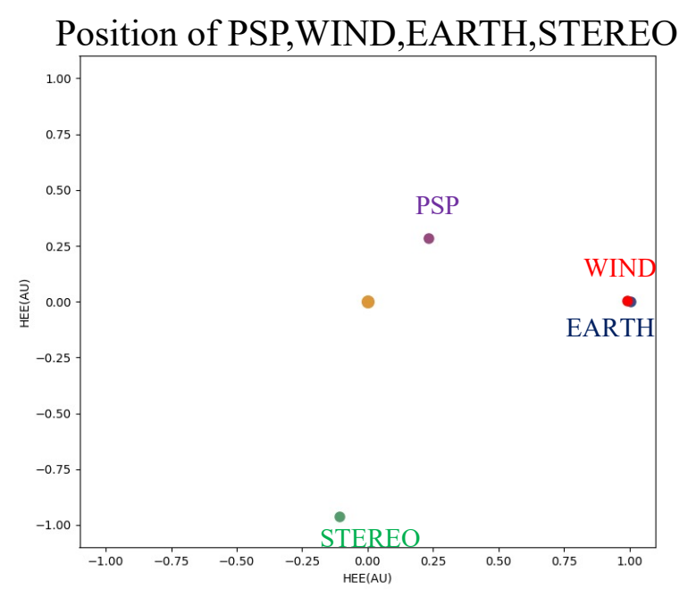


Fig 3:From top to bottom's data is from EOVSA, STEREO A, WIND, PSP

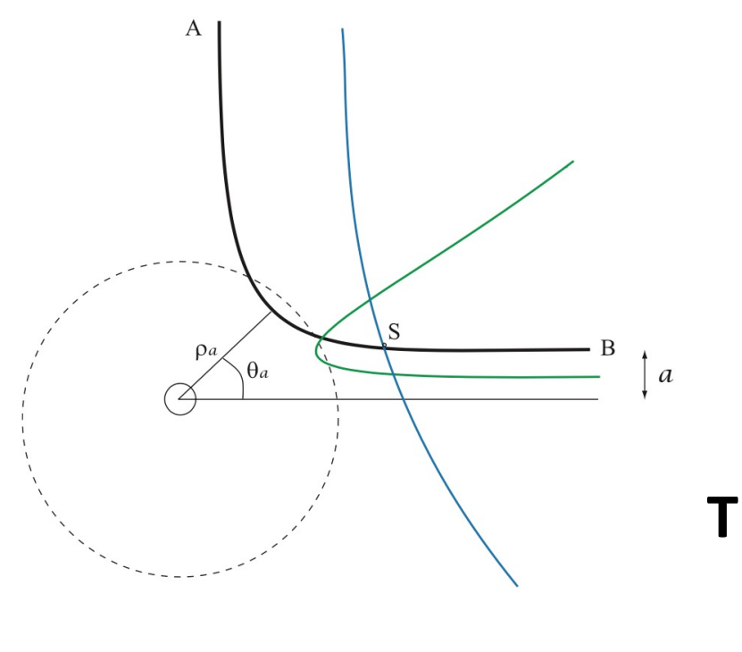
The time difference between the onset time of type III radio burst can be observed by four instruments. We can use this to located the radio source.



RESULTS

1.1.1 Techniques

The radio source radial distance is determined by the ray tracing calculations.



Calculate the ray trajectories and use the measured time difference to determine the source position.

Thejappa et al. (2010)

We assume the radio source directivity follows an exponential shape as a function of μ. Using the peak intensity(SFU) of STEREO, WIND and PSP to fit the directivity function as follows.

$$F(\mu) = C_0 \exp\left(-\frac{(1-\mu)}{\Delta\mu}\right)$$

$$\mu = \cos(\varphi - \varphi_0)$$

source longitude

following **S. Musset (2021);**(private communication)

1.1.2 Results

Figure 4(A) shows the result of the source location using the techniques above. This radio burst seems to approaching to the PSP. Using the ray tracing calculation get the results that the radial distance is changed with frequency. The longitude of the source around 700kHz is ~50°

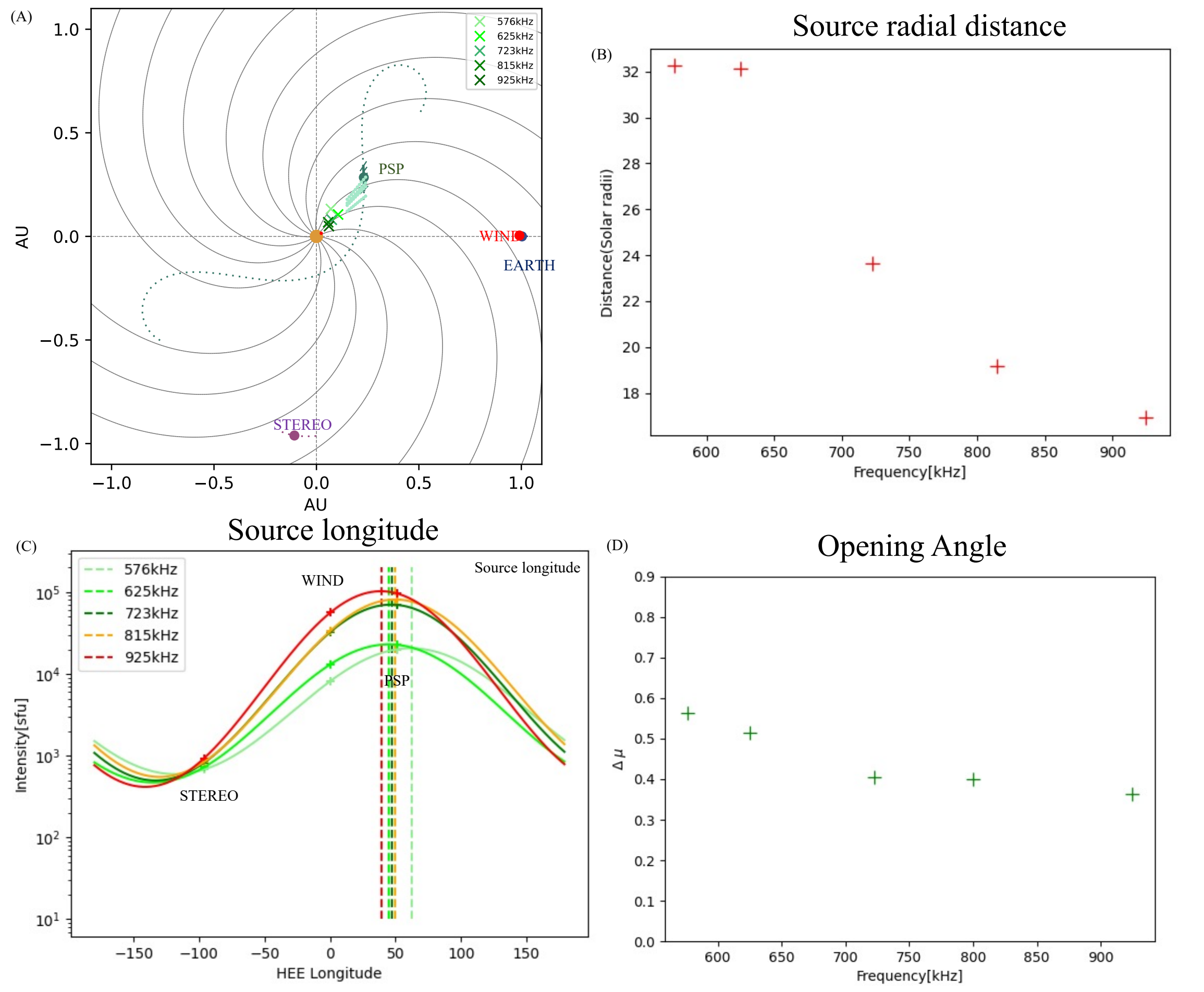


Fig 4(A) Type III radio source location in HEE frame. The five cross points are different frequencies' source location vary from different colors. The light green dash line is the directivity of the radio source. The grey solid line is the parker spiral curve. The grey dash line is the PSP's trajectory in Perihelion 2. 4(B): The source radial distance from the sun for five frequencies showed in 4(A) using the ray tracing calculations. 4(C): the directivity fitting result. The cross points are the peak intensity with five different frequencies measured by three spacecrafts. 4(D): results of parameter $\Delta\mu$ determined by the fitting results which is ~0.4.

1.2 Magnetic connectivity

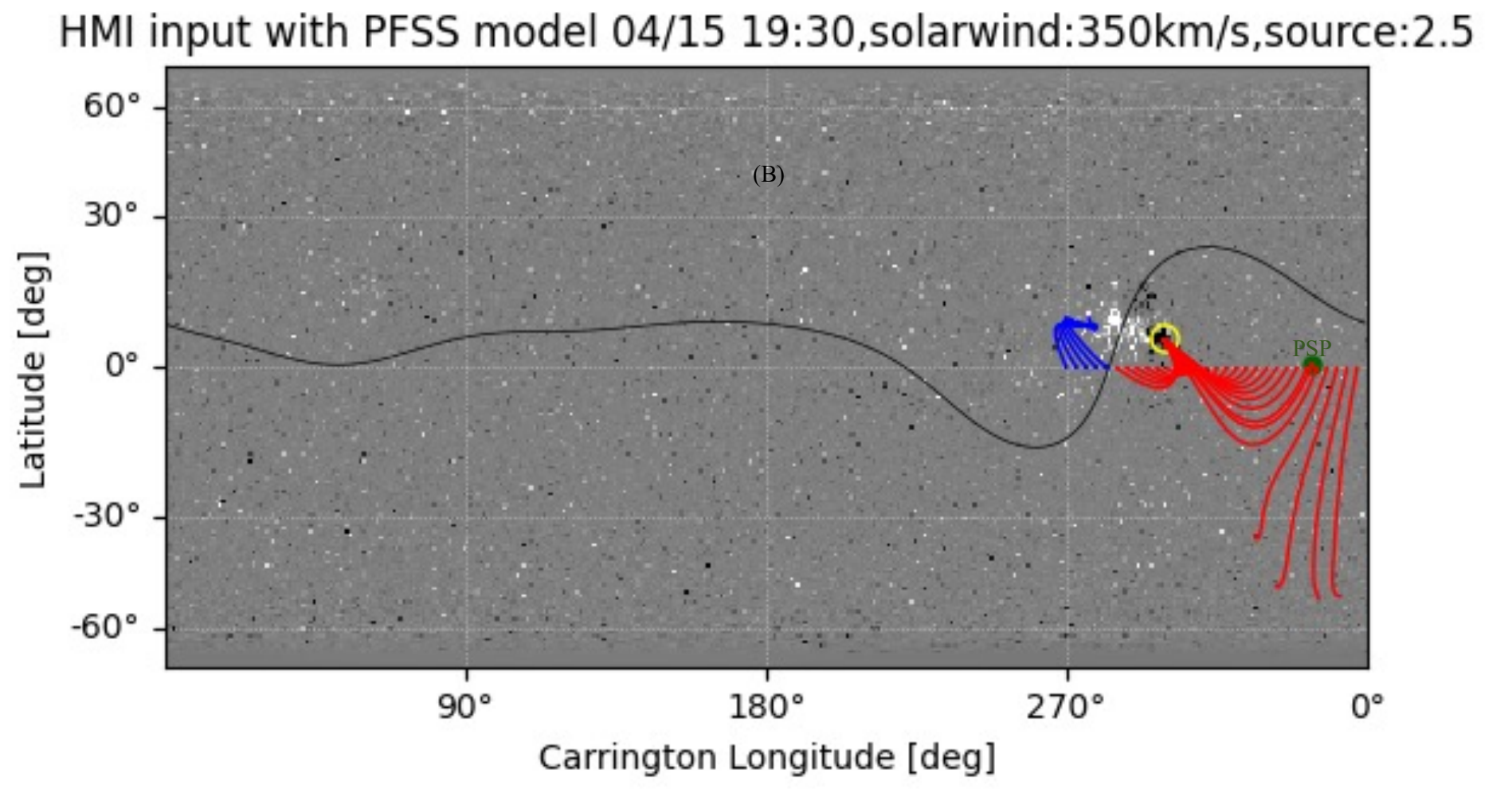


Fig 5: PFSS model with HMI mapped to a synoptic magnetic map in Carrington coordinates during the Carrington 2216. The green point is the PSP location in 2.5 solar radii tracing from 79 solar radii using parker spiral curve and PSP/SWEAP spacecraft velocity data. The yellow open circle is the active region showed in Fig 1. The black solid line is the magnetic neutral line on the source surface. The red and blue lines are the field lines traced from the map to the equatorial plane at 2.5R.(Red is positive, Blue is negative)

RESULTS

We use PFSS modeling. Combined with parker spiral curve and solar wind velocity data from SWEAP to connect the spacecraft to the source surface. A source surface height of 2.5R is assumed. Despite the simplicity of the model, our results show that the PSP is magnetically connected with the active region during the type III burst

1.31 Angular & Energy distribution

Fig 6(A): The electron distribution at the spacecraft has an anti-sunward beam-like component.

Fig 6(B): Differential electron energy flux below 15º increases during the active time range compared with the quietscent time range. The time integrated energy spectra seems to have the double-power-law shape with a break at near 500 eV.

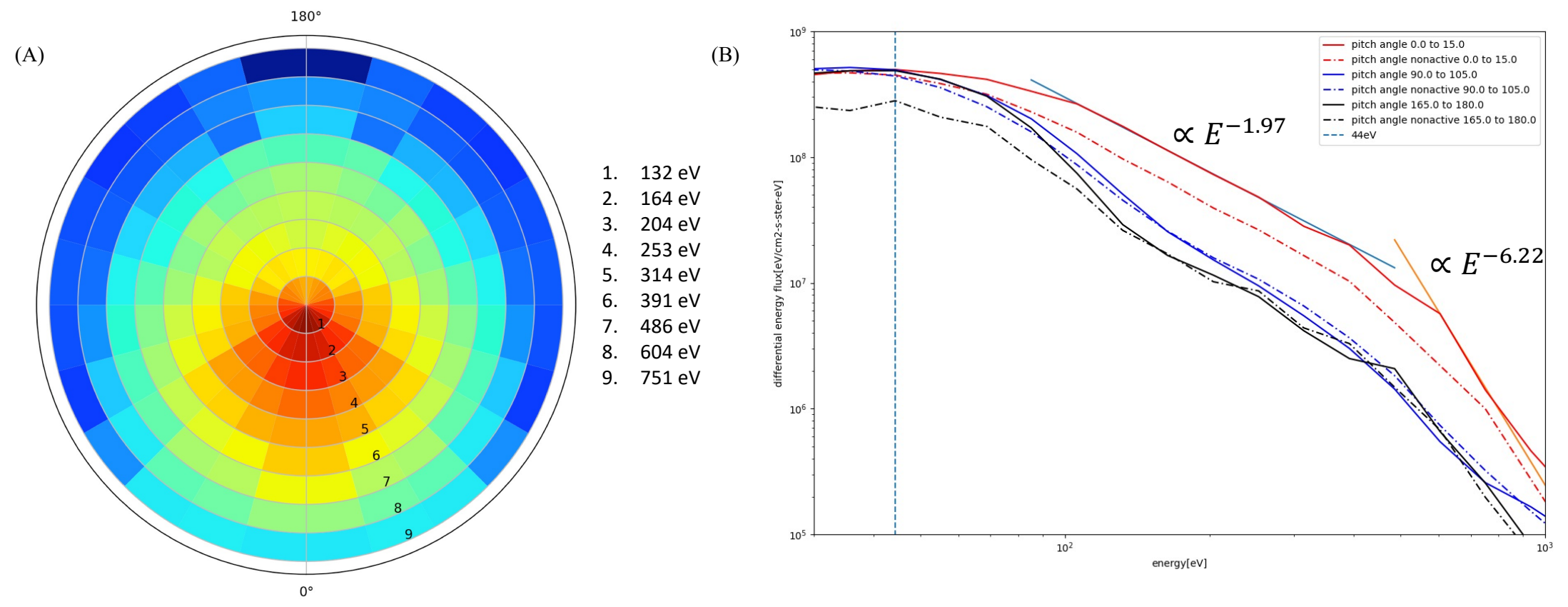


Fig 6(A): Pitch angle distribution in nine different energy bins from PSP/SWEAP. 6(B):Time integrated energy spectra. The red solid line is the differential energy flux vary with different energy bins adding up pitch angle 0 degree to 15 degree from 19:34~19:39 UT. The red dash line is the same pitch angle range from the time before the type III burst(18:04~18:19UT). The blue and black curve are the same time range with the red one but for different pitch angle(blue:90 degree to 105 degree, black: 165 degree to 180 degree). Angles of 0 degree are co-aligned with the magnetic vector. The vertical dash line is the peak energy of the curve.

1.31 Electron transport model

We use the coronal and solar wind density model to compute the effect of the electrons' traversing the corona.

Fig 7(A) The coronal and solar wind density model used for the computed electron spectra.

Fig 7(B) The computed electron spectra is obtained at 79R(the PSP location), started with a power-law electron spectrum $\frac{dJ}{dE} = E^{-\gamma}, \gamma = 9$ from different source height and considered the energy loss of electrons in the coronal and solar wind plasma via Coloumb Collison (Lin, R.P 1985)

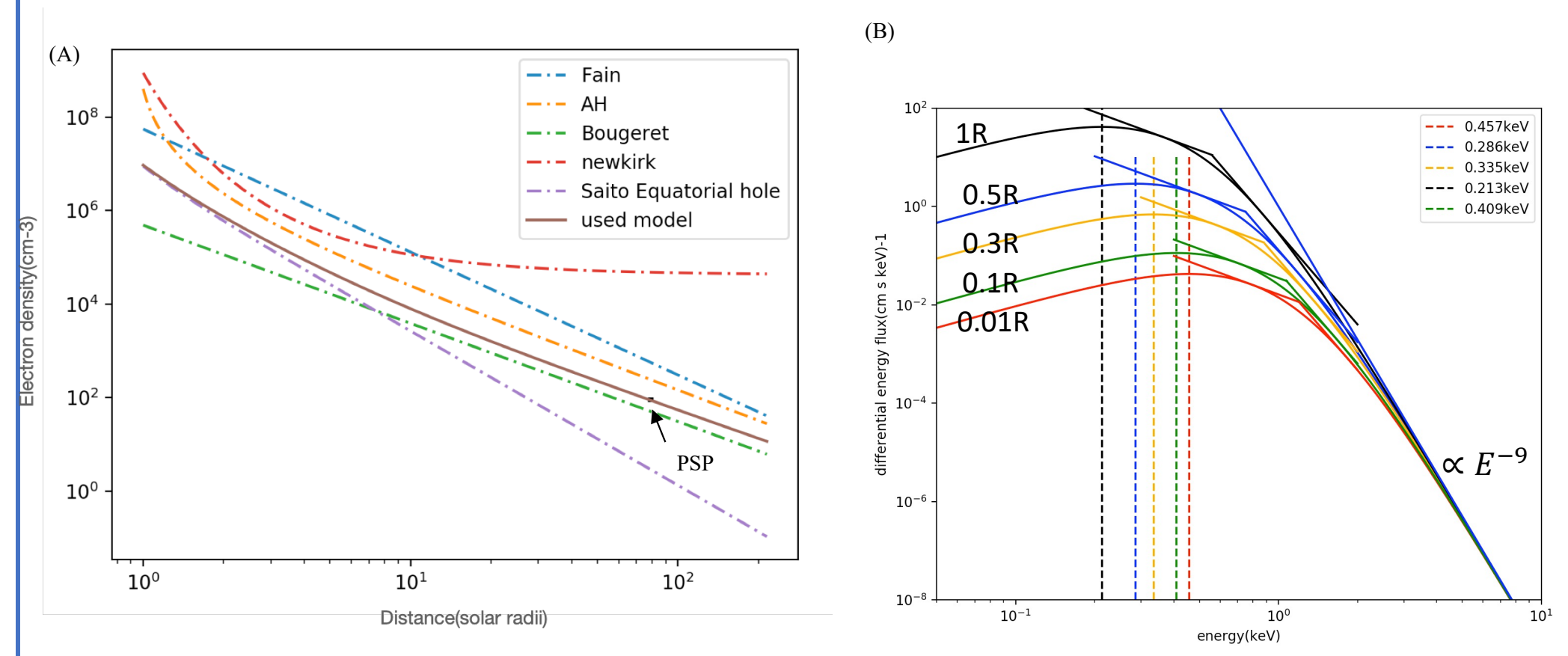


Fig 7(A): The coronal density model used in Fig 7(B). 7 (B): Calculated electron spectra at PSP's location(~79R) resulting from injection of a power-law spectrum at different heights above solar surface. The double-power-law shape line is the red curve in Fig 6(B) matched in the spectra model.

This preliminary transfer model shows that the break energy is ~500 eV at 1R source height, ~750eV at 0.5R source height, ~880eV at 0.3R and >1keV at lower height. We note that the source height and break energy are very sensitive to the choice of γ.

Reference

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