# Magnetic Connectivity Tool

## A tutorial

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**<u>Articles describing some features of the tool</u>:**

**Rouillard et al, 2020**, *Models and Data Analysis Tools for the Solar Orbiter mission*
Astronomy and Astrophysics, A&A 642, A2 (2020)
https://www.aanda.org/articles/aa/pdf/2020/10/aa35305-19.pdf

https://doi.org/10.1051/0004-6361/201935305

**Poirier et al. 2021,** *Exploiting white-light observations to improve estimates of magnetic connectivity*, Frontiers in Space Physics, submitted
Available on the Magnetic Connectivity Tool website:

**Technical issues, please send an email to** Mikel Indurain: mindurain@irap.omp.eu

**Tool location: http://connect-tool.irap.omp.eu/**

# ▼ Magnetic Connectivity Tool

**SPACECRAFT :**

- ◉ EARTH
- ○ PARKER SOLAR PROBE
- ○ STEREO A
- ○ SOLAR ORBITER
- ○ BEPICOLOMBO
- ○ ALL

**CORONAL MAGNETIC FIELD :**

| PFSS | MFM | PFSS/SCS |
|---|---|---|
| ☐ WSO | ☐ *DUMFRIC* | ☐ *WSA* |
| ☐ NSO | | |
| ☑ ADAPT | | |

**INTERPLANETARY MAGNETIC FIELD :**

| BALLISTIC | MHD |
|---|---|
| ◉ PARKER | ○ *ENLIL* |
| | ○ *HELIOCAST* |

**PROPAGATION MODE :**

| | SC ↓ SUN | SUN ↓ SC |
|---|---|---|
| SW LAG | ○ | ○ |
| EM LAG | ◉ | ○ |

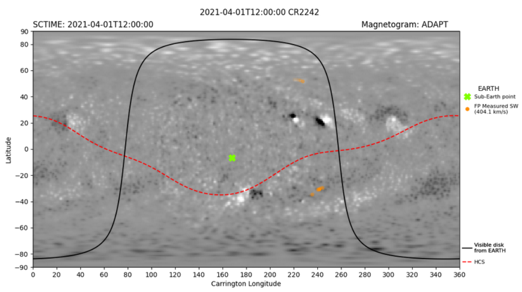
**DATE :** 01 / 04 / 2021

**TIME (UTC) :**

- ○ 00:00
- ○ 06:00
- ◉ 12:00
- ○ 18:00

Search

## adapt




Mode : SCIENCE

Coronal Model : PFSS (rss = 2.5 Rsun)

Magnetogram : ADAPT-4 (2021-04-01 06:00:00 UTC)

**Reliability Test (WL) :** 66.29%

▸ Download Data    Download image

## DISPLAY OPTIONS

**Background**

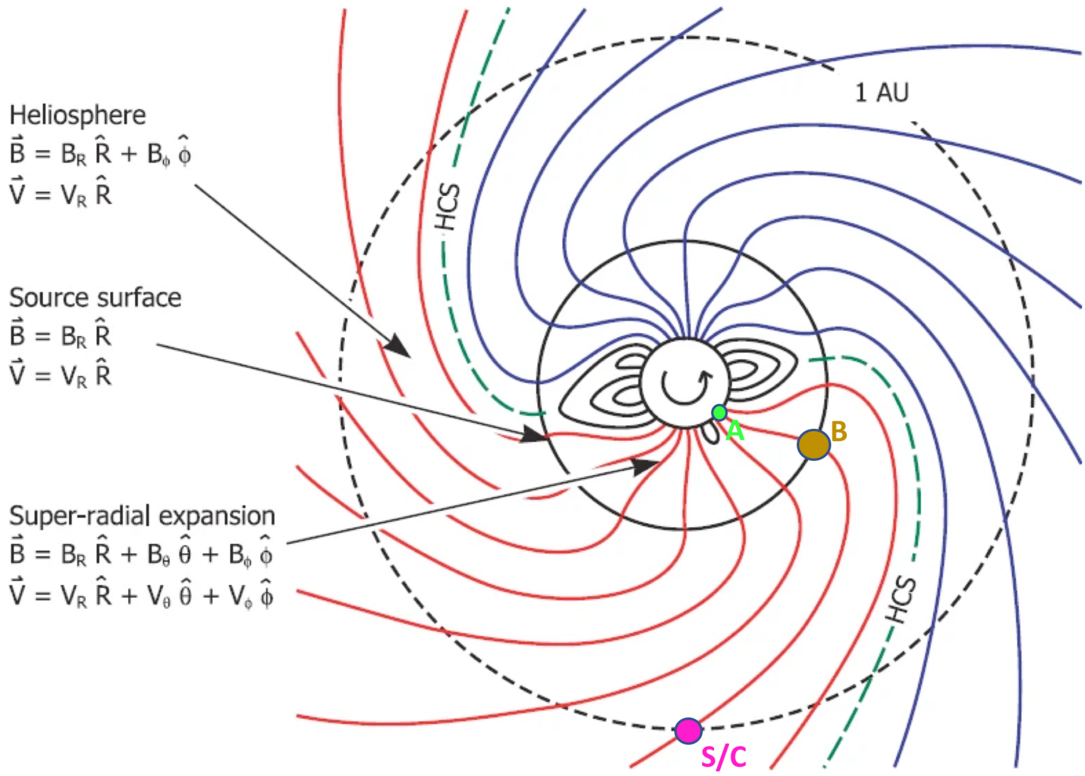
- ◉ Magnetogram
- ○ EUV 171
- ○ EUV 193
- ○ EUV 304
- ○ White Light

**Features**

- ☑ Legend
- ☑ Sub-SC/Planet point
- ☑ Connectivity points
- ☑ HCS
- ☑ Visible Disk
- ☐ Flare
- ☐ X Flare
- ☐ Coronal Hole
- ☐ CME
- ☐ Active Region
- ☐ *Polarity*
- ☐ *QSL map*

Reset

**General information:** The Magnetic Connectivity Tool can help you estimate the solar source location of the solar wind and energetic particles measured by different spacecraft. In doing so, the tool will model the coronal and interplanetary magnetic field based on different assumptions and techniques. Currently the coronal model is primarily based on a magnetostatic reconstruction technique called the Potential Field Source Surface (PFSS) model and the interplanetary magnetic field is assumed to be a Parker spiral. This is schematised in the following diagram.




**Schematic 1. Schematic illustrating how magnetic connectivity is established in the Magnetic Connectivity Tool. showing the location of a spacecraft S/C, the intersection of the Parker Spiral (B) and the photospheric/low corona magnetic footpoint of field line (A). [Schematic taken from Owens and Forsyth 2013]**

There are two possible directions of propagation, either from the Sun to a S/C or from a S/C to the Sun.


A first critical parameter to define magnetic connectivity will be the speed of the solar wind at the spacecraft because this speed will define the shape of the Parker spiral considered in the tracing. This spiral will define the longitudinal difference between the spacecraft of interest (S/C) and point B at the outer boundary of the coronal model (Schematic 1). Once point B is determined by the tool, the latter knows which field line to trace from B to the solar surface in the coronal model. When solar wind speed measurements are available (public data), the tool uses those specific measurements to compute the shape of the spiral (the speed is then displayed in the legend of the Carrington map as ‘*FP measured SW’ and give you the speed considered*). For Solar Orbiter the tool will either use the scientific fully calibrated data from the Proton Alpha Sensor or if the data is not yet available it will retrieve the Low Latency Data from PAS released by the Solar Orbiter archive. So information about the solar wind speed is obtained in quasi real time.

When solar wind speed data is not available (never obtained or not public) then the tool assumes two possible speeds for the solar wind, either slow (300 km/s) or fast (800 km/s). These two extreme speeds will be used to compute with the corresponding two spirals the two connectivity points B and then trace from these two points (B) down to the solar surface (A) in the coronal model (see the corresponding legend in the Carrington map). In fact the tool does more than that, it will consider a distribution (cloud) of possible points around each point B and trace hundreds of field lines to give you an estimate of the level of uncertainty in the tracing. This is why you see two clouds of coloured points at the solar surface for each spacecraft.

A second critical parameter that must be computed by the tool is the difference between the time a solar wind parcel (or an energetic particle) has been measured by a spacecraft and its release time from the Sun that will in turn define the time of the coronal model to be considered. For example if you decide to start at a spacecraft and go back to the Sun (because you have identified a feature of interest at the spacecraft and want to find its source at the Sun) then the propagation time of that feature from point B to S/C will be calculated by the tool and used to define the date of the magnetogram that should be considered to reconstruct the coronal magnetic field reconstruction. A nearly relativistic particle will have a much shorter propagation time (a few minutes) compared with a solar wind parcel (typically 1-5 days depending on wind speed and the heliocentric distance of the spacecraft). Therefore the tool offers in addition to considering solar wind propagation times (SW lag), the possibility to assume the time of propagation of electromagnetic radiation (EM lag) so that someone who wants to find the source location of very fast solar energetic particles can also use the tool. The EM lag is currently set to zero because the cadence of the data/images shown in the tool is typically of the order of 6 hours compared with EM propagation time of photons from the Sun to the different spacecraft of a few minutes only. Once a lag type (SW lag or EM lag) is chosen the tool will take the spacecraft date/time and calculate the launch date/time at the Sun and consequently identify the magnetogram that should be used to model the coronal magnetic field.

The tool will provide estimates of magnetic connectivity either at the solar surface if you compare say your connectivity with a magnetogram or an EUV image (that capture features located in the corona but very close the solar surface) or higher up in the atmosphere (5 solar radii) if you consider a map of helmet streamers taken by coronagraphs (since 5 solar radii is above the outer boundary of the model, the tool only uses a Parker spiral for tracing and no coronal model is considered).

You can choose from a broad range of maps from the tool as catalogues of identified features (active regions, flares and soon CME sources).

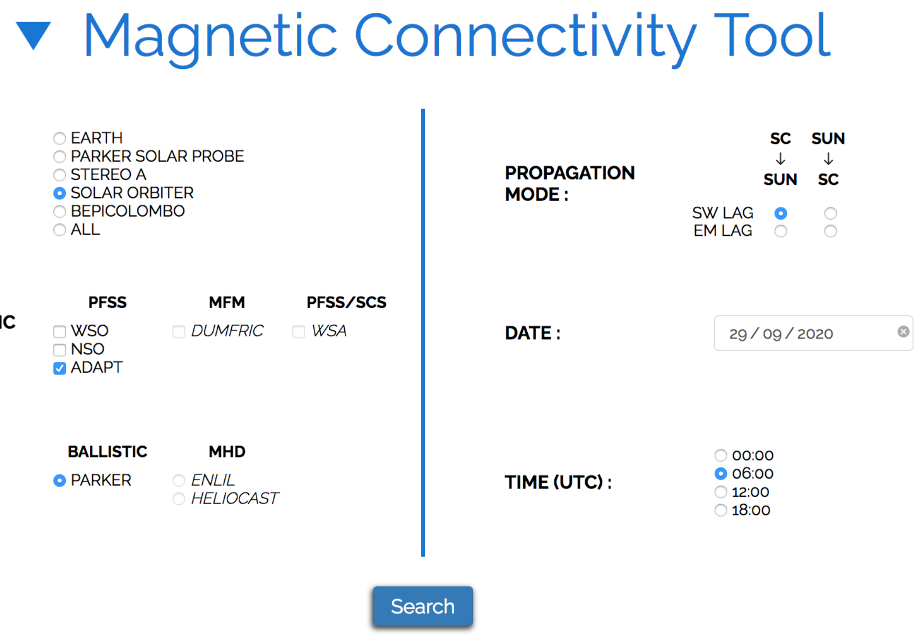
If the date/time falls in the future, the tool uses forecasts of magnetic connectivity provided by the ADAPT project. Forecasts of magnetic connectivity will be useful to Solar Orbiter operations and are provided up to 10 days out in the future. We will show an example below.

You can even retrieve information on the likelihood of a flare occuring in the future (but that is for the next school in 2021!)

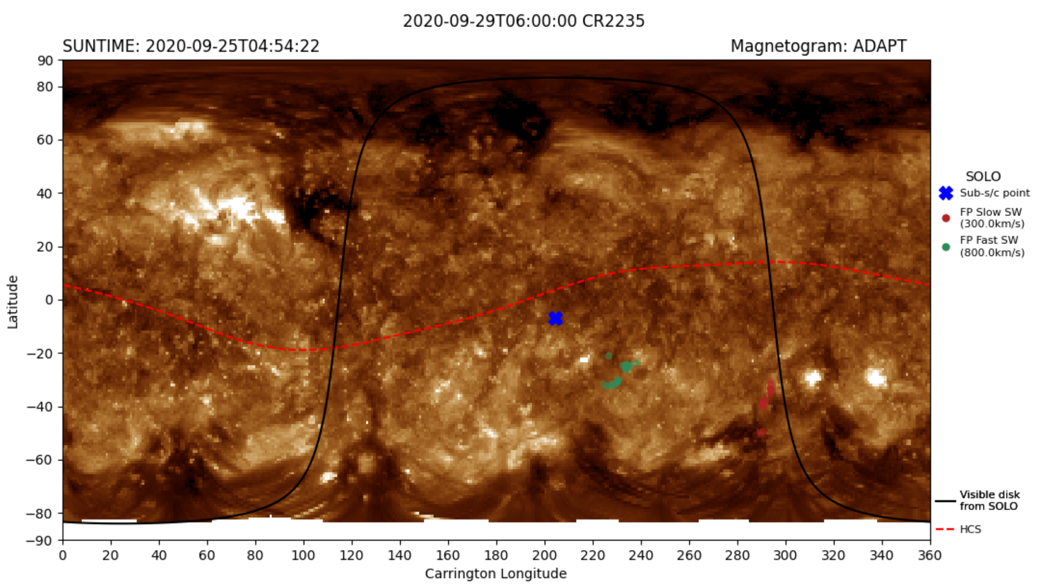
Let’s try it out! In the following page you will be shown some specific case studies that can be carried out with this tool.

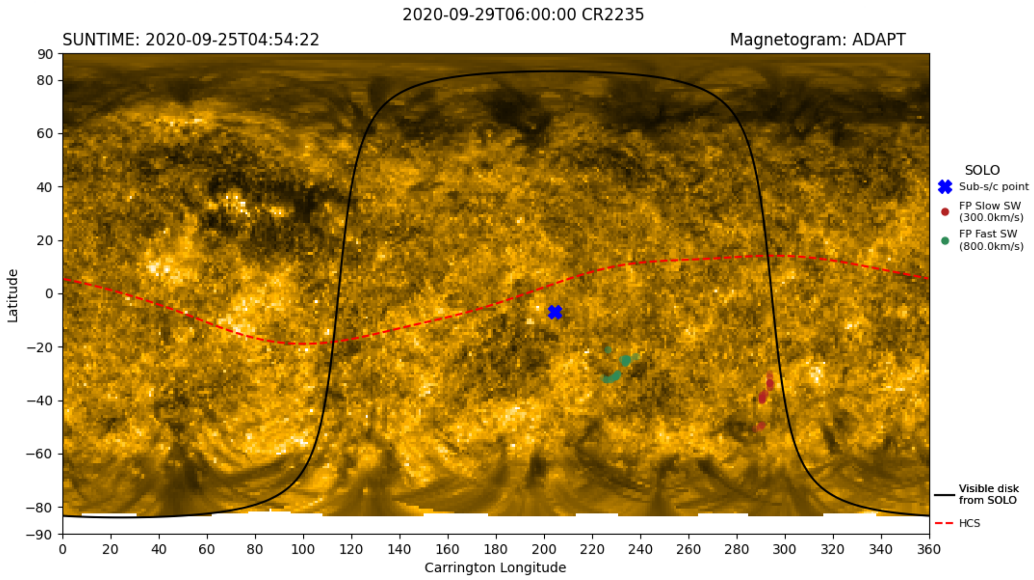
**Case study 1:**

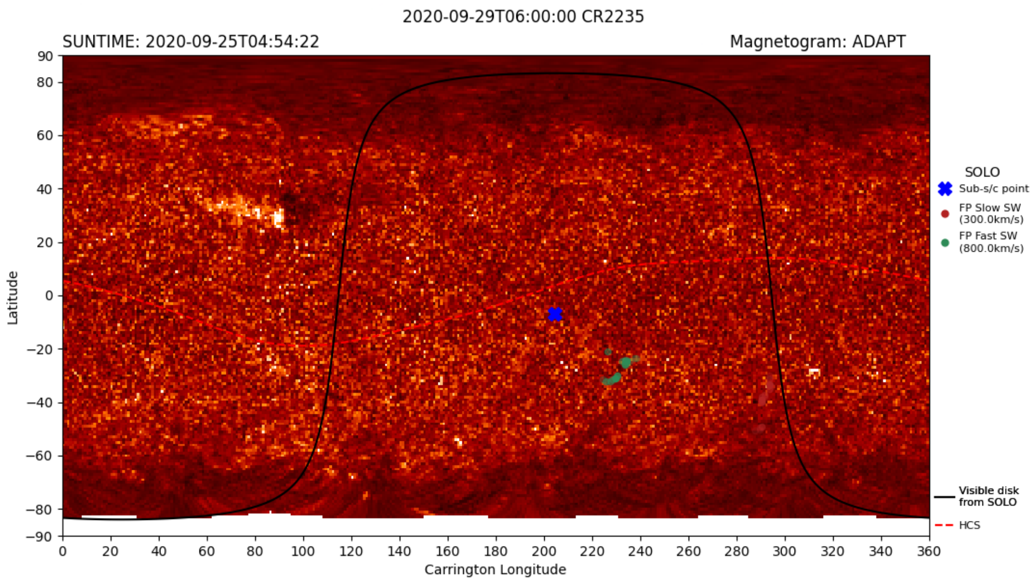
1) Estimate the source region of the solar wind measured on September 29 2020 at 6UT by Solar Orbiter (therefore spacecraft time).



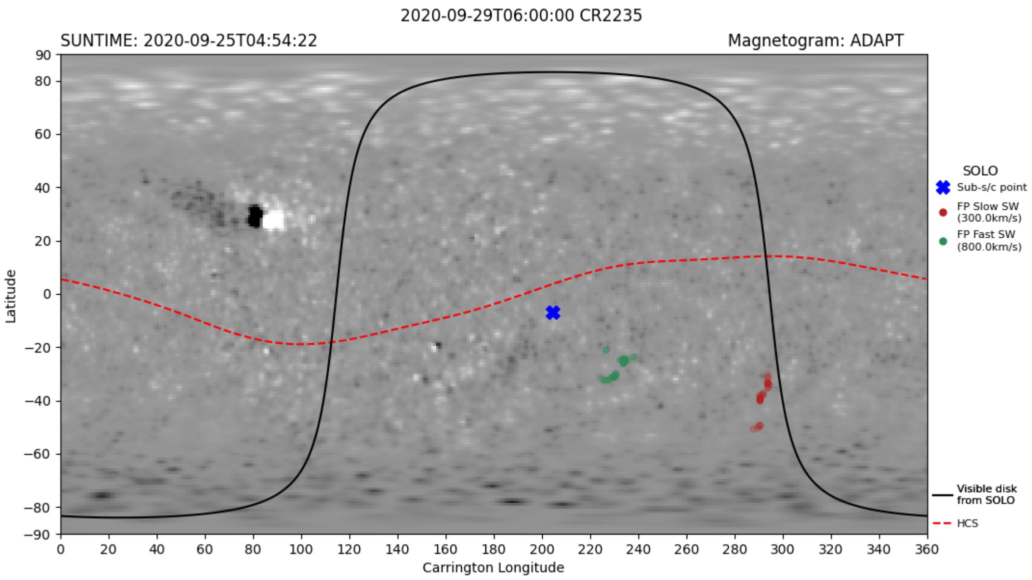

Compare the estimated connectivity footpoints with the location of coronal holes in EUV. Download the image with all labels to your computer. When did the plasma escape the Sun? Which wavelength seems to be the best suited to detect coronal holes?

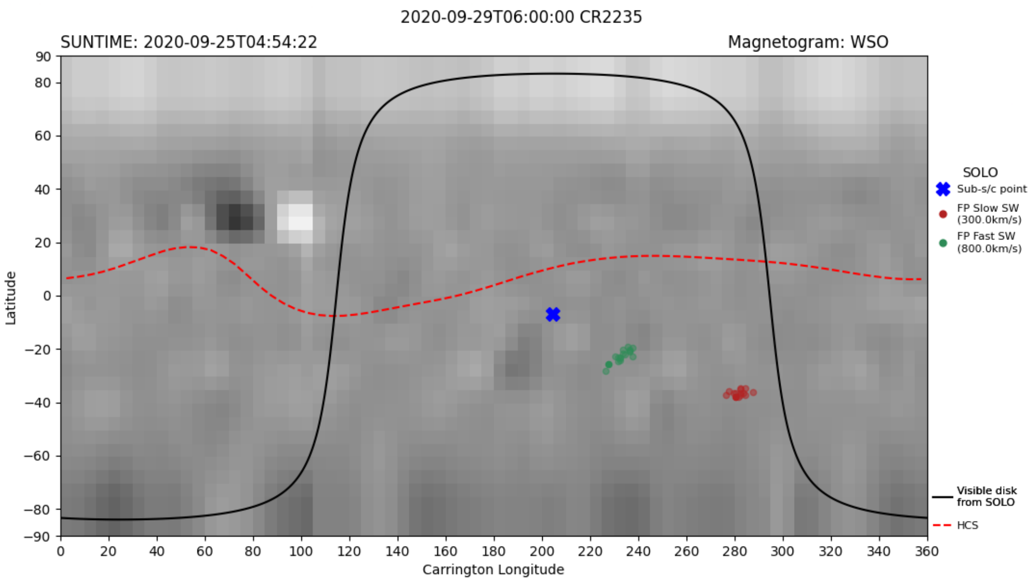



2020-09-29T06:00:00 CR2235
SUNTIME: 2020-09-25T04:54:22
Magnetogram: ADAPT
Latitude
Carrington Longitude
SOLO
Sub-s/c point
FP Slow SW (300.0km/s)
FP Fast SW (800.0km/s)
Visible disk from SOLO
HCS

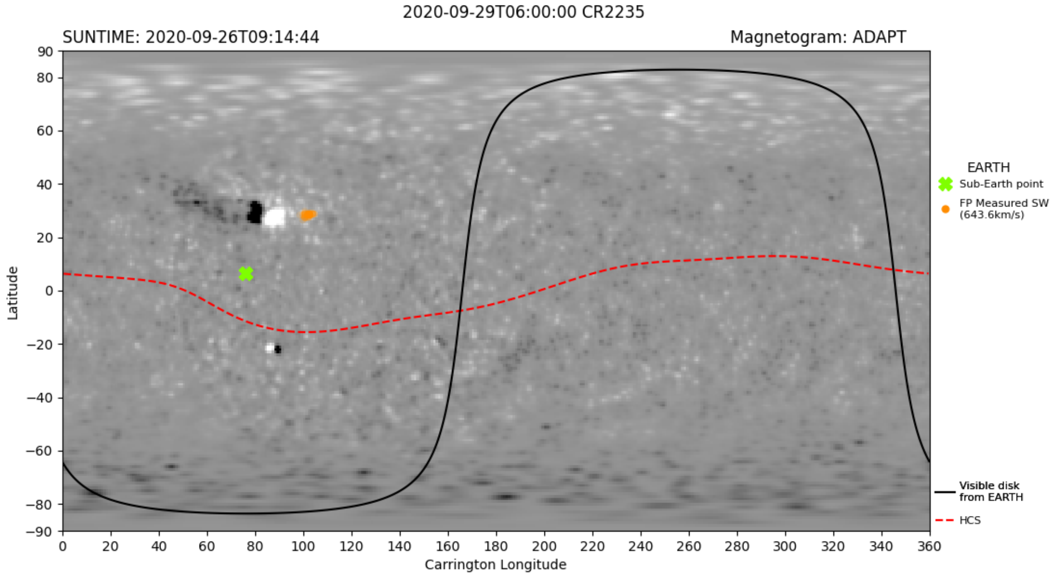

2020-09-29T06:00:00 CR2235
SUNTIME: 2020-09-25T04:54:22
Magnetogram: ADAPT
Latitude
Carrington Longitude
SOLO
Sub-s/c point
FP Slow SW (300.0km/s)
FP Fast SW (800.0km/s)
Visible disk from SOLO
HCS

3) Compare estimates from ADAPT and WSO magnetograms. Do you see differences ?

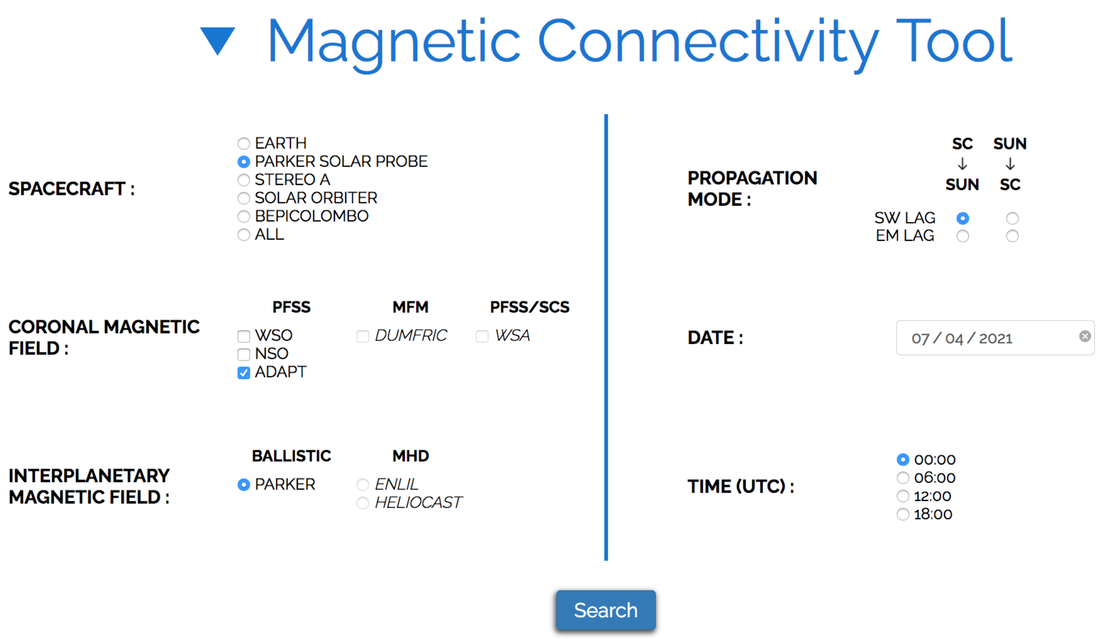


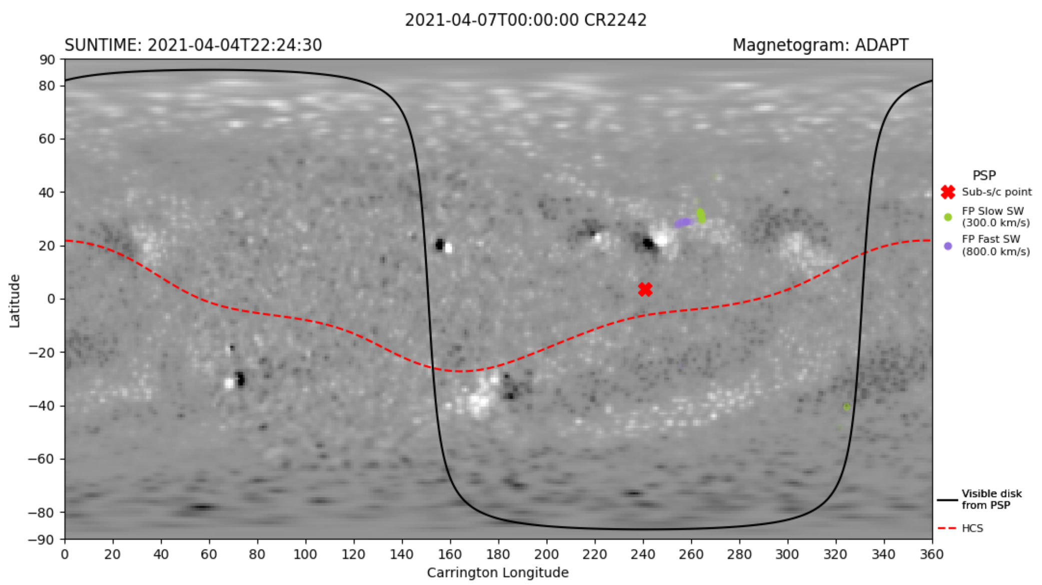



4) How do you interpret the difference between magnetic connectivity estimates assuming a slow and fast background solar wind? What happens if you select the Earth as your starting point estimate on that date (2020-09-29 06:00UT spacecraft time)?

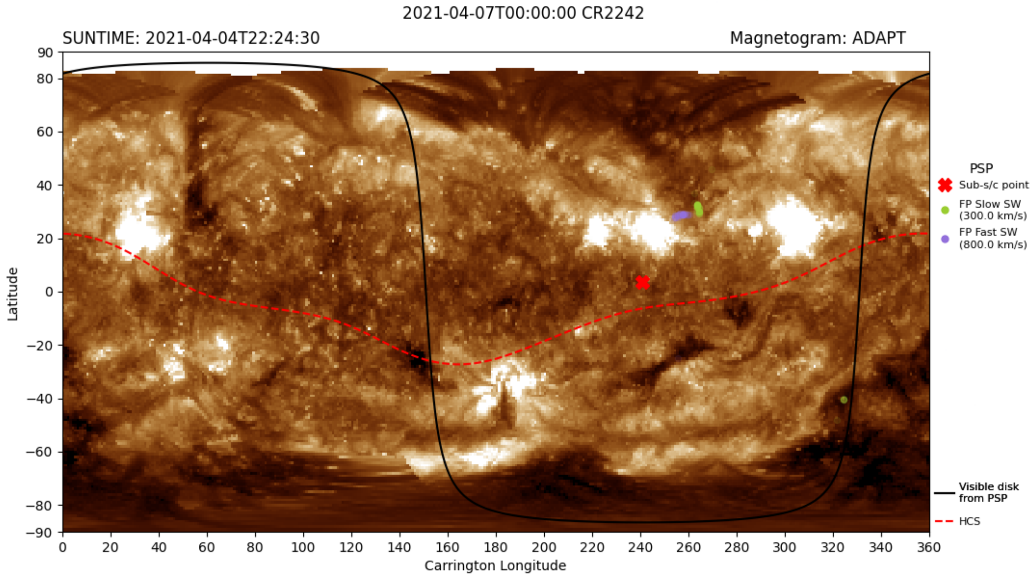


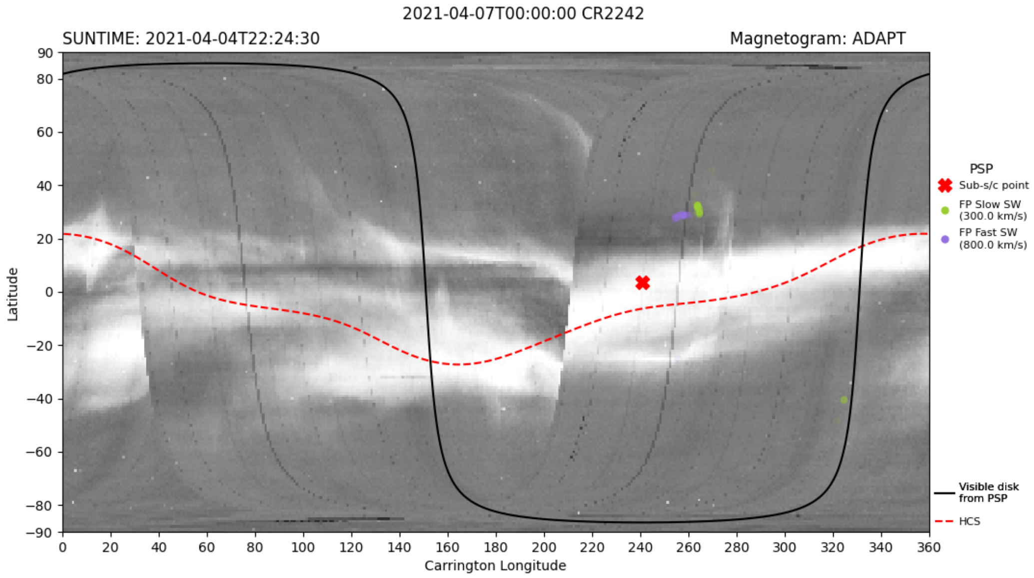
**Case study 2:** Predict the source region of the solar wind measured by Parker Solar Probe one day from now (here this example was produced on 06-04-2021 therefore one day in the future was 07-04-2021 00:00UT defined as the time of plasma impact at the spacecraft: spacecraft time).




When and where was the solar wind released? Use EUV and WL maps to study the types of solar wind source regions.


2021-04-07T00:00:00 CR2242
SUNTIME: 2021-04-04T22:24:30
Magnetogram: ADAPT
Latitude
Carrington Longitude
PSP
Sub-s/c point
FP Slow SW (300.0 km/s)
FP Fast SW (800.0 km/s)
Visible disk from PSP
HCS


2021-04-07T00:00:00 CR2242
SUNTIME: 2021-04-04T22:24:30
Magnetogram: ADAPT
Latitude
Carrington Longitude
PSP
Sub-s/c point
FP Slow SW (300.0 km/s)
FP Fast SW (800.0 km/s)
Visible disk from PSP
HCS

**Case study 3:**

**Attached files : movie_slow.mov, movie_fast.mov**
The movies (http://filez.irap.omp.eu/a1dt0nfbdbo9) (prepared using HelioPy) show the trajectory in the Carrington rotating frame of the Sun of Solar Orbiter, Parker Solar Probe and Earth. The grey line is the Parker Spiral starting from PSP position and going outward for assumed wind speed of 300 km/s (slow) and 800 km/s (fast).

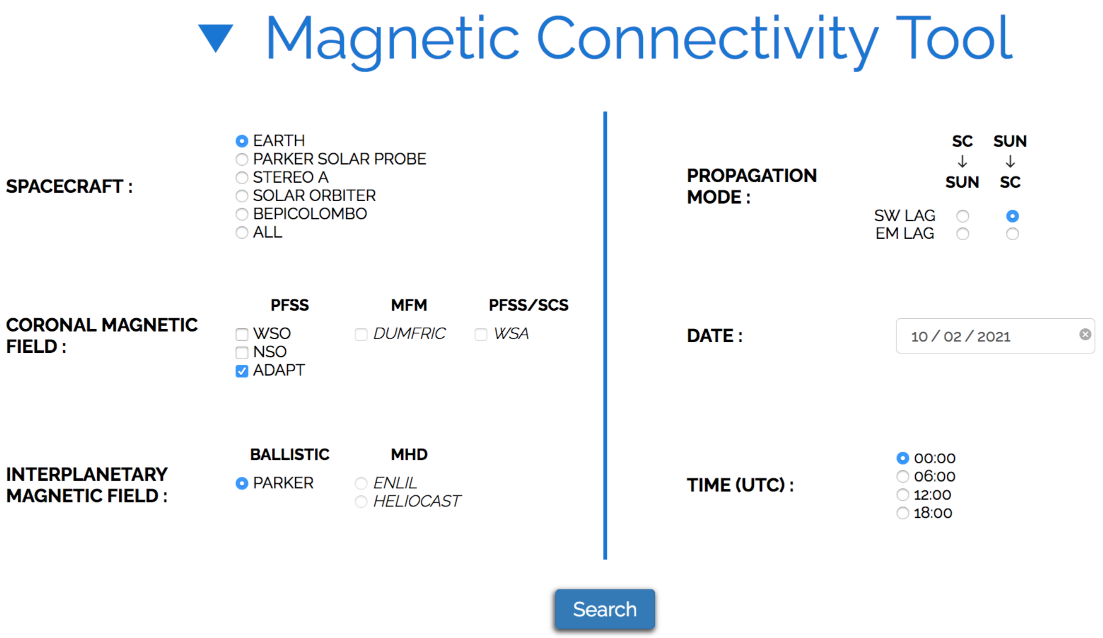
1) Using the movies, estimate the date when Solar Orbiter and Parker Solar Probe were aligned, depending on the wind speed.

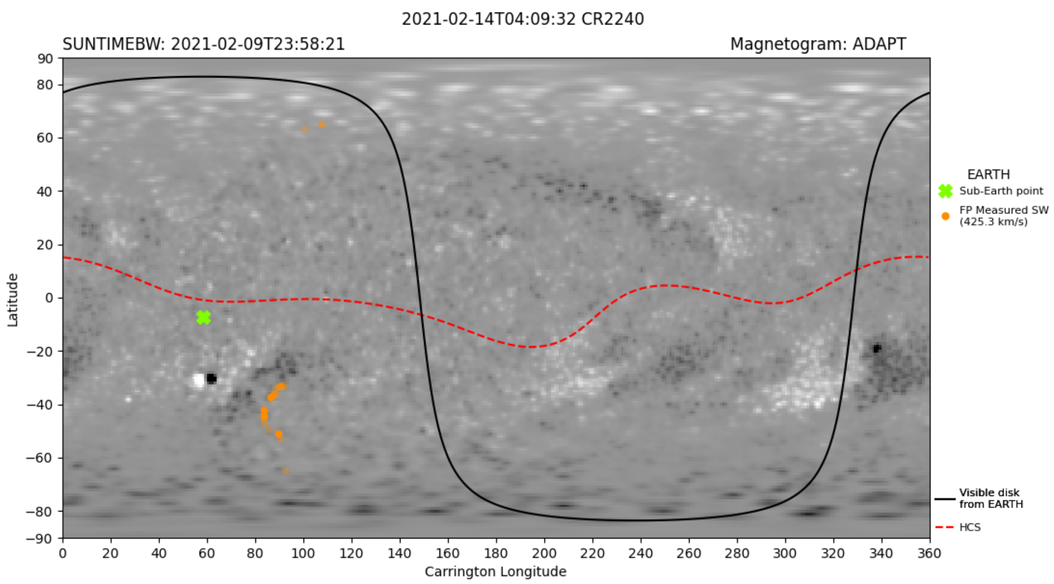
2) Verify these estimates on the Magnetic Connectivity Tool.

## Case study 4: The different types of propagations (EM and SW)

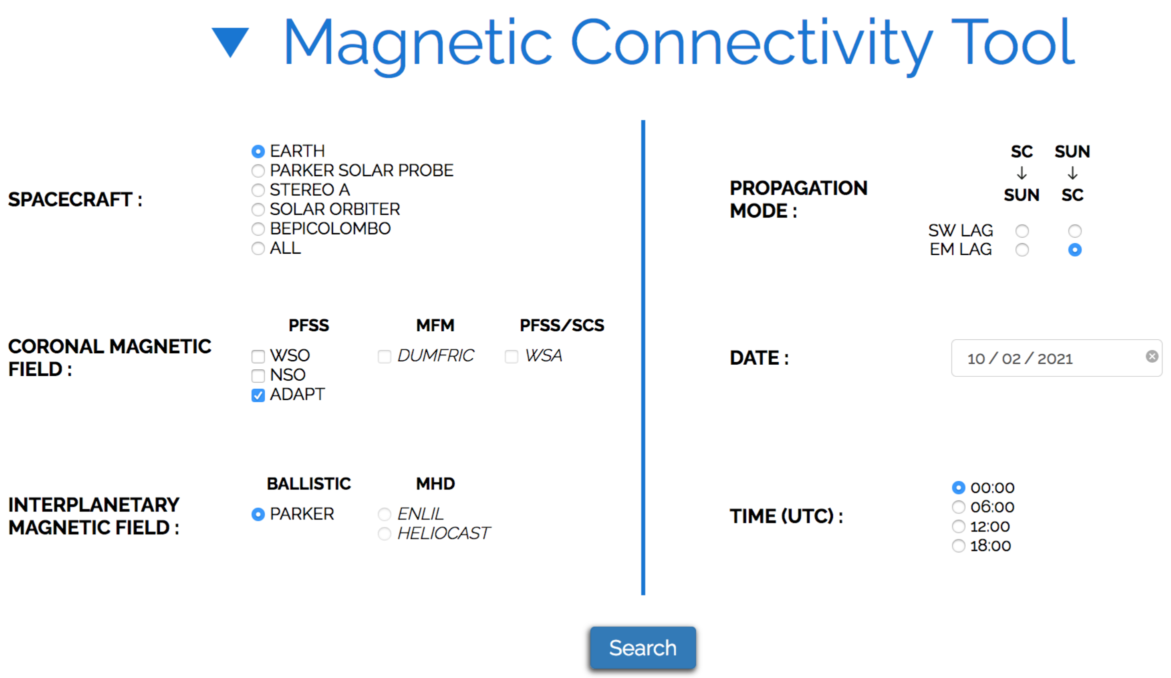
We are now going to highlight the important differences between Sun and Spacecraft Time as well as SW lag and EM lag.
Let's consider the connection between near-Earth spacecraft and the Sun. We will start from the Sun and consider first propagation from the Sun outwards.
Let's consider a past date of 10/02/2021 and compare SW and EM propagation. What differences do you see?

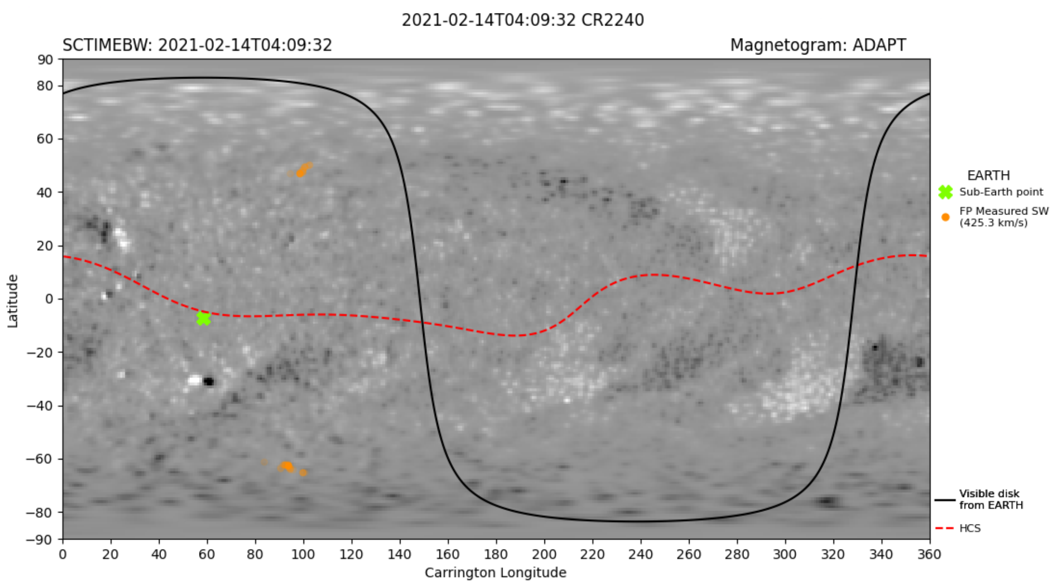
**SW propagation:**



## Electromagnetic Propagation:



**Case study 5:**

Exercise: Estimate source locations of the SEPs measured by Solar Orbiter on 29 November 2020: