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# Intro to Solar-MACH

## Multi-spacecraft longitudinal configuration plotter

Jan Gieseler for the Solar-MACH team

PyHC summer school  
1 June 2022

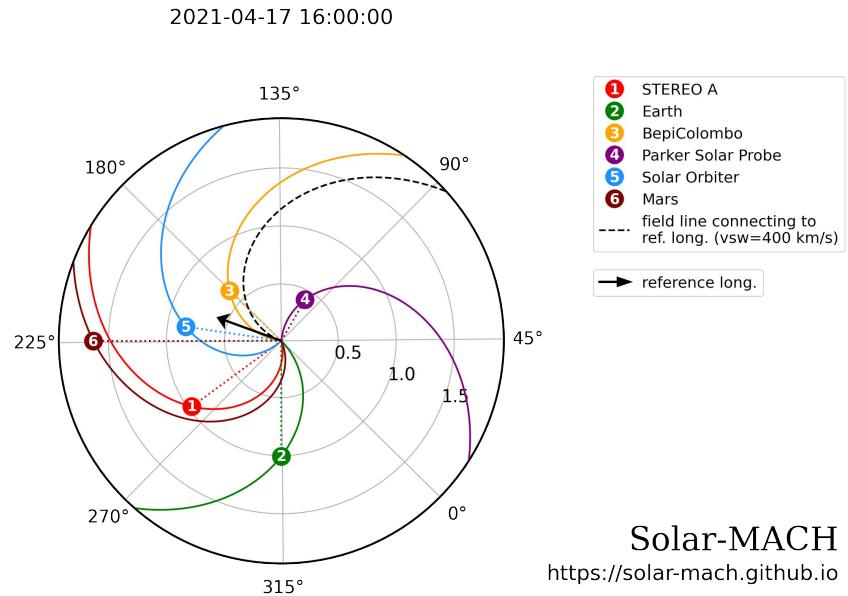


# What is Solar-MACH?

- *Solar MAgnetic Connection Haus* tool
- Multi-spacecraft spatial configuration and solar magnetic connection plotter
- Originally developed at the University of Kiel, Germany, and further discussed within the [ESA Heliophysics Archives USer \(HAUS\) group](#)
- Development is continuing at University of Turku, Finland, within the EU Horizon 2020 project [SERPENTINE](#)

Available as:

- Python pip/conda package, e.g. for Jupyter Notebooks
- Web-app <https://solar-mach.github.io> using Streamlit to run the Python code

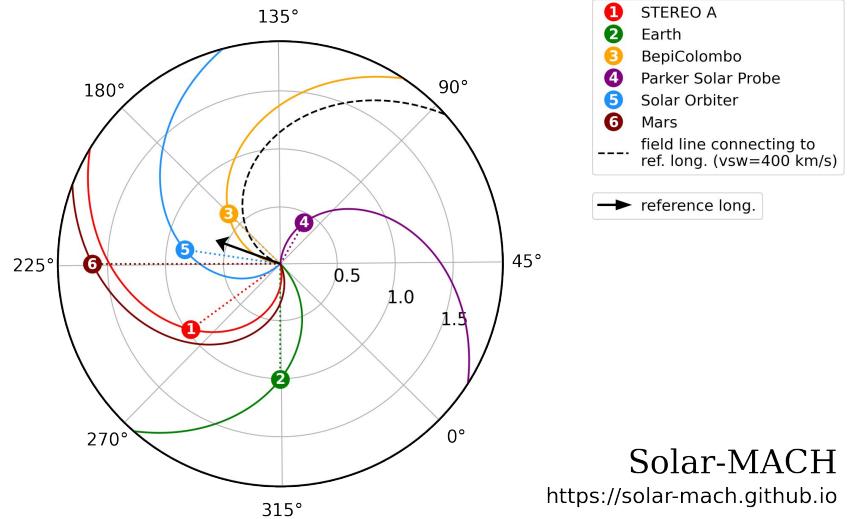


Solar-MACH  
<https://solar-mach.github.io>

# Content

- What is Solar-MACH?
- Scientific motivation
- Examples
- Under the hood
- Outlook
- Summary

2021-04-17 16:00:00



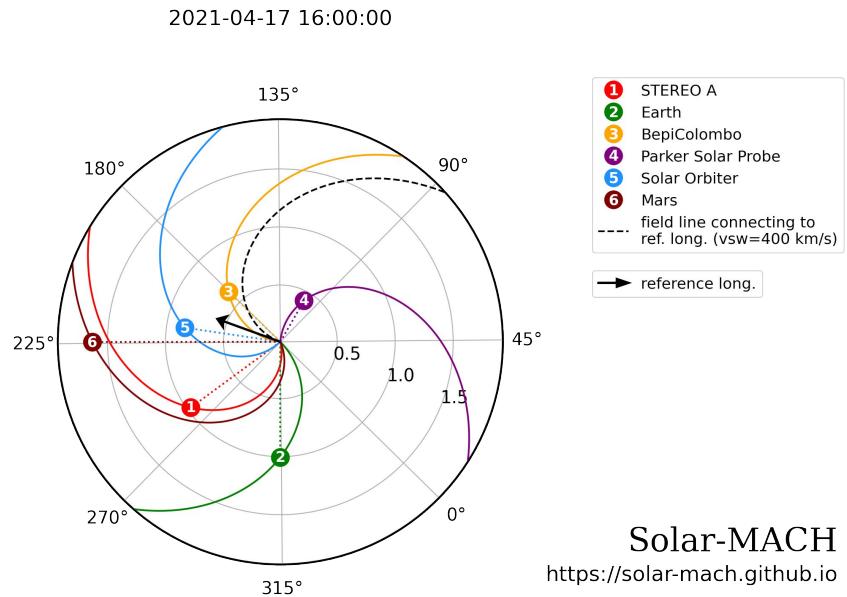
Solar-MACH  
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# Scientific Motivation

Get a quick overview and investigate the observer (i.e., spacecraft) situation in the inner heliosphere, e.g., to analyze:

1. Solar Energetic Particle (SEP) events
2. Coronal Mass Ejections (CME)
3. Stream/Corotating Interaction Regions (SIR/CIR)



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<https://solar-mach.github.io>



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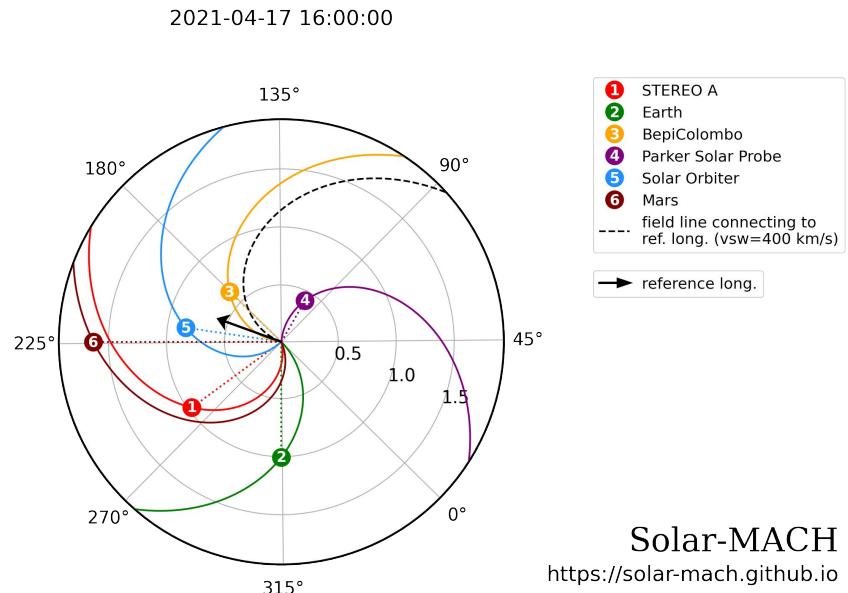
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Especially important for the recently expanded spacecraft fleet:

- Parker Solar Probe (2018)
- BepiColombo (2018)
- Solar Orbiter (2020)



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The infographic is titled "PARKER SOLAR PROBE" in large white letters at the top right. It features a central image of the Parker Solar Probe spacecraft, which has a large, white, cylindrical heat shield on its front. The background shows the Sun's surface with solar flares and the "SOLAR WIND" flowing away from it. A vertical sidebar on the left is divided into three sections: "THE MISSION" (top), "SCIENCE QUESTIONS" (middle), and "LAUNCH" (bottom).

- THE MISSION:** A red box containing text about the mission's purpose: "Humanity's First Mission to Touch the Sun". It explains that the probe will fly directly into the Sun's corona to sample particles and measure fields. It also notes that the probe is named after Dr. Eugene N. Parker, who predicted the solar wind.
  - The Coronal Heating Problem:** The Sun's outermost layer, the corona, is over 300 times hotter than the surface layer below it. The text suggests this is like walking away from a fire and feeling the temperature rise! One theory views waves as the source of heating; another, proposed by Dr. Parker himself, attributes it to many small explosions called nanoflares.
  - Corona (THE SUN'S OUTER ATMOSPHERE):** The Sun's outermost layer, the corona, is over 300 times hotter than the surface layer below it. The text suggests this is like walking away from a fire and feeling the temperature rise! One theory views waves as the source of heating; another, proposed by Dr. Parker himself, attributes it to many small explosions called nanoflares.
  - Solar Energetic Particles:** Even the fastest solar wind is no match for solar energetic particle events – bursts of protons and electrons that can make it to Earth in under one hour. Scientists believe they are driven by solar flares and coronal mass ejections, but the detailed physics remains unknown. Parker Solar Probe will measure solar energetic particles right at their source regions to determine their acceleration and transport mechanisms.
- SCIENCE QUESTIONS:** A middle section with three boxes:
  - The Coronal Heating Problem:** The Sun's outermost layer, the corona, is over 300 times hotter than the surface layer below it. The text suggests this is like walking away from a fire and feeling the temperature rise! One theory views waves as the source of heating; another, proposed by Dr. Parker himself, attributes it to many small explosions called nanoflares.
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- LAUNCH:** The bottom section shows the probe's elliptical orbital path around the Sun, passing close to Venus and Earth. Labels indicate "LAUNCH", "Mercury", "Venus", "Earth", and "Sun". A callout box states: "Parker Solar Probe will reach within 3.83 million miles of the solar surface." The URL "www.nasa.gov/sunearth" is at the bottom.

For more information, please visit: [nasa.gov/sunearth](http://nasa.gov/sunearth)



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National Aeronautics and Space Administration



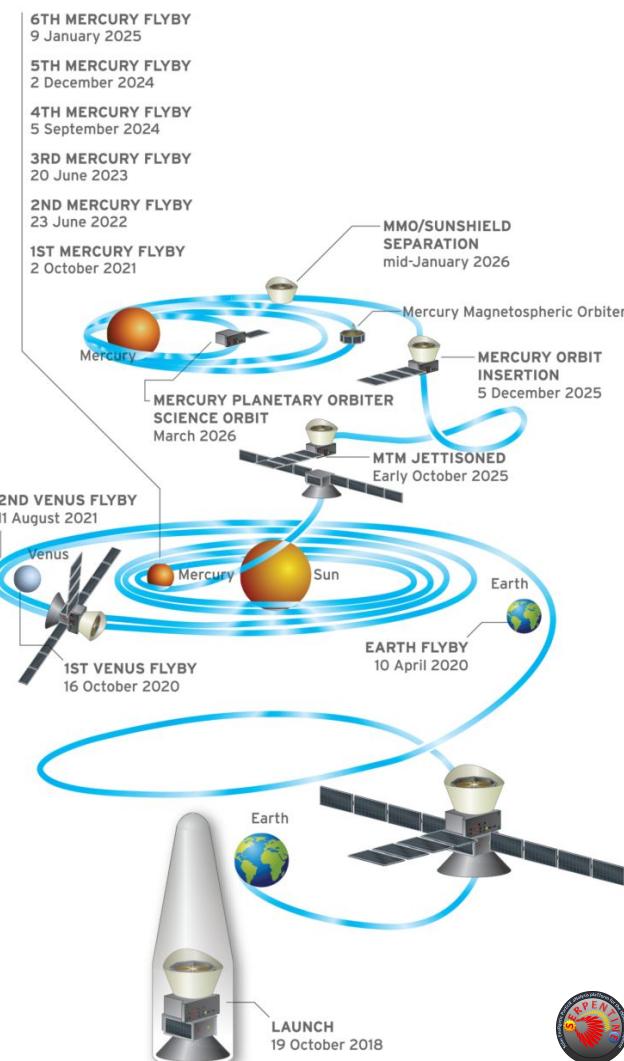
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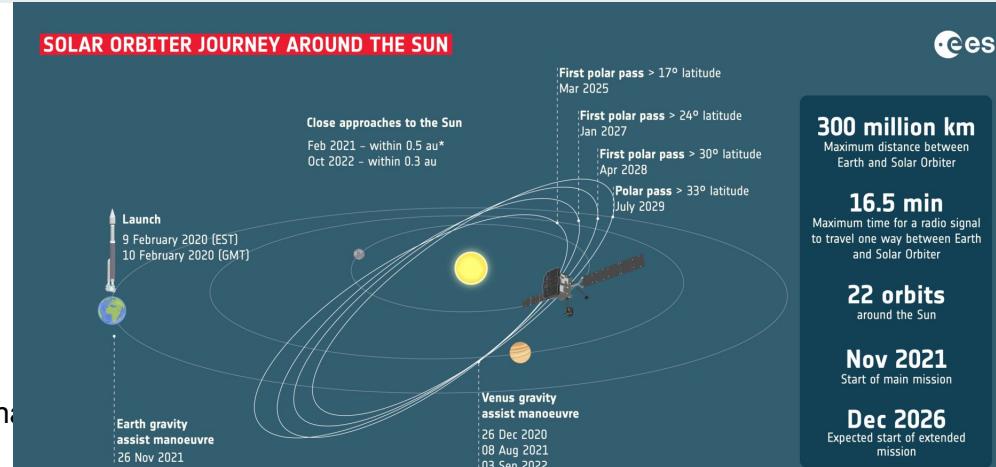


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**300 million km**  
Maximum distance between Earth and Solar Orbiter

**16.5 min**  
Maximum time for a radio signal to travel one way between Earth and Solar Orbiter

**22 orbits**  
around the Sun

**Nov 2021**  
Start of main mission

**Dec 2026**  
Expected start of extended mission



Especially important for the recently expanded spacecraft fleet:

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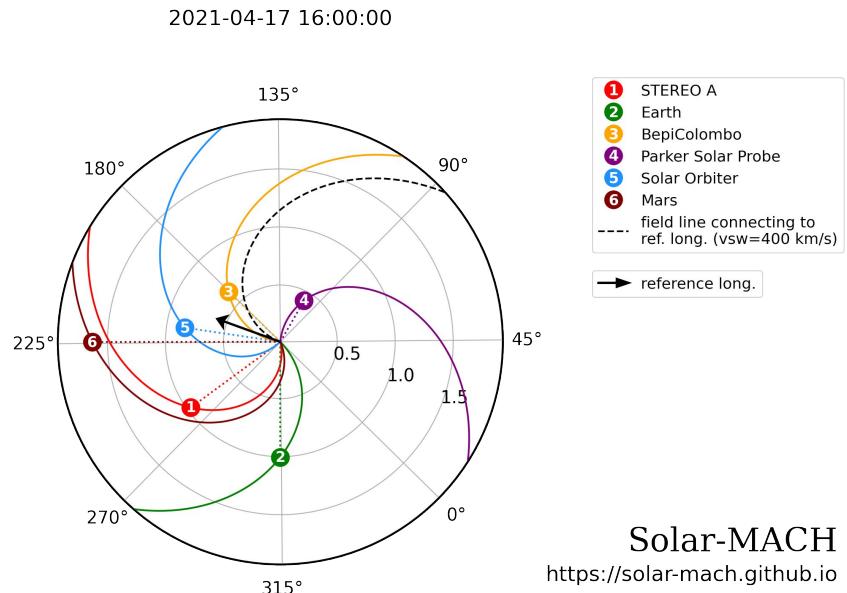
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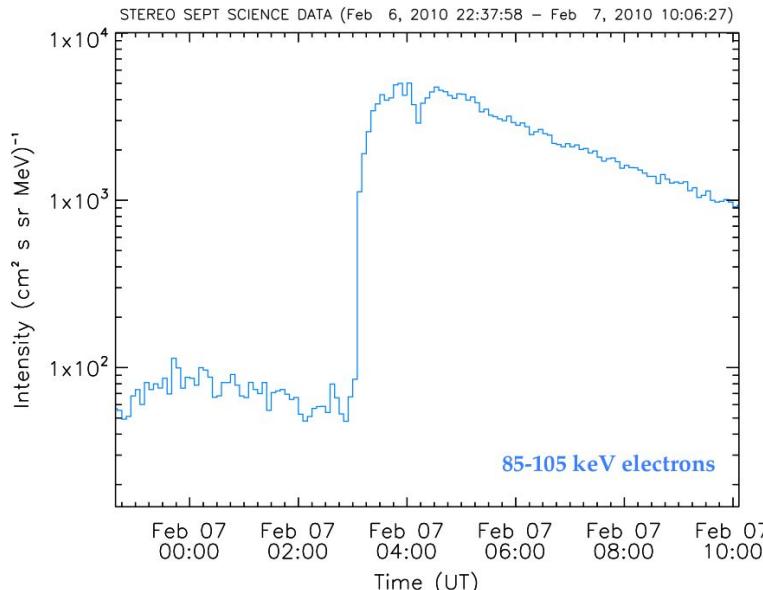
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# 1. Solar Energetic Particle (SEP) Events



Solar energetic particles are:

- Electrons up to tens of MeV
- Protons up to GeV
- ‘Heavy’ ions

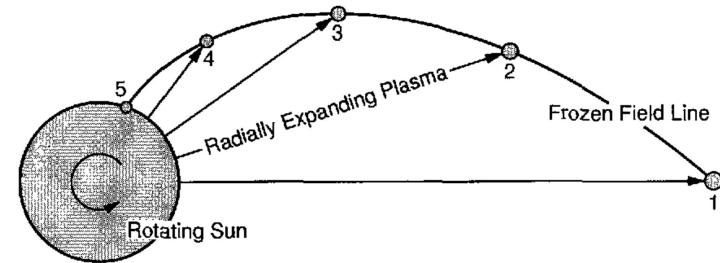


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## Reminder: Heliospheric Magnetic Field

- The solar wind (an ionized gas) streams out radially into the heliosphere
- The Sun rotates
- Open magnetic field lines at the sun are 'frozen in' and carried out by the solar wind



Baumjohann and Treumann, 1996

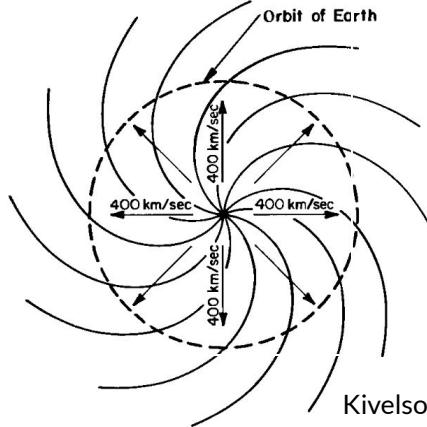


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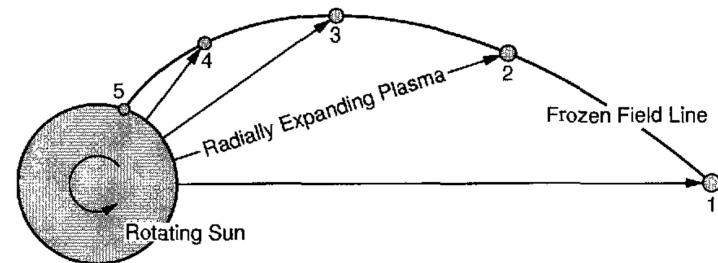
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⇒ Archimedean spiral  
(curvature depending  
on solar wind speed)



Kivelson and Russel, 1995

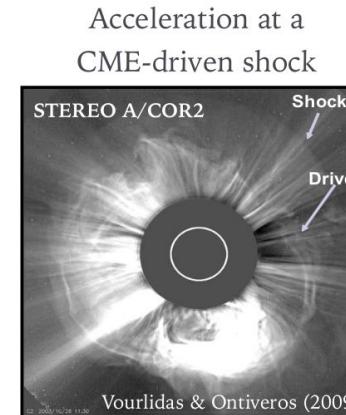
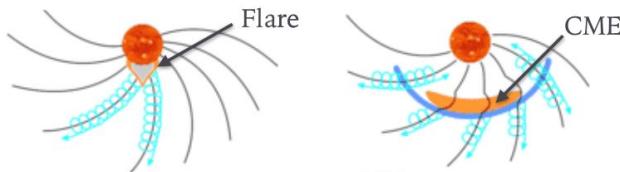


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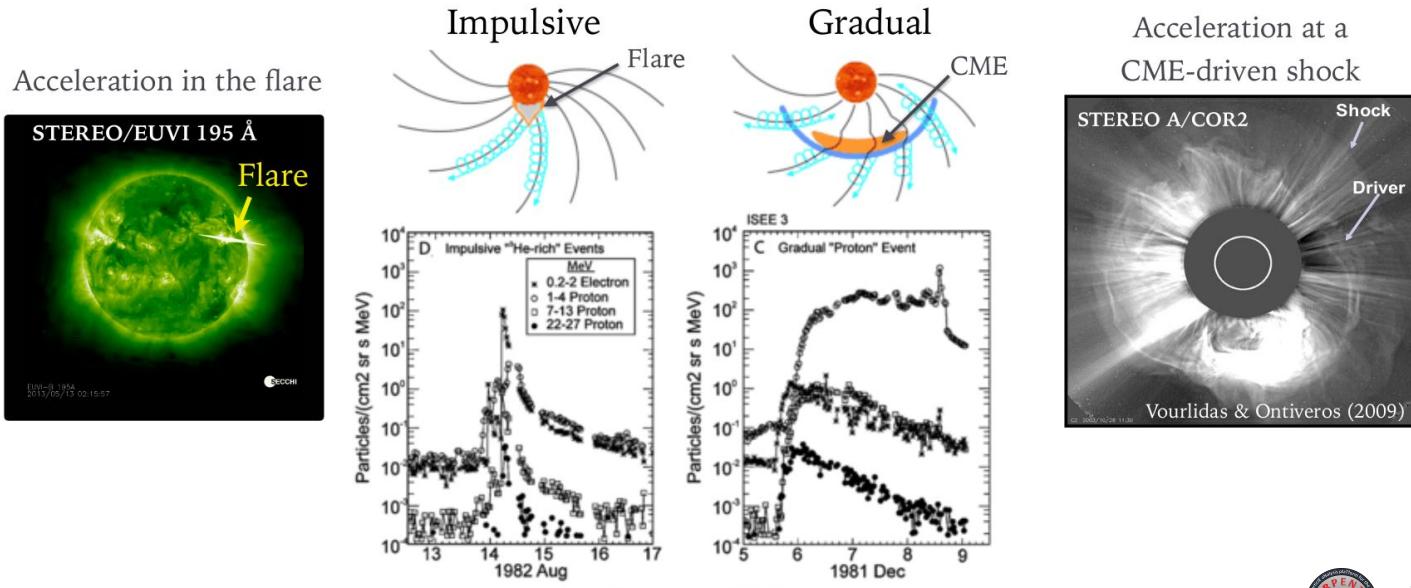


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# The Two Sources of Solar Energetic Particle Events

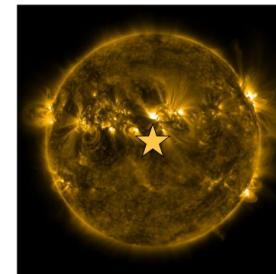
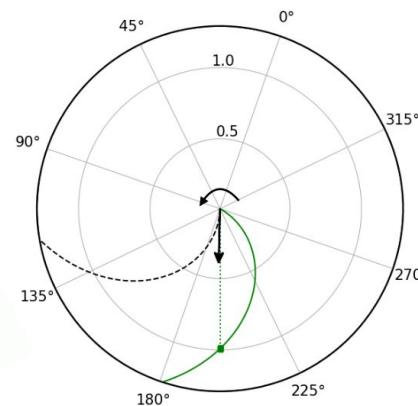
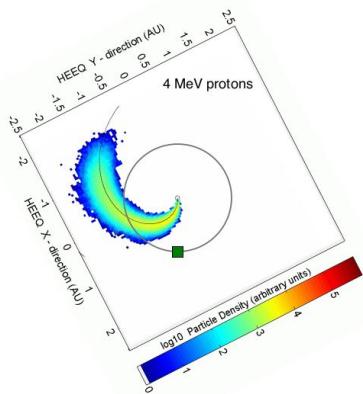


# The Two Sources of Solar Energetic Particle Events



# Transport of Solar Energetic Particles

- Energetic particles travel along the magnetic field spirals



■ Earth  
--- field line connecting to  
ref. long. ( $v_{sw}=400$  km/s)  
→ reference long.

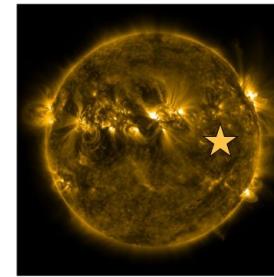
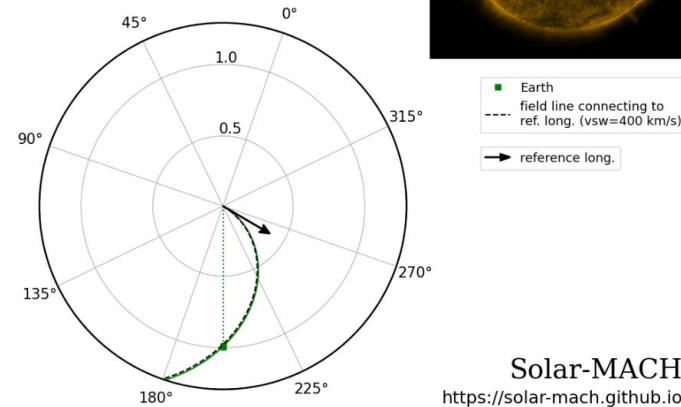
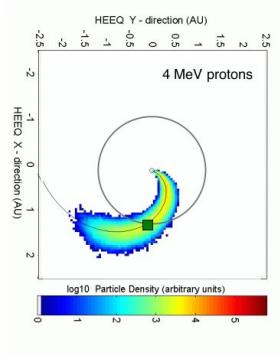
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# Transport of Solar Energetic Particles

- ▶ Energetic particles travel along the magnetic field spirals
- ▶ The Earth is well connected to a point  $60^\circ$  to the right  
“West 60 (W60)”



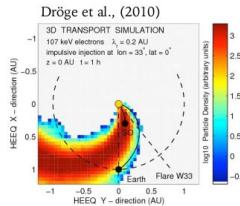
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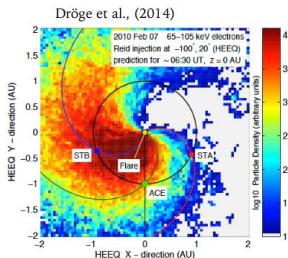
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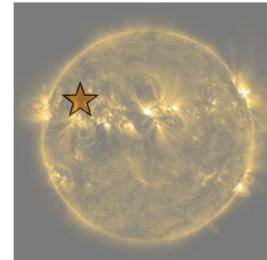
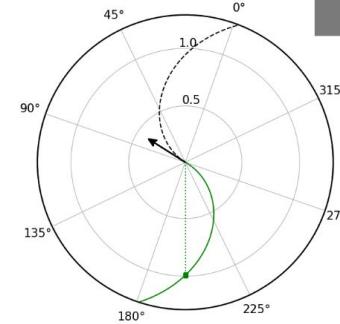
- Energetic particles travel along the magnetic field spirals
- The Earth is well connected to a point  $60^\circ$  to the right
- Even particles from backside events can make it to Earth!



Weak perpendicular  
transport



Strong perpendicular  
transport



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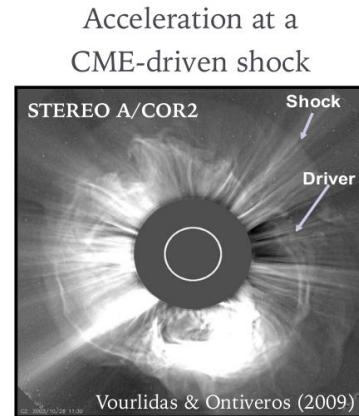
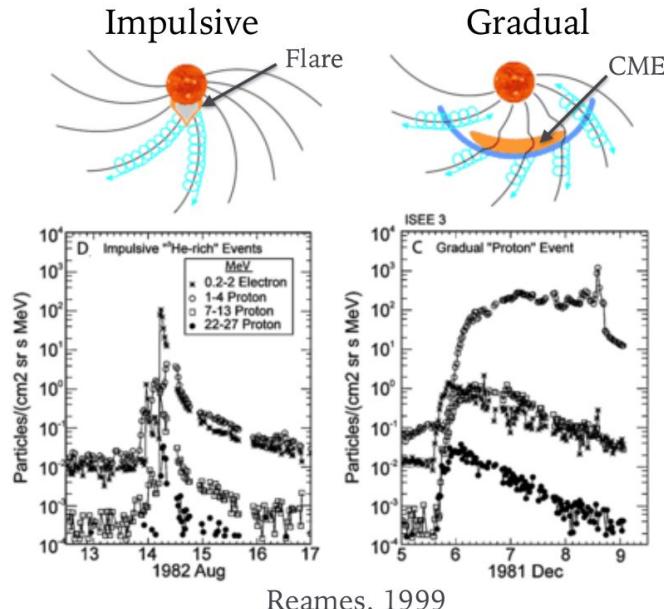


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# The Two Sources of Solar Energetic Particle events



Gradual time profiles and wide SEP spreads can also be generated by strong perpendicular transport!

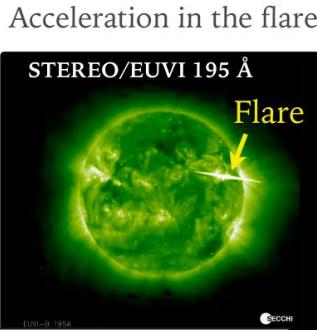


Acceleration at a  
CME-driven shock

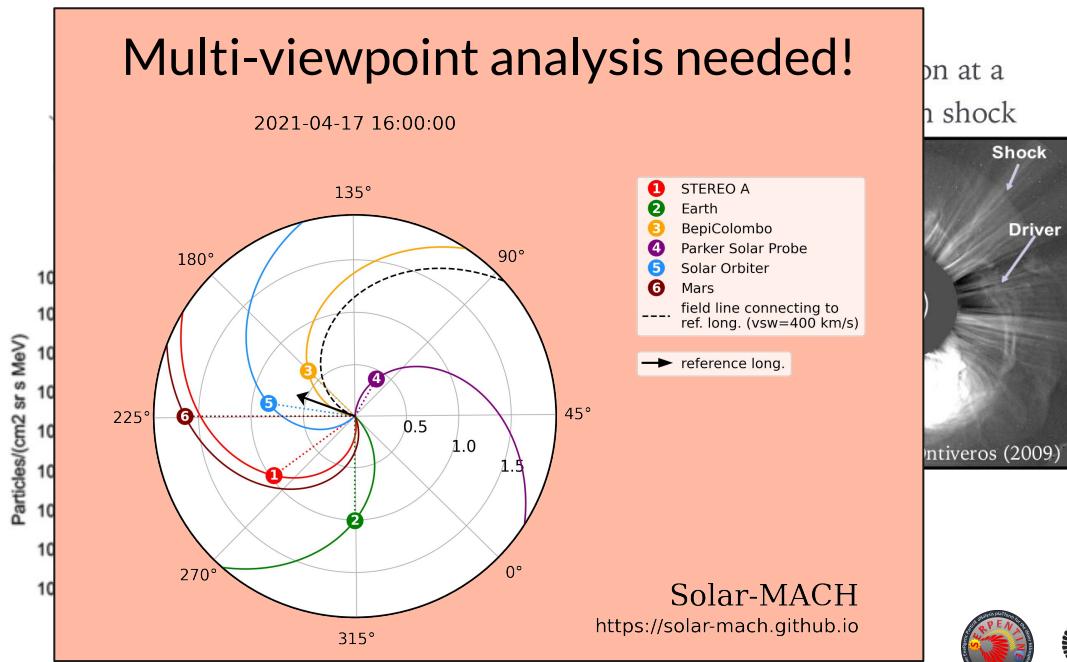


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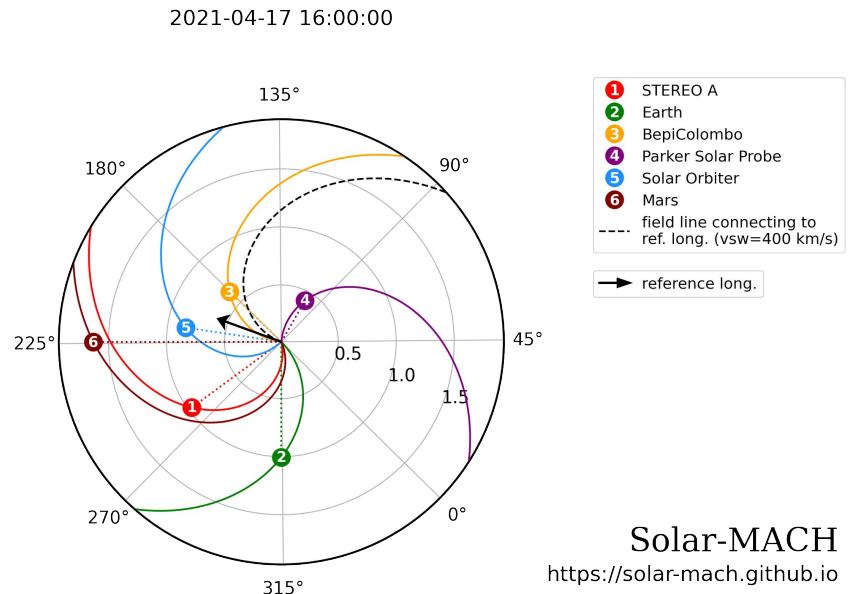
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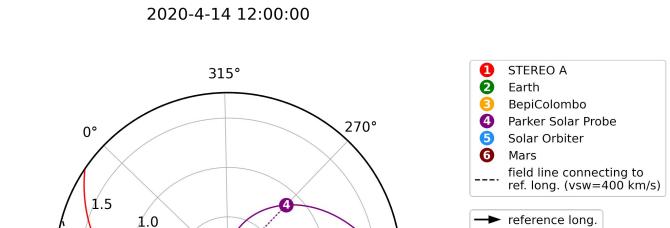
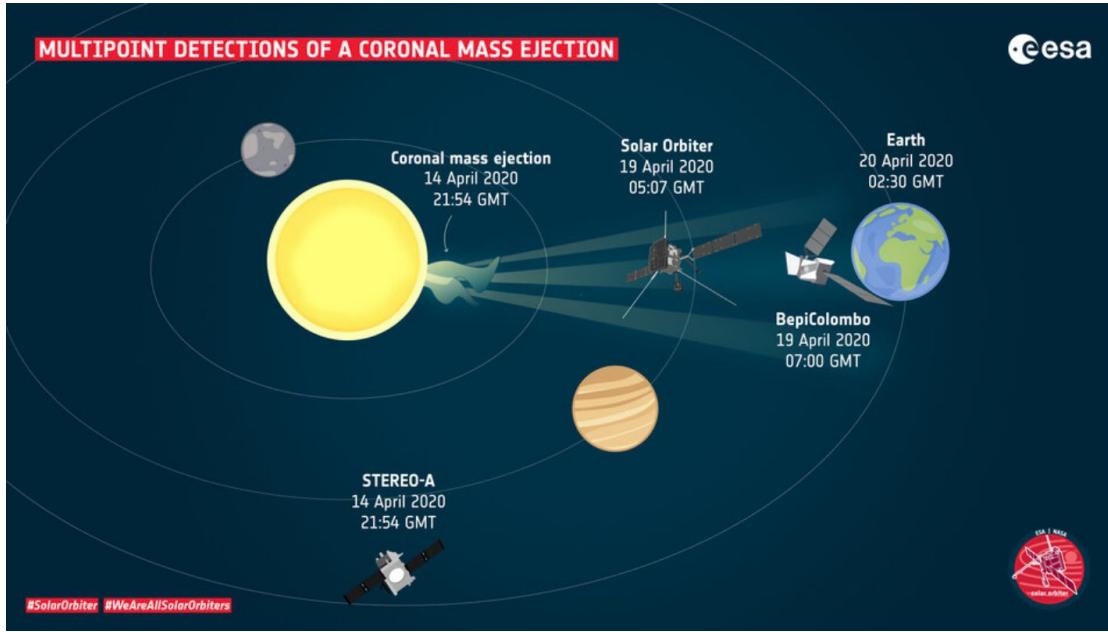
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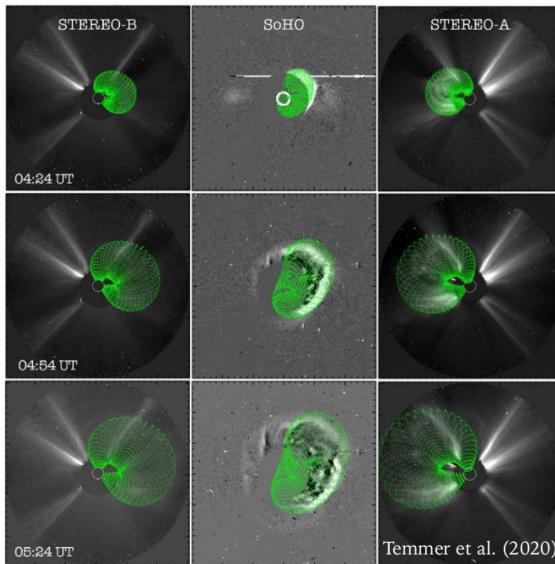
## 2. Multi-point and side view of CMEs



Solar-MACH  
<https://solar-mach.github.io>

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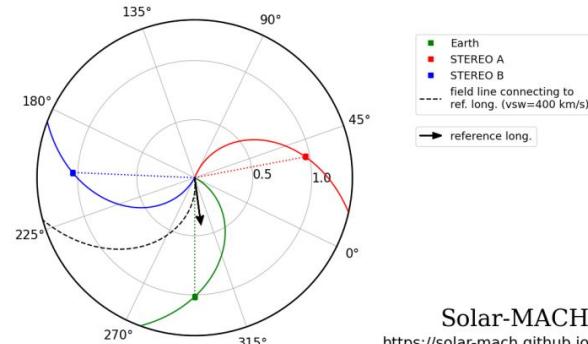
- Geometric reconstruction of a coronal mass ejections using three spacecraft



2011-08-04 01:30:00

For example, utilizing  
<https://github.com/AthKouloumvakos/PyThea>

See next PyHC Telecon on June 13!

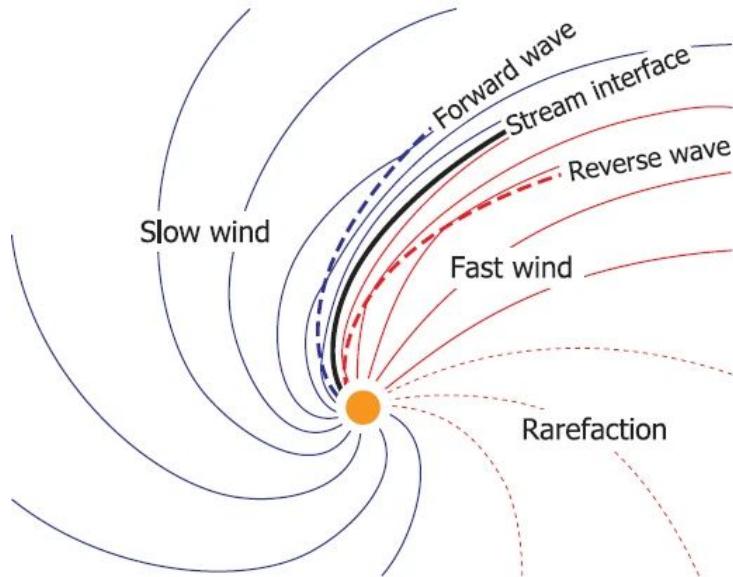


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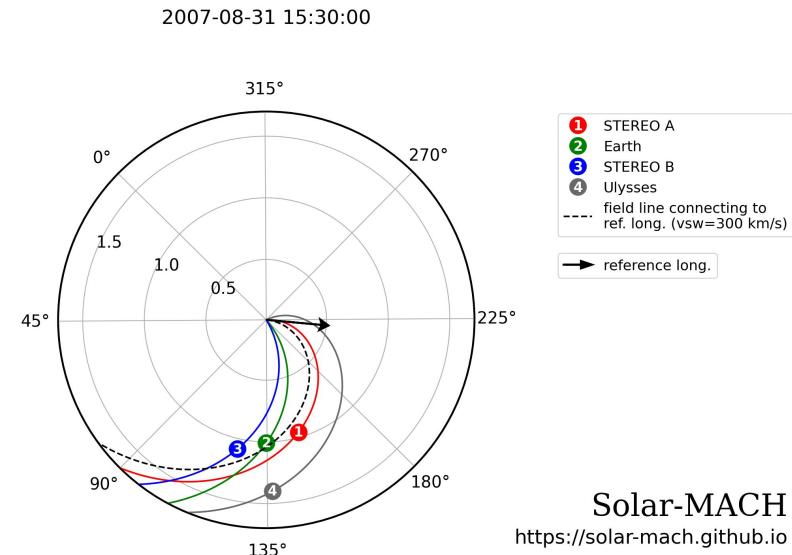


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### 3. Stream/Corotating Interaction Regions (SIR/CIR)



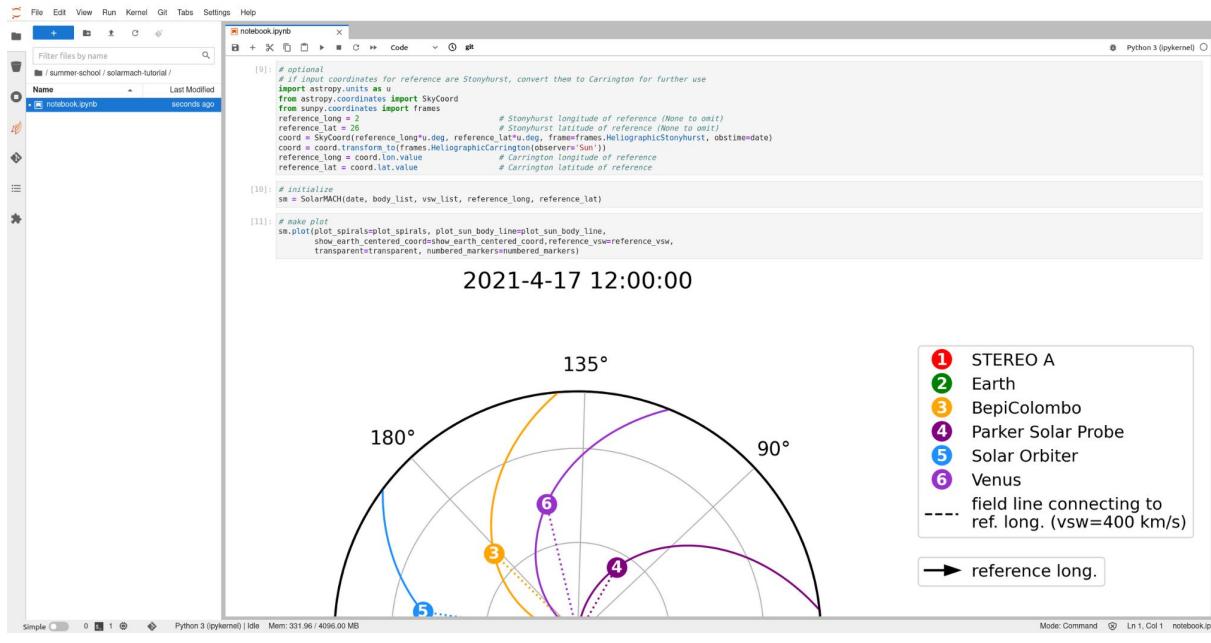
Owens & Forsyth, *Living Rev. Sol. Phys.* **10**, 5 (2013).



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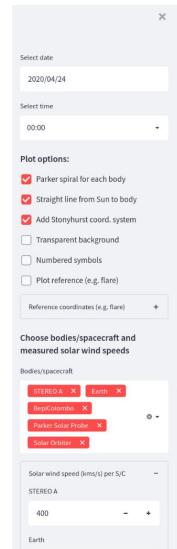
# Examples in Jupyter Notebook



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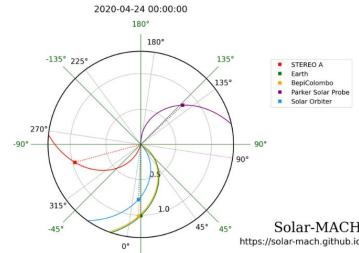
# Examples in Streamlit web app

- [Streamlit](#) easily turns scripts and notebooks into shareable web apps
- Python & open-source  
(\$\$ for more advanced hosting)



## Solar-MACH

Multi-spacecraft longitudinal configuration plotter



Download figure as .png file

	STEREO A	Earth	BepiColombo	Parker Solar Probe	Solar Orbiter
Carrington longitude [°]	294	8	7	142	6
Carrington latitude [°]	-7	-5	-5	4	-3
Heliocentric distance [AU]	0.97	1.01	1.01	0.81	0.78



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# Under the hood

- <https://github.com/jgieseler/solarmach> (pip/conda package)
- <https://github.com/jgieseler/Solar-MACH> (streamlit app)

The screenshot shows a GitHub repository page for `jgieseler/solarmach`. The main navigation bar includes links for Pull requests, Issues, Marketplace, and Explore. Below the header, there are buttons for Unpin, Unwatch, Fork, and Star. The repository is marked as public. The navigation bar also includes links for Code, Issues (3), Pull requests, Actions, Projects, Wiki, Security, Insights, and Settings.

The main content area shows the `_init_.py` file. It has 426 lines (349 sloc) and is 18 KB in size. The file content is as follows:

```
1 # Licensed under a 3-clause BSD style license - see LICENSE.rst
2
3 from pkg_resources import get_distribution, DistributionNotFound
4 try:
5     __version__ = get_distribution(__name__).version
6 except DistributionNotFound:
7     pass # package is not installed
8
9 import math
10 from copy import deepcopy
11
12 import astropy.units as u
13 import matplotlib.patches as mpatches
```

# Participate!

- <https://github.com/jgieseler/solarmach/issues>
- <https://github.com/jgieseler/Solar-MACH/issues>

The screenshot shows the GitHub Issues page for the repository `jgieseler/solarmach`. The page displays three open issues:

- #3: Plot distance projected to the ecliptic plane instead of radial distance (optionally) - enhancement, good first issue. Opened 3 days ago by `jgieseler`.
- #2: Provide option to return plot object - enhancement. Opened 28 days ago by `jgieseler`.
- #1: Add Stonyhurst coordinate system - enhancement. Opened on Mar 14 by `jgieseler`.

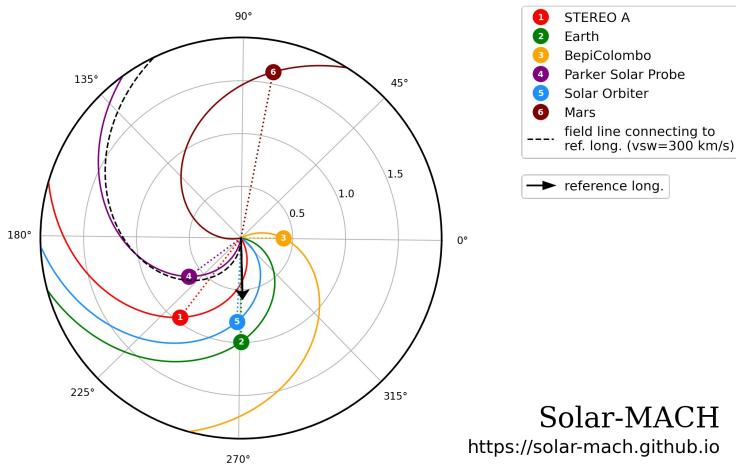
At the top right of the page, there is a green "New issue" button. An orange arrow points to this button.

Or just contact me: [jan.gieseler@utu.fi](mailto:jan.gieseler@utu.fi) / [@JanGieseler](https://twitter.com/JanGieseler)

# Outlook

Two-step backmapping using ballistic and  
PFSS (Potential Field Source Surface) model  
backmapping

2021-10-28 15:20:00



# Outlook

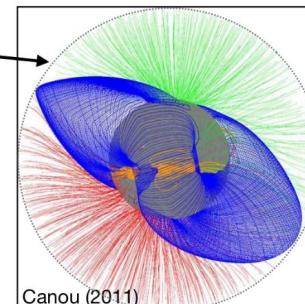
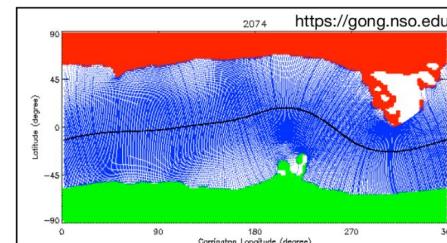
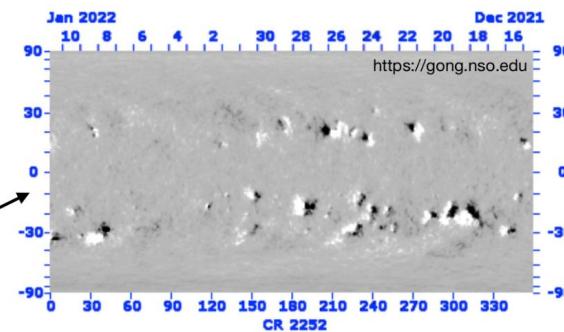
A Potential Field Source Surface (PFSS) model\* assumes a current-free corona:

$$\nabla \cdot B = 0; \nabla \times B = 0$$

and extrapolates the magnetic field lines from the solar surface (lower boundary) to the Source Surface (SS, upper boundary)

Lower boundary: the magnetic field at the solar surface provided by a magnetogram map

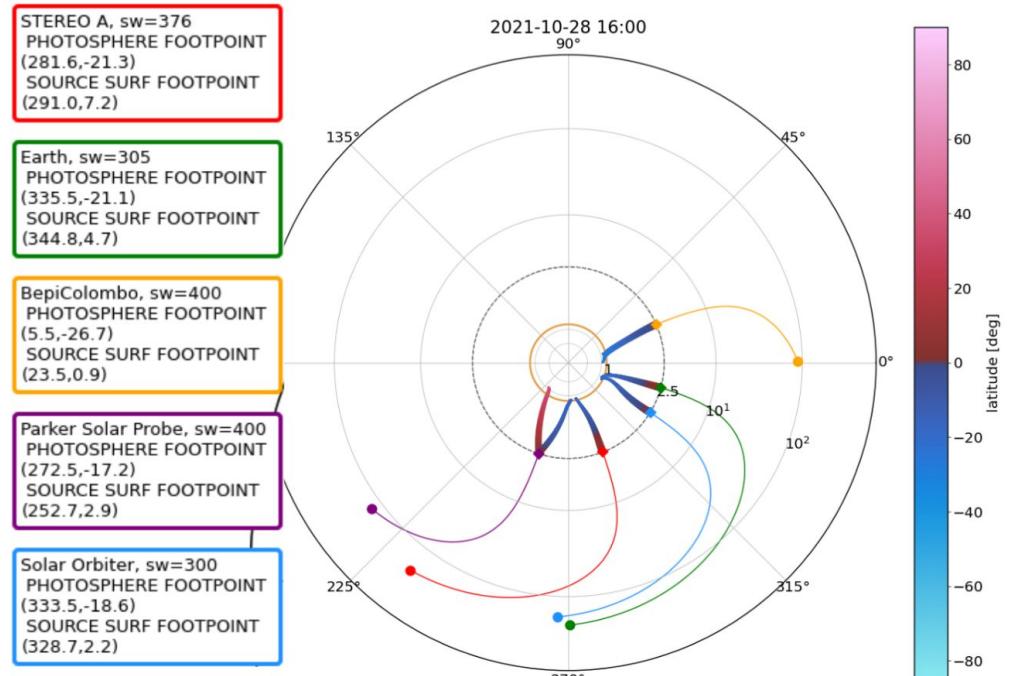
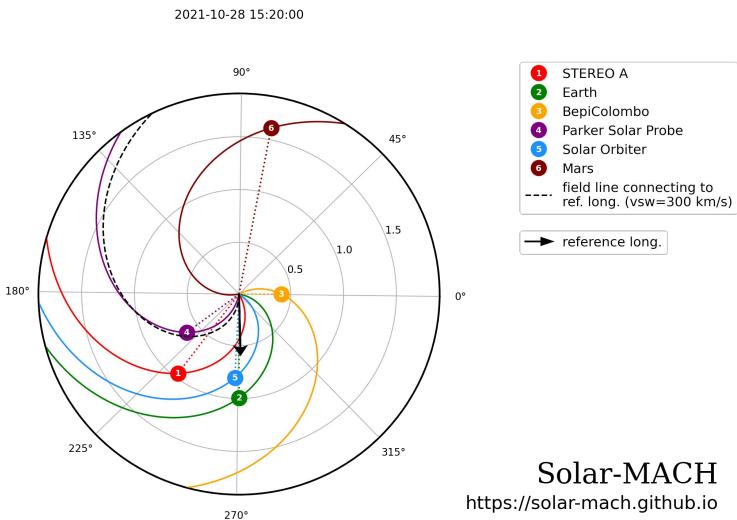
Upper boundary: above all field lines are forced to be radial, often assumed to be at  $2.5 R_s$



\*initially developed by Schatten, Wilcox & Ness (1969) and Altschuler & Newkirk (1969)

# Outlook

Two-step backmapping using ballistic and PFSS (Potential Field Source Surface) model backmapping



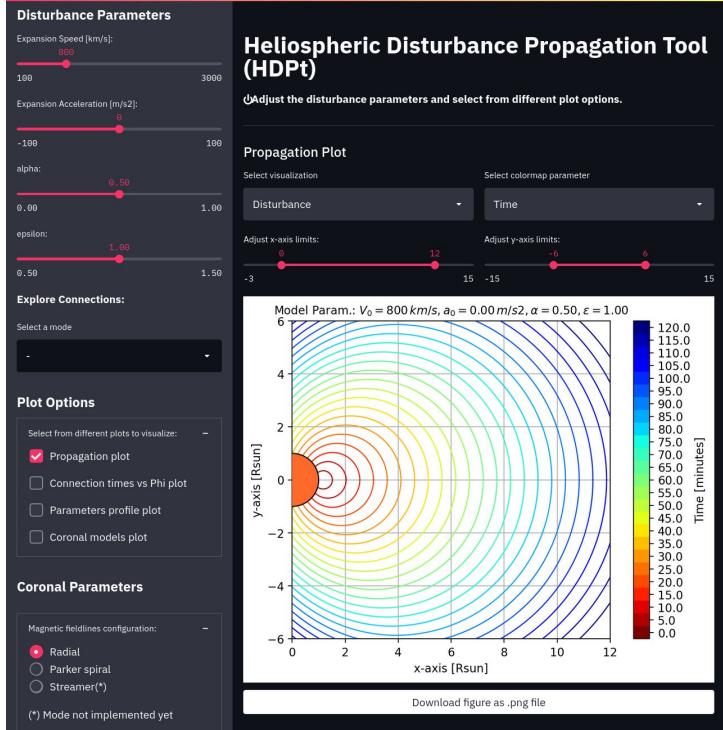
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# SERPENTINE project



*“The Solar EneRgetic ParticIE aNalysis plaTform for the INner hEliosphere (SERPENTINE) project will answer several outstanding questions about the origin of Solar Energetic Particle (SEP) events and provides an advanced platform for the analysis and visualization of high-level datasets to benefit the wider heliophysics community.”*

- Upcoming other open source tools (*very soon!*):
  - Jupyter Notebooks (data loading & plotting)
  - PFSS + 3D visualisation
  - CME shock parameter analysis
  - <https://athkouloumvakos.github.io/HDPmt/>
- <https://serpentine-h2020.eu> & Newsletter (see “Contact”)
- <https://twitter.com/H2020Serpentine>

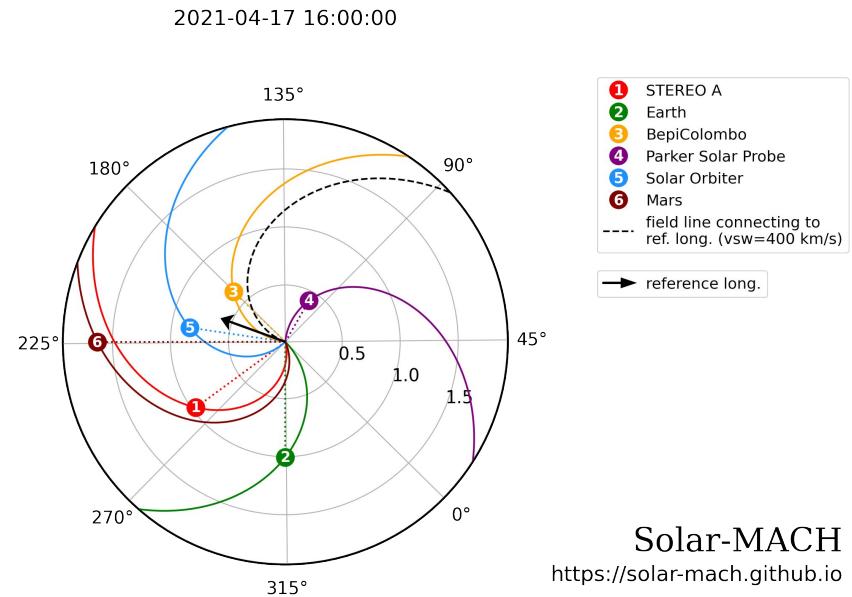


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# Summary

Solar-MACH is a really easy to use tool to derive and visualize the spatial configuration and solar magnetic connection of the heliospheric observer fleet at different times, providing publication-ready figures.

-  <https://github.com/jgieseler/solarmach>
-  <https://solar-mach.github.io>
-  [jan.gieseler@utu.fi](mailto:jan.gieseler@utu.fi)
-  <https://twitter.com/JanGieseler>



Solar-MACH  
<https://solar-mach.github.io>