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# Role of the heliospheric current sheet (HCS) in high energy proton transport through modelling of historic GLE events

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# Role of the heliospheric current sheet (HCS) in high energy proton transport through modelling of historic GLE events

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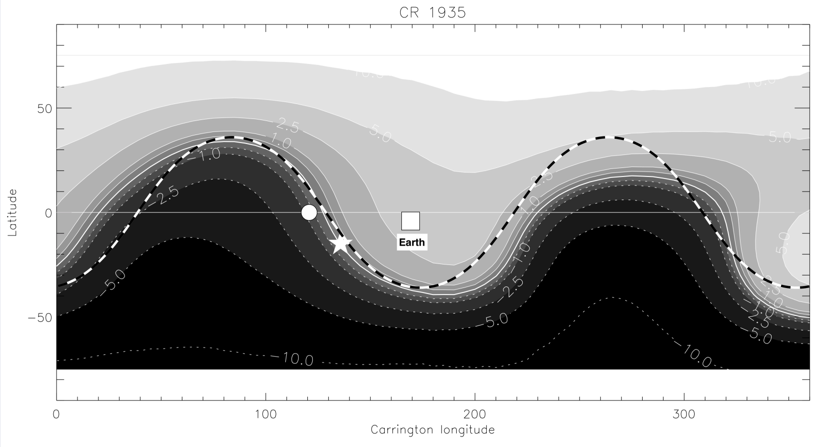
- The heliospheric current sheet has previously been suggested to effect the transport of solar energetic particles within the heliosphere, e.g. Augusto et al. 2018, Battarbee et al. 2018
- Understanding more about the role the HCS has in the propagation of high energy particles is important for forecasting energetic events near Earth
- In this work we investigate the influence the HCS has on relativistic particle propagation with 3D test particle modelling of historic GLE events
- The 3D test particle model, SPEC (Dalla & Browning 2005), includes: drifts due to curvature and gradient of the Parker spiral and HCS drift – important at the high energies typical of GLE events
- For each event, 3 million protons ($300<E<1200$ MeV) are injected at the flare location ($10^{o}$x$10^{o}$ injection region) and allowed to propagate through the heliosphere for 72 hours

- A total of 20 sub-GLE and GLE's from 1989-2017 are simulated
- The historic events are modelled both with and without a current sheet to see the effect on particle propagation at 1AU
- The events are chosen to ensure a range of current sheet configurations are covered
- In particular, the effect of the proximity of the flare (and Earth's footpoint) to the HCS is explored
- The model HCS is fit to the neutral line of Wilcox Solar Observatory $r=2.5R_{\odot}$ source surface map's with a sinusoidal function, the fit's parameters are then input into SPEC
- The following slide shows all 20 simulated events, followed by example results from modelling GLE 70




**Example source surface map with HCS fit for 2nd May 1998:**
Star: Flare location
Square: Earth footpoint
Circle: meridian at time of flare
Solid white line: neutral line
Dashed line: HCS fit to SSM neutral line

# Table of all simulated events

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| Event | GLE # | Flare class | CME v | Flare loc | Polarity | SPEC Vsw |
|---|---|---|---|---|---|---|
| 29th September 1989 | 42 | X9.0 | | S36W90 | - | 500 |
| 21st May 1990 | 47 | X5.0 | | N35W36 | + | 500 |
| 23rd March 1991 | | X9.4 | | S26E28 | + | 500 |
| 25th June 1992 | 53 | X3.9 | | N09W67 | + | 400 |
| 6th November 1997 | 55 | X9.0 | 1556 | S18W63 | + | 350 |
| 2nd May 1998 | 56 | X1.1 | 938 | S15W15 | + | 600 |
| 6th May 1998 | 57 | X2.0 | 1099 | S11W65 | + | 500 |
| 24th August 1998 | 58 | X1.0 | | N35E09 | + | 400 |
| 15th April 2001 | 60 | X13 | 1199 | S20W85 | - | 500 |
| 28th October 2003 | 65 | X17 | 2459 | S16E08 | - | 700 |
| 4th November 2003 | | X17 | 2459 | S16E08 | - | 700 |
| 20th January 2005 | 69 | X7.1 | 2585 | N14W61 | - | 600 |
| 7th September 2005 | | X17 | 1725 | S11E77 | - | 400 |
| 13th December 2006 | 70 | X3.4 | 1774 | S06W23 | - | 600 |
| 7th March 2011 | | M3.7 | 2125 | N30W47 | - | 350 |
| 23rd January 2012 | | M8.7 | 2175 | N28W36 | - | 400 |
| 7th March 2012 | | X5.0 | 2684 | N17E27 | - | 500 |
| 9th January 2014 | | X1.0 | 1830 | S15W11 | + | 400 |
| 6th September 2017 | | X9.3 | 1571 | S08W33 | + | 400 |
| 10th September 2017 | 72 | X8.2 | 3163 | S08W88 | + | 500 |

Table 1: All events (GLE and sub-GLEs) modelled so far with SPEC.

**SPEC Vsw**: solar wind speed used in SPEC

**Polarity**: + describes an A+ configuration where the magnetic field points outwards in the northern hemisphere and inwards in the south, with the opposite being true for -

# Example results from SPEC for historic event: GLE 70 (1)

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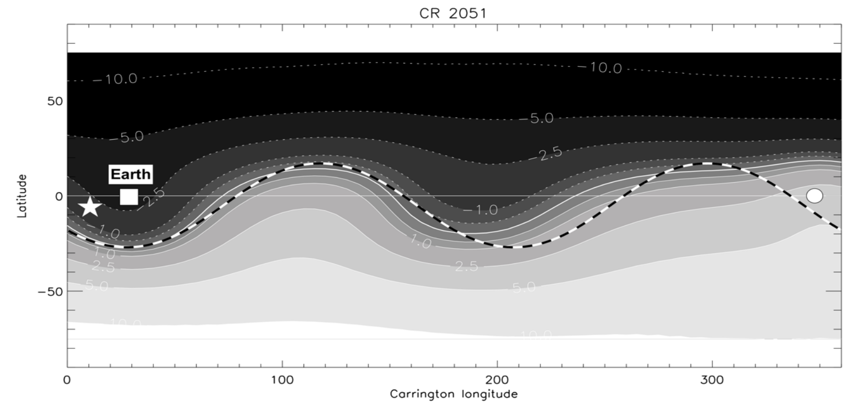
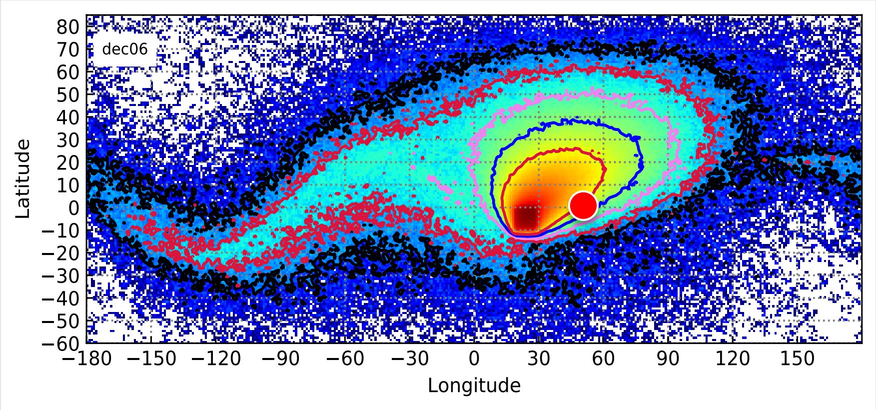
- GLE 70 has a flare close to the HCS with a small longitudinal separation between the Earth's footpoint and flare
- Lower plot shows the cumulative proton crossings at 1AU for GLE 70 simulation
- The flare is close to the HCS, allowing for drift along it to the East (West for an A+ configuration)
- A- polarity also causes gradient and curvature drift away from the HCS towards the poles (A+ leads to drift towards the CS)
- Corotation is included, causing the Westward extension of the crossing locations in all simulations
- An intensity profile can be extracted at Earth's location: ● (next slide)




**Source surface map:**
Star: Flare location
Square: Earth footpoint
Circle: meridian at time of flare
Dashed line: HCS fit to SSM
Polarity: A-




**Simulation parameters:**
Injection location: [23,-6]
Number of particles: 3 million
E range: 300-1200MeV
Power law index: 1.5
Simulation period: 72 hrs

Contours:
Inner Red: 1000 crossings
Pink: 100 crossings
Black: 10 crossings

# Example results from SPEC for historic event: GLE 70 (2)

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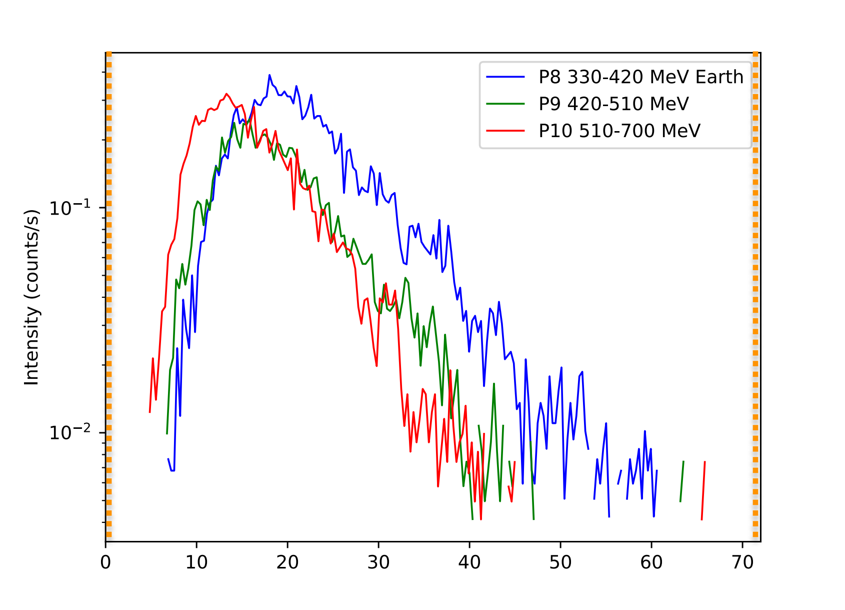
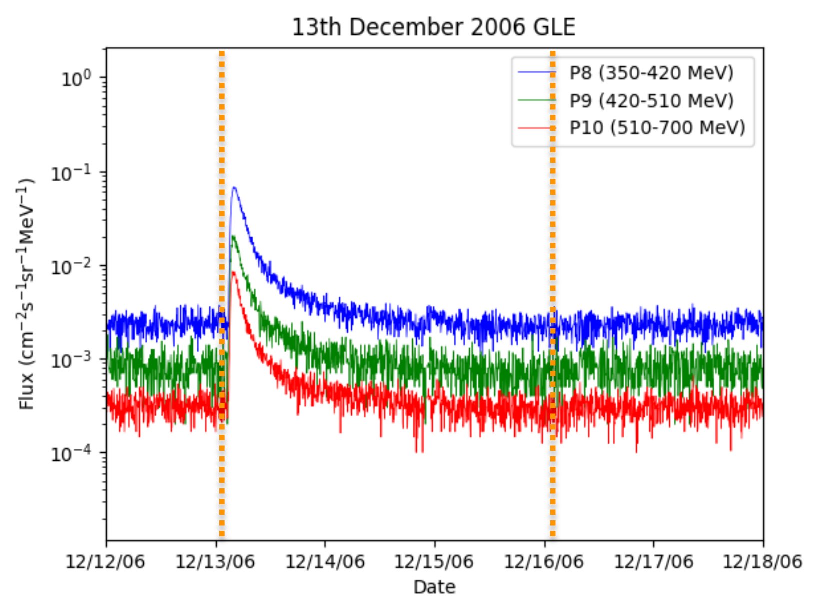
- Intensity profile at Earth's footpoint are produced for each event (for GLE 70 - left figure)
- The intensity profile is shown for 3 high energy bands corresponding to HEPAD channels
- Model profiles can be compared to observations, e.g. HEPAD fluxes onboard GOES (right), Neutron monitor data, etc



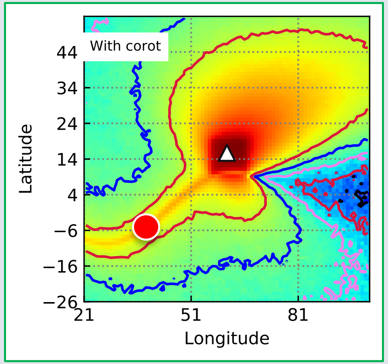

**1AU modelled intensity profile at Earth's location**



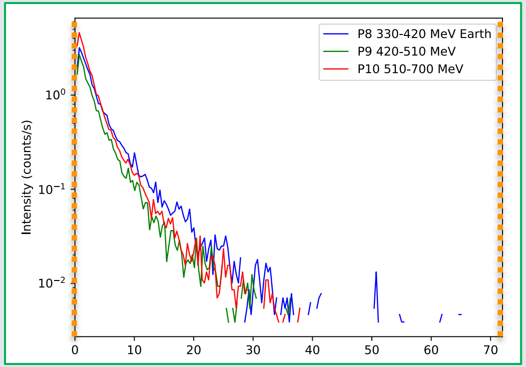

**GOES HEPAD profile**

# Exploring the largest recorded historic events: GLE 69

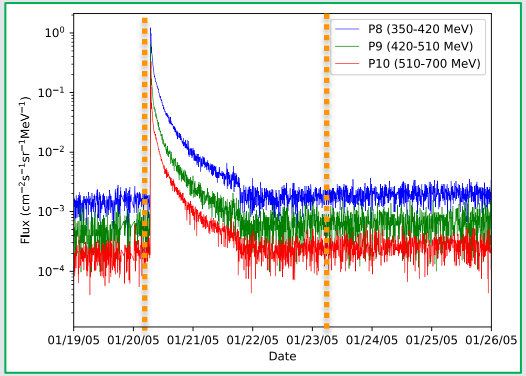
- Historic events with the largest HEPAD fluxes (and neutron monitor increases) are of particular interest in determining the influence of the HCS
- Simulations of two of the most powerful events, GLE 42 and GLE 69, indicate that the HCS had a prominent role in the propagation of energetic particles towards Earth at these times
- For example, the results of modelling GLE 69 (20 January 2005) are shown below
- Both the flare location △ and Earth's footpoint ● lie directly on the current sheet, but with a longitudinal separation >30° between them. The Earth's footpoint is advantageously located – directly in the path of the drift along the HCS
- This leads to a simulated profile at Earth that has an agreeable shape and duration with the HEPAD profile




**1AU cumulative crossing map for GLE 69**



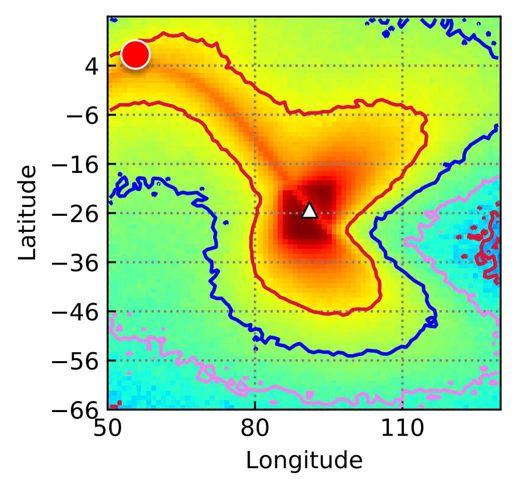

**Intensity profile at Earth's location**



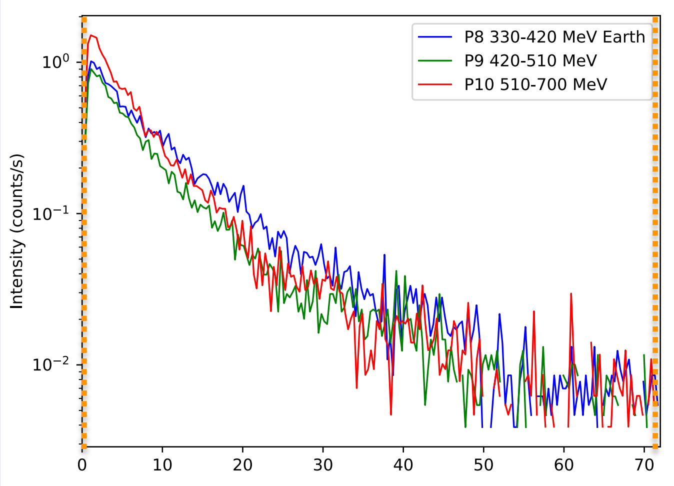

**GOES HEPAD profile**

# Exploring the largest recorded historic events: GLE 42

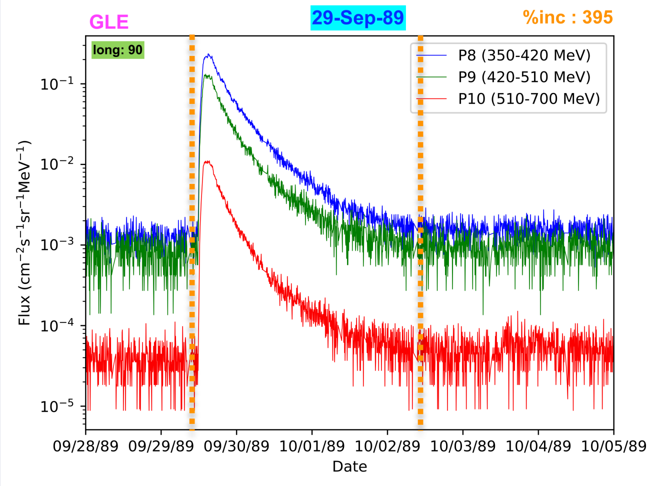
- Similar plots but for GLE 42
- Again, the flare and Earth's footpoint are located directly on the HCS, with a longitudinal separation >20 degrees
- The Earth is favourably located in the direction of drift along the HCS from the source location △ at [90,-26]
- The profiles are again comparable with the HEPAD fluxes during the event




1AU cumulative crossing map for GLE 42




Intensity profile at Earth's location

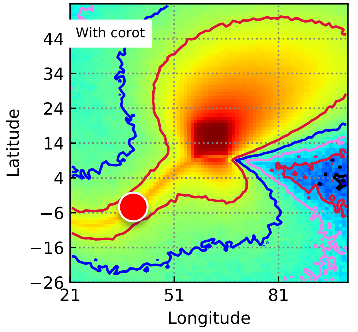


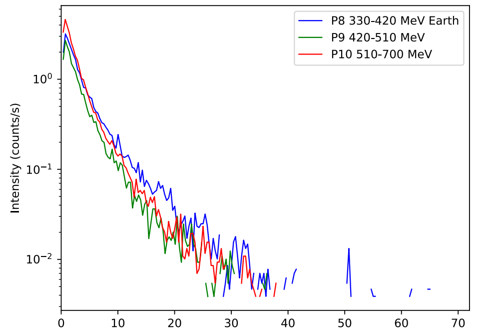

GOES HEPAD profile

# Effect of removing the heliospheric current sheet

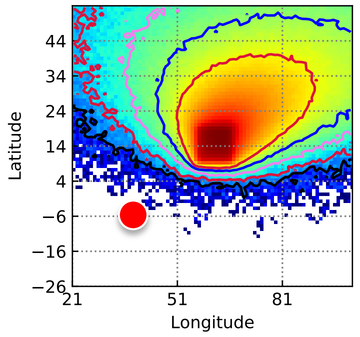
- The role the HCS plays in these powerful events is even more apparent when the HCS is removed from simulations
- The below plots show the results of removing the current sheet from the simulations for GLE 69
- When the current sheet is removed the direction of the particle propagation is away from the Earth's footpoint, producing zero counts at Earth's location
- The same is true for the other large event (GLE 42), however, the relevance of the HCS in our simulations varies depending on the configuration. The next slide again lists the modelled events, and indicates when we have found the HCS to be necessary

HCS included




No HCS




No particle counts at Earth

GLE 69

# Table of all historic events modelled with SPEC

| Event | GLE # | Flare class | CME v | Flare loc | Polarity | SPEC Vsw | CS matter? |
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Table 1: All events (GLE and sub-GLEs) modelled so far with SPEC.

**CS matter?:**

Yes: presence of HCS in simulation effects the model profile at Earth's footpoint

No: HCS makes no difference to model profile

# The role of the HCS in simulations of historic events

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- According to our simulations, the HCS plays an important role in high energy proton propagation in 75% of our simulated GLEs
- The HCS has a most dominant role in those events where both the Earth's footpoint and flare are situated directly on the current sheet with some degree of longitudinal separation between them
- The historic events with this configuration are some of the largest events on record - GLE 42 and 69
- Other 'smaller' GLE events where the HCS is still relevant have configurations where the Earth and/or flare are slightly further (>5 degrees) from the current sheet
- Events where the HCS makes no difference are primarily when the flare is far (>30 degrees) from the current sheet, or the separation between the flare and Earth footpoint is <10 degrees
- In conclusion, the majority of simulated events have an Earth/flare configuration relative to the current sheet that necessitates the inclusion of the HCS
- Our simulations enable us to produce model profiles at Earth that can be compared to existing HEPAD and neutron monitor observations, as well as for use in developing future forecasting models