Parker Solar Probe

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Integrated Science Investigation of the Sun

Seed Population Pre-Conditioning and Acceleration Observed by Parker Solar Probe

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Abstract (1/2)

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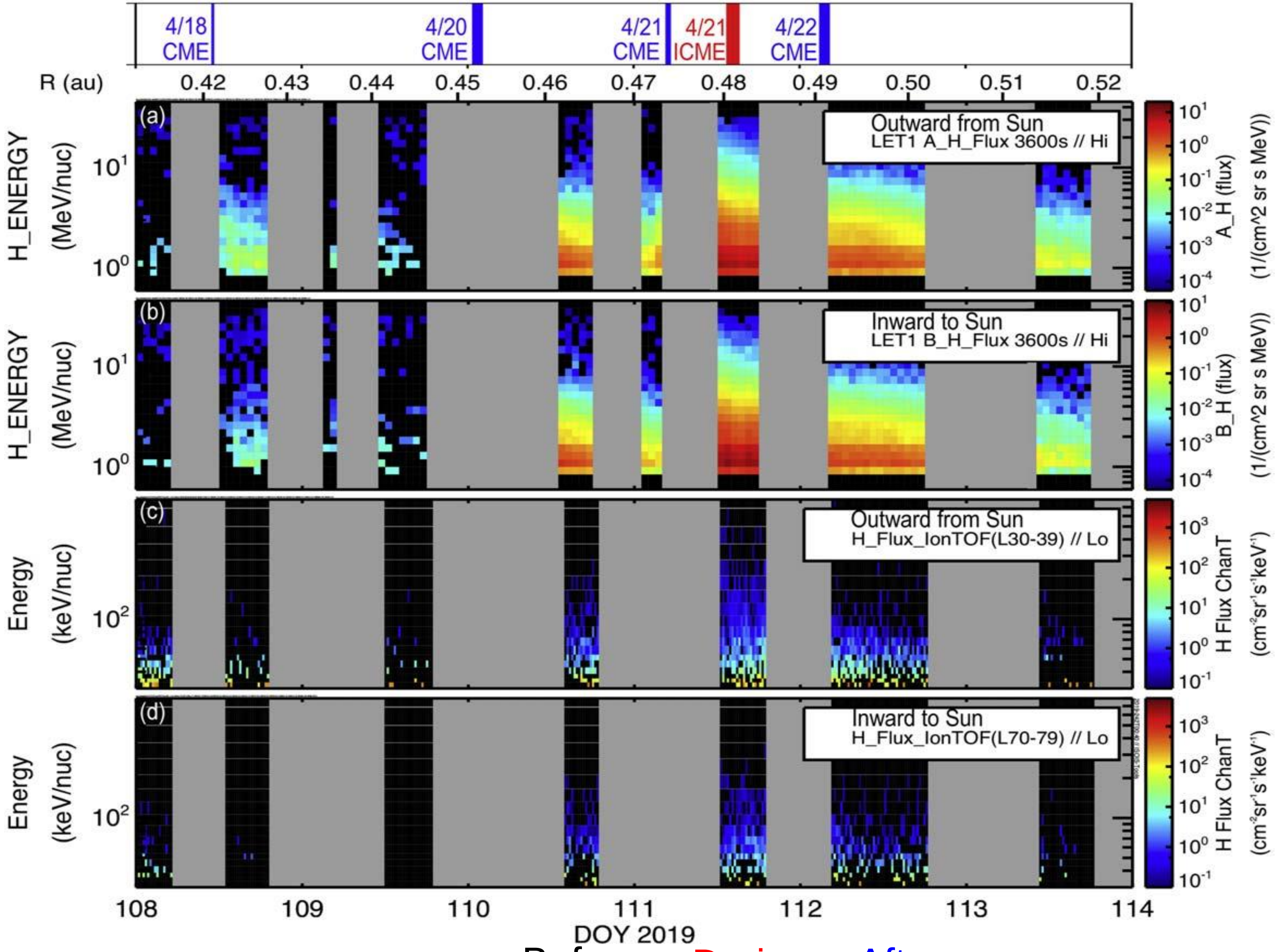
A series of solar energetic particle (SEP) events were observed at Parker Solar Probe (PSP) by the Integrated Science Investigation of the Sun (IS⊙IS) during the period from April 18, 2019 through April 24, 2019. The PSP spacecraft was located near 0.48 au from the Sun on Parker spiral field lines that projected out to 1 au within ~25° of near Earth spacecraft. These SEP events, though small compared to historically large SEP events, were amongst the largest observed thus far in the PSP mission and provide critical information about the space environment inside 1 au during SEP events. During this period the Sun released multiple coronal mass ejections (CMEs). One of these CMEs observed was initiated on April 20, 2019 at 01:25 UTC, and the interplanetary CME (ICME) propagated out and passed over the PSP spacecraft.

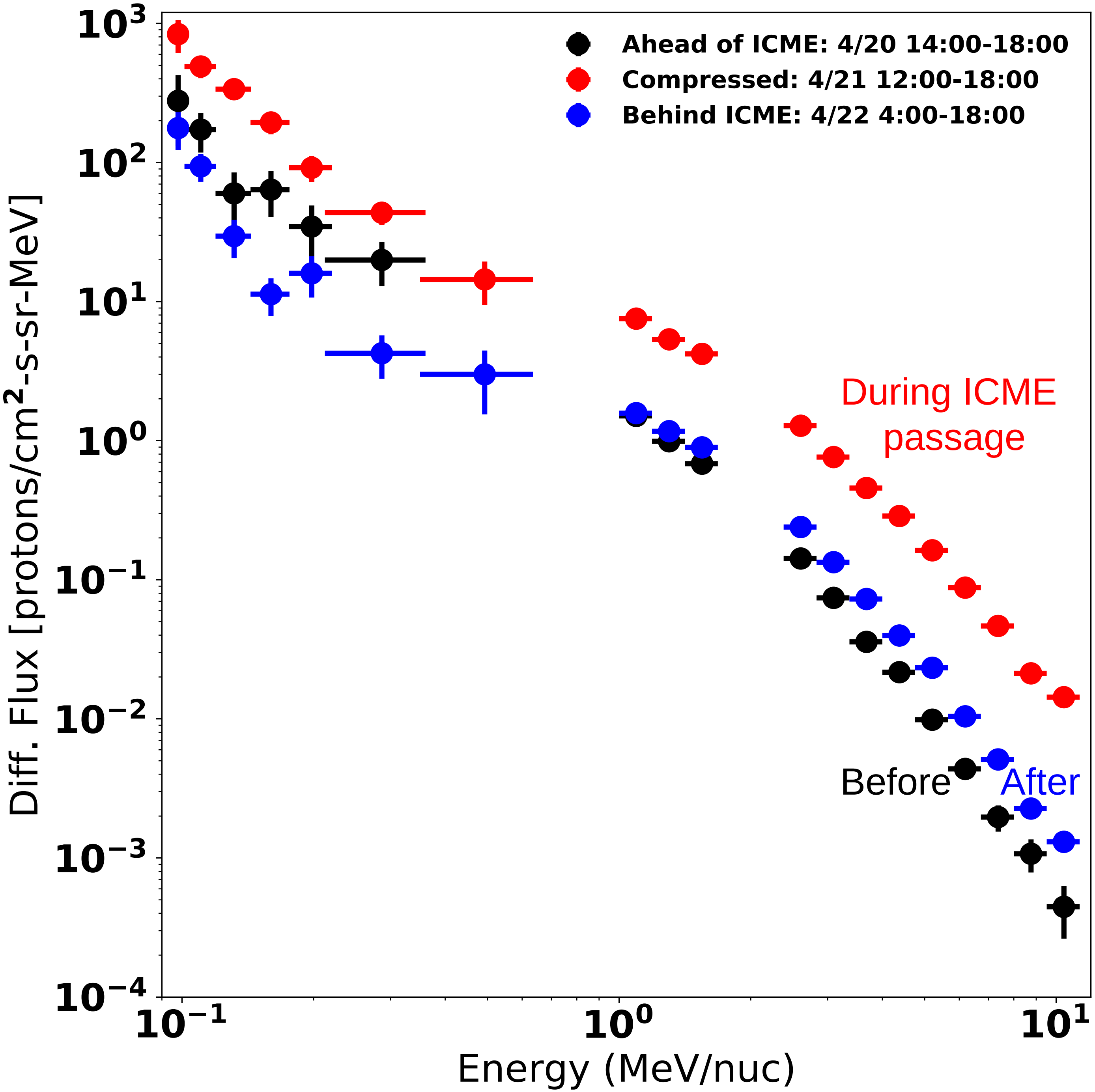
Abstract (2/2)

Observations by the Electromagnetic Fields Investigation (FIELDS) show that the magnetic field structure was mostly radial throughout the passage of the compression region and the plasma that followed, indicating that PSP did not directly observe a flux rope internal to the ICME, consistent with the location of PSP on the flank of the ICME. Analysis using relativistic electrons observed near Earth by the Electron, Proton and Alpha Monitor (EPAM) on the Advanced Composition Explorer (ACE) demonstrates the presence of flare-accelerated seed populations during the events observed. The energy spectrum of the IS⊙IS observed seed population below 1 MeV is consistent with the superposition of acceleration processes near the limit of plasma stability. IS⊙IS observations reveal the compression and acceleration of seed populations during the passage of the ICME, which is likely a key part of the pre-acceleration process that occurs close to the Sun and pre-conditions the energetic particle acceleration process.

CME released 4/20 reached PSP 4/21



Before During After



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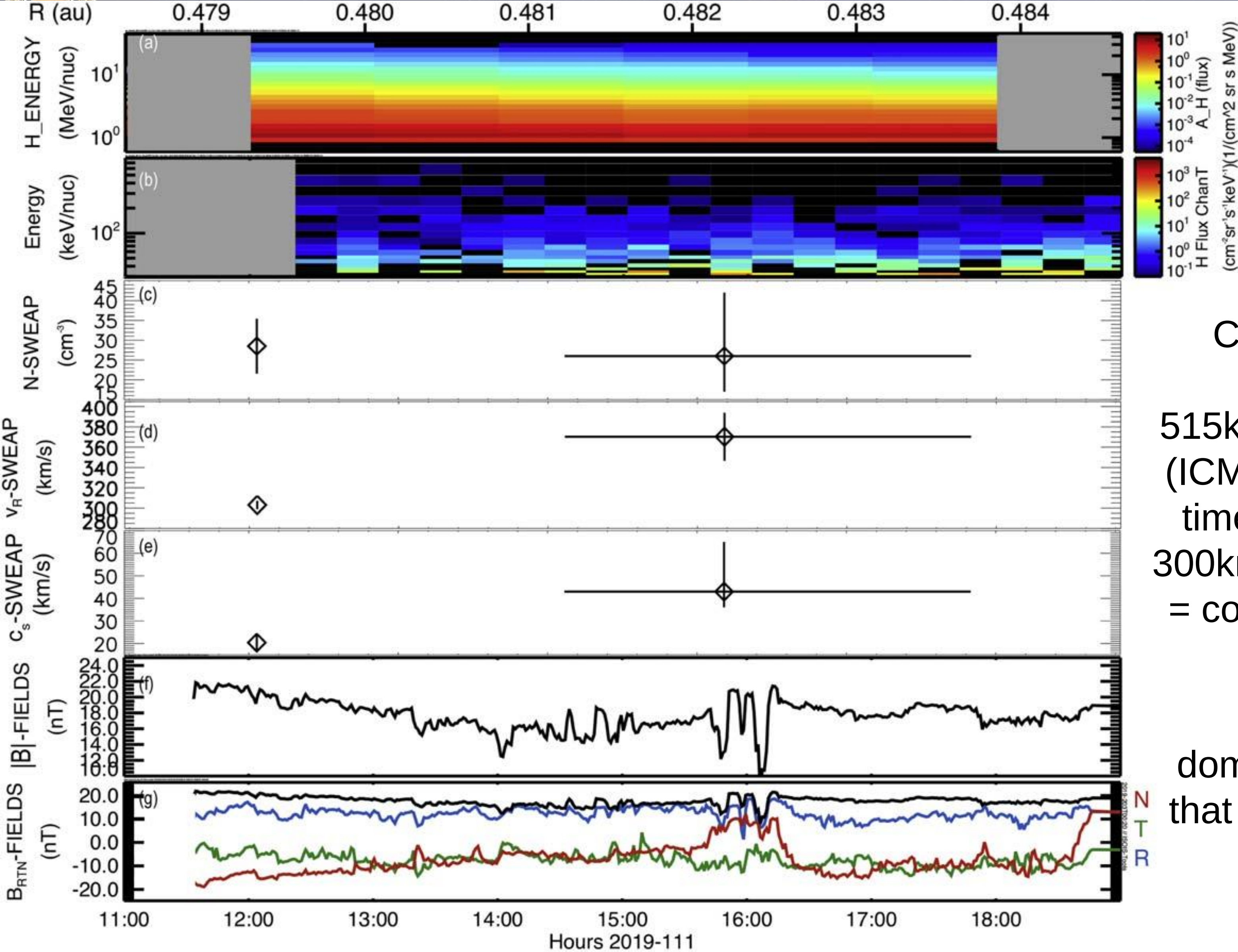
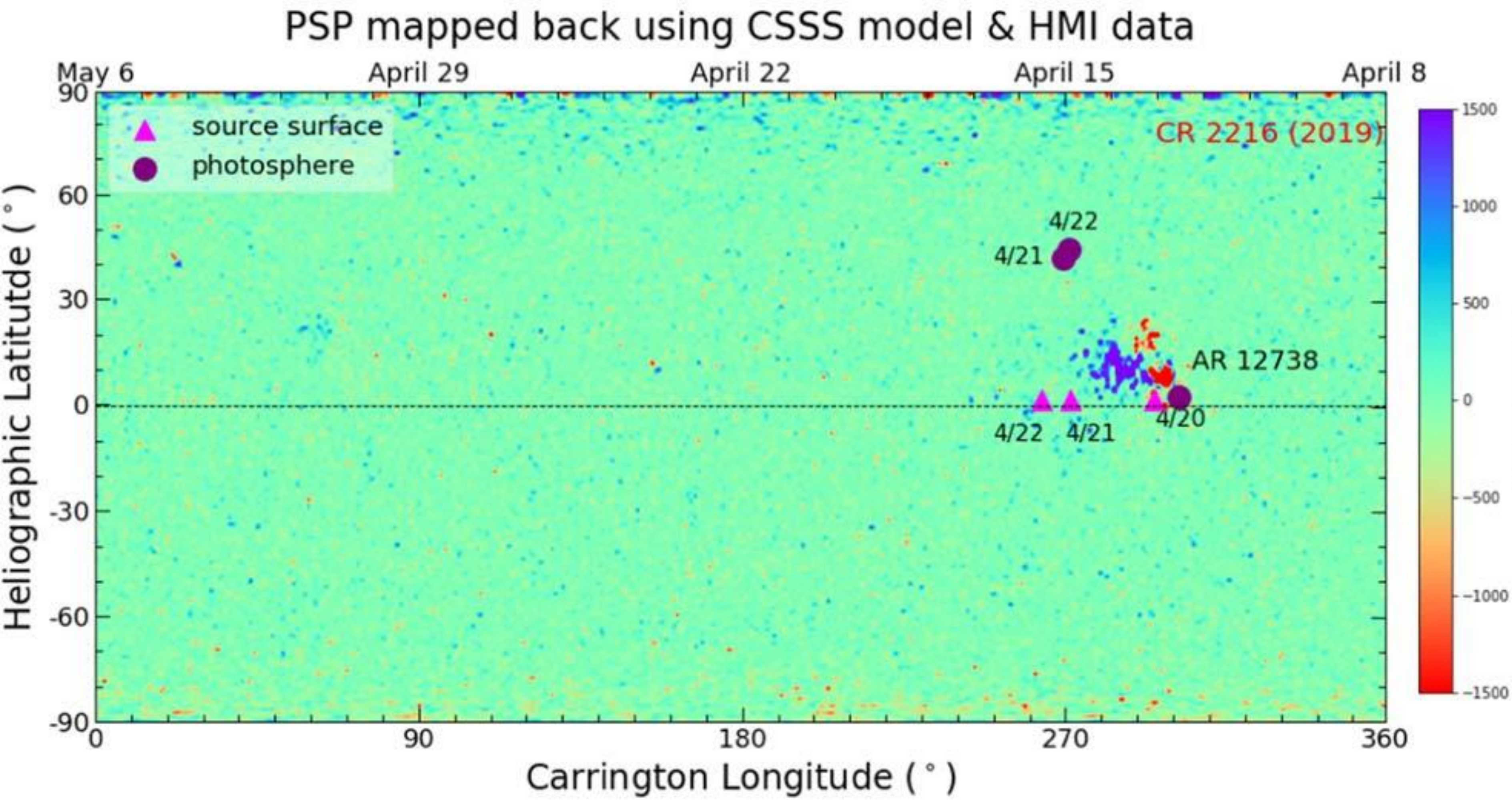
ICME passage



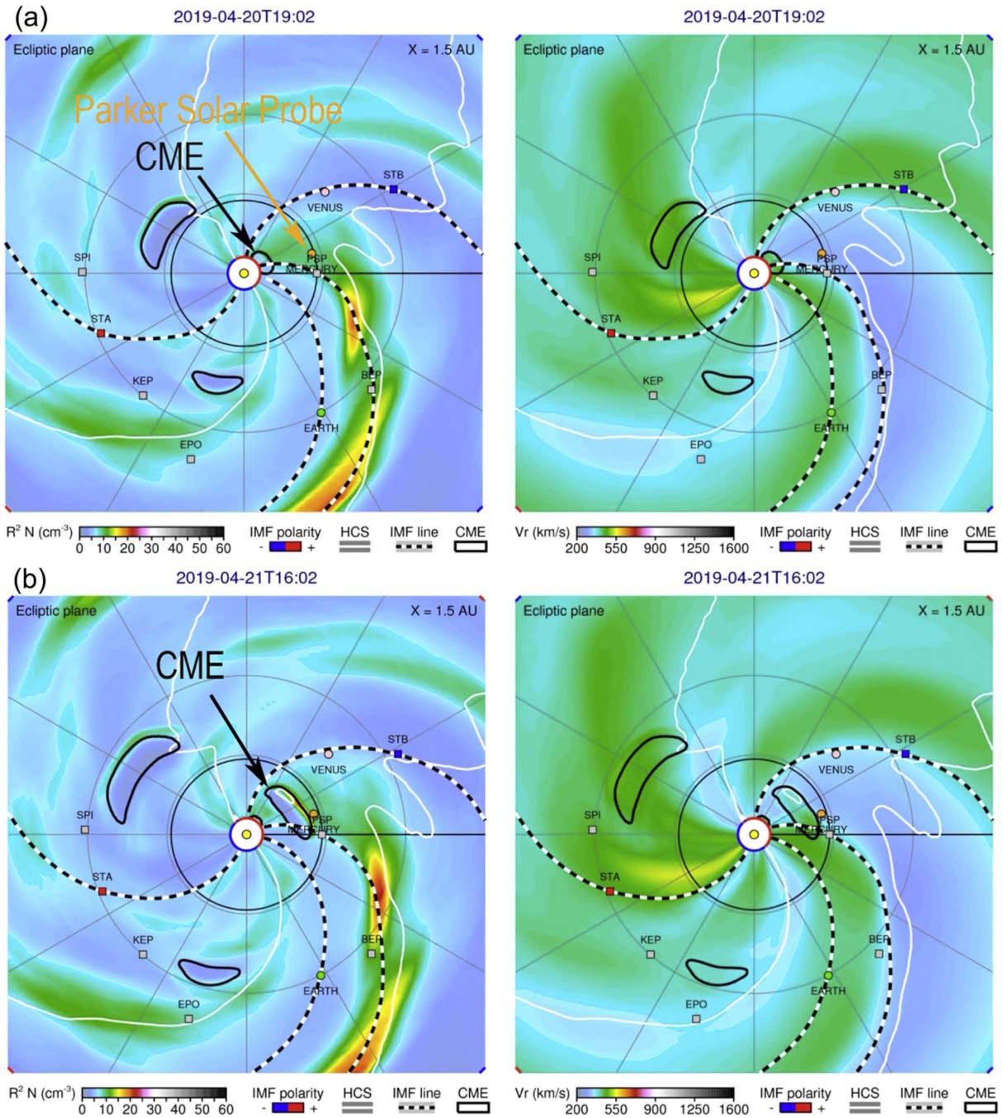
Compression signature 515km/s fast speed (ICME propagation time) / measured 300km/s slow speed = compression 1.7

Radial field dominates, unlikely that saw flux rope in CME

PSP connected to active region

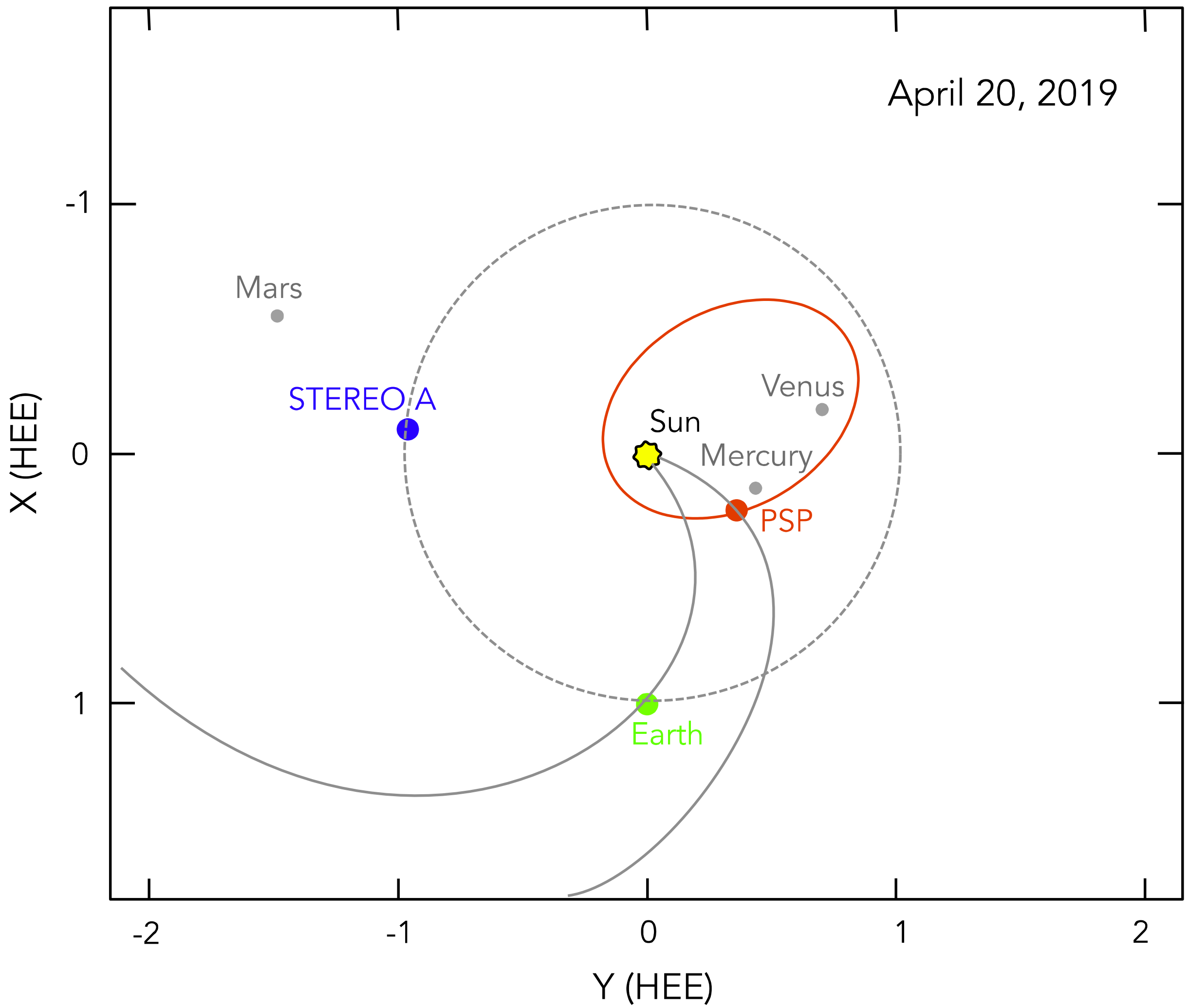


ENLIL supports ICME flank interaction

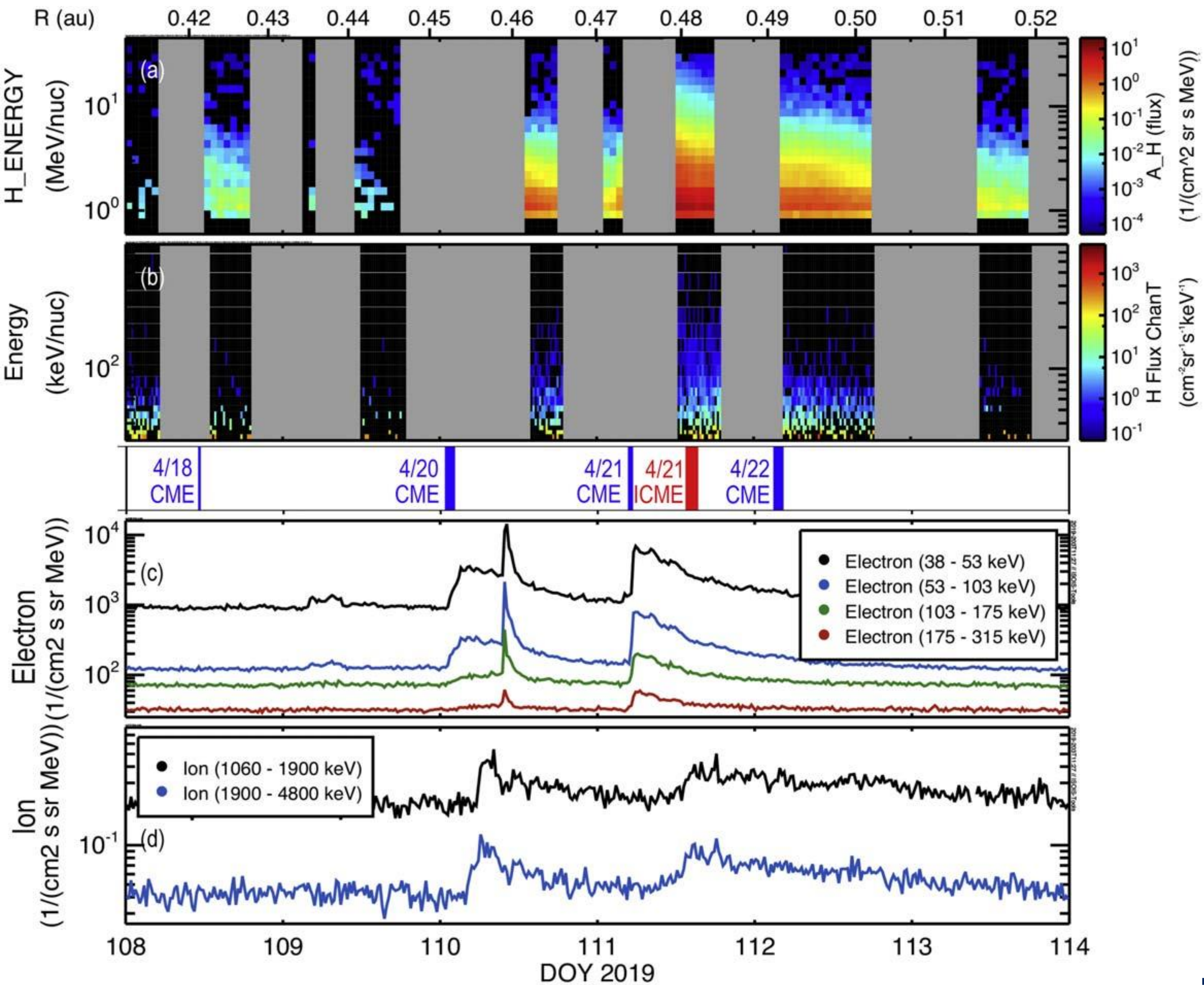


- ICME compression may have begun passing over PSP while instruments off (0.07 AU width measured, 0.25 modeled)
- ICME may be merging into SIR

PSP near field lines connected to L1



Prompt electron events at ACE



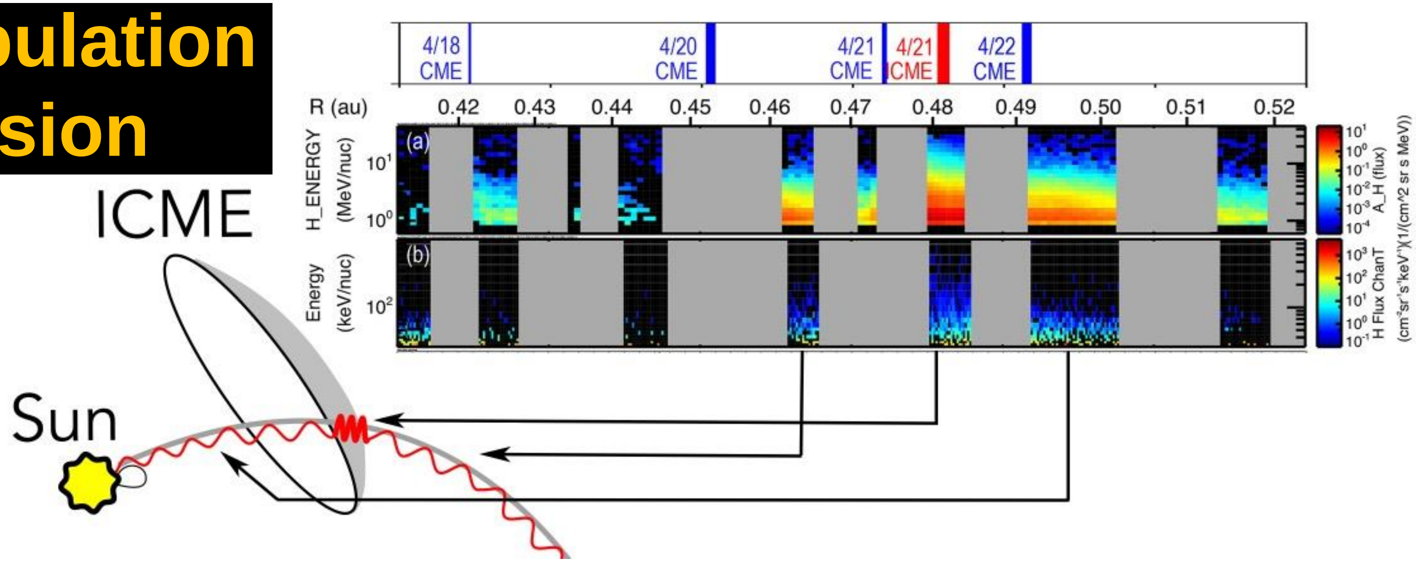
- Originated at Sun ~40min before CME release
- 3He also observed at PSP (Wiedenbeck 2020)
- Type III radio bursts at WIND (not shown)

Consistent with flare-accelerated seed populations

1MeV MFP outside ICME ~0.1AU

- 1MeV proton 13.8 Mm/s, 11.2 hr from eruption to particle observation at PSP
  - Causal limit is 3.7 AU
- Actual distance 0.48 AU, so assume diffusive limit and $f_D \propto \exp(-\frac{x^2}{4\kappa_{\|} t})$, and $\kappa_{\|} = \lambda v/3$
- Use characteristic distance as ½ intensity at source, solve for λ=0.1AU for propagation of seed particles from source to PSP

Seed Population Compression



Restricted propagation

$$\frac{\partial f_0}{\partial t} + \mathbf{u} \cdot \nabla f_0 - \nabla \cdot (\mathbf{K} \cdot \nabla f_0) - \frac{\nabla \cdot \mathbf{u}}{3} p \frac{\partial f_0}{\partial p} = 0$$

$$u \frac{\partial f_0}{\partial x} > \frac{\partial}{\partial x} \left(\kappa \frac{\partial f_0}{\partial x} \right)$$

$$\lambda < 3u\delta x / v.$$

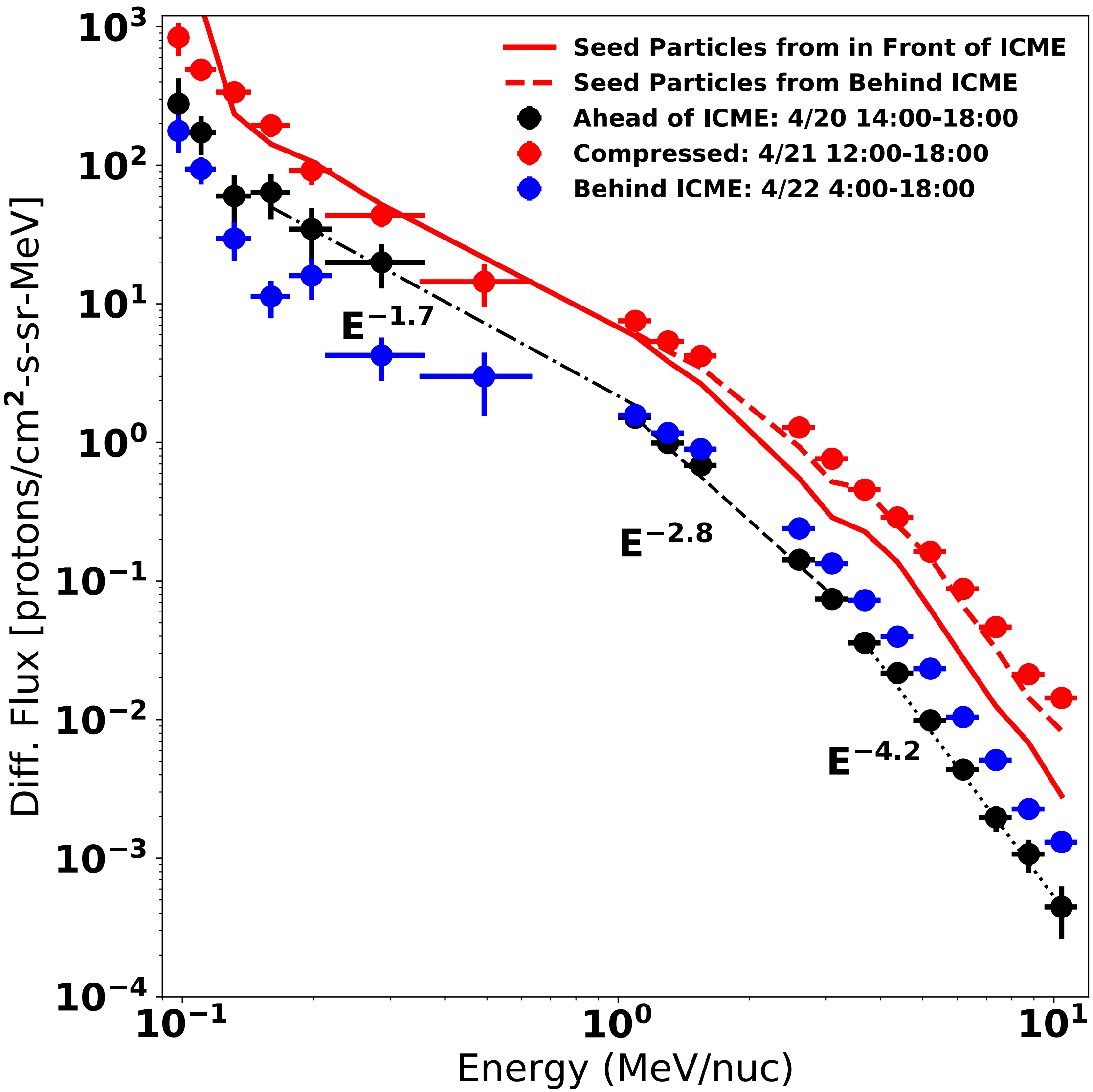
Wave-particle interaction
Field structure within compression

Local compression acceleration requires MFP ~0.006 au within ICME compression

17 times smaller than 0.1 au MFP for outside ICME compression

$$u \frac{\partial f_0}{\partial x} - \frac{1}{3} \frac{\partial u}{\partial x} p \frac{\partial f_0}{\partial p} = 0 \quad \rightarrow \quad f_c = r_c^{\gamma/3} \tilde{f}_0$$

Spectral change at 1MeV



- No ramp, so inconsistent with DSA, but good fit to local compressional
- Below 1MeV, using the population ahead of ICME as seed population for compressional acceleration is best fit to observations in ICME (solid red)
- Above 1MeV, population behind ICME fits better (dashed)
- Compressional acceleration has access to the seed population behind ICME above 1MeV, but not below

Other spectral features

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- <1MeV less mobile, cannot propagate ahead of ICME
  - Longer interaction period before caught by ICME resulting in very hard ($E^{-1.7}$) spectrum
  - Possibly superposition from multiple events, suggesting reservoir of seed population closer to sun
  - Close to maximum hardness in stationary distribution!
- Consistent with diffusive shock acceleration 1-3 MeV
  - Expected $E^{-2.6}$ for compression ration 1.7, measured $E^{-2.8}$
- Softer above 3MeV ($E^{-4.2}$)
- Proposed mechanisms for broken power law above 1MeV require strong shock/compression, short MFPs low in corona to provide rapid acceleration

Conclusions

- Direct Observation of Seed Populations fed into acceleration at CMEs
  - Provides enhanced seed population for shock acceleration at greater distances
- Compressional acceleration indicative of drastically reduced particle propagation within the ICME
  - Direct result of compression?
  - Feature of ICME?
- Seed population as observed requires strong acceleration mechanisms low in corona

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