Statistical Survey of Reservoir Phenomenon in Energetic Proton Events Observed by Multiple Spacecraft

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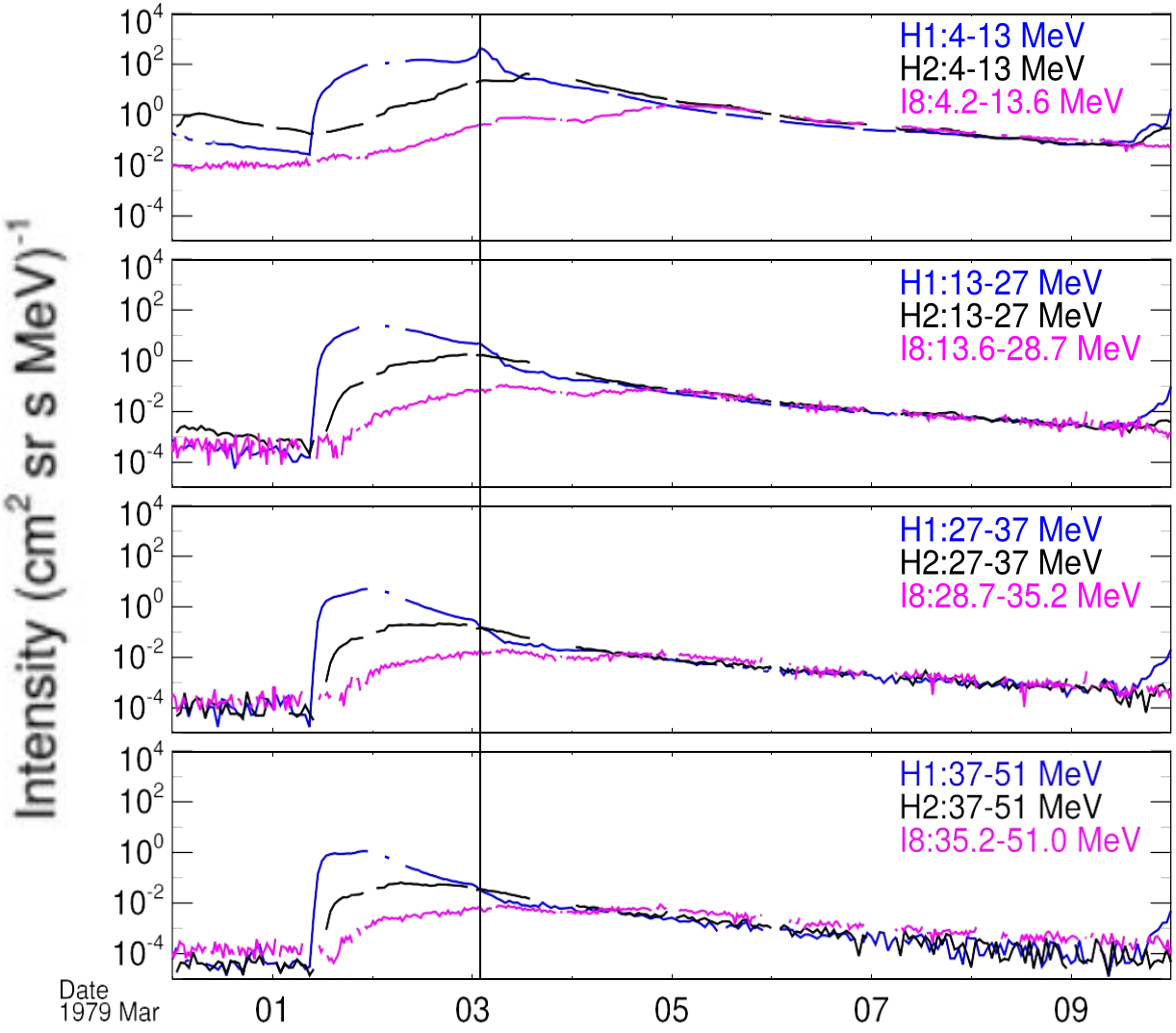
Motivations

1. What are the causes of the reservoir phenomenon of solar energetic particles (SEP)?

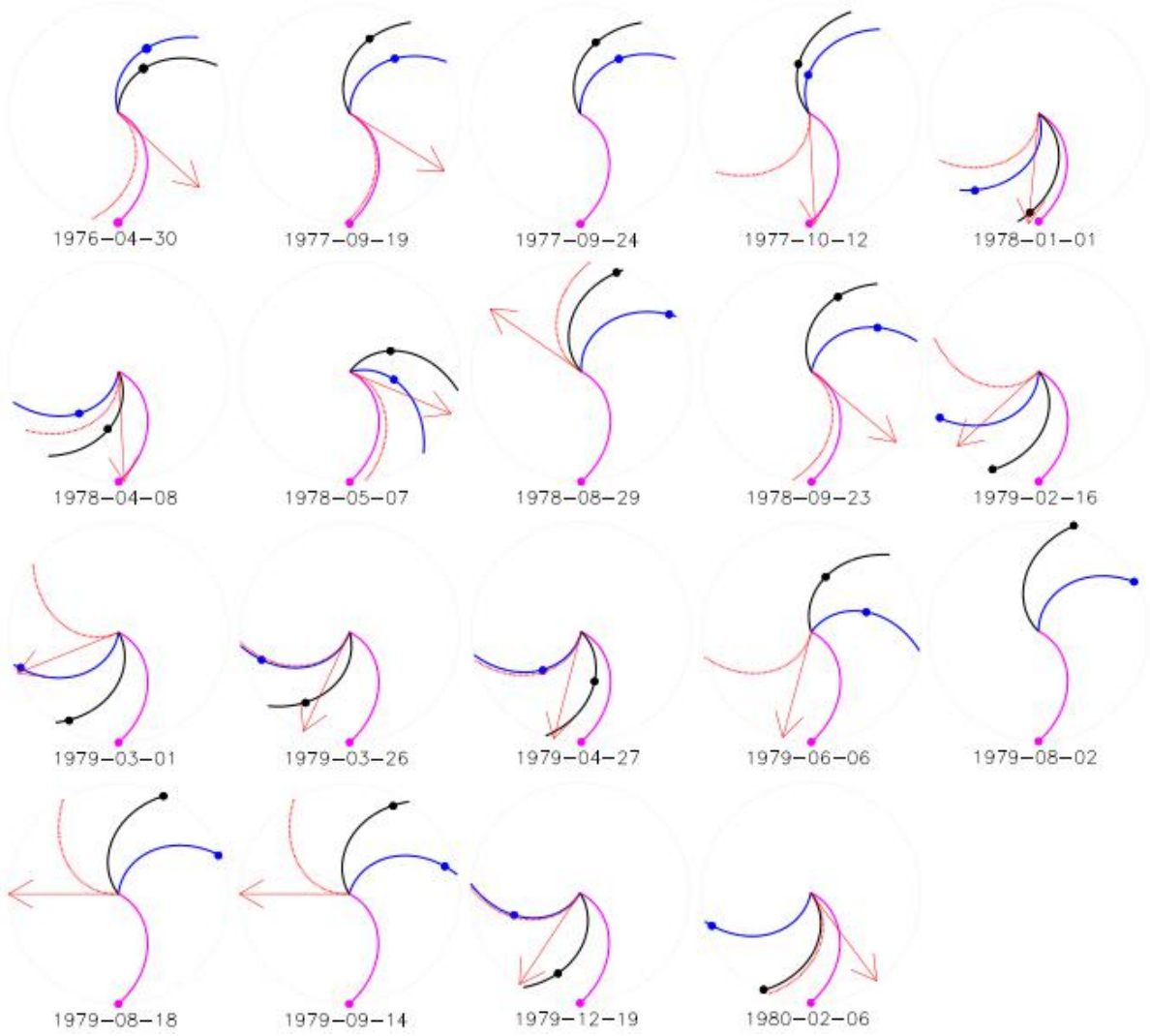
2. Which mechanism dominates the generation of reservoir phenomenon, perpendicular diffusion or magnetic boundary effect?

Reservoir Phenomenon



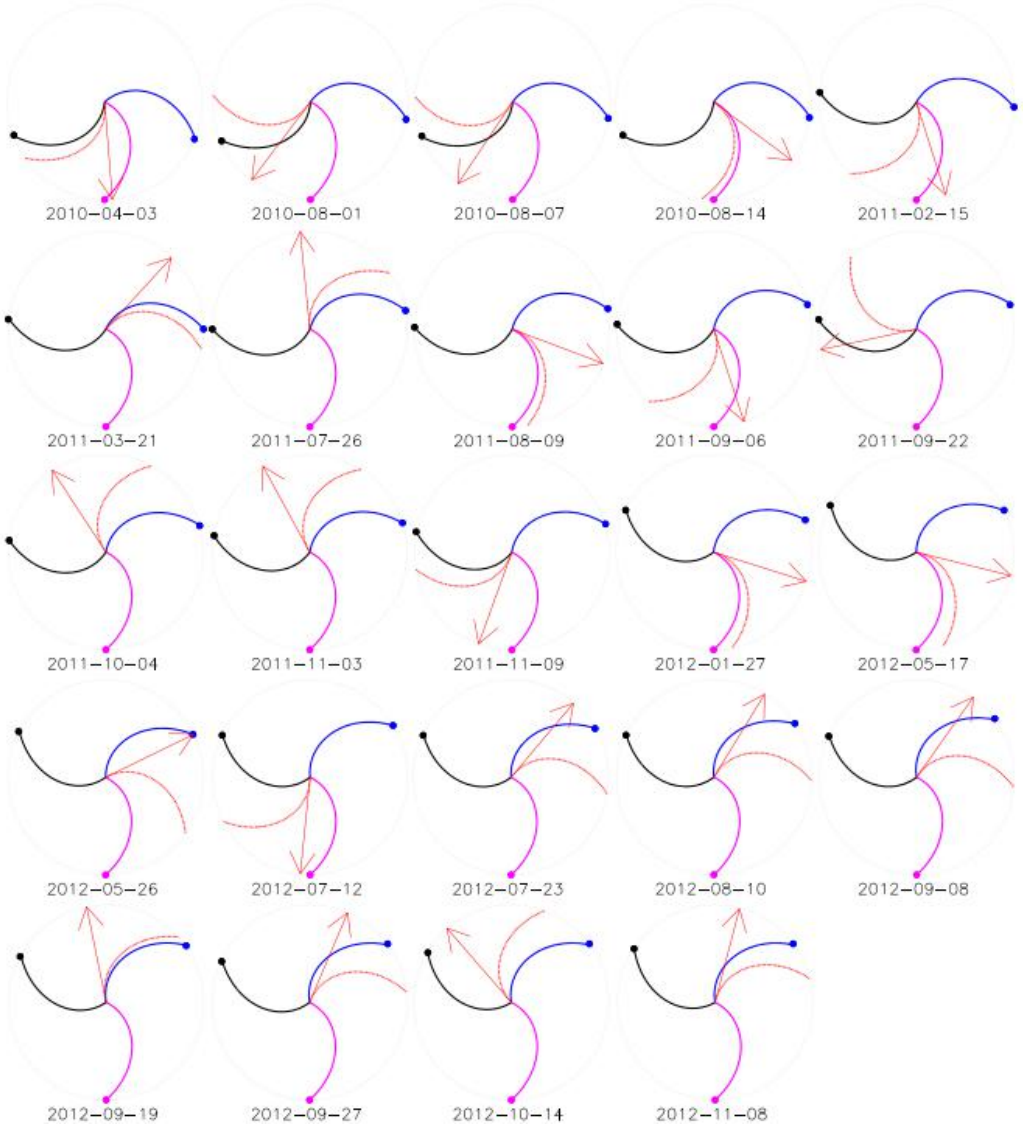
The SEP fluxes observed by Helios 1, Helios 2, and IMP 8 in the ecliptic at different longitudes.

Reservoir Events Observed by Helios 1, Helios 2,and IMP 8



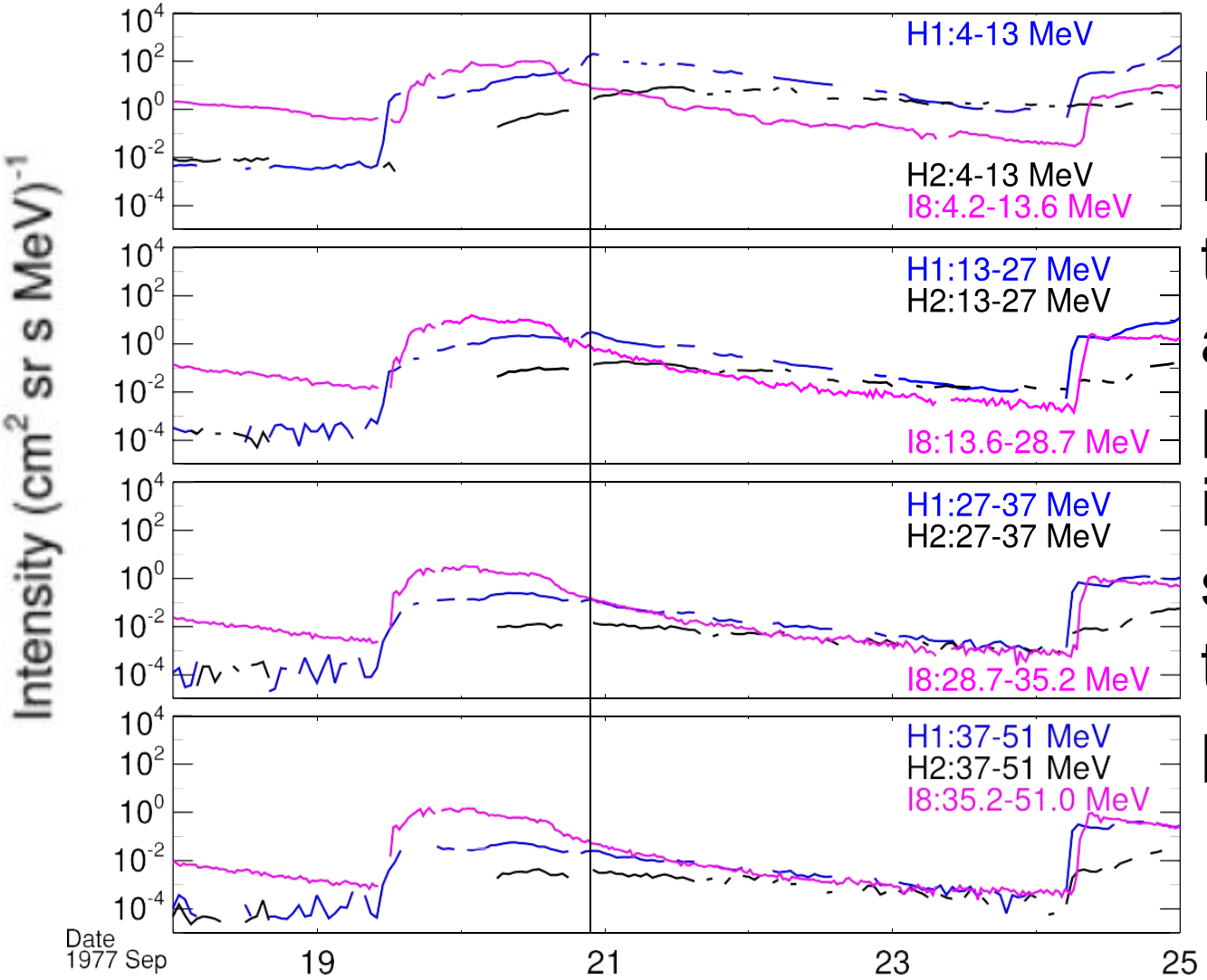
The longitude difference between Helios 1 and Helios 2 was less than 60° in all events, but the longitude between Helios and IMP 8 could be as large as about 170° in some reservoir events.

Reservoir Events Observed by STEREO A, STEREO B, and SOHO



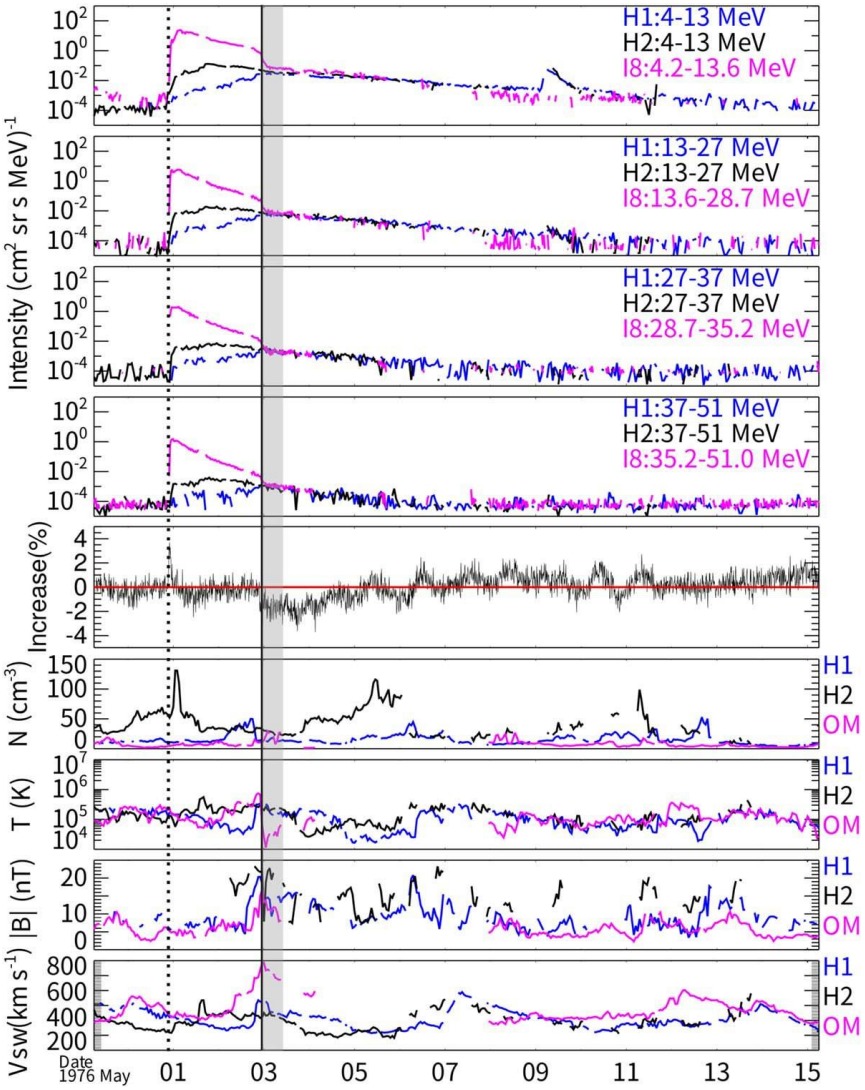
The reservoir phenomena are observed by spacecraft in almost all longitudes in the ecliptic at 1 au.

Effects of acceleration of shock waves on reservoir phenomena



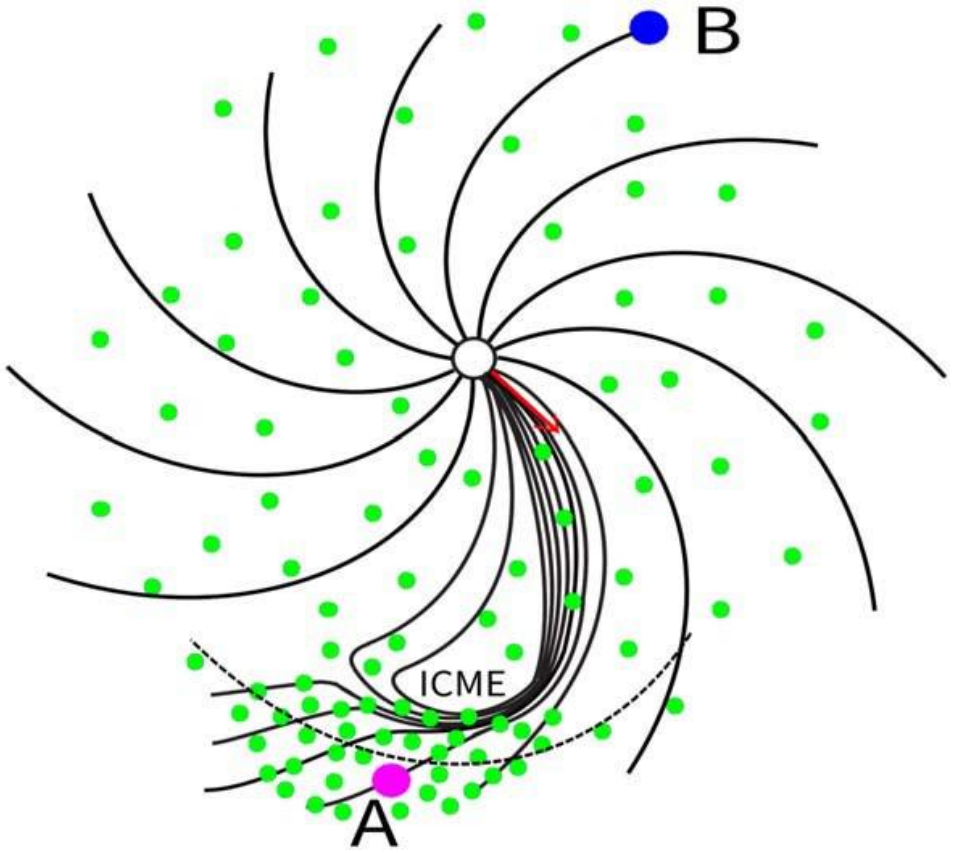
In the 4–13 MeV channel, the continuous acceleration of protons by the interplanetary shock masked the reservoir phenomenon.

The effect of magnetic boundary in the reservoir phenomenon



The effect of magnetic boundary that led less particles to diffuse into the reservoir region observed by IMP 8. In this event, the particle intensity gradients between IMP 8 and the two Helios spacecraft suddenly decreased. At this point, the reservoir phenomenon appeared.

Cartoon illustrating the effects of perpendicular diffusion and the magnetic boundary



The ICME could build a barrier and reduce the intensities of SEPs behind the magnetic boundary.

Conclutions

1. The occurrence probability of reservoir phenomenon, which is sensitive to the energy of SEPs, increases as particle energy increases. Since interplanetary shocks could continuously accelerate and inject low-energetic protons (below 10 MeV) into the heliosphere, in most low-energetic proton events, the effects of perpendicular diffusion are masked.

Conclutions

2. Most of the reservoir phenomena are observed by spacecraft in almost all longitudes in the ecliptic at 1 au. Since, compared to low-energetic SEPs, very few high-energetic SEPs could be produced in interplanetary space, perpendicular diffusion could play a greater role in high-energy proton events than low-energy proton events.Therefore, the high-energy particles are more likely to show the reservoir effect.

Conclutions

3. The perpendicular diffusion may play an important role in explaining the uniform distribution of SEPs in interplanetary space. It needs a long time for the effects of perpendicular diffusion to reduce the intensity gradients in SEP intensities that are observed at different locations. The long duration of the SEP decay phase is usually associated with the reservoir phenomenon.

Conclutions

4. The effect of magnetic boundary could help form the reservoir phenomenon, since the effect of magnetic boundary leads less particles to enter the region of reservoir. But the reservoir phenomenon cannot be explained by the effect of magnetic boundary alone.

Thank you!