ETH zürich
Contact: NJANITZEK@ETHZ.CH
Royal Observatory of Belgium
Universidad de Alcalá
Christian-Albrechts-Universität zu Kiel
Mathematisch-Naturwissenschaftliche Fakultät

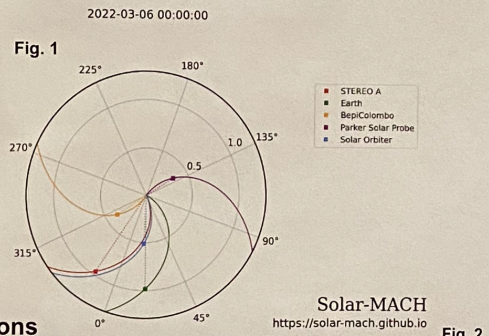
Linking solar flare observations to a series of impulsive solar energetic particle events measured by Solar Orbiter at 0.5 au

N. P. Janitzek, M. Roco, K. Barczynski, L. K. Harra, L. Berger, R. Gómez-Herrero, G. M. Mason, A. F. Battaglia, S. Musset, A. P. Walsh, G.C. Ho, R. F. Wimmer-Schweingruber, S. Krucker, D. Berghmans, E. Kraaikamp, D. Lario, O. E. Malandraki, J. Rodriguez-Pacheco, et al.

The flare-associated SEP event series on 5-6 March 2022

We investigate a series of four solar energetic particle (SEP) events that were measured in-situ by Solar Orbiter (SolO) on 5-6 March 2022 at a solar distance of 0.51 au. The spacecraft constellation in the inner heliosphere during the event series is shown in Fig 1. We can see that Solar Orbiter (blue dot) was close to the Sun-Earth line (dashed green line) which allows for the analysis of simultaneous remote-sensing observations with the Solar Dynamics Observatory (SDO). In our study we combine these remote-sensing observations with the SolO in-situ data to gain new insights into SEP acceleration and release processes in flaring active regions.

Fig. 1



Linking remote-sensing and in-situ observations

Fig. 3

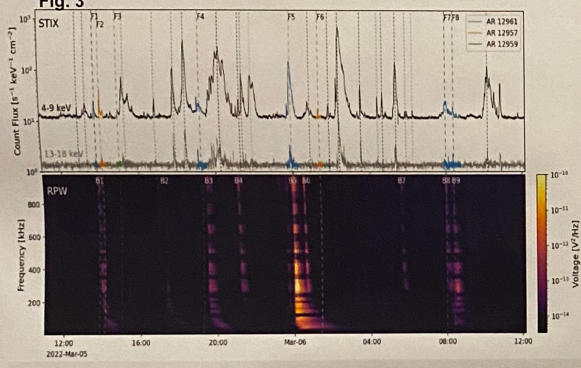


Fig. 1: Spacecraft locations in the inner heliosphere on 5/6 March 2022.
Fig. 2: Series of SEP ion (S1 – S4) events as measured with EPD onboard SolO. Events S3 and S4 include simultaneous electron injectons S3e and S4e.
Fig.3 X-ray light curve observations from STIX (upper panel) and radio observations from RPW onboard SolO. The colored observations mark flares from active regions in the west of the solar disk. The best agreement between Type-III radio bursts and the flares is seen for the flares in AR12961 (marked in blue).
Fig 5: AIA and HMI observations of AR12961 with a major flare-associated loop eruption observed (E3).

Fig. 2

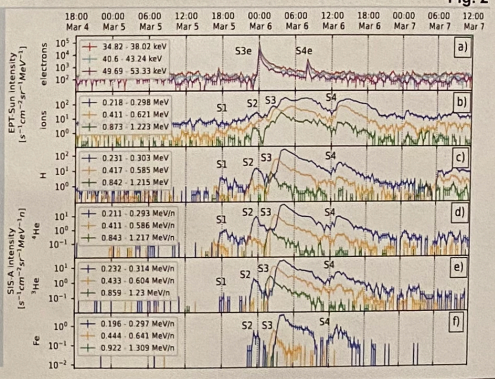


Fig. 4

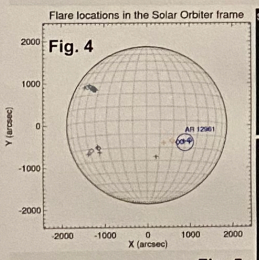
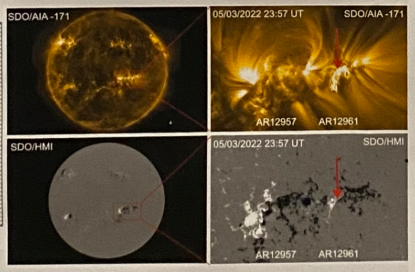


Fig. 5



Date in 2022	Flare Time UT [hh:mm]	Erupt. Time UT [hh:mm]	Burst Start UT [hh:mm]	SEP El. Inject. UT [hh:mm± min]	SEP Ion Inject. UT [hh:mm]
05/03	13:44 - 13:49 (F1)	13:51 – 13:58 (E1)	13:48 (B1)	-	$14:07^{+7}_{-61}$ (S1)
05/03	19:03 - 19:30 (F4)	19:25 – 19:48 (E2)	19:27 (B3)	-	$19:58^{+20}_{-22}$ (S2)
05/03	23:41 - 00:14 (F5)	23:47 – 00:18 (E3)	23:48 (B5)	23:46±1 (S3e)	$23:47^{+13}_{-36}$ (S3)
06/03	07:55 - 08:44 (F7 / F8) [a]	08:00 - 08:50 (E5)	08:06 / 08:21 (B8 / B9)	07:54±1 / ≈08:15 (S4e)	≈08:00 (S4)

Notes. All times are given in UT at the Sun (corrected for signal run times to the observing spacecraft). [a] Flare, eruption, and ion injection times cannot be determined individually due to the close spatial and temporal proximity with flare F7 / F8, respectively.

The combination of multi-spacecraft remote-sensing observations and unprecedented in-situ measurements from SolO allowed to establish a plausible link between solar events - such as the observed flare-associated jets and loop eruptions - and the solar energetic particle events. We find that all SEP-related eruptions originate within the same active region AR12961.

Comparing flare-associated solar eruptions and SEP characteristics among the events

The precise linkage between flare-associated plasma eruptions and SEP events allows for the direct comparison of the events. Furthermore, due to the proximity of SolO to the Sun, the transport effects in the SEP events are small and the obtained SEP spectra are thus likely to contain direct information of the acceleration process during the eruptive events (E1 –E4). We find that the first events (with ion injections S1 and s2) are related to more confined jet-like eruptions (E1 and E2) while injections S3 and S4 are related to more complex loop eruptions (clearest seen for event E3). Interestingly, these larger eruptions show not only higher intensities, but also about 5 times higher He3/He4 ratios. This ratio is a sensitive marker for the SEP acceleration process – and potentially related to an increased presence of ion-cyclotron waves during the eruption.

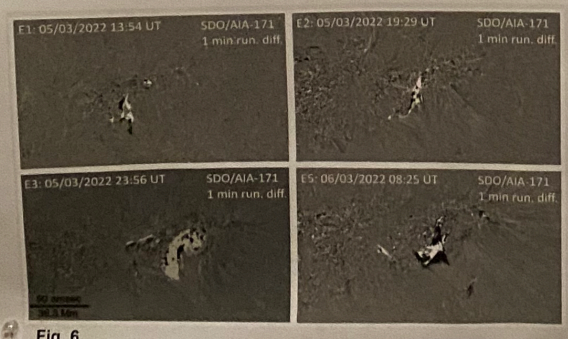


Fig. 6

Fig 6: Running-difference images of the observed flare-associated plasma eruptions (E1 – E4) observed in EUV with SDO/AIA-171 (1 minute cadence). The spatial scales of the panels are the same for all four panels and the events originate in the same active region Ar12961.

Fig 7: Energy spectra of the corresponding SEP ion injections S1 – S4. The He3/He4 ratio is clearly increased for S3 and S4 compared to S1 and S2. We also note that S3 and S4 are accompanied by in-situ electron events S3e and S4e. This is not the case for S1 and S2 (despite the Type-III bursts observed for all events).

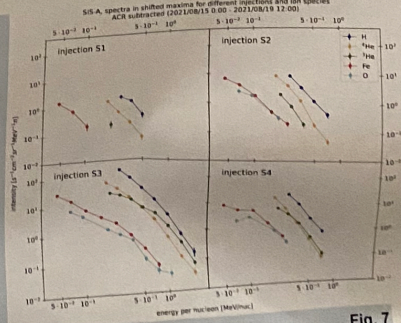


Fig. 7