Nowcasting Solar Energetic Particle Events for Mars Missions

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Abstract

In addition to the omnipresent Galactic Cosmic Rays (GCRs), sudden solar energetic particle (SEP) events present considerable health hazards for manned space missions. These events not only contribute to an increased long-term cancer risk, but can, in extreme cases, cause acute radiation syndromes. Forecasting their imminent occurrence could significantly reduce radiation exposure by warning astronauts to move to shelter. However, all currently available tools are primarily designed for the Earth or Earth-Moon system, which limits their applicability to future Mars missions. To address this, we developed a nowcasting system for SEP events applicable in deep space and on the Martian surface, which serves as a reliable last-resort backup when forecasts fail. The methodology of this system is based on dose rates measured by the Radiation Assessment Detector (RAD) onboard the Mars Science Laboratory (MSL), which recorded 5 SEP events during the 7-month flight to Mars and 17 since its landing on Mars on 6 August 2012. An SEP event is triggered, and an astronaut is warned as soon as dose rates exceed the omnipresent background level by at least 25%. This approach suggests that our system can provide astronauts with at least 30 min to avoid both peak radiation exposure and the majority of the cumulative dose from SEP events. Our nowcasting system is robust, easily implementable in real-life scenarios, and achieves a near-zero false alarm rate both in deep space and on the Martian surface.

1. The Radiation Environment for Mars Missions

The high radiation exposure of astronauts due to omnipresent GCRs and sporadic SEP events represents one of the major hazards of a crewed Mars mission. Figure 1 shows the radiation environment, expressed as dose rates, measured by MSL/RAD during the seven-month transit to Mars and over more than 12 years on the Martian surface.

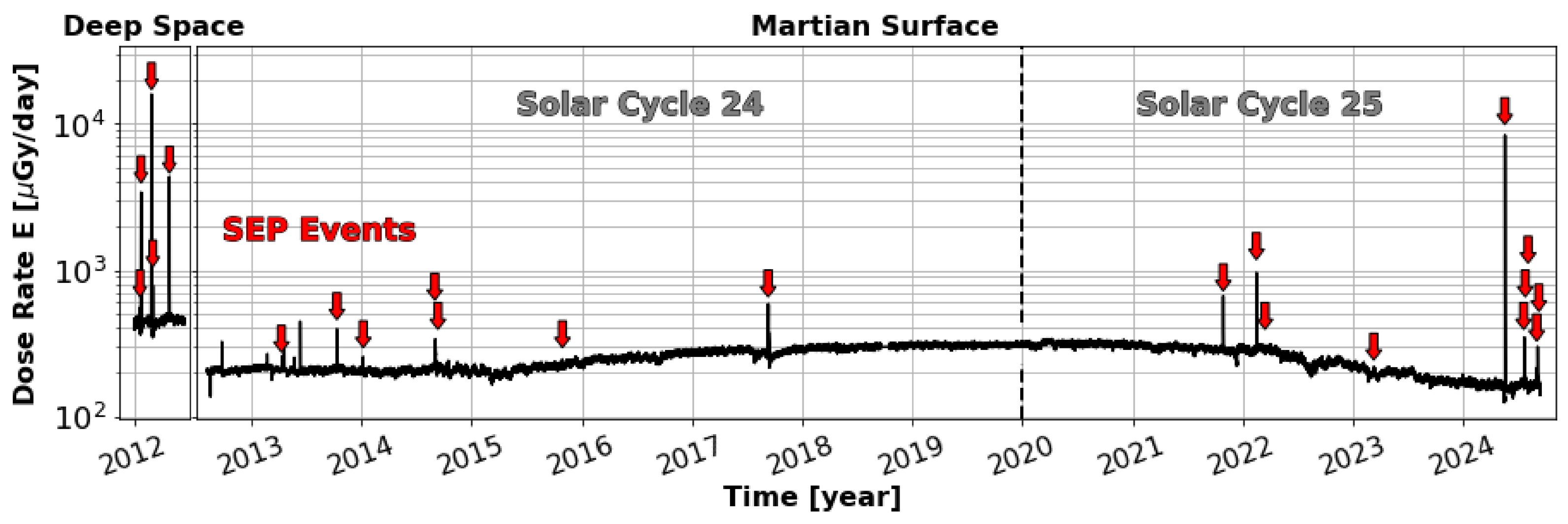

Figure 1. Dose rate measured by the MSL/RAD in deep space (left) and on the Martian surface (right).

The total dose of a ~500-day round trip to Mars (≈**930 mSv** [1]) exceeds the NASA-established career dose limits for astronauts (≈**600 mSv** [2]) significantly. Mitigating radiation exposure during a Mars mission is therefore of critical importance. The most effective strategy against SEP doses is forecasting these events to allow timely protective action.

2. Forecasting SEP Events for Mars Missions

Existing forecasting methods, as illustrated in Figure 2, are exclusively designed for the Earth or the Earth–Moon system. Since Mars and the vehicle during the cruise phase are not always magnetically well connected to Earth, **none of the available forecasting approaches can provide full coverage of an entire Mars mission.**

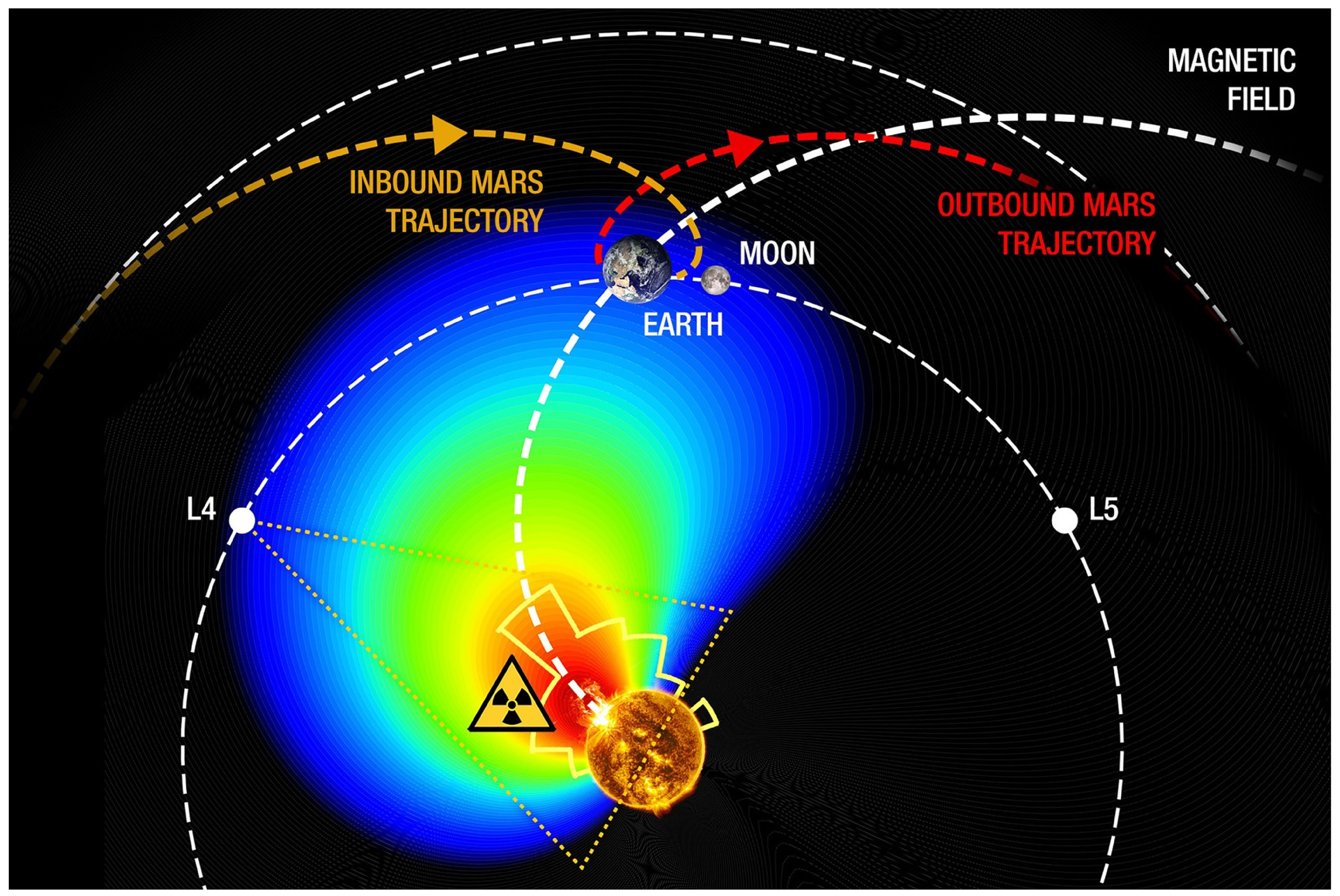

Figure 2. Conceptual illustration of SEP forecasting for Earth and its potential extension to Mars missions [3].

3. Nowcasting SEP Events for Mars Missions

Given that forecasting cannot be guaranteed throughout a Mars mission, a backup approach is essential. Crew active dosimeters must worn by astronauts with continuous readout for mission durations. This leads to the key question of our study: **Is nowcasting based on dose rates still effective?**

Our nowcasting system triggers on SEP events and alerts the astronaut as soon as dose rates exceed a background threshold. The measurements from MSL/RAD, cf. Figure 1, are used to empirically investigate our nowcasting concept for Mars missions. Each detected SEP event is analyzed based on the parameters defined in Figure 3.

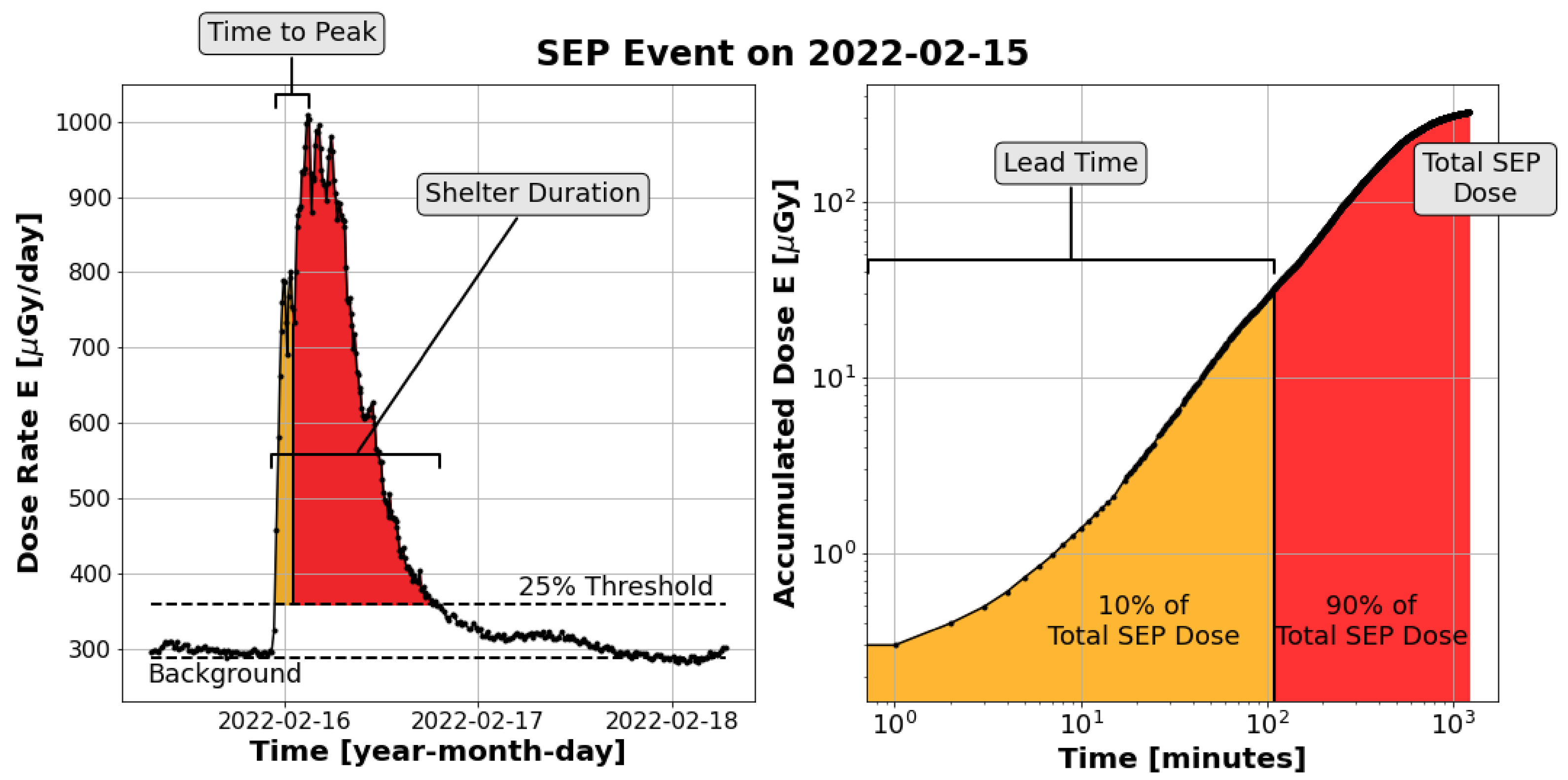

Figure 3. Key parameters for validating the operational capability of our nowcasting approach.

4. False Alarm Rate (FAR)

Figure 4 shows that the FAR is ~0% in deep space and ~25% on the Martian surface using the 25% trigger threshold, indicating that **our nowcasting system is robust and reliable.**

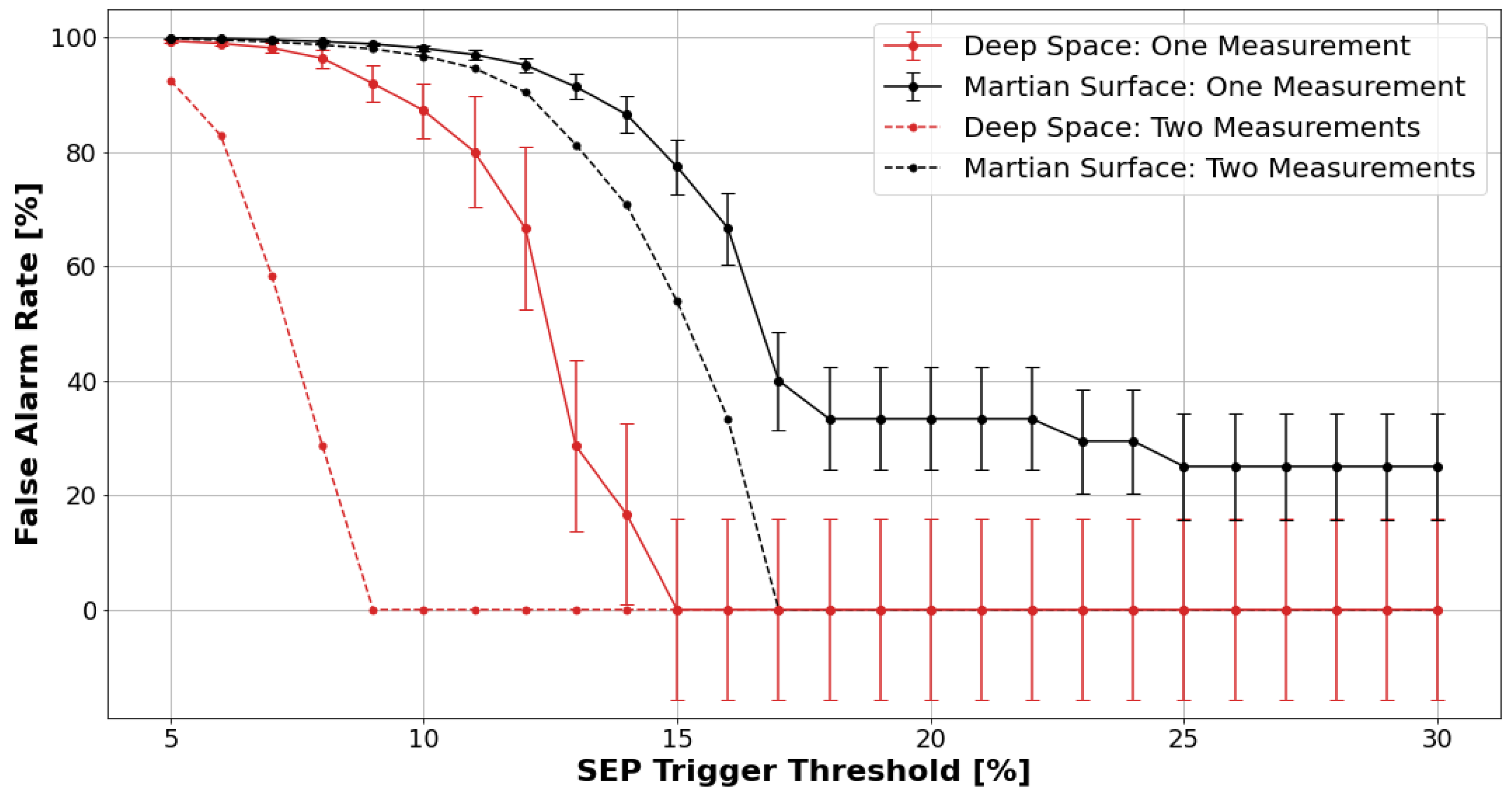

Figure 4. FAR in deep space (red) and on the Martian surface (black) depending on different SEP trigger thresholds.

5. Is There Still Time to Hide?

The following Table summarizes the evaluation of all SEP events recorded by MSL/RAD, with respect to the parameters introduced in Figure 3.

	SEP Event [year-month-day]	Shelter Duration [day hour:minute]	Time to Peak [day hour:minute]	Lead Time [day hour:minute]	Total SEP Dose [μGy]
DEEP SPACE	2012-01-23	00d 03h:09m	00d 02h:09m	00d 00h:17m	12.71
	2012-01-27	02d 05h:54m	00d 02h:52m	00d 02h:11m	1466.30
	2012-03-07	03d 07h:33m	01d 12h:34m	00d 16h:43m	9901.40
	2012-03-13	00d 10h:16m	00d 00h:36m	00d 00h:35m	86.05
	2012-05-17	01d 00h:43m	00d 01h:25m	00d 00h:51m	1170.20
MARTIAN SURFACE	2013-04-11	00d 05h:33m	00d 01h:28m	00d 01h:28m	9.22
	2013-10-11	00d 11h:15m	00d 02h:07m	00d 01h:07m	32.32
	2014-01-06				
	2014-09-01	01d 14h:17m	00d 09h:01m	00d 02h:47m	125.93
	2014-09-10	00d 01h:41m	00d 01h:02m	00d 00h:02m	2.09
	2015-10-29				
	2017-09-10	01d 08h:01m	00d 06h:49m	00d 03h:44m	261.79
	2021-10-28	00d 17h:47m	00d 05h:12m	00d 02h:01m	161.44
	2022-02-15	00d 20h:31m	00d 03h:55m	00d 01h:50m	323.75
	2022-03-14				
	2023-03-13	00d 01h:23m	00d 01h:08m	00d 00h:05m	1.22
	2024-05-20	01d 17h:55m	00d 00h:53m	00d 00h:57m	1730.55
	2024-07-22	00d 13h:16m	00d 02h:16m	00d 01h:20m	57.98
	2024-07-26				
	2024-08-05				
	2024-09-03	00d 01h:25m	00d 00h:34m	00d 00h:08m	2.89
	2024-09-05	00d 08h:35m	00d 00h:33m	00d 00h:33m	25.52

10× rec. dose limit on Earth (9901.40)

1.7× rec. dose limit on Earth (1730.55)

Our study suggests that, for all hazardous SEP events, **our nowcasting system can provide astronauts with at least 30 minutes to avoid both the peak intensity and more than 90% of the total SEP dose.**

References

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