Prediction of Space Radiation Exposure on Mars

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Abstract:

Physics-based model of solar protons is necessary to quantitatively predict the radiation exposure at Mars. We developed a model called WASAVIES [1,2,3], which was developed for aircrews flying over the Earth, and can modify it for Mars. Coronal mass ejections evolve, magnetic connections between planets and shocks change, and the shock parameters there also change in time. All of these data are essential to model the solar protons in the inner heliosphere, and SUSANOO-CME model [4] is now ready to provide them. New neutron/muon observation also started at Syowa Station, Antarctica. We briefly report some preliminary results and the basic strategy toward Mars-version WASAVIES.

References:

[1] Kataoka, R., T. Sato, Y. Kubo, D. Shiota, T. Kuwabara, S. Yashiro, and H. Yasuda (2014), Radiation dose forecast of WASAVIES during ground level enhancement, Space Weather, 12, doi:10.1002/2014SW001053.

[2] Kataoka, R., Sato, T, S. Miyake, D. Shiota, and Y. Kubo (2018), Radiation Dose Nowcast for the Ground Level Enhancement on 10-11 September 2017, Space Weather, 16, https://doi.org/10.1029/2018SW001874.

[3] Sato, T, R. Kataoka, D. Shiota, Y. Kubo, M. Ishii, H. Yasuda, S. Miyake, I. Park, and Y. Miyoshi (2018), Real-Time and Automatic Analysis Program for WASAVIES: Warning System of Aviation Exposure to Solar Energetic Particles, Space Weather, 16, https://doi.org/10.1029/2018SW001873.

[4] Shiota, D., and R. Kataoka (2016), Magnetohydrodynamic simulation of interplanetary propagation of multiple coronal mass ejections with internal magnetic flux rope (SUSANOO-CME), Space Weather, 14, 56–75, doi:10.1002/2015SW001308.

Some preliminary results and our modeling strategy

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Motivation

- Somebody will come to Mars.
- Physics-based model of solar protons is necessary to quantitatively predict the radiation exposure at Mars.
- We have a model called WASAVIES, which was developed for aircrews flying over the Earth, and can modify it for Mars.

What is WASAVIES?

1. Solve 1D focused transport equations for many possible cases, in advance.
2. Select one which is best-fitted to Obs.

Warning system for aviation exposure to solar energetic particles

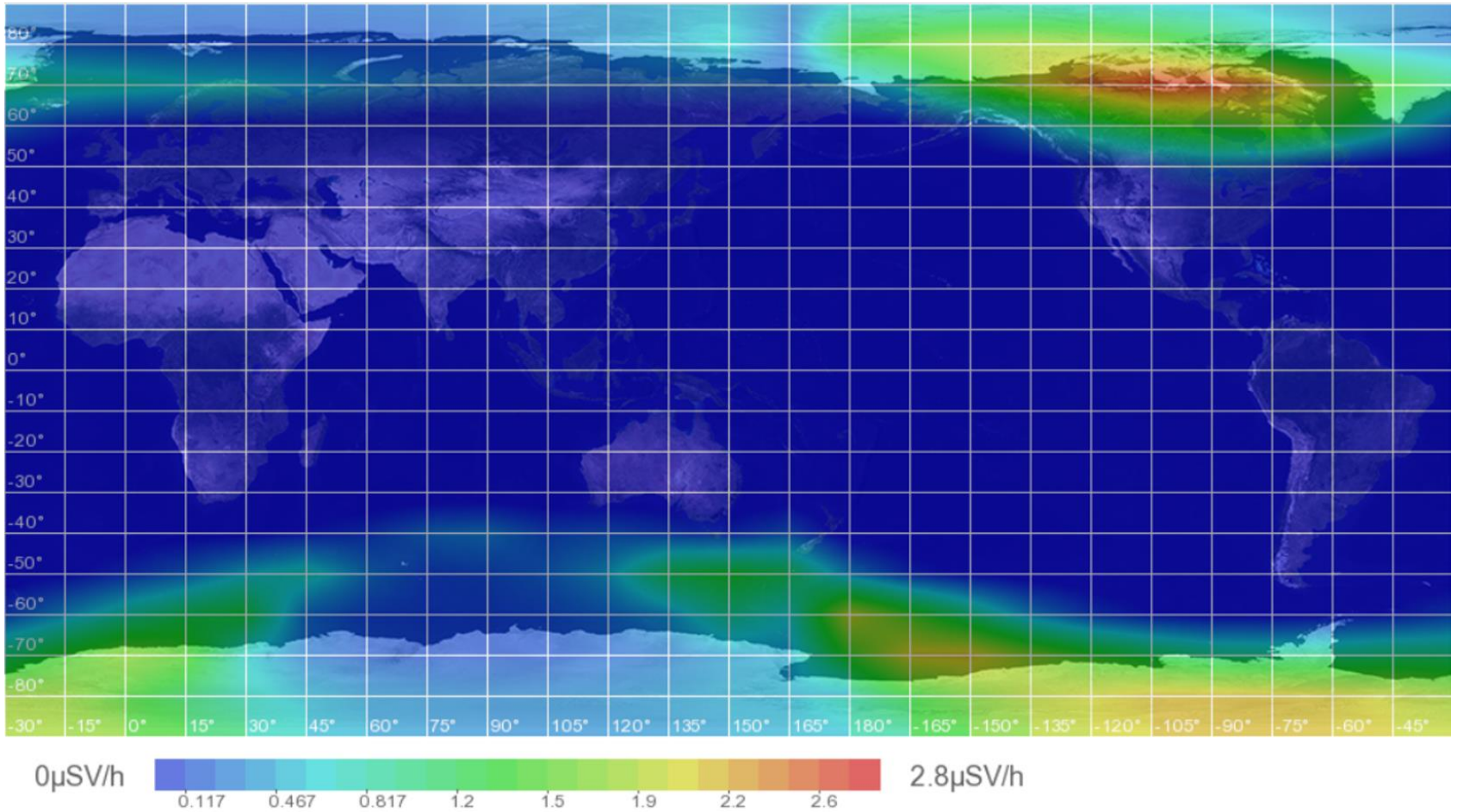

Figure 4. Global map of the calculated effective dose rates due to SEPs at a 12 km altitude at 18:00 UT on 10 September 2017.

Kataoka et al. (2018, Space Weather)

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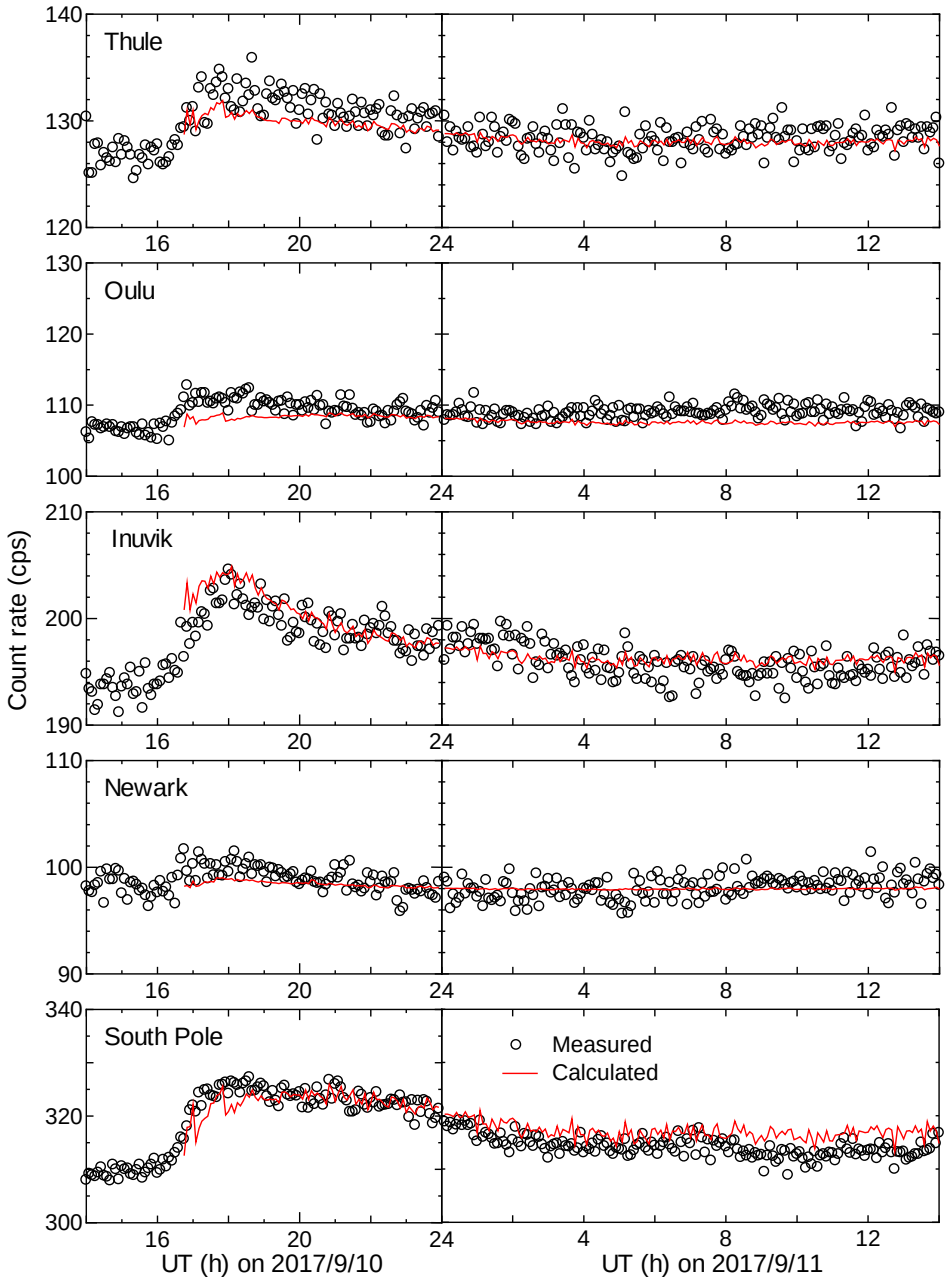
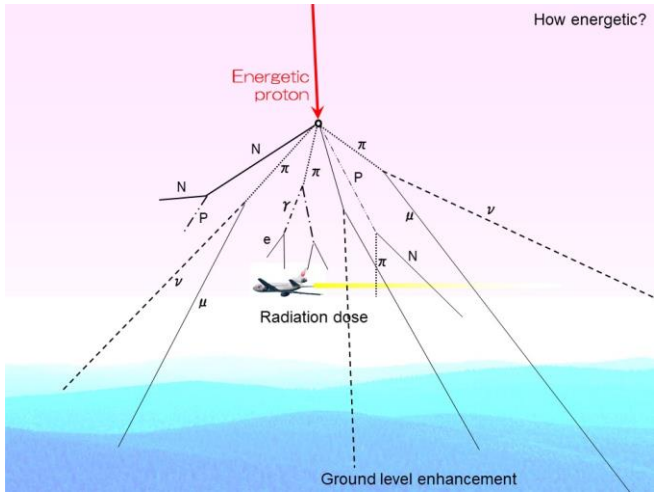




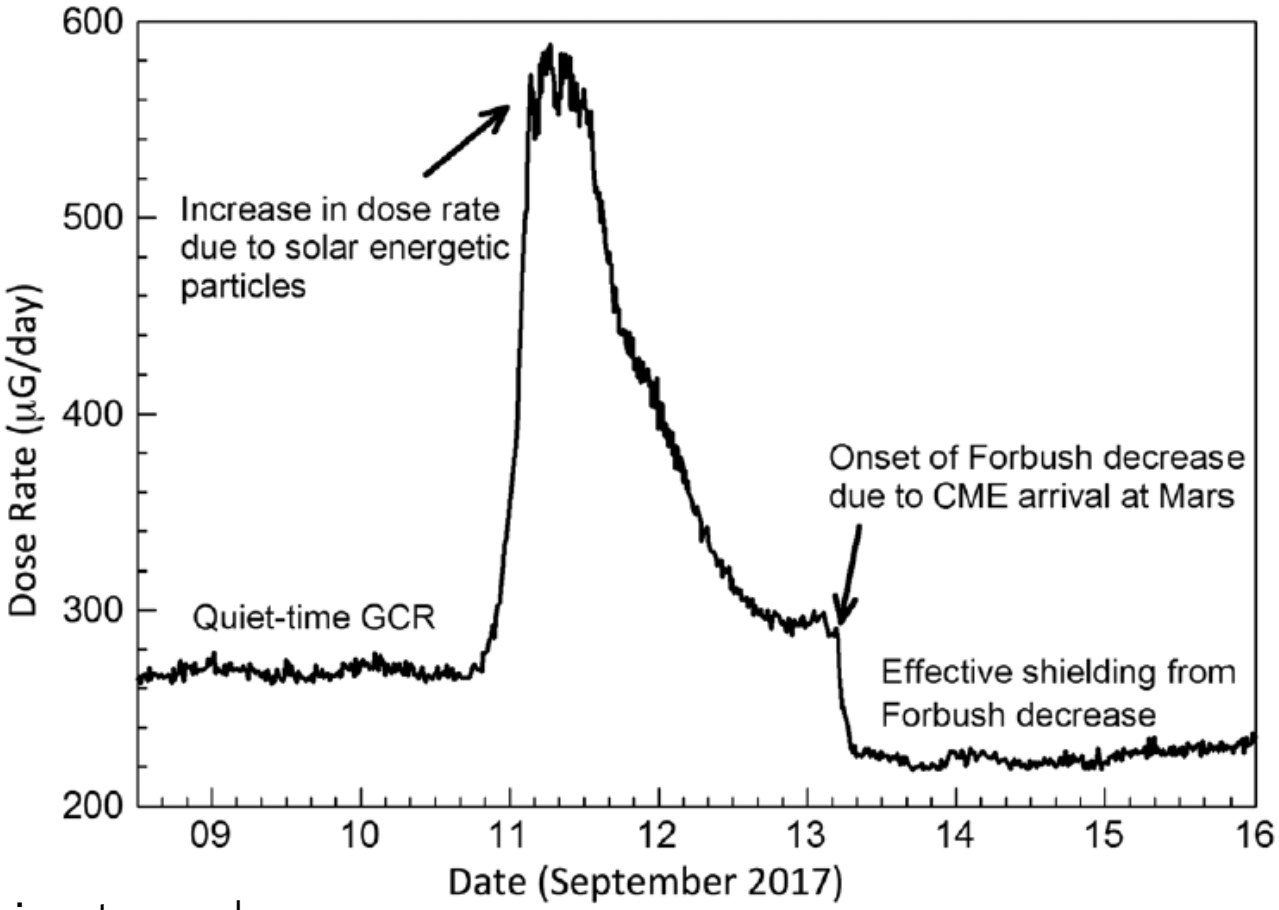
Air shower is calculated by PHITS

Figure 1. Measured count rates (circles) at the neutron monitors at Thule (76.5° N, 68.7° W), Oulu (65.05° N, 25.47° E), Inuvik (68.36° N, 133.72° W), Newark (39.68° N, 75.75° W), and South Pole (90.0° S) during GLE 72, compared against our calculated data (red lines).

Mars during the September 2017 event?

A: dose

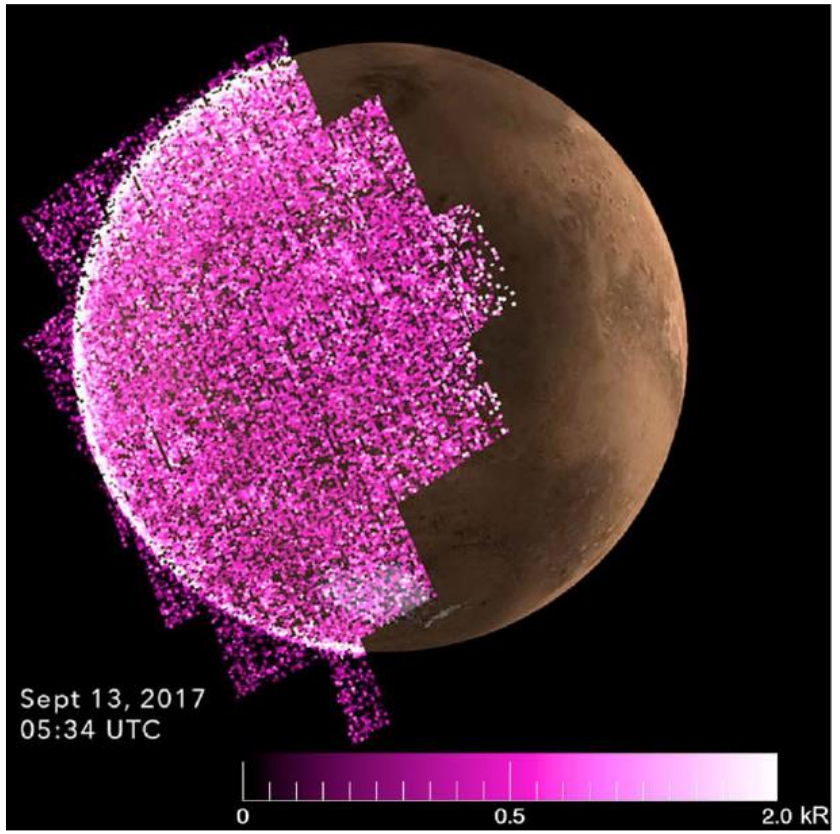
Hassler et al. (2018)



Thin atmosphere

B: aurora

Schneider et al. (2018)

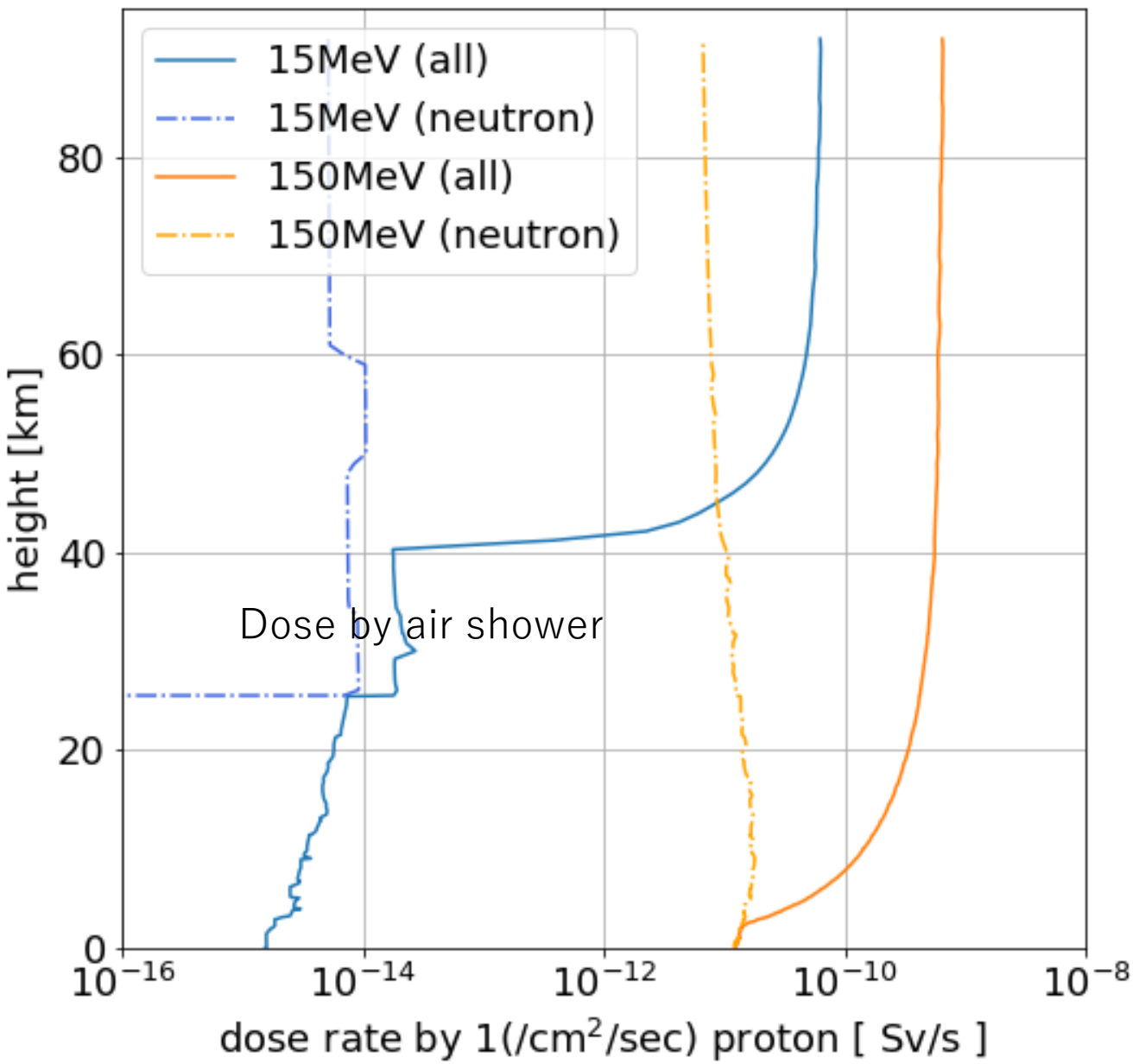


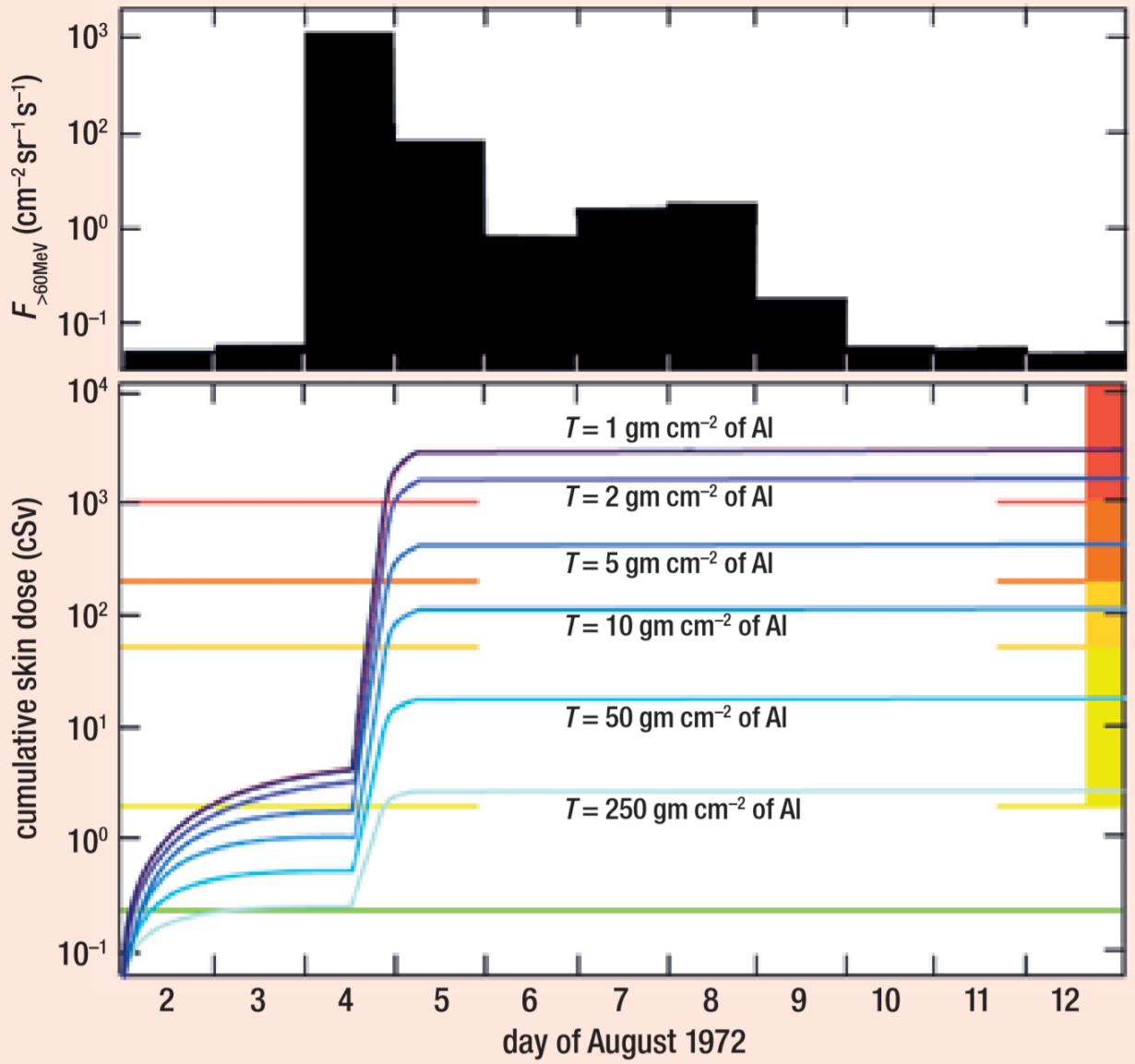
No magnetic moment

A: Cause of dose?

- >150 MeV protons
  - reach to the surface and directly contribute to dose
- >15 MeV protons
  - all stop at 40 km altitude
  - Contribute to dose during cruising phase to Mars

PHITS simulation results at Mars





9 (a): The variation of daily mean values of the flux of protons with energies exceeding 60 MeV during the August 1972 SEP event (the largest event in figure 3). (b): The growth on the cumulative skin dose behind aluminium shields of thickness (from dark to light blue) 1, 5, 10, 50 and 250 gm cm^{-2}. The thresholds used in figure 3 are also given, using the same colour scheme.

Say, 60 MeV p flux on the moon

0.3 mm Al thick spacesuits

3 cm Al wall

B. Aurora by protons or electrons?

Top of Mars atmosphere at 93 km

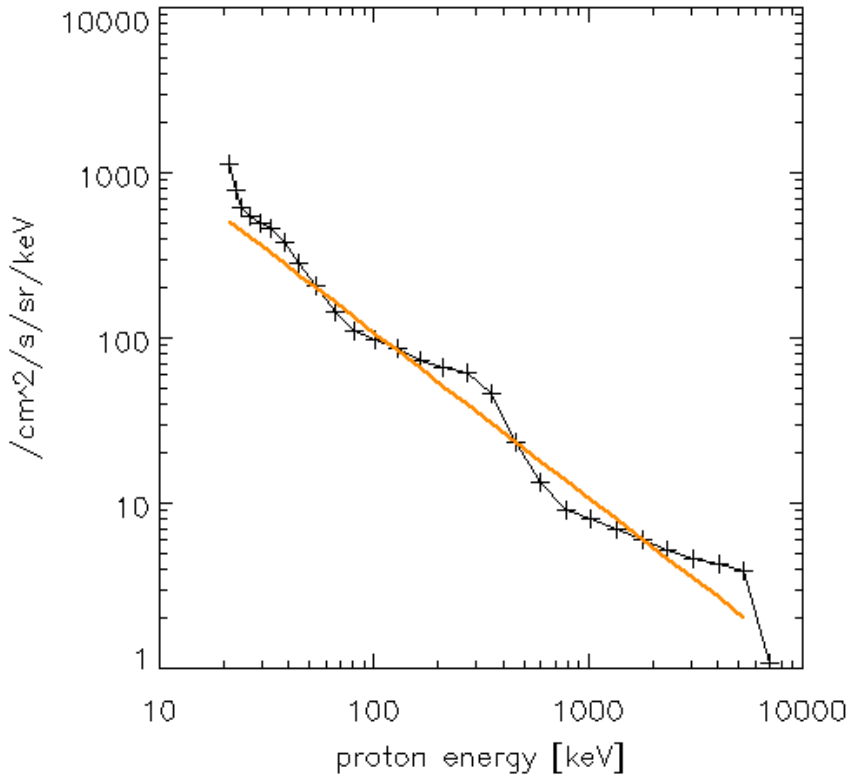
Composition of air, %

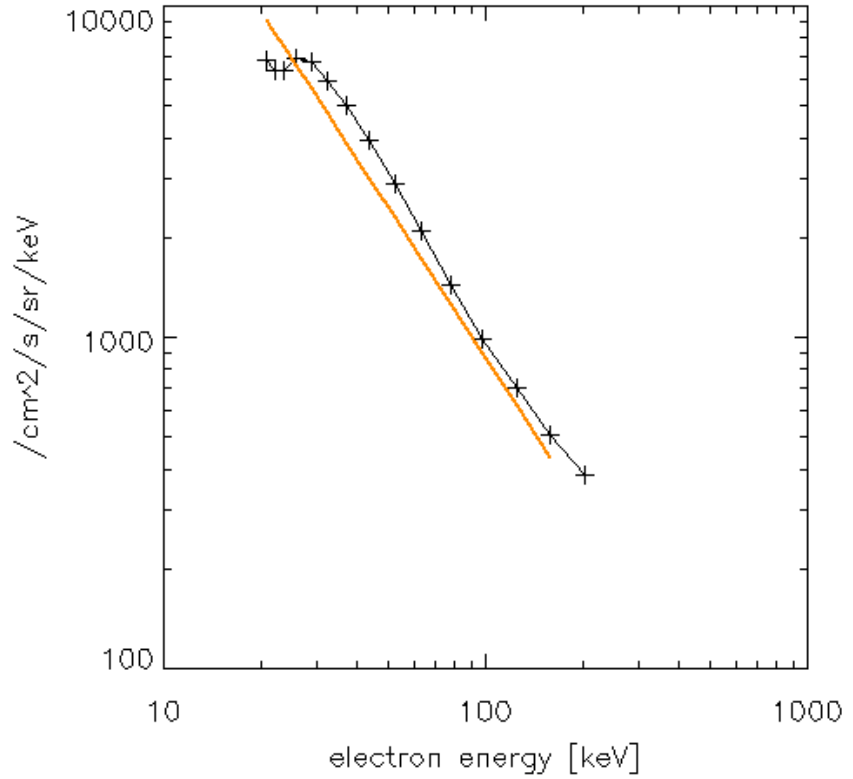
CO2	95.7
N	2.7
Ar	1.3

Composition of ground

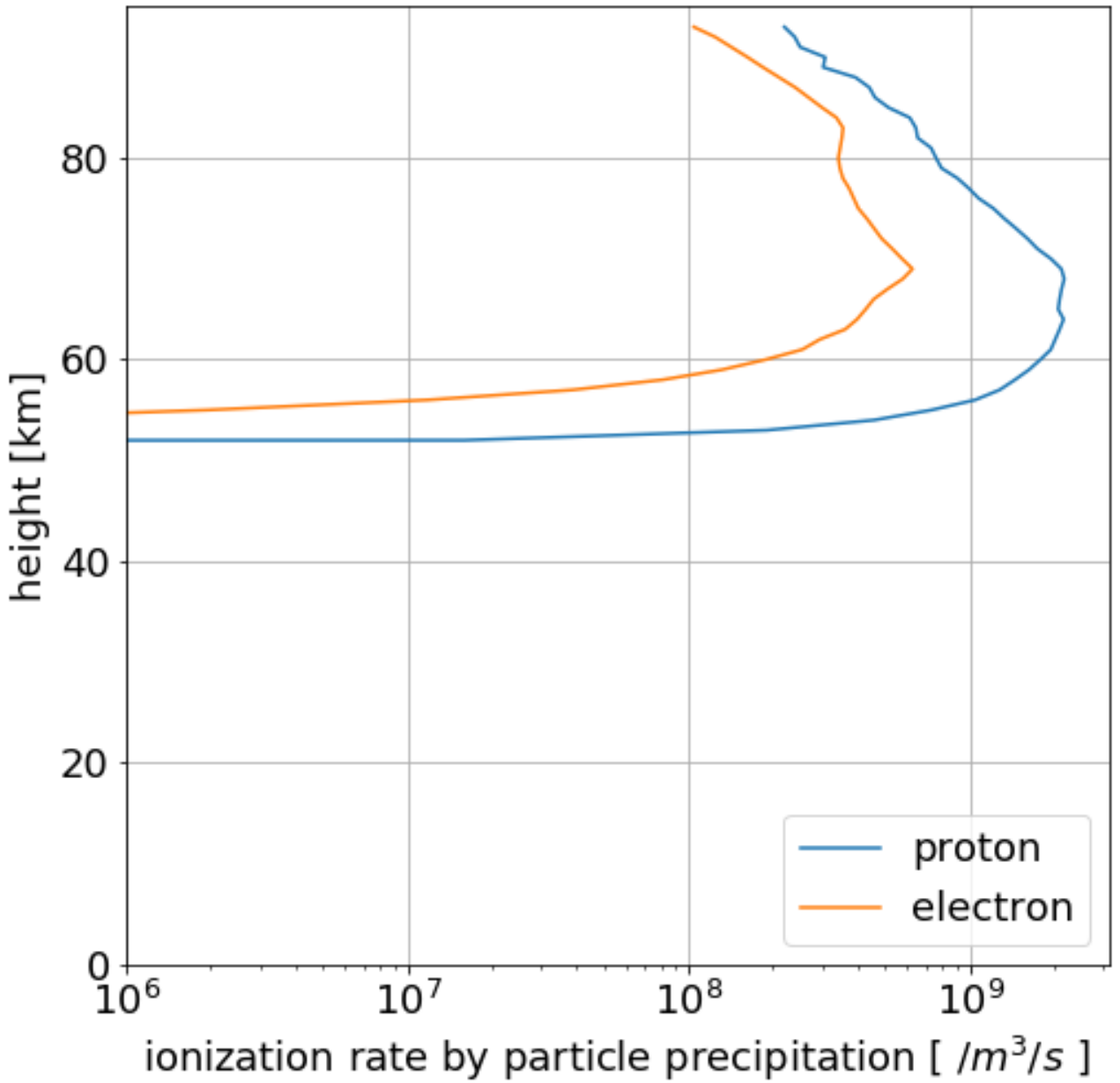
H	2.11
O	51.49
Na	9.12
Mg	4.56
Al	9.12
Si	7.28
K	9.12
Ca	4.56
Fe	2.64

MAVEN-SEP average differential flux 2017/09/13 0100-0200 UT





MAVEN-SEP average differential flux 2017/09/13 0100-0200 UT



50-70 km

Very interesting to quantitatively model the MeV protons at Mars

The problem:

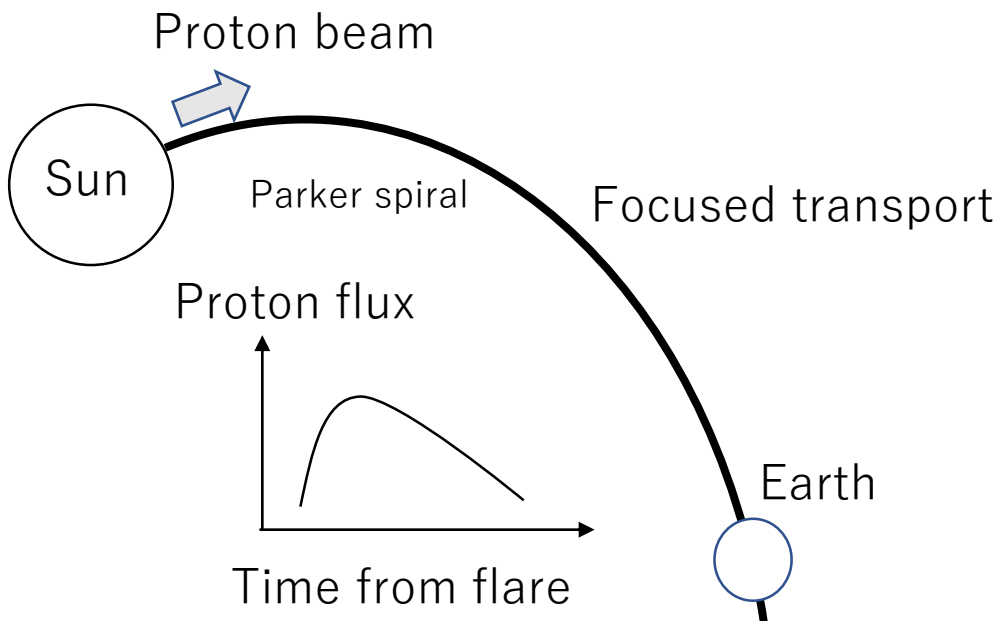
Understanding interplanetary shocks is essential for modeling MeV protons

- Coronal mass ejections evolve, magnetic connections between planets and shocks change, and the shock parameters there also change in time.

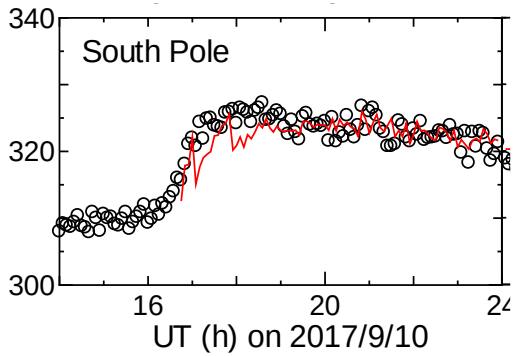
- SUSANOO-CME is now ready to provide these info.
  - Shiota and Kataoka, 2016, Space Weather

- Quickly checked what parameters are likely important.
  - PSTEP-CDAW-SEP Workshop in Japan (Aug, 2019)

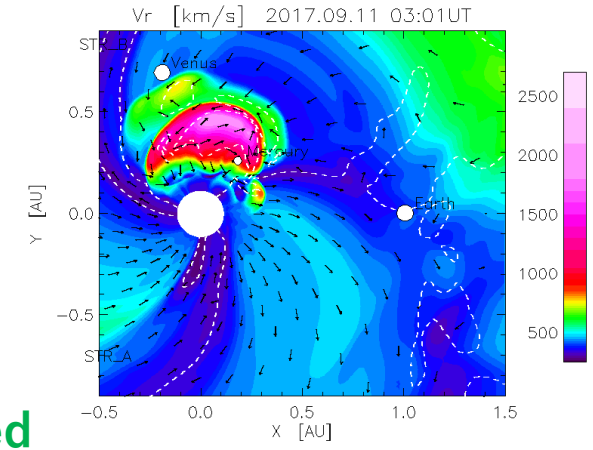
High-E component（>100 MeV）
＝ WASAVIES



Kataoka et al. (2018, Space Weather)

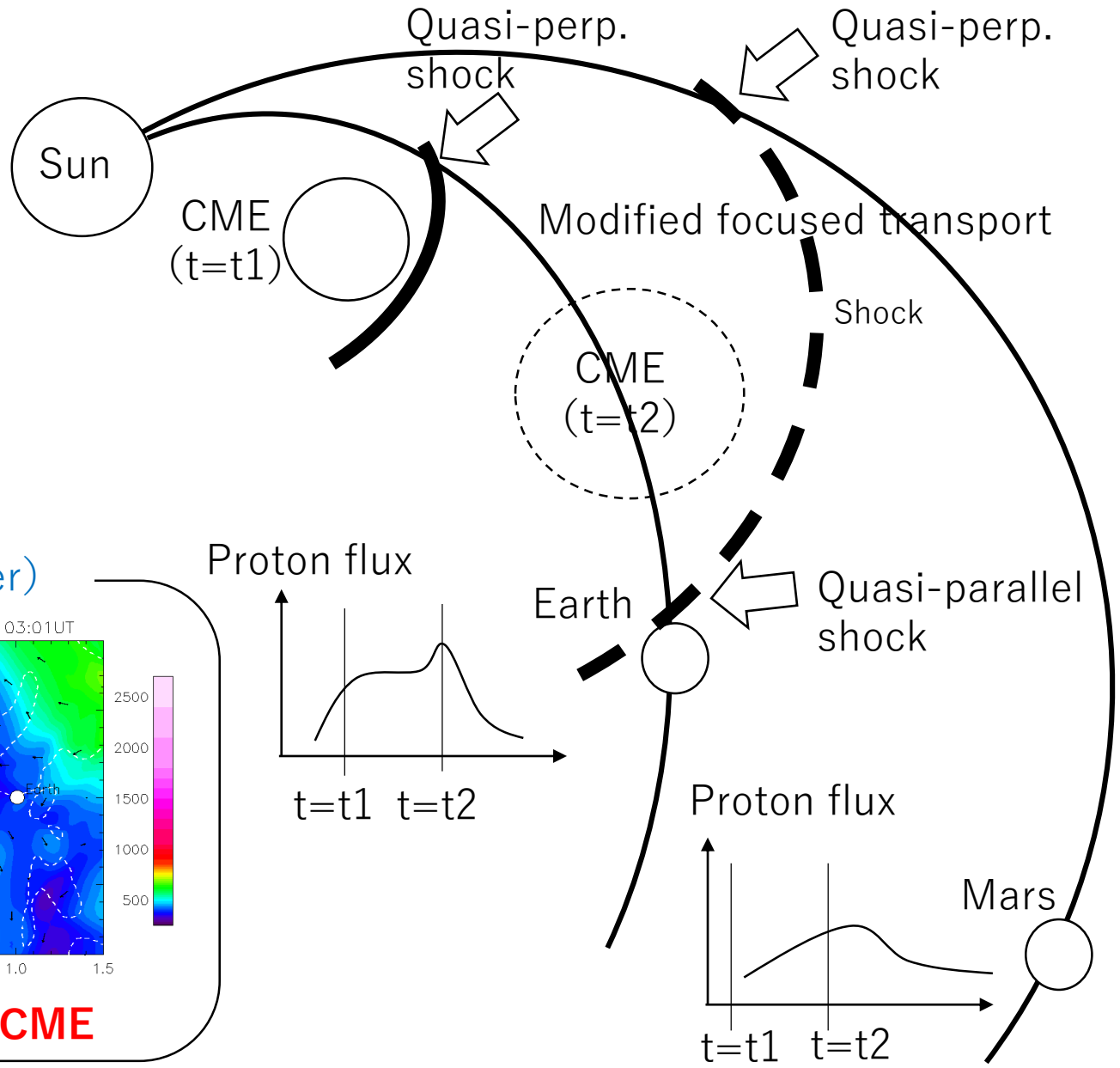


CR obs@Syowa started since Feb 2018

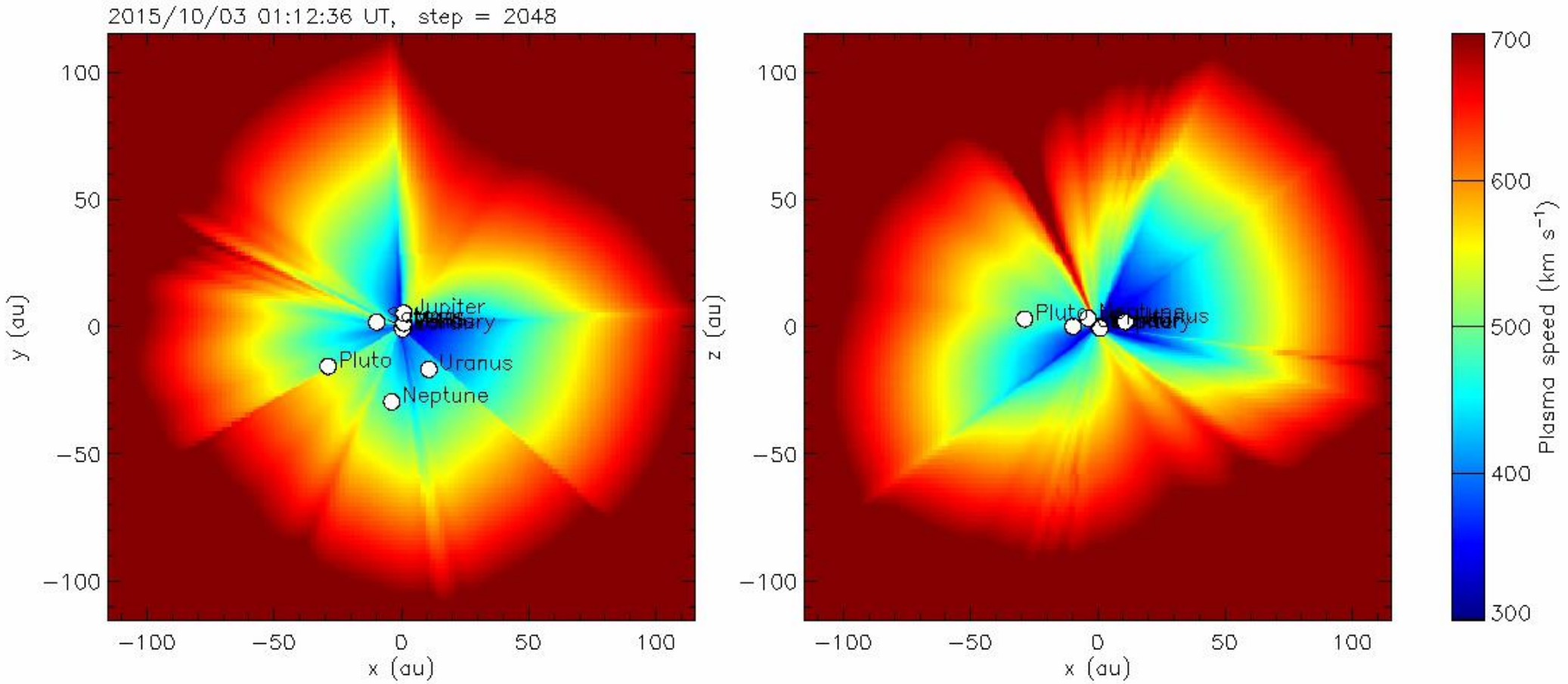


SUSANOO-CME

+Low-E component（<100 MeV）

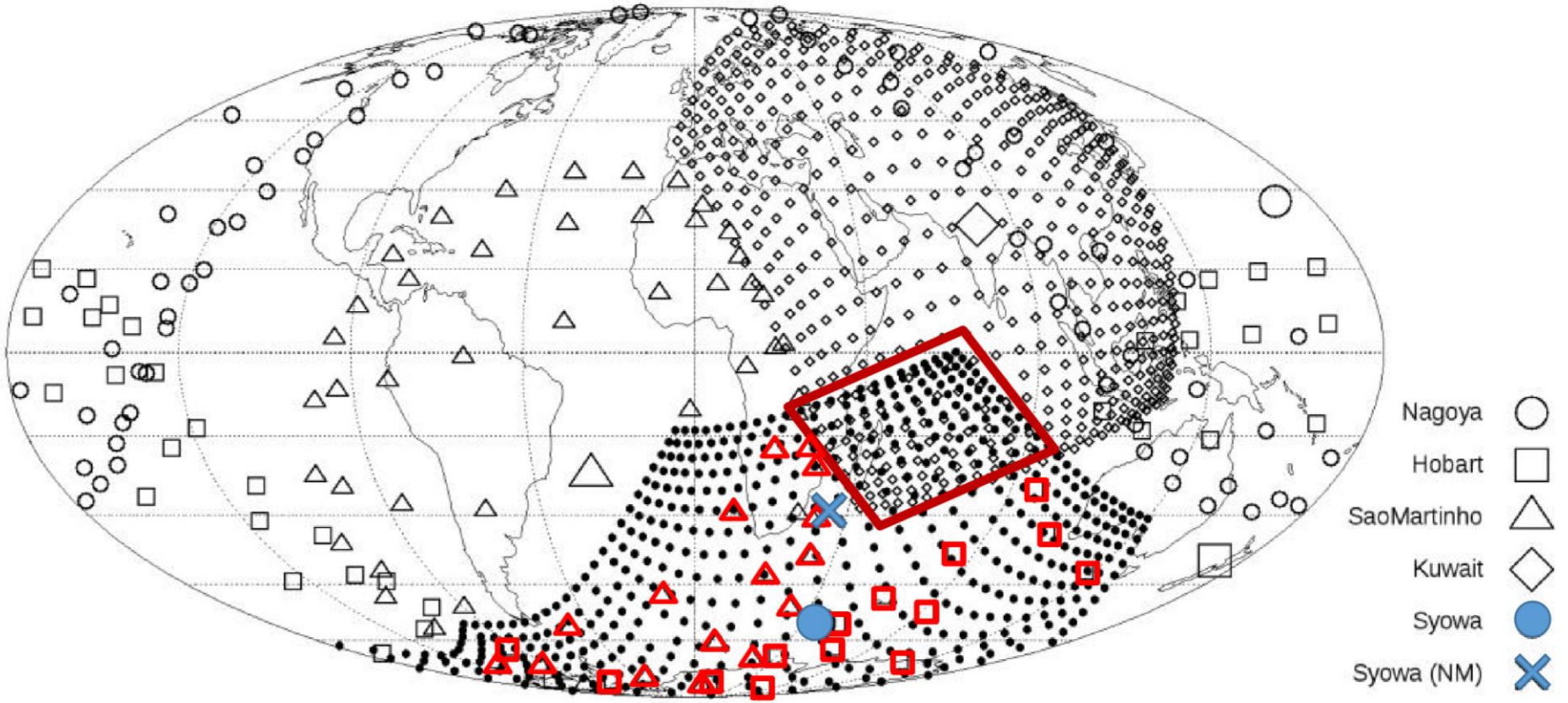


Good news from Gm7: Adaptive Mesh Refinement now works for high-res. MHD studies of SWx



Matsumoto, Shiota, Kataoka et al. (2019)

Cross-calibration be completed by SYO



Summary

- We briefly reported the basic strategy toward Mars-version WASAVIES.

☑ PHITS air-shower simulation is ready for Mars
  - Quantitative studies of dose, aurora, etc. at Mars

☑ SUSANOO-CME is ready to provide the shock parameters
  - Complex behavior of <100 MeV protons may be untangled by reproducing all SEP events in the past. The simulated database will be open to public.
  - AMR technique will help the high-resolution studies.

☑ New neutron/muon observation started at Syowa Station, Antarctica
  - WASAIVES will also be updated to provide the extrapolated proton flux at Mars.

- We hope to contribute to the coming new era of planetary science.