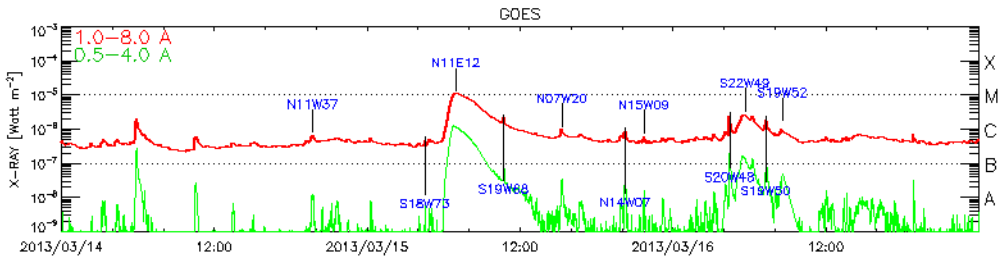
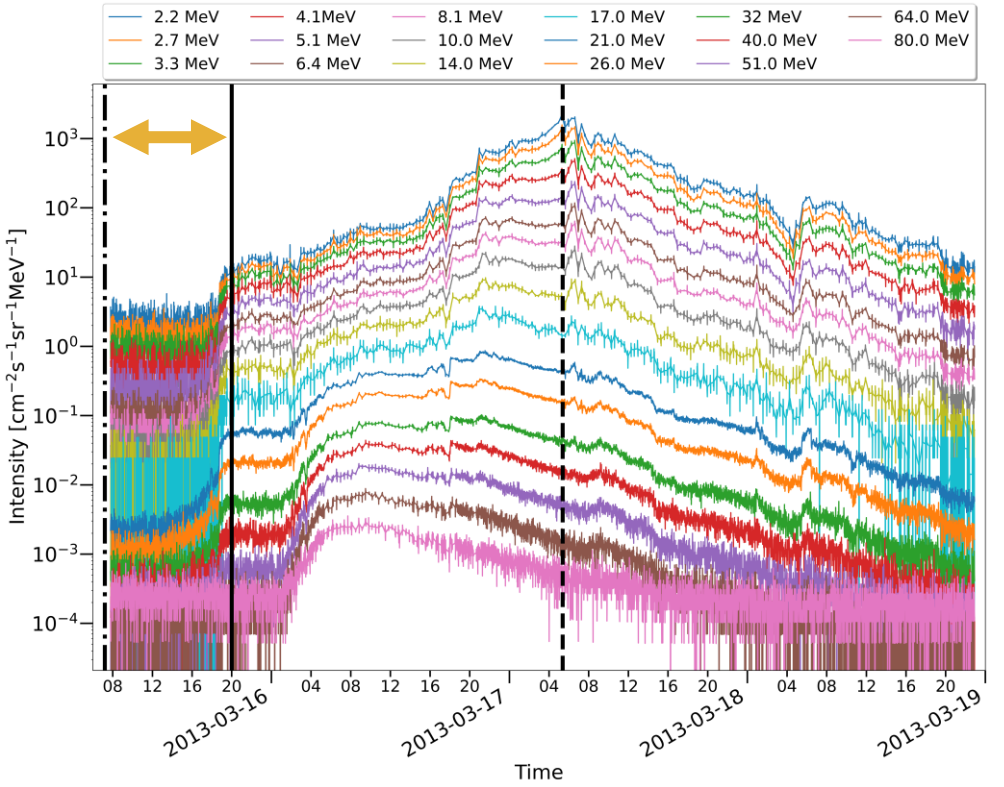
Analysis of the CME and associated gradual SEP event of March 2013

Antonio Niemela, Nicolas Wijsen, Angels Aran, Luciano Rodriguez, Jasmina Magdalenic, Stefaan Poedts

Event Analysis



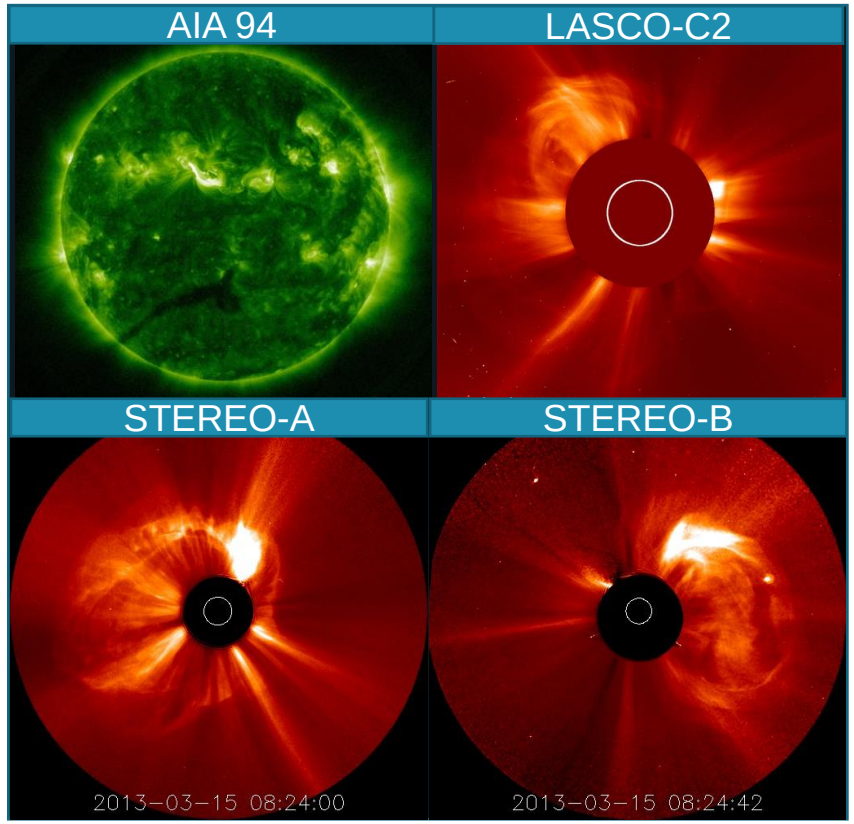


Event starts with a long duration M1.1 X-ray flare seen on the 15 March 2013 at 5:46UT.

Enhanced proton flux starting at 20:00UT.

Particles arrive at Earth with a 12-hour delay.

Intensities have different characteristics.



The Halo CME is captured by LASCO-C2 at 7:12UT with a small northward component seen with STEREO-A and B.

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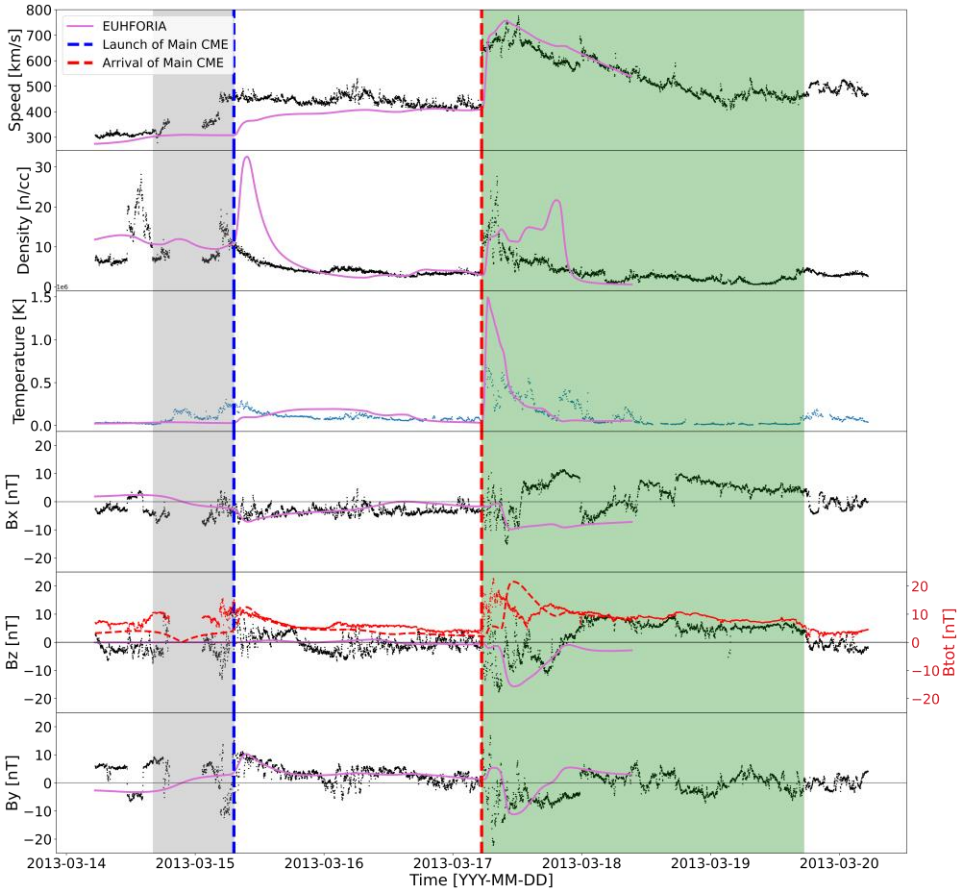
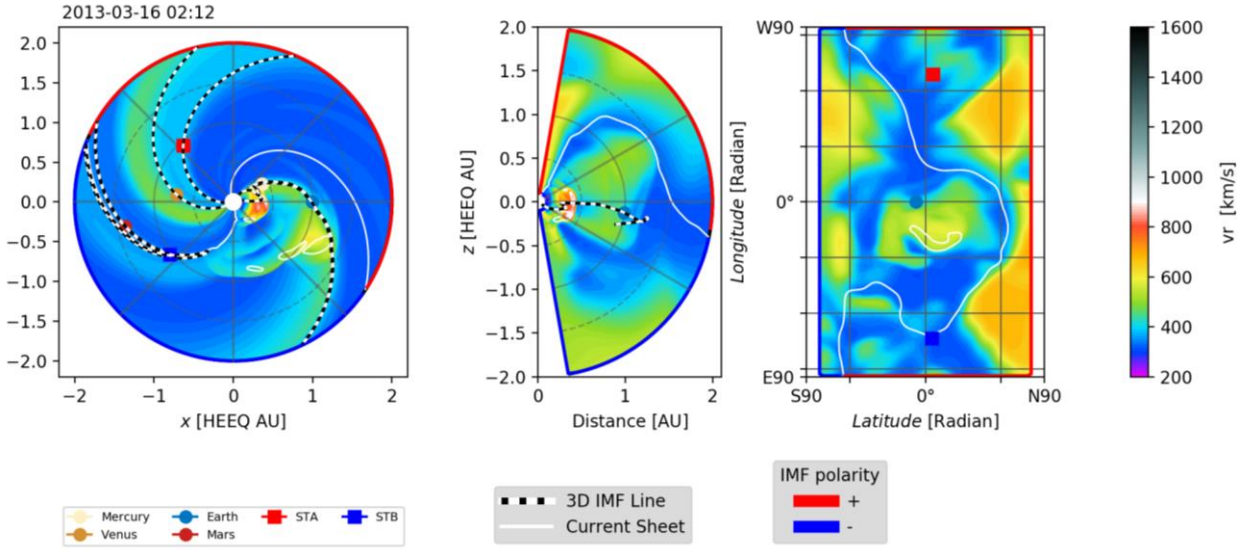
Center for mathematical Plasma Astrophysics
antonioesteban.niemela@kuleuven.be
KU LEUVEN

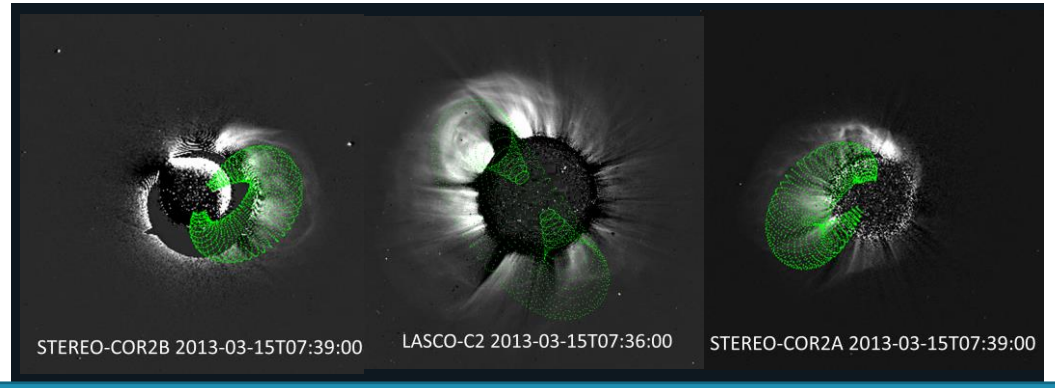
Simulations

EUHFORIA



Very active period, with 2 preceding CMEs





GCS reconstruction

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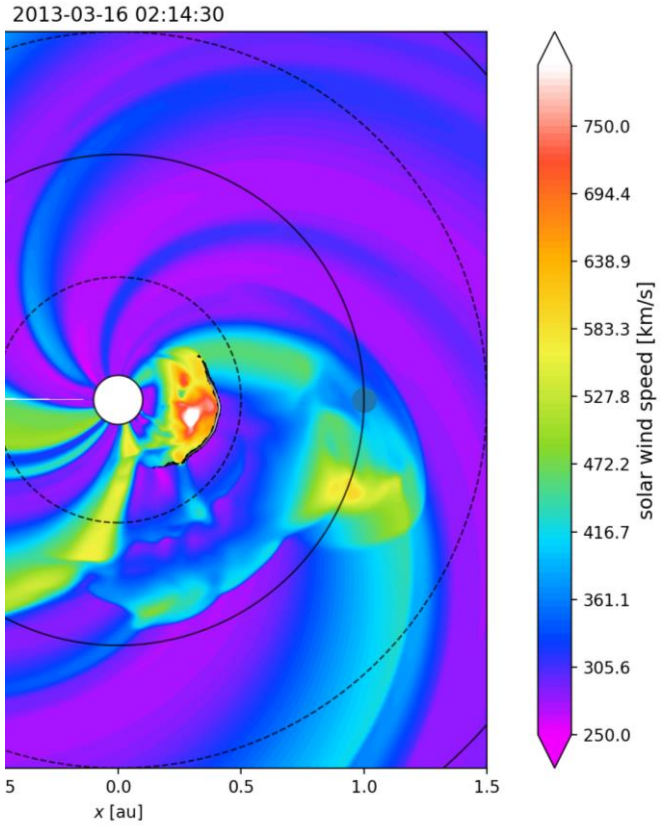
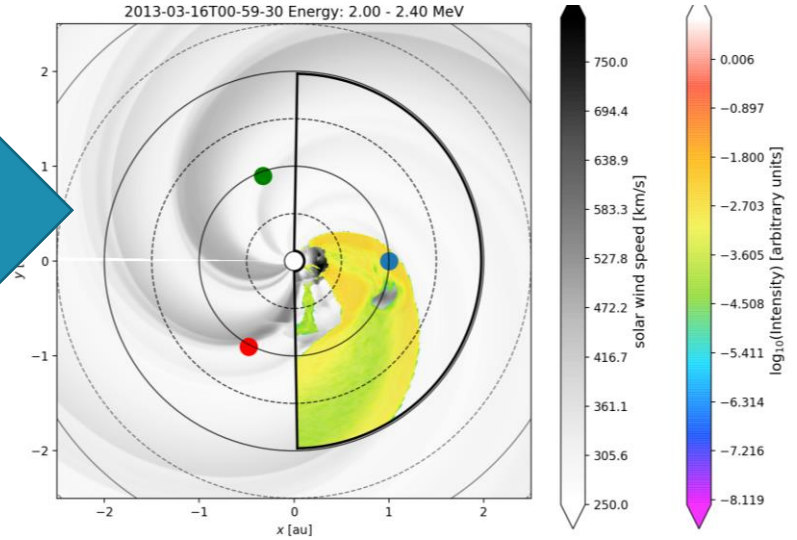
antonioesteban.niemela@kuleuven.be
KU LEUVEN

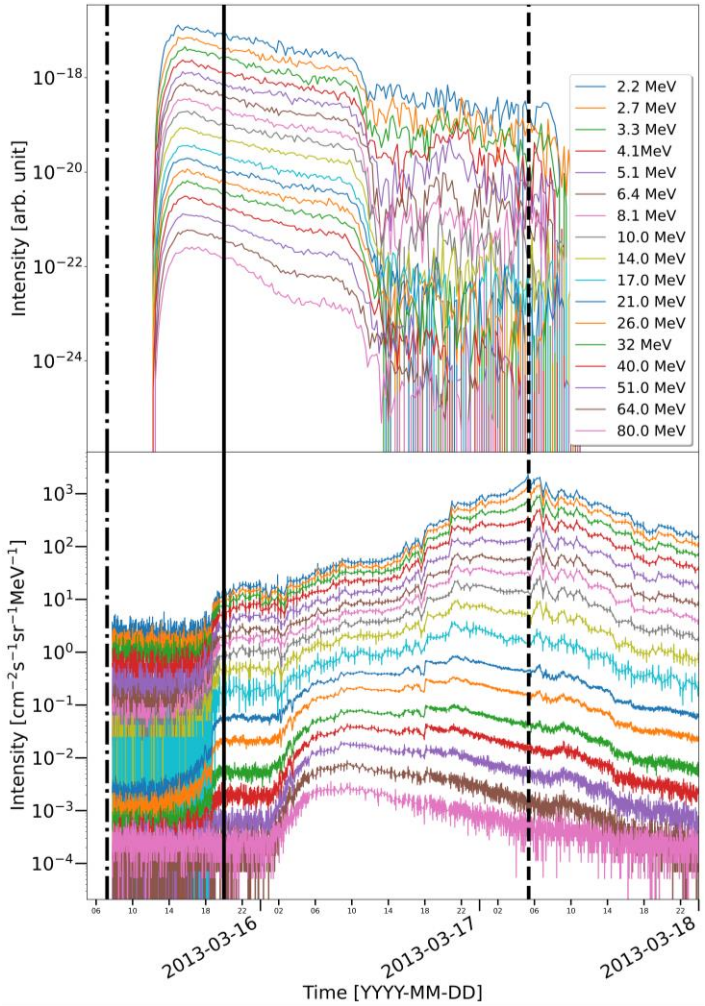
Simulations

PARADISE



Particle Injection





PARADISE captures a delay of 6 hs in the particle arrival

Intensities drop too early to “background” levels.

Blockade CME misses Earth

Shock tracing method does a good job at delimiting shocks.

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Plasma and astrophysics-Department of Mathematics
antonioesteban.niemela@kuleuven.be

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Thank you for your attention

Summary

- EUHFORIA capture the background solar wind very accurately.
  - 3 spheromak CMEs injected into the domain.
- Shock tracing methods delimit the shock generated by the Main CME → Particles are injected on top of it to simulate the real shock acceleration.
- PARADISE captures a delay in the arrival of particles.
  - The preceding CME acts as a blockade for particles, but not close enough to Earth to generate an extra delay.

Future Work

- Better description of the particle population for more accurate predictions.
- Get the intermediate CME to affect Earth and quantify its effect on delaying particles
- Publication already in preparation.

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antonioesteban.niemela@kuleuven.be

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EXTRA INFORMATION

References

•GCS model: Graduated Cylindrical Shell Model:

- Thernisien, A., Vourlidas, A. & Howard, R.A. Forward Modeling of Coronal Mass Ejections Using STEREO/SECCHI Data. *Sol Phys* 256, 111–130 (2009). https://doi.org/10.1007/s11207-009-9346-5

•CCSOM constraining CMEs and Shocks by Observation and Modelling:

- https://wwwbis.sidc.be/ccsom/

•EUHFORIA: EUropean Heliospheric Forecasting Information Asset:

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- Pomoell J, Poedts S. 2018. EUHFORIA: European heliospheric forecasting information asset. *J. Space Weather Space Clim.* **8**: A35

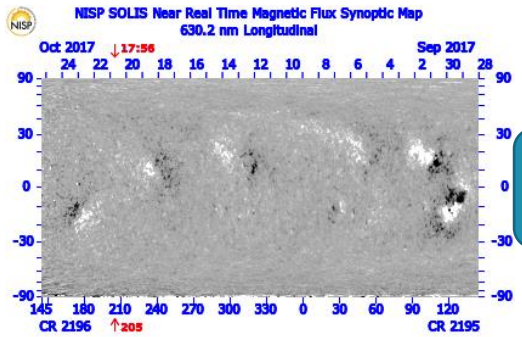
•PARADISE: PArticle Radiation Asset Directed at Interplanetary Space Exploration:

- Wijsen, Nicolas. PARADISE: a Model for Energetic Particle Transport in the Solar Wind. 2020.

•Spheromak Model for CMEs:

- Gibson, S. E. and Low, B. C., “A Time-Dependent Three-Dimensional Magnetohydrodynamic Model of the Coronal Mass Ejection”, *The Astrophysical Journal*, vol. 493, no. 1, pp. 460–473, 1998. doi:10.1086/305107.

EUHFORIA basics



GONG
GONG-ADAPT
Custom

Synoptic magnetogram

PFSS model
$1.0\,R_\odot \rightarrow 2.3\,R_\odot$

SCS model
$2.3R_\odot \rightarrow 0.1$ AU

$B_r = \mathrm{sgn}(B_{\mathrm{corona}})B_{\mathrm{fsw}}(v_r/v_{\mathrm{fsw}})$

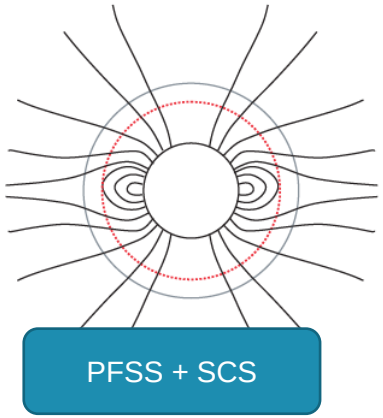
B_r at 0.1 AU

$v = v(f, d)$
$f = (R_\odot/R_p)^2 |B_r(R_\odot)/B_r(R_p)|$

v_r at 0.1 AU

Density, Temperature at 0.1 AU

$\rho = \rho_{\mathrm{fsw}}(v_{\mathrm{fsw}}/v)^2$
$T = T_{\mathrm{fsw}}(\rho_{\mathrm{fsw}}/\rho)$



PFSS + SCS

J. Pomoell and S. Poedts: J. Space Weather Space Clim. 2018, 8, A35

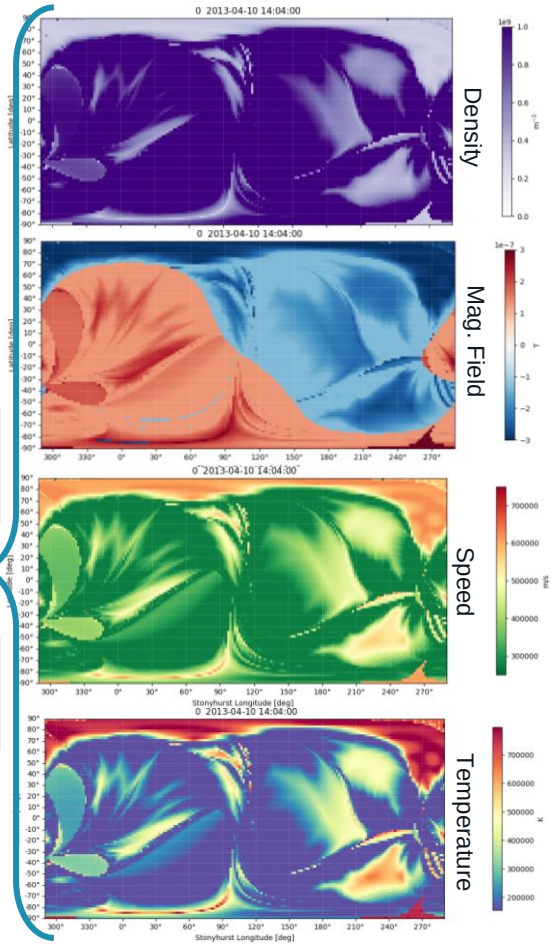


Fig. 1. Schematic of the steps involved in constructing the semi-empirical coronal model that provides the boundary conditions for the heliospheric MHD model.

PARADISE basics

'Particle Radiation Asset Directed at Interplanetary Space Exploration'

- **PARADISE** solves the FTE by integrating the equivalent SDEs forward in time, i.e.,

$$d\mathbf{x} = \left(\frac{d\mathbf{x}}{dt} + \nabla \cdot \mathbf{D}_{\perp}\right) dt + \sqrt{2\mathbf{D}_{\perp}}\, d\mathbf{w}_{\mathbf{x}},$$

$$d\mu = \left(\frac{d\mu}{dt} + \frac{\partial D_{\mu\mu}}{\partial \mu}\right) dt + \sqrt{2D_{\mu\mu}}\, dw_{\mu},$$

$$dp = \frac{dp}{dt} dt,$$

Integrate and sample ~10^8 pseudo-particles

- The average SW velocity and magnetic field are obtained from the 3D ideal MHD model **EUHFORIA**

- The diffusion coefficient are derived from a composite slab/2D turbulence model with the assumptions of QLT or a non-linear theory (modular)