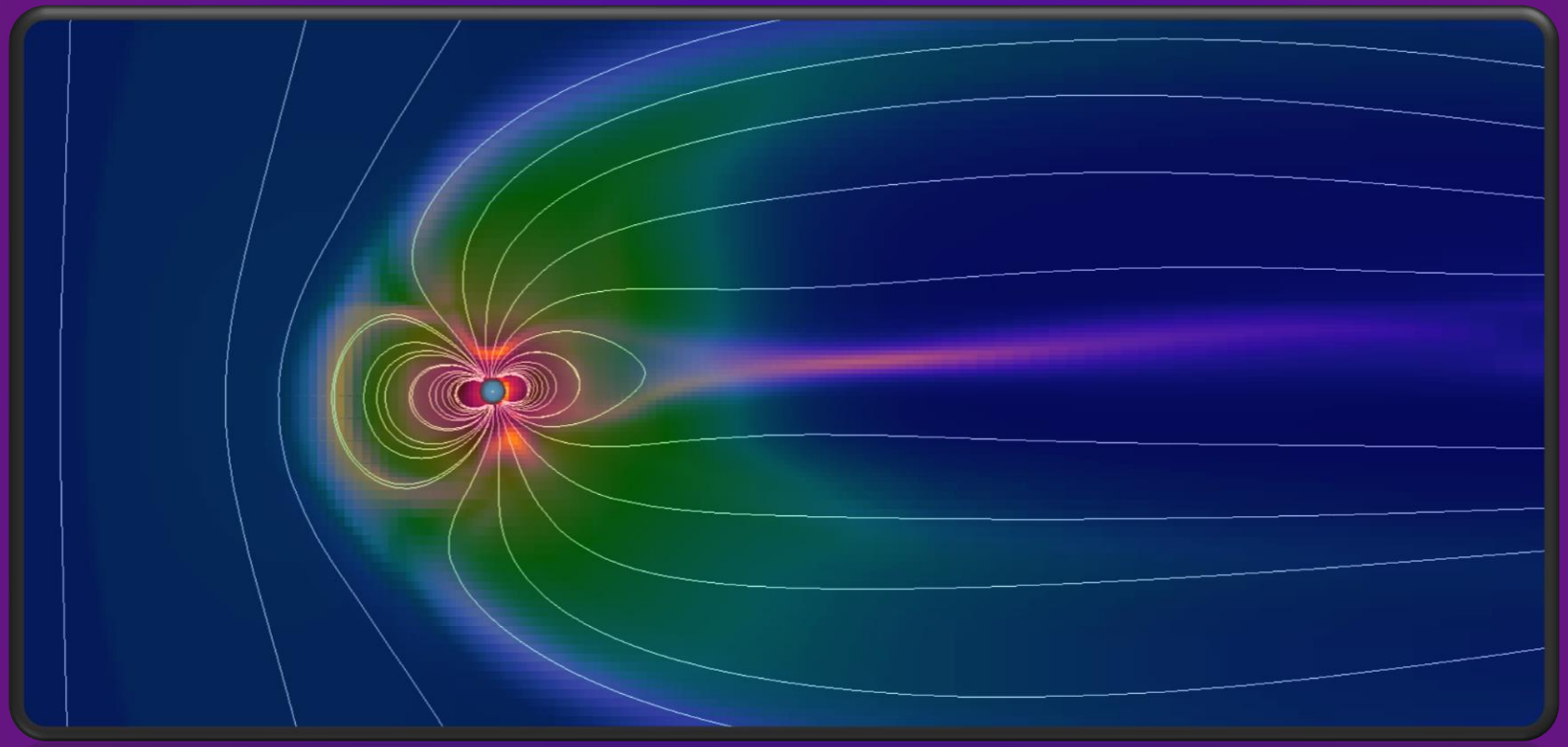
Modelling the Impact of Magnetic Storms on Planetary Environments



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EGU General Assembly #vEGU21

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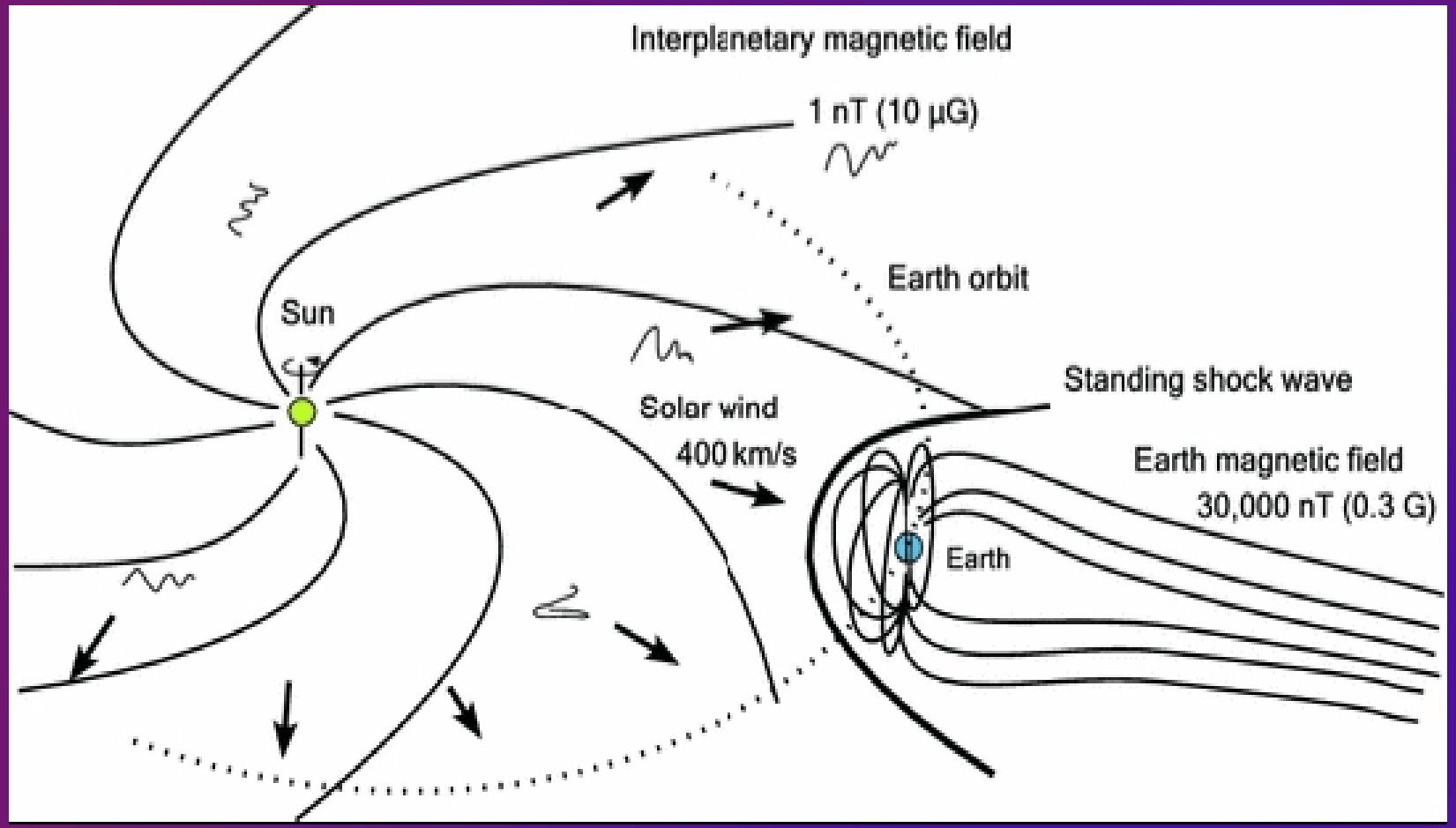
Overview of this Presentation

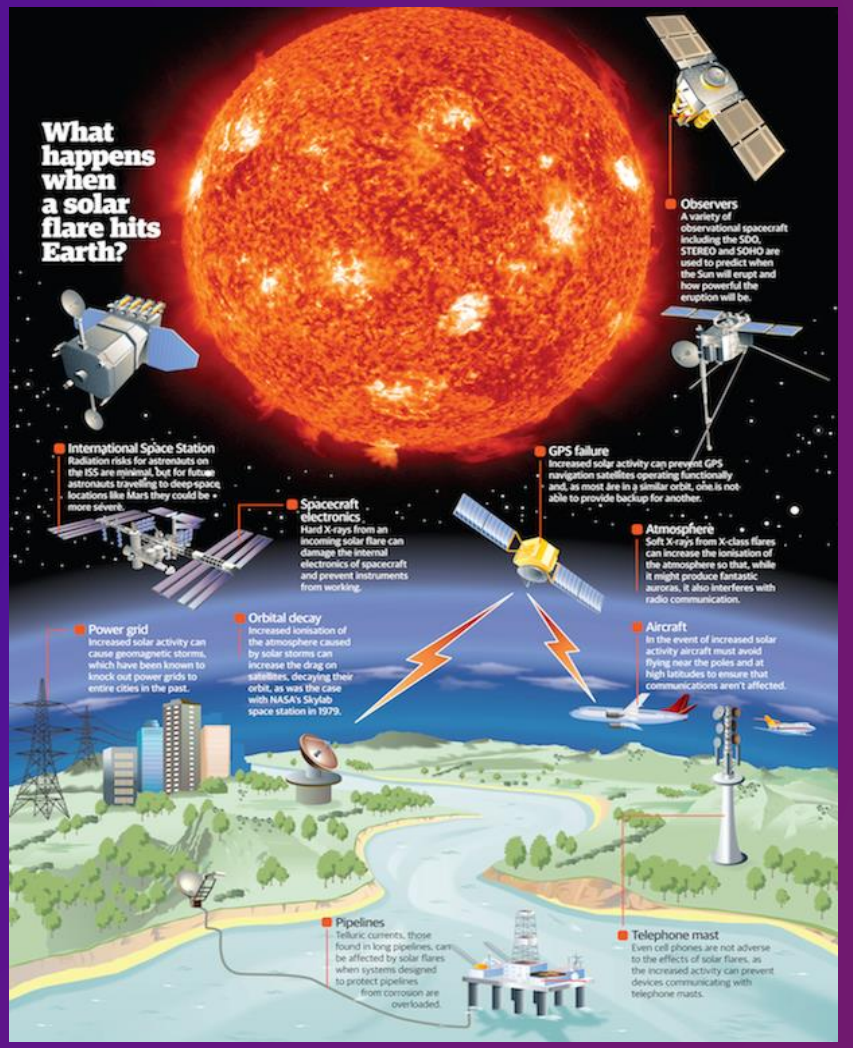
- The physics of star-planet interactions.
  -- CESSI – Star Planet Interaction Module (CESSI-SPIM)

- Modelling of the flux rope.
  -- Interplanetary coronal mass ejection and SPIM

- Results
  -- Temporal evolution of magnetosphere and magnetopause
  -- Virtual satellite observations
  -- Magnetospheric current systems
  -- Mass flows
  -- Helicity Injection

- Concluding remarks





- Aurora formation [Liou et al. 1998]
- Space weather variations [Schwenn 2006; Pulkkinen 2007]
- Geomagnetic storms [Dal Lago et al. 2006]
- Effects on satellites and space missions [Kumar 2014]

https://www.spaceanswers.com/news/effects-of-massive-solar-storm-to-bombard-earth-through-to-saturday-predict-experts/

CESSI Star Planet Interaction Module

The Physics: Astrophysical Magnetohydrodynamics

$$\frac{\partial \rho}{\partial t} + \vec{\nabla} \cdot (\rho \vec{v}) = 0$$

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \vec{\nabla})\vec{v} + \frac{1}{4\pi\rho}\vec{B} \times (\vec{\nabla} \times \vec{B}) + \frac{1}{\rho}\vec{\nabla} P = \vec{g}$$

$$\frac{\partial E}{\partial t} + \vec{\nabla} \cdot [(E + P)\vec{v} - \vec{B}(\vec{v} \cdot \vec{B}) + (\eta \cdot \vec{J}) \times \vec{B}] = \rho \vec{v} \cdot \vec{g}$$

$$\frac{\partial \vec{B}}{\partial t} + \vec{\nabla} \times (\vec{B} \times \vec{v}) + \vec{\nabla} \times (\eta \cdot \vec{J}) = 0$$

Assumptions:

- "Far out" earth-like planet
- Intrinsic dipolar planetary magnetic field
- Stellar wind as magnetised shock
- Non-relativistic, compressible,
- Adiabatic fluid: Gamma = 5/3
- High Magnetic Reynolds number

Simulated on PLUTO V4.3

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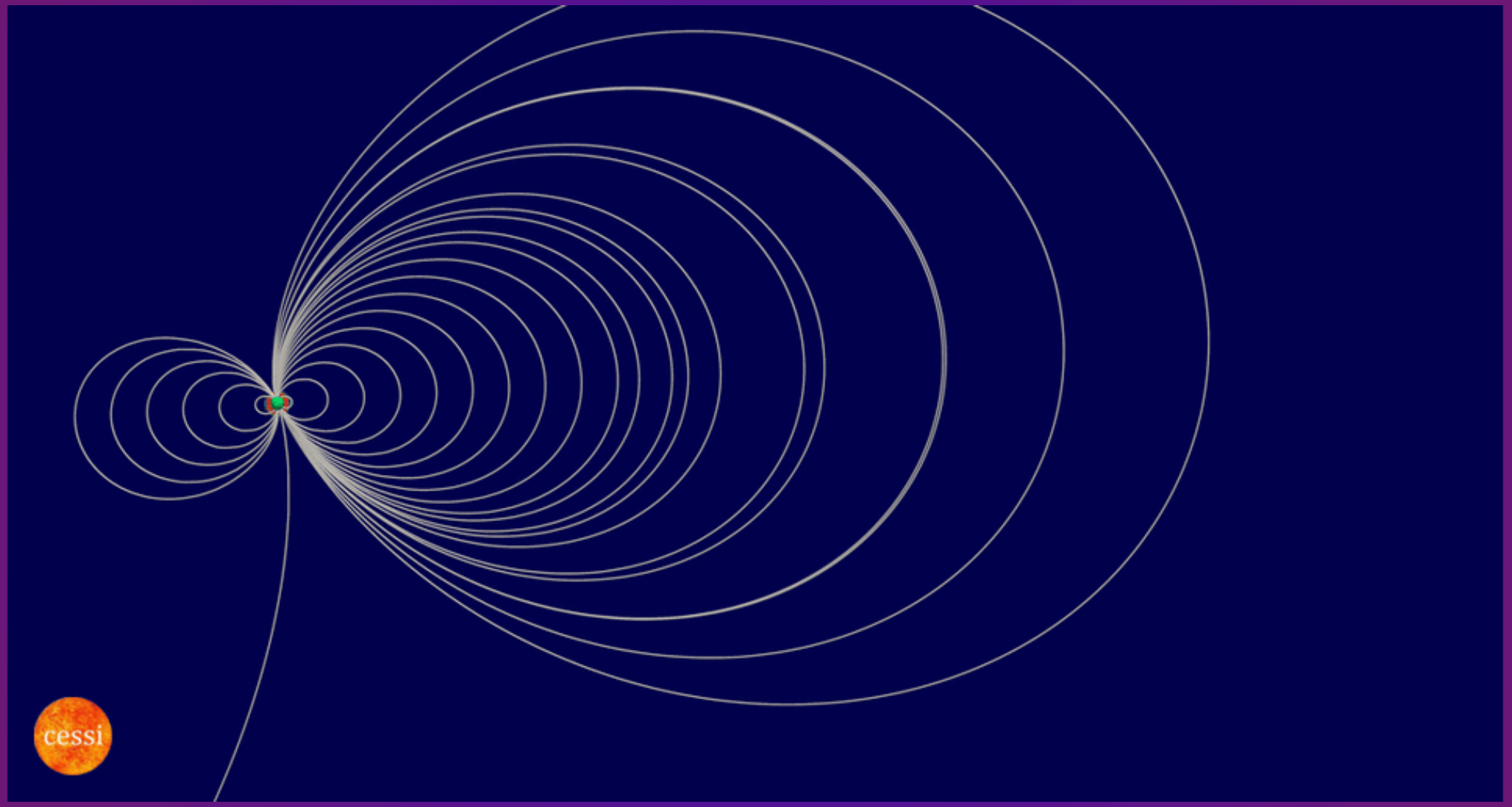
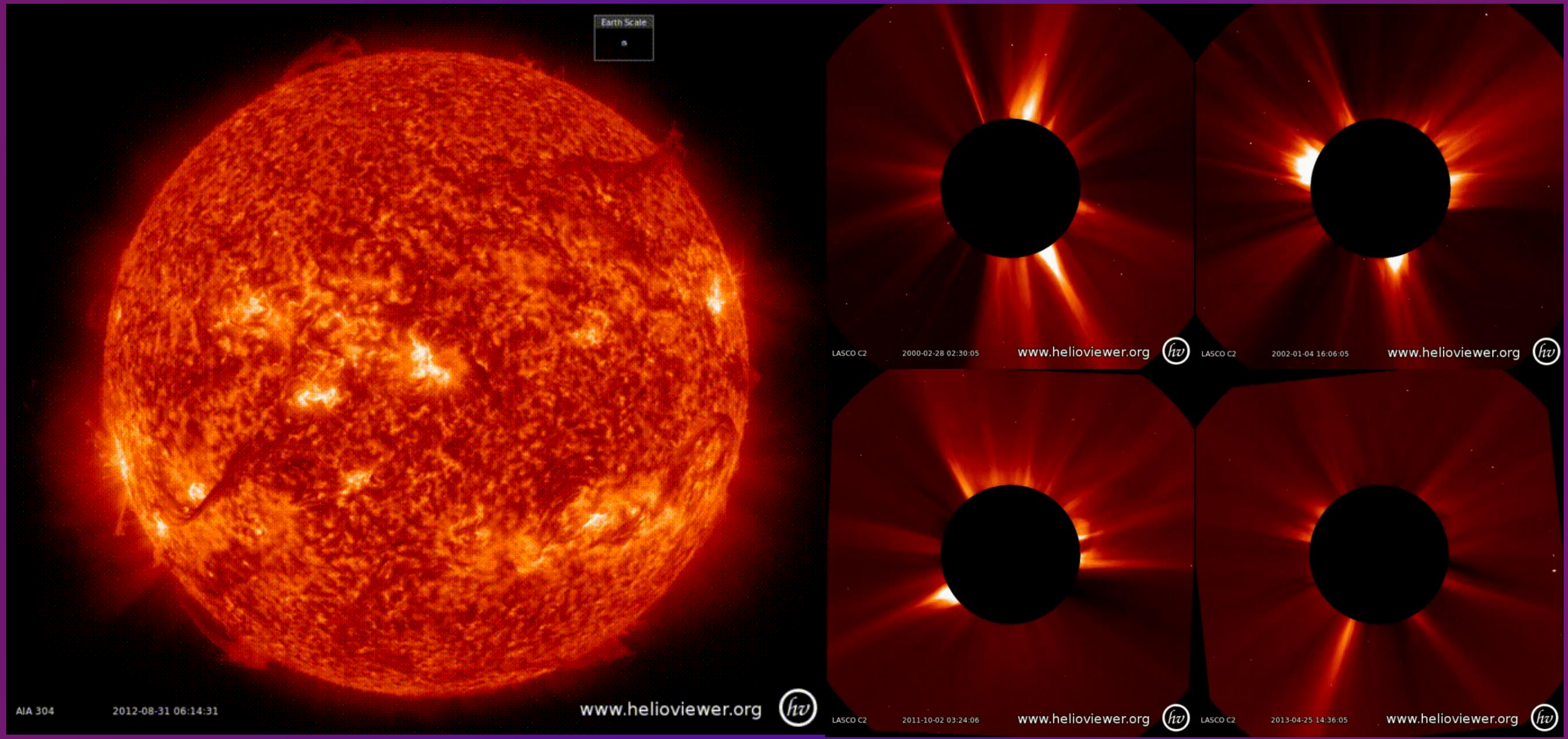
CESSI Star Planet Interaction Module

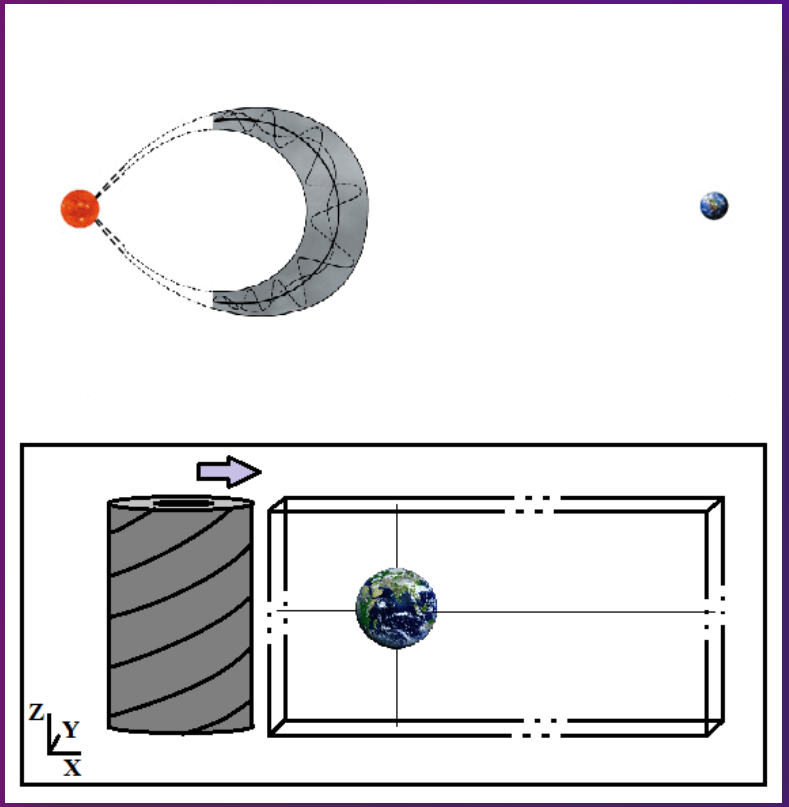


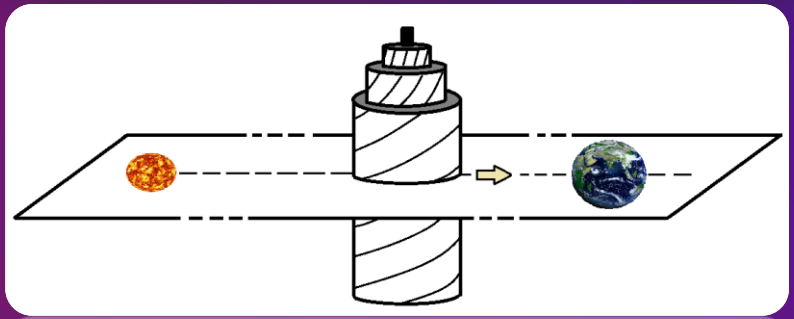
- Srijan Bharati Das et al 2019 ApJ 877 80
- Basak and Nandy 2021 MNARS 502 3



CME eruption events on (Left) 31/08/2012, (Middle-Top) 27/02/2000, (Right-Top) 04/01/2000, (Middle-Bottom) 02/10/2011, and (Right-Bottom) 25/04/2013. Data source: AIA304 (left), SOHO LASCO C2 (others). Image courtesy: Helioviewer. (https://www.helioviewer.org/)

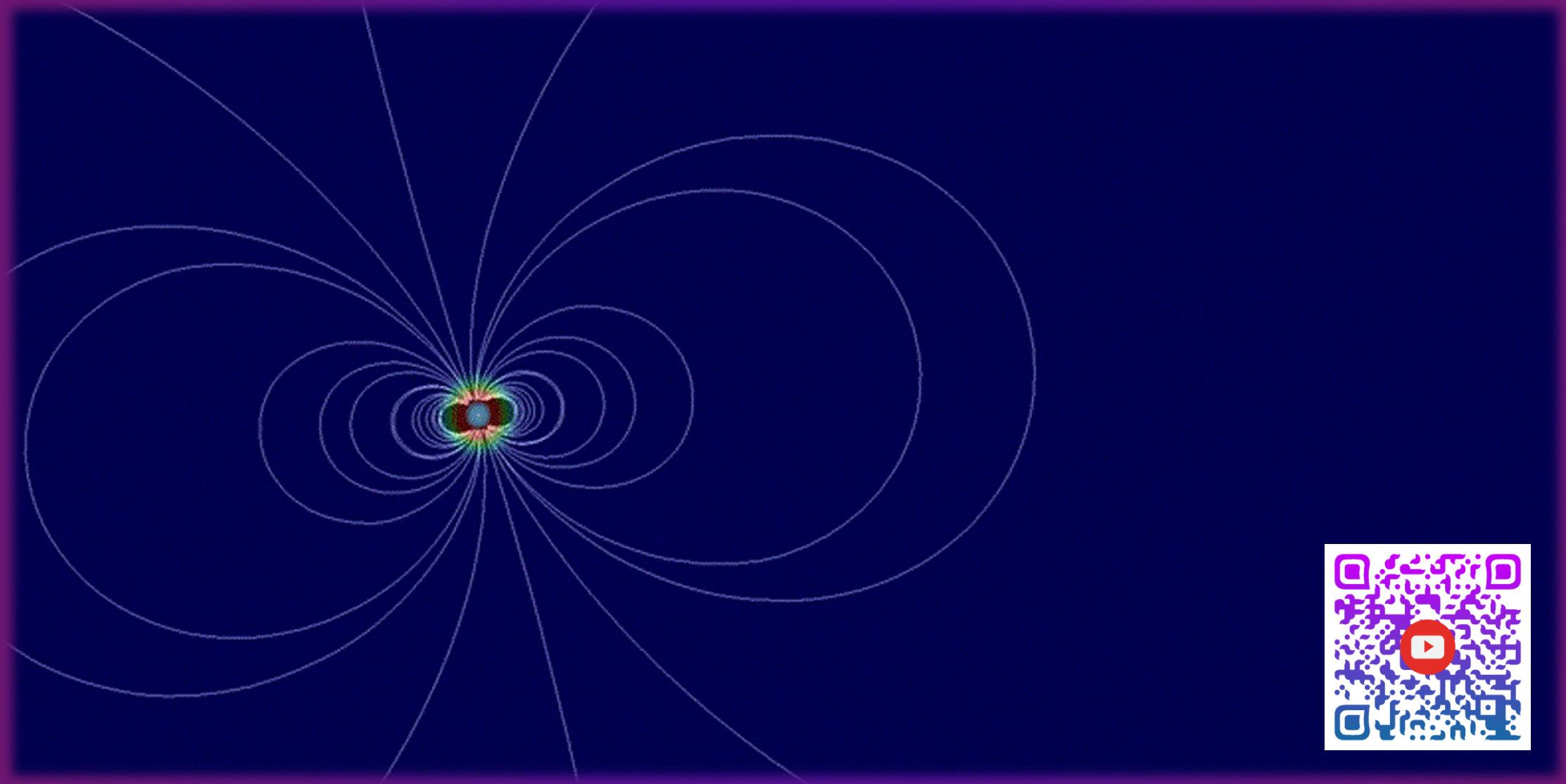
Modelling a Interplanetary Coronal Mass Ejection Associated Flux Rope





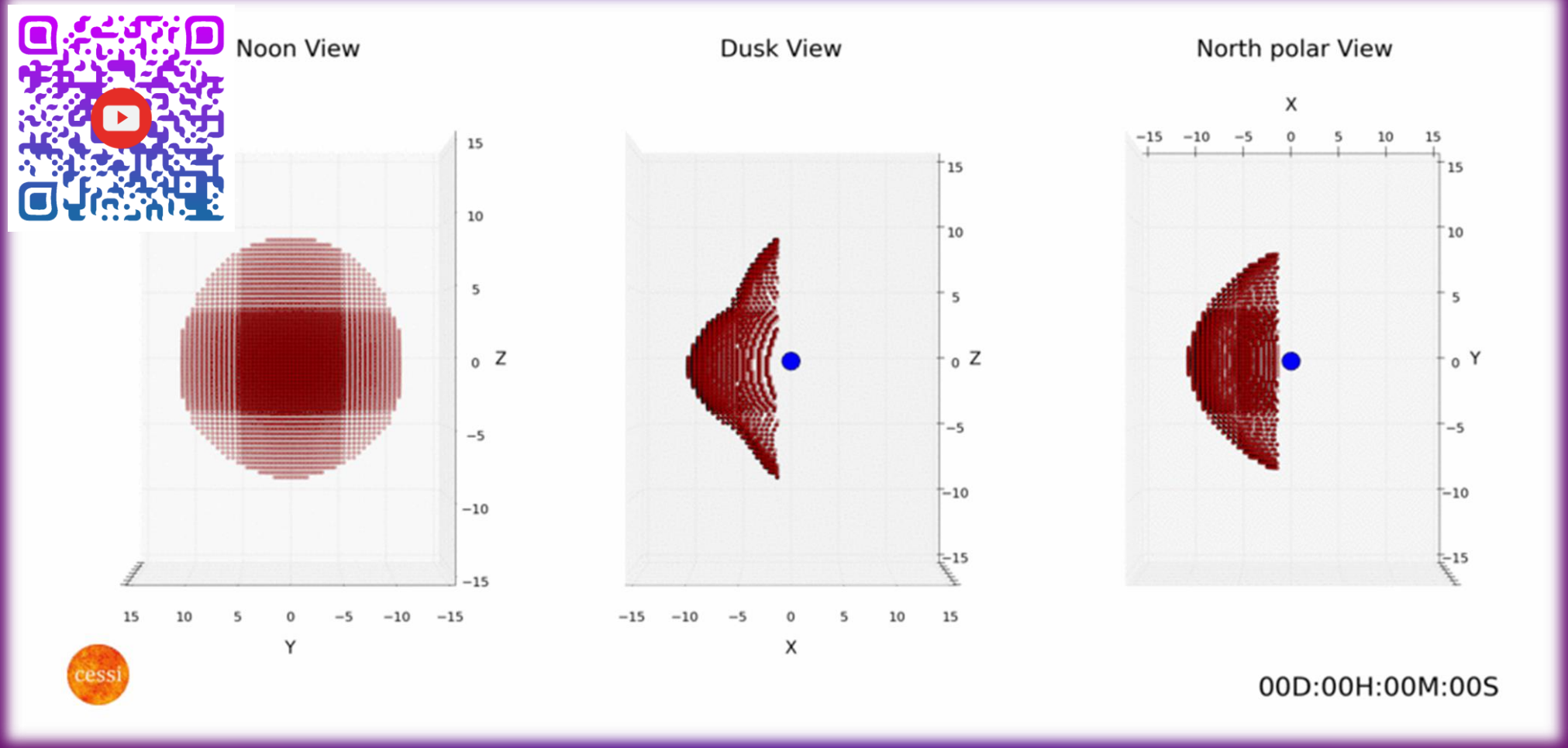
- Cylindrical Gold-Hoyle (GH) flux rope with no axial curvature
- Flux rope expansion is assumed negligible during computation
- Flux rope central axis is normal to ecliptic plane, core passes through Earth
- Initial magnetosphere is in a dynamical steady state – computed by CESSI-SPIM
- At t = 0, shock wave crosses the left boundary followed by the ICME.

Time Evolution of The Magnetosphere



Deformation of the Magnetosphere

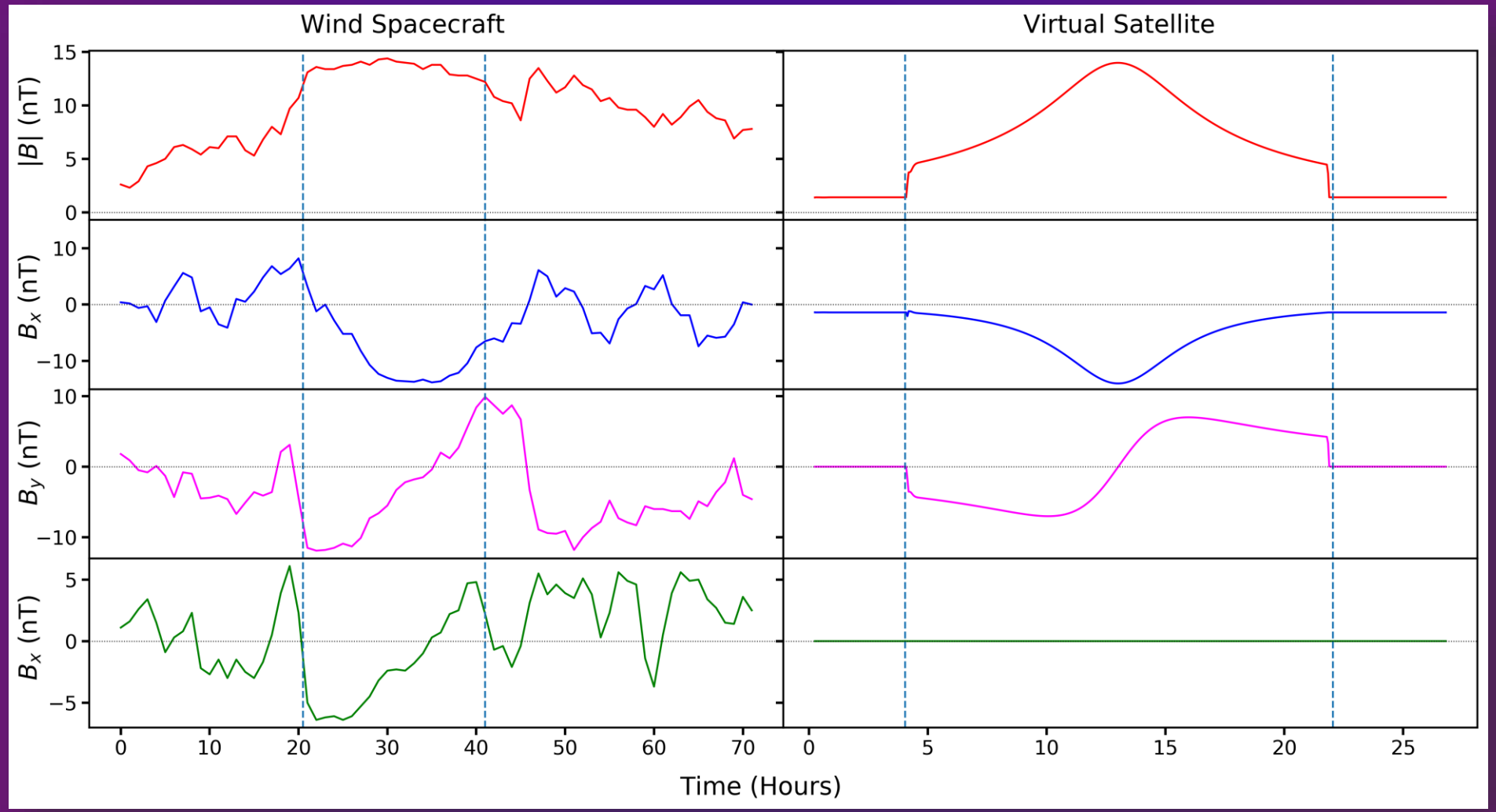
Dynamic Pressure ⟷ Magnetic Pressure



Virtual Satellite Observation of the ICME

A fixed point in space, measuring B with time

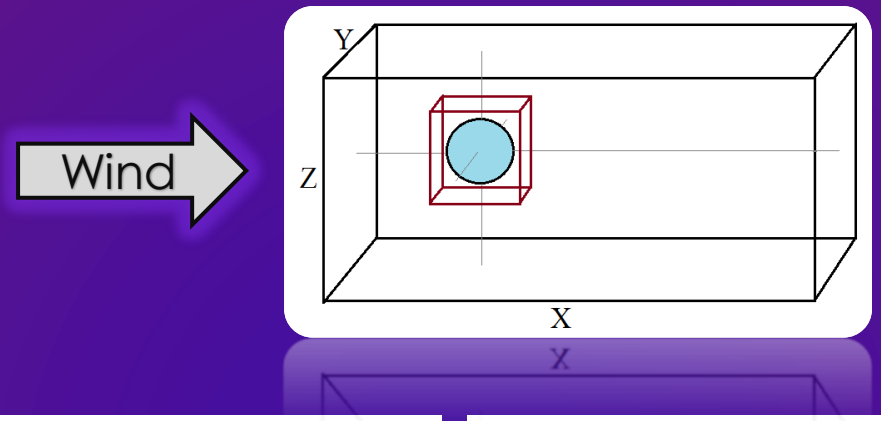
L1 Point



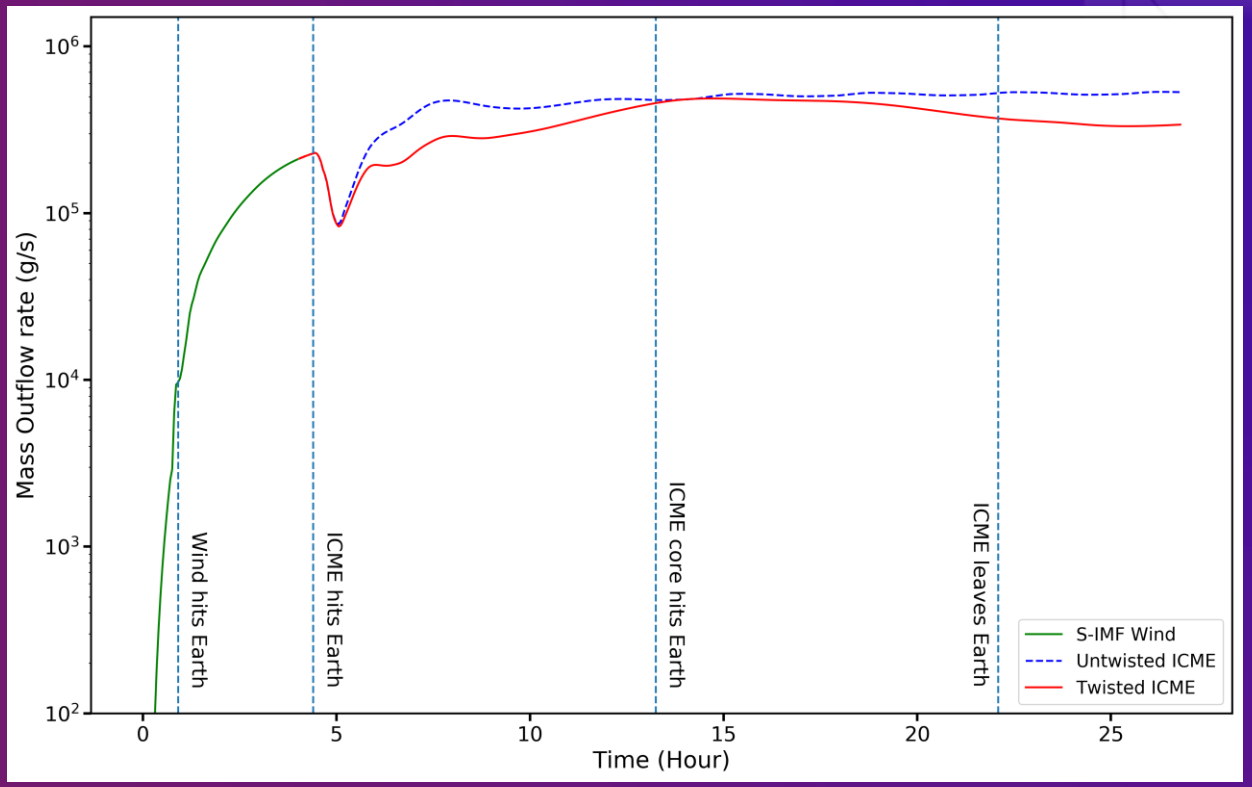
100 R_{Earth}

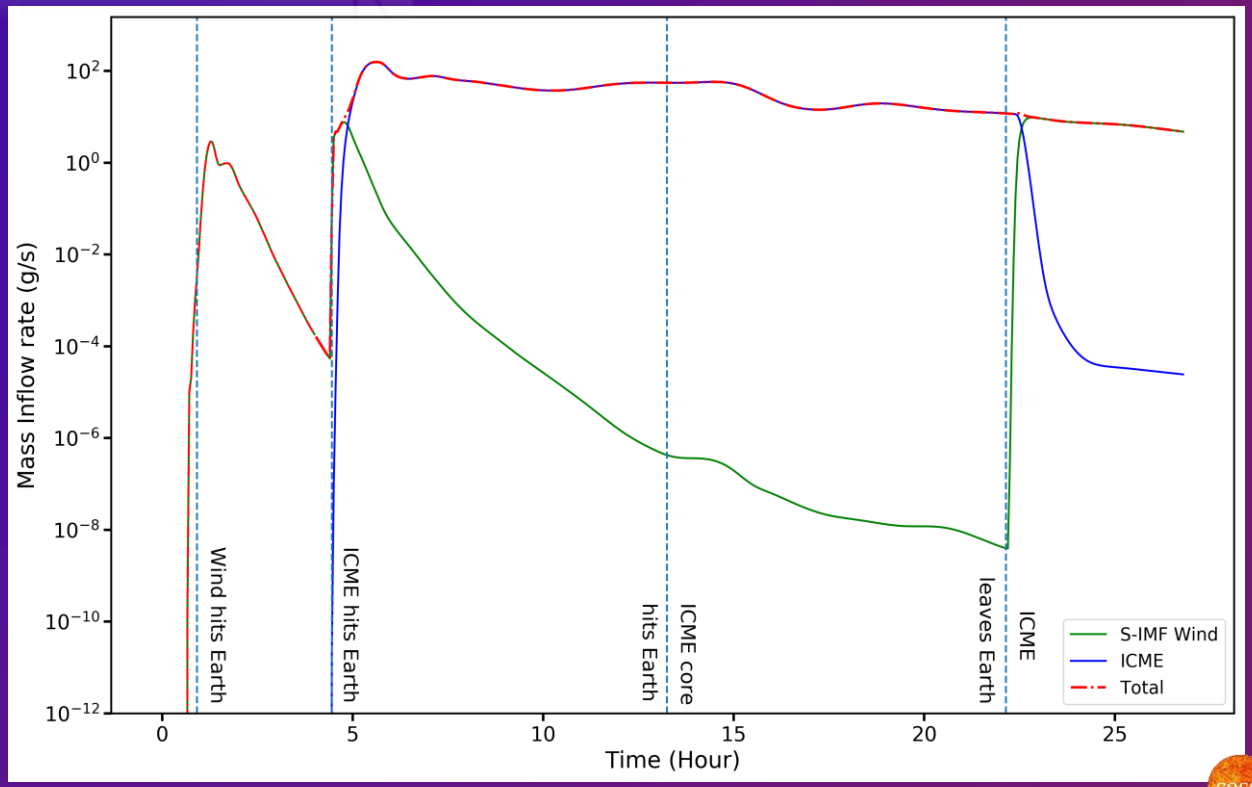
Data source: https://spdf.gsfc.nasa.gov/index.htm

Mass Loss, Mass Gain

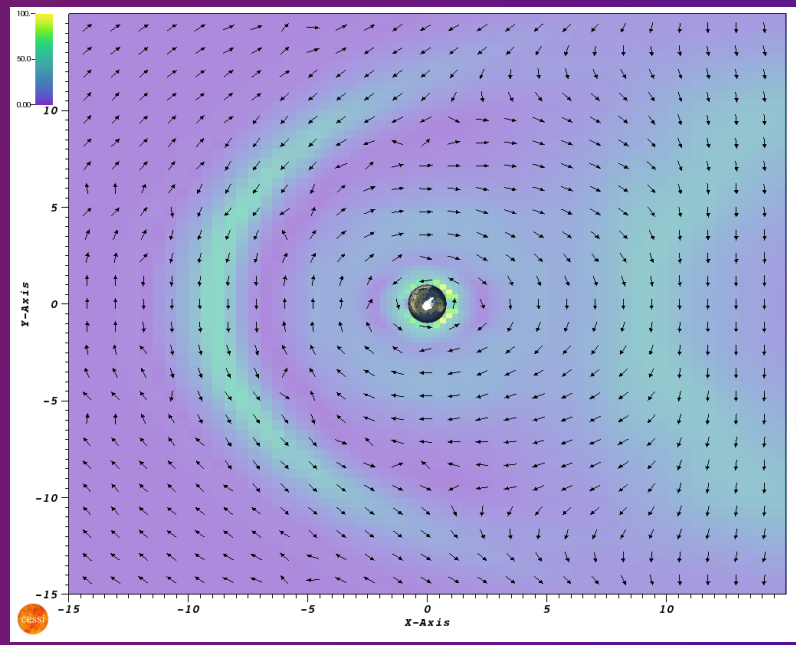


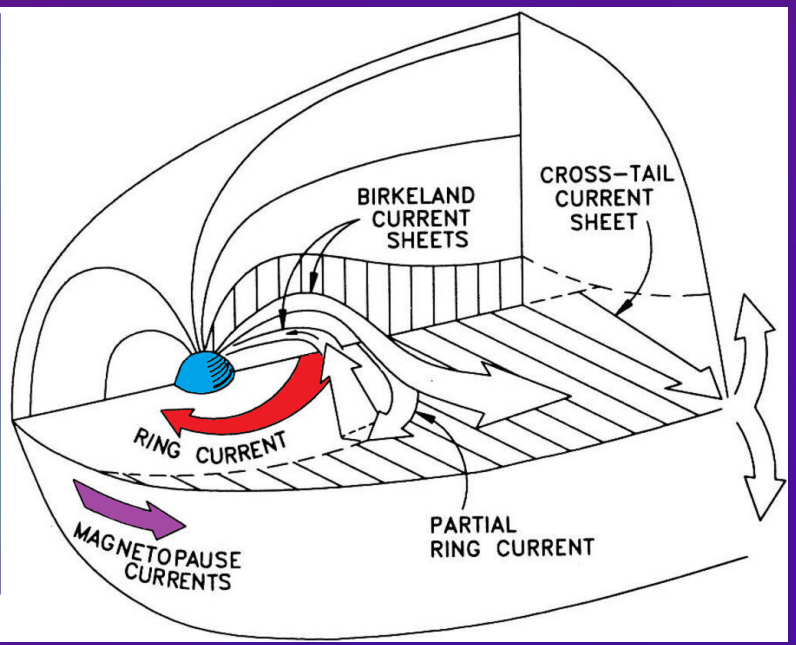
Box (R_{Earth}): 10 X 10 X 10





Ring Current and DST index



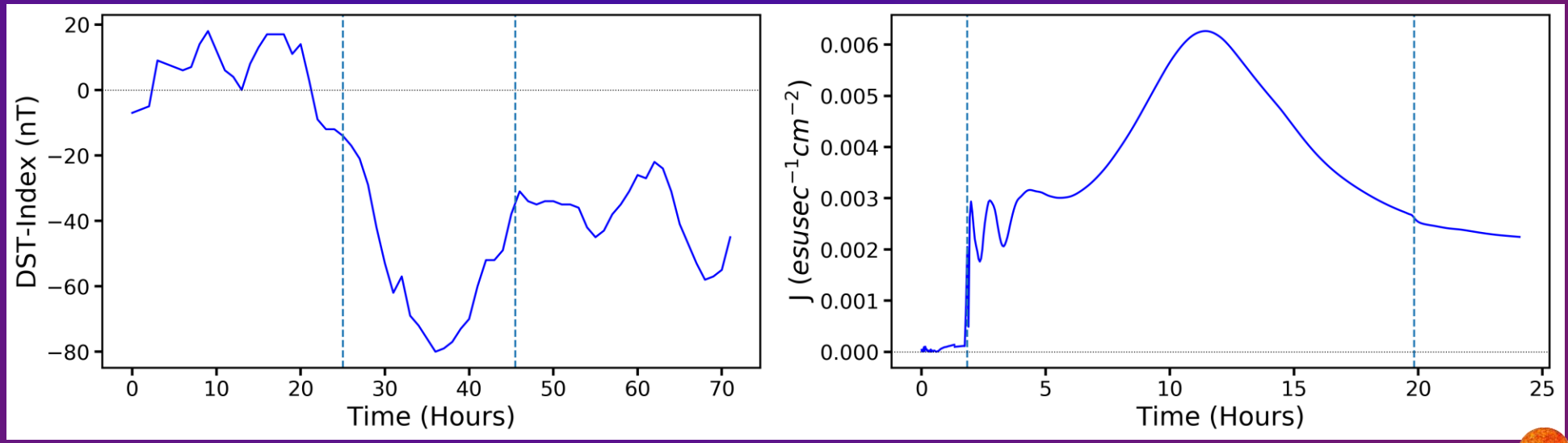


Disturbance storm time (DST) index gives information about the strength of the ring current around Earth caused by Solar Wind particles

Negative DST Index

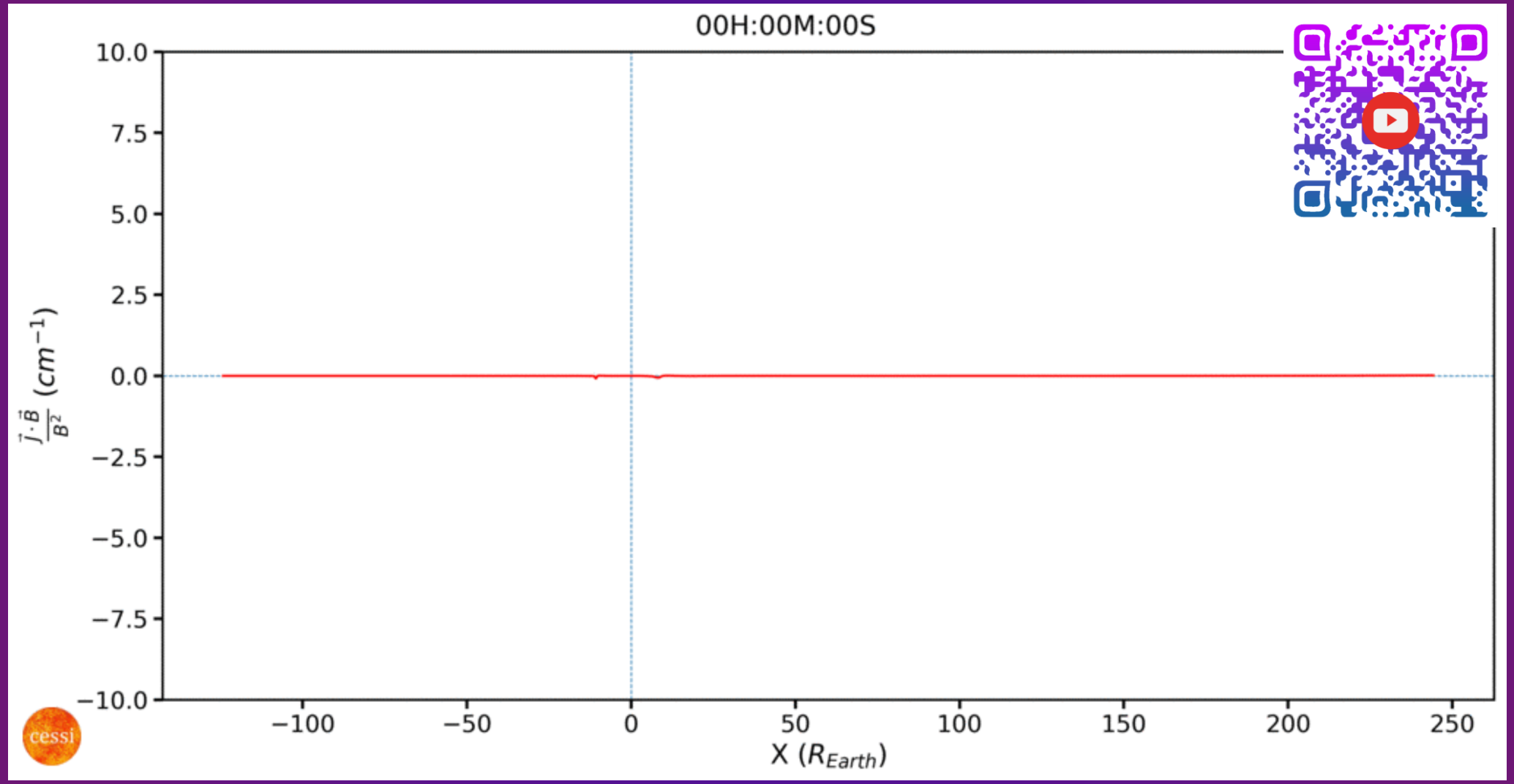
Weaker Geomagnetic Field

Higher Ring Current



Data source: https://spdf.gsfc.nasa.gov/index.html

Helicity injection in Magnetotail



Concluding remarks

- In-situ observations support CESSI-SPIM results and make it a more important tool to probe and predict space weather conditions in future.
- Solar wind forcing leads to a steady and dynamic magnetosphere and ICME is a perturbation to the steady-state. The day-side magnetopause is pushed further towards the Earth by the Interplanetary Coronal Mass Ejection (ICME)
- Magnetic helicity of the flux rope distorts the shape of the magnetosphere and magnetotail current system. Current enhancement around Earth and magnetotail during the geo-storm.
- ICME comparatively enhances the in and outflow rate of mass around Earth. The mass-loss rate is comparatively high when the core is passing.
- In-situ DST index measurement correlates with current enhancement inside magnetopause. Flux ropes can inject helicity in the magnetotail.

Thank You