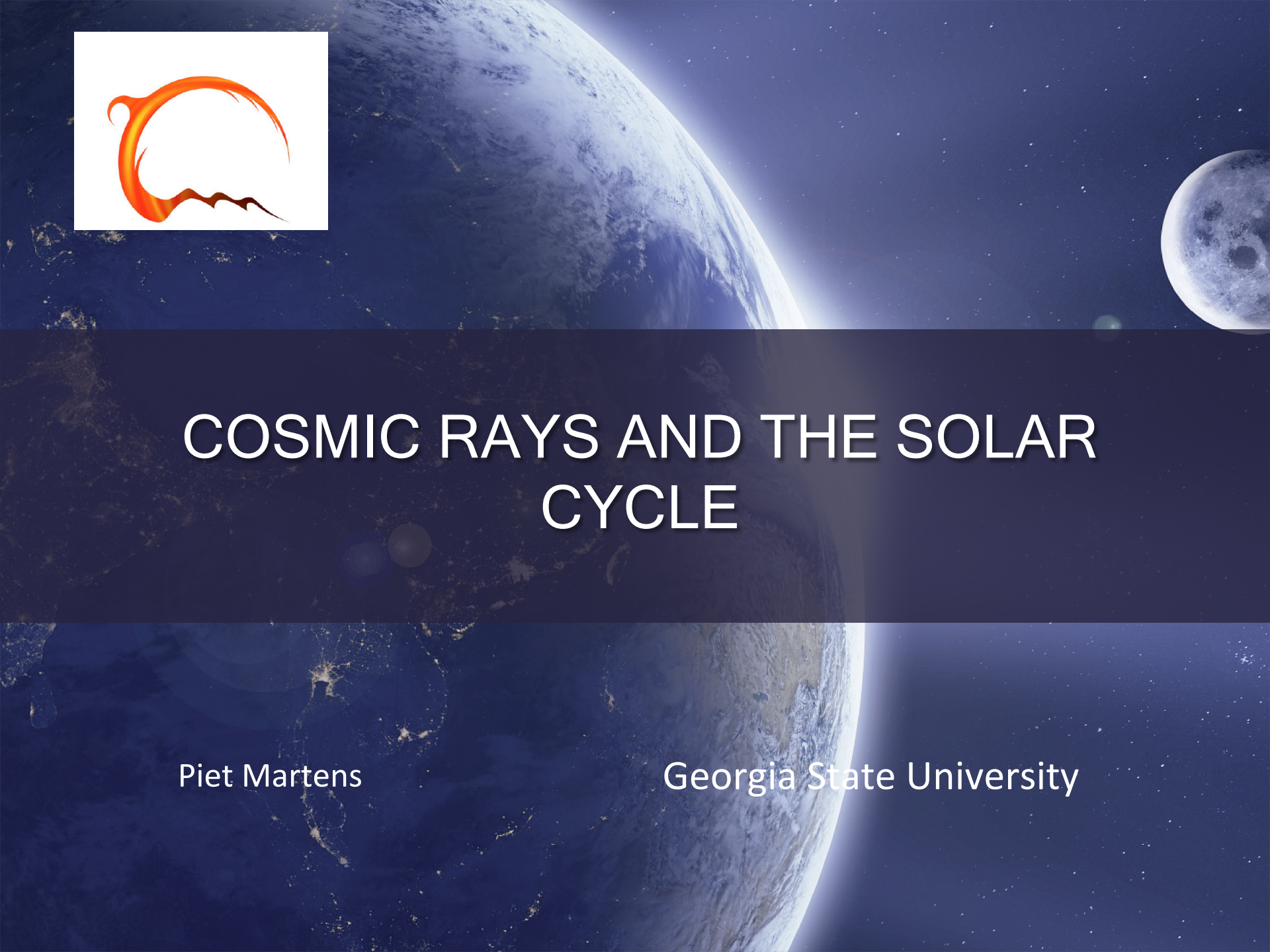
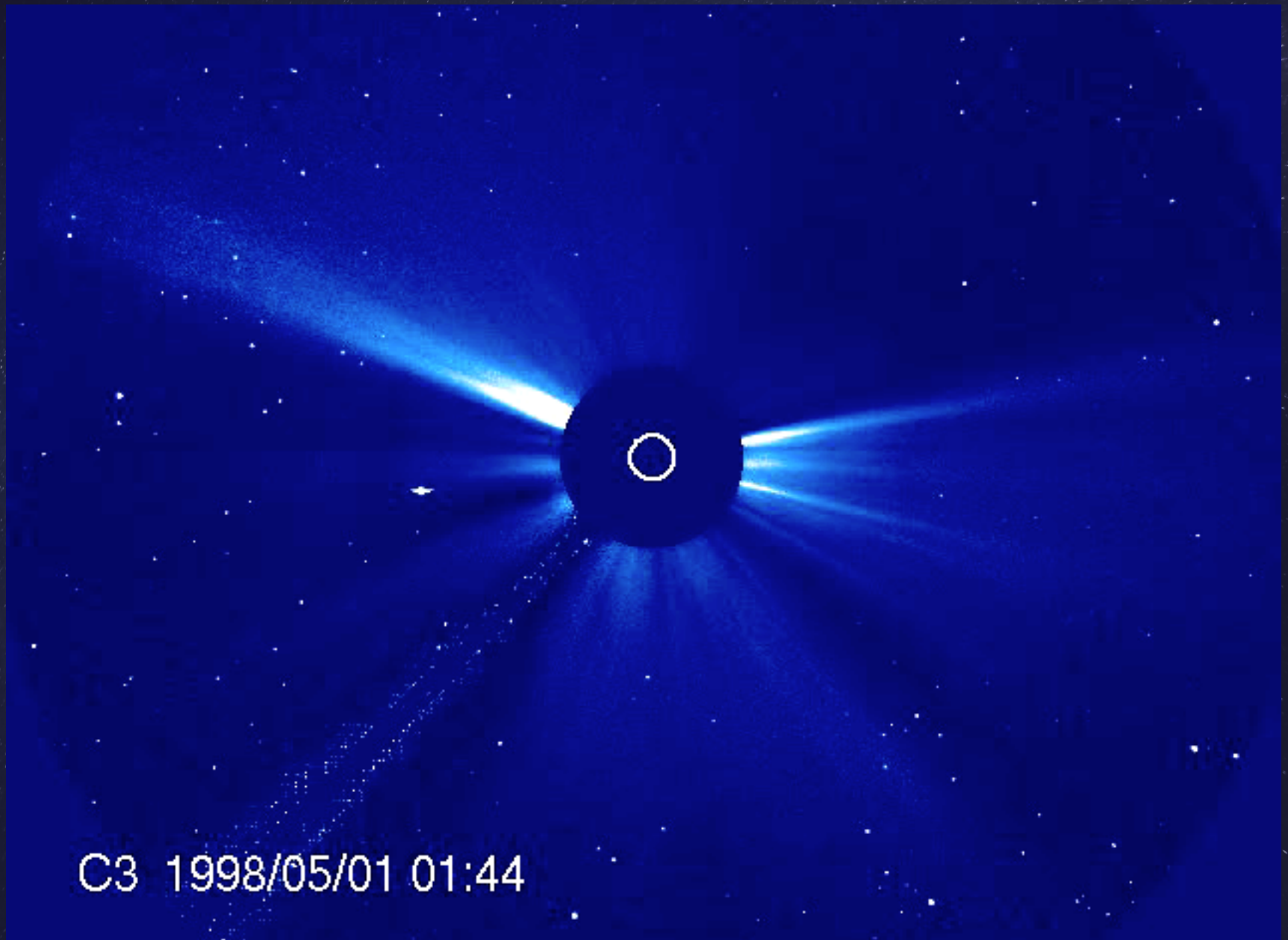


COSMIC RAYS AND THE SOLAR CYCLE

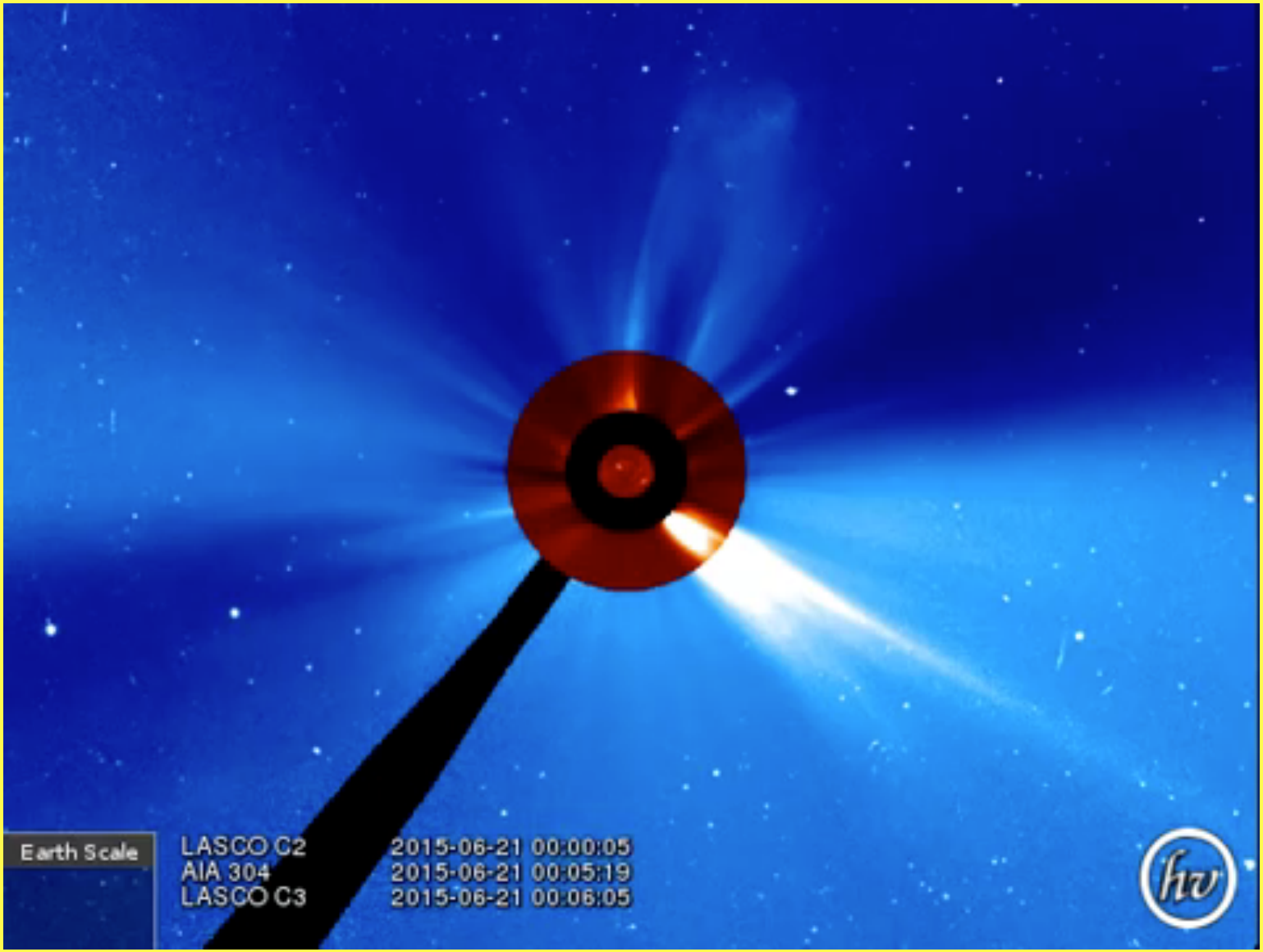
Piet Martens

Georgia State University

THE EVERLASTING ECLIPSE.....

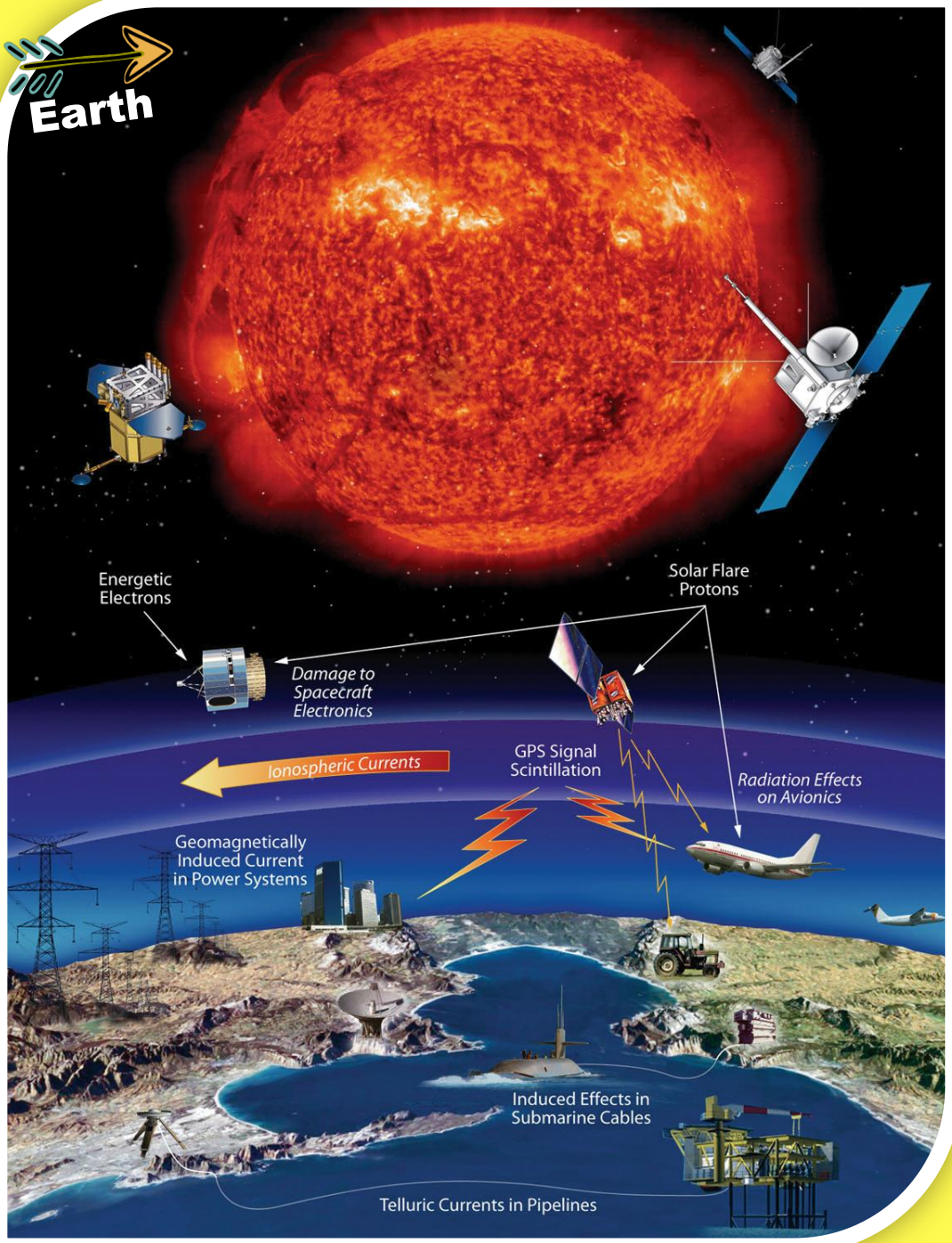


Earth Directed CME



GEOMAGNETICALLY INDUCED CURRENTS

On 03/13/1989, a magnetic storm burned up a $36 million transformer in New Jersey and **collapsed the entire power grid in Quebec**, Canada (in less than 2 minutes!), leaving **6 million people without electricity for 9 hours**.



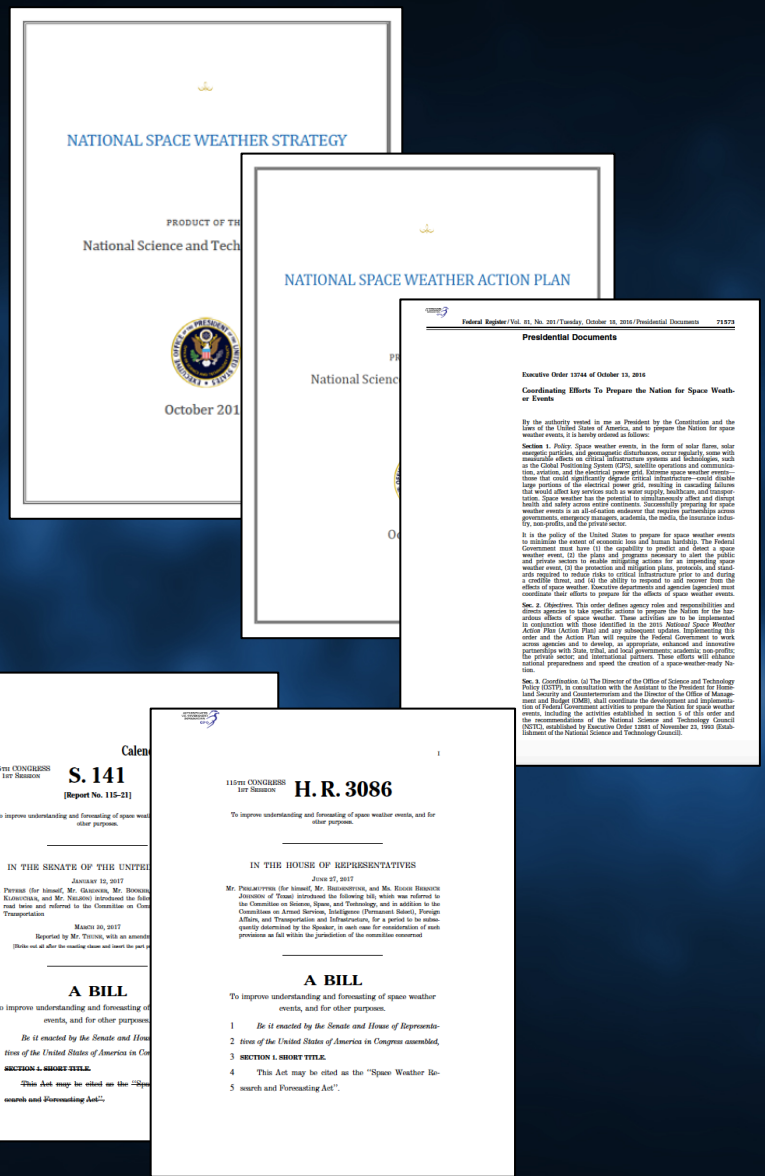
Effects of Solar Storms

- Space-crew safety (radiation)
- Re-routing of airline's polar routes
- Distortion of radio signals and navigation devices (GPS)
- Damage to communication satellites
- Geomagnetically induced currents!!!

Martens: F2019 Grad Students

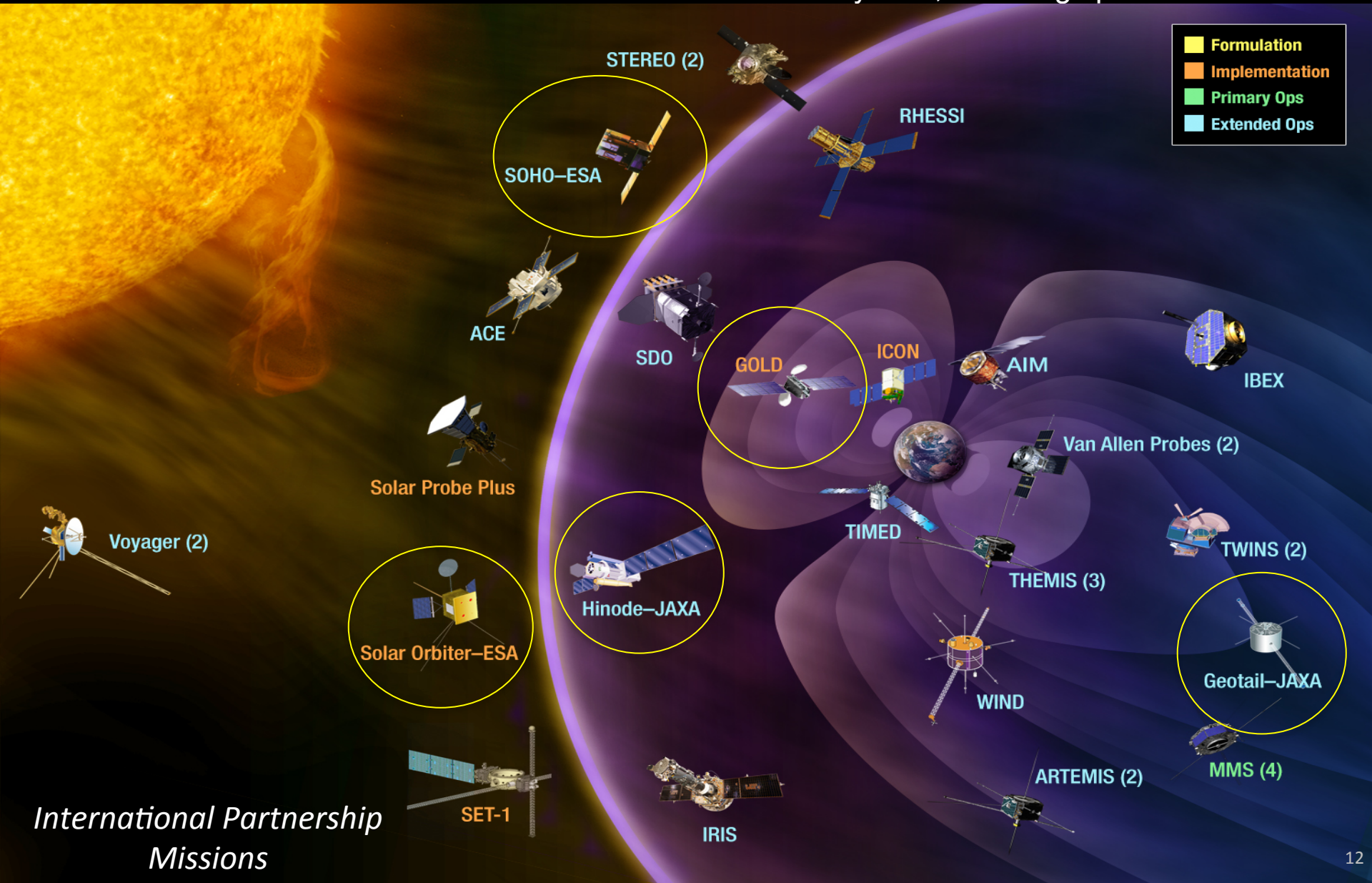
R2O: National Effort

- White House
  - ➢ National Space Weather Strategy and Action Plan
  - ➢ Executive Order 13744
- Congress
  - ➢ Space Weather Research and Forecasting Acts
    - Senate (S.141) - passed
    - House (H.R.3086) - introduced

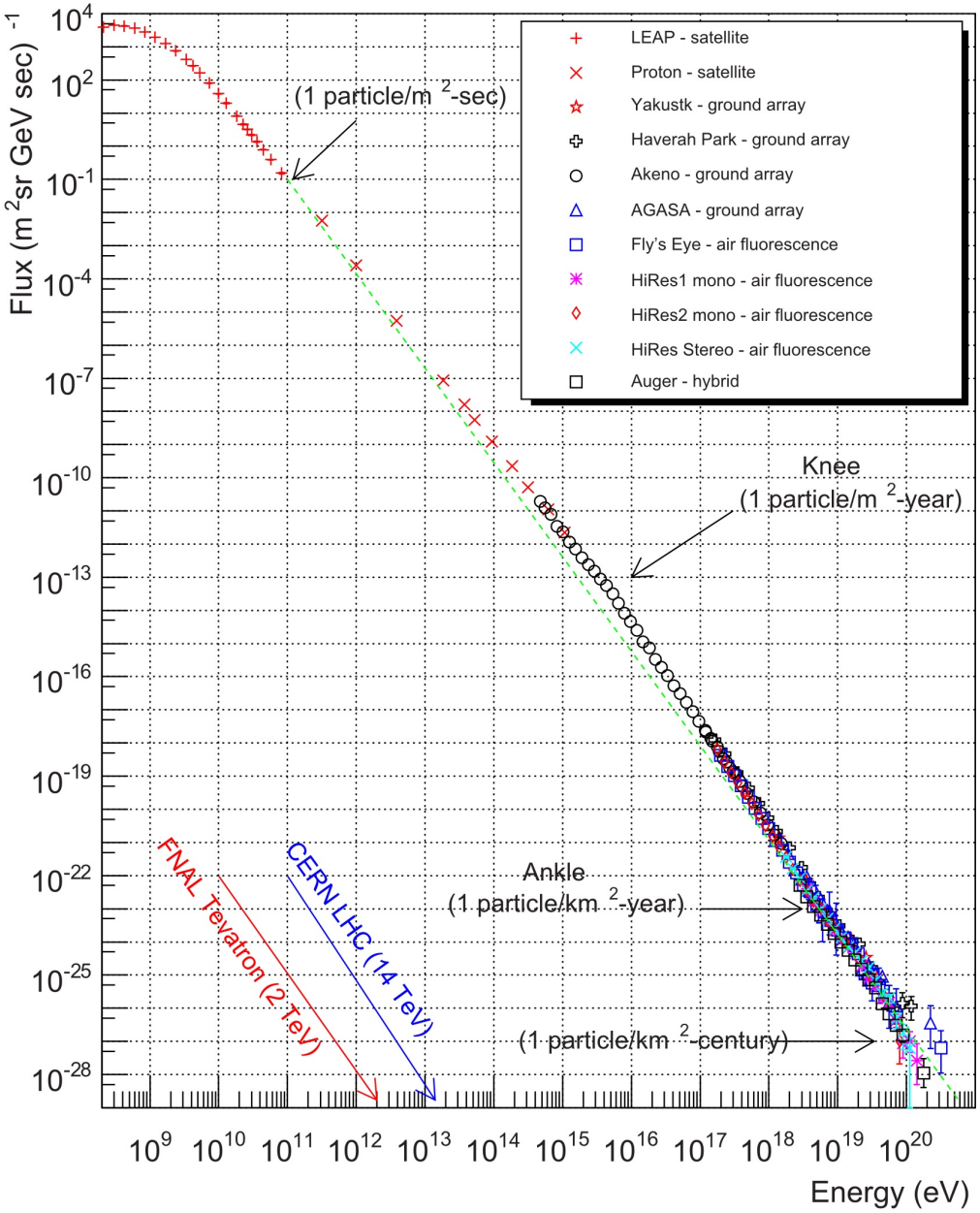


Heliophysics System Observatory

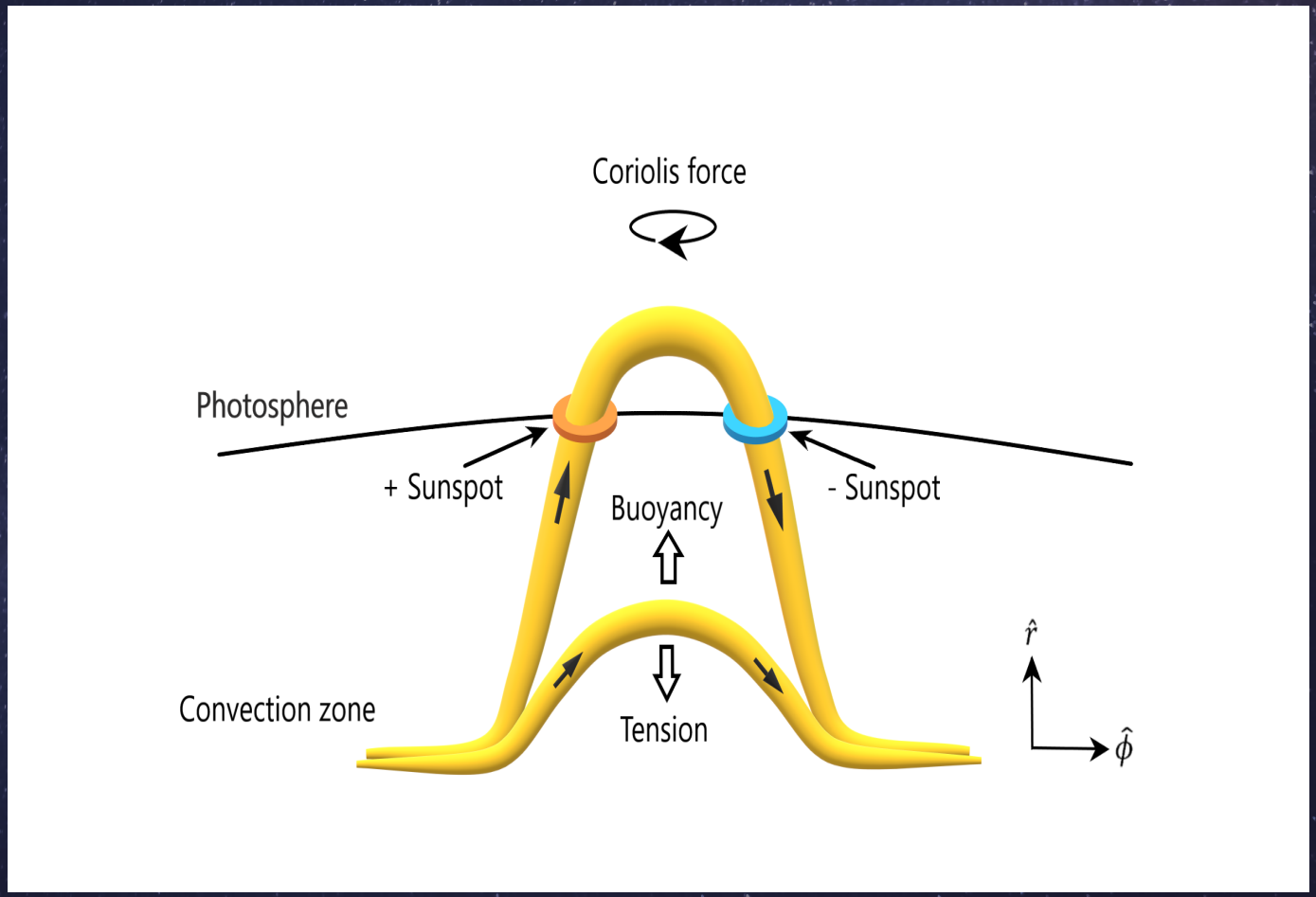
A coordinated and complementary fleet of spacecraft to understand
the Sun and its interactions with Earth and the solar system, including space weather



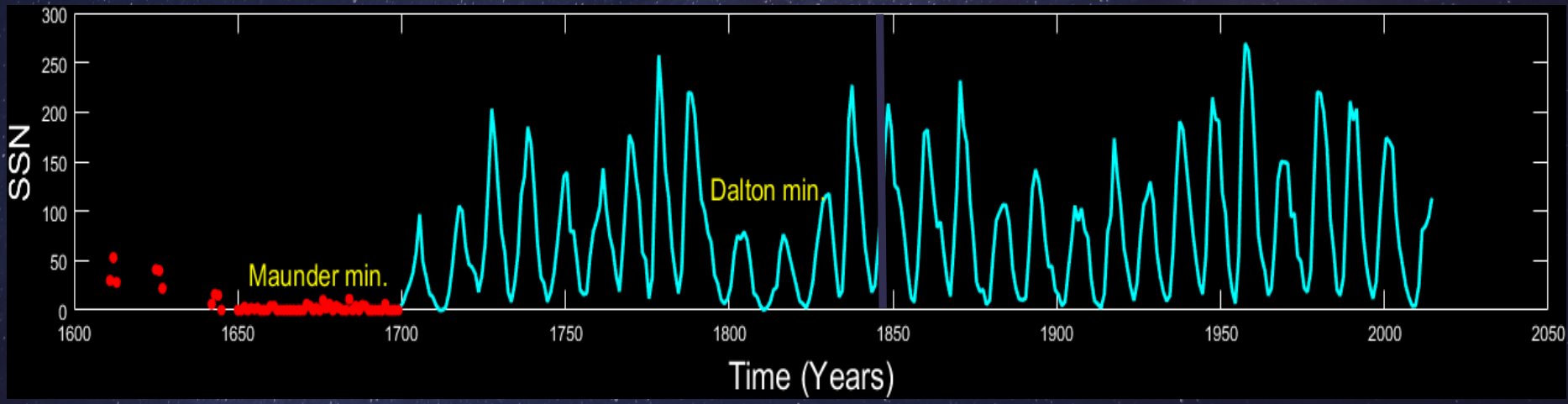
Cosmic Ray Spectra of Various Experiments



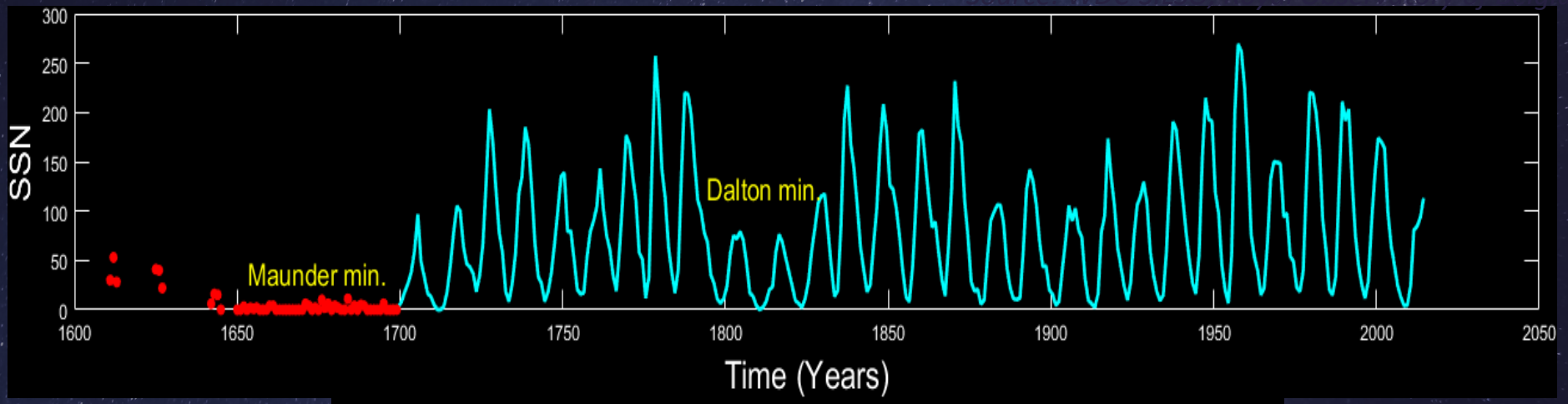
MAGNETIC BUOYANCY (PARKER 1955)

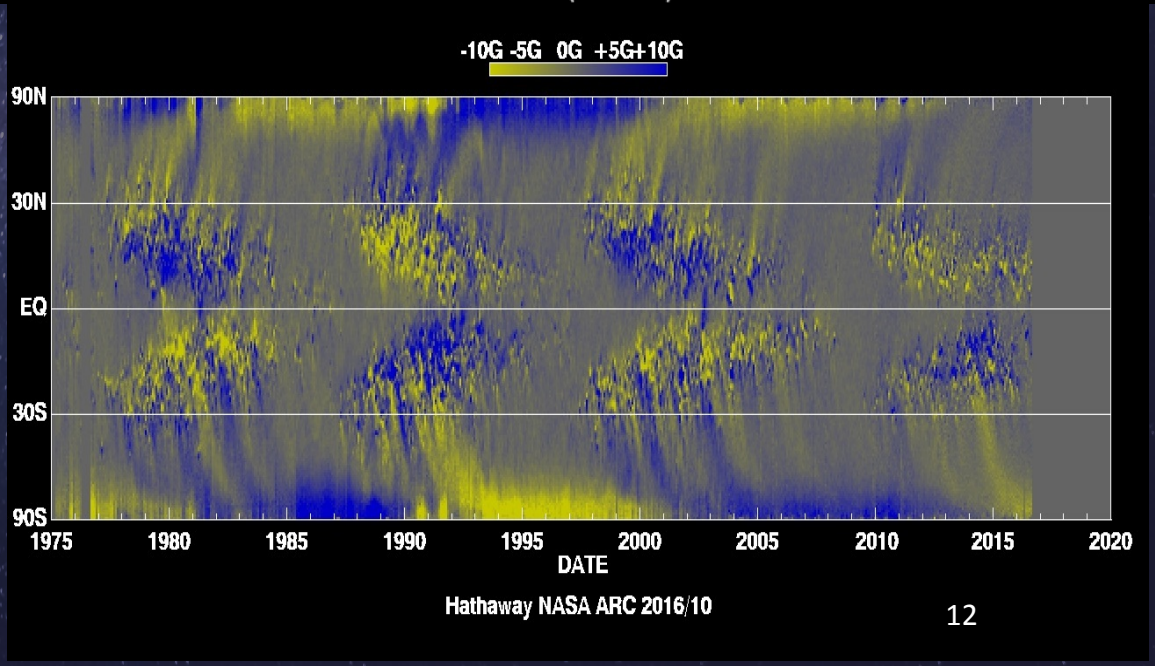


1843 AD: HEINRICH SCHWABE DISCOVERS PERIODICITY!



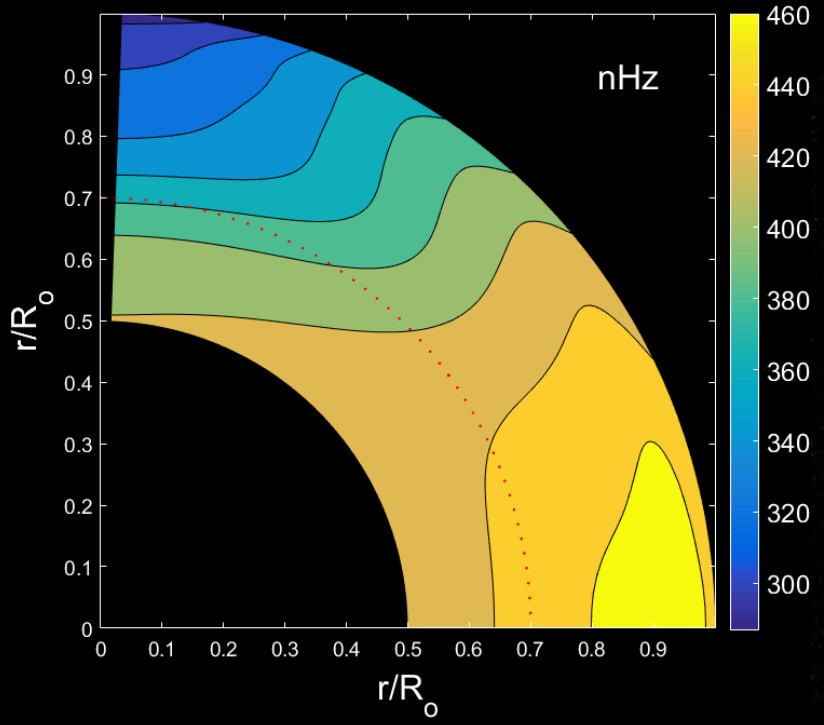
409 YEARS AND COUNTING...





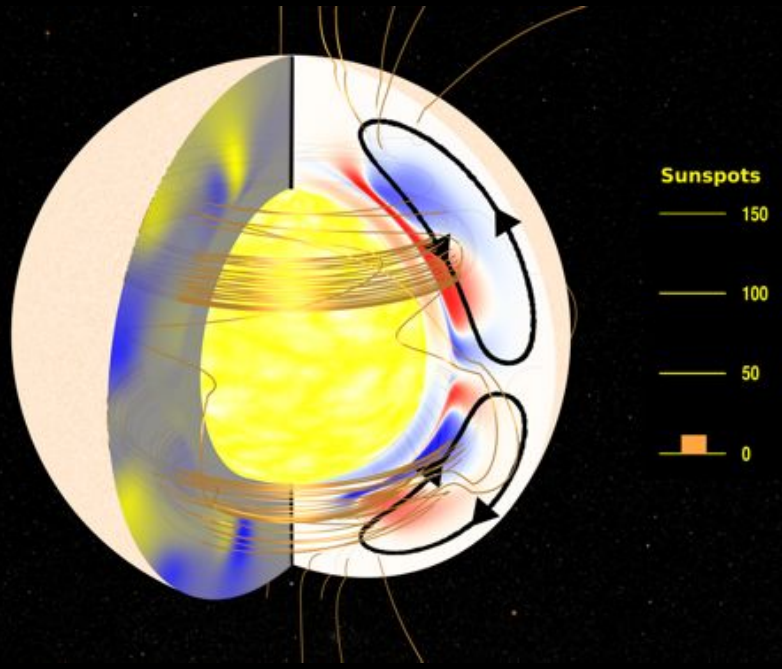
Plasma Flows inside the Sun

Differential Rotation: creates toroidal field



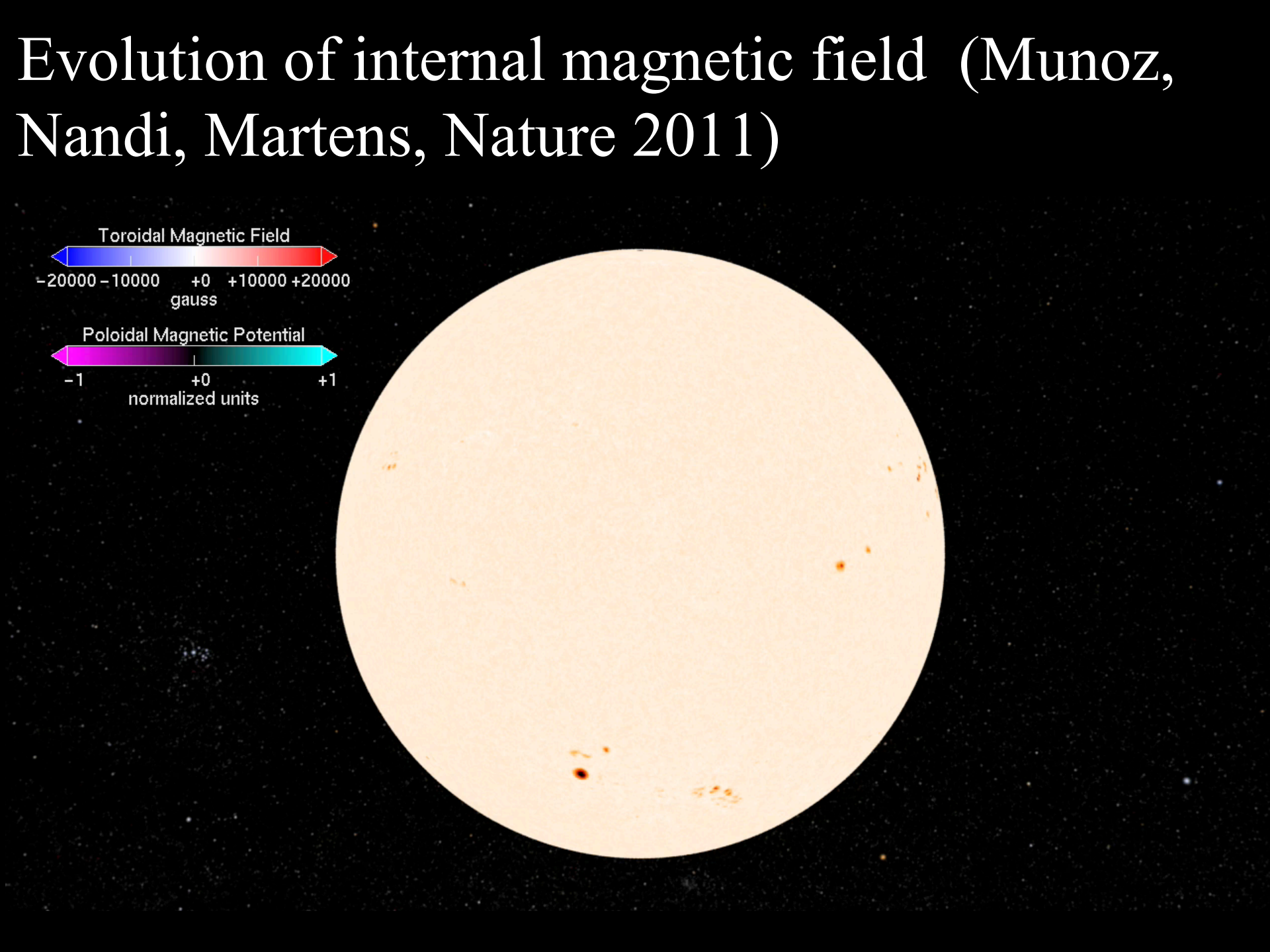
Data from GONG reduced by Antia et. al. (2011)

Meridional Flow: sets cycle period & active latitude migration



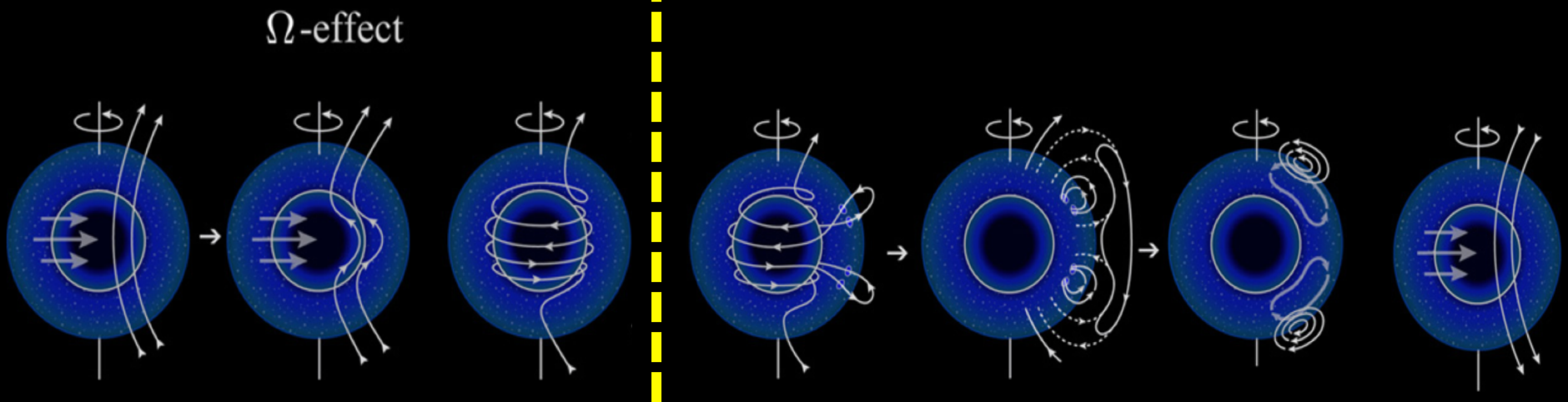
Courtesy: Nandy, Muñoz-Jaramillo & Martens 2011, Nature

Evolution of internal magnetic field (Munoz, Nandi, Martens, Nature 2011)



Current Understanding of the Solar Dynamo

Poloidal → Toroidal → Sunspots → Poloidal



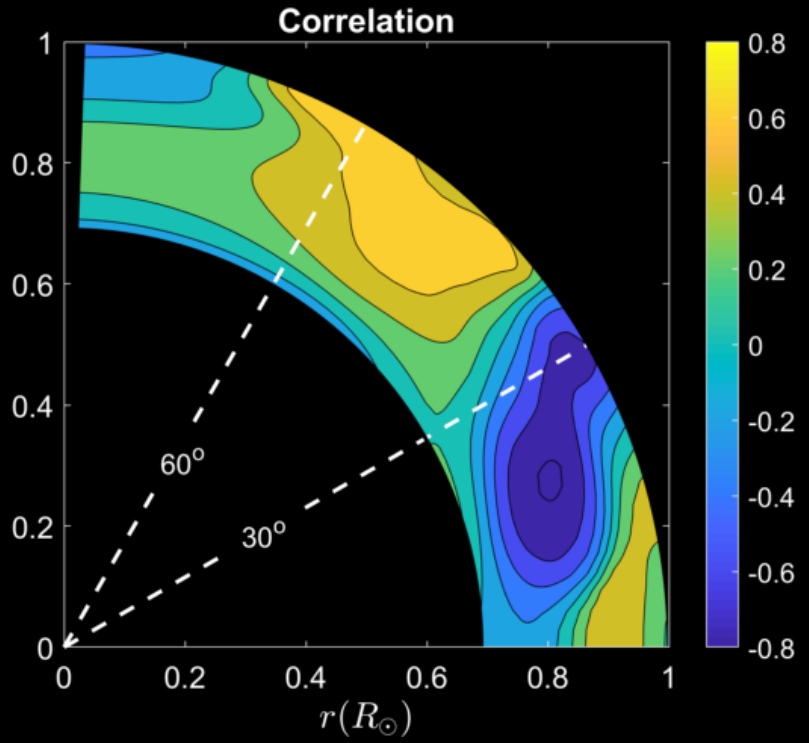
Not Observed yet

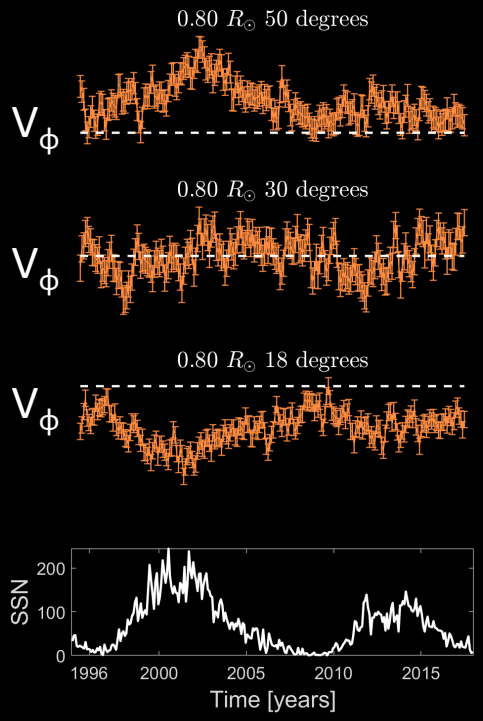
Observed on the surface

Image *Courtesy: Sanchez, S., Fournier, A., & Aubert, J. 2014, ApJ, 781, 8*

Where does Parker's Ω-effect operate?

Correlation of Torsional Oscillation with SSN

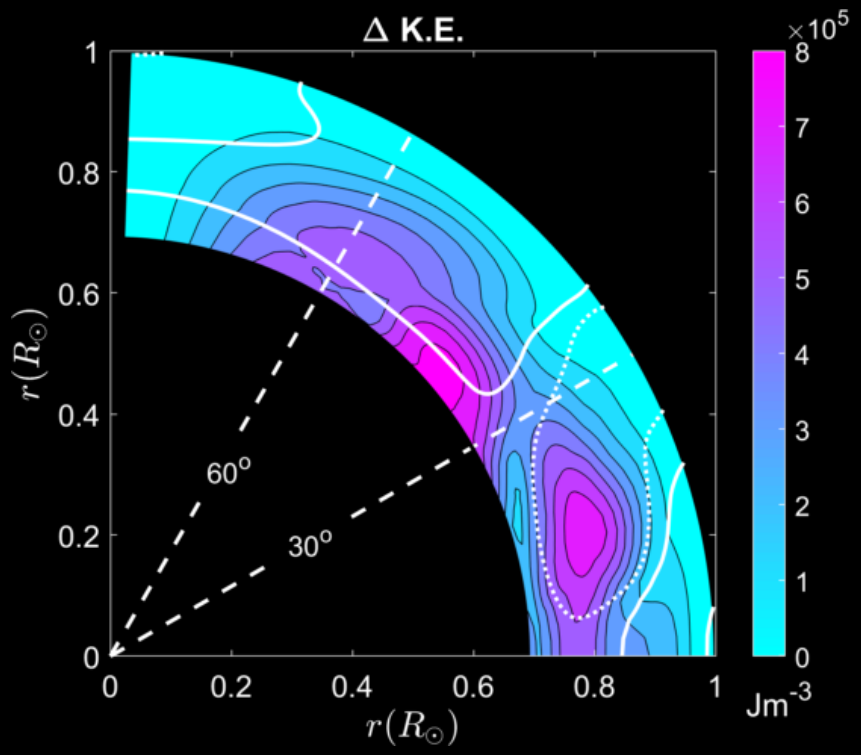




Energy content in Torsional Oscillations

- The energy in torsional oscillations is concentrated deep inside the SCZ

$\Delta K.E. =$

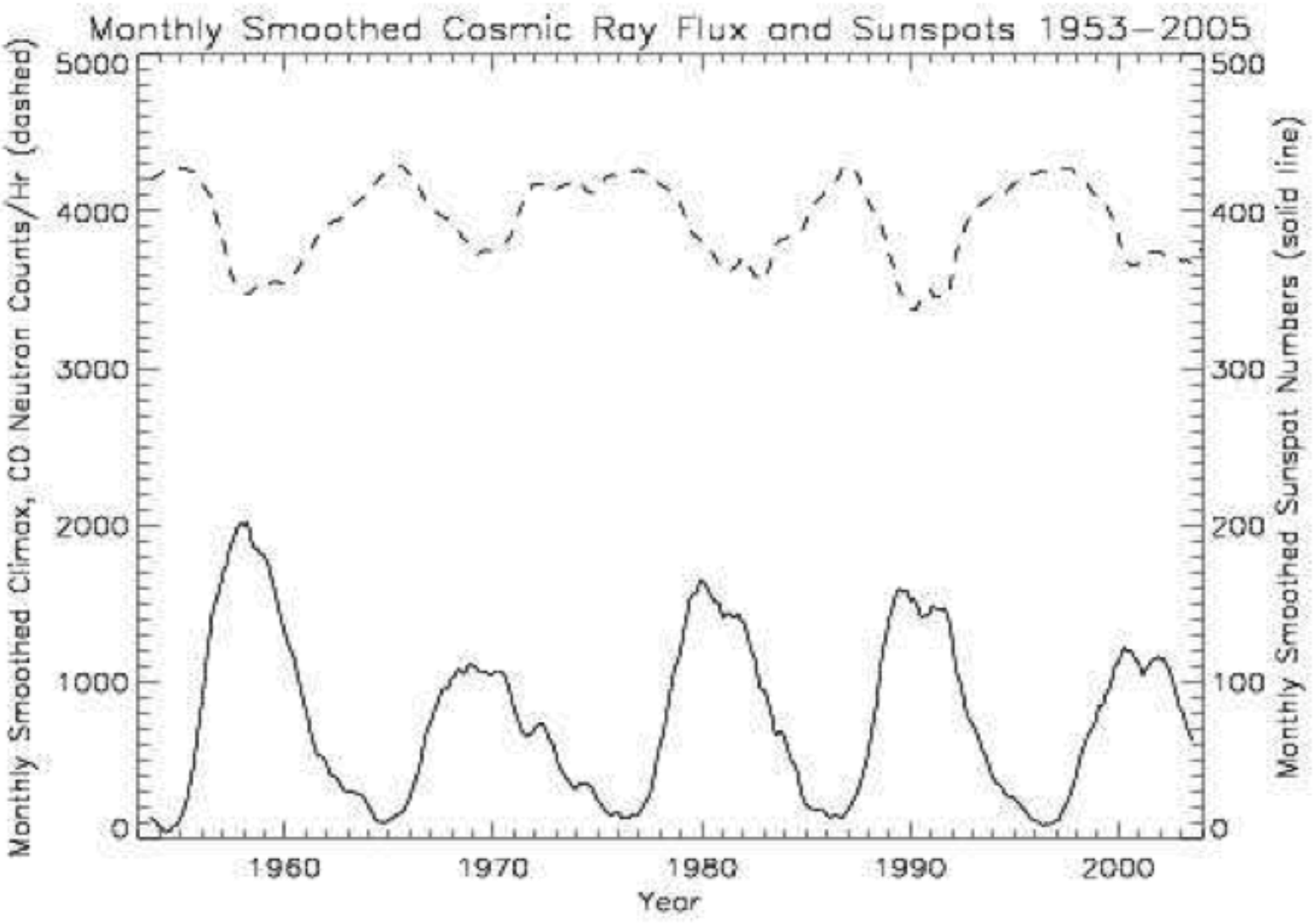


Data from GONG reduced by Antia et. al. (2011)

The solar dynamo derives its energy from differential rotation deep in the convection zone — just as we expected.

Mahajan, Nandi & Martens, Science, submitted

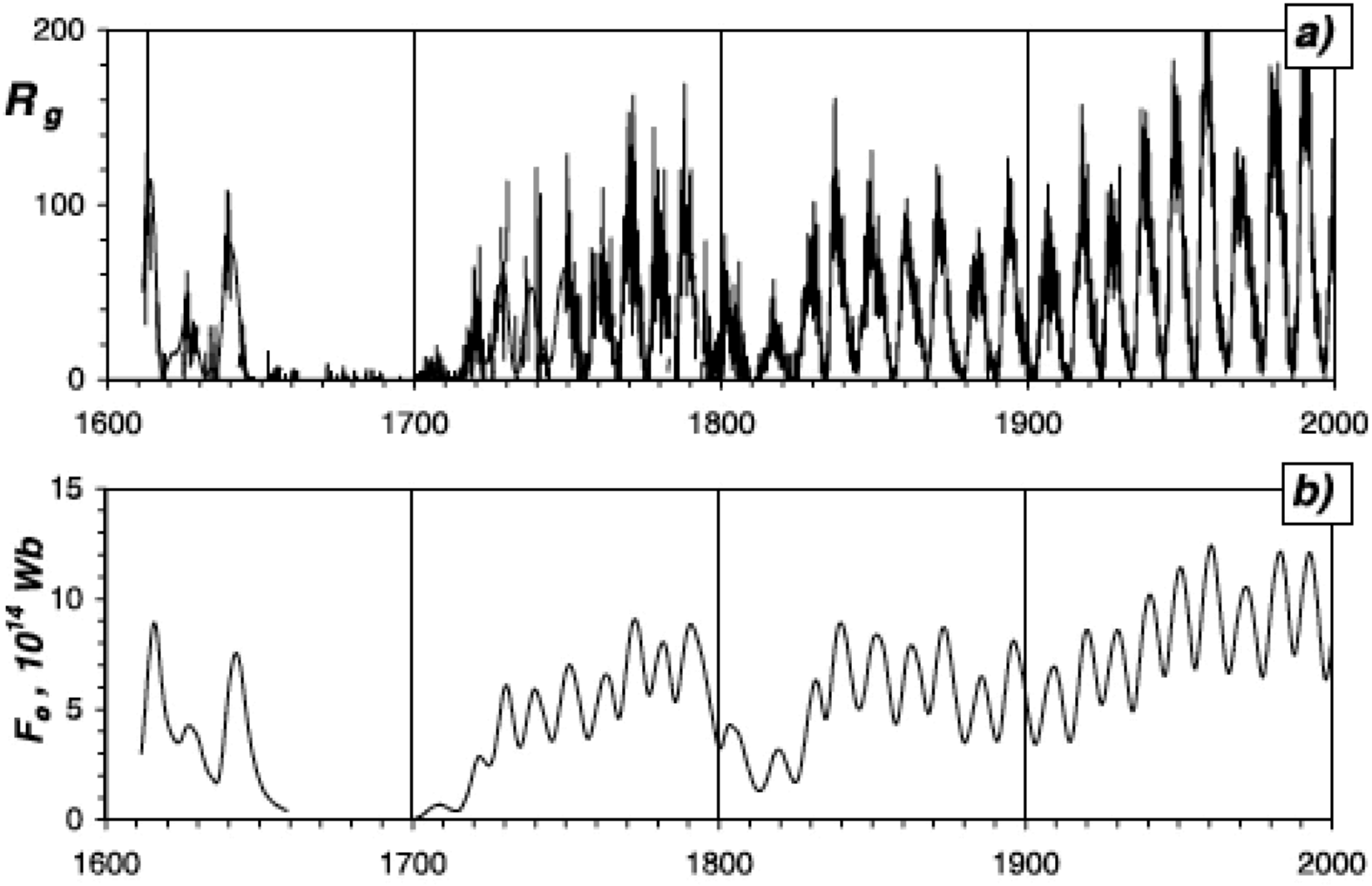
Correspondence with Cosmic Rays (Observed)



Reconstructed Open Flux From Sunspot Record

Sunspot number

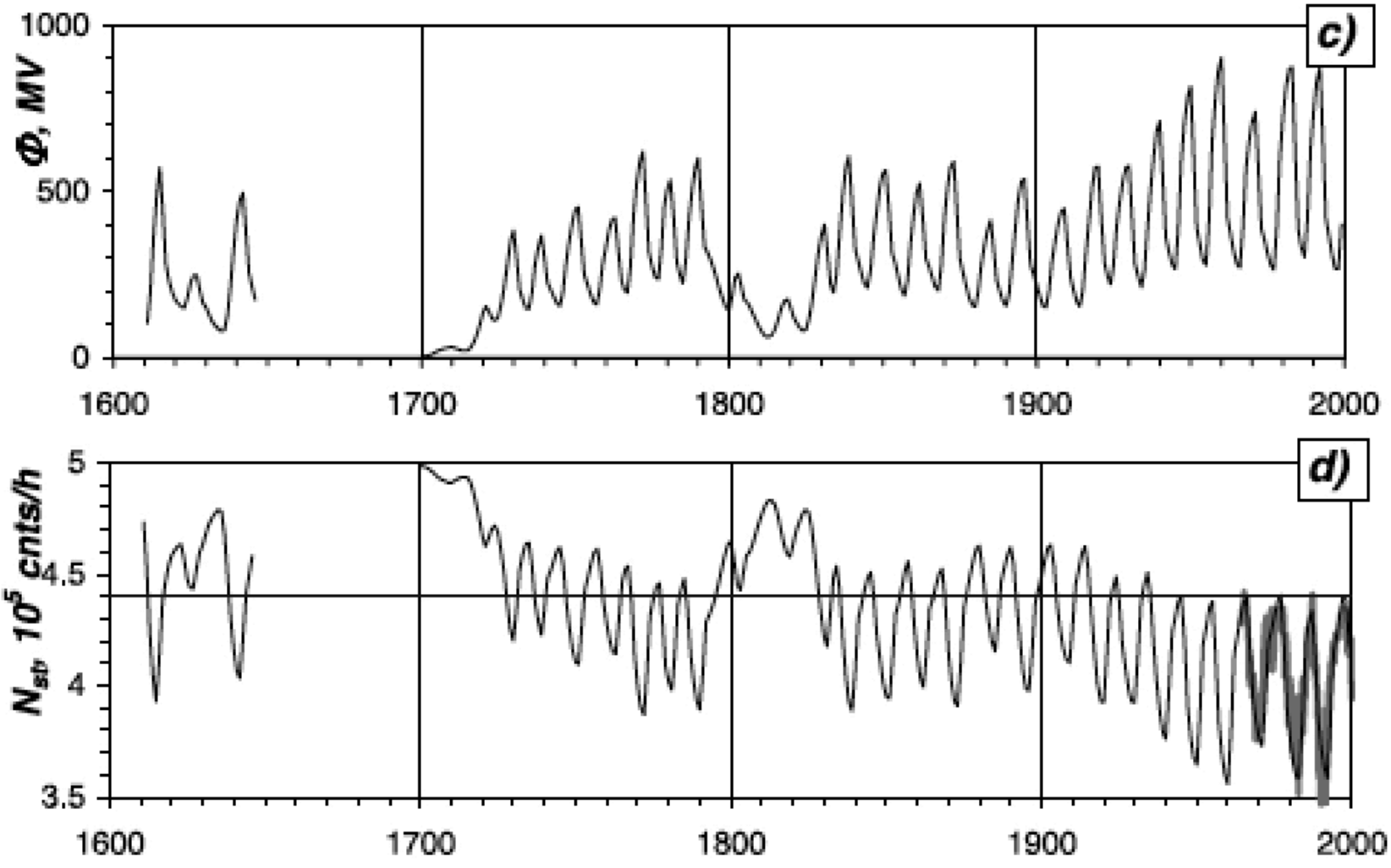
Open Magnetic Flux



Reconstructed Cosmic Rays From Open Flux

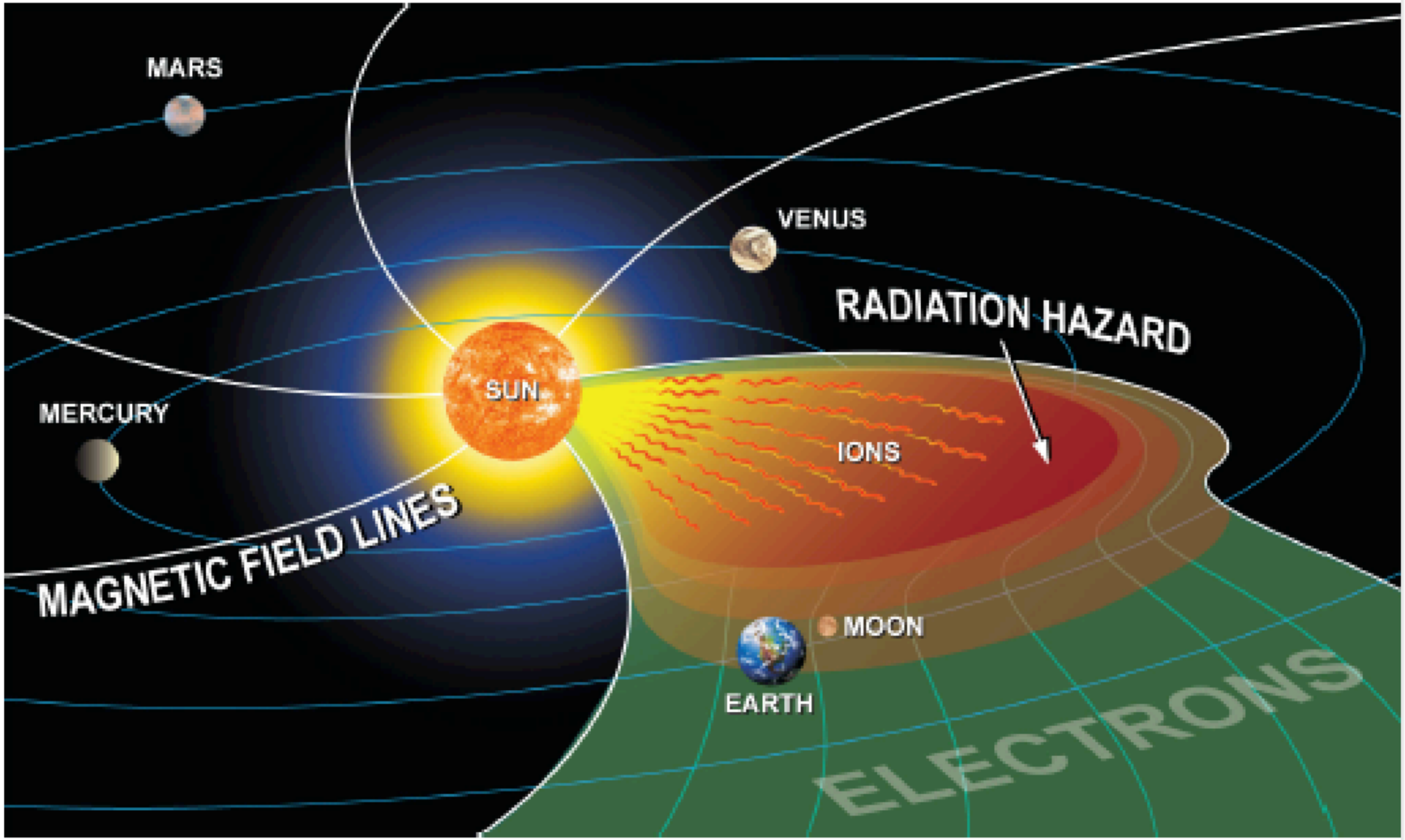
CR Modu-lation

Oulu NM Count Rate

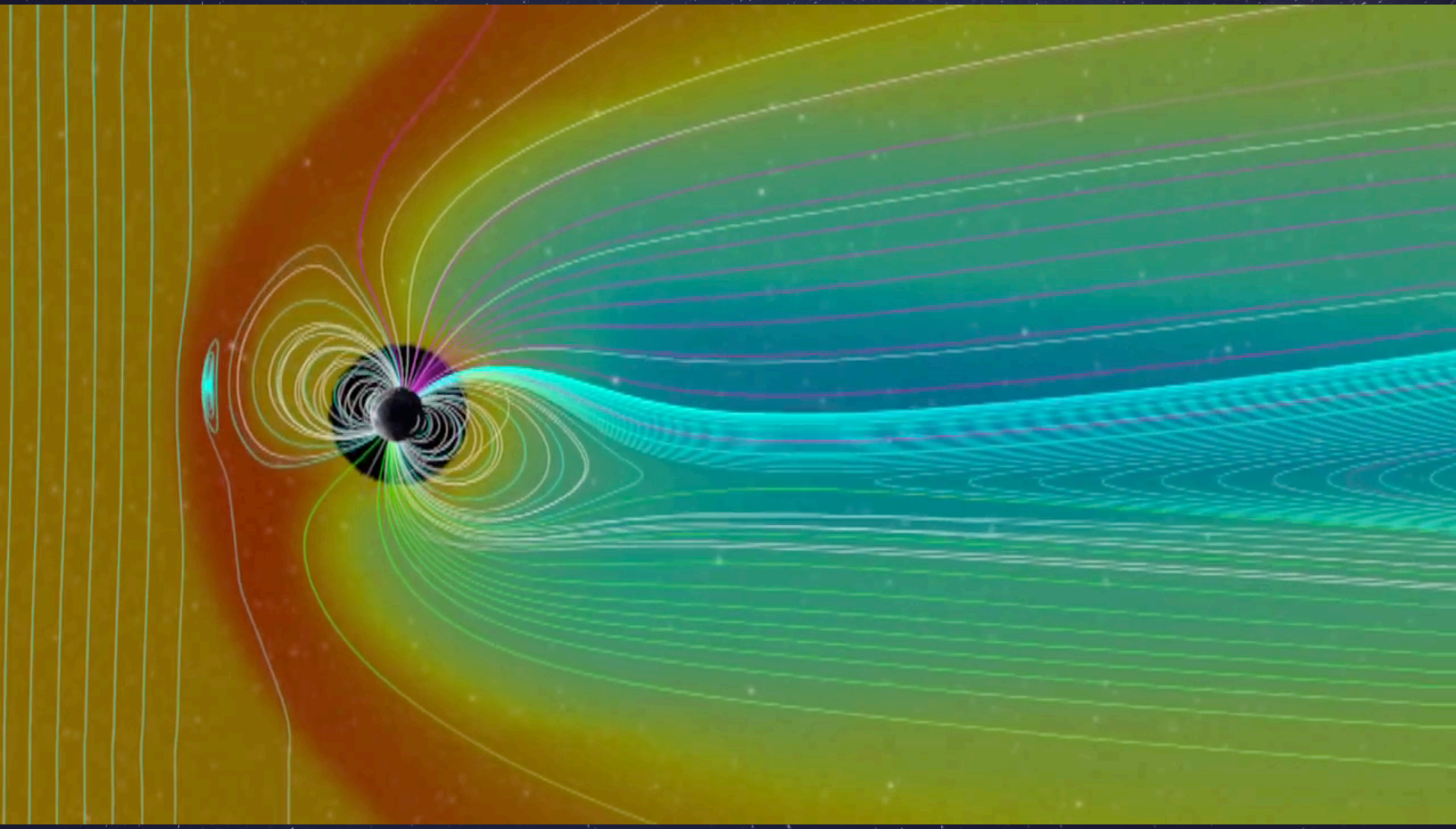


A physical reconstruction of cosmic ray intensity since 1610
Ilya G. Usoskin et al. JGR 107, 1374 (2002).

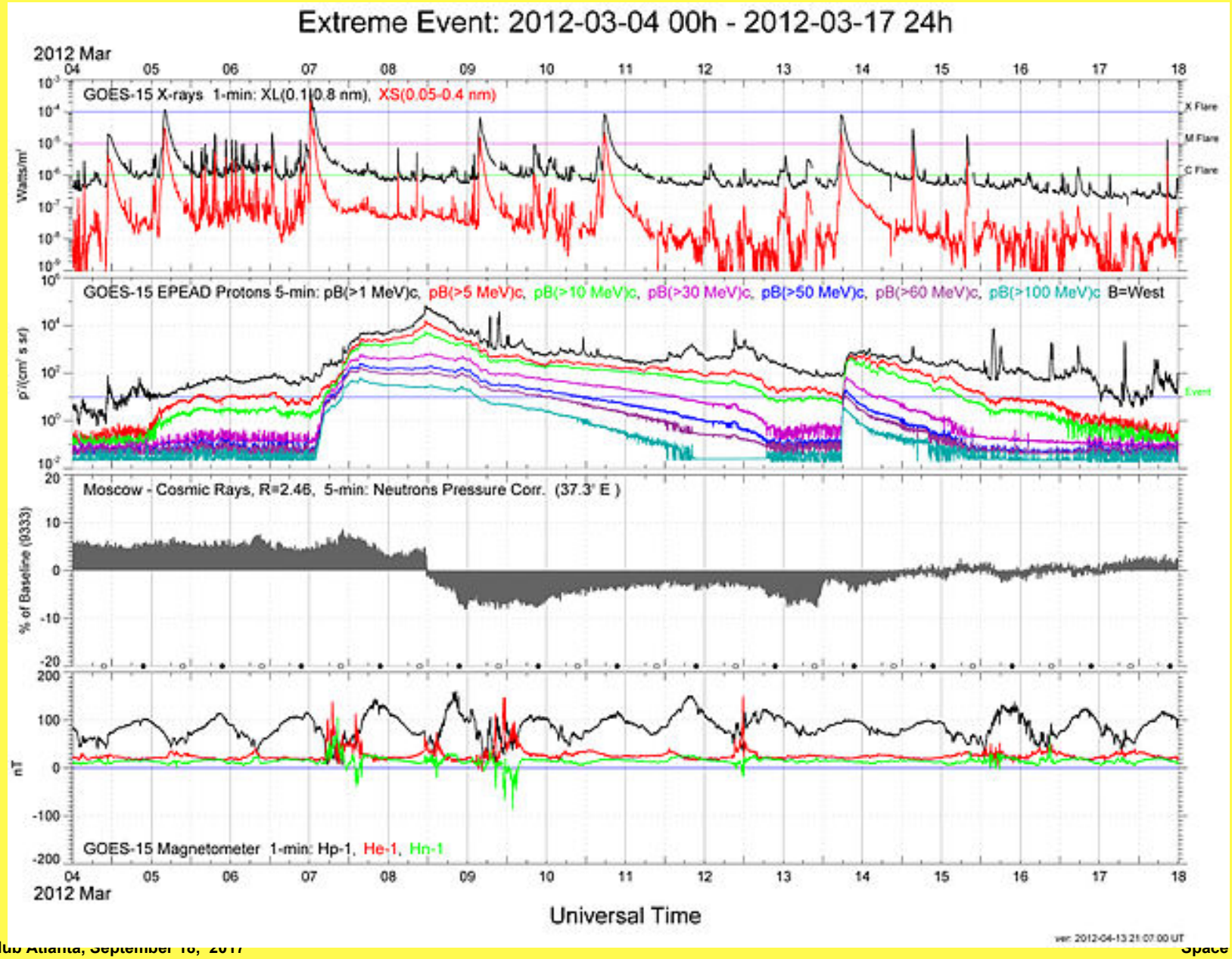
High Energy Protons from Solar Flares Are Lethal for Unprotected Astronauts



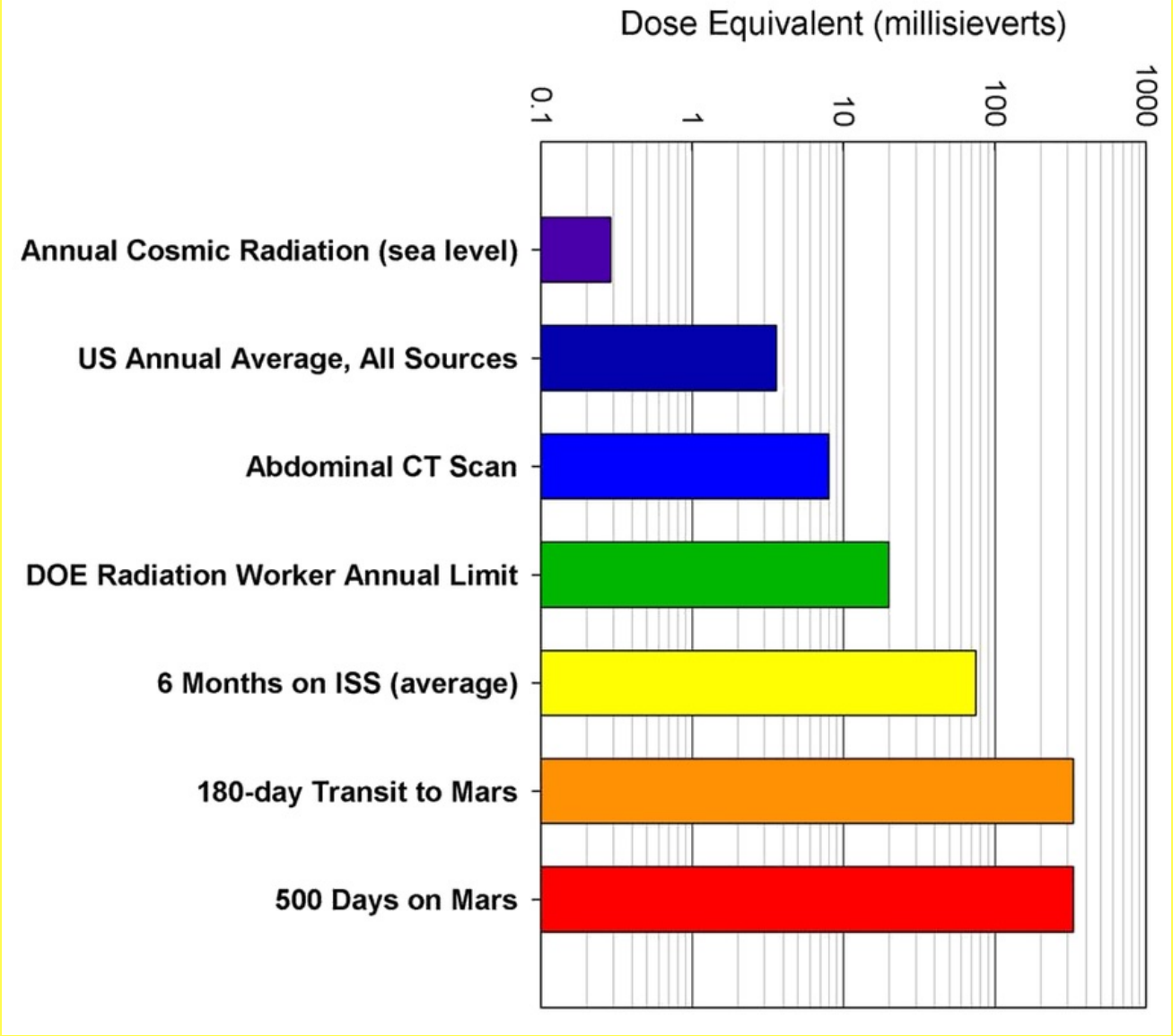
THE 1859 CARRINGTON FLARE/CORONAL MASS EJECTION



The Forbush Decrease



Space Travel to Mars: CR Exposure



The Peta-byte Challenge

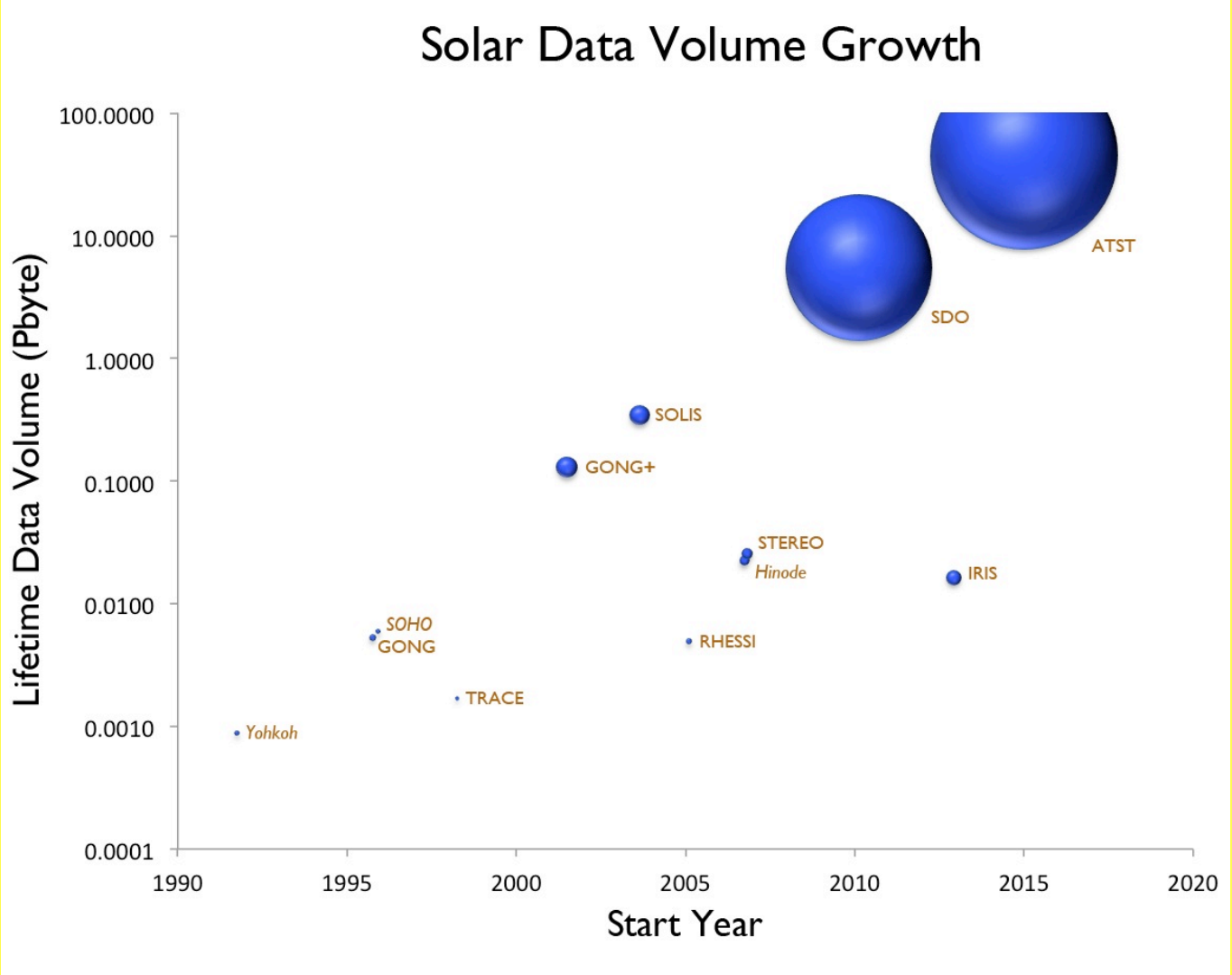
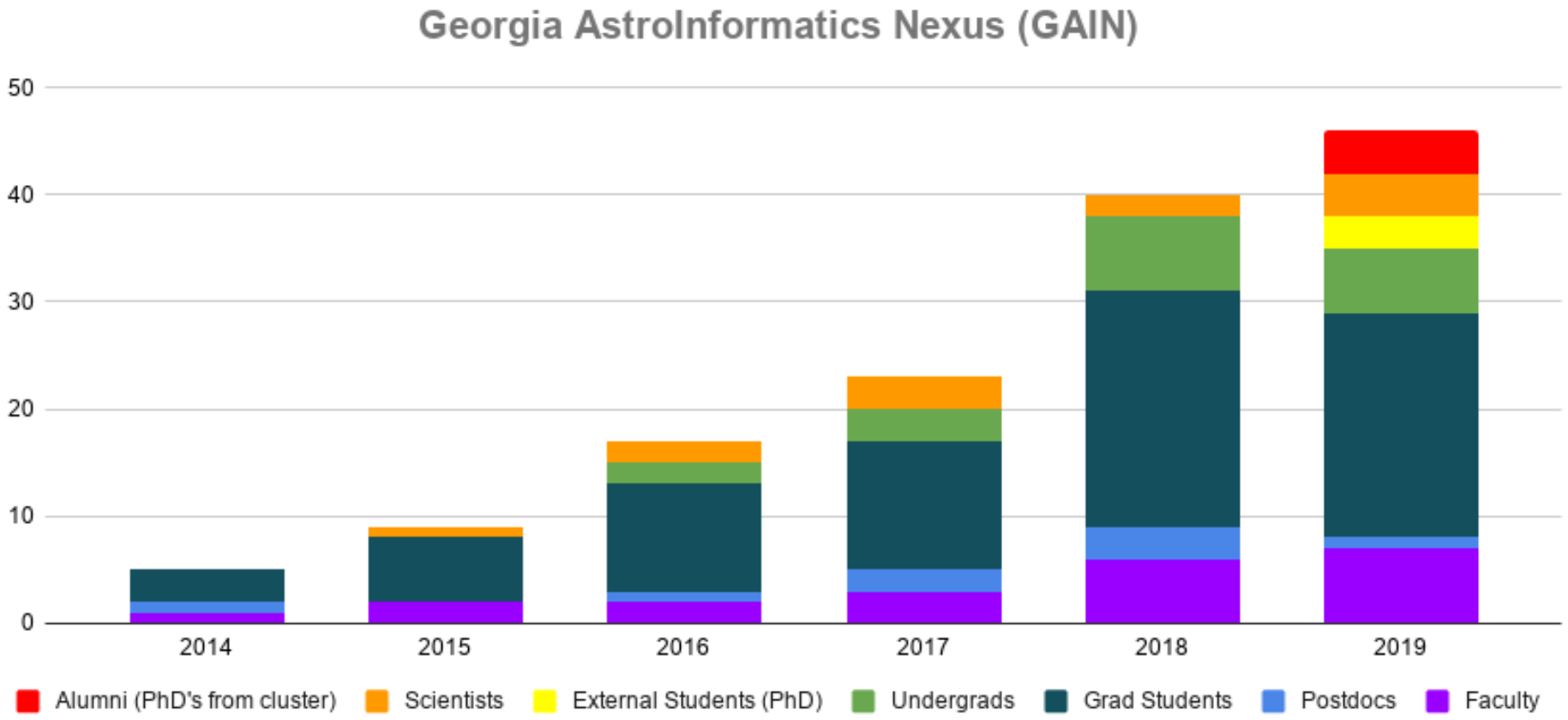


Figure courtesy of Joe Gurman (NASA)

Solar-Stellar Informatics and Imaging Cluster: Truly Interdisciplinary





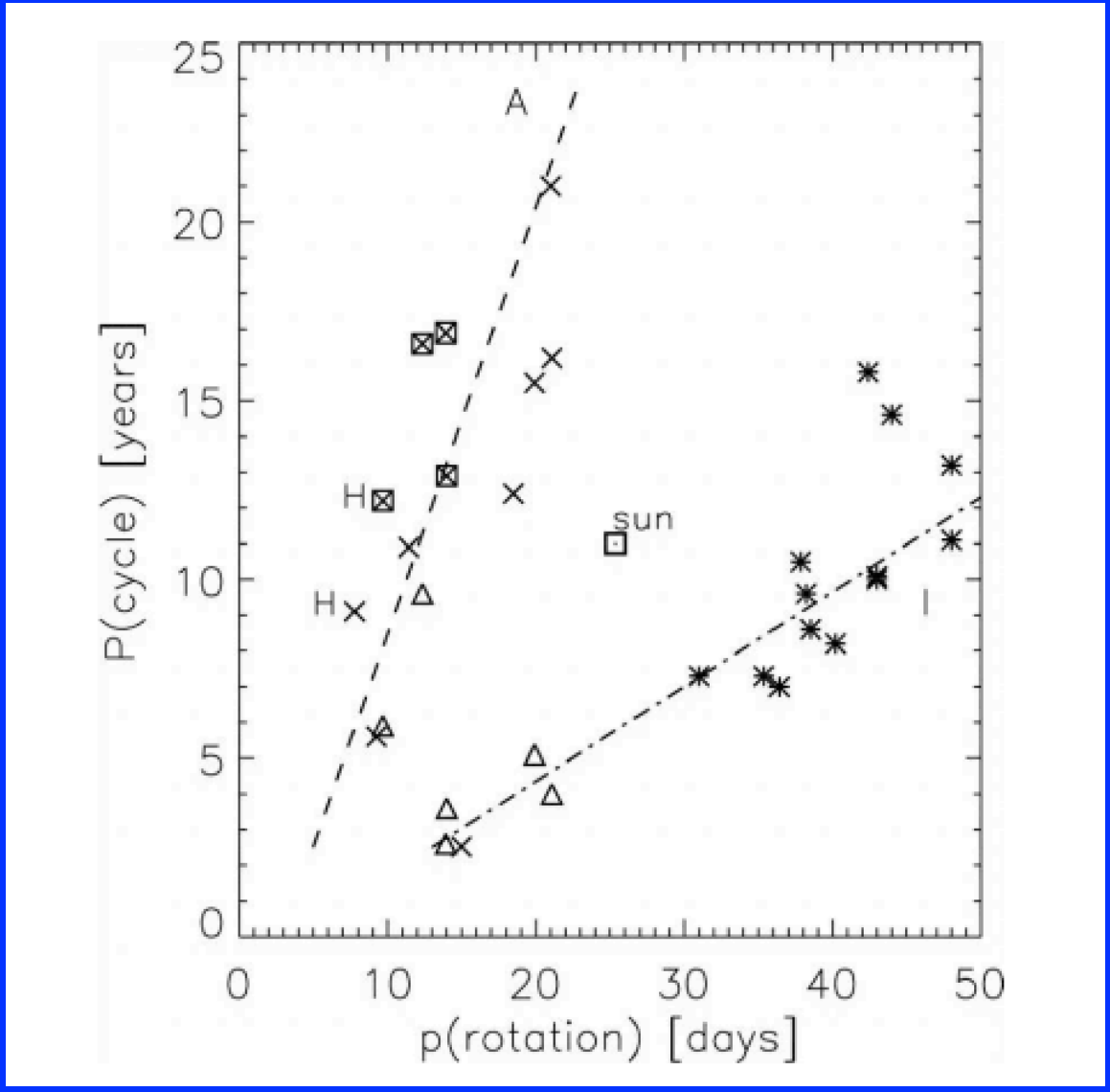
48 members currently, 6 TT and 2 RP faculty,
23 graduate students, 1 upcoming TT hire

Dynamo Domains

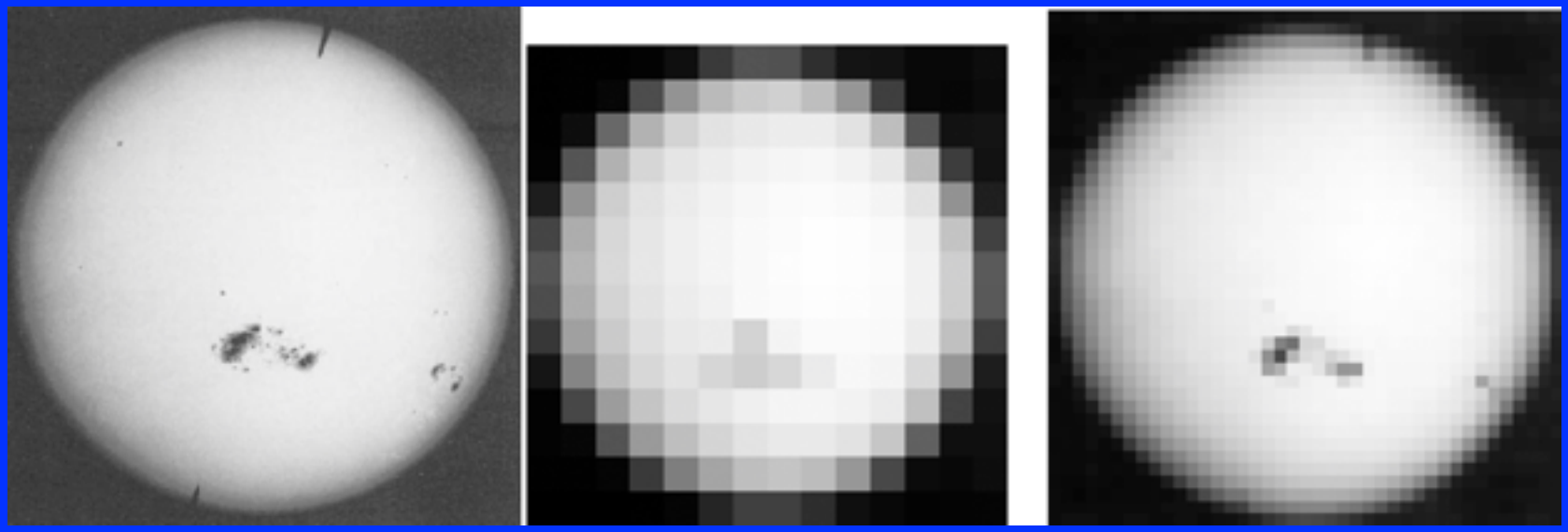
From Böhm-Vitense (2007), reject Lovis et al. (2011) data

Interpretation: Gap between two dynamo domains, with the Sun in transition!

Active Branch: P(cycle) ~ 400 P(rot), Rossby number < 1,
Inactive Branch: P(cycle) ~ 90 P(rot),
Rossby number > 1



Testing Dynamo Models on Other Stars With CHARA



Left: The Sun on April 18, 1947
Middle: Same as imaged by CHARA
Right: As observed with proposed CHARA upgrade

Future Plans, Major Projects

NASA DRIVE (Diversify, Realize, Integrate, Venture, Educate) Science Center: Integrate Simulations and Machine Learning, proposal submitted (Martens PI), joint with Predictive Science Inc, San Diego

Solar Event Prediction: Continue to apply cutting edge machine learning techniques to forecast hazardous solar events , NSF proposal funded (Angryk PI). NASA proposal submitted (Georgoulis PI). NSF Cyber infrastructure development (Aydin PI)

Space Situational Awareness Center: Space Weather, Space Debris, Impacting Asteroids, Foreign Satellites. Under consideration (Jefferies, PI)

GSU Imaging Innovation Hub : Build a community of scholars that bridges the disciplines in work on imaging. GSU NGFP, funded (Jefferies, PI)