Space weather research: The flip side of effective forecasting

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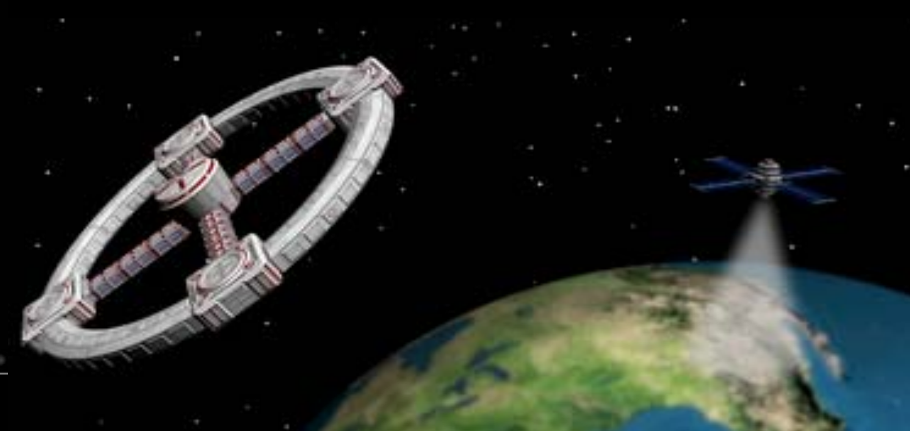
Advancing the Science of Space Weather Prediction through Research ……

The vision for the future is that humankind will work, learn, operate and live safely in space.
-- National Space Policy 2010

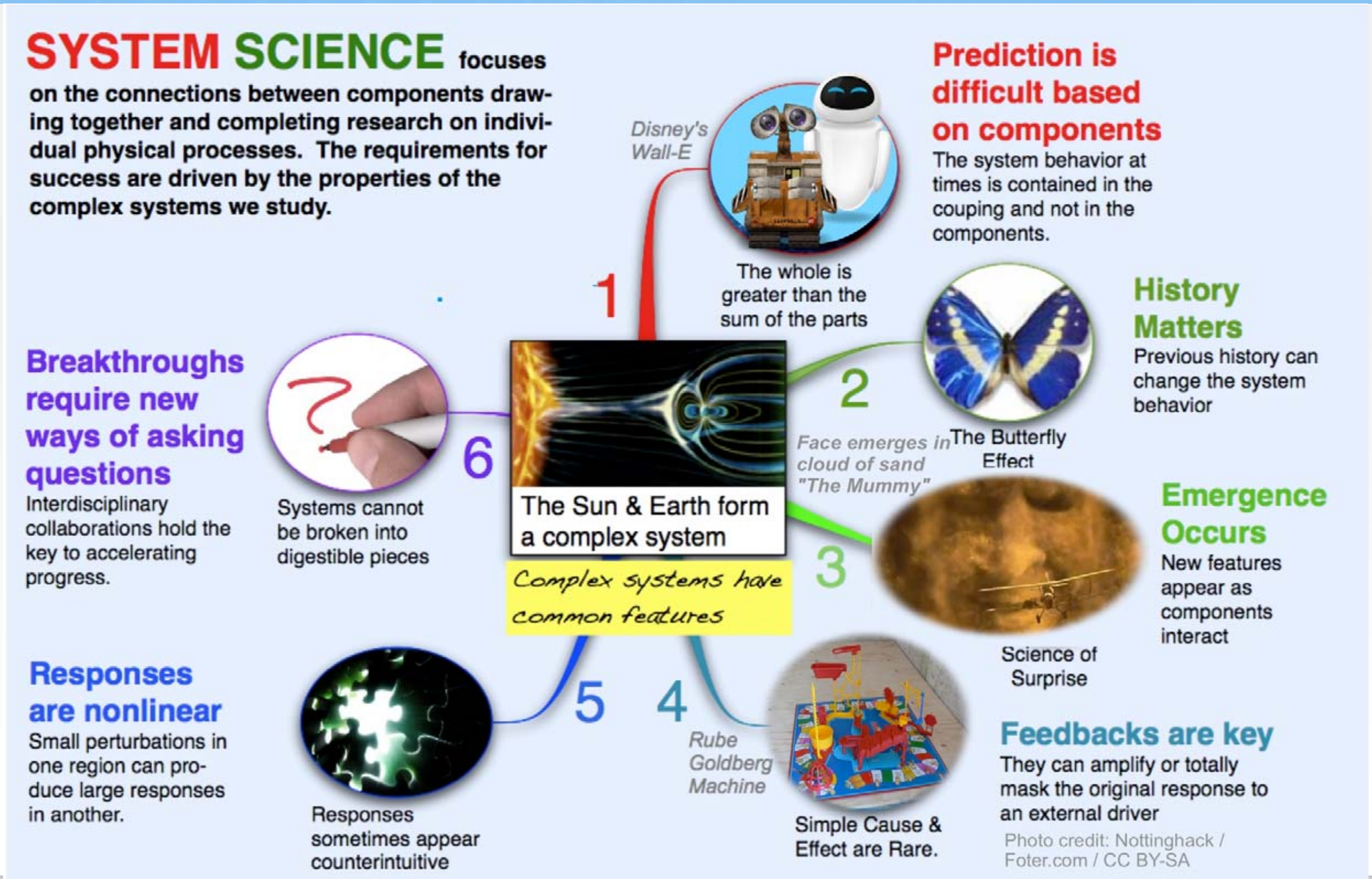


Advancing the Science of Space Weather Prediction through Research ……

When US industry, tourism and national security are building our future in space

Will we have the knowledge to safeguard their journey & to protect life and critical infrastructures on Earth?

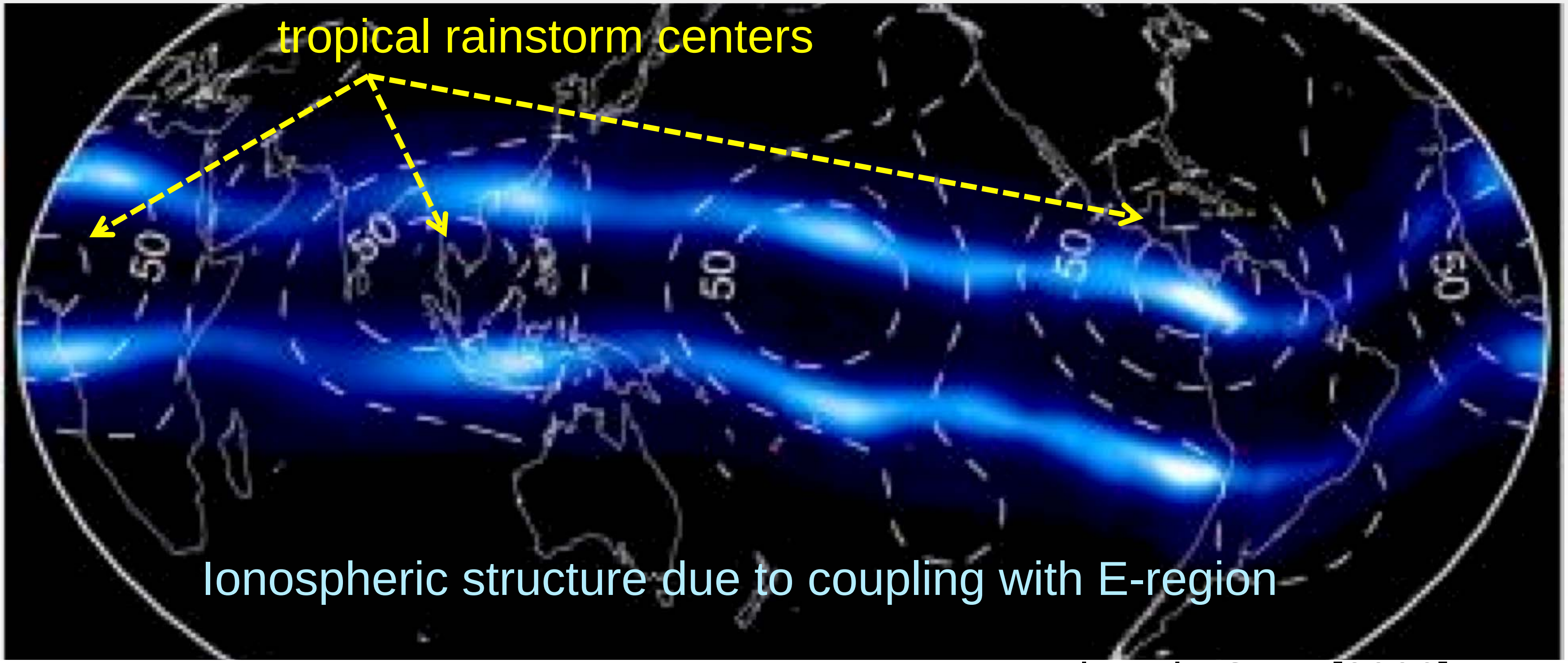
Understanding the Sun-Earth system is one of the greatest challenges of our generation - What's so difficult?



Some Key Unknowns

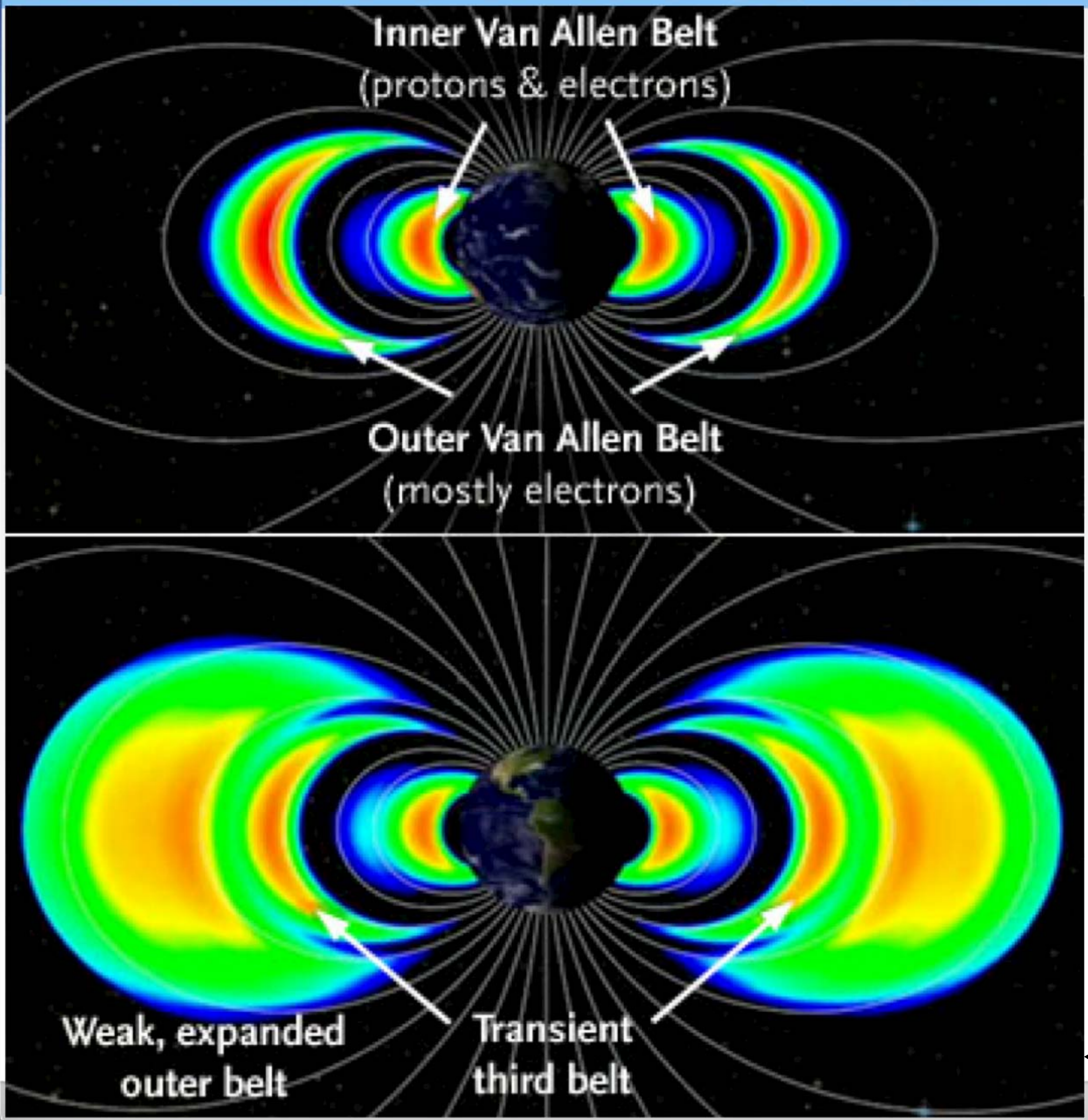
- Triggers of catastrophic energy release in flares and CMEs
- Orientation and intensity of the interplanetary magnetic field in eruptive events
- How does propagation to Earth change geo-effectiveness?
- What causes extreme events (100-year storms)? Are they predictable?
- Acceleration and transport of energetic solar particles? Radiation belts?
- How do asymmetries in longitude, offset of the geographic & geomagnetic poles, and the South Atlantic anomaly create ionospheric structures and gradients? Are there preferred longitudes?
- What are the global patterns of ITM coupling and feedback? How do they determine geospace responses to solar wind inputs?

Recent System Science Breakthroughs: Global space weather driven by surface weather



Immel et al., GRL, [2006]

New Puzzles: Temporary Radiation Belt



Van Allen Probes observed a third electron radiation belt appear and disappear over the course of a month (Sept 1 – Oct 1, 2012). An interplanetary shock apparently destabilized and destroyed the belt

CREDIT: NASA/SDO/AIA/GSFC

Probable source of the new belt – 31 Aug 2012 giant filament eruption

← *NASA / JHU-APL / Univ. of Colorado*

New Observations: First views of the core flux rope formation from SDO

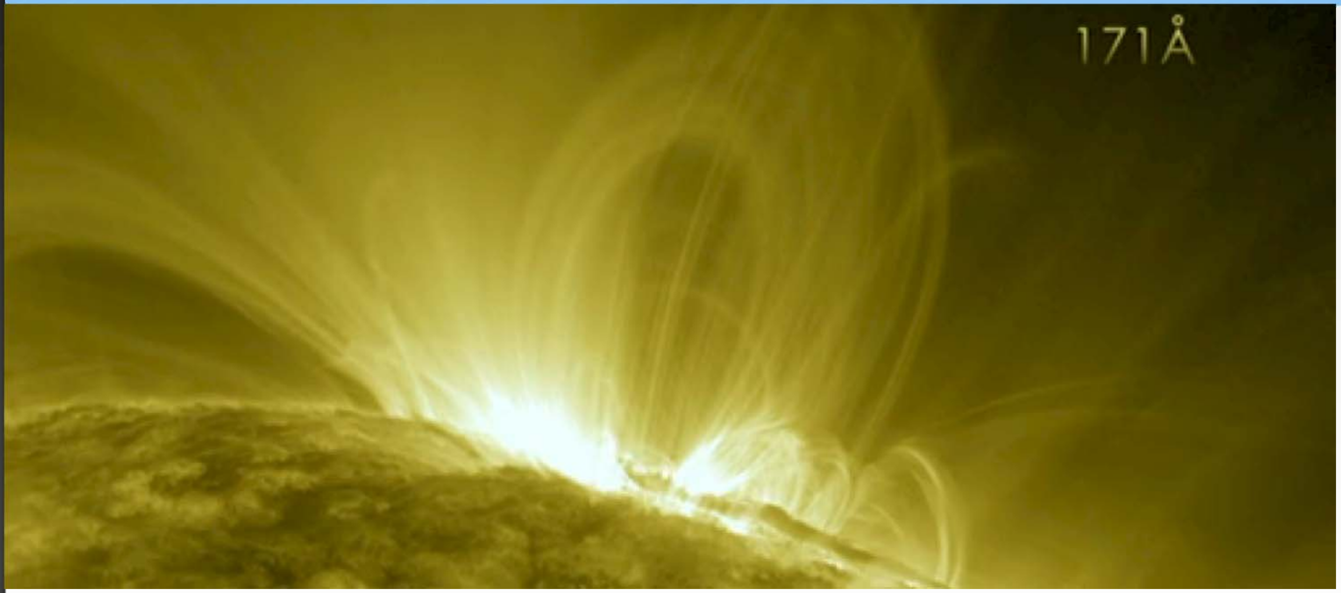
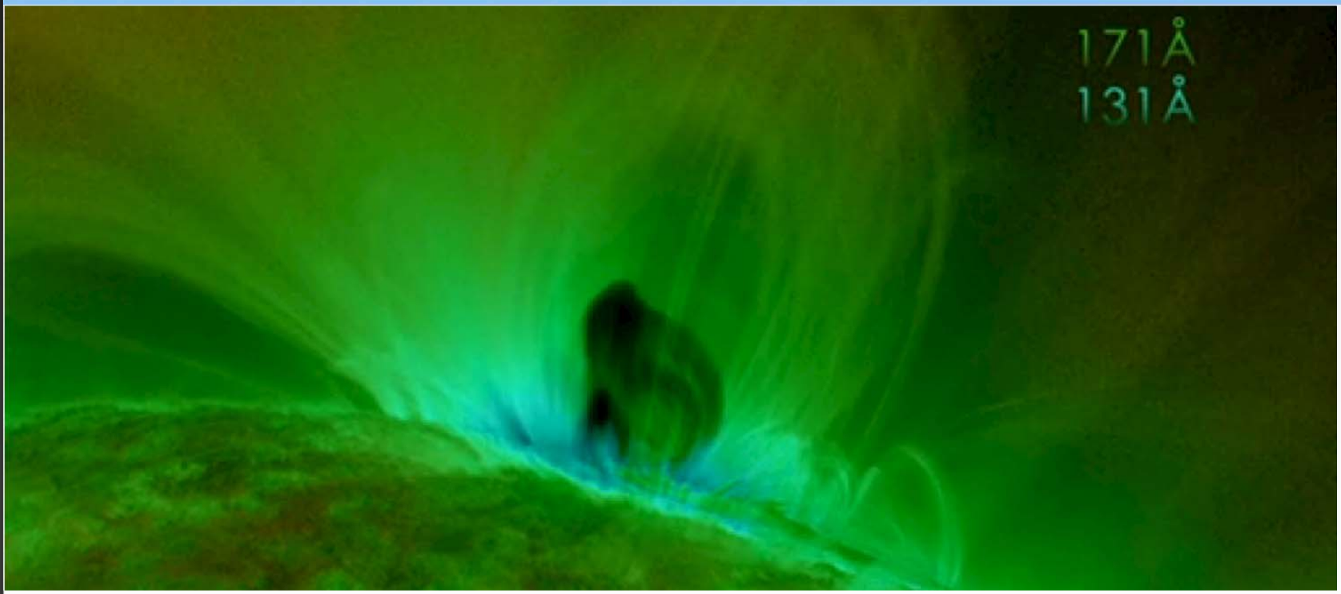


Image of an active region in 171Å emissions.

19 July 2012 Credit: NASA/SDO/GSFC 171Å

New Observations: First views of the core flux rope formation from SDO



First observations of the early formation of the kinked flux ropes at the heart of a coronal mass ejection. Not visible at 171Å - only seen in the 131 Å channel on SDO (plasma at ~10,000,000 K).

19 July 2012 Credit: NASA/SDO/GSFC 131Å

Such direct observations take us a step closer to predicting eruptive events, a major source of space weather

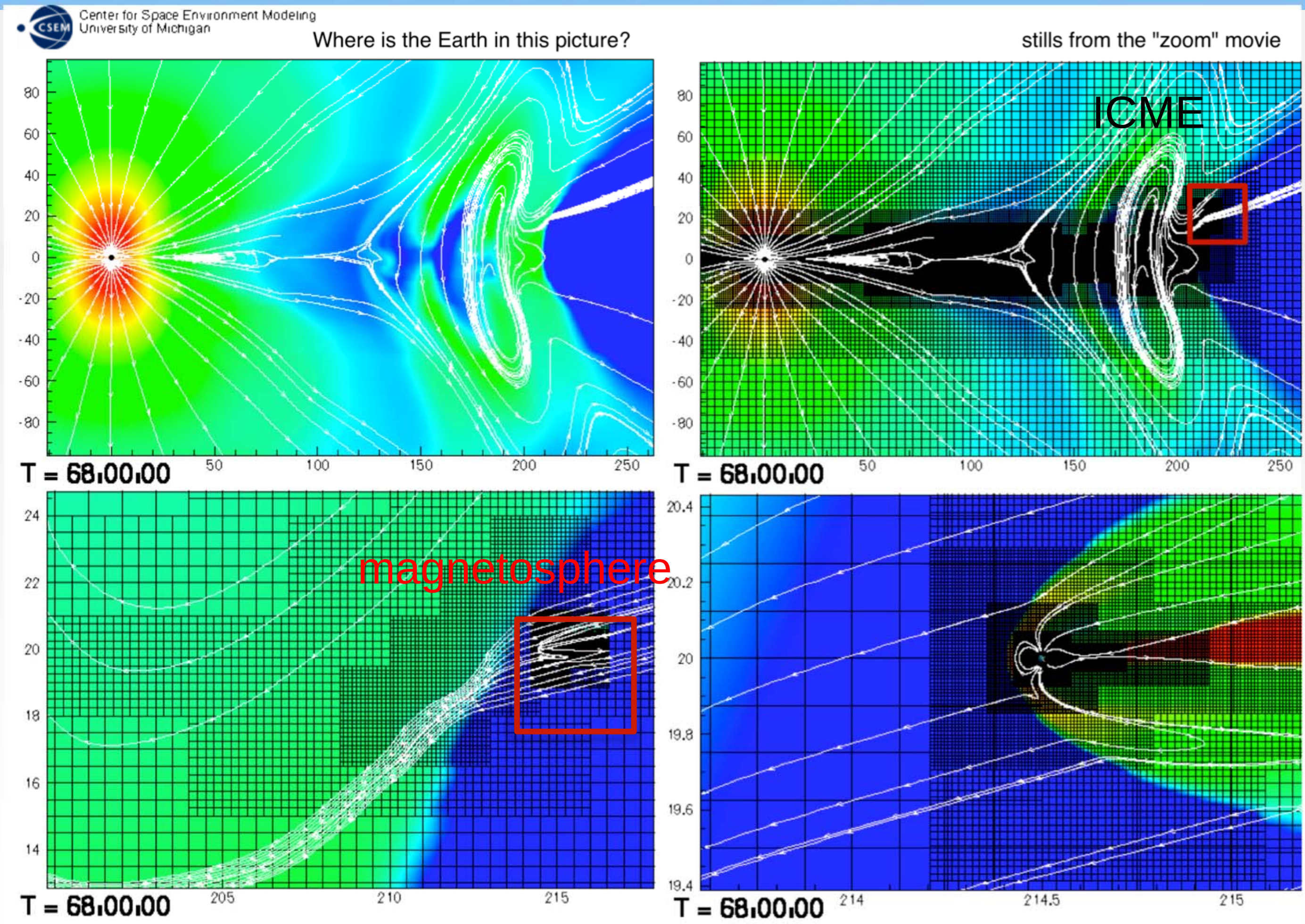
New requirements on research: Must investigate global coupling while deepening knowledge of individual pieces

Important resources

See upcoming talks by Victoria Elsbernd (NASA) , Richard Behnke (NSF)

- Heliophysics Systems Observatory (HSO)—supported by NASA and NSF. Augmented by a constellation of missions operated by NOAA and DOD. Remarkable potential to support simultaneous observations from distributed, strategically chosen vantage points
- Network of Virtual Observatories (VxOs)
- Program Support for Global Model Development - NASA LWS Critical Capabilities, NSF Science & Technology Centers, Space Weather Program, additional AFOSR, DoD programs
- Loosely organized collaborations: LWS Targeted Research & Technology (TR&T) Focused Science Topics (FST) with space weather applications
- Community Coordinated Modeling Center (CCMC) – Scientific validation of models, scientific development of new forecast products
- Ongoing development of more capable computers - peta-scale supercomputers

Potential of Peta-scale supercomputers: Sun to Earth simulations in real-time



- Scales
  - ICME few 100 Rs
  - Magneto-sphere few tenths Rs

Credit: Center for Space Environment Modeling (CSEM), Univ. of Michigan

International Programs that Coordinate between Nations and Discipline Areas

Map of the internet, OPTE project

IPY2007, IHY2007 , eGY2007, CAWSES, ICESTAR , ILWS

Innovation happens as ideas are cobbled together

Shared mistakes, liquid networks, lots of different ideas, different interests

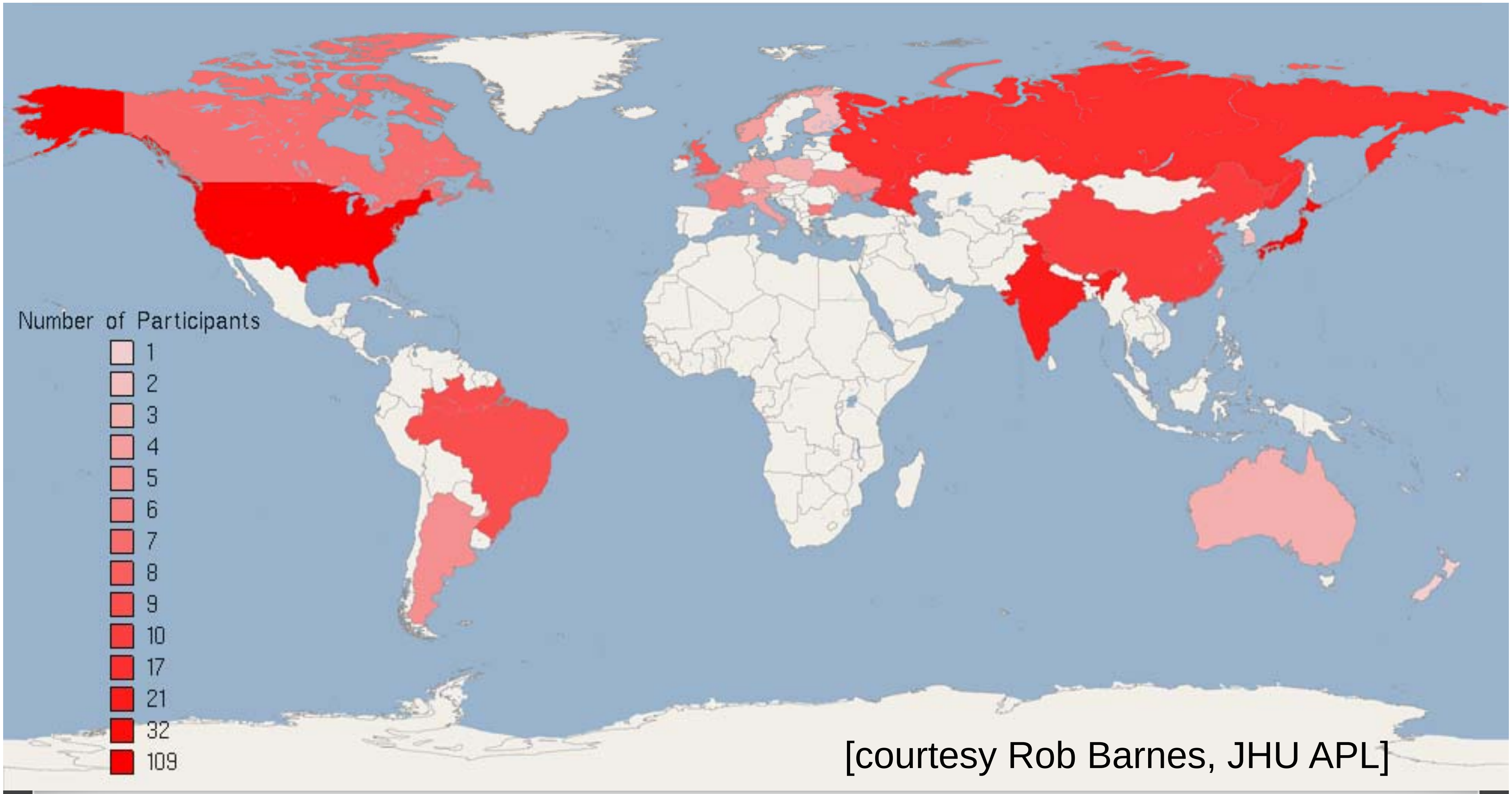
Cost of communications through the floor

Unlike institutes - nonexclusive

Recent research indicates “chance for innovation” favors the connected mind

Worldwide Participation

270 Registered Participants, 21 different countries, 120,000 total hits on the website



[courtesy Rob Barnes, JHU APL]

Conclusions

- Great opportunities for science and for society are within reach
- Understanding systems is the greatest task of our generation and is key to developing needed forecast capabilities for space weather.
- Data is not enough. Research is required to turn data into knowledge.
- Global simulations combined with observations are a primary means of investigating complex, nonlinear natural systems -- shear size, complexity & range of scales demand high-performance computational technologies.
- Data assimilation is the next crucial step forward. Requires observations throughout ***all major*** components of the Sun-Earth system to continue.
- Reaching space weather forecast goals requires framework to feed new discoveries back into working forecast models (CCMC, Computational Centers).
- Knowledge has exploded, requires specialization; while system science requires ***group successes***. Both are critical. Evaluations of these efforts are *not* the same. Resource requirements for progress are not the same.

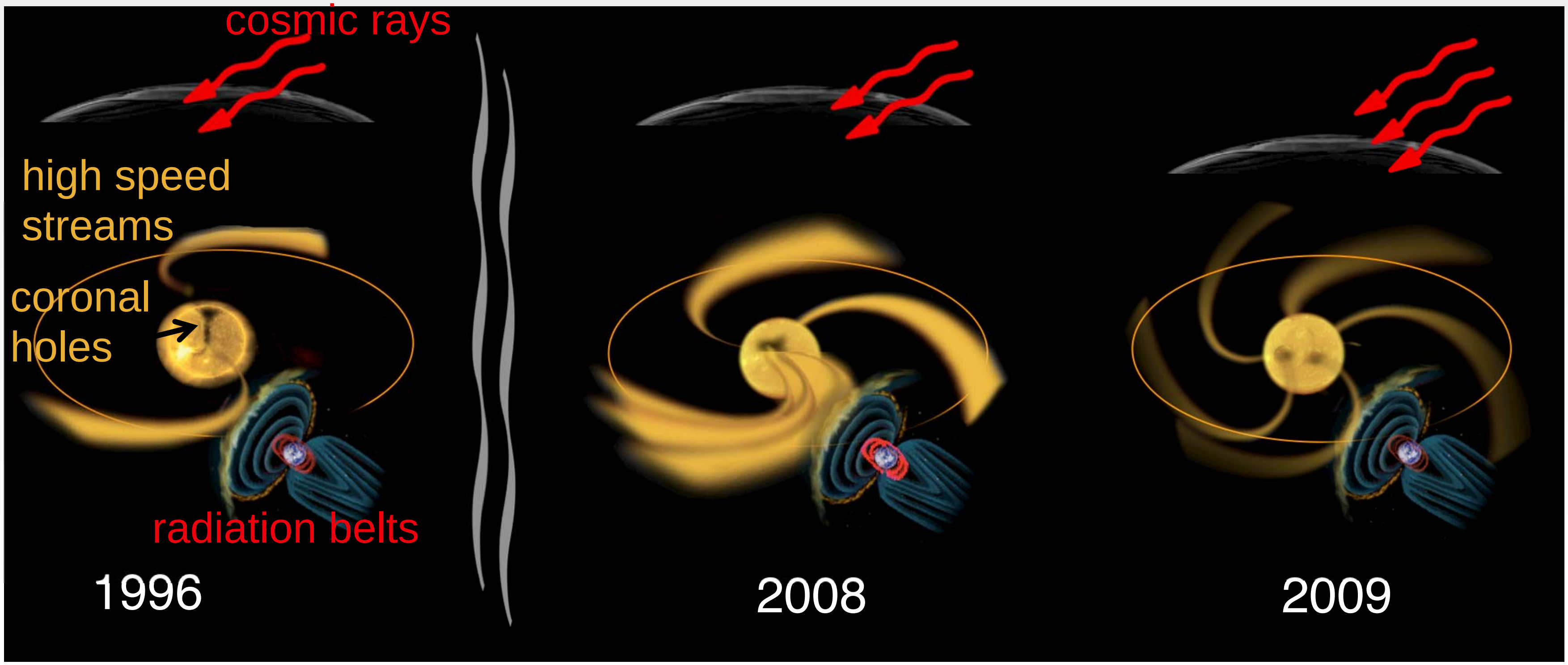
EXTRA SLIDES

Broad scientific areas ripe for transformative advances -NRC 2012 Heliophysics Decadal Report

- *Determine the origins of the Sun's activity and predict the variations in the space environment.*
- *Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs.*
- *Determine the interaction of the Sun with the solar system and the interstellar medium.*
- *Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe.*

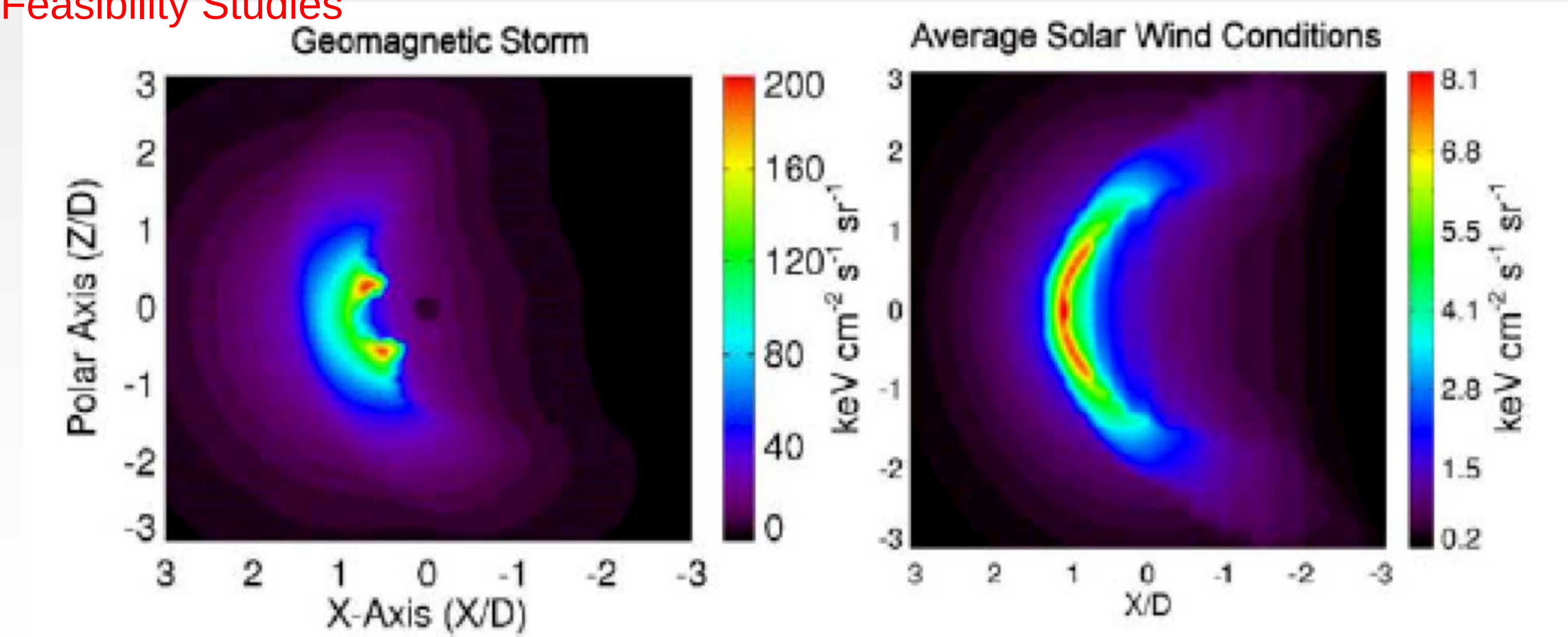
Recent System Science Breakthroughs: Surprises during the last solar minimum

Solar minimum 22-23 | Solar minimum 23-24



New Technique: Xray imaging of global solar wind – magnetosheath interaction

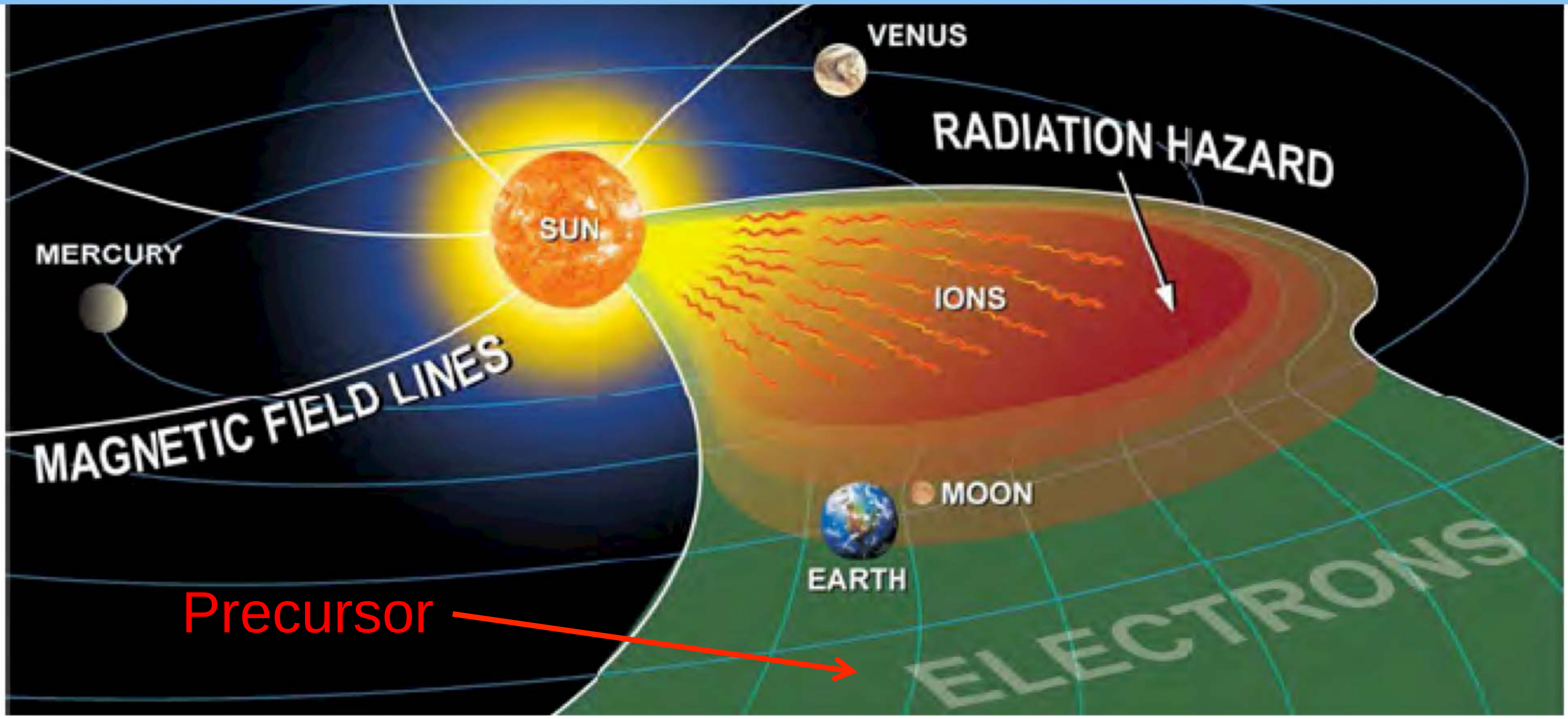
Feasibility Studies



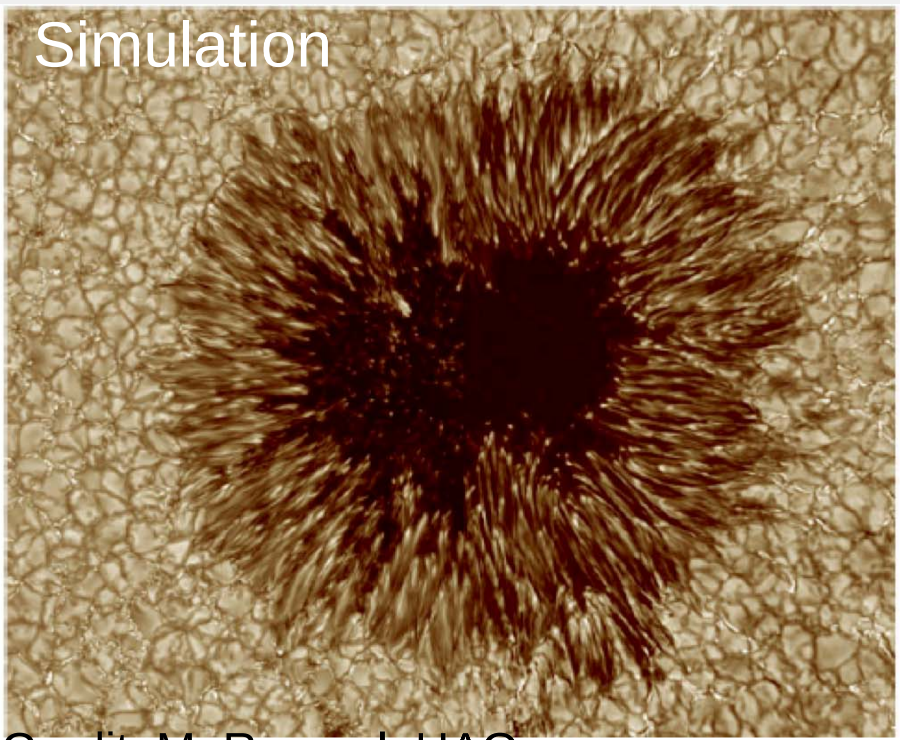
Charge transfer collisions between heavy solar wind ions and exospheric neutrals

Robertson et al., JGR, 2006

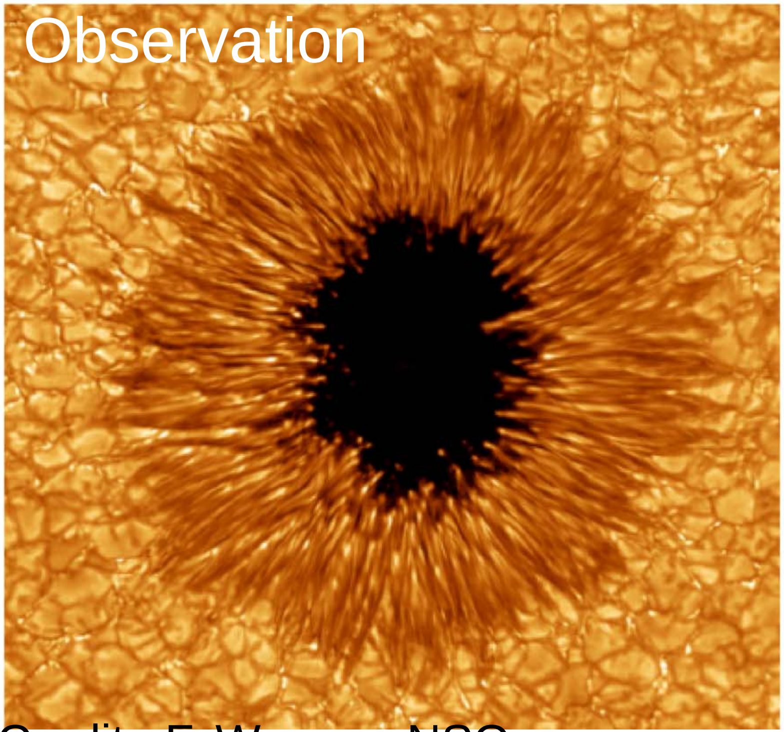
New Forecast Capabilities: Predicting arrival of solar particle event



Potential of Peta-scale supercomputers: Modeling Sunspots



Credit: M. Rempel, HAO



Credit: F. Woeger, NSO