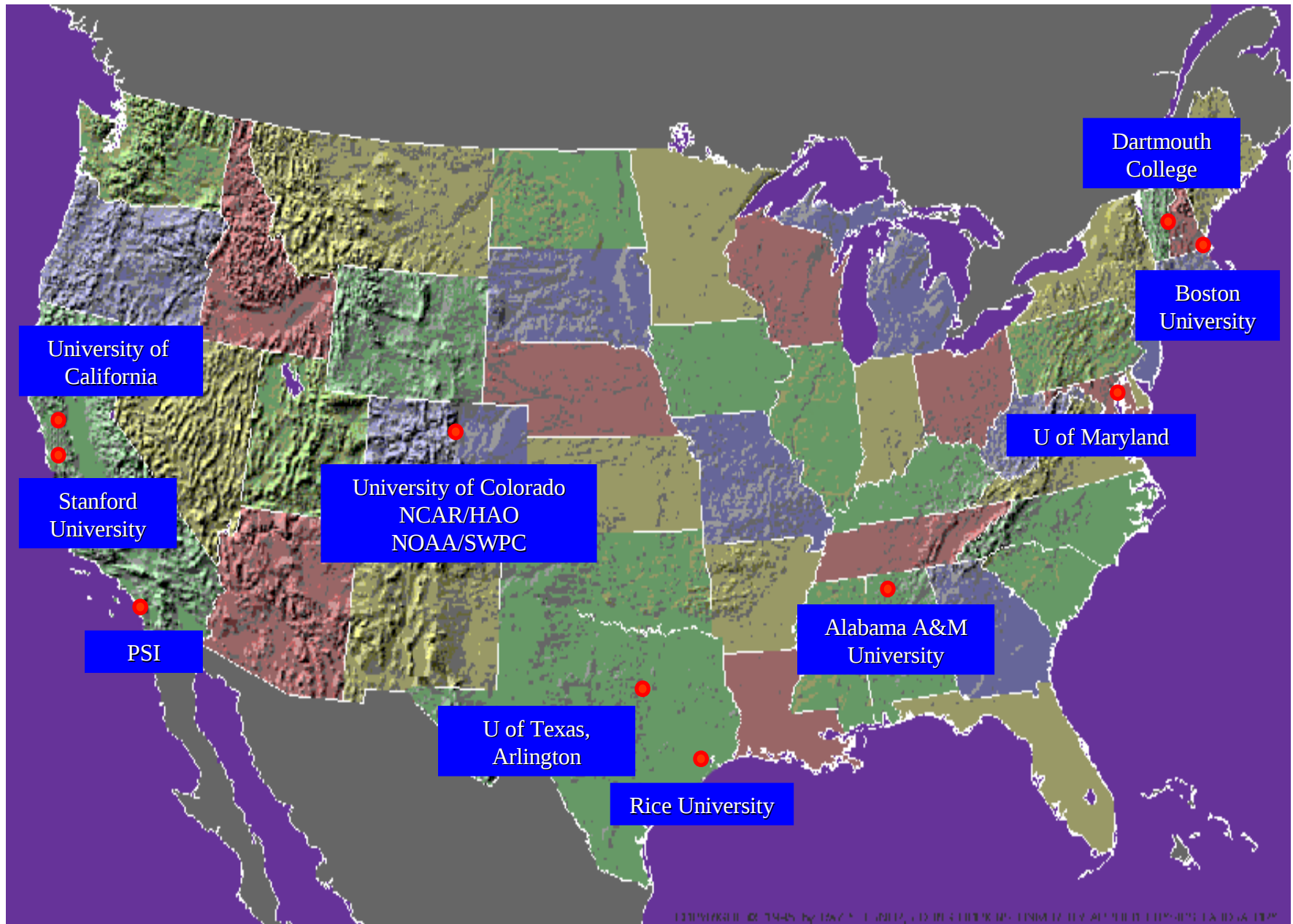


# Impact of Space Weather on Human Technology

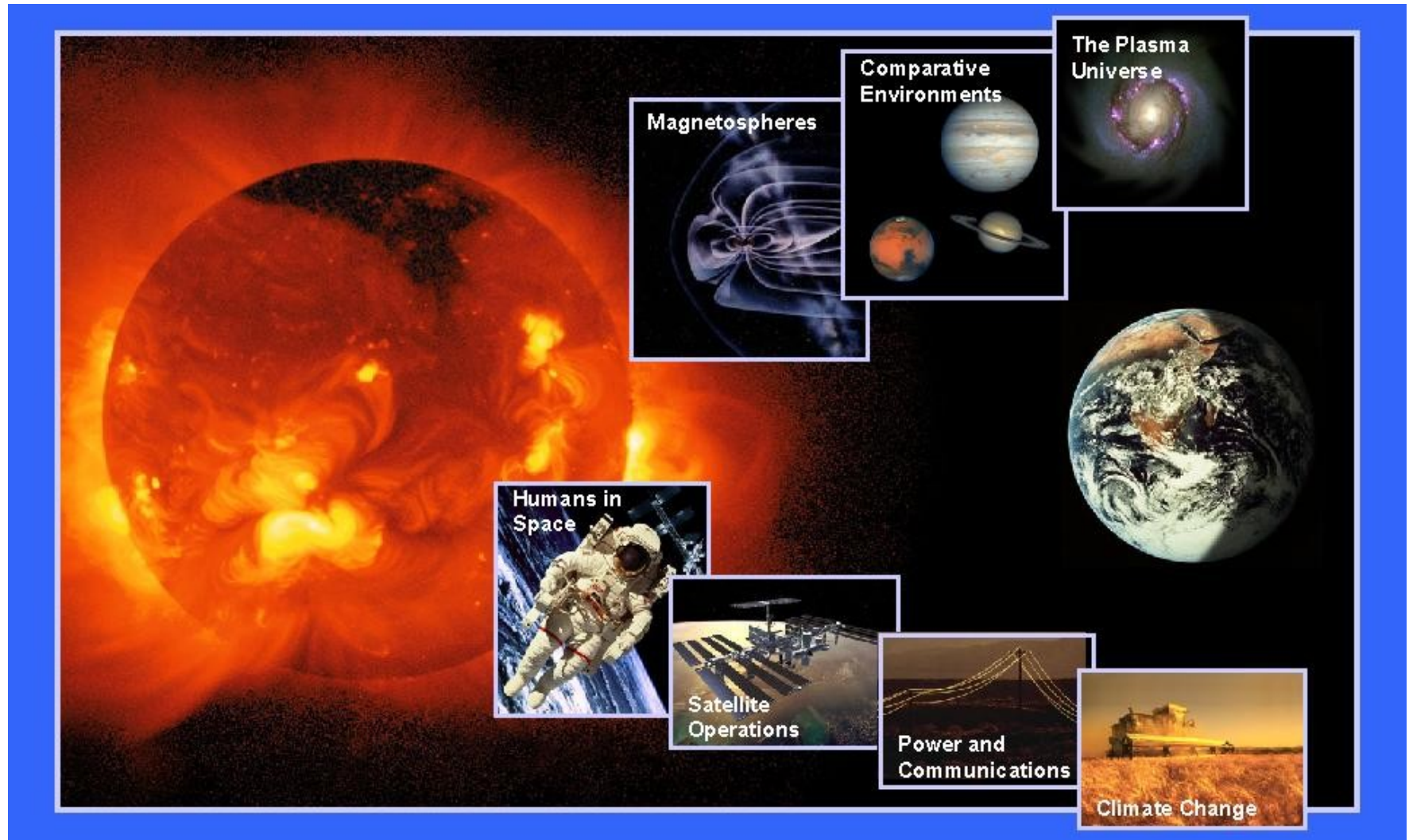
Daniel N. Baker ( Co-Director CISM)  
Laboratory for Atmospheric and Space Physics  
Astrophysical and Planetary Sciences Department  
Department of Physics  
University of Colorado, Boulder

# Center for Integrated Space Weather Modeling (CISM)



# Understanding Sun-Earth Connections

LASP Media Workshop - Boulder



[Courtesy NASA]

“Conversation about the weather is the last refuge of the unimaginative.”

“Don’t knock the weather; nine-tenths of the people couldn’t start a conversation if it didn’t change once in a while.”

-Oscar Wilde

-Kin Hubbard

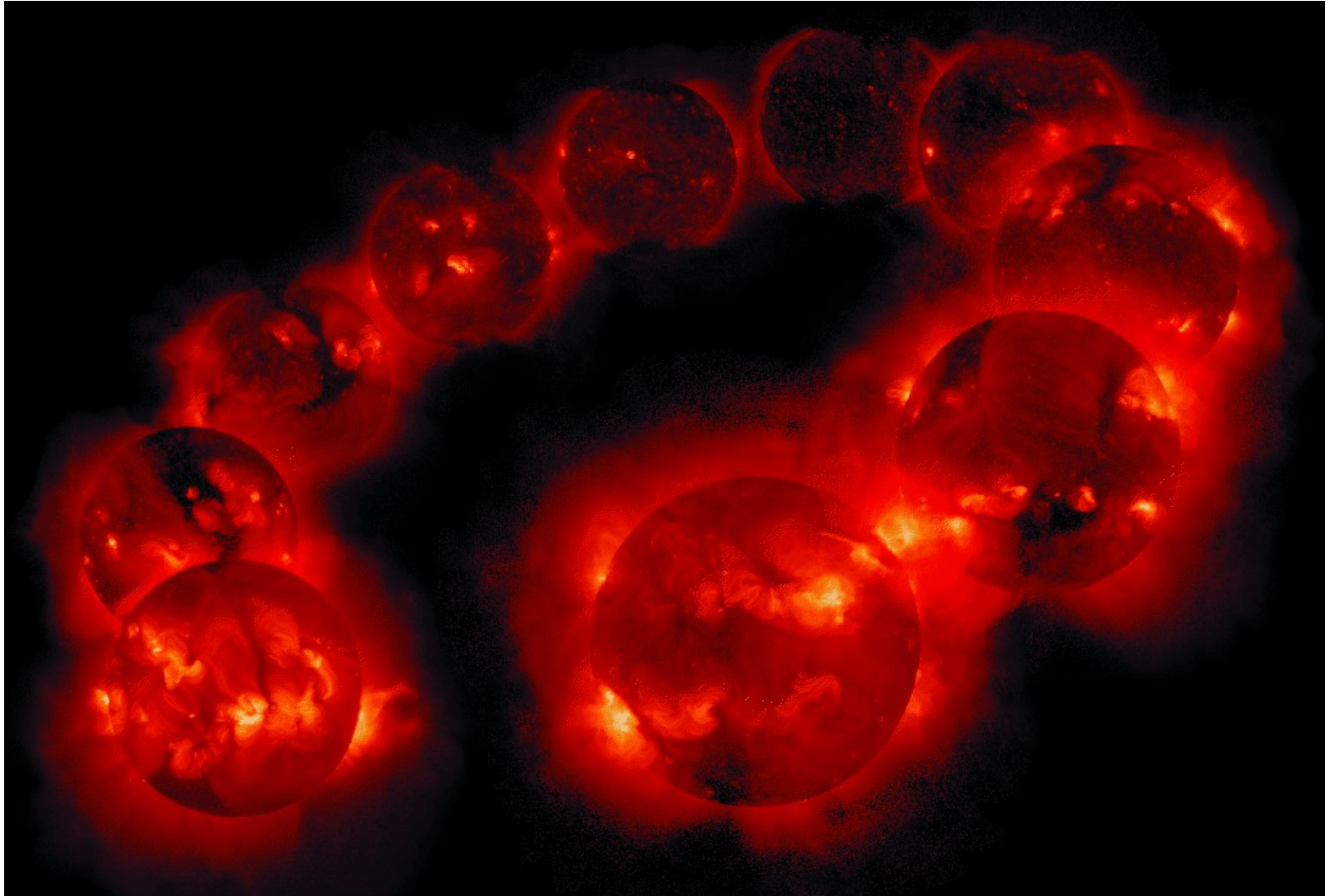
“Space Weather” refers to conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and endanger human life and health. Adverse conditions in the space environment can cause disruption of satellite operations, communications, navigation, and electronic power grids, leading to a panoply of socio-economic losses.

National Space Weather Program  
Strategic Plan (March 1995)



# Yohkoh Soft X-rays: The 11-Year Solar Activity Cycle

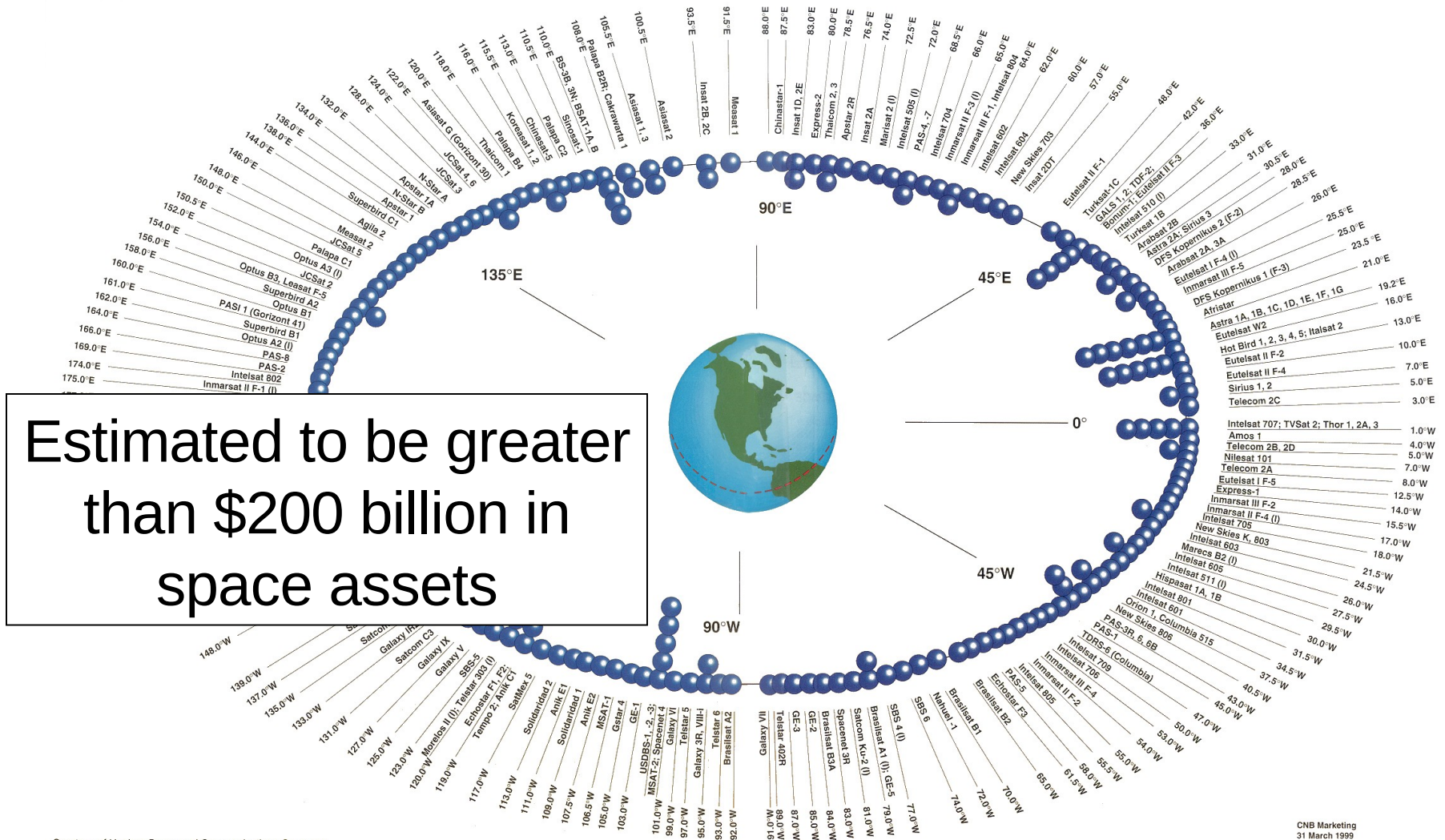
LASP Media Workshop - Boulder



[Courtesy NASA]

# Civilian Spacecraft at Geostationary Orbit

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# Coronal Mass Ejection - Earth Impact

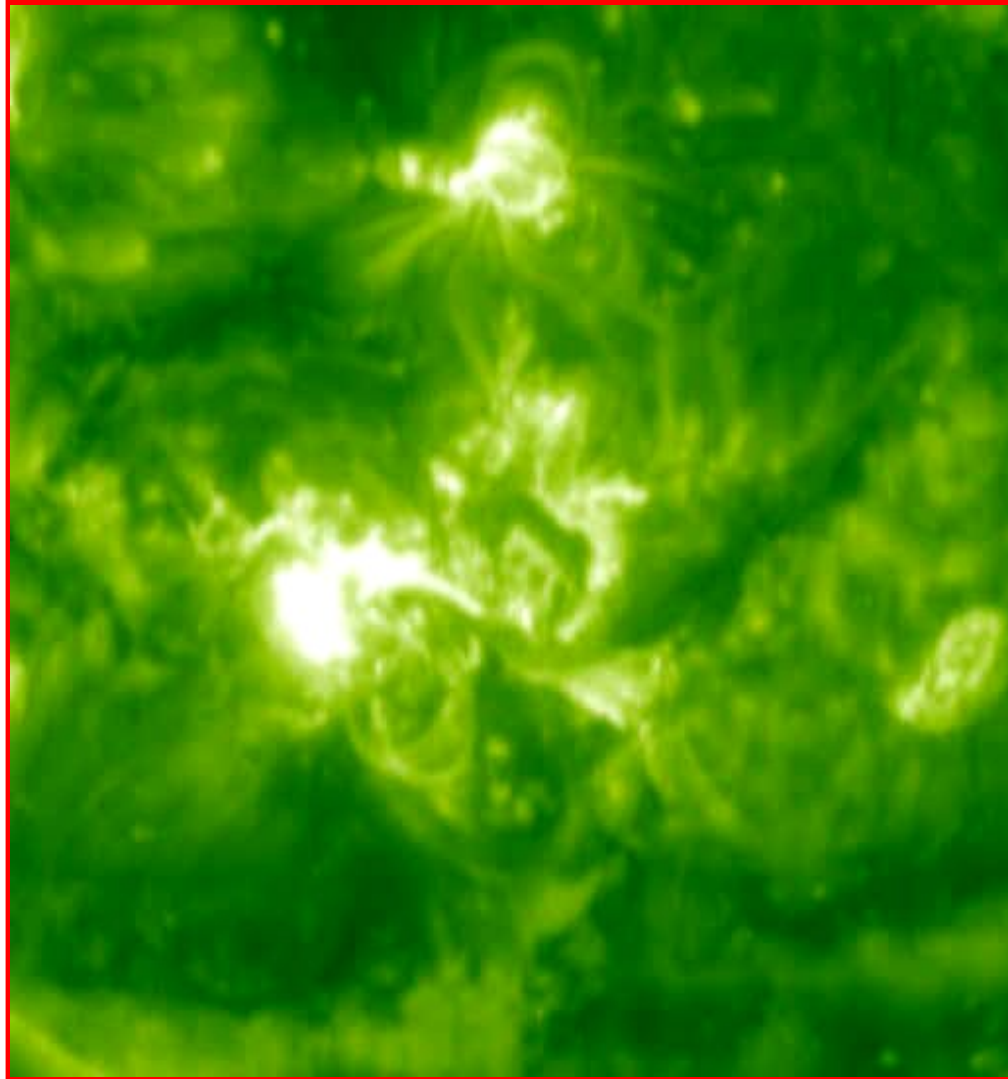
LASP Media Workshop - Boulder

Courtesy of NASA



# SOHO: Images of the Sun—October 2003

LASP Media Workshop - Boulder



[NASA SOHO Program]

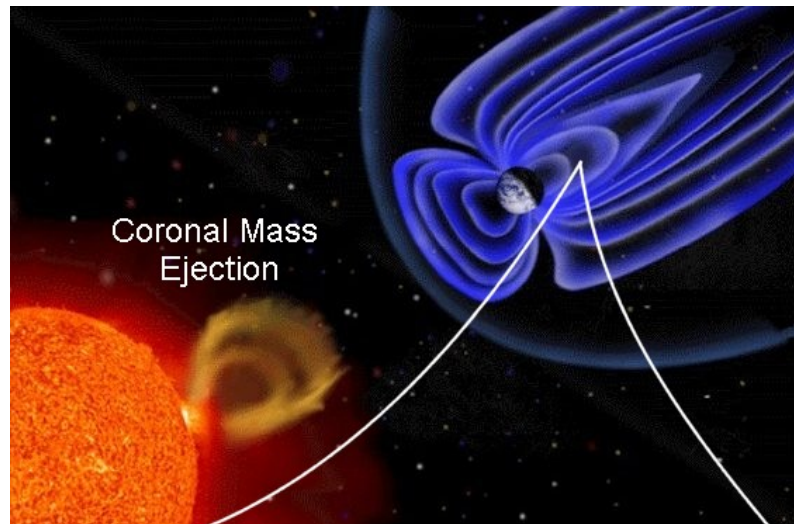


# The Halloween Storms in the Heliosphere

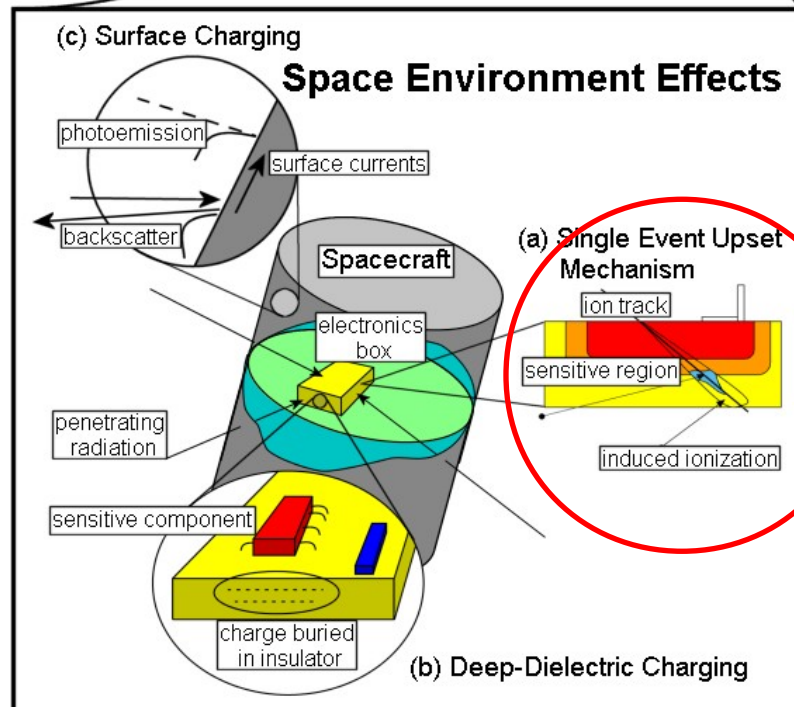
LASP Media Workshop - Boulder



[NASA]



Coronal Mass Ejection

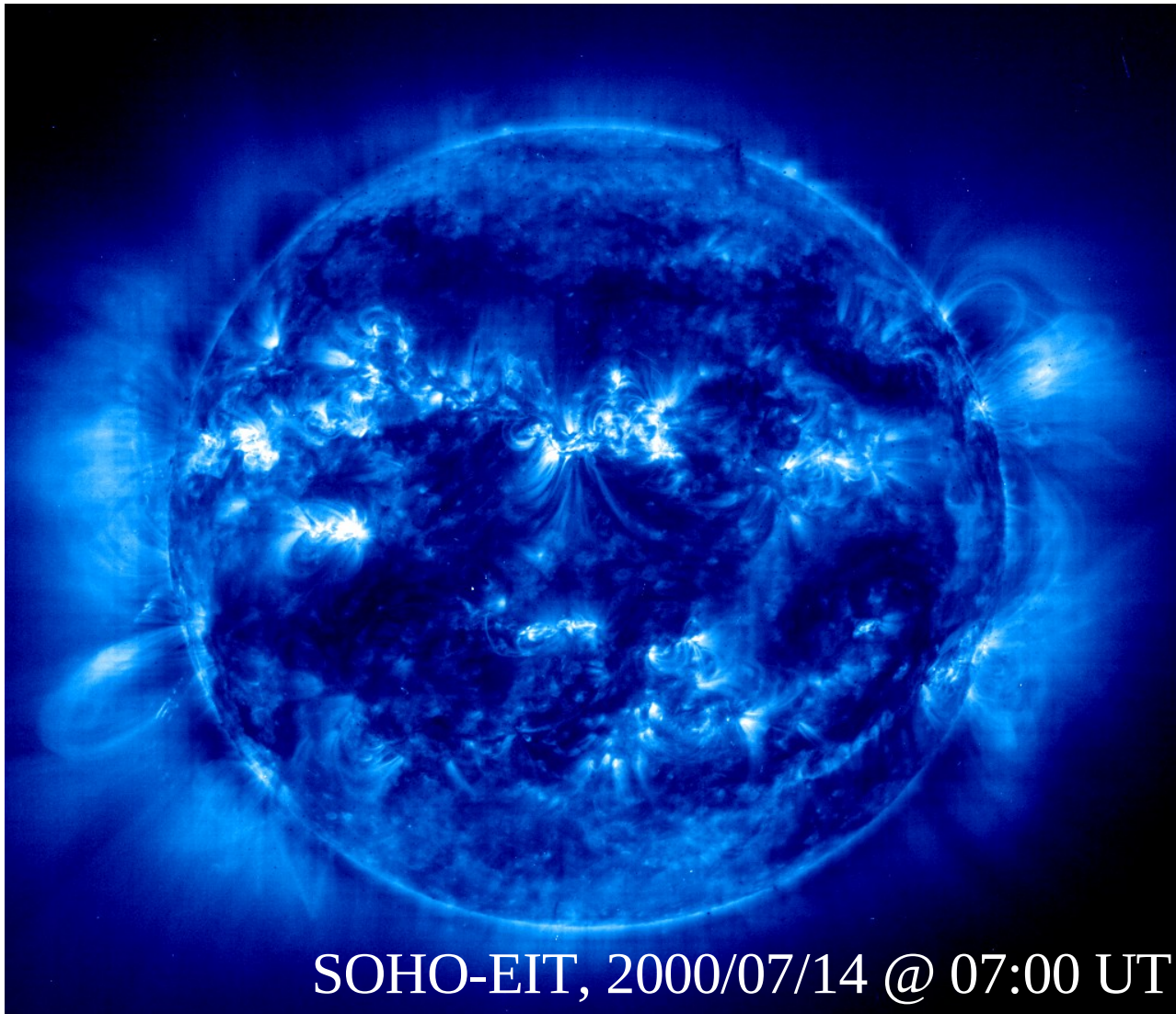


## High-Energy Ion Effects

D.N. Baker "How to Cope with Space Weather," *Science*, 297, 1486, 2002

# The Active Sun: July 2000

LASP Media Workshop - Boulder

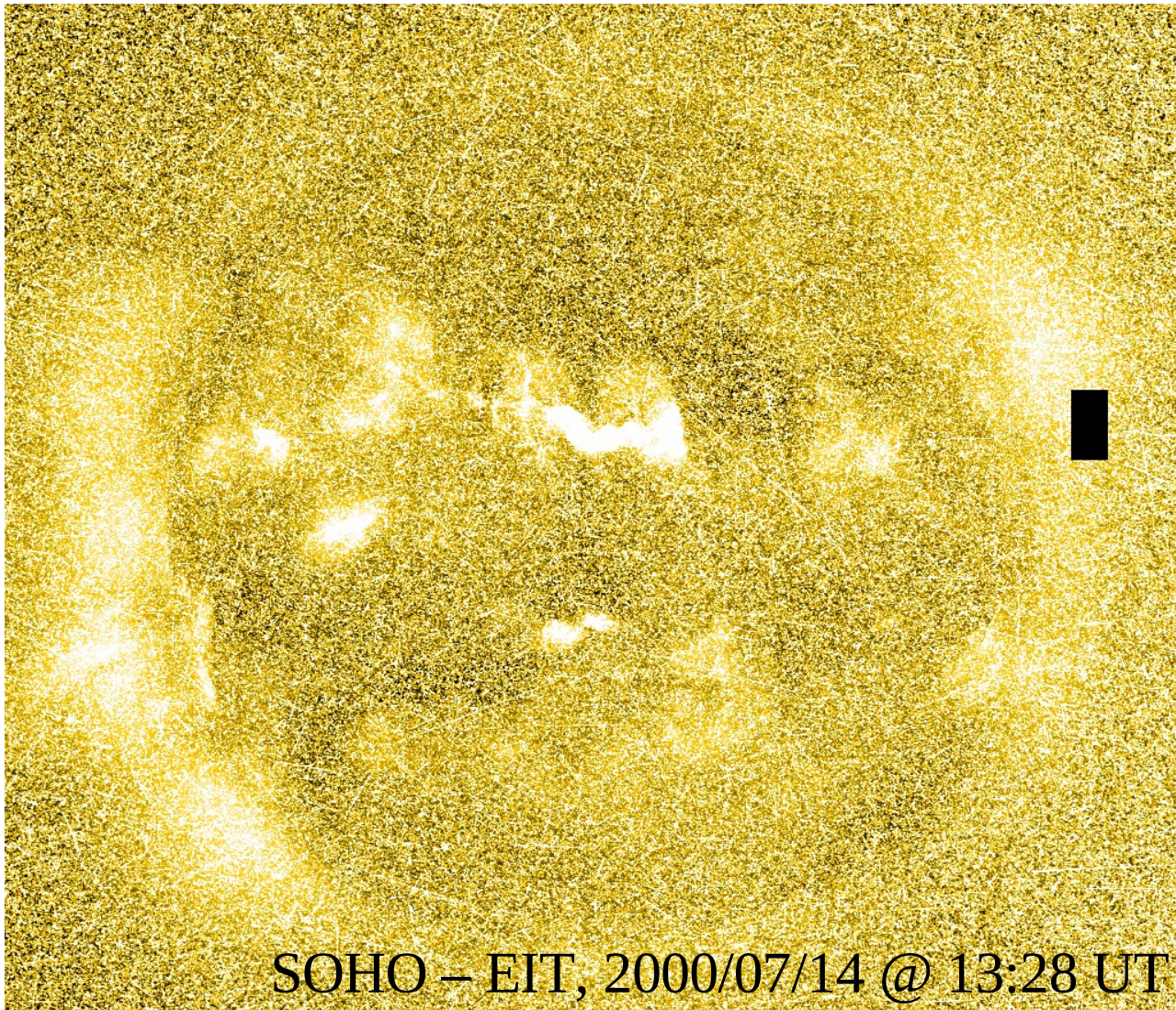


SOHO-EIT, 2000/07/14 @ 07:00 UT

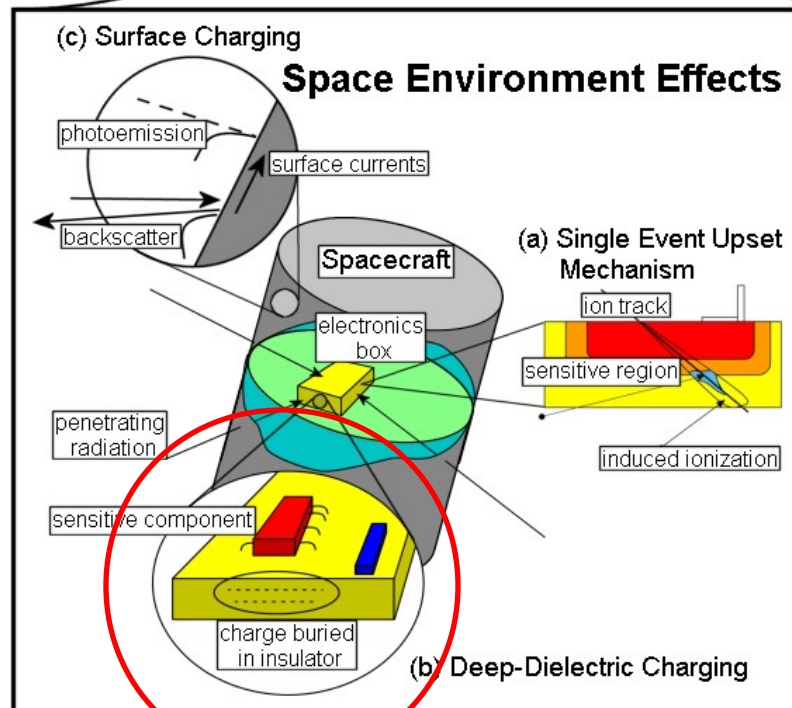
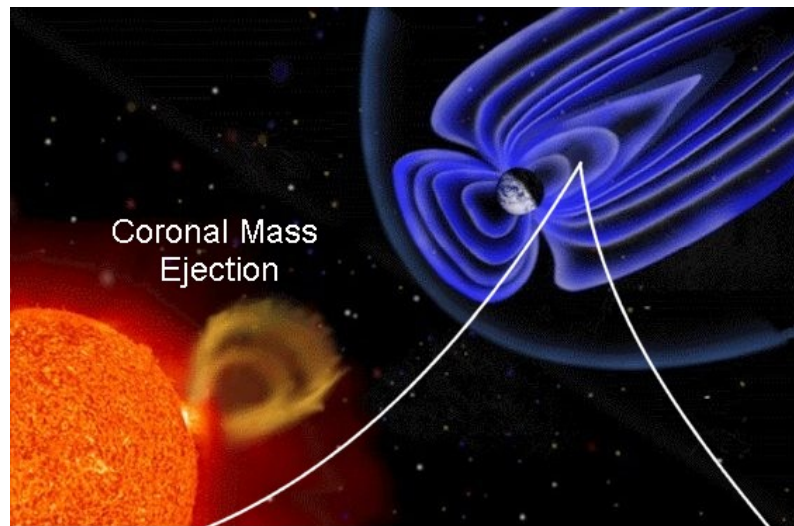


# Background Due to Solar Energetic Particles

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# Electrostatic Discharge (ESD)

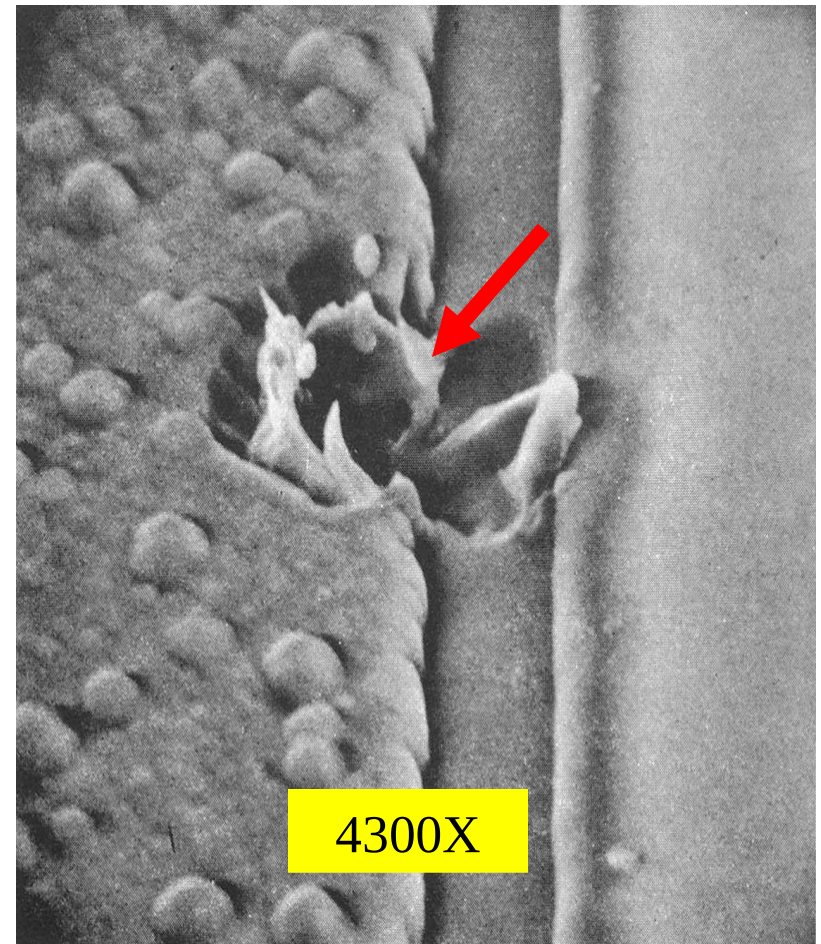
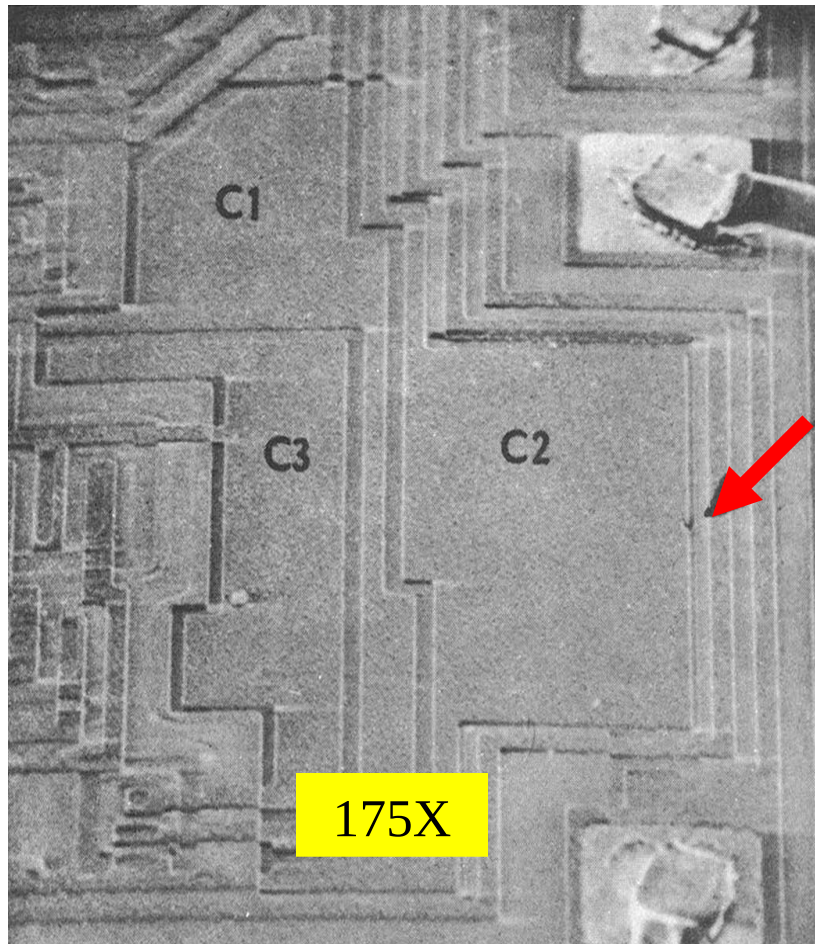
LASP Media Workshop - Boulder



- Definition:
  - A transfer of electrostatic charge between bodies at different electrostatic potentials caused by direct contact or induced by an electrostatic field.

# ESD Damage

LASP Media Workshop - Boulder

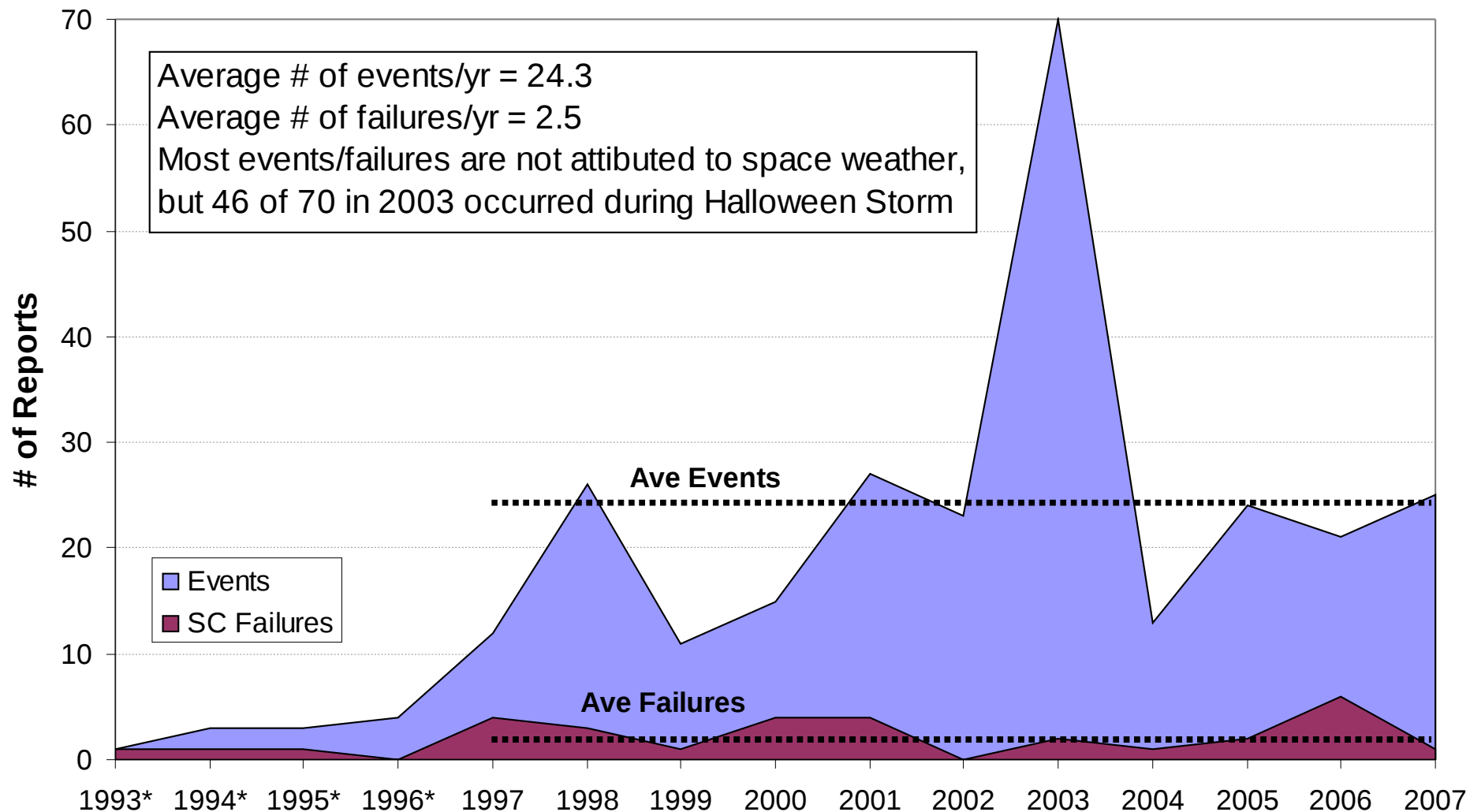


HA-2700 surface damage in the C2 MOS capacitor  
(Courtesy of JPL)



# Spacecraft Anomalies and Failures

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[National Research Council]



# GPS Growth

LASP Media Workshop - Boulder

Global Positioning System used: In-vehicle navigation systems, railway control, highway traffic management, emergency response, commercial aviation, and much more...

GPS Global Production Value—expected growth:

2003 - \$13 billion

2008 - \$21.5 billion

2017 - \$757 billion

Industrial Technology Research Institute (ITRI) – Mar 2005

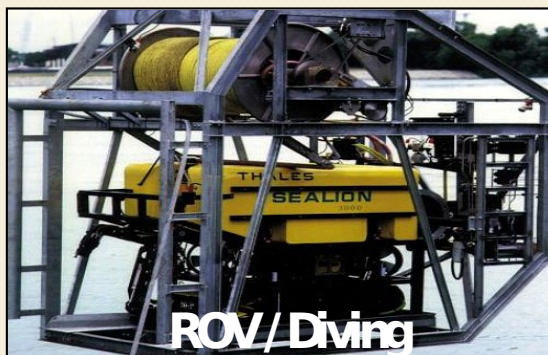
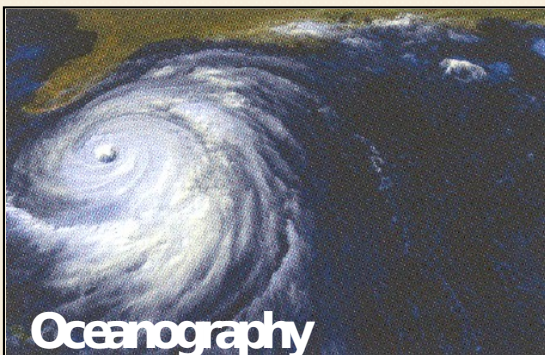
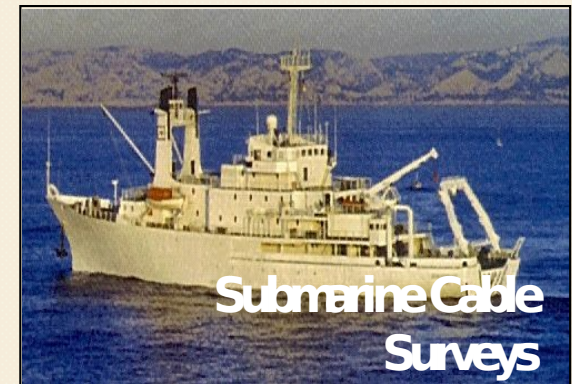
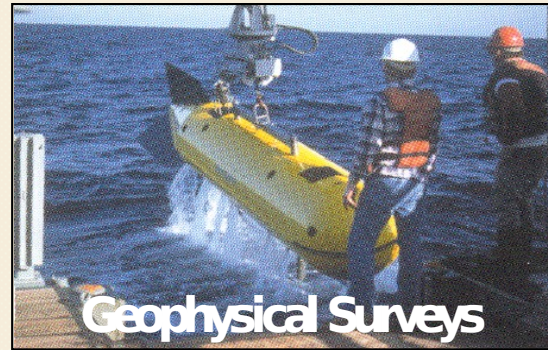
**NAVSTAR - USA**  
**GLONASS - Russia**  
**Galileo - Europe**



Space weather creates positioning errors larger than 50 meters  
—A mid-latitude problem (where most users reside!)



# Business Lines





# WAAS

Wide Area Augmentation System

GPS Satellites



● Wide-area Reference Station (WRS)



Wide-area Master Station (WMS)

● International WRS's



Ground Uplink Station

GEO Satellite

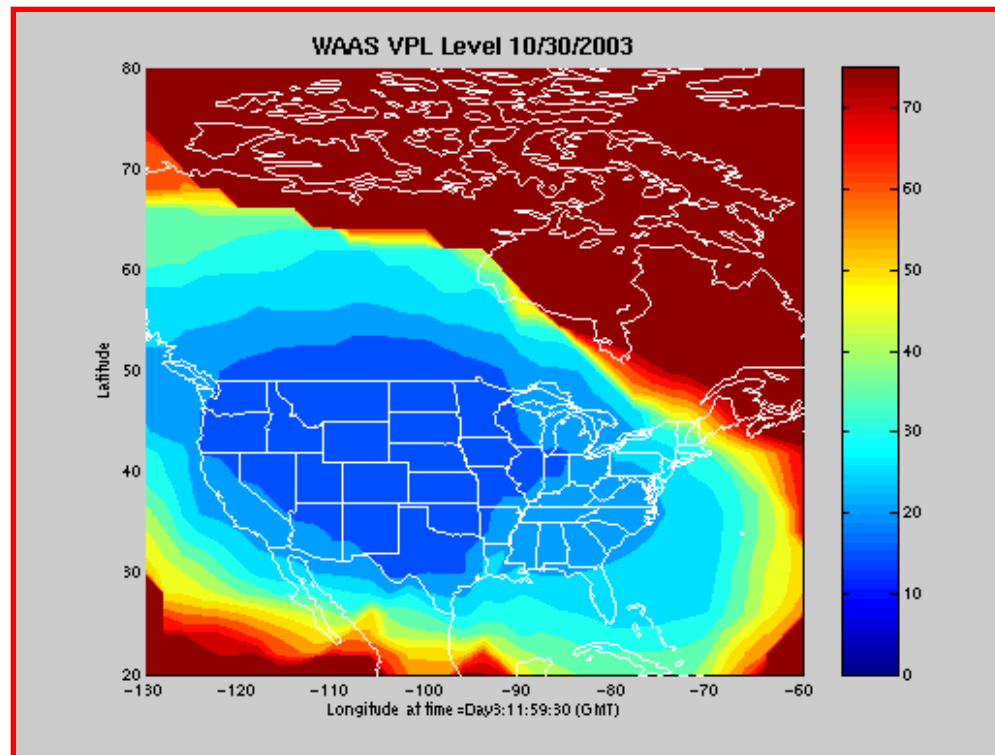
GEO Satellite

# Wide Area Augmentation System (Oct. 2003)

## LASP Media Workshop - Boulder

Ionosphere disturbances impact vertical error limits, defined by the FAA's Lateral Navigation/Vertical Navigation (LNAV/VNAV) specification to be no more than 50 meters.

Commercial aircraft unable to use WAAS for precision approaches.

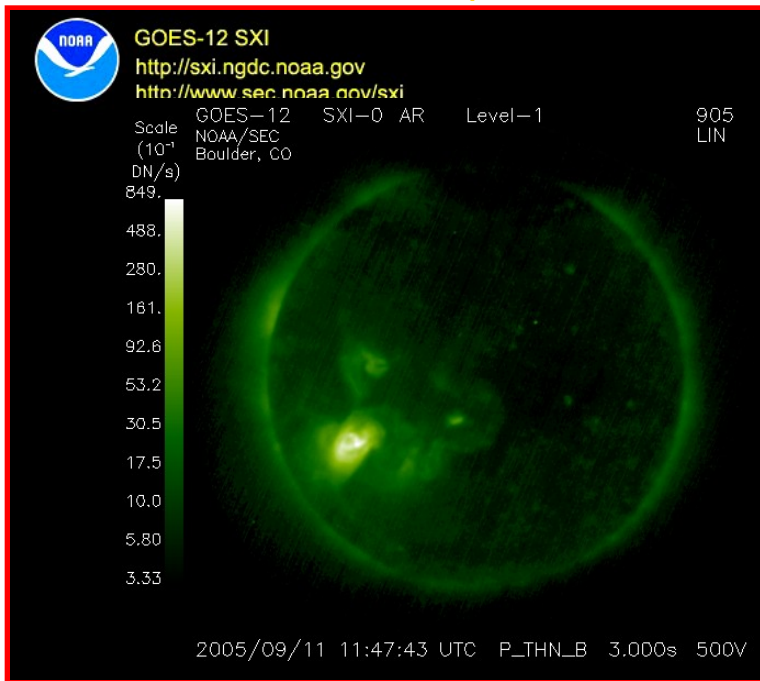


[Courtesy NOAA]

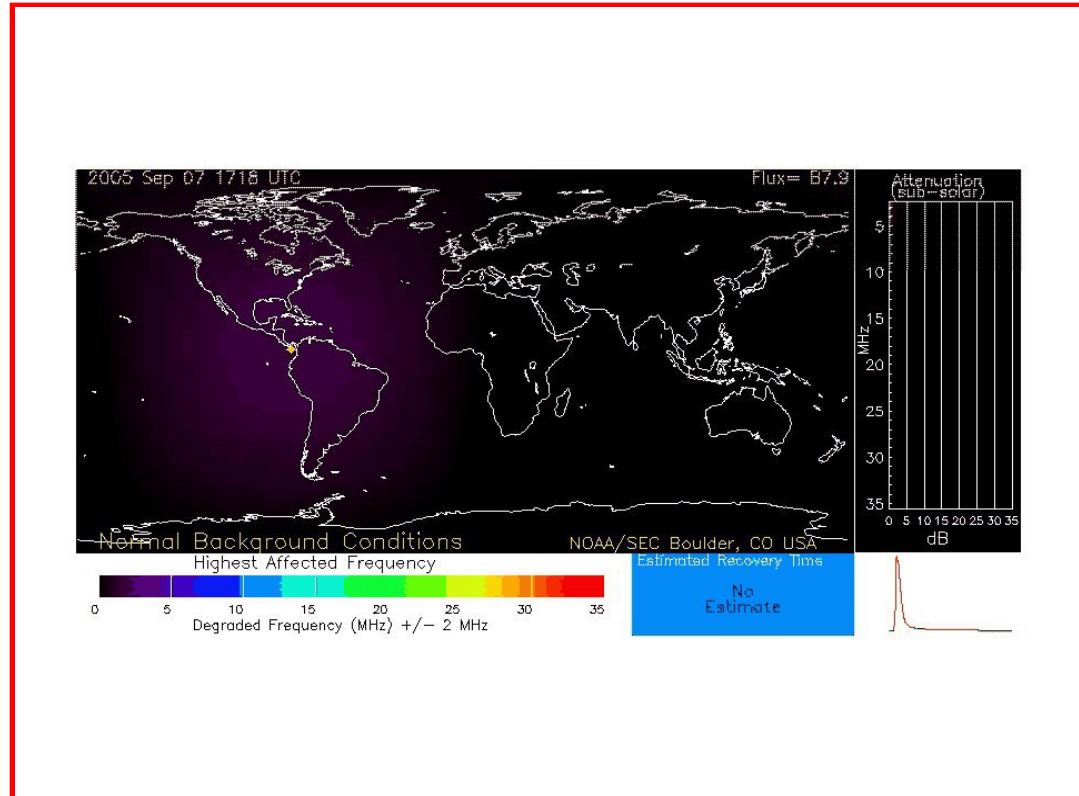
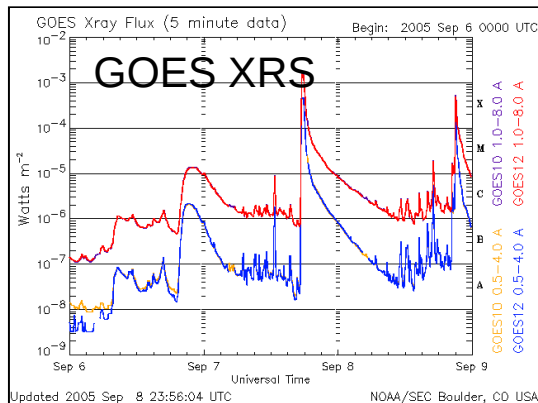


# Airlines and Space Weather

## LASP Media Workshop - Boulder



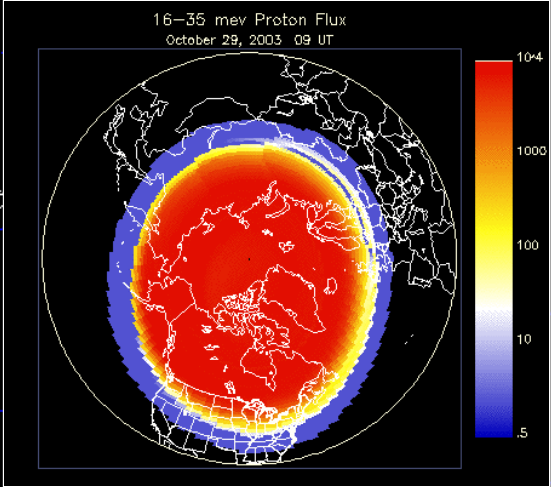
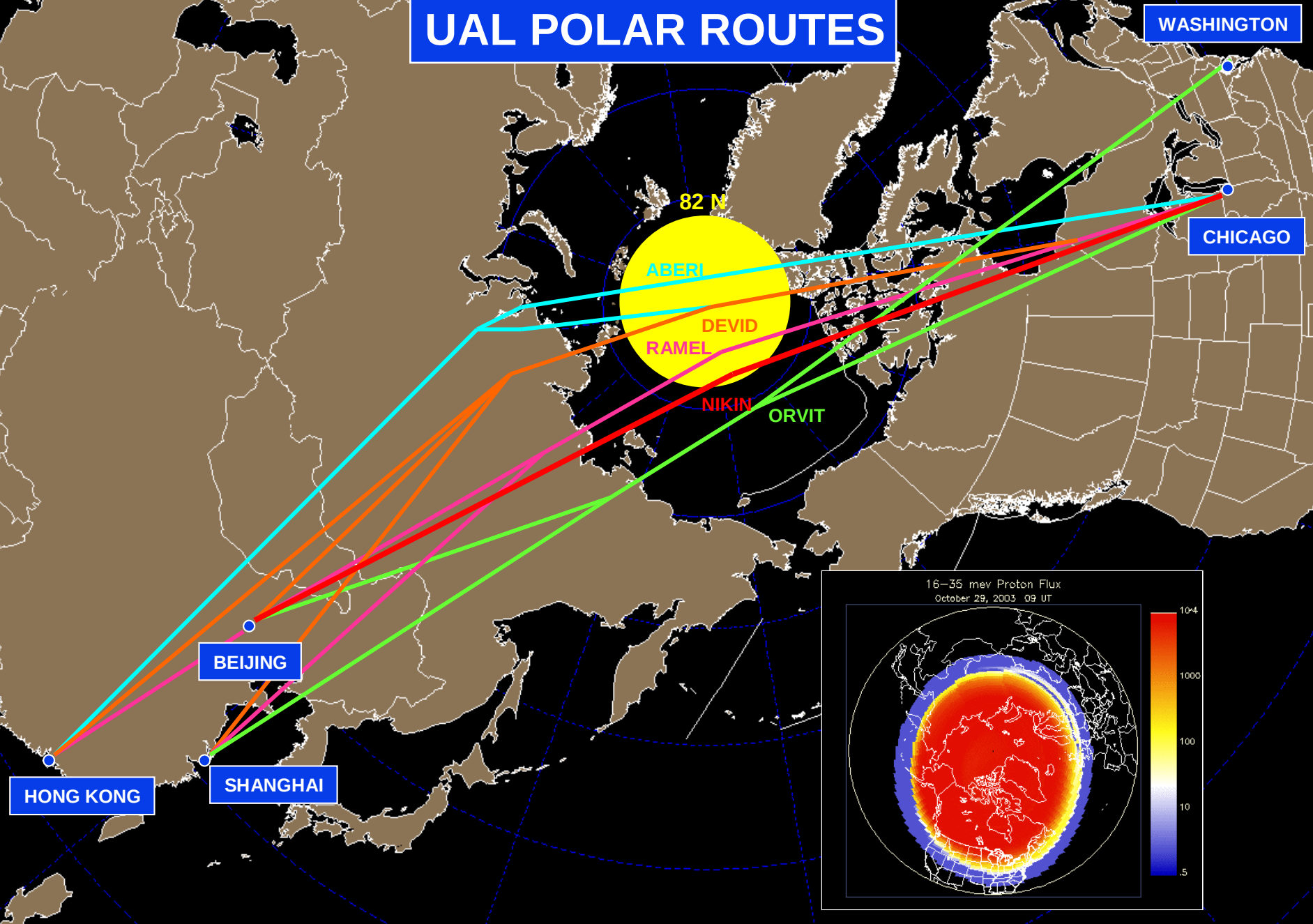
GOES SXI



Loss of High Frequency (HF) communications during a solar flare.  
The night-side of the Earth is unaffected

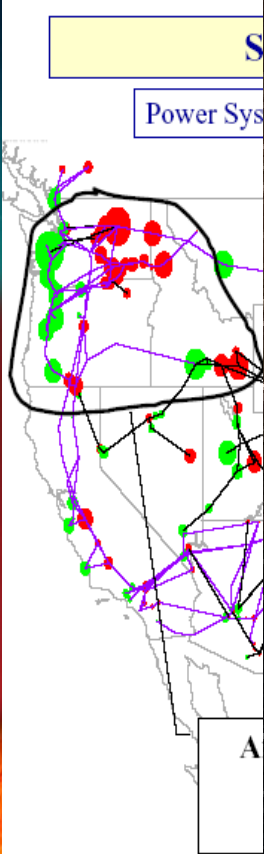
Image from NASA SOHO Satellite

# UAL POLAR ROUTES



# Economic Impacts of Space Weather

- Airborne Survey Data Collection: \$50,000 per day
- Marine Seismic Data Collection: \$80,000-\$200,000 per day
- Offshore Oil Rig Operation: \$300,000-



## Space Radiation Hazards and the Vision for Space Exploration



2008 - \$21.5 billion  
2017 - \$757 billion

# Task

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- An ad hoc committee of the Space Studies Board (SSB) of the National Academies was charged to convene a workshop to assess the current and future ability to manage space weather events and their societal and economic impacts.
  - What are the socioeconomic consequences of severe space weather events?
  - How likely are very intense space weather storms and what might be the consequences of such events?
  - Are there specific ground- or space-based sensors or other approaches that might mitigate or avoid the effects of future severe space weather events?



# Committee on the Societal and Economic Impacts of Severe Space Weather Events

---

- DANIEL N. BAKER, University of Colorado at Boulder, Chair
  - ROBERTA BALSTAD, Center for International Earth Science Information Network, Columbia University
  - J. MICHAEL BODEAU, Northrop Grumman Space Technology
  - EUGENE CAMERON, United Airlines, Inc.
  - JOSEPH F. FENNELL, Aerospace Corporation
  - GENENE M. FISHER, American Meteorological Society
  - KEVIN F. FORBES, Catholic University of America
  - PAUL M. KINTNER, Cornell University
  - LOUIS G. LEFFLER, North American Electric Reliability Council (retired)
  - WILLIAM S. LEWIS, Southwest Research Institute
  - JOSEPH B. REAGAN Lockheed Missiles and Space Company, Inc. (retired)
  - ARTHUR A. SMALL III, Pennsylvania State University
  - THOMAS A. STANSELL, Stansell Consulting
  - LEONARD STRACHAN, JR., Smithsonian Astrophysical Observatory
- 
- Staff
  - SANDRA J. GRAHAM, Study Director
  - THERESA M. FISHER, Program Associate
  - VICTORIA SWISHER, Research Associate
  - CATHERINE A. GRUBER, Assistant Editor

# The Societal and Economic Impacts of Severe Space Weather Events: A Workshop

- May 22-23, 2008 in DC
- Approximately 80 attendees from academia, industry, government, and industry associations
  - Association reps aggregated data and helped avoid concerns about proprietary or competition-sensitive data
- Analyses in specific areas; e.g., GPS, power industry, aviation, military systems, human and robotic exploration beyond low-Earth orbit
- Econometric analysis of value of improved SpaceWx forecasts



# Anticipated Benefits

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- Economic Impacts analysis would provide:
  - Better guidance for policy makers on investment in SWx systems
  - Better rationale for agency budgeting
  - Better understanding of “high-payoff” forecasts
  - Clearer guidance for future human exploration
  - Improved societal appreciation for SWx risks



# Impacts of Space Weather

LASP Media Workshop - Boulder

- Industry-specific Space Weather Impacts
  - Electric power, spacecraft, aviation, and GPS-based positioning industries can be adversely affected by extreme space weather
  - January 2005: 26 United Airlines flights diverted to nonpolar or less-than-optimum polar routes during several days of disturbed space weather
  - October-November 2003: FAA's recently implemented GPS-based Wide Area Augmentation System disabled for 30 hours
  - January 1994: Outage of two Canadian telecommunications satellite. Recovery took 6 months and cost \$50 million to \$70 million.

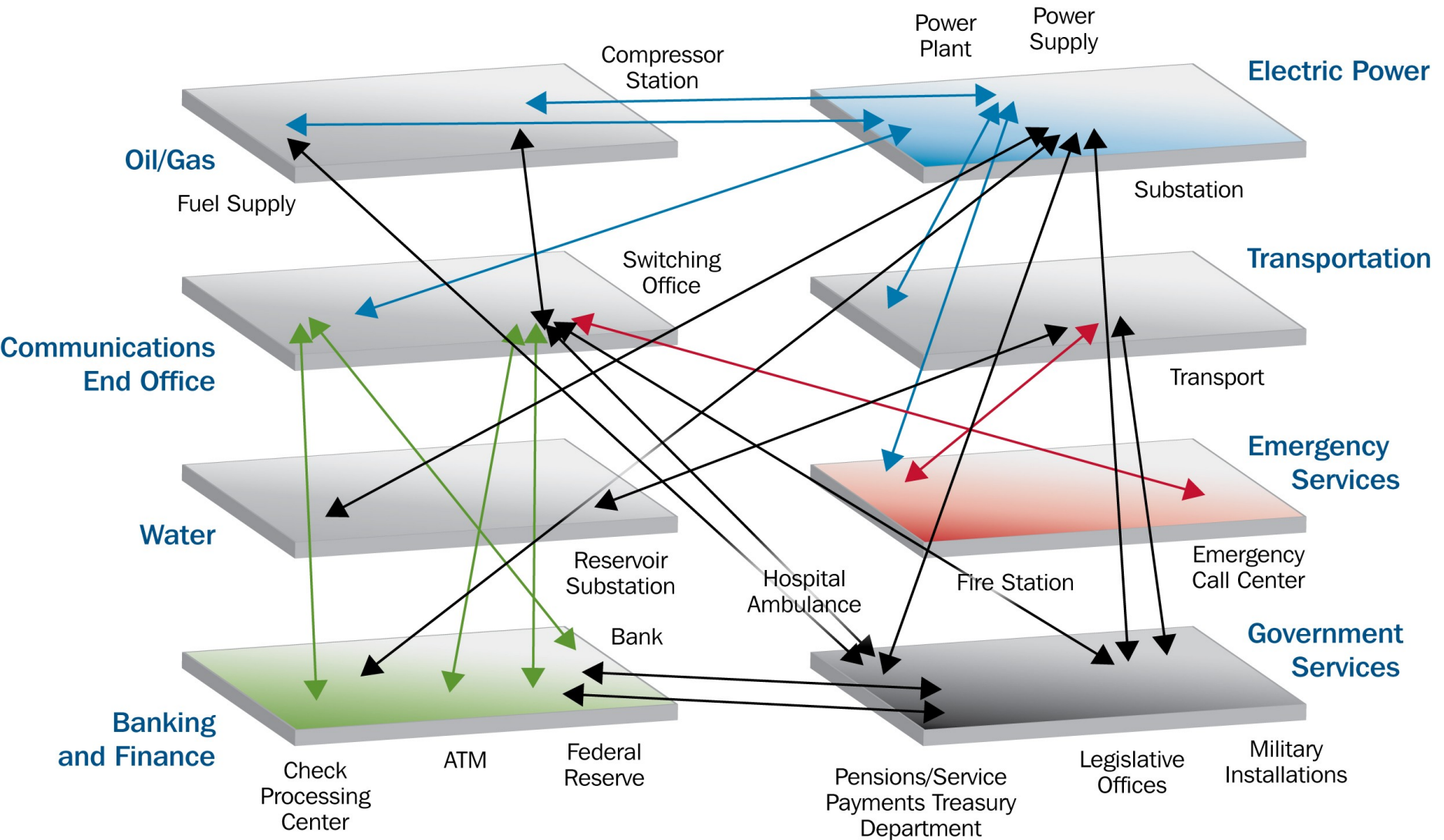
# What Were Goals and Some Outcomes?

---

- Identify decisions that can be improved using a reliable forecast
- Differences with and without forecast (the expected value of a forecast)
- When best design decisions are made
- Economic impact of events
  - Repair damaged S/C: \$50-70M
  - Replace commercial S/C: \$250-300M
  - Cost of major power blackout: \$4-10B
  - Extreme storm (a la 1859): \$1-2 Trillion

# The Interdependencies of Society

LASP Media Workshop - Boulder



[NRC Study]



# Electrical Power Grid...

## LASP Media Workshop - Boulder

**The grid is becoming increasingly vulnerable to space weather events** *Future Directions in Satellite-derived Weather and Climate Information for the Electric Energy Industry – Workshop Report Jun 2004*

**“...blackouts could exceed even that of the very large blackout that occurred in August 14, 2003. And there is no part of the U.S. power grid that is immune to this... we could impact over 100 million population in the worst case scenario.”** John Kappenman - before U.S. House Subcommittee on Environment, Technology & Standards Subcommittee Hearing on “What is Space Weather and Who Should Forecast It?”

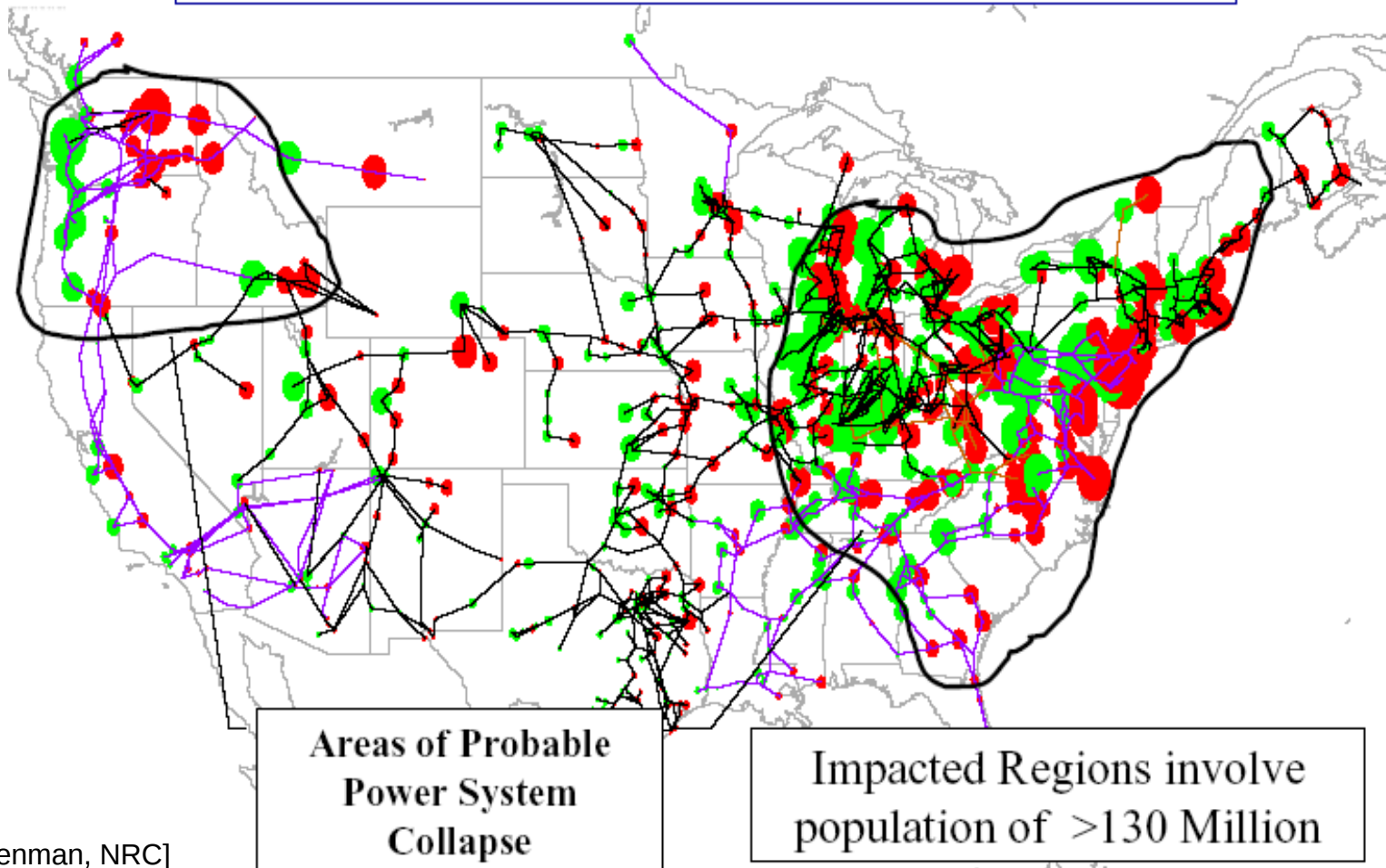


# Regional Power Grid Disruptions

LASP Media Workshop - Boulder

## Severe Electrojet Disturbance Scenario

Power System Disturbance and Outage Scenario of Unprecedented Scale



[J. Kappenman, NRC]

# Impacts of Space Weather

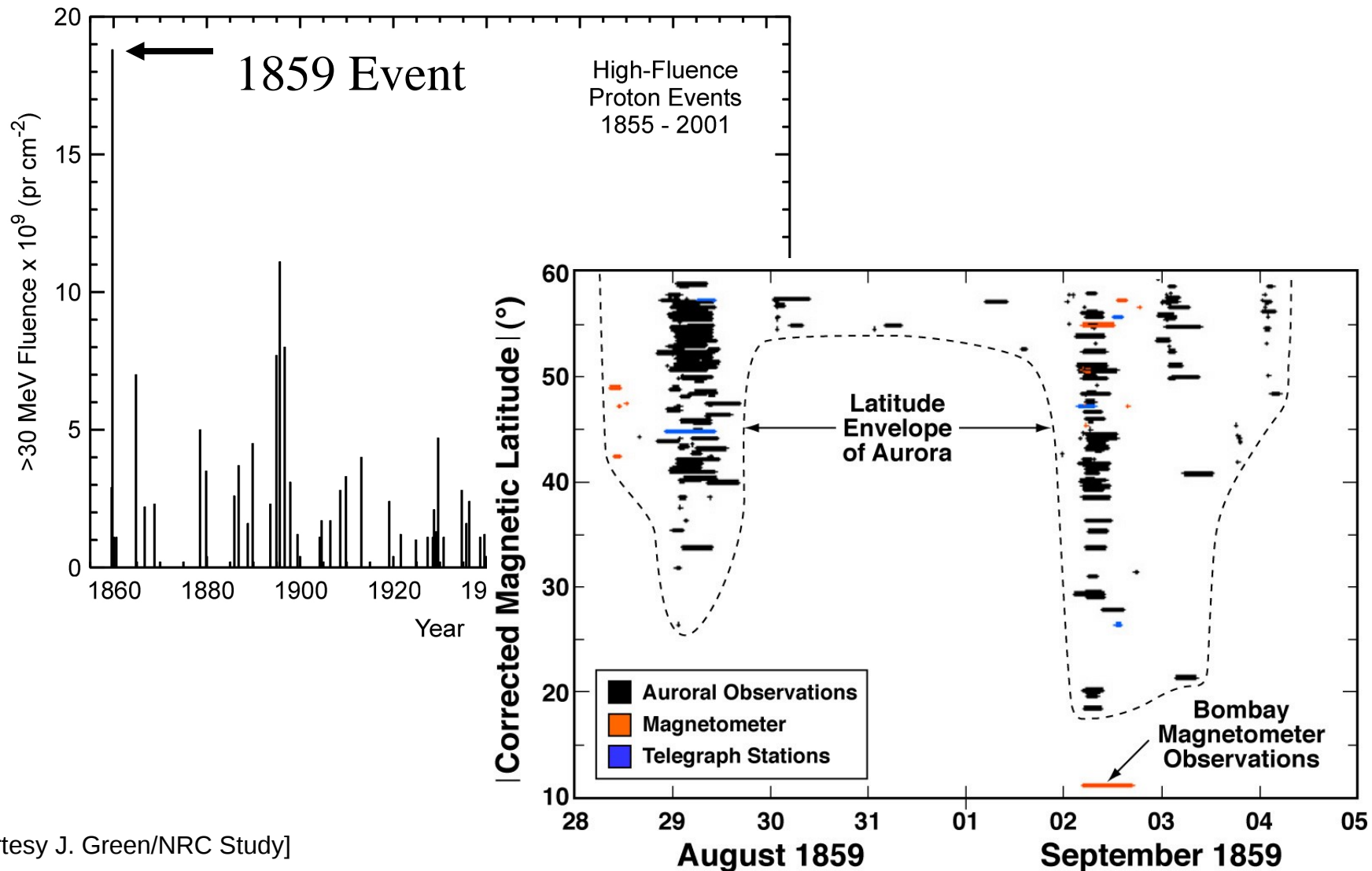
## LASP Media Workshop - Boulder

- Collateral Impacts of Space Weather
  - “Electric power is modern society’s cornerstone technology, the technology on which virtually all other infrastructures and services depend”
  - “Collateral effects of longer-term outage would likely include, for example, disruption of the transportation, communication, banking, and finance systems, and government services; the breakdown of the distribution of potable water owing to pump failure; and the loss of perishable foods and medications because of lack of refrigeration.”
  - “...it is difficult to understand, much less predict, the consequences of future LF/HC events. Sustaining preparedness and planning for such events in future years is equally difficult.”



# An Extreme Event: Carrington 1859

LASP Media Workshop - Boulder



[Courtesy J. Green/NRC Study]

# Space Weather Raises Concerns...

E-mail ( "With much admiration") received 30 January 2009:

"I would like to say how much I am impressed with your work...I am not a scientist but for the last 3 years I've been studying the effect of solar storms and the next peak coming. I have gathered information that could mean that we are heading for big trouble. My gut feelings tell me that this could be the ONE solar tempest that destroys our modern civilization.

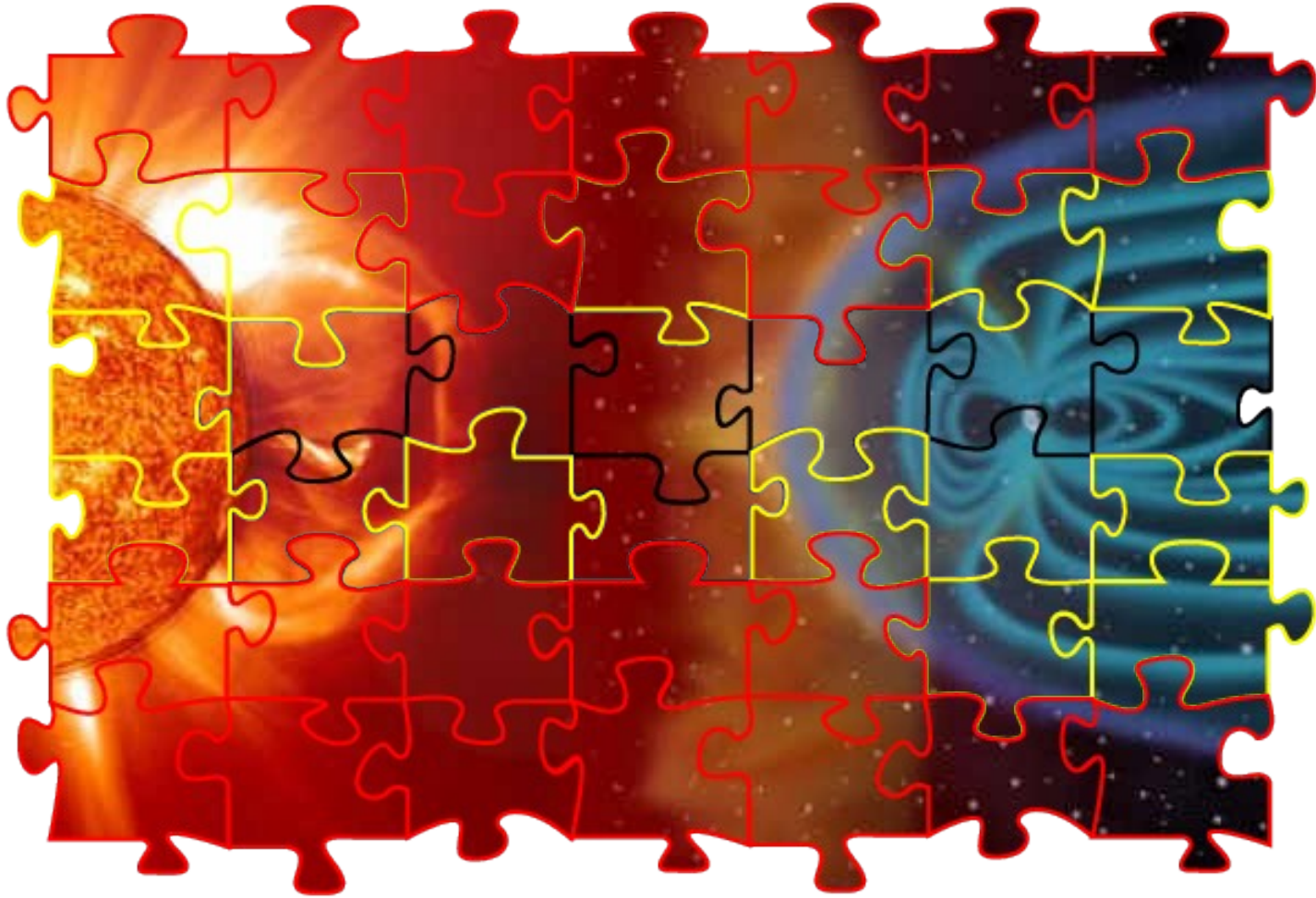
"I wish I could do something but don't know what to do. It is clear that if some things were done we could save at least maybe some lives. I know that prevention is very important and I wonder if my government, in France, knows about this...Since all we hear is about the economic crisis, I doubt they would take this seriously. Besides, the net of emergency services told me that they can't even consider this because they think on a scale of natural catastrophes it is the worst one that could ever happen!! One person told me I would buy a big cake and eat it all and wait for the end of our world. [Emphasis added]

"I want to thank you for your great achievements and your expertise."

--Yaelle Byrd

# Solving The Space Weather Puzzle

LASP Media Workshop - Boulder



CISM Core



CISM Partners



Community



# Growth of Space Weather Customers

Munitions



Commercial Space Transportation  
Airline Polar Flights  
Microchip technology  
Precision Guided

Cell phones  
Atomic Clock  
Satellite Operations  
Carbon Dating experiments  
GPS Navigation

Ozone Measurements  
Aircraft Radiation Hazard  
Commercial TV Relays

Communications Satellite Orientation  
Spacecraft Charging  
Satellite Reconnaissance & Remote Sensing  
Instrument Damage

Geophysical Exploration.  
Pipeline Operations  
Anti-Submarine Detection  
Satellite Power Arrays

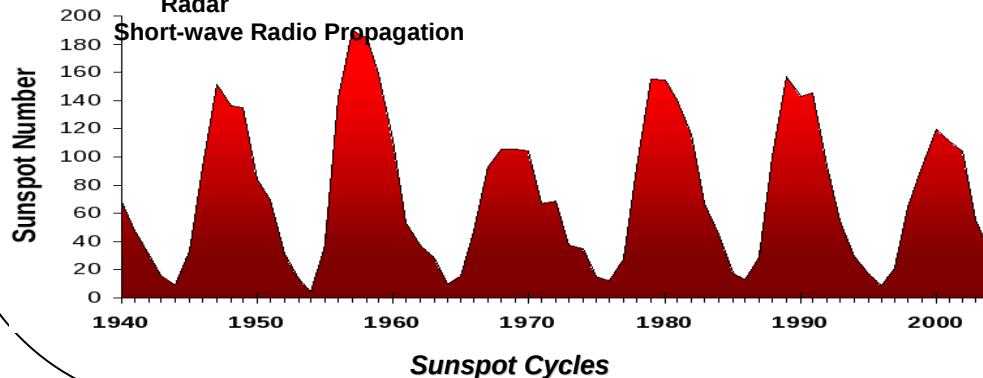
Power Distribution  
Long-Range Telephone Systems  
Radiation Hazards to Astronauts  
Interplanetary Satellite experiments  
VLF Navigation Systems (OMEGA, LORAN)  
Over the Horizon Radar  
Solar-Terres. Research & Applic. Satellites  
Research & Operations Requirements

Satellite Orbit Prediction  
Solar Balloon & Rocket experiments

Ionospheric Rocket experiments

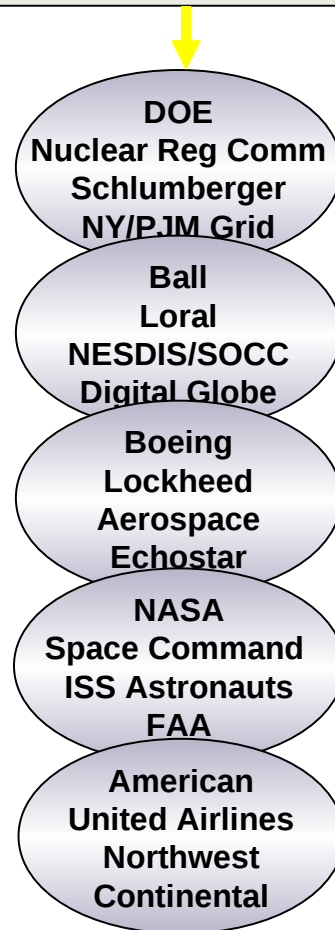
Radar

Short-wave Radio Propagation



A few of the agencies and industries that rely on space weather services today:

- U.S. power grid infrastructure
- Commercial airline industry
- Dep. of Transportation (GPS)
- NASA human space flight activities
- Satellite launch and operations
- DoD Operations



# Summary

LASP Media Workshop - Boulder

- The challenges associated with space weather affect all developed and developing countries
- Work on space weather specification, modeling, and forecasting has great societal benefit: **It is basic research with a high public purpose**
- Future space exploration and most human endeavors will require major advances in physical understanding and improved transition of space research to operations
- CISM models offer real hope of Sun-to-Earth space weather models and forecasts

Thank you.

Questions?



