

Introduction to the space environment and spacecraft interactions

Lecture 1

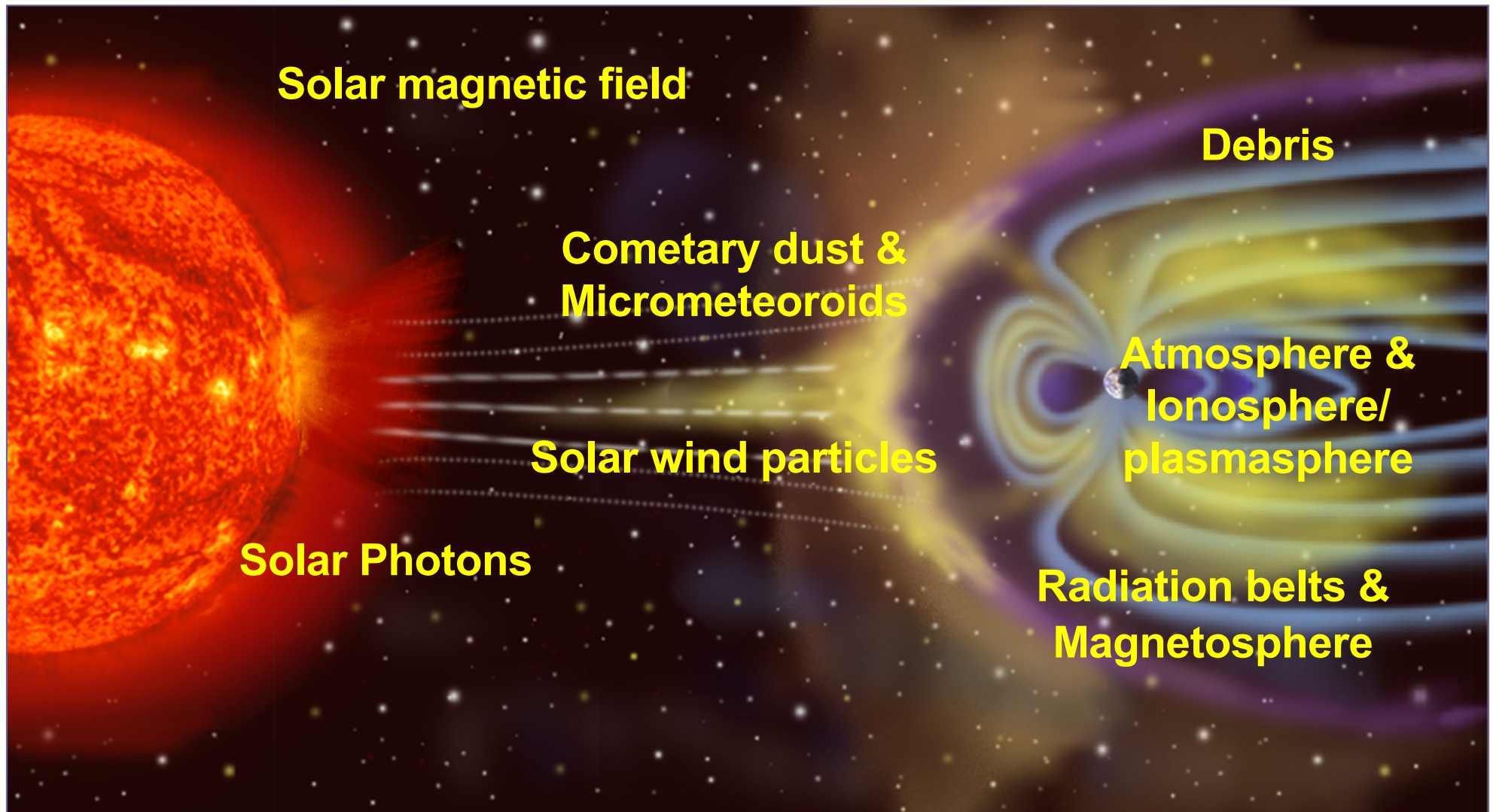
W.K. Tobiska

Space Environment Technologies

Dr. W. Kent Tobiska



The space environment



Lecture Overview

Definitions

Space environment

Space weather

Conceptual framework for space weather

Conceptual framework for spacecraft,
space systems, ground systems
interactions with space weather

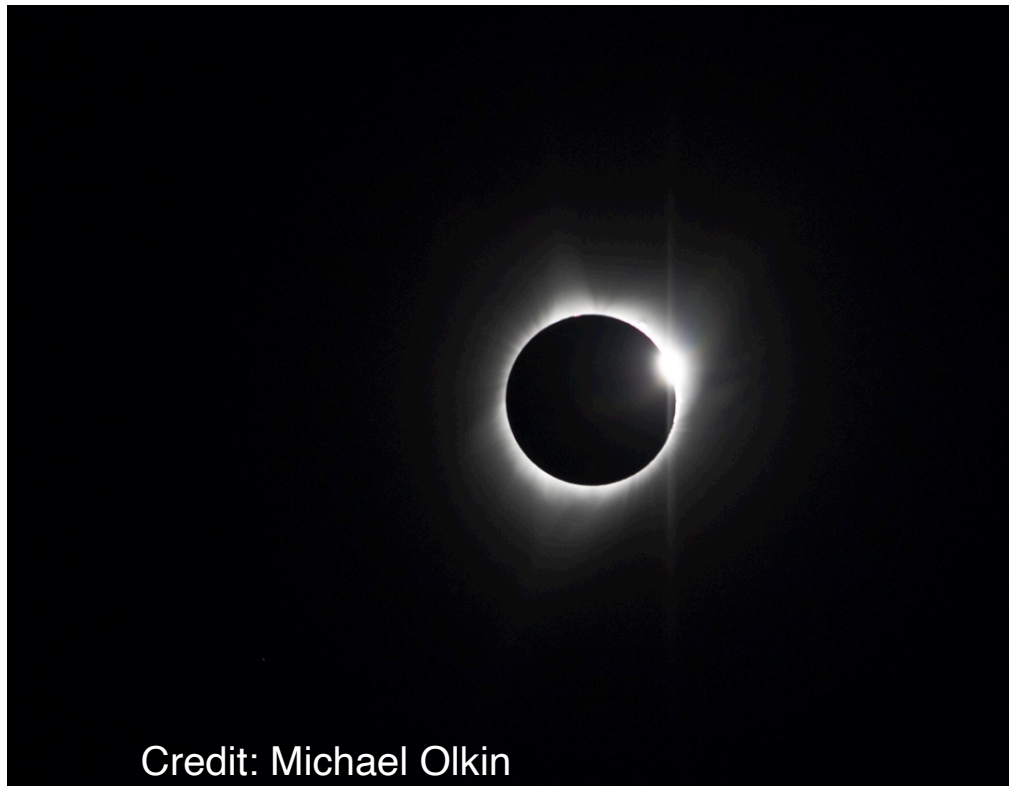
Standards and guidelines

Supplementary material

The space environment



The Earth and Sun
are energetically
connected.



Solar Eclipse August 21, 2017

Definitions

The Space Environment is comprised of three types of energy/matter

Photons

Galactic, Solar, Planetary, Other

Particles

neutral

Galactic, Planetary, Other

charged

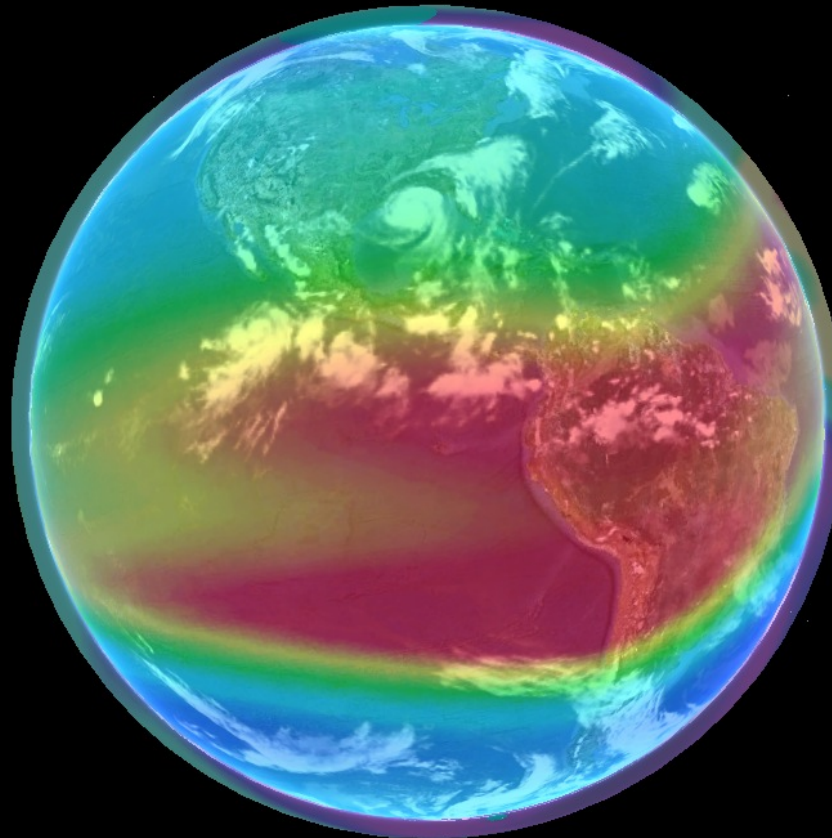
Galactic, Solar, Planetary, Other

Fields

Magnetic, Electric, Gravitational



0 10 20 30 40



Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google earth

2012-08-29 00:15 UTC

2°35'50.86" N 91°44'49.35" W elev -2164 m

Eye alt 23143.33 km

<https://SpaceWx.com>

W. Kent Tobiska ktobiska@spacewx.com

9

Credit: SET & SEC



Vandenberg launch





Space weather

Definitions

Space weather

Sun's short-term interaction with the Earth

Photons, particles, fields

It affects natural planetary environment

- Ocean

- Land

- Atmosphere

- Near space

It affects human technological systems

- Space-based

- Ground-based

Definition of Space Weather

- The Earth's near space environment and our technology are affected by space weather.
- **Space weather is the dynamical transfer of energy from the Sun to the Earth in the form of solar photons, charged particles, and fields that vary on multiple time and spatial scales.**
- This variability occurs primarily through direct photo-absorption processes in the terrestrial upper atmosphere and, secondarily, through solar wind/magnetosphere coupling with the terrestrial ionosphere.

Impacts of Space Weather

Great disasters move us to improve the human condition

Katrina Hurricane in Gulf of Mexico

August 29, 2005

Great East Japan Earthquake

March 11, 2011

Credit: Tobiska

Hurricane Katrina

Katrina

+

Solar Flare

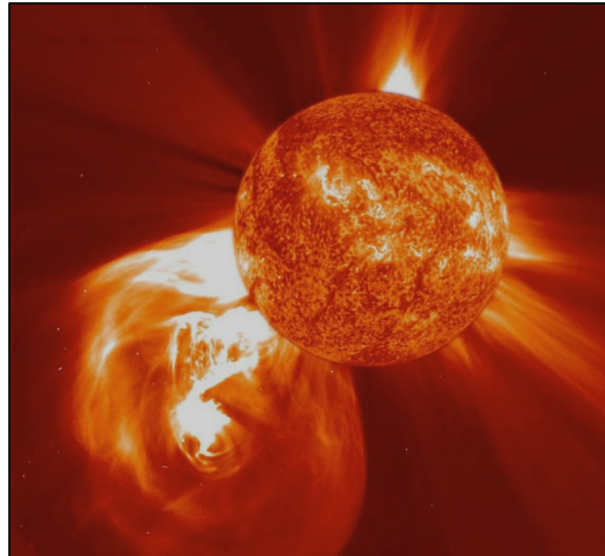
=

Compounded
Hazard



Aug. 29, 2005

<https://SpaceWx.com>



Sept. 7, 2005
(4th largest flare
in history)

W. Kent Tobiska ktobiska@spacewx.com



Loss of ship-to-
helicopter
communications

Credit: Tobiska

Great East Japan Earthquake

Massive destruction





Demolished infrastructure

\$300 billion in damages

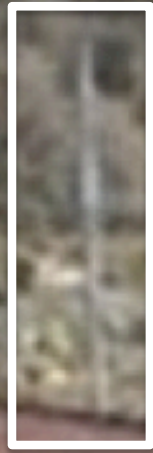


10,000 missing





14,000 dead



Unusable
cell phone
tower



Technologies affected by Space Weather

- **Aviation** – HF communication loss; radiation above 26,000 ft.; GPS position error
- **Navigation** – GPS position and timing error
- **Communication** – D-region absorption; HF loss; HF/UHF/L-band radio signal scintillation
- **Satellite operations** – LEO orbit error from drag; GEO spacecraft charging; SEUs and latchup
- **Energy production** – drill-bit misalignment from magnetometer error in oil/gas drilling
- **Power grid** – transformer loss from GIC surges

Credit: Tobiska

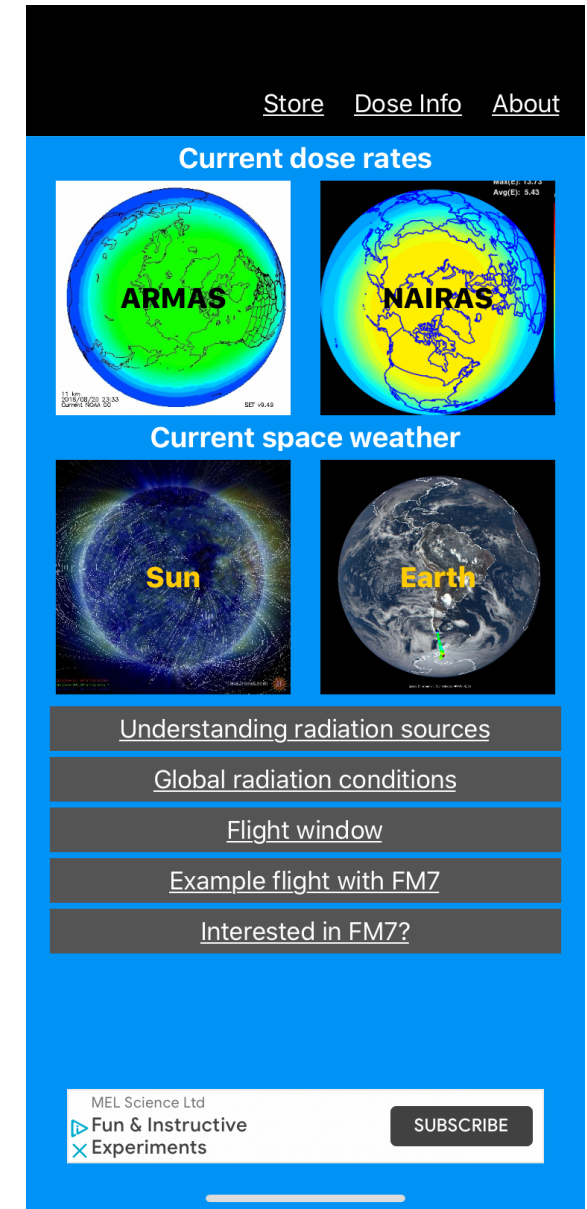


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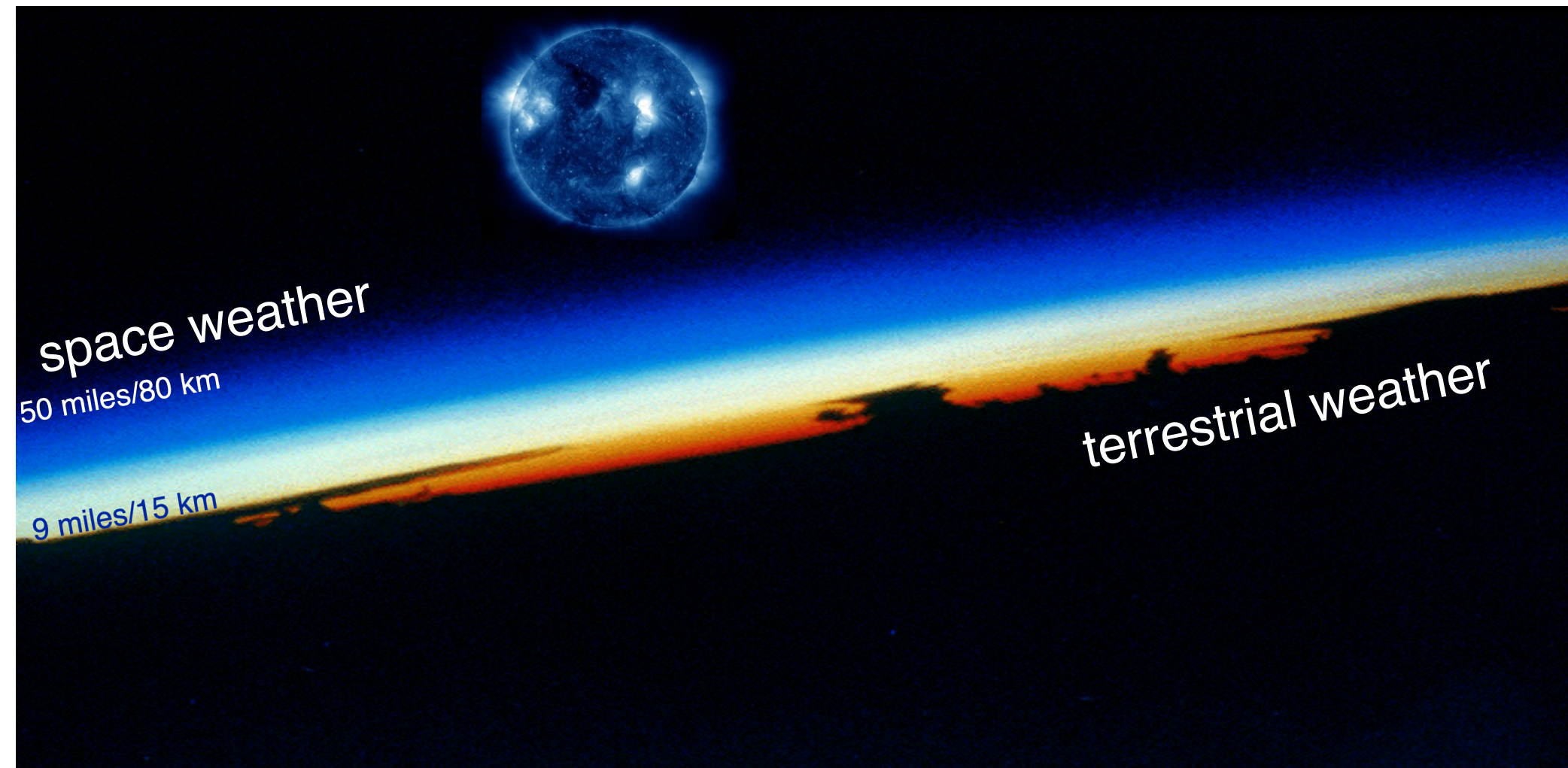
BREAK

Conceptual framework for space weather

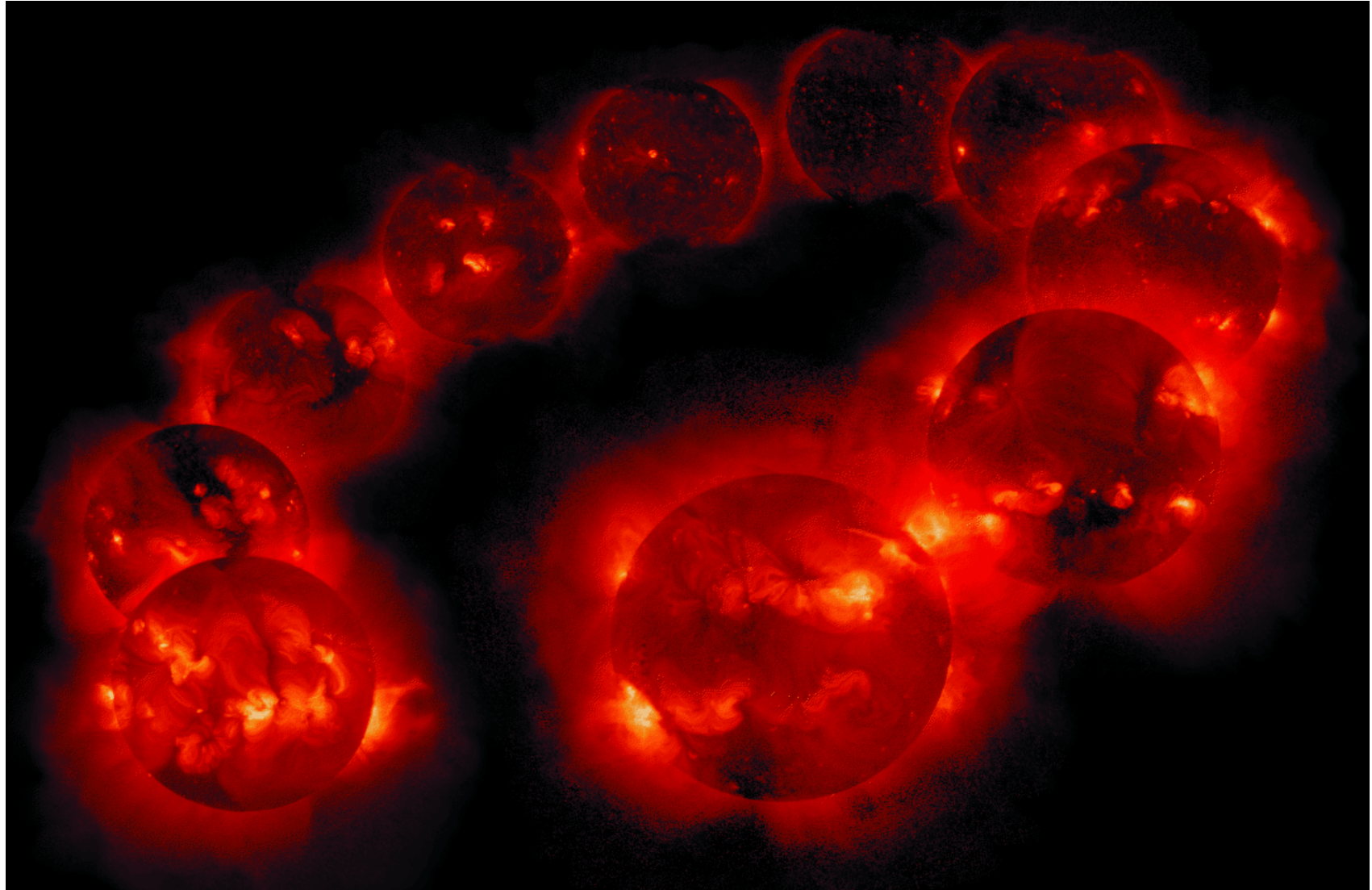
(*ARMAS* app)



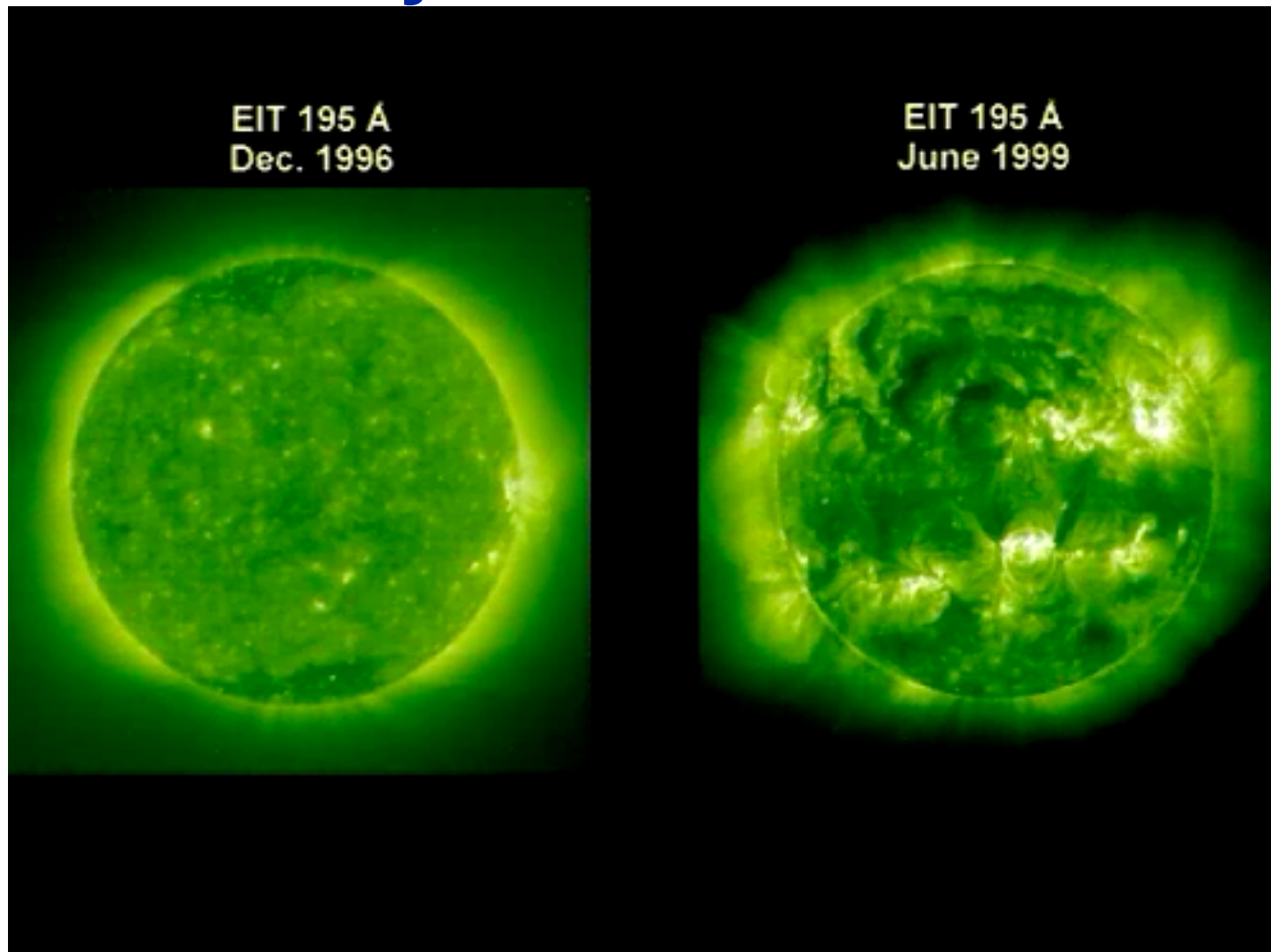
Space weather originates from the Sun



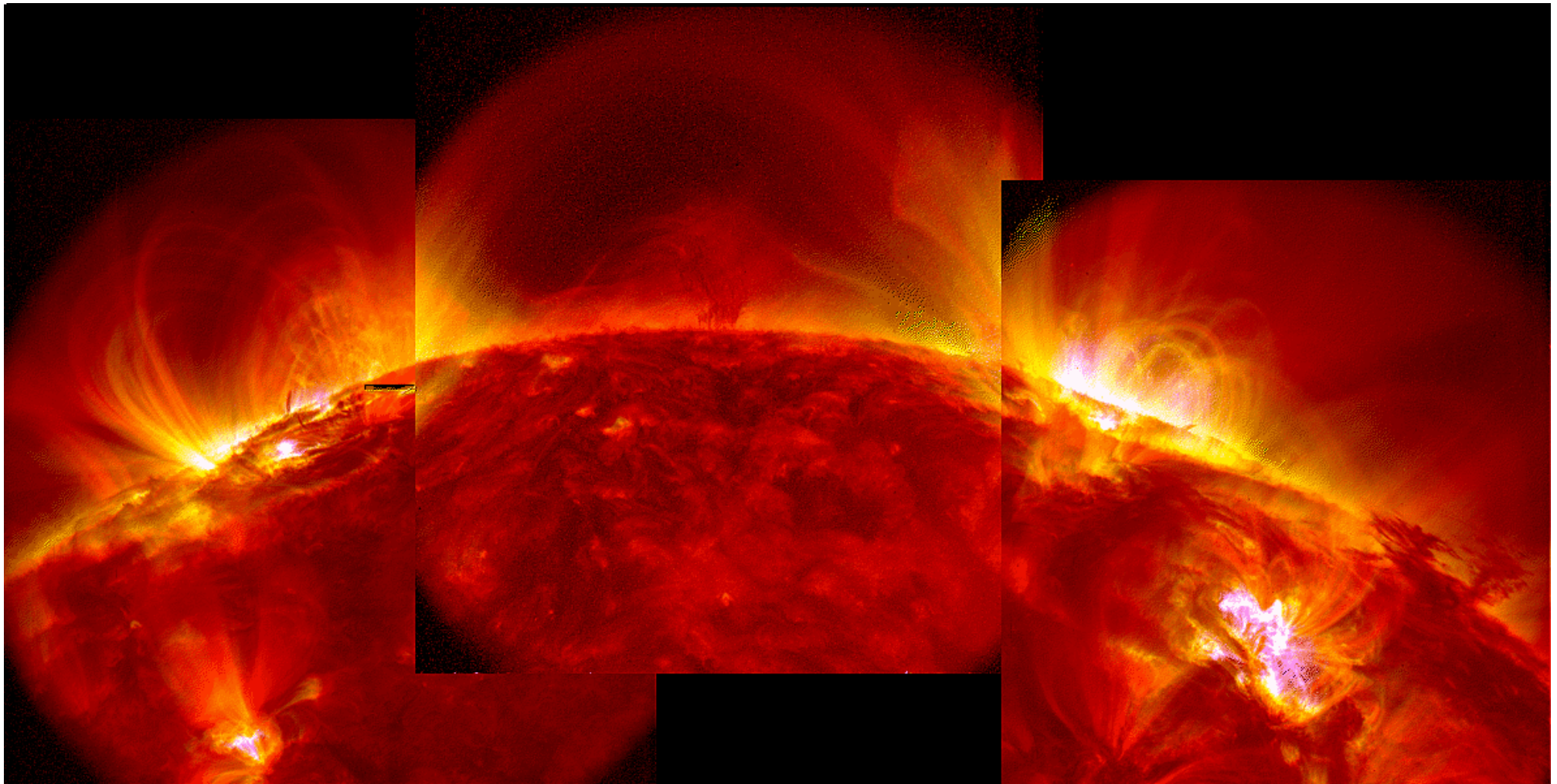
11-Year Solar Activity Cycle



27-Day Solar Rotation



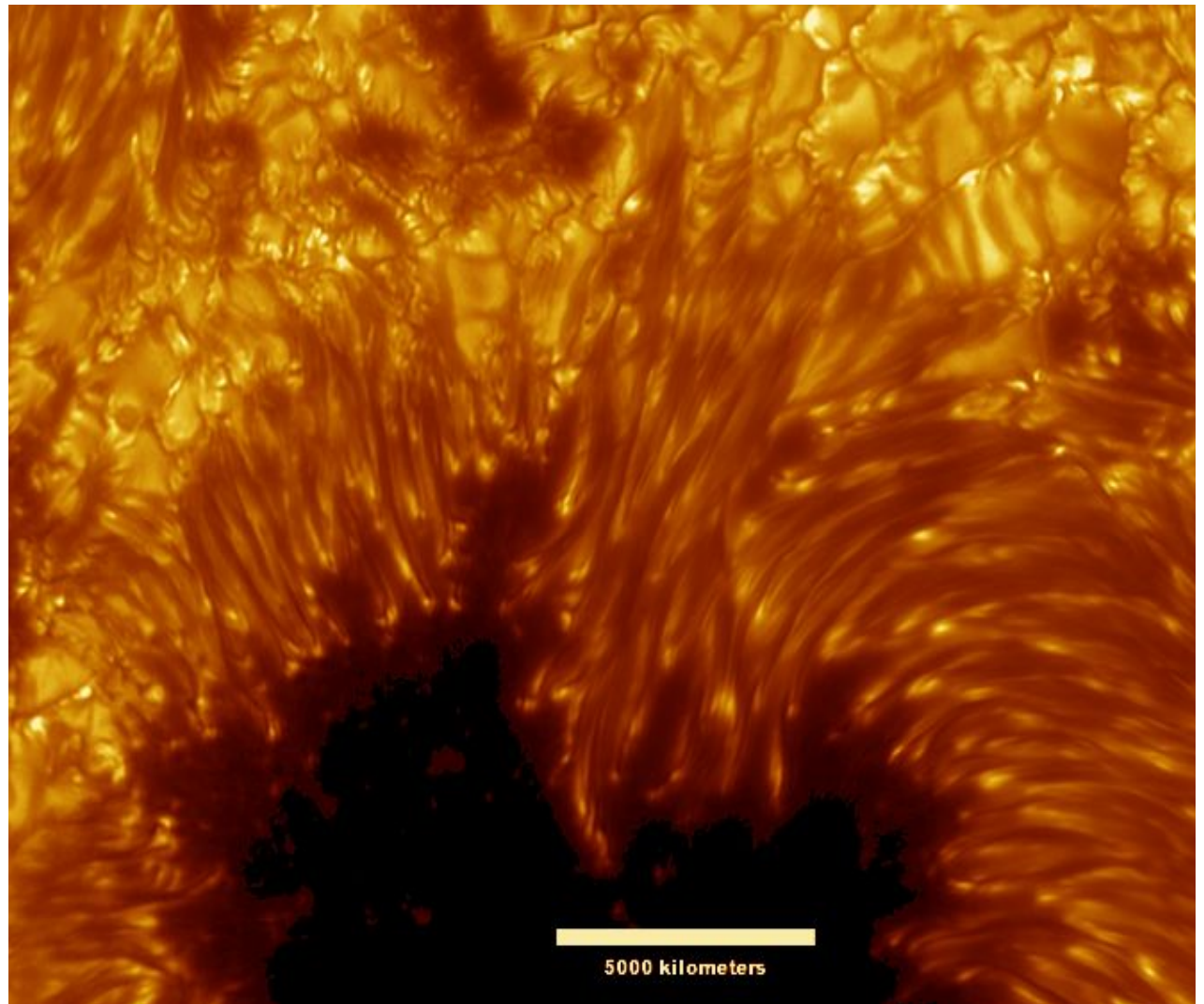
Detailed Solar Structure



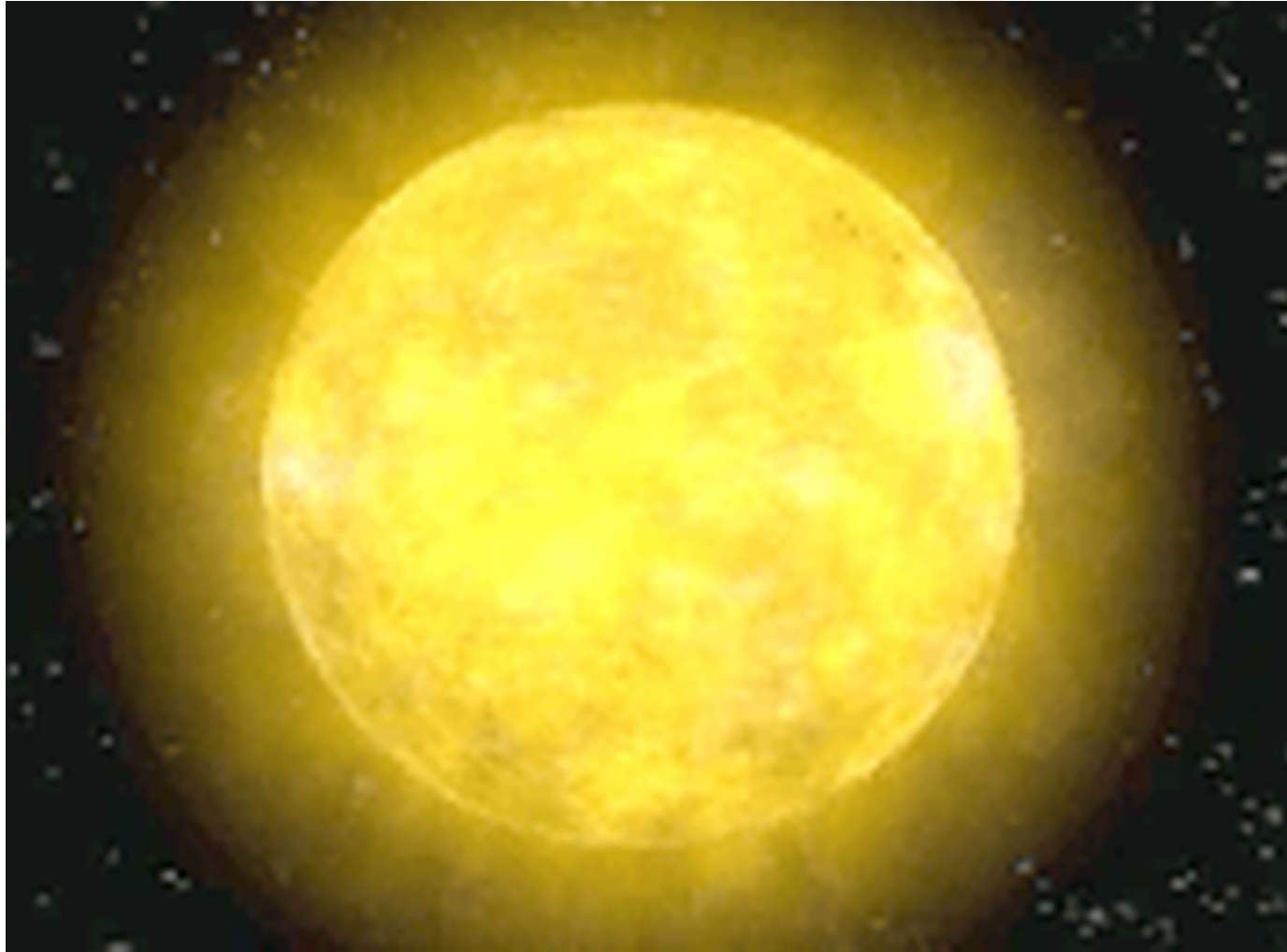
Sources of solar variations

**Highest
resolution
image of a
sun spot**

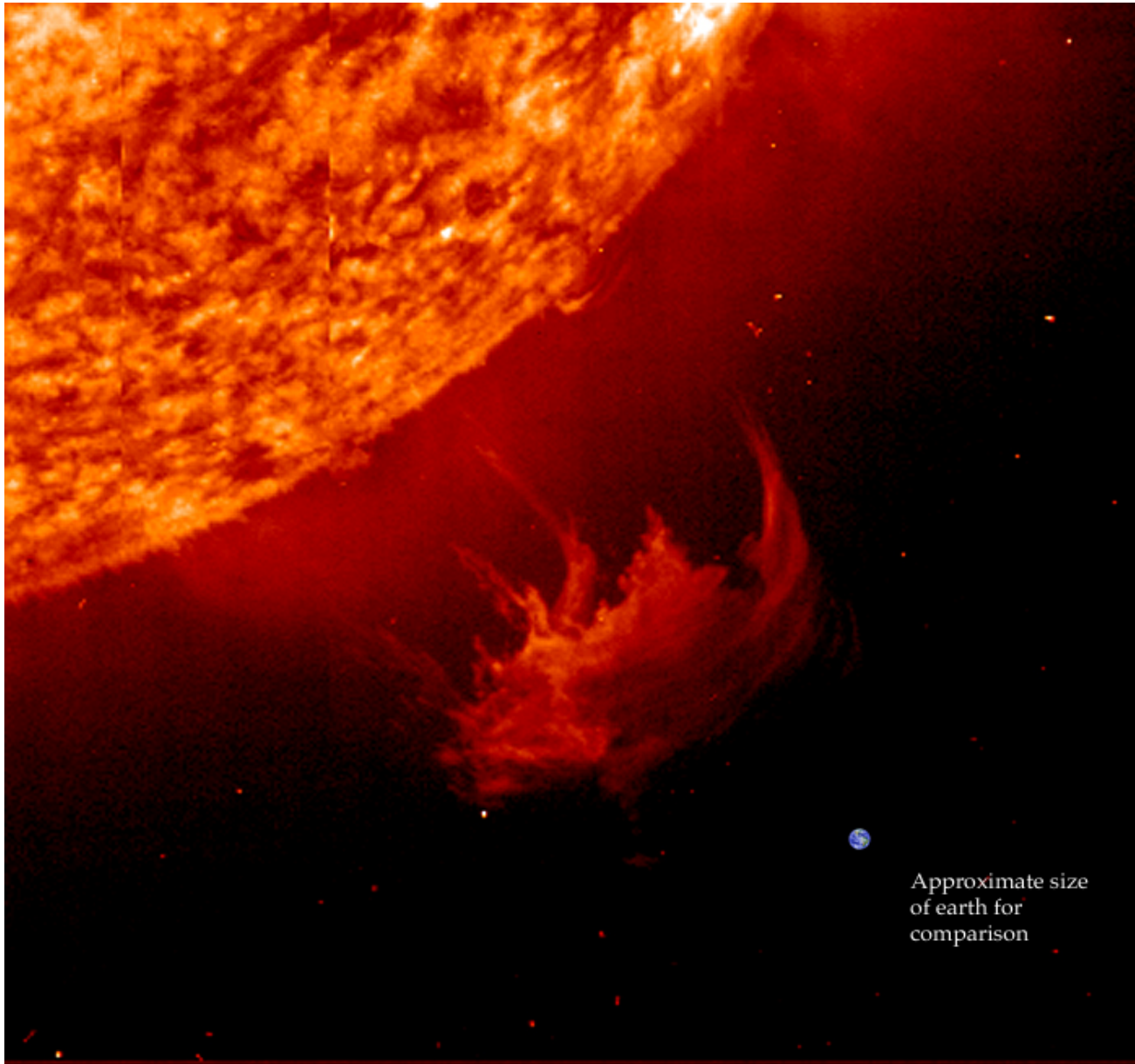
Credit: Swedish
Observatory



Flares and coronal mass ejections



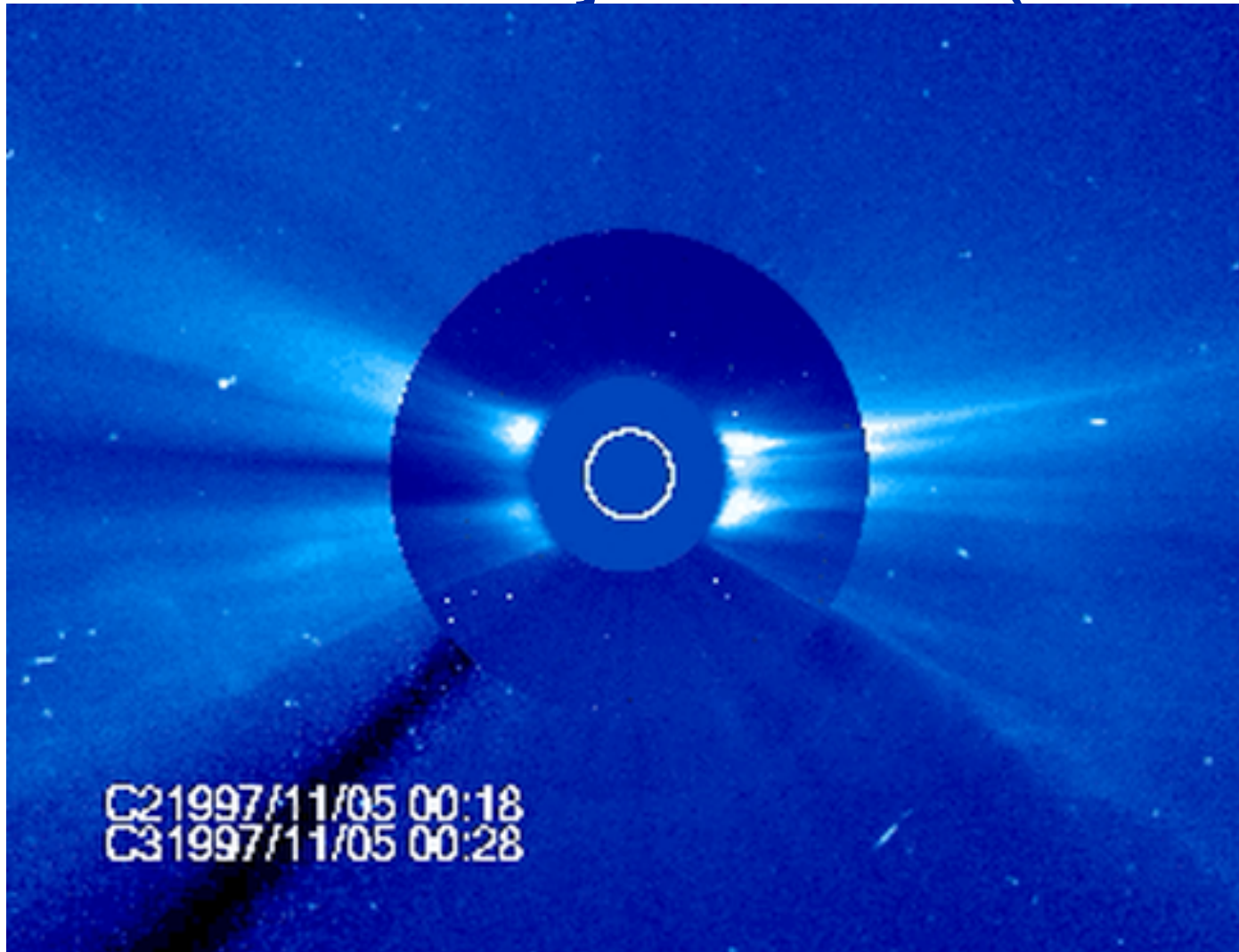
Credit: NASA



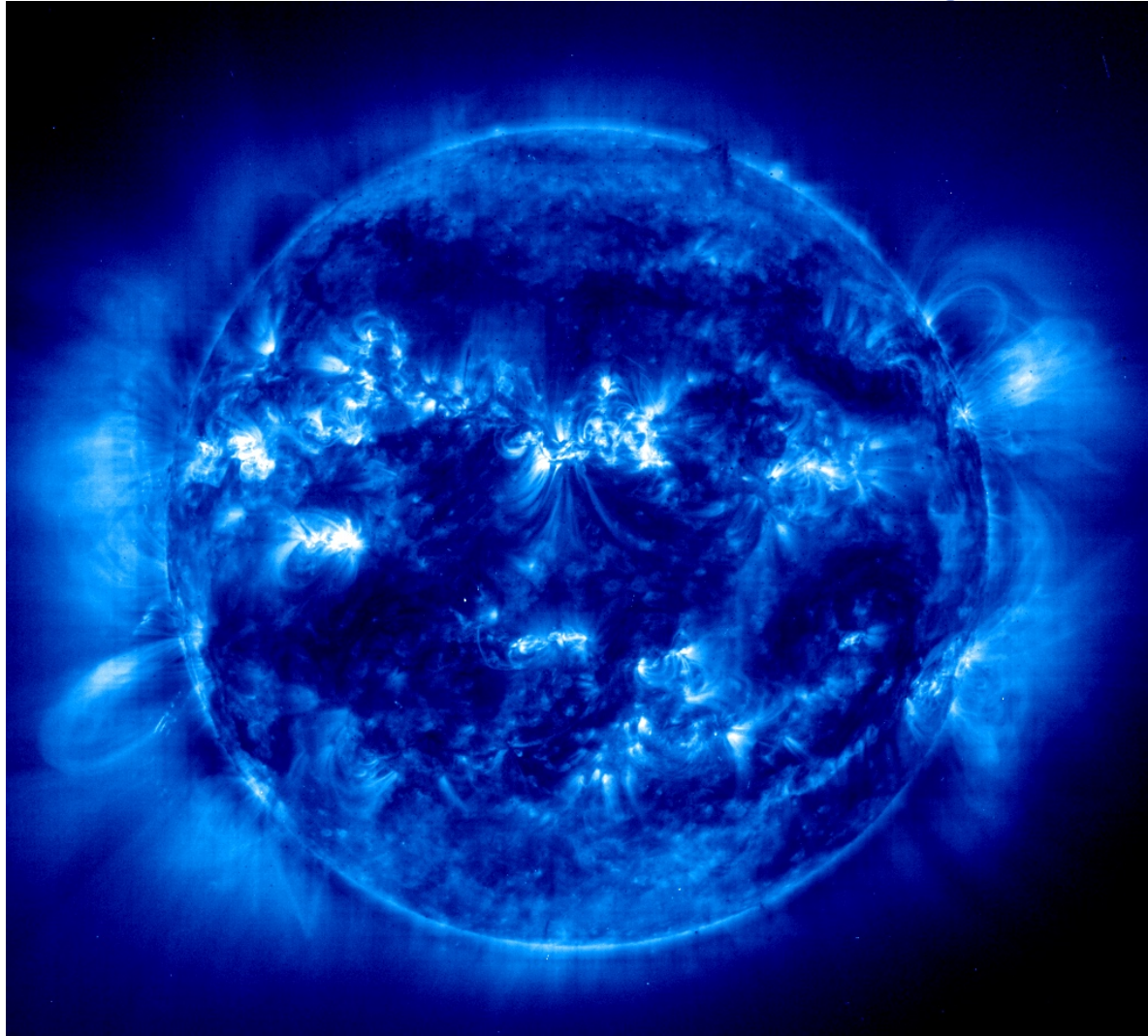
CME Relative to the Earth

Credit: SDAC NASA GSFC

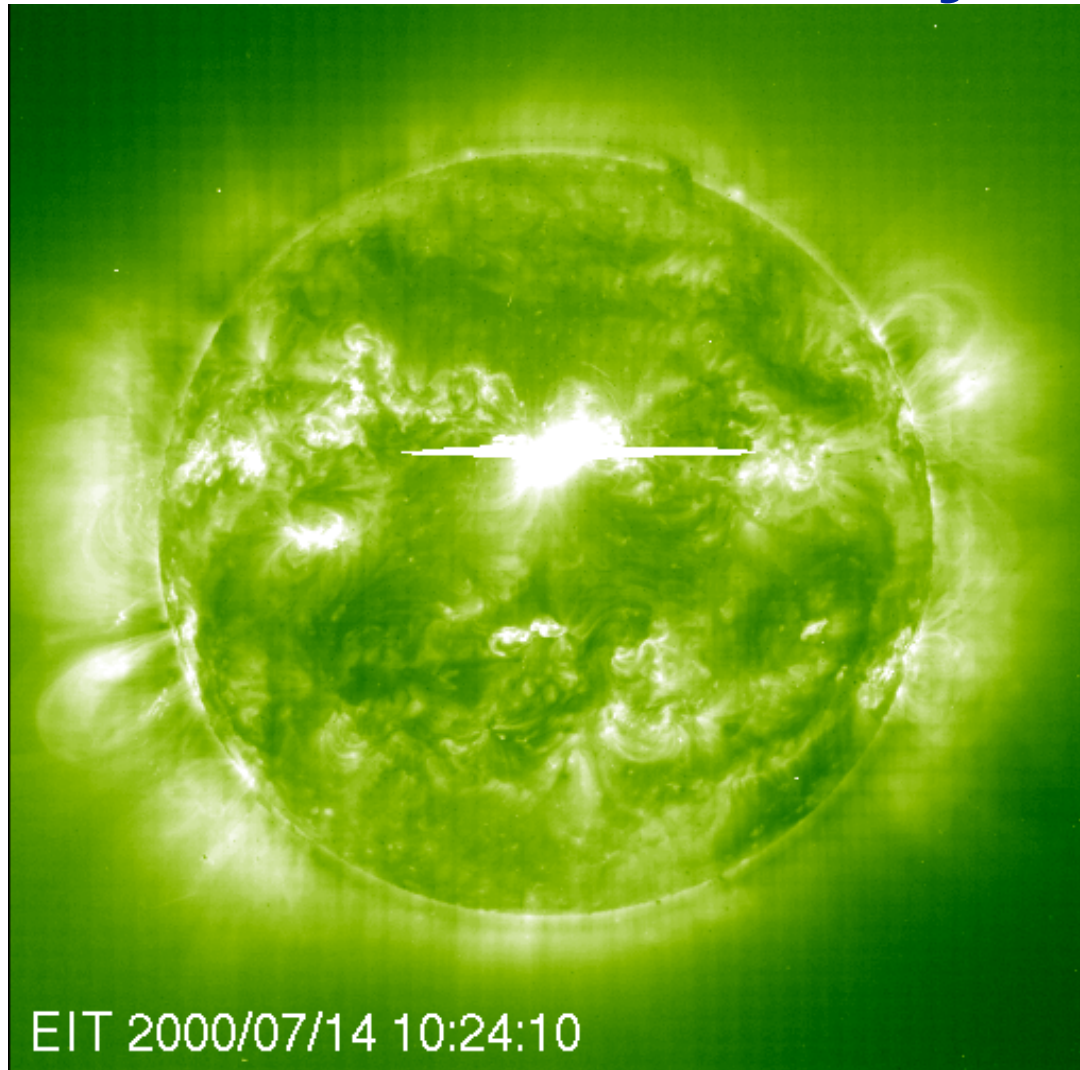
Coronal Mass Ejections (CMEs)



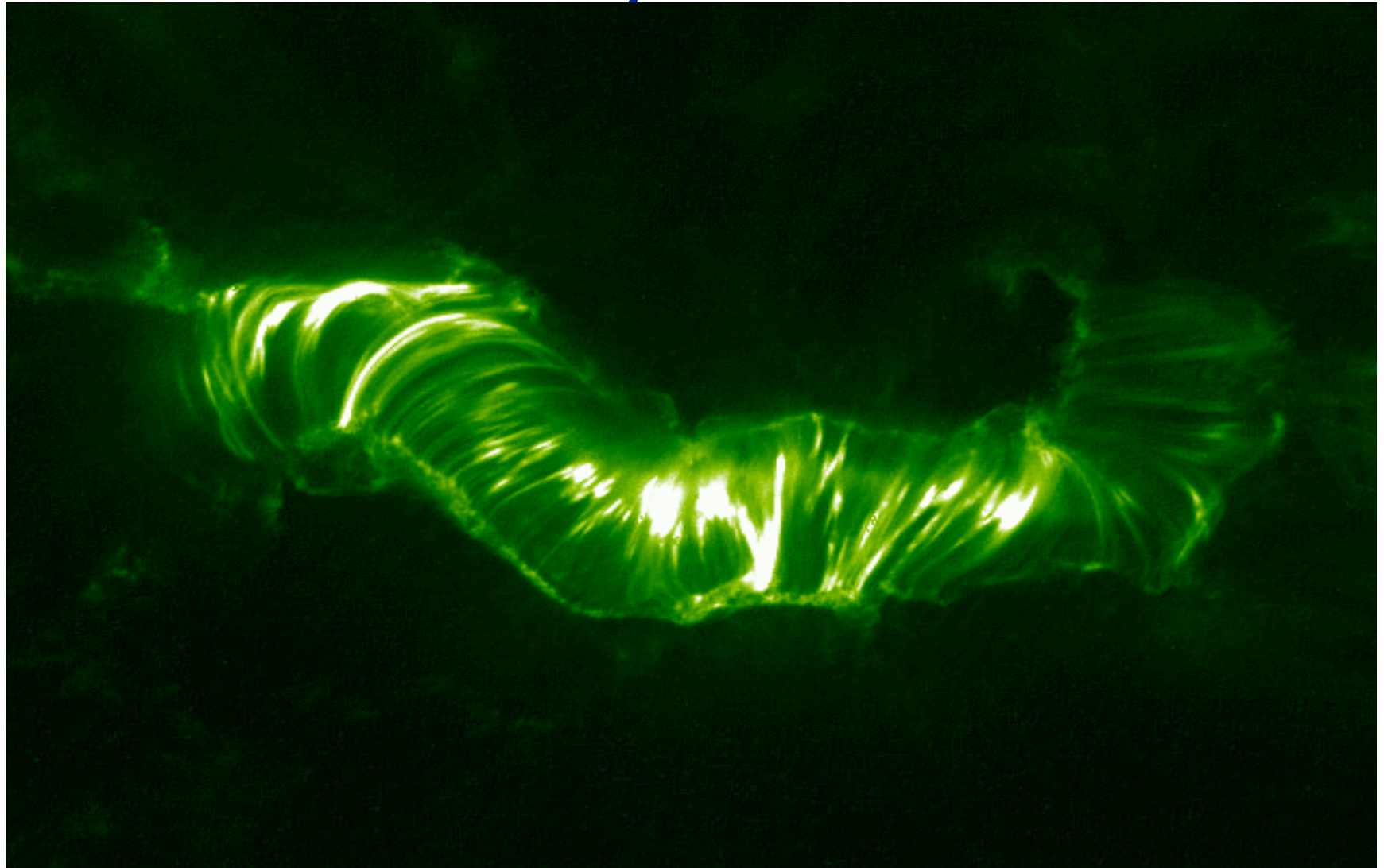
The Active Sun: July 2000



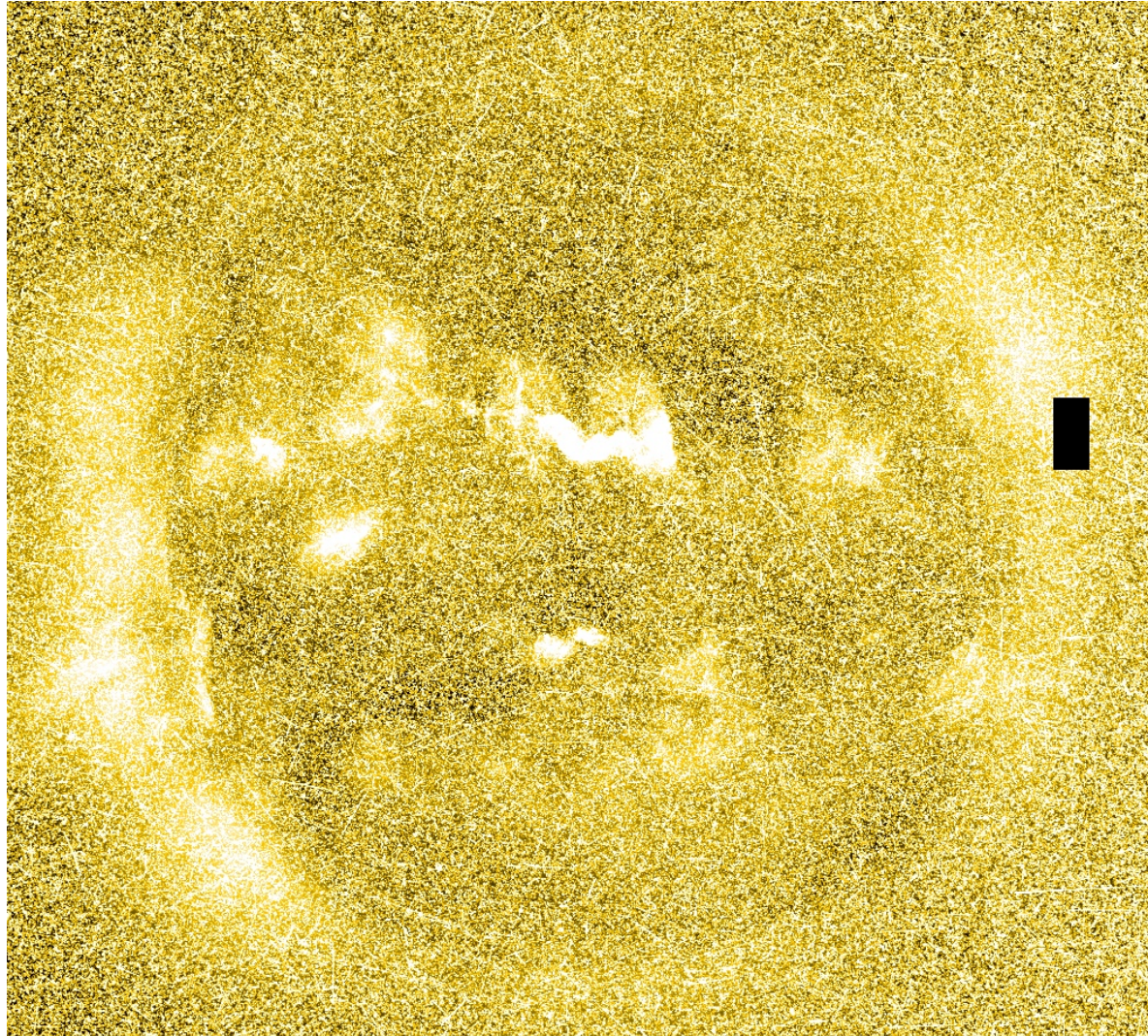
The Active Sun: July 2000



Bastille Day 2000 Event



Solar Energetic Particles



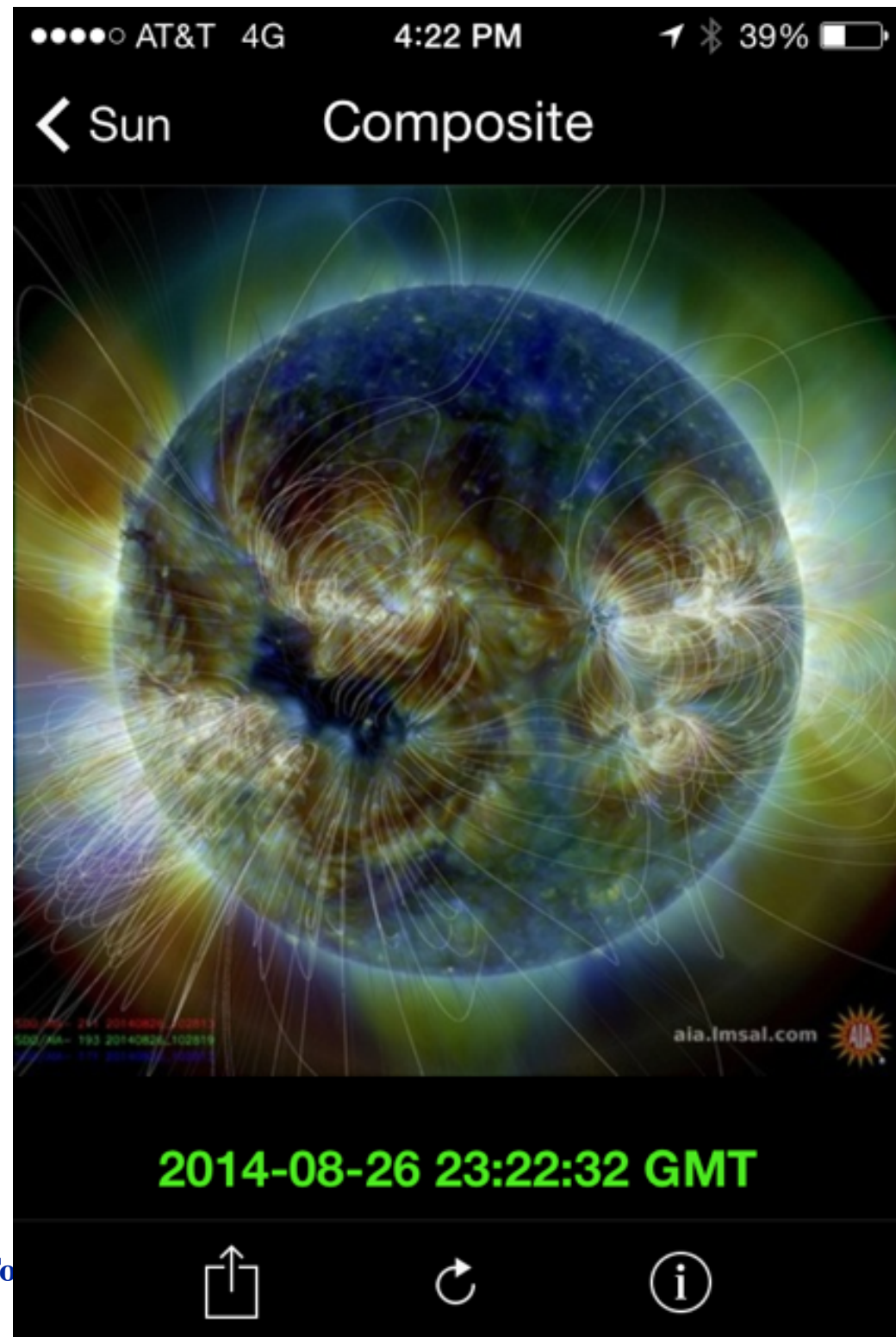


SDO AIA image of the Sun 26 August 2014 23:22 UT

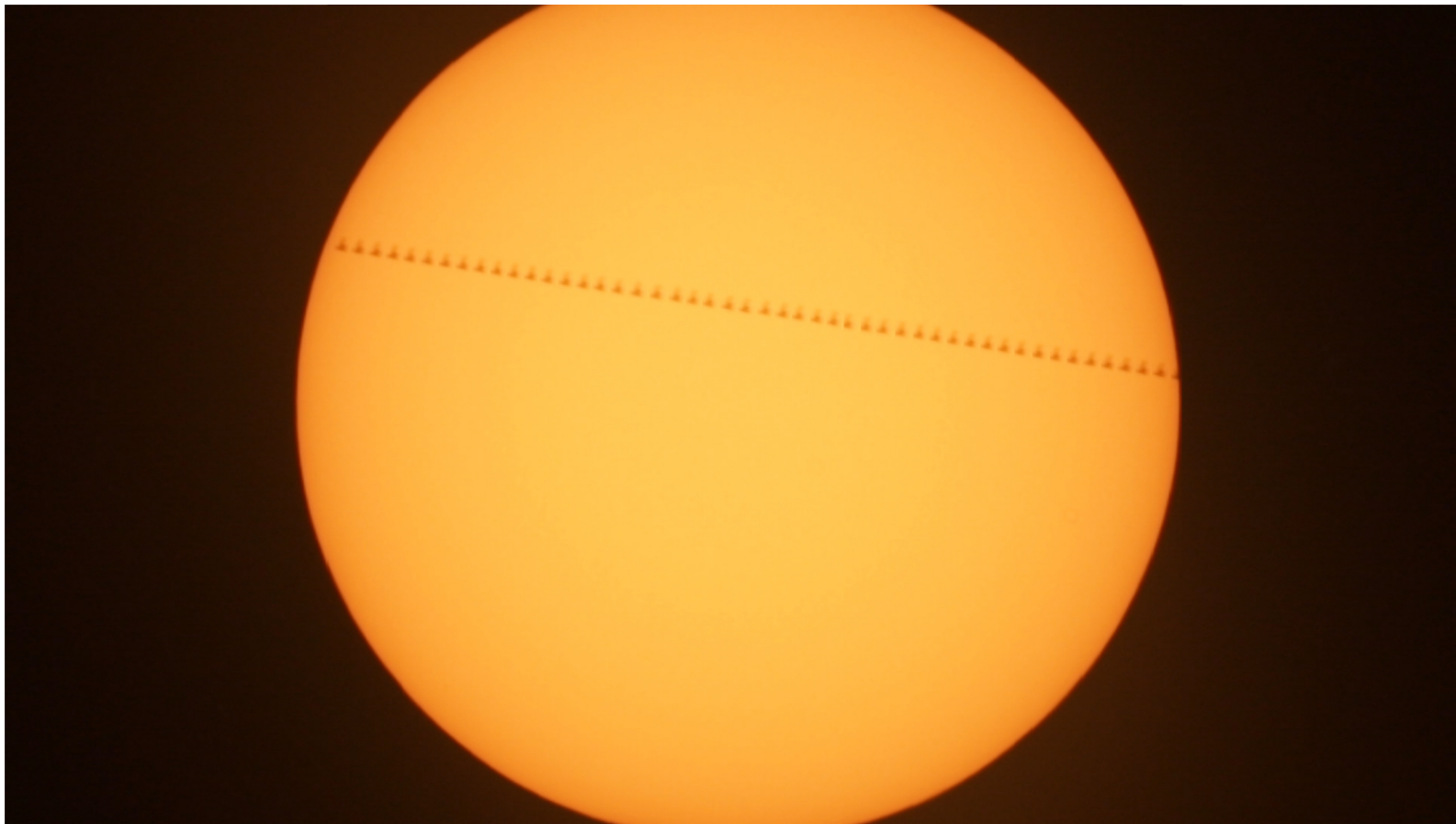
Credit: SET

<https://SpaceWx.com>

W. Kent To



ISS transiting the Sun from Camarillo, CA Oct 12, 2019 @ 10:23 am



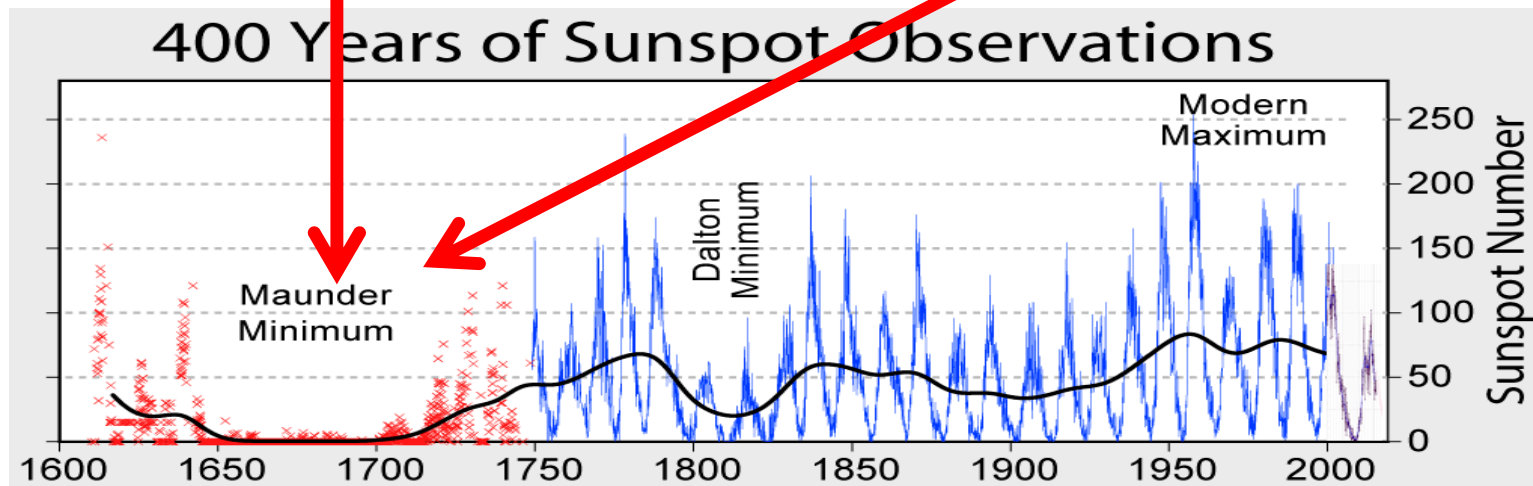
Credit: Ethan Geipel

Conceptual framework for spacecraft, space systems, and ground systems interactions with space weather

Space Environment MAY Effect Climate



LOW CENTRAL EUROPEAN TEMPERATURES

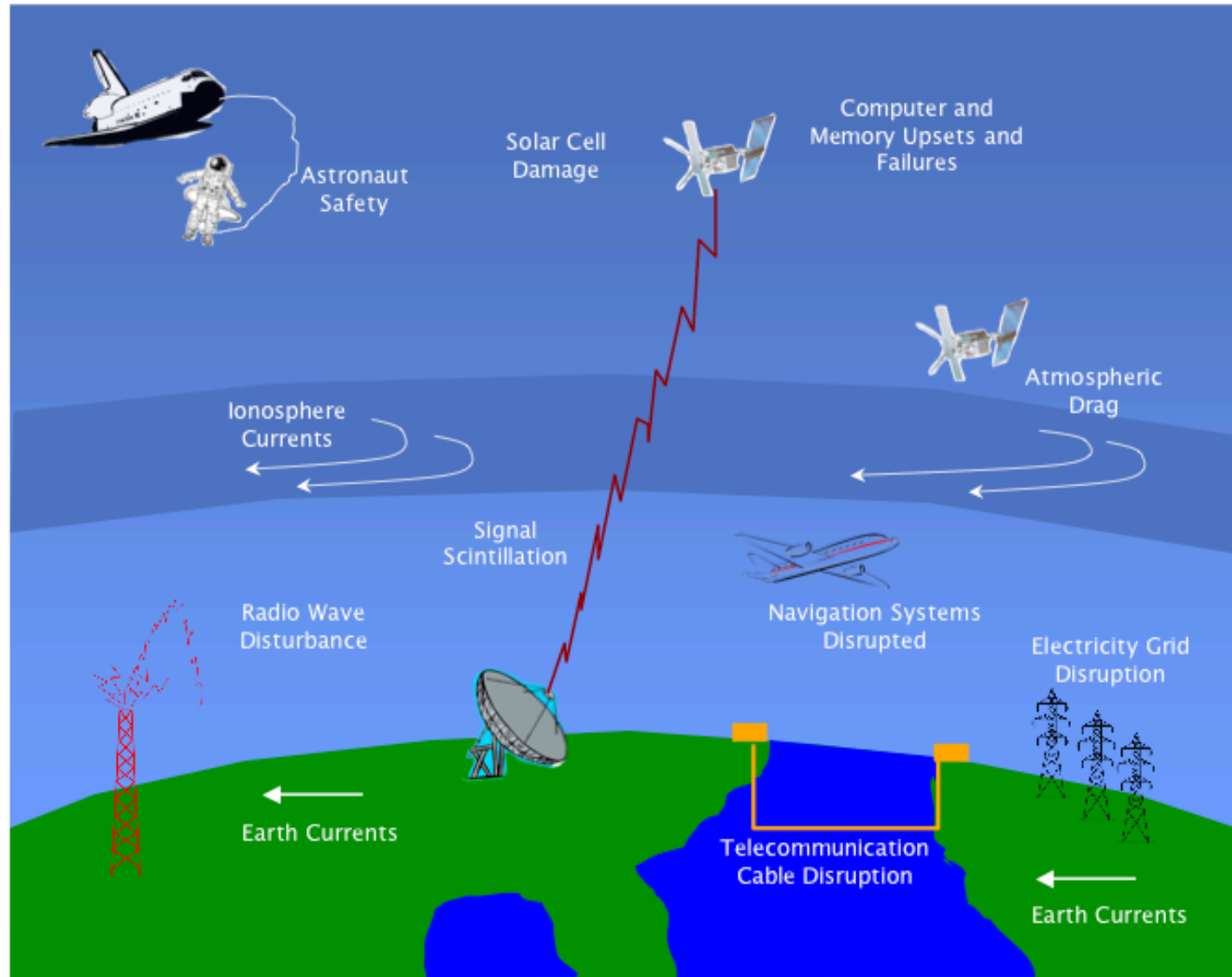


Human Activities Affected by Space Weather

GPS Satellites
at 15,000 Miles

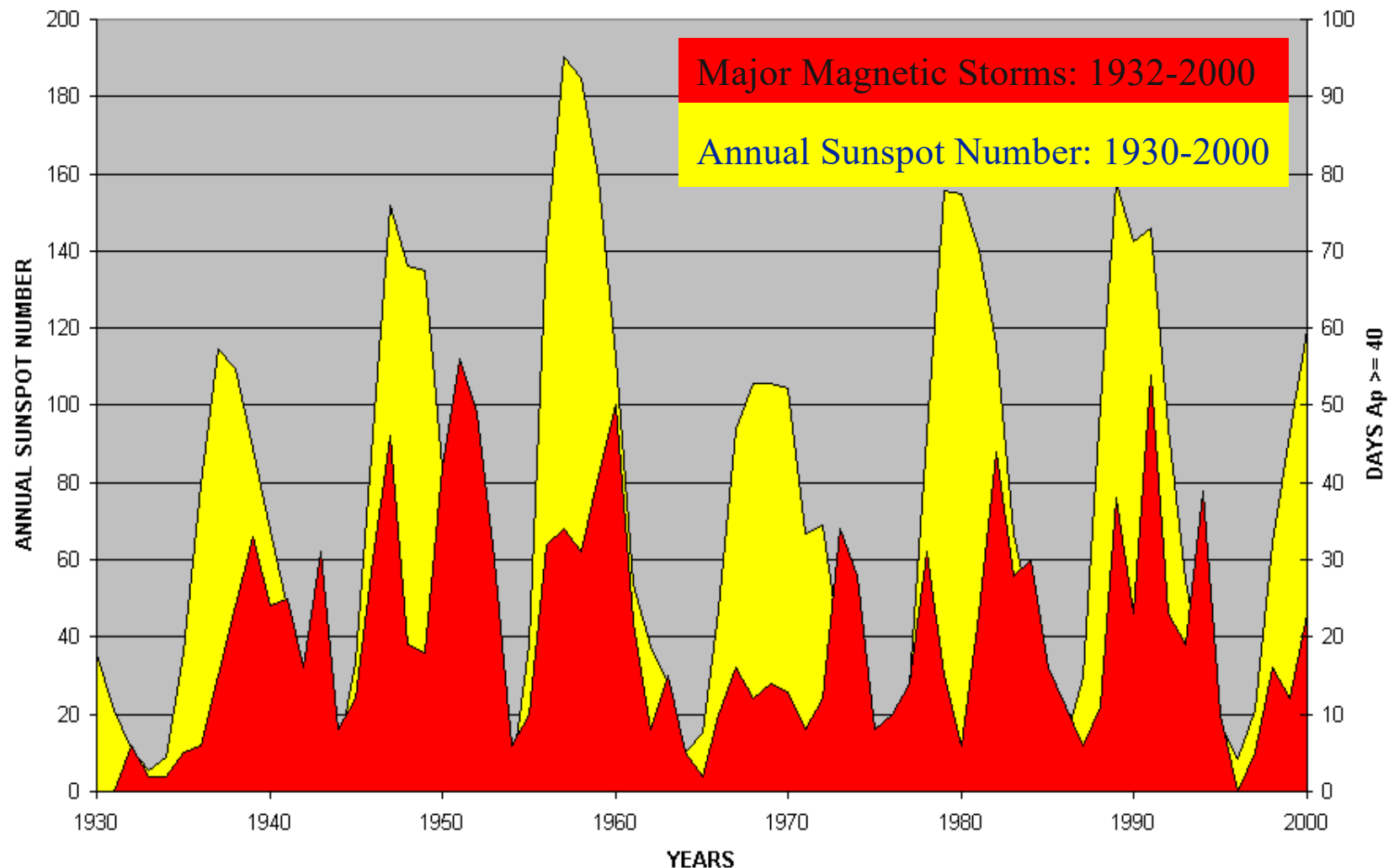
240 miles

50 miles



Sunspots and Magnetic Storms

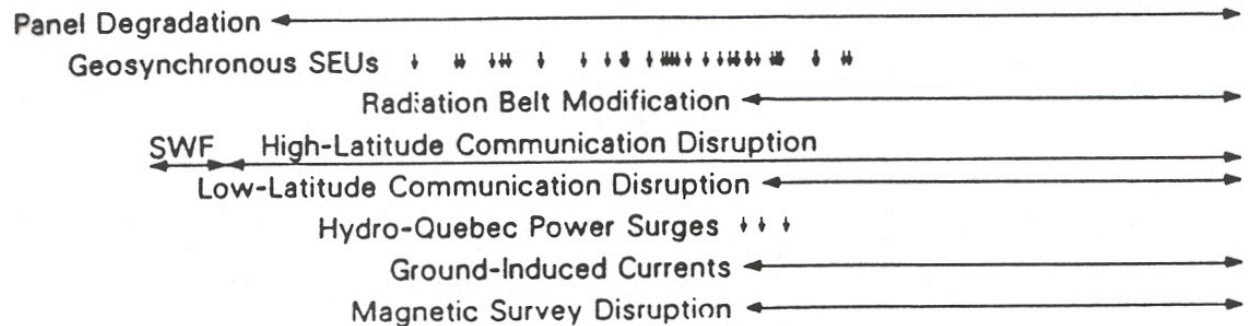
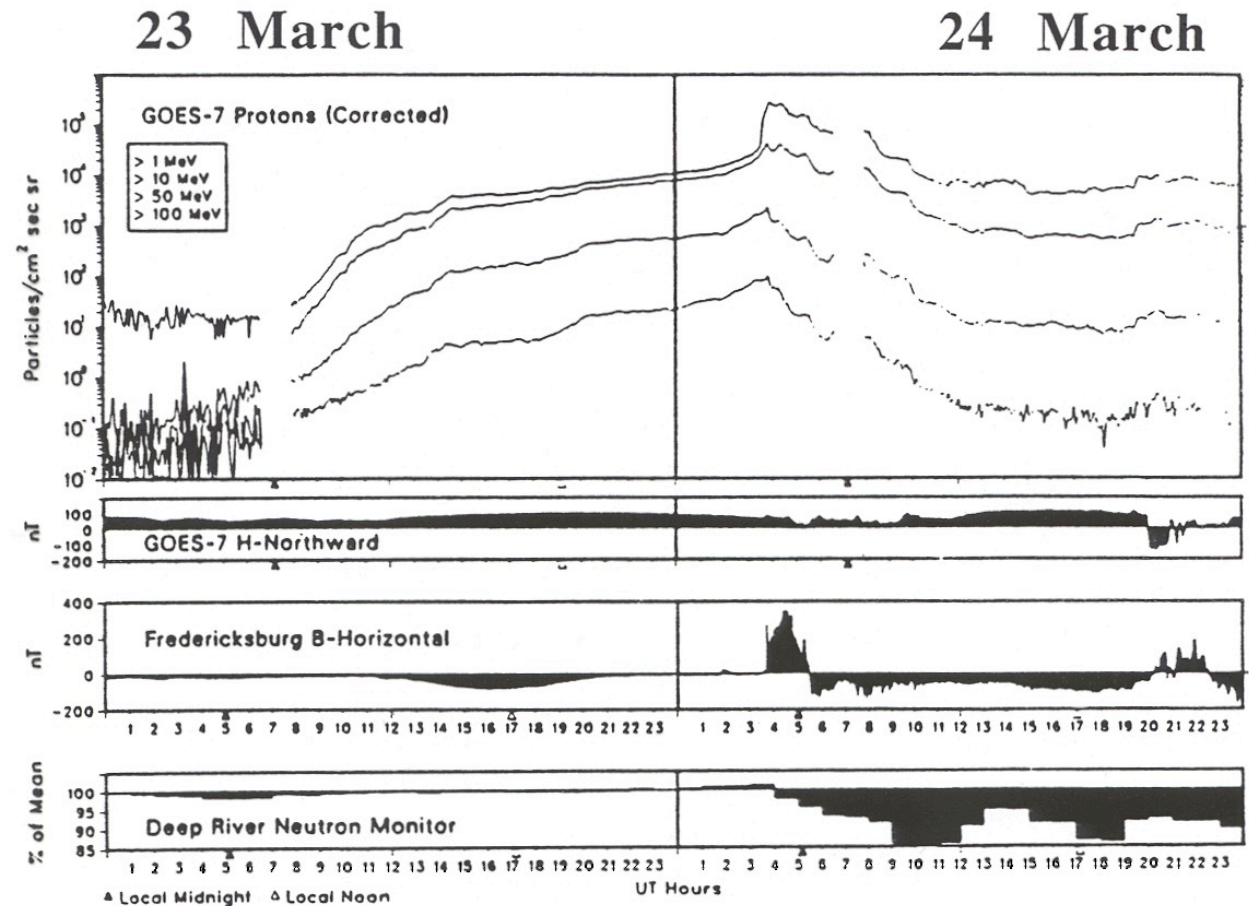
ANNUAL SUNSPOT NUMBER & Ap DAYS ≥ 40



Aurorae



Geomagnetic Storm Example: March 1991





Lecture 1

Impact of Solar Flares March 1991

Satellite

MARECS-A

INTELSAT 602
GOES 7

TDRSS
INTELSAT
CRRES

DOD

DMSP
NOAA 11

NORAD

Effects

Satellite failure

Permanent power degradation
(Decrease of satellite lifetime by 2-3 years)

Single Event Upsets
Soft errors
(Increase from 1 per day to 10-20 per day)

Spacecraft charging and Deep dielectric charging

Loss of automatic attitude control

Satellite drag (Loss of 200 vehicles from catalogue)

Space environment affects on GEO space systems

Civilian Spacecraft at Geostationary Orbit



Credit: AGI

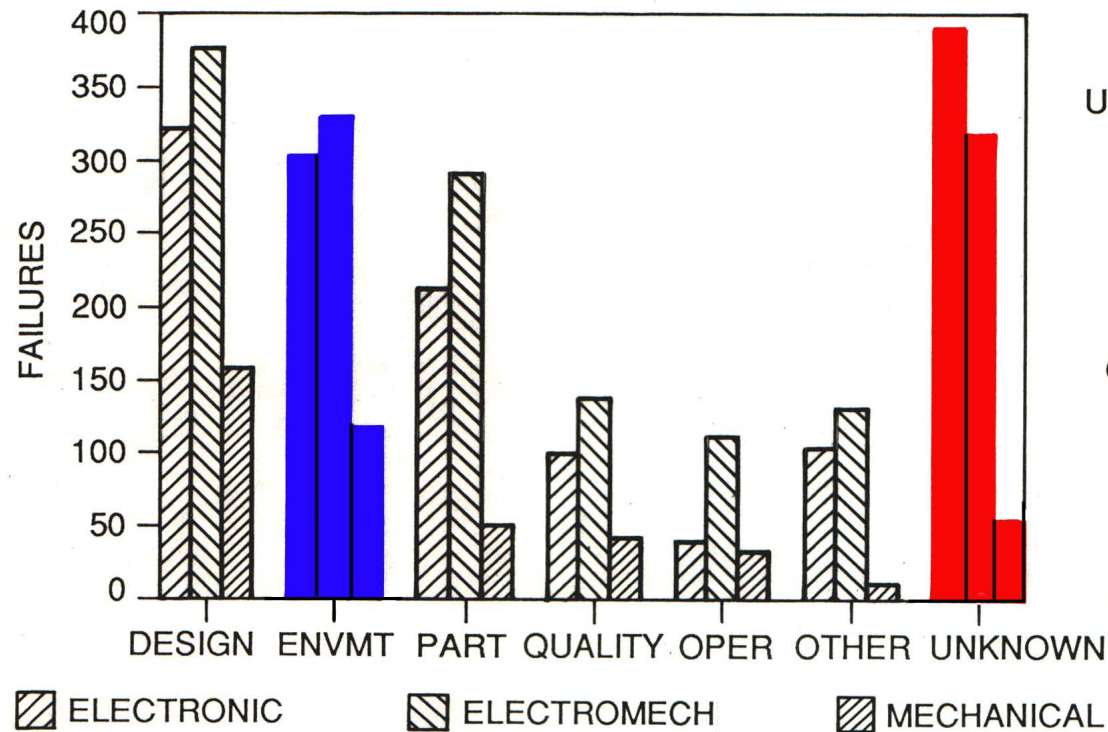


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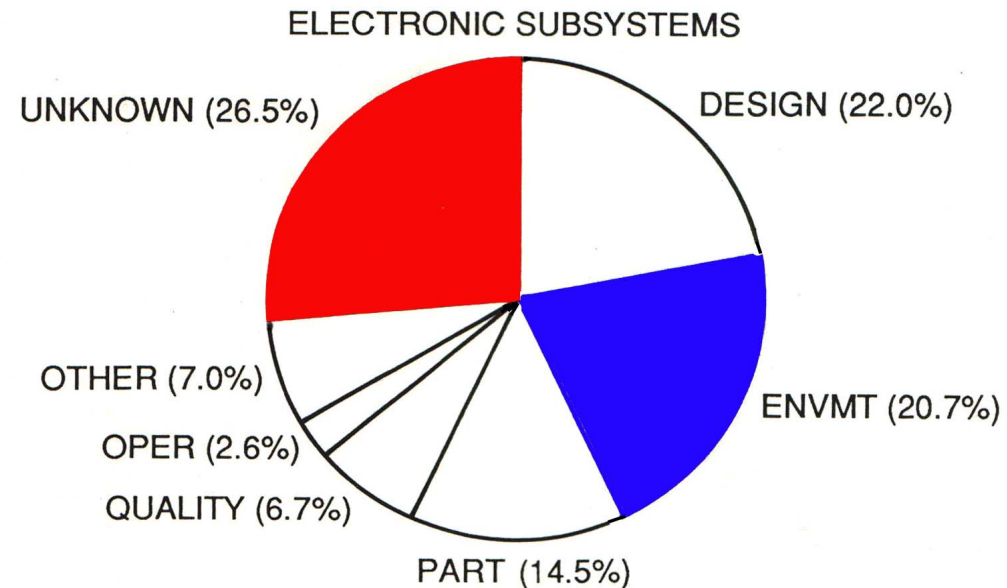
SUBSYSTEM IN-FLIGHT FAILURE CAUSES

(HECHT, 1985)

FAILURE CAUSES BY SUBSYSTEM CATEGORY



FAILURE CAUSES IN ELECTRONIC SUBSYSTEMS



Credit: Hecht



Lecture 1

THE IMPACT OF THE SPACE ENVIRONMENT ON SPACE SYSTEMS[†]

Distribution by Anomaly Diagnosis

Diagnosis	Number of Forms
ESD - Internal Charging	74
ESD - Surface Charging	59
ESD - Uncategorized	28
Surface Charging	1
Total ESD & Charging	162
SEU - Cosmic Ray	15
SEU - Solar Particle Event	9
SEU - South Atlantic Anomaly	20
SEU - Uncategorized	41
Total SEU	85
Solar Array - Solar Proton Event	9
Total Radiation Dose	3
Materials Damage	3
South Atlantic Anomaly	1
Total Radiation Damage	16
Micrometeoroid/Debris Impact	10
Solar Proton Event - Uncategorized	9
Magnetic Field Variability	5
Plasma Effects	4
Atomic Oxygen Erosion	1
Atmospheric Drag	1
Sunlight	1
IR background	1
Ionospheric Scintillation	1
Energetic Electrons	1
Other	2
Total Miscellaneous	36

[†]Koons, H.C., J. E. Mazur, R. S. Selesnick, J. B. Blake, J. F. Fennell, J. L. Roeder, and P. C. Anderson, "The Impact of the Space Environment on Space Systems", presented at Charging Conference, Nov 1998.

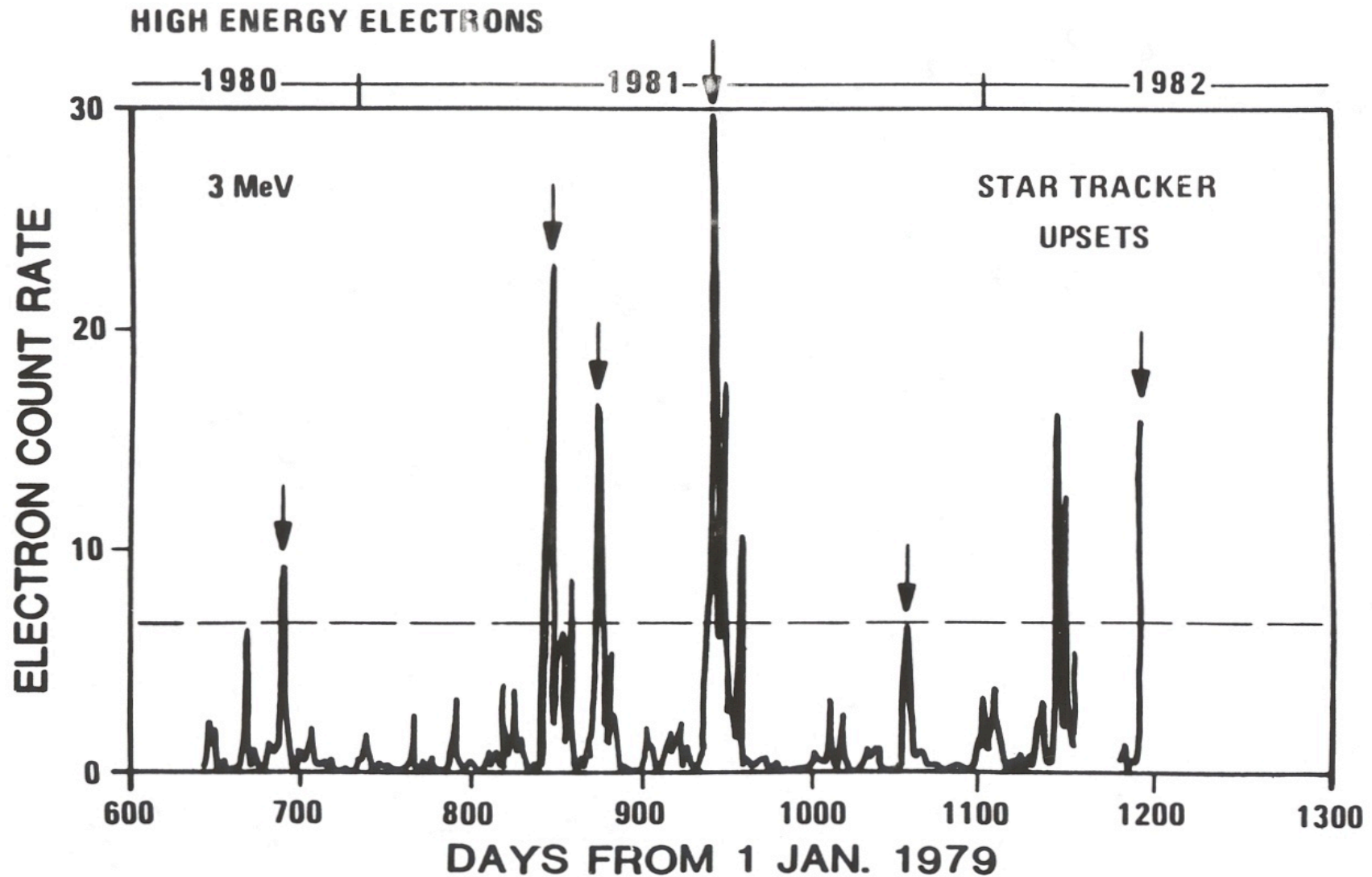
Missions Lost/Terminated Due to Space Environment

Vehicle	Date	Diagnosis
DSCS II (9431)	Feb 73	Surface ESD
GOES 4	Nov 82	Surface ESD
DSP Flight 7	Jan 85	Surface ESD
Feng Yun 1	Jun 88	ESD
MARECS A	Mar 91	Surface ESD
MSTI	Jan 93	Single Event Effect
Hipparcos*	Aug 93	Total Radiation Dose
Olympus	Aug 93	Micrometeoroid Impact
SEDS 2*	Mar 94	Micrometeoroid Impact
MSTI 2	Mar 94	Micrometeoroid Impact
IRON 9906	1997	Single Event Effect
INSAT 2D	Oct 97	Surface ESD

*Mission had been completed prior to termination

Credit: Hecht

Star Tracker Anomalies at GEO

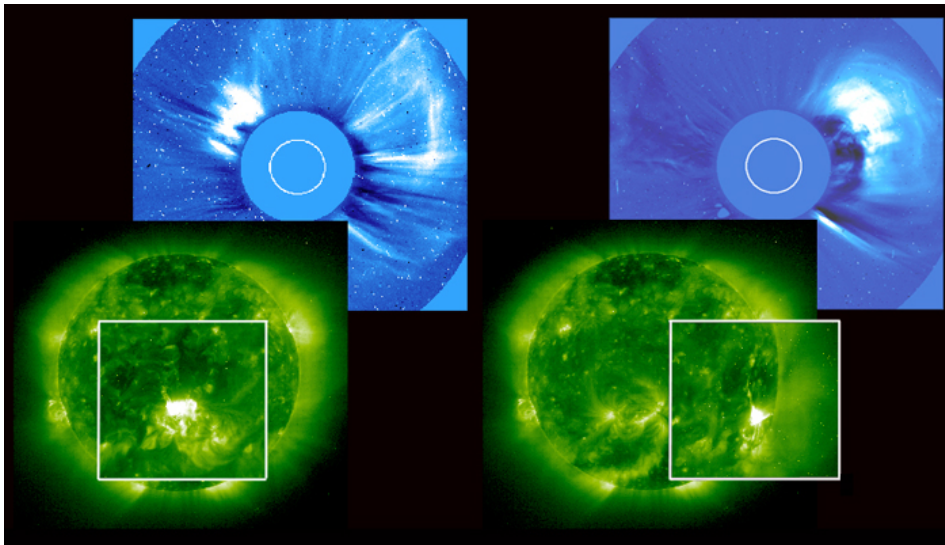




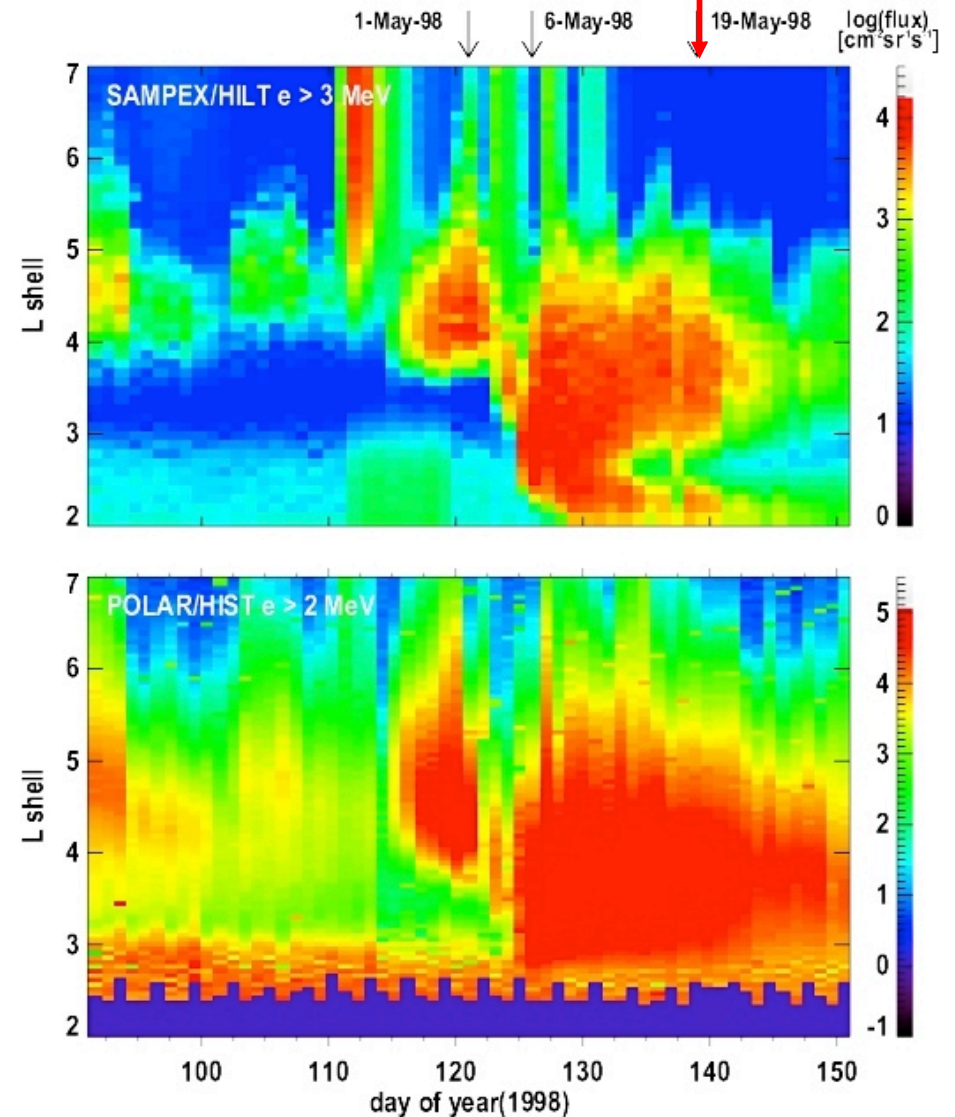
News Accounts of Galaxy-4 Failure

Galaxy-4 Satellite Failure

April-May 1998 Special
Analysis Interval



Lecture 1

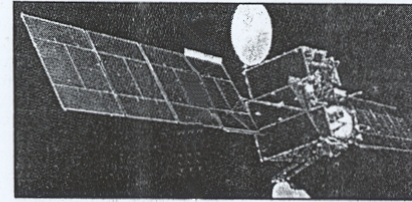


SAMPEX and POLAR

The Hamilton Spectator

Established 1846 • Mon-Fri 47¢ + 3¢ GST

P-ANIK!



High-tech chaos as satellites spin out of control

Plug pulled on phones, TV, radio, papers

OTTAWA — Telesat Canada was facing some tough questions today as it tries to explain how its two main communication satellites tumbled out of control, interrupting TV, radio, newspaper and telephone signals across the country.

After struggling for more than eight hours to bring the wobbly Anik E-1 under control, Telesat technicians thought they had the problem licked late yesterday.

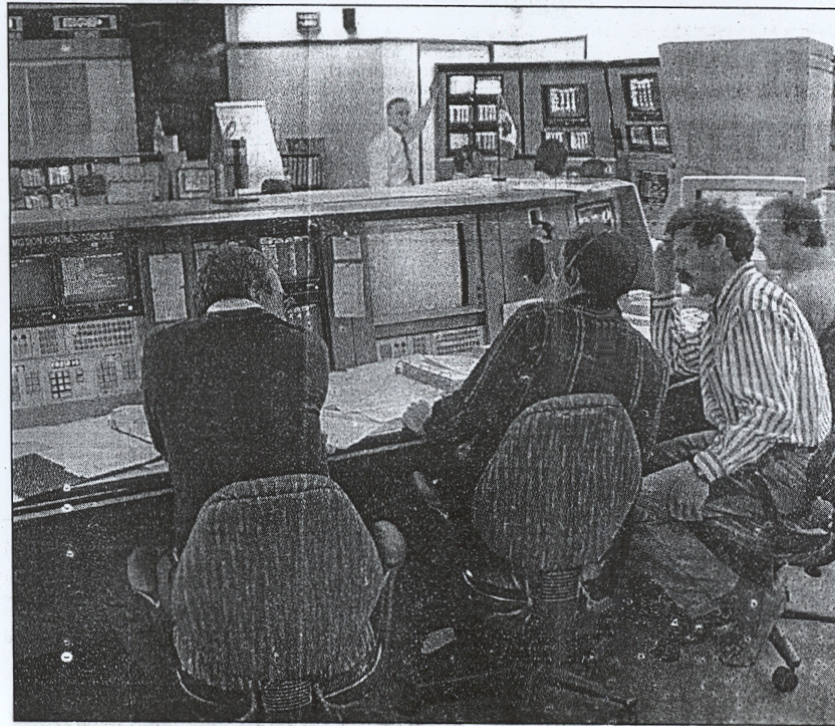
The were only half right.

Shortly after 9 p.m. EST, as Anik E-1 settled back into position, Telesat's primary broadcasting satellite, Anik E-2, also got a bad case of the shakes.

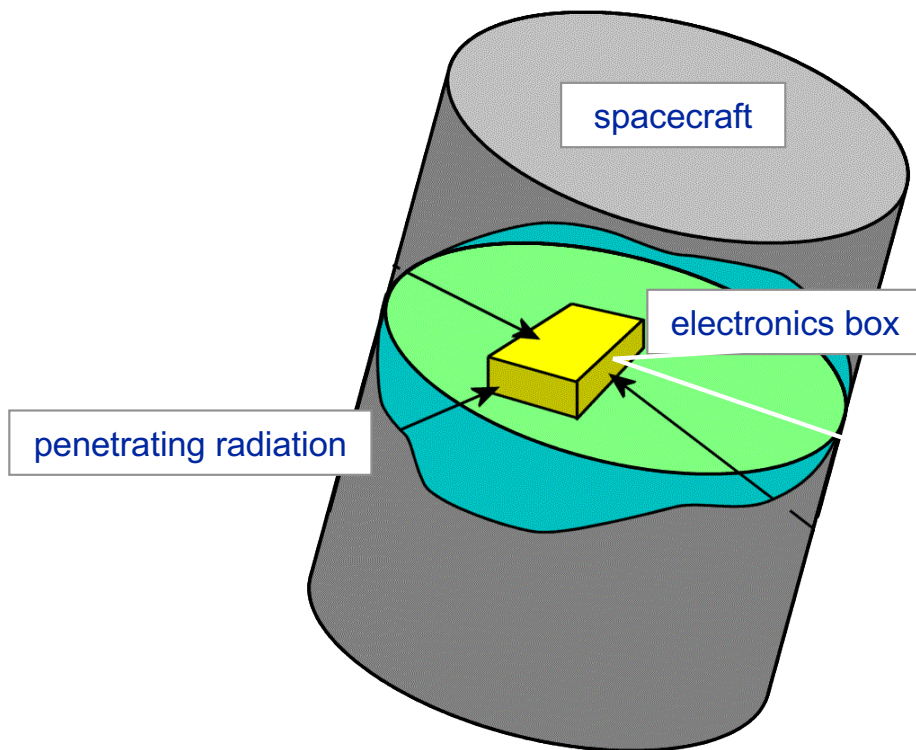
CBC Newsworld and other national specialty cable channels, including MuchMusic, TSN, Vision and the Weather Channel, were knocked off the air. Partial service, with signals carried by fibre-optic cable, was later restored in some major centres, including Toronto.

In Hamilton local cable companies and police communications were unaffected. The Mt. Hope weather office had minor disruptions.

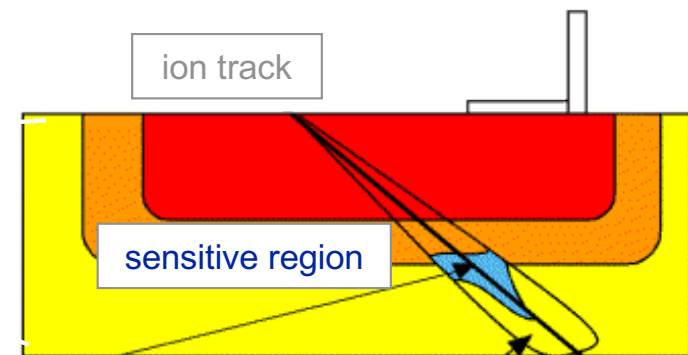
"We don't know how it was brought about," said Chris Frank, Telesat's director of public affairs.



Space Environment Effects



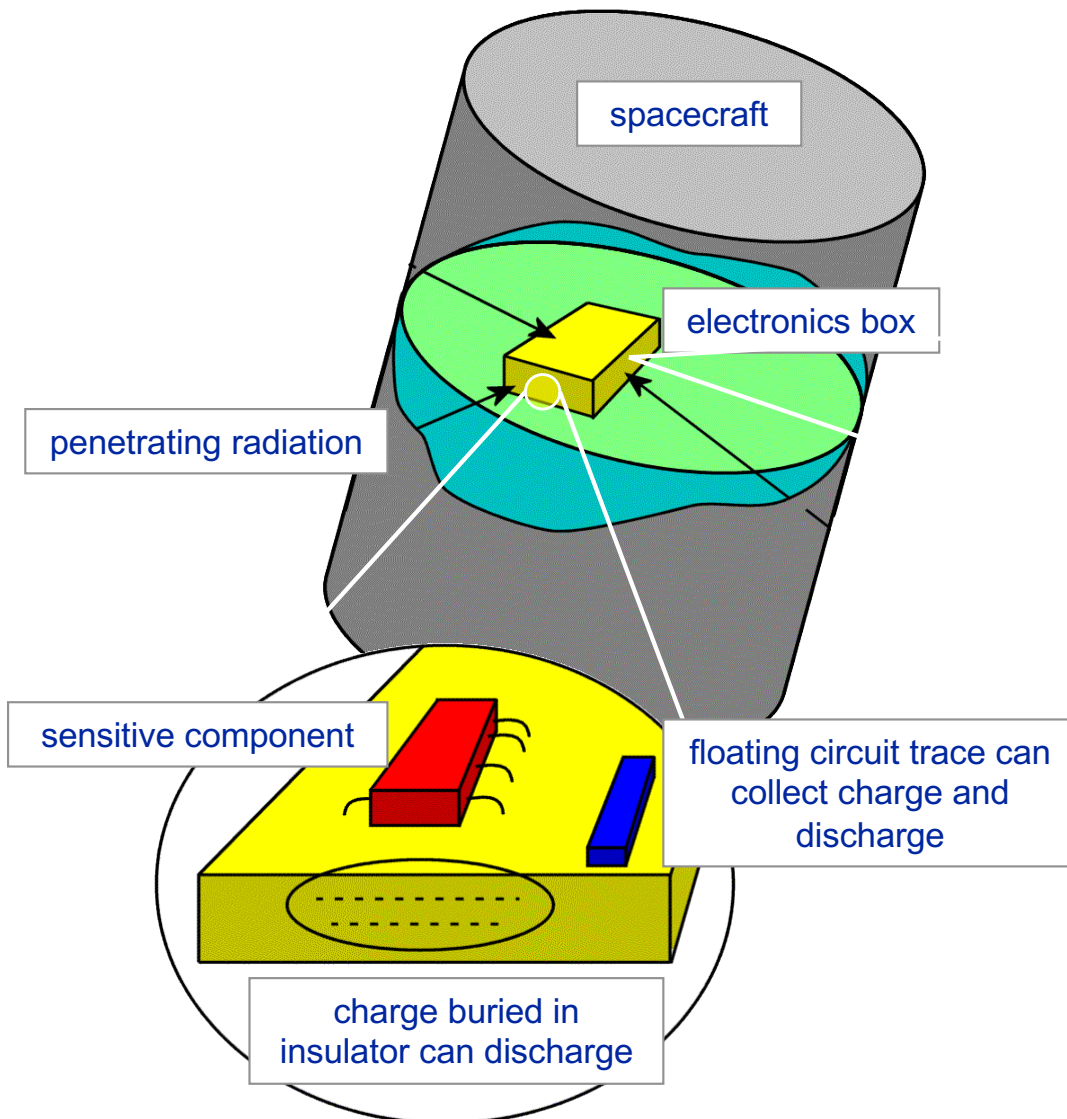
(a) Single Event Upset Mechanism Direct Ionization



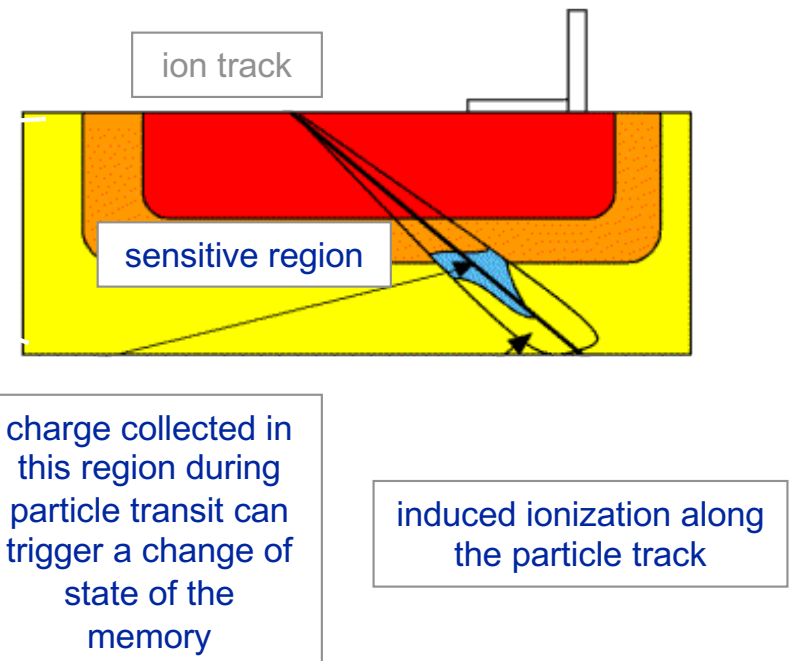
charge collected in this region during particle transit can trigger a change of state of the memory

induced ionization along the particle track

Space Environment Effects



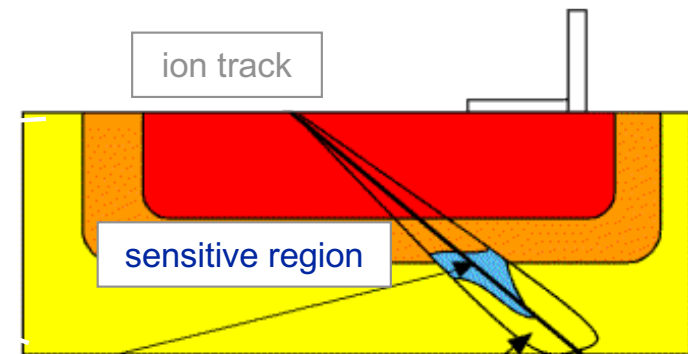
(a) Single Event Upset Mechanism Direct Ionization



Lecture 1

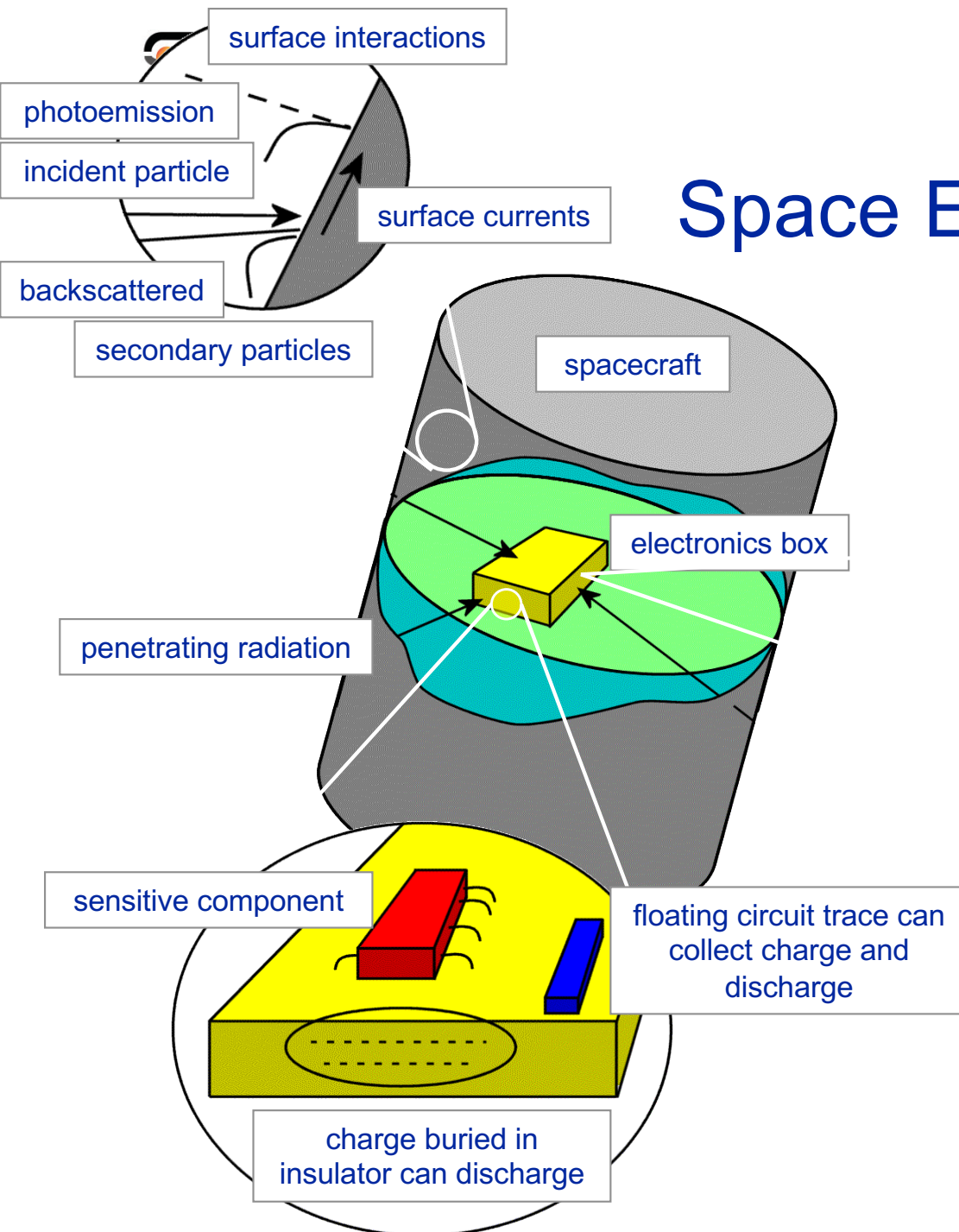
Space Environment Effects

(a) Single Event Upset Mechanism Direct Ionization



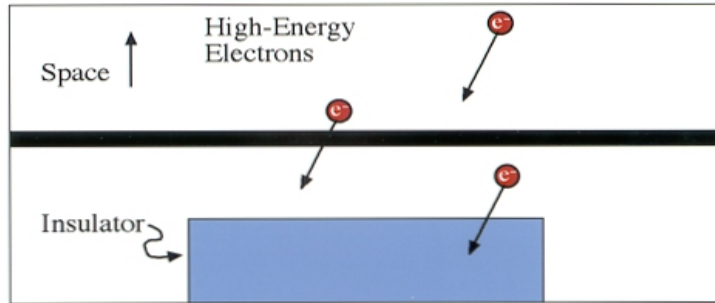
charge collected in this region during particle transit can trigger a change of state of the memory

induced ionization along the particle track

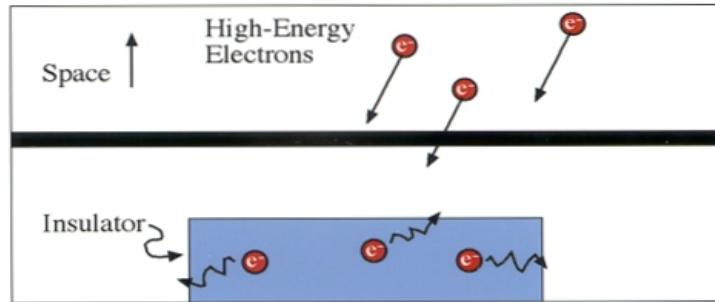


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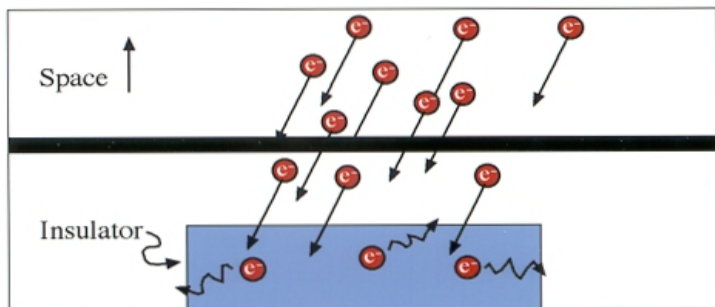
High-Energy Electrons: Deep- Dielectric Charging



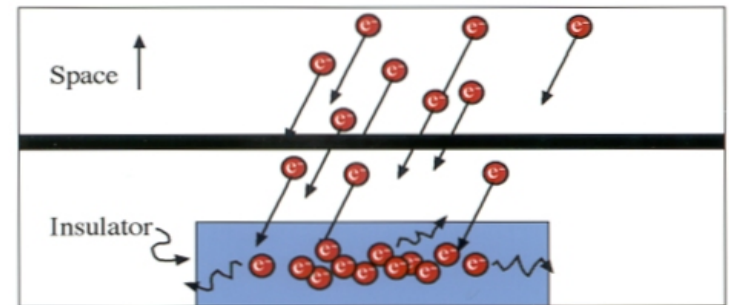
1. Electrons bury themselves in the insulator



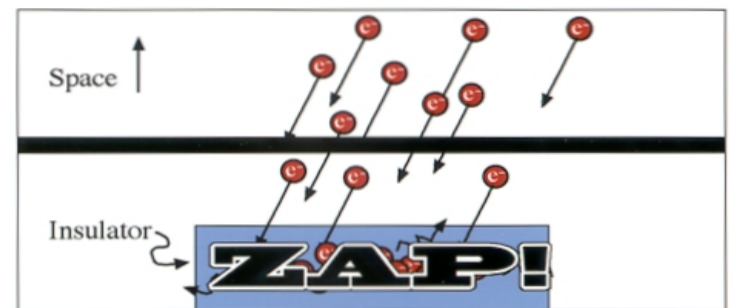
2. Electrons slowly leak out of the insulator



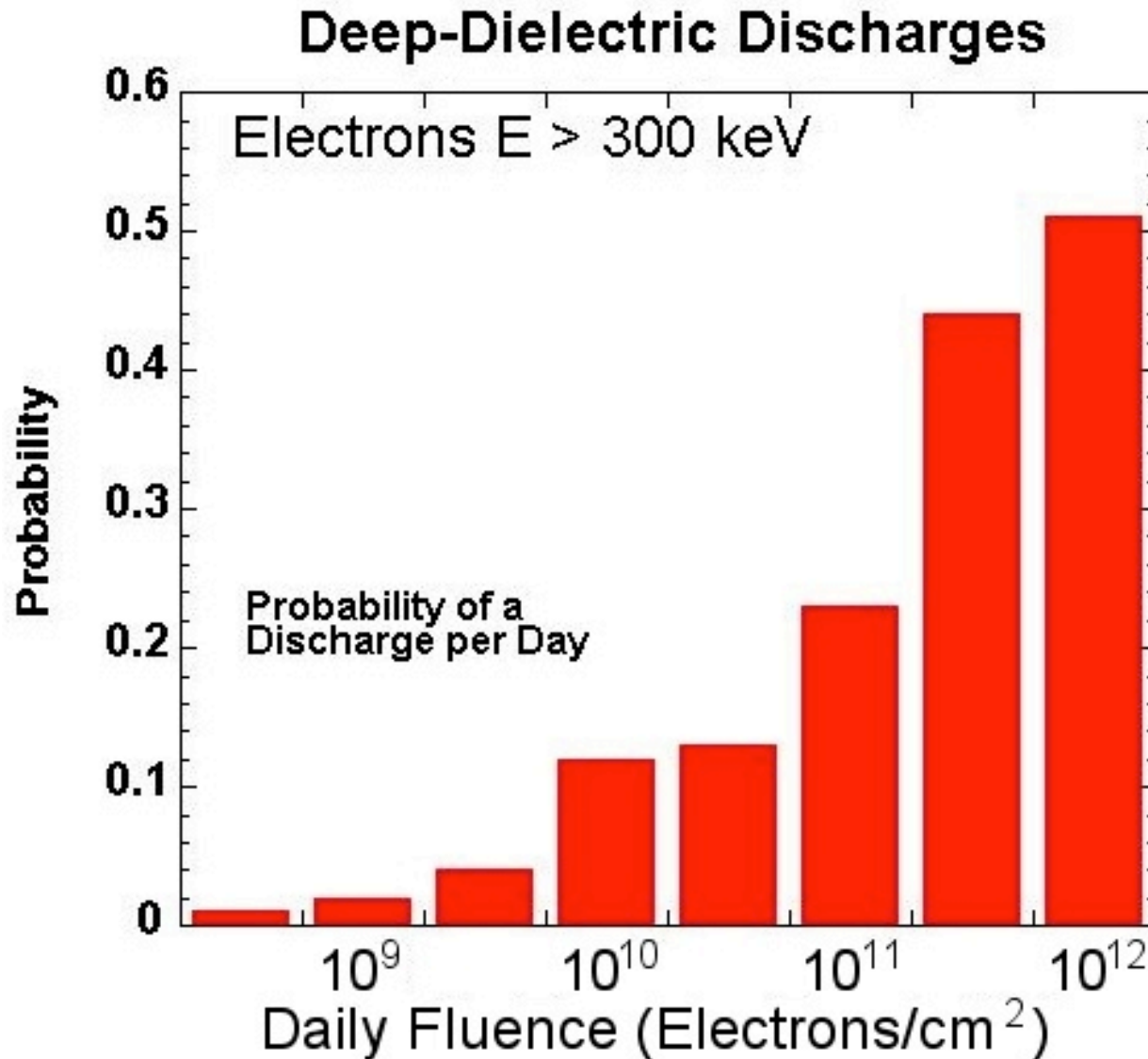
3. Influx of electrons increases to levels higher than the leakage rate



4. Electrons build up faster than they leak off

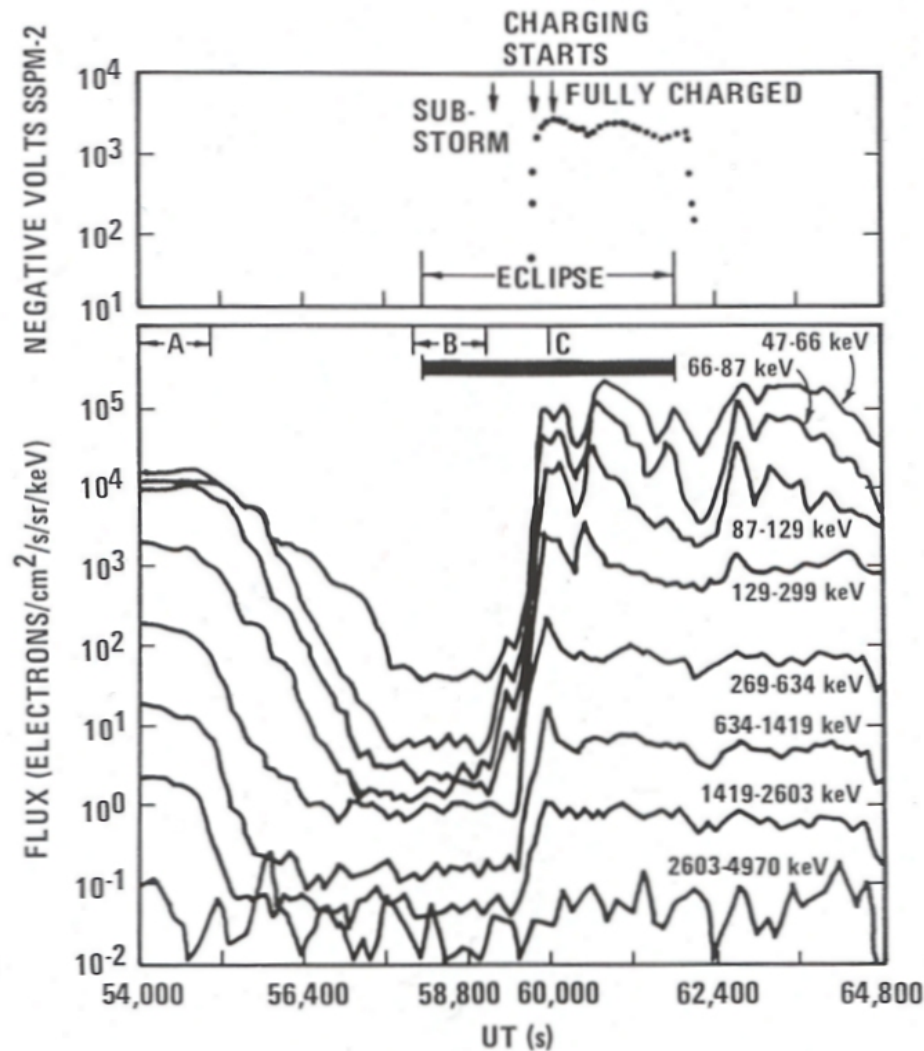


5. Discharge (electrical spark) that damages or destroys the material



Anomalies Due to Dielectric Charging

Probability of discharges goes up dramatically with increasing electron fluence.



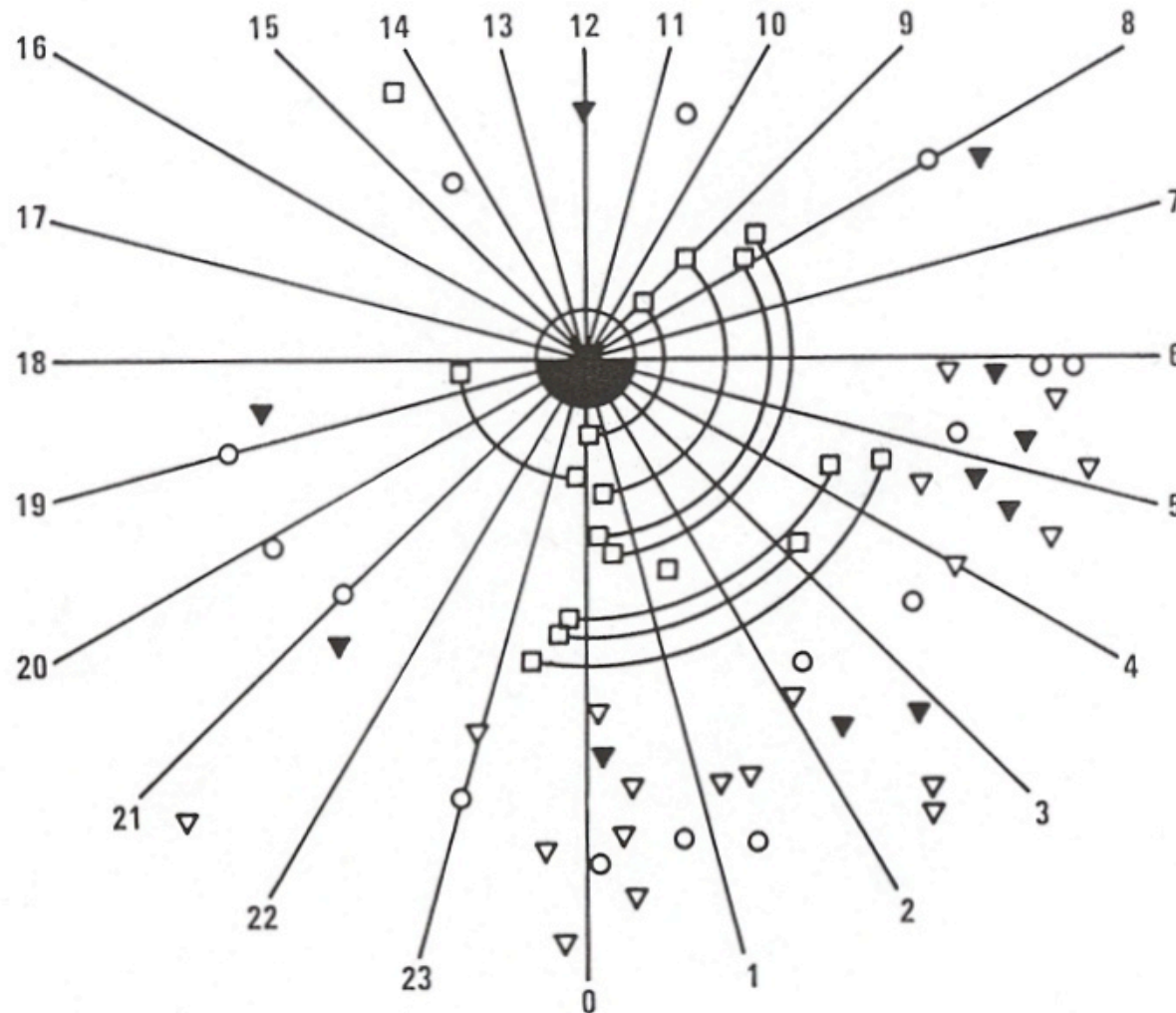
SCATHA (Reagan et al., 1981)

UT	15.00	15.67	16.33	16.67	17.33	18.00
LT	21.90	22.74	23.52	23.89	0.59	1.25
L	6.63	6.90	7.14	7.26	7.51	7.76

Surface Charging: SCATHA Spacecraft

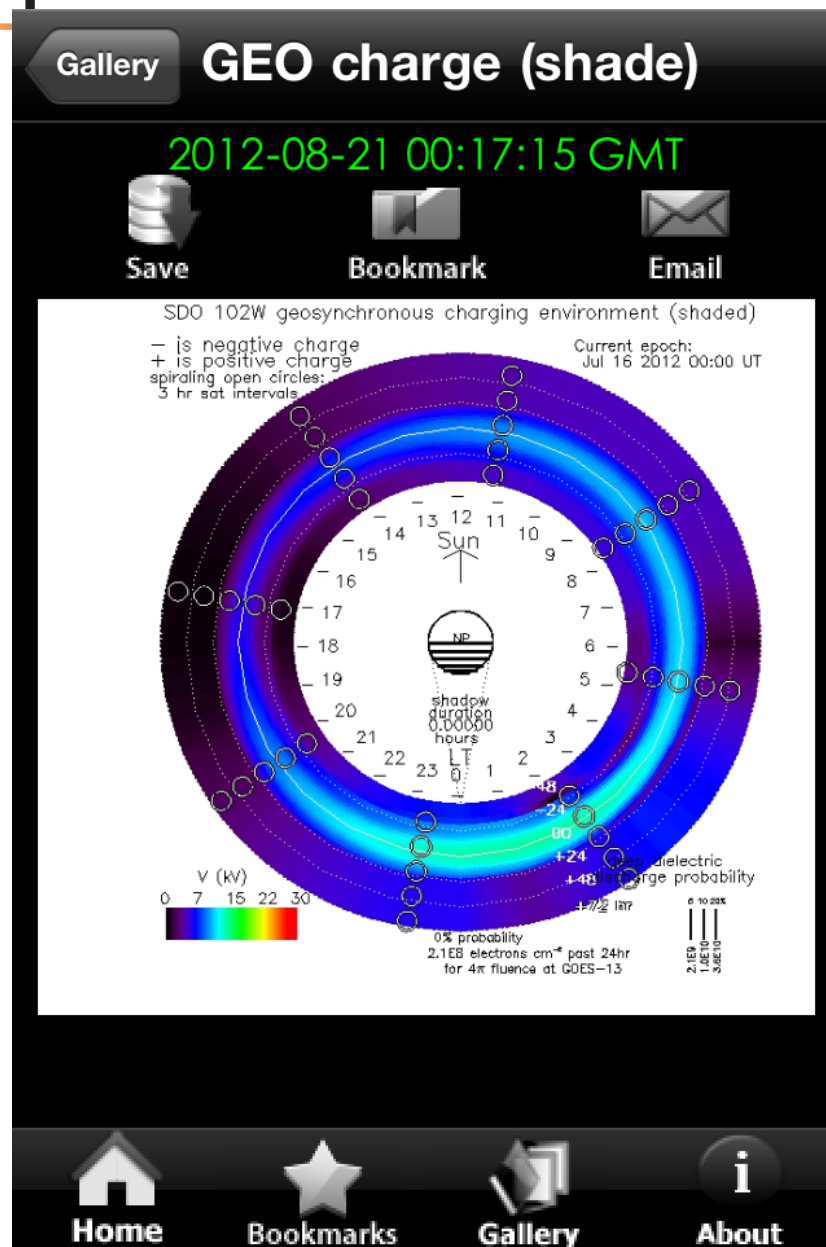
Credit: H. Garrett

Local Time Plot of Various Satellite Disruptions and Anomalies



∇ DSP LOGIC UPSETS
 $\square$ DSCS II RGA UPSETS
 $\blacktriangledown$ INTEL SAT IV
 $\circ$ INTEL SAT III

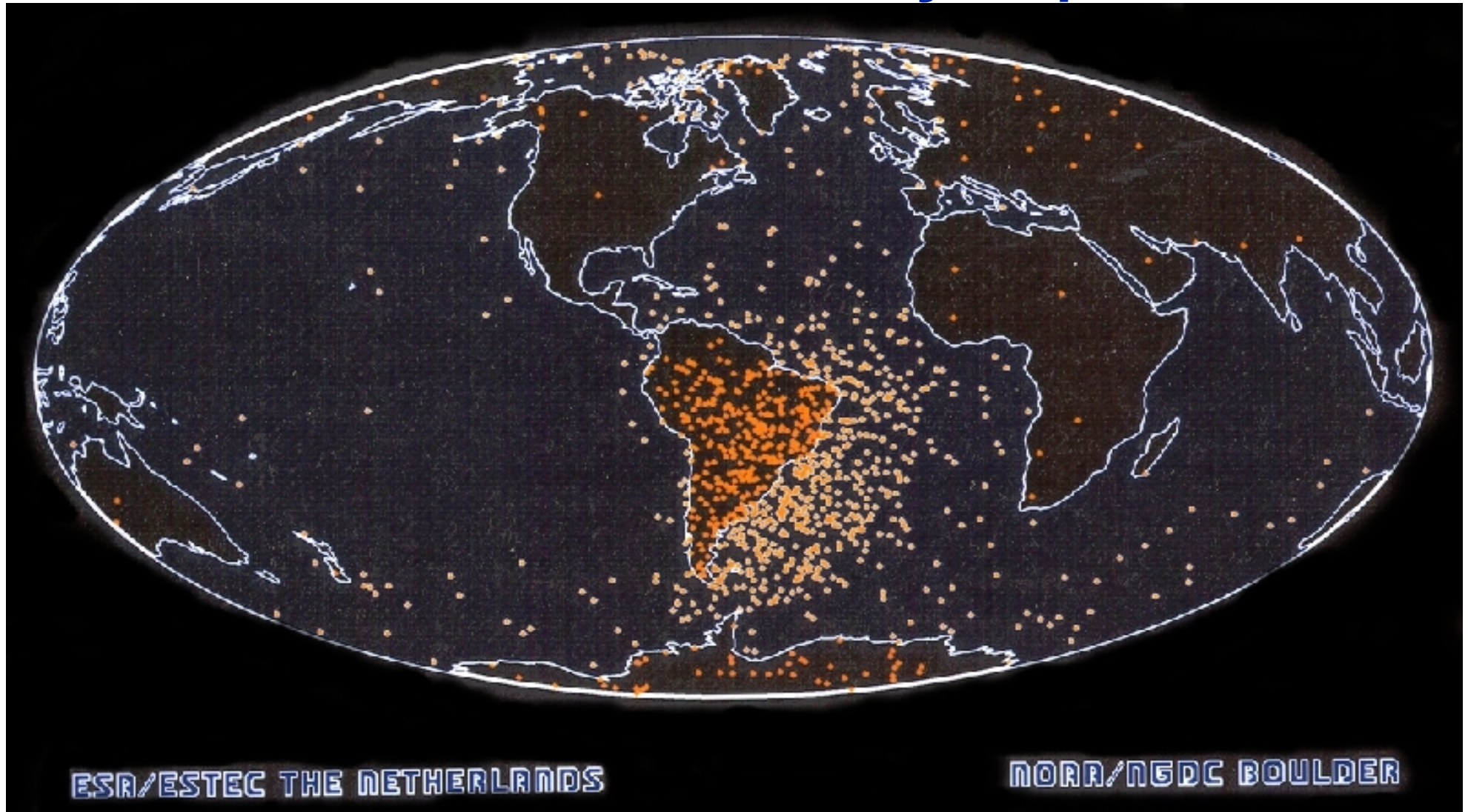
Local Time plot of SET's real- time GAPS GEO alert system



Credit: SET

Space environment affects on MEO and LEO space systems

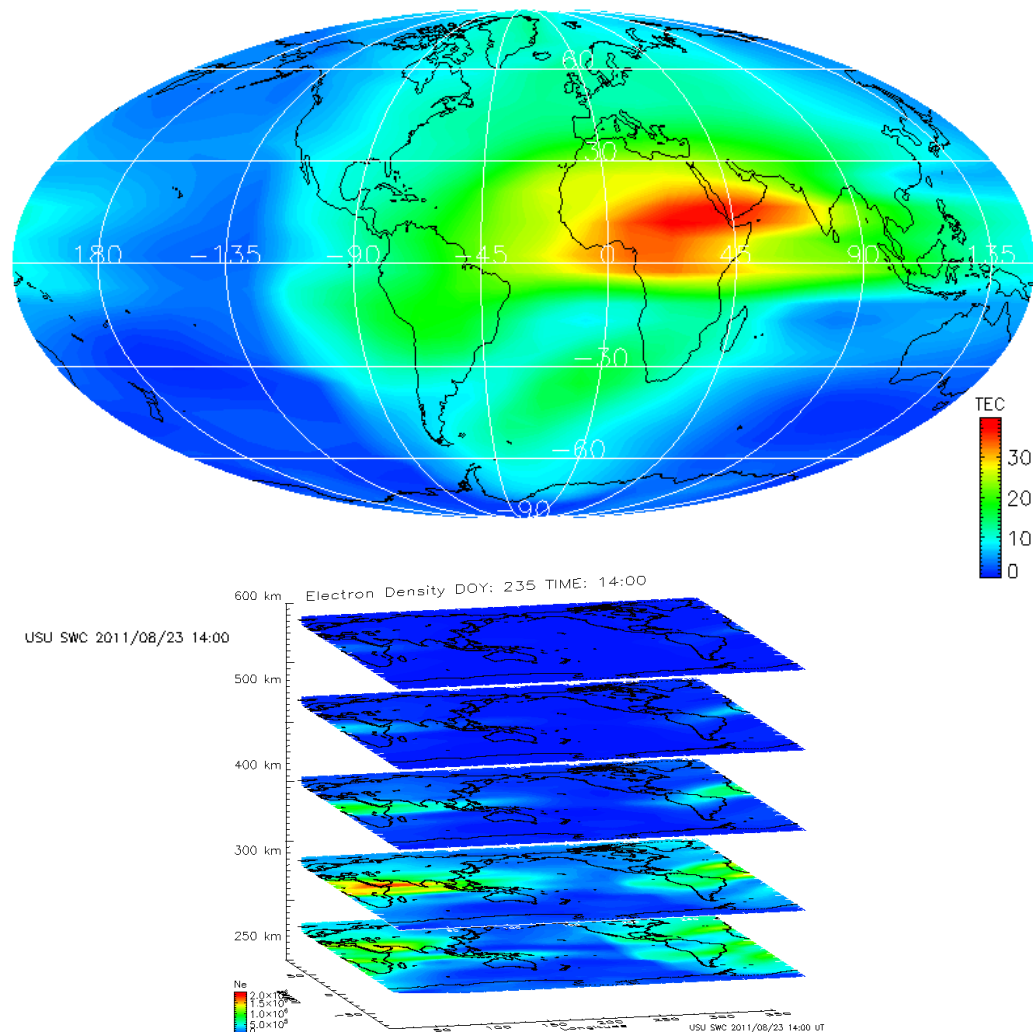
UOSAT-2 Memory Upsets

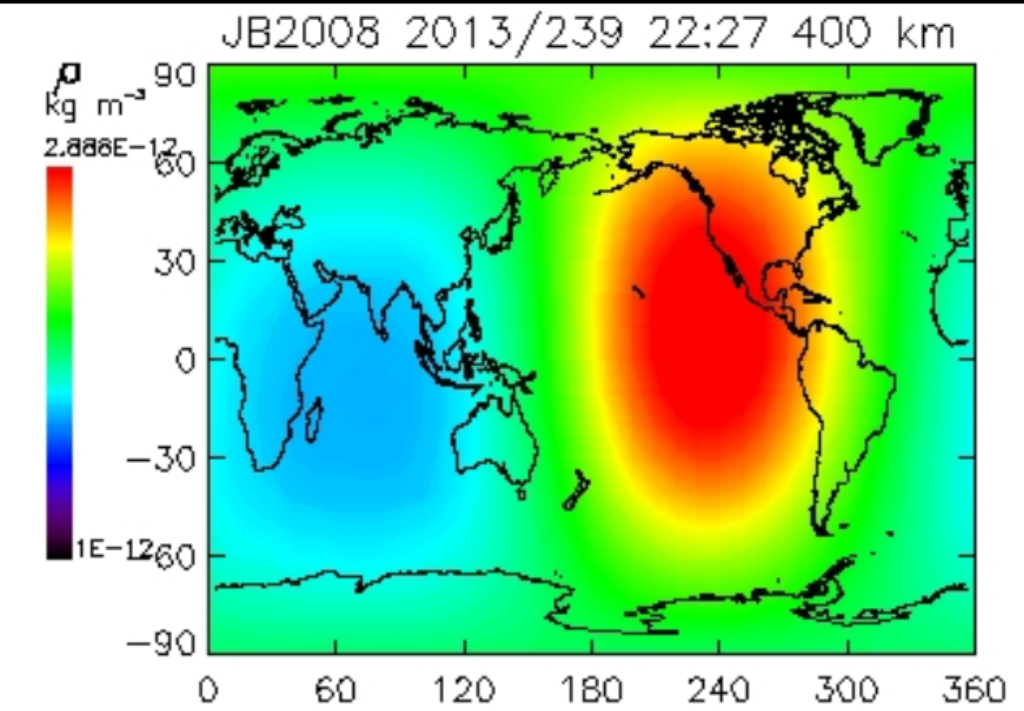
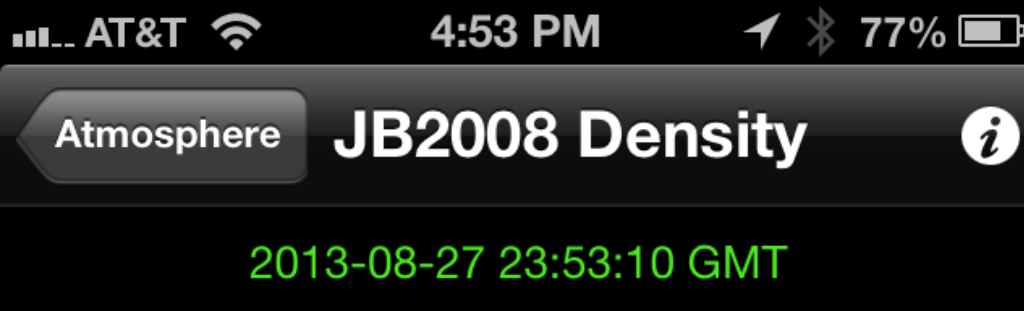


Ionosphere variability

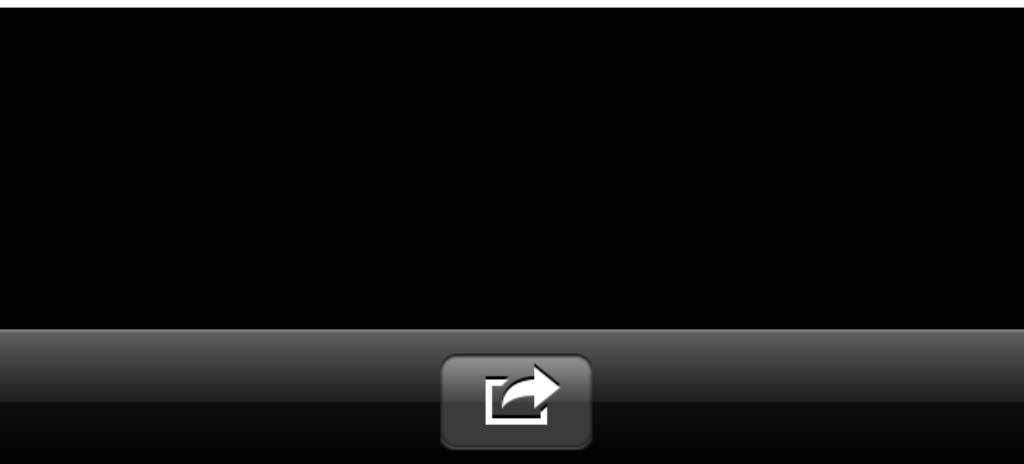
Total Electron Content (TEC):

- slant and vertical TEC provided on latitude, longitude, and time grid for a given GPS receiver
- real-time data useful for situational awareness while next 24-hours forecast TEC useful for mission planning and “go/no-go” decision-making.





Upper Atmospheric Densities in real-time from JB2008

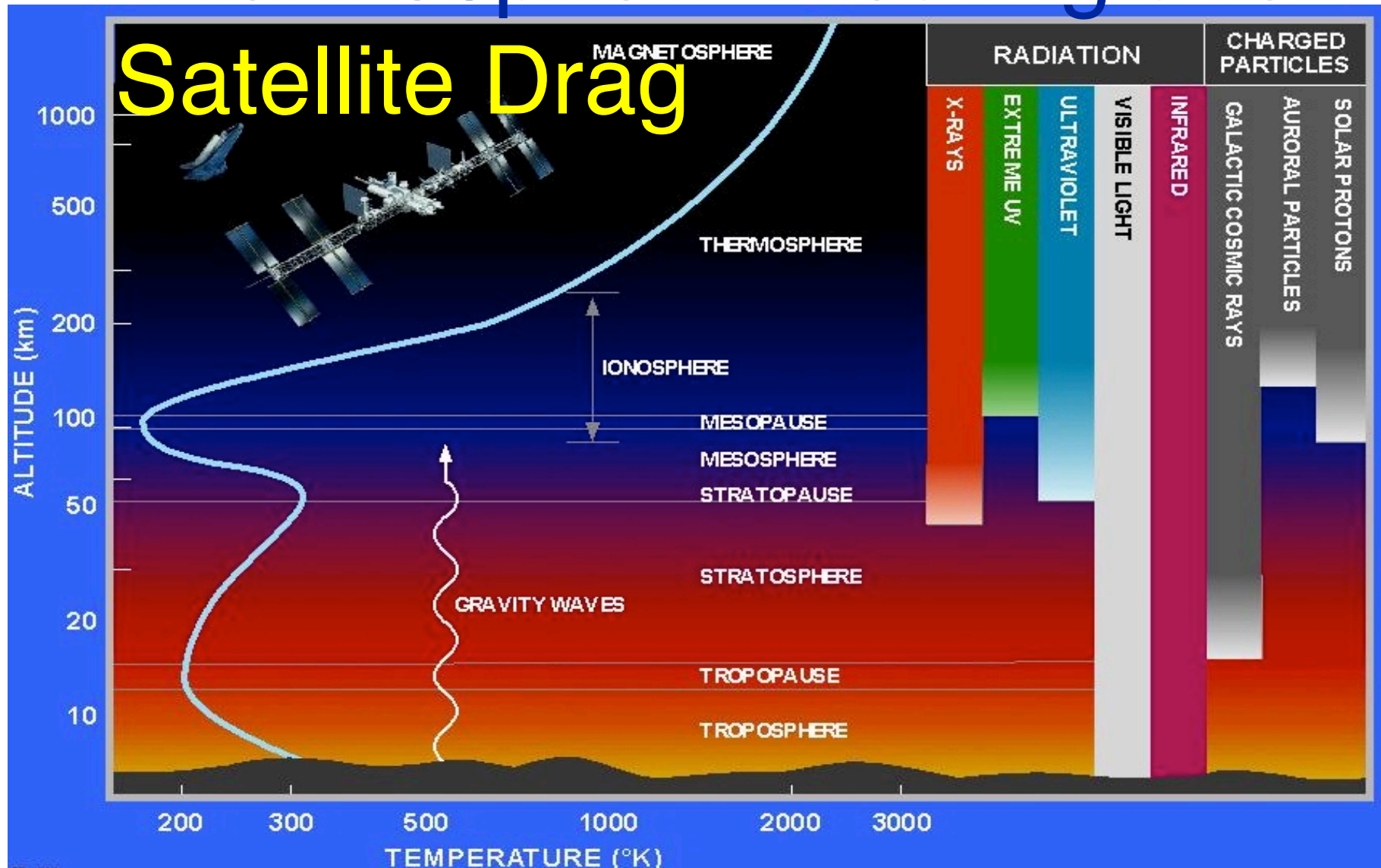


Credit: SET

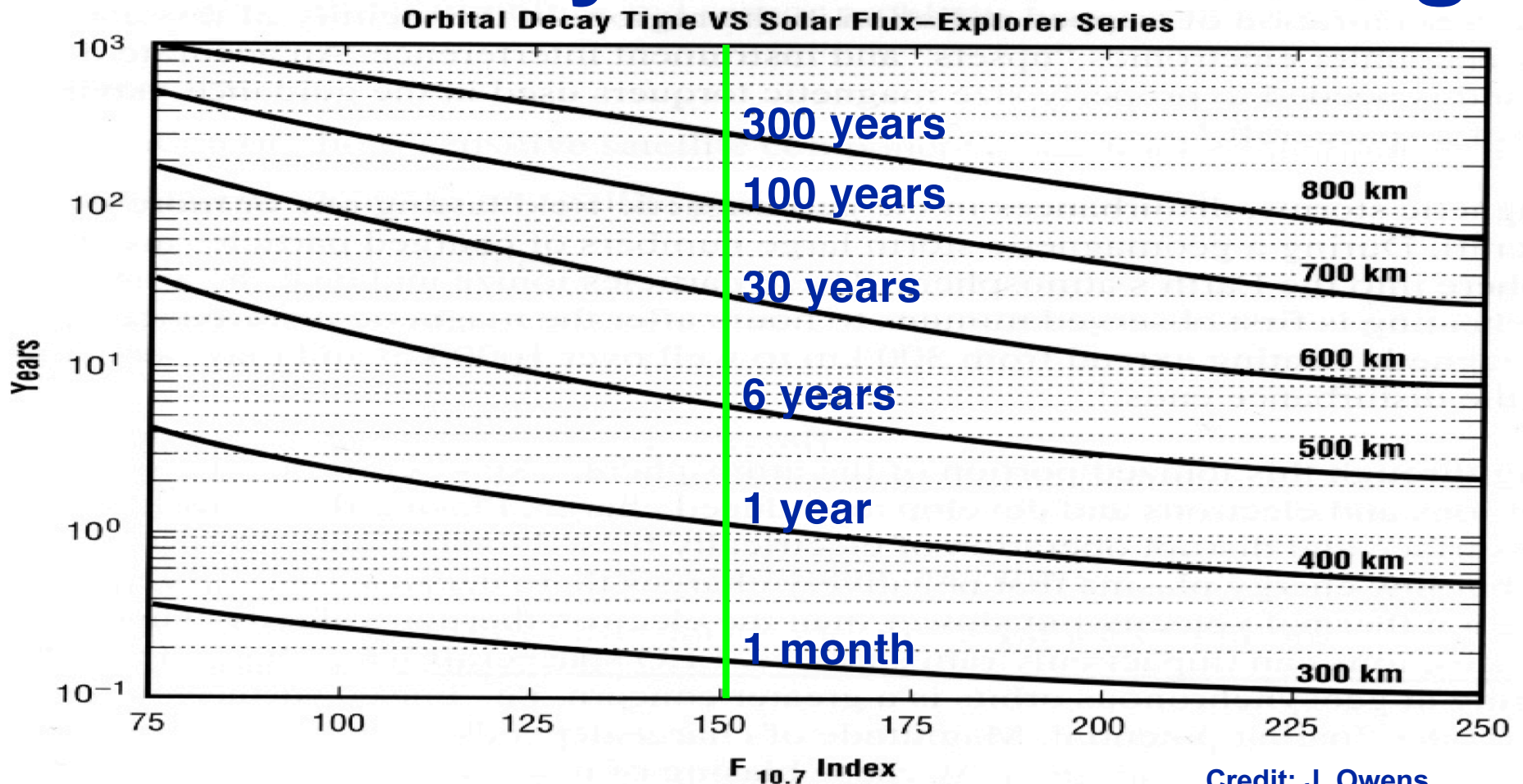
biska ktobiska@spacewx.com

Thermospheric Heating and

Satellite Drag

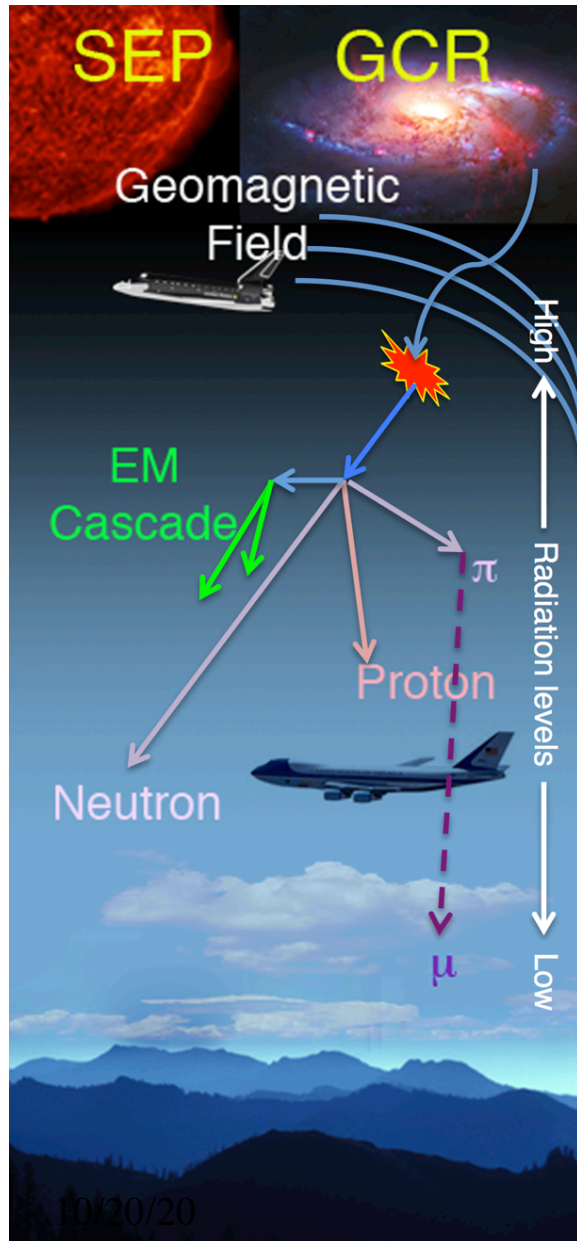


Effects of Upper Atmospheric Variability on Satellite Drag

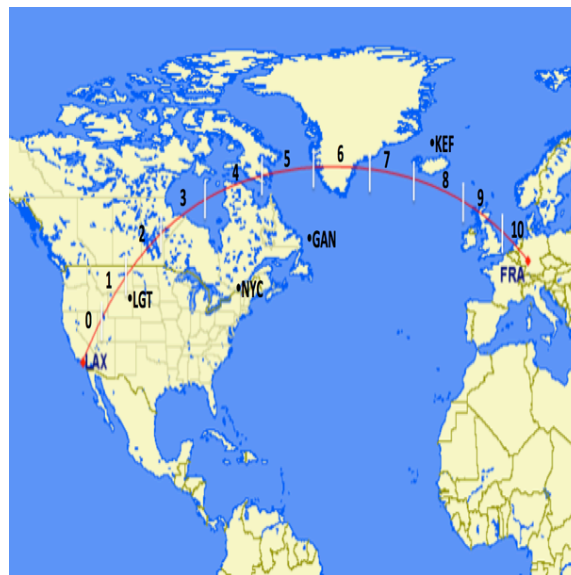
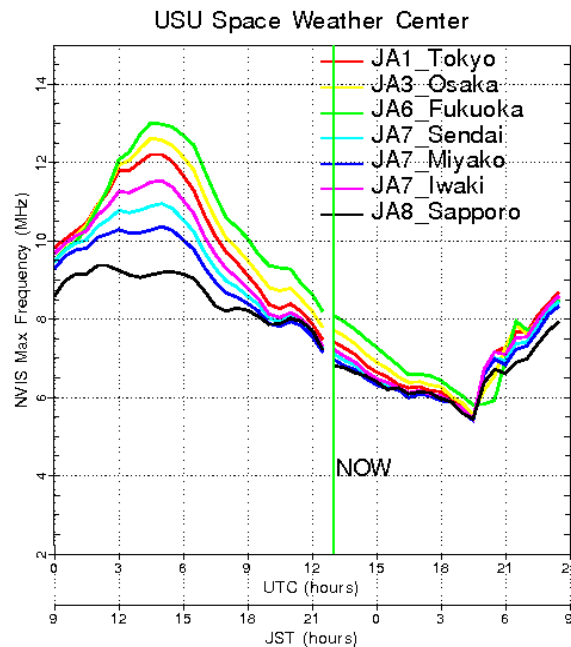


Credit: J. Owens

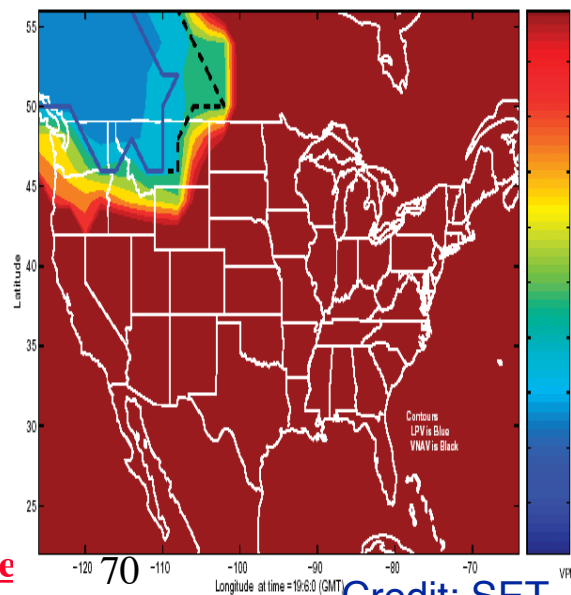
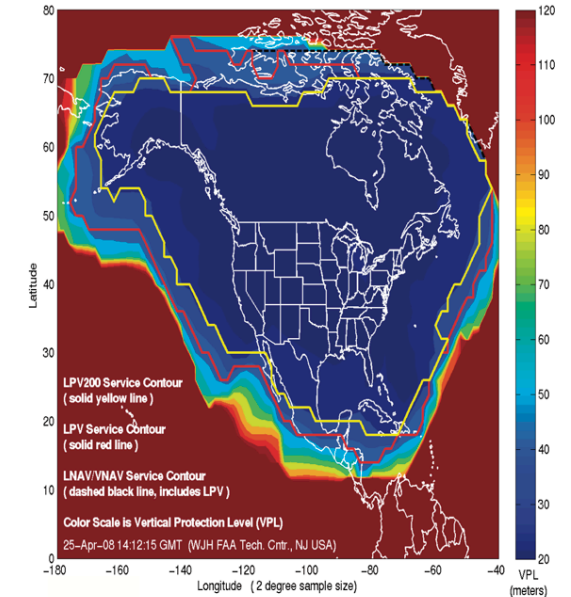
Radiation exposure



HF communication outages

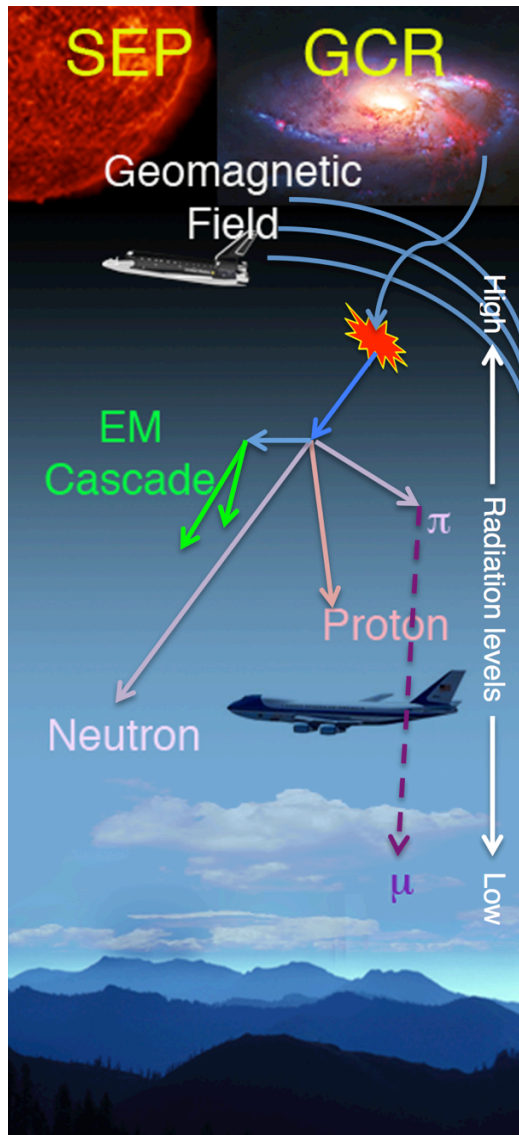


WAAS navigation error



Context? space weather creates a dynamic radiation environment at aviation altitudes

Radiation sources above 8 km



<https://SpaceWx.com>

- ✓ **global phenomenon** GCRs (career health issue and avionics SEUs)
- ✓ **higher latitude phenomenon**
 - ✓ **Extended major events** SEPs (fleet operations and aircrew/passenger safety issue)
 - **Short-term minor events** secondary radiation from precipitating energetic particles (career health issue)

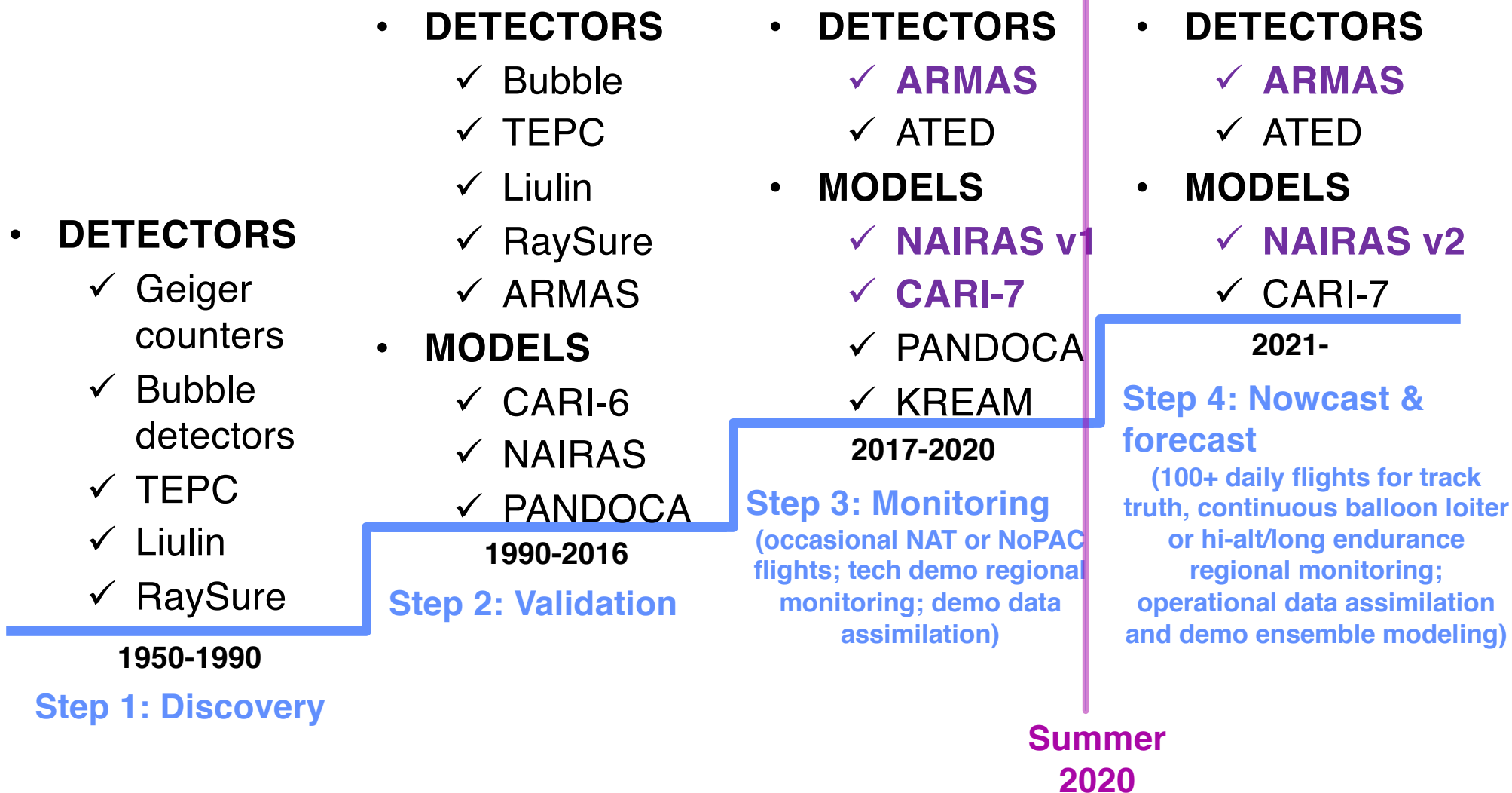
W. Kent Tobiska ktobiska@spacewx.com



Where are we today?

Progress towards aviation radiation nowcast & forecast

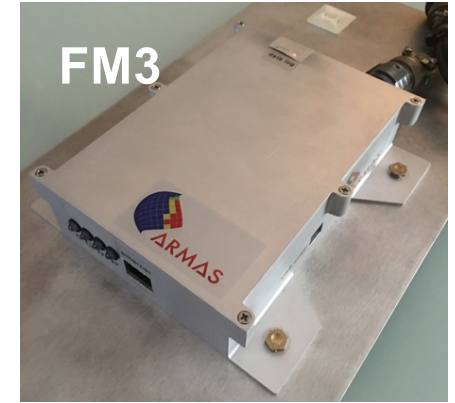
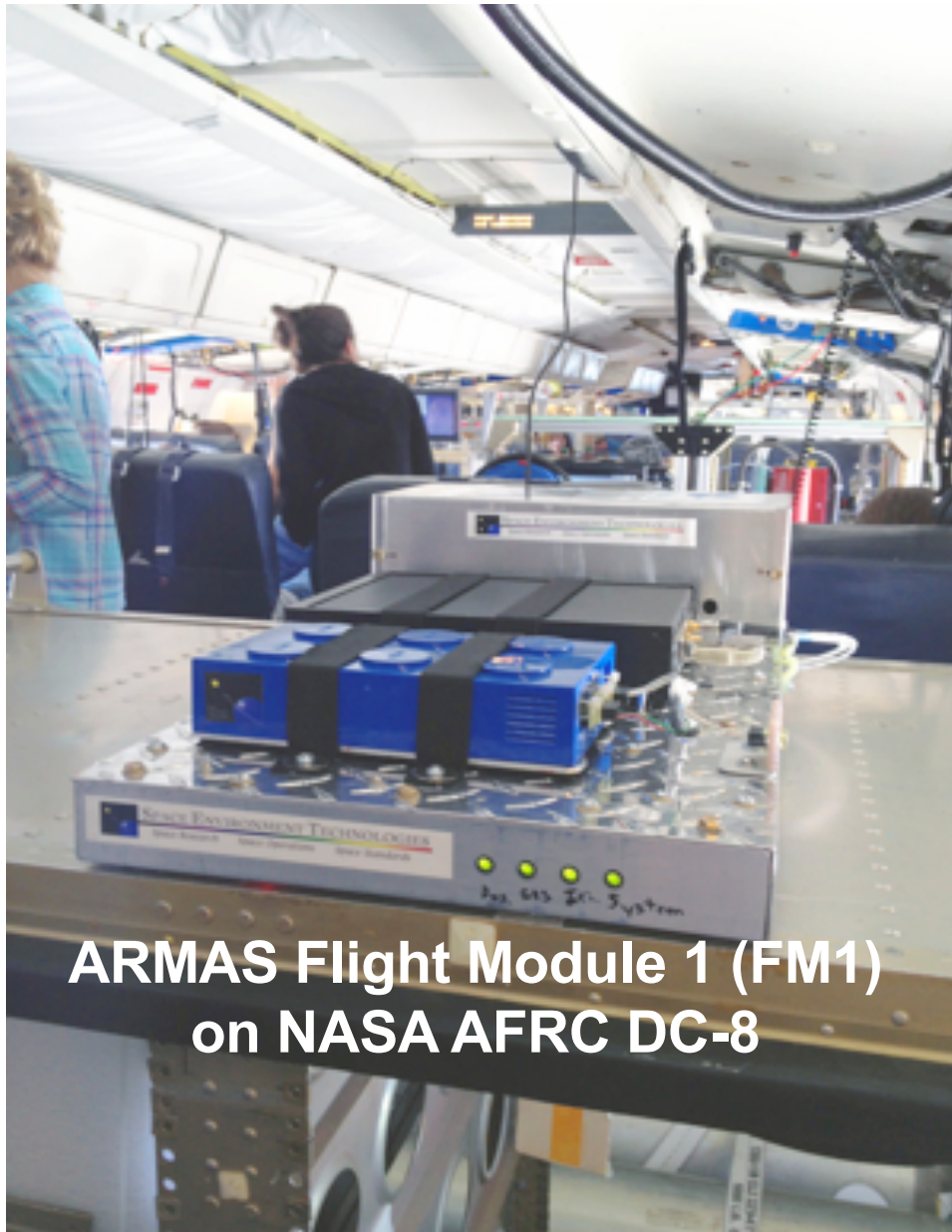
Lecture 1





Lecture 1

ARMAS real-time measurements legacy



Features:

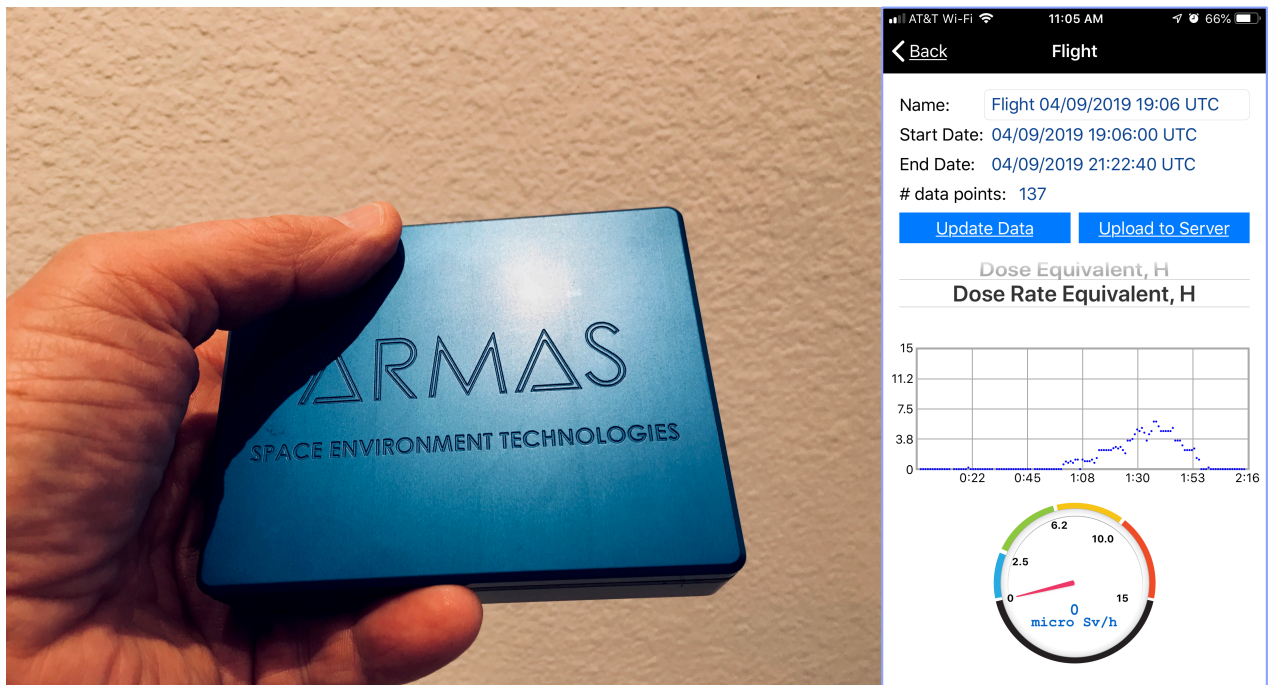
- ◆ Measures absorbed dose in silicon
- ◆ Small size and mass
- ◆ Data retrieval via Bluetooth paired with iOS app available from Apple Store
 - Current and post-flight dose rate status displayed on app that is paired with FM7
 - Dose rate can be transmitted to ground as needed using WiFi
- ◆ Real-time dose rates: measured absorbed and derived equivalent, ambient dose equivalent

Availability:

- ◆ 8 units delivered 2018-2019
- ◆ 4th production run in progress Q3 2020

<https://SpaceWx.com>

State-of-the-art radiation monitoring: ARMAS Flight Module 7 (FM7) using Bluetooth and app



W. Kent Tobiska ktobiska@spacewx.com



ARMAS Flight history 2013–2019

629 flights
quality data

& 175,000+ minutes of science

✓ Aircraft

- ✓ **AFRC:** DC-8 (a), ER-2 (d), G-III, SOFIA (B747)
- ✓ **NOAA:** G-IV (b)
- ✓ **NSF:** G-V (c)
- ✓ **FAA:** Bombardier Global 5000
- ✓ **Commercial:**
 - ✓ Boeing 737, 747, 757, and 777
 - ✓ Airbus 319 and 320
 - ✓ Bombardier Q200
 - ✓ CRJ 200, 700; Embraer 175

✓ Balloons

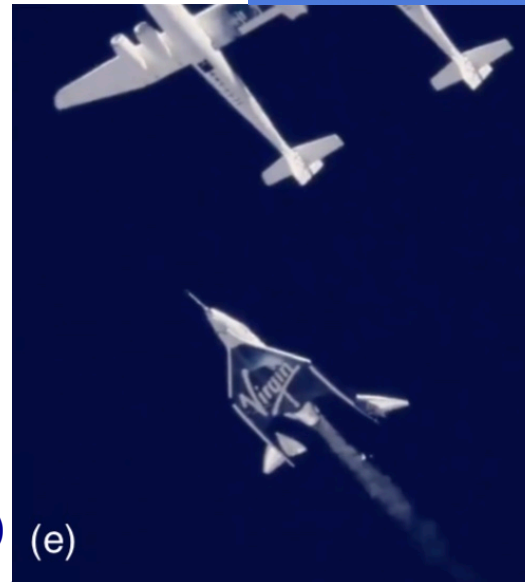
- ✓ **World View:** Stratollite (f)

✓ NASA space stations

- ISS
- Gateway

✓ Proprietary vehicles

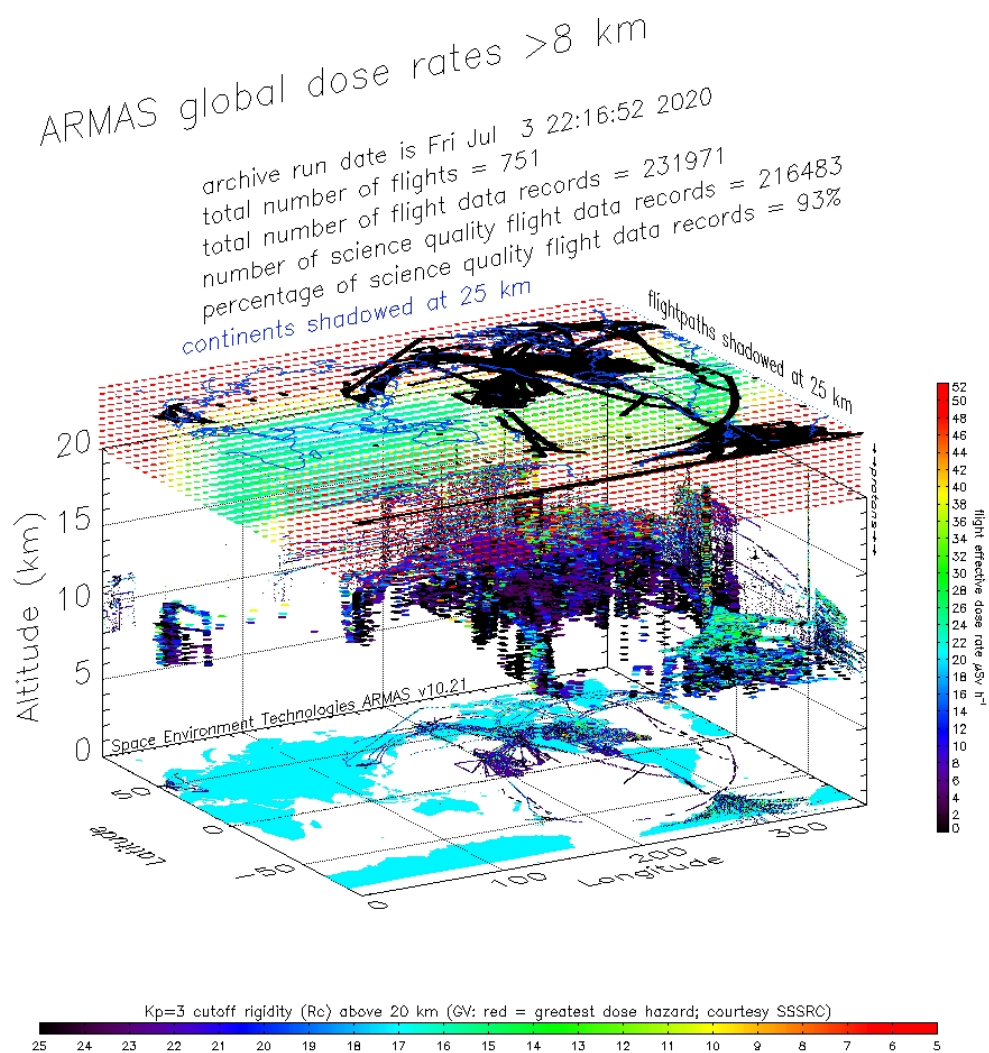
- ✓ Stratospheric glider
- ✓ **Virgin Galactic SS2 and WK2 (e)**
- **Blue Origin New Shepard**
- Cubesat
- Lunar lander



- ✓ Flown
- In progress
- Potential



Global ARMAS measurements

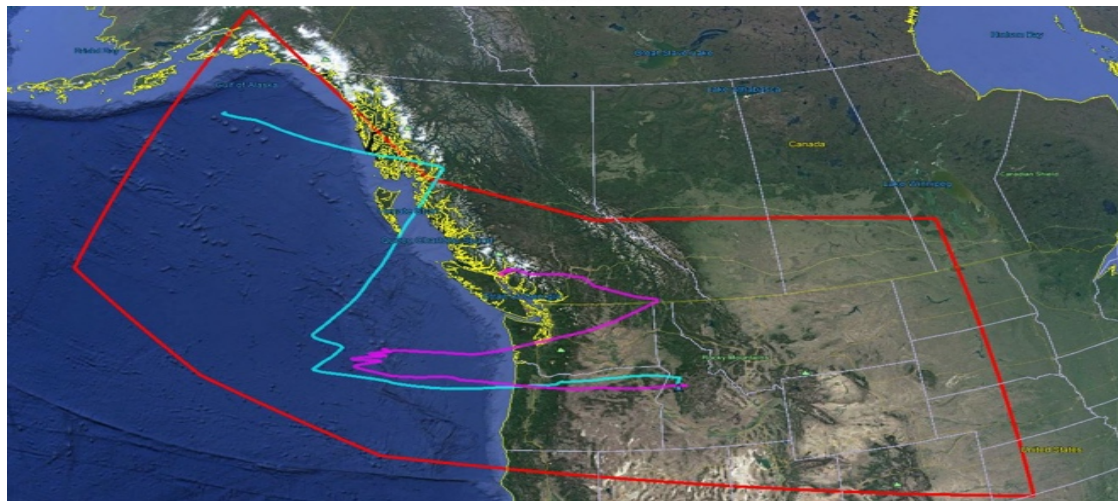
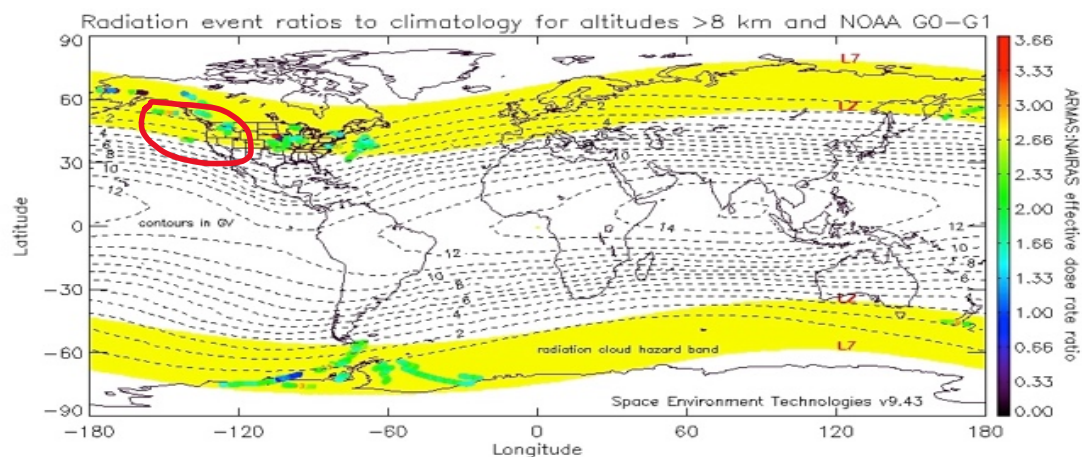


ARMAS Dual Monitor: Goals

- Demonstrate real-time **regional ionizing-radiation monitoring** at high altitudes using a long-duration balloon
- **Game-changing technology** for global aviation safety
- **Specify the radiation environment consistently** from the surface to high altitudes for space tourism and access to space operations
- Provide **ALOT of observations** for assimilation into the physics-based radiation models
- Better **understand the dynamic and variable radiation environment** due to all sources by measuring both total ionizing dose and gamma-rays



ARMAS Dual Monitor: demonstrate operational aviation radiation monitoring





ARMAS Dual Monitor: Transition to ops

Lecture 1

Launch & loiter



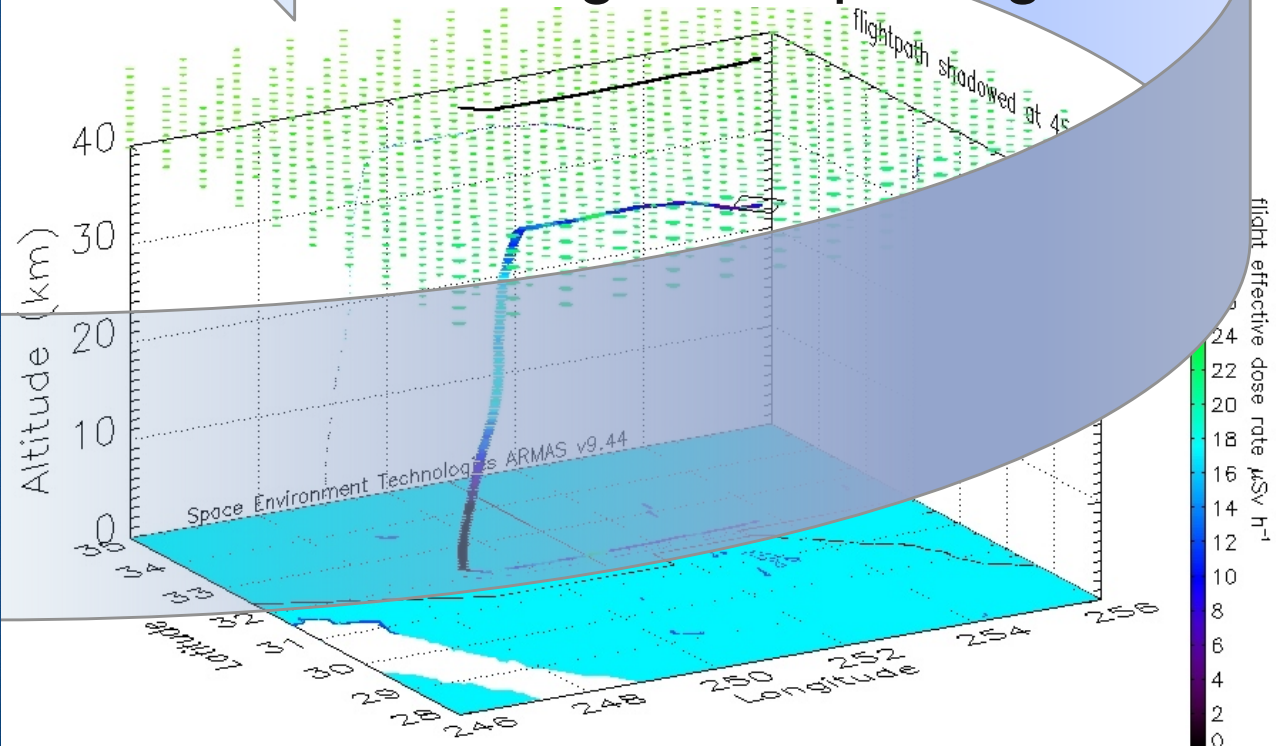
ATC coordination



NOTAMS

03/256 (A1808/19) - NAV GPS (MHRC GPS 19-01) (INCLUDING WAAS, GBAS, AND ADS-B) MAY NOT BE AVBL WI A 459NM RADIUS CENTERED AT 422722N1153829W (BOI147070) FL400-UNL, 408NM RADIUS AT FL250, 327NM RADIUS AT 10000FT, 330NM RADIUS AT 4000FT AGL, 287NM RADIUS AT 50FT AGL. 29 MAR 16:00 2019 UNTIL 29 MAR 20:30 2019. CREATED: 26 MAR 16:29 2019

Monitoring and reporting

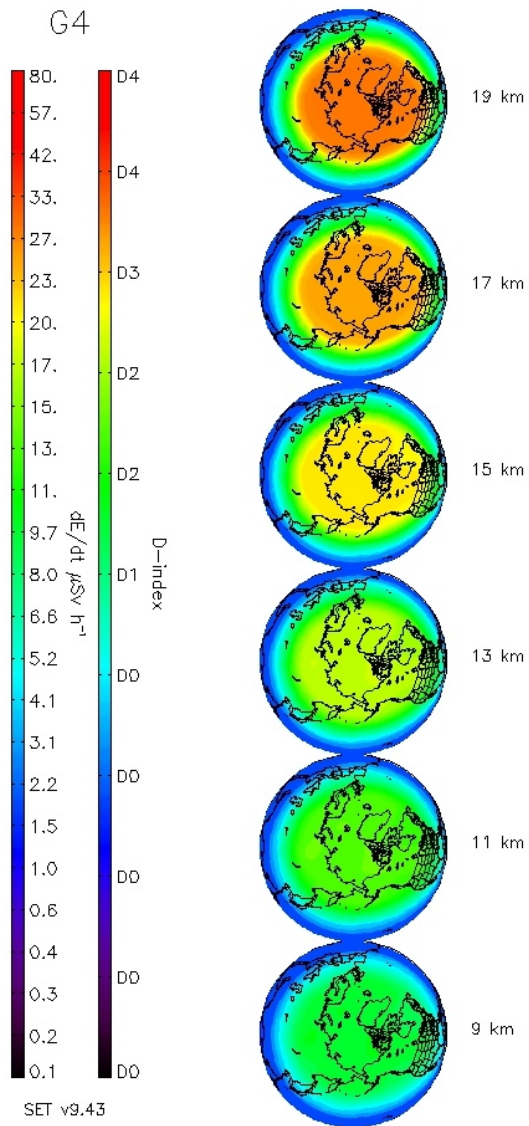




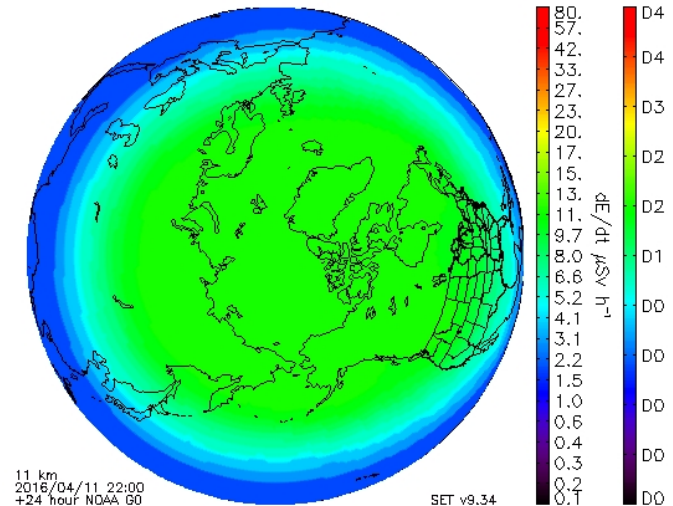
Lecture 1

ARMAS Dual Monitor: Benefit SpWx services

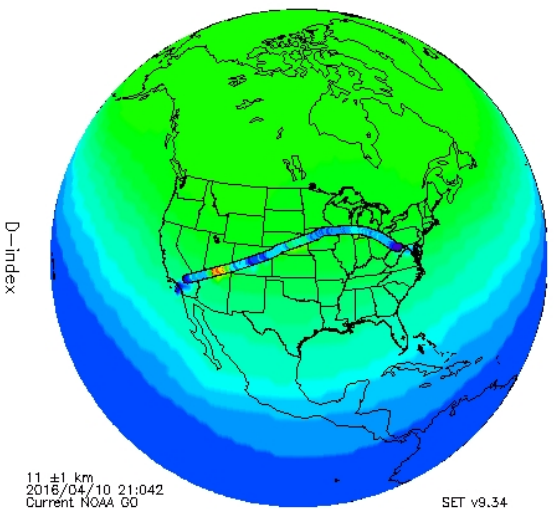
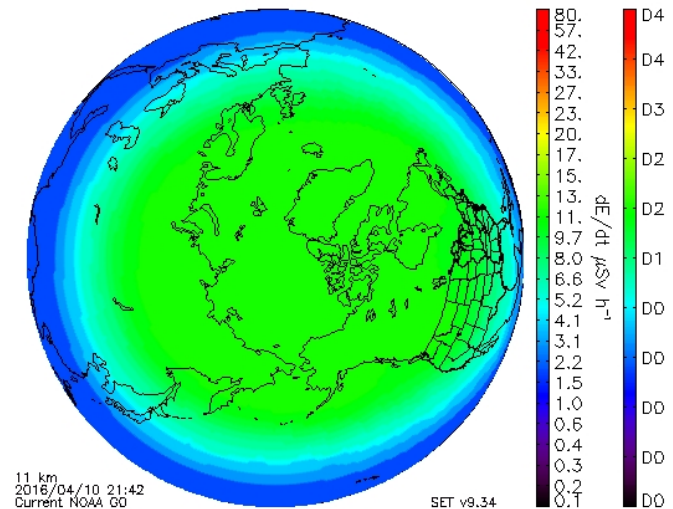
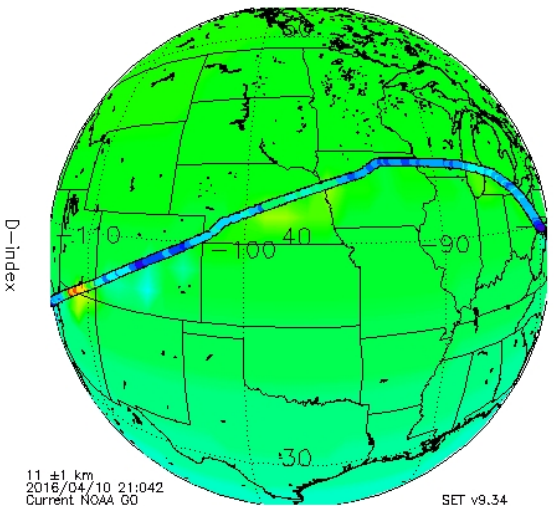
Global Forecasts



Regional nowcasts



Flight forecasts

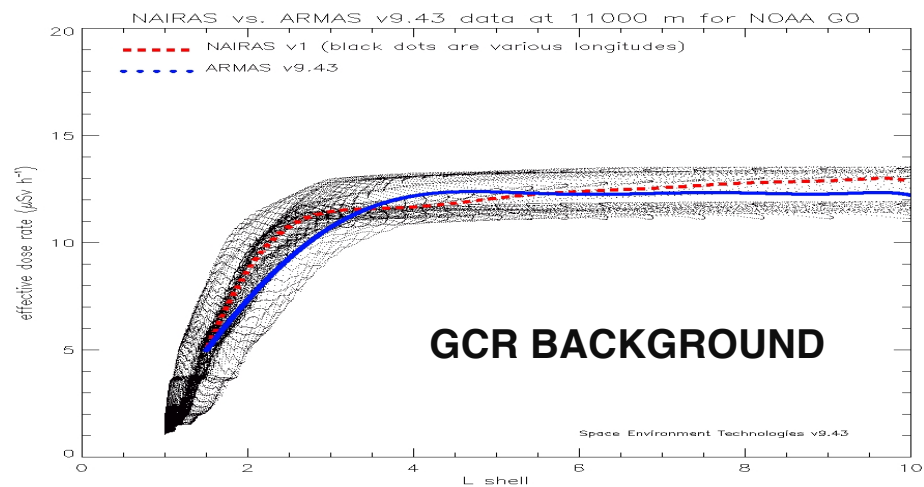
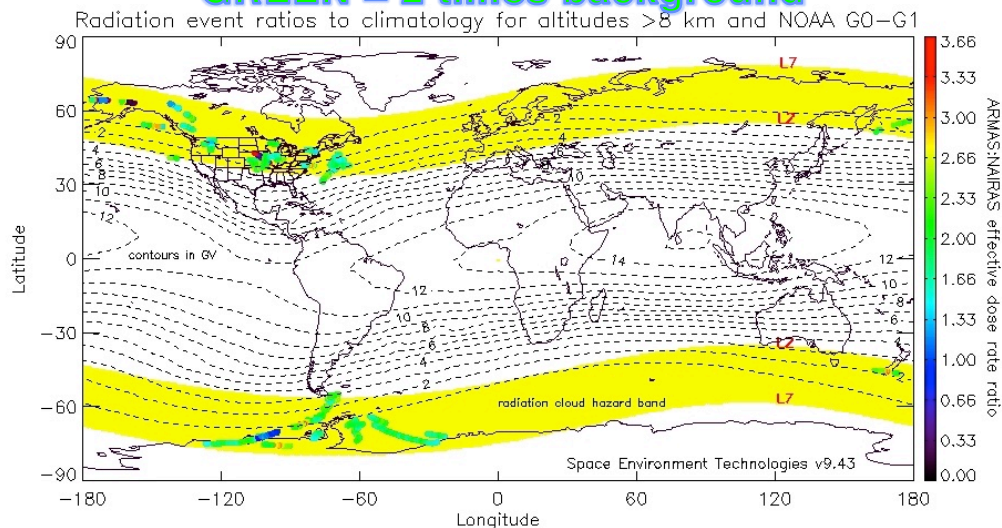




Lecture 1

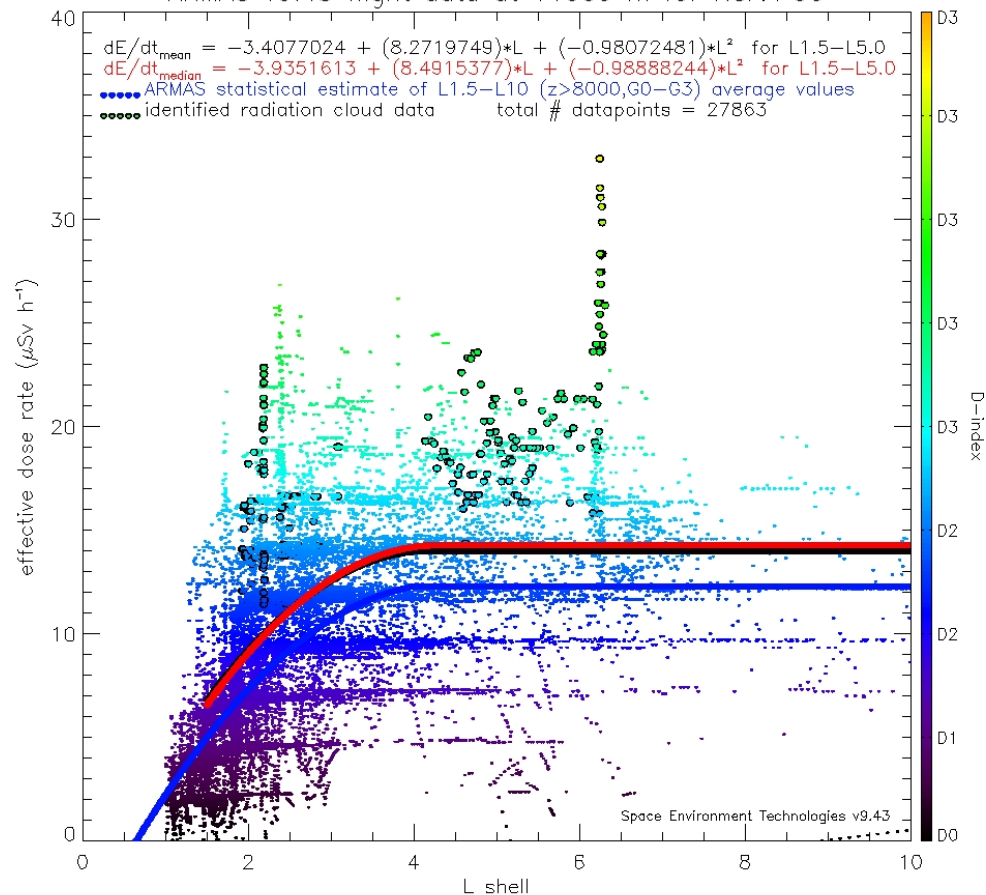
Dose rates at $2 < L < 7$ and 11 km during NOAA G0 conditions are $> \text{GCR background}$

GREEN = 2 times background



ARMAS GCR + REP MEASURED DOSE

ARMAS v9.43 flight data at 11000 m for NOAA G0





Recent cancer risk medical studies findings

Recent publications' (*JAMA Dermatol.*, 2015; *Occup. Environ. Med.*, 2003; *Environ. Health*, 2017) conclusions:

- 1) Pilots, aircrew have 2 times incidence of melanoma and other cancers
- 2) Occupational exposure may contribute to melanomas (UV-A photons?)
- 3) Pilot & aircrew lifestyle is not contributing factor for increased risk
- 4) Melanoma and basal cell carcinoma are induced by ionizing radiation
 - These cancers found to increase with occupational exposure criterion for pilots
 - **Melanoma and BCC were common in the trunk region of pilots – this precludes occupational UV-A exposure being responsible since UV-A would not penetrate the clothing and BCCs, melanomas are found in cabin crew members that aren't near the windows often**
 - **Gamma and X-rays are the energy range (5.0–0.5 MeV) that would penetrate clothing and give a dose to the underlying skin**
 - Cosmic rays¹ & solar energetic protons² would give mostly deep tissue dose from penetrating secondary neutrons and protons (prostate cancer, lymphoma, etc.)

Commercial Aviation Routing Incident

September 7, 2005 1931 UT:

- A major solar flare occurs
- The event creates a complete radio blackout on the sunlit hemisphere
- A Chicago to Hong Kong flight on a polar route forced to divert to Anchorage at a schedule penalty of 180 minutes and additional fuel
- Per incident-plane costs for route diversions start at \$250,000



Polar Route Radio Coverage

Arctic Radio HF

Arctic Radio VHF

Edmonton Ctr

Winnipeg

Minneapolis Ctr

Chicago Ctr

Credit: G. Camerpn

NOT FOR NAVIGATION

Polar Routes

North Pole

Chicago

Polar 1

Polar 2

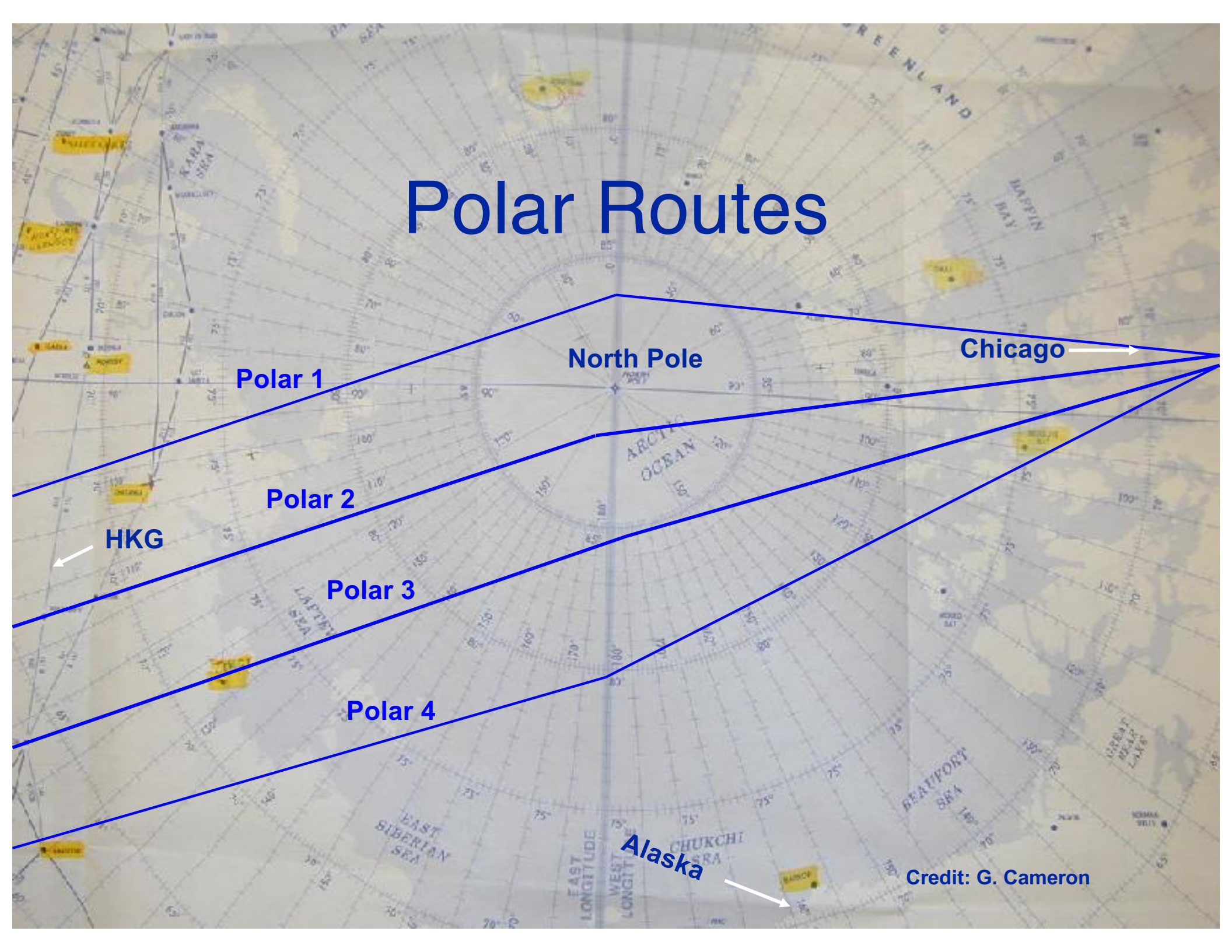
Polar 3

Polar 4

HKG

Alaska

Credit: G. Cameron

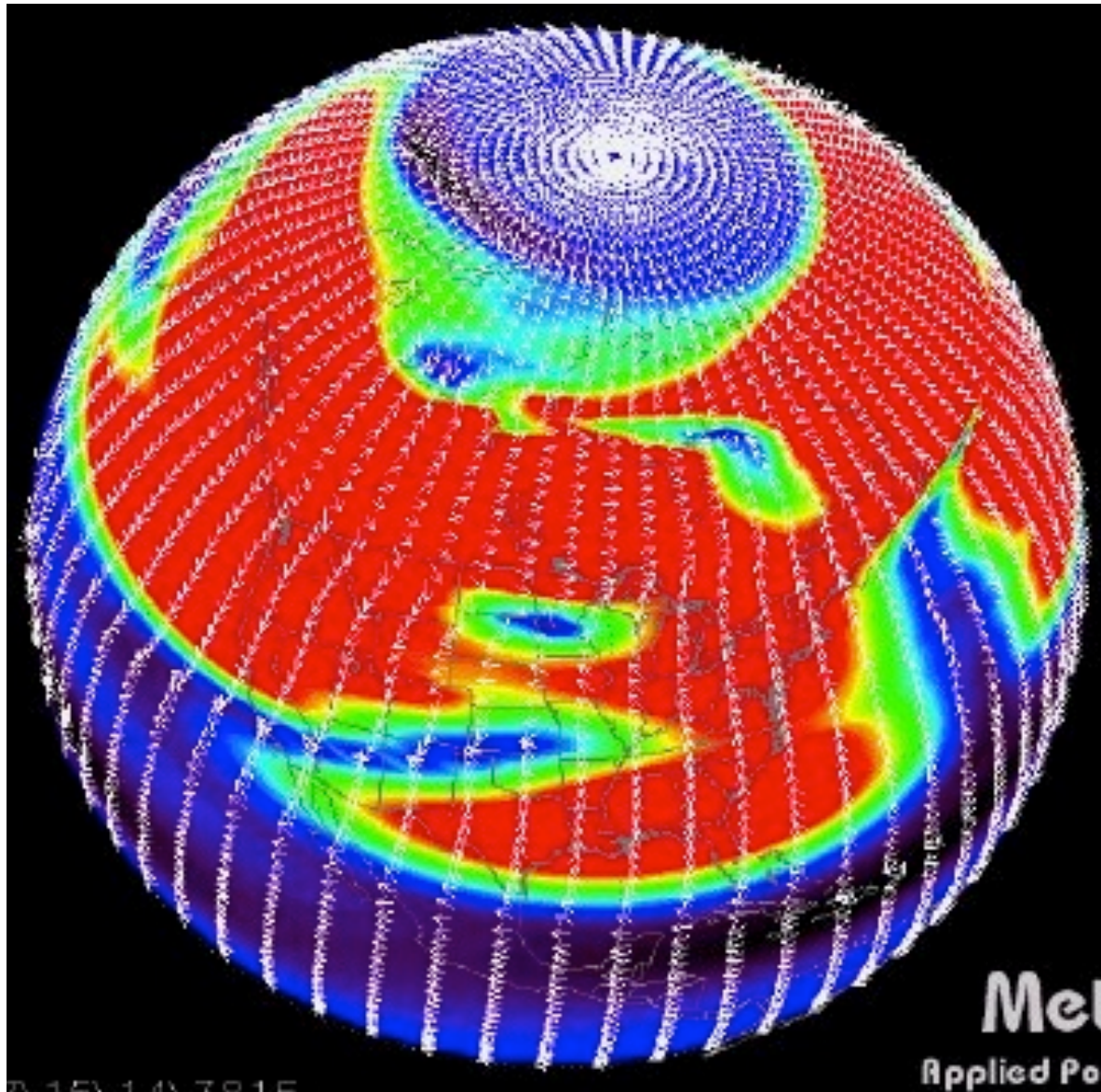


Space environment affects on ground systems



Credit: SET

July 15, 2000: Auroral Currents and GICs



Plot of ground-level
magnetic field
disturbances at time
14:38:15 UT on July 15,
2000

Credit: J. Kappenman

March 1991: Ground- Induced Currents

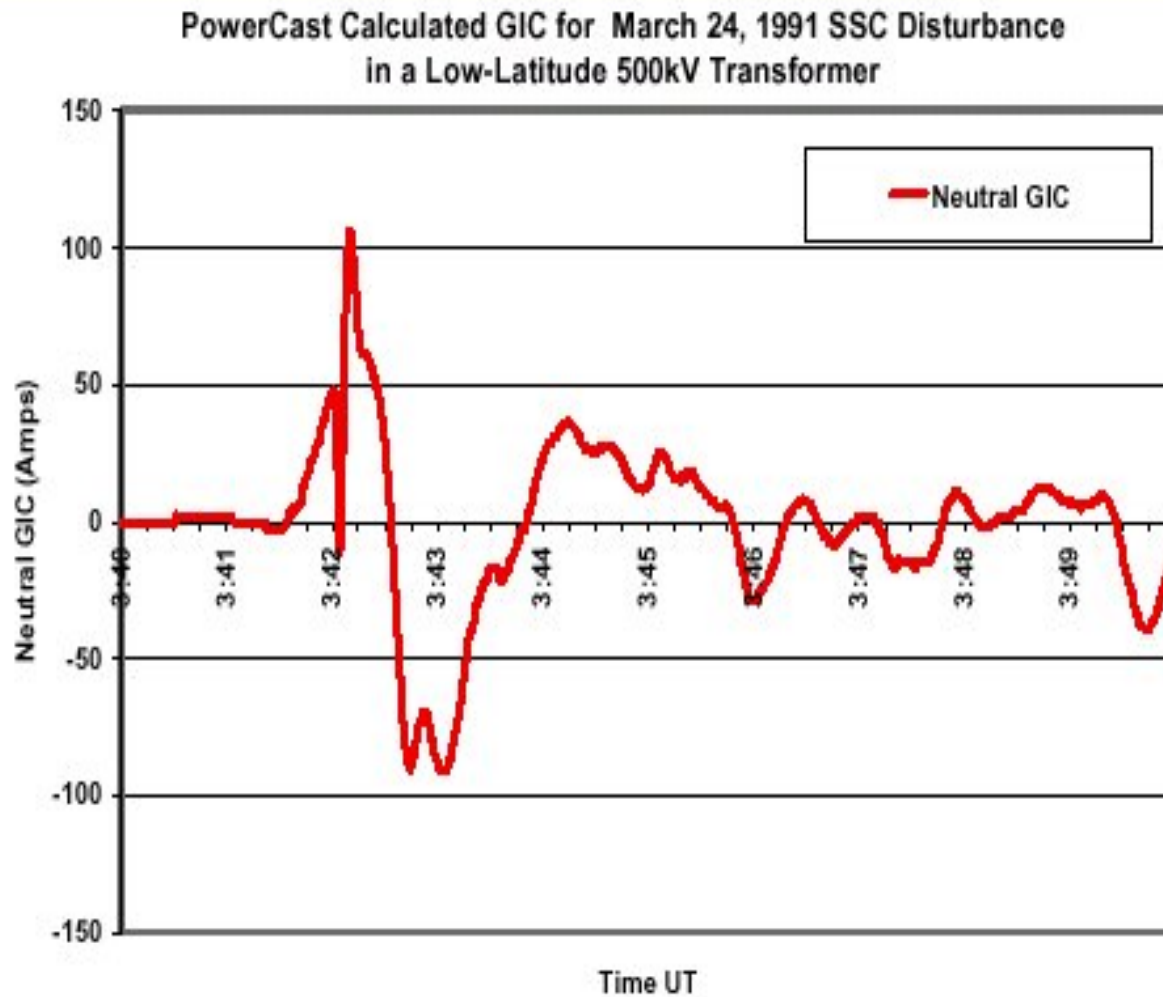
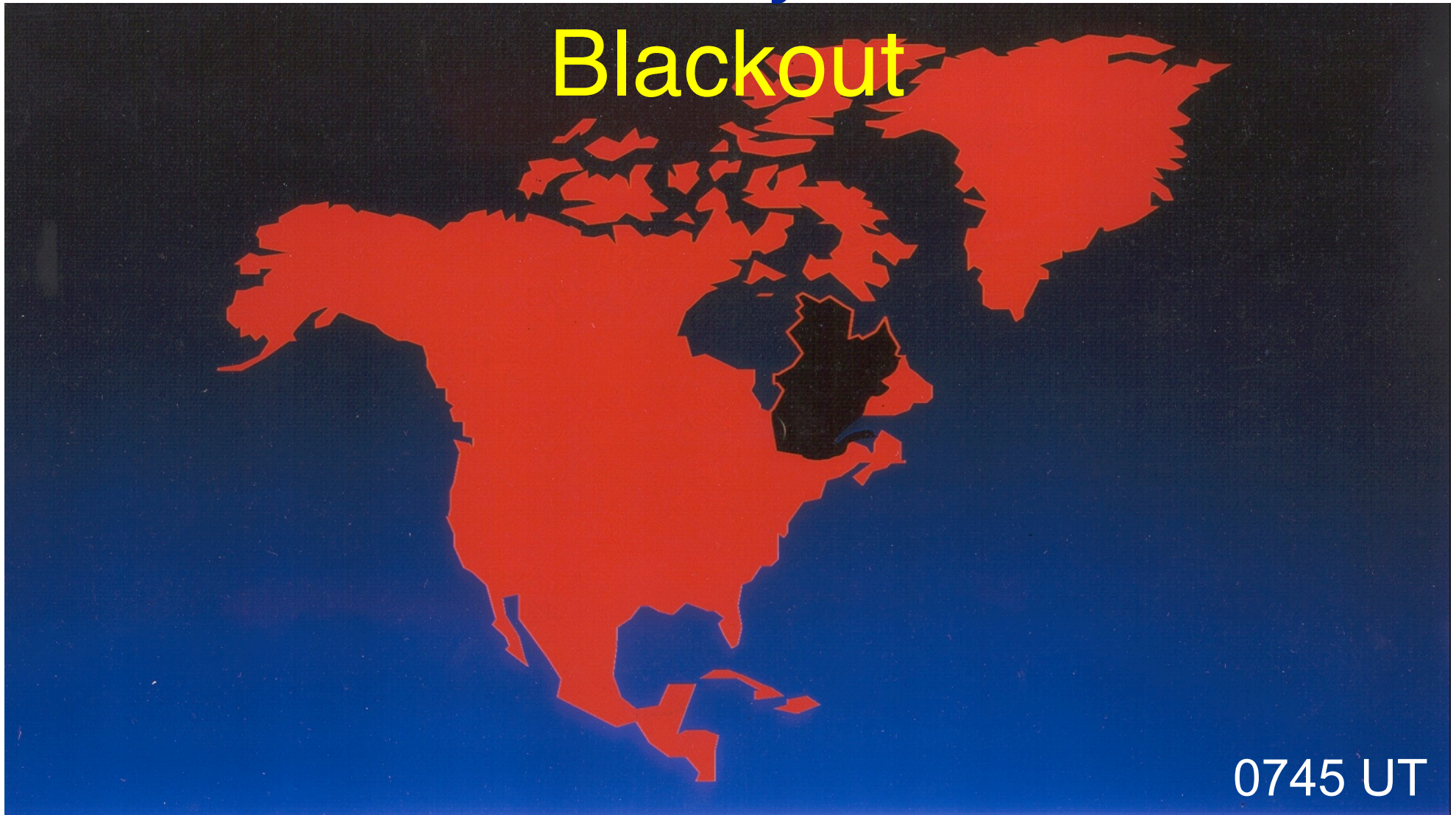


Figure 2 – PowerCast™ Models of a power grid can calculate GIC flows in every transformer for actual and hypothetical storm scenarios. This is an example from a large SSC in March 1991.

March 1989: Hydro Quebec

Blackout

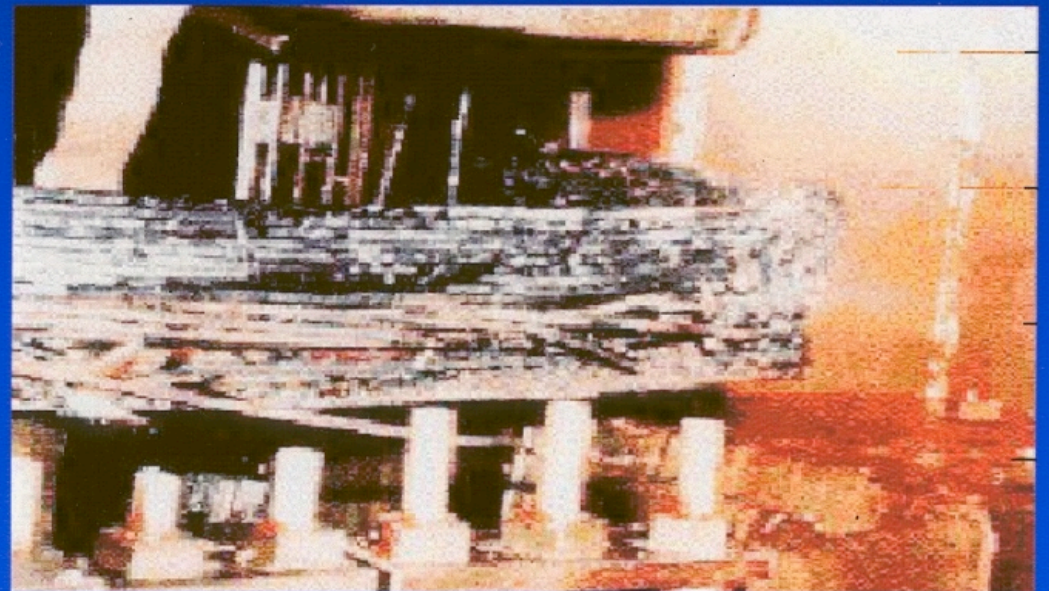


0745 UT

March 1989: Transformer Failure

PJM Public Service Step Up Transformer

Severe internal damage caused by
geomagnetic storm, 13 March 1989



Space Environment Standards – ISO TC20/SC14 WG4

Why space environment standards?

- ◆ Standards provide common definitions, data, products, practices and transactions between diverse communities of users and producers to facilitate communication and commerce.
- ◆ Standards are developed at international, national, and organizational levels



Terrestrial and Lunar Space Environment
Space Systems and Operations Orbital Domains

Lecture 1

	Published, In process, To be initiated	LEO	PEO	MEO	GEO	>GEO
Testing		15856, 17851	15856, 17851	15856, 17851	15856, 17851	15856, 17851
Cosmic Rays		15390, 17520, N0764	15390, 17520, N0764	15390, 17520, N0764	15390, 17520, N0764	15390, 17520, N0764
Solar photons		21348	21348	21348, 19923	21348, 19923	21348, 19923
Solar particles		16698, 17520, 18147, N0764 (solar wind)	16698, 17520, 18147, N0764 (solar wind)	16698, 17520, 18147, N0764 (solar wind)	16698, 17520, 18147, N0764 (solar wind)	16698, 17520, 18147, N0764 (solar wind)
Solar fields		16698 (solar wind)	16698 (solar wind)	16698 (solar wind)	16698 (solar wind)	16698 (solar wind)
Main magnetic field		16695, 16698	16695, 16698	16695, 16698	16695, 16698	16695, 16698
Magnetosphere		16695, 16698, 20584, N0764	16695, 16698, 19923, 20584, N0764	16695, 16698, 22009, 19923, 20584, N0764	16695, 16698, 22009, 19923, 20584, N0764	16695, 16698, 22009, 19923, 20584, N0764
Radiation Belts		17761, 20584, N0764 (AEP9, internal chrg)	17761, 20584, N0764 (AEP9, internal chrg)	20584, N0764 (AEP9, internal chrg)	20584, N0764 (AEP9, internal chrg)	20584, N0764 (AEP9, internal chrg)
Plasmasphere		16457, 20584	16457, 19923, 20584	16457, 19923, 20584	16457, 19923, 20584	16457, 19923, 20584
Ionosphere		16457, 16698, 20584	16457, 16698, 20584			
Neutral atmosphere		14222, 11225, 16698, (AO, sat drag)	14222, 11225, 16698, (AO, sat drag)			
Micrometeoroids		14200	14200	14200	14200	14200
Debris		14200	14200	14200	14200	14200
Lunar						10788



Lecture 1



Resources

Space Environment Technologies (SET) provides multiple resources for the space weather and space systems communities. We provide insight into standards in development, we make available team member publications, and we support K-14 educational activity. Standards provide common definitions, data, products, practices and transactions between diverse communities of users and producers to facilitate communication and commerce. Standards are developed at international, national, and organizational levels. Our Standards links identify ISO, AIAA, Corporate, ECSS, and SIF standards related to space weather and the space environment. Our Publications links provide a broad range of original scientific and engineering papers and documents from all areas of SET's team member activity. Our Service links present useful tools for individuals, for teachers, for students, and for the public.

Standards

Publications

Service



Standards for space environment and space systems

Credit: Tobiska

Resources providing space weather information



Space Weather resources

Space Weather apps for smartphones

◆ Recommended Apple iPhone, iPod touch, iPad app

- *ARMAS* (education, free, developed by Space Environment Technologies; real-time solar, heliosphere, magnetosphere, ionosphere, and atmosphere space weather data streams)

◆ Other Apple iPhone, iPod touch apps

- *Solar Monitor* (\$1.99, developed by commercial electronics provider Thomas Ebbert)
- *3-D Sun* (education, free, developed by astronomer Tony Phillips)
- *SWx Monitor* (weather, free, developed by the South Korean Space Environment Laboratory (SELab))
- *Planets, SunClock, CliMate, NASA SWx, Sun Viewer, iDream, SpaceStorms, Sunspot*

◆ Recommended Android app

- *SpaceWx* (weather, free, developed by USU Space Weather Center and Space Environment Technologies; 122 real-time solar, heliosphere, magnetosphere, ionosphere, and atmosphere space weather data streams from 19 institutions)

◆ Other Android apps

- *SpaceWeather* (education, free, developed by ASTRA)

Credit: Tobiska



Space Weather resources

Recommended Twitter feeds

- ◆ @spacenvironment
- ◆ @spacenv
- ◆ #spacewx
- ◆ #spacenvironment
- ◆ #solarflares



Space Weather resources

Recommended Space Environment and Space Weather websites

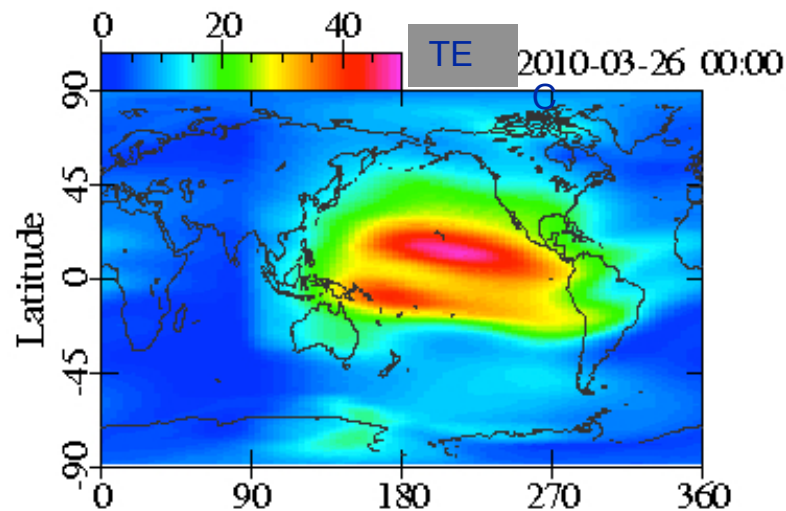
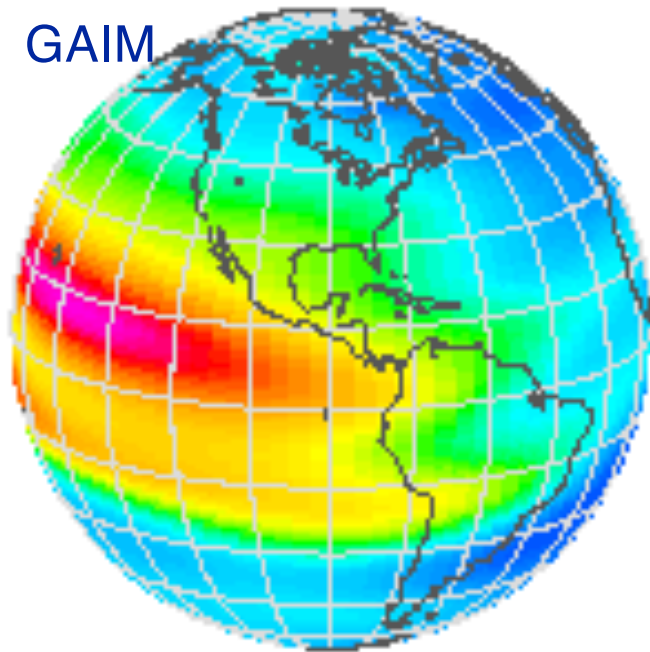
- **Space Weather Now:** Current and forecast space weather including solar irradiances, flare alerts, ionosphere and HF conditions, GEO charging conditions, radiation environment conditions, JB2008 model: http://spacewx.com/Space_Weather_Now.html
- **Space environment standards:** Draft space environment standards from ISO and AIAA (in preprint/review form): <http://www.SpaceWx.com/> (Standards link)
- **Atmosphere:** Code and indices for JB2008 thermosphere: <http://sol.spacenvironment.net/~JB2008/>
- **Ionosphere and Radio:** Real-time global and CONUS ionosphere GAIM TEC and HF ray-trace maps: <http://spaceweather.usu.edu>
- **Radiation:** Real-time commercial aviation altitude radiation environment: <http://sol.spacenvironment.net/~nairas/index.html>
- **NASA space weather (CCMC):** <http://iswa.gsfc.nasa.gov/iswa/iswa.html>
- **NOAA space weather (SWPC):** Solar protons, electrons, wind, fields: <http://www.swpc.noaa.gov/>

Other Space Environment and Space Weather websites

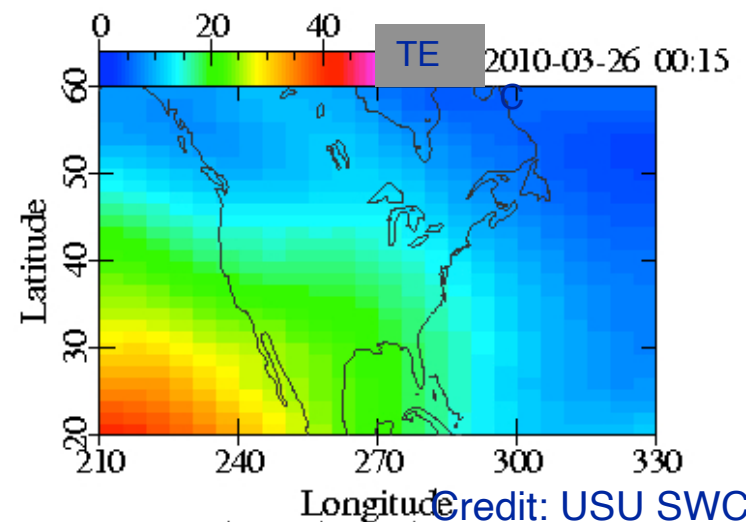
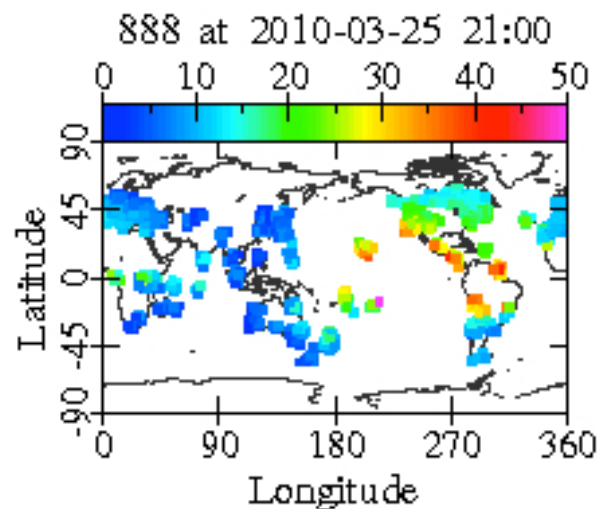
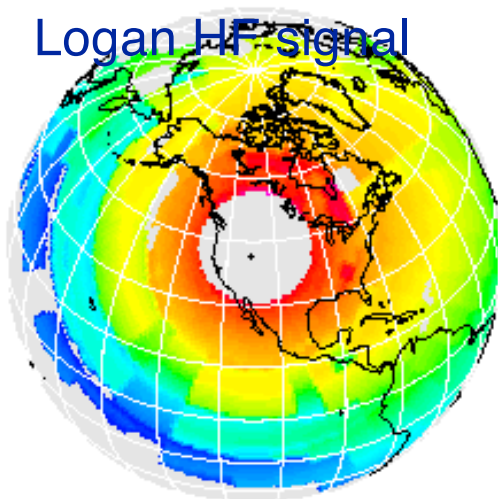
- Earth ionosphere and TEC: <http://spaceweather.usu.edu/>
- Space Weather at Earth: <http://www.windows.ucar.edu/spaceweather/>
- NOAA data archive: <http://www.ngdc.noaa.gov/ngdc.html>
- SPENVIS (Space Environment Information System)

Credit: Tobiska

GAIM

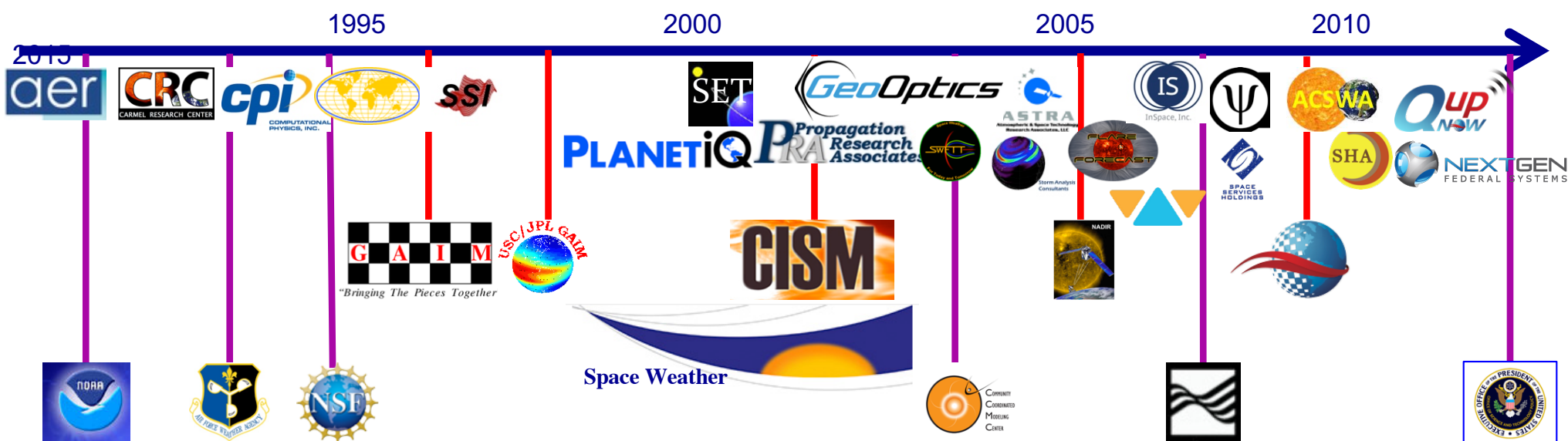
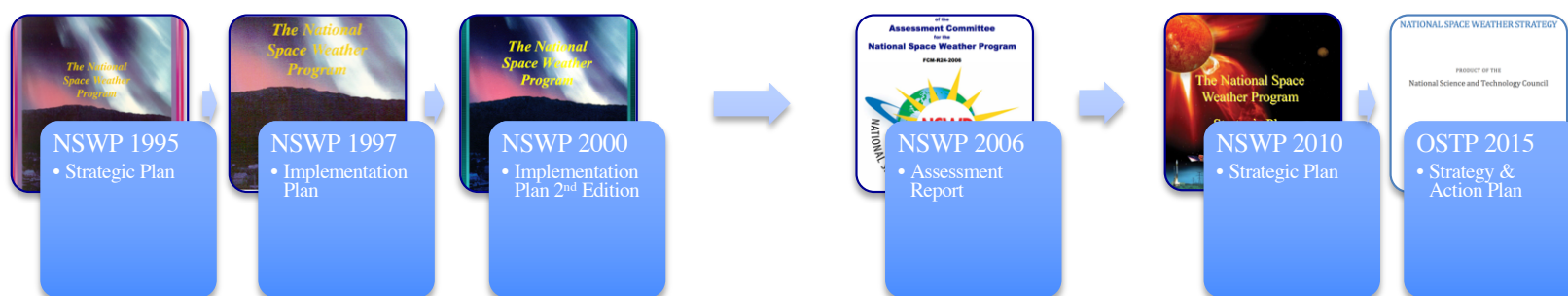


Logan HF-signal



National space weather enterprise

- **National Space Weather Program** (1995, 1997, 2000, 2006, 2010, 2016)
- **Agencies** (OSTP, NOAA SWPC, AFWA, NSF, NASA CCMC, USGS)
- **Academia** (GAIM MURI, CISM, NADIR MURI, USU SWC)
- **Industry** (19 U.S. companies in ACSWA as of January 1, 2016)



Commercial Space Weather

See YouTube
news item
link at
<http://spacewx.com>

Credit: Tobiska

<https://SpaceWx.com>



W. Kent Tobiska ktobiska@spacewx.com

Summary

- ✓ **Definitions**
 - ✓ Space environment
 - ✓ Space weather
 - ✓ Conceptual framework for space weather
 - ✓ Conceptual framework for spacecraft, space systems, ground systems interactions
- ✓ **Standards and guidelines**
- ✓ **Supplementary material**