Space Weather Conditions at the Time of the Galaxy 15 Spacecraft Anomaly (SH31D-03)

Report of the NOAA Tiger Team:

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Galaxy 15 satellite. Photo Credit: Orbital Sciences

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ABSTRACT

AGU Fall Meeting 2010 (SH31D-03)

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Space environmental conditions at the time of the Galaxy 15 satellite anomaly on 05 April 2010 are reviewed and discussed. Reports released by the system owner, Intelsat, indicate that at 09:48 UTC this geosynchronous communications satellite stopped responding to ground commands. The satellite manufacturer, Orbital Sciences, subsequently noted that the anomaly was the likely result of an “unusually violent solar activity that week that damaged the spacecraft’s ability to communicate with ground controllers". At the time of the anomaly, the geosynchronous satellite was located just past local midnight having recently come out of eclipse into a disturbed local space environment at GEO. Information sources contributing to an overall assessment of space weather conditions at this time include solar and interplanetary imagery and datasets, geosynchronous satellite particle and field measurements, observations from satellites in polar low-earth orbit, and ground-based magnetic observatory records. Initial analysis indicates that the Galaxy 15 anomaly occurred shortly after the start of a modest geomagnetic storm with a timely magnetic substorm that greatly perturbed the local space environment in the midnight sector. The intent of this presentation is to describe the space environmental conditions both globally and in close proximity to Galaxy 15 to facilitate ongoing spacecraft anomaly studies.

OUTLINE

Space Weather Conditions – 05 Apr 10

Space Weather describes changes in the interconnected system from the Sun to Earth

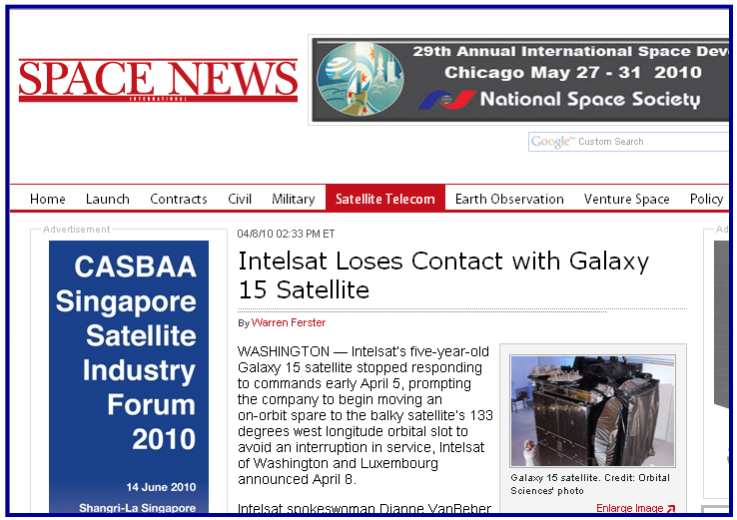
This presentation follows space weather conditions progressing from the sun to near the Galaxy 15 location showing:

1. **Events that occurred at the sun**
2. **Resulting global changes in the near-earth space environment**
3. **Local changes near Galaxy 15 in the energetic charged particles that can cause satellite charging and electronic component failure**

Summary

- ✓ **Solar activity was elevated but not remarkable**
- ✓ **Global geomagnetic activity described by the AL auroral electrojet index and Kp were extreme. Other SWx indices were more moderate**
- ✓ **Local measurements near Galaxy 15 show that a large geomagnetic substorm occurred 48 minutes prior to the anomaly. The substorm caused remarkable increases in the measured local flux of energetic particles known to cause surface or internal satellite charging**

Background (1 of 2)
Galaxy 15 Satellite Anomaly - Impacts


SPACE NEWS

29th Annual International Space Dev
Chicago May 27 - 31 2010
National Space Society

Home Launch Contracts Civil Military Satellite Telecom Earth Observation Venture Space Policy

CASBAA Singapore Satellite Industry Forum 2010
14 June 2010
Shangri-La Singapore

04/8/10 02:33 PM ET

Intelsat Loses Contact with Galaxy 15 Satellite

By Warren Ferster

WASHINGTON — Intelsat's five-year-old Galaxy 15 satellite stopped responding to commands early April 5, prompting the company to begin moving an on-orbit spare to the balky satellite's 133 degrees west longitude orbital slot to avoid an interruption in service, Intelsat of Washington and Luxembourg announced April 8.

Galaxy 15 satellite. Credit: Orbital Sciences' photo

Enlarge Image

Intelsat spokeswoman Dianne VanReher


SPACE NEWS

29th Annual International Space Dev
Chicago May 27 - 31 2010
National Space Society

Home Launch Contracts Civil Military Satellite Telecom Earth Observation Venture Space Policy

CASBAA Singapore Satellite Industry Forum 2010
14 June 2010
Shangri-La Singapore

04/20/10 02:05 PM ET

Orbital Blames Galaxy 15 Failure on Solar Storm

By Peter B. de Selding

PARIS — The in-orbit failure of the Orbital Sciences-built Intelsat Galaxy 15 telecommunications satellite April 5 was likely caused by unusually violent solar activity that week that damaged the spacecraft's ability to communicate with ground controllers, Orbital officials said April 20.

Galaxy 15 satellite. Credit: Orbital Sciences' photo

Enlarge Image

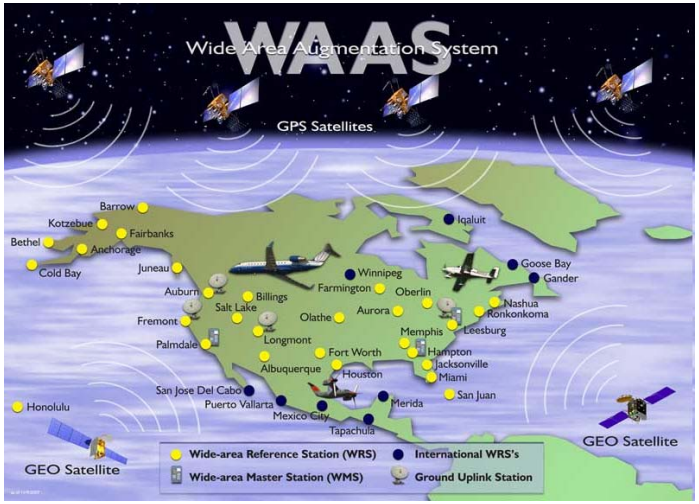
Similar events have occurred, if less severely, on other Orbital spacecraft

08 Apr 2010 – Intelsat reports that the Galaxy 15 stopped responding to ground commands (Anomaly time: 05 April @ 09:48 UTC)

10 Apr 2010 – FAA predicts erosion of WAAS capability due to Galaxy 15 failure

20 Apr 2010 – Orbital attributes the loss of Galaxy 15 to space weather

30 Apr 2010 – Intel reports Galaxy 15 still adrift and threatens nearby satellites (i.e. frequency interference)



Background (2 of 2)
Operational Timeline

```
:Product: 0404RSGA.txt
:Issued: 2010 Apr 04 2201 UTC
# Prepared jointly by the U.S. Dept. of Commerce, NOAA,
# Space Weather Prediction Center and the U.S. Air Force.
#
Joint USAF/NOAA Report of Solar and Geophysical Activity
SDF Number 094 Issued at 2200Z on 04 Apr 2010
IA.  Analysis of Solar Active Regions and Activity from  03/2100Z
to 04/2100Z:  Solar activity was very low. No flares were observed
during the past 24 hours. New Region 1060 (N24E58) was assigned
today and appears to be a small bipolar region.
IB.  Solar Activity Forecast:  Solar activity is expected to be very
low. However, there is a chance for an isolated C-class event during
the next three days (05-07 April).
IIA.  Geophysical Activity Summary 03/2100Z to 04/2100Z:
The geomagnetic field was mostly quiet to unsettled. However, there
was an isolated active period at mid-latitudes from 0600-0900Z which
was accompanied by storm level activity at some high latitude
stations. Solar wind speed observed by the ACE spacecraft were
elevated throughout the day, typically between 460-540 km/s. The
greater than 2 MeV electron flux at geosynchronous orbit reached
high levels during the past 24 hours.
IIB.  Geophysical Activity Forecast:  The geomagnetic field is
expected to be quiet with a chance for unsettled periods for the
first day (05 April) and partway through the second day (06 April).
An increase to mostly unsettled levels with a chance for active
periods is expected sometime late on the second day or early on the
third day (07 April) in response to a favorably positioned coronal
hole. Yesterdays halo CME appears to be primarily directed south of
the ecliptic plane. However, it is possible that the flank of the
CME could contribute to somewhat elevated activity on the third day.
III.  Event Probabilities 05 Apr-07 Apr
Class M    01/01/01
Class X    01/01/01
Proton     01/01/01
PCAF       green
IV.  Penticton 10.7 cm Flux
Observed         04 Apr 079
Predicted   05 Apr-07 Apr  080/080/085
90 Day Mean       04 Apr 083
V.  Geomagnetic A Indices
Observed Afr/Ap 03 Apr  005/008
Estimated Afr/Ap 04 Apr  010/010
Predicted Afr/Ap 05 Apr-07 Apr  005/007-007/010-012/012
VI.  Geomagnetic Activity Probabilities 05 Apr-07 Apr
A.  Middle Latitudes
Active             05/25/35
Minor storm          01/10/20
Major-severe storm    01/01/05
B.  High Latitudes
Active             10/30/40
Minor storm          05/15/30
Major-severe storm    01/01/10
_ _ _ _ _ _ _ _ _ _ _ _ _ _ _
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Operational Timeline – Universal Time (UT)

April 3, 2010

09:54 B7 solar flare (sunspot region 1059)

10:33 CME first visible

22:04 SWPC Daily Forecast issued

- *Notes Flare and Coronal Mass Ejection (CME)*
- *Geomagnetic quiet expected: 04-05 April*

April 4

22:01 Daily Forecast issued (left text)

- *Flank of CME may contribute to elevated activity on April 7*

April 5

05:33 Warning issued: K=4

05:44 Alert issued: K=4

08:04 Warning issued

- *Sudden Impulse (CME hits ACE @ 07:56 UT)*

09:16 Warning issued: K=5

09:17 Alert issued: K=5

09:22 Alert issued: K=6

09:48 *Galaxy 15 anomaly*

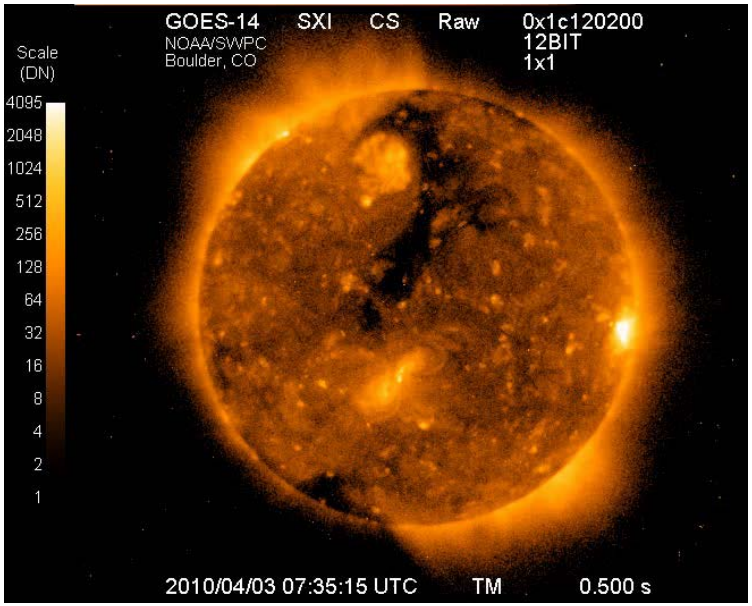
09:56 Alert issued: K=7

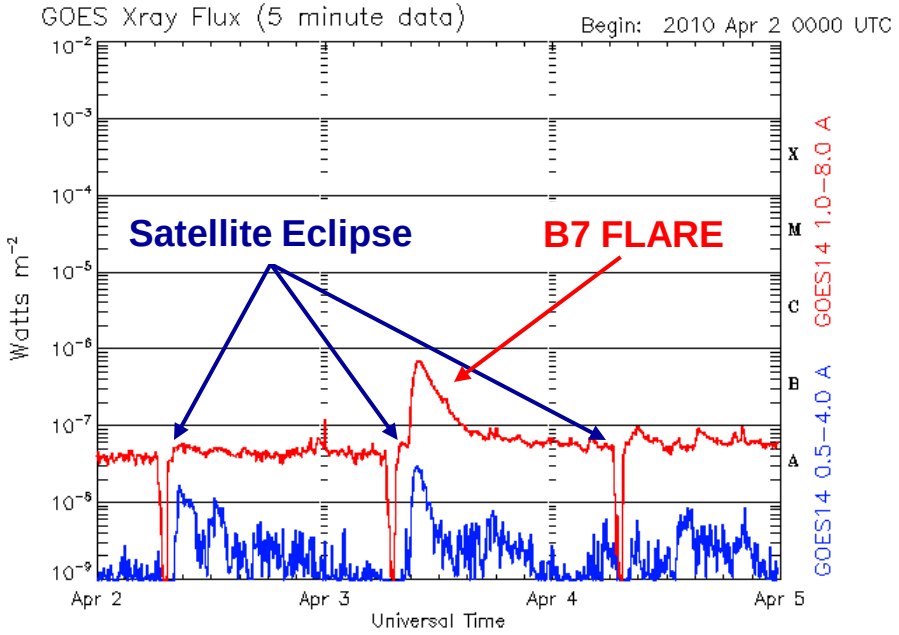
Space Weather Conditions
1. Events at the Sun (1 of 2)

Solar activity prior to the Galaxy 15 anomaly on April 05 at 9:48 was elevated but unremarkable.

On 03 April @ 9:54 UT (2 days prior to the anomaly) a solar B7 flare was observed by the NOAA GOES-14 X-Ray Sensor (XRS)

- **Flares of this intensity are not usually associated with intense space weather**
- **In solar cycle 23 there were >14,000 flares more intense than a B7-level flare**
- **There have already been 278 flares more intense than B7 in the new cycle**
- **Source of the flare was decaying active region 1059 (S22W15) with 4 sunspots**



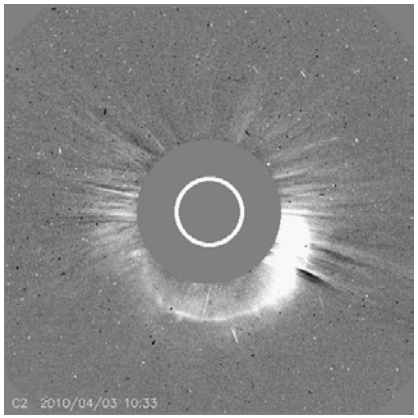


Space Weather Conditions
1. Events at the Sun (2 of 2)

April 03 @ 10:33 UT ~30 minutes after the flare an earthward directed coronal mass ejection (CME) was observed

- **SOHO/LASCO imager showed a modest partial Halo event**
- **Side view of the CME from the NASA STEREO COR2 instrument indicated that it was moving southward and only the 'edge' would graze earth**
- **Measured plane of sky speed was 512 km/s**
- **Moderate speeds and 'edge' impacts such as these typically cause weaker, shorter duration geomagnetic storms**
- **Solar cycle 23 had ~500 faster Earth directed CME's**

SOHO/LASCO

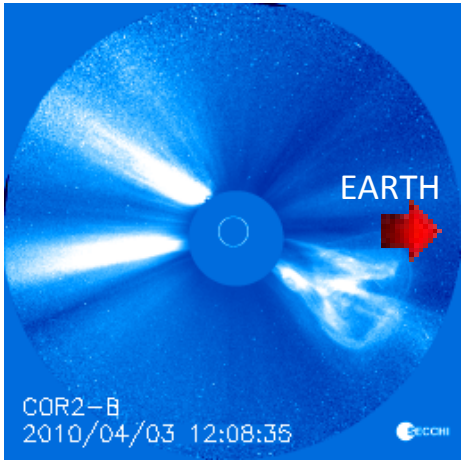


NASA/ESA

This event was classified as a moderate CME ejected from an otherwise quiet sun

- **F10.7 was 77 sfu, the sunspot count was 27 and the x-ray background was a modest 3.9×10^{-8} Watts m^{-2}**
- **At solar maximum, F10.7 is expected to be about 150 sfu and the sunspot count to be at least 3x greater**

STEREO COR2



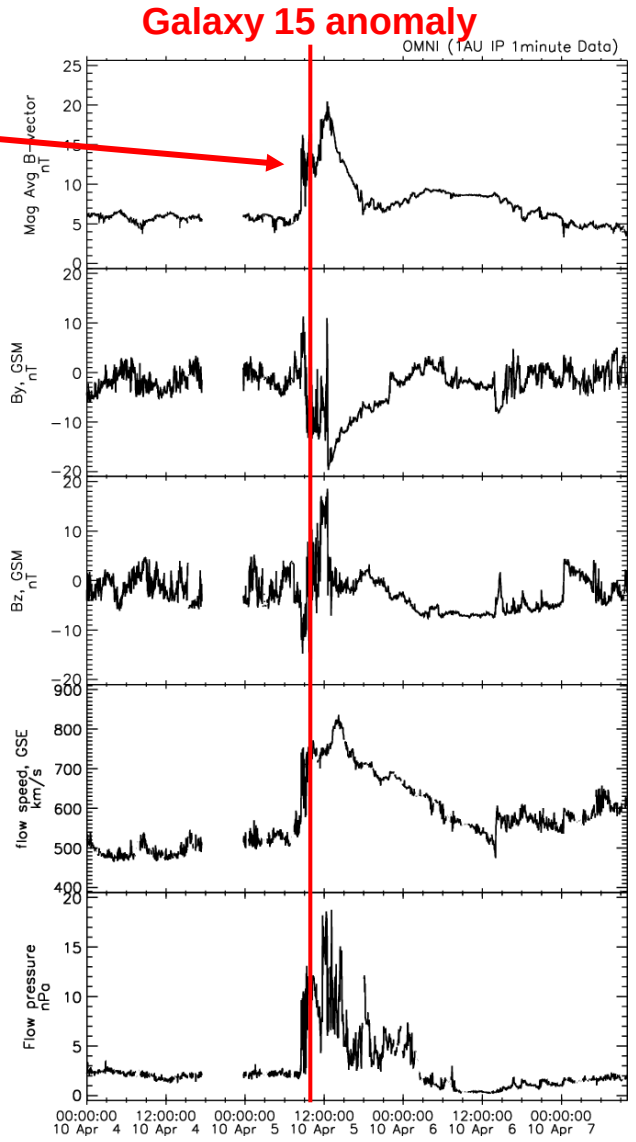
NASA

Space Weather Conditions
2. Global Environment At Earth (1 of 2)

April 05 07:56 UT – Nearly 2 days after the CME lifted off from the sun, it was observed by the NASA ACE satellite upstream of earth

- **It takes ~30 minutes for the solar wind to propagate from ACE to Earth**
- **The solar wind magnetic field turned southward (negative)**
- **The solar wind speed increased from ~500 to >700 km/s**

Such solar wind conditions often result in a moderate geomagnetic storm



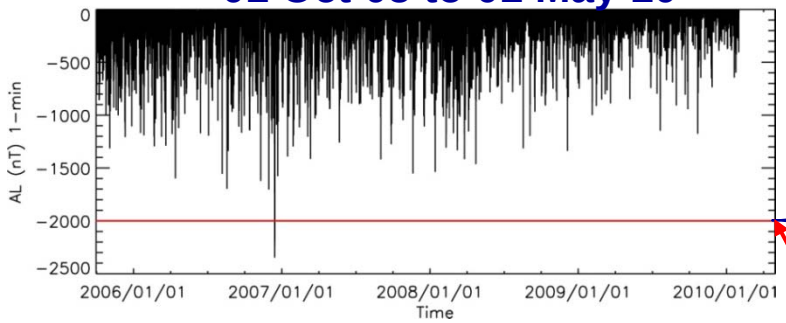
Data Source: NASA Omni

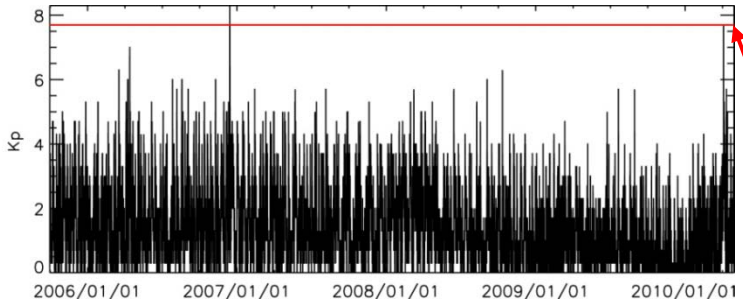
Note: ACE is the NASA Advanced Composition Explorer located in a halo orbit near the L1 sun-earth Lagrangian point approximately ~1.5x10^6 km in the sunward direction. Plot shows solar wind parameters observed at ACE, time-shifted to Earth.

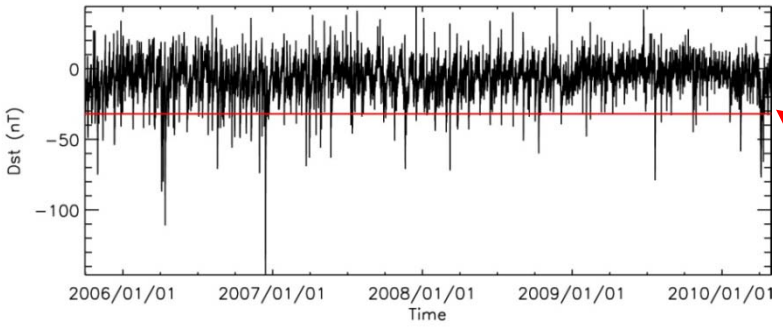
Space Weather Conditions
2. Global Environment At Earth (2 of 2)

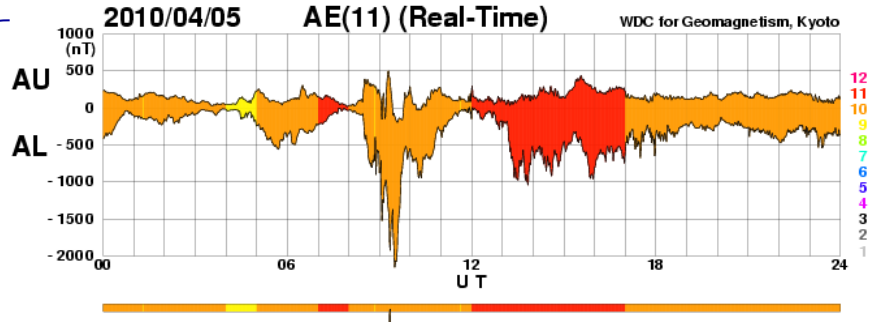
Some (but not all) global geomagnetic activity indicators were extreme immediately prior to the anomaly

01 Oct 05 to 01 May 10









Currently only quick look plots are available for April

AL index was <-2000 nT prior to the anomaly. Larger values observed only once previously during Galaxy 15 lifetime (*launched: 13 Oct 05*)

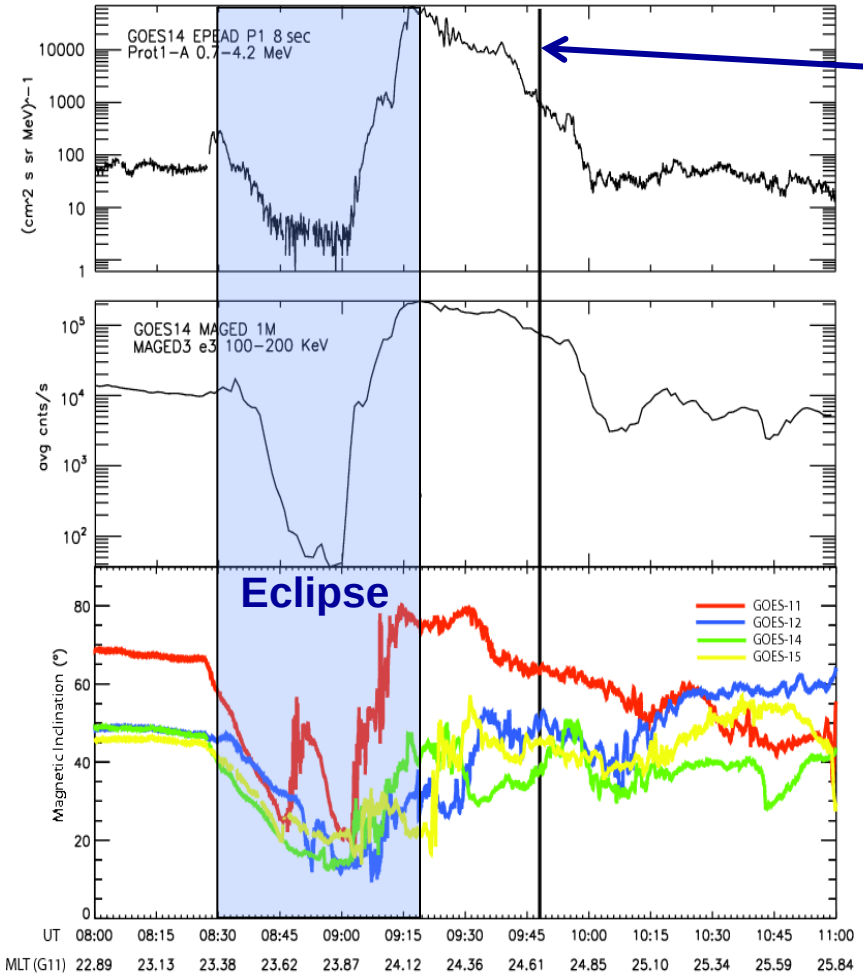
Kp index reached 7.7 prior to the anomaly – larger values were observed only once previously during the Galaxy 15 lifetime

? However, Dst index reached -32 nT prior to anomaly indicating only a **moderate storm –** similar to many previously observed levels during the Galaxy 15 lifetime

Data Source: Kyoto World Data Center & German Research Centre for Geosciences

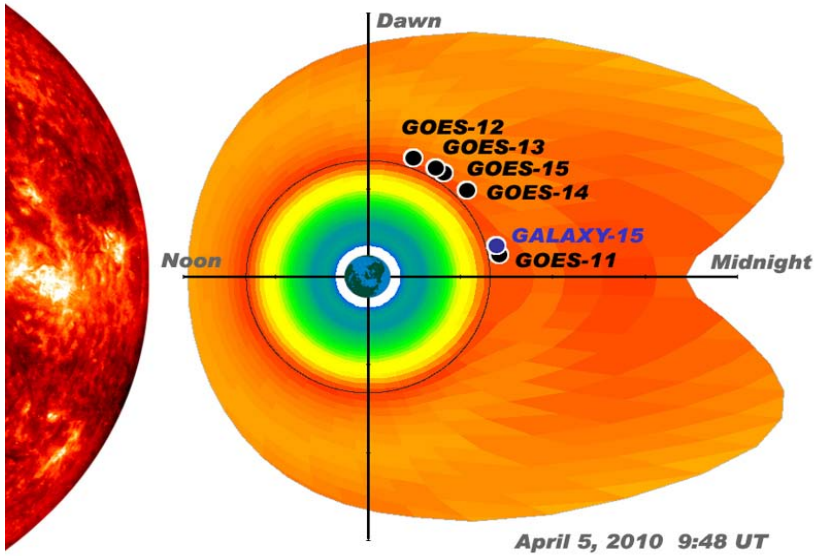
Space Weather Conditions
3. Local Environment At Galaxy 15 (1 of 4)

April 05 @ 09:00 UT: GOES magnetometers and particle instruments showed a major reconfiguration of the magnetosphere indicative of a substorm and injection of energetic particles into the nightside, geosynchronous orbit location



Galaxy 15 (133 W) Anomaly 09:48 UT

Satellite Locations



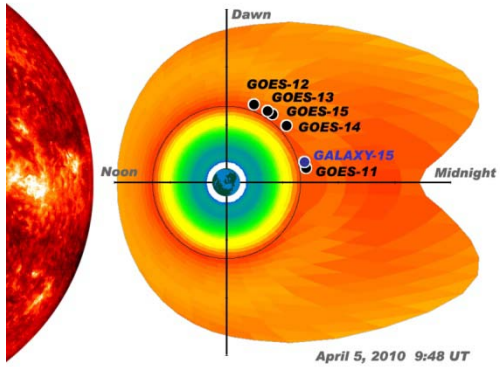
Space Weather Conditions
3. Local Environment At Galaxy 15 (2 of 4)

Surface Charging: Electron Environment (Low-to-Medium Energy Electrons)

- **April 05 @ 9:00 – 48 minute prior to the Galaxy 15 anomaly the 40-to-475 keV electron flux increased at GOES 14 and 15**
  - **75-to-475 keV electron flux was the highest observed since GOES 14 was turned on in July 2009 and since GOES 15 was turned on in April 2010**
  - **High electron fluxes are notable although surface charging potentials cannot be accurately estimated without lower energy (<40 keV) particle measurements and detailed modeling of their interactions with specific satellite surface materials**

GOES 14 -----
GOES 15 -----

Satellite Locations

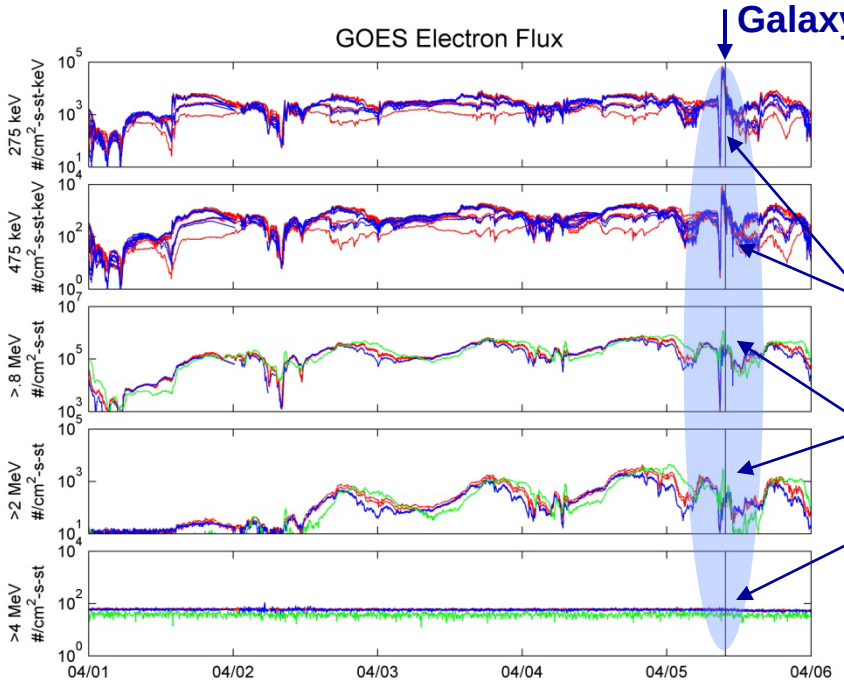


Note: Multiple curves for each GOES satellite correspond to different telescope "look" directions

Space Weather Conditions
3. Local Environment At Galaxy 15 (3 of 4)

Internal Charging: Electron Environment (Medium-to-High Energy Electrons)

- **April 05 @ 9:00 – 48 minutes prior to the anomaly 275-475 keV electron flux increased at GOES 14 and 15**
  - **Flux of 275-475 keV electrons was the highest observed since GOES 14 was turned on in July 2009 and GOES 15 since April 2010 (GOES 11 does not measure electrons below .8 MeV**
  - **Flux of >.8 MeV electrons measured by GOES 11, 14 and 15 did not increase above prior levels**



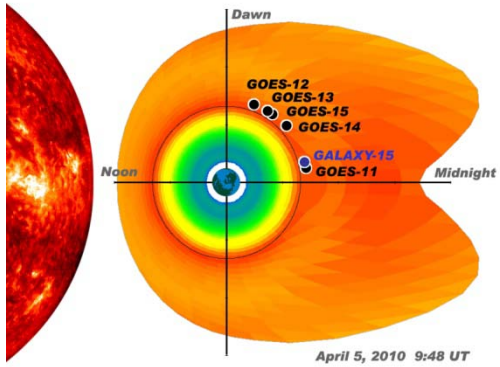
GOES 14 -----
GOES 15 -----
GOES 11 -----

Flux increase
(275 keV / 475 keV)

Moderate increase
(>.8 MeV / >2 MeV)

No increase
(>4 MeV)

Satellite Locations



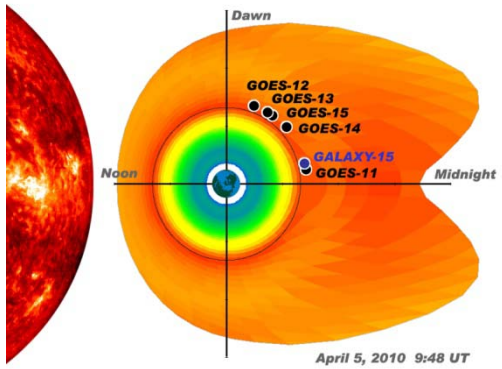
Space Weather Conditions
3. Local Environment At Galaxy 15 (4 of 4)

Single Event Upsets / Latchups / Burnouts: Proton Environment

- **April 05 @ 9:00 – GOES 11, 14 and 15 measured increased proton flux limited to the 2.5 MeV channel**
  - **Flux increase was notable although GOES 11 measured numerous events with higher flux rates over the lifetime of Galaxy 15**
  - **Protons with energies >5 MeV required to penetrate typical spacecraft shielding (3 mils Al)**
  - **GOES 11, 14 & 15 measured no increase in the 6.5 MeV and 11.5 MeV channels**

GOES 14 -----
GOES 15 -----
GOES 11 -----

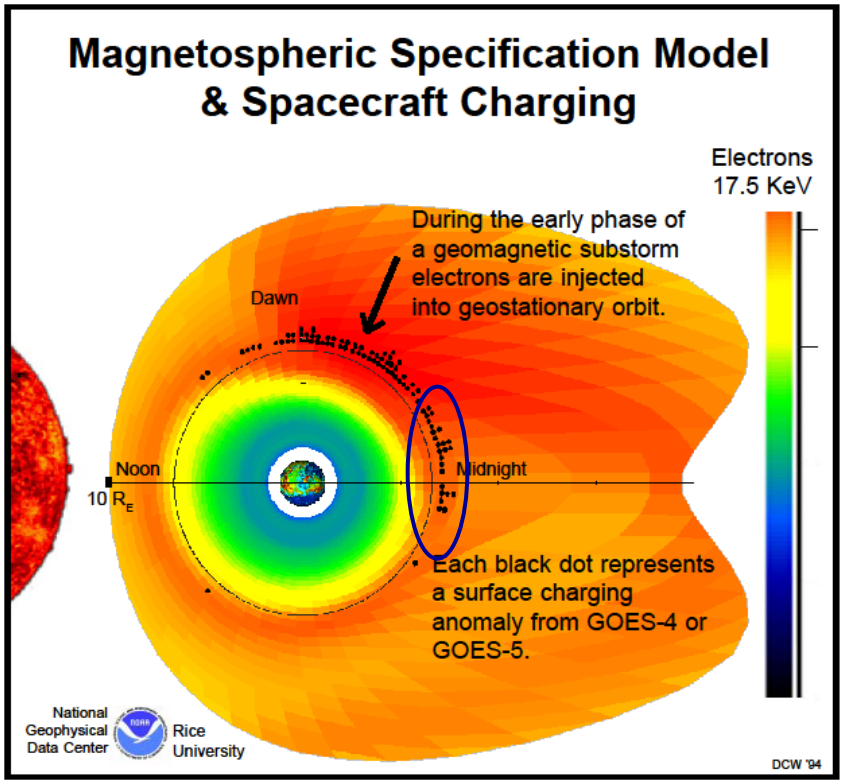
Satellite Locations



Space Weather Conditions
Galaxy 15 Anomaly (05 Apr 2010 0948 UT)

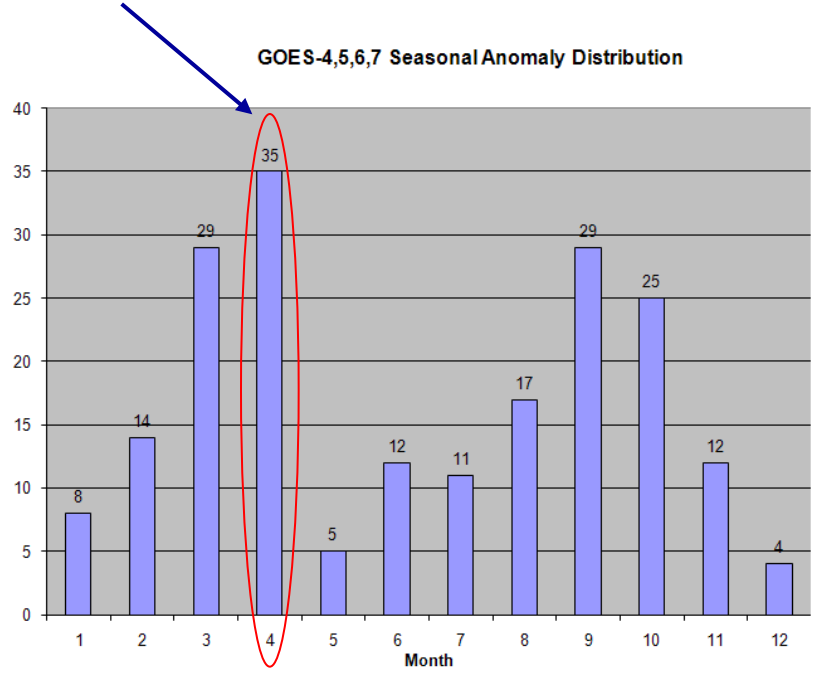
Statistical Distribution of Spacecraft Anomalies

GALAXY 15 anomaly occurred in the midnight to dawn local time sector, where anomalies are most likely to be observed.



GALAXY 15 anomaly occurred near equinox which is the time of year where anomalies are most likely to occur

Around equinox is also the time of year where geosynchronous spacecraft encounter eclipse periods and elevated geomagnetic activity



Summary

SWx Conditions for Galaxy 15 – 05 Apr 10

Conclusions:

- Energetic particle flux measurements (protons & electrons) in the GEO space environment near midnight and on the dawn flanks for 05 April 2010 are available for use in Galaxy 15 anomaly investigations
- Measured electron fluxes at low to moderate energies are consistent with increased risk factors for surface and internal spacecraft charging
- Measured high-energy proton fluxes are not consistent with increased risk of single-event upsets, latchups and burnouts by sensitive electronic components\

Related talks:

SM13B-1805 A Perfect Substorm: ICME-driven Magnetic Activity Catches Galaxy 15 in the Wrong Place at the Wrong Time. (*M. G. Connors et al.)*

SM22B-05 Multipoint Observations of the Large Substorm Associated with the Galaxy 15 Anomaly (*H.J. Singer et al.)*

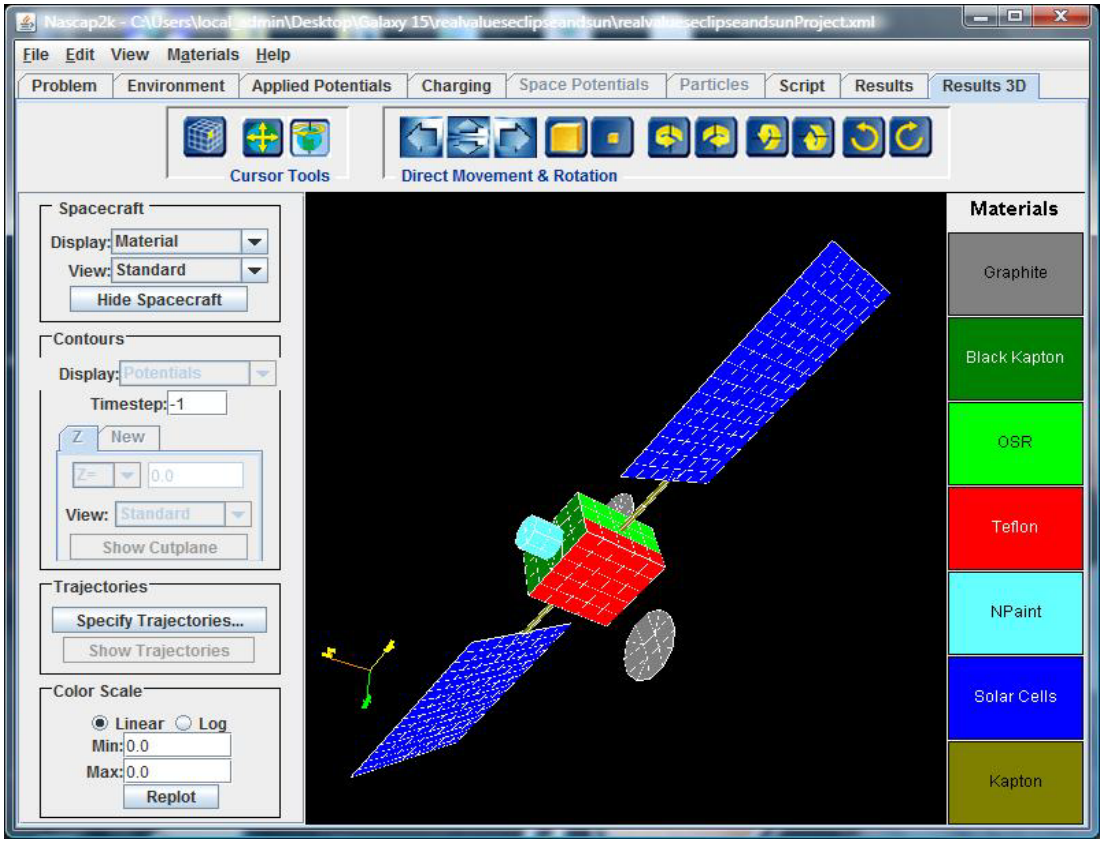
See also: http://www.ngdc.noaa.gov/stp/satellite/anomaly/2010_sctc/docs/1-2_WDenig.pdf

Acknowledgements: Thanks to all for providing a wealth of environmental data that proved useful in this assessment. Particular thanks are due to NASA and the associated satellite science teams, the World Data Centers (Kyoto), German Research Center for Geosciences (Potsdam), and INTERMAGNET (notably the USGS and NRC). The GOES spacecraft are part of the NOAA satellite observing system.

Related Work
Galaxy 15 Anomaly (05 Apr 2010 0948 UT)

Ongoing Work to be Reported Elsewhere

A simple satellite representation has been used in a NASCAP-2k simulation to estimate possible charging potentials experienced by Galaxy 15 prior to and around the time of the anomaly. The environmental conditions used in the simulation are based on GOES particle data and a new moments calculation of electron temperatures.[1] The environmental conditions are compared to previous "worse case" particle environments for GEO spacecraft. The results of the simulation will be reported on by *Ferguson et al.* at the upcoming AIAA meeting, 04-07 January 2010, Orlando, FL.



[1]GOES-R Moments and Spacecraft Charging Algorithm and Application to Anomaly Studies, J.V. Rodriguez et al., Proceedings of 11th Spacecraft Charging Technology Conference, 20-24 September 2010, Albuquerque, NM

QUESTIONS?