



7th Space Weather & NASA Robotic Mission Ops Workshop

September 29-30, 2015

Earth Science Mission Operations
EOS Aqua & Aura Space Weather View

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Satellites & Space Weather



- **Effects of space weather on spacecraft systems are well documented** (Ref: NOAA Space Weather Prediction Center)
 - Surface Charging/Electrostatic Discharge (ESD)
 - Deep dielectric or bulk charging
 - Single Event Upset (SEU)/Single Event Latch-up (SEL)
 - Solar proton events (SPEs)
 - Galactic cosmic rays (GCRs)
 - Spacecraft drag
 - Total dose effects
 - Solar radio frequency interference and telemetry scintillation
 - Debris
 - Spacecraft orientation
 - Photonics noise
 - Materials degradation
 - Meteorite impact



Spacecraft Anomalies & Space Weather



Anomaly Investigation – How Space Events are Blamed

Many spacecraft anomalous events occur throughout a mission

- Hardware Failures – EOS Aura Solar Panel Connector
- Degradation – EOS Aqua and Aura Solar Array Degradation
- Debris and micrometeorite impact – EOS Terra Battery and Aura Solar Panel
- Single Event Upsets (SEUs) – Experienced by all 3 EOS missions
- Single Event Functional Interrupt (SEFI) – EOS Aura FMU/SSR
- Single Event Latch-up (SEL)
- Electrostatic Discharge (ESD)

Anomaly Investigations usually start with understanding the Space Environment and geographical location of spacecraft at the time of anomaly

Contributing Factors often considered during investigation:

- Solar Events
- Cosmic Rays? Is this information available and presented in a way that is useful?

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[Satellites and Space Weather - Space Environment Center](#)

www.swpc.noaa.gov/info/Satellites.html ▾ Space Weather Prediction Center ▾

Space weather effects on satellites vary according to orbit, spacecraft local time, spacecraft position relative to certain regions in space, stage of the 11-year ...

[IPS - Space Weather - Space Weather Effects](#)

www.ips.gov.au ▾ Educational ▾ Ionospheric Prediction Service ▾

Interplanetary Scintillations - [Satellite Communications and Space Weather ... Facts on Space Weather Effects](#) - A Remarkable Period of [Space Weather ...](#)

[Space weather's effects on satellites | MIT News Office](#)

newsoffice.mit.edu/2013/space-weather-effects-on-satellites-0917 ▾

Sep 17, 2013 - Lohmeyer says a better understanding of space weather's effects on satellites is needed not just for current fleets, but also for the next ...

[\[PDF\] Extreme space weather: impacts on engineered system...](#)

www.raeng.org.uk/.../space-weather-full-... ▾ Royal Academy of Engineering ▾

Extreme space weather: impacts on engineered systems and infrastructure 5. 1.

Executive summary on the 2003 storm, is that up to 10% of satellites could ...

[Space Weather: What impact do solar flares have on ... - Nasa](#)

hesperia.gsfc.nasa.gov/sftheory/spaceweather.htm ▾

Space Weather: ... This increases the drag on Earth-orbiting satellites, reducing their lifetime in orbit. ... The Human Impacts of Solar Storms and Space Weather.

[Space weather - Wikipedia, the free encyclopedia](#)

en.wikipedia.org/wiki/Space_weather ▾ Wikipedia ▾

Jump to [Observing space weather with satellites](#) - After Explorer I discovered that space was not a void, many ... [Satellite \(GOES\) weather satellite](#) and many communication satellites. ... affect the magnetosphere and ionosphere, ...



Conjunction Assessment & Collision Avoidance



Space Weather Events around Time of Closest Approach

- Joint Space Operations Command (JSpOC) uses High Accuracy Satellite Drag Model (HASDM) which accounts for predicted space weather
- Typically Debris Avoidance Maneuver (DAM) planning begins ~24 to 72 hours prior to Time of Closest Approach (TCA) using the predicted space weather
 - Use latest tracking data
 - Use latest predicted space weather and atmospheric density models
 - Allow sufficient time for flight support team to work the maneuver planning and screening process to ensure that the planned maneuver is safe to execute
- DAM planning is a joint effort by all parties of the Flight Support Team
 - Flight Operations Team (FOT)
 - Flight Dynamics Team (FDT)
 - Conjunction Assessment and Risk Analysis (CARA) Team
 - JSpOC GSFC Orbital Safety Analyst (OSA)
- Uncertainties due to space weather exist and complicate DAM planning:
 - Arrival, confidence and magnitude of Solar Event effects projected miss distances
 - Uncertainties on arrival time and magnitude of Solar Events prior to TCA complicate evaluation in determining if a DAM is warranted or could possibly make matters worse



Aura vs. 89477

Short-notice

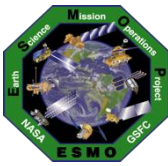
Debris Avoidance Maneuver

High Interest Event

Identified Friday, August 28, 2015 as potential high-risk close approach
Time of Closest Approach (TCA): Saturday, Aug 29, 2015 at 07:51:15 GMT
Intensive 16-hours of DAM planning, screening and approving
Maneuver waived-off Saturday, August 29, 2015 around 0300 GMT
Event complicated by intense solar and geomagnetic activity



Aura vs. 89477



(TCA: 8/29 at 07:51:15 GMT)

- **August 29th Aura predicted close approach was particularly challenging High Interest Event (HIE).**
- **Late notice with dramatic change to the risk highlights the need to be able to detect changes and respond faster.**
- **Changes in predicted drag a few days prior to the conjunction resulted in a high-risk (1 in 1300) with only about 16-hours of response time.**
- **The ESMO Flight Support Team (FST) did an amazing job and were prepared to execute a debris avoidance maneuver on short notice.**
- **Updated tracking just hours prior to the conjunction resulted in the risk rolling off after the prime burn opportunity had been waived-off to allow more time to collect and analyze the data.**
- **Overall the Aura HIE was very similar to the Terra HIE that occurred on June 24th and a number of other short-notice HIEs.**

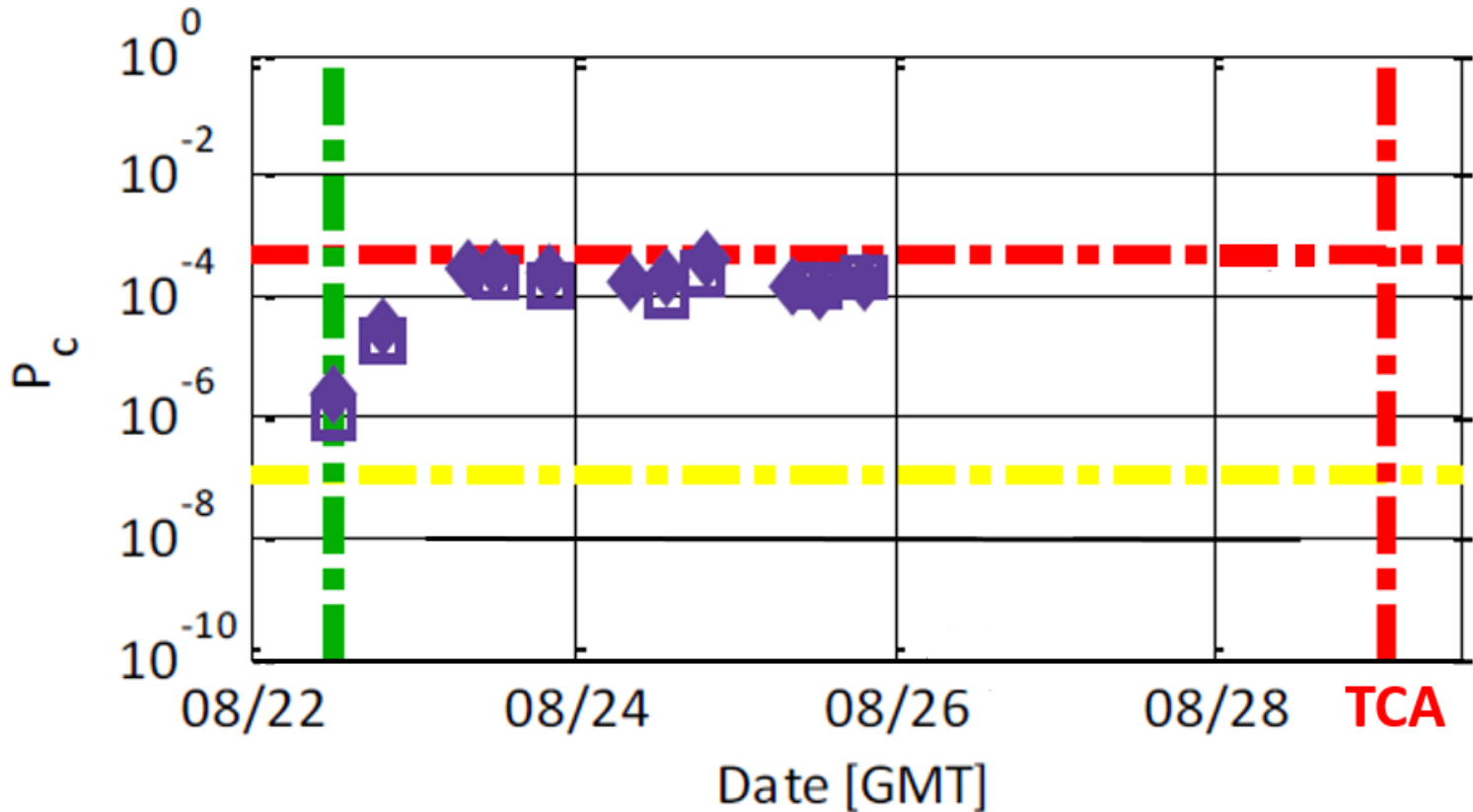


3-days until TCA



(data point #11)

Screening Report received Wednesday 8/26 at 12:57am EDT



Probability-of-collision (P_c) has been near the CARA RED threshold for about 3-days – TCA is still 3.1 days away

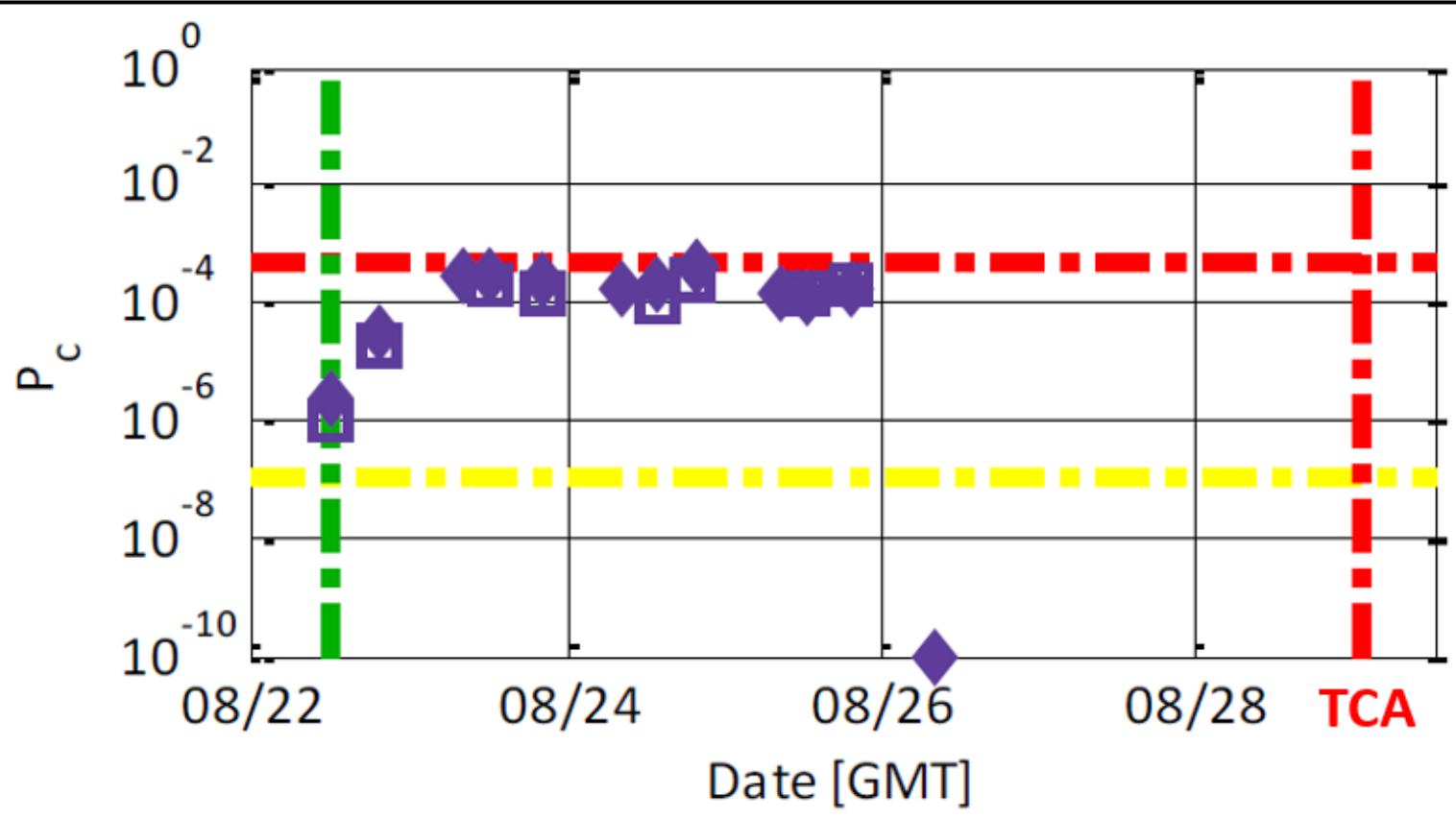


Next Screening Report



(data point #12)

Screening Report received Wednesday 8/26 at 11:24am EDT



**Probability-of-collision (P_c) suddenly drops to LOW-RISK
TCA is still 2.7 days away – appears risk has self-mitigated**

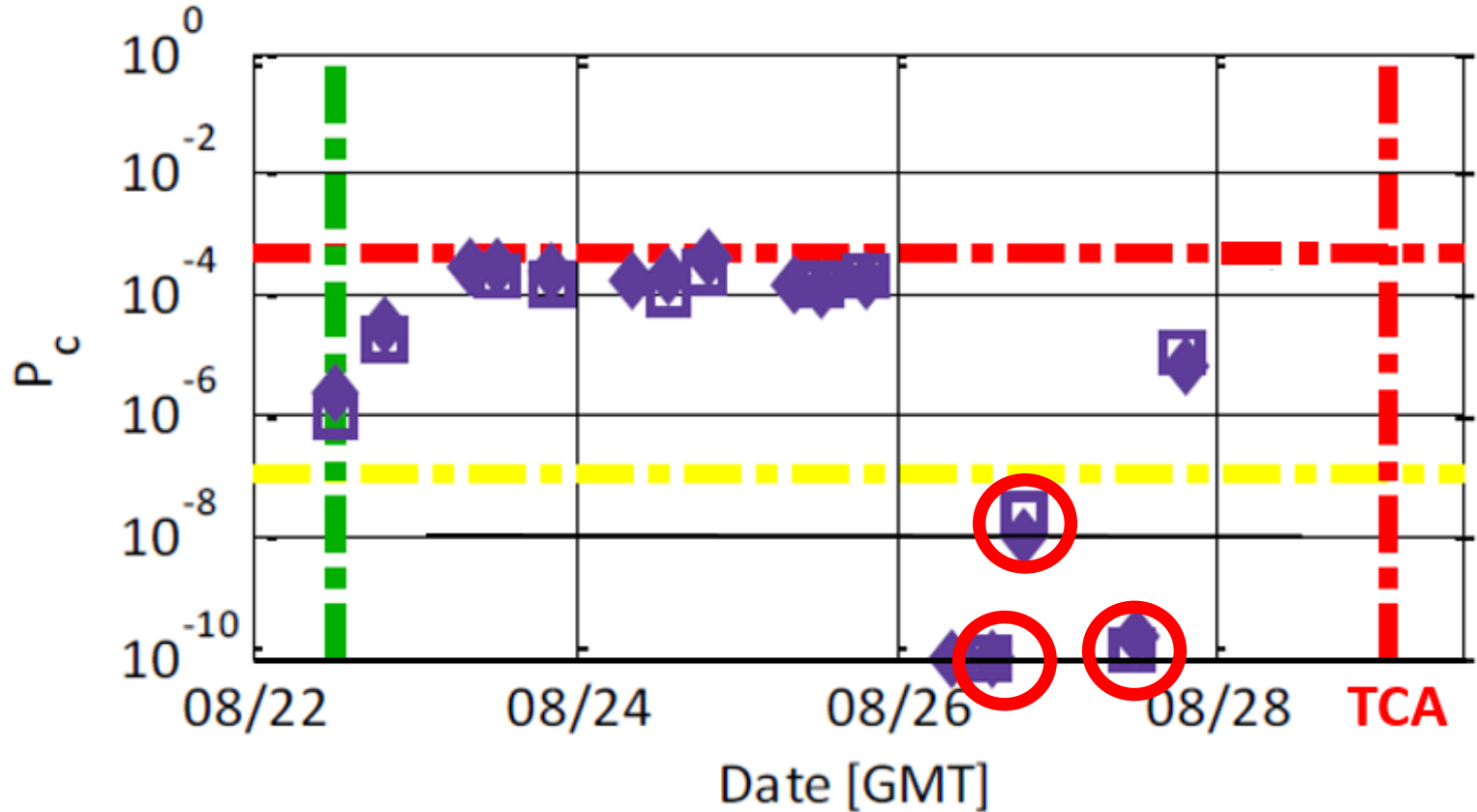


Just over 1-day until TCA



(data point #16)

Screening Report received Friday 8/28 at 1:30am EDT



Pc increases from low-risk to medium-risk but is still only 6.62E-06 or about 1 in 151K – TCA is 1.1 days away

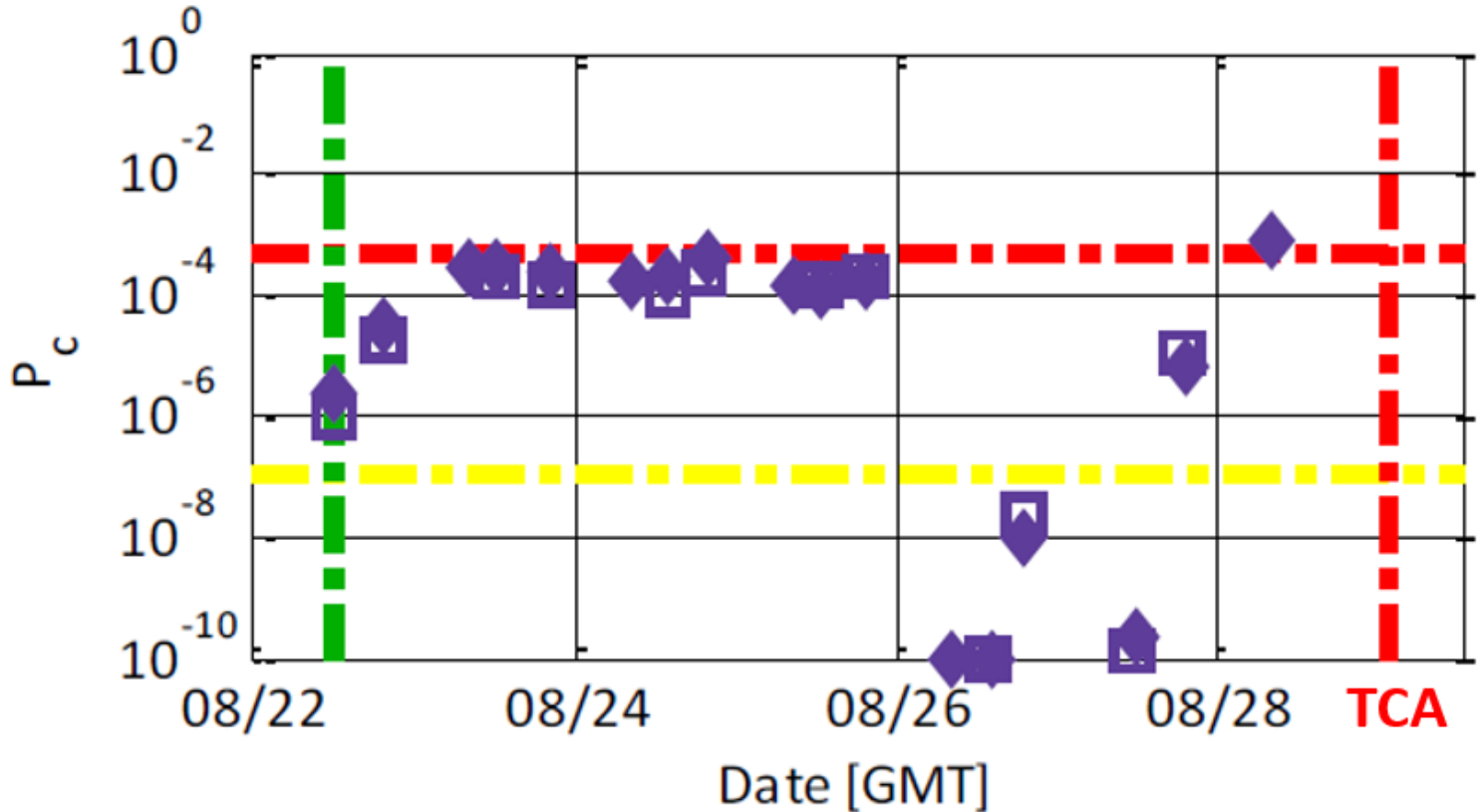


Next Screening Report



(data point #17)

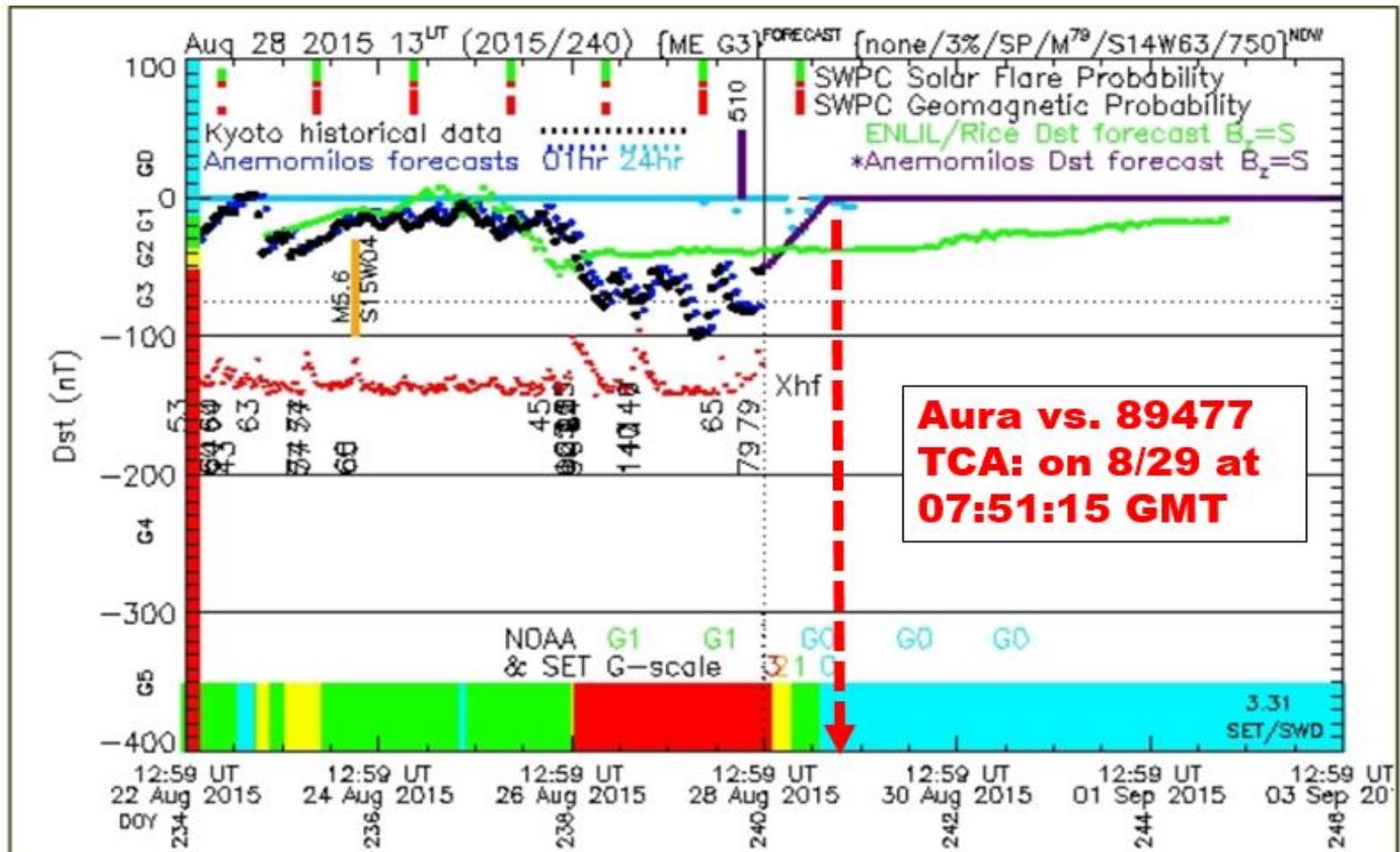
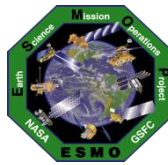
Screening Report received Friday 8/28 at 11:51am EDT



Probability-of-collision (P_c) dramatically increases with only 16-hours to Time-of-Closest-Approach (TCA) during period of intense solar and geomagnetic activity



Space Weather



Intense solar and geomagnetic activity resulted in changes in predicted drag that changed predicted miss distances & probability-of-collision (Pc). Pc peaked at about 1 in 1300

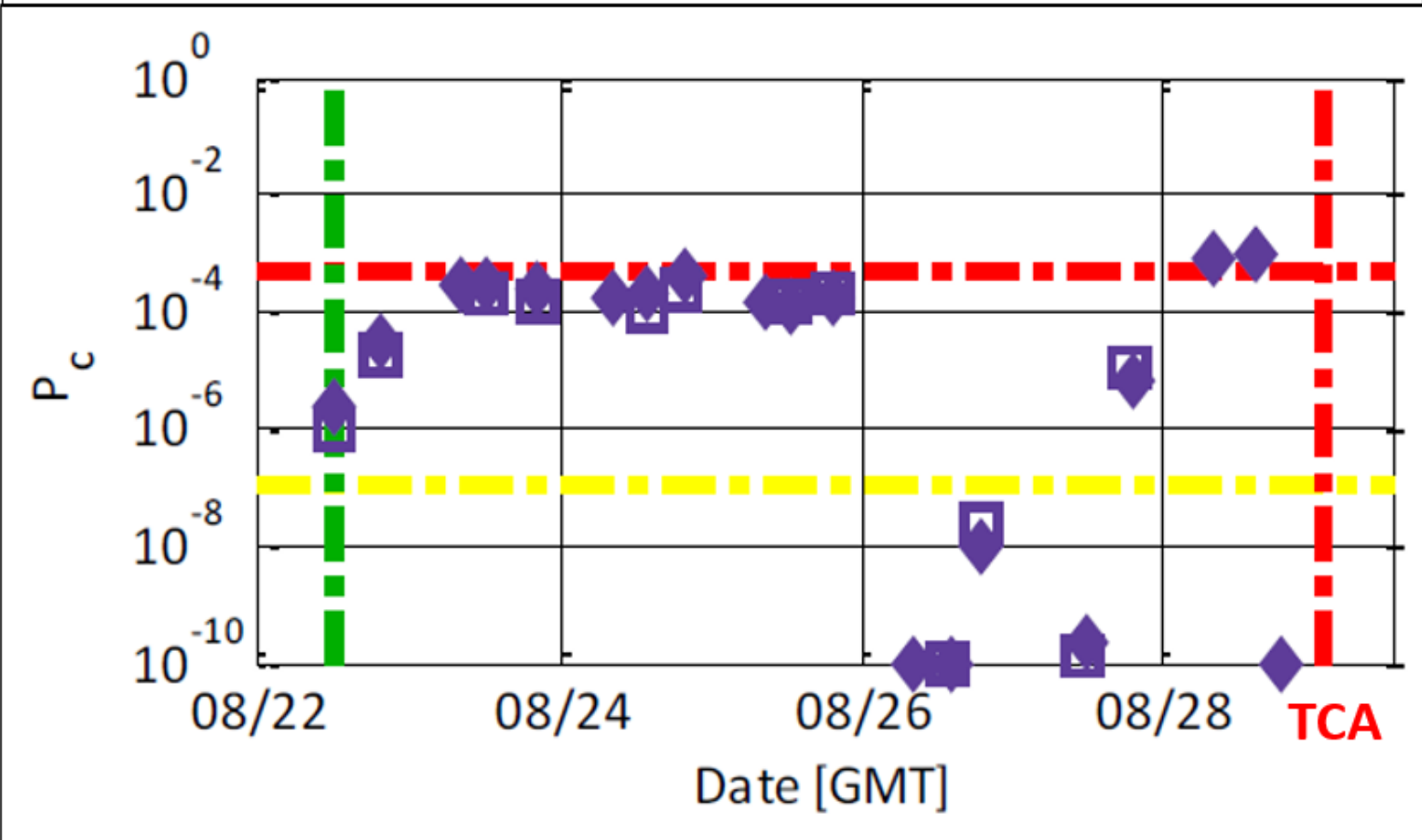


Aura vs. 89477



(data points #18 and #19)

Screening Report received Friday 8/28 at 10:18pm EDT



P_c stayed high-risk (about 1 in 1300) for a second data point prior to eventually dropping off a few hours from TCA



Some things that worked



- **Flight Operations Team (FOT) Collision Avoidance Engineer notified the Aura Mission Director during their weekly Monday tag-up meeting that he was monitoring a potentially high-risk Aura conjunction that has been just below the CARA Red Threshold for a couple of days**
- **Mission Director included the conjunction in the Weekly Top Ten Issues reviewed with the flight support team on Tuesday**
- **Various Space Weather alerts and warnings were issued starting on Wednesday**
- **Flight support team monitoring Space Weather (Dst, Ap, ...)**
- **Risk level dropped off and conjunction appeared to self-mitigate**
- **Unexpectedly, with only about 16-hours to TCA the risk level became elevated to above the CARA Red Threshold**
- **Flight support team did an amazing job on short-notice and were prepared to execute debris avoidance maneuver if necessary**



Some Questions



- **Why did the Pc drop off to such a low value over 2 days prior to TCA, after being in the E-04 range for many days, even though the overall miss distance was continuing to decrease**
- **During periods of intense solar activity what changes are being made at the JSpOC with their atmospheric density models**
- **How long are the changes modeled for**
- **How frequently are updates made to the models**
- **When are the models returned to “normal”**
- **What magnitude of changes can be expected in predicted miss distances, covariance and probability of collision**