6th Space Weather & NASA Robotic Mission Ops Workshop

September 17-18, 2014

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?

EOS Aura & Space Weather

EOS Aura – Microwave Limb Sounder (MLS) internal mechanism electronics are subject to potentially destructive latch up by high energy protons and should be powered off during confirmed 10 MeV proton flux alerts of 100,000 pfu (S5 alert from the SWPC).

- NOAA Space Weather Prediction Center (SWPC) notifies EOS-Aura Operations team of Proton Flux greater than category S5.
- Instrument Team starts to evaluate at category S3 and monitors trend. Will request power off if think Proton Flux could reach S5.
- Alert is sent via email/text message to multiple locations
  - Flight Operations Team and MLS Instrument Operations Team
    - Pagers/Cell phones
    - Email
  - Email to system being monitored for proton flux alert message
    - Forwards message to Online Command & Telemetry System
    - Triggers Limit violation
    - Flight Operations Team executes response to power off Mechanisms

- Never performed MLS Power Off on orbit due to Proton Flux Concerns

SEUs and the SAA

Significantly greater likelihood of Single Event Upsets in the South Atlantic Anomaly (SAA), North and South Poles

Preventative Actions typically used by many Low Earth Orbiting Satellites

- Avoid performing special activities during significant Solar Flares
- Avoid issuing commands or uploading code while traversing SAA

Terra:

- High Gain Antenna Motor Drive Assembly – opticoupler susceptibility results in temporary loss of communications
- Science Data Format Equipment (SFE) – susceptibility results in temporary loss of science data formatting

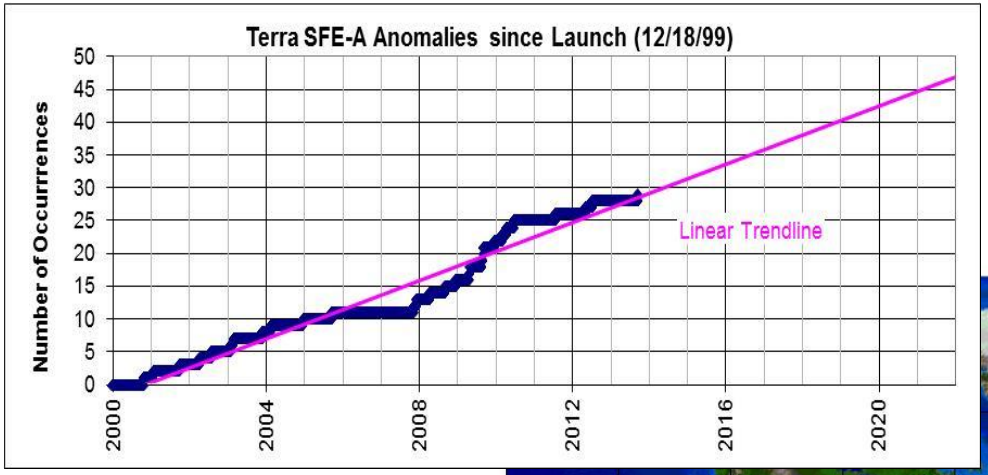
Aqua:

- Various instrument anomalies have been attributed to SEUs

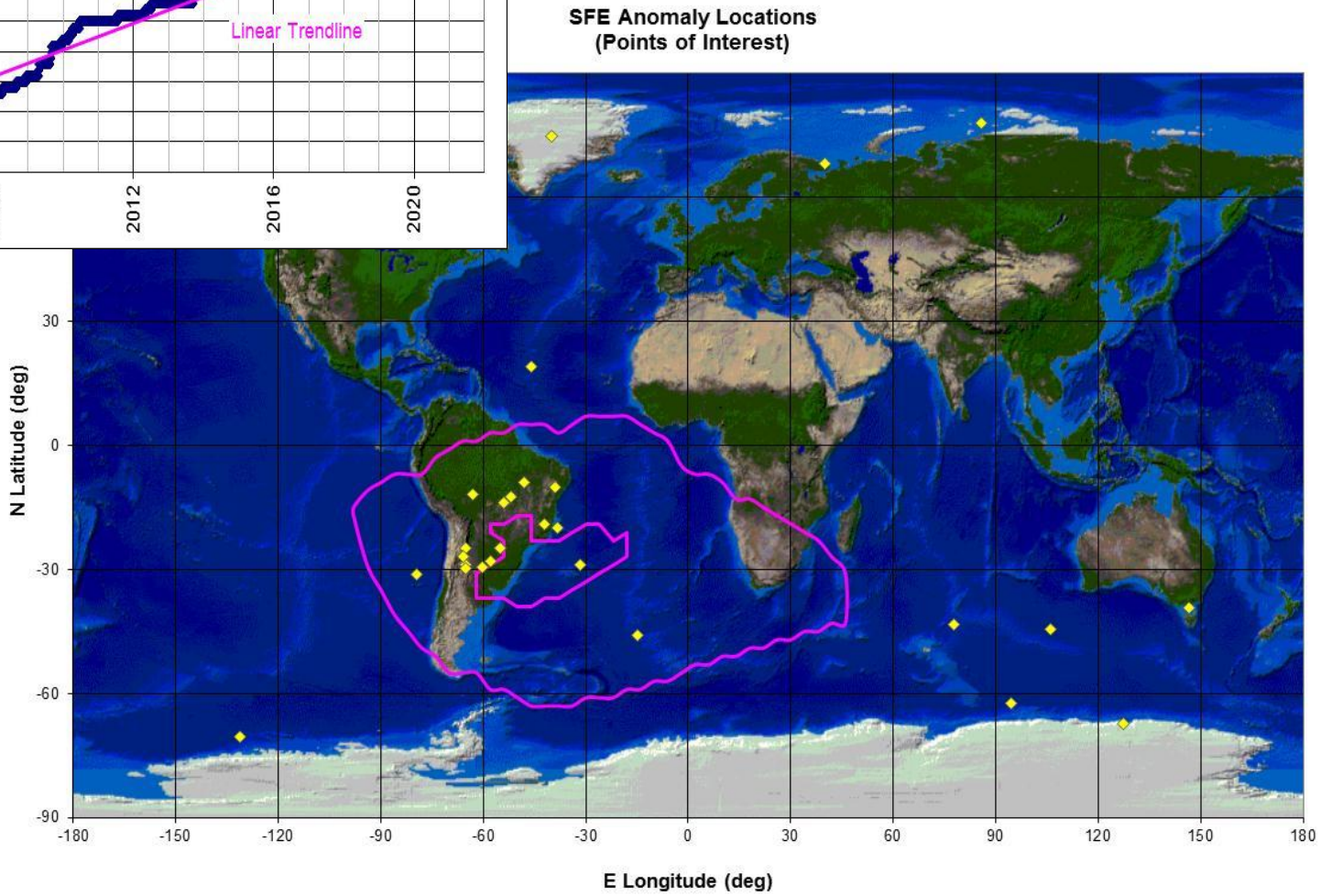
Aura:

- Various instrument anomalies have been attributed to SEUs

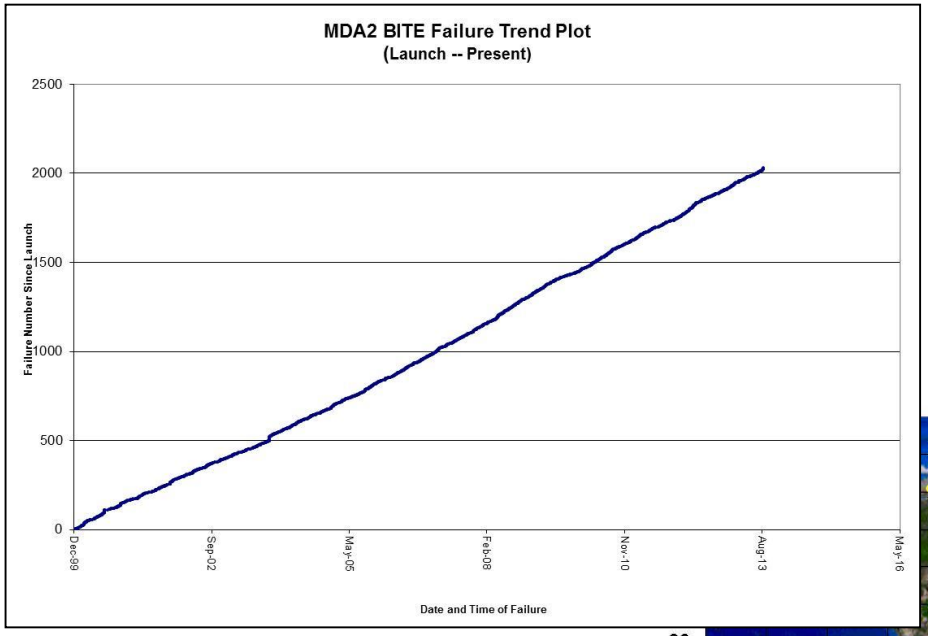
Terra Anomalies due to Single Event Upsets



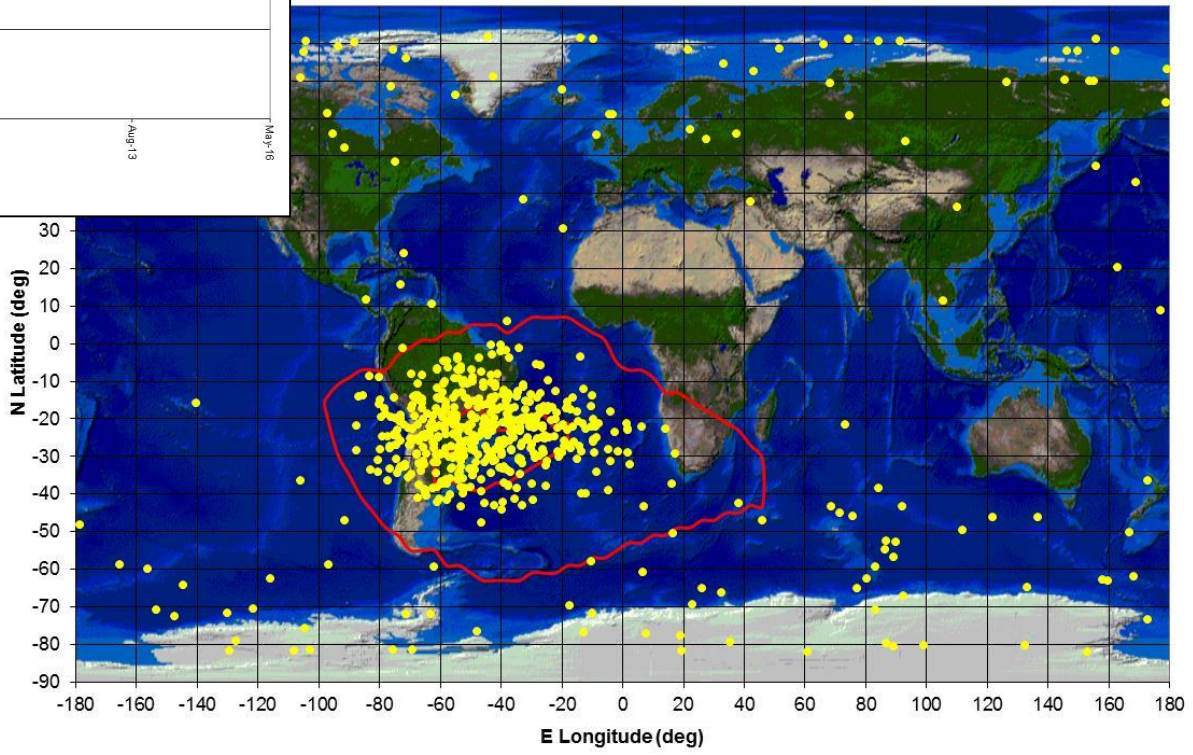
Terra Science Format Equipment (SFE)



Terra Anomalies due to Single Event Upsets



Terra High Gain Antenna Motor Drive Assembly (MDA)



Degradation & Space Weather

Solar Array (SA) Degradation is expected: long-term exposure to low earth orbit causes gradual degradation of SA power generation. Causes include: Ionizing and ultraviolet emissions, contamination of protective glass by the products of destruction of the outer surface materials of spacecraft, thermal cycling, radiation electrization, and plasma thruster plumes

Terra:

- Solar Array degradation over time

Aqua:

- Solar Array degradation over time
- Solar flare of 5 November 2003, an X28 - the strongest ever recorded according to NOAA, caused greater than 1% degradation of the Aqua SA

Aura:

- Solar Array degradation over time

Conjunction Assessment & Collision Avoidance

Solar Events around Time of Closest Approach

- Typically Risk Mitigation Maneuvers (RMM) are performed ~24 hours prior to Time of Closest Approach (TCA) using the predicted Solar Events
  - Use latest tracking data
  - Keep burn durations small
  - Allow sufficient time for change in velocity to increase separation
- Joint Space Operations Command (JSpOC) uses High Accuracy Satellite Drag Model (HASDM) which accounts for some of the space weather changes
- Uncertainty due to Solar Effects still exist:
  - Arrival, Confidence and Magnitude of Solar Event effects projected Miss Distances

Event Issue Date: **2013-09-19 12:44:59.0 GMT**
CME Arrival Time: **2013-09-22 14:14:49.0 GMT**
Arival Time Confidence Level: **± 6 hours**
Disturbance Duration: **24 hours**
Disturbance Duration Confidence Level: **± 8 hours**
Magnetopause Standoff Distance: **6.6 R_e**

  - Uncertainties on arrival time and magnitude of Solar Events prior to TCA complicate evaluation in determining if a RMM is warranted or could possibly make matters worse

Aura DMUM #64
(Potential DAM)

Identified Tuesday, February 11, 2014

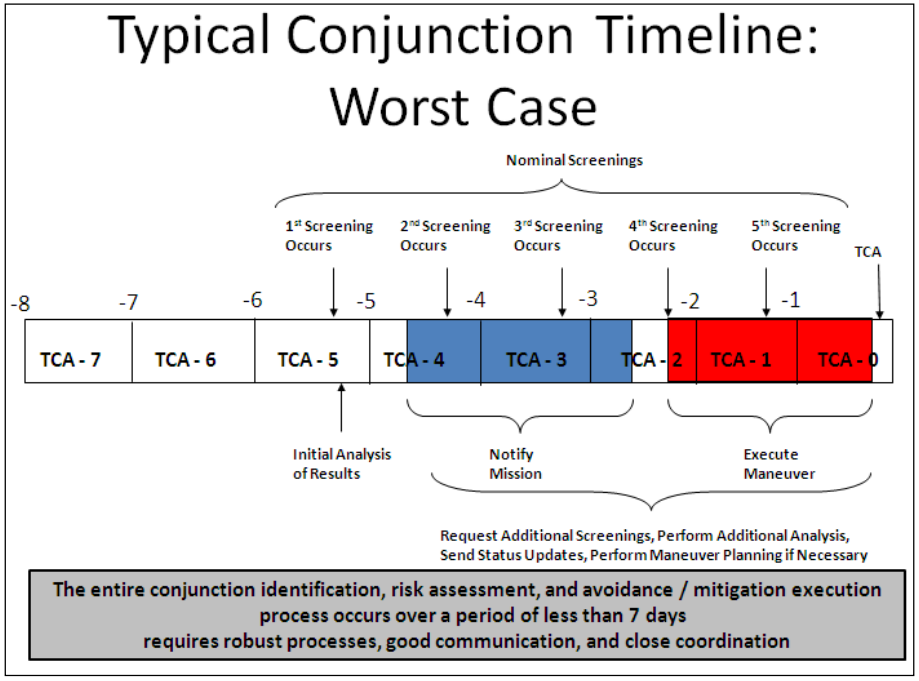
Time of Closest Approach Sunday, February 16, 2014

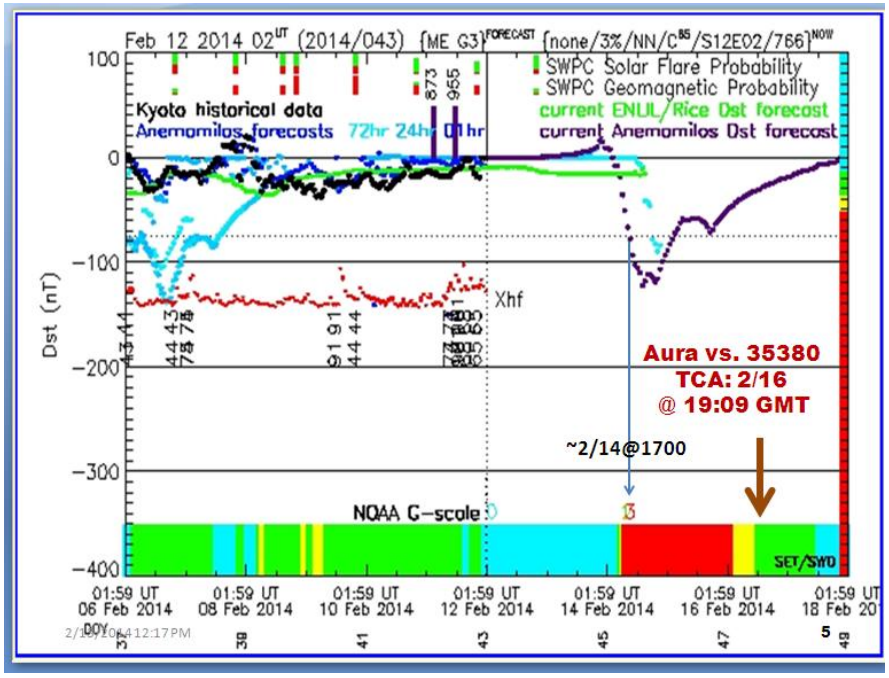
Maneuver waived-off Saturday, February 15, 2014

Edited slides for OCO-2 on May 6, 2014

Aura DMUM #64 (Potential DAM) – Day 1

- Tue 2/11: 9:02pm CARA Screening – First data point (DP #1) for CA with 35380 on 2/16
  - Screening Epoch 2/11 at 23:27 GMT, TCA 2/16 at 19:08:59 GMT, Pc = 1.29E-04 (1:7752)
  - **TCA is about 5-days from screening epoch** (~ 2-days later than expected)
  - MD Requested additional information and maneuver trade space plots at 10:06pm
    - CARA acknowledged the request at 10:48pm – will provide Wednesday morning
  - **HIE complicated by local weather forecast and Space Weather activity (CMEs & Dst forecast)**
- With the first data point being around TCA minus 5-days the conjunction timeline will be more typical of a worse case scenario – but not as bad as an emergency/short-notice conjunction

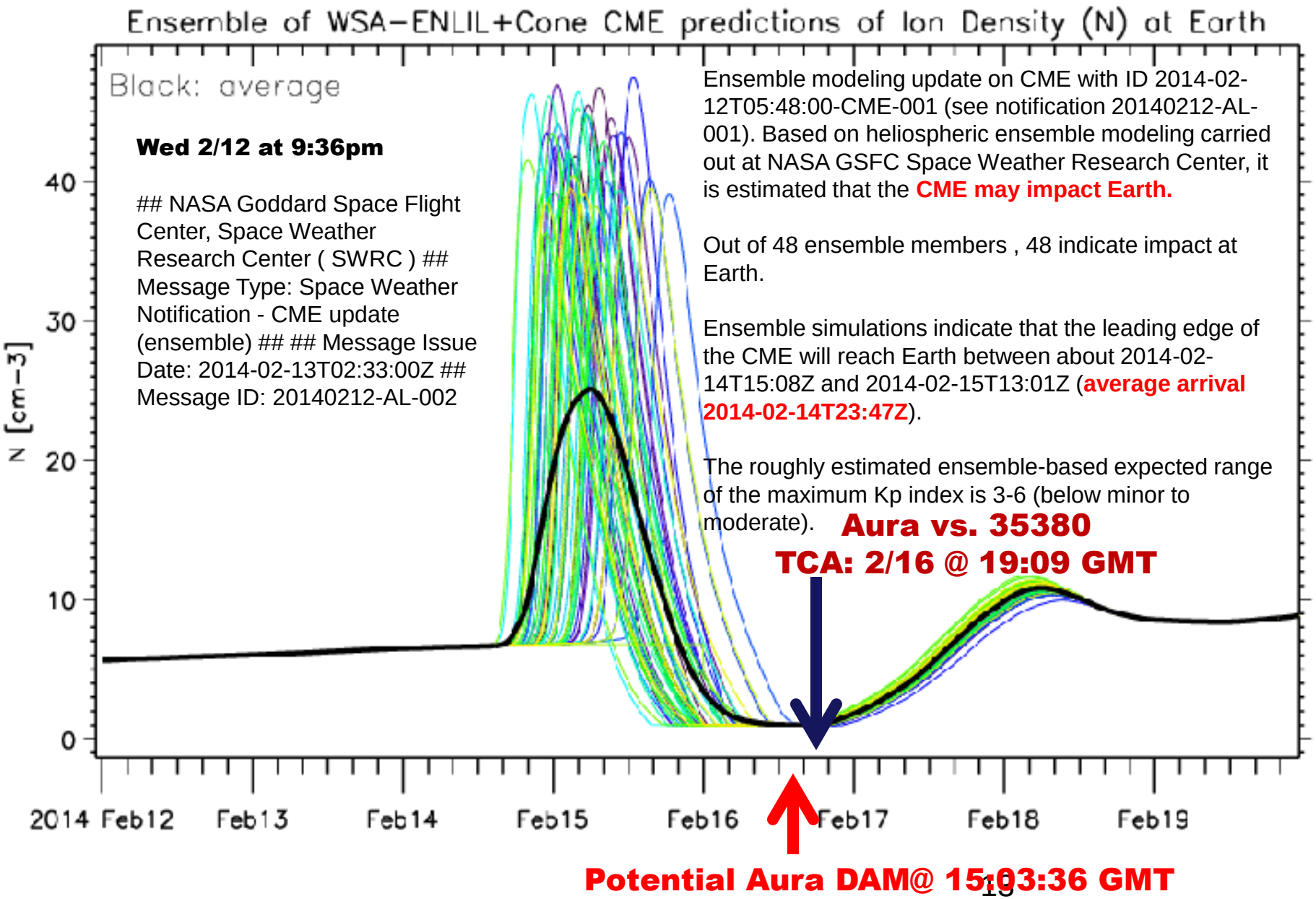




Aura DMUM #64 (Potential DAM) – Day 2

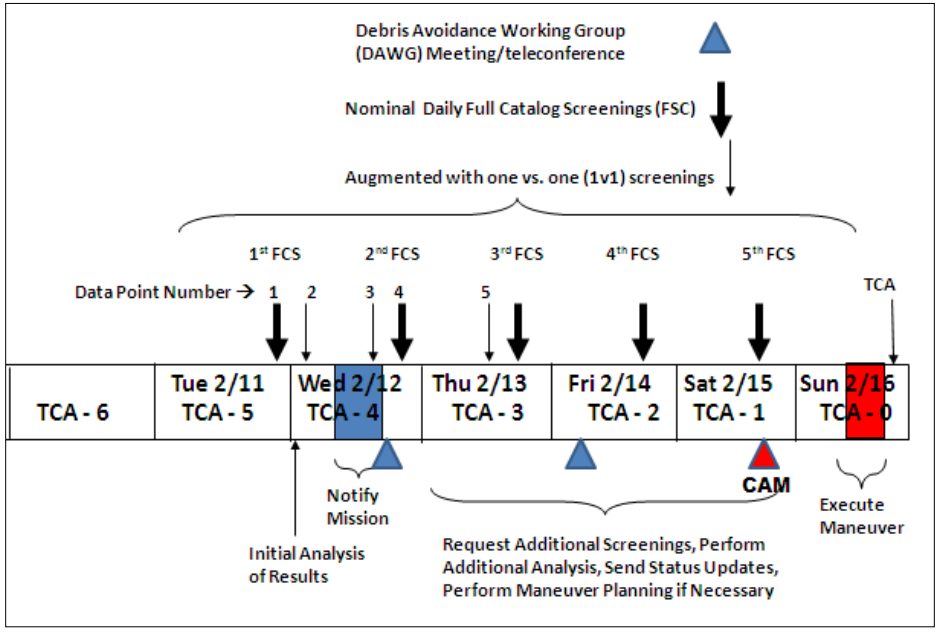
- Wed 2/12: 1:12am CARA Screening (1v1) – DP #2
  - Pc = 3.68E-04 (1:2717) – Screening Epoch 2/12 at 04:58 GMT
- **Wed 2/12: 9:30am CARA provided RMM Planning Maneuver Trade Space Plots and recommendations**
  - Secondary conjunction with 37343 (TCA 2/18 at 04:03:05 GMT), Pc = 1.52E-09 – NOT A CONCERN
  - CARA provided 8 potential maneuver options (5 on Sat 2/15, 3 on Sun 2/16) – recommends Sunday DAM
  - FOT/FDT focuses in on 15:03z (5.45 cm/sec) and 16:42z (5.35 cm/sec) options
  - FDT builds maneuver ephemeris files and delivers to CARA (CARA acknowledges receipt and sends to JSpOC)
- Wed 2/12: 1:53pm CARA Screening (1v1) – DP #3
  - Pc = 2.63E-04 (1:3802) – Screening Epoch 2/12 at 16:49 GMT
- Wed 2/12: 3:00pm **CARA provided full HIE briefing at DAWG #1 (based on 3 data points)**
  - Secondary object is moderately tracked (average of about 1.3 tracks per day – by single tracking station)
  - No new tracking with the DP #3 update
  - Position uncertainty is large as with the miss distances
  - Avoidance maneuver plans have been screened by the JSpOC and analyzed by the CARA team
  - No additional post-maneuver conjunctions of concern were identified in screening of S02 and S03 ephems
  - **RECOMMENDATION: Continue with RMM planning**
- Wed 2/12: 8:02pm CARA Screening (Full Catalog) – DP #4
  - Pc = 2.55E-04 (1:3922) – no (?) new tracking on secondary
- **Wed 2/12: 9:39pm GSFC, Space Weather Research Center (SWRC) Message**
  - **Type: Space Weather Notification - CME update (see next slide)**
  - **CME may impact Earth - average arrival 2/14 at about 23:47z (~ 30-hours prior to planned avoidance maneuver)**

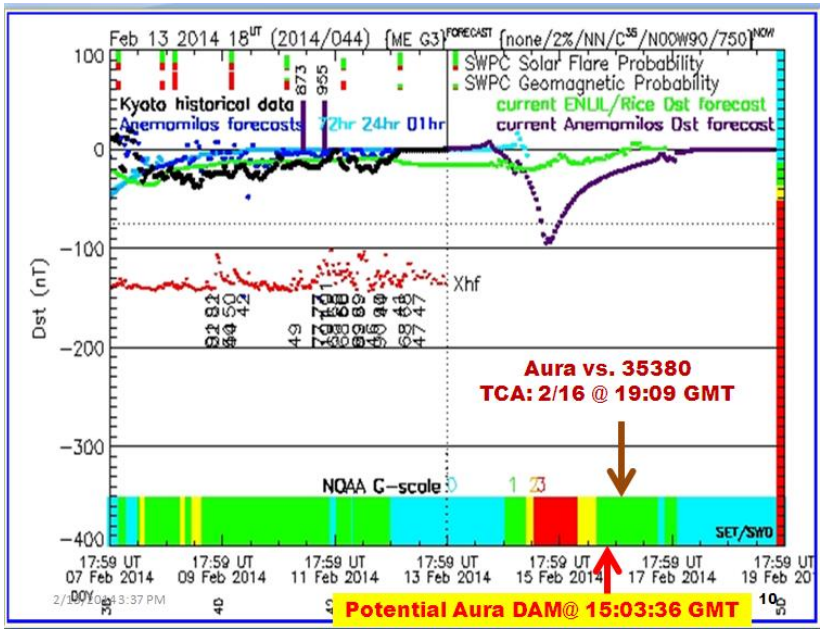
http://iswa.gsfc.nasa.gov/ENSEMBLE/2014-02-12_nc...



Aura DMUM #64 (Potential DAM) – Day 3

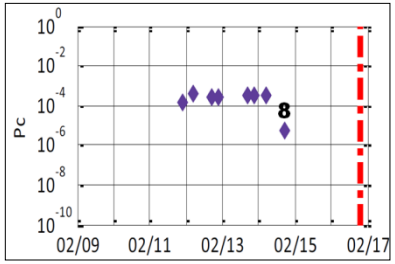
- Thu 2/13: 9:00am MD provides summary from DAWG #1 and plans for following the HIE
  - **GSFC Code Red**
- Thu 2/13: 12:49pm CARA Screening (1v1) – DP #5
  - Pc = 3.27E-04 (1:3058) – Screening Epoch 2/13 at 16:41 GMT – no (?) new tracking on secondary
  - **Radial miss component decreased from about 50 meters to about 11 meters**
  - Magnitude of the predicted Solar disturbance appears to be decreasing (based on predicted Dst values)
- Thu 2/13: 8:36pm CARA Screening (FCS) – DP #6
  - Pc = 3.27E-04 (1:3058) – Screening Epoch 2/13 at 23:23 GMT – no (?) new tracking on secondary
  - Miss distances essentially the same as the 16:41 GMT screening, Pc's identical





Aura DMUM #64 (Potential DAM) – Day 4

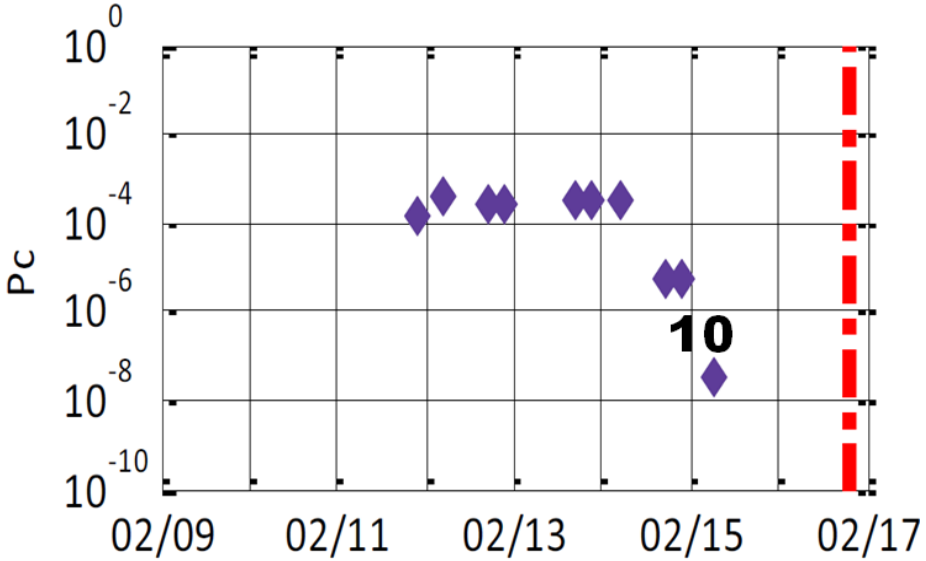
- Fri 2/14: 8:18am CARA provides email summary from the previous day's screenings
  - There has been no recent tracking on object 35380. The last track was the only new track that we've seen since the initial identification, which was around 00:00 UTC on 12 Feb (7 PM EST Tuesday night).
- Fri 2/14: 8:30am MD provides plans for following the HIE
  - Continue to monitor the conjunction – have a couple of viable maneuver options available if needed
  - Requested generation of additional options with smaller delta-v's - DAWG Meeting planned for 1pm
- Fri 2/14: 1:40am CARA Screening (1v1) – DP #7
  - Pc = 3.22E-04 (1:3106) – ASW Screening Epoch 2/14 at 04:38 GMT – no (?) new tracking on secondary
  - Radial miss component increased from about 11 meters to about 39 meters
- Fri 2/14: 12:56pm CARA provides full HIE briefing – contains little change since no new tracking
  - CARA reports recent tracking on object 35380 that will be in the next update – requests delay until 2pm
- Fri 2/14: 1:36pm CARA Screening (1v1) – DP #8
  - Pc = 5.19E-06 (1:193K) – ASW Screening Epoch 2/14 at 17:11 GMT – new tracking on secondary
- Fri 2/14: 2:00pm CARA provided full HIE briefing at DAWG #2 (based on 8 data points)
  - **Received new tracking with the DP #8 update**
  - **Position uncertainty has contracted somewhat with new tracking**
  - **Significant reduction in the risk level based on the single update**
  - MD would like to see additional consistent screenings
  - Will provide direction tomorrow morning by 8am
  - RECOMMENDATION: Continue with RMM planning

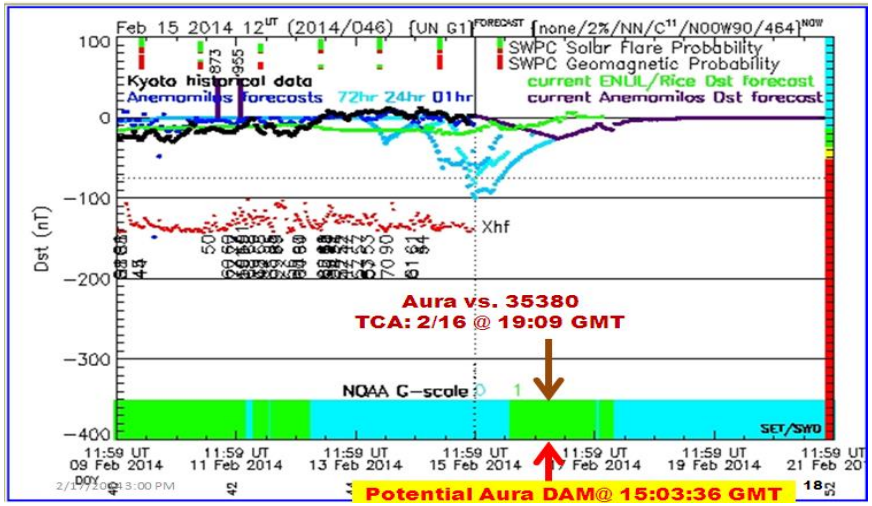


- Fri 2/14: 3:57pm Flight Dynamics delivers small delta-v maneuver ephemeris files to CARA
- Fri 2/14: 6:00pm CARA indicates JSpOC screening of new ephemeris files came back clean
- Fri 2/14: 9:13pm CARA Screening (FCS) – DP #9
  - Pc = 5.55E-06 (1:180K) – ASW Screening Epoch 2/14 at 23:37 GMT – no (?) new tracking on secondary
  - Miss distances and Pc very similar to data point #8

Aura DMUM #64 (Potential DAM) – Day 5

- Sat 2/15: 2:31am CARA Screening (FCS) – DP #10
  - Pc = 3.12E-08 (1:32M) – ASW Screening Epoch 2/15 at 06:00 GMT – new tracking on secondary (???)
  - Radial miss component increases to about 73 meters from about 33 meters for DP#9
  - Magnitude of the predicted Solar disturbance dropped off (based on predicted Dst values)





- **Sat 2/15: 8:00am MD waives off further maneuver planning**
- Sat 2/15: 12:24pm CARA email
  - 06:00Z result did NOT include new tracking. The decreased Pc from the nominal delivery is likely due to the increased miss prediction in the additional run.
- Sat 2/15: 4:55pm CARA Screening (1v1) – DP #11
  - Pc = 9.54E-08 (1:10M) – ASW Screening Epoch 2/15 at 20:15 GMT – new tracking on secondary (TBC)
  - Radial miss component increases to about 73 meters from about 33 meters for DP#9

Aura DMUM #64 (Potential DAM) – Day 5

- Sun 2/16: 2:31am CARA Screening (1v1) – DP #12
  - Pc = 8.14E-08 (1:12M) – ASW Screening Epoch 2/16 at 02:54 GMT – no (?) new tracking on secondary (TBC)
  - Total miss distance of about 6.4km
- Sun 2/16: 12:53pm CARA Screening (1v1) – DP #13
  - Pc = 0, ASW Screening Epoch 2/16 at 16:37 GMT – no (?) new tracking on secondary (TBC)
  - Total miss distance of about 8.2km