THE CLOUDSAT ANOMALY AND RETURN TO THE A-TRAIN:

LESSONS LEARNED FOR SATELLITE CONSTELLATIONS

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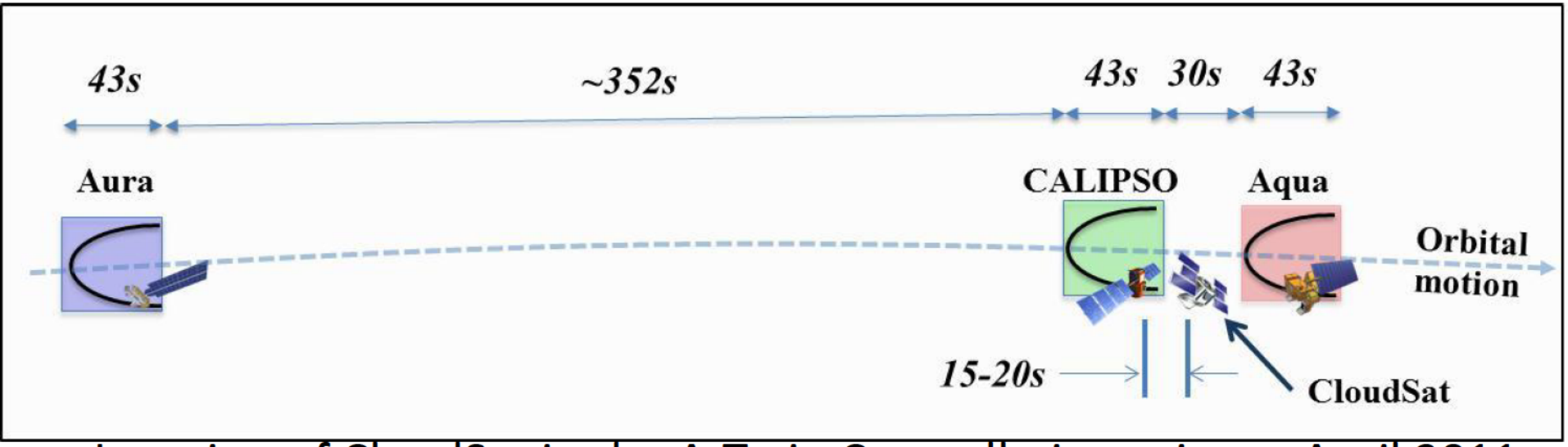
Background

- CloudSat launched in April 2006, carrying a Cloud Profiling Radar
  - Measures the vertical structure of clouds and their moisture content
- CloudSat is part of NASA's Afternoon Constellation ("A-Train")
  - A group of Earth-observing satellites covering the same ground track
  - Crosses the equator at about 13:30 local time every orbit
  - Concurrent observations from multiple instruments on multiple satellites allows for greatly increased science return
  - CloudSat was initially positioned **17 along-track seconds** in front of CALIPSO
- Each A-Train satellite flies within its own 'control box' and is governed by a set of agreements and procedures developed through the A-Train Constellation Coordination Group.



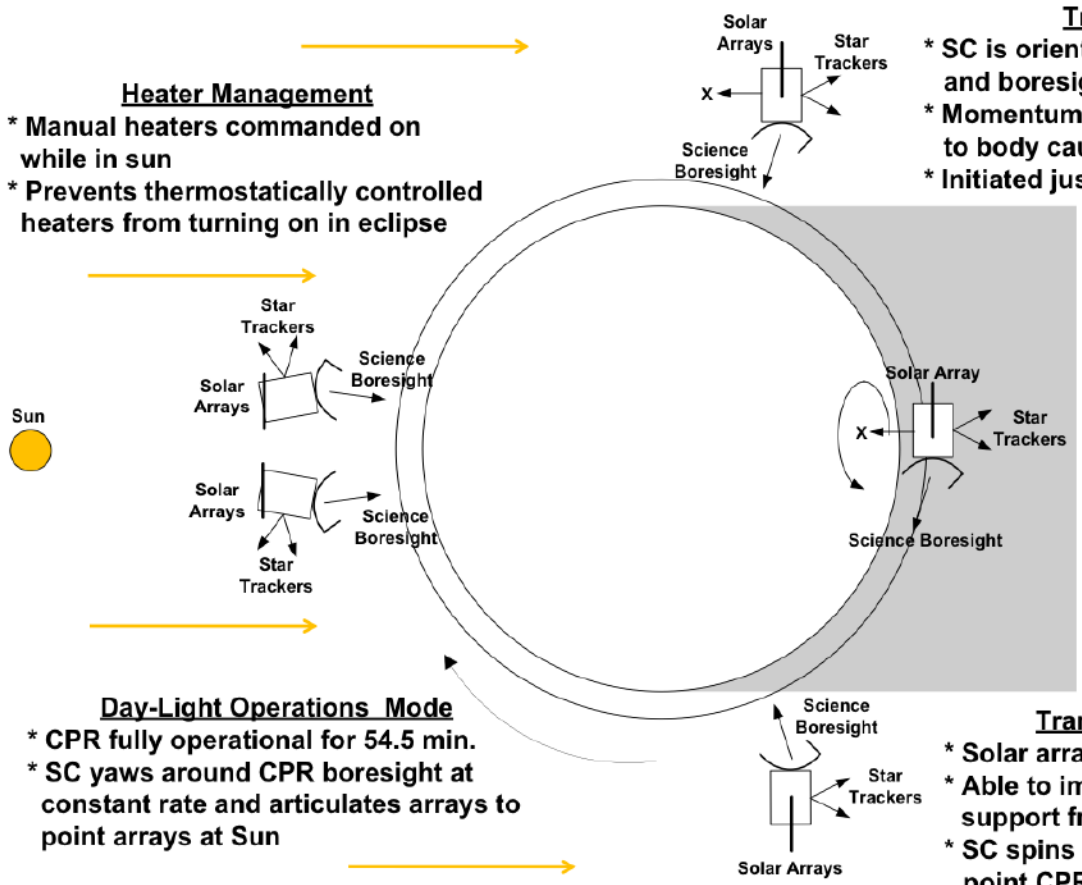
Location of CloudSat in the A-Train Constellation prior to April 2011

CloudSat's Battery Anomaly and Recovery Timeline

- On 18 April 2011, CloudSat experienced a sudden, significant decrease in battery performance and the vehicle entered its highest level of undervoltage fault protection (UV-3)
  - CloudSat was not commandable nor maneuverable and was drifting slowly toward Aqua.
  - Aqua prepared for a possible evasive maneuver.
- On 18 June 2011, CloudSat managed to bring the spacecraft computer on-line and execute a burn to exit the A-Train.
- Over the next months, as CloudSat orbited under the A-Train, the CloudSat spacecraft team at Ball Aerospace developed a new mode of operation: Daylight-Only Operations (DO-Op!)

DO-Op movie

DO-Op (Daylight Only Operations)



Heater Management

* Manual heaters commanded on while in sun
* Prevents thermostatically controlled heaters from turning on in eclipse

Transition to Hibernate

* SC is oriented with Y-axis normal to Sun and boresight pointed at Nadir
* Momentum stored in wheels is transferred to body causing SC to spin around X-axis
* Initiated just prior to eclipse entrance

Hibernate

* Nearly all loads shed including Attitude Control System
* Very low power consumption
* Battery easily supports loads through eclipse
* Spin stabilization maintains SC attitude with respect to the Sun

Day-Light Operations Mode

* CPR fully operational for 54.5 min.
* SC yaws around CPR boresight at constant rate and articulates arrays to point arrays at Sun

Transition to Operations Mode

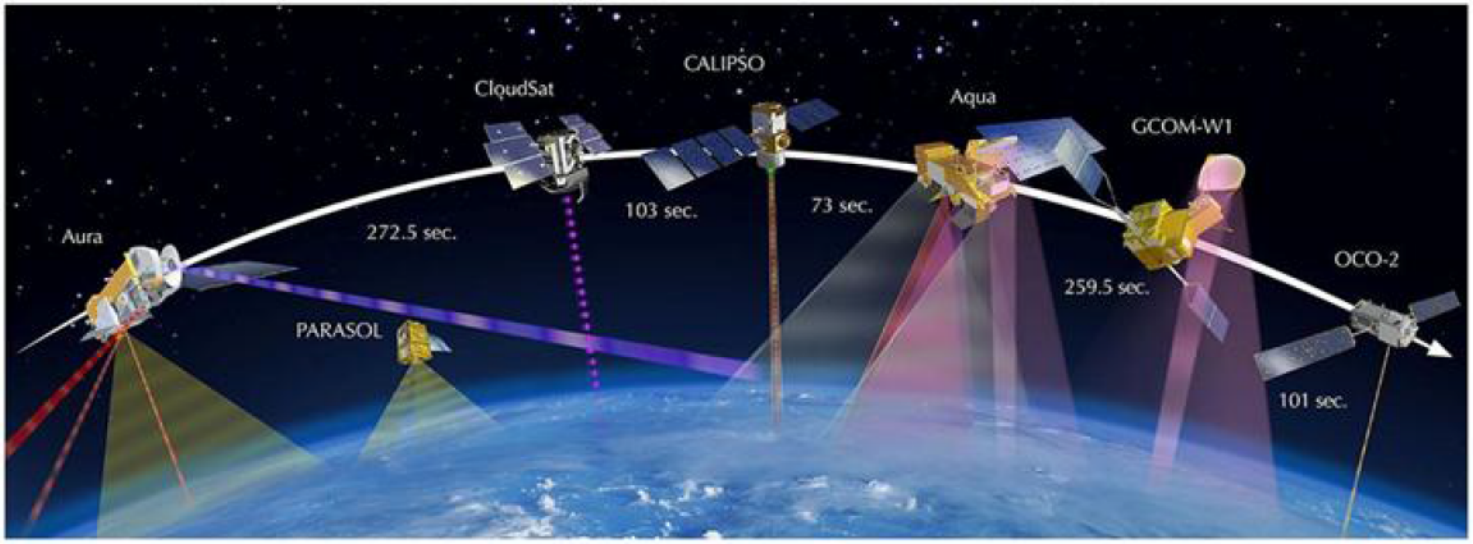
* Solar array is pointed at Sun at eclipse exit
* Able to immediately start recovery without support from battery
* SC spins down and maneuvers to point CPR boresight at nadir

Should CloudSat re-enter the A-Train?

- By October 2011, the team had successfully demonstrated DO-Op as a robust operating mode.
- CloudSat considered 3 options:
  1. Orbit under the A-Train? **– loss of continuous co-incident observations with CALIPSO and MODIS.**
  2. Move to the terminator orbit? -**- eliminated due to the unfavorable thermal environment for the spacecraft at the terminator**
  3. Return to the A-Train? - **MOST DESIRABLE OPTION**
- CloudSat requested permission from NASA and from the A-Train members to return to the A-Train.
- Due to the nature of CloudSat's UV-3 response and the weakened battery, the A-Train MOWG asked CloudSat to take a new position in the A-Train behind CALIPSO and in front of Aura.

CloudSat's Return to the A-Train

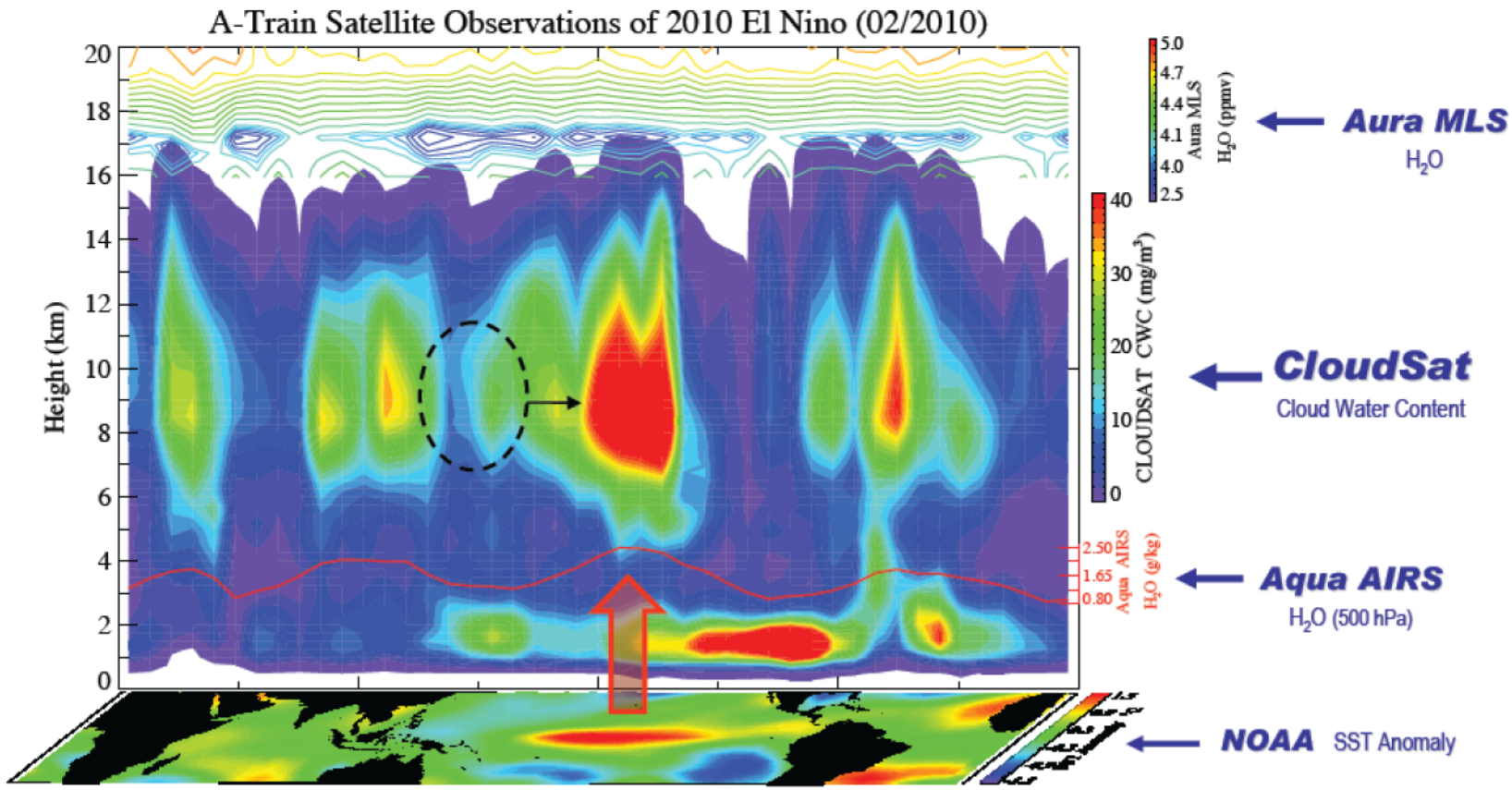
- Following the A-Train exit, CloudSat's orbit was lower than that of CALIPSO and the rest of the A-Train
- CloudSat's position was drifting with respect to A-Train
- CloudSat was completing a circuit and passing underneath the A-Train once every ~60 days
- The first attempt to return to the A-Train in February 2012 failed due to a blinded star tracker.
- Very challenging re-planning took place, and CloudSat was able to re-enter the A-Train in May 2012, prior to the GCOM-W1 launch, which was a complicating factor.
- CloudSat has been operating successfully in this new A-Train position since May 2012 and continues to formation-fly with CALIPSO.



Location of CloudSat in the A-Train after May 2012

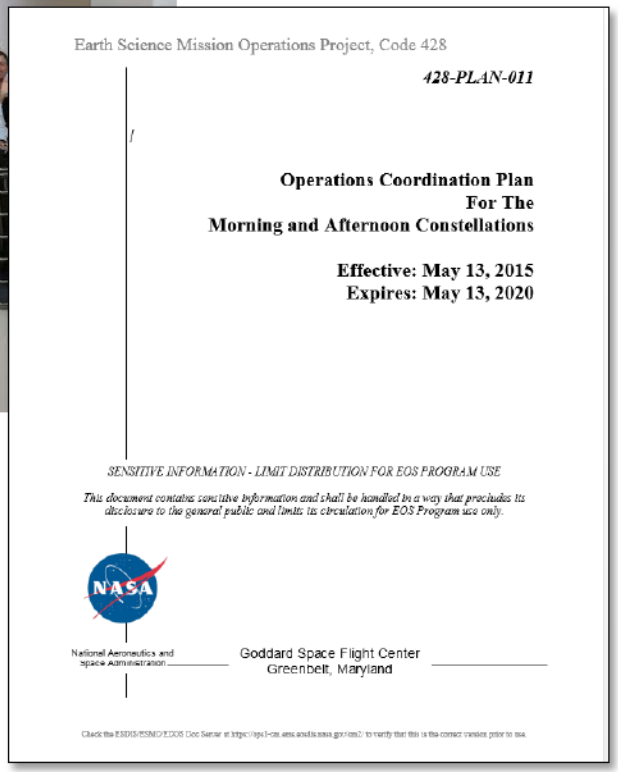
Lessons Learned?

1. Constellations are good for science and worth the challenges and risks



Hui Su et al, 2011

2. A coordination group such as the A-Train MOWG is essential for developing agreements and procedures.



Earth Science Mission Operations Project, Code 428

428-PLAN-011

Operations Coordination Plan
For The
Morning and Afternoon Constellations

Effective: May 13, 2015
Expires: May 13, 2020

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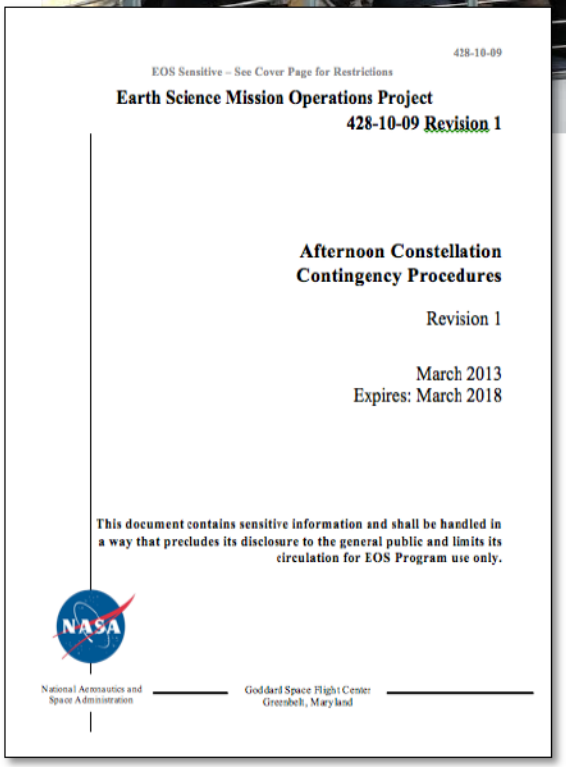

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Earth Science Mission Operations Project
428-10-09 Revision 1

Afternoon Constellation
Contingency Procedures

Revision 1

March 2013
Expires: March 2018

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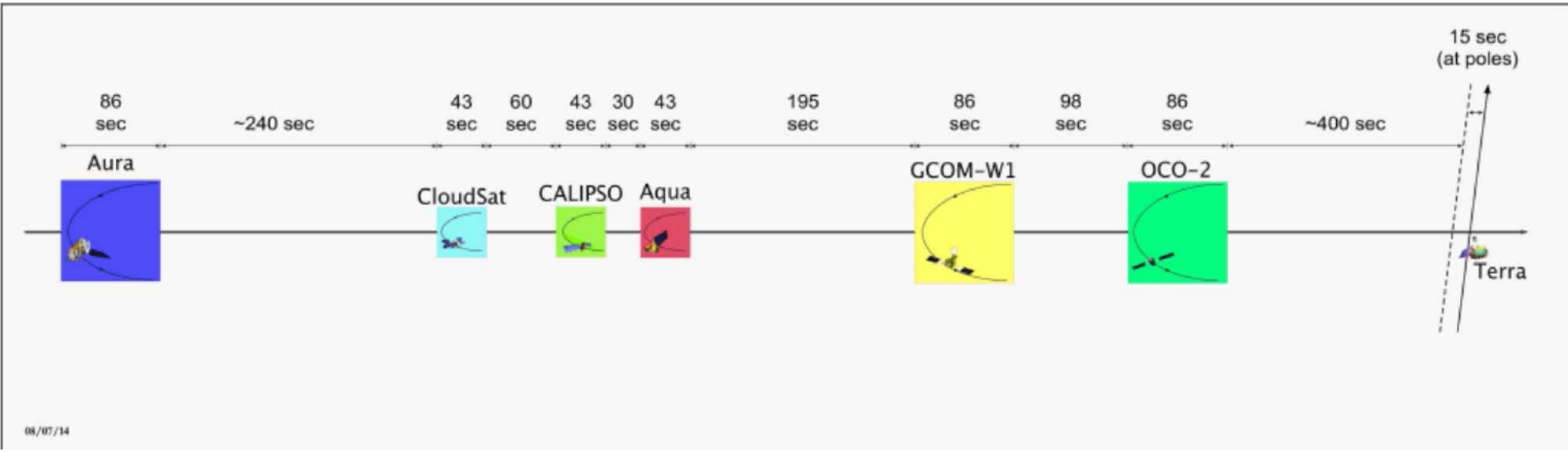
3. Pre-agreed-to contingency procedures provide an extra measure of safety when anomalies happen.

4. Control boxes have proved their value in constellation architecture.



They allow autonomy of operations, while defining limits on excursions.

The Constellation Control System (CCS) is a web-based warning system that communicates to all members of the constellation a control box violation or a satellite operations anomaly.

5. Leaving a constellation deserves as much thought and planning as entering a constellation, although it usually isn't considered until long after the constellation is created.

- Following the return to the A-Train, CloudSat established performance criteria for A-Train exit and we have loaded the A-Train exit burns into spacecraft memory to facilitate quick execution.
- CloudSat's unique DO-Op mode and daylight-only burns have made the exit-burn strategy even more challenging.

<u>Don't wait until something happens to start planning for contingencies!</u>

Thank you for your attention.