



CALIPSO – CLOUDSAT
Ten-Year Progress Assessment and Path Forward
8 – 10 June 2016



The A-Train Constellation

9 June 2016

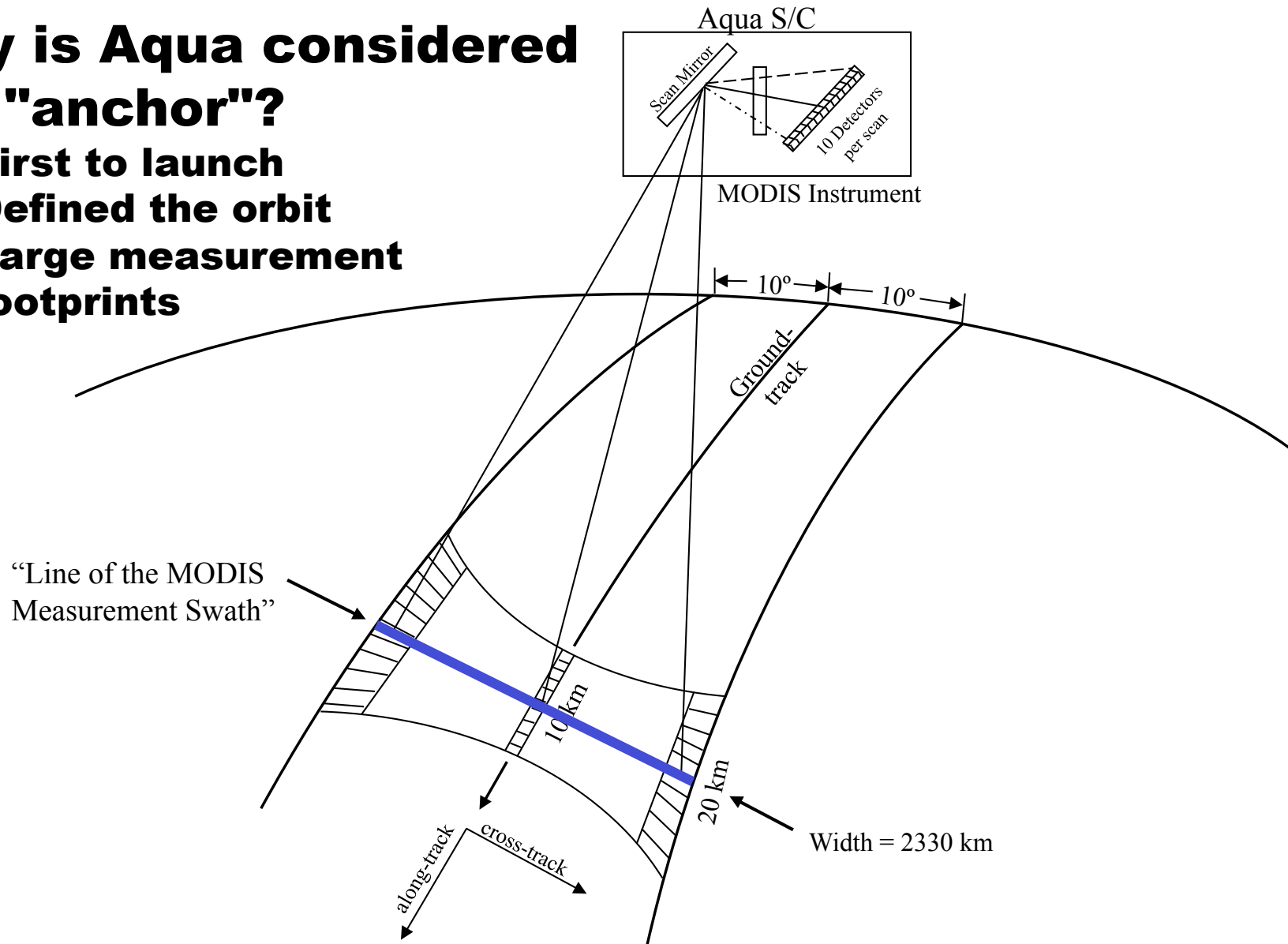
Ronald Boain
JPL/Caltech/NASA

What's in a Name?

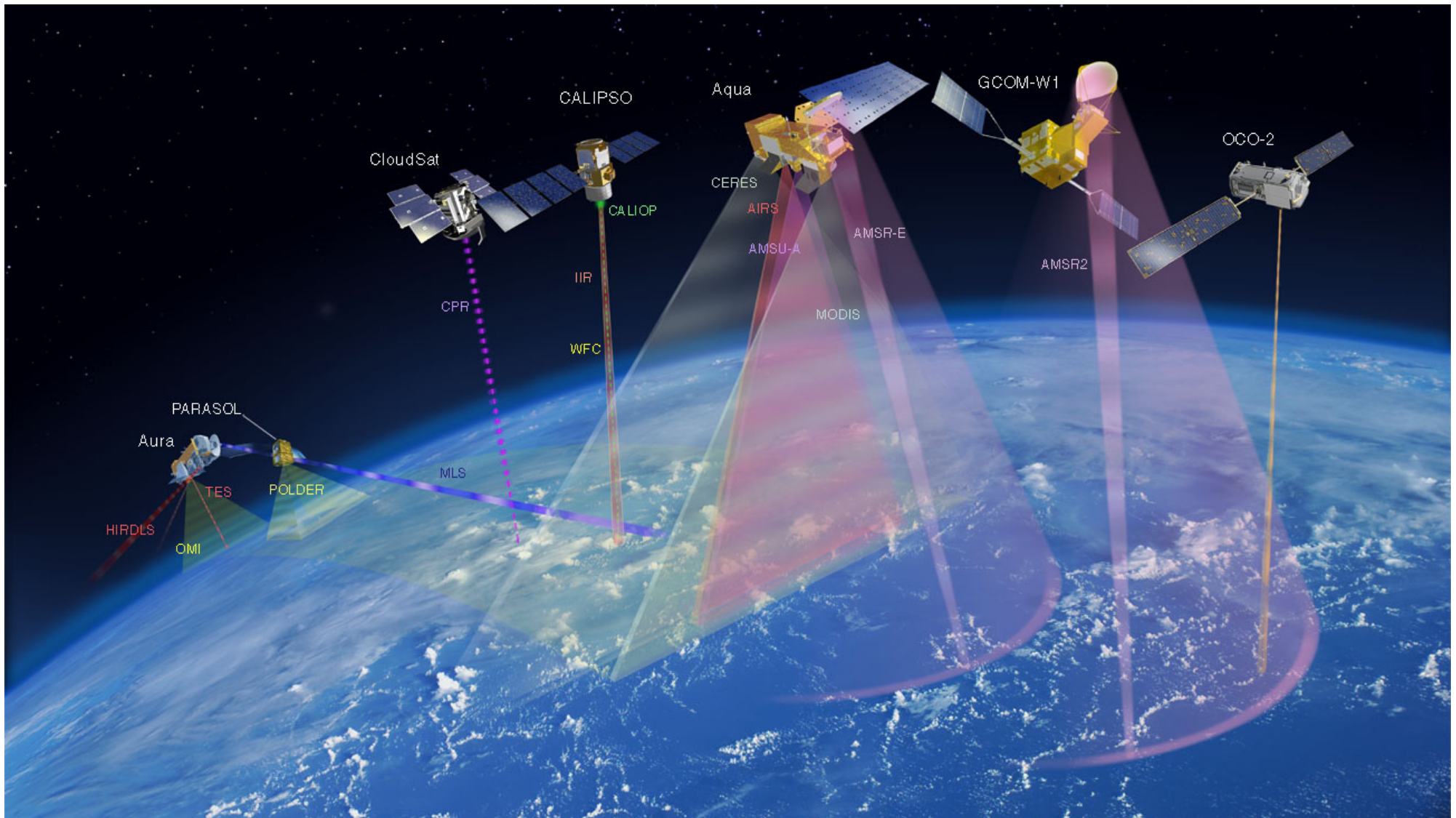
- The A-Train Constellation is known by several names:
 - P. M. Constellation
 - P. M. stands for post meridiem giving reference to the Mean Local Time of the Ascending Node occurring after the noon meridian as contrasted with the A. M. (ante meridiem) Constellation, a.k.a. the Morning Constellation
 - Afternoon Constellation or A-Train Constellation
 - Most often and simply: "The A-Train"
- The A-Train is a collection of six satellites from three countries all moving in nearly the same orbit plane with very close to the same orbital period, all with the objective of making earth science measurements
 - Starting at the front, the satellites are: OCO-2, GCOM W-2, Aqua, CALIPSO, CLOUDSAT, and Aura
 - PARASOL is recognized as a former, charter member of the A-Train now orbiting below and no longer a part of the constellation
 - All are lined up on orbit, one after another
 - Aqua is considered the A-Train "anchor"

Why is Aqua considered the "anchor"?

1. First to launch
2. Defined the orbit
3. Large measurement footprints



A-Train Science Graphic



Constellation History

- The **A-Train Constellation** began with the Aqua launch in May 2002, followed by Aura in July 2004, PARASOL in December 2004, and the joint CALIPSO/CloudSat launch in April 2006 ("formation flying")
- The **A-Train Mission Operations Working Group (MOWG)** was formed and officially met for the first time in March 2003, preceded by exploratory discussions between LaRC (John Stadler and the CALIPSO Team) and GSFC (Angie Kelly, Bill Guit and Lauri Newman) in 2002
- **Later A-Train missions followed:**
 - **OCO (2010) and Glory (2011)** launches failed due to launch vehicle fairing problems
 - **GCOM-W1** successfully launched in May 2012
 - **OCO-2** successfully launched in July 2014
- The **A-Train Mission Operations Working Group** remains open to overtures by space-fairing nations interested in pursuing earth science to joining the A-Train in the future

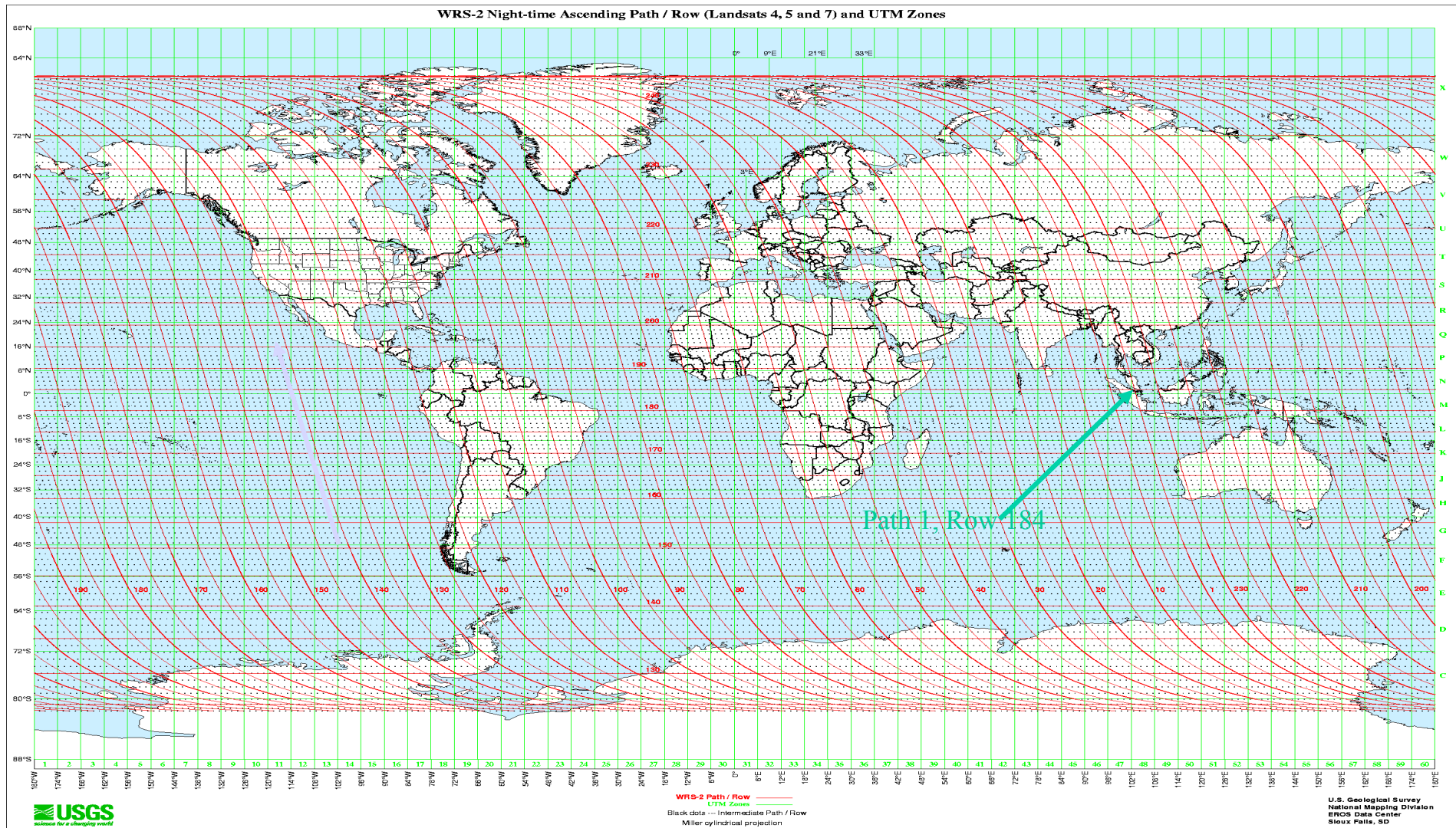
A-Train Purpose

The Constellation enables its member satellites to make near simultaneous scientific observations and to share those observations with each other by coordinating their operations and cooperating with one another to ensure safe operations of the whole constellation

The A-Train Orbit

- Repeat groundtrack: 233 revs in exactly 16 days
 - This property sets the period and semi-major-axis
 - The constellation overflies the WRS-2 reference groundtrack grid
 - ≈ 180 km between each ascending node (and descending node)
 - Path 1 Longitude for the Ascending nodes is at 103.0395° east longitude
- Sun-Synchronous: 705 km equatorial altitude, 98.2° inclination
 - Mean Local Time of Ascending Nodes centered on $\approx 13:30$ hours
 - MLTAN for the other A-Train satellites differ with values before or after the above value according to the separation between their respective control boxes
 - The orbits are frozen; this means they are very close to circular

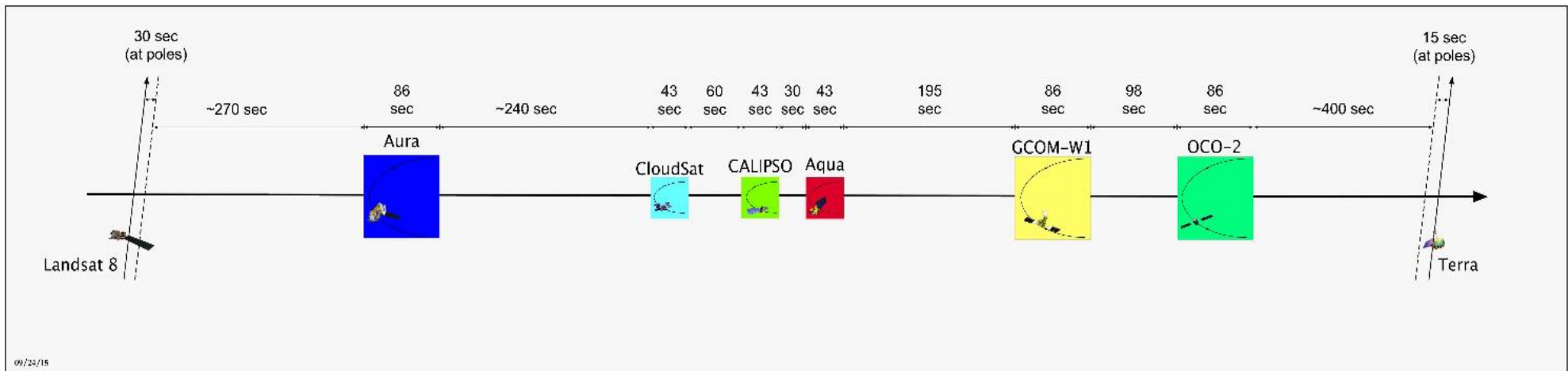
WRS-2 Reference Groundtrack Grid (AN)



The Control Box

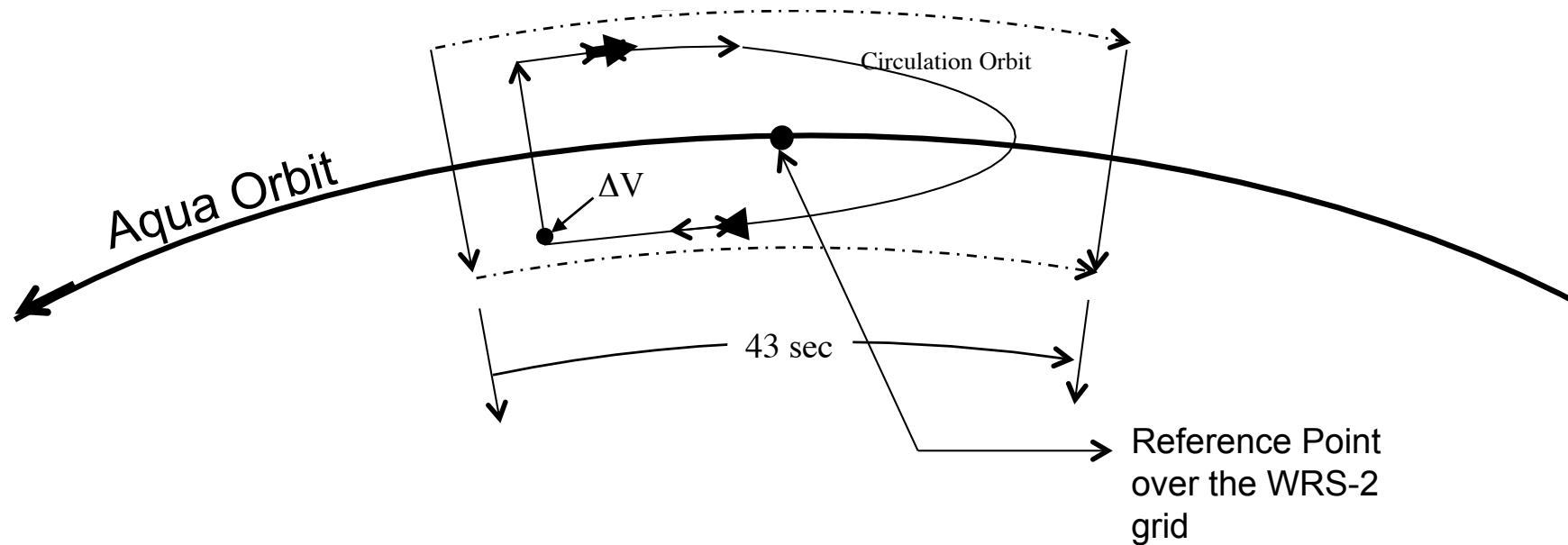
- The concept that allows each mission to operate its satellite independently and still provide safety to the operations of all constellation satellites is the "control box"
- Each satellite is subject to a drag force due to the thin atmosphere at the orbit's altitude (705 km)
 - This drag force will eventually cause the orbit to decay and re-entering the atmosphere (≈ 100 yrs or more)
- The along-track positions of satellite's control boxes are defined with respect to a reference position on the orbit relative to Aqua's reference position; this is another reason Aqua is called the A-Train anchor
- Carefully designed Drag-Make-Up maneuvers are used to periodically lift the orbit and maintain the natural along-track motion of a satellite within its "control box"

Afternoon Constellation Current Orbital Configuration (A Control Box Map)

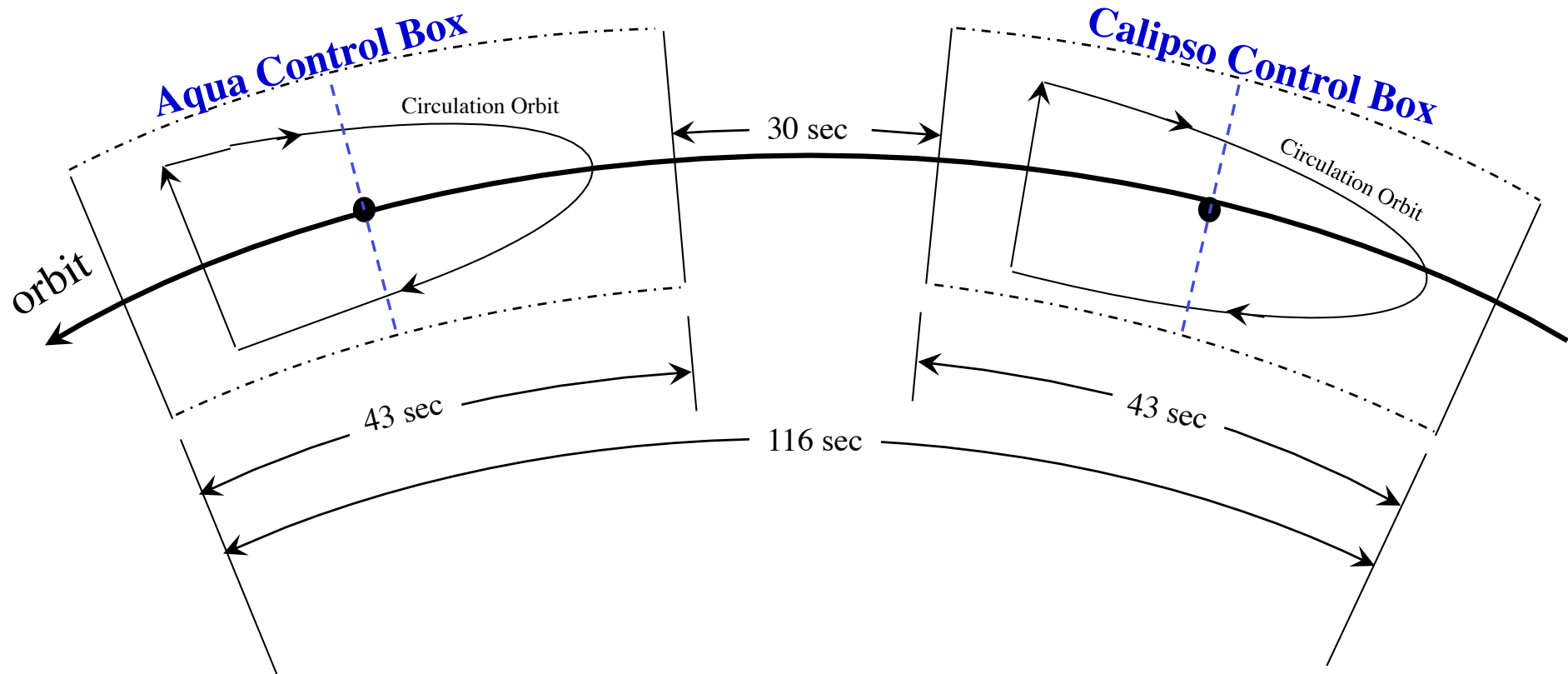


Note: This figure was updated in September 2015 to show the available spaces at the front and back ends of the constellation.

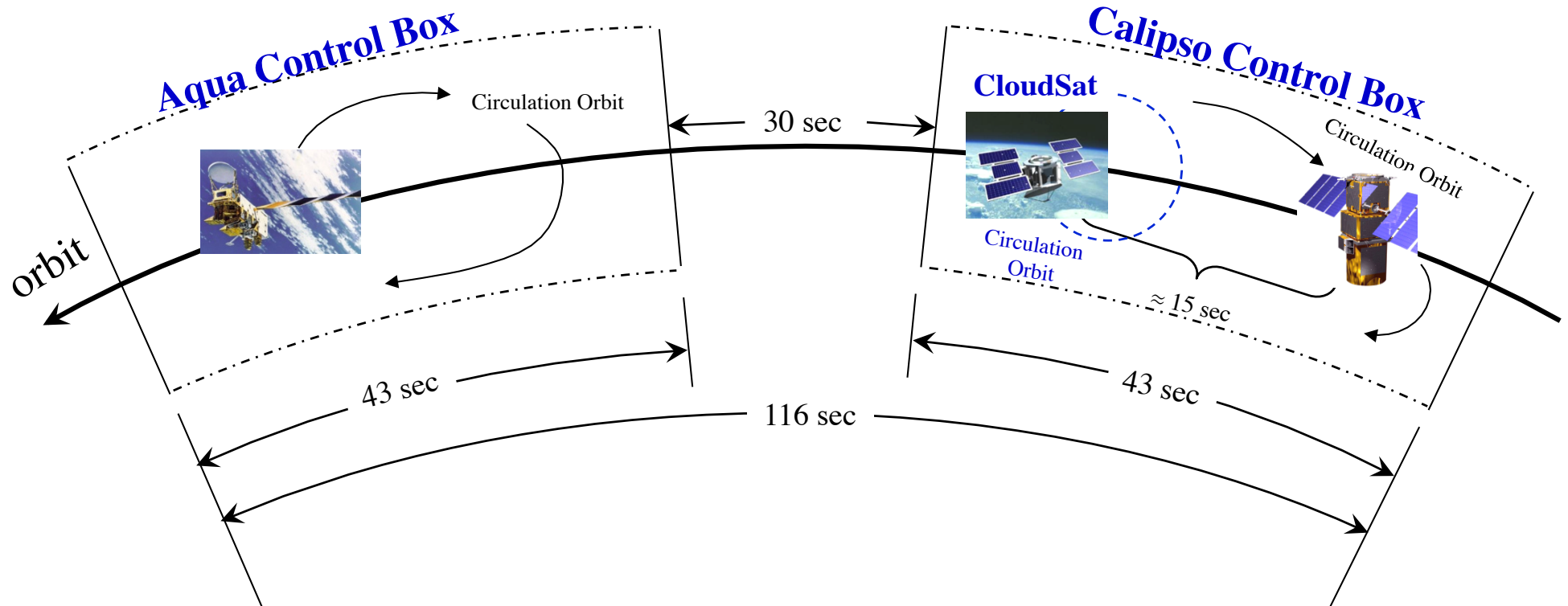
Aqua's Control Box



Aqua's control box is defined to be ± 10 km cross-track with respect to the WRS-2 groundtrack grid and ± 22 seconds along-track with respect to the Reference Point. Spacecraft propulsive maneuvers at the ΔV point shown raise the semi-major axis a few tens of meters and re-initialized the motion around the circulation orbit.



Aqua and CALIPSO shown constellation flying with each moving along a circulation orbit constrained inside their respective control boxes. With this arrangement, CALIPSO is never more than 118 seconds behind Aqua.



CALIPSO and CLOUDSAT shown in their original formation configuration (before April 2011). Aqua leads. CALIPSO follows but maintains its motion independent of Aqua within its control box. CloudSat follows a small circulation orbit, ± 2.2 seconds along-track, positioned ≈ 15 seconds in front of CALIPSO, formation flying.

The Real A-Train

The men and women who coordinate and operate each of the A-Train satellites, i.e., the MOWG members who make it work

Early MOWG Meetings



**MOWG meeting
Hampton, Virginia
March 2004**

- **March 2003** NASA Goddard
- **May 2003** Technical interface meeting at CNES
- **March 2004** Near NASA Langley in Hampton, VA
- **June 2004** NASA JPL



Constellation Mission Operations Working Group (MOWG)
Meeting
Boulder, Colorado
April 12-14, 2016



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The End