CubeSat Laser Communication Crosslink Pointing Demonstration

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The Aerospace Corporation

6 August 2019

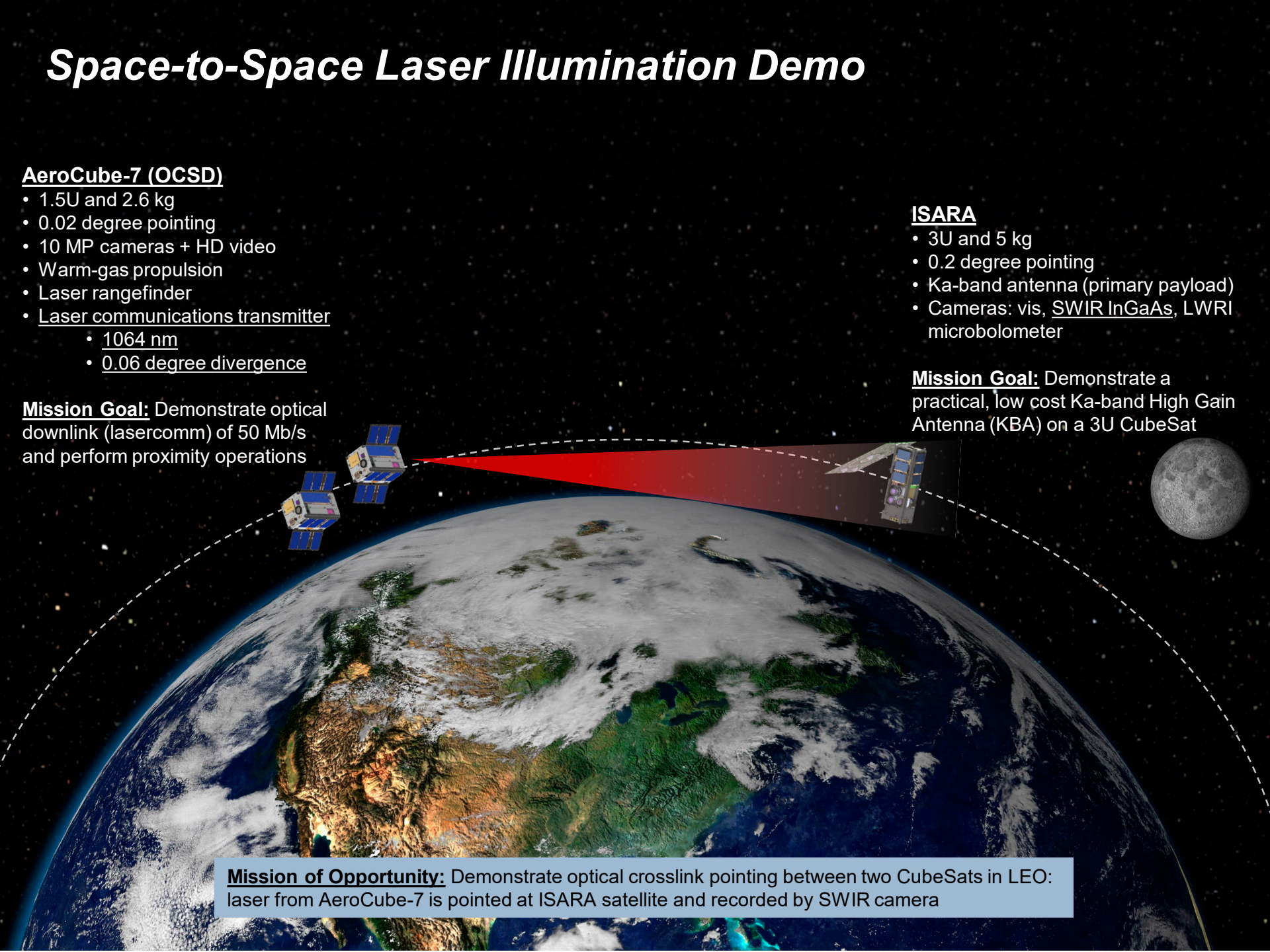
Space-to-Space Laser Illumination Demo

AeroCube-7 (OCSD)
- 1.5U and 2.6 kg
- 0.02 degree pointing
- 10 MP cameras + HD video
- Warm-gas propulsion
- Laser rangefinder
- Laser communications transmitter
  - 1064 nm
  - 0.06 degree divergence

Mission Goal: Demonstrate optical downlink (lasercomm) of 50 Mb/s and perform proximity operations

ISARA
- 3U and 5 kg
- 0.2 degree pointing
- Ka-band antenna (primary payload)
- Cameras: vis, SWIR InGaAs, LWRI microbolometer

Mission Goal: Demonstrate a practical, low cost Ka-band High Gain Antenna (KBA) on a 3U CubeSat

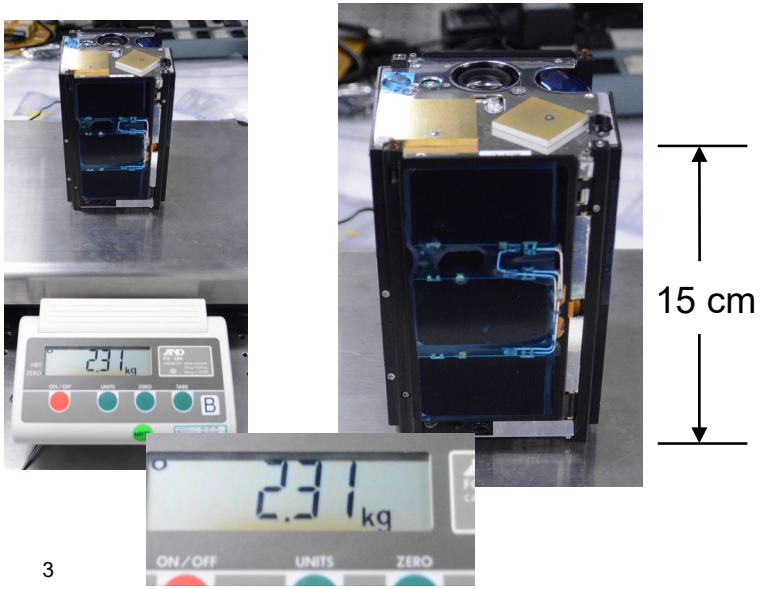


Mission of Opportunity: Demonstrate optical crosslink pointing between two CubeSats in LEO: laser from AeroCube-7 is pointed at ISARA satellite and recorded by SWIR camera

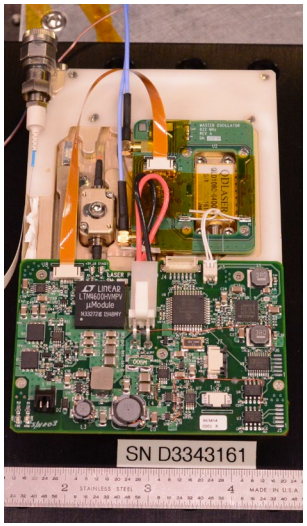
Why Laser Communication?

- Potential to reduce complexity and mass of space-based communication networks
  - *Enabler for CubeSat-scale, low-cost, high-density LEO relay network*
- Previous demonstrations of space-based laser communication used terminals with a mass of ~30 kg and cost in excess of $20M per terminal
  - *Much of the cost is in the two-axis pointing system*
  - *Far too massive and expensive for high-density LEO constellation*
- Current optical systems rely on GEO relay to get signal to ground
  - *Requires massive/expensive terminal on LEO satellites to reach GEO*
- Body pointing presents a simple, low-cost, alternative to two-axis gimbal systems

OCSD



CubeSat laser terminal



OPAL laser terminal

NASA Photo

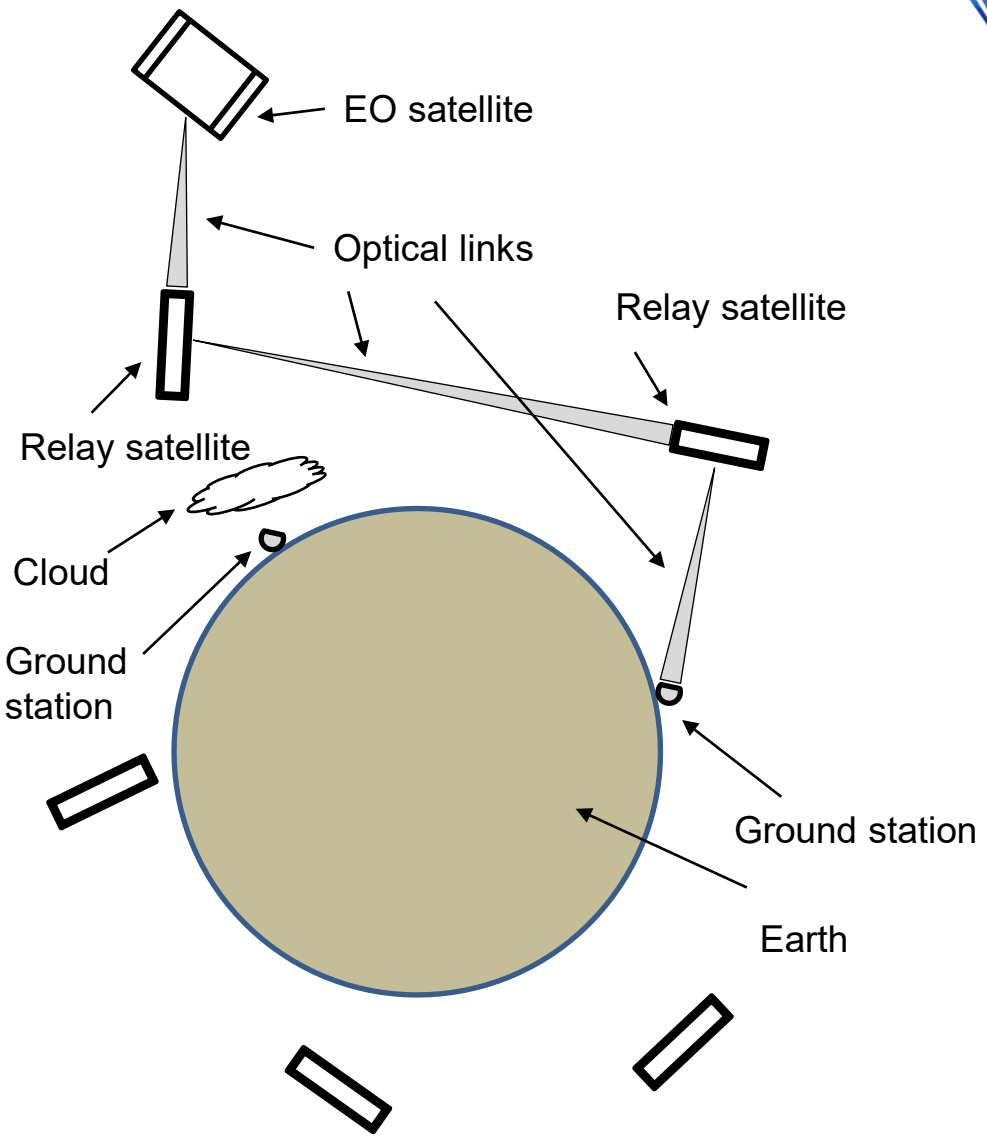
Why Crosslinks?

Applications

- High-volume, short-range download from satellites in LEO
- Low-latency download from satellites in LEO
- Low-latency Earth-to-space-to-Earth data transfers

Requirements

- Lasers
- Detectors
- Pointing and tracking
- Data handling/management



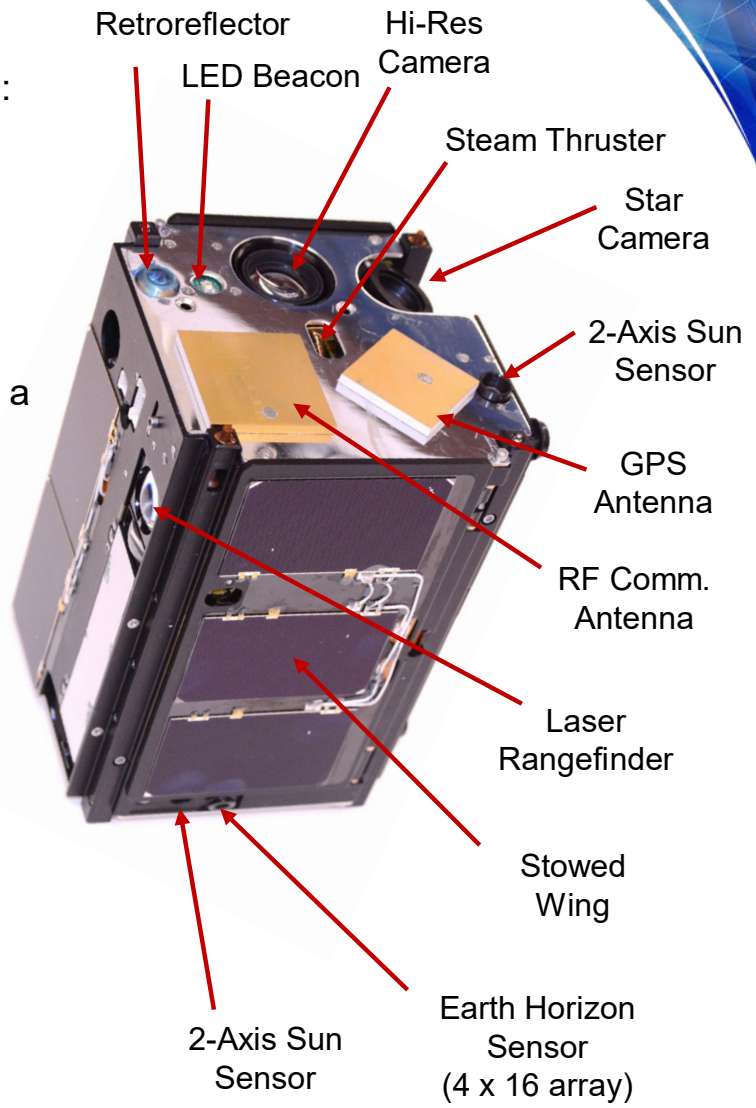
Optical Communication and Sensor Demonstration (OCSD)

Laser Downlinks and Proximity Operations

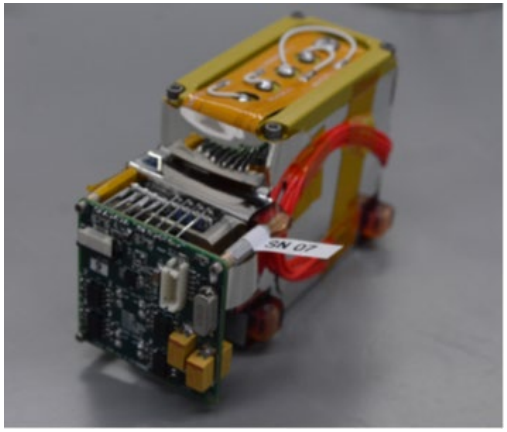
Two 1.5-unit CubeSats launched in November 2017 with five goals:

(Achieved) (In progress)

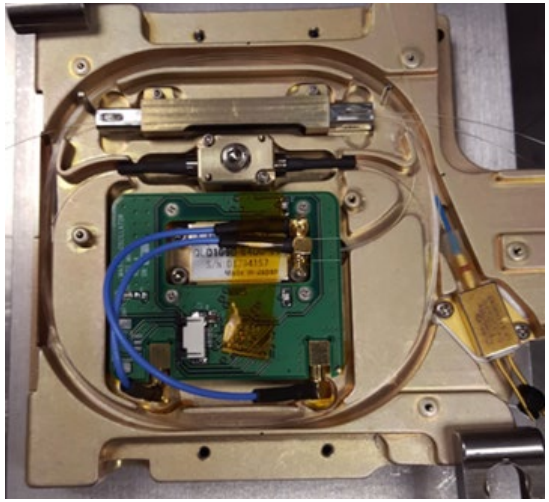
- Demonstrate optical communications from a CubeSat to a ground station from low Earth orbit at rates between 5 and 50 Mb/s (actual result was 200 Mb/s)
- Demonstrate relative maneuvering to within 200 meters
- Demonstrate tracking of a nearby cooperative spacecraft using a commercial off-the-shelf (COTS) laser rangefinder
- Demonstrate orbit control using variable drag
- Demonstrate propulsive orbit control using a steam thruster



Steam Thruster



Communications Laser

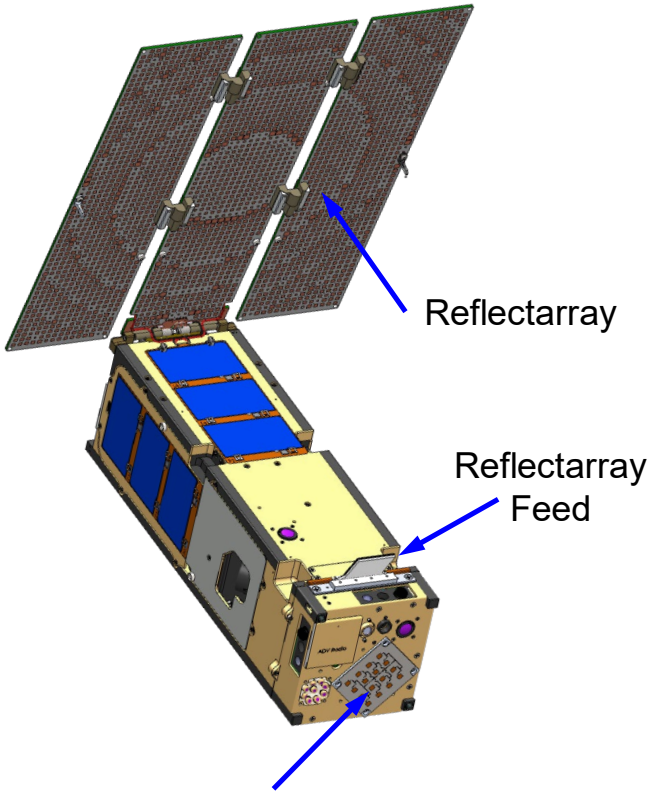


OCSD is supported through NASA's Small Spacecraft Technology Program

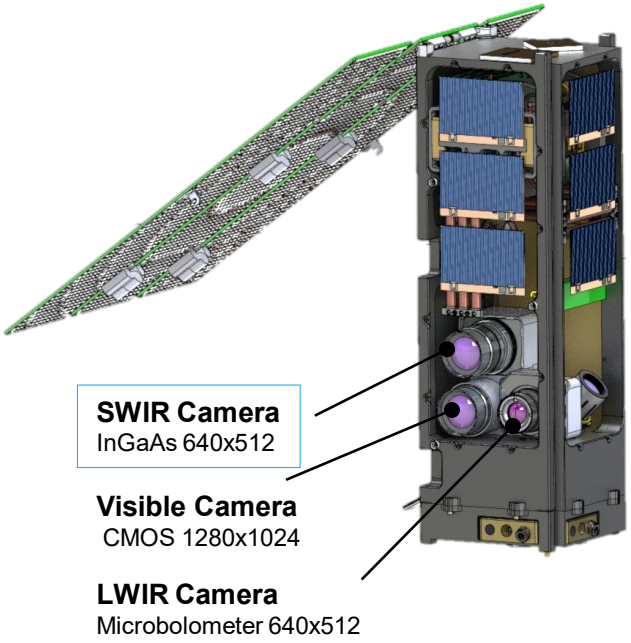
Integrated Solar Array and ReflectArray (ISARA)

A CubeSat with a hosted payload

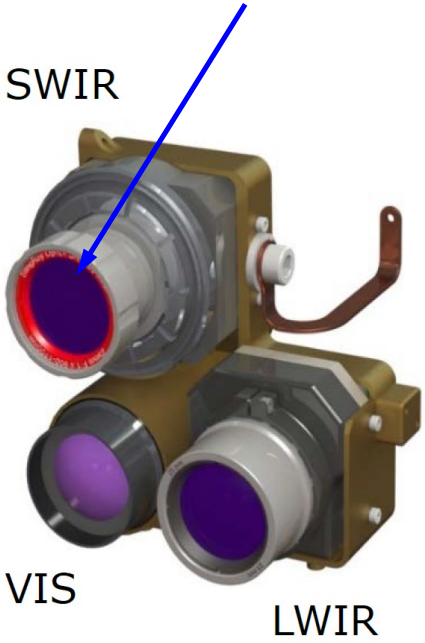
Primary Mission: Ka-band communications



Hosted Payload: CubeSat Multispectral Observation System (CUMULOS)

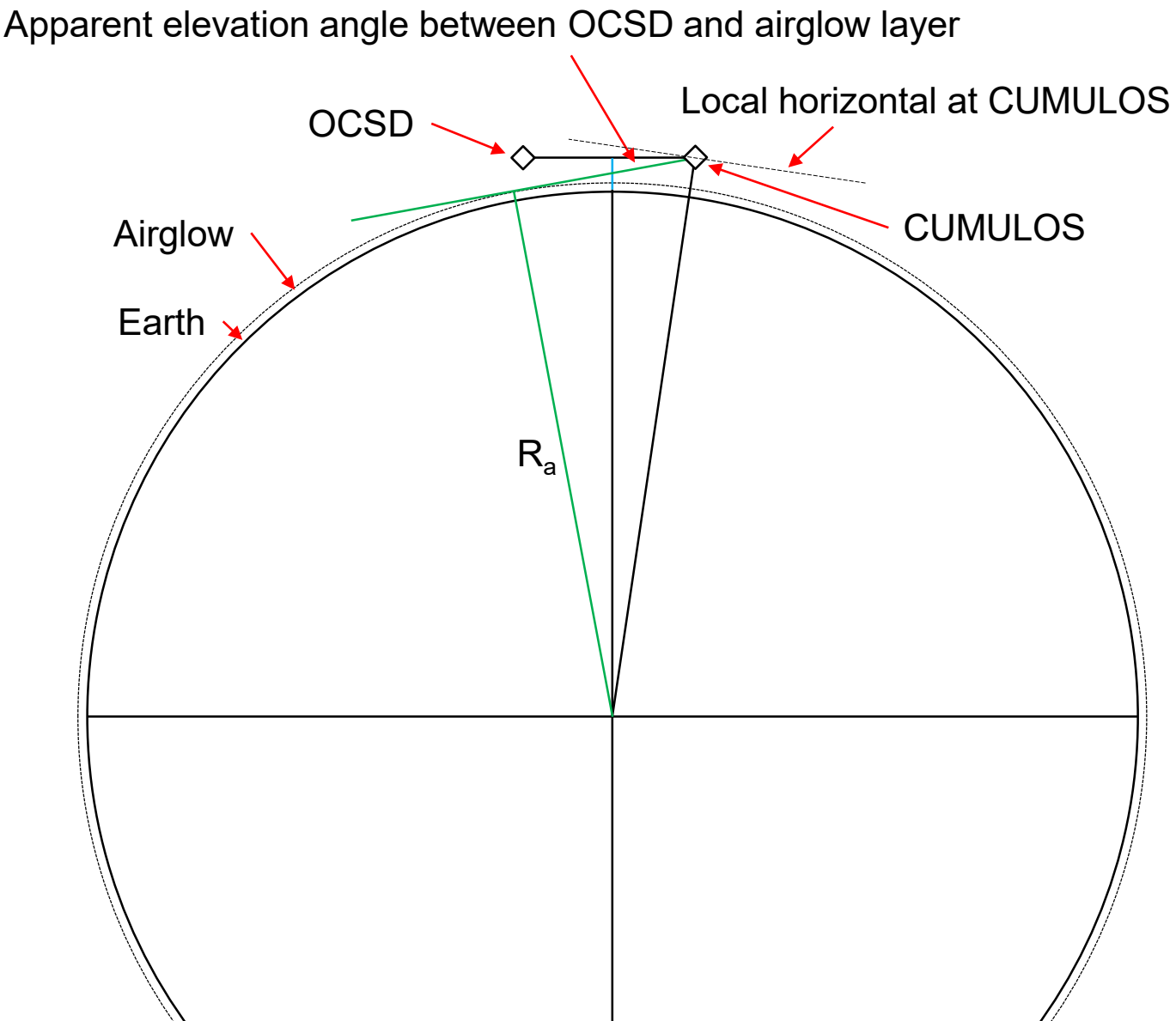


Sensitive to OCSD laser wavelength



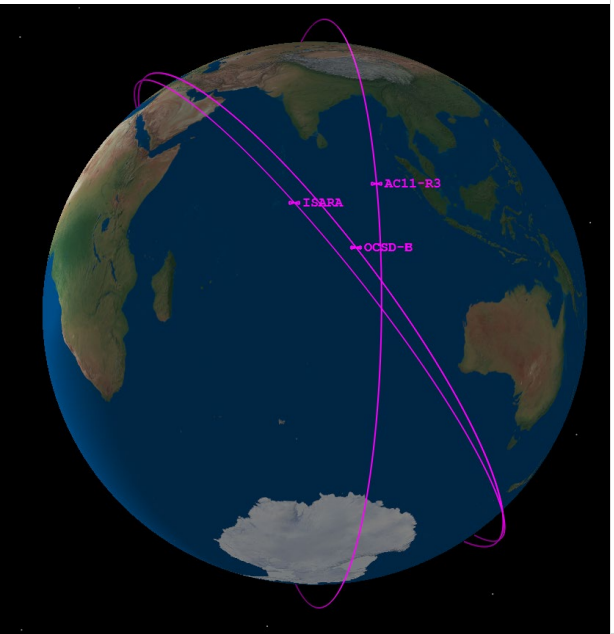
Secondary payload included on a "do no harm basis." Turned on after completion of primary mission.

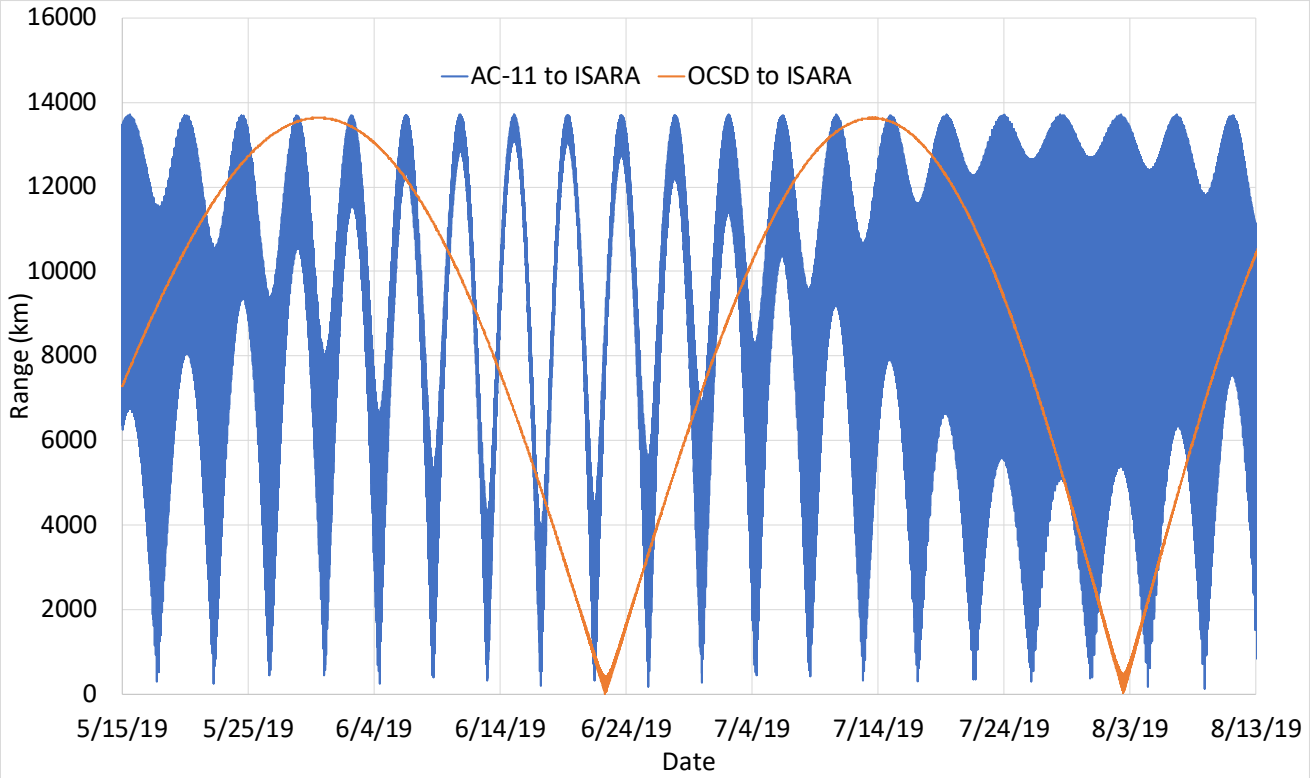
Crosslink Geometry

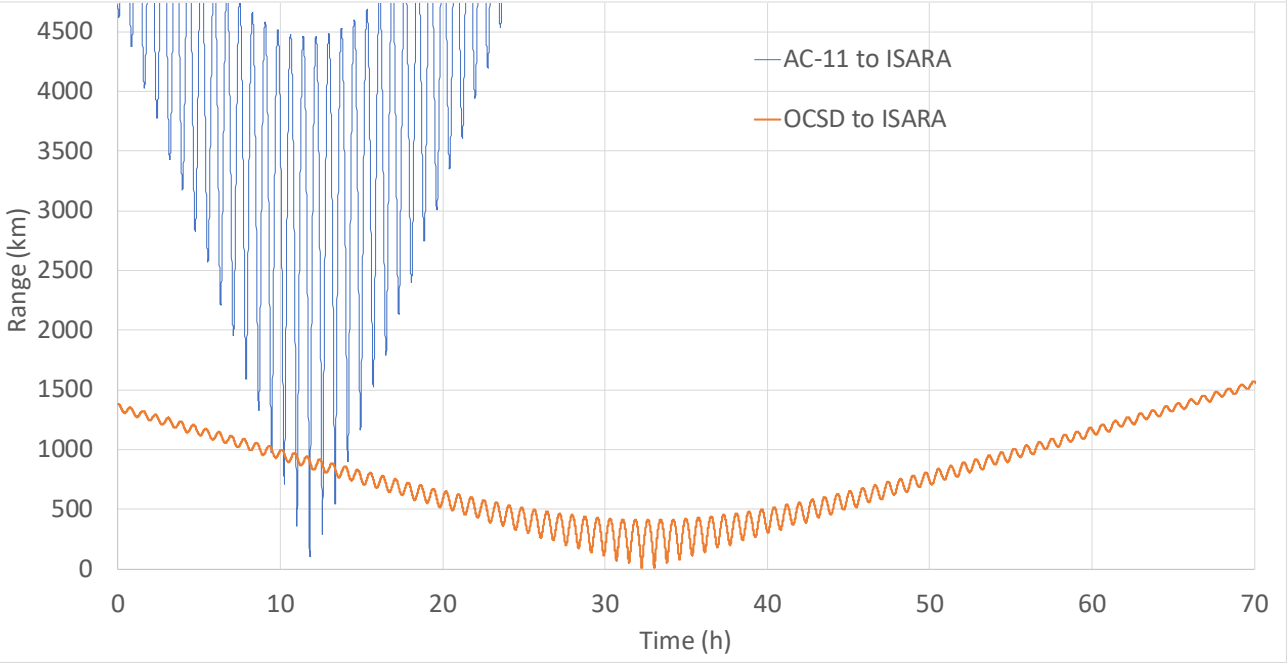


Orbital Dynamics

- OCSD to ISARA crosslink pointing tests are possible for ~8 days every 6 weeks
- R3 to ISARA crosslink pointing tests are possible for ~24 hours every five days



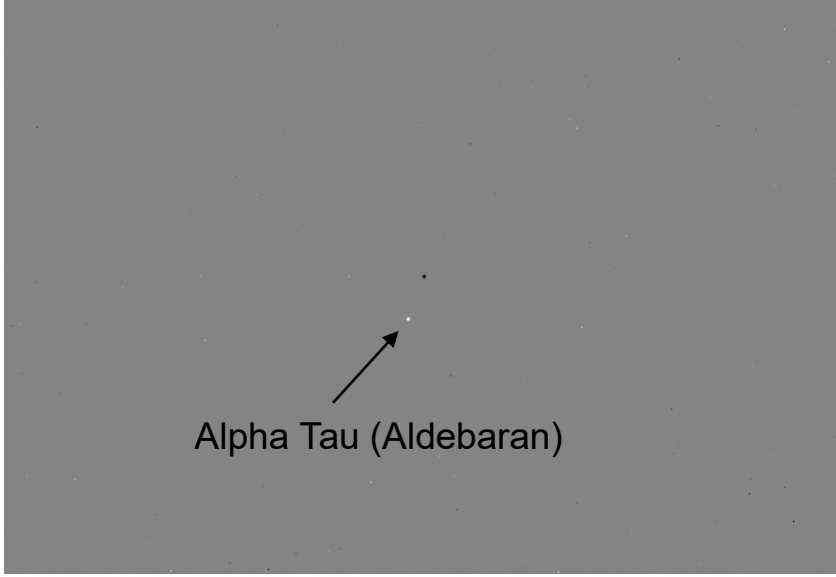




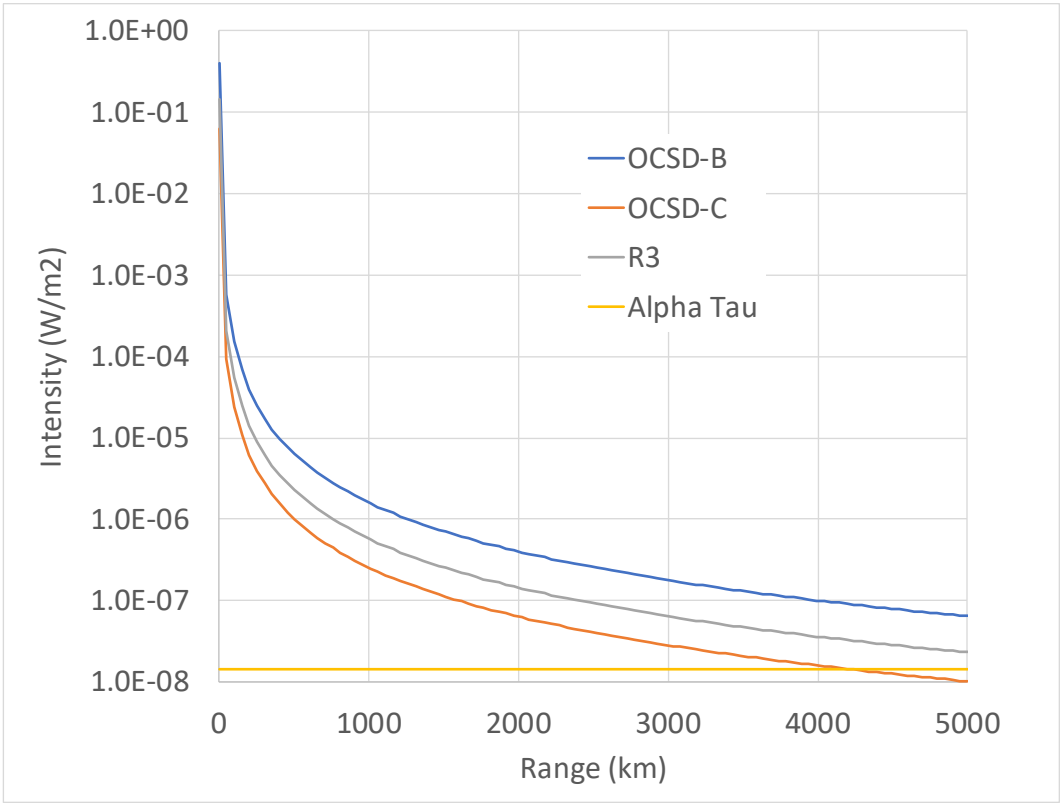
Centerline Beam Flux

Can we see it?

- Compared expected centerline laser intensity to integrated IR intensity of reference star
- All three lasers are at least as bright as Alpha Tau out to maximum crosslink range
- OCSD-B is an order of magnitude brighter at 4000 km

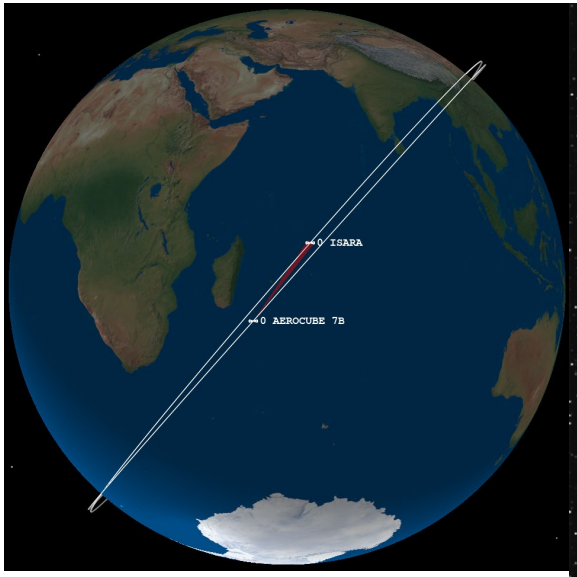


CUMULOS SWIR image (subtracted)



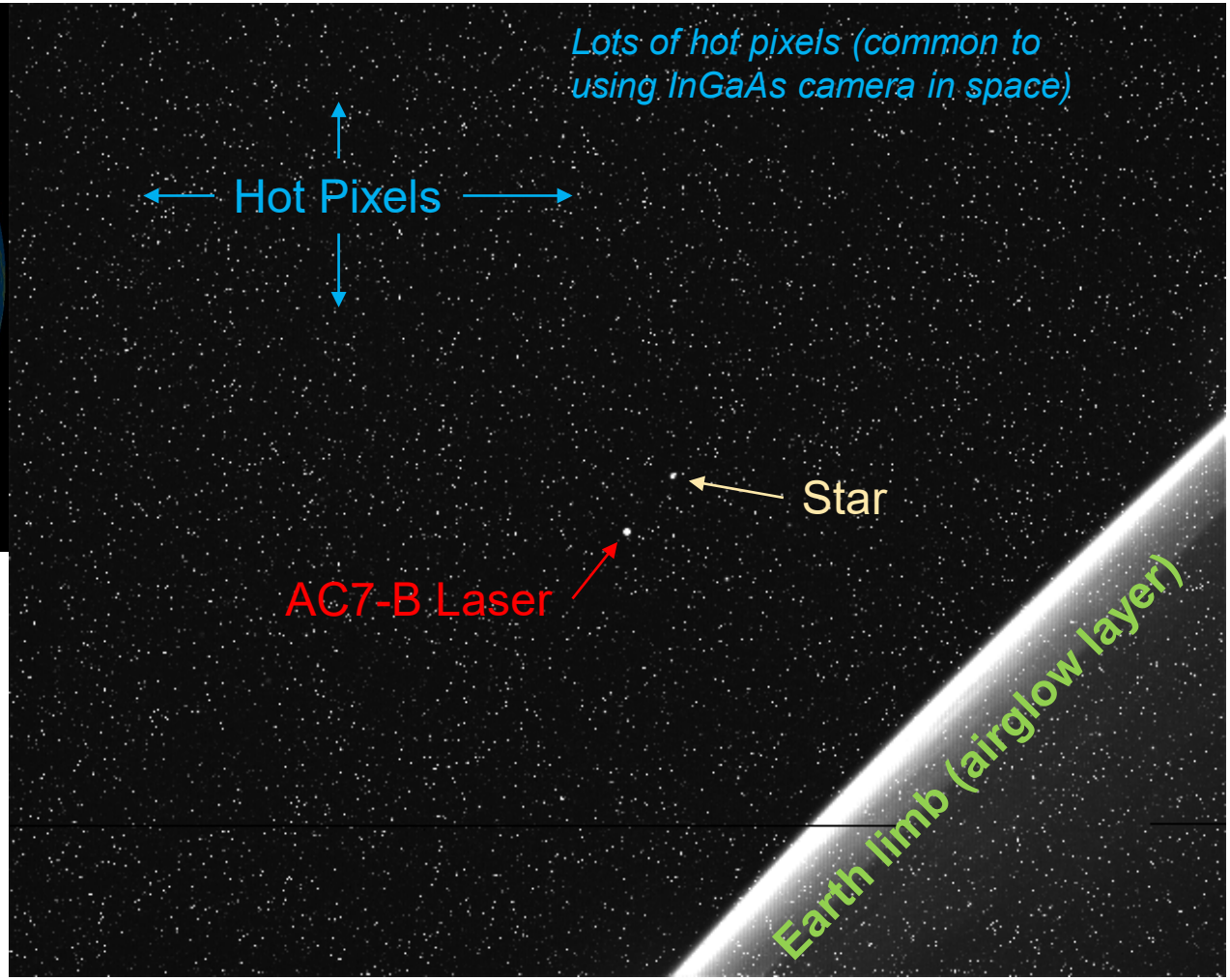
ISARA Illuminated by AC7-B, Raw Image

9 January 2019



Date/Time: 2019-01-09 19:13:16Z
Range: 1996 km

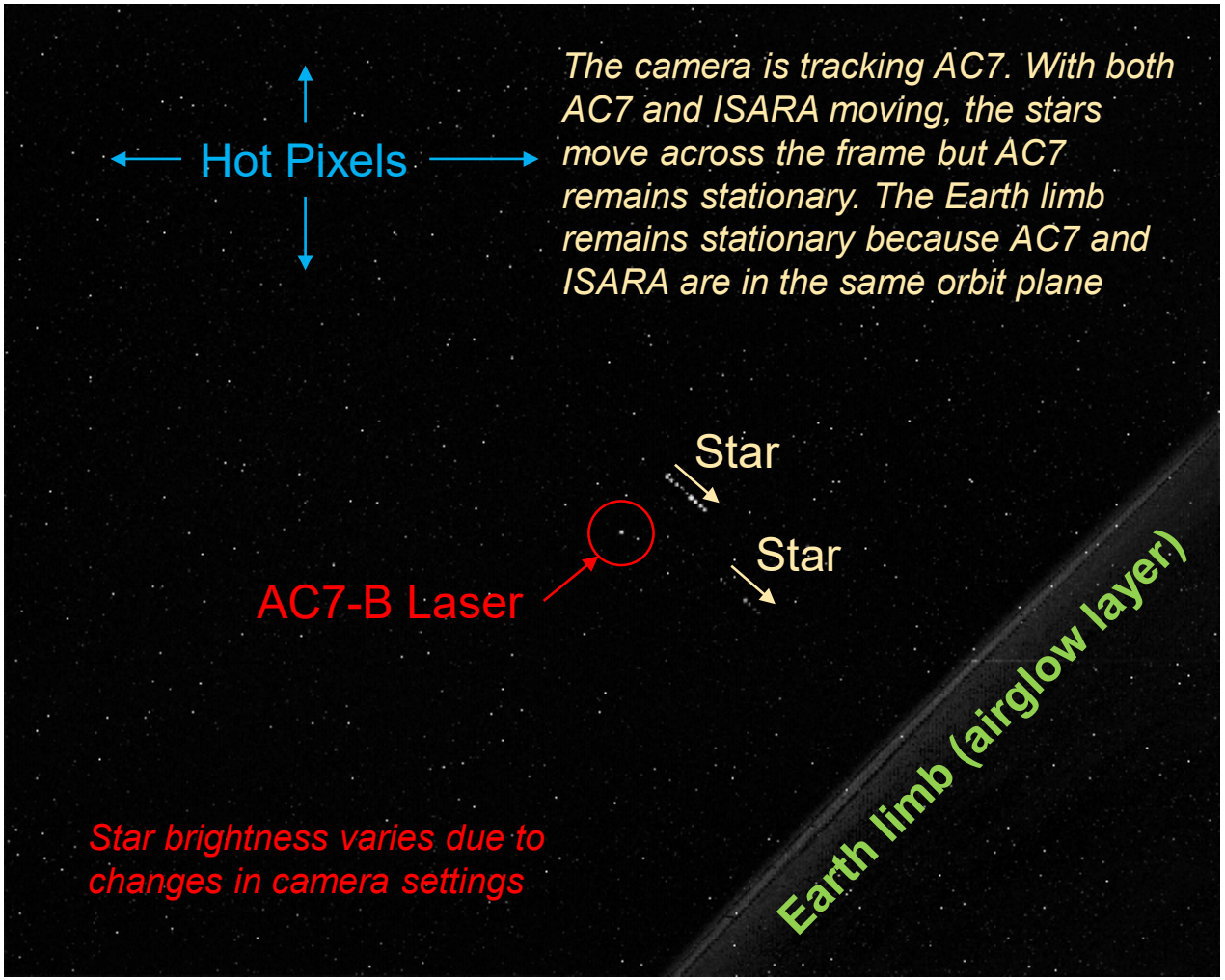
AeroCube-7B (SCC #43042)
ISARA (SCC #43050)



ISARA_CUMULOS_CrossLink_04_1346_0

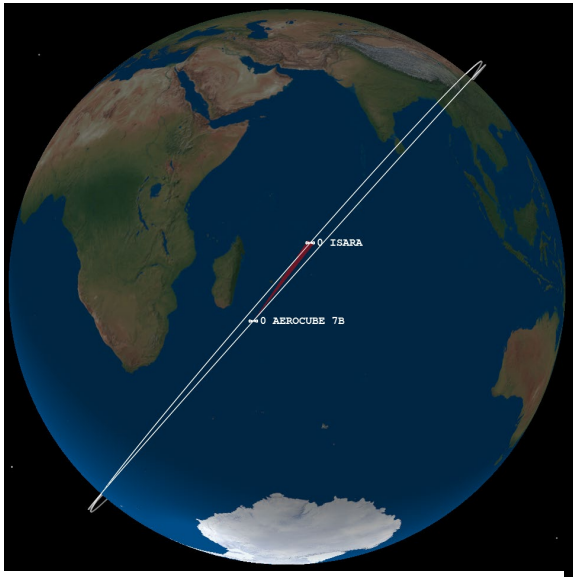
Image Series: 9 Combined Images

Subtraction Removes (Most) Hot Pixels



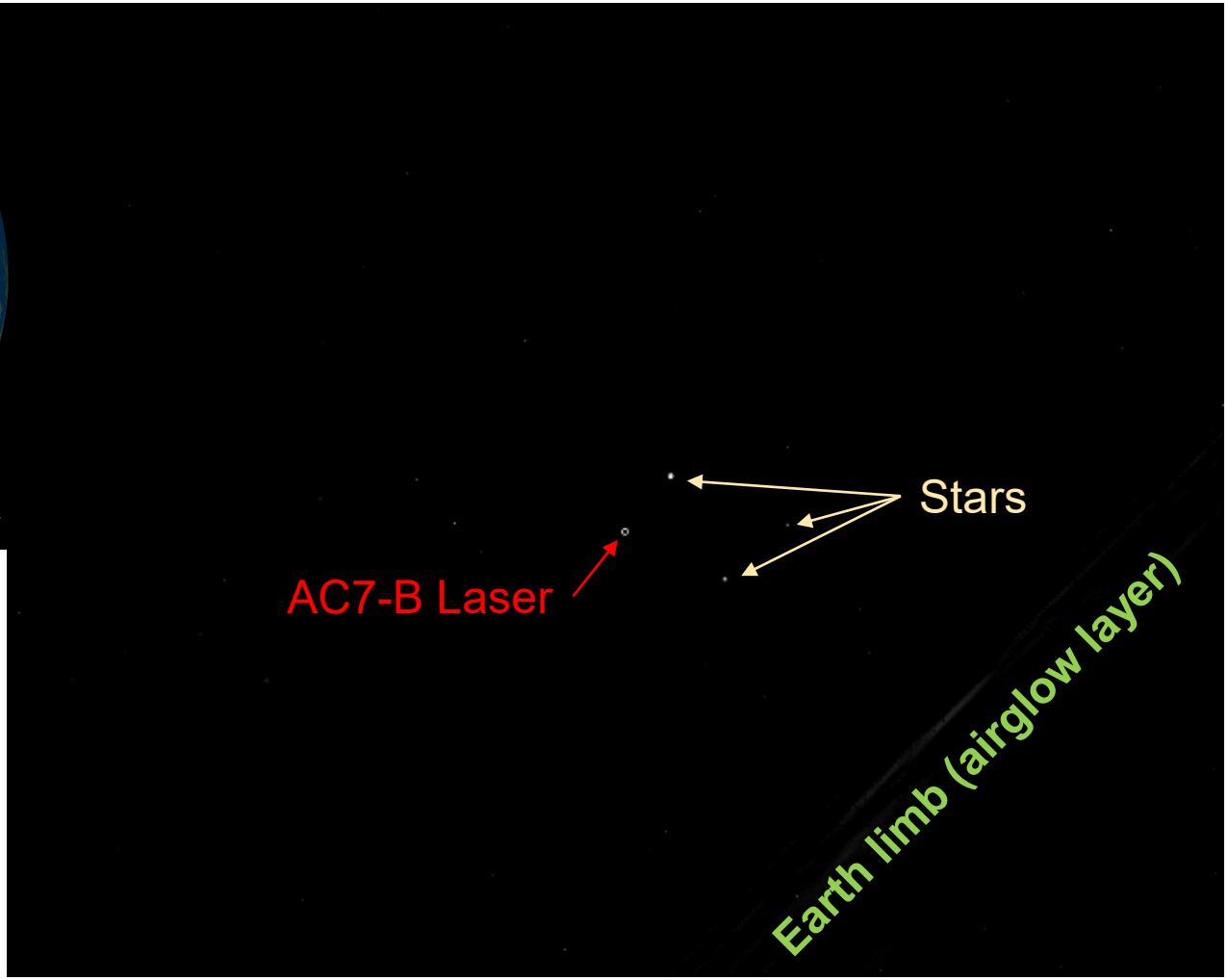
ISARA Illuminated by AC7-B, Hot Pixels Subtracted

9 January 2019



Date/Time: 2019-01-09 19:13:16Z
Range: 1996 km

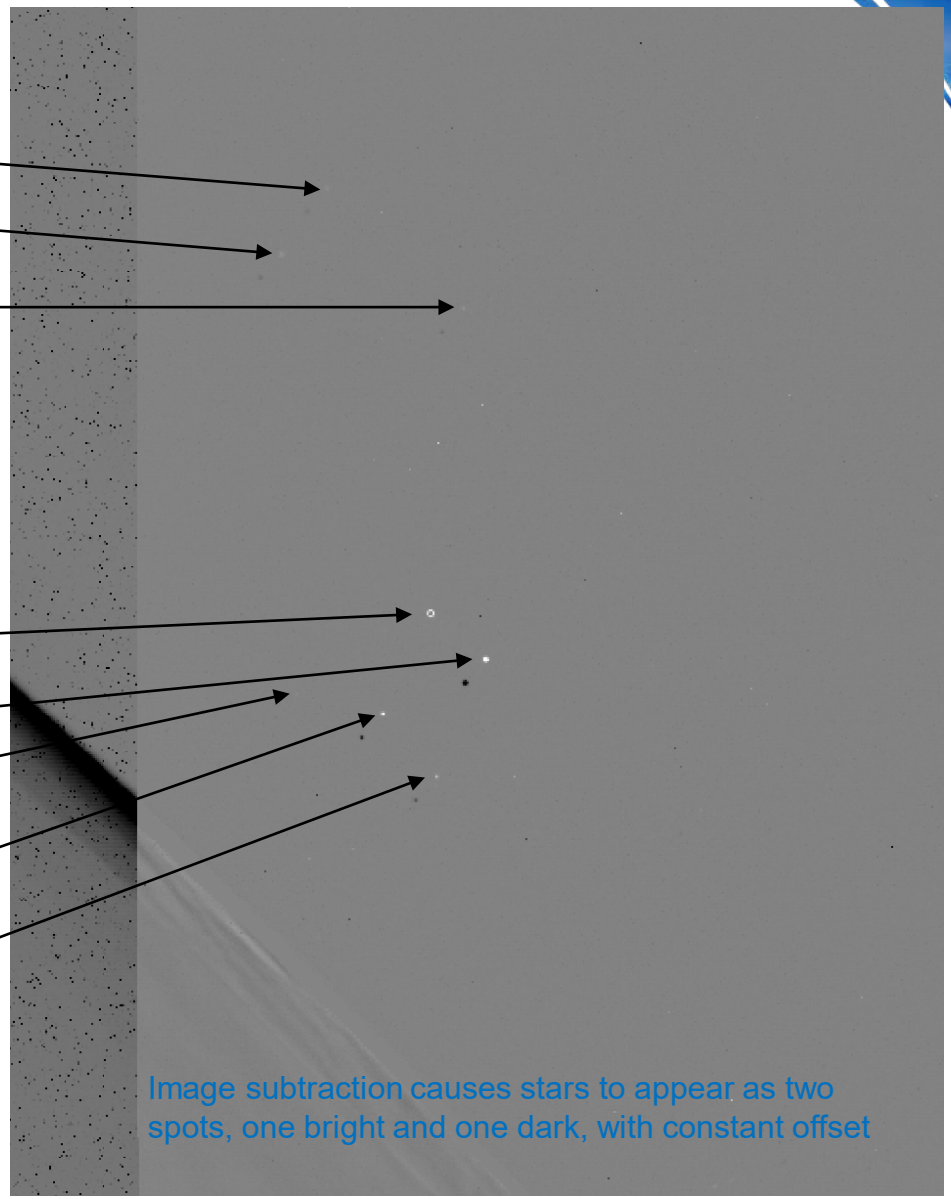
AeroCube-7B (SCC #43042)
ISARA (SCC #43050)



ISARA_CUMULOS_CrossLink_04_1346-1351_0

IR Starfield

Image 1351 subtracted from image 1346

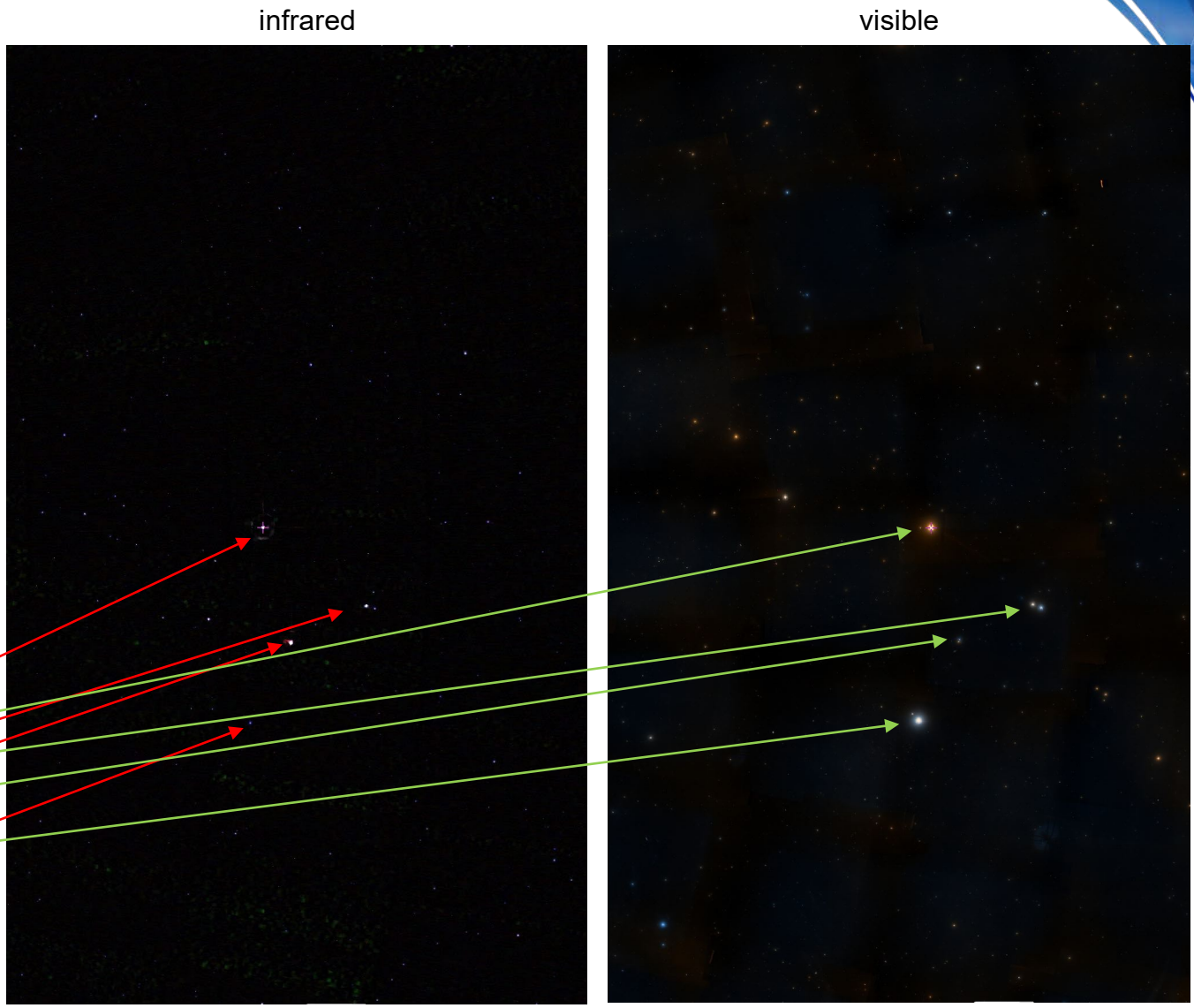


Bright visible stars are not necessarily bright in IR

Some very dim visible starts are bright in IR

Starfield Identification

The CUMULOS SWIR camera sees the infrared sky, which is very different from the visible sky.

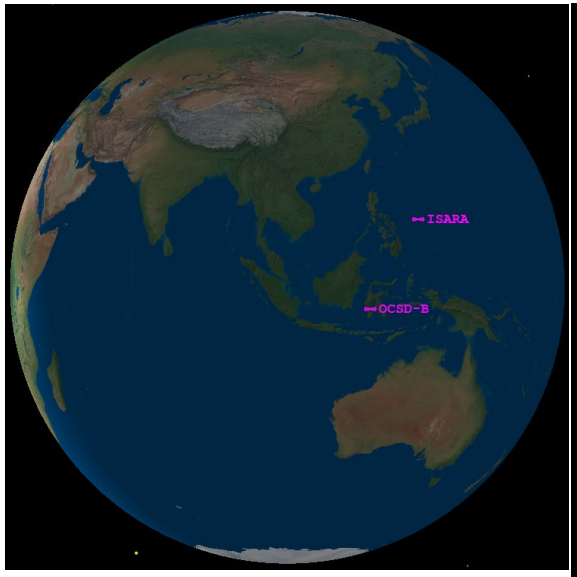


Atlas image obtained as part of the Two Micron All Sky Survey (2MASS), a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by NASA and NSF.

The Digitized Sky Survey was produced at the Space Telescope Science Institute under U.S. Government grant NAG W–2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. The plates were processed into the present compressed digital form with the permission of these institutions.

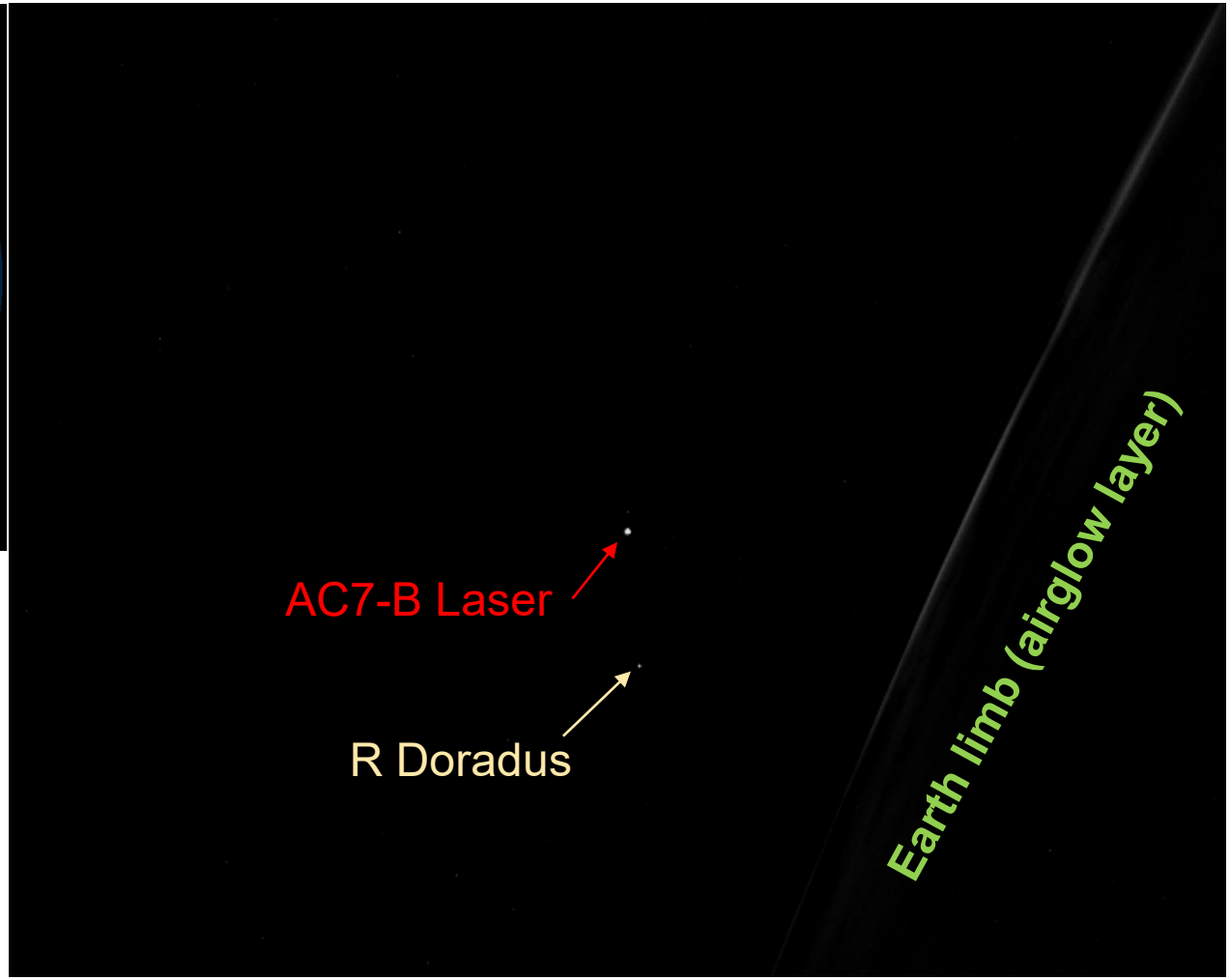
ISARA Illuminated by AC7-B, Dark Subtracted

15 March 2019



Date/Time: 2019-03-15 14:51:53Z
Range: 2292 km

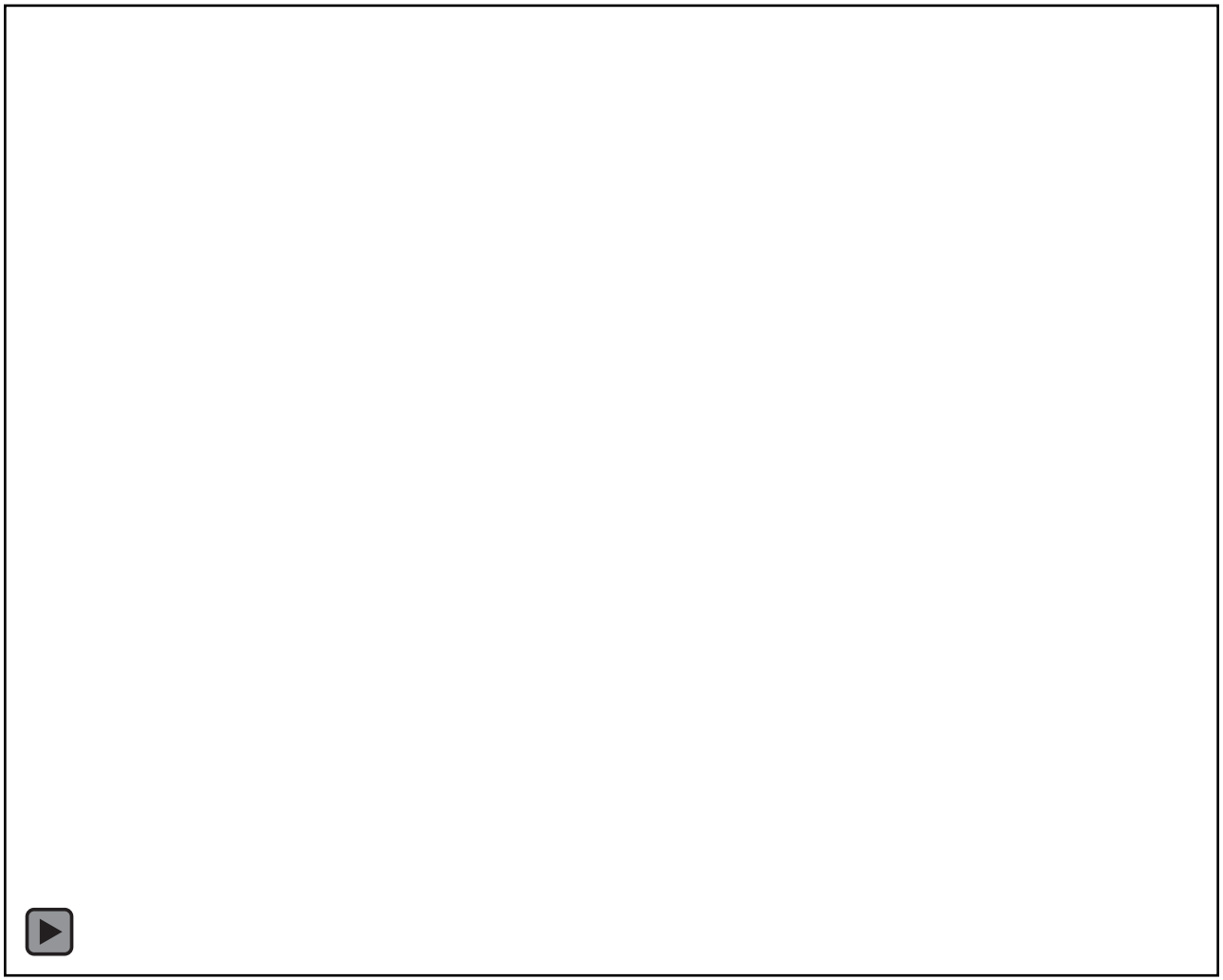
AeroCube-7B (SCC #43042)
ISARA (SCC #43050)



ISARA_CUMULOS_CrossLink_10_1839_0

Beam Profile

OCSD commanded to sweep beam across CUMULOS at 2292 km range



What Next?

Following up on a mission of opportunity

- OCSD-to-ISARA crosslink pointing tests provided proof-of-principle demonstration for CubeSat-scale optical crosslinks
  - *Open-loop pointing for communication*
    - <1-mrad accuracy by both transmitter and receiver
  - *Beam-profile measurement technique that avoids atmospheric effects*

- Future experiments
  - *Identify alternate cameras*
  - *Beam profile measurements*
    - OCSD B and C
    - R3
  - *More-challenging orbits*
    - Higher slew rates
    - More frequent opportunities

Acknowledgments

Multiple missions of opportunity

- The OCSD spacecraft were built by Aerospace with support from NASA's Space Technology Mission Directorate through the Small Spacecraft Technology Program

- The ISARA program was led by JPL, with support from NASA's Space Technology Mission Directorate through the Small Spacecraft Technology Program; JPL and Aerospace collaborated on the build of the ISARA spacecraft

- The CUMULOS payload was built by Aerospace and hosted on ISARA with permission from NASA and JPL

- The work described in this presentation was funded by The Aerospace Corporation's Independent Research and Development program