

LightSail 2 Image-Based Engineering Assessment



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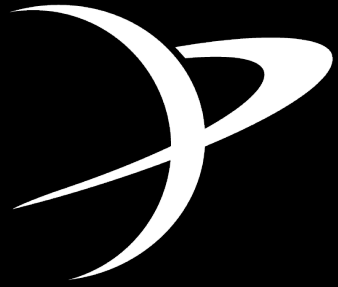


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Vestigo Aerospace

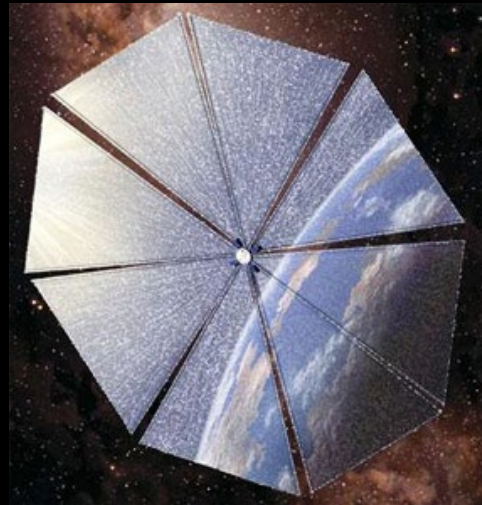
LightSail Program Team over Time

Spacecraft design and construction	Stellar Exploration, Inc.
Lead contractor for integration and testing	Ecliptic Enterprises Corporation
LightSail testing facilities and mission control	Cal Poly San Luis Obispo
Ground stations	Cal Poly San Luis Obispo Georgia Tech Purdue University Kauai Community College
Contractors	Boreal Space, Georgia Tech, Purdue, Aquila Space, NXTRAC, Aerospace Corp., Vestigo Aerospace
LightSail 1 launch provided by	NASA's Educational Launch of Nanosatellites program
LightSail 2 launch provided by	University Nanosat Program, Air Force Research Laboratory with the Georgia Tech Prox-1 spacecraft

Background



**THE
PLANETARY
SOCIETY**



TPS COSMOS 1

Launch failure 2005

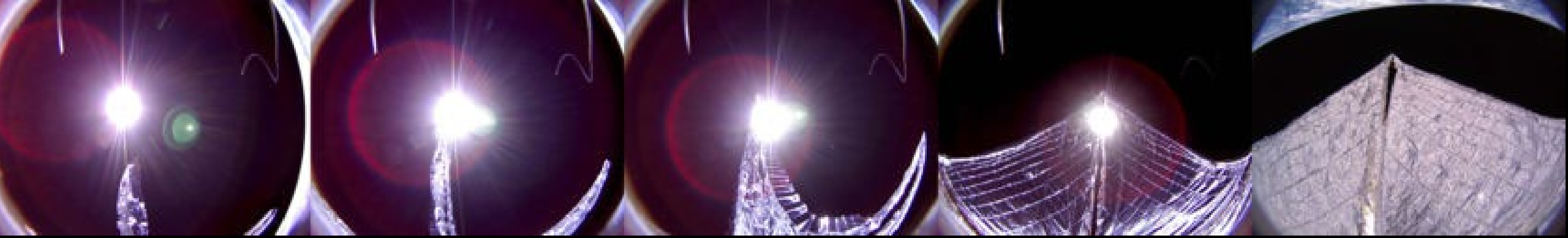
Inflatable booms
8 rotatable blades

Sail area: 600 sq. m

Mass: 105 kg

TPS LightSail Program





LightSail program goals:

- ✓ Demonstrate controlled CubeSat solar sail propulsion
- ✓ Raise the public and technical profile of solar sailing
- ✓ Excite and engage the public
- ✓ Share results with missions, tech. community, public.



LightSail 1

Goal: To develop and test spacecraft functions and sail deployment prior to a later flight that will include controlled solar sailing.

Launched: May 20, 2015

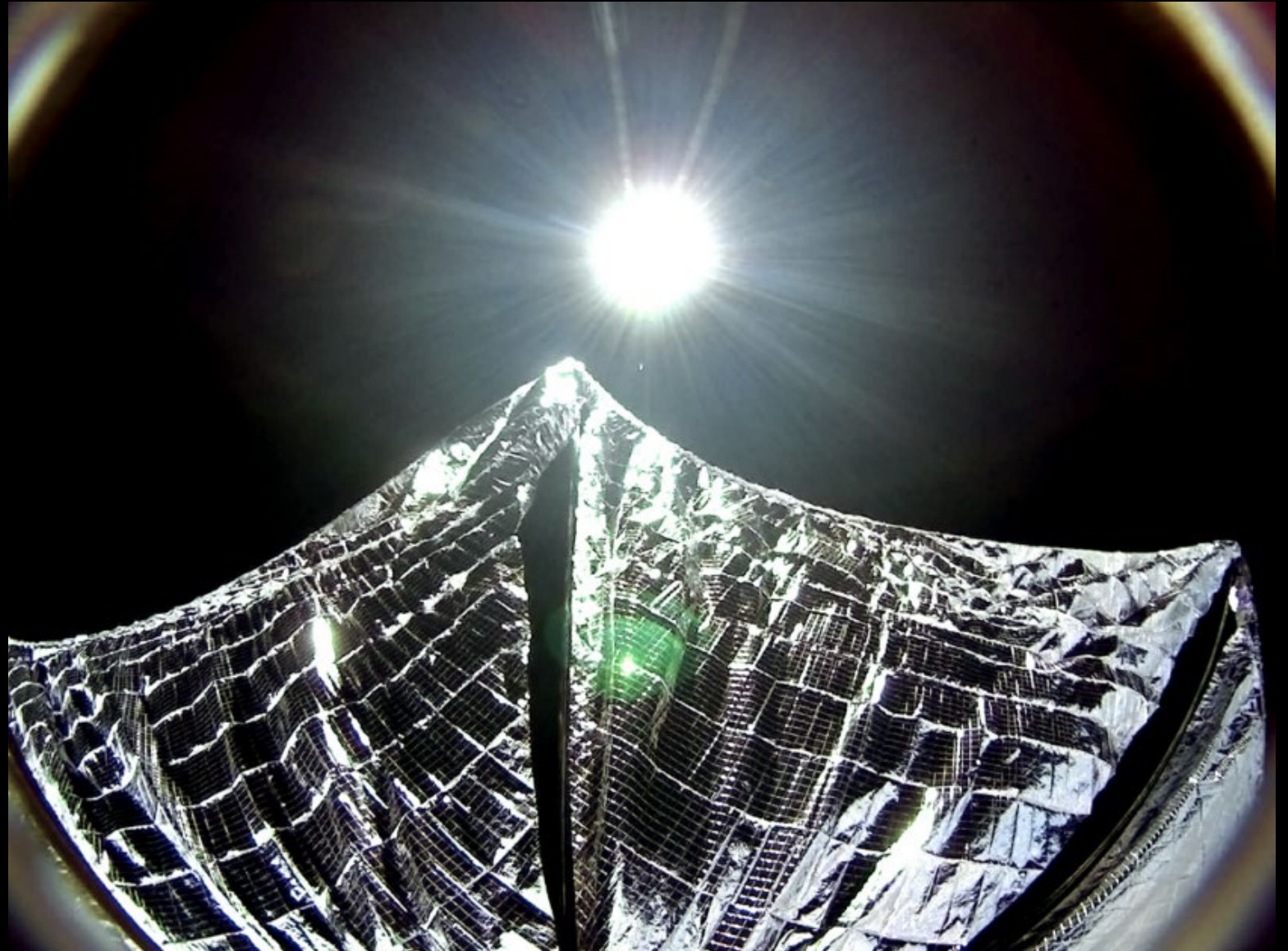


LightSail 1

Sail deployment:
June 7, 2015

Test Mission Result:

Success
+
Lessons
Learned



LightSail 2

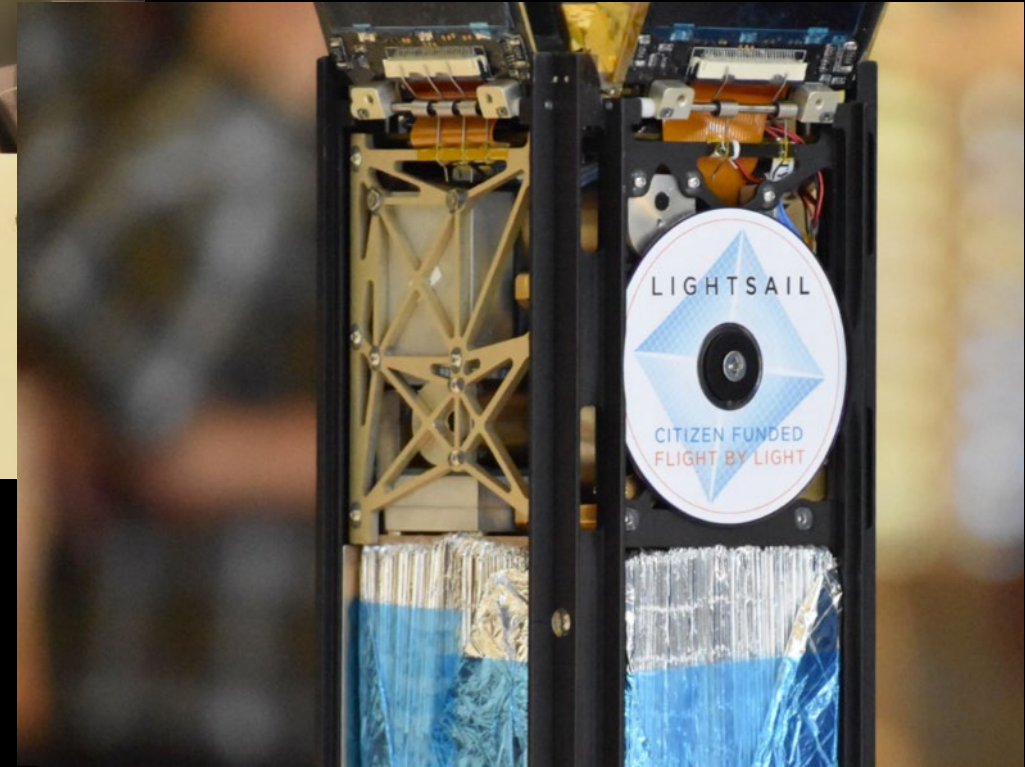
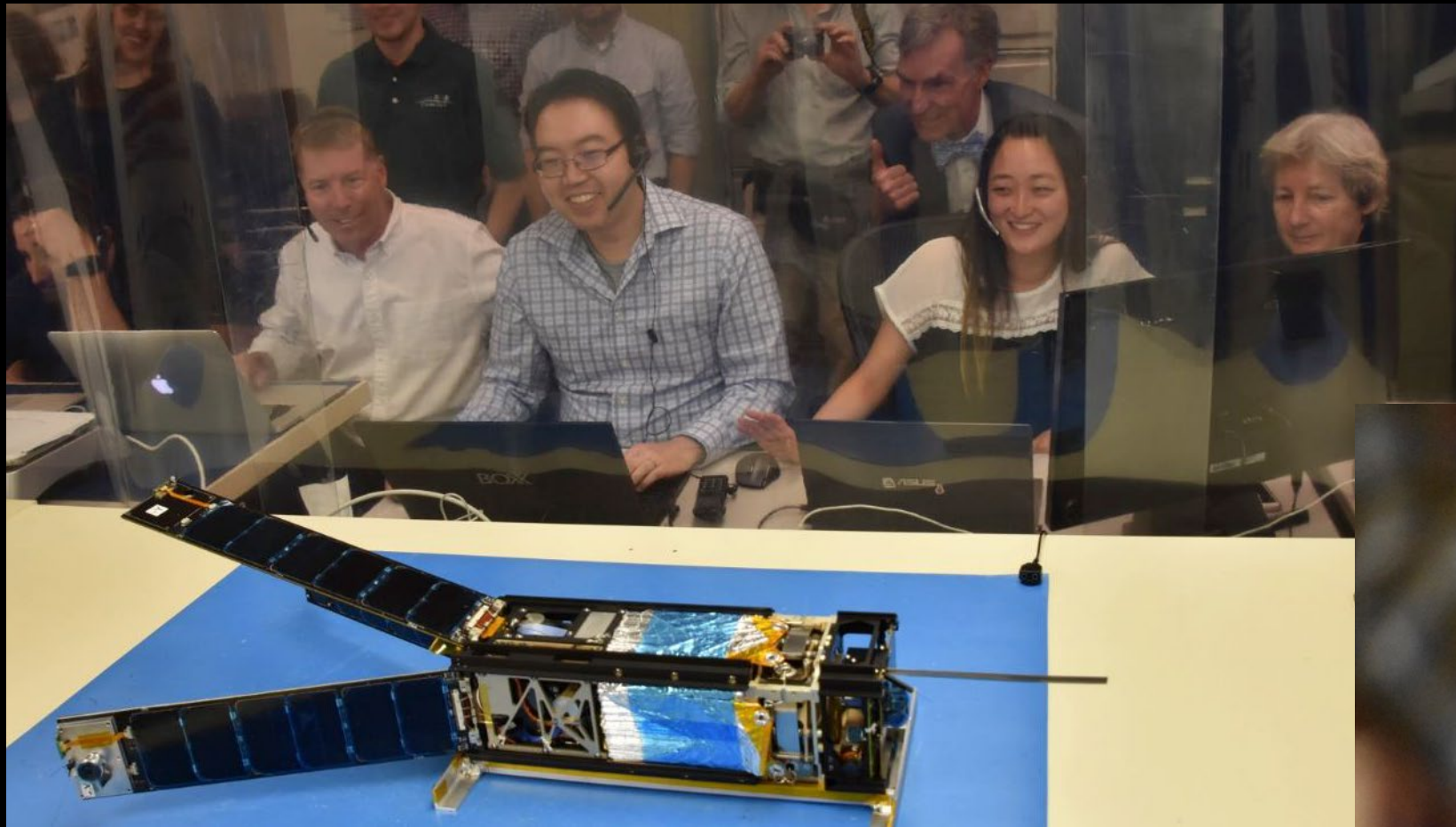


LightSail 2 Technical
Goal:

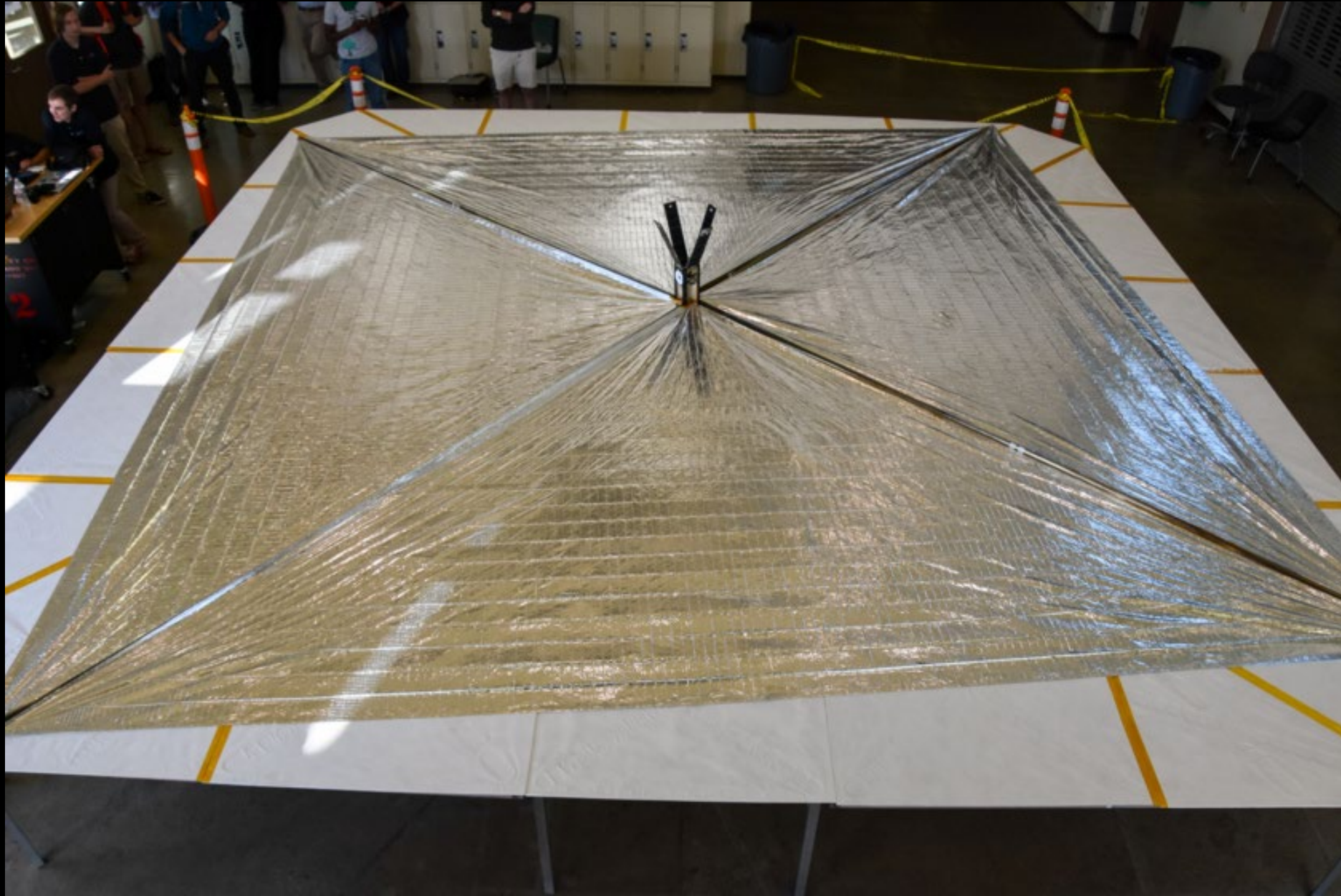
Demonstrate
controlled CubeSat
solar sailing

How?: by
demonstrating a
modification in orbit
due to solar sailing

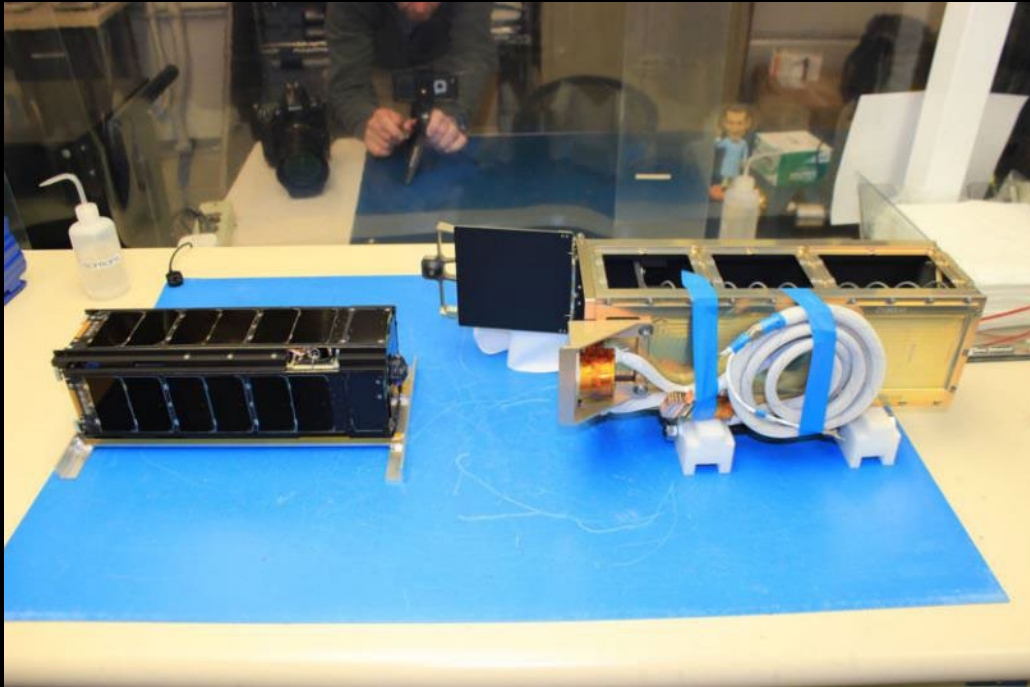
LightSail 2 Testing at Cal Poly San Luis Obispo



LightSail 2 Deployment test



LS2 Integrated into P-POD



LightSail 2 Mission Summary



- Launched June 25, 2019 on the 3rd Falcon Heavy after years of uncertain delays
- Deorbited November 2022



One week after launch...

ANTENNA DEPLOYED

SIZE

11.3 x 11.3 x 48.7 cm
(4.5 x 4.5 x 19.2 in)

WEIGHT

5 kg
(11 lbs)

SIZE REFERENCE

Loaf of Bread

AVIONICS

Torque rods &
momentum wheel
for maneuvering

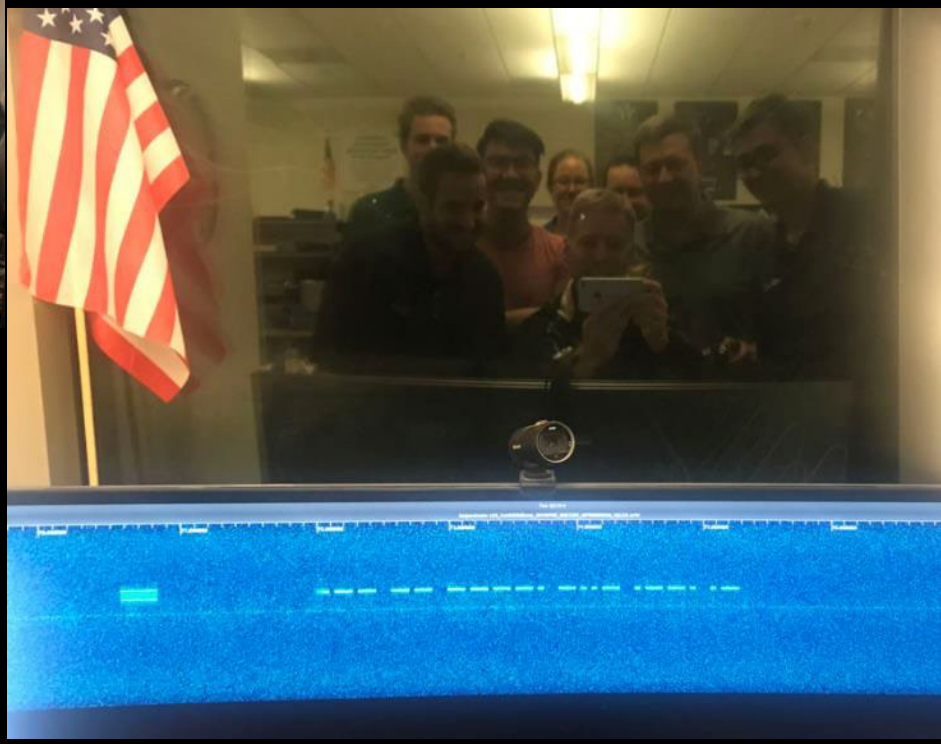
HULL

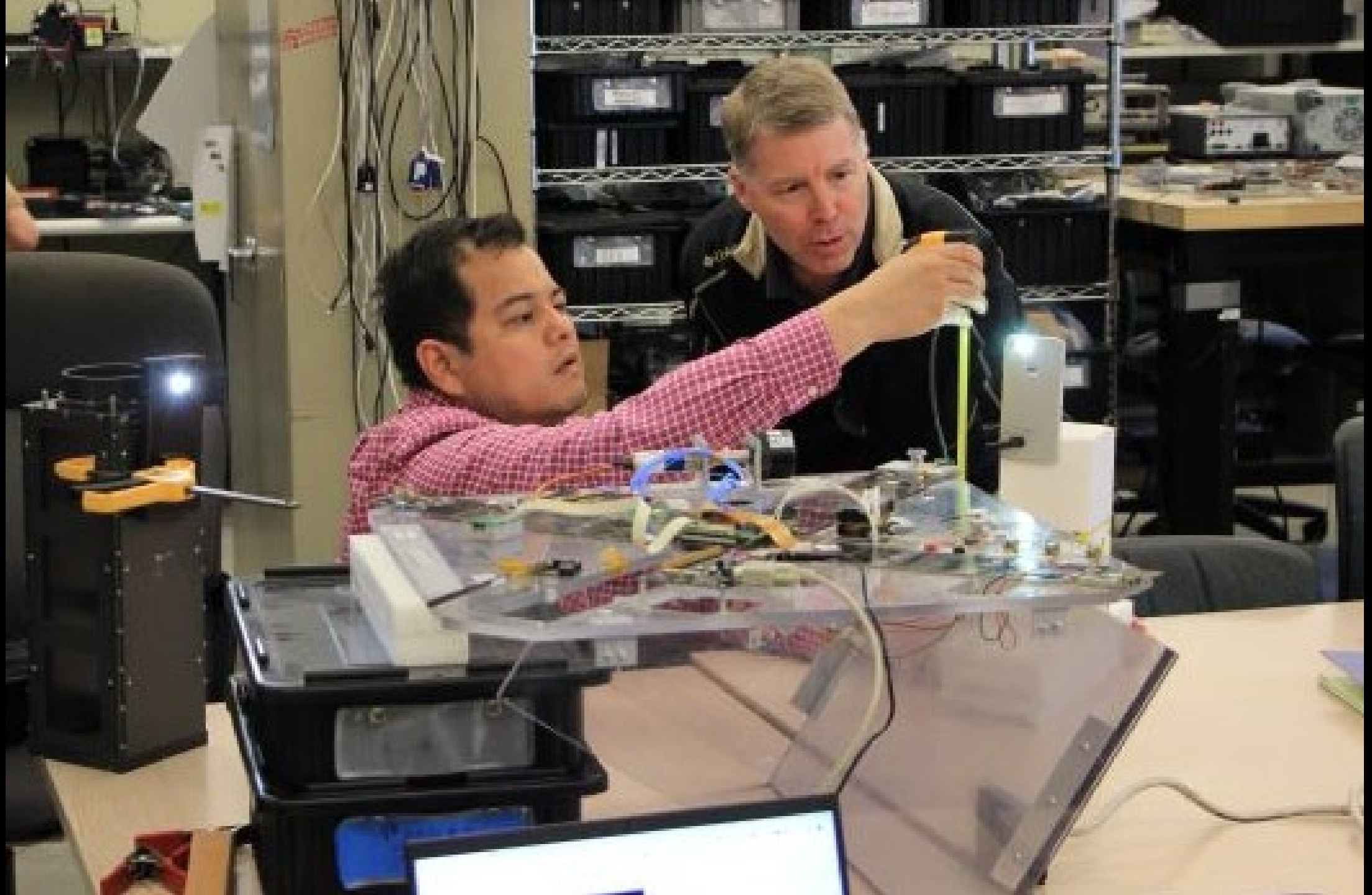
Lightweight
aluminum alloy

COMMUNICATIONS

RF monopole antenna



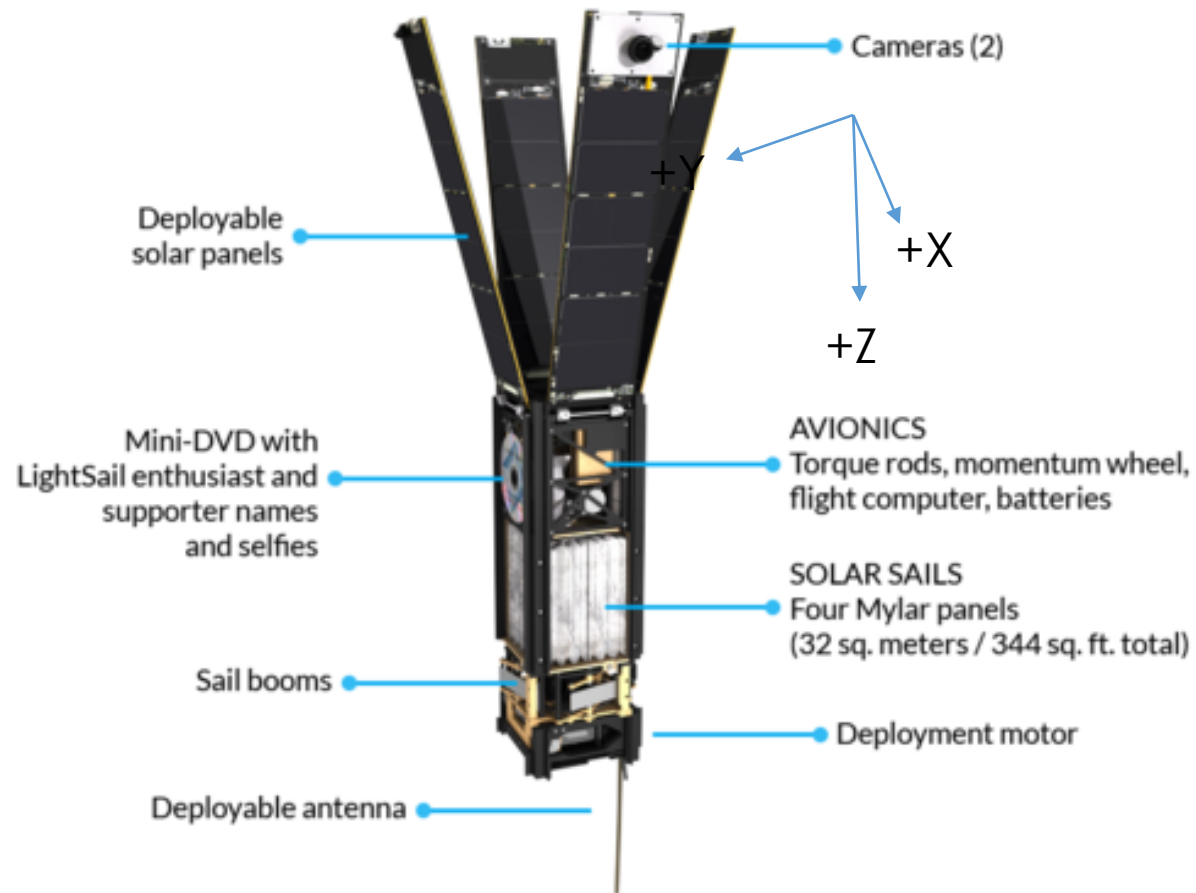




Imaging including Engineering Assessment

LIGHTSAIL 2 Major Components

- 2 fisheye cameras
- Opposite sides of the spacecraft
- To image most of the sail as well as Earth and/or space
- For
 - Engineering assessment
 - Public excitement



sail.planetary.org

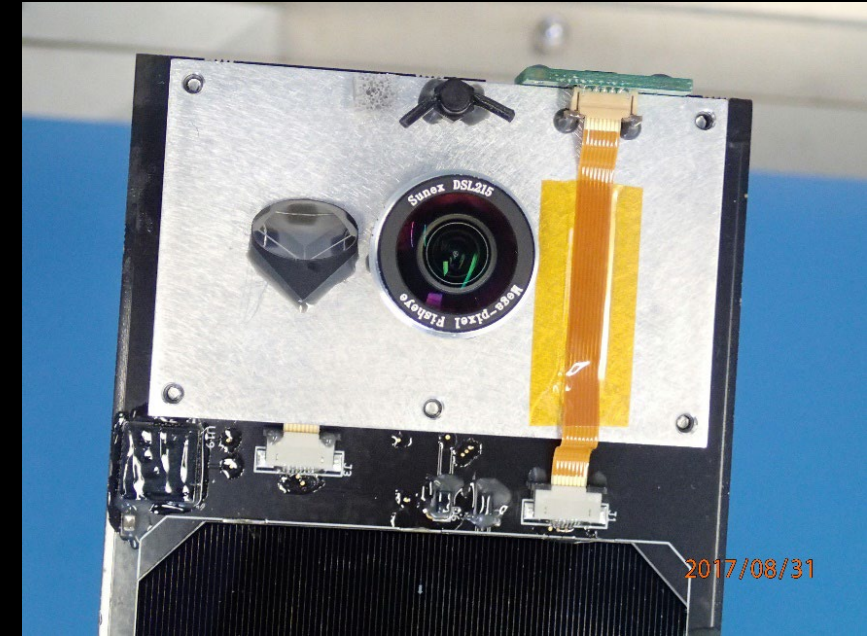
Camera 1 is on +X panel

Camera 2 is on -X panel

Panel deployment angles are all about 155 deg except +Y which did not fully deploy and is thought to be about 90 deg.

LightSail 2 Cameras Summary

- 2 identical PSCAM (Planetary Society Cameras) produced by the Aerospace Corporation
- Located on opposite sides of spacecraft
- 185 degree fish eye lenses capture most of the sail
- Each image capture takes a thumbnail (120x90px) and a high resolution (1600x1200px) image.
- Typically, near simultaneous image captures are acquired for both cameras whenever images are taken.
- Thumbnails downlinked automatically. High res downlink commanded based on thumbnails and downlink data availability.
- High res image corruption issues (later fixed) occurred with some high res images in the first few months of the mission
- Result of last 2 points is there are more thumbnails on the ground than high res, and gaps in image taking dates early in the mission as we debugged.





Sail Deployment

SOLAR SAIL DEPLOYED

Four triangular sail segments of aluminized Mylar were deployed to 32 m² of sail area using four Elgiloy metal alloy TRAC booms.

<u>SIZE</u>	<u>BOOM LENGTH</u>	<u>TOTAL SAIL AREA</u>	<u>SIZE REFERENCE</u>
5.6 x 5.6 m (18.4 x 18.4 ft)	4 m (13 ft)	32 m ² (344 ft ²)	Boxing Ring

PROPULSION

Sails have 'rip-stop' seams every few cm to prevent tear spreading from space debris

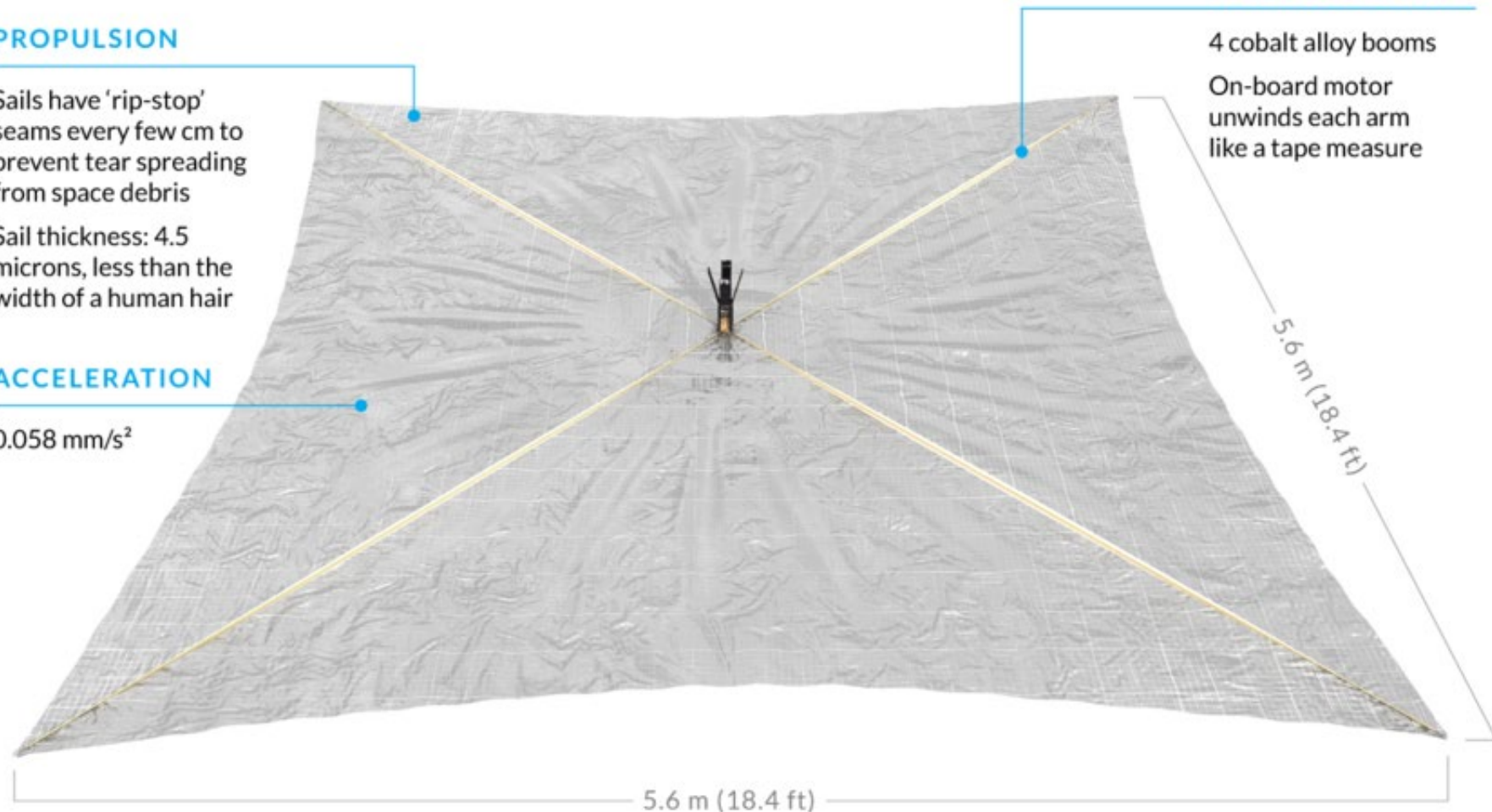
Sail thickness: 4.5 microns, less than the width of a human hair

ACCELERATION

0.058 mm/s²

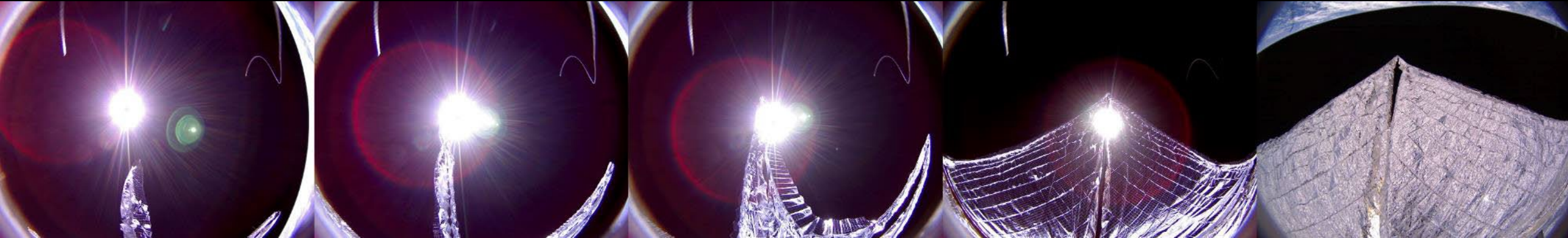
SAIL DEPLOYMENT

4 cobalt alloy booms
On-board motor unwinds each arm like a tape measure



07/23/19
Sail Deployment

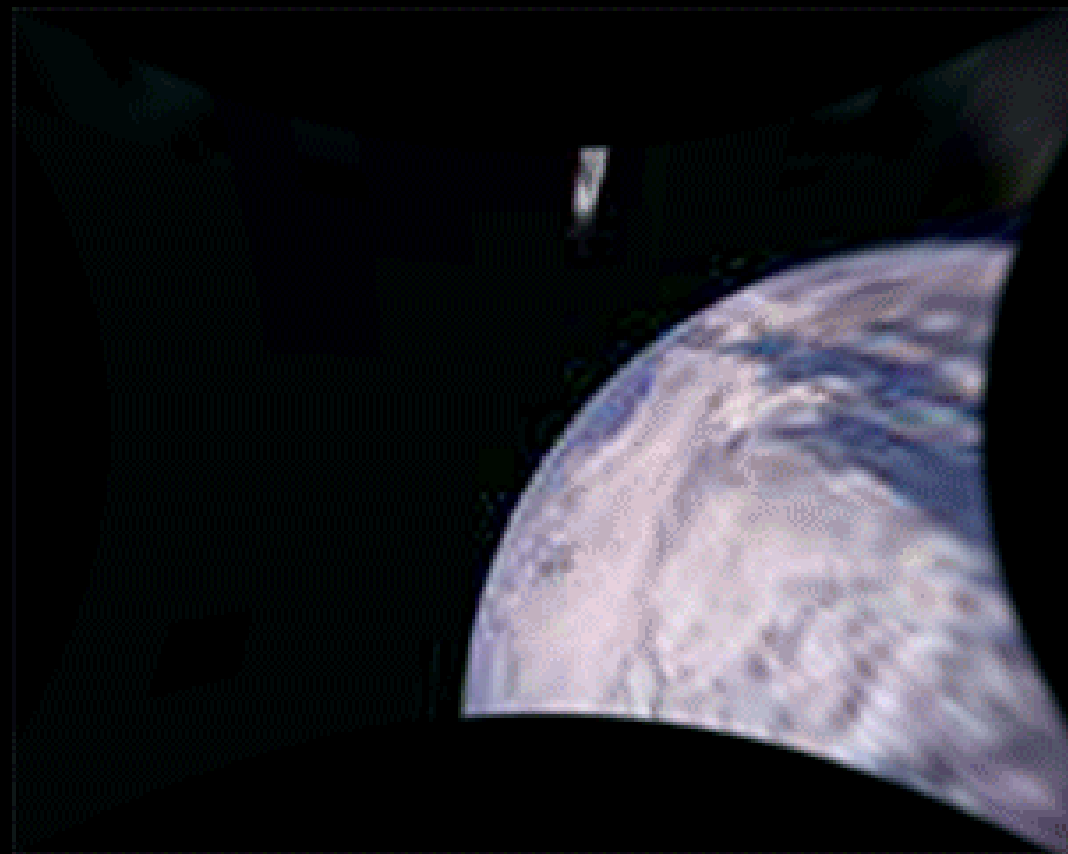
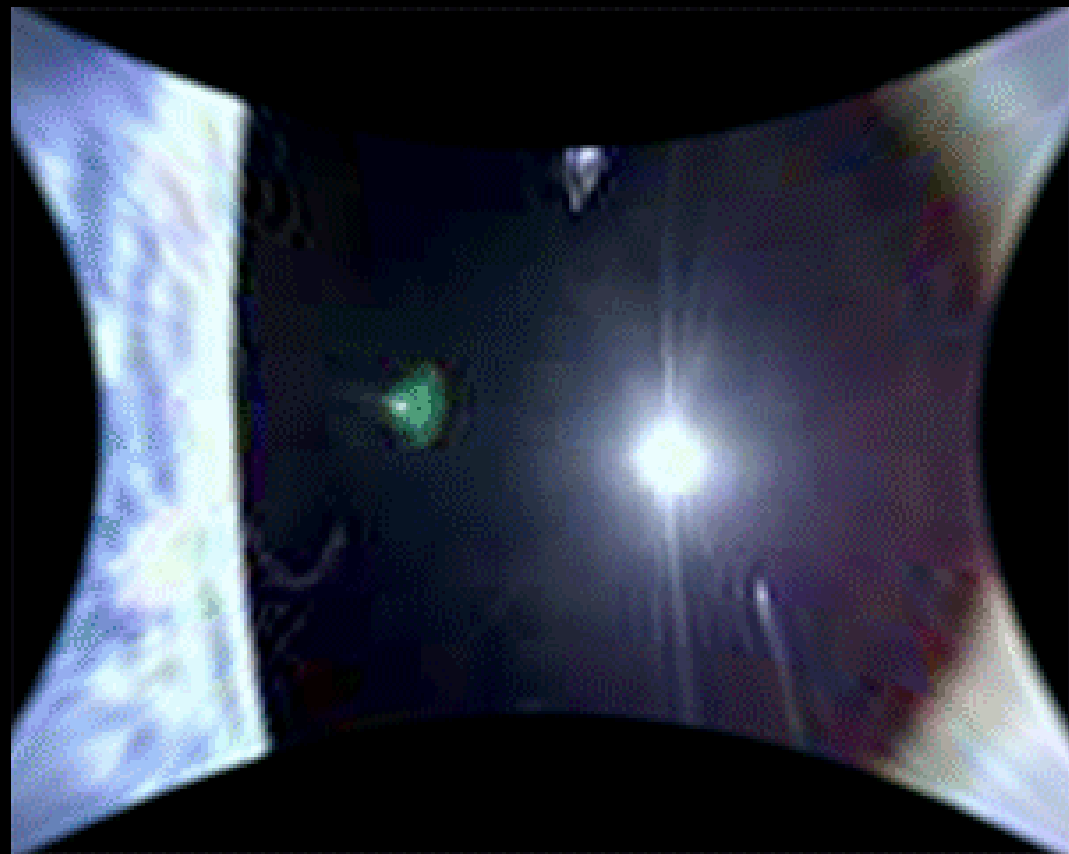
Camera 1

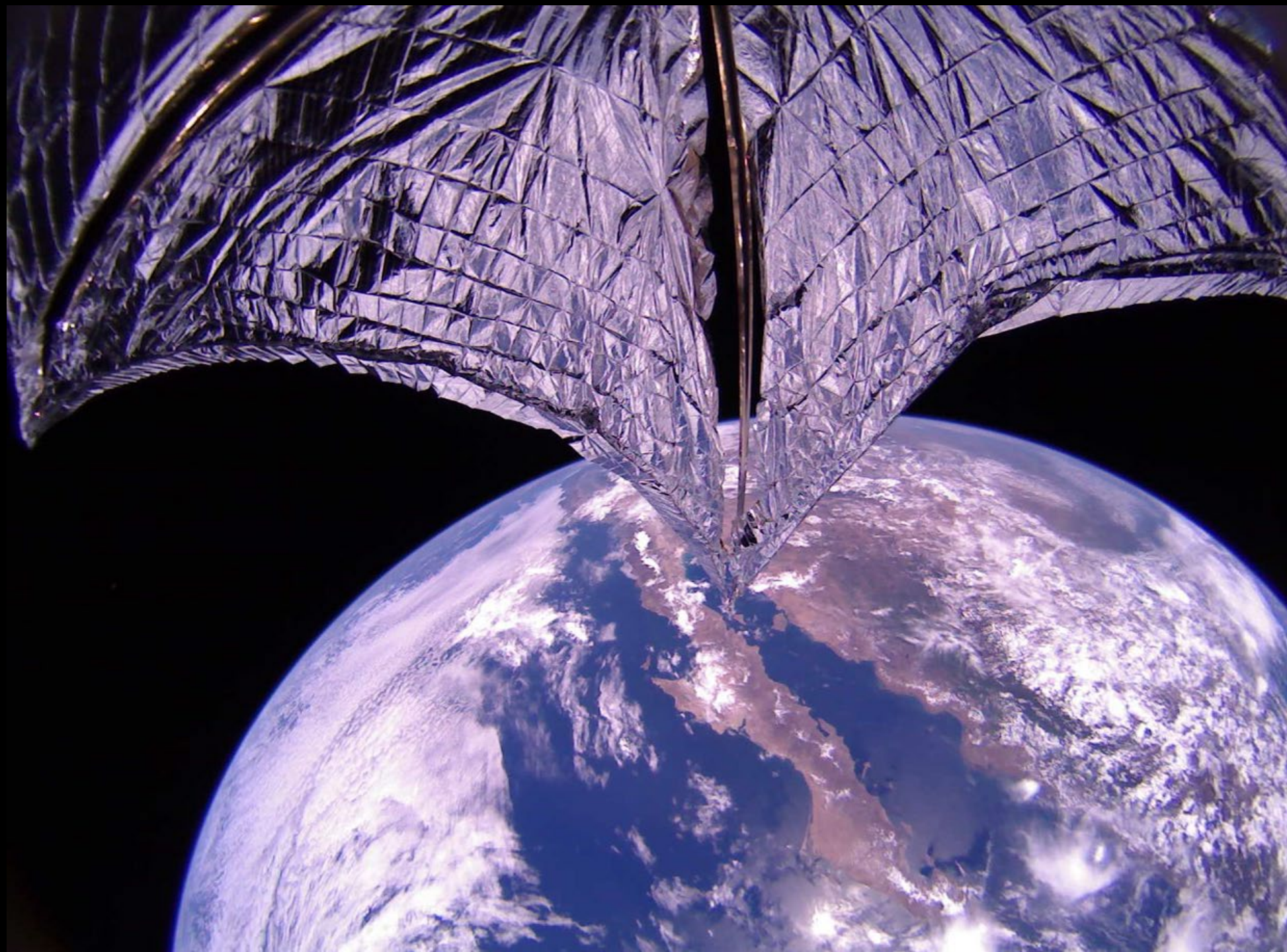


Camera 2 including Baja California

Cameras 1 and 2 thumbnail movies of deployment

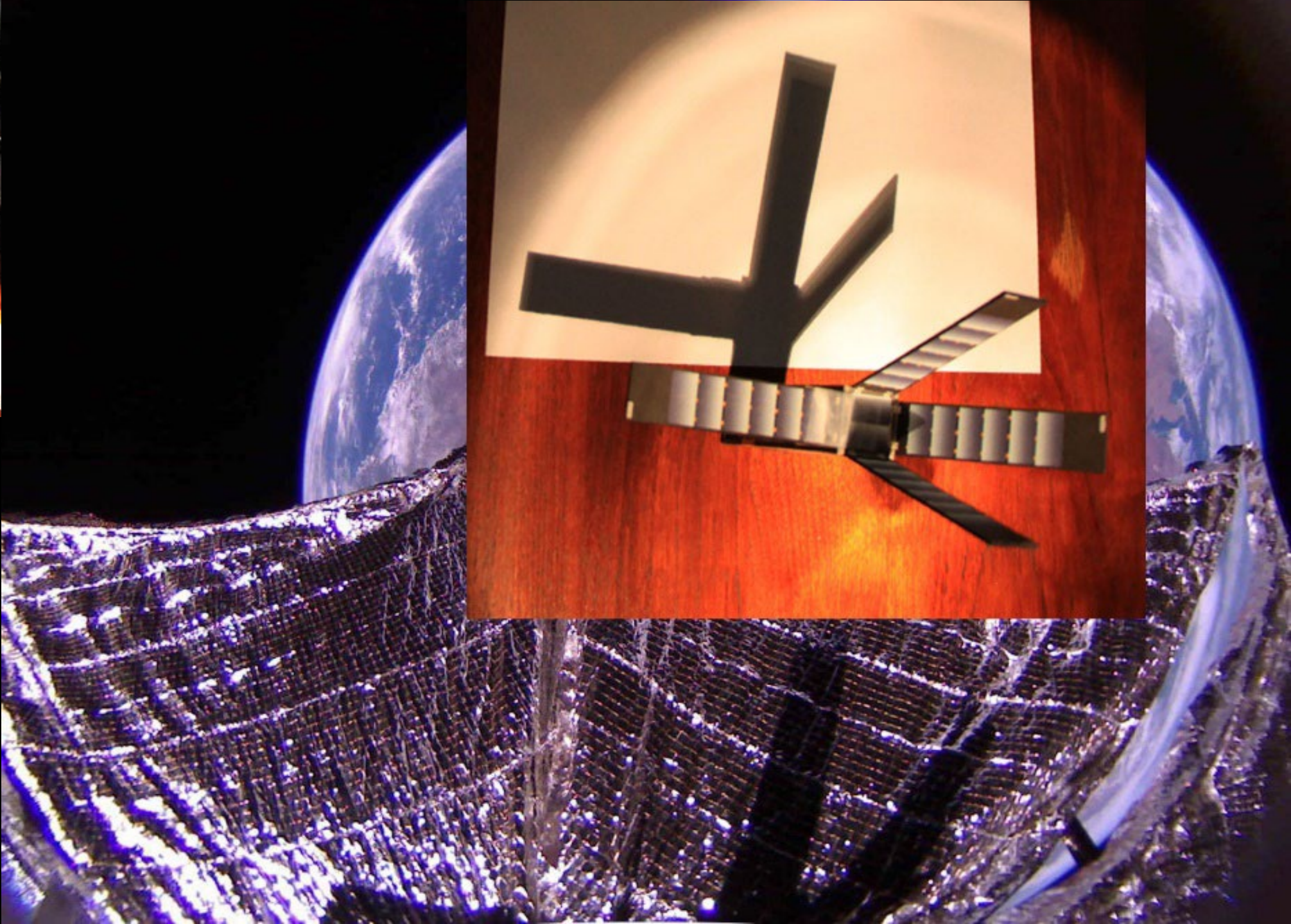
(Note for deployment, image acquisition was alternated between the cameras, so the exact timing of the images in the two movies does not match up)





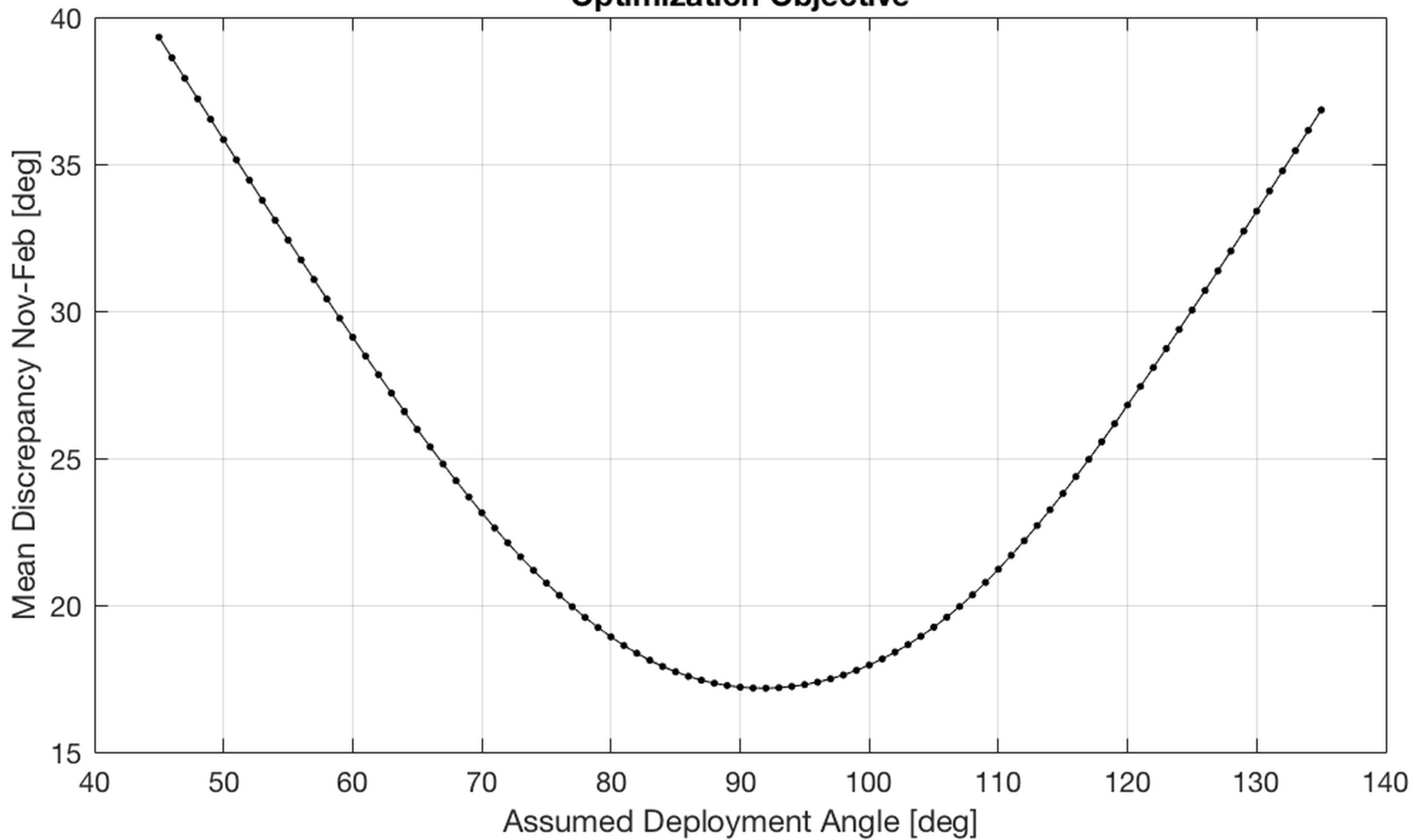


Anomalies detected through imaging included the incomplete deployment of a solar panel, which was then compensated for...



Eastern
Australia. N
at left.
Shadows
on sail.

Optimization Objective

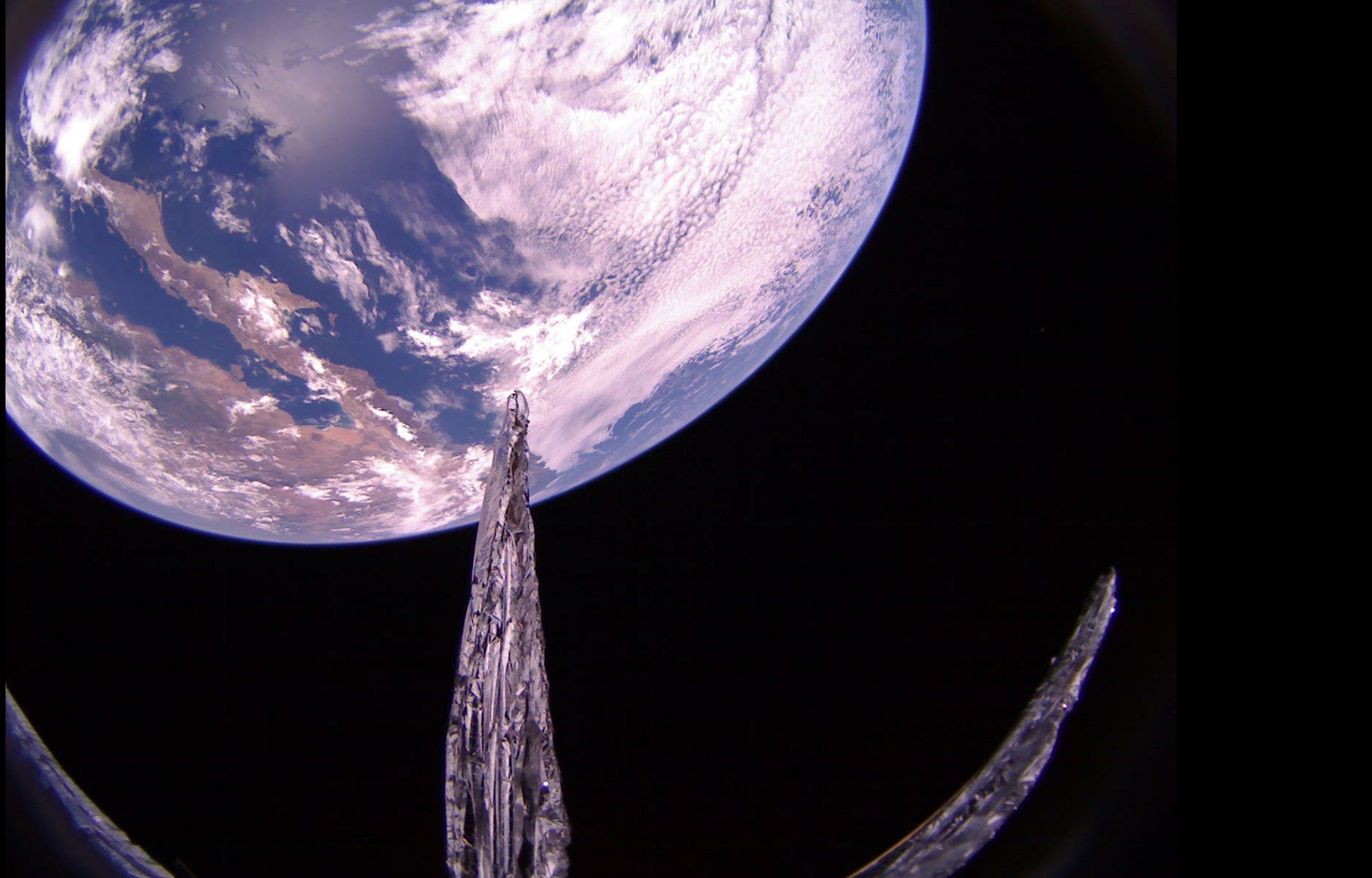


Buckled Boom Anomaly: Visible from Camera 2, one of the 4 spacecraft booms (-Y) buckled, seemingly in a Z-fold pattern, becoming worse over the first 125 days after deployment, then changing very little after that.

07/23/19
D=0
deployment



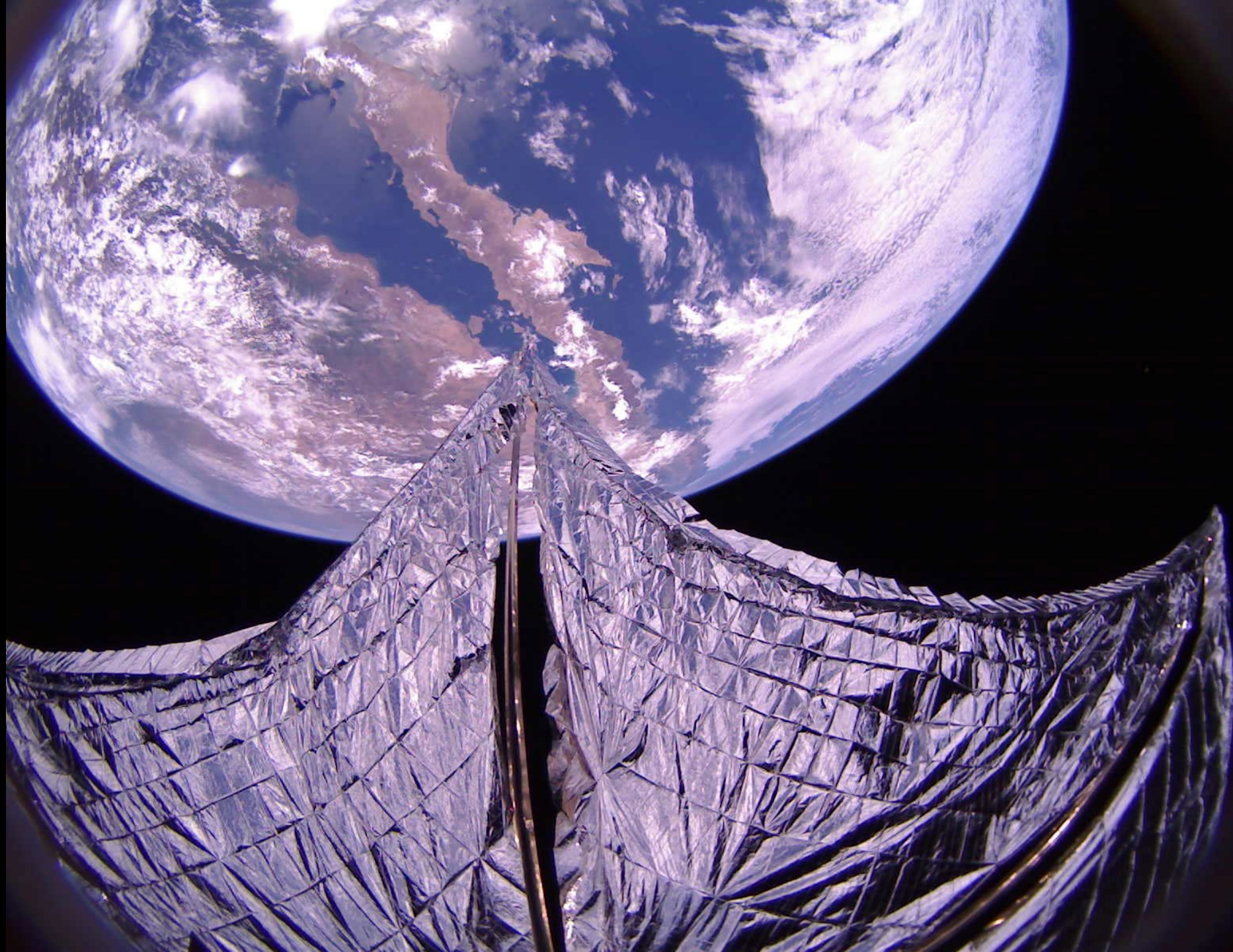
07/23/19
deployment



07/23/19
deployment



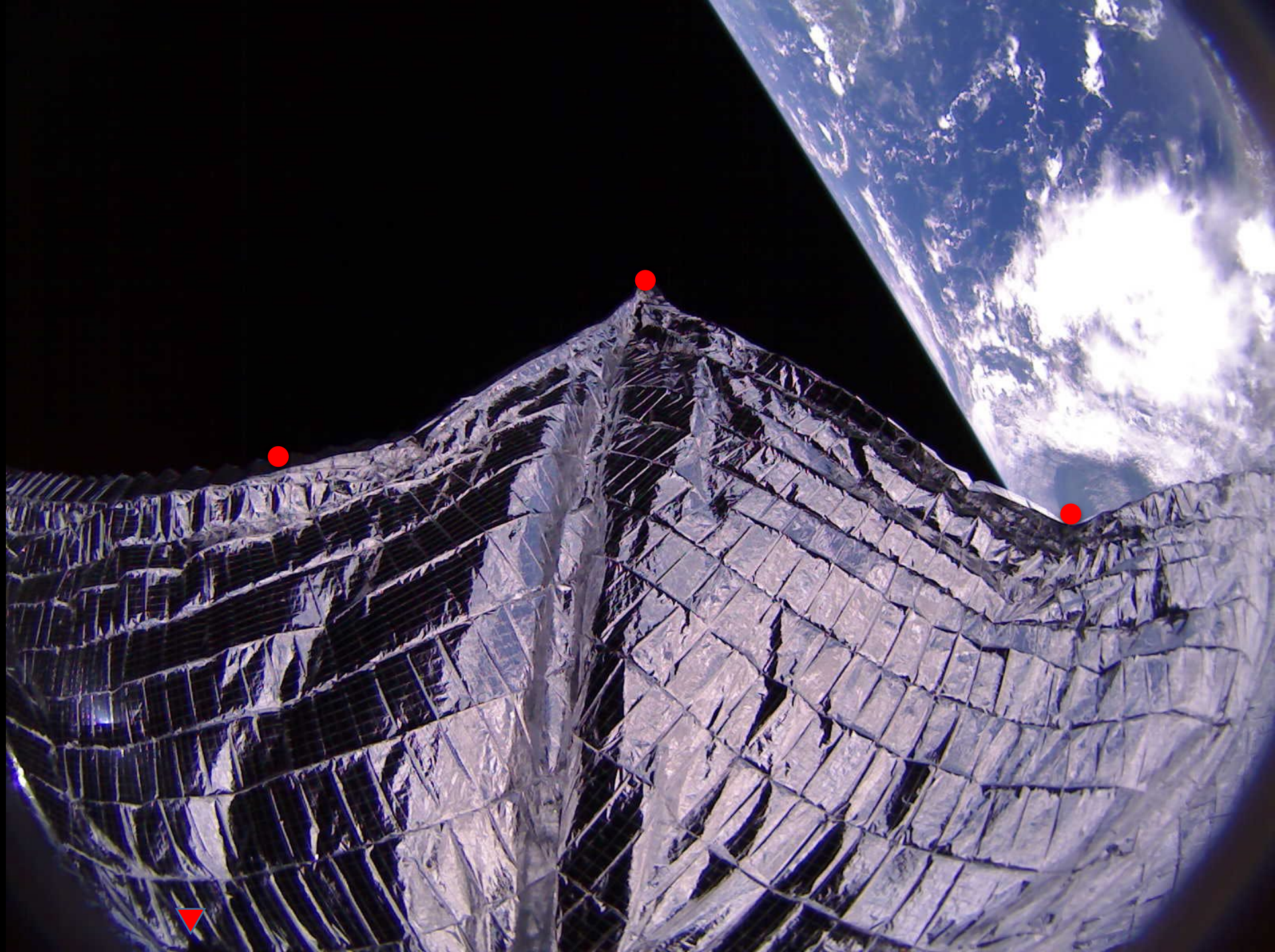
07/23/19
deployment



07/23/19

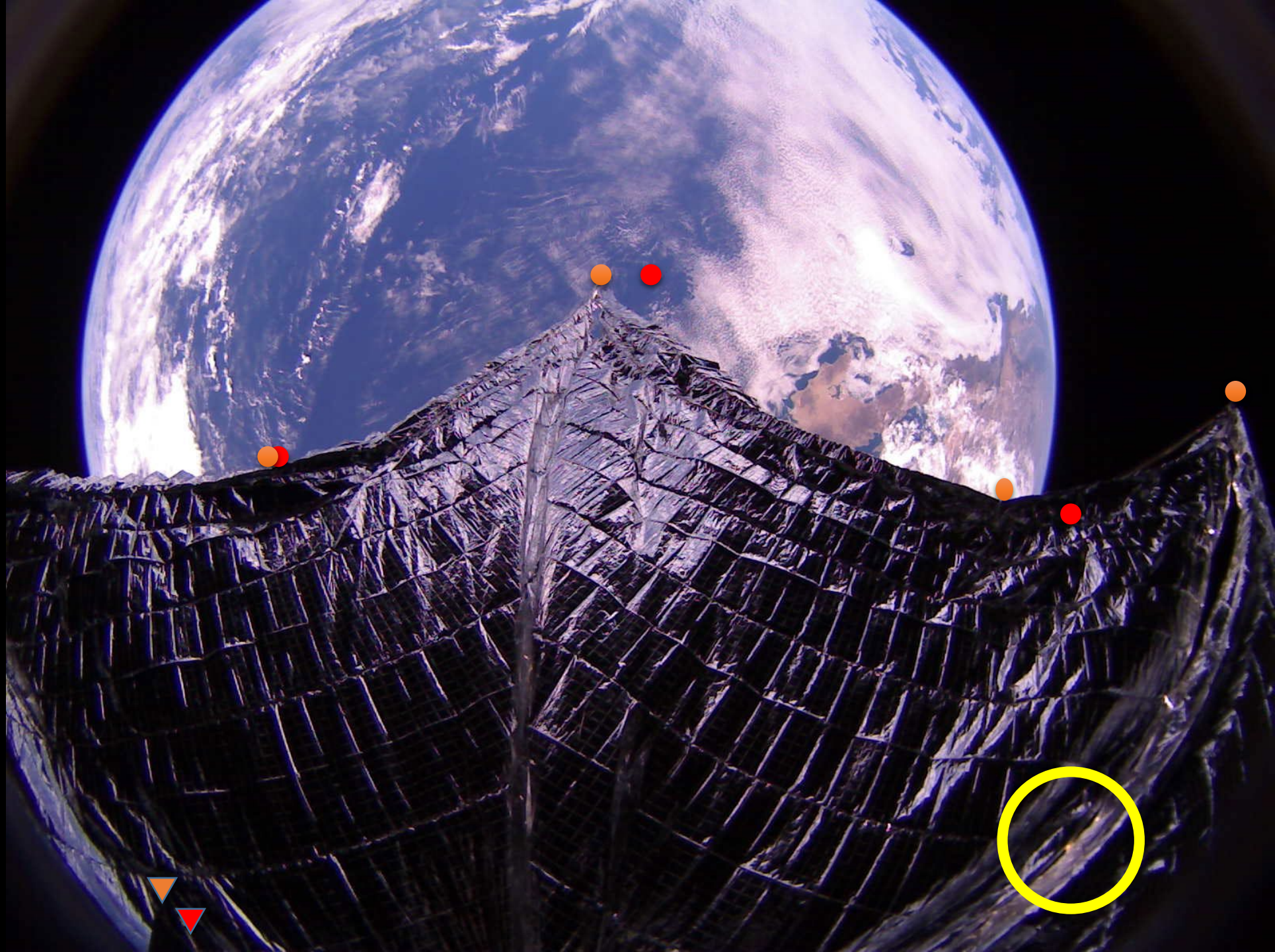
D=0

Fully
deployed
sail with
red dots
indicating
tip of center
boom (-X),
right boom
(-Y), and
shortest
sail point
between.
Triangle is
not fully
deployed
+Y panel.



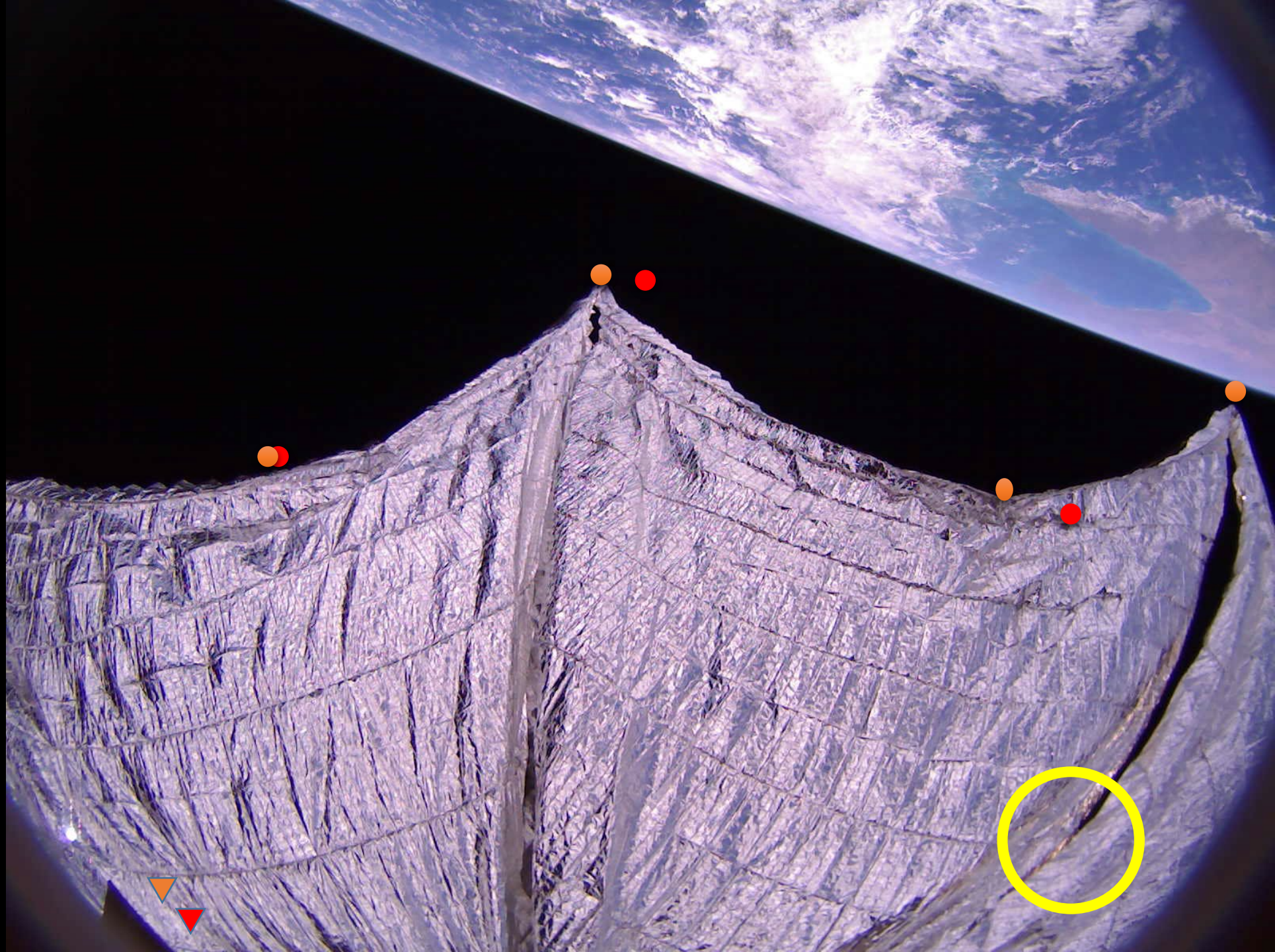
● ?

07/31/19
D+8
Compare
orange
dot
positions
(this
image)
with red
dots from
D=0.
Triangles
are +Y
panel
corner

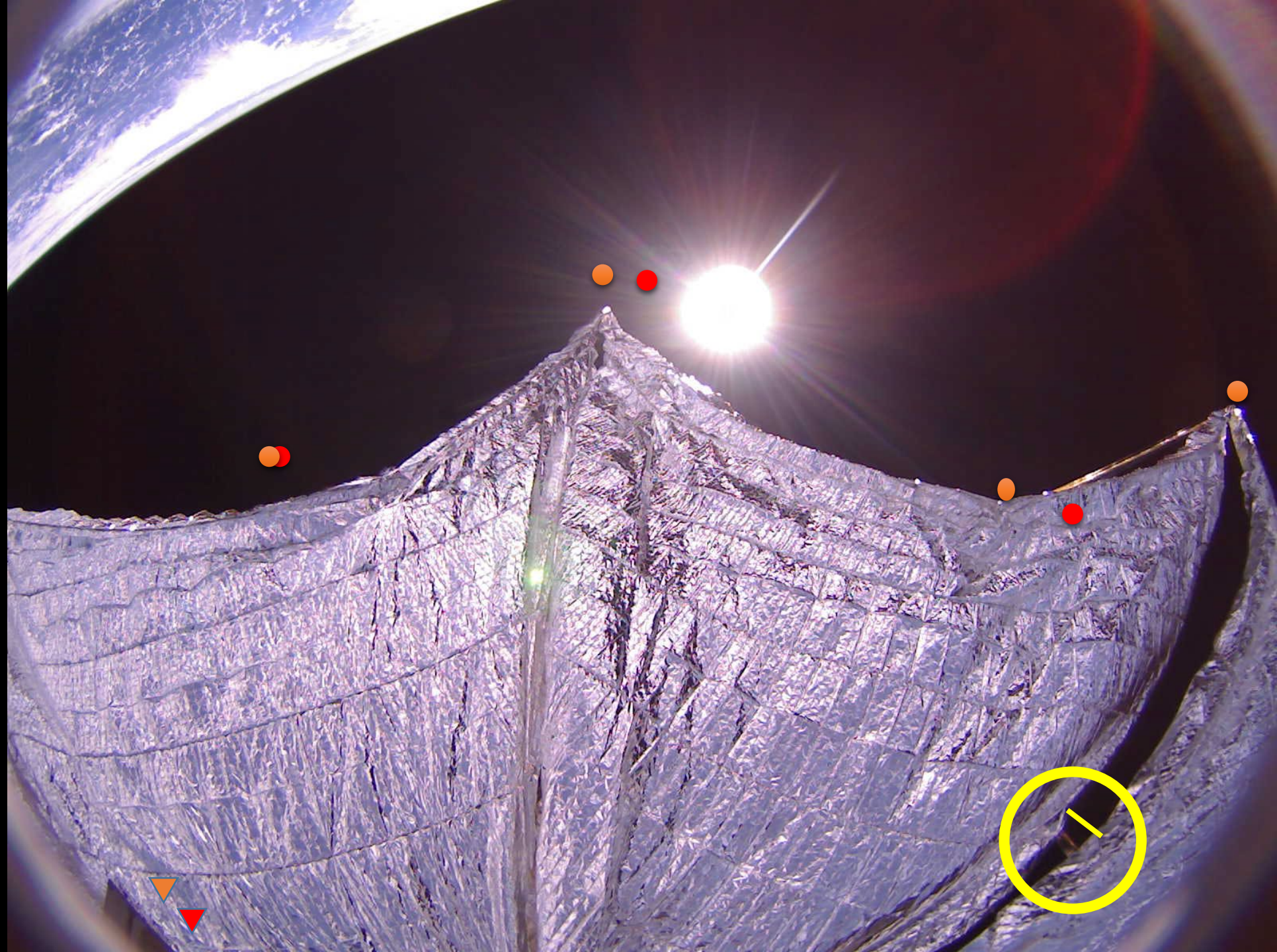


08/29/19
D+37

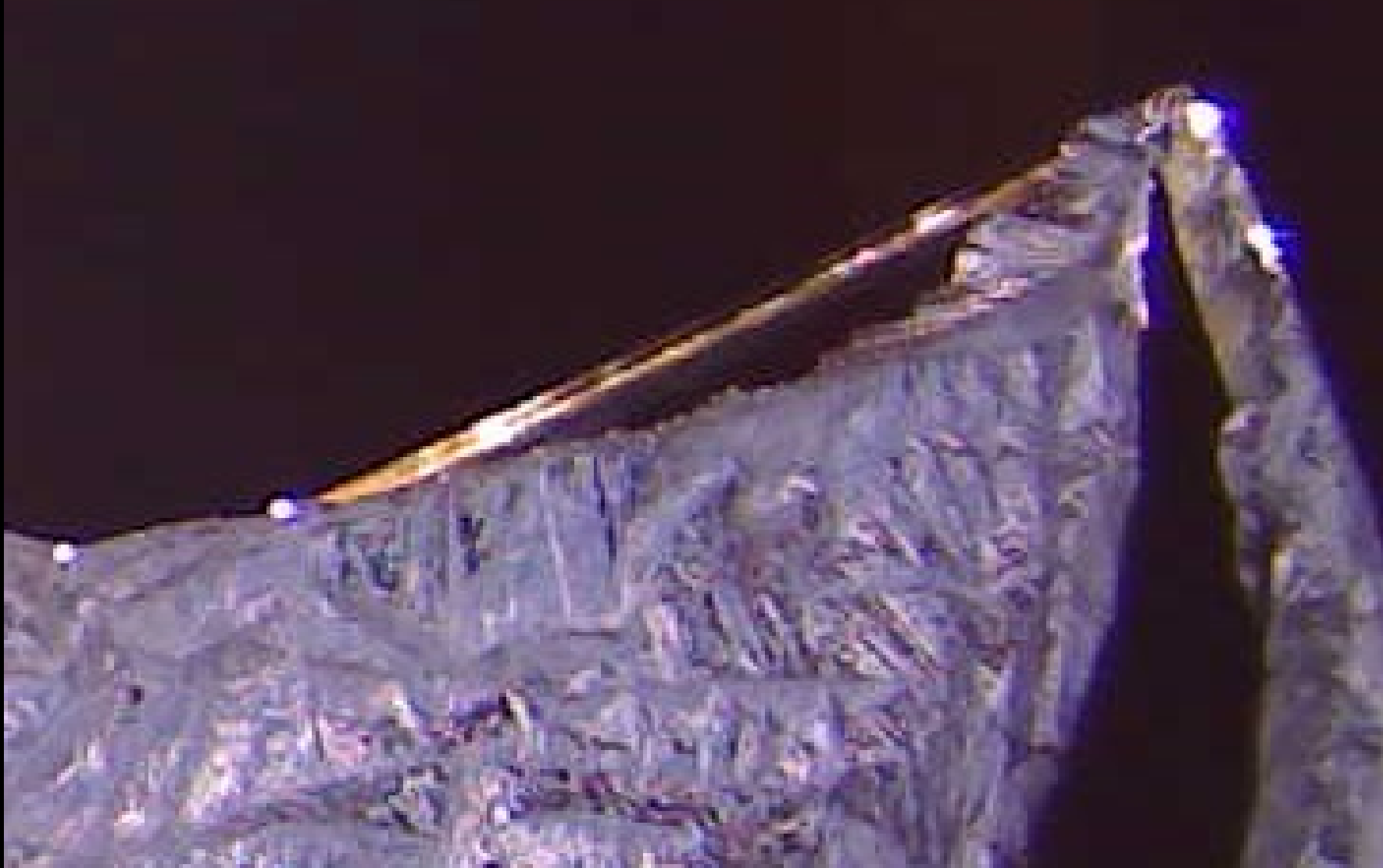
No boom
change.
Gap
opening.
Significant
+Y panel
movement

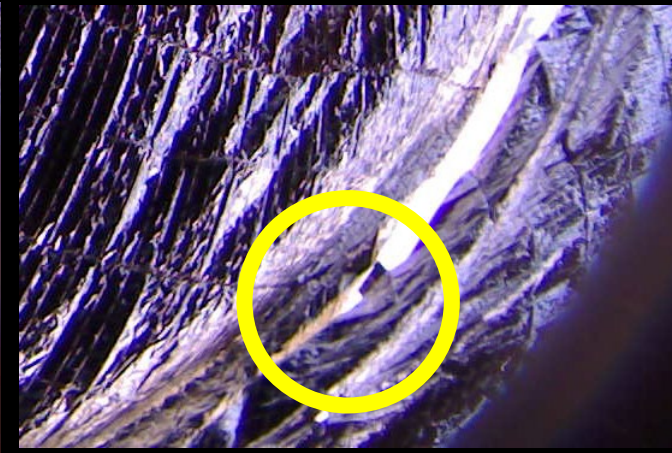
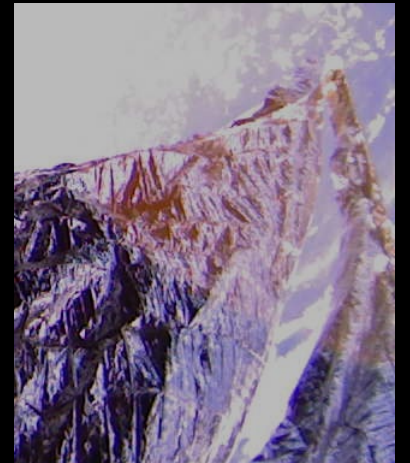
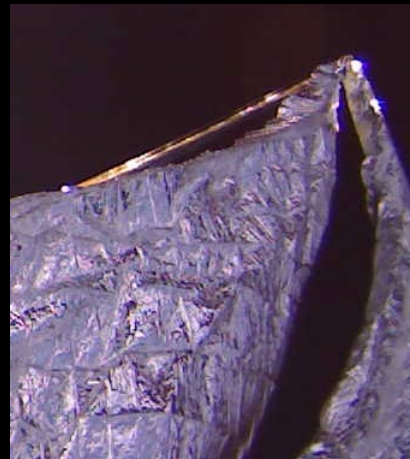
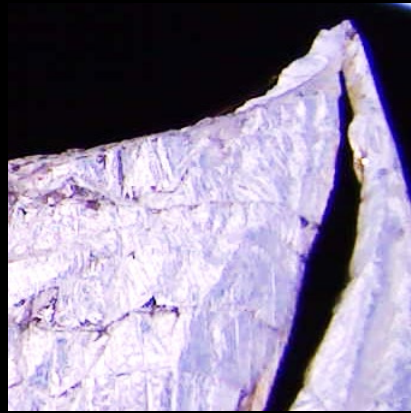


09/02/19
D+41
Gap
opening.
Note
orthogon
al boom
segment
parallel to
yellow
line.



- In the previous image (9/2 D+41) we see the now very obvious linear feature parallel to the sail edge connecting to the boom tip. This is the last image in which it appears.





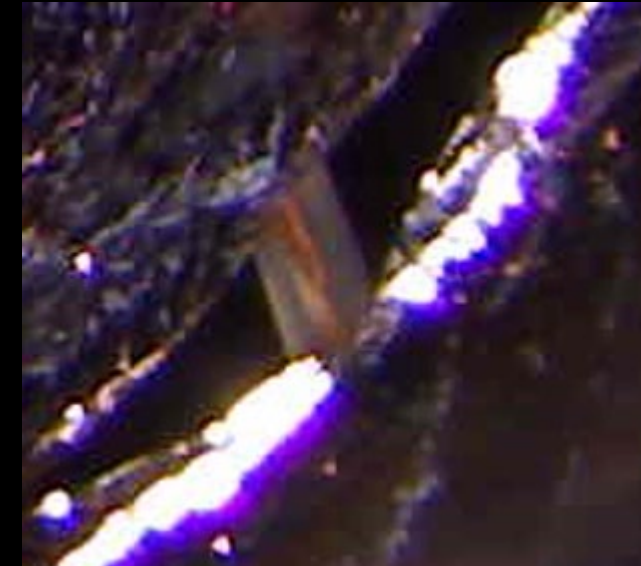
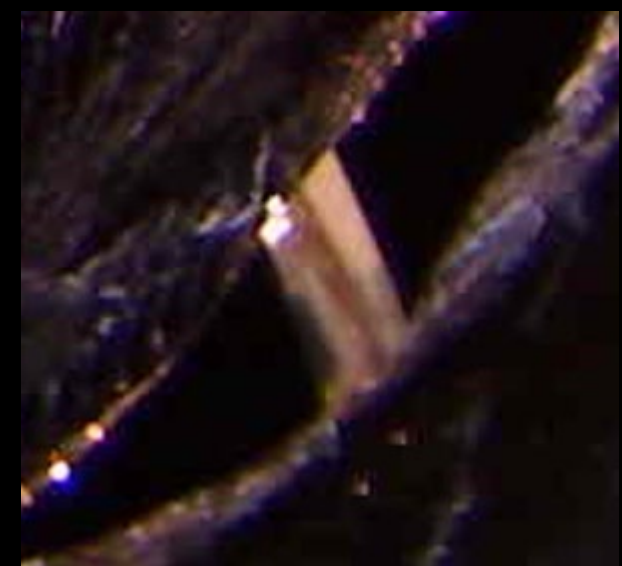
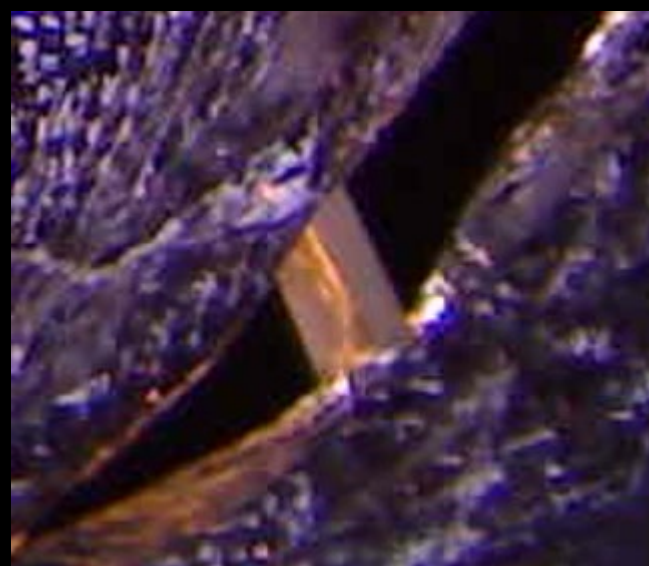
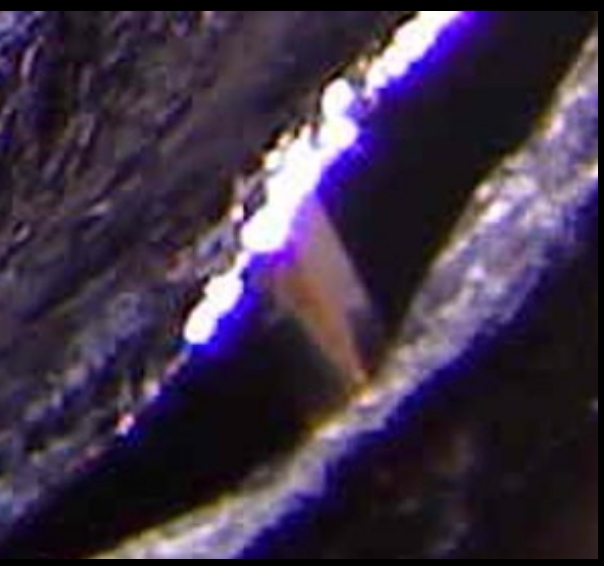
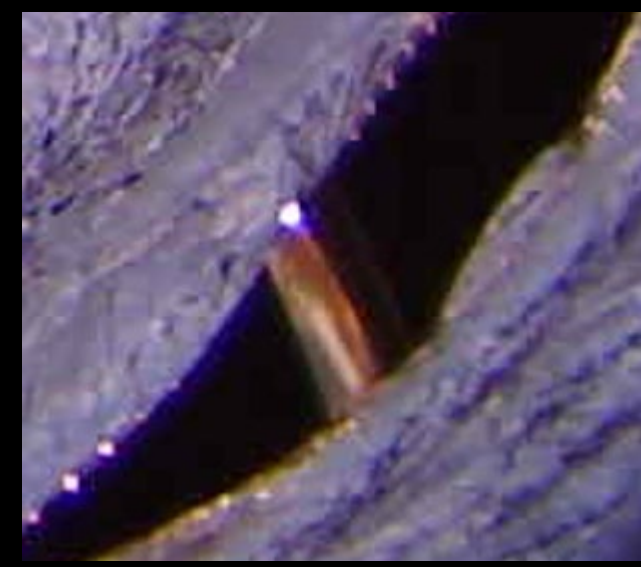
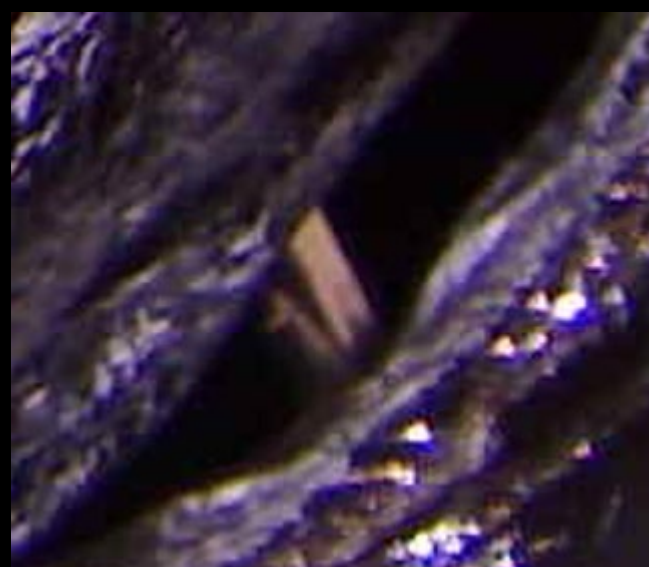
7/31 D+8

8/29 D+37

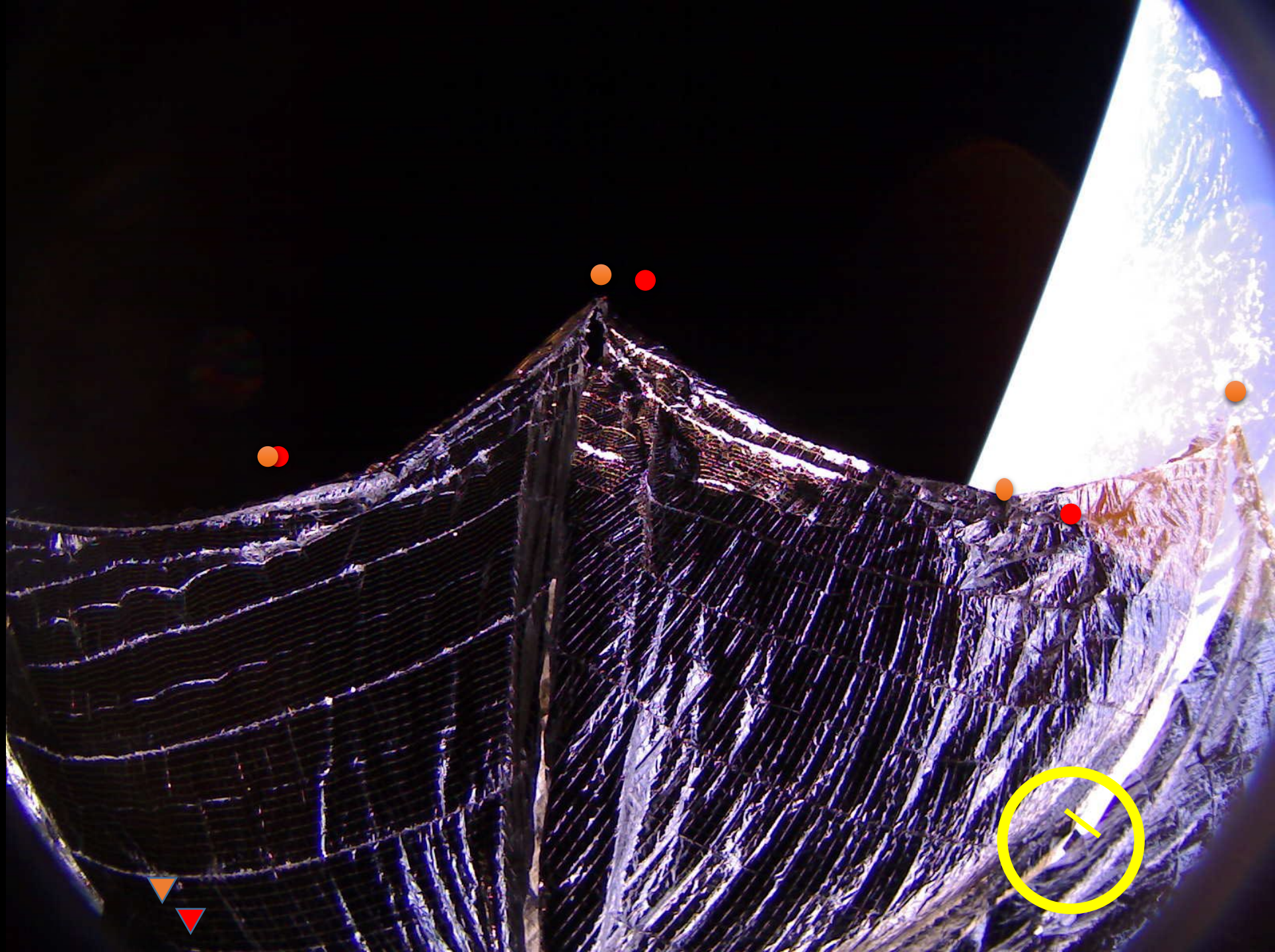
9/2 D+41

9/3 D+42

The “buckle” throughout the mission: interpretation – boom is bent not split?



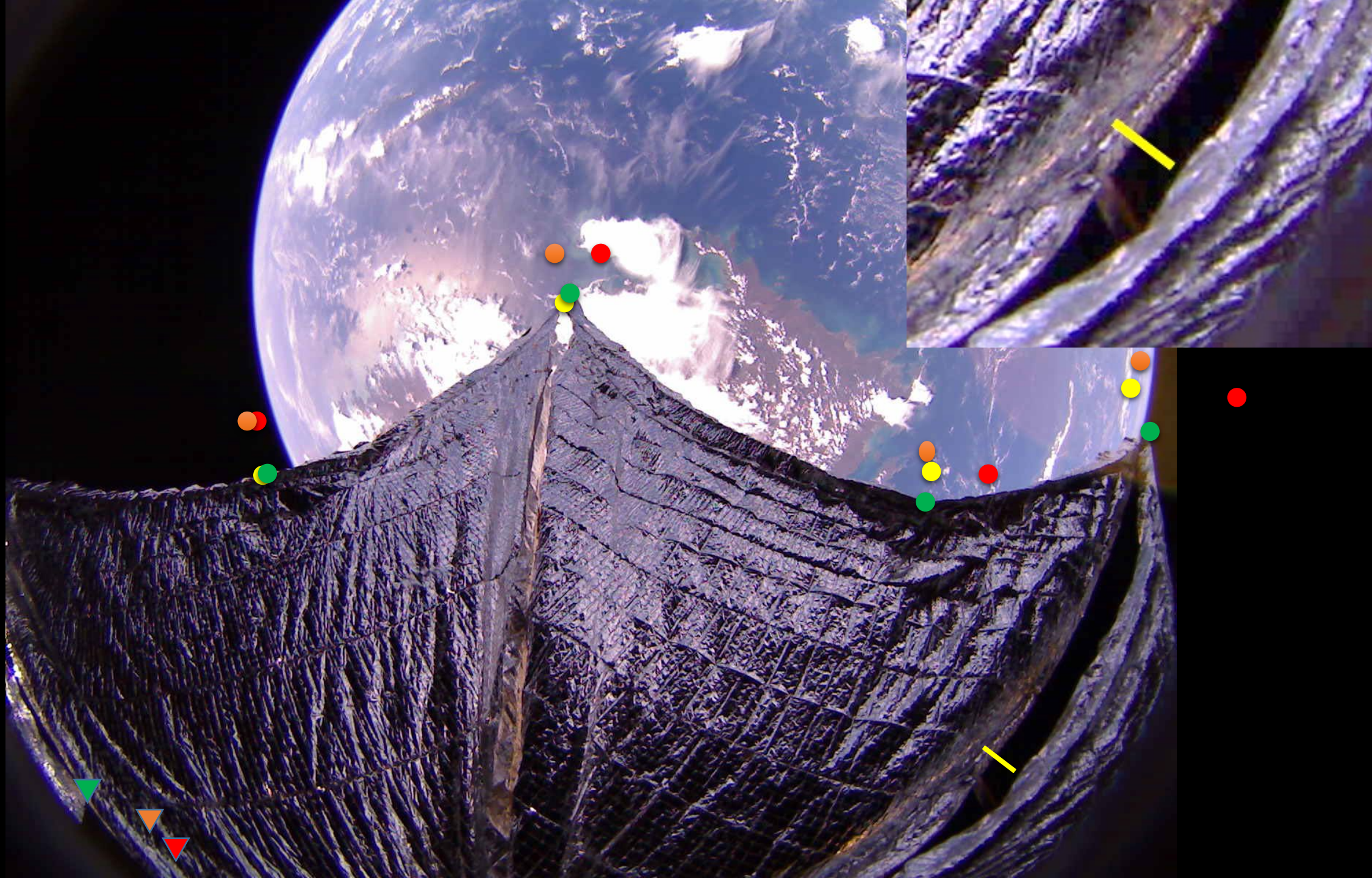
09/03/19
D+42.



09/28/19
D+67.
Orange
dots are
still 7/31.
Orthogon
al boom
segment
below
yellow
line.
New
yellow
dots for
future
comparis
ons.



11/25/19
D+125
Yellow
dots are
still 9/28.
New
green
dots for
future
comparis
ons.



● D=0
(end of
deploy)
07/23/19

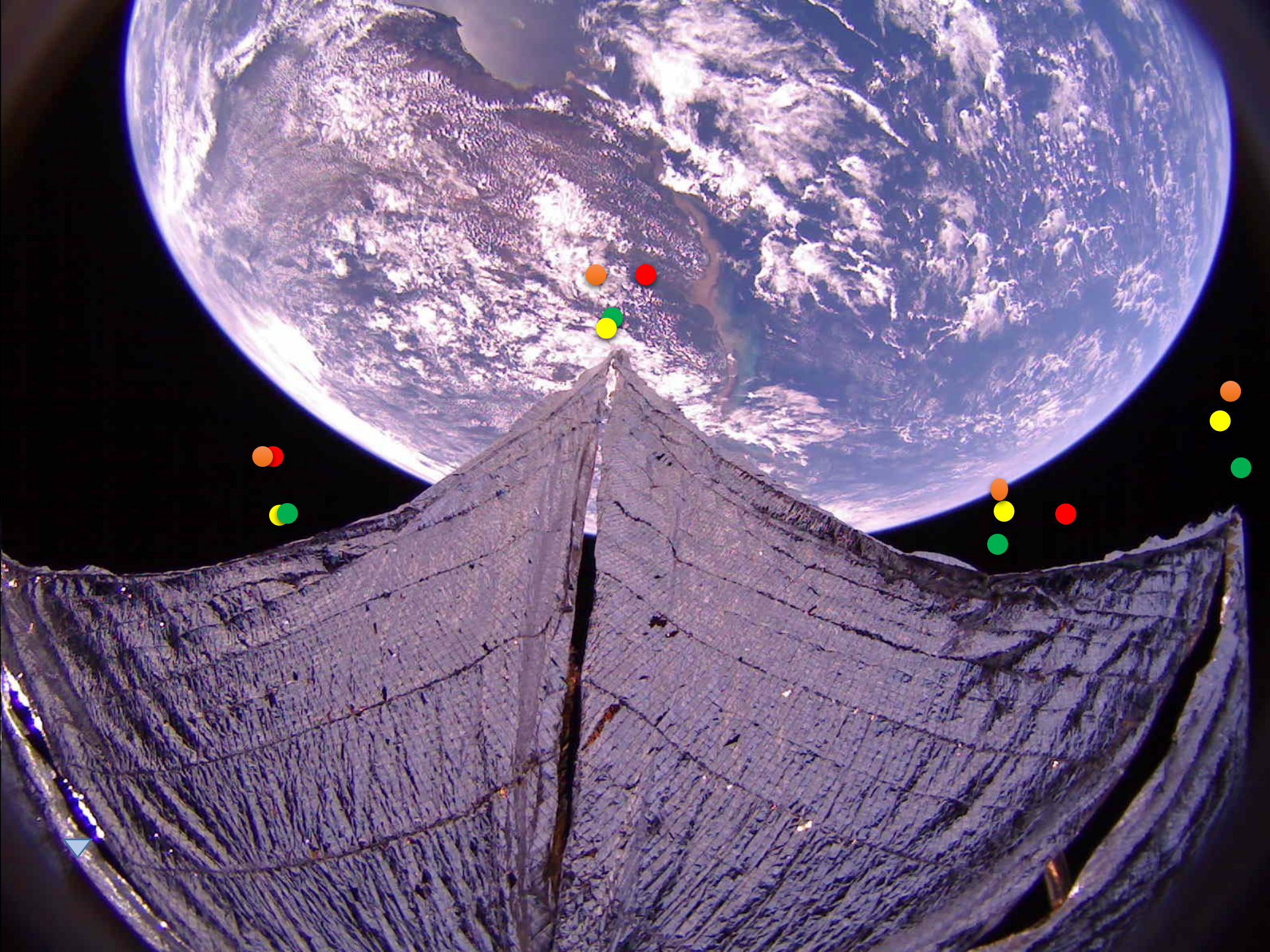
● D+8
07/31/19

● D+67
09/28/19

● D+125
11/25/19

D+577
02/19/21

Camera
2

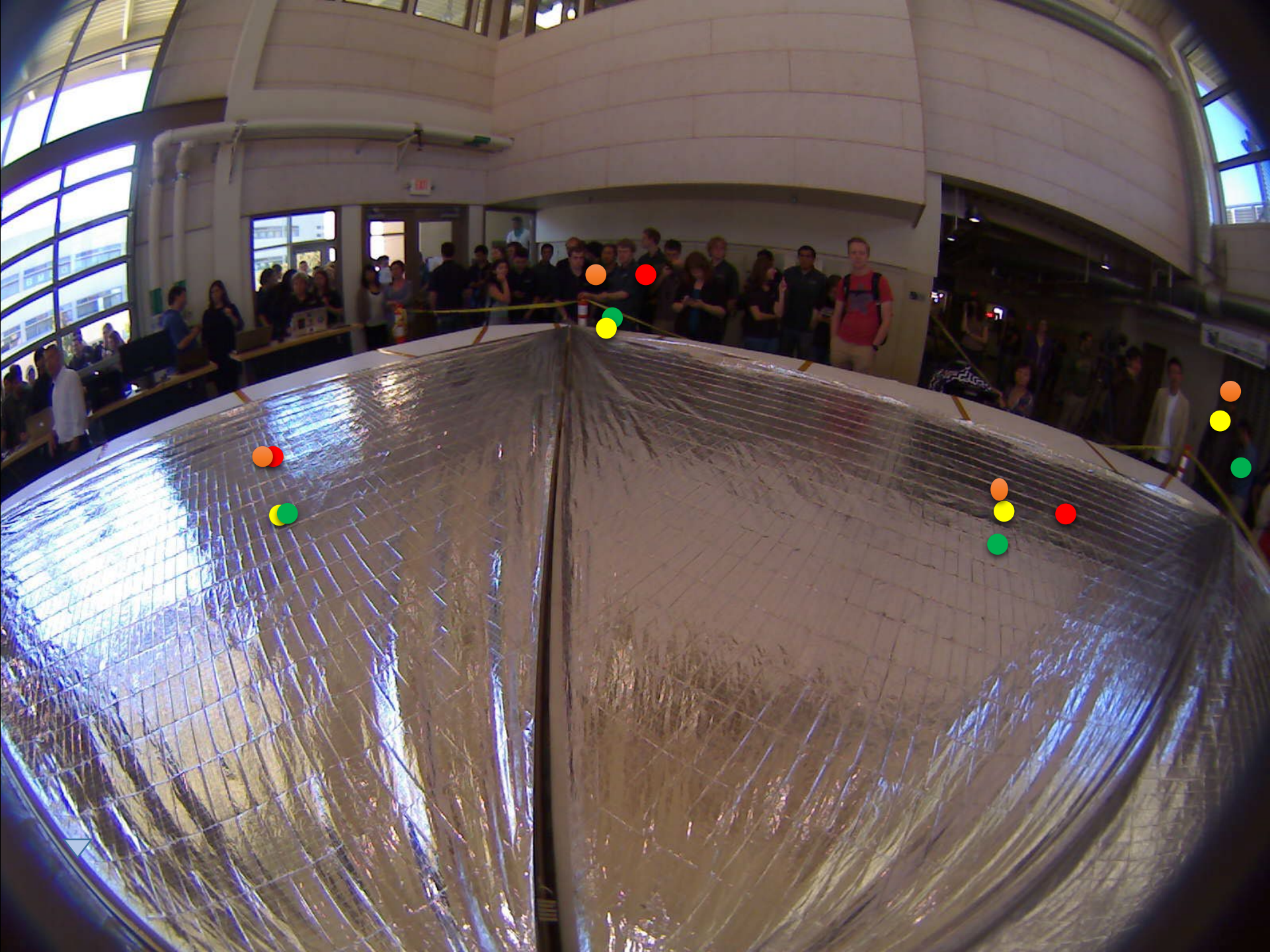




D+1189
10/24/23

Comparisons with Ground Test Image

Deploy
test.
Camera
2.
On-orbit
Camera 2
dots are
shown.



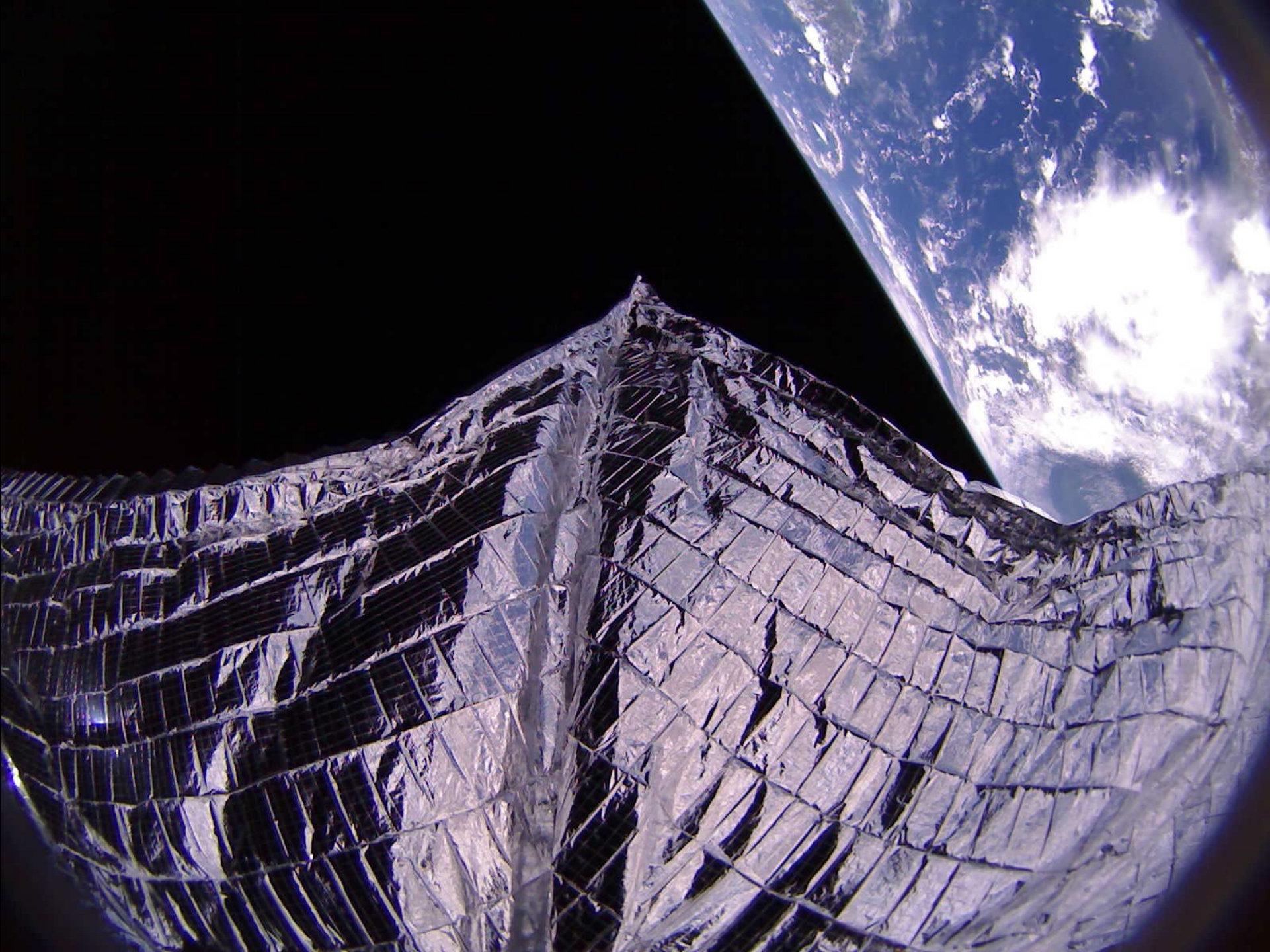
Summary of Boom and Sail Movement

- Visible from Camera 2, one of the 4 spacecraft booms (-Y) buckled, becoming worse over the first 125 days of the mission then stabilizing
- Over time, the angle of the plane of the sail shifted systematically as seen in both cameras.
- Small variations in boom position were also noted on timescales of minutes, likely due to thermal expansion and contraction of the Elgiloy booms.

**Sail degradation over the
course of the mission**

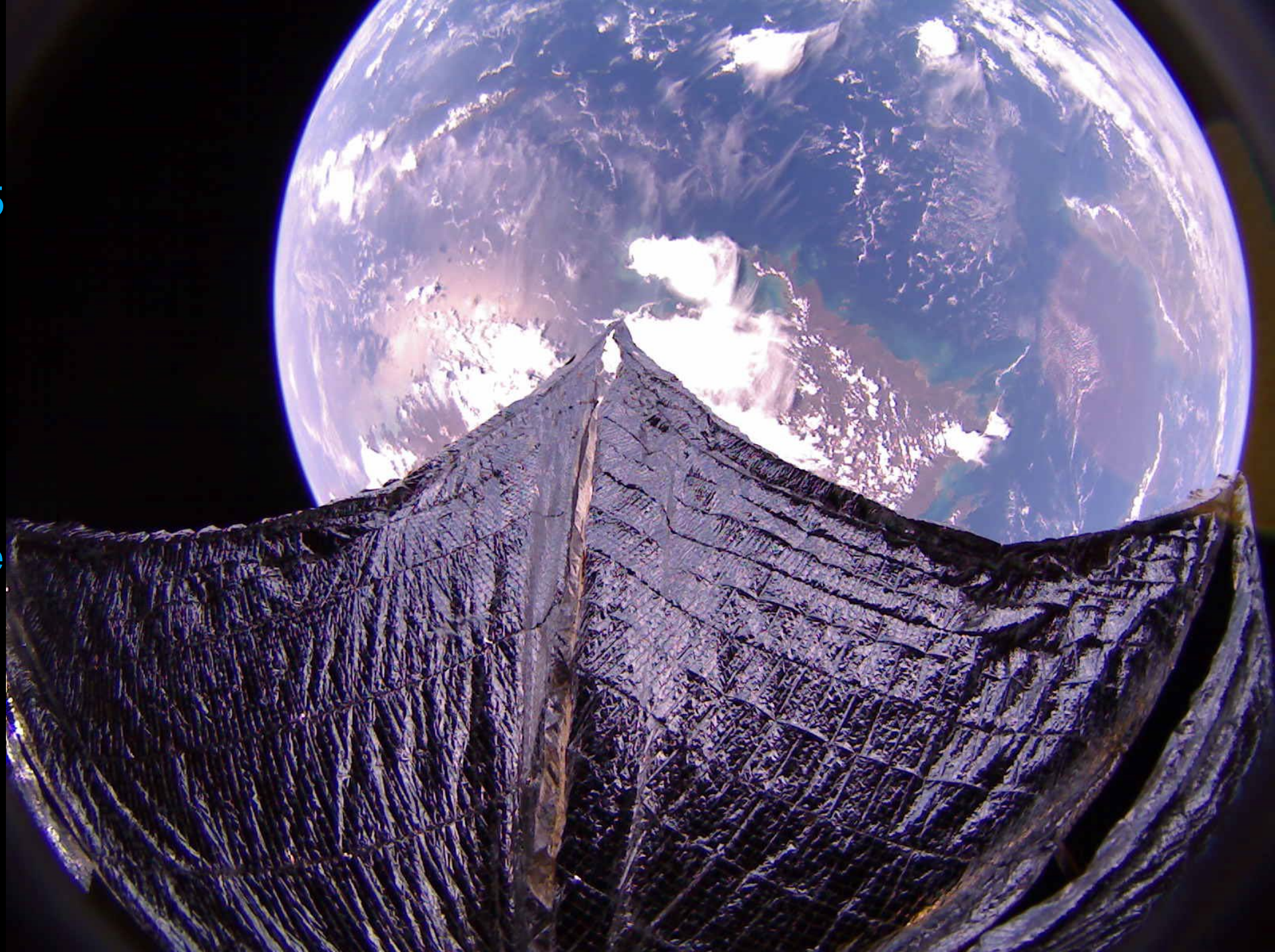
Crinkles appeared and got worse in the first weeks of the mission.

Shown here is a C2 image just after deployment.

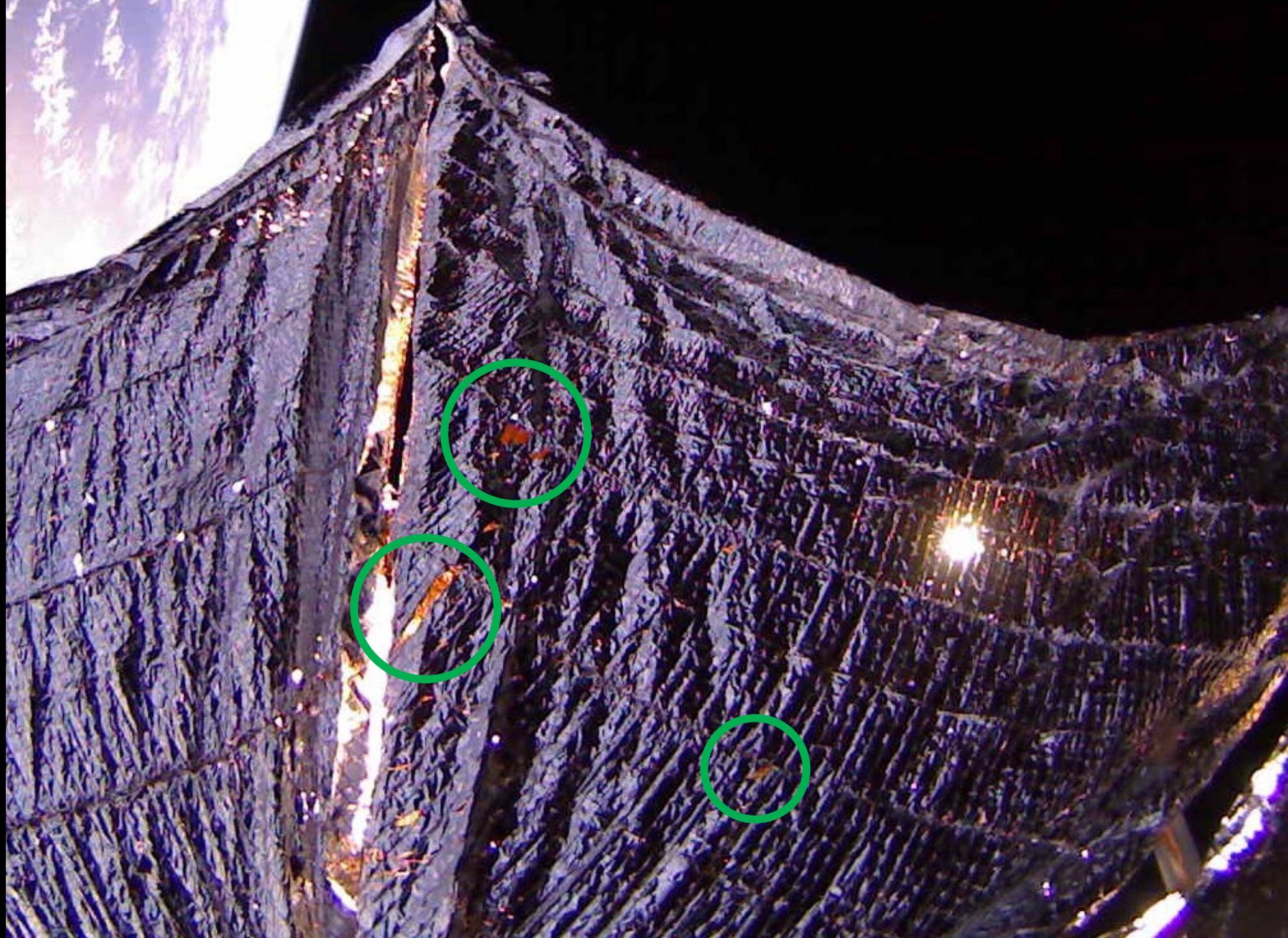


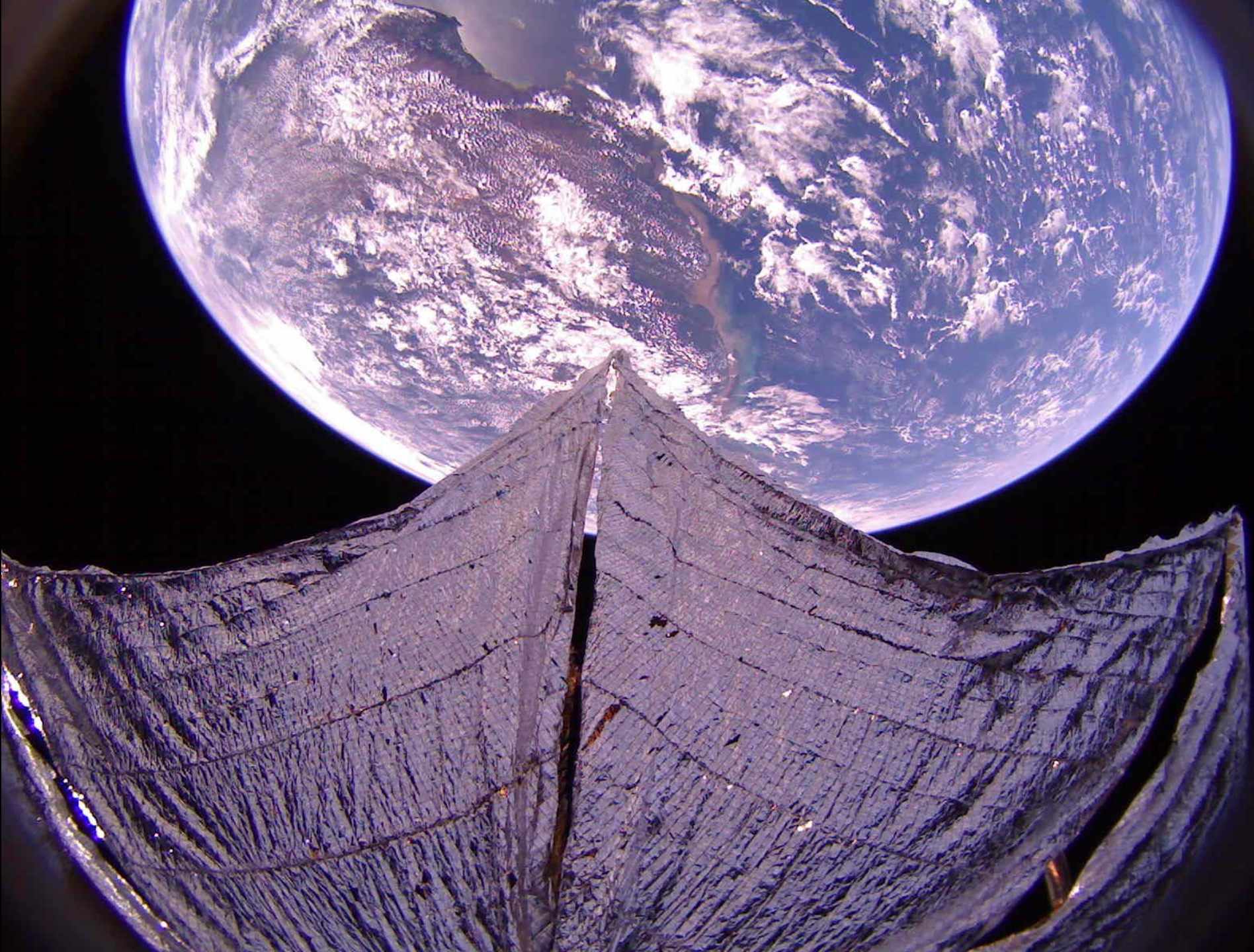
Shown here is a C2 image on D+125 11/25/19.

Compared to the last image notice the crinkles.



As shown in this C2 D+525 1/8/21 image, small areas, particularly on the camera 2 side, appear orange and to let light through more when lit from behind. They often appear darker than the surroundings when back lit. They appeared, most clearly months into the mission..





D+577
02/19/21



D+1189
10/24/23

Summary of sail degradation over the course of the mission:

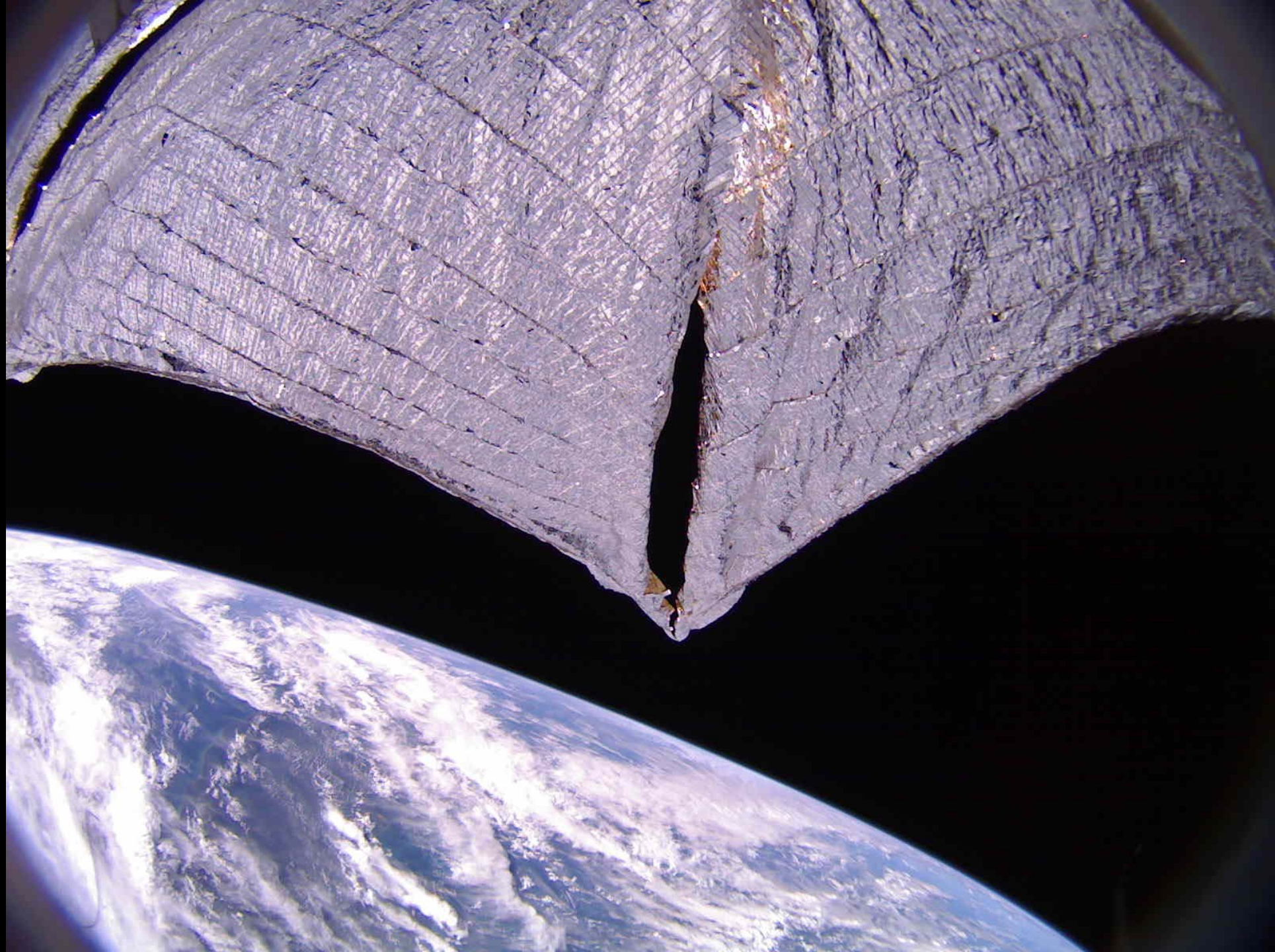
Several sail degradation processes were observed, likely mostly caused by atomic oxygen at the approximately 700 km altitude of most of the mission.

- Wrinkles developed within days to weeks then stabilized.
- Small areas of aluminum delamination and the development of small holes occurred over months to years.
- Sagging occurred over time but no loss of integrity predicted by some lab experiments
- Rip stop threads did seem to prevent very large holes

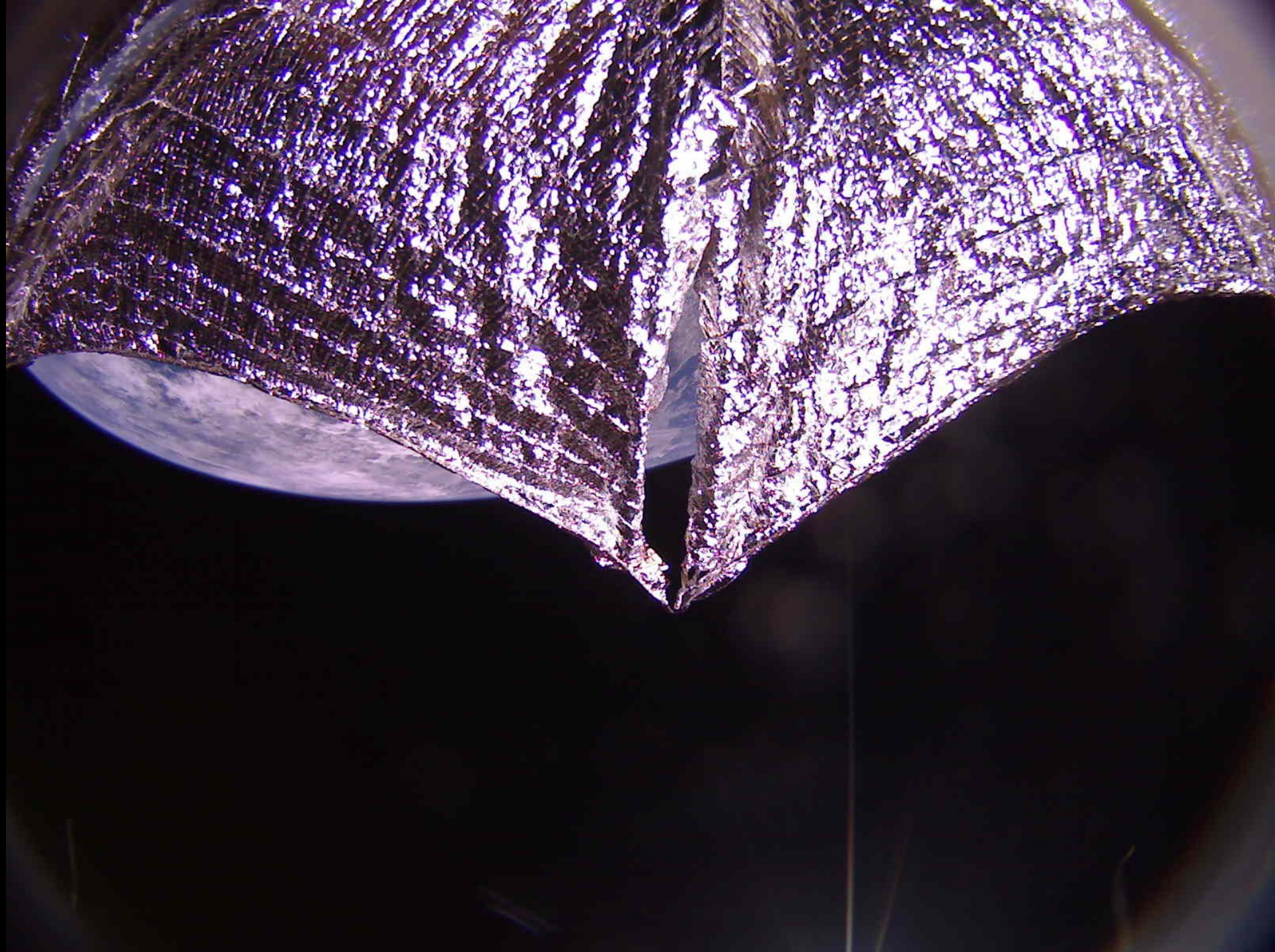
Mystery Spots?

LS2
Camera 1
12/4/20

No spots



LS2
Camera 1
12/10/20
OITL
Spots

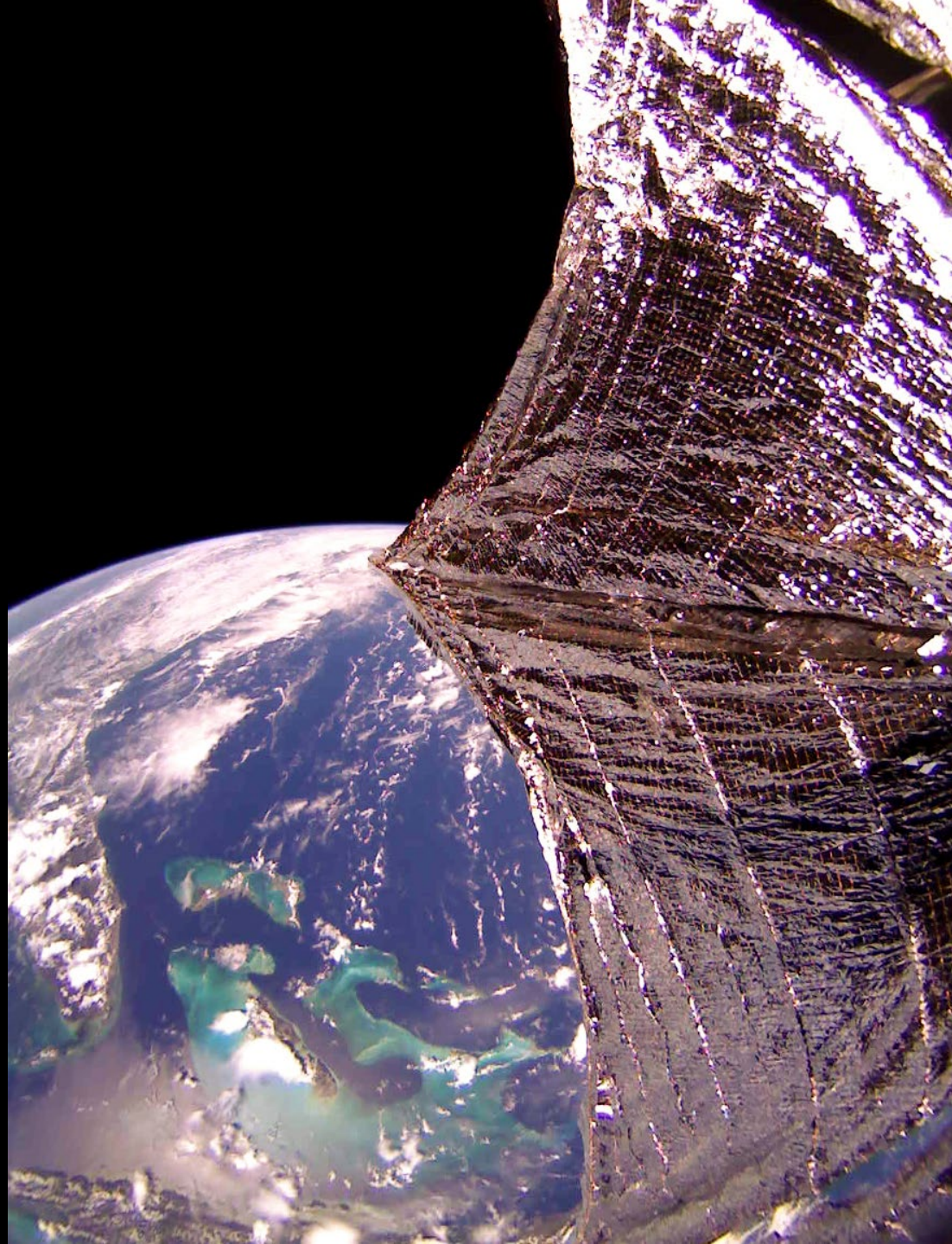


LS2
Camera 1
01/06/21
Spots



Images have also been extremely valuable for sharing the mission with the public. Stunning pictures raised awareness and developed interest in solar sailing from the public, the technical community, and space agencies.

8/16/20
Bahamas
U.S. East
Coast.
N at top



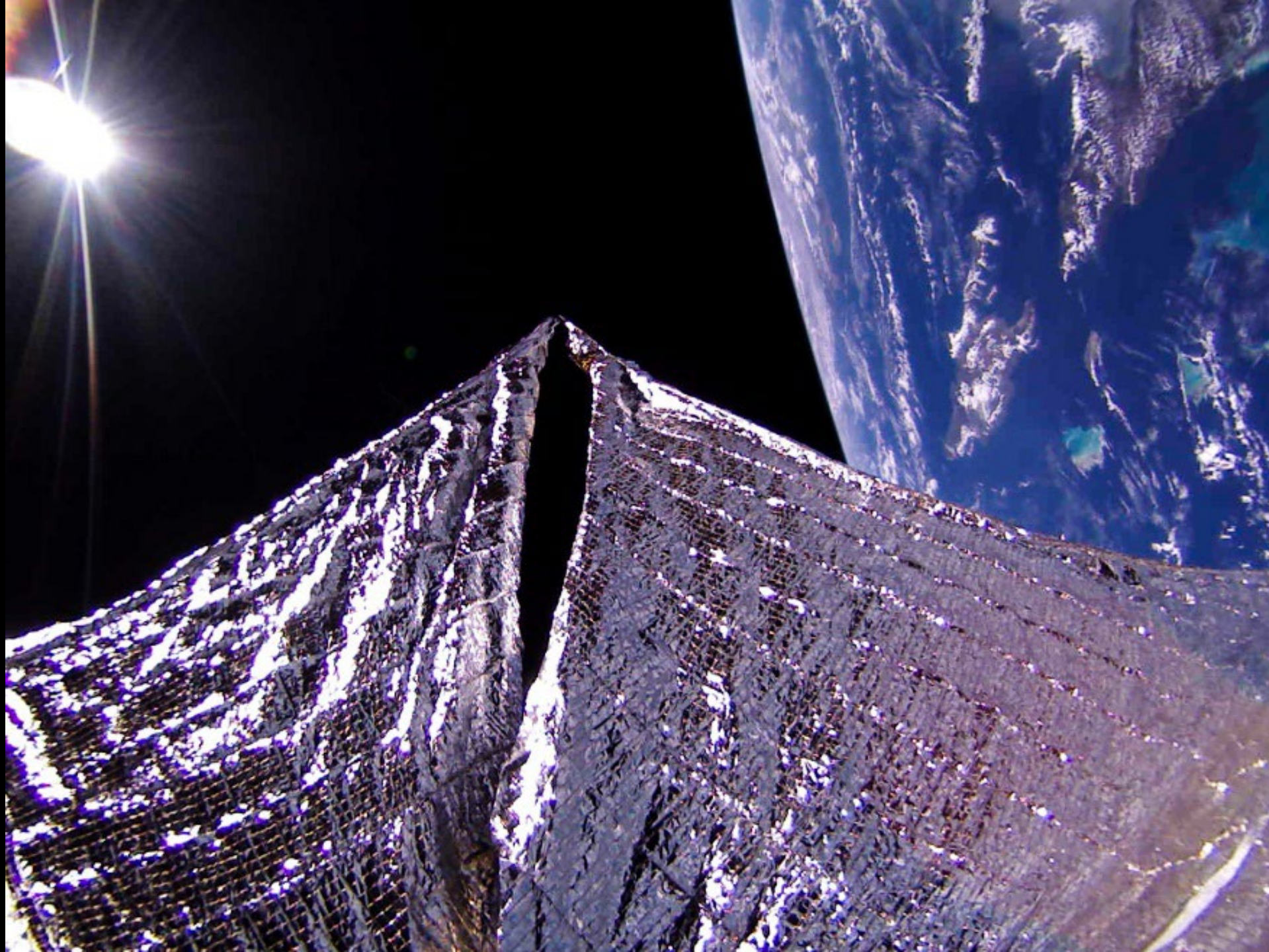
01/21/20
W. Coast
of India.
105839UT
N at right



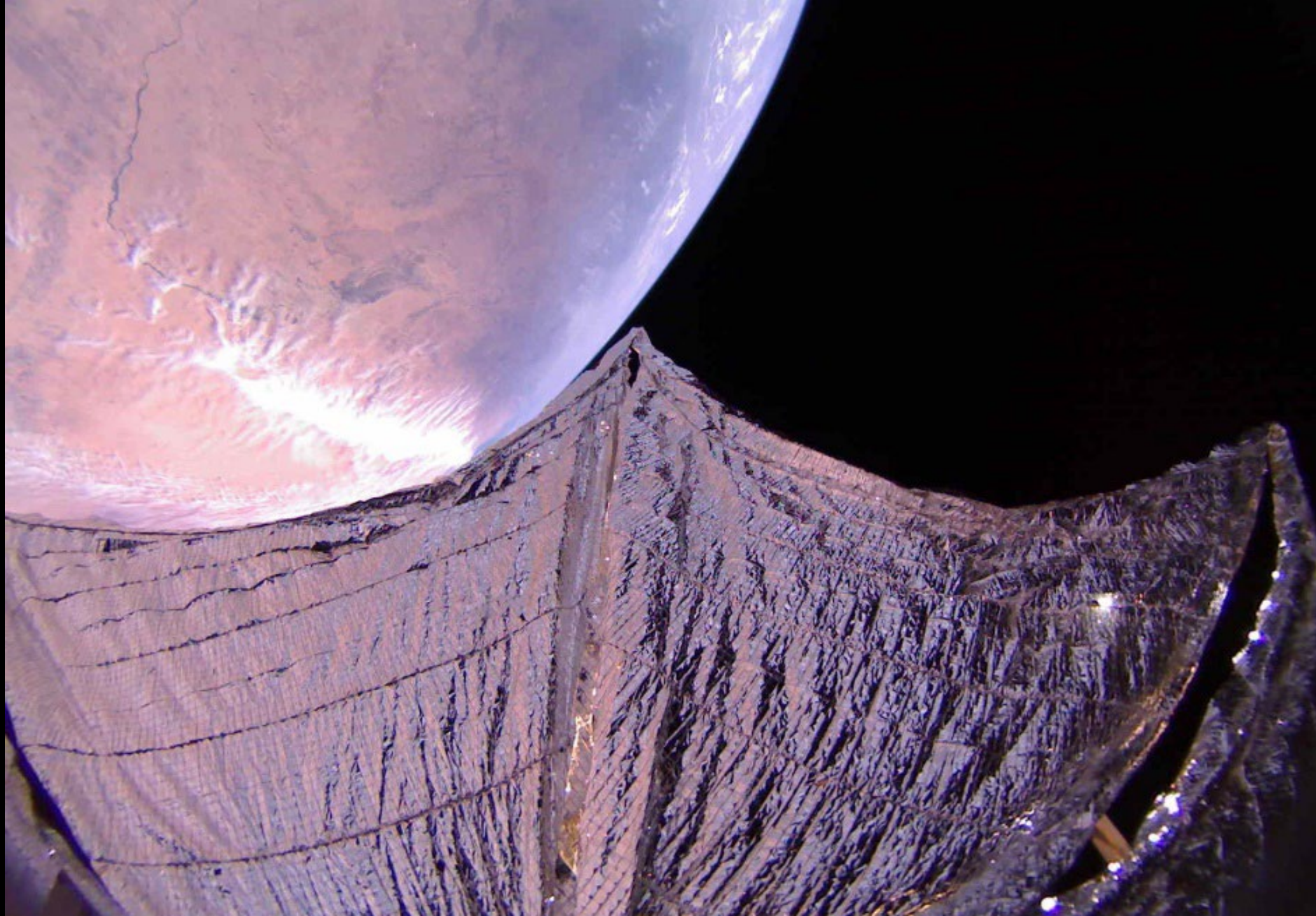
01/06/20
SW
Coast of
Australia.
N~at
lower
right



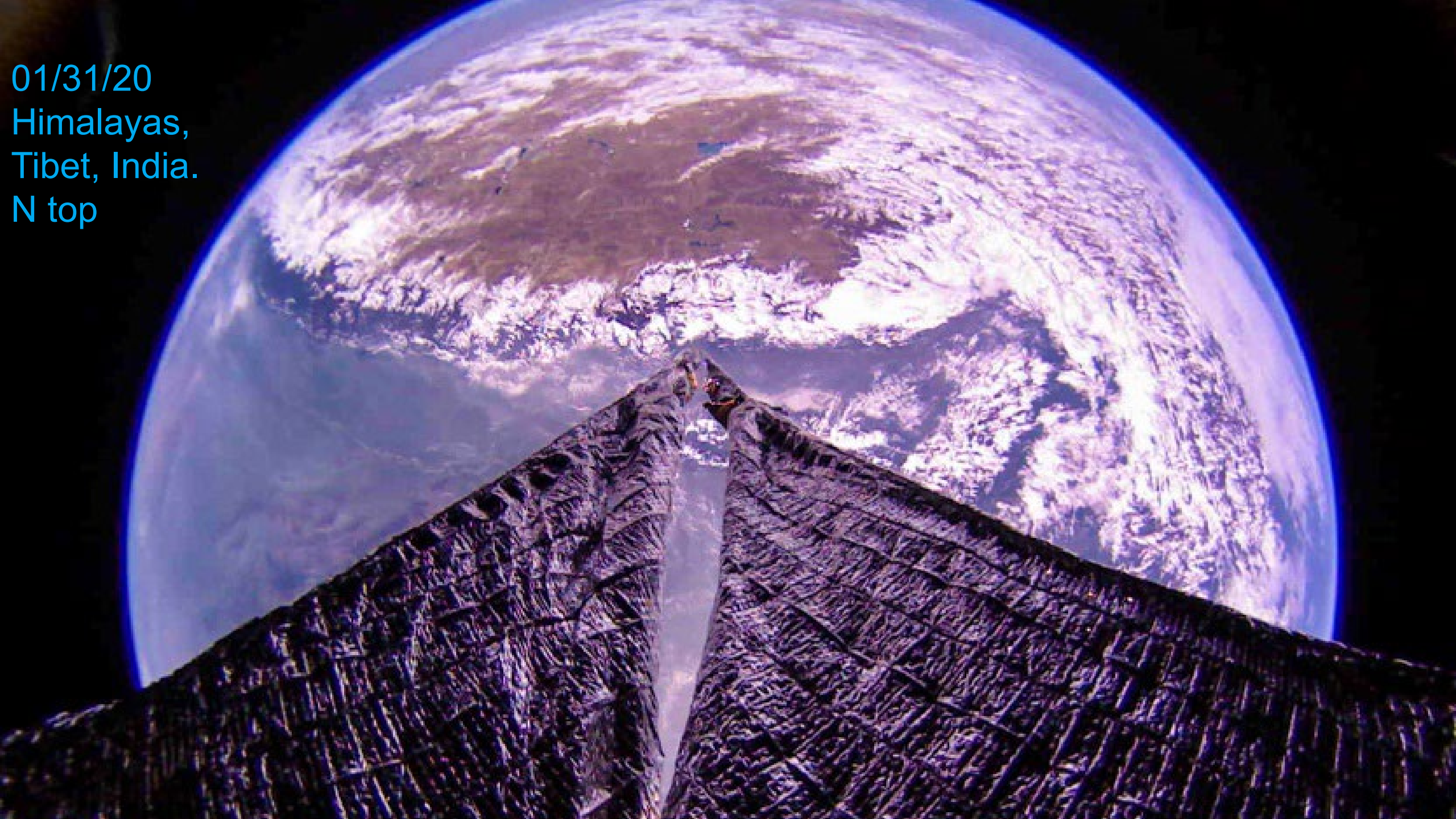
01/30/20
Caribbean.
East tip of
Cuba,
Hispaniola,
Turks and
Caicos.
N~at right



2/8/20
Western
Africa:
Mali,
Niger
River,
Burkina
Faso.
N at lower
left.



01/31/20
Himalayas,
Tibet, India.
N top



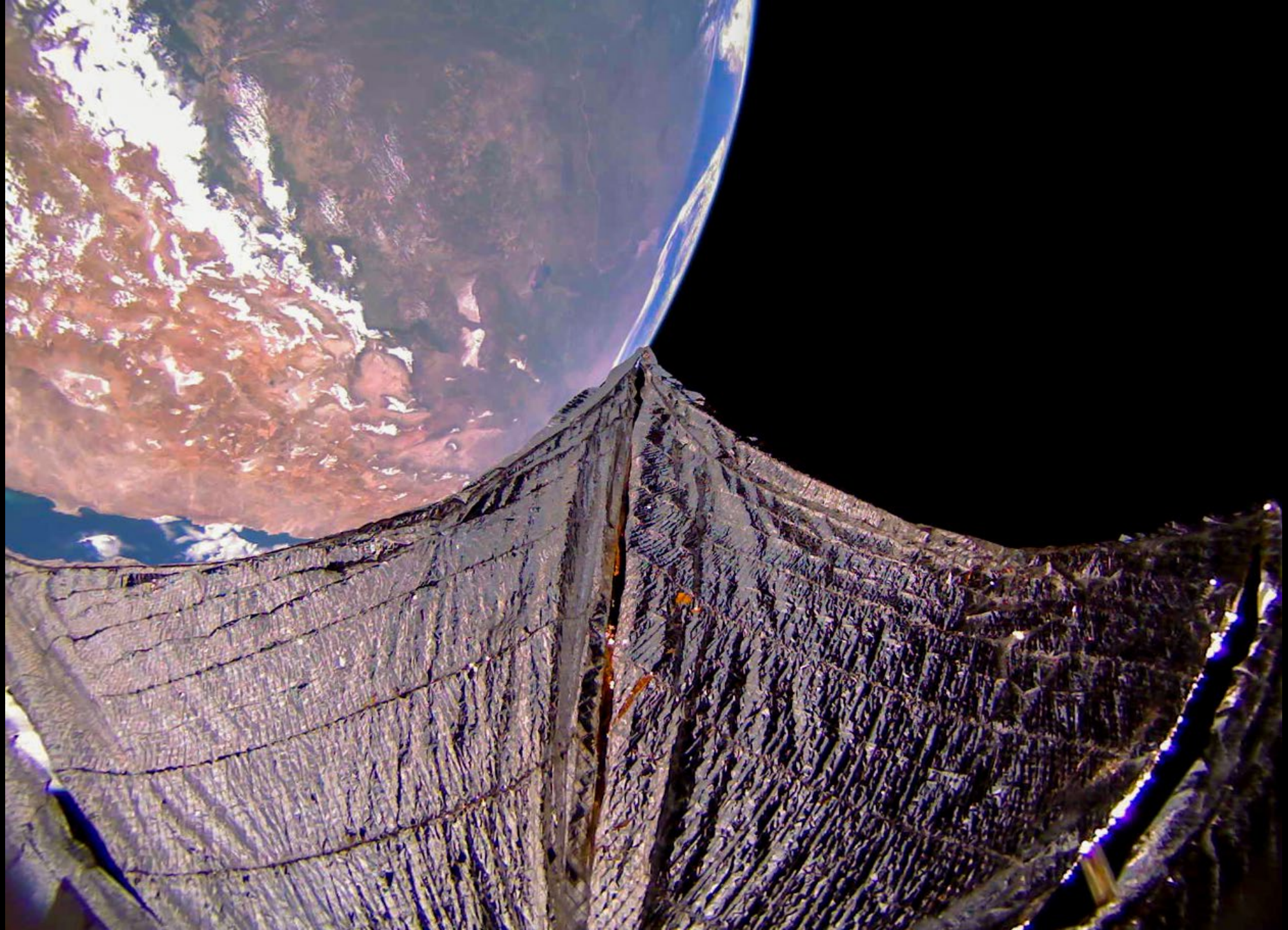
11/13/20
Typhoon
Vamco
and
Philippines
N at top



10/1/20
NW India
N left



2/20/21
Andes
N up left



2/27/21
Med. Sea
Red Sea
Nile
N top



The Planetary Society's LightSail 2 solar sail mission showed the enormous value of cameras to image the sails for engineering assessment and public outreach.



sail.planetary.org

Contact: bruce.betts@planetary.org