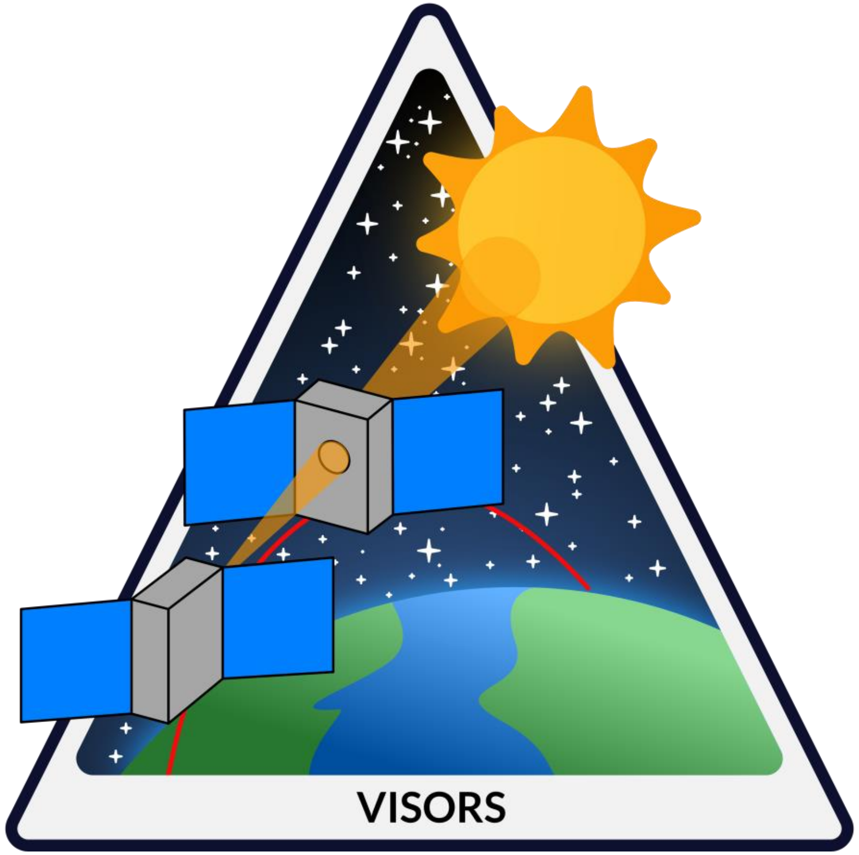


VISORS (**VI**rtual **S**uper-**O**ptics with **R**econfigurable **S**warms) Mission Overview

SSDL Meeting 11/16/2021

Maximilian Kolhof – Lead Student Systems Engineer

Institutions

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

NASA

Goddard Space Flight Center

Stanford

NM STATE

Georgia Tech

LASP

Laboratory for Atmospheric and Space Physics

University of Colorado **Boulder**

WASHINGTON STATE UNIVERSITY

MONTANA STATE UNIVERSITY

PURDUE UNIVERSITY

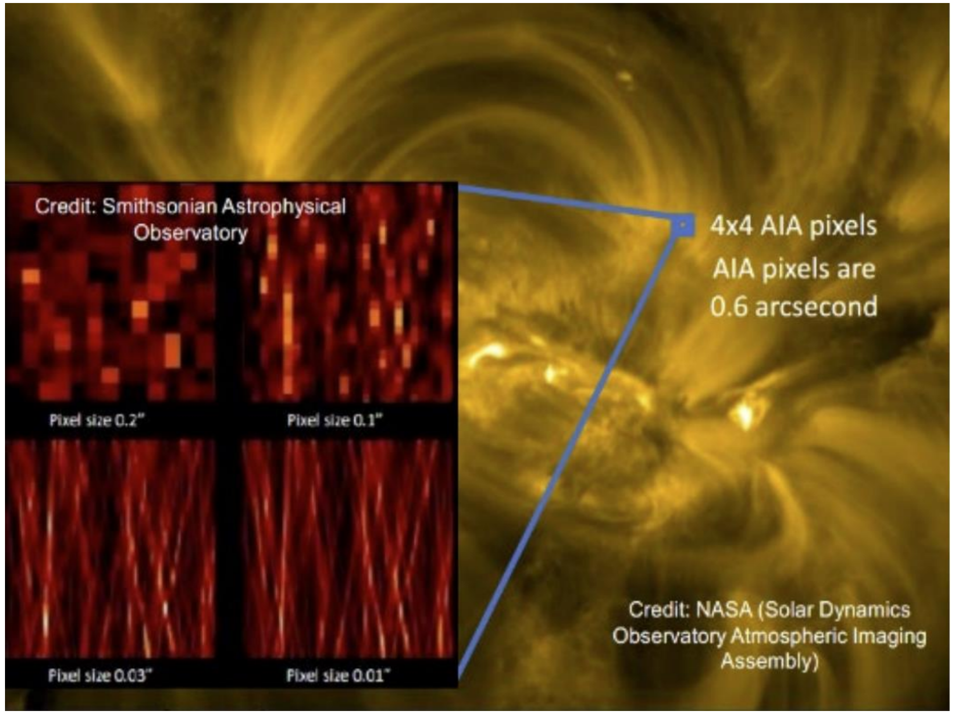
THE OHIO STATE UNIVERSITY

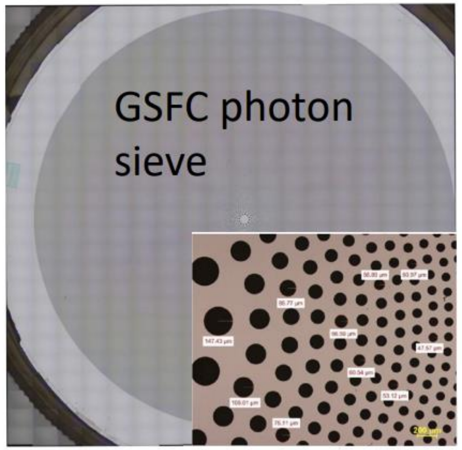
UC San Diego

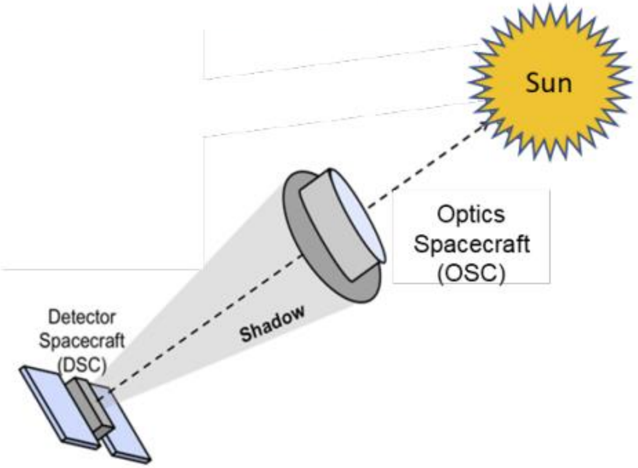
Overall Goals

- Science Mission and Technology Demonstration:
  - Obtain high resolution images of solar corona
  - Highly complex GNC algorithms
  - Unique Inter-satellite link system (near-full sky coverage)

- Education and Collaboration:
  - 11 institutions
  - Various levels of s/c design experience

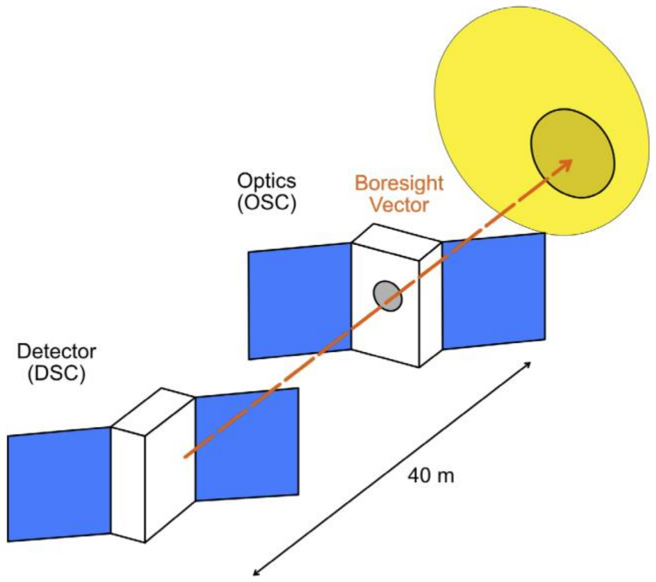






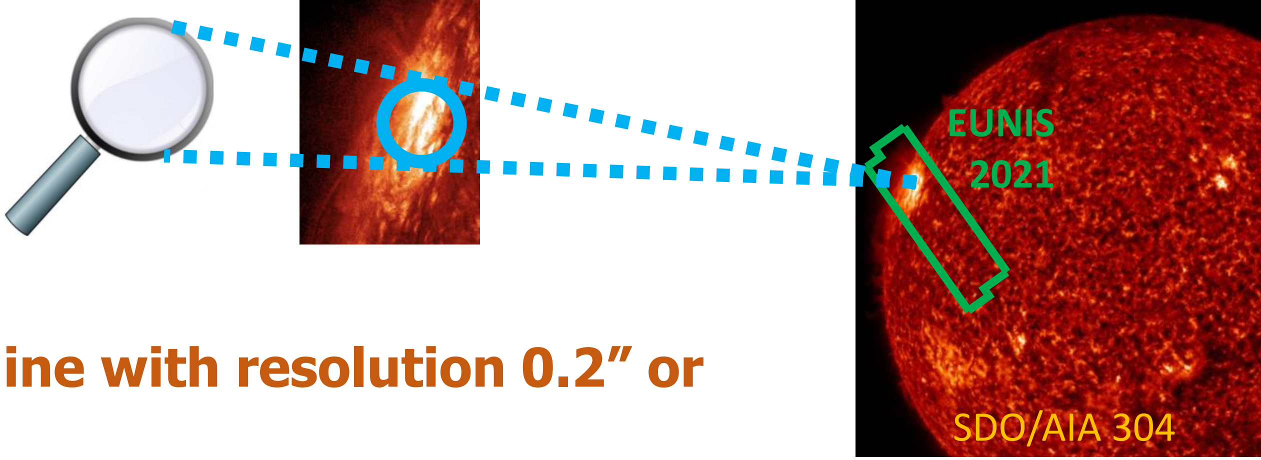
VISORS Telescope

- Detector spacecraft (DSC) houses the Extreme Ultra-Violet (EUV) detector
- Optics spacecraft (OSC) houses the photon sieve optics
  - OSC solar arrays also act as sun shade to block stray light from reaching detector
- Formation flying of distributed elements replicates functionality of 40m long telescope



The Science

Science Goals

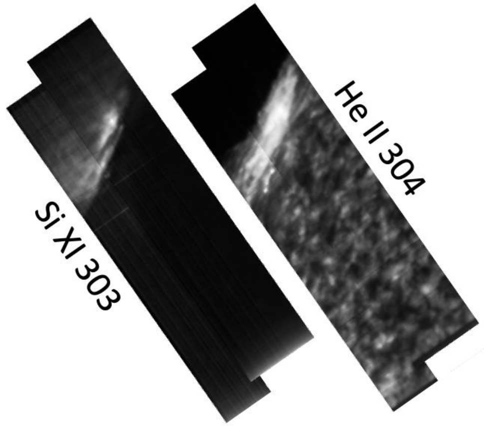


Baseline:

- **Obtain an image of the Sun in He II 304 line with resolution 0.2” or better**

Extended goals:

- Obtain images in He II 304 line with resolution ~ **0.1”**
- Image is recorded by the LASP Compact Spectral Imager Electronics (CSIE) at up to 7.5 frames per second, full frame: 2000x1504 $(0.036'')^2$ pixels
    - **Would be highest resolution EUV images of the Sun to date**
    - **First EUV images with sub-second cadence**



- Evolution of active region (if same region/FOV is successfully targeted again)
- Solar eruptive events (flares, CMEs) if targets of opportunity arise on the Sun

VISORS can bring new insight into energization of the corona.

- **Serve as a pathfinder for future Explorer-class and larger missions**

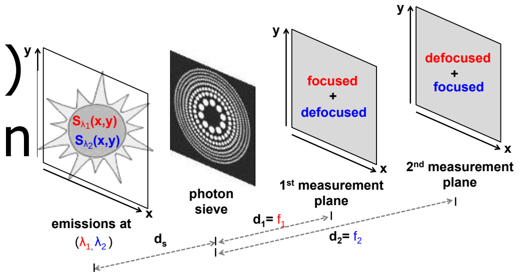
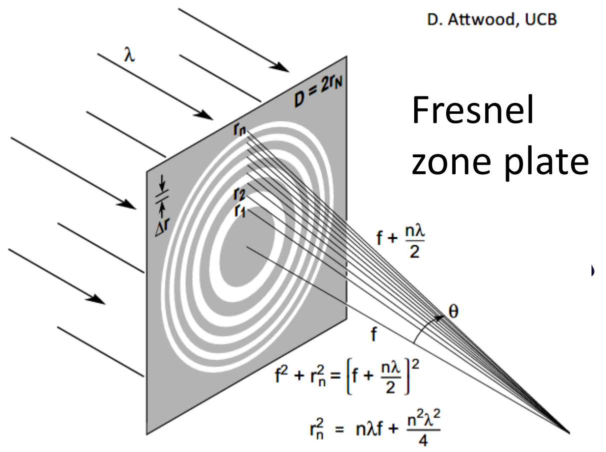
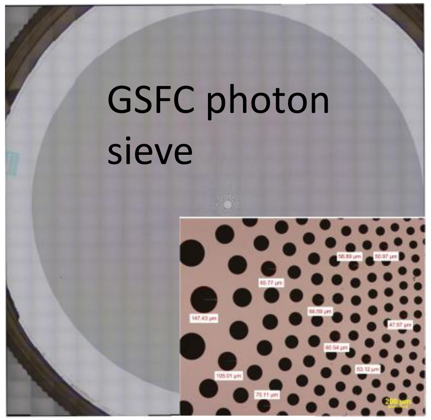


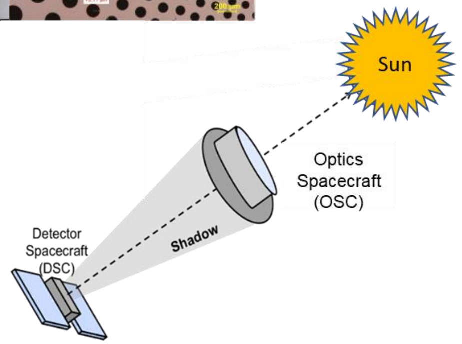
Image processing is another field VISORS can contribute to.

Science Implementation

- Coronal heating is best observed at extreme ultraviolet (EUV) and x-ray wavelengths because the highly ionized atoms at coronal temperatures emit most strongly at those wavelengths.
- However, conventional EUV telescopes based on mirror optics typically fail by an order of magnitude to reach the required diffraction limit.
- VISORS will demonstrate a scalable imaging technology using a novel diffractive optic known as a photon sieve, a refinement of the classical Fresnel zone plate.
- **The catch:** the focal length of an EUV photon sieve is too long for a single spacecraft. Therefore, the telescope must be distributed, with the sieve on one craft and the detector on another. This is the premise and challenge of VISORS.
- 2x the length of James Webb



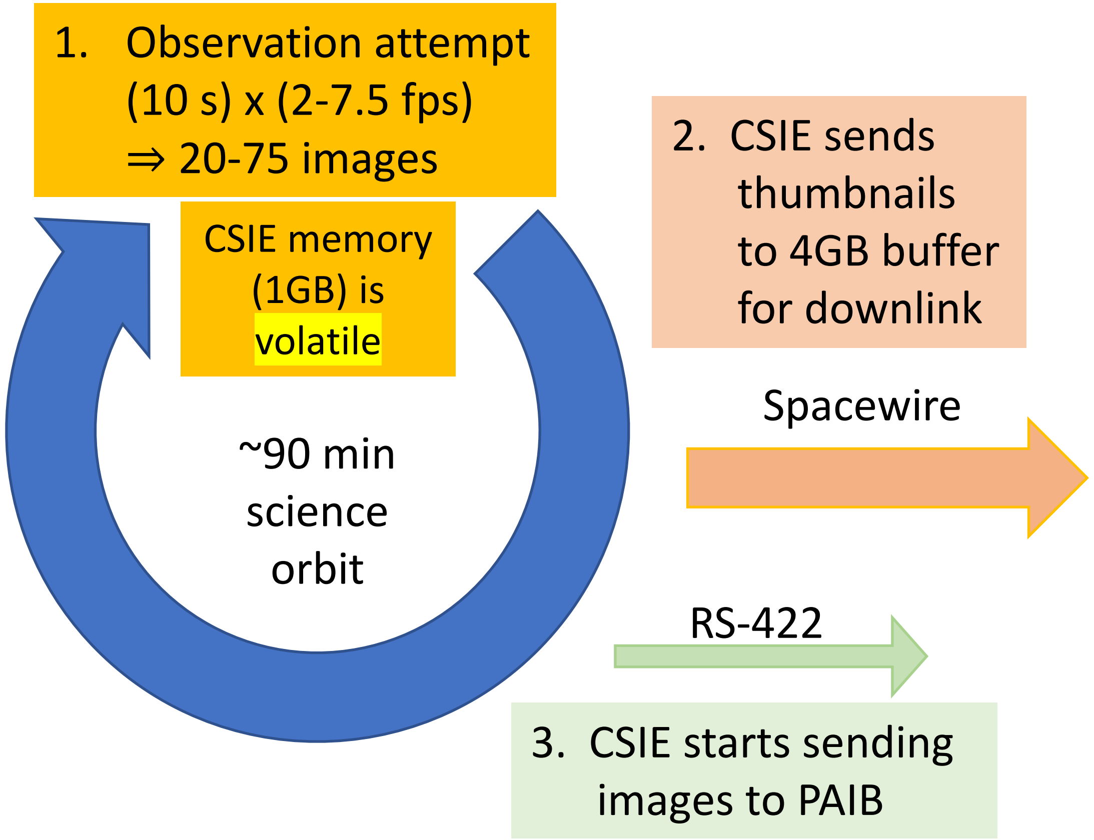




A "Science Campaign"

N_{obs} observation attempts (science orbits) in a row.

Sequence of data flow operations per orbit:

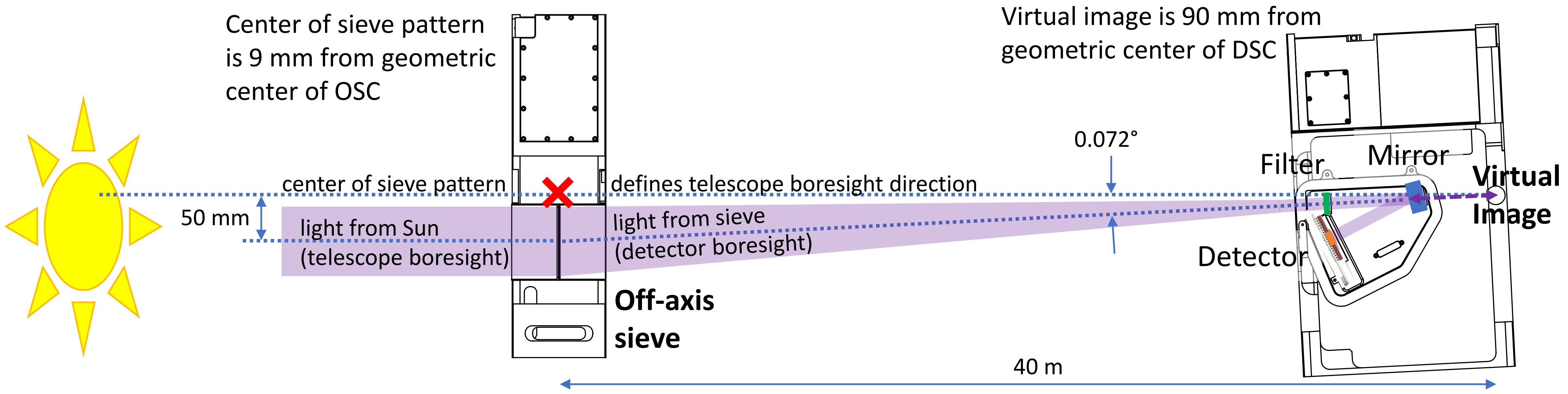


Key Points for Science Data

- OSC-DSC formation requirements:
  - **In focus** (range)
  - **On target** (relative lateral position)
  - **Not smeared** (relative lateral drift)
- Difficult to achieve all 3 simultaneously. Mission level requirement is **20% chance** of achieving all 3 in single observation attempt

VISORS Telescope Configuration

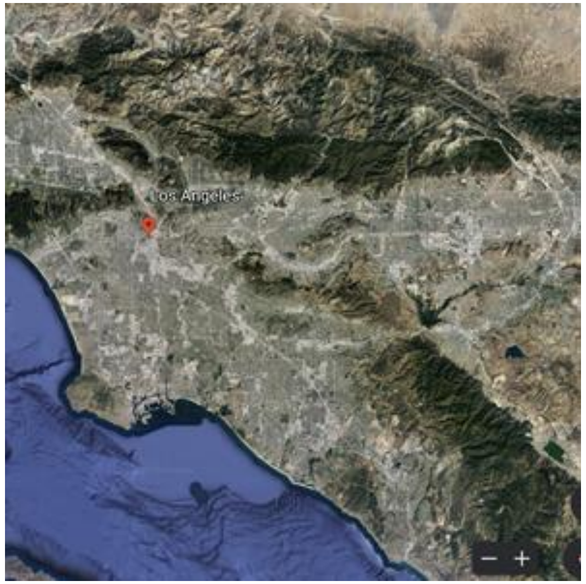
- Detector boresight points at geometric center of sieve
- Telescope boresight defined by center of sieve pattern (center of zones)
- Off-axis sieve focuses the light and bends it 50 mm/ 40 m = 0.072°
- Spacecraft maintain inertial pointing, keeping both GPS antennae within 20° of zenith.

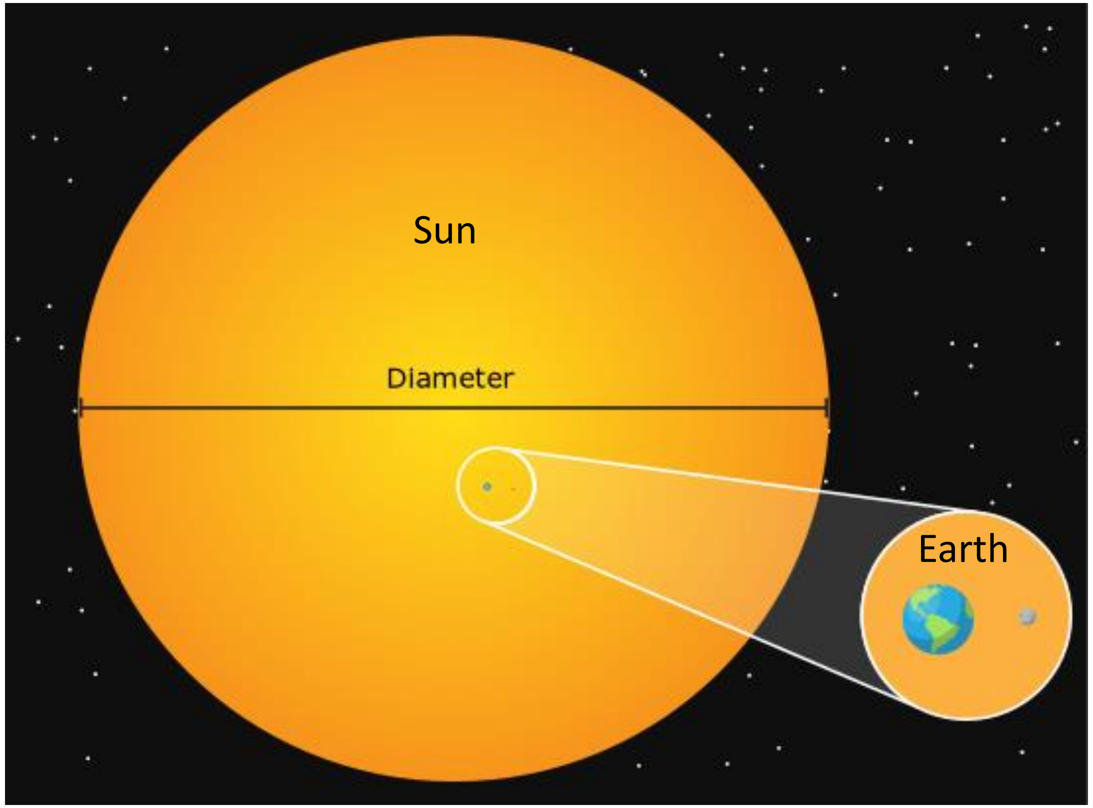


What do we expect to see?

- VISORS has the ability to observe filamentary coronal structures as narrow as 0.12 arcsec (87 km on the Sun)

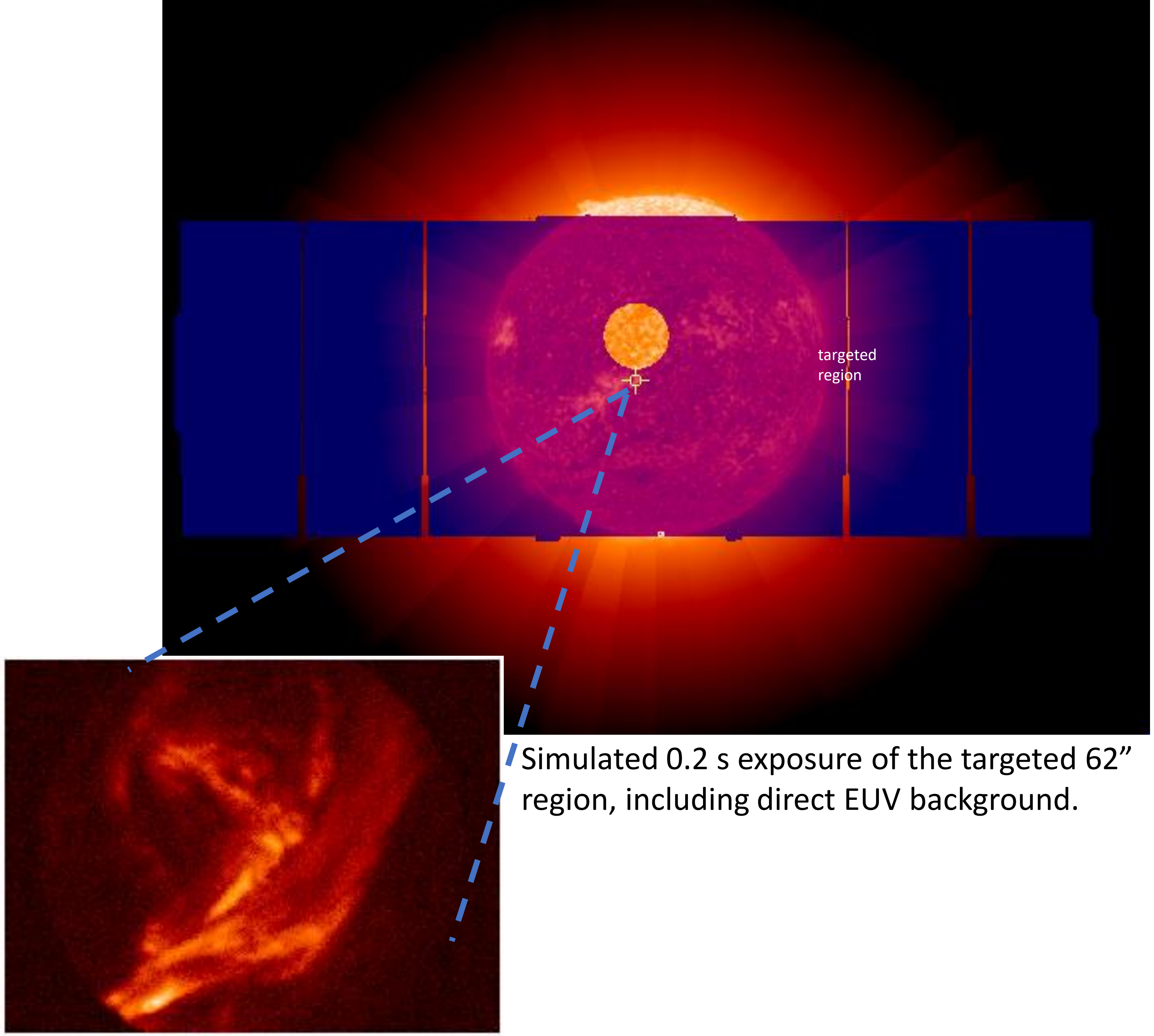
One large sunspot is about the size of Earth. The VISORS field of view is about 20 Earths across. One pixel is the size of Metropolitan Los Angeles.





What does the detector see?

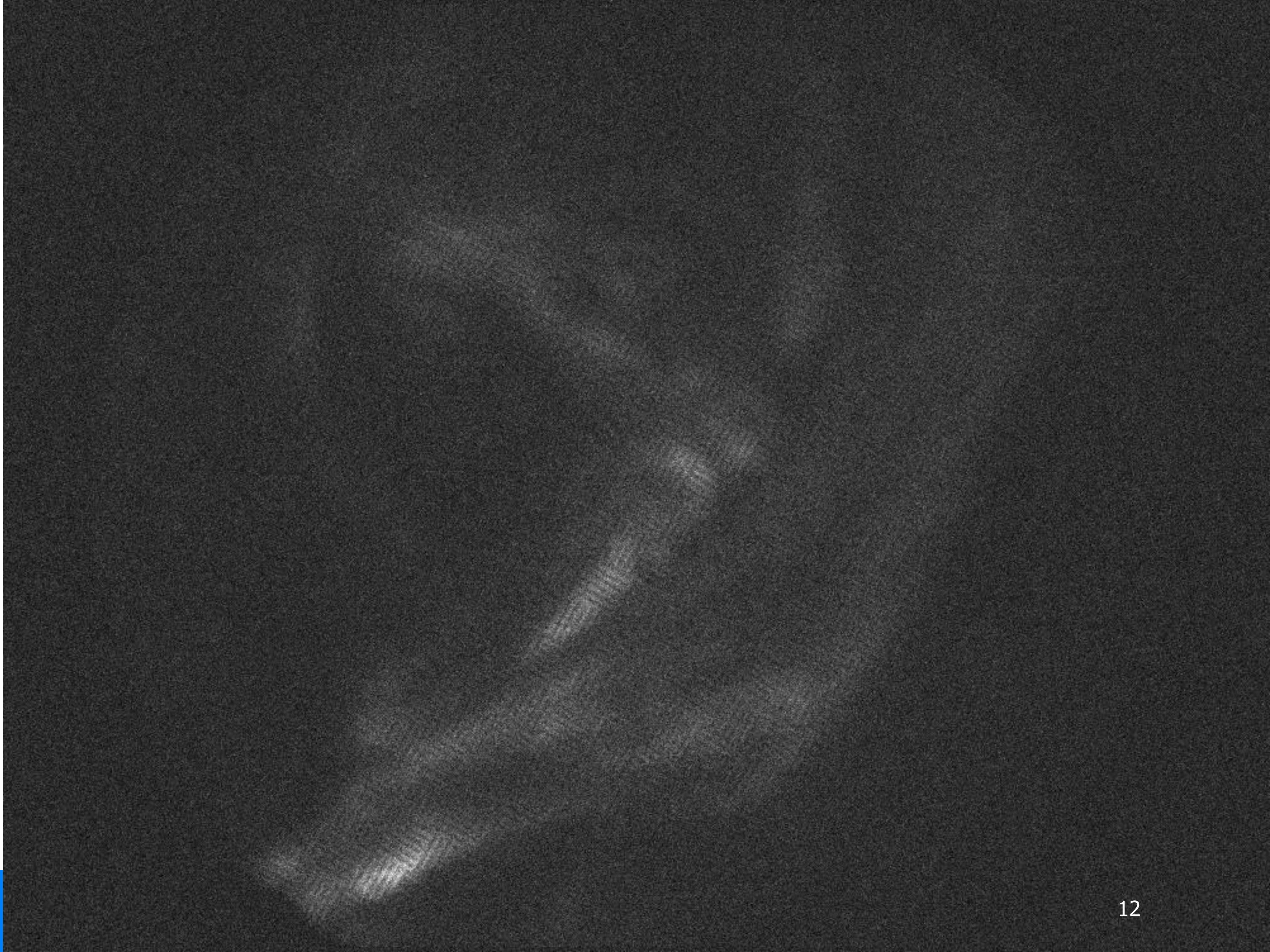
- For maximum signal-to-noise, target bright active regions.
- OSC cross section is shown on a SDO/AIA He II 304 image (20 Dec 2012: same phase of the solar cycle as shortly after VISORS launch) with a simulated 0.2 s exposure, including all sources of noise and background.
- This photon sieve is an off-axis optic, allowing the telescope boresight to point through the CM of the OSC (white cross) and for “zero order” light (geometric shadow through sieve) of the target to separate from the image.



Simulated 0.2 s exposure of the targeted 62” region, including direct EUV background.

What will we see on the ground?

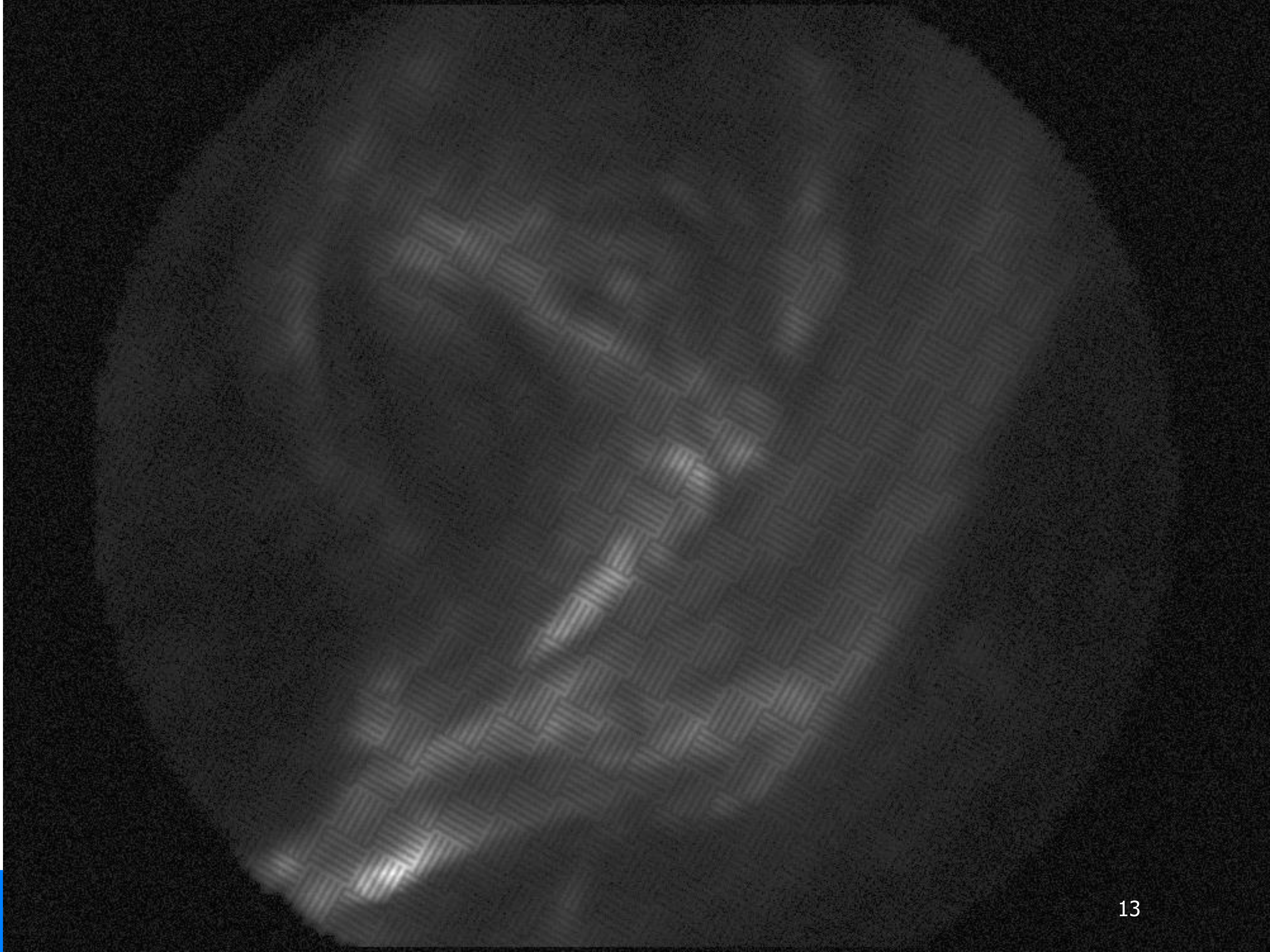
Simulated *single* 0.2 s exposure, including all sources of noise and back-ground, 0.18” telescope resolution, with 50% of expected throughput.



What will we see on the ground?

Summed observation

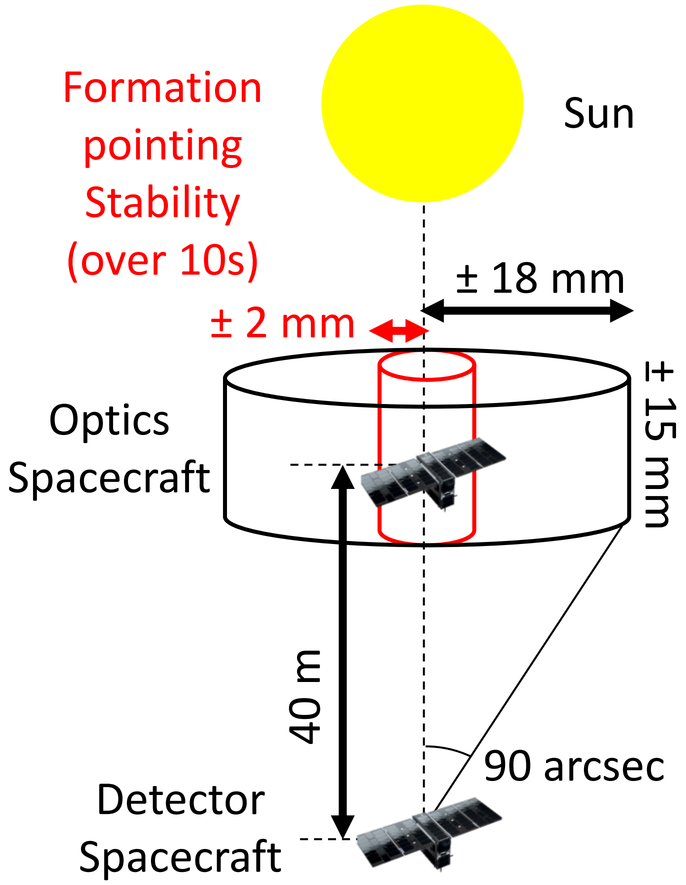
10 s of data simulated as per the previous slide (50% throughput, same scene from 2012 Dec 20 as on S/N and shading slide)



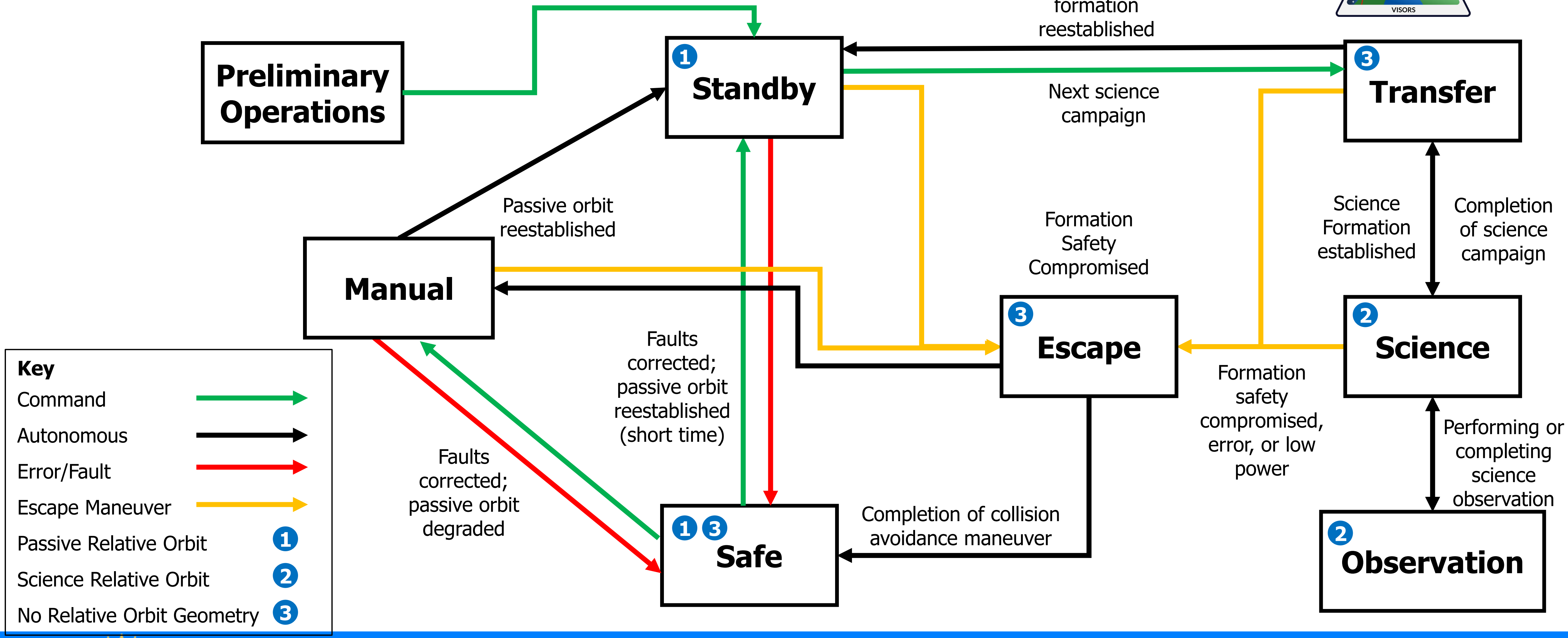
The Engineering

GNC Challenge

- The formation *optical elements* must satisfy challenging requirements during observations
  - <18mm lateral relative position error
  - <15mm longitudinal relative position error
  - <200um/s lateral relative velocity error
  - >20% success likelihood for each attempt
- Orbit must ensure near-zero relative acceleration perpendicular to line of sight during observations

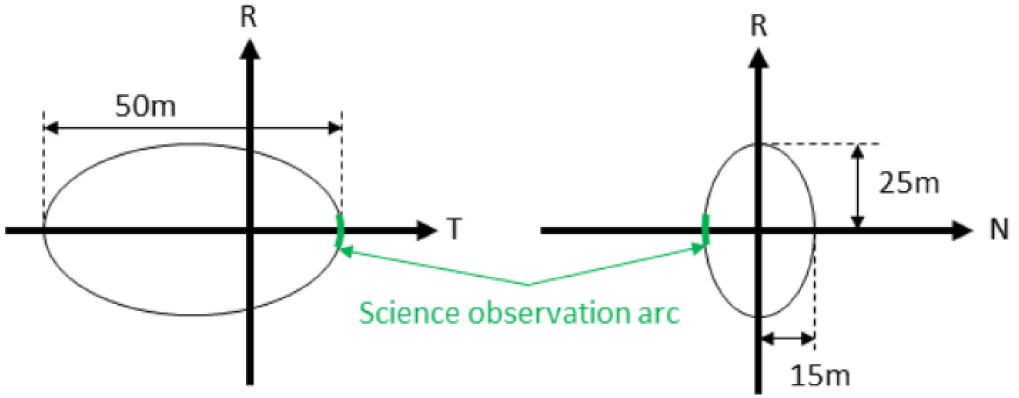


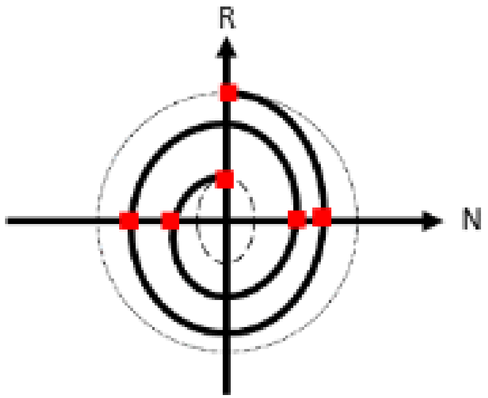
Mission/Formation Modes

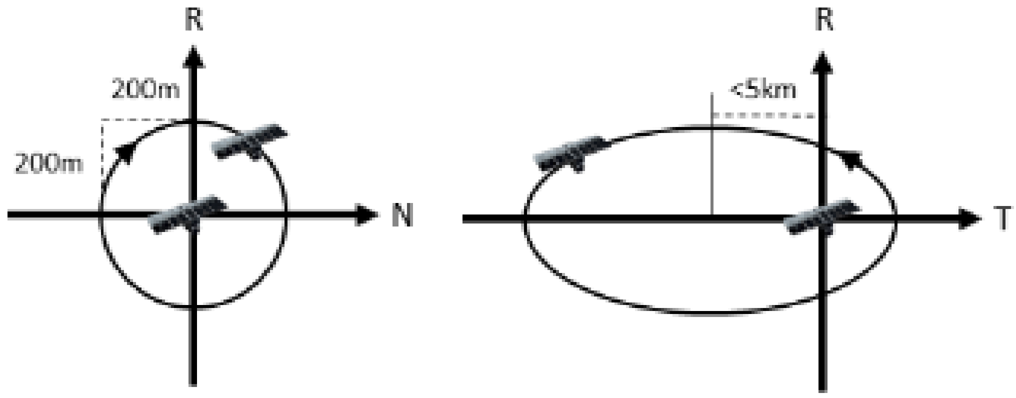


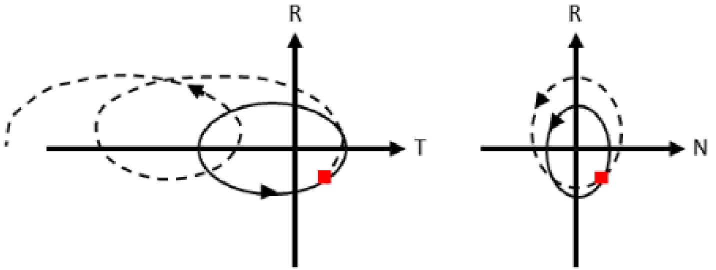
Formation Configurations

Science <--> Transfer <--> Standby







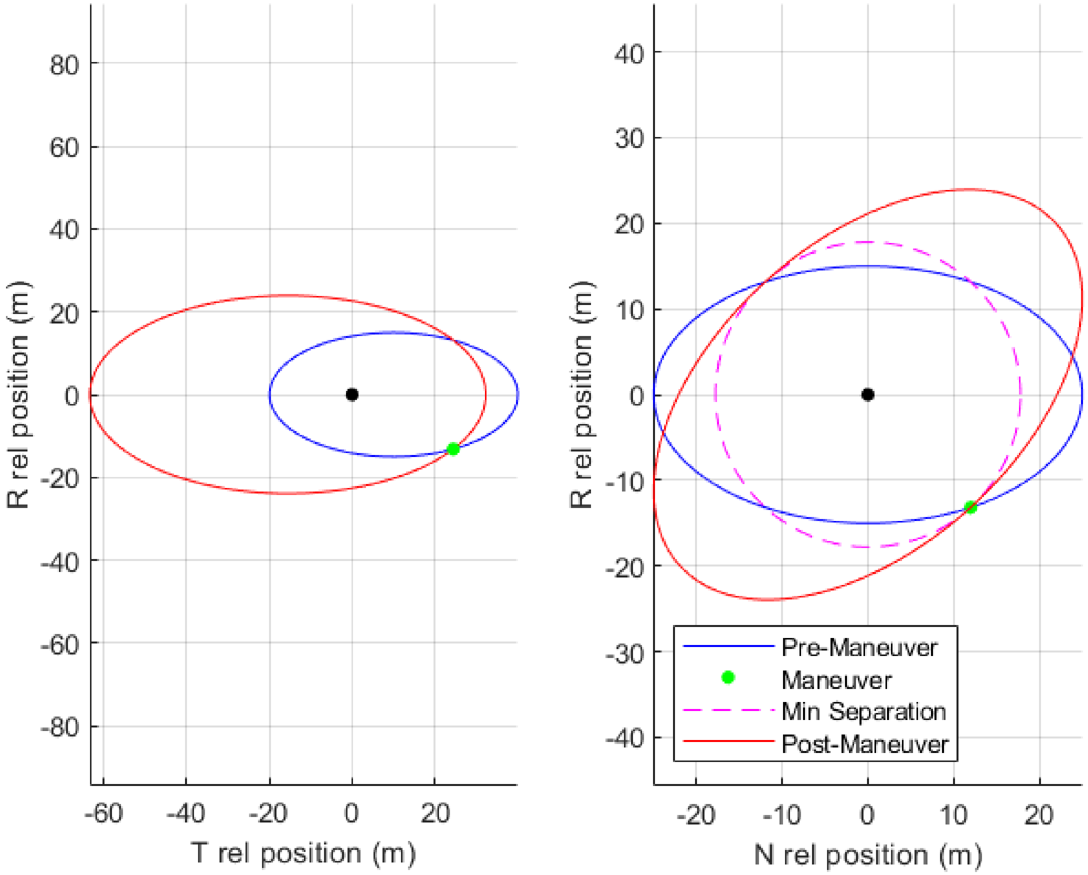


Example Escape (from Science)

RN Passive Safety

- Relative motion between the spacecraft can be decomposed into RT and RN plane
  - Relative orbit geometry using the HCW equations (designed using rel. eccentricity / inclination vector separation)
  - Unperturbed RN motion is stable
  - A specified minimum RN separation ≤ the current separation can be achieved with one maneuver

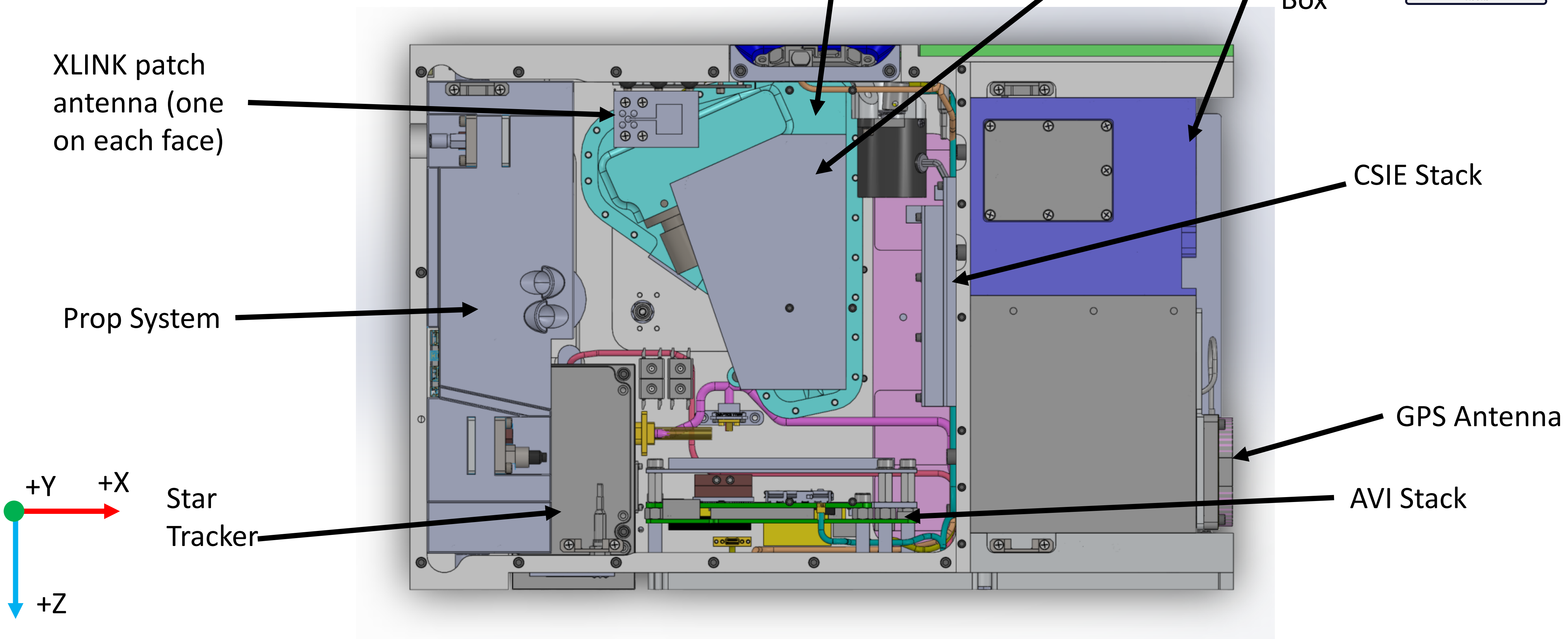
Science mode relative orbit in RT and RN



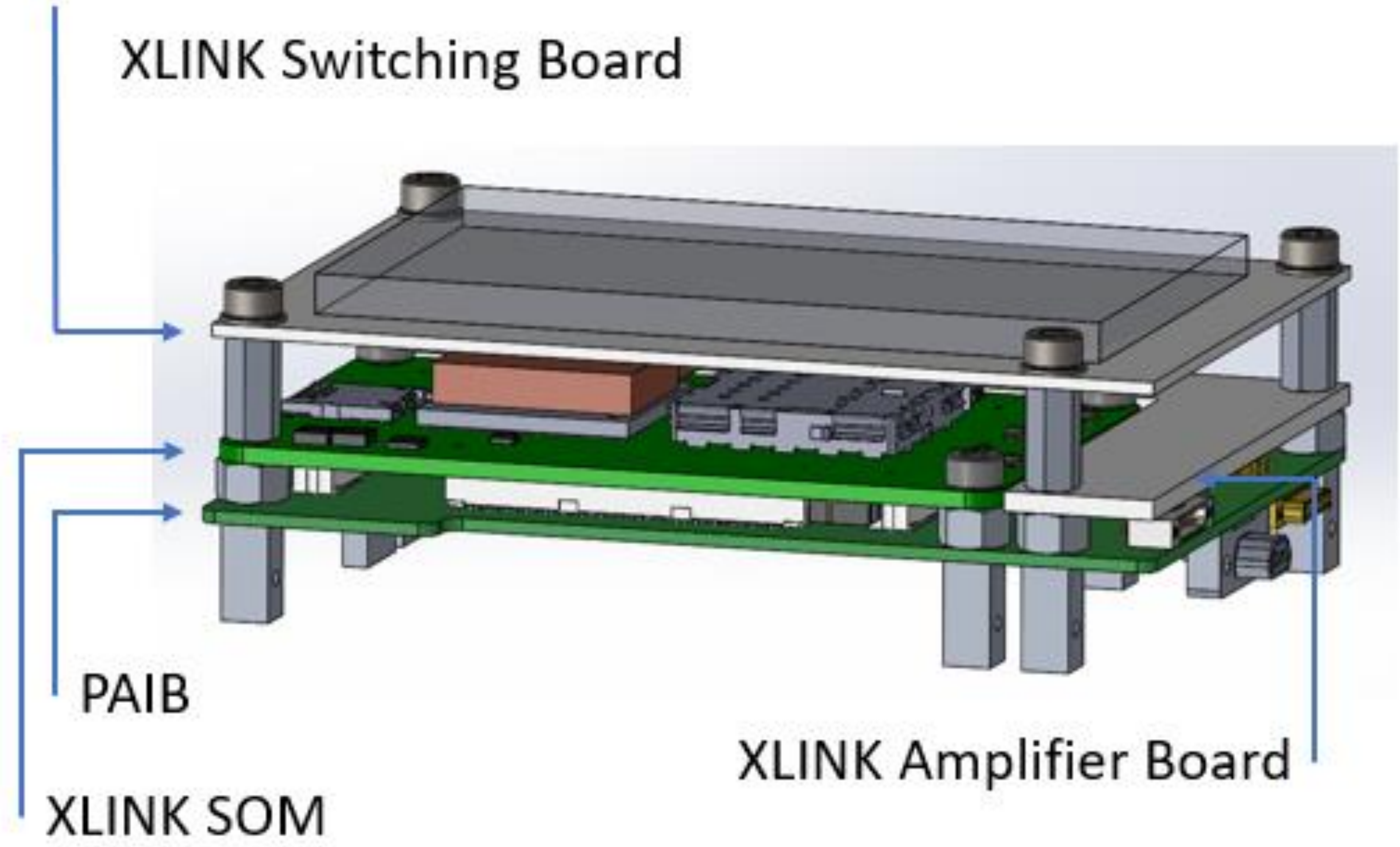
Possible VISORS Science Mode Relative Orbit Parameters

Parameter	aδa	aδλ	aδex	aδey	aδix	aδiy
Value (m)	0	10	15	0	25	0

DSC Internal View

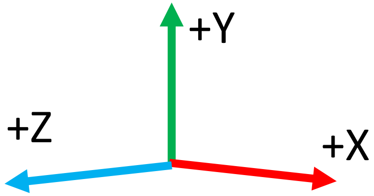


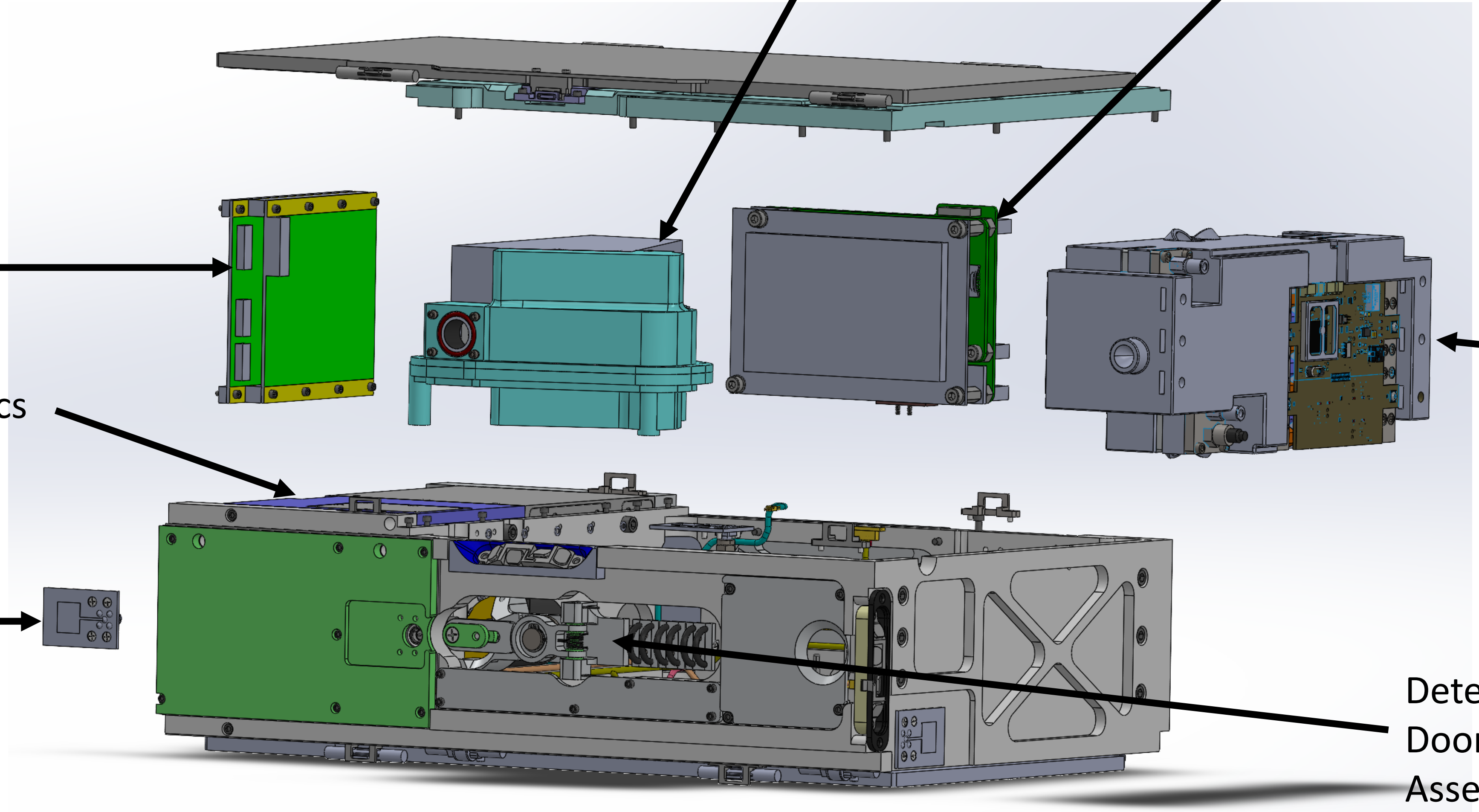
Avionics Stack



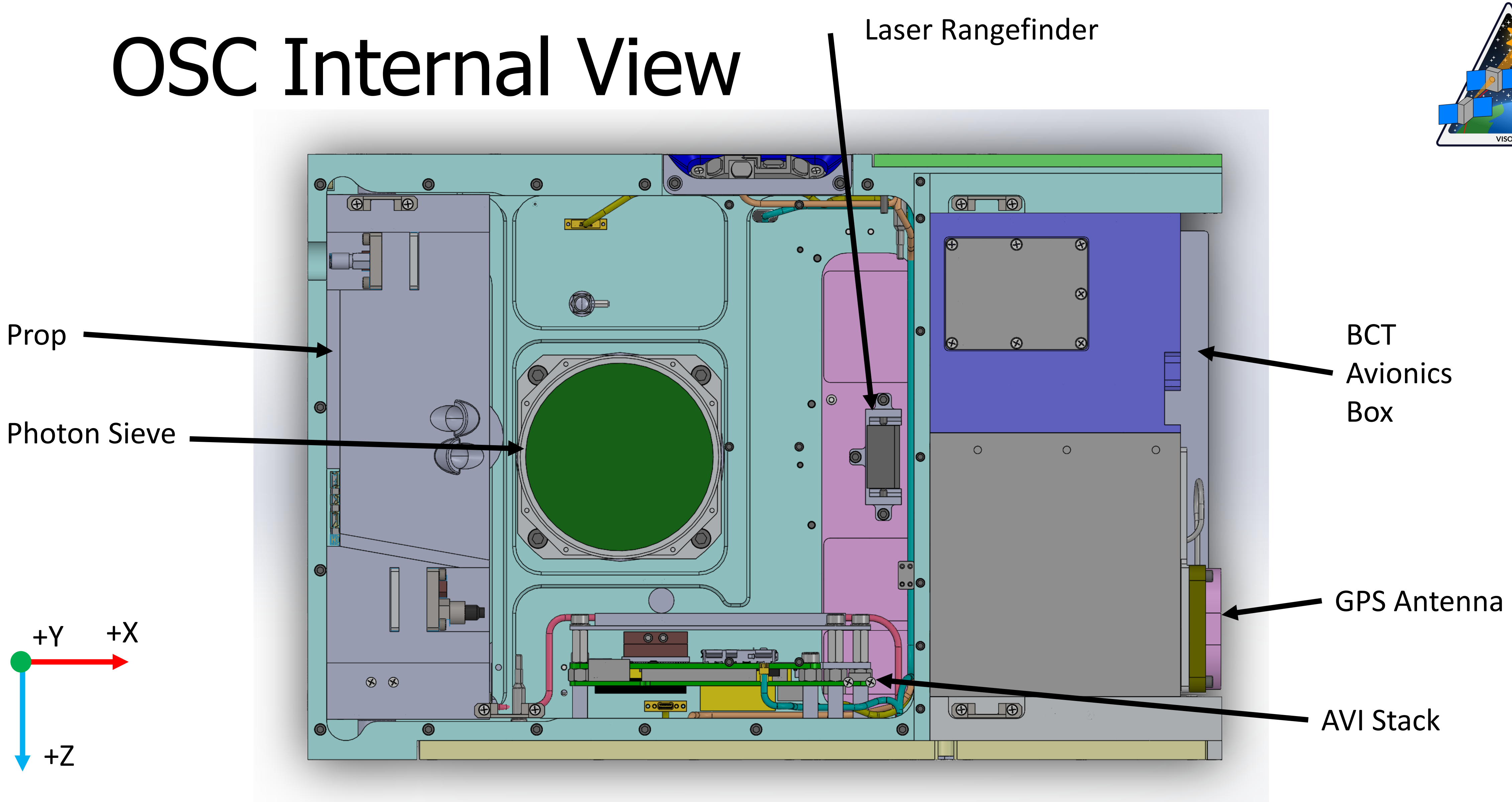
VISORS AVIONICS STACK

DSC Exploded View

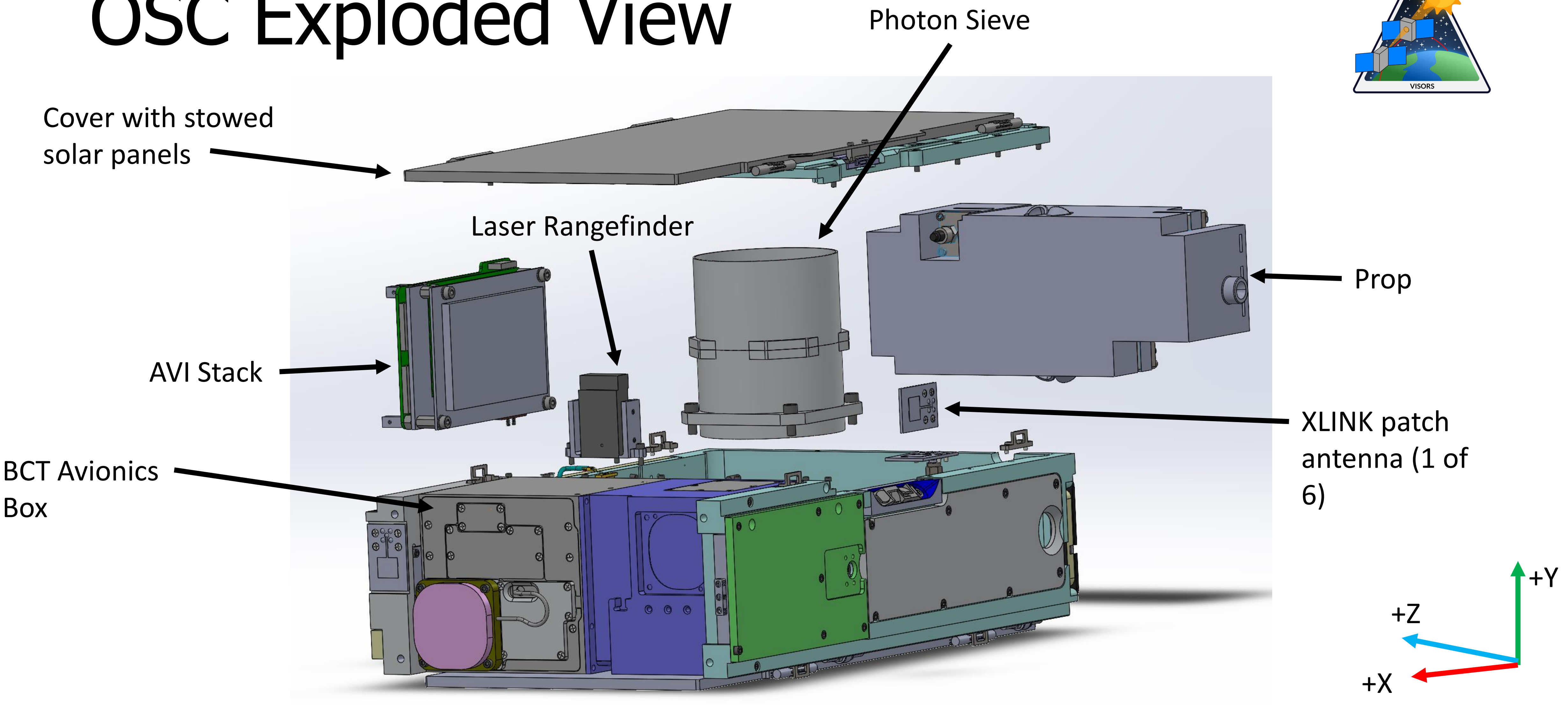




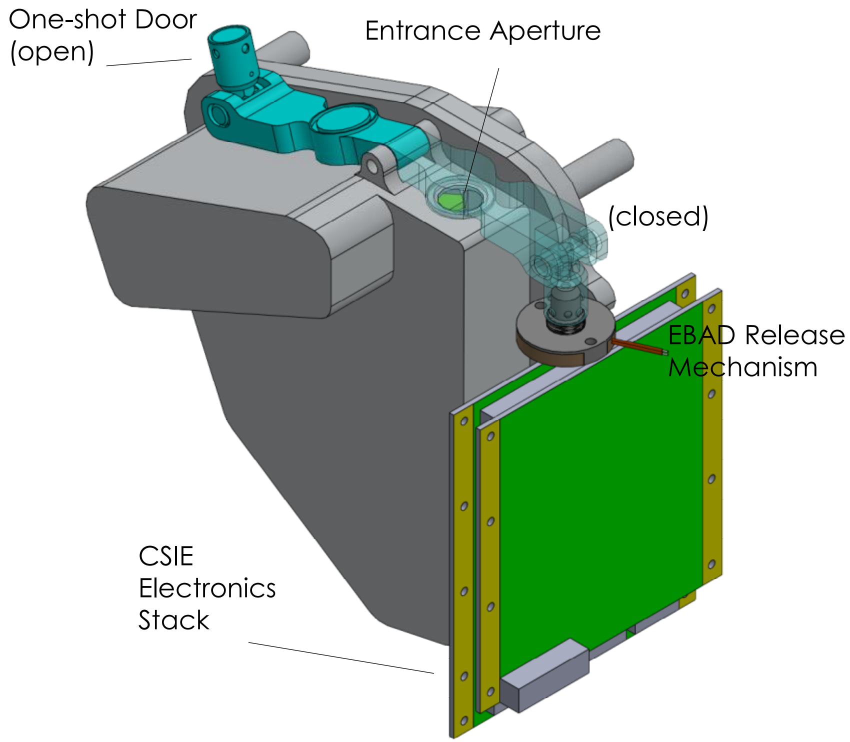
OSC Internal View

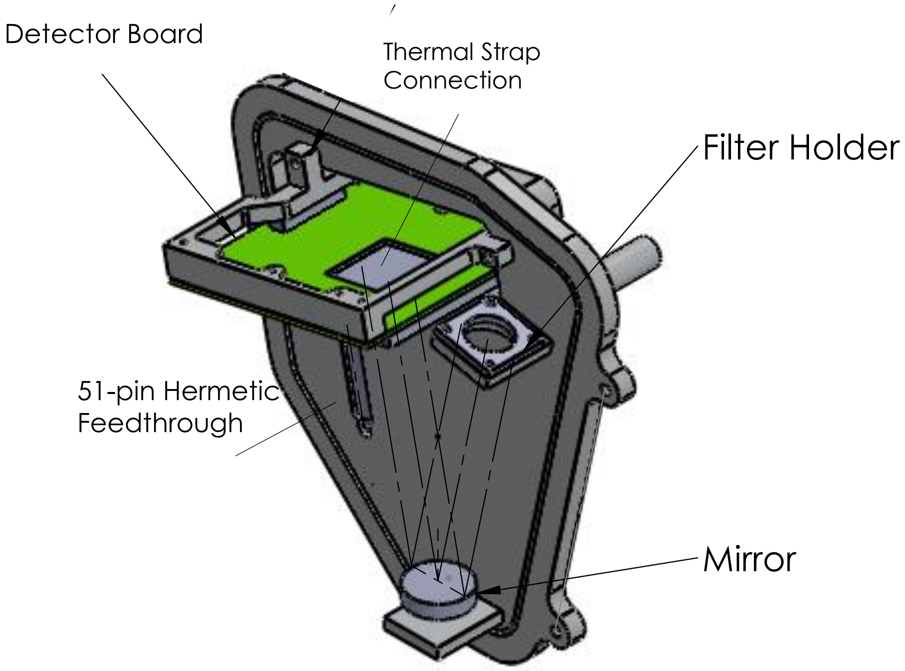


OSC Exploded View



Optics Chamber





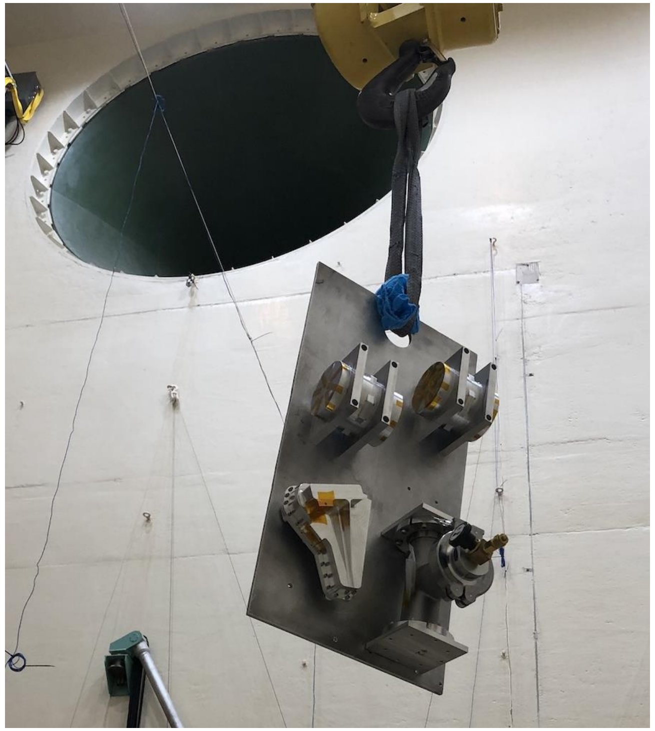
Optical components:

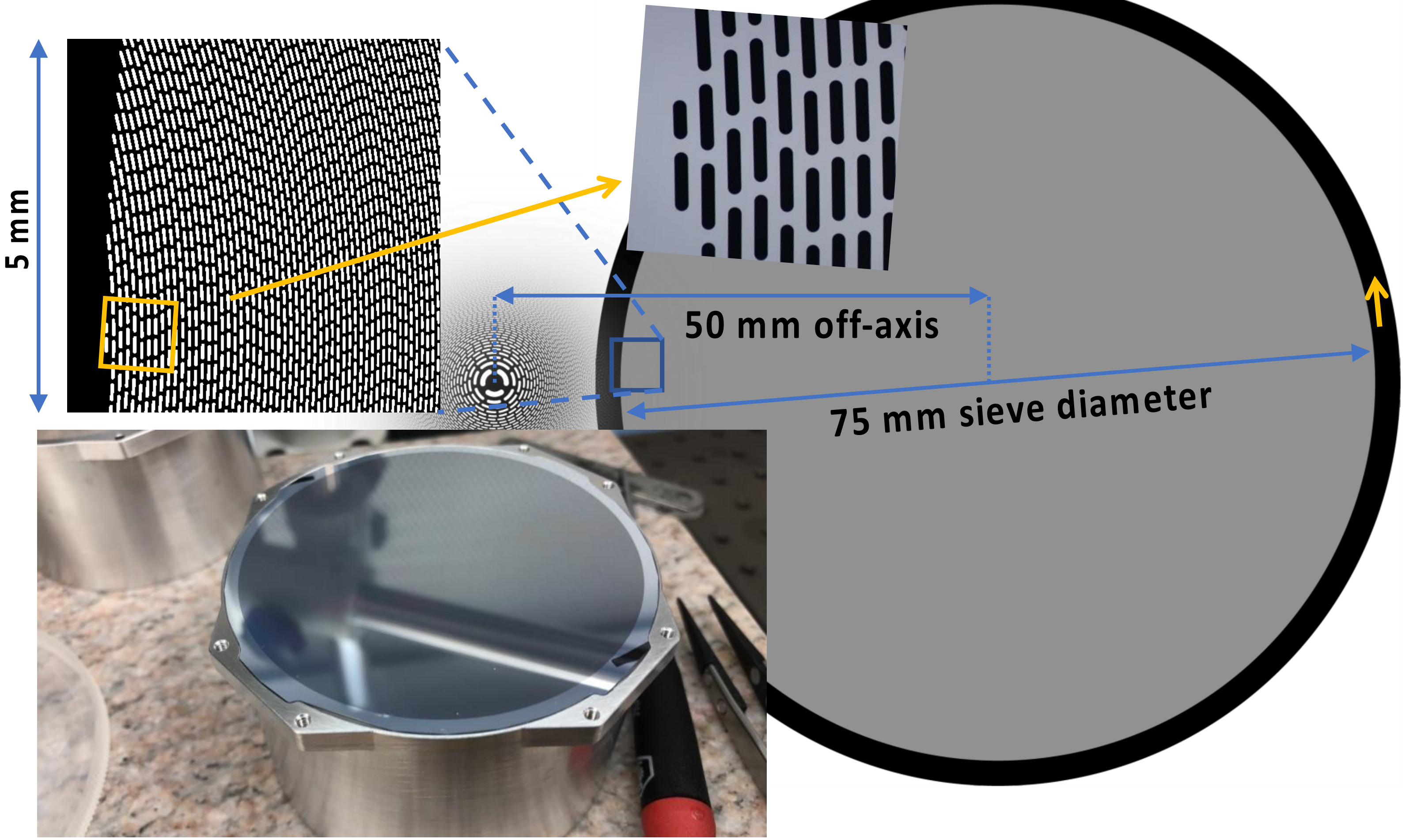
- Entrance aperture (12 mm dia.) limits light entering chamber and FOV to 62"
- Luxel thin film Al filter to reject visible light
- Multilayer-coated (RXO/Windt or LBNL/Gullikson) fold mirror to limit bandpass
- Teledyne/e2v CIS115 Back-Side Illuminated CMOS Sensor, 2000x1504, 7μm pixels

- Hermetically sealed chamber, filled with N_2 prior to integration and launch. On orbit, the door opens once to uncover the entrance aperture.

Photon Sieve

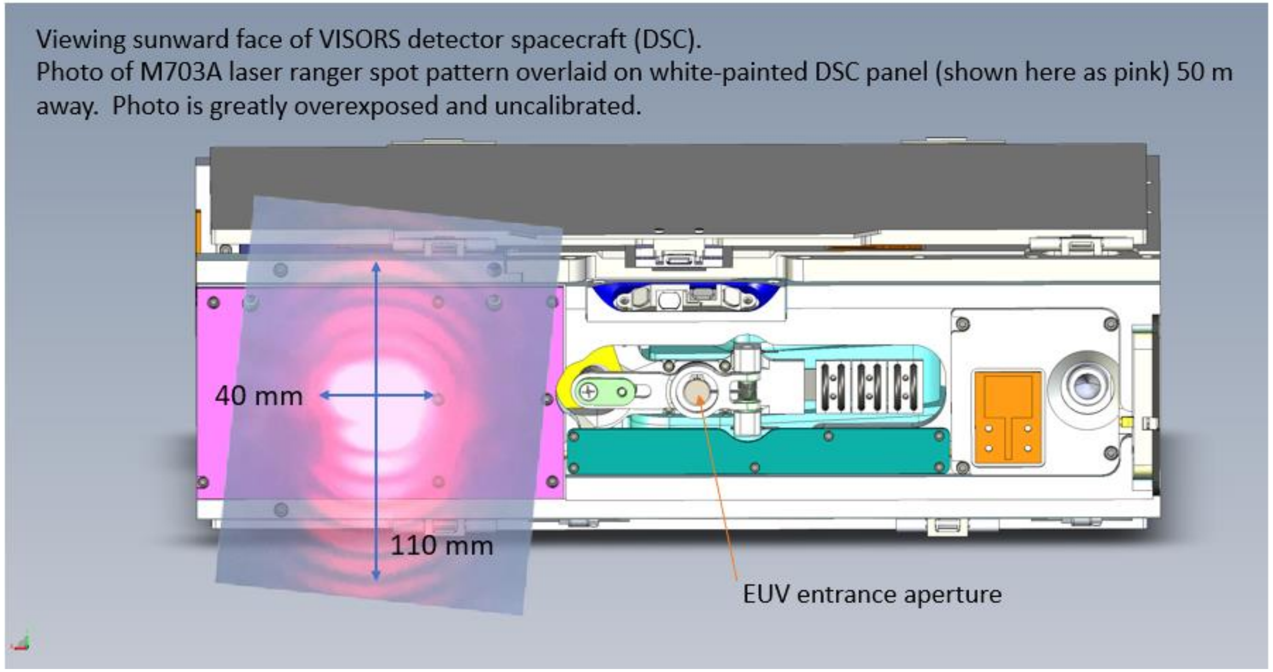
- Al-coated silicon membrane, 75 µm thick, fabricated from SOI wafer with 400 µm thick handle around circumference

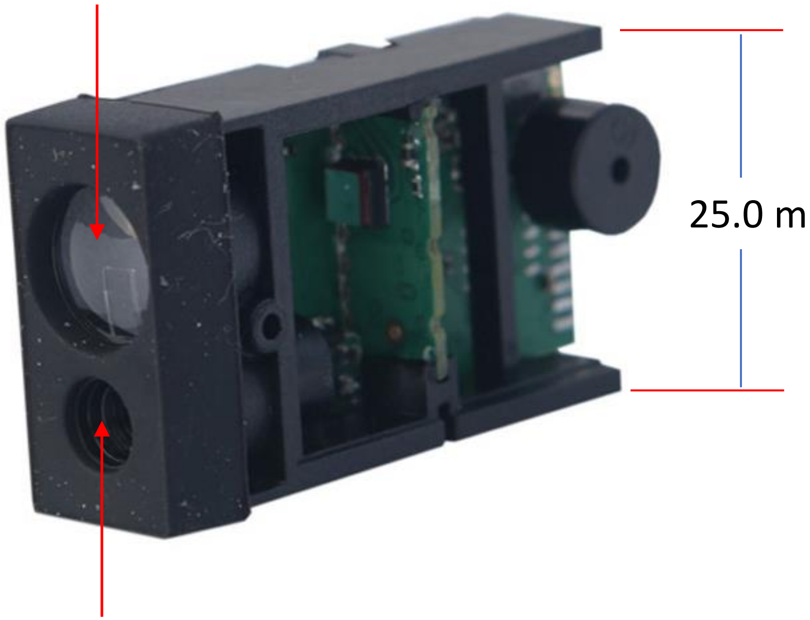




Laser Range Finder (LRF)

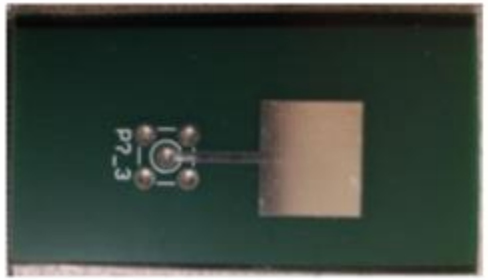
- LRF measures OSC-DSC separation every 2 s with accuracy ±3 mm and precision ±1 mm when the separation is <60 m.
- LRF range measurement is more accurate and precise than GNSS data.

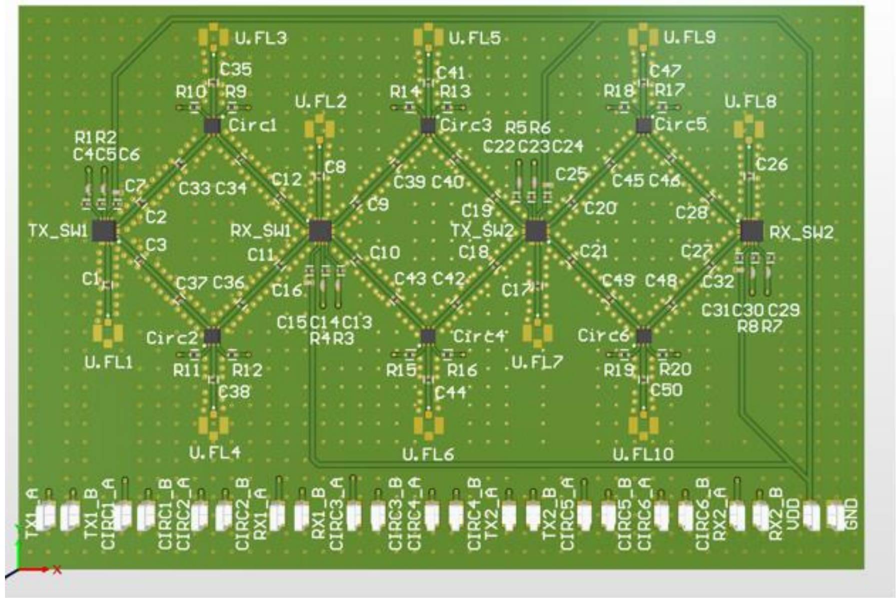




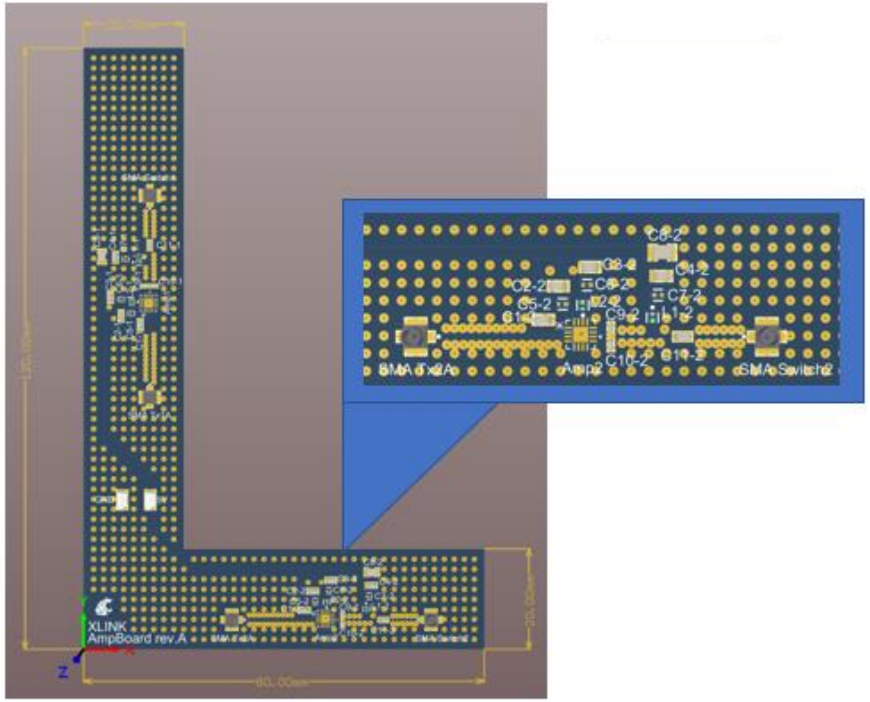
XLINK System

- Analog Devices AD9361-BBCZ Integrated RF Agile Transceiver™
- Xilinx Zynq XC7Z035-L2 FBG676I AP SoC
- Dual ARM® Cortex™-A9 MPCore™ running at 800MHz
- 4 TX and 4 RX ports
  - Switching configuration to utilize 6 antennas required





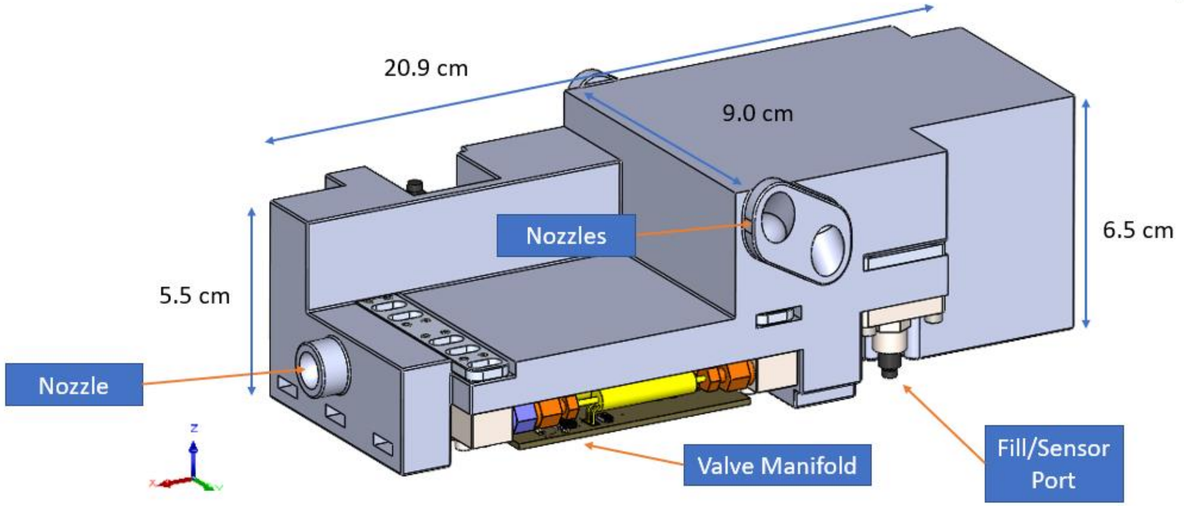
Switching Board

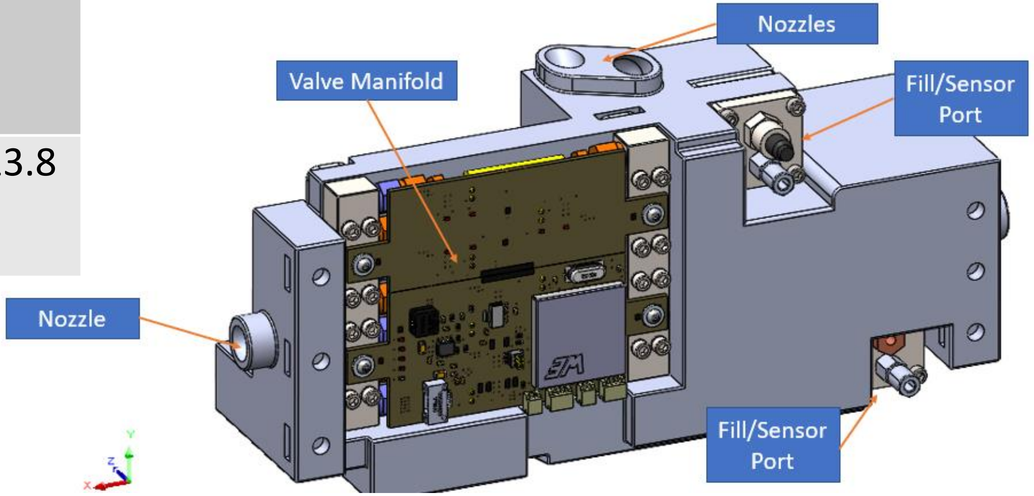


Amplifier Board

Propulsion System - DSC

Parameter	Value	Parameter	Value
Wet Mass (kg)	1.278	Main Tank Volume (cm^3)	242
Dry Mass (kg)	1.031	ΔV (m/s)	8.4 (assuming 13.8 kg spacecraft)





Questions?

Sources

- Significant portions of this presentation include materials from VISORS PDR and CDR charts from the following parties:
  - Adrian Daw, Goddard Space Flight Center
  - Doug Rabin, Goddard Space Flight Center
  - Elizabeth Kimmel, Georgia Institute of Technology
  - Samuel Hart, Georgia Institute of Technology
  - Tommaso Guffanti, Stanford University
  - Gabriel Adamson, Washington State University
- Special thanks to the entire VISORS team for their efforts in maturing the spacecraft design up to this point!