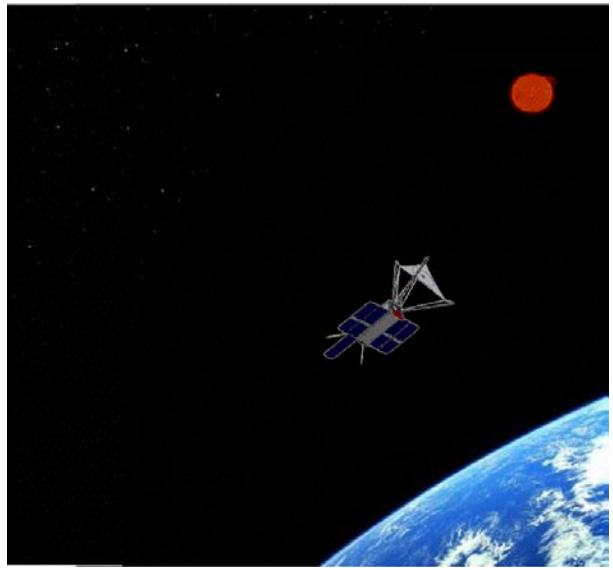
Peregrine: A deployable solar imaging CubeSat mission



C1C Samantha Latch

United States Air Force Academy

20 April 2012 CubeSat Workshop

Air Force Academy

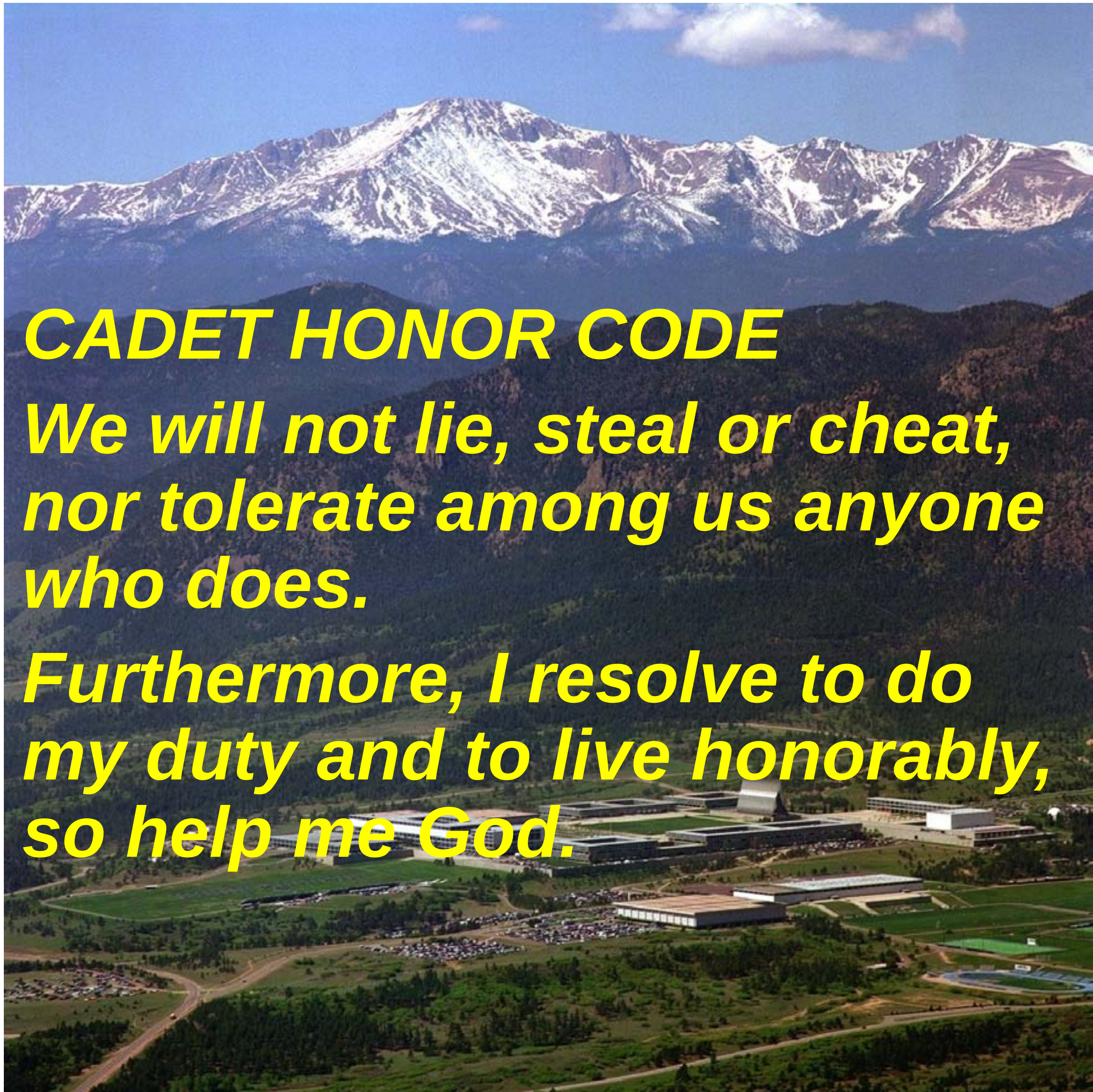
U.S. AIR FORCE

U.S. Air Force Academy
Colorado Springs
Colorado, USA

2,100 m (MSL)
18,000 acres (73 km^2)

~4,400 cadets
700+ faculty

Pillars
-Academics
-Military
-Athletics
-Character and Honor



Air Force Academy Mission & Vision

MISSION STATEMENT

To educate, train, and inspire men and women to become officers of character, motivated to lead the United States Air Force in service to our nation

VISION STATEMENT

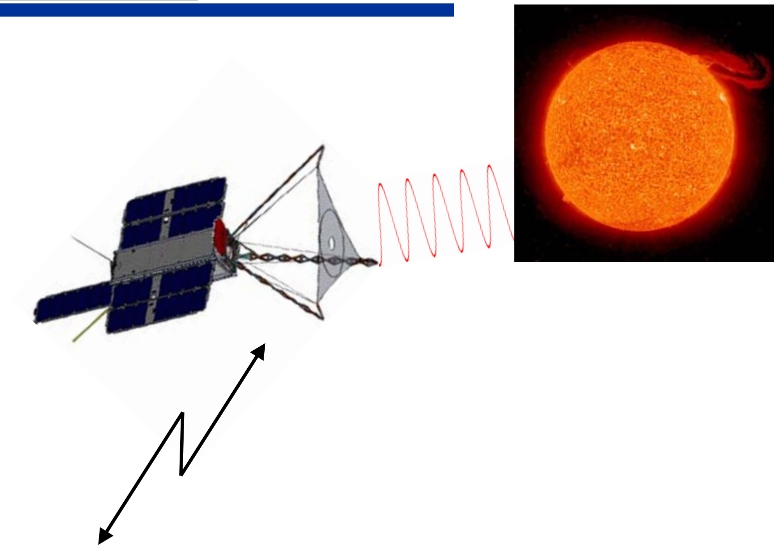
The United States Air Force Academy …

the Air Force's premier institution for developing leaders of character

FS-7 Program

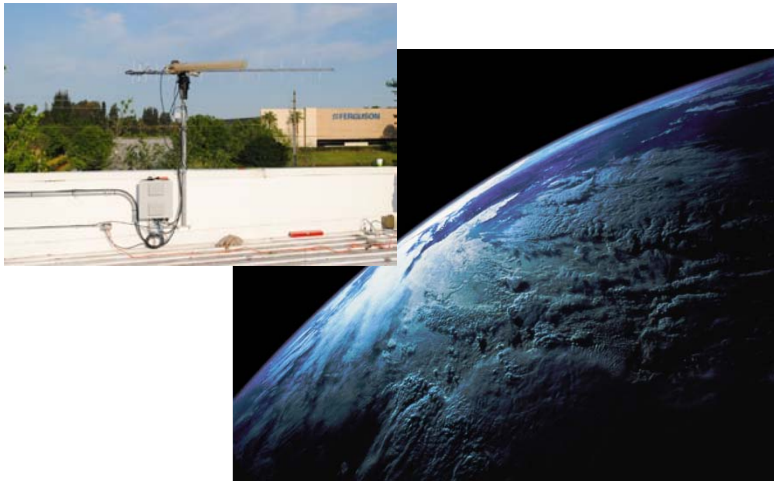
Mission Statement

Develop photon sieve technology for applications to warfighter, intelligence, surveillance, and reconnaissance, and scientific missions



Mission Objectives

- Cadets “learn space by doing space”
- Get flight heritage on a polyimide photon sieve
- Deploy a photon sieve from folded configuration
- Determine performance of a photon sieve in space
- Once proven, technology can be scaled to meter ground resolution for space-based ISR applications

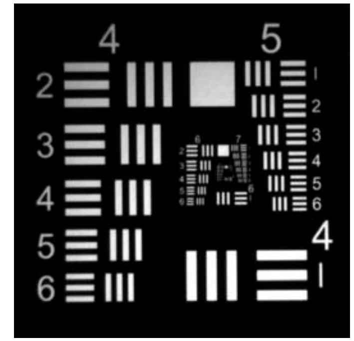


Background

Problem: Imaging satellites are costly and heavy due in part to the size of the primary optic necessary for acceptable ground resolution

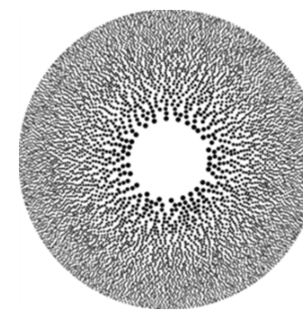
Solution: Membrane optics enable larger apertures, lower mass, and cheaper costs for imaging missions

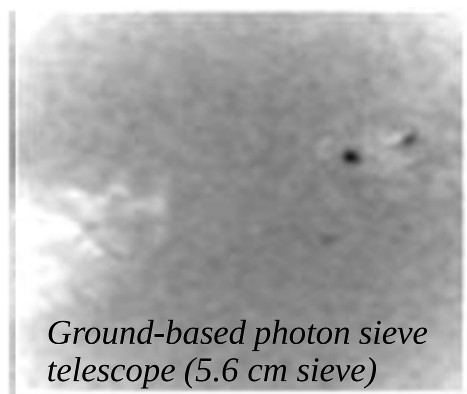
- Photon sieve optical elements
  - Uses diffraction to focus light
  - Surface requirements relaxed by 100 times or greater compared to traditional optics
  - Very lightweight and can be “folded”
  - Inherently narrow-band due to chromatic aberration
  - Optical transmission (or reflection) less than traditional optics
  - Diffraction-limited imaging performance



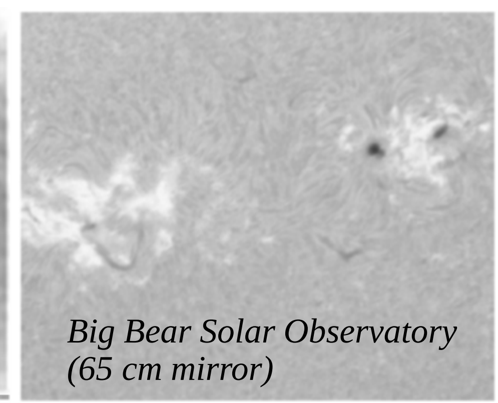
Diffraction-limited imaging performance

Photon sieve





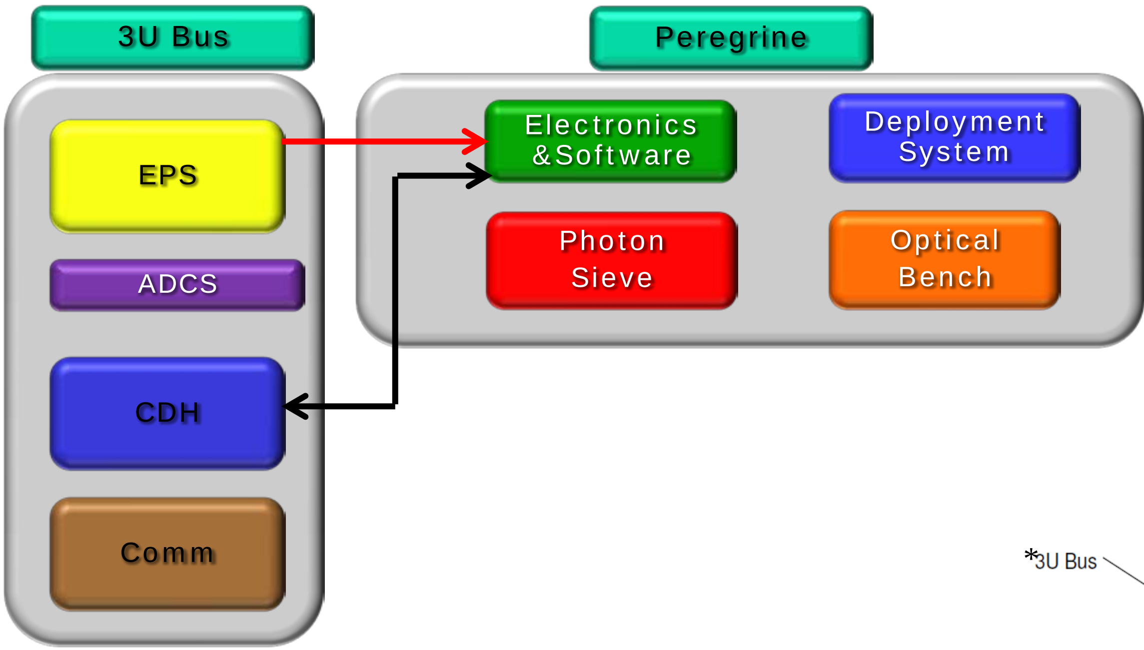
Ground-based photon sieve telescope (5.6 cm sieve)



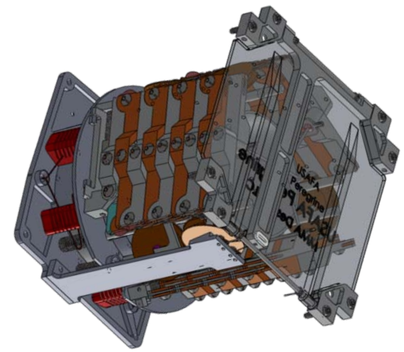
Big Bear Solar Observatory (65 cm mirror)

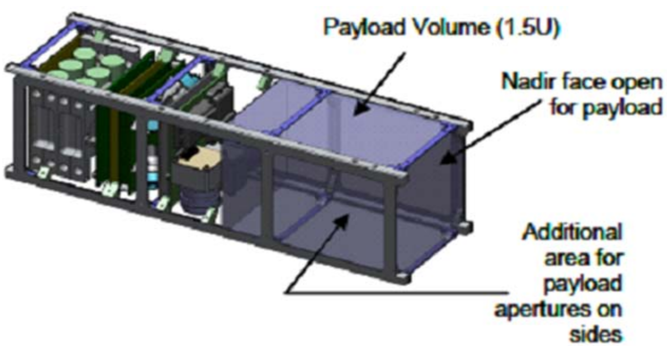
[Images courtesy of NASA Goddard]

FalconSAT-7 Space Segment System Configuration

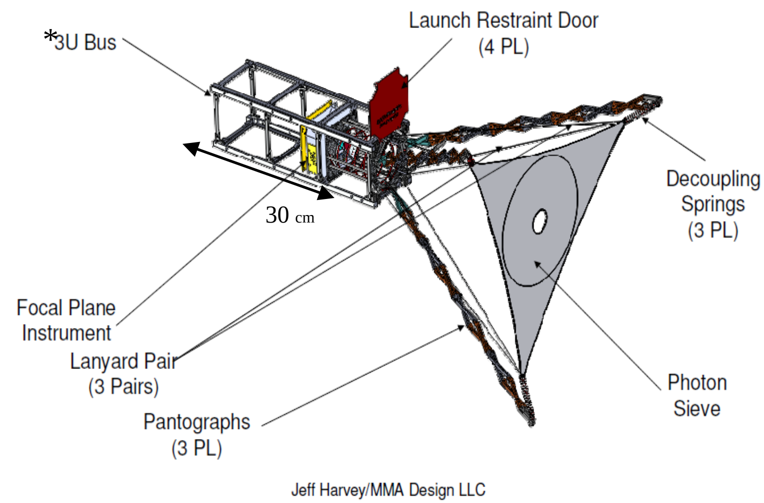


Peregrine Payload Stowed





3U CubeSat Bus



Peregrine Payload Deployed

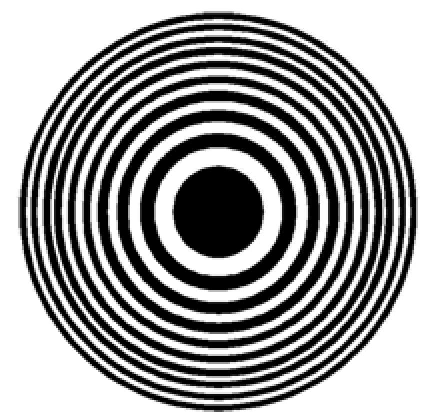
Photon Sieve

- Essentially a Fresnel Zone Plate with rings broken up into individual holes
  - 2.5 billion pinholes with 2-277 mm diameters
  - 20 cm diameter with a 40 cm focal length
  - Designed for H-alpha: 656.3 nm

$$r_n^2 = 2nf\lambda + n^2\lambda^2$$

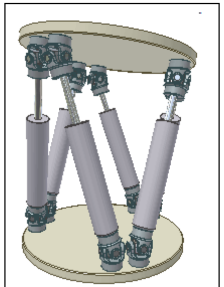
- In simplest version, holes are same diameter (d) as ring width (w)
- Can be randomly or regularly distributed with angle
- Can have any density (fill) in each zone as desired

$$w = \frac{\lambda f}{2r_n}$$

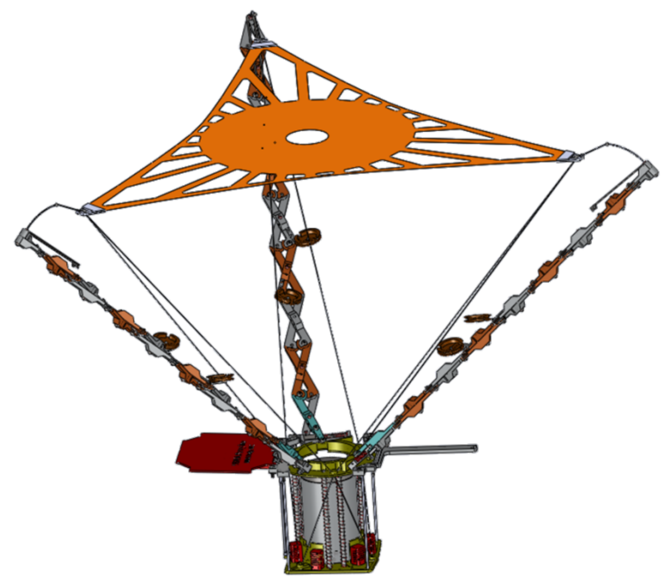


Deployment System

- Deploy sieve with spring powered and synchronized pantographs
- Forms the photon sieve plane with tensioned lanyards forming a determinate HEXAPOD
  - Structurally and thermally stable in micron range once deployed
  - Lanyards low or zero CTE material
- Store sieve within 6 cm hole in sieve center to prevent creases

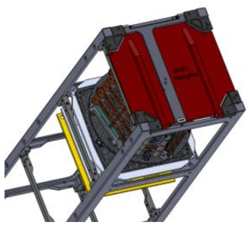


Common Hexapod (Ref: Wikipedia)

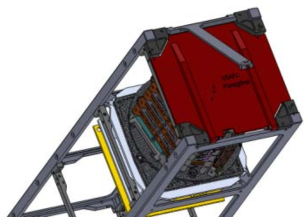


Micro-G experiment characterizes position accuracy of deployment system

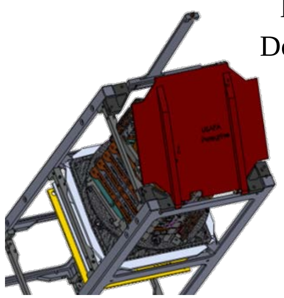
Deployment Sequence



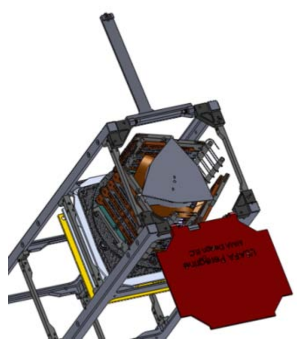
Melt Wire
Is Energized



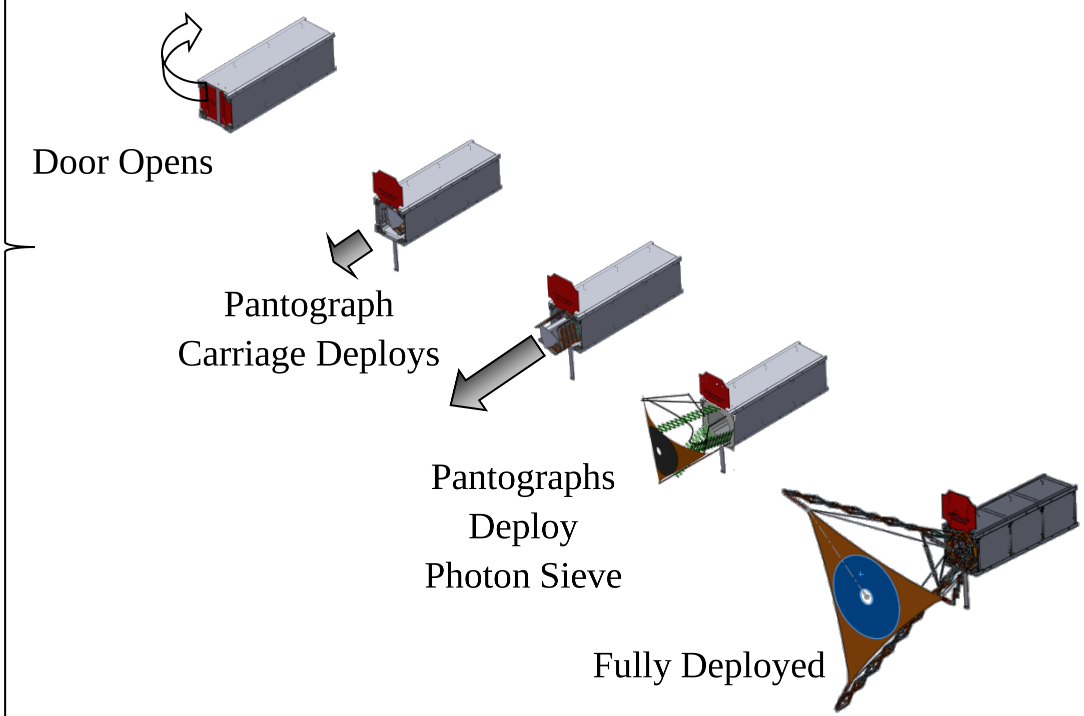
Melting Releases
Door Restraint Strap



Springs Rotate The
Door Restraint Strap
At 90 Degrees
The Door Begins to Open

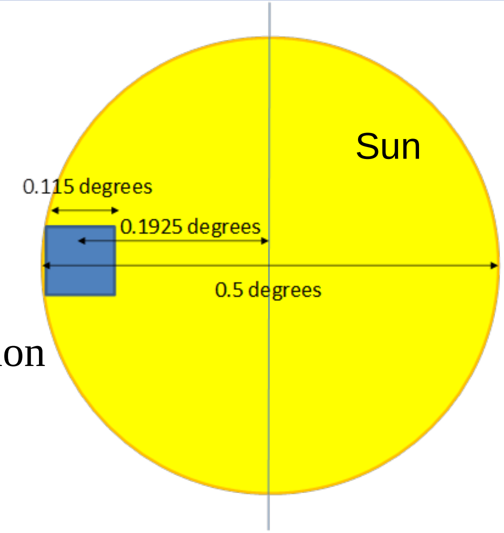


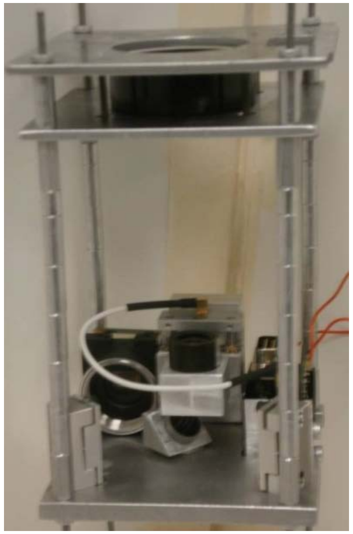
When Door Is Open
Carriage Plate Begins
Deployment



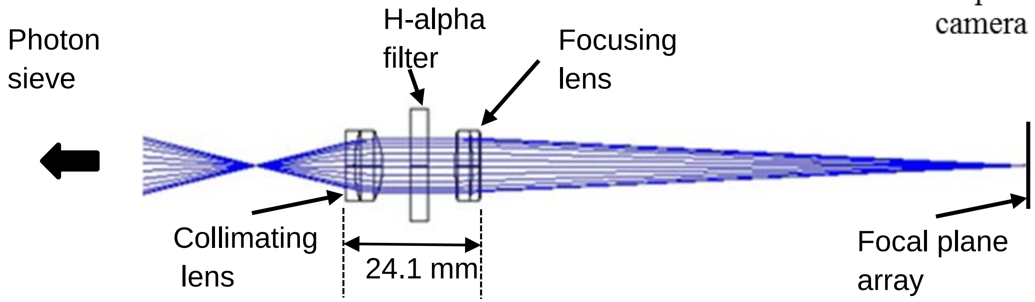
Optical Bench Subsystem

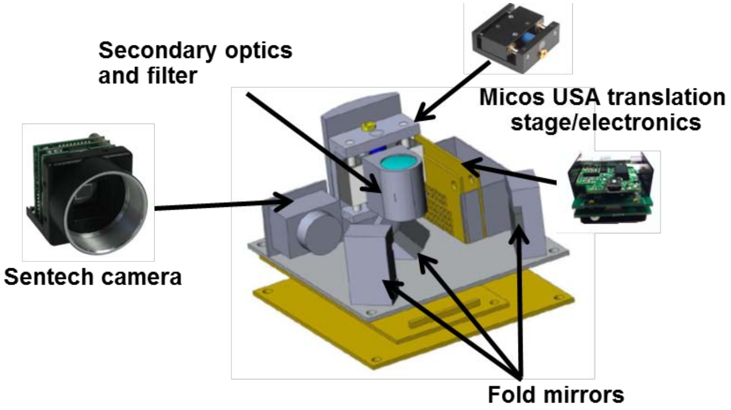
- Optical system design
  - Two secondary lenses and H-alpha filter
  - Commercial digital camera
  - Commercial translation stage
  - Secondary camera for deployment inspection
- Optical system performance
  - 4 μrad resolution, 600 km at Sun surface
  - ~0.1 degree FOV
  - 1 Å spectral bandwidth
  - SNR of >17 for 10 μsec exposure





Inspection camera





Electronics Subsystem

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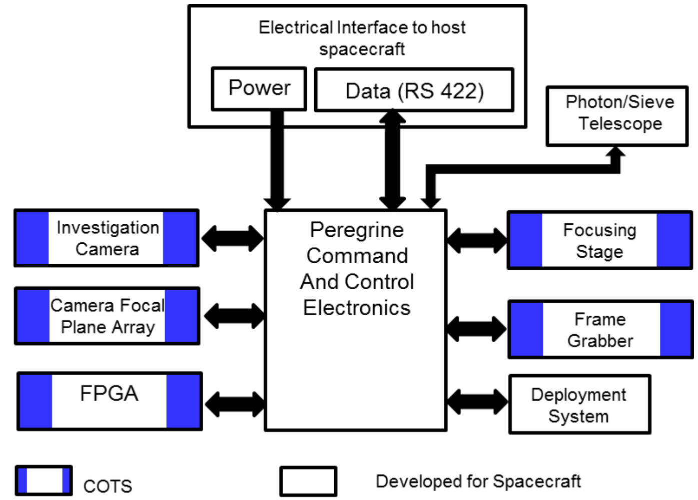
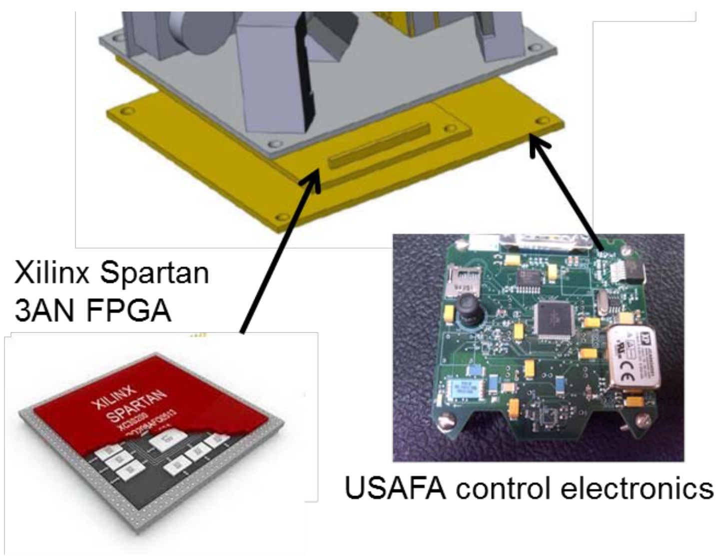
Hardware interfaced to AVR32

- FPGA
- To Lab View Bus Emulator (Serial)
- Sentech Camera
- Translation Stage and Controller
- Deployment System (Burn Wire)
- Inspection Camera



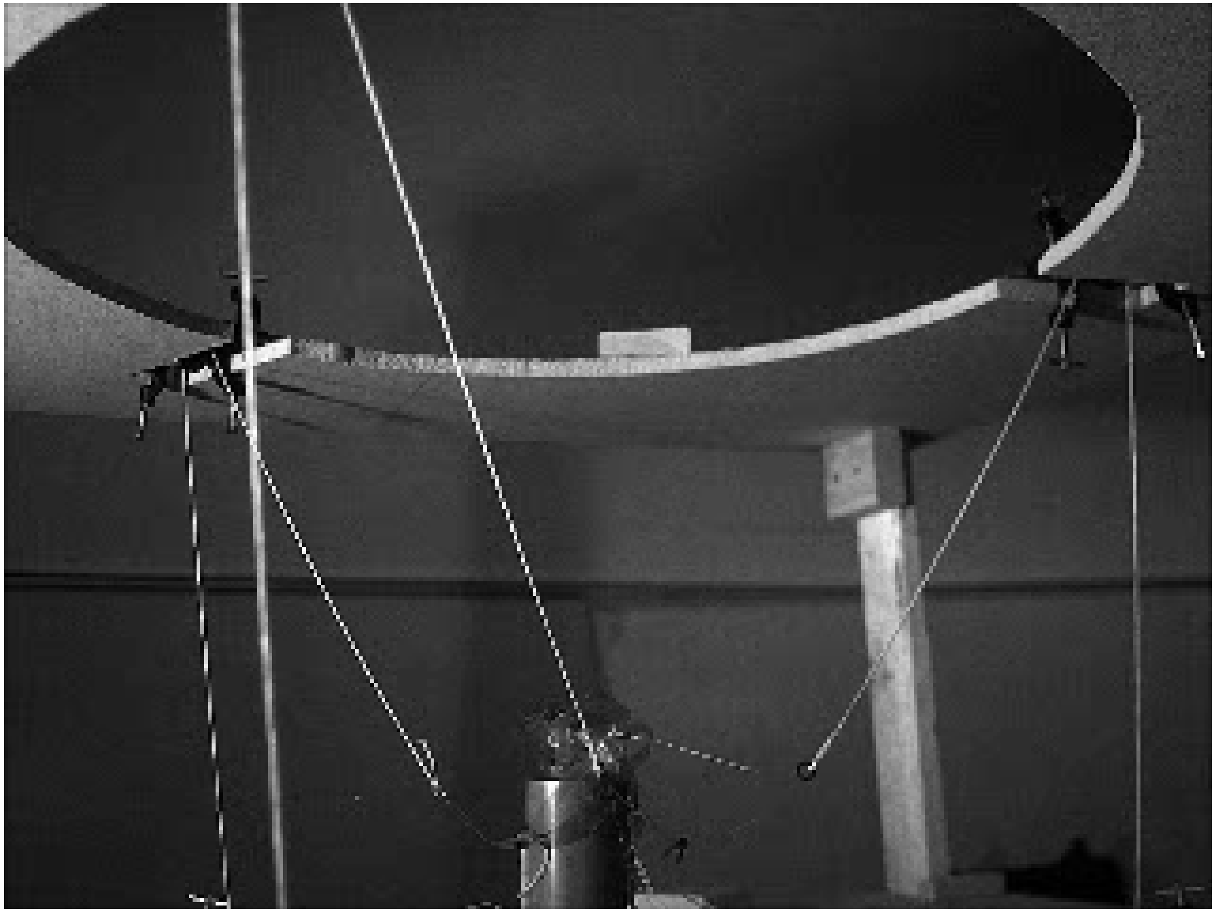


Electronics Communication Connections

- Xilinx FPGA
  - Serial to AVR32
  - Raw digital (10Bit) to Sentech Camera
- Micos USA translations Stage
  - GPIO to AVR32
- Other hardware
  - Temperature sensors (LM50) – SPI
  - Burn wire – GPIO
  - Inspection Camera – analog

Peregrine Deployment Testing

- Tested fall 2011 with stationary stand, deployment achieved by weights over pulleys



Micro-Gravity Test Concept

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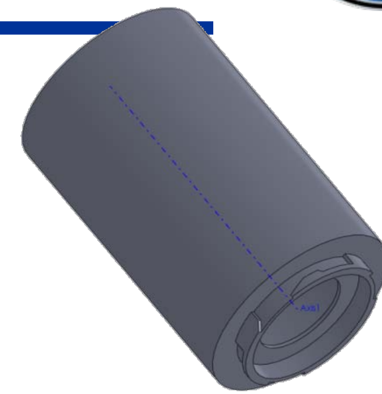
- Test deployment mechanics in micro-g on C-9B
  - No optics, electronics, burn wire
  - 14 trials over 30 arcs
  - Crew of 4 (minimum): Engineer, Faculty, 2 Cadets
- Reload with Pristine Canisters
  - Use bayonetted cylinder design
  - Pre-packed prior to flight
  - 4 Novastrat, 10 kapton, 0 patterned
- Diagnostics
  - Video taken with high speed cameras
  - Video from 2 perspectives
  - Crew observations



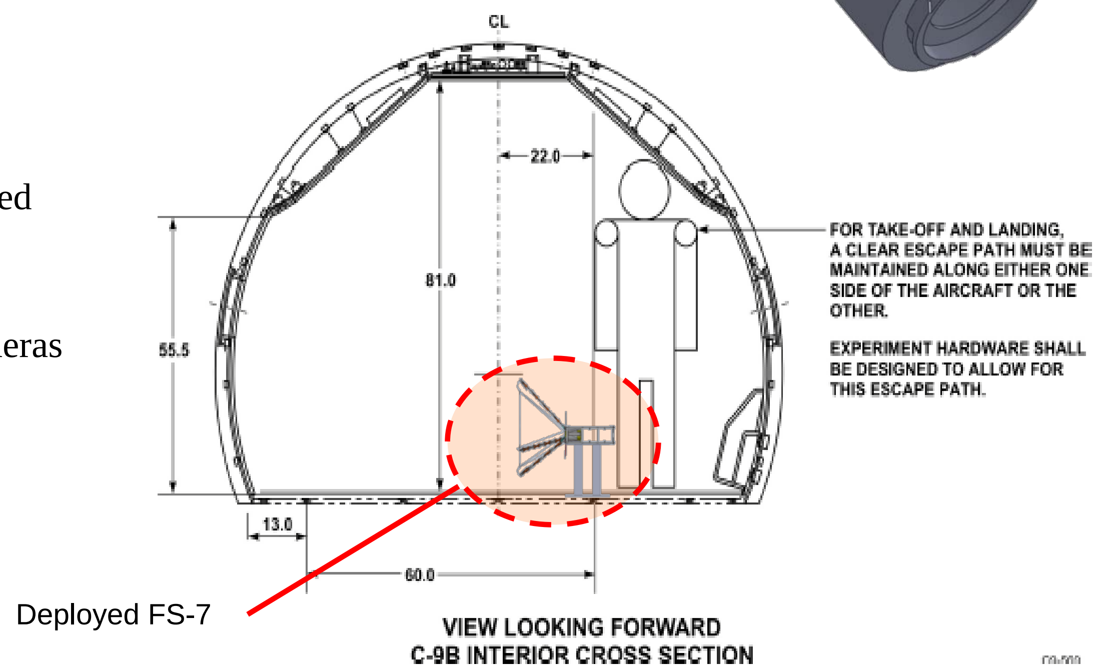
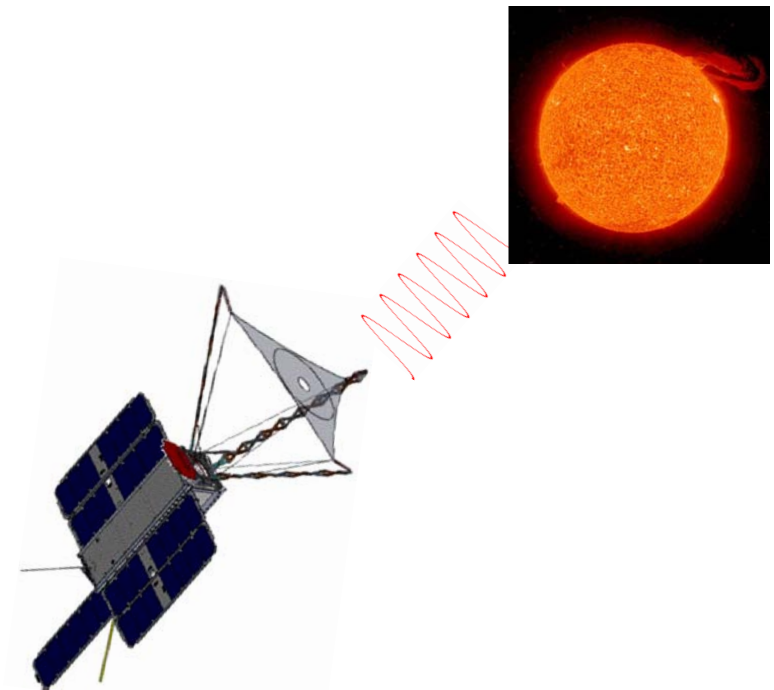


Figure 3. Take-off and Landing Escape Path Example

FalconSAT-7 Programmatics



Schedule

- Dec 2011: CubeSat mission PDR
- Aug 2012: Micro-G test of deployment system
- Dec 2012: CubeSat mission CDR
- May 2013: CubeSat flight model finished
- Aug 2013: CubeSat I&T complete

Micro-g Test Objectives

- Deploy a photon sieve from folded configuration
- Determine optical alignment of photon sieve

CubeSat Mission Objectives

- Image the Sun in the hydrogen alpha wavelength
- Determine imaging performance of a photon sieve in space

Development Path

- ➢ Micro-gravity experiment – NASA/DoD
- ➢ CubeSat mission– funded
- ➢ ESPA-class or 6U CubeSat mission

Conclusion

FalconSAT-7 is an exciting initiative using advanced technology with high risk but even higher payoff