High Energy Replicated Optics to Explore the Sun: Hard X-Ray Balloon-Borne Telescope

NASA MSFC PI: Jessica A. Gaskin

NASA GSFC PI: Steven D. Christe

- HEROES Flight: September 2013!
- Launch Site: Ft. Sumner, NM
- Website: http://goo.gl/Psis7

- **H**ands-**O**n **P**roject **E**xperience (HOPE)

- The awards are presented annually by the NASA Academy of Program/Project & Engineering Leadership (APPEL), with NASA's Science Mission Directorate (SMD), Office of the Chief Engineer (OCE) and Office of the Chief Technologist (OCT).

HOPE Objective	HEROES Project Objective
1. Hands-on Training	HPO 1 Training: Enhance the project leadership and technical skills and share the learning experiences gained by team members through the execution of a full life cycle balloon science project while satisfying the requirements of NASA Interim Directive (NID) 7120-97.
2(i): New and complementary science data	HPO 2 Science: a. Perform Solar observations (NASA Strategic Goal 2, Outcome 2.2, Heliophysics) b. Perform Astrophysical Observations (NASA Strategic Goal 2, Outcome 2.4, Astrophysics)
2(ii): Advanced Capability	HPO 3 Advanced Capability: a. Leverage both daytime solar and nighttime astrophysical observations with the same balloon flight. b. Advance the TRL levels of the Solar Aspect System, the Alignment Monitoring System, and the Star Camera Shutter.

HEROES Science Objectives

- HEROES's scientific goals and objectives can be summarized with the following overarching goals:

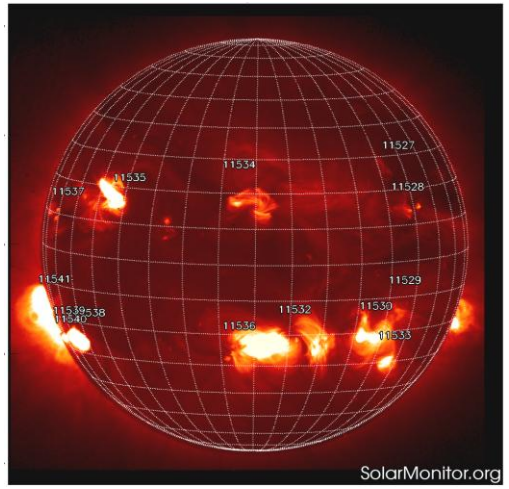
NEW!

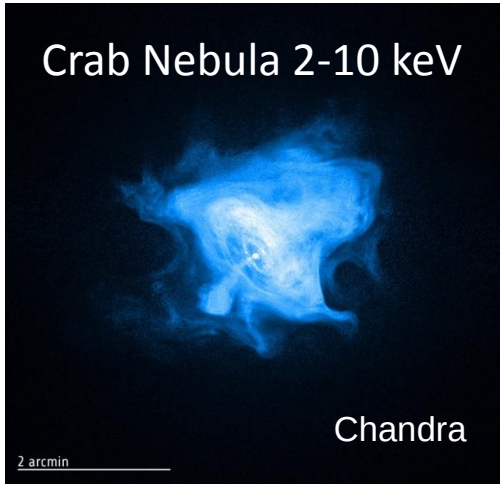
Helio

- Investigate electron acceleration in the non-flaring solar corona by searching for the hard X-ray signature of energetic electrons.
- Investigate the acceleration and transport of energetic electrons in solar flares.

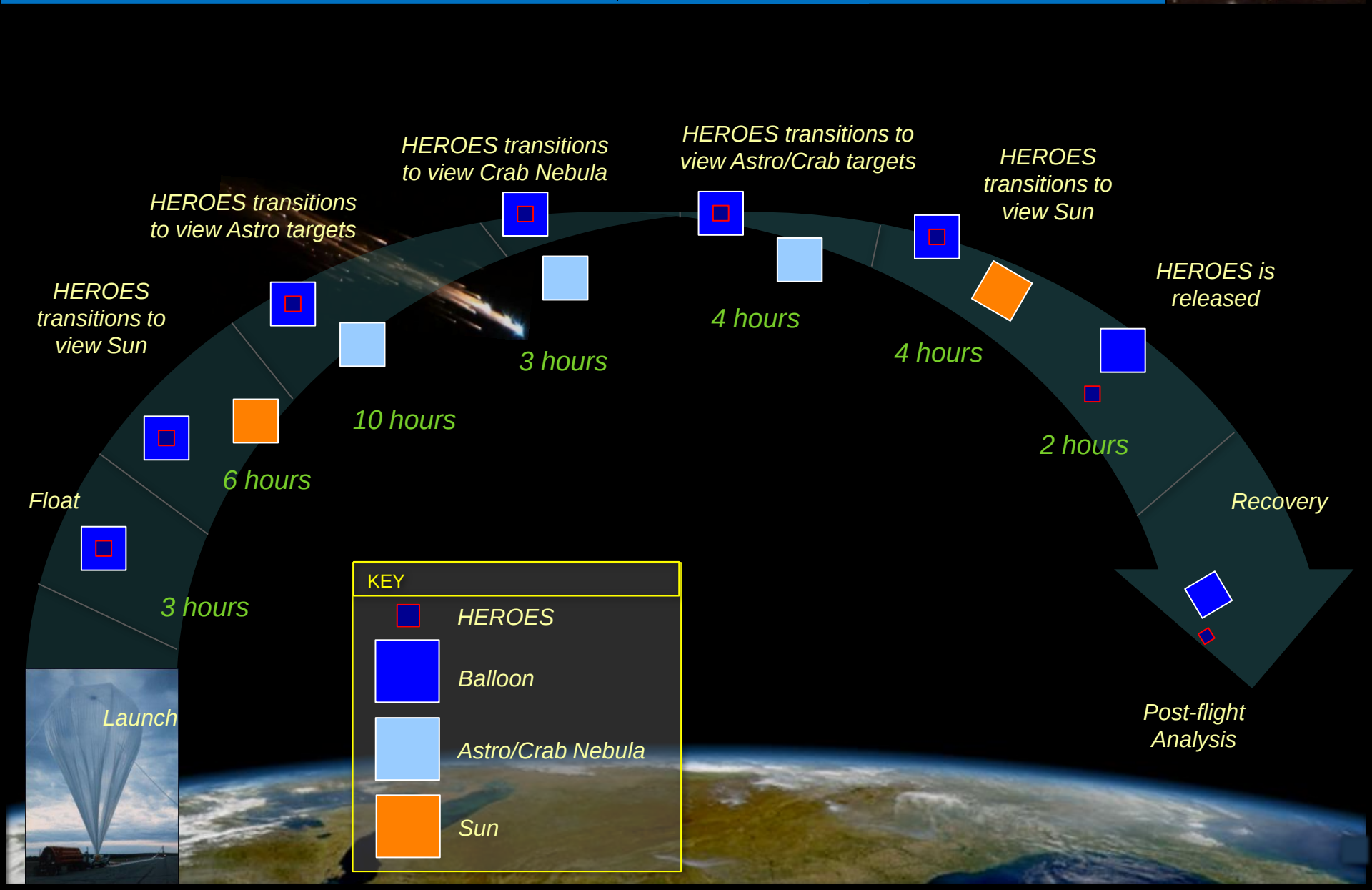
Astro

- Investigate the scale of high energy processes in a pulsar wind nebula.
- Investigate the hard X-ray properties of astrophysical targets such as X-ray binaries and active galactic nuclei.





MSFC & GSFC

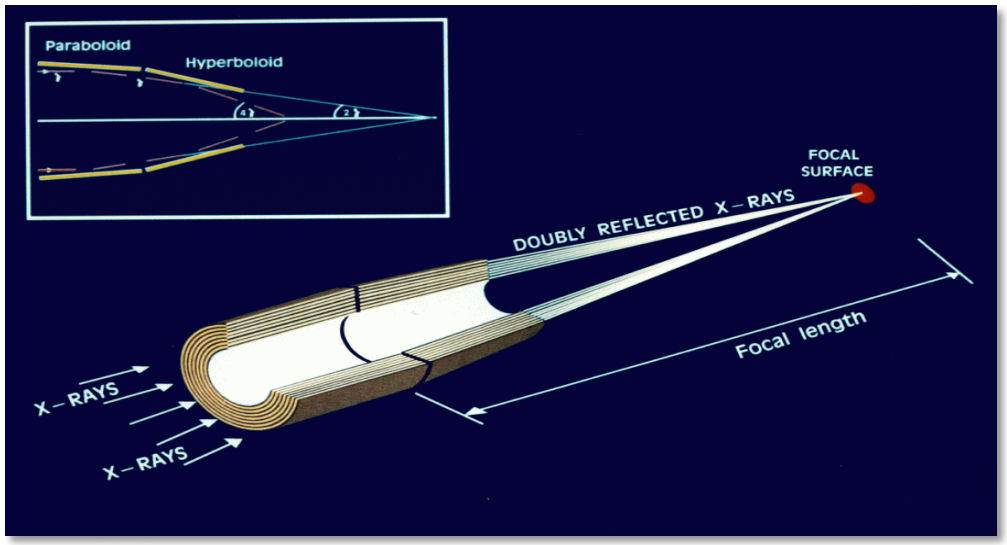

HEROES transitions to view Crab Nebula
HEROES transitions to view Astro/Crab targets
HEROES transitions to view Sun
HEROES transitions to view Astro targets
HEROES transitions to view Sun
HEROES is released
3 hours
4 hours
4 hours
10 hours
6 hours
2 hours
Float
Recovery
3 hours
KEY
HEROES
Balloon
Astro/Crab Nebula
Sun
Launch
Post-flight Analysis

High Energy Replicated Optics (HERO)

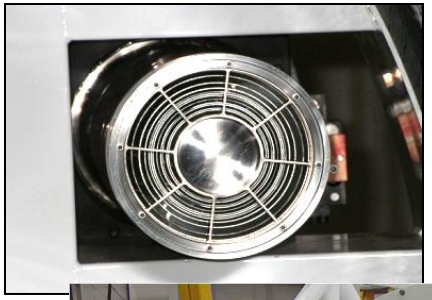
- Existing MSFC-developed balloon-borne payload for direct imaging and spectroscopy of hard X-ray sources in the 20-75 keV range. (PI: Dr. Brian Ramsey)
- Has flown 4 times; most recently in 2011 from Alice Springs, Australia
- Has observed a number of astrophysical targets but **does not have the ability to point to the Sun**.

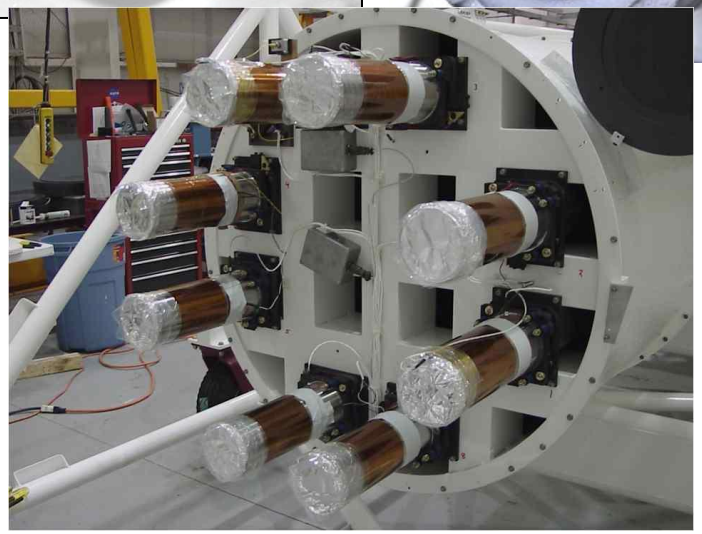
HERO Optics

Mirror shells per module	14 (6 mod), 13 (2 mod)
Inner, outer shell diameters	50, 94 mm
Total shell length	610 mm
Focal length	6 m
Coating	Sputtered iridium
Number of mirror modules	8
Effective area	~ 85 cm^2 at 40 keV, ~ 40 cm^2 at 60 keV
Angular resolution (module)	~25-30 arcsec FWHM
Field of View	9 arcmin at 40 keV 5 arcmin at 60 keV

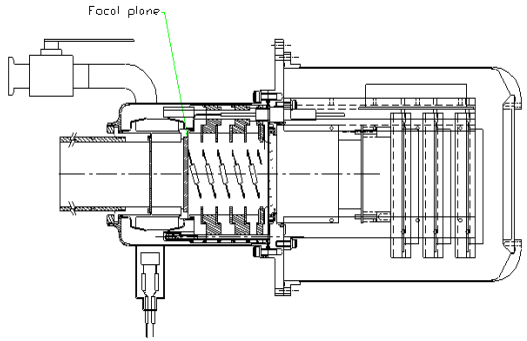


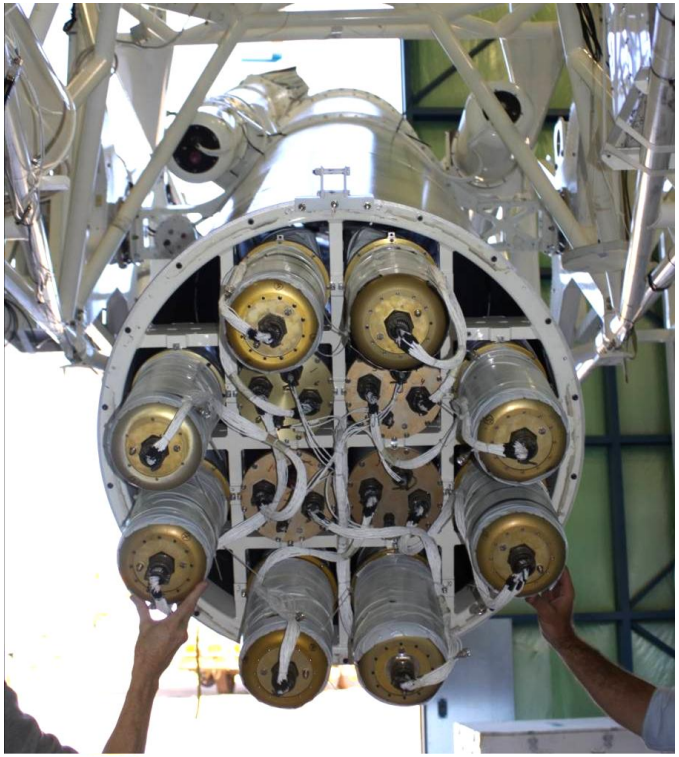
- HERO hard X-ray optics are full-shell electroformed-nickel-replicated mirrors coated with iridium.
- They are conical approximations to Wolter Type 1 geometry, with a monolithic shell structure containing both “parabolic” and “hyperbolic” segments.





HERO Detectors

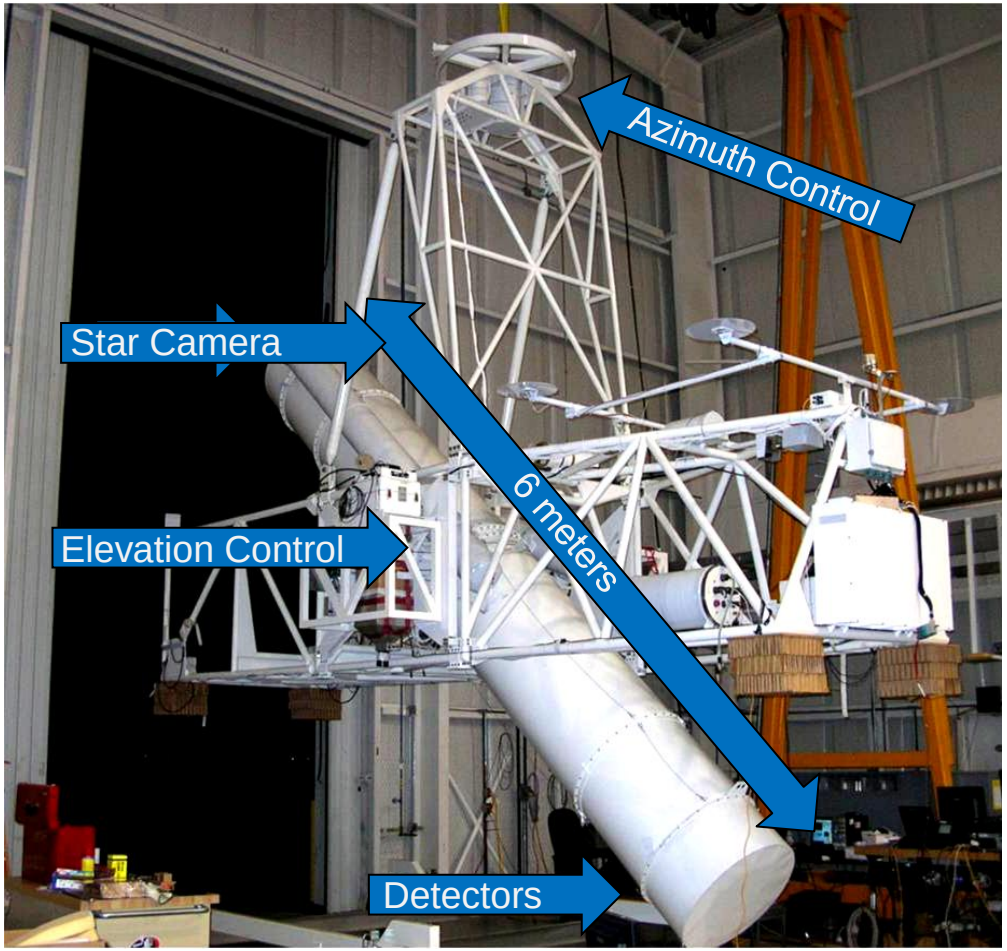




Imaging Gas Scintillation Proportional Counters

Total Sensitive Area	Approximately 20 cm^2
Fill Gas	56 mm of Xenon + Helium (96/4) at 10^6 Pa
Entrance Window	3.2 mm Be
Light Emitting Region	4 mm deep
Exit Window	7 mm Sprasil
Phototube	Hammamatsu 4268, position sensitive, quartz window
Quantum Efficiency	99% @ 40 keV 89% @ 60 keV
Energy Resolution (FWHM)	5% @ 30 keV 3% @ 60 keV
Position Resolution (FWHM)	420 um (15-25 keV) 330 um (25-35 keV) 400 um (35-35 keV)

HERO Optical Bench



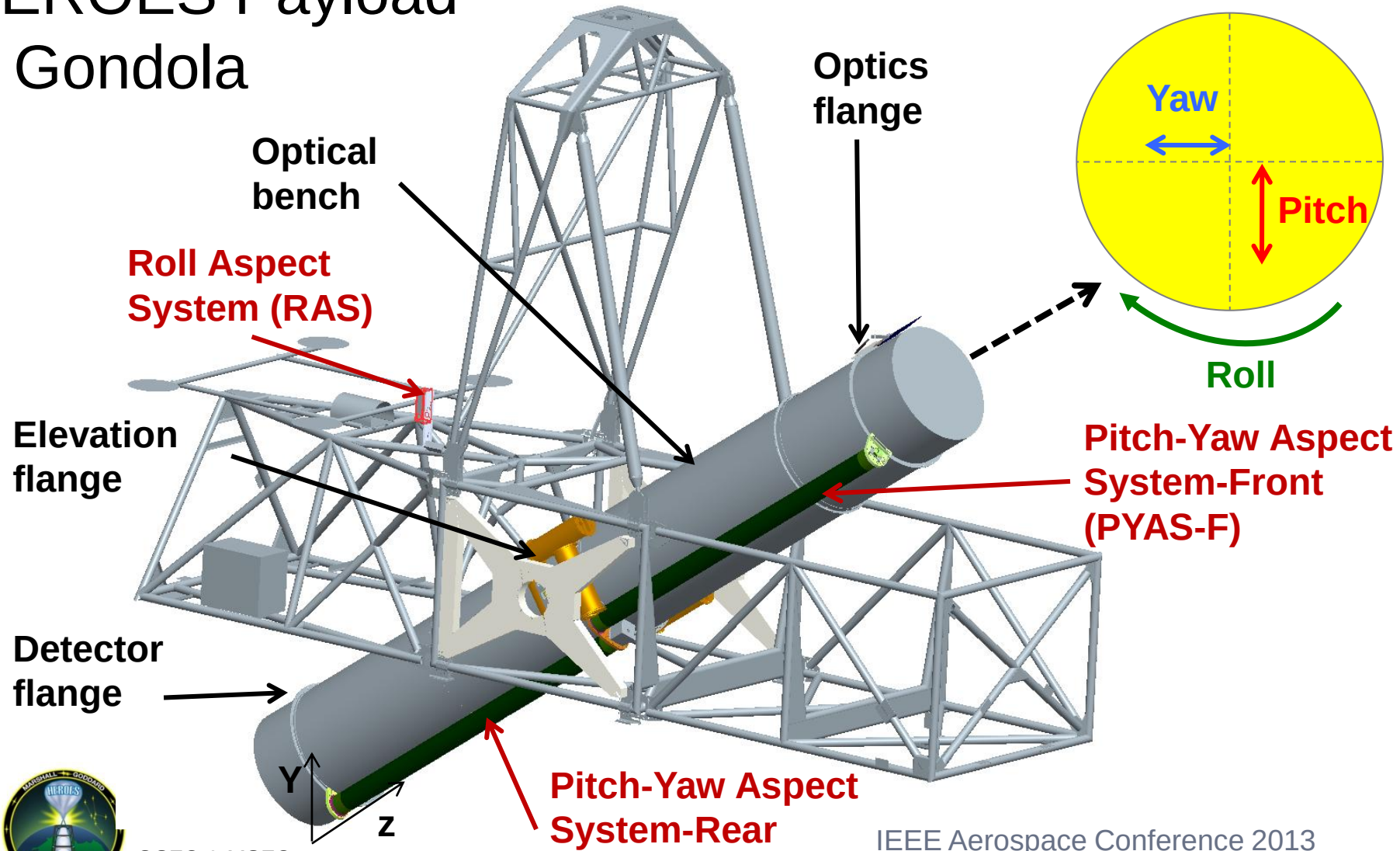
New HEROES Systems

1. Solar Aspect System
   1. Pitch-Yaw Aspect System
   2. Roll Aspect System
2. Alignment Monitoring System
   1. Star Camera Alignment Monitoring System
   2. Bench Alignment Monitoring System
3. Star Camera System
   1. New Lens
   2. Shutter System
   3. New Housing
   4. New Mount
4. Heritage Modifications and Upgrades
   1. GPS
   2. ACS Software
   3. GSE
   4. FDR
   5. Flight Software
   6. Core Network Switch

Solar Aspect System Overview

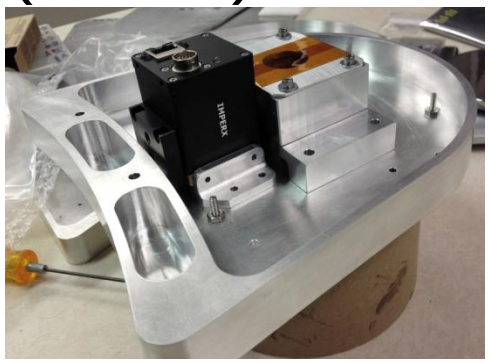
- A **Solar Aspect System** (SAS) provides solar pointing knowledge; allowing HEROES to be able to point at the Sun.
- To meet science objectives, SAS must provide
  - Relative pointing accuracy of < 15 arcsec in pitch and yaw
    - Resolution of optics + detectors
  - Absolute pointing accuracy of < 1 arcmin (60 arcsec)
    - Alignment requirements derived from this
- SAS will provide precise (~20 arcsec) pitch-yaw pointing solutions to the Pointing Control System (PCS) (roll is not controlled, only measured)
- SAS will store pointing knowledge (pitch, yaw, roll) for post processing image reconstruction

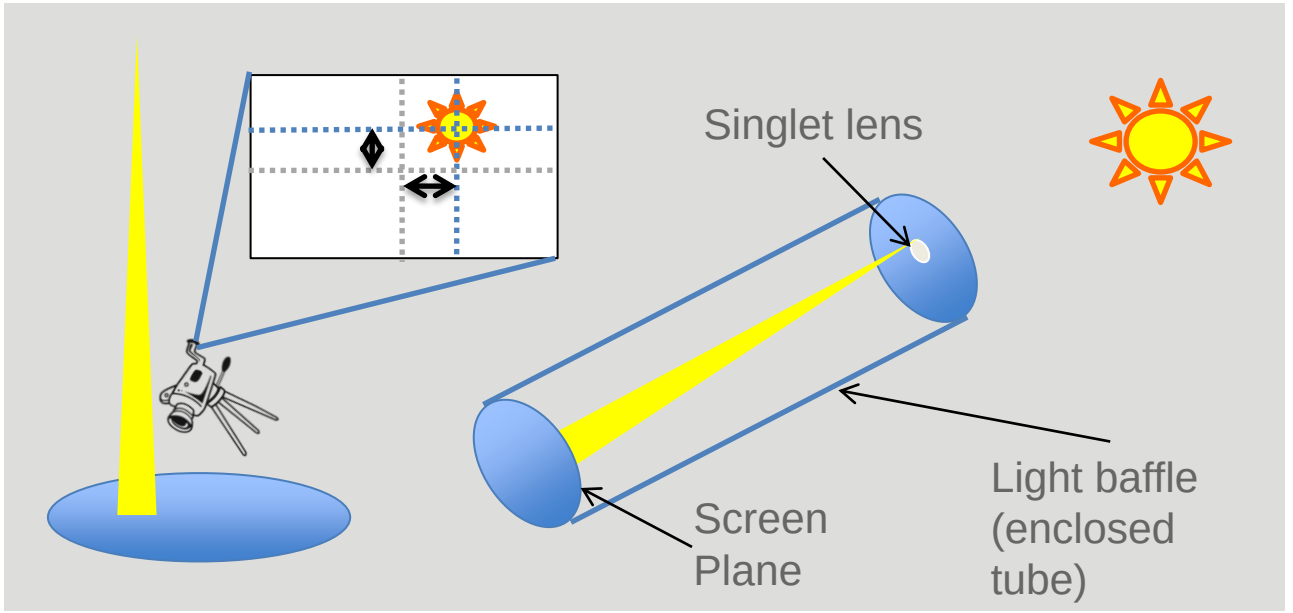
HEROES Payload & Gondola

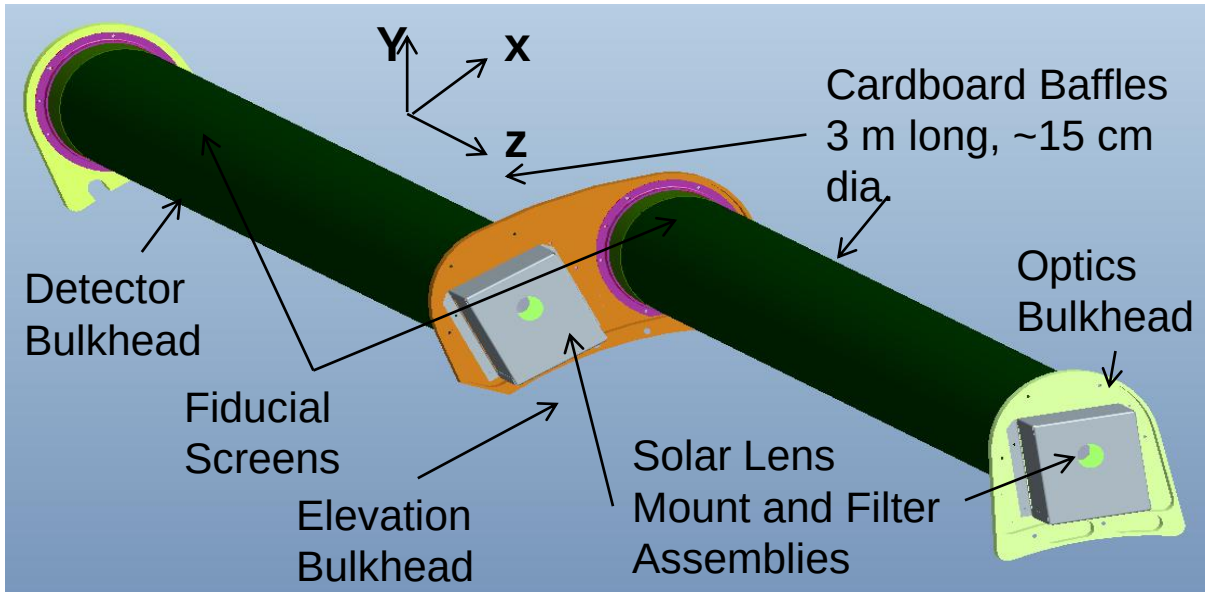


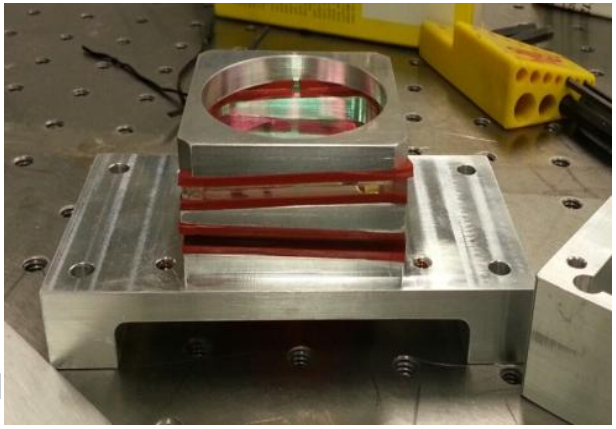
GSFC & MSFC

Pitch-Yaw-Aspect System (PYAS)



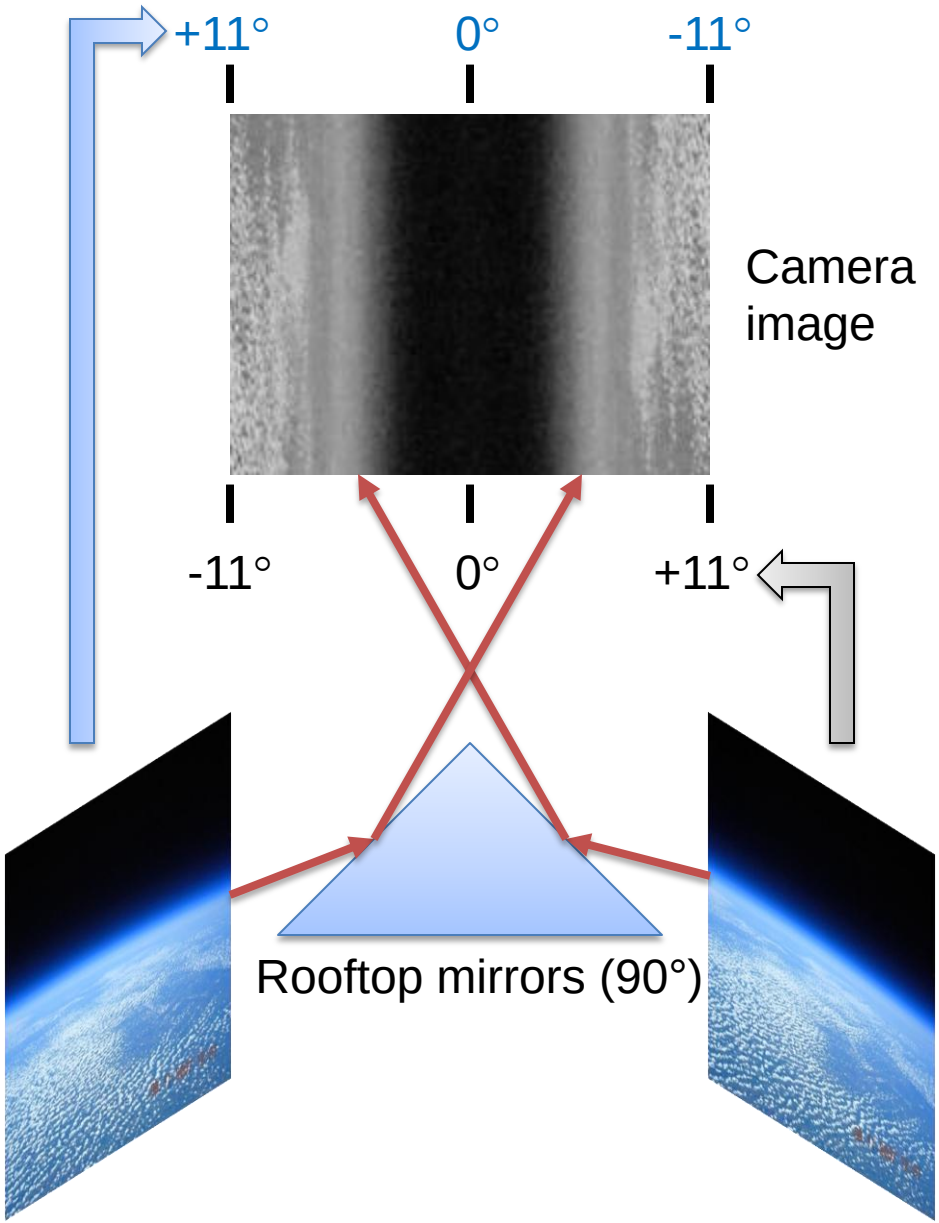






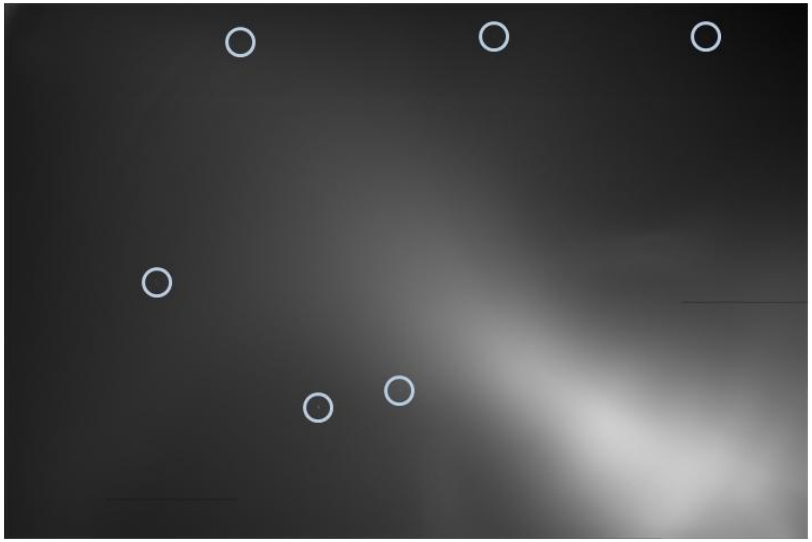
Roll Aspect System (RAS)

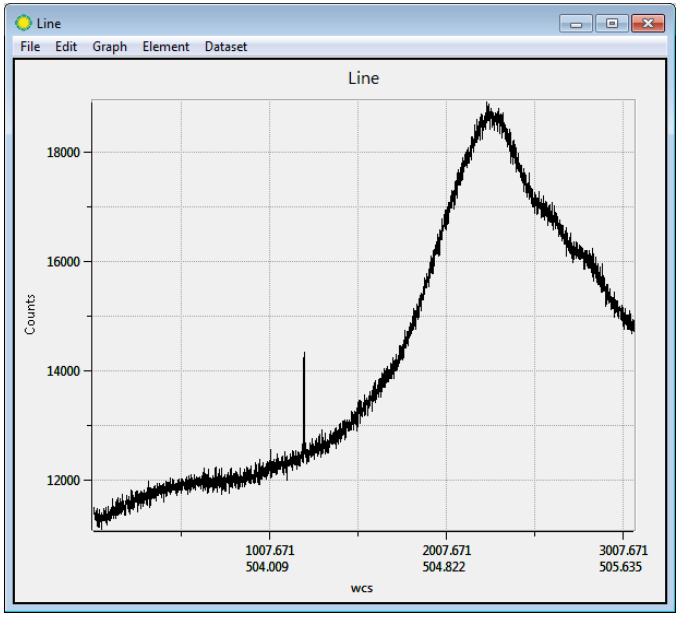
- Rooftop mirrors, with an apex angle of 90°, combine the horizon views from opposite directions into a single camera
- The camera FOV is 22°×17° and is filtered to only accept red wavelengths
- At float altitude, the horizons are about 6° below the external horizontal and do not overlap
- As the payload rolls, the two horizons will shift in tandem to the “left” or to the “right” (see animation)



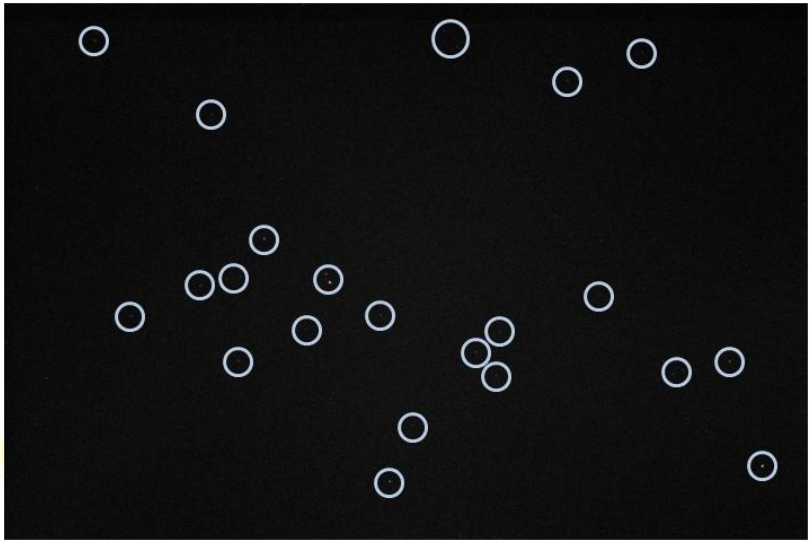
GSFC & MSFC

Daytime Image





Nighttime Image



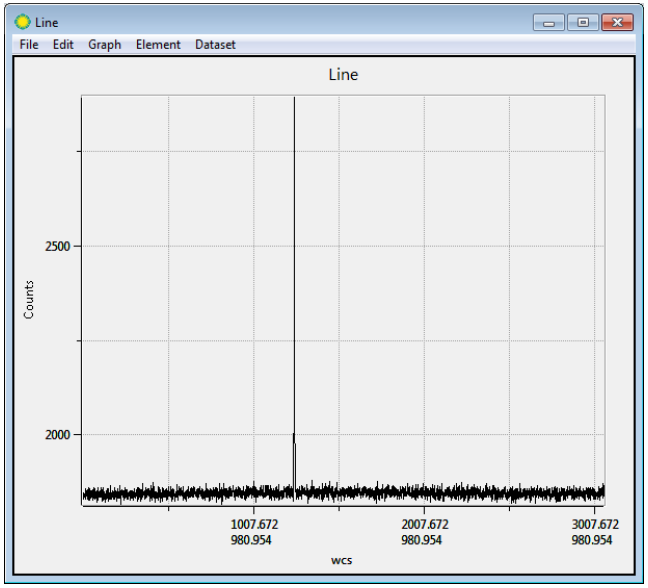
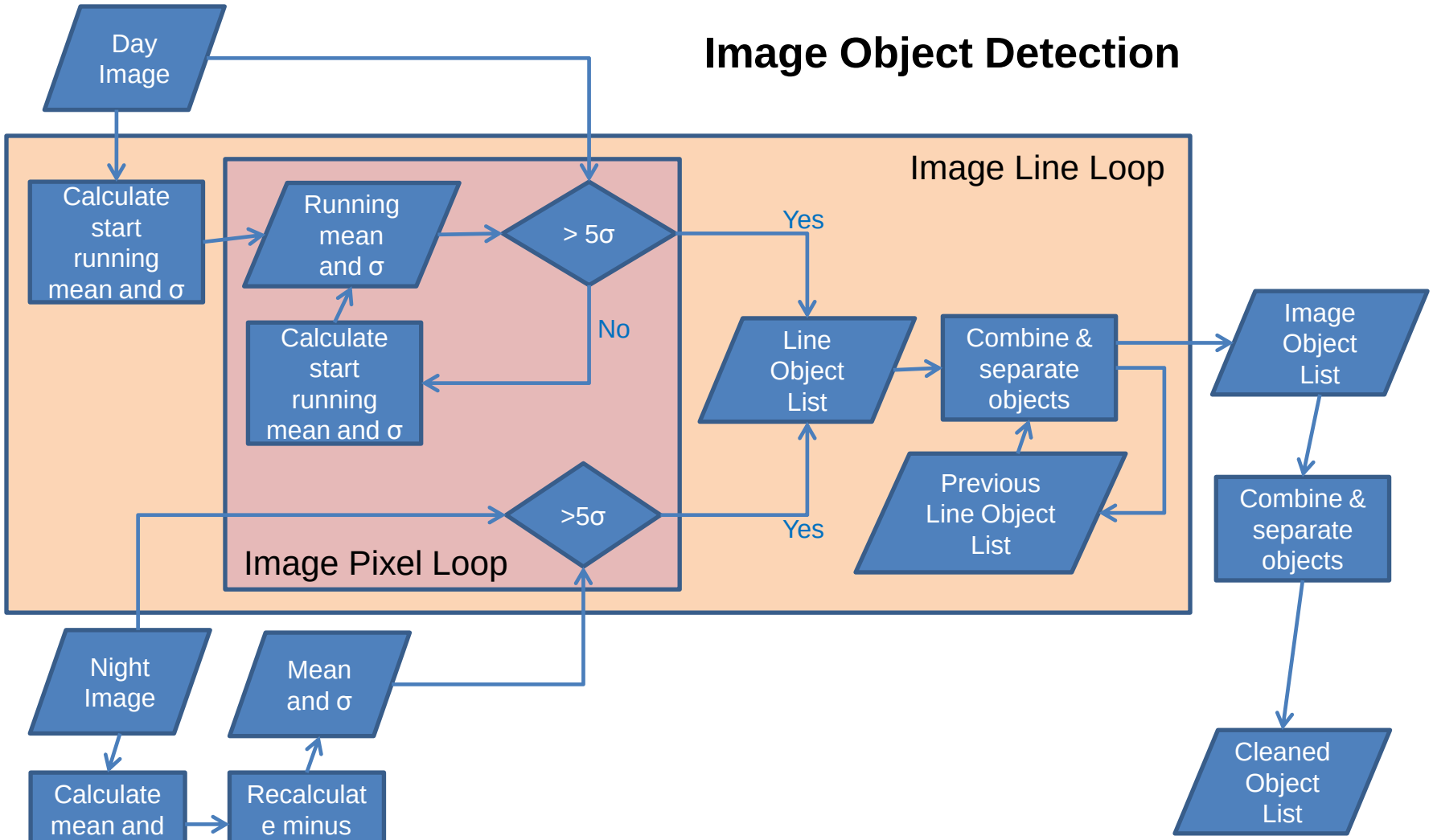
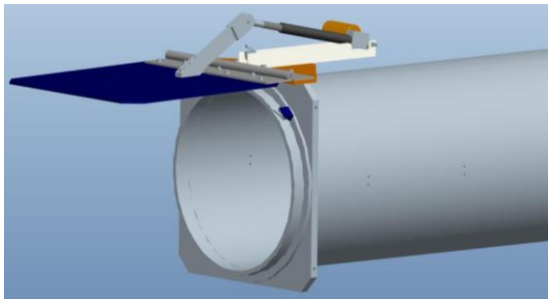


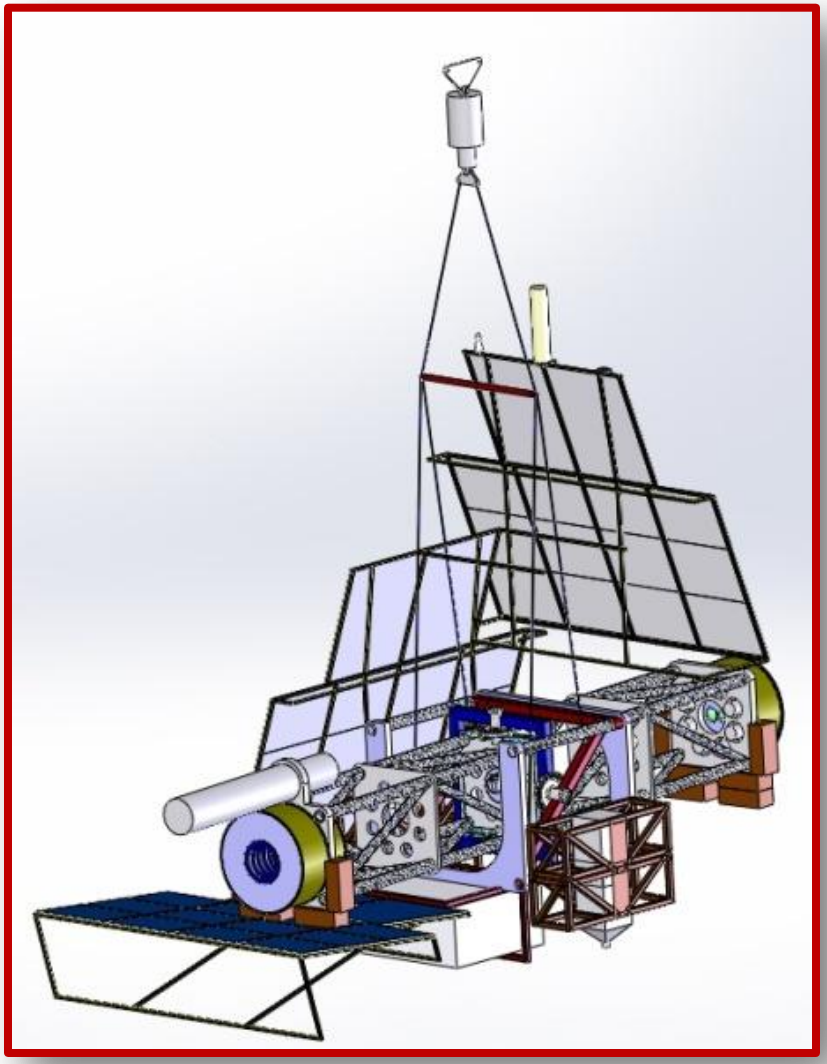
Image Object Detection



Star Camera Modifications



SuperHERO



SuperHERO is the next generation HEROES payload (hard X-Ray telescope). A redesign of the HEROES payload for a Long Duration Balloon Flight from Antarctica.

Improvements over HEROES:

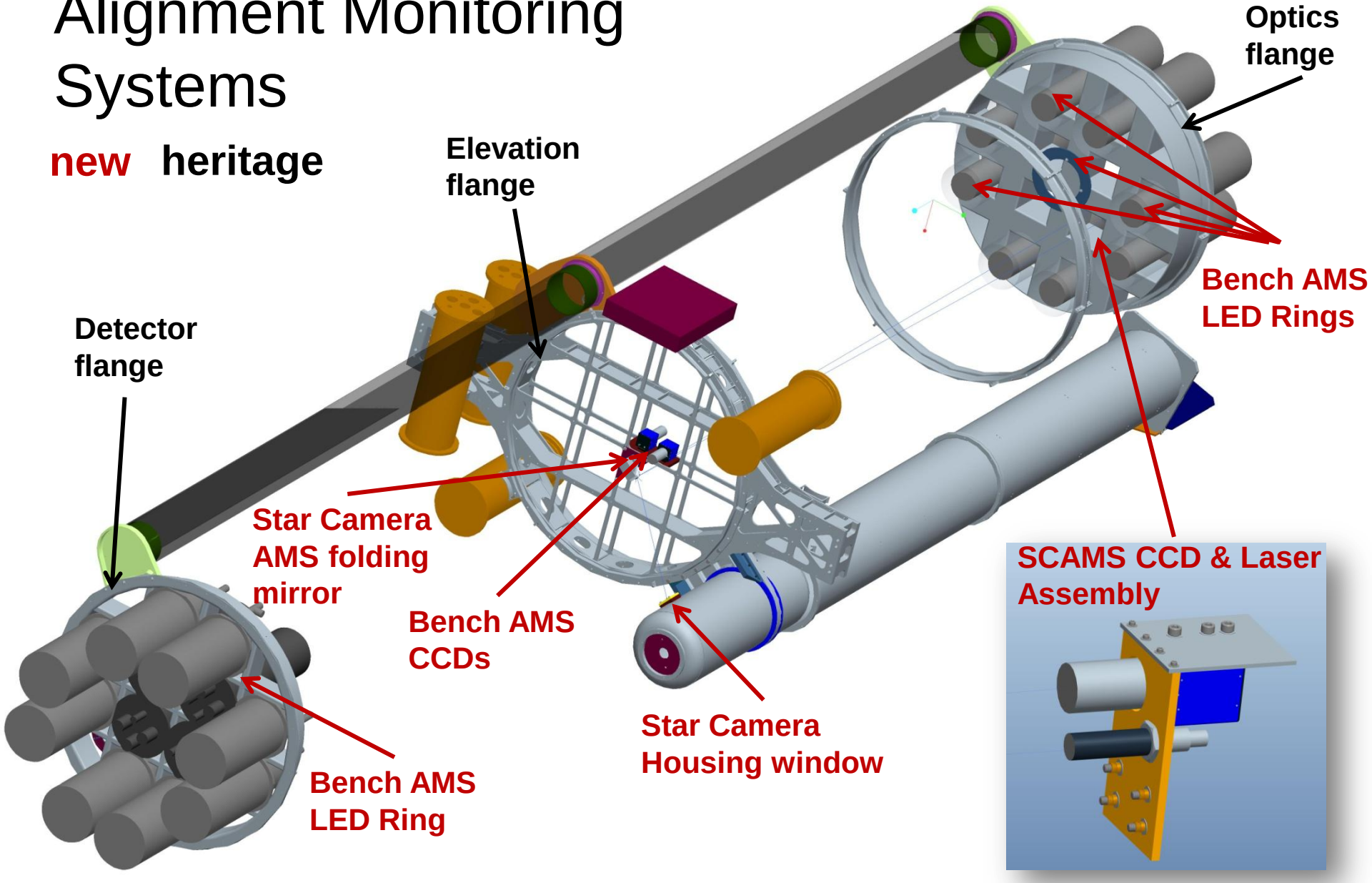
- Exchange existing detectors for CdTe fine-pixel detectors (250μm pitch) & add active shielding
- Realign & remount existing optics
- Add optics
  - Increased Effective Area
  - wider Field of View
- Integrate Wallops Arc Second Pointer (WASP)
  - Improved Pointing & Pointing Stability
- Light-Weight structure for Long Duration Flight to significantly improved sensitivity (~2 week long flight).
- New integrated Solar Aspect System, improved star camera position & baffle, power redesign (solar panels), etc…

HEROES Team and Mentors			
Name	**Position**	**Primary Mentor**	**Position**
MSFC			
Jessica Gaskin	Principal Investigator	Brian Ramsey	Senior Research Astrophysicist, ZP12
Colleen Wilson-Hodge	Project Scientist	Jeff Kolodziejczak	Senior Research Astrophysicist, ZP12
Leigh Smith	Project Manager	Larry Hill	Manager of the Science and Space Technology Projects Office, ZP21
Katherine Chavis	Lead System Engineer	Todd Macleod	Technical Assistant Systems Engineering & Integration, ES10
Heather Koehler	Software Systems & Integration	Kurt Dietz	Software, Instrument Development Branch, ES62
Andrew Hanks	Safety and Mission Assurance	Kyle Daniel	S&MA, Flight Program & Partnerships, QD22
Miguel Rodriguez Otero	Power Systems	Jeff Apple	Team Lead Instrument Development Branch, ES63
Brain O'Connor	Thermal Systems	Ken Kittredge	Thermal Analysis & Control Engineer, Thermal Analysis & Control Branch, EV34
Megan Dawson	Software Systems & Integration	Jeff Apple	Team Lead Instrument Development Branch, ES63
Alex Sobey	Gondola Mechanical Engineer/SAS	Mark Cox	ME Mechanical & Hardware Integration Team, ES63
Jonathon Pryor	Avionics Lead	Jeff Apple	Team Lead Instrument Development Branch, ES63
Tomasz Lis	AMS Support	Brian Ramsey	Senior Research Astrophysicist, ZP12
Jose Molina	Electrical Support	Jeff Apple	Team Lead Instrument Development Branch, ES63
Nancy Hill	Configuration Management	Amy Hempken	CM/DM Configuration & Data Management Office, EE12
GSFC			
Steven Christe	Principal Investigator	Brian Dennis	Senior Astrophysicist, Solar Physics Laboratory, 671
Albert Shih	Project Scientist	Brian Dennis	Senior Astrophysicist, Solar Physics Laboratory, 671
Marcello Rodriguez	SAS Systems Engineer	Edward Amatucci	Aerospace Engineer, 592
M Edgerton	SAS Mechanical Engineer	Tom Wallace	Flight Structures Engineer, 544
Alex Cramer	SAS Electrical Engineer	Gary Brown	Senior Electronics Engineer, Electromechanical Systems Branch, 544
Kyle Gregory	SAS Electrical Support		

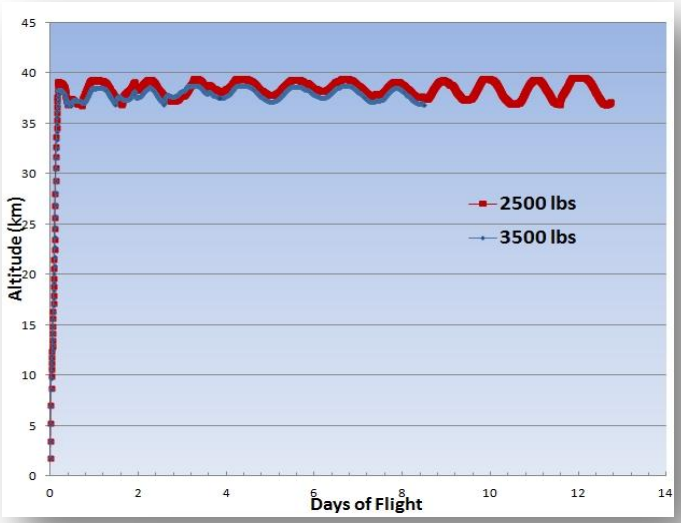
BACK UP SLIDES
HERO

Alignment Monitoring Systems

new **heritage**



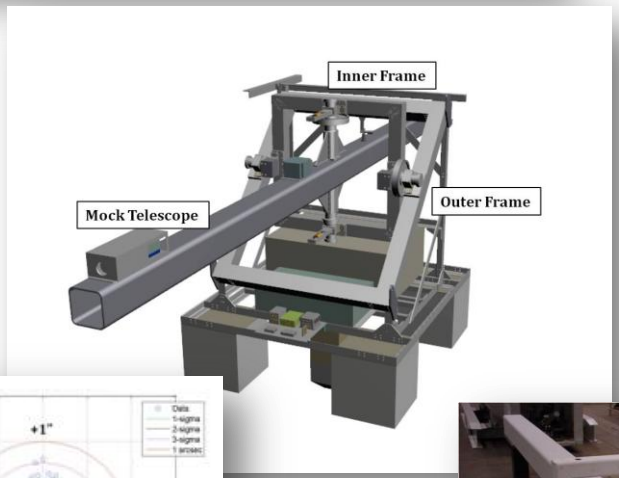
Explanation of Concept



LDB Mission
Long Duration Balloon Mission

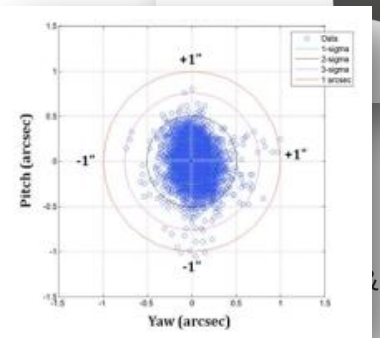
Traverses continents (Antarctica) or even around the world. LDB flights may last up to three weeks and satellite-based electronic systems are utilized for command and data. Long-duration flights mean much greater HERO sensitivity but necessitates re-design of whole payload.

- **Mass Minimization**
- **Power (Solar Panels)**
- Thermal Analyses
- **Flight Profiles (with assistance from CSBF)**

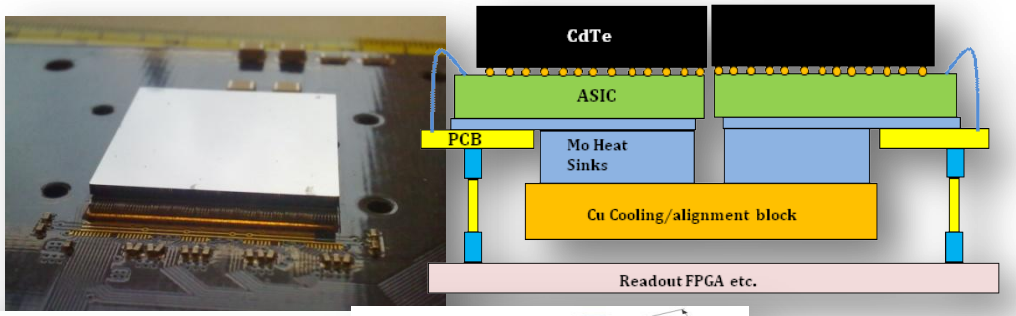


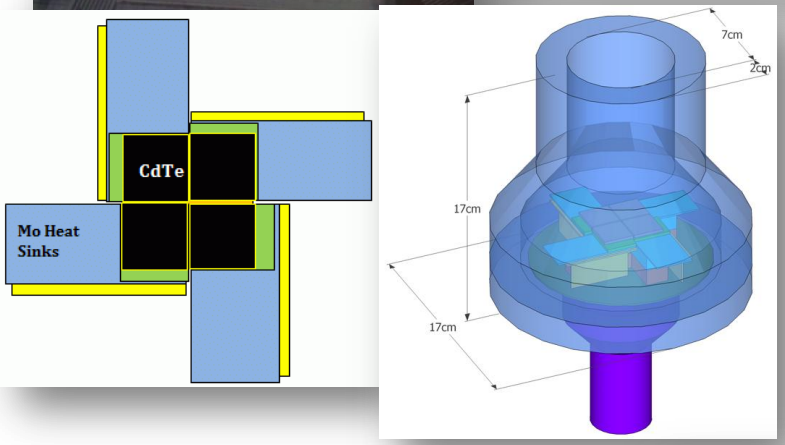
WASP
Wallop's Arc-second Pointing System

- Orthogonal pair of pitch & yaw gimbals for fine motion
- First flight test gave <1 arc-second pointing (consistent with lab tests)
- WASP can accommodate a telescope that is 6-7m long and 1m in diameter (HERO)
- Can allow for both astrophysical and solar pointing
- Budget?



Explanation of Concept





Rutherford Appleton Laboratory (RAL) CdTe Many Pixel Detectors

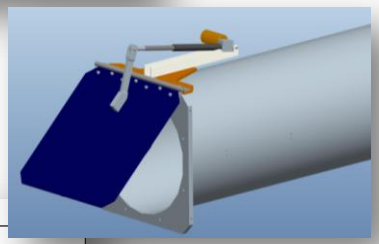
These detectors allow for improved spatial resolution, and improved response and improved background rejection when coupled with active shielding.

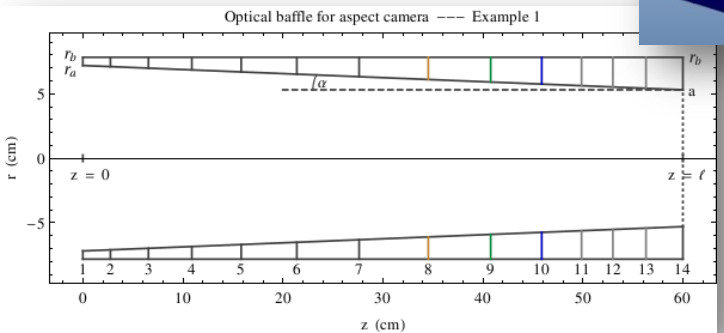
•RAL's detectors were designed for use with the HERO optics! These detectors will provide a complete telescope suitable for Explorer mission opportunities.

•Power schemes have been explored – minimization

•Cooling schemes have been explored for optimal performance (and also to minimize power)

•RAL is working on a quote to supply all detectors and characterization.





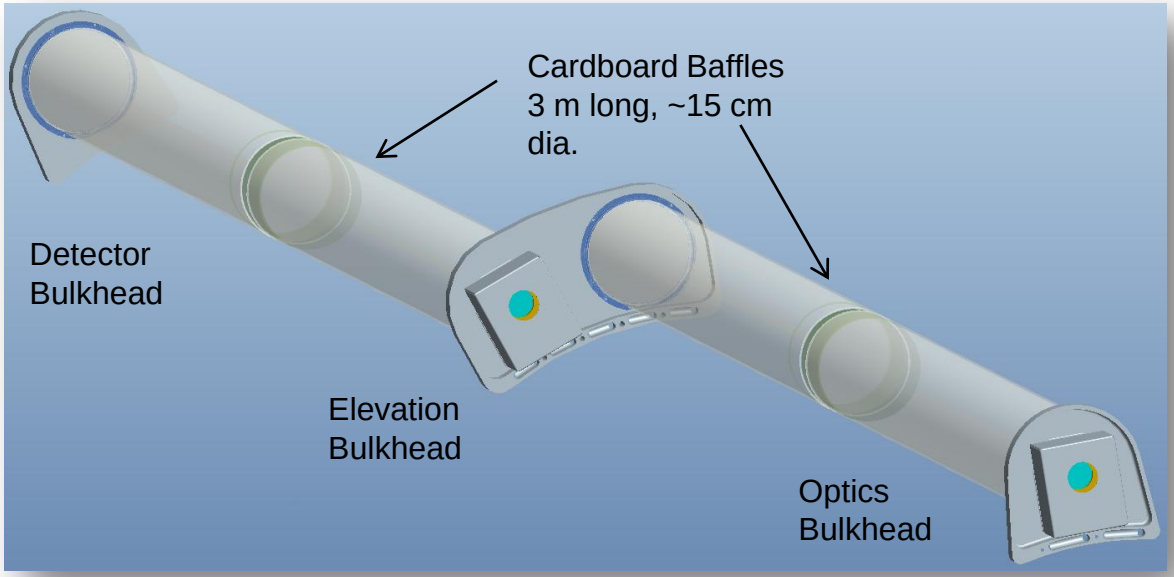
Baffle, Star Camera & Shutter

•Baffle can be shortened to 2 to 4 feet, allowing for alternative mounting point.

•Star Camera software has been improved (bugs seen on previous missions have been found and eliminated)

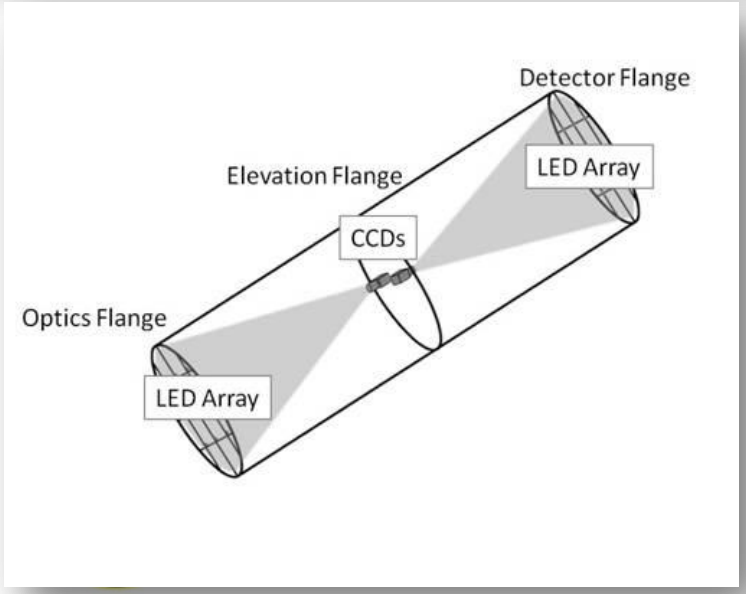
•Star Camera will be mounted directly to optics flange and a shutter will be added for solar observations.

Explanation of Concept



Solar Aspect System

- Required for solar pointing knowledge for HEROES
- SAS will provide precise (20 arcsec) pitch-yaw pointing solutions to the Pointing Control System (PCS) (roll is not controlled, only measured)
- SAS will store pointing knowledge (pitch, yaw, roll) for post processing image reconstruction

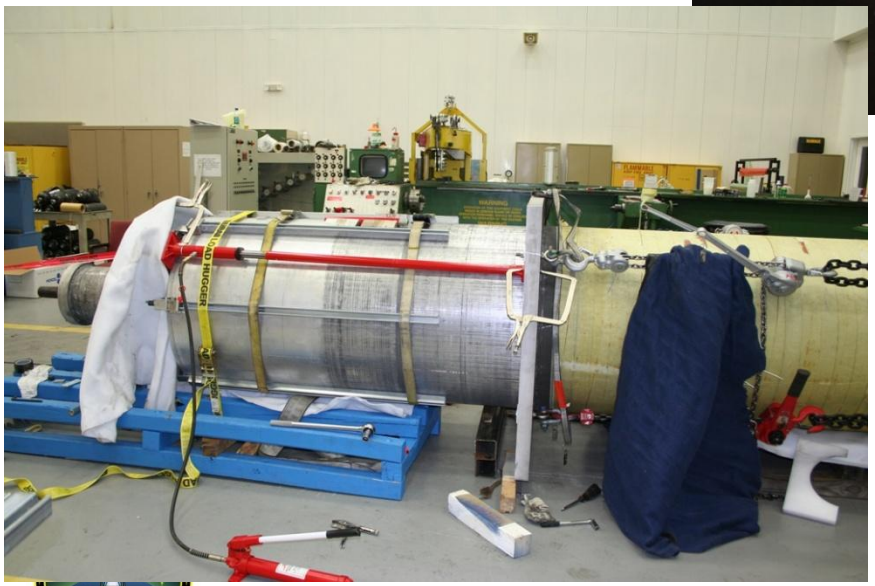


Alignment Monitoring Systems

•Bench Alignment Monitoring System: Monitors thermal effects and gravitational effects on optical bench.

•Star Camera Alignment Monitoring System: Monitors absolute position of the star camera relative to the optical bench.

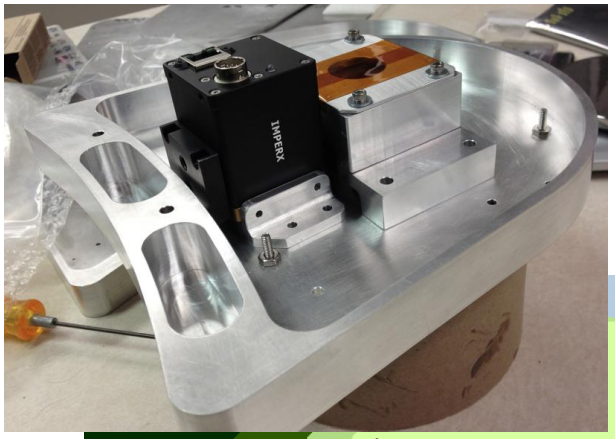
HERO Optical Bench

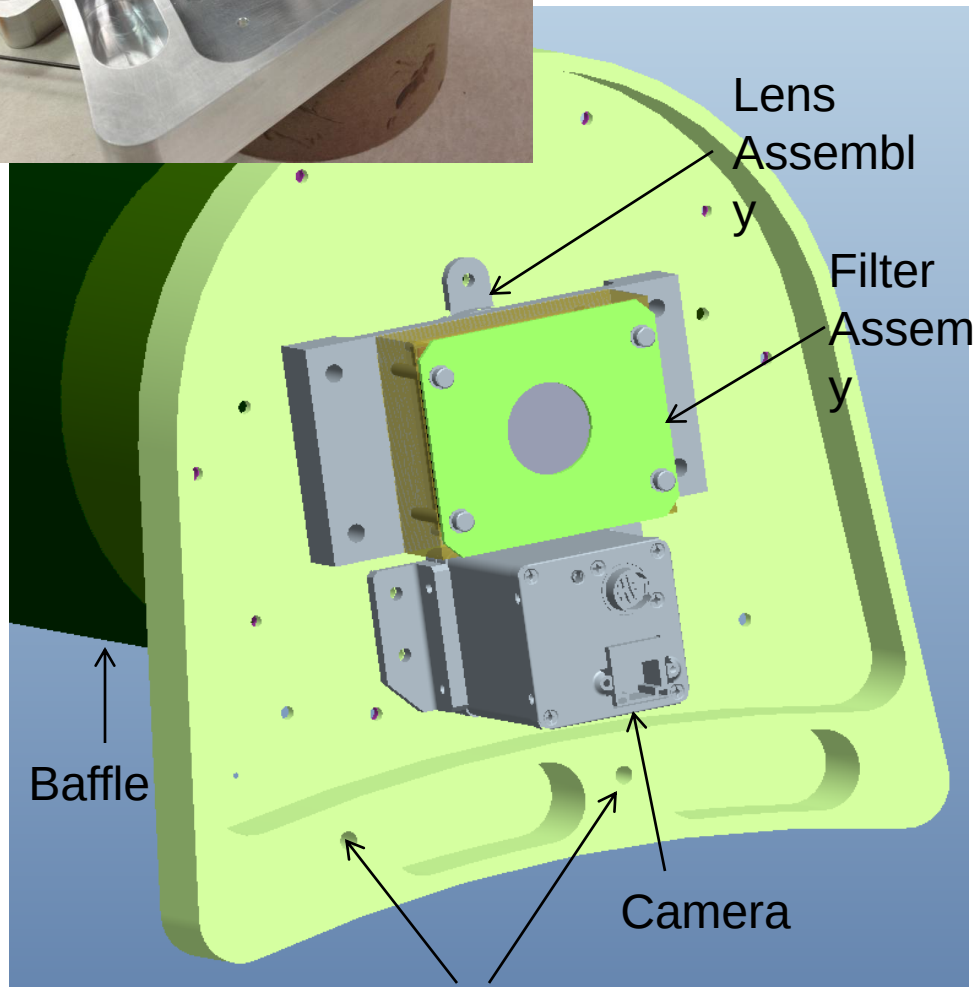


MSFC & GSFC

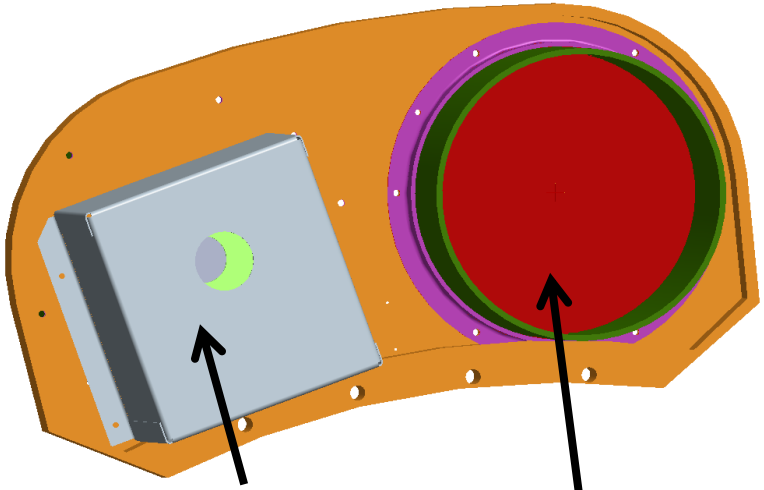
Optics Bulkhead

- Camera mounted below and angled to view center of screen
- Components shielded from sun by a cover
- Center section is 0.125” aluminum surrounded by 1” high rim
- Interface using #10 bolts
  - Will be shimmed to keep parallel relative to optics flange
- Interface bolt pattern with flange is based on MSFC fit check alignment (12/17/12)

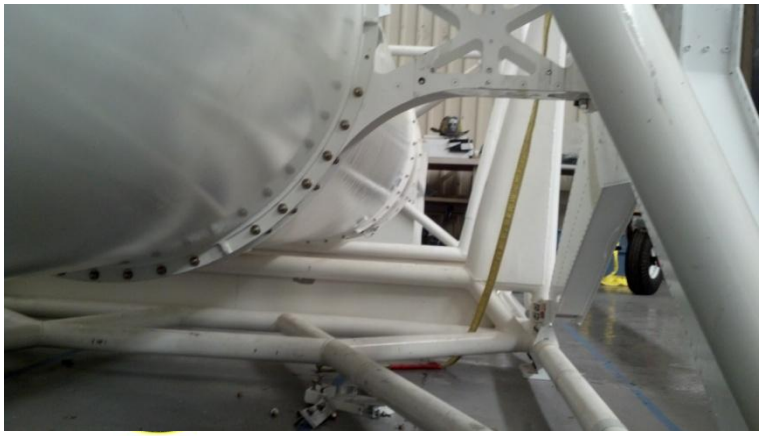


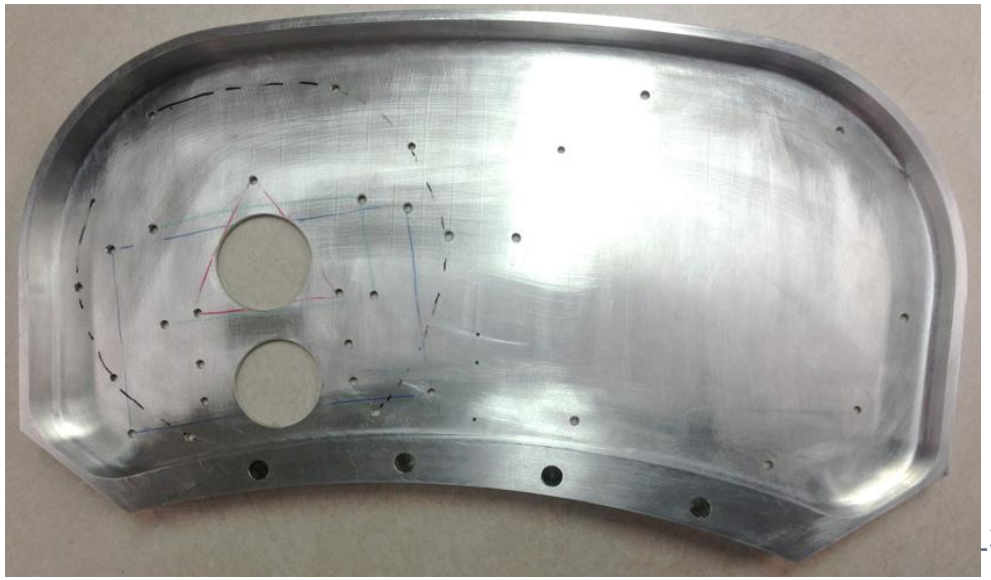


Elevation Bulkhead



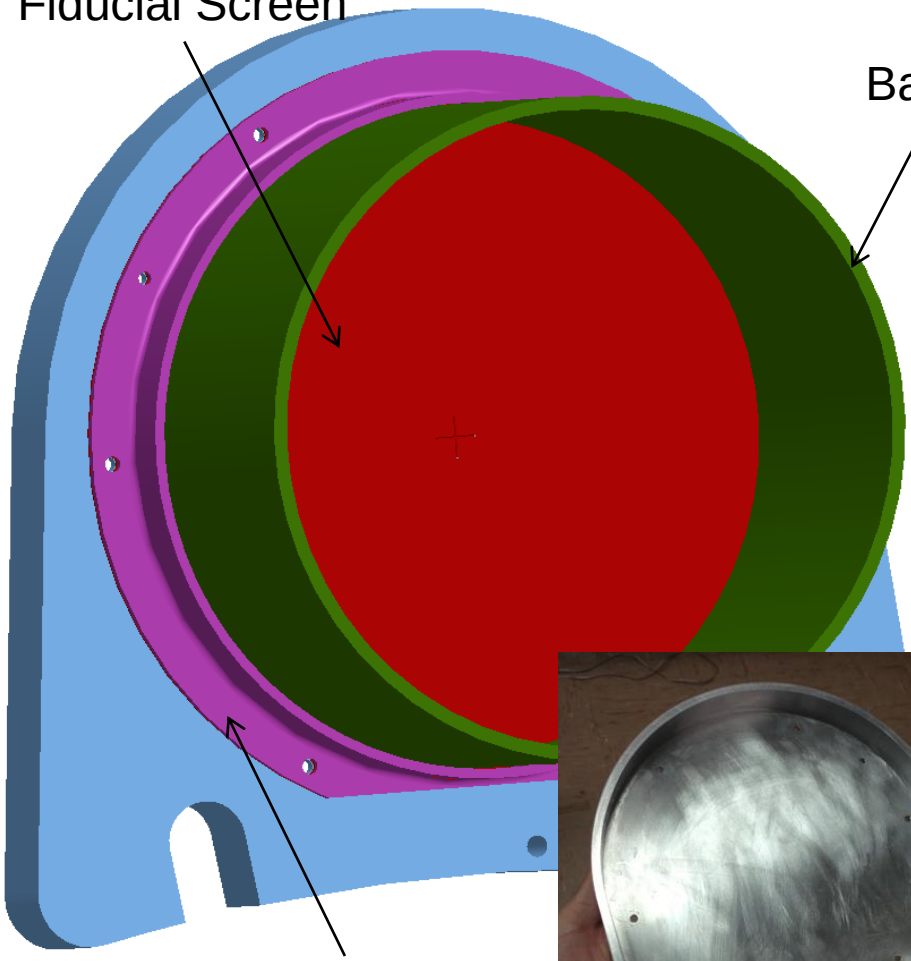
- Mounted to center flange on optical bench
- Screen (shown on right) is bolted on bulkhead at focal plane of solar lens
- Lens, filters, and camera of rear PYAS mounted on the left (shown with cover)
- Interface bolt pattern with flange is based on MSFC fit check alignment





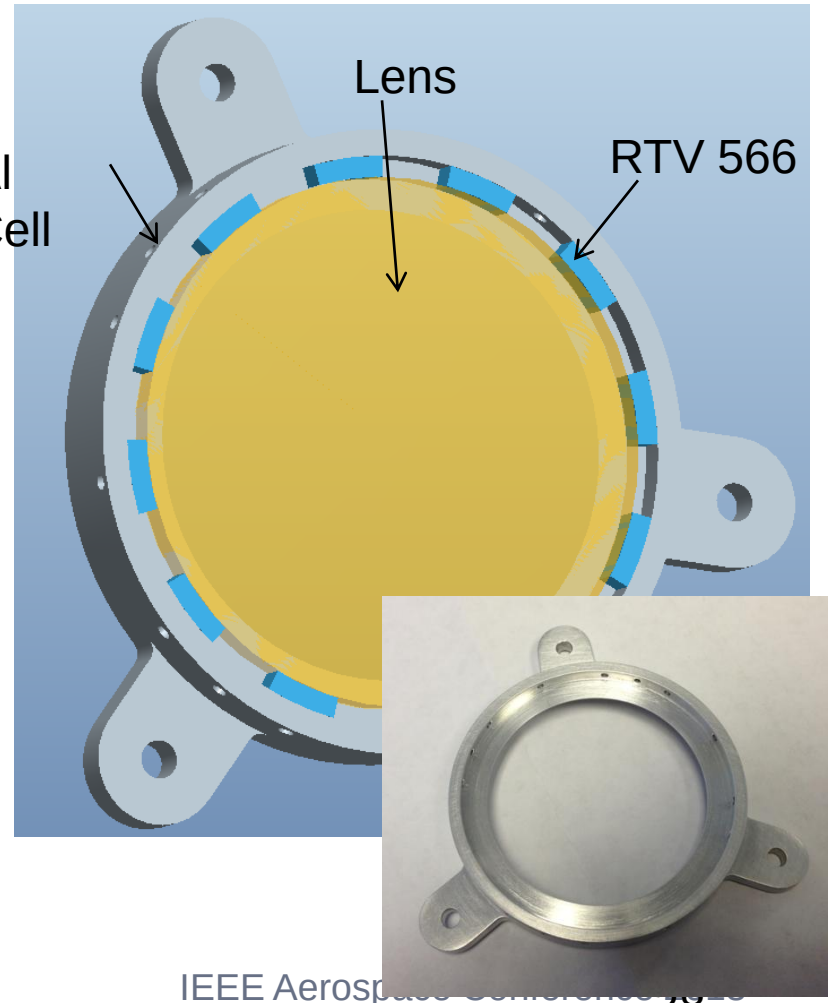
Detector Bulkhead

- Mounted on rear flange of optical bench on detector flange
- Interface bolt pattern with flange based on MSFC fit check alignment
  - Only one through hole available
  - Other holes will be match drilled



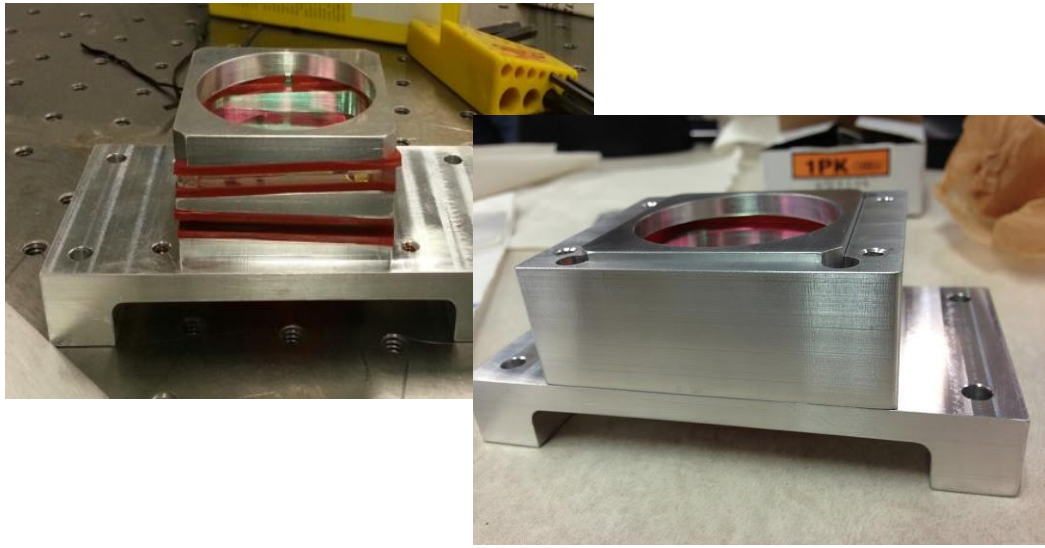
Solar Lens Mount Assembly

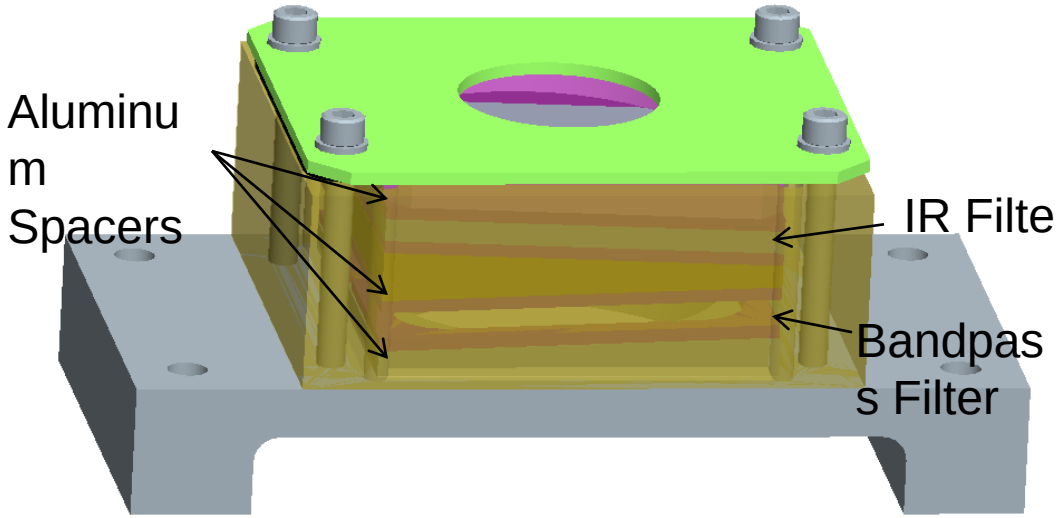
- 2” dia. lens (BK7) mounted in aluminum cell
- Three point mounting system with spherical washers to reduce stress induced during assembly
- Four threaded holes for set screws to be used during alignment
- Lens is bonded into cell with RTV 566
  - RTV 566 adhesive is very compliant
  - 0.080” bond thickness
  - Beaded bondline allows adhesive to expand during temperature changes
  - Injection holes around circumference



Filter Assembly

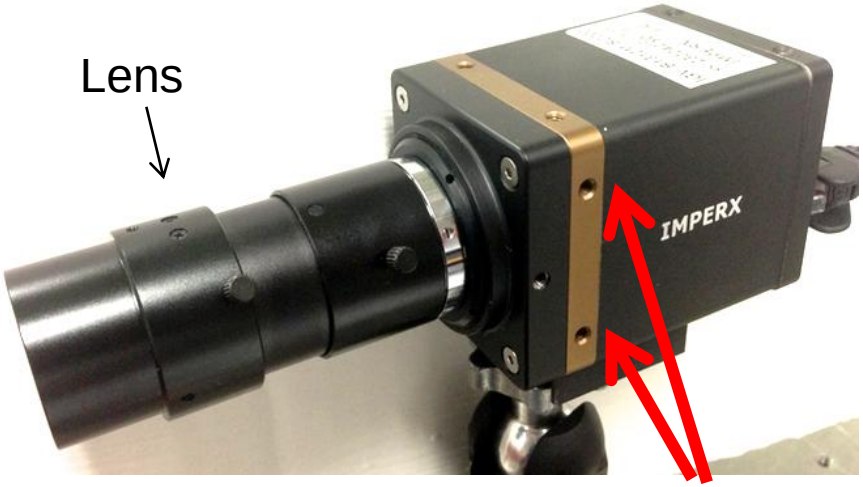
- Bandpass filter and IR filter mounted in front of lens to reduce heat and unwanted wavelengths
- 2” square filters mounted at 2° from horizontal to prevent internal reflections
- Separated by angled spacers and rubber gaskets
- Enclosure and spacers are aluminum

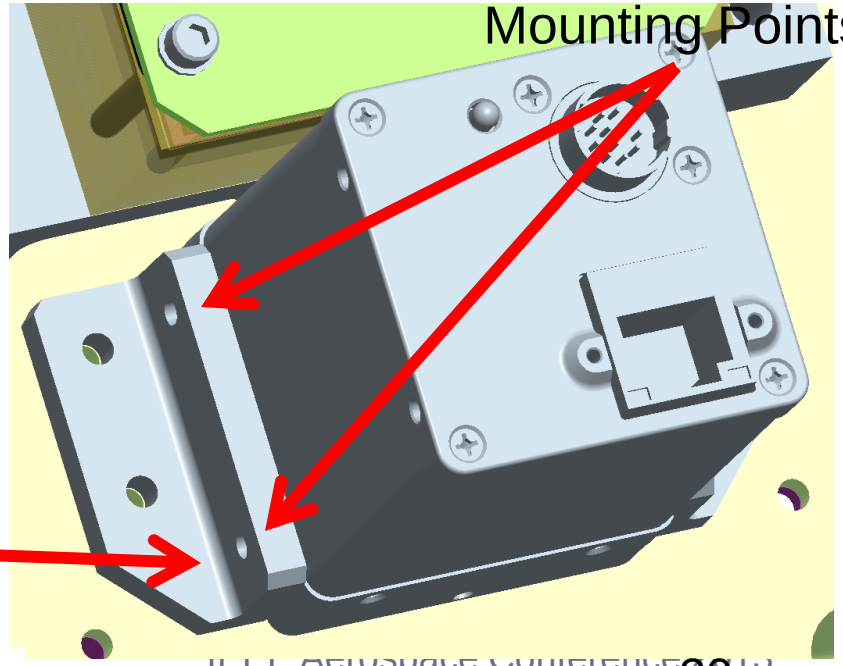




Camera Mount

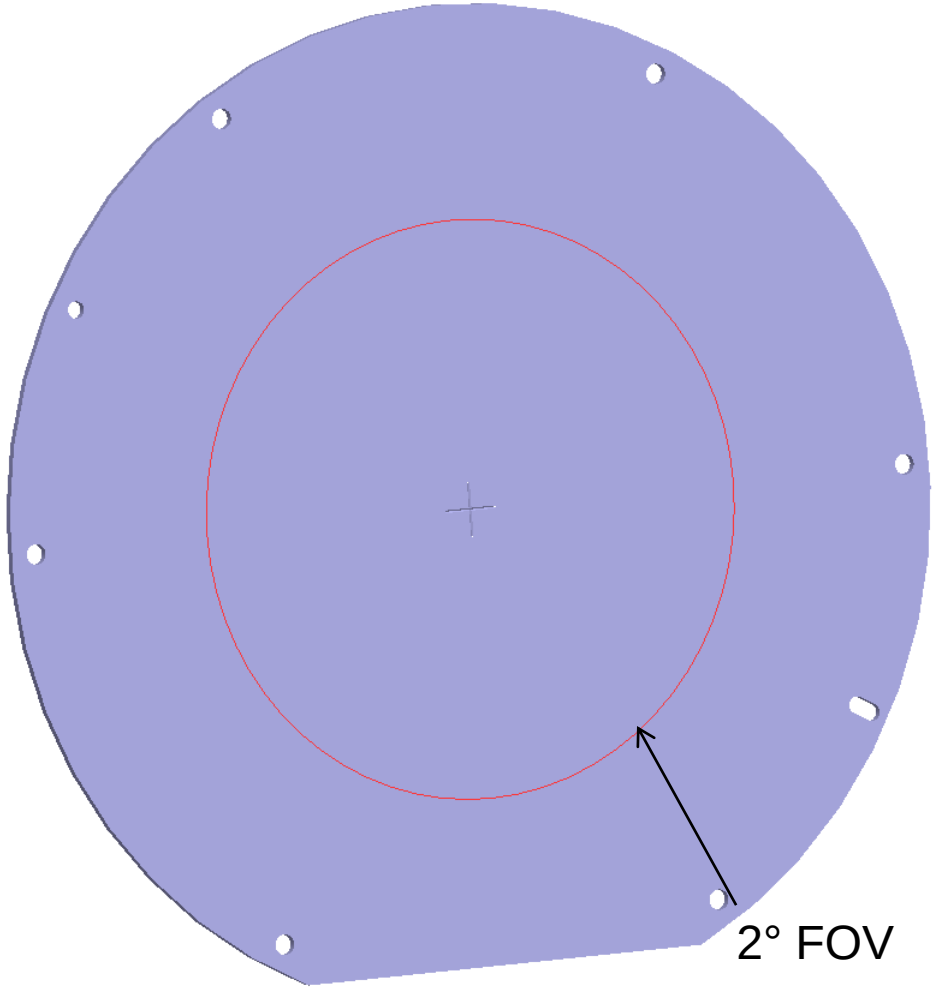
- Camera will be shimmed in front to point 1° above horizontal to view center of screen
- Camera will be mounted using two threaded holes in front and two on side
  - Side mounting points will be bolted using brackets, shown to the right





Fiducial Screen

- Projection target at focal length of lens (3 m)
- 4.92” diameter allows for 2.39° field of view (greater than required 2°)
- Fiducial will be screen printed onto the screen.



Observation Goals

Baseline Mission

Baseline mission objectives to meet science objectives

- Solar observations for 7 hrs
  - data collection with SAS solutions
- Crab Nebula observation for 3 hrs
- Astrophysics Observations for 3 hrs

Instrument Characteristics

- Energy Range: 20-75 keV
- Angular Resolution: ≤ 30 arcsecs
- Optical alignment: ~1 arcmin
- Pointing stability: ~1 arcmin
- Energy Resolution:

  3 keV FWHM @ 60 keV
- Field of View:

  9 arcmin @ 40 keV,

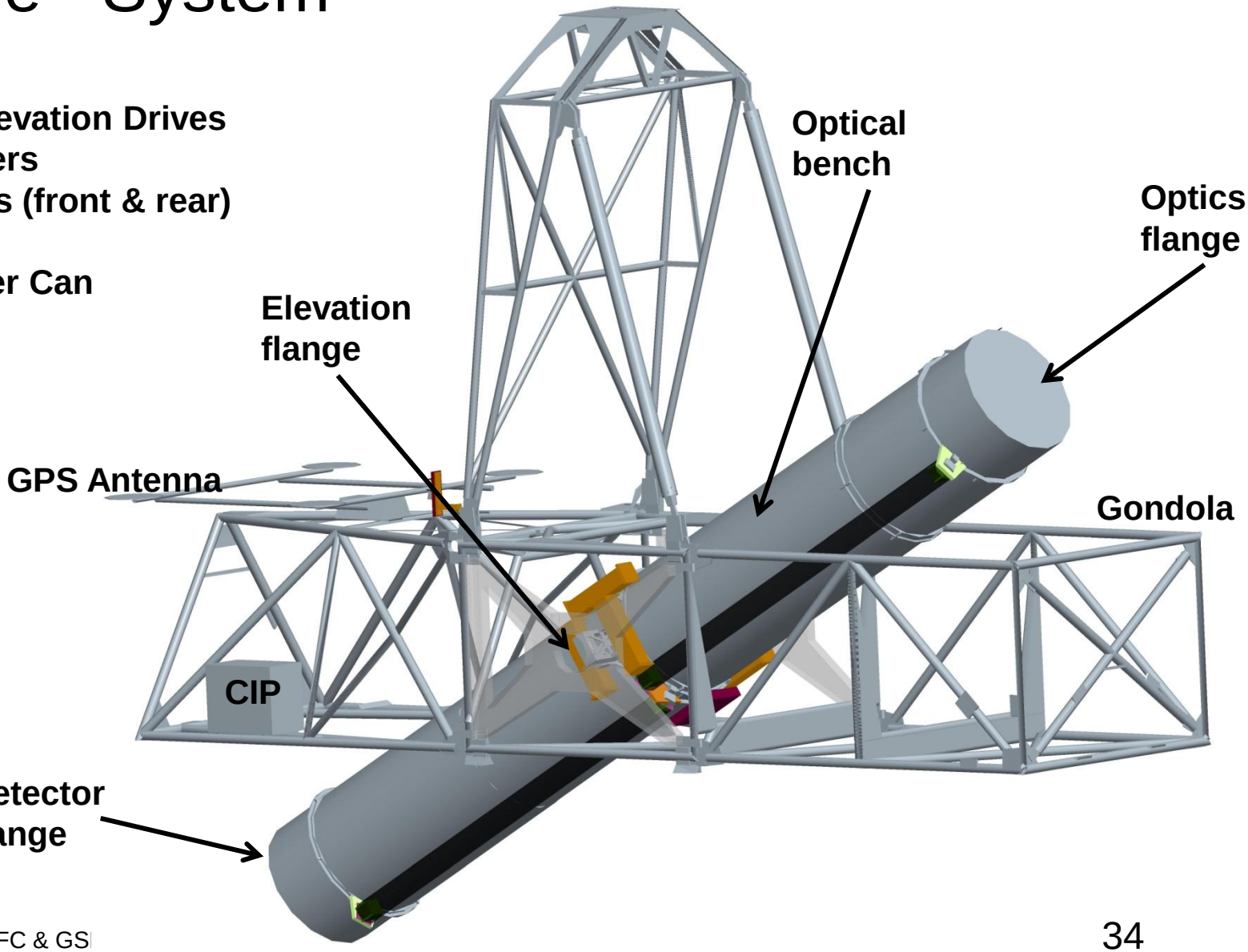
  5 arcmin @ 60 keV

Level 1 Requirements

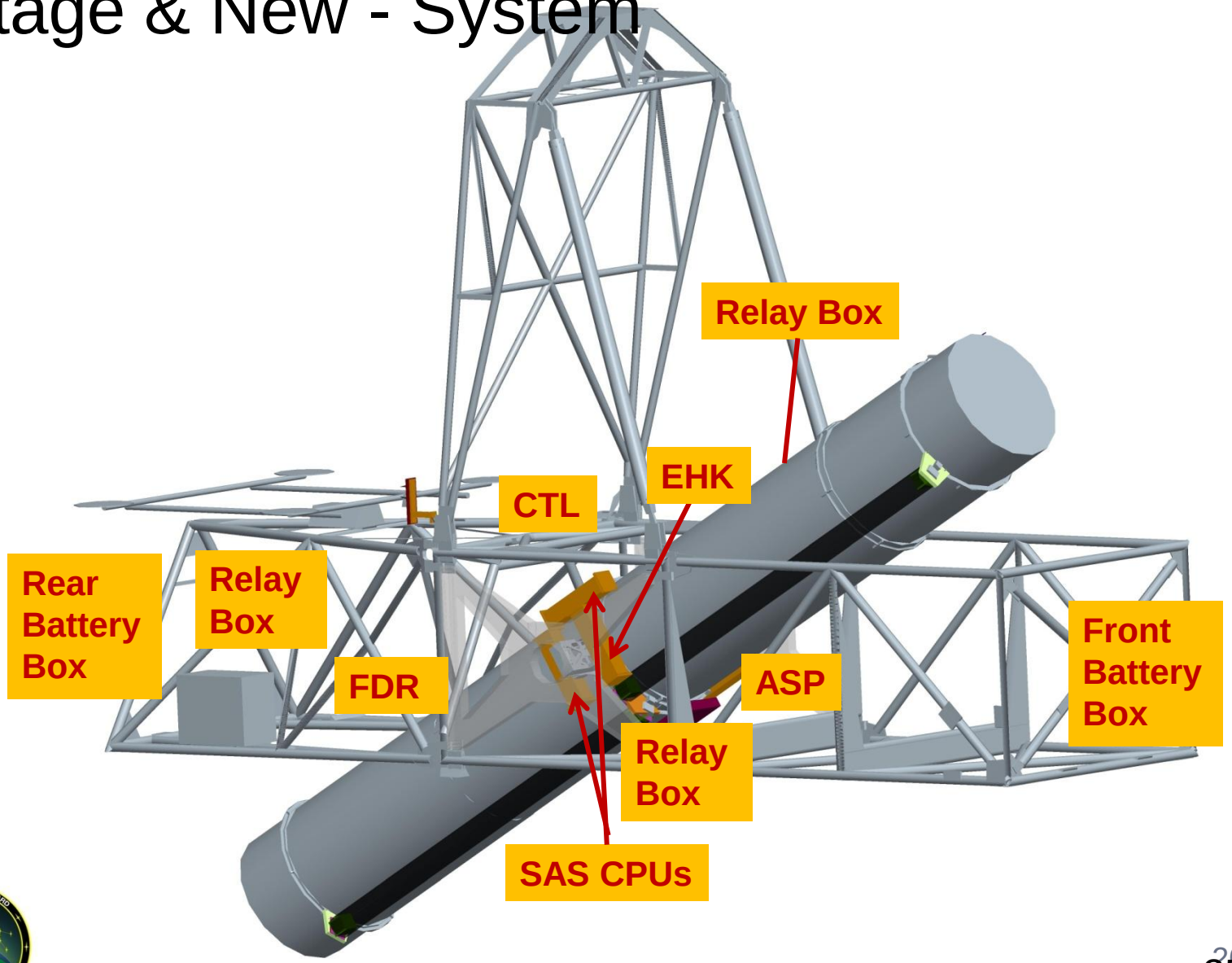
- **[R.HER-A]** HEROES shall observe the Sun for a total duration of 7 hours with all detectors working or equivalent (e.g. 12 hours for half working detectors) at a minimum float altitude of 37 km.
- **[R.HER-B]** HEROES shall observe the Crab nebula for a total duration of 3 hours at a minimum float altitude of 37 km.
- **[R.HER-C]** HEROES shall observe additional astrophysical targets for a total duration of 3 hours at a minimum float altitude of 37 km.
- **[R.HER-D]** The HEROES Project shall collect science data at an altitude of at least 37 km.
- ***[R.HER-E]*** *Solar aspect knowledge shall be 10 arcsecs (TBC) or better.*

Heritage - System

<u>Not Shown</u>:
Azimuth & Elevation Drives
Ballast/hoppers
Battery Boxes (front & rear)
Relay Boxes
CTL Computer Can



Heritage & New - System

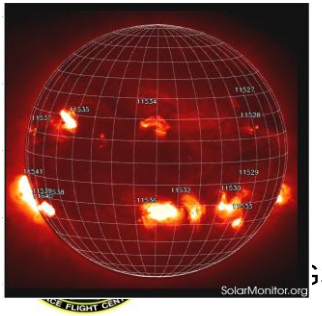


High Energy Replicated Optics to Explore The Sun (HEROES)

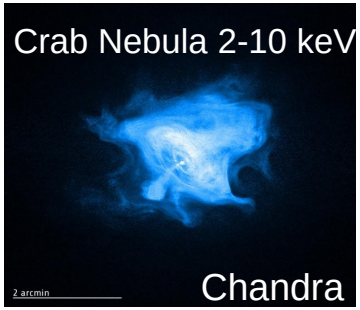
HEROES mission is to upgrade the *HERO* telescope to observe the Sun during the day and astrophysical objects at night. As part of the Hands On Training Experience (HOPE), *HEROES* mission is to also train scientists and engineers to fly science payloads.

New Systems

1. Solar Aspect System
2. Alignment Monitoring System
3. Star Camera System
4. Heritage Modifications and Upgrades



GSFC



New Science

Heliophysics (New!)

- Investigate electron acceleration in the non-flaring solar corona by searching for the hard X-ray signature of energetic electrons.
- Investigate the acceleration and transport of energetic electrons in solar flares.

Astrophysics

- Investigate the scale of high energy processes in a pulsar wind nebula.
- Investigate the hard X-ray properties of astrophysical targets such as X-ray binaries and active galactic nuclei.

MSFC & GSFC Team Members with Dr. Paul Hertz