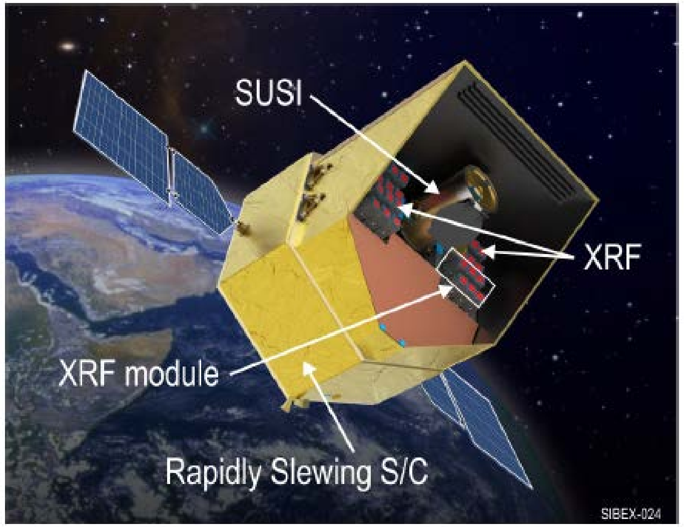
SIBEX UV Spectrograph and Imager (SUSI)



SOUTHWEST RESEARCH INSTITUTE®

Michael Davis, on behalf of the SIBEX team

6 October 2022

SIBEX Mission

- Shock Interaction Breakout EXplorer (SIBEX) proposed to 2021 NASA MIDEX call
  - Not selected, but rated Category 1
- Primary mission to observe shock breakout (SBO) explosions from supernovae and neutron star mergers (NSMs) in the X-ray and far-to-mid UV (136-300 nm)
  - Wide-field X-ray sensor detects shock breakout
  - S/C points UV imager to target within 1 minute of X-ray detection
  - Target position pinpointed with imager and UV spectrograph slit moved to target within 1 minute of initial pointing
  - UV spectroscopy continues on main target while surrounding field is imaged for reference
  - Ground can override pointing in case of special events, but not normal mode of operation

SIBEX Mission (continued)

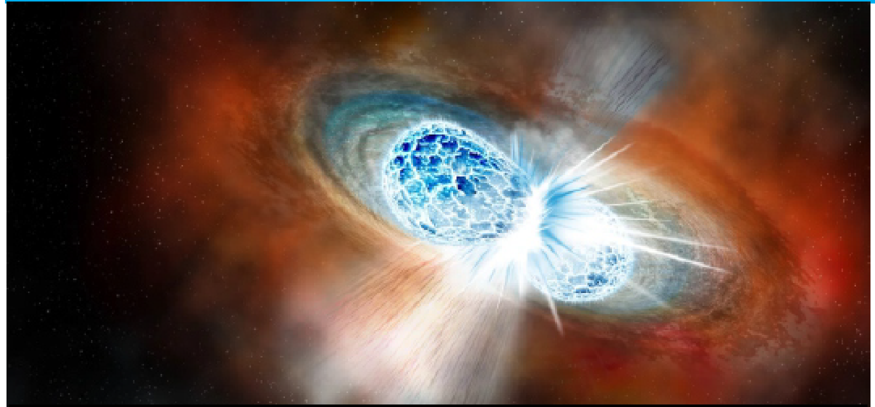
Science Goal 1: Characterize the early emission from SNe to both differentiate and probe the properties of stellar progenitors and supernova (SN) explosions, including inhomogeneities and asymmetries.

SN Science Objectives: SIBEX shall…

1) Determine density inhomogeneities in stars and their winds on short-timescale with 30% uncertainty.
2) Determine stellar radii with 33% uncertainty.
3) Determine density gradient of transition region between the star and stellar wind with 10% uncertainty.
4) Distribute X-ray and UV brightness, position, and timing of SN SBOs to astronomical community in <1 minute.
5) Perform a population study of SNe discovered within one hour of SBO in X-ray and UV to 99% CL (sample accuracy of 10%).

SIBEX fills in the lifecycle gap of massive stars by providing the most direct probe of engines behind SBO explosions and their immediate surroundings.

Science Goal 2: Detect and localize NSMs and constrain properties of their jets, compact remnants, and ejecta.



Early time observations with SIBEX provide critical insights into the merged core surrounded by NSM disks.

NSM Science Objectives: SIBEX shall…

1) Determine existence and lifetime of a magnetar in NSMs out to 330 Mpc.
2) Constrain composition and mass of wind ejecta from NSMs.
3) Distribute X-ray and UV brightness, position, and timing of NSMs to astronomical community in < 1 minute. (NASA's Swift mission has demonstrated similar distribution performance for gamma-ray bursts for over 17 years.)
4) Observe >20 NSMs in X-ray and UV within 1 hour after merger.

SIBEX Mission (continued)

Mission Science Motivations

1) Understanding SNe is fundamental to many areas of astrophysics (e.g., chemical enrichment of universe, galaxy evolution, star formation rate, stellar evolution, compact objects/remnants, circumstellar material/ composition, interstellar dust formation, cosmology).

2) To understand the first stars in the universe (which are thought to be massive), we must understand ones in our backyard.

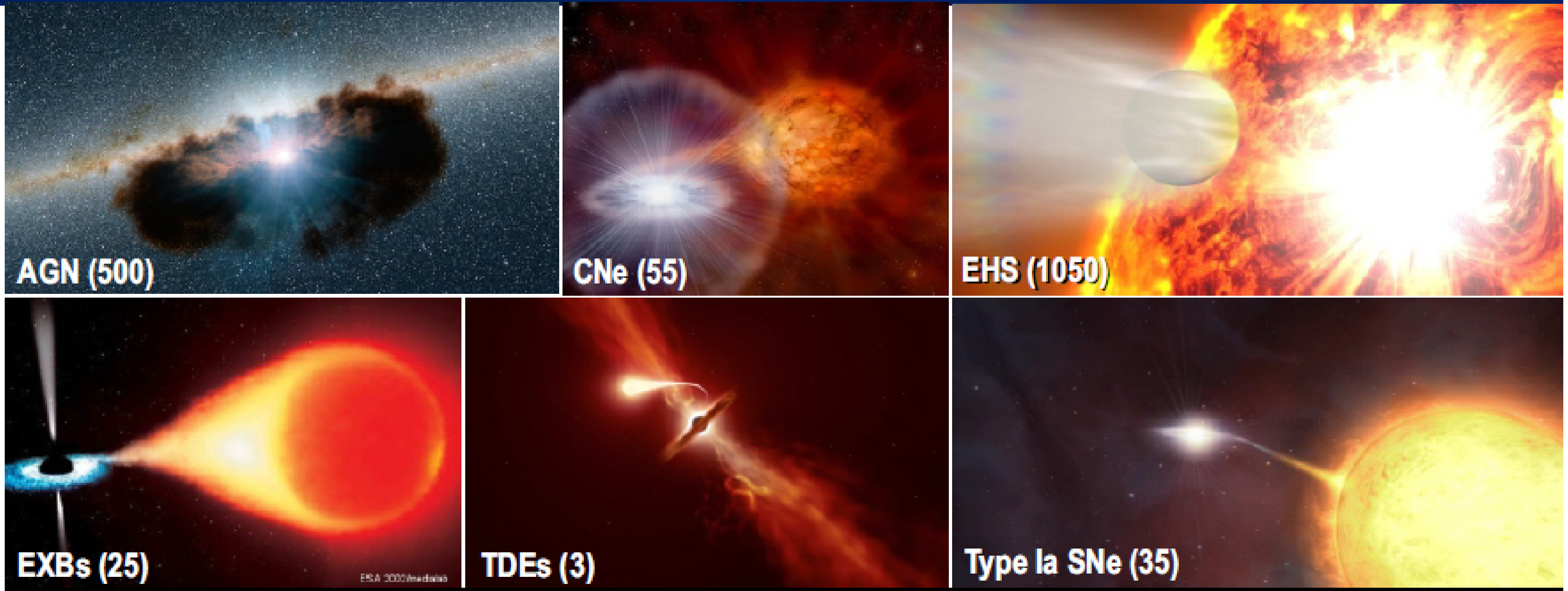
3) SNe enable detailed autopsies of stars (for which SIBEX provides a key missing step).

4) NSMs are thought to produce half of chemical elements heavier than Fe.

5) NSMs are prime multi-messenger sources and unique laboratories of gravity and extreme physics.

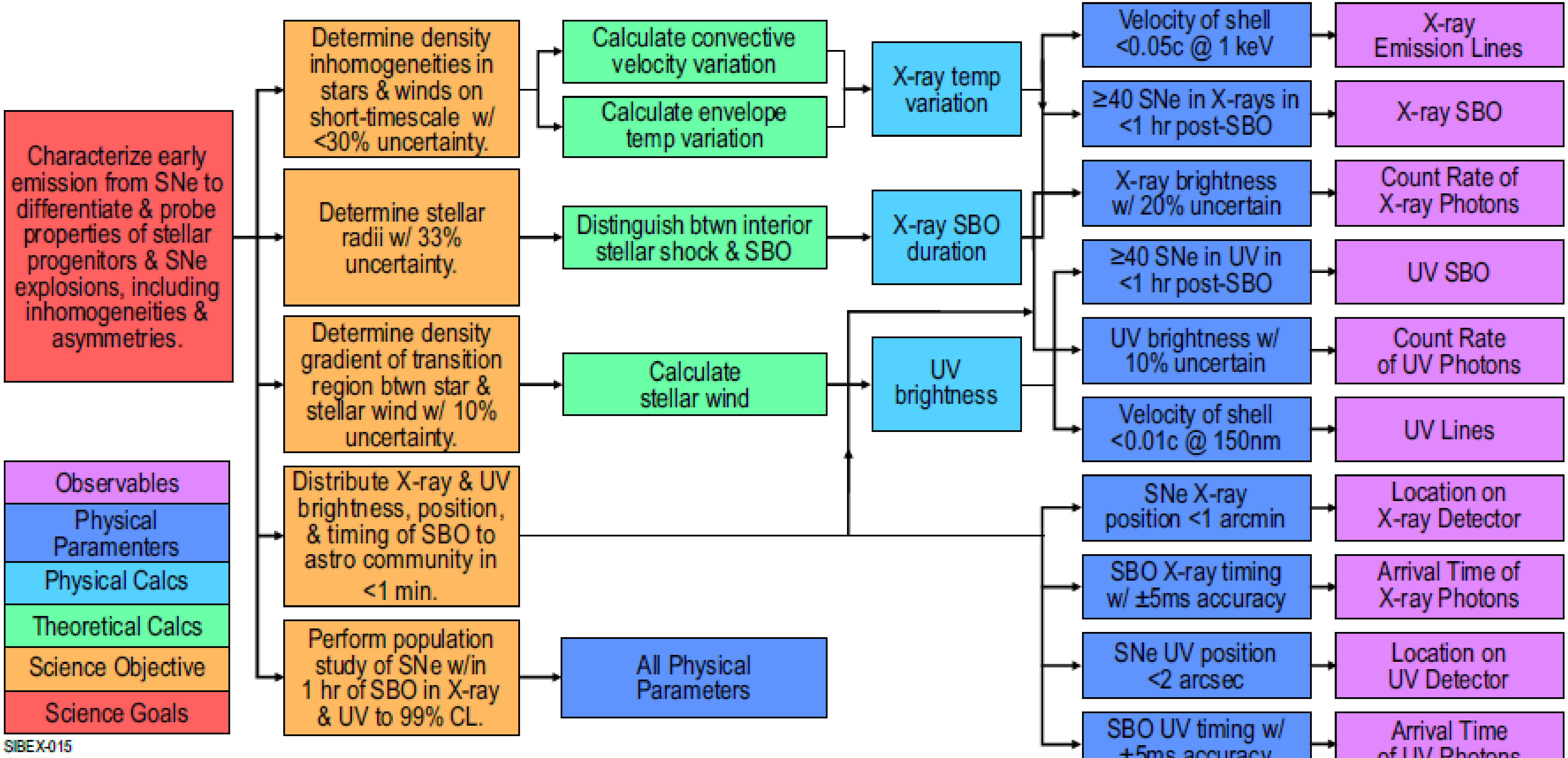
Secondary Science Targets (SSTs) for Free

While searching for SN SBOs and NSMs, a large number of SSTs can be followed with SIBEX's unique instrumentation. SIBEX's science operations concept includes observations of these targets as part of a pre-planned schedule which will automatically be interrupted by SIBEX detected SBOs and NSMs. These SSTs are also observed by the UV instrument when it is not observing primary science targets. *Some* of the SSTs to be observed by SIBEX include: active galactic nuclei (AGN), classical novae (CNe), exoplanet host stars (EHS), extragalactic X-ray binaries (EXBs), tidal disruption events (TDEs), and Type Ia SNe.



Values in parenthesis are the approximate number of SIBEX observed targets per year.

SIBEX Science Requirement Flow



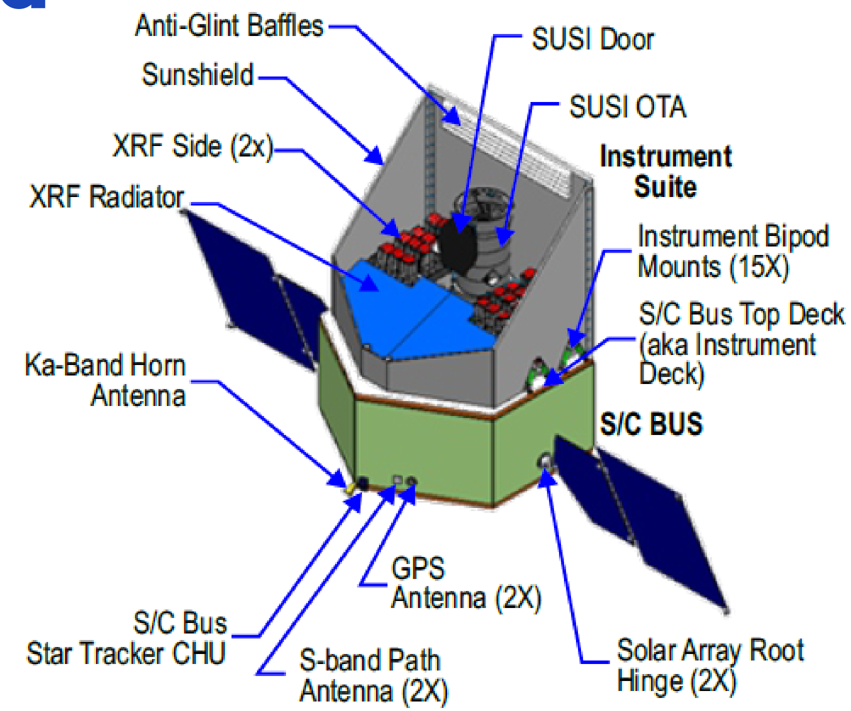
SUSI Driving Requirements and Expected Performance

Instrument Functional Requirements		Projected Performance	Margin
UV Instrument 5σ-sensitivity in a 800-second exposure at 136 nm	3.0E^{-14} erg/cm^2/s	2.2E^{-14} erg/cm^2/s	36%
UV Instrument Wavelength Range for a QE > 1%	136-300 nm	136-300 nm	Compliant
UV Imaging Field-of-View	0.08 sq-deg	0.25 sq-deg	211%
UV Instrument Pointed Transient Resolution	1 s	0.3 s	233%
UV Instrument Localization Accuracy	2.0 “	1.0 “	100%
UV Instrument Spectral Resolution at 150 nm	100	230	130%
UV Spectral Field-of-View	20 sq-arcmin	30 sq-arcmin	50%

SIBEX Spacecraft and Payload

- Two sets of XRF modules act a wide-field X-ray finders
  - 12 telescopes per module for a total of 24 identical telescopes
  - Each X-Ray telescope has 6°×6° FOV, separated by 5.25°; 5 arcmin resolution
  - Two telescopes are co-aligned with SUSI boresight for redundancy
  - Most instrument mass & power allocated to XRF

Observatory



A. Orbit/Launch Vehicle
- Baseline orbit: 30° inclination, 600 km altitude
- AO LV: compatible with Scenario 2 AO LV
- Launch mass: 716.4 kg out of worst case 950 kg possible

B. Observatory
- 1 Observatory in LEO orbit
- Hosting 1 UV Telescope and 1 X-ray Instrument (with 24 telescopes)

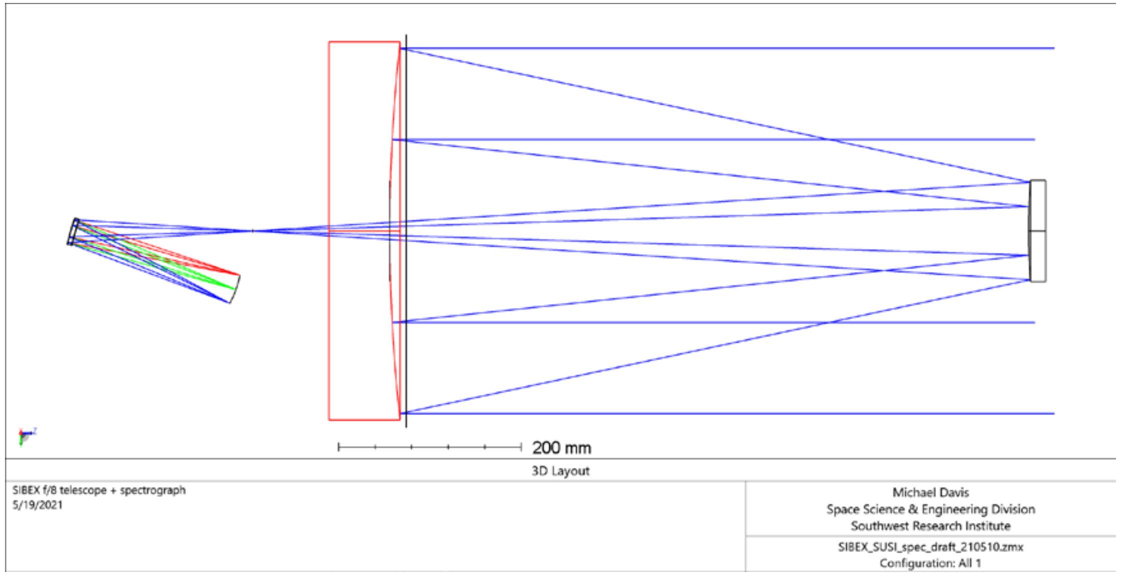
C. Instrument Accommodations
- Instrument Mass (MEV): 292.9 kg
- Instrument Power (MEV): 307.2 W
- Average Total Science Data Rate: 640 kb/s
- Pointing: Inertial pointed, 3 axis stabilized, 1 arc-sec control

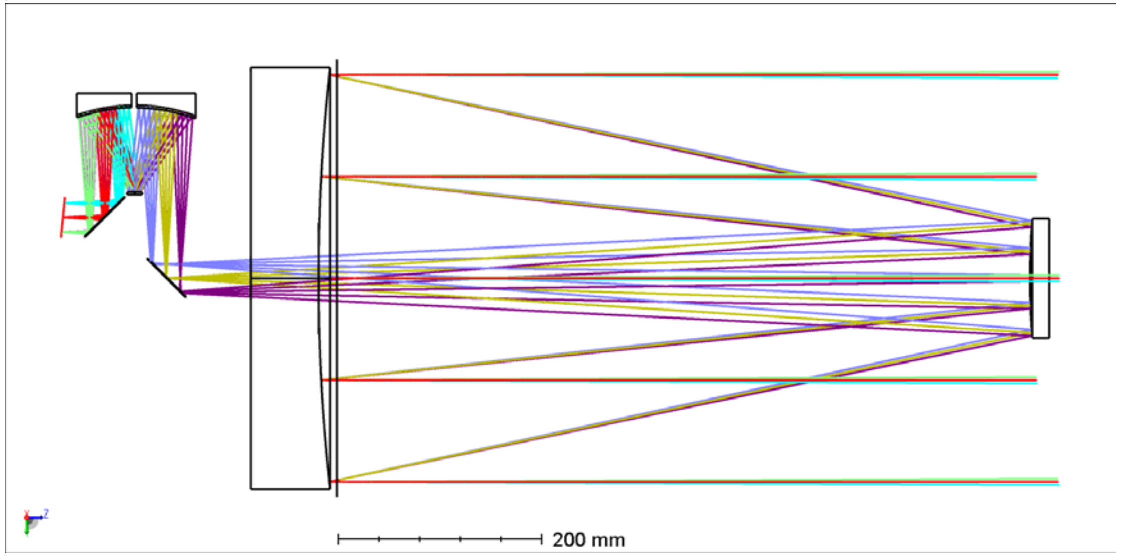
Instrument Design Considerations

- Optical:
  - Aperture size driven by sensitivity requirement
  - F/number and spatial resolution driven by sensitivity requirement
  - 136nm - 300nm wavelength range and sensitivity requirement drive Al+MgF2 mirror coatings and detector "filter" window
  - Contamination driven by sensitivity requirement
  - Imager shares UV spectrograph optical path
  - FWHM PSF requirement drives optical design
  - Optical alignment tolerances drive metering structure and mirror materials
- Electronics:
  - Temperature sensors
  - Cover deployment actuators
- Mechanical:
  - Launch Environments & Modal/Frequency Requirements
- Thermal:
  - Optical alignment tolerances drive thermal requirements

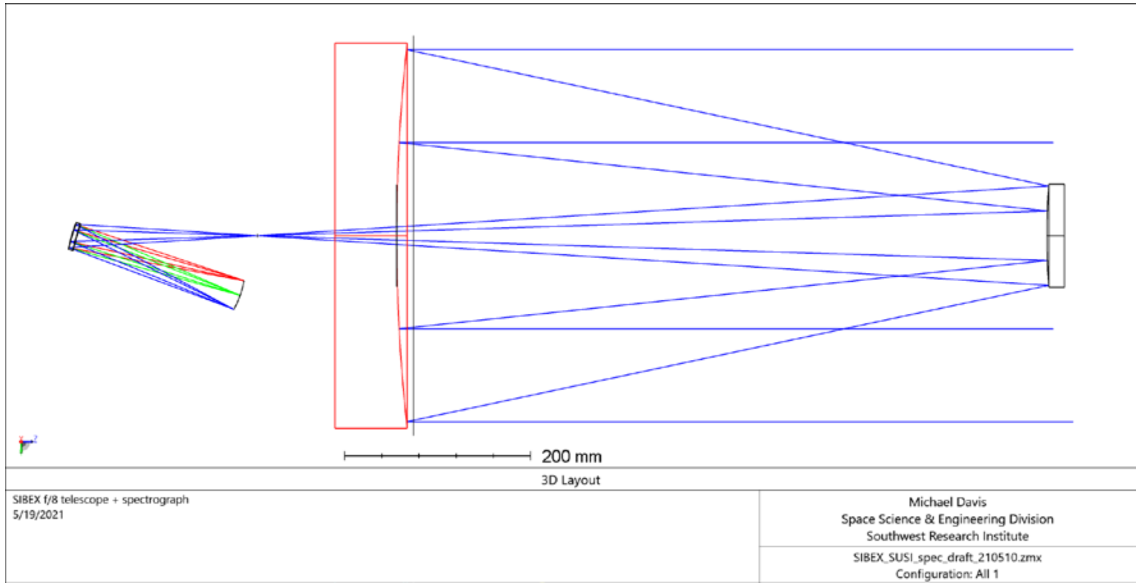
Design Overview

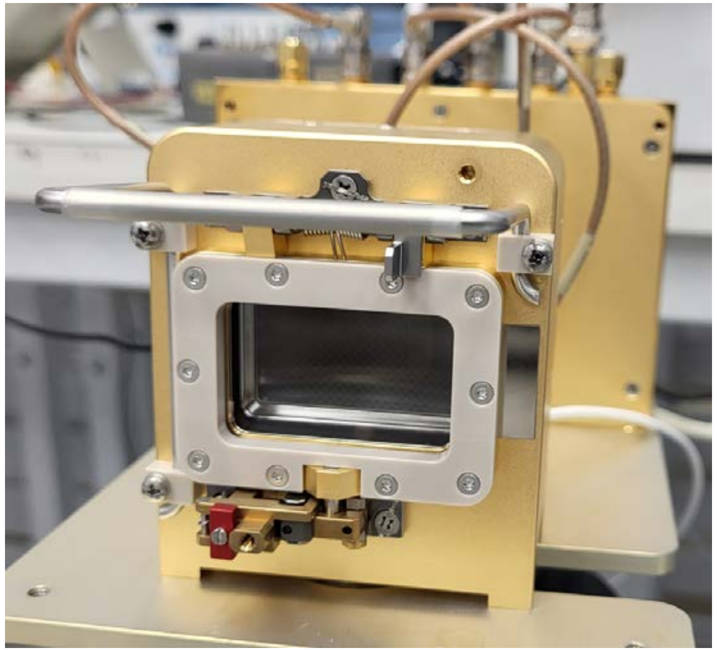
- Telescope is Ritchey-Chrétien design with 40 cm primary aperture and 320 cm focal length (f/8)
- Spectrograph is Rowland circle design with toroidal grating and cylindrically curved MCP detector
  - Heavily influenced by SwRI's planetary Alice/UVS design
- Imager is modified Offner with flat MCP detector
  - FUV requires all-reflective re-imager
- Detector is sealed-tube with BaF_2 window to block geocoronal oxygen





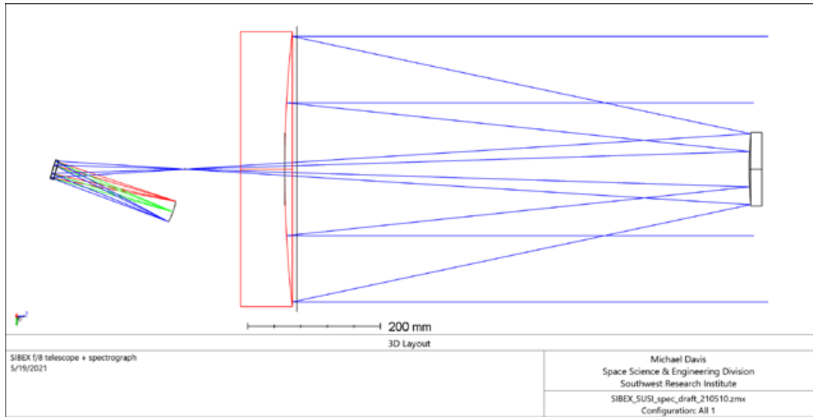
SUSI Spectrograph

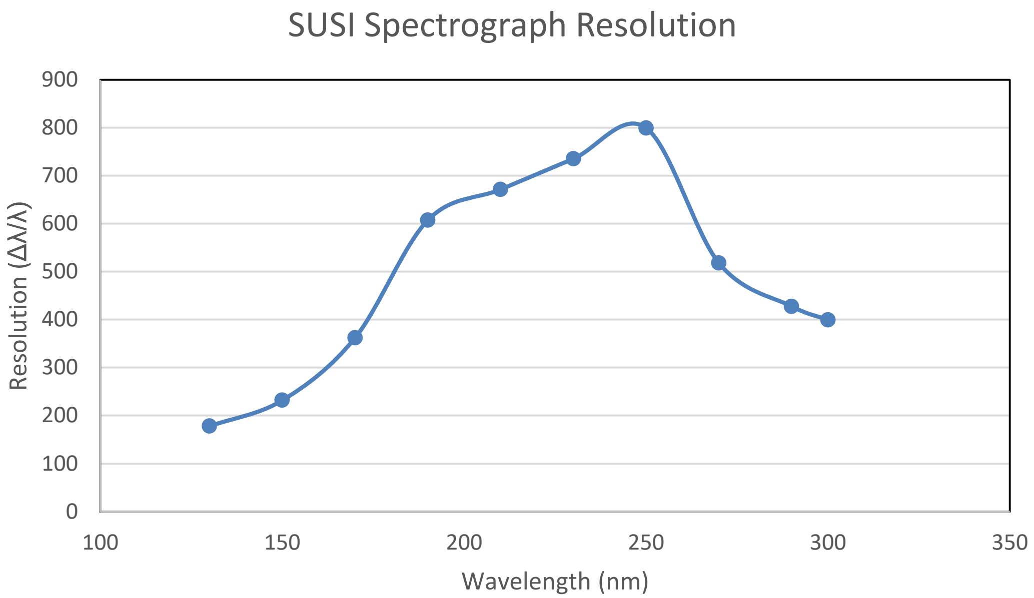




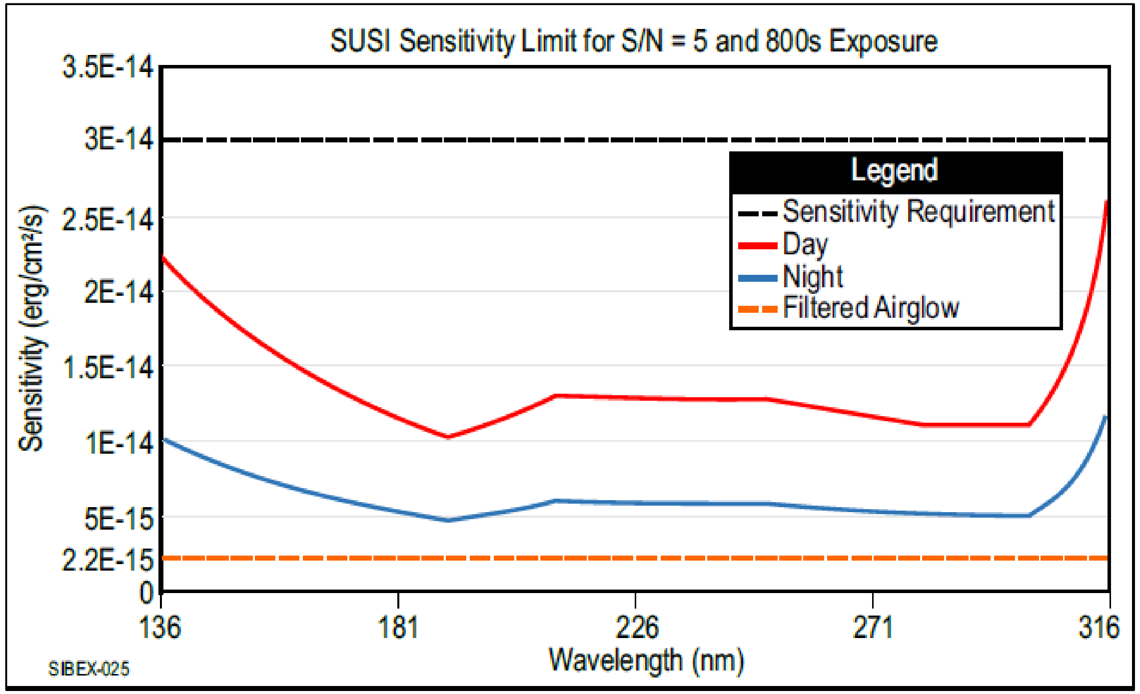
- F/8 Rowland Circle (slower than Alice F/3)
- Grating: 200 mm radius, 1000 lines/mm
- Detector: Borosilicate MPC z-stack, 100 mm radius

SUSI Spectrograph (cont.)

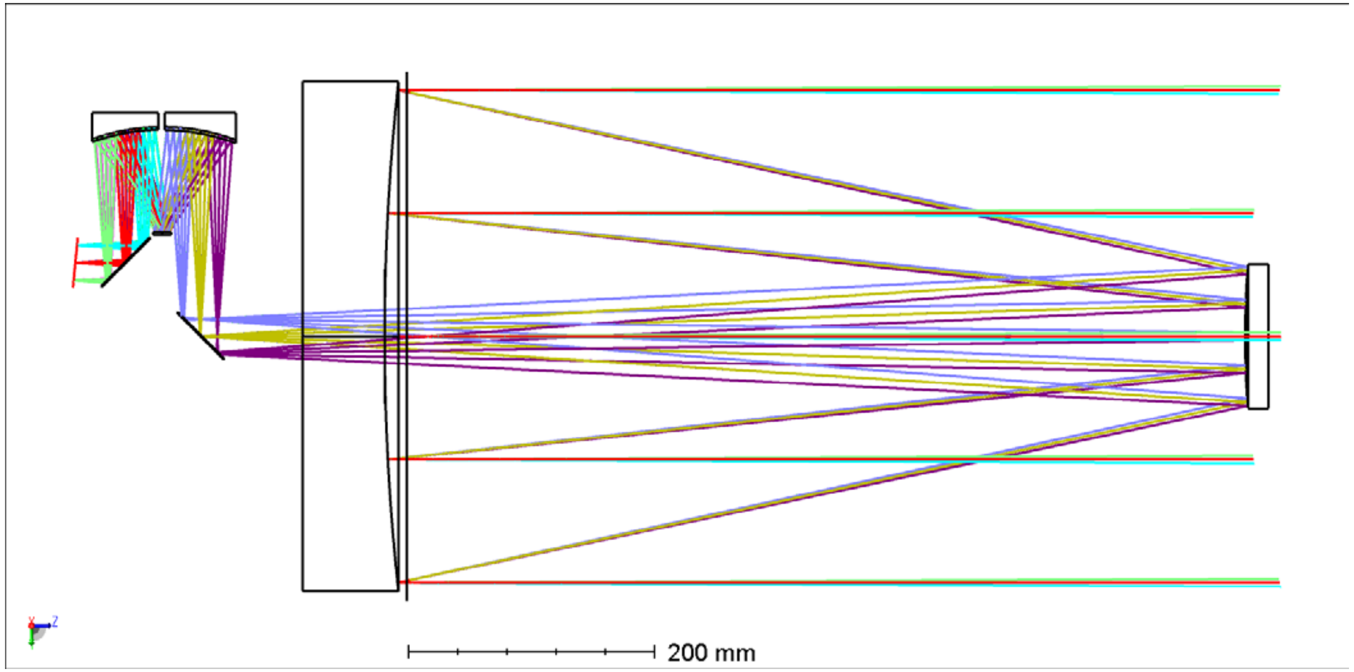


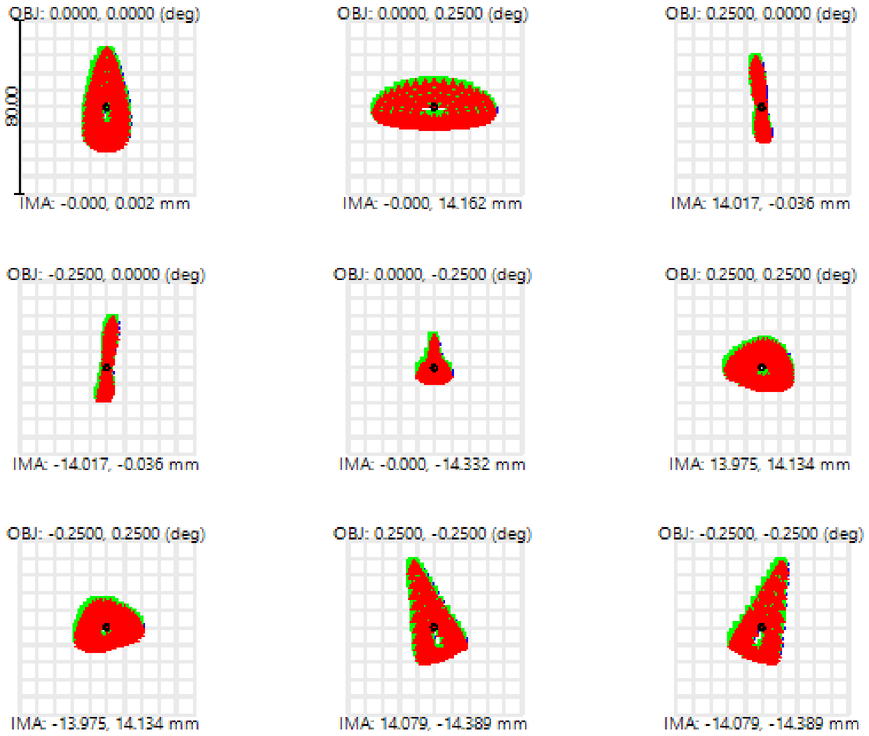


- Resolution varies slightly across the Rowland Circle
  - Peak R~800 @ 250 nm
  - Requirement is R>150 at 150 nm
    - Expected R~230 at 150 nm



SUSI Imager



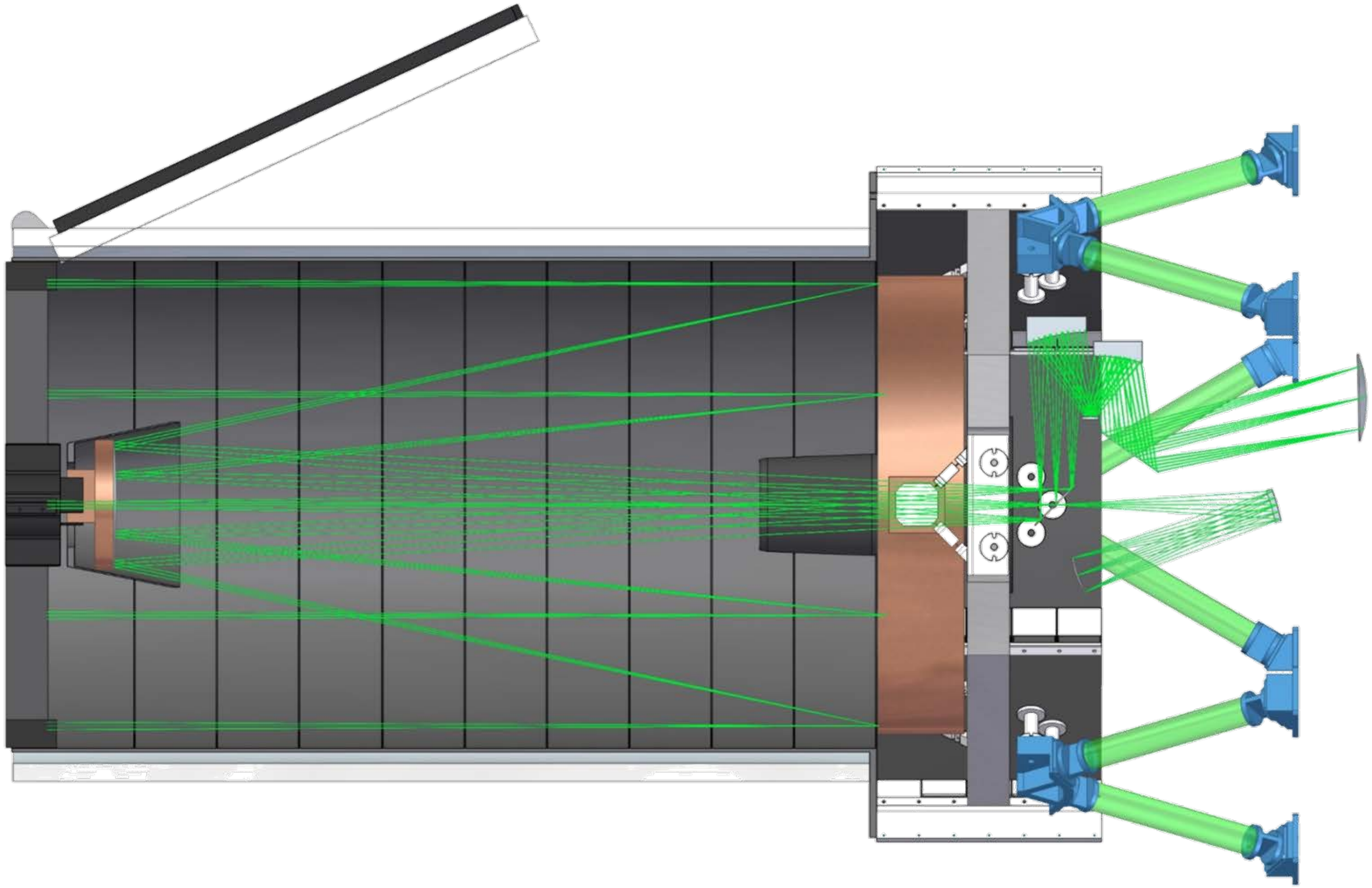


- FOV is 0.5° per side, for 0.25 sq. deg.
- Max spot size is 1.5 arcsec; Nyquist sampling improves positioning to better than 1 arcsec
- Detector is flat borosilicate MCP stack

A few words on detectors

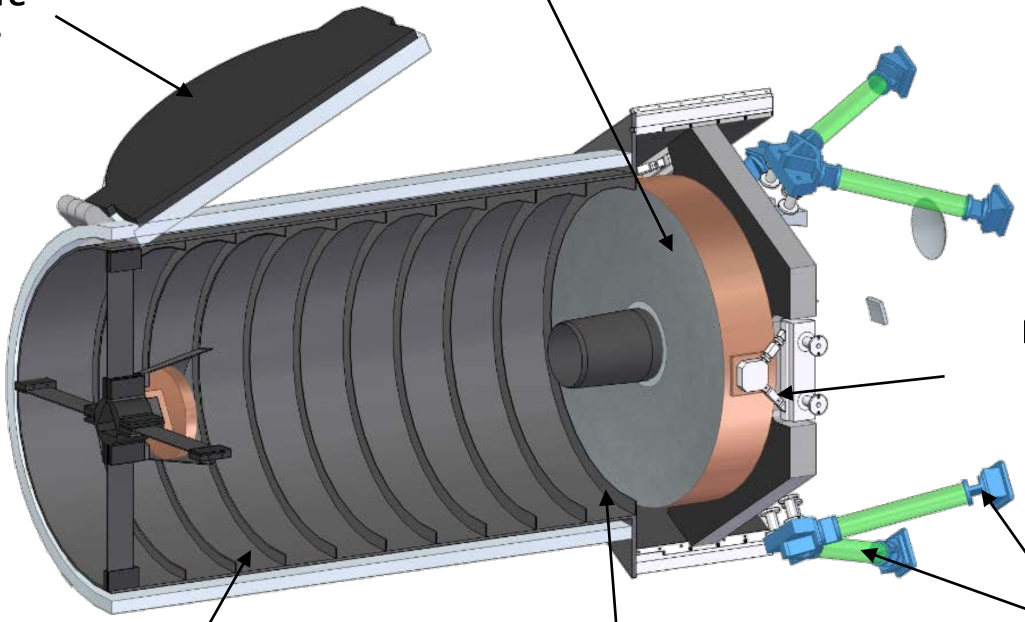
- Spectrograph and Imager have slightly different shapes (cylindrically curved vs. flat), but otherwise share identical properties
  - Borosilicate MCP z-stack (Europa Clipper and SPRITE heritage)
  - Sealed tube with BaF_2 window to block Ly-alpha & oxygen geocorona
    - Sealed tube allows easier ground testing and fewer handling restraints
- Detector features bi-alkali cathode for simultaneous FUV & NUV response on same detector
- Cross-delay-line readout electronics
  - Heritage going back to GALEX & COS
  - SwRI heritage includes Juno- (in flight 10+ years), JUICE-, and Europa Clipper-UVS
- Data taken in time-tagged mode but can be co-added to form an image histogram
  - JUICE- and Europa-UVS provide experience with programmable histograms with 1/s cadence

SUSI Overview – Ray Trace



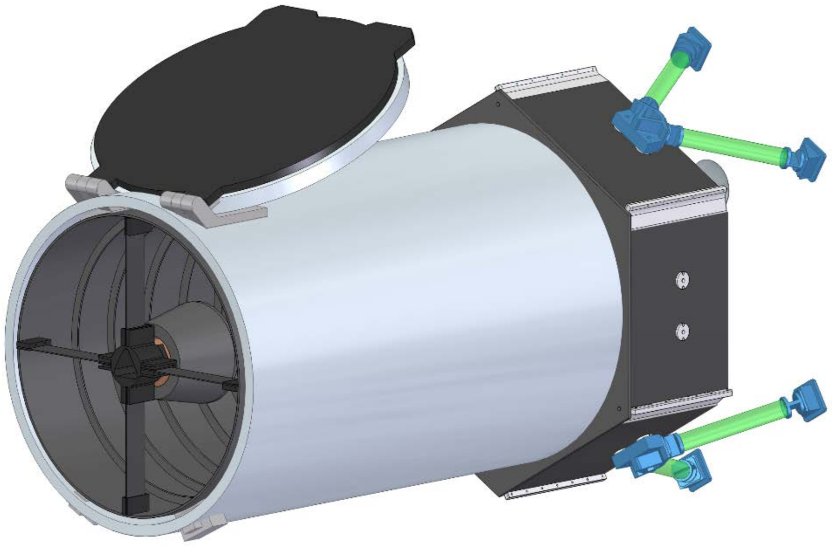
Spectrograph structure and rear close-out cover not shown

SUSI Section View – Front

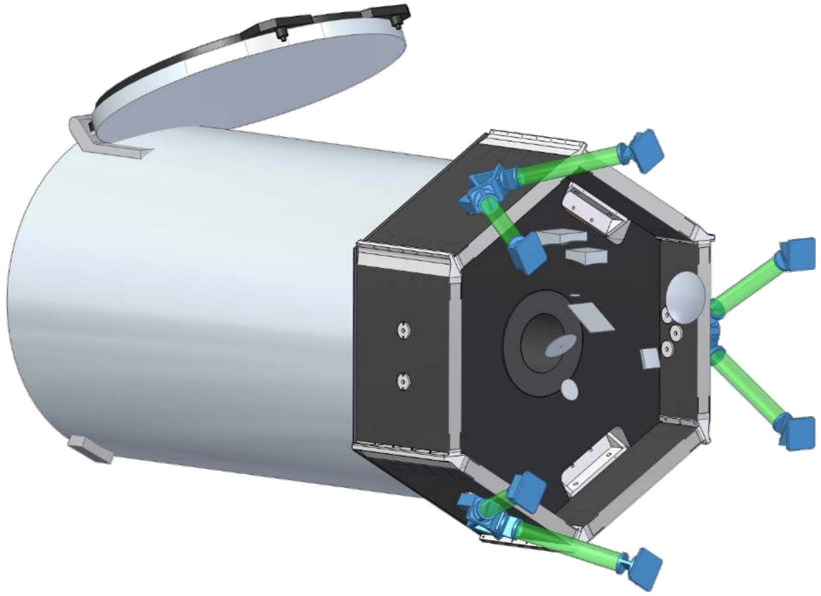


Spectrograph structure and rear close-out cover not shown

Design Overview



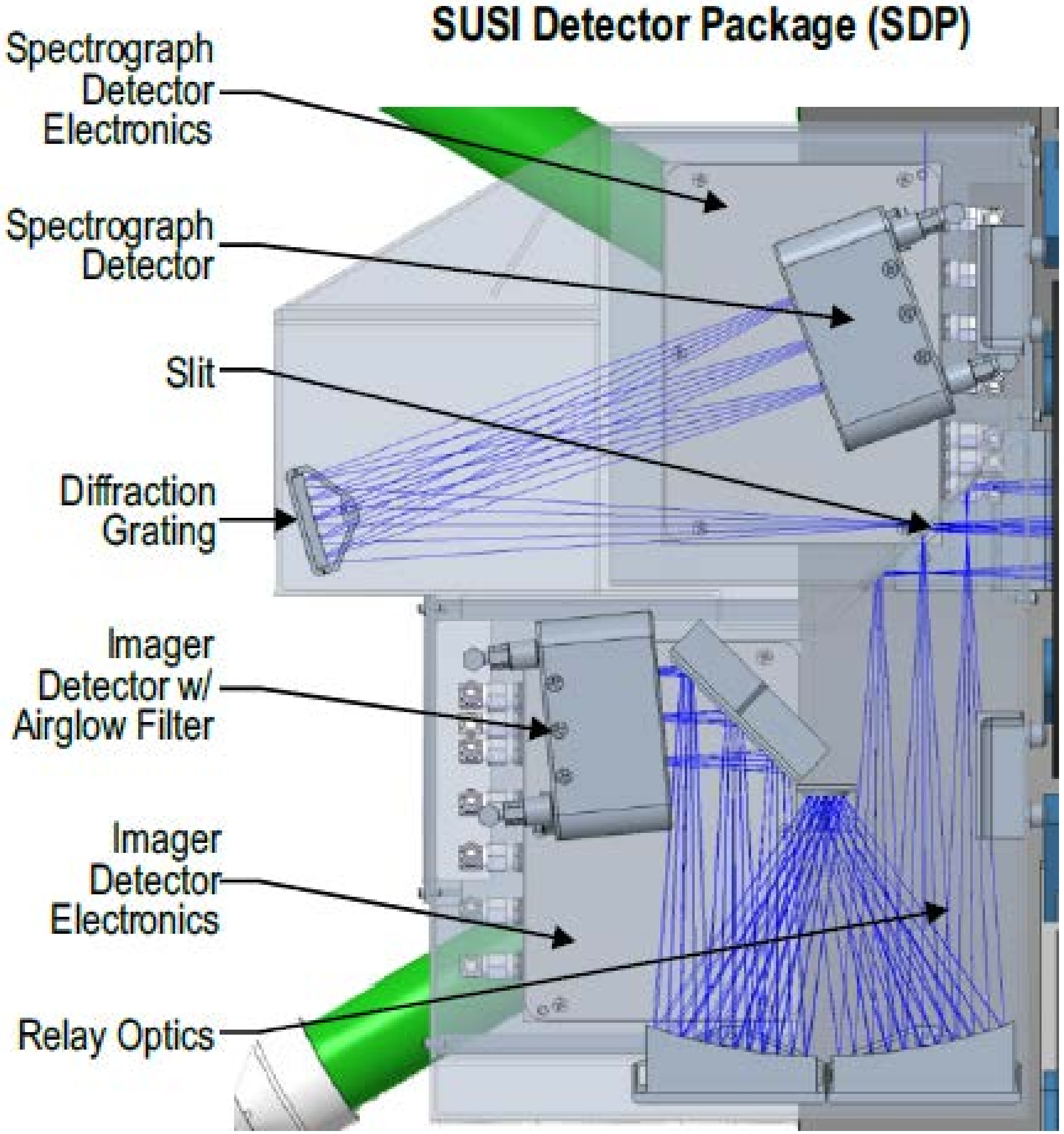
Front View



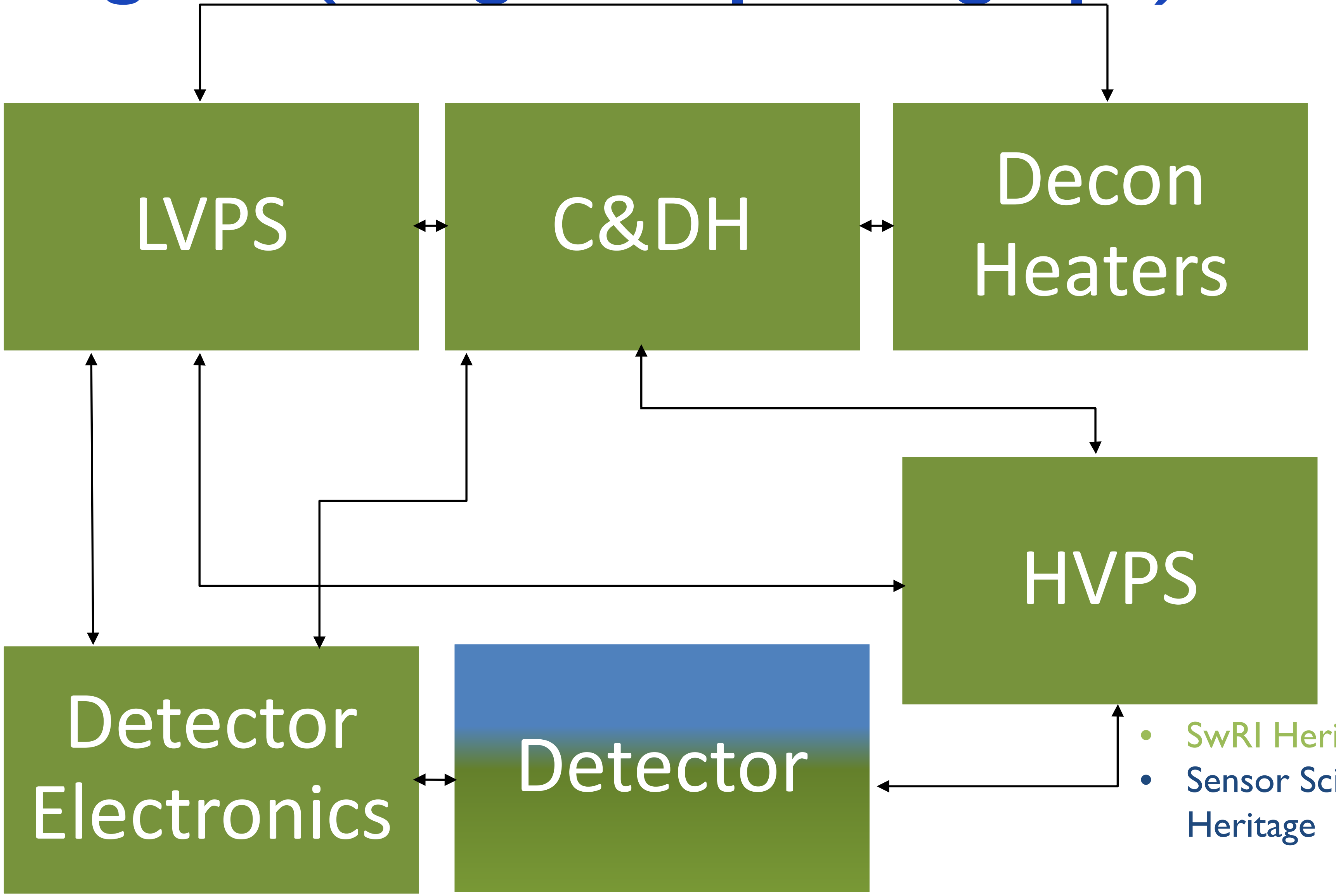
Rear View

Spectrograph structure and rear close-out cover not shown

SUSI Detector Package (i.e. imager and spectrograph)



Block Diagram (Imager & Spectrograph)



- SwRI Heritage
- Sensor Sciences Heritage

SUSI I/F Electrical Requirements

- HV connections between detector and HVPS
  - Heritage from multiple previous instruments
- High-speed interface prefers spacewire, but heritage has included LVDS
  - Proposed spacewire, but future S/C may desire something different
- Power heritage assumes "standard" 28V S/C bus, but can be adjusted for other reasonable voltage values
- Total operational instrument power is ~32 W during decontamination, ~16 W for nominal science ops (essentially 2x Europa Clipper power)

Power Budget

- Current CBE is 15.6 W for nominal operations
  - Detector Electronics 4W
  - HVPS 0.5 W
  - LVPS 1.5 W
  - C&DH 1.8 W
  - Based on as-built values for Europa-UVS, 7.8 W per instrument head
- Assumes no operational heaters needed, just decontamination heaters
  - Depending on thermal analysis, trim heaters may be necessary to maintain temperature during operations, raising operational power to ~32 W

SUSI I/F Mechanical & Thermal Requirements

- Mechanical:
  - SUSI Instrument mechanical interface to SC - bipods bolted to top of SC payload bench
- Thermal
  - Thermal isolation between Telescope and SC provided by bi-pods
- Spectrograph interfaces with telescope on optical bench behind M1
- Spectrograph is glass optics w/composite structure
  - Detector housings are Al per heritage, electronics dump 4 W each
- Total instrument mass (Telescope + SDP + bipods): 66 kg after ~18% contingency

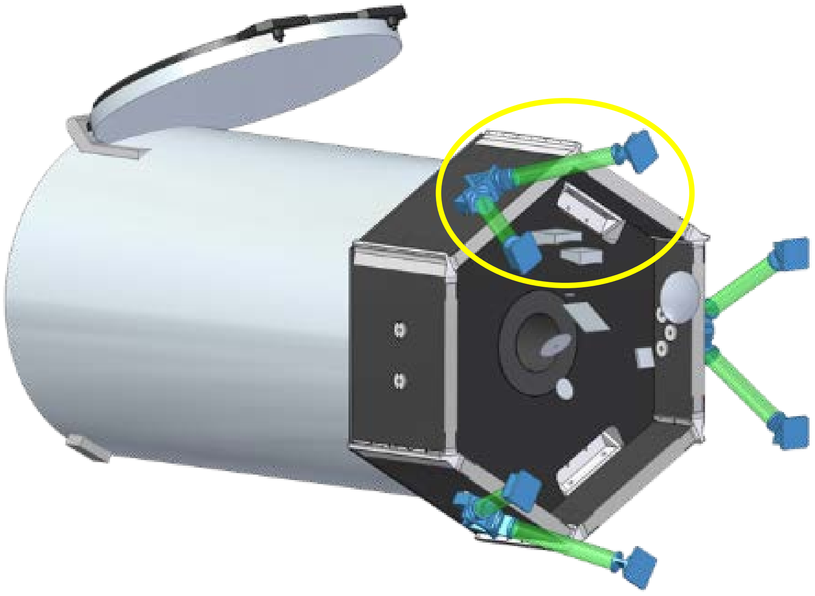
SUSI Thermal Design – Overview

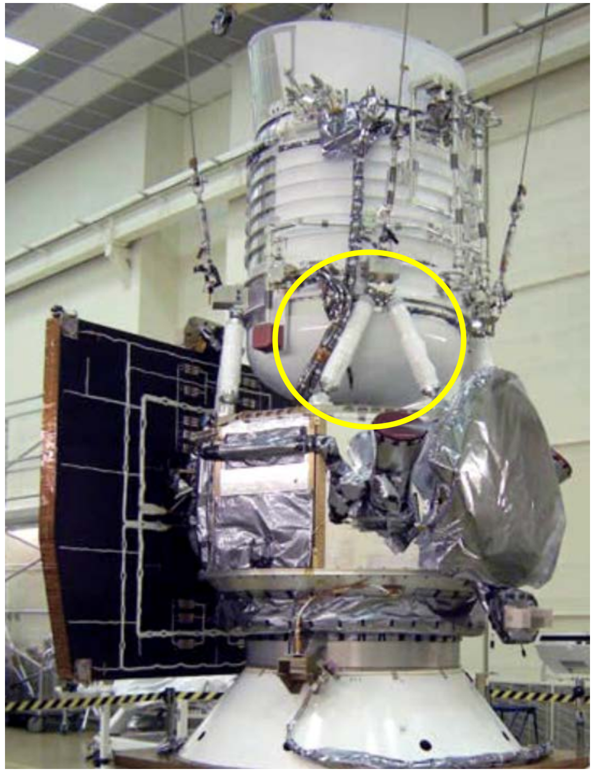
- Telescope thermally isolated from bus by titanium/fiberglass bipod mounts
  - MLI around housing to further isolate from S/C
- Sunshade can be used as a radiator to pull heat from electronics as needed
  - Use heritage pyrolytic graphite sheet (PGS) thermal straps for radiator thermal bus

- Telescope metering structure made of M55J / cyanate ester composite system with near-zero CTE layup to maximize thermal stability
  - Trim heaters and MLI used as needed to maintain stable temperature
  - Temperature sensors on the barrel will provide monitoring to calibrate readings

SUSI Thermal Design – S/C Bus Isolation

- Instruments thermally isolated from bus by low conductivity titanium/fiberglass bipod mounts
- MLI blanketing will provide further radiative isolation from bus and radiators





Pointing Budget/FOV

- Imager sees 0.5° FOV with multiple guide stars
  - Guide star positions are read out with 100 ms cadence and fed to S/C pointing system
    - Guide stars taken from Vincent Hue's Juno-UVS catalog of thousands of UV stars
- Spectrograph has 3 arcsec x 10 arcsec slit
  - Telescope PSF is 0.5 arcsec at slit-jaw interface, so 1 arcsec stability needed to keep PSF in slit without vignetting

High Level Test/Calibration Req'ts/Plan

- OTA will be assembled and calibrated by SDL
  - Calibration includes alignment, focus, and throughput tests
- Imager and Spectrograph subsystems will be assembled and calibrated by SwRI
  - Imager calibration includes alignment, focus, effective area, and FOV tests
  - Spectrograph calibration includes alignment, focus, effective area, spectral characterization (bandpass, resolution, position), stray/scattered light rejection
- Integrated SUSI (OTA+Imager+Spectrograph) will be assembled and calibrated by SDL
  - Final Calibration includes alignment, focus, effective area, simultaneous imaging/spectroscopy check, and wavelength resolution

Heritage/TRL by Subsystem

- Orbital Environments
  - Orbit is ~600km LEO and 30° inclination
  - Pointing ≥45° off from sun
- All electronics have heritage in Jupiter orbit, much harsher than LEO
- Mechanical components have launch heritage ranging from Delta II to Atlas V 551

- Missions
  - New Horizons: Kuiper Belt, 16+ years of operation
  - OCI PACE: LEO ~ 700km, space qualified, not launched
  - WISE: Sun-synch ~ 500km
  - SABER: LEO ~ 600km
  - LRO-LAMP: Lunar orbit, 13 years of continuous HV operations
  - Juno: Jupiter orbit, 10 years of operation (6 at Jupiter)
  - ICON MIGHTI: LEO ~ 600km
  - Roman Space Telescope: L1, space qualified, not launched
  - JUICE: Jupiter, space qualified, not launched
  - Europa Clipper: Jupiter, space qualified, not launched

SUSI Contamination Control

- Contamination control efforts, specifically managing moisture absorption, particulate accumulation, and controlling molecular contamination will be critical to meet the SUSI performance requirements.
- All assembly, alignment, and testing will be performed in a Class 1000 or better cleanroom or a verified clean vacuum chamber.
- SDL and SwRI use best practices to prevent, clean, monitor, and protect the sensitive SUSI hardware from contamination. SDL and SwRI both have significant experience in the application of contamination control theory and practice, modeling, materials characterization, cleaning and cleanliness certification. Test facilities support continuous GN2 purge; bake-out; particulate (tape lifts, rinses, or direct microscope imaging) and NVR (DRIFTS or GC/GC) contamination control monitoring, sampling; and analysis to IEST-STD-CC1246D (sample analysis), ASTM E595 (%TML & %CVCM), and ASTM E1559 (outgassing kinetics).
- T-0 filtered GN_2 purge

SUSI Contamination Control

- Standard procedures for UV instruments include:
  - Particulates
    - Cleaning (GN_2 and/or swab)
    - CO_2 snow cleaning after installation (if necessary)
  - Molecular
    - Bakeouts with RGA and QCM monitoring
    - NVR analysis of surfaces and scavenger plate collection
    - UV ozone scrub of mirrors after coating (if necessary)
    - CO_2 snow cleaning after installation (if necessary)
  - Inspections
    - White light and UV/black light with magnification
  - Monitoring
    - Witness mirrors
- SwRI has delivered six UV spectrographs and three UV sounding rockets (multiple launches each) without contamination degradation

Future trades/improvements for next round

- MCP vs. CMOS for imager
- Improve imager optical design
  - Is Offner best option?
- Drop mid-UV and go solely FUV
  - A possible descope listed in proposal
  - Else split spectrograph into two detectors or two photocathodes
    - Rosetta- and New Horizons-Alice both featured split photocathodes with a Lyman-alpha gap
- Any need for higher resolution spectroscopy?
- All of these are internal discussions – only one (irrelevant) SUSI PMW returned by reviewers
  - A question about SUSI grism
    - SUSI does not feature a grism, and the word never appears in the proposal. Draw your own conclusions. ☺

SIBEX Mission Team

- Southwest Research Institute
  - Mission PI (Pete Roming), PM (Michael McLelland), MOC, SOC
  - SUSI PM, I&T, imaging channel, spectrograph, electronics, & calibration
- Space Dynamics Laboratory
  - XRF instrument build & management
  - SUSI telescope build under SwRI guidance
- Millennium Space Systems
  - Spacecraft build, I&T, and management
- University of Miami
  - XRF PI (Masimiliano Galeazzi)
- University of Texas
  - SUSI PI (Cyndi Froning)

Summary

- SIBEX proposed to latest (2021) MIDEX call
  - Category 1, but not selected for further study
- SIBEX answers many key questions in UV time-delay astrophysics
- SIBEX Ultraviolet Spectrograph and Imager designed from systems with extensive spaceflight heritage
  - Key personnel have decades of experience supporting UV instrumentation across multiple disciplines and mission categories
- Hopefully we can propose some form of SIBEX and/or SUSI to a future opportunity
  - SUSI itself could fit in a SMEX-class mission if the science is right
  - Easy to scale up to a future PROBE if an opportunity arises

Backup Slides

Science Traceability Matrix (aka Eye Chart)