MIRIS, A Compact Infrared Space Telescope

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Background

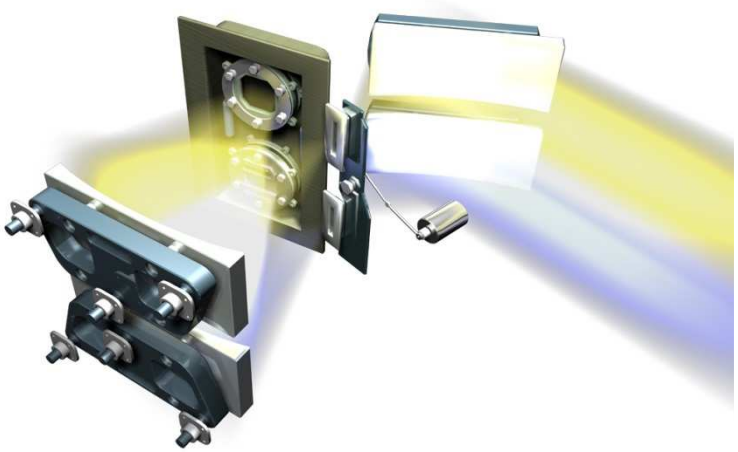
- Korea Science & Tech Satellite (STSAT) began 1999
- FIMS : KASI developed FIMS*, Main Payload of STSAT-1, in collaboration with KAIST & UC Berkeley
- FIMS was (STSAT-1, Main Payload) Launched in 2003
- FIMS Science Results were Published on ApJL, 2006

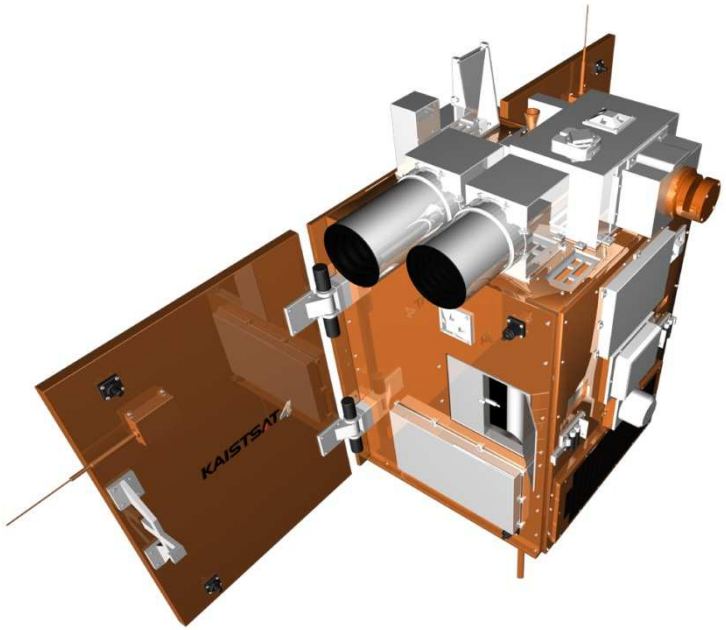
(*FIMS is also known as SPEAR)

- STSAT-3 Program started in 2008, Launched 2013
- KASI Proposal, MIRIS was Selected as Main Payload
- MIRIS is compact wide-field IR Space Telescope

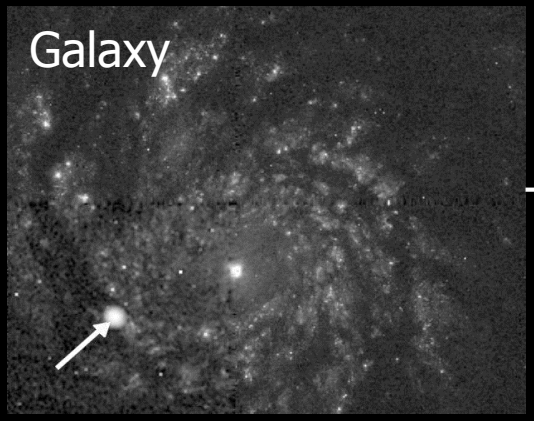
[Multi-purpose Infra-Red Imaging System]

STSAT1- FIMS (Far-UV IMaging Spectrograph)

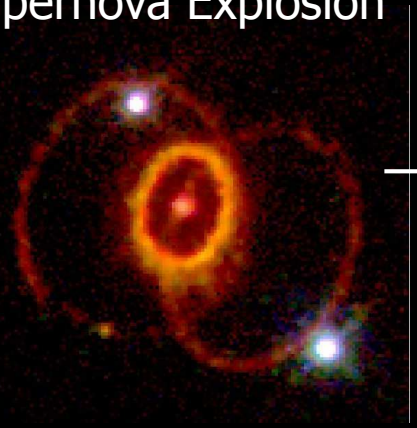


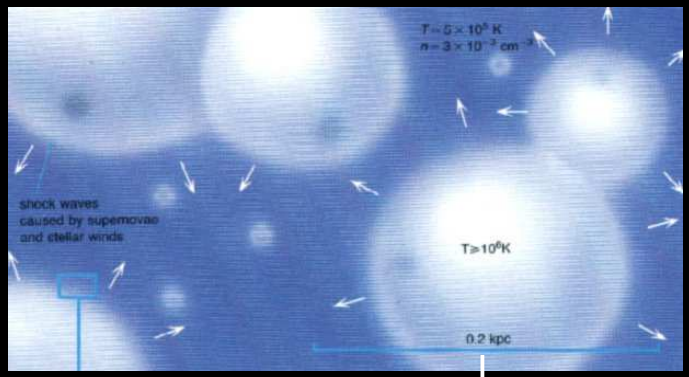


FIMS : Main Science

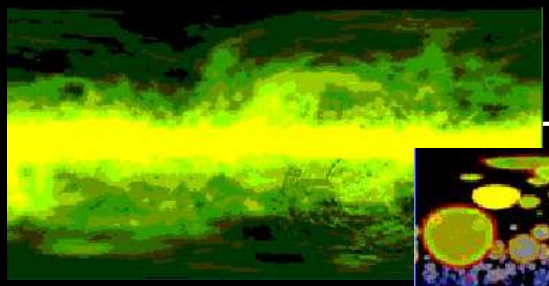


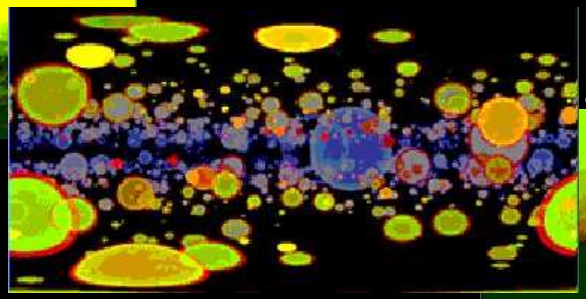
Supernova Explosion

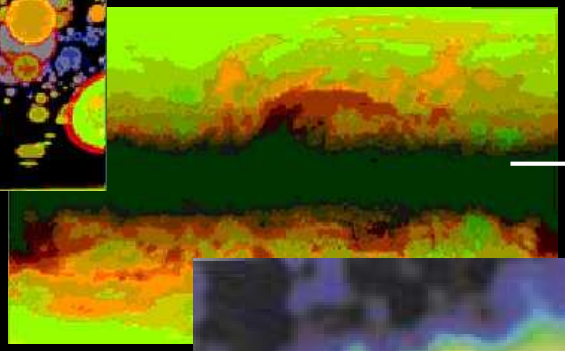




Models for Hot Gas







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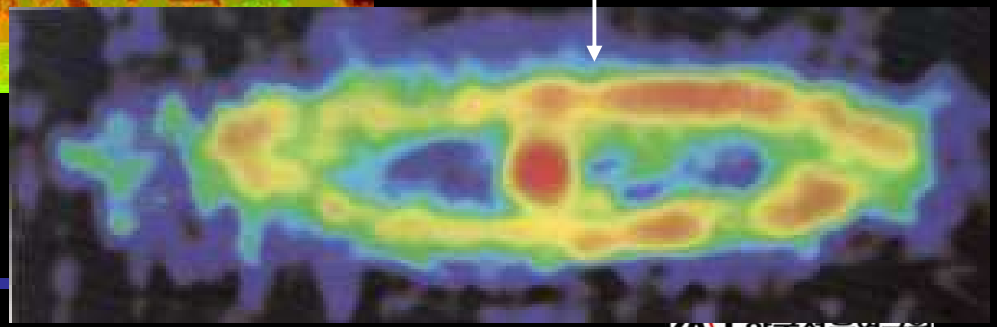
What's the nature of the Hot Gas in our Galaxy ?



To Study Distribution, Properties of Hot Gas, ISM in Galaxy


SaTReC
KAIST


2003 9 25

FIMS/STSAT-1

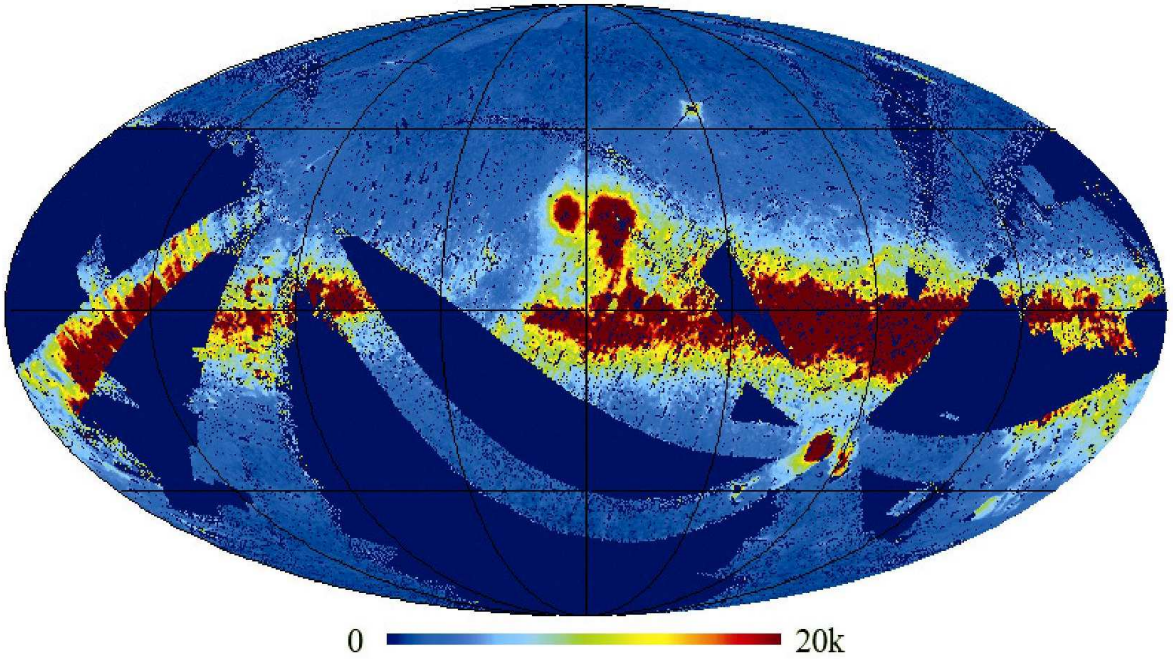
Launch : 27 Sep 2003

Russia, Plesetsk

By Cosmos Rocket

Successfully Launched

FIMS Heritage



Total diffuse intensity map of the sky for the SPEAR/FIMS L-band (1360-1730 A) observations. Evident features include the Galactic plane, the Sco-Cen association, and the LMC.

- ApJL FIMS Special Issue, 2006, Vol 644
  - First results from the FIMS Mission
  - Since 2006, more than 50 papers were published including mainly ApJ papers by FIMS observation

MIRIS

Multi-purpose Infra-Red Imaging System
The Main Payload of STSAT-3

MIRIS Project Summary

- Objectives
  - Space observation camera (SOC)
    - Pa-α emission line Galactic plane survey
    - Extragalactic Cosmic IR Background (CIB) observation
  - Earth observation camera (EOC)
    - Wide angle NIR imaging of Korean peninsula
    - Developing space IR technologies

- Spacecraft : STSAT-3 (SaTReC, KAIST Develop)
- Duration : 2008. 05 ~ 2013. 11 (6 years)

- Participants : KASI, SaTReC, KARI, KBSI, SNU, ISAS/JAXA
  Green Optics, Genesia

MIRIS : Science Mission (1/3)

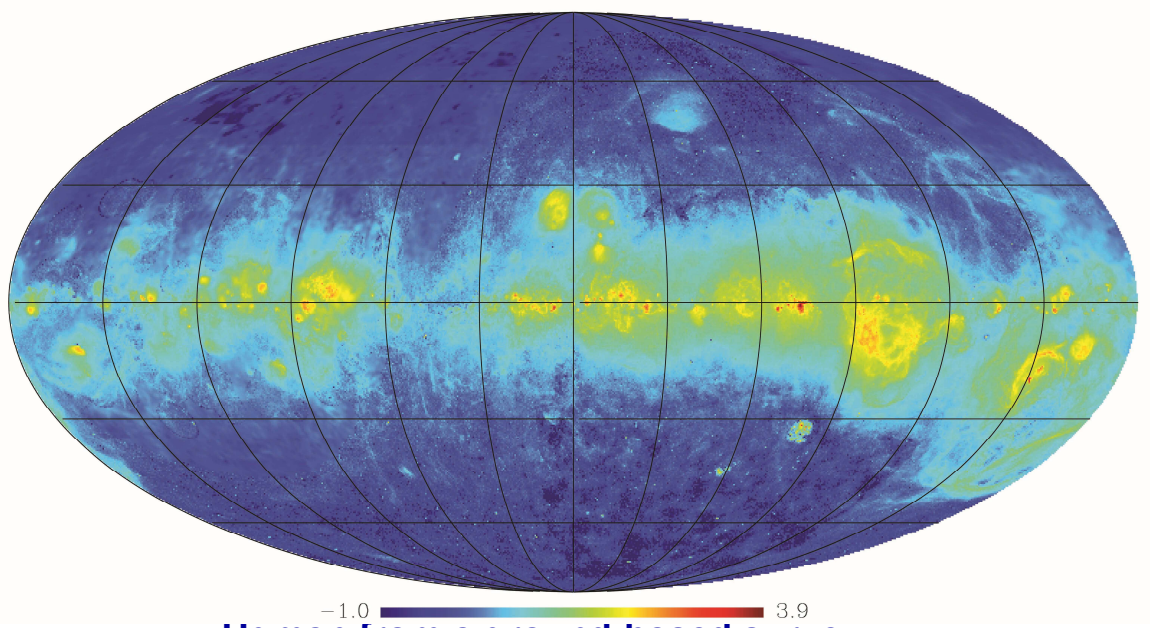
- Galactic Plane Survey (1/2)

Origin of the Warm Ionized Medium (WIM)

- Challenge to the current paradigm of the Ionization theory
- Test the effect of Dust scattering for the WIM observation

Observation : Paα survey

- Paα (MIRIS) vs. Hα (Ground-based) : Scattering difference
- Paα is better than Hα in the turbulence study of the WIM because of the lower dust-extinction



Hαmap from a ground-based survey

Science Mission (2/3)

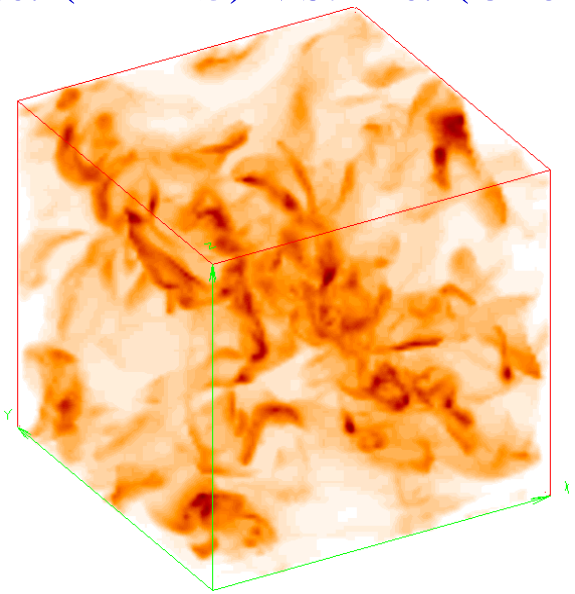
- Galactic Plane Survey (2/2)

Physical Properties of Turbulence in the Galaxy

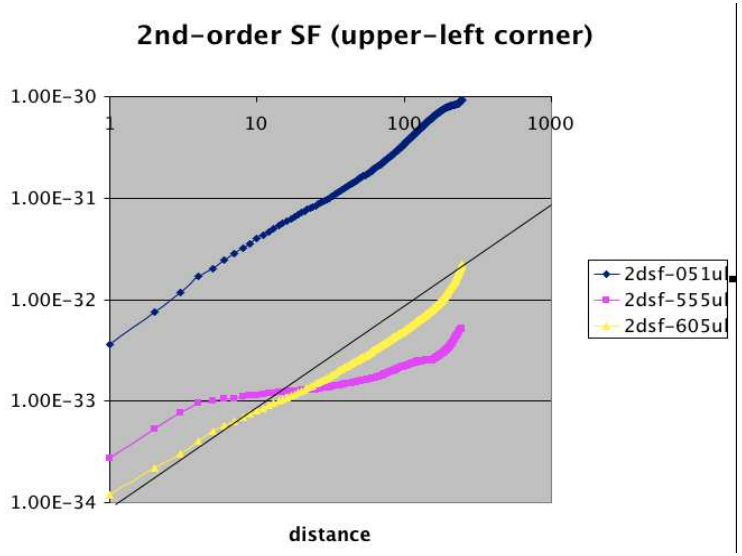
- Survey the physical parameters of turbulence in the Galaxy
- Derive Magnetic field strength from the structure characteristics of turbulence

Observation : Paα survey

- Paα (MIRIS) vs. Hα (Ground-based) : Extinction difference



Turbulence model

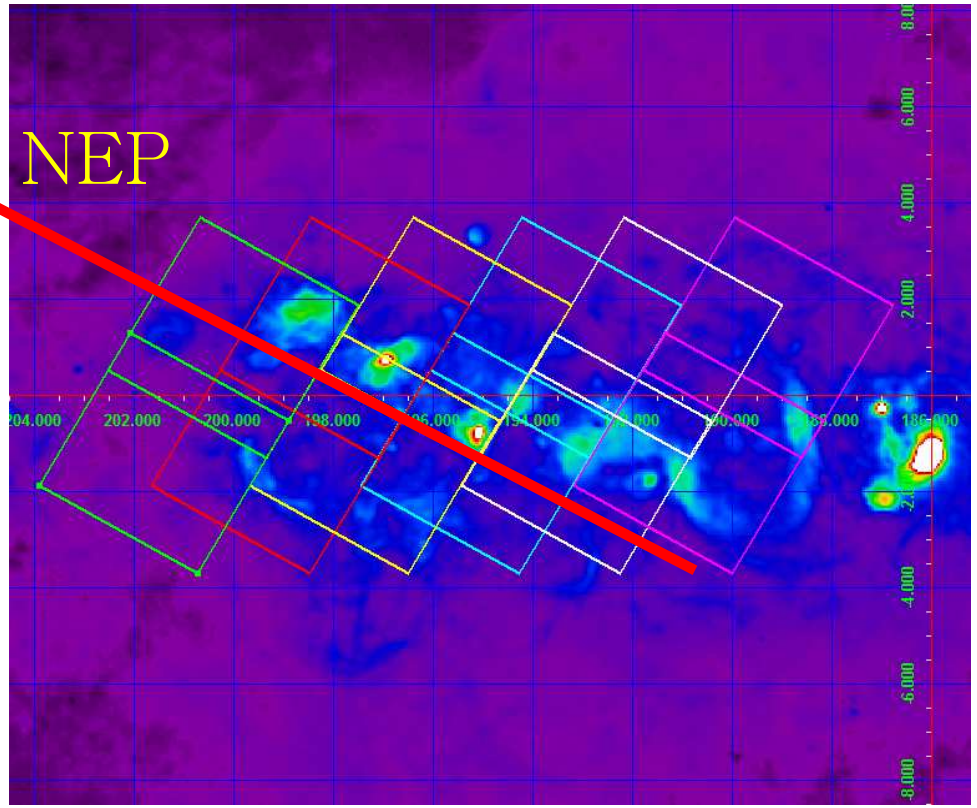


Measurement of the turbulence structure

Paα Observation Plan

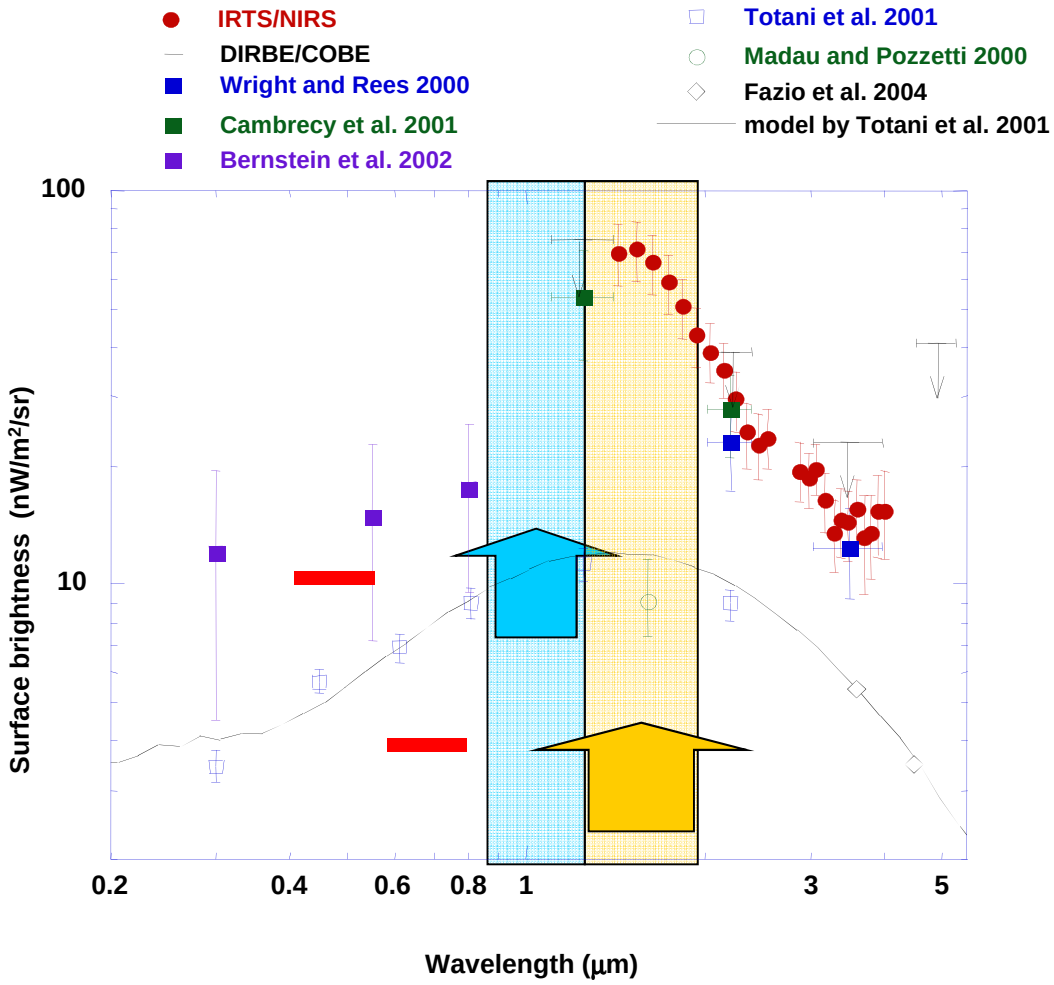
- Galactic Plane Survey
  - Simple Satellite Control

- Current plan
  - 2 filters
  - Rotated detector FoV: 3.67 deg.
    → 20% increase of survey capability
  - ~50% overlap
  - Width: 5.9 ~ 7 deg.
  - Total survey time = 10 months



Science Mission (3/3)

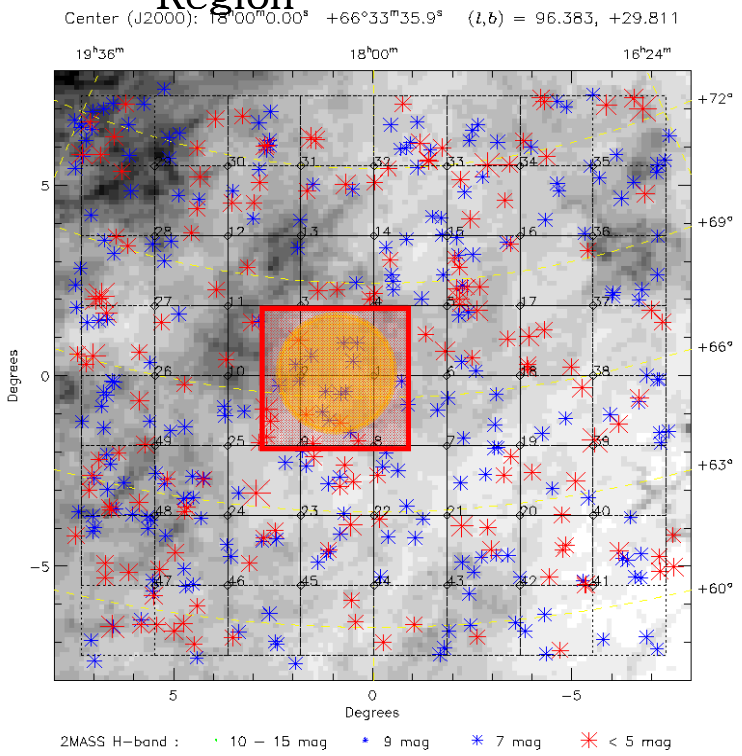
- CIB Observations:
  To reveal the origin of CIB
- Expected MIRIS Sensitivity
  (3σ, Instrumental noise only)
  - I band: 18.6 AB mag.
  - H band: 19.1 AB mag.
- Confusion-limited observation
- Two bands: I & H bands
  → peak of CIB?



CIB Observational Plan

- Filters: I & H bands
  Blank (dark calibration)
- CIB dedicated phase: 1 month
- Primary target
  NEP (North Ecliptic Pole)
  - 6.2 sq. deg. observed by AKARI
  - Whole area: 10°x10°
  - 7 x 7 fields
  - 1 sec. integration x 600 frames
- Secondary targets
  - SEP (South Ecliptic Pole)
  - NGP (North Galactic Pole)
  - SGP (South Galactic Pole)

MIRIS NEP Obs Region

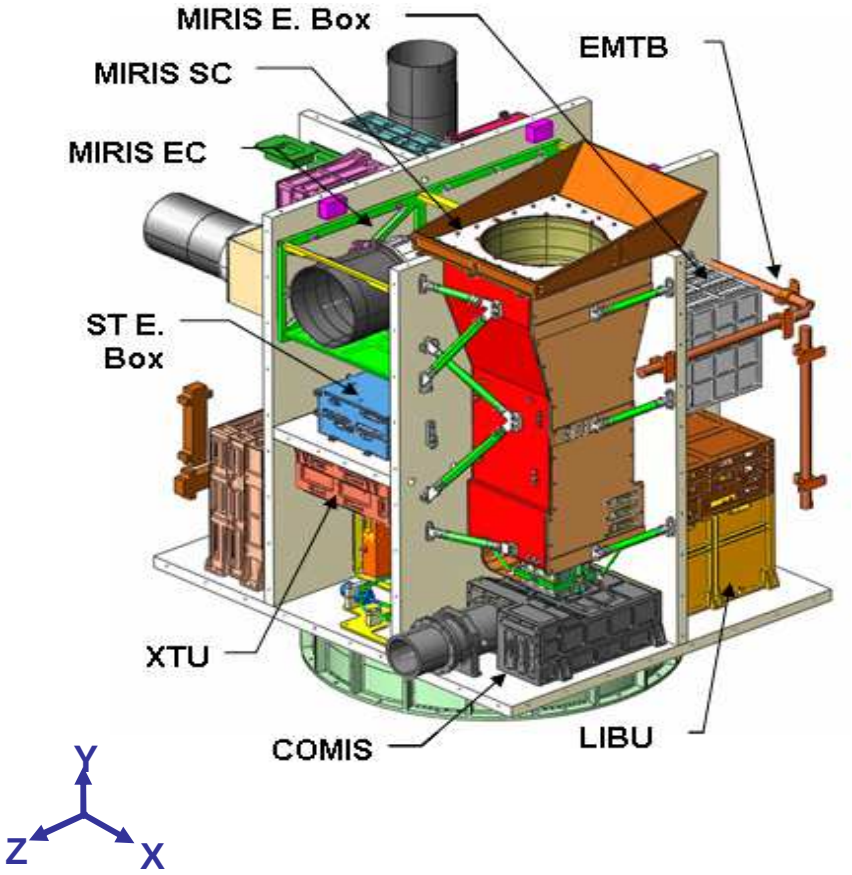


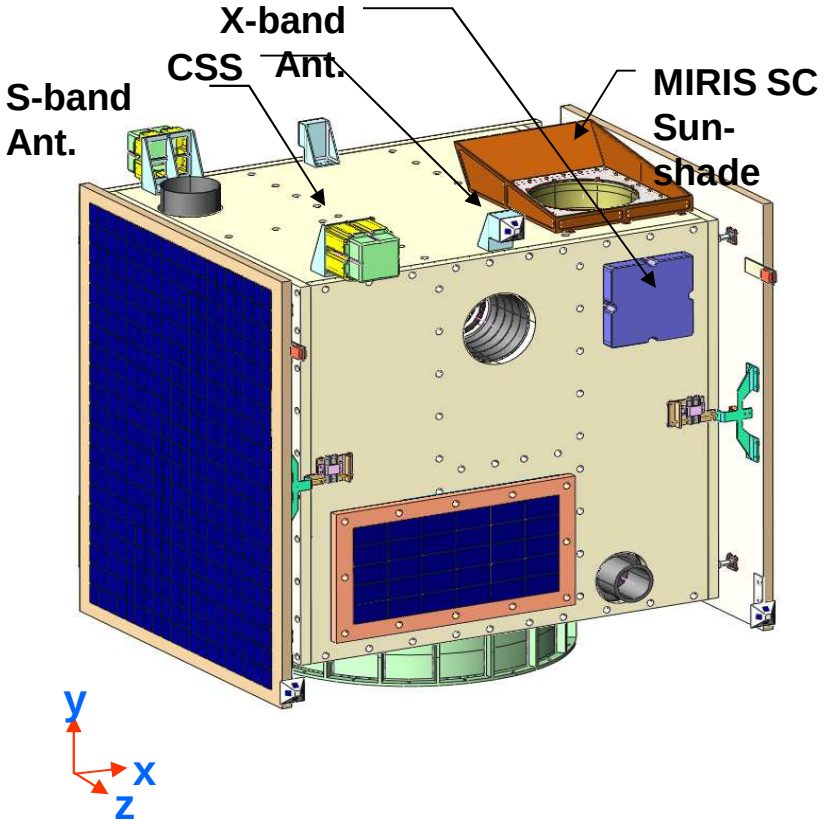
: AKARI Obs Region

: MIRIS FoV

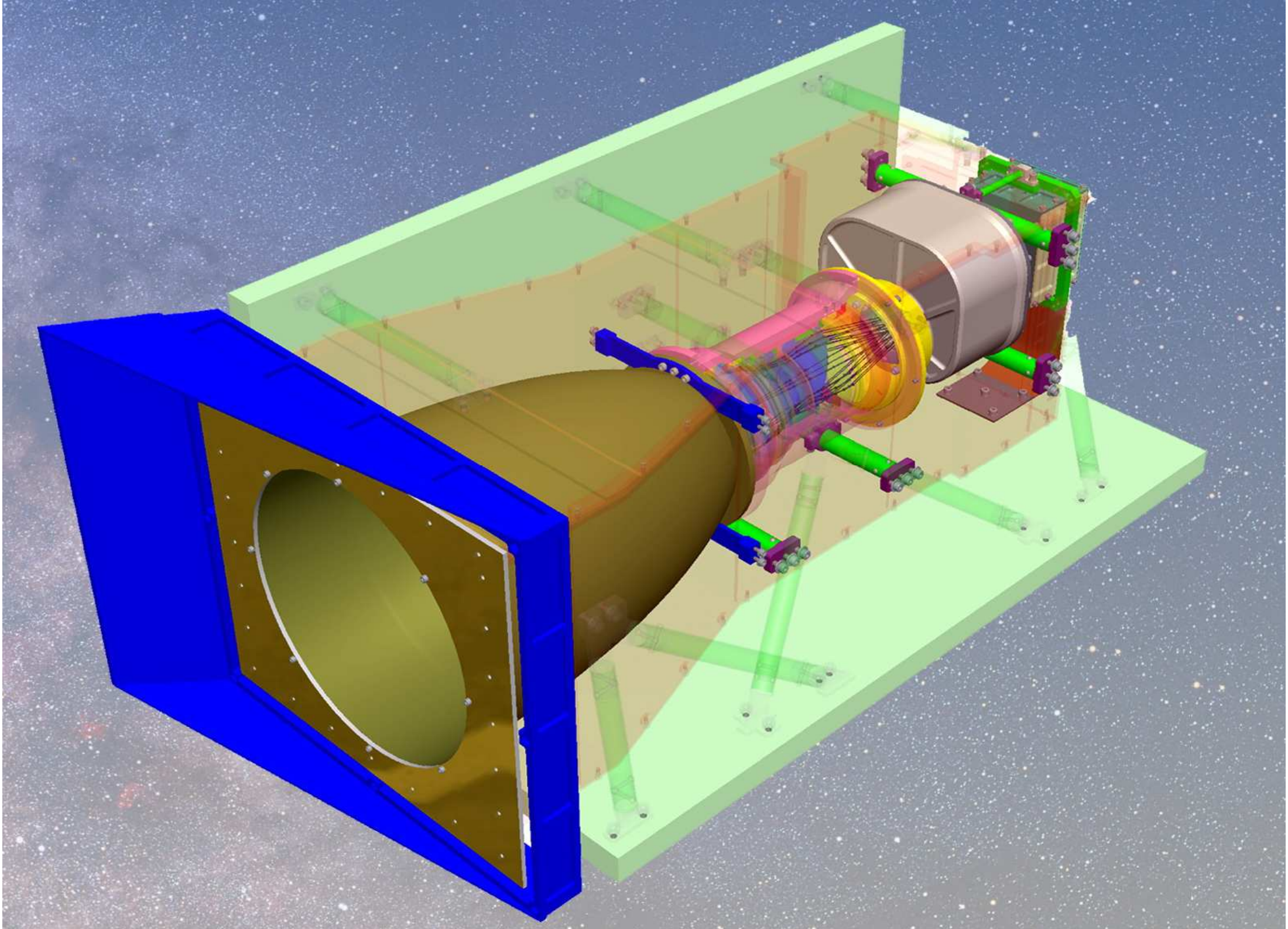
MIRIS System Design

STSAT-3 Summary





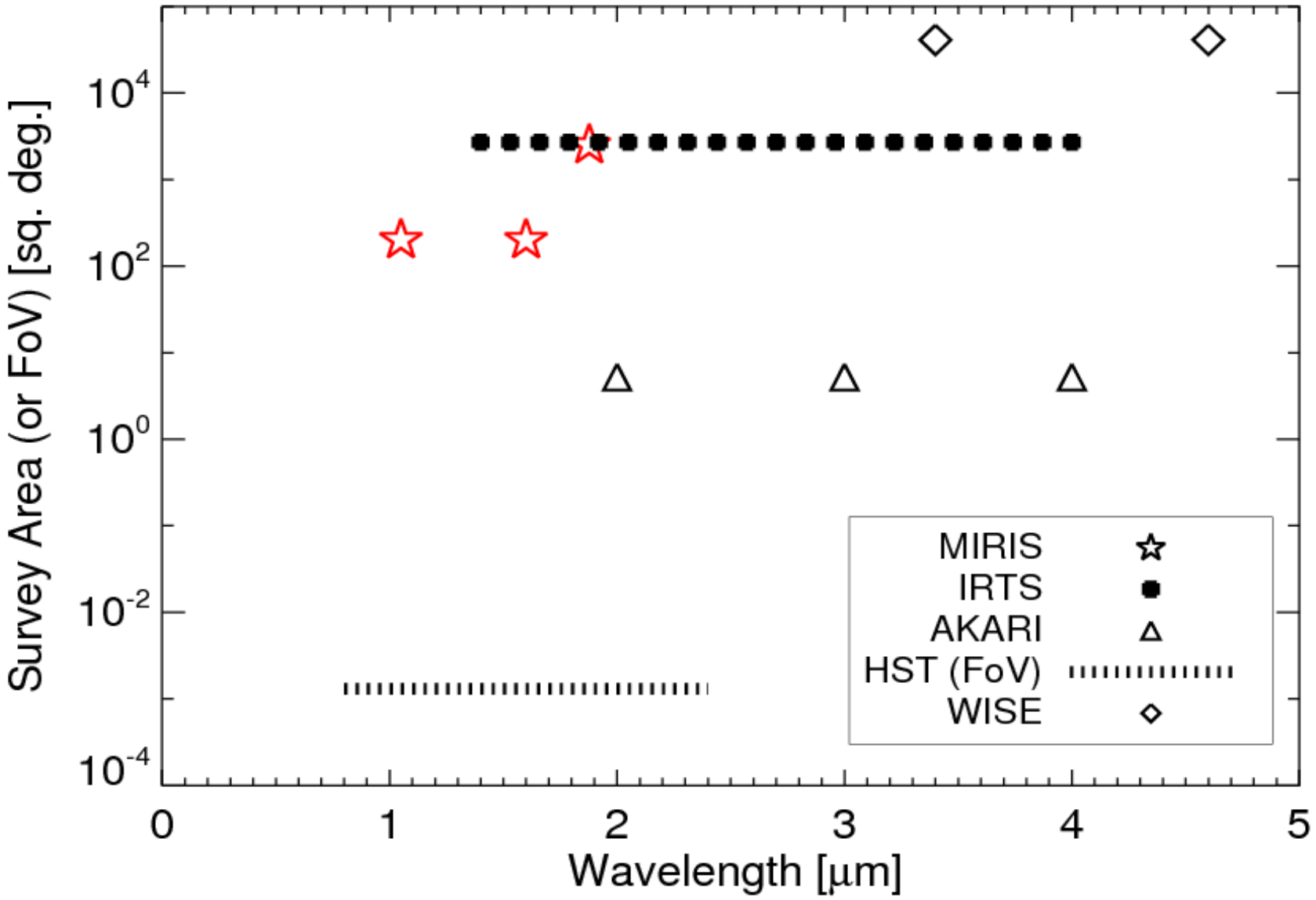
Item	Specification
Mission Orbit	595 ~ 635 km, Sun synchronous
Mission Life	2 years
Satellite Mass	~ 175 kg



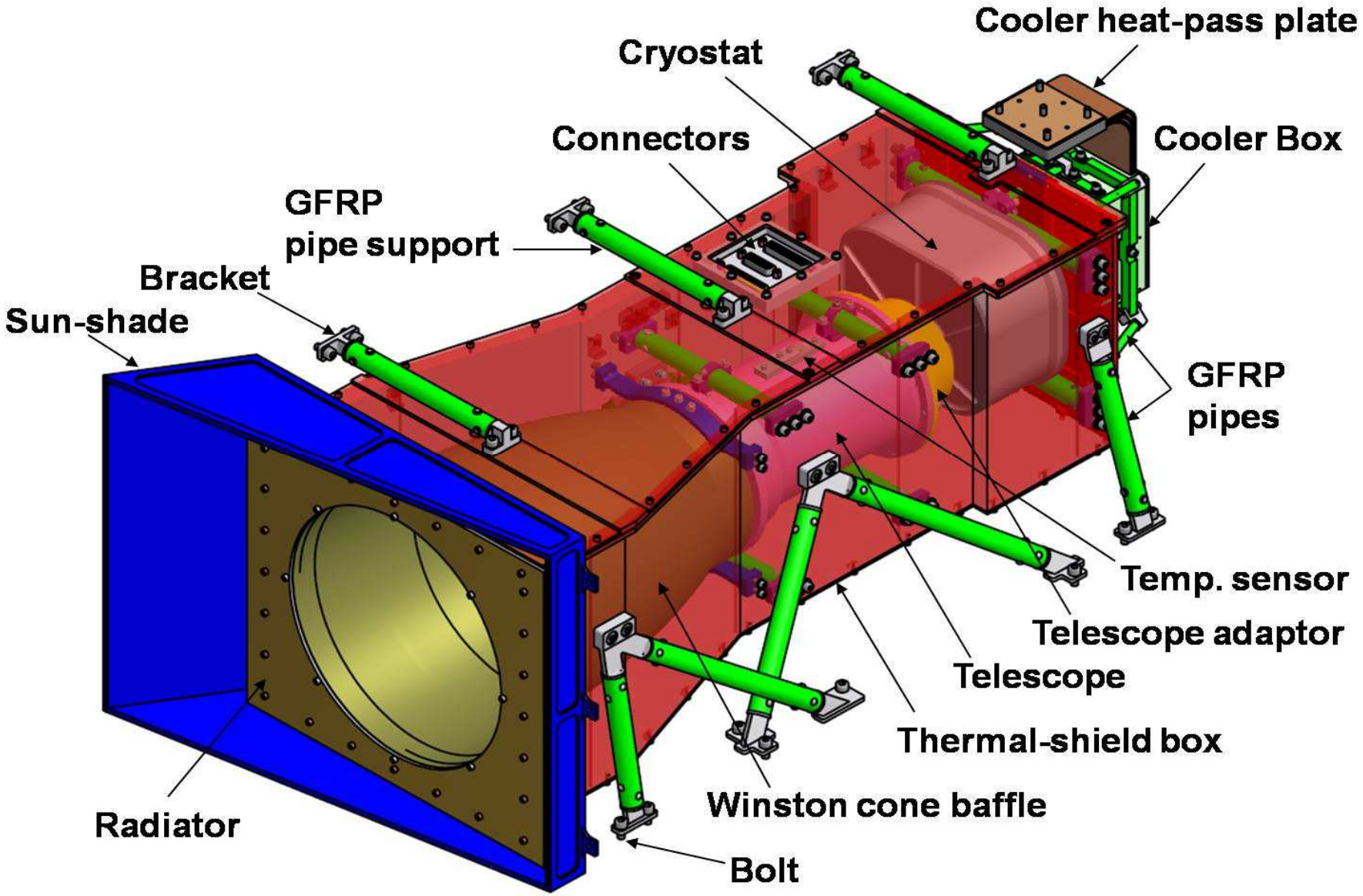
MIRIS Specifications

	MIRIS SPEC
Wavelength	0.9 ~ 2 um (Very Near Infra-red)
Aperture	80 mm
Effective Focal Length	160mm
Focal ratio	f/2
Pixel FOV	51.6 arcsec
Instrument FOV	3.67° x 3.67° (Very Wide Field)
Sensor	Teledyne PICNIC, 256x256
Filter	Filter Wheel (6 filters)
Telescope Temp	190 ~ 200 K (Passive Cooling)
Sensor Temp	90 K (with Cryogenic Motor)
Performance	MTF > 60%

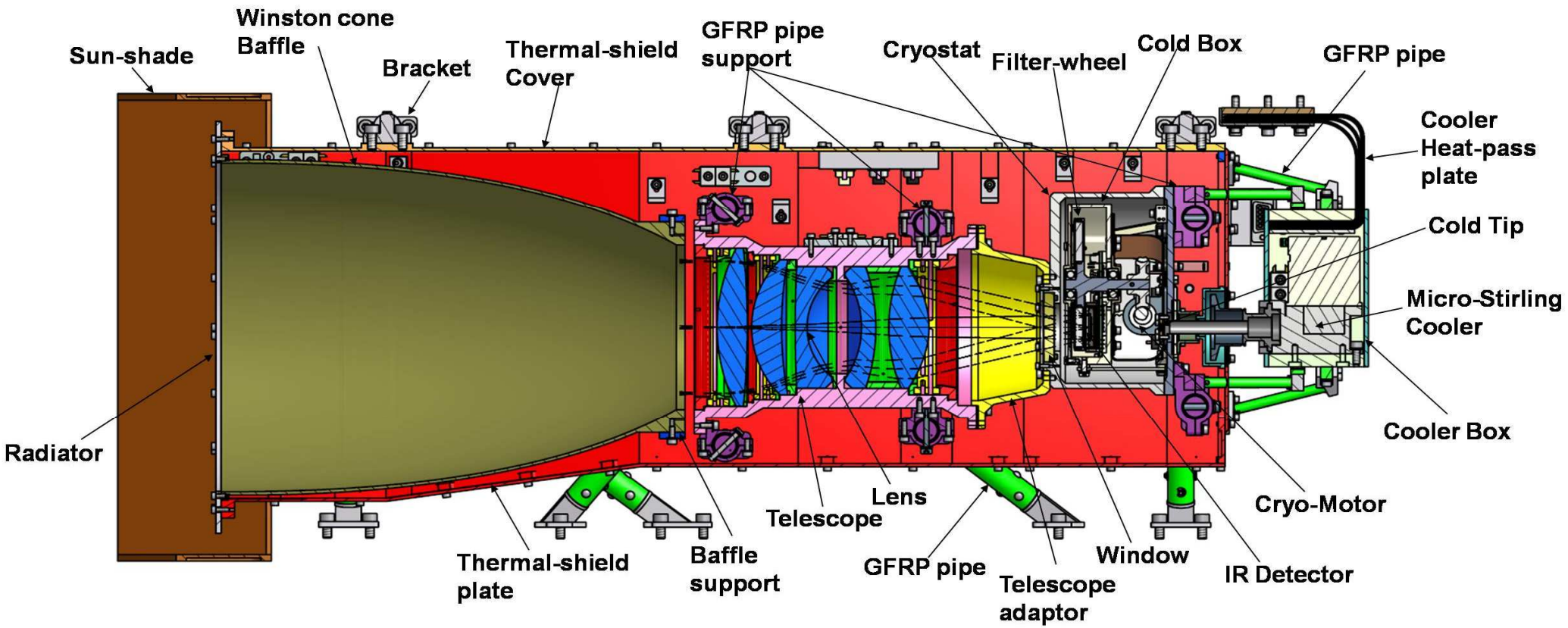
Survey Area for other Missions & MIRIS



MIRIS System External Layout



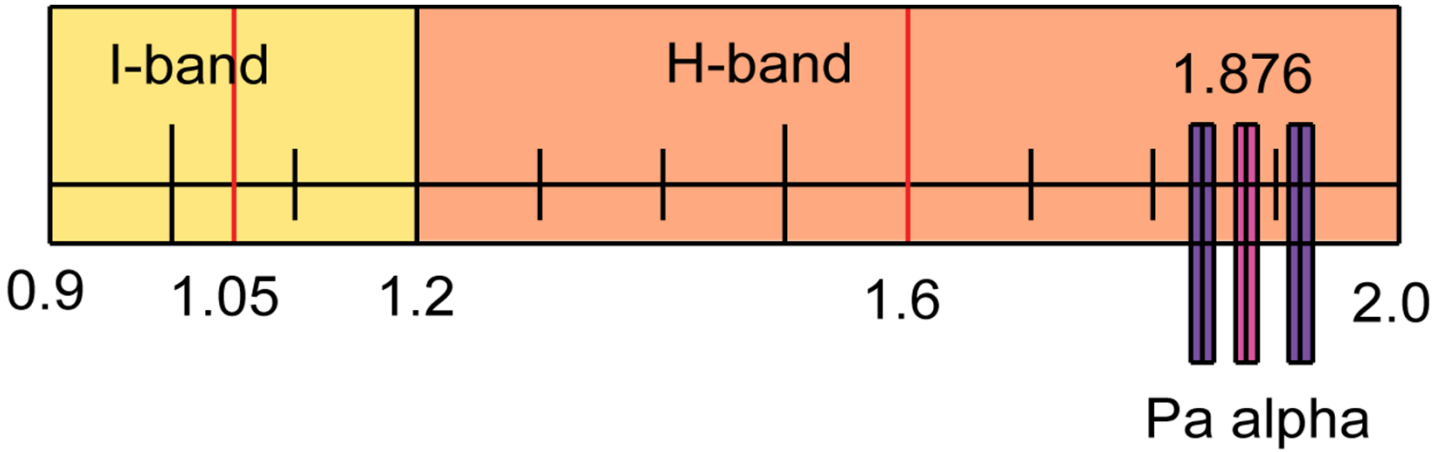
MIRIS System Internal Layout



MIRIS Optics Specification

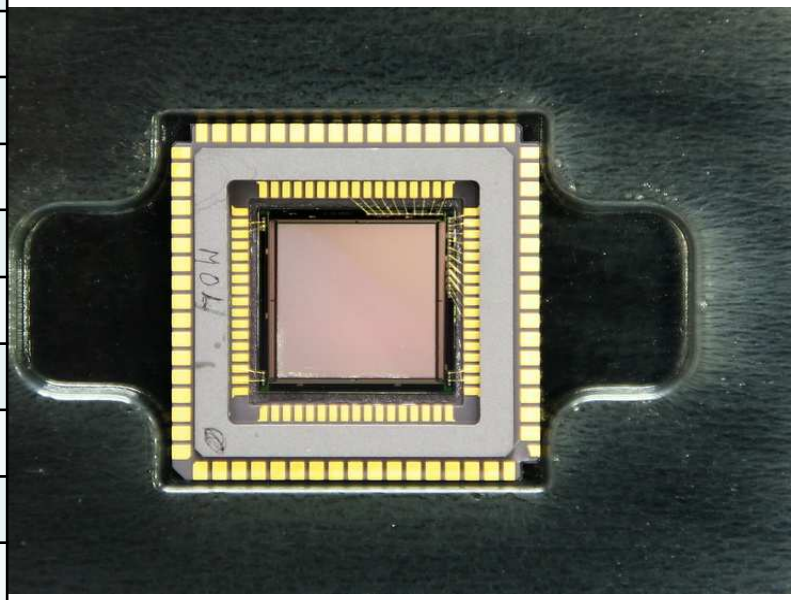
- Specifications of Space Observation Camera

  - Wavelength: 0.9 ~ 2μm
  - Aperture: 80 mm
  - Pixel FOV: 51.6 arcsec
  - Detector FOV: 3.67° x 3.67°
  - Telescope & Sensor Temp.: 180 ~ 200K (Passive Cooling), 100K
  - Filters (6 filters)
    - I (1.05μm), H (1.6μm), blank
    - Pa α (1.876μm), Pa α Cont1, Pa α Cont2
    - Pa α Cont1, Pa α Cont2 → Double band filter



PICNIC IR Array Specification

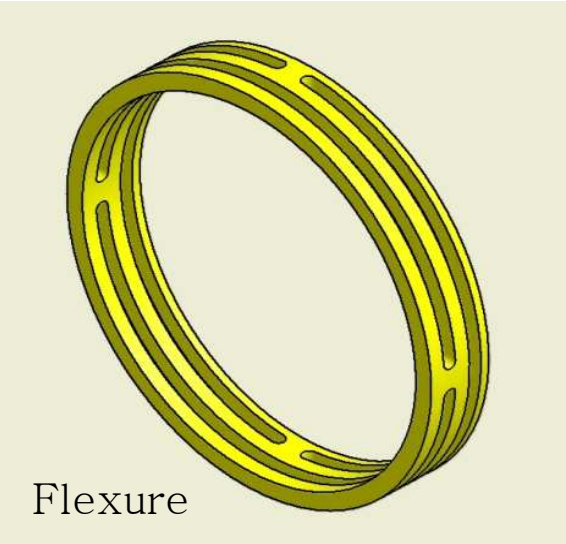
Parameter	Specification
Detector technology	HgCdTe(PACE)
Detector input circuit	SFD
Readout mode	Ripple(per quadrant)
Pixel readout rate	Up to 200kHz
Pixel format	256x256
Pixel pitch	40um
Fill factor	>90
Output ports	4 total(1 per quadrant)
Clocks	6
Spectral range	0.9 ~ 2.5um
Quantum Efficiency @2.3um	>75%
Read noise: multiple sample	<20
Dark current	<0.2 e-/sec(@77K)
Well capacity	200,000 e-
Pixel operability	>99%

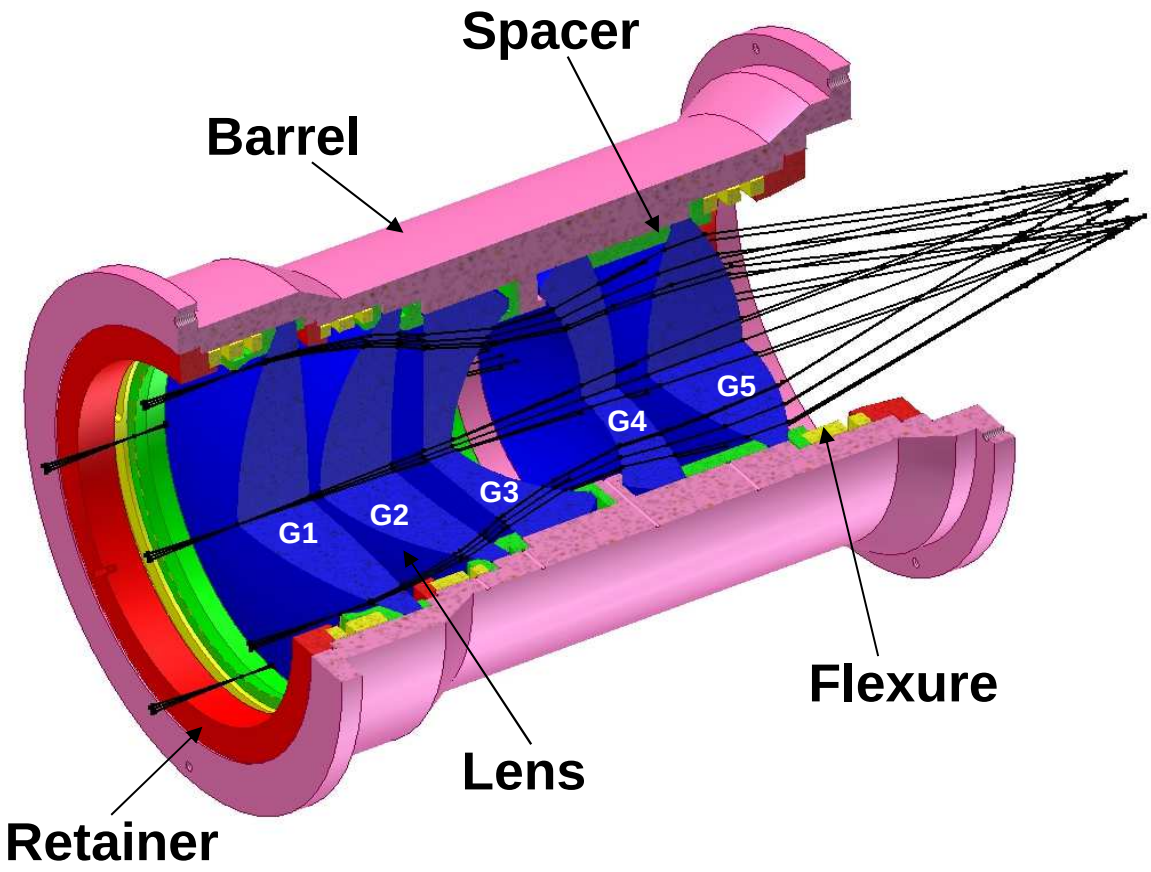


PICNIC sensor

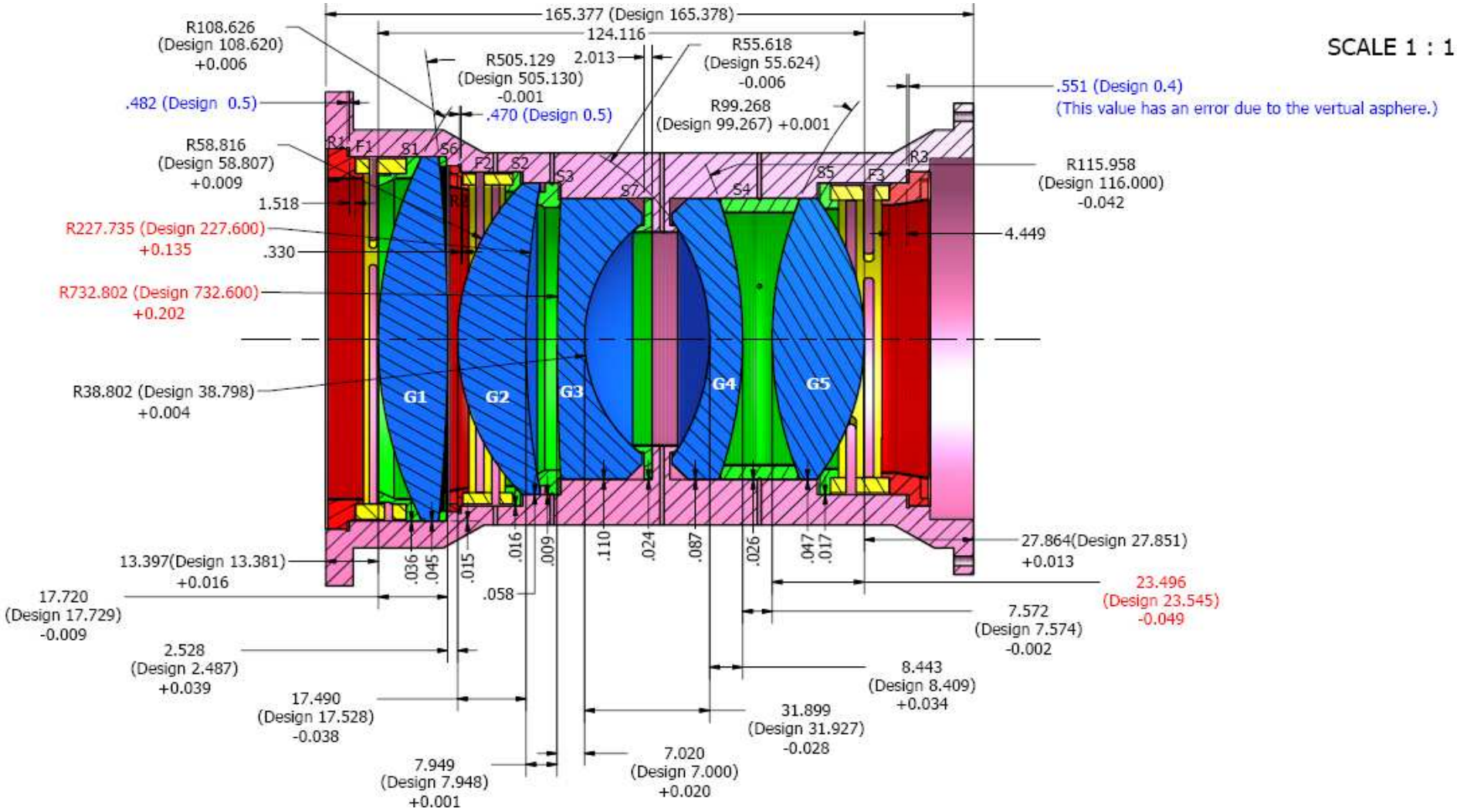
MIRIS Optics Layout

- Operation temp. : 300K => 180K



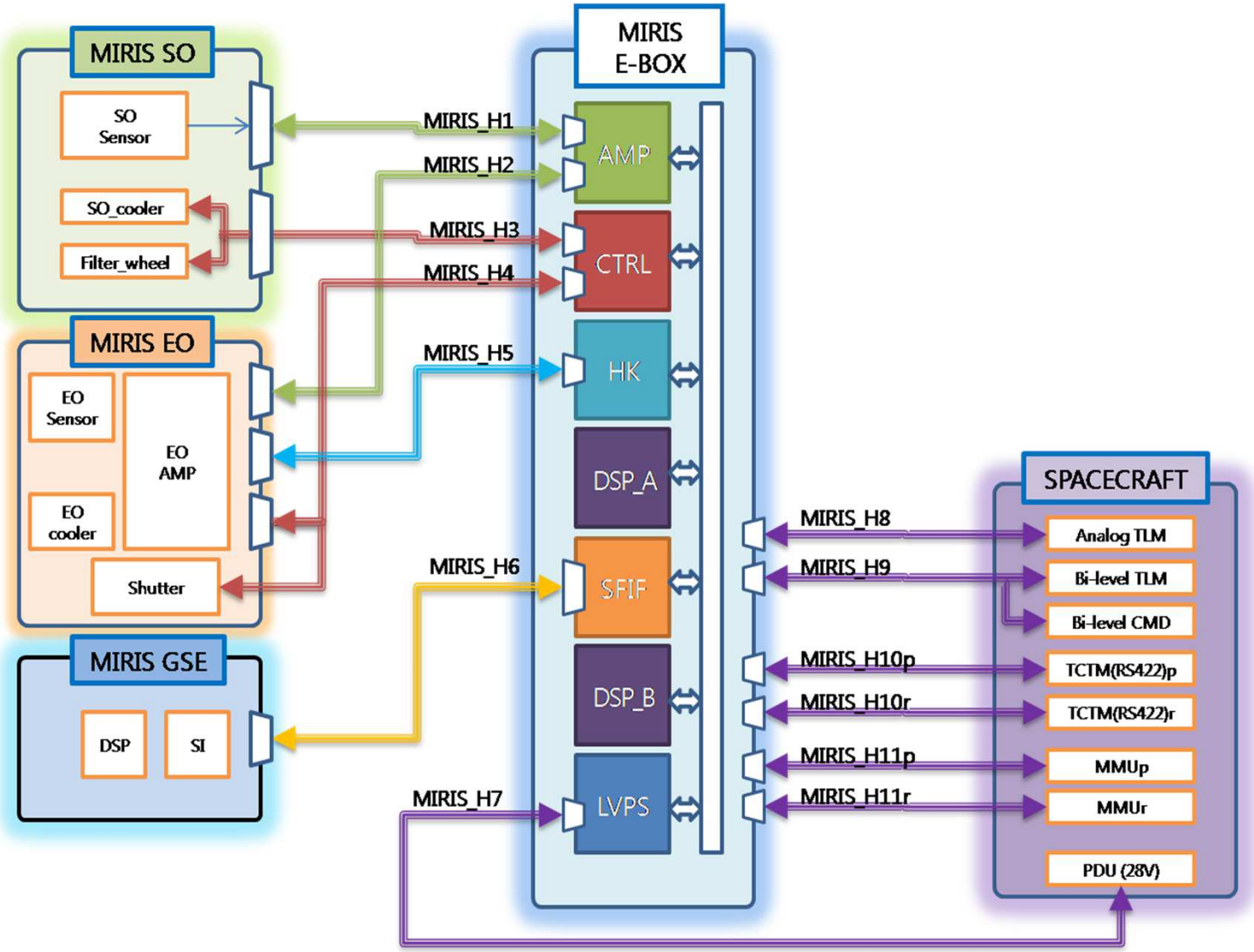


CAD Assembly of Flight Model



- CAD Assembly for simulation reference, before practical pre-Assembly,.

MIRIS Electronics



Test Plan

Part

Optics
- Lens (SO, EO)
- Barrel (SO, EO)
- Baffle (SO, EO)

Mechanics
- E-box
- Dewar/Filters (SO)
- Cooler box/Cooler (SO)
- Skin (SO, EO)
- MLI (SO)
- Supporters (SO)

Electronics
- PCBs
- Harness/Connectors
- Sensors

Module

Optics
- SO Function test
- EO Function test

Mechanics
- Filter wheel test (SO)

Electronics
- Image acquisition (SO)
- Image acquisition (EO)
- SCIF test
- Radiation test

System

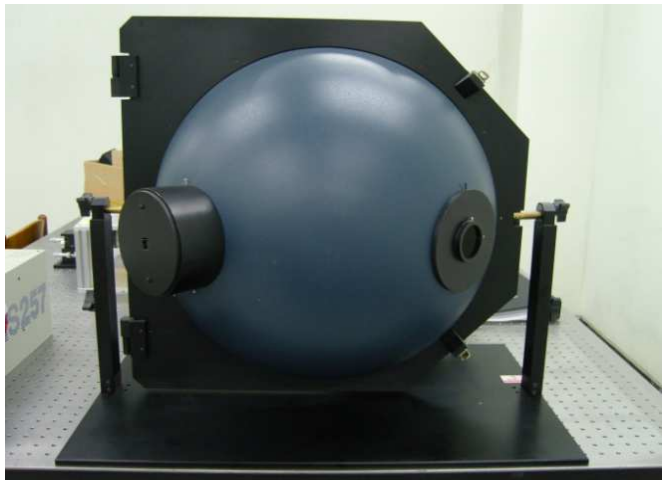
SO
- Cooling test
- Focus test
- Noise test

EO
- Field test

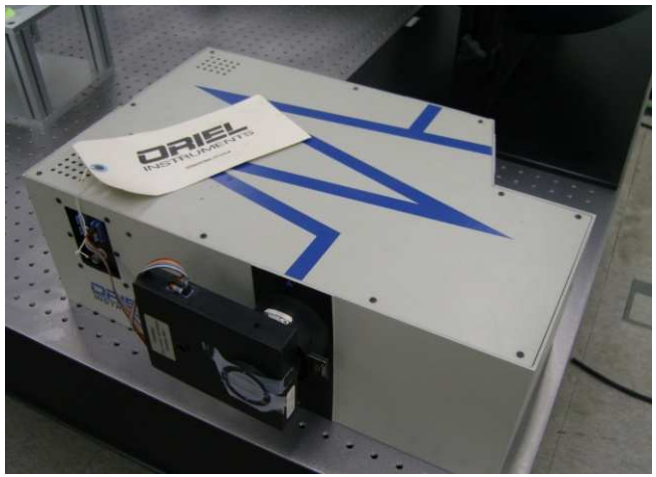
Environmental test
- Vibration test
- Thermal/Vac test

Test Equipment
- Vacuum chamber
- Collimator
- Light source
- GSE

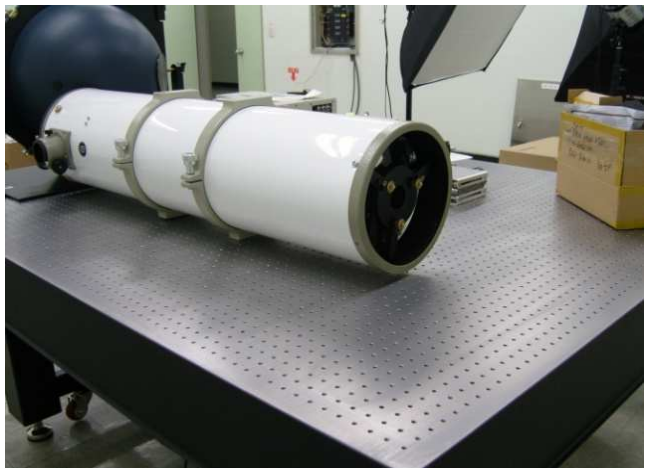
Test Equipment



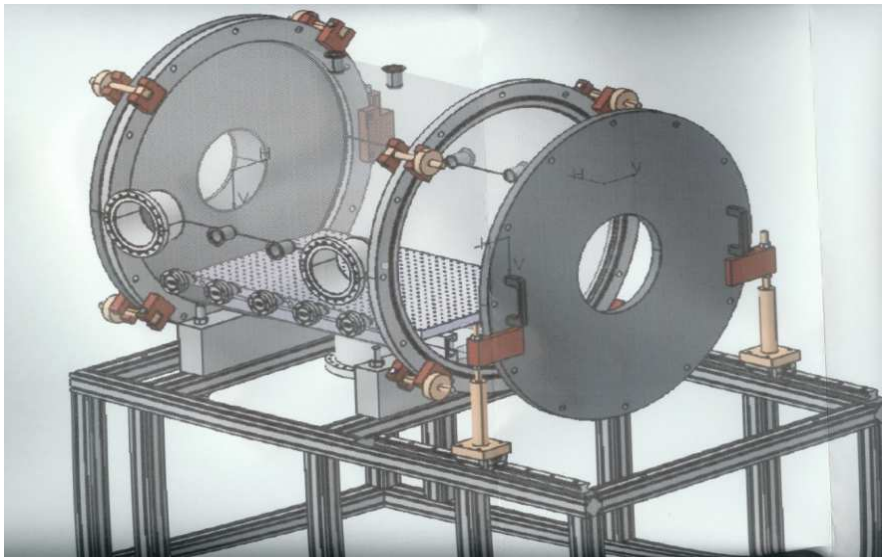
Integrating sphere



Monochrometer



Collimator & Optical Table

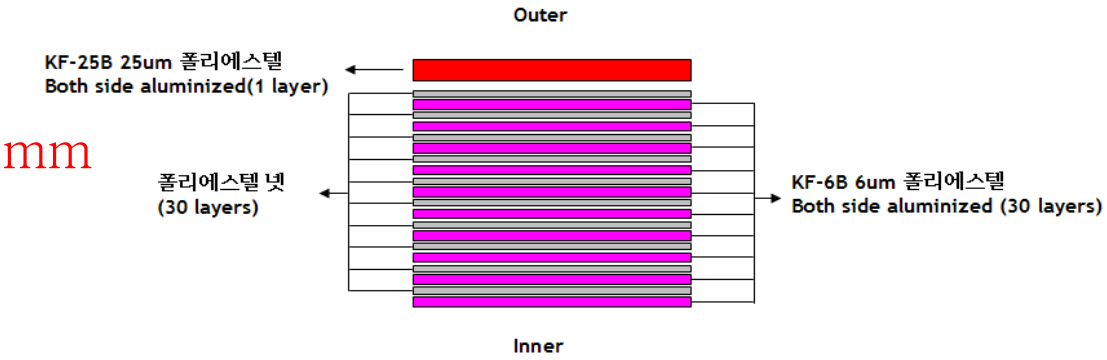


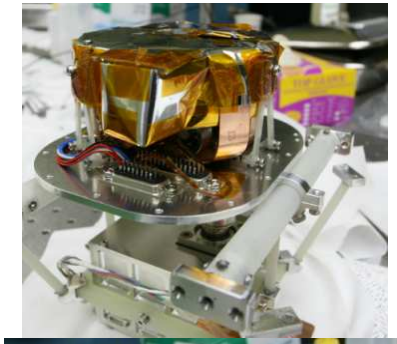
Thermal-cryo vacuum chamber

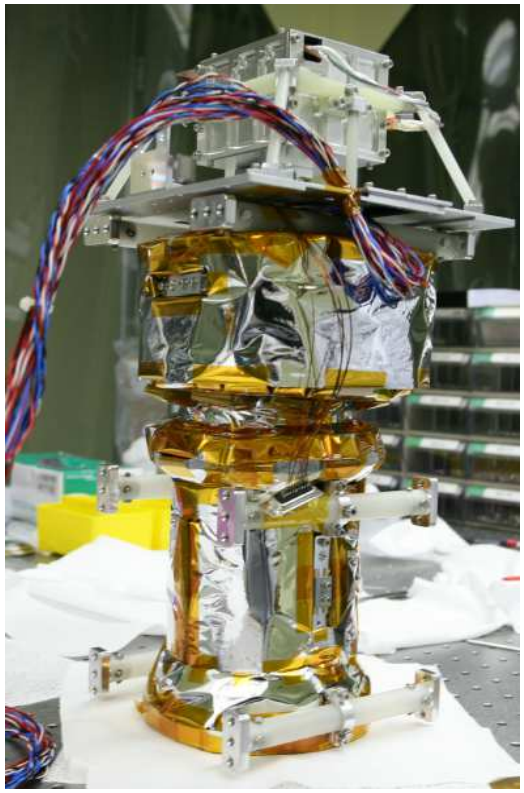
Vacuum Chamber

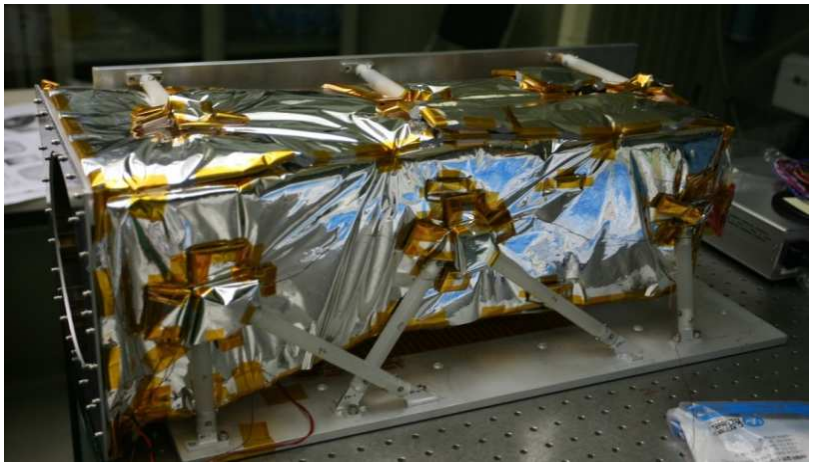
MIRIS Flight Model Assembly

- MLI Cover
  - Thickness of 30 layers: 5.2mm
  - Precheck
  - Bake-out process

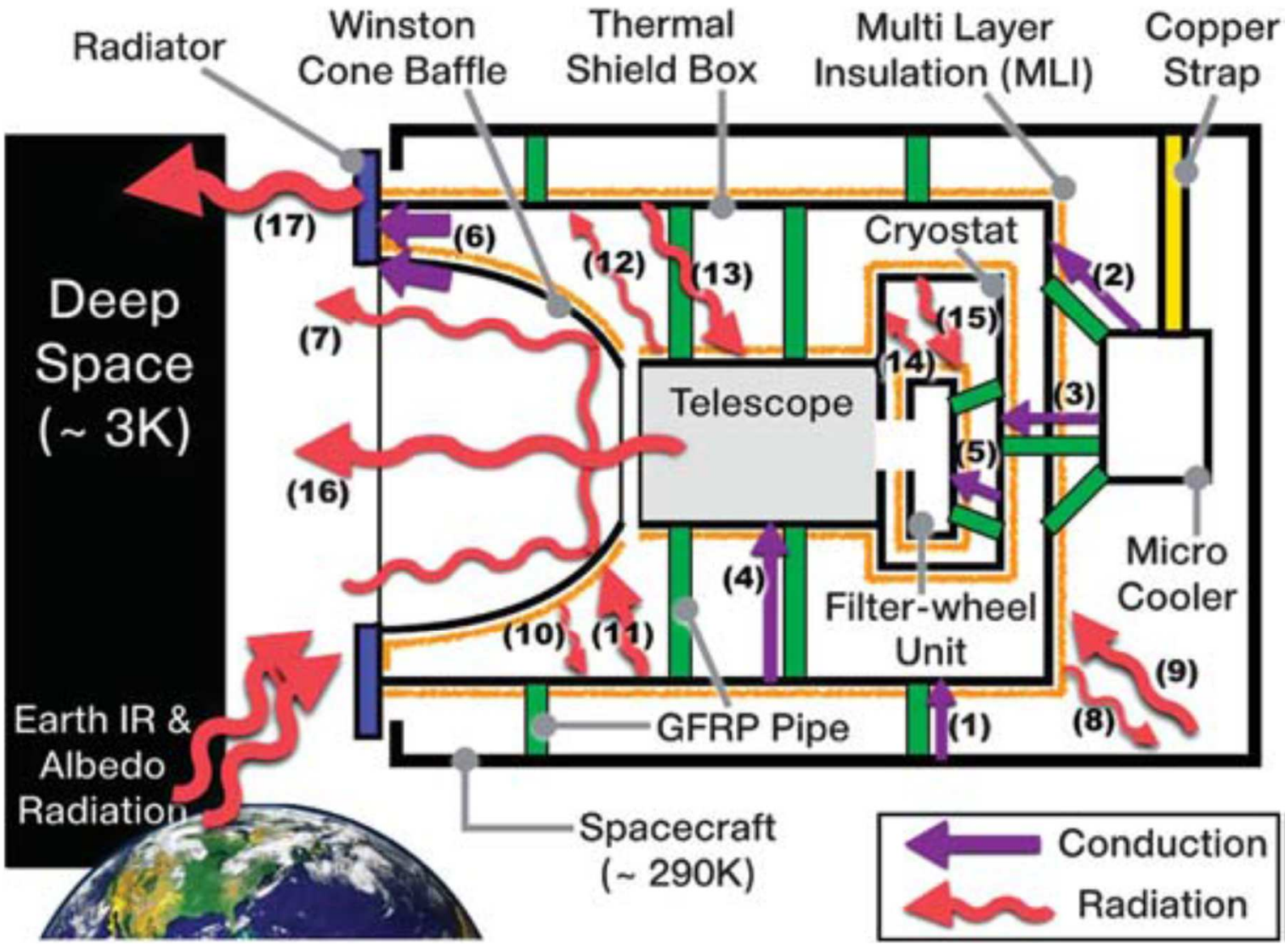




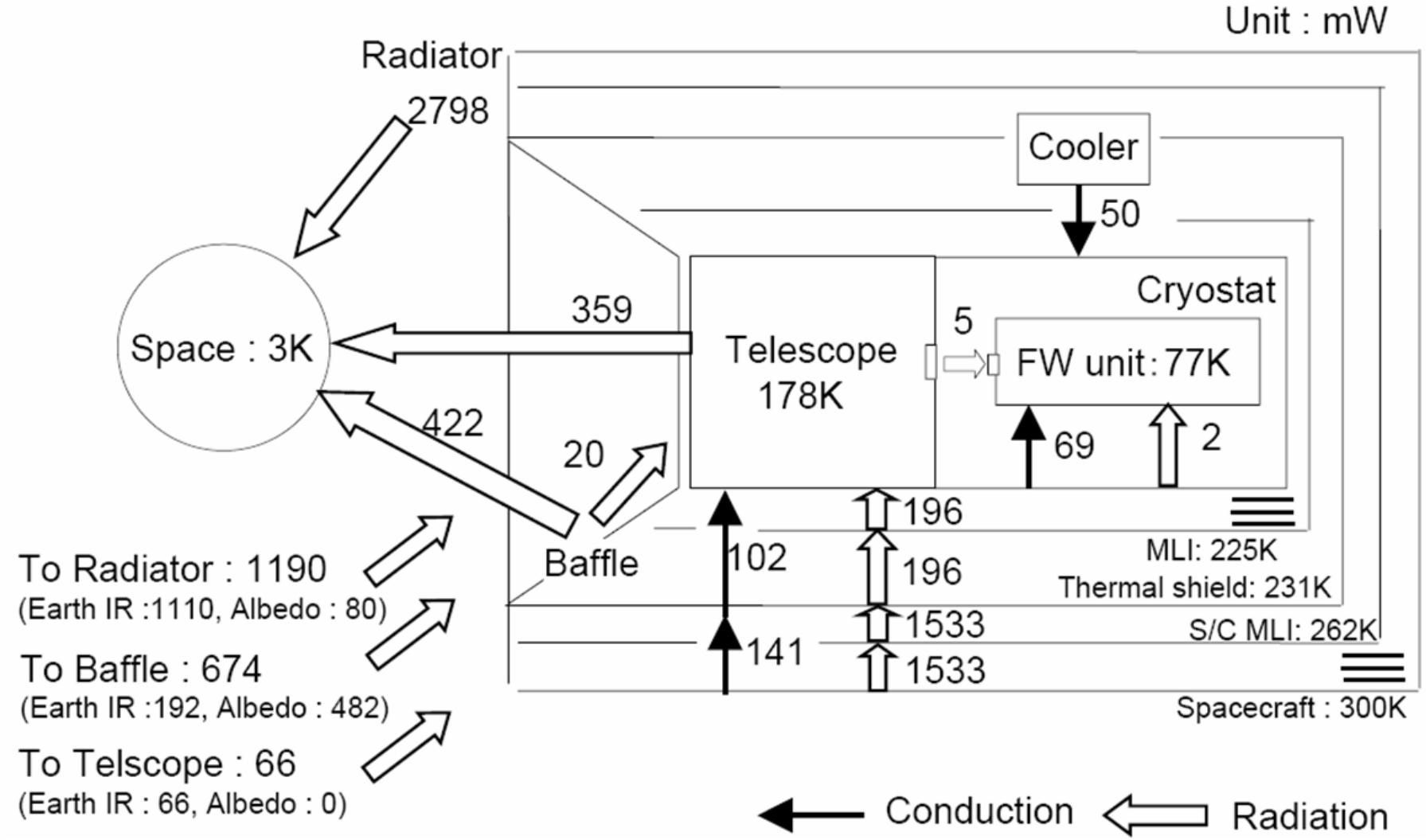




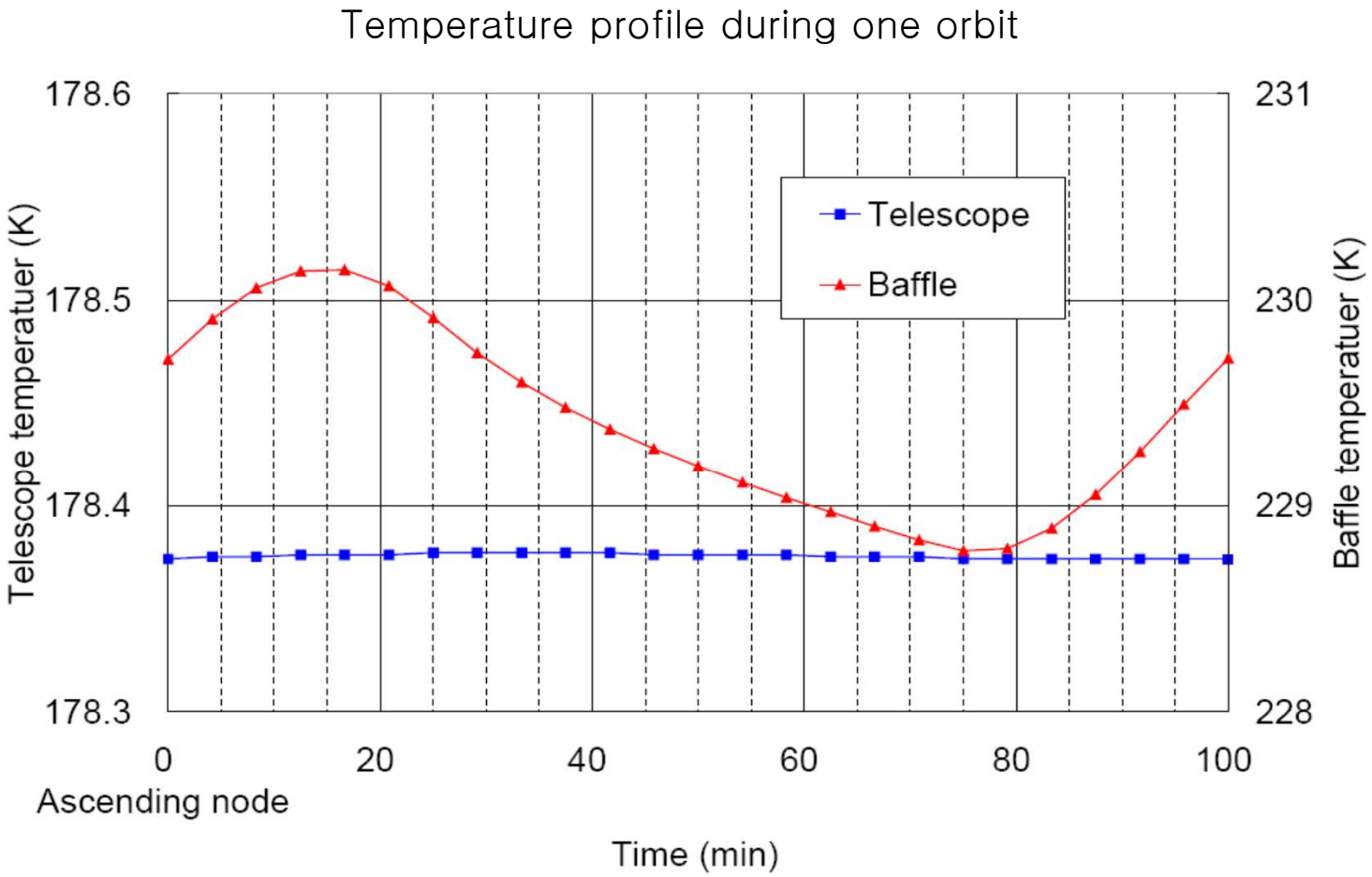
Passive Cooling Heat Transfer Concept



Passive Cooling Simulation



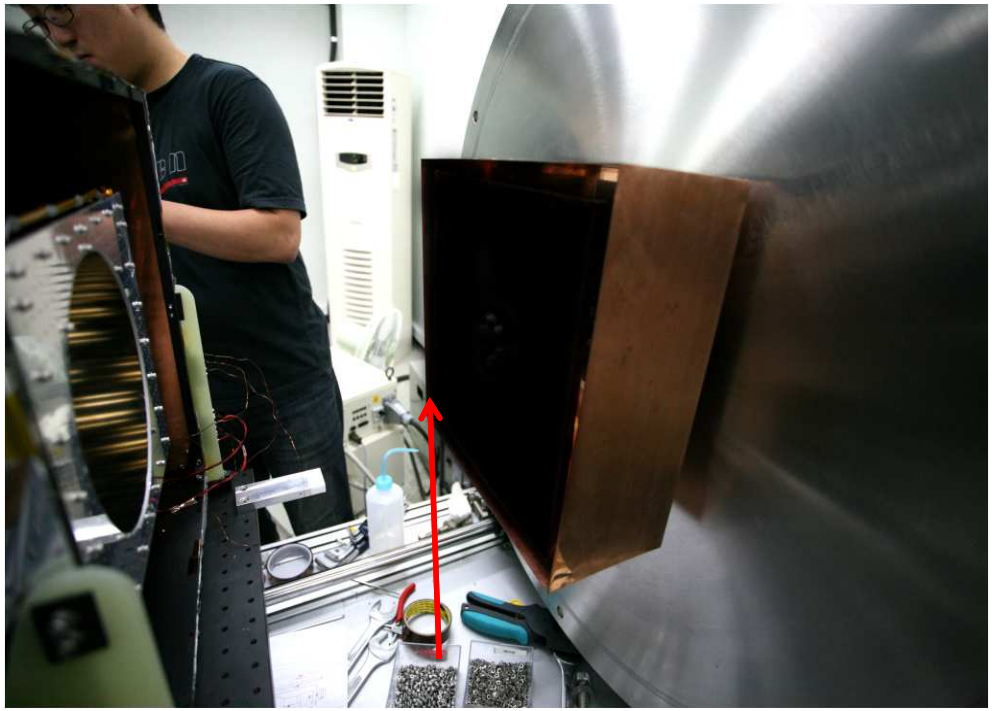
Passive Cooling Simulation (3/3)

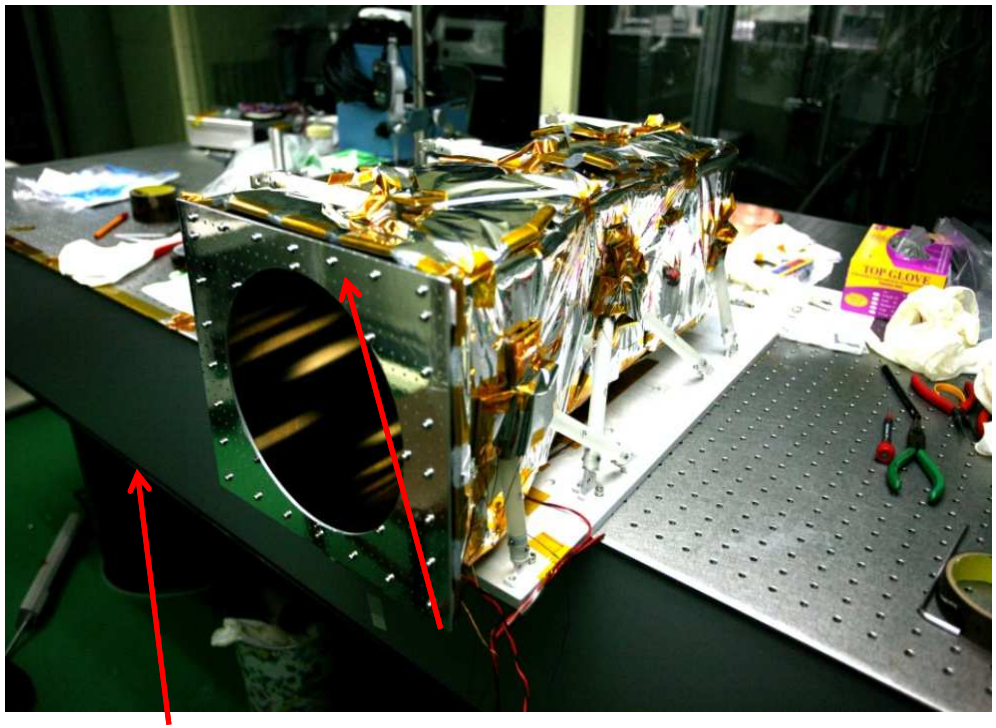


(1) The telescope can be cooled below the goal temperature of 200K
(2) The detector can be cooled below the goal temperature of 80K
- Simulation by Sumitomo Heavy Industry (SHI)

MIRIS Passive Cooling Test

- Test Configuration

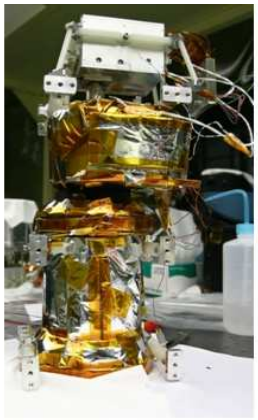




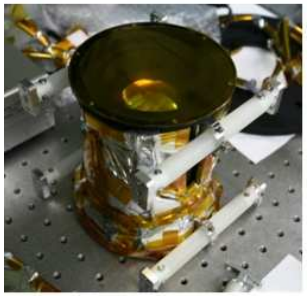
MLI

Flat black velvet painted copper (e~0.94) : radiator
Cooling Power 6W (30K), Cryogenic Cooler

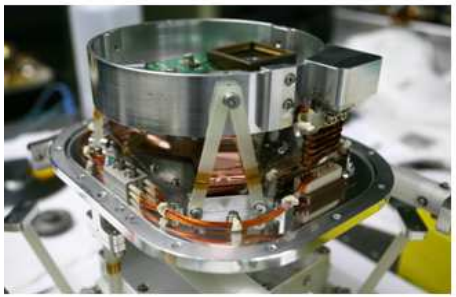
Flight Model Assembly





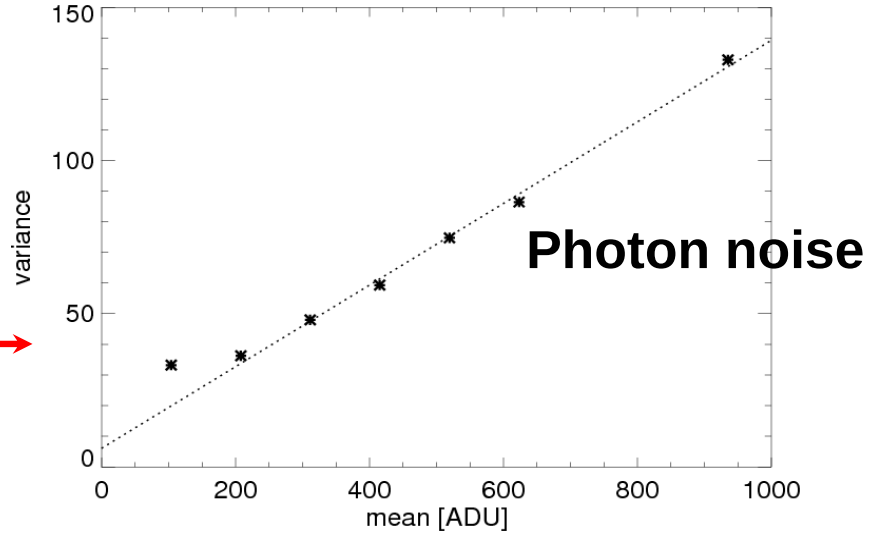




MIRIS Gain Estimation

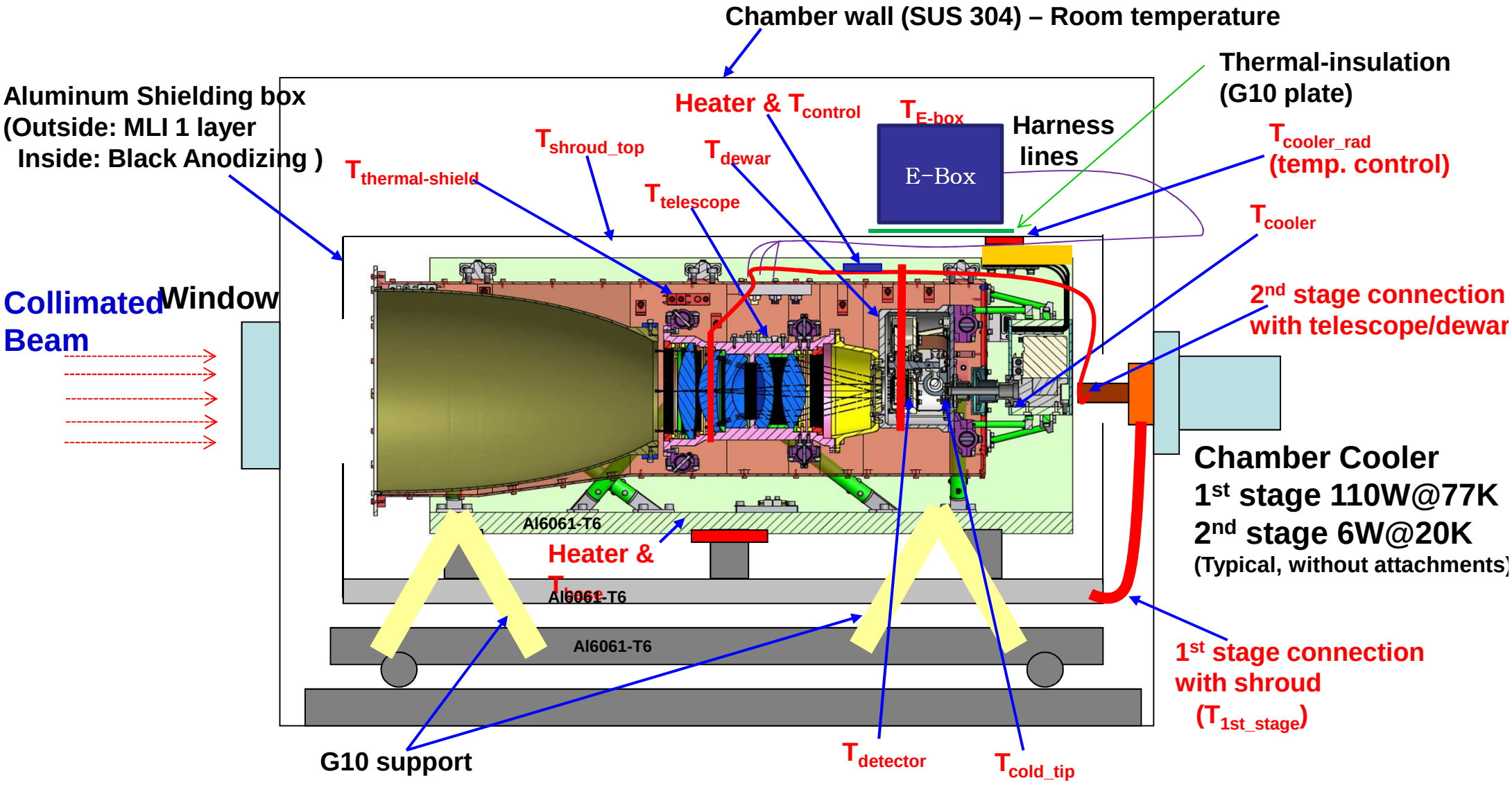
- Mean-Variance
  - Readout noise ~ 45e^-
  - 45e^- < 50e^-
    (performance estimation)
- Gain [e^-/ADU]
  - Mean-Variance test: 8 ~ 11
  - Dark current: ~10
- Consistent!

Readout noise dominant

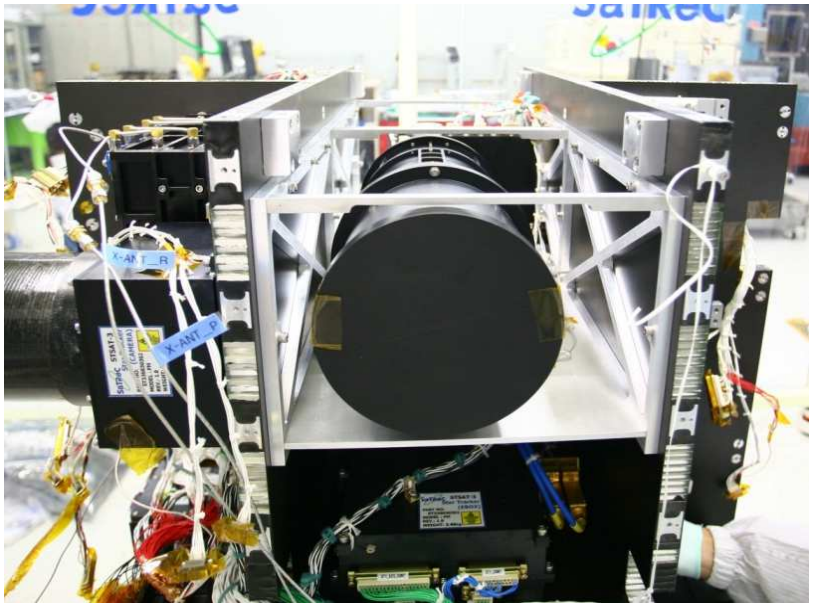


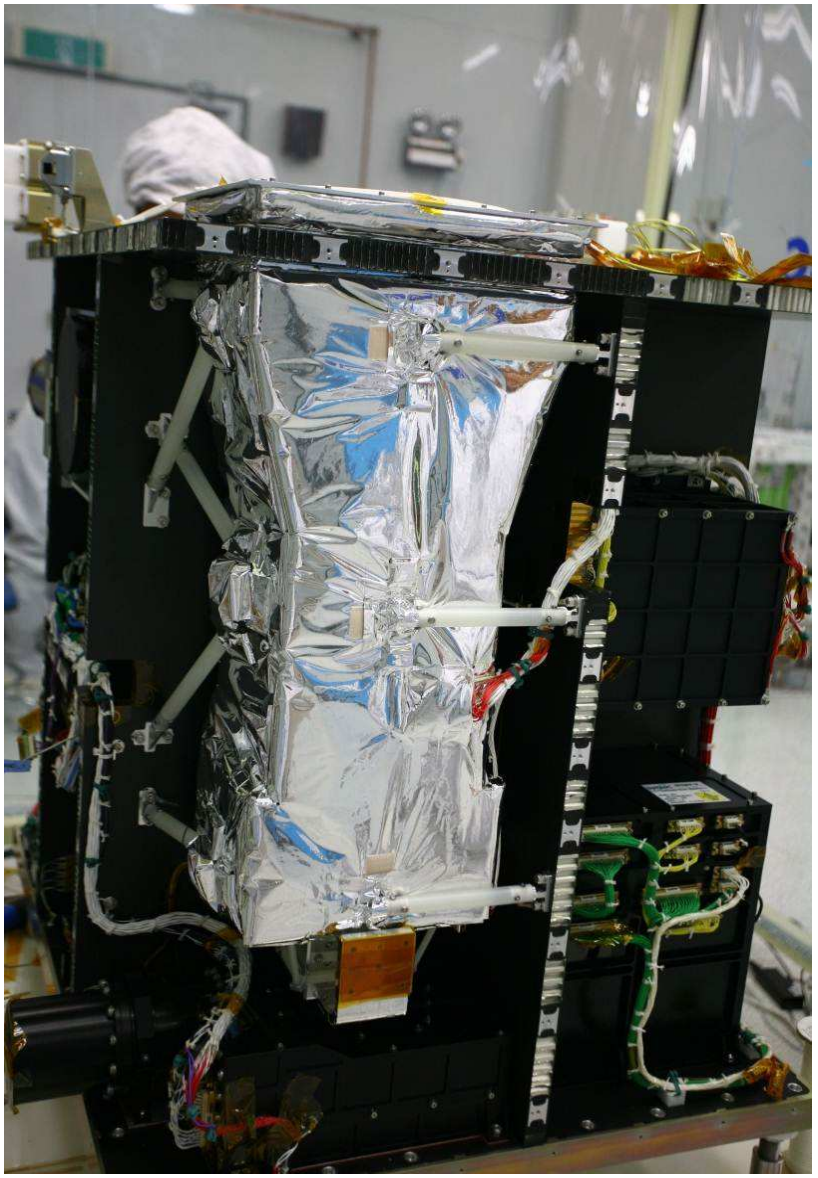
FM Thermal-Vacuum Test

- SOC FM Thermal Vacuum Test & setup



Integration & Test – Assembly



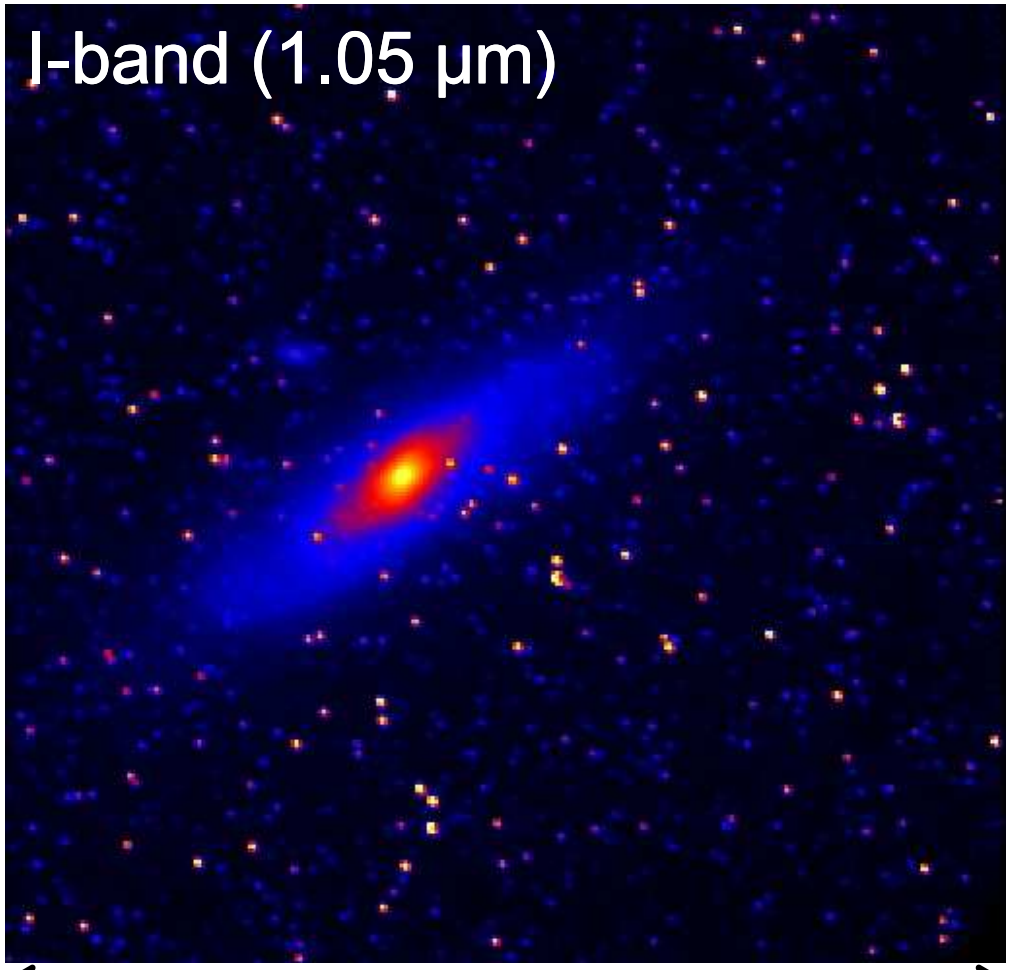


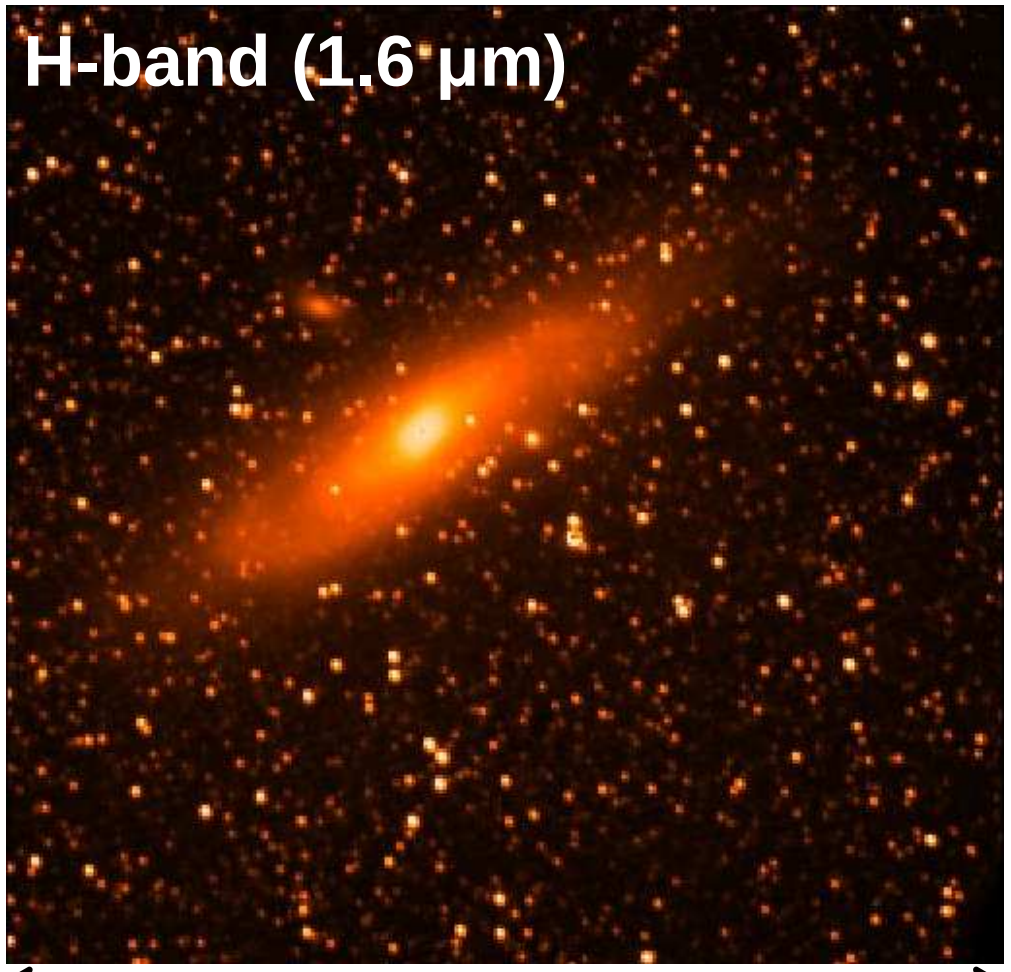
Launch & Early Operation

Launch Campaign

MIRIS First Light

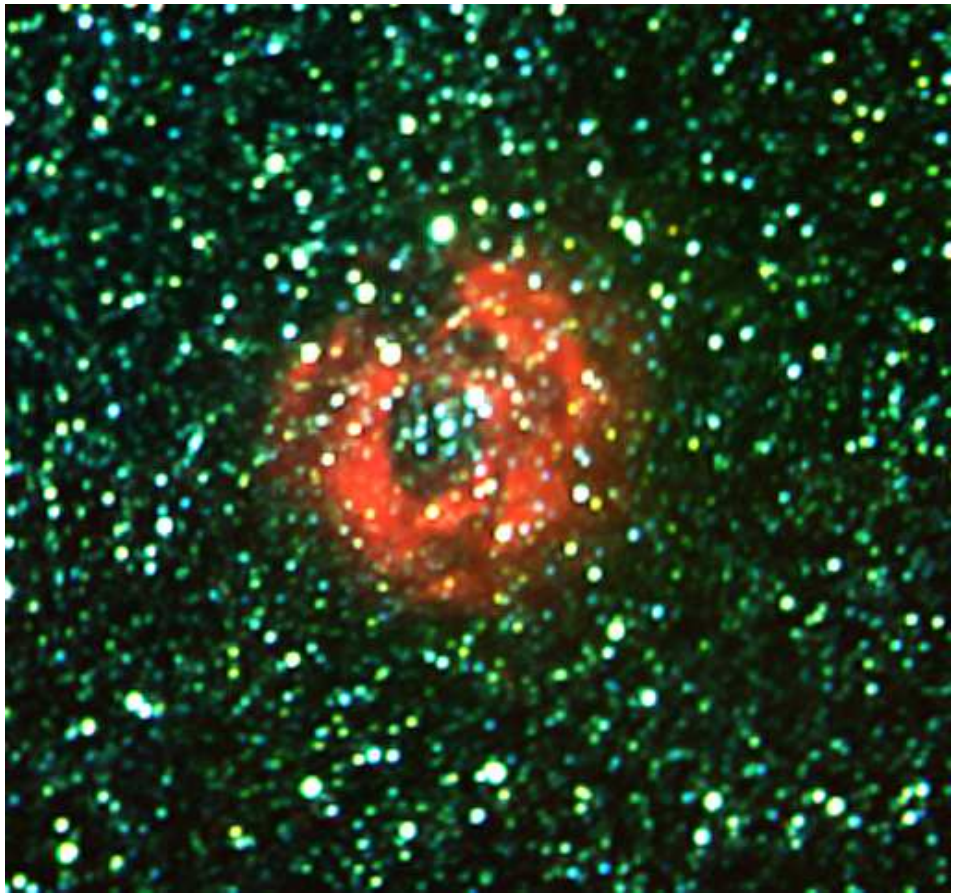
- SOC Imaging: Andromeda Galaxy (2013. 12. 17)





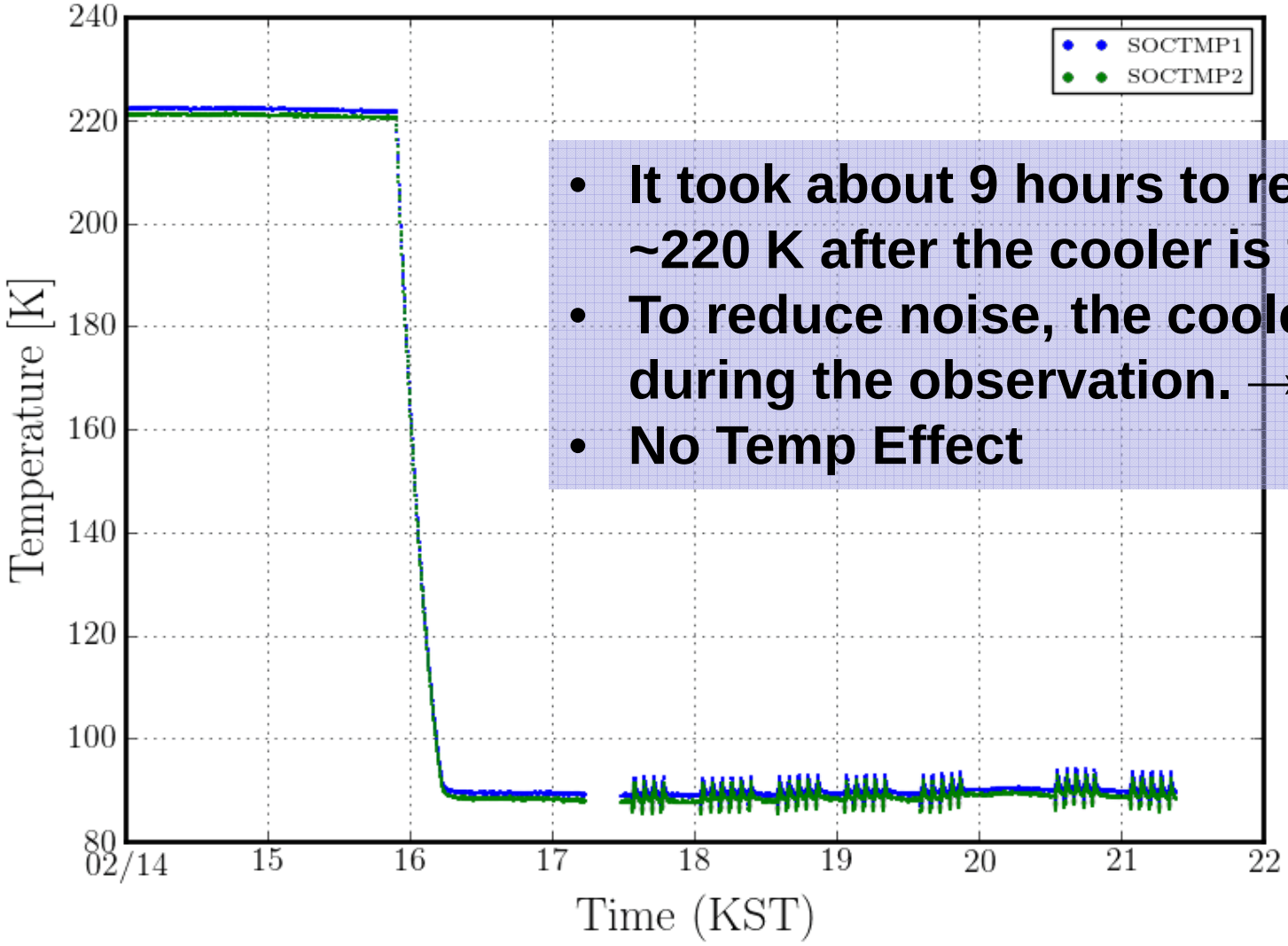
MIRIS First Light

- SOC Imaging: Rosette Nebula (2013. 12. 23)



Passive Cooling

- SOC Detector Temperature



- **It took about 9 hours to reach ~90 K from ~220 K after the cooler is turned on.**
- **To reduce noise, the cooler is turned off during the observation. → Δ*T* ~ 3 K**
- **No Temp Effect**

Initial Performance

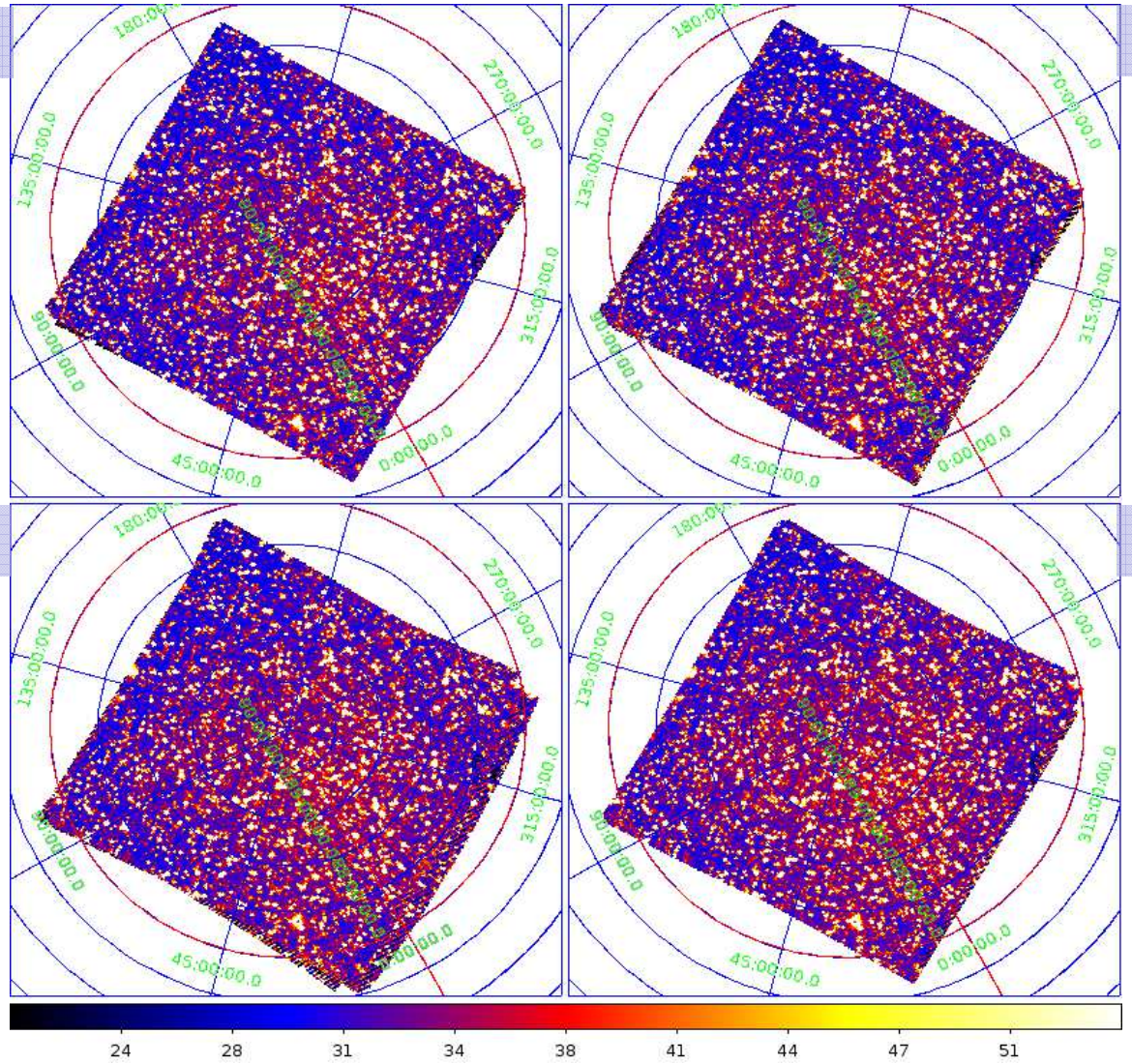
- IR Imaging: North Ecliptic Pole (2014. 1. 17, I-band)

Exposure 1.5 sec

Exposure 2.0 sec

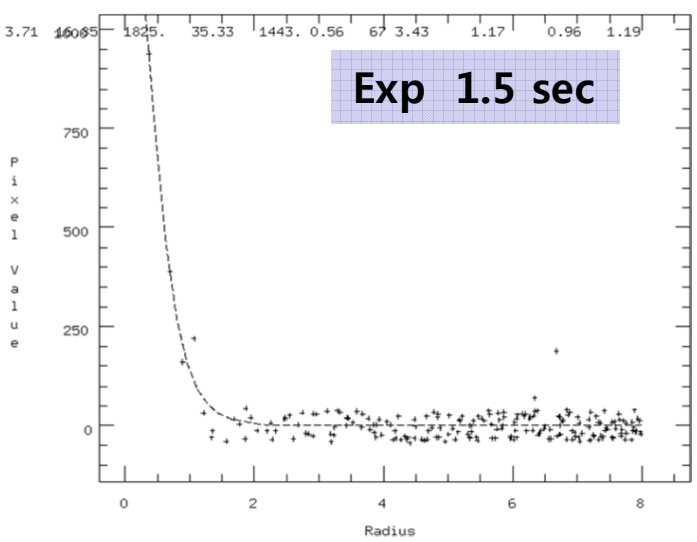
Exposure 3.0 sec

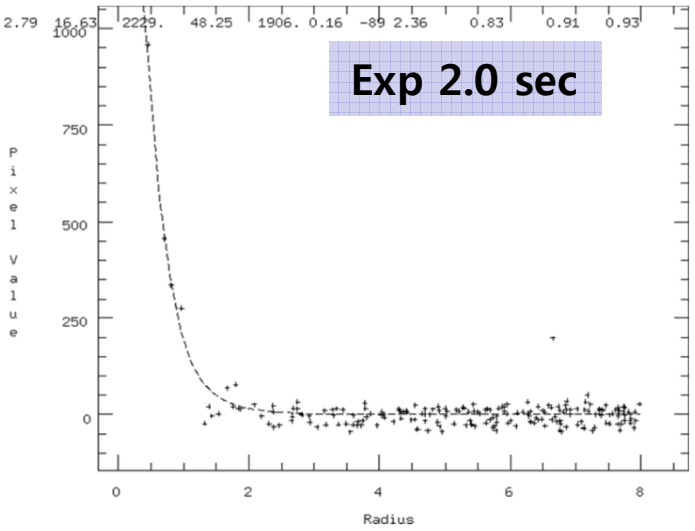
Exposure 5.0 sec

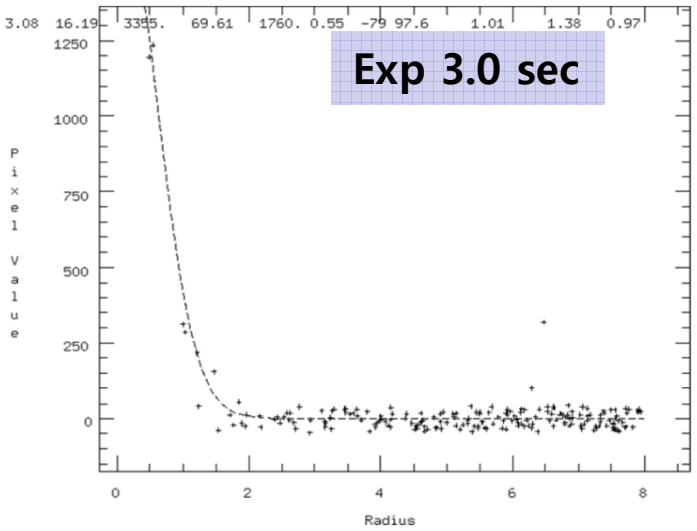


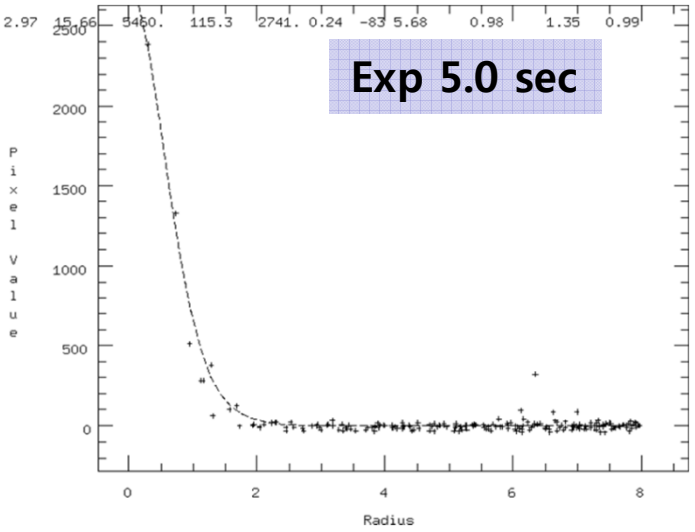
Performance & Enhancement

- SOC Imaging: Radial Profile of Stars









Exposure	FWHM
1.5 s	1.19 pixels
2.0 s	0.93 pixels
3.0 s	0.97 pixels
5.0 s	0.99 pixels

→ Indicate Good Pointing Accuracy of the Satellite

MIRIS : Main Sciences

Main Sciences

- Cosmic Infrared Background Radiation
  - Measure the absolute background blightness and fluctuation
- Paα Emission Line of the Galaxy
  - Study WIM (Warm Ionized Medium)
  - Compare Paα with Hα and Far-IR Data

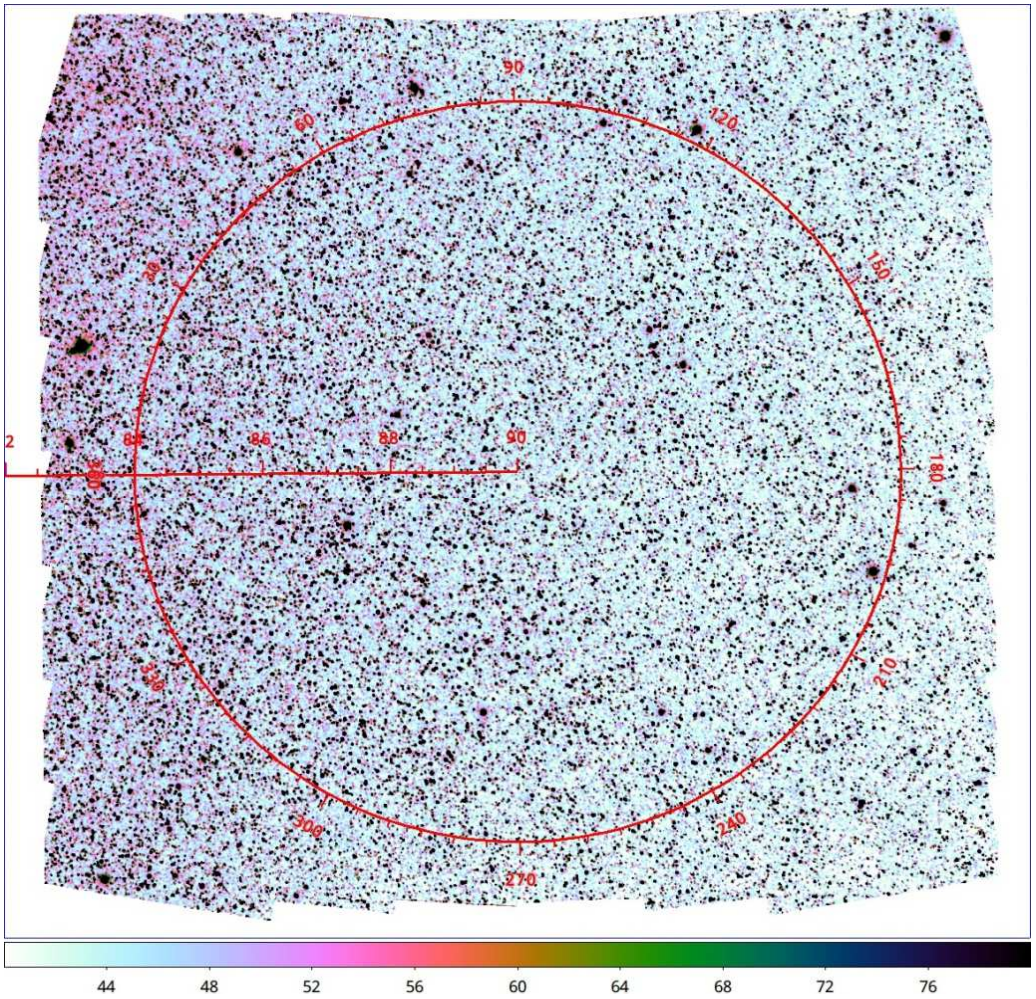
Cosmic Infrared Background

- Targets: North Ecliptic Pole (NEP)
  North Galactic Pole (NGP)
  South Galactic Pole (SGP)
- 7×7 pointing observations with 50% overlap
  → 4 times observations of ~10°×10° area
- Wavelengths: *I* - and *H* -bands
- Observe for 8 minutes for each band (2 sec, 200 Frm)
  (effective exposure: 6.5 minutes due to Reset)
- Additional observations: NEP Monitoring (1 field)
- Observe NEP every two days (*I* - and *H* -bands)
- Can be used to study zodiacal light and for instrument calibration

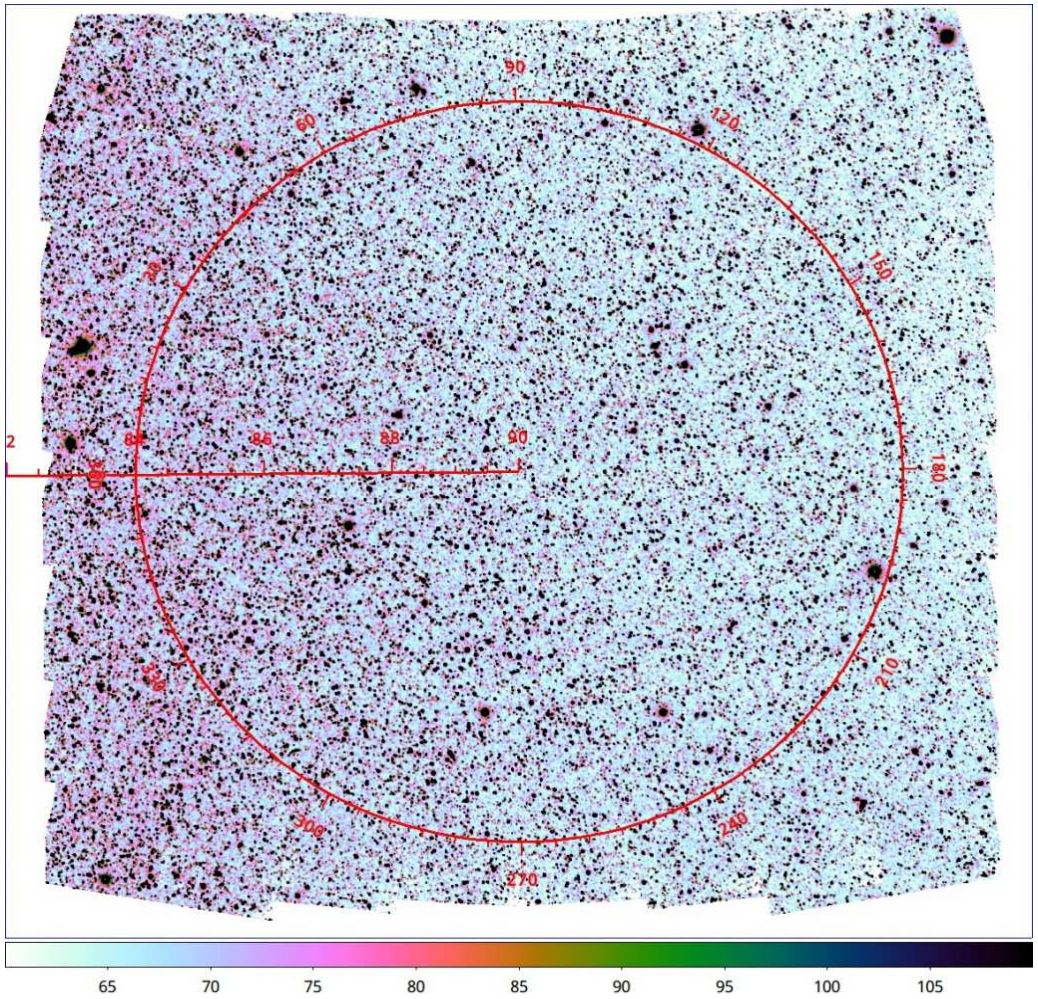
Cosmic Infrared Background

- NEP Wide Field Observations (2014. 3.)

I-band



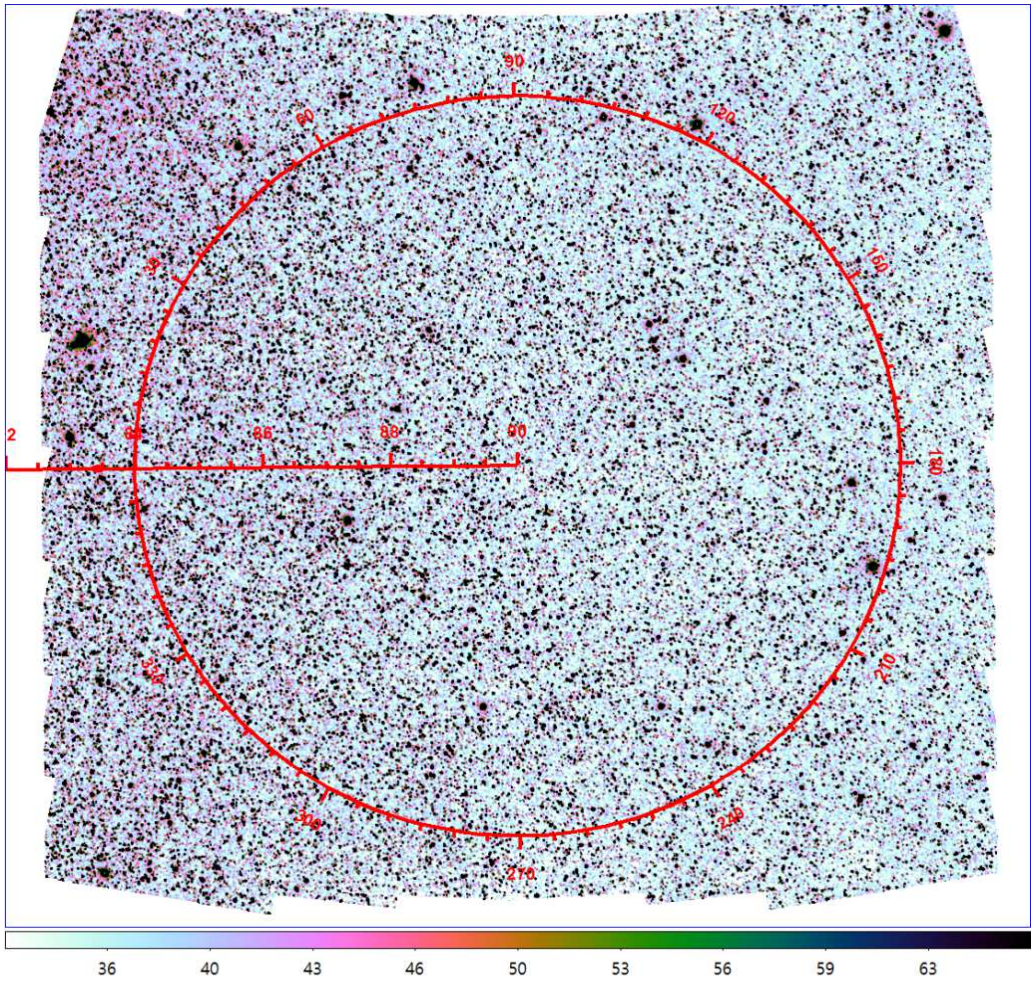
H-band



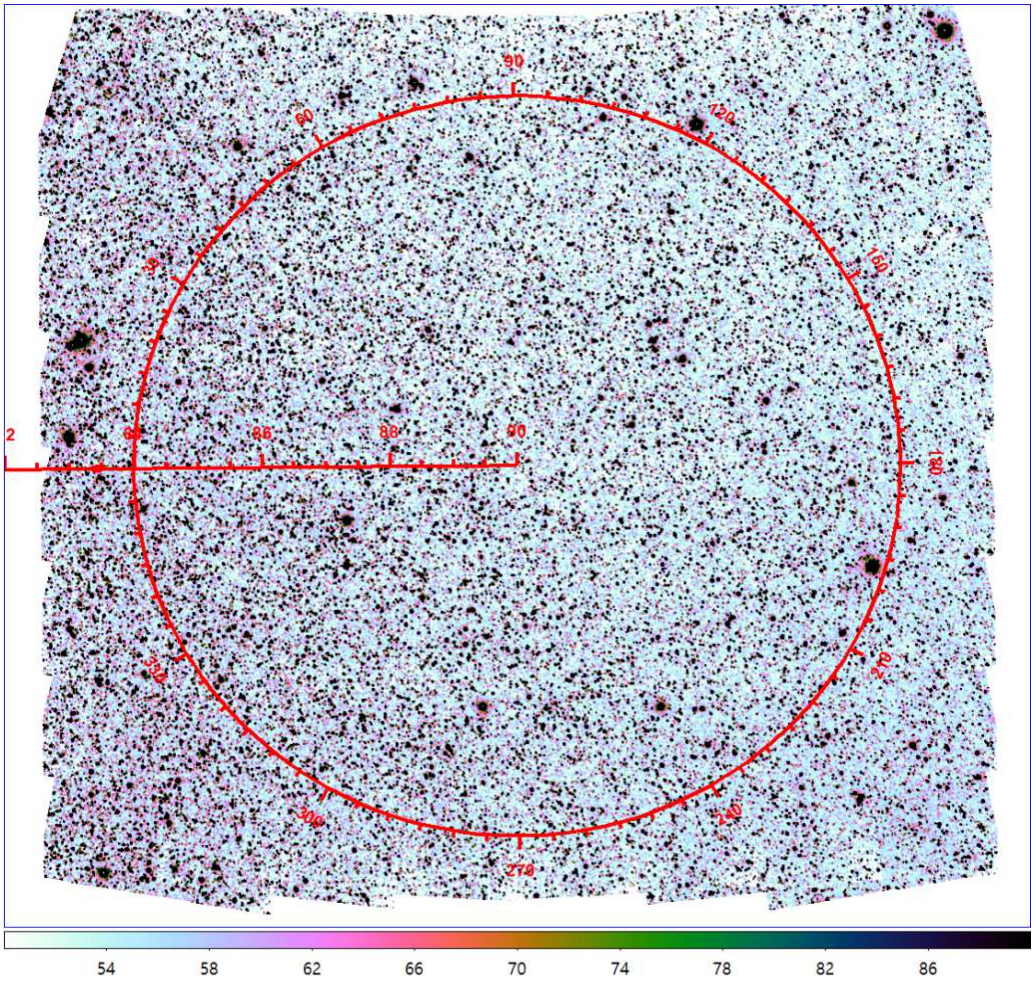
Cosmic Infrared Background

- NEP Wide Field Observations (2014. 9.)

I-band



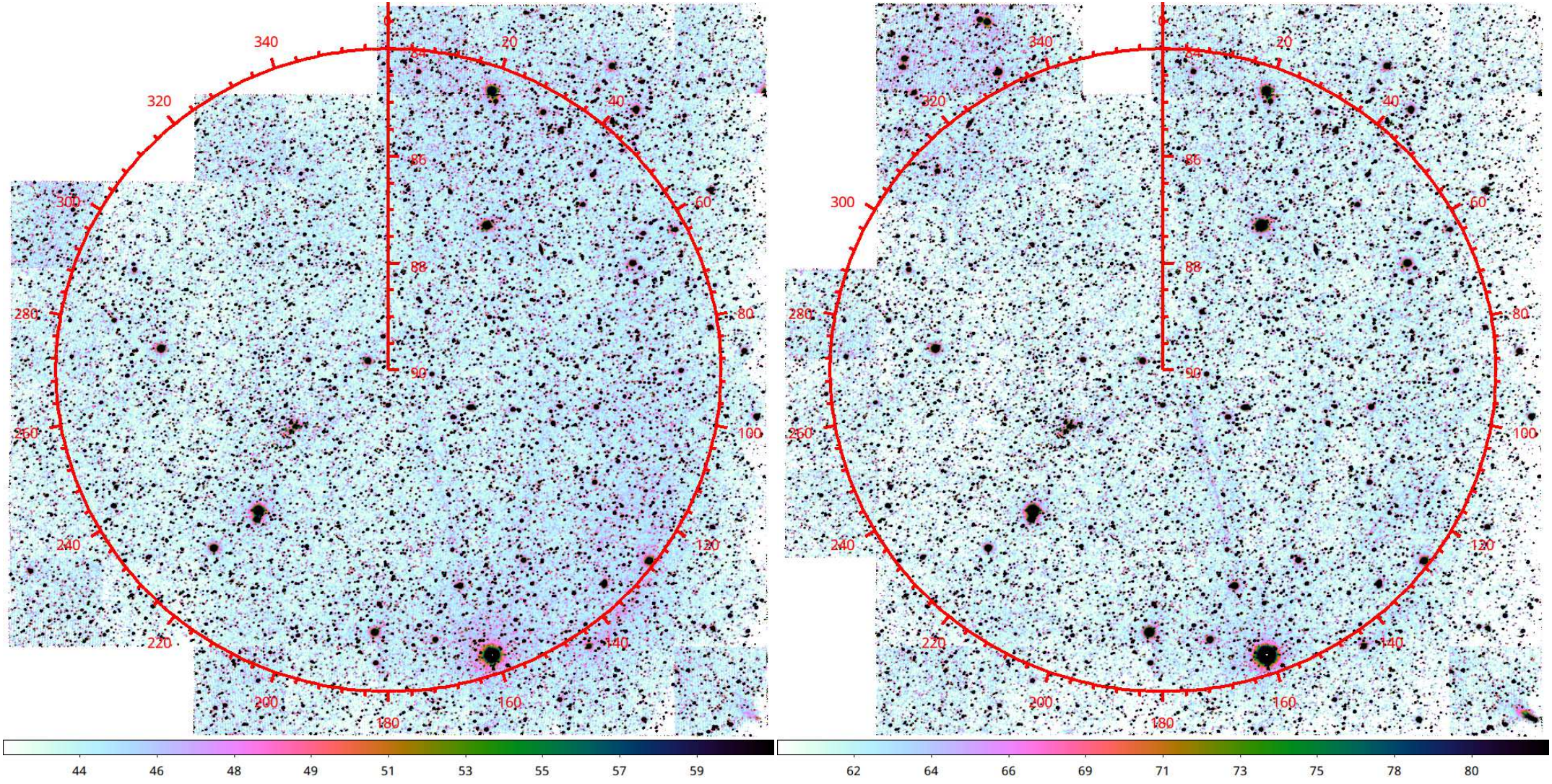
H-band



STSAT-3

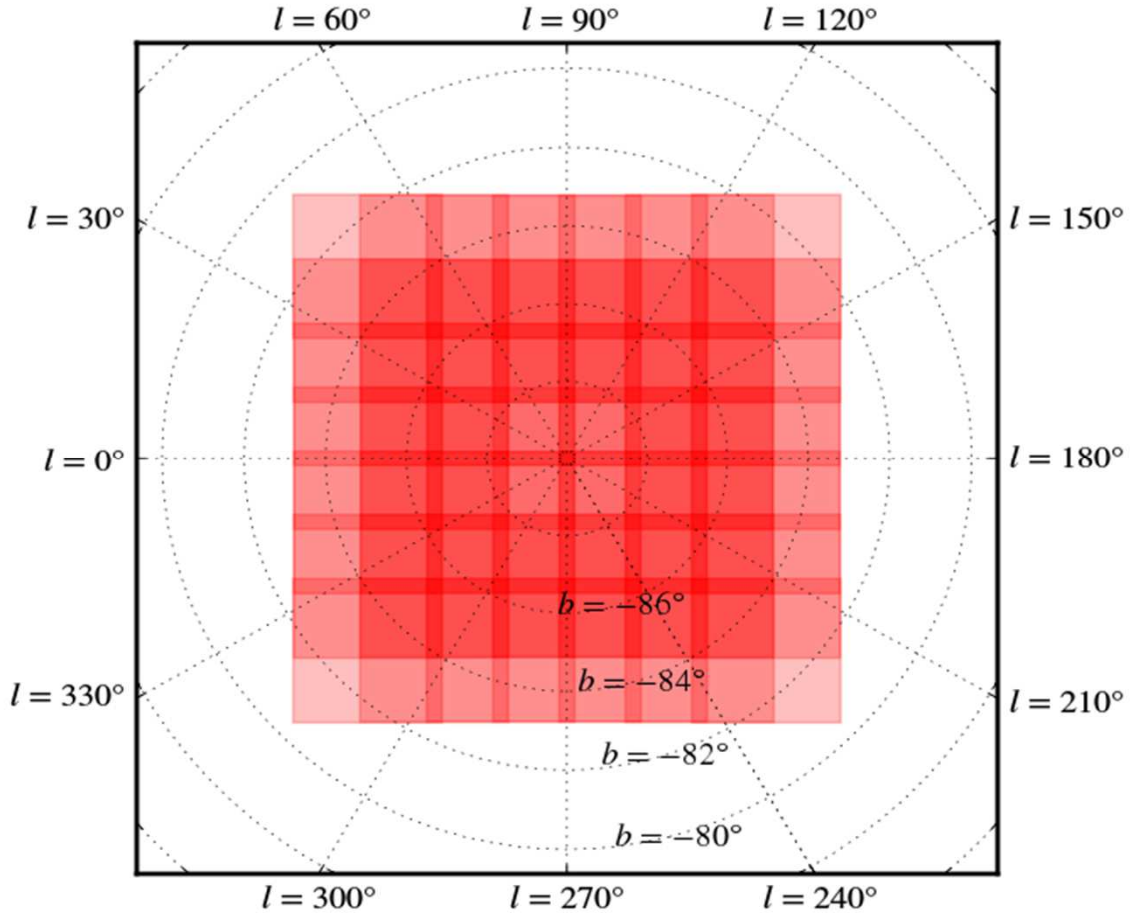
Cosmic Infrared Background

- NGP Wide Field Observations (2014. 3.)



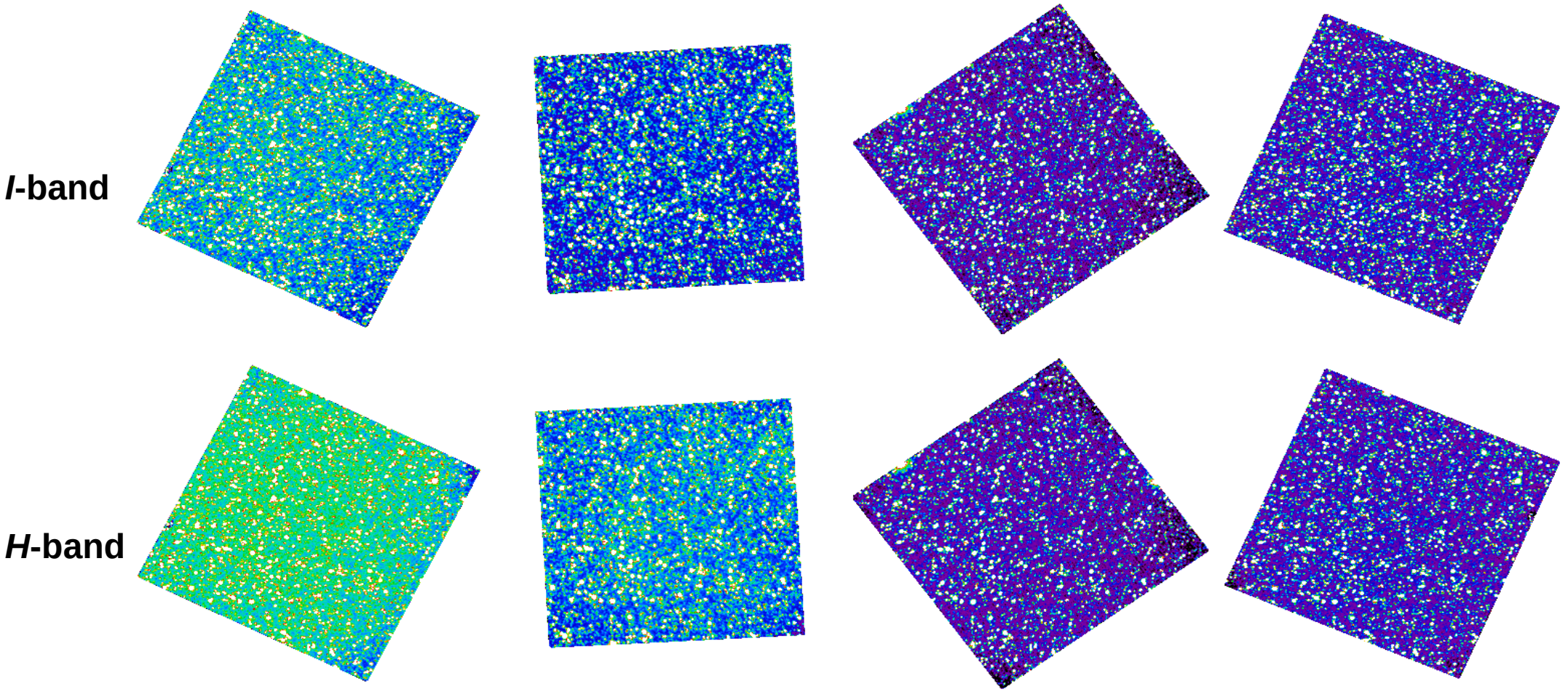
Cosmic Infrared Background

- South Galactic Pole, Wide Field Observations (2014. 10.)



Cosmic Infrared Background

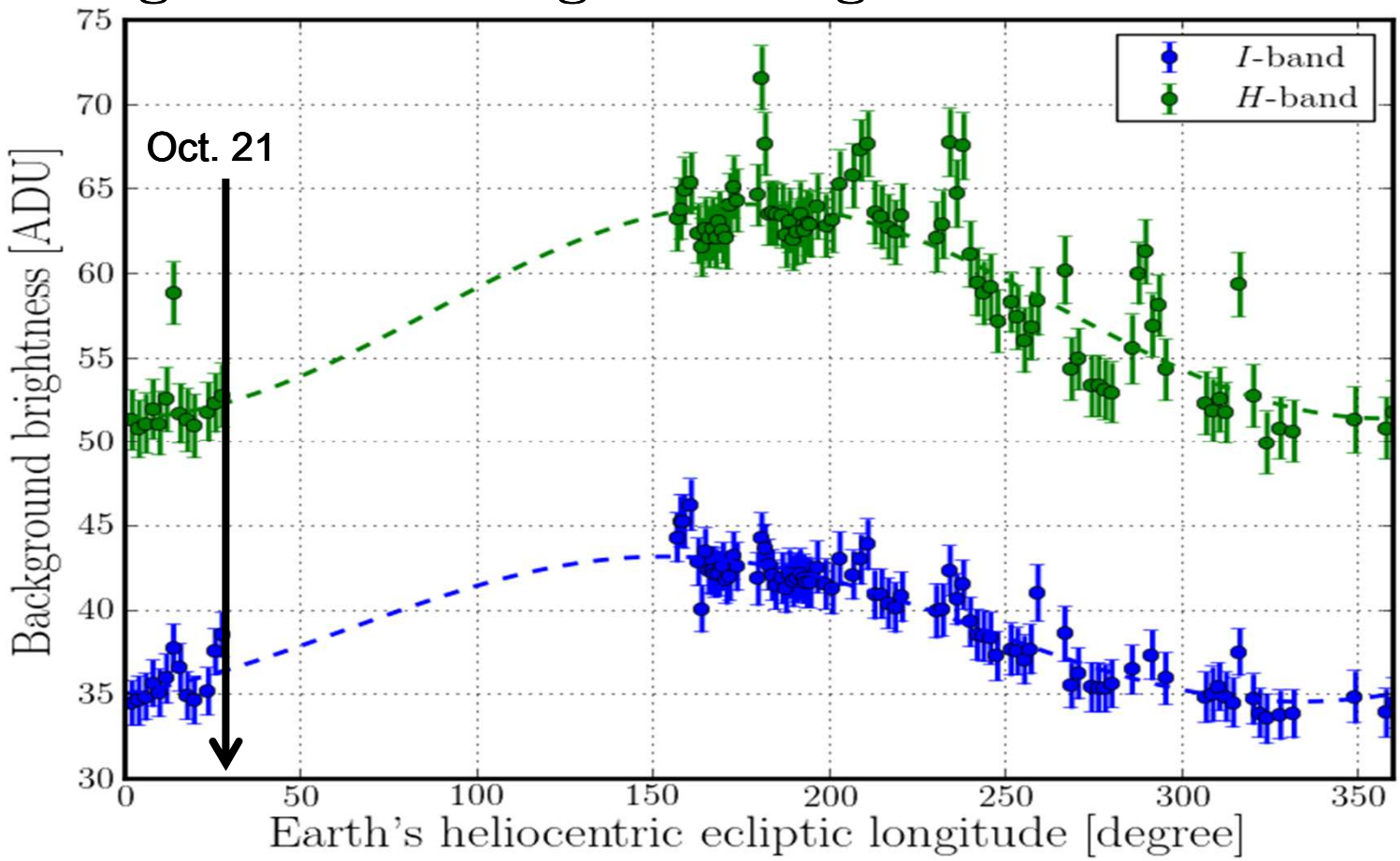
- North Ecliptic Pole Monitoring Observations



Cosmic Infrared Background

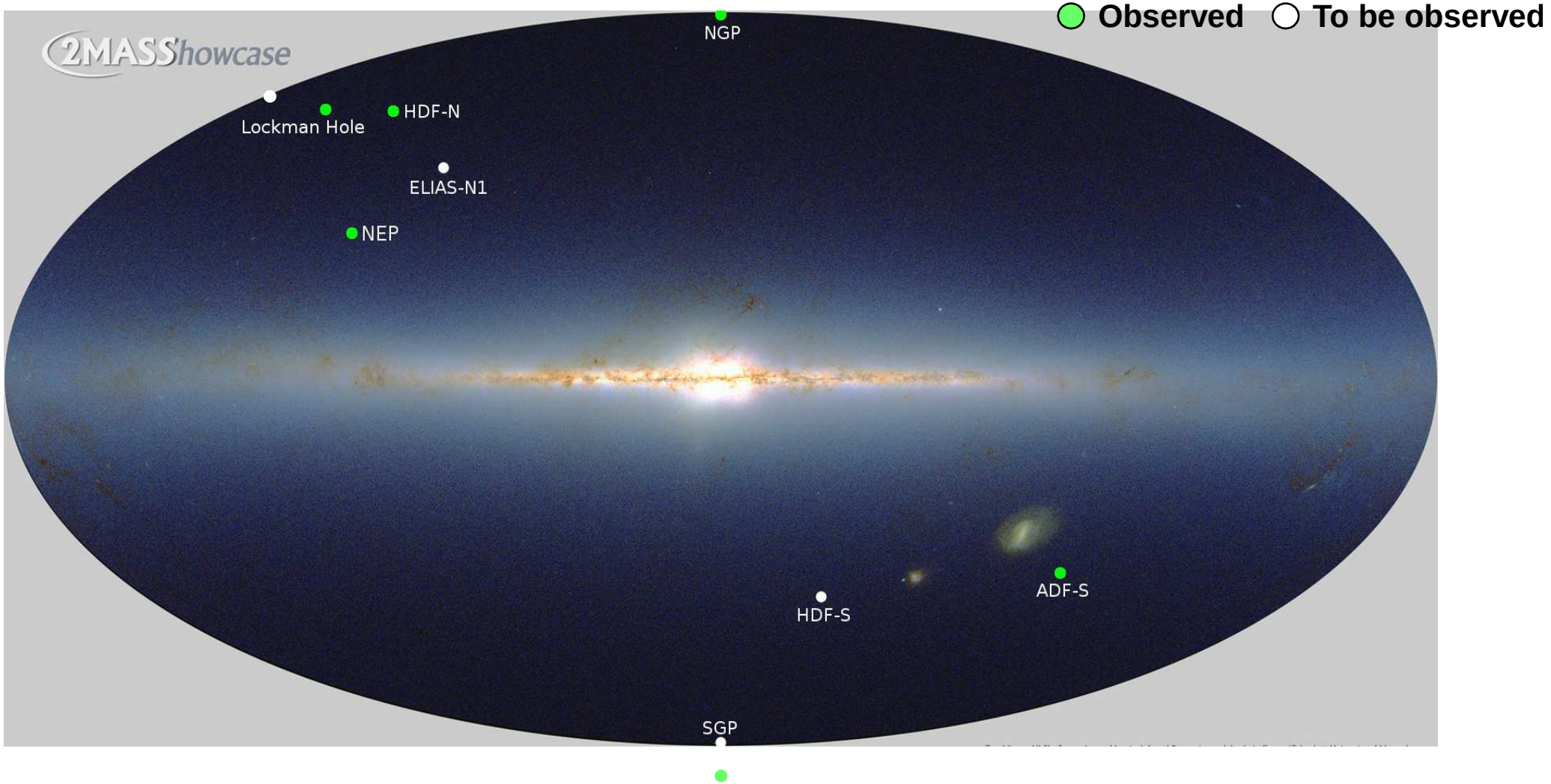
- NEP Monitoring Observations

Change of NEP background brightness due to zodiacal light



Cosmic Infrared Background

- Observations of Deep Sky Fields



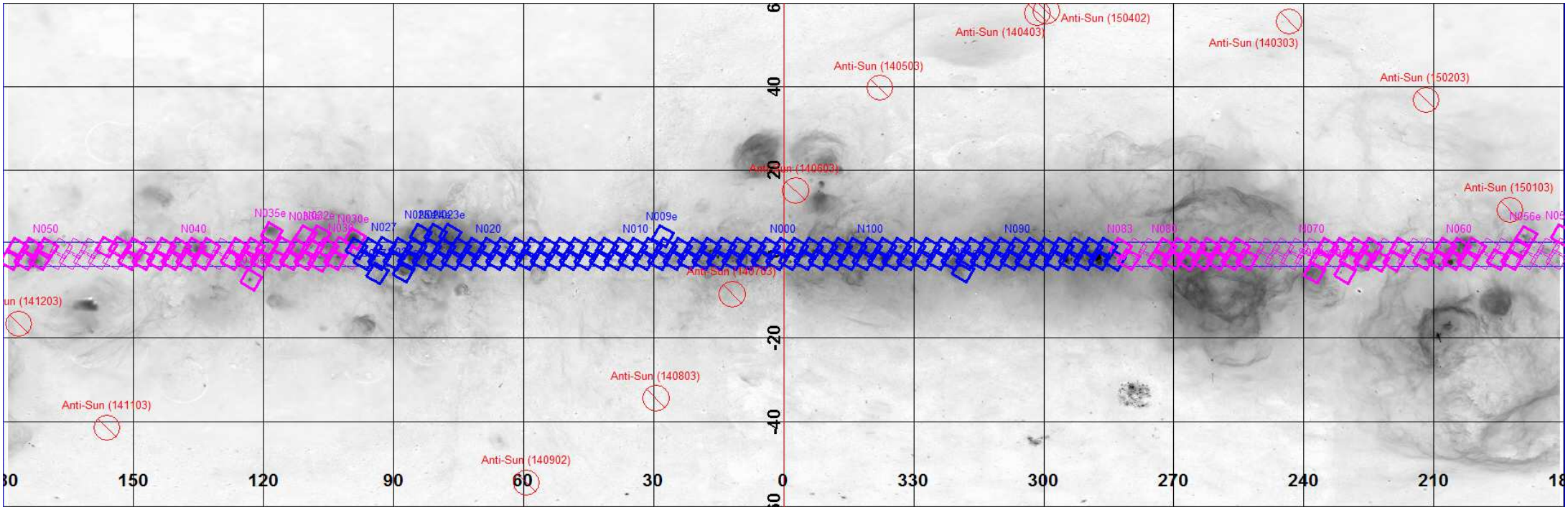
Paα emission observations

1. Galactic Plane Survey

◆Cover 360°along Galactic plane within −3°< b < +3°.

◆Total 228 fields : 106 north fields + 106 south fields + 16 extended.

◆Effective exposure : ~20 minutes (3 orbits) per field per filter



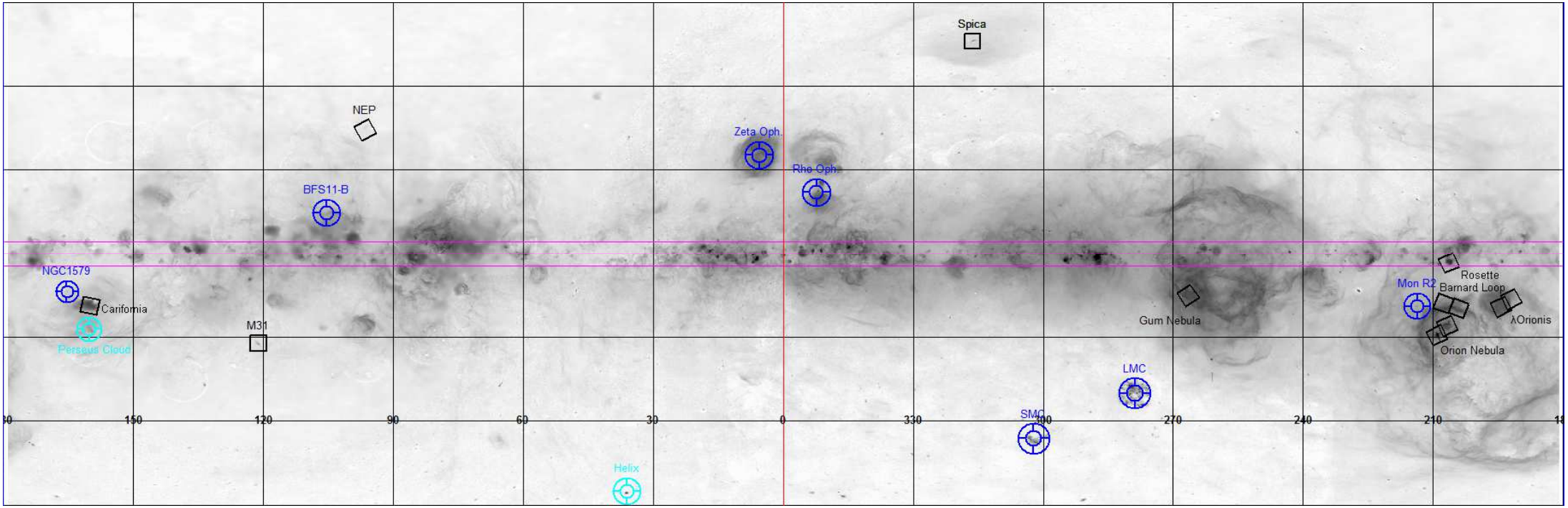
◆2014 Apr.-2014 Aug. : l = −80°to +100° (observed).

◆2014 Nov.-2015 Apr. : l = +100°to +280° (in observation).

Paα emission observations : Plan

2. Additional Pointing Observations

◆Select some interesting targets in the high galactic latitude.



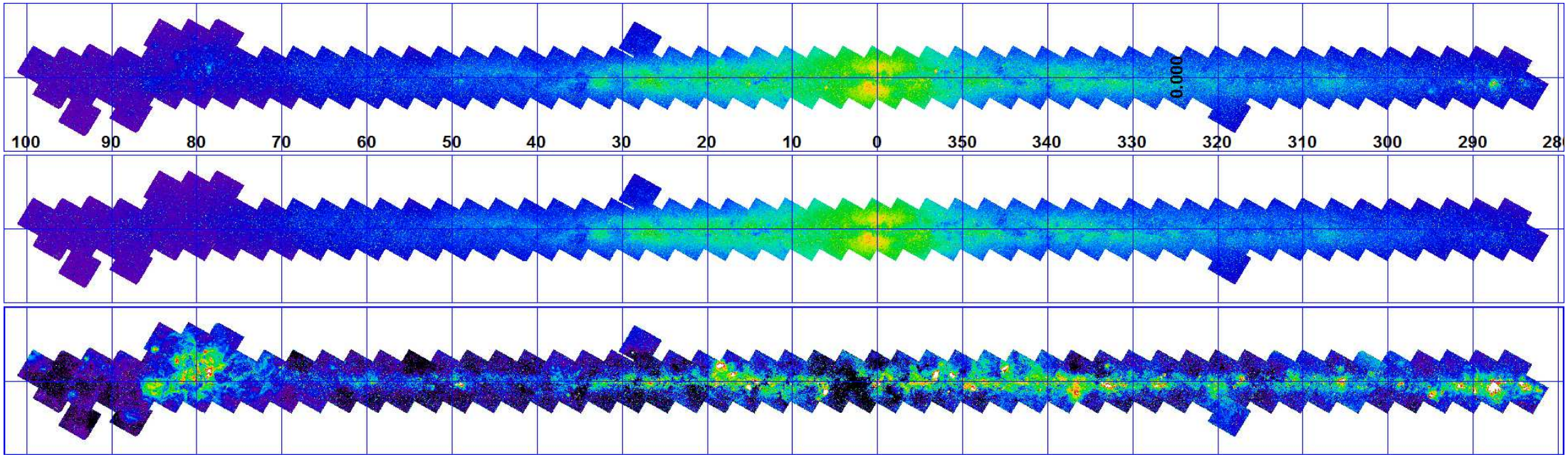
◆2013 Dec.-2014 Feb. : total 12 fields **(observed).**

◆2014 Apr.-2014 Aug. : Zeta Oph., Rho Oph., SMC, LMC **(observed).**

◆2014 Nov.-2015 Mar. : BFS11-B (Star Forming Molecular Cloud), NGC1579, Mon R2.

Paα emission observations : Early Results

1. Galactic Plane Survey



MIRIS PAAL filter image

MIRIS PAAC filter image

MIRIS Paα emission line (PAAL-PAAC) image

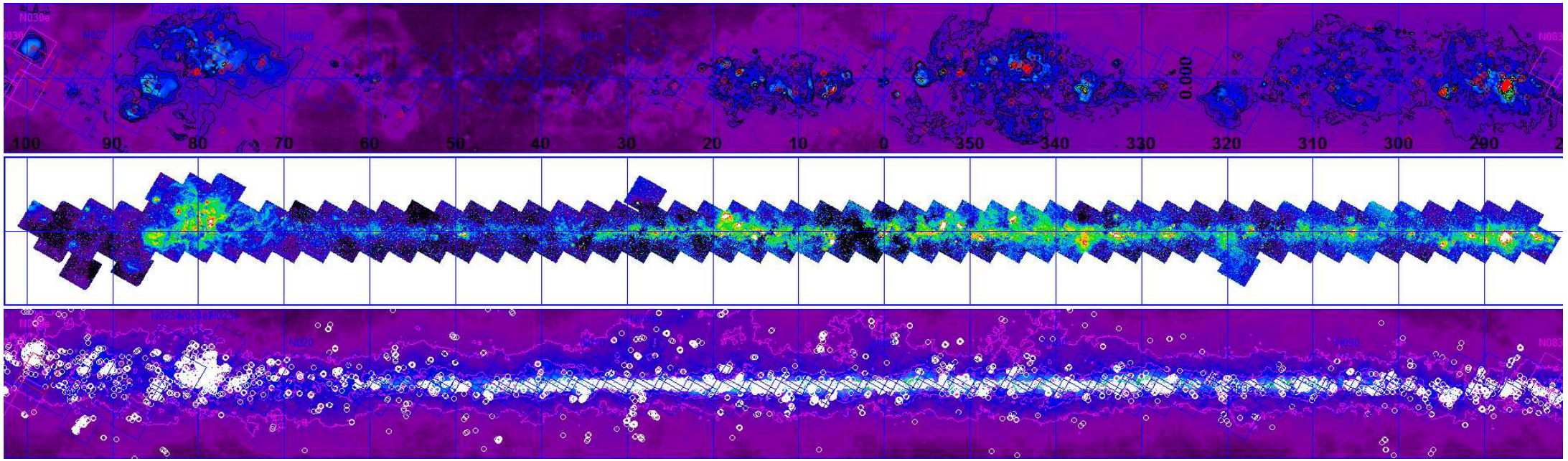
◆Paα emission line image was made using fixed scale factor (0.55) subtraction :

PAAL - 0.55 × PAAC (NEP Obs calculated, PAAL/PAAC Filter Ratio).

◆incompletely processed images : no removal of detector background, no on-orbit flat field correction, no flux calibration.

Paα emission observations : Early Results

1. Galactic Plane Survey



Hα image (Finkbeiner, 2003, ApJS, Ground Obs)

MIRIS Paα emission line (PAAL-PAAC) image (This Paper)

FIR + IRAS, SFD E(B-V) (Schlegel et al. 1998)

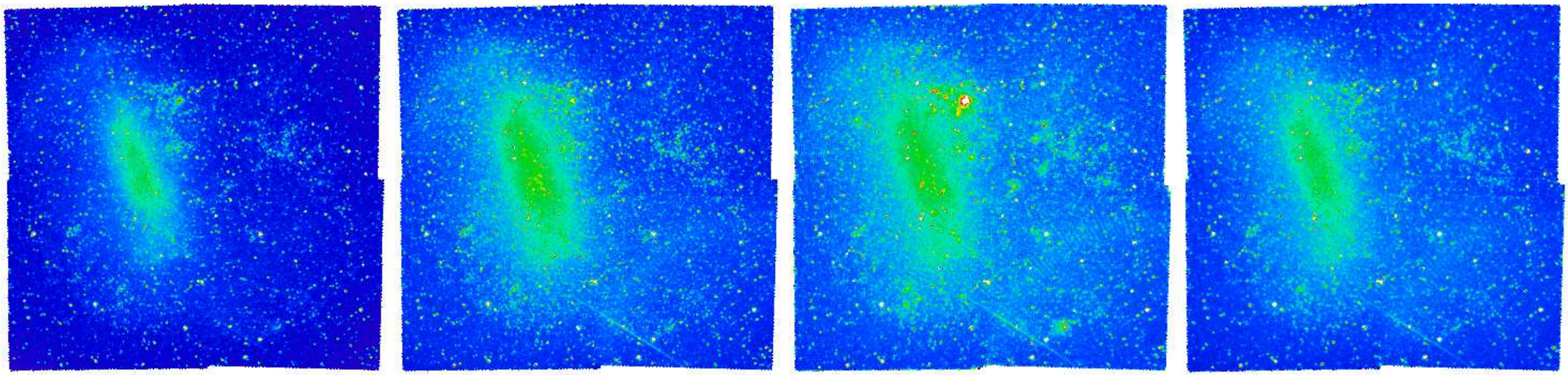
◆Many of detected Paα features are brighter than predicted by the Hα observations (some of them are invisible in Hα).

◆Bright Paα blobs coincide well with dense cloud regions (Star Forming Cloud).

Paα emission observations : Early Results

2. Additional Pointing Observations

◆One sample result : LMC (7°×7° Field) : Well Known Star Forming Region



MIRIS I H PA-AL PA-AC filter images

◆Cover the whole LMC (Large Magellan Cloud) region with 4 field observations.

◆I & H filter : 1 orbit observation per field.

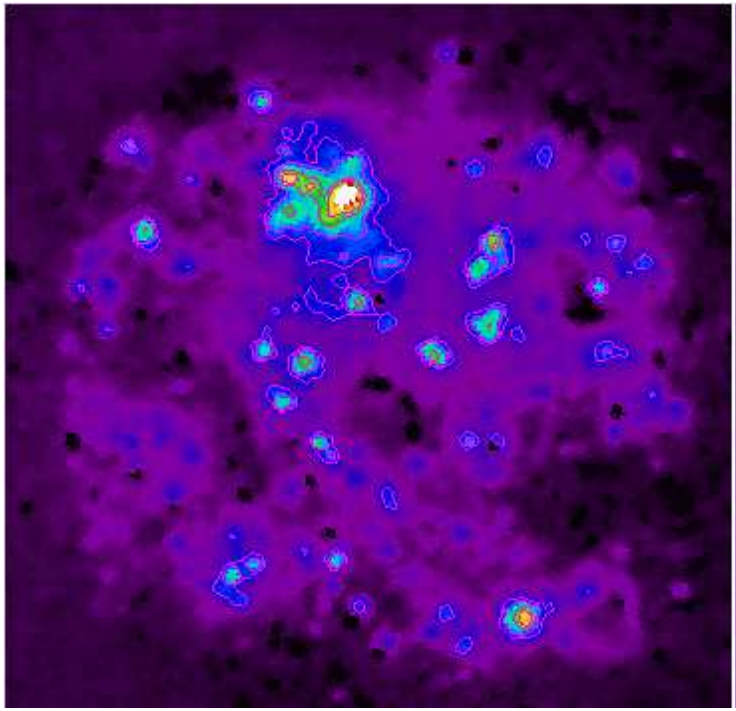
◆PAAL, PAAC filter : 5 orbits observations per field.

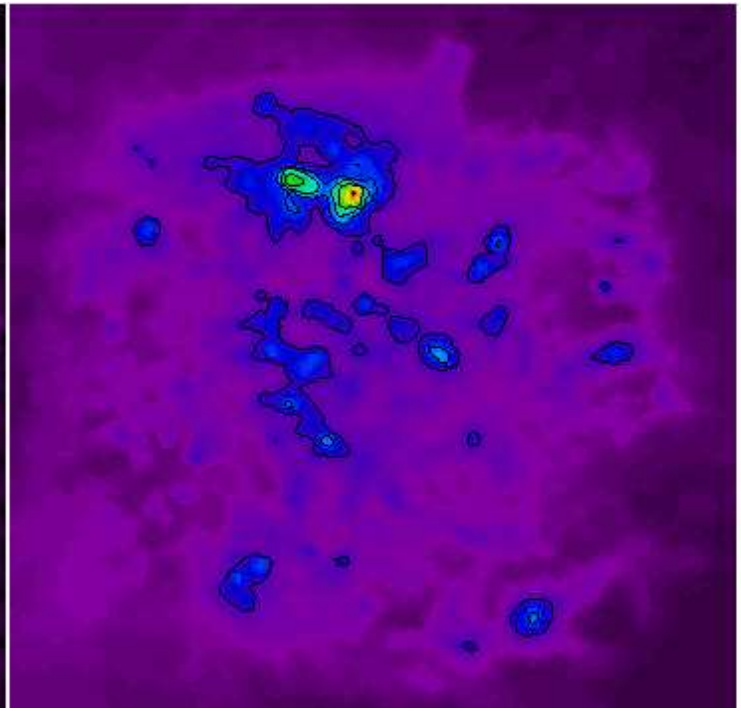
◆incompletely processed images : no removal of detector background, no on-orbit flat field correction, no flux calibration.

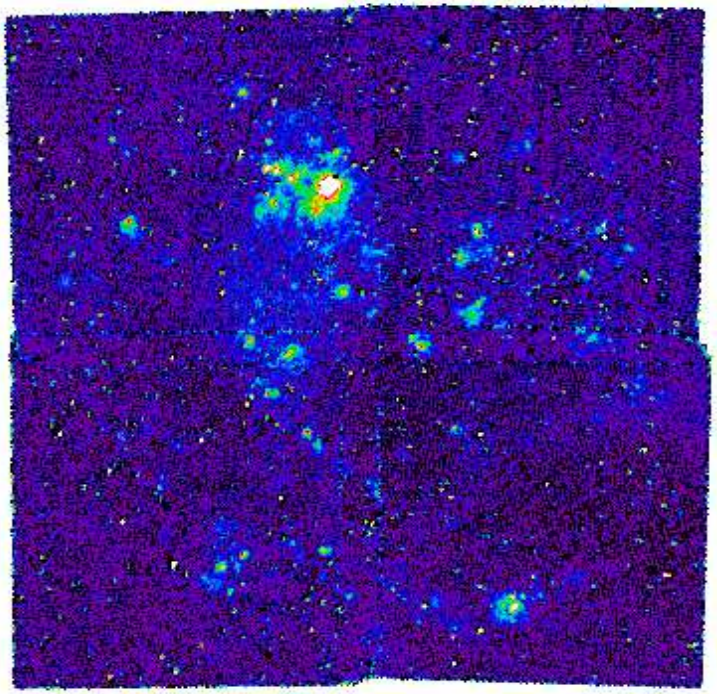
Paα emission observations : Early Results

Additional Pointing Observations

◆One sample result : LMC







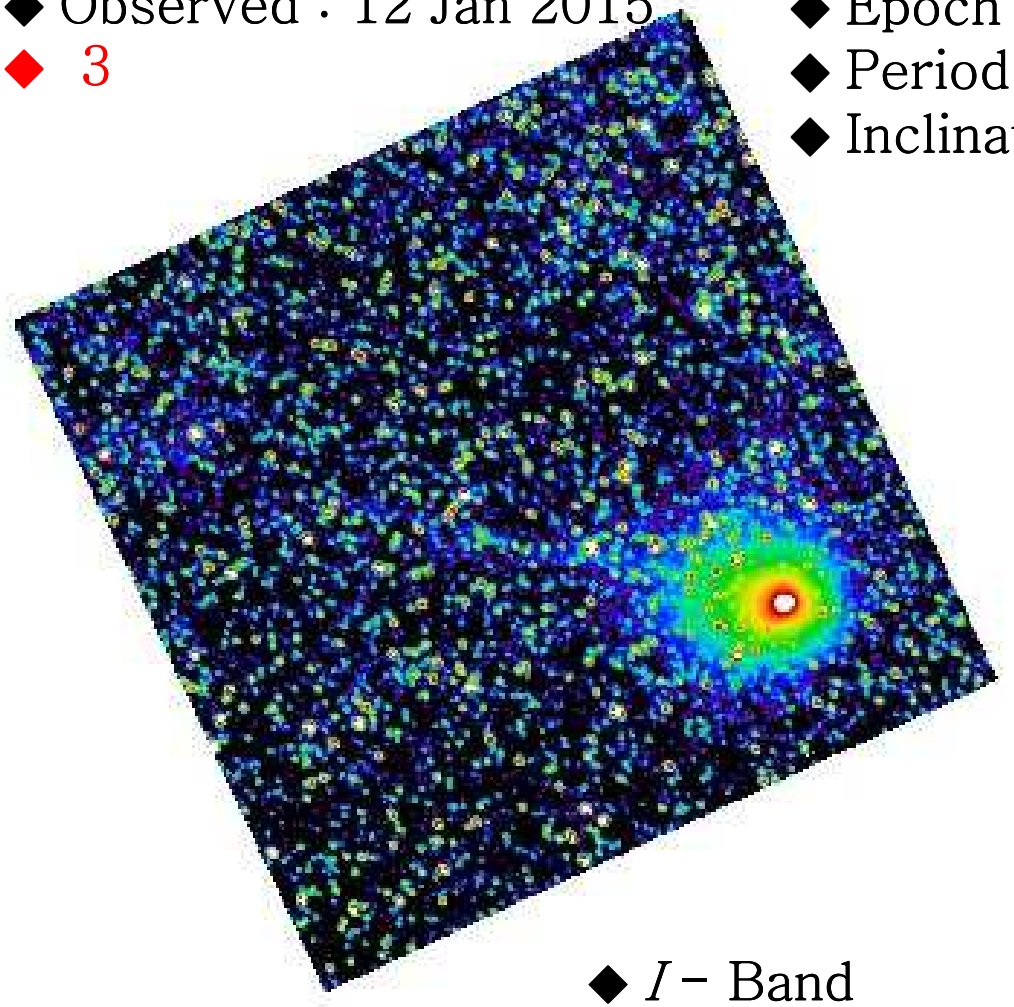
Hα image (Finkbeiner, 2003) SFD E(B-V) (Schlegel et al. 1998) MIRIS Pa-α emission line (PAAL-PAAC) image

◆ We can see the similarities and differences depending on wavelengths

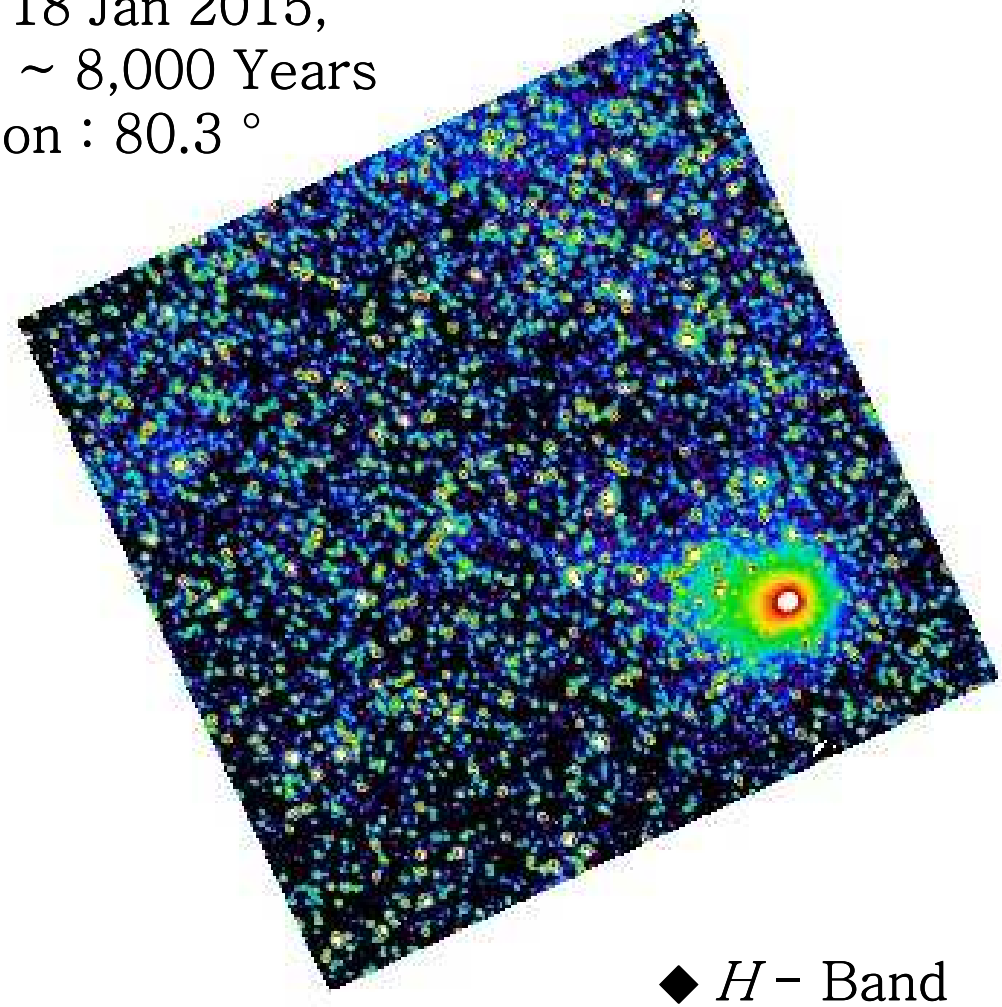
Comet /2014 Q2 (Lovejoy) : IR Images

◆ Observed : 12 Jan 2015
◆ 3

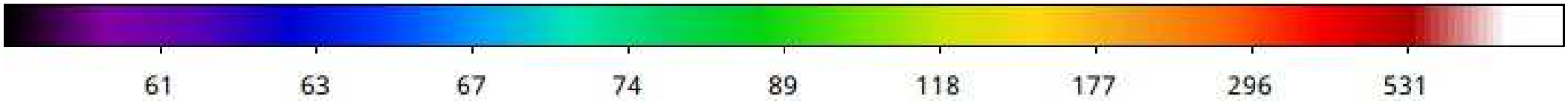
◆ Epoch : 18 Jan 2015,
◆ Period : ~ 8,000 Years
◆ Inclination : 80.3 °



◆ *I* - Band

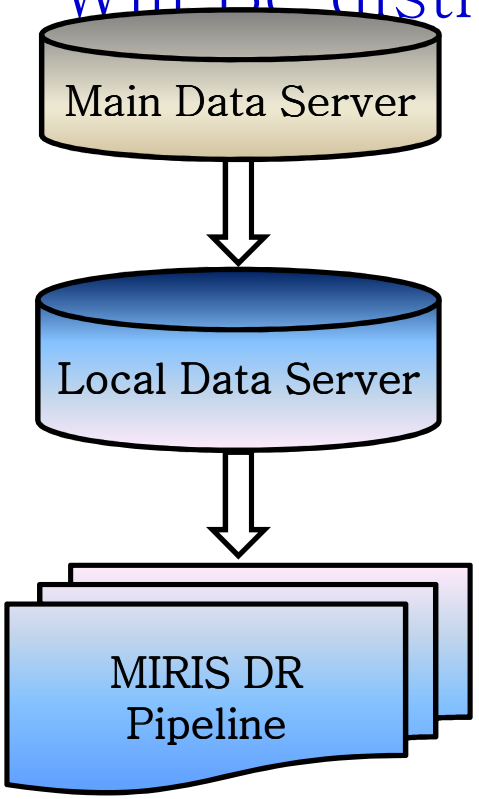


◆ *H* - Band



Data Distribution System

- MIRIS Data PipeLine
  - Data Reduction S/W Developed (with Lynux, Python)
  - Will Be distributed by KASI, Big Data Center



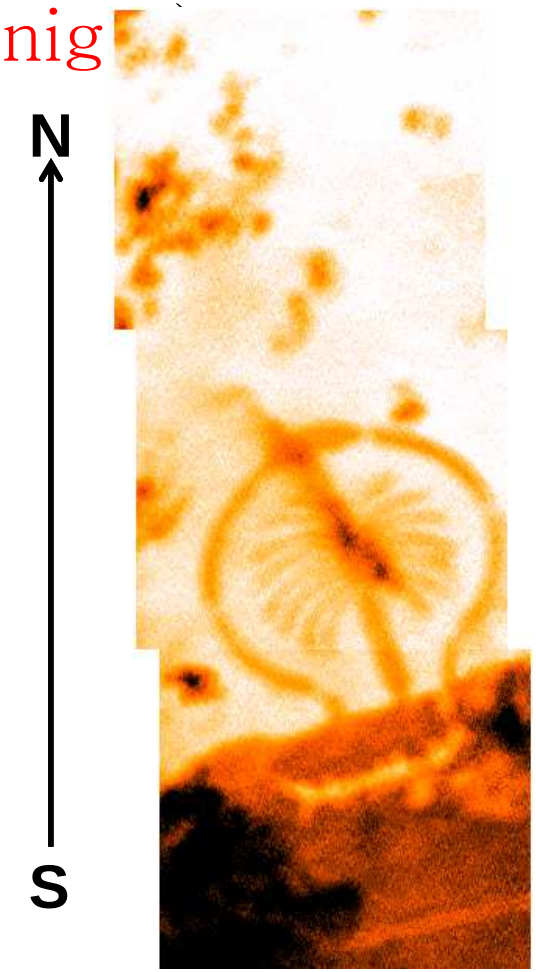
  - Main data server: Download Data from Satellte
  - Local data server (inside KASI)
    - Download from Main Server
    - Header Record Obs Info such as Obs Bands, Position
    - FITS Image produce
    - Register each database
  - MIRIS DR (Data Reduction) Pipeline: Image Production for Science Analysis

MIRIS Earth Obs Camera Images

◆ MIRIS Earth Observation Camera is a separate Infrared Imaging System using Korean IR Sensor.

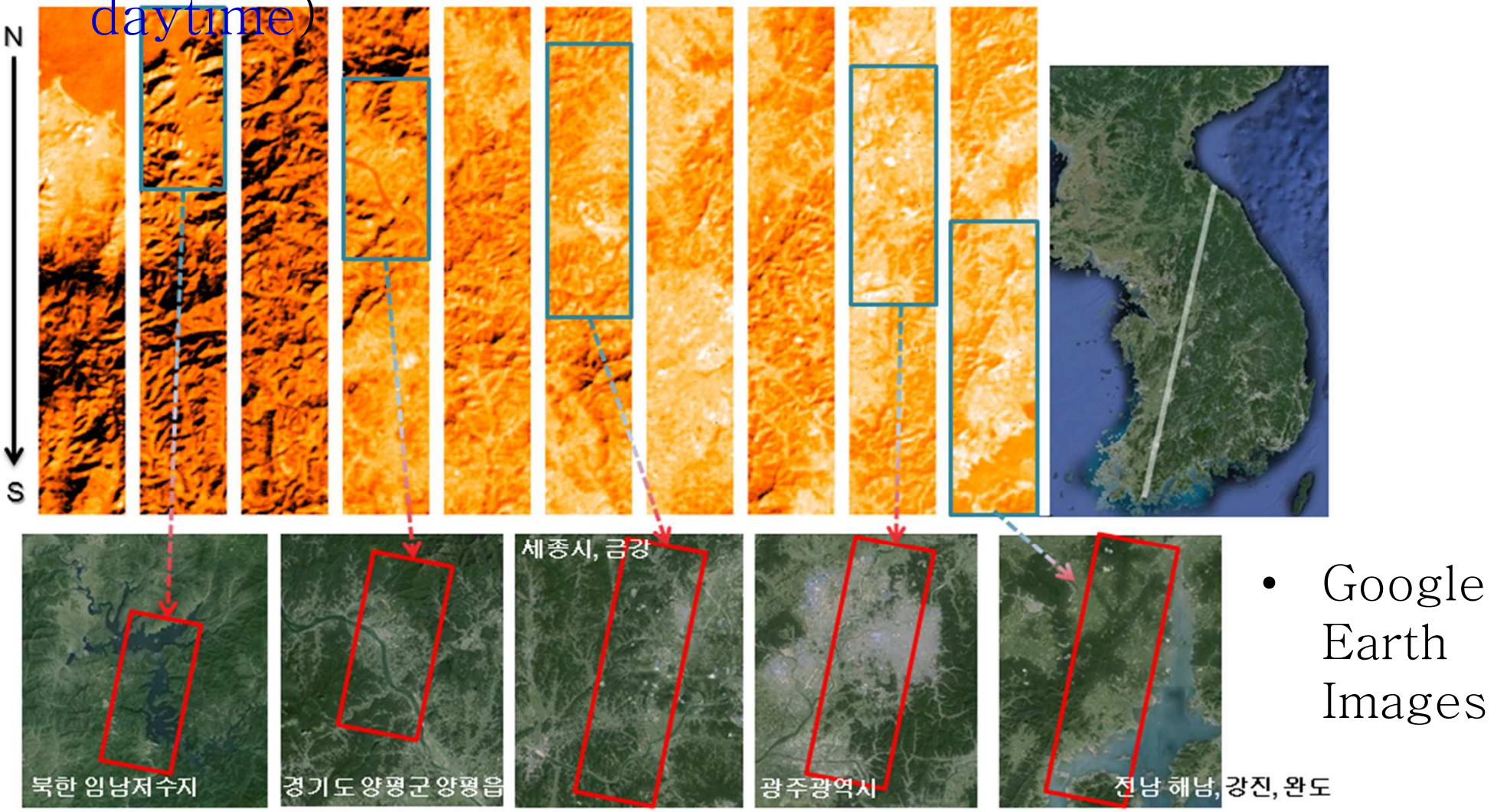
MIRIS EOC Images

- EOC Imaging: Palm Jebel Ali, Dubai (2014. 1. 31., nig



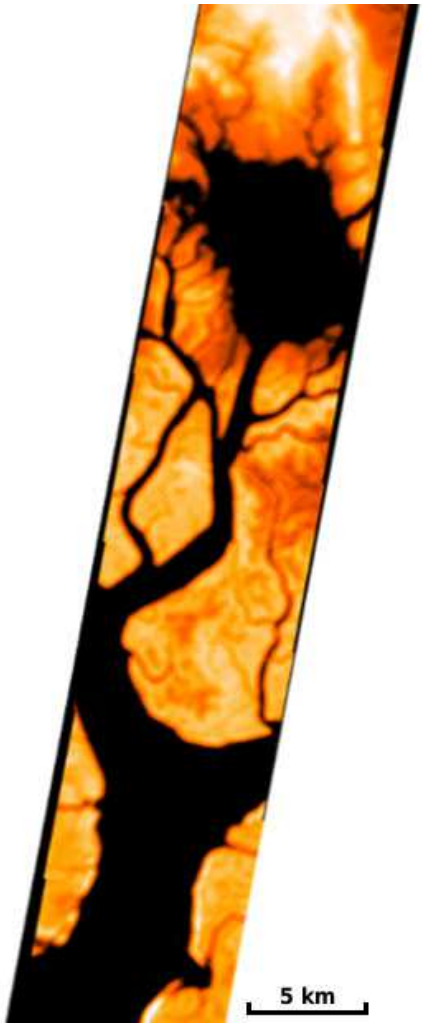
MIRIS EOC Images

- EOC Imaging: Korean Peninsula (2014. 1. 15, daytime)



- Google Earth Images

MIRIS EOC Images

- EOC Imaging: Creeks, Pakistan (2014. 1. 17, daytime)
  - 

  - 
  - Google Earth Images

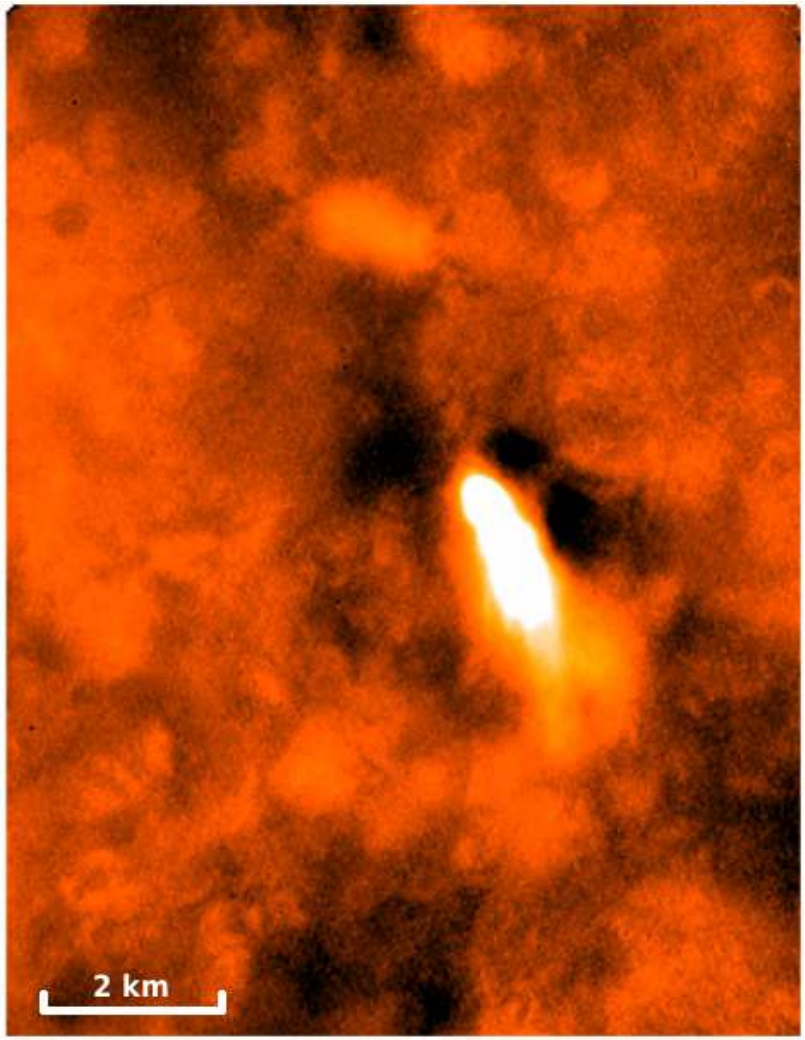
MIRIS EOC Images

- EOC Imaging: Gangwhado, Korea (2014. 1. 31, nightime)

- Google Earth Images

MIRIS EOC Images

- EOC Imaging: Volcano, Mt. Sinabung, Indonesia (2014. 2. 4., night)



Future Plans for Science Obs

- Follow-Up Observation of Deep Sky Fields
  - Lockman Hole
  - AKARI Deep Field South
  - Hubble Deep Field North / South
  - Elias Fields
  - North / South Galactic Poles
  - *etc.*

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→ Han *et al.*, Publ Astro Soc Pac, *Vol.* ,126, 2014 Sept

MIRIS: A Compact Wide-field Infrared Space Telescope

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ABSTRACT. A compact infrared space telescope called MIRIS (Multi-purpose Infra-Red Imaging System) was developed by the Korea Astronomy and Space Science Institute (KASI), and launched onboard the *Science and Technology Satellite-3* of Korea (*STSAT-3*) in 2013 November. The main mission of MIRIS is the Paschen-α emission line survey along the Galactic plane and the cosmic infrared background (CIB) observation, particularly around the north ecliptic pole region. For these missions, a wide field of view ($3.67 \times 3.67°$) with an angular resolution of $51.6''$ and wavelength coverage from $0.9 \sim 2.0$ μm have been adopted for MIRIS, having optical components consisting of a 80 mm main lens and four other lenses with F/2 focal ratio optics. The opto-mechanical system was carefully designed to minimize any effects from shock during the launch process and thermal variation. Also, the telescope was designed to use a passive cooling technique to maintain the temperature around 200 K in order to reduce thermal noise. A micro Stirling cooler was used to cool down the Teledyne PICNIC infrared array to 90 K, which was equipped in a dewar with four filters for infrared passbands of I, H, and Paschen-α and a dual-band continuum line filter. MIRIS system was integrated into the *STSAT-3* as its primary payload and successfully passed required tests in the laboratory, such as thermal-vacuum, vibration, and shock tests. MIRIS is now operating in sun synchronous orbits for initial tests and has observed its first images successfully.

1. INTRODUCTION

The *Science and Technology Satellite* (*STSAT*) program of Korea was established in 1999, mainly to encourage science programs in the fields of space astronomy, space physics, and space environment. The primary payload of the first program of *STSAT* (FIMS, Far-ultraviolet Imaging Spectrograph) was developed by KASI for ultraviolet wavelength observations in collaboration with the Satellite Technology Research Center (SaTReC) of the Korea Advanced Institute of Science and Technology (KAIST) and UC Berkeley, as described in detail by Edelstein et al. (2006). The *STSAT-1* was successfully launched in 2003 and operated for two years, leading to 50 scientific papers so far. The *STSAT-3* program was also started in 2008 for infrared space observations. SaTReC was responsible for developing the satellite bus system of STSAT-3, while KASI developed the main payload MIRIS. After the successful launch in 2013 November, the *STSAT-3* is now operating its initial stage in a sun-synchronous orbit of altitude around 600 km. For two years, MIRIS will perform astronomical observations in near-


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