Status of IR Spectro-Photometric Survey Missions in Space
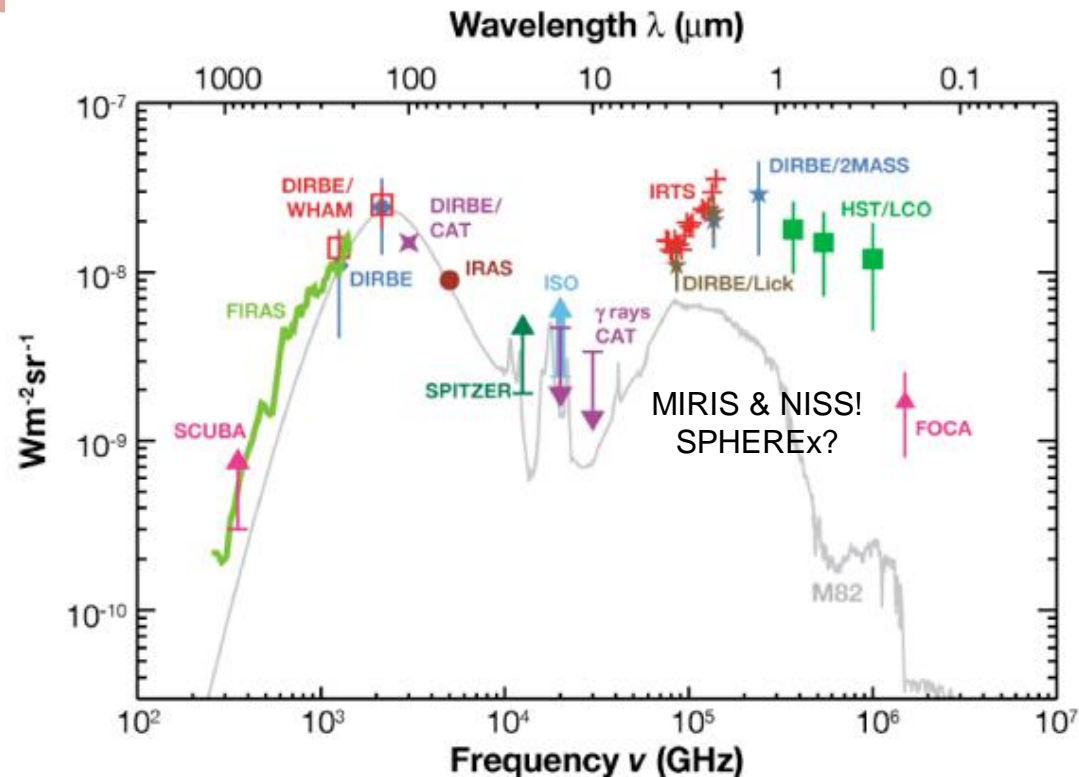
Woong-Seob Jeong

KASI, Korea

KASI 한국천문연구원
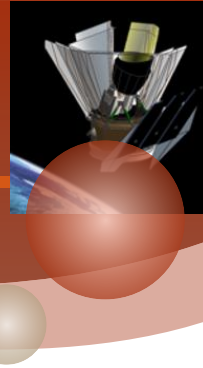Korea Astronomy & Space Science Institute
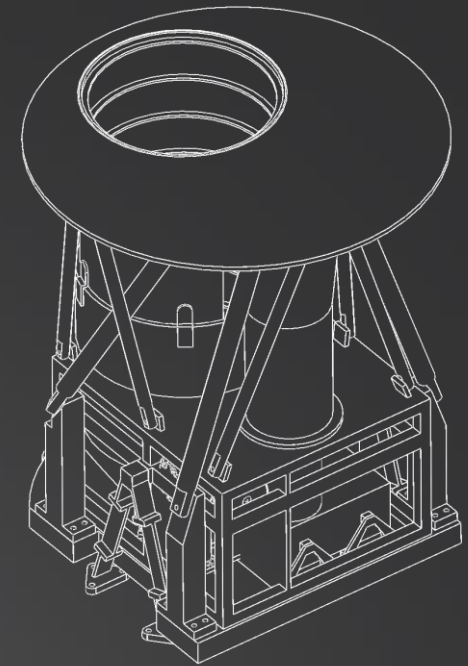
Epoch of Reionization?
Modern Galaxies form?

Excess emission in near- & far-infrared

- High-redshift objects: first stars or first galaxies
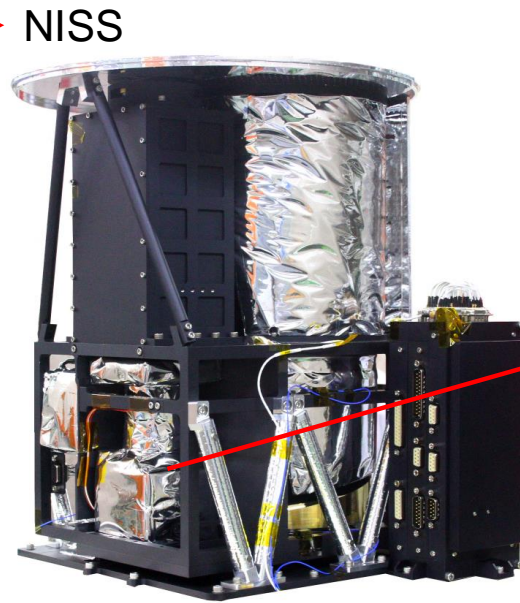- Low-redshift objects: merging galaxies or stars around galaxy

NISS: Near-IR Imaging Spectrometer onboard NEXTSat-1 (2018~2020)

- Wavelength range: 0.9 ~ 2.5μm

- Array format: 1024 x 1024, FoV: ~2 deg. X 2 deg. (15"resol.)

- 15cm aperture, Imaging & Low-Resolution Spectroscopy (R~20), Sensitivity ~17 AB mag. – spectrophotometric survey area ~150 deg² (2-year operation)

NISS

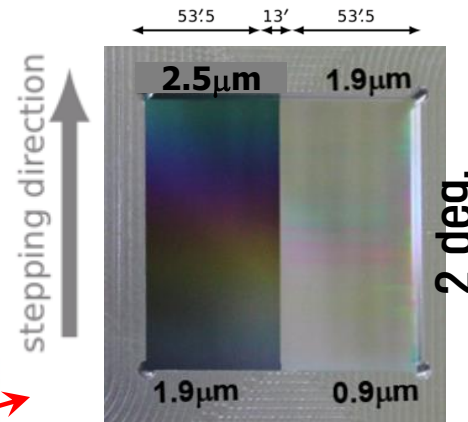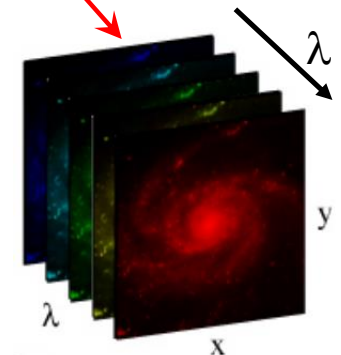stepping direction

53ʹ.5 13ʹ 53ʹ.5

2.5μm   1.9μm

1.9μm   0.9μm

2 deg.

2LVFs

Passive (180K) & active cooling (80K)

λ

y

λ

x

NEXTSat-1

290mm(L)×270mm(W)×392mm(H), 13.6kg
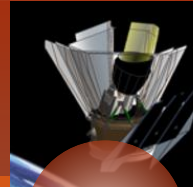
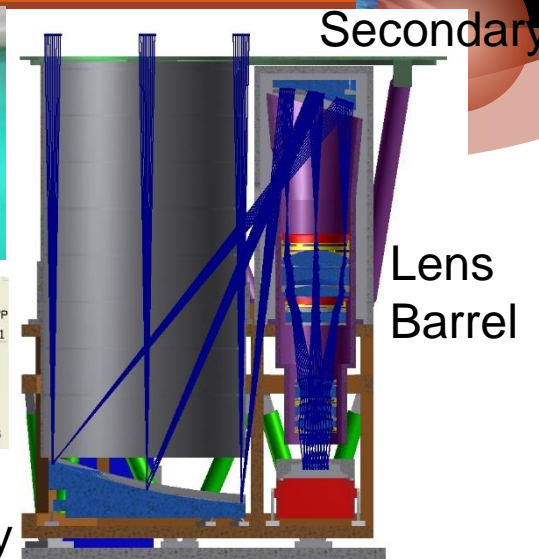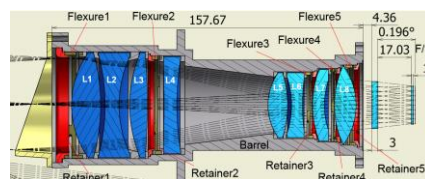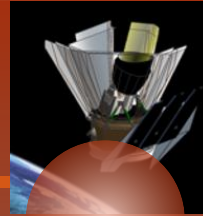## Optics

- Space optics: shock/vibration, radiation, thermal-vacuum condition
- Off-axis optics / Barrel
  - Reduction of obscuration
  - Afocal system
  - → independent alignment
  - Barrel: flexure / spacer
- Wide wavelength range
  - Filters
  - Coating of lens

Secondary

Lens Barrel

Primary
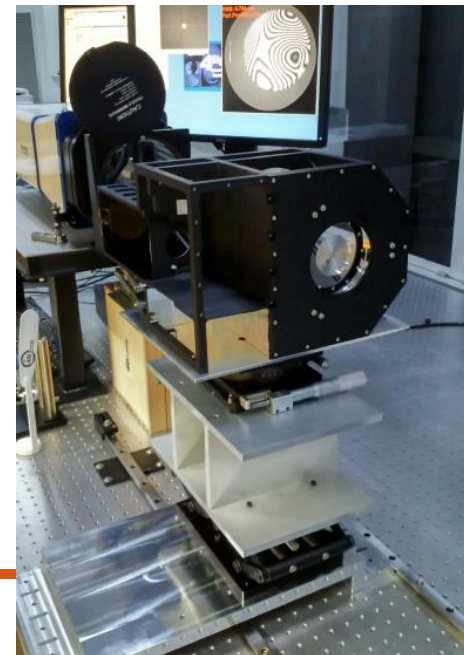
○ Opto-mechanics/Structure
- Shock/vibration: FEM analysis & Support of mirrors
- Stress/Deformation for mirrors
  - 1G gravity
  - Thermal deformation
  - Mis-alignments
- Very compact dewar
- Passive/Active cooling
  - Telescope: ~180K
  - IR sensor: ~80K
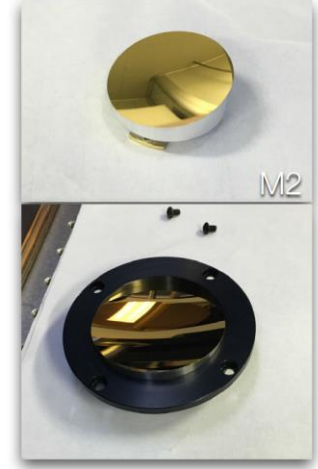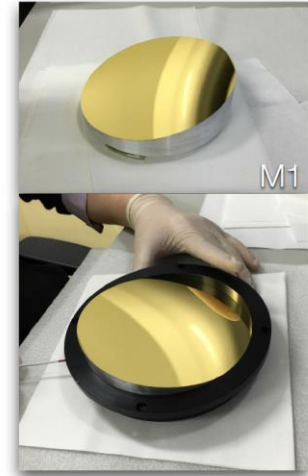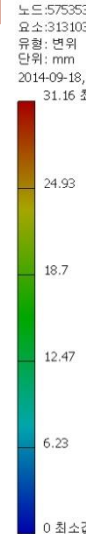
Compact dewar
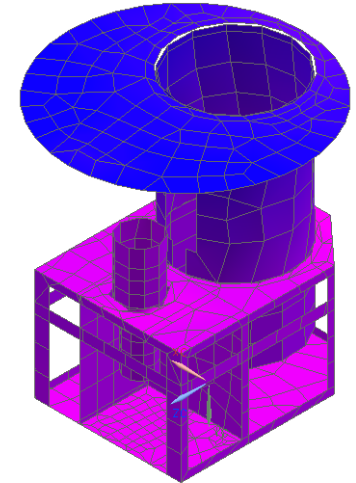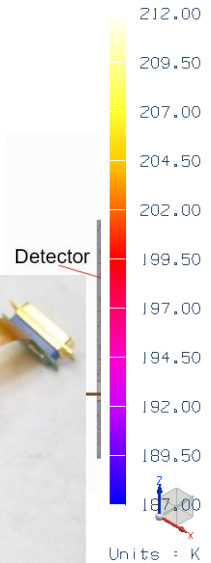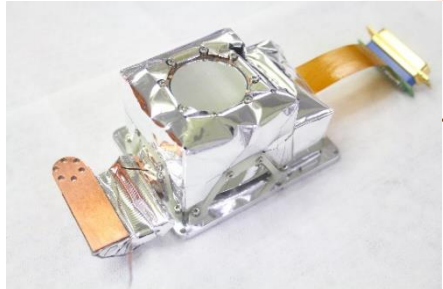
- Construction of Test Facilities
  - Cryo-chamber for system calibration
  - IR collimating system for optics test
  - Monochromator system for spectral calibration
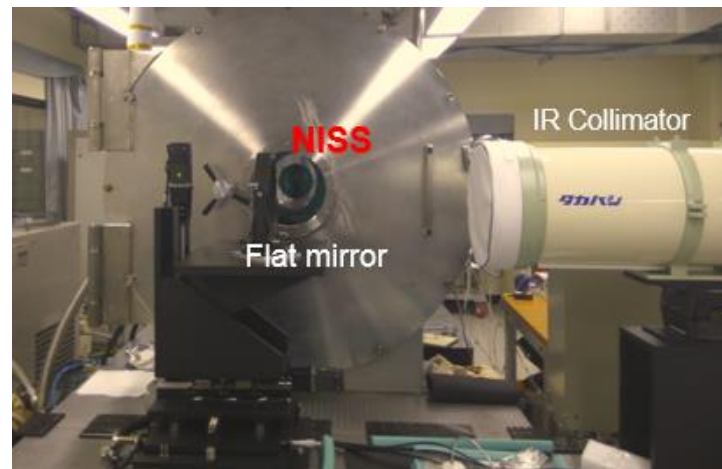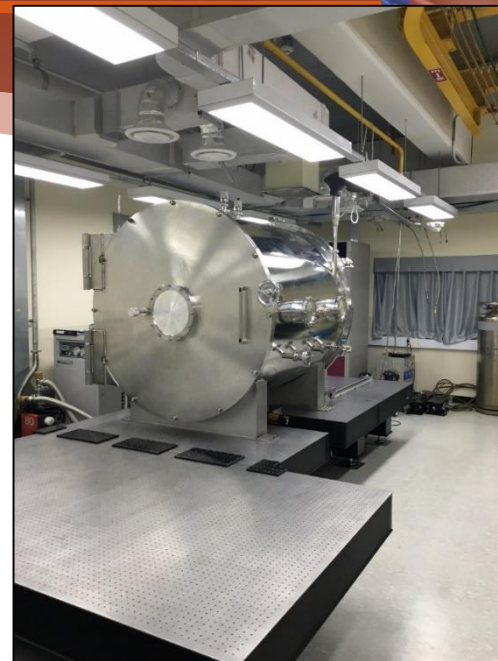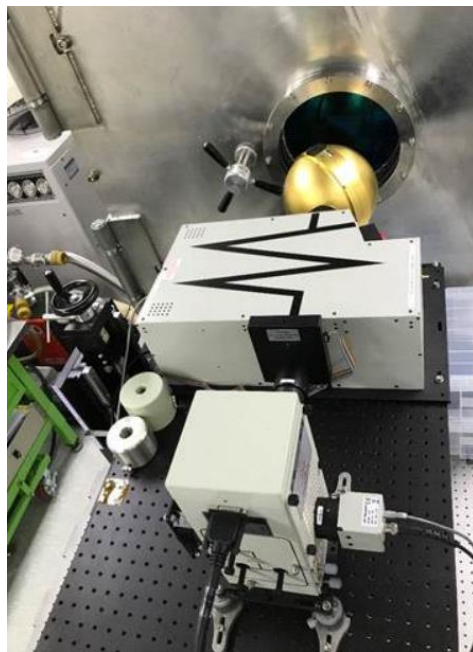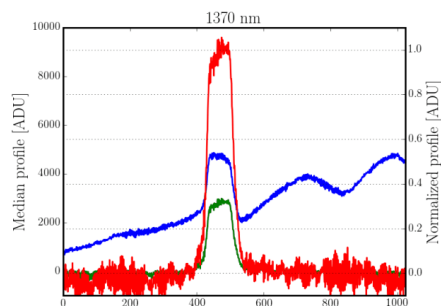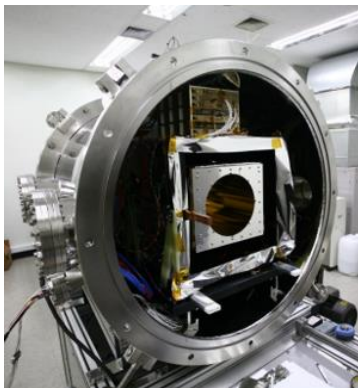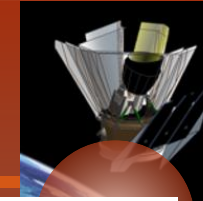
Dark measurements

994 nm

1370 nm
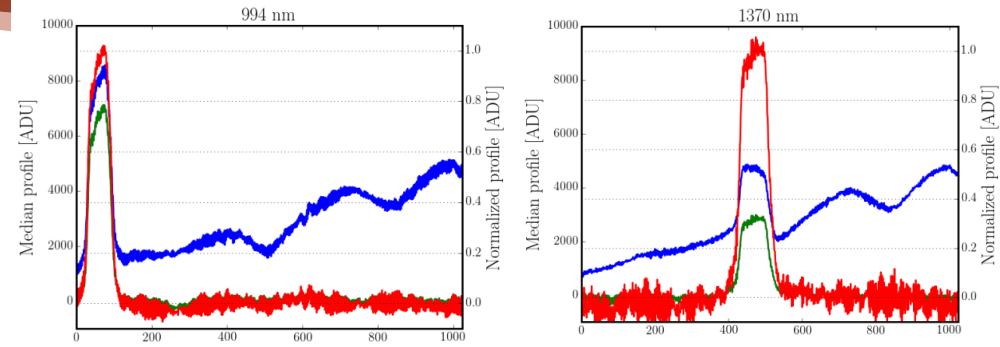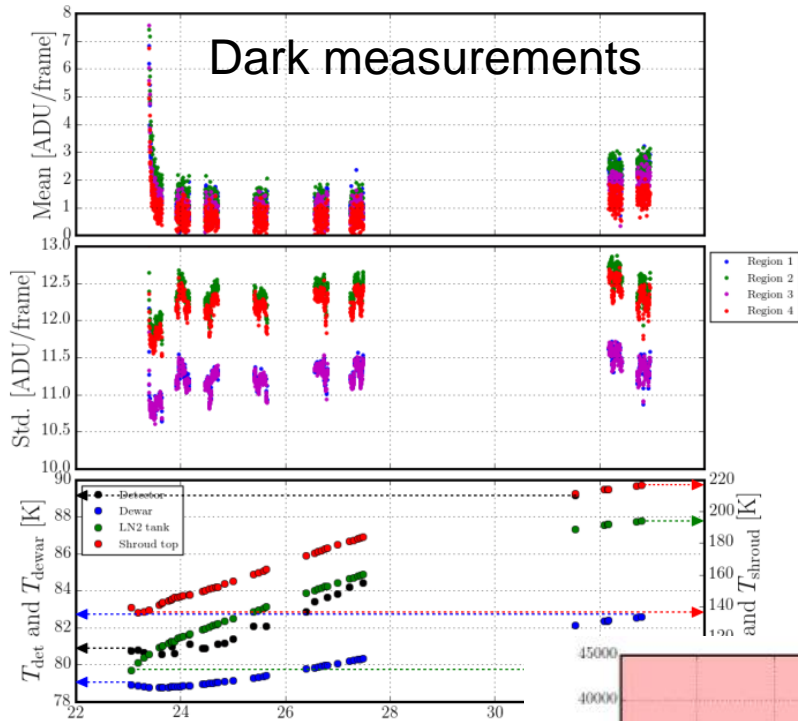
Wavelength calibration

$\lambda_c = (936.5 \pm 0.4) + (0.9321 \pm 0.0009)x$
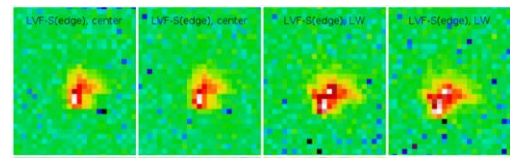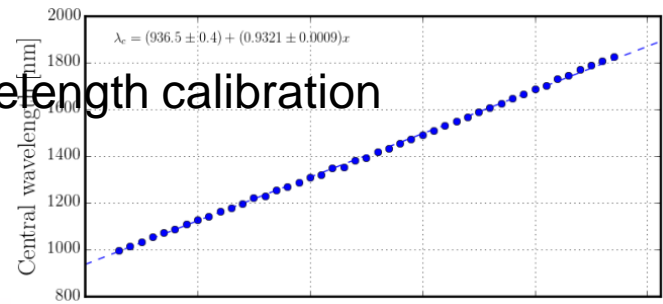
PSF measurements
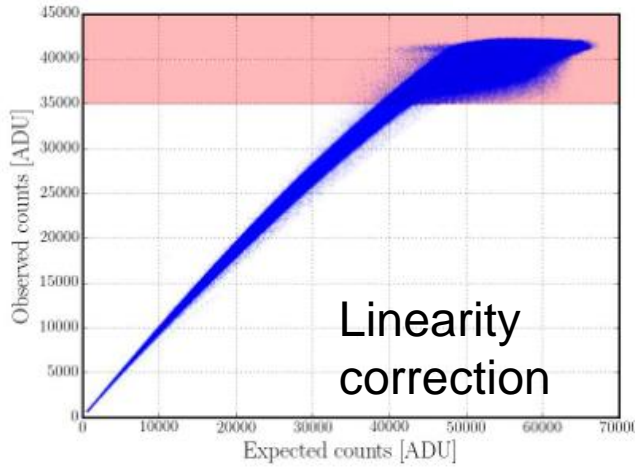
Linearity correction
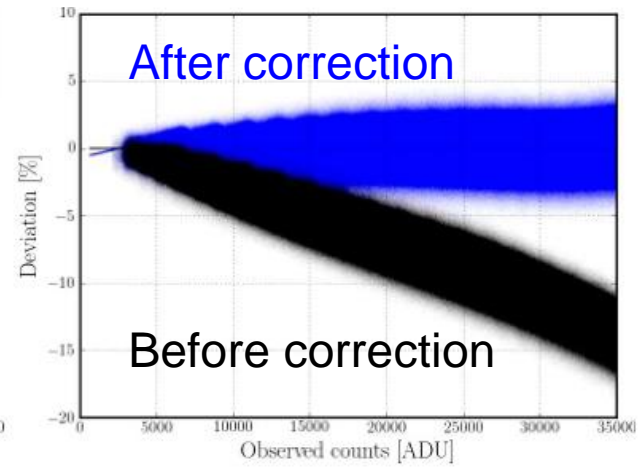
After correction

Before correction

NEXTSat-1 Test
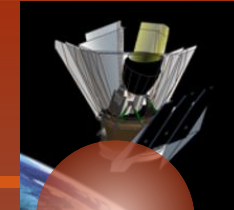
- Integration of NISS
- Thermal-Vacuum Test
- Vibration Test

NISS

ITAR Item

Functional Test
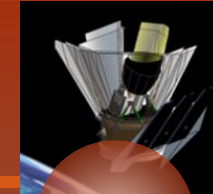
Near-IR Imaging Spectroscopy

- ⊙ Large Nearby galaxies
- ⊙ Clusters of galaxies
- ⊙ Star-forming regions
- ⊙ Cosmic Near-Infrared Background

WISE

NISS

λ (μm)	line	Type
1.26, 1.64	[Fe II]	Emission
1.875	**Paα**	**Emission**
1.96	[Si IV]	Emission
2.212	**H$_2$ 1-0 S(1)**	**Emission**

Near-infrared spectral lines

MIRIS
NISS

Kim et al. 2017, submitted
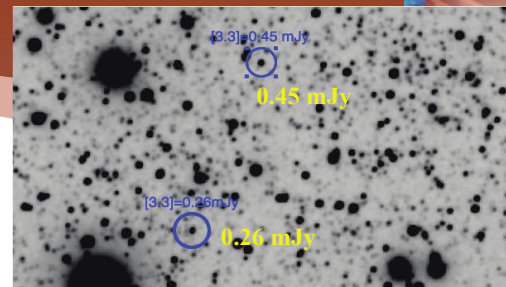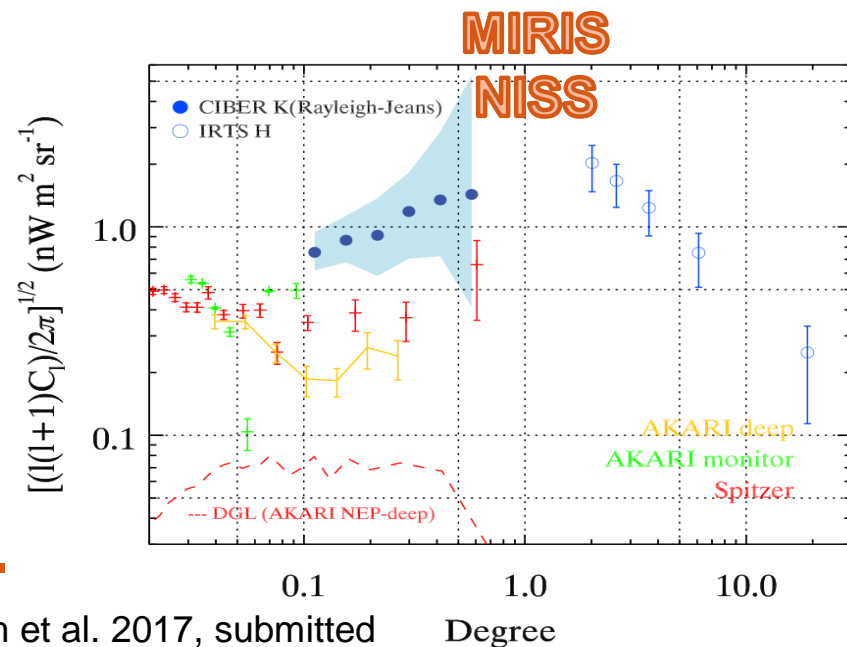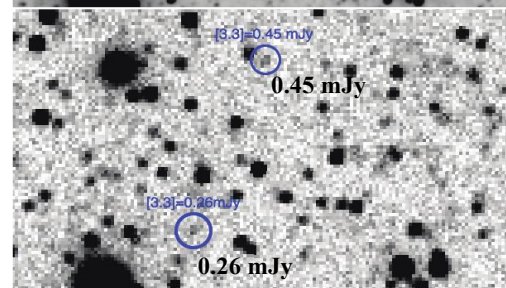
Next Schedule
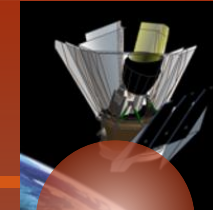
- Launch @ late 2018: Falcon9 @ SpaceX
- Operation (TBD)
  - Initial operation period: ~3 months
  - Main observation: ~17 months
  - User observation: ~4 months
- New science cases: inviting!

Scientific Targets

Category	Target
Nearby galaxy	~15 objects (e.g, M31, NGC628)
Cluster of galaxy	1~2 objects (e.g., Abell 2199)
Star-forming region	~6 regions (e.g., LMC, SMC)
CIB observation	1~3 regions (e.g., NEP, SEP)

All-Sky Spectral Survey Mission: SPHEREx

SPHEREx
An ALL-SKY Spectral Survey
DESIGNED TO EXPLORE:

THE ORIGIN OF THE UNIVERSE
THE ORIGIN AND HISTORY OF OUR GALAXIES
THE ORIGIN OF WATER IN PLANETARY SYSTEMS

ASTROPHYSICS EXPLORER 2014, STEP 2
AO NNH14ZDA013O
JULY 19, 2016

James J. Bock   *Elizabeth J. Hisserich*

DR. JAMES BOCK PRINCIPAL INVESTIGATOR
CALIFORNIA INSTITUTE OF TECHNOLOGY
AND JET PROPULSION LABORATORY

AUTHORIZING OFFICIAL: ELIZABETH HISSERICH
ASSISTANT DIRECTOR, OFFICE OF SPONSORED RESEARCH
CALIFORNIA INSTITUTE OF TECHNOLOGY

JPL   Ball   ipac   CfA   UCI   OHIO STATE UNIVERSITY

One of 3 MIDEX Candidates (Aug. 2017)

August 09, 2017
RELEASE 17-069
NASA Selects Proposals to Study Galaxies, Stars, Planets

NASA has selected six astrophysics concept study proposals as part of the agency's Explorers Program. The proposed studies would study various emissions from galaxies, galaxy clusters, and neutron star systems, as well as exoplanet atmospheres, as a way to fill in the gaps between the agency's larger missions.
Credits: NASA

3.5 deg
3.5 deg

OBJECT 1   OBJECT 2   OBJECT 3
FLUX
0.75 1.0 1.25   0.75 1.0 1.25   0.75 1.0 1.25
WAVELENGTH (μm)

Spectro-photometry with LVF

Review for SMEX (Nov. 2016) Failed → MIDEX
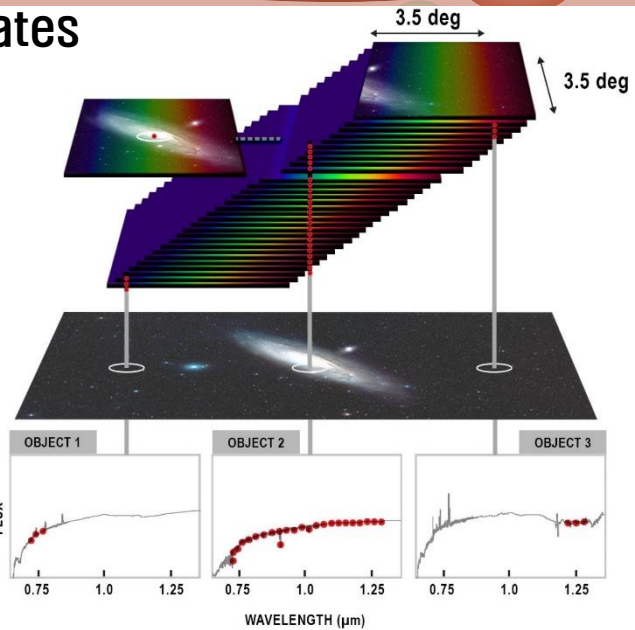
❖ **SPHEREx (MIDEX mission)**

▪ **Korean contributions: H/W, S/W & Science**

▪ **In Phase-A study**

KIAS
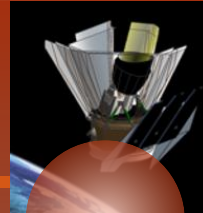
- **S**pectro-**PH**otometer for the **E**xtragalactic structure, **R**eionization and ices **Ex**plorer

  as a candidate of NASA MIDEX Mission: Phase-A Study
- Spectro-photometric all-sky survey: 1.4B spectral catalog

  (0.75 ~ 4.8μm, R=40 ~150)
  - Galaxies (Emission Line Galaxies)
  - QSOs
  - Galaxy clusters
  - Mass-losing stars
  - Brown dwarfs
  - H_2O ices, …
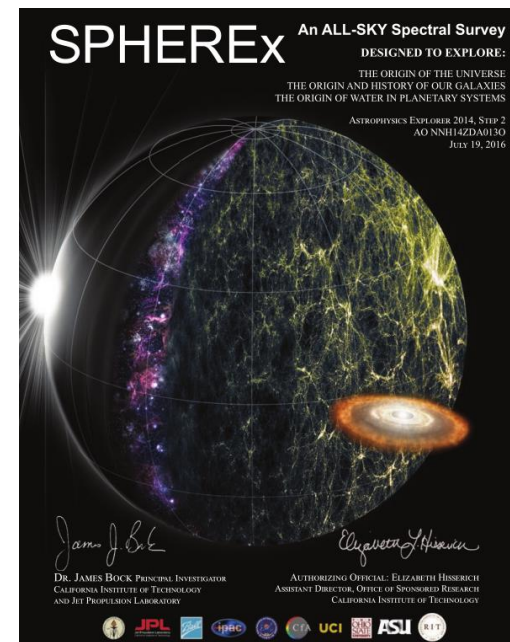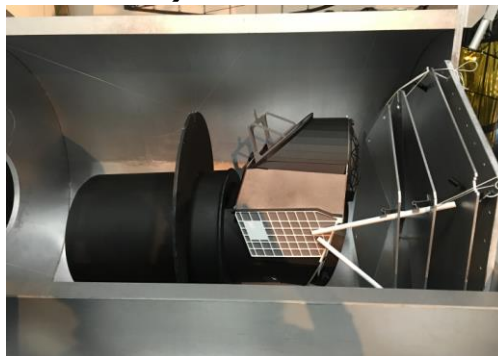
- SPHEREx is the upgraded mission of the NISS

SPHEREx: All-Sky Legacy Archive

Legacy Science Opportunities: A Few Examples

Notable Features of the SPHEREx All-Sky Survey

- High S/N spectrum for every 2MASS source
- Solid detection of faintest WISE sources
- Catalogs ideal for GMT/JWST observations
- Redshifts for other surveys
  (e.g., eRosita X-Ray survey)
- Photo baselines for wide-field transient survey
- Mapping 3D distribution of Galactic ices
- …

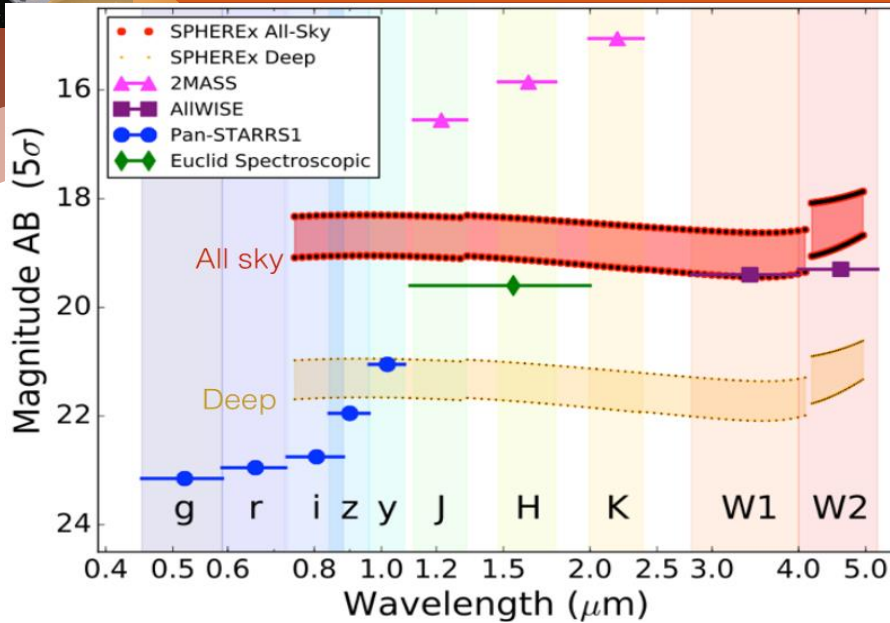| Object	# Sources	Legacy Science	Reference
Detected galaxies	1.4 billion	Properties of distant and heavily obscured galaxies	Simulation based on COSMOS and Pan-STARRS
Galaxies $s(z)/(1+z) < 0.03$	120 million	Study (H, CO, O, S, H_2O) line and PAH emission by galaxy type. Explore galaxy and AGN life cycle	
Galaxies $s(z)/(1+z) < 0.003$	9.8 million	Cross check of Euclid photo-z. Measure dynamics of groups and map filaments.	
QSOs	>1.5 million	Understand QSO lifecycle, environment and taxonomy	Ross et al. (2013) plus simulations
QSOs at z > 7	0-300	Determine if early QSOs exist. Follow-up spectroscopy probes EOR through Lya forest	
Clusters with ≥ 5 members	25,000	Redshifts for all eRosita clusters. Viral masses and merger dynamics	Geach et al., 2011, SDSS counts

X-ray source characterization	>100,000	In conjunction with eROSITA, detect X-ray source SEDs (e.g., AGNs) and their spectroscopic redshifts	Workshop White Paper (Doré et al., 2016)
Missing baryon studies	>10,000	In conjunction with CMB experiments, measure the kSZ signal of galaxy groups and clusters	Doré et al. (2016) Ferraro et al. (2016)
Exoplanet characterization	>1000	Determine precise radii for exoplanets from host star studies (§E.9.1.2)	Doré et al. (2016)
Deuterated PAH search	~100	Probe and possibly map deuterated PAHs; complete inventory of D in local ISM	Doré et al. (2016) Doney et al. (2015)
Lowest metallicity stars	~1000	Identify low-mass stars throughout the Galaxy by their IR signatures; and map their distribution	Doré et al. (2016)
Asteroids and comets	10,000/ 100	Spectrally classify numerous asteroids; CO/CO_2 ratio in comets	Doré et al. (2016)
Nearby, resolved galaxies	~100	Spectrally image galaxies to trace stellar populations, star formation, etc.	Doré et al. (2016)

ORIGIN OF THE UNIVERSE

Time Since Big Bang
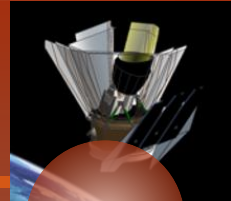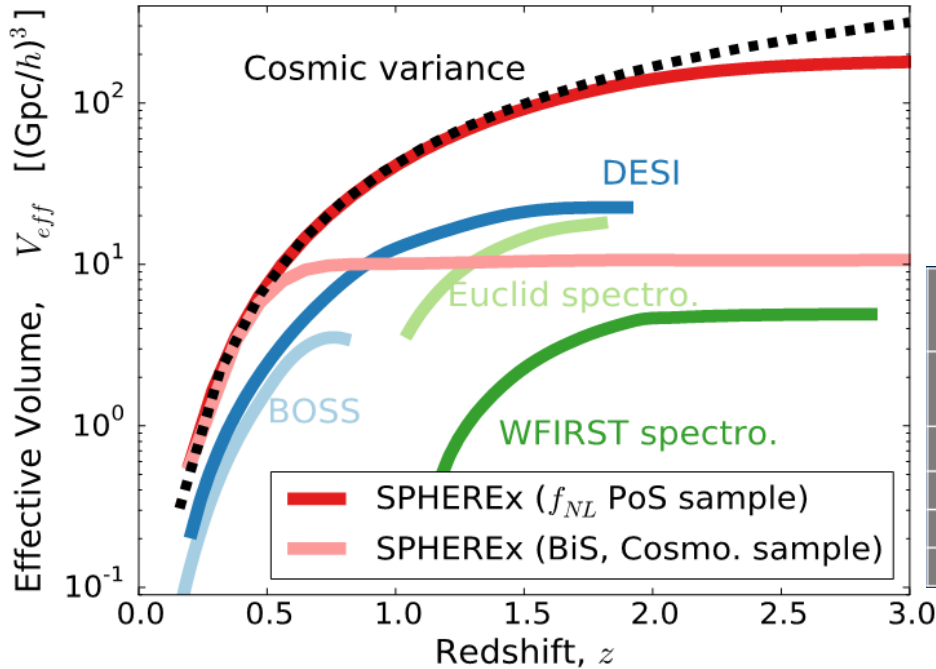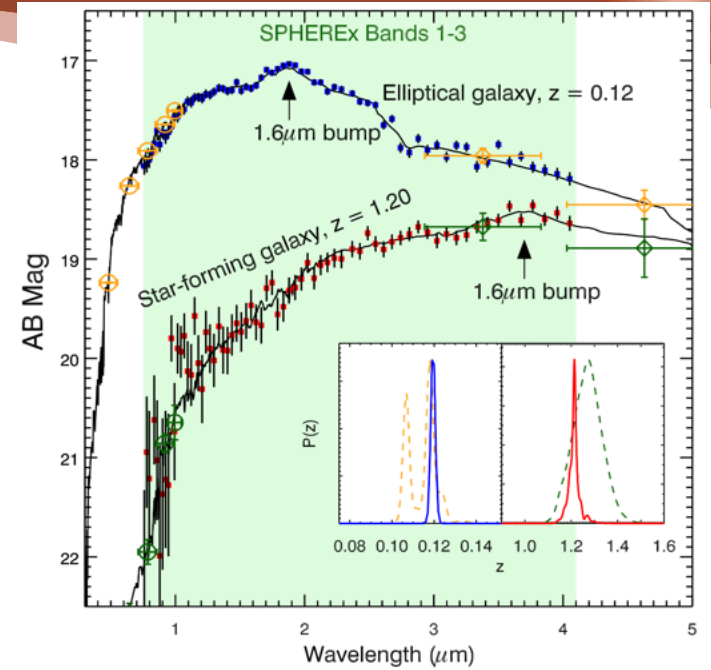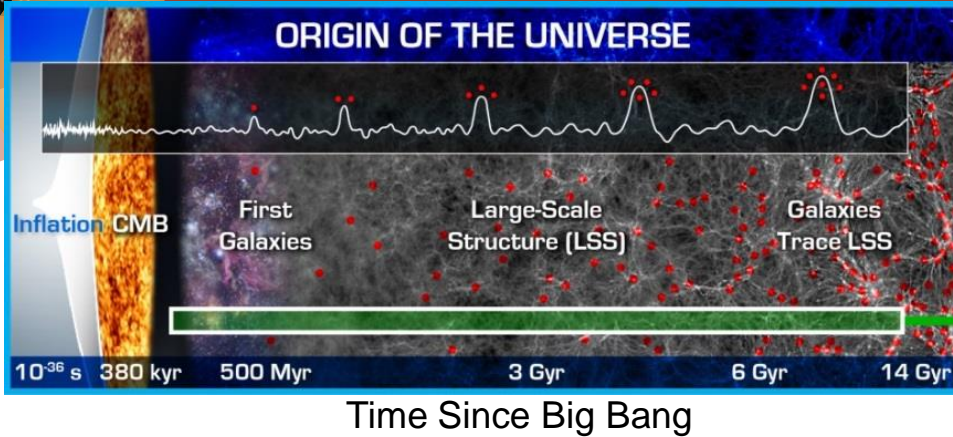
1σ errors, statistical (systematics)	SPHEREx (MEV)			Euclid (GC)	Current
	PoS	BiS	PoS+BiS		
f_{NL}	0.86 (0.15)	0.23 (0.05)	0.15 (0.03)	5.59	5.0
Spectral Index n_s (x 10^{-3})	2.6	1.5	1.4	2.6	4.0
Running α_s (x10^{-3})	1.0	1.0	0.49	1.1	7.5
Curvature Ω_k (x10^{-4})	7.6	9.5	6.6	7.0	20
Dark Energy FOM	381	NC	NC	309	14

ORIGIN OF THE UNIVERSE

Inflation CMB · First Galaxies · Large-Scale Structure (LSS) · Galaxies Trace LSS

10^{-36} s · 380 kyr · 500 Myr · 3 Gyr · 6 Gyr · 14 Gyr

Time Since Big Bang

ORIGIN AND HISTORY OF GALAXIES

Dark Ages · First Stars Turn On · Reionization · Star Formation Peaks · Clusters Form

500 Myr · 1 Gyr · 3 Gyr · 6 Gyr · 9 Gyr · 14 Gyr
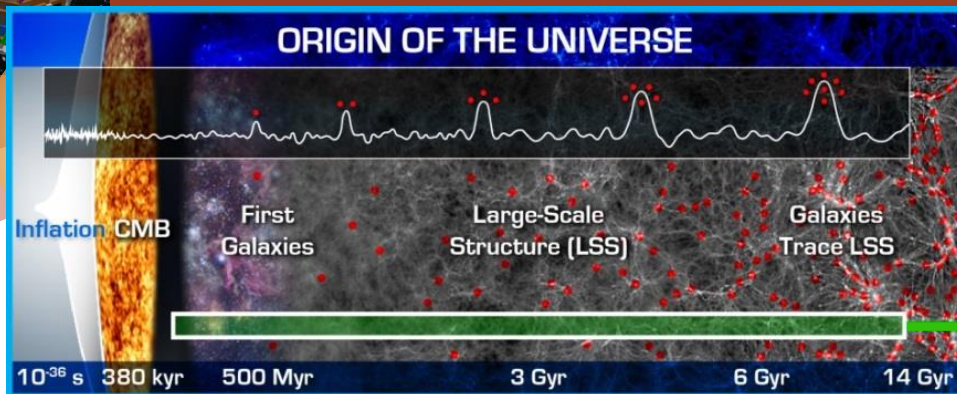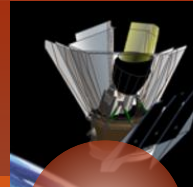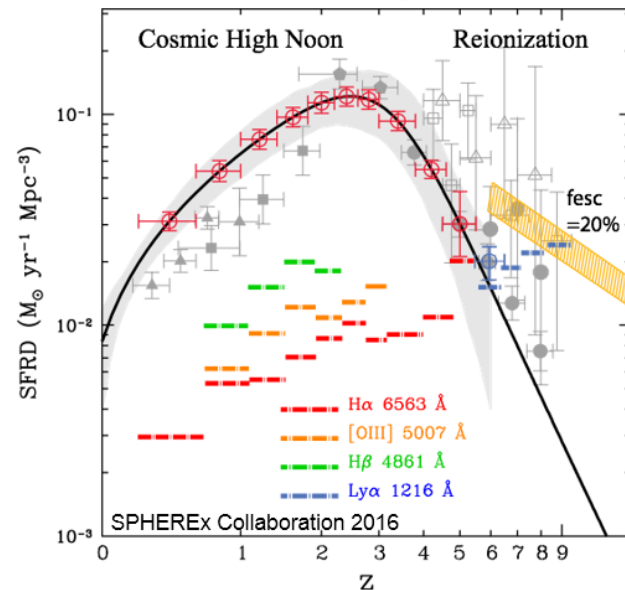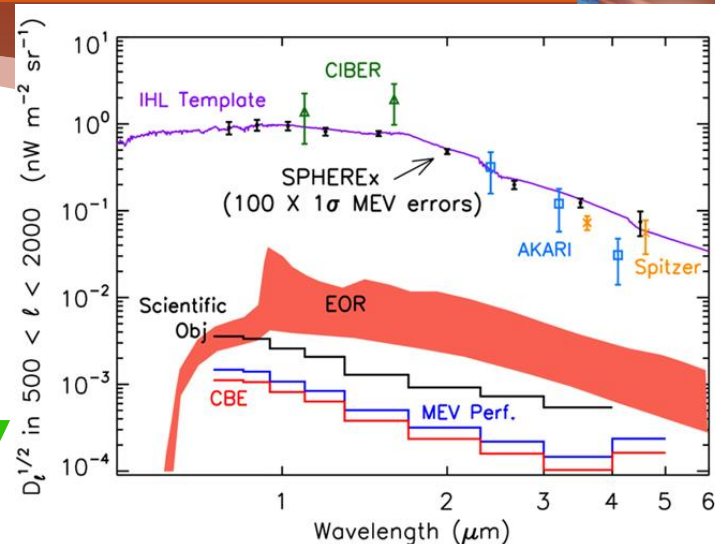
- Expected Lyman EOR features, with SNR >100 on the RMS fluctuations
- Faint EOR signal using distinctive spectral features and cross-correlations.
- Minimum EOR signal
- Line Intensity Mapping: Amplitude of linear clustering in multiple lines

SPHEREx: Ice Survey

ORIGIN AND HISTORY OF GALAXIES

First Stars Turn On

Dark Ages

Reionization

Star Formation Peaks

Clusters Form

500 Myr   1 Gyr   3 Gyr   6 Gyr   9 Gyr   14 Gyr
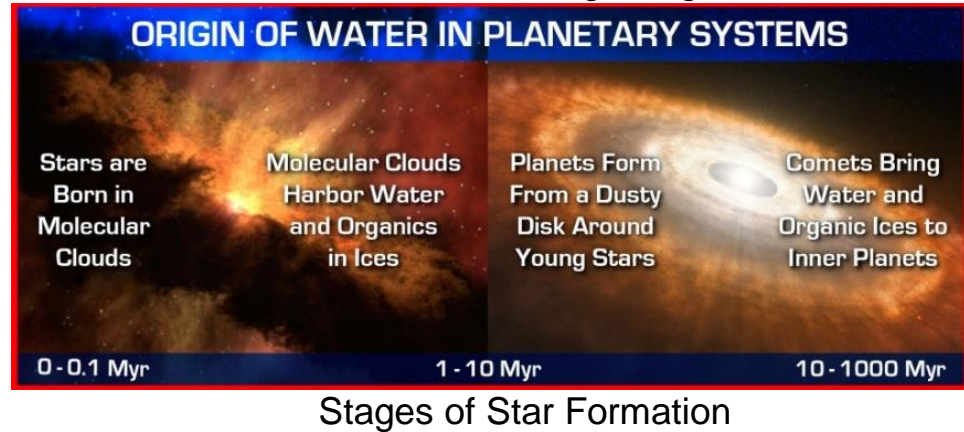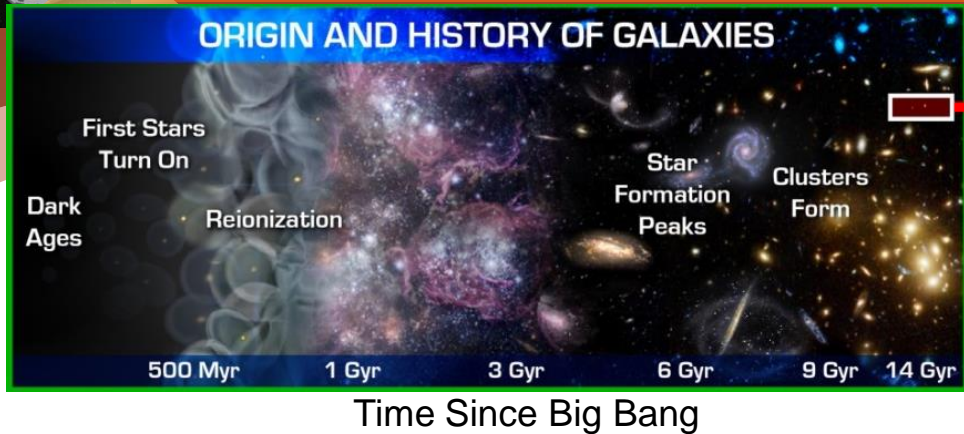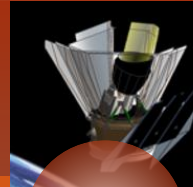
Time Since Big Bang

ORIGIN OF WATER IN PLANETARY SYSTEMS

Stars are Born in Molecular Clouds

Molecular Clouds Harbor Water and Organics in Ices

Planets Form From a Dusty Disk Around Young Stars

Comets Bring Water and Organic Ices to Inner Planets

0 - 0.1 Myr   1 - 10 Myr   10 - 1000 Myr

Stages of Star Formation

Abundance and composition of biogenic ices (H_2O, CO_2, CO, XCN and CH_3OH) in dense molecular clouds and protoplanetary disks

W33A

H_2O CH_3OH CO_2 $^{13}CO_2$ XCN   CO

Flux (Jy) vs Wavelength (microns)

SPHEREx All-Sky Survey Depth (mJy)

CBE Survey Depths (100σ)
MEV Survey Depths (100σ)

WISE 3.4 μm
WISE 4.6 μm

Level 1 Required No. of Ice Spectra

Number of Good Background Sources

SPHEREx All-Sky Survey Depth (AB Mag.)

- Data reduction pipeline (L0 & L4)

- Science (especially extragalactic science)
  - 2018 Science Workshop @ CfA, Boston
  - Pre-study with NISS

- Ground support equipment for characterizing the instrument (cryo. Chamber, integrating sphere, ground station electronics)
  - Re-design of cryo. chamber
  - Test items: optics & system
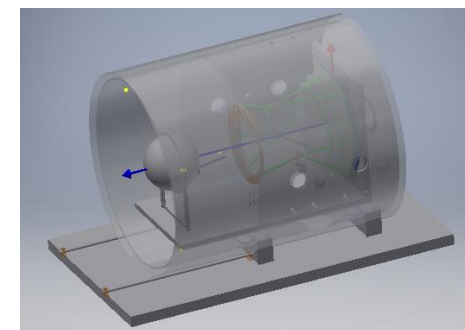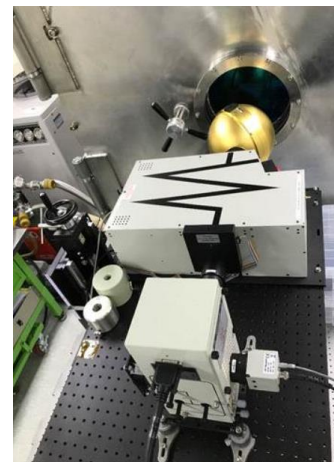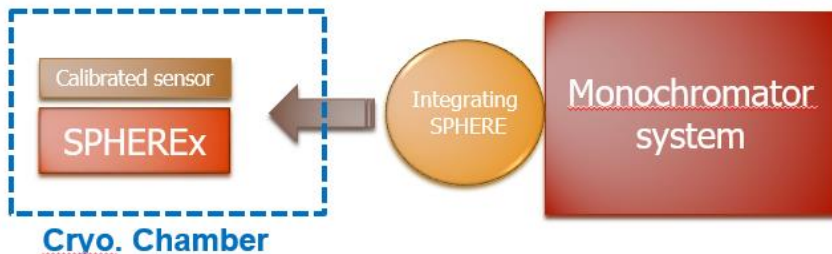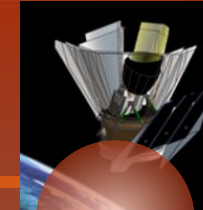

Chamber for SPHEREx
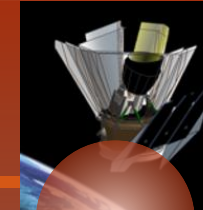
- L0 & L1: System calibration data sets
- L2 ~ L4: Sequential release in public
  - L2: Calibrated Spectral Images
  - L3: All-Sky Spectral Catalog
  - L4: Scientific Research – Intensity mapping
    - L4-IC: Cosmological Parameters
    - L4-GI: Galactic Ice Parameters
    - L4-GF: Galaxy Formation Parameters

Summary

- NISS (2018)
  - Full development in Korea: limited resources & manpower!
  - Technical demonstration: spectro-photometry with LVFs
  - Spectro-photometric survey > 150 deg^2
  - Launch @ late 2018: Falcon9 @ SpaceX → 2-yr operation
  - New science cases: inviting!

- Contributing sources to CIB?

- SPHEREx (MIDEX mission): all-sky spectro-photometric survey @ 2022?