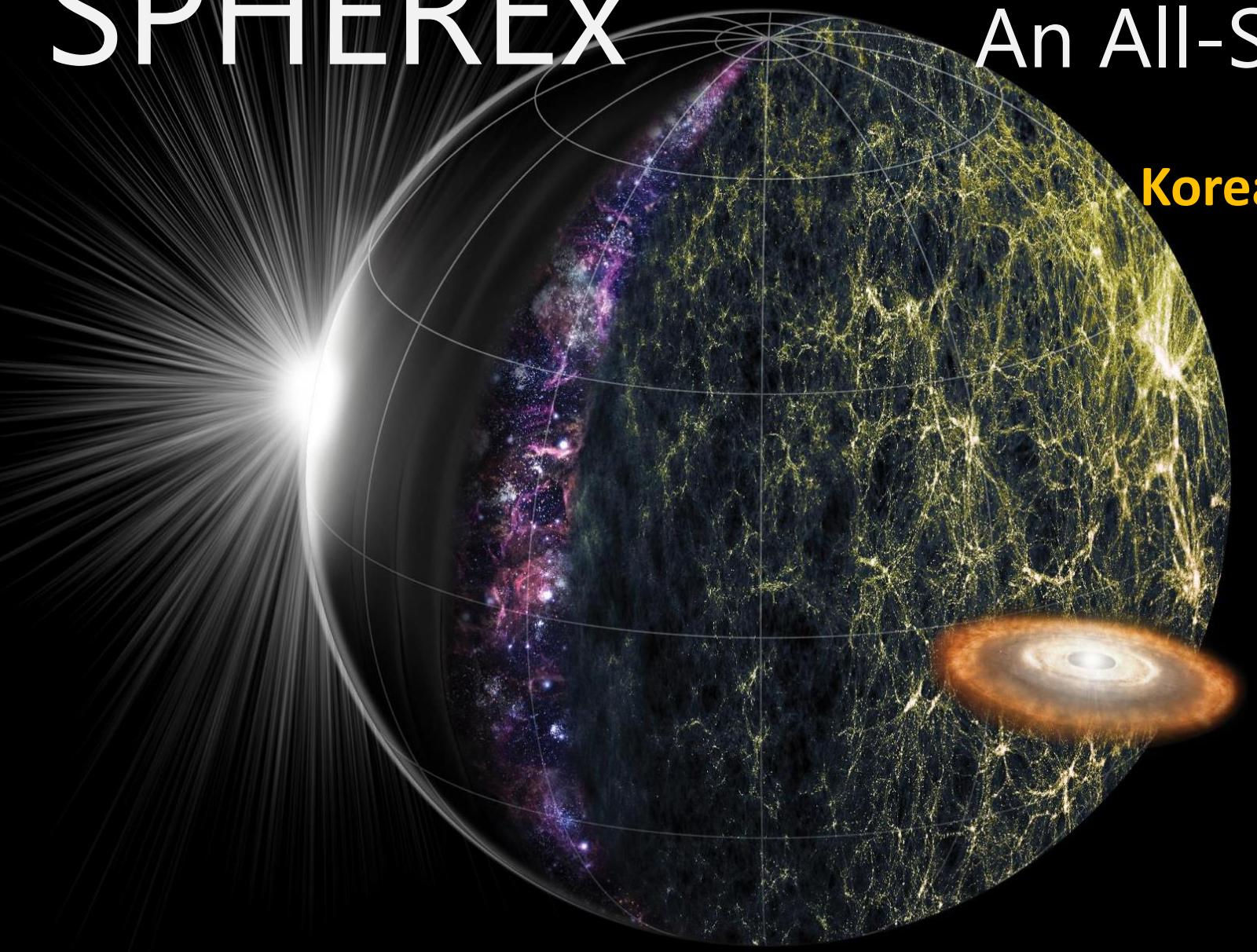
SPHEREx

An All-Sky Spectral Survey



Korean Contribution to SPHEREx: Status Report

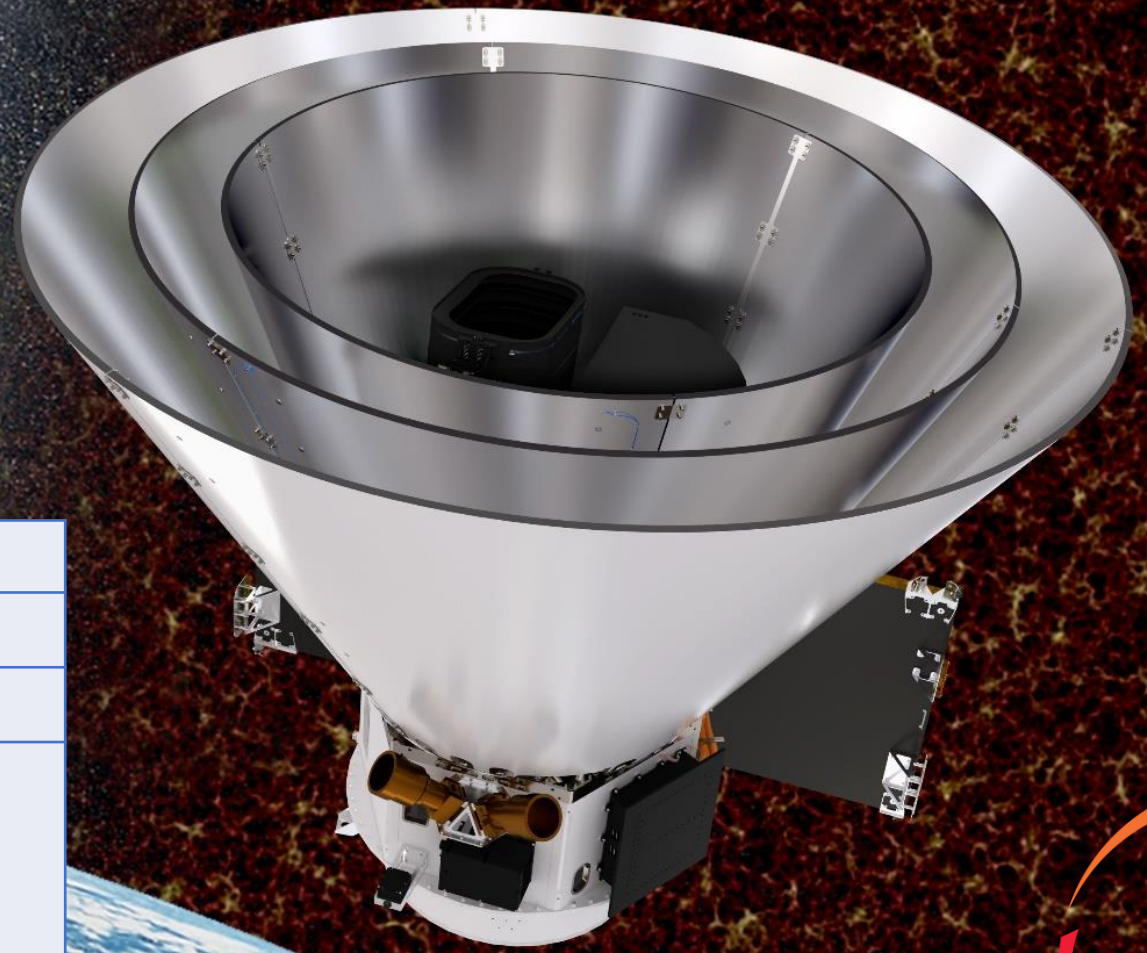
Woong-Seob Jeong
KASI SPHEREx Team

Survey Science Workshop, High-One Resort (2024.01.29)

SPHEREx

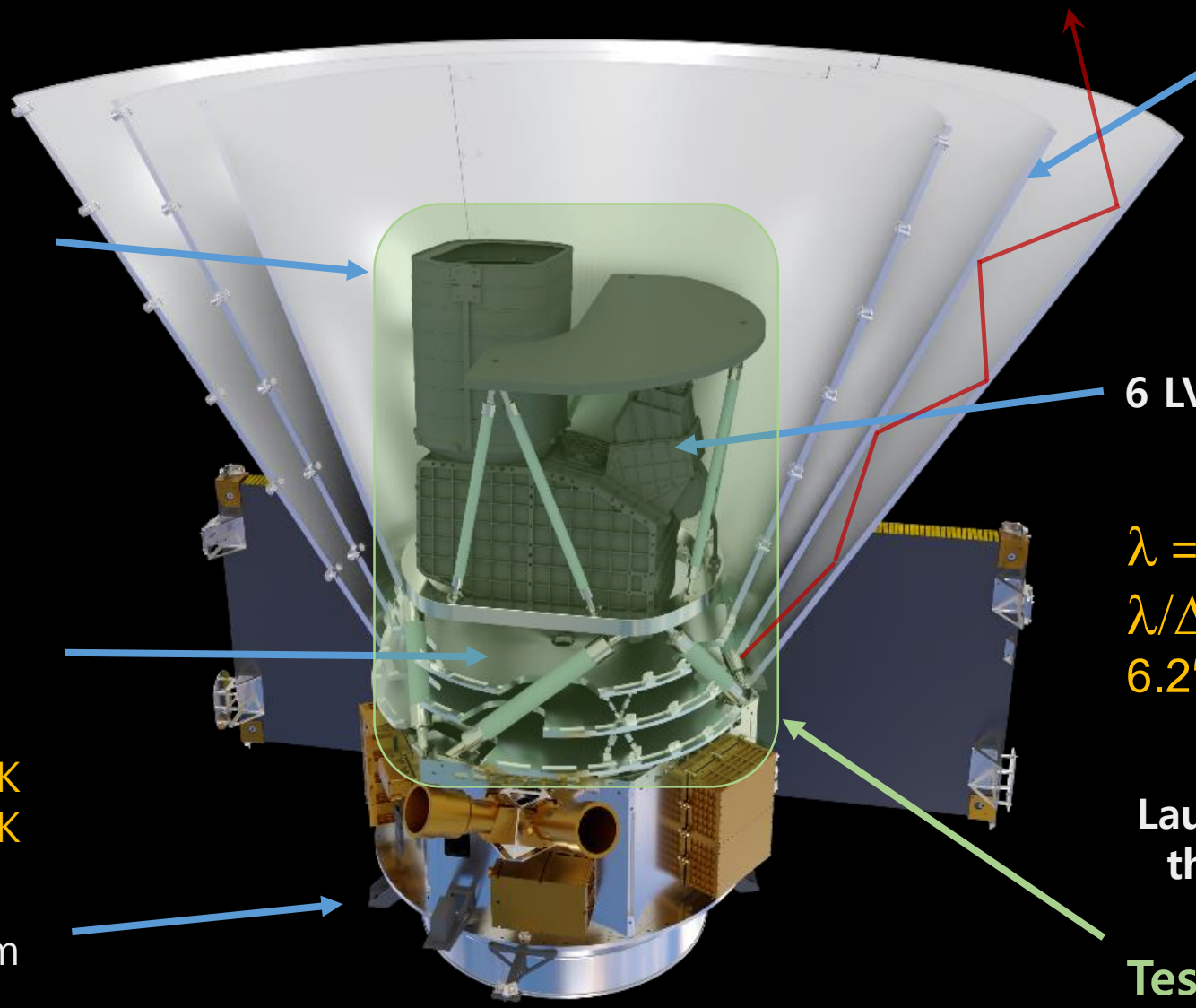
NASA MIDEX Mission
(PI Institute: Caltech)
KASI: unique international partner (from 2016)
First All-Sky Infrared Spectro-Photometric Survey
(4 times all-sky surveys during 2.5 years)
~1 Billion Spectral Catalog
Launch: no earlier than Feb. 2025

Telescope aperture	20cm (effective)
Pixel Size	6.2″ x 6.2″
Field of View	3.5° x 11.3°
Resolving Power and Wavelength Coverage	λ= 0.75 - 2.42 μm (R=41) λ= 2.42 - 3.82 μm (R=35) λ= 3.82 - 4.42 μm (R=110) λ= 4.42 - 5.00 μm (R=130)
N(Channels)	102



SPHEREx

SPHEREx



Photon Shield

20cm telescope
(FoV: 3.5° x 11.3°)

6 LVFs

2m

λ = 0.75 – 5 μm
$\lambda/\Delta\lambda$ = 35 – 130
6.2″ pixels

V-Grooves for
Passive Cooling

Telescope < 80K
Sensor < 50K

Launch: no earlier than Feb. 2025

Bus system

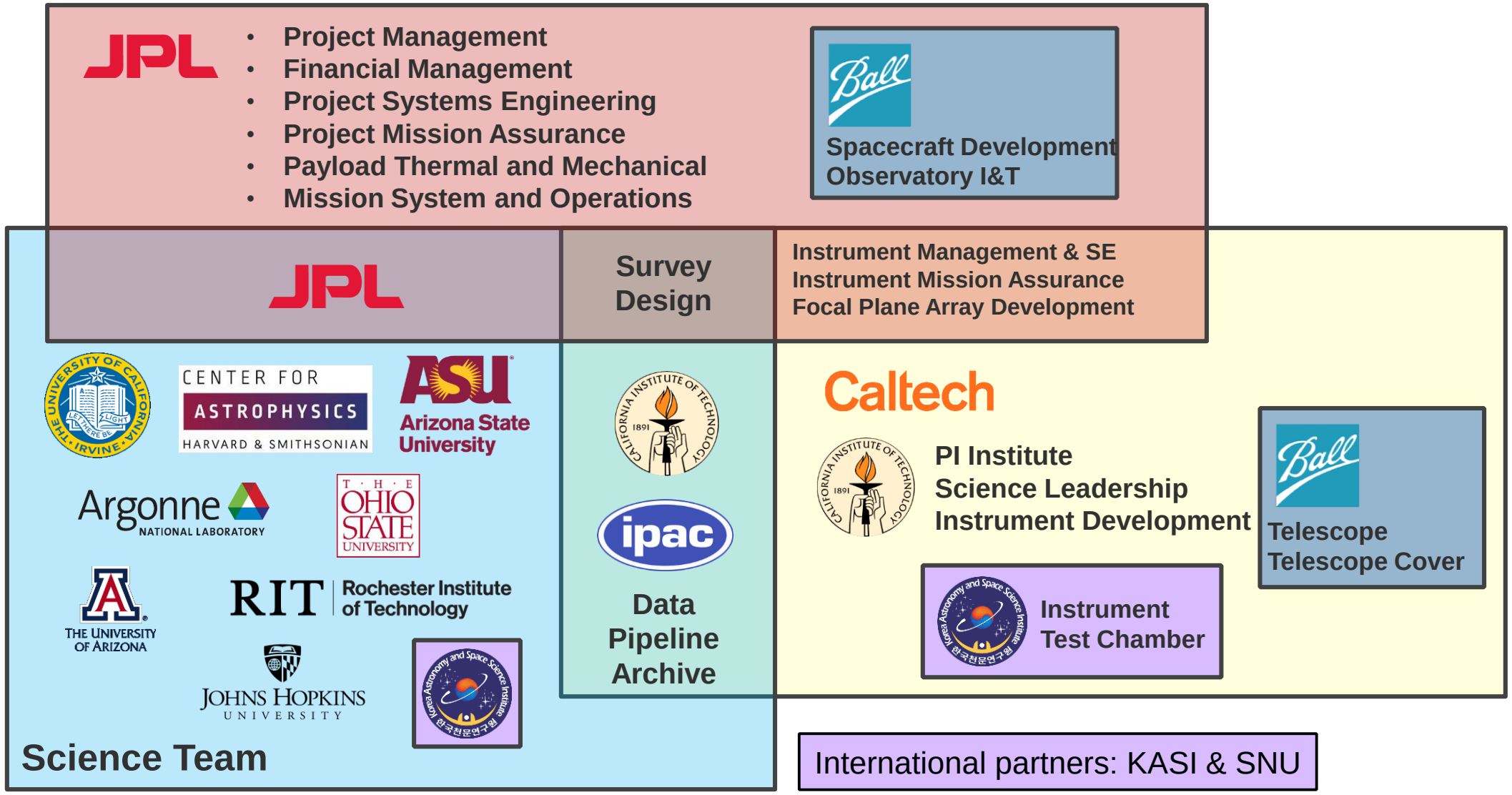
Test with KASI Chamber

SPHEREx Project Update (since KAS 2022 Fall)

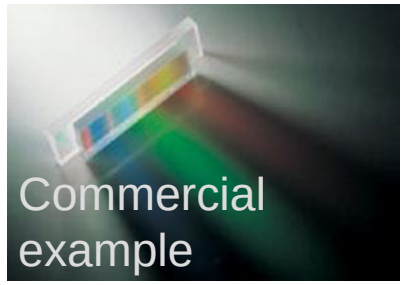
- Hardware
  - Cryogenic Chamber delivered by KASI (2022. 06)
  - Chamber integrating sphere & Winston cone delivered by KASI (2023.04)
  - Telescope and sub-thermal systems delivered (2023.05)
  - KASI TVAC (Thermal-VACuum): TVAC-0, TVAC-0.5 (2023.04 - 05)
  - KASI TVAC-1 & 2 (focus test) complete
  - KASI TVAC-3 & 4 (focus after vibration test, wavelength calibration) – 천문연 참여
  - Vibration test of Photon Shield (2023. 12)

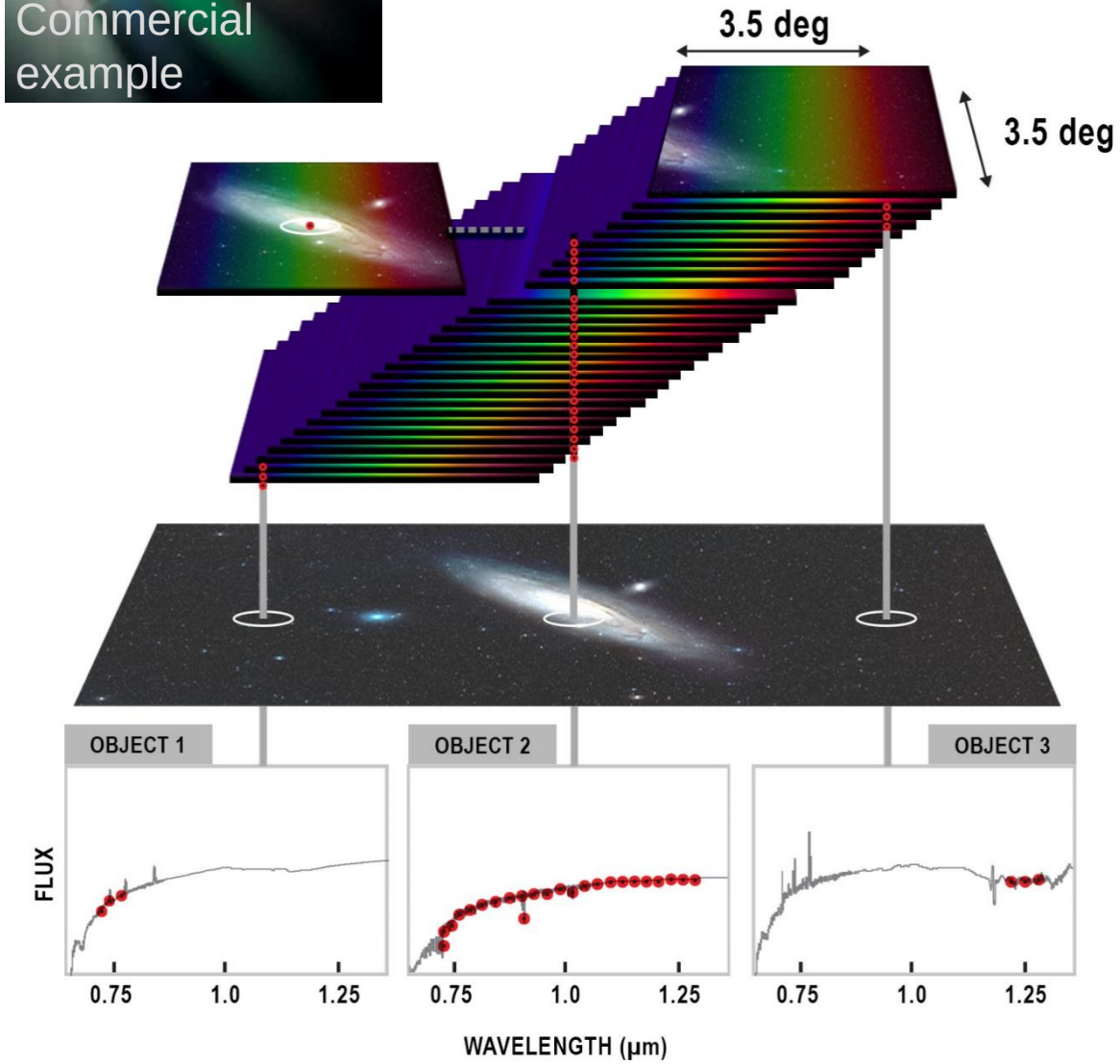
- Science, Meetings & Reviews
  - SPHEREx AGN Splinter Meeting (2022.10.22): KASI – ASIAA
  - SPHEREx 기초연구실 AGN 워크숍 (2023.01.12-13): 경북대 – 충남대 – 부산대 추최
  - SPHEREx F2F Meeting (2023.02.07-09)
    - 2019년 이후 첫 대면 미팅, 한국 측 총 9명 참여
    - SPHEREx Ices Splinter session 참여
  - SPHEREx F2F & SIR Science peer-review (2023.9.19-21)
  - System Integration Review (SIR) Pass (2023.11.14-16)

Project Partners



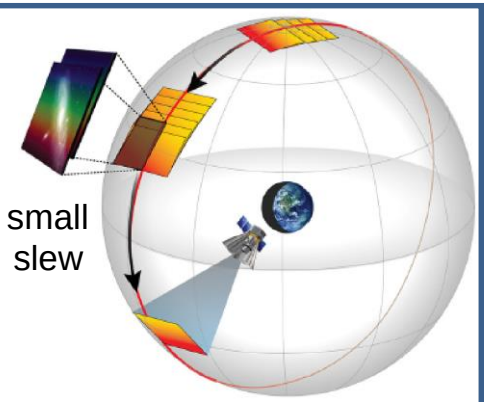
Mapping the Sky with LVFs



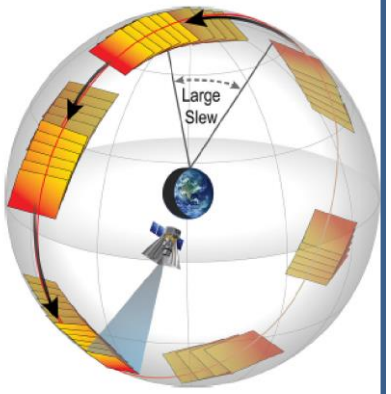


A complete spectrum is made from a series of images

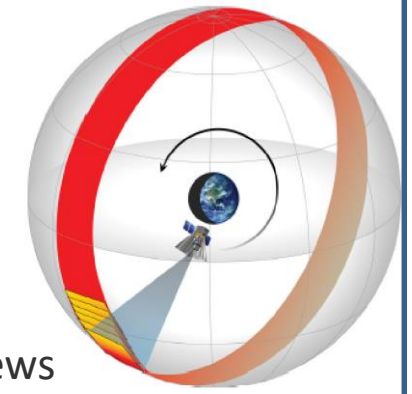
1 orbit



2 orbits

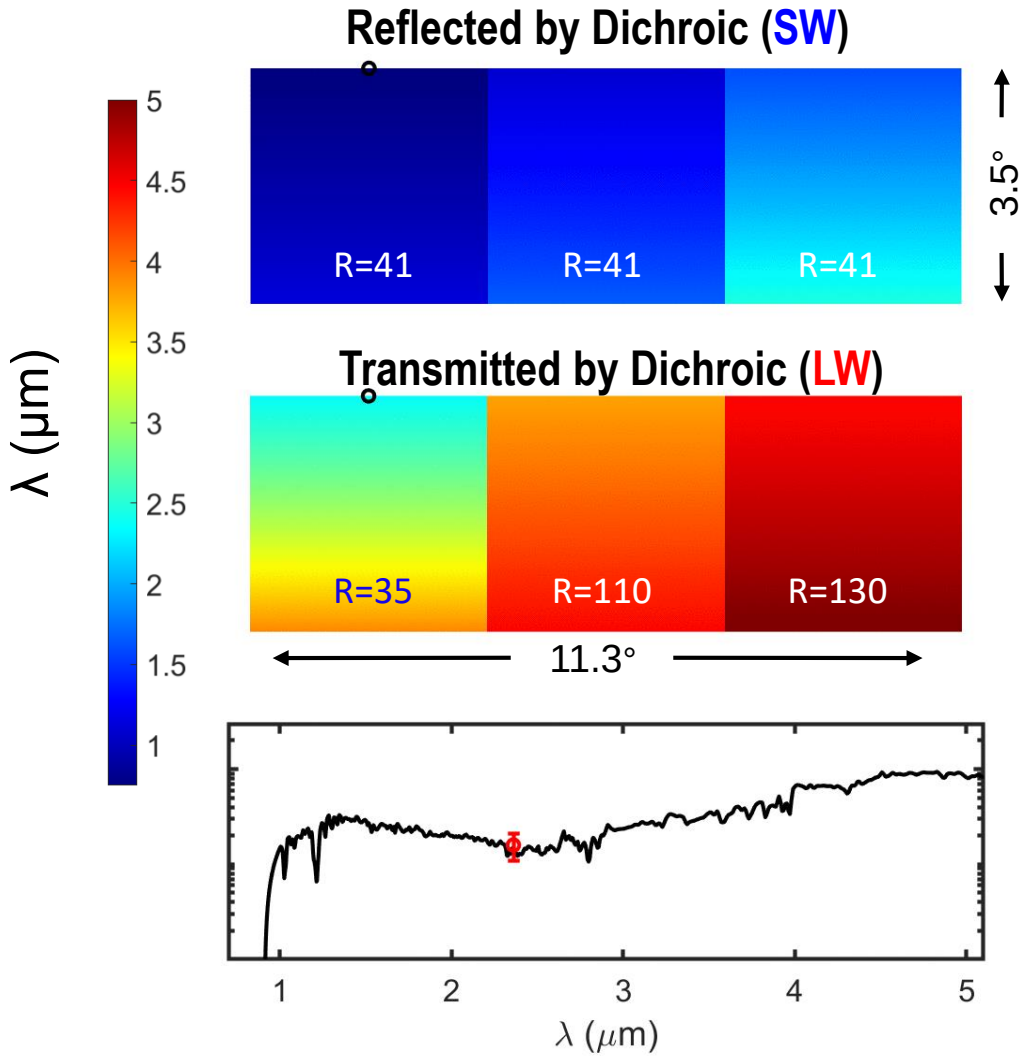


N orbits



SPHEREx maps the sky
over multiple orbits
with large and small slews

Spectral Mapping using Linear Variable Filters

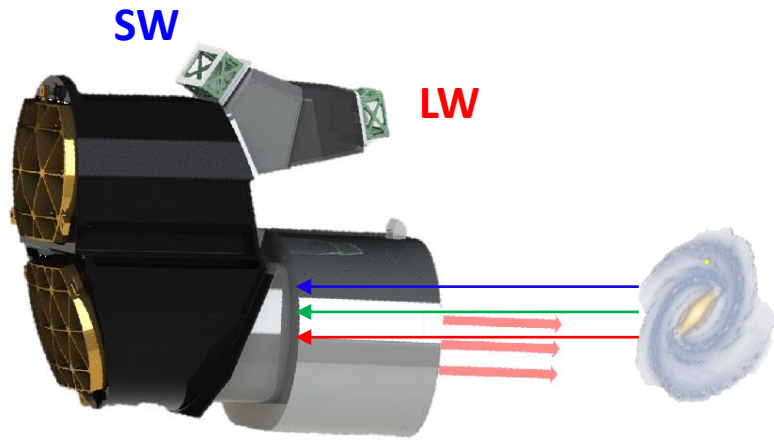


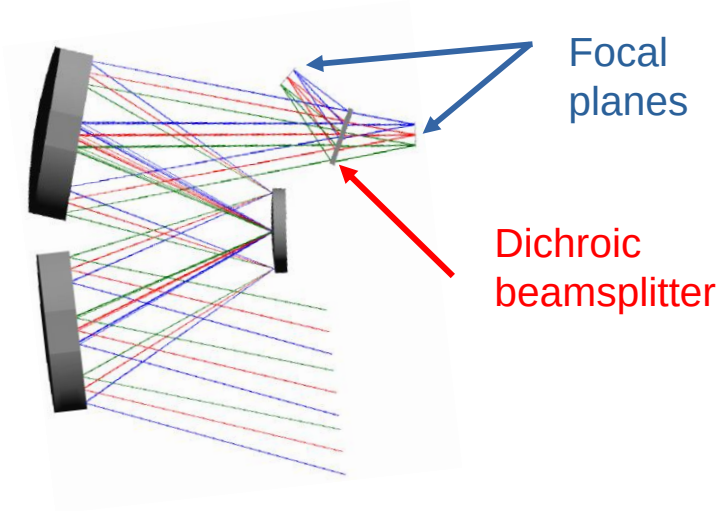
Assembled spectrum from 51 pointings

→ **17 channels × 3 bands = 51 pointings**

→ **51 pointings × 2 detectors = 102 channels**

Dithering the Spacecraft attitude modulates the wavelength at which an object is measured.

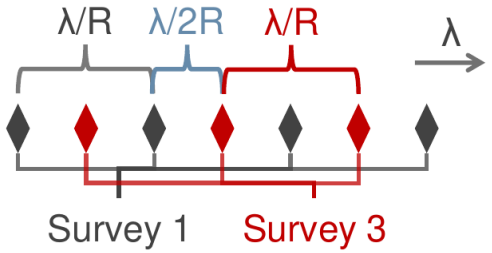




All-Sky Surveys / Mapping

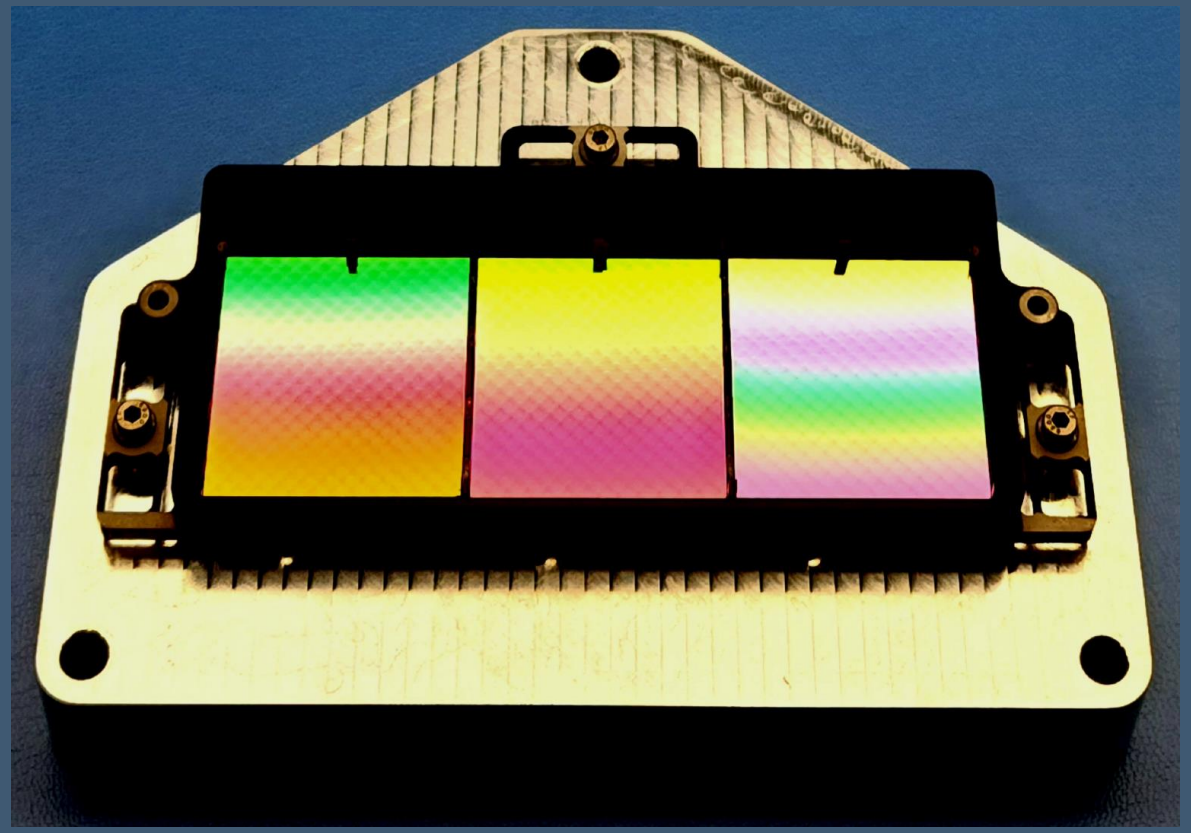
- There are 4 independent all-sky surveys, each takes 6 months to complete
  - Each with >98% coverage
  - Each of 102 spectral channels
  - Each survey is spectrally under-sampled at $\Delta\lambda = \lambda/R \sim \Delta\lambda(\mathrm{FWHM})$

- Offset spectral coverage between all-sky surveys 1&2 and 3&4 to yield Nyquist-sampled spectra
  - S3/S4 surveys shift the sampling by $+\lambda/2R$



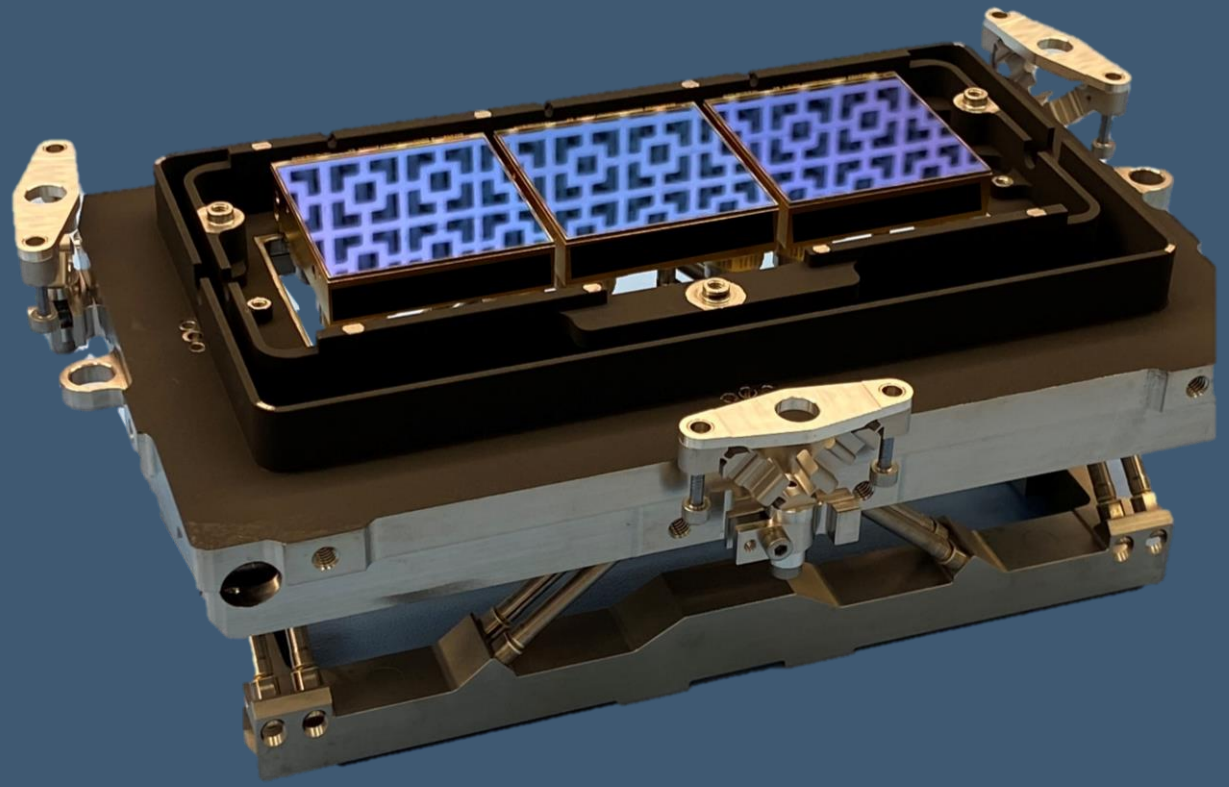
- Deep surveys at North and South ecliptic poles with surface brightness sensitivity at the spatial/spectral scales needed to probe extragalactic background light, and repeated coverage needed to isolate systematic effects on measurements

SPHEREx Linear Variable Filters & FPA



SWIR: band 1-3
(H2RG x 3)

MWIR: band 4-6
(H2RG x 3)



"KASI" Chamber Delivery (2022. 06)

Test Chamber for NASA's New Cosmic Mapmaker Makes Dramatic Entrance

Aug. 16, 2022

The SPHEREx mission will create a 3D map of the entire sky. Its cutting-edge instruments require a custom-built chamber to make sure they'll be ready to operate in space.



Custom built by the Korean Astronomy and Space Science Institute (KASI), a large stainless steel test chamber for NASA's SPHEREx telescope required a very special delivery to Caltech in Pasadena, California, where it will be used to ensure the spacecraft can withstand the rigors of space. Credit: NASA/JPL-Caltech

경향신문 2022년 8월 17일 수요일 016면 경제 기획

한국 연구진, NASA 최첨단 우주망원경 시험 장비 개발

천문연 '극저온 진공 체임버' 완성
영하 220도 환경서 장비 작동 점검
미국과 우주 연구협력 확대 발판

하늘을 넓은 시야로 촬영해 우주 생성 초기에 나온 빛을 감지하고, 생명체가 존재할 만한 외계행성을 잡아낼 미국 최첨단 우주망원경의 성능 시험 장비를 한국 연구진이 개발했다. 앞으로 미국과의 우주 협력을 확대하는 계기가 될 것으로 보인다.

과학기술정보통신부와 한국천문연구원은 미국 항공우주국(NASA)이 개발하고 있는 적외선 감지 우주망원경 '스피어엑스(SPHEREx)'의 성능을 시험할 '극저온 진공 체임버'를 개발했다고 17일 밝혔다. 천문연구원은 스피어엑스 개발에 참여하고 있는 유일한 미국 외 협력기관이다.

천문연구원은 극저온 진공 체임버를 2019년 8월부터 개발했으며 지난 6월 미국으로 이송해 설치를 마쳤다. 진공 체임버를 이용한 성능 시험은 내년부터 시행된다.



적외선 감지 우주망원경 '스피어엑스'가 지구 저궤도에서 다른 천체로부터 날아오는 적외선을 감지하는 상상도. 한국천문연구원 제공

스피어엑스는 열, 즉 적외선을 102개 영역으로 잘게 쪼개 정밀 관측하는 우주망원경이다. 은하나 별까지의 거리를 구하고 이를 통해 우주의 3차원 지도를 만드는 게 목표다. 천문연구원은 스피어엑스를 통해 별 20억개에 관한 정보를 얻을 수 있을 것으로 보고 있다.

스피어엑스를 쓰면 결과적으로 사람이 볼 수 있는 모든 하늘을 넓은 시야로 조망해 집중 관찰할 만한 별을 골라낼 수 있다. 우주 생성 초기에 생긴 빛이나 생명체가 있을 법한 행성을 선별하는 데 기여할 수 있는것이다. 스피어엑스는 2025년 4월 발사돼 지구 궤도 700㎞를 돌면서 2년 6개월간 관측에 들어갈 예정이다.

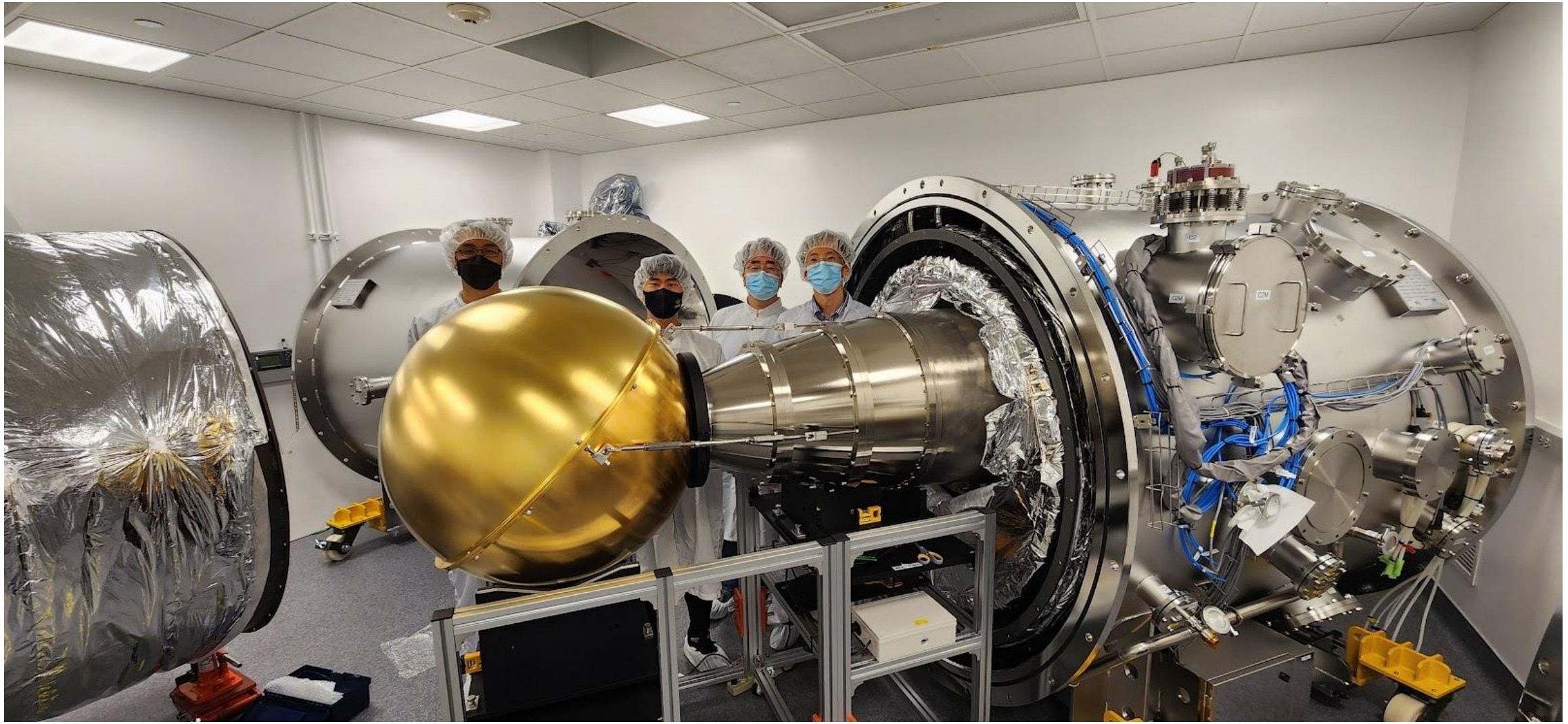
스피어엑스의 가장 큰 특징은 매우 차가운 상태, 즉 영하 220도에서 운영해야 한다는 점이다. 우주의 일반적인 온도보다 춥게 관리해야 별에서 나오는 미약한 적외선을 예민하게 감지할 수 있다.

태양계 행성인 목성의 경우 표면 온도가 영하 148도인데, 영하 220도로 유지되는 스피어엑스 입장에선 아주 따뜻한 천체로 인식되는 셈이다. 손을 차가운 물에 오랫동안 담갔다가 미지근한 물에 옮기면 순간적으로 무척 뜨겁게 느껴지는 것처럼 스피어엑스도 평소 아주 차갑게 관리해 관측 성능을 높이는 것이다.

천문연구원은 극저온 진공 체임버 안에 스피어엑스를 밀어 넣은 뒤 영하 220도를 구현해 스피어엑스에 달린 각종 촬영 장비들이 정상 작동하는지 확인할 예정이다. 특히 사진의 초점이 이 같은 극저온에서도 잘 잡히는지 검증할 계획이다.

이정호 기자 run@kyunghyang.com

Spectral Calibration/Winston Cone Assembly (2023.4.7)



KASI SPHEREx Team: 양유진, 조영수, 박성준, 정웅섭 (왼쪽부터)

Telescope arrived at Caltech (2023.5.18)



arrival from Ball

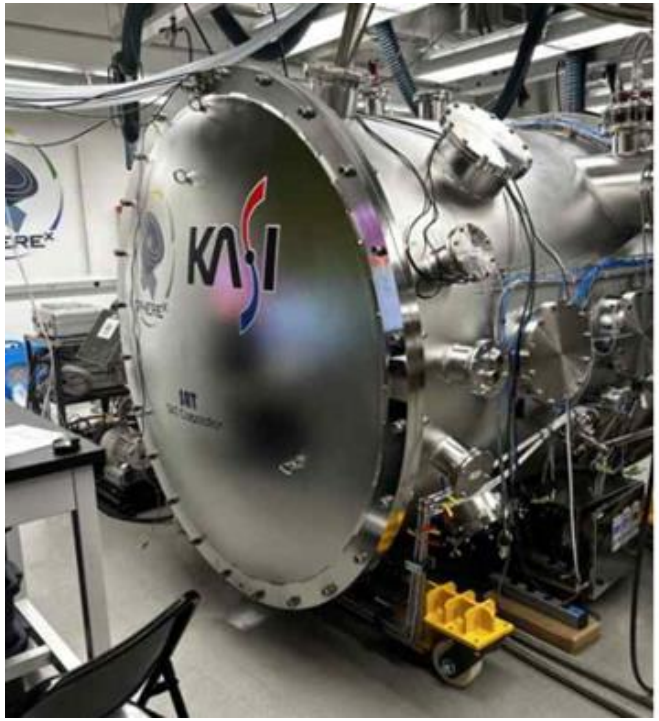


transfer to flotron

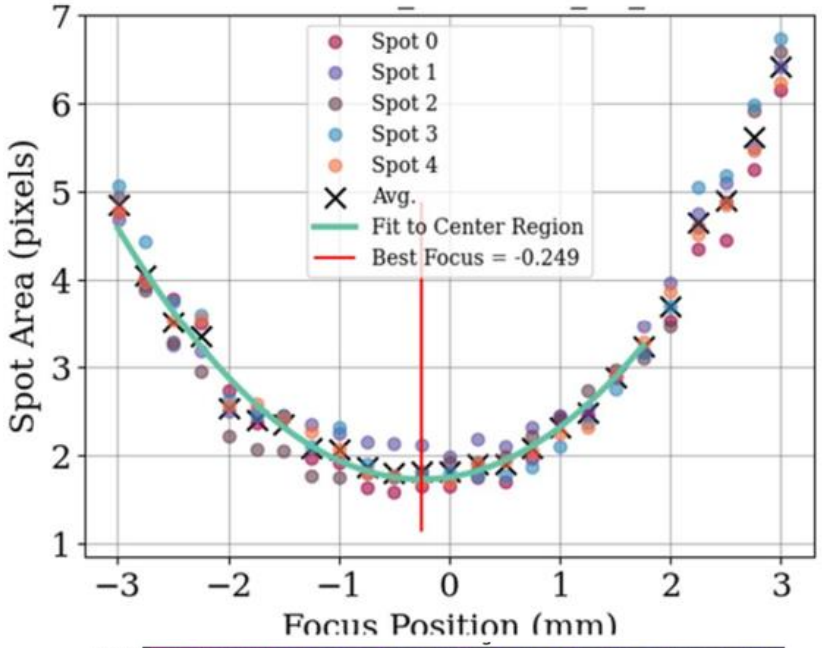


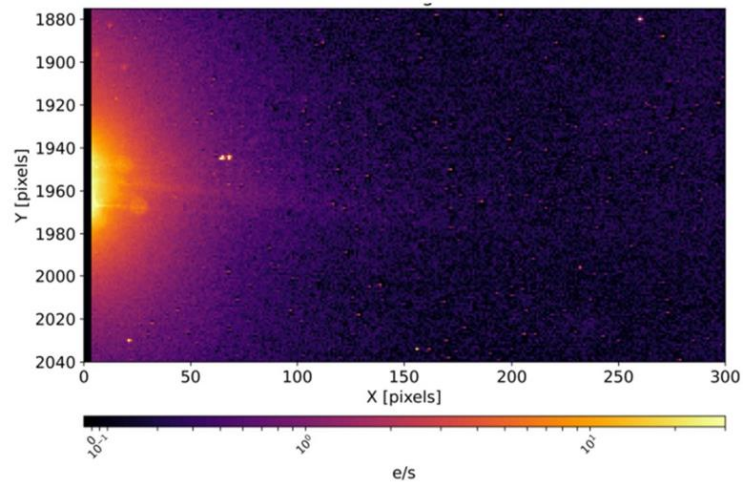
prep. for warm focus test

Focus Test: TVAC(KASI) 1-3 (2023.7 -10)



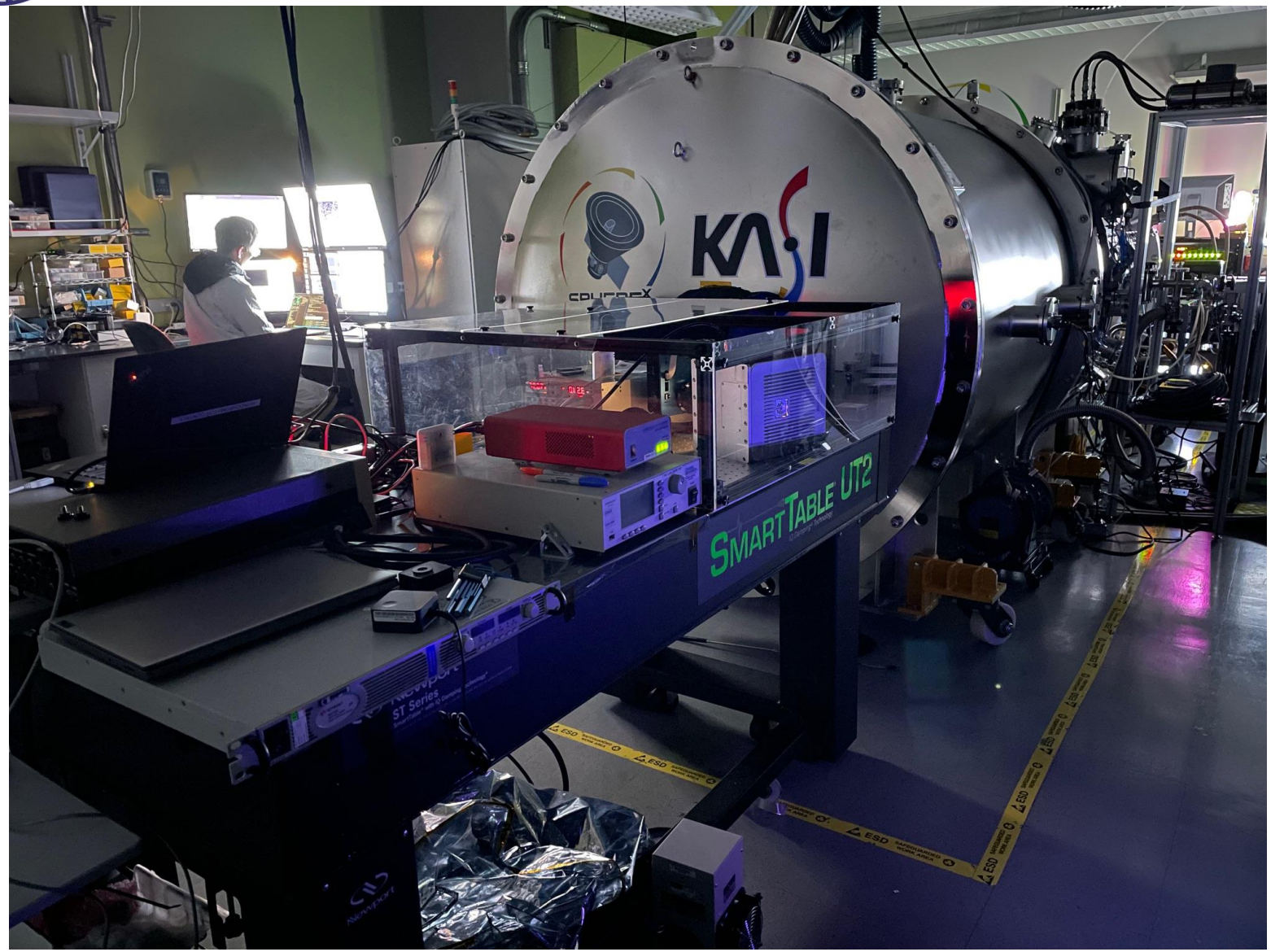




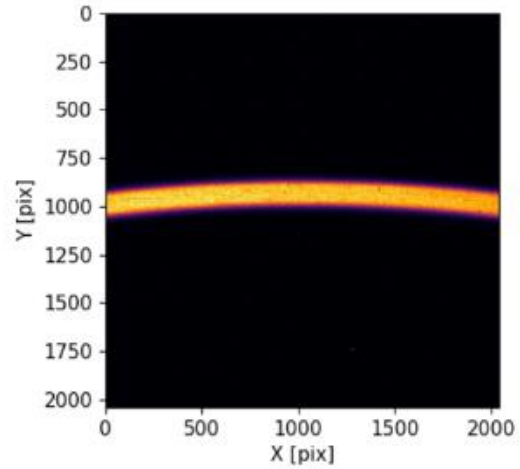


- TVAC1: first focus
- TVAC2: shim adjustment
- Vibration test
- TVAC3: confirm focus

Dark Calibration: TVAC4 (2023.11 – 2024.01)



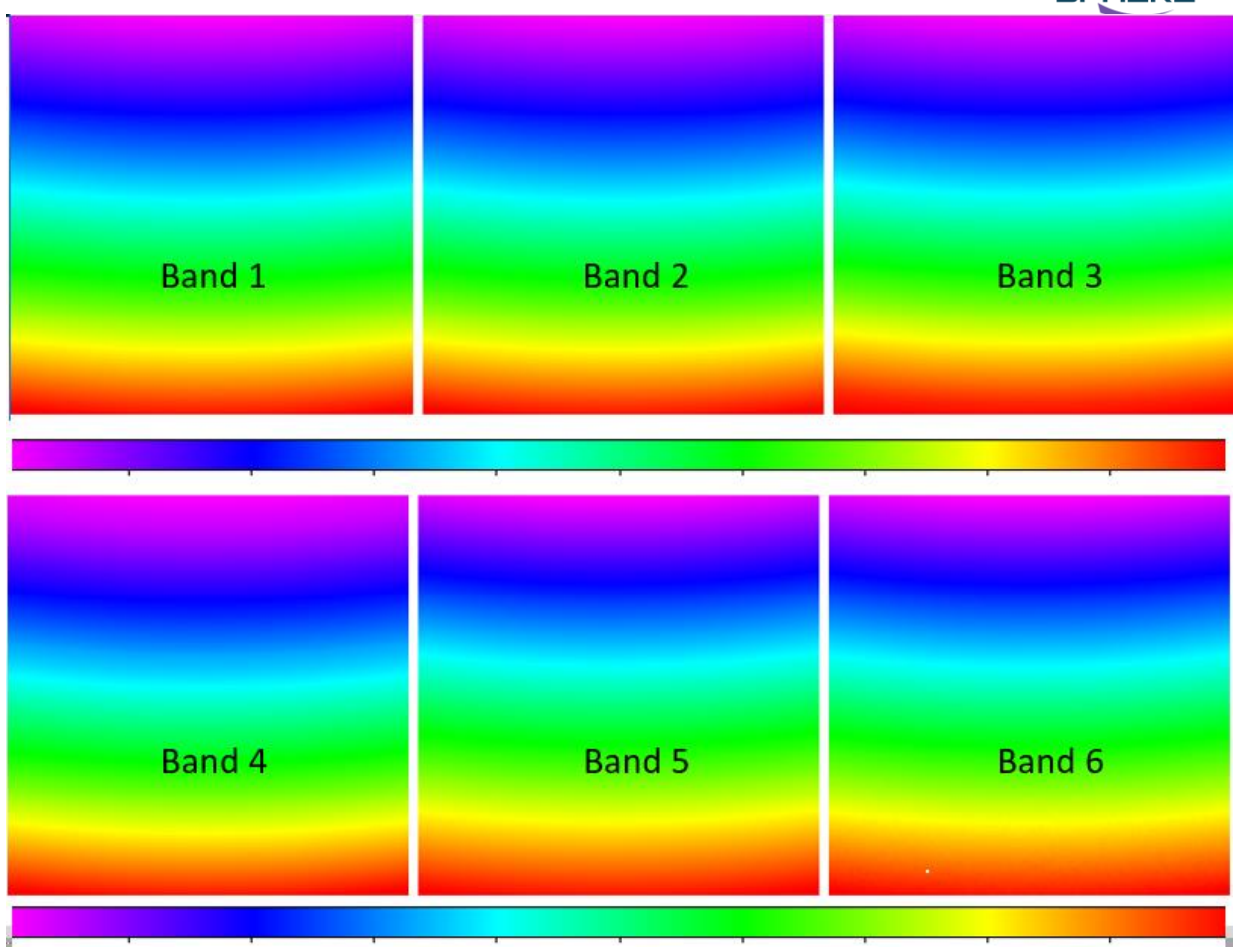
- Main calibration: ~2 weeks (overnight)
- Data reduction: wavelength solution by KASI and Caltech

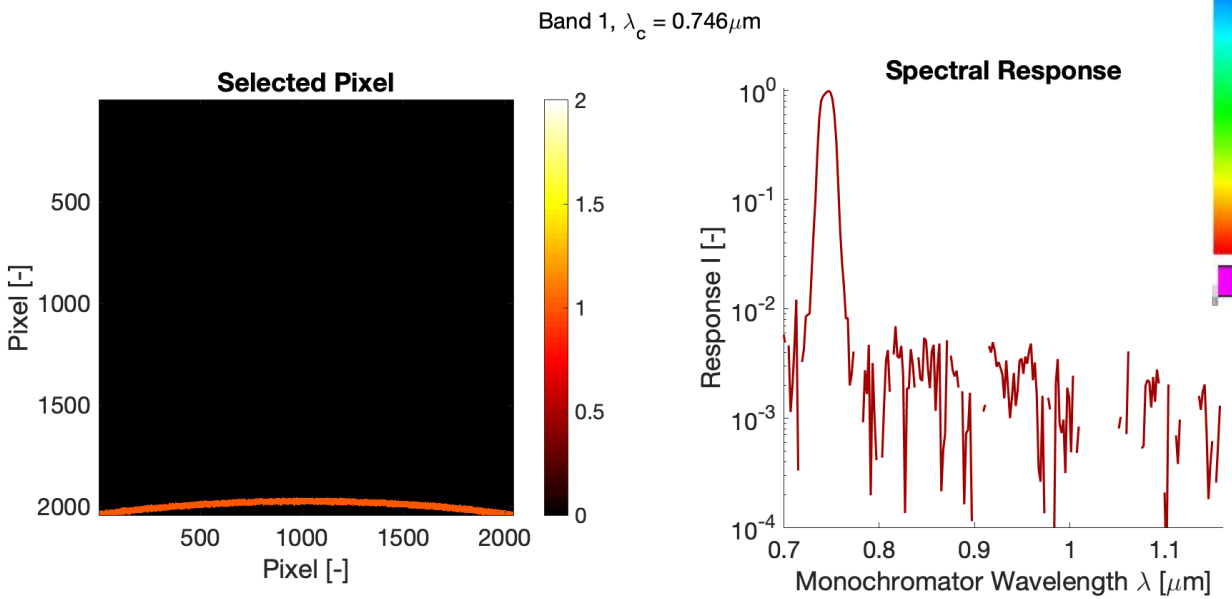


Wavelength Calibration

- Band1: 0.737 – 1.119 μm
- Band2: 1.088 – 1.655 μm
- Band3: 1.620 – 2.415 μm
- Band4: 2.399 – 3.827 μm
- Band5: 3.795 – 4.421 μm
- Band6: 4.397 – 5.006 μm

Wavelength solution from KASI's method





- Evaluation of leaks @ LVF
- Detector persistence / transient
- Data compression, …

Photon Shield: Ready! (2023.12)



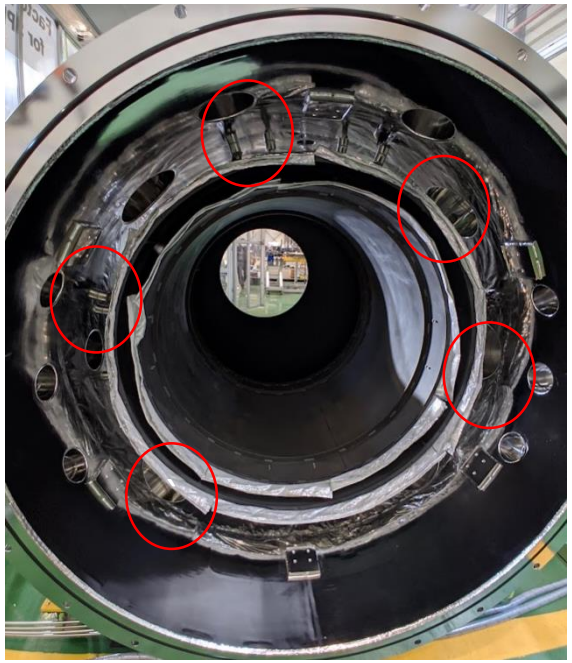
- ’24. 02: Payload
  → Ball Aerospace
- Integration into satellite
- Space environmental test
- ‘24. 12: PSR
- Launch:
  no earlier than ’25. 02

Newly Developed Technologies

- Double shrouds
  - inner (< 80K), outer (< 100K): up to 5μm
  - FPA: ~50K @ Red & ~80K @ Blue
  - Support structures: flexure
- Operation of Pulse-Tube Coolers
- Accurate loading of telescope (TCA)
- Small chamber for testing of IR detector

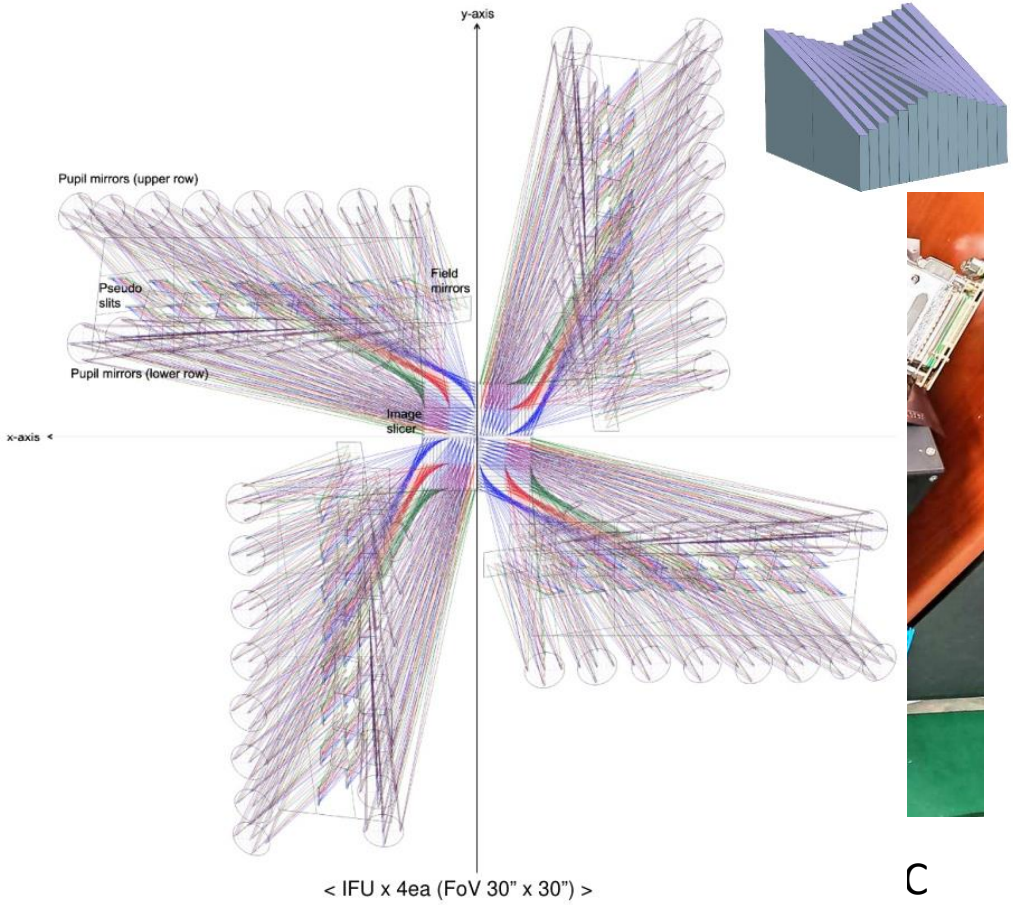
✓ **Operation of IR detector with low noise**

✓ **IFU Spectroscopy**









Double shrouds & Ti Flexures Pulse-Tube Cooler + Remote motor De C

SPHEREx – Three Key Science Cases



How did the Universe begin?

Probe inflation through studies of primordial non-Gaussianity



How did galaxies begin?

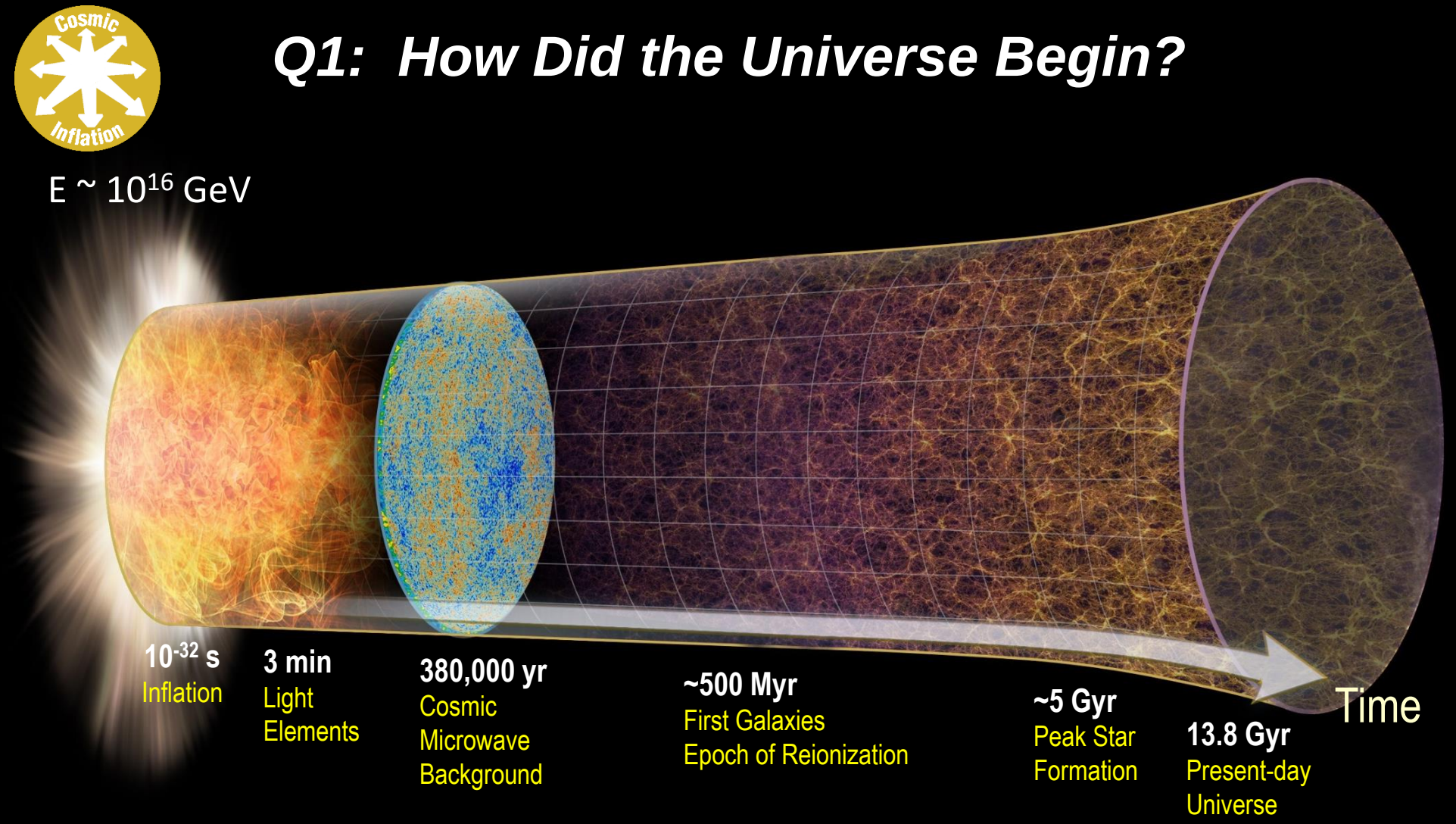
Study the history of the cosmic light production
through NIR background fluctuations



What are the conditions for life outside the solar system?

Survey the Milky Way for water and other Biogenic Ices

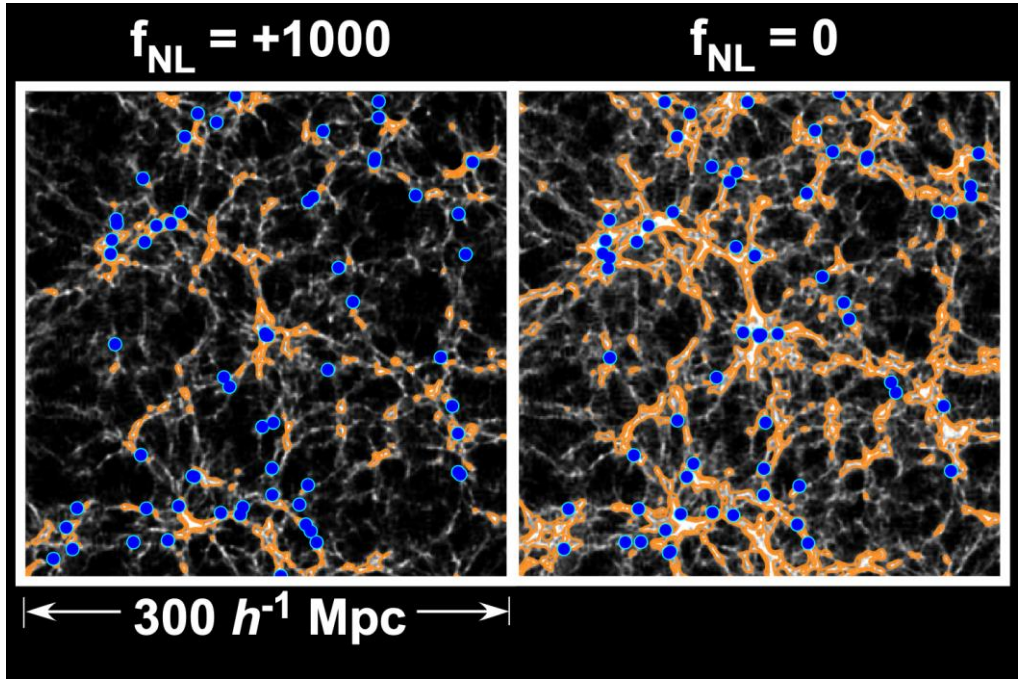
Q1: How Did the Universe Begin?

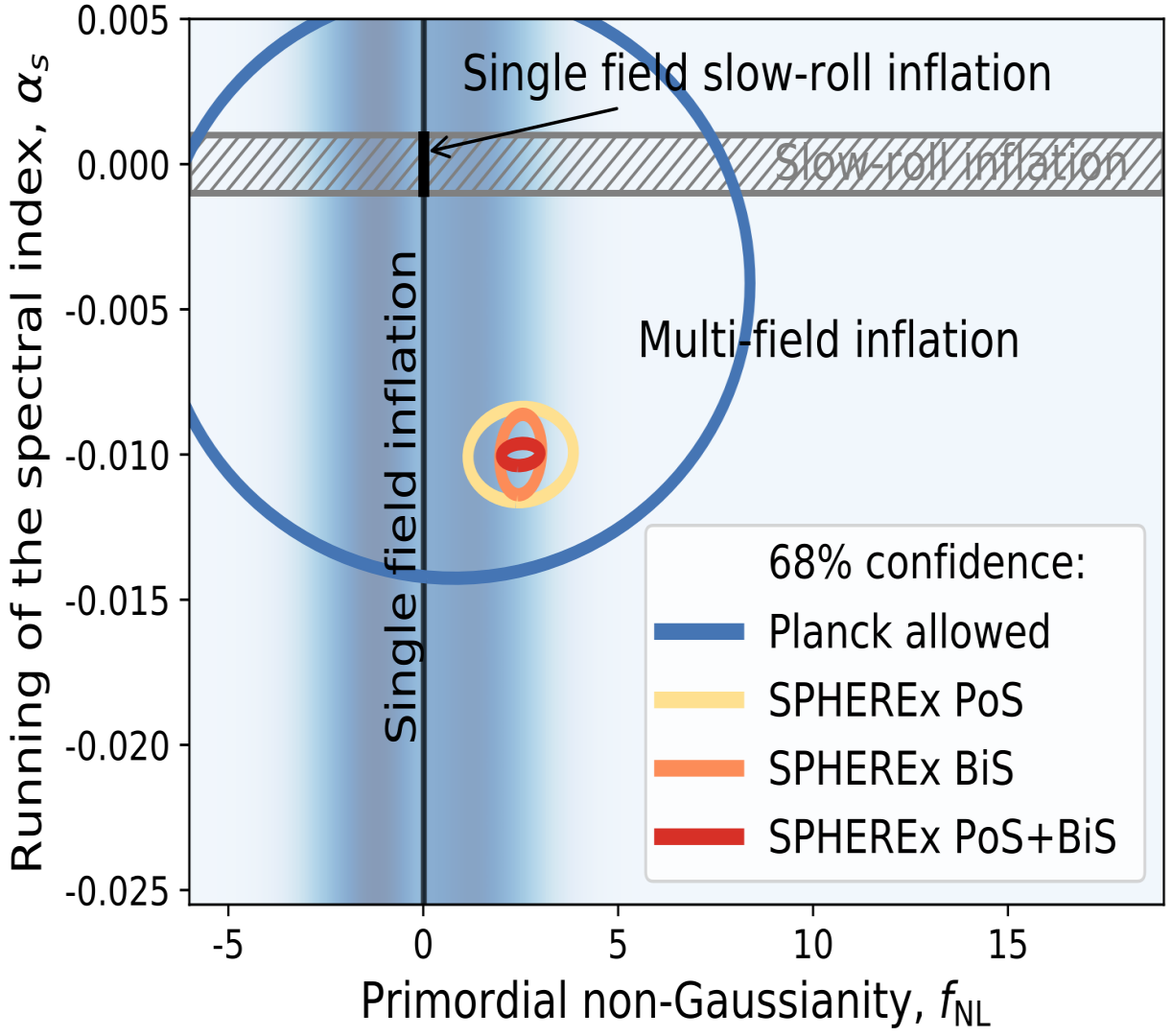


SPHEREx observes the 3D distribution of galaxies,
uses Non-Gaussianity *to probe inflation physics*

Cosmology LSS: Testing Inflation r & f_{nl}

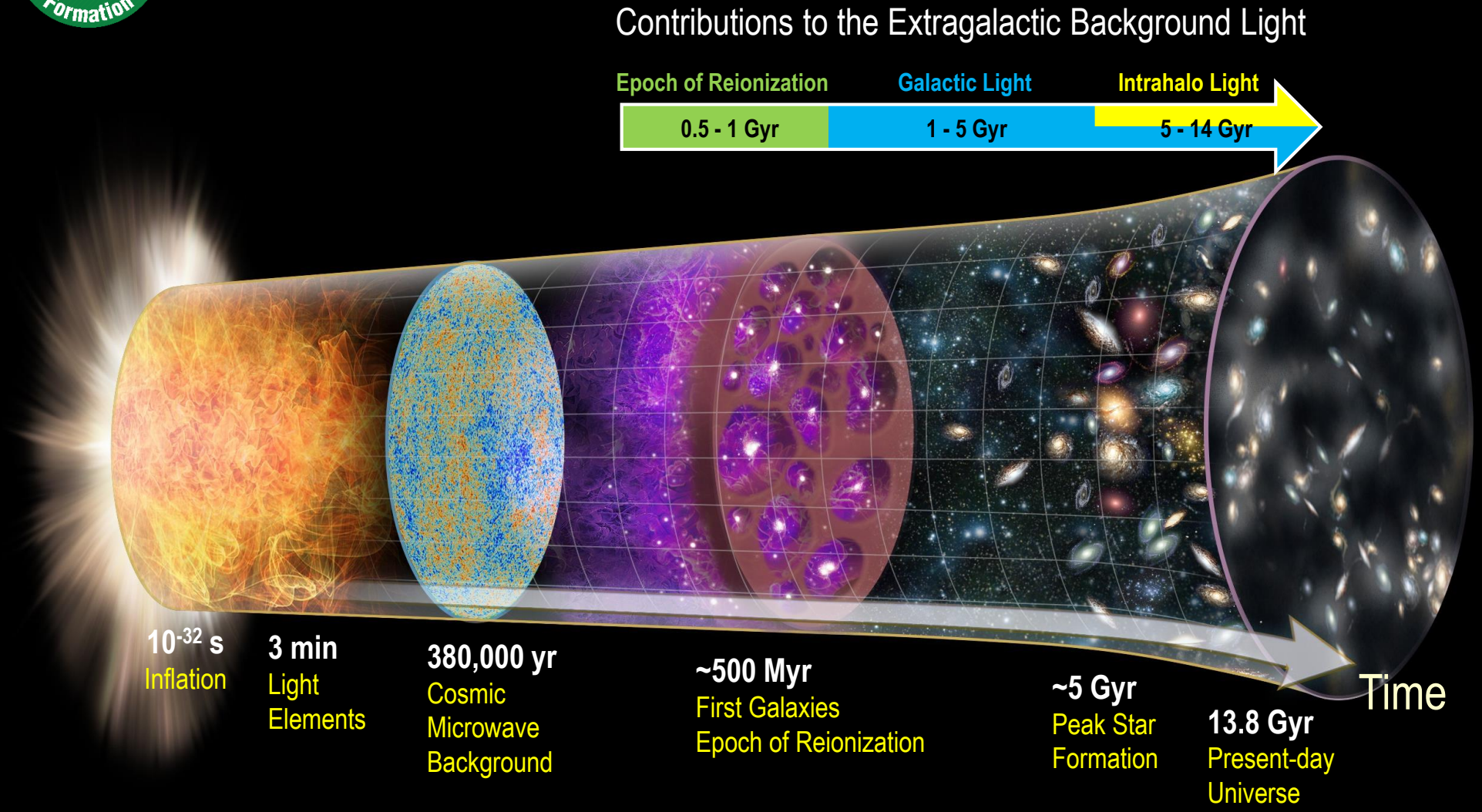
- SPHEREx improves limit on f_{nl} by a factor of 10
  - Δf_{nl} ~5 accuracy today to Δf_{nl} <0.5 with SPHEREx
- Measure running of spectral index to also constrain inflation
- Combine with CMB data to robustly probe inflation





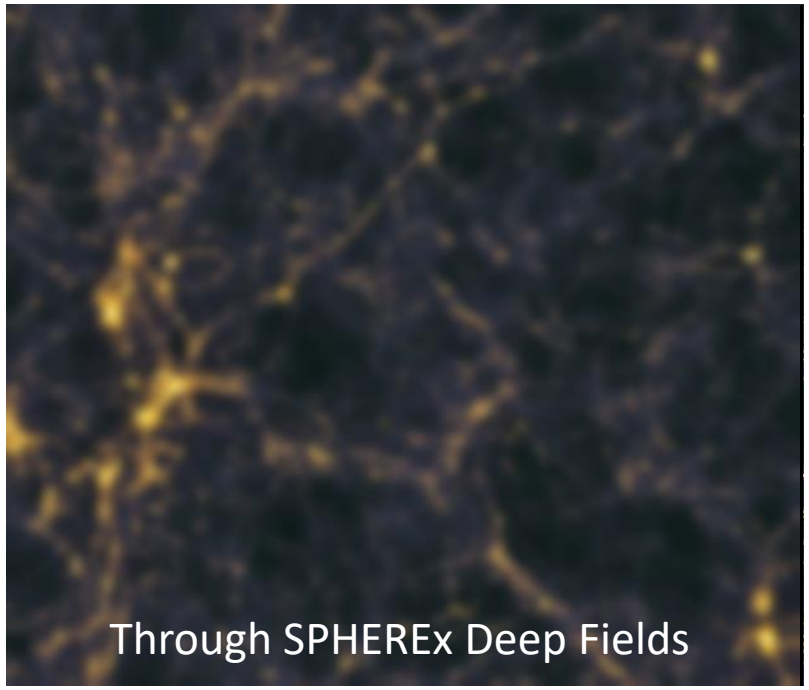
Slide: SPHEREx Team

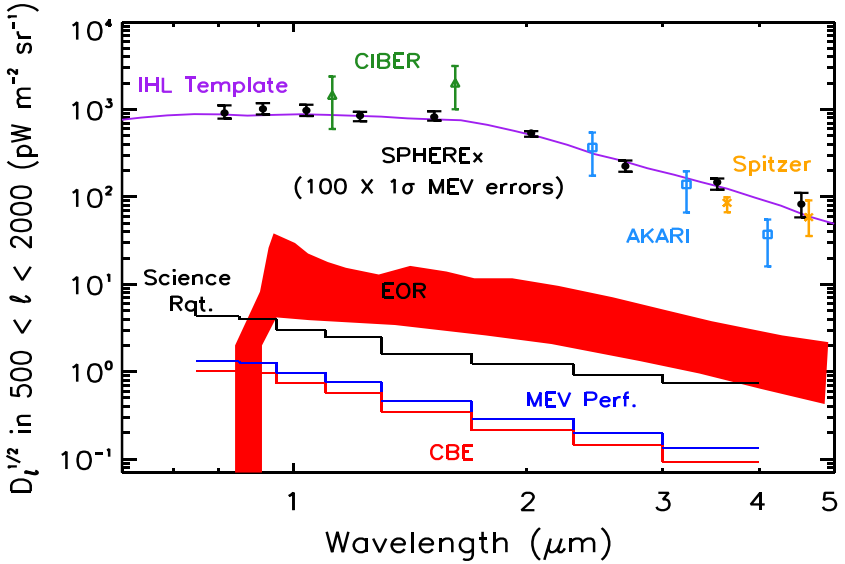
Q2: How Did Galaxies Begin?



SPHEREx extragalactic background light measurements determine the total light emitted by galaxies

Surveying Cosmic History of Galaxies

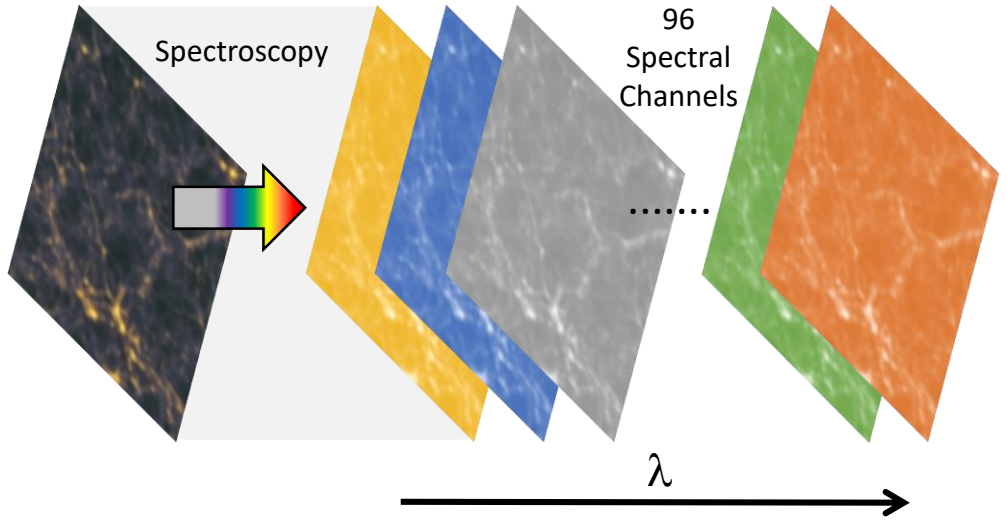




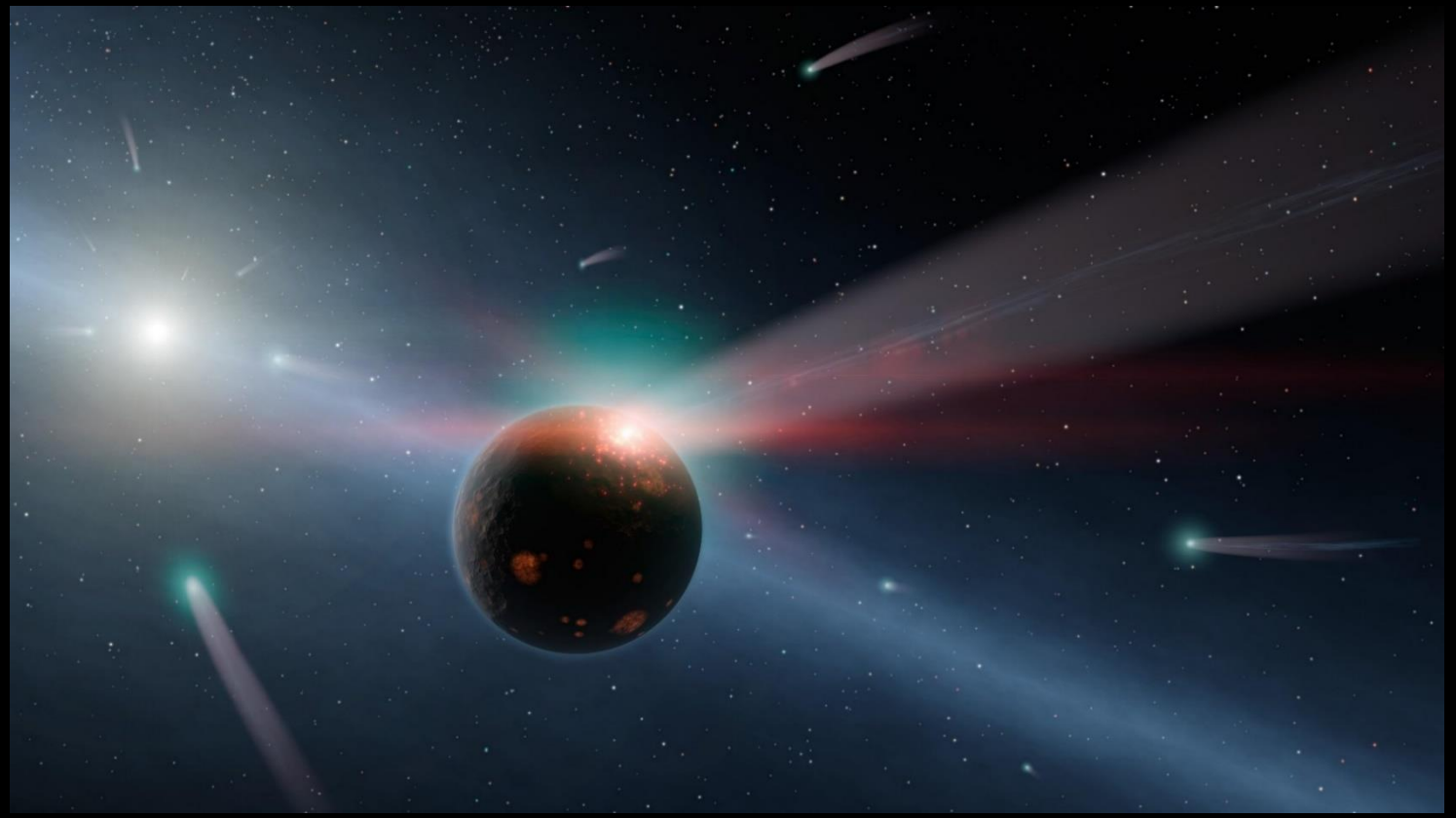
Intensity mapping measures light emitted by *everything that gravitationally clusters*

- Traces faint light associated with dark matter
  - Emission from all galaxies
  - Dwarf galaxies responsible for reionization
  - Diffuse emission from stripped stars
  - Dark matter decay (?)
  - Complements galaxy-by-galaxy surveys
- Method used on CIBER, Spitzer, AKARI, Herschel, Planck

Spectroscopy is key for untangling cosmic history



Q3: What Are the Conditions for Life Outside the Solar System?



Sourced by **interstellar ices**, rich in biogenic molecules: H_2O, CO, CO_2, CH_3OH…

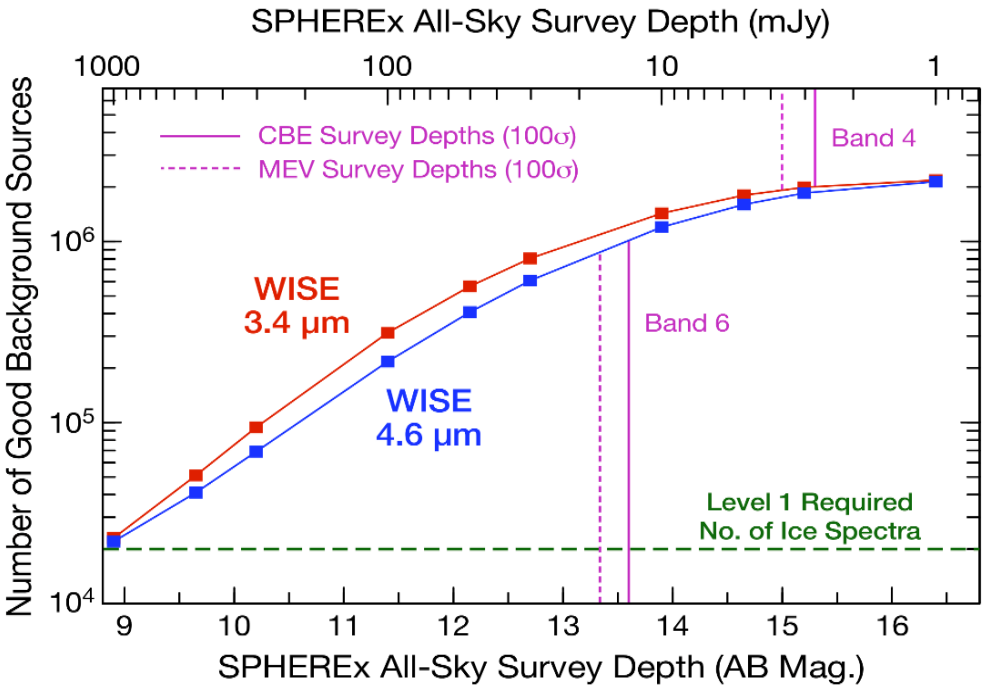
Current debate: did earth's water come from the Oort cloud, Kuiper belt or closer?

Did water arrive from asteroids or comets?

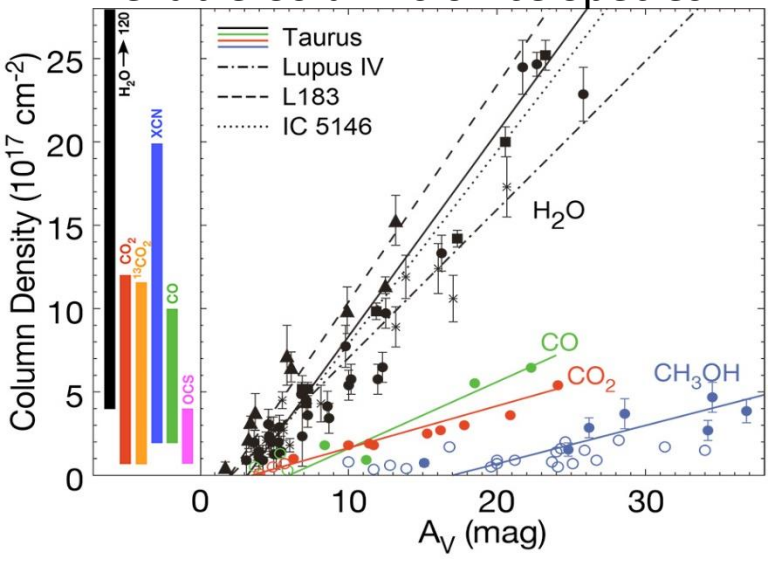
SPHEREx will measure the H_2O, CO, CO_2, CH_3OH ice content in clouds and disks, determining how ices are inherited from parent clouds vs. processed in disks

SPHEREx Galactic Ice Survey

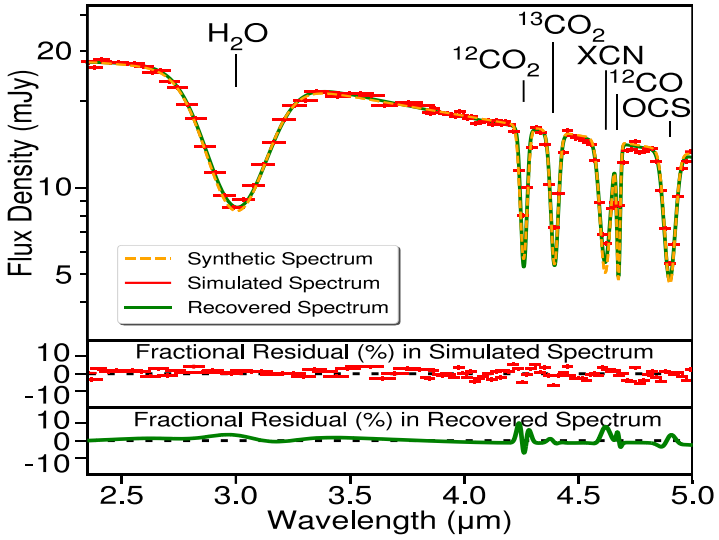
- "High-quality ice source"
  - Embedded behind dust
  - Bright (SNR > 100 per channel)
  - Isolated



Reliable Columns of Ice Species



Estimated Errors on Absorption Depth

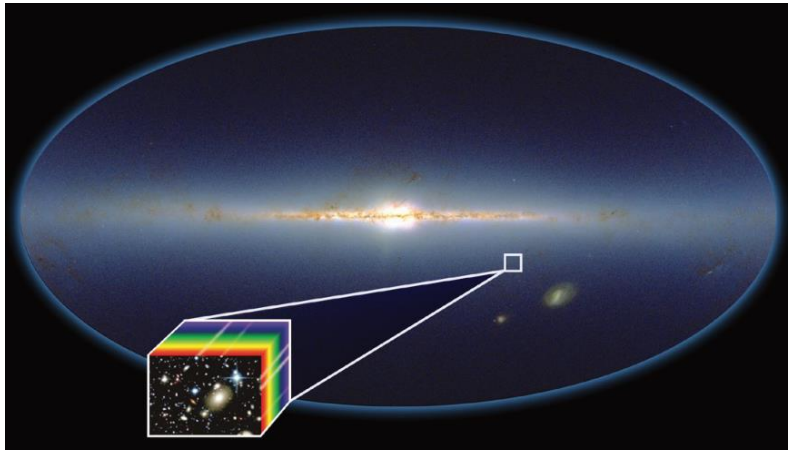


SPHEREx Data Products & Tools

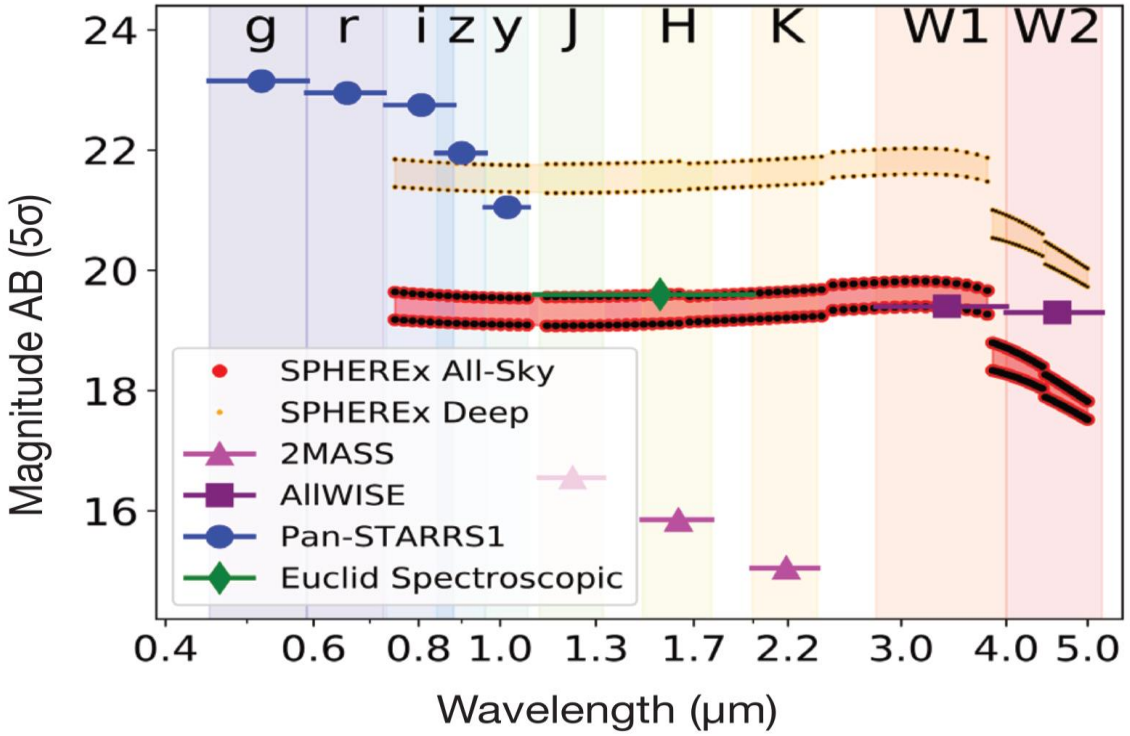
- **LVF images** (spectral images)
- **All-sky Data Cubes**
- **High Reliability Source Catalogs**

- **Legacy Data Products**
  - Legacy Galaxy Catalog
  - Legacy Deep Field Mosaics
  - Legacy Ice Column Density Catalog

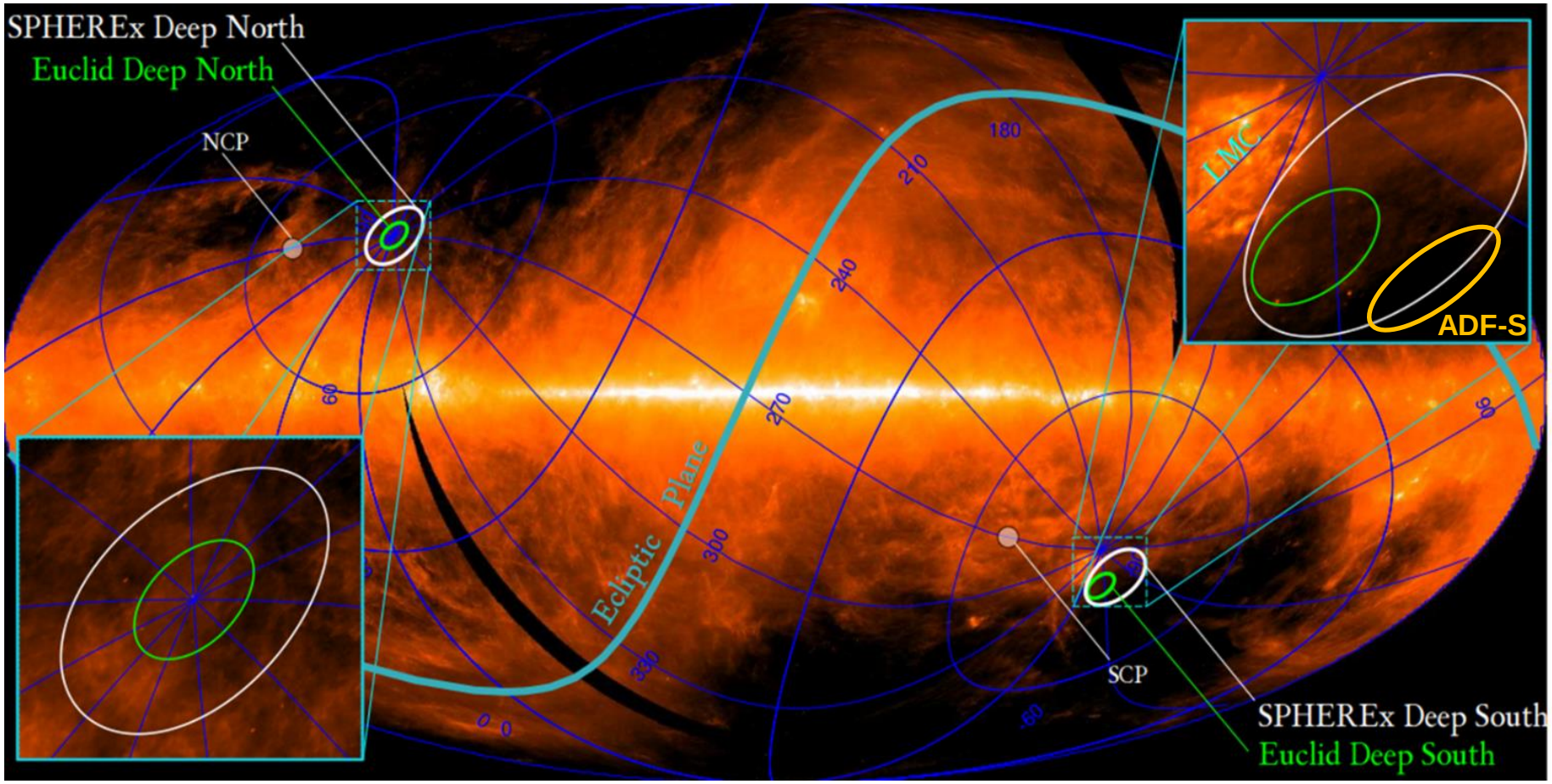
- Data will be delivered to IPAC Infrared Science Archive (IRSA)



- **IRSA-provided SPHEREx tools**
  - Spectrophotometry (forced phot.)
  - Source Discovery
  - Custom Mosaic
  - Spectral Cube Cutout
  - LVF Image Cutout

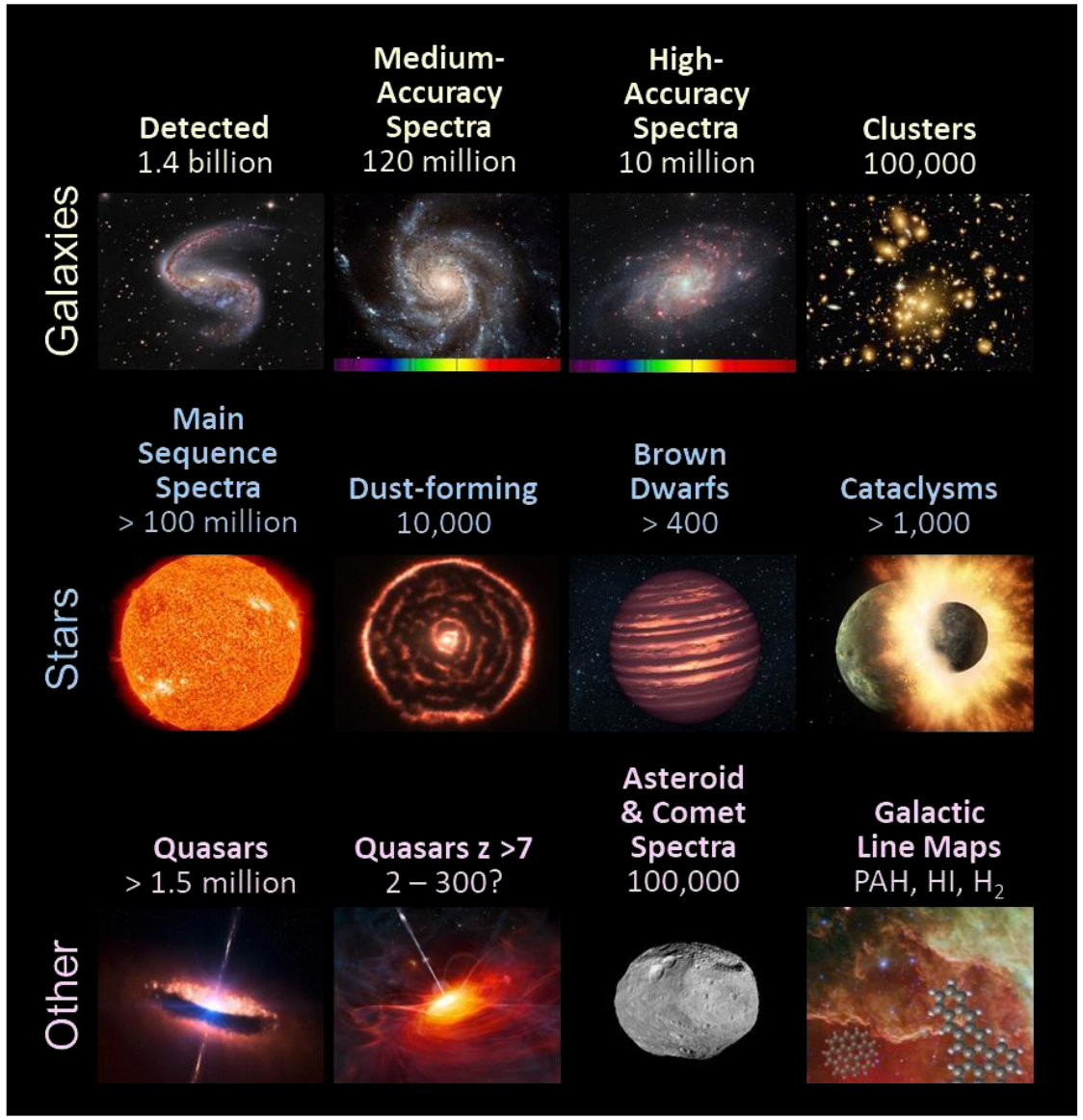


SPHEREx Deep Survey Fields



- North/South Ecliptic Pole (NEP/SEP) Deep Fields: 100 + 100 sq. deg.
  - Average 60x deeper than all-sky survey. Exact locations: TBD
  - Coverage not uniform, but include Euclid Deep Fields and eROSITA
  - Overlap with AKARI Deep Fields (NEP/SEP)

A Rich All-Sky Spectral Archives

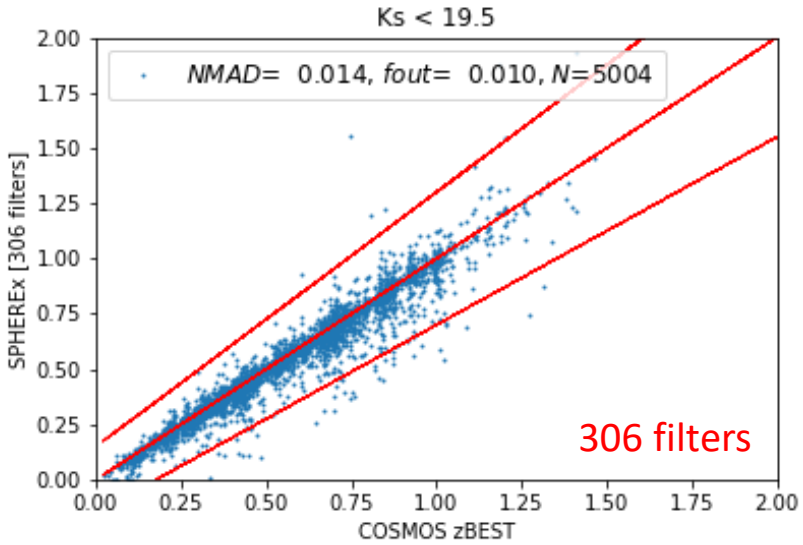


- SPHEREx will be the first all-sky near infrared spectroscopic survey
- All-sky surveys demonstrated high scientific returns with lasting data legacy used across astronomy (COBE, IRAS, GALEX, WMAP, Planck, WISE, 2MASS)
- Many exciting discoveries will come from the community (US & Korea)

→ **Legacy Science Cases**

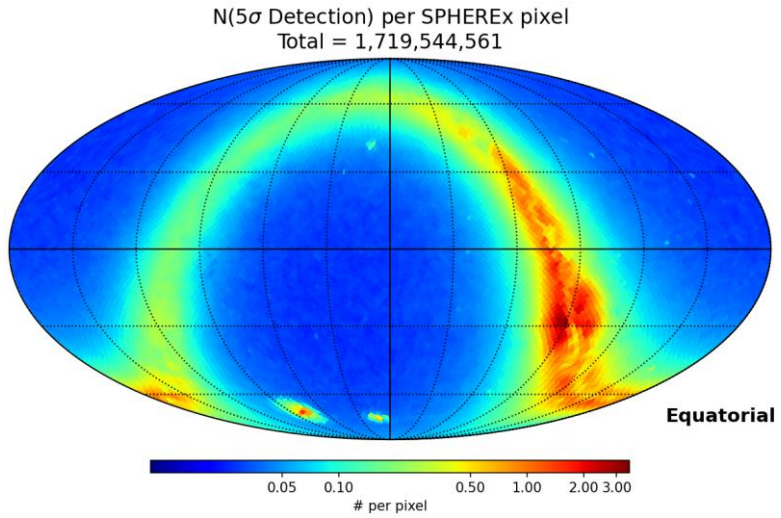
SPHEREx Science & Pipelines: Korean Contribution

- L4. SPHEREx Ices major contributor
- L4. SPHEREx redshift pipeline
- L3. SPHEREx Reference Catalog
- SPHEREx Simulator
  - SPHEREx-Sky-Simulator, QuickerCatalog
  - SPHEREx-Sky-Simulator on-line version
- SPHEREx Forced Photometry
- Galaxy Cluster Legacy Catalog



SPHEREx Ices Target List (SPLICES)



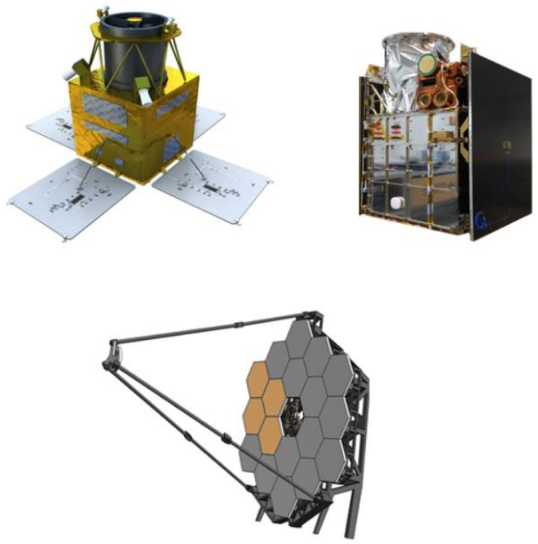


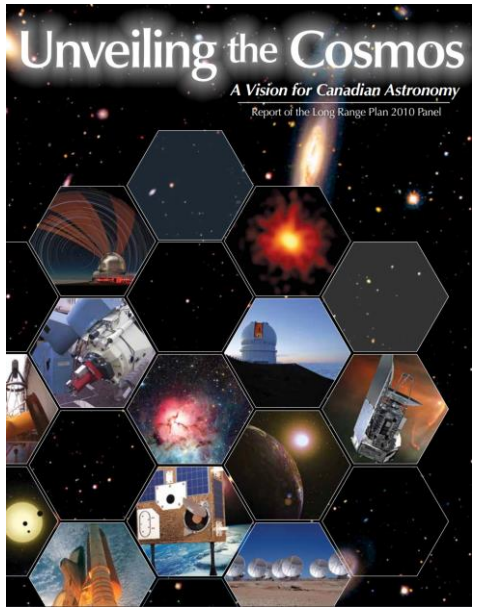
KASI SPHEREx Team

Category	Team Members
Instrumentation and calibration (KASI Chamber)	정웅섭, 조영수, 양유진 방승철, 유영삼, 차상목, 양호연, , Shankar Bhattarai
Inflation Cosmology	이보미, 김용정
Galaxy Formation (EBL)	정웅섭, 강재환 (Caltech)
Biogenic Ices	김재영, 강미주, 양성철, 이재준, 이호규, 석지연, 김일중, 천상현 이정은(서울대), 김철환(서울대), 노진영(서울대), 권우진(서울대), Carlos Contreras (서울대)
SPHEREx-Sky-Simulator	표정현, 이재준, 박윤수, 양유진
SPHEREx Reference Catalog	양유진, 홍성용, 이준협
Tractor photometry	표정현, 김성재, 문병하
SPHEREx AGN Science (External Collaborators)	김민진(경북대), 우종학(서울대), 김도형(부산대), 오규석
SPHEREx Solar System Objects	박윤수
SPHEREx Galaxy Cluster	황호성(서울대), 박형욱(서울대)
Legacy Science Cases	신윤경, 이준협, 이종철, 김상철, 손지원(경북대) + 모든 팀 멤버

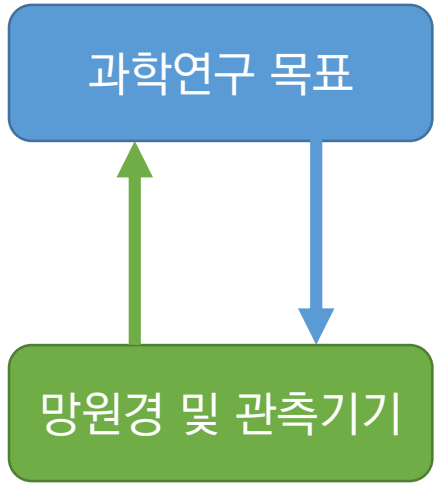
Pre-project for Korea-led Space Telescope

- 한국천문연구원 미래유망과제(Qrontier)로 선정 (2+1년)
  - 과학연구 주제 설정
  - 국내주도/국제협력 전략 수립
  - 현실성 있는 개발 로드맵 수립











Summary

- **SPHEREx: first all-sky infrared spectro-photometric survey**
  - Three major scientific themes + Legacy sciences
  - Spacecraft & payload are assembled and tested.

- **KASI & Korea's contribution**
  - Hardware: calibration facility ("KASI" chamber)
  - Data reduction pipelines
  - Key & Legacy Sciences

- Calibration of SPHEREx telescope with KASI chamber: **System-level performance test → completed!**

- Launch: **no earlier than Feb. 2025**

- KASI Qrontier Project: Pre-project for Korea-led Space Telescope (2+1 yrs)


2024 SPHEREx-7DT Joint Workshop
2024 Jan. 24-26, RESTREE, Jecheon, Chungcheongbuk-do
NRF