SPHEREˣ: An All-Sky Infrared Spectral Survey Satellite

Small Mission, Big Science

- Origin of the Universe
- Origin and History of Galaxies
- Origin of Water in Planetary Systems
- First All-sky Infrared Spectral Survey

Flight Hardware Largely in Hand

Coming Milestones this Year

- Instrument Testing and Delivery
- Science Phase E/F Budget Determined

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JPL Sr. Research Scientist & Fellow

SPHEREX ADDRESSES 3 FUNDAMENTAL QUESTIONS

How Did the Universe Begin?

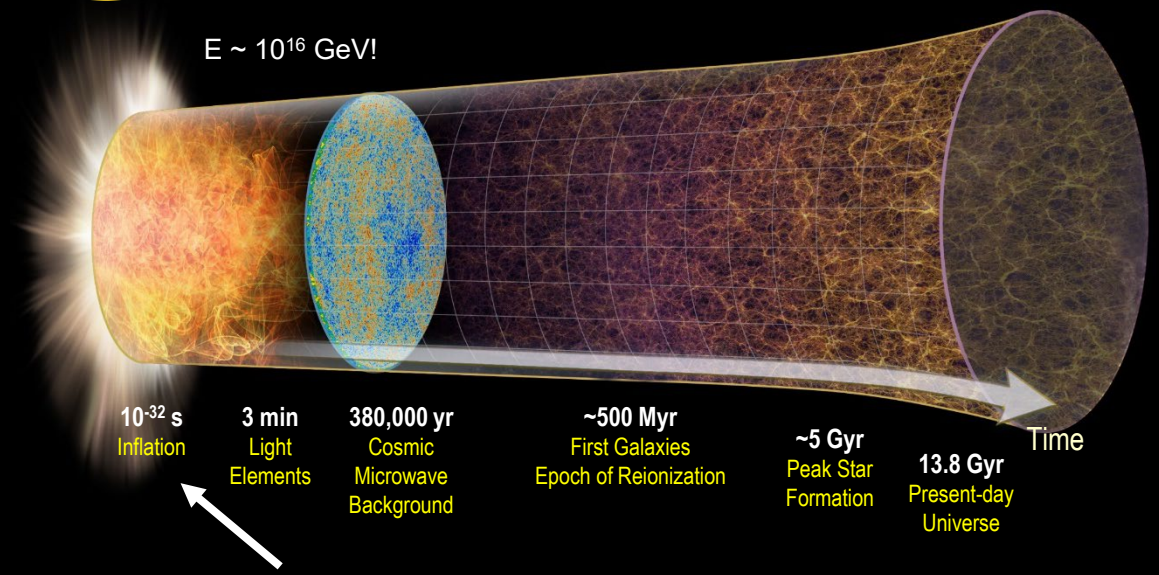
How Did Galaxies Begin?

What are the Conditions for Life Outside the Solar System?

…While Creating a Unique All-Sky Spectral Survey

Each theme coincides with a driving Level-1 science requirement

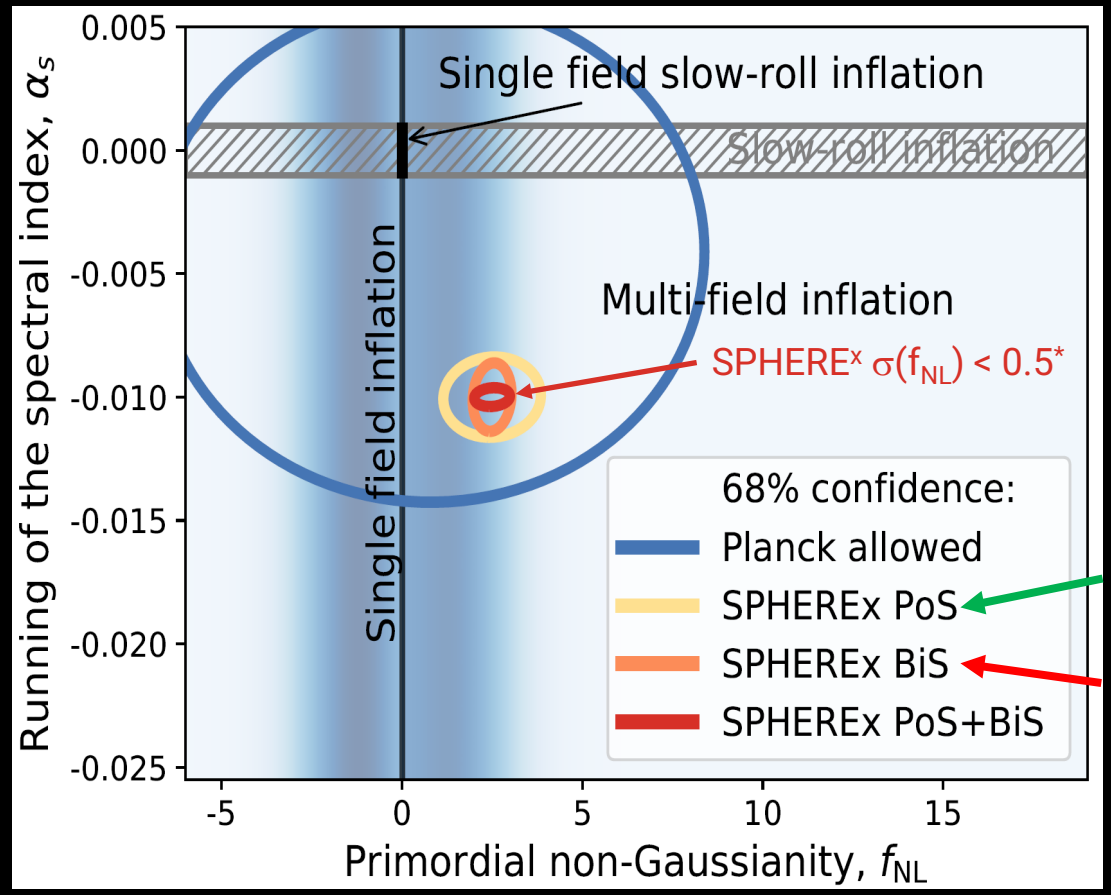
HOW DID THE UNIVERSE BEGIN?



Probing ***Inflation*** with Non-Gaussianity (f_{NL})

- **Single-field models** predict $f_{NL} < 0.01$
- **Multi-field models** predict $f_{NL} > 1$
- **Non-inflationary models** (Steinhardt *et al.*) predict $f_{NL} \sim 1$

Did Multiple Fields Drive Inflation?

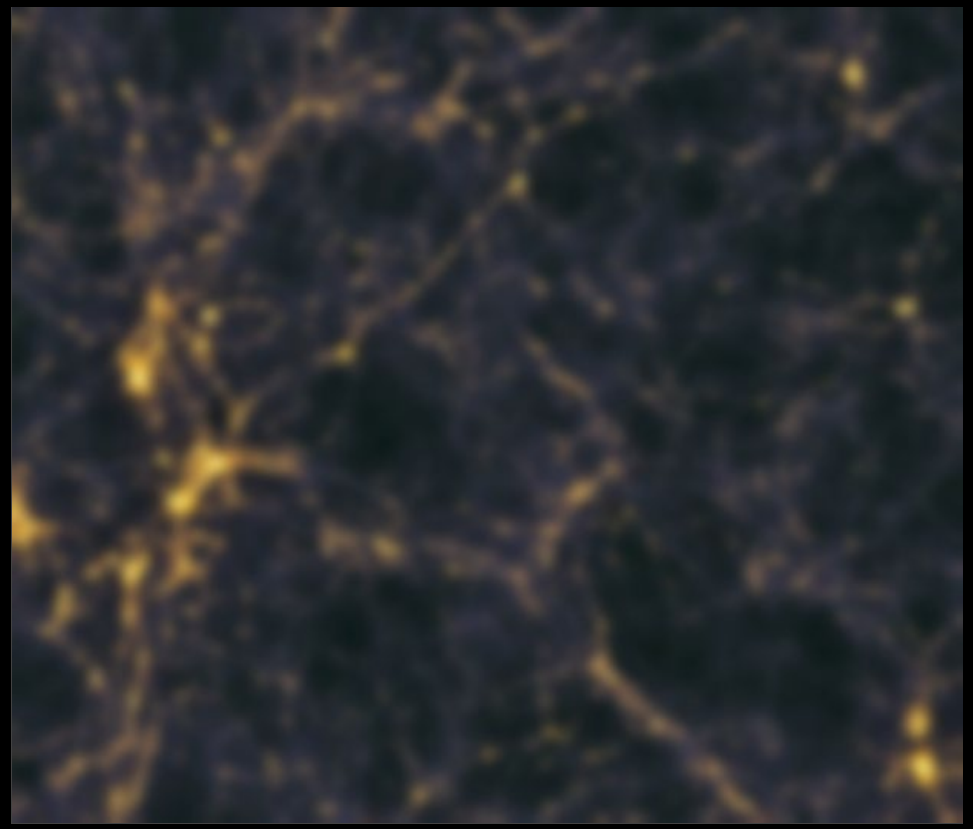


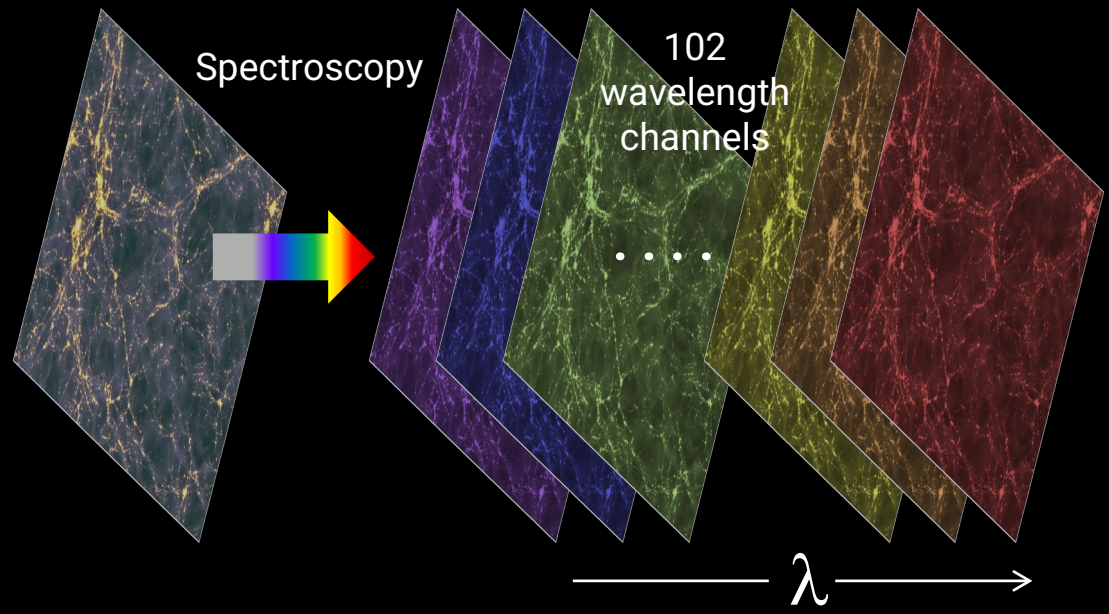
*Multi-tracer analysis exploiting LPNG bias (b_ϕ) may offer further improvement!

2020 Astro Decadal: "The search for primordial non-Gaussianity, either to detect a signal or to constrain f_{NL} to be below 1… is particularly important"

HOW DID GALAXIES BEGIN?

Intensity Mapping





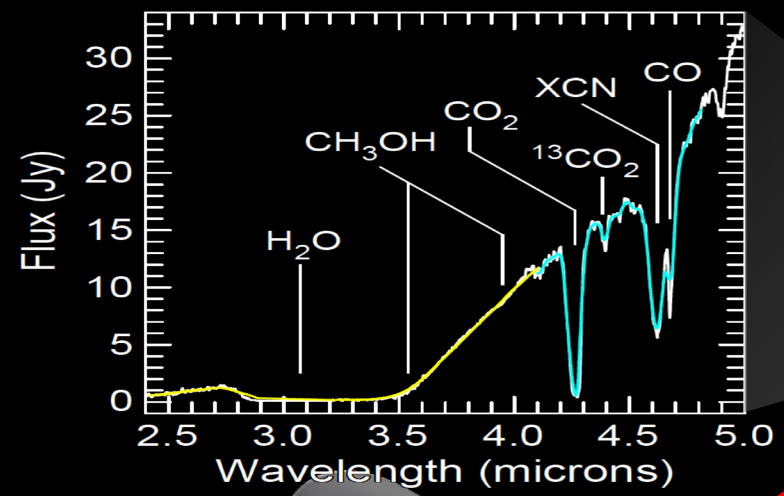
Spectral Decomposition Determines

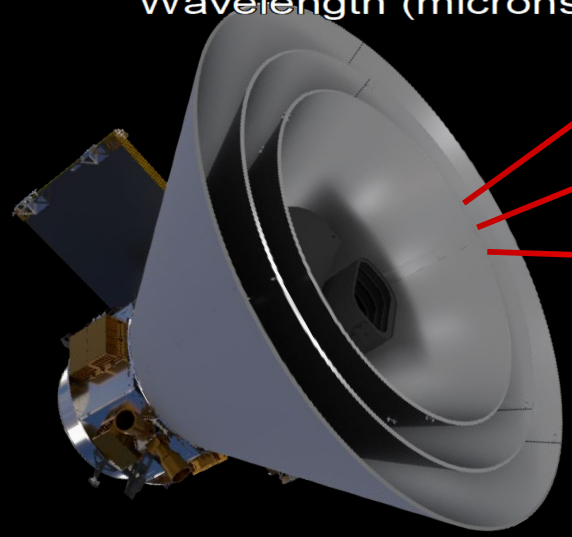
- Emission from all galaxies
- Dwarf galaxies responsible for reionization
- Diffuse emission from stripped stars
- Dark matter decay (?)

- Complements galaxy-by-galaxy surveys
- Method used on CIBER, Spitzer, Herschel, Planck

Intensity Mapping captures the light emitted from *everything that gravitationally clusters*

WHAT ARE THE CONDITIONS FOR LIFE OUTSIDE THE SOLAR SYSTEM?





Background star

Dense Clouds

Young Stellar Envelopes

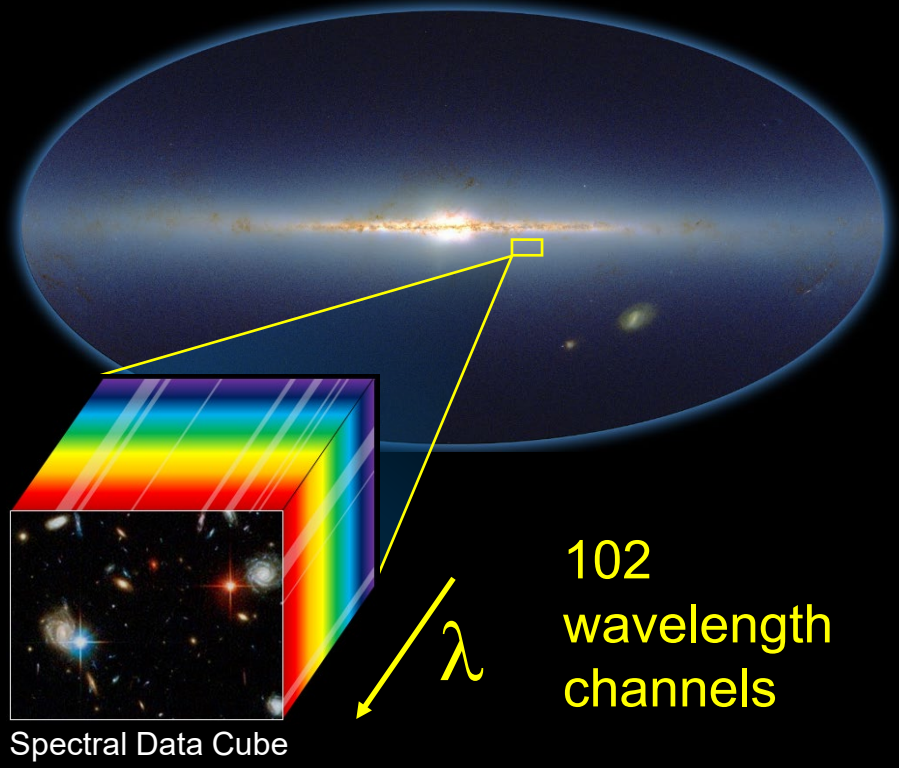
Protoplanetary Disks

Young Solar Systems

More than 99 % interstellar water is locked in ice: *'Follow the Water'* means *'Follow the Ice'*

SPHEREX PROVIDES A RICH ALL-SKY SPECTRAL CATALOG

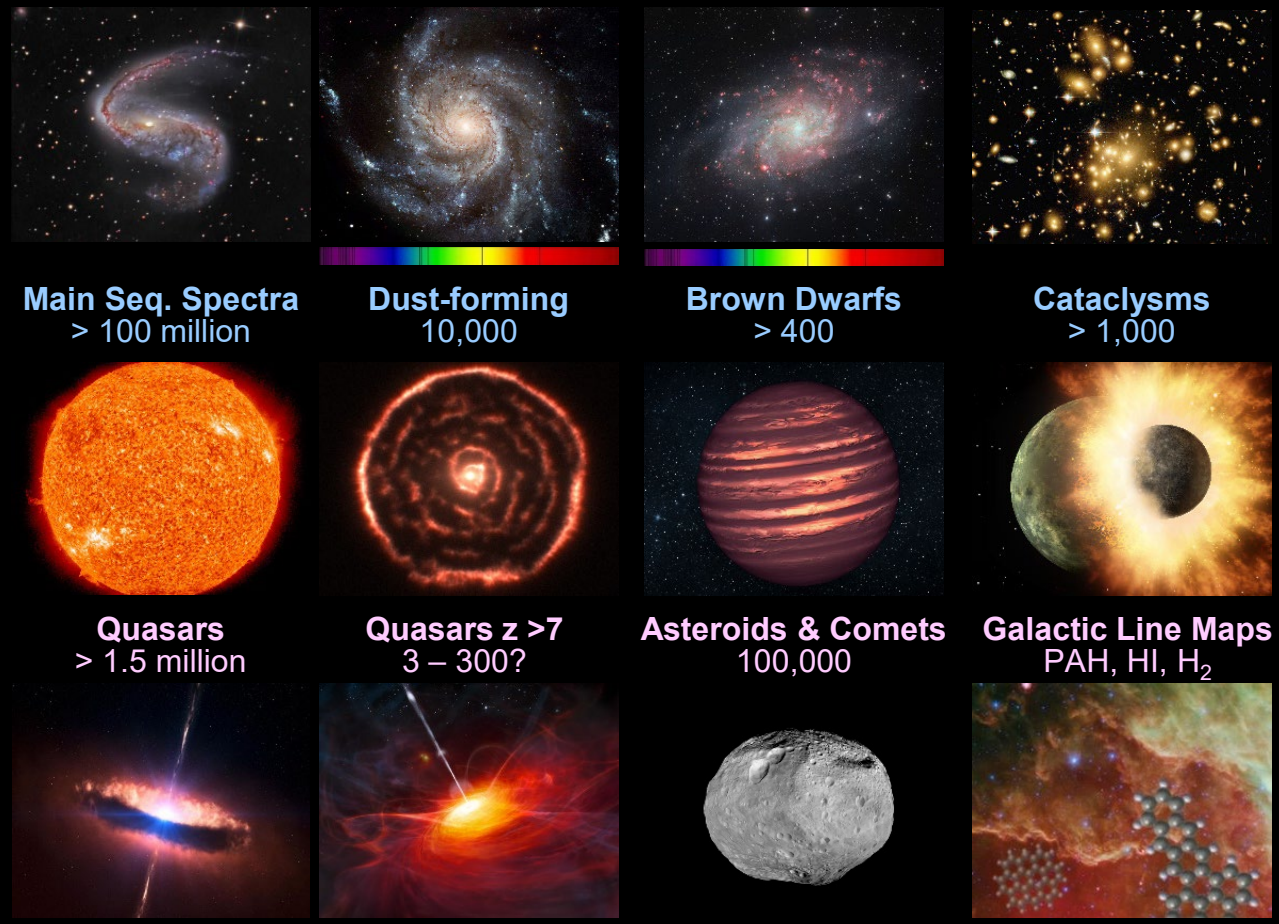
All-Sky Survey



SPHEREx provides a new and unique dataset

a complete near-infrared spectrum for every 6″ pixel on the sky

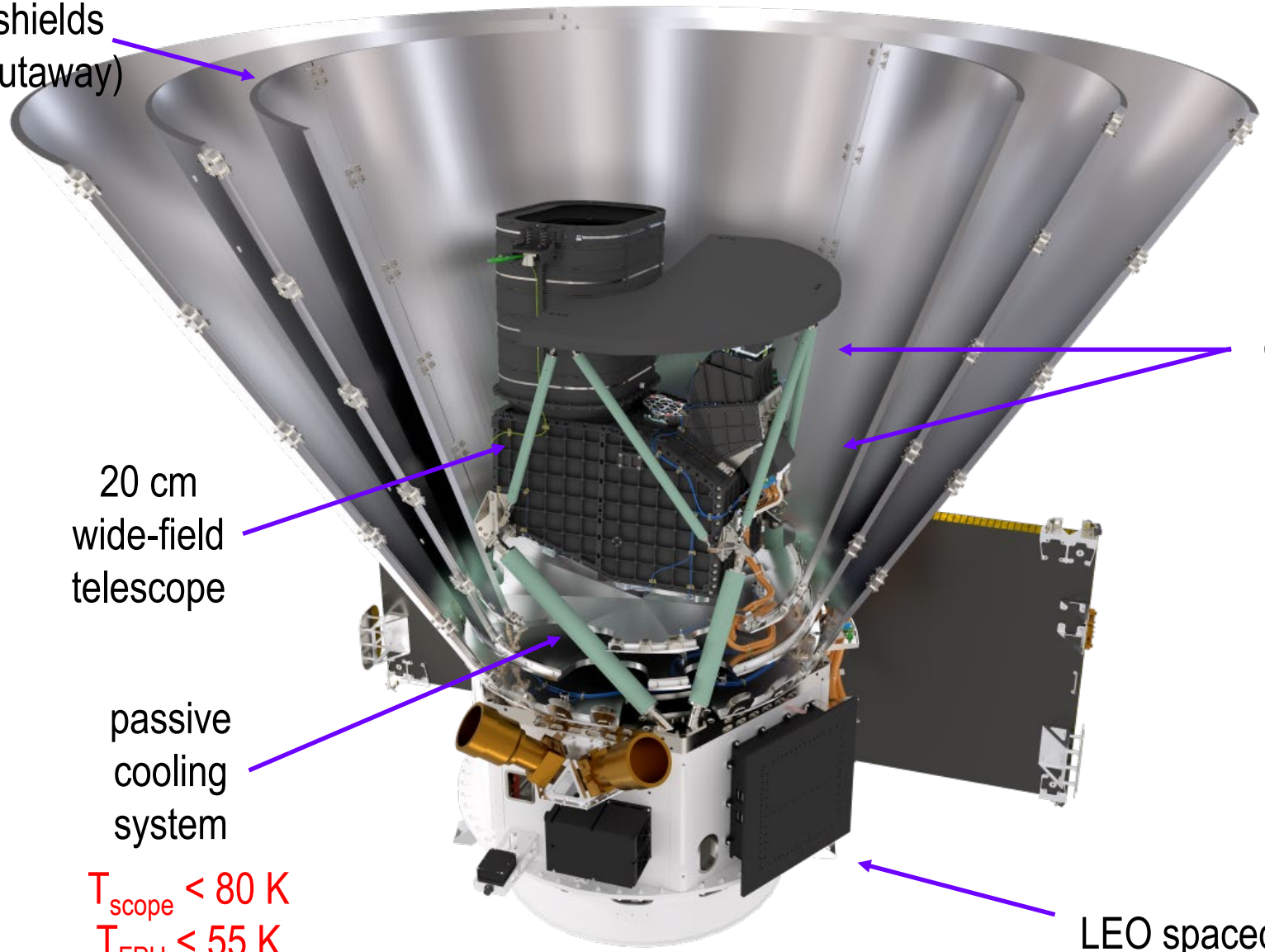
	Detected	Med. Accuracy Spectra	High Accuracy Spectra	Clusters
Galaxies	1.4 billion	120 million	10 million	100,000
Stars	Main Seq. Spectra > 100 million	Dust-forming 10,000	Brown Dwarfs > 400	Cataclysms > 1,000
Other	Quasars > 1.5 million	Quasars z >7 3 – 300?	Asteroids & Comets 100,000	Galactic Line Maps PAH, HI, H_2



We expect many exciting discoveries to come from the community

- IPAC rapidly delivers calibrated ‘spectral images’ to public
- IPAC also provides basic photometry tools for public use

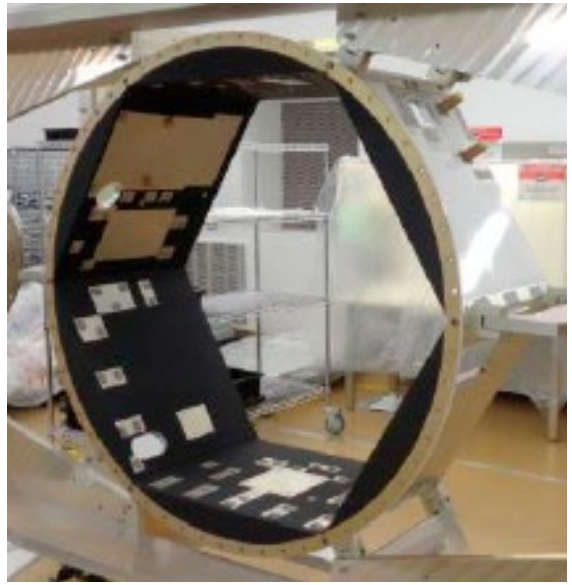
SPHEREx IN A NUTSHELL



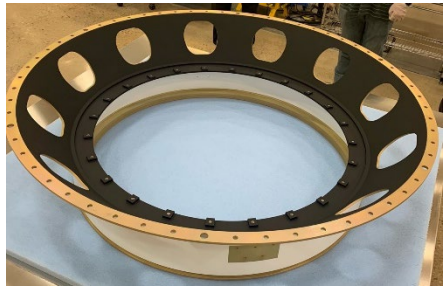
FLIGHT HARDWARE RECEIVED

Delivered

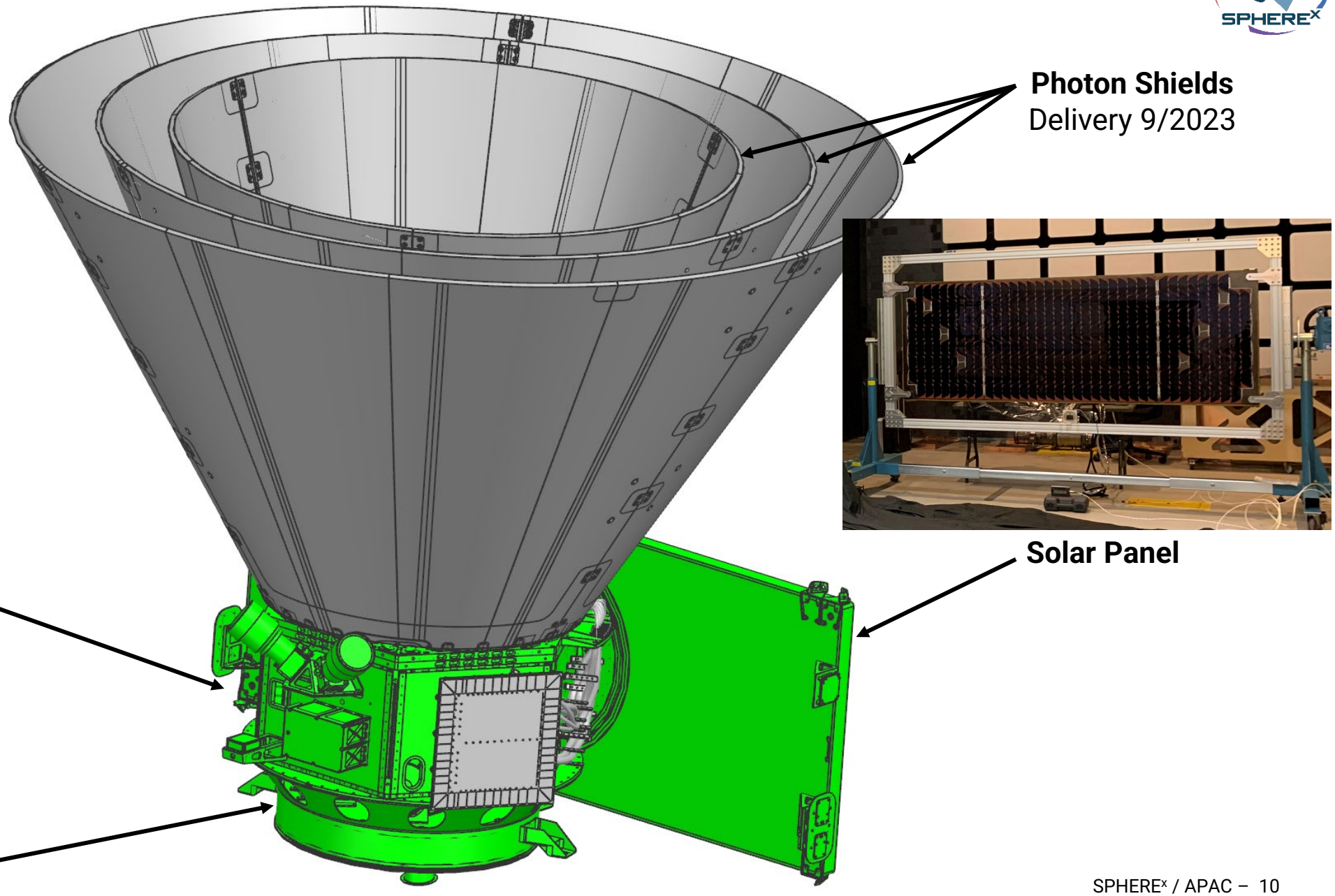
Delivery Pending



Spacecraft Structure



LV Conic Adapter



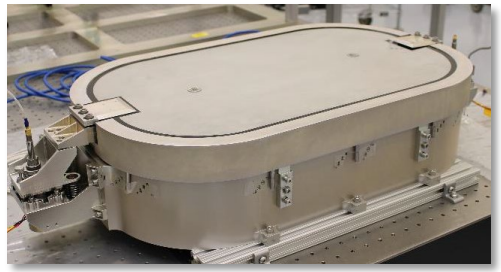
Photon Shields
Delivery 9/2023

Solar Panel

FLIGHT HARDWARE RECEIVED

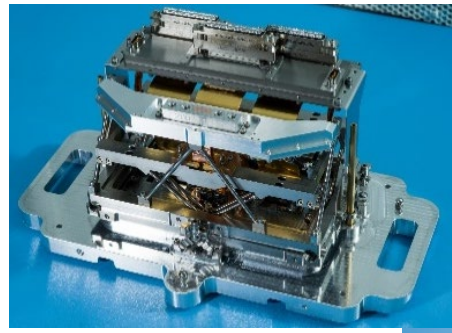
Delivered

Delivery Pending

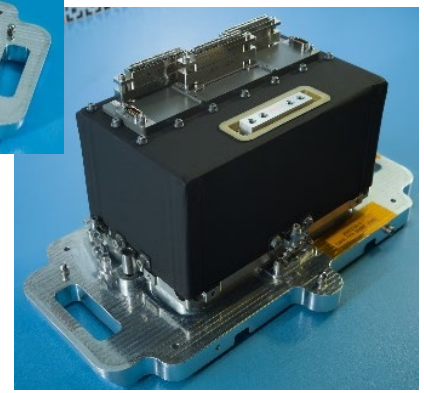


Cover

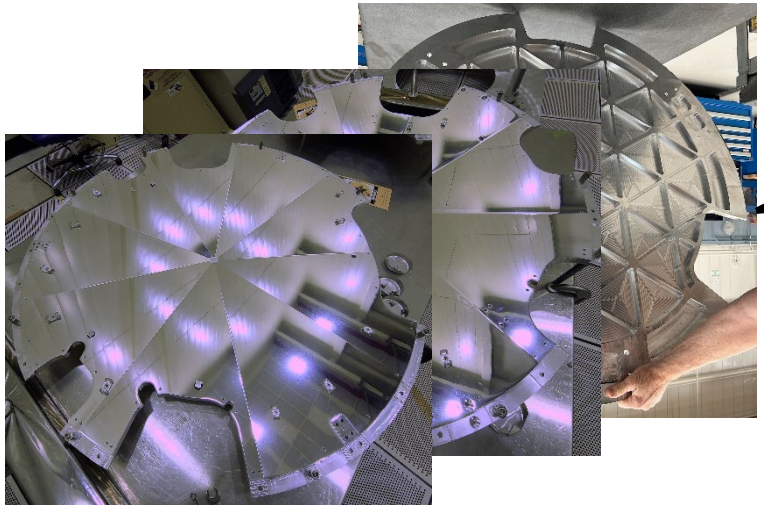
Focal Plane Radiator
Delivery 5/2023



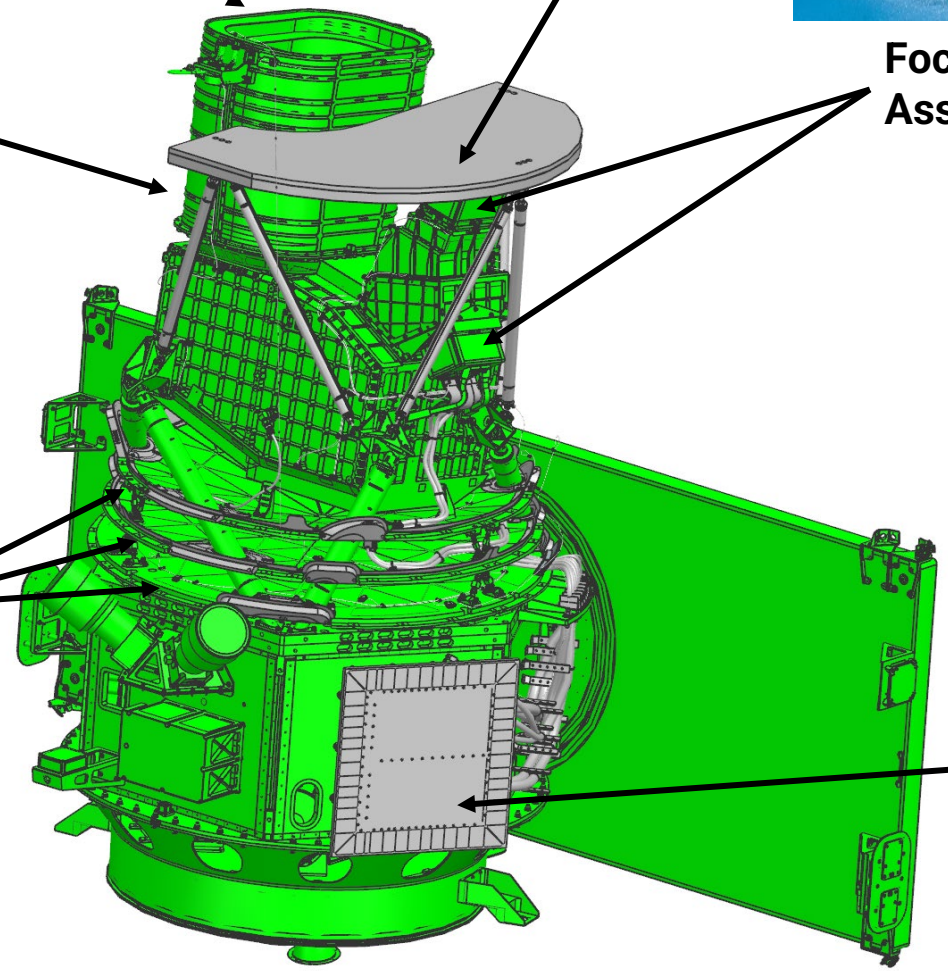
Focal Plane Assemblies



Telescope



V-Groove Coolers



Instrument Electronics
EM unit assembled
FM boards mid-delivery

FLIGHT HARDWARE RECEIVED

Delivered

Delivery Pending

Batteries

GPS Antennas

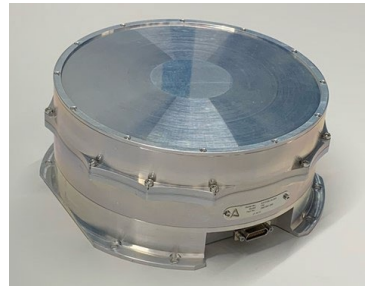
Integrated Avionics Unit
In rework, 6/2023

GPS Receiver

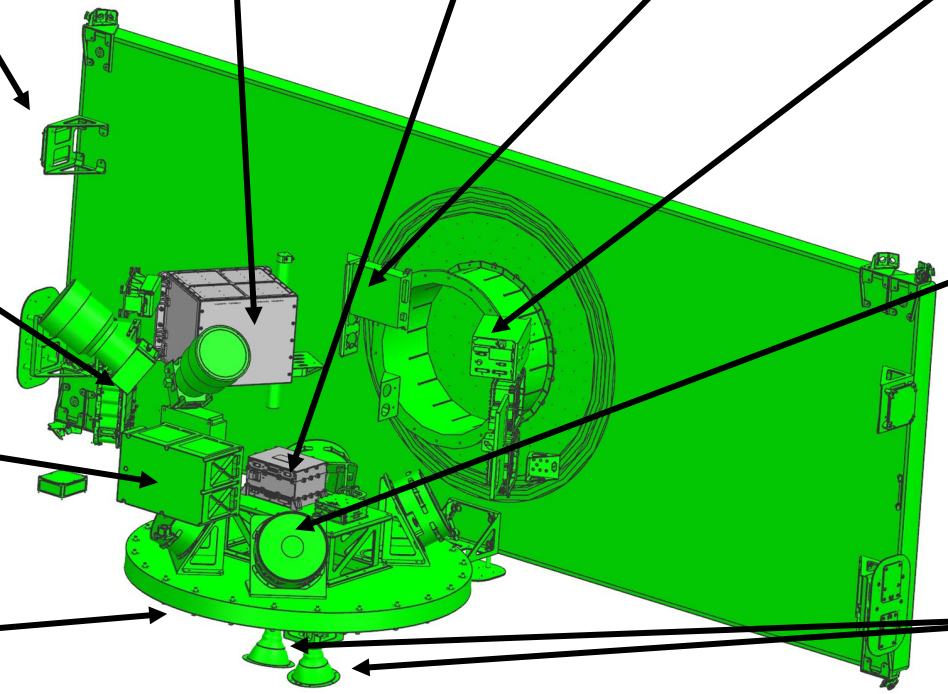
S-Band Transceiver

Ka-Band Transmitter
Delivery 4/2023

SSIRU



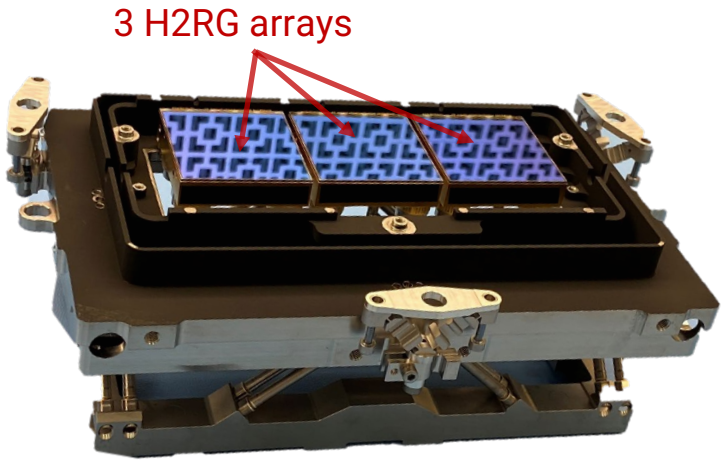
Reaction Wheels

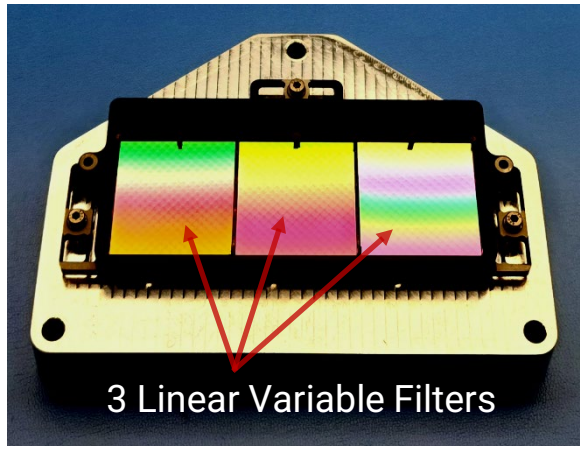


Torque Rods

Medium Gain Antennas

FOCAL PLANES TESTED – SPECTRAL RESPONSE

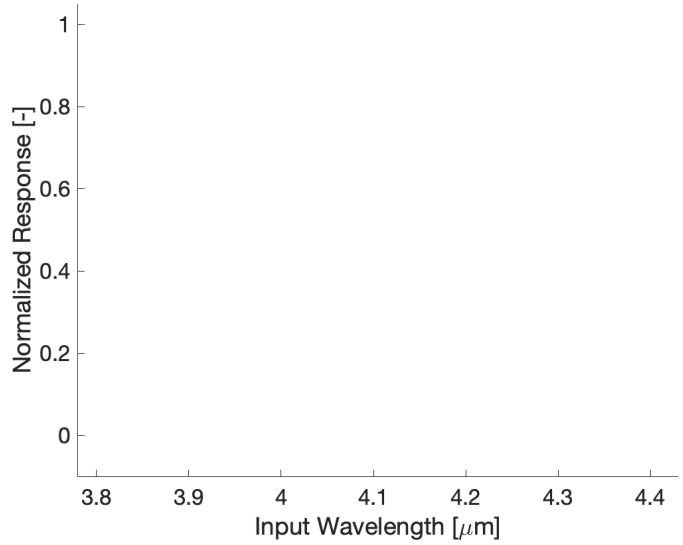


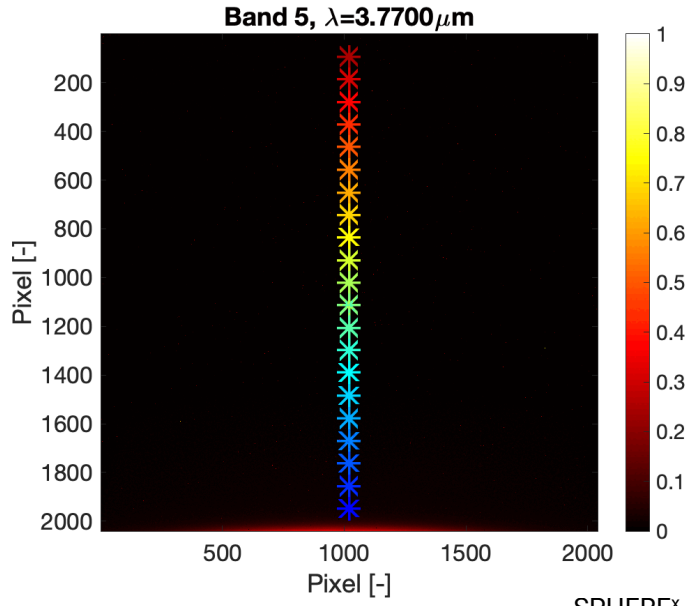


Mid-wave focal plane assembly

All 6 LVF/H2RG pairs have passed environmental and optical/dark performance testing

Measured Spectral Response



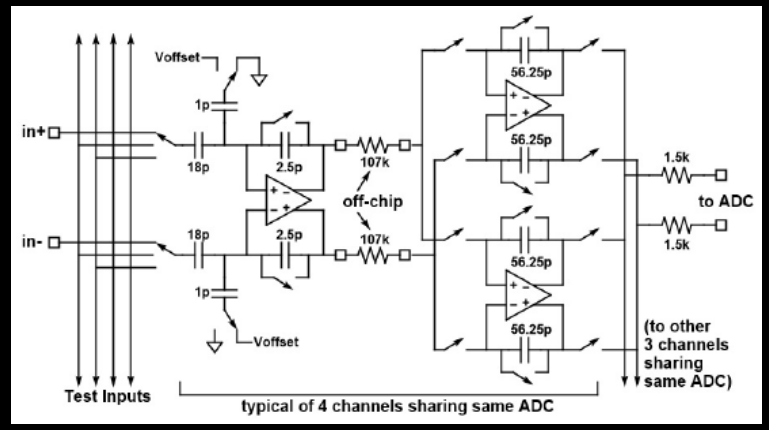


INTENSITY MAPPING WITH H2RG ARRAYS

H2RG

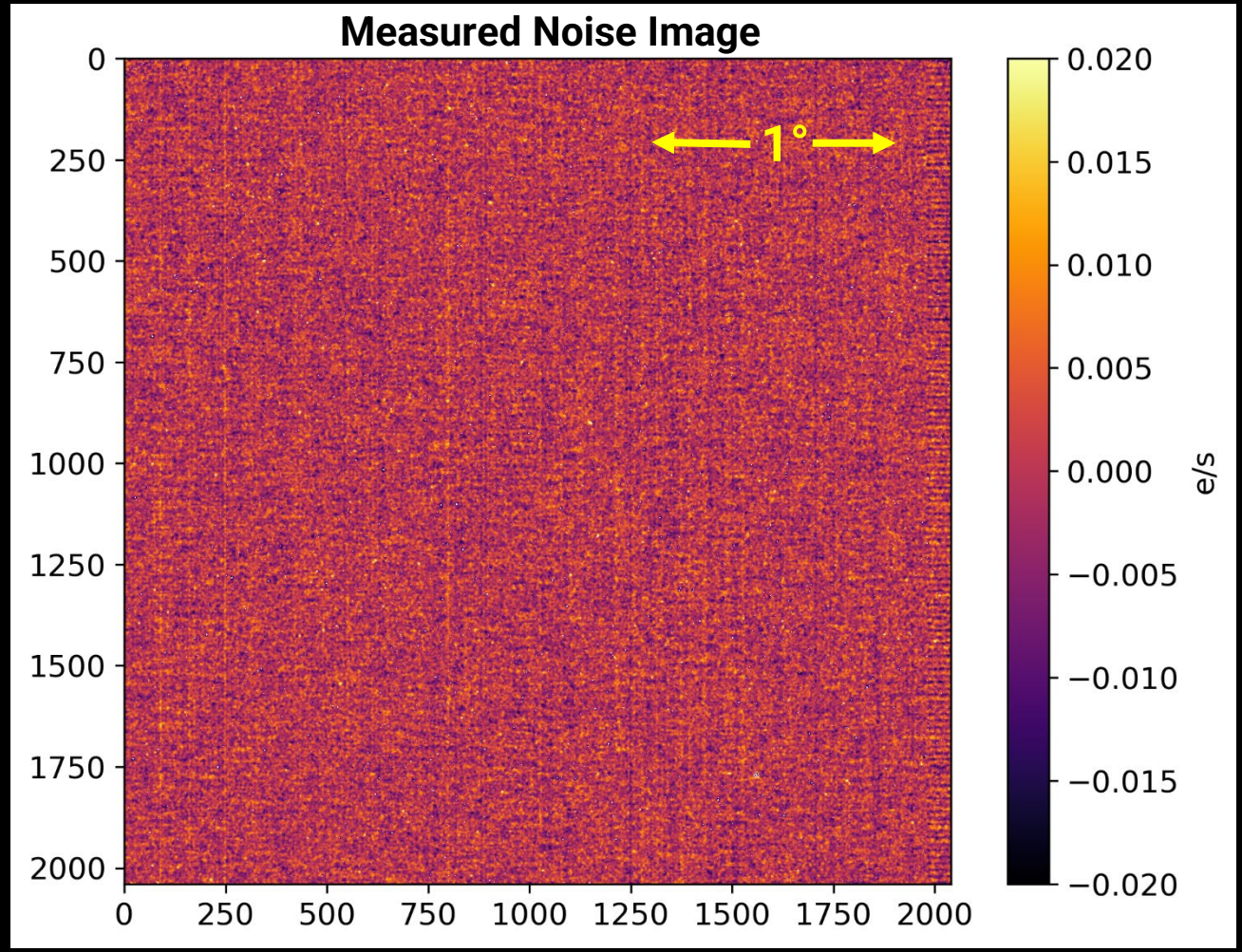
1 of 32 channel outputs

VIDEO8 Amplifier



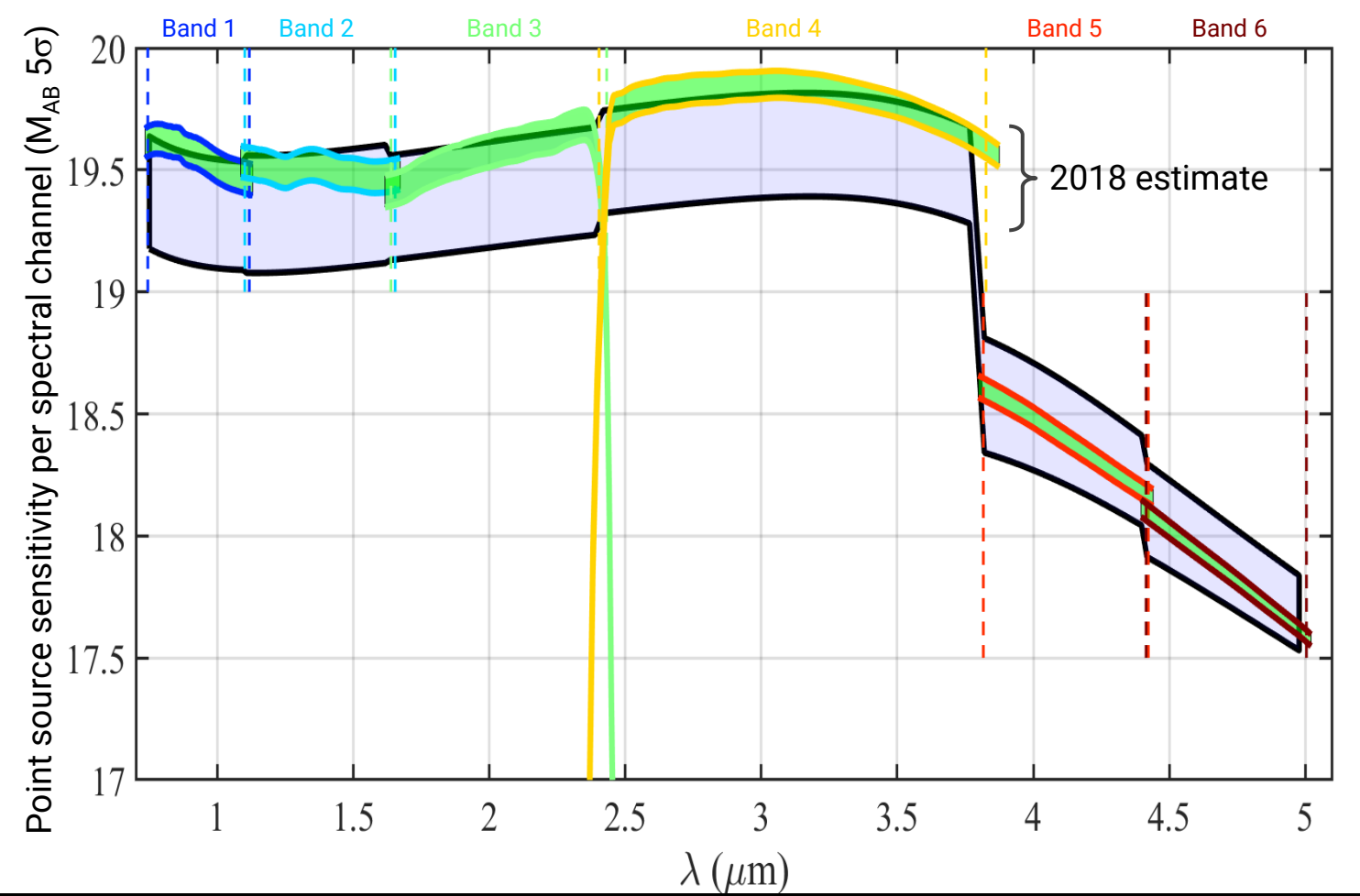
Steps to Remove Spatial 1/f Noise

- Use VIDEO8: custom ASIC developed by Caltech
  - Low amplifier noise (< 2 e-)
- Switch inputs to ground intermittently
  - "Phantom pixels" in data stream
  - Removes amplifier drift and 1/f noise
- "Row Chopping" to skip rows in readout order
  - Mixes 1/f noise to high frequencies in y direction
- Subtract residual offset in each channel
  - Sources most of the remaining noise on x-axis
  - Can use reference pixels or channel median



Demonstrated noise control on the ~20' angular scale of linear clustering

POINT SOURCE SENSITIVITY FORECAST



Current estimate from measured hardware

- Filter optical efficiency
- Detector optical efficiency
- Electronics and detector noise
- Detector dark current

Unmeasured components use Req't / CBE

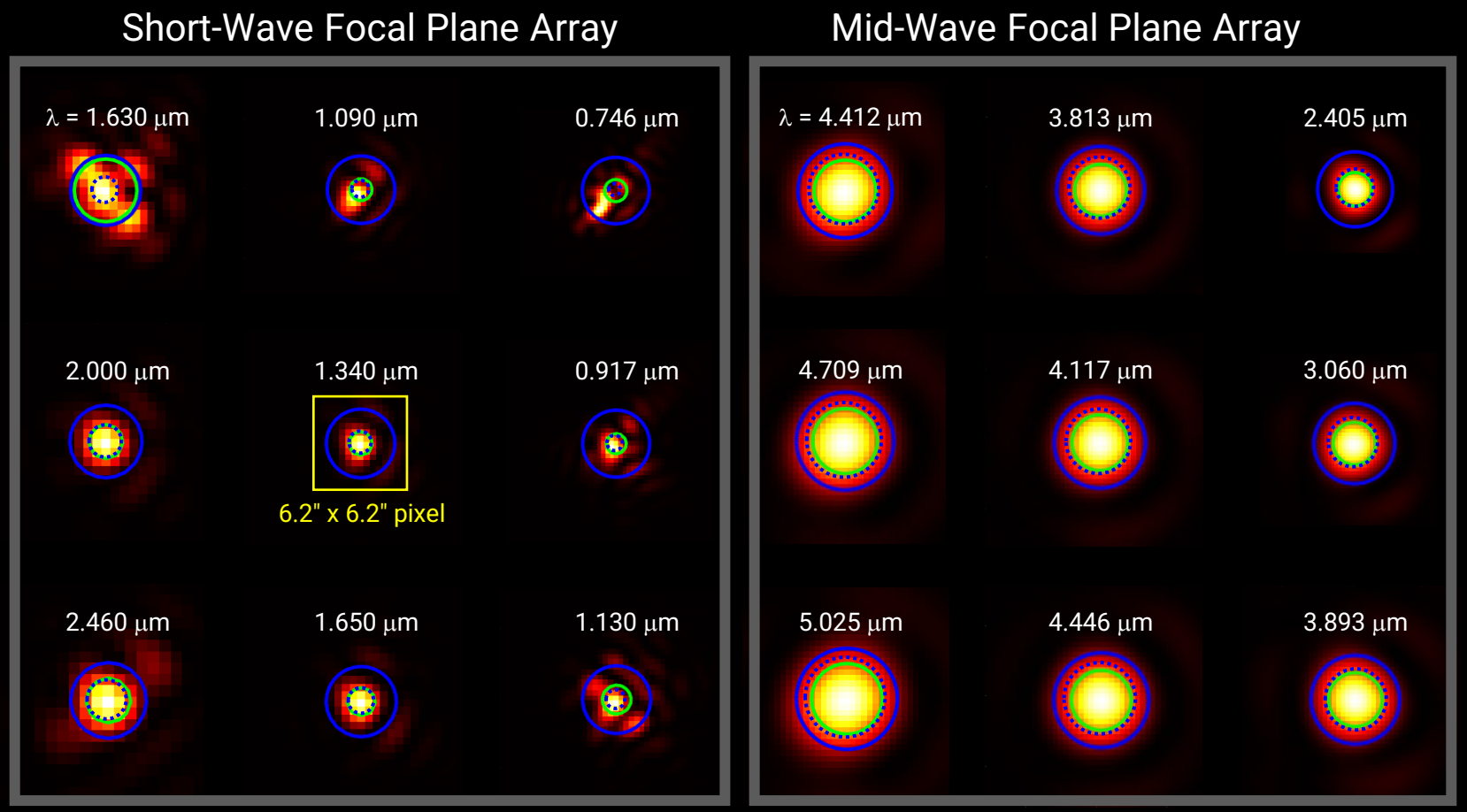
- Telescope PSF
- Pointing jitter
- Integration time

Comparing with 2018 CSR forecast

- Bands 1-4 at best-case performance
- Bands 5-6 in the middle of range
- Uncertainties now much smaller

TELESCOPE PSF MEASUREMENTS

Interferometry testing at Ball



- Interferometry at 290 K → convolved with diffraction at observed wavelength → spatial PSF
- PSF shape is complex at short wavelengths, as expected
- PSF size meets requirement over the full FOV
- Aberrations degrade PSF at extreme FOV corner (1.63 μm)

Required FWHM
Measured FWHM
Diffraction FWHM

TELESCOPE LID DEPLOYMENT

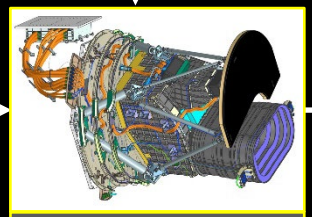
Lid also passed cryogenic deployment test!

UPCOMING INSTRUMENT TESTS

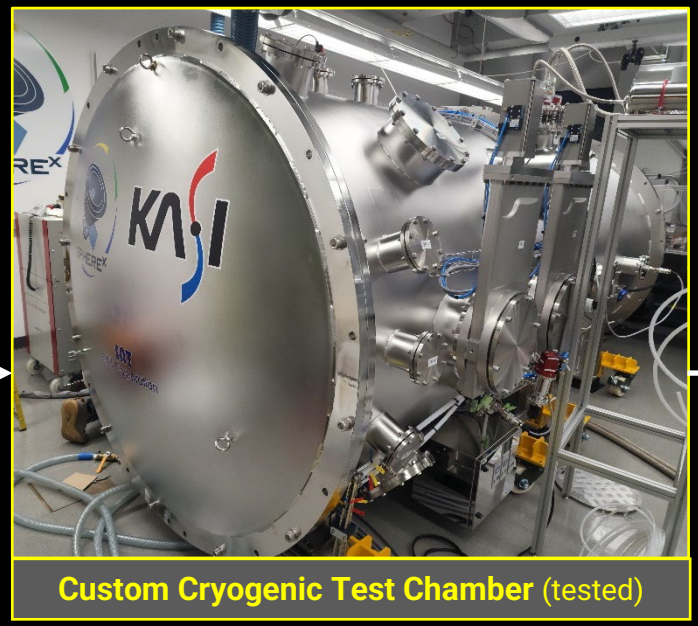
Telescope Cryo Focus
(test in progress)

Vibe

Focus Repeatability



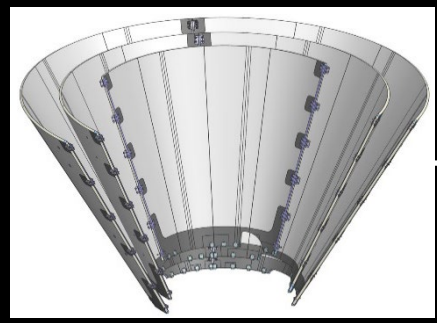
Instrument Sub-Assembly



Custom Cryogenic Test Chamber (tested)

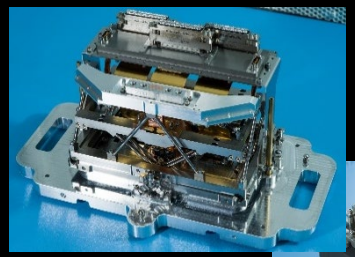
Focus → Vibe → Focus → Calibration

Deliver to Spacecraft March 2024

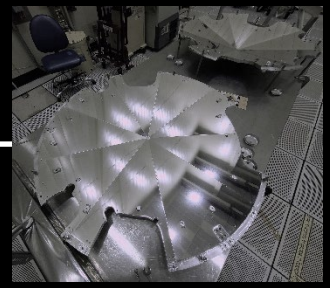


Photon Shields
(in fabrication)

Deliver to Spacecraft March 2024



Focal Plane Assemblies
(tested)



Thermal Sub-System
(in assembly)

Flight Electronics
(in board-level test)

CONCLUSIONS

It hasn't been easy getting here!

- With a Feb 2019 selection, SPHEREx bore the full brunt of the COVID pandemic
  - COVID resulted in a large expenditure of reserves and added 5 months of schedule
  - Cost and schedule ABC caps have not changed
- Science funding had to be replanned to prioritize hardware
  - Cosmology and galaxy formation level-1 science is at risk
  - These themes require a CMB-style integrated analysis pipeline
  - Resolution at SIR review in November 2023

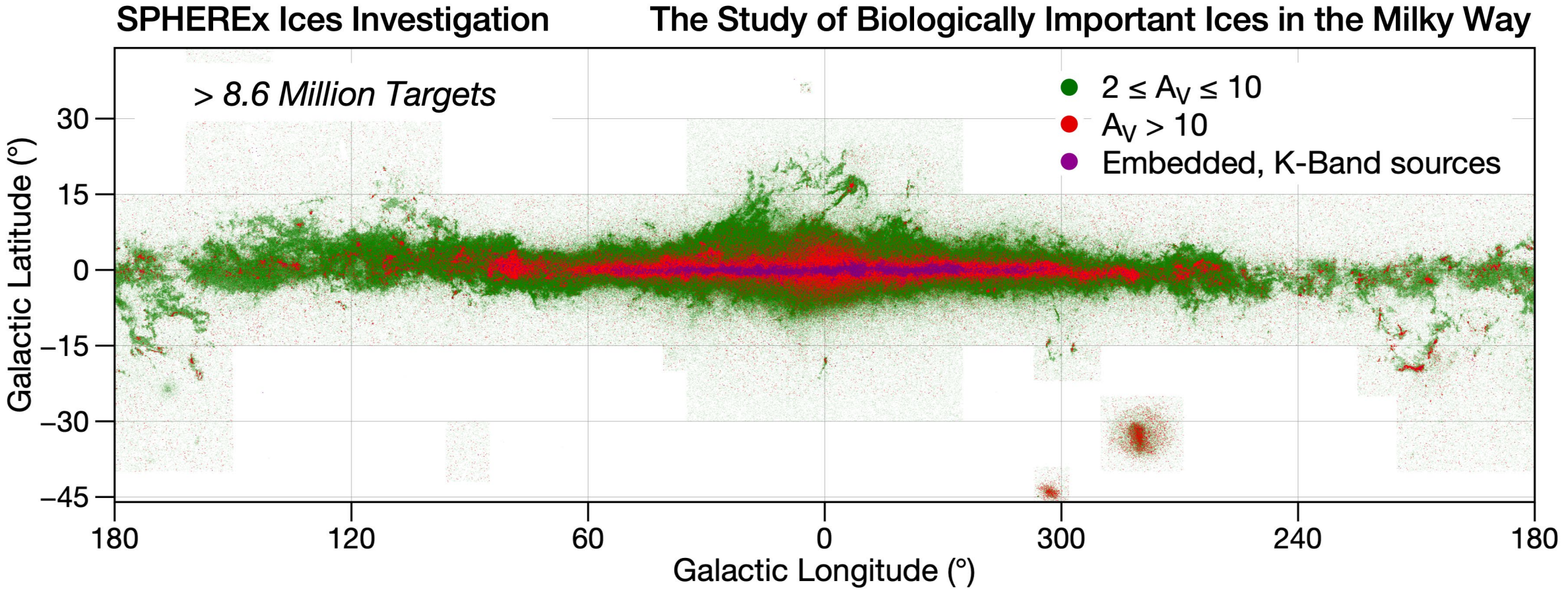
Flight hardware is mostly complete and performing well thus far

- Measured sensitivity near best-case 2018 estimates

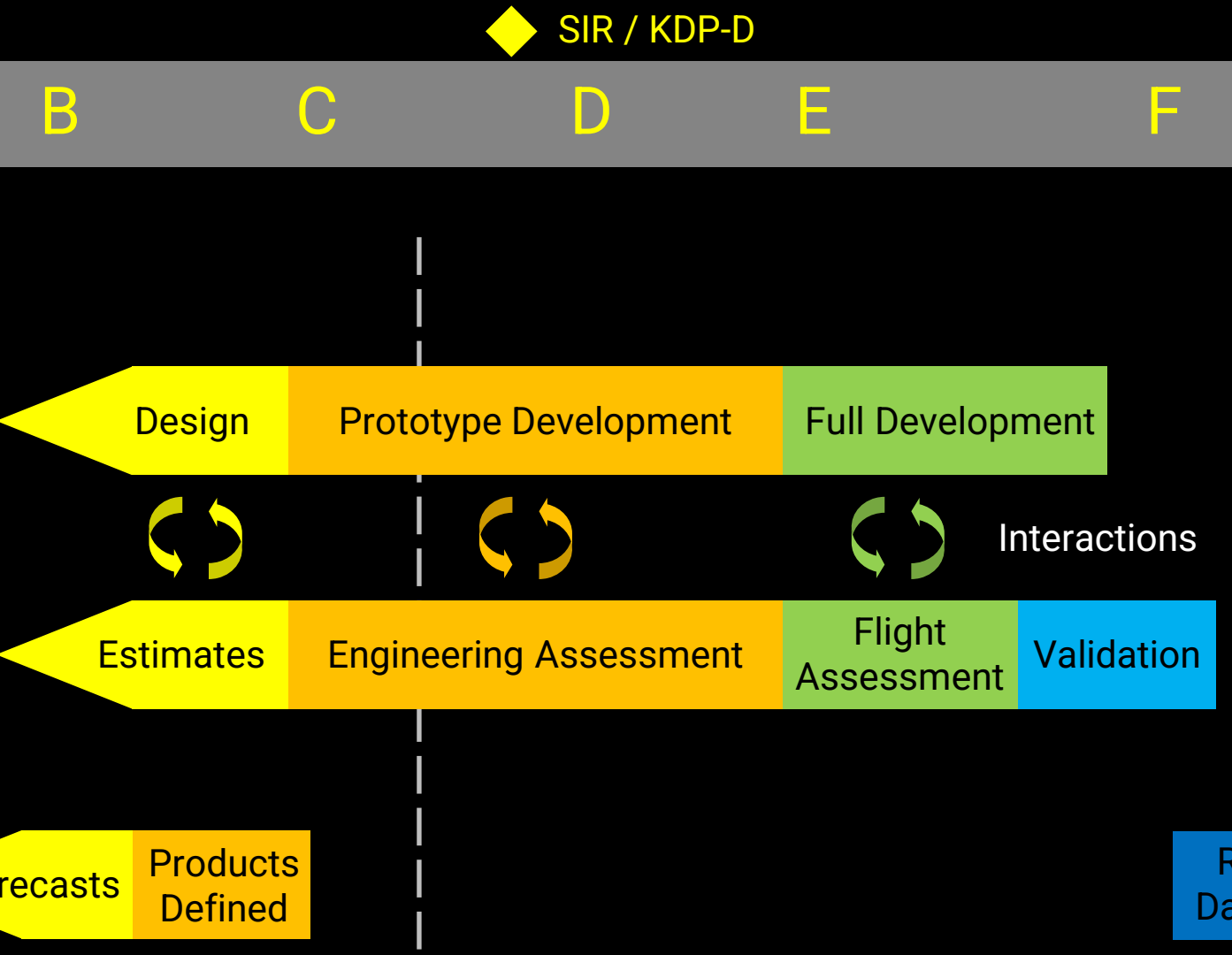
We are looking forward to instrument testing this year

BACKUP

SPHEREX CONDUCTS A COMPREHENSIVE ICES SURVEY



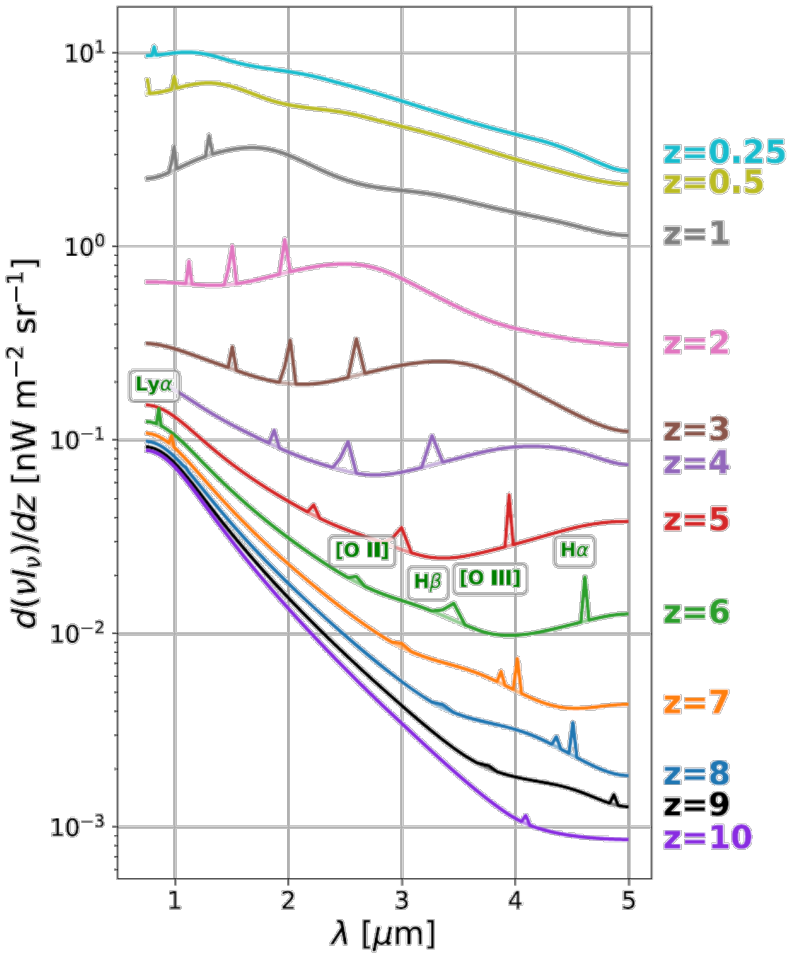
COSMOLOGY REQUIRES AN INTEGRATED ANALYSIS PIPELINE



Pipeline development, systematics control and validation are characteristic in cosmology

LIGHT PRODUCTION IN REDSHIFT SLICES

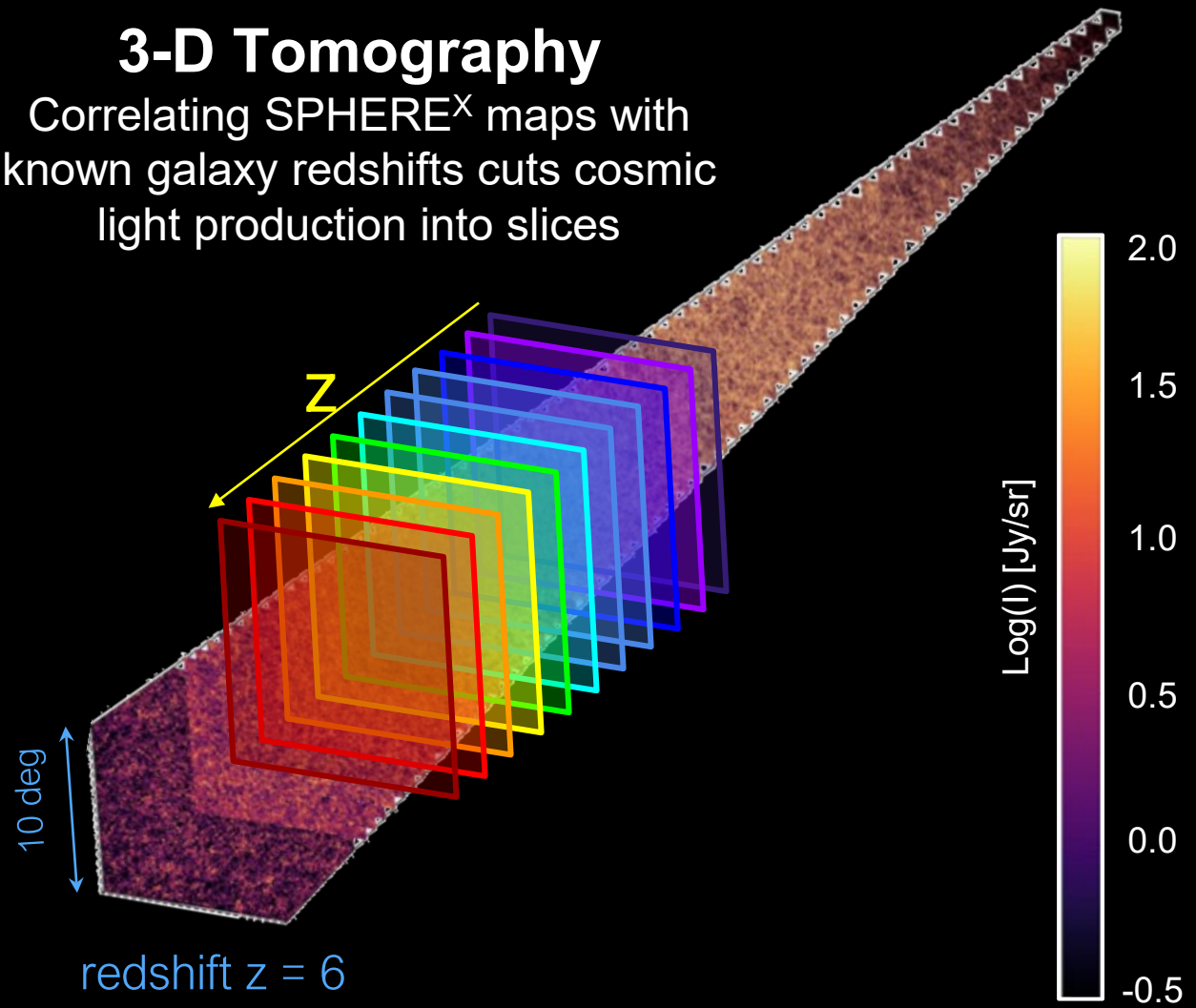
Cosmic Light Production vs. Redshift



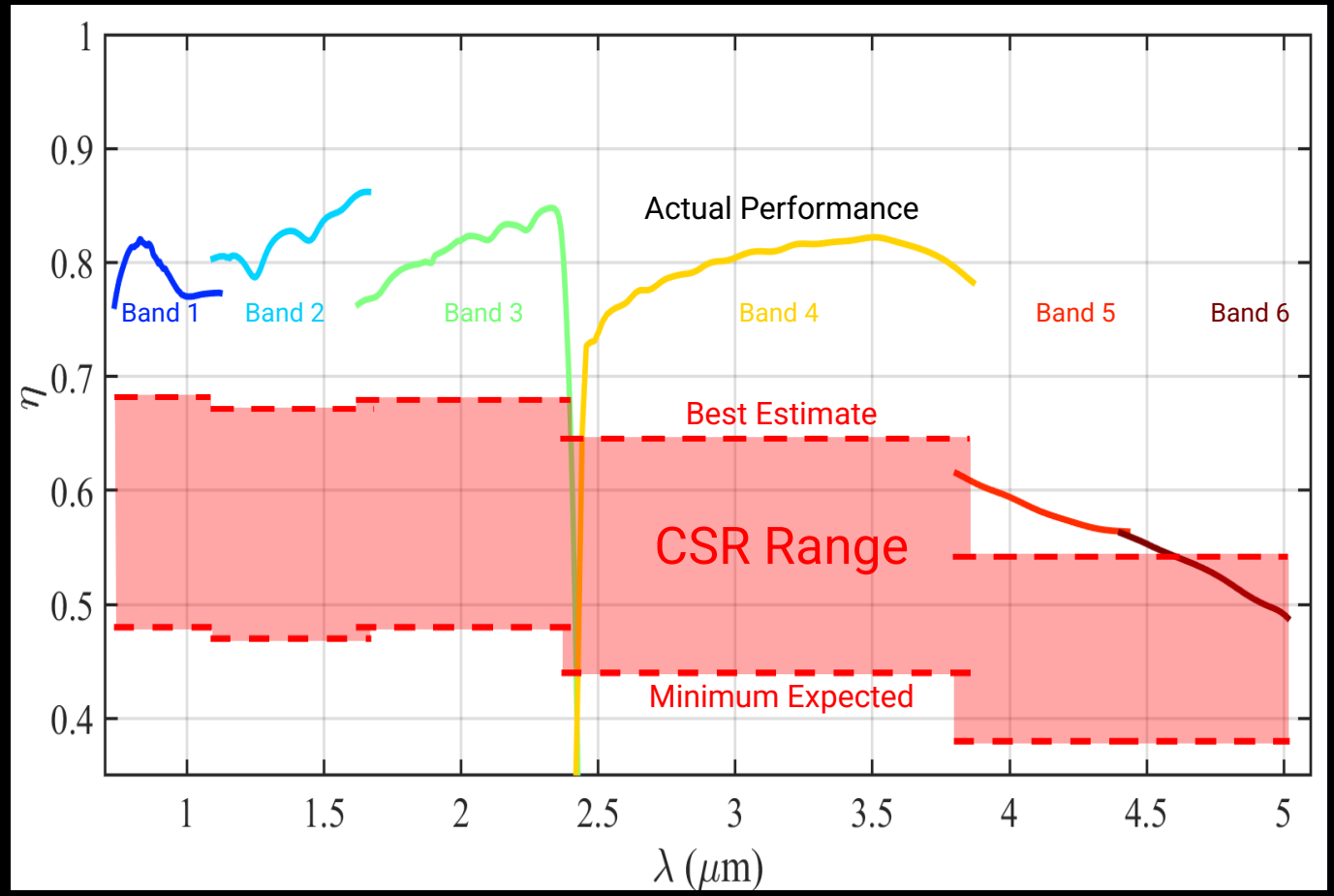
Cheng & Chang (2021) forecast solid detections of the EBL spectrum from 0 < z < 6

3-D Tomography

Correlating SPHEREˣ maps with known galaxy redshifts cuts cosmic light production into slices

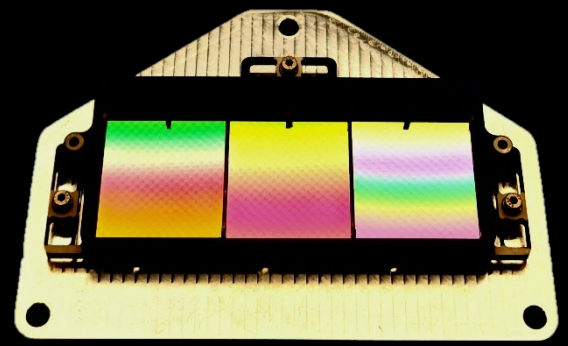


END-TO-END OPTICAL EFFICIENCY



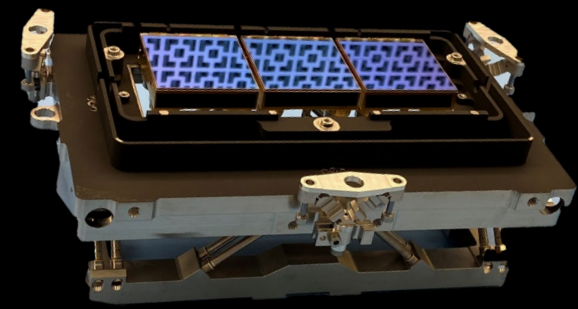
Measured Efficiency on Every Component

Telescope Efficiency



Linear Variable Filters

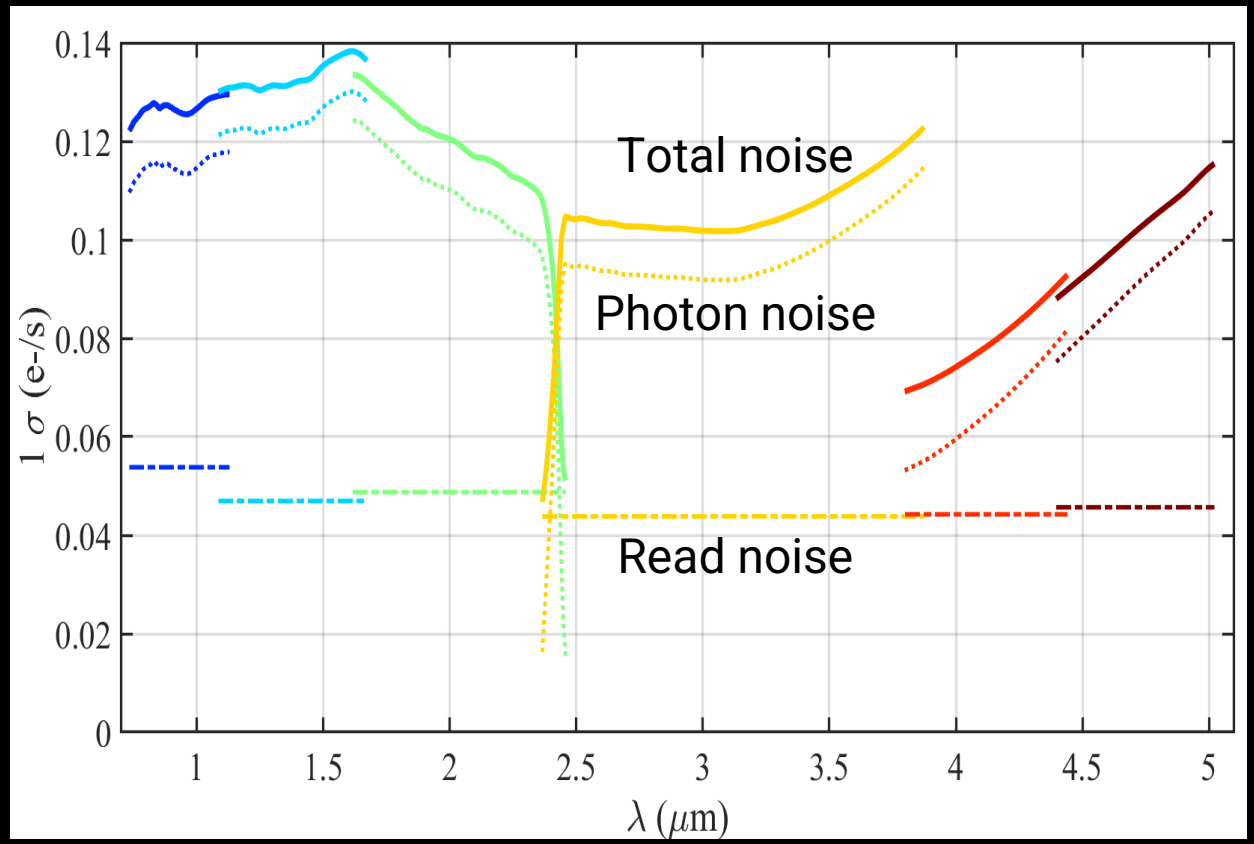
Dichroic Beamsplitter



H2RG Detectors

NOISE PERFORMANCE

Measured Noise in 112 s Integrations



- Read noise measured in full integrations
- SPHEREx is photon noise limited!