The SPHEREx All-Sky Infrared Spectral Survey: Science Overview

Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer

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https://spherex.caltech.edu

SPHEREx Team

SPHEREX DESIGNED TO ADDRESS THE MOST IMPORTANT QUESTIONS IN ASTROPHYSICS

- How did the Universe begin?
  - ➡ Probe the physics of the young inflationary Universe through the 3D spatial distribution of galaxies

- How did Galaxies begin?
  - ➡ Study the cosmic history of light production through near-infrared background fluctuations

- What are the Conditions for Life Outside the Solar System?
  - ➡ Survey the Milky Way for water ices and other biogenic molecules

SPHEREx probes the origin of the Universe, galaxies, and life

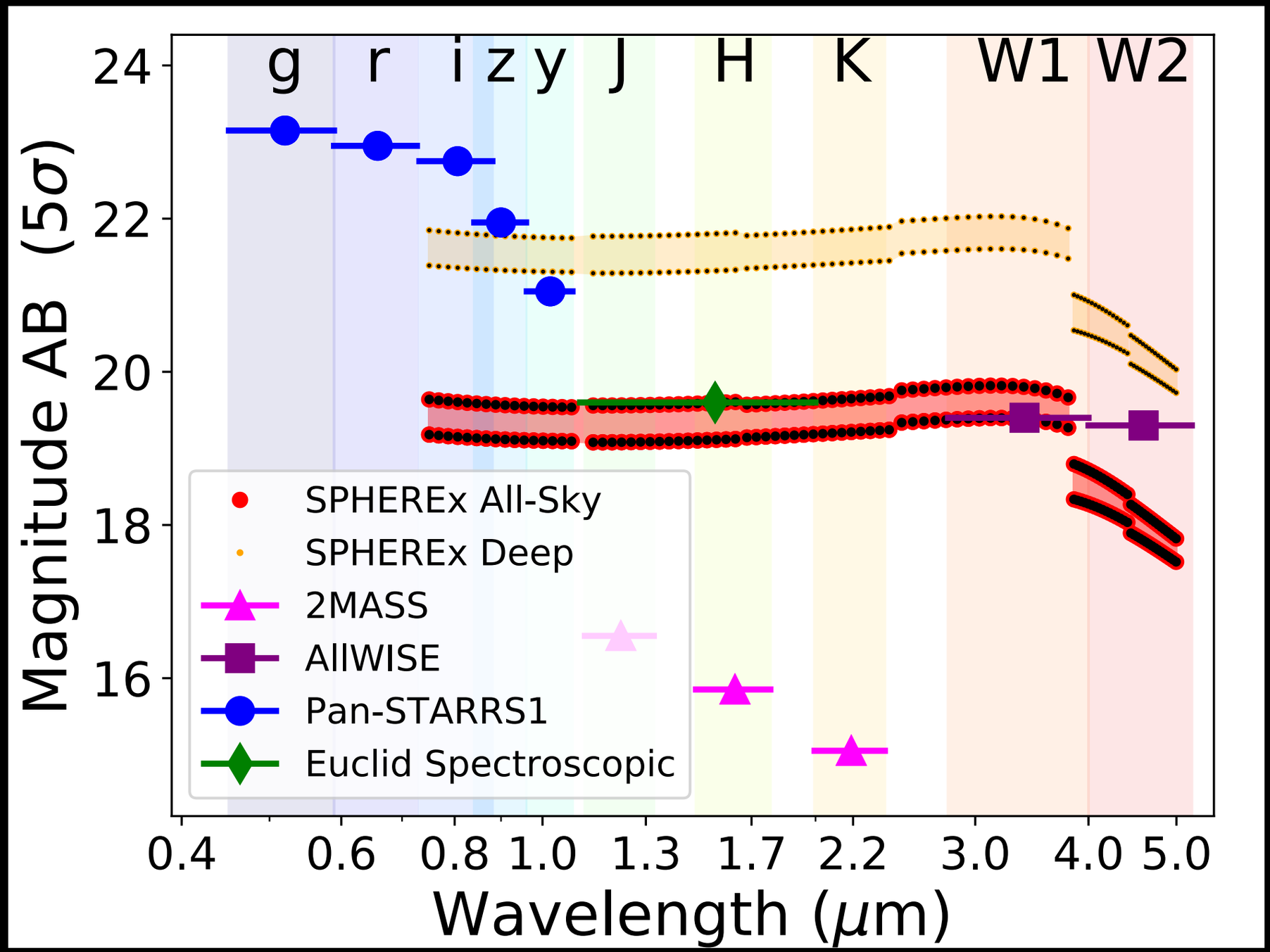
We will do so by constructing the first all-sky near-infrared spectral survey

SPHEREX: AN ALL-SKY SPECTRAL SURVEY

SPHEREx Dataset:

- For every 6.2” pixel over the entire sky:
  - ➡ R=35-41 spectra spanning 0.75 μm < λ < 3.82 μm
  - ➡ R=110-130 spectra spanning 3.82 μm < λ < 5.0 μm
- ≃ all-sky survey with 102 fine photometric bands

SPHEREX SURVEY DEPTH



Deep survey

All-sky survey

Plot generated in 2018 but actual performances in the lab consistent

SPHEREX SCIENCE TEAM

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

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Michael Werner	JPL
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Soung-Chui Yang	KASI
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Michael Zemcov	RIT

ca. March 2023

& strong and experienced engineering team @ JPL and Ball Aerospace

Image Credit: Illustris TNG

SPHEREX TEAM

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

ca. November 2023

Marveling at the Heavens with SPHEREx

Camille Flamarion 1888

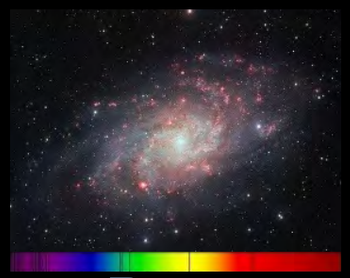
SPHEREX PROVIDES A RICH ALL-SKY SPECTRAL ARCHIVE

Galaxies

Detected
> 1 billion

Med. Accuracy z's
> 100 million

High Accuracy z's
10 million



Clusters
25,000

Stars

Main Seq. Spectra
> 100 million

Dust-forming
10,000

Brown Dwarfs
> 400

Cataclysms
> 1,000

Other

Quasars
> 1 million

Quasars z >7
3 – 300?

Asteroid Spectra
10,000

Galactic Line Maps
PAH, HI, H_2

➡ All-Sky surveys demonstrated high scientific returns with lasting data legacy used across astronomy (COBE, IRAS, GALEX, WMAP, Planck, WISE)

➡ Many exciting discoveries will come from the community

OD++16,18

AGGRESSIVE DATA RELEASE PLAN
"CONVEYOR BELT MODEL"

- L : Launch no later than April 2025
- L+1 : End of commissioning
- L+2n: Within 2 months of collection, for 24 months
  - ➡ Release spectral images data (L2 product)
- L+6n : Every 6 months, we complete a full sky survey
  - ➡ Release full-sky products (L2 and data cubes) within 6 months of survey completion
- L+12n: Every 12 months, complete two full sky surveys
  - ➡ Release source catalogs within 2 months of 3d survey data release
- L+24 : End of nominal mission + 1yr of analysis
  - ➡ Release L4 (science) catalogs (galaxy, ices, maps, legacy catalogs)

- Archive hosted by IRSA at IPAC/Caltech (http://irsa.ipac.caltech.edu)
  - ➡Will also host tools to do on the fly mosaic, forced photometry on a catalog, time variable sources photometry, etc.

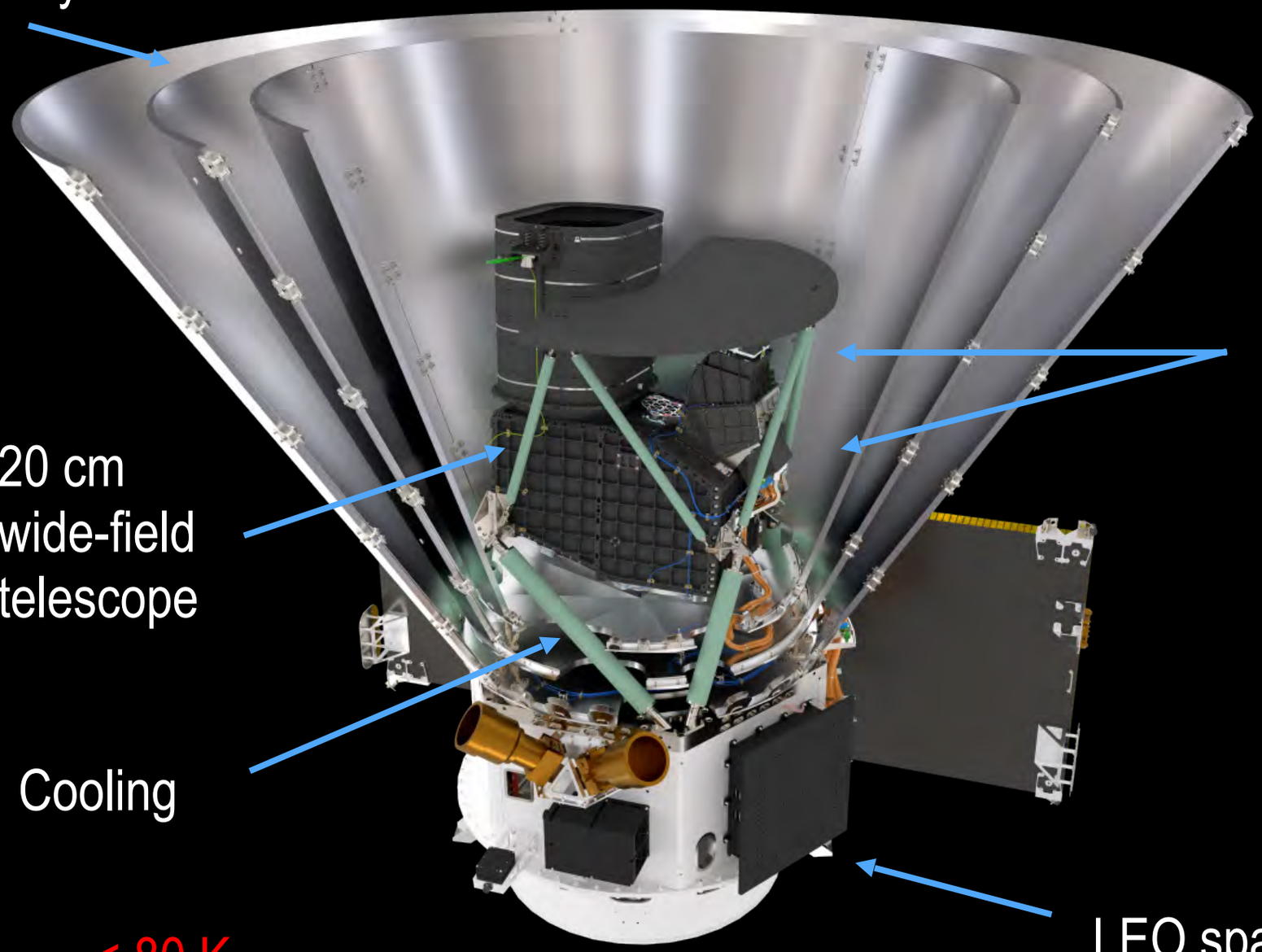
SPHEREX: THE YEARS AHEAD

- 08/18-09/18: Phase A
  - ➡ Concept Study
- 02/19: Selection
- 05/19-12/20: Phase B
  - ➡ Preliminary functional design, final trade studies, pipeline development planning, etc.
- 01/21-01/24: Phase C
  - ➡ Final design, fabrication, system assembly
- 02/24-04/25: Phase D
  - ➡ Assemble, integrate, test, and launch using SpaceX F9 @ Vanderberg, AFB
- 02/25-04/27: Phase E
  - ➡ Operate for 2 years
- 05/27-05/28: Phase F
  - ➡ Final analysis

SPHEREx IN A NUTSHELL

Photon shields
(shown cutaway

2.0 m



20 cm
wide-field
telescope

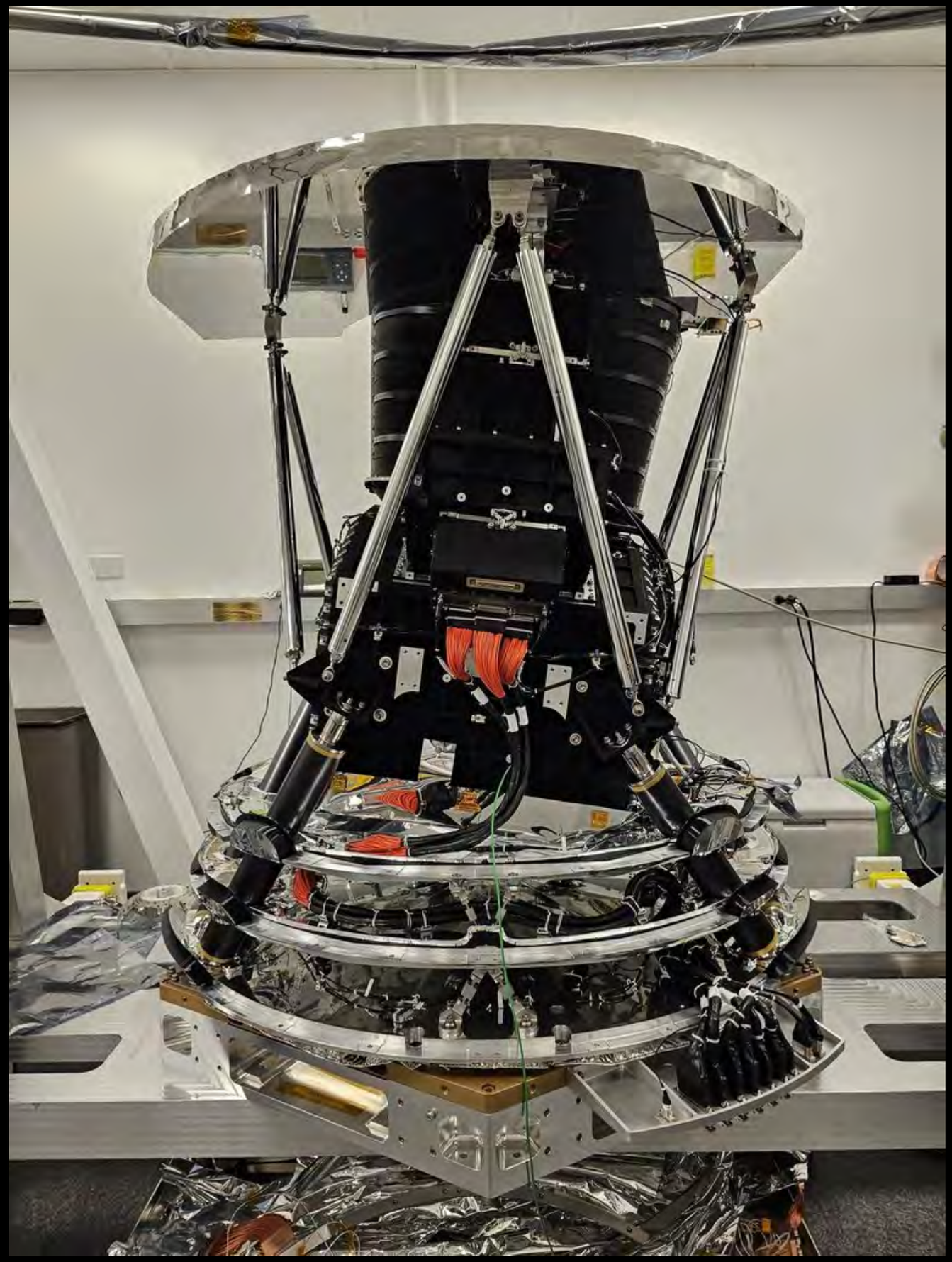
Cooling

$T_{scope} < 80$ K
$T_{FPU} < 55$ K

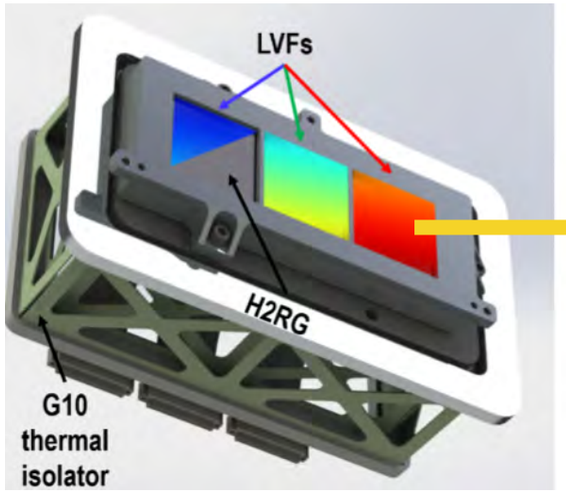
Detectors and LVF
spectrometers

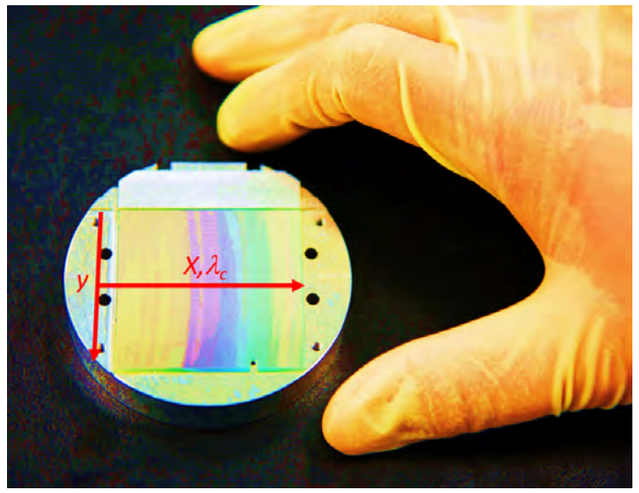
$\lambda = 0.75 – 5\ \mu m$
$\lambda/\Delta\lambda = 35 – 130$
6.2" pixels

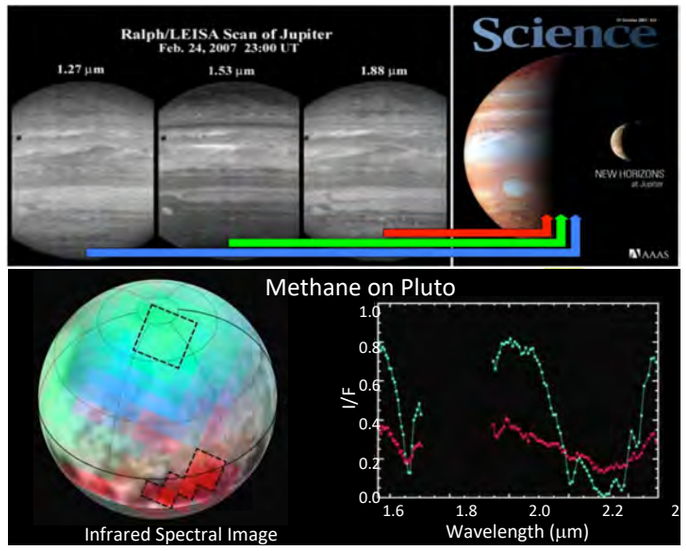
LEO spacecraft (Ball)



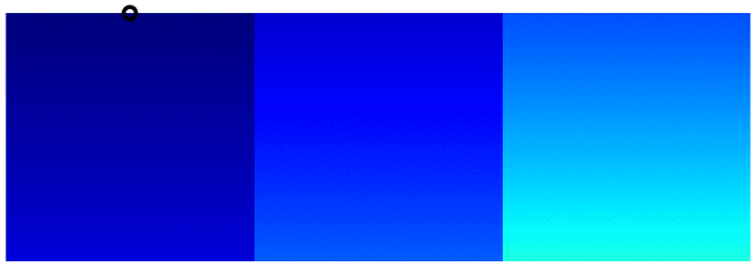
High-Throughput Linearly Variable Filters Spectroscopy

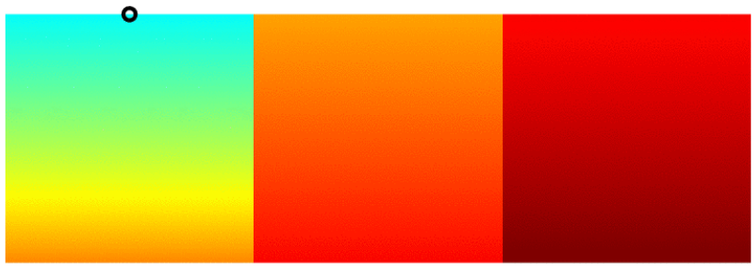


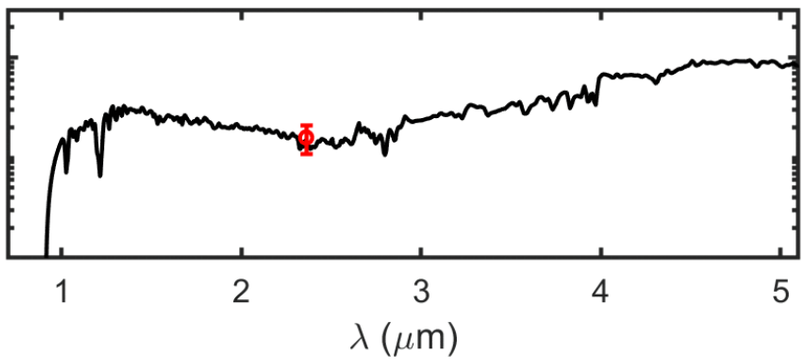


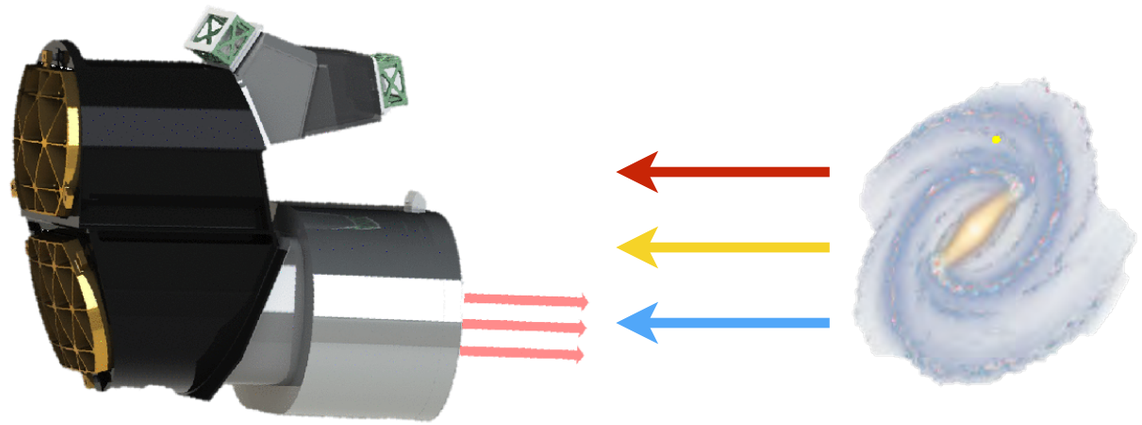


LVF used on ISOCAM, HST-WPC2, New Horizons LEISA, OSIRIS-REx









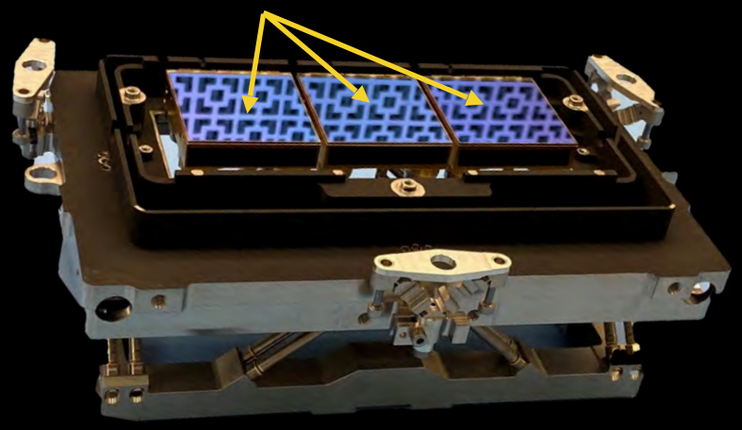
Spectra obtained by stepping sources over the FOV in multiple images: no moving parts

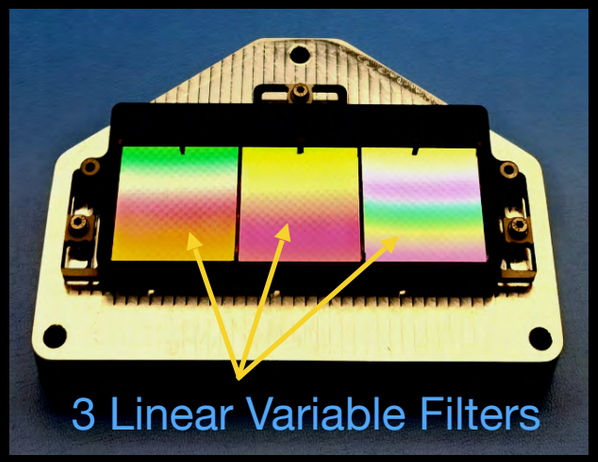
FAST PACE ASSEMBLY AT CALTECH, BALL, AND JPL

https://www.jpl.nasa.gov/news/test-chamber-for-nasas-new-cosmic-mapmaker-makes-dramatic-entrance

FOCAL PLANES TESTED – SPECTRAL RESPONSE

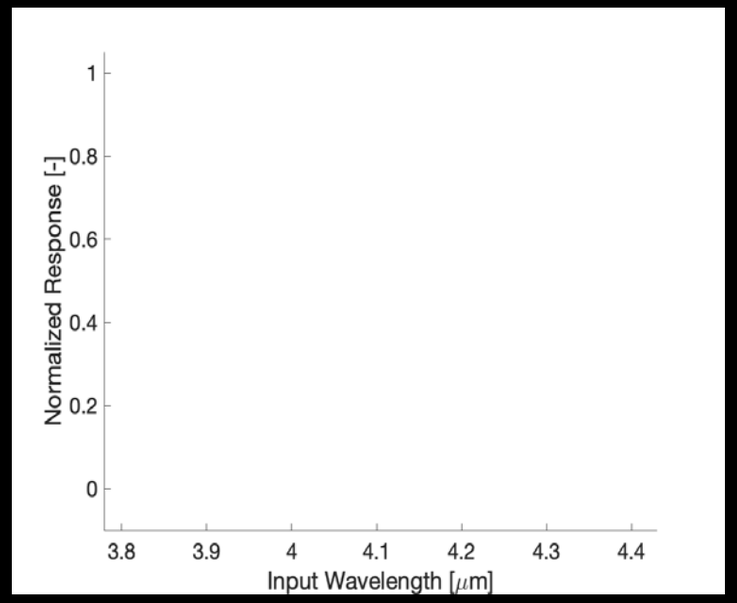
3 H2RG arrays

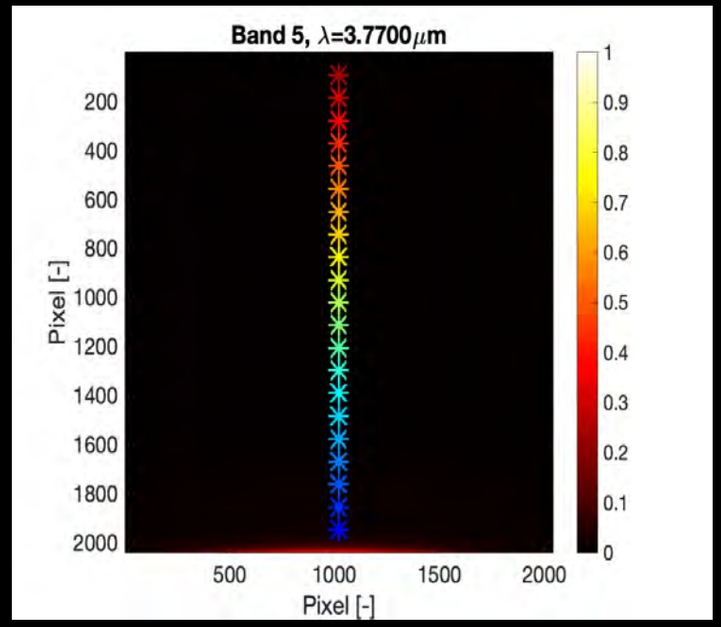




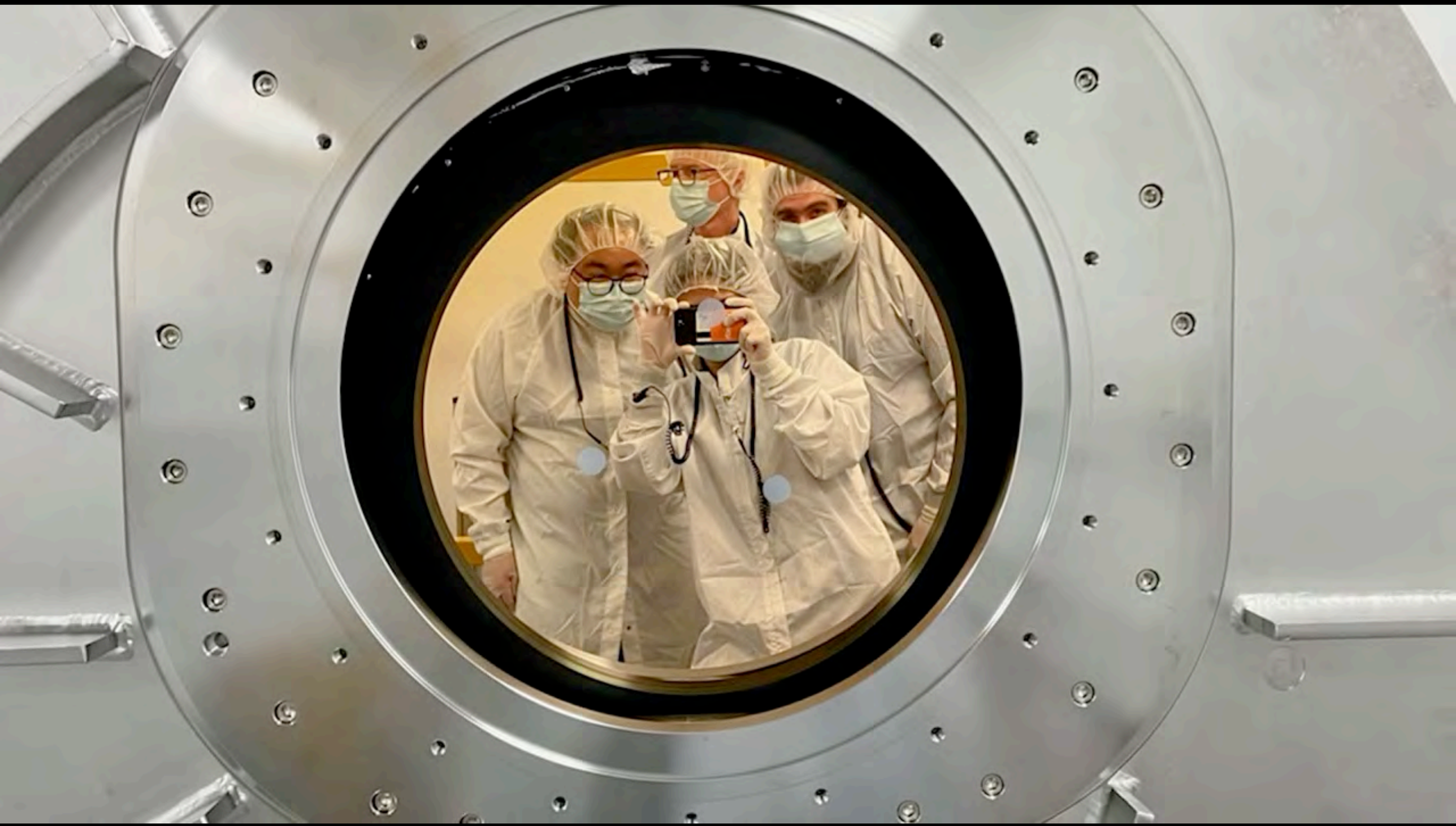
All 6 LVF/H2RG pairs have passed environmental and optical/dark performance testing

Measured Spectral Response

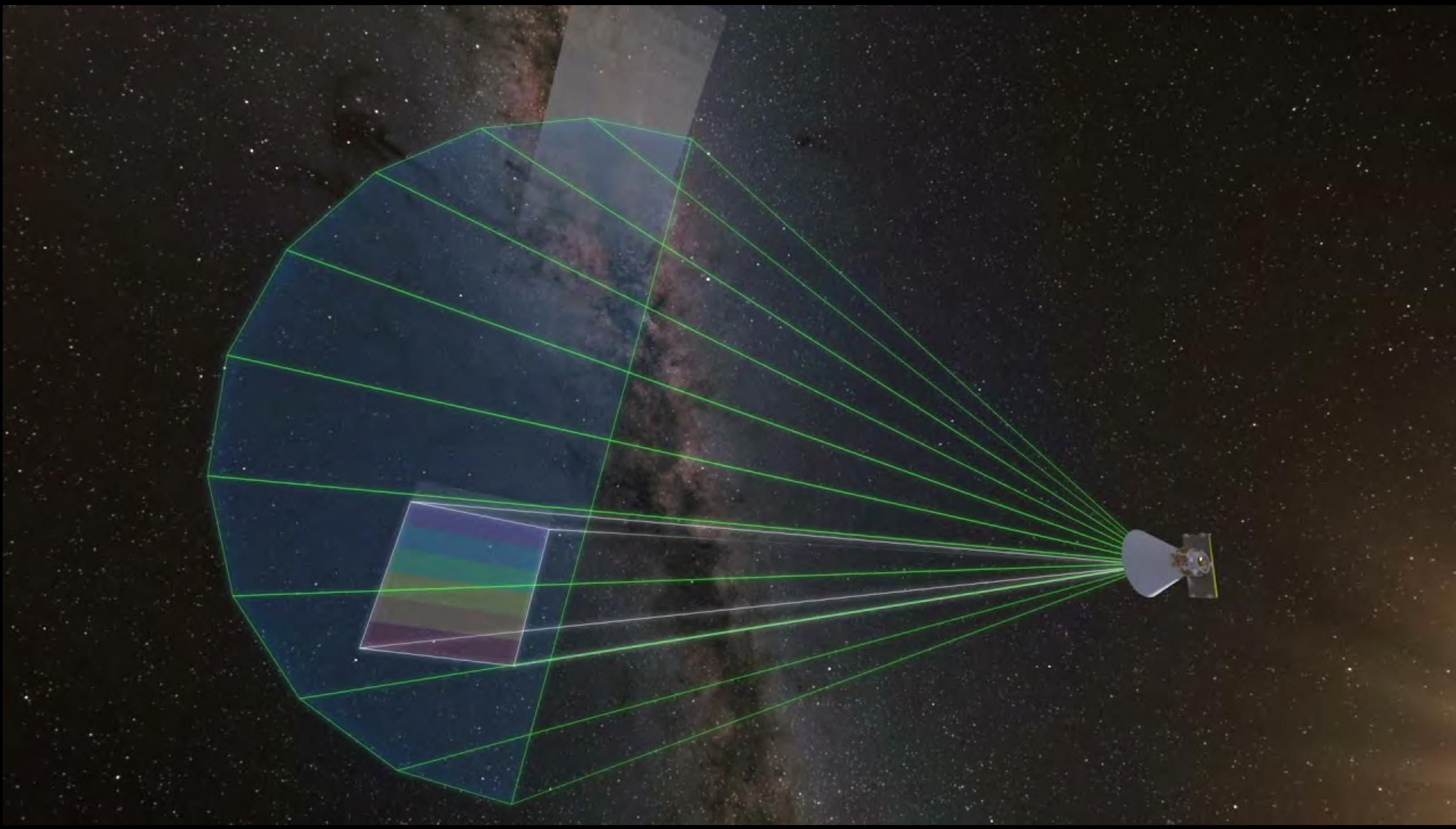




PUTTING SPHEREX TO THE TEST



PRE-PROGRAMED SCANNING STRATEGY



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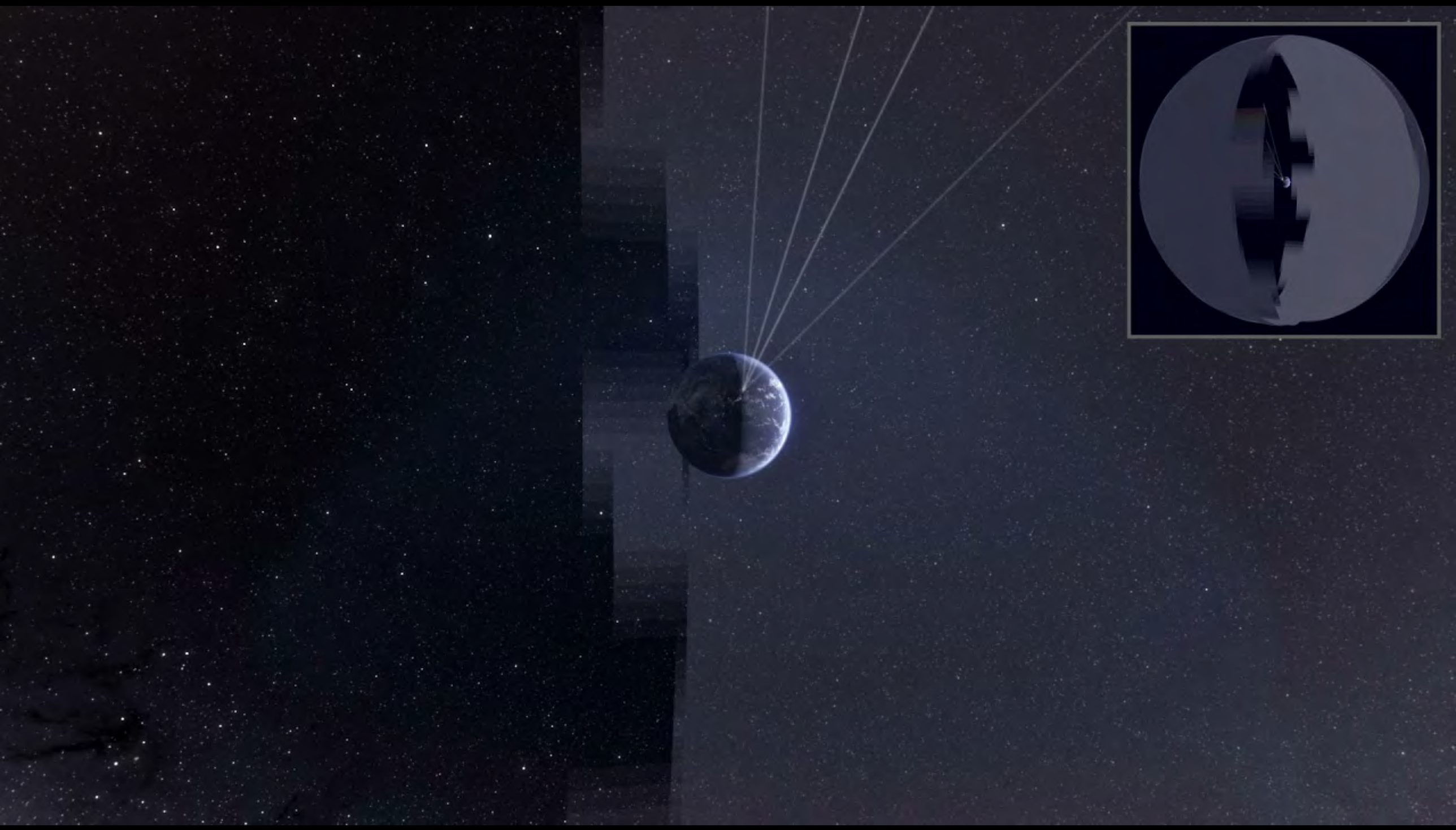
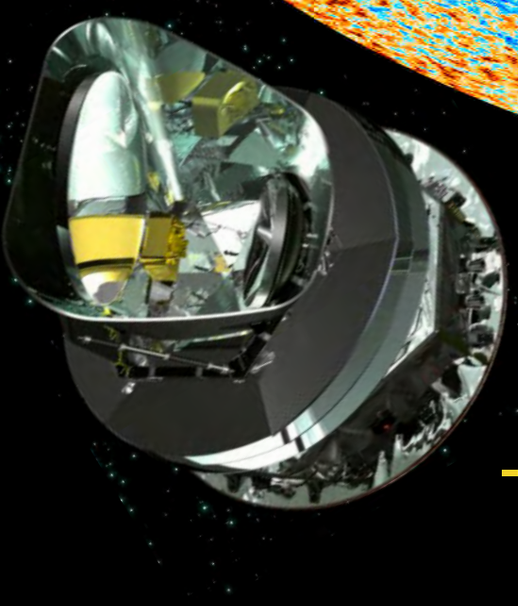


INFLATION INVESTIGATION

PLANCK MAP OF THE YOUNG UNIVERSE



-300 μK +300

ESA/NASA Planck 2018

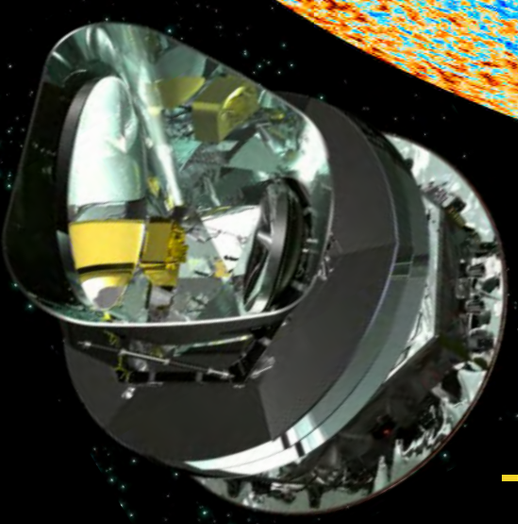
PLANCK MAP IS GAUSSIAN

Number of pixels

Temperature

$\propto f_{NL}$

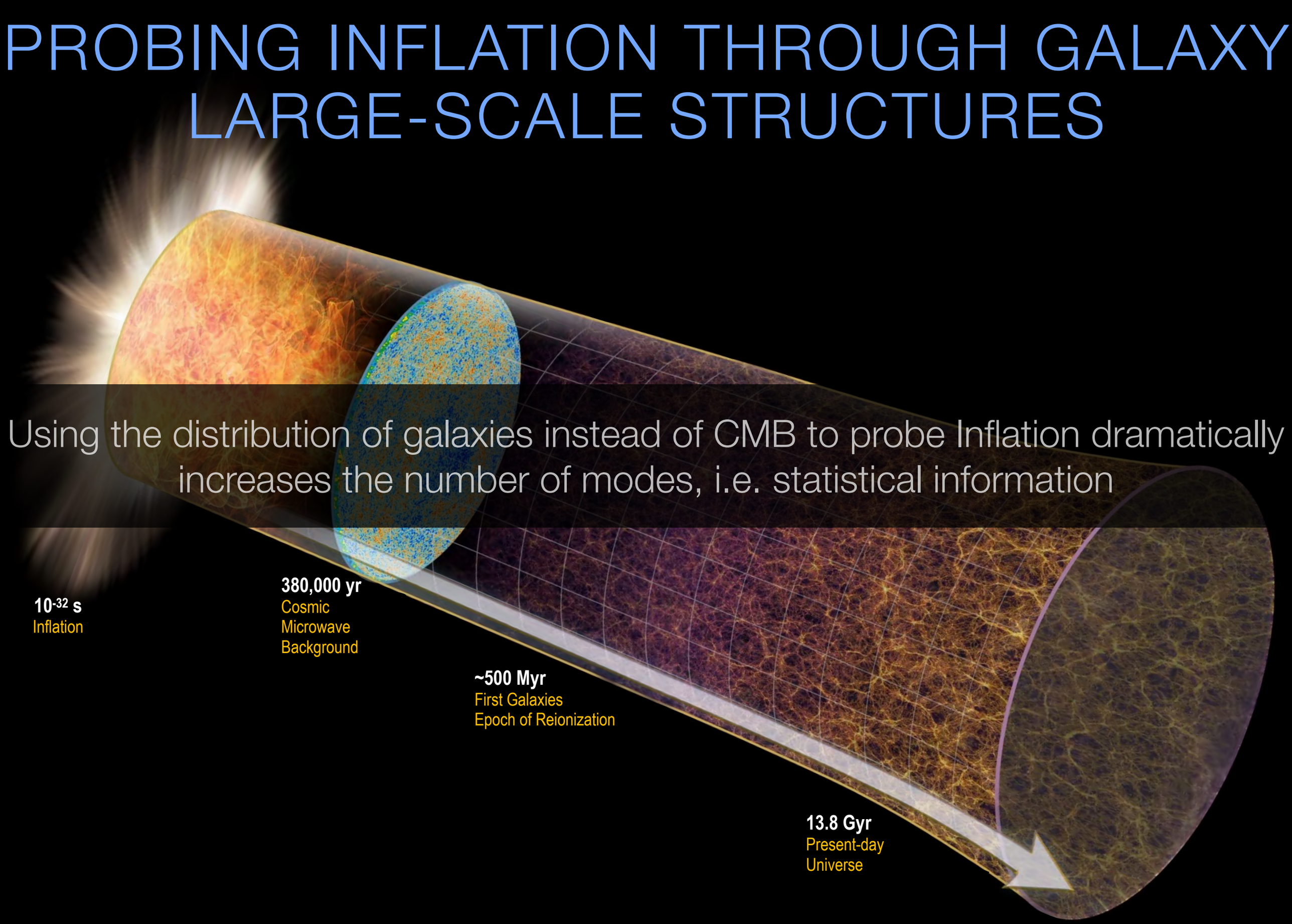
One of SPHEREx main goal is to improve our measurement of the f_{NL} parameters by an order of magnitude



-300 μK +300

ESA/NASA Planck 2018

PROBING INFLATION THROUGH GALAXY LARGE-SCALE STRUCTURES

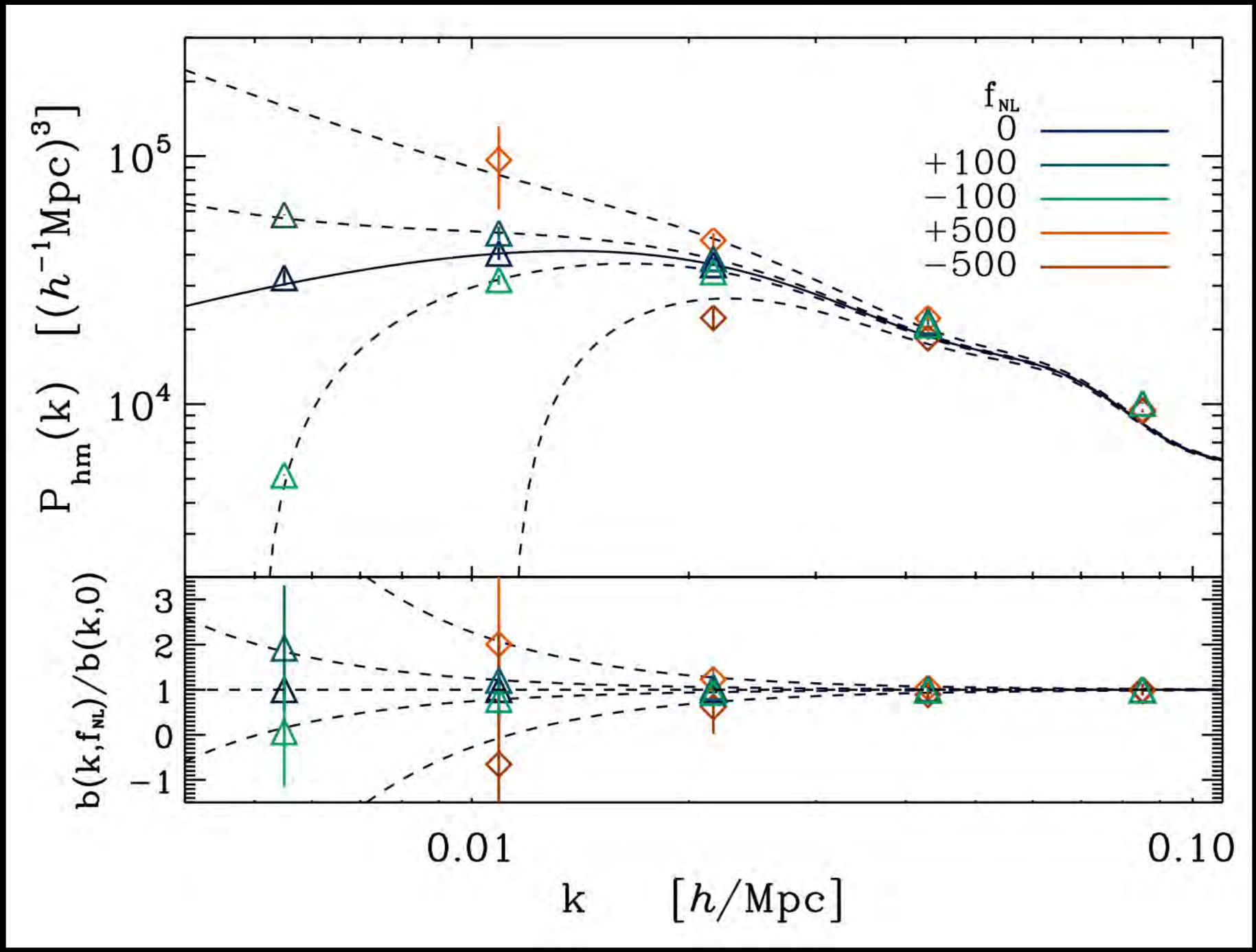


Using the distribution of galaxies instead of CMB to probe Inflation dramatically increases the number of modes, i.e. statistical information

PRIMORDIAL NON-GAUSSIANITY AND BIASING

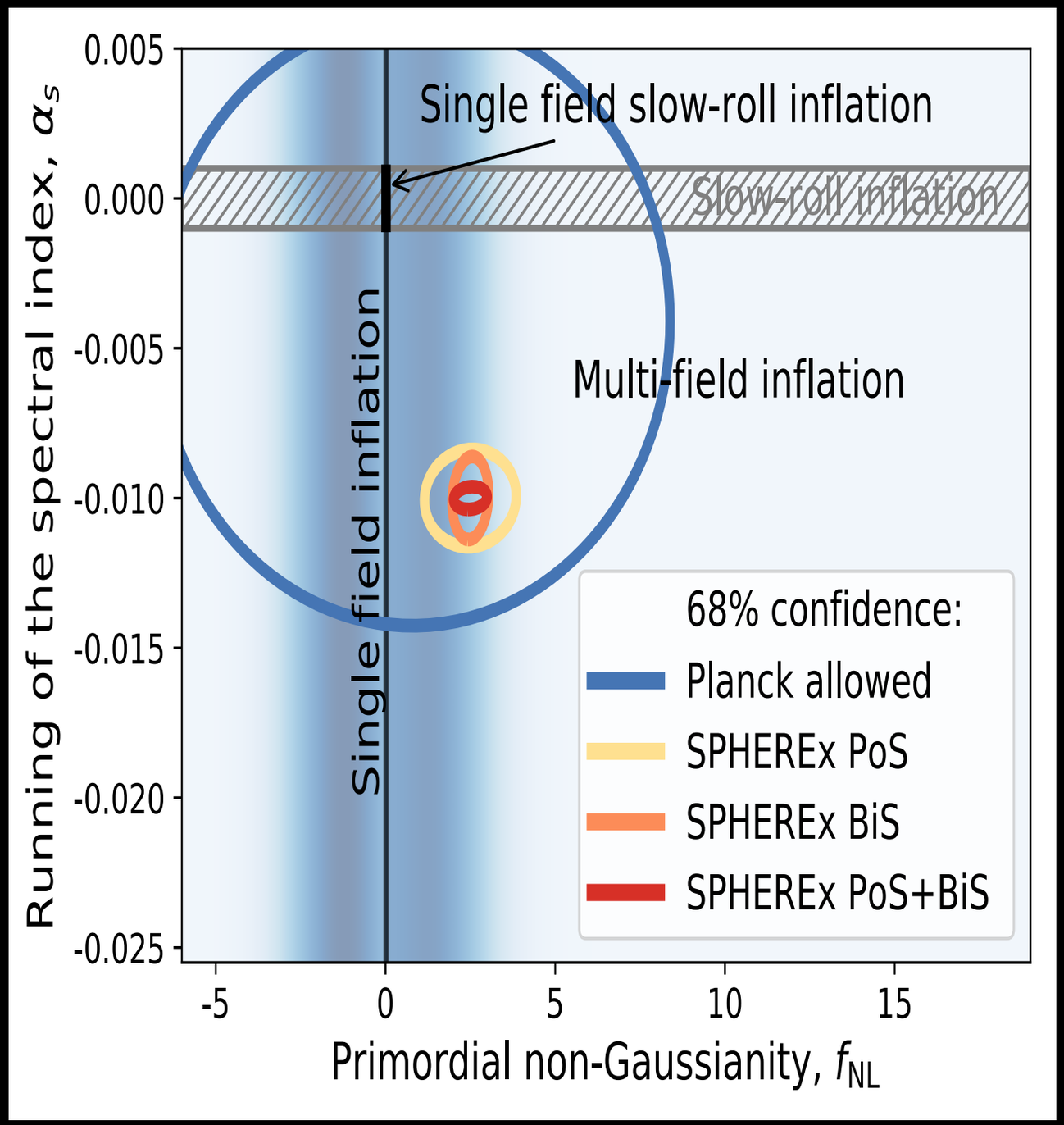
$$b_{NG}^{loc}(q) \propto f_{NL}^{loc} \frac{1}{T(q)q^2}$$

bias(k) bias(k) $P_{mm}(k)$



Dalal, OD, Huterer, Shirokov 07

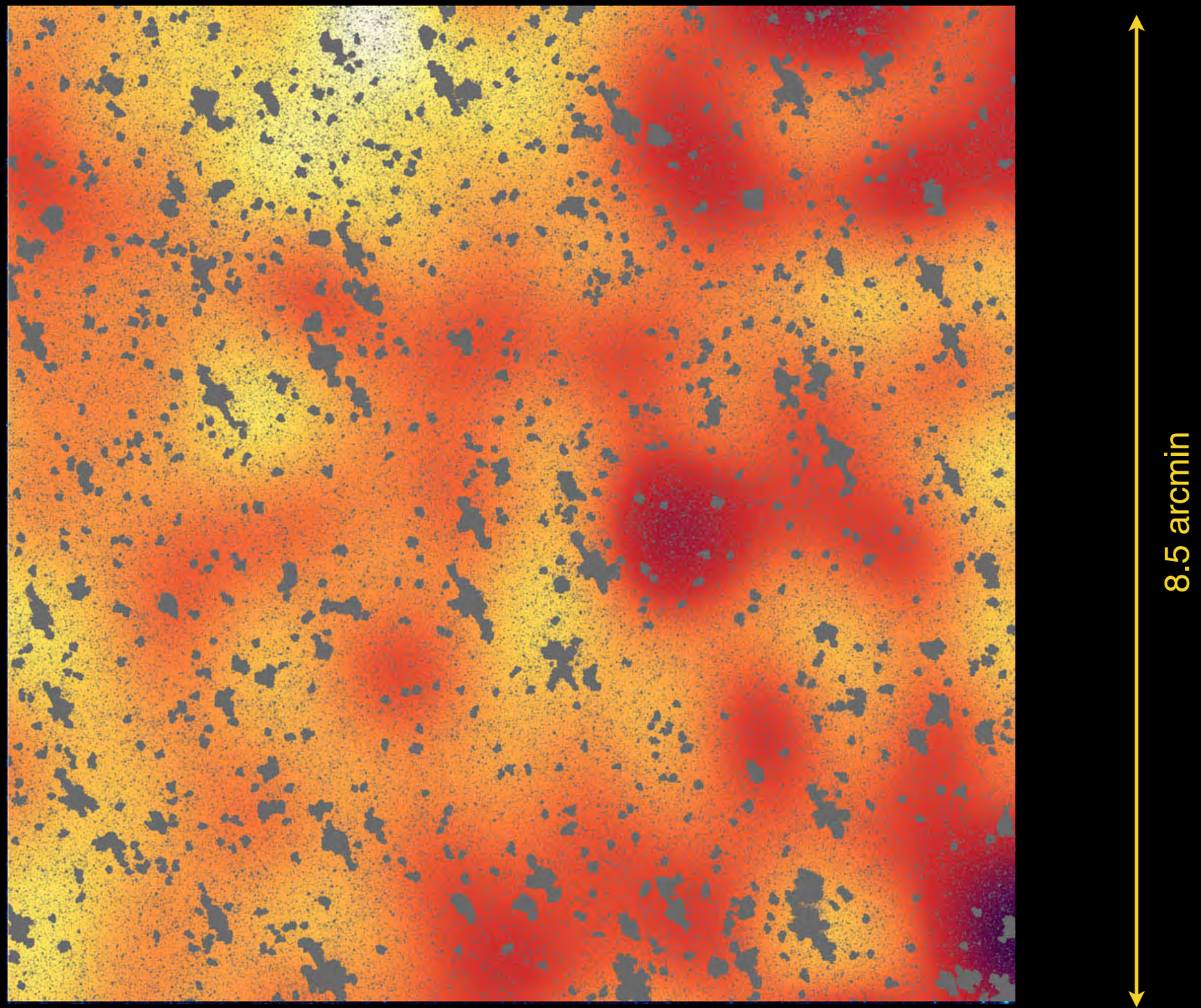
SPHEREX AND INFLATION



- SPHEREx produces a unique 3-D galaxy survey
  - ➡ Optimized for large scales to study inflation
  - ➡ Two ~independent tests of non-Gaussianity
- SPHEREx improves non-Gaussianity accuracy by a factor of ~10
  - ➡ Improves $\Delta f_{NL} \sim 5$ accuracy today to $\Delta f_{NL} < 0.5$
- Discriminates between models
  - ➡ Single-field inflation $f_{NL} << 1$
  - ➡ Multi-field inflation $f_{NL} \gtrsim 1$

EXTRA-GALACTIC BACKGROUND LIGHT INVESTIGATION

MAPPING EXTRA-GALACTIC BACKGROUND LIGHT



Spitzer @ 3.6 μm

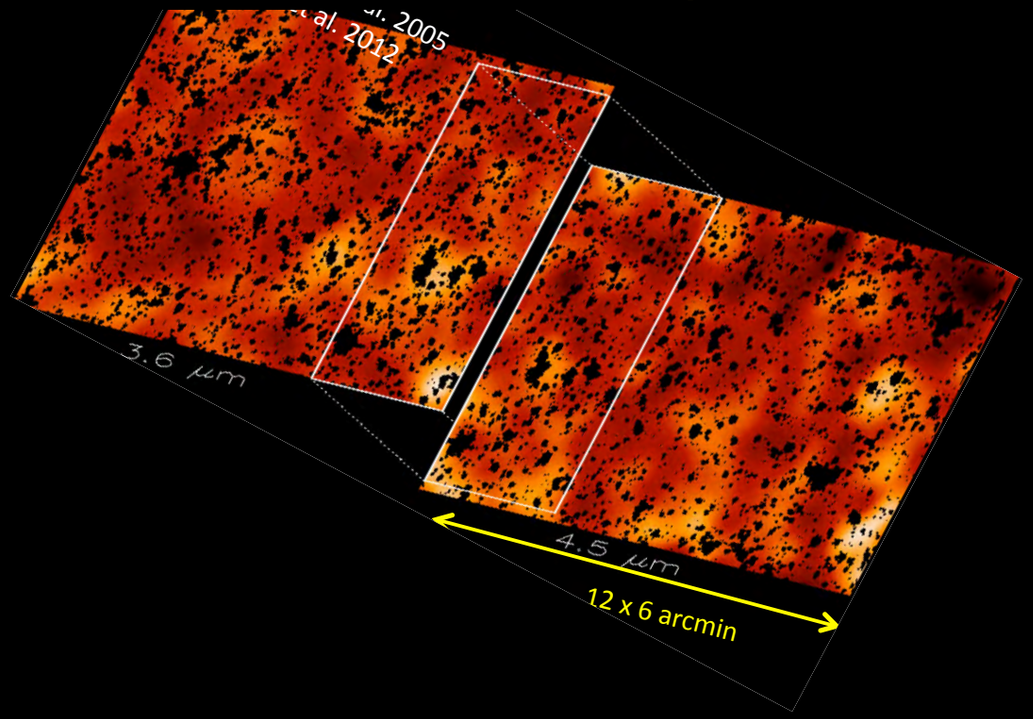
Cooray++07

HOW DID GALAXIES BEGIN?

MEASURING THE SPECTRA OF THE INTEGRATED COSMIC LIGHT THROUGH NIR FLUCTUATIONS

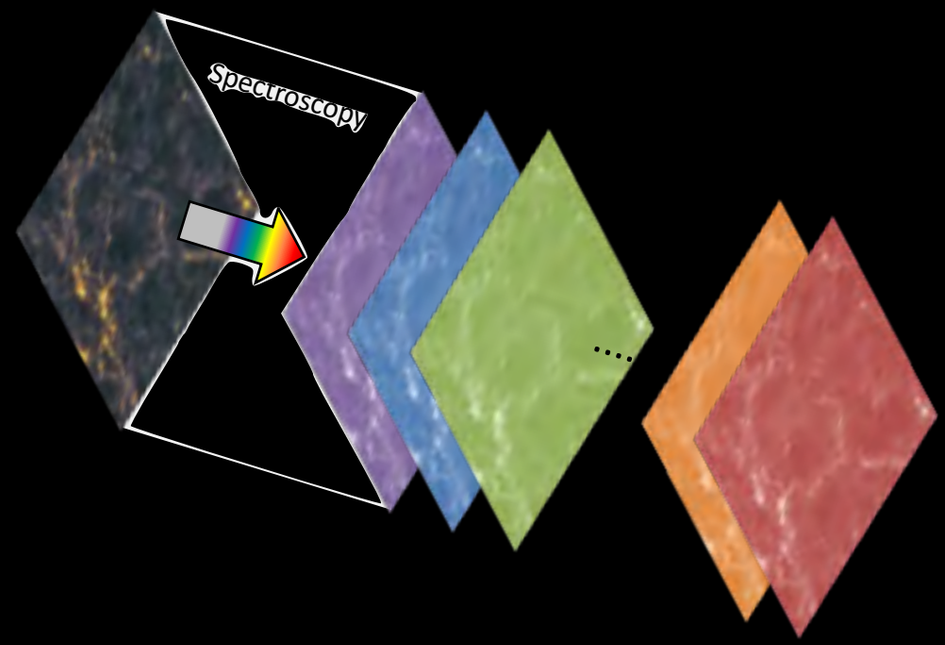
Spitzer (but also DIRBE, Planck, Akari, or Herschel)

NIR in 2 bands and 72 sq. arcmin



SPHEREx

Extends to 102 bands and 200 sq. deg.

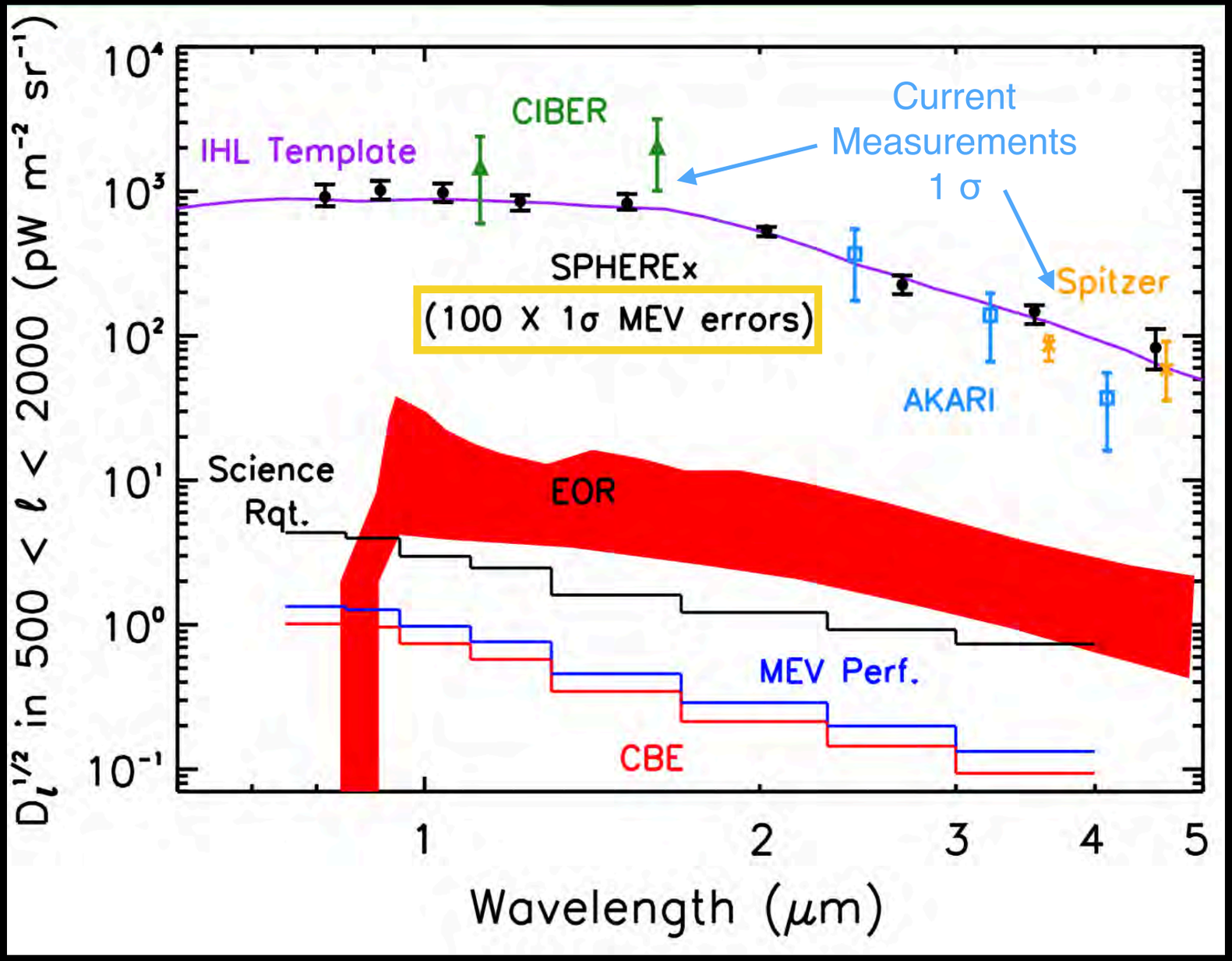


- SPHEREx observes every orbits ~2 x 100 sq. deg near the ecliptic poles
  - ➡We can reliably map light fluctuations over these *deep fields*

- Fluctuations receive contributions from all galaxies (incl. the dwarf galaxies responsible for reionization), but also from stars from stripped galaxies, etc.
  - ➡SPHEREx will measure the *spectra* of these fluctuations
  - ➡These spectra allow the extraction of the emission from the first galaxies (Feng++19)

PROBING THE EPOCH OF REIONIZATION

Fluctuations in 9 broad continuum bands



Can also extend to higher spectral resolution to do line intensity mapping

ICE INVESTIGATION

What Are the Conditions for Life Outside the Solar System?

- Sourced by biogenic molecules: H_2O, CO, CO_2, CH_3OH…

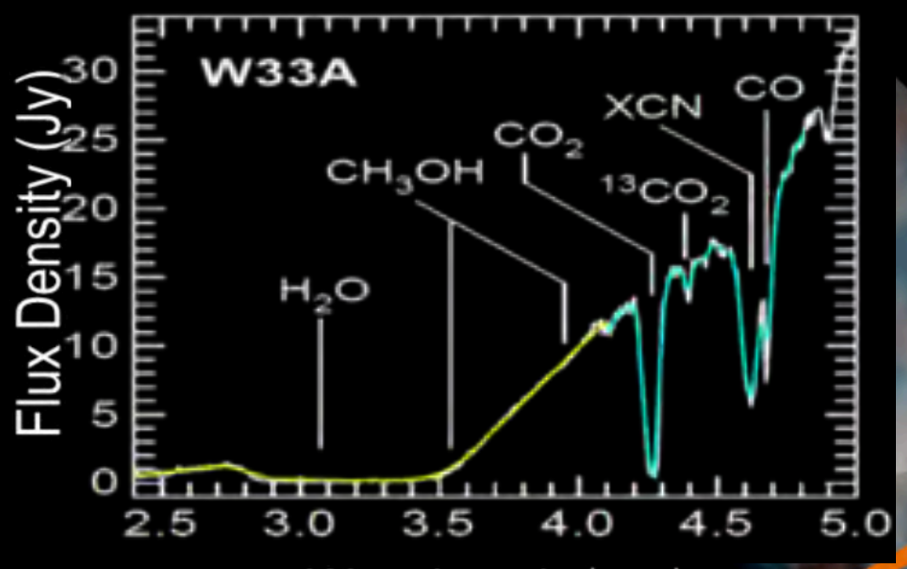
- More than 99 % interstellar water is locked in ice:
  - ➡'Follow the Water' means 'Follow the Ice'

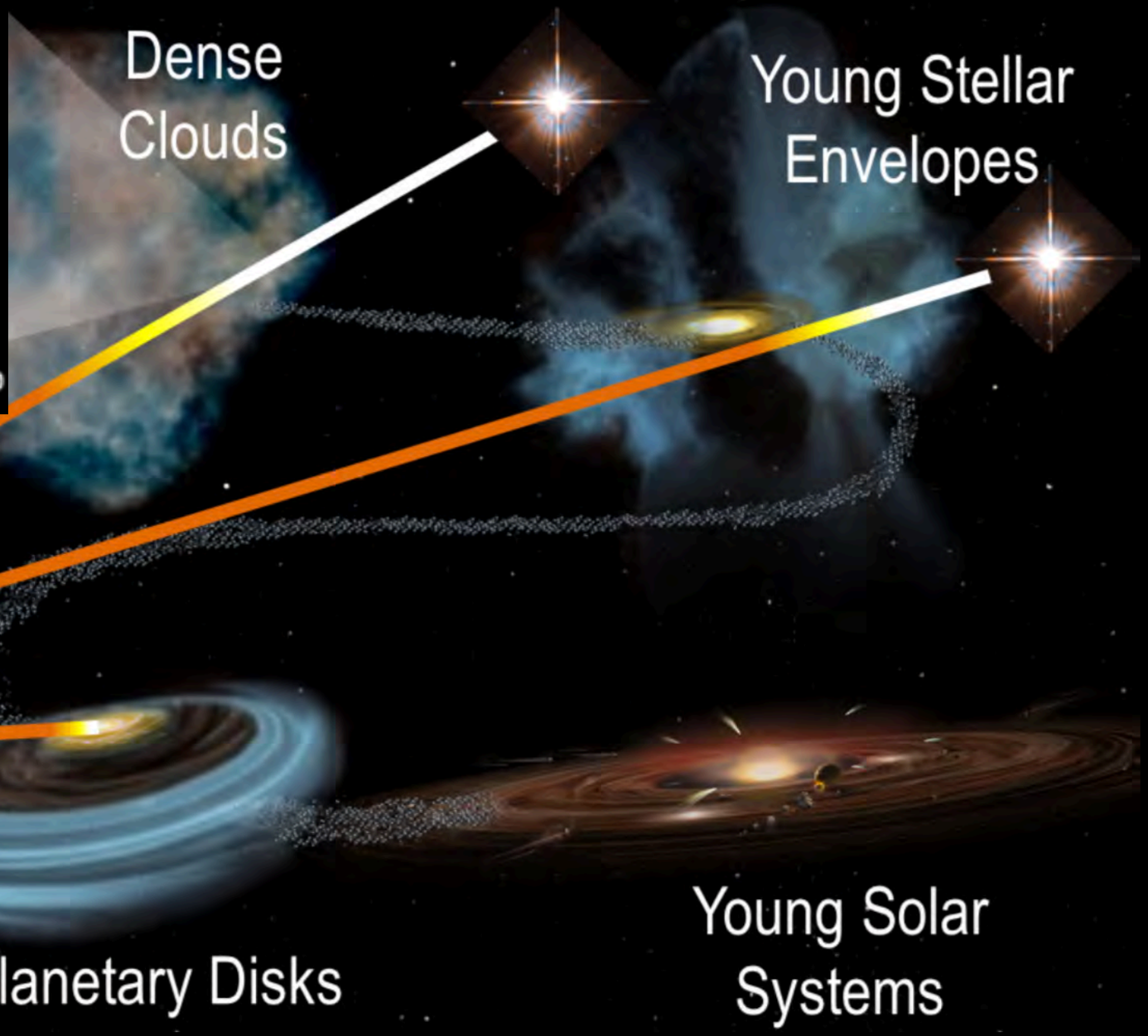
- Where do these molecules (in particular H_2O) come from:
  - ➡Did water arrive from the late bombardment (~500 MY) or before?
  - ➡Did earth's water come from the Oort cloud, Kuiper belt or closer?

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

WHAT ARE THE CONDITION FOR LIFE OUTSIDE THE SOLAR SYSTEM?

SPHEREX SURVEYS ICES IN ALL PHASES OF STAR FORMATION





SPHEREx will measure ice abundance towards >> 20,000 sources (currently ~200 known) and determine how water and biogenic ices evolve from molecular clouds to young stars to proto-planetary disks

SUMMARY

- SPHEREx will create the first all sky near-infrared spectroscopic survey:
  - ➡ A quickly released public dataset of lasting legacy
  - ➡ Many discoveries will come from the community

- SPHEREx offers a simple and very robust design and modus operandi:
  - ➡ Enables a high control of systematics thanks to multiple built-in redundancy, the CMB way

- SPHEREx will enable multiple and powerful studies:
  - ➡ Primordial non-Gaussianity to learn about Inflation
  - ➡ Extra-galactic background light from z=0 till the reionization era
  - ➡ Origin of water and biogenic ices in young stellar objects and proto-planetary systems
  - ➡ …

- SPHEREx has strong synergies with current and future observatories
  - ➡Rubin, DESI, JWST, Roman, Euclid, SDSS-V, TESS, e-ROSITA, SO, CMB-S4, UVEX…

- A very exciting decade ahead!

FIN