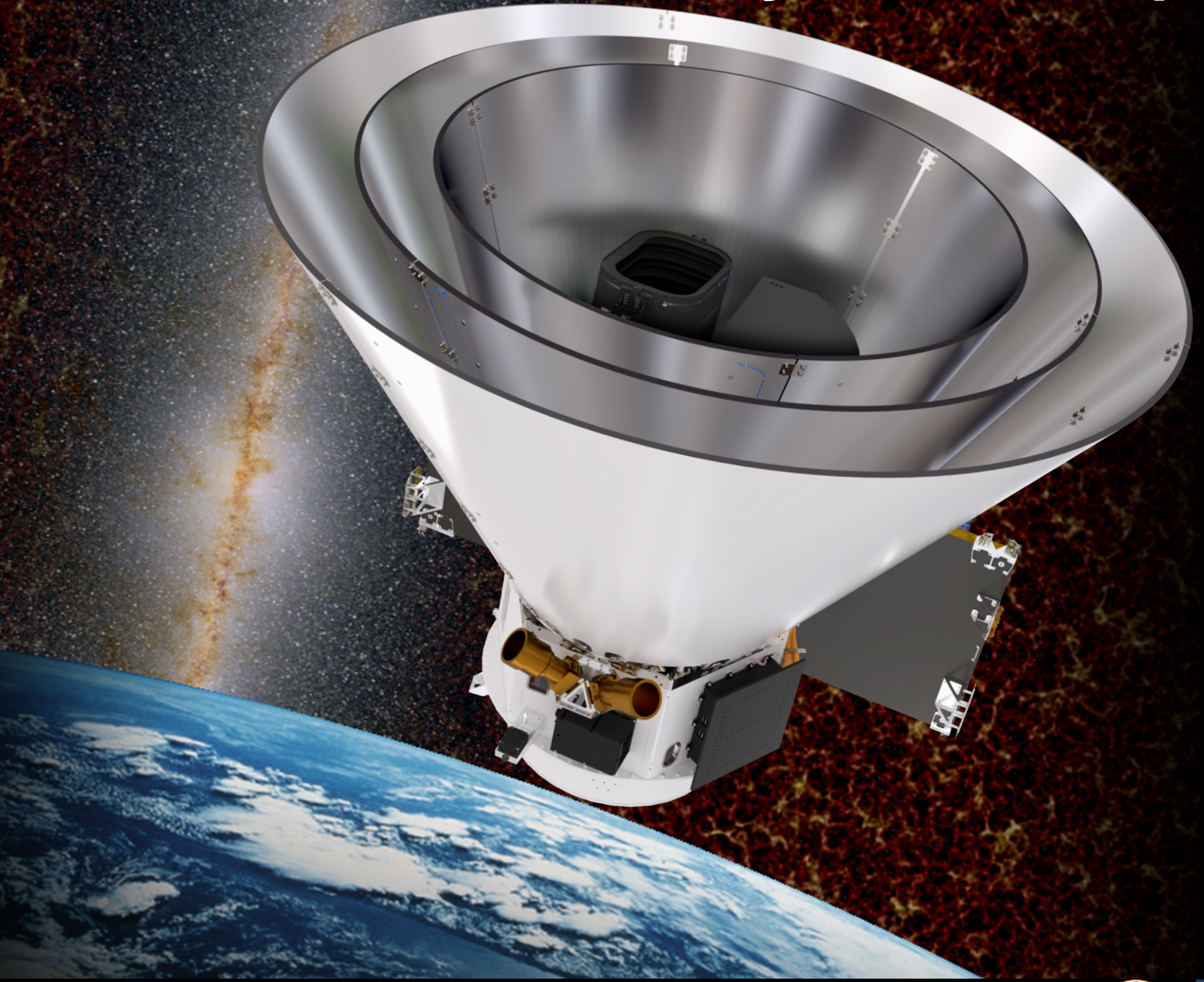
SPHEREx: An All-Sky Infrared Spectral Survey Satellite



Designed to Explore

- Origin of the Universe
- Origin and History of Galaxies
- Origin of Water in Planetary Systems

First All-Sky Near-IR Spectral Survey

A Rich Legacy Archive for Astronomy
with 100s of Millions of Stars and Galaxies

Elegantly Simple

- Single Observing Mode
- No Moving Parts in Instrument

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For the SPHEREx Collaboration

SPHERE^{x} Science Team

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- Past members

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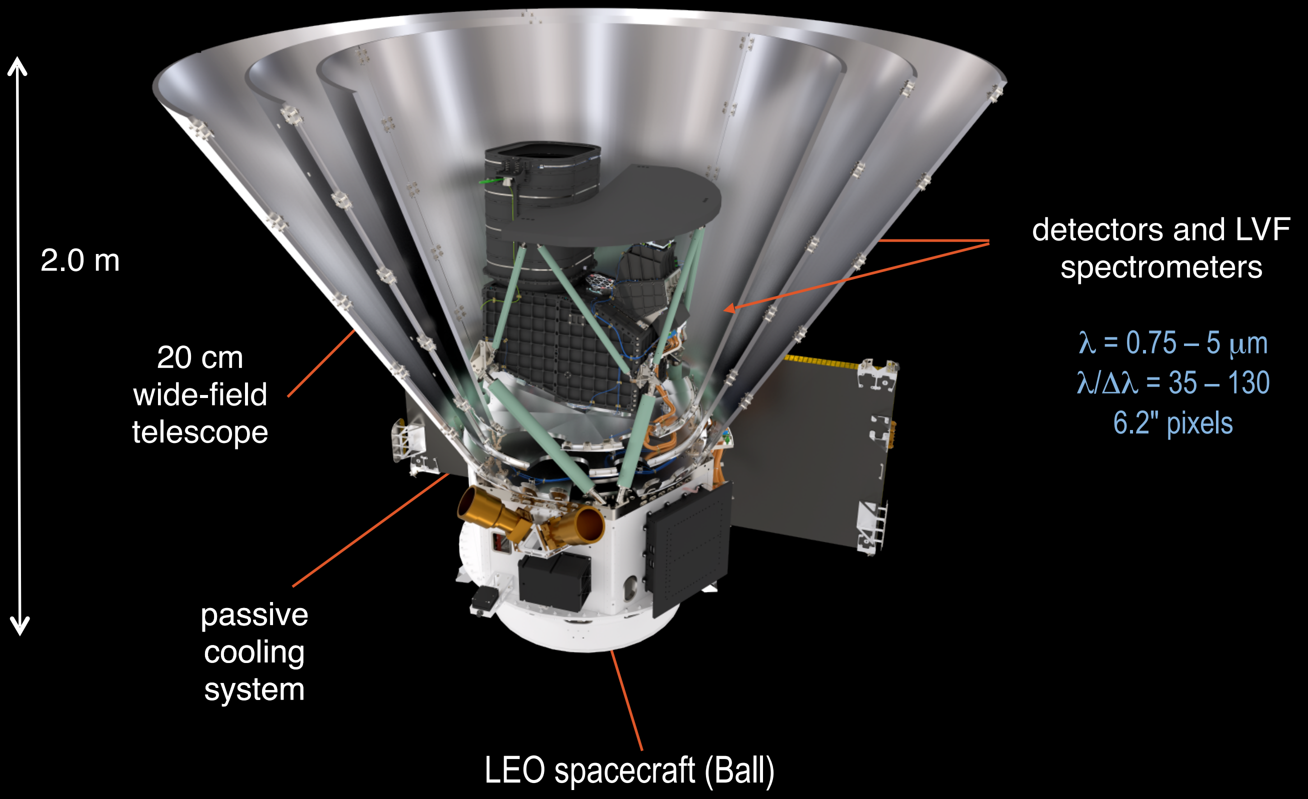
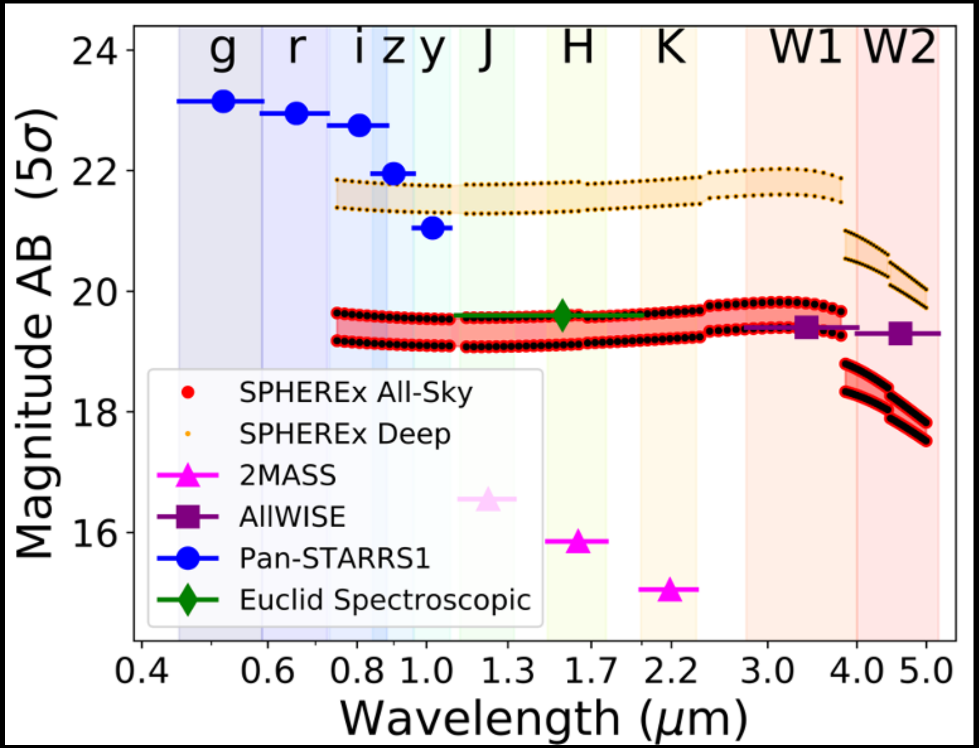
SPHEREx instrument

- 3-Mirror off-axis anastigmat
- 20 cm effective aperture
- 3.5° x 11.3° FOV
- 25 million 6.2" pixels

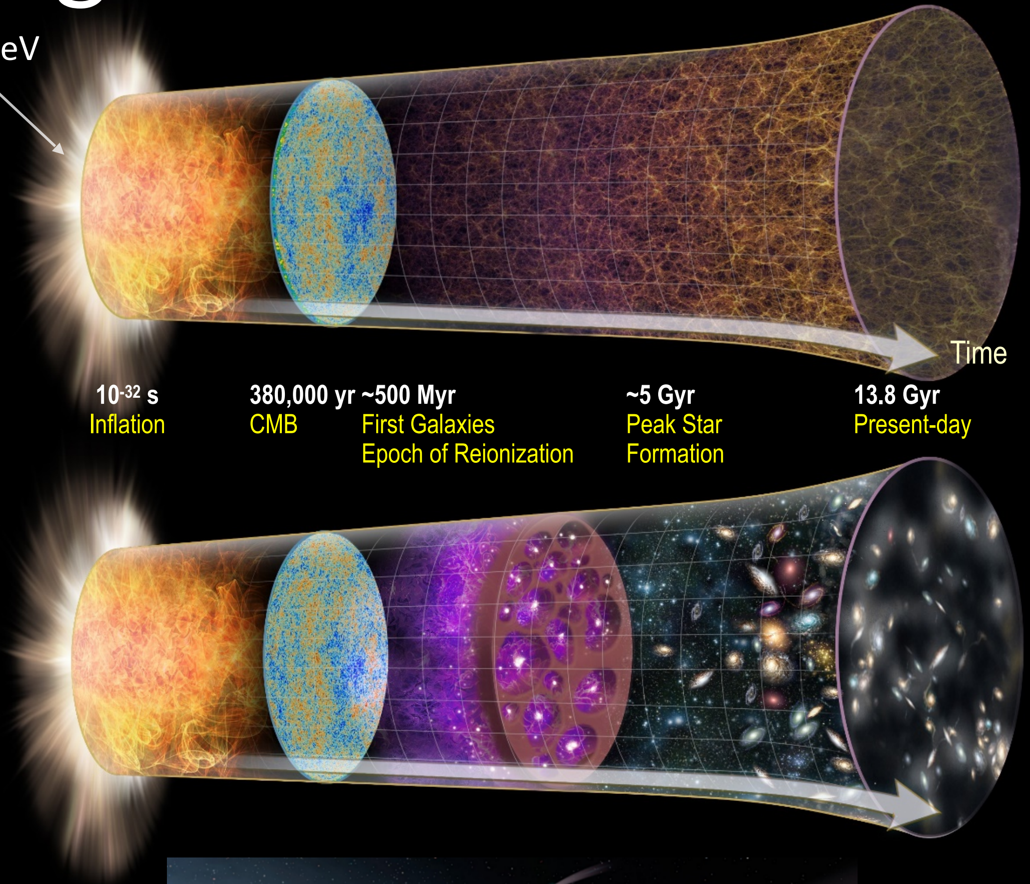




SPHEREx core science program

How did the Universe Begin?

SPHEREx observes the 3D distribution of galaxies, measuring ‘Non-Gaussianity’ to probe inflation physics

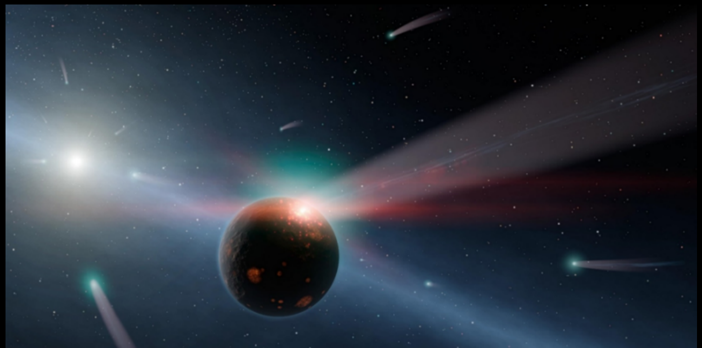


How did Galaxies Begin?

SPHEREx extragalactic background measurements determine the total light emitted by galaxies

What are the Conditions for Life?

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


Interstellar ices sourced Earth’s water

OBSERVABLE TO PROBE INFLATION: NON-GAUSSIANITY

1. Inflationary gravitational waves – CMB polarization, B-modes
2. Non-Gaussianity – Sensitive to Inflaton field, single- or multi-field

CMB Non-Gaussianity: $f_{NL} < 10.8$ (2σ) limited by cosmic noise

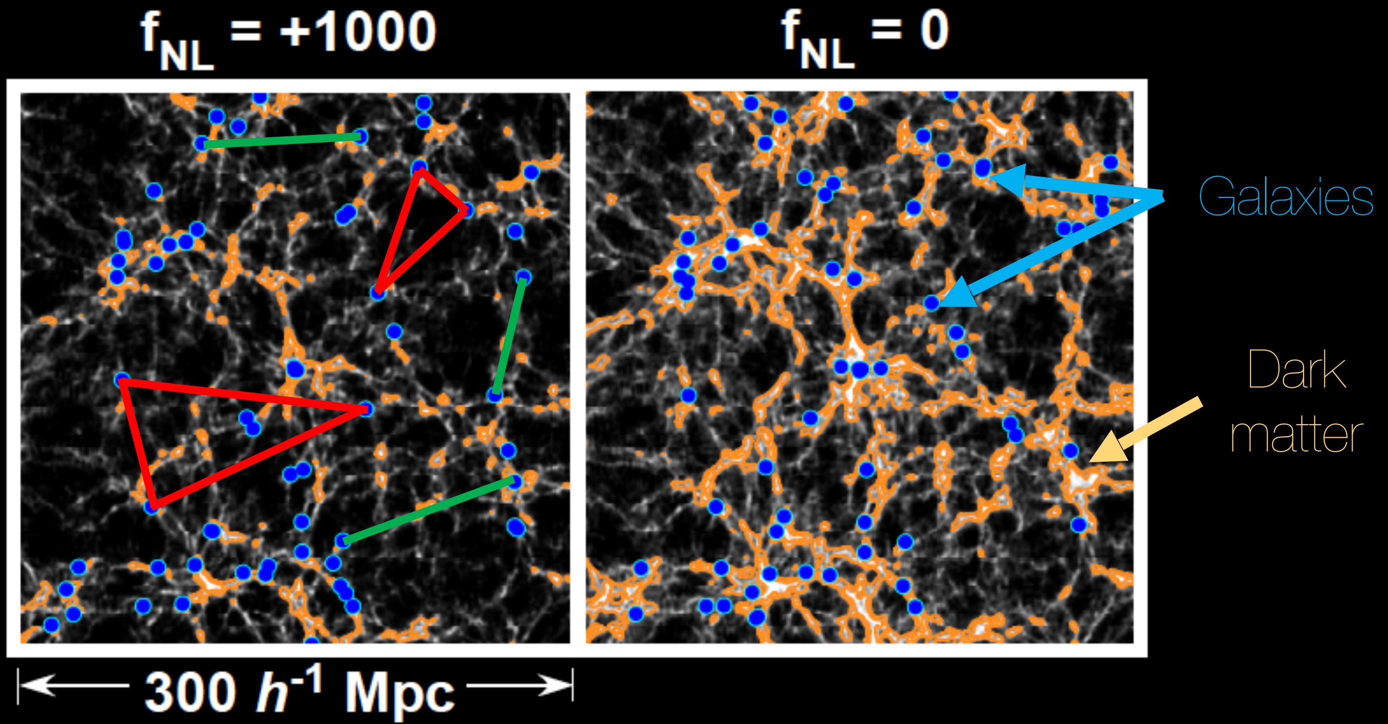
Planck
2015 results

Large-Scale Structure will give best non-Gaussianity measurements

Quantified by 3D correlations between galaxies:

Pairs
(power spectrum)

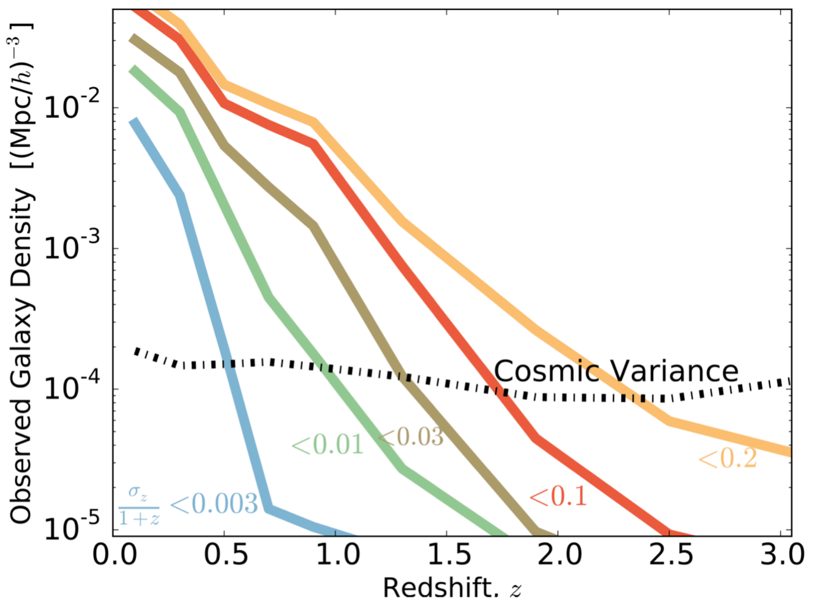
Triples (bispectrum)



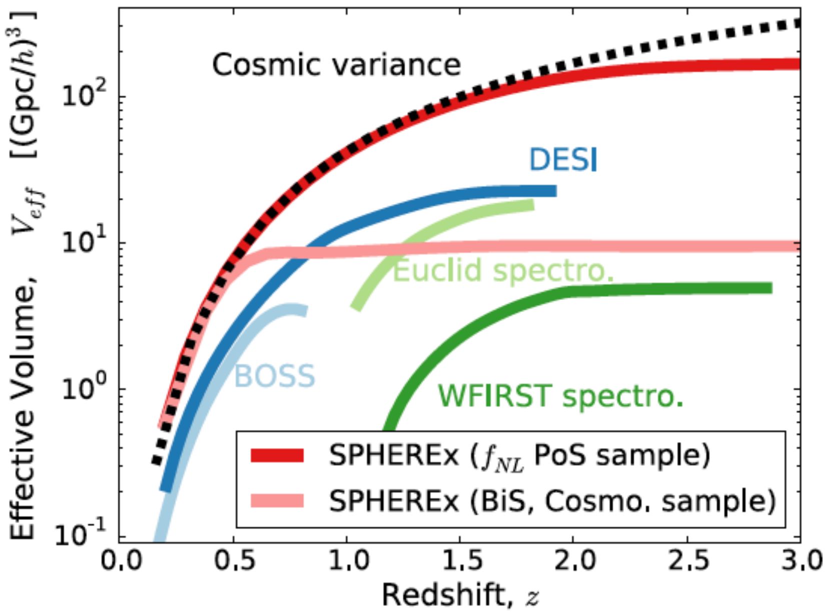
Non-Gaussianity requires <u>fidelity on large spatial scales</u>

SPHEREx LARGE VOLUME GALAXY SURVEY

Catalog Split into Redshift Accuracy Bins



SPHEREx Surveys Maximum Cosmic Volume



SPHEREx Large-Volume Redshift Catalog

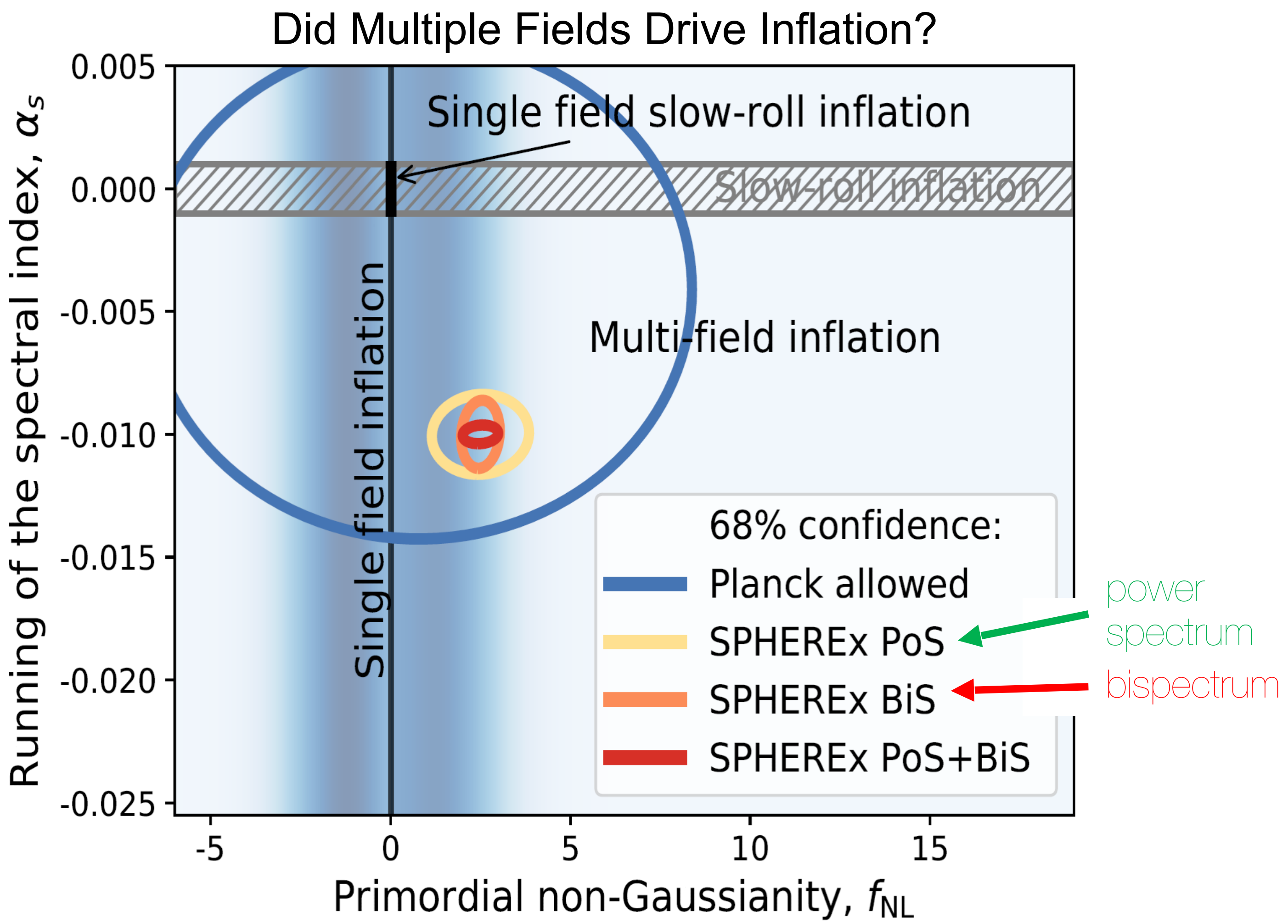
- Largest effective volume of any survey, near cosmic limit
- Excels at z<1, complements dark energy missions (Euclid, Roman) targeting z~2
- SPHEREx + Euclid/Roman/Rubin measures galaxy-galaxy lensing, calibrates photometry and photo-zs

Survey Designed for Two Tests of Non-Gaussianity

- Large scale power from Power Spectrum: large number of low-accuracy redshifts
- Modulation of fine-scale power from Bispectrum: fewer high-accuracy redshifts

SPHEREx TESTS INFLATIONARY NON-GAUSSIANITY

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



SPHEREx improves accuracy to σ(fNL) < 0.5

>10x improvement better than current CMB f_{NL} measurements

CLUSTER REDSHIFTS MACHINE

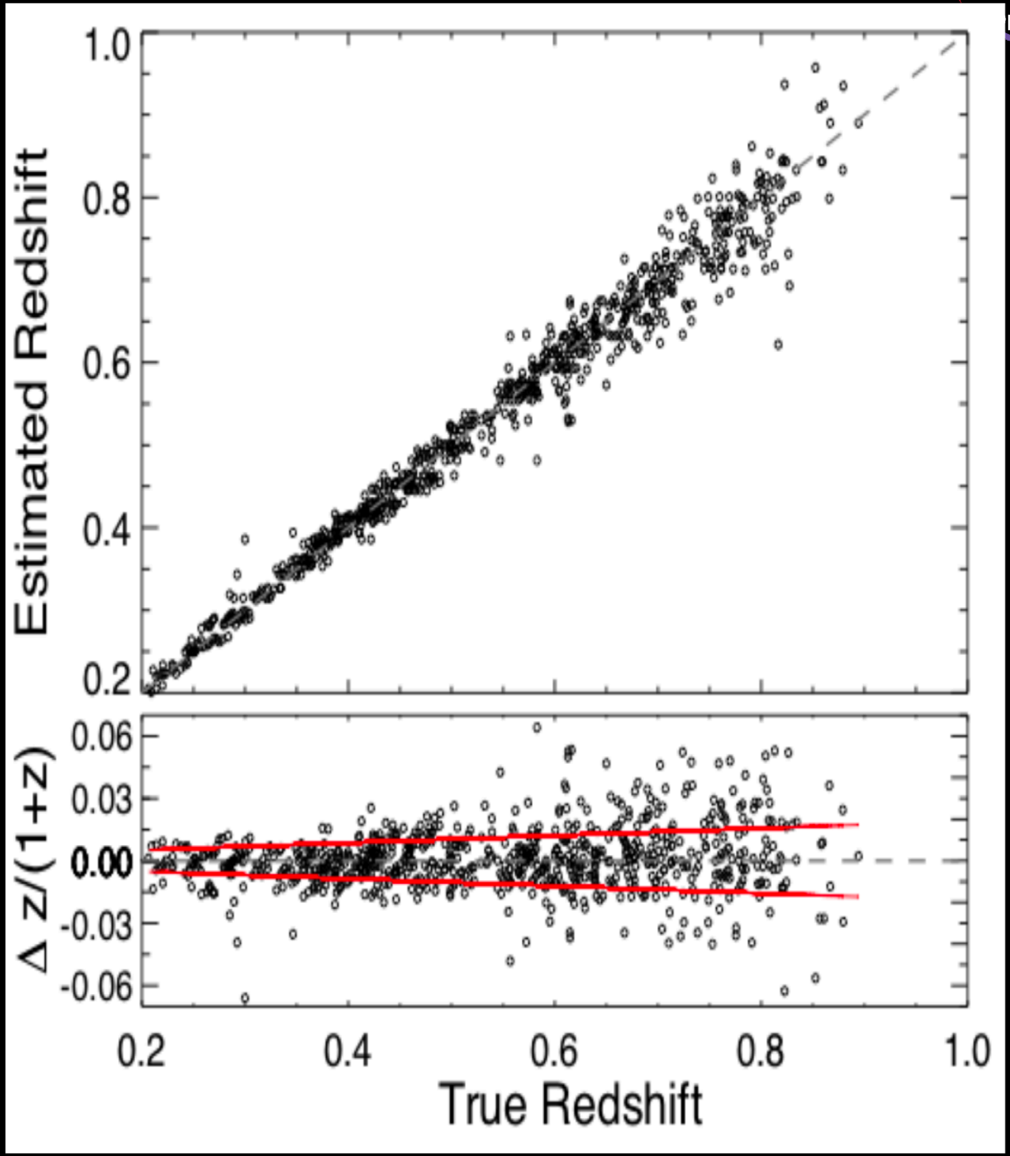
Cluster Identification and Redshifts
CMB-S4 + eROSITA will find 100,000+ massive clusters.
Intracluster medium-based observables contain limited-to-no redshift information.

SPHEREx cluster redshift error over the full sky will
Equal or exceed current optical surveys for redshifts $z \lesssim 0.6$
$\sigma_z/(1+z) < 0.03$ up at $z \sim 0.9$

SPHEREx will also find > 30,000 clusters independently
With high precision redshift information
Median redshift of these clusters $z_{median} \sim 0.2$

SPHEREx provides a useful redshift cross-check
For clusters at redshifts near the 4000Å break transitions between optical filters, as SPHEREx uses the smooth 1.6um feature.

Combining with CMB-S4 allows for tomographic reconstruction of the tSZ signal from these clusters.
3D tSZ map enable us to study the evolution of the thermal properties of the intracluster medium (ICM)
Constrain cosmological parameters directly



Doré, Werner ++ 16
Plot by Bleem

KSZ CROSS-CORRELATION

SPHERE^X

SPHEREx + CMB-S4 will greatly increase our ability to measure the baryon component with kinematic Sunyaev-Zel'dovich effect.

kSZ amplitude directly proportional to the electron number density, unbiased probe of the total electron abundance and gas profile.

Typically requiring spectroscopic redshifts or photometric redshifts at $\sigma(z) \lesssim 0.01$.

Using the velocity reconstruction method, using only the two highest redshift accuracy samples, total number of galaxies N~24.5M galaxies

S/N ~ 55, with $f_{sky} = 0.5$, and CMB map noise = 14μK-arcmin. (Ferraro, Schaan)

Using direct cross-correlation between T^2 and δ_{gal} allows a statistical measurement with less stringent requirements on redshift errors:

S/N > 100 can be achieved by combining SPHEREx with CMB-S4 data (Ferraro, Hill et al.)

Measure the velocity fluctuation power on large scales which can help the f_{NL} measurement.

Expect a factor few improvement over PoS alone (Kumar et al., Münchmeyer et al.)

CROSS CORRELATION WITH CMB-LENSING

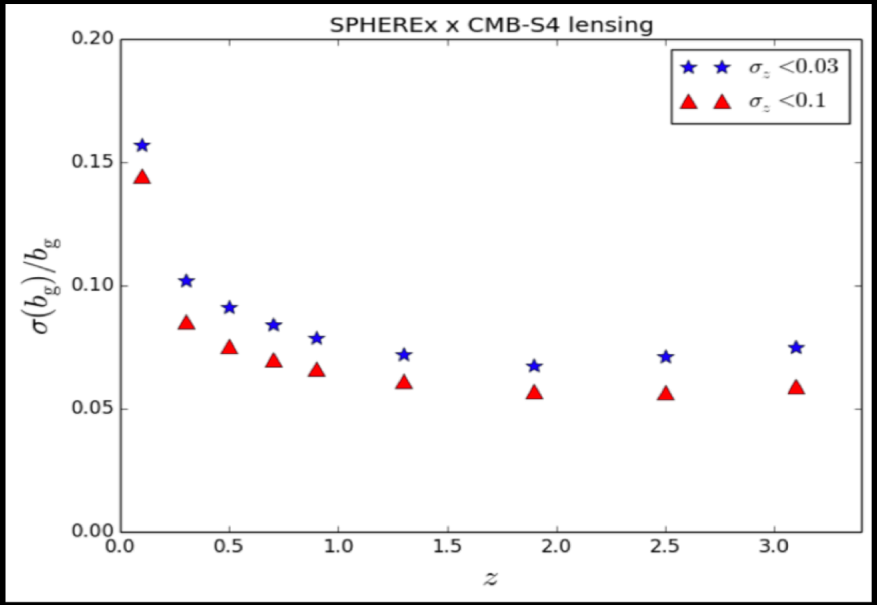
SPHEREx galaxy clustering measurement covers the full sky and it is cosmic variance limited on large scales

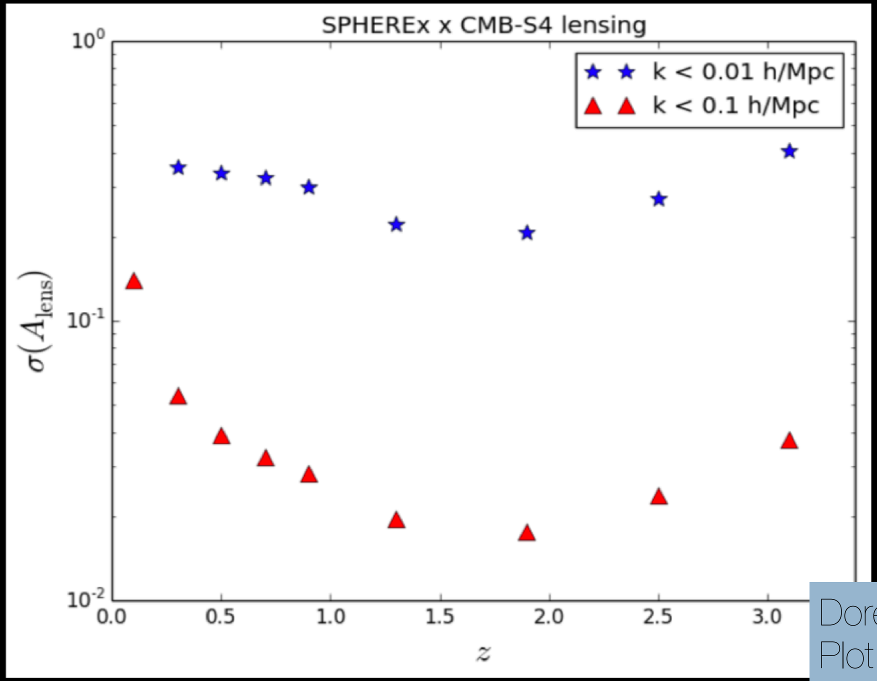
SPHEREx determiners galaxy bias b_g from the galaxy power spectrum analysis

- **Fractional constraints on b_g, assuming f_{sky} = 0.5**

Given b_g, galaxy-CMB lensing:

- **Constrains the amplitude A_{lens}**
- **Probes gravity on large scales**





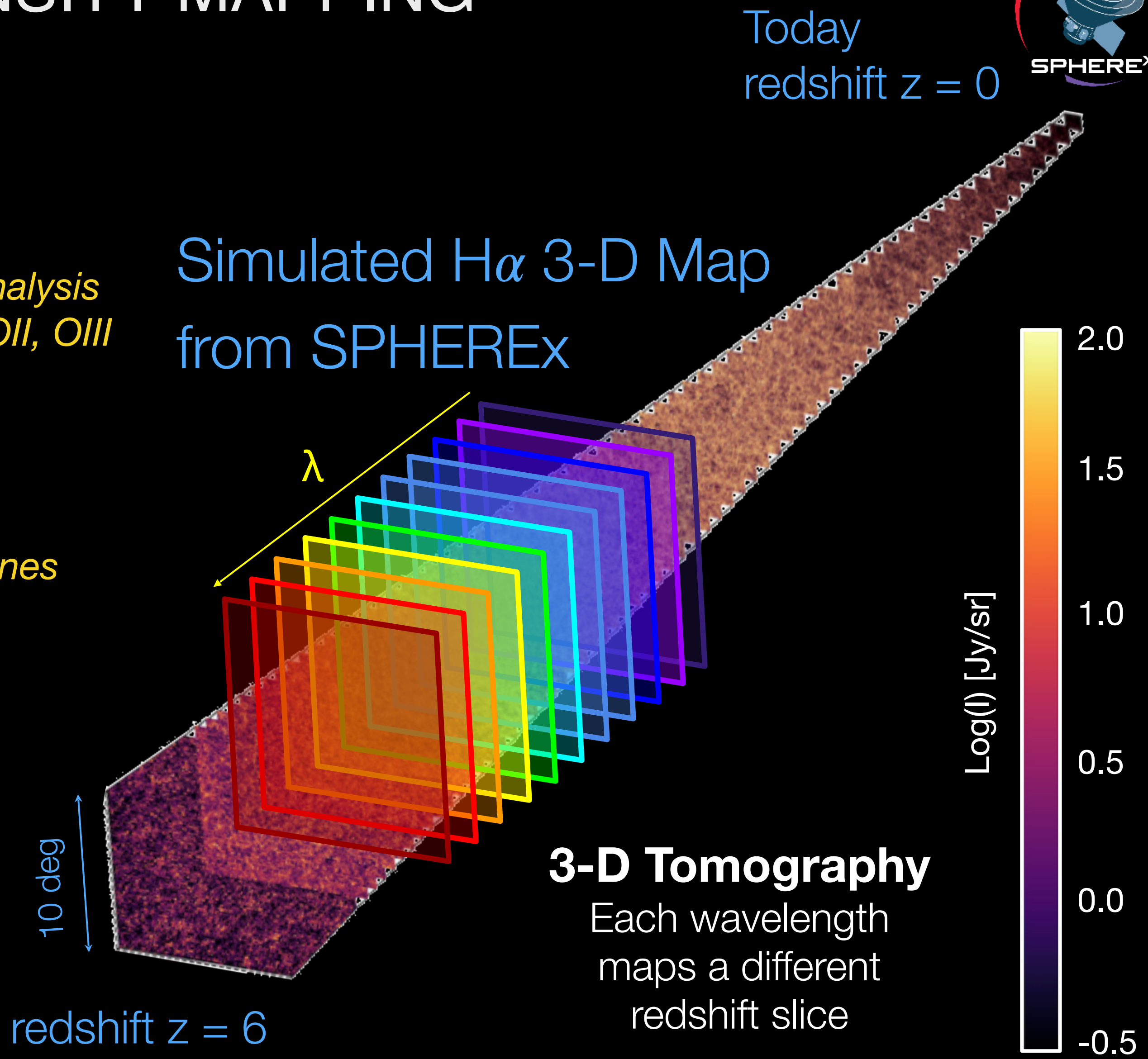
Doré, Werner ++ 16
Plot by Schaan

LINE INTENSITY MAPPING

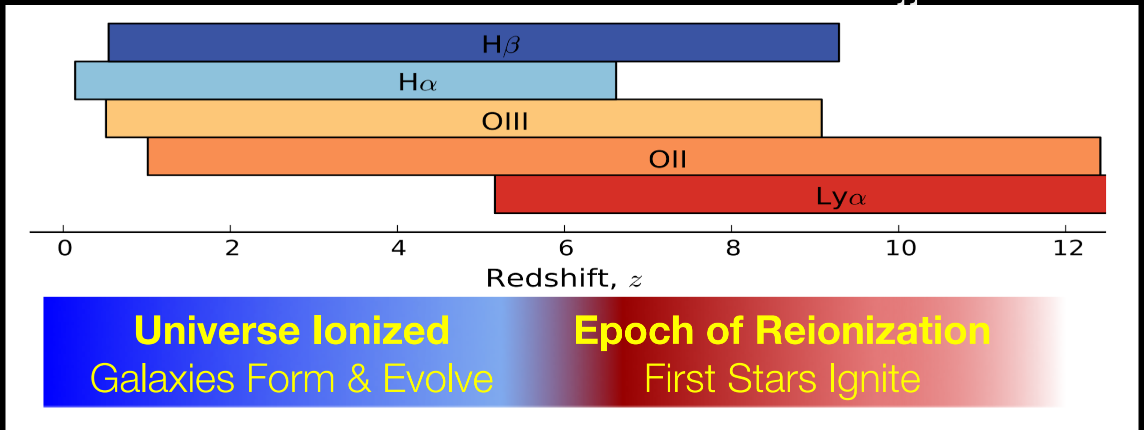
How does line intensity mapping work?
Maps large scale structure using collective light from galaxies
Line emission uniquely gives the redshift

SPHEREx can provide
All of the deep field maps will be ready-built for spectroscopic analysis
Line emission maps expected to be readily detected in Hα, Hβ, OII, OIII
Lyα line accessible at high redshifts z > 5.2
(Cheng, Chang, Bock 2020)

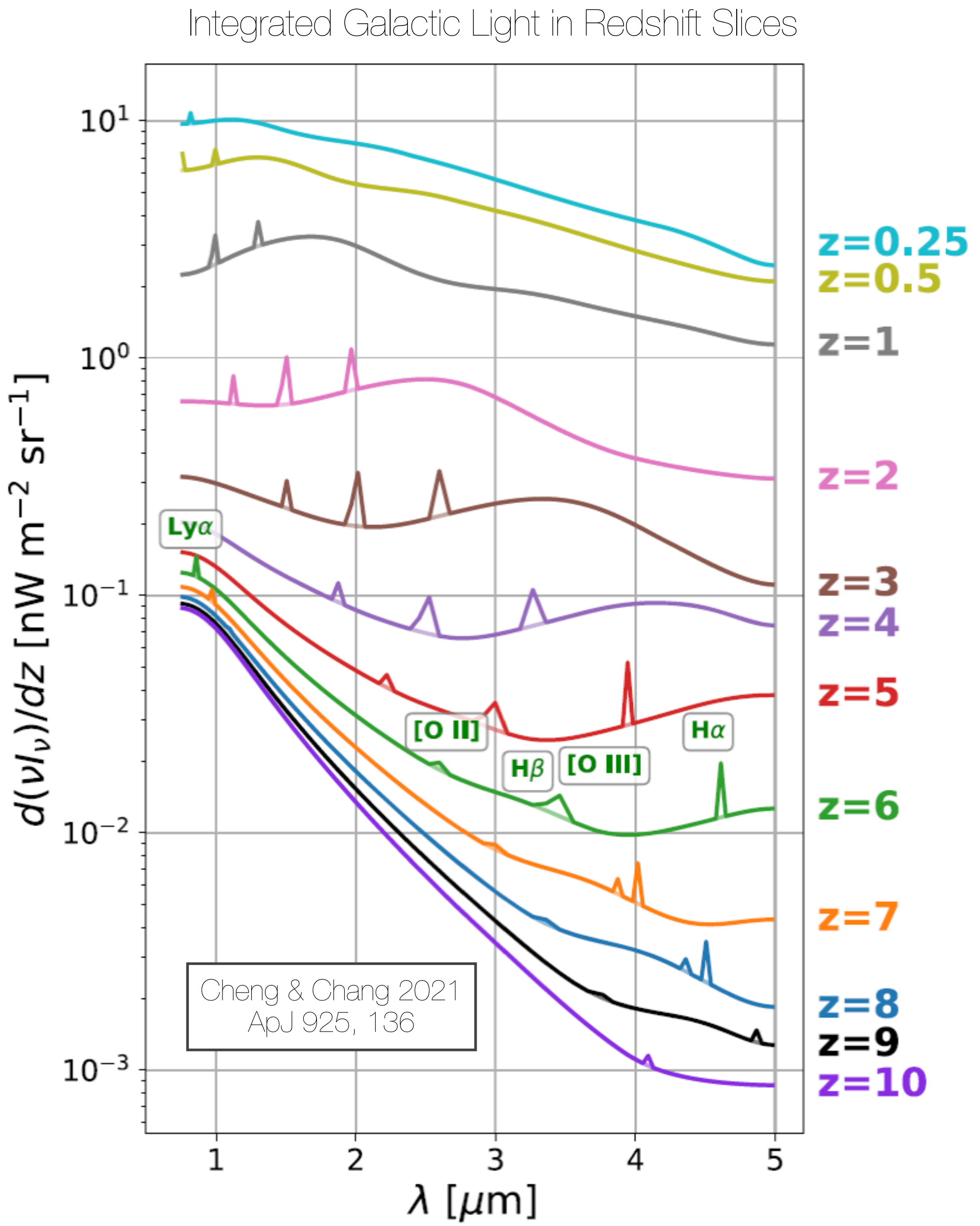
Scientific Opportunity
Map the entire History of Galaxy and Star Formation in multiple lines
New insights on the Epoch of Reionization through Ly and OIII
Unique measurements on the Geometry of the Universe at High Redshift (z ~4-5)

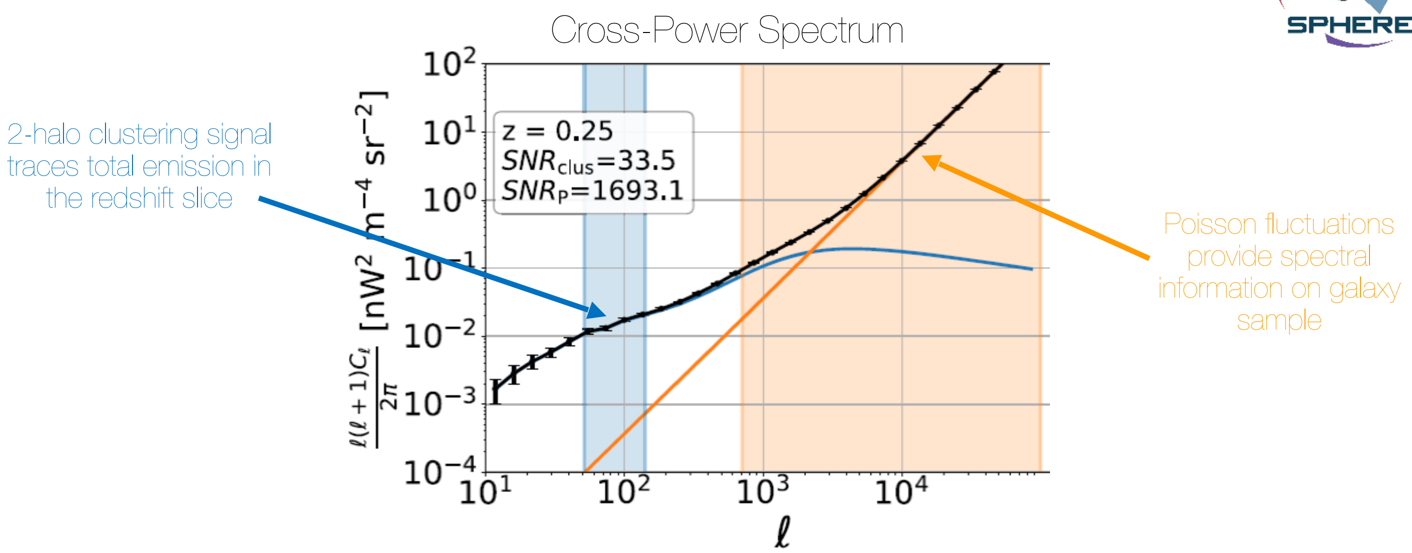


Emission Lines Observable by SPHEREx



LINE-INTENSITY MAPPING WITH GALAXY CROSS-CORRELATIONS





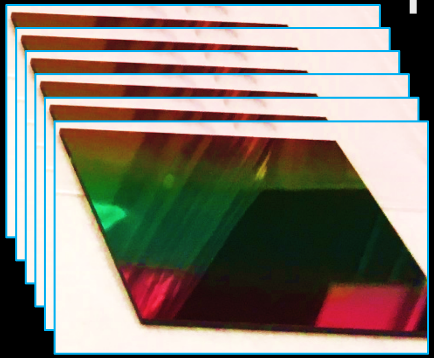
Redshift	Δz slice	SNR per channel*	Galaxy Redshifts	Lines in range
0.25	0.1	50 – 65	SPHERE^X	Hα
0.5	0.2	100 – 120	SPHERE^X	Hα, OIII, Hβ
1	0.4	100 – 150	SPHERE^X	Hα, OIII, Hβ
2	1	15 – 25	SPHERE^X	Hα, OIII, Hβ, OII
3	1	6 – 9	DESI	Hα, OIII, Hβ, OII
4	1	15 – 30	Rubin LBG	Hα, OIII, Hβ, OII
5	1	5 – 20	Rubin LBG	Hα, OIII, Hβ, OII
6	1	3 – 10	Rubin LBG	Hα, OIII, Hβ, OII, Lyα
7	1	0.2 – 2	Roman LBG	OIII, Hβ, OII, Lyα

*There are 102 spectral channels in total

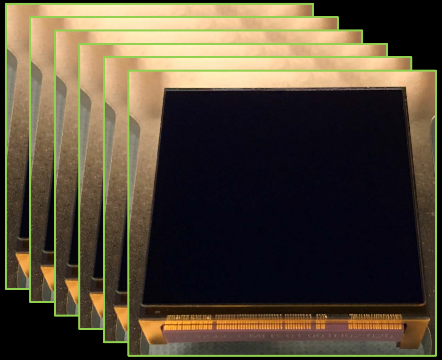
RECENT DEVELOPMENTS

SPHEREx

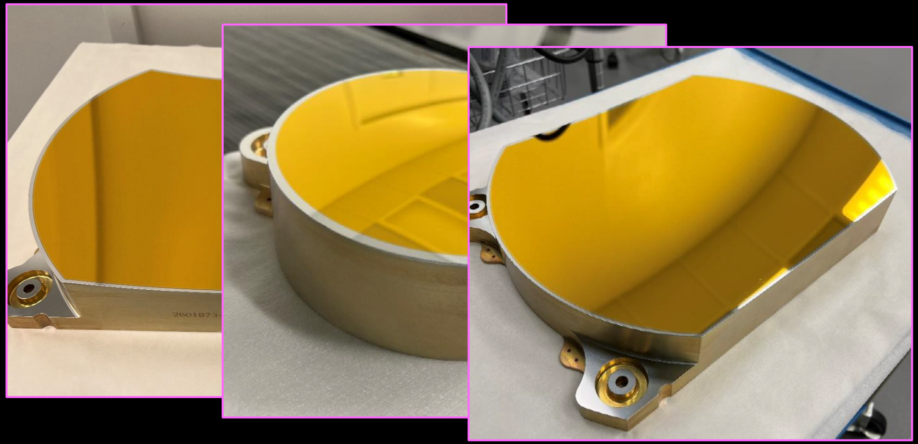
Falcon IX vehicle selected



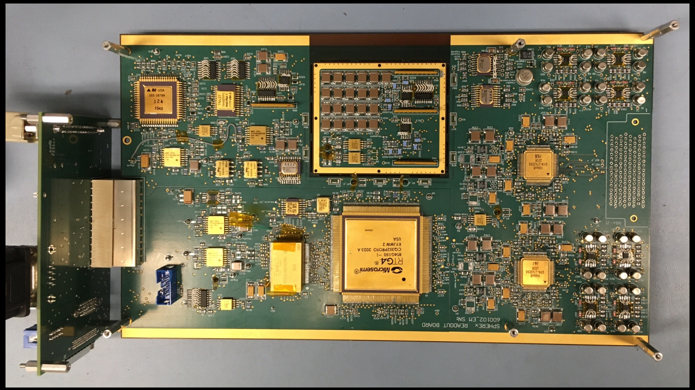
Flight LVF spectrometers



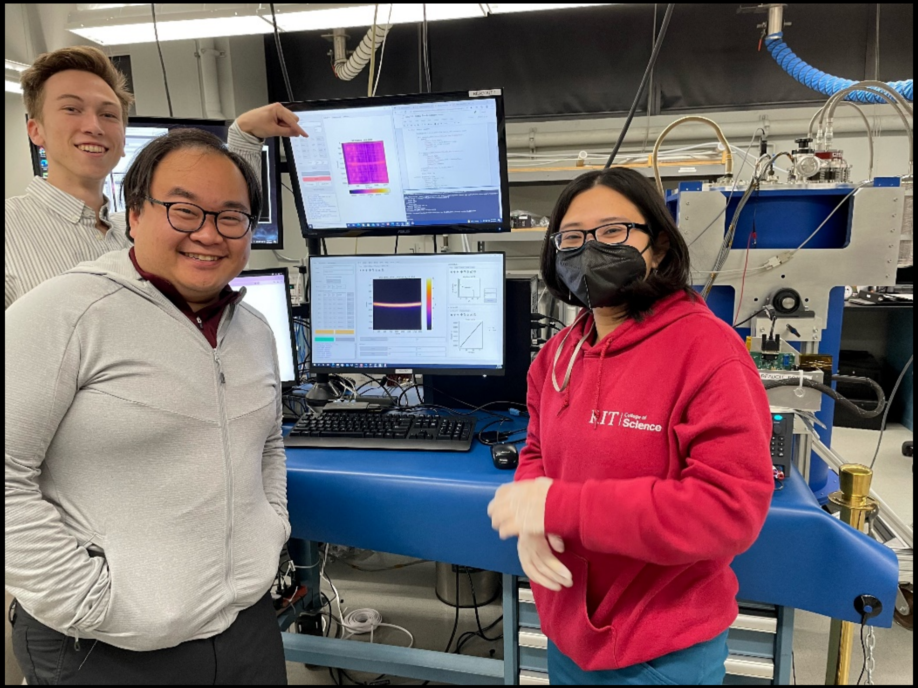
Flight detector arrays



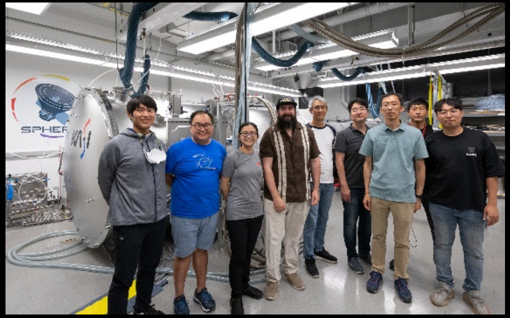
Flight mirrors delivered



EM readout electronics boards completed



End-to-end test of detector array with LVF and readout electronics



Cryogenic test chamber delivered from Korea

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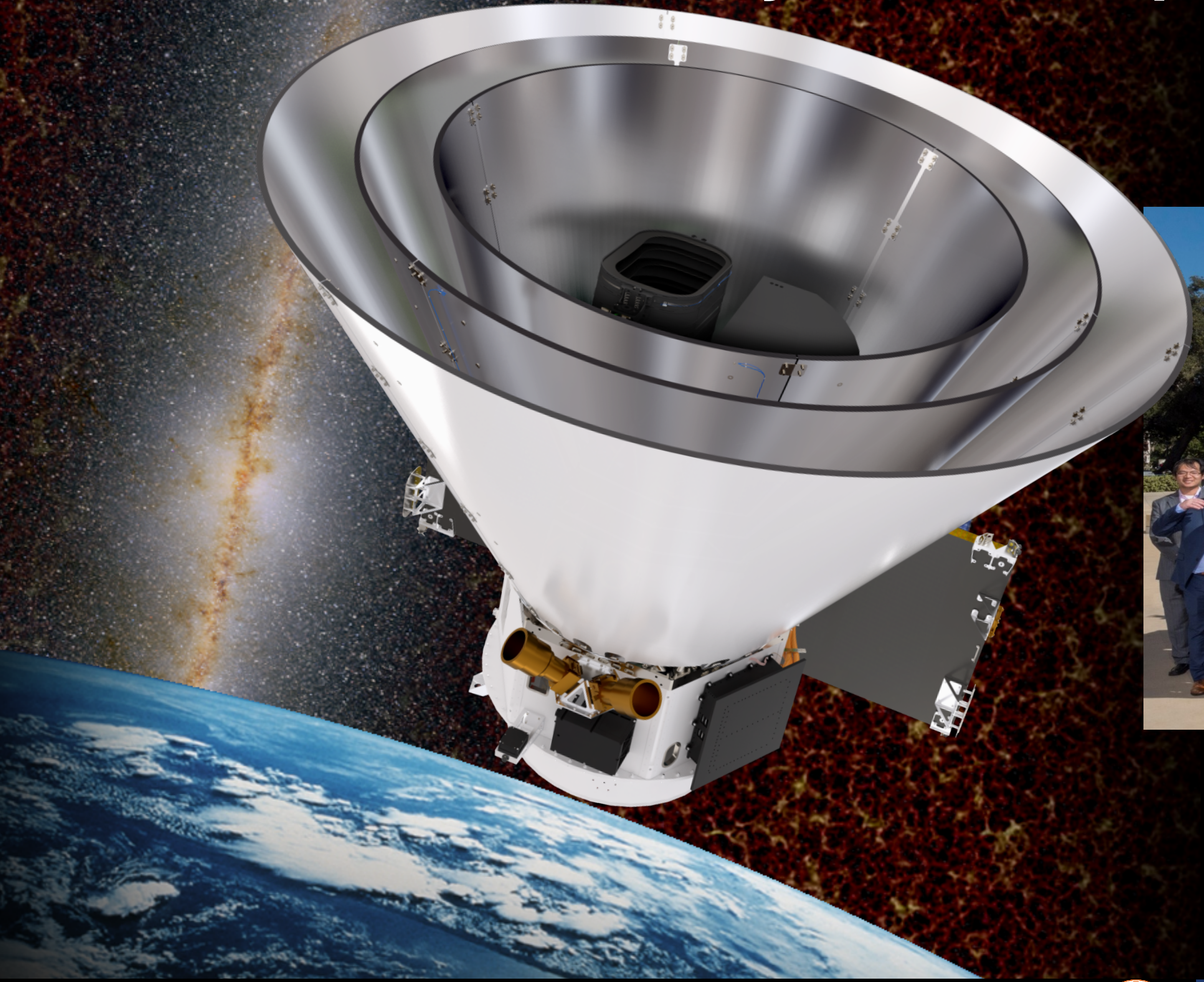

Looking forward to launch in early 2025!

For more Information:
spherex.caltech.edu

BACKUP

REDSHIFTS FROM LOW-RESOLUTION SPECTROSCOPY

We extract the spectra from *known* galaxy positions
Controls blending and confusion

We compare each spectrum to a template library:
For each galaxy: redshift, type and redshift error

Many self-consistency tests using SPHEREx data, spectral models, and external redshift catalogs

Detected galaxies	> 1 billion
Galaxies $\Delta z/1+z < 10\ \%$	> 450 million
Galaxies $\Delta z/1+z < 0.3\%$	> 10 million