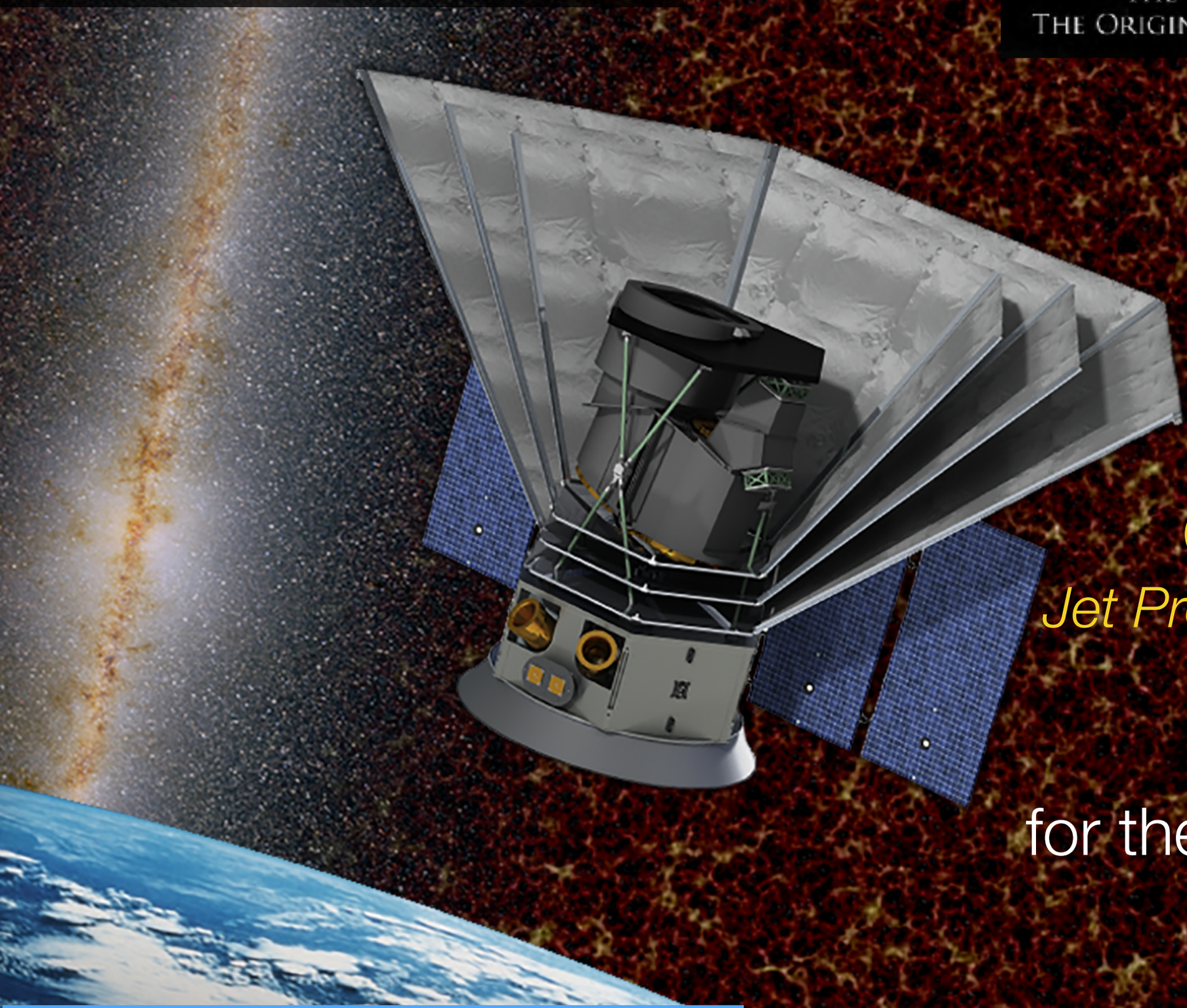
SPHEREx

An All-Sky Spectral Survey

Designed To Explore:

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



Olivier Doré
Jet Propulsion Laboratory
Caltech

for the SPHEREx Team

Pre-Decisional Information
For Planning and Discussion
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http://spherex.caltech.edu

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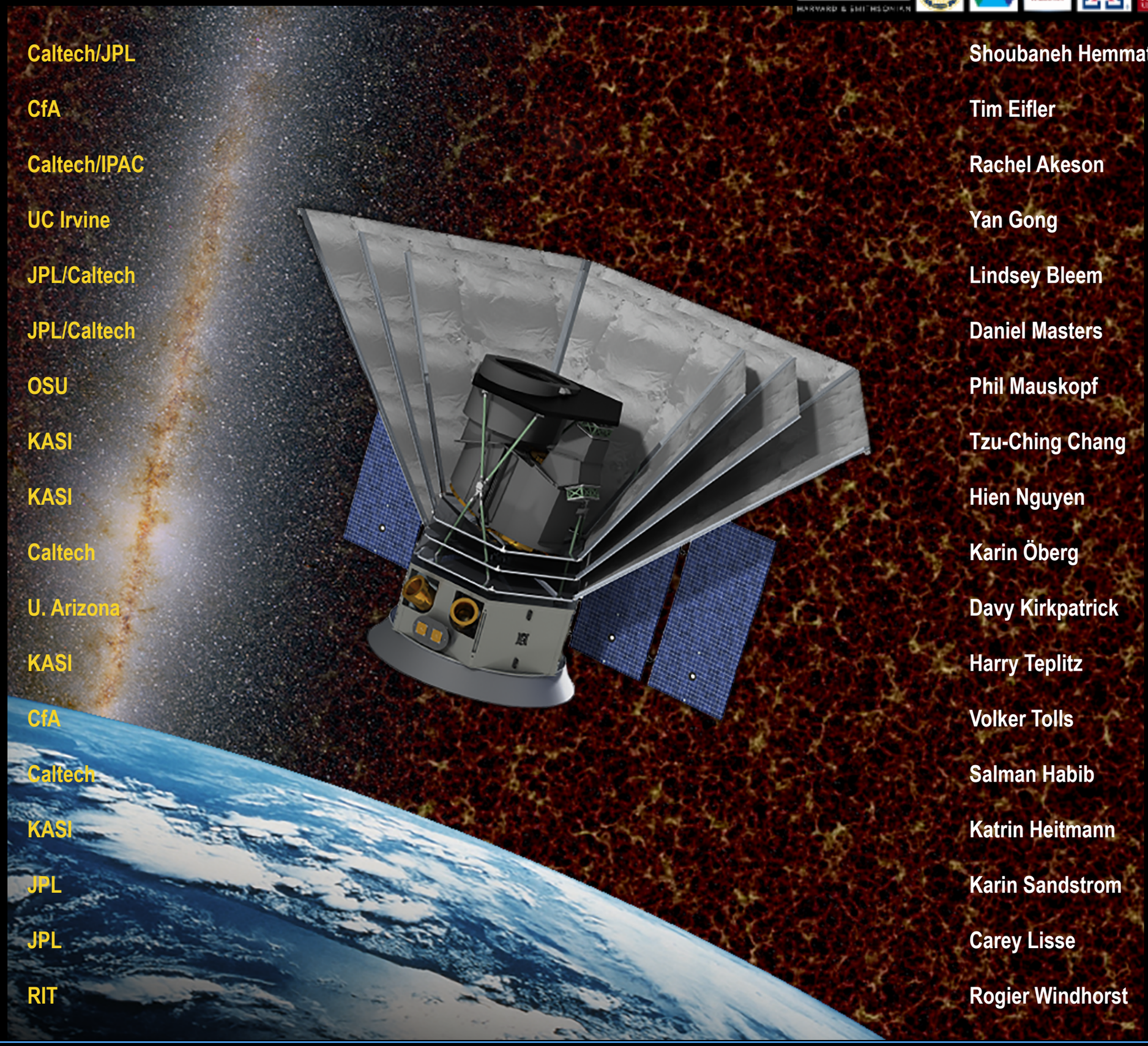
SPHEREX SCIENCE TEAM



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SPHEREX: AN ALL-SKY SPECTRAL SURVEY

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

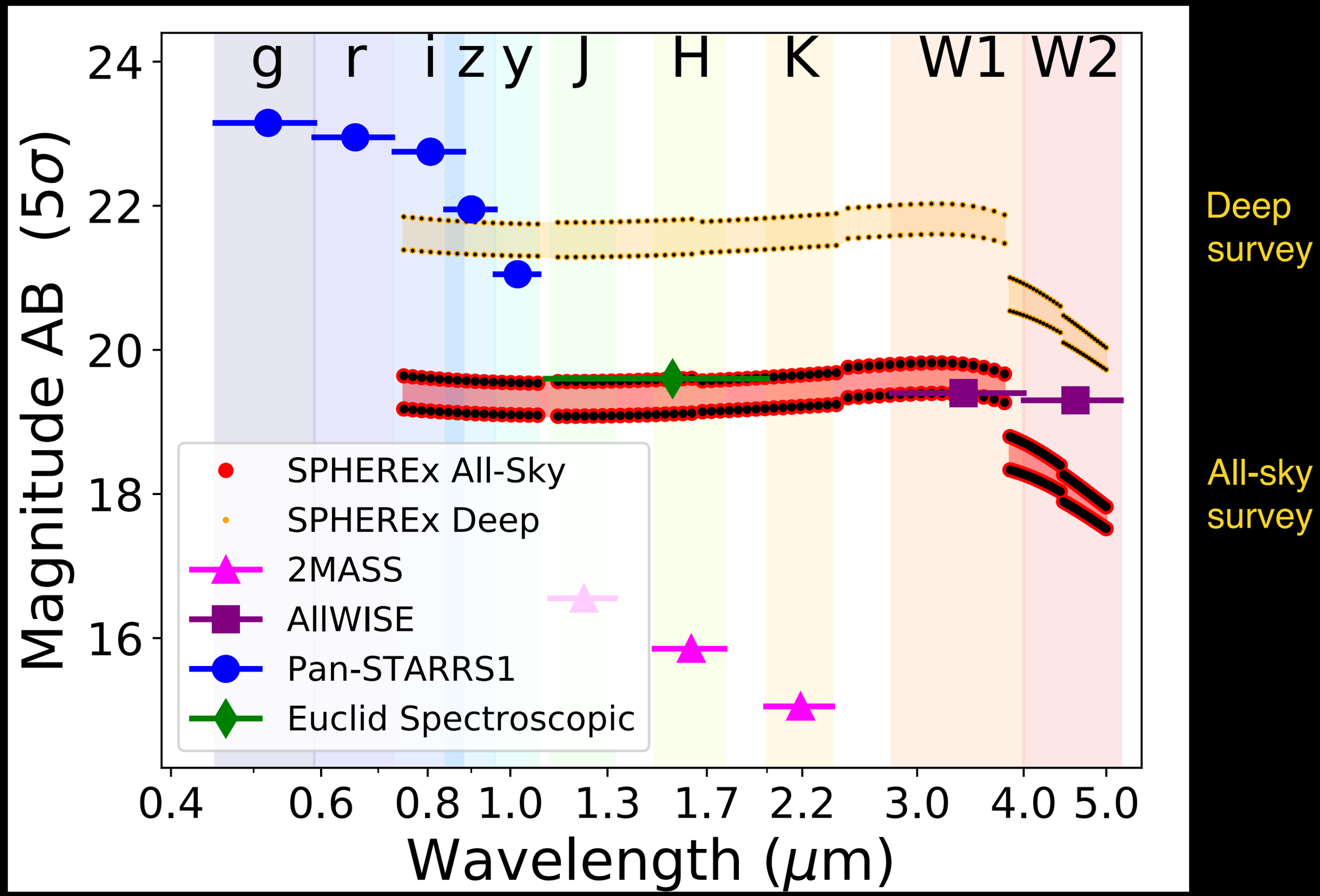
SPHEREx Dataset:

- 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 96 fine photometric bands

SPHEREX SURVEY DEPTH



AN AGGRESSIVE DATA RELEASE PLAN

- L : Launch in September 2023
- L+1 : End of commissioning
- L+n : Every month after for 24 months:
  - ➡ Release spectral images data (L2 product)
- L+6n: Every 6 month, we complete a full sky survey.
  - ➡ Release local wavelength maps
- L+12n: Every 12 month, complete two full sky surveys
  - ➡ Release source catalogs
- L+24 : End of nominal mission.
  - ➡ Release L4 catalogs (galaxy, ices, maps, legacy catalogs)

- Archive hosted by IRSA at IPAC/Caltech (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 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 a lasting data legacy used across astronomy

COBE
IRAS
GALEX
WMAP
Planck
WISE

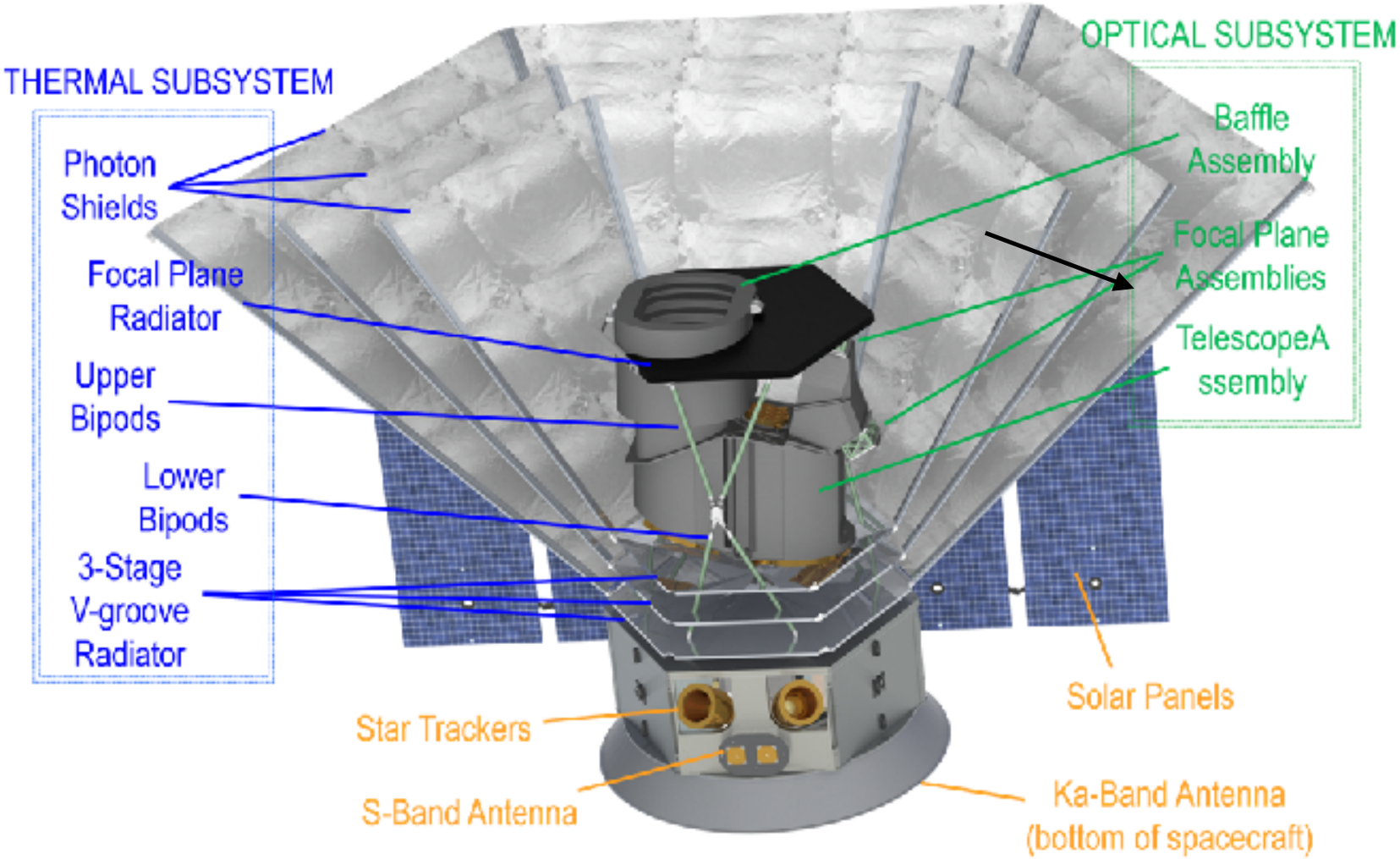
OD++16,18

SPHEREX THREE LEGACY CATALOGS

- Spectral catalog of comets and asteroids (lead C. Lisse)
- Star catalog (lead R. Akeson)
  - ➡ Precise spectra of stars of target planet-bearing stars from the Kepler, K2, TESS, Gaia, and other transit and radial velocity surveys
  - ➡ Atlas of spectra of late M dwarfs and all accessible brown dwarfs, down to the coolest Y dwarfs, to facilitate the study of our lowest mass stellar neighbors
- Spectral catalog of clusters of galaxies (lead L. Bleem)
- Support immediate community utilization of SPHEREx data

OD++16,18

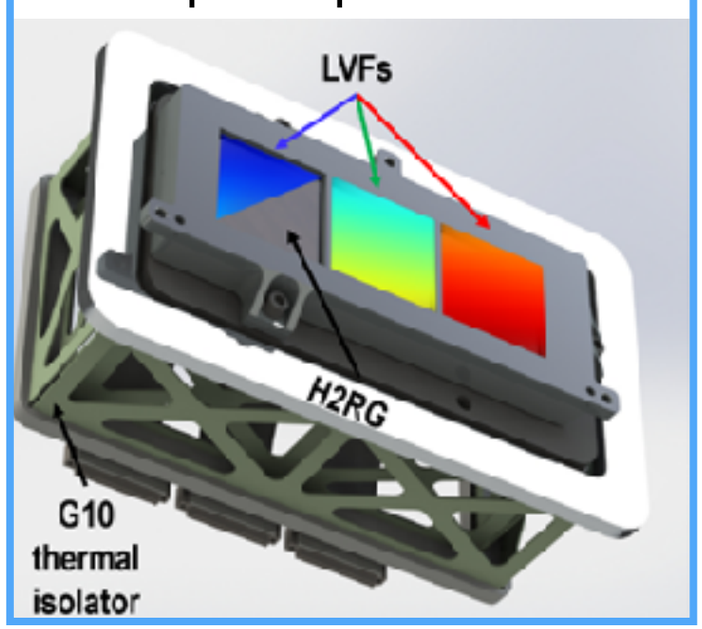
An Innovative Architecture Based on Mature Technologies



Wide field telescope

Parameter	Value
Telescope eff. diameter	20 cm
Field of view	3.5 x 11 deg.^{2}
Pixel size	6.2 arcsec
Wavelength range	0.75 – 5 μm
Resolving power $\lambda/\Delta\lambda$	35-130

Compact spectrometer



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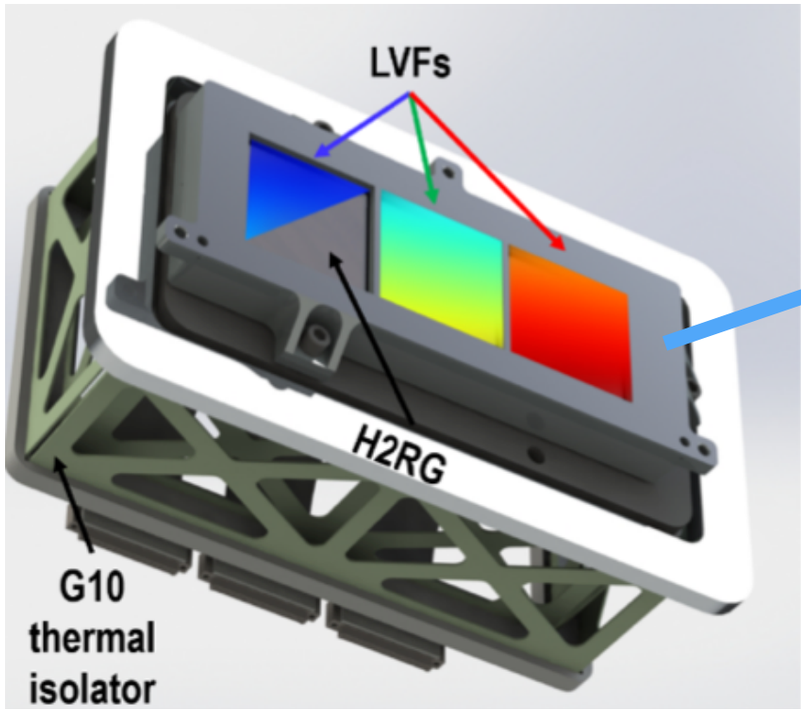
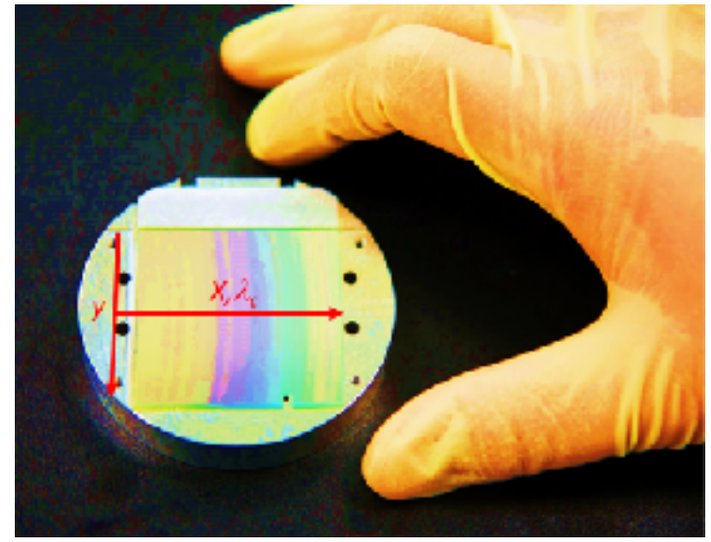
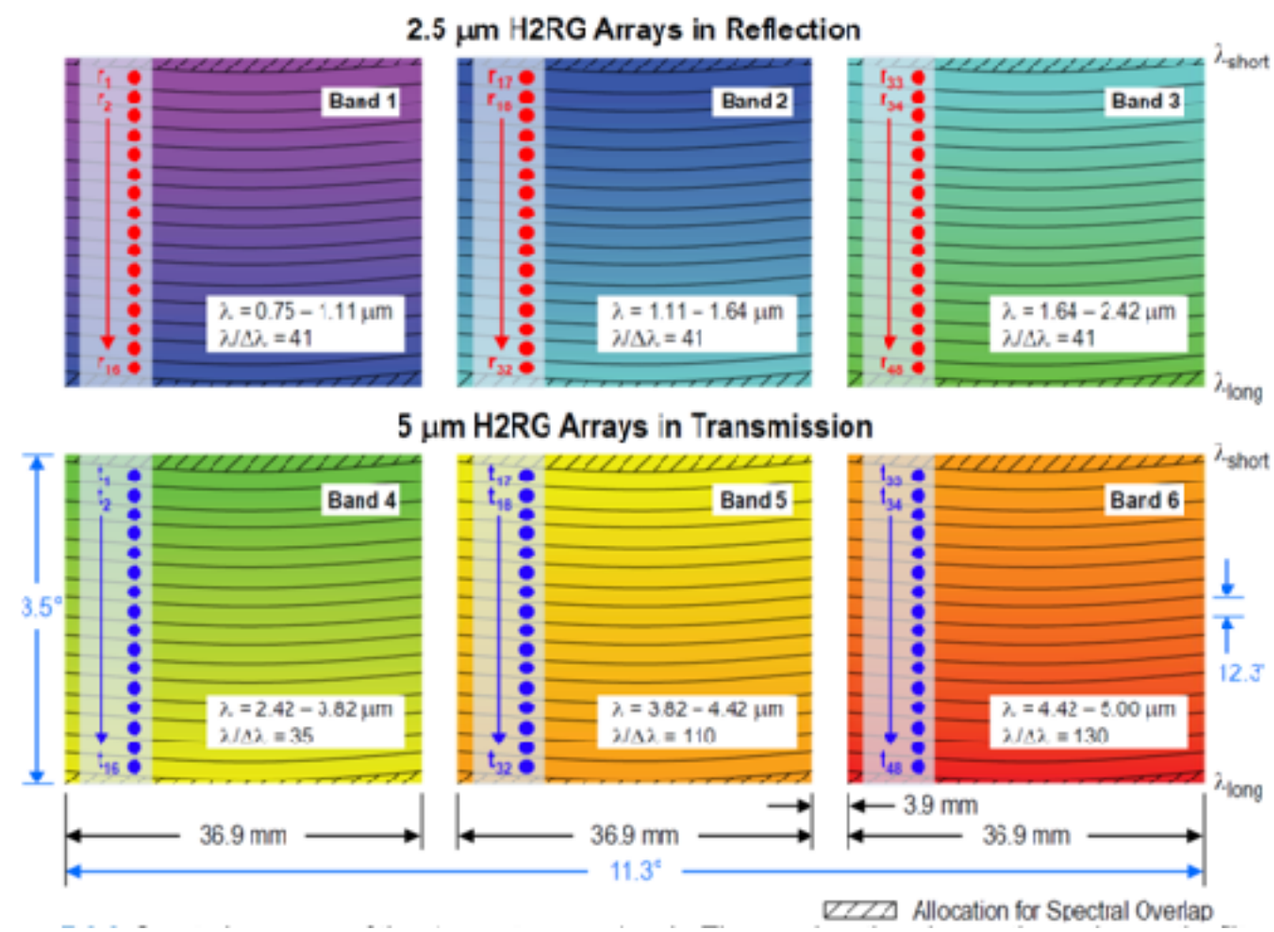
High-Throughput LVF Spectrometer



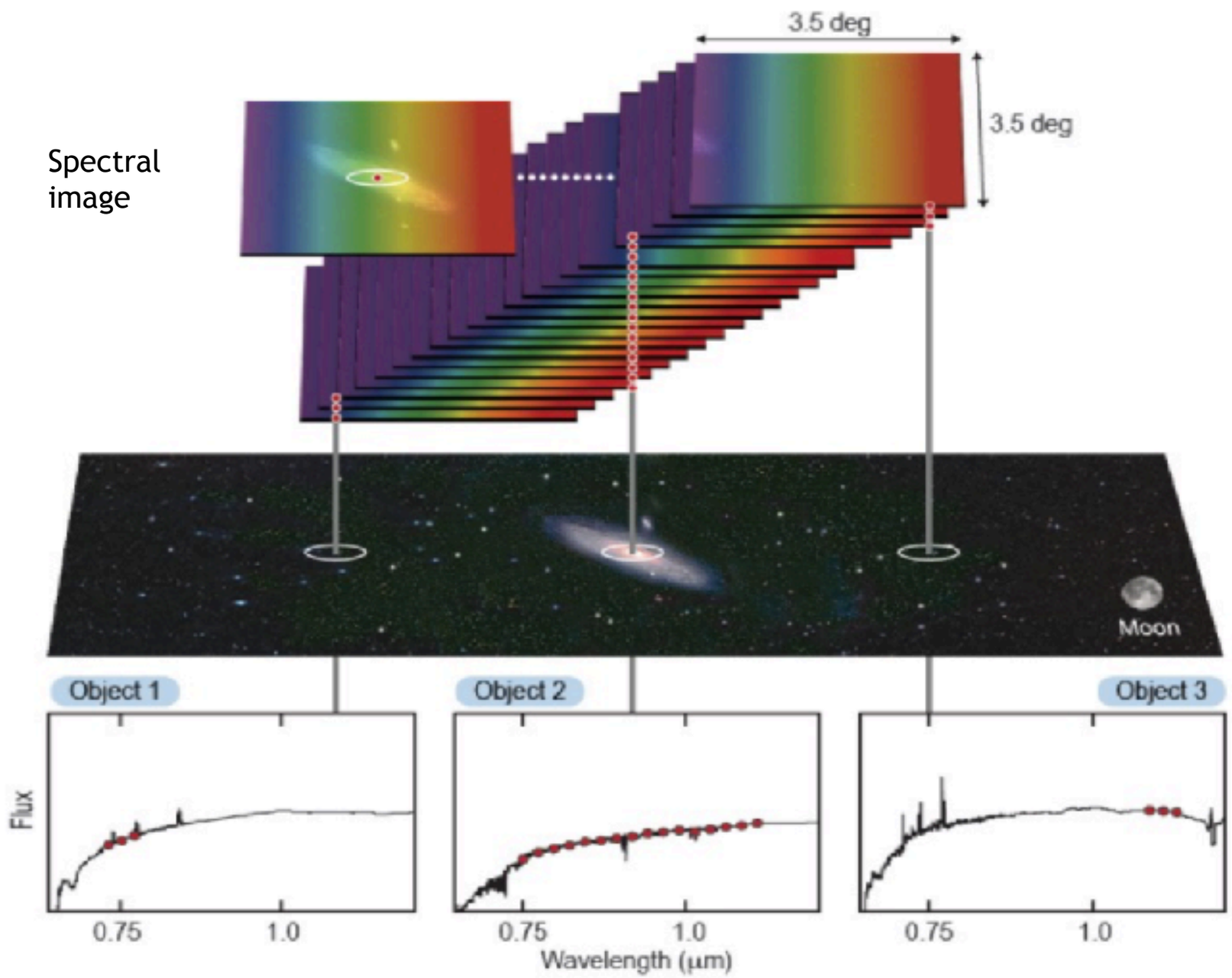




Spectra obtained by stepping source over the FOV in multiple images: <u>no moving parts</u>

Mapping the Sky with LVFs

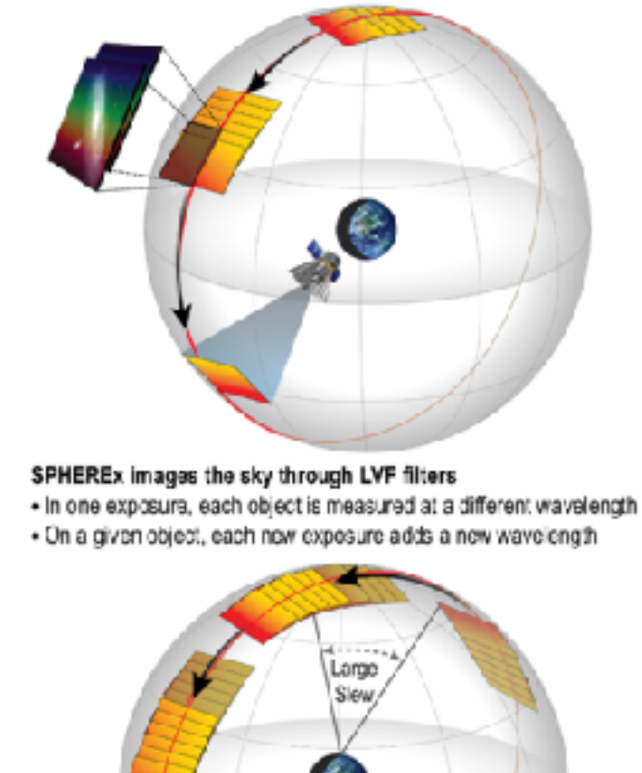
Spectral image



A complete spectrum is made from a series of images

SPHEREx uses a single observing mode, with no moving parts from a low earth orbit.

1 orbit



2 orbits

~3 days

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

SPHEREX ADDRESSES THREE MAJOR QUESTIONS IN ASTROPHYSICS

- How did the Universe begin?
  - ➡Probing Inflation with the 3D clustering of galaxies
    - Survey the z<1.5 Universe to fundamental limits to measure signatures of inflation (non-Gaussianity, primordial power spectrum shape) and dark energy
    - Complement Euclid & WFIRST which survey smaller area at z>1

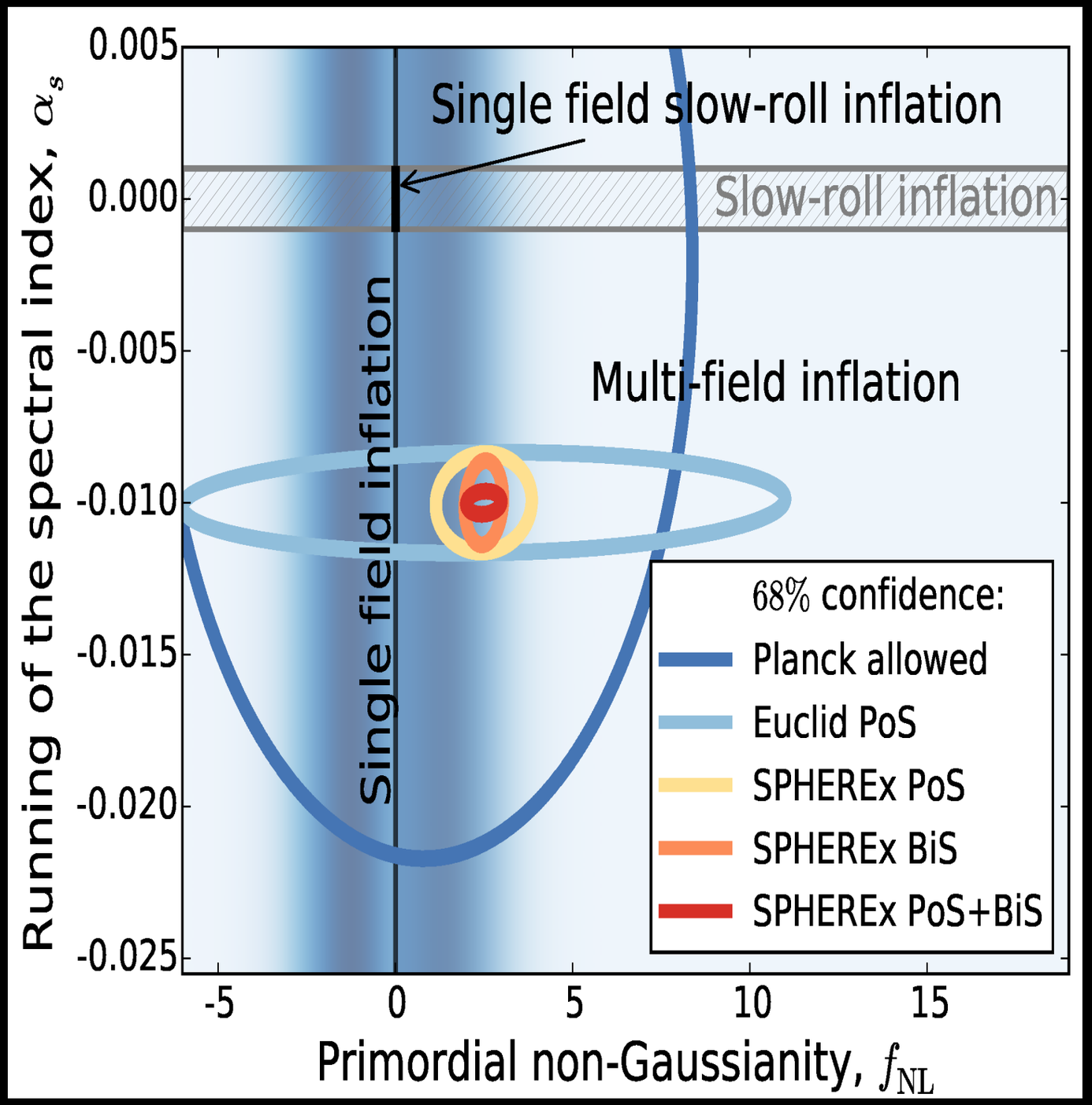
- What are the Conditions for Life Outside the Solar System?
  - ➡Measure broad ice absorption features in stellar spectra to explain how interstellar ices bring water and organic molecules into proto-planetary systems

- How did Galaxies begin?
  - ➡Measure the extra-galactic background light (EBL) to probe the epoch of reionization (EOR)

FLYING THROUGH THE SPHEREX SURVEY

- Blue particles show large-scale dark matter distribution from a cosmological simulation
- Galaxies follow the underlying dark matter
- Density of galaxies matches the density of galaxies with SPHEREx redshift measurement, but only 130 sq. deg out of 30,000

SPHEREX AND INFLATION



- 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 $f_{NL} \gtrsim 1$
- SPHEREx improves non-Gaussianity accuracy by >10
  - ➡ SPHEREx produces a unique 3-D galaxy survey
  - ➡ Optimized for large scales to study inflation
  - ➡ Two independent tests of non-Gaussianity

What Are the Conditions for Life Outside the Solar System?

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

Current debate:

Did earth's water come from the Oort cloud, Kuiper belt or closer?

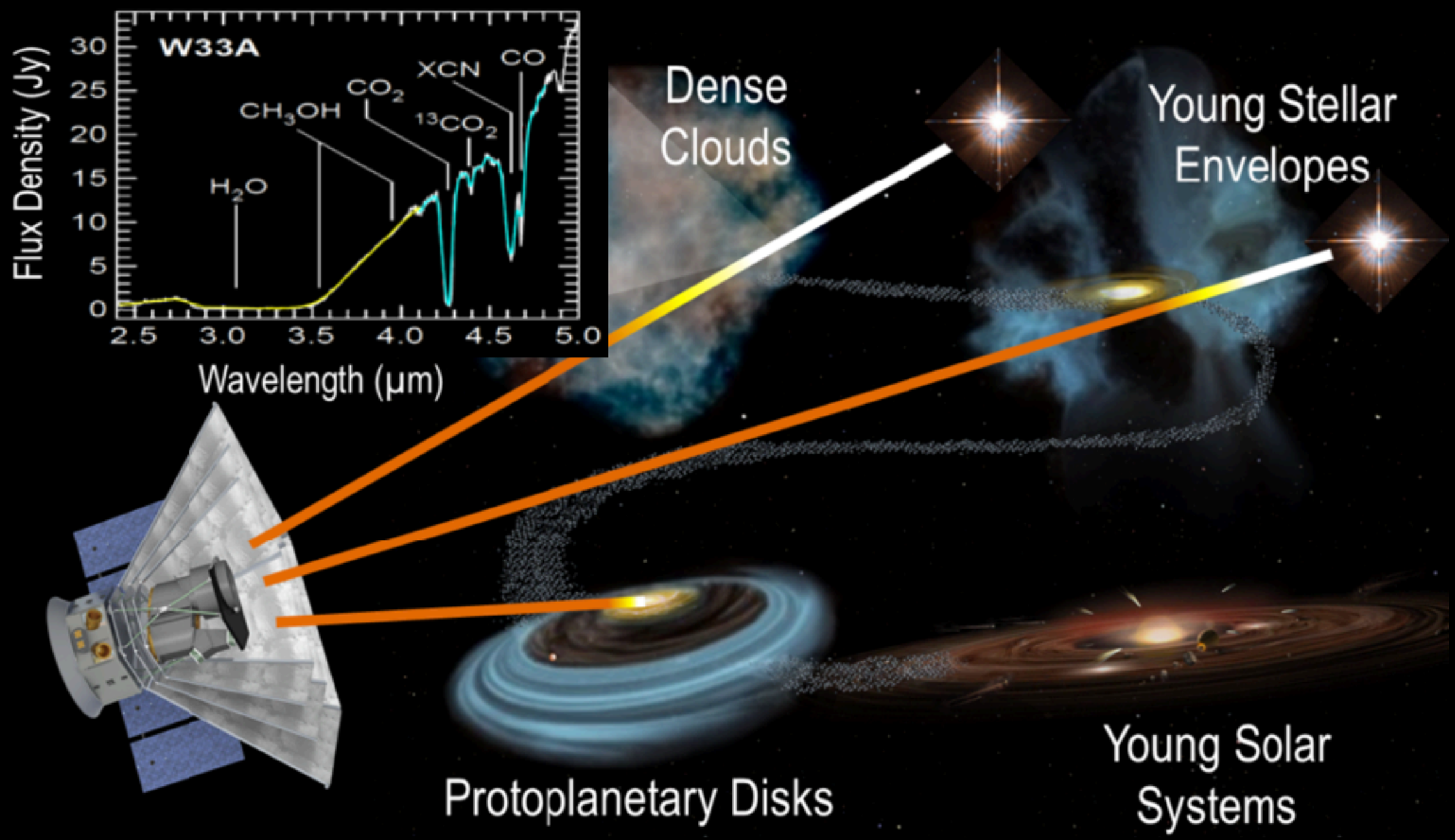
Did water arrive from the late bombardment (~500 MY) or before?

More than 99 % interstellar water is locked in ice

'Follow the Water' means 'Follow the Ice'

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 SURVEYS ICES IN ALL PHASES OF STAR FORMATION

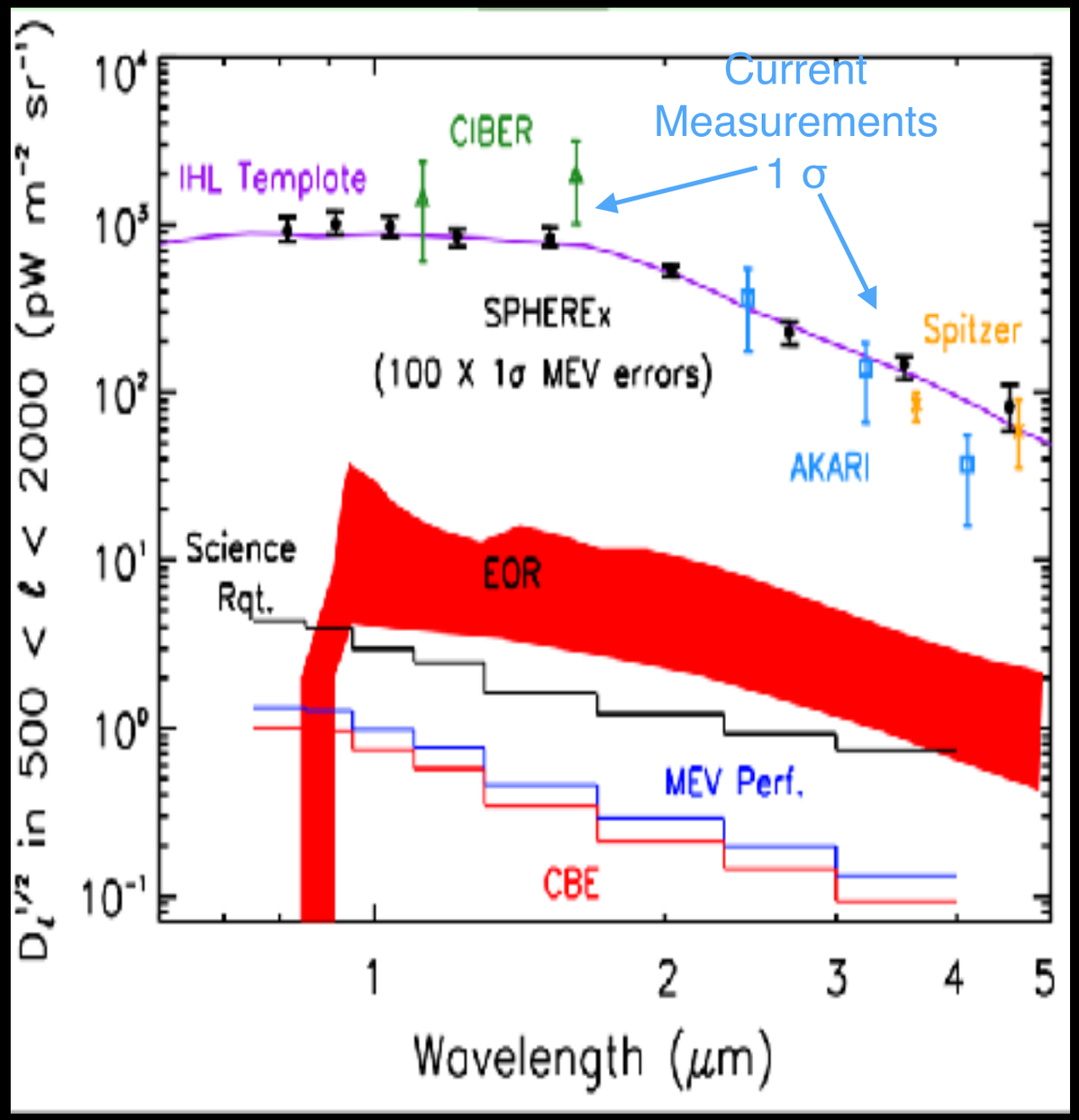


SPHEREx will measure ice abundance towards >> 20,000 sources and determine how water and biogenic ices evolve from molecular clouds to young stars to proto-planetary disks

PROBING THE EPOCH OF REIONIZATION

- SPHEREx orbits enable deep/frequent observations of about 200 sq. deg near the ecliptic poles (great for systematics!)
- SPHEREx wavelength coverage and resolution will enable large-scale measurement of spatial fluctuations in the Extragalactic Background Light (EBL)
- In particular, SPHEREx will monitor/explain the Intra-Halo Light and its evolution (CIBER, Zemcov++14)
- SPHEREx has the raw sensitivity to probe the expected EOR signal (but separation with low z signal will be challenging)
- The sensitivity in this region will enable deep intensity mapping regimes using multiple lines at all redshift, and maybe Lyα at high redshift (see Croft++15, 18)

Fluctuations in Continuum Bands



SUMMARY

- SPHEREx selected as the next MIDEX. Launch planned in Sept 2023.

- SPHEREx will create the first all sky near-infrared spectroscopic survey:
  - ➡ A dataset of lasting legacy.

- SPHEREx offers a simple and very robust design and modus operandi:
  - ➡ Naturally enables a high control of systematics thanks to multiple built-in redundancy.

- 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
  - ➡LSST, JWST, WFIRST, TESS, e-ROSITA,…

- Please contact me if you want to investigate this more thoroughly

http://spherex.caltech.edu

FIN