SPHEREx

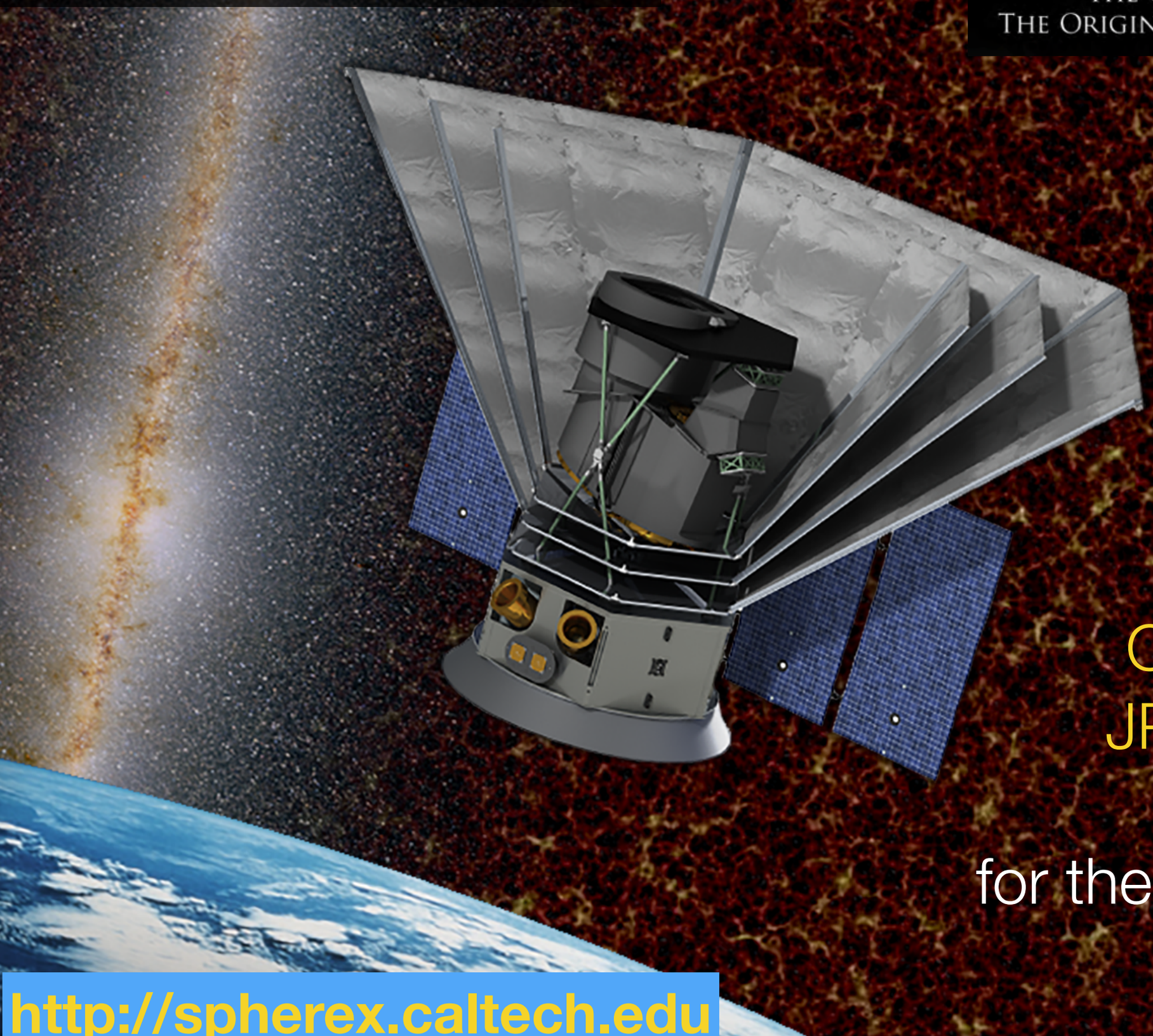
An All-Sky Spectral Survey

Designed To Explore:

The Origin of the Universe

The Origin and History of Galaxies

The Origin of Water in Planetary Systems



Olivier Doré

JPL / Caltech

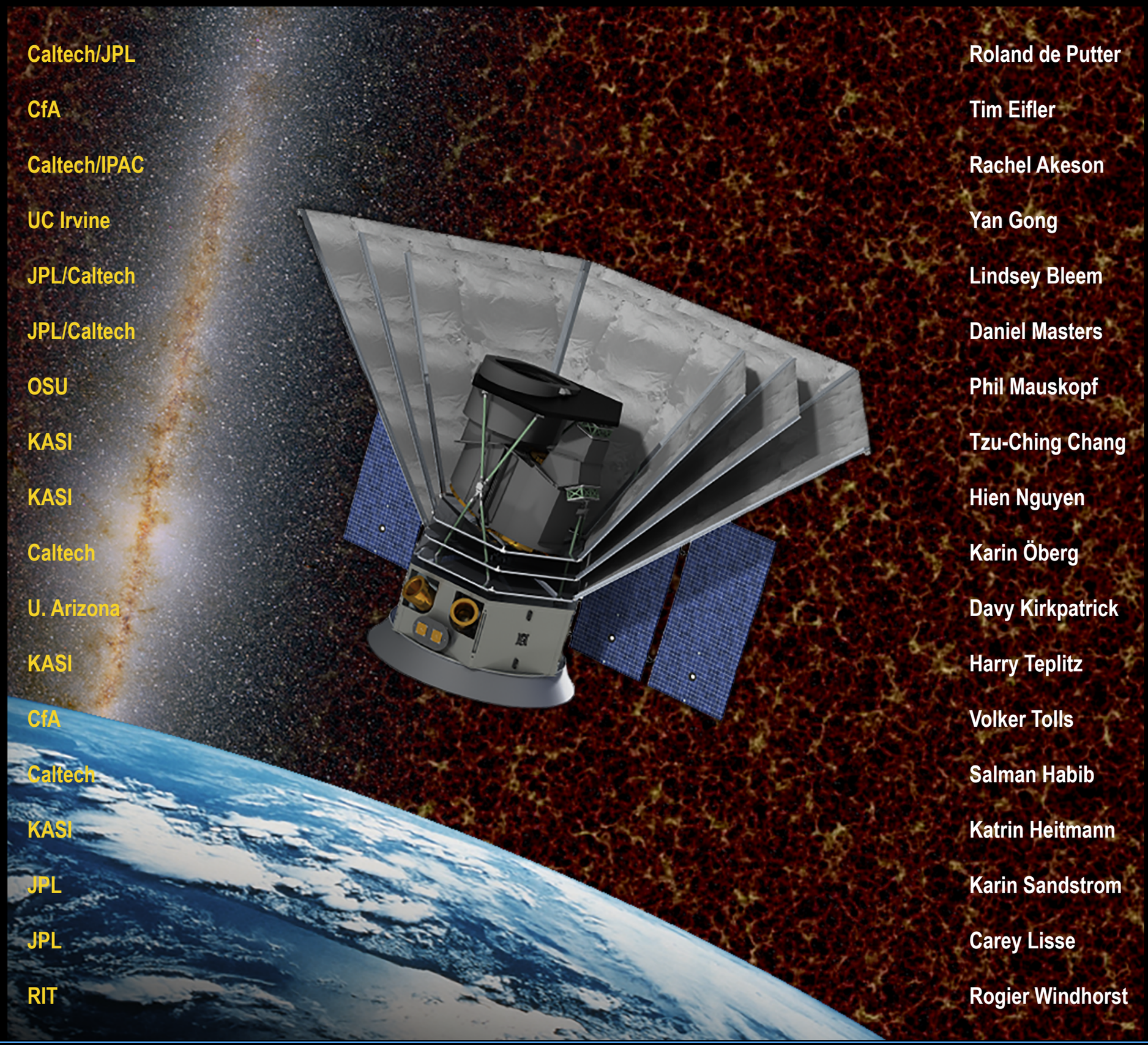
for the SPHEREx Team

http://spherex.caltech.edu

Pre-Decisional Information
For Planning and Discussion
Purposes Only

SPHEREX SCIENCE TEAM

Jamie Bock (PI)	Caltech/JPL	Roland de Putter	Caltech
Matt Ashby	CfA	Tim Eifler	U. Arizona
Peter Capak	Caltech/IPAC	Rachel Akeson	Caltech/IPAC
Asantha Cooray	UC Irvine	Yan Gong	UC Irvine
Brendan Crill	JPL/Caltech	Lindsey Bleem	Argonne
Olivier Doré (PS)	JPL/Caltech	Daniel Masters	JPL/Caltech
Chris Hirata	OSU	Phil Mauskopf	ASU
Woong-Seob Jeong	KASI	Tzu-Ching Chang	JPL/Caltech
Minjim Kim	KASI	Hien Nguyen	JPL
Phil Korngut (IS)	Caltech	Karin Öberg	CfA
Elisabeth Krause	U. Arizona	Davy Kirkpatrick	Caltech/IPAC
Dae-Hee Lee	KASI	Harry Teplitz	Caltech/IPAC
Gary Melnick	CfA	Volker Tolls	CfA
Roger Smith	Caltech	Salman Habib	Argonne
Yong-Seon Song	KASI	Katrin Heitmann	Argonne
Stephen Unwin	JPL	Karin Sandstrom	UCSD
Michael Werner	JPL	Carey Lisse	JHU
Michael Zemcov	RIT	Rogier Windhorst	ASU



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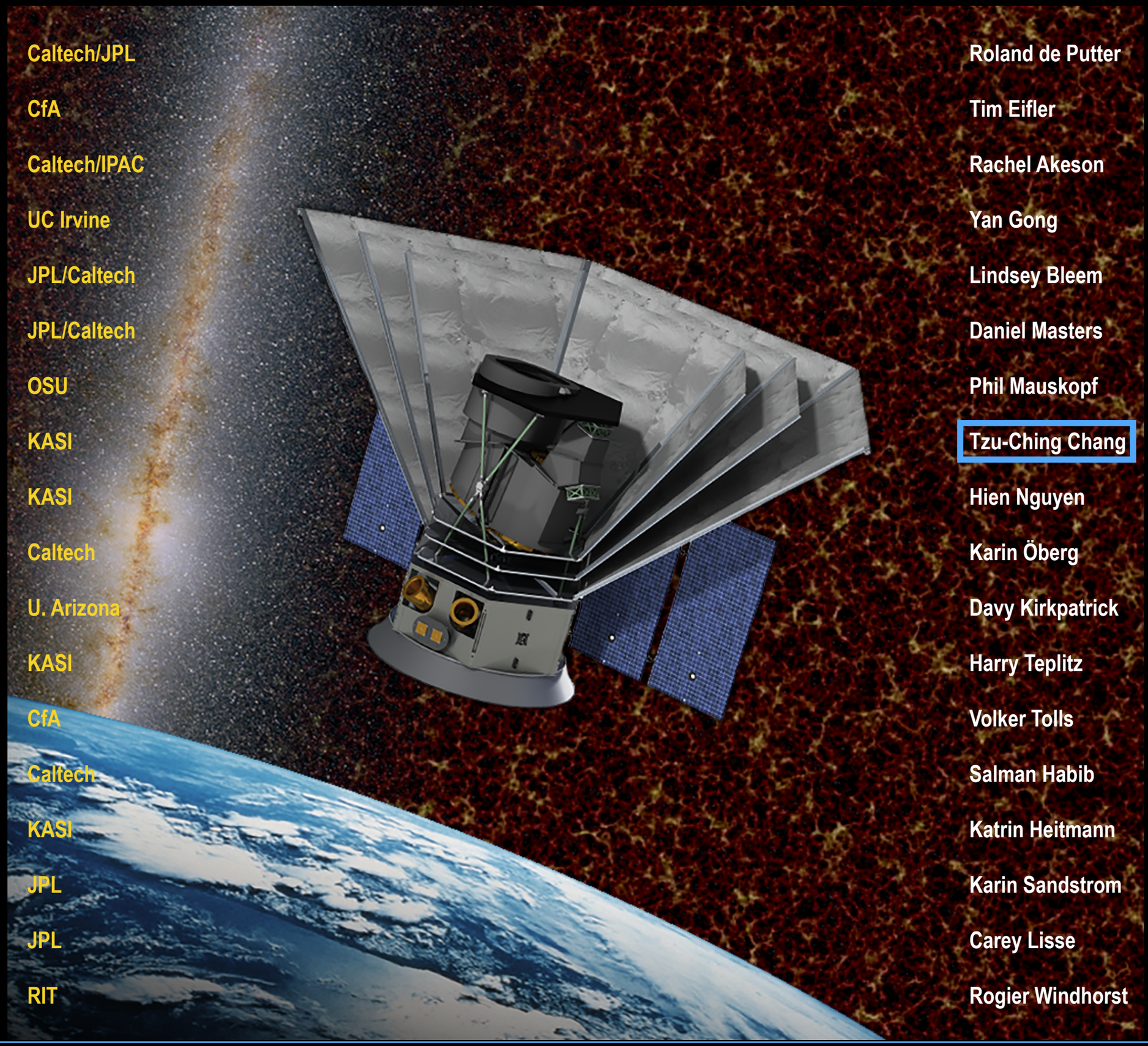

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THANK YOU!

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 96 fine photometric band

AGGRESSIVE DATA RELEASE PLAN

Survey / Data Release (DR)	Date	Data Volume	Products
Survey 1 starts	L+1 mo		
Quick Release Data	L+2 mo. +monthly until survey end IMS UID #6116	1.6 TB / month	Monthly release of L2 Spectral Images

Archive hosted by IRSA at IPAC/Caltech

AGGRESSIVE DATA RELEASE PLAN

Analysis Tool	Description
On-the-Fly Mosaic Tool	Create mosaics of SPHEREx images built from custom temporal and spatial data selections.
Forced Photometry Tool	Produce SPHEREx spectra from SPHEREx spectral images using optimal photometry for user-provided positions and times.
Spectral Data Cube Extractor	Extract SPHEREx data cube products for a user-selected region of the sky.
Variable Source Extractor	Extract and display a time series of photometry of sources at user-provided positions at multiple epochs.
Source Discovery Tool	Generate a catalog of source detections using user-defined signal-to-noise and color metrics on a selected sky region.

Archive hosted by IRSA at IPAC/Caltech

SPHEREX THREE LEGACY CATALOGS

- Spectral catalog of comets and asteroids (lead C. Lisse)

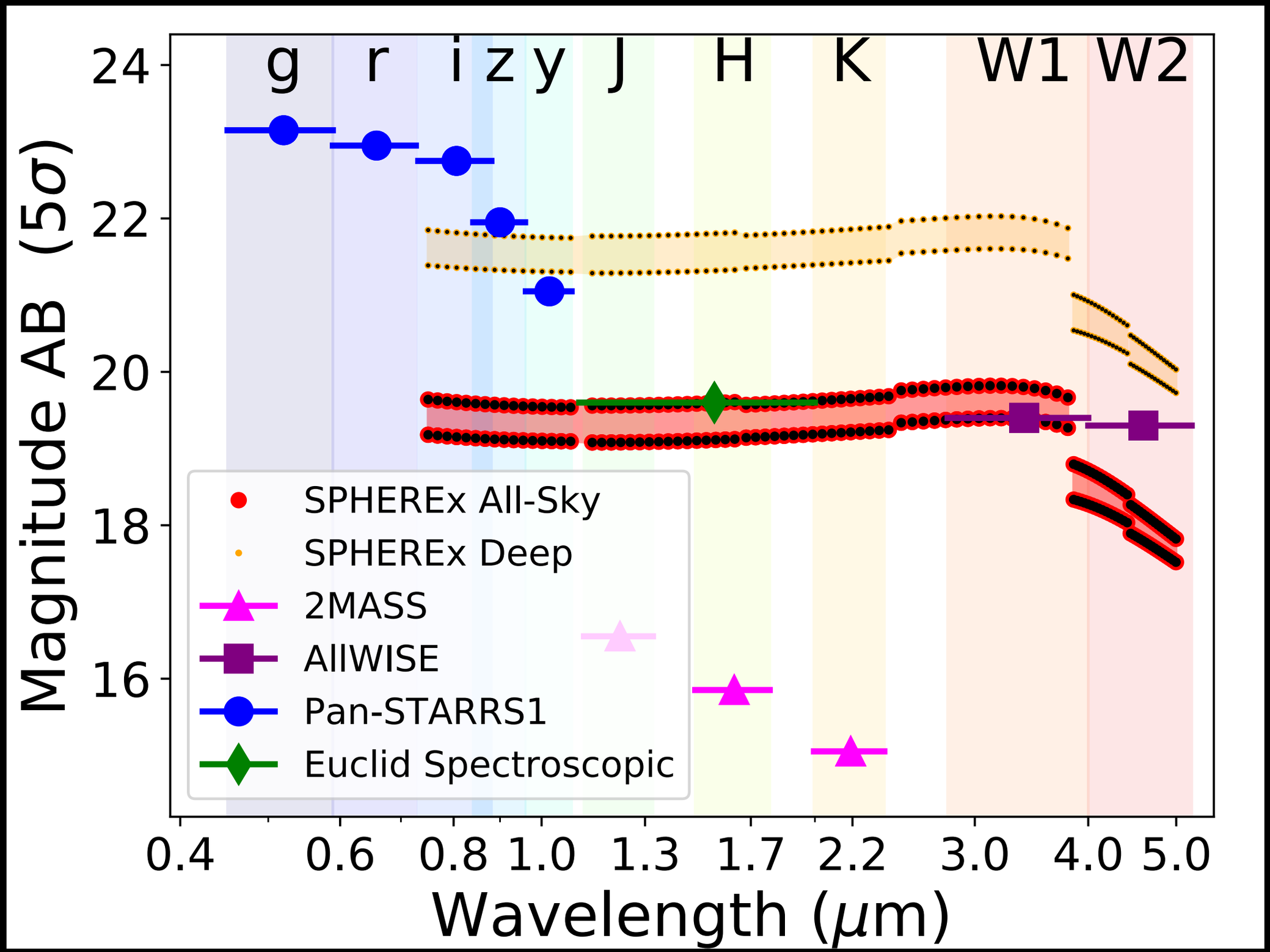
- Star catalog (lead R. Akeson)
  - ➡ Precise spectra of stars of target planet-bearing stars from the Kepler, K2, TESS, Gaia, and other transit and radial velocity surveys
  - ➡ Atlas of spectra of late M dwarfs and all accessible brown dwarfs, down to the coolest Y dwarfs, to facilitate the study of our lowest mass stellar neighbors

- Spectral catalog of clusters of galaxies (lead L. Bleem)

- These catalogs support immediate community utilization of SPHEREx data

OD++16,18

SPHEREX SURVEY DEPTH



Deep survey

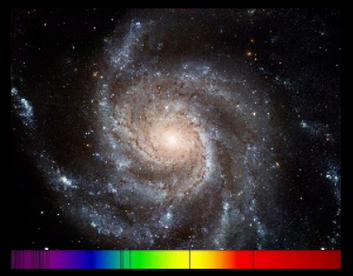
All-sky survey

SPHEREX PROVIDES A RICH ALL-SKY SPECTRAL ARCHIVE

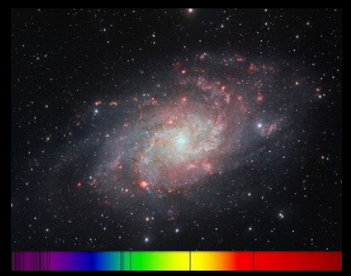
Galaxies

Detected
> 1 billion

Med. Accuracy z's
> 100 million



High Accuracy z's
10 million

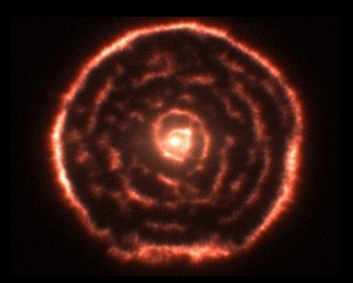


Clusters
25,000

Stars

Main Seq. Spectra
> 100 million

Dust-forming
10,000



Brown Dwarfs
> 400

Cataclysms
> 1,000

Other

Quasars
> 1 million

Quasars z >7
2 – 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

Data processing and archive will be hosted at IPAC

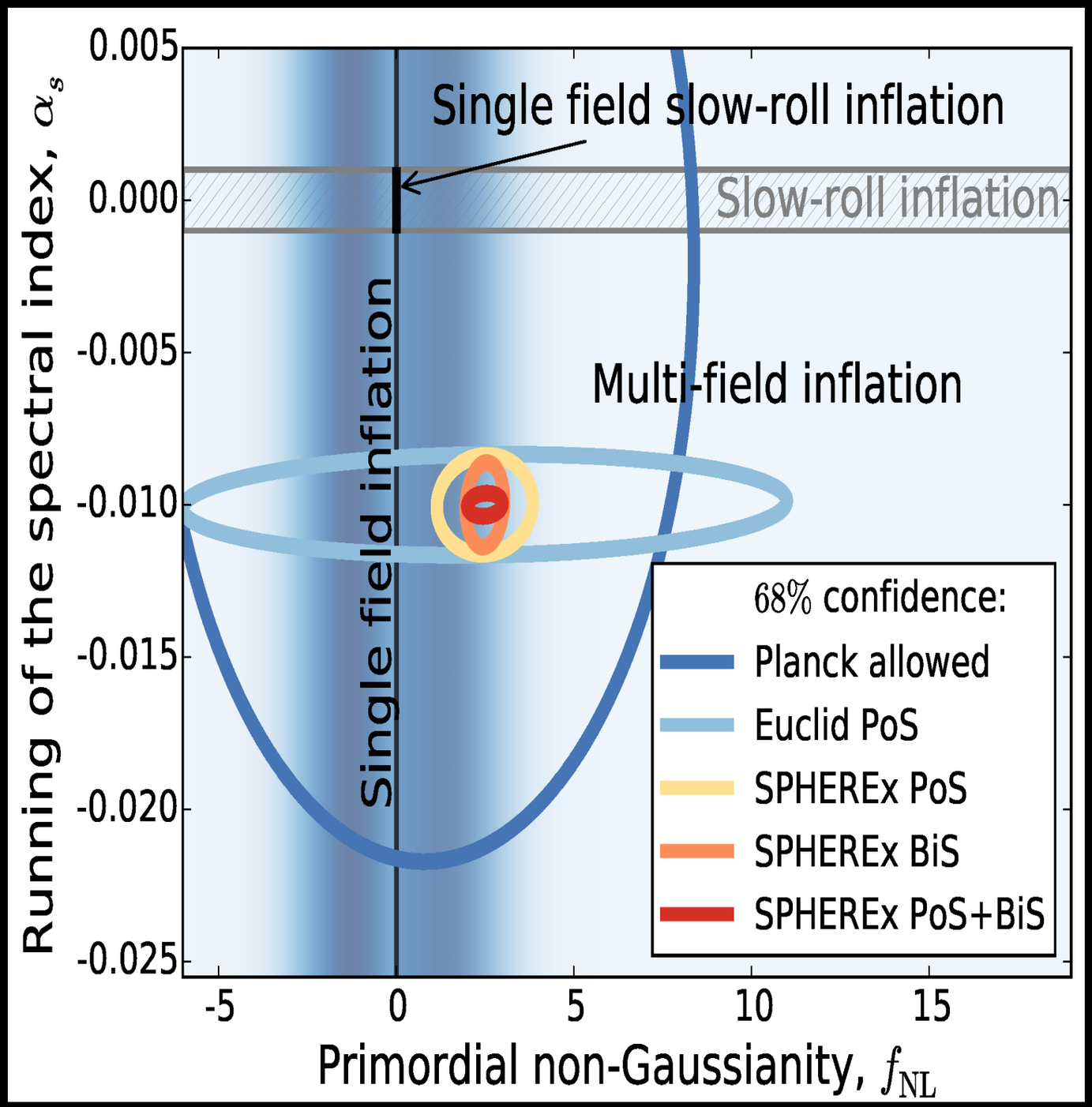
SPHEREX ADDRESSES THREE MAJOR QUESTIONS IN ASTROPHYSICS

- 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)

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:

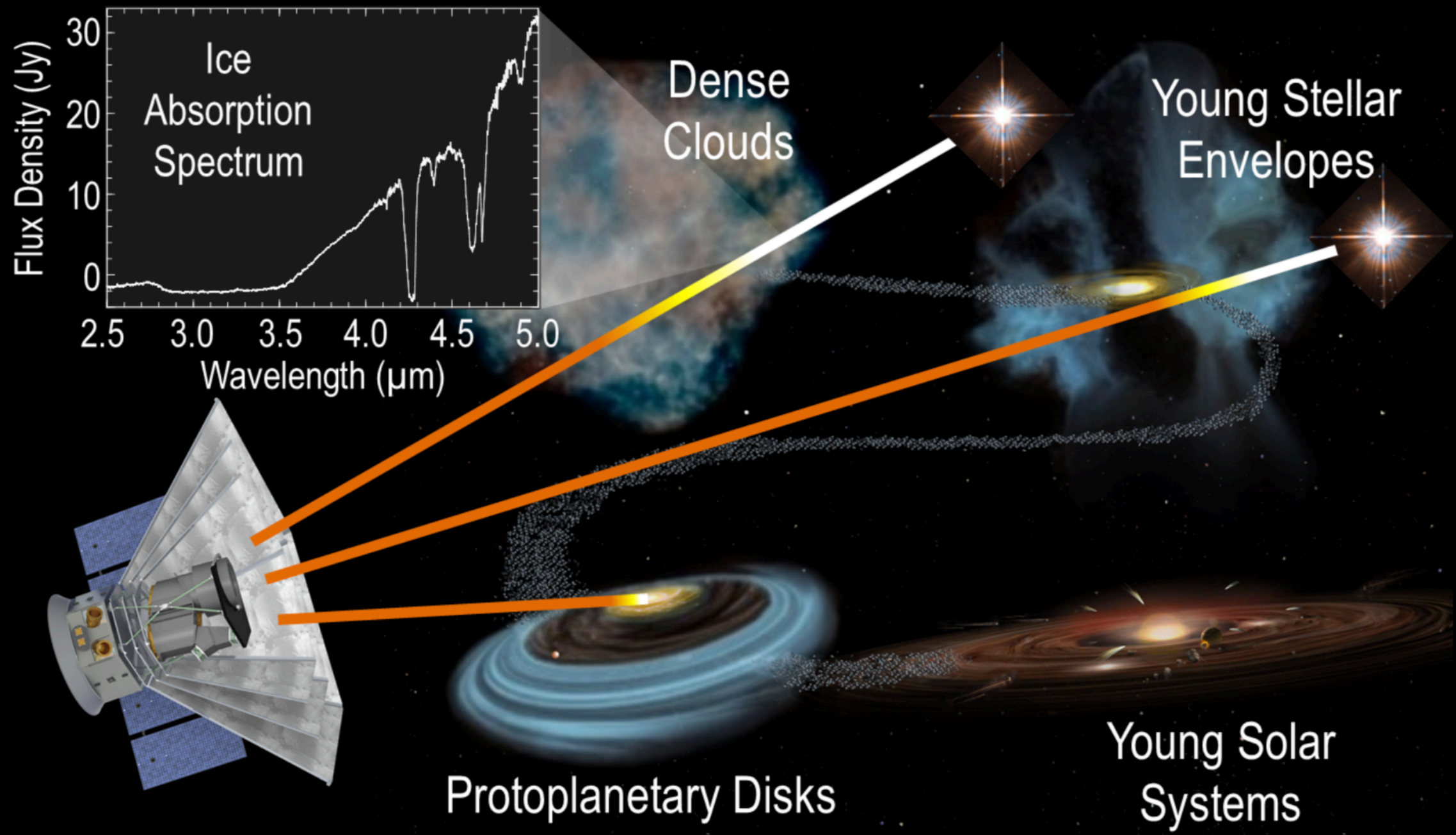
- Did earth's water come from the Oort cloud, Kuiper belt or closer?
- Did water arrive from the late bombardment (~500 MY) or before?

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

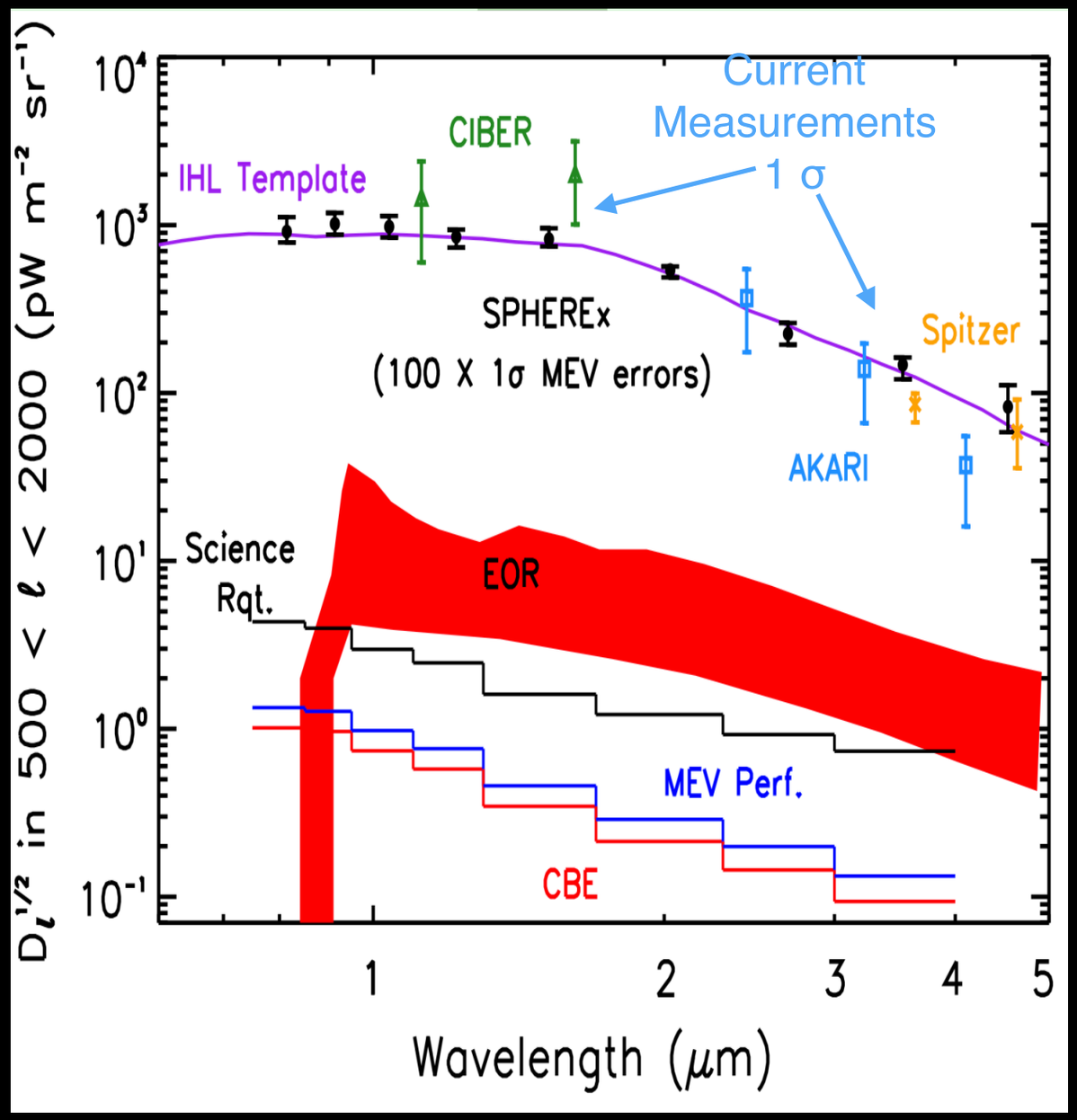


SPHEREx will measure ice abundance towards >> 20,000 sources and determine how water and biogenic ices evolve from molecular clouds to young stars to proto-planetary disks

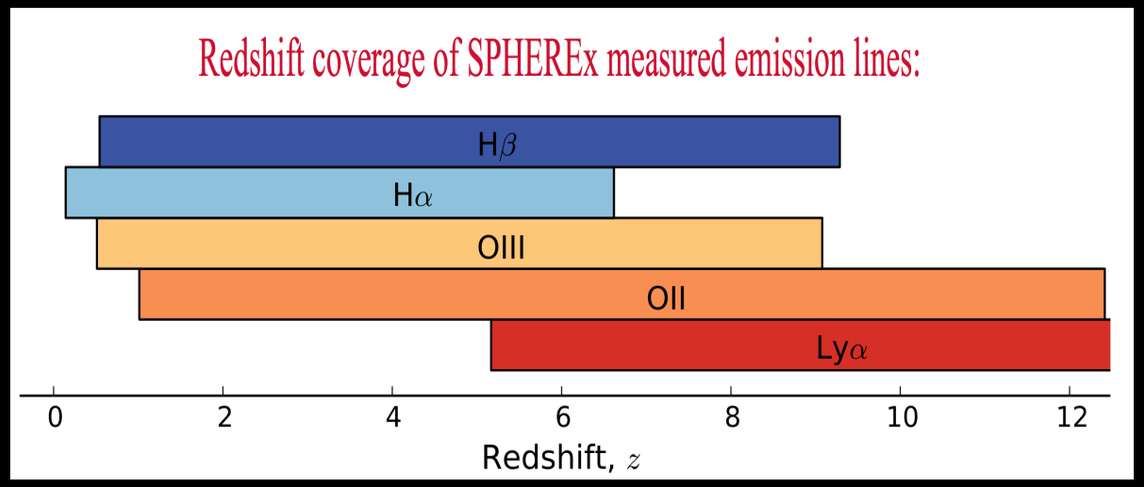
PROBING THE EPOCH OF REIONIZATION

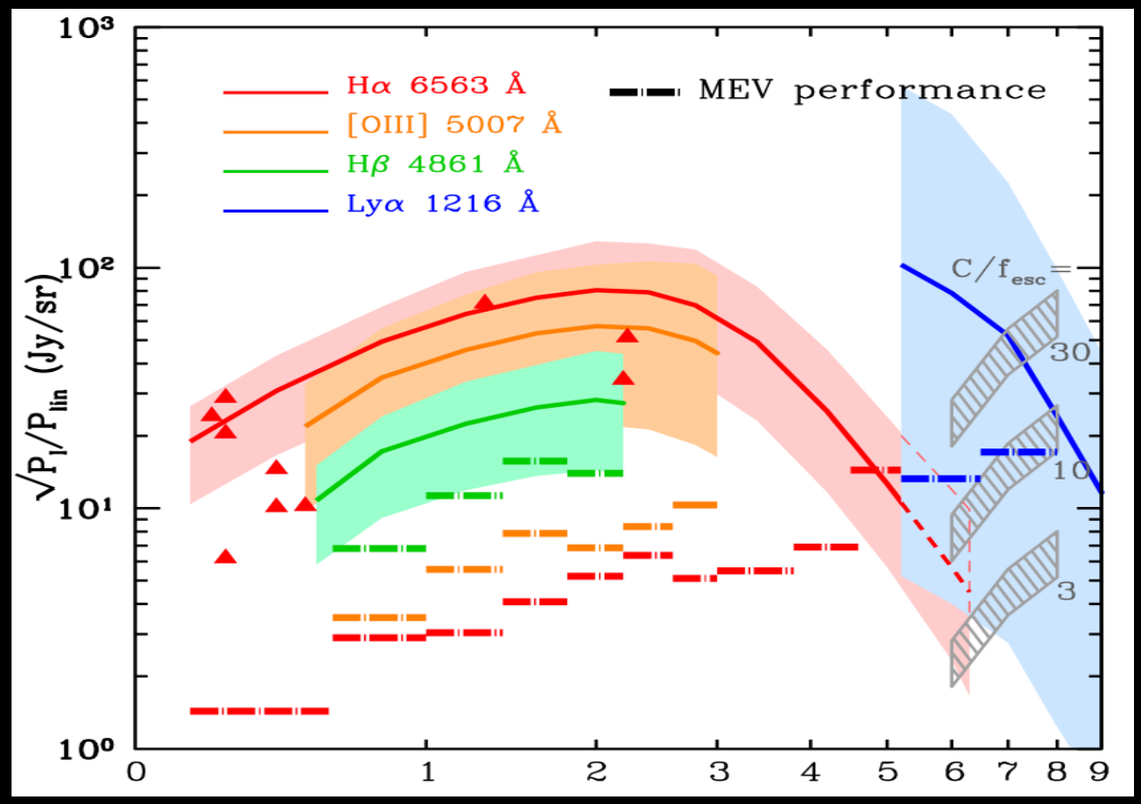
- SPHEREx orbits enable deep/frequent observations of about 200 sq. deg near the ecliptic poles (great for systematics!)
- SPHEREx wavelength coverage and resolution will enable large-scale measurement of spatial fluctuations in the Extragalactic Background Light (EBL)
- In particular, SPHEREx will monitor/explain 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



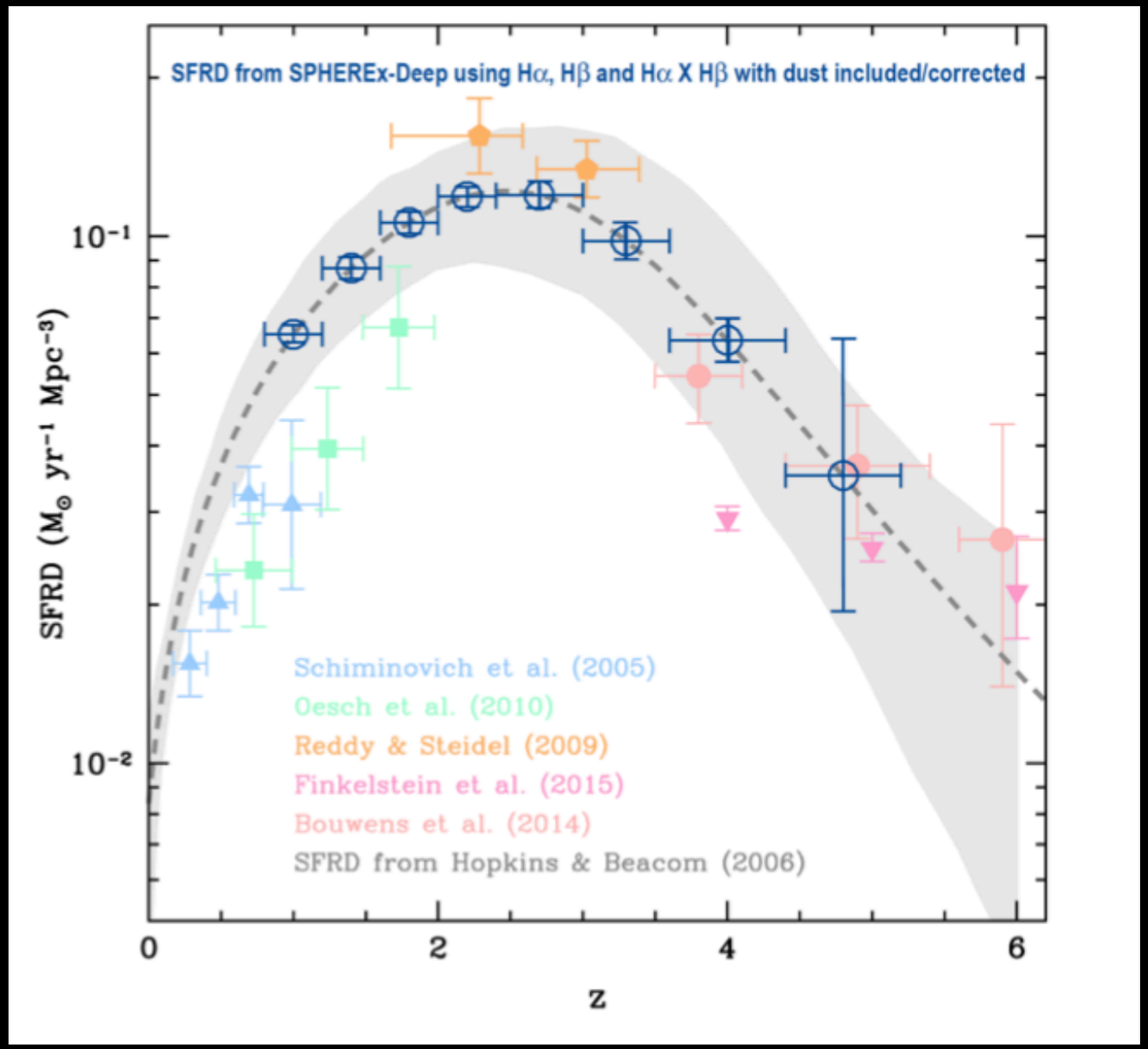
LINE INTENSITY MAPPING WITH SPHEREX





- SPHEREx will measure with high SNR the line luminosity weighted bias at multiple redshifts with multiple emission lines.

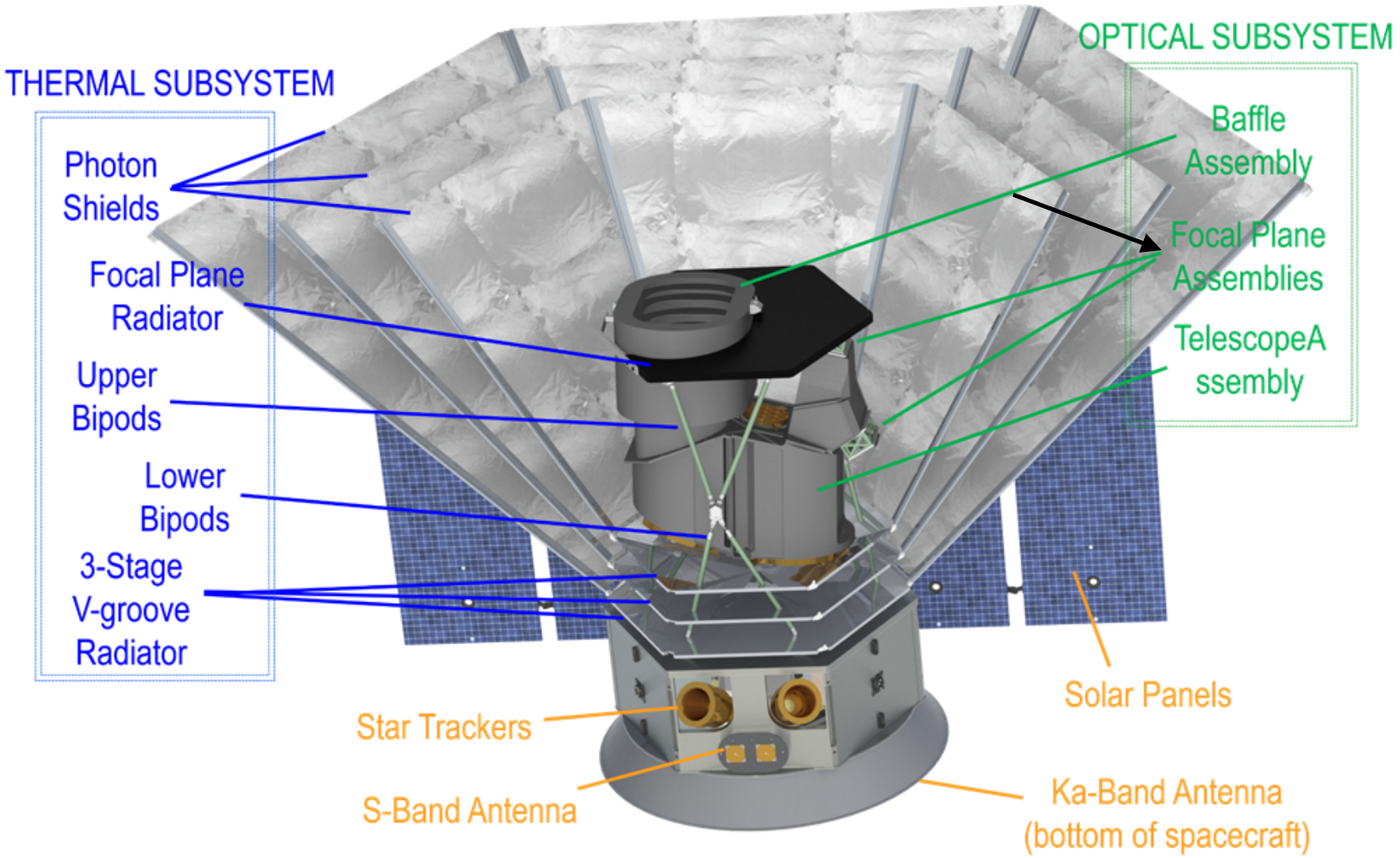
MAPPING SFR THROUGHOUT COSMIC TIMES, WHEN IT INCREASES, PEAKS AND DECLINES



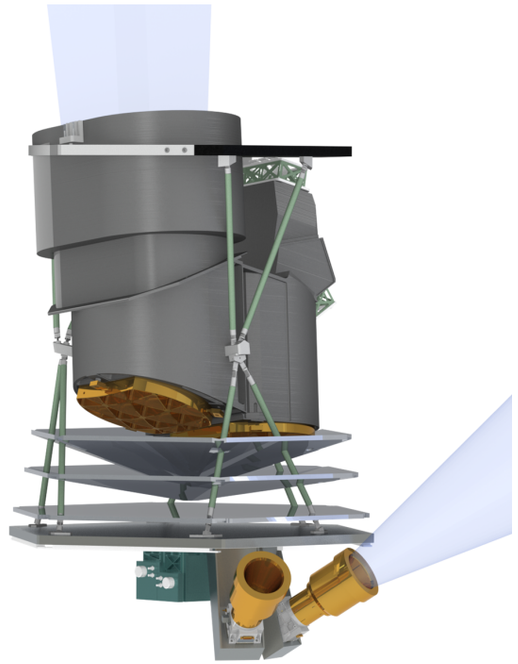
Using Hα and Hβ to solve for SFD and dust attenuation simultaneously (Gong++17)

- Multiple line traces SFR history:
  - ➡Hα for z<5; OIII and Hβ for z<3
  - ➡Lyα probes EoR models for z>6
  - ➡Hα and Lyα cross-over region 5<z<6

An Innovative Architecture Based on Mature Technologies

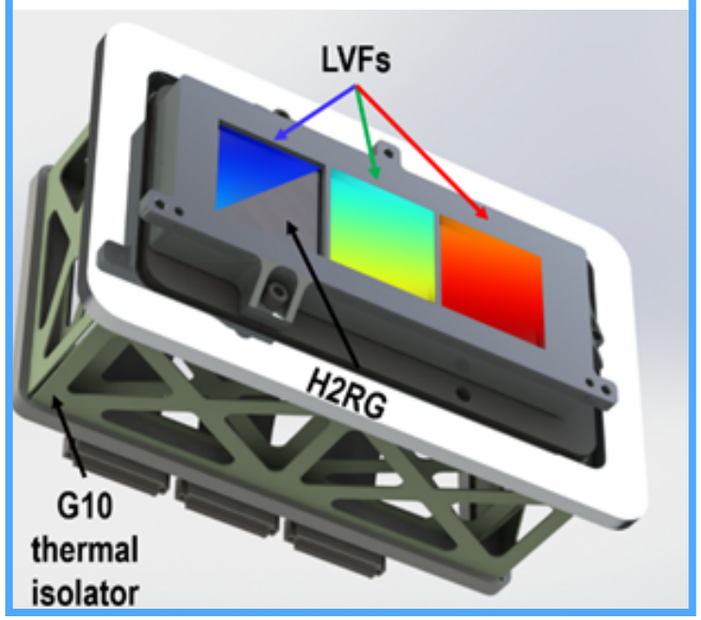


Wide field telescope



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



Pre-Decisional Information
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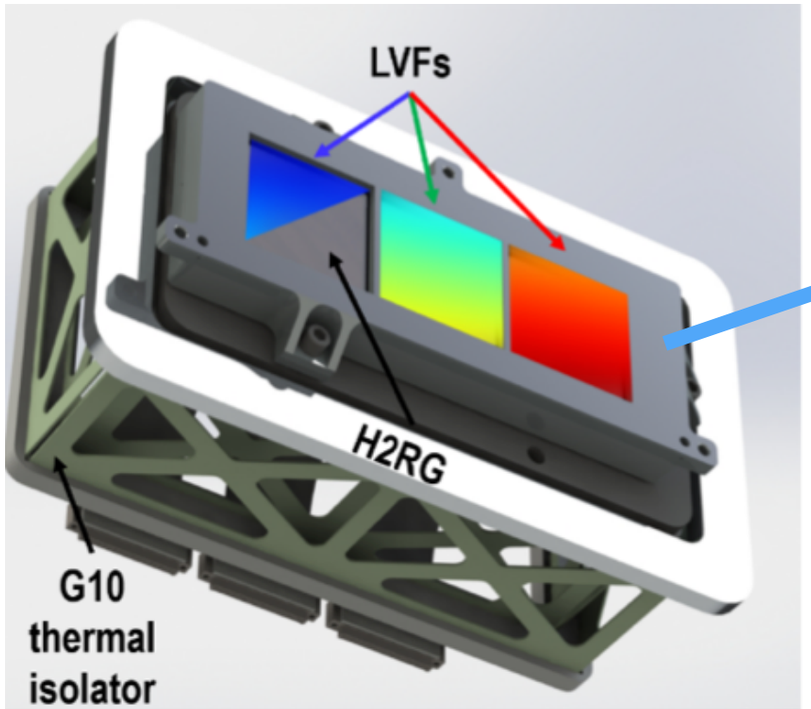
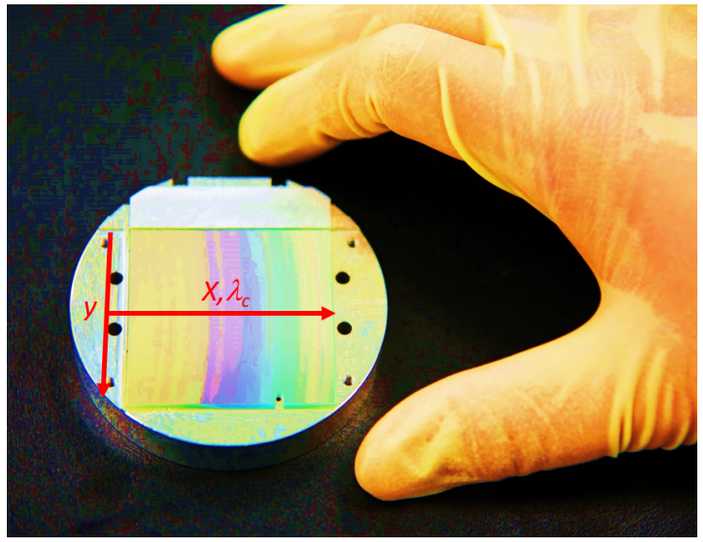
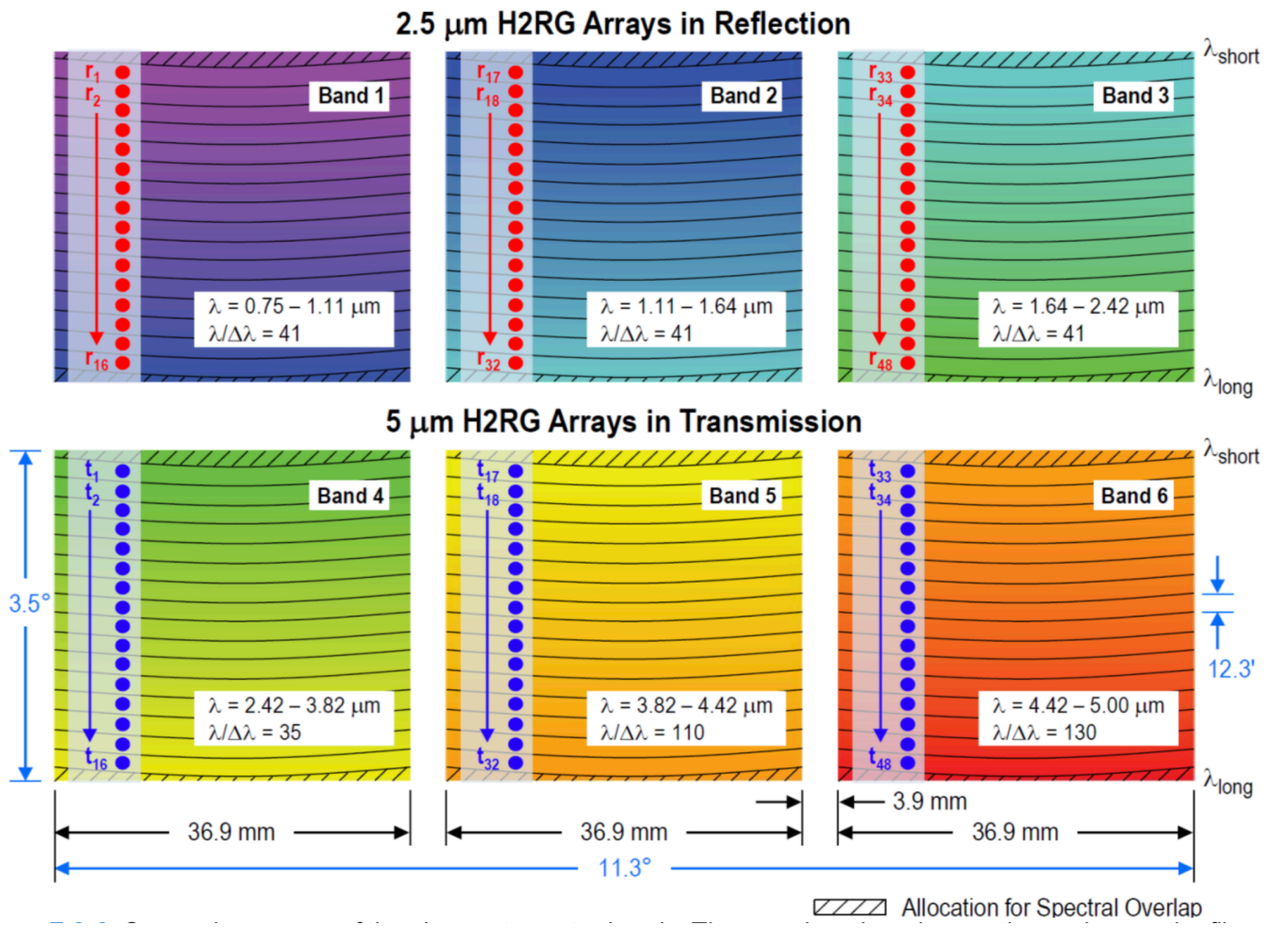
High-Throughput LVF Spectrometer



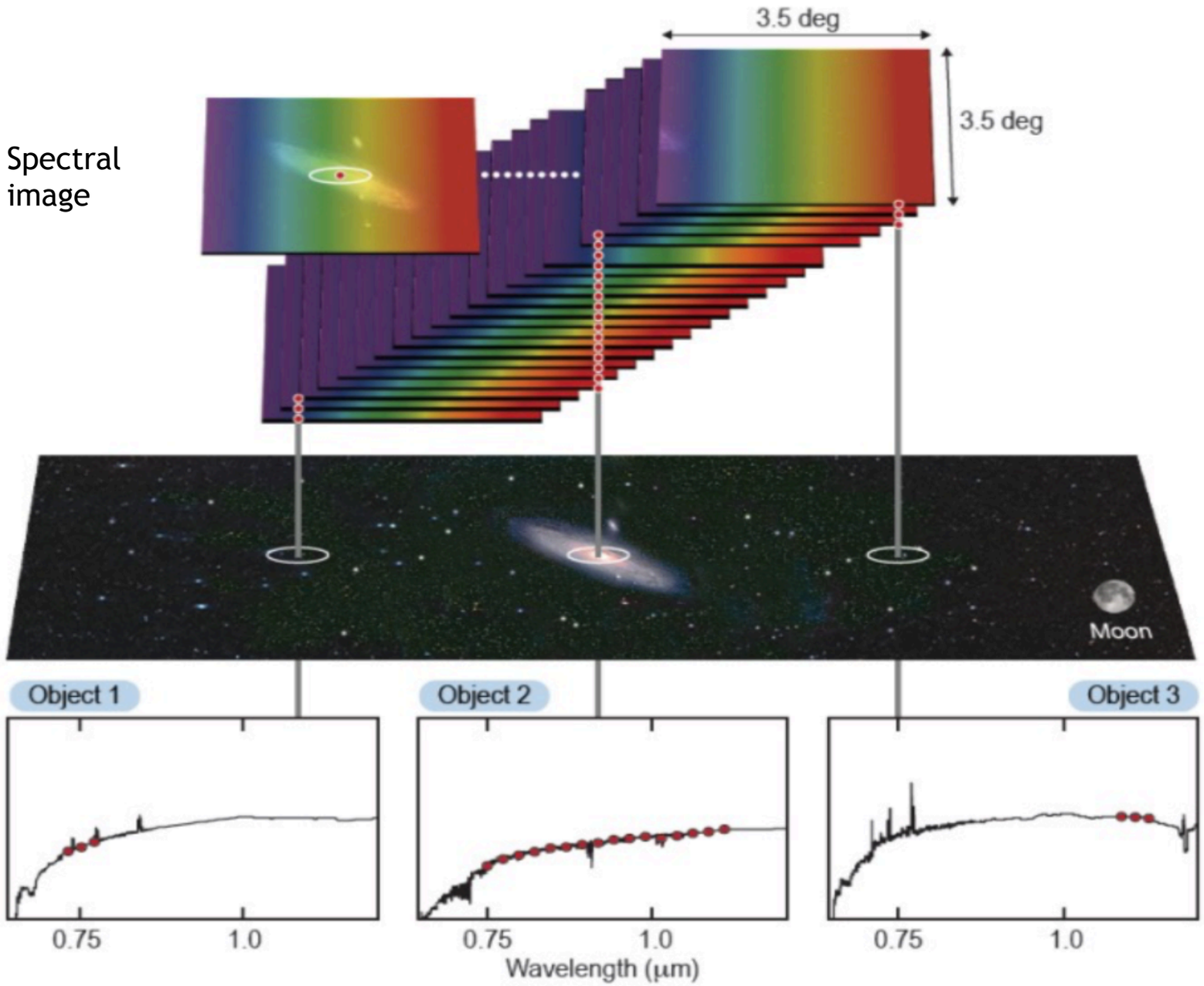




Spectra obtained by stepping source over the FOV in multiple images: no moving parts

Mapping the Sky with LVFs

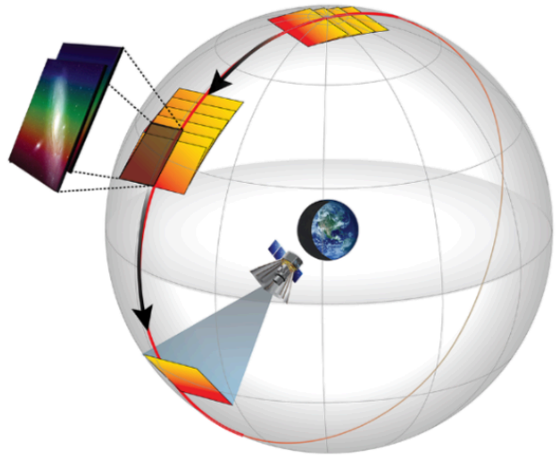
Spectral image



A complete spectrum is made from a series of images

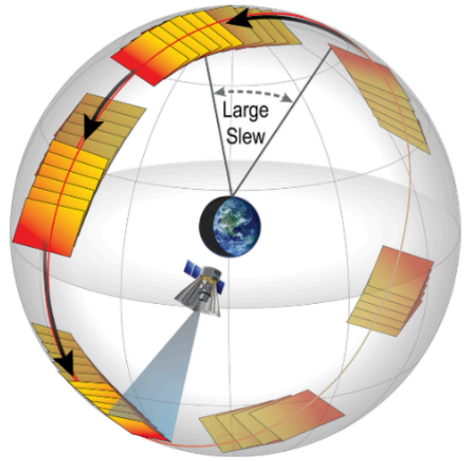
SPHEREx uses a single observing mode, with no moving parts from a low earth orbit.

1 orbit



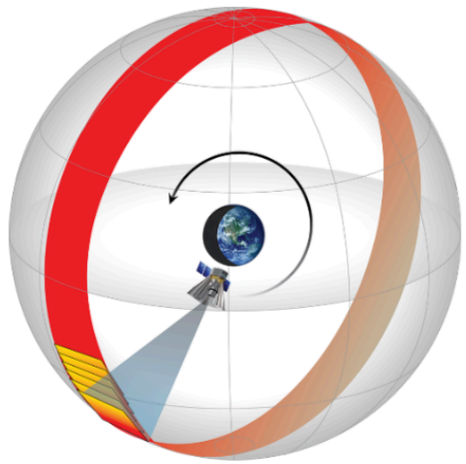
SPHEREx images the sky through LVF filters
- In one exposure, each object is measured at a different wavelength
- On a given object, each new exposure adds a new wavelength

2 orbits



SPHEREx produces spectra from multiple pointed exposures
- SPHEREx takes exposures separated by small and large slews
- Successive exposures approximately follow a great circle 90° from the Sun. The great circle rotates 360° over a year.

~3 days



SPHEREx obtains complete spectra in every survey
- A given region is typically completed in a few days
- The entire sky is completely sampled in six months

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

SPHEREX AVOIDANCE CRITERIA

PRE-PROGRAMMED SCANNING STRATEGY

SUMMARY

- SPHEREx selected as the next MIDEX. Launch planned in April 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
  - ➡JWST, WFIRST, TESS, e-ROSITA,…

http://spherex.caltech.edu

FIN