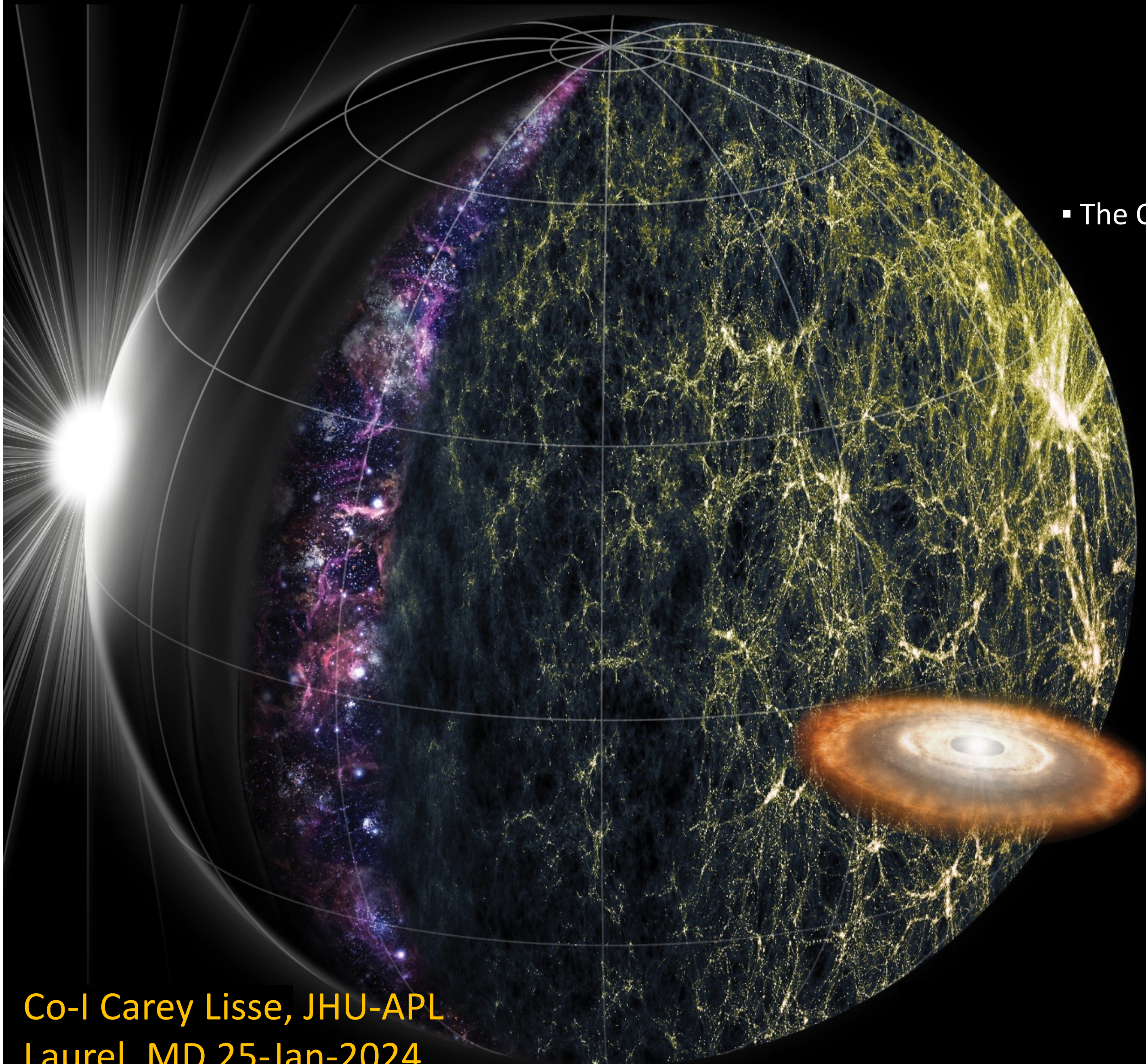
SPHEREx: A NASA MIDEX All-Sky 0.75-5.0 um Spectral Survey



Designed to Explore

- The Origin of the Universe
- The Origin and History of Galaxies
- The Origin of Water in Planetary Systems
- PI Jamie Bock, CalTech

The First All-Sky Near-IR Spectral Survey

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

Low-Risk Implementation

- 2025 Falcon 9 Launch
- Single Observing Mode
- Large Design Margins
- No Moving Optics

Co-I Carey Lisse, JHU-APL
Laurel, MD 25-Jan-2024

SPHERE^{x} IN A NUTSHELL

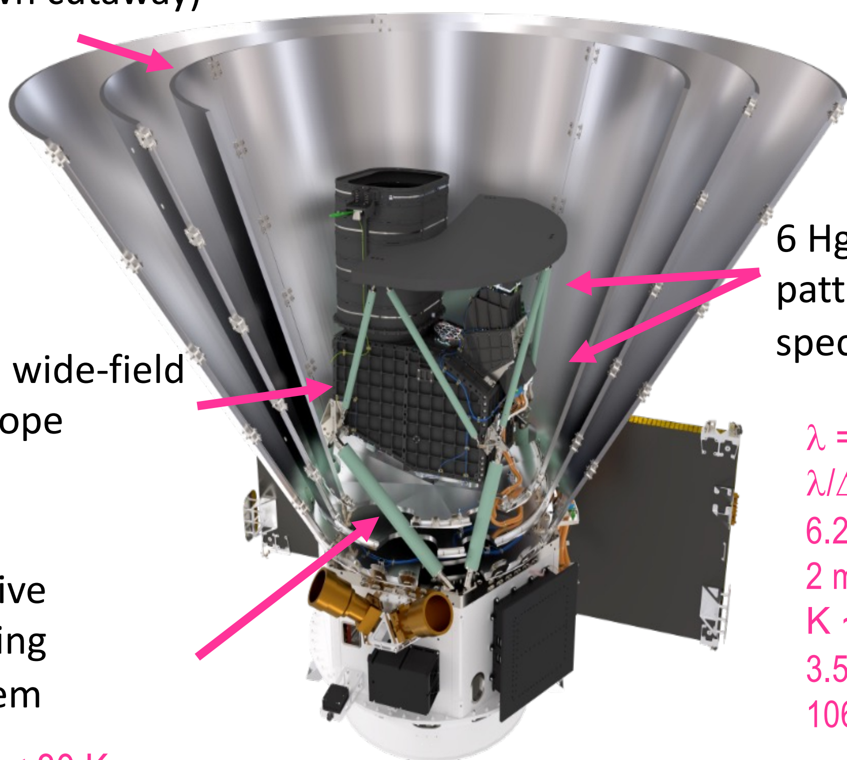
photon shields
(shown cutaway)

2.0 m

20 cm wide-field
telescope

Passive
cooling
system

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



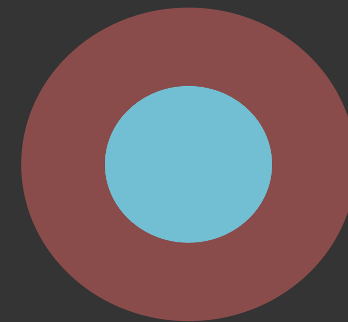
LEO spacecraft (Ball)

6 HgCdTe 2kx2k LVF
patterned detectors/
spectrophotometers

$\lambda = 0.75 – 5.0\ \mu m$
$\lambda/\Delta\lambda = 35 – 130$
6.2″ pixels
2 min exposures
K ~ 19 sensitivity
3.5° x 11° IFOV
106 independent bands

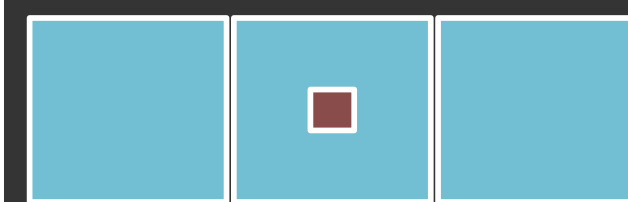
WISE vs. SPHEREx

Mirror: WISE has 4x greater area



WISE: 40 cm
SPHEREx: 20 cm

FOV: SPHEREx's is 65x greater

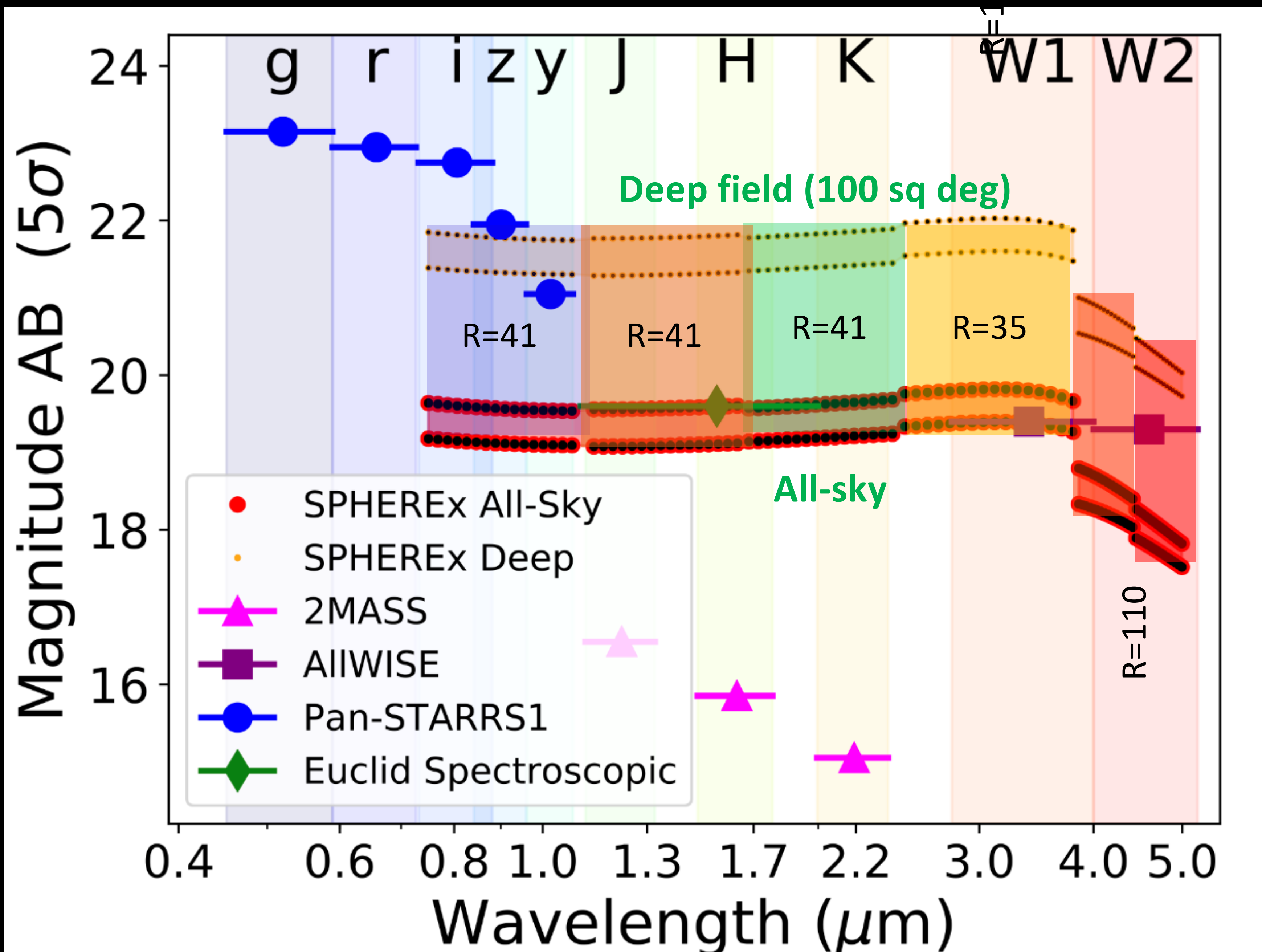


WISE: 0.61 sq. deg
SPHEREx: 39.6 sq. deg.

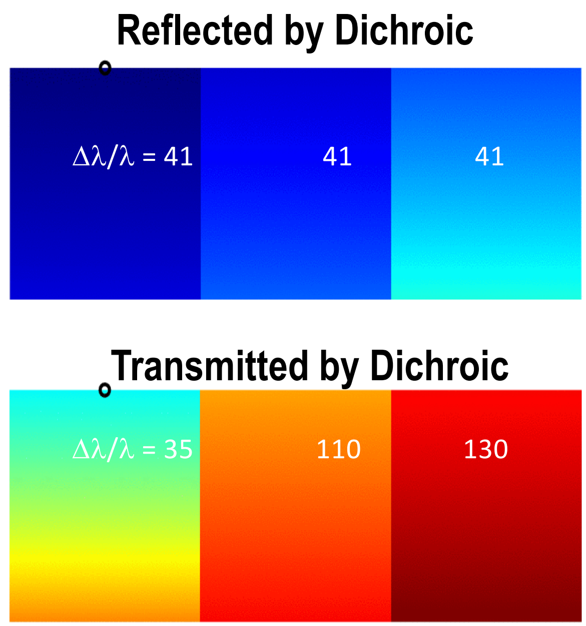
AΩ Product: SPHEREx's is 16x greater

SPHEREx = "All-Sky IRTF/SpeX Prism in Space"
or "LEISA at LEO, Tiling the Entire Sky 4x Over 2 Yrs"

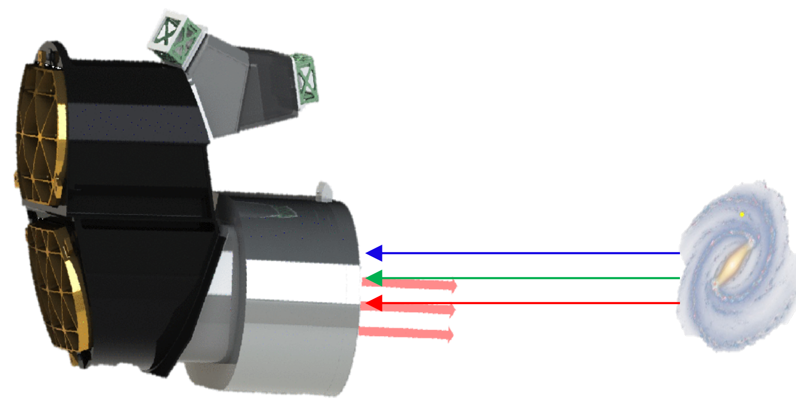
SPHEREx Creates an All-Sky Legacy Archive at High Sensitivity

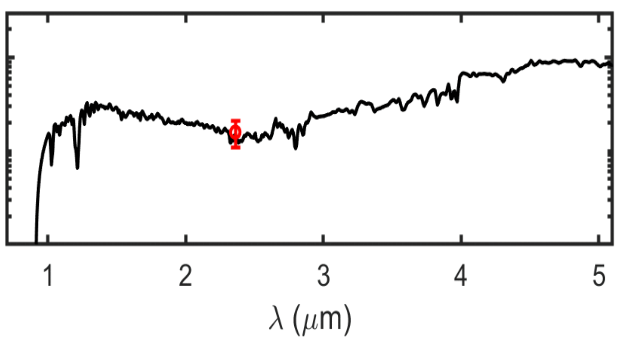


SPECTROSCOPY WITH LINEAR VARIABLE FILTERS (LVFs)

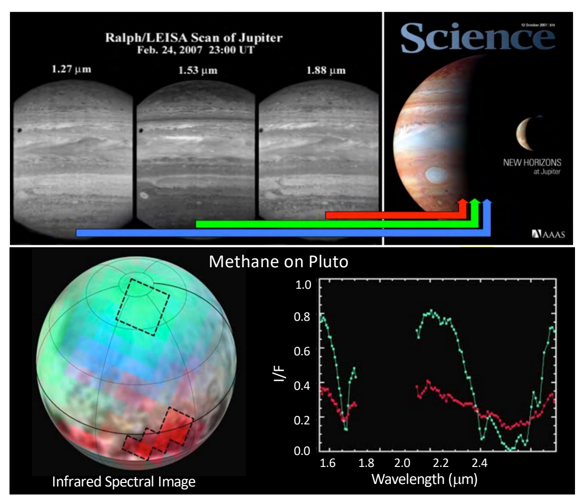


Shifting the spacecraft pointing modulates the wavelength at which an object is observed.





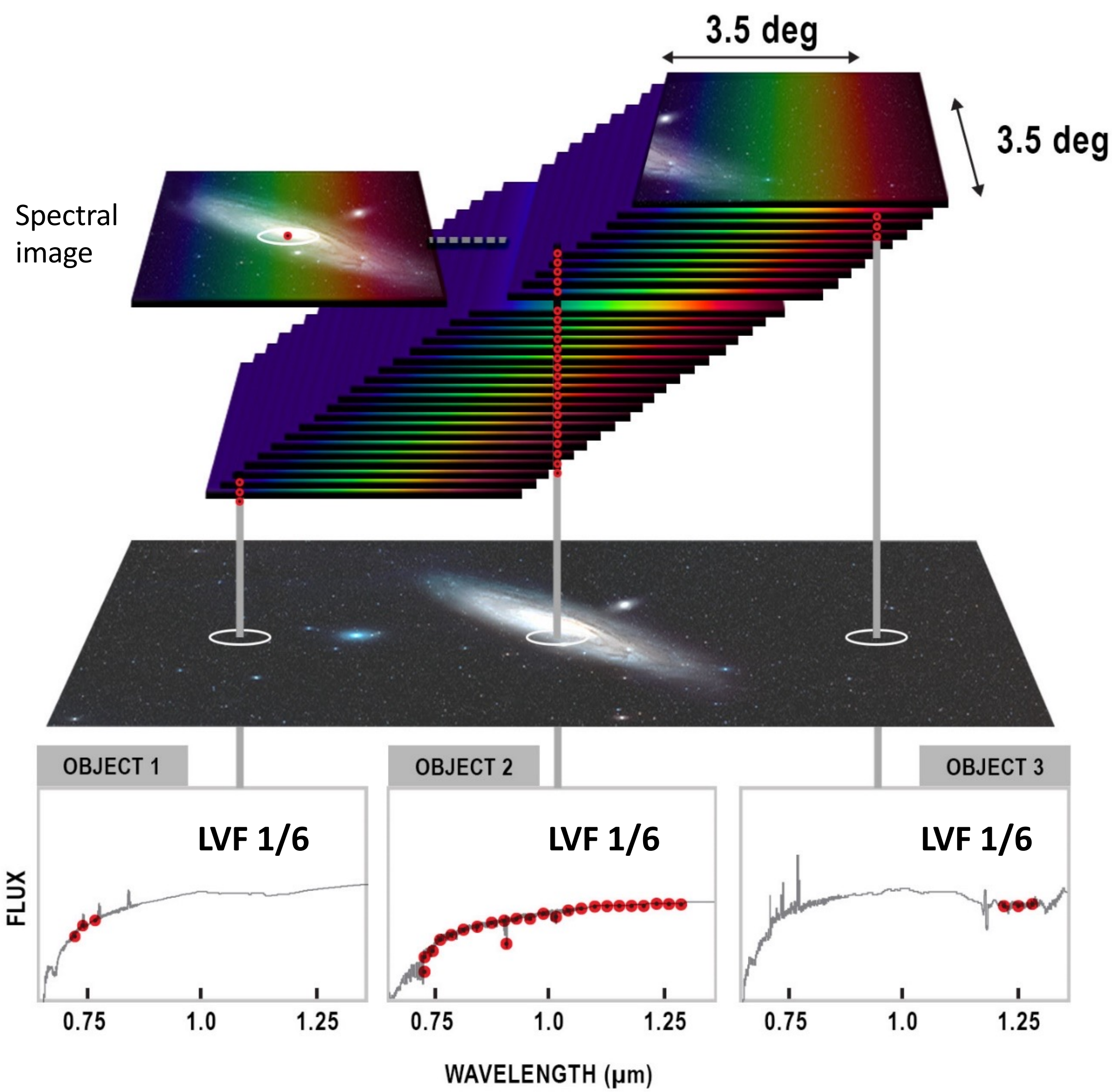
A complete spectrum in 51 exposures
Each exposure takes 112s. 1 complete spectrum/ sky location every 6 months (taken over days-weeks)



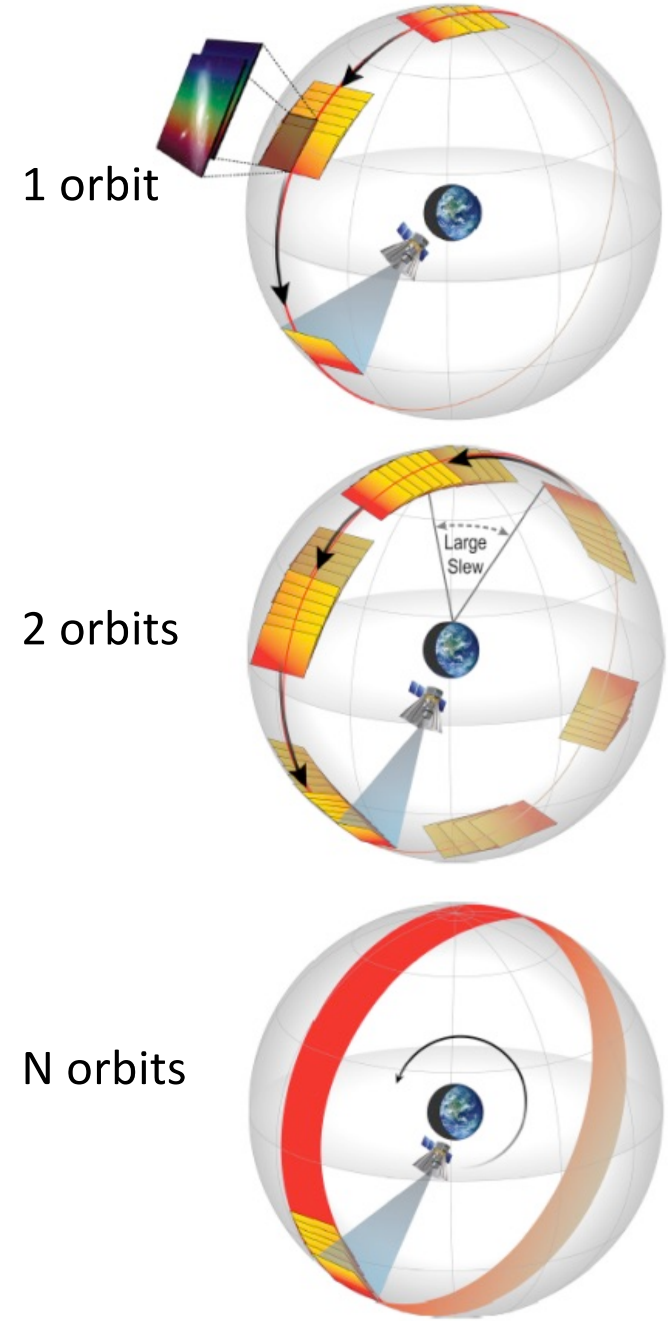
LVF surveys are new to astronomy but have been used for great results in planetary science

LEISA - New Horizons: 1.25 - 2.5, 250 channels, R~400

Mapping the Sky with LVFs

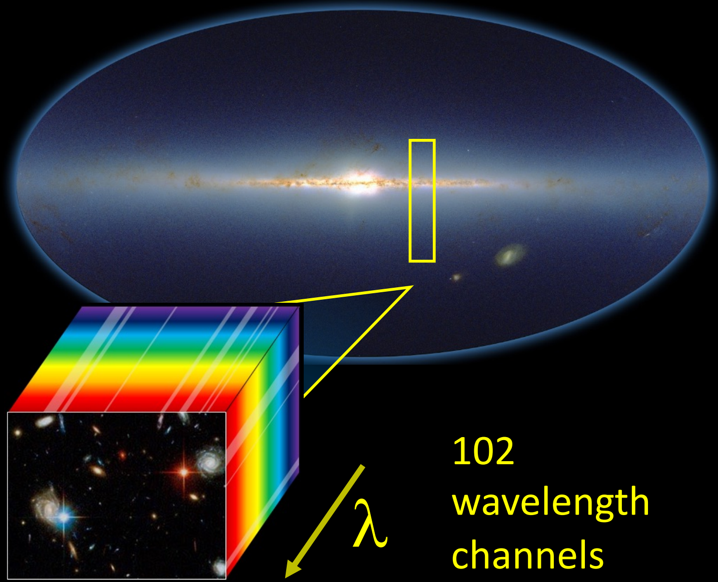


A complete spectrum is made from a series of images



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

SPHEREx (2025-2027): All-Sky 0.75 – 5.0 µm Spectral Legacy Archives



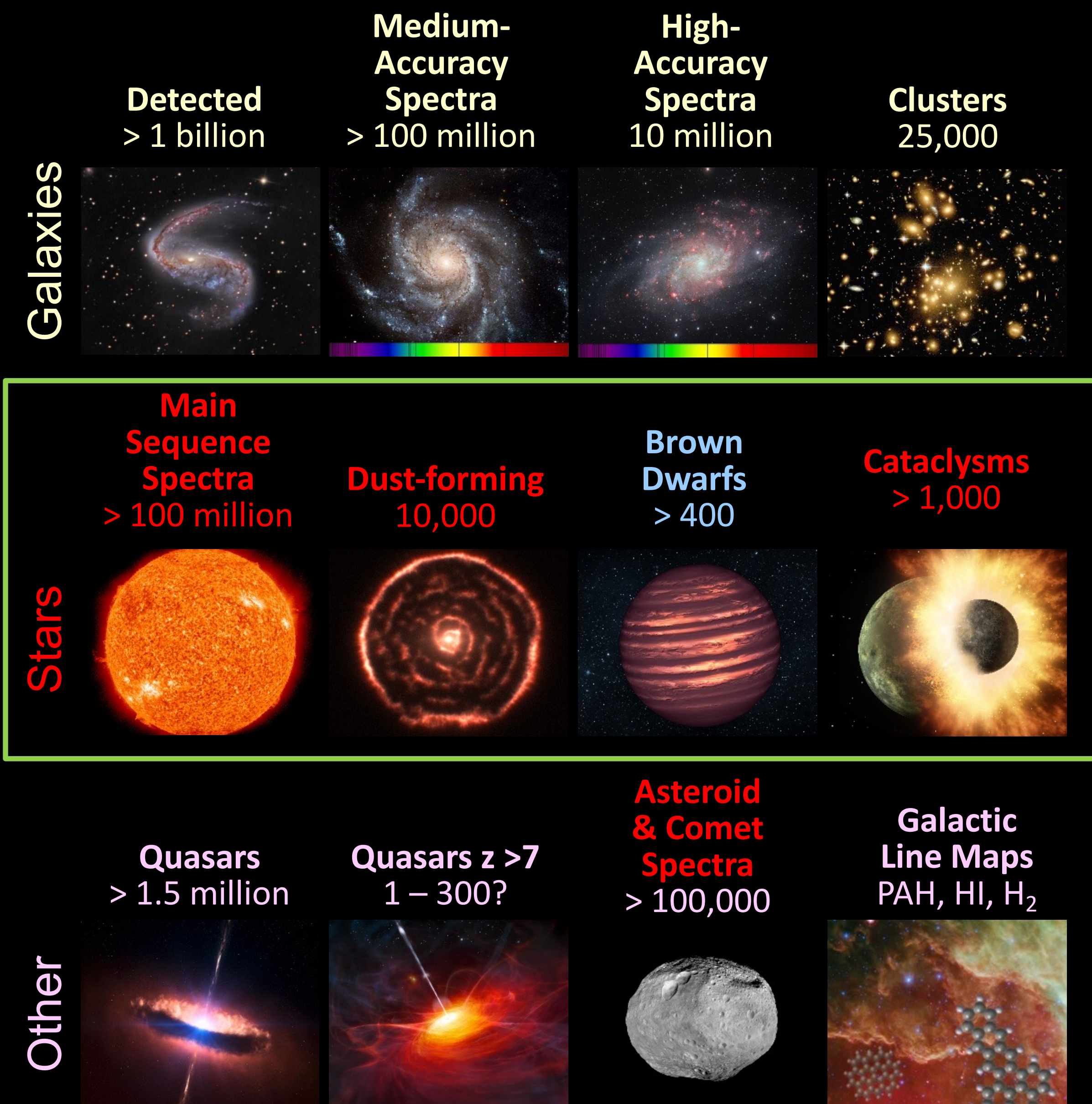
SPHEREx provides a a complete near-infrared spectrum for every 6” pixel on the sky

All-Sky surveys demonstrate high scientific returns with a lasting data legacy used across astronomy

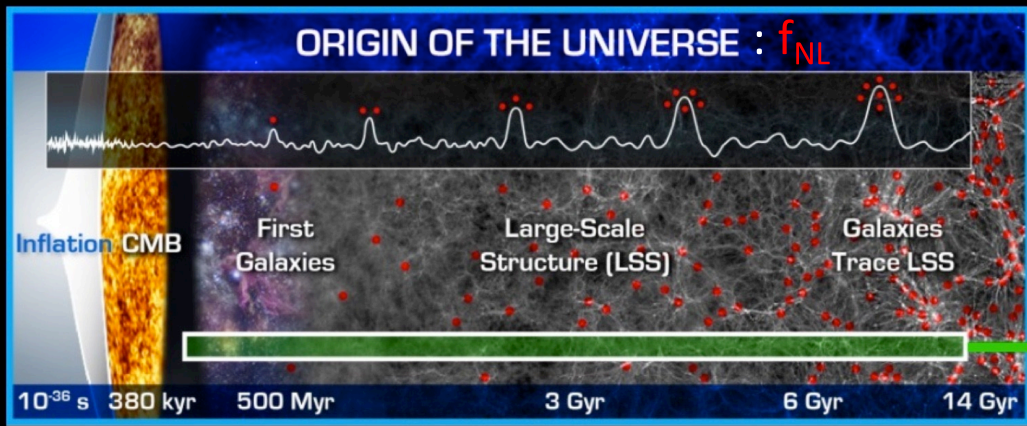
For example:

COBE, IRAS
WMAP, WISE
GALEX, Planck

More than 400,000 total citations!

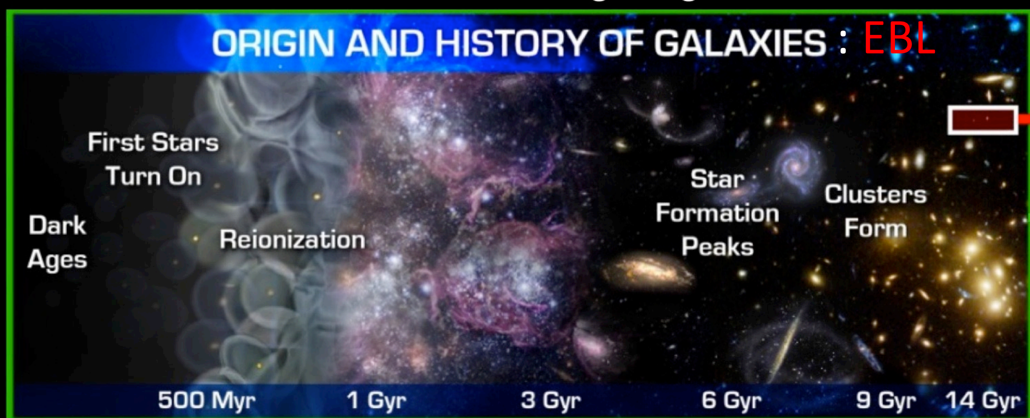


SPHEREx 3 Main Science Themes: f_{NL}, EBL, Ices



Time Since Big Bang

Maps the large scale structure of galaxies to study the process of Inflation in the early universe, addressing NASA's objective to ***Probe the origin and destiny of the Universe.***

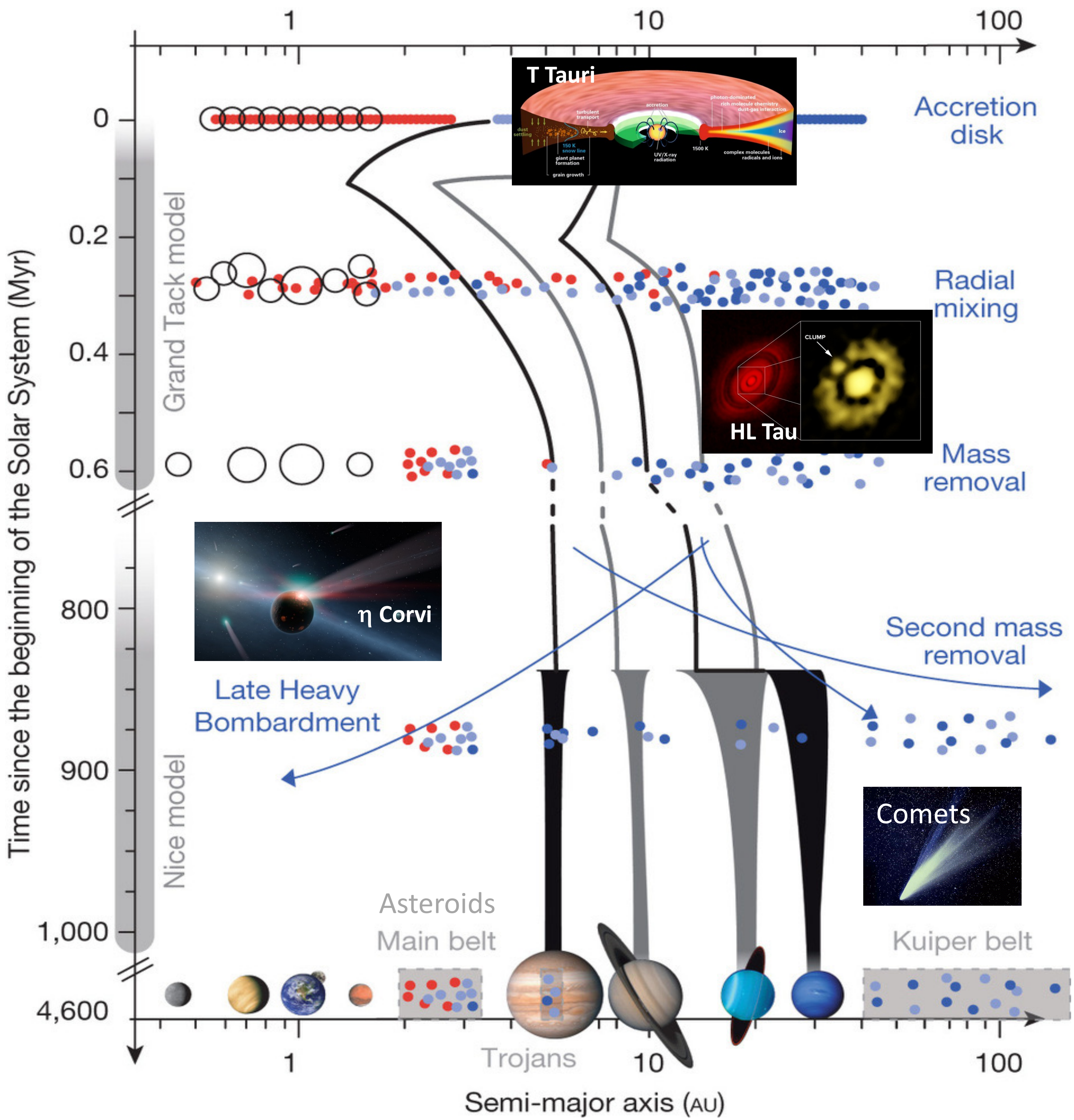


Time Since Big Bang

Measures the total light production from stars and galaxies across cosmic history, addressing NASA's objective to ***Explore the origin and evolution of galaxies.***

Stages of Star Formation

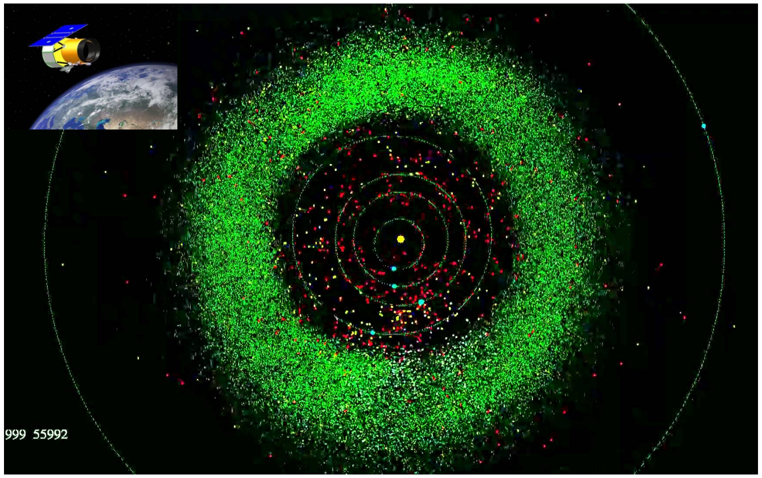
Determines how interstellar ices bring water and organics into proto-planetary systems, furthering NASA's objective to ***Explore whether planets around other stars could harbor life.***



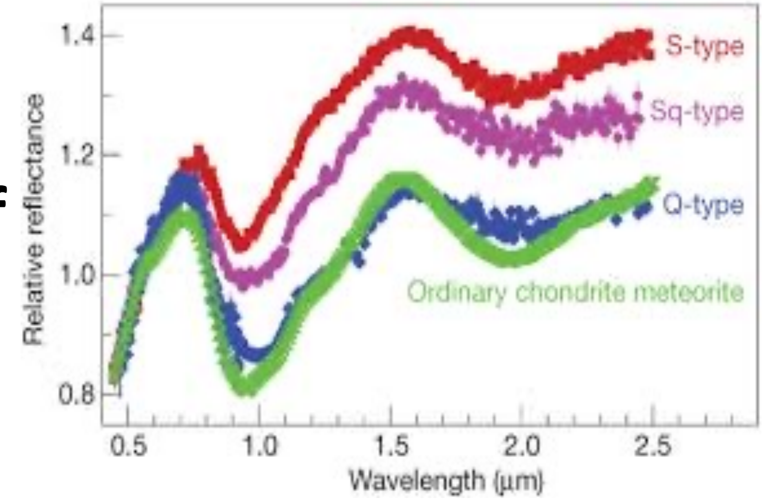
Of Course There is Also Great Potential For the "Local Stuff!"

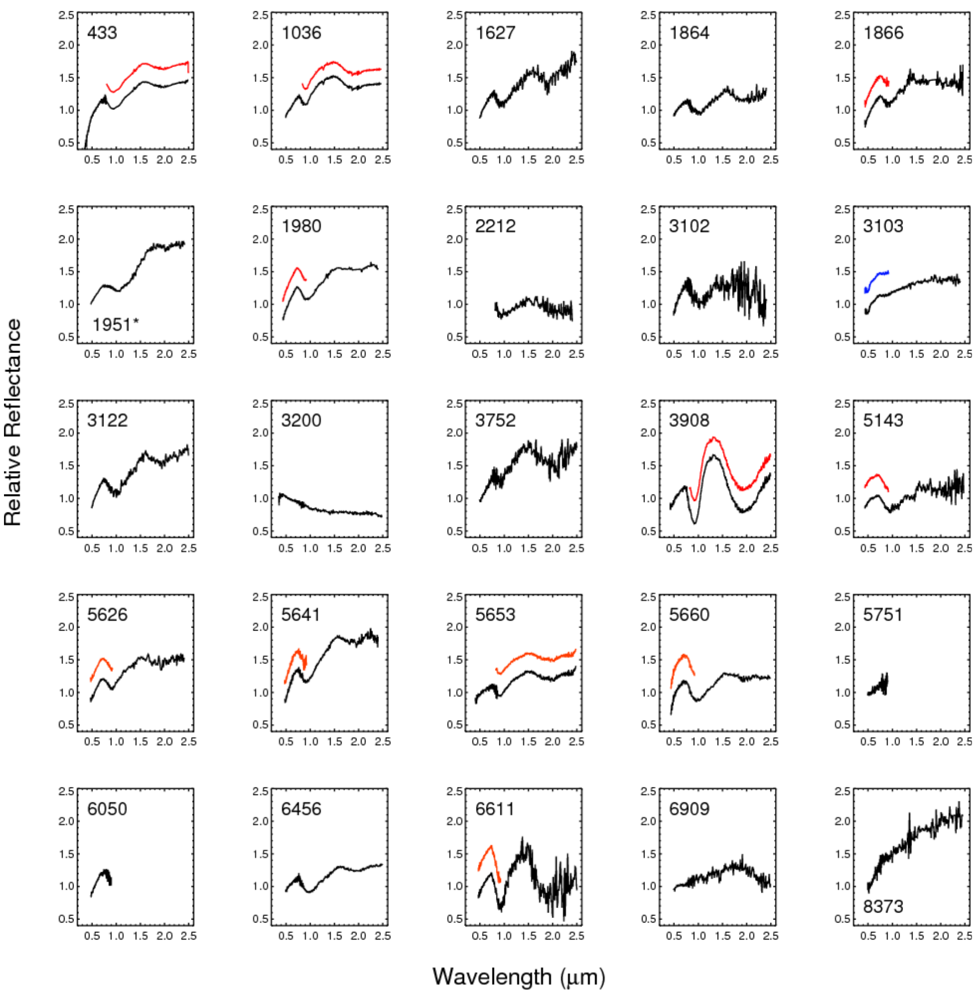
Overarching SPHEREx Solar System Science Goal: Determine The Local Cosmology (*i.e* Origin & Evolution of the Nearest Exosystem from Protostar to Today)

(Motivation for Cosmologists Who Think Galaxies are Point Particles and 4.6 Gyrs is *only* Z~0.45)

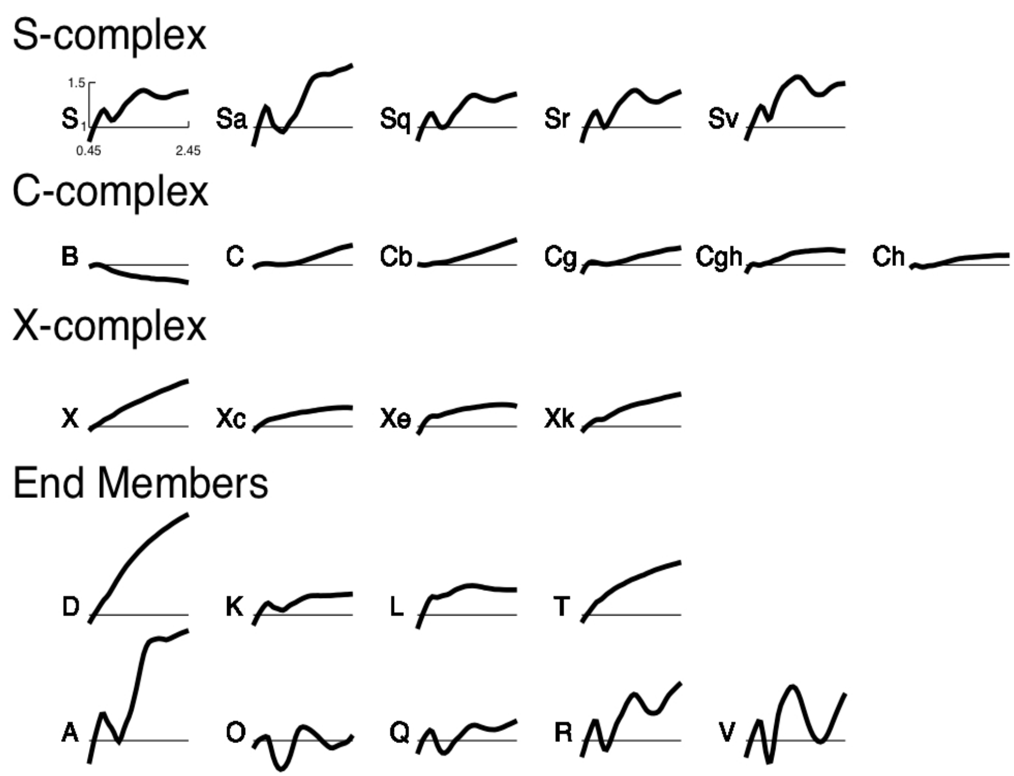


Spectral Characterization of ~50,000 Asteroids



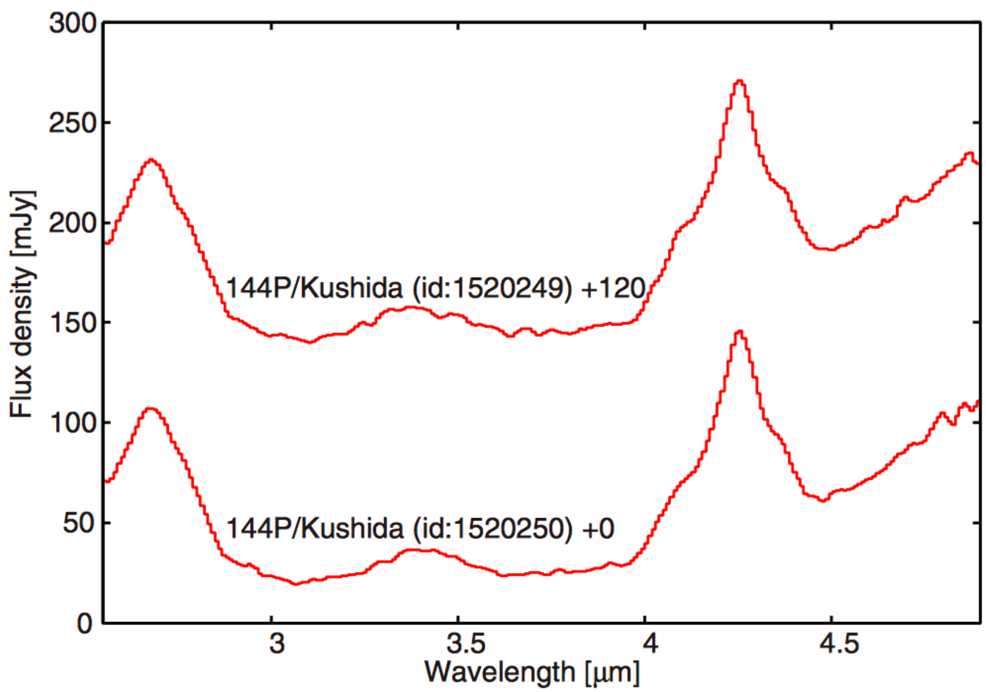


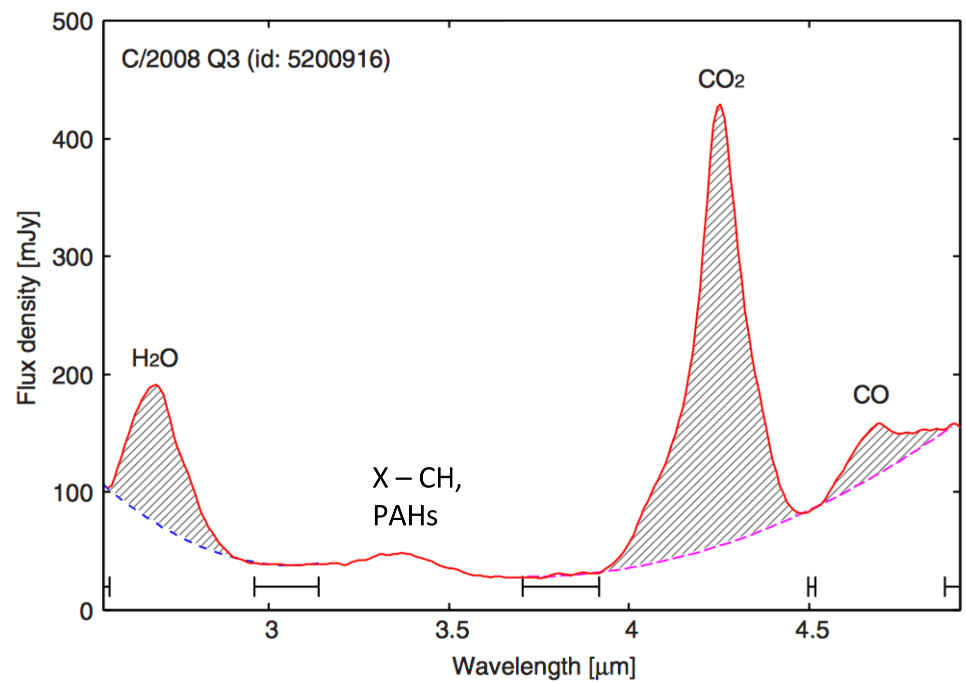
Bus-DeMeo Taxonomy Key



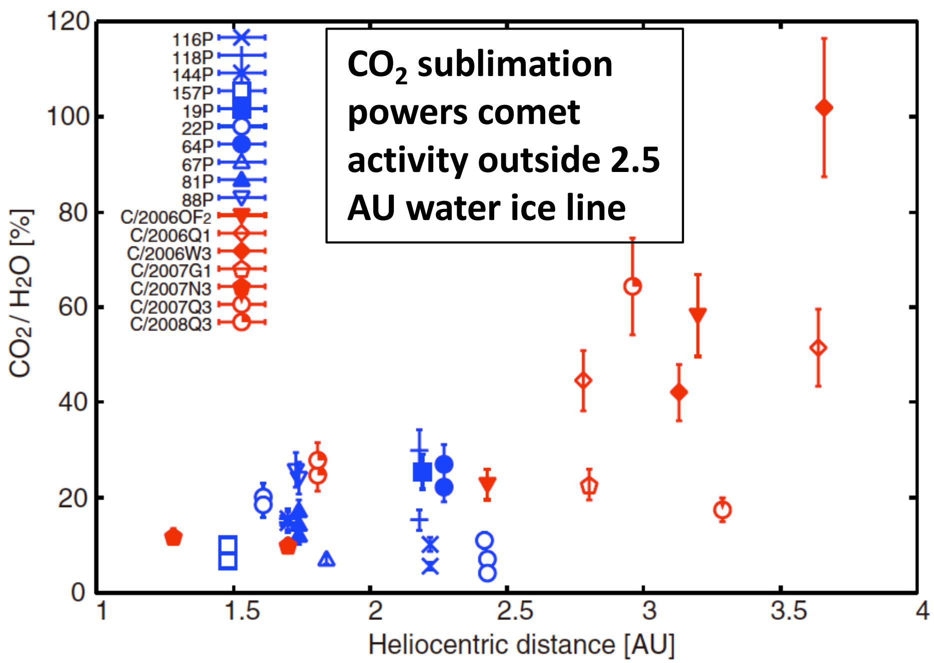
http://smass.mit.edu/busdemeoclass.html

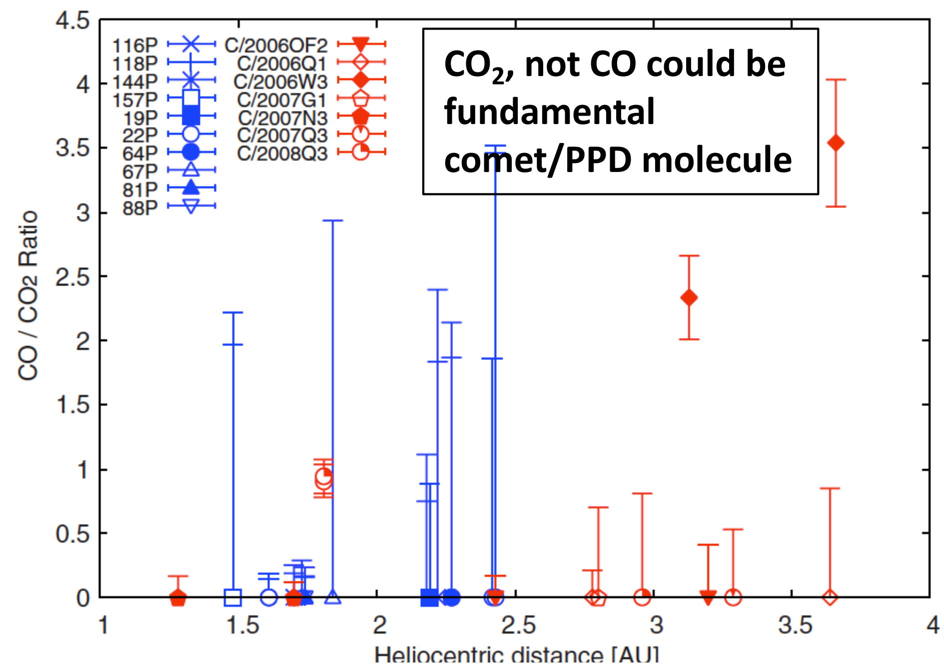
F. E. DeMeo, R. P. Binzel, S. M. Slivan, and S. J. Bus. Icarus 202 (2009) 160-180

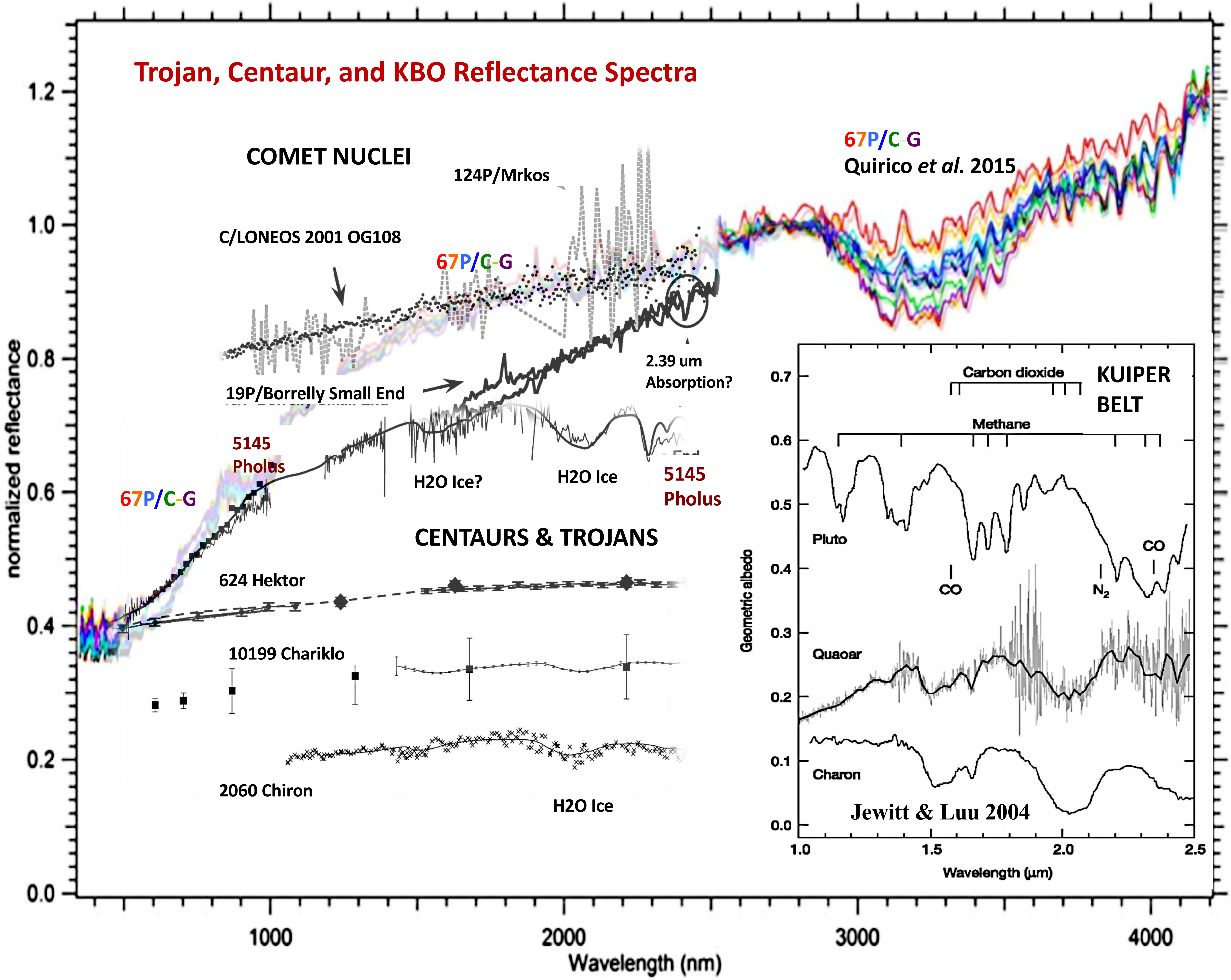




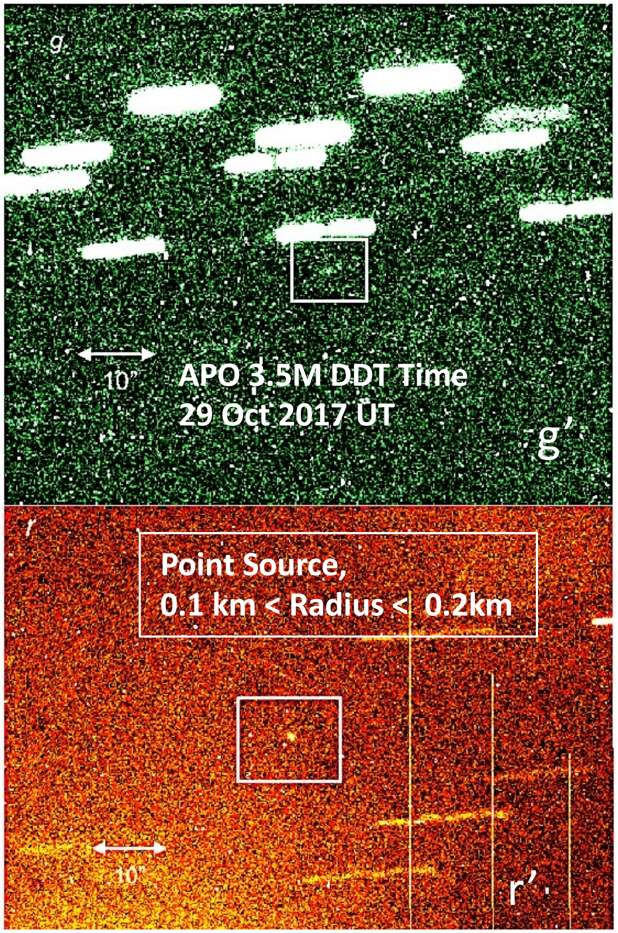
Comet Spectroscopy of H_2O/CO/CO_2 : SPHEREx Will Return 100's of Spectra Like These (18 Total) AKARI R~100 Measurements







Trojan, Centaur, and KBO Reflectance Spectra
COMET NUCLEI
124P/Mrkos
C/LONEOS 2001 OG108
67P/C-G
19P/Borrelly Small End
2.39 um Absorption?
5145 Pholus
67P/C-G
H2O Ice?
H2O Ice
5145 Pholus
CENTAURS & TROJANS
624 Hektor
10199 Chariklo
2060 Chiron
H2O Ice
67P/C-G
Quirico et al. 2015
normalized reflectance
Wavelength (nm)
KUIPER BELT
Carbon dioxide
Methane
Pluto
CO
N2
CO
Quaoar
Charon
Geometric albedo
Jewitt & Luu 2004
Wavelength (μm)



SPHEREx would have provided Spectrophotometric Imaging of 1st Detected Interstellar Object in the Solar System:

1I/'Oumuamua

[Sept-Nov 2017 asteroid passage]

See: Bolin, Weaver, Fernandez, Lisse+ 2017 *ApJ Lett* **853**, L8

$r_{perihelion}$ = 0.25 AU
$r_{perigee}$ = 0.20 AU
eccentricity = 1.19

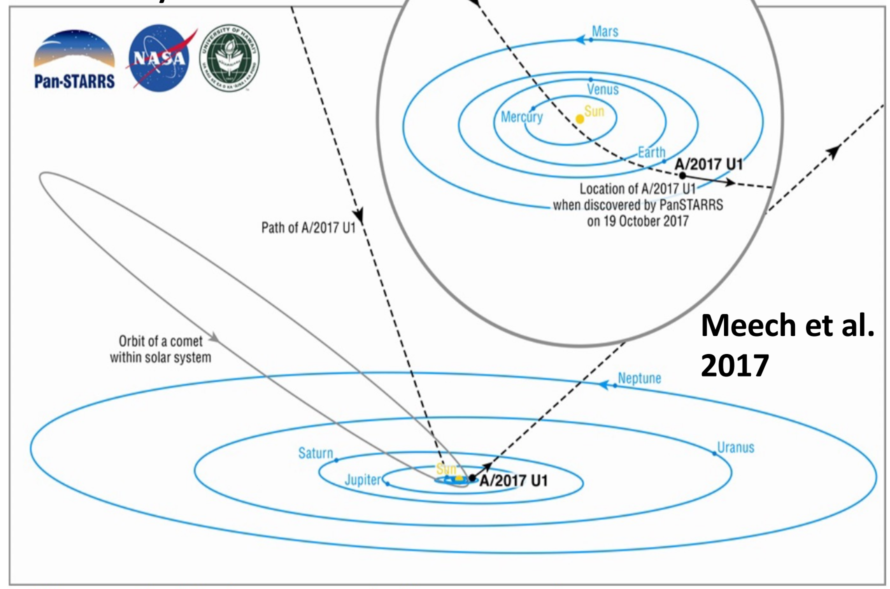
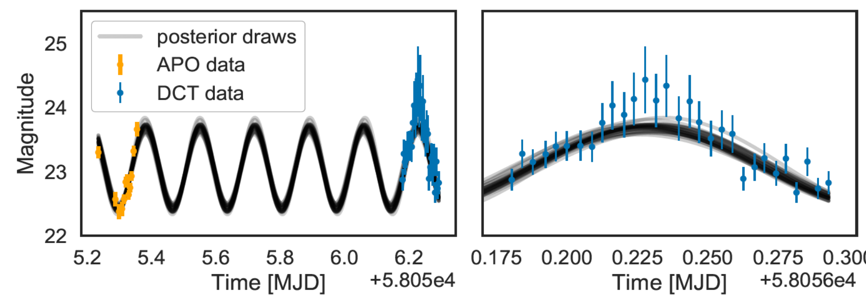
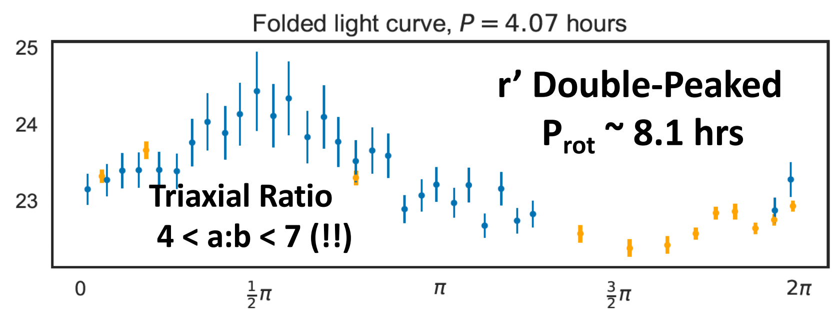
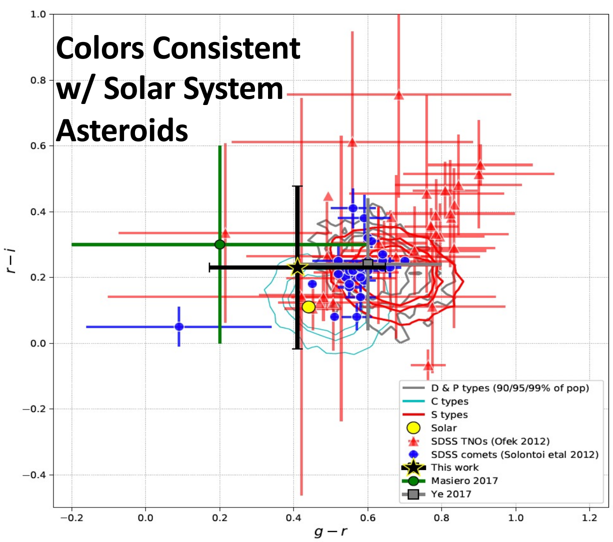


Figure 1: Trajectory and discovery circumstances for A/2017 I1-'Oumuamua.

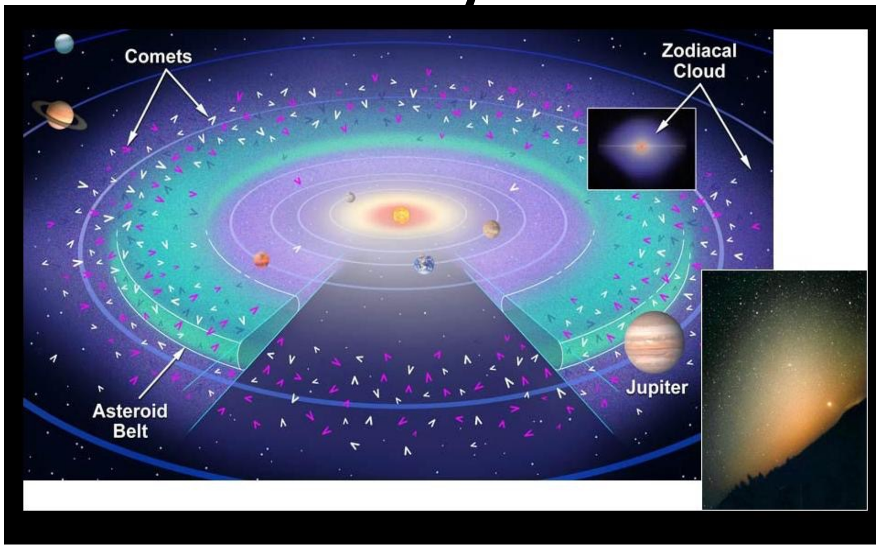
Football Shaped Spheroid

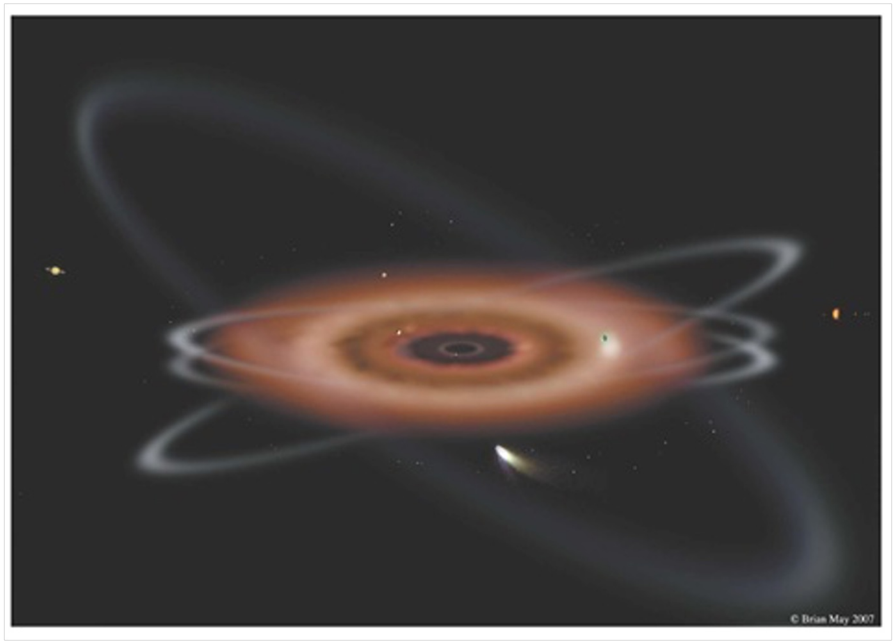


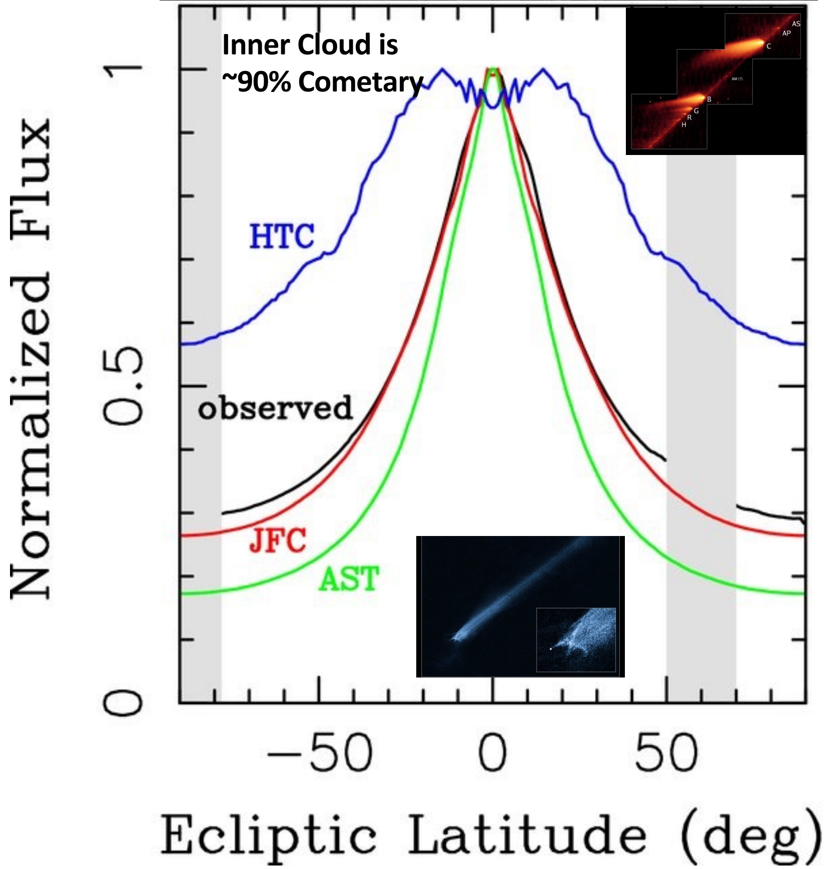




SPHEREx Will Also Do a Fantastic Job of Spectrally Mapping the Inner Zody (Dust Debris) Cloud, a Mix of Asteroidal & Cometary Dust







SPHEREx vs LSST, NeoCAM, JWST; Dawn, Lucy, Psyche

- *SPHEREx* will get down to AB magnitude ~ 19 (5σ) in the W1 passband, which => V ~ 20.5 for solar colored (i.e., neutral/grey objects), V~ 21-22 for reddish objects.
- ***LSST*** has a limiting sensitivity of ~24.5 at V, or about 3 mags fainter than *SPHEREx*'s 3σ limit for a neutral grey object. Therefore everything *SPHEREx* detects will be in the LSST survey, but not vice-versa.
- **JWST**: SPHEREx's all-sky survey will find the most interesting and high-value targets for NASA's slowly slewing premier telescope of the 2020's.
- ***NEOSurveyor*** is a 50 cm space telescope with a single imaging instrument operating at ~35K in two wavelength ranges: 4 - 5 µm and 6 - 10 µm. *NeoCAM* will have a limiting sensitivity about 2 mags more sensitive than *SPHEREx* at 4-5 um. Therefore everything *SPHEREx* detects will be in the *NEOCam* survey, but not vice-versa, but *SPHEREx* will provide unique spectra for ~ 10^5 of *NEOCam's* 0.1 – 100 km radius targets, allowing detailed spectral characterization for future hazard and resource utilization applications.
- ***Dawn, Lucy, Psyche***: all require absolutely calibrated 1.0-3.5 um NIR reference spectrum of the mission targets. Ground based spectra cannot cover the entire wavelength range, especially in the 2.7 – 3.1 um water bands. Dawn ASSUMED that Vesta was a water-poor, rocky body with a simple spectrum, and used this as the reference calibration spectrum for Ceres. *SPHEREx* will provide this spectrum, for 16 Psyche and all of Lucy's Trojan targets, assuming they are not confused.

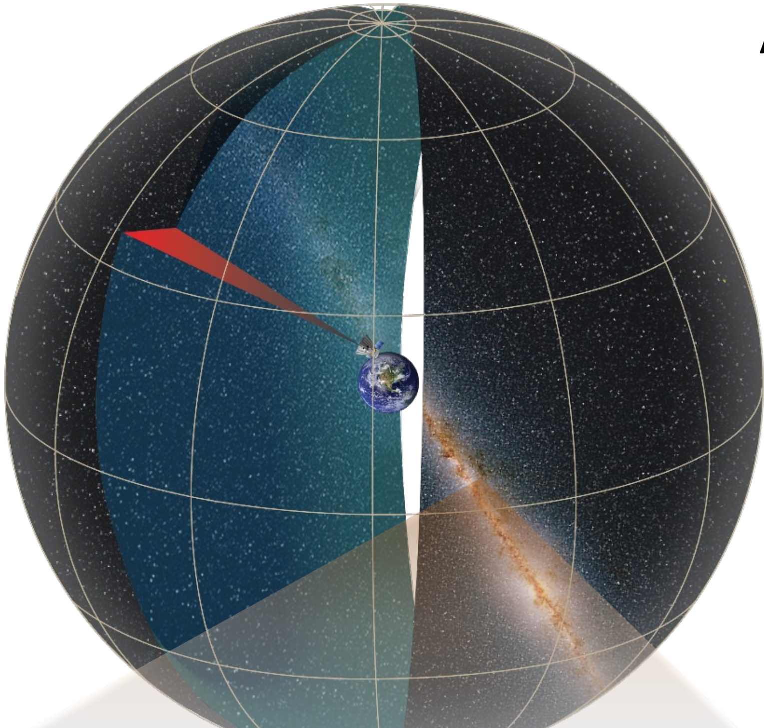
Sample SPHEREx Solar System Projects

- Spectral studies & lightcurves of the largest **KBOs** – e.g. the CO/CH_4 peaks of Pluto's lightcurve [K ~ 13], coordinated with the ice-rich Sputnik Plenum glacier
- Chemical abundances of **Comets** as tracers of the PPD. E.g CO_2 in Comets – the Fundamental Carbon Bearing Molecule in the PPD? And by extension in all molecular clouds and hot cores?
- Monitor world (**Planets + Giant Moons**) atmospheric weather: CH_4, H_2O clouds & hazes
- **Icy Moon** water, CO_2, CO, CH_4 trends w/time, parent body, r_h
- **Giant Planet** H_3^+ aurorae
- Spectral classification of the **Trojan Asteroids**
- Spectral survey of $>10^6$ of **Asteroids** – better reckoning of the origin and dynamical evolution of their types – formed in zones of the PPD then scattered E.g: Hydrated minerals vs Ammoniated Phyllosilicates from the Outer Solar System on Ceres
- Solar System Wide Survey of **Astrobiologically Important Molecules** H_2O, CO, CO_2, CH_4, C_2H_6, CN, CH_3OH, H_2CO, NH_3, PAHs
- **Follow the Wat**er throughout the Solar System:

  Search for episodic water emission from Ceres, Europa

  Study water temporal, spatial patterns on the Moon – implantation followed by sublimation under daylight?
- **Zodiacal (Debris) Cloud** Mapping vs Time, Compositional Measurement
- **Hβ, Paschen α, Brackett** $\alpha/\beta/\gamma$ Hydrogen Line solar system object albedos

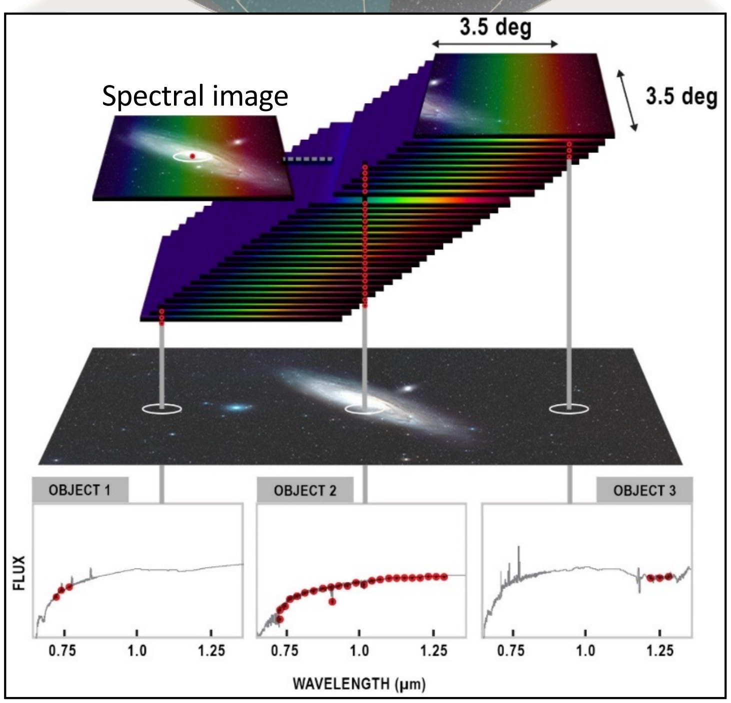
Ivezic+ 2022, Icarus 371:114696 - Estimated SPHEREx All-Sky Survey Planetary Science Return



Predicted counts of asteroids with SPHEREx spectra.[a]

Population	r (AU)	$D_{1\sigma}$	p_V	$H_{1\sigma}$	N(5σ)	N(2.5σ)	N(1σ)	N(0.5σ)
S MBA	2.4	2.1	0.25	15.5	4,288	10,887	33,440	69,293
C MBA	3.2	8.0	0.06	14.1	489	1,328	4,739	11,526
red TR5	5.2	9.2	0.05	14.0	784	1,678	4,623	9,885
less-red TR5	5.2	10.8	0.05	13.7	186	397	1,095	2,341
TNO	40	557	0.05	5.1	17	52	222	661
Total counts					5,764	14,343	44,120	93,706

[a]Table lists cumulative counts of dominant asteroid populations for three values of the single-spectrum signal-to-noise ratio at 2.4 μm: 5σ limit defines the highest-quality spectral sample, 1σ limit will enable "photometric" studies by binning in wavelength direction, and 2.5σ and 0.5σ limits assume that such studies can be extended deeper by co-adding four spectra obtained at different epochs. For a chosen heliocentric distance, the limiting size $D_{1\sigma}$ is obtained using simulated SPHEREx spectra, and then used with the visual albedo, p_V, to estimate absolute magnitude H, and finally corresponding cumulative counts, as described in text.



Rotational Correction & Spectral Typing

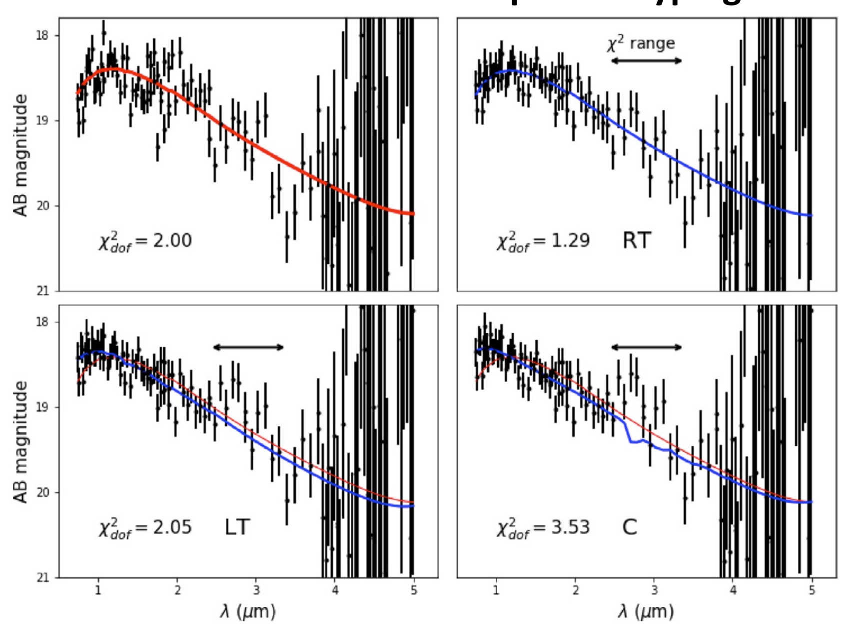
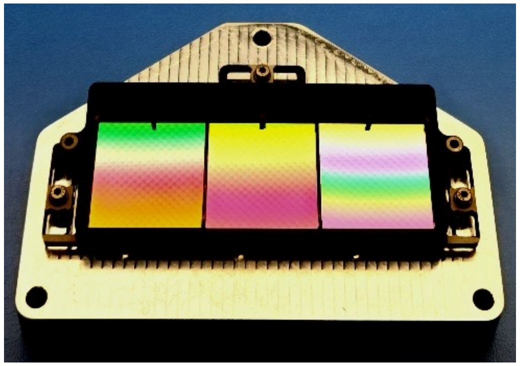
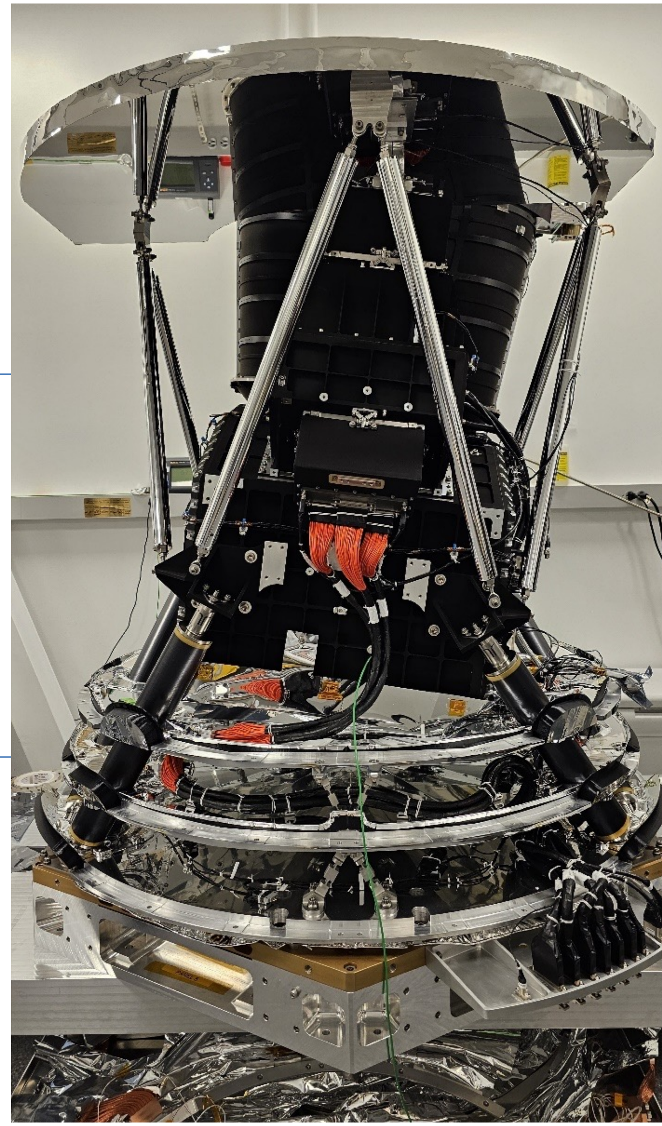
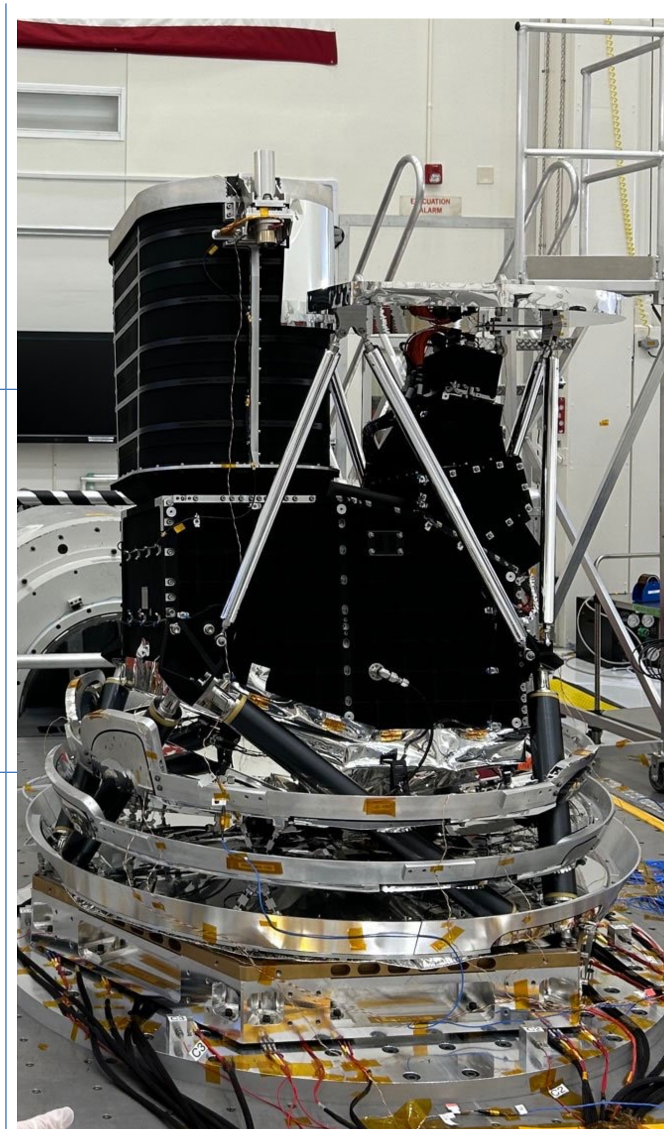


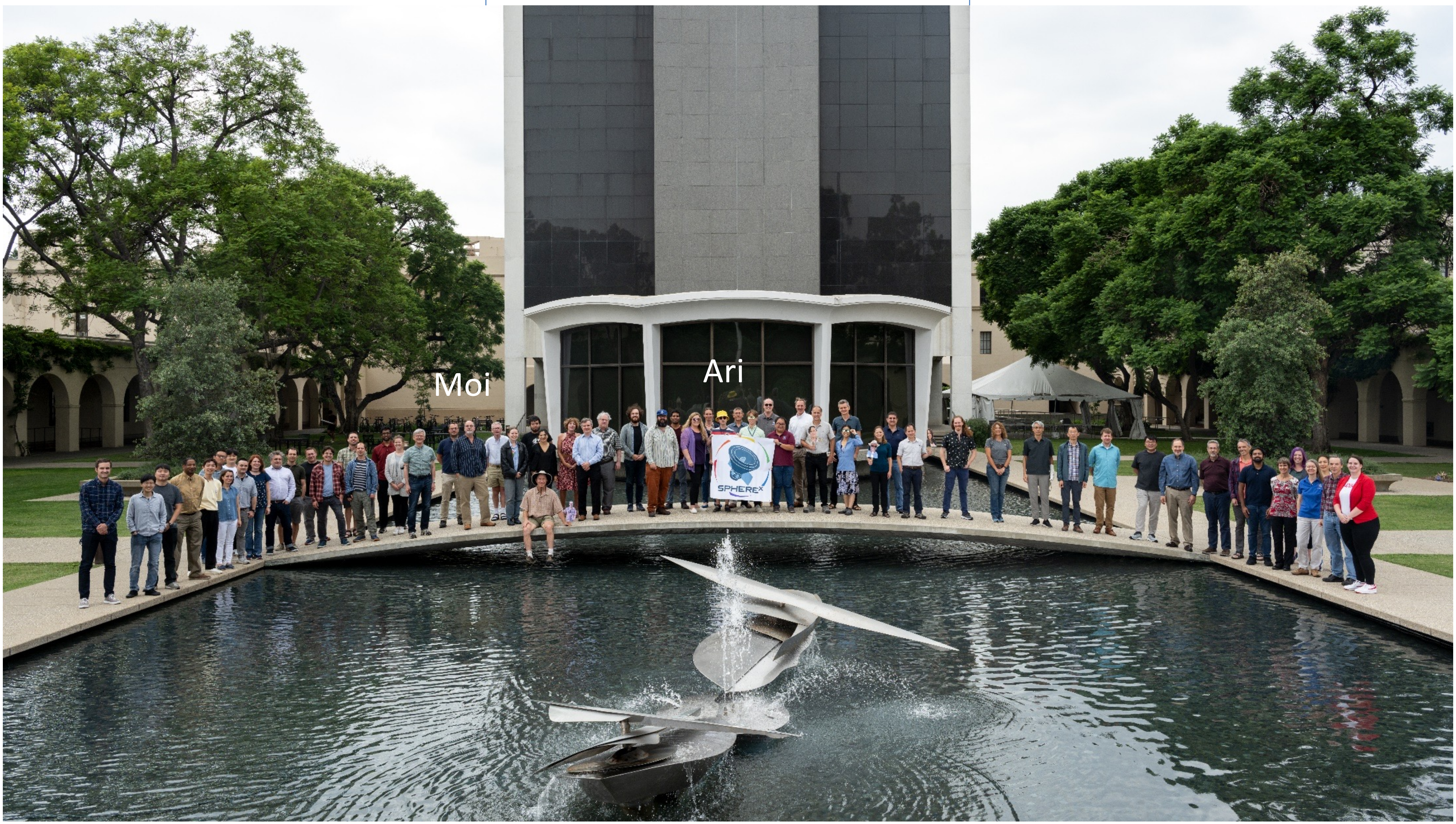
Fig. 14. Illustration of the correction algorithm for rotationally induced variability for Jovian Trojan asteroid (1143) Odysseus. Analogous to Fig. 12. Odysseus is at 5.2 a.u. and assumed to have a diameter of 20 km and "red" taxonomic type. The chosen size yields a signal-to-noise ratio at 2.4 μm of about 5. The templates are marked as RT ("red"), LT ("less red") and C (carbonaceous).

PHASE C Latest Developments
(Phase D to Start Mar 2024)

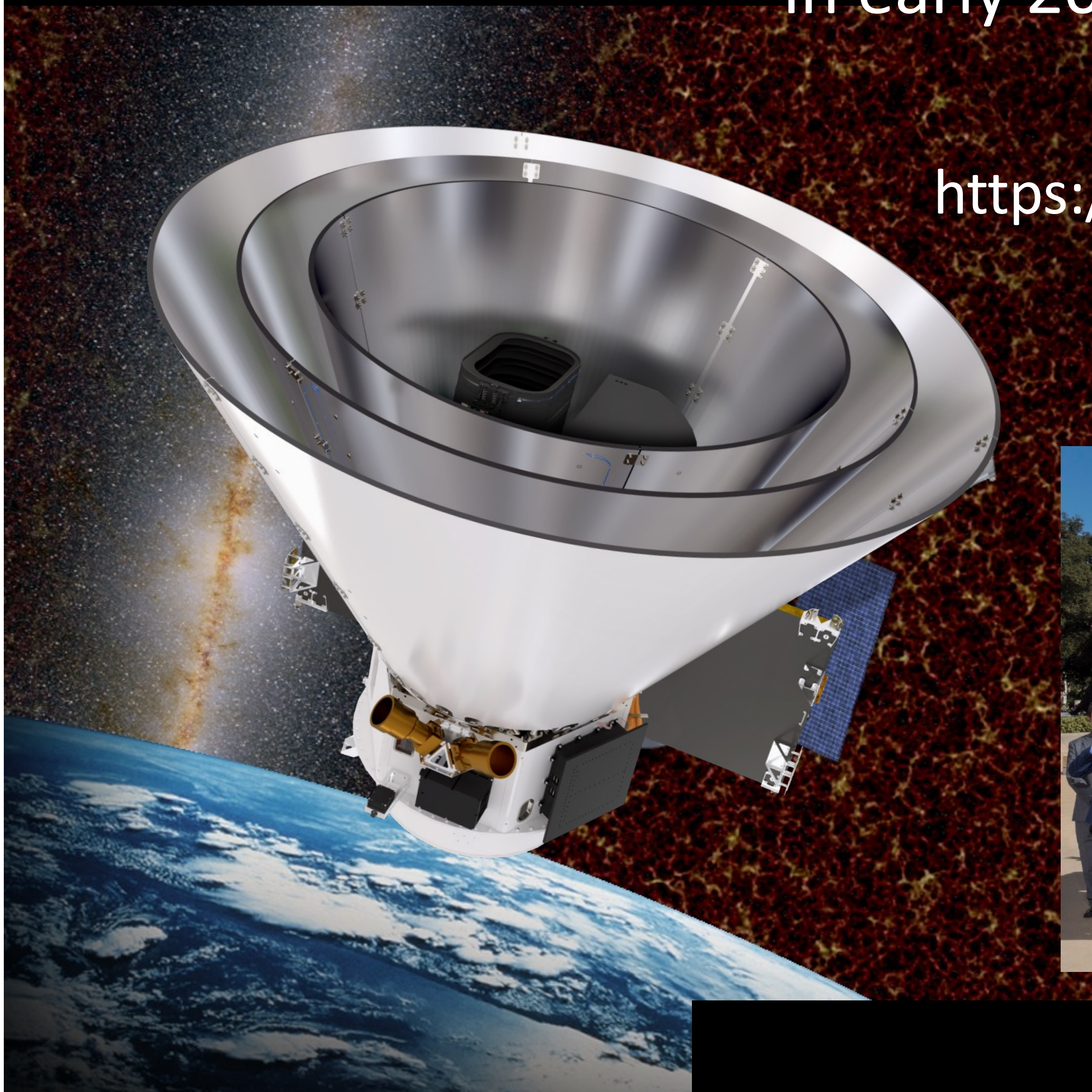


Team Photo, Caltech, Sept 2023



Looking forward to our Falcon 9 launch in early 2025!



https://spherex.caltech.edu

JPL Jet Propulsion Laboratory California Institute of Technology
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ASU
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JOHNS HOPKINS UNIVERSITY
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Argonne NATIONAL LABORATORY