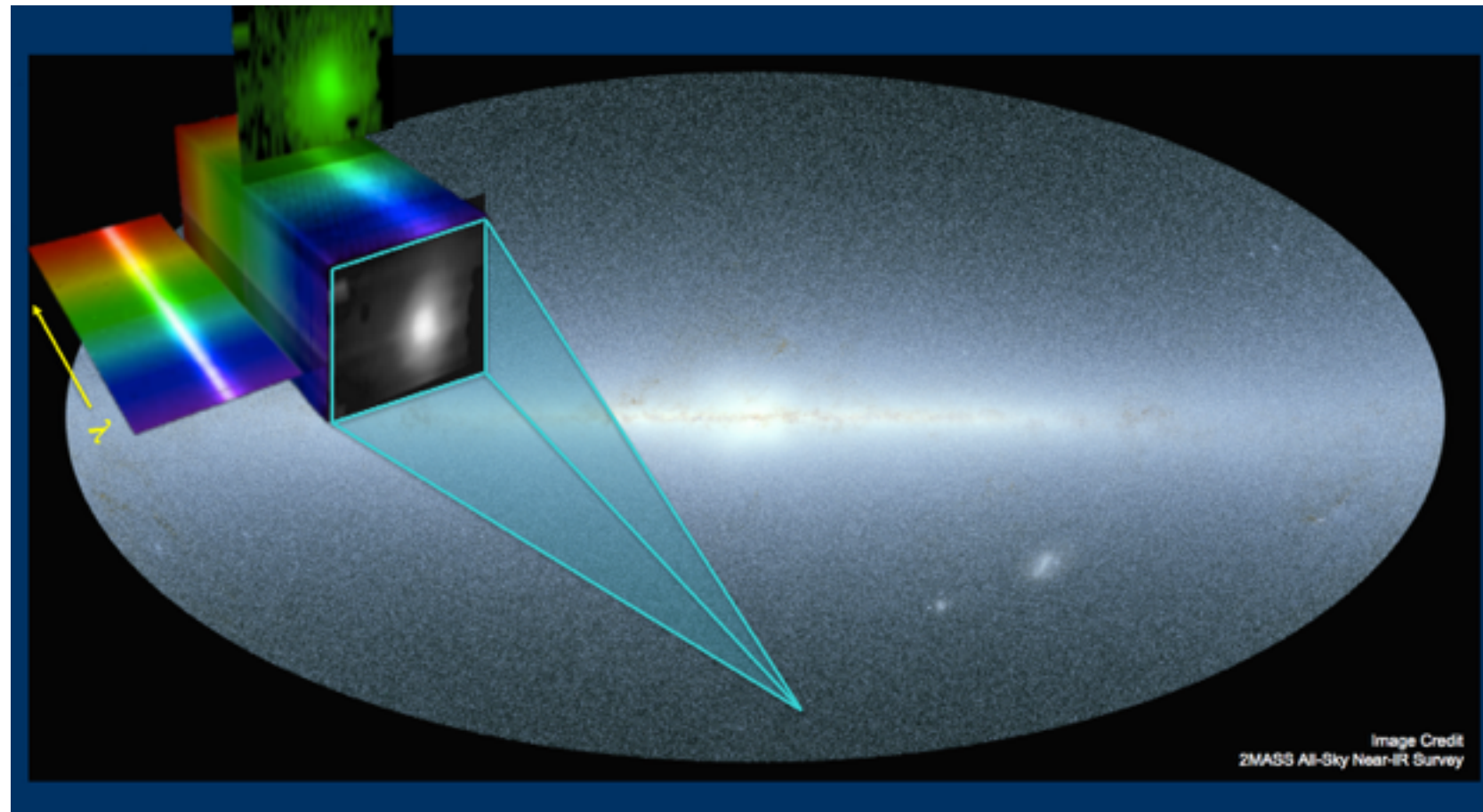


Optical/IR RM of QSOs with SPHEREx



Minjin Kim

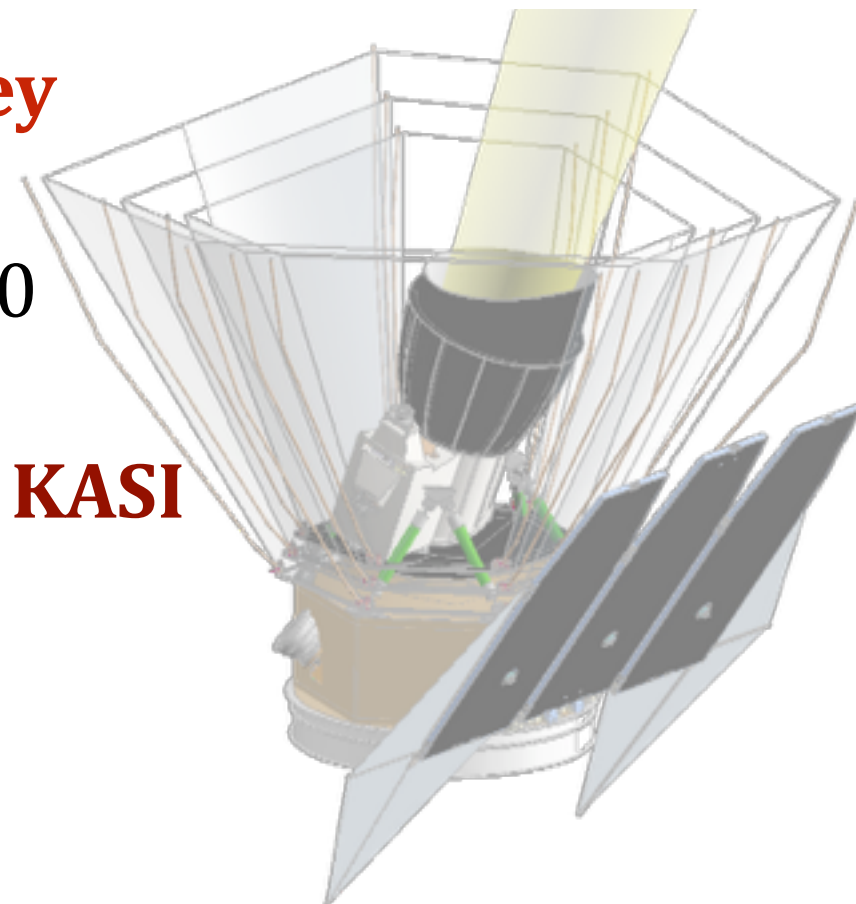
Woong-Seob Jeong, KASI SPHEREx team
[Korea Astronomy and Space Science Institute (KASI)]

Outline

- SPHEREx space mission
- Planned RM project with SPHEREx

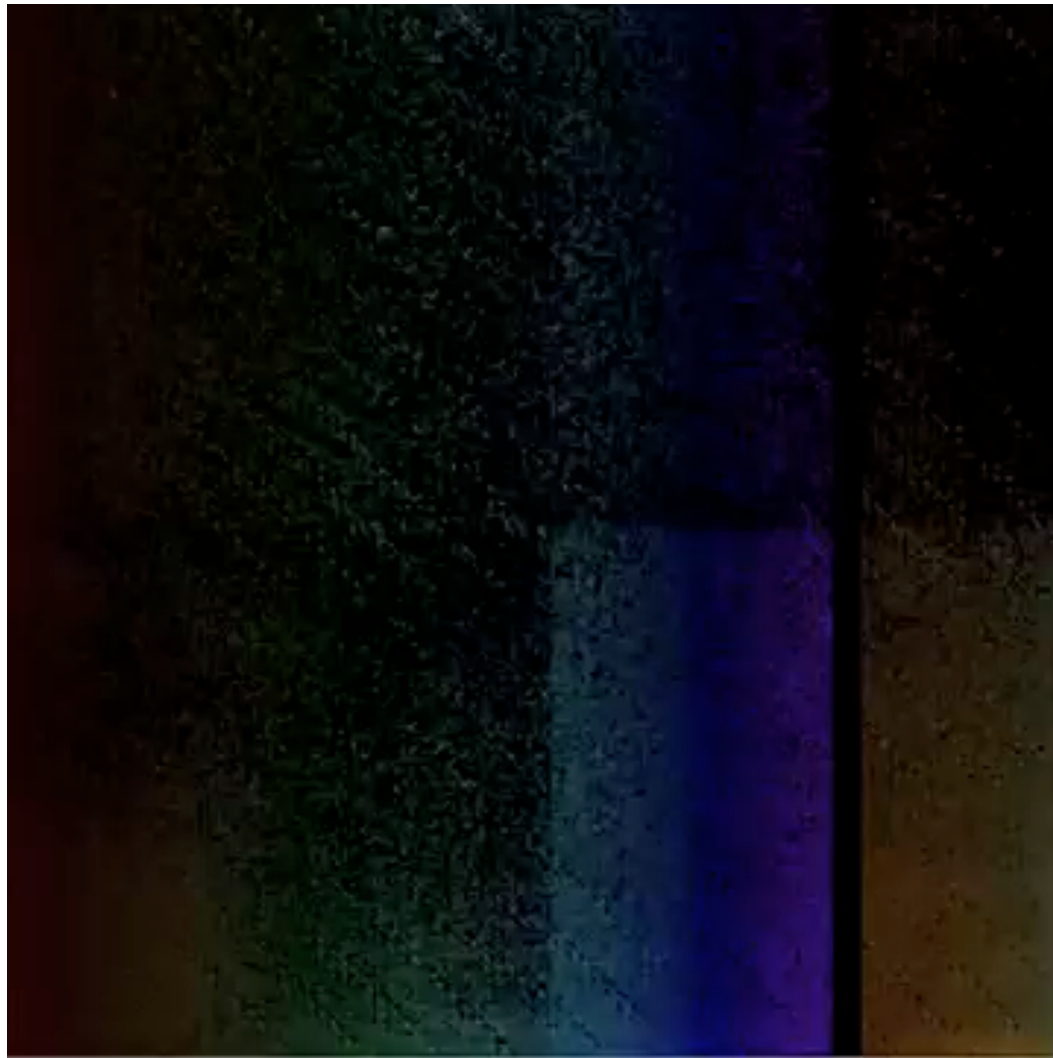
Overview of SPHEREx

- Spectro-**PH**otometer for the **E**xtragalactic structure,
Reionization and ices **E**xplorer
- SMEX mission in **Phase A** (Final selection in Jan. 2017.)
- **The first all-sky optical/NIR spectral survey**
- Wide spectral coverage : **0.75-5um, R~40/150**
- Led by JPL (PI: Jamie Bock) : 7 US institutes + **KASI**
- Science operation : 2020-2023



How it works?

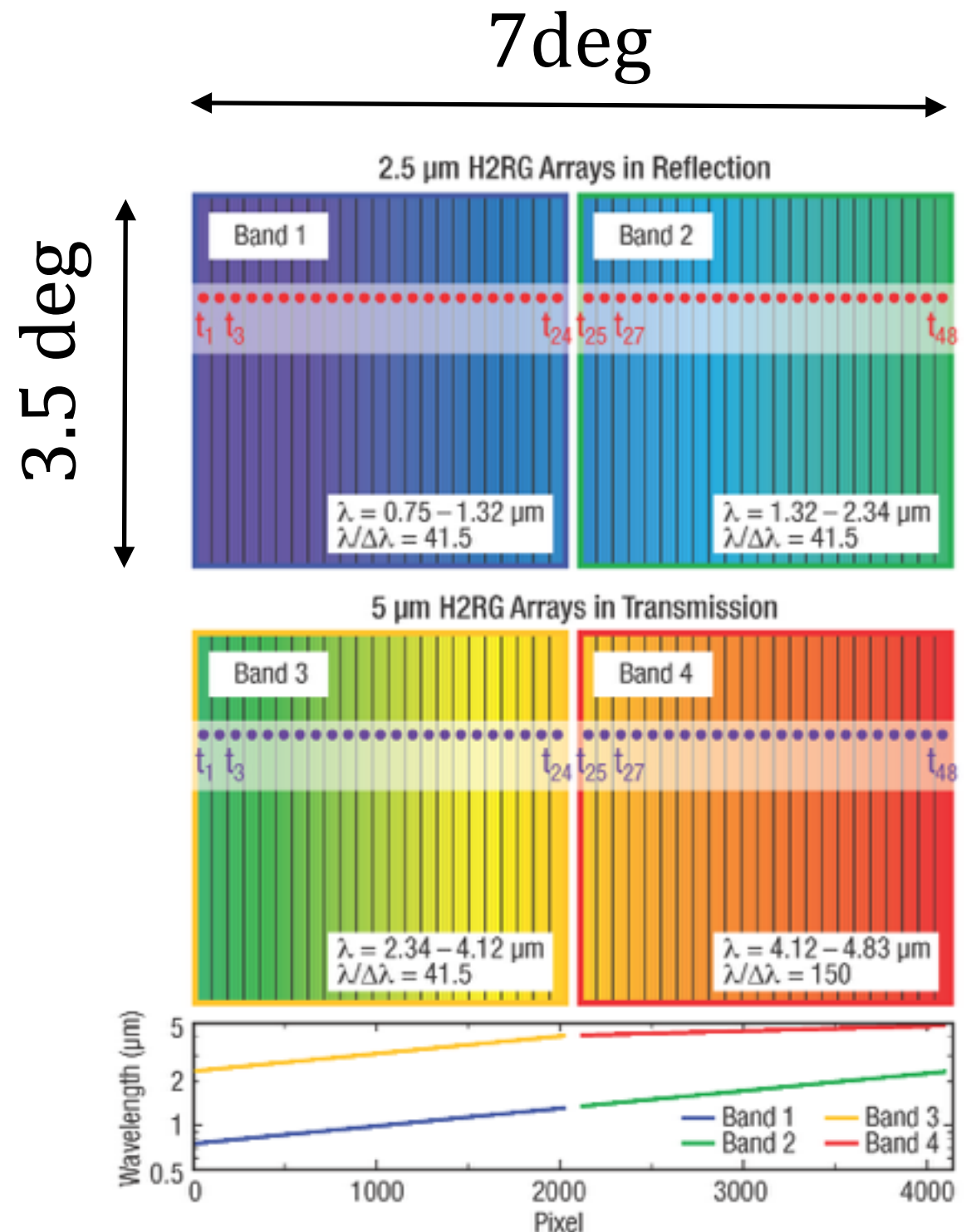
Linear Variable Filter (LVF)



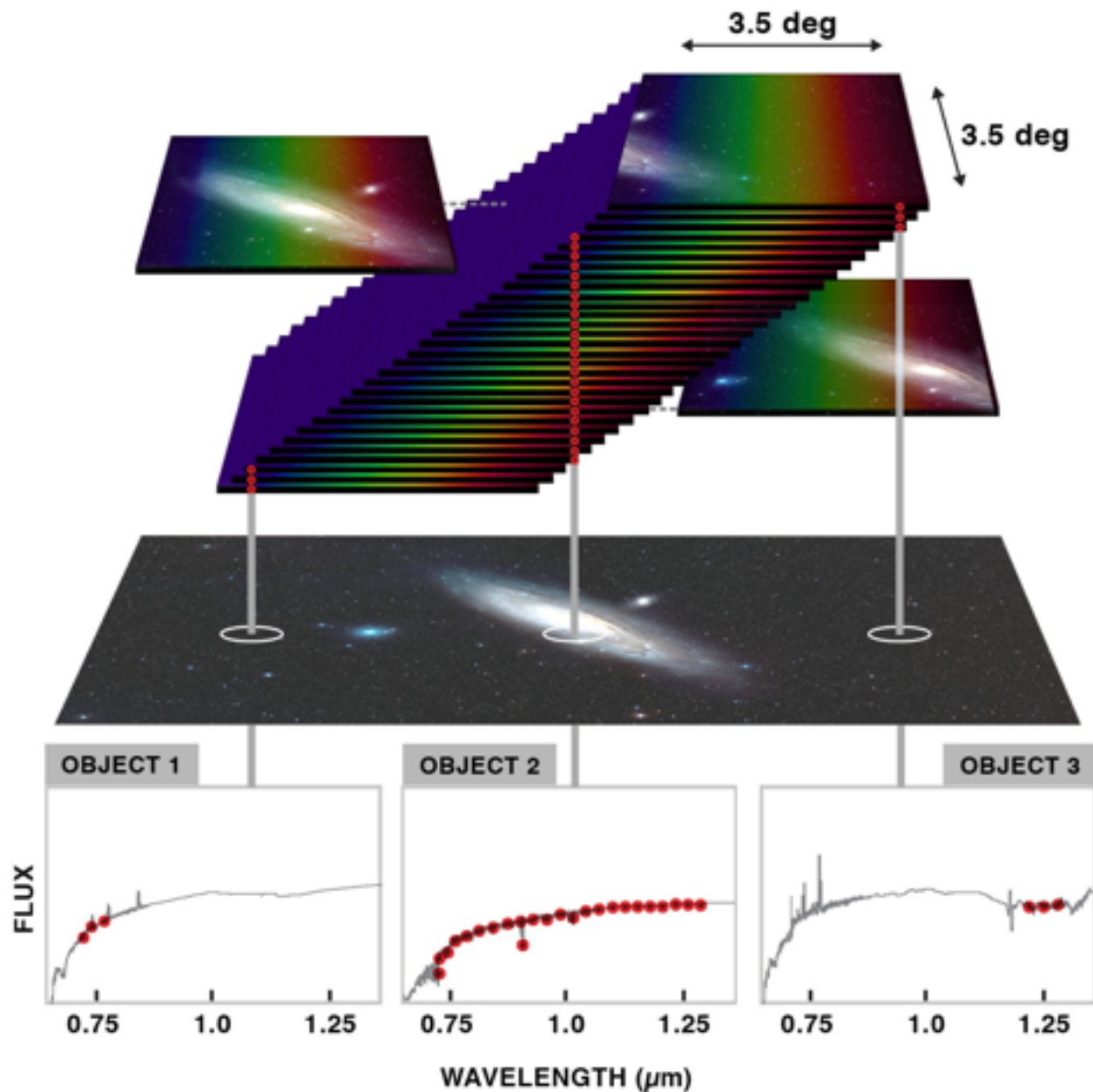
Wavelength



Pluto from New Horizons

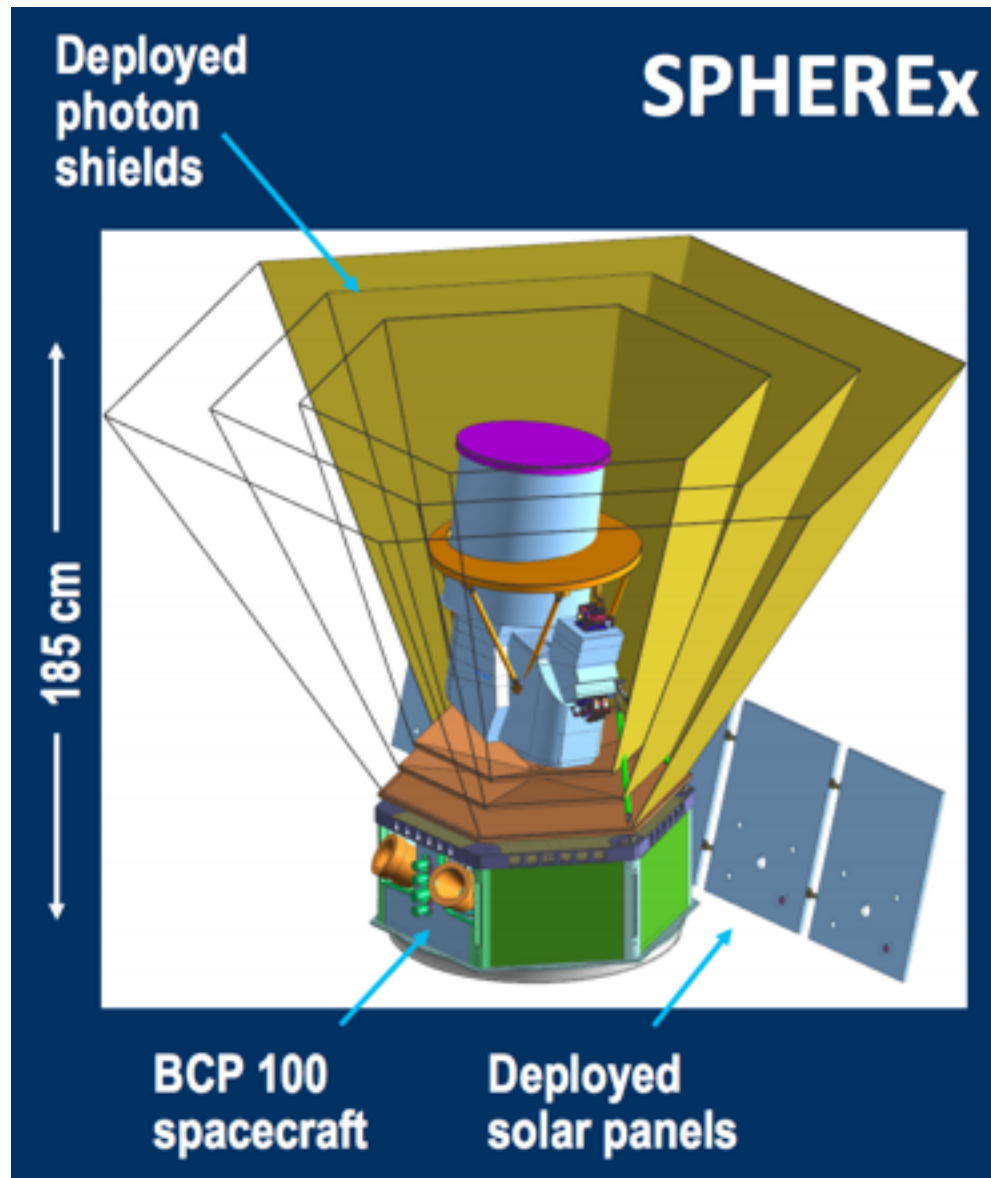


How it works?



- 24 multiple scan images
-> full spectrum
- Imaging spectroscopy

SPHEREx hardware

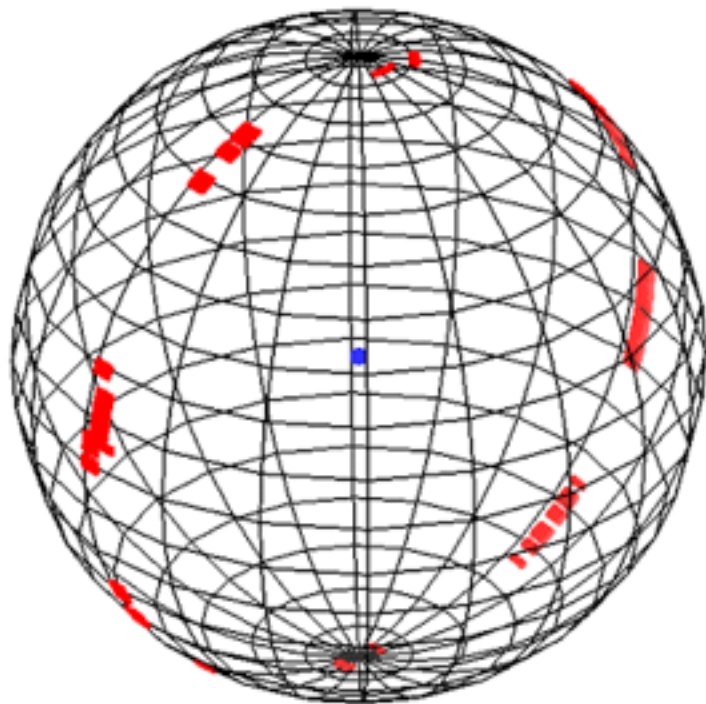


Parameter	Required Value	Capability Value
Telescope aperture	20 cm	
Focal ratio	3	
Band 1	0.75 – 1.25 μm ; $\lambda/\Delta\lambda = 40$; H2RG-2.5 μm	
Band 2	1.25 – 2.10 μm ; $\lambda/\Delta\lambda = 40$; H2RG-2.5 μm	
Band 3	2.10 – 3.50 μm ; $\lambda/\Delta\lambda = 40$; H2RG-5 μm	
Band 4	2.60 – 5.00 μm ; $\lambda/\Delta\lambda = 150$; H2RG-5 μm	
Total FOV	3.5 deg x 7 deg	
Pixel size	6" x 6" ~PSF size	
Optics temperature	80 K	
5 μm array temperature	50 K	
Total efficiency	30 %	50 %
Pointing jitter (1σ , 200 s)	3"	1.5"
Large (70°) slew time	150 s	90 s
Small (10') slew time	20 s	10 s
Read noise CDS	18/15 e^-	10.5 e^-

Survey strategy

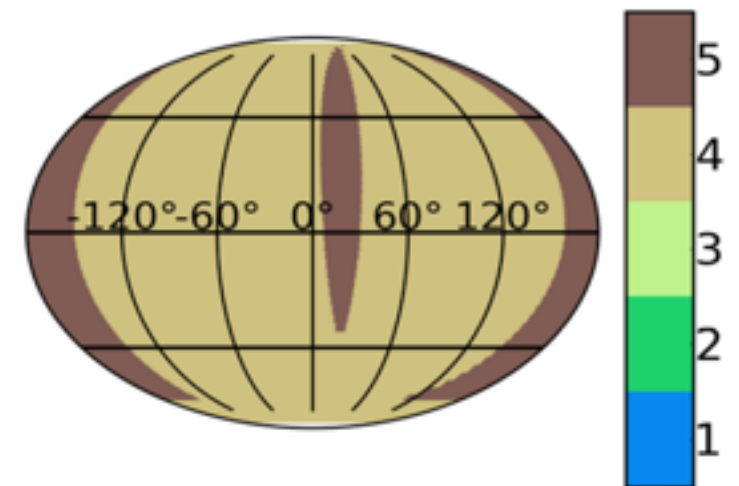
survey baseline is 2 yrs

day=1

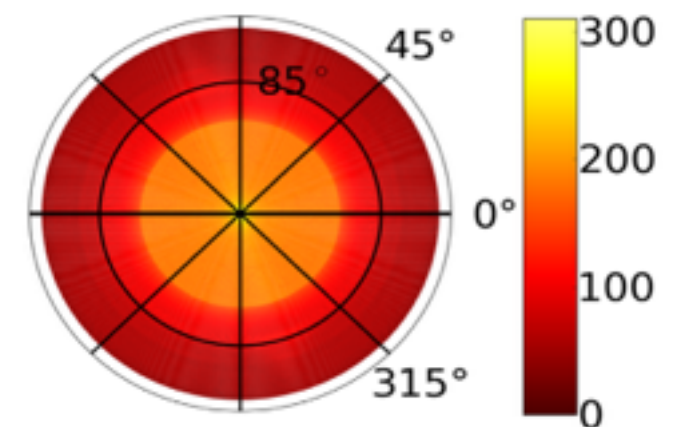


whole sky in 6 months

All-Sky Coverage for 2 years

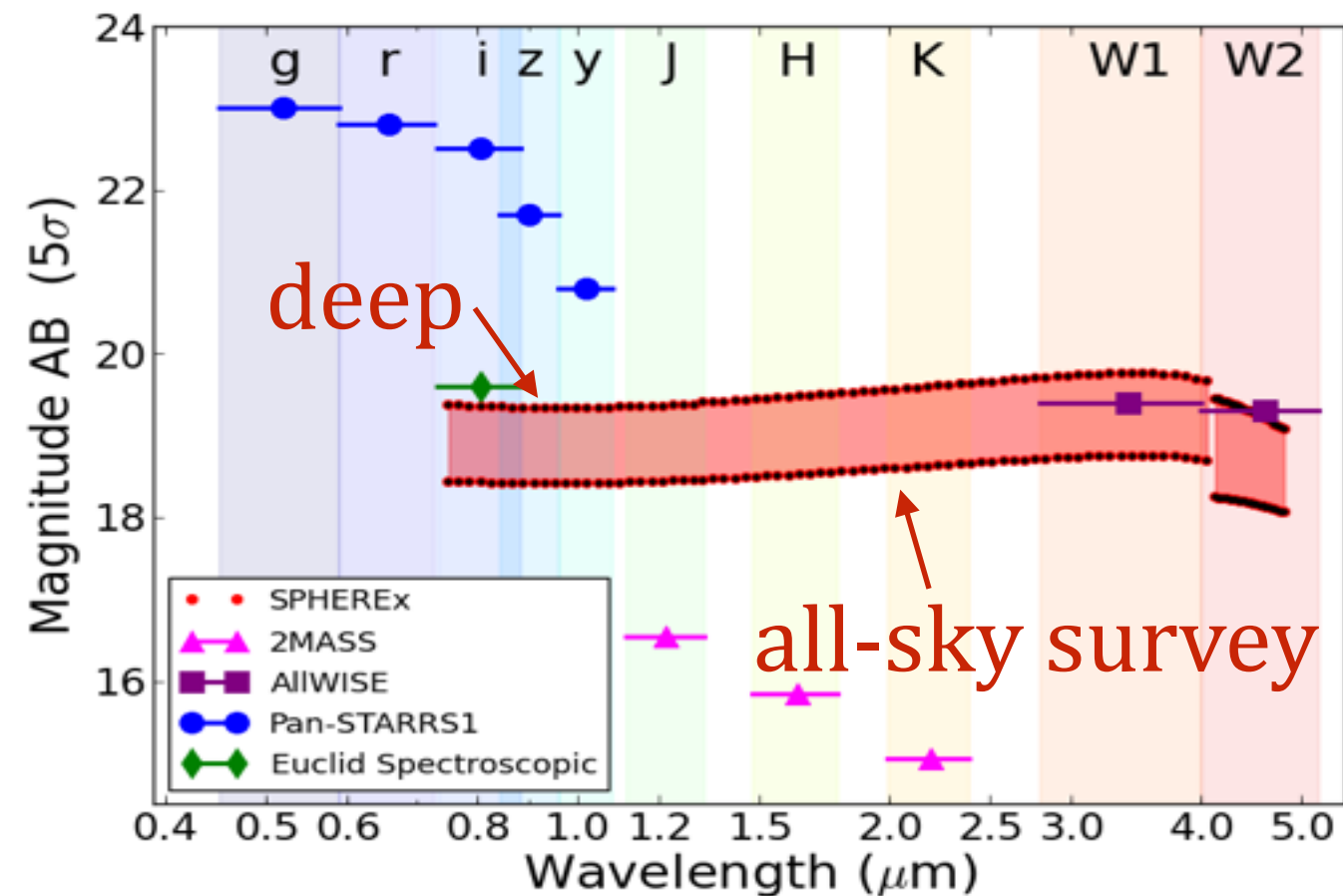


Deep Surveys at Poles



Survey Depth

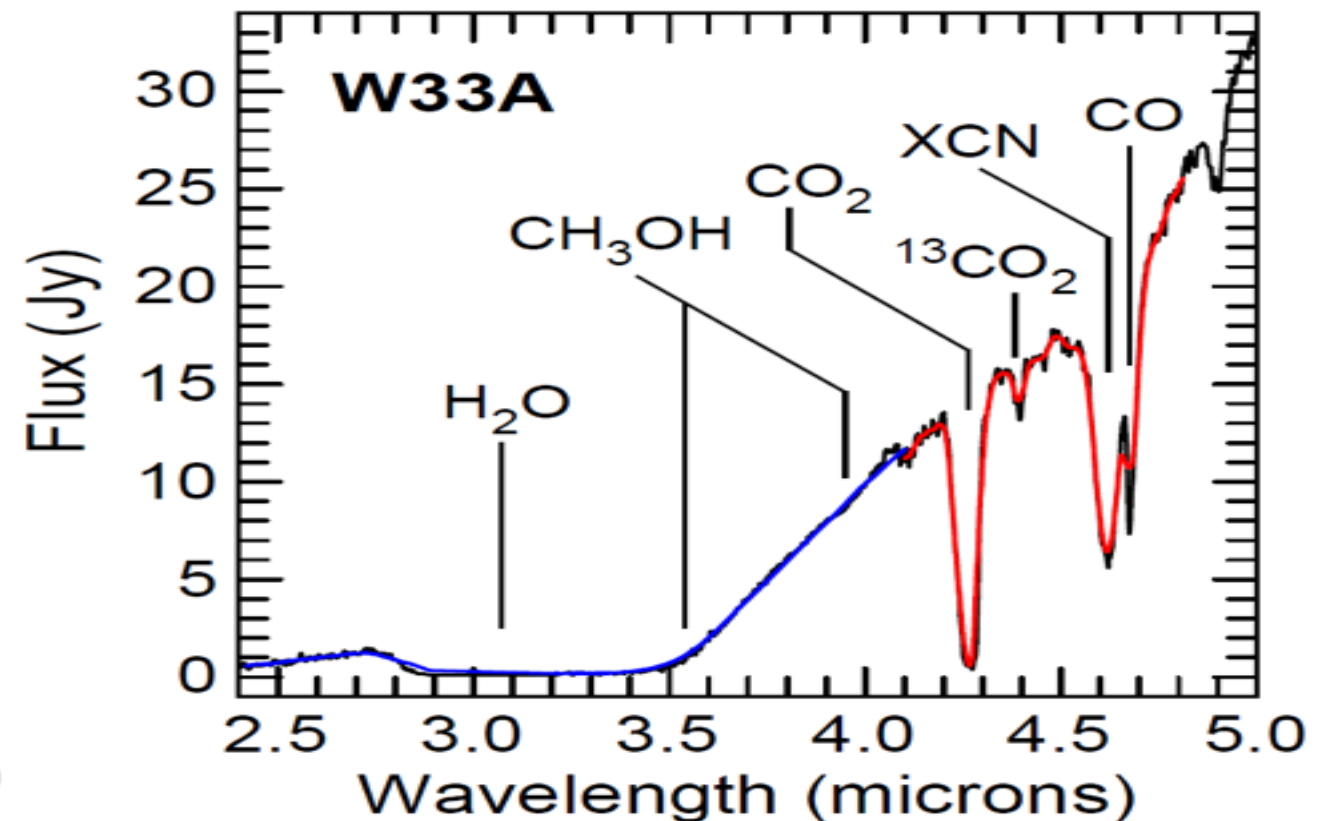
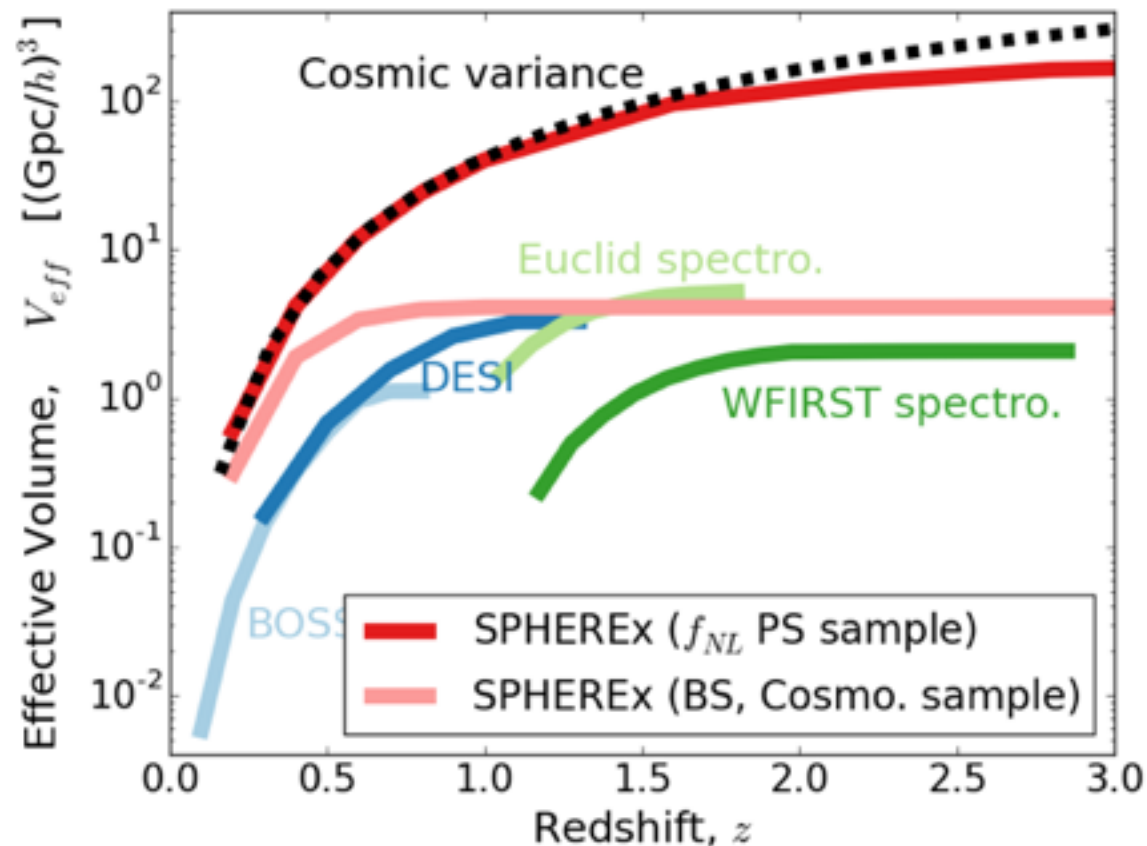
- Depth : 18-19 mag; Comparable to WISE
- Spectral data : better constraint on the redshift



All Sky-Survey	
Extragalactic	10^8 Galaxies
	10^7 Galaxies $dz < 0.3\%$
	2×10^6 QSOs with redshift
	Up to 100 QSOs at $z > 6$
	35,000 Galaxy Clusters
Galactic	10^7 stellar spectrum
	$> 10^6$ embedded stars
	> 2000 brown dwarfs

Main Science Topics

1. The Origin of the Universe (large scale structure)
2. The Origin and History of Galaxies (cosmic SF history)
3. The Origin of Water (Ices) in Planetary Systems



KASI's contribution

1. Hardware for electronics : Test of 4 H2RG detectors & screening
2. Hardware for optics : Baffle tube structure for wide-field telescope
3. Optical Filters : 4 Linear Variable Filters, Dichroic filters
4. Ground support equipment for characterizing the instrument : cryo. Chamber, integrating sphere, ground station electronics
5. **Pipeline development** and Science Operation

Other Science impacts!

- Two white papers are posted in Astro-ph.

Science Impacts of the SPHEREx All-Sky Optical to Near-Infrared Spectral Survey: Report of a Community Workshop Examining Extragalactic, Galactic, Stellar and Planetary Science

Olivier Doré, Michael W. Werner, Matt Ashby, Pancha Banerjee, Nick Battaglia, James Bauer, Robert A. Benjamin, Lindsey E. Bleem, Jamie Bock, Adwin Boogert, Philip Bull, Peter Capak, Tzu-Ching Chang, Jean Chiar, Seth H. Cohen, Asantha Cooray, Brendan Crill, Michael Cushing, Roland de Putter, Simon P. Driver, Tim Eifler, Chang Feng, Simone Ferraro, Douglas Finkbeiner, B. Scott Gaudi, Tom Greene, Lynne Hillenbrand, Peter A. Höflich, Eric Hsiao, Kevin Huffenberger, Rolf A. Jansen, Woong-Seob Jeong, Bhavin Joshi, Duho Kim, Minjin Kim, J. Davy Kirkpatrick, Phil Korngut, Elisabeth Krause, Mariska Kriek, Boris Leistedt, Aigen Li, Carey M. Lisse, Phil Mauskopf, Matt Mechtley, Gary Melnick, Joseph Mohr, Jeremiah Murphy, Abraham Neben, David Neufeld, Hien Nguyen, Elena Pierpaoli, Jeonghyun Pyo, et al. (16 additional authors not shown)

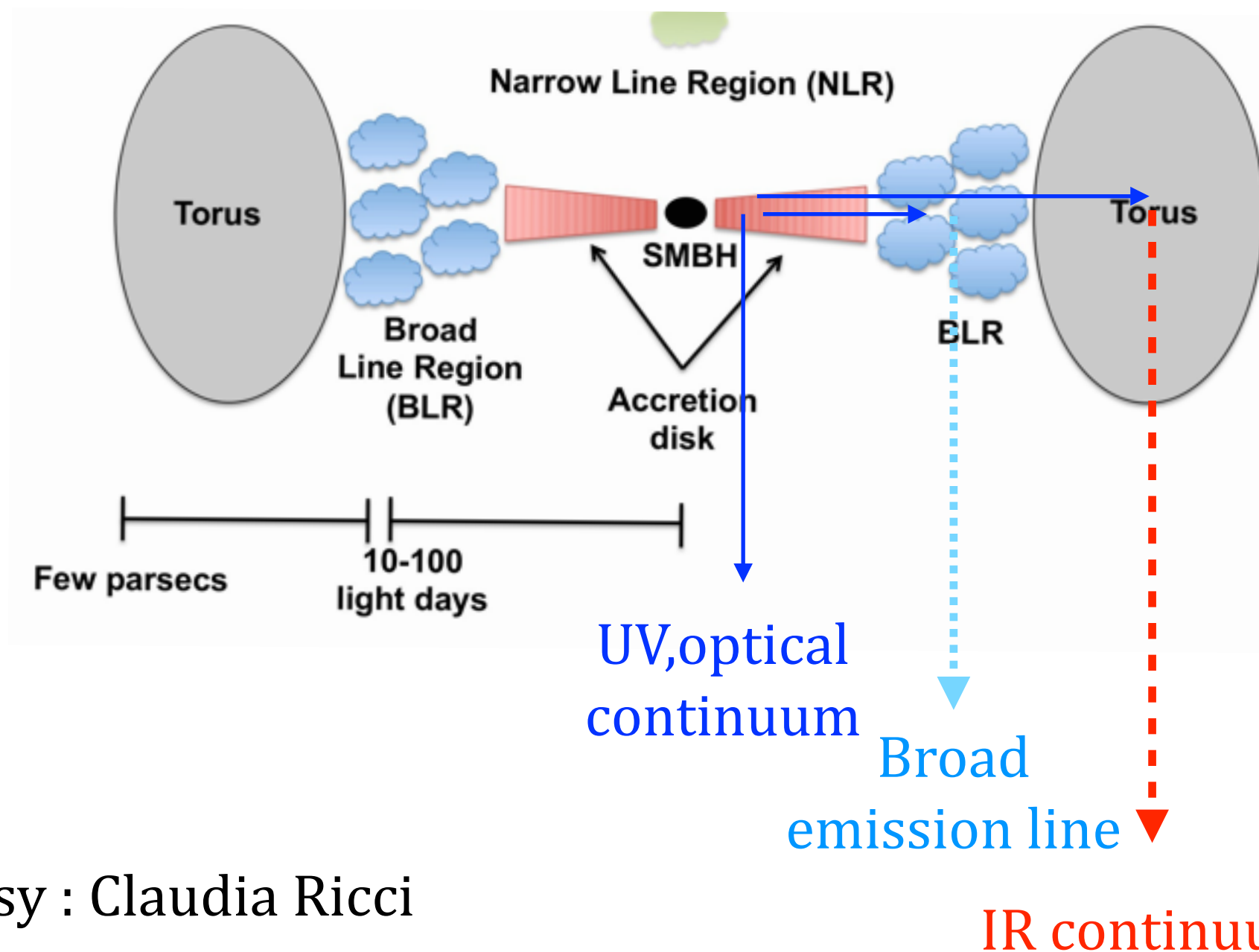


AGN science with SPHEREx

- **Central structure of AGNs**
 - **Optical/IR reverberation mapping**
- AGN unification
 - Demography of Type 2 Quasars
- BH-host coevolution
 - SFR in AGNs
- And much more!!! (Synergies with other surveys; e.g., eRosita, LSST, EUCLID, WFIRST etc.)

Optical/IR reverberation

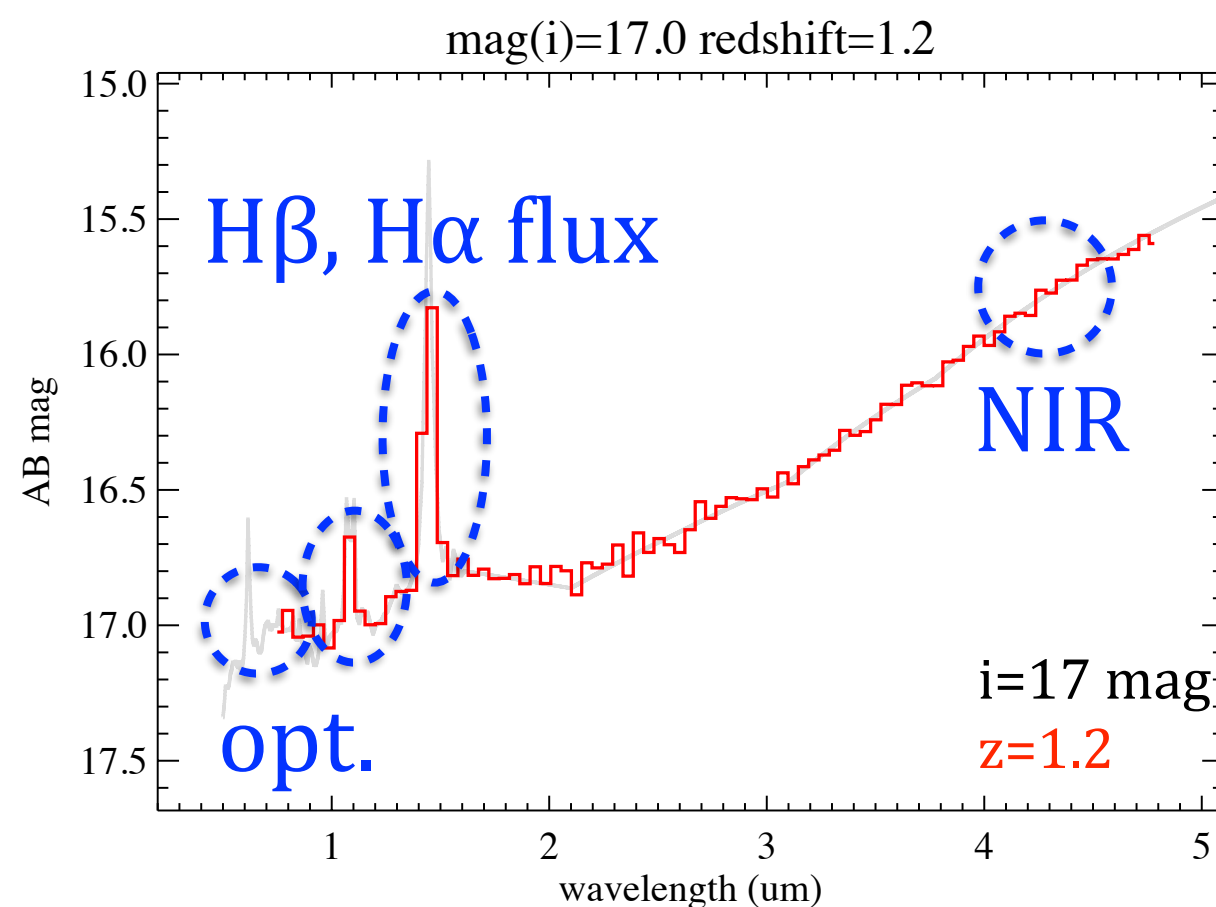
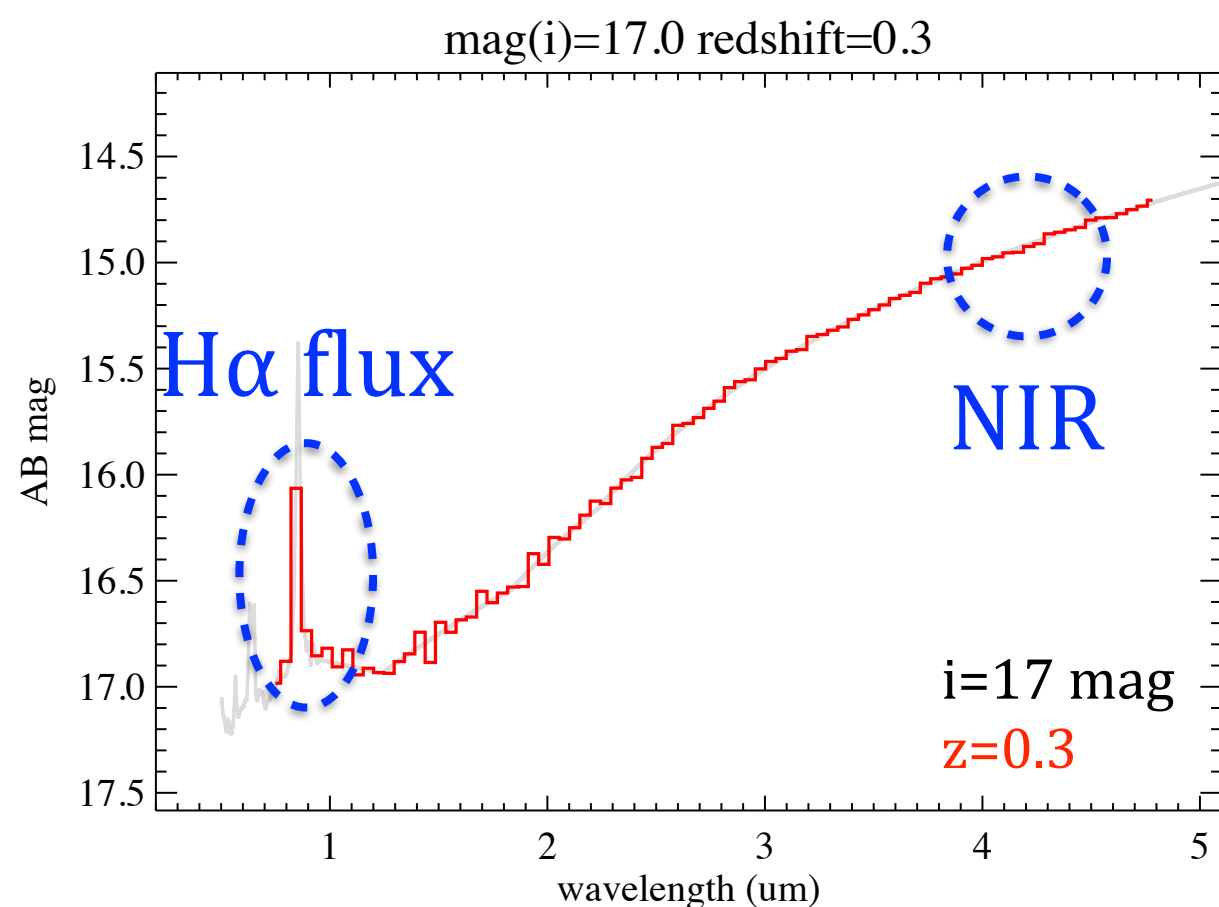
Time lags among UV (optical), broad lines, IR
-> size of BLR and TORUS



Courtesy : Claudia Ricci

QSO Spectrum from SPHEREx

- line flux + NIR continuum (Opt. continuum)
(no atmospheric extinction, slit loss, etc.)



Original spectra from Shang et al. 2011

Optical/IR reverberation

- SPHEREx data will uniquely provide
 1. **Simultaneous** variability measurement of broad emission lines ($H\alpha$ or $Pa\alpha$) and IR/opt continuum
-> structure of accretion disk, BLR and torus at the same time
 2. **Variability in IR color** ->
Torus structure : smooth vs. clumpy Torus

Optical/IR reverberation

- Requirements

(1) multi-epoch data (variability)

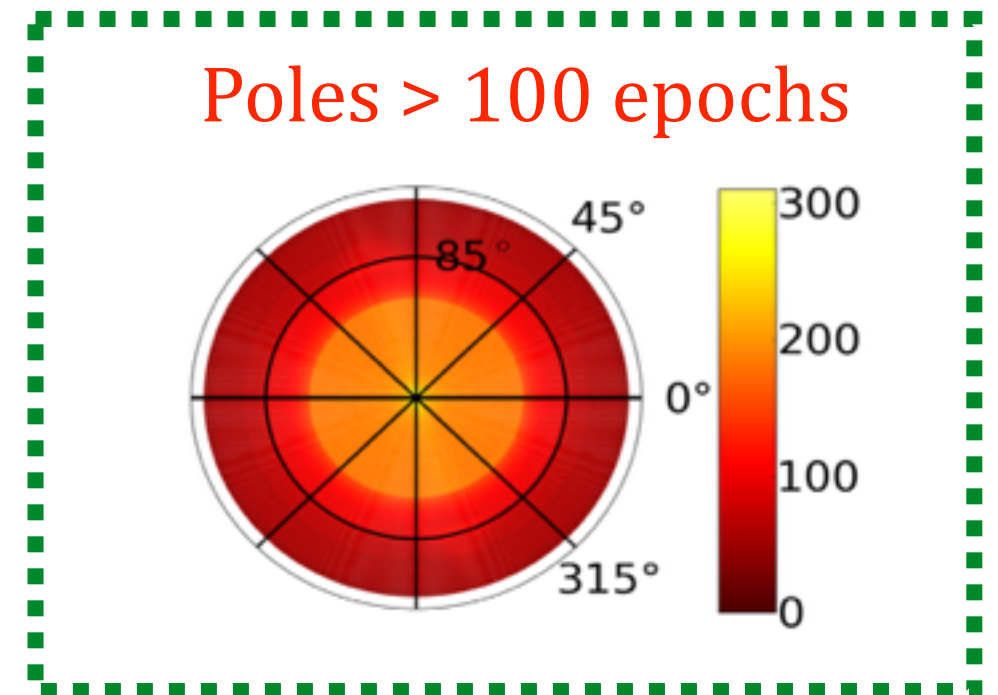
- data from each visit

(2) relatively high S/N data

-> Poles!

(3) missing dataset :

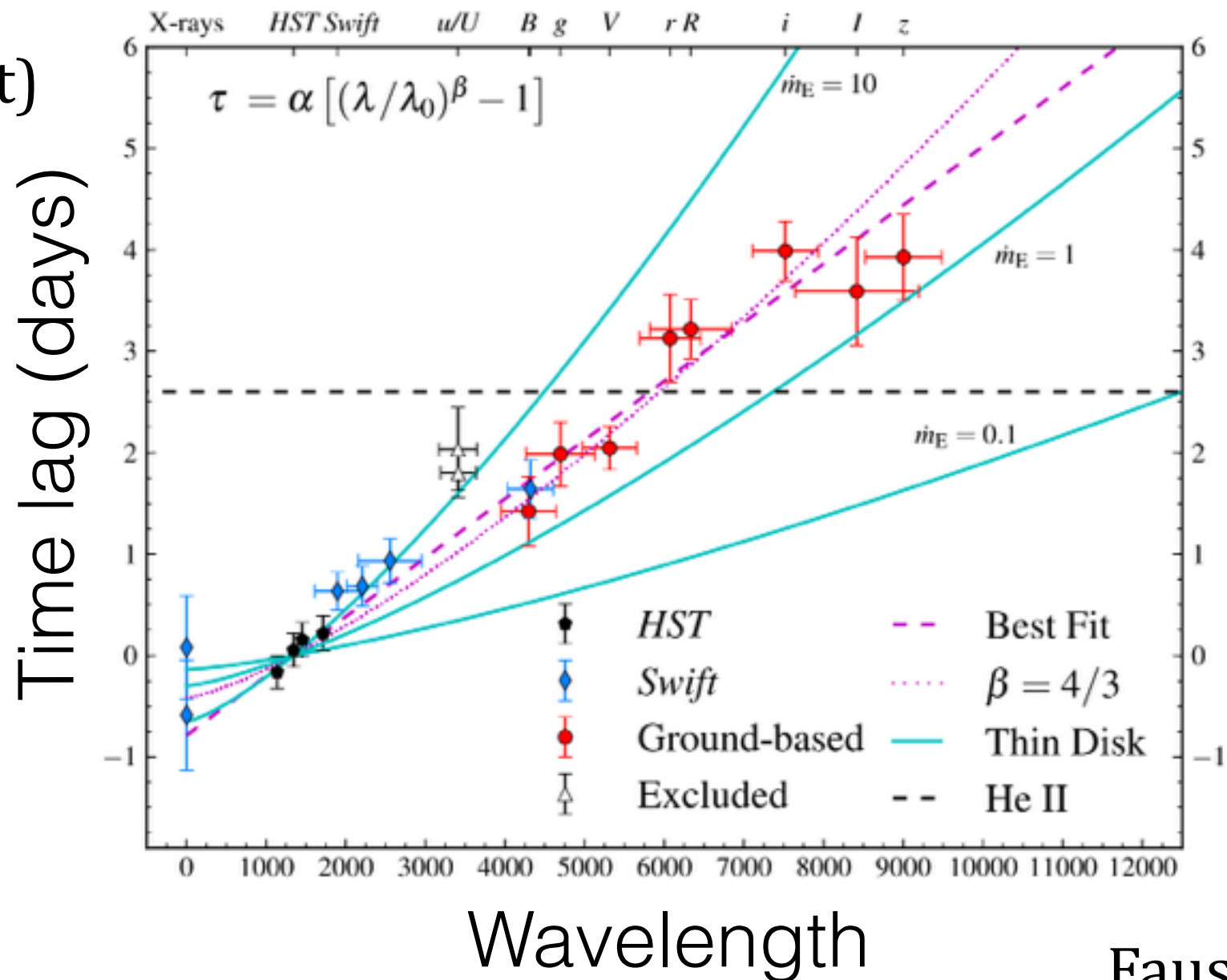
UV/optical photometry and (high R) spectroscopic data



(Additional) optical photometry

Time lags among the continuum bands
-> structure of the accretion disk

NGC5548
(STORM project)



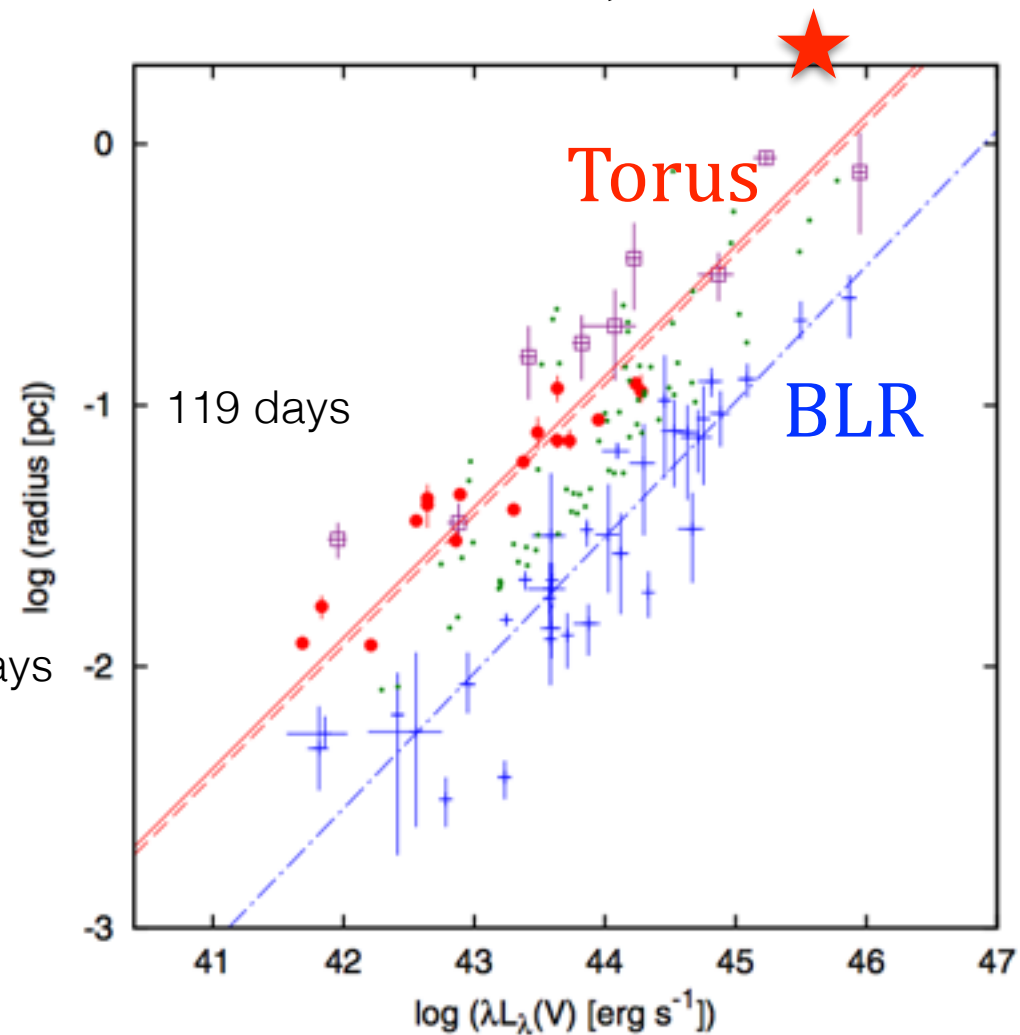
Complimentary dataset

1. UV/Optical multi-band photometric data : multi-epoch
 2. Spectral data (line width) : single-epoch (or multi-epoch)
- Synergy with other (Korean) facilities
 - Optical photometry : KMTNet, LOAO, LSG telescope, several 1m class telescopes in Korea
 - Optical Spectroscopy : MMT, Gemini (2-4m class telescope)

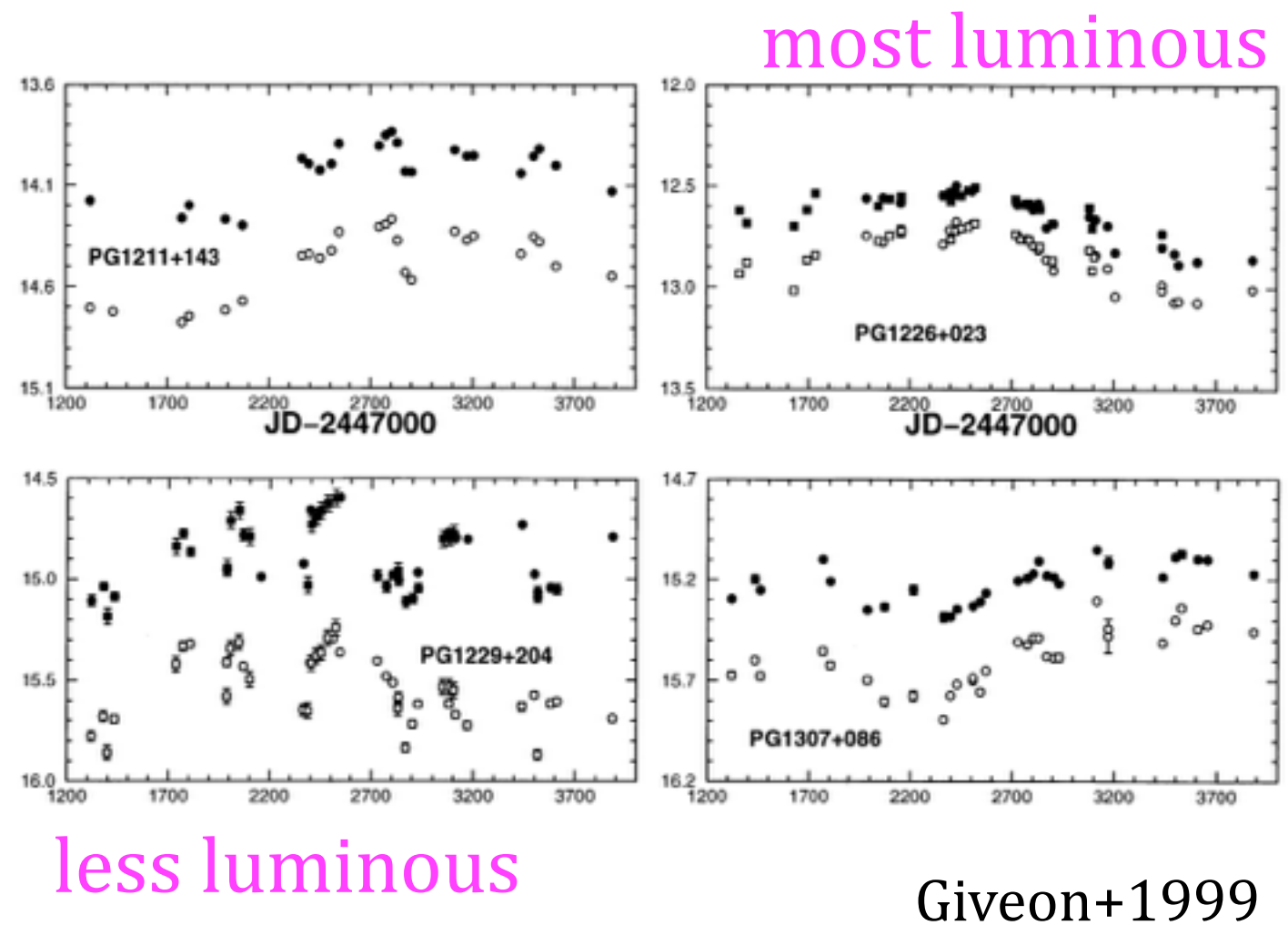
2 yrs of baseline is too short?

- But, relatively large time lags compared to survey baseline (2yrs)

Jun et al. 2015



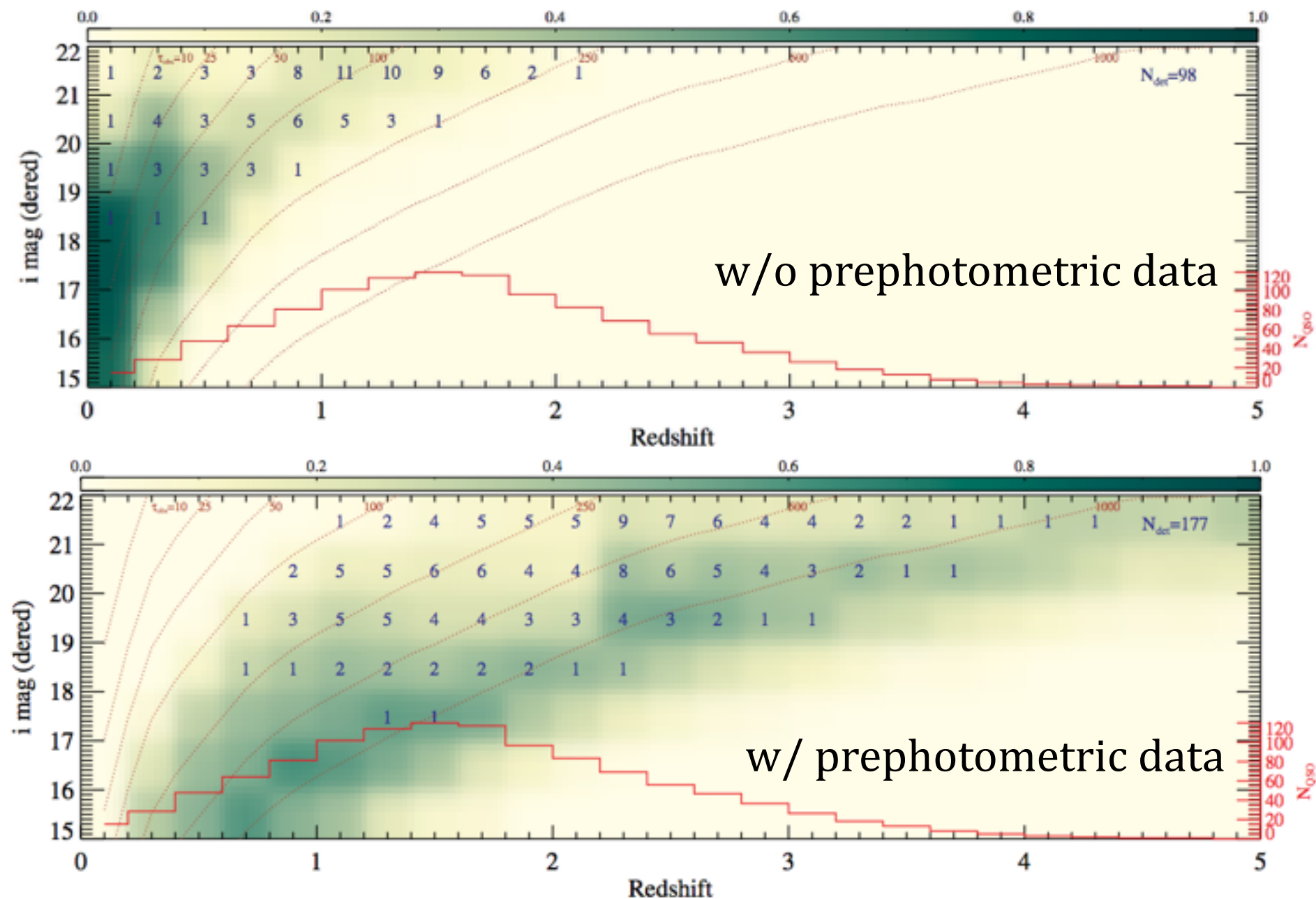
Koshida et al. 2014



Giveon+1999

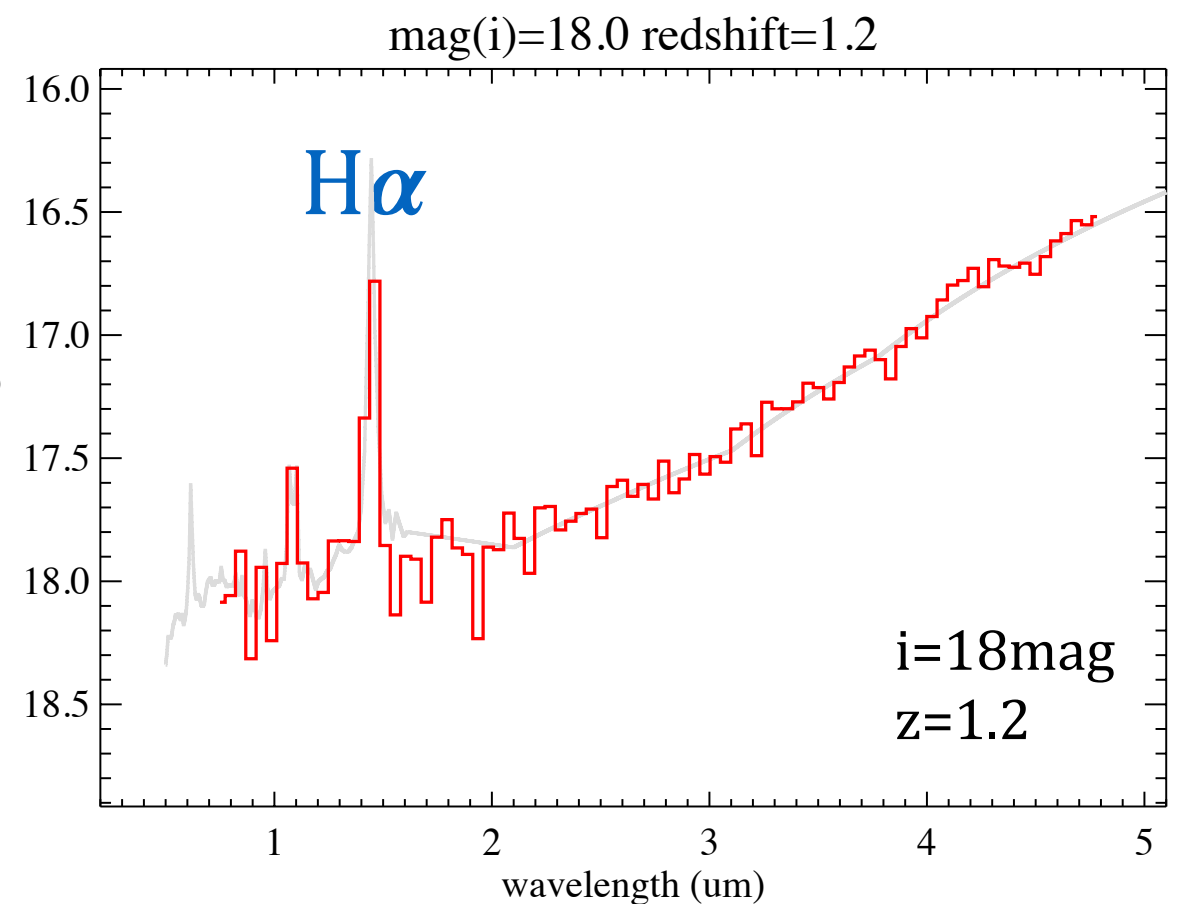
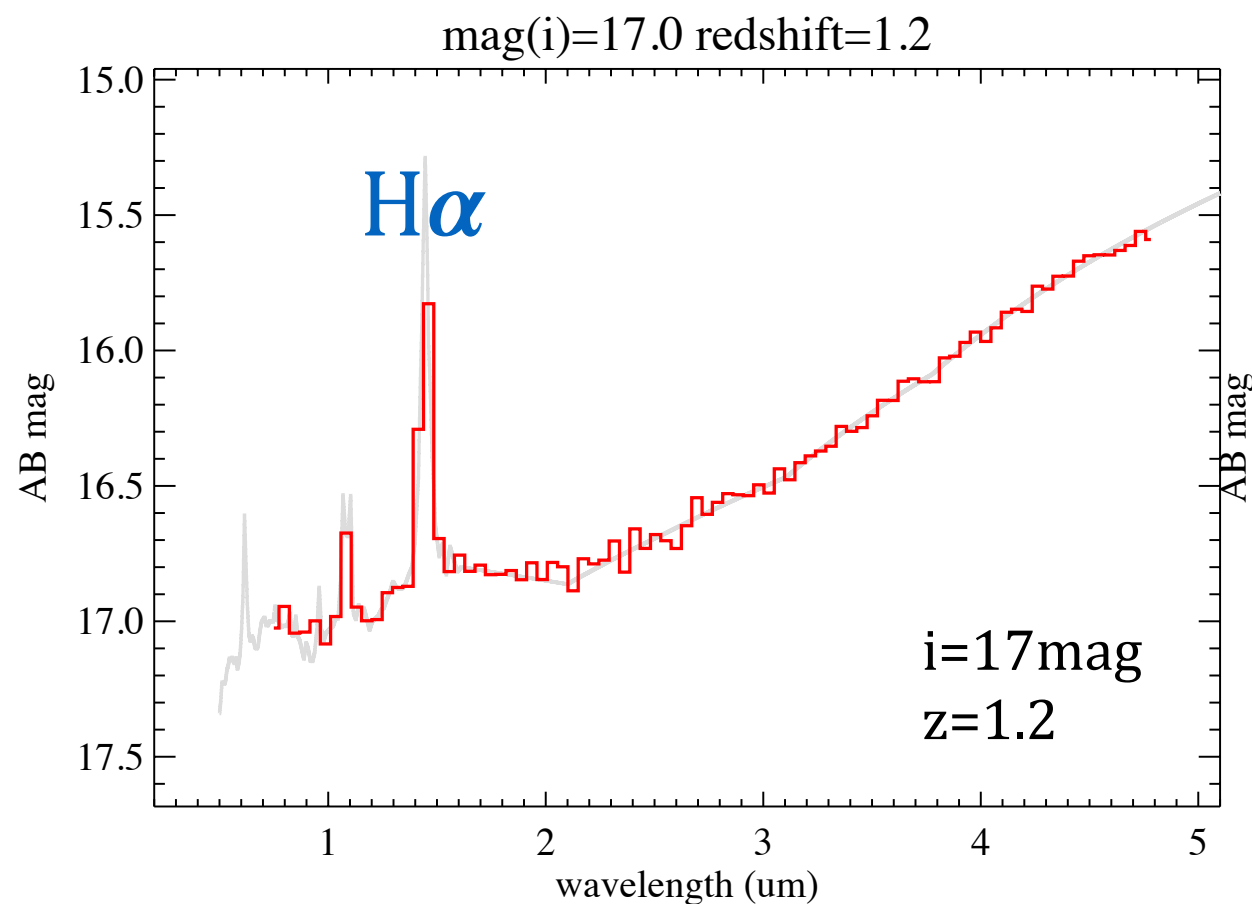
Pre-photometric data

Pre-photometric (spectroscopic) data before the launch of SPHEREx



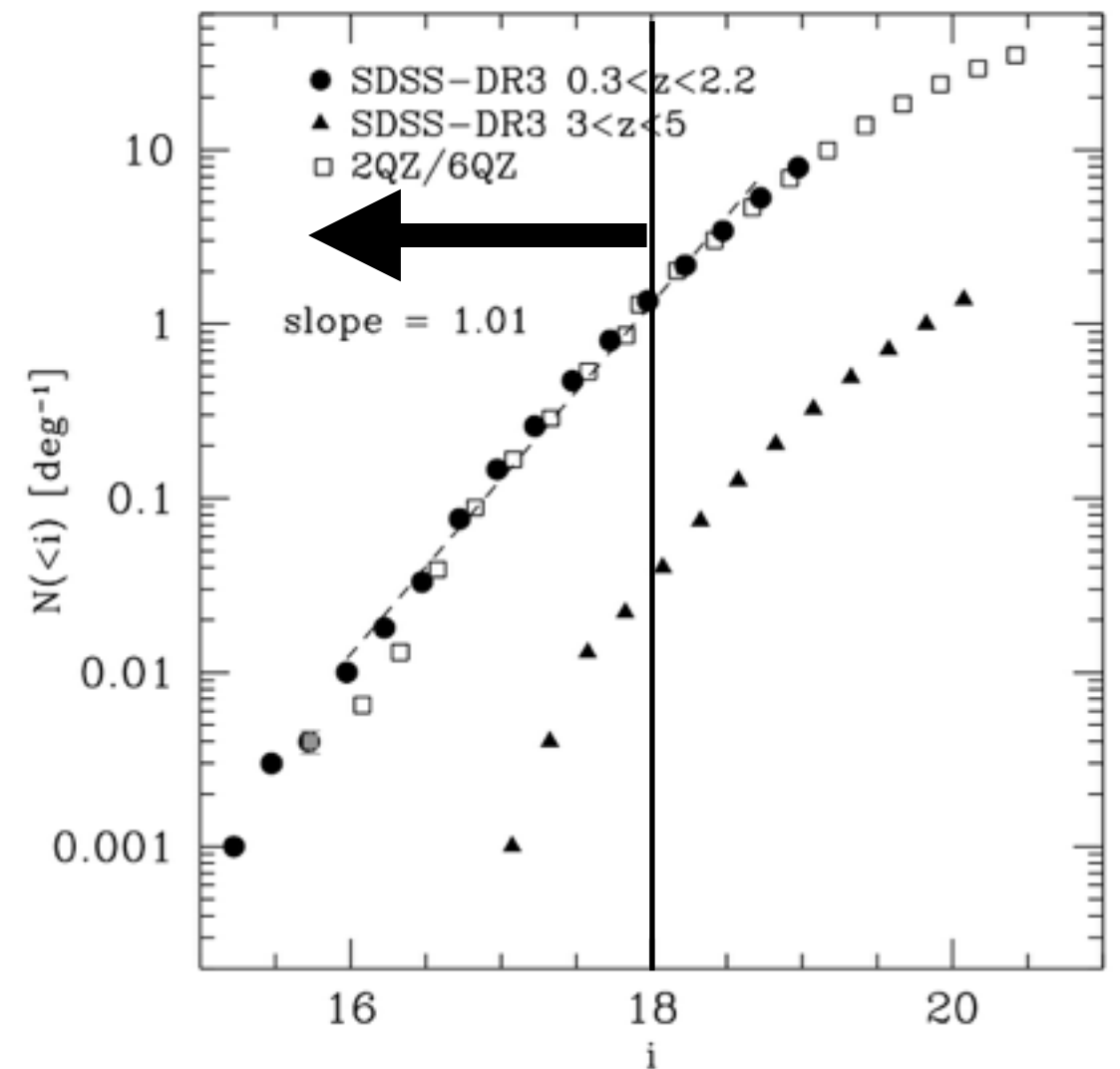
Sample

- enough sample? S/N?
 - $i < 17-18$ mag
 - $z > 0.3$, IR continuum+ $H\alpha$ reverberation



Sample

- enough sample? S/N?
 - $i < 17$ mag, $\sim 0.2/\text{deg}^2$
 - ~ 40 QSOs in poles
 - $i < 18$ mag $\rightarrow \sim 200$ QSOs
 - $i < 19-20$ mag for IR RM



Summary

- SPHEREx will conduct **the first all sky spectral survey** with spectral coverage of 0.75-5um.
- SPHEREx has the potential to have an impact comparable to the other great wide-field surveys of the 2020's (M. Strauss).
- **SPHEREx will provide unique dataset for Opt/IR RM experiments.**
- **The final selection will be made in Jan-2017. Stay tuned!**
- **Any comments/suggestions will be appreciated!**

Thank you!