Statistical Measurements of Faint Reionizing Sources with Emission Line Intensity Mapping

Michael Zemcov

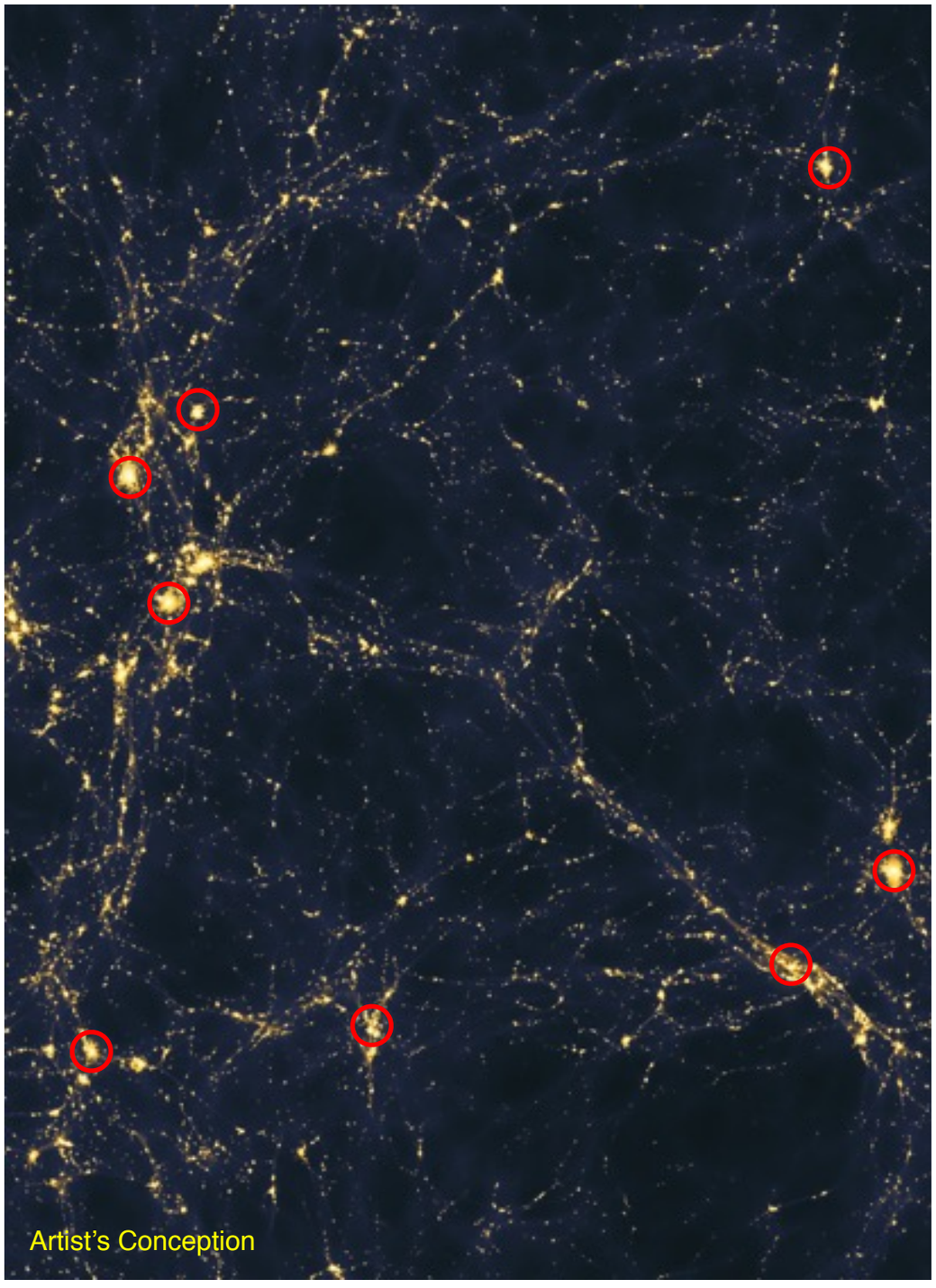
Rochester Institute of Technology

Aspen Winter Meeting 2016: The Reionization Epoch: New Insights and Future Prospects

March 9, 2016

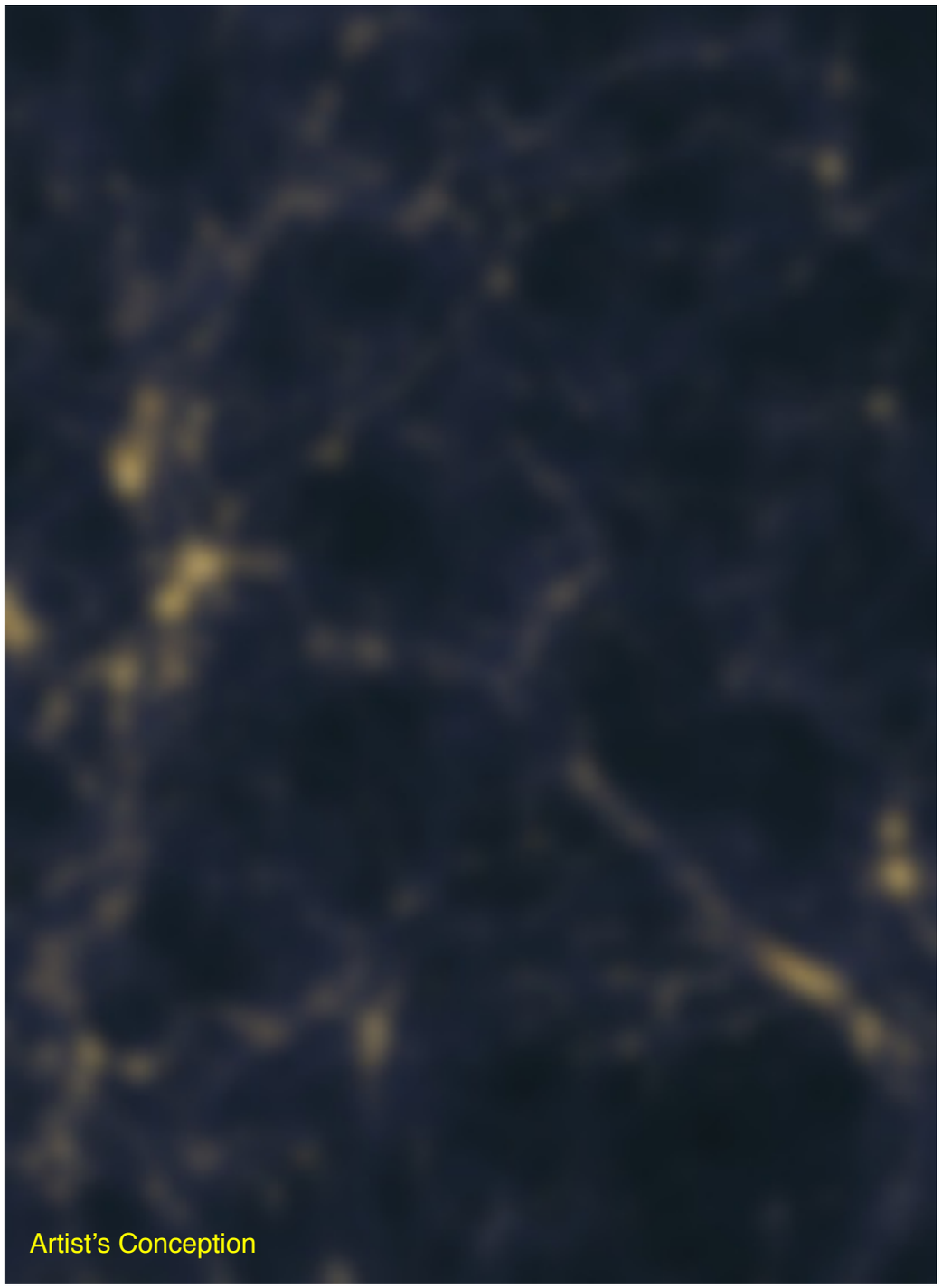
R·I·T

An Introduction to Intensity Mapping



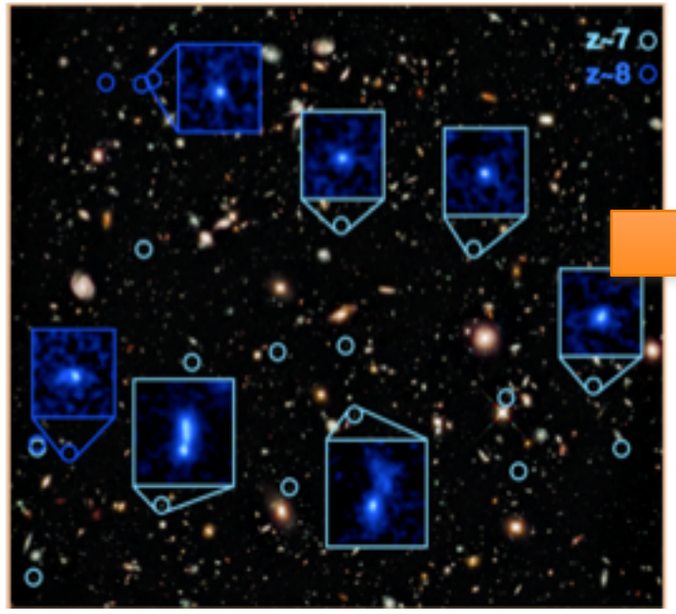
- What is the large scale structure of the universe?
- To find out, we could identify individual sources of emission.

An Introduction to Intensity Mapping

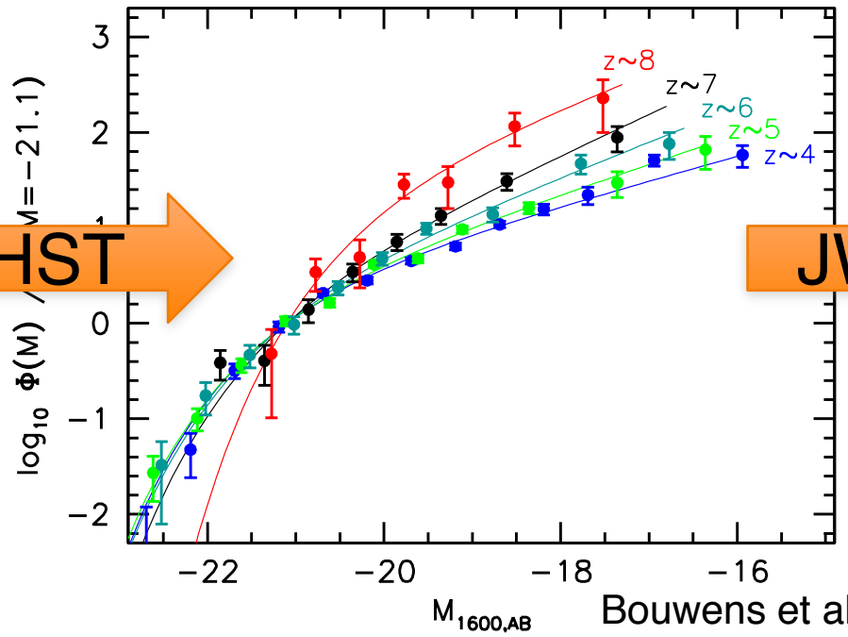

Artist's Conception

- What is the large scale structure of the universe?
- To find out, we could identify individual sources of emission.
- Alternatively, we could sum all the emission in large areas and measure fluctuations.
- This is called Intensity Mapping.

An Application: Searching for the Sources Responsible for Reionization

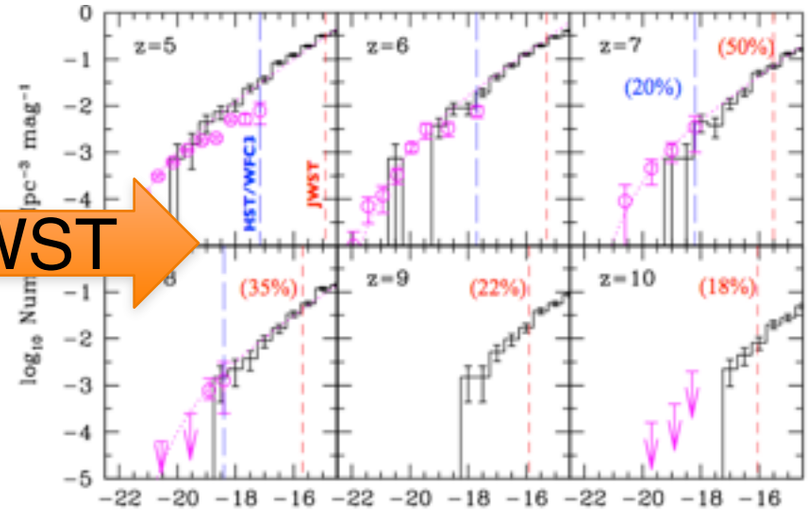


HST



Bouwens et al. (2014)

JWST

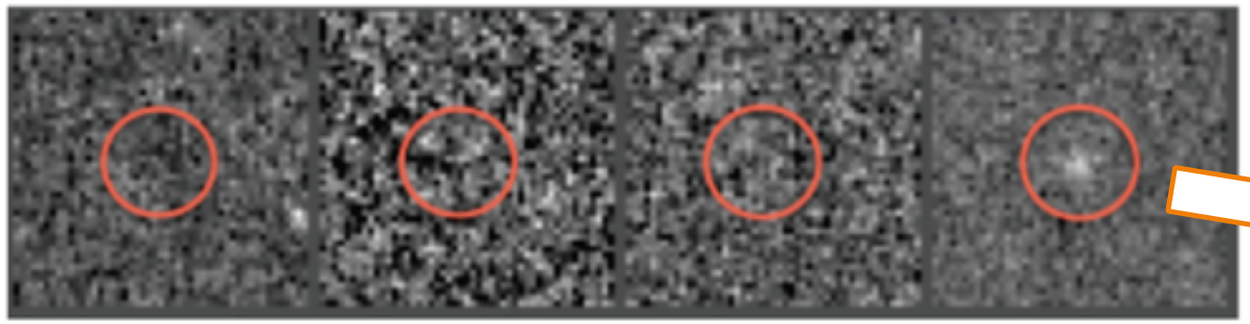


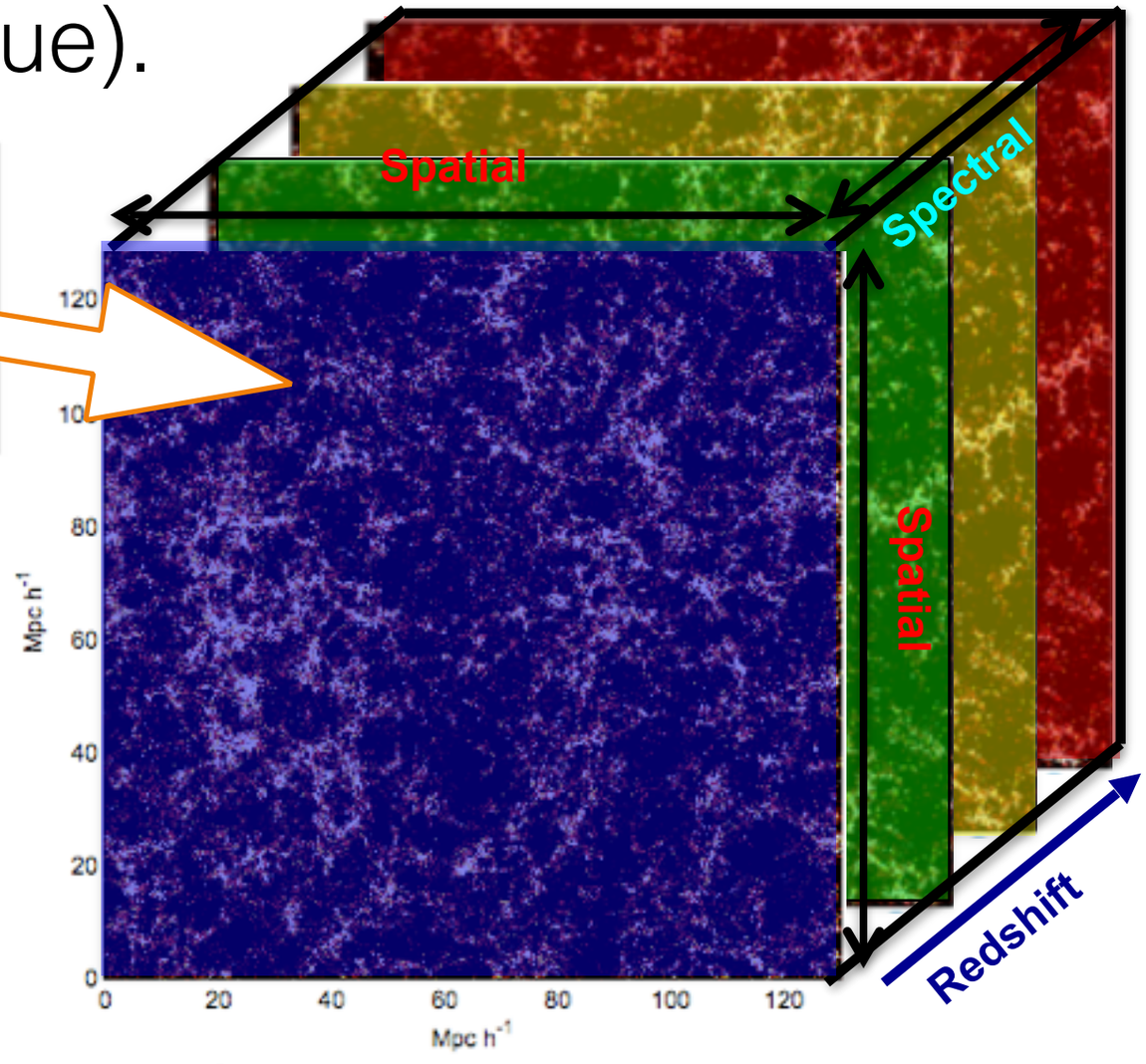
Salvaterra et al. (2010)

- Galaxy counts miss faint sources that may dominate the reionization budget.
- Estimates of the SFRD at high redshift require huge extrapolations of UV luminosity function to explain reionization.
- IM studies are sensitive to the total luminosity emitted by all galaxies -> **Intensity Mapping offers an advantage.**

Line Intensity Mapping

We can also map fluctuations in *line* emission vs z (analogy with dropout technique).



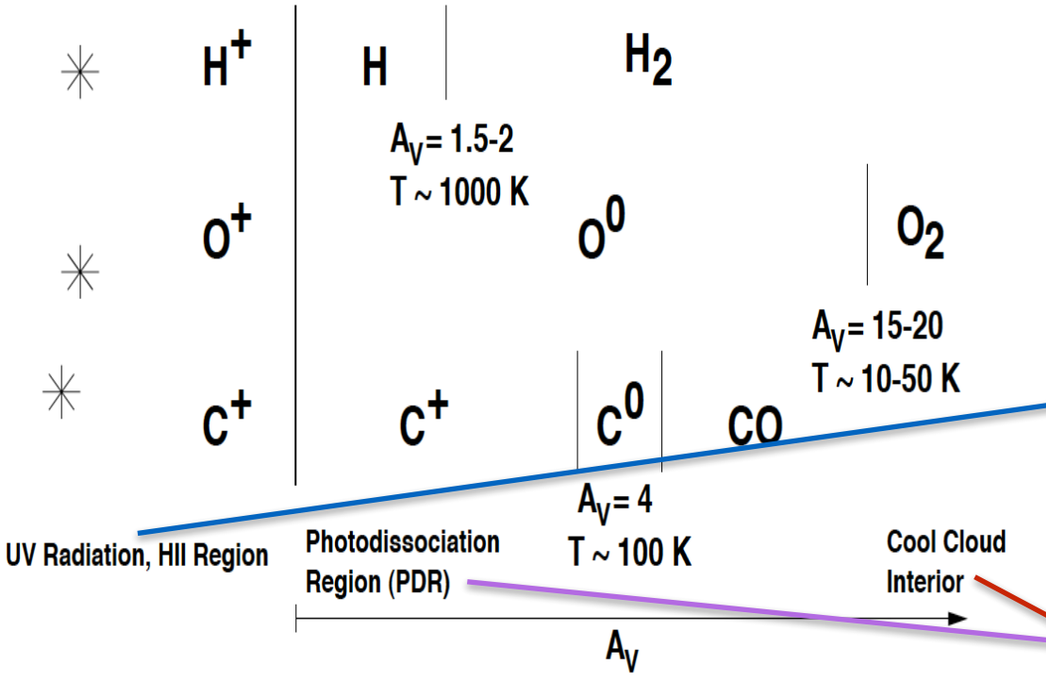


Some proposed line tracers:

- Radio: 21 cm, CO
- Sub-mm: [CII]
- Optical: Hα, Hβ, [OII], [OIII]
- UV: Lyα

+ cross correlations between any of them.

[CII]: Tracing the Emplacement of Metals in the IGM



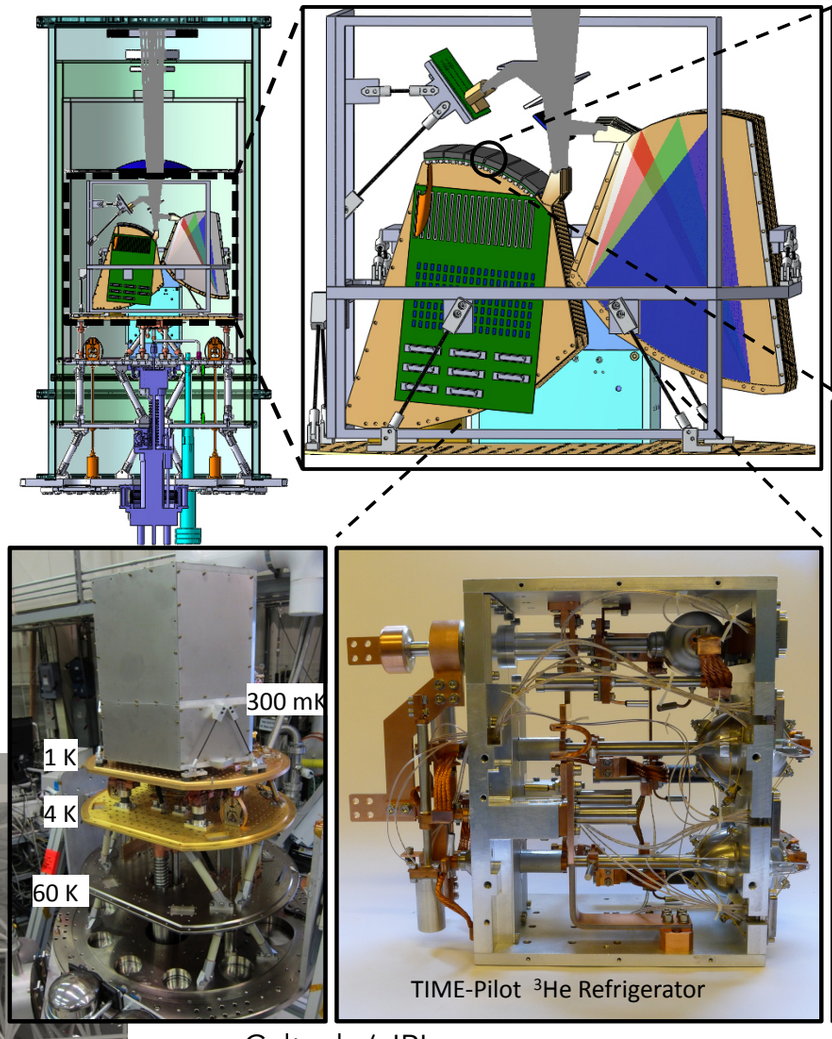
C+ ionization potential 11.6 eV, so it exists in neutral gas where much of the energy is input into the interstellar medium.

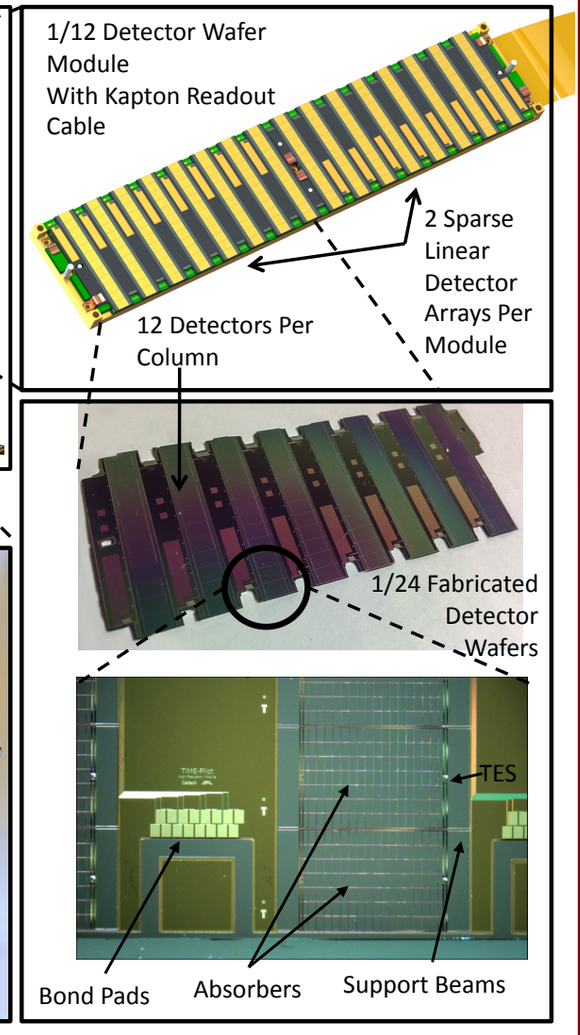
- Easily thermalized with a critical density of 3×10^3 H_2 cm^{-3} or ~50 e^- cm^{-3}
- C+ carries a large fraction of the gas cooling (30-50%, (of the 1% of the total))
- Among the most luminous spectral line in the spectra of galaxies.
  - ➡less dust to gas means more C+ to far-IR

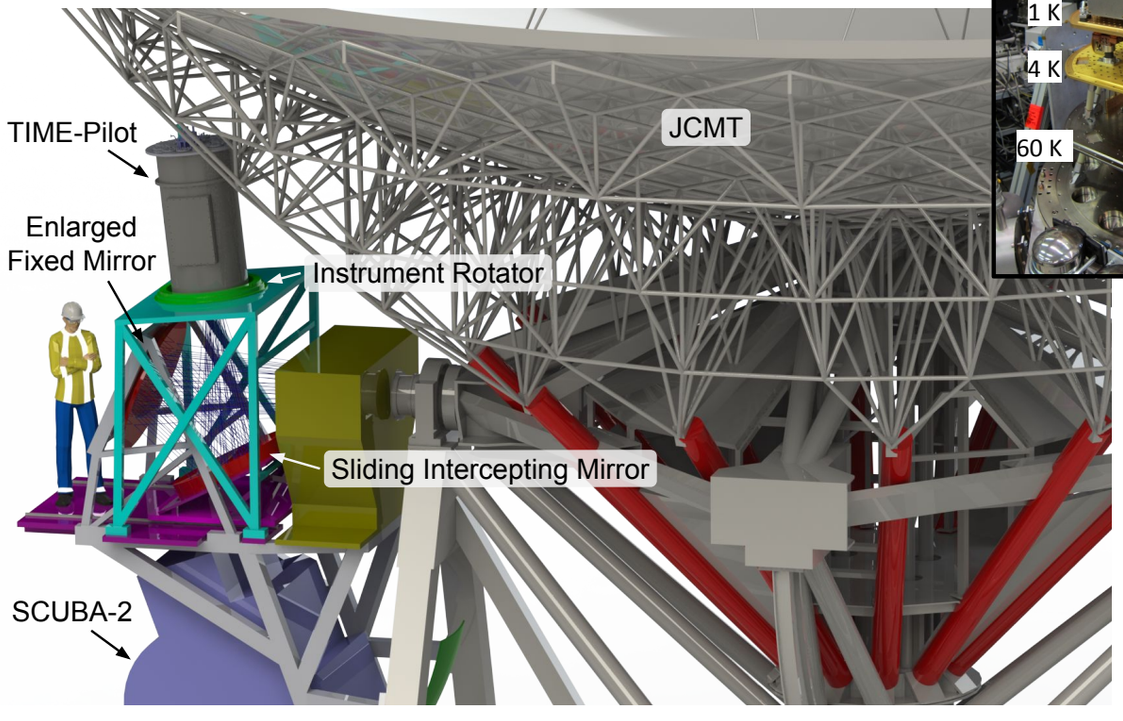
Also traces diffuse ionized gas.

TIME-*Pilot*

- 32 waveguide grating spectrometers (based on Z-Spec technology).
- $\lambda/\Delta\lambda$=100, 60 detectors per spectrometer covering 186-324 GHz.
- 16 independent dual-pol spectrometers arranged in a line to maximize sensitivity to modes of interest.
- 1800 absorber-coupled TES bolometers
  - time-domain (NIST) SQUID MUX, as per SCUBA-2, BICEP-2 heritage.
- NEP of 3×10^{-18} well in hand.







Caltech / JPL
Jamie Bock
Matt Bradford
Bruce Bumble
Yun-Ting Cheng
Abby Crites
Steve Hailey-Dunsheath
Jonathon Hunacek
Roger O'Brient
Jason Sun

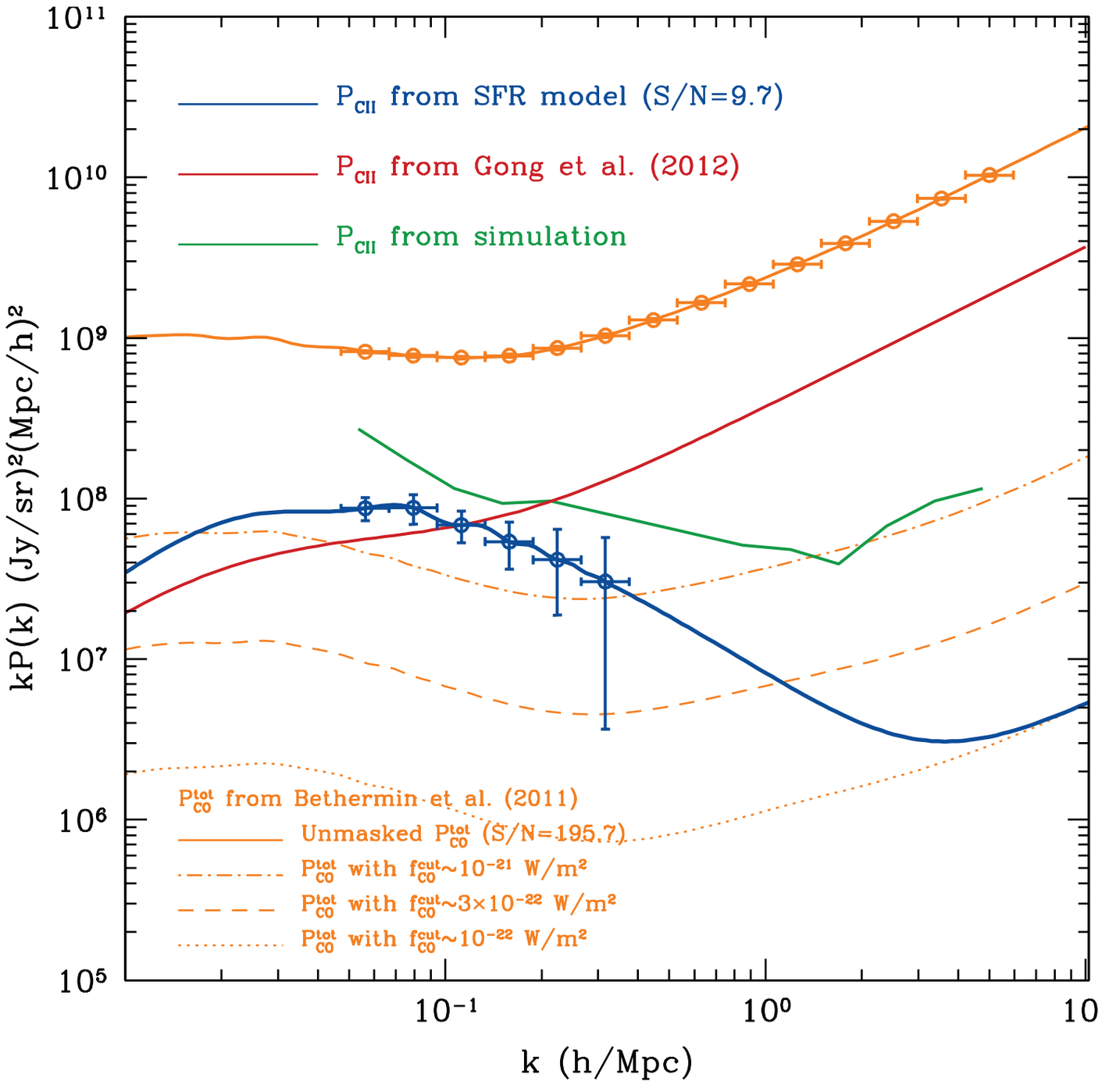
ASIAA
Tzu-Ching Chang
Patrick Koch
Chao-Te Li

UC Irvine
Asantha Cooray
Yan Gong
Bade Uzgil

U. Chicago
Erik Shirokoff

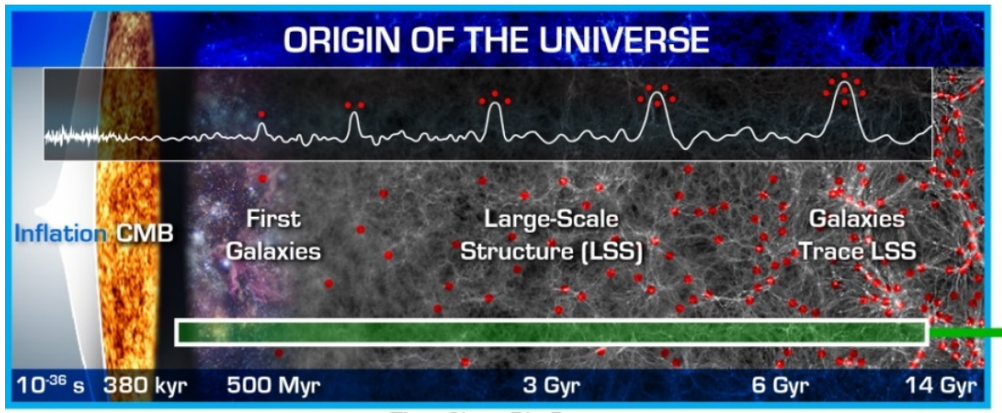
RIT
Mike Zemcov

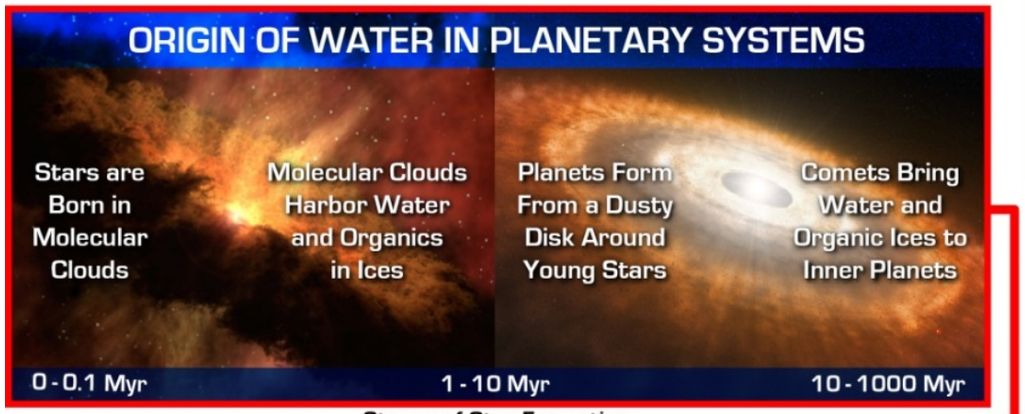
Time-*Pilot* Expected Sensitivity

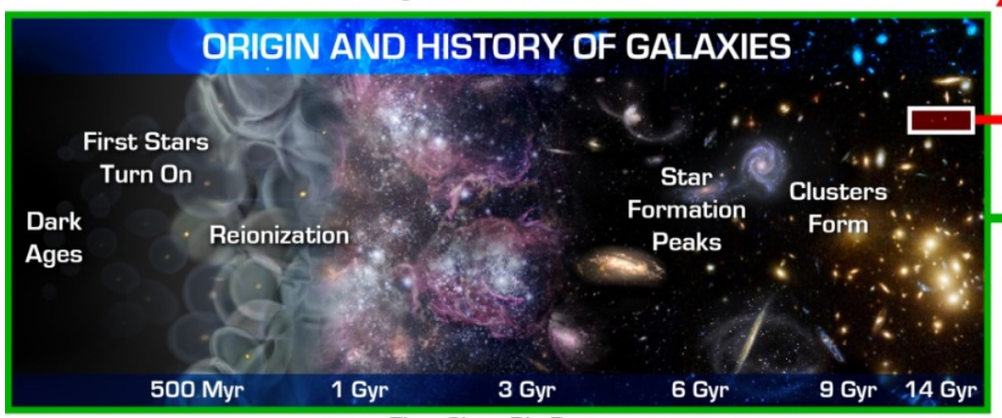


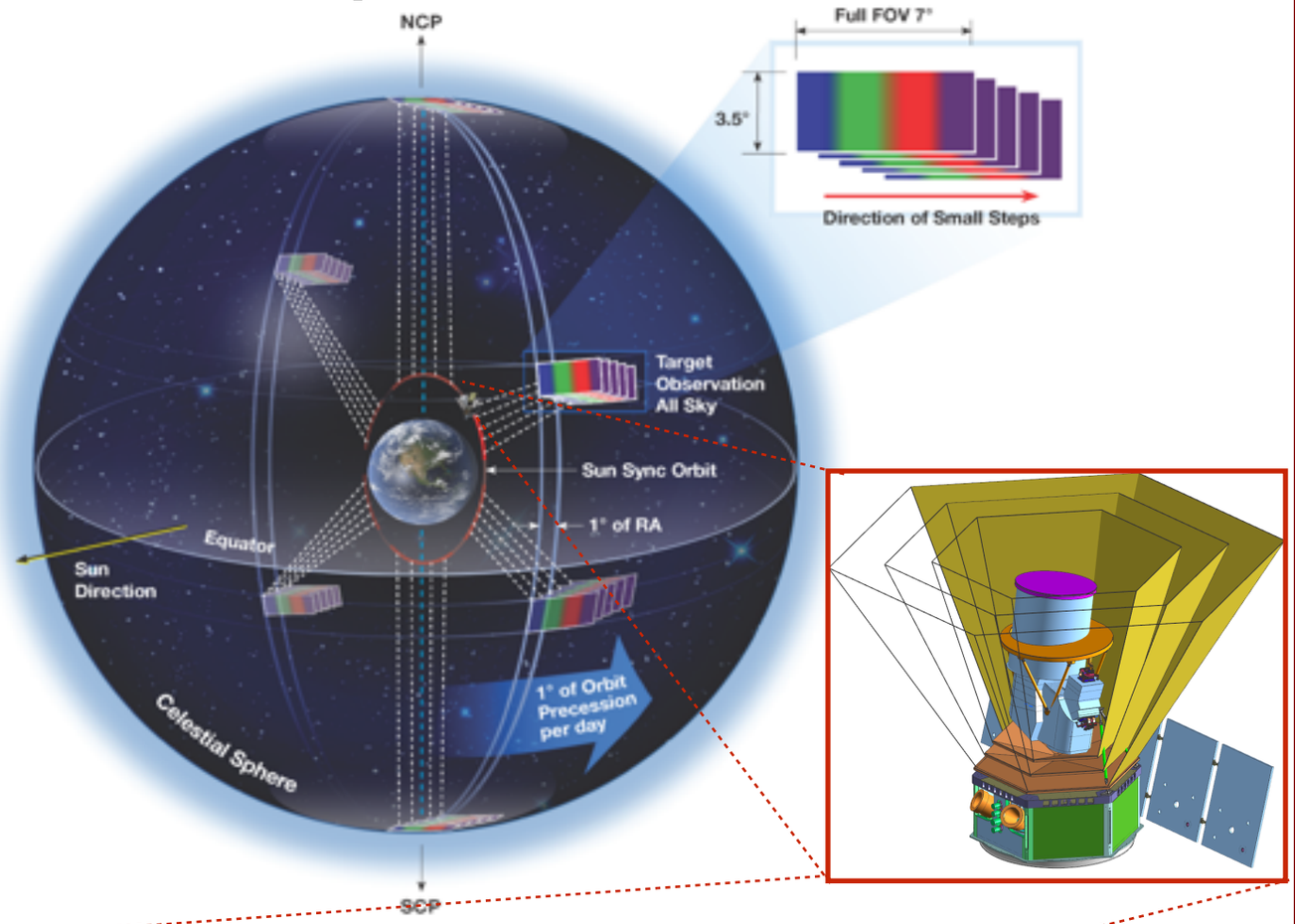
- [CII] autocorrelation spectra over the full TP band.
- [CII] EoR signal strength not known, consider various models.
  - Constant SFR
  - Gas physics calculation
  - Millennium sim x 3e-3
- Error bars correspond to 240 hours on sky w/ JCMT.
- CO from z ~ 0.5 to 3 (multiple lines) is dominant signal in raw map (shown referred to CII survey geometry), but can be masked using galaxy catalogs.
- Cross correlations at CO frequencies with galaxy surveys can provide a CO census

SPHEREx: An All Sky Spectral Survey





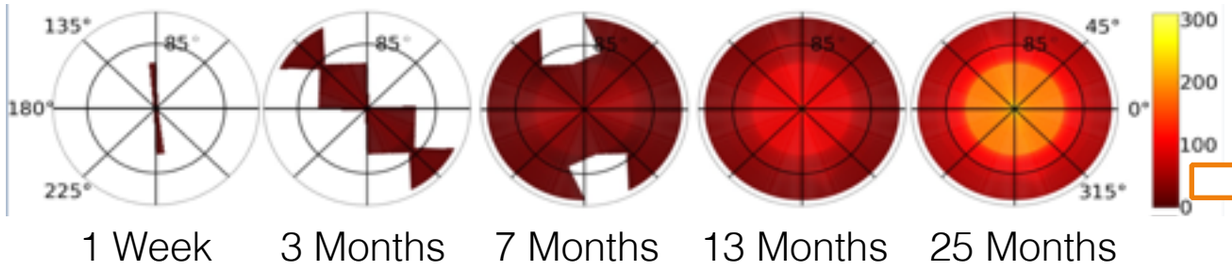




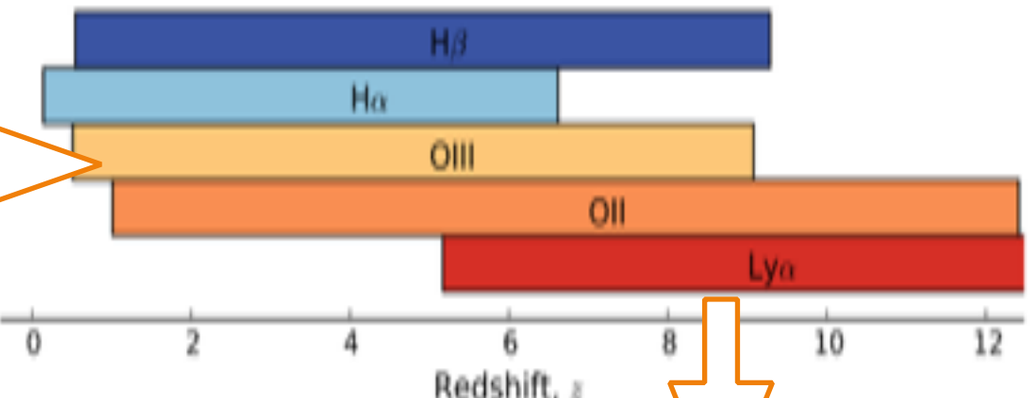
An Optical-IR imaging spectrometer
λ= 0.75-4.1 μm R=41.5
λ= 4.1-4.8 μm R=150
20cm telescope
Passively cooled
6.2”x6.2” pixels
2x(3.5x7) sq. deg. FOV

SPHEREx Collaboration (2014)

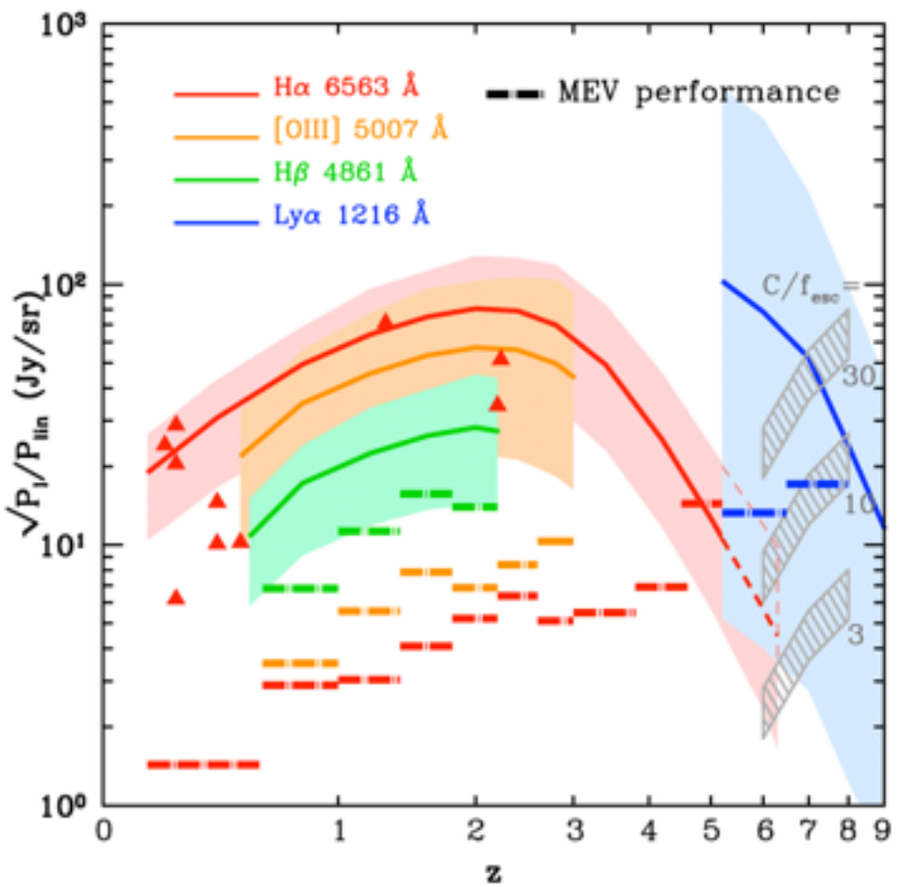
SPHEREx: An All Sky Spectral Survey

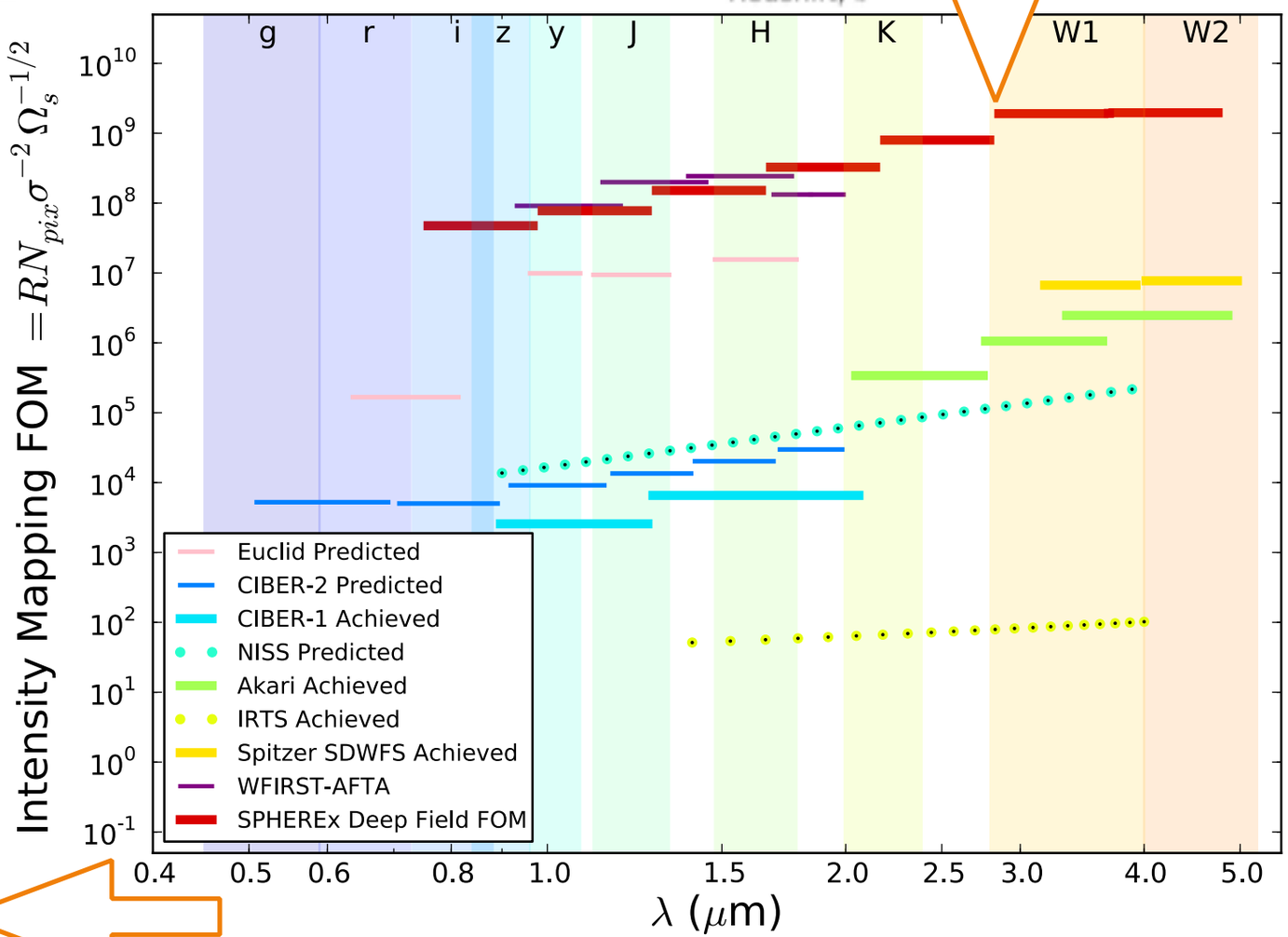


1 Week 3 Months 7 Months 13 Months 25 Months



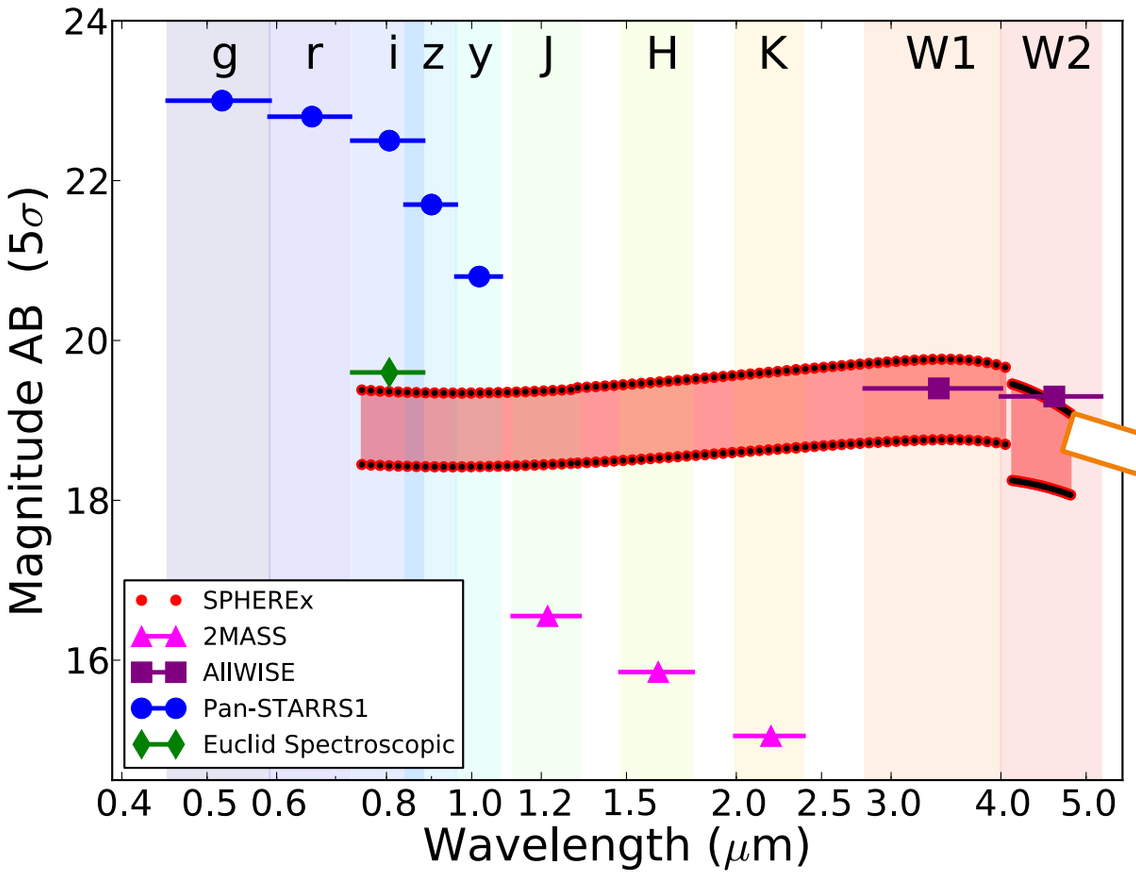
SPHEREx is an intensity mapping machine.

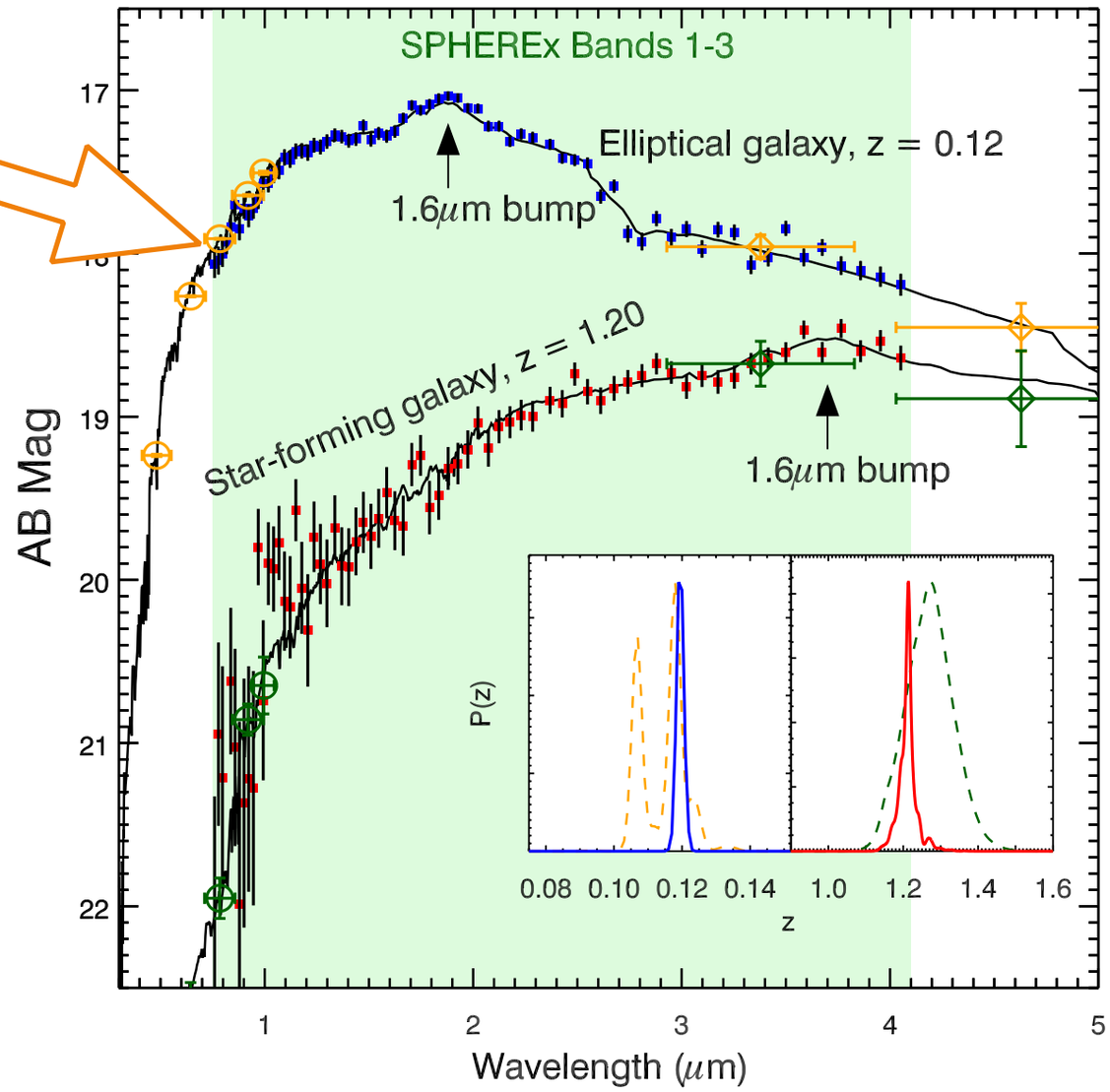




SPHEREx Collaboration (2014)

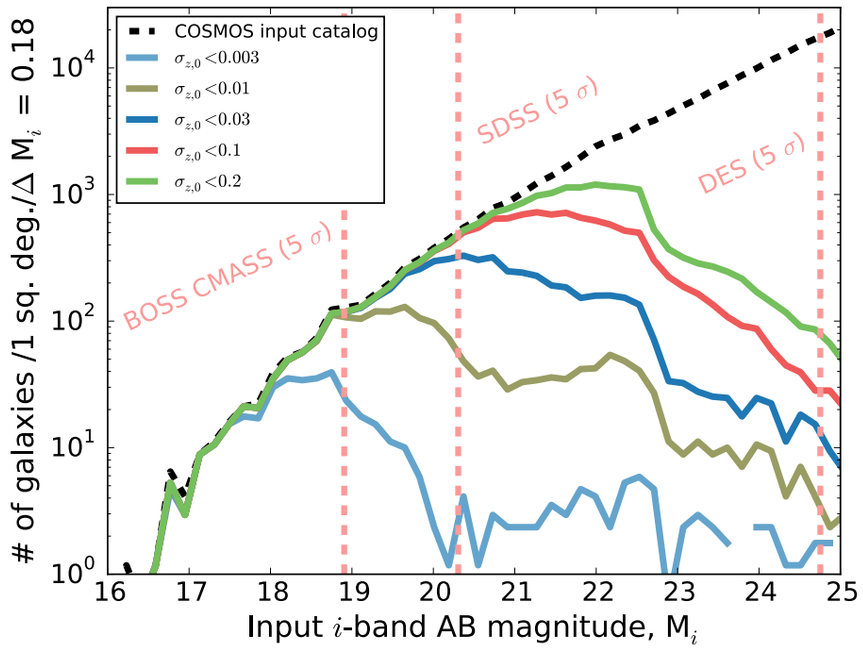
Probing Inflation with SPHEREx

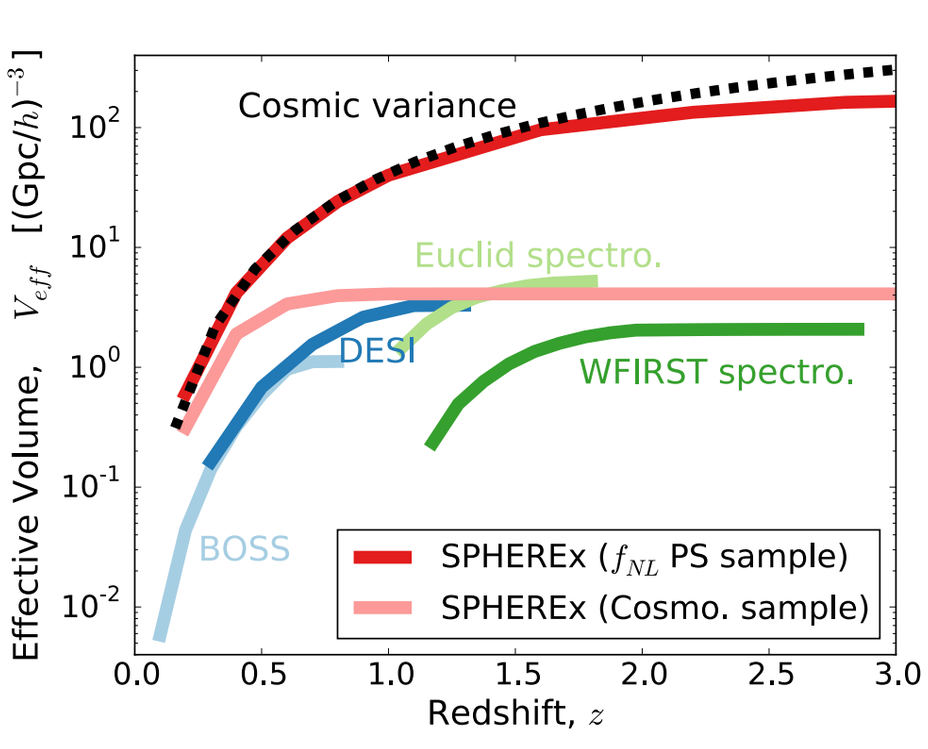


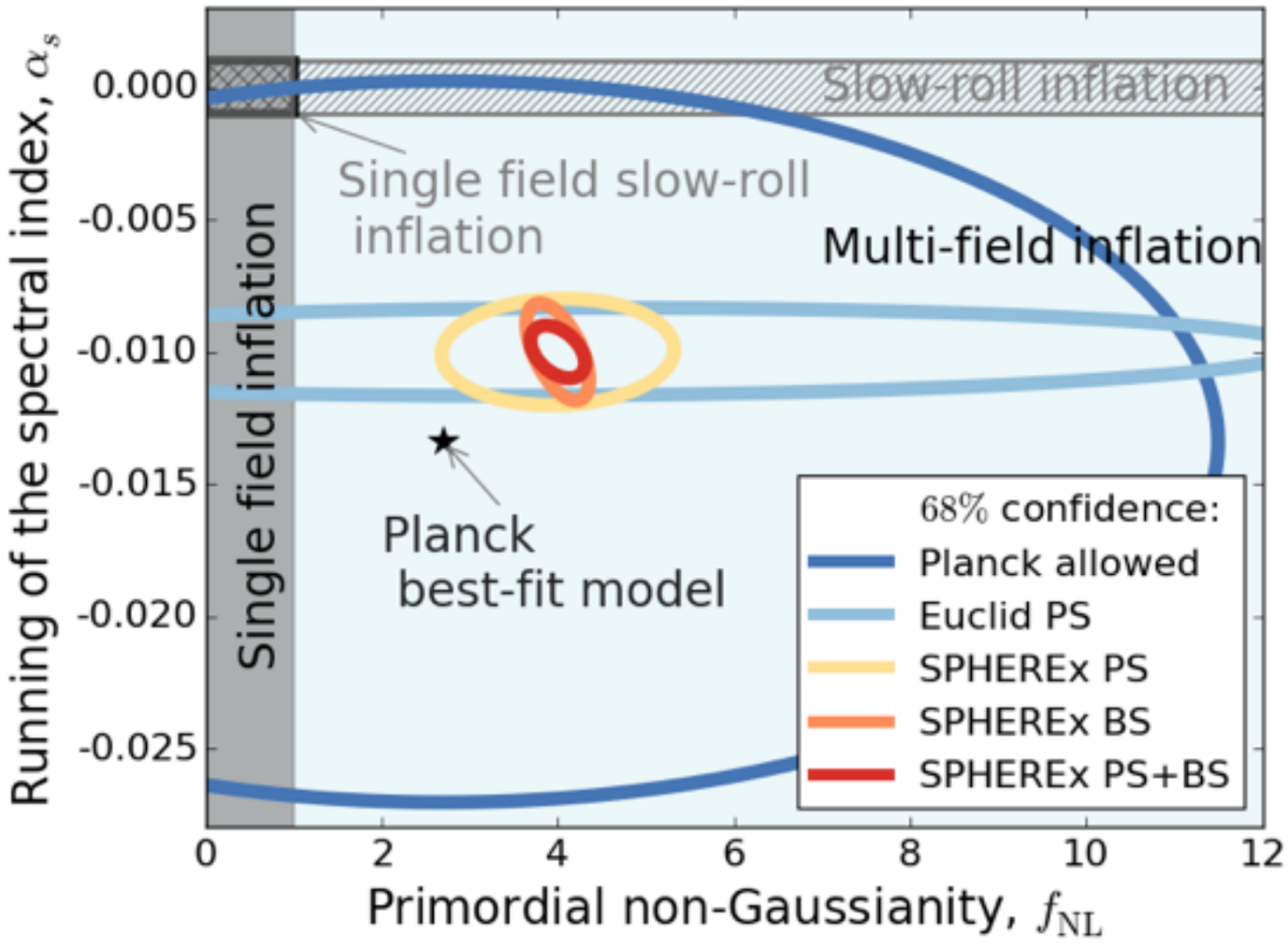


See Dore et al. (2014) astro-ph/1412.4872

Probing Inflation with SPHEREx







z-accuracy requirement supported by e.g. the Prism Multi-object Survey (PRIMUS; Cool et al 2013)

SPHEREx Produces a High-Legacy Catalog

Object	# Sources	Legacy Science	Reference
Detected galaxies	1.4 billion	Properties of distant and heavily obscured galaxies	Simulation based on COSMOS and Pan-STARRS
Galaxies with $\sigma(z)/(1+z) < 0.1$	301 million	Study large scale clustering of galaxies	Simulation based on COSMOS and Pan-STARRS
Galaxies with $\sigma(z)/(1+z) < 0.03$	120 million	Study (Hα, Hβ, CO, OII, OIII, SII, H_2O) line and PAH emission by galaxy type. Explore galaxy and AGN life cycle	Simulation based on COSMOS and Pan-STARRS
Galaxies with $\sigma(z)/(1+z) < 0.003$	9.8 million	Cross check of Euclid photo-z. Measure dynamics of groups and map filaments. Cosmological galaxy clustering, BAO, RSD.	Simulation based on COSMOS and Pan-STARRS
QSOs	> 1.5 million	Understand QSO lifecycle, environment, and taxonomy	Ross et al. [81] plus simulations
QSOs at $z > 7$	1-300	Determine if early QSOs exist. Follow-up spectroscopy probes EOR through Lyα forest	Ross et al. [81] plus simulations
Clusters with ≥ 5 members	25,000	Redshifts for all eRosita clusters. Viral masses and merger dynamics	Geach et al. [82]

Summary

- Line intensity mapping has great promise for helping to understand the history of star formation in the universe.
- Naturally sensitive to faint and diffuse emission, as we would expect from reionizing sources.
- TIME is tuned to [CII] 158 micron line, sensitive to the ionization state and metallicity of the IGM.
- SPHEREx will map the history of star formation using Lyα, Hα, Hβ, [OII] and [OIII].
- Come chat with me for more information!