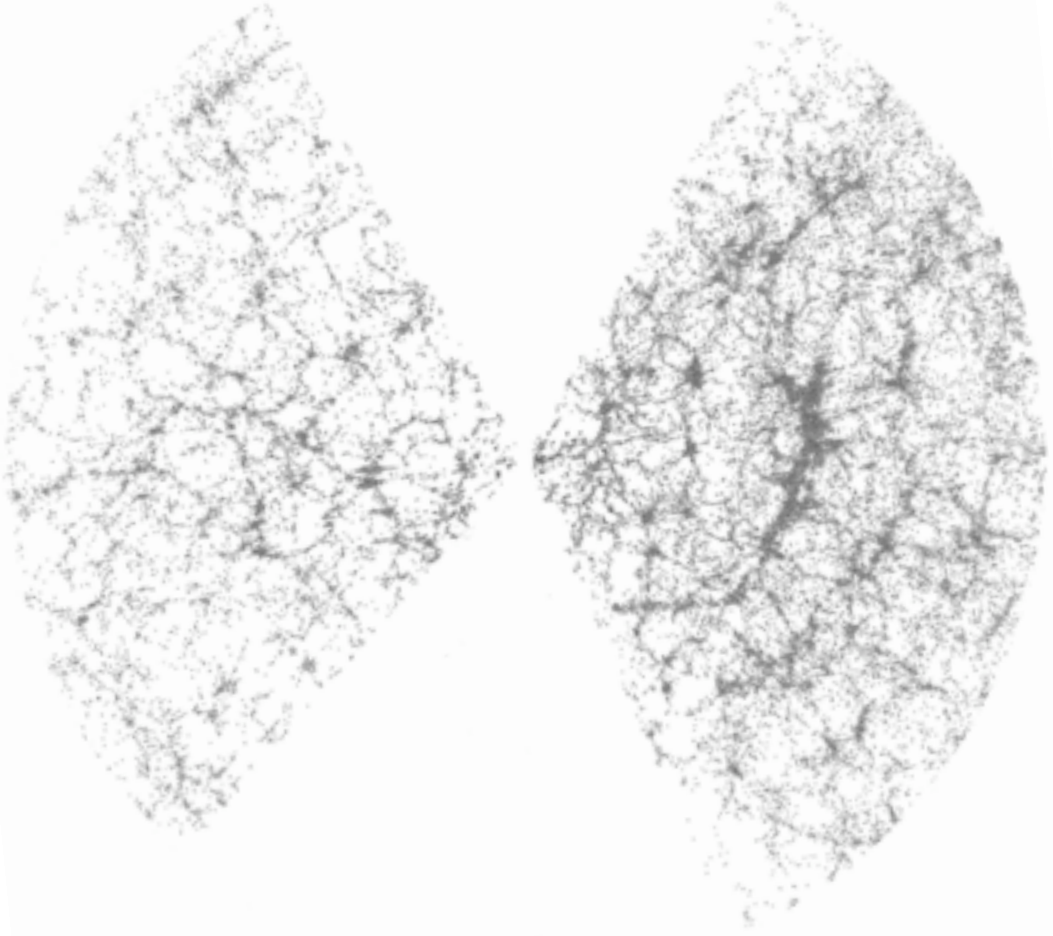
CRT@FNAL: Science Motivation

Probing Dark Energy with Intensity Mapping of HI 21cm Emission



21 cm Internal Review

4/26/10

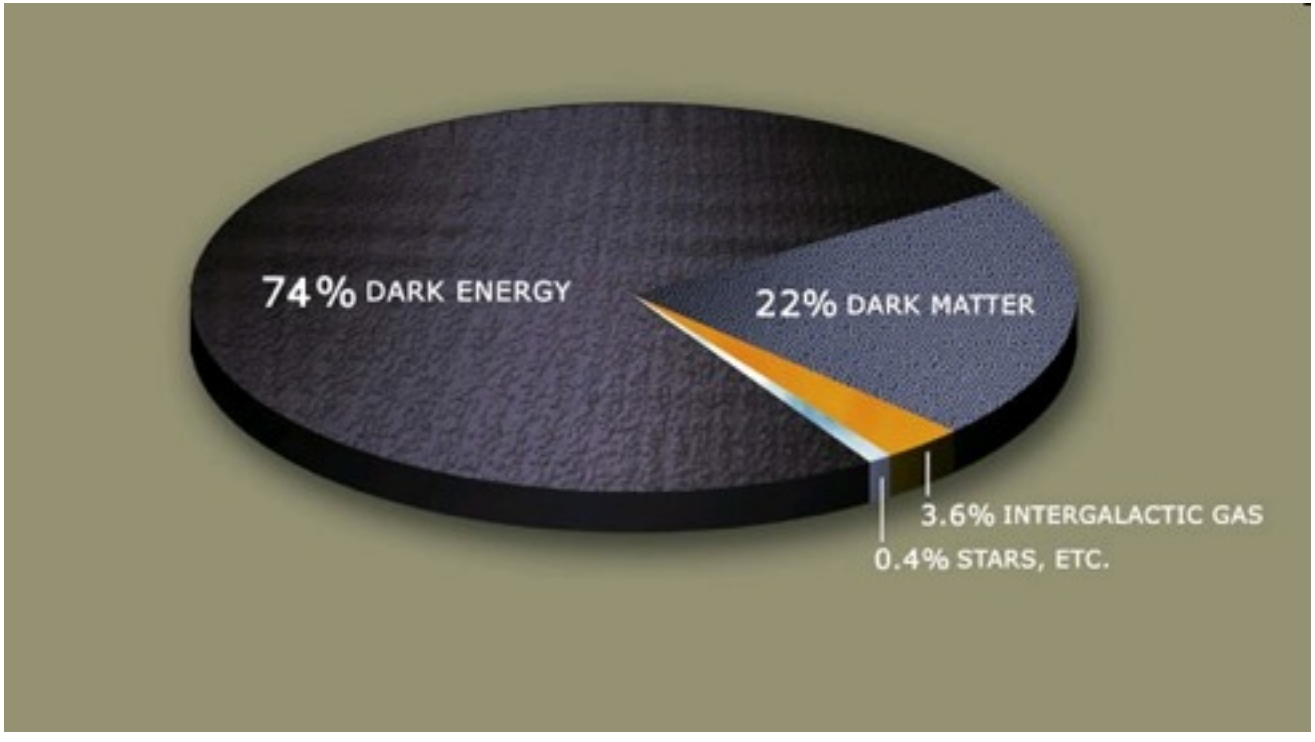
Albert Stebbins

FNAL

Cosmology @ FNAL

Fundamental Physics From Cosmology

Dark Sector



Dark Energy @ FNAL

"Biggest Mystery in the Universe"

Not only because it is 75% of the stuff in the universe.
It likely has fundamental implications for particle physics and/or the nature of space and time.

FNAL & DOE have a record supporting research to characterize Dark Energy

Theory, SDSS (II), DES, SNAP/JDEM, LSST (@LLNL, SLAC).
Many projects emphasize their "dark side" (dark energy dollars).
For CRT Dark Energy is the main goal!

Cosmology By Cartography

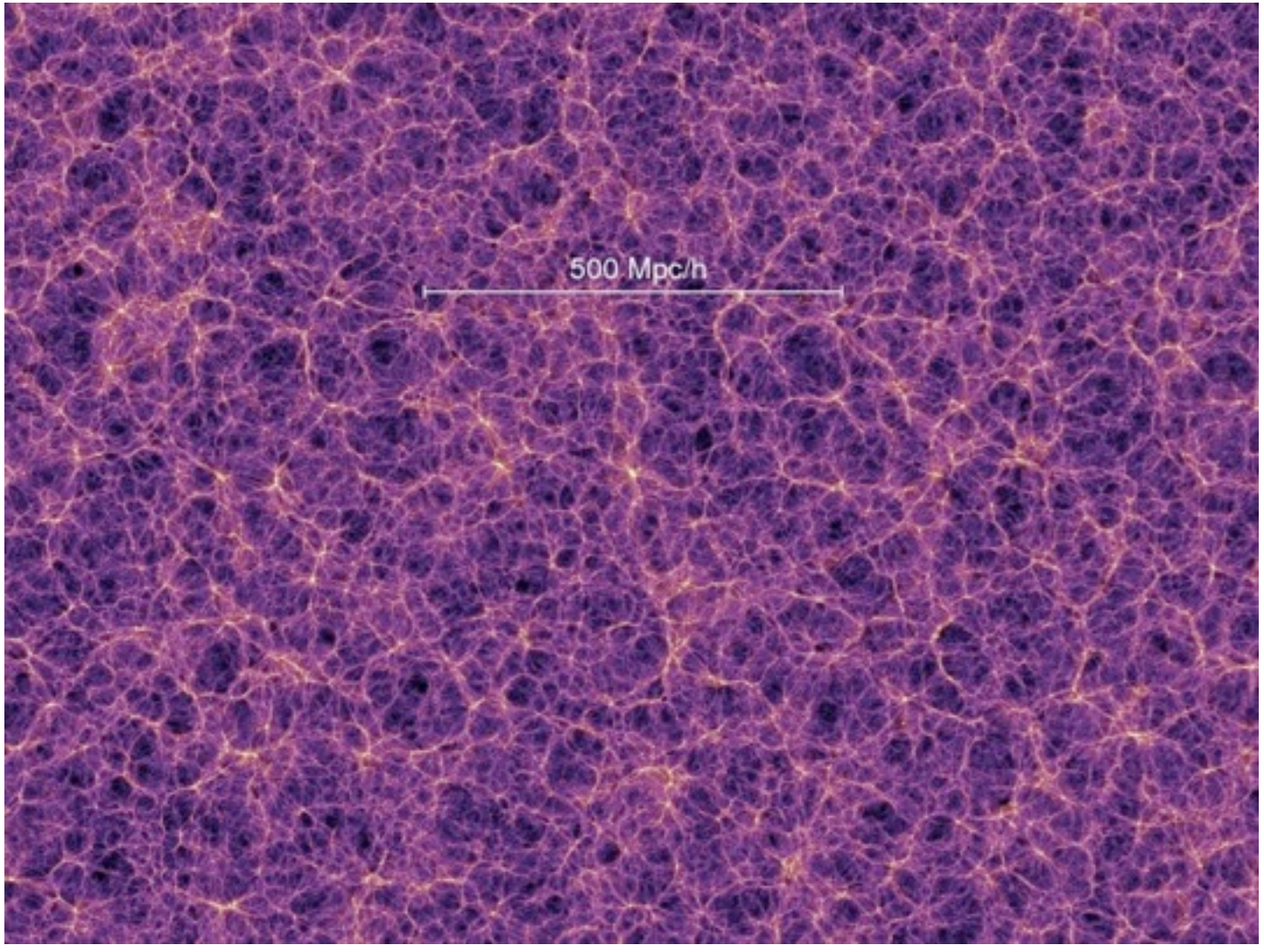
To study cosmology we need to study the things in the universe: e.g. galaxies, clouds, *etc*.

These things are generated as random noise!

To characterize this random noise we need good statistics - *i*.e. large volumes, solid angle, *etc*.

Cosmology By Cartography

The noise we study is the Large Scale Structure



Millennium Simulation

Baryon Acoustic Oscillations

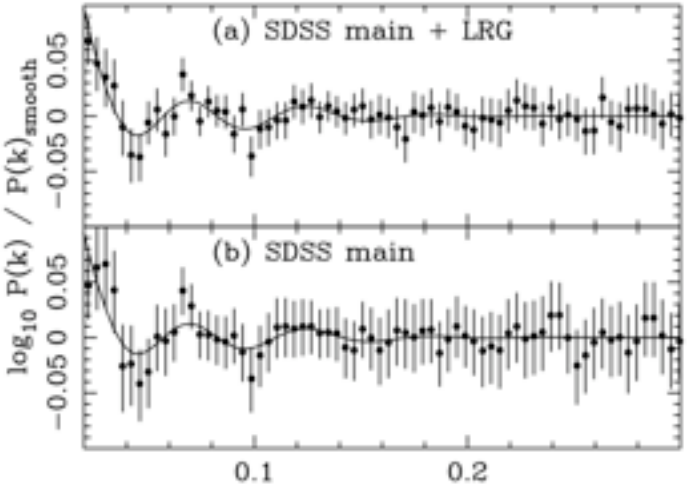
Small wiggles is in the LSS power spectrum / correlation function are the remnants of cosmic sound waves which were fossilized when the sound speed dropped rapidly at recombination.

It is presently standard procedure to focus on this unique signature of LSS - using them as a **standard ruler** to measure the expansion

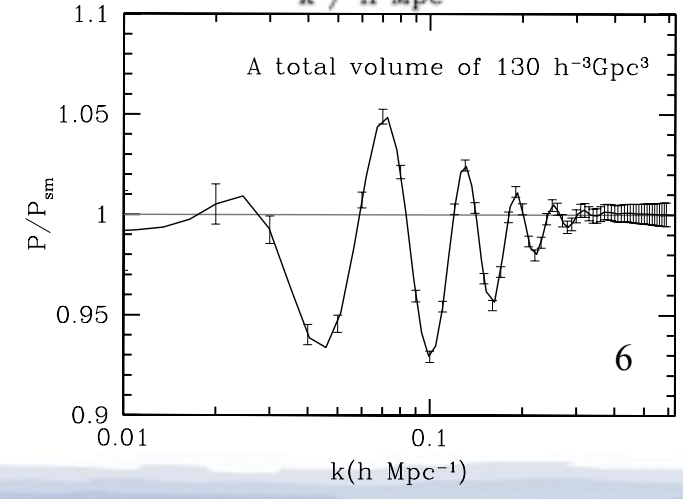
$$H[z] = \sqrt{\frac{8\pi G\,\Omega[z]\,\rho[z]}{3}}$$

$$D_{co}[z] = \int_0^z dz\,\frac{c}{H[z]}$$

$$D_{A,co}[z] = \frac{c\,\mathrm{Sin}\left[\frac{H_0}{c}\sqrt{\Omega_0 - 1}\,D_{co}[z]\right]}{H_0\sqrt{\Omega_0 - 1}}$$

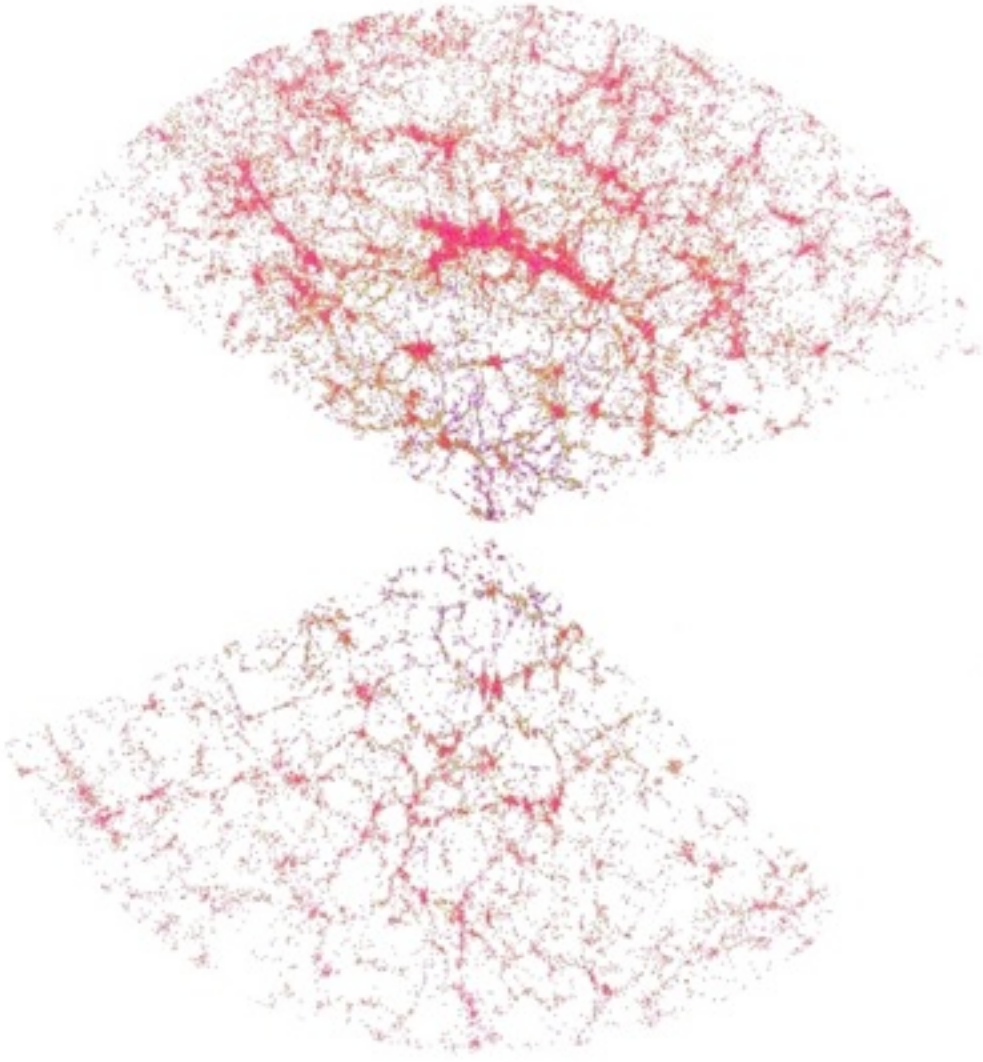


Percival et. al 2007



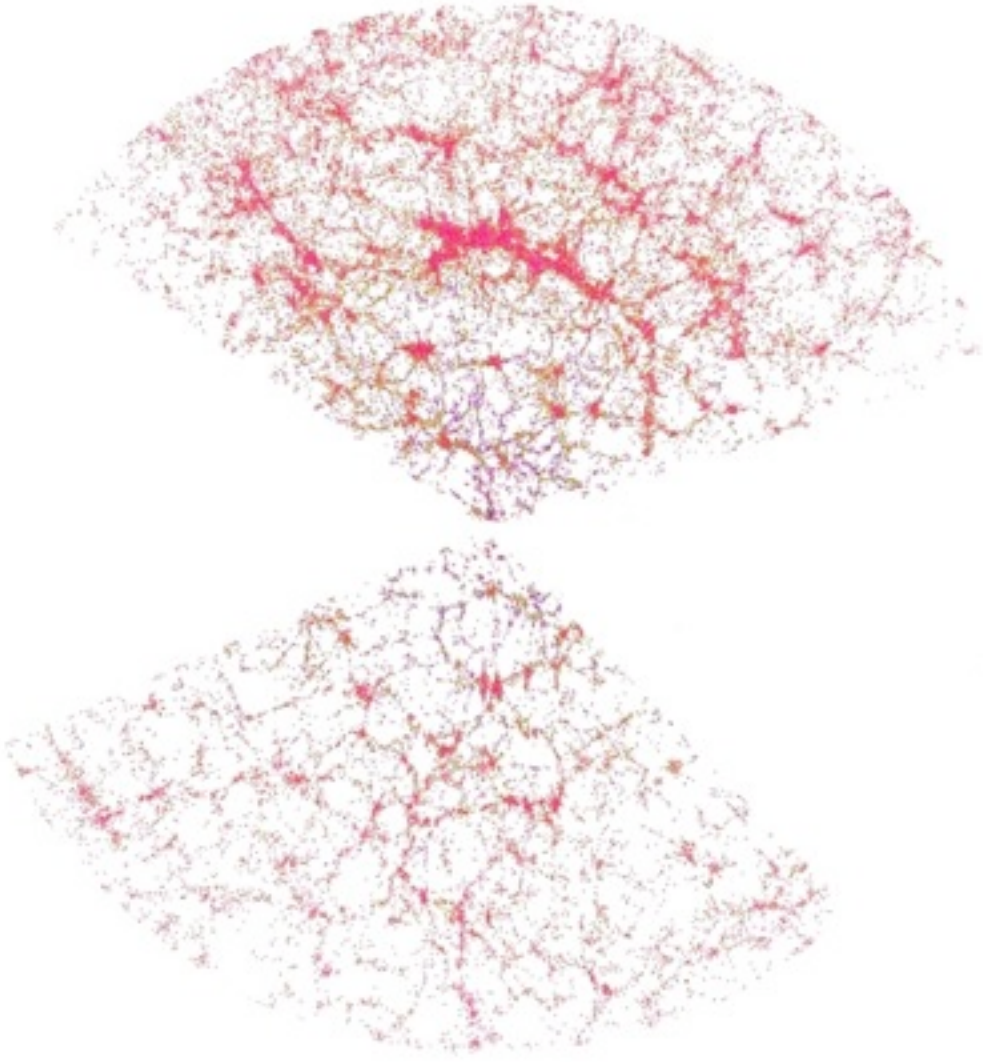
CRT Seo et. al 2010

LSS in Optical / IR



multi-band: COLOR - get galaxy types

LSS in Optical / IR



multi-band: COLOR - get galaxy types

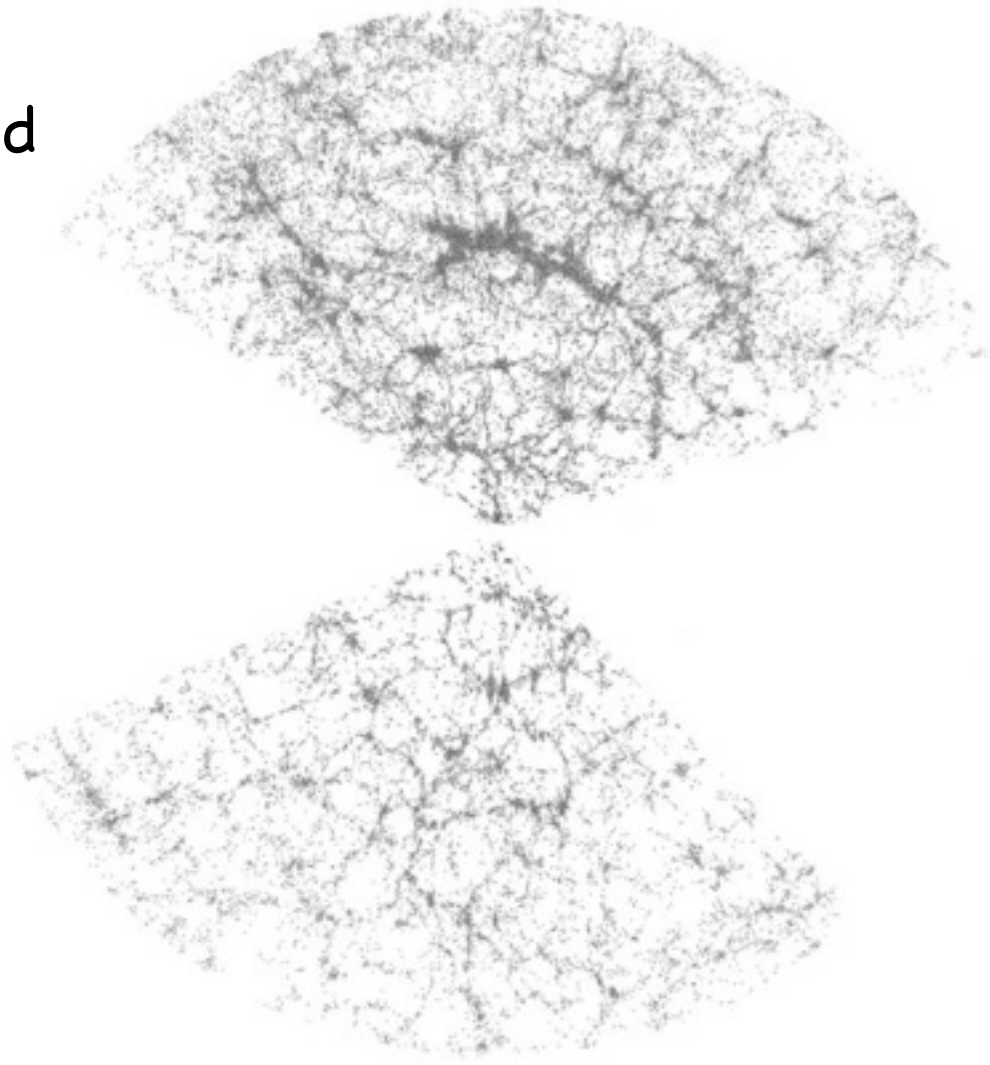
+ spectroscopic survey

LSS in 21cm

All-In-One

photometry and

spectroscopy!



no colors - just redshifts: GRAYSCALE

LSS in 21cm

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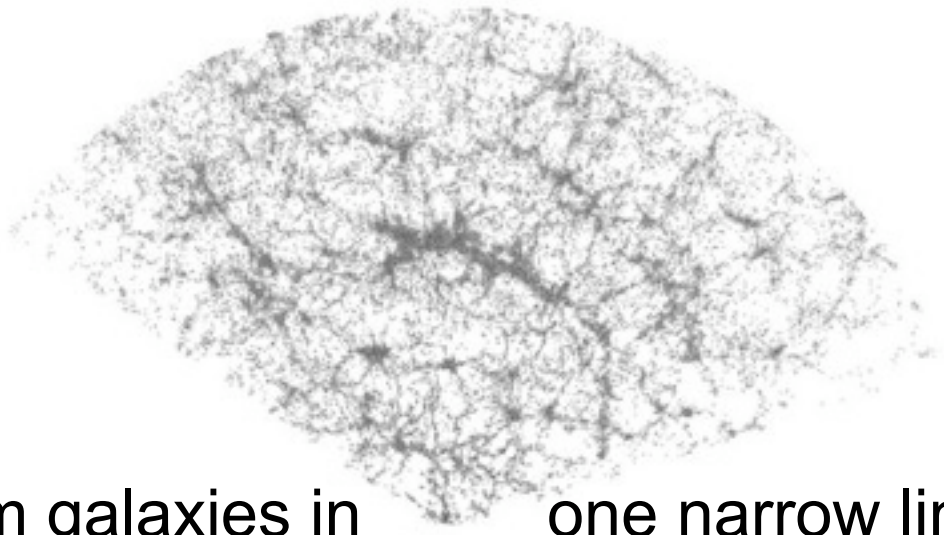
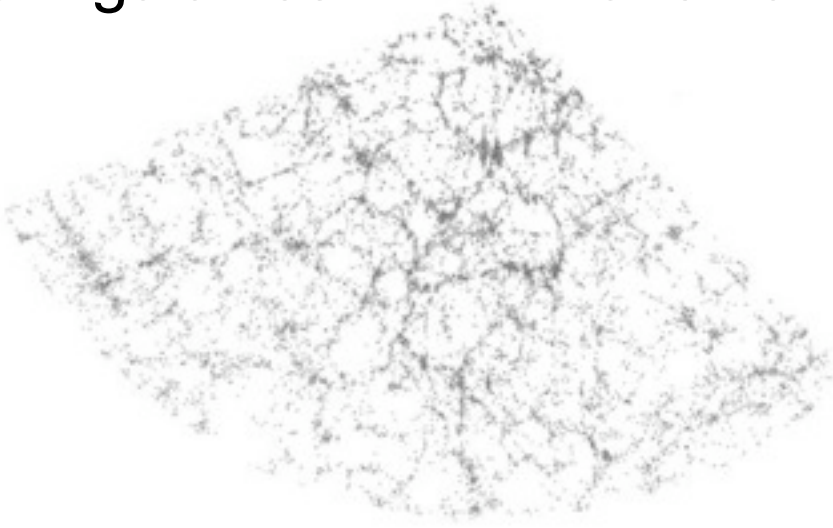


all emission from galaxies in one narrow line emission



no colors - just redshifts: GRAYSCALE

Redshift Resolution

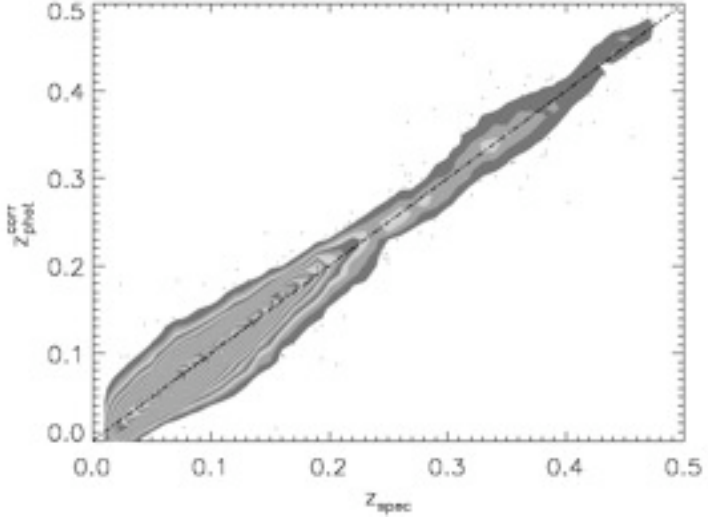
Unlike Optical / IR for 21cm

Redshift Determination is Easy and Cheap

FFT RF spectral analyzer of incoming signal (1GHz).

Imaging and spectroscopy in same observation.

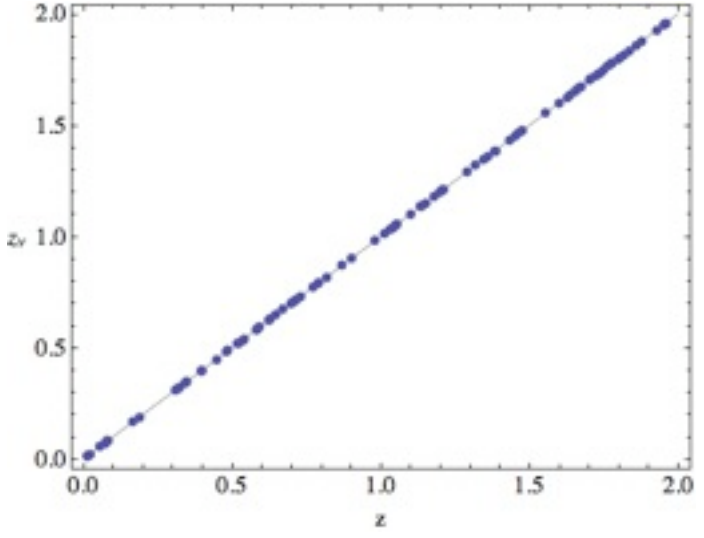
cheap photometric z



D'Abrusco 2007

versus

cheap radio z



good radial resolution

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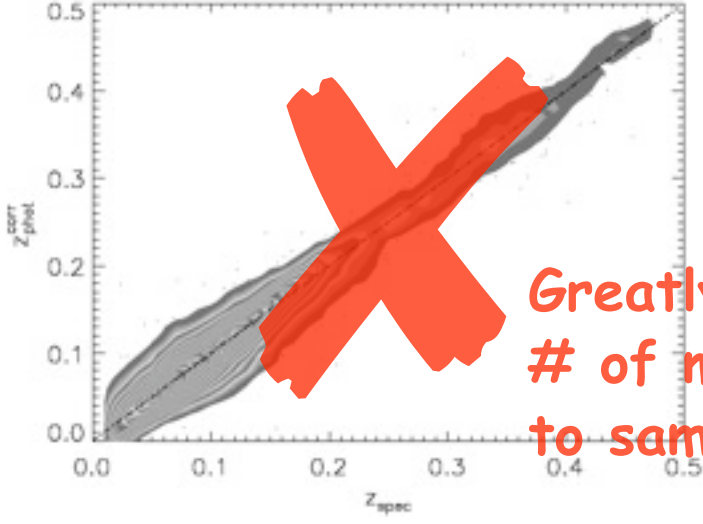
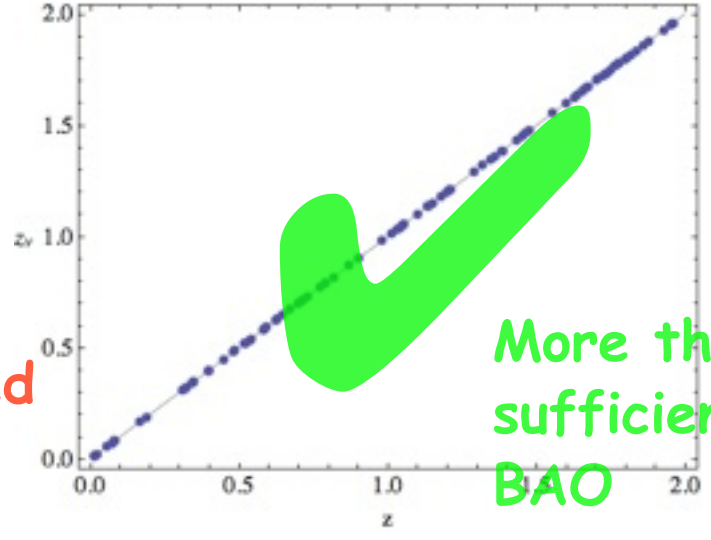


Greatly limits # of modes used to sample BAO

D'Abrusco 2007

versus

cheap radio z



More than sufficient for BAO

good radial resolution

$\theta \sim \lambda / D$

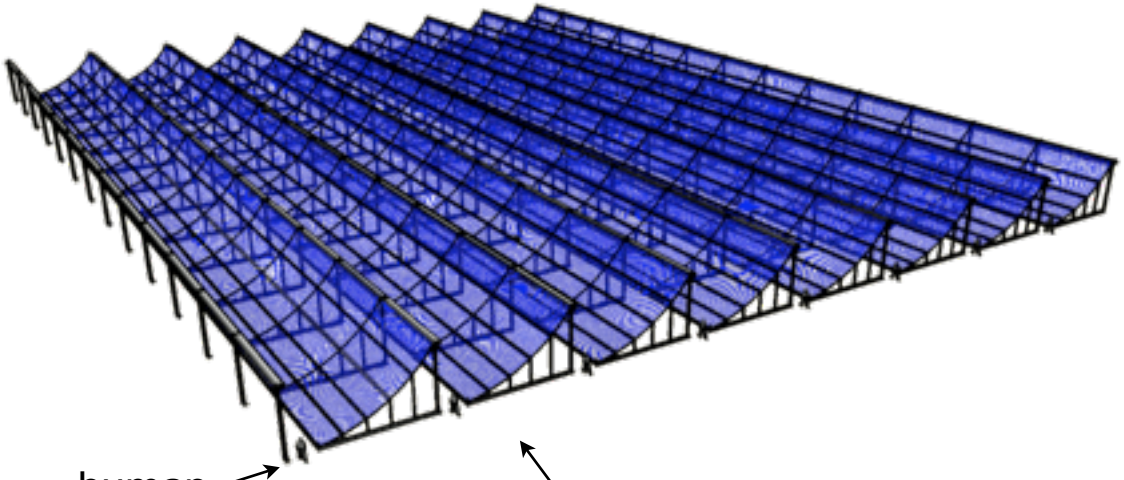
Angular Resolution is more challenging for 21cm than for optical / IR because of diffraction limit.

Need 100m telescope for only 10' resolution!

Fortunately cost per unit area is small.

SDSS 2.5 m

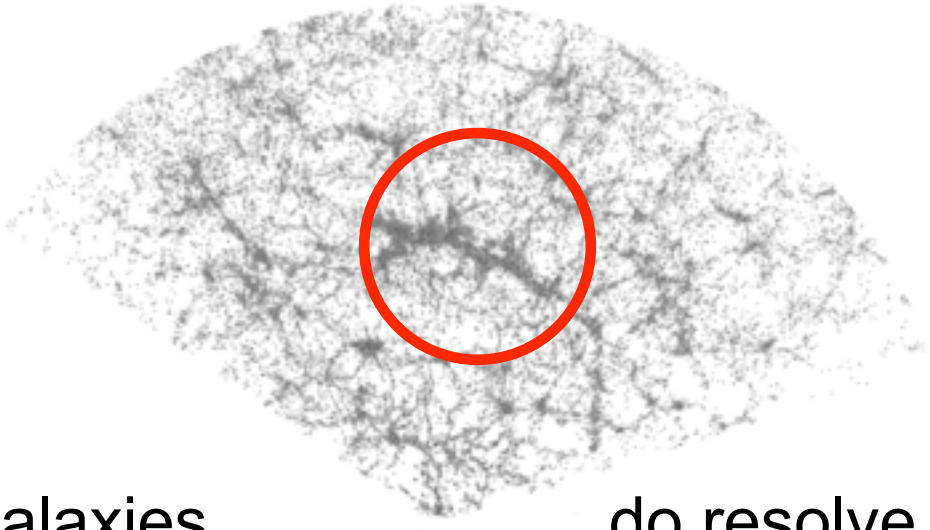
DES 4 m (Blanco)



human

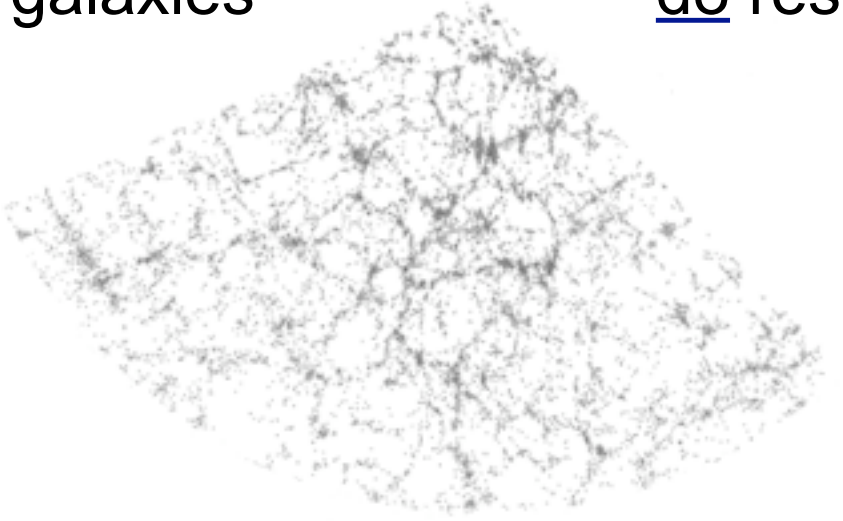
CRT 100 m

INTENSITY MAPPING



do not resolve galaxies

do resolve LSS / BAO



Peterson *et al* 2006

Wang *et al* 2006

Seo et al. 2010.

Expensive to resolve individual galaxies (e.g. SKA)

instead only resolve what is needed for BAO features!

INTENSITY MAPPING

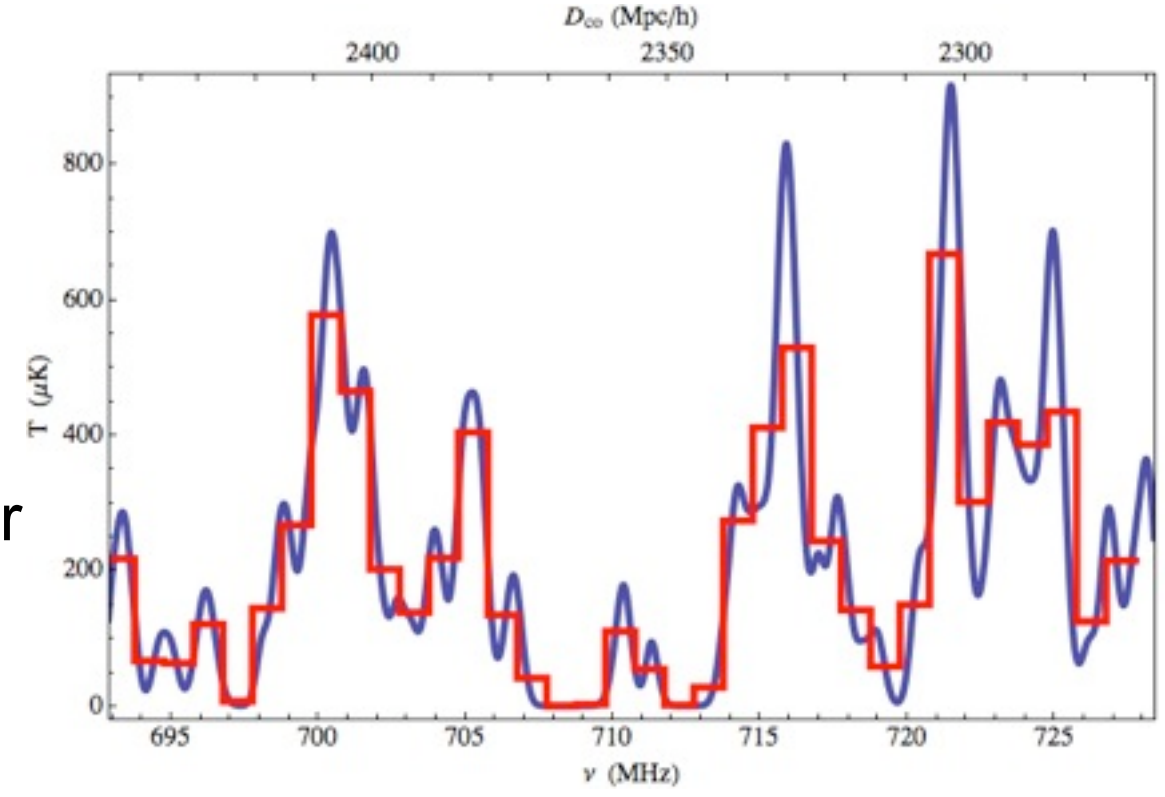
DEEP2

Δv=1 MHz

$\Delta\theta$=10’

Tully-Fisher

$M_{HI} \propto L_B$

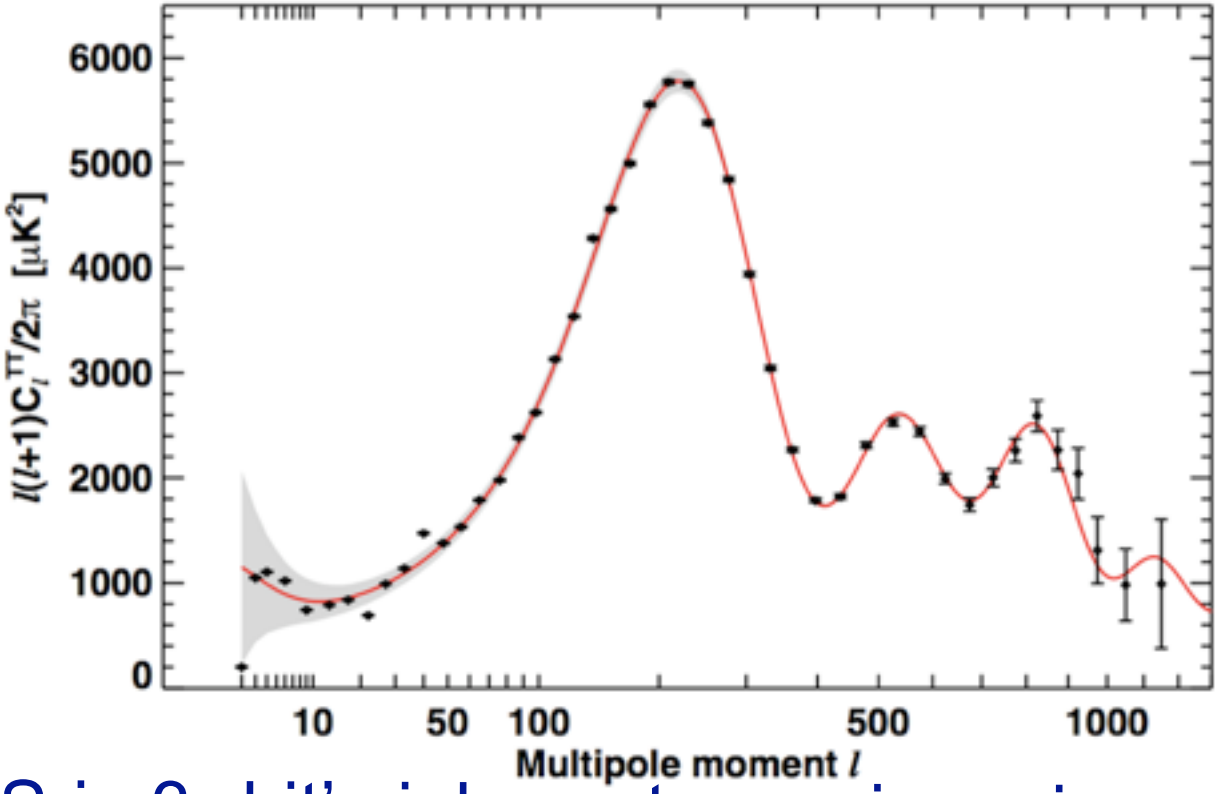


CRT

We can <u>nearly</u> resolve galaxies in redshift space.

Is 21cm the Future of Cosmic Cartography?

Sample variance has been one of the major limitations in using cosmic maps to accurately determine cosmological parameters!



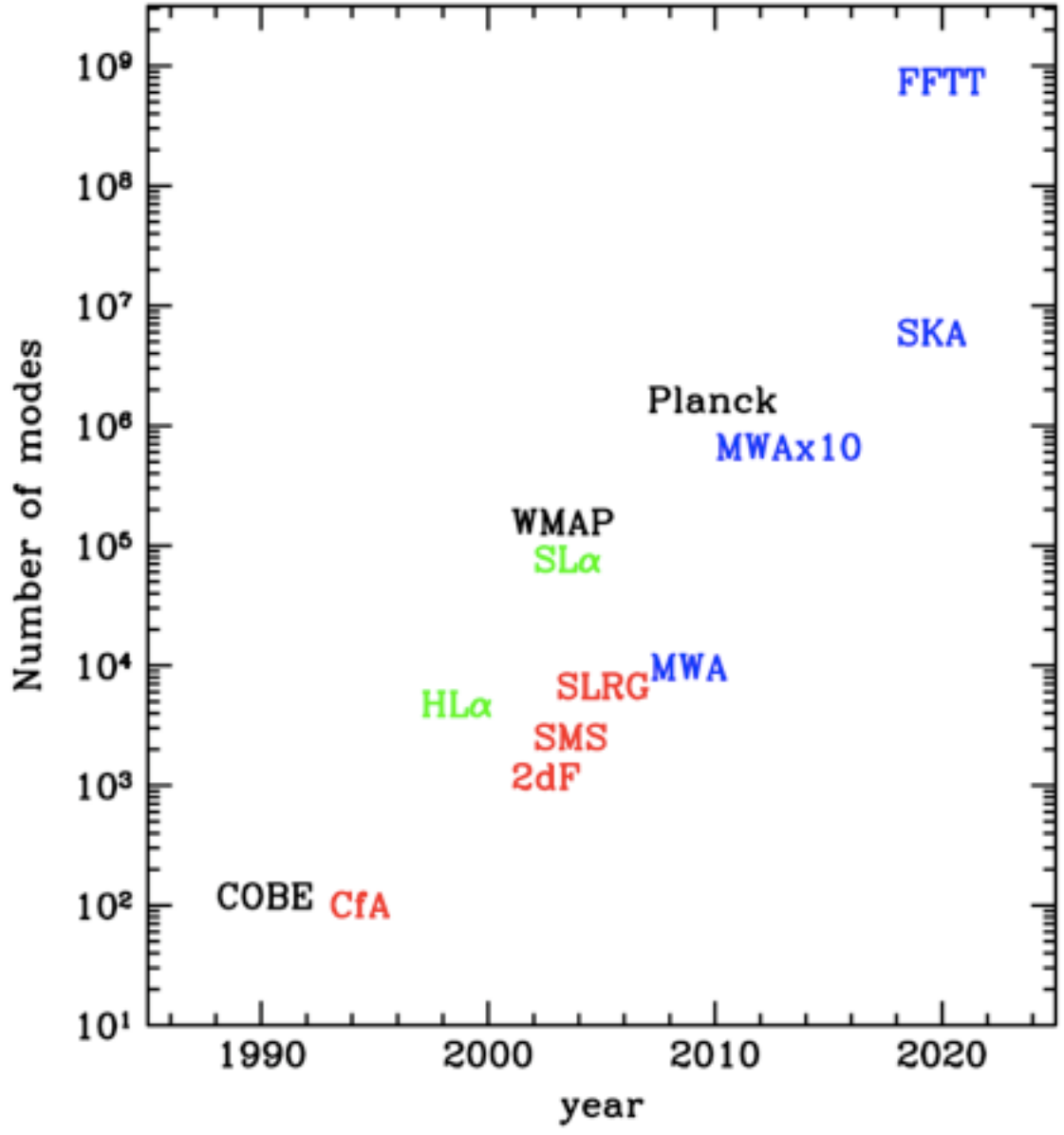
WMAP 7yr data

cosmic variance "noise"

Larson et al 2010

Since LSS is 3-d it's inherent cosmic variance limits are less than that for 2-d CMBR maps.

Sensitivity ~ 1/√(# of modes)



Tegmark Zaldarriaga 2008

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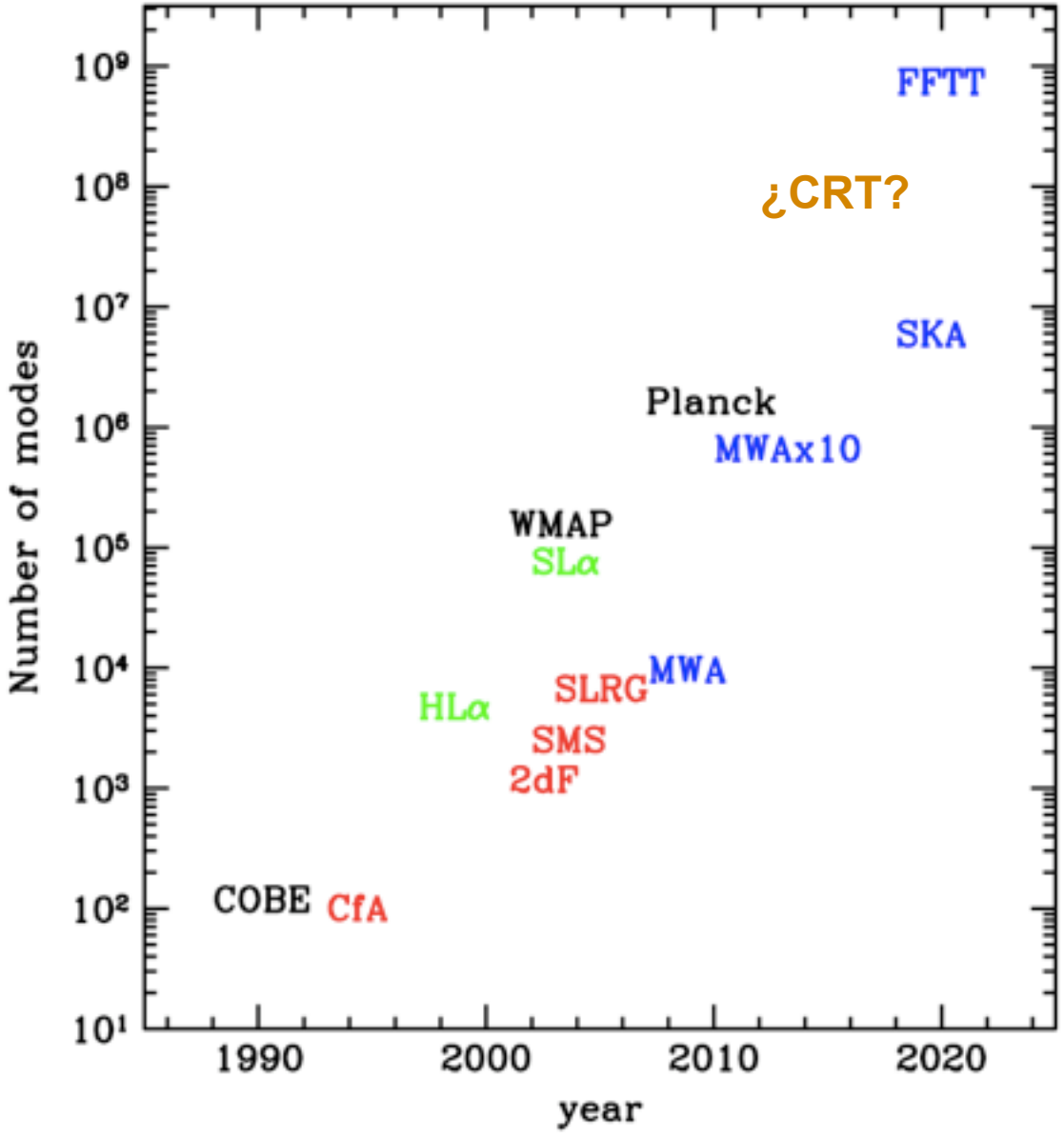

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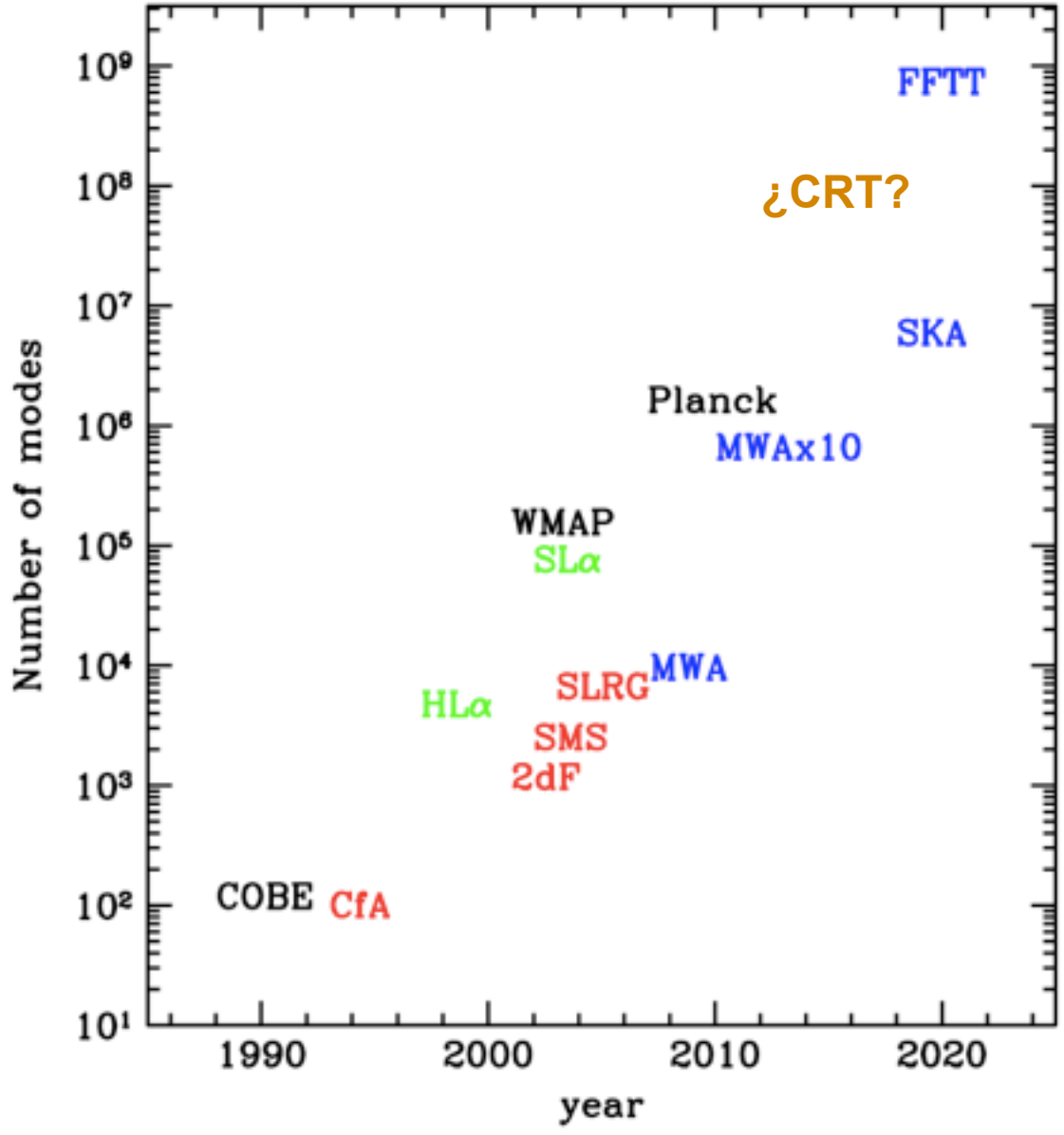
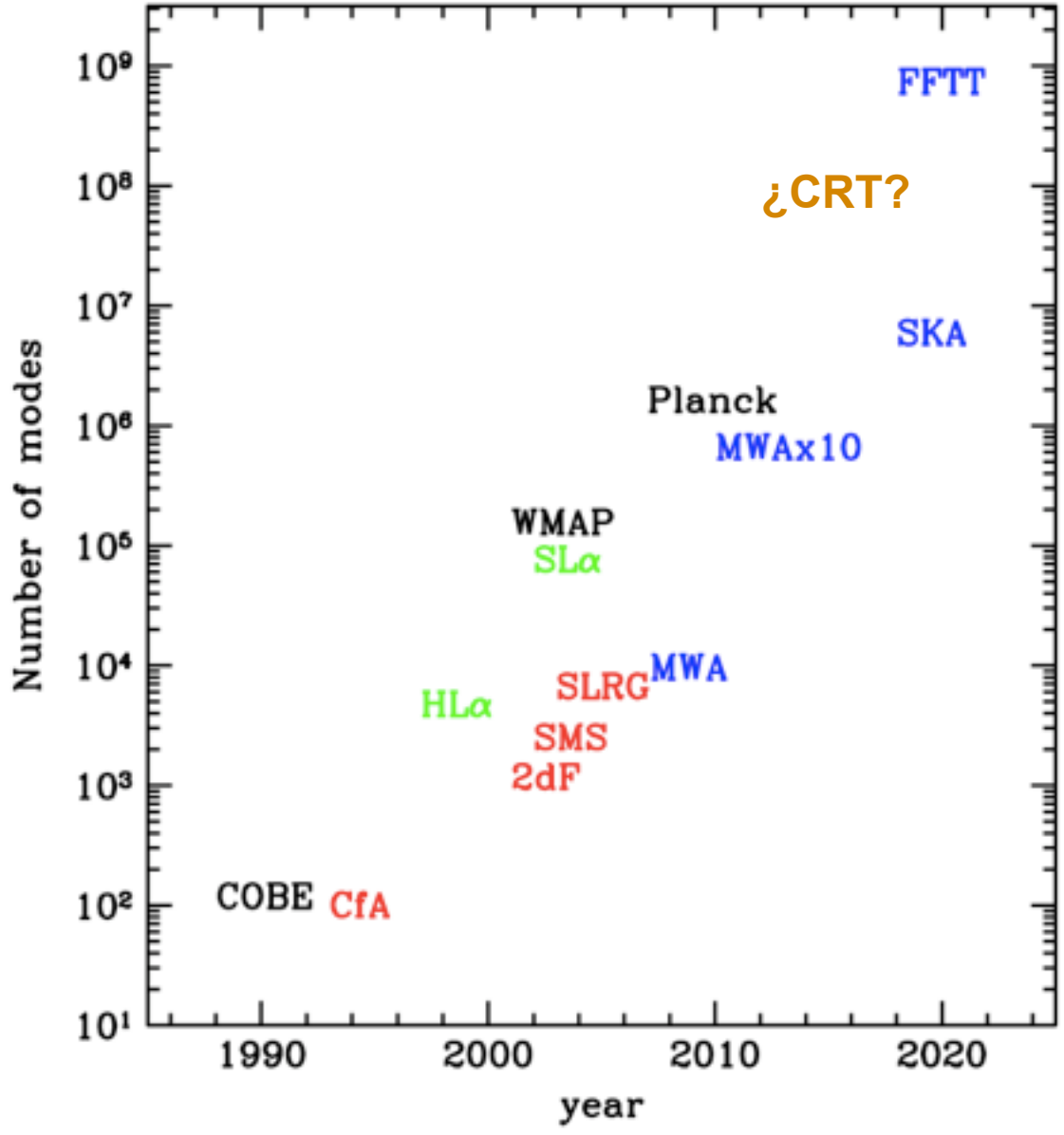


Tegmark Zaldarriaga 2008

Or course both quality and quantity matters!

Understanding systematic errors will be an essential part of the CRT program.

Sensitivity ~ 1/√(# of modes)



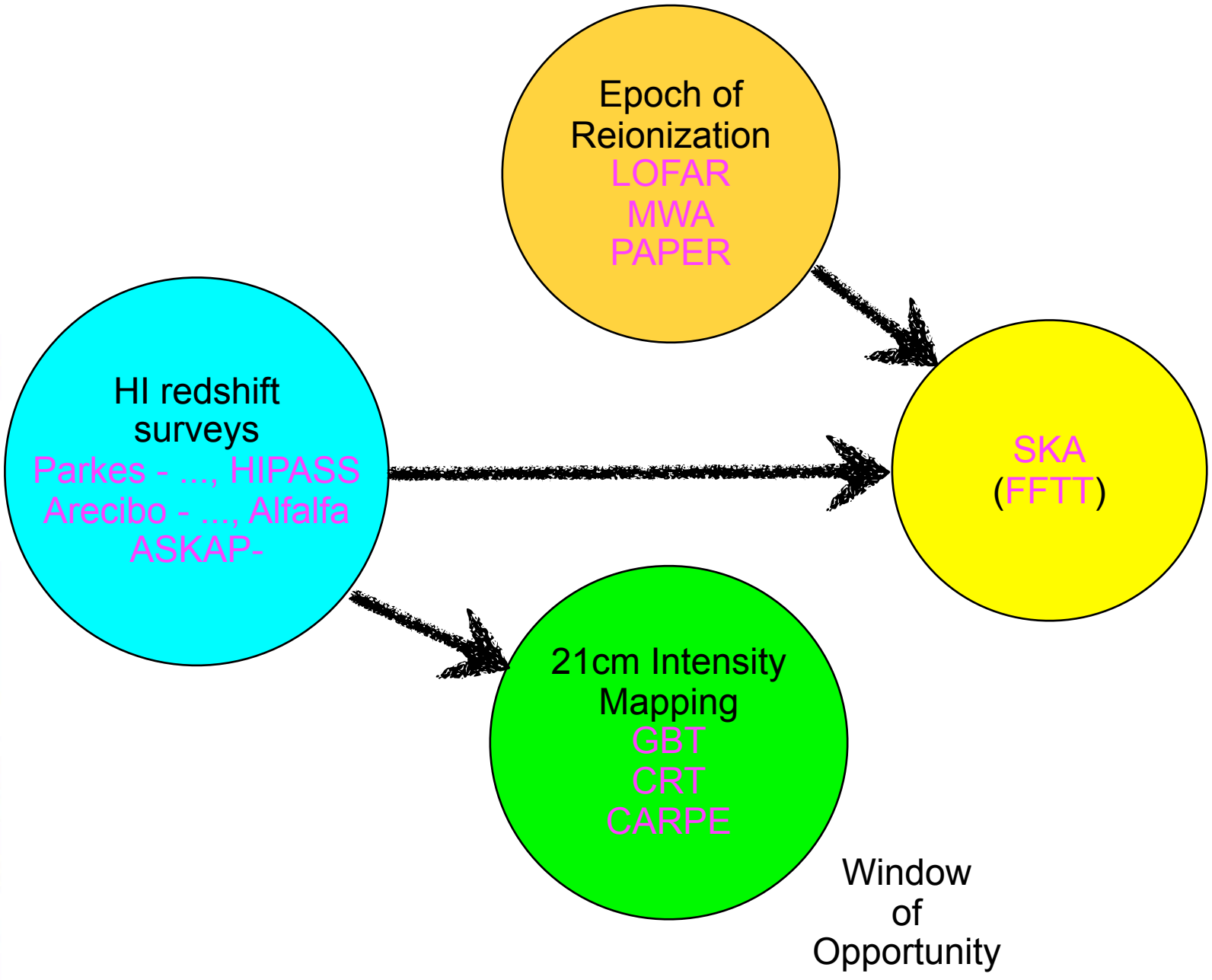
Tegmark Zaldarriaga 2008

Or course both quality and quantity matters!

Understanding systematic errors will be an essential part of the CRT program.

This project would allow FNAL to get in on the "ground floor" to the "era of 21cm cosmology".

Era of 21 cm Cosmology



Cosmic Cartography

Resolved galaxies

Unresolved galaxies

Gas - The Dark Ages

Epoch of Recombination

Galaxy Evolution

21cm

Synchrotron emission

Cosmic Magnetism

Science with SKA (circa 2004)

KEY PROJECTS (3/5)

3. Strong-field tests of gravity using pulsars and black holes

4. The origin and evolution of cosmic magnetism

5. Galaxy evolution, cosmology and dark energy with the Square Kilometre Array

6. Probing the dark ages with the Square Kilometre Array

OTHER SCIENCE PAPERS

11. Strong gravitational lensing with SKA

12. Measuring changes in the fundamental constants with redshifted radio absorption lines

13. Sunyaev-Zeldovich effects, free-free emission, and imprints on the cosmic microwave background

14. Searching for intergalactic shocks with the Square Kilometre Array

19. The accretion history of the Universe with the SKA

23. From gas to galaxies

24. Predictions for the SKA from hierarchical galaxy formation model

27. HI imaging the low red-shift cosmic web

29. SKA observations of the cosmic web

40. Strong-field tests of gravity using pulsars and black holes

44. Observing gravitational radiation with QSO proper motions and the SKA

49. Exploration of the unknown

DE Prospects

There are different concepts for how to do a 21cm BAO survey, but generally speaking

- Unlike optical / IR - redshifts (high & low) are relatively easy (*e.g.* z ~ 0.5 - 2)
- Unlike optical / IR - very large survey areas are also easy (*e.g.* 3π steradians).
- We expect a Stage-III+ DE probe might cost $20M.

Additional Slides

Has Anyone Done This Before?

A positive signal was found in cross-correlation between HIPASS intensity map and 2df galaxy survey (Pen et al. 2008)

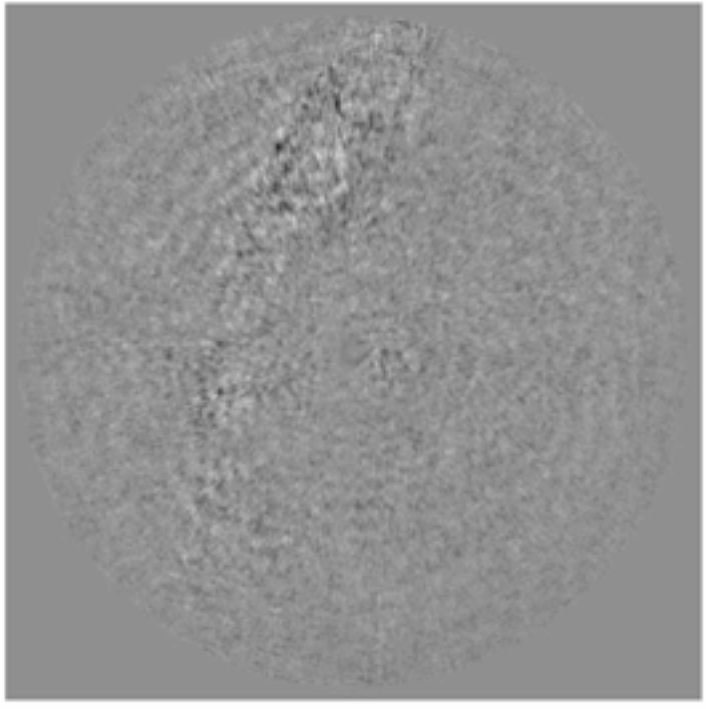


Figure 1. The HIPASS data cube $R < 127h^{-1}$ Mpc, projected in a cartesian coordinate system towards the south pole.

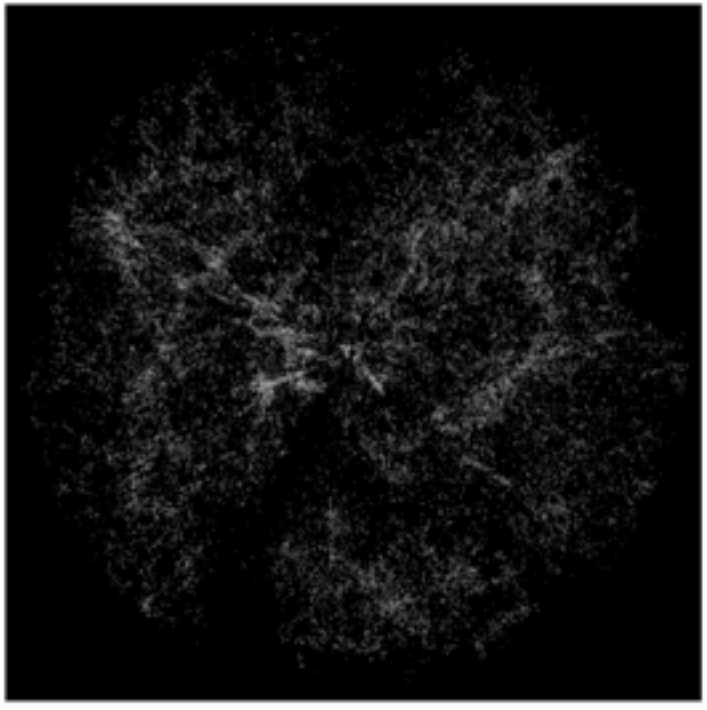


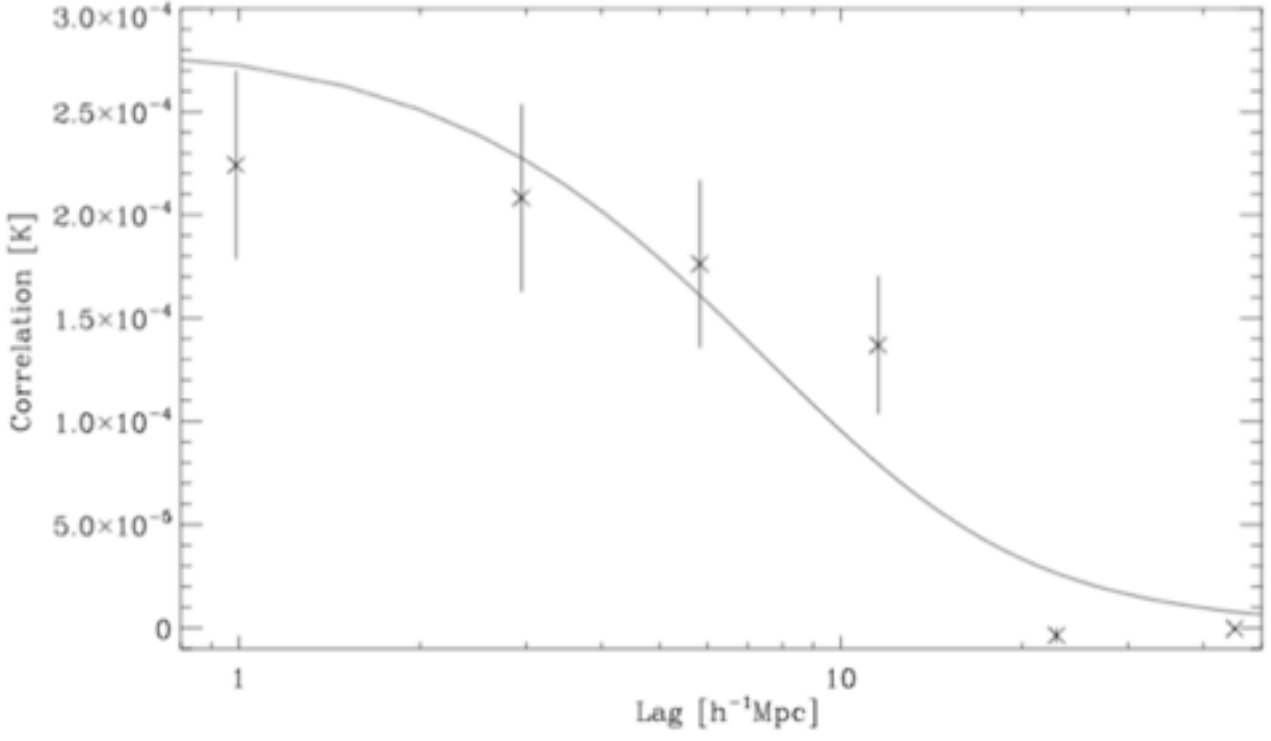
Figure 2. The 6dFGS catalog for $R < 127h^{-1}$ Mpc, also projected towards the south pole. The missing wedges are the galactic plane.

For DE one would need auto-correlation!

Has Anyone Done This Before?

HI & Optical cross-correlation at z~0.8

- Shows correlation between hydrogen and Deep2 optical galaxy surveys to 10 Mpc



Chang, Pen, Peterson, Bandura, submitted