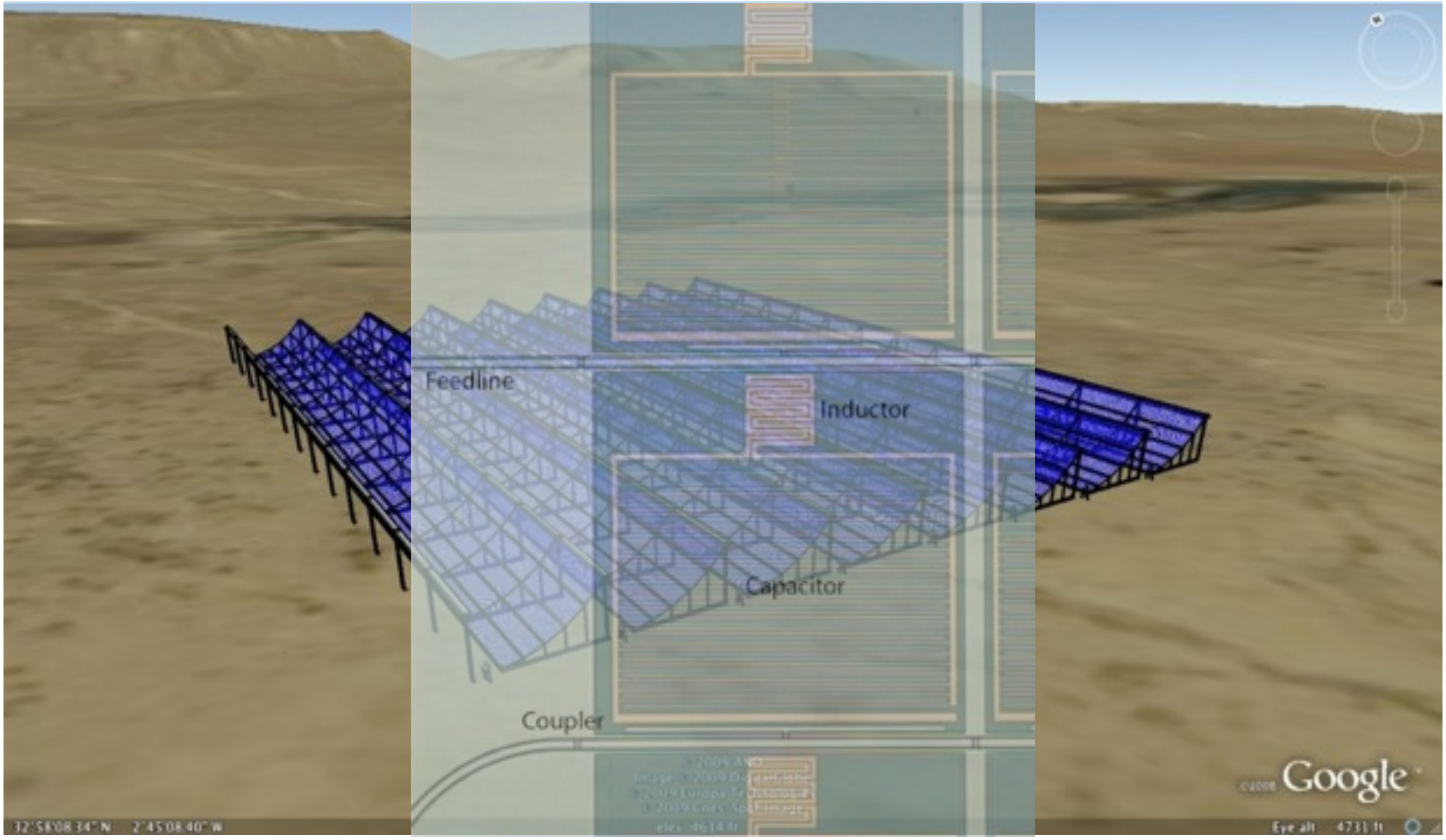
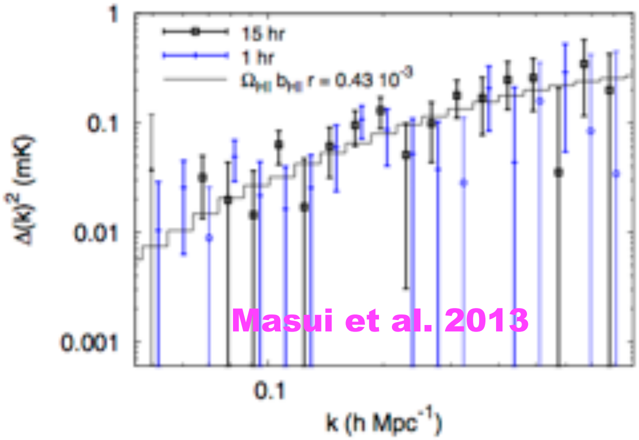
Mapping Redshift Space:
HIM & MKIDs & Photometric Surveys



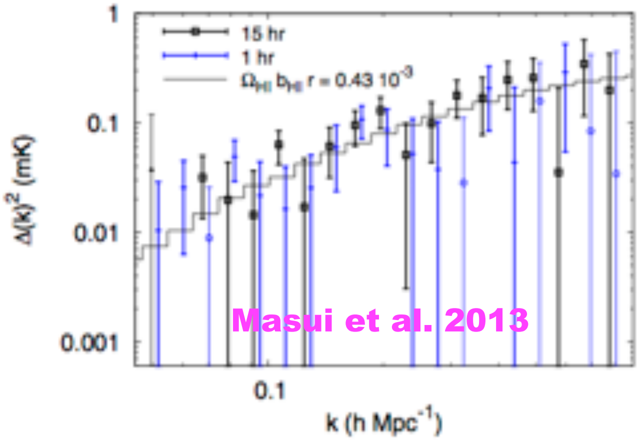
MKIDs and Cosmology
26 August 2013
Fermilab
Batavia, USA

Albert Stebbins
Fermilab
Tzu-Ching Chang & Jean Coupon
ASIAA, Taiwan



15 hr
1 hr
$\Omega_{HI}\, b_{HI}\, r = 0.43\; 10^{-3}$
Masui et al. 2013
$\Delta(k)^2$ (mK)
1
0.1
0.01
0.001
0.1
k (h Mpc^{-1})

HI Intensity Mapping not Vaporware!



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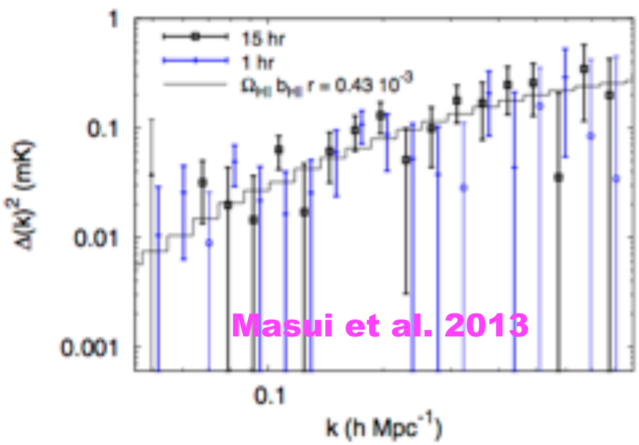

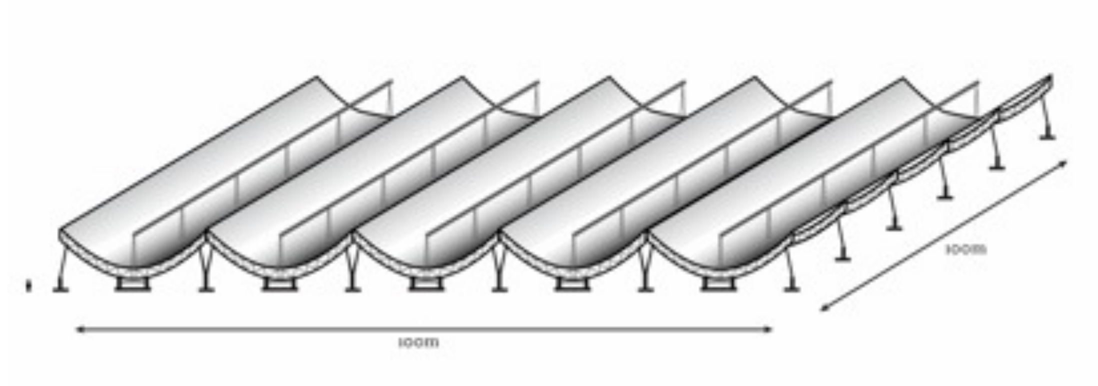

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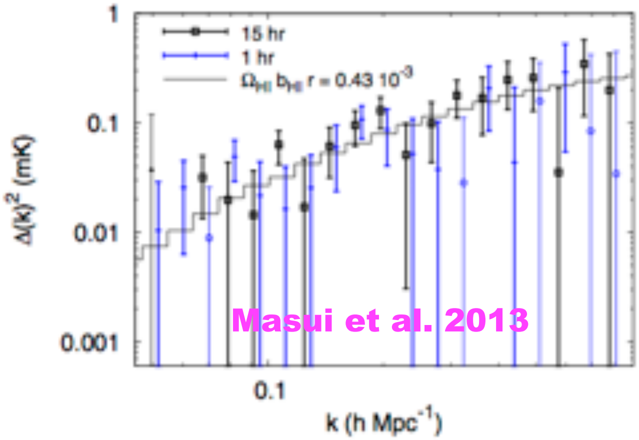
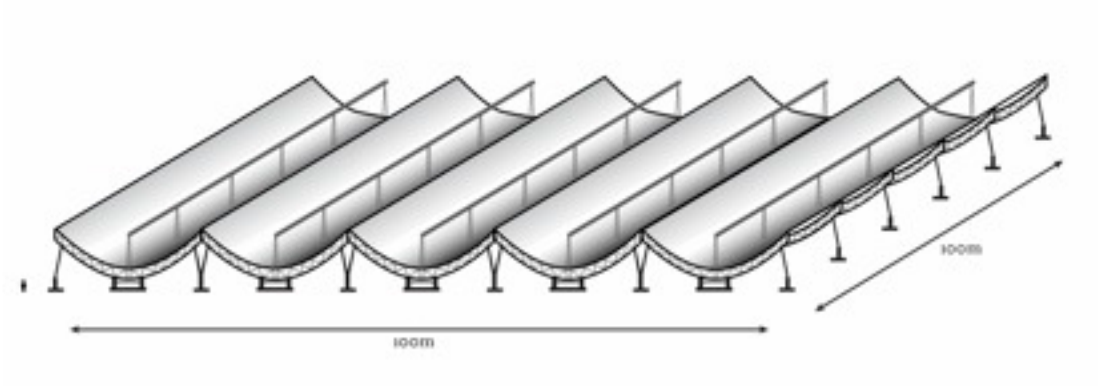




Green Bank Telescope
results

Canadian Hydrogen Intensity Mapping Experiment
DRAO, British Columbia
construction phase

天籁 / Tianlai / “Heavenly Sound”
Xinjiang, China

>20,000 sq. deg. at a time

Redshift Resolution

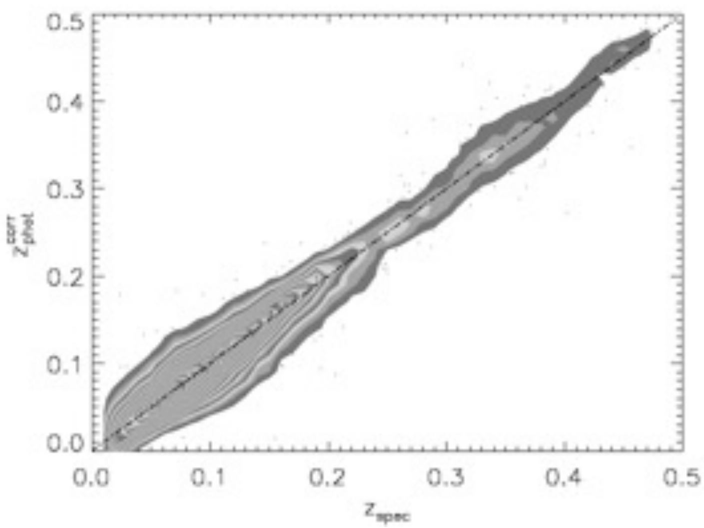
Unlike Optical / IR for 21cm

Redshift Determination is Easy and Cheap

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

Imaging and spectroscopy in same observation.

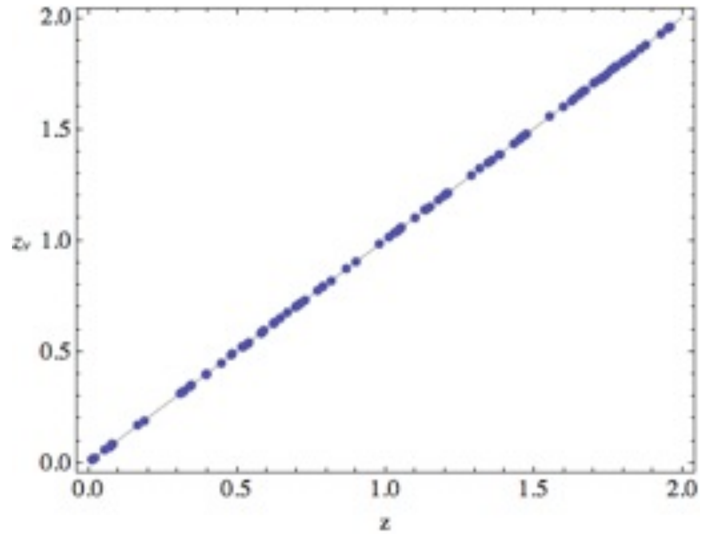
cheap photometric z



D'Abrusco 2007

versus

cheap radio z



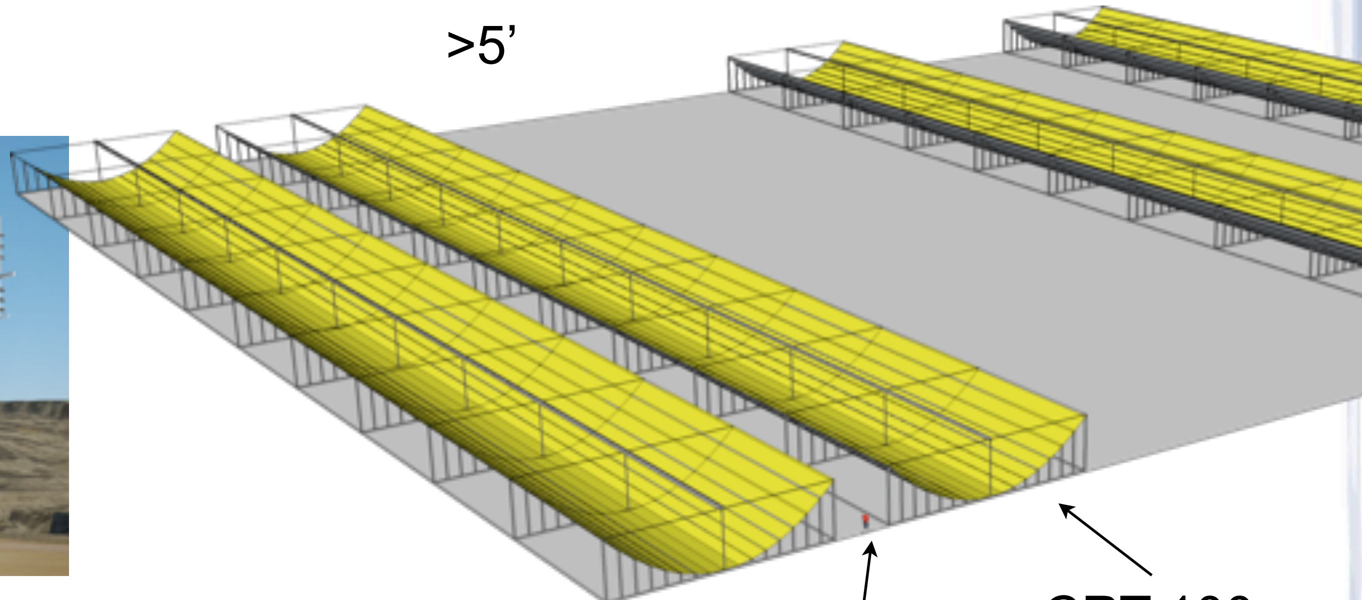
good radial resolution

$\theta \sim \lambda / D$

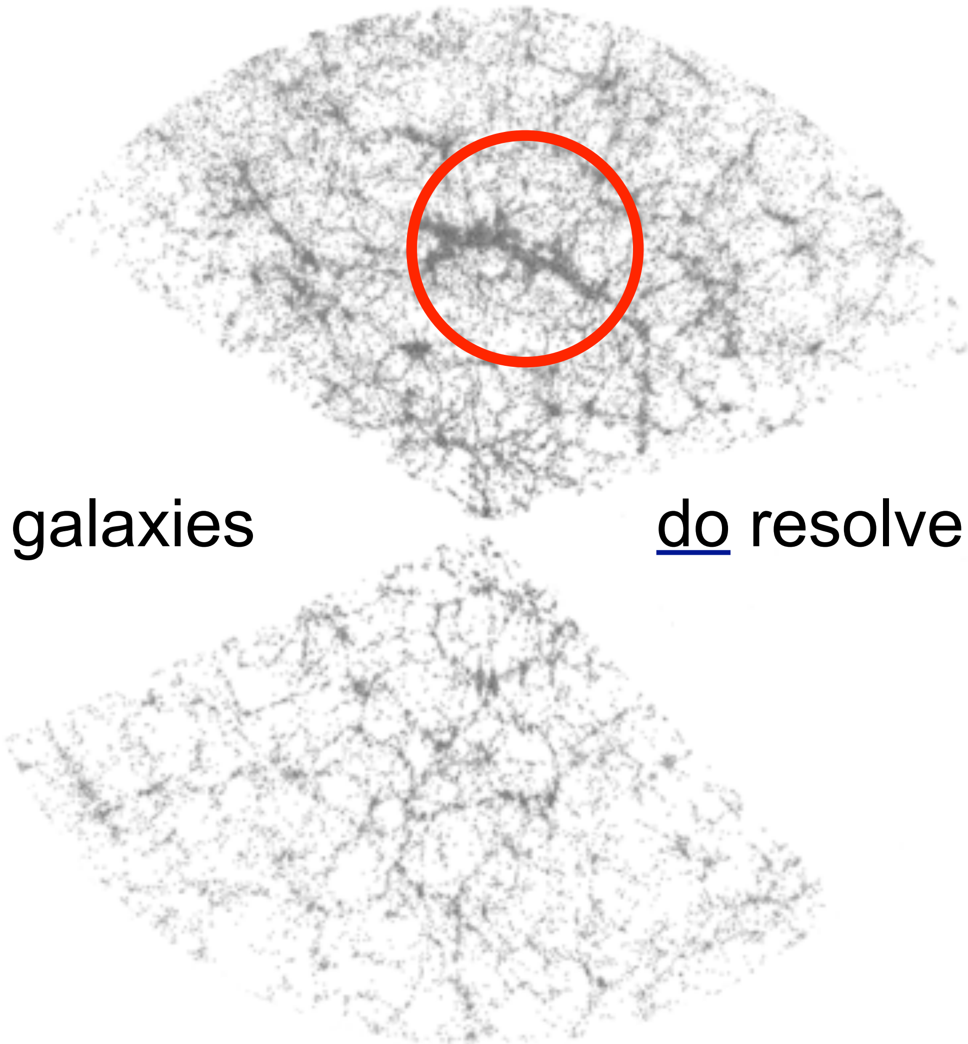
Angular Resolution is more challenging for 21cm than for optical / IR because of diffraction limit.

Need 100m telescope for only 10’ resolution!

Fortunately cost per unit area is small.



INTENSITY MAPPING



<u>do not</u> resolve galaxies

<u>do</u> resolve LSS / BAO

Peterson *et al* 2006

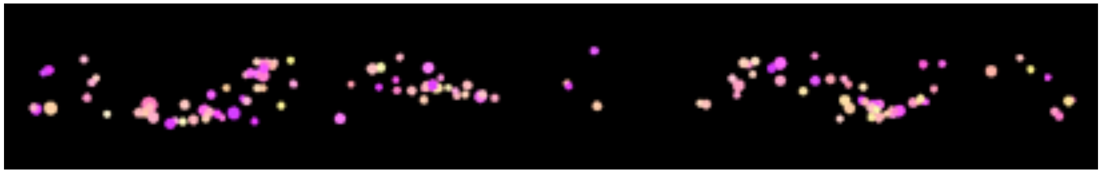
Wang *et al* 2006

Seo et al. 2010.

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

instead only resolve what is needed for BAO features!

NON-GAUSSIAN INTENSITY MAPS



DEEP2

Davis ++ 2004++

see **Wang ++ 2006**

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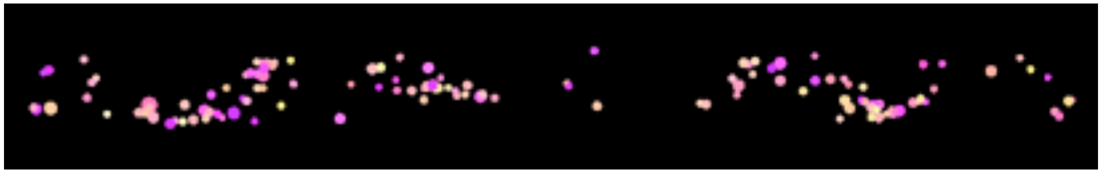

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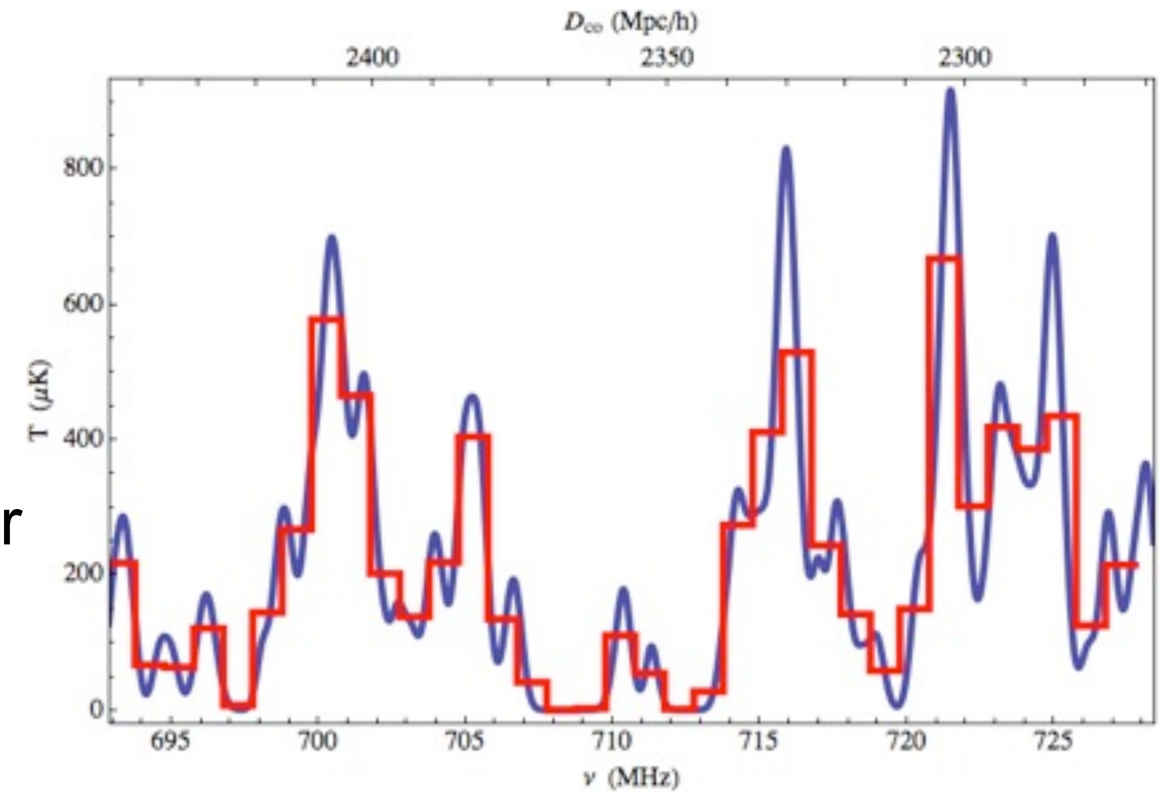

see **Wang ++ 2006**

$\Delta\nu$=1 MHz

$\Delta\theta$=10'

Tully-Fisher

$M_{HI} \propto L_B$

HI

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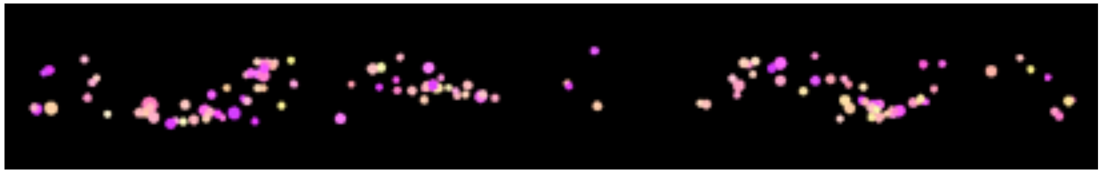

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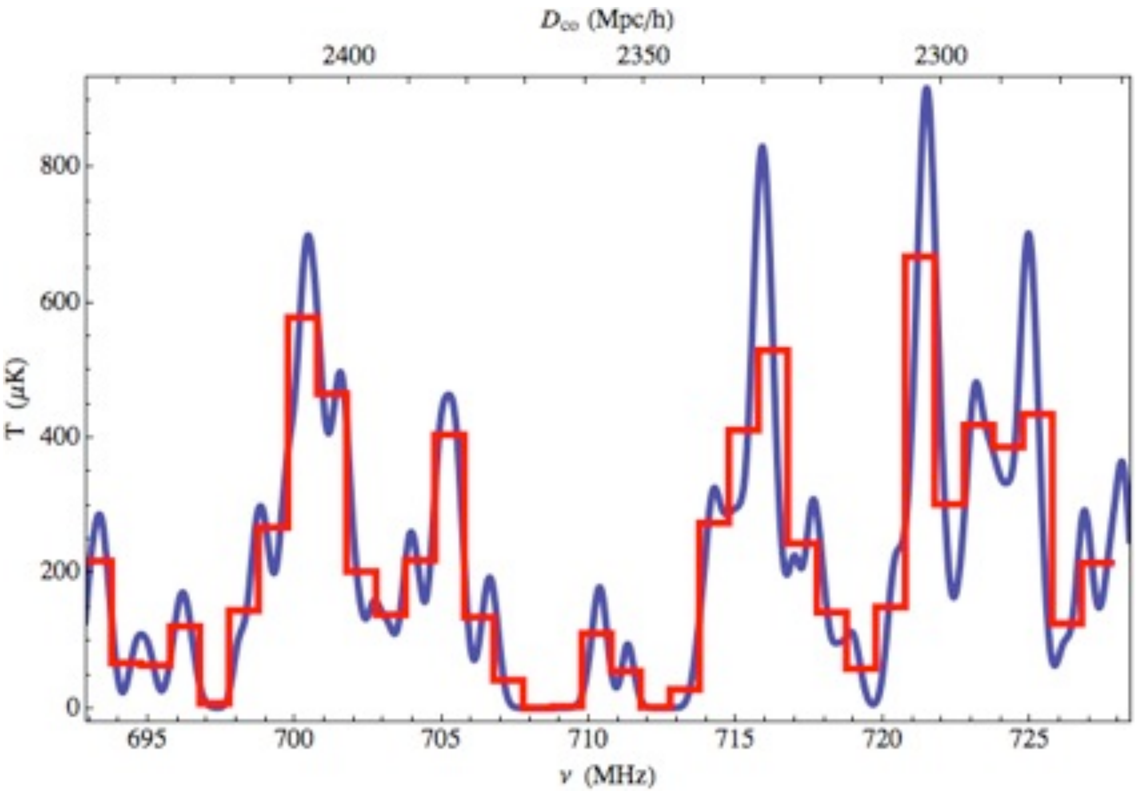


see **Wang ++ 2006**

$\Delta\nu$=1 MHz

$\Delta\theta$=10'

Tully-Fisher

$M_{HI} \propto L_B$

HI

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

Foreground Subtraction

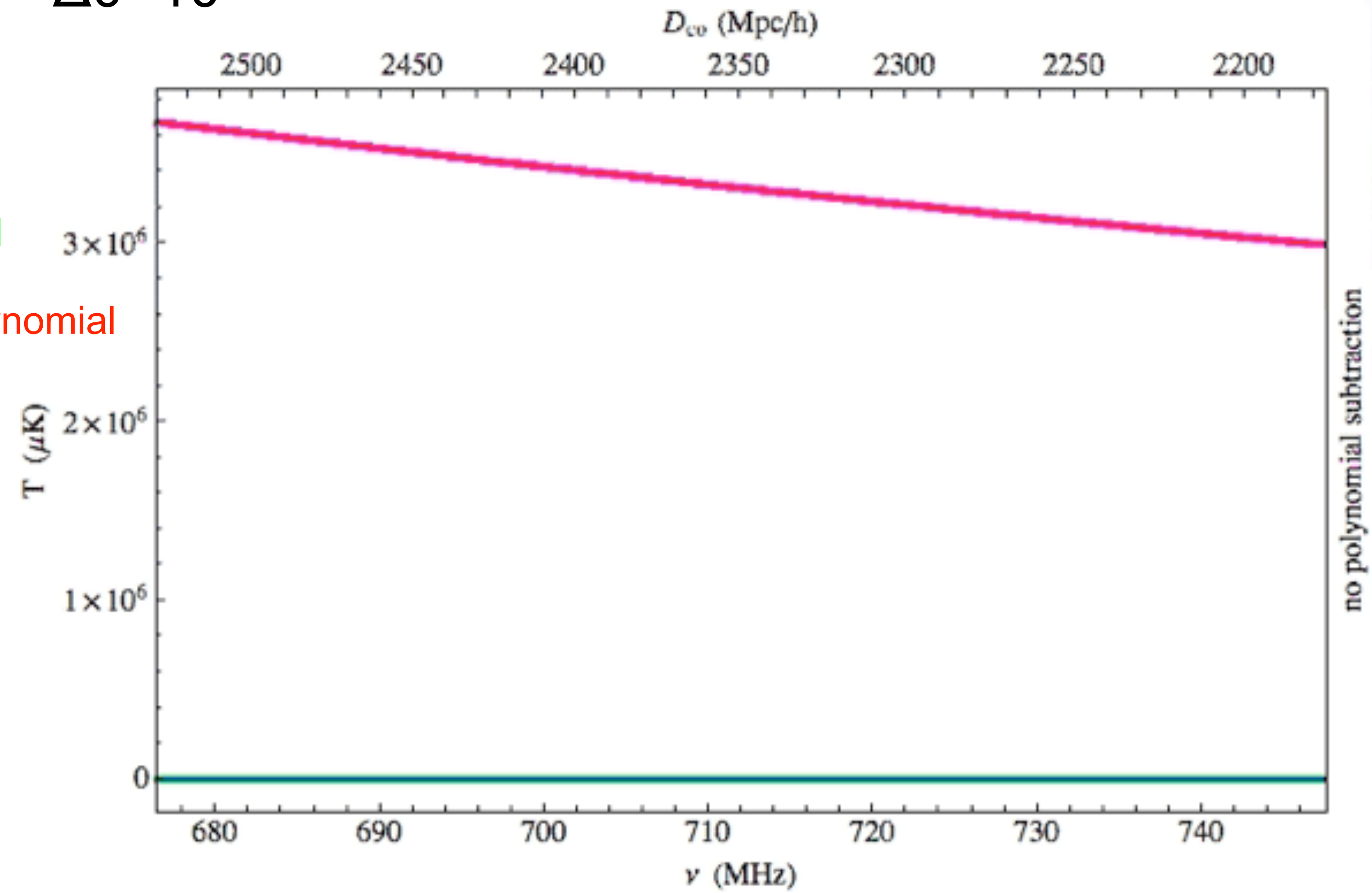
Δθ=10'

21 cm signal

21cm-polynomial

21 cm+synch-polynomial

residual

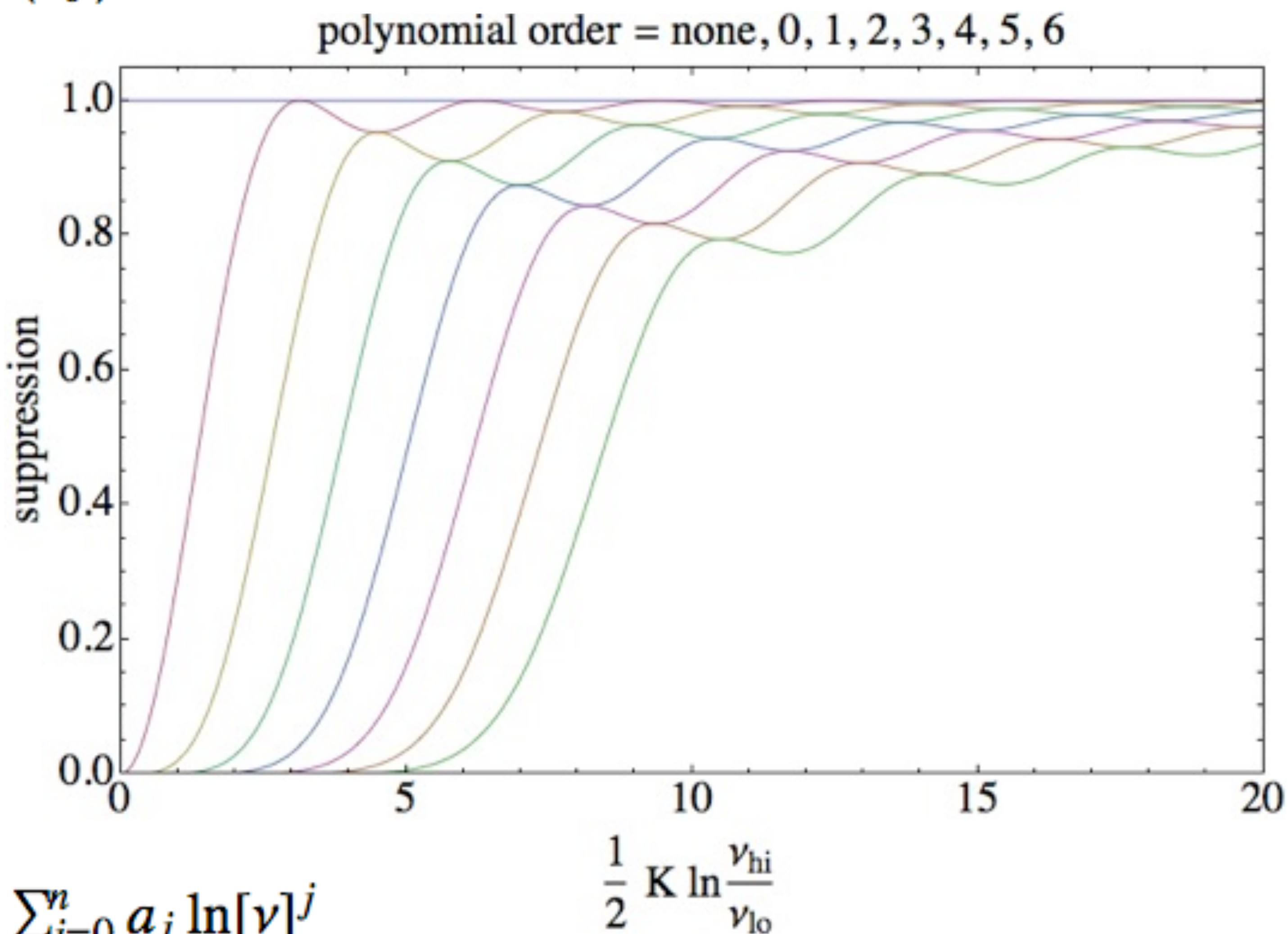


Model: Maximally Curved Synchrotron + DEEP2 galaxies

see also **Wang ++ 2006**

Loss From Polynomial Subtraction

$$I_\nu^{\text{sync}}[\hat{\boldsymbol{n}}] = \frac{I_0}{2\pi}\left(\frac{\nu}{\nu_0}\right)^p \int_{-\infty}^{\infty} dK\, e^{iK\ln\left[\frac{\nu}{\nu_0}\right]}\, \tilde{I}^{\text{obs}}_{(p)}[K]$$

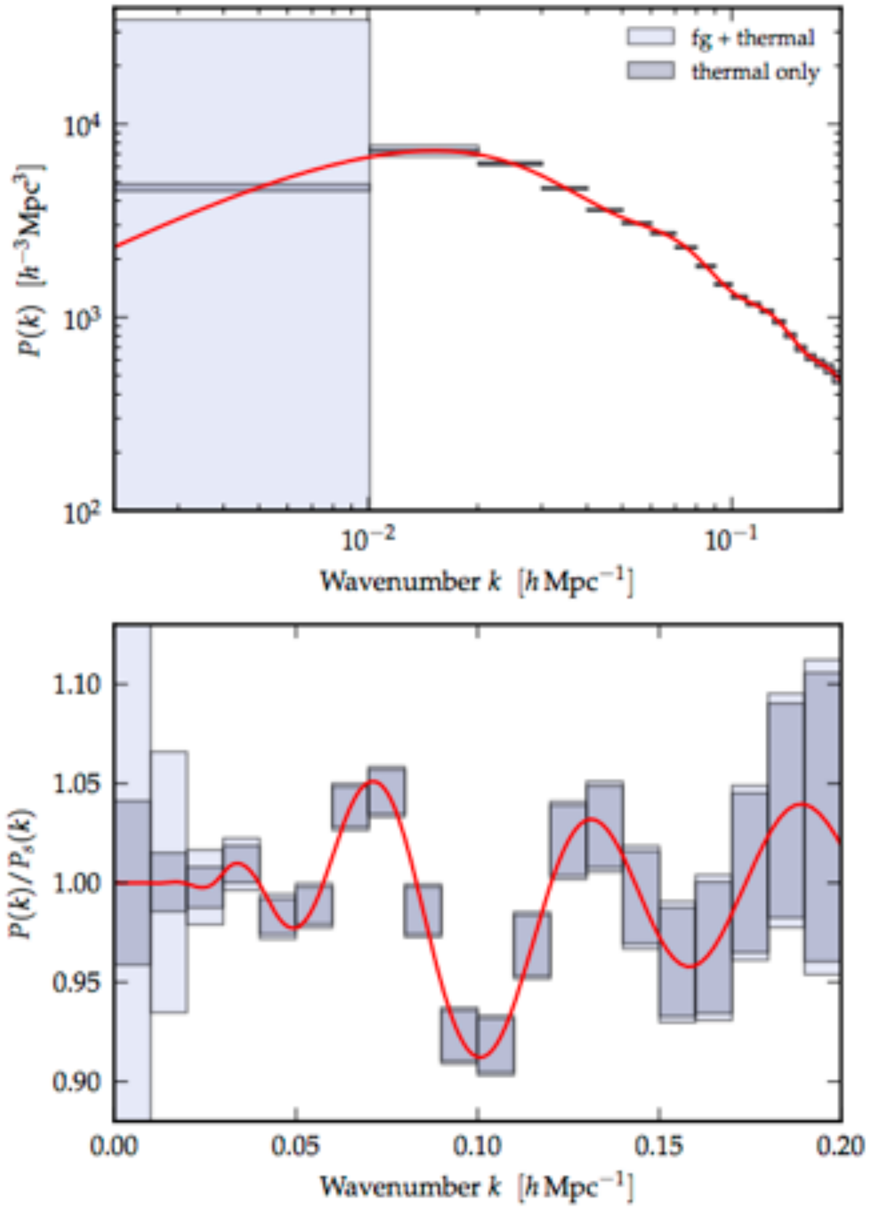


$$I_\nu^{\text{fit}} = (\nu/\nu_0)^p \sum_{j=0}^{n} a_j \ln[\nu]^j$$

Foreground Subtraction

More detailed simulation of residual foreground contamination for a cylinder telescope

Shaw *et al.* 2013



2 x 15m x 100m cylinders

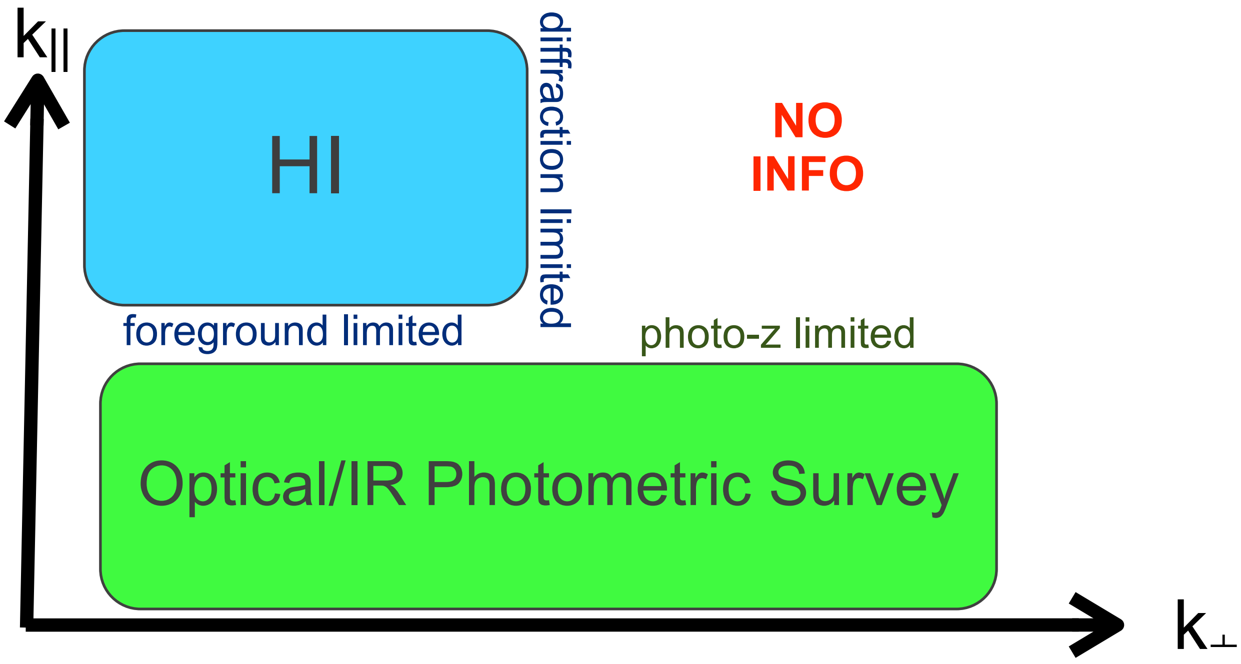
2 x 60 dual polarization feeds

T_{sys} = 50K

2 full years observation time

Better Together

spectral resolution of HI intensity mapping survey
angular resolution photometric optical / IR survey



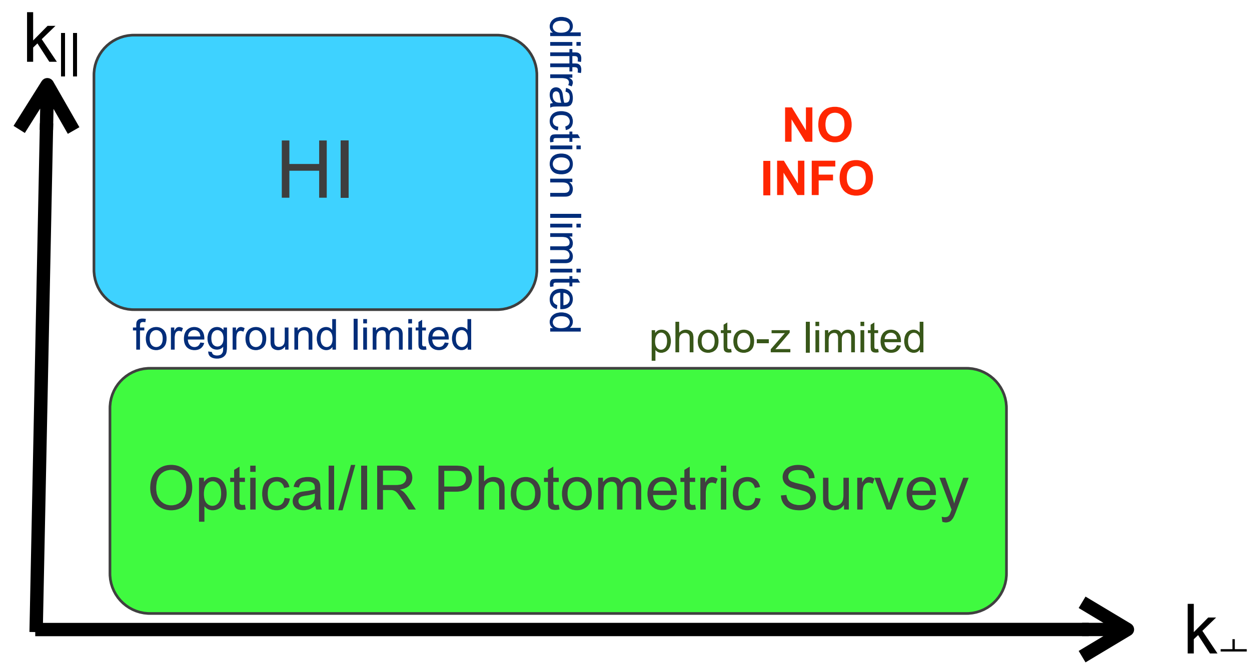
Better Together

spectral resolution of HI intensity mapping survey
angular resolution photometric optical / IR survey

Naive Combination:

inverse variance weighted estimates in k-space

$$\delta\rho/\rho(\mathbf{k}) = (\sigma_{opt}(\mathbf{k})^2\, \delta\rho/\rho_{HI}(\mathbf{k}) + \sigma_{HI}(\mathbf{k})^2\, \delta\rho/\rho_{opt}(\mathbf{k}))/(\sigma_{opt}(\mathbf{k})^2 + \sigma_{HI}(\mathbf{k})^2)$$



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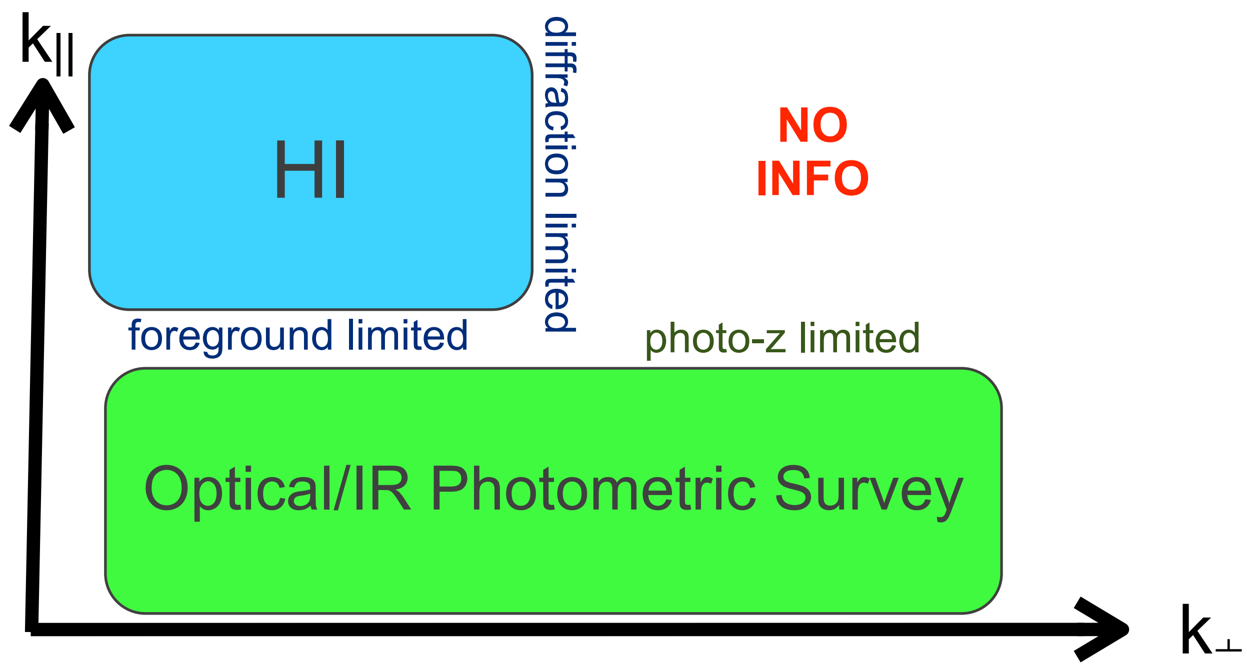


In linear (homogeneous Gaussian) theory this is optimal.

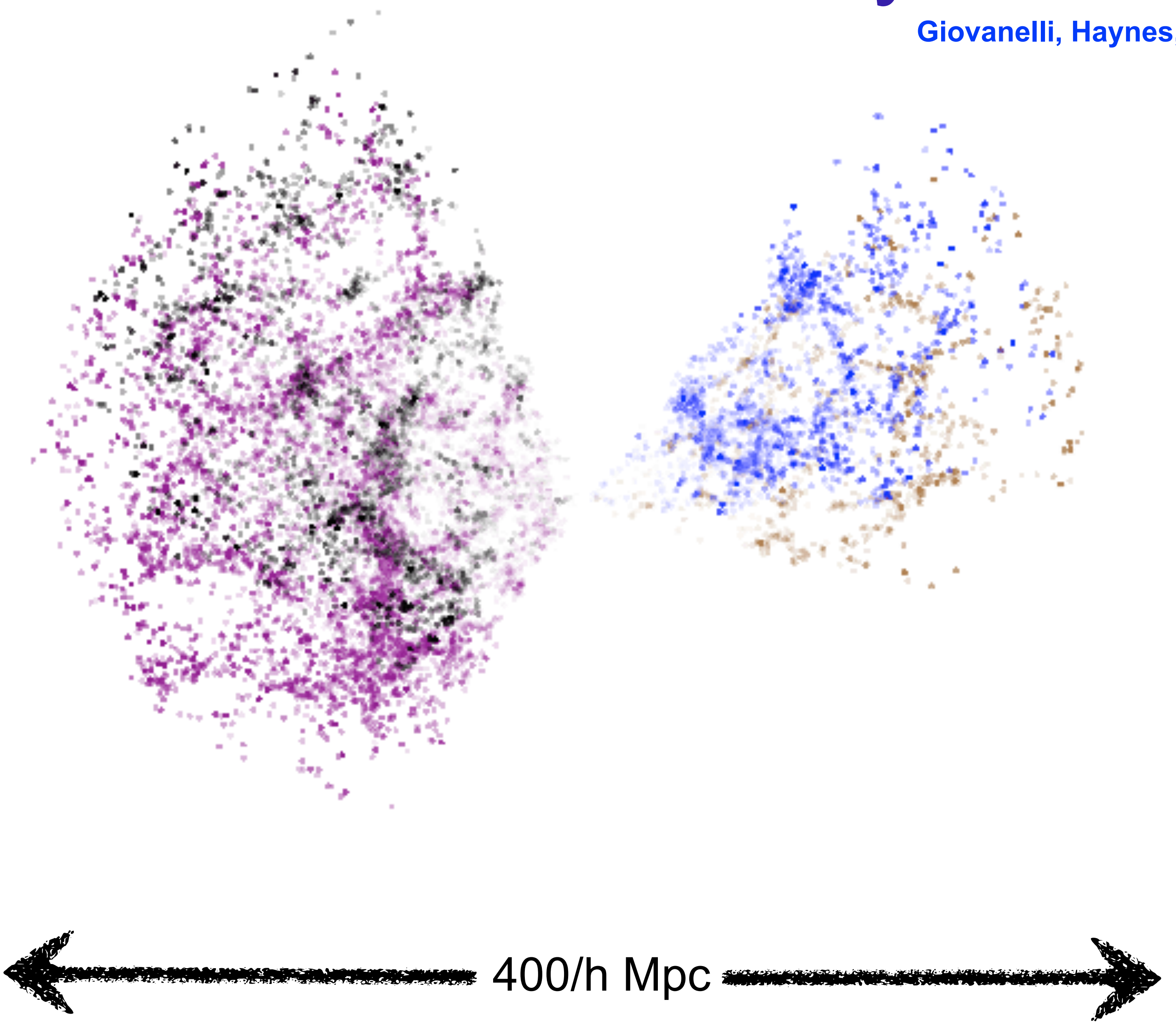
Alfalfa Survey

Giovanelli, Haynes, ++   2005++

400/h Mpc

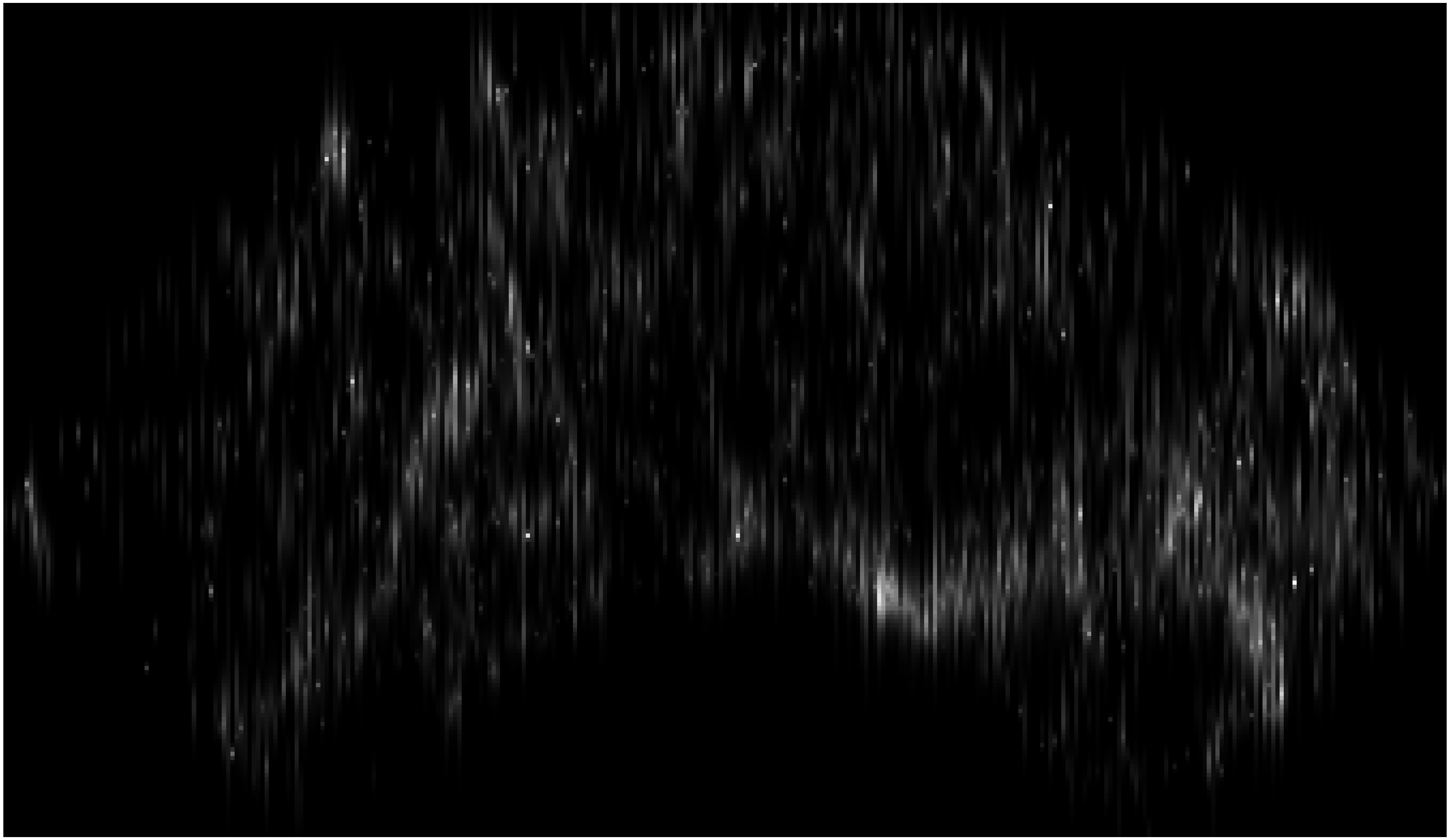
Alfalfa Survey

Giovanelli, Haynes, ++   2005++

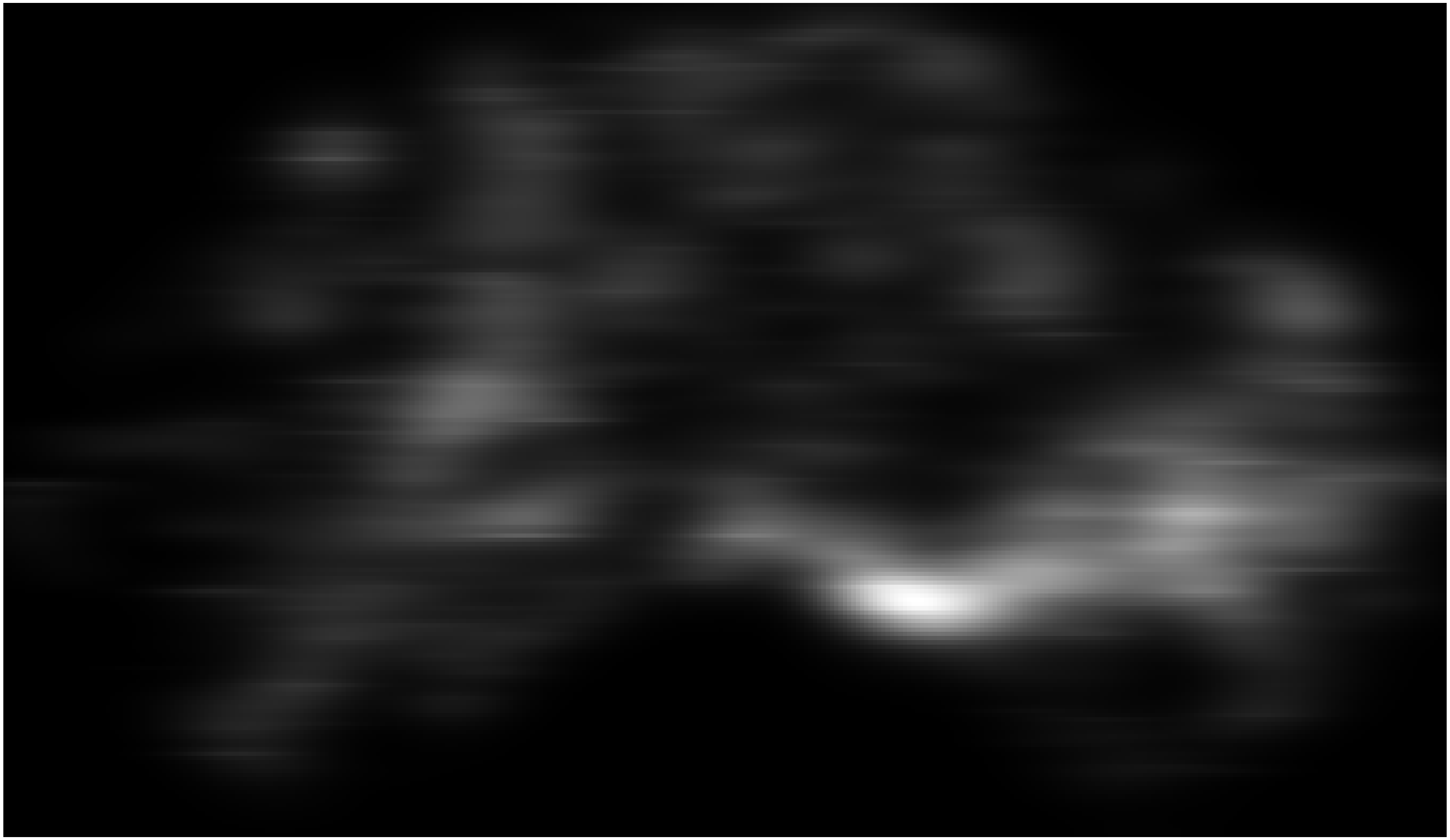


Slice Through ALFALFA Catalog

Slice through ALFALFA w/ Linewidth



ALFALFA @ z=1 w/ 10' beam



Alfalfa Survey

Moved to z=1
Convolved with 10' beam

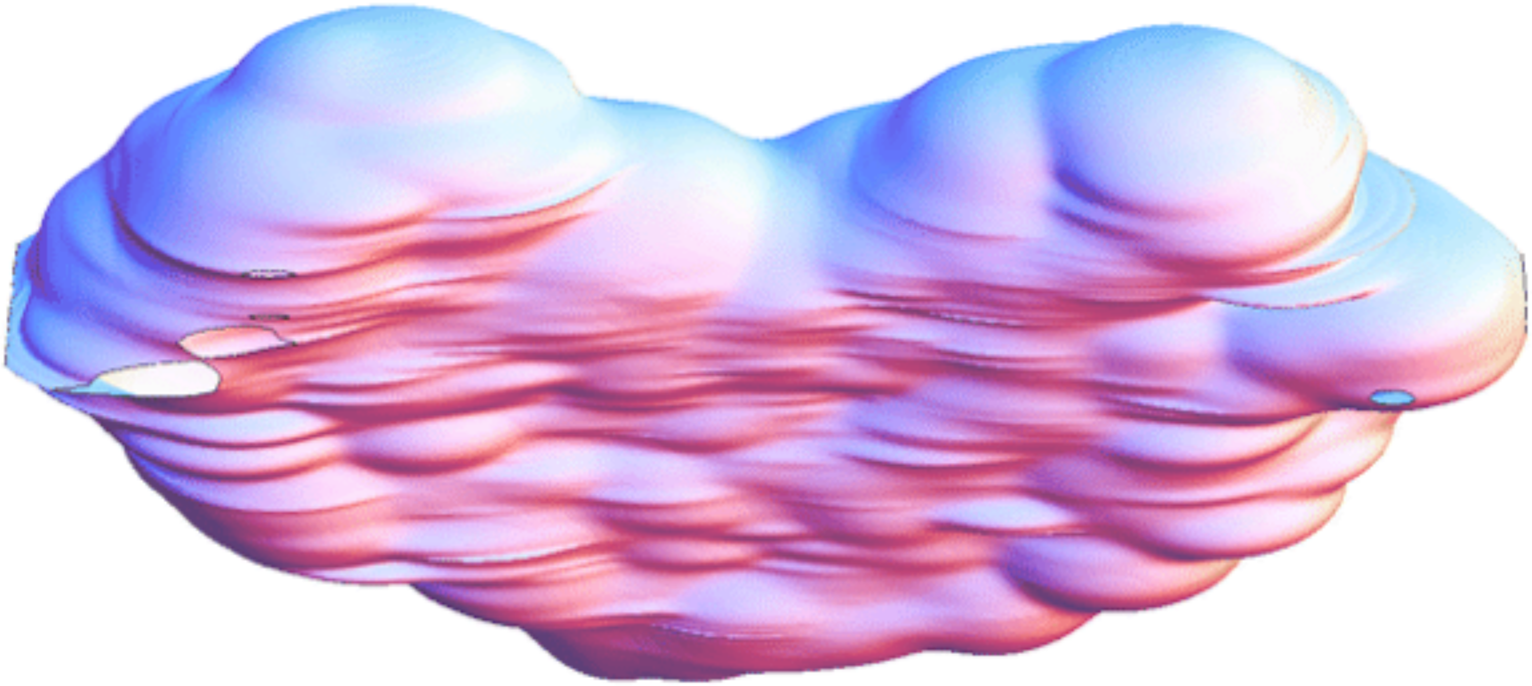
Giovanelli, Haynes, ++   2005++

300/h Mpc

Alfalfa Survey

Moved to z=1
Convolved with 10' beam

Giovanelli, Haynes, ++ 2005++



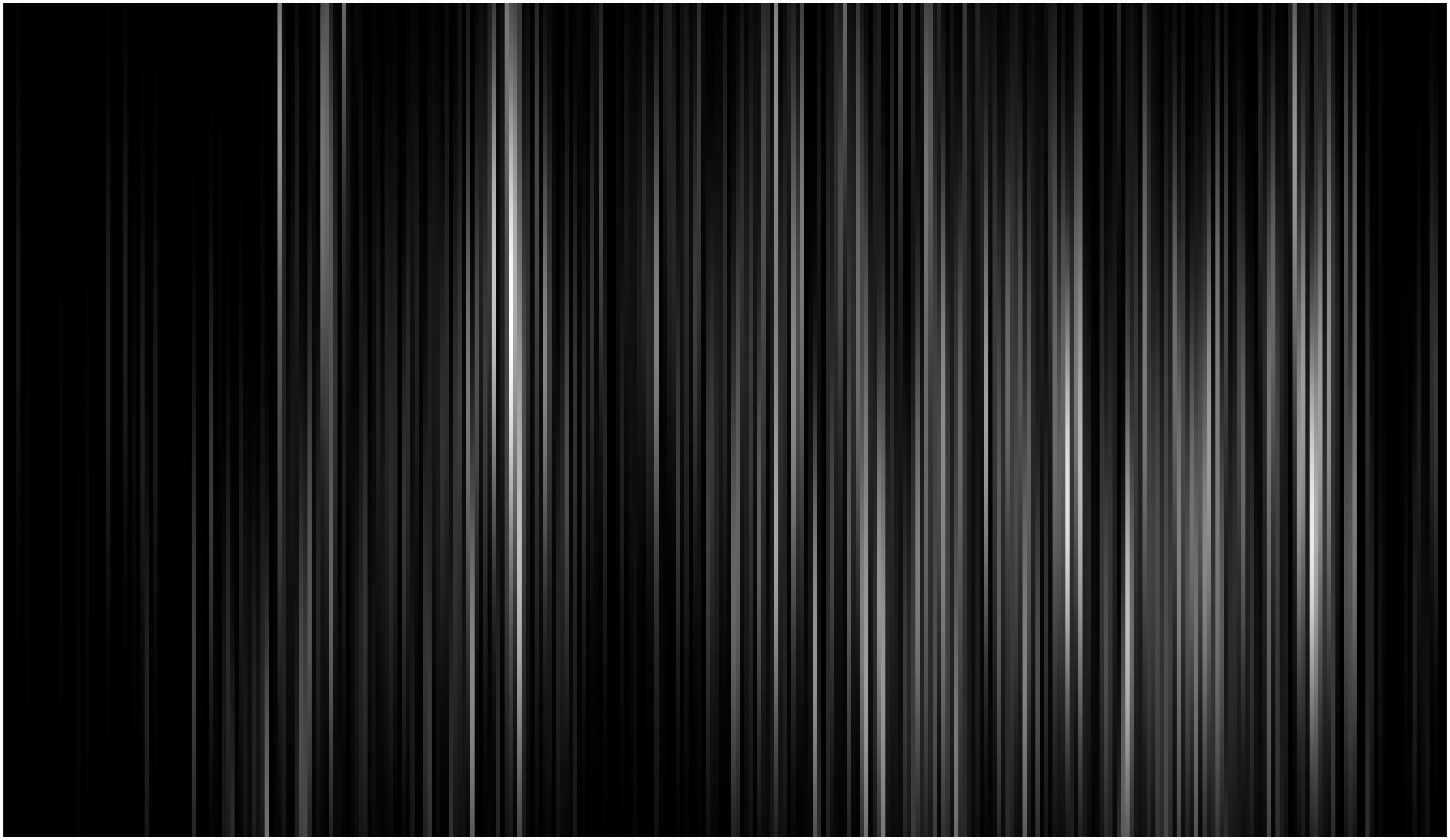
$T_{RJ} = 1\mu K$

300/h Mpc

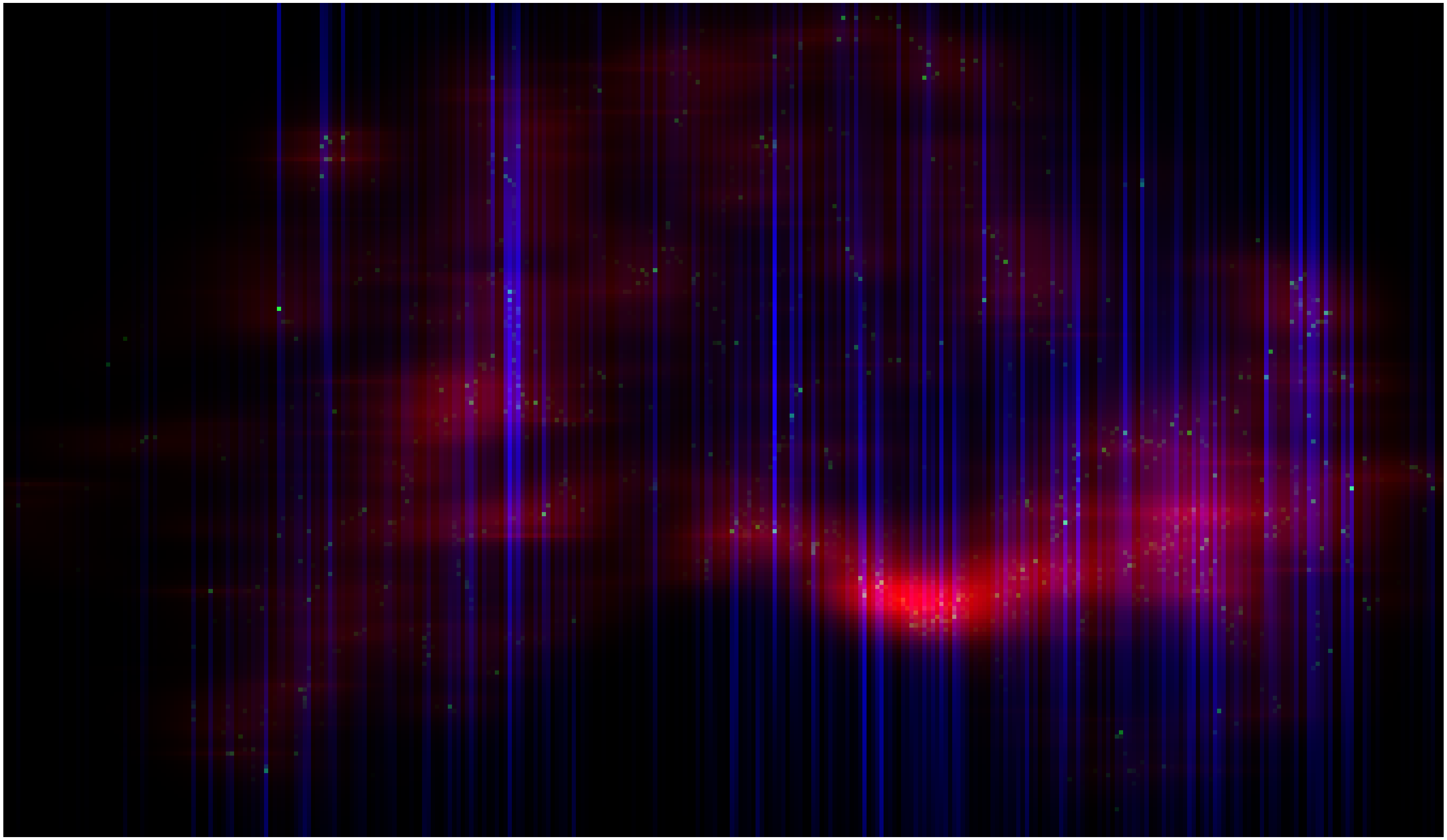
ALFALFA slice @ z=1 w/ σ_z = 0.01

Photometric+MKID Survey

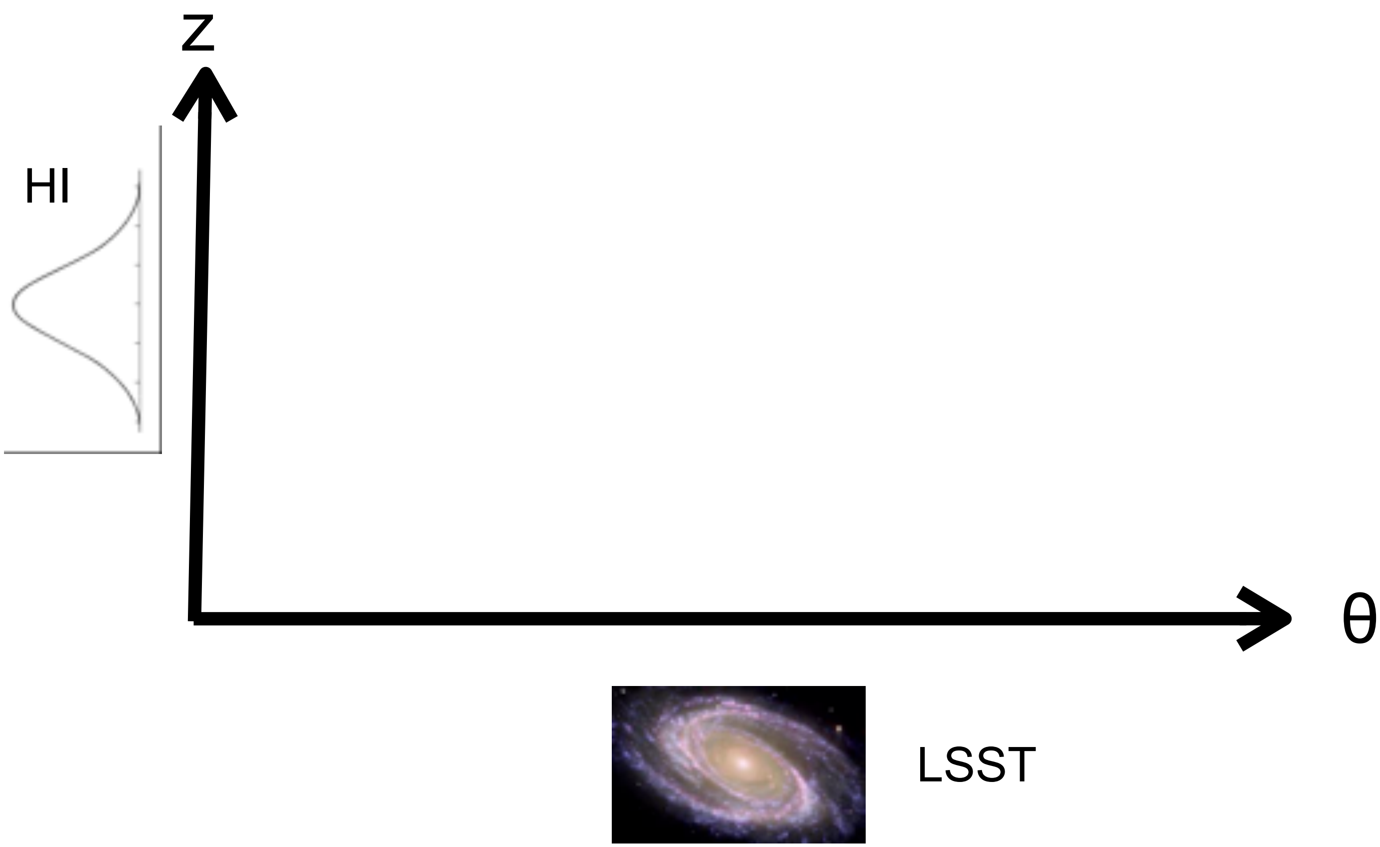
z=1, σ_z = 0.1 ALFALFA distribution



Composite: HI + Optical w/ Answers



How To Use Non-Gaussianity I



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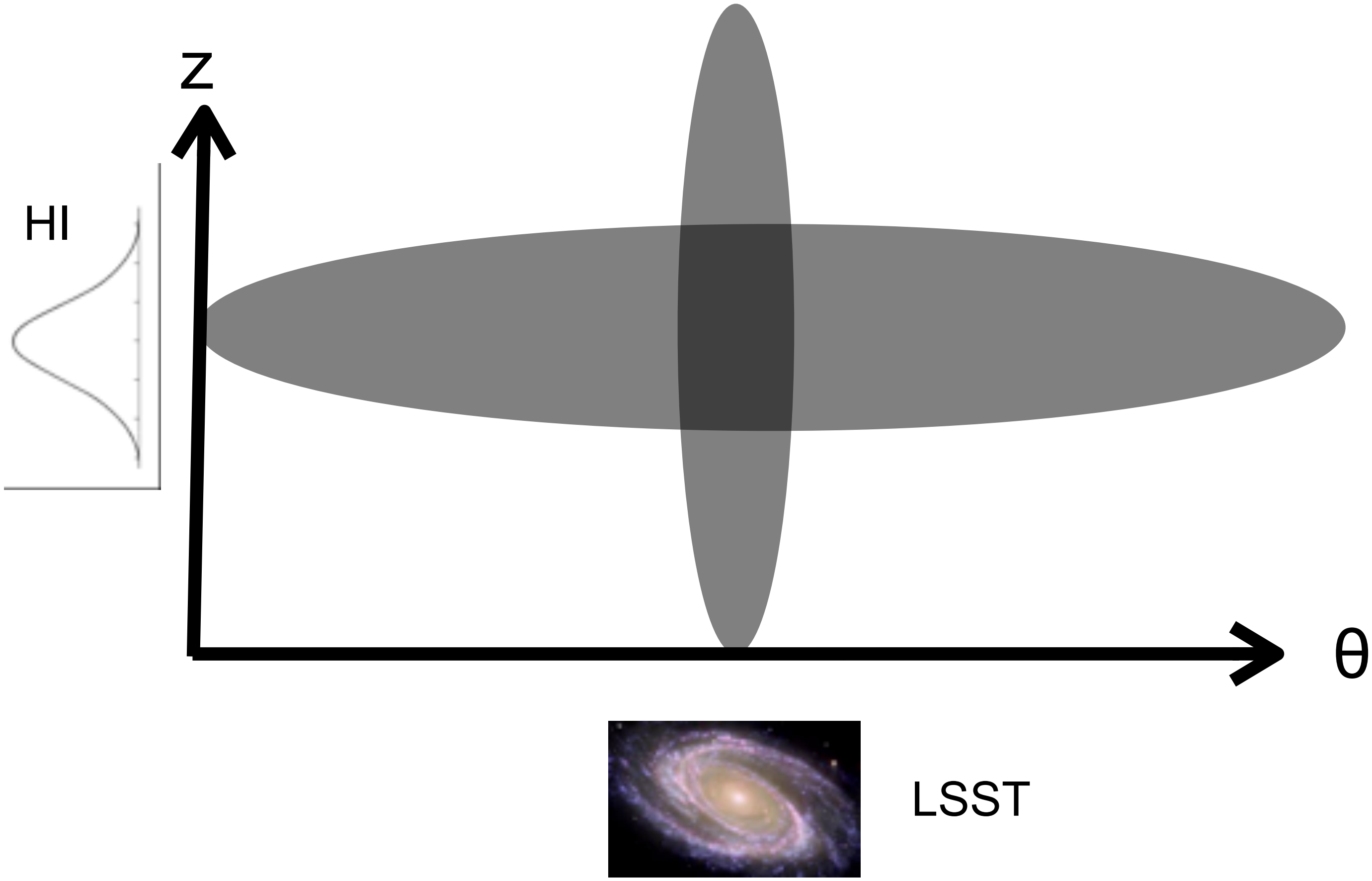

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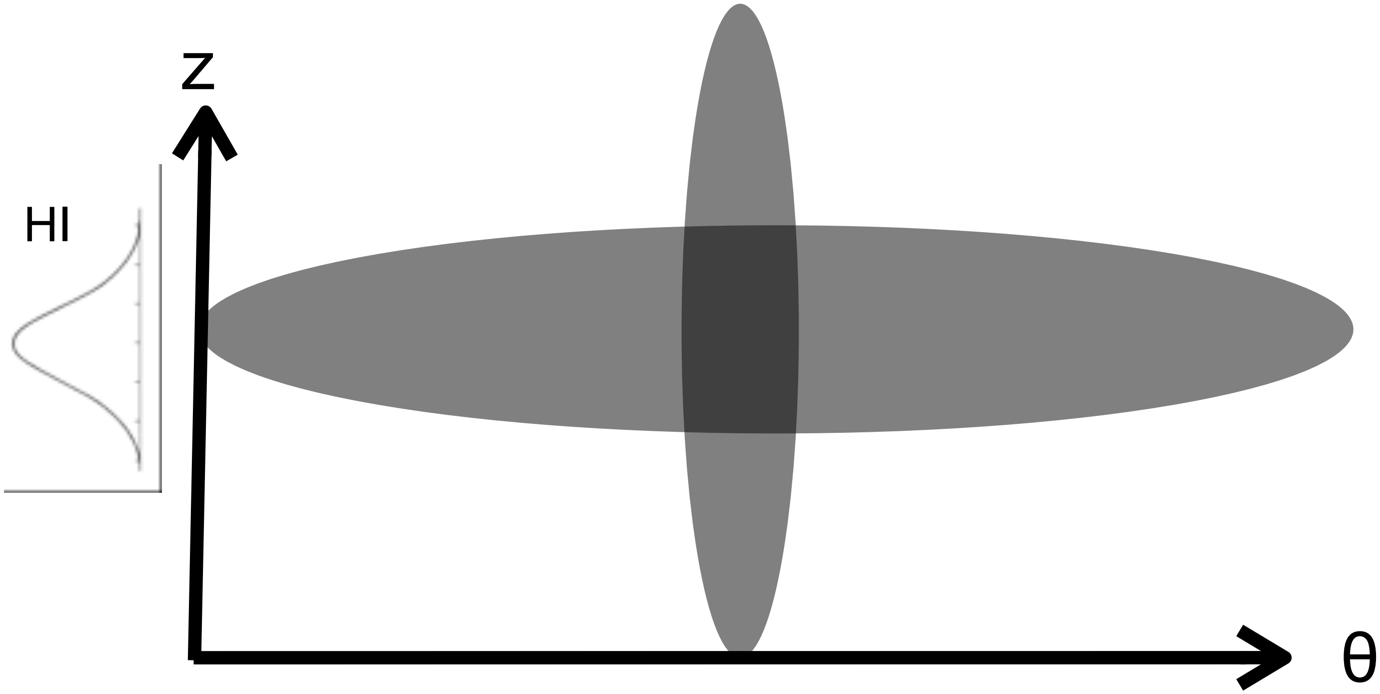
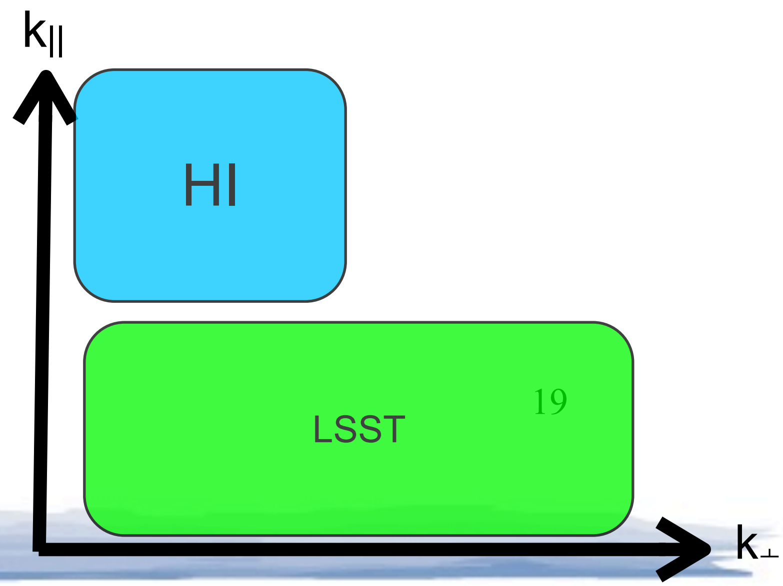


LSST



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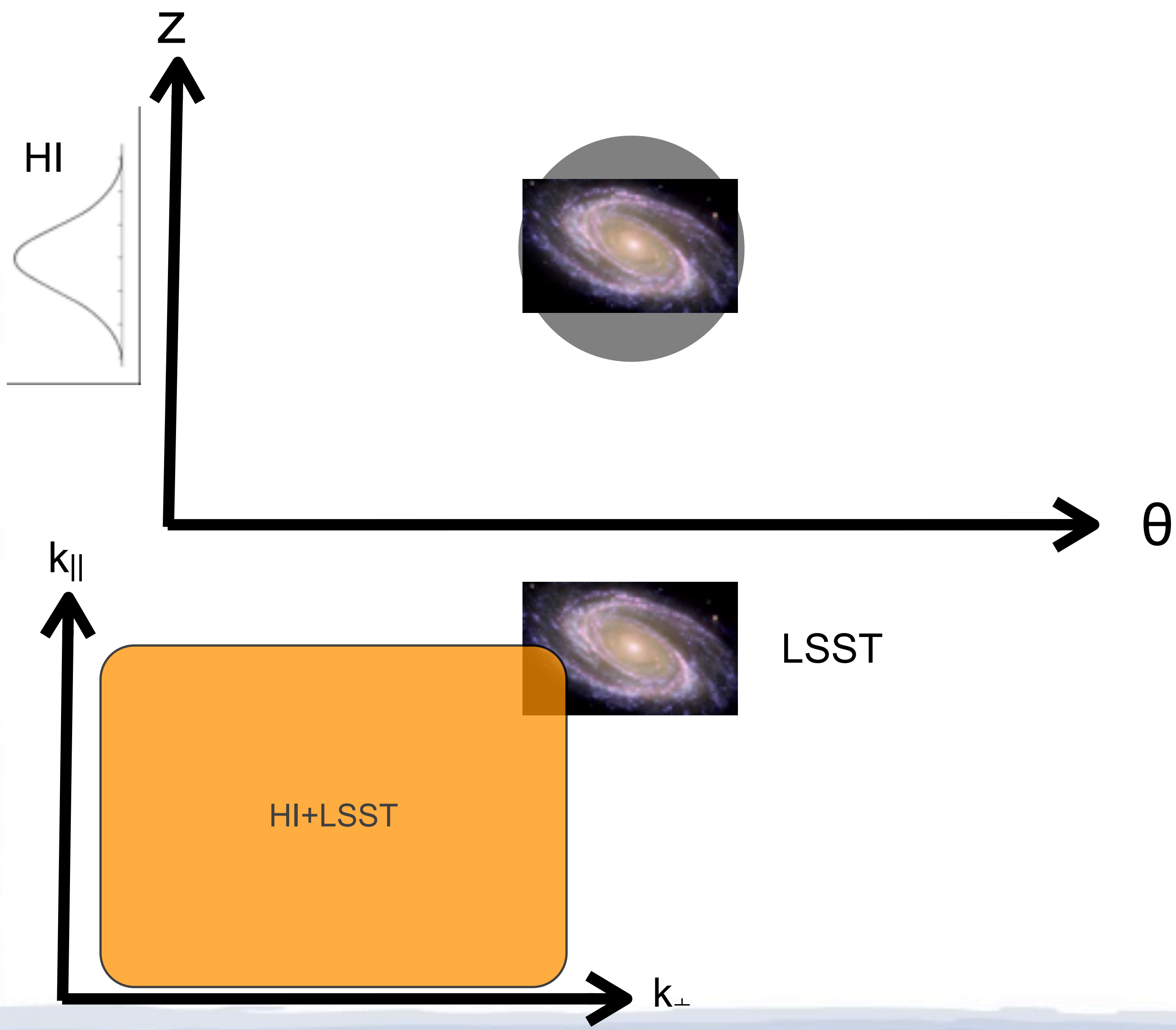
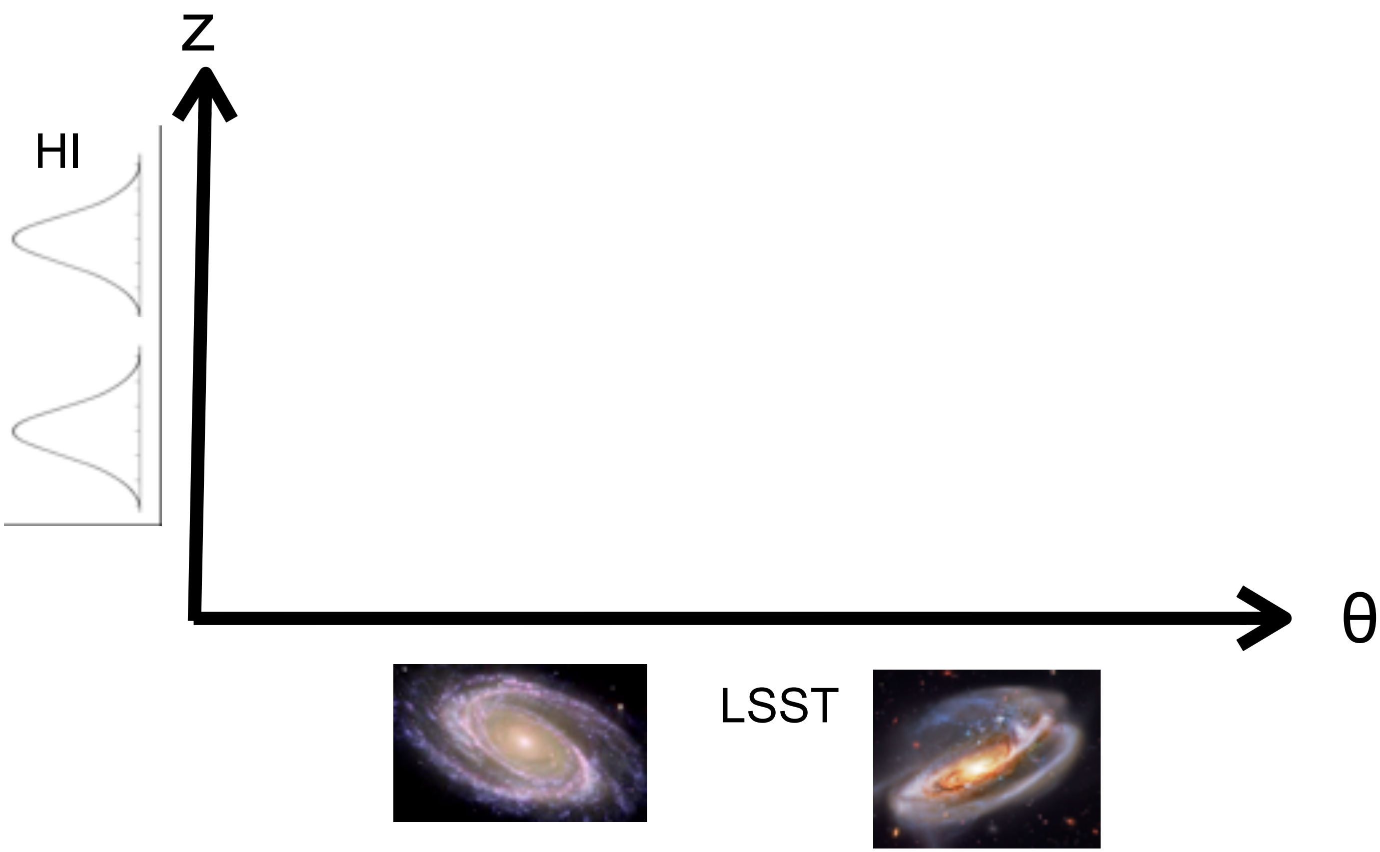


How To Use Non-Gaussianity II



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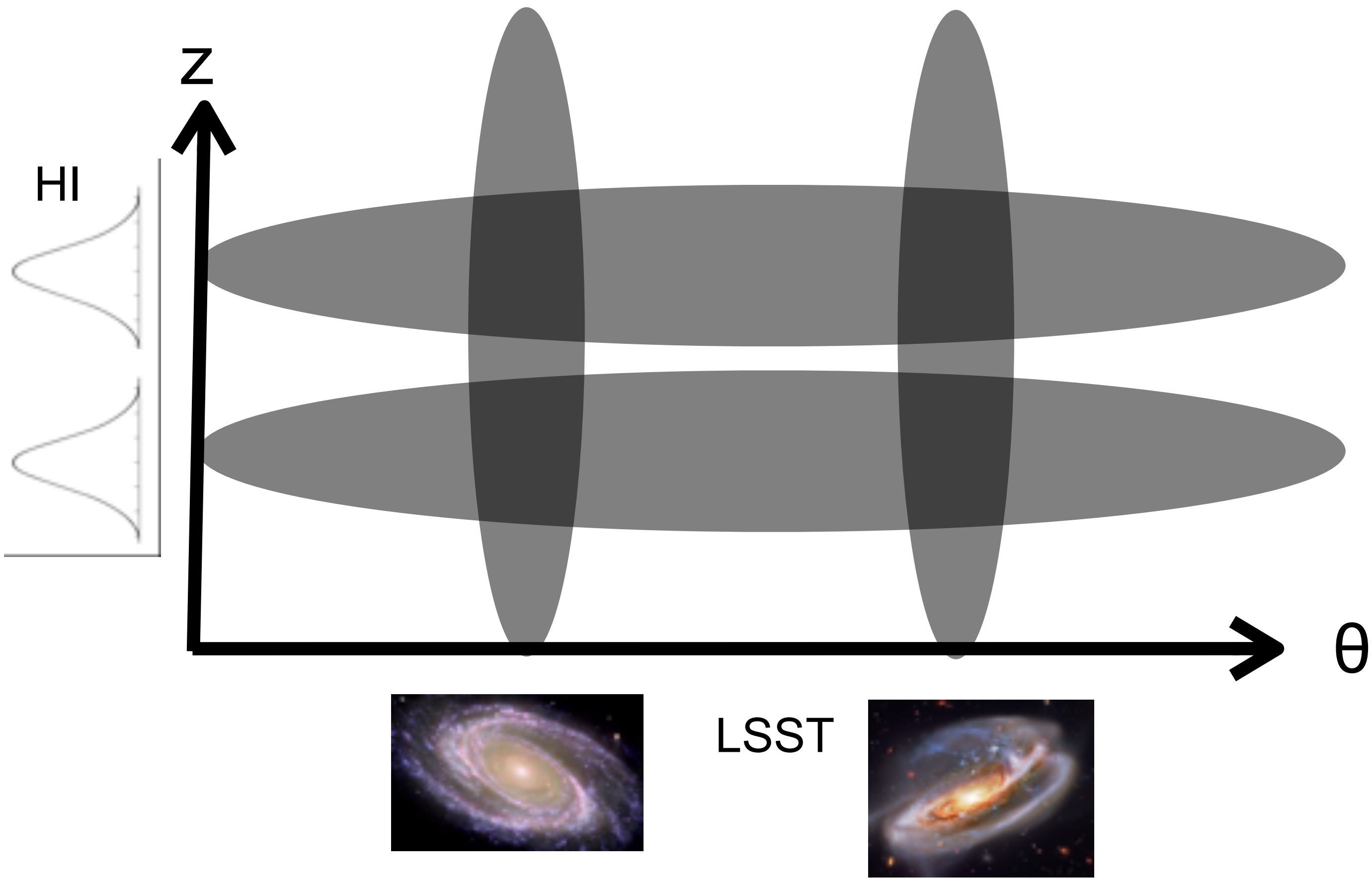

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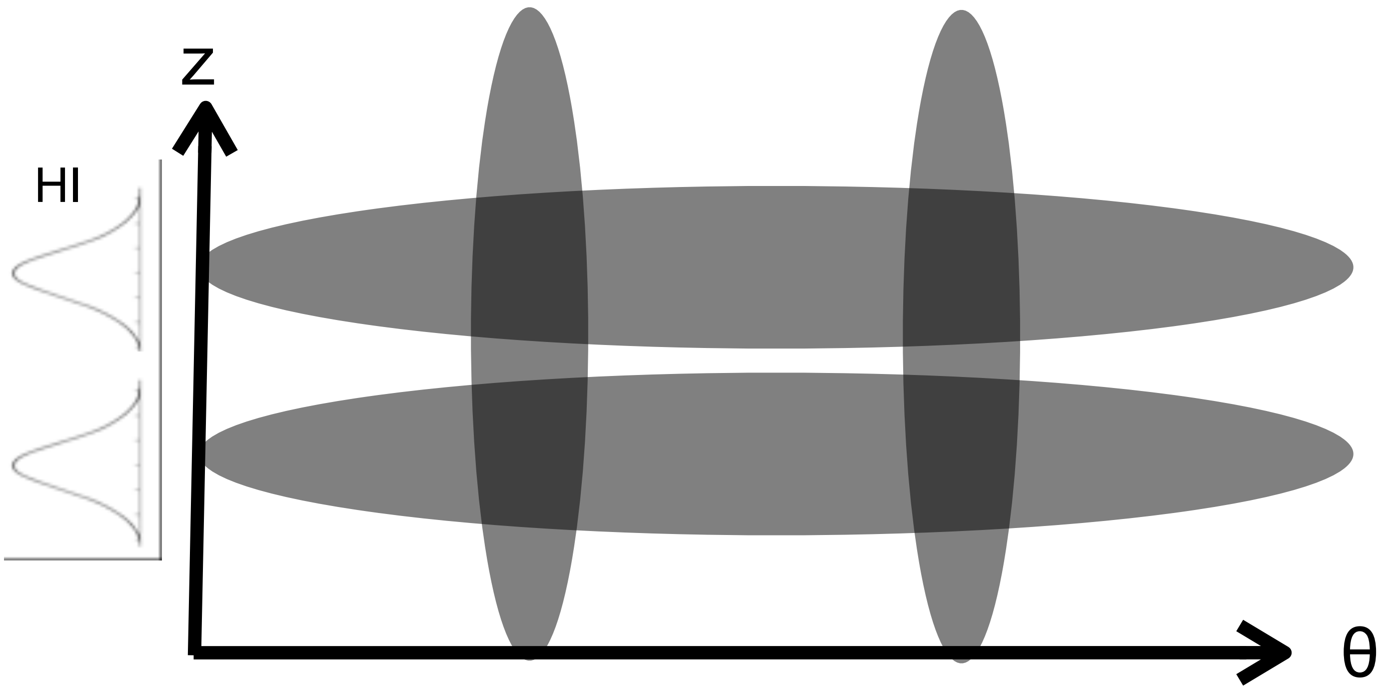

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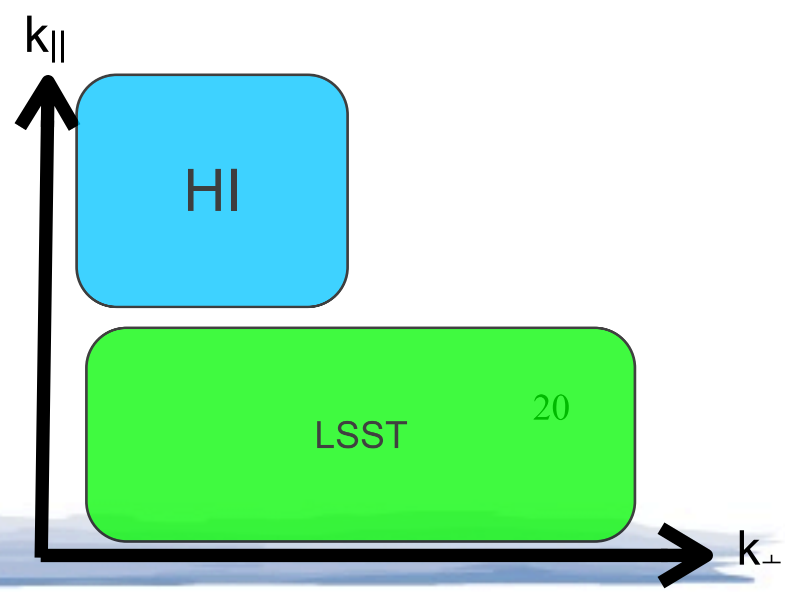

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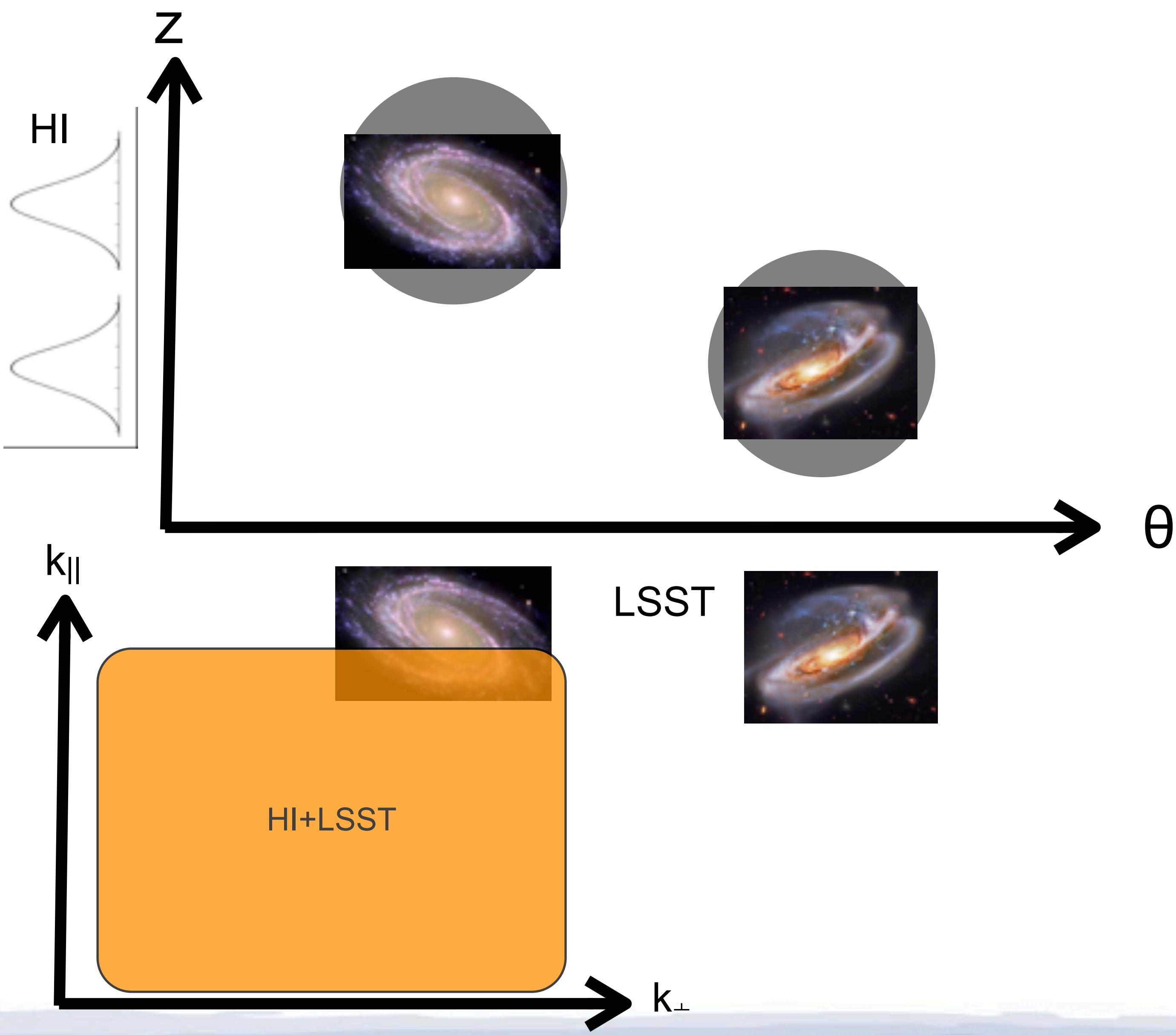

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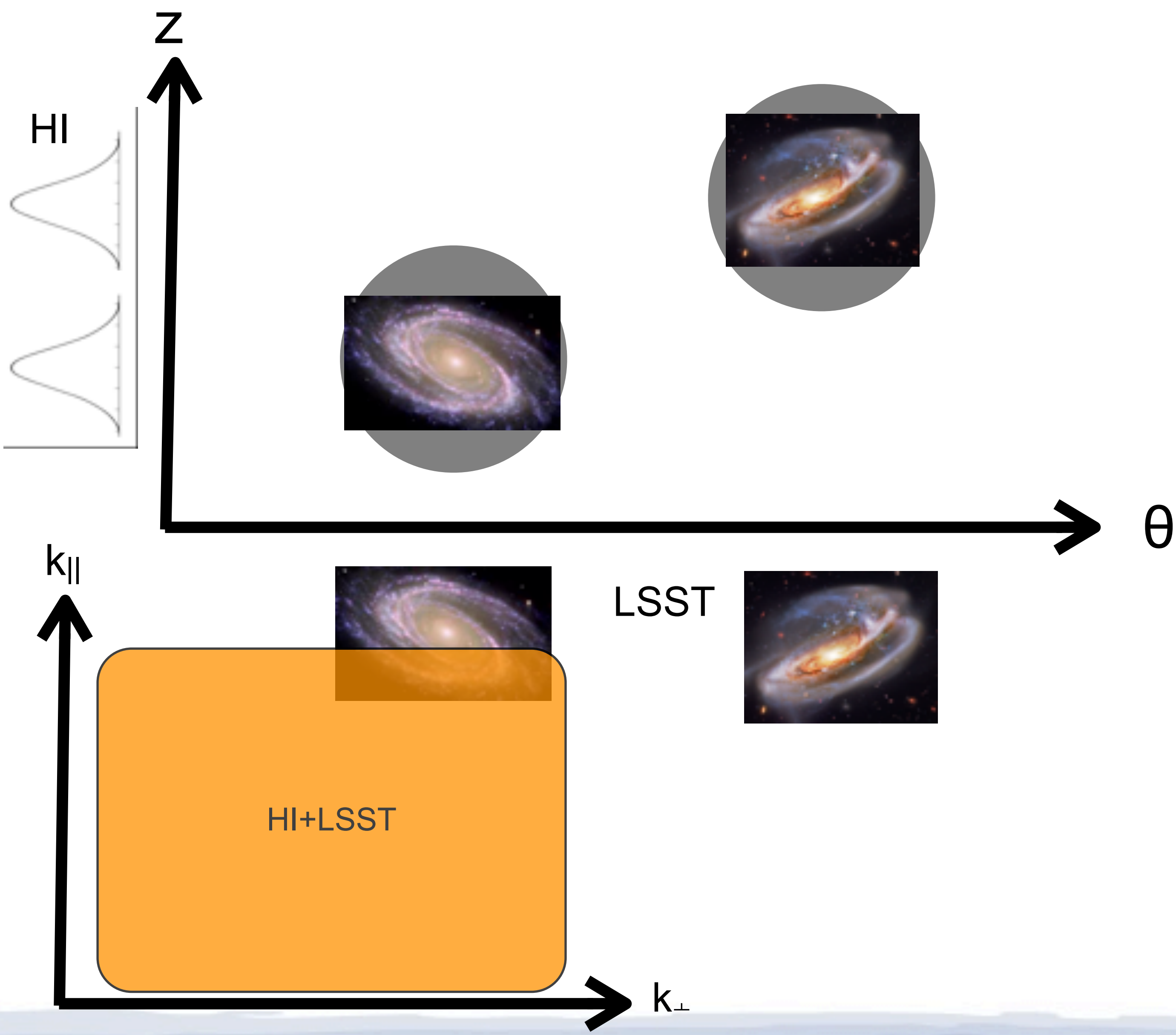
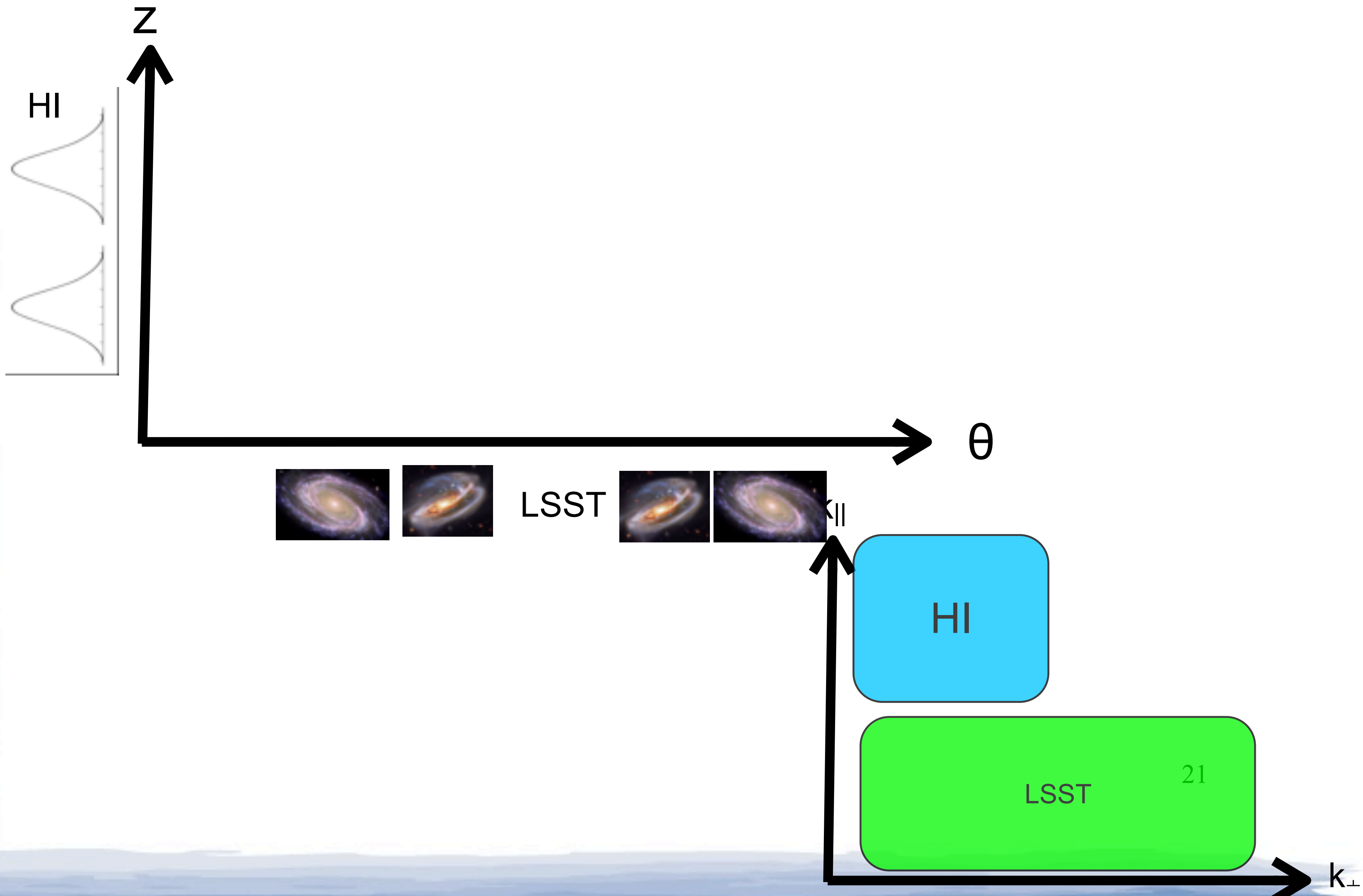
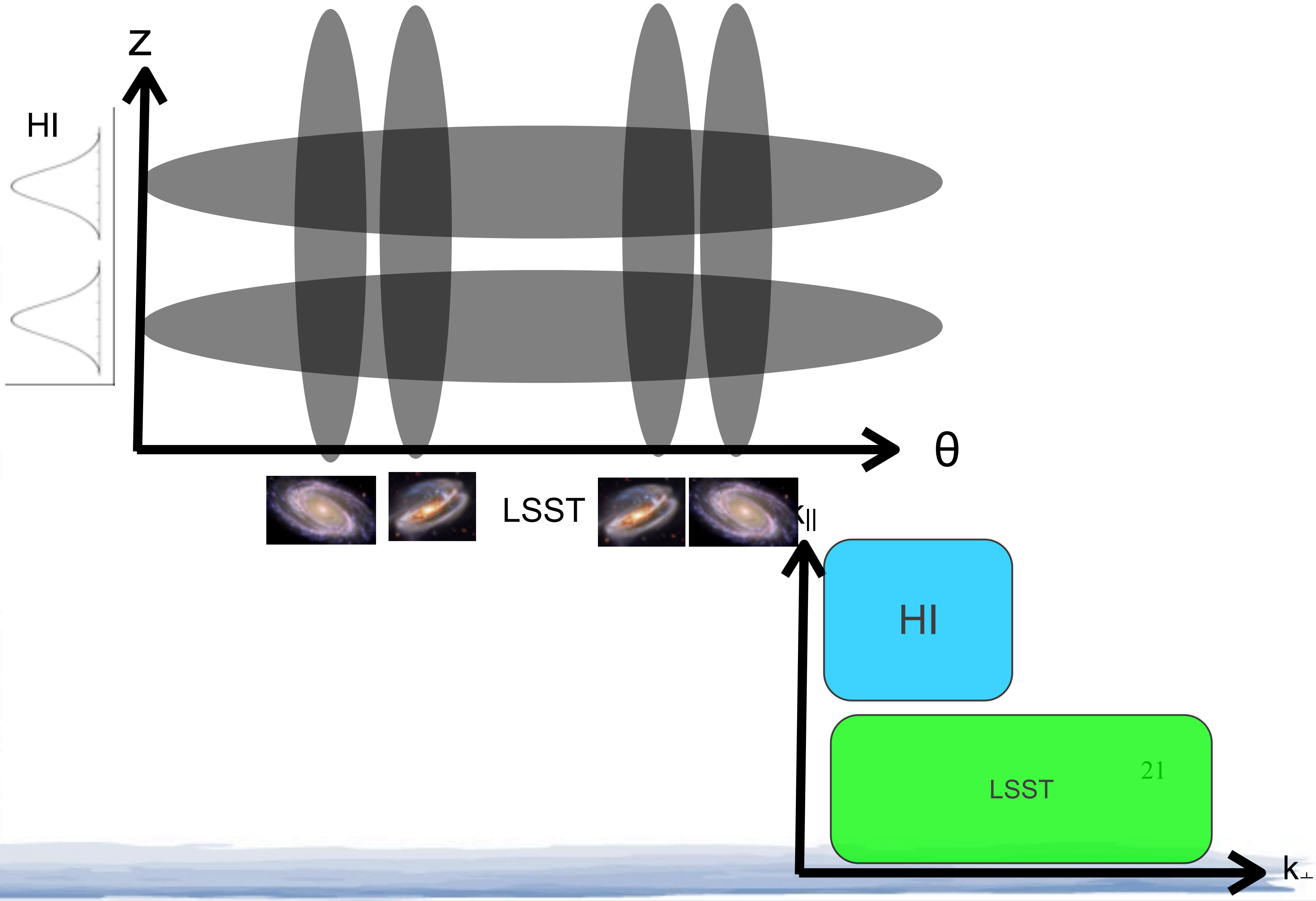


Ambiguity in galaxy locations

How To Use Non-Gaussianity III



How To Use Non-Gaussianity III



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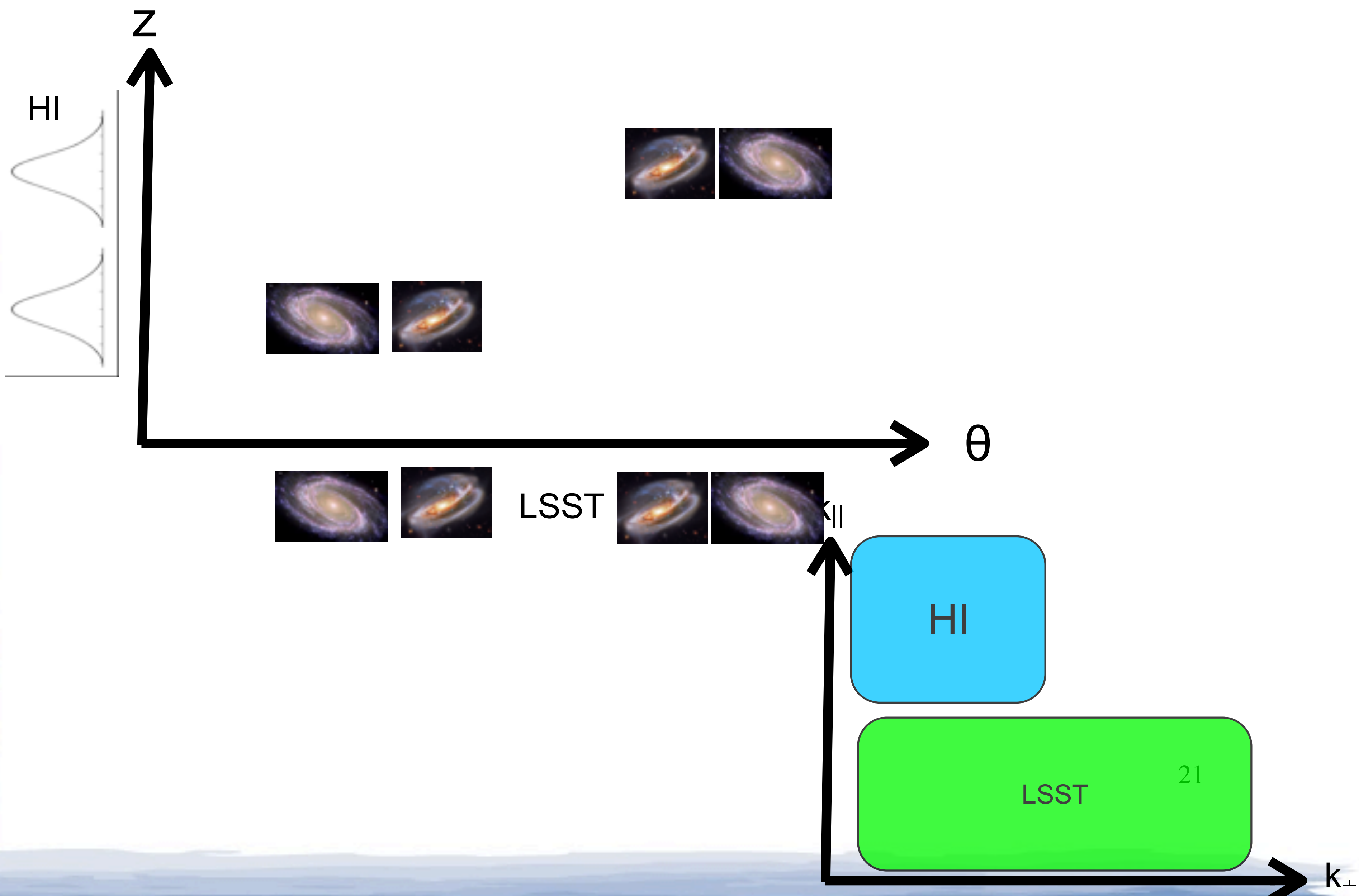
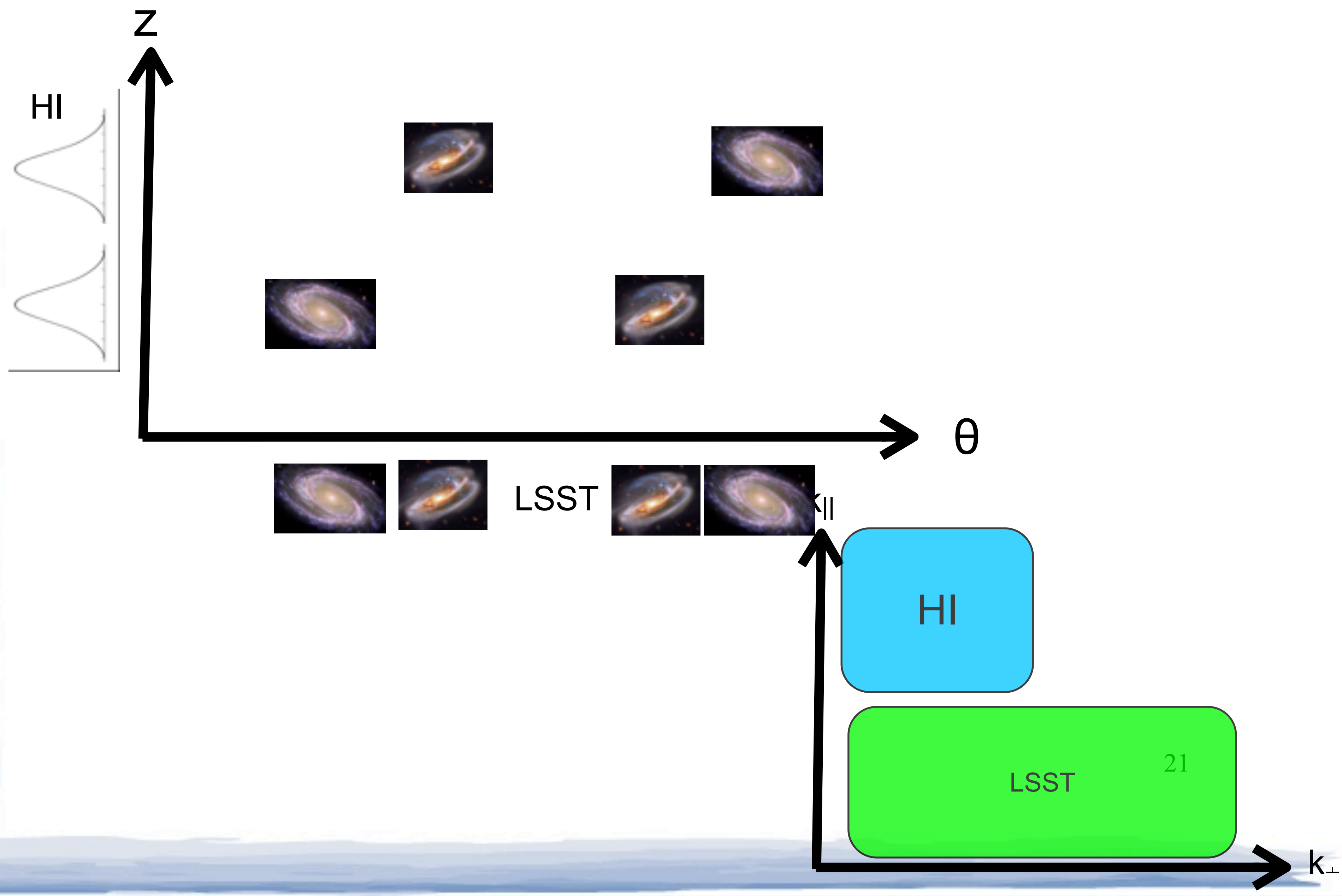


Monday, August 26, 13

How To Use Non-Gaussianity III



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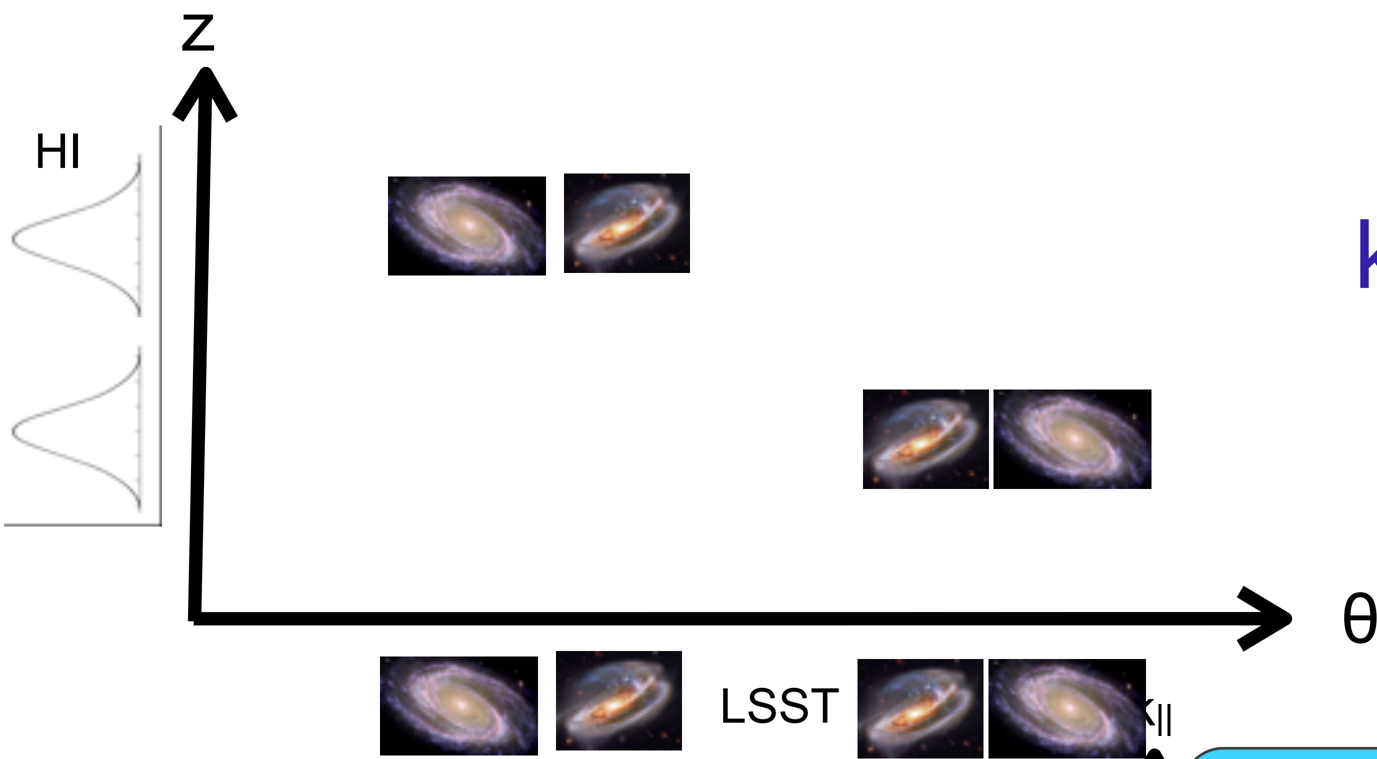
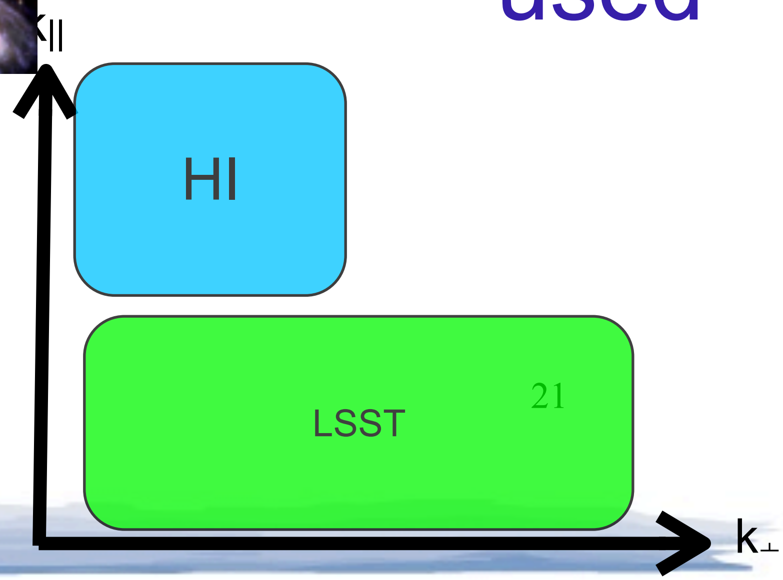


Prior knowledge of galaxy clustering should be used



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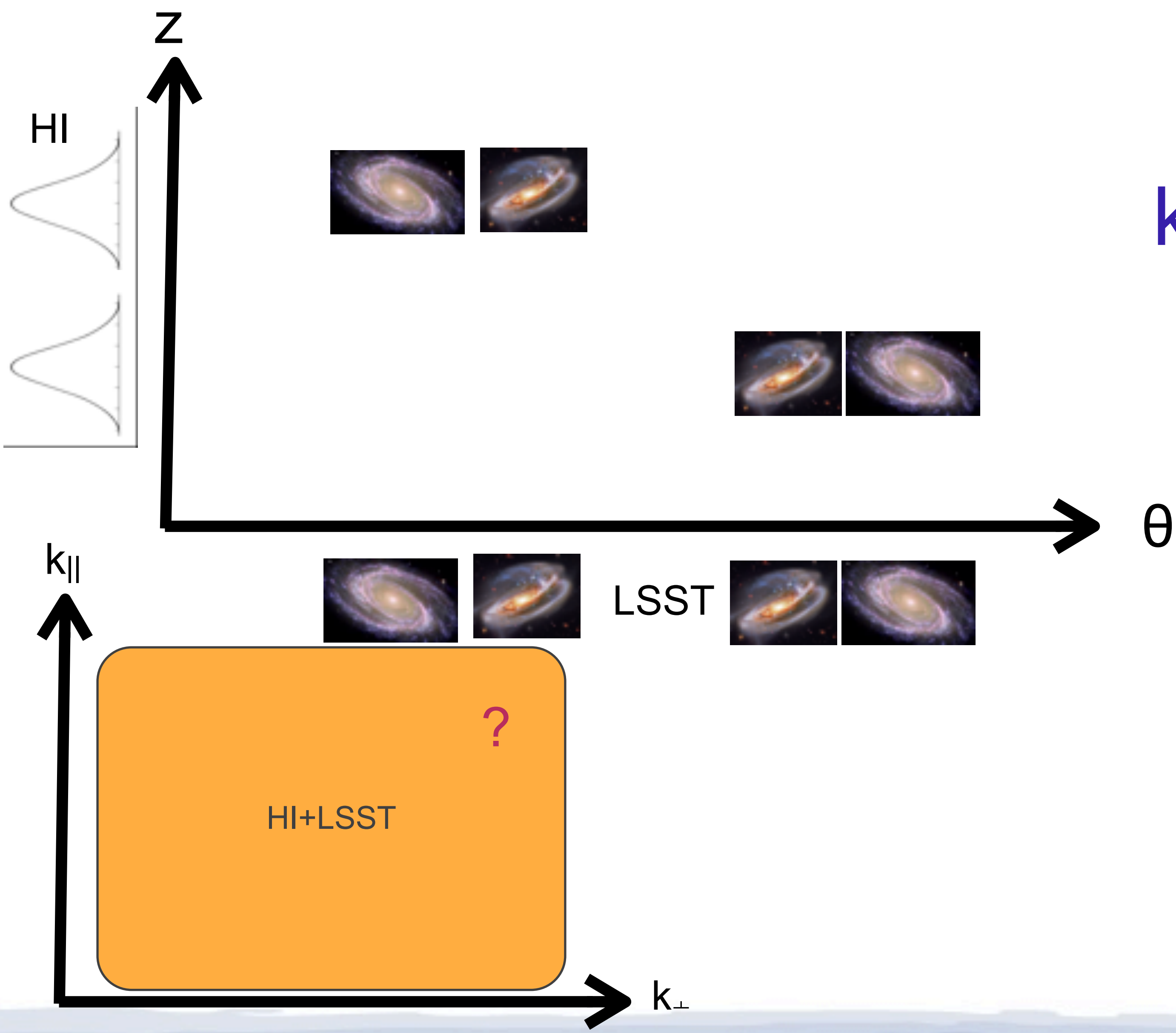

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  - conventional photo-z's have very high ambiguity

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  - Higher order statistics?
  - More precise inferences can be obtained using, *e.g.* a Monte Carlo Markov Chain.

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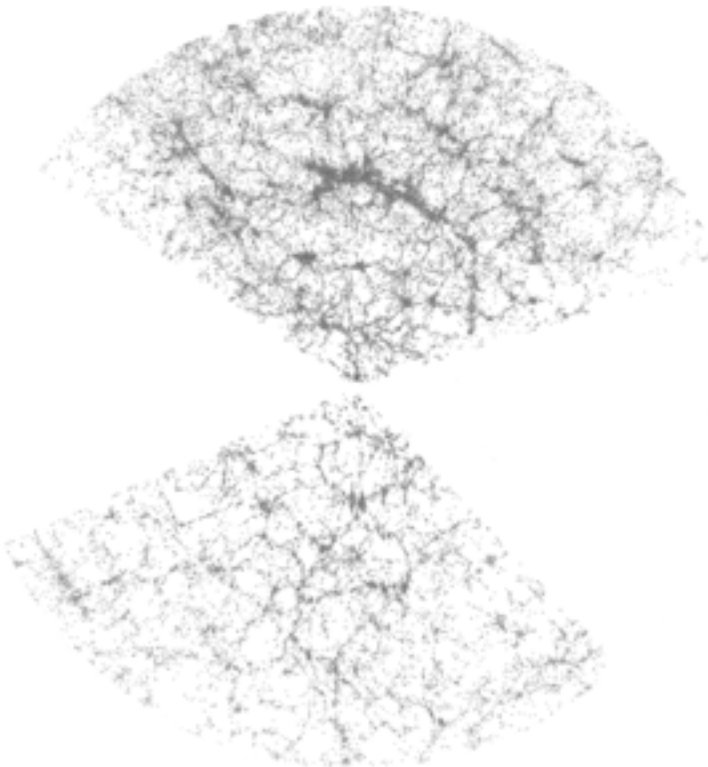
  - Angular resolution degraded toward South unless one has changing baselines.
- Does this complement / compete w/ optical /IR spectroscopic efforts (Euclid, BigBOSS,DESpec, ...)
  - these mostly target early type (luminous red) galaxies in dense environments in contrast to HI in late type galaxies in less dense environments.

Provocative Question

- Can you do Intensity Mapping with MKIDs?
  - multiple redshifts from blended galaxies?
  - few detectors needed on focal plane
  - use all the photons



Conclusions

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- We soon will know better if HI intensity mapping for LSS lives up to it's promises (e.g. CHIME, TianLai, BINGO, BAOBAB, ...)