INTENSITY MAPPING
WHAT CAN IT DO FOR YOU (THAT CAN'T BE DONE OTHER WAYS)?

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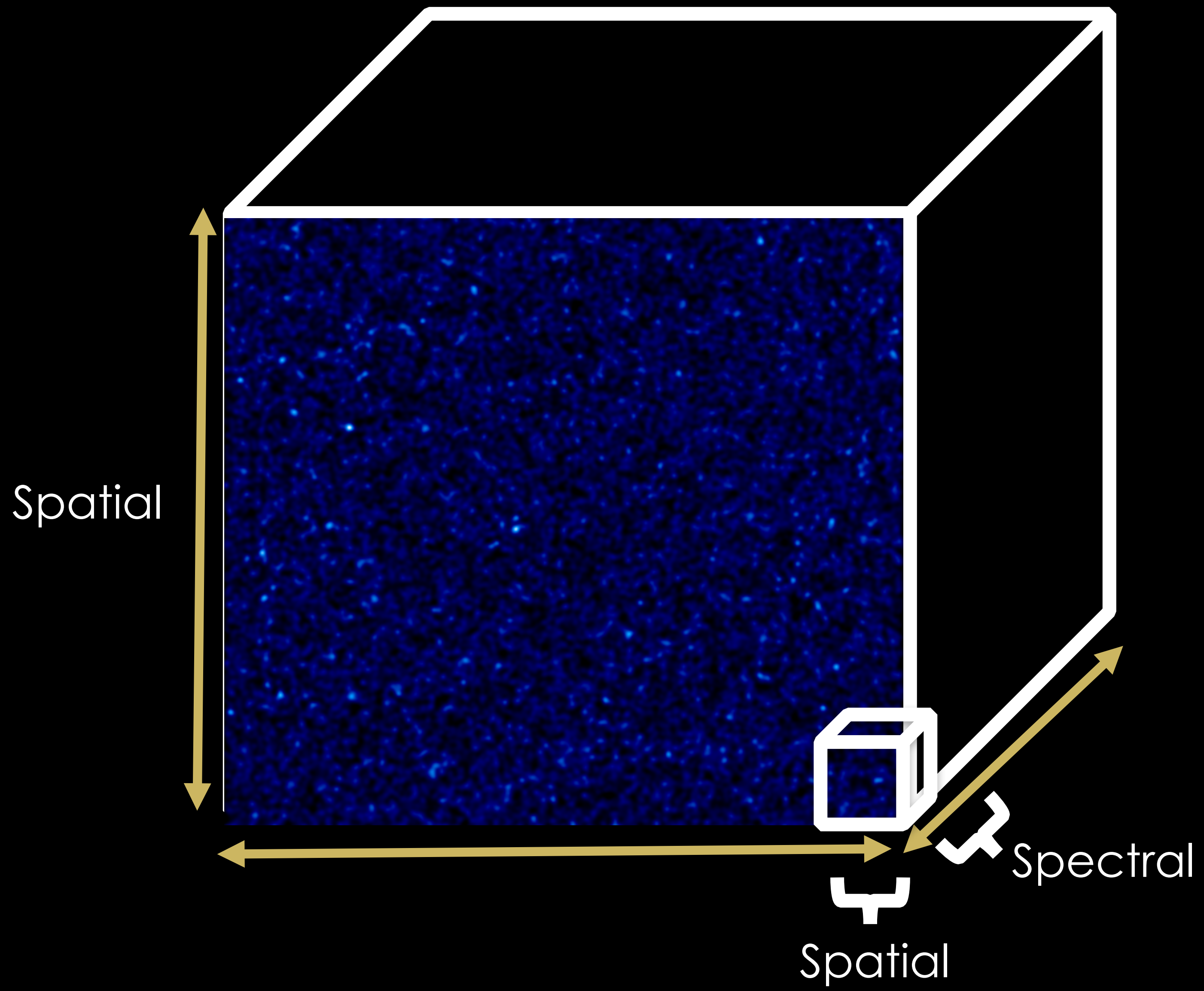
for the AAS FIRSIG

OUTLINE

- What is intensity mapping?
  - Motivation
  - Formalism
  - Current detections
- What can be done with it?
  - Integral constraints on line emission
  - Constraints on star formation and connection to halo models
  - Determination of clustering (intra/inter-halo) connection to SF
  - Cosmological parameters
  - Epoch of reionization studies
- Some future missions to look for
- Conclusions

WHAT IS (LINE) INTENSITY MAPPING?

- Statistical observation of spatial fluctuations in intensity of spectral line emission without requiring either the sources of emission to be resolved, or high resolution in the spectral dimension
- Intensity mapping creates a *data cube*



- Recent review of the field in Kovetz et al 2017

MOTIVATION FOR INTENSITY MAPPING

Cosmology

- Evolution of Large Scale Structure
- Clustering
  - Intrahalo correlations
  - Halo-halo correlations
- Halo / LSS – SF connection

MOTIVATION FOR INTENSITY MAPPING

Astrophysics

- Halo / LSS – SF connection

- Evolution of the cosmic mean of L_{line}/L_{FIR} for of ISM coolants
- Evolution of metal abundance
- Evolution of SFRD

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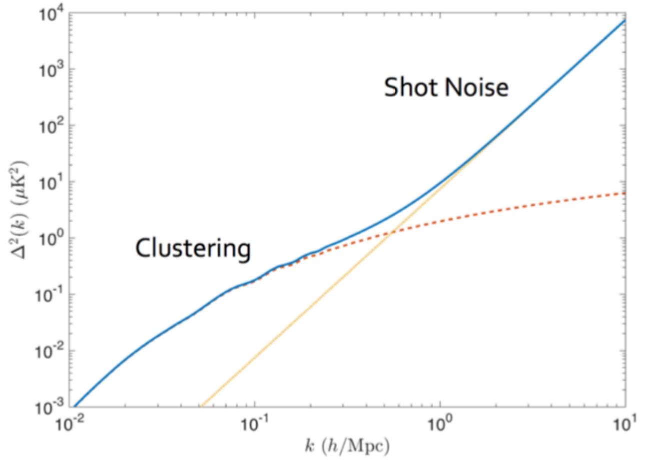
FORMALISM

- Statistical observation of spatial fluctuations in intensity of spectral line emission

$$\delta_X(\vec{x}, z) = S_X(z)b(z)\delta(\vec{x}, z)$$

- Fluctuations typically characterized by power spectrum

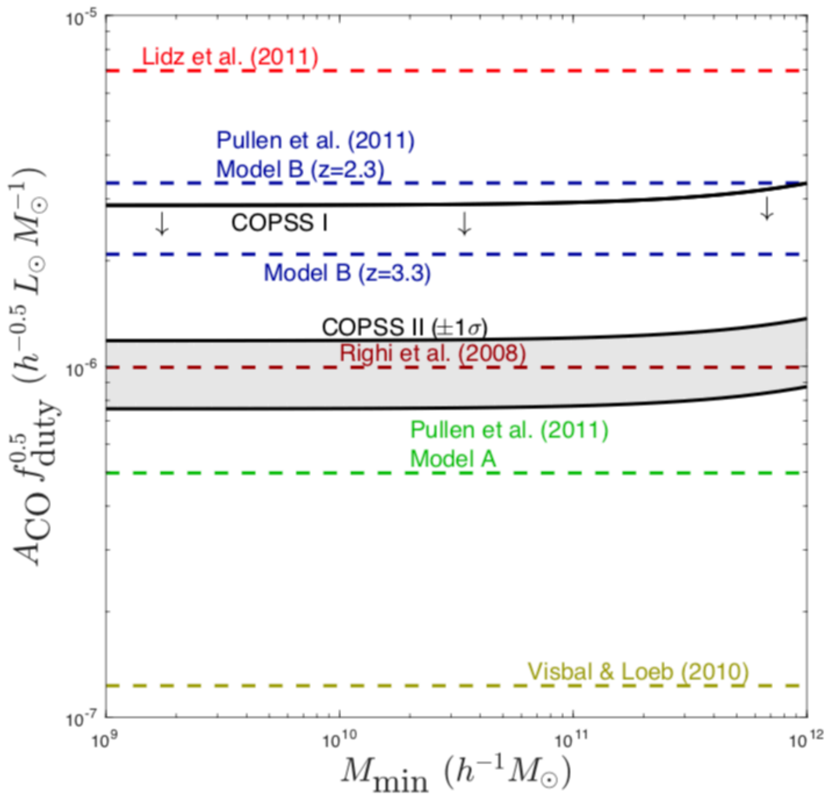


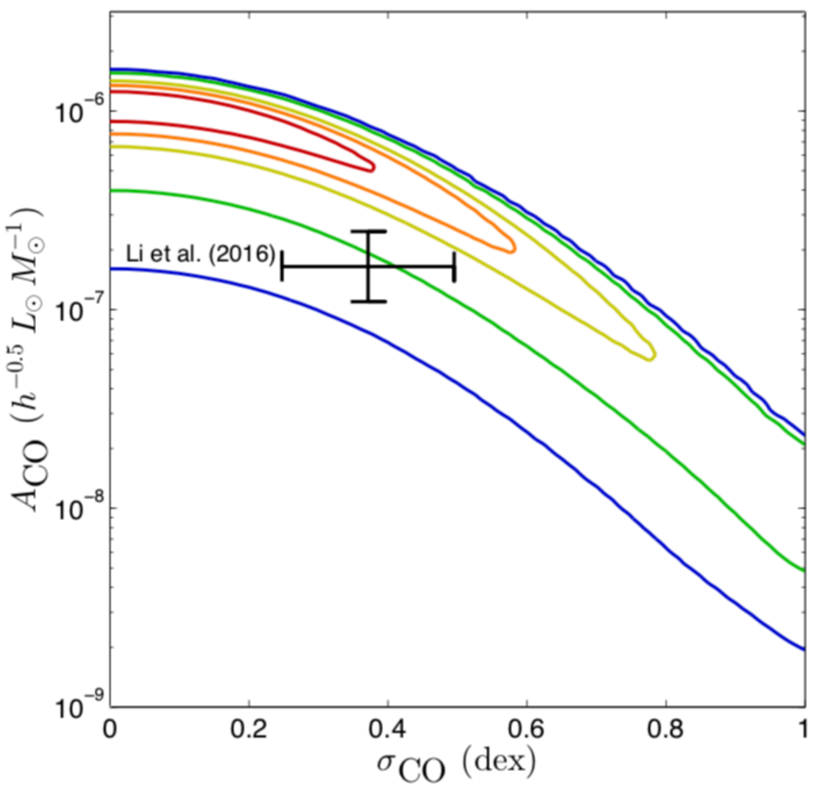
$$P(\vec{k}, z) = |\delta_X(\vec{k}, z)|^2$$

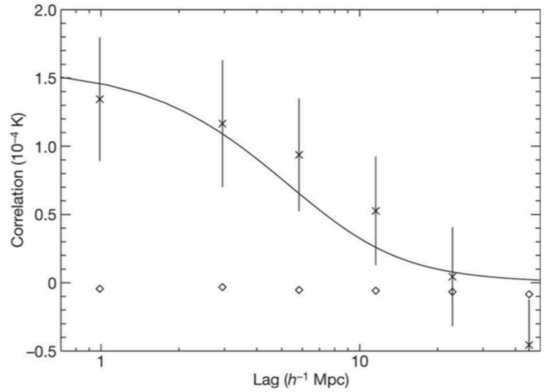
$$= \bar{S}_X^2(z)\bar{b}^2(z)P_{\delta\delta}(\vec{k}, z) = \langle I(z)\rangle^2 b^2(z)P_m(k, z) + P_{\rm shot}(z)$$

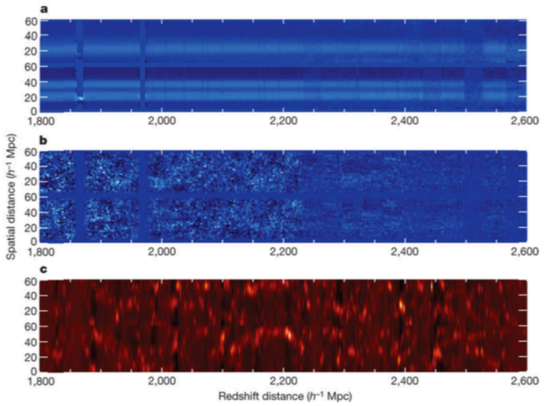
$$\langle I(z)\rangle \propto \int_0^\infty L\Phi(L, z)dL, \qquad P_{\rm shot}(z) \propto \int_0^\infty L^2\Phi(L, z)dL.$$

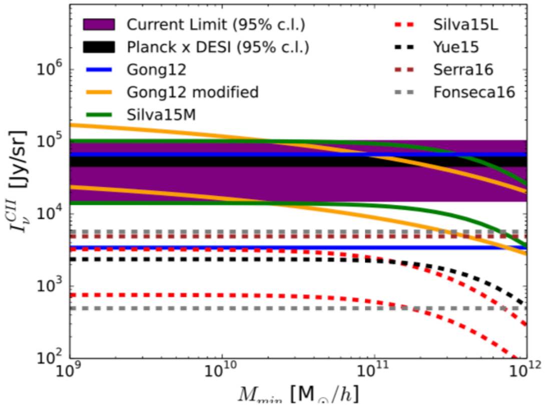
- Can also make use of non-Gaussianity in the cubes (1-point distribution, potentially higher-order statistics)











DETECTIONS

Detections in

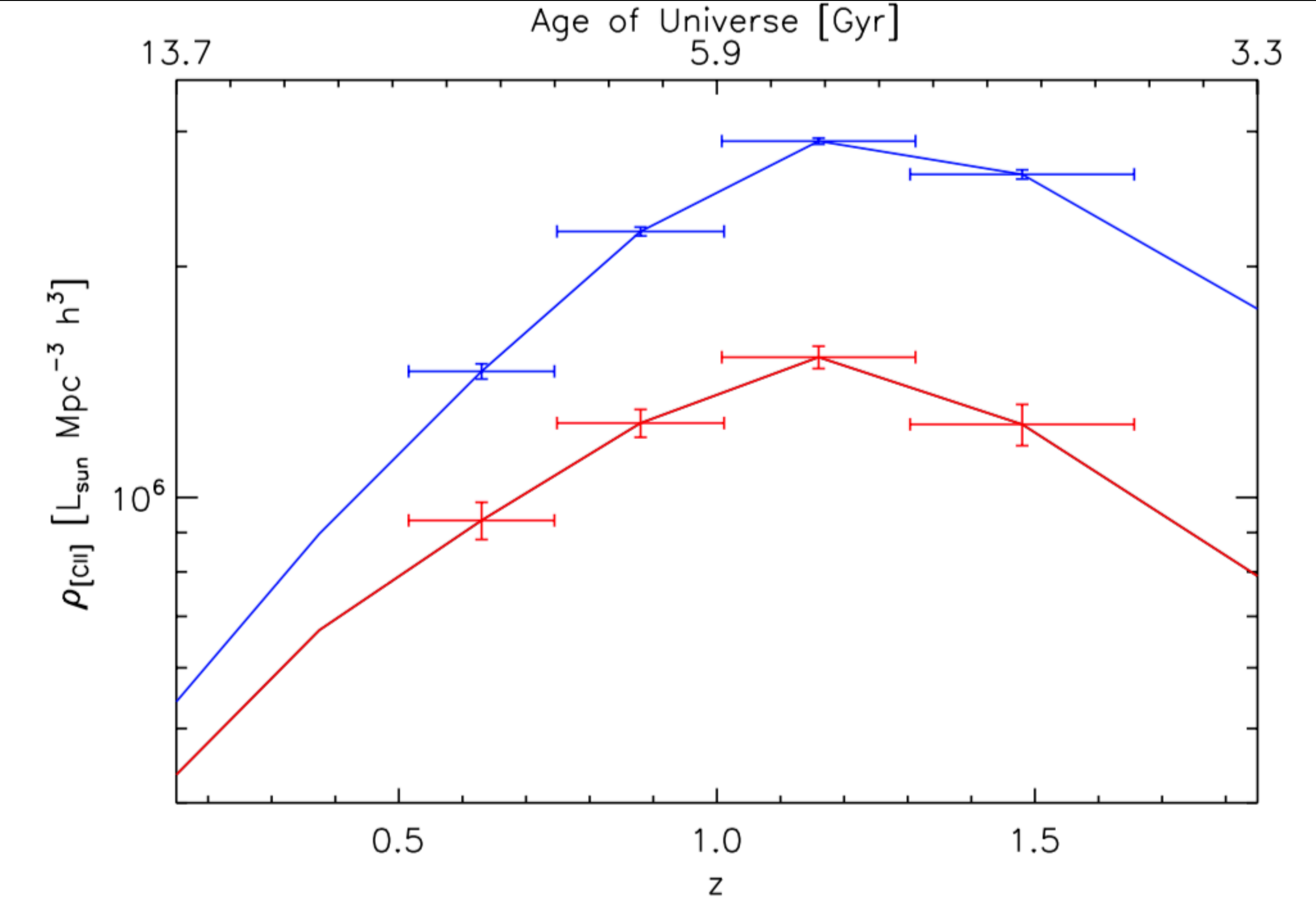
- CO from COPSS (Keating et al 2016)
- HI from GBT (Switzer et al 2013, Masui et al 2013)
- CII from Planck (tentative; Pullen, Serra, Chang, Dore & Ho 2017)

THE FIRAS EXAMPLE

- Attempts to resolve the FIR background measured their success against the FIRAS integral measure
- No other instrument could provide such a measure, but absolute measurements are hard
- LIM provides a "differential" method for producing integral constraints
- Very difficult with galaxy surveys to measure the full integrated light, especially spectroscopically
- <u>LIM can provide a unique constraint for galaxy formation models</u>

INTEGRAL CONSTRAINTS

- Integral constraints on the (bias-weighted) line emission are possible with high accuracy with modest missions.
- Right are forecasts for CII(158 micron) for the proposed balloon-borne STARFIRE (adapted from Uzgil, Aguirre, Bradford & Lidz 2014)



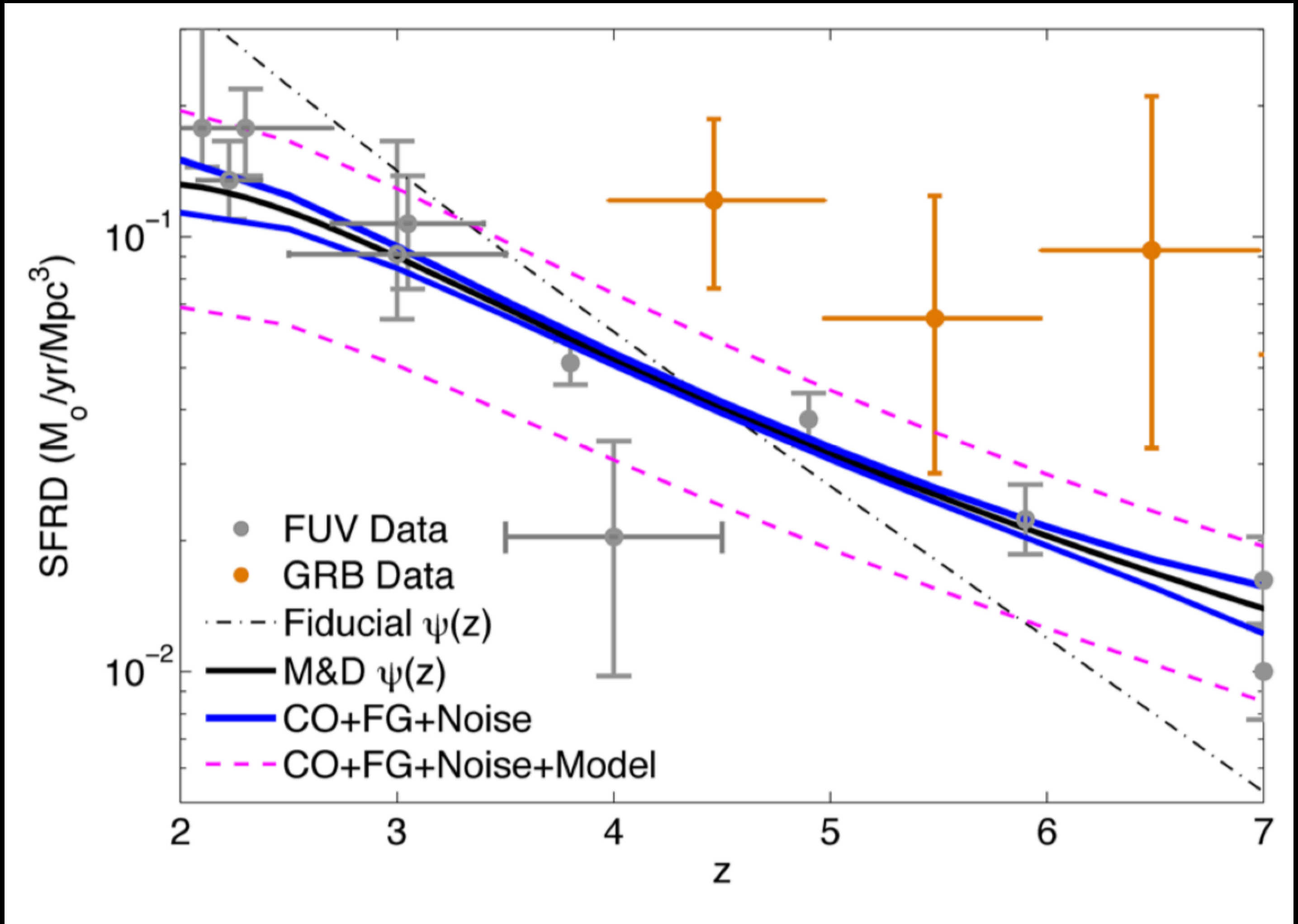
CONSTRAINING THE STAR FORMATION HISTORY

- Relations between line emission, star formation rate, and halo mass allow the construction of the SFRD, subject to uncertainties in these conversion factors

$$\frac{L_{\rm FIR}}{\rm L_\odot} = C_{\rm FIR}\left(\frac{L'_{\rm CO}}{\rm K\ km\ s^{-1}\ pc^2}\right)^{X_{\rm FIR}}$$

$$\frac{\rm SFR}{\rm M_\odot/yr} = C_{\rm SFR}\frac{L_{\rm FIR}}{\rm L_\odot}$$

$$\mathrm{SFR}(M) = 9.8\times10^{-18}\left(\frac{A_{\rm CO}}{2\times10^{-6}}\right)M^{5b_{\rm CO}/3}$$



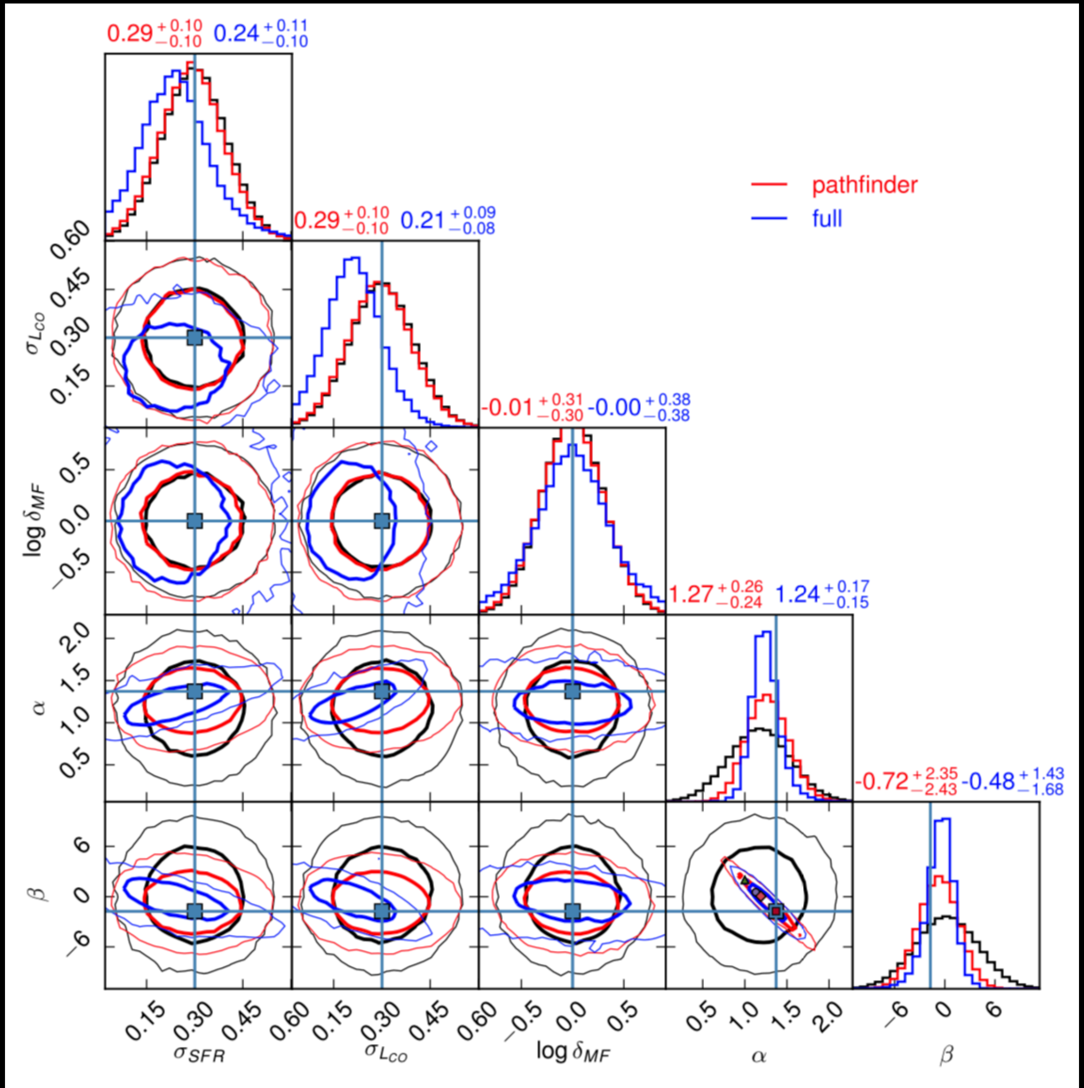
Breysse, Kovetz & Kamionkowski 2016

CONSTRAINING HALO-SFR CONNECTION

- More detailed aspects of models can also be constrained
- In principle, HOD or other kinds of halo model can be constrained, as was done with Herschel continuum data (Viero et al 2013)

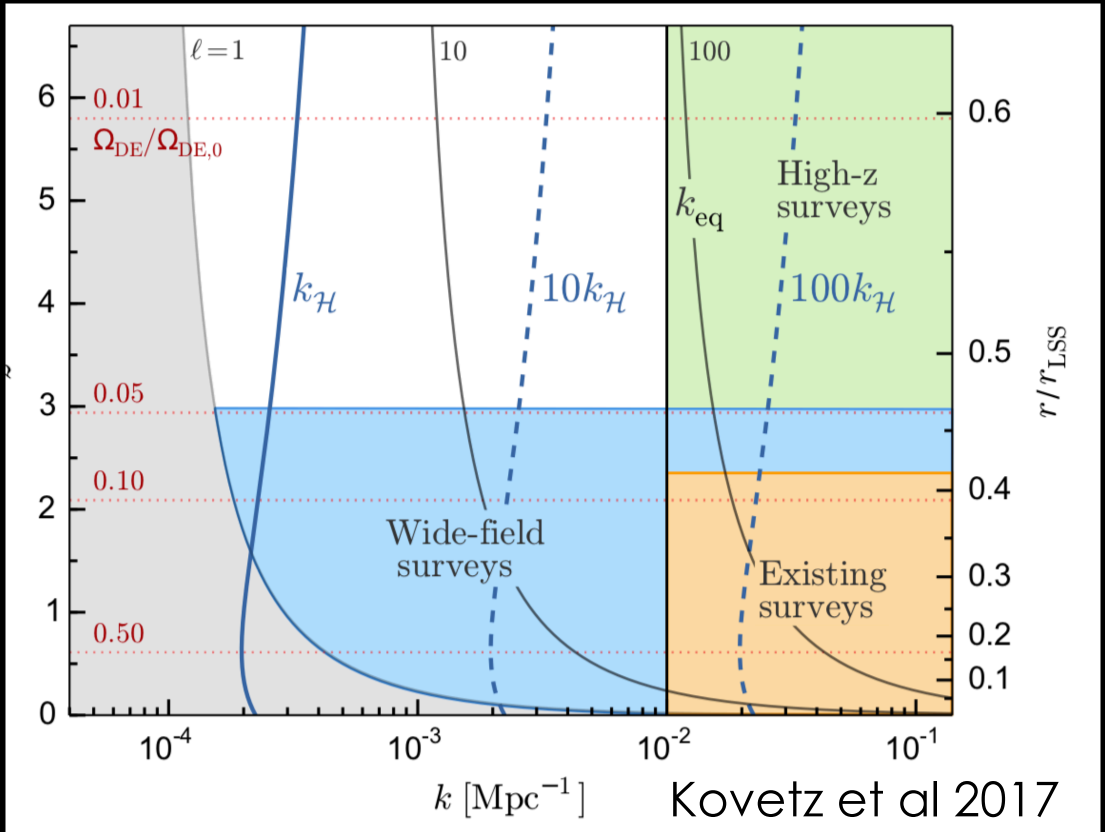
σ_{SFR}	Halos $\rightarrow$ SFR	Log-scatter in SFR
$\log \delta_{\mathrm{MF}}$	SFR $\rightarrow L_{\mathrm{IR}}$	SFR–L_{IR} scaling
α	$L_{\mathrm{IR}} \rightarrow L_{\mathrm{CO}}$	L_{IR}–L_{CO} log-slope
β	$L_{\mathrm{IR}} \rightarrow L_{\mathrm{CO}}$	L_{IR}–L_{CO} log-intercept
$\sigma_{L\mathrm{CO}}$	$L_{\mathrm{IR}} \rightarrow L_{\mathrm{CO}}$	Log-scatter in L_{CO}

Li, Wechsler, Devaraj & Church 2016



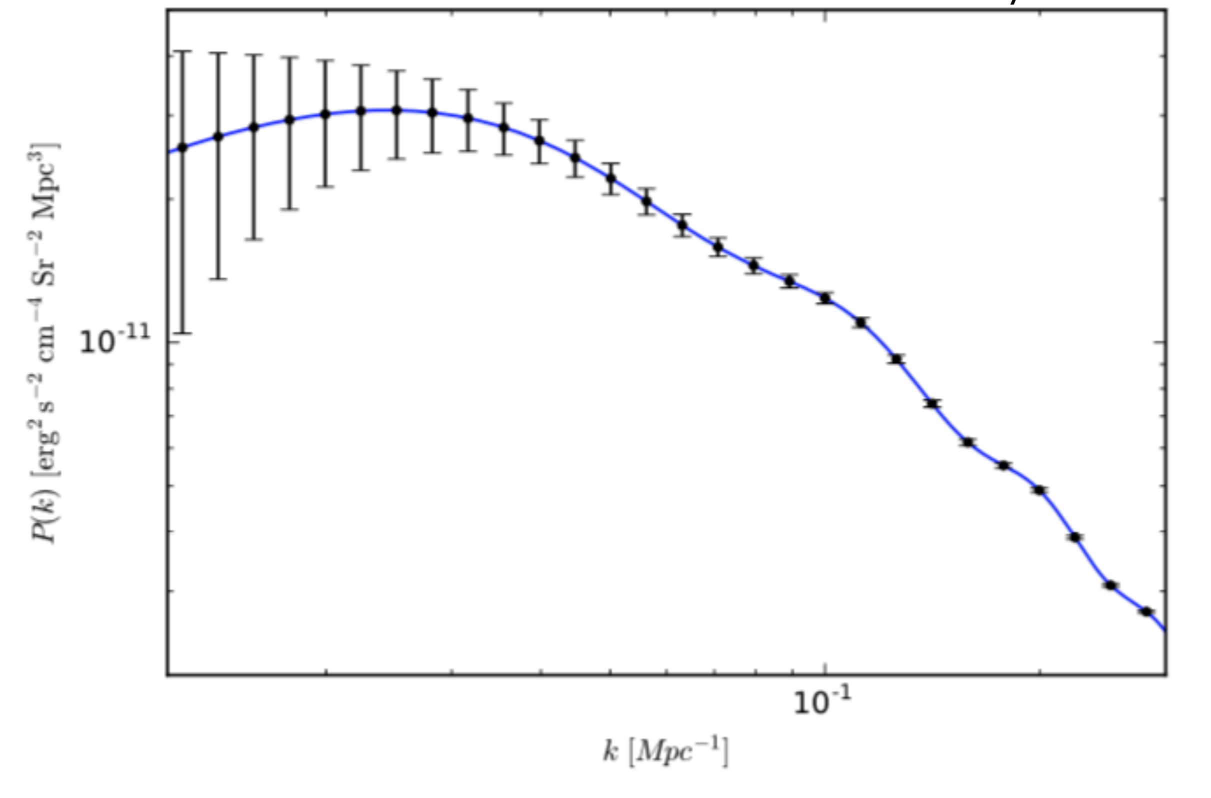
COSMOLOGY

- Great reach in both redshift and k-space possible with intensity mapping
- Cosmological measurements from BAO (e.g., CHIME) and primordial non-Gaussianity



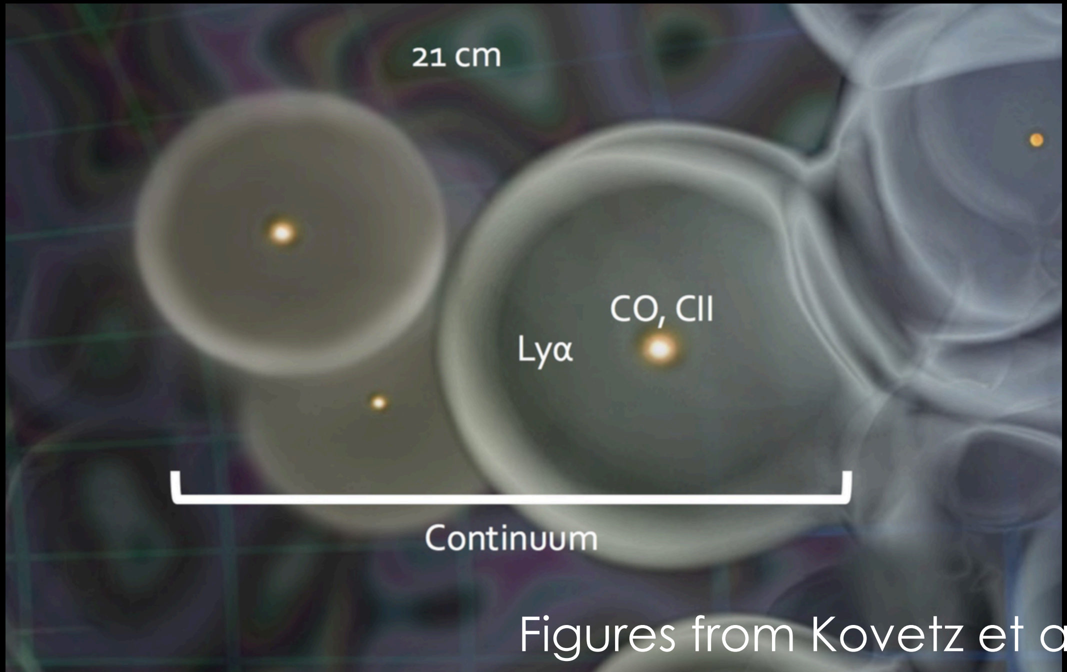
Kovetz et al 2017

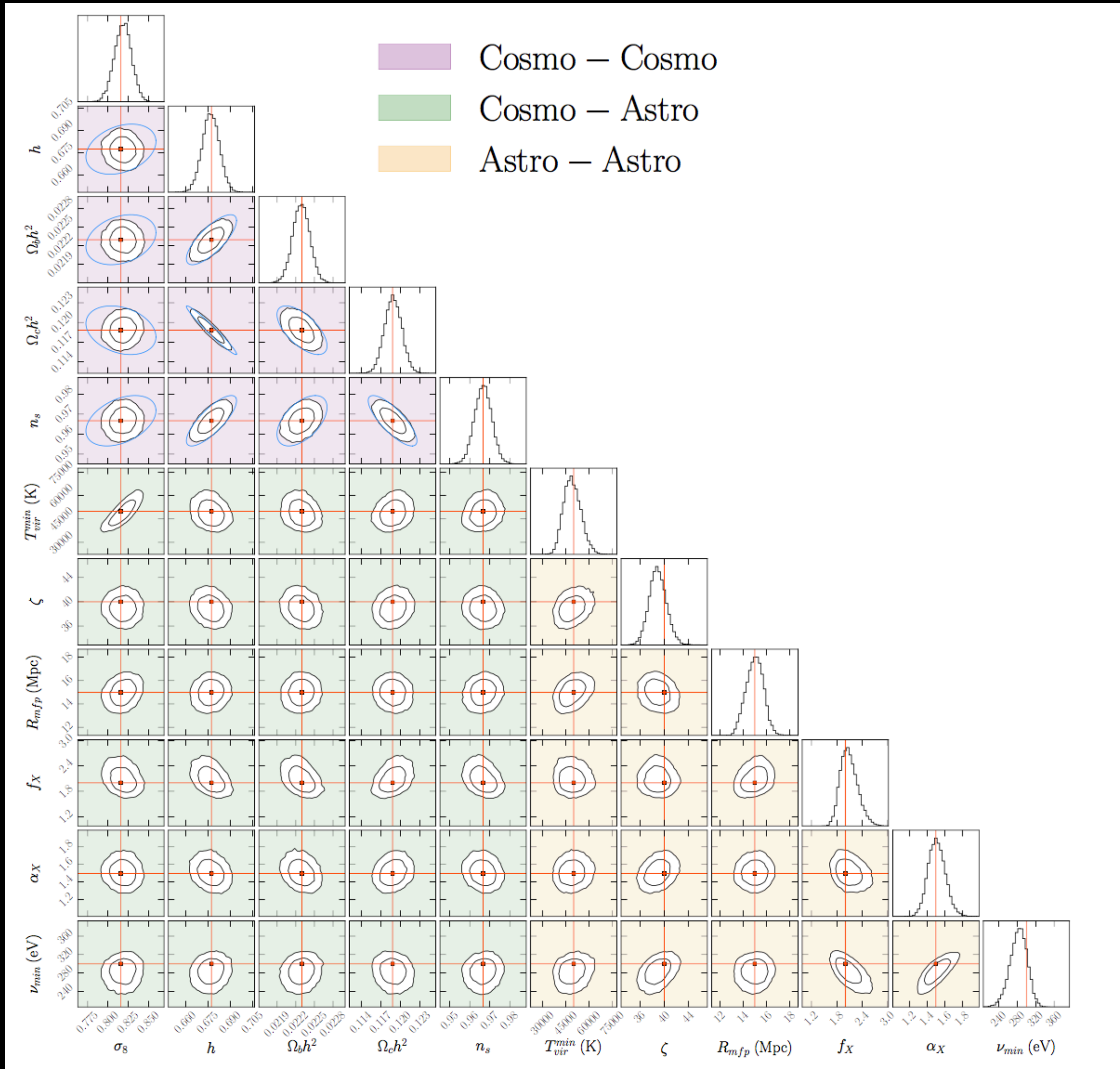
Fonseca, Silva, Santos & Cooray 2017



EPOCH OF REIONIZATION

- “Typical” galaxies during the EoR will be difficult to detect, even with JWST or future instruments (OST)
- Cross-correlations with upcoming 21 cm experiments (HERA, SKA) should prove very fruitful

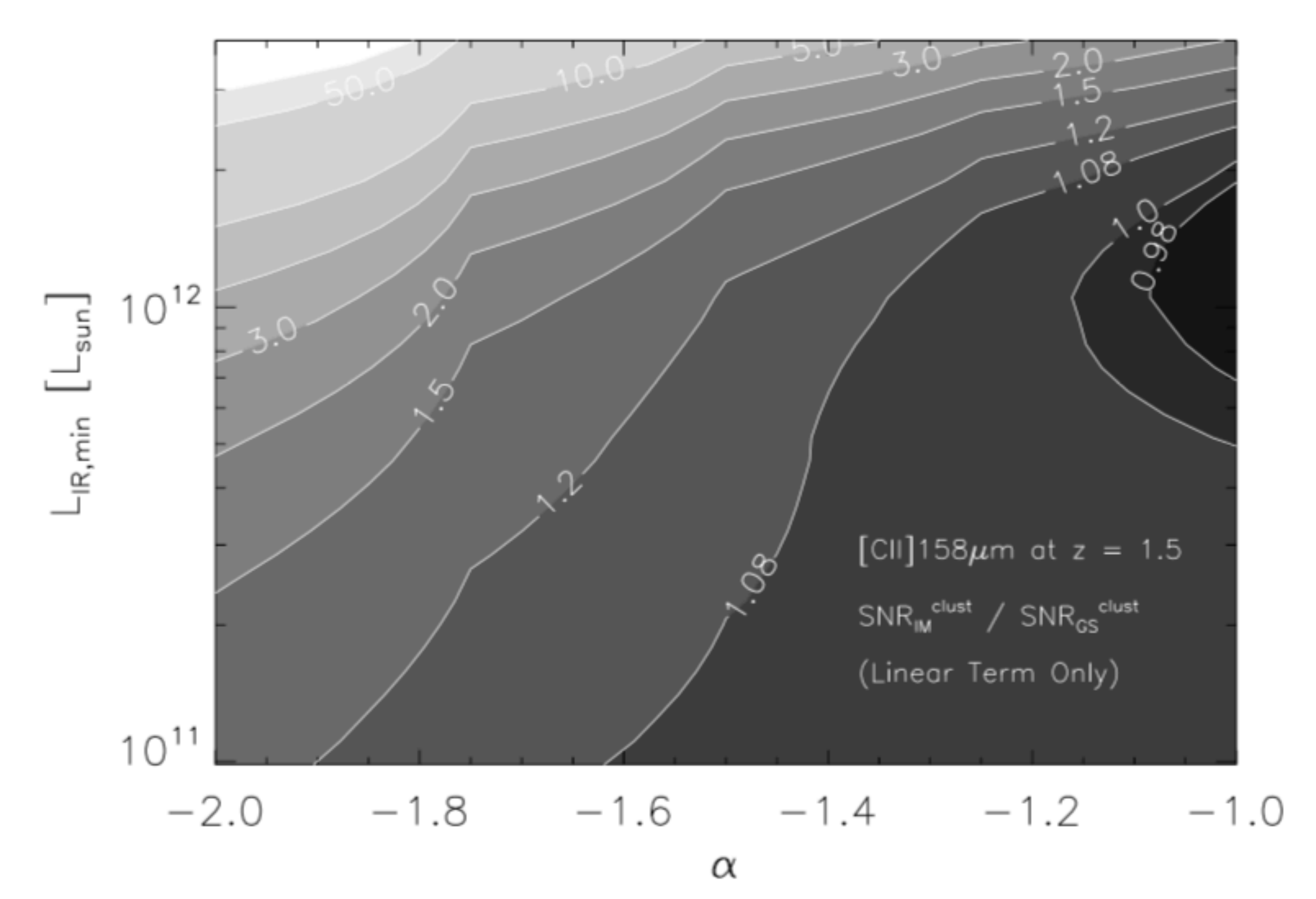




Figures from Kovetz et al 2017

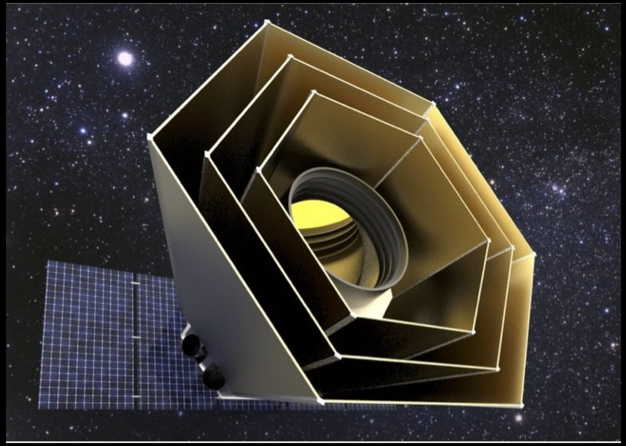
INTENSITY MAPPING VS. GALAXY SURVEYS

- How do galaxy surveys compare against intensity mapping for determining P(k), for fixed observing area and time?
- Generically, intensity mapping does a better job than a traditional survey if the number counts are steep, and the limiting depth of the survey is shallow

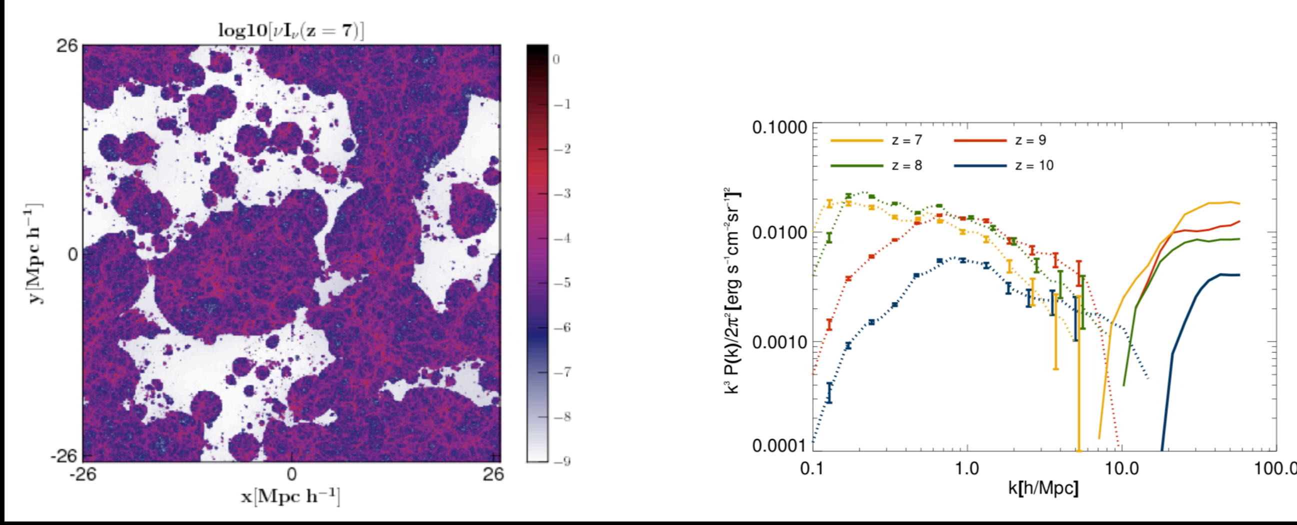


Uzgil, Aguirre, Bradford & Lidz 2014

COSMIC DAWN INTENSITY MAPPER (CDIM)



- NASA Probe-class Mission Study
- R~500 spectroscopy from 0.75 – 7.5 micron
- Among other things: 3D intensity fluctuations during reionization in both Lya and Ha
- PI: A. Cooray



Cooray et al 2016 (arXiv:1602.05178)

GALAXY EVOLUTION PROBE (GEP)

- NASA Probe-class Mission Study
- *Large mid/far-infrared galaxy surveys* with PAH photometric redshifts for a cosmic census of star formation and supermassive black hole accretion
- PI: J. Glenn

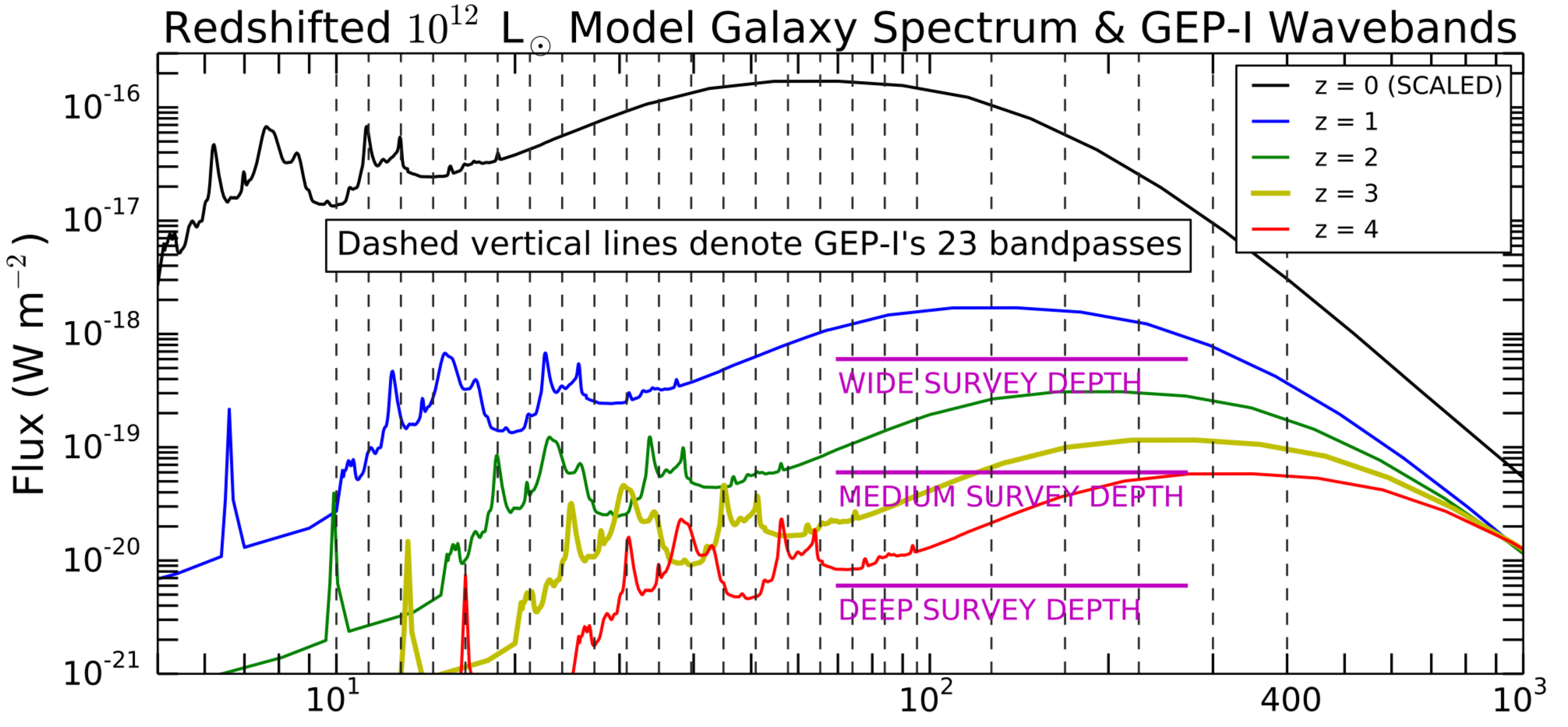


Figure courtesy Jason Glenn

Models from Dale et al. 2014 – *models do not include MIR/FIR atomic fine-structure lines*

CONCLUSIONS

- Intensity mapping can produce integral constraints on line emission that are useful and unique in constraining galaxy evolution models
- Under some circumstances, intensity mapping can outperform galaxy surveys for measuring the power spectrum
- Intensity mapping can provide complementary cosmological constraints to current probes
- Reionization is expected to be a particularly rich area where intensity mapping is useful