



Bond@KITP 23 02.09

is bond old and grey and in the way?



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well still colourful, if mystifying



# BSMc Transport from Early U Generation to all Correlated lensed Cosmic Web Probes to entanglement bases

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**MPeakPatches+Hydro+Usims+ coarse-grain halo+field & fine-grain stochastic response functions bias-RG-flows**

THEN BBKS, BCEK, B+Myers91,93,96, BKP96 cosmic web @kitp96, BW97 Lya,.. NOW: CITA mini-industry Alvarez, Bond, Stein 2013- 18-20-22 Berger, Battaglia, **Togay**, Codis, van Engelen, Motloch **Lokken, Lague, Braden, Morrison, Haider, Huang, Frolov, Carlson**, Keating, Breysse, Chung, Padmanabhan, **Li, Liang, Lahklani, patrick h, bruno, connor, ronan, furen, anita, louis, remi, jason Lee, jaafar, clara, Liang, Murray, Thompson, Pustovoit**

SuperWeb of all fields: XYZT,  $\phi^A$

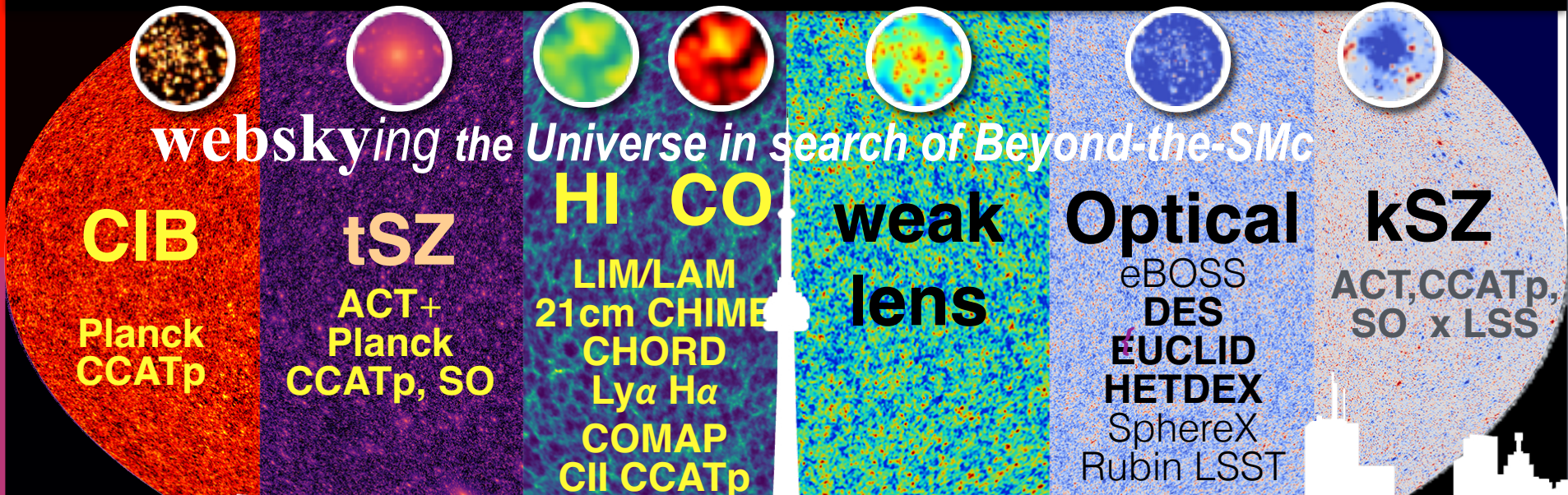
Instabilities & Phase Transitions fission/fusion in deformed vacua Casimir

=>Intermittent nonGaussian C BSMc =>

09-23+



need validation  $\checkmark\checkmark$  & speed to build (all-sky large-dynamic-range light-cone) ensembles need all signals to be correlated, 1, 2, 3, .. Npt .. & to be lensed need End to End mocks for BSMc: nonG  $\zeta, \zeta_{isoc}$  cDE/modG  $m_{DM}$ , FuzzyDM, Mnu,..



other BSMc Coupled DE funny DM

VMO ring of fire >VMBH clusters 82-86, 23-

one single vast entangled multi-messenger experiment probing the underlying BSMc to explore with novel statistical analyses

## $\psi$ SR SI CITA =Cosmic Information Theory & Analysis

from SuperWeb simplicity (?) to complex Intermittency in the Cosmic Web Studying the Cosmic enTanglement Universe=System+Res =Signal+Noise Duals

the Universal story:  $U \Rightarrow$  entropy / information currents + phase / action currents (tensors) coupling duals of collective charges  $Q = Q$ -field; eg E/M, P, LSZ, LCIB

Planck, AdvACT, SO, CMB-S4, CCATp, Spider LITEBIRD + SPT, BK, CLASS,.. optical/IR SDSSn, EUCLID, LSST, DES, HSC, DESI, SphereX, WFIRST radio LIM CHIME, HIRAX, COMAP, CHORD, EXCLaiM,...SKA, HERA, LOFAR, ..



**Bond @ (K)ITP 1980: Entropy, Neutrinos & Supernovae (Shocking Matters)**

**Bond @ KITP 2020: Entropy, Phonons & Phase Transitions  
in stochastic inflation, during and after (Shocking Matters)**

$$3\zeta_{\text{tot}}(x,t) = \int_{\text{field-path}} (dE+pdV)/(E+pV) \sim \int TdS/(E+pV) \text{ observable1 } \mathbf{S_{CMB}} + \mathbf{S_{CnuB}} \text{ obs2}$$

Bond Braden Chakrani Haider Morrison Stein @CITA Frolov Huang @exCITA Carlson, Chung @CITAZensUnited

bond@kitp2023 could be Entropy, the Cosmic Web and Entropic Emissions / Absorptions (LIMLAM)

# SuperWeb = $\zeta$ -scape

= one single vast entangled  
multi-messenger experiment  
probing the mother of us all:

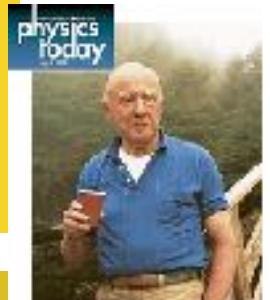


Entropic vision aphorisms and some definitions  
Particle production = entropy production  
History of the universe from an entropic view  
History of Bond's talks at KITP in relation to human cosmic history  
The  $\zeta$  story aka phonon story - after inflation  
Stochastic inflation through my ages  
Quantum cf stochastic and a fDM aside  
End on new way of looking at stochastic inflation

$m^2 > 0$  spectrum for cosmic collider  $m^2 < 0$  more spectacular chaos



"Now I am in the grip of a new vision, that *Everything Is Information*. The more I have pondered the mystery of the quantum and our strange ability to comprehend this world in which we live, the more I see possible fundamental roles for logic and information as the bedrock of physical theory. ... I continue to search."





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uhuh, perhaps alas for you: bond is bound to U all in our interconnected CosmicWeb,  
entangled as we all are in the Uweb, the Superweb,  
indeed in this SuperDuperWeb we inhabit,  
celebrating here and now - once again at kitp in 2023, where “cosmic web” as concept  
began formally in 1996 via B, K and P, a wedding/webbing of east/west ideas



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deformation tensors aka tribeins aka exp(strain) aka tides in an Rg flow  
- in scale space: our AdS/cRFT





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- in scale space: our AdS/cRFT

and i hope for your healthy gastrophysical digestion but i fear for your indigestion

& cheers to the forever young, einasto and the soon to arrive@kitp sergei shandarin (bond grand-unifies with shandarin at a greek taverna in crete in 1982, bond a rare one to tune into the zeldovich school - the west then saw only spherical cows in U)





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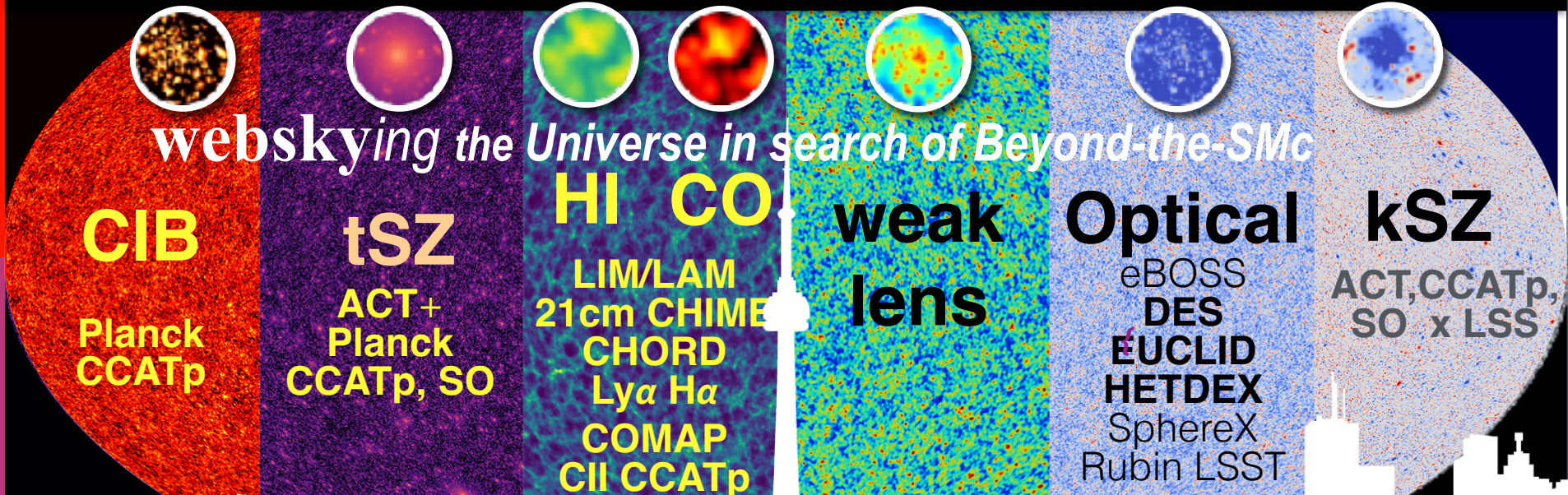
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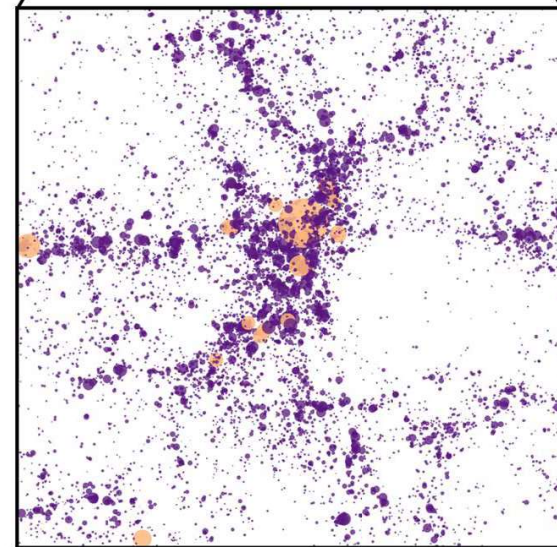
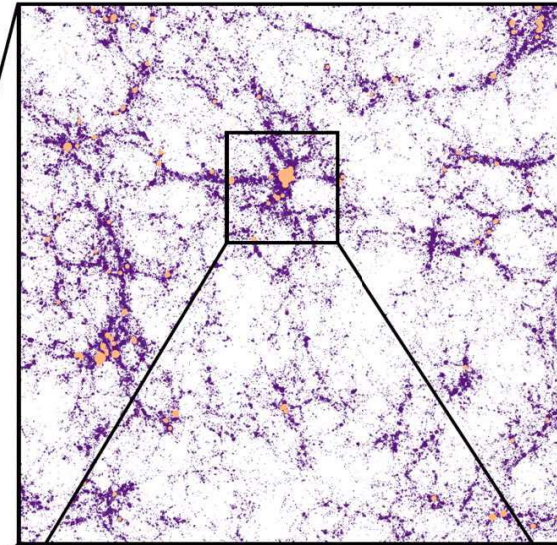
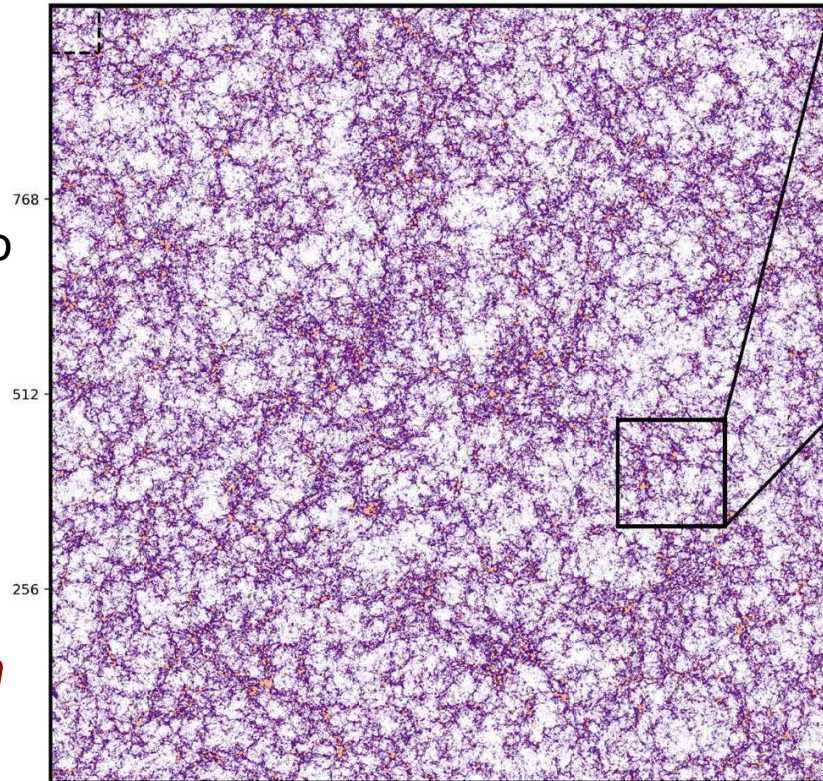
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1 Gpc<sup>3</sup>, 8192<sup>3</sup>, z=2, n<sub>tile</sub> = 16



Halos above 10<sup>12</sup> coloured orange.

does pkp work?  
bias analytic pkp perfect  
cf. n-body pkp sim  
pkp halo overlap n-body halo  
Euclid tests: power, corr fn

*dynamics:*  
*ellipsoidal for triaxial collapse*  
*2LPT for halo motion & field*  
*TBD improvement using*  
*gravitational potential shells in*  
*ellipsoid dynamics to stop*  
*pkp 2LPT pass-through*

**pkp perfectly suited for light cones, cross-box z-variations if cells.**

**HI needs hierarchical multigrid for hires + huge sky - in original BM96 pkp, now ~perfect cell coherence**



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2013 MOCKing HEAVEN: bond@Cosmic Web cross-correlations in theory & in observations, Cross-Correlating Cosmic Fields Conference, Shanghai, Oct

novel statistical methods: beyond / as well as the usual cross power spectra etal.

m=0, 2, 4: oriented stacks via tidal tensor, strain tensor, Hessian of density (log) & m= 1, 3 parity broken stacks, multiscale on cluster/peak points with LSS constraints. tSZxDES (Martine Lokken), CMB (Planck, ACT)

symmetry broken stacks on key cols (prominent saddles) e.g., in ISM web - dust. beautiful images but not better than multiscale peak constraints

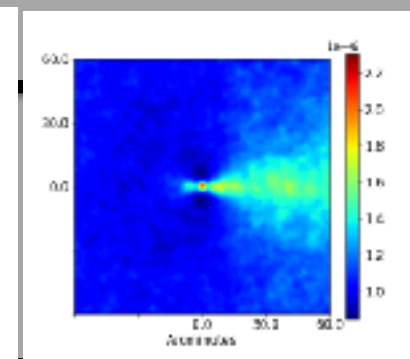
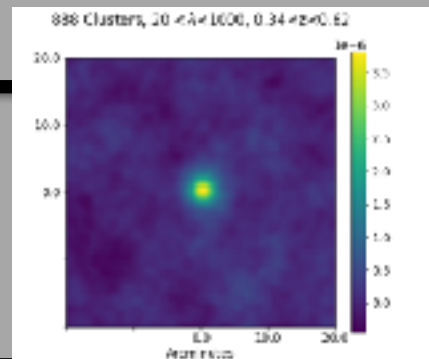
stacks give correlation functions wrt the special catalogue points, but can also be transformed into response functions

novel statistical methods:

relative entropy of PDFs, needlet filtered (partition of unity, Lband, Delta Lband) amplitudes of templates for model improvement and weak lensing amplitude - applied to lensed cf. unlensed CIB

local quests for p-nonG may be better than bispectra templates for novel nonG, e.g., intermittent p-nonG with localized zeta-prominences - TBD

$\langle y_C | n_{cl} \rangle$  tidal tensor oriented results:  
e.g., ACT  $\gamma$  X DES cls/gals - Martine  
e.g., WebSky vs SDSS x Planck - Connor



e.g., Vintage Nov 2018 : oriented CO on HETDEX. CO on CO peaks, soon: 2023 COMAP X LSS carefully

# High Column Density Lyman Alpha Absorption

- (galactic halo) pkp with hod, does include low mass dwarflets dotting the filaments as per BW97 and Hyunbae Park @ kitp23

Galaxy Halo  
Properties



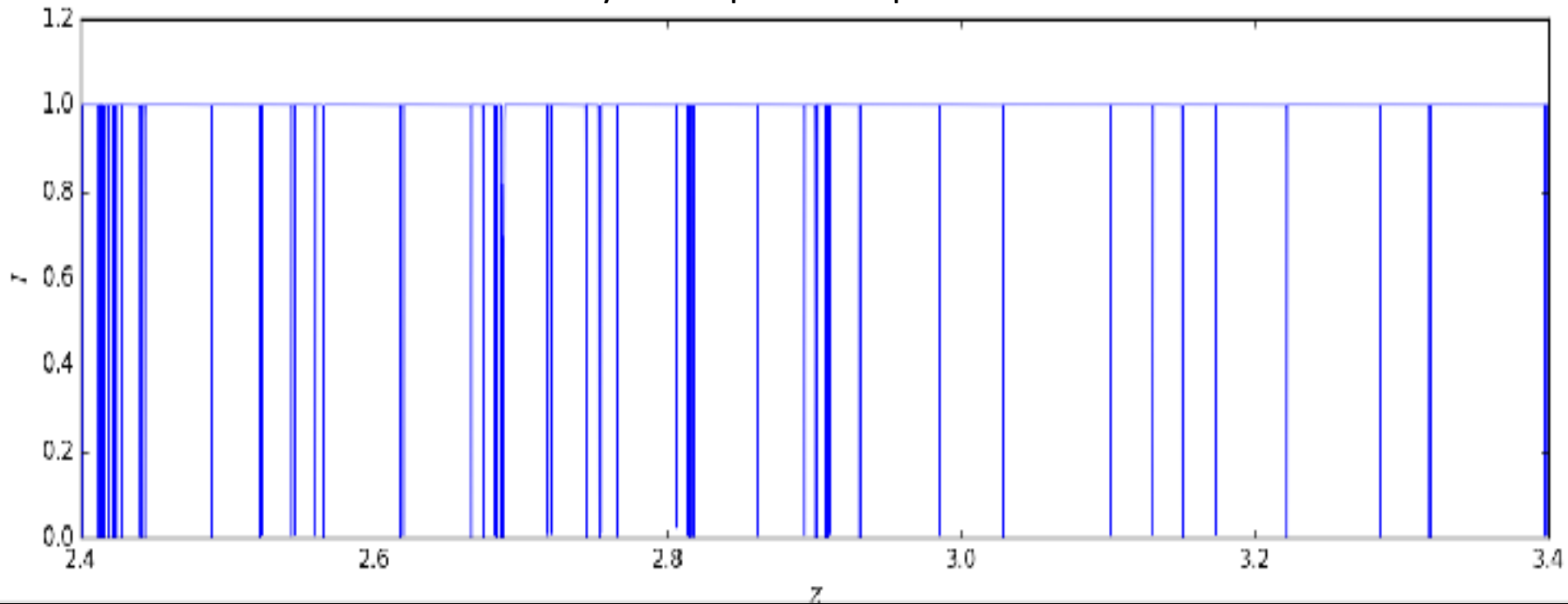
Neutral Hydrogen  
Density



Absorption Line  
Strength

Ronan Kerr + Dick Bond, George Stein, Marcelo Alvarez

Lyman Alpha Absorption

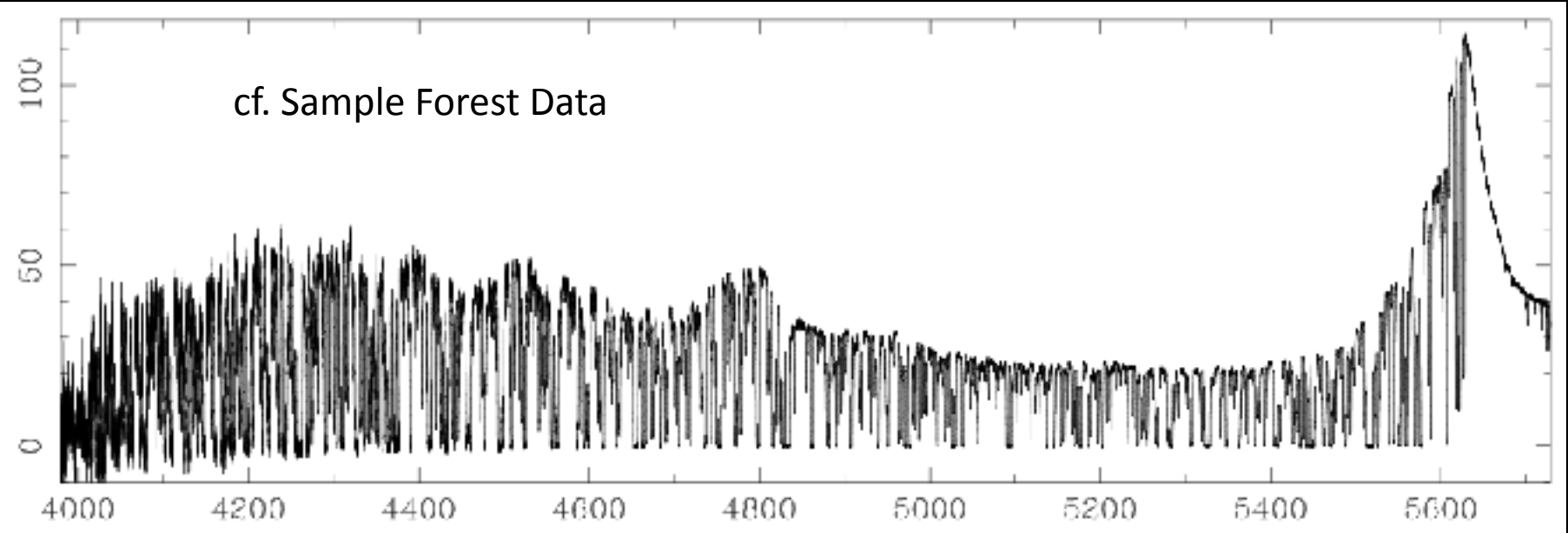
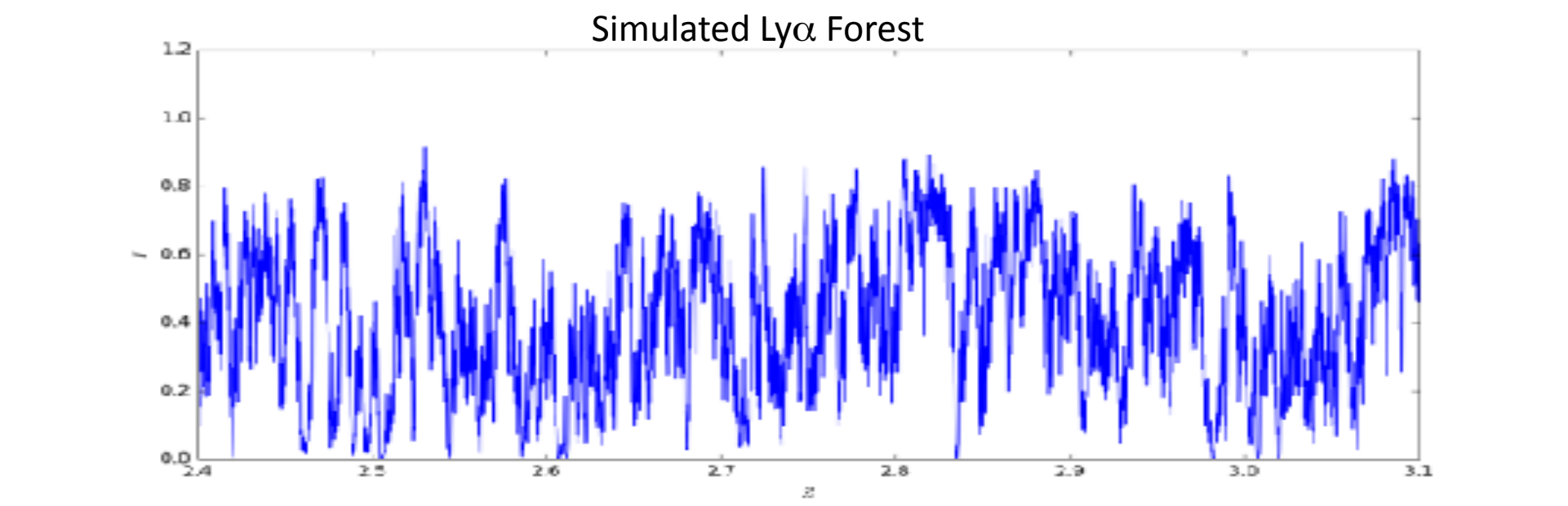
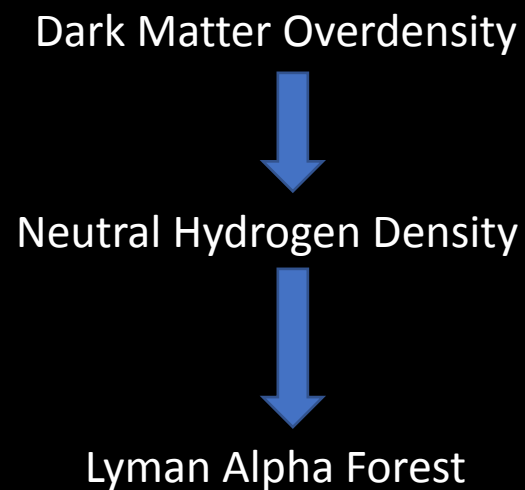


## & H $\alpha$ Emission Spectra etc

HOD + halo flows + velocity dispersion in halos (internal galaxy dispersion not needed for LIM/LAM)

# Lyman Alpha Forest

Lya field Response function from Lee et al. 2014  $\langle n_{\text{HI}} | \rho_{\text{dm}}(x) \rangle$  local  
Low Column Density regions (the intergalactic medium) pkp-excluded 2LPT field



thus halo+field Lya from pkp  
is great for correlated  
large scale modulated  
 $n_{\text{gammaUV}}$   
e.g. QSO proximity effects,  
with qso-embedded in pkp halos



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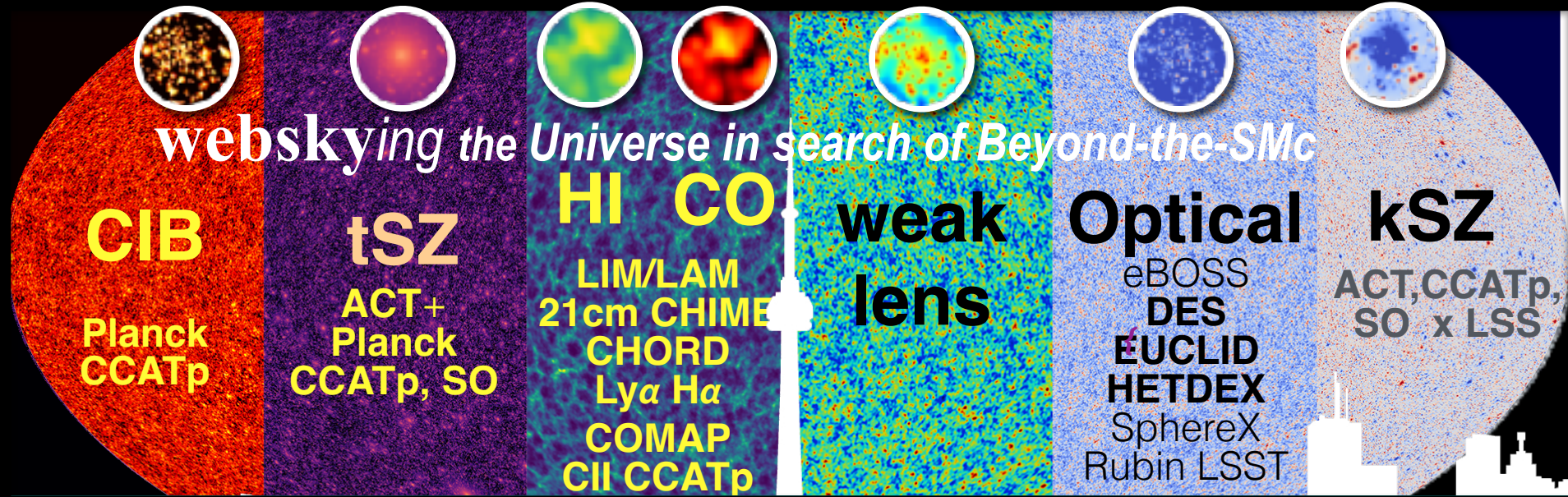
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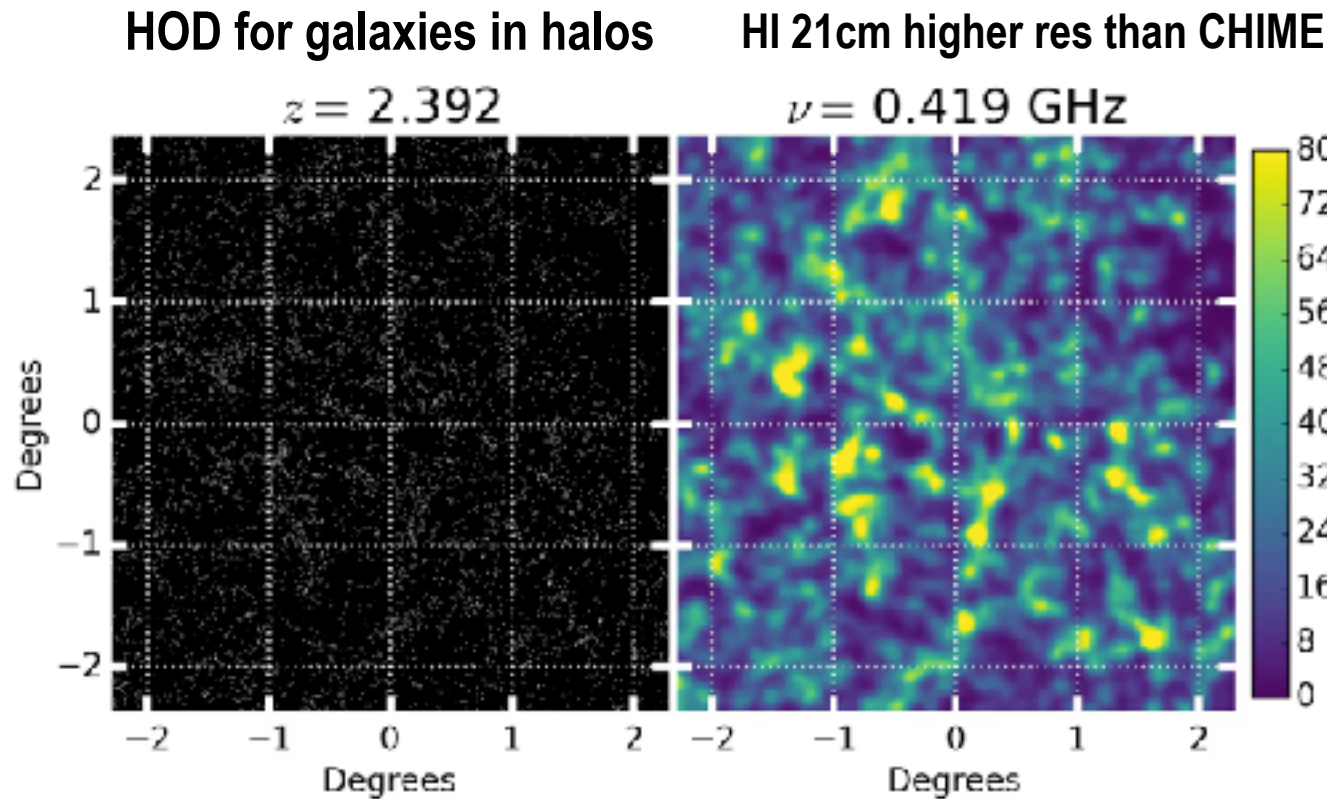
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# Line Intensity Mapping: HI 21cm CHIME, HIRAX, CHORD, SKA, ..

CHIME  $z=0.8-2.5$ ,  $\sim(8 \text{ Gpc})^3 \sim 60'$  CHIME, still good for fuzzy web BAO target but need  $M_{\text{min}}$  below  $10^{11} M_{\text{sun}}$

*hence: fully coherent hierarchical boxes; could do OK with original 91-94 pkp, because great  $k$ -sampling but berger+ is better*



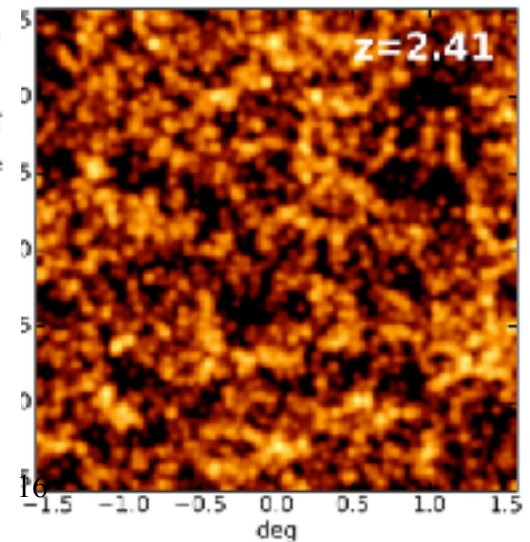
## CIB buildup:

$z=2.4-3.4$

52M halos

$M_{\text{halo, min}} = 2.5(10) M_{\text{sun}}, (4096)^3$

CIB processed with 6' fwhm for illustration



*original HI response function Villaescusa-Navarro et al. 2014*

*improved HI response data driven: Hamsa Padmanabhan 2018 @ CITA*

*TBD: newer HI response FIRE sim driven: Togay+ 202x @ CITA*

*original CIB response function Planck 13, 15*

*TBD: newer CIB response FIRE sims @ CITA*

*- correlated stochasticity to be built in*

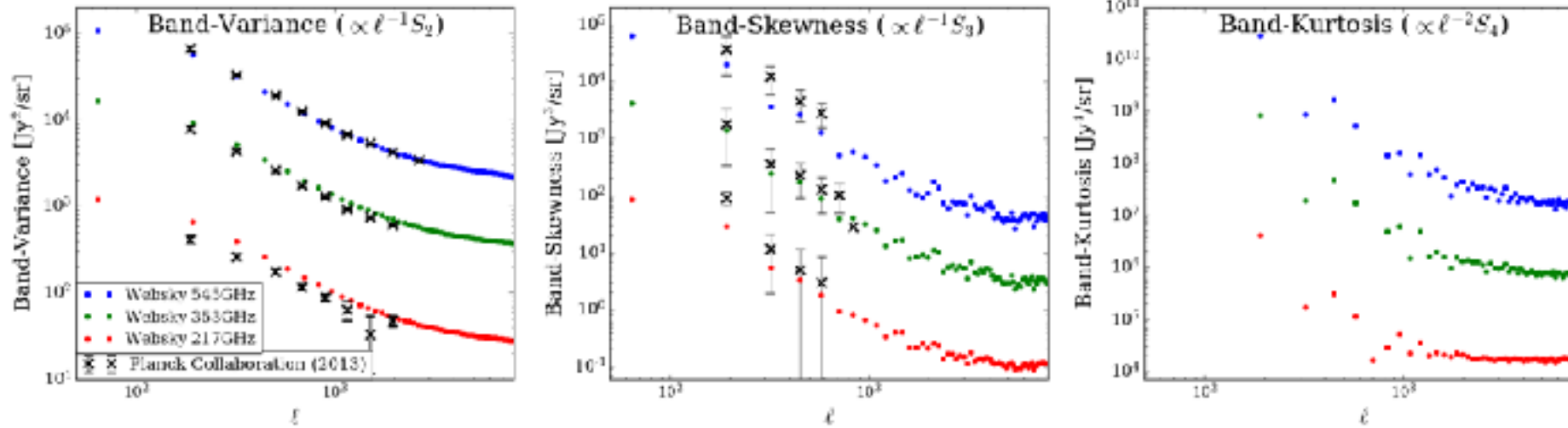


## Websky - beyond Planck with a Planck fluxcut

=> power  $C_L$

=> bispectrum over a limited L region

=> trispectrum unmeasured



=> CIB  $\langle L \rangle$  (Mgal, z) response models do not capture known CIB physics

e.g., stochastic star bursting at all masses e.g., bright end

effects of gas flow perturbations, eg mergers

$L_{\text{CIB}}(t)$  cf.  $L_{\text{CII}}(t)$  cf.  $L_{\text{CO}}(t)$  for individual galaxies, mini-ensembles?

*Liang+22 using FIRE Tolgay+23 using FIRE*

stochastic effects using log-normal to mimic time-dependent luminosities

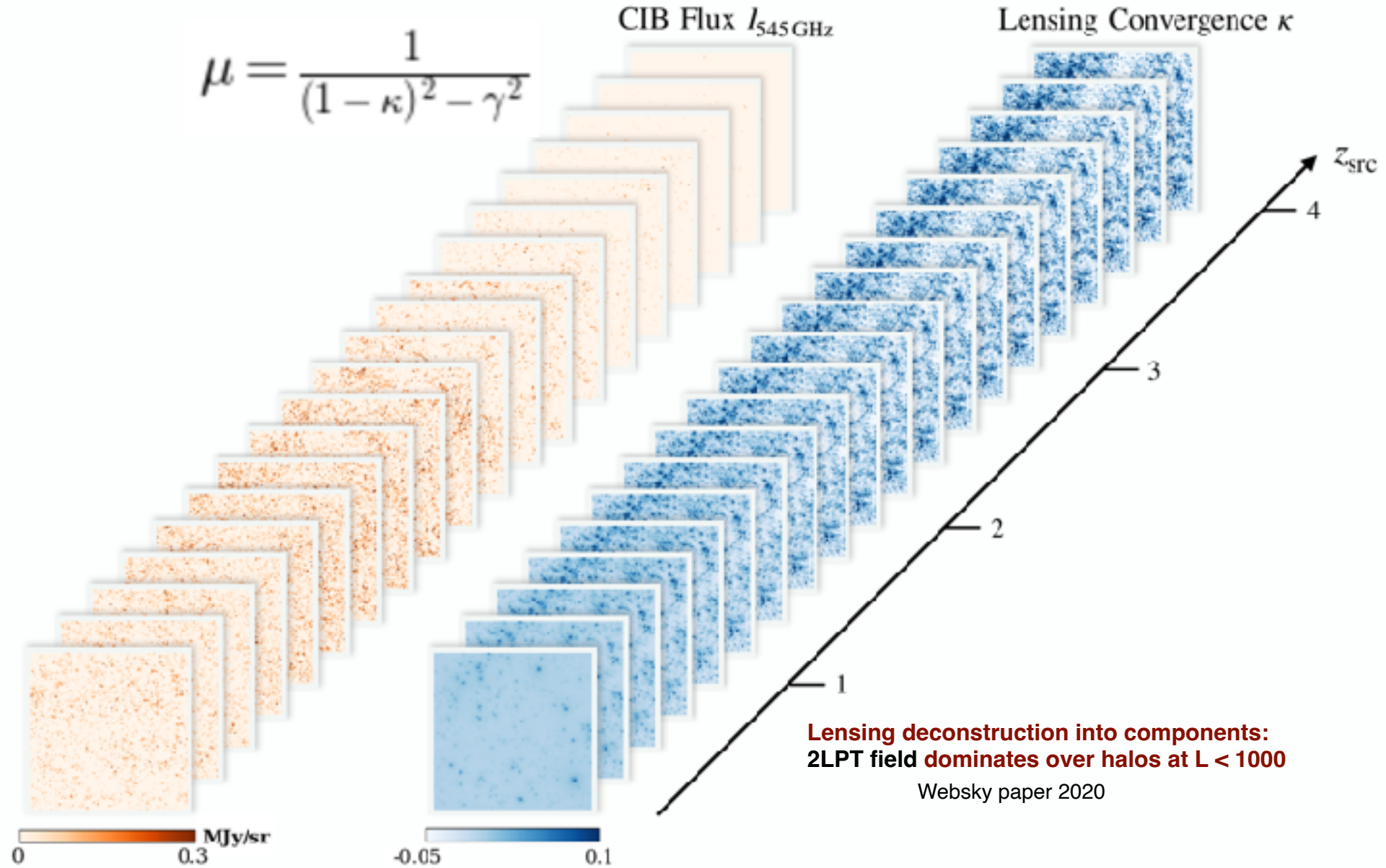
$\ln L(\text{Mgal}, z) = \ln \langle L \rangle(\text{Mgal}, z) + \sigma_{\ln L} * \eta$ ,  $\eta = \text{gaussian random deviate, i.e.,}$

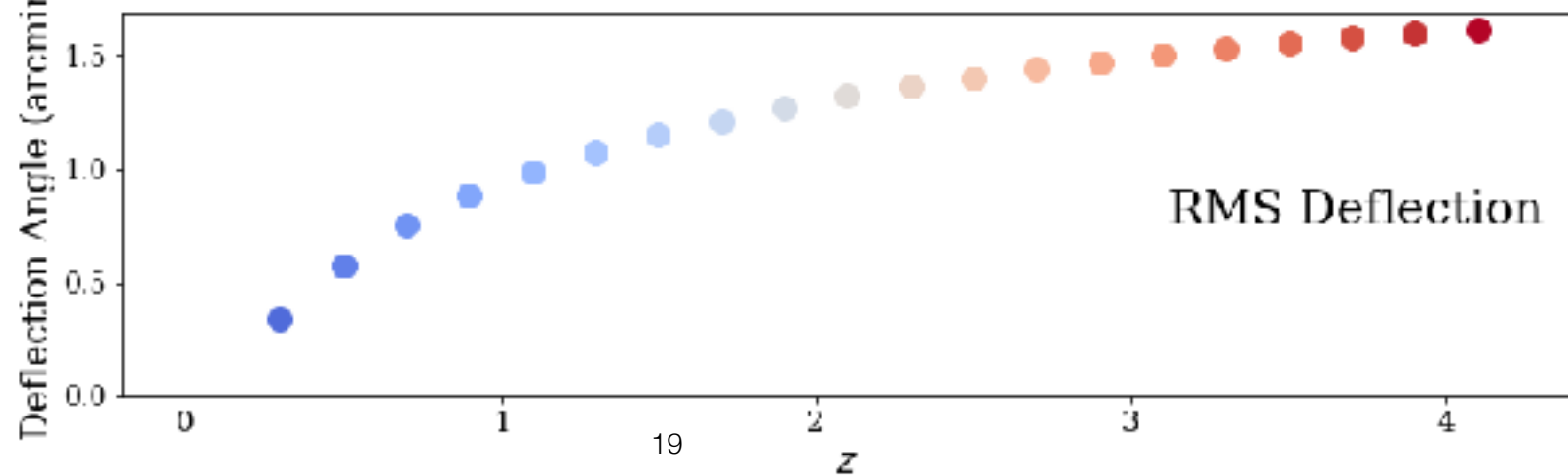
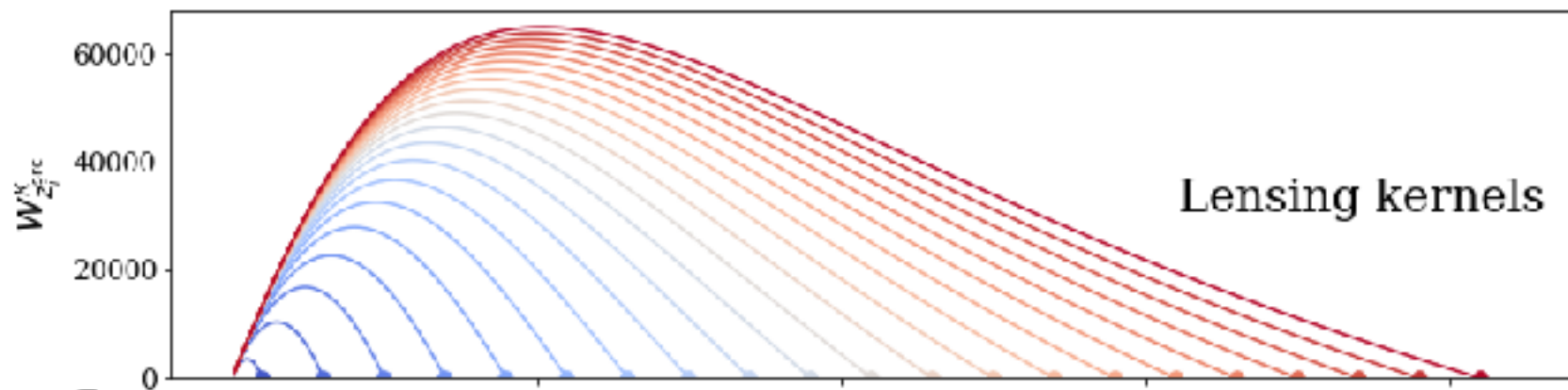
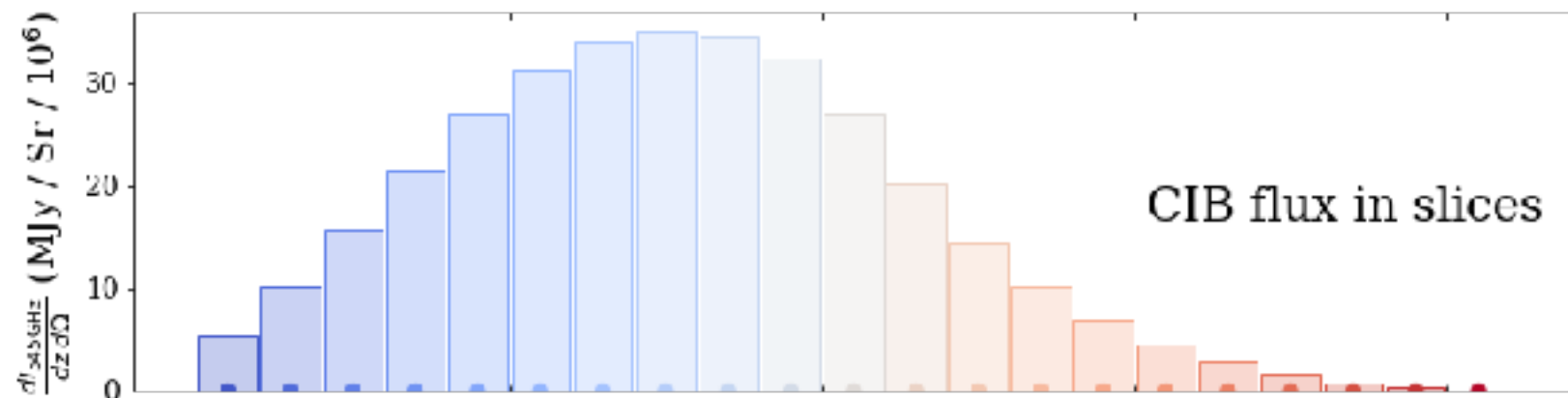
$\text{Prob}(\ln L) d \ln L = \exp(-(\ln L(\text{Mgal}, z) / \langle L \rangle)^2 / 2 \sigma_{\ln L}^2) / \sqrt{2\pi} \sigma_{\ln L} d \ln L$

CIB Lensing Method: band CIB into redshift slices aka source planes  
 band Lensing Convergence into lower-z lensing planes, make the slices cumulative  
 => shear, lensing displacement and magnification

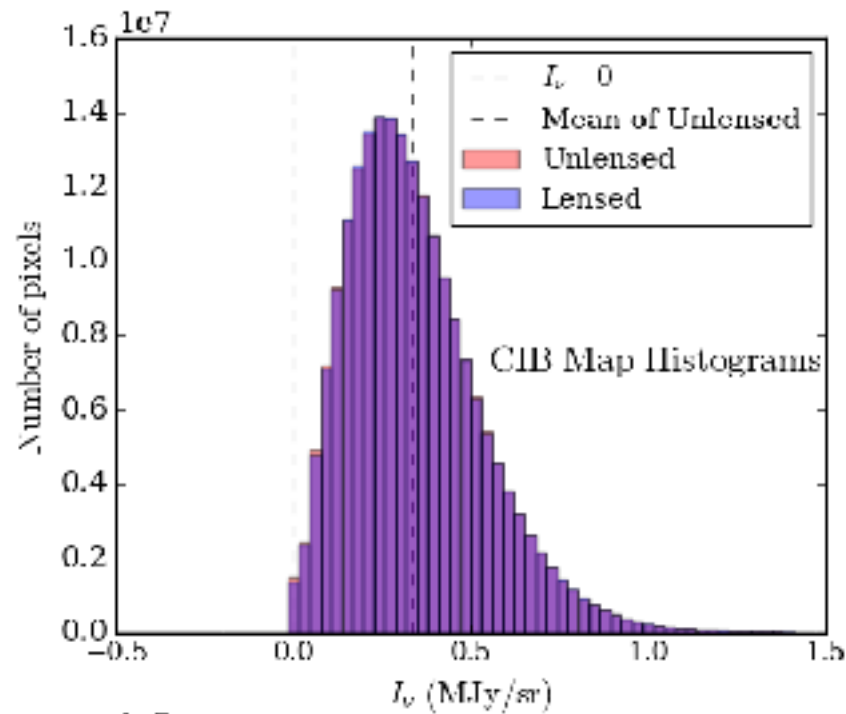
Websky paper 2020

CIB  $z_{\max} > 4.5$  unused component      Lens  $z > 4.5$  important





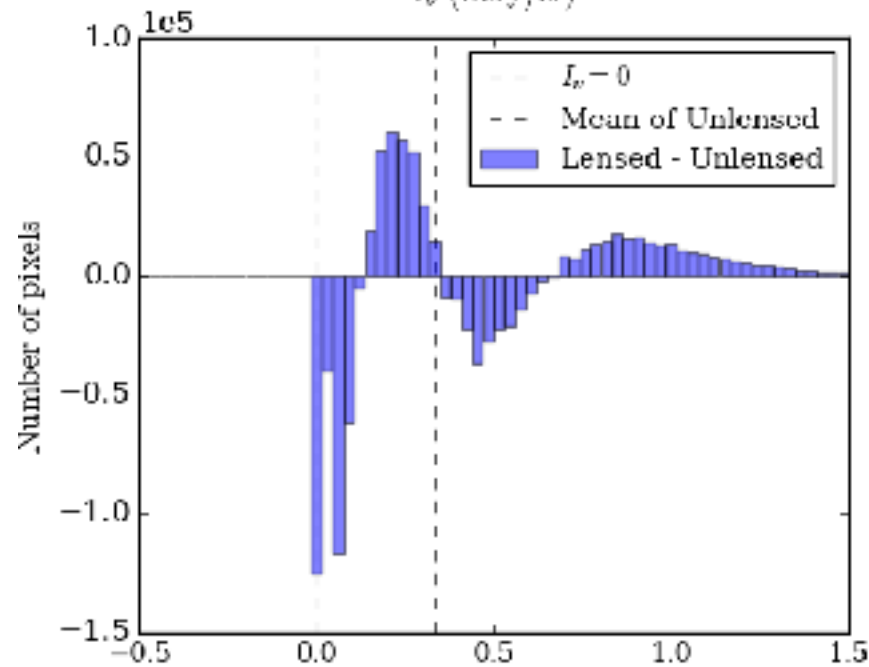
# ProbDist Function of needlet L-banded maps => order-n band-cumulant spectra



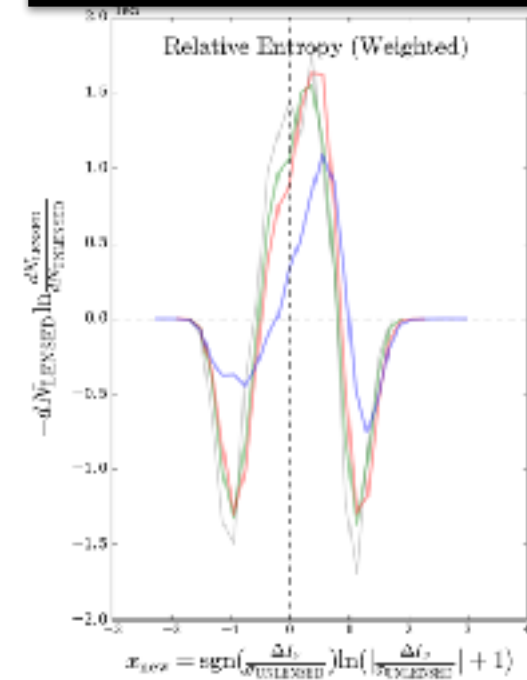
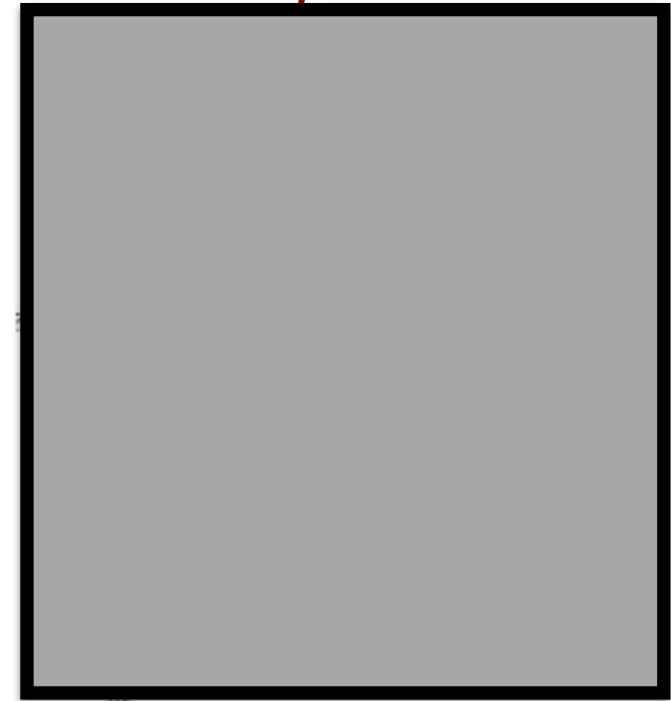
blind analysis - fit in powers  
aka cumulants  
=> band-n-point spectra

use relative entropy  
(KL divergence)  
between distributions to  
construct templates  
i.e.,  
search for 'orthogonal modes'  
& adjust to minimize residuals

*lensing template is just one*



an  $L_b$  pdf template,  
could give  $A_{\text{Lens}}(L_b)$  spectra,  
consistency





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Casimir

=>Intermittent

nonGaussian **C**

BSMc =>

09-23+



other BSMc  
Dynamical DE  
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funny DM  $\phi$ DM

first \*s  
VMO ring of fire  
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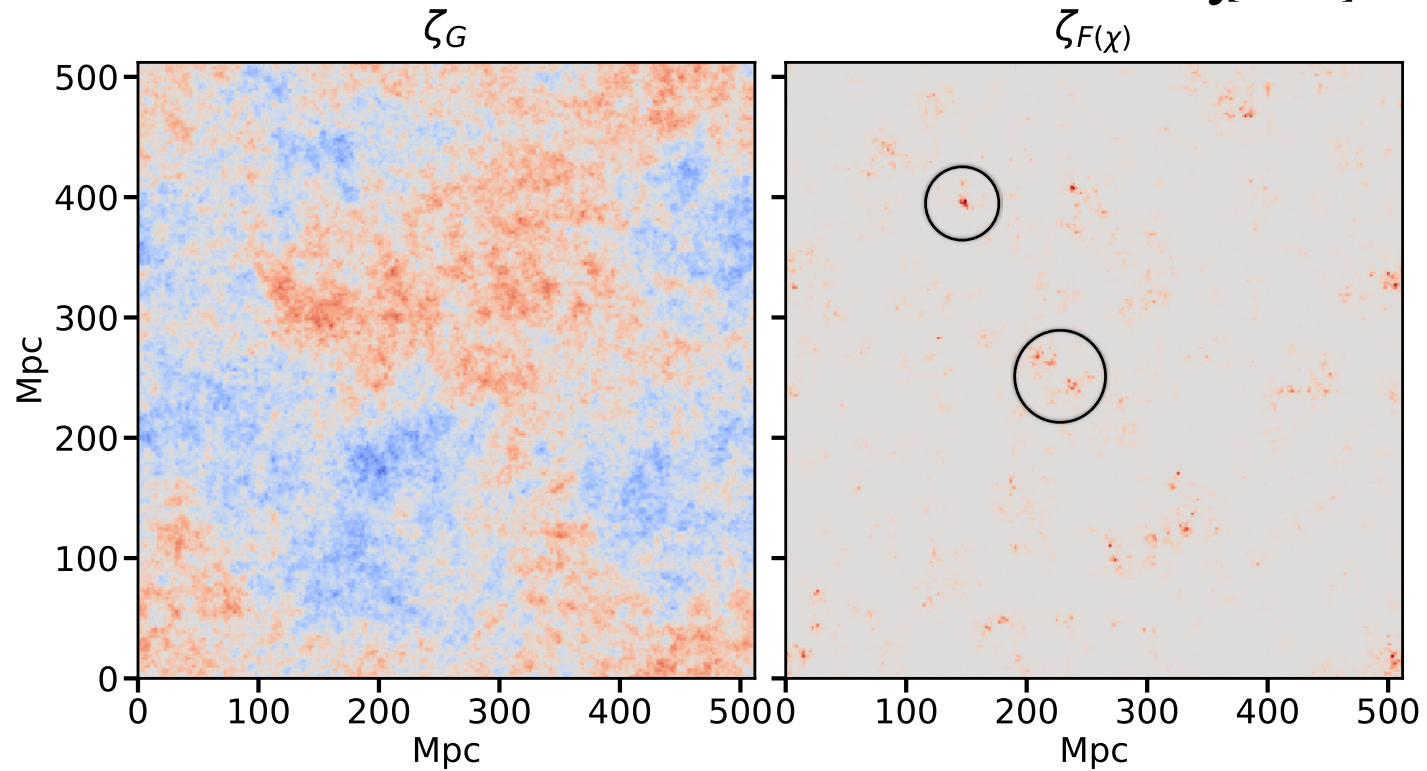
one single vast entangled multi-messenger

**$\psi$  SR SI CITA =Cosmic Information Theory & Analysis** the Universal story: U => entropy / information

**Primordial Non-Gaussianity in observable Webskys using  
the mass-Peak Patch method + gas-halo response functions/susceptibilities**

sample Intermittent Non-Gaussian case

***uncorrelated***  $\zeta$ [GRF]

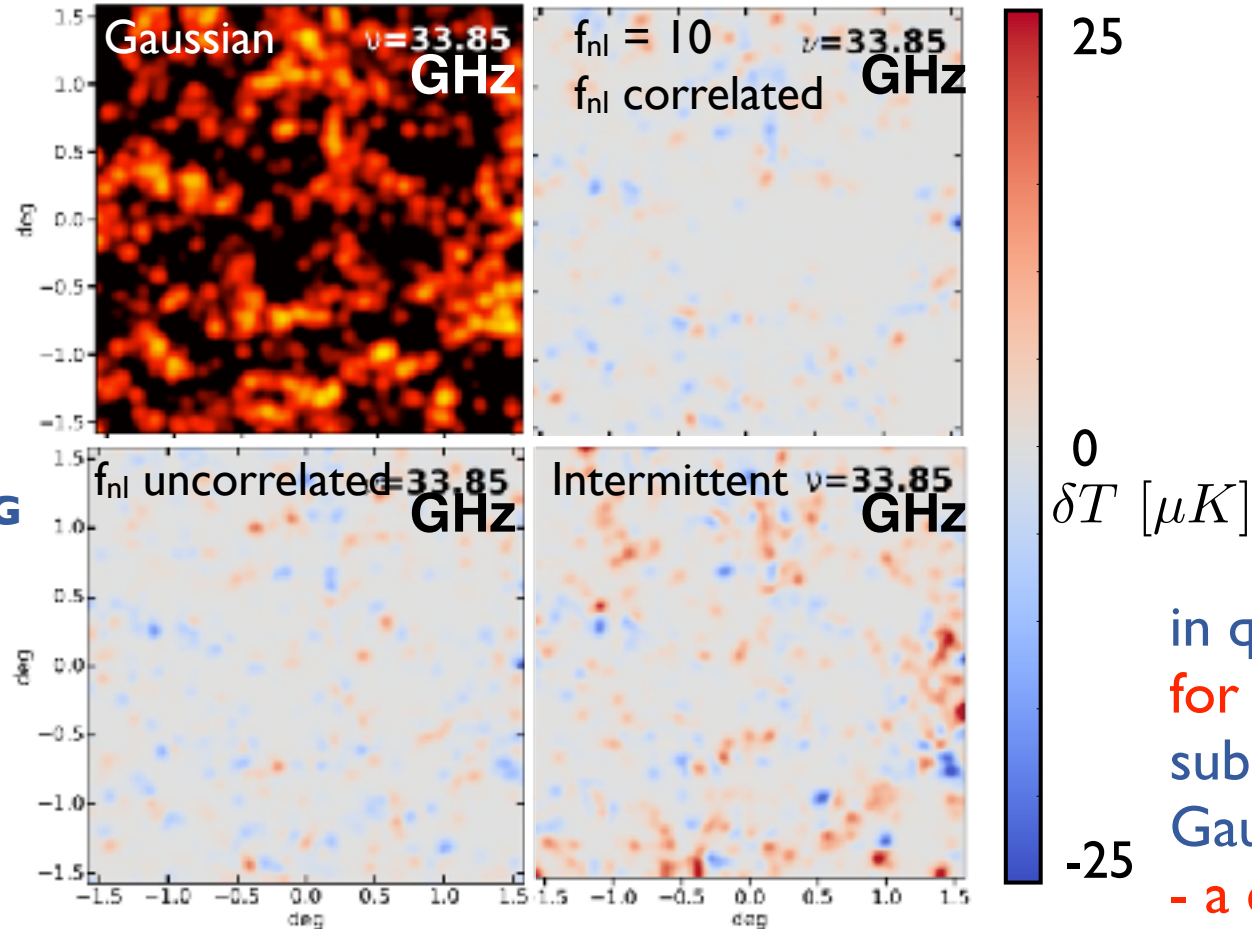


*Bond , Huang, Stein; Braden, Morrison, **Carlson**...*

***after /during inflation modulated nonG  
need a very light  $\chi$  to modulate into the CMB/LSS regime***

# Line Intensity Mapping: CO lines COMAP, CII: EXCLAIM, CCATp; HI of course

$$\sigma_8 = 0.82 \text{ In all cases}$$



in quest of **templates** for the **entangled pnG** subdominant to the base Gaussian  
- a component separation problem => TBD

**pnG in COMAP**; want large scale => much larger volume CHIME/CHORD HI 21cm

Our LIM/LAM future:  
HI, CII, CO correlated/entangled with the "classic" optical LSS survey  
in quest of subdominant nonG  
CHIME HIRAX CHORD COMAP CCATP  
SphereX  
+ Euclid, WFIRST, WebbST,  
+ DES, DESI, LSST +++  
+ eROSITA +

## nonlinear entanglement of $\Delta\zeta_{nG}$

uncorrelated pnG is correlated with pG in the nonlinear halos and their emissions.

can be constructive or destructive interference, or  $\sim 0$  (intermittent)

**pkp => Websky summary:** fast halo finding for ensembles & BSMc works well, very cf. NBody  
“mocking heaven” apps: tSZ, CIB, Xray =original motivation =>kSZ, Lens => galaxies, dGs, 1st stars,..  
=> tSZxCIB, etal => LIM/LAM all correlated & lensedCIB etal

2013 MOCKing HEAVEN: Cosmic Web cross-correlations in theory & in observations, Cross-Correlating Cosmic Fields Conference, Shanghai, Oct 14, 2013

**optical galaxies via HOD for CMASS, Euclid, LSST, .. DES, HSC, sphereX**  
**“intensity mapping” of HI (CHIME, HIREX, CHORD, ..,SKA) of CO CMap, CII CCATp**  
**well suited: to cross-correlation studies of all sorts**  
**well suited: to characterize correlated/non-Gaussian errors**  
**well suited: light cones automatic, no interpolation**  
**peak-patch +++: multigrid for hi res; 2LPT -> hierarchical ellipse dynamics**  
**BSMc Physics: beyond Lambda: dynamical DarkEnergy, modified gravity**  
**fdm, hcdm, LSS non-Gaussianity: perturbative, intermittent, scale-dependent bias**

(stochastic) response functions to stimuli= mean susceptibilities / form factors - & internal halo structures

fluctuations inside controlled? outside 2LPT and subgrid halos adequate?

tSZ in pkp controlled; CO out of pkp control?

**all WebSkys must be Lensed: CMB, CIB all LIMs**

**why do LIM/LAM? just to understand galactic weather / storms?**

a theorist’s hope: component-separate gas physics to reveal

fundamental BSMc physics

e.g., using LSS/LIM to further develop the  $\zeta$  map of the early universe - stacked  $\zeta$  primordial nonG  
of all sorts in 3D. intermittent modulated nonG