CITA | ICAT

Canadian Institute for Theoretical Astrophysics

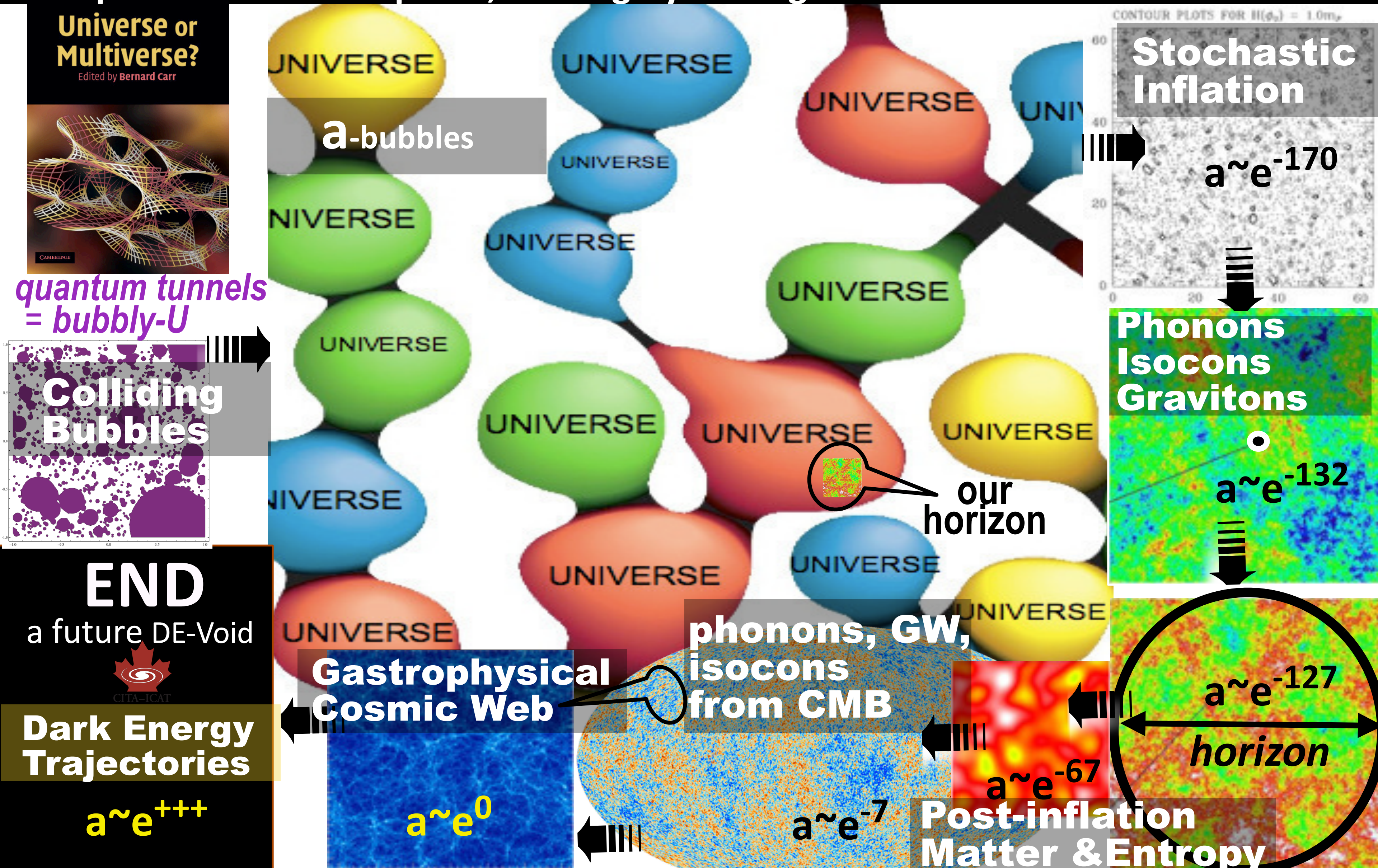
L'institut Canadien d'astrophysique théorique

Jamboree 2015

Dick Bond, CITA & CIFAR

SuperWeb of ultra-Ultra Large Scale Structure of the Universe

a highly strained & stressed state in the universe at large *(very, very),* randomly simple in our Hubble patch, and highly entangled in the small to medium scale



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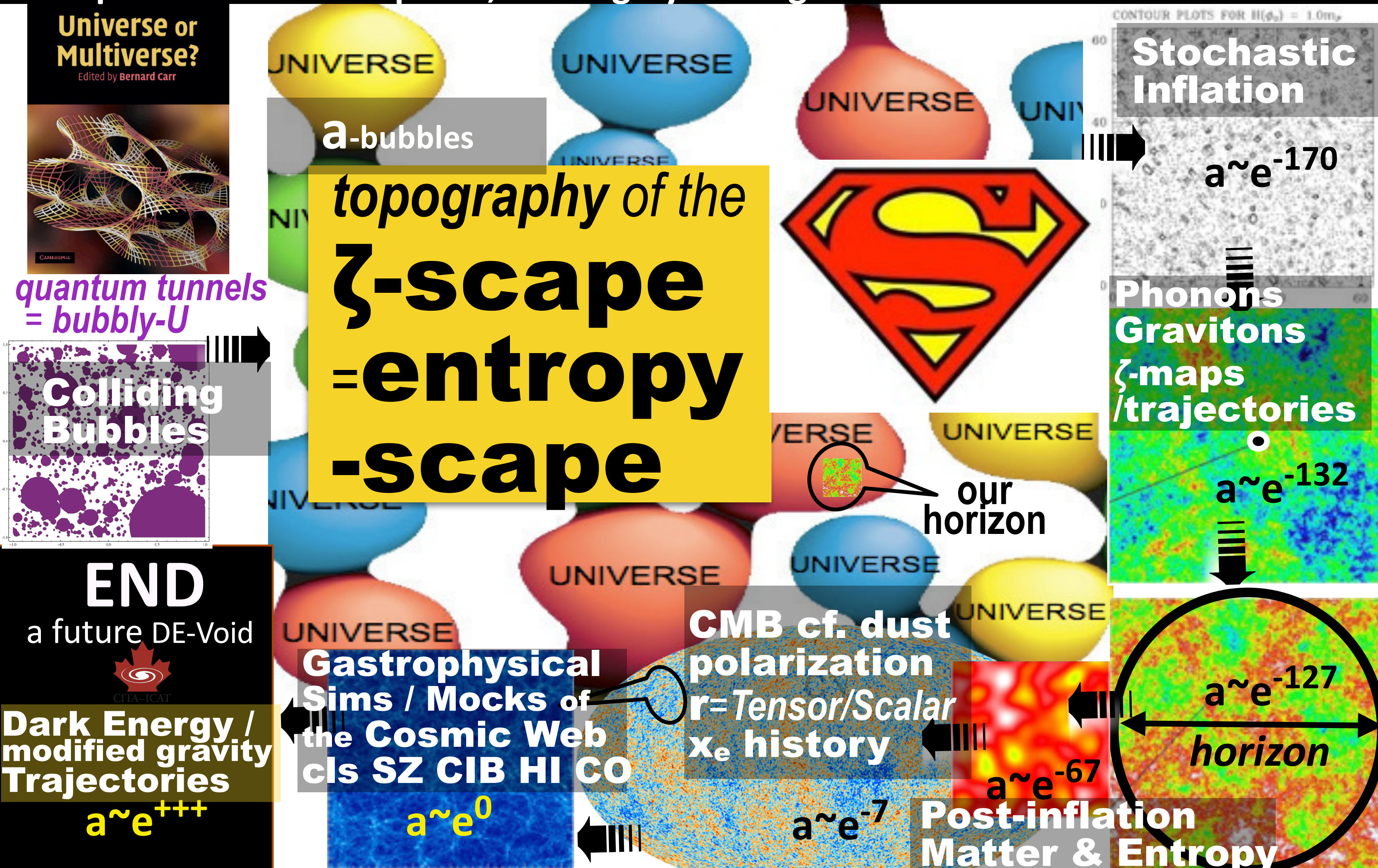

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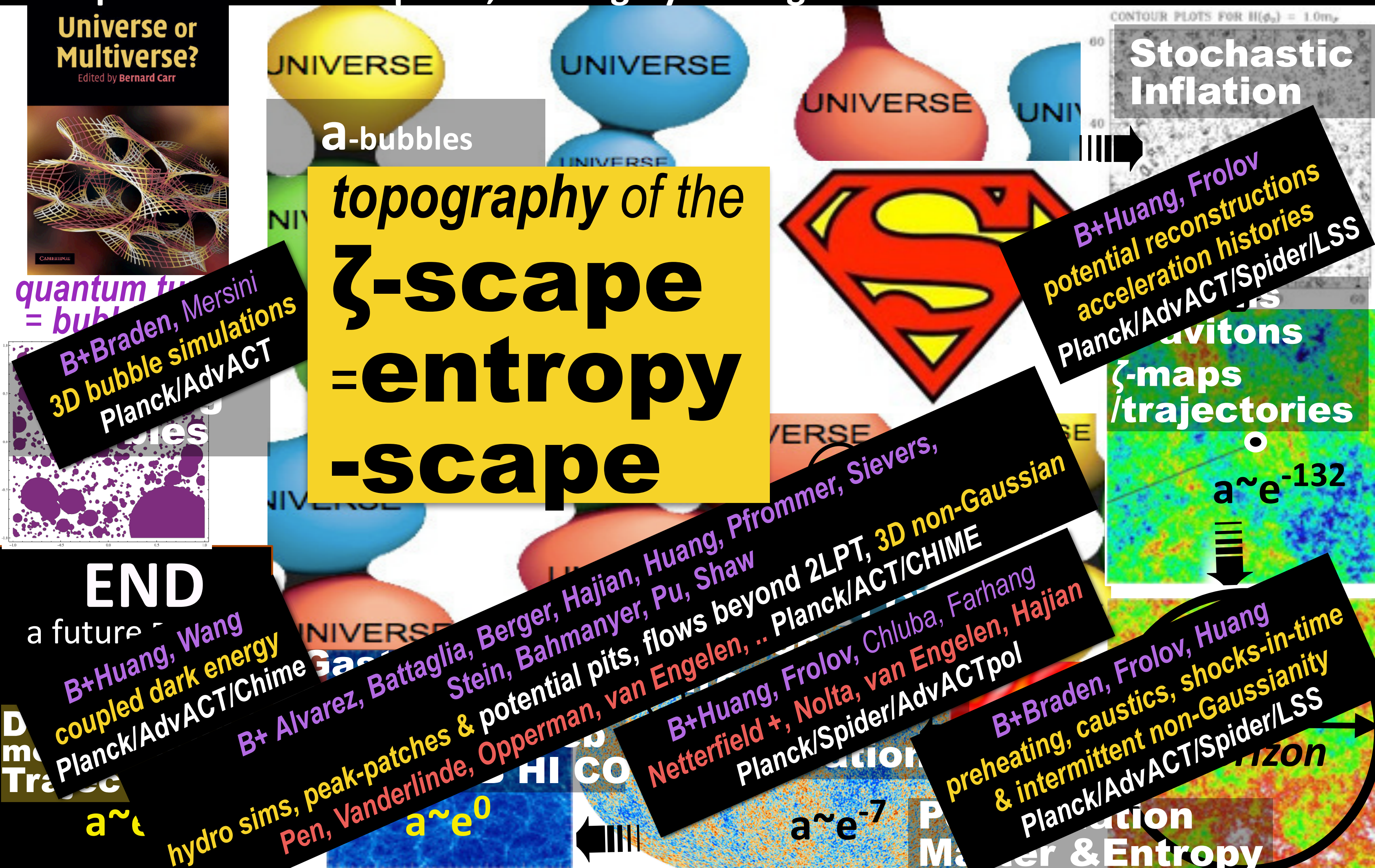


Beyond the Standard Model of cosmology? SMc = *tilted*ΛCDM+r ($\zeta, h_{+\times}$)

BSMc = SMc + primordial anomalies

~10,000,000 T/E modes = *t*ΛCDM, ≲500 modes of anomaly

vast unexplored parts of the *ζ-scape* CMB is 2D

hope to use 3D **LSS tomography** $\mathbf{f_{sky}\ L_{max}^2\ k_{max}\ d_{max}}$

CMB TT power L~ 20-30 dip =>
Grand Unified ζ-Spectrum k-dip

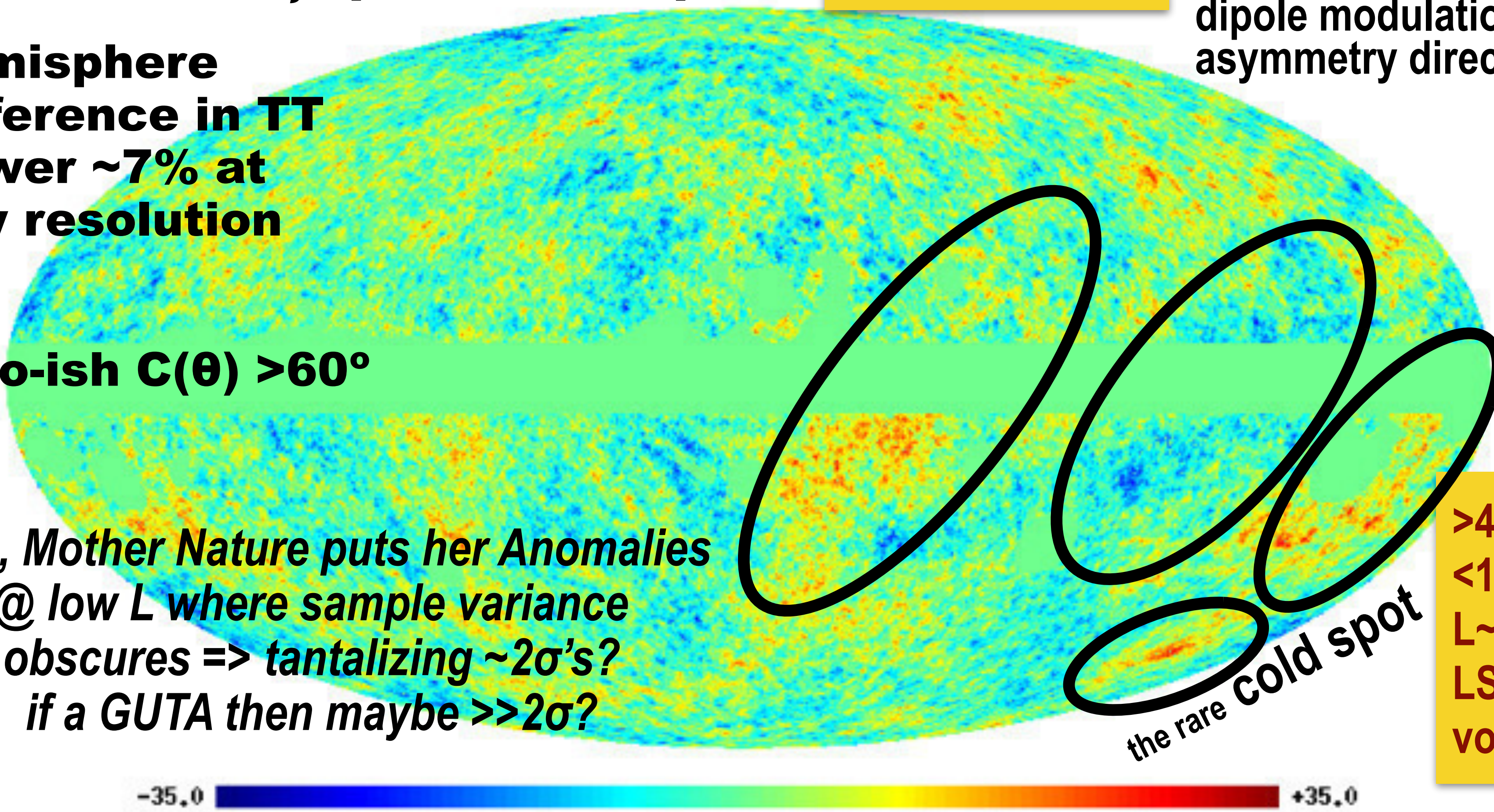
<ζ|*T,E-pol*>

octupole/quadrupole alignment

dipole modulation/ asymmetry direction

hemisphere difference in TT power ~7% at low resolution

zero-ish C(θ) >60°



sigh, Mother Nature puts her Anomalies @ low L where sample variance obscures => tantalizing ~2σ's? if a GUTA then maybe >>2σ?

>4.5σ
<1%
L~20
LSS
void?

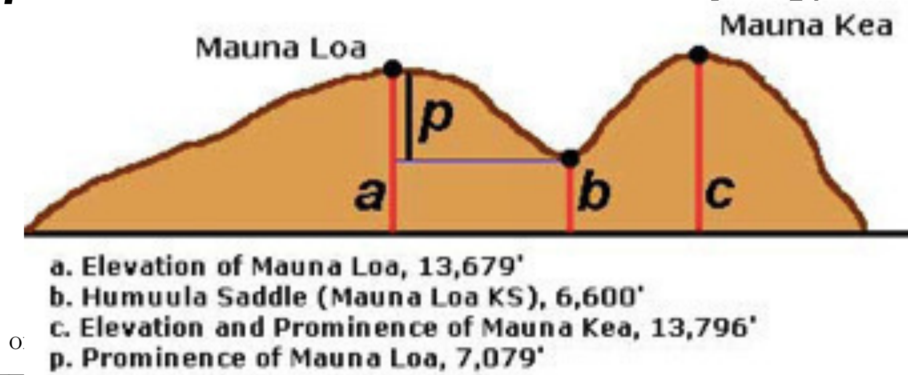
GUTA = Grand Unified Theory of Anomalies? TBD **intermittent**?

Topography of the CMB Web & Interstellar Web

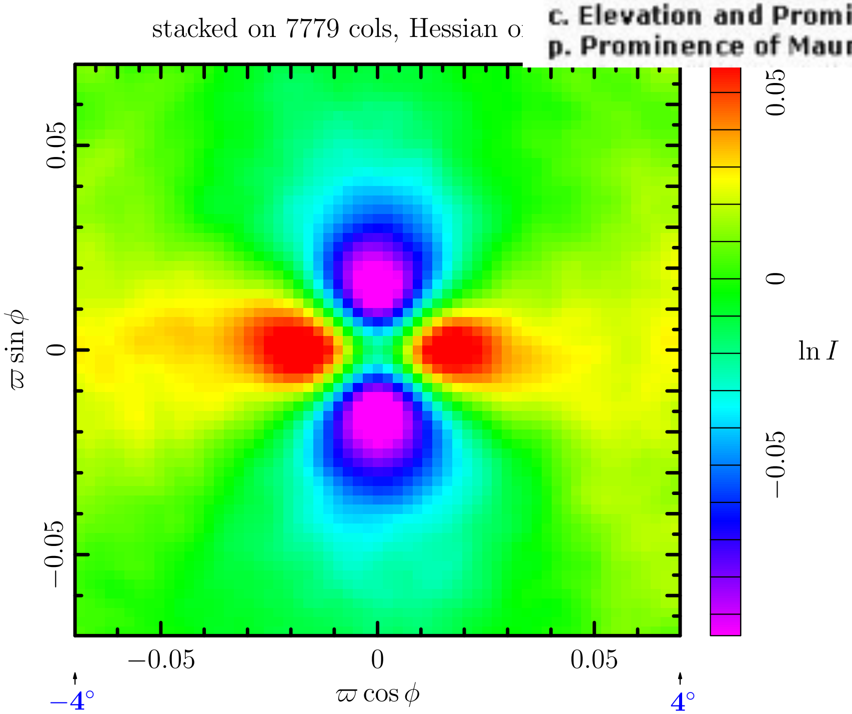
statistics of CMB / dust / synch intensity & polarization of maps
oriented stacking on field points, peaks & saddle points (cols, passes)
to aid in component separation, e.g., of the B-mode of polarization

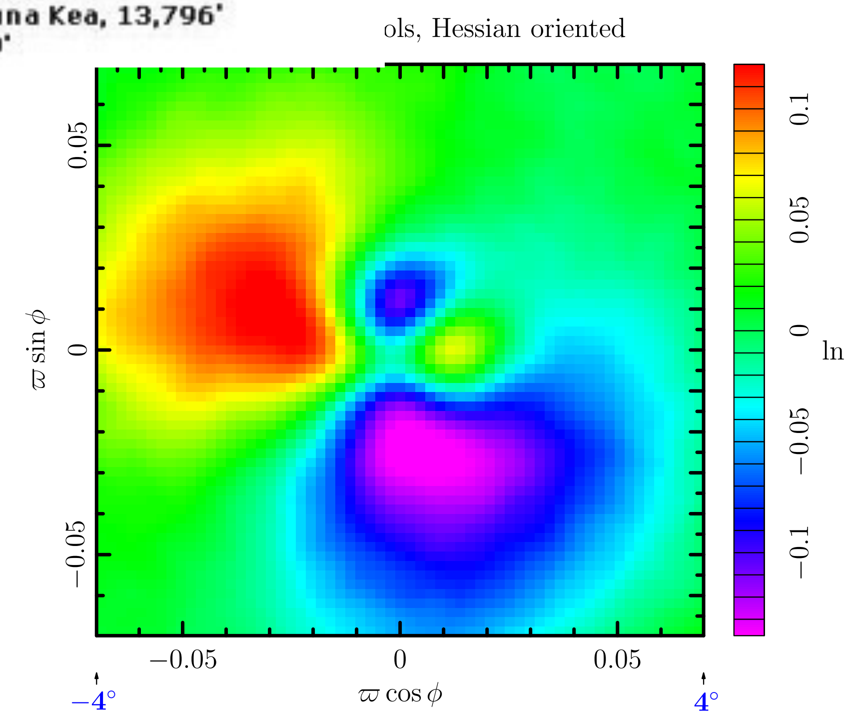
e.g., Planck2015 353 GHz dust = anisotropic non-Gaussian random field
quest for prominences & filament ubiquity, size, shape.

stacked + Hessian
<ln I | I-saddle>



stacked + Hessian
+ direction info
<ln I | I-saddle
broken symm>





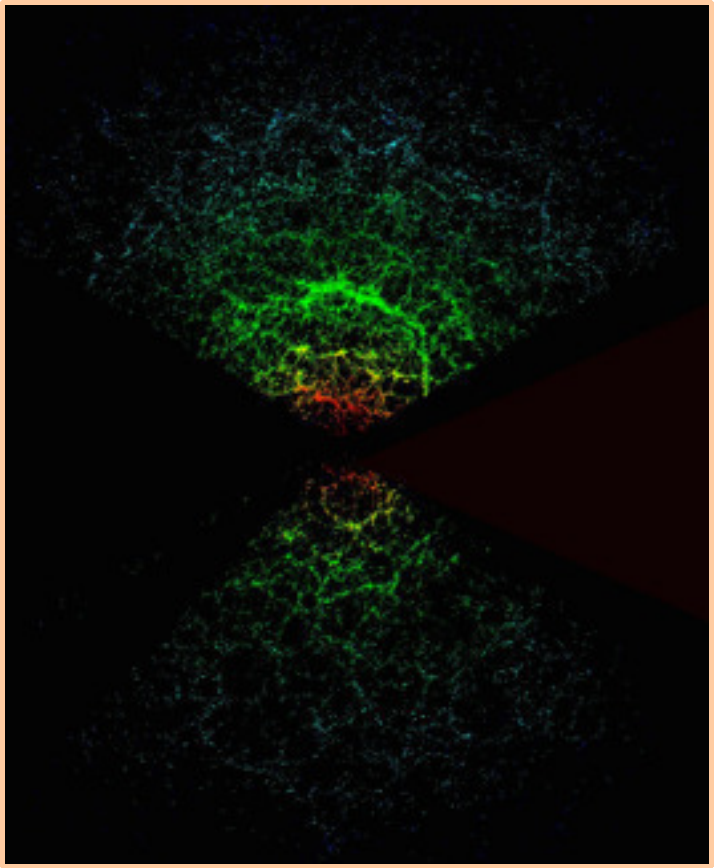
Taking Structure Formation out of the Black Box

Marcelo Alvarez

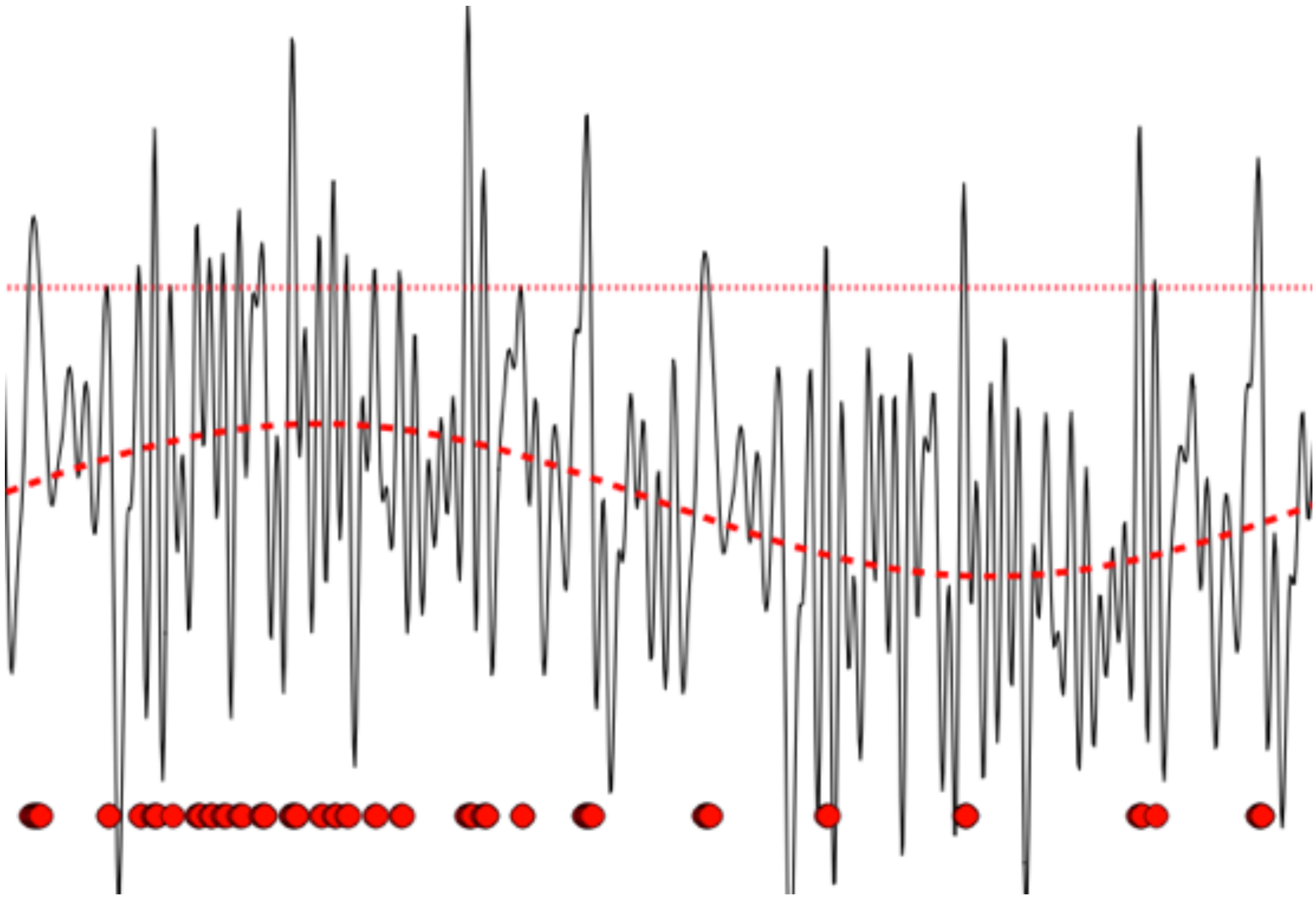
Collaboration

J. R. Bond, U.-L. Pen, Z. Huang, P. Berger, G. Stein, A. Bahmanyar, B. Pu (***CITA***)
T. Abel, R. H. Wechsler, T. Li (**Stanford**)
H. Park (***KASI***)
N. Battaglia (***Princeton***)

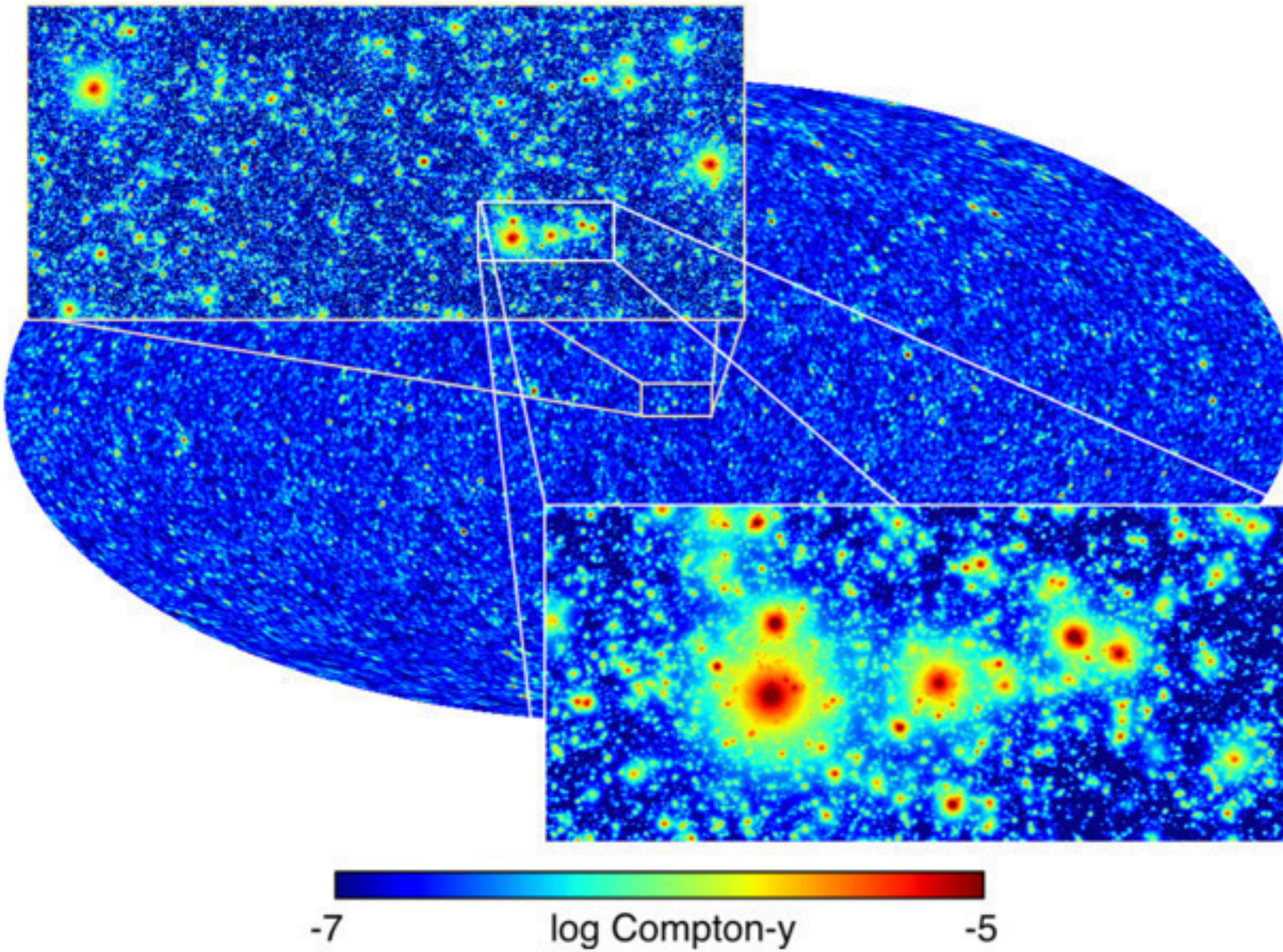
Galaxies & Galaxy Clusters Live in Dark Matter Halos



Dark Matter Halos form from Peaks in Primordial Fluctuations



Simulated tSZ Maps with Peak Patches



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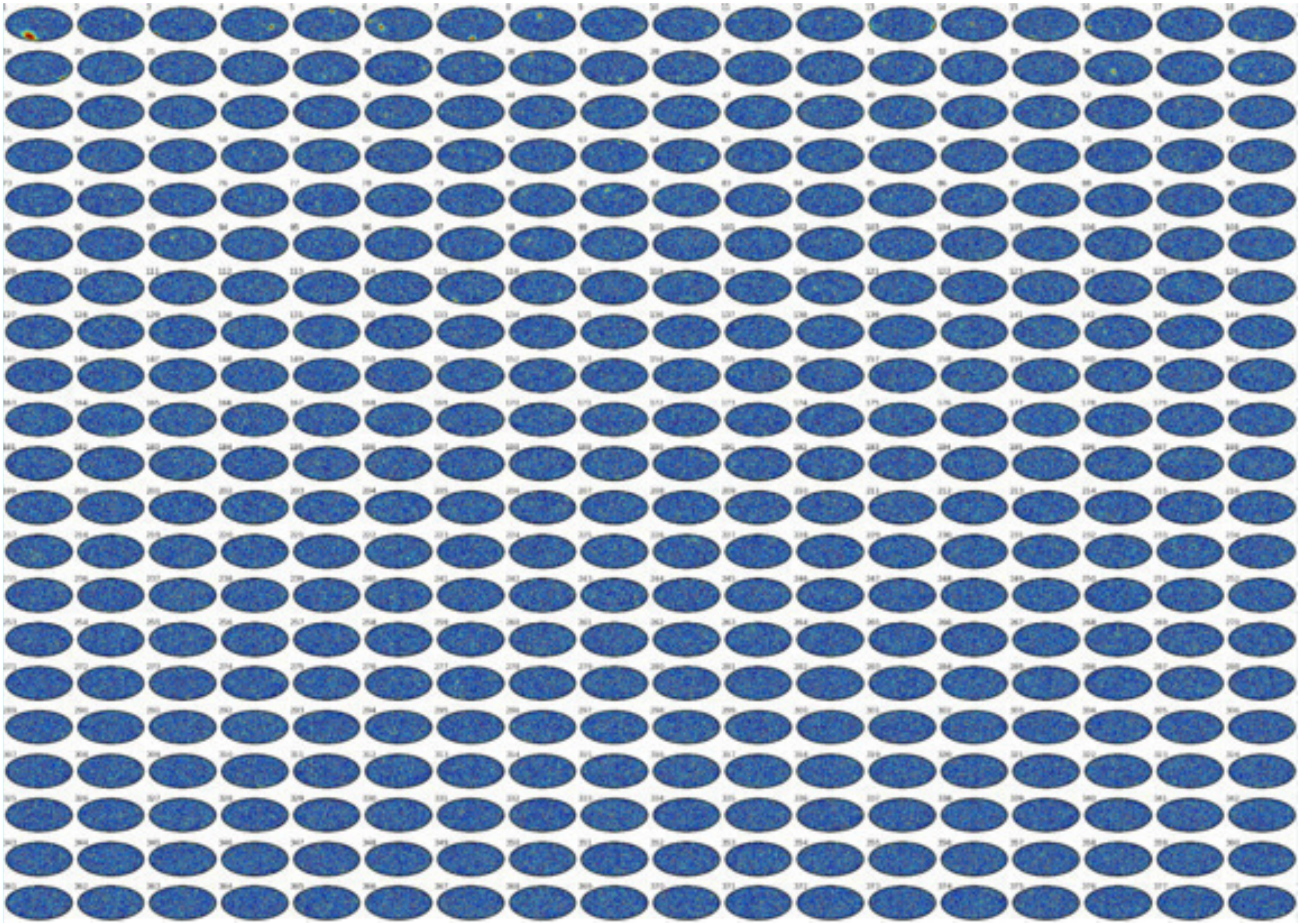

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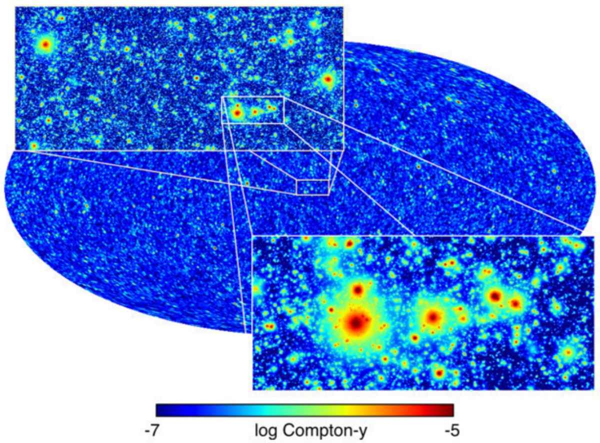
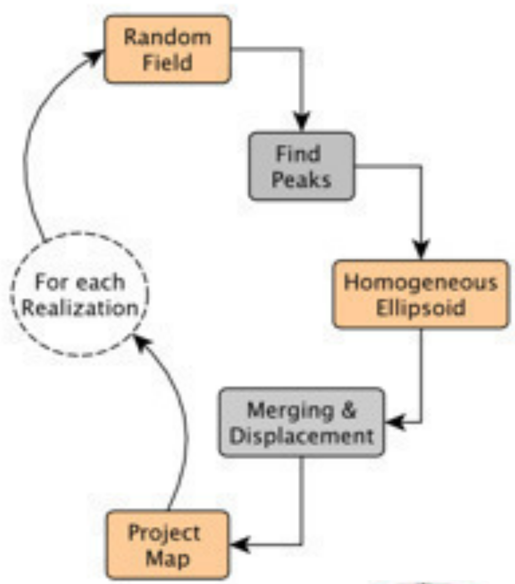
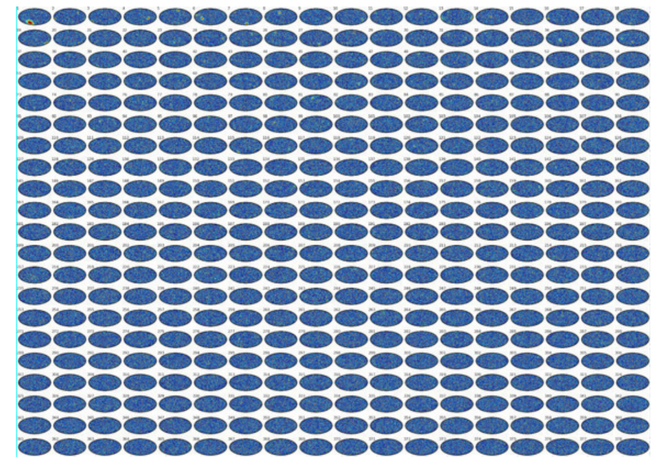
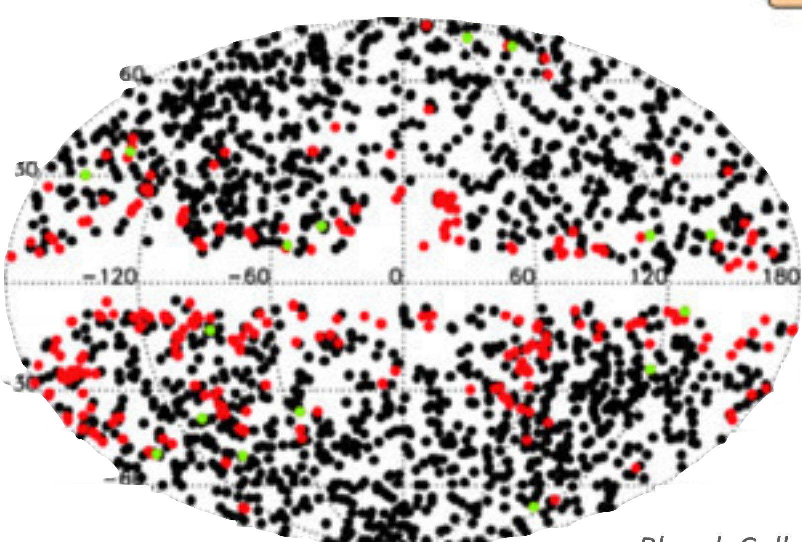
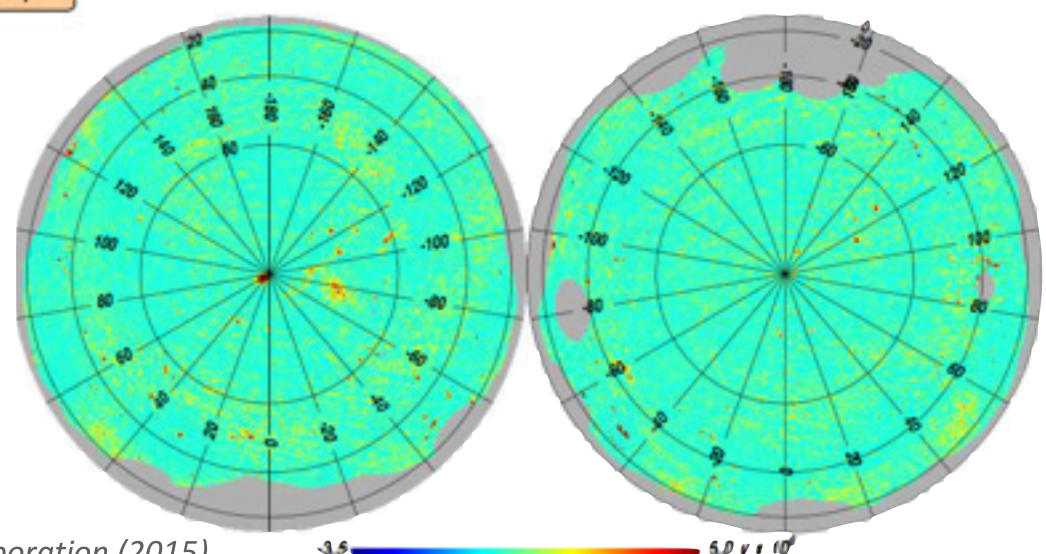




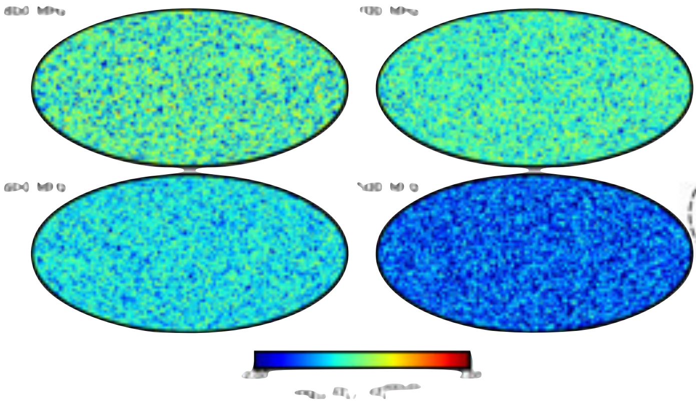


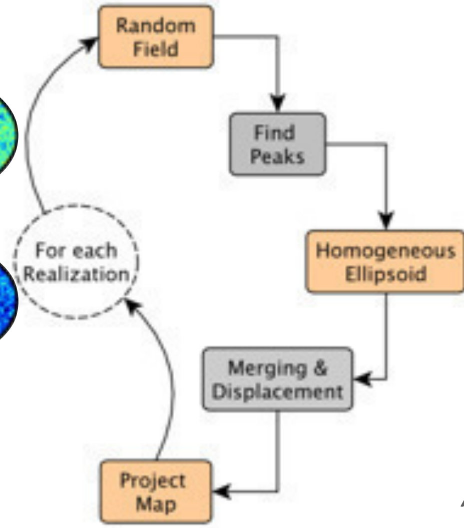


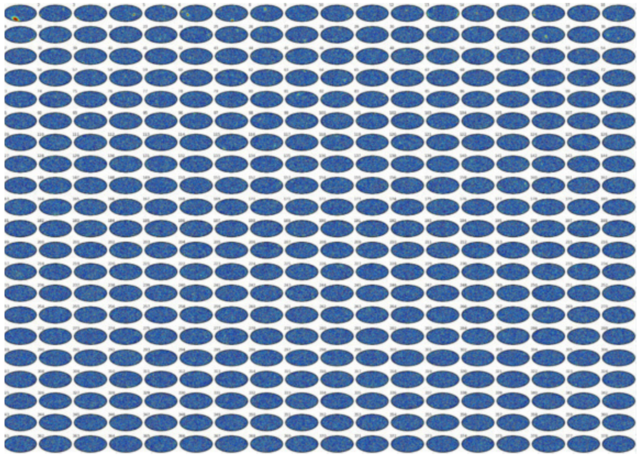


Planck Collaboration (2015)

Can do Same for CHIME







Alvarez et al. (2015)

K. Vanderlinde,
CHIME Collaboration

Summary

New cosmological surveys require simulations with fast, accurate, and high dynamic ranges

Our **new parallel implementation of the peak patch approach** reproduces N-body halo masses and positions ~1000 times faster and allows **efficient exploration of cosmological theory space**

First application is of Monte Carlo **all-sky realizations of tSZ maps** from galaxy clusters

Current Work & Future Directions

Current & future work focuses on Cluster **Sunyaev-Zel'dovich** effect, **Non-Gaussianity, Cosmic Infrared Background**, and **Hydrogen and CO/C Intensity Mapping**

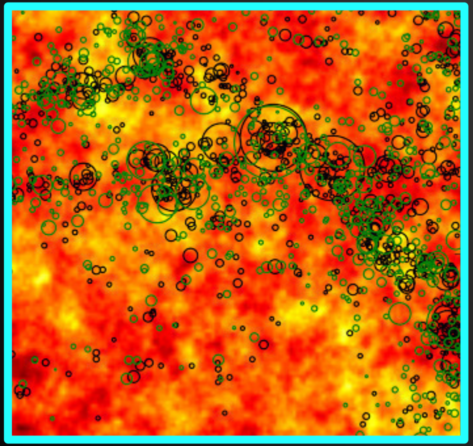
Our parallel peak patch code will be **publicly released**

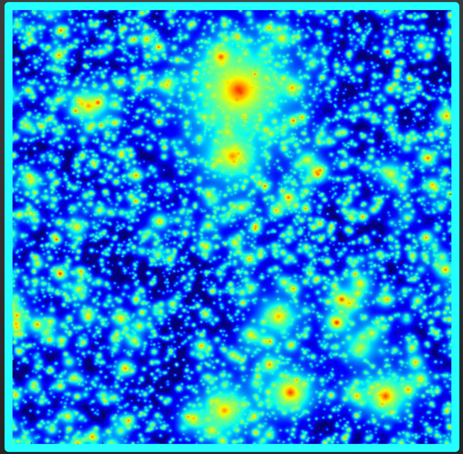
George Stein

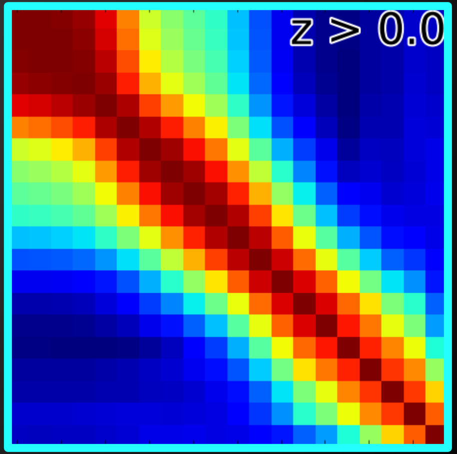
MP 1212

Full-Sky Mock Simulations with the Peak Patch Approach

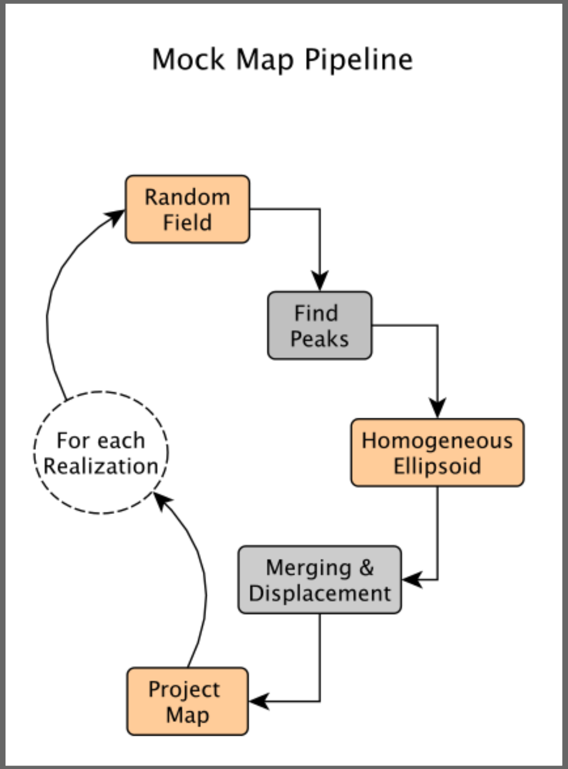
CITA Collaborators:
M. Alvarez, J.R. Bond

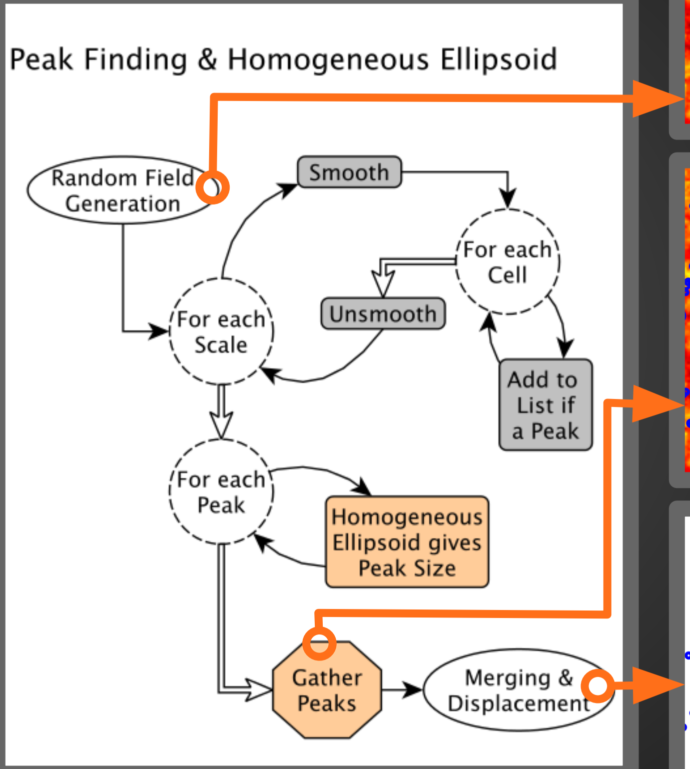


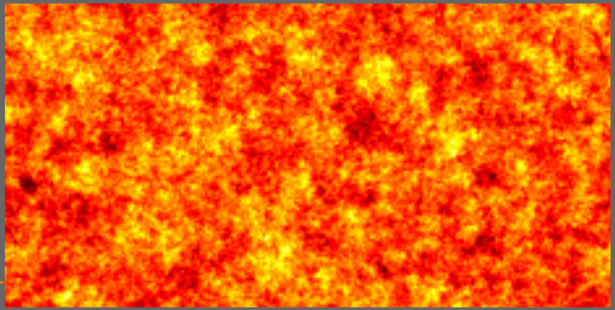


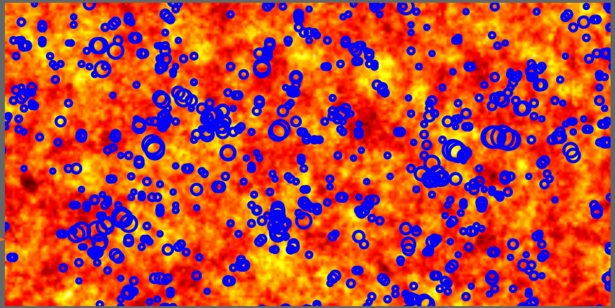


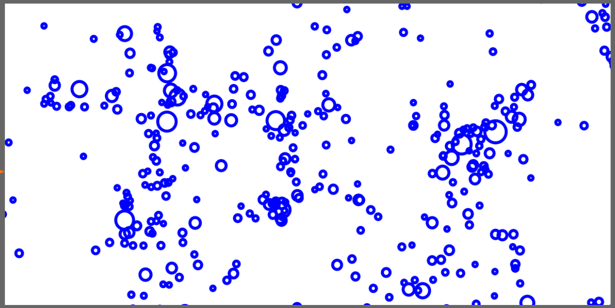
Peak Patch - Method





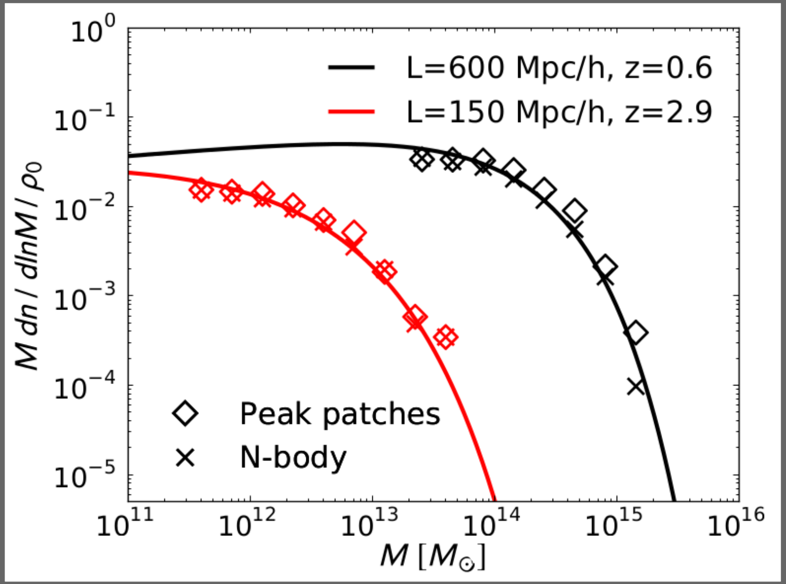


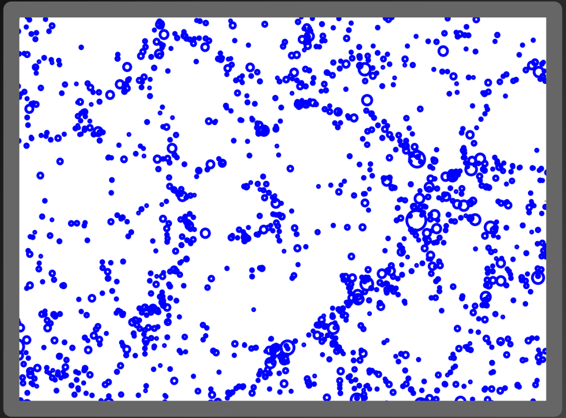




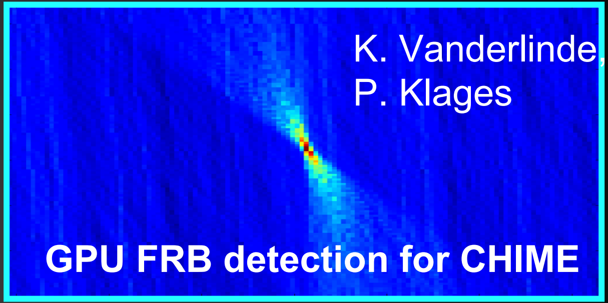
Peak Patch - Usage

```
gpc-f102n084-ib0-$ peak-patch.py param/param.params

Copying source
Generating filter bank
Compiling hpkvd
Compiling merge_pkvd
Creating batch file for parallel run

Time elapsed to run was 52.1714069843 seconds

gpc-f102n084-ib0-$ qsub 512Mpc_nb40_13579.sh
```



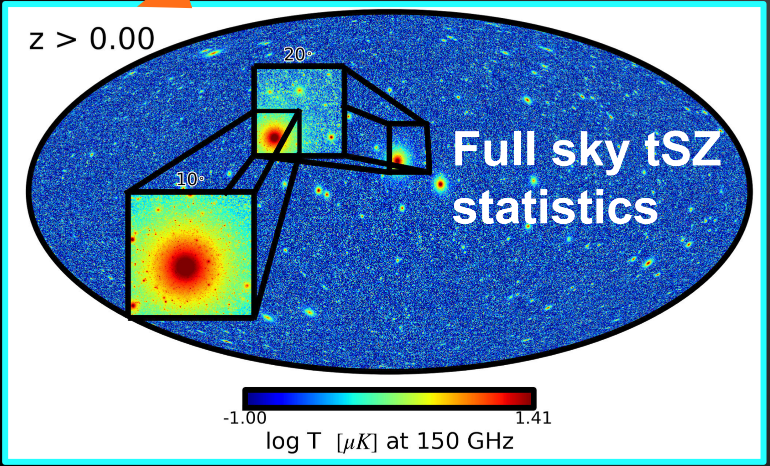


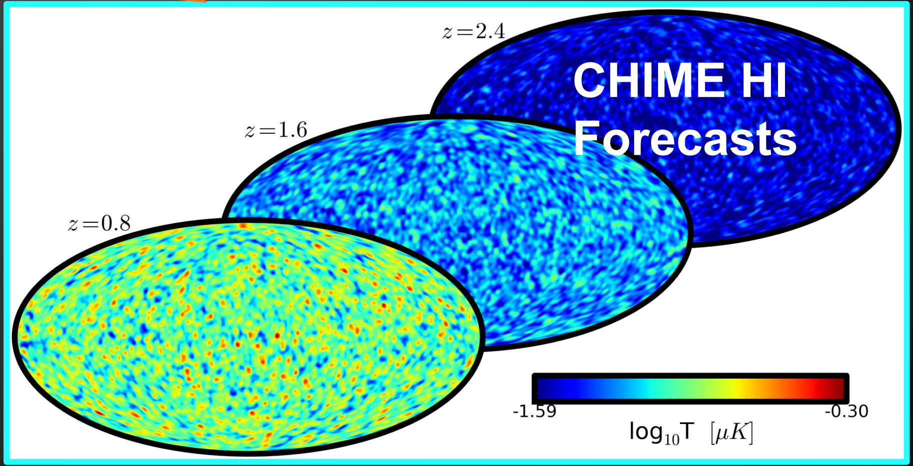
Other Academic Interests: Cosmology, LSS Simulations, Inflation, Peculiar Velocities, Radio Astronomy, GPU Computing



M. Alvarez, J.R. Bond,
A. Hajian

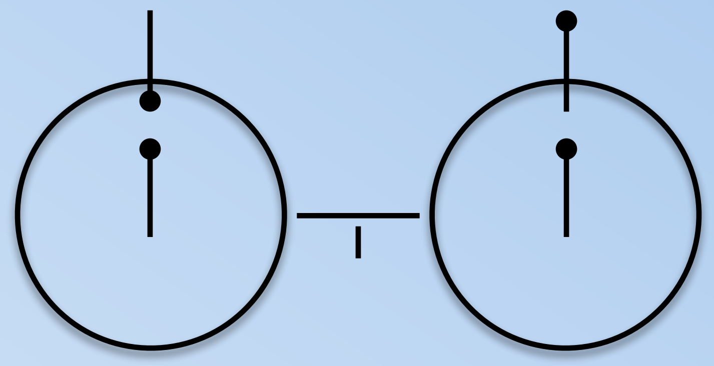
P. Berger, M. Alvarez,
J.R. Bond





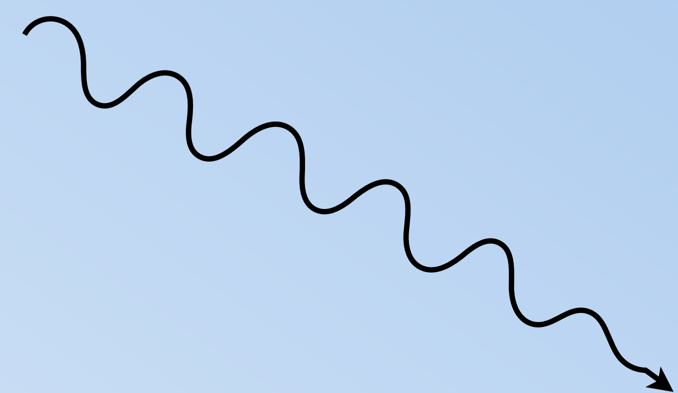
The 21 cm line: From Emission to Observation

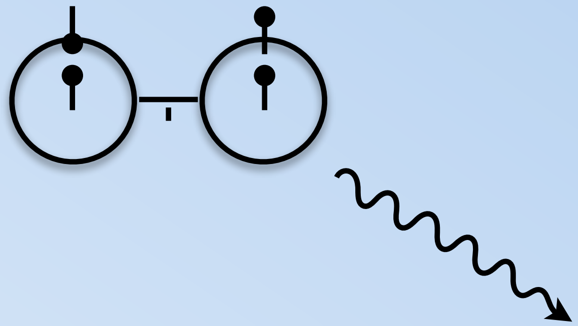
Philippe Berger
Advisors: Ue-Li Pen and Richard Bond



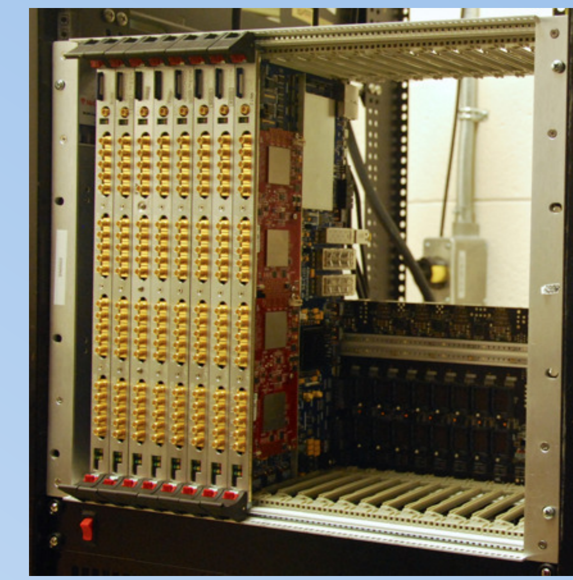
Abundance:
Traces dark matter

Depends on:
- Cosmology
- UV background
- Star formation
- Supernovae
- Quasars



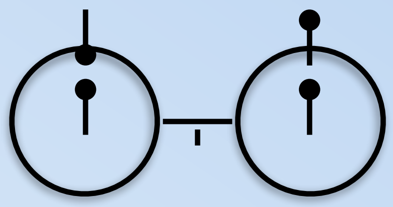


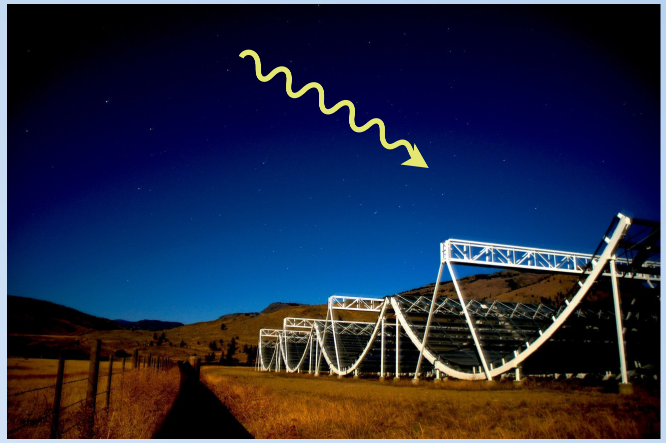
CHIME

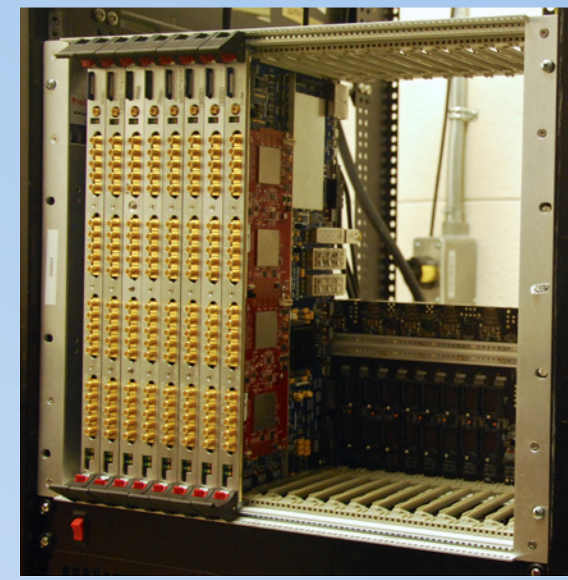


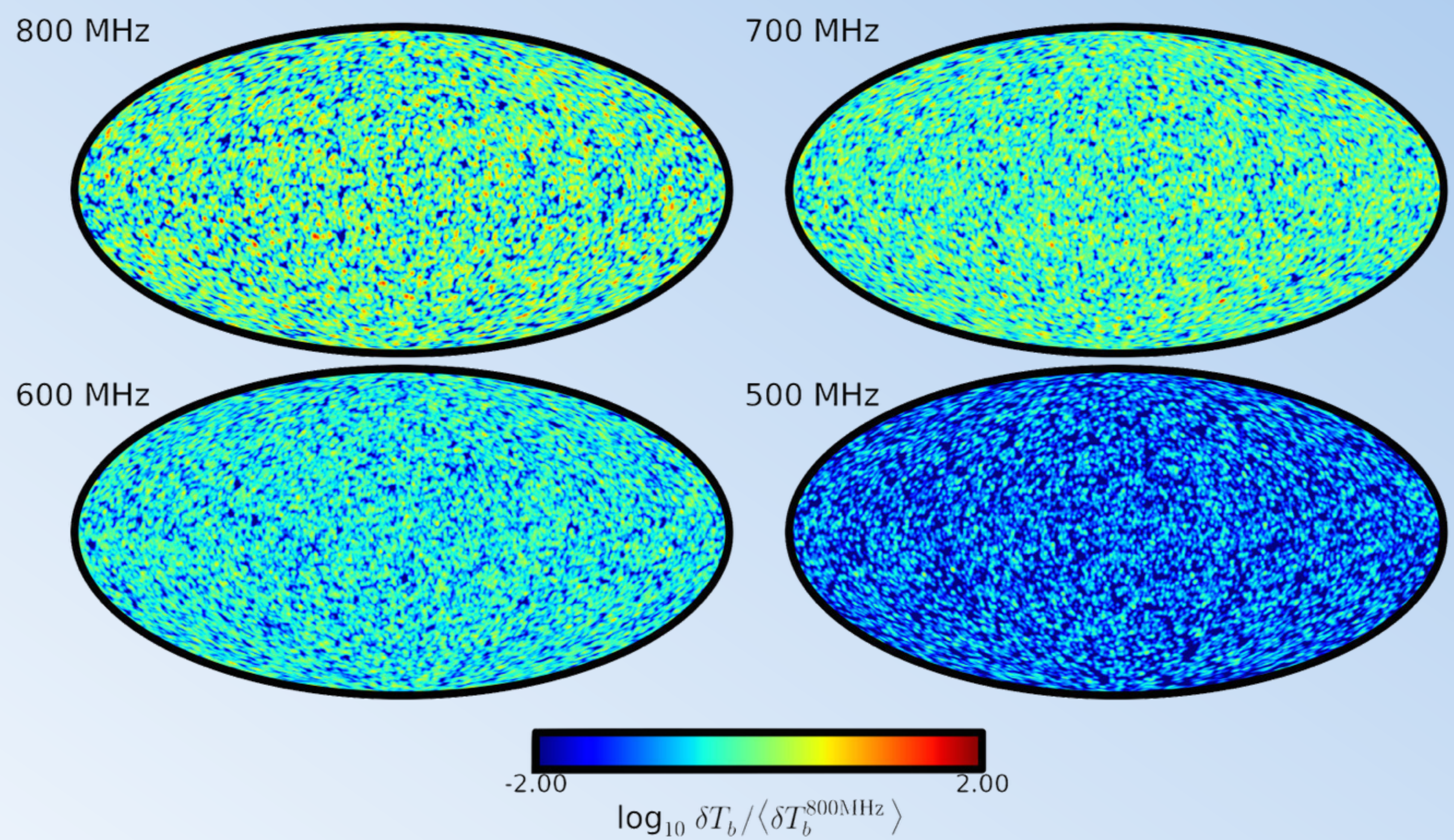
- 20m x 80m
- 2x1024 dipole antennas
- 1024 frequencies

PEAK PATCH



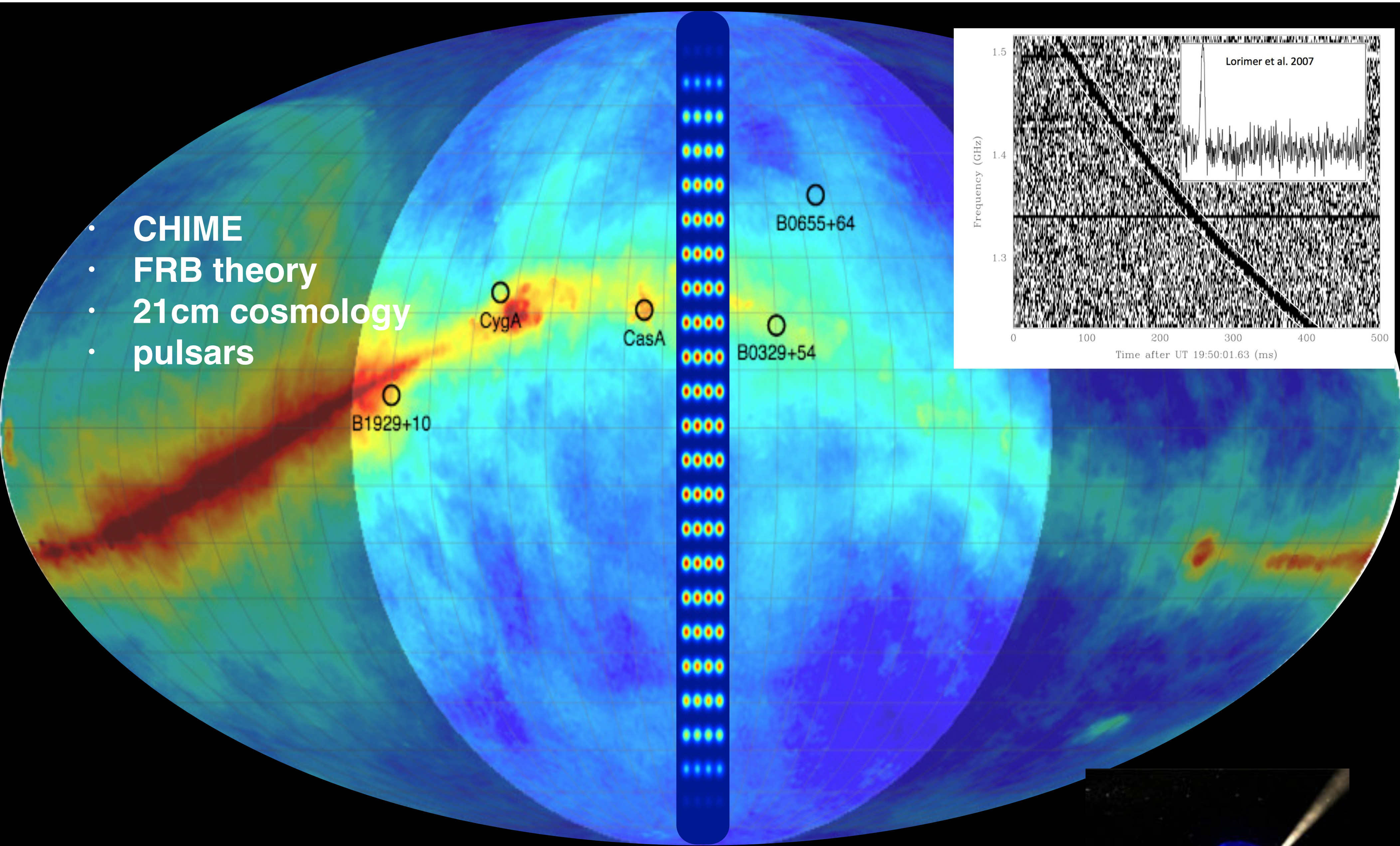


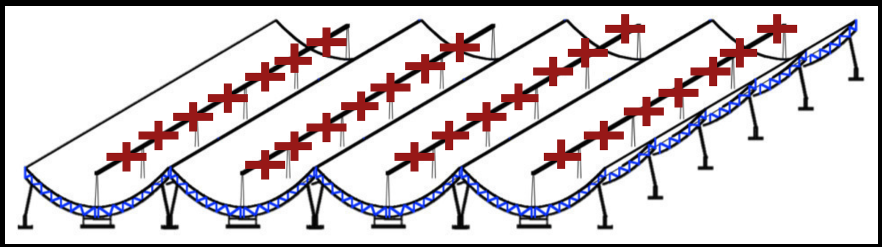




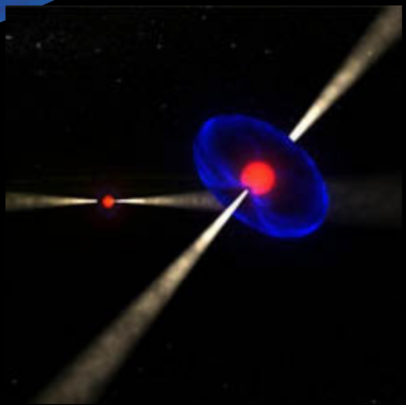
- 1024 maps
- z=0.8-2.5
- 730 Gpc^3
- 1.4 x 10^{12} halos
- M_h->M_{HI}

- CHIME
- FRB theory
- 21cm cosmology
- pulsars



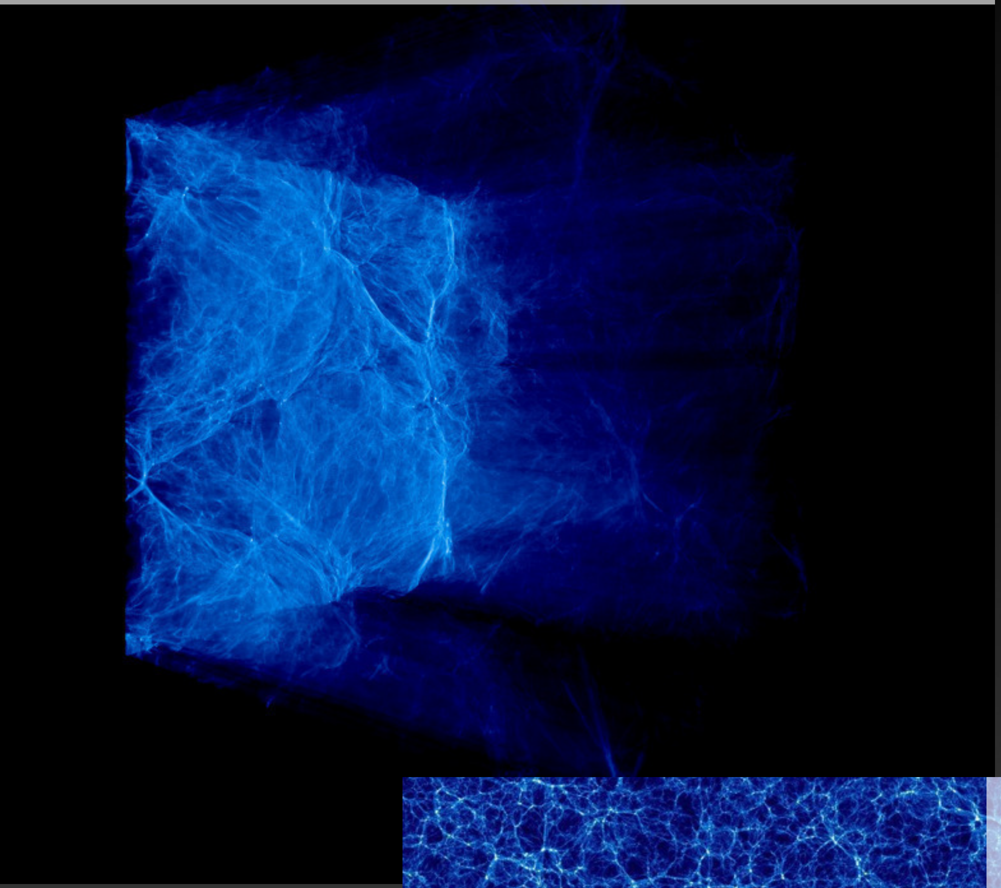


Liam Connor



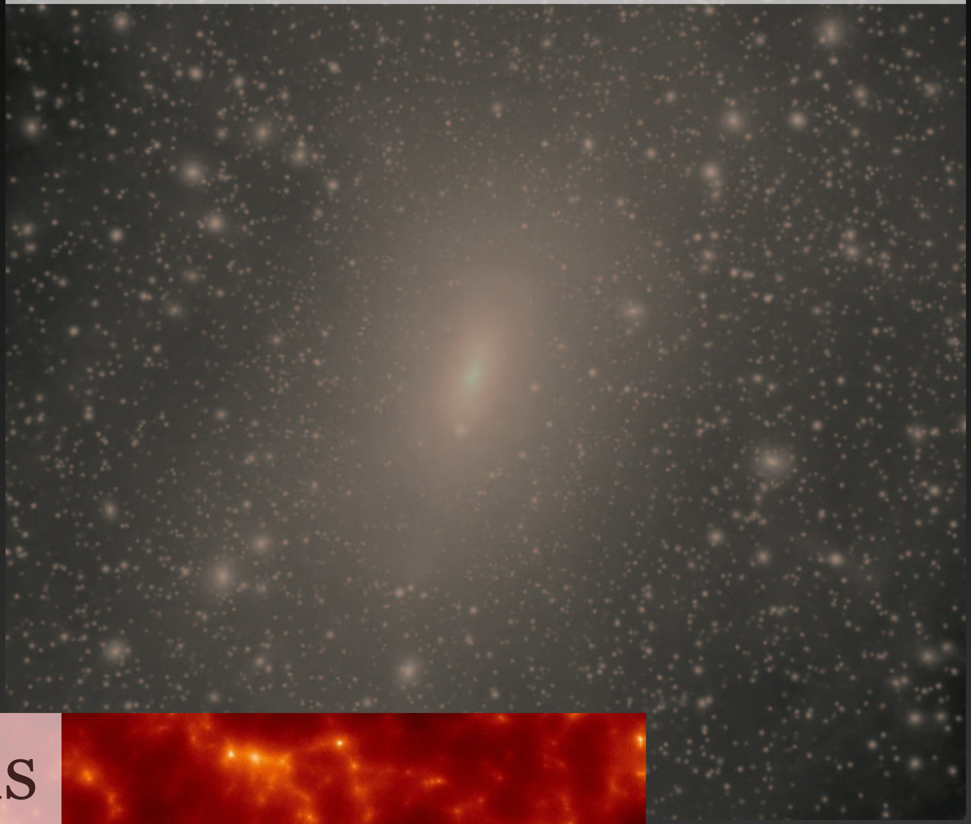
JD Emberson

Reionization Simulations

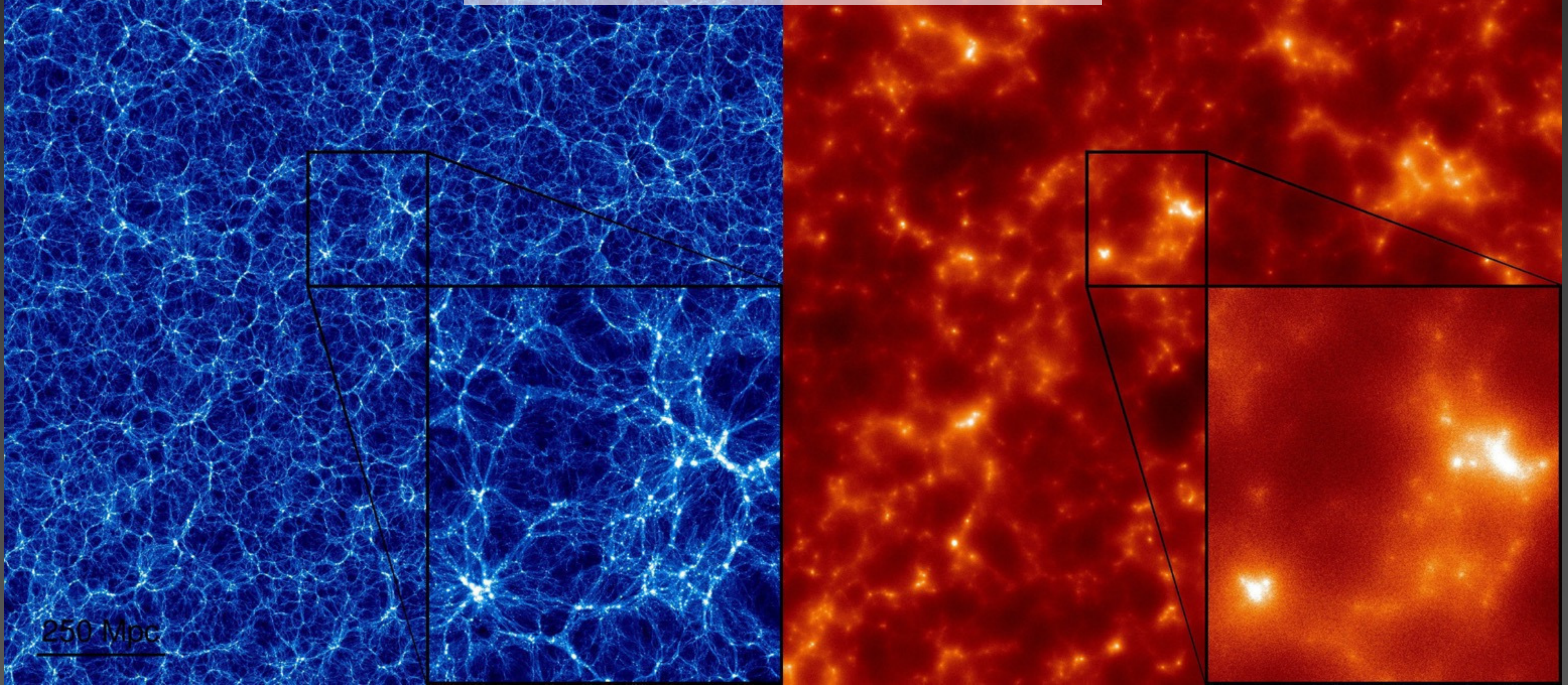


Substructure Evolution

Image Credit: Diemand et al. (2007)



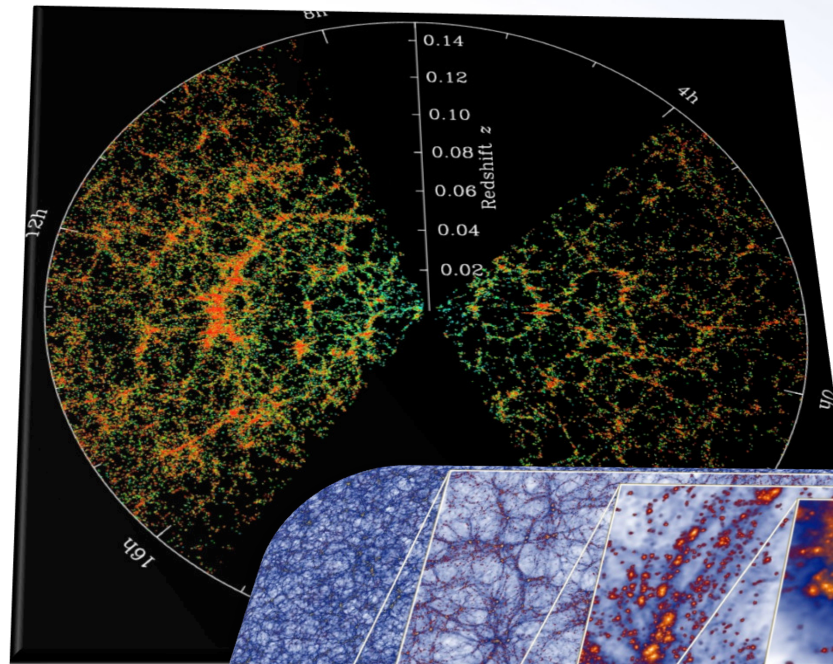
Neutrino Simulations



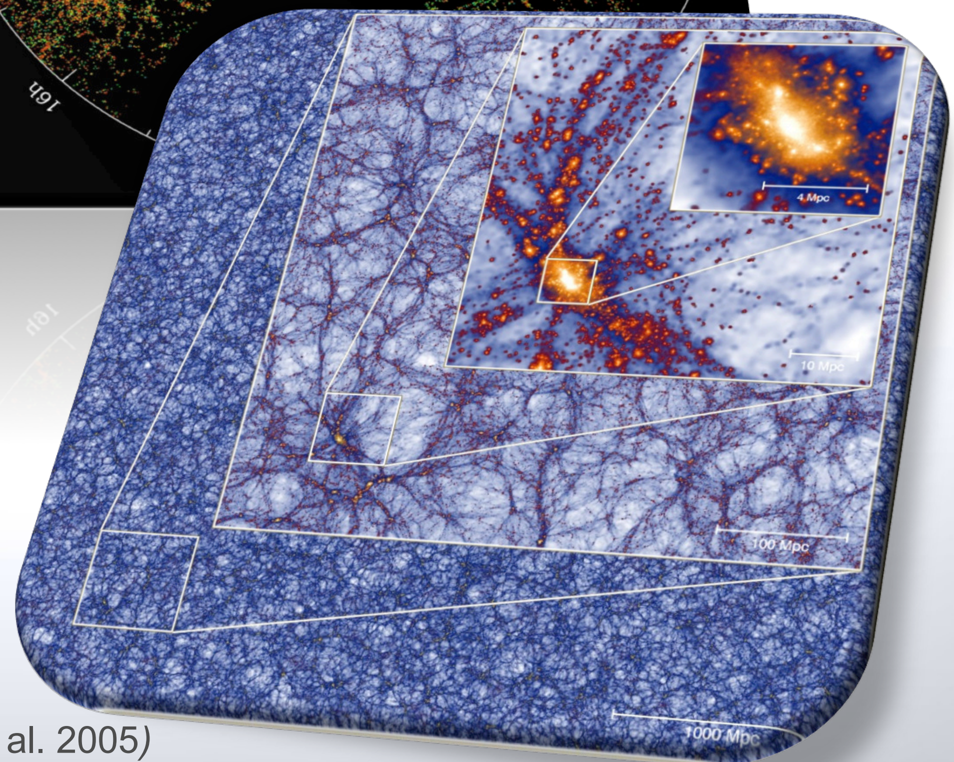
Understanding Non-linear Structure Formation

Xin Wang

- **Structure formation**
  - Galaxy biasing
  - Redshift distortion
  - Vorticity generation
  - Small scale dynamics
  - Dark energy, modified gravity
- **LSS survey**
  - galaxies, 21cm
  - BAO, clusters, lensing, LSS topology



SDSS



*Millennium Run (*Springel et al. 2005*)*

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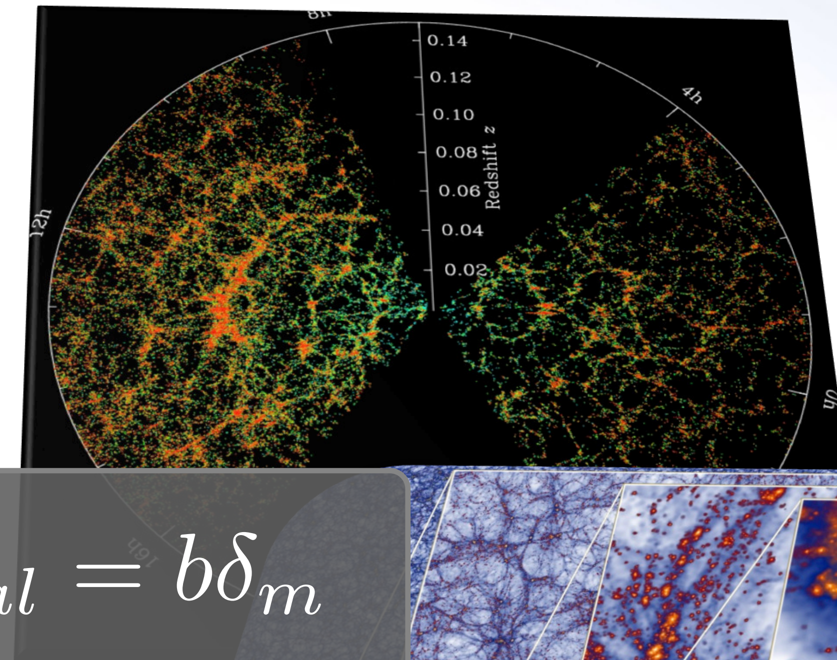
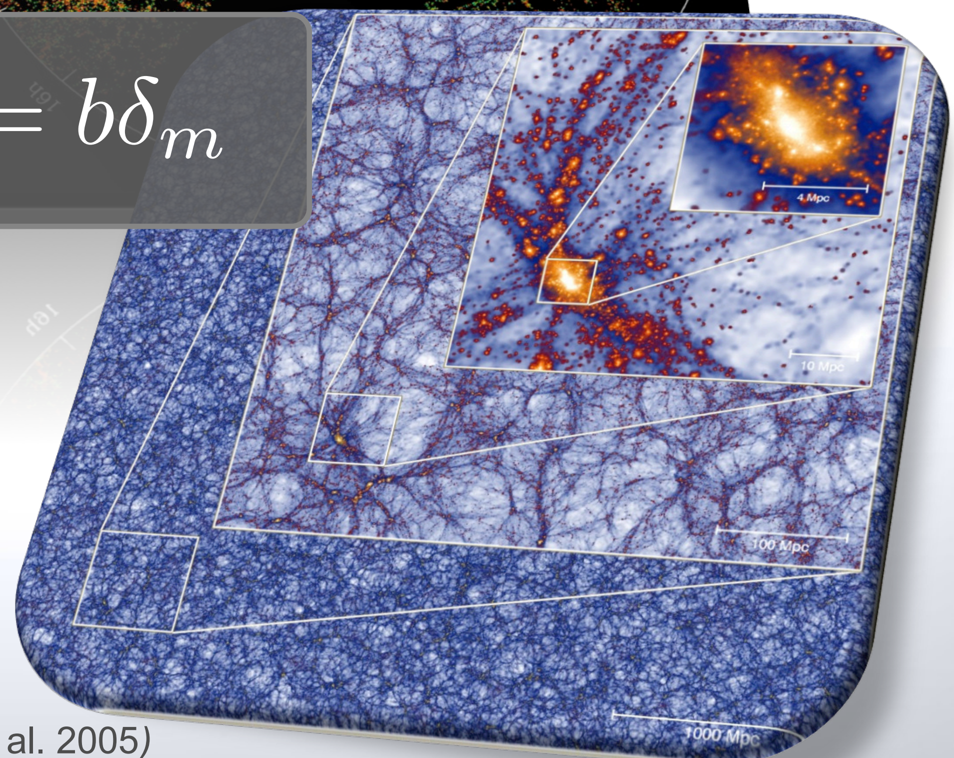


SDSS

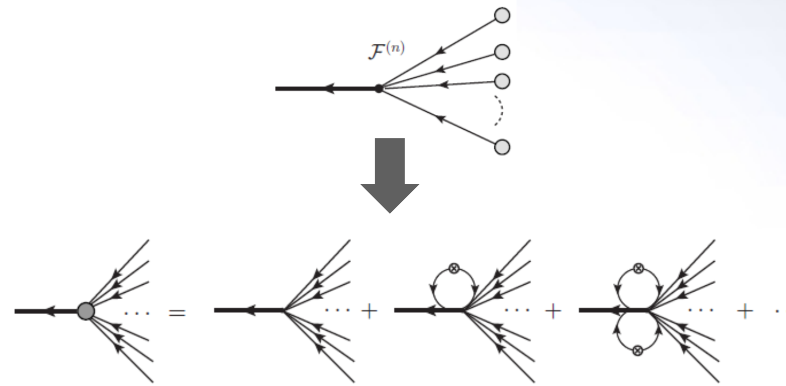
$$\delta_{gal} = b\delta_m$$



Millennium Run (Springel et al. 2005)

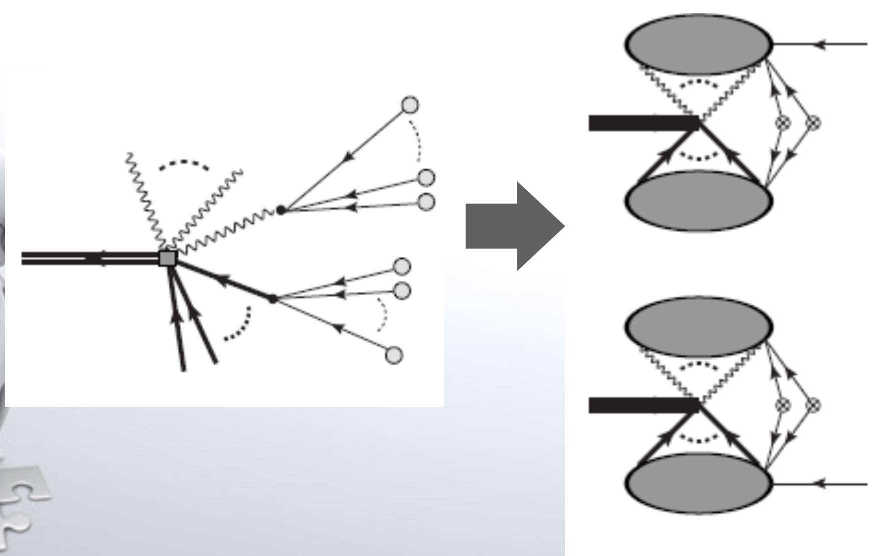
Structure Formation – Intermediate Scale

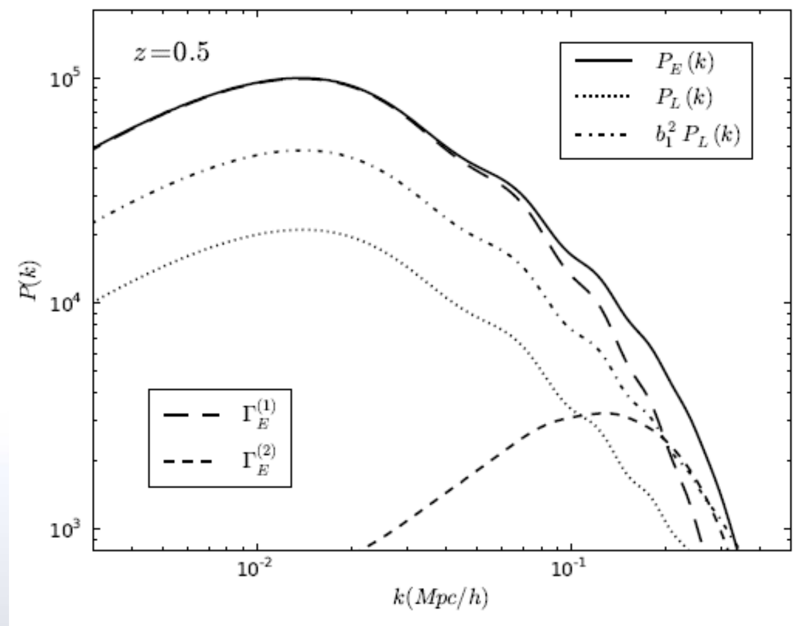
- **Perturbative calculation of nonlinear bias model**



$$\delta_g(\mathbf{k},\eta_0) \;=\; \Xi_g(\mathbf{k},\eta_0) = \int_{\eta_{min}}^{\eta_0} d\eta\; f(\eta)\Delta_g(\mathbf{k},\eta,\eta_0).$$

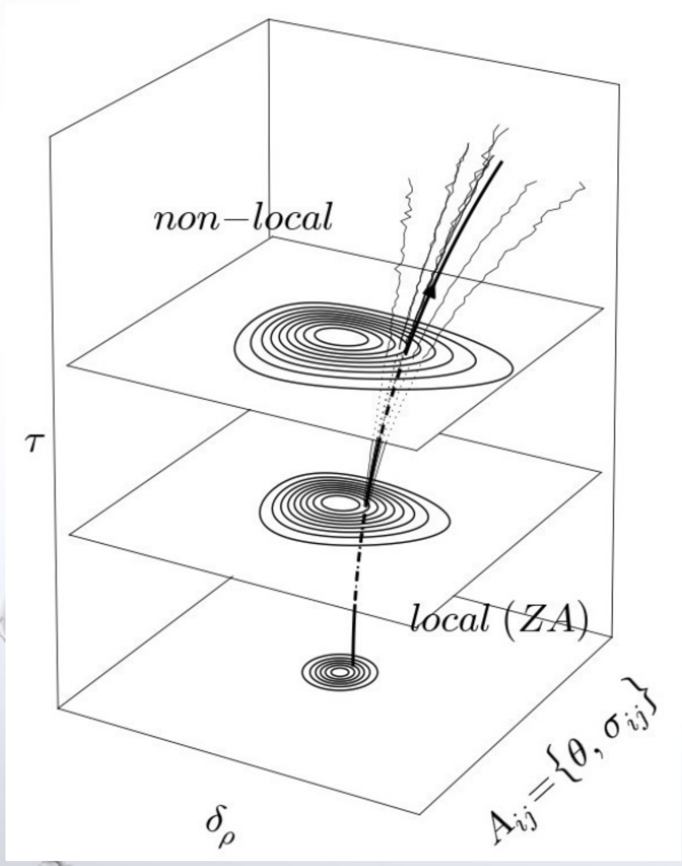
$$\begin{aligned}\Delta_g(\mathbf{k}) \;&=\; \int d^3\mathbf{q}\; e^{-i\mathbf{k}\cdot\mathbf{q}}\left[F_g[\delta_m(\mathbf{q},\eta),\eta]e^{-i\mathbf{k}\cdot\mathbf{\Psi}_g(\mathbf{q},\eta,\eta_0)} - 1\right] \\ &=\; \left[\widetilde{F_g} * \widetilde{e^{-i\mathbf{k}\cdot\mathbf{\Psi}_g}}\right](\mathbf{k},\eta,\eta_0) - \delta_D(\mathbf{k})\end{aligned}$$

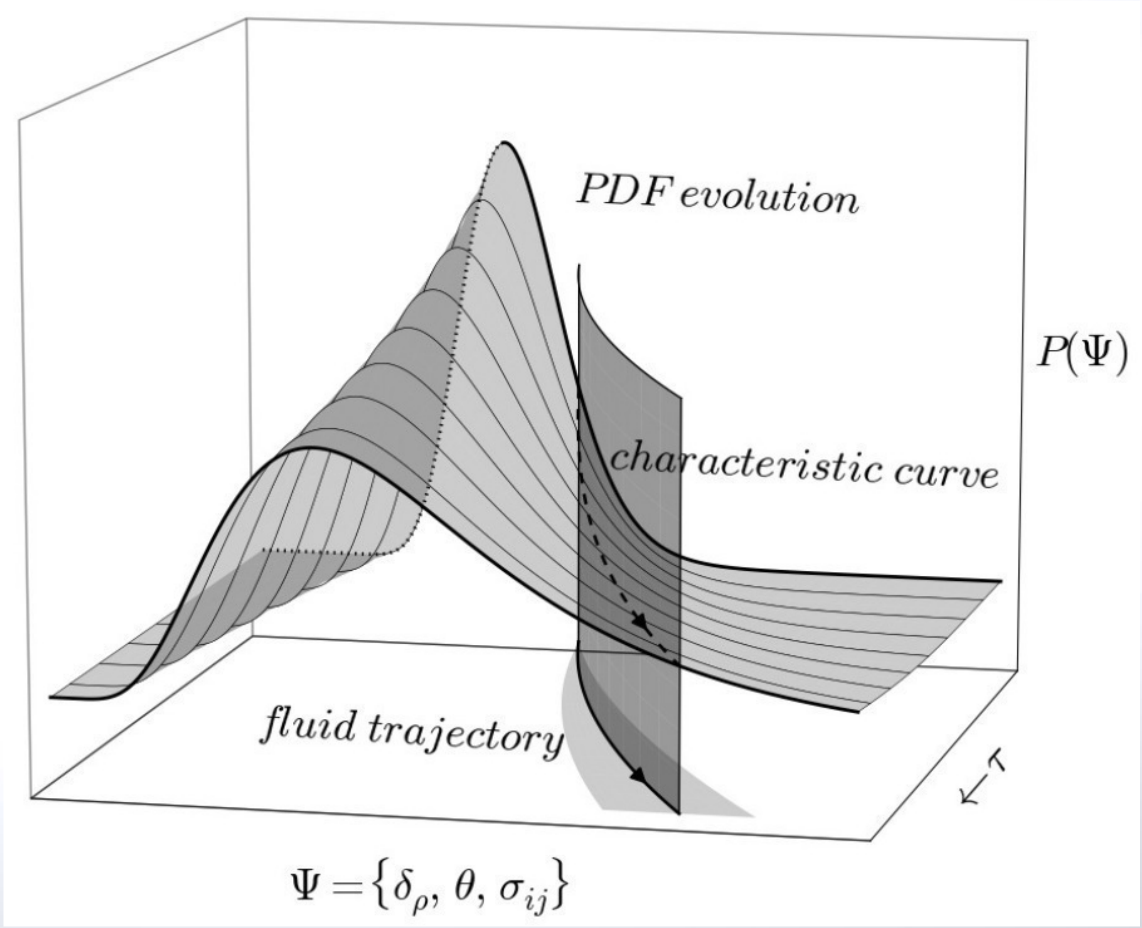




Structure Formation – Small Scale

- **PDF-based Dynamical Closure**



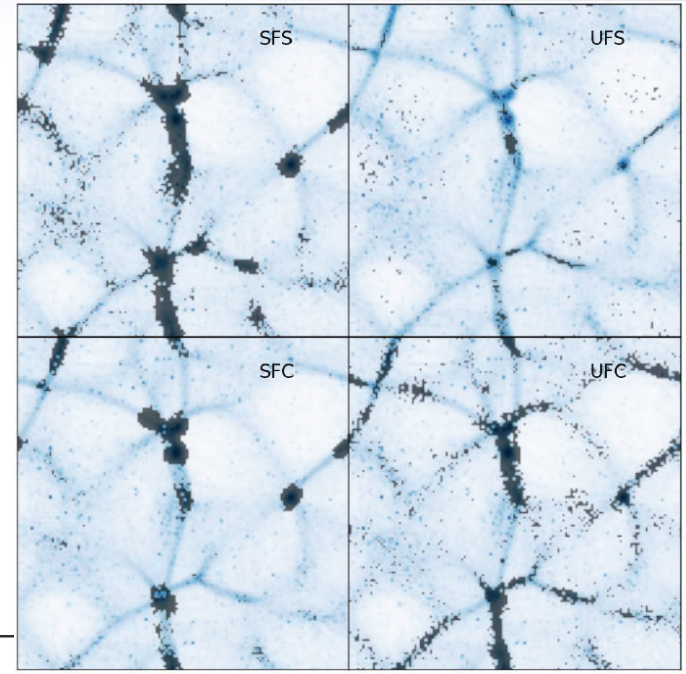


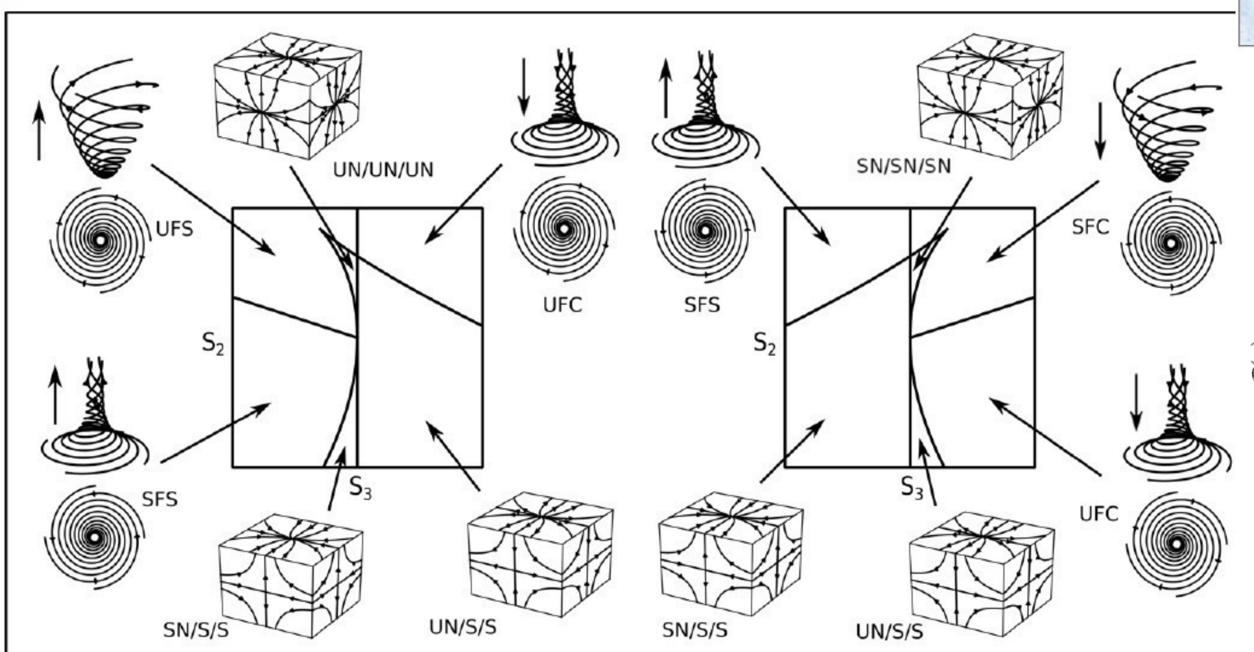
Structure Formation – Small Scale

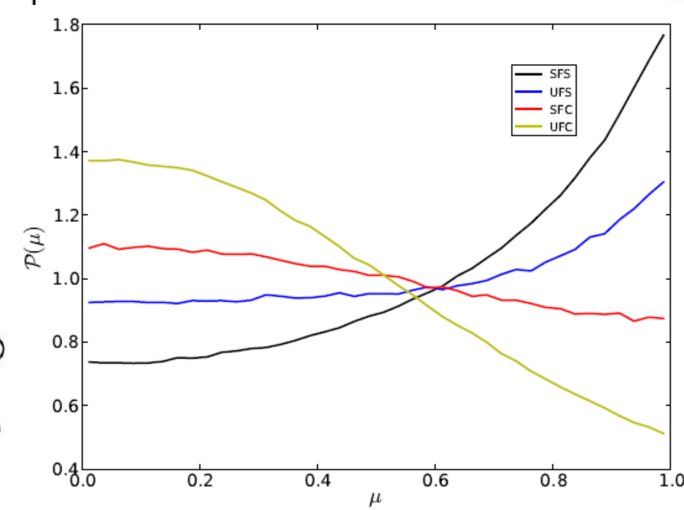
- **Cosmic web with rotational dof**

$$A_{ij}(\mathbf{x},\tau) = \frac{\partial u_i}{\partial x_j}(\mathbf{x},\tau).$$

$$\det[\mathbf{A} - \lambda \mathbf{I}] = \lambda^3 + s_1\lambda^2 + s_2\lambda + s_3 = 0,$$

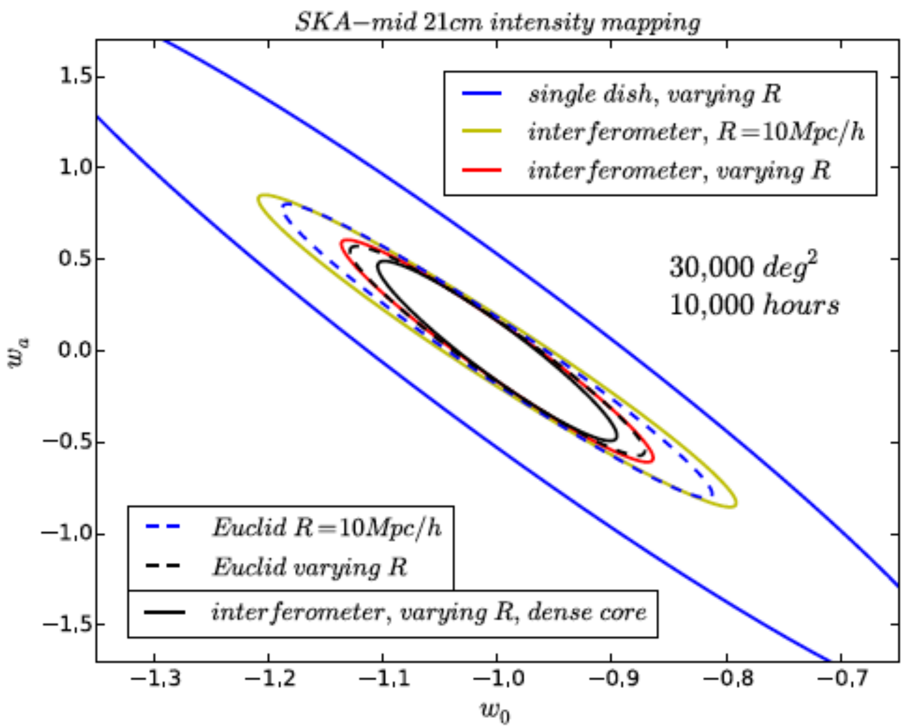


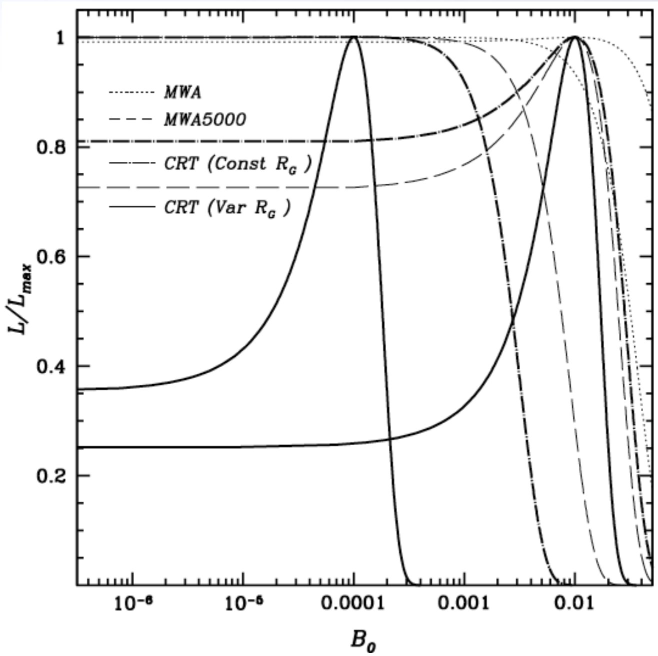


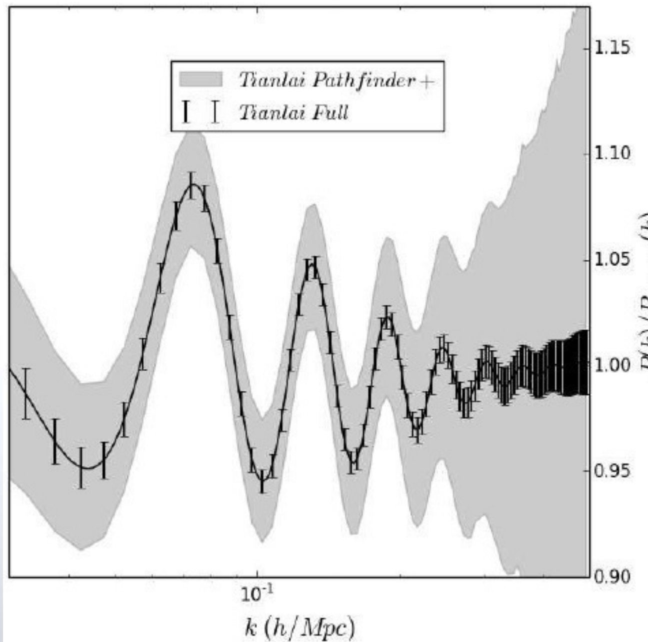


LSS surveys

- **Understanding various LSS constraints on DE & MG**



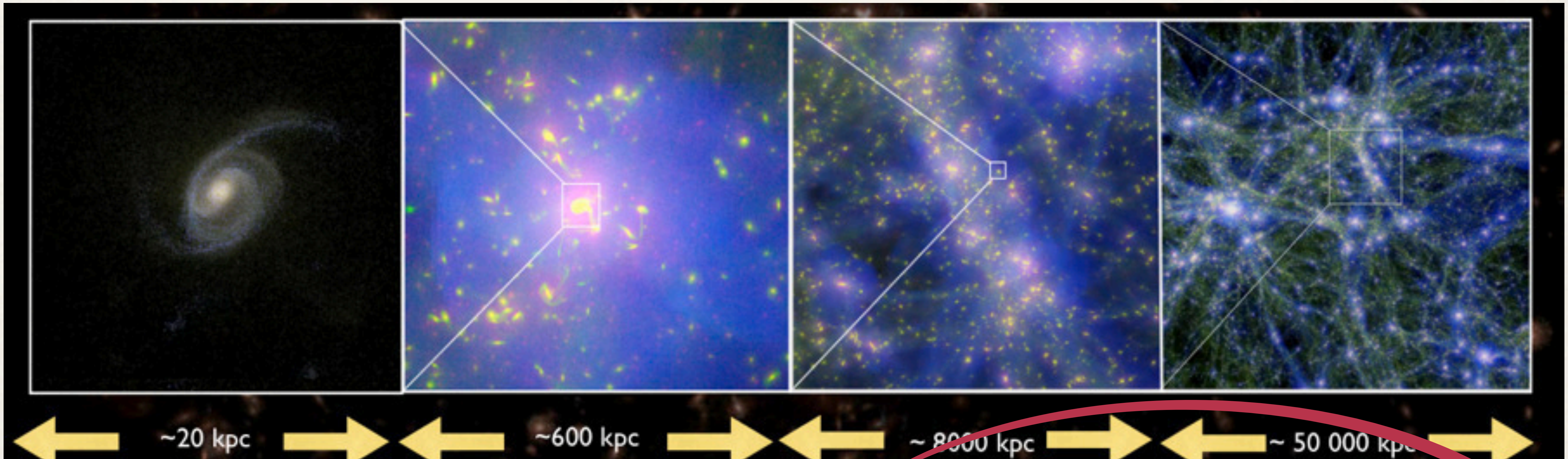




Sandrine Codis

CITA post-doctoral fellow

Numerical and theoretical study of the **large-scale structure** and its interplay with cosmology and galaxy formation.



small-scale
baryons

What is the influence of the environment
-set by the cosmic web- on galaxies?

Large-scale
clustering of dark matter

How can we efficiently extract cosmological
information from the large-scale structure?

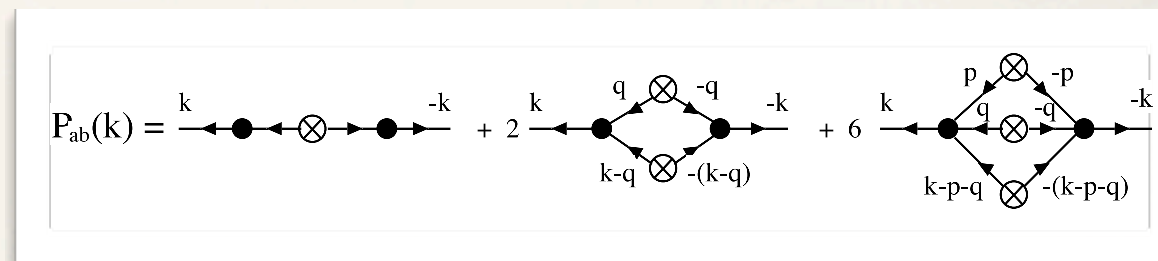
Cosmology and the LSS

In the context of high-precision cosmology, it is worth developping new observables that
- ➢ can be predicted from first principles
- ➢ are robust (noise, bias,...)
- ➢ can be computed in the mildly non-linear regime

★ Perturbation theory and renormalization schemes

Taruya'12

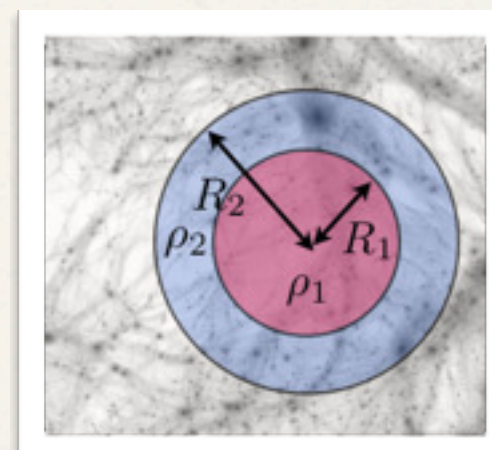
only valid on very large scales...



★ Probing cosmology using «count-in-cell statistics» : density PDF, profiles, ...

Bernardeau'14, Bernardeau'15

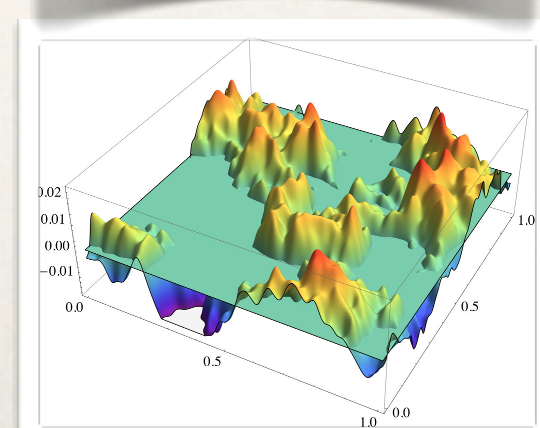
suprisingly accurate predictions even in the mildly non-linear regime at few percent level until $\sigma^2=0.7$!



★ Probing cosmology using the topology of the density field in redshift space...

Codis'13

more robust information?



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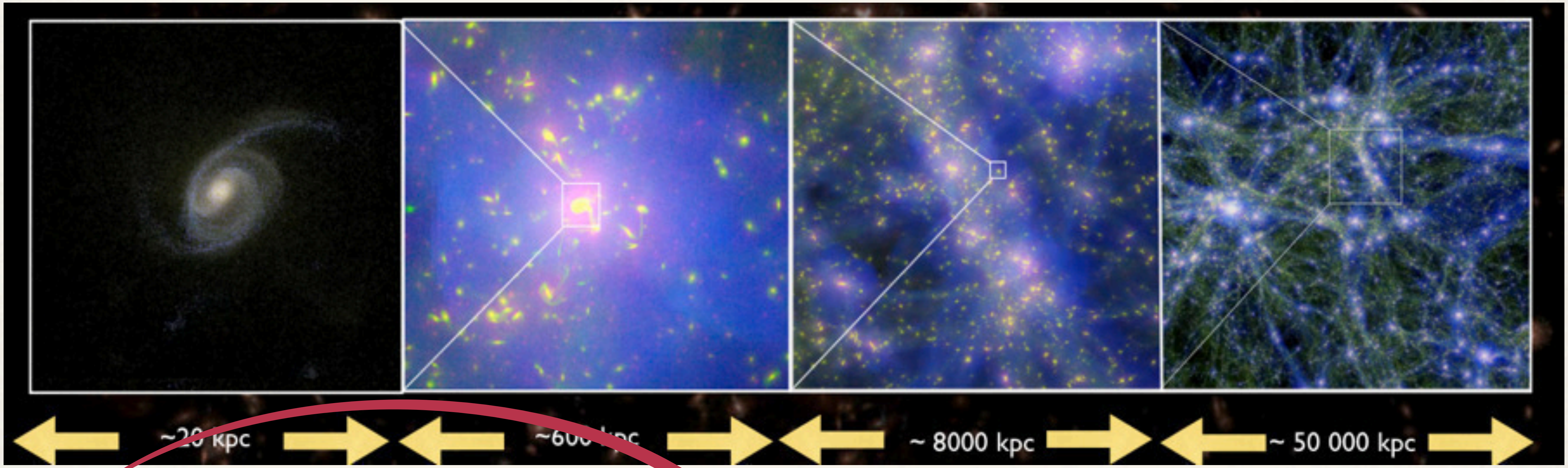


small-scale
baryons

What is the influence of the environment -set by the cosmic web- on galaxies?

Large-scale
clustering of dark matter

How can we efficiently extract cosmological information from the large-scale structure?

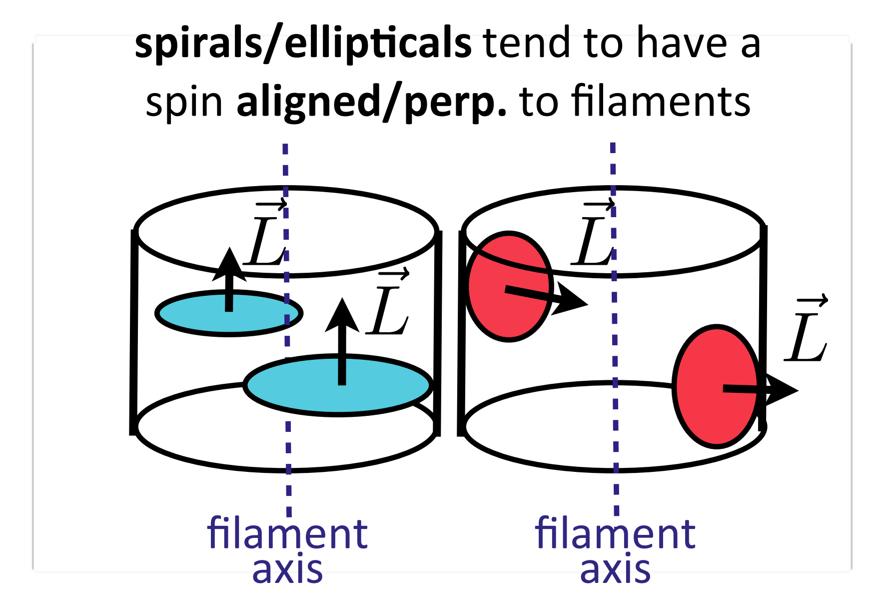
Galaxies within the LSS

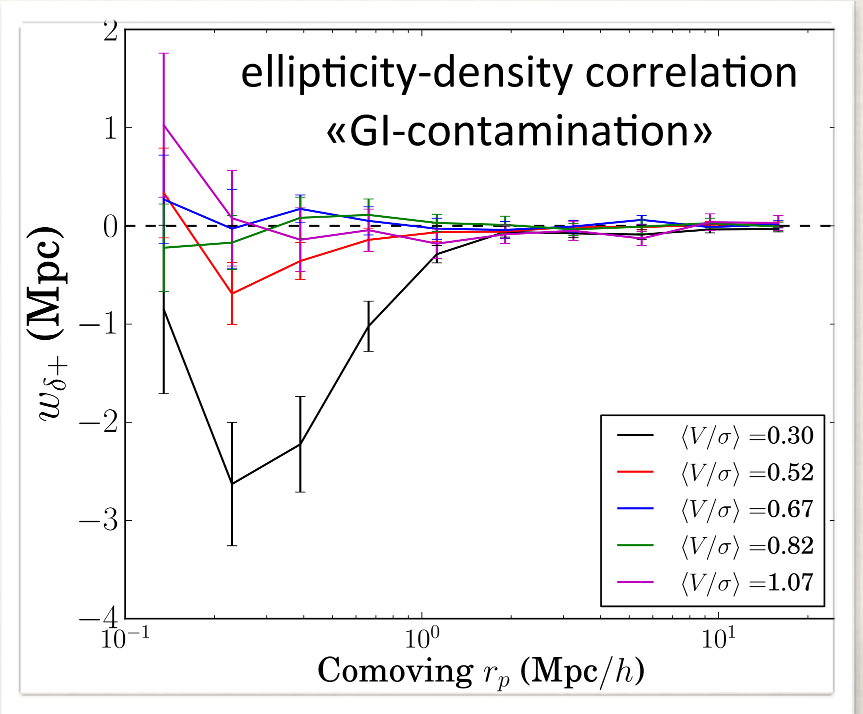
How is the cosmic web shaping galaxies? This is crucial for
➢ galaxy formation
➢ intrinsic alignments (contaminant of weak lensing surveys)

★ Galaxy's morphology and spin are correlated to the filaments' axis in DM and hydro simulations, as a result of the folding of the cosmic web.
Codis'12, Dubois'14

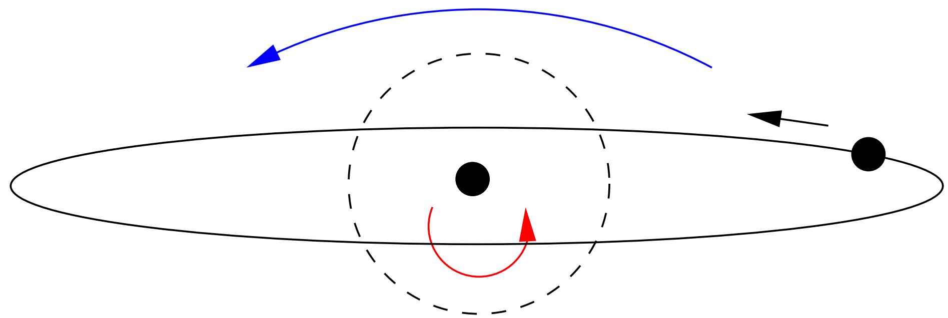
★ Those correlations can be understood in Lagrangian space if the standard theory of **spin acquisition** by tidal torquing accounts for the anisotropy of the filamentary cosmic web
Codis'15b

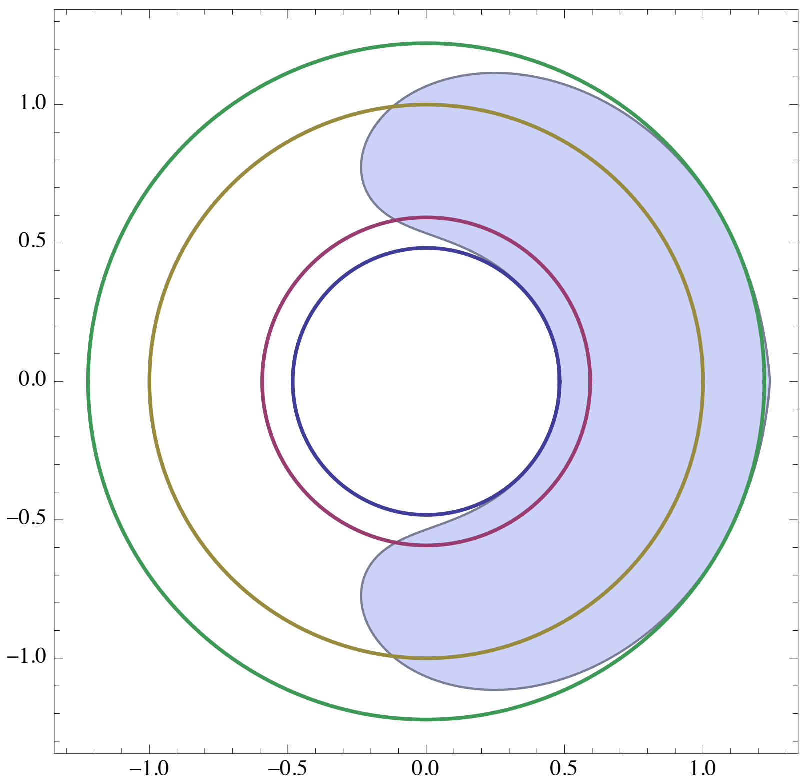
★ This large-scale coherence of galaxy's properties could induce some non-negligible level of contaminations for weak lensing experiments (**intrinsic alignments**) that can be studied in hydro simulations.
Codis'15a, Chisari'15

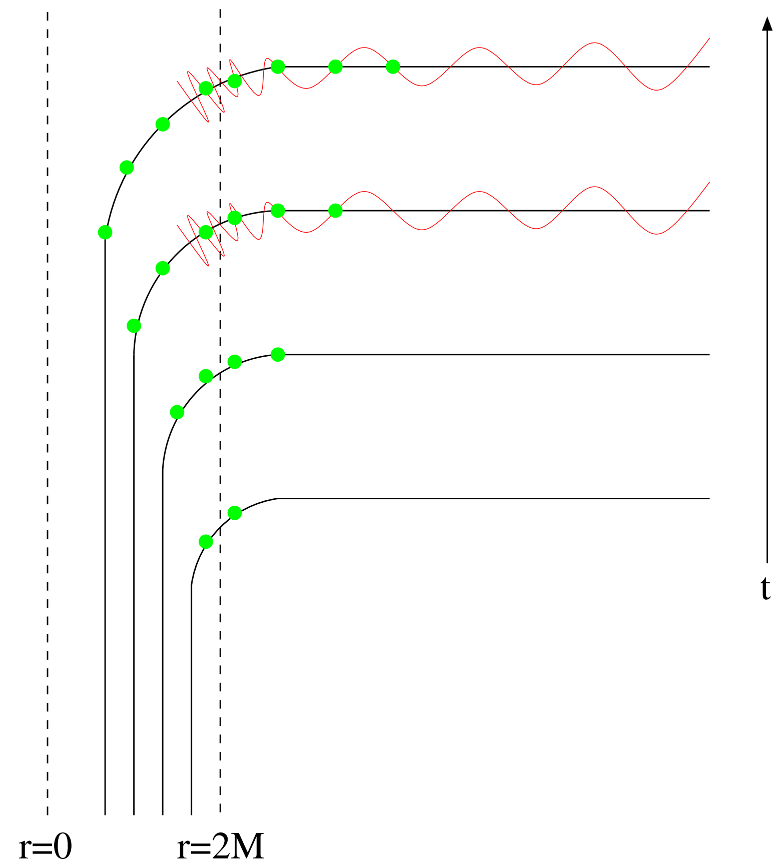


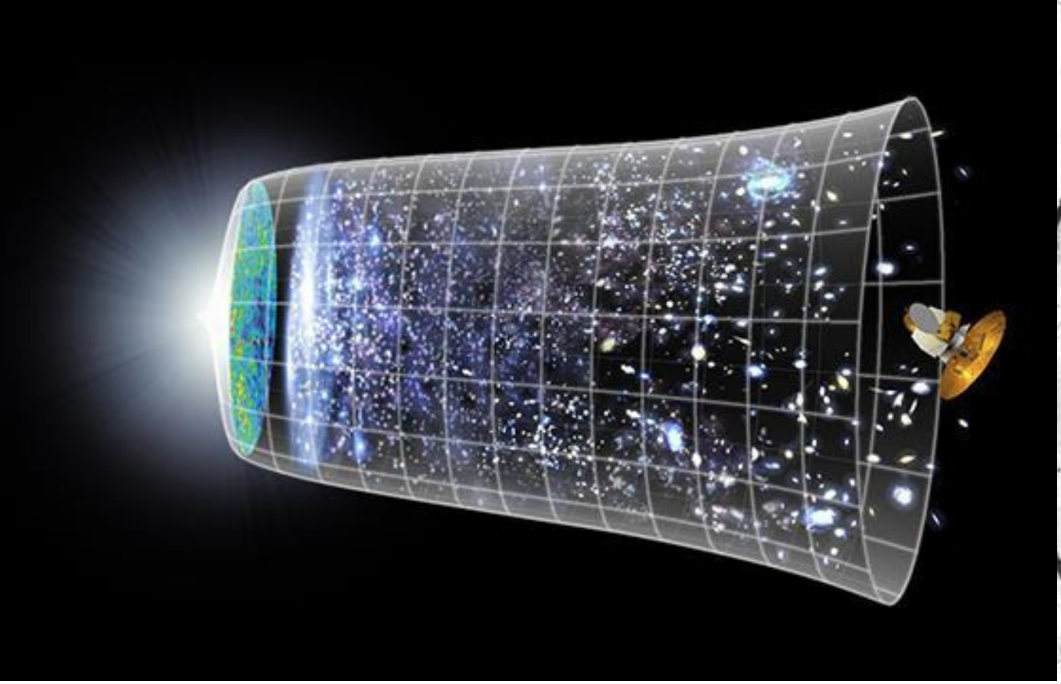


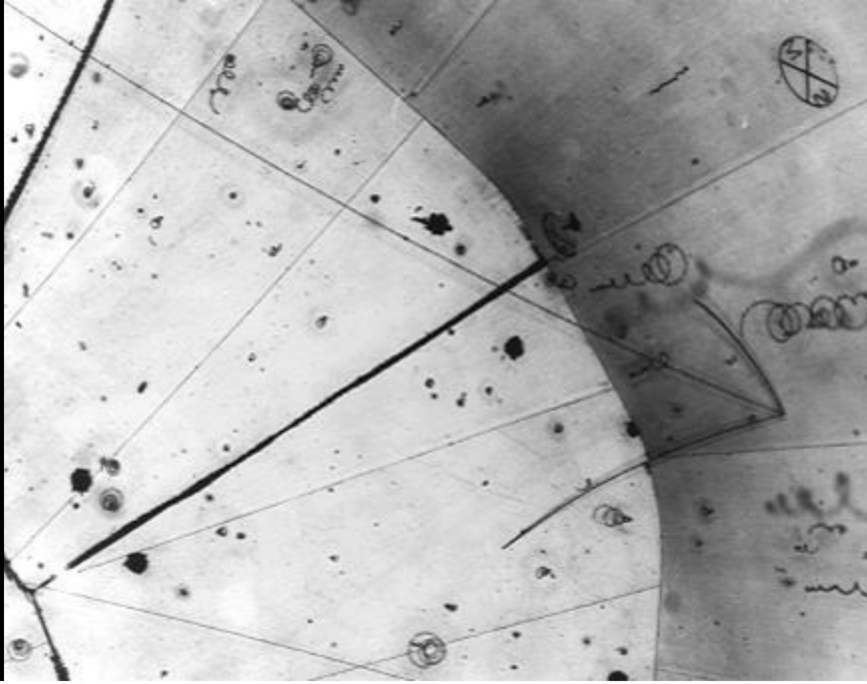
Everything about Gravity – *I-sheng Yang*











The Cosmic Neutrino Background

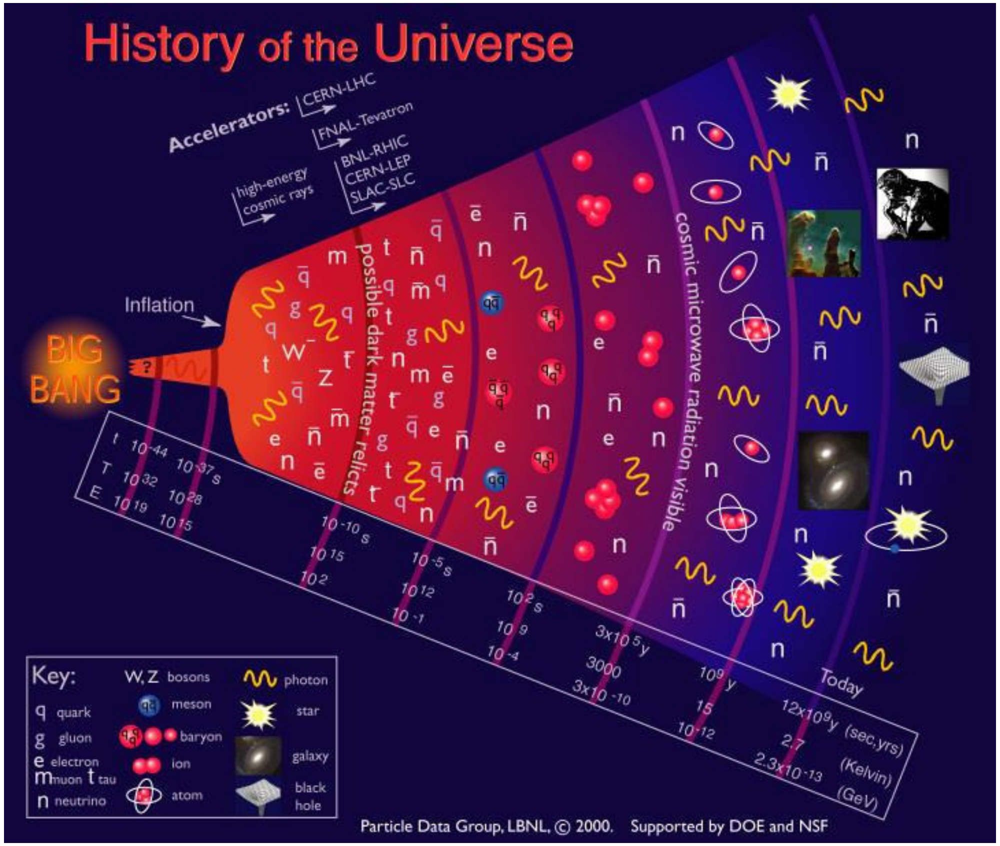
Joel Meyers

CITA Jamboree 2015

October 7, 2015

Theoretical Expectation

- The standard models of cosmology and particle physics make very definite and detailed predictions about the existence and properties of the cosmic neutrino background
- Neutrinos were in thermal equilibrium, decoupled about 1 second after the end of inflation, and have a nearly perfect Fermi-Dirac distribution

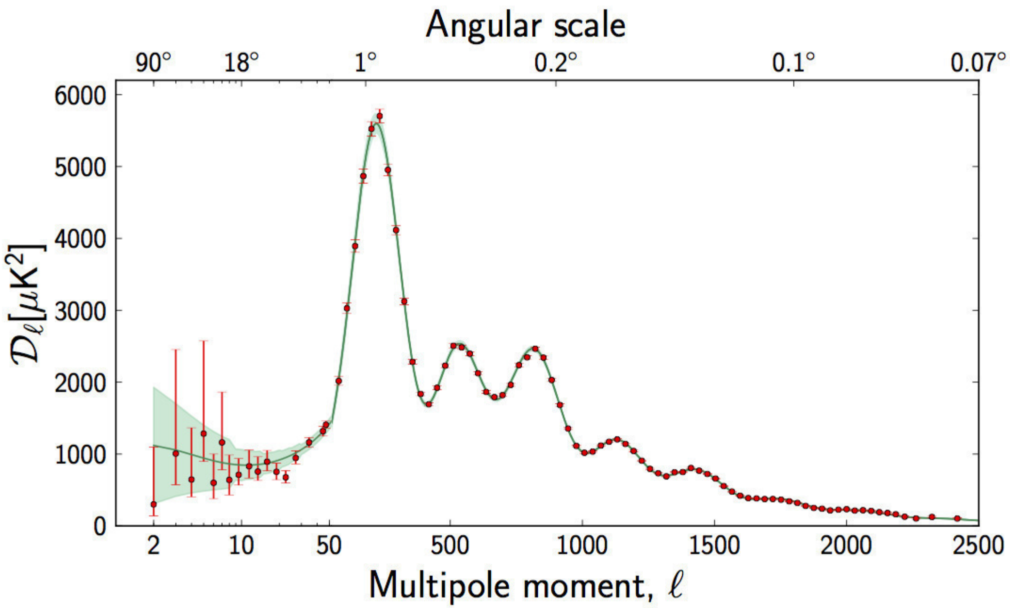


$$f_\nu(p, T_\nu) = \frac{1}{\exp\left(p/kT_\nu\right) + 1}$$

Gammow, et al. (1960s); PDG (2013)

Observational Status - CMB

- We have indirectly detected the cosmic neutrino background through its gravitational effects
- Current constraints are primarily summarized in just two numbers giving the total energy density and sum of neutrino masses



$$\rho_r = \rho_\gamma \left(1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{\rm eff}\right)$$

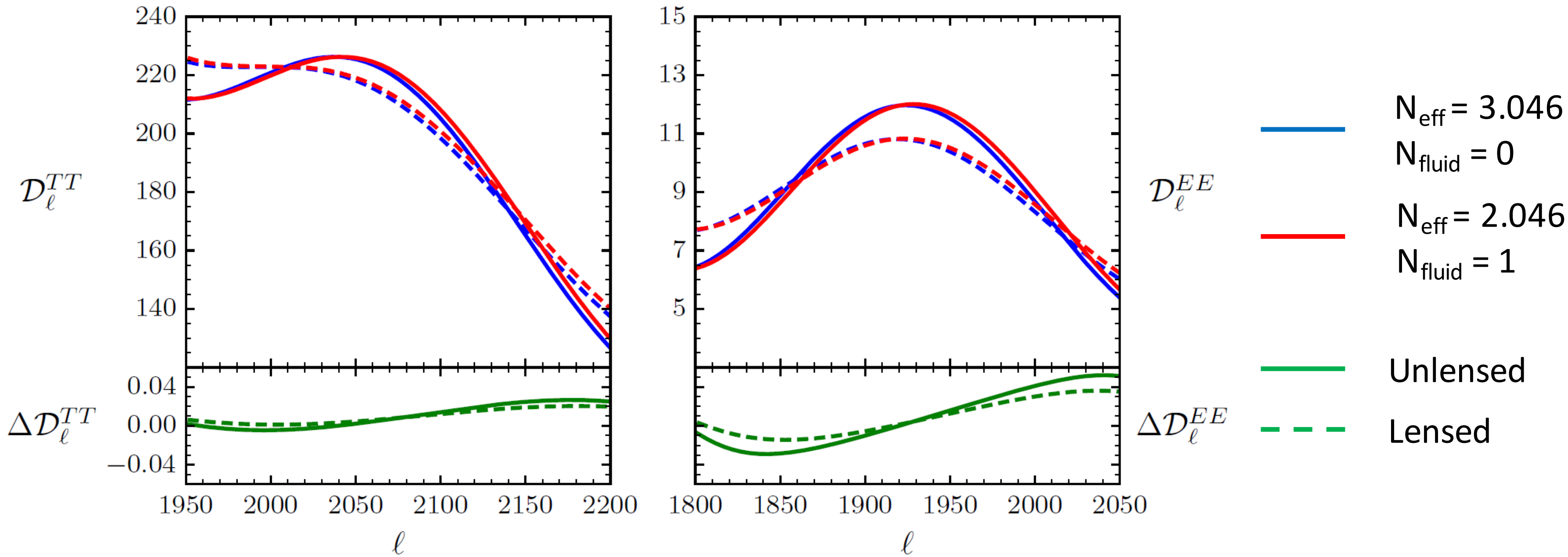
$$N_{\rm eff}^{\rm SM} = 3.046$$

$$\sum m_\nu < 0.23\,{\rm eV}$$

$$N_{\rm eff}^{\rm CMB} = 3.04 \pm 0.18$$

Planck (2015)

Free Streaming and the Phase Shift



- Anisotropic stress leads to a characteristic phase shift of the acoustic peaks of the CMB power spectrum which can be used to distinguish between free streaming and non-free streaming radiation species
- The phase shift is most easily detectable in the delensed EE spectrum due to the sharper peaks

Baumann, Green, JM, Wallisch (2015)

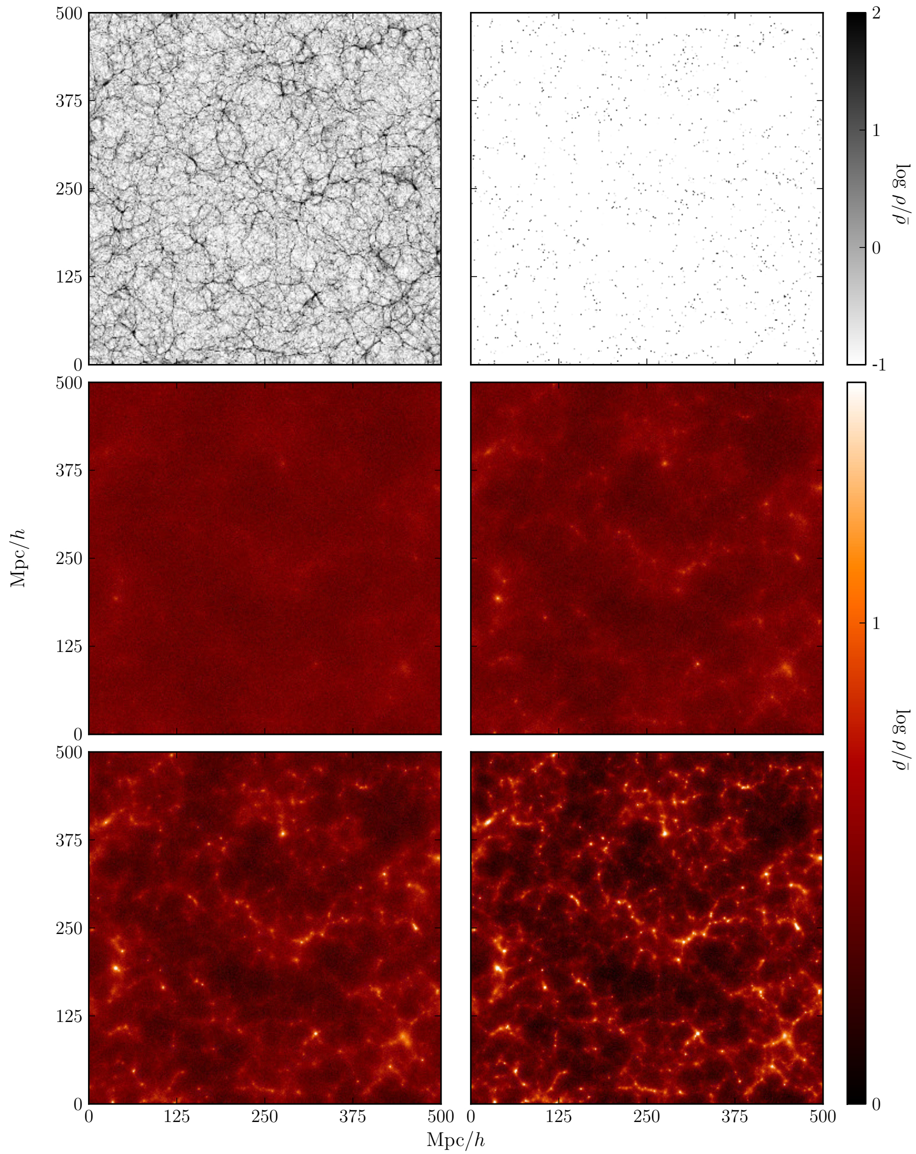
Conclusions

- Understanding the cosmic neutrino background lies at the interface of cosmology and particle physics
- We have indirect evidence of the existence of the CvB and some weak constraints on its properties
- Our standard model makes much more detailed predictions than can currently be tested with observation
- Observational constraints on the CvB naturally constrain a huge number of extensions to the standard cosmic history

10^{12} cosmic neutrinos pass through this loonie each second!

Derek Inman
(CITA) Collaborators: JD Emberson,
Hao-Ran Yu, Joachim Harnois-Déraps,
Ue-Li Pen

Neutrino Simulations



Projects

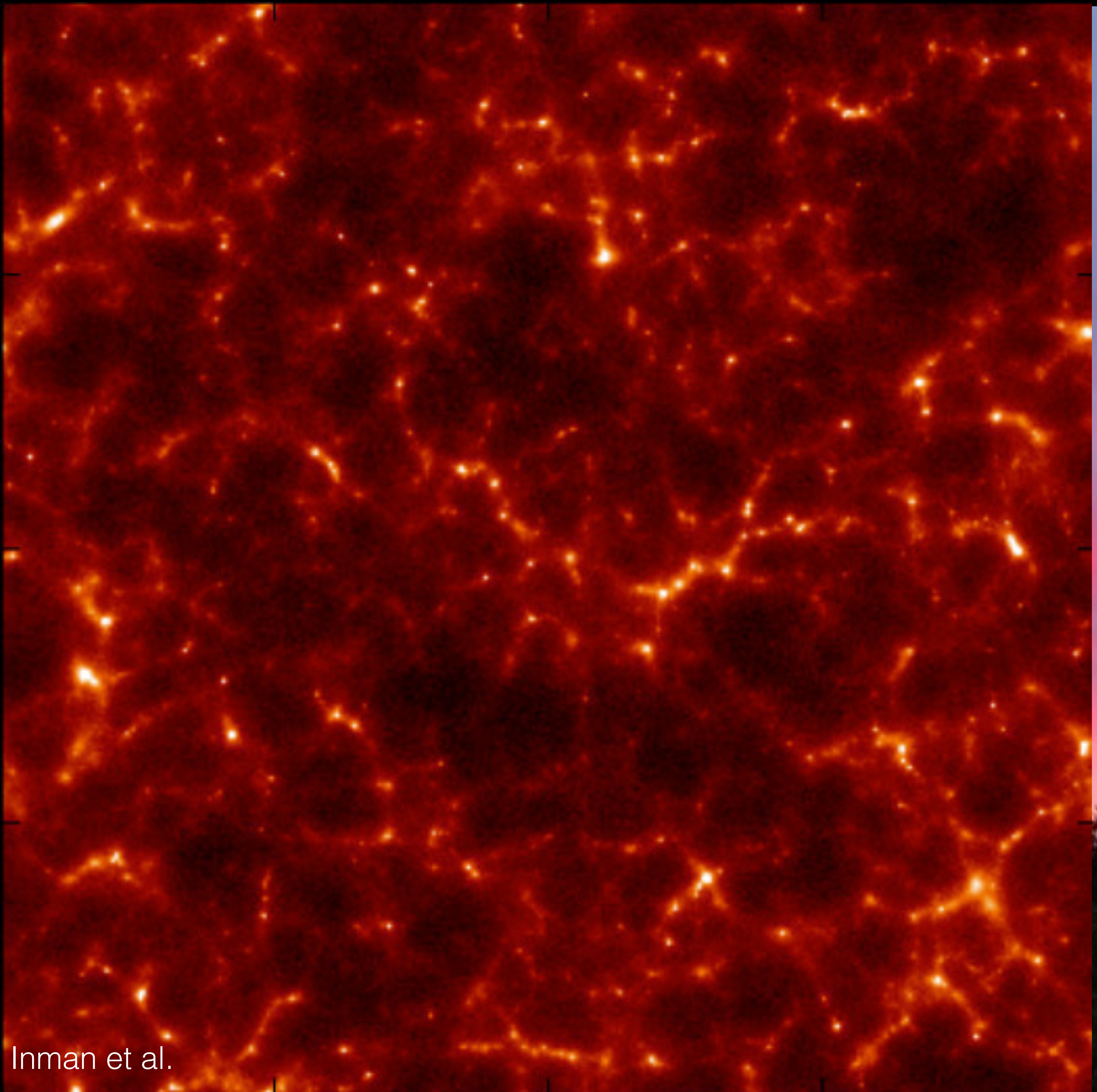
- TianNu Simulation
  - Dipole Effect
- BGQ Simulation
  - Particle Re-weighting
- Iterative Method
  - Explaining higher order effects

arXiv:1503.07480

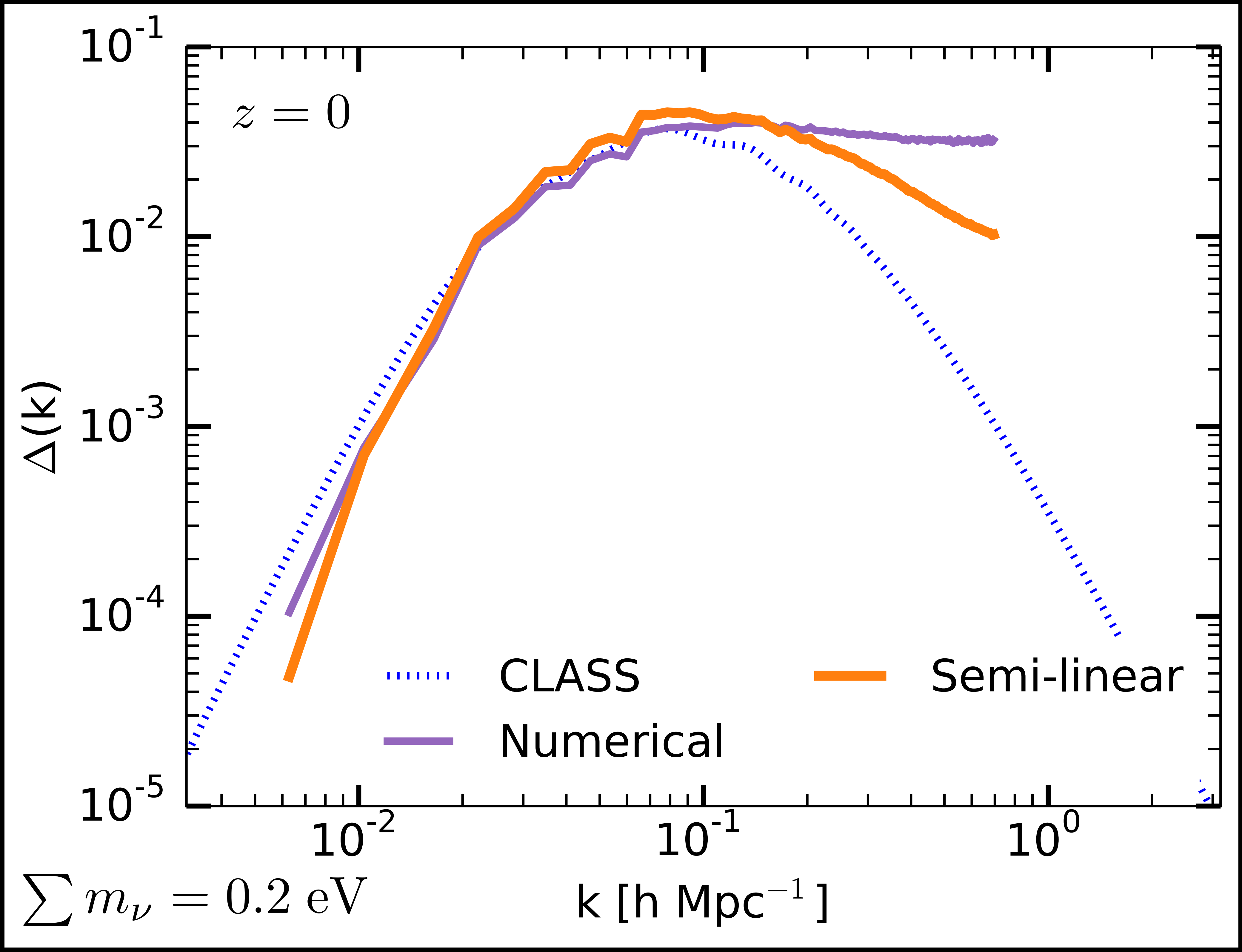
Dana Simard

CITA Jamboree 2015

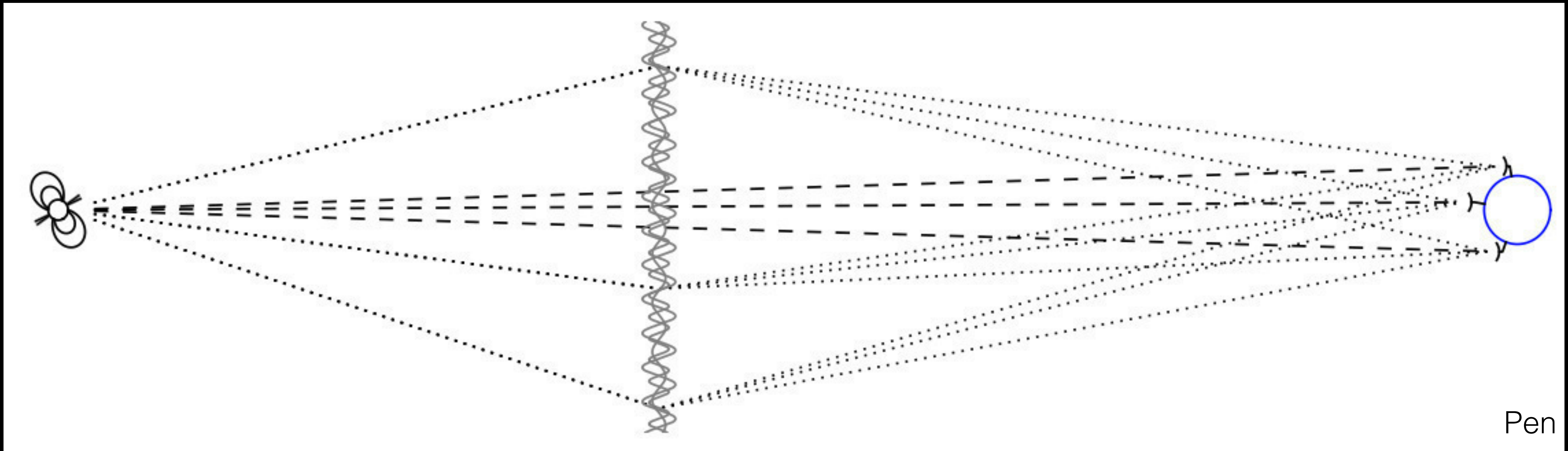
Cosmic Neutrino Background + Pulsar Scintillometry

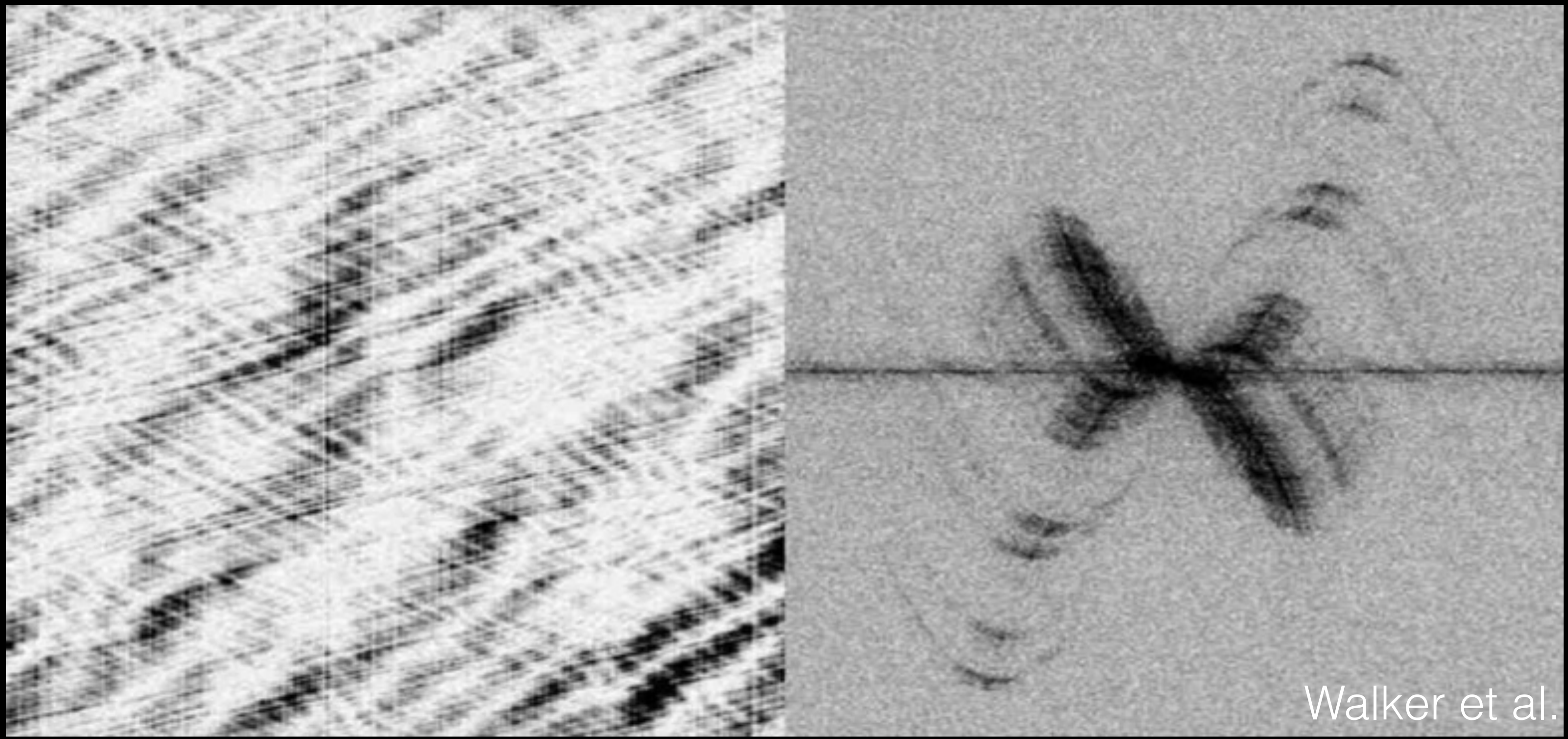


Cosmic Neutrino Background



Pulsar Scintillometry





Is ΛCDM Still Our Best Bet?

Zhiqi Huang

Postdoc 2013-2016

Member of:

Planck HFI Core/Core2

ACTPol

EUCLIDE Theory WG

CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut Canadien d'astrophysique théorique

Research interests:

CMB theory & data

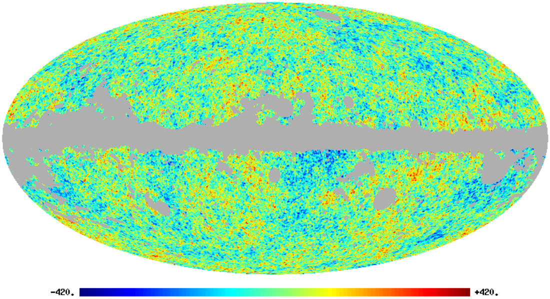
Dark Energy/Modified Gravity

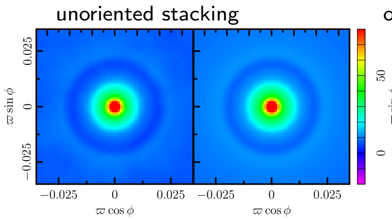
Numeric 2nd-order perturbations

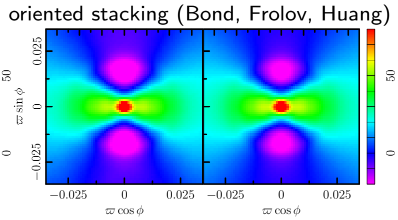
Early-Universe inflation/preheating

Galactic dust polarization foreground

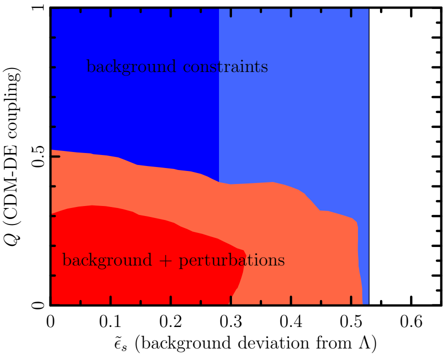
Cosmic Microwave Background: Oriented Stacking







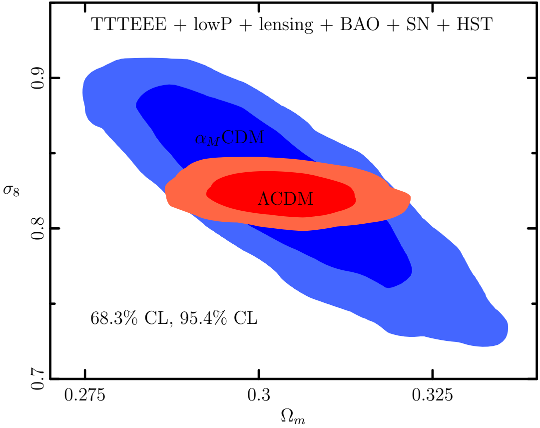
Coupled Cold Dark Matter (CDM) and Dark Energy (DE)



Collaboration with J. R. Bond and Chao Wang (summer student)

- ΛCDM ($Q = \tilde{\epsilon}_s = 0$) still best-fit. The strength of coupling is constrained by CMB data ($Q < 0.5$).

Effective Field Theory Dark Energy Model



α_MCDM model allows a lower σ_8 that is more compatible with weak lensing and cluster data.

$$\alpha_M = \frac{d \ln M^2_{p,\mathrm{eff}}}{d \ln a}$$

CMB as a backlight

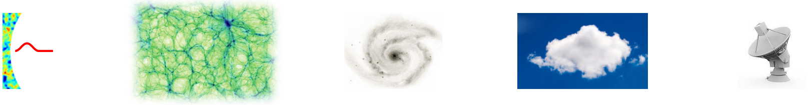
Alex van Engelen

CITA

7 Oct 2015

From pristine CMB to dirty data

At the surface of last scattering



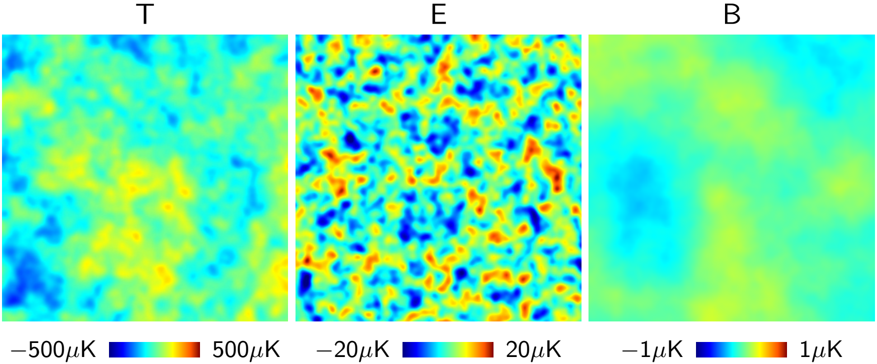
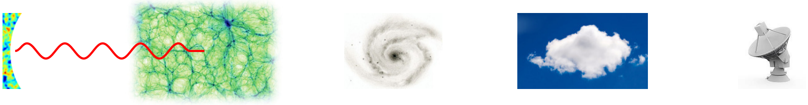


Image credits: Sigurd Naess

From pristine CMB to dirty data

Lensing by large-scale structure



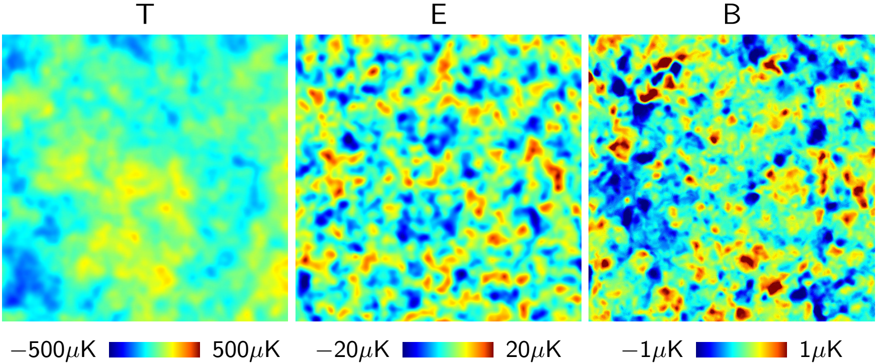
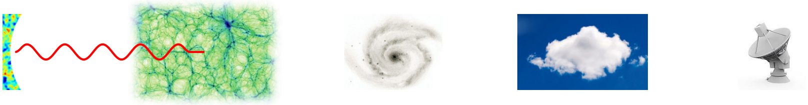


Image credits: Sigurd Naess

From pristine CMB to dirty data

Dusty galaxies, radio sources, SZ clusters



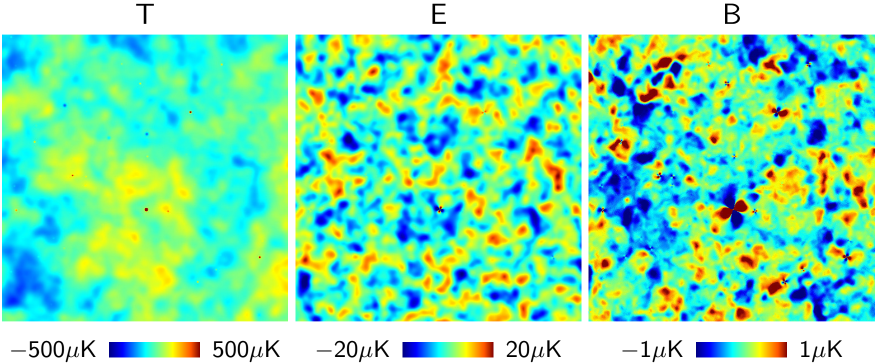
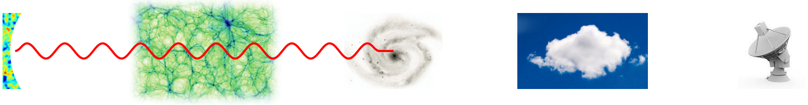


Image credits: Sigurd Naess

From pristine CMB to dirty data

Faraday rotation



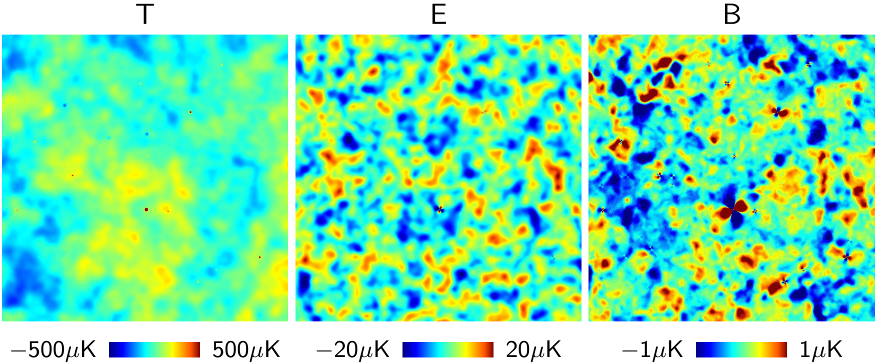
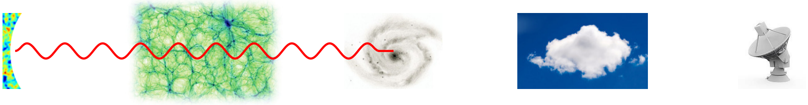


Image credits: Sigurd Naess

From pristine CMB to dirty data

Galctic dust, synchrotron, etc



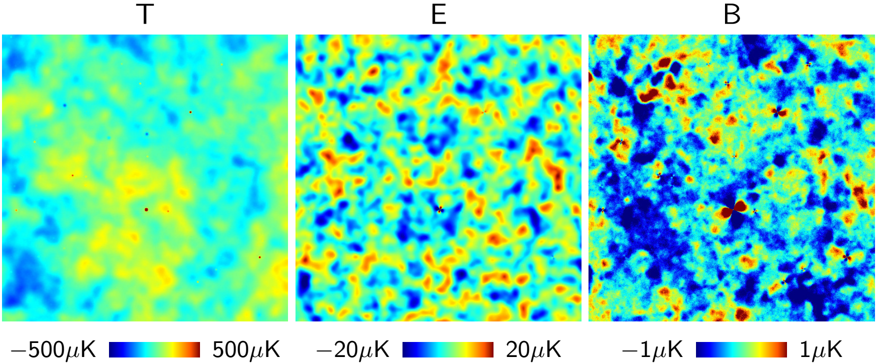
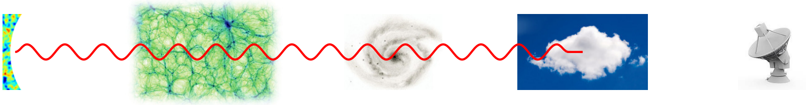


Image credits: Sigurd Naess

From pristine CMB to dirty data

Atmospheric emission



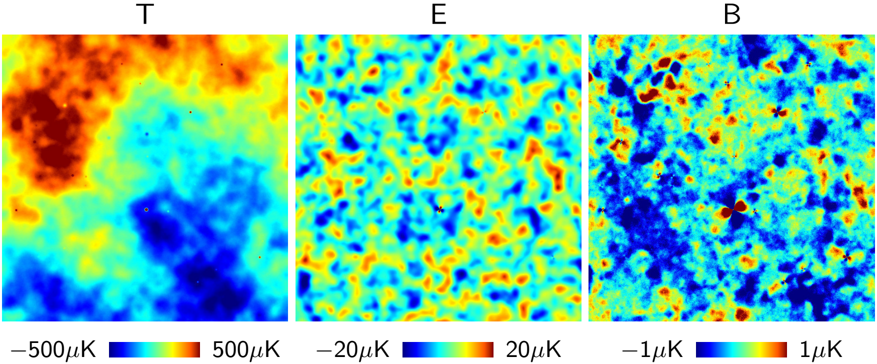
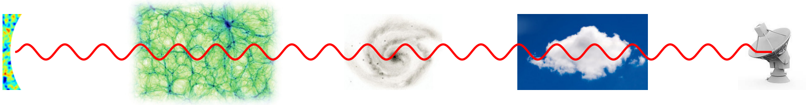


Image credits: Sigurd Naess

From pristine CMB to dirty data

Absolute polarization offset (1° example)



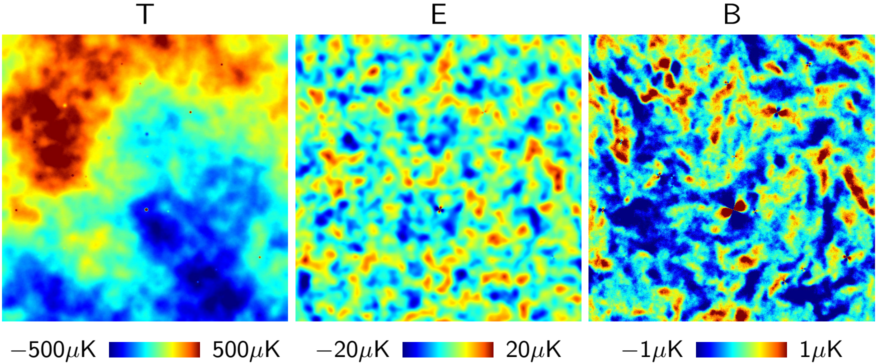
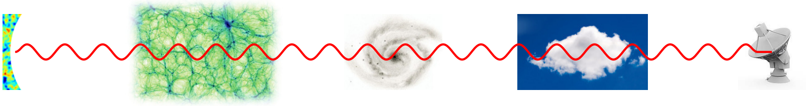


Image credits: Sigurd Naess

From pristine CMB to dirty data

Telescope optics (w. sidelobe)



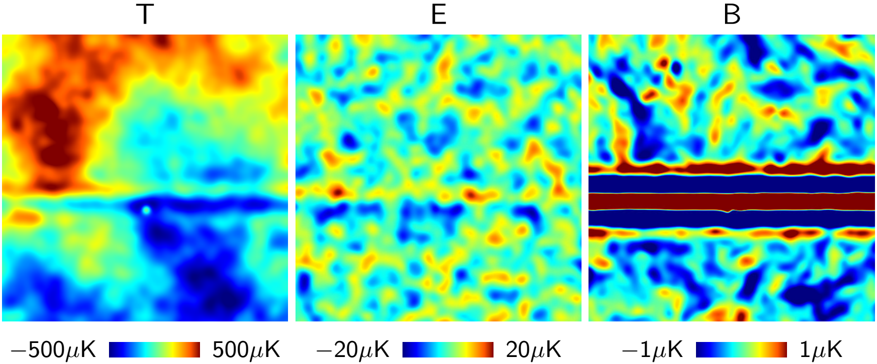
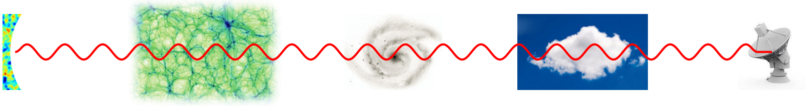


Image credits: Sigurd Naess

From pristine CMB to dirty data

Detector noise



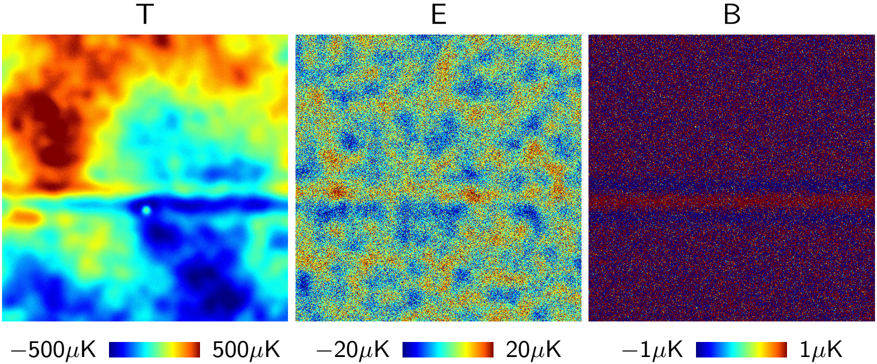
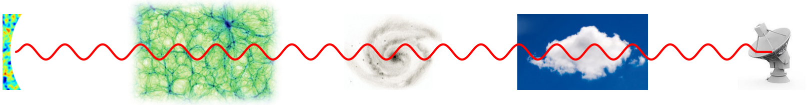


Image credits: Sigurd Naess

From pristine CMB to dirty data

Glitches



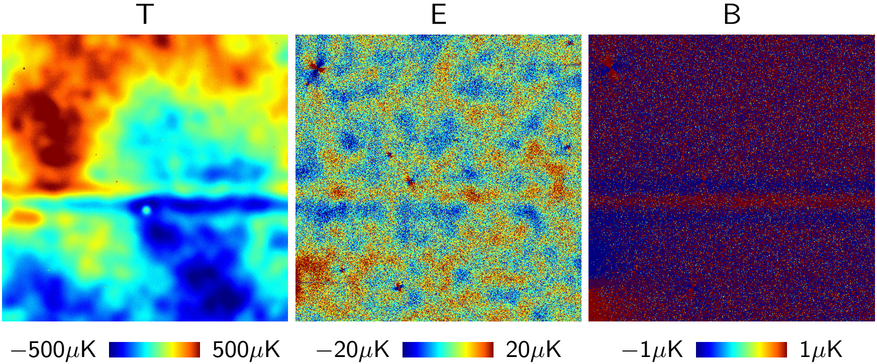
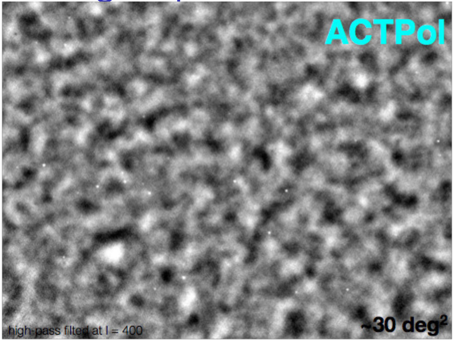
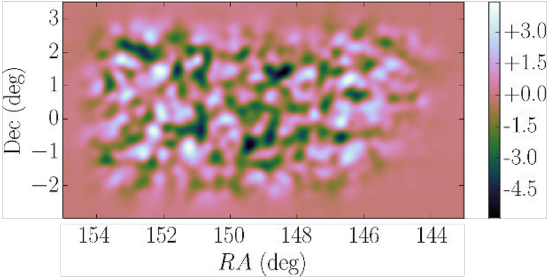


Image credits: Sigurd Naess

Real CMB and lensing maps



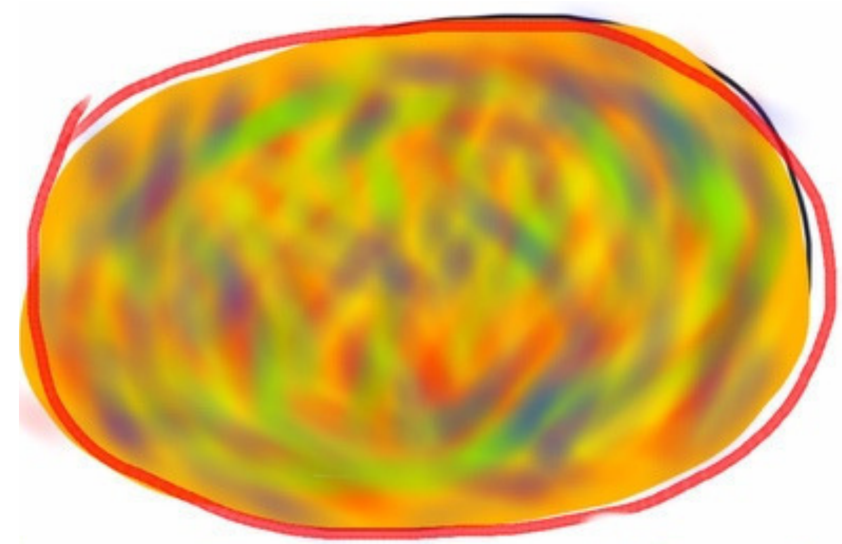



the
CoSmIC
LAB

inflation → tracers

$$\Phi \to \{T, P\}$$

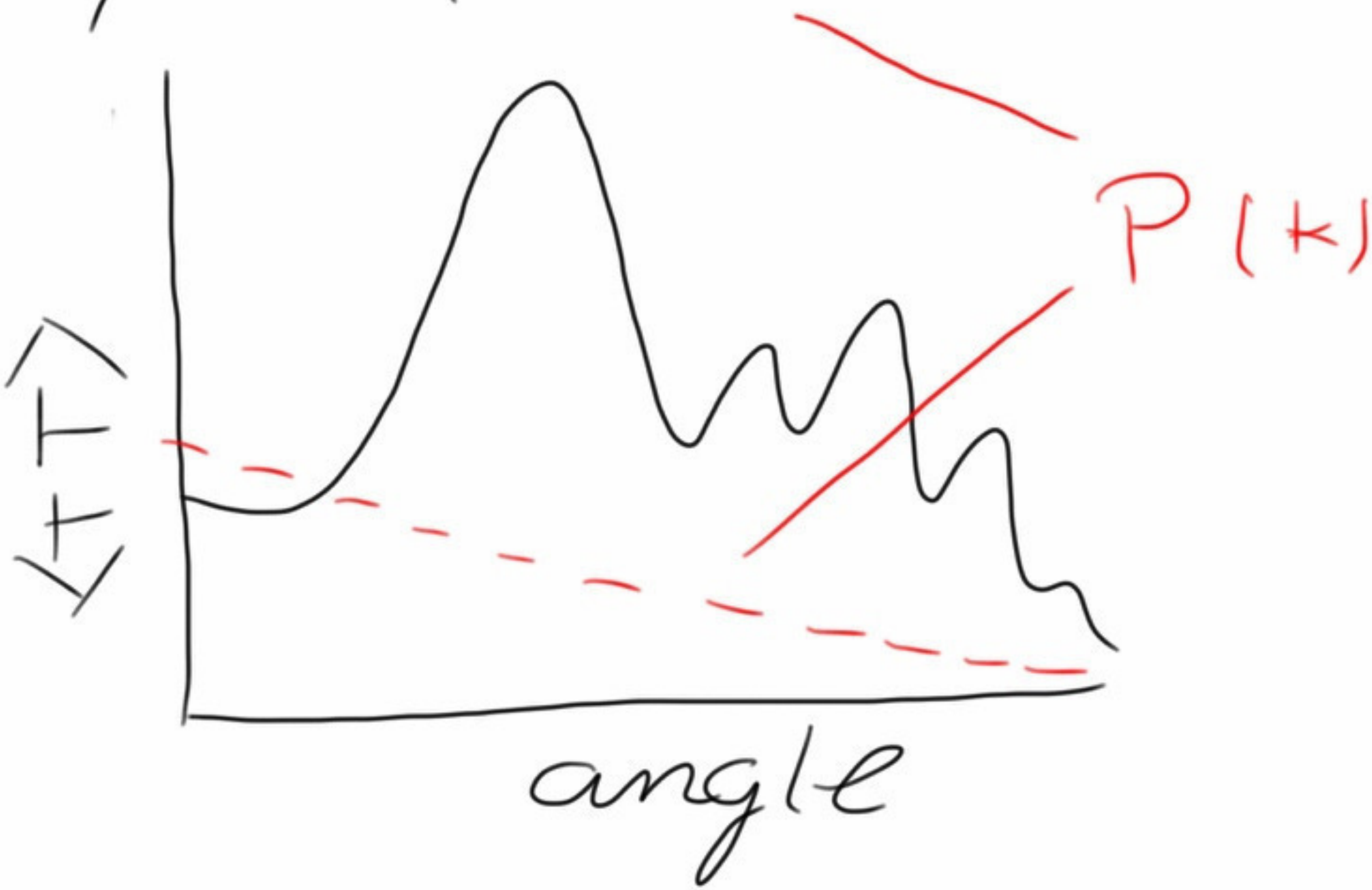
Large Scale Structure (LSS)



Cosmic Microwave Background (CMB)

CMB

$$\langle TT \rangle \longrightarrow \langle \Phi \Phi \rangle \longrightarrow \mathcal{L}(\Phi)$$



CMB

$\langle TT \rangle$

$\langle TTT \rangle$

$\vdots$

$\langle EE \rangle$

$\langle TE \rangle$

$\langle TTE \rangle$

$\vdots$

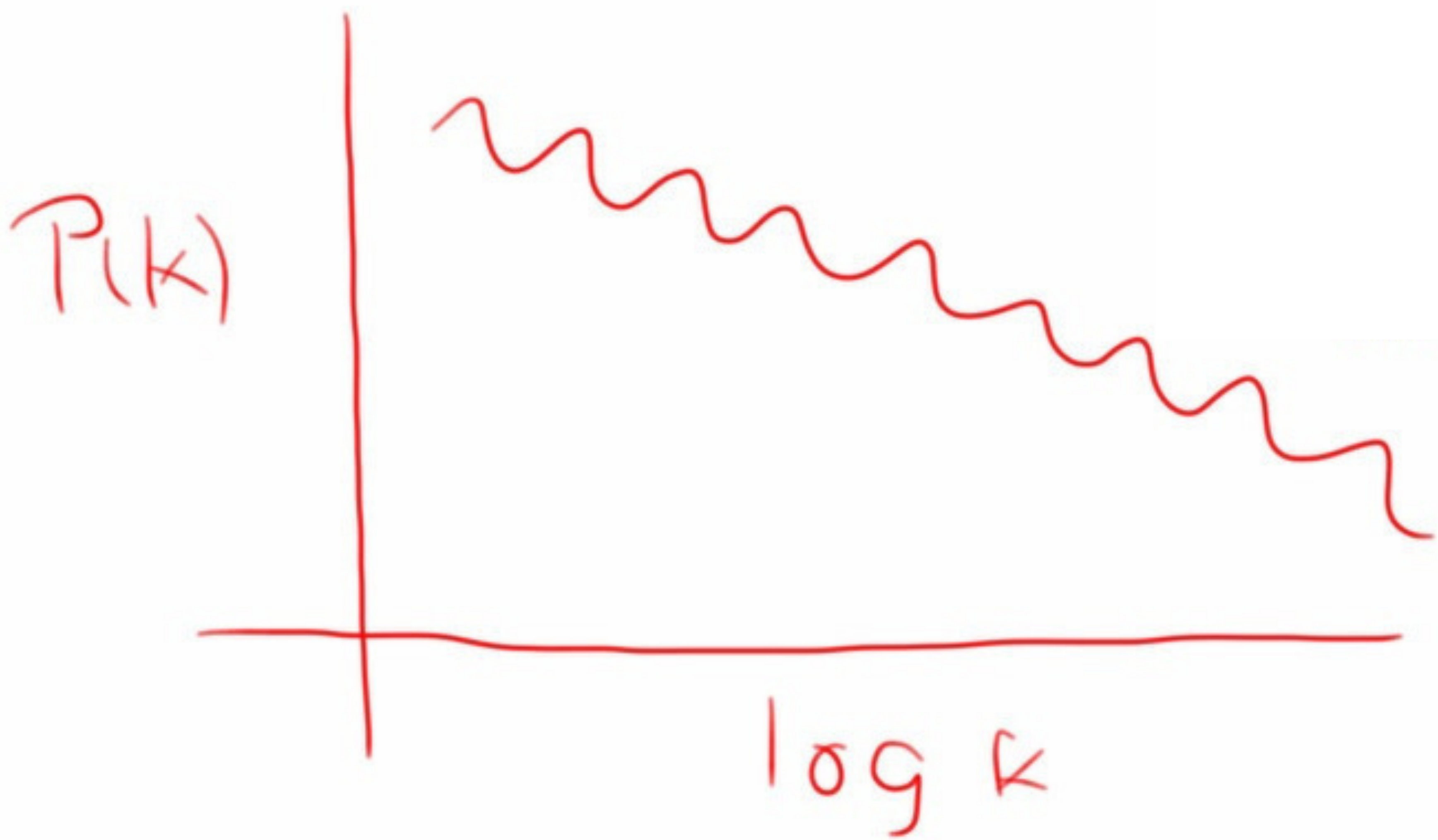
$\langle BB \rangle$

$\rightarrow \mathcal{L}(\Phi)$

reconstruct physics of the early Universe

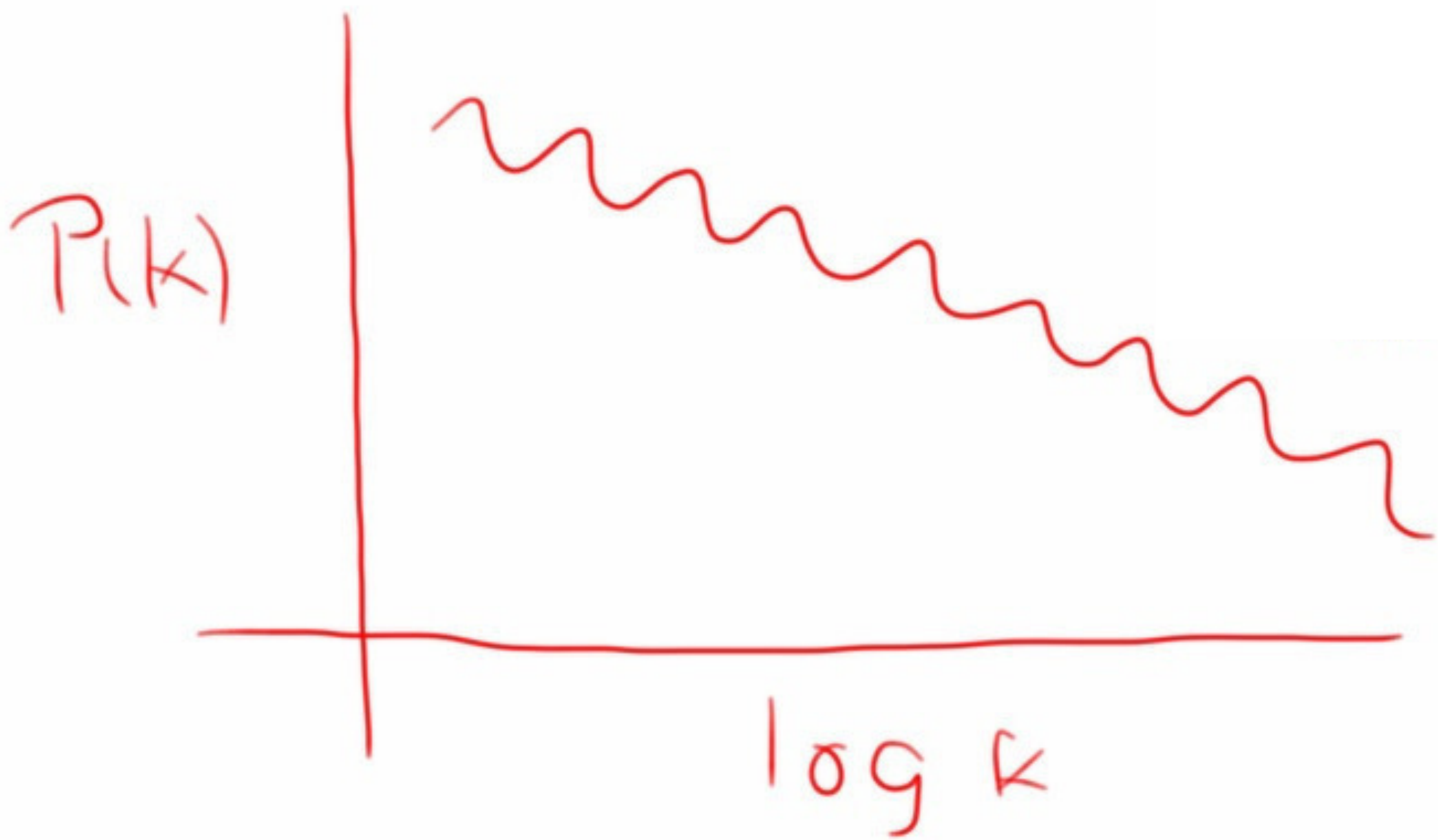
$\mathcal{L}(\bar{\Phi}) \subset V(\bar{\Phi})$?

specific model: $V(\Phi) \propto \cos(\omega \bar{\Phi})$



$\mathcal{L}(\bar{\Phi}) \subset V(\bar{\Phi})$?

specific model: $V(\varphi) \propto \cos(\omega \bar{\Phi})$

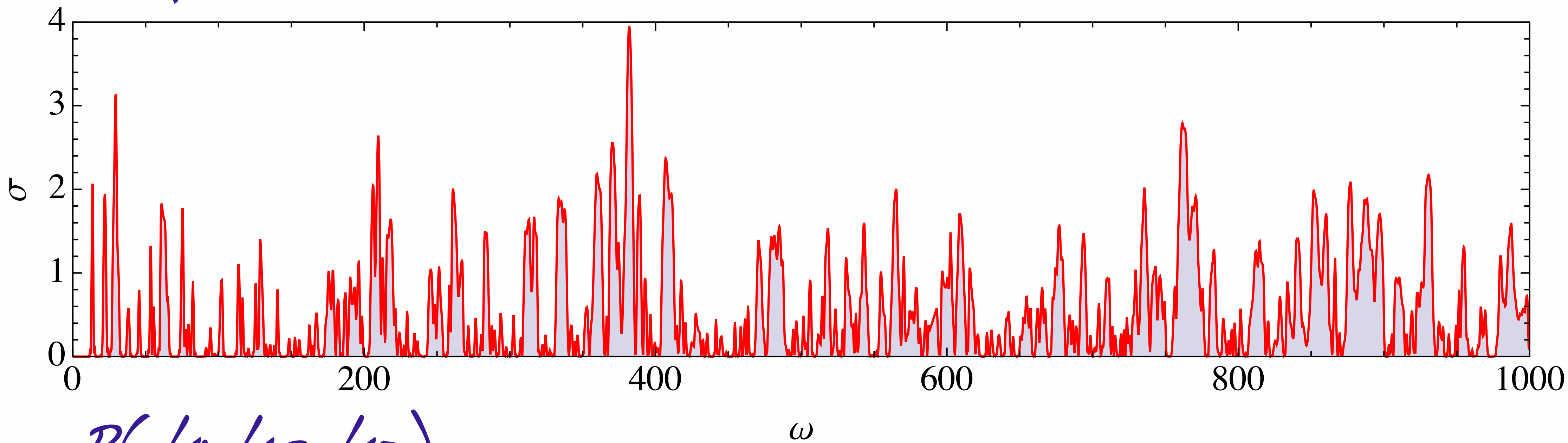


In $P(k)$ but also in $B(k_1, k_2, k_3)$

Search (methods) for this in CMB, LSS

w/ Moritz Münchmeyer, Ben Wandelt, David Spergel

P(k)



B(k1,k2,k3)