



**Dick Bond**

**CITA = Cosmic Information Theory & Analysis**

from *SuperWeb simplicity to complex Intermittency in the Cosmic Web*  
*IT from BIT, from BITs in IT, Studying the Cosmic Tango*  
*Universe=System+Res, =Data+Theory en-TANGO-ment*

**CIFAR Cosmology & Gravity Program: >1985, Bond Director 2002-17 20 Sr Fellows & Fellows (5@UofT), 21 associates + 6 Advisory Board members; CITA: 6+ faculty, >20 PDFs & Sr RAs + ~15 grad students; Bond: projects 3 grad students, 2 SrRAs, 2 (++) PDFs**

**Cosmic standard model SMC =  $\Lambda$ CDM,  $\Lambda$ =dark energy+tilt: what is U made of? Planck15 dark energy, dark matter, baryons, CMB, CIB, CnuB, GW:  $\rho_{\text{dm}}/\rho_{\text{b}}=5.43$**

$\rho_{\text{de}}/\rho_{\text{dm}}=2.53$   $\Omega_{\text{m}}=0.32 \pm 0.009$ ,  $\Omega_{\Lambda}=0.68 \pm 0.009 \Rightarrow$

**BSMC Beyond the SMC** eg  $\Omega_{\Lambda}(t,x)$ , neutrino properties, inflation anomalies

**How Structure in the Universe Arose?: fluctuation generation in curvature from an early inflaton:  $P_{\text{POWER}}|_{\text{na, isoc}}$ ,  $\text{GW}(k)$ : isocurvature, Gravity Wave;**  
(coherence + quantum noise  $\Rightarrow$  incoherence via entropy/information generation) via nonlinear lattice simulations of multiple scalar fields at the end of inflation & “ballistics”

$\Rightarrow$  **CMB/LSS Anomalies and intermittent non-Gaussianity cf. perturbative non-Gaussianity, correlated & uncorrelated. probe with CMB + LSS large surveys**

**CMBology** precision cosmic parameters **Planck 2013-15-17 intensity + polarization + ACTpol + BKP + SPT + LSS  $\Rightarrow$  Spider, Advanced ACTpol  $\Rightarrow$  Simons Obs  $\Rightarrow$  CMB Stage 4, ..**

**LSSology** CHIME, COMAP, Euclid ... cross correlations: **CMBxLSS**

**morphs** into the nonlinear **Cosmic Web**: clusters SZ, filaments, voids; galaxies Mass-peak-patches, N-body, gas to “Mock Heaven” tSZ, kSZ, CIB, CO, HI, optical (HOD), CIB, CO, HI

**What is the fate of the U: (coupled?) dark energy driving late inflation**



from SuperWeb to complex Intermittency in the Cosmic Web  
IT from **bits** in IT, Studying the Cosmic Tango  
Universes, =Data+Theory **en-TANGO-ment**

**Dick Bond**

**CIFAR Cosmology & Gravity** >1985, Bond Director 2002-17 **20 Sr Fellows & Fellows (5@UofT)** + **6 Advisory Board members**; CITA: **6+ faculty, >20 PDFs & Sr RAs + ~15 projects**; Bond: **projects 3 areas**, **2 SrRAs, 2 (++) PDFs**

Cosmic model  $\Lambda$ CDM =  **$\Lambda$ CDM** energy: **U: what is U made of?** dark energy, dark matter, CMB, CIB,  $\rho_{dm}/\rho_b=5.43$

**B+Braden, Mersini**  
**3D bubble simulations**  
Planck/AdvACT

**B+Meyers+Wilson+Fuller+Grohs**  
**cosmic neutrino decoupling & BBN**

**B2FH: B+Braden, Frolov, Huang**  
**preheating, caustics, shocks-in-time**  
Planck/AdvACT/Spider/LSS

**B+Huang, Frolov**  
**In  $a(x,t)$  early U maps**  
**potential reconstructions**  
**acceleration histories**  
Planck/AdvACT/Spider/LSS

**B+ Alvarez+ Stein Battaglia, Berger, Hajian, Huang, Pfrommer, Sievers,**  
**Bahmanyar, Pu, Shaw**  
**hydro sims, peak-patches & potential pits, flows beyond 2LPT, 3D non-Gaussian**  
**Pen, Vanderlinde, Opperman, van Engelen, ..** Planck/ACT/CHIME  
**Netterfield, Padilla +, Nolta, van Engelen, Hlozek, ...**  
**CMB analysis: Planck/Spider/AdvACTpol**

**CMBology** precision cosmology + **ACTpol + BKP + SPT**  
**LSS** galaxy clustering

**Web: Cosmic Web: voids, filaments, voids**  
**Mock Heavens: MSZ, CIB, CO, HI**

**What is the fate of the U: (coupled?) dark energy driven inflation**

**BSMc = SMc + primordial anomalies**

*sigh, Mother Nature puts her Anomalies @ low L where sample variance => tantalizing ~ 2σ's?*

**early Universe maps of curvature fluctuations from CMB data**

**$\langle \zeta | T, E \rangle + \delta \zeta$ ,  $\zeta = \ln a(x, t) |_{\mathcal{H}}$  Planck 2015 XVII nonGaussianity paper**

40 arcmin fwhm

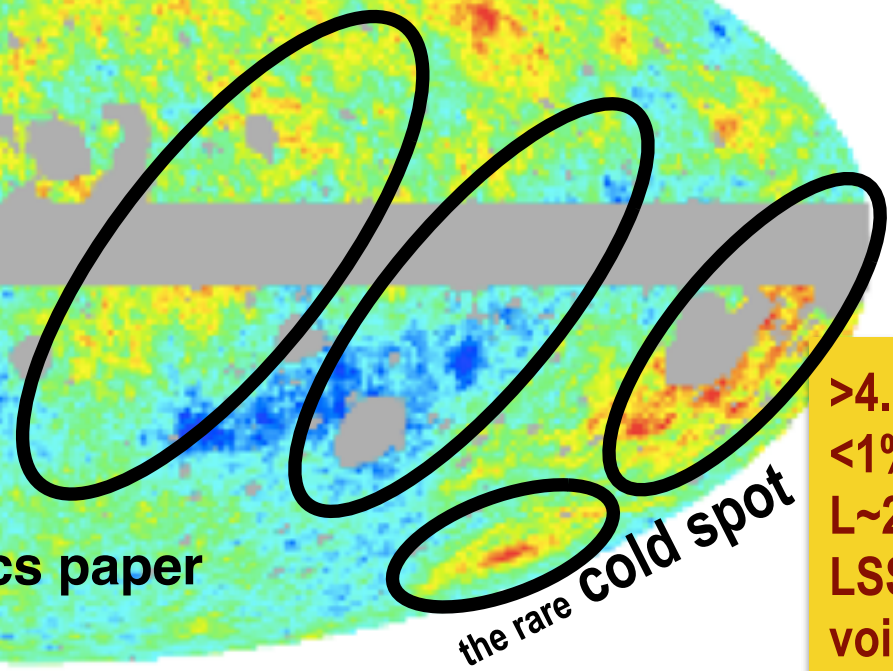
**B+Huang, Frolov**  
**In  $a(x, t)$  early U maps**  
**potential reconstructions**  
**acceleration histories**  
**Planck/AdvACT/Spider/LSS**

**Planck 2015 XX Inflation paper**

**CMB anomaly in power**

**Planck 2015 XVI Isotropy & Statistics paper**

**hemisphere difference in power ~7% at low resolution**



**>4.5σ**  
**<1%**  
**L~20**  
**LSS**  
**void?**

**intermittent?**



**Compton Scattering (Sunyaev-Zeldovich)**  
**Simulations for ACT, Planck, Simons Obs**  
**& CMB Stage 4 Cluster Observations**  
**Using high res Gas Hydro Sims**

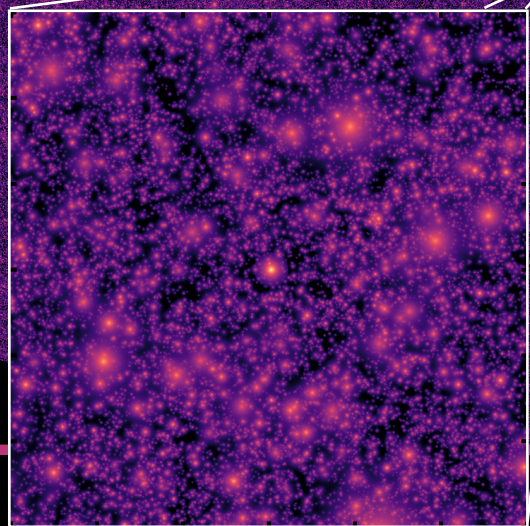
**HI Intensity Mapping**  
**simulations of CHIME / HIRAX ..**  
 **$z=0.8-2.5, \sim(8 \text{ Gpc})^3$**

$0.00 < z < 1.25$   
8Gpc,  $4096^3$  Box

$z=0.81, \nu = 784.11, \delta\nu = 0.39$

**tSZ**

**HI**



Gaussian

$\delta T_b [\mu\text{K}]$



6 deg





**Compton Scattering (Sunyaev-Zeldovich)**  
**Simulations for ACT, Planck, Simons Obs**  
**& CMB Stage 4 Cluster Observations**  
**Using high res Gas Hydro Sims**

**HI Intensity Mapping**  
**simulations of CHIME / HIRAX ..**  
 **$z=0.8-2.5, \sim(8 \text{ Gpc})^3$**

$0.00 < z < 1.25$   
8Gpc,  $4096^3$  Box

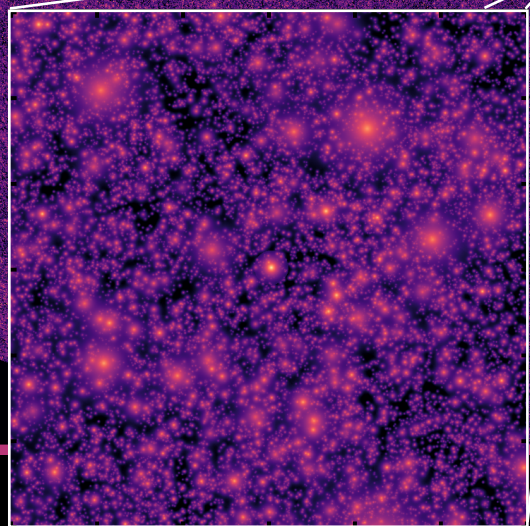
**tSZ**

**HI**

$z=0.81, \nu = 784.11, \delta\nu = 0.39$

uncorrelated  
modulated  
preheating  
intermittent  
nonG

**Gaussian Spike**



6 deg

$\delta T_b [\mu\text{K}]$

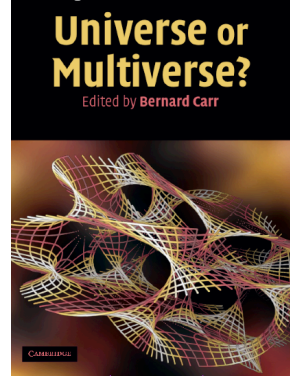




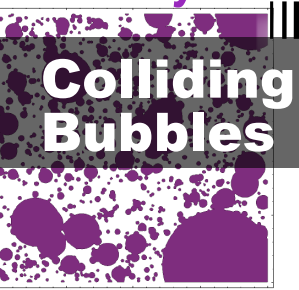
**Dick Bond, CITA & CIFAR**

# SuperWeb of ultra-Ultra Large Scale Structure of the Universe

a highly strained & stressed state in the universe at large (*very, very*). it is randomly simple in our Hubble patch, but highly NL-entangled in the small to medium scale

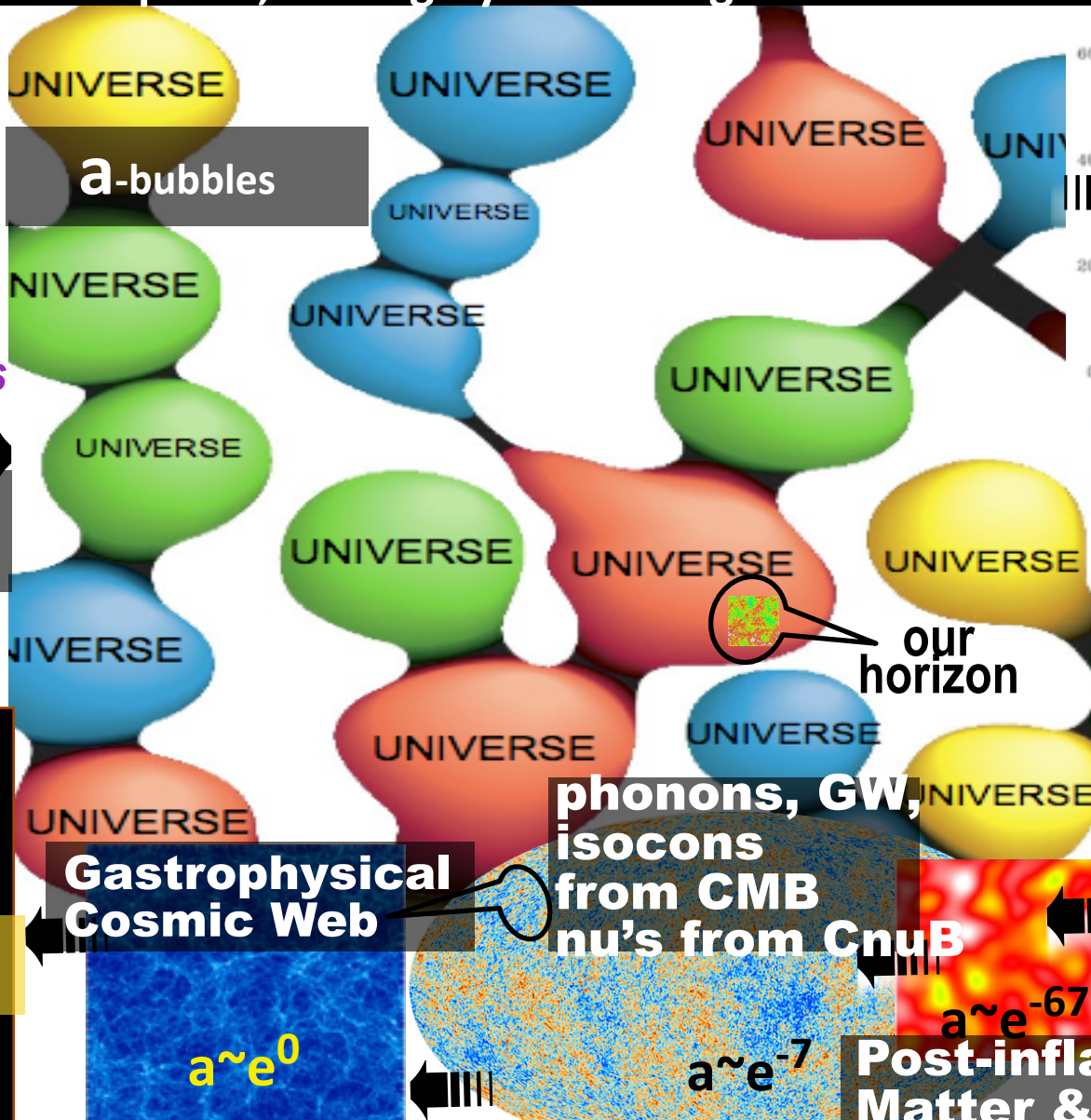


quantum tunnels = bubbly-U



**END**  
a future DE-Void

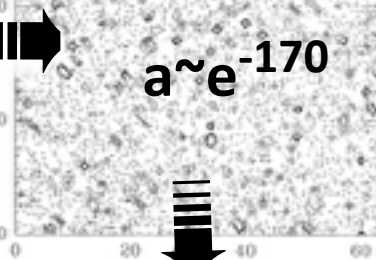
**Dark Energy Trajectories**  
 $a \sim e^{+++}$



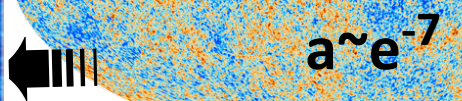
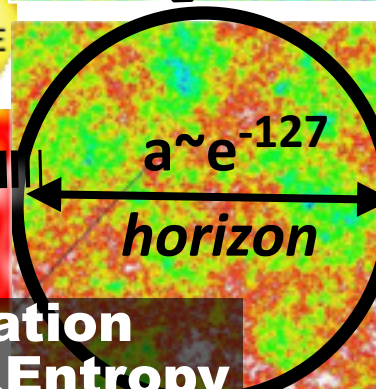
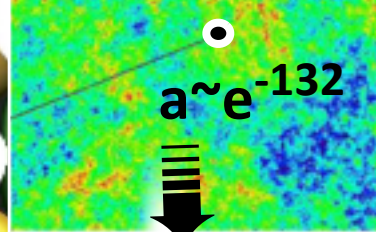
**Gastrophysical Cosmic Web**

phonons, GW, isocons from CMB  
nu's from CnuB

CONTOUR PLOTS FOR  $H(d_s) = 1.0m_s$   
**Stochastic Inflation**



**Phonons Isocons Gravitons**



**Post-inflation Matter & Entropy**  
 $a \sim e^{-67}$