Title: The Transport of Specific Entropies in the Cosmic SuperWeb: CnuB, CMB, CgwB, CnucB, CIB as CsB components

Speakers: Richard Bond

Collection/Series: Charting the Future Symposium

Subject: Cosmology, Particle Physics, Strong Gravity

Date: August 29, 2025 - 11:30 AM

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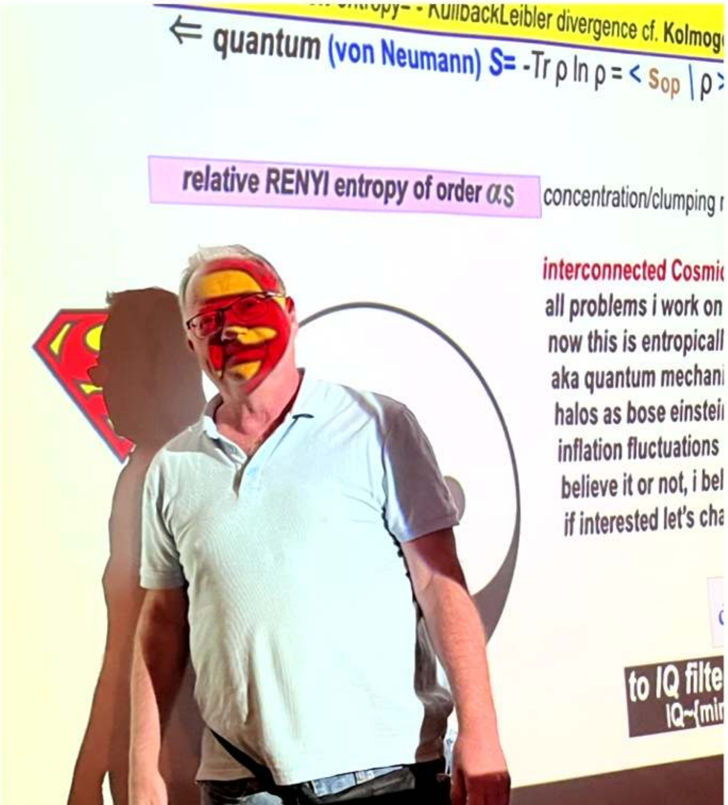
Bond@ PI@25 The Transport of Specific Entropies in the Cosmic SuperWeb: CnuB, CMB, CgwB, CnucB, CIB as CsB components
=> CITA inc @40 May 25-30 2026, CITA@42, CIFAR@40



credit: Brent Tully @ cosmic web @KITP23

where we are headed: entropic vision

the medium is the message
McLuhan 1964 UofT

"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." Wheeler 70s

Gleick's 'popular book' The Information

A History
A Theory
A Flood

$\psi(U) = exp(-$ ☯ $)$

$\psi = exp(i\ s_R - s_I)$,
i action - entropy/2
we transport ψ & N ~ $\psi\psi^\dagger$ N(xk,tω) or in-out N(xf tf | xi ti)

transport in specific entropy s_c = dS/dNc, c = ν, γ, DM, B, species, early U fields,
… to life (Schrodinger's negentropy), … to ideas
cf. transport in N_c

Websky Extragalactic Simulations @ mocks.cita.utoronto.ca => Websky2.0 (*Nate Carlson + B 2025*)

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, ..

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

nats/baryon ~ 0.7 X bits/B

S/B~1 SNcore (Bethe)

~1 atmosphere

~19 solar core, 1/40 in s_Υ

~190 clusters + S/DM !

5.2 bits/ϒ 6.1 bits/ν

SU,m+r ~$10^{88.6}$ Hubble Volume

after CMB/CnuB , most S in waste heat from dust re-emission of starlight CIB

in B+DM, $S_{th,clusters}$ ~10^{76}

compressed onto 7 cosmic parameters

ρB, ρDM, ρVac ~ M_P^4 / S_G

Tγ ≈2.725K => $\rho\gamma$, $\rho\nu$ & 1/H0 ≈14 Gyr

$S_G = 2\, M_P^2\, \beta_H^2 \sim 10^{122.5}$

GibbonsHawking

$\beta_H = 2\pi / H$ = 1/Hawking temperature

$\beta_r \sim \sqrt{(\beta_H M_P^{-1})}$ radiation temperature

cf. $S_{BH} = M_{bh}^2 / 2M_P^2$

1980 Entropy, Neutrinos and Supernovae @!st ITP Bethe++ & my first APS talk

after PhD 78

Prigogine 77 Nobel etc.

nonequilibrium thermodynamics

maximum entropy generation rate

gives diffusions.

but *not* far-from-equilibrium

entropy current

$$J_S^i \sim \beta\, J_E^i + \beta^P J_P^i + \boldsymbol{\alpha}^c J_{Nc}^i$$

far from equilibrium transport aka ($is_R - s_I$)

gravo-thermal *'catastrophe'*

now entropic scalar

$S = \boldsymbol{\alpha}^c N_c$

now entropic tensor

$\boldsymbol{\alpha}^c{}_\mu N_c{}^\nu = S_\mu{}^\nu$

entropic current *(& luminosity)* $S_0{}^\nu$

now action S_R -entropy

$d\delta S_R = dt_R / d\beta_I\, d\delta S_I$

$\sim d\boldsymbol{\alpha}/d\mathit{ln}\beta_I\, d\delta S_I$

inflation => $dS_I/d\boldsymbol{\alpha} \sim \boldsymbol{\varepsilon}\, S_G$

$dS_R/d\boldsymbol{\alpha} \sim -S_G\,(1\text{-}2\boldsymbol{\varepsilon}/3)$

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comp

ρ**B,**

Tγ ≈2.72

S

$\beta_H = 2\pi$

$\beta_r \sim \sqrt{(\beta}$

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gravo-thermal *'catastrophe'*

Bond writing to self July 1979 ***"the idea is that entropy is imaginary action"***
"belief that (inverse) temperature is imaginary time is profound, and that action and entropy principles are the key to physics"
thus Bond is still crazy after all these years

S measures Quantity *not* Quality Q ~ dS_R / dS_I ~ ω_R / ω_I ~ $\omega_R\, \tau_{Damp}$

IQ=information quality

to IQ filter, compress, reduce, marginalize

IQ~{minimal length messages/codes | error tolerance}, equations, recipes +
expansion in prominences, *AI, in cosmology,* halos, key cols, *low-k structure*

0^ν

G

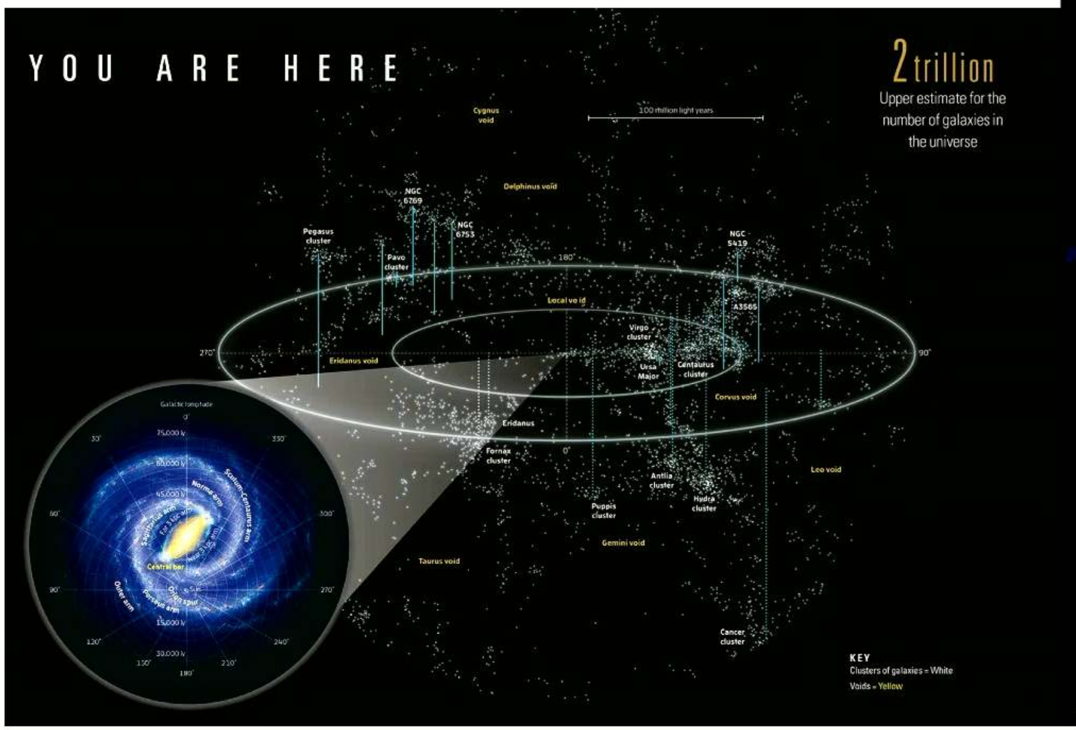
interconnected **cosmic web** (*XYZT*) => ***SuperWeb of all fields: XYZT,ϕ^A Instabilities & Phase Transitions***

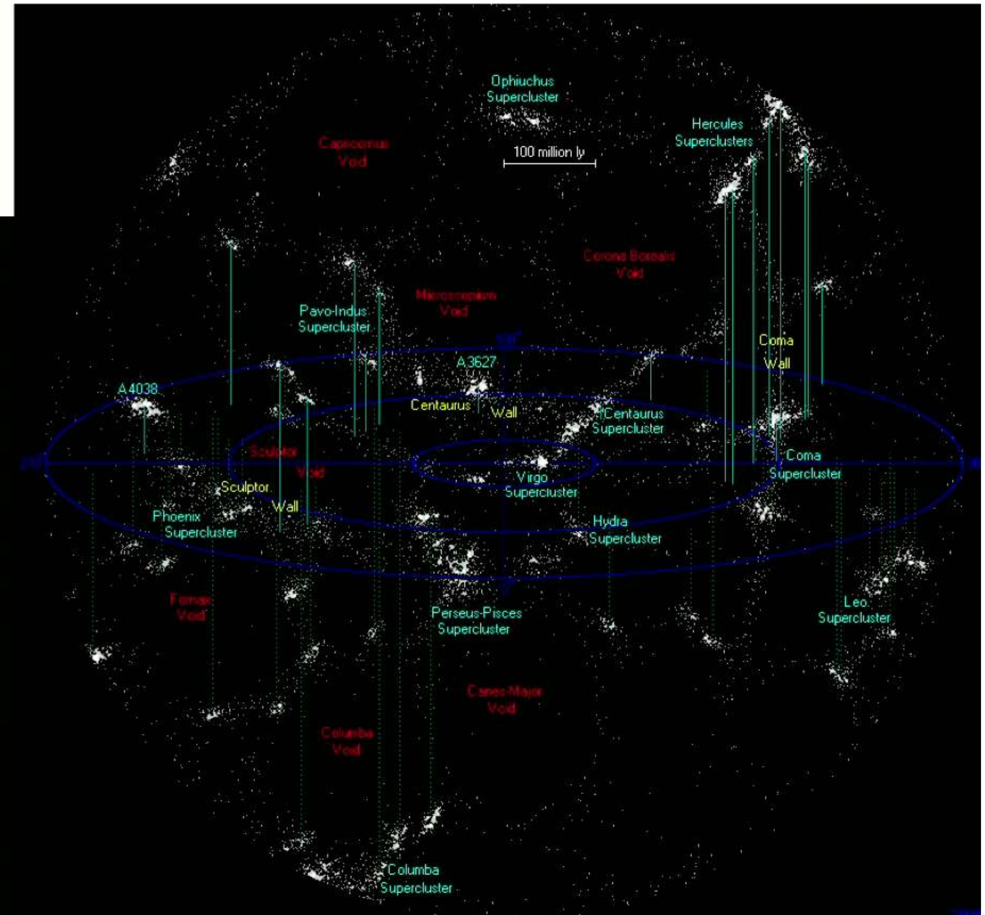
fission/fusion in deformed vacua Casimir Schwinger => pinGpongG

Primordial Intermittent nonGaussian ⊂ eU BSMc => 86-96, 09-23+

Brent Tully local U in 3D @KITP23

gravo-thermal ***'catastrophe" how gravity operates.***
entropy radiates into core-halo-aurora,
cores become black holes (k-space instability ~ BH),
aurora = "voids = expanding space (x-space instability~ WH)





entropy intermittency *in the cosmic web, via gravitation-induced shocks (then E/S-feedback)*

Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

400
Mpc

ΛCDM

WMAP5

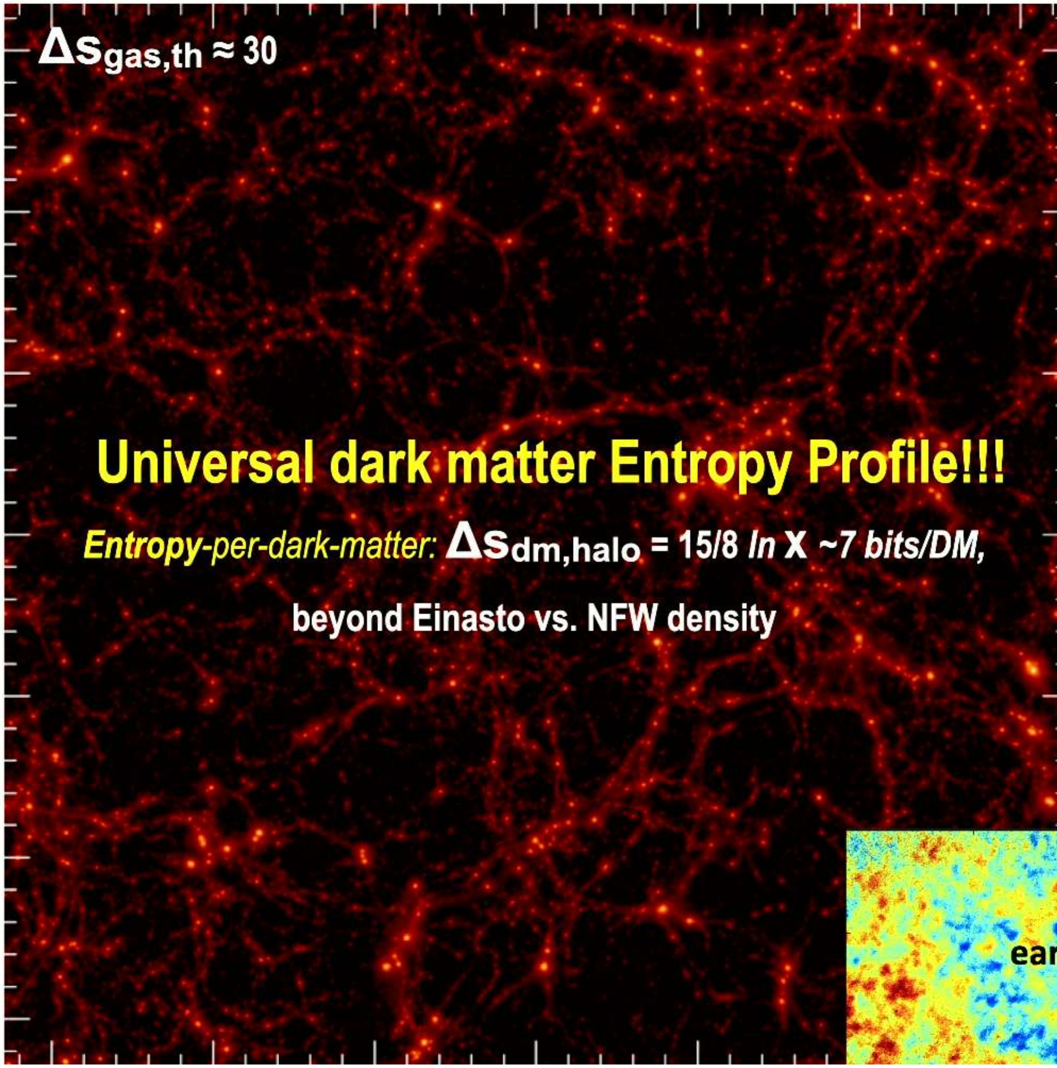
gas
pressure

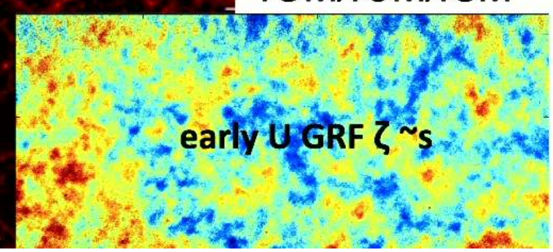
Gadget-3
SF+
SN E+
winds+
CRs

512^3

BBPSS10

BBPS1,2,3,4





$s_{b,th}(x,t)$

CMB gets entangled in the cosmic web

descending into the real gastrophysics of cosmic weather

the energetic, turbulent, dissipative, compressive

life of the IGM/ICM/ISM

entropy intermittency *in the cosmic web, via gravitation-induced shocks (then E/S-feedback)*

Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

400 Mpc

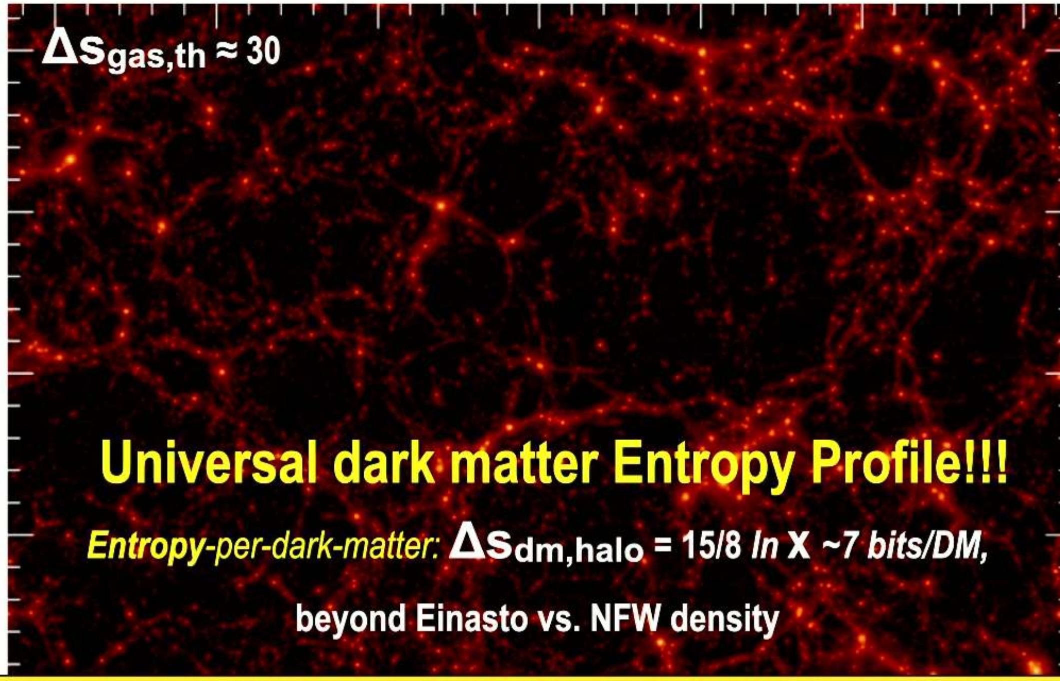
ΛCDM

WMAP5

gas pressure

Gadget-3

SF+



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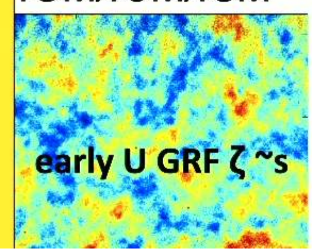


gps-cls ~150-**190 bits/baryon,** Δs_{th}**~12 bits/b ;** $s_{kin+th}-s_{th}$**~1bit/b**

Δs_{dm} **= 1/2 Tr *ln* <δkδk><δxδx>** *~7 bits/DM* Δs_{dm} **~5/8 ΔlnV**

zero point depends on type of DM, WIMP or axion or ...

cf. $s_{\gamma+\nu} / n_b \sim 1.66\times10^{10}/(1+\delta_b)$ bits/b

cf. **AGN's black hole entropy** $S_{bh} = M_{bh}^2/2M_P^2 \sim 10^{22} S_b$;

$\tau_{bh} \sim 10^{100}$yrs NO, accreting CMB

Renormalization Group Flow in the nonlinear Cosmic Web

and the inhomogeneous

Effective Field Theory of LSS

KolomgorovSinai X-entropy trajectories

beget Shannon XK-entropy trajectories

at gravitational shocks *shell crossing*

break $kc = \nabla Sc(Xc,tc)$ laminar flow via *en*TANGO*ment of kx orbits*

early => late Entropic adventures

TBD

redo transport in dS/dNc matrix variables

CνB (x,t)

BFGMW24 <CνB> (t) linear response of BBN to n_ν

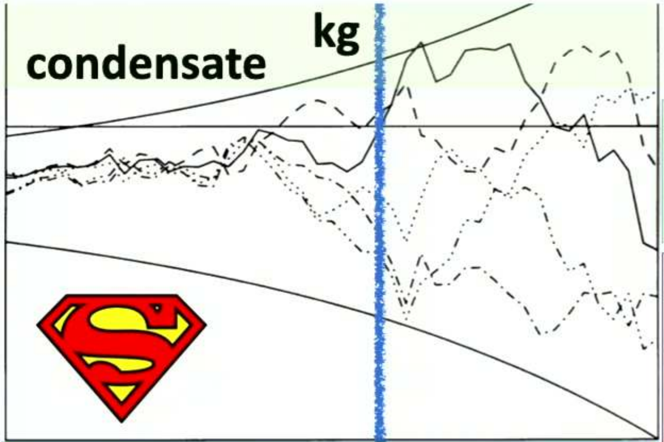
BFGM2x
CνB (x,t) inhomogeneous BBN via nonG small scale influence etc

CγB (x,t)
B95 in ΔT/T in *les houches 96* ***=> B25 in s_c***

+ CgwB (x,t) CIB (x,t) CszB(x,t) etc etc

THEN *BBKS, BCEK, B+Myers91,93,96, BKP96* ***interconnected cosmic web*** *@kitp96, BW97 Lya,..* **NOW: CITA mini-industry 2013+ 41 pdfs, GS, UG, profs**

23.12From BCEK, C for Cole, K for Kaiser, to Webskying the Entangled Multimessenger Universe



wavenumber k (comoving)

δ_Lc(ev,pv) threshold
aka absorbing barrier

= - SX(Xc,tc,kg)
X-entropy trajectories

total entropy SK∪X
@ "gravitational shocks"
break kc = ∇ Sc(Xc,tc)
en*TANGO*ment of kx orbits

Hc,ij = D∇∇Sc equilibrates

trajectories in Scale Space
cf. ADS / CFT Rg flow => EFTofLSS Rg(Xc,tc) !
or kg = sharp k-cut *= gave PS missing factor of 2*
Rg^2=D* β **= Imaginary time = h/Temperature**

cf. kg = 1/RTH usual Mpkpatch
cf. kg=1/RG Gaussian
BM90-96 peakpatch fcrit_i= ln(200)/3 halos,

nonlinear ellipsoid equation *(inhomogeneous)*
dH_ij/dt+(HH)_ij + tide_Gij+ tide_Mij + tide_Vij =0
Raychaudhuri ish
halo where H_ii "gravitationally shocks", i=3,2,1
oriented peak/void tides begat cosmic web BKP

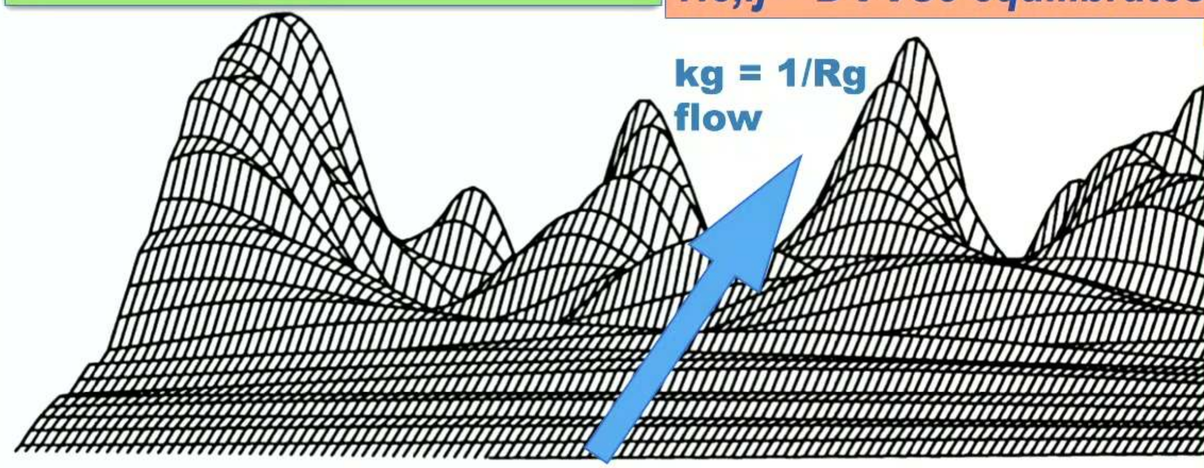


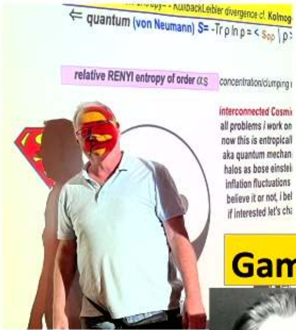
FIG. 1*a*

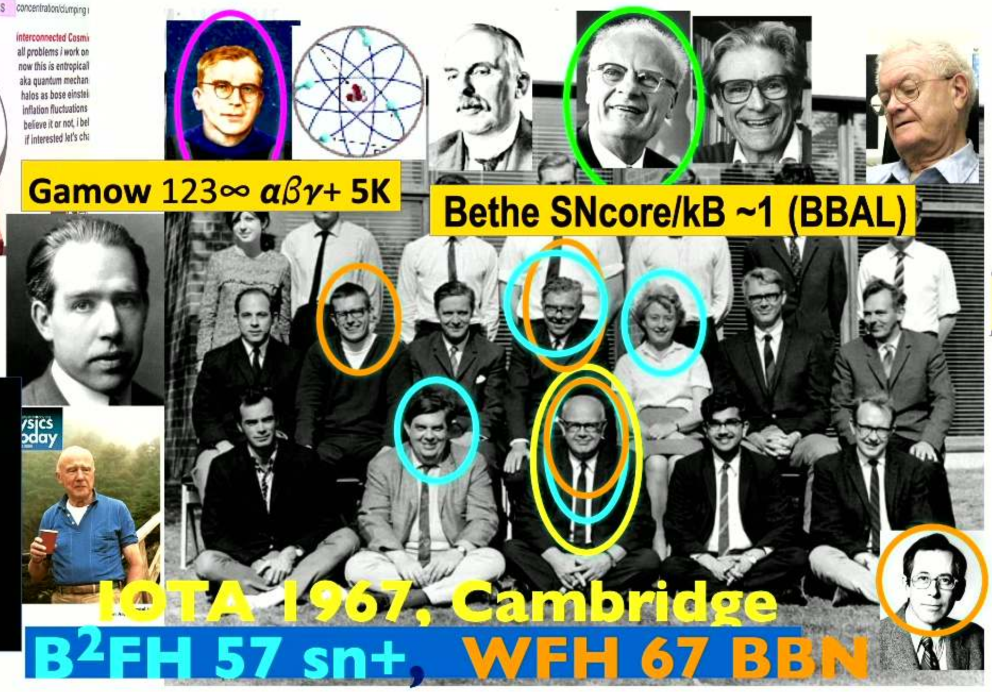
∫ Kolmagorav-Sinai entropy
of SX(Xc,tc,kg)= -*ln*(ρ/<ρ>)
= Tr *ln* <δXδX|f> <δXδX|i>$^{-1}$ /2
SK|X(Xc,tc,kg)= Tr *ln* C(k|X) /2
SK∪X = SK|X + SX Shannon entropy

Entropy in a Coherent Universe:
the Quantum Information in the Action of the Cosmic SuperWeb

Dick Bond @ APS 24 04 04 **Bethe**Talk

1980 Entropy, Neutrinos and Supernovae @!st ITP Bethe++
=> 2020 Entropy, Phonons and Phase Transitions @*KITP*
during and after inflation





fission
particles
=> fields
=>
quantum
information

U=
S∪N
S∪R
p∪h

$\psi(U) = exp(-$ ☯$)$

Have Transport will Travel Collective Quest UofT73 => ManyBody **νN** Caltech 73-78, Bky -81, Cam, SU, CITA

NuclearAstro, Neutrinos & Supernovae @ Caltech Five decades of cosmic **ν CνB**

SMν =>BSMν ... SMγ =>BSMγ **=> *Quantum Information and its transport is what we do***

=> Cosmic Neutrino Decoupling and its Observable Imprints:Insights from Entropic-Dual Transport BFGMW24

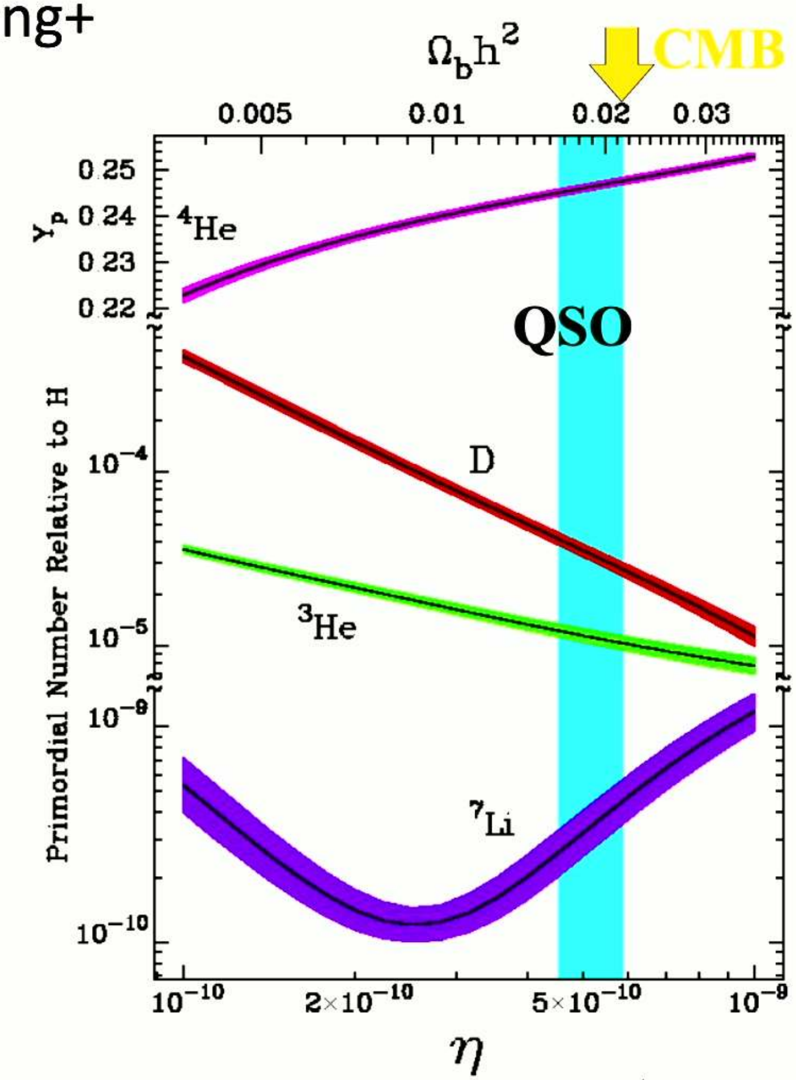
Cosmic Neutrino Background decoupling, novel dual transport and Light Element nucleosynthesis

slide from ~2000, Boomerang+

Big Bang Nucleosynthesis

Light Element Abundances are cooked in the "first 3 minutes"

observations of deuterium lines in QSO absorption spectra allow D abundances to be estimated, hence the baryon abundance



beware Subaru He HII regions?? see Tait talk

$\Omega_b h^2$ has been stable since pre-WMAP

Bond, Fuller, Grohs, Meyers, Wilson (2024) arXiv:2403.19038

Cosmic Neutrino Decoupling and its Observable Imprints: Insights from Entropic-Dual Transport

ν transport
Wigner df condensate

$$DN_c/dt = -\gamma_c (N_c - N_{eqc}) = C[N_{f|c}]$$

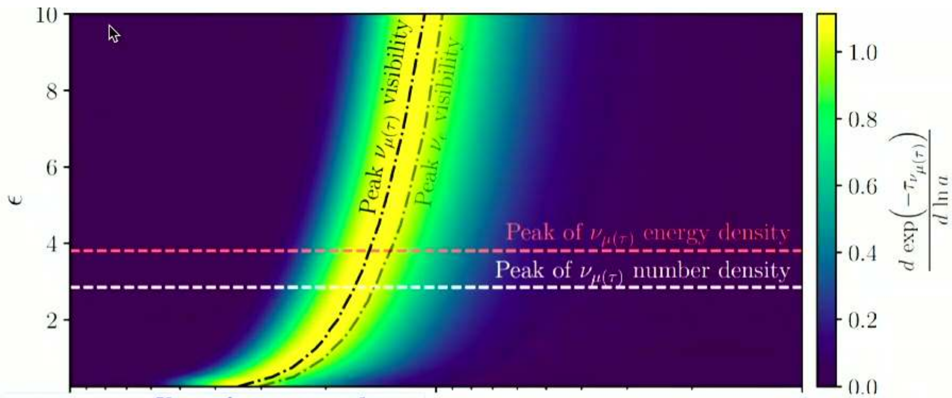
map into the **dual** $\alpha_c[N_c] = dS/dN_c$

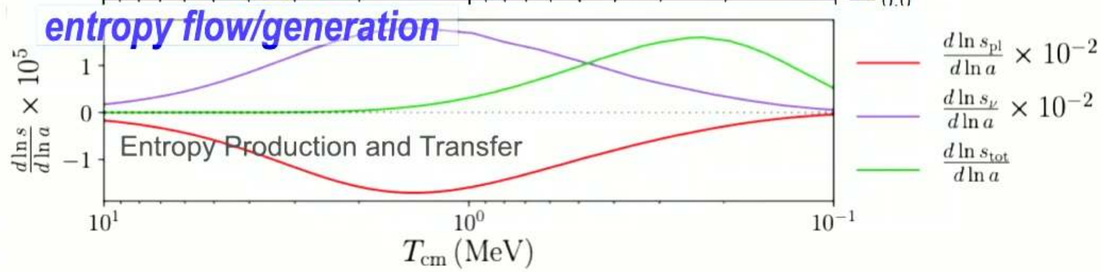
compress onto

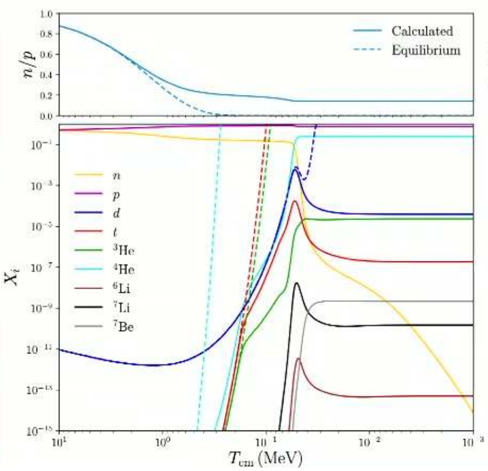
$$s_c = \alpha_0 + \alpha_1 E^1 + \alpha_2 E^2.$$

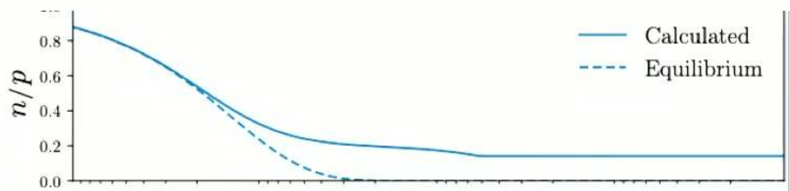
aka $\alpha\beta\gamma$

r	Weak Interaction Process
1	$\nu_i + \nu_i \leftrightarrow \nu_i + \nu_i$
2	$\nu_i + \nu_j \leftrightarrow \nu_i, +\nu_j$
3	$\nu_i + \bar{\nu}_i \leftrightarrow \nu_i + \bar{\nu}_i$
4	$\nu_i + \bar{\nu}_j \leftrightarrow \nu_i + \bar{\nu}_j$
5	$\nu_i + \bar{\nu}_i \leftrightarrow \nu_j + \bar{\nu}_j$
6	$\nu_e + e^- \leftrightarrow e^- + \nu_e$
7	$\nu_{\mu(\tau)} + e^- \leftrightarrow e^- + \nu_{\mu(\tau)}$
8	$\nu_e + e^+ \leftrightarrow e^+ + \nu_e$
9	$\nu_{\mu(\tau)} + e^+ \leftrightarrow e^+ + \nu_{\mu(\tau)}$
10	$\nu_e + \bar{\nu}_e \leftrightarrow e^- + e^+$
11	$\nu_{\mu(\tau)} + \bar{\nu}_{\mu(\tau)} \leftrightarrow e^- + e^+$









out-of-equilibrium ν scattering => ν spectral distortions, Neff 3 => 3.044
response of n/p + BBN products + Neff to changes in ν + leptonic physics

TBD: 1. worked BSMν decaying leptons, sterile ν, ..
2. nonG ζ constraints on small scale = viscous dissipation + inhomogeneous BBN
3. QKE in α(ff'ss' px} & oscillations

slide from ~2000, Boomerang+

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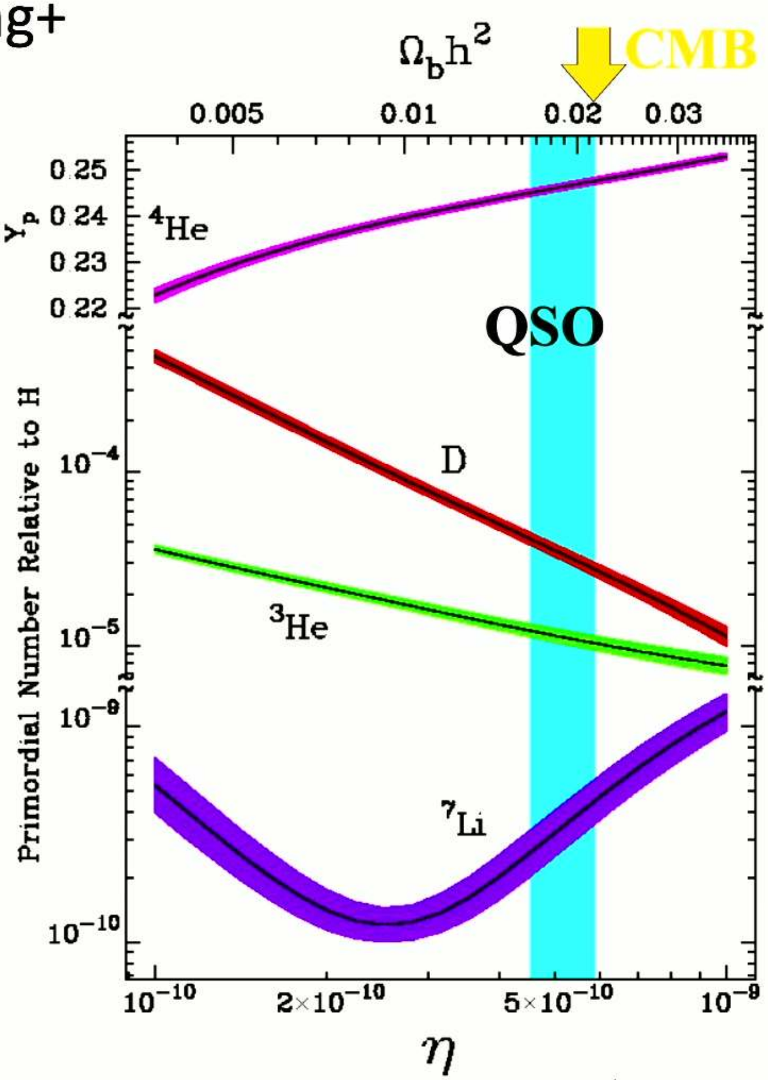

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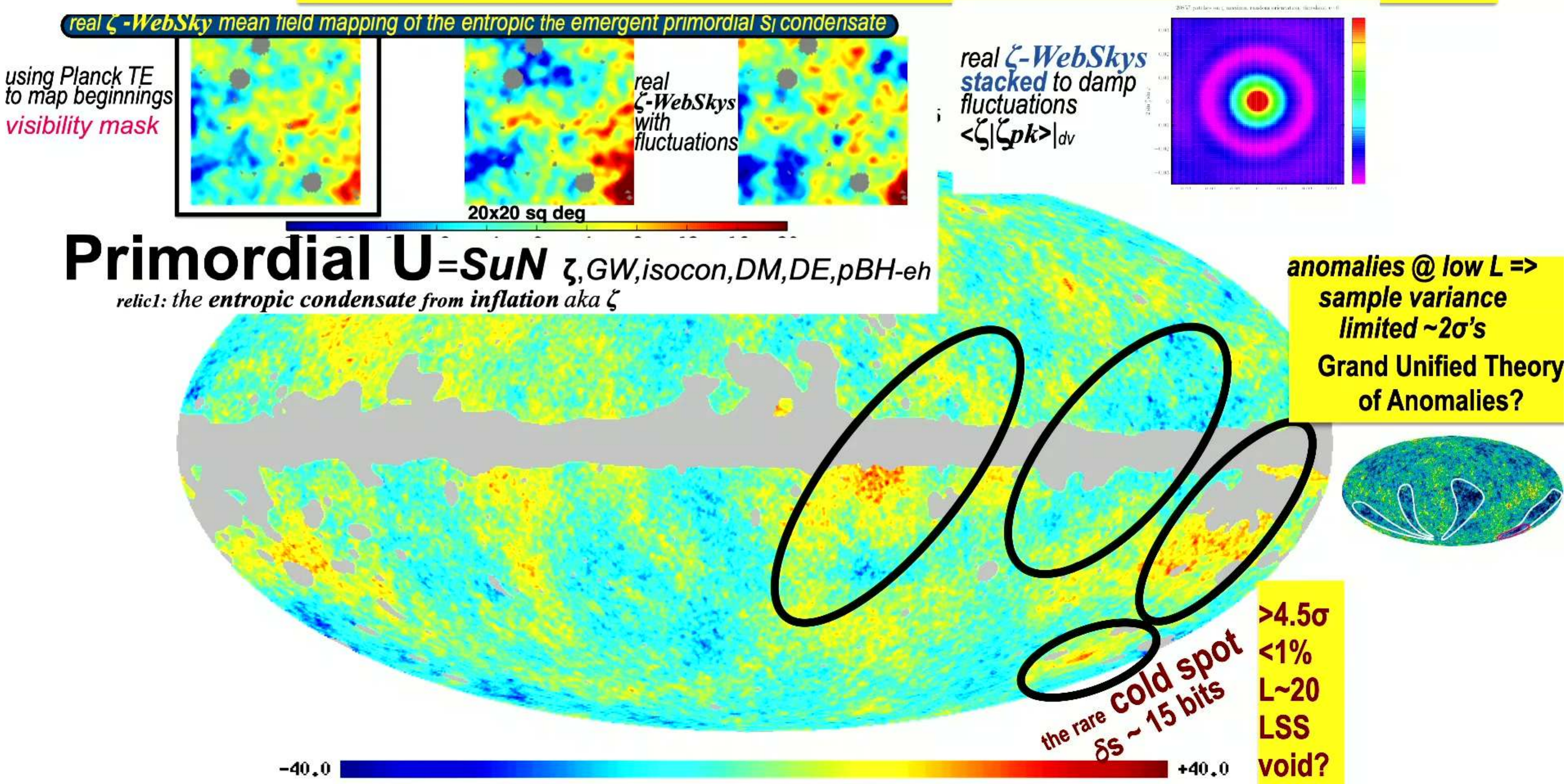
$\Omega_b h^2$ has been stable since pre-WMAP

CMB maps of Primordial Universe ζ

Wiener maps of s~3ζ show uLSS anomalies

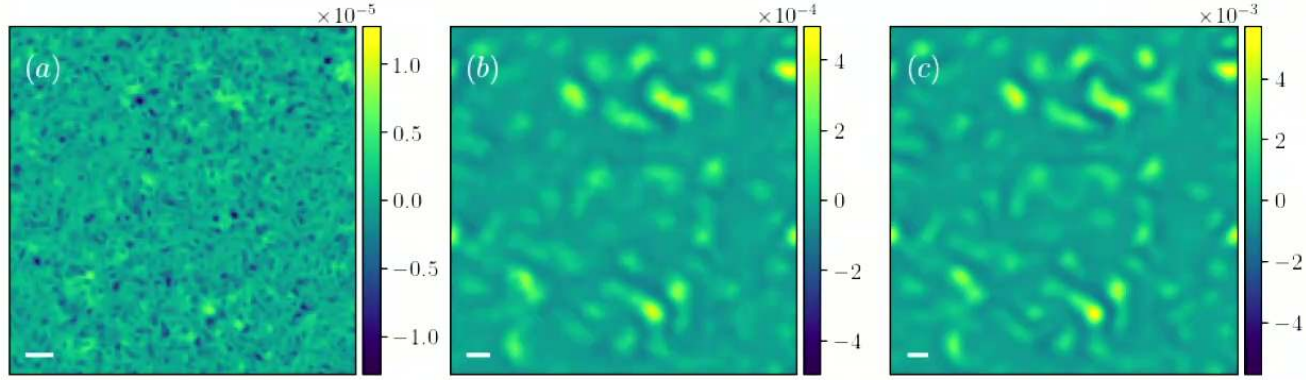
Beyond the Standard Model of cosmology? SMc = *tilted*ΛCDM +r aka (ζ, h_{+x})

<ζ |T,E-pol> BSMc = SMc + primordial anomalies in the true ζ -WebSky

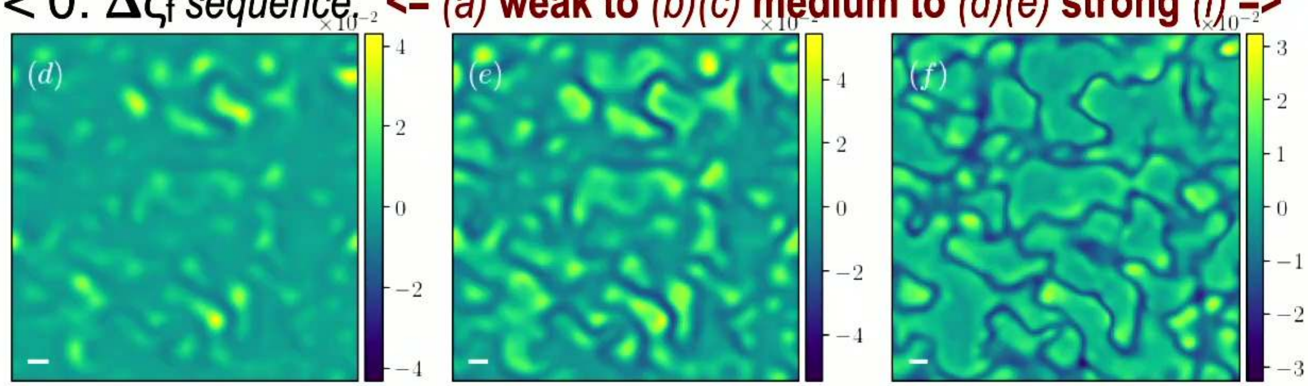


Varieties of Non-Gaussianity from early U Entropy Intermittency

$\boldsymbol{\zeta}_f(x \mid \Delta V+V_0$; *Bunch-Davies GRF IC*$) = \Delta\boldsymbol{\zeta}_f + \boldsymbol{\zeta}_f(x \mid V_0$; *BD GRF IC*$)$

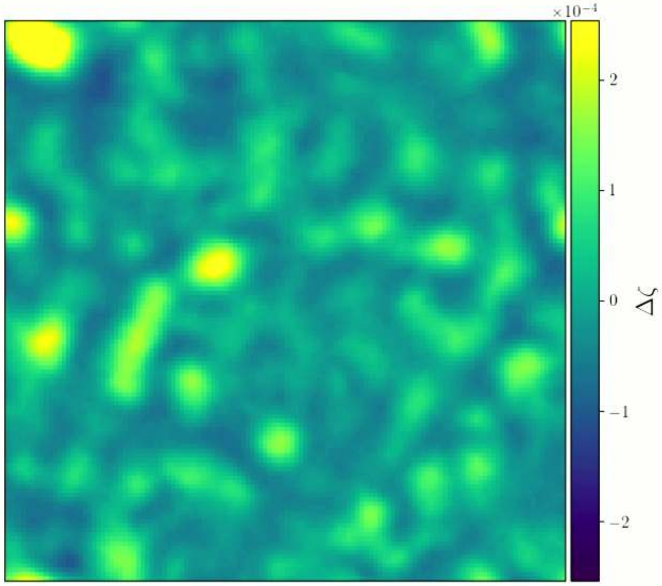


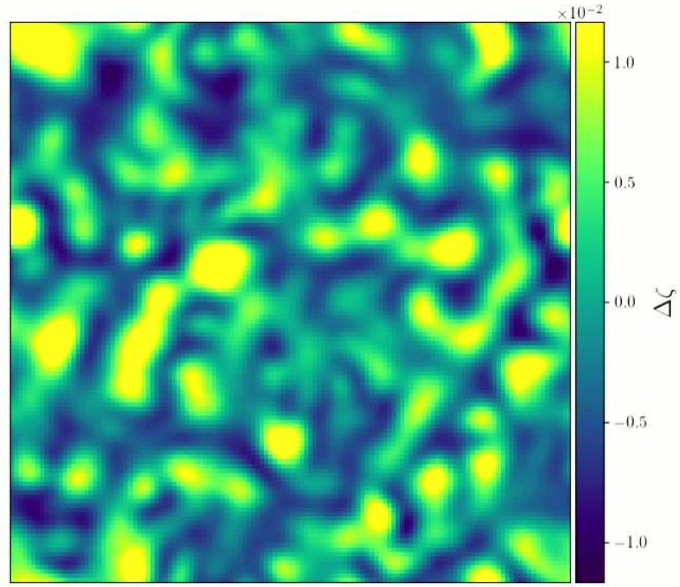
$m_{\perp\perp}^2 < 0$: $\Delta\zeta_f$ *sequence:* **<= *(a)* weak to *(b)(c)* medium to *(d)(e)* strong *(f)* =>**



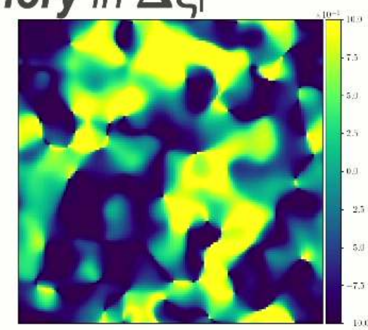
domain ***wall memory*** *in* $\Delta\zeta_f$

$\zeta_f(x \mid \Delta V+V_0$; *Bunch-Davies GRF IC*$) = \Delta\zeta_f + \zeta_f(x \mid V_0$; *BD GRF IC*$)$





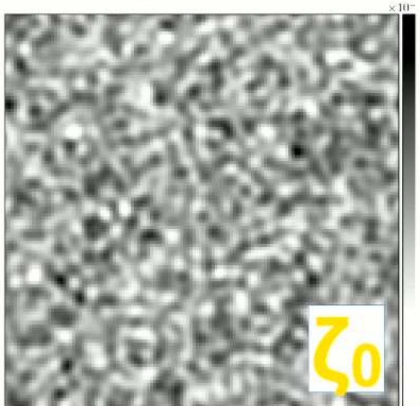
***string memory** in $\Delta\zeta_f$*



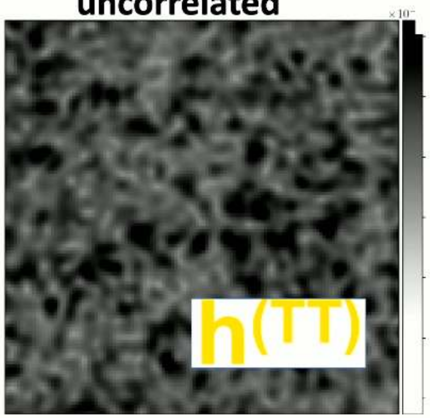
$\mathbf{m}_{\perp\perp}^{\mathbf{2}} < 0$: $\Delta\zeta_f$ *sequence:* **medium to strong =>**

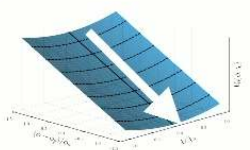
GRF from V0

scaling √r ~4 √ε0



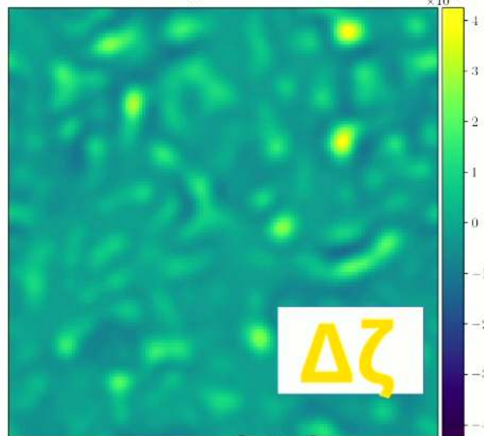
uncorrelated



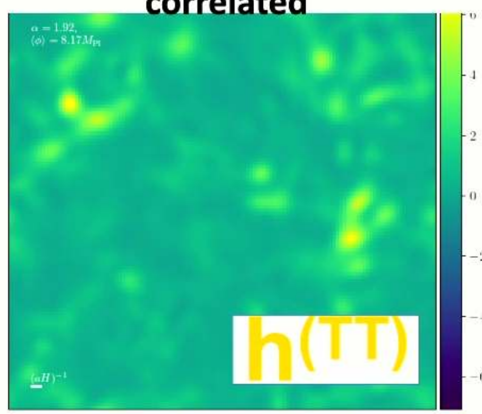


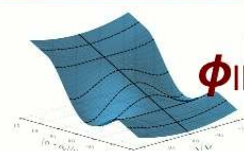
pinG from ΔV

scaling ~1/100



correlated



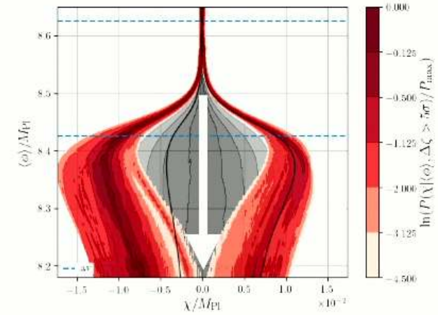


$\phi_{||p}$ α_p k_p

GRF controlled by ε0

cf

pinG controlled by instability strength



strong frozen pinG GW enter horizon then stream to a stochastic background, "tunable" GW frequency < 30 GHz, down to ~ 10^{-20} Hz

ζ_0 (CMB) ~$10^{-4.3}$

PBH target is Δζ > .01 to .1

pinGponGs less radical than PBHs, which are super-strain ponGs, clustered ponGs near proto-PBHs

Δζ >1: diffusion > drift
=> coherent Hc emerge from Δζ < 1

Dick Bond

Quantum Inflation in the Planck Era & Beyond

what are the degrees of freedom / parameters of the ultra early Universe? TBD

relics not yet seen: in quest of what lies Beyond *the Standard Model of cosmology* SMc

from inflation

local nonG for $\Phi_N = G + f_{nl} G^2$ $f_{nl} = -0.9 \pm 5.1$ P18

non-Gaussian features in ζ from weak nonlinearities *(very nearly)* **Gaussian random field**

large nonG from instabilities localized in k - open at high k. primordial black holes?

gravity waves (not so far - obscured by dust) P18+BK15 $r<0.06$ now $< .04$ uniform n_s

cf. $0<r<.07$ 95% CL P15+BK15 12 knots

isocon relic (not so far) - Planck on CDM isocurvature, neutrino, correlated

< 1.3% - 1.7% isocurvature role

bubble remnants of tunneling during inflation

from heating

isocon memories (not so far)

strong subdominant but intermittent nonlinearities in ζ (e.g., spikes)

curvatons oscillons strings domain walls - short lived .. primordial black holes?

rare WIMPzillas as dark matter

from later quark gluon plasma

late phase transitions - whence first order?

anomalies in CMB & LSS & SSS. correlated GW-scalar signals?

could be *primordial. large-scale, intermittent? statistics of just a few (modes, spatial rare events)?*

varieties of pinGs, depends upon

instability wavenumber k_p

instability strength $m^2 < 0$

duration

we chose a symmetry breaking S_{Gc} Higgs-like (+-)

also tried string-like $(0,2\pi)$

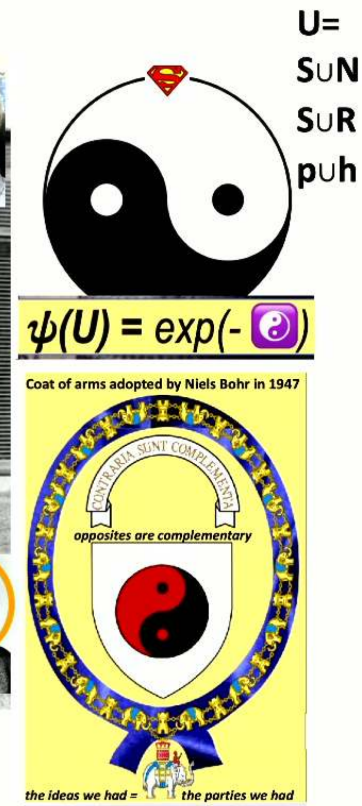
+ many different effective potentials

=> pinGponG results are generic

Entropy in a Coherent Universe:
the Quantum Information in the Action of the Cosmic SuperWeb

Dick Bond @ *APS 24 04 04* **Bethe***Talk*

1980 Entropy, Neutrinos and Supernovae @!st ITP Bethe++
=> **2020 Entropy, Phonons and Phase Transitions** @*KITP*
during and after inflation



Have Transport will Travel Collective Quest UofT73 => ManyBody **νN** Caltech 73-78, Bky -81, Cam, SU, CITA

NuclearAstro, Neutrinos & Supernovae @ Caltech Five decades of cosmic **ν CνB**

SMν =>BSMν … SMγ =>BSMγ **=> *Quantum Information and its transport is what we do***

=> Cosmic Neutrino Decoupling and its Observable Imprints:Insights from Entropic-Dual Transport BFGMW24