

Title: From Black Holes to Big Bang, and Back

Date: Sep 30, 2014 11:00 AM

URL: <http://pirsa.org/14090088>

Abstract: <span>By now, both black hole astrophysics and big bang cosmology are empirically well-established disciplines of physics and astronomy. They are also the only circumstances in nature where Einstein's general relativity can be seen in its full glory, and yet contain within them, its eventual and inevitable folly. Here, I will outline subtle lines evidence for why a phenomenologically successful description of big bang cosmology and black hole horizons may be intimately connected. These lines include a holographic description of big bang, thermal tachyacoustic cosmology, and the firewall controversy. Astrophysical observations, ranging from CMB and dark energy probes, to astrophysical neutrinos could shed further light on these potential connections. </span>

# From Black Holes, to Big Bang, and Back!

Niayesh Afshordi



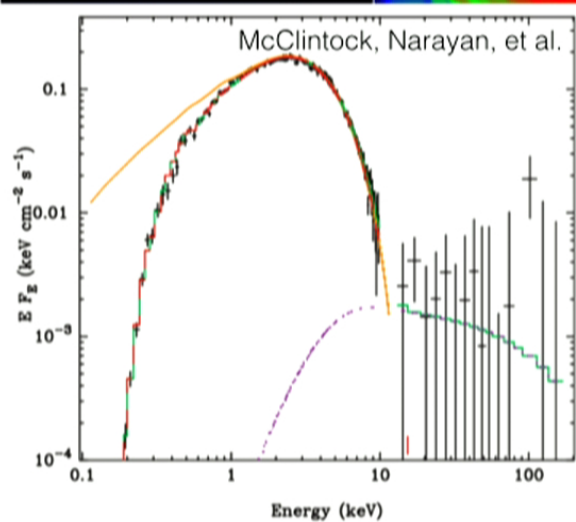
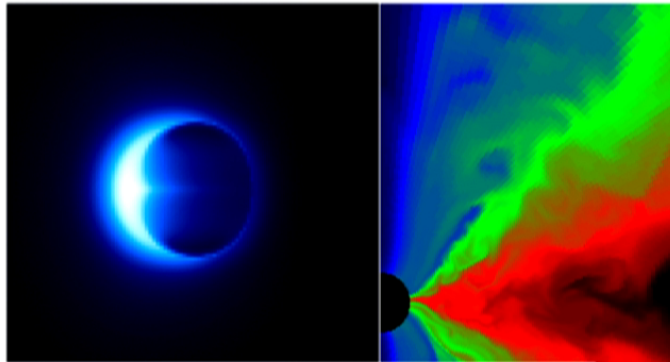
**UNIVERSITY OF WATERLOO**  
FACULTY OF SCIENCE  
Department of Physics & Astronomy



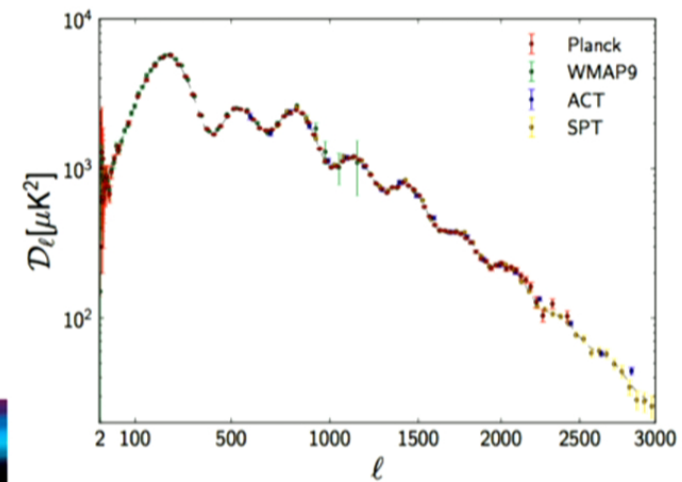
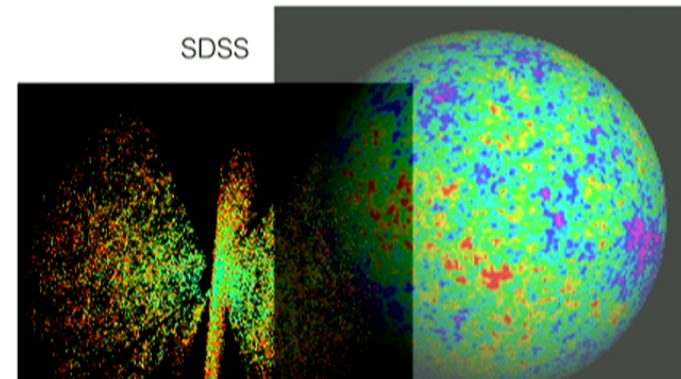
# A Renaissance of General Relativity

Event Horizon Telescope

Courtesy Jim Stone

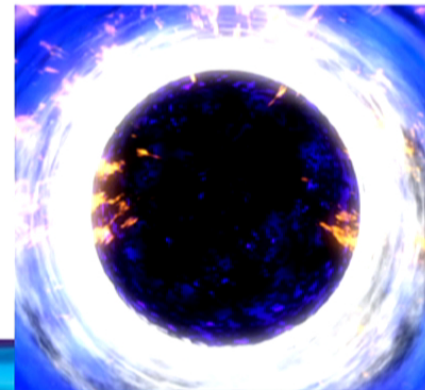
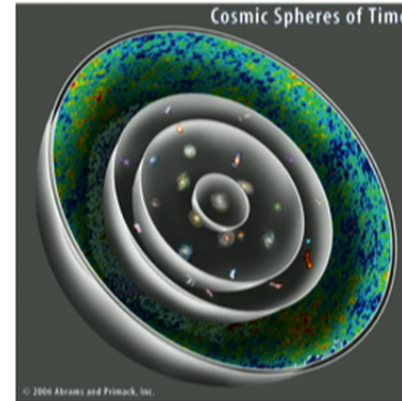


WMAP



# “sky” is the limit!

- both Big Bang, & BH horizons have infinite redshift
- preferred frame set by killing vectors
- but curvature is only divergent for Big Bang (maybe?)
- Could BH horizons and Big Bang share more similarities than we've imagined?





# outline

- demystifying Firewalls
- from Firewalls to Big Bang
- a Holographic Bang
- *(a very subjective)* perspective

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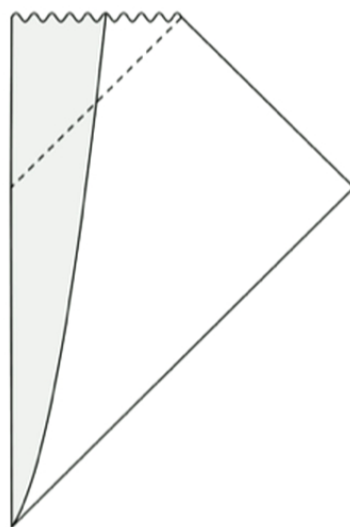
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# Firewalls!

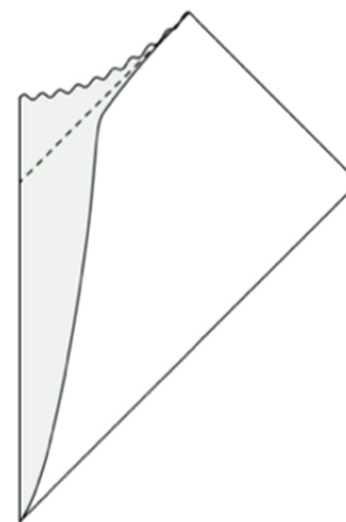


# why “spacetime” may end at “horizon”

- **Information paradox:** unitary black hole evaporation, not consistent with local physics + smooth horizon (*Hawking ... AMPS 2013*)
- **Quantum Tunnelling:**  $\exp(-S_E) \times \exp(\text{entropy}) \sim 1$
- **Fuzzballs:** (*a la* Mathur): classical horizon-less spacetimes, that account for BH entropy
- **Dark Energy:** pressure eq. with stellar BH firewalls,  
→ scale of dark energy (*Presocd-Weinstein, NA, Balogh 2009*)



How to form a Black Hole



How to form a Firewall?!

# Firewalls and Astrophysics

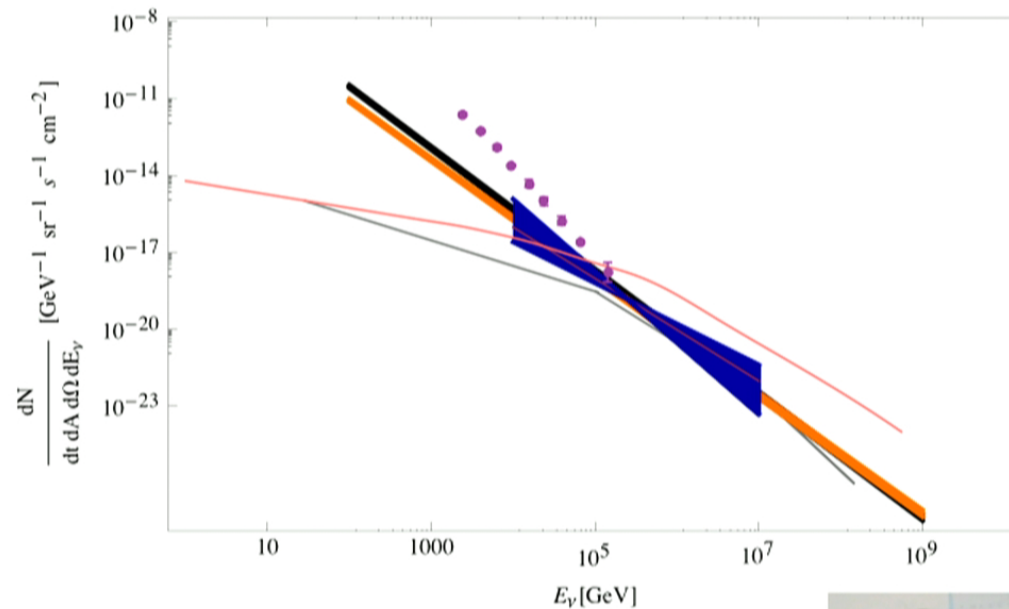
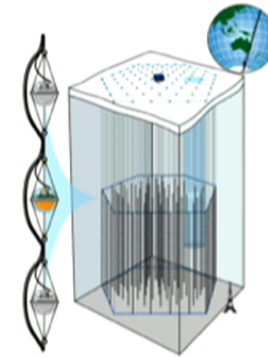
- We know firewalls cannot emit light (*Broderick, Loeb, Narayan 2009*)
- What about **neutrinos**?
- Core collapse supernovae emit most energy in neutrinos; **can escape much more easily** from dense environments
- assume 1st order fermi acceleration for neutrinos:  $dN/dE \sim E^{-p}$ ;  $p \sim 2$

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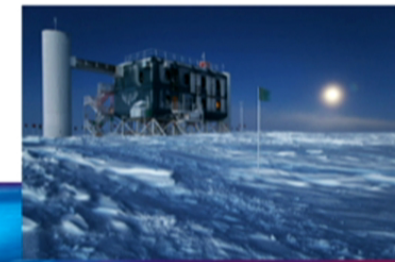


# Have we already seen firewall neutrino's?!

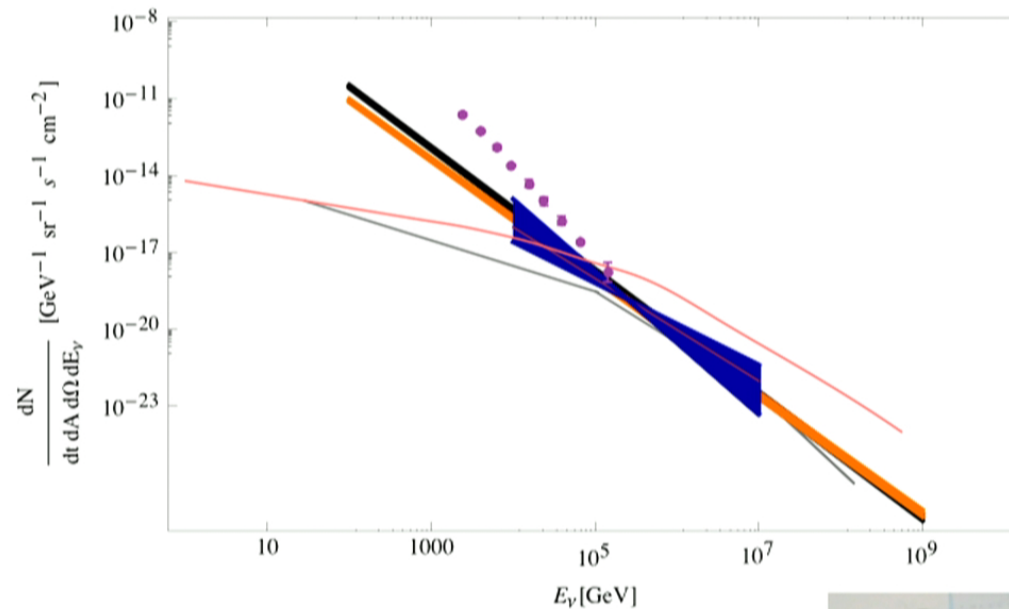
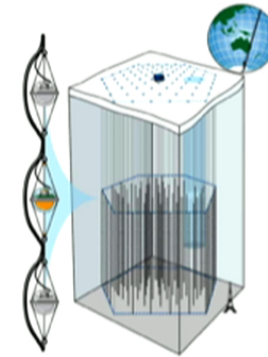


- AMANDA II  $\nu_\mu$
- IceCube
- AGN
- GRB
- BH,  $\epsilon_\nu = .4$ ,  $p = 2.40 \pm 0.01$
- SMBH,  $\epsilon_\nu = .4$ ,  $p = 2.30 \pm 0.01$

Yasaman Yazdi, & NA, in prep.

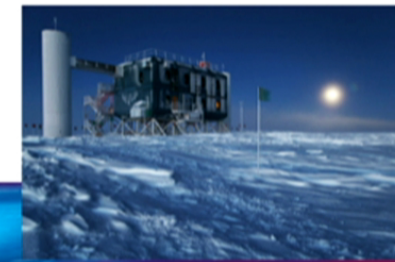


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# *Incompressible* Firewalls

- Assume space-time ends at stretched horizon
- Israel Junction condition +  $Z_2$  symmetry:
  - membrane has vanishing surface density
  - integrated (surface) pressure: = Unruh Temperature/4
  - Entropy per unit area =  $1/4$  (*Bekenstein-Hawking*)!



Saravani, NA, Mann 2012

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# Thermal Tachyacoustic Cosmology (TTC)



- Abrupt thermal phase transition in speed of sound can explain scale-invariant scalar spectrum

(Magueijo 2008);  $c_s \sim a^{-\beta}$

$$\langle \mathcal{P}_\zeta(k) \rangle_{T_*} \simeq 2.4 \left( \frac{\beta}{77} \right) \left( \frac{g_*}{100} \right)^{1/2} \left[ \frac{T_{\text{exit}}(k)}{M_{\text{p}}} \right]^3,$$

$$T_{\text{exit}}(k = 0.05 \text{ Mpc}^{-1}) \simeq \left( \frac{g_*}{100} \right)^{-1/6} (2.368 \pm 0.021 \pm 0.154) \times 10^{15} \text{ GeV},$$

$$\beta = 77^{+17}_{-12}$$

Agarwall & NA 2014



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$$r \equiv \frac{\mathcal{P}_T}{\mathcal{P}_\zeta} \gtrsim 1 \times 10^{-3} \left( \frac{g_*}{100} \right)^{1/3},$$

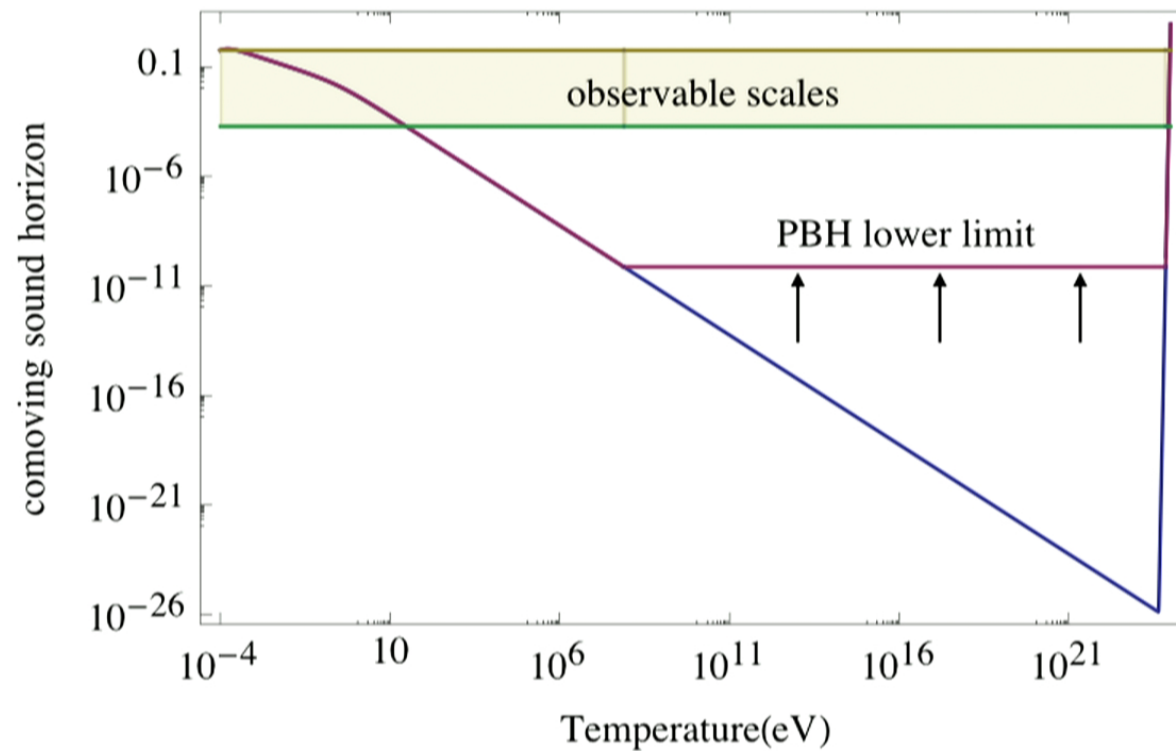
Agarwall & NA 2014

coupling to Horava-Lifshitz gravity



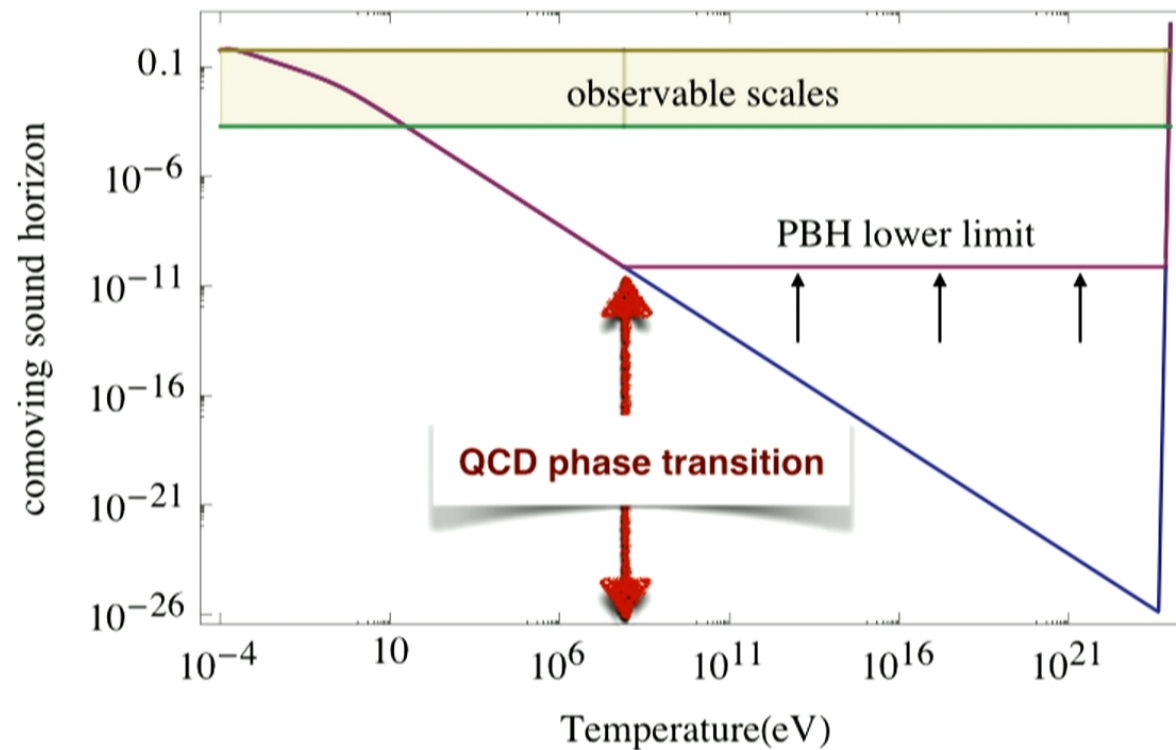


# Cosmic Acoustic History

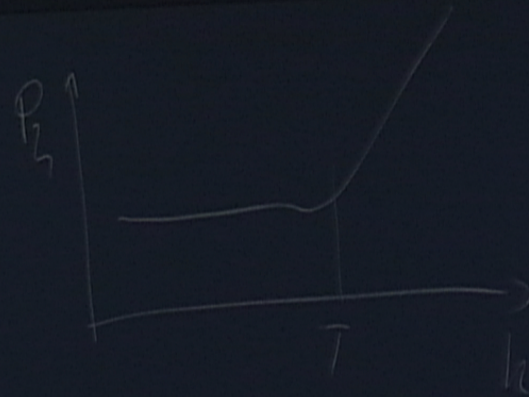




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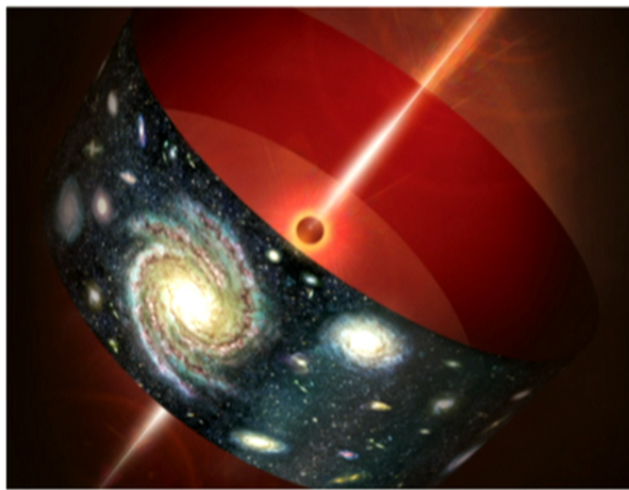


$$n(E) = \frac{1}{e^{E/T} - 1} + \frac{1}{2}$$



# Out of the White Hole:

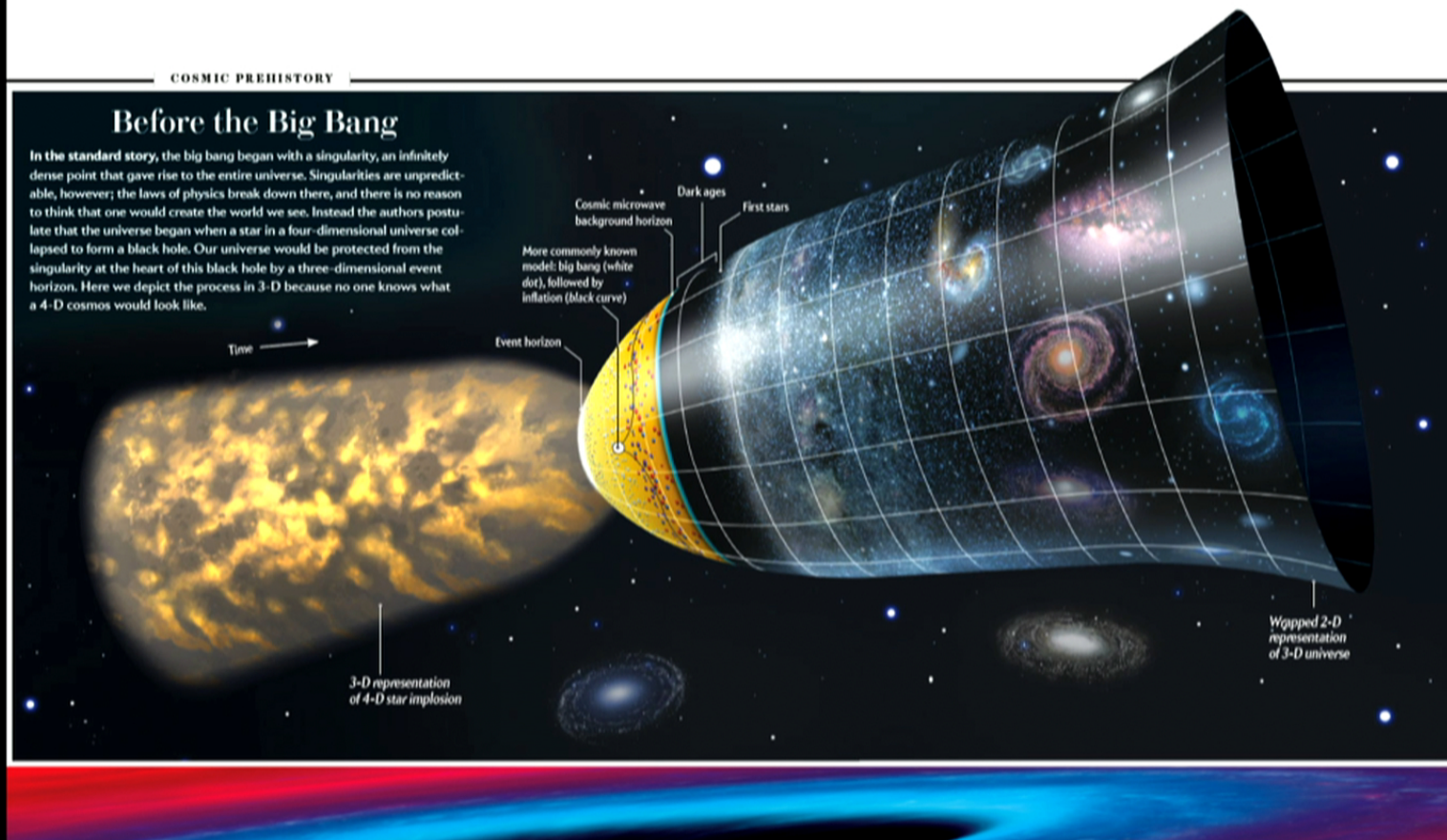
## A holographic origin for the big bang



Pourhasan, NA, Mann 2014

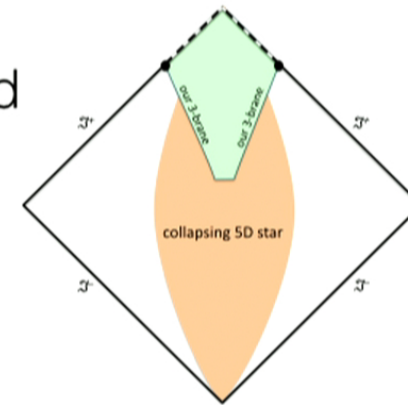


# Is Big Bang just a mirage?



# A Holographic Big Bang

- White hole singularities are only artifacts of static approximation, and cannot form in our Universe
- Could the same be true for the big bang? → Collapse of 5D “star”
- A thermal atmosphere for the brane leads to scale-invariant metric fluctuations:



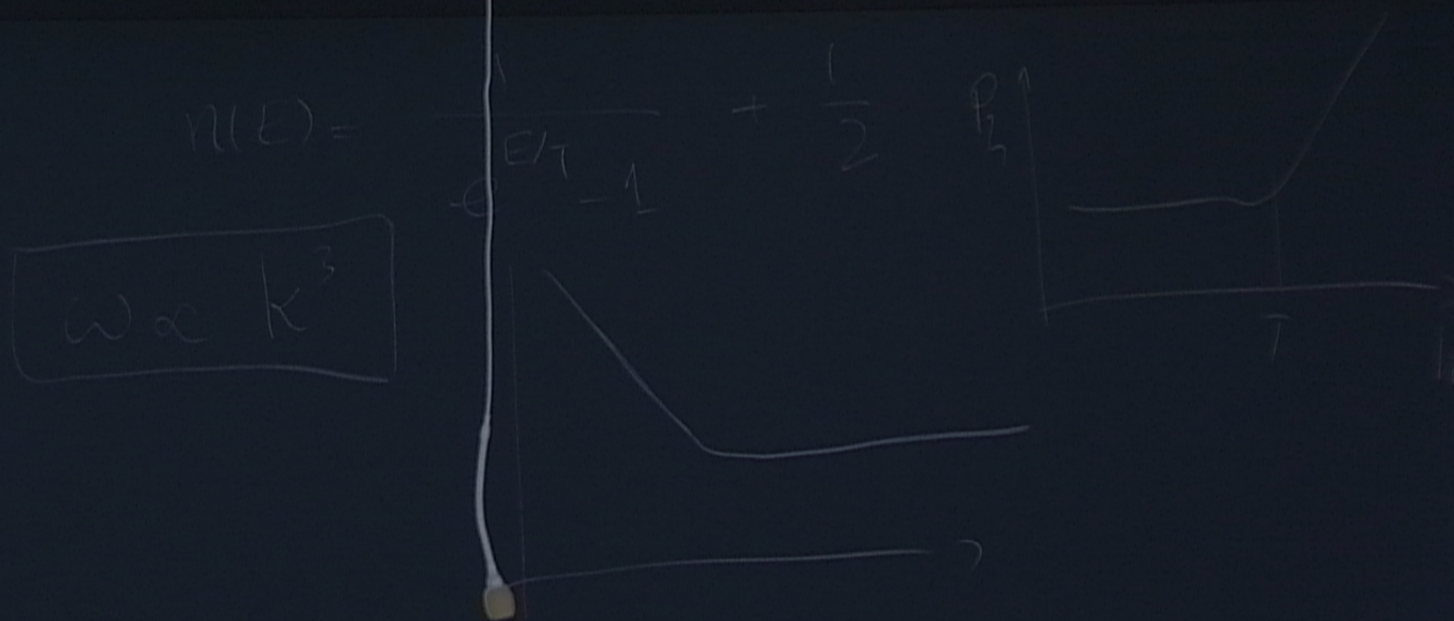
Planck

$$\frac{k^3}{2\pi^2} P_\zeta(k) \simeq \left[ 8.66 \times 10^{-5} + \mathcal{O}\left(\frac{k}{a_b T_b}\right)^2 \right] \left(\frac{T_b}{M_5}\right)^6 \quad \frac{T_b}{M_5} = 0.17139 \pm 0.00077,$$

# *a very subjective* **perspective!**

- An incompressible phase of quantum gravity at  $T_{\text{GUT}} \sim 10^{15} \text{ GeV}$ 
  - **UV-completion:** Horava-Lifshitz gravity
  - **Big Bang:** Horizon problem, primordial scalar modes, *tensor modes?*, *superluminal QCD plasma?*
  - **Firewalls:** BH entropy, *PeV neutrinos?*, *Dark Energy?*
- Holographic Big Bang: an alternative to inflation, but testable! → *DGP cosmology?*, *BBN?*







$$\omega \propto k^3$$

Horava's proposal