Title: PSI 2016/2017 Cosmology (Review) - Lecture 15

Date: Feb 17, 2017 10:15 AM

URL: http://pirsa.org/17020075

Abstract:

WE QUANTIZED THE TEST SCALAR FIELD

SPEC

$$S = \int d\eta\, d^3x\, \frac{1}{2}\left(v'^2 + v D^2 v + \frac{a''}{a} v\right)$$

$\Rightarrow$ POWER SPECTRUM $P(k) = \dfrac{|f_k|^2}{a^2}$

WHERE f_k SOLVE'S MUKHANOV'S EQ:

$$f_k'' + \left(k^2 + \frac{a''}{a}\right) f_k = 0$$

W/ B-D VACUUM AT EARLY TIMES $f_k = \dfrac{1}{\sqrt{2k}} e^{-ik\eta}$

SPEC. FOR dS $|f_k|^2 = \frac{1}{2k^3\eta^2} \propto \frac{1}{k^3}$ .. SCALE INV. SPECTRUM,

LET'S SUMMIT !

REAL CALCULATION: STUDY COUPLED SCALAR/TENSOR PERTURBATIONS

$$S = m_{pl}^2 \int d^4x \sqrt{-g} \left(\frac{1}{2}R - \frac{1}{2}(\partial\phi)^2 - V(\phi) \right)$$

BACKGROUND: $g_{\mu\nu}$ ... FRW (K=0)

$\phi(t)$ .. INFLATON

$= \frac{1}{\sqrt{2\eta}} e^{-ik\eta}$

CONSIDER PERTURBATIONS

$$g_{\mu\nu} \to g_{\mu\nu} + h_{\mu\nu}$$

$$\phi \to \phi + \varphi$$

TO EXTRACT TRUE DOF
NEED TO GAUGE FIX

$\Rightarrow$ 3 DOF

- SVT DECOMPOSITION = BASIS OF

$h_{\mu\nu}$: $h_{00} = -\Phi$, $h_{0i} = a(V_i + \partial_i B)$

$h_{ij} = a^2(\gamma_{ij} + 2\partial_{(i} W_{j)} + \partial_i\partial_j \chi + 2\zeta\delta_{ij})$

φ $\quad \partial^i \gamma_{ij} = 0$, $\gamma^i{}_i = 0$, $\partial^i W_i = 0$, $\partial_i V^i = 0$

USEFUL BECAUSE THE MODES DECOUPLE & CAN BE TREATED SEPARATELY

- PLUG INTO S ... EXPAND TO QUADRATIC ORDER

- GAUGE FIX: ζ GAUGE : $\varphi = 0$ &

DOF ARE ENTIRELY CAPTURED BY

$\boxed{\zeta \,,\, \gamma_{ij}}$

$$S_\gamma = \frac{M_{pl}^2}{8} \int d^4x\, a^3 \left(\dot{\gamma}_{ij}^2 + \frac{1}{a^2} \gamma_{ij} \nabla^2 \gamma_{ij} \right)$$

$$S_\zeta = M_{pl}^2 \int d^4x\, a^3 \varepsilon \left(\dot{\zeta}^2 + \frac{1}{a^2} \zeta \nabla^2 \zeta \right)$$

ε = SLOW-ROLL PARAM.

$$\varepsilon = -\frac{\dot{H}}{H^2} = \frac{\frac{1}{2}\dot{\phi}^2}{m_{pl}^2 H^2}$$

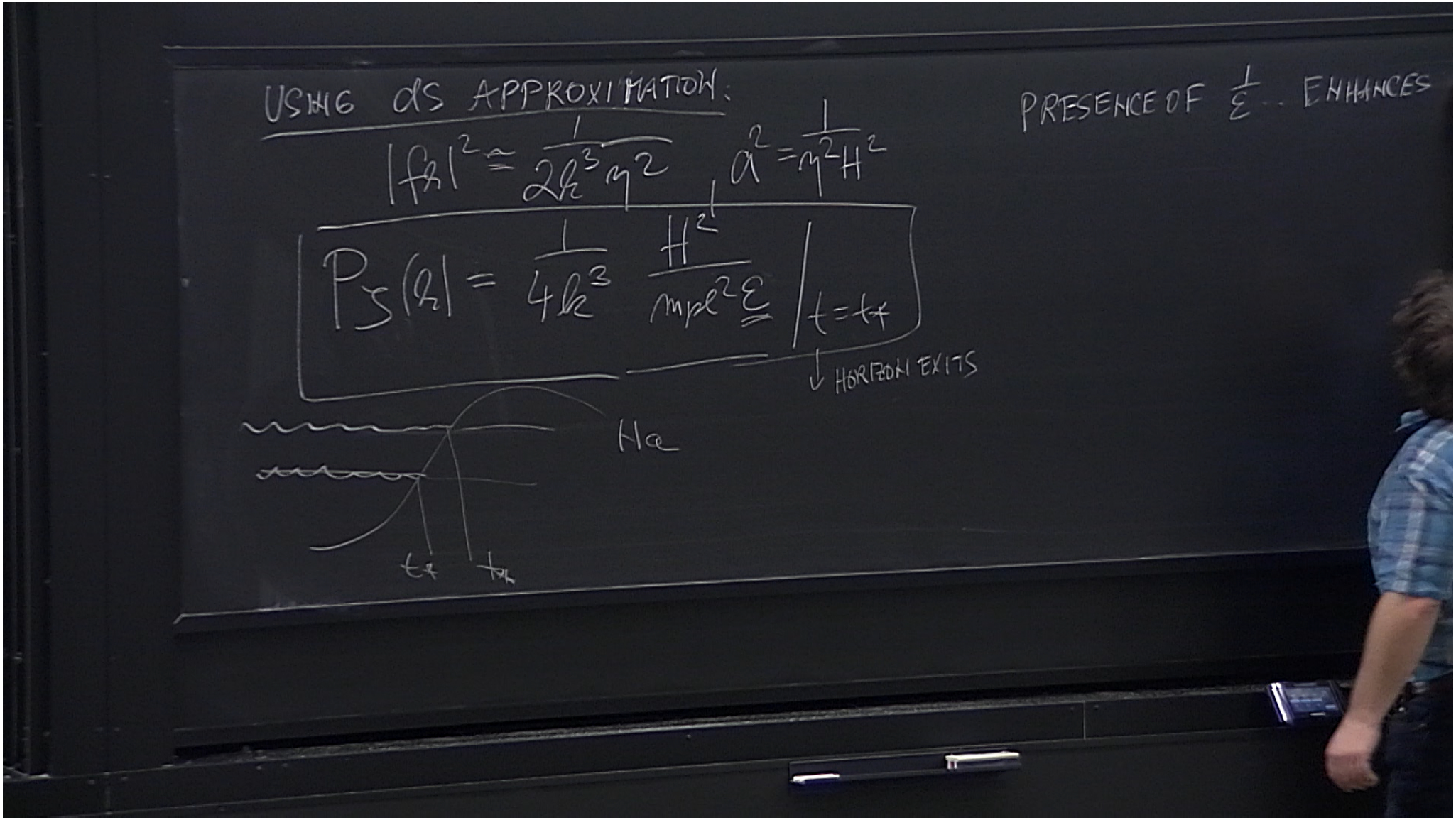
- SCALARS: $dt \to d\eta$, $V = z\zeta$, $z^2 = 2a^2 m_{pl}^2 \varepsilon$

$$S_\zeta = \int d^3x\, d\eta\, \frac{1}{2}\left(V'^2 + V\nabla^2 V + \frac{z''}{z} V^2\right)$$

$$P_\zeta = \frac{|f_{rel}|^2}{z^2}$$

$\nabla^2 \gamma_{ij}$)

$\zeta \nabla^2 \zeta$)


USING dS APPROXIMATION:
$|f_k|^2 \simeq \frac{1}{2k^3\eta^2}$, $a^2 = \frac{1}{\eta^2 H^2}$
$P_S(k) = \frac{1}{4k^3} \frac{H^2}{m_{pl}^2 \varepsilon}\Big|_{t=t_*}$
PRESENCE OF $\frac{1}{\varepsilon}$ ENHANCES
↓ HORIZON EXITS
Ha
t_*
t_{eq}

PRESENCE OF $\frac{1}{\varepsilon}$ ENHANCES THE MODE?

FOR SCALARS?

$$k\frac{dt}{da} = \frac{k}{\dot{H}a + H^2 a} = \frac{Ha}{a H^2\left(\frac{\dot{H}}{H^2}+1\right)} = \frac{1}{H(1-\varepsilon)}$$

- SPECTRAL INDEX:

$k = Ha$ AT t_*

$$1 = \frac{dH}{da}a + H\frac{da}{da} = \dot{H}\frac{dt}{da}a + H\dot{a}\frac{dt}{da}$$

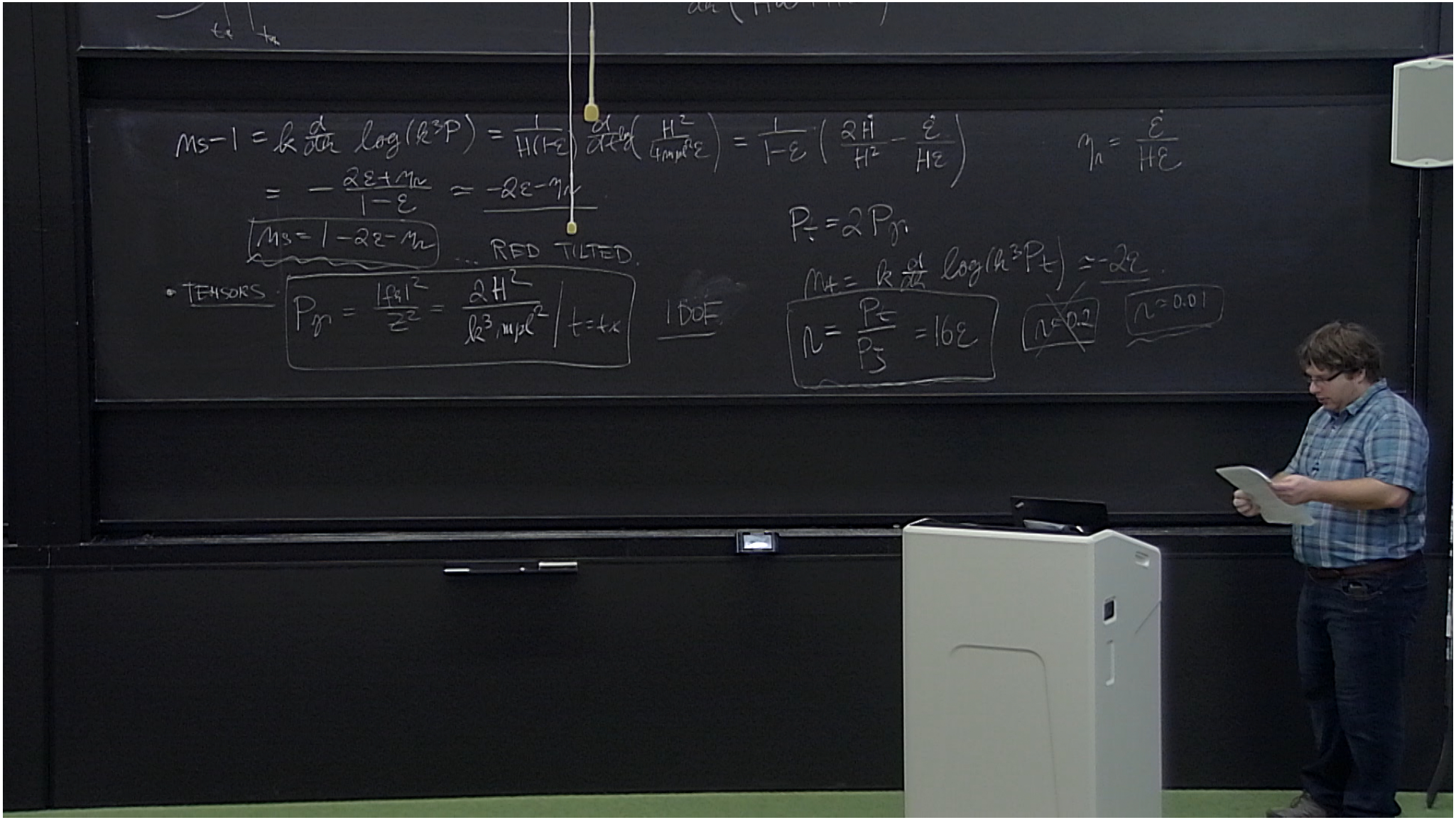
$$= \frac{dt}{da}\left(\dot{H}a + H^2 a\right)$$

$$n_s - 1 = k\frac{d}{d\ln k}\log(k^3 P) = \frac{1}{H(1-\varepsilon)}\frac{d}{dt}\log\left(\frac{H^2}{4\pi m_{pl}^2 \varepsilon}\right) = \frac{1}{1-\varepsilon}\left(\frac{2\dot{H}}{H^2} - \frac{\dot{\varepsilon}}{H\varepsilon}\right)$$

$$= -\frac{2\varepsilon + \eta_N}{1-\varepsilon} \simeq \underline{-2\varepsilon - \eta_N}$$

$$\boxed{n_s = 1 - 2\varepsilon - \eta_N} \quad \ldots \text{ RED TILTED.}$$




$n_S - 1 = k\frac{d}{dk}\log(k^3 P) = \frac{1}{H(1-\varepsilon)}\frac{d}{dt}\left(\frac{H^2}{4\pi M_{pl}^2 \varepsilon}\right) = \frac{1}{1-\varepsilon}\left(\frac{2\dot{H}}{H^2} - \frac{\dot{\varepsilon}}{H\varepsilon}\right)$
$\eta = \frac{\dot{\varepsilon}}{H\varepsilon}$
$= -\frac{2\varepsilon + \eta_V}{1-\varepsilon} \simeq -2\varepsilon - \eta_V$
$n_S = 1 - 2\varepsilon - \eta_V$
... RED TILTED.
$P_T = 2P_R$
$n_T = k\frac{d}{dk}\log(k^3 P_T) \simeq -2\varepsilon$
• TENSORS
$P_R = \frac{|f_R|^2}{Z^2} = \frac{2H^2}{k^3 \pi M_{pl}^2}\Big|_{t=t_k}$
1 DOF
$r = \frac{P_T}{P_R} = 16\varepsilon$
$r = 0.2$
$r = 0.01$

$$n_S - 1 = k\frac{d}{dk}\log(k^3 P) = \frac{1}{H(1+\varepsilon)}\frac{d}{dt}\log\left(\frac{H^2}{4\pi m_{pl}^2 \varepsilon}\right) = \frac{1}{1-\varepsilon}\left(\frac{2\dot{H}}{H^2} - \frac{\dot{\varepsilon}}{H\varepsilon}\right) \qquad \eta_n = \frac{\dot{\varepsilon}}{H\varepsilon}$$

$$= -\frac{2\varepsilon + \eta_n}{1-\varepsilon} \simeq \underline{-2\varepsilon - \eta_n}$$

$$\boxed{n_S = 1 - 2\varepsilon - \eta_n} \quad \ldots \text{RED TILTED.}$$

$$P_t = 2P_{gw}$$

$$n_t = k\frac{d}{dk}\log(k^3 P_t) \simeq \underline{-2\varepsilon}.$$

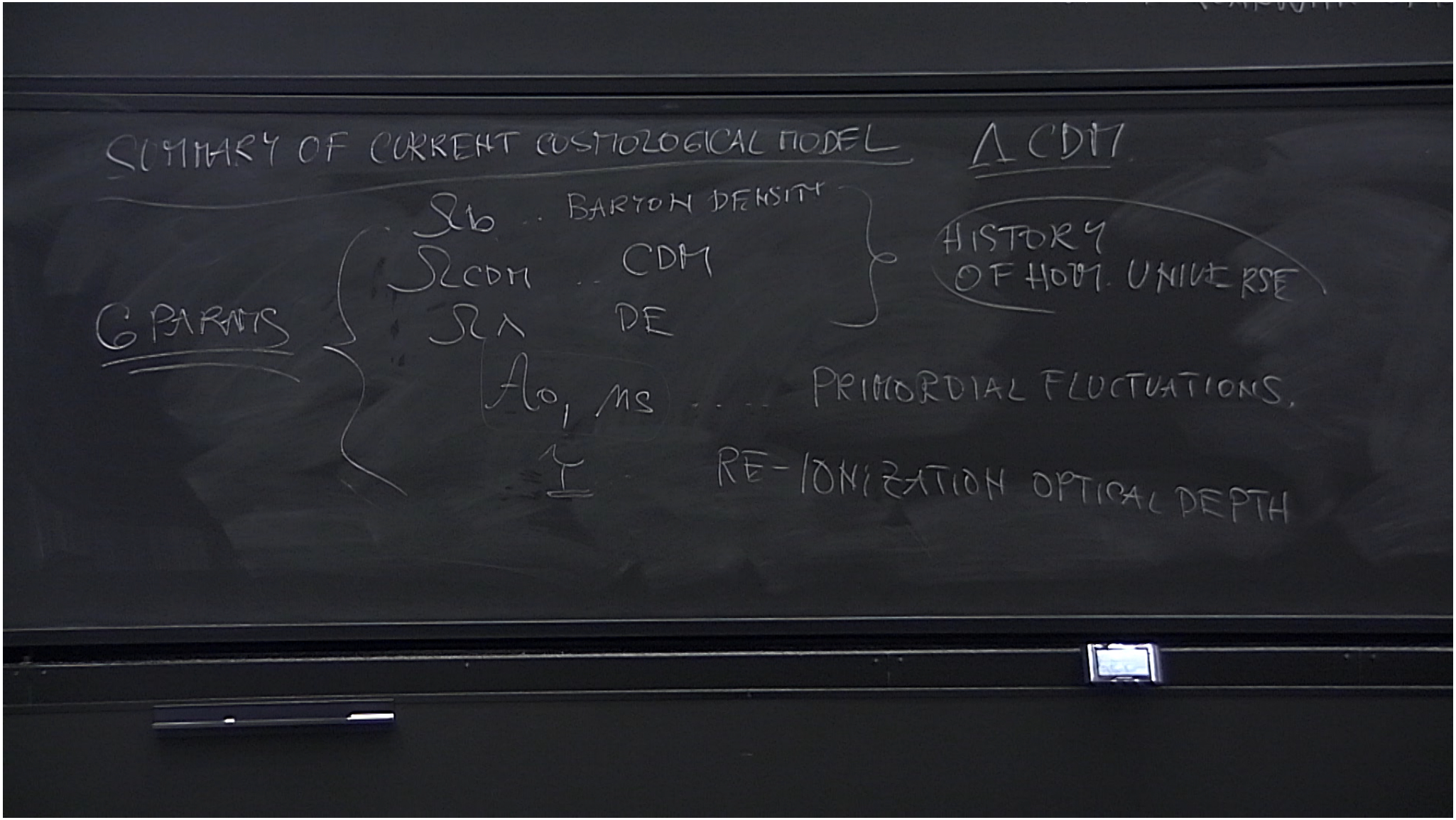
- TENSORS.

$$\boxed{P_{gw} = \frac{|f_q|^2}{Z^2} = \frac{2H^2}{k^3 m_{pl}^2}\Big|_{t=t_k}}$$

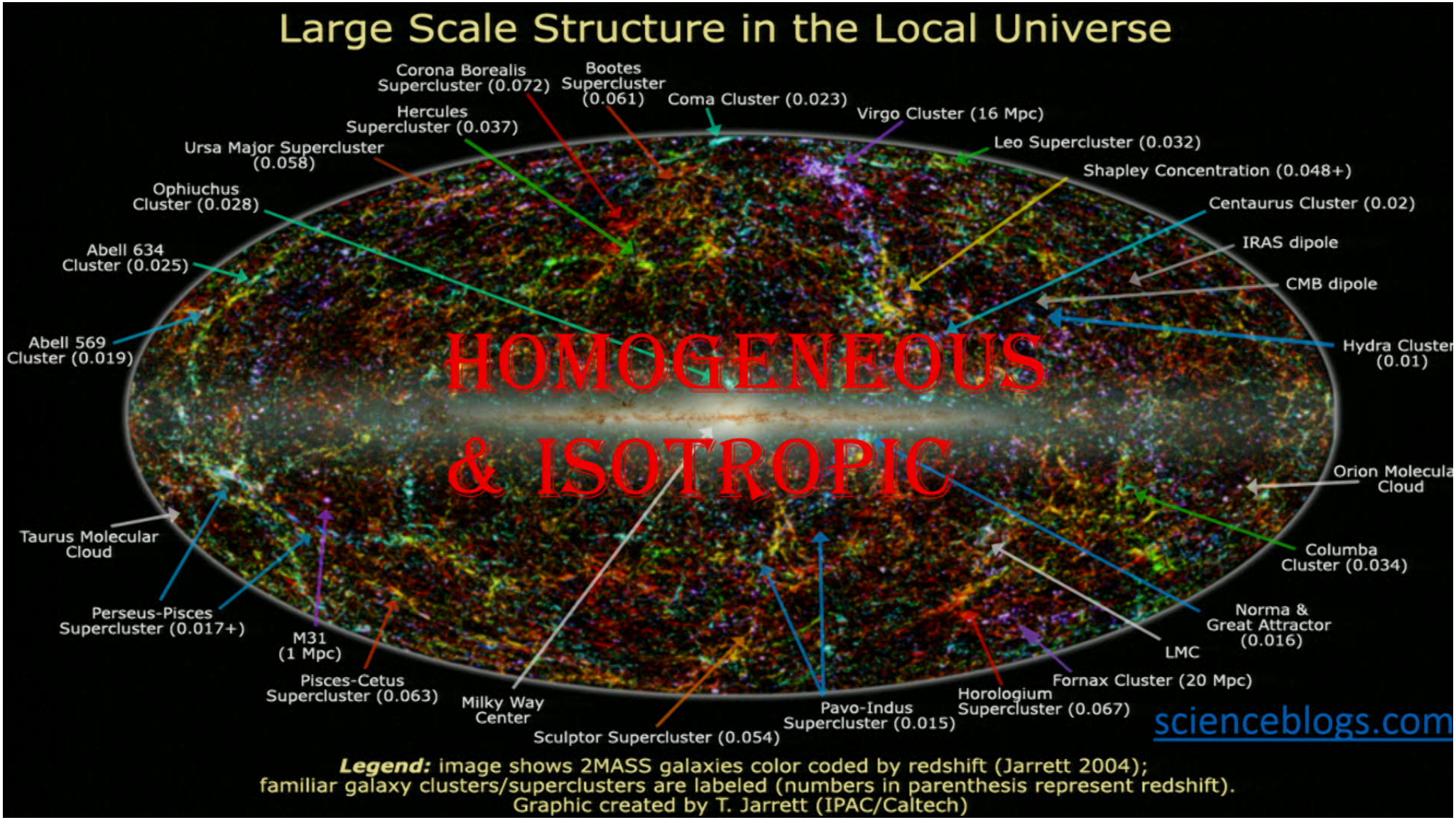
1 DOF.

$$\boxed{r = \frac{P_t}{P_S} = 16\varepsilon}$$

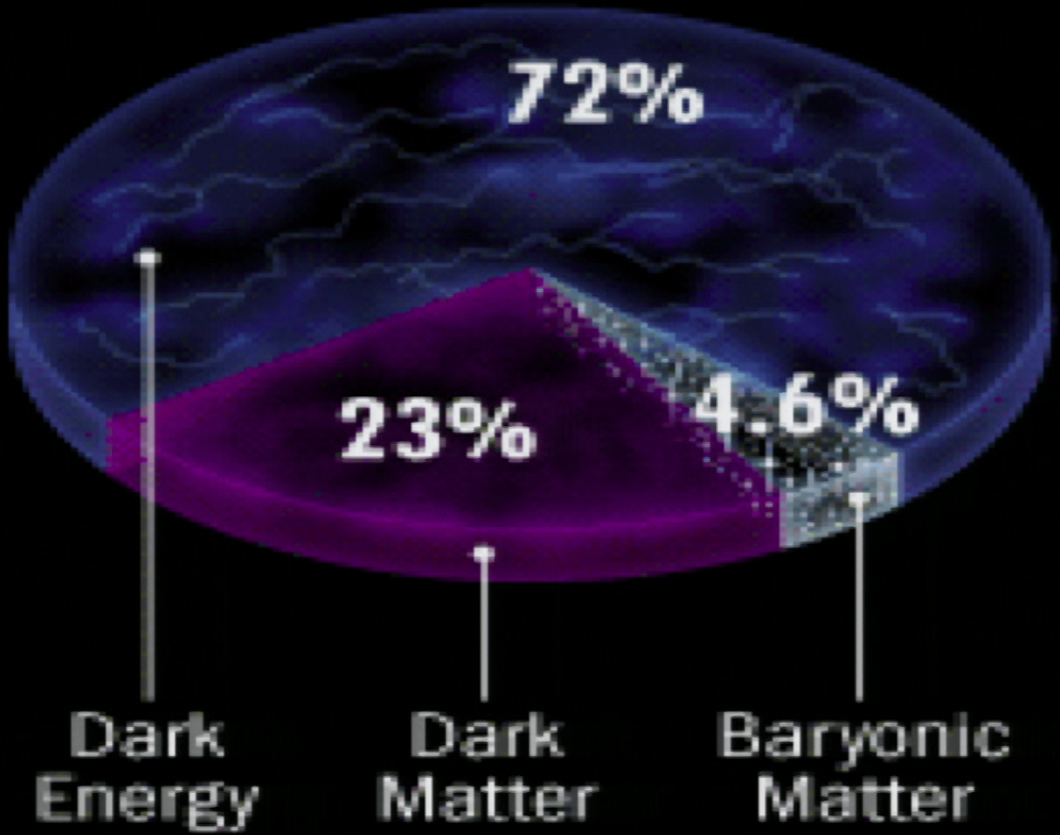
~~$r = 0.2$~~ $r = 0.01$


SUMMARY OF CURRENT COSMOLOGICAL MODEL
ΛCDM
6 PARAMS
Ωb .. BARYON DENSITY
ΩCDM .. CDM
ΩΛ .. DE
HISTORY OF HOM. UNIVERSE
A0, ns .... PRIMORDIAL FLUCTUATIONS.
τ .. RE-IONIZATION OPTICAL DEPTH

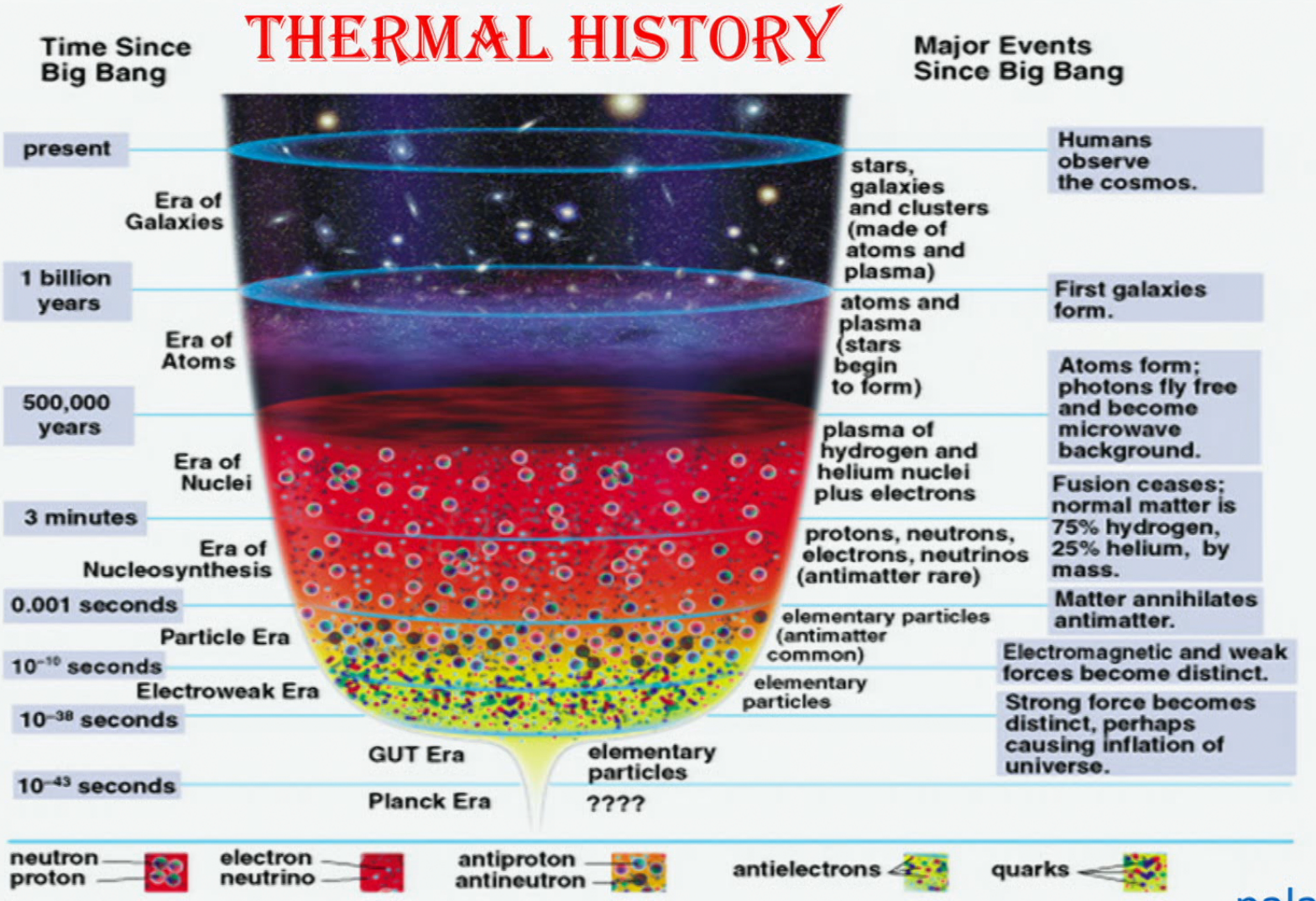

THE UNIVERSE
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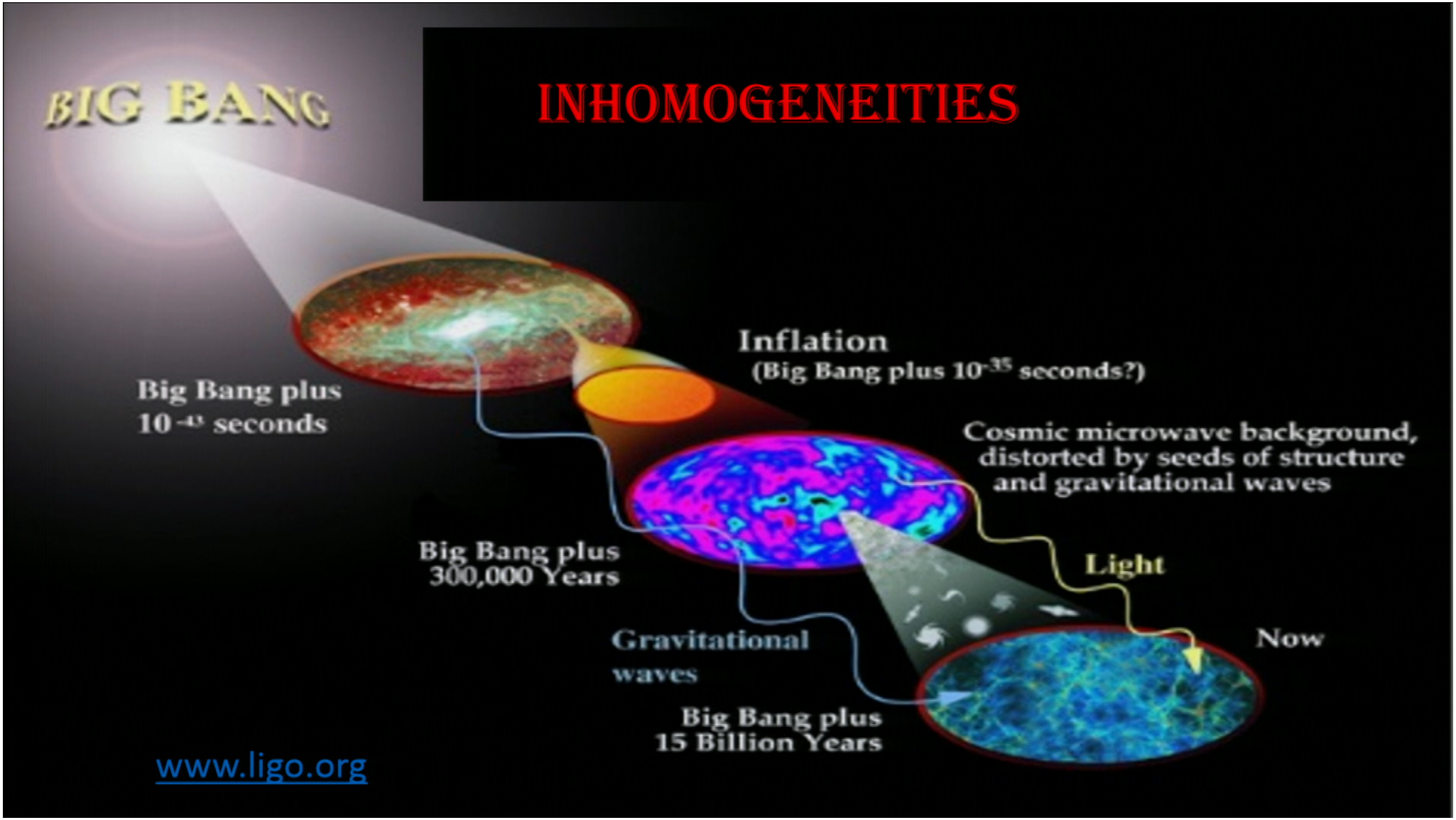

Large Scale Structure in the Local Universe
Corona Borealis Supercluster (0.072)
Bootes Supercluster (0.061)
Coma Cluster (0.023)
Virgo Cluster (16 Mpc)
Hercules Supercluster (0.037)
Leo Supercluster (0.032)
Ursa Major Supercluster (0.058)
Shapley Concentration (0.048+)
Ophiuchus Cluster (0.028)
Centaurus Cluster (0.02)
Abell 634 Cluster (0.025)
IRAS dipole
CMB dipole
Abell 569 Cluster (0.019)
Hydra Cluster (0.01)
HOMOGENEOUS
& ISOTROPIC
Orion Molecular Cloud
Taurus Molecular Cloud
Columba Cluster (0.034)
Perseus-Pisces Supercluster (0.017+)
Norma & Great Attractor (0.016)
M31 (1 Mpc)
LMC
Pisces-Cetus Supercluster (0.063)
Fornax Cluster (20 Mpc)
Milky Way Center
Horologium Supercluster (0.067)
Pavo-Indus Supercluster (0.015)
Sculptor Supercluster (0.054)
scienceblogs.com
Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004);
familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent redshift).
Graphic created by T. Jarrett (IPAC/Caltech)

WITH THE FOLLOWING MATTER CONTENT:

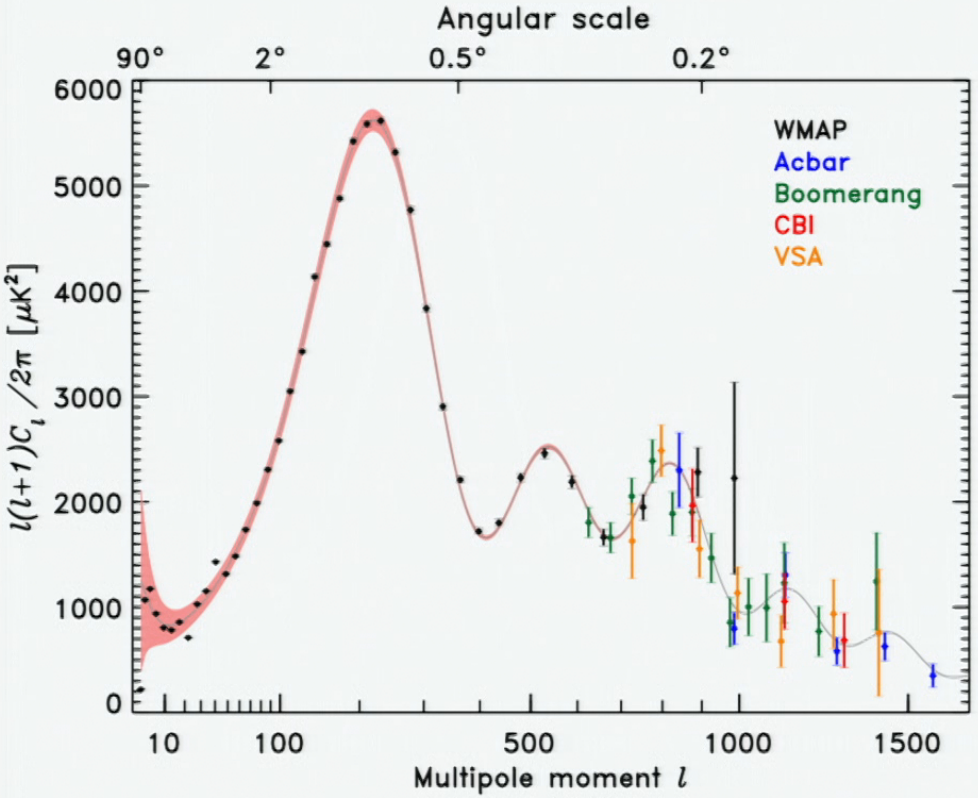


science.howstuffworks.com


THERMAL HISTORY
Time Since Big Bang
Major Events Since Big Bang
present
Era of Galaxies
1 billion years
Era of Atoms
500,000 years
Era of Nuclei
3 minutes
Era of Nucleosynthesis
0.001 seconds
Particle Era
10^{-10} seconds
Electroweak Era
10^{-38} seconds
GUT Era
10^{-43} seconds
Planck Era
stars, galaxies and clusters (made of atoms and plasma)
atoms and plasma (stars begin to form)
plasma of hydrogen and helium nuclei plus electrons
protons, neutrons, electrons, neutrinos (antimatter rare)
elementary particles (antimatter common)
elementary particles
elementary particles
????
Humans observe the cosmos.
First galaxies form.
Atoms form; photons fly free and become microwave background.
Fusion ceases; normal matter is 75% hydrogen, 25% helium, by mass.
Matter annihilates antimatter.
Electromagnetic and weak forces become distinct.
Strong force becomes distinct, perhaps causing inflation of universe.
neutron
proton
electron
neutrino
antiproton
antineutron
antielectrons
quarks
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BIG BANG
INHOMOGENEITIES
Inflation
(Big Bang plus 10-35 seconds?)
Big Bang plus
10 -43 seconds
Cosmic microwave background,
distorted by seeds of structure
and gravitational waves
Big Bang plus
300,000 Years
Light
Gravitational
waves
Now
Big Bang plus
15 Billion Years
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Λ-CDM MODEL



physics.stackexchange.com

6 parameters:

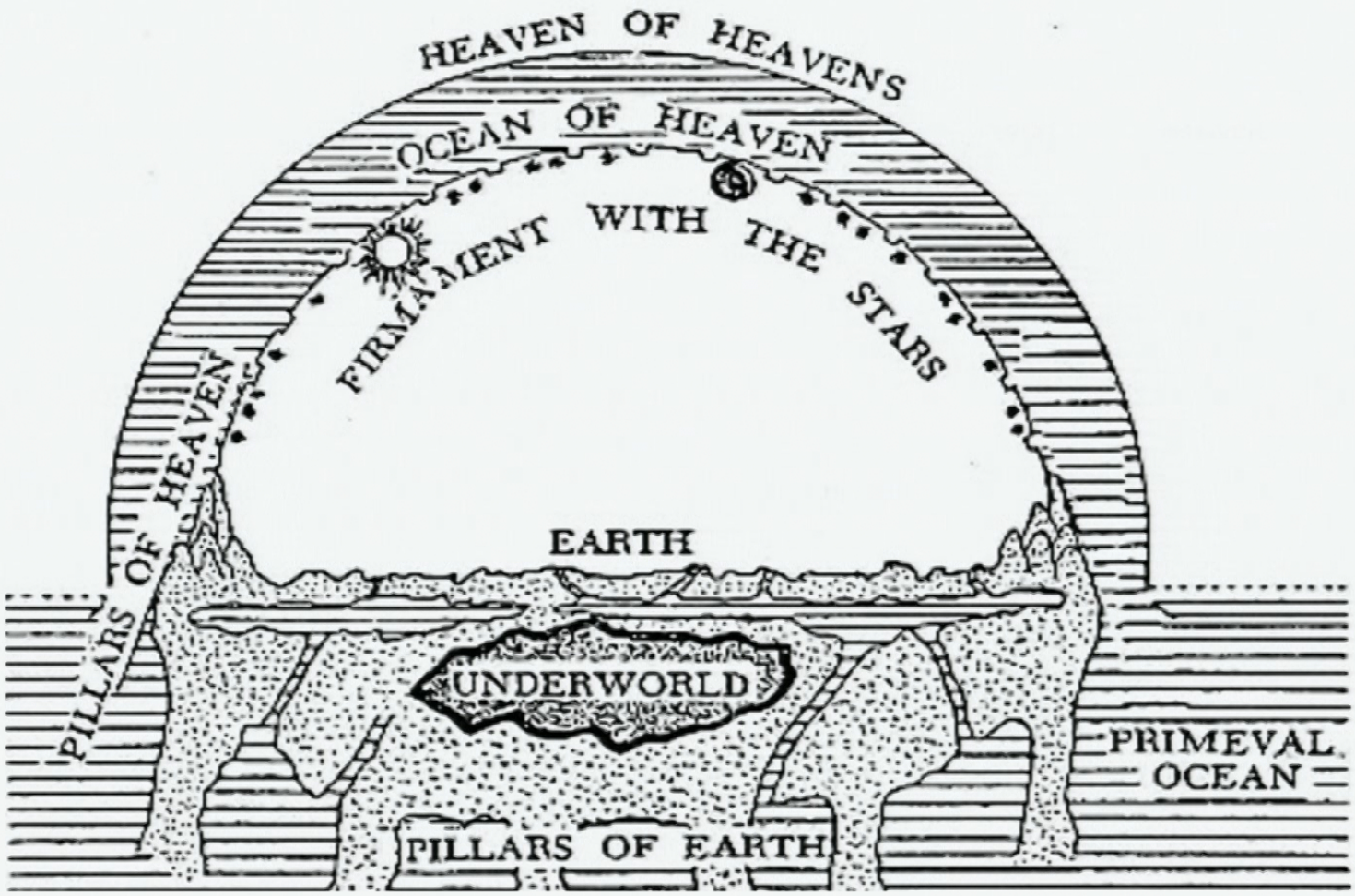
Baryon density	Ω_b
Cold Dark Mater density	Ω_{CDM}
Dark energy density	Ω_Λ
Scalar spectral index	n_s
Primordial power spectrum amplitude	$\mathcal{A}_0$
Re-ionization optical depth	τ


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HAIDA CULTURE



www.virtualmuseum.ca



www.webpages.uidaho.edu


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ATTENTION & GOOD LUCK IN
YOUR FUTURE ENDEAVOURS !
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