BJORKEN
FEB '04

WARNING !!

THE FOLLOWING MATERIAL IS RATED

TO

ITS CONTENTS INCLUDE SOCIALLY UNACCEPTABLE WORDS SUCH AS:

MULTIVERSE
ANTHROPIC PRINCIPLE

DIGESTION OF THIS MATERIAL MAY LEAD TO FUTURE UNHEALTHY EMPLOYMENT PROSPECTS.

J. BJORKEN
JAN-FEB 2004

THE CLASSIFICATION OF UNIVERSES

I. EXPOSITION

MULTIVERSES
ANTHROPICS
OUR UNIVERSE
THE LOCAL ENSEMBLE
A MORE DISTANT ENSEMBLE?
BJORKEN (RE)SCALING
HIERARCHY PROBLEMS "SOLVED"

II. DEVELOPMENT

QCD AND DARK ENERGY
TWO UNIVERSES ??
THE BEGINNING OF INFLATION

III. (RE)CAPITULATION

LESSONS LEARNED ?
IS THIS SCIENCE ?

I. EXPOSITION

MULTIVERSES:

MARTIN REES

"OUR COSMIC HABITAT"
"JUST SIX NUMBERS"

ANTHROPICS:

JOHN BARROW
FRANK TIPLER

"THE ANTHROPIC COSMOLOGICAL PRINCIPLE"

FINE TUNING:

FRED HOYLE
ET. AL.

$\alpha + \alpha \rightarrow Be^8$

$\alpha + Be^8 \rightarrow C^*$

$\alpha + C^* \not\rightarrow O^*$

"FACTS" ABOUT OUR UNIVERSE:

- DARK ENERGY (time independent?)
- SPATIALLY FLAT ("criticality")
- WE SEE ONLY A TINY PIECE OF THE COSMOS.

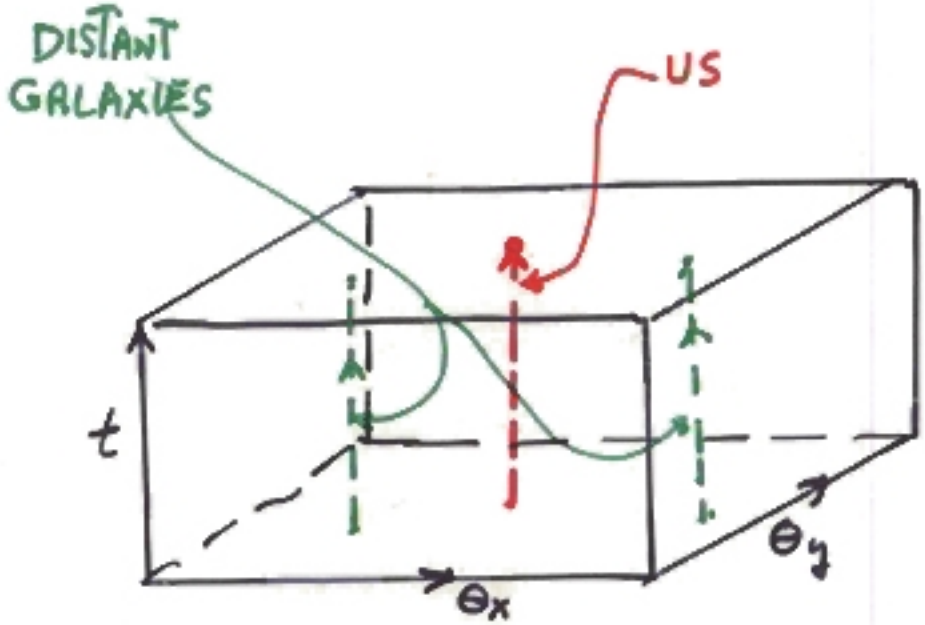
NO THEORY EXISTS FOR

- THE BEGINNING OF TIME
- THE END OF TIME
- THE BOUNDARY OF (FLAT) SPACE

THERE ARE PLENTY OF SPECULATIONS

DEFINE A UNIVERSE AS THE INTERIOR OF A (COMOVING) SPACETIME BOX

THE SPACETIME BOX



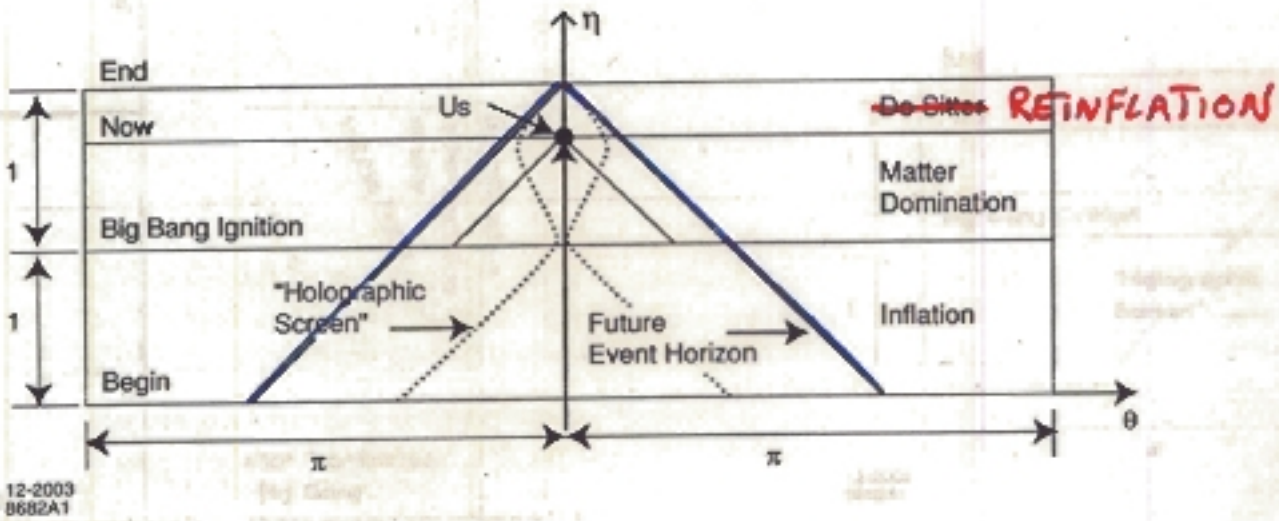
FRIEDMANN - ROBERTSON - WALKER METRIC

$$ds^2 = dt^2 - a^2(t)\left(d\theta_x^2 + d\theta_y^2 + d\theta_z^2\right)$$

$$H^2(t) \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi}{3M_{pl}^2}\rho(t)$$

THE SPACETIME BOX IN CONFORMAL COORDINATES

$$\eta = -\int_t^\infty \frac{dt'}{a(t')}$$



$$ds^2 = a^2(\eta)\left(d\eta^2 - d\theta_x^2 - d\theta_y^2 - d\theta_z^2\right)$$

EQUATION FOR "HOLOGRAPHIC SCREEN":

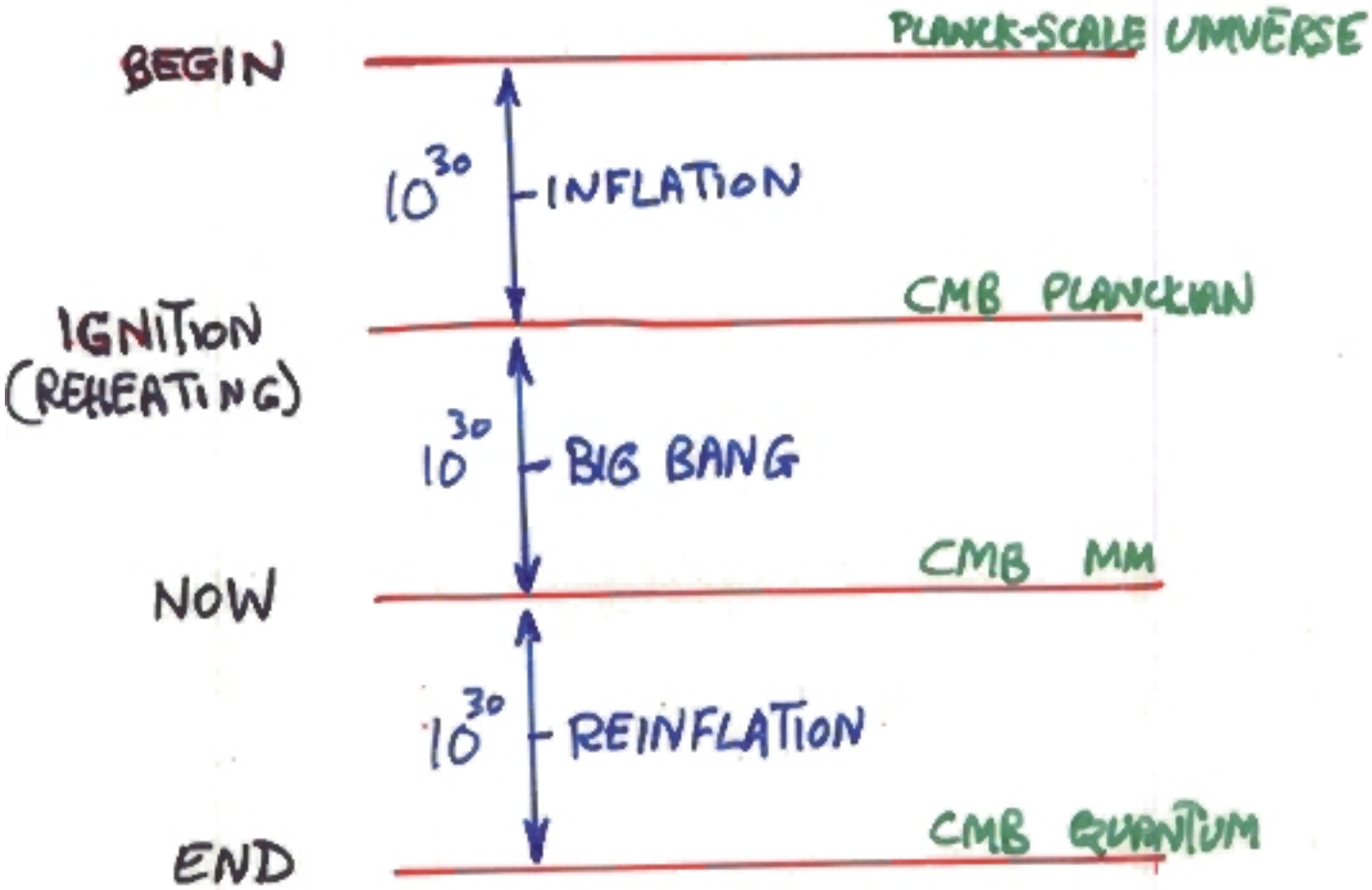
RADIUS $R(\eta) = a(\eta)\,|\eta| = H(\eta)^{-1}$

THE UNIVERSE FOR DUMMIES

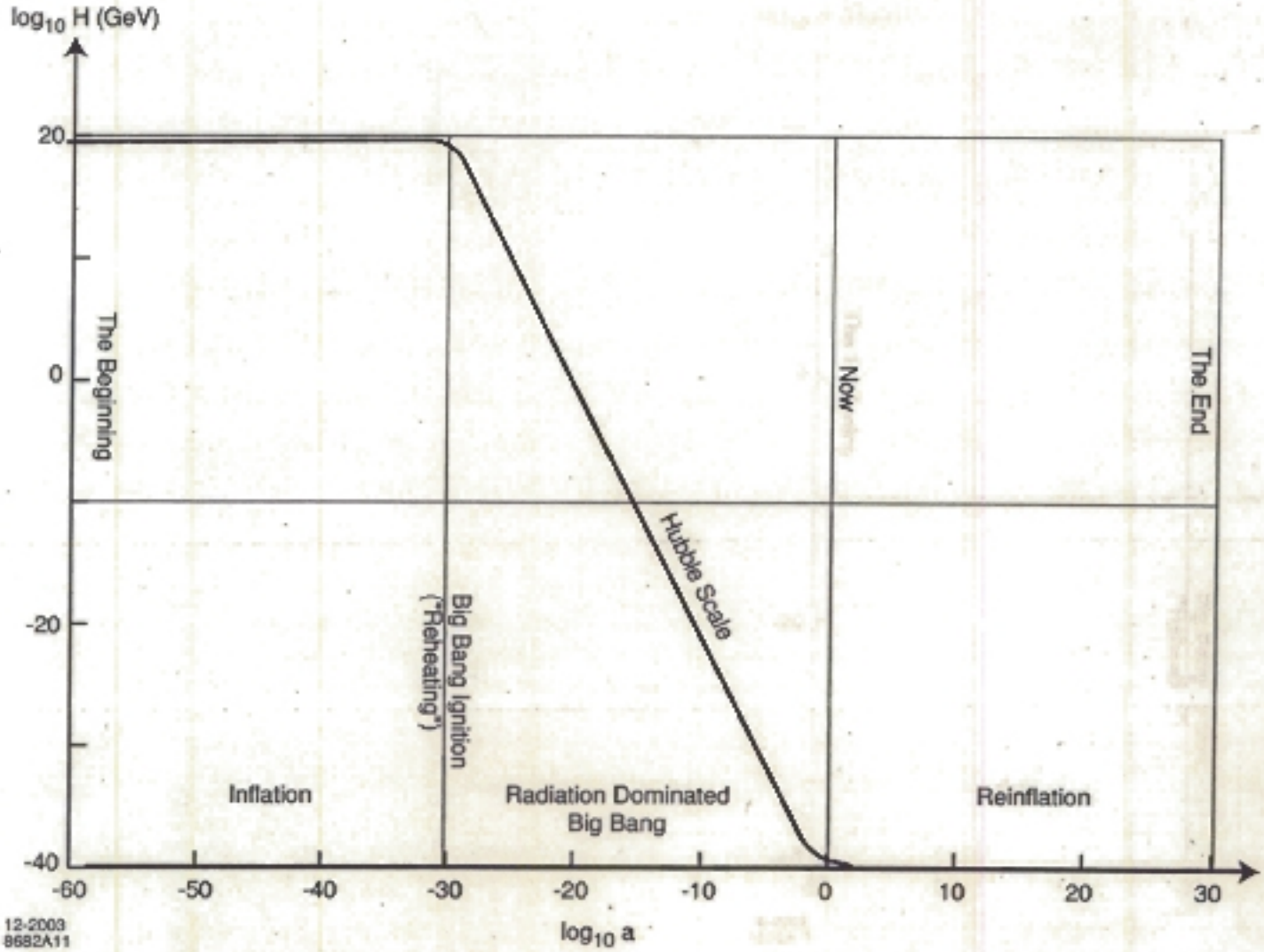
OMIT ORDINARY MATTER

OMIT DARK MATTER

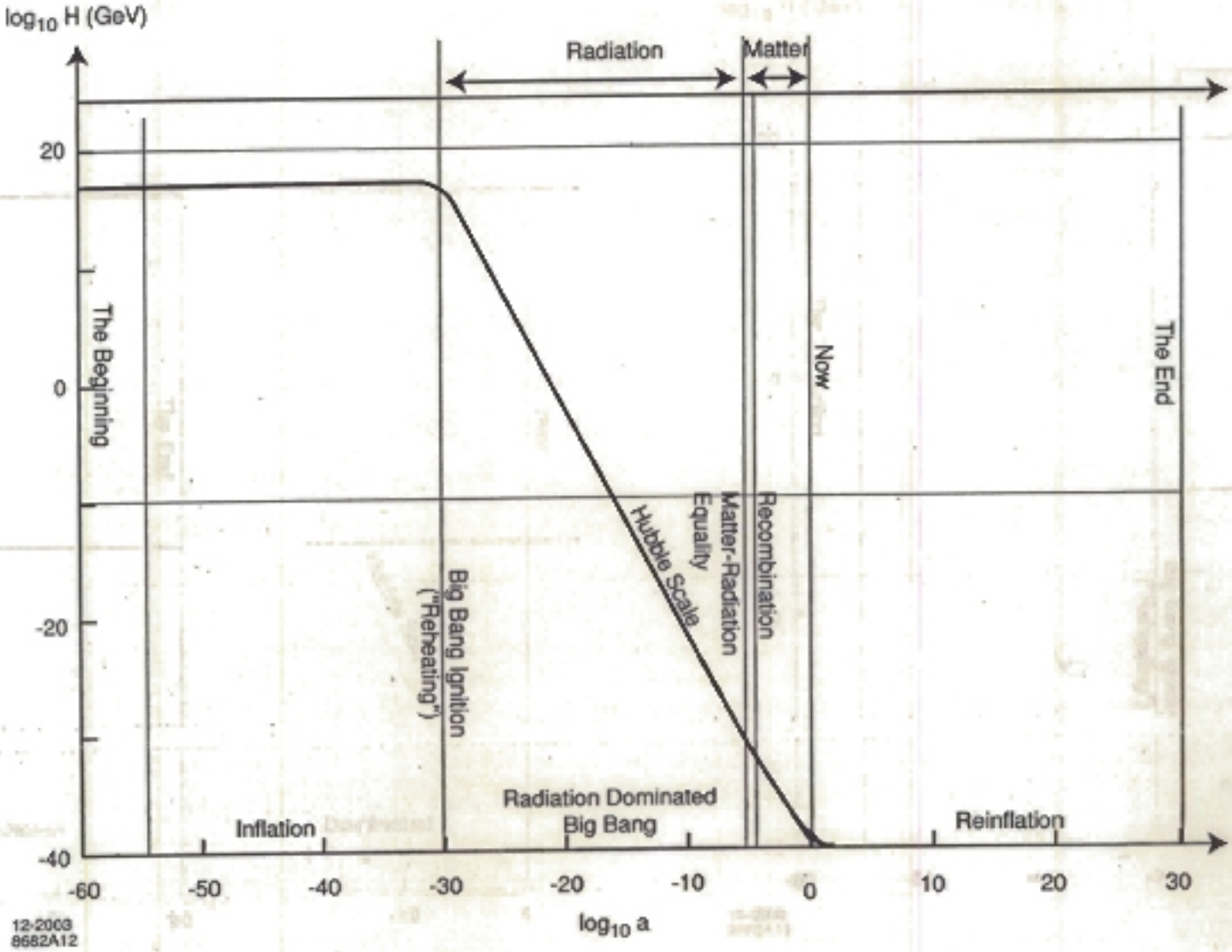
INFLATION SCALE ≈ PLANCK SCALE



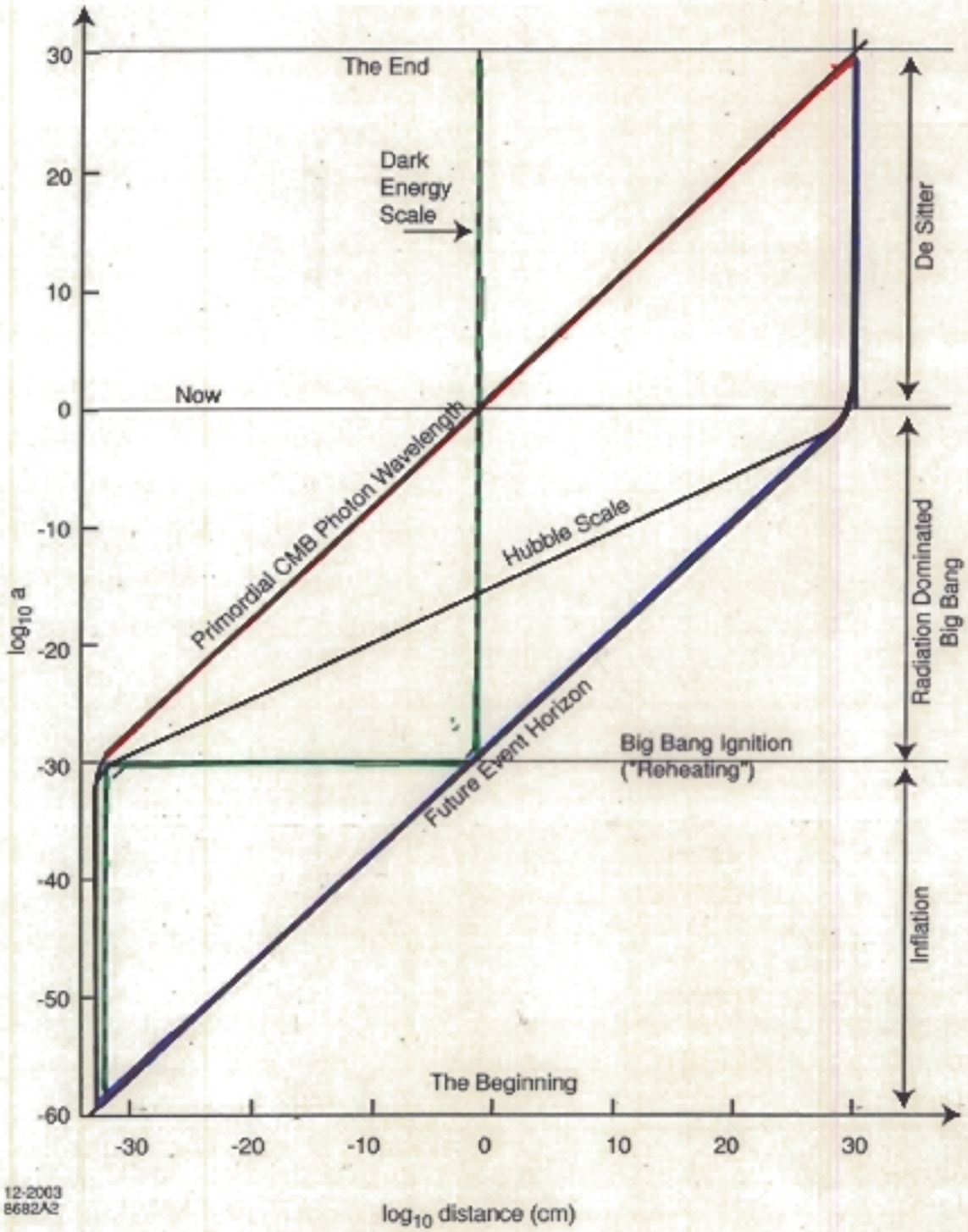
THE UNIVERSE FOR DUMMIES



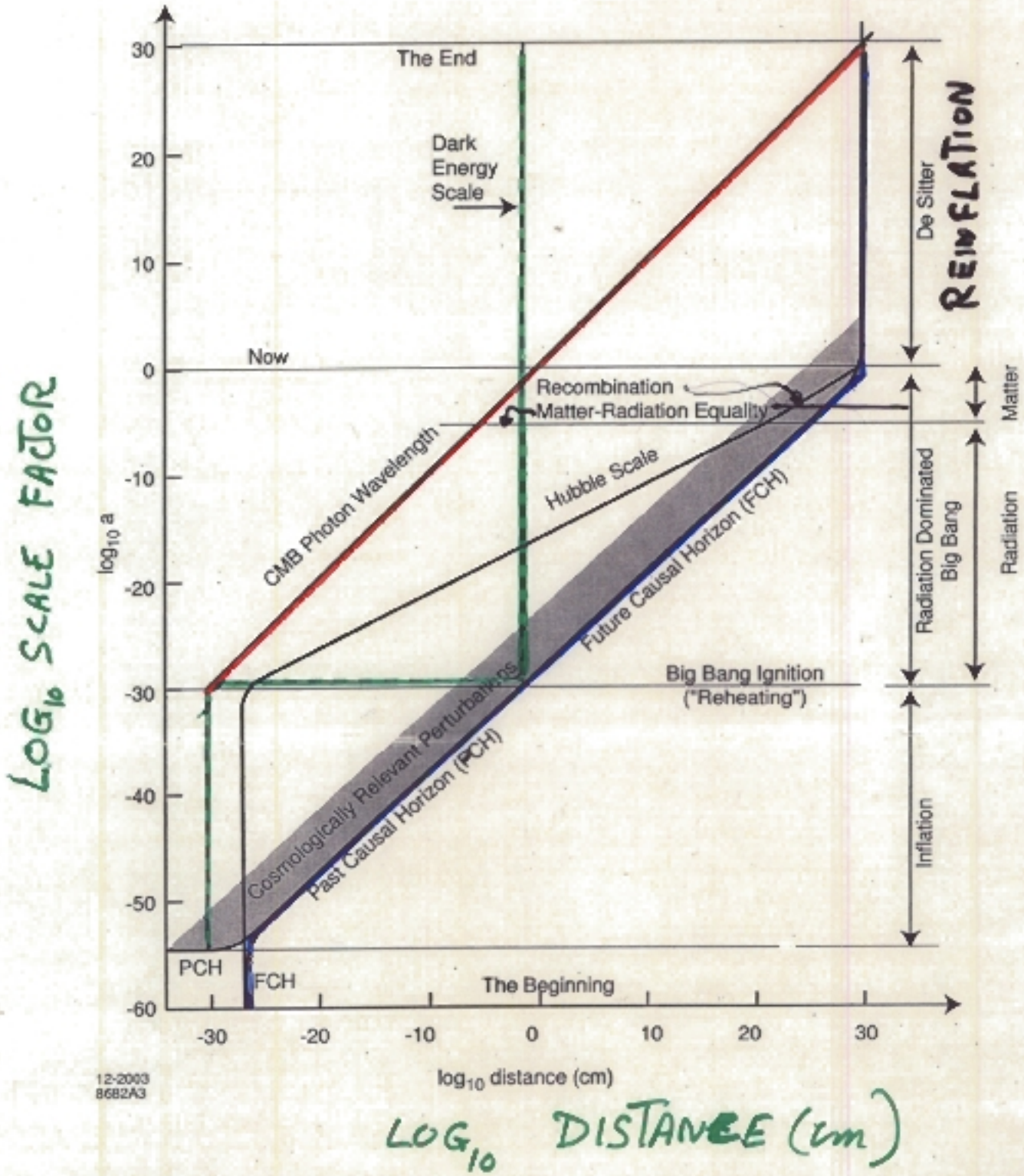
OUR UNIVERSE



DISTANCE SCALES IN THE UNIVERSE FOR DUMMIES



DISTANCE SCALES IN OUR UNIVERSE



- FACTOR 10^{30} APPEARS EVERYWHERE

- IT IS RATIO OF DARK ENERGY SCALE μ TO PLANCK SCALE M_{pl}.

- DARK ENERGY DENSITY $\mu^4 \sim \frac{meV}{(mm)^3}$

- DEFINE SIZE OF UNIVERSE IN TERMS OF DARK ENERGY SCALE:

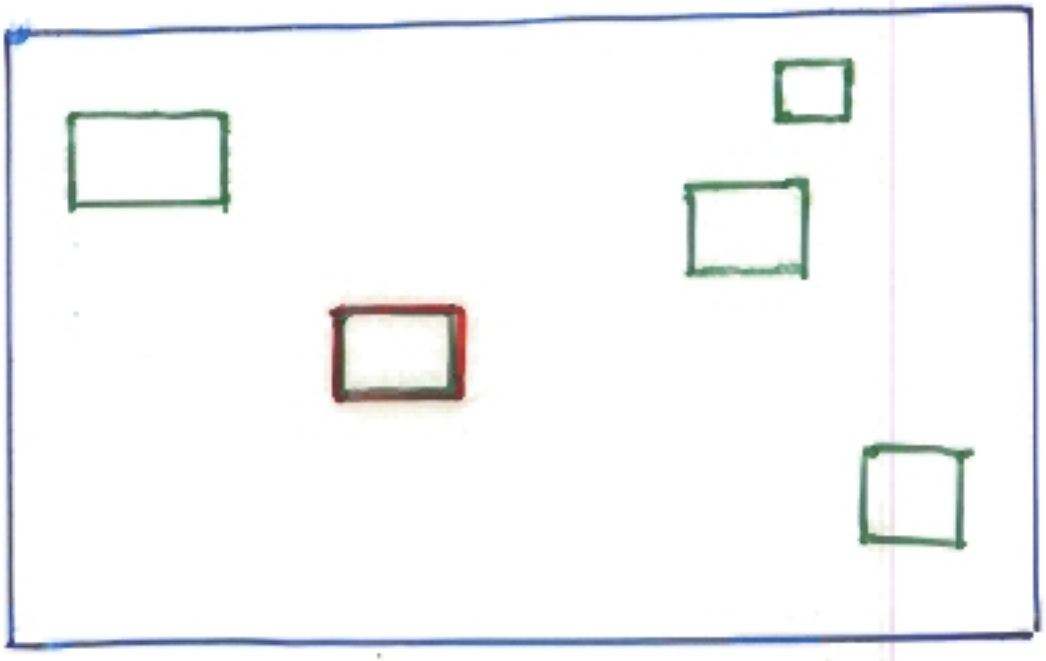
FRW: $$H^2 = \left(\frac{\dot{a}}{a}\right)^2 \rightarrow \frac{8\pi}{3M_{pl}^2}\mu^4$$

$$H \sim \frac{\mu^2}{M_{pl}}$$

$$\text{"SIZE"} = H^{-1} \sim \frac{M_{pl}}{\mu^2}$$

NOMENCLATURE:

- COSMOS: ALL OF SPACETIME
- UNIVERSE: OUR SPACETIME BOX
- MULTIVERSE: ENSEMBLE OF SIMILAR BOXES



(DATA-DRIVEN) ASSUMPTION:

COSMOS $\gg$ UNIVERSE

ENSEMBLES OF UNIVERSES:

LOCAL:
- IDENTICAL (?) COPIES
- MAYBE SOME VACUUM CONDENSATES DIFFER A BIT (e.g. AXIONS)

WILCZEK

MORE DISTANT:

SELECTION CRITERIA:
- SIMILAR HISTORY
- NONVANISHING DARK ENERGY AT LATE TIMES
- SPATIALLY FLAT
- SAME STANDARD-MODEL LAWS
- DIFFERENT STANDARD-MODEL (AND COSMOLOGICAL) PARAMETERS

BJORKEN (RE)SCALING:

- IN THE MORE-DISTANT ENSEMBLE THE VALUES OF MOST STANDARD MODEL PARAMETERS ARE CORRELATED WITH THE VALUE OF THE DARK ENERGY ("SIZE")

- A SPECIFIC HYPOTHESIS ON THE NATURE OF THE CORRELATION IS PROPOSED

  SIMPLE

  MINIMAL

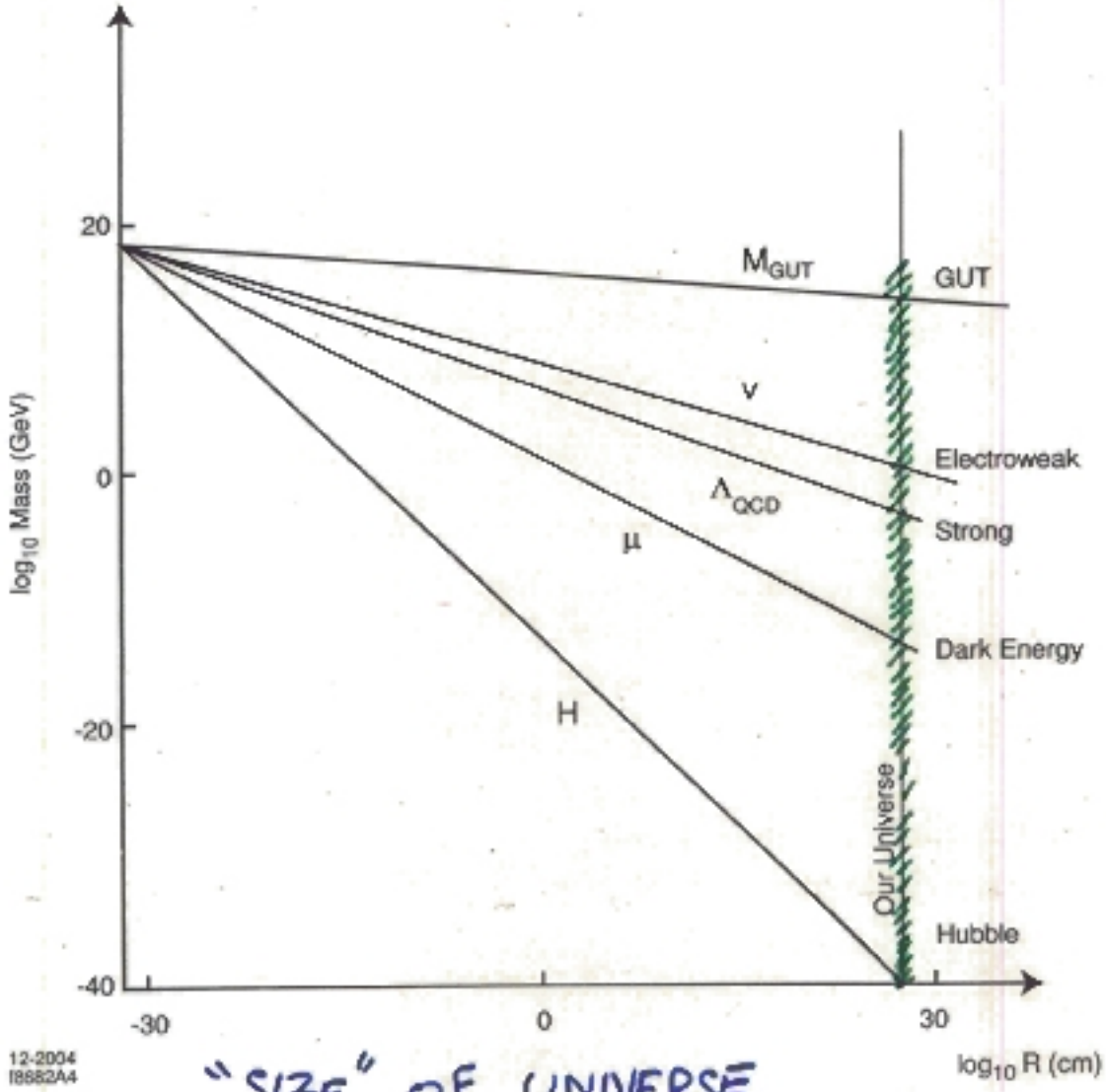
  NOT MOTIVATED BY UNDERLYING THEORY

- SMALL UNIVERSES ARE STRONGLY INTERACTING

- THE INFINITE UNIVERSE CONTAINS NO STANDARD MODEL INTERACTIONS

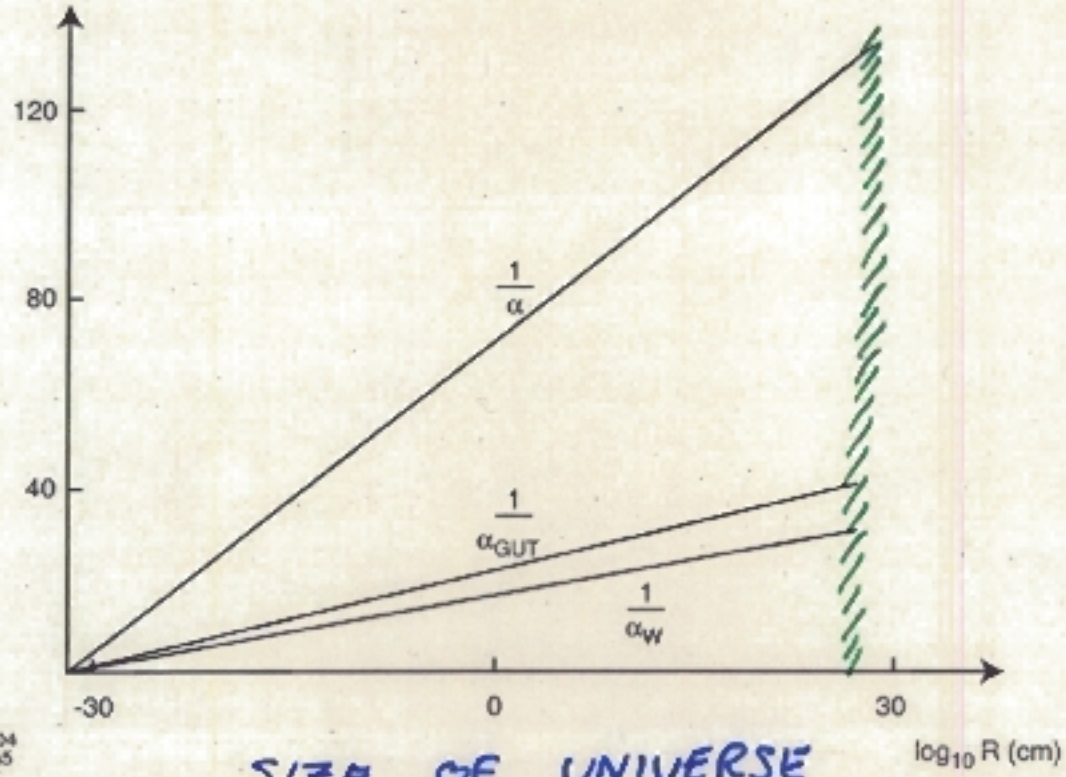
- HIERARCHY PROBLEMS ARE "SOLVED",

BJÖRKEN (RE)SCALING



"SIZE" OF UNIVERSE

COUPLING CONSTANT SCALING



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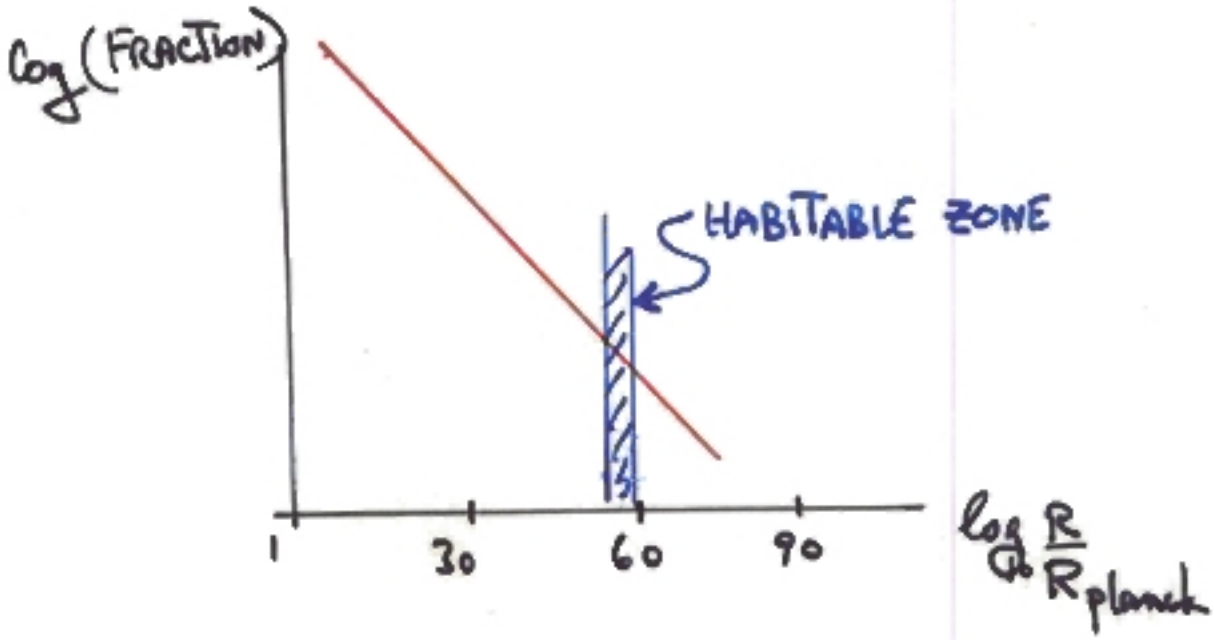
SIZE OF UNIVERSE

GUESS THE SIZE DISTRIBUTION OF UNIVERSES IS POWER-LAW:

$$R \frac{dN}{dR} \sim R^{-p}$$

$$\left\{ \begin{array}{l} \text{FRACTION OF UNIVERSES} \\ \text{WITH SIZE} > R \end{array} \right\} \sim \left(\frac{R_{min}}{R} \right)^{p} \gtrsim 10^{60p}$$



THE MAIN MESSAGES

- ALL "HIERARCHY PROBLEMS" SOLVED
- A NEW AND DIFFERENT PROBLEM REPLACES THEM:
  - × EXPLAIN THE "RESCALING" EXPONENTS
- ARE THERE MORE "ANTHROPIC" PARAMETERS?
  - × SMALL QUARK/LEPTON MASSES
  - × CKM MIXINGS
  - × DARK [redacted] MATTER
  - × CMB AMPLITUDE

⋮

II. DEVELOPMENT

A. QCD AND DARK ENERGY: WHY IS THE RESCALING EXPONENT 1/3 ??

ZELDOVICH '67
NOVELLO et al '01
SCHUTZHOLD '02
CARNIERO '03

- REINFLATING UNIVERSE HAS A HORIZON (BLACK HOLE INSIDE-OUT)
- HORIZON RADIUS $R_H = H^{-1} \approx 1.4 \times 10^{28}$ cm.
- BEKENSTEIN-HAWKING ENTROPY ON HORIZON $\sim 10^{122}$
- PADMANABHAN CONNECTS THIS ENTROPY WITH EINSTEIN-HILBERT LAGRANGIAN

PADMANABHAN TECHNOLOGY:

ENSEMBLE OF GEOMETRIES:

$$ds^2 = (1 - u(r))\,dt^2 - \frac{dr^2}{(1-u(r))} - r^2(\sin^2\theta\, d\varphi^2 + d\theta^2)$$

$$u = \begin{cases} \dfrac{2M}{r M_{pl}^2} & \text{SCHWARZSCHILD BLACK HOLE} \\[2ex] H^2 r^2 & \text{DE SITTER INFLATION} \\[2ex] -\dfrac{Q^2}{M_{pl}^2 r^2} & \text{REISSNER-NORDSTROM CHARGE} \end{cases}$$

HORIZON CRITERIA:

$$u = 1$$

$$\frac{du}{dr} = \underset{\text{(ACCELERATION)}}{\text{SURFACE GRAVITY}} = \underset{\text{(TEMPERATURE)}}{4\pi T}$$

EINSTEIN-HILBERT LAGRANGIAN:

$$L = \frac{M_{pl}^2}{16\pi} \int d^3x \, R(u)$$

$$= \frac{M_{pl}^2}{4} \int dr \, \frac{d}{dr}\left[r^2 \frac{du}{dr} + 2ru \right]$$

LOOK AT SURFACE TERM AT HORIZON R:

$$L = \frac{M_{pl}^2}{4}\left[4\pi R^2 T + 2R \right]$$

$$= \underset{\text{(ENTROPY TERM)}}{TS} + \underset{\text{(ENERGY TERM)}}{M}$$

B-H ENTROPY:

$$S = \frac{1}{4} M_{pl}^2 \cdot (4\pi R^2)$$

MASS INSIDE HORIZON:

$$M = \frac{M_{pl}^2 R}{2}$$

$$H^2 = \frac{8\pi}{3M_{pl}^2}\mu^4 = R^{-2}$$

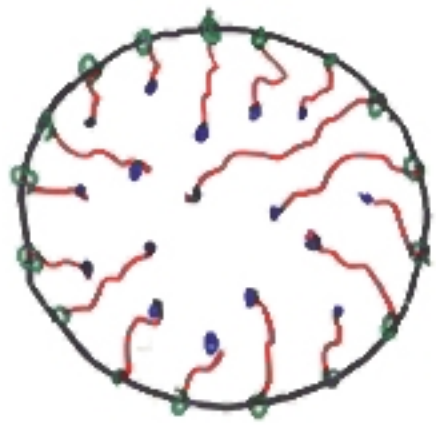
$$M = \mu^4 \cdot \left(\frac{4}{3}\pi R^3\right)$$

$$= \frac{1}{2} H^2 M_{pl}^2 R^3$$

$$= \frac{M_{pl}^2 R}{2}$$

THE MESSAGE (?!?):

ENTROPY TERM IS INTEGRAL OVER A UNIFORM DENSITY - JUST LIKE THE MASS TERM.



BULK DENSITY:

$$\frac{S}{V} \sim \frac{10^{120}}{10^{180}} \sim 10^{-60} \sim \left(0.3\,\mathrm{fm}^{-1}\right)^3 \sim \left(\frac{\Lambda_{QCD}}{3}\right)^3$$

ENERGY PER OBJECT:

$$\varepsilon = \frac{M}{S} = \frac{1}{2\pi R} = T$$

BJORKEN RESCALING:

$$\Lambda_{QCD}^3 \sim \frac{M_{pl}^2}{R} \quad \text{or} \quad \boxed{\Lambda_{QCD} \sim R^{-1/3}}$$

WHAT ARE THE OBJECTS ??

QCD MONOPOLE CONDENSATE

VORTICES

* TOPOLOGICAL CHARGE

$$L_{CP} = \frac{\Theta}{24\pi^2}\int d^3x\, E\cdot B = \Theta\int d^3x\, \frac{\partial K_\mu}{\partial x_\mu} = \Theta \dot{N}$$

$$N = \int d^3x\, K_0 = \text{TOPOLOGICAL CHARGE}$$

MAYBE $\langle N \rangle \sim 10^{120}$

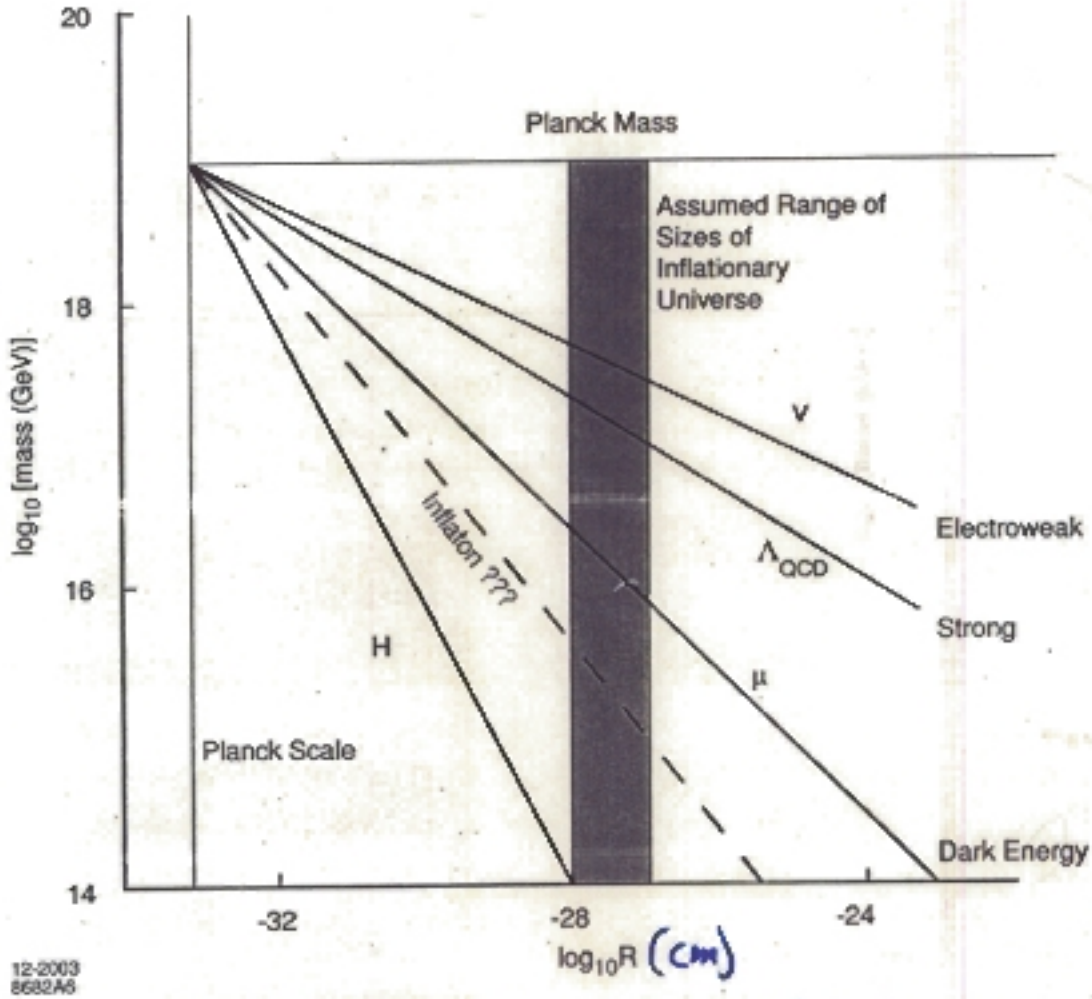
IF SO, INSTANTON-INDUCED FLUCTUATIONS ARE NEGLIGIBLE.

B. IS THE INFLATIONARY UNIVERSE A SEPARATE UNIVERSE?

- HUGE DARK ENERGY
- DARK ENERGY SCALE IS COMPARABLE TO QCD AND ELECTROWEAK SCALES (UNIFICATION ??)
- INFLATON ENERGY SCALE MAY BE SMALLER
- WITH TWO UNIVERSES IN CAUSAL CONTACT, MIGHT NOT $\hbar$, c, & M_{pl} CHANGE DURING BIG BANG IGNITION ??

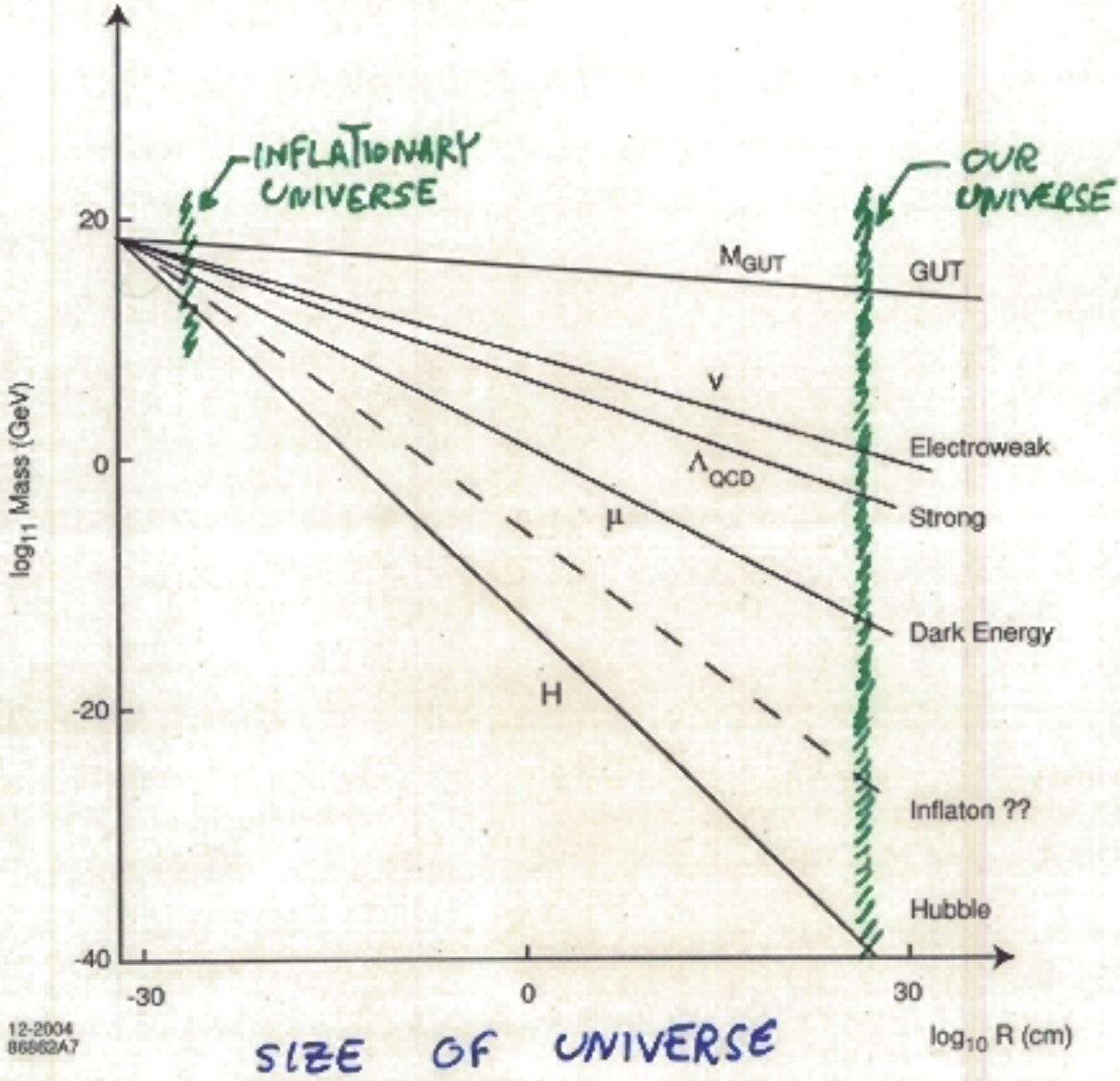
BOTTOM LINE: UNDERSTAND BIG-BANG IGNITION

STANDARD MODEL PARAMETERS IN THE INFLATIONARY UNIVERSE



SIZE OF UNIVERSE

WHAT IS THE INFLATON IN OUR UNIVERSE ??



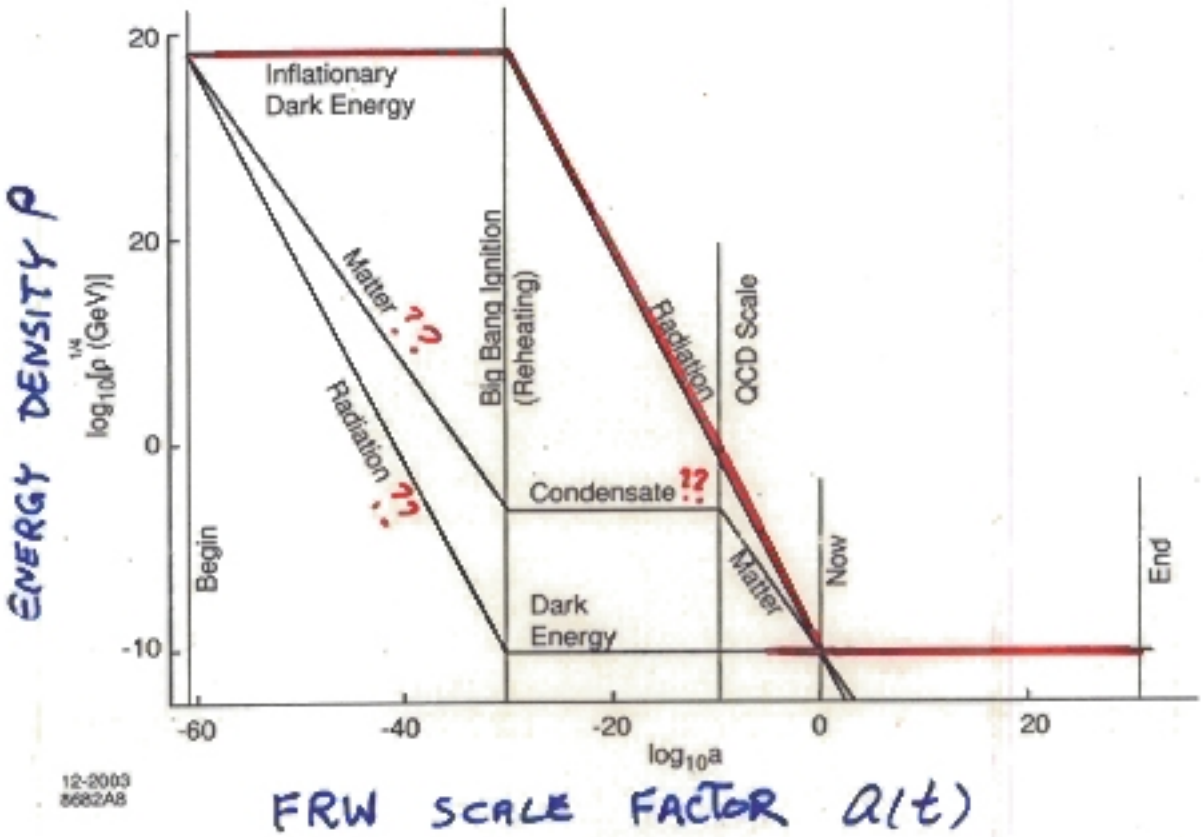
SIZE OF UNIVERSE

C. THE BEGINNING OF INFLATION:

UNIVERSE-FOR-DUMMIES IDEALIZATION

(N) RED: WHAT PURPORTEDLY EXISTS

THE REST: SPECULATION



$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi}{3M_{Pl}^2}\rho$$

- WHAT IS THE INFLATIONARY STUFF?

  RADIATION: SU(5) COSET GLUONS?

  MATTER: AXIONS ??

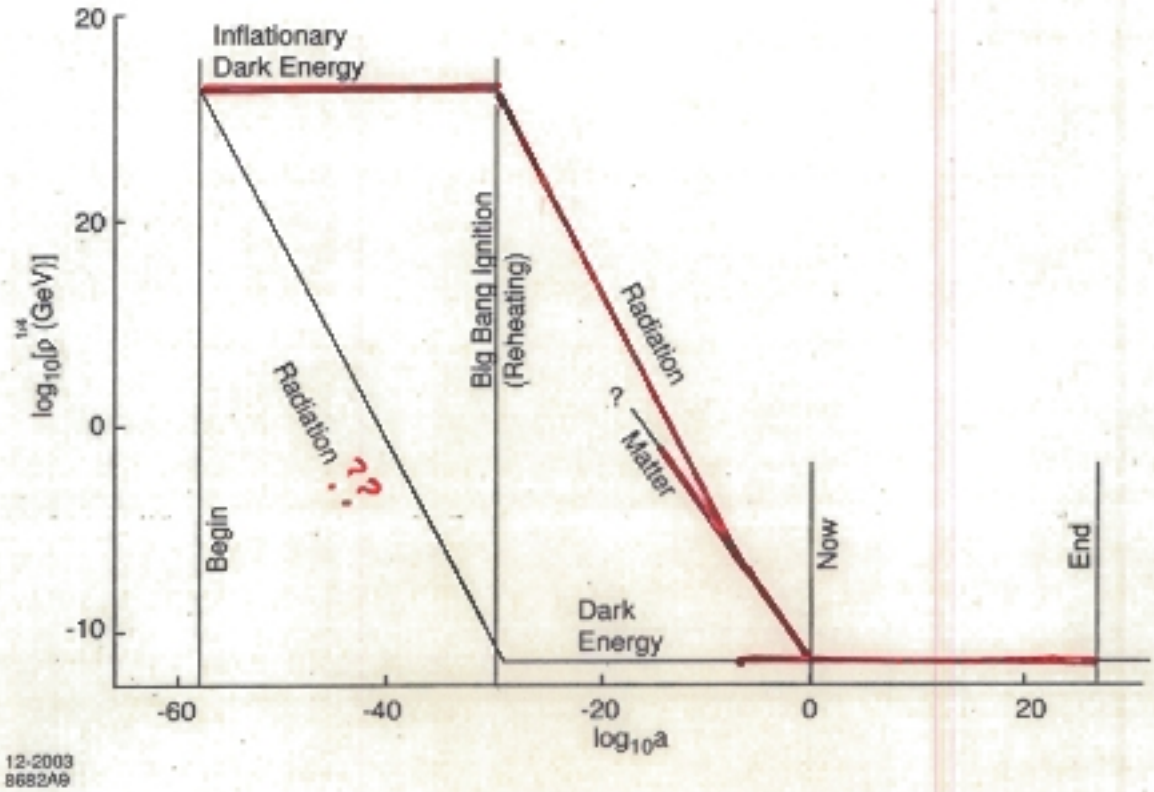
- WHY DOES THE INFLATIONARY DARK ENERGY DECAY?

  THE REASON MAY GO VERY DEEP

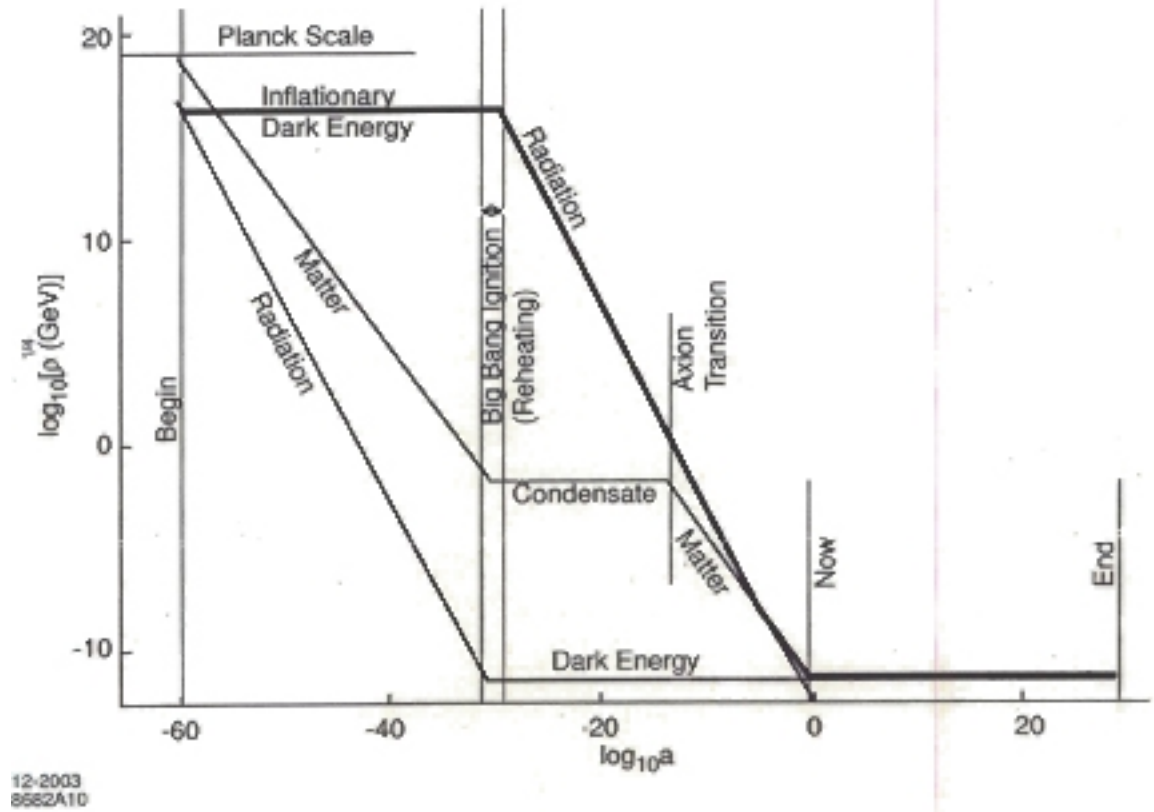
- BOTTOM LINE: UNDERSTAND BIG-BANG IGNITION

SAME IDEA: THE REAL UNIVERSE

(MATTER CONTRIBUTION DISREGARDED)



SAME IDEA: THE REAL UNIVERSE



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III. RECAPITULATION

- LOCAL MULTIVERSE : DATA - DRIVEN
- EXTENDED MULTIVERSE : DATA - DRIVEN
- COSMOLOGICAL CONSTANT IS ANTHROPIC PARAMETER
- WHERE DOES ANTHROPIC REASONING STOP? (IF AT ALL)
- BJORKEN RESCALING
- DOES IT DELIVER?
- IS IT SCIENCE?