IS COSMIC DYNAMICS SELF-REGULATING?

[arXiv:2211.11708]

Presented at the

The Dark Side of The Universe

ICTP-EAIFR

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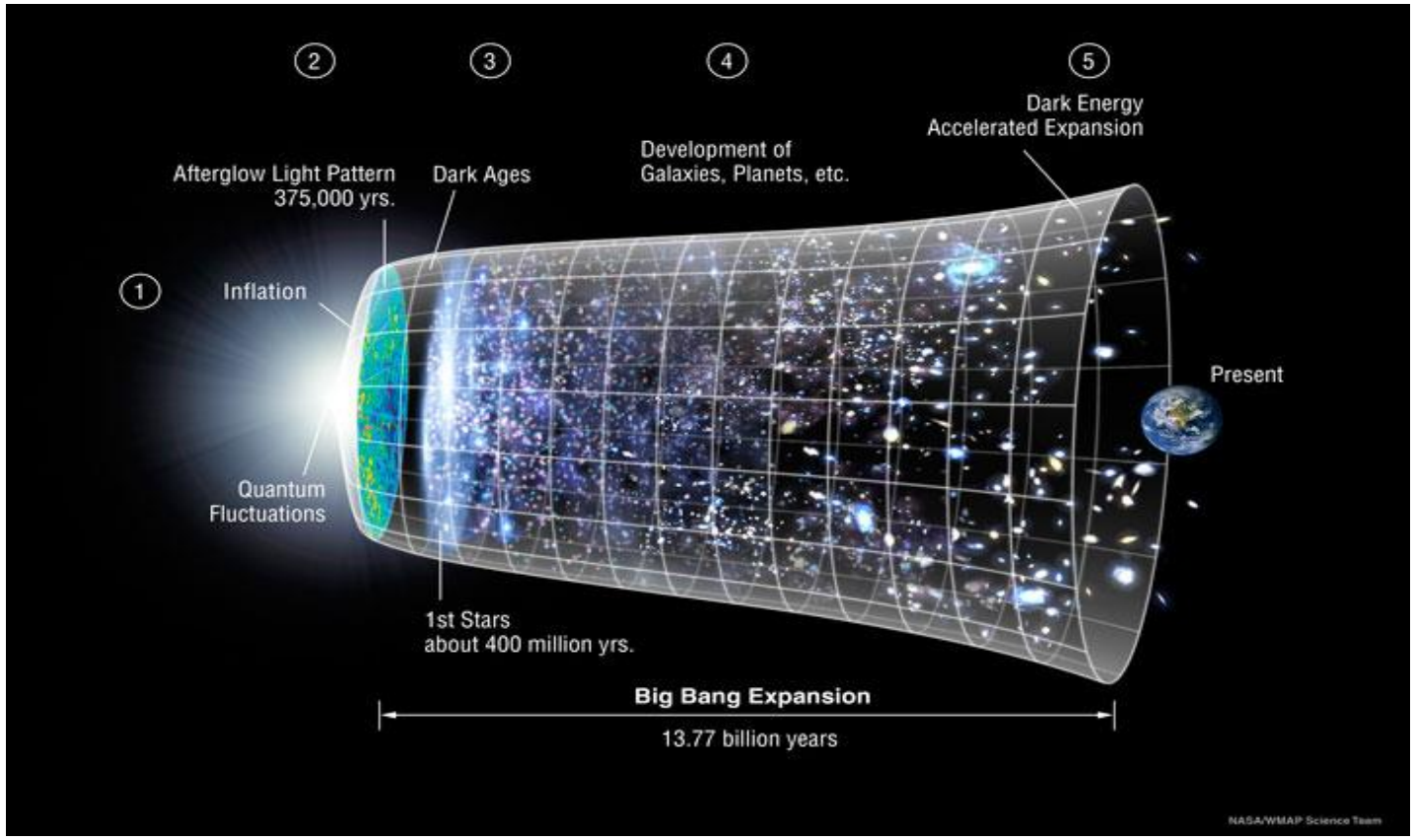
Manasse Mbonye

University of Rwanda

STANDARD MODEL: KOWNS, UNKNOWNS AND QUESTIONS

- Cosmology current picture
  - Inflation (flatness, horizon, monopole)
  - Big Bang
  - Radiation Era (CMB)
  - Structure Formation
  - Cosmic Acceleration

- Leads to current model (Lambda CDM)
- Success interpreting observations

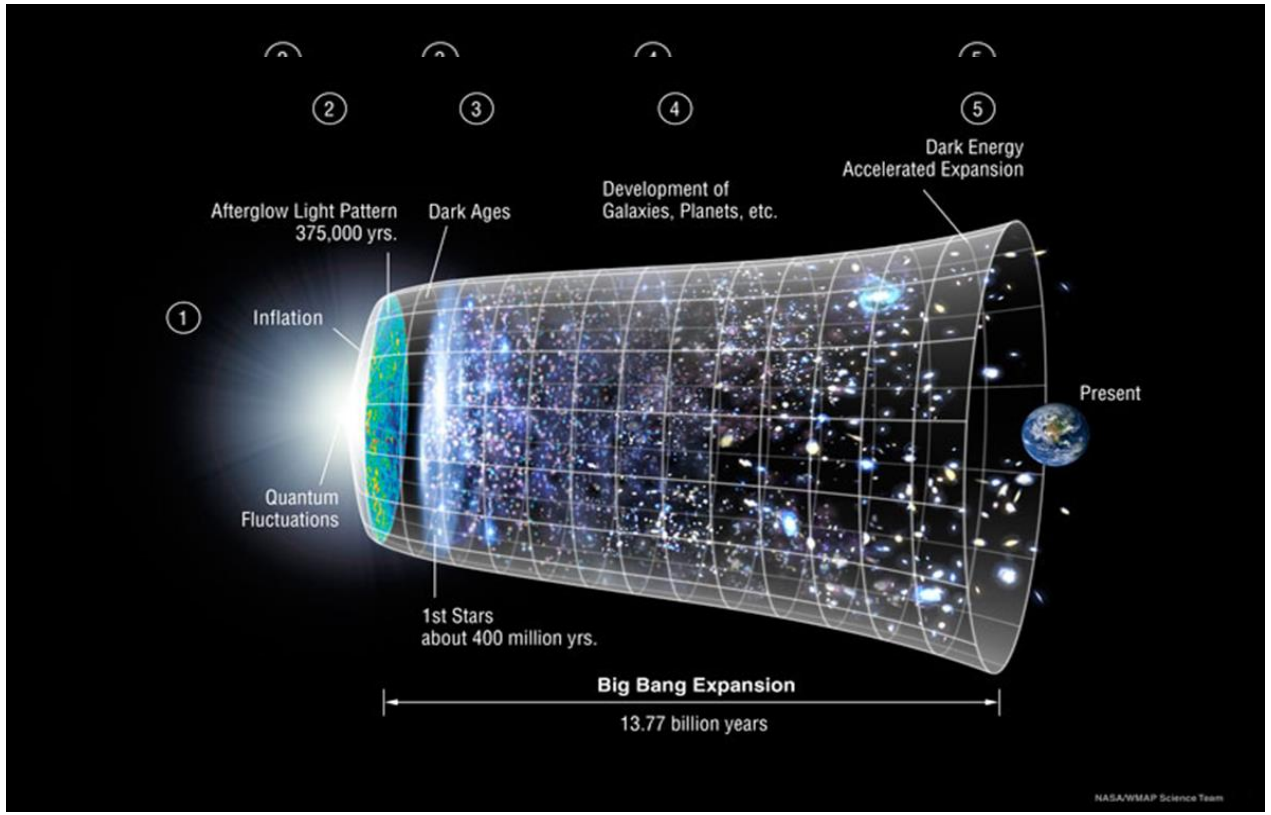


STANDARD MODEL: KOWNS UNKNOWNS AND QUESTIONS

Still LCDM is not without questions:

Including:

- Source of inflaton?
- Dimensionless age riddle: why is $H_0 t_0 \approx 1$?
- Tensions in: H and S8
- JWST: Mature galaxies and black holes at high z(s)



- Is there need to improve LCDM?
- *Is there need for a new paradigm?*
- ***Opinion:*** Cosmology needs a guiding Principle for a bigger picture (connecting epochs).

BACKGROUND NOTE AND RATIONALE

- In this talk we introduce a model of **a universe** with features of **self-regulation** (*suggests big picture?*)

Ingredients:

1. ***Basic space*** has structure and is the fundamental player in cosmic dynamics
2. ***Free matter-energy*** emerges as a perturbative ingredient to the structure, with perturbative effect on cosmic dynamics

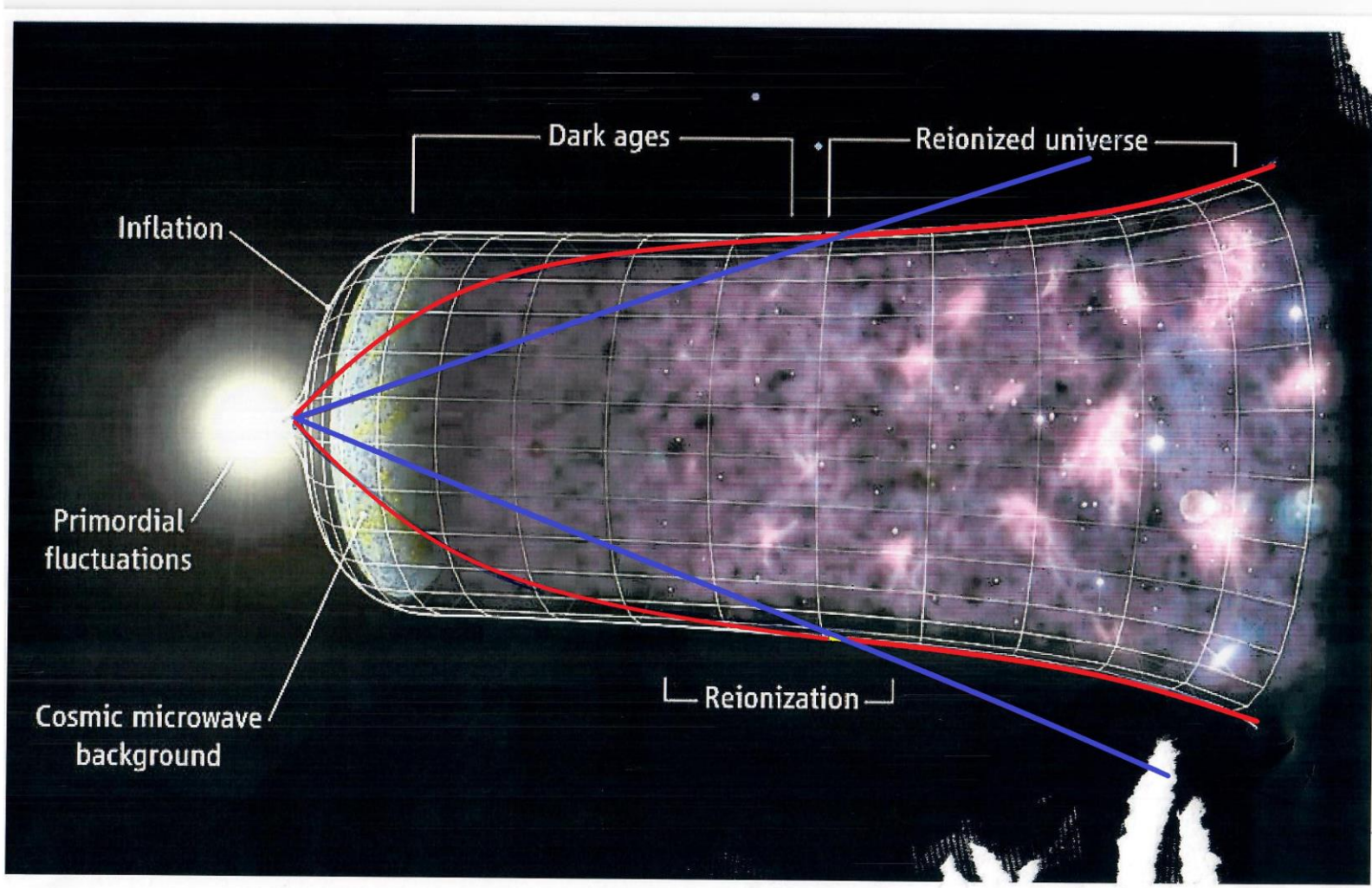
   Approach consistent with GR

Consequences:

- 1 & 2 imply cosmic dynamics characterizes a ***universe seeking to restore its unperturbed dynamical state.***
- Leads to a universe (stable to perturbations) with self-regulating characteristics. ***It is also eternal.***
- Model predicts the ***4 cosmic epochs,*** and reproduces observed values of standard parameters, e.g. $H_0, t_0, \Omega_m, \Omega_{de}, e.t.c..$

PRE-EMPTING THE RESULT

- Picture outline shows the inflationary model
- The blue shows the coasting R = ct model
- The red shows our model. Evolution virtually coincides from LCDM from t = 9.69 Gyrs to t = 19.38 Gyrs



TALK OUTLINE

Contents:

- Model of a self-regulating universe
  - discuss geometry of ***basic space*** and its contribution to ***cosmic dynamics***
  - discuss ***matter-energy*** perturbative contribution to ***cosmic dynamics***
  - discuss resulting full cosmic dynamics
  - establish consistency of the model with cosmological observations
  - **predictions and resolutions**: end of dark energy domination, S8 etc..
  - closing remarks

2. (MODELED) BASIC SPACE AND ITS CONTRIBUTIONS TO COSMIC DYNAMICS (CONT.)

Standard Cosmology

- Cosmological Principal: Space is isotropic and homogeneous defined by R-W-L solution

$$ds^2 = dt^2 - a(t)^2\left(\frac{dr^2}{1-kr^2} + r^2 d\Omega^2\right).....(2.1)$$

The metric is solution to Einstein $G^{\mu}_{\nu} = 8\pi T^{\mu}_{\nu}$ for perfect fluid and leads to Friedman Equations

Above symmetry leaves 2 independent equations

$$\frac{\dot{a}^2}{a^2} + \frac{k}{a^2} = \frac{8\pi G}{3}\rho.....(2.2)$$

and

$$2\frac{\ddot{a}}{a} + \frac{\dot{a}^2}{a^2} + \frac{k}{a^2} = -8\pi G p.....(2.3)$$

Whose combination gives rise to $\frac{\ddot{a}}{a} - 8\pi G(\rho + 3p) = 0.....(2.4)$

And the non independent $\dot{\rho} + 3\frac{\dot{a}}{a}(\rho + p) = 0.....(2.5)$

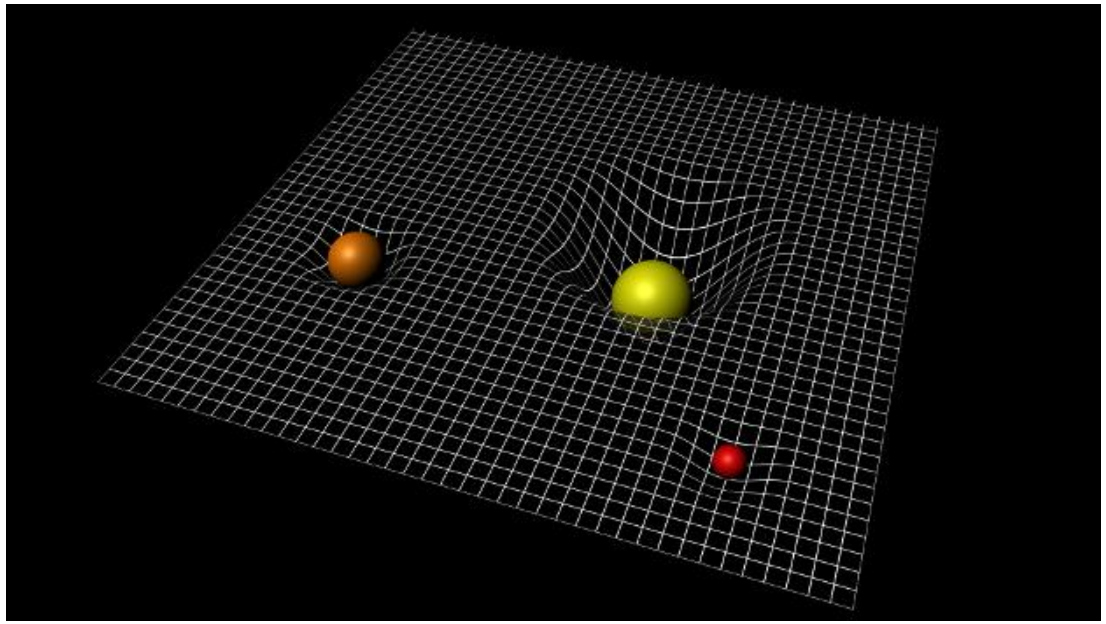
(MODELED) BASIC SPACE AND ITS CONTRIBUTIONS TO COSMIC DYNAMICS (CONT.)

Modeled basic space characteristics

- Obs. 1: Space expands (Hubble)
  Q1. What is it about space that expands?
- Obs. 2: Space curves (G. lensing)
  Q2. What is it about space that curves?
- Obs. 3: Space accelerates (Permute, Riess)
  Q3. What is it about space that accelerates?
- Obs. 4: Space can deform pulsatively (Ligo)
  Q4. What is it about space that deforms?
- Obs. 5: Space may be discrete at small length scales (quantum inferences)
  Q5. What is it about space that discretizes?

- **Each and all of these observations suggest that space does have a structure!**

Matter curves space



(MODELED) BASIC SPACE AND ITS CONTRIBUTIONS TO COSMIC DYNAMICS (CONT.)

Basic space characteristics

- Structure of basic space: - should be energy-like

  - but with a neutral (gravitational) charge.

Note:

- Not first to infer space structure: quantum loop theory suggests this.
- Therefore, this is not a theory of space
- Here will discuss emergent macroscopic effects of the fundamental structure of basic space on cosmic dynamics

- Later to introduce effects of matter-energy on cosmic dynamics (2^{nd} ingredient).
- Finally combine the 2 effects into full cosmic dynamics.

(MODELED) BASIC SPACE AND ITS CONTRIBUTIONS TO COSMIC DYNAMICS (CONT.)

Dynamics induced by basic-space

Assume at macroscopic length scales space can be described as an effective perfect fluid $T_{\nu}^{\mu} = diag(\sigma_s, -\hat{\pi}_s, -\hat{\pi}_s, -\hat{\pi}_s)$

with size identified by scale factor a(t) (*see also E.W. Kolb 1998*).

In absence of deforming matter fields, fluid rests in its inertial frame, so $\ddot{a} = 0$

Then

$$\frac{\dot{a}_s^2}{a_s^2} = \frac{8\pi G}{3}\sigma_s \ldots\ldots\ldots\ldots (2.6)$$

$$\frac{\dot{a}_s^2}{a_s^2} = -8\pi G\hat{\pi}_s, \ldots\ldots\ldots\ldots (2.7)$$

These give

$$\hat{\pi}_s = -\frac{1}{3}\sigma_s \ldots\ldots\ldots (2.8)$$

Guaranteeing gravitational charge neutrality through $\sigma_s + 3\hat{\pi}_s = 0$

(MODELED) BASIC SPACE AND ITS CONTRIBUTIONS TO COSMIC DYNAMICS (CONT.)

Dynamics induced by basic space (cont.)

Integration of the conservation eq. 2.5 In our case leads to $\sigma_s \sim \frac{1}{a_s^2}$ which when compared to Eq. 2.6 shows $a_s \sim t$

$$a_s = v^* t \ldots\ldots\ldots (2.9)$$

Thus scale factor is time linear (basic space expands!). Eq. 2.9 into 2.1 gives, subject to k = 0 gives

$$ds^2 = dt^2 - (v^* t)^2 (dr^2 + r^2 d\Omega^2) \ldots\ldots\ldots (2.10)$$

Conclusions: 2 Results

1) Basic Space has non-vanishing energy density
2) In absence of any matter-energy basic-space (fundamental ingredient) still expands, contributes to cosmic dynamics!

……..

We seek to model a universe which in presence of matter-energy has a full evolutionary expansion of the form:

$$a(t) = a_s(t) + \delta a(t) \ldots\ldots\ldots (2.11)$$

3. CONTRIBUTIONS TO COSMIC DYNAMICS FROM MATTER-ENERGY

Thermodynamics of matter/energy generation

With the background dynamics here controlled by basic space, matter/energy contribution is perturbative.

For a fluid of N particles in a volume V conservation implies $N^{\mu}_{;\mu} \equiv n_{;\mu}u^{\mu} + n\Theta = 0$ with n = N/V and Θ is expansion

For a matter generating fluid source $n_{;\mu}u^{\mu} + n\Theta = n\Gamma \ldots\ldots\ldots (3.1)$

Where $\Gamma > 0$ is matter generation rate and $\Gamma < 0$ is matter annihilation rate

If the particles have density ρ and pressure p, Gibbs entropy eq. evolves as

$$Tds = d(\tfrac{\rho}{n}) + pd(\tfrac{1}{n}) \ldots\ldots\ldots (3.2)$$

Under adiabatic conditions (Tds = 0) Eq. 3.2 evolves as

$$\dot{\rho} + \Theta(\rho + p) - (\rho + p)\Gamma = 0 \ldots\ldots\ldots\ldots (3.3)$$

3. CONTRIBUTIONS TO COSMIC DYNAMICS FROM MATTER-ENERGY (CONT.)

Creation by basic space

In our case with the background basic space we have, on setting $\Theta = 3H$ that

$$\dot{\sigma}_s + 3H(\sigma_s + \hat{\pi}_s + P_c) = 0 \ldots\ldots\ldots (3.4)$$

Where $P_c = -\frac{1}{3H}(\sigma_s + \hat{\pi}_s)\Gamma$ is the particle creation pressure

Using Eqs. 2.6 and 2.8 we can eliminate the density and pressure to get a purely perturbative result

$$\frac{\ddot{a}_m}{a_m} - \frac{1}{3}\Gamma H_m = 0 \ldots\ldots\ldots (3.5)$$

Where $H_m = \frac{\dot{a}_m}{a_m}$ is the contribution due to matter-energy on the dynamics

4. DYNAMIC EQUILIBRIUM PROTECTION PROPOSAL (DEPP)

- Proposal with 3 propositions to link the basic space and matter-energy ingredients into one framework:

Propositions:

1. *The contribution of a flat and specific time-linear (or coasting) expanding background, by basic-space structure, constitutes an **idealized** dynamic equilibrium state to the universe.*
2. *The universe stays in **perpetual search** for stability against perturbations that would tend to shift it from its dynamic equilibrium state. (Such density perturbations could originate from quantum fluctuations)*
3. *When perturbed, the universe seeks to restore its dynamic equilibrium state by suppressing the perturbations through creation of matter-energy of a net gravitational charge opposite that causing the perturbations.*

4.2 REGULATION THROUGH ANNIHILATION

- *By Proposition 3*,
- whenever the Universe happens to be in a state dominated by a net positive gravitational mass density $\rho_r + 3p_r > 0$ so that its dynamics is characterized by cosmic deceleration, $\ddot{a} < 0$, away from equilibrium,
- then, in order to off-set such influence of net positive matter-energy domination, and in search of restoring its dynamic equilibrium state,
- the universe will generate (or equivalently decay the former into) matter-energy with net negative gravitational mass density $\rho_d + 3p_d < 0$, by triggering $\Gamma < 0$
- The reverse is true, whenever the dominating charge is reversed. Effect triggers $\Gamma > 0$

2 REGULATION THROUGH ANNIHILATION

- the annihilation statement implies modification of Eq. 3.5 to now take the form $\frac{\pm\ddot{a}_m}{a_m} - \frac{\mp|\Gamma|H_m}{3} = 0$, so that it is satisfied independent of the sign of $\ddot{a}$.
- This can simply be rewritten in a compact form as $\frac{\ddot{a}_m}{a_m} + \frac{1}{3}|\Gamma|H_m = 0$

On setting $\frac{1}{3}|\Gamma|H_m = \omega^2 = constant,$

We have that $\ddot{a}_m + \omega^2 a_m = 0 \ldots\ldots\ldots (3.6)$

Eq. 3.6 describes effect of matter energy on cosmic dynamics, in the model. It has harmonic solutions:

$$a_m = a_{\max} \sin(\omega t + \psi) \ldots\ldots\ldots (3.7)$$

Recall (Eq. 2.11) the full solution should be $a(t) = a_s(t) + \delta a_s$ where now $\delta a_s = a_m(t) = a_{\max} \sin(\omega t + \psi)$

This gives the model solution $a(t) = v^* t + a_{\max} \sin(\omega t + \psi) \ldots\ldots\ldots (4.1)$

4.1 BOUNDARY AND INITIAL CONDITIONS

No collapsing condition:

Need a non-collapsing Universe then at $\omega t + \psi = \pi(2n+1), n = 0, 1, 2..$ we have that $\dot{a}_{\min} = \upsilon^* - a_{\max}\omega = 0$

which gives $a(t) = \upsilon^*\left[t + \tilde{\tau}\sin\left(\frac{t}{\tilde{\tau}} + \psi\right)\right] \ldots\ldots\ldots (4.3)$

and $H(t) = \frac{1+\cos\left(\frac{t}{\tilde{\tau}}+\psi\right)}{t+\tilde{\tau}\sin\left(\frac{t}{\tilde{\tau}}+\psi\right)} \ldots\ldots\ldots\ldots (4.4)$

$$\tilde{\tau} = \frac{\tau}{2\pi} = \frac{1}{\omega}$$

4.1 BOUNDARY CONDITIONS (CONT.)

Phase angle considerations

Recall results

$$a(t) = v^*\left[t + \tilde{\tau}\sin\left(\frac{t}{\tilde{\tau}} + \psi\right)\right]$$

$$\dot{a}(t) = v^* + a_{\max}\omega\cos(\omega t + \psi)$$

$$H(t) = \frac{1+\cos\left(\frac{t}{\tilde{\tau}}+\psi\right)}{t+\tilde{\tau}\sin\left(\frac{t}{\tilde{\tau}}+\psi\right)}$$

Initial conditions

- Thus at t = 0, we have that

$$a_{t=0} = v^*\tilde{\tau}\sin\psi$$

$$\dot{a}_{t=0} = v^*(1+\cos\psi)$$

$$H_{t=0} = \left(\frac{\dot{a}}{a}\right)_{t=0} = \frac{1+\cos\psi}{\tilde{\tau}\sin\psi}$$

Therefore this universe initially emerges from non-singular conditions

5. CONSISTENCY WITH OBSERVATIONS

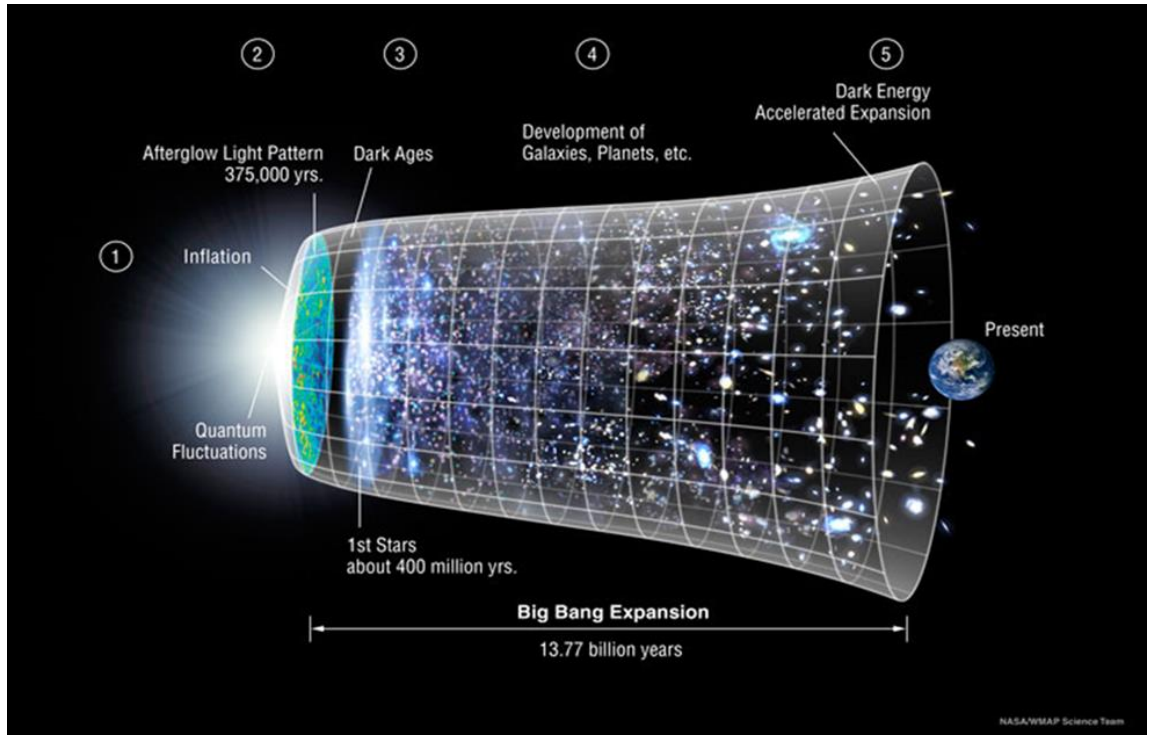
- Recall $H(t) = \frac{1+\cos\left(\frac{t}{\tilde{\tau}}+\psi\right)}{t+\tilde{\tau}\sin\left(\frac{t}{\tilde{\tau}}+\psi\right)}$

Now set $\psi = 0$ so that $H(t) = \frac{1+\cos\frac{t}{\tilde{\tau}}}{t+\tilde{\tau}\sin\frac{t}{\tilde{\tau}}}.$

If recent acceleration started t_{ac} years ago

Then $\tilde{\tau} = \frac{t_0 - t_{ac}}{\pi}$

What we really solve for is $H_0 t_0 = \frac{1+\cos\left(\frac{\pi t_0}{t_0 - t_{ac}}\right)}{1+\left(\frac{t_0 - t_{ac}}{\pi t_0}\right)\sin\left(\frac{\pi t_0}{t_0 - t_{ac}}\right)}$



CONSISTENCY WITH OBSERVATIONS (CONT.)

Consistent with observations [BAO, SNe] we set

$$H_0 t_0 = \frac{1+\cos\left(\frac{\pi t_0}{t_0 - tac}\right)}{1+\left(\frac{t_0 - tac}{\pi t_0}\right)\sin\left(\frac{\pi t_0}{t_0 - tac}\right)} \simeq 0.96$$

Observations also indicate (Frieman et al 2008) $t_{ac} \sim 4Gyr$

We have used the range $4.02 \leq t_{ac} \leq 4.12$

to find a corresponding t_0

- Then used t_0 values to calculate H_0 and τ

CONSISTENCY WITH OBSERVATIONS (CONT.)

General Results

Input	*Output*			
t_{ac}/Gyr	t_0/Gyr	$H_0/kms^{-1}/Mpc$	τ/Gyr	t_{sy-1}/Gyr
4.02	13.59	69.08	19.14	13.69
4.04	13.66	68.697	19.24	13.76
4.06	13.72(5)	68.40(35)	19.33	13.82(5)
4.07	13.76	68.22	19.38	13.86
4.08	13.79	68.11	19.42	13.89
4.10	13.86	67.739	19.52	19.96
4.12	13.93	67.37	19.62	14.03

Best results

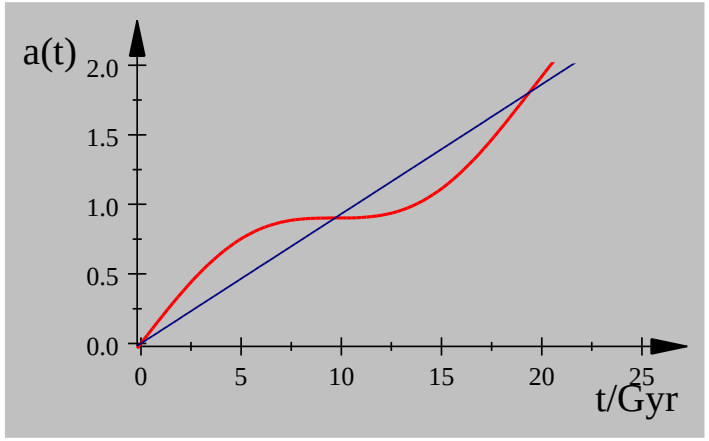
t_{ac}/Gyr	t_0/Gyr	$H_0/kms^{-1}/Mpc$	τ/Gyr	t_{sy-1}/Gyr
$\mathbf{4.07}^{+0.05}_{-0.05}$	$\mathbf{13.76}^{+0.17}_{-0.17}$	$\mathbf{68.22}^{+0.87}_{-0.85}$	$\mathbf{19.38}^{+0.24}_{-0.24}$	$\mathbf{13.86}^{+0.17}_{-0.35}$

Table2：Estimates of cosmological parameters.

SOME FEATURES

1. At t = 0 universe emerges from accel
2. Regular period of cosmic evolution including:

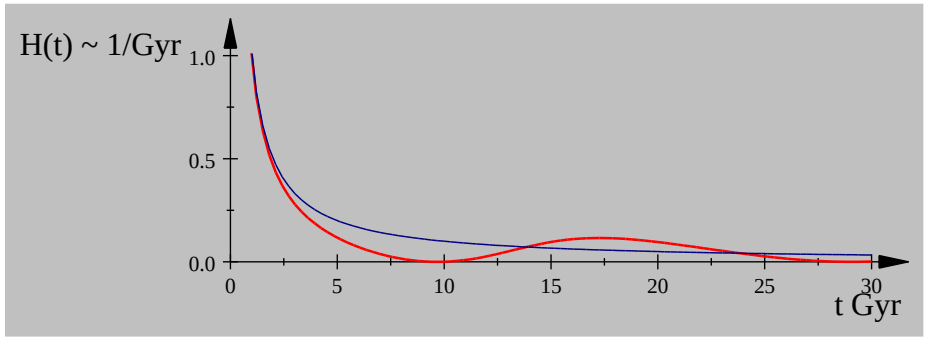
   i) radiation era, ii) structure formation, iii) current accel



3. At t = 9.69 Gyr universe

   - at min expansion rate

   - begins to accel again
4. At t = 19.38 Gyr exits accel gracefully (next BB)
5. t = 19.38 Gyr end of cosmic cycle



CREATED MATTER-ENERGY DRIVES THE DYNAMICS

Recall $$\frac{\ddot{a}}{a} + \frac{4\pi G}{3}(\rho + 3p) = 0$$

- Set $$\Delta = \rho + 3p = -\frac{\ddot{a}}{a} = \frac{3}{4\pi G}\left[\frac{\frac{t}{\tilde{\tau}}\sin\frac{t}{\tilde{\tau}} + \sin^2\frac{t}{\tilde{\tau}}}{a^2}\right]$$
- And $$\Delta = \Delta_{++} + \Delta_{+-}$$
- so $$\Delta_{+-} = \frac{3}{4\pi G}\left[\frac{\frac{t}{\tilde{\tau}}\sin\frac{t}{\tilde{\tau}}}{a^2}\right]$$
- And $$\Delta_{++} = \frac{3}{4\pi G}\left[\frac{\sin^2\frac{t}{\tilde{\tau}}}{a^2}\right]$$
- Find $$\Omega_{de} = \left[\frac{\left|\Delta_{\frac{1}{2}(+-)}\right|}{\left|\Delta_{\frac{1}{2}(+-)}\right| + \Delta_{++}}\right]_{t=t_0} = 0.69721 \text{ and } \Omega_m = \left[\frac{\Delta_{++}}{\left|\Delta_{\frac{1}{2}(+-)}\right| + \Delta_{++}}\right]_{t=t_0} = 0.30279$$

RESULT SUMMARY TABLE

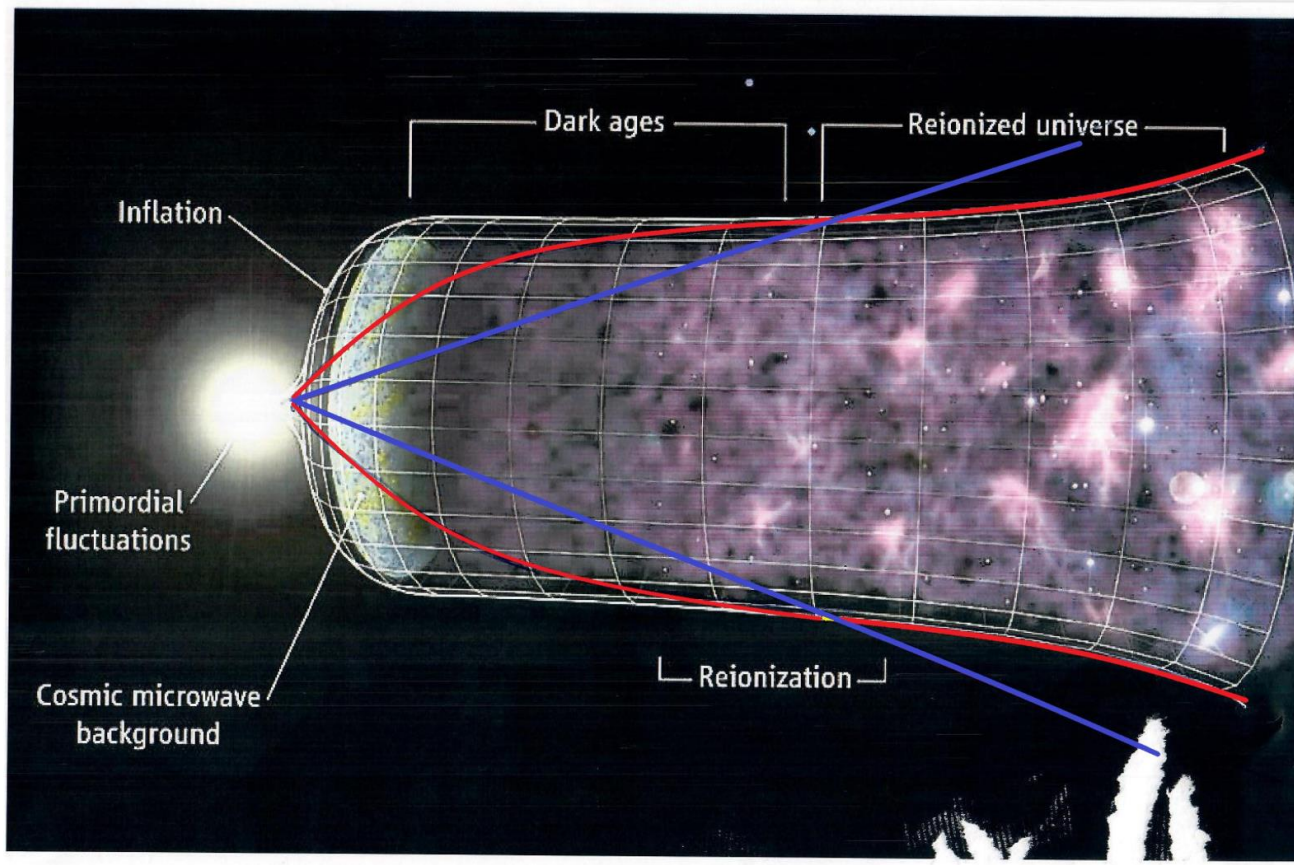
Input	*Output*					
t_{ac}/Gyr	t_0/Gyr	$H_0/kms^{-1}/Mpc$	τ/Gyr	t_{sy-1}/Gyr	Ω_{de}	Ω_m
$\mathbf{4.07}^{+0.05}_{-0.05}$	$\mathbf{13.76}^{+0.17}_{-0.17}$	$\mathbf{68.22}^{+0.87}_{-0.85}$	$\mathbf{19.38}^{+0.24}_{-0.24}$	$\mathbf{13.86}^{+0.17}_{-0.35}$	69.7%	30.3%

Table2 : Summary of model's calculated best estimates of cosmological parameters.

UNIVERSE TIMELINE:

Conclusion:

- model:
  - depicts self-regulating universe
  - depits eternal universe
  - reproduces all the 4 evolutionally epochs
  - implies BB preceded by non-exponential accel
  - reproduces observed parameters
  - suggests way out of the H & S8 tensions



MURAKOZE!

THANK YOU!

FOR YOUR ATTENTION!!!