Accelerated expansion?

Or

Cosmic backreaction as an alternative cosmological model

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Outline

The standard model of cosmology

The standard model

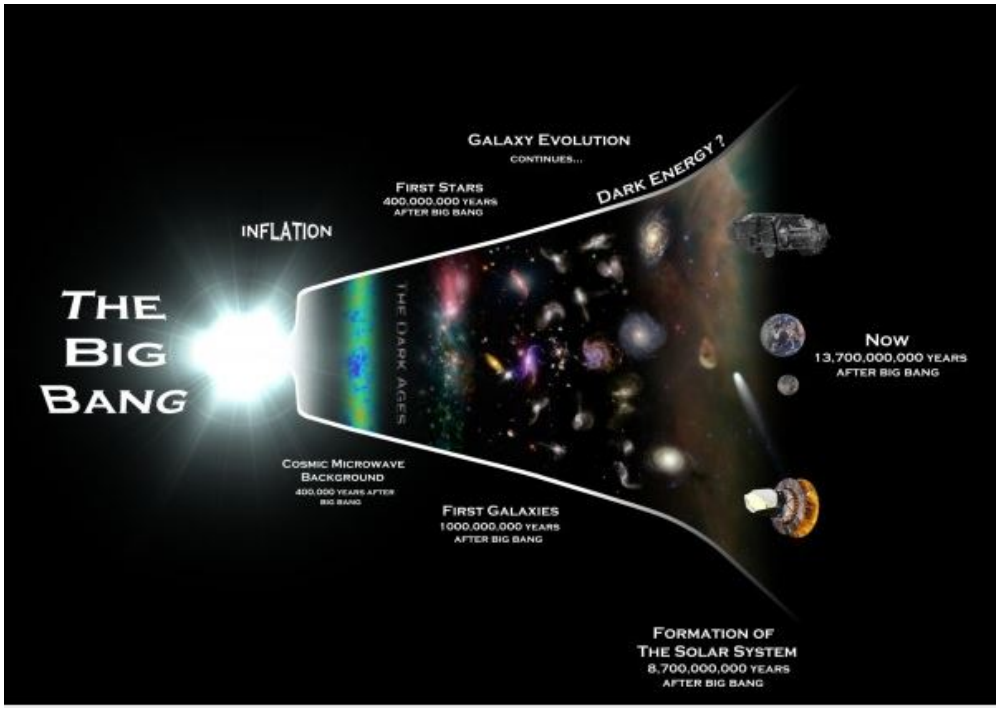
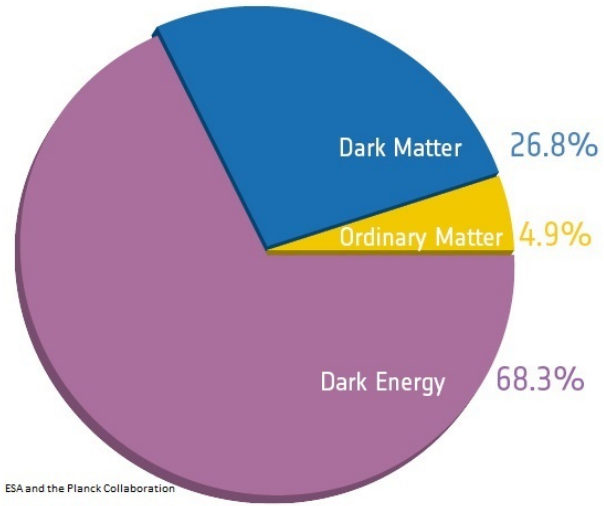


Image credit: Rhys Taylor, Cardiff University.

- Big Bang 13.7 Gyr ago
- Describes primordial nucleosynthesis
- Predicts CMB
- Inflations solves flatness, monopole, horizon problems
- Inflation predicts form of primordial fluctuations

The ΛCDM model

- Based on FLRW spacetime
- Predictions based on FLRW models are impressively consistent with observations
- ...but only if we introduce "dark energy" and "dark matter"!
  $\rightarrow$ ΛCDM
  - Physical origin entirely unknown



Observational issues

- ^{7}Li/H (Lack of ^{7}Li in metal poor stars compared to ΛCDM-CMB expectation)
- Wrong amount of structure on large and small scales (from weak lensing and the CMB)
- Alignments and (a-)symmetries in CMB in tension with ΛCDM
- H_0-tension (and related short sound horizon distance)

Future observations

- Enormous amount of data to be used for pinpointing phenomenology of DE
- Data can also be used to test FLRW assumption
  - If observations fail FLRW consistency relations, the main foundation of cosmology is lost

Cosmic Backreaction

Cosmic backreaction

$\langle\cdot\rangle$ = volume average over some spatial domain

- $G_{\mu\nu} = \frac{8\pi G_N}{c^4} T_{\mu\nu} \nRightarrow \langle G \rangle_{\mu\nu} = \frac{8\pi G_N}{c^4} \langle T \rangle_{\mu\nu}$
- Spatial averaging and temporal development do not commute in general relativity

The Buchert equations

a = scale factor = scales lengths as Universe expands/contracts
$a_D \propto (V_{proper})^{1/3}$ = "volume average" scale factor

$$\left(\frac{\partial_t a}{a}\right)^2 = \frac{8\pi G_N}{3c^2}\epsilon - \frac{\kappa c^2}{R_0^2 a^2} + \frac{\Lambda}{3}, \quad \text{Friedmann 1}$$

$$\left(\frac{\partial_t a_D}{a_D}\right)^2 = \frac{8\pi G_N}{3c^2} < \epsilon > - \frac{< R >}{6} + \frac{\Lambda}{3} - \frac{Q}{6}, \quad \text{Buchert 1}$$

$$\frac{\partial_t^2 a}{a} = -\frac{4\pi G_N}{3c^2}\epsilon + \frac{\Lambda}{3}, \quad \text{Friedmann 2}$$

$$\frac{\partial_t^2 a_D}{a_D} = -\frac{4\pi G_N}{3c^2} < \epsilon > + \frac{\Lambda}{3} + \frac{Q}{3}, \quad \text{Buchert 2}$$

Backreaction

- Can in principle explain DE (*and* DM?)
- Solve observational issues? - perhaps in combination with other extensions
- Backreaction is predicted theoretically

So why is backreaction ignored in standard cosmology?

- Complicated to use and to quantify
- Spatial averages are not related to observations in an obvious way!

My work on backreaction

- Objective: Determine relation between spatial averages and observations on light cone
- Method: Construct exact solutions with backreaction

Basics of Swiss cheese models

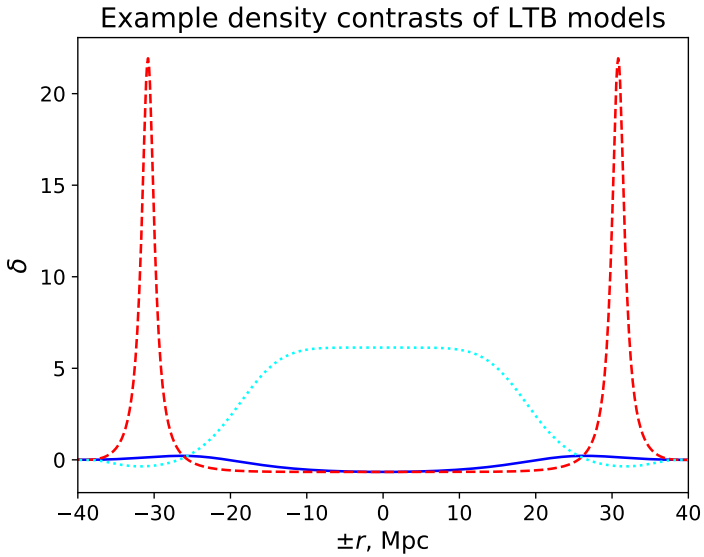
- Remove "holes" from FLRW background and insert inhomogeneous model, fulfilling Darmois junction conditions
- Advantage: Statistically homogeneous and isotropic

Lemaitre-Tolman-Bondi models

$$ds^2 = -c^2 dt^2 + \frac{A_{,r}^2}{1-k} + A^2 d\Omega^2$$

$$\frac{1}{c^2} A_{,t}^2 = \frac{2M}{A} - k + \frac{1}{3c^2}\Lambda A^2 \implies$$
$$c(t - t_{bb}(r)) = \int_0^A \frac{d\tilde{A}}{\sqrt{\frac{2M}{\tilde{A}} - k + \frac{1}{3c^2}\Lambda \tilde{A}^2}}$$

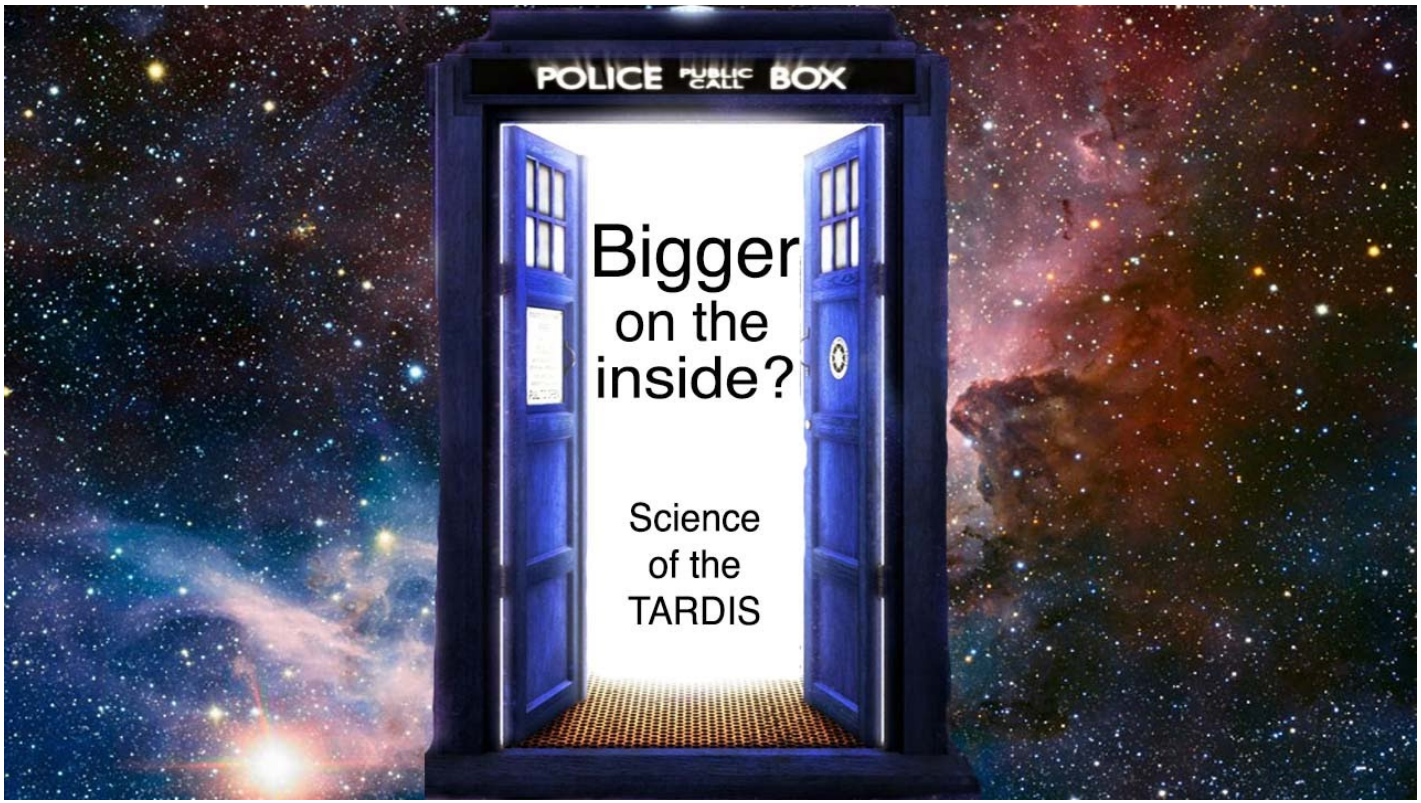
$$\rho = c^4 \frac{2M_{,r}}{8\pi G_N A^2 A_{,r}}$$



How to get backreaction

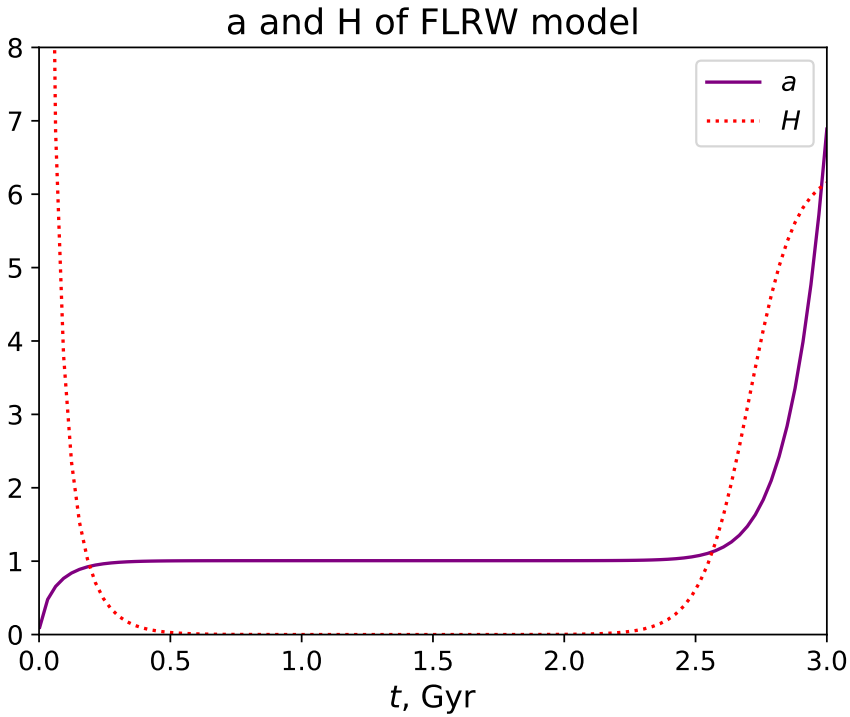
Theorem from JCAP12(2013)051 (Mikko Lavinto, Syksy Rasanen, Sebastian J. Szybka: Average expansion rate and light propagation in a cosmological Tardis spacetime, arXiv:1308.6731v2 [astro-ph.CO])

Basic point: Look at the volume $V \propto \int_0^{r_b} dr \frac{|A_{,r}|A^2}{\sqrt{1-k}} \approx a^3 r_b^3$



Loitering FLRW universe

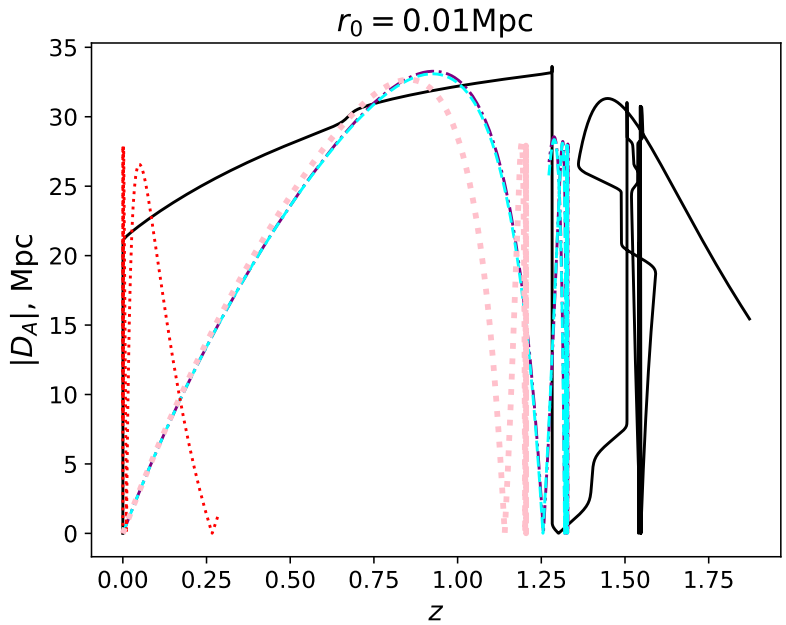
Astrophys.J. 385 (1992) 1-8 Varun Sahni, Hume Feldman, Albert Stebbins: Loitering universe



- Loitering = semi-static phase: $\dot{a} \simeq 0 \simeq \ddot{a}$
- Achieve by adding substance with $-1 \leq \omega \leq -1/3$
- Occur as inflection points or as asymptotic towards static universe

Cons

- Non-trivial t_{bb}
- BIG background curvature instead of flat ($\Omega_{m,1} = 16000$, $\Omega_{\Lambda,1} = 7845.91355$)
- Large local effects (impedes light propagation studies)



Summary

- Standard model of cosmology successful but mainly phenomenological and observational issues are appearing
- Near-future possibility to falsify FLRW foundation of cosmology
- Cosmic backreaction possible candidate to take over as standard model of cosmology
- Important to identify relation between light cone and spatial averages to asses results from upcoming surveys