Backreaction in Swiss cheese models

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Outline

Motivation

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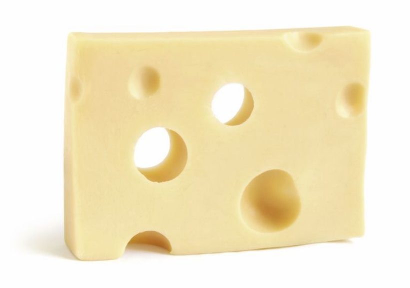
Exact solutions are not realistic enough for realistic quantifications of backreaction, but:

- Sanity checks of numerical codes
- Simple $\rightarrow$ Good for proof-of-principle/concept
- Light propagation: Identify relation between observables and spatial averages
  - Several different suggestions in the literature, e.g. Julien Larena et al. 0808.1161 vs. Syksy Rasanen 0812.2872
  - Relation to FLRW consistency tests

Swiss cheese models

Basics of Swiss cheese models

- Remove "holes" from FLRW background and insert inhomogeneous model, fulfilling Darmois junction conditions
- Typical structures: Schwarzschild/Kottler, LTB, Szekeres
- Draw back: No interaction between holes
- Advantage: Statistically homogeneous and isotropic (Method for close-packed random packing of structures: S. M. Koksbang arXiv:1703.03572)

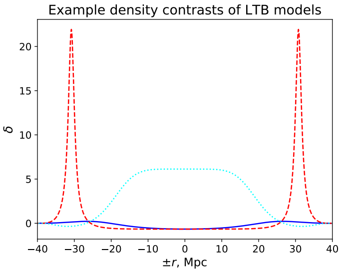


Lemaitre-Tolman-Bondi models

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

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

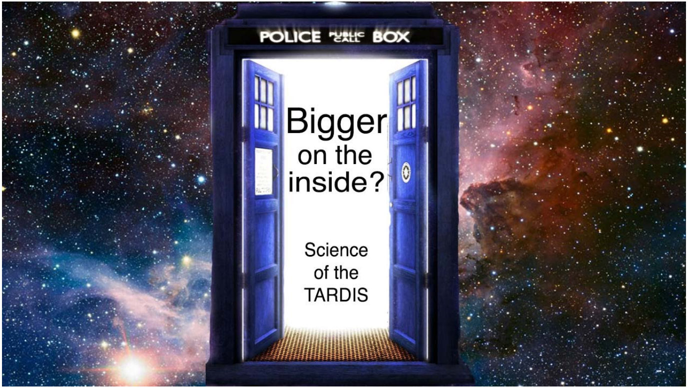
$$\rho = c^4 \frac{2M_{,r}}{8\pi G_N A^2 A_{,r}}$$



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 $V \propto \int_0^{r_b} dr \frac{|A_{,r}|A^2}{\sqrt{1-k}} \approx a^3 r_b^3$



How to get backreaction

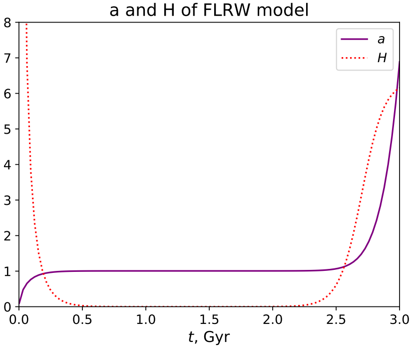
- In JCAP12(2013)051 $A_{,r} \geq 0$ was violated
  - Surface layers, affecting light propagation studies
- For dust spacetimes, large curvature implies short lives or shell crossings
- Avoid by adding pressure

Example

(based on 1907.08681)

Loitering FLRW universe

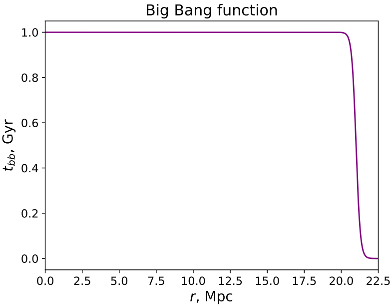
Astrophys.J. 385 (1992) 1-8 Varun Sahni, Hume Feldman, Albert Stebbins: Loitering universe



- 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

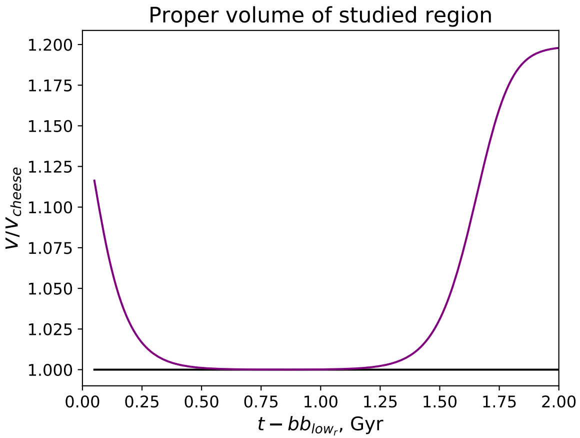
Inhomogeneous t_{bb}

Turn Loitering FLRW universe into inhomogeneous LTB structure by using inhomogeneous t_{bb}

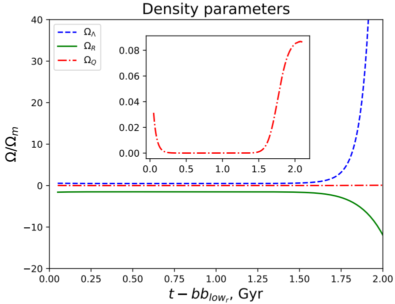


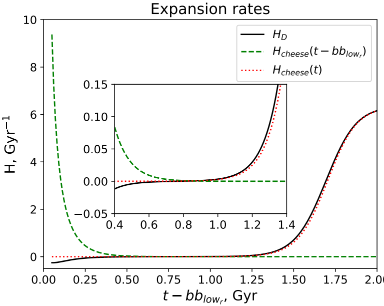
$$t_{bb}(r) = \frac{t_{low_r} e^{t_{slopelocation}{}^{t_{slope}}} + t_{high_r} e^{t_{slope}{}^{r}}}{e^{t_{slopelocation}{}^{t_{s}{}^{lope}}} + e^{t_{slope}{}^{r}}}$$

Resulting volume



Kinematical backreaction and expansion rate



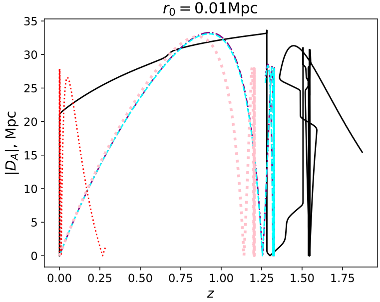


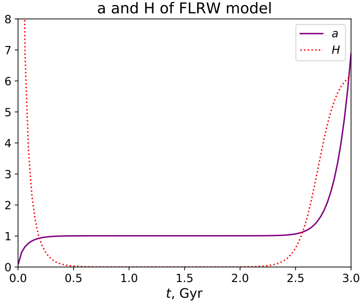
Pros

- Non-negligible cosmic backreaction
- Long lived
- Smooth everywhere (no surface layers)

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)





Future work

Holes made of inhomogeneous cosmological models with inhomogeneous pressure components

- Lemaitre models
- Interacting dark energy-dark matter models with LTB and Lemaitre metric: astro-ph/0503609, 1705.08351
- LTB and Szekeres-Szafron metrics with Ideal gas source (viscosity, anisotropic pressure): gr-qc/9710069, gr-qc/9810027, gr-qc/0111010
- N decoupled fluids (spherical symmetry): 1105.6099, 1811.03634

Summary

- Perfect fluid Swiss cheese models with cosmic backreaction possible
- USEFUL perfect fluid Swiss cheese models with cosmic backreaction PROBABLY possible
- Exact solutions good for sanity checks and testing numerical relativity, proof-of-principle, light propagation