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on cosmological observables in a swiss-cheese universe

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Light-cone averages in a swiss-cheese universe

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The “safe” consequence of the success of the concordance model is that the isotropic and homogeneous LCDM model is a good observational fit to the real inhomogeneous universe.

And this is, in some sense, a verification of the cosmological principle: the inhomogeneous universe can be described by means of an isotropic and homogeneous solution.
smoothing out of inhomogeneities?

dual point of view

mean-field description

d_L(z) [using LTB solutions]

Buchert’s formalism

light-cone averages

fitting approach

observer in a void

“homogeneous” profile

Swiss cheese

constant-time averaging

observationally meaningful

c. principle works

[the “back-reaction”]
Swiss cheese

matching at
\[ r_h = 0.042 \approx 350 \, \text{Mpc} \]
Dynamics

CURVED CASE

\[ t = 0 \text{ (divided by 10)} \]

\[ t = -0.4 \]

\[ t = -0.8 \]

\[ r_h \]

\[ \rho(r, t) / \rho(\infty, t) \]

\[ v(r, t) \]

\[ Y(r, t) \]

Graph showing the evolution of density, velocity, and mass fraction with respect to radial coordinate \( r \) for different times \( t \) in a curved case scenario.
\[ d_L = (1 + z)^2 d_A \]

**concordance model:** $\Lambda CDM$ with $\Omega_M = 0.3$, $\Omega_{DE} = 0.7$
$q_0 = \Omega_M/2 - \Omega_{DE} = -0.55$

**reference model:** $\Lambda CDM$ with $\Omega_M = 0.6$, $\Omega_{DE} = 0.4$
$q_0 = \Omega_M/2 - \Omega_{DE} = -0.1$

**EdS model:** $\Lambda CDM$ with $\Omega_M = 1$, $\Omega_{DE} = 0$
$q_0 = \Omega_M/2 - \Omega_{DE} = 0.5$
Mean-field description: fitting problem

cosmological principle

observational cosmology

Ellis, Stoeger 87
Fitting along the light cone

phenomenological model

\[
\frac{\rho_{\text{FIT}}}{\rho_0} = \Omega_M (1 + z)^3 + \Omega_\Lambda (1 + z)^{3(1 + w_0 + w_a)} \exp \left(-3w_a \frac{z}{1 + z}\right)
\]

\[w(z) = w_0 + w_a \frac{z}{1 + z}\]

\[
\langle Q^{\text{SC}} \rangle_{EO_i} = \left[ \int_E^{O_i} dr \frac{Y'}{W} \right]^{-1} \int_E^{O_i} dr \frac{Q^{\text{SC}}(r, t(r)) Y'(r, t(r))}{W(r)}
\]

\[
\langle Q^{\text{FIT}} \rangle_{EO_i} = \left[ \int_E^{O_i} dr \ a_{FIT} \right]^{-1} \int_E^{O_i} dr \frac{Q^{\text{FIT}}(t_{FIT}(r)) a_{FIT}(t_{FIT}(r))}{W(r)}
\]

This method will be intermediate between the fitting approach and the averaging approach.
\[ w \approx 0 \]

\[ w_0 = -1.95, \ w_\alpha = 4.28 \]
Beyond spherical symmetry

Swiss-cheese model with spherically symmetric holes

$\langle \rho \rangle$

density is not particularly sensitive to spherical symmetry

Swiss-cheese model with non-spherically symmetric holes

photon redshift not affected by inhomogeneities

a photon spending most of its time in voids should have a different redshift history

photon redshift affected by inhomogeneities

model behaving similarly to the concordance model
Renormalizing the cheese

\[ \rho_{\text{FIT}}^{\text{FIT}} = (1 + z)^{3(1+w_0^R+w_a^R)} \exp \left( -3w_a^R \frac{z}{1+z} \right) \]

\[ w^R(z) = w_0^R + w_a^R \frac{z}{1+z} \]

**Best fit for:** \( r_h = 250 \text{ Mpc} \)

\[
\begin{align*}
  w_0^R &= -1.4 & w_0 &= -1.03 \\
  w_a^R &= 0.67 & w_a &= 2.19
\end{align*}
\]

\[
\begin{align*}
  \frac{w_0^R(n)}{w_0^R(0)} &= q_0 \left( \frac{r_h(n)}{r_h(0)} \right)^{p_0} & p_0 &= p_a \approx 1.00 \\
  \frac{w_a^R(n)}{w_a^R(0)} &= q_a \left( \frac{r_h(n)}{r_h(0)} \right)^{p_a} & q_0 &= q_a \approx 0.88
\end{align*}
\]
Conclusions

- Need to define how to smooth out inhomogeneities
- *Faster-than-cheese expanding voids as crucial ingredient*
- Fitting along the light cone as a way to go beyond spherical symmetry

Work in progress

- *More realistic (less toy) Swiss-cheese*
- *Swiss-cheese models in Newtonian gauge*
References

- V. Marra, E. W. Kolb, S. Matarrese, A. Riotto
  *On cosmological observables in a swiss-cheese universe.*
  *Phys. Rev. D* 76, 123004 (2007)

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  *Light-cone averages in a swiss-cheese universe.*

- V. Marra, E. W. Kolb, S. Matarrese
  *Swiss-cheese models in Newtonian gauge.*
  *Coming soon!*
THANKS