Ways to settle the backreaction conjecture

Syksy Räsänen

University of Helsinki

Department of Physics,
Helsinki Institute of Physics

A factor of 2

- Around 10 billion years, the expansion rate rises by about 50% relative to the FRW EdS model. ($H_0 t_0 \approx 1$ instead of $H_0 t_0 = 2/3$.)

- Observations are consistent with a FRW model with cosmological constant Λ.
  - Posterior for any model that did not predict small deviation from ΛCDM is lower than 20 years ago.
  - Models with significant deviations from ΛCDM are still observationally allowed.

A possibility

- **The backreaction conjecture:** the reason for the failure of the exactly homogeneous and isotropic dust model is the known breakdown of local homogeneity and isotropy.

1. Structure formation has a preferred timescale of ~10 billion years, imprinted on the CDM transfer function in the combination $A^{-3/2}\, t_{eq}$. (SR: 0801.2692)
2. There is a simple mechanism for acceleration: the fraction of volume in faster expanding regions increases, so the average expansion rate rises. (Kai et al: gr-qc/0605120, SR: astro-ph/0605632, astro-ph/0607626)
3. Local variations in the expansion rate are of the same order of magnitude as the observed deviation from EdS.

- Is change in the mean of the same size as local variations?

Average acceleration

120 **40**

120 x 0.5 + 40 x 0.5 = 80

100 **10**

100 x 0.9 + 10 x 0.1 = 91

What we know

- In Newtonian gravity, variations in the expansion rate cancel in the average. (Ehlers and Buchert: astro-ph/9510056)
  - In GR, this is not the case. (It would be equivalent to a conservation law for the spatial curvature.)

- If the metric, its 1st derivatives and the four-velocity are perturbatively close to FRW, then: (SR: 1107.1176)
  1. Redshift is close to FRW.
  2. Average expansion rate is close to FRW.
  3. Distance is not necessarily close to FRW. (But if the universe is statistically homogeneous & isotropic, it likely is.)

- Three ways to settle the conjecture.

Analytical work

- Perturbative studies.
  - If is shown that the metric remains close to FRW, we will establish that backreaction is small.
  - If it is shown that metric does not remain close to FRW, this does not establish that backreaction is large.

- Statistical models.
  - Using collections of regions, it has been shown that backreaction could lead to acceleration.
  - The difference between Newtonian and relativistic constraints has to be carefully addressed.

Simulations

- Have perturbative GR simulations established that perturbations remain small? (Adamek, Daverio, Durrer, Kunz: 1308.6524,1408.3352, 1509.01699,1604.0606)

- Non-perturbative GR simulations can establish whether backreaction is small or large. (Giblin, Mertens, Starkman: 1511.01105, 1511.01106, 1704.04307; Bentivegna and Bruni: 1511.05124, 1610.05198; Macpherson, Lasky, Price: 1611.05447)

- Non-perturbative simulations so far have not been realistic.

- Intermediate step: showing that the effect can be large in a reasonable toy model.

Observations

- If we can observationally rule out the FRW metric, this would provide strong support for backreaction.
- Backreaction has a unique observational signature: deviations from FRW consistency conditions. (Clarkson, Bassett, Lu : 0712.3457)

$$k_H = \frac{1 - h(z)^2 d'(z)^2}{d(z)^2}$$

$$d(z) = H_0(1+z)D_A(z)$$
$$h(z) = H(z)/H_0$$
$$k_H = -\Omega_{K0}$$

- See Francesco Montanari's talk on Thursday.
- If consistency is pushed to better than 1%, backreaction seems unlikely.

Consistency condition: distance sum rule

- In a spatially flat FRW universe, comoving angular diameter distances add up linearly.

$$d(0, z_s) = d(0, z_l) + d(z_l, z_s) \Leftrightarrow d_s = d_l + d_{ls}$$

- With spatial curvature, distances instead add up as

$$d_{ls} = d_s \sqrt{1 - k_S d_l^2} - d_l \sqrt{1 - k_S d_s^2} \ .$$

- For FRW, k_S is constant (SR, Bolejko, Finoguenov: 1412.4976):

$$k_S = -\frac{d_l^4 + d_s^4 + d_{ls}^4 - 2d_l^2 d_s^2 - 2d_l^2 d_{ls}^2 - 2d_s^2 d_{ls}^2}{4d_l^2 d_s^2 d_{ls}^2}$$

- Strong lensing gives d_{ls}, allowing to check this. Current constraints are $-0.08 < k_S \lesssim 1$.

Consistency condition: angular diameter and parallax

- Parallax gives an independent notion of distance from luminosity/angular diameter.
  $$D_P = \delta x / \delta \varphi$$
- Comparison of angular diameter and parallax distance provides another test of the FLRW metric. (SR: 1308.6731)

$$k_P = \frac{1}{d^2} - \left(\frac{1}{d_P} - 1 \right)^2$$

$$\begin{aligned} d(z) &= H_0 (1+z) D_A(z) \\ d_P(z) &= H_0 D_P(z) \\ h(z) &= H(z)/H_0 \end{aligned}$$

- Gaia measurements of quasars (and perhaps galaxies) may be used to determine D_P on cosmological scales.

Conclusions

- Backreaction is a possible explanation for the observed change in the expansion rate.
- There does not appear to be an obvious reason for why the change would be as close to ΛCDM as observed.
- Perturbative studies could show the change is small, non-perturbative simulations could show it is large.
- It is possible to observationally test whether the FRW metric is valid. If no deviation from FRW (or ΛCDM) is seen, the plausibility of backreaction decreases.