Voids as cosmological structures

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Large Scale Structure and Galaxy Flows

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* Lambda effect in the cosmological expansion of voids. *H.H. Fliche, R.Triay* - JCAP 11:022 (2010)
* Dynamics of Void and its Shape in Redshift Space. *K. Maeda, N. Sakai, R.Triay* - JCAP 08:026 (2011)
* Isotropization of voids. *N.D. Nguyen, R.Triay* - in preparation

The cosmological constant effect

- **Voids** are **non linear structures** — e.g., Traveling Wavelets approach to the Gravitational Instability theory. – One dimensional Wavelets . – N. Benhamidouche, B. Torresani, R. Triay. MNRAS 302,807(1999) :
  — This might be the reason why the universe looks so empty

- « vacuum gravitational repulsion » ?
  e.g., Schwarzschild solution of Einstein Eq. with a Cosmological Constant

$$\vec{g} = \left(-\mathrm{G}\frac{m}{r^3} + \frac{\Lambda}{3}\right)\vec{r}$$

$$r_\circ = \sqrt[3]{3m\mathrm{G}/\Lambda}$$

No effect in the Solar neighborhood $r_\circ \sim 10^2 h^{-2/3}\ \mathrm{yr}$
Small effect in the outerpart of the Galaxy $r_\circ \sim 5\,10^5 h^{-2/3}\ \mathrm{yr}$
Intervenes at the edge of LSC $r_\circ \sim 4\,10^8 h^{-2/3}\ \mathrm{yr}$
Homogeneity scale $(\sim 100\,\mathrm{Mpc})$

- The dimensional analysis of Einstein equations shows that the cosmological constant effect intervenes (solely) at cosmological scale.

The dynamics of voids

- Modeling **a "single void" embedded in a Friedmann Lemaître Universe** (as a first step to a more realistic investigation…)

  - - (sphere) Newton - Friedmann model
  - - (sphere) GR "FL^{in} - FL^{out}" Model
  - - (ellipsoid-revolution) Newton - Friedmann model

Friedmann - Newton Model

Covariant global solution to Euler- Poisson Eqs. System

Reference Coordinates $(t, \quad \vec{x} = \frac{\vec{r}}{a}), \qquad a > 0$

$$H = \frac{\dot{a}}{a} = \sqrt{\frac{\Lambda}{3} - \frac{K_\circ}{a^2} + \frac{8\pi \mathrm{G}}{3}\frac{\rho_\circ}{a^3}}$$

$$K_\circ = \frac{8\pi \mathrm{G}}{3}\rho_\circ + \frac{\Lambda}{3} - H_\circ^2 \leq \sqrt[3]{(4\pi \mathrm{G}\rho_\circ)^2\,\Lambda}, \qquad a_\circ = 1$$

$$\vec{v}_c = \alpha \vec{x}, \qquad \vec{g}_c = \beta \vec{x}$$

$$\frac{\mathrm{d}\alpha}{\mathrm{d}t} + 4\alpha^2 + 2H\alpha - \frac{2\pi \mathrm{G}}{3}\frac{\rho_c}{a^3} = 0$$

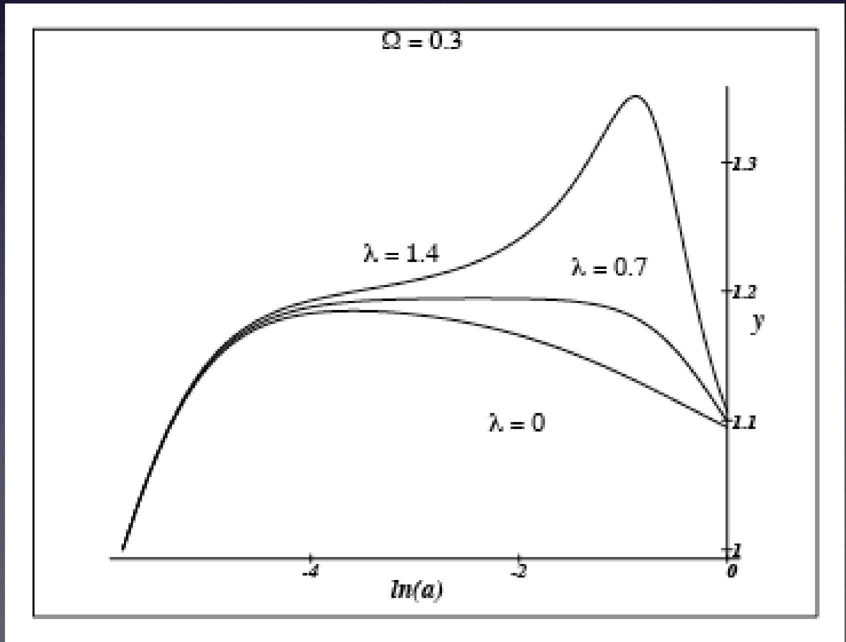
$$\beta = \frac{4\pi \mathrm{G}}{a^3}\left(\frac{\rho_c}{3} - \frac{(\rho \mathrm{S})_c}{2x}\right)$$

Magnification & Expansion Rates

$$\vec{v}_c = \alpha \vec{x}, \qquad \vec{g}_c = \beta \vec{x}$$

$$X = \frac{x}{x_i}, \qquad Y = \frac{\alpha}{H_\circ}$$

y : Corrective factor to Hubble expansion



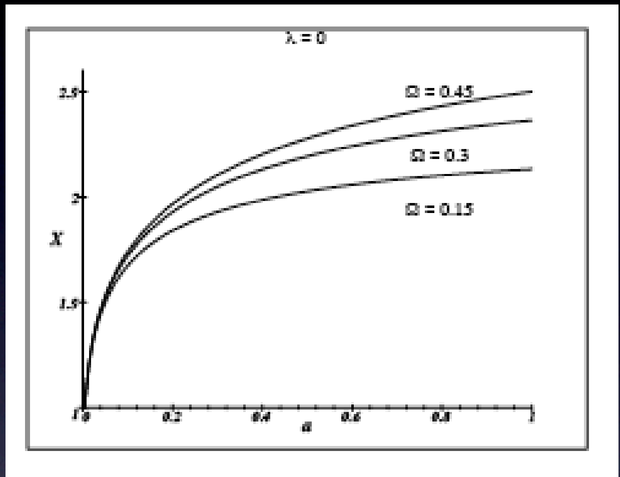
$$\vec{v} = yH\vec{r}, \qquad y = 1 + \frac{Y}{h}, \qquad h = \frac{H}{H_\circ}$$

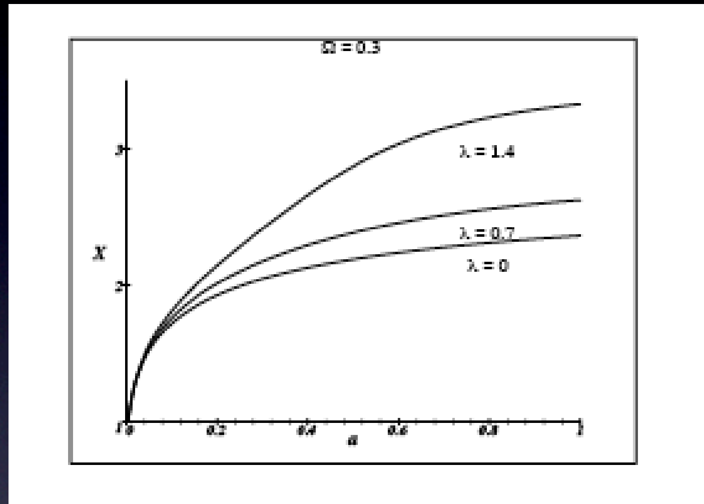
$$\lambda_\circ = \frac{\Lambda}{3H_\circ^2}, \qquad \Omega_\circ = \frac{8\pi G\rho_\circ}{3H_\circ^2}, \qquad k_\circ = \frac{K_\circ}{H_\circ^2}$$

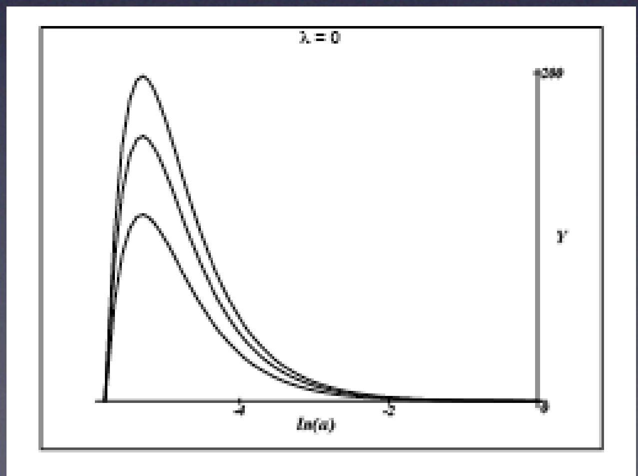
Observational Signature of $K_\circ$

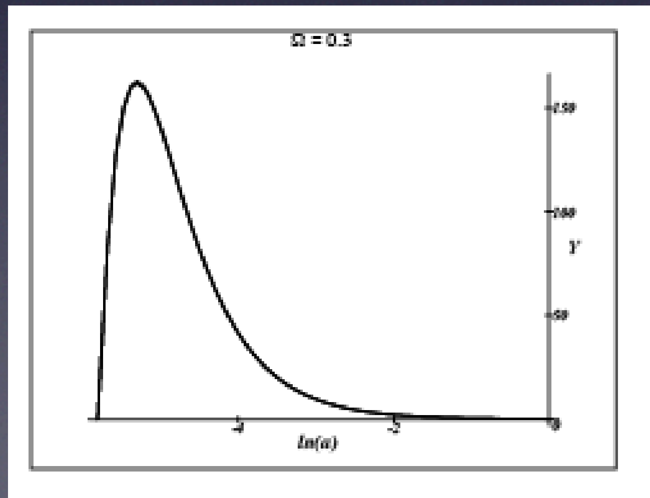
$$H_m = H_\infty \sqrt{1 - \frac{K_\circ^3}{\Lambda\,(4\pi G\rho_\circ)^2}}, \qquad H_\infty = \lim_{a\to\infty} H = \sqrt{\frac{\Lambda}{3}}$$

Dependence on cosmological parameters

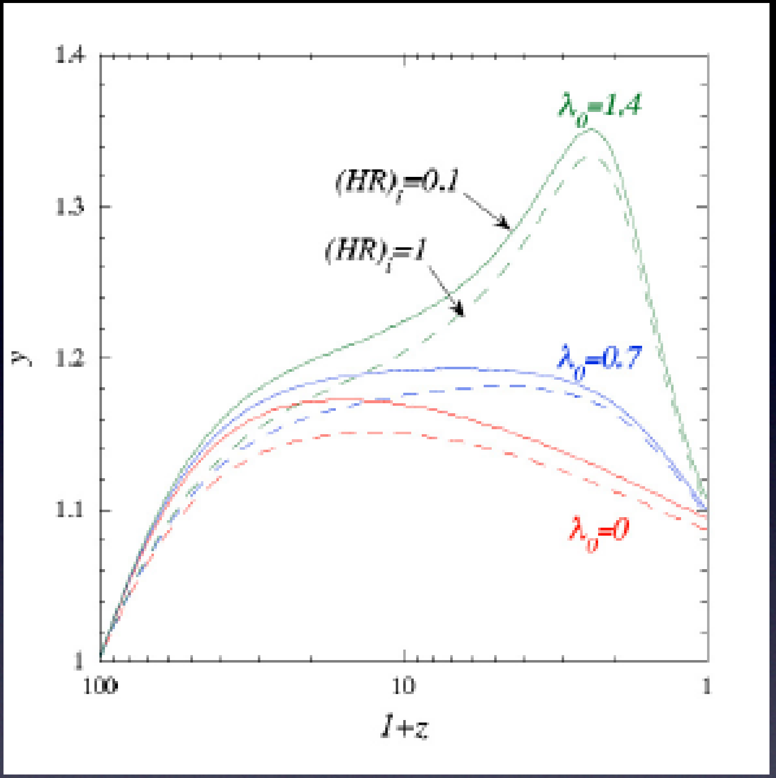








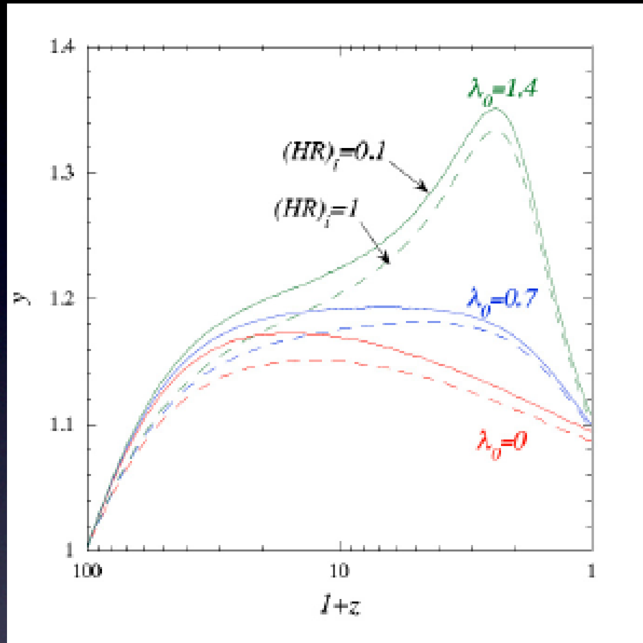
GR Model



1. The voids always grow faster than Hubble expansion ($i.e.$, $y > 1$) along their evolution. The peculiar velocity starts with a huge burst and decreases asymptotically toward Hubble velocity; the present value is higher than the Hubble flow by about 10%.

2. The smaller the radius gets, the higher the peculiar velocity is. Namely, the void with the largest initial size $R_i = H_i^{-1}$ grows slightly slower, which provides us with the minimal peculiar velocity.

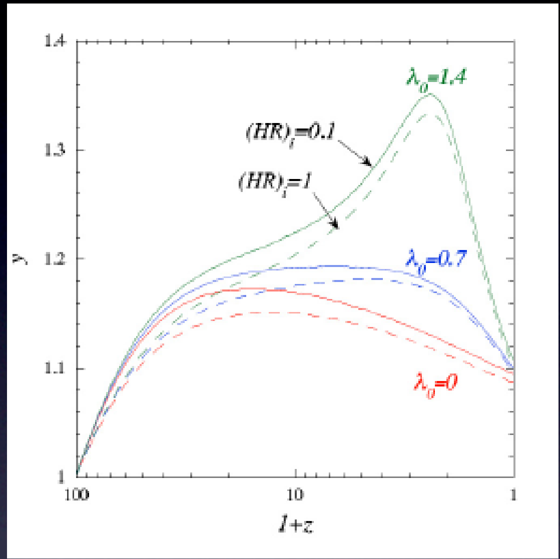
GR Model



3. While the dependence on λ_0 is not significant in the beginning, its effect eventually appears in the evolution, and the correction factor y increases with λ_0. With $\lambda_0 = 0.7$, the peculiar velocity reaches the value higher than the Hubble expansion at $z \sim 10$ by about 20%.

4. The redshift $z^\star$ when y reaches its maximum $y_{\max} = y(z^\star)$ decreases with λ_0. It corresponds to $z^\star \sim 40$ for $\lambda_0 = 0$ and to $z^\star \sim 1.7$ for $\lambda_0 = 1.4$. For the intermediate value $\lambda_0 = 0.7$,for which the corresponding curve shows a plateau, Λ gives the maximal contribution to v at $z^\star \sim 1.7$, which corresponds to 30% of that of the matter density (when it is compared to the case of $\lambda_0 = 0$).

GR Model

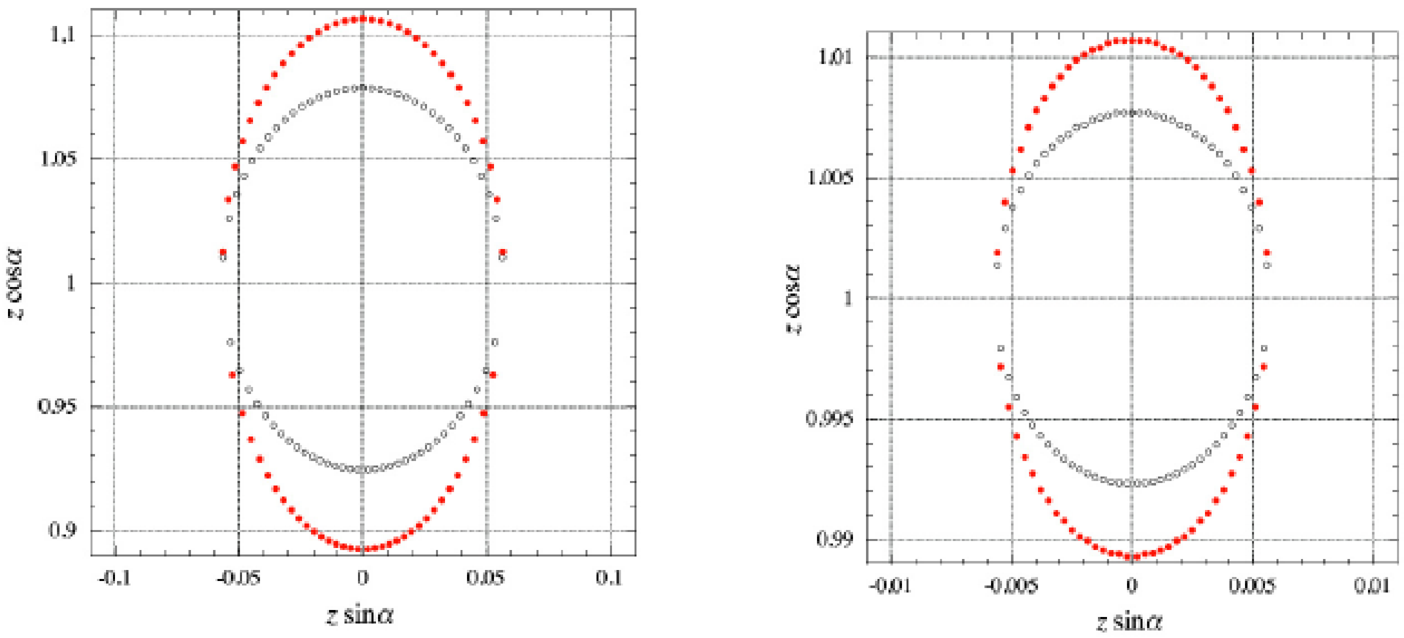


5. Let us pay attention to the presence of a bump on the curve, which becomes visible for $\lambda_0 > 0.7$ (*i.e.* when $k > 0$). It is caused by the fact that the universe experiences a loitering period of cosmological expansion, while the void then continues its own expansion.

6. The present values y_0 related to $\Omega_0 = 0.3$ but to different values for $\lambda_0 \in \{0, 0.7, 1.4\}$ are very close to each other, while the variation of y with time (or with z) depends undeniably on λ_0. In other words, the Λ effect, which accounts for a deviation between these curves, is not substantial nowadays.

7. It is remarkable that the present GR approach for the sub-horizon void confirms the previous result found in the Newtonian dynamics [13]. Even for a relativistic spherical void with a horizon size radius $R_i = H_i^{-1}$, the relativistic effect turns out to be weak.

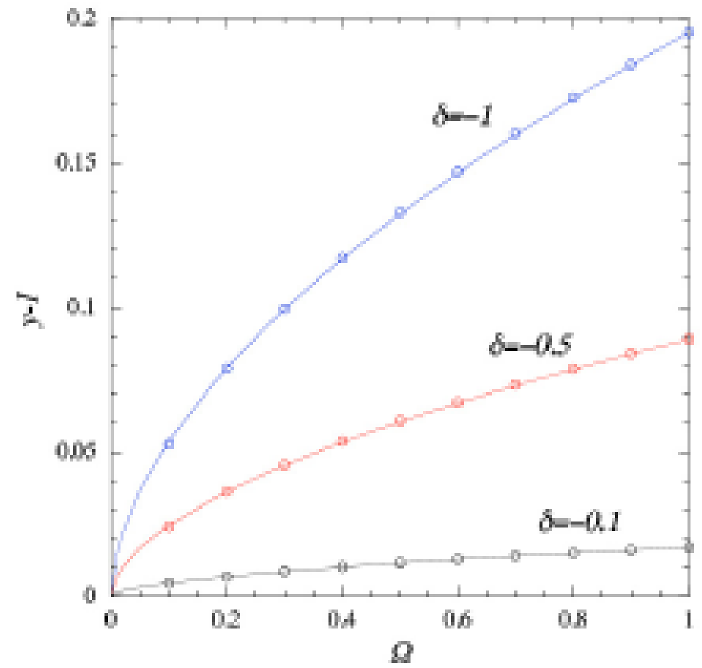
Image of a Void in the redshift-space



(a) $R_0 = 0.1H_0^{-1}, \quad z_V = 1$ (b) $R_0 = 0.01H_0^{-1}, \quad z_V = 1$

Figure 3. Empty spherical voids in the redshift space. — The images (red dots) of their boundary layers (*i.e.*, the void shell S) are depicted for the case of $\Omega_0 = 0.3$ and $\lambda_0 = 0.7$. The present values of their radii are (a) $R_0 = 0.1H_0^{-1}$ and (b) $R_0 = 0.01H_0^{-1}$. The observed radii at $z_V = 1$ are : (a) $R_V = 0.0437H_0^{-1}$ and (b) $R_V = 0.00437H_0^{-1}$. The images of the standard static spheres (small black dots) are also displayed.

Non Empty Voids



Velocity y versus Ω and δ^-.

Figure 7. The velocity y of a non-empty void. — We assume $\Omega + \lambda = 1$ and $\delta^- \in \{01, -0.5, -0.1\}$. The circles and the continuous lines correspond respectively to our numerical results and to the fitting formula given in Eq. (3.2).

Conclusion

In addition to provide us with a method for estimating the cosmological parameters, this test enables us to characterize clearly the sign of the spatial curvature of the FL universe. In other words, it provides an answer to the question on whether the space is finite or infinite, which is a crucial issue for the primordial cosmology.

Thank you