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Deformation of an Expanding Void in Redshift Space

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Introduction

- Peculiar velocity of a spherical void is detemined by Ω and δ. [1]
- Cross-correlation between CMB & LSS indicates existence of nonlinear voids > 100Mpc[2,3]

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Can we test universe model by observation of voids?

How does expanding void look in z-space?

References

[1] NS, K. Maeda, H. Sato, 1993, PTP

[2] B. Granett, M. Neyrinck & I. Szapudi, 2008, ApJL

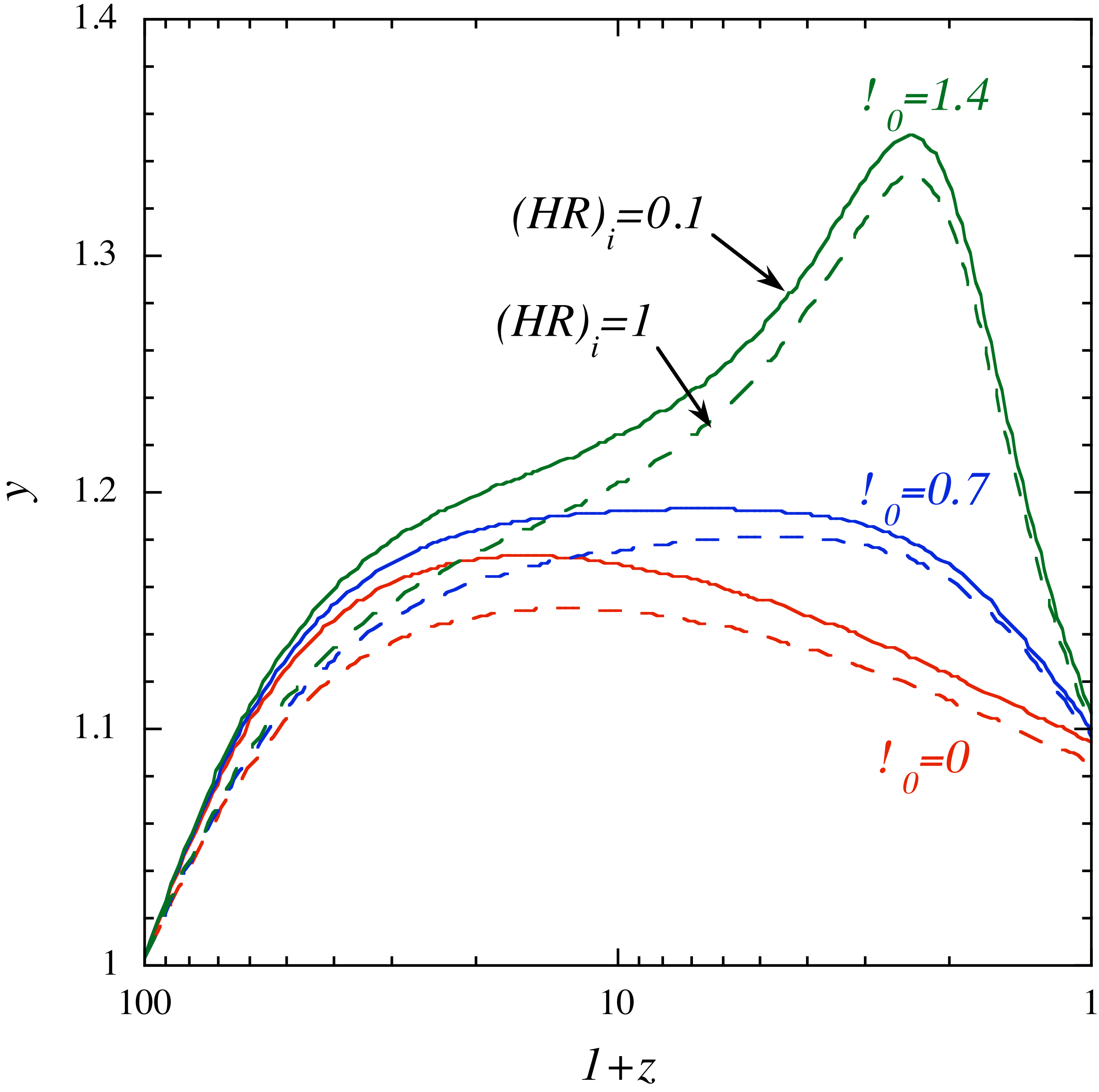
[3] K. Inoue, NS & K.Tomita 2010, ApJ

Dynamics of void

- **Time evolution of shell velocity of empty void**

$y \equiv 1 + v/HR$

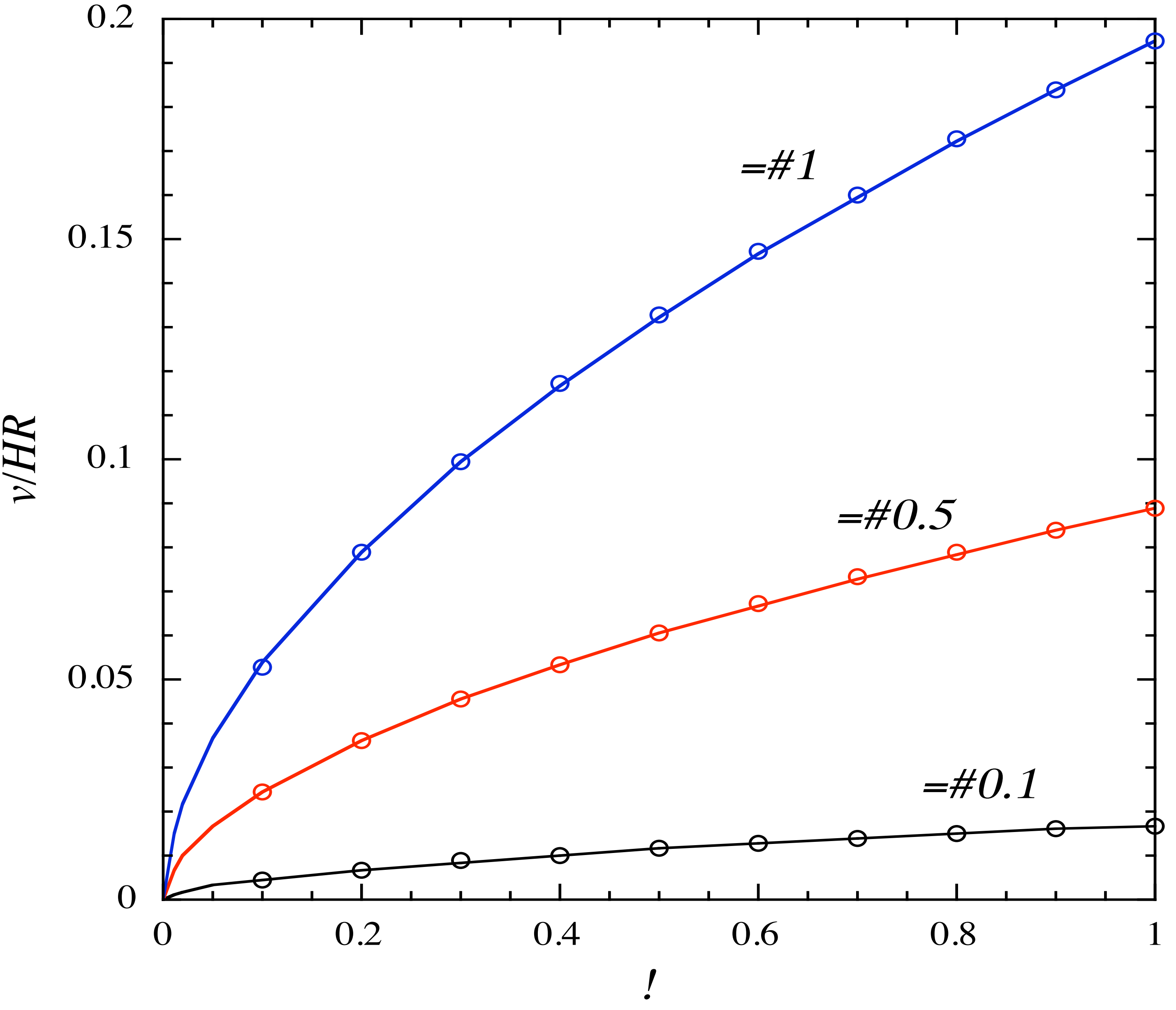
Fix Ω_0=0.3 and change λ_0.



- **Velocity vs *Ω* and *δ* for non-empty voids**

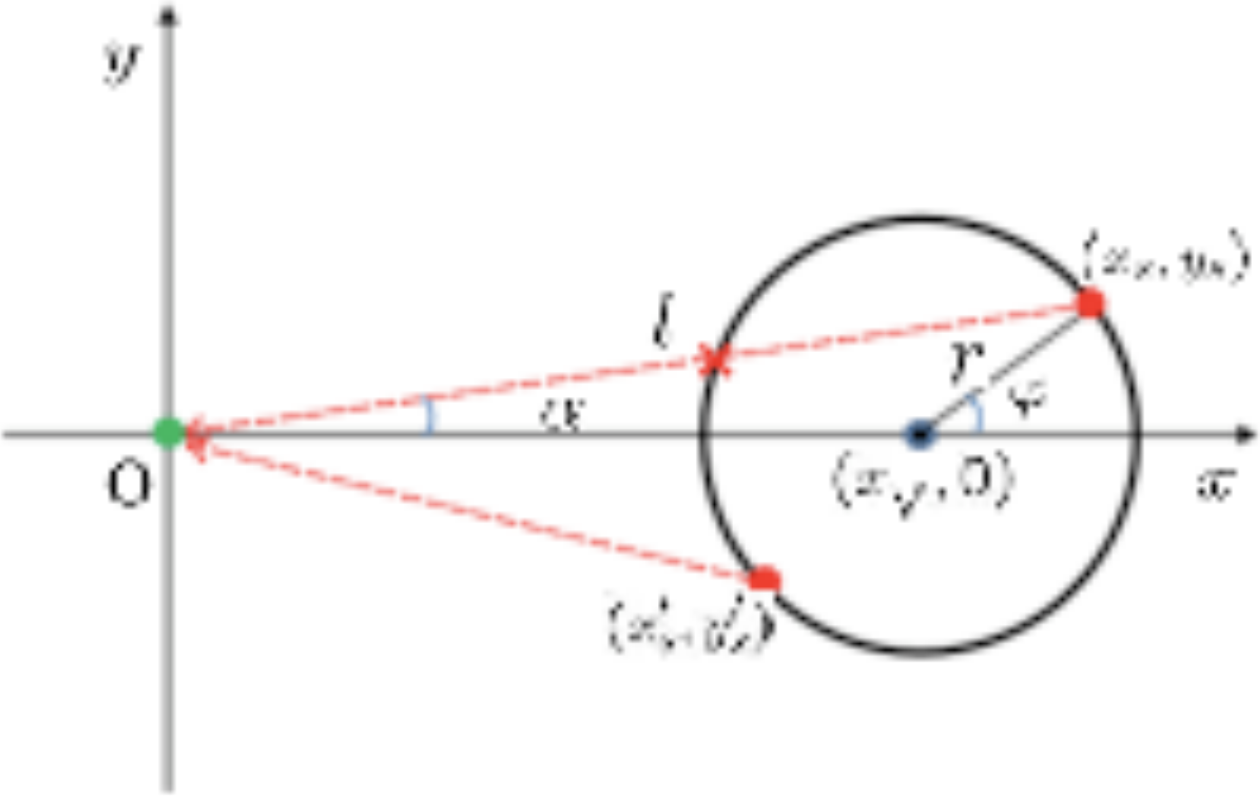
  Fitting formula:

$$y - 1 = \frac{v}{HR} = \frac{\Omega^{0.56}}{6}(|\delta| + 0.1|\delta|^2 + 0.07|\delta|^3), \quad \text{for} \quad \Omega + \lambda = 1$$



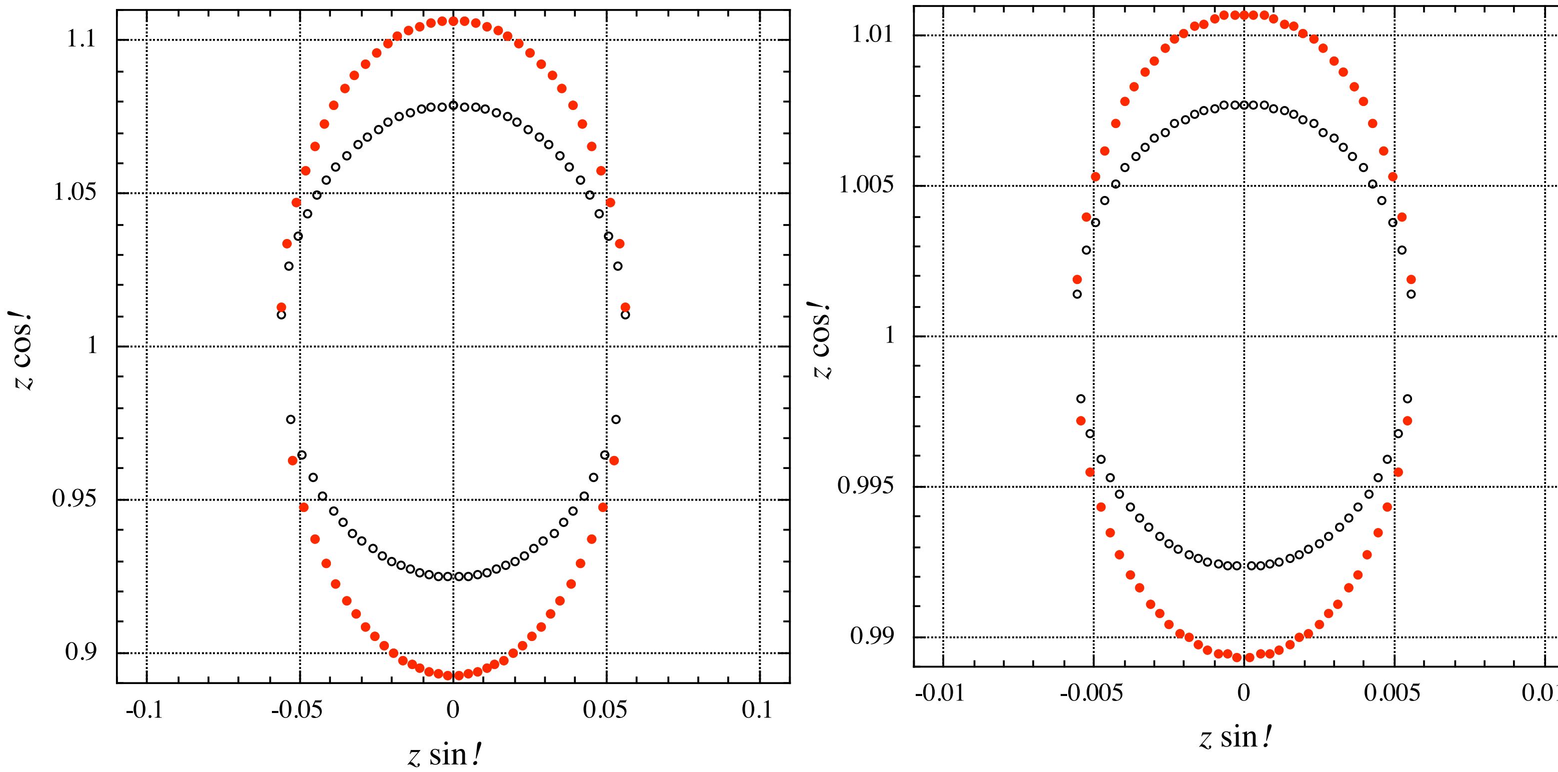
Deformation of void in redshift space

- **Analysis method**
  - Solve equation of motion of shell.
  - Solve null geodesic equations from shell to observer.



- **Dependence on void size**

  Deformation ratio is almost independent of size.



(a) $0.1H_0^{\;1}$,　　(b) $0.01H_0^{\;1}$

Figure 3: The image in the redshift space of an empty void at $z_V = 1$. The observer is located at the origin $(0, 0)$. We show two voids with different scales, i.e., the present sizes of voids are (a) $R_0 = 0.1H_0^{\;1}$ and (b) $0.01H_0^{\;1}$, respectively. Note that the observed sizes of voids are $R_V(z_V = 1) = 0.0437H_0^{\;1}$ for (a) and $0.00437H_0^{\;1}$ for (b), respectively. The red dots denote the image in the redshift space for the universe with $\Omega_0 = 0.3$ and $\lambda_0 = 0.7$. For a reference, we also show a r =constant surface ($r = r(z = 1)$) in the $\Omega_0 = 0.3$ universe by the small black circles. Although the void is spherical, the shape of the r=constant surface is not spherical because the physical radius with r=constant changes in time.

- **Dependence on *z* (location)**

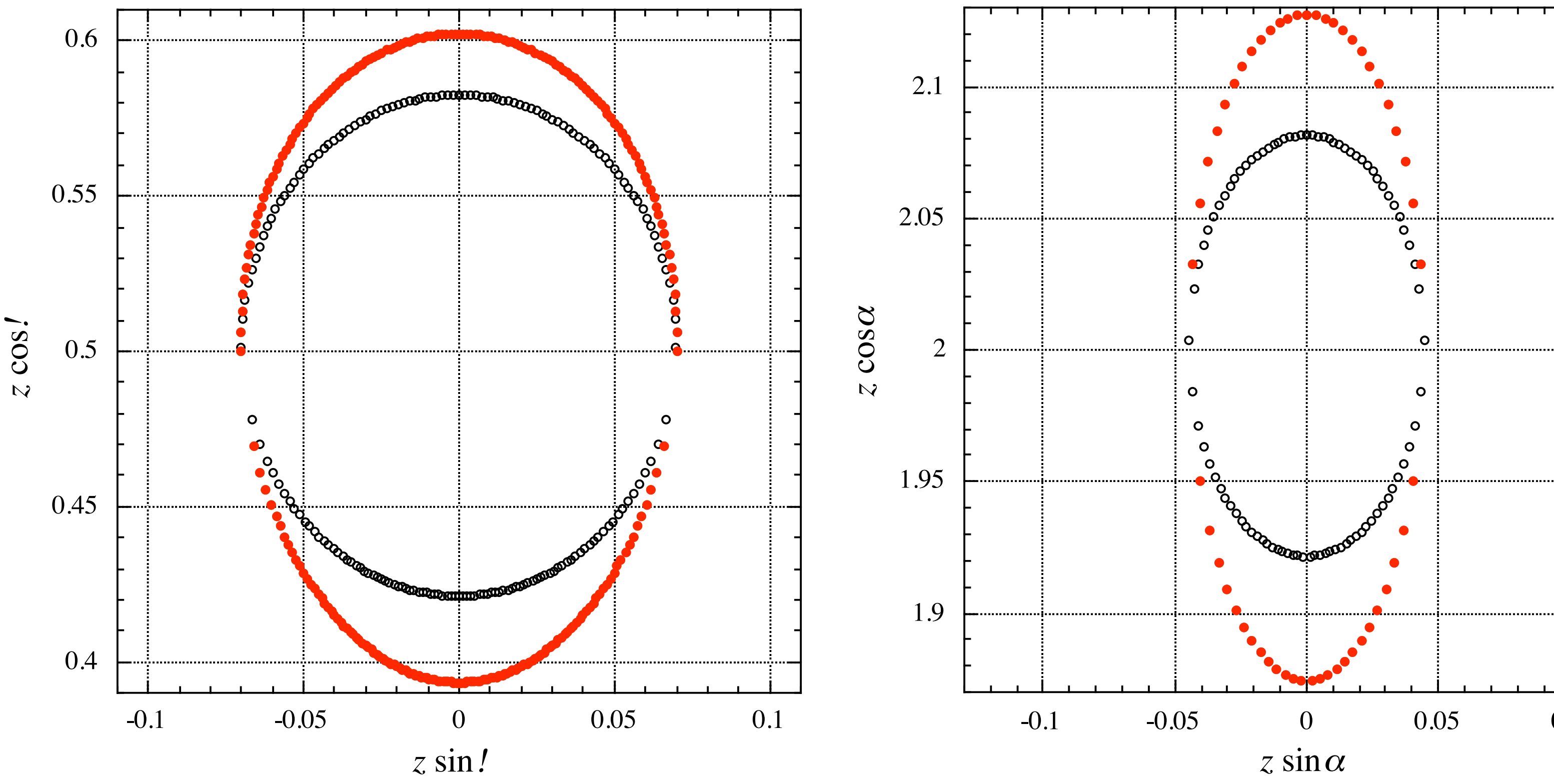
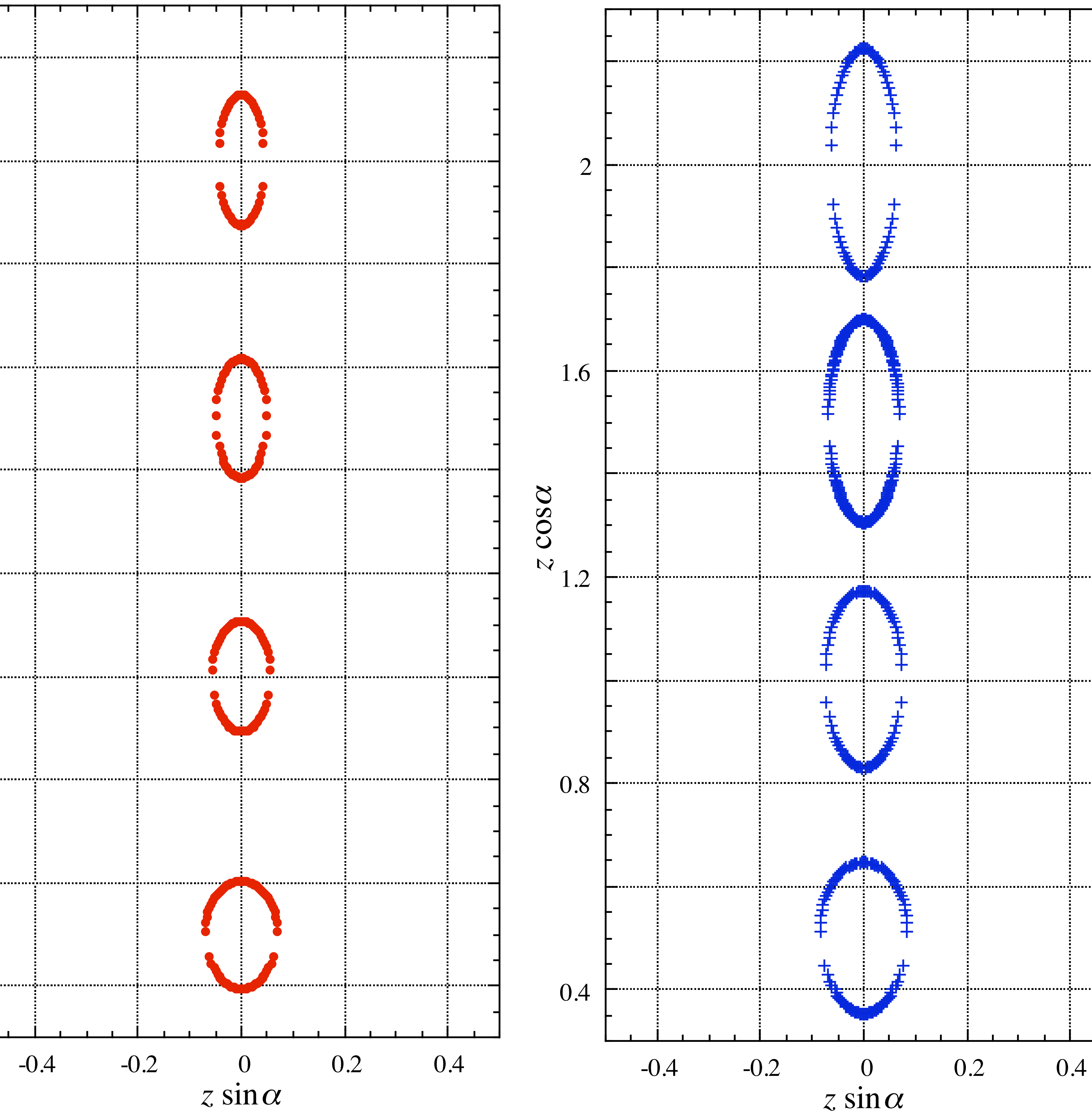


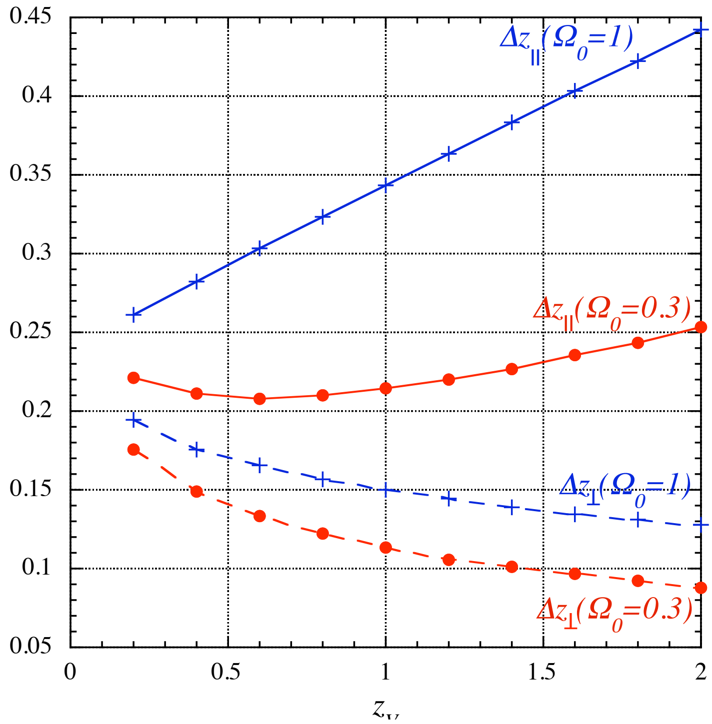
Figure 4: The image in the redshift space of an empty void located at $z_V = 0.5$ (a) and at $z_V = 2$ (b). We choose the scale of the void is $R_0 = 0.1H_0^{-1}$. The red dots and the small black circles are the same as those in Fig. 4. Note that the observed sizes of voids are $a_0 r(z = 0.5) = 0.0616H_0^{-1}$ (a), and $a_0 r(z = 2) = 0.0269H_0^{-1}$ (b), respectively.

Dependence on universe model

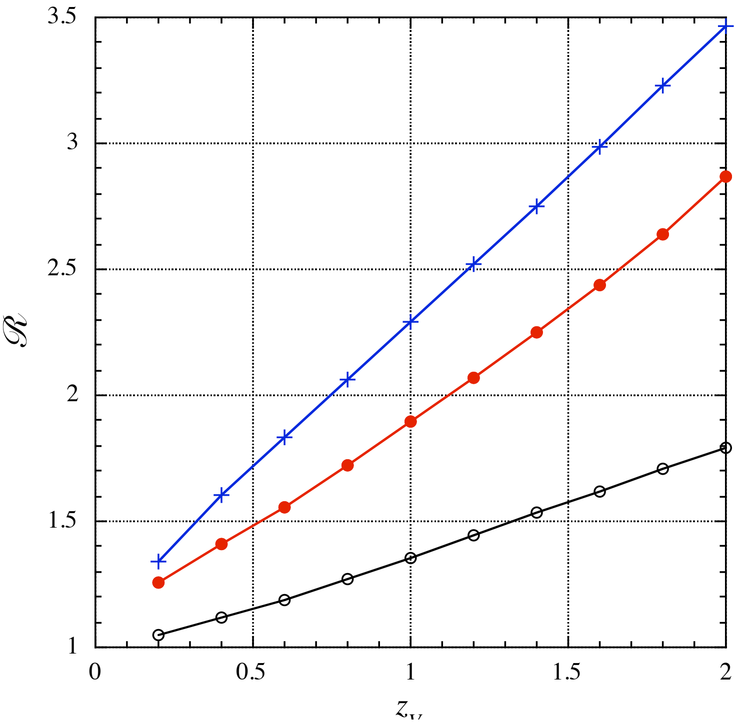


Ω_0=0.3, λ_0=0.7 Ω_0=1, λ_0=0

Summary: how much is shape of void deformed?



(a) $\Delta z_\perp$ and $\Delta z_{||}$



(b) The deformation ratio $\mathcal{R}$

Figure 6: (a) The semi-major axis $\Delta z_{||}$ and the semi-minor axis $\Delta z_\perp$ in terms of the distance z_V. We find that $\Delta z_\perp$ always decreases as z_V increases because the observed void size gets small. On the other hand, $\Delta z_{||}$ increases as z_V increases due to the Doppler effect except for nearby voids for $\Omega_0 = 0.3$. (b) The deformation ratio $\mathcal{R}$ of the shape of a void in the red shift space, which is defined by $\mathcal{R} = \Delta z_{||}/\Delta z_\perp$, where $\Delta z_{||}$ and $\Delta z_\perp$ are the semi-major axis and semi-minor axis radii of the void shape in the redshift space, respectively. The ratio $\mathcal{R}$ increases as the distance z_V increases. We also find the ratio $\mathcal{R}$ higly depends on the background cosmological model, which may give us some information on a cosmological constant.

Conclusions

- We show dynamics of spherical void and its deformation in redshift space.
  - Expanding void is prolonged in light of sight.
  - Deformation ratio depends on universe model and void location, but independent of size.
- If voids >100Mpc at $z \sim 1$ exist, we will find such a deformation in future deep sky survey, and confirm existence of Λ.