Emergence of spatial curvature

arxiv: 1707.01800, 1704.02810

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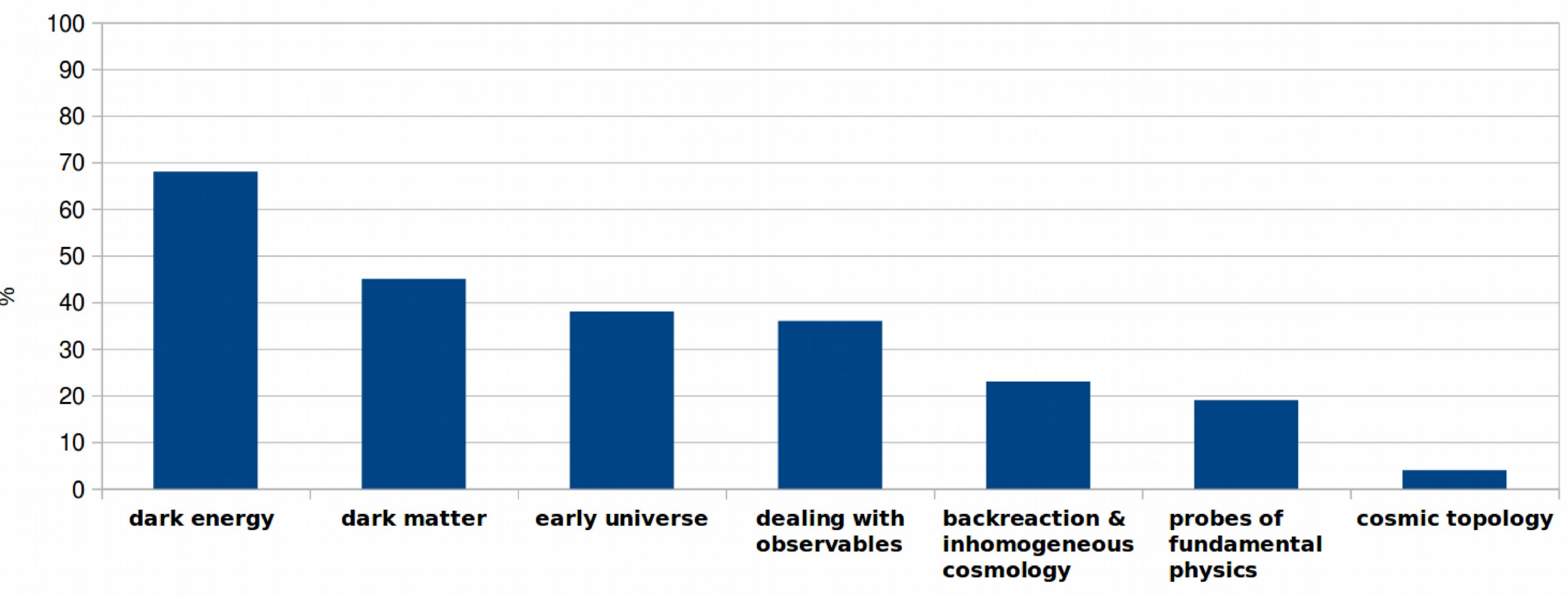
7 July 2017, Inhomogeneous Cosmologies 2017, Toruń

Outline

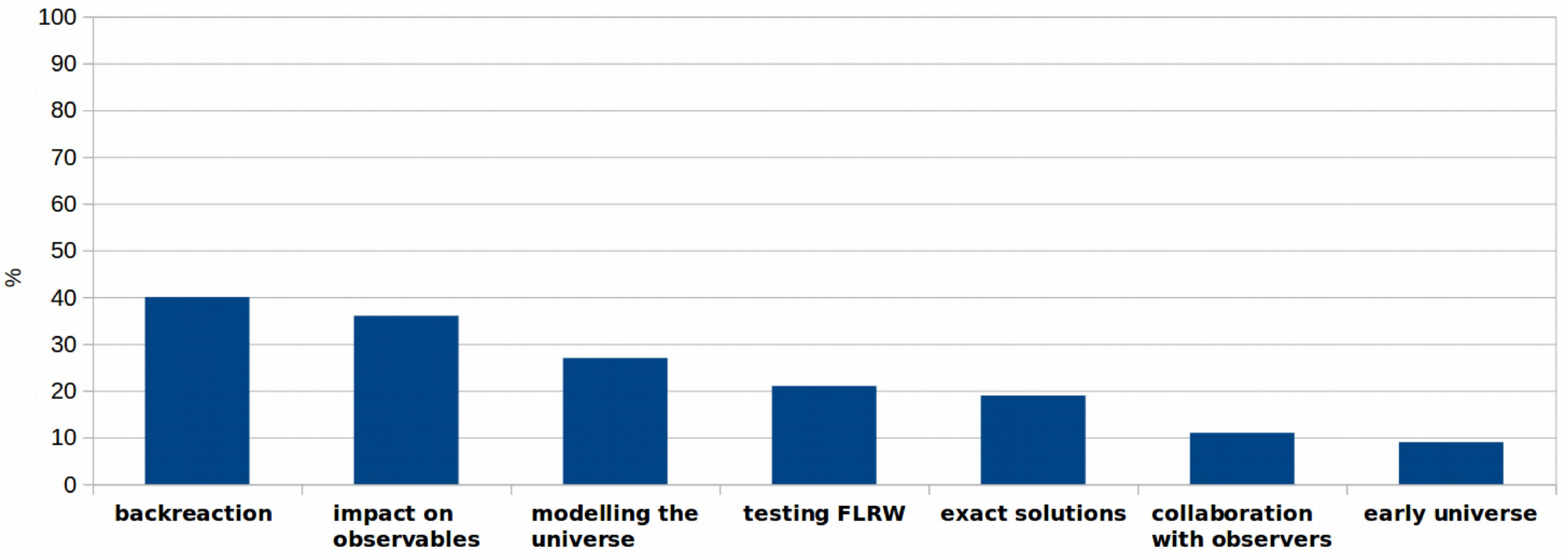
- Inhomogeneous community
- Generic features of silent universes
- Future prospects

The most important topic/topics in cosmology?



Bolejko & Korzyński, IJMPD 26, 1730011 (2017)
arXiv:1612.08222

The most important topic in inhomogeneous cosmology?



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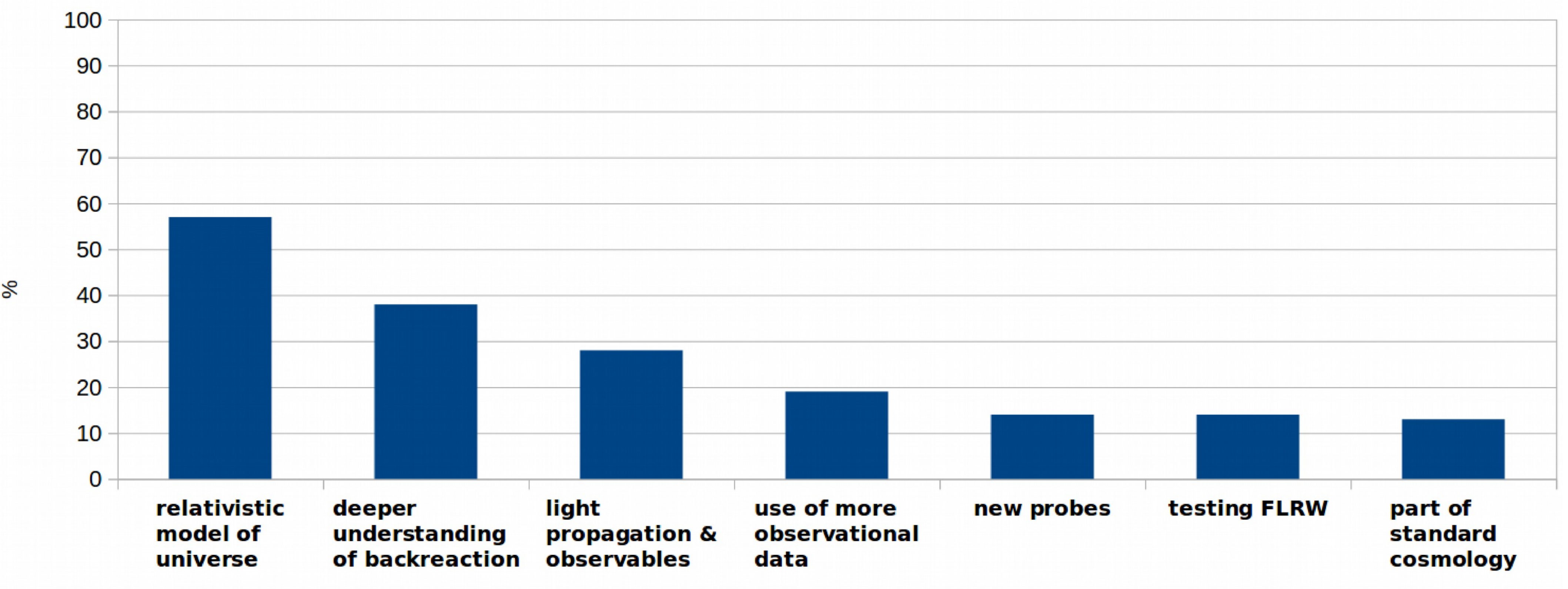
Future prospects (5-10 years)?



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$$G_{ab} - \Lambda g_{ab} = T_{ab}$$

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Numerical:
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Exact models:
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$$\boldsymbol{G_{ab} - \Lambda g_{ab} = T_{ab}}$$

$$T_{ab} = \rho u_a u_b + p h_{ab} + \pi_{ab} + q_a u_b + u_a q_b$$

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$$u_{a;b} = \omega_{ab} + \sigma_{ab} + \frac{1}{3} h_{ab} \Theta - A_a u_b ,$$

$$G_{ab} - \Lambda g_{ab} = T_{ab}$$

conservation equation

$$T^{ab}{}_{;b} = 0$$

$$G_{ab} - \Lambda g_{ab} = T_{ab}$$

conservation equation

$$\dot{\rho} + \Theta(\rho + p) + \sigma^{ab}\pi_{ab} + q^{a}{}_{;a} + q^{a} A_{a} = 0$$

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Ricci identities

$$u_{a;d;c} - u_{a;c;d} = R_{abcd} u^{b}$$

$$G_{ab} - \Lambda g_{ab} = T_{ab}$$

conservation equation

$$\dot{\rho} + \Theta(\rho + p) + \sigma^{ab}\pi_{ab} + q^{a}{}_{;a} + q^{a}A_{a} = 0$$

Ricci identities

$$\dot{\Theta} = -\tfrac{1}{3}\Theta^2 - \tfrac{1}{2}(\rho + 3p) - 2(\sigma^2 - \omega^2) + D^a A_a + A_a A^a + \Lambda$$

$$\dot{\sigma}_{\langle ab \rangle} = -\tfrac{2}{3}\Theta\sigma_{ab} - \sigma_{c\langle a}\sigma^{c}{}_{b\rangle} - \omega_{\langle a}\omega_{b\rangle} + D_{\langle a}A_{b\rangle} + A_{\langle a}A_{b\rangle} - E_{ab} + \tfrac{1}{2}\pi_{ab}$$

$$\dot{\omega}_{\langle a \rangle} = -\tfrac{2}{3}\Theta\omega_a - \tfrac{1}{2}\,curl\,A_a + \sigma_{ab}\omega^b$$

$$G_{ab} - \Lambda g_{ab} = T_{ab}$$

conservation equation

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$$\dot{\omega}_{\langle a\rangle} = -\tfrac{2}{3}\Theta\omega_a - \tfrac{1}{2}\, curl\, A_a + \sigma_{ab}\omega^b$$

Bianchi identities

$$R_{ab[cd;e]} = 0$$

$$G_{ab} - \Lambda g_{ab} = T_{ab}$$

conservation equation

$$\dot{\rho} + \Theta(\rho + p) + \sigma^{ab}\pi_{ab} + q^{a}{}_{;a} + q^{a} A_{a} = 0$$

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$$\dot{\omega}_{\langle a\rangle} = -\tfrac{2}{3}\Theta\omega_a - \tfrac{1}{2}\, curl\, A_a + \sigma_{ab}\omega^b$$

Bianchi identities

$$\dot{E}_{\langle ab\rangle} = -\Theta E_{ab} - \tfrac{1}{2}(\rho + p)\sigma_{ab} + curl\, H_{ab} - \tfrac{1}{2}\dot{\pi}_{ab} - \tfrac{1}{6}\Theta\pi_{ab}$$
$$+\; 3\sigma^{c}_{\langle a}\left(E_{b\rangle c} - \tfrac{1}{6}\pi_{b\rangle c}\right) + \epsilon_{cd\langle a}\left[2A^c H^d_{b\rangle} - \omega^c\left(E_{b\rangle}{}^{d} + \tfrac{1}{2}\pi^d_{b\rangle}\right)\right]$$

$$\dot{H}_{\langle ab\rangle} = -\Theta H_{ab} - curl\, E_{ab} + \tfrac{1}{2}\, curl\, \pi_{ab} + 3\sigma^{c}_{\langle a} H_{b\rangle c} - \epsilon_{cd\langle a}\left(2A^c E^d_{b\rangle} + \omega^c H^d_{b\rangle}\right)$$

$$G_{ab} - \Lambda g_{ab} = T_{ab}$$

conservation equation

$$\dot{\rho} + \Theta(\rho + p) + \sigma^{ab}\pi_{ab} + q^{a}{}_{;a} + q^{a} A_{a} = 0$$

Ricci identi

$$\dot{\Theta} = -\frac{1}{3}\Theta^{2} -$$

$$\dot{\sigma}_{\langle ab\rangle} = -\frac{2}{3}\Theta$$

$$\dot{\omega}_{\langle a\rangle} = -\frac{2}{3}\Theta$$

$$\boldsymbol{\omega_{ab} = 0} \qquad \boldsymbol{A_{a} = 0} \qquad \boldsymbol{q_{a} = 0}$$

$$\boldsymbol{p = 0} \qquad \boldsymbol{\pi_{ab} = 0} \qquad \boldsymbol{H_{ab} = 0}$$

Bianchi identities

$$\dot{E}_{\langle ab\rangle} = -\Theta E_{ab} - \frac{1}{2}(\rho + p)\sigma_{ab} + curl\, H_{ab} - \frac{1}{2}\dot{\pi}_{ab} - \frac{1}{6}\Theta\pi_{ab}$$
$$+ \; 3\sigma^{c}_{\langle a}\left(E_{b\rangle c} - \frac{1}{6}\pi_{b\rangle c}\right) + \epsilon_{cd\langle a}\left[2A^{c}H^{d}_{b\rangle} - \omega^{c}\left(E_{b\rangle}{}^{d} + \frac{1}{2}\pi^{d}_{b\rangle}\right)\right]$$

$$\dot{H}_{\langle ab\rangle} = -\Theta H_{ab} - curl\, E_{ab} + \frac{1}{2} curl\, \pi_{ab} + 3\sigma^{c}_{\langle a}H_{b\rangle c} - \epsilon_{cd\langle a}\left(2A^{c}E^{d}_{b\rangle} + \omega^{c}H^{d}_{b\rangle}\right)$$

Silent Cosmology

$$\dot{\rho} = -\Theta\,\rho$$

$$\dot{\Theta} = -\frac{1}{3}\Theta^2 - \frac{1}{2}\rho - 2\,\Sigma_1^2 - 2\,\Sigma_1\,\Sigma_2 - 2\,\Sigma_2^2 + \Lambda$$

$$\dot{\Sigma}_1 = -\frac{2}{3}\Theta\,\Sigma_1 + \frac{2}{3}\Sigma_2\left(\Sigma_1 + \Sigma_2\right) - \frac{1}{3}\Sigma_1^2 - W_1$$

$$\dot{\Sigma}_2 = -\frac{2}{3}\Theta\,\Sigma_2 + \frac{2}{3}\Sigma_1\left(\Sigma_1 + \Sigma_2\right) - \frac{1}{3}\Sigma_2^2 - W_2$$

$$\dot{W}_1 = W_1\left(\Sigma_1 - \Sigma_2\right) - W_2\left(\Sigma_1 + 2\,\Sigma_2\right) - \Theta\,W_1 - \frac{1}{2}\rho\,\Sigma_1$$

$$\dot{W}_2 = W_2\left(\Sigma_2 - \Sigma_1\right) - W_1\left(\Sigma_2 + 2\,\Sigma_1\right) - \Theta\,W_2 - \frac{1}{2}\rho\,\Sigma_2$$

Silent Cosmology

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$$\dot{\Sigma}_1 = -$$

$$\dot{\Sigma}_2 = -$$

$$\boldsymbol{curl\,\sigma_{ab} = 0 \qquad \epsilon_{abc}\,\sigma^{b}{}_{d}\,E^{cd} = 0}$$

$$\dot{W}_1 = W_1\left(\Sigma_1 - \Sigma_2\right) - W_2\left(\Sigma_1 + 2\,\Sigma_2\right) - \Theta\,W_1 - \frac{1}{2}\rho\,\Sigma_1$$

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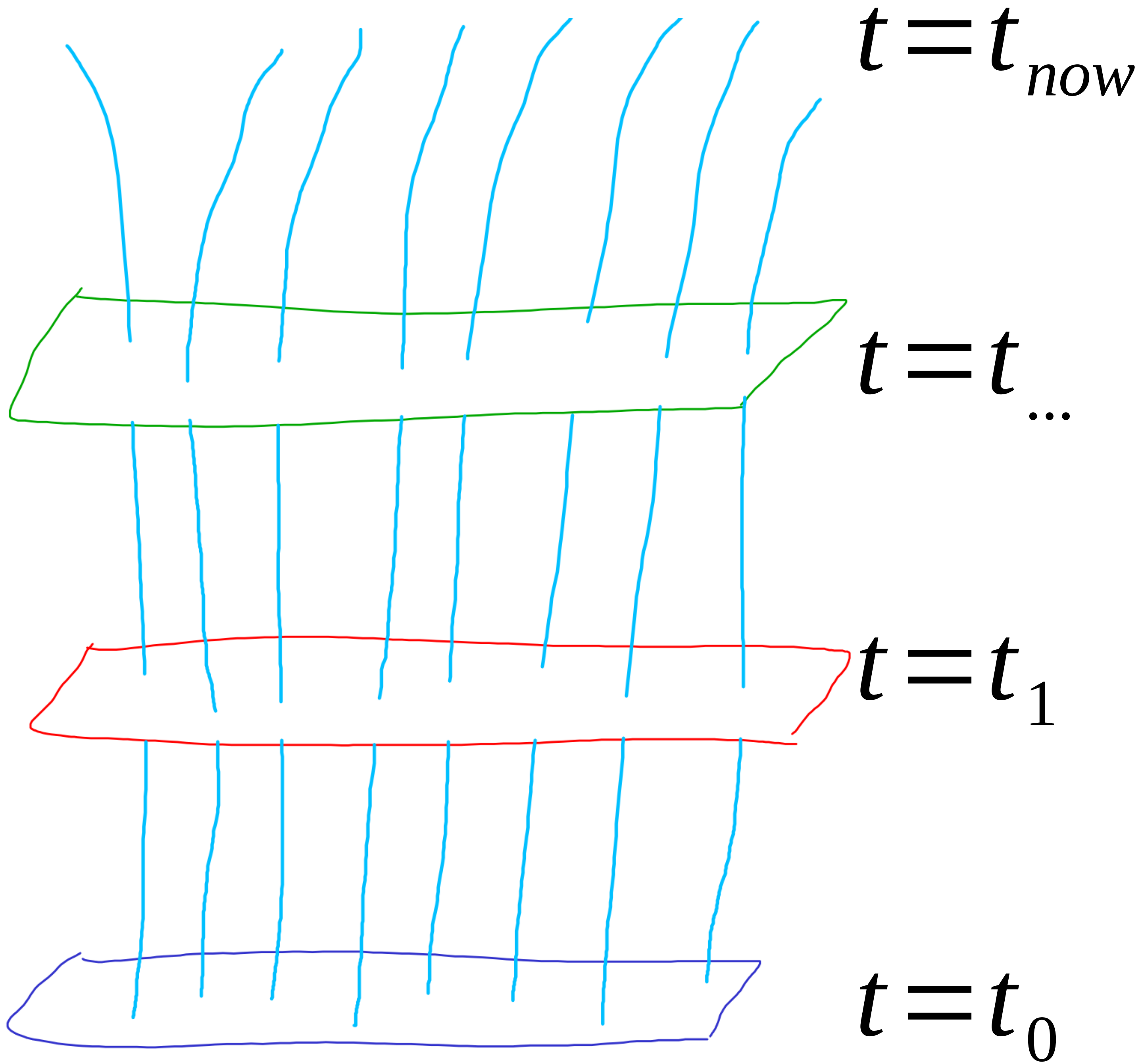
Silent Cosmology

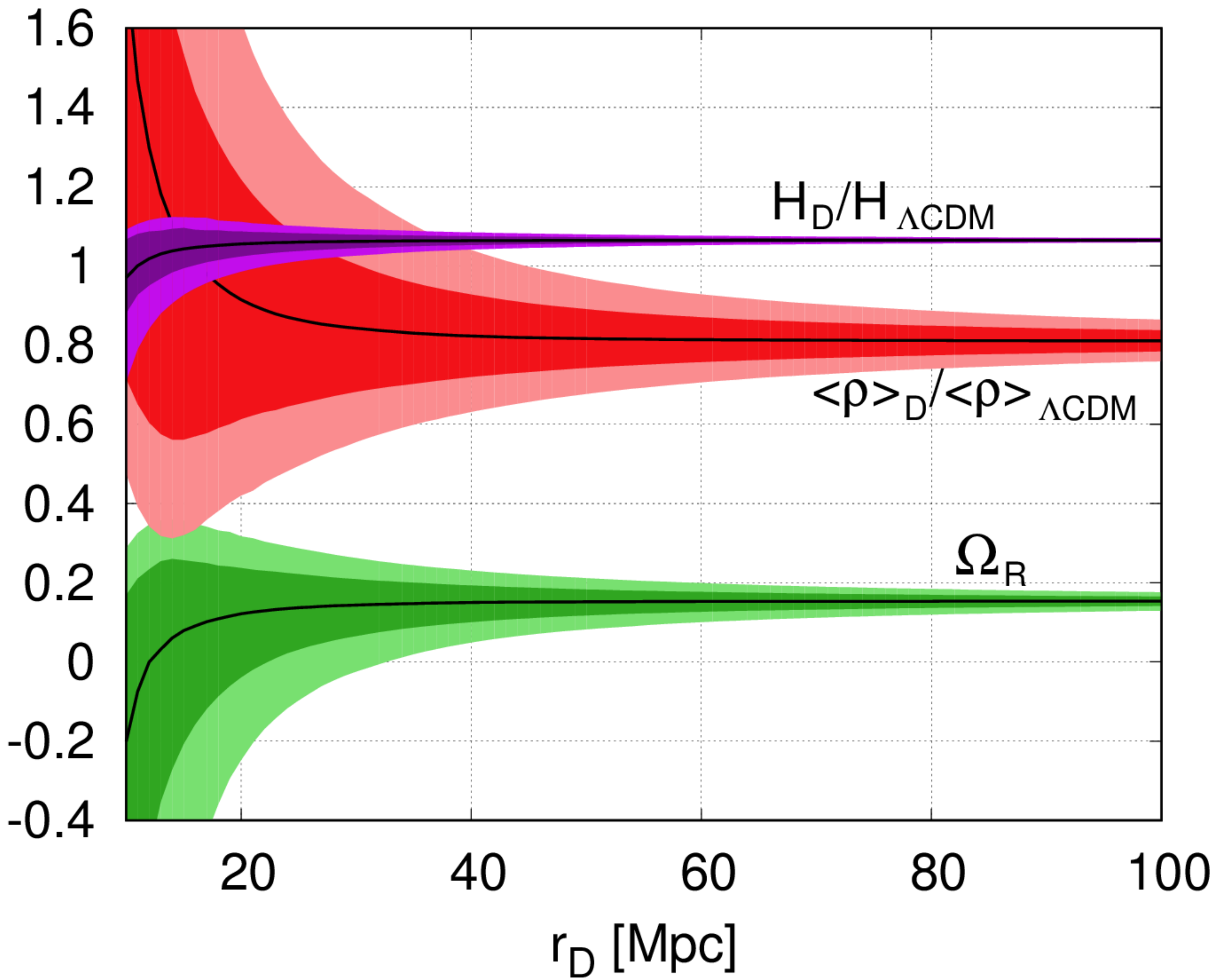
$$\dot{\rho} = -\Theta\,\rho$$

$$\dot{\Theta} = -\frac{1}{3}\Theta^2 - \frac{1}{2}\rho - 6\,\Sigma^2 + \Lambda$$

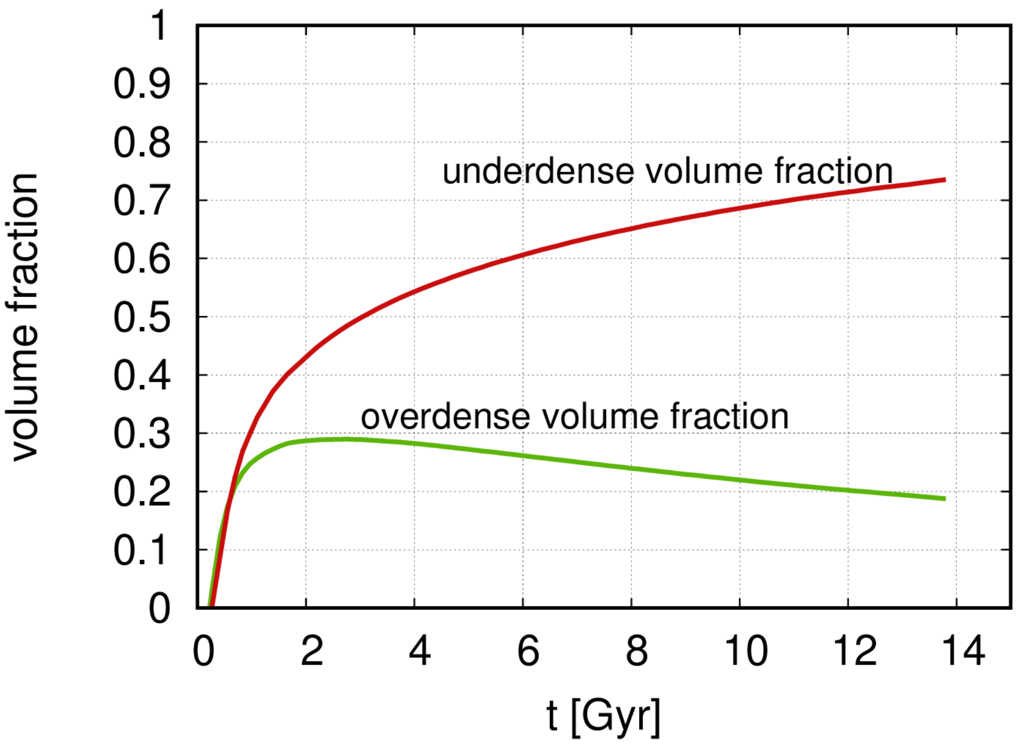
$$\dot{\Sigma} = -\frac{2}{3}\Theta\,\Sigma + \Sigma^2 - W$$

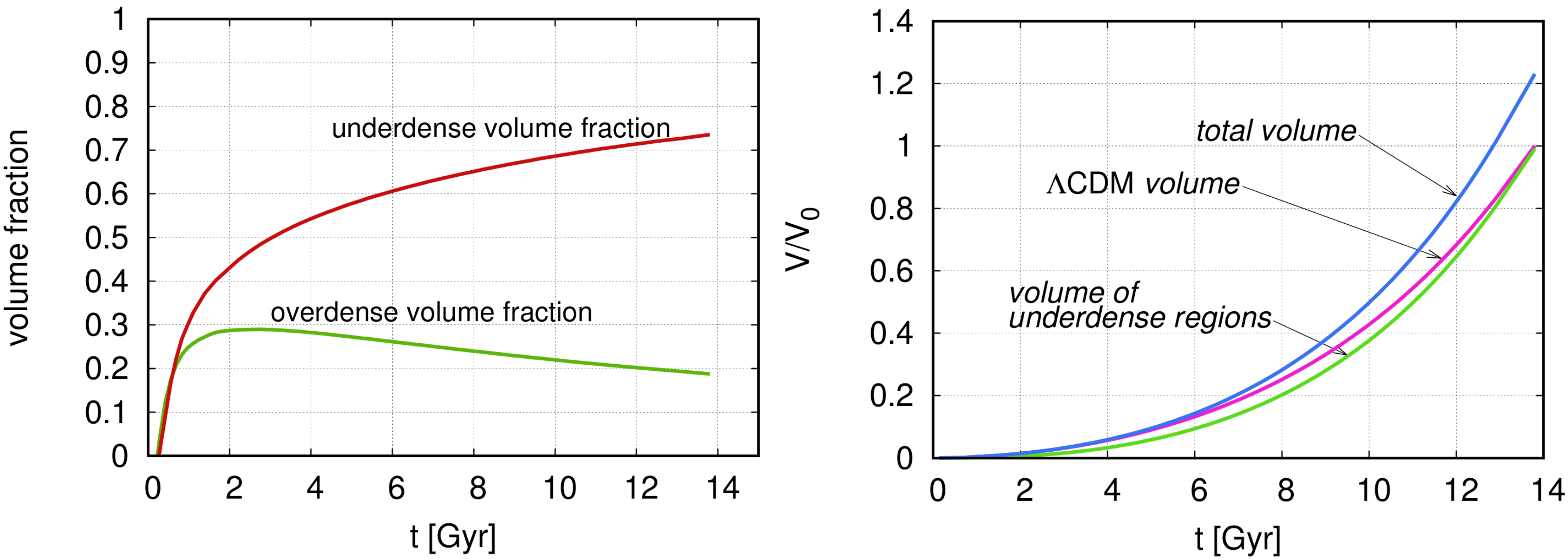
$$\dot{W} = -\Theta\,W - \frac{1}{2}\rho\,\Sigma - 3\,\Sigma\,W$$

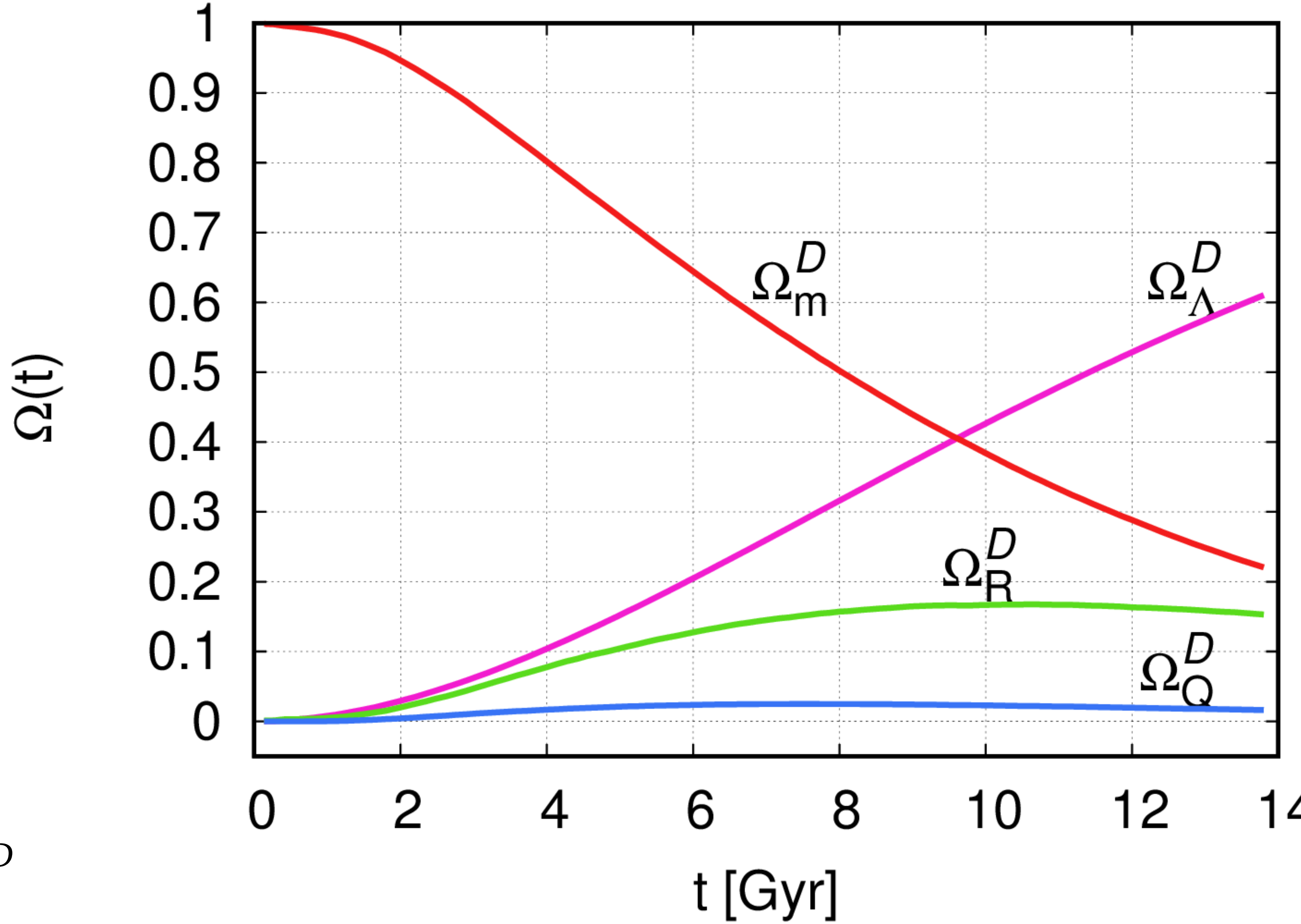

$t = t_{now}$
$t = t_{...}$
$t = t_1$
$t = t_0$



1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
20
40
60
80
100
r_D [Mpc]
H_D/H_ΛCDM
<ρ>_D/<ρ>_ΛCDM
Ω_R


underdense volume fraction
overdense volume fraction
volume fraction
t [Gyr]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2
4
6
8
10
12
14


volume fraction
underdense volume fraction
overdense volume fraction
t [Gyr]
V/V0
total volume
ΛCDM volume
volume of
underdense regions
t [Gyr]



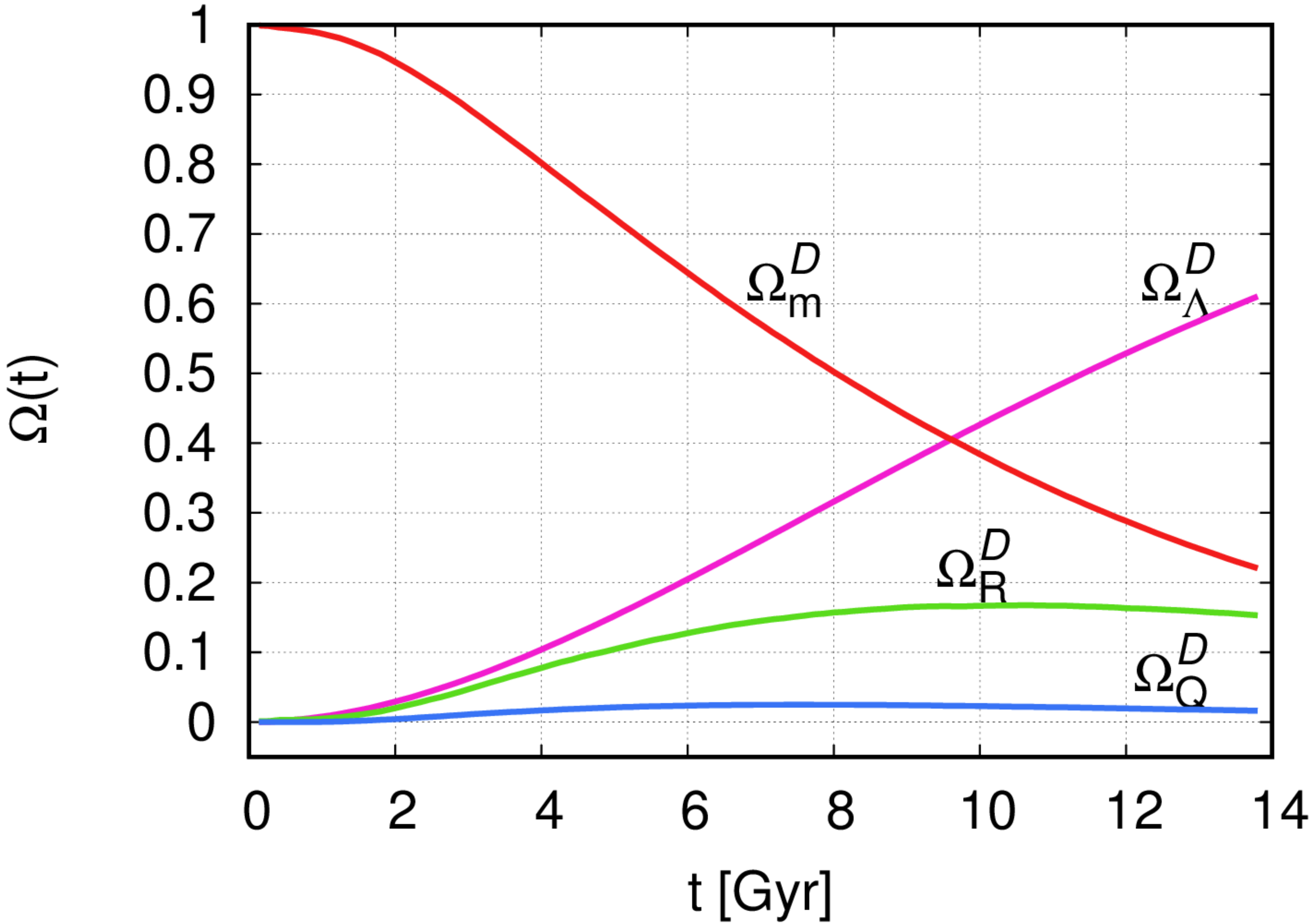
$$H_D = \frac{1}{3}\langle \Theta \rangle_D$$

$$\Omega_R^D = -\frac{\langle R \rangle_D}{6 H_D^2}$$

$$\Omega_m^D = \frac{8\pi G}{3 H_D^2}\langle \rho \rangle_D$$

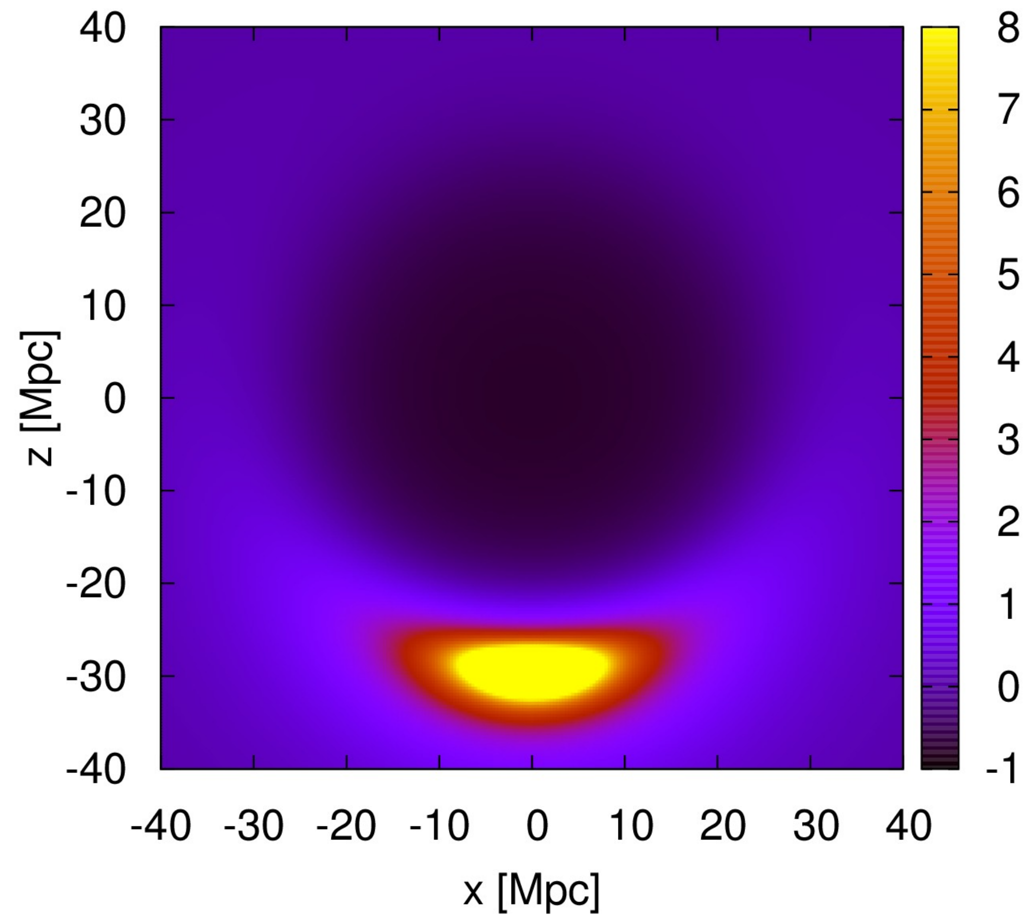
$$\Omega_\Lambda^D = \frac{\Lambda}{3 H_D^2}$$

$$\Omega_Q^D = \frac{1}{H_D^2}\left(\langle \Sigma^2 \rangle_D + \frac{1}{9}\langle \Theta^2 \rangle_D - H_D^2 \right)$$



$\Omega(t)$
t [Gyr]
Ω_m^D
Ω_Λ^D
Ω_R^D
Ω_Q^D
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2
4
6
8
10
12
14

$$\delta = \frac{\rho - \rho_{\Lambda CDM}}{\rho_{\Lambda CDM}}$$



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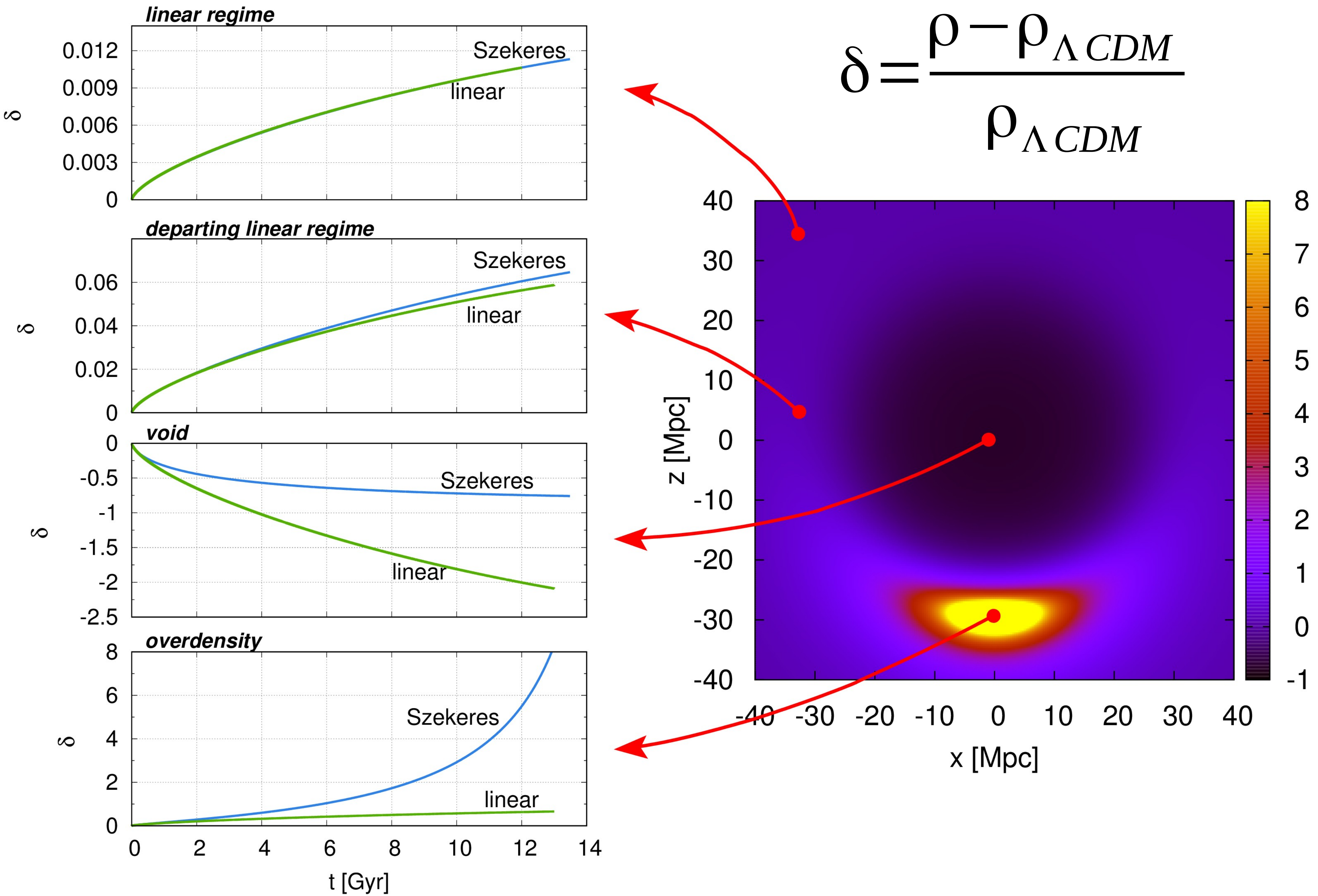

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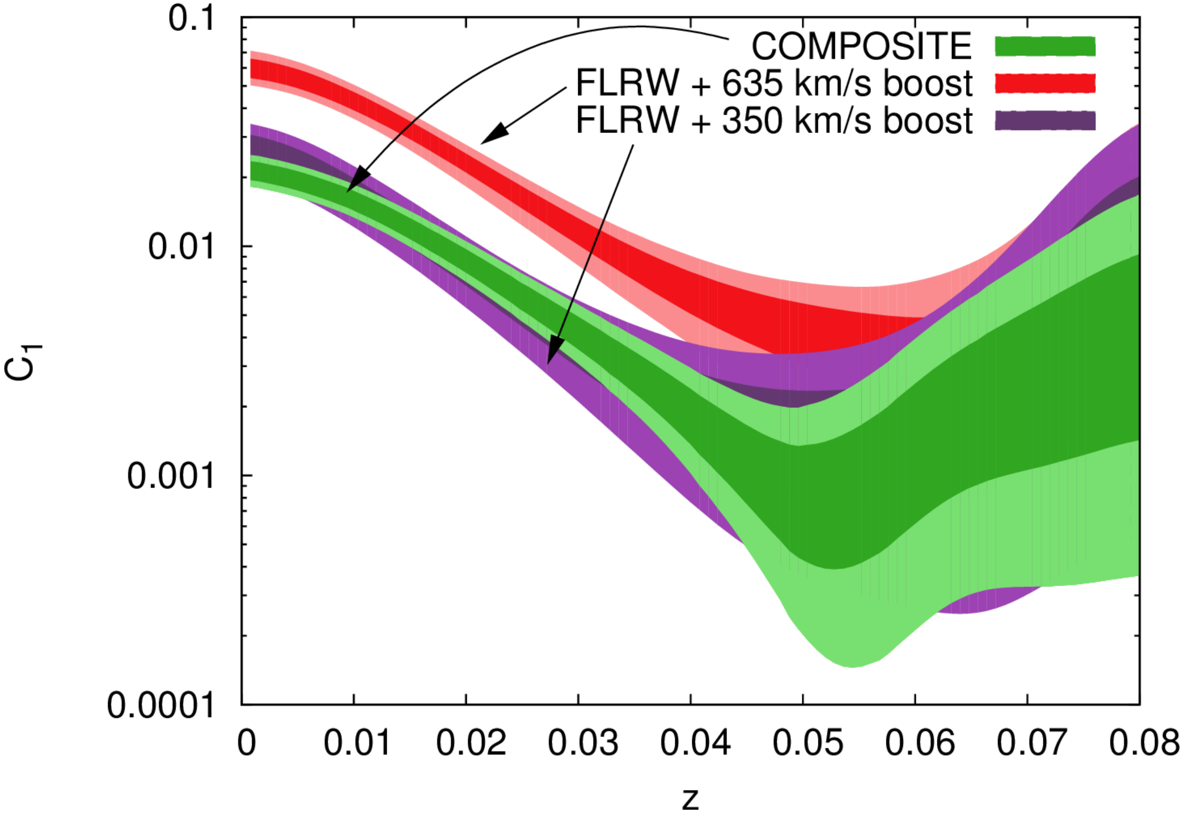
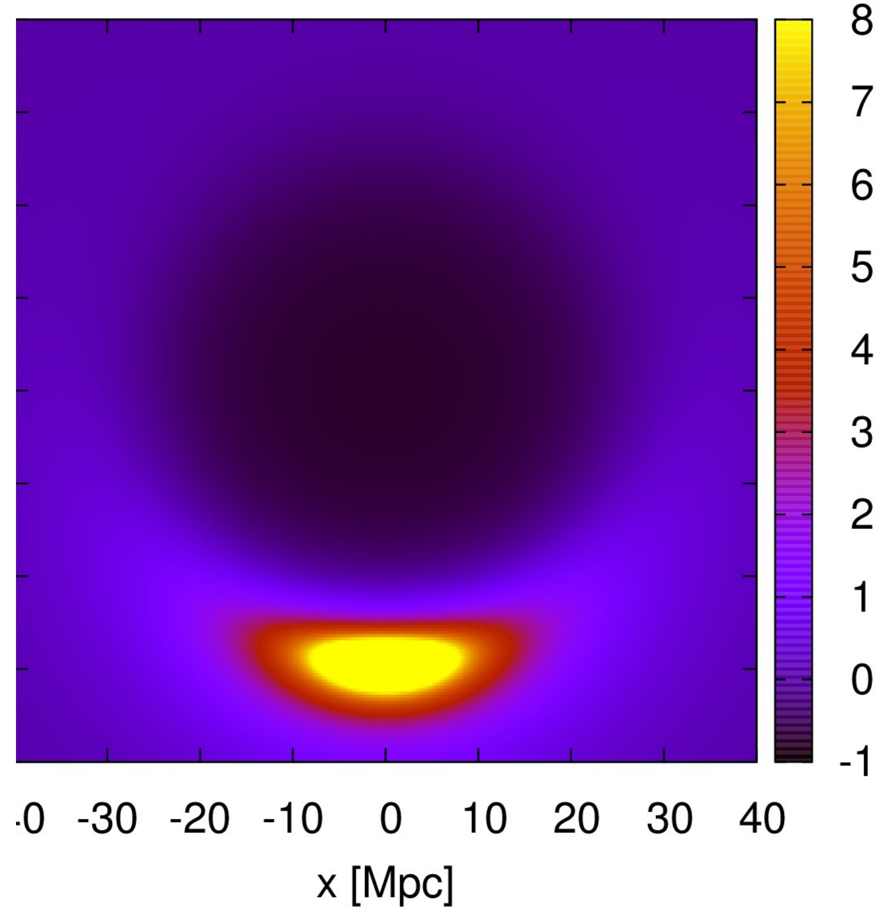


Bolejko, Nazer, Wiltshire, JCAP06(2016)035



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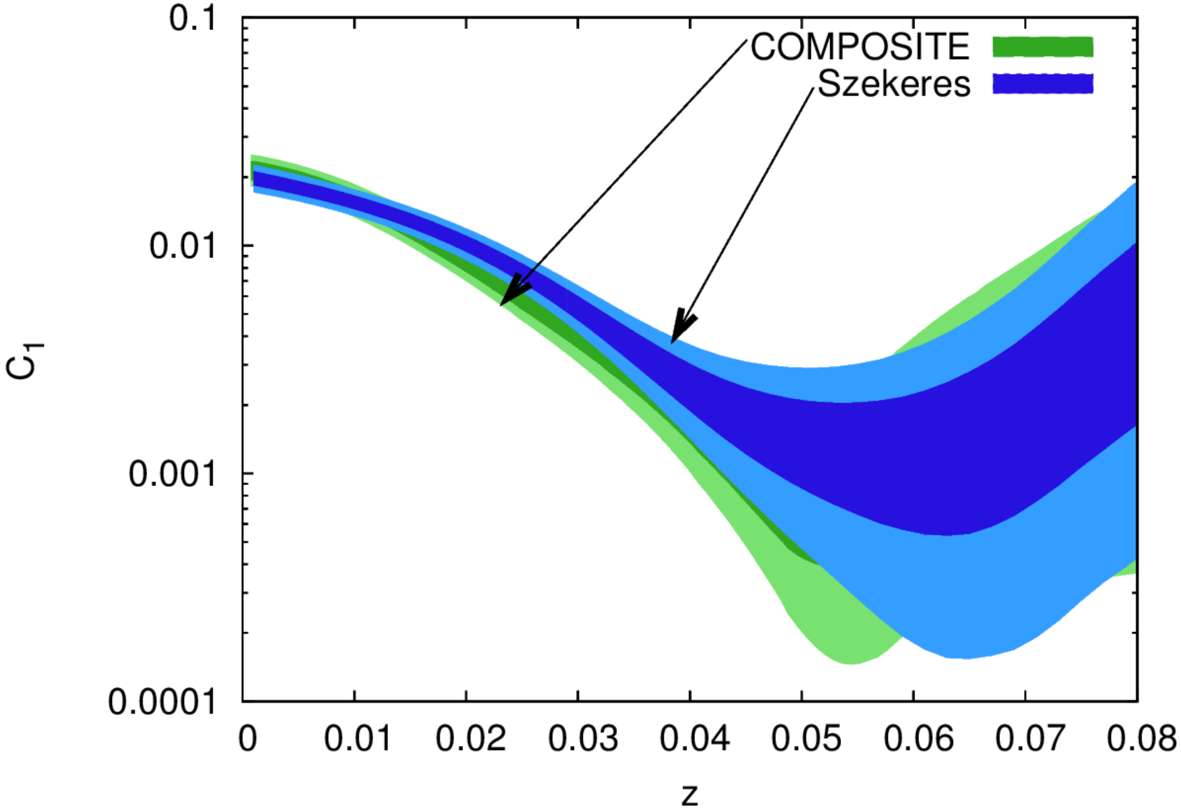

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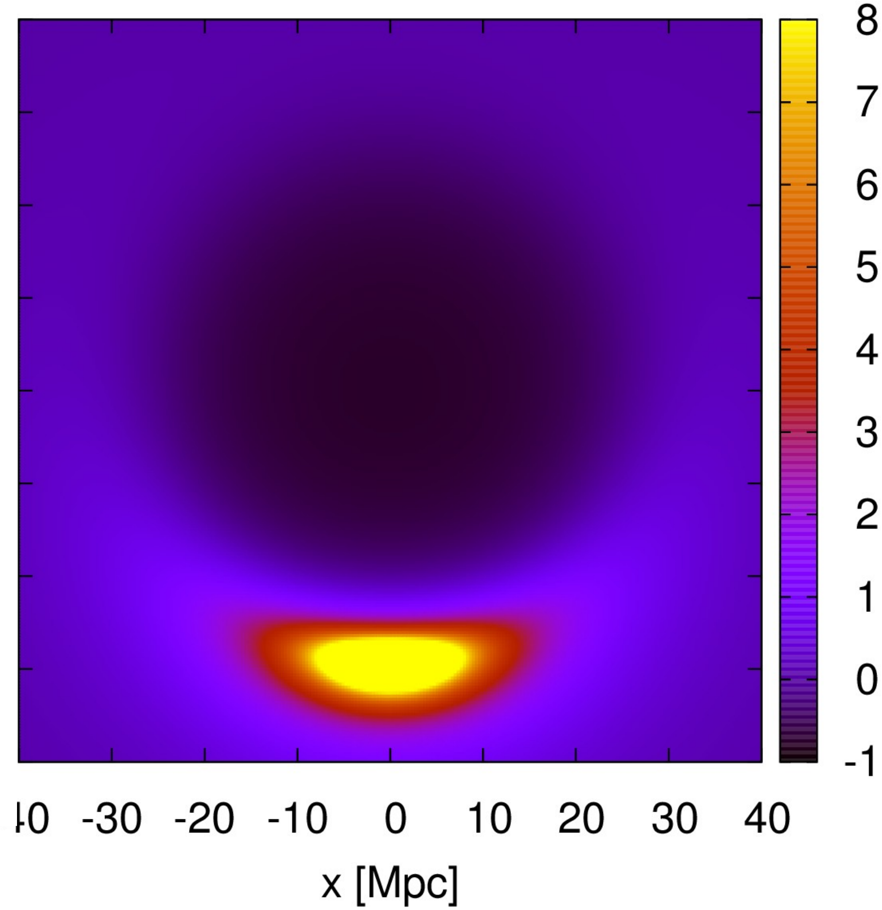

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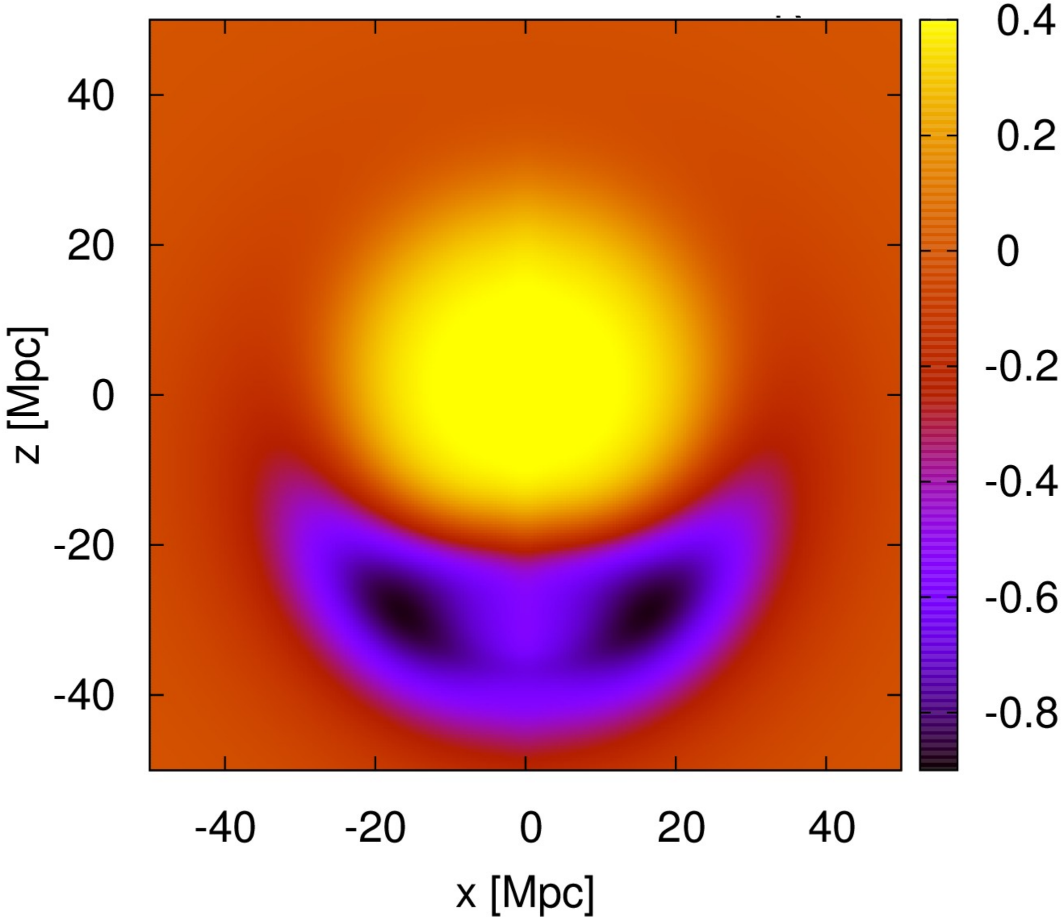

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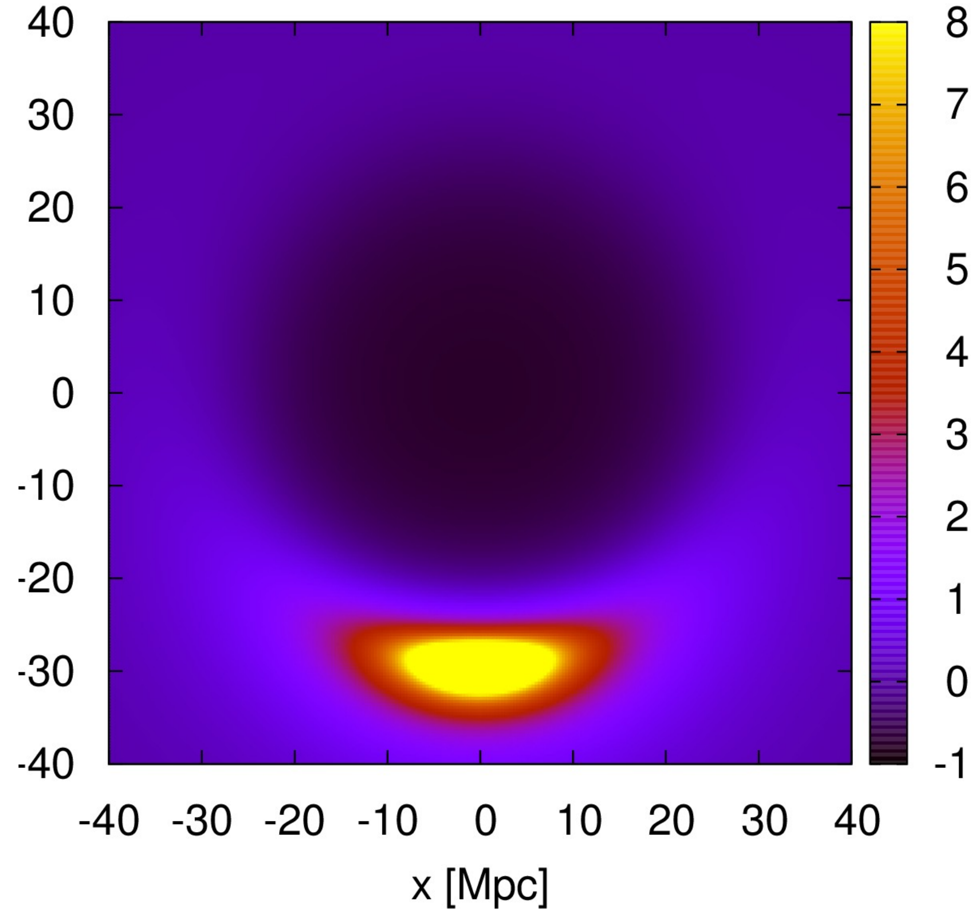
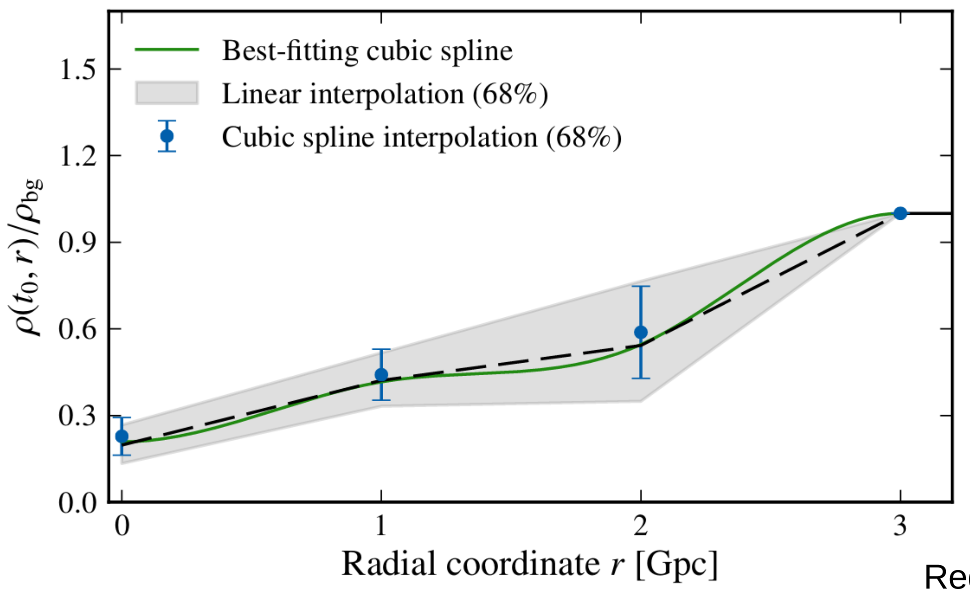


Giant void



Redlich, Bolejko, Meyer, Lewis, Bartelmann A&A 570, A63 (2014)

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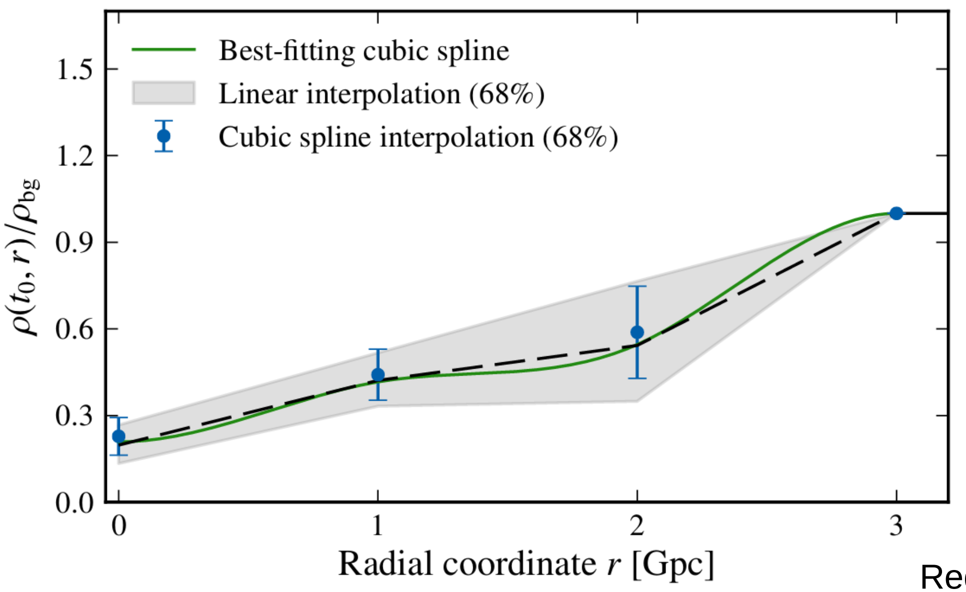

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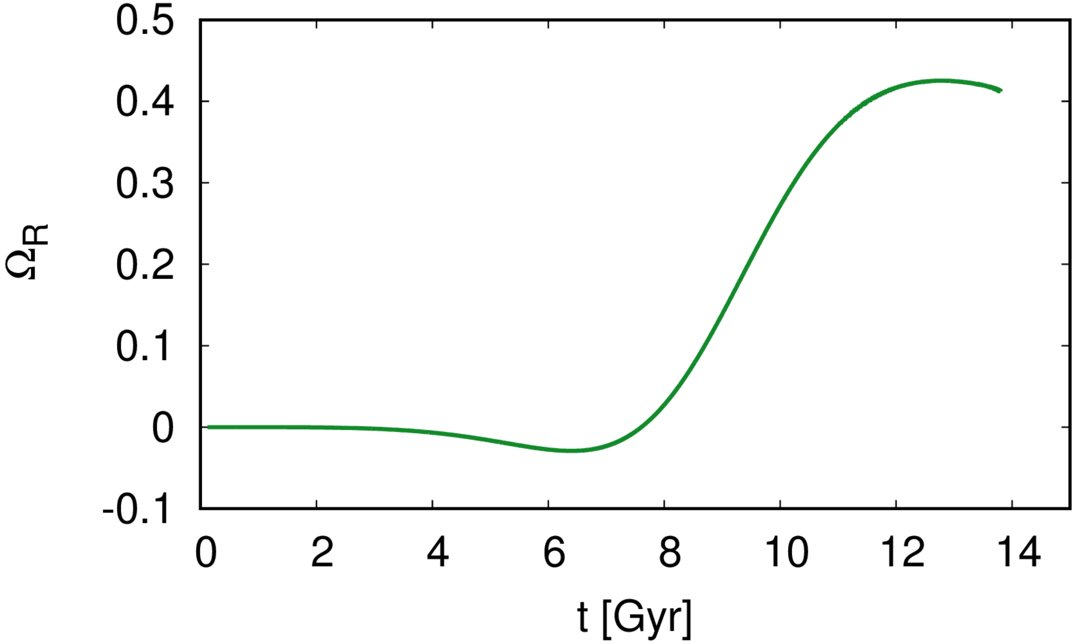

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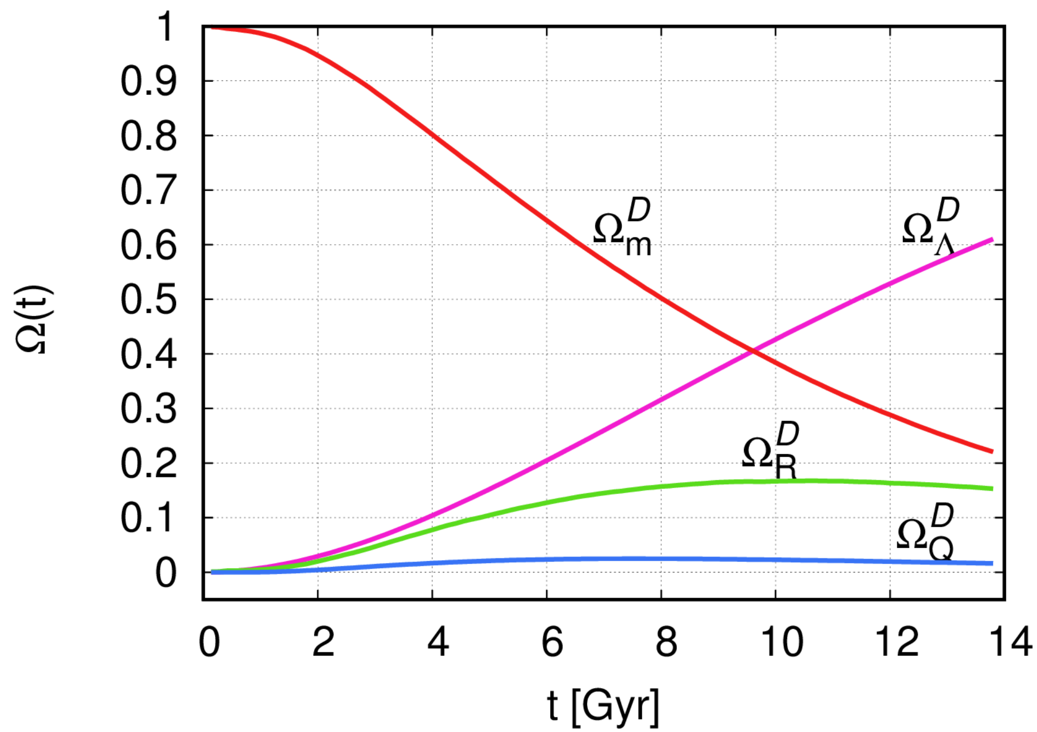

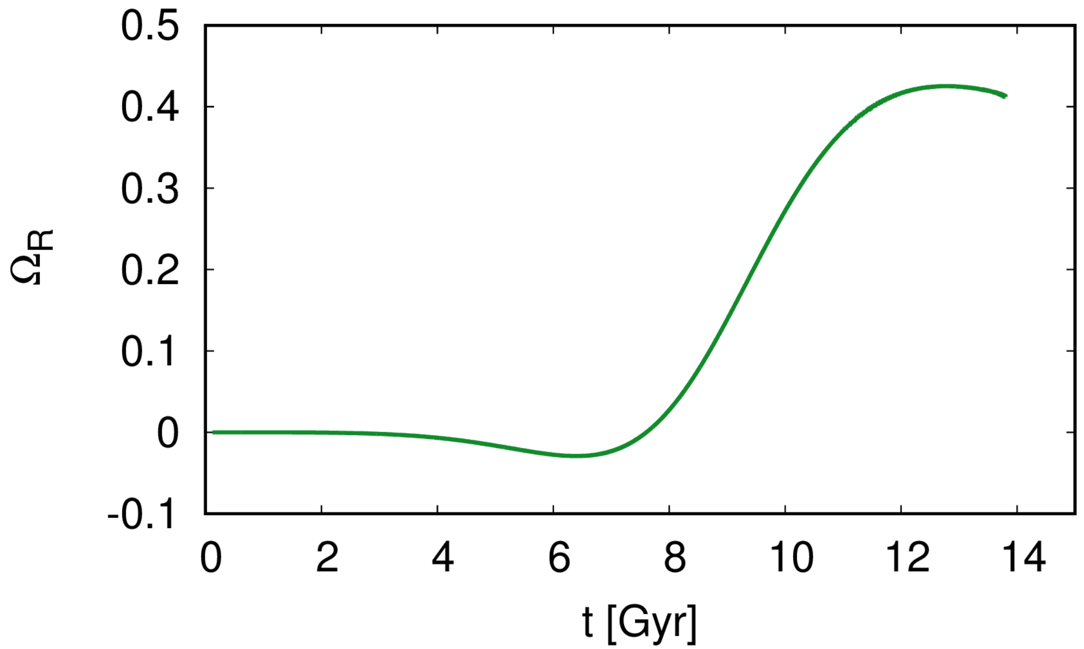

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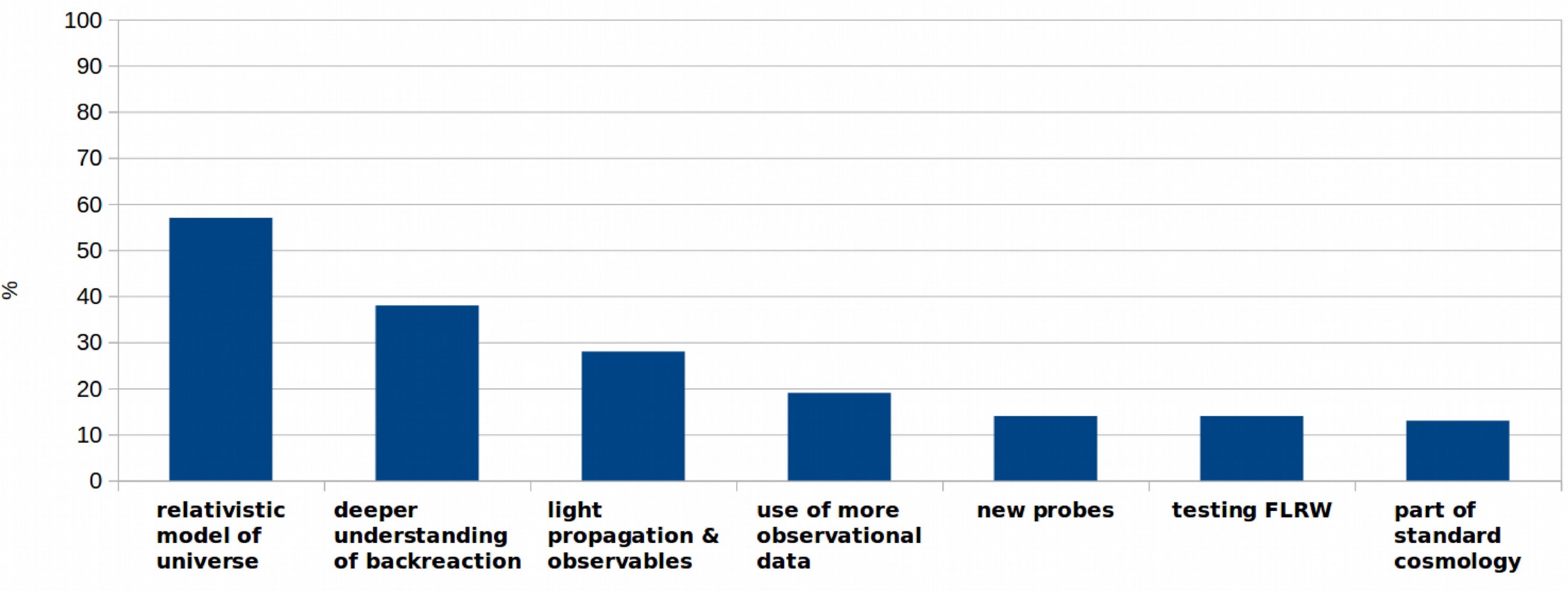

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