Type Ia supernovae observations in the Lemaître-Tolman model

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Outline

- Sn Ia as distance indicators,
- dim supernovae — dim or remote?
- light propagation in the inhomogeneous Universe,
- conclusions.

Supernova event

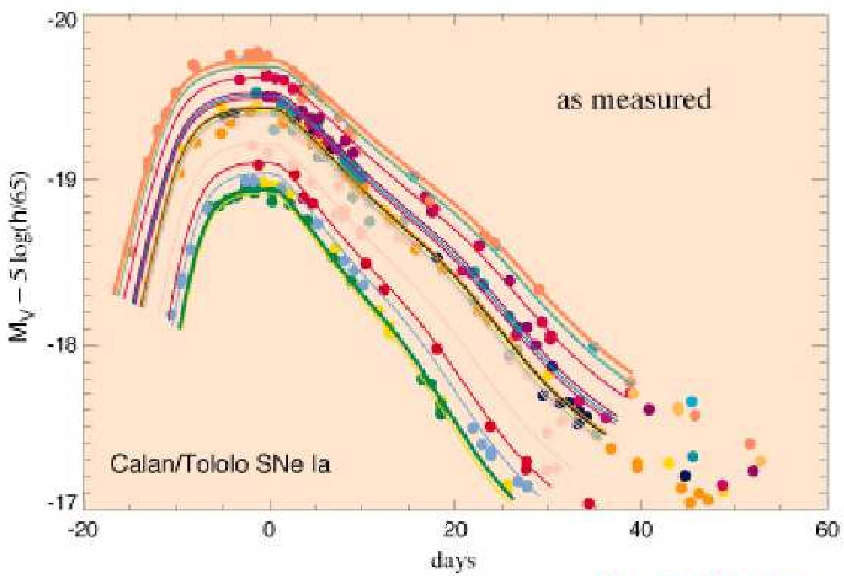
Type I:
(H deficit)

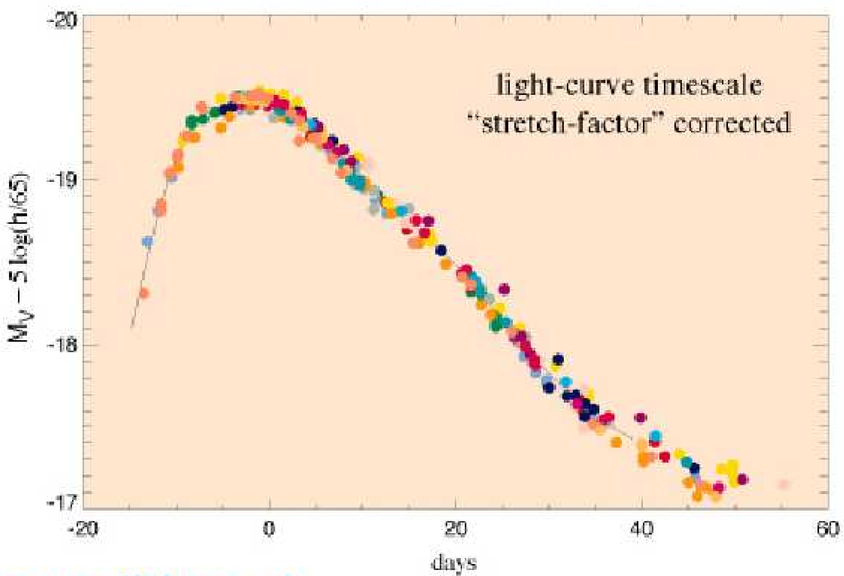
Type II:
(H exhibit)

- Ia — strong Si II
- Ib — no Si II but He I
- Ic — neither Si II nor He I

Standard candles

$$M_{B\ std.candl.} = -18.54 \pm 0.06 + 5\log(H_0/85); \quad \sigma_{obs} = 0.3$$





http://www-supernova.lbl.gov/

$$\sigma_{BATM} = 0.22 \qquad \sigma_{MLCS} = 0.12$$

$$\sigma_{\Delta m15} = 0.17 \qquad \sigma_{SF} = 0.05$$

Data interpretation

distance modulus:

$$m - M = 5 \log D_L \left(z, \Omega_m, \Omega_\Lambda, H_0, \mathbb{P} \right) + 25.$$

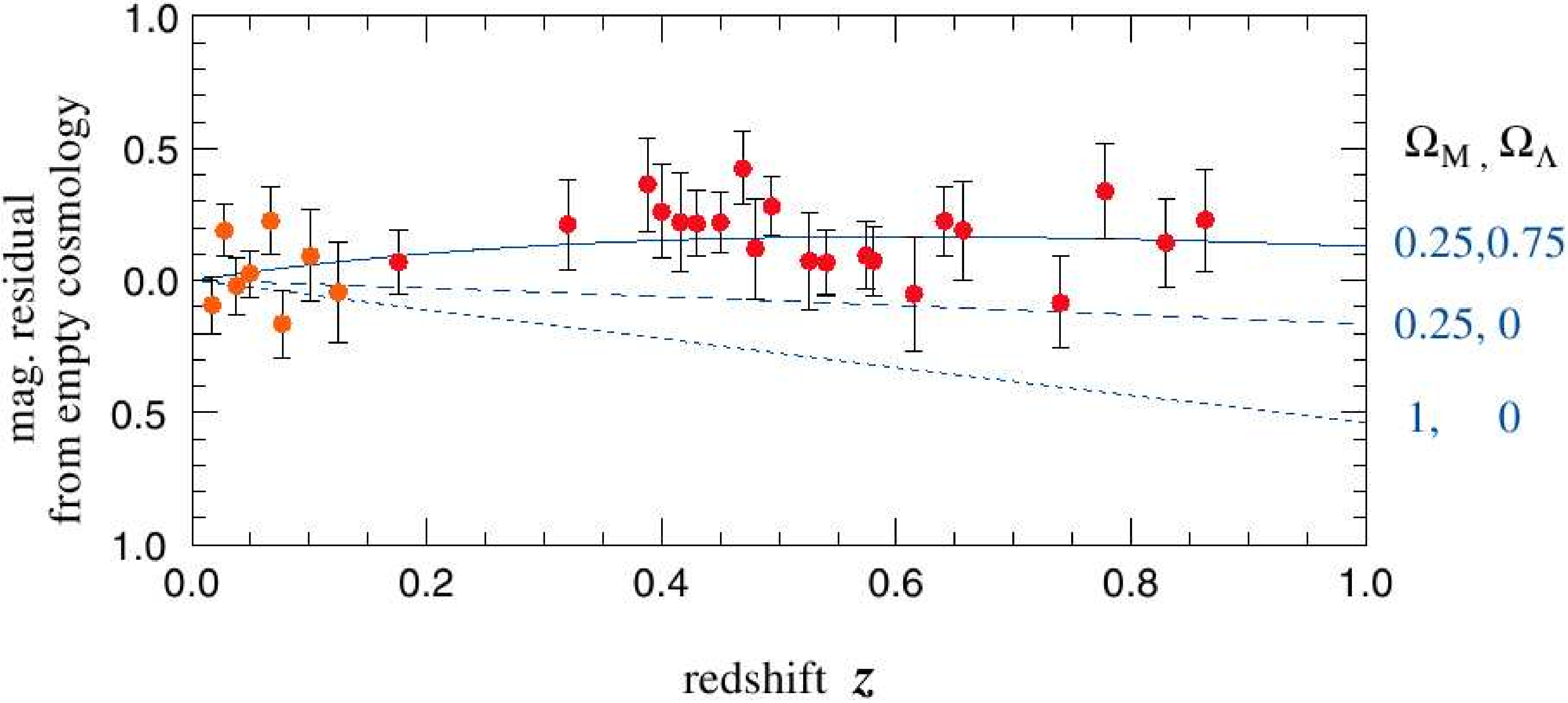
residual from empty cosmology:

$$\Delta m = m - m^{emp} = 5 \log \frac{D_L}{D_L^{emp}},$$

$$\Delta m > 0 \longrightarrow \text{acceleration},$$

$$\Delta m < 0 \longrightarrow \text{deceleration}.$$

Residual Hubble diagram



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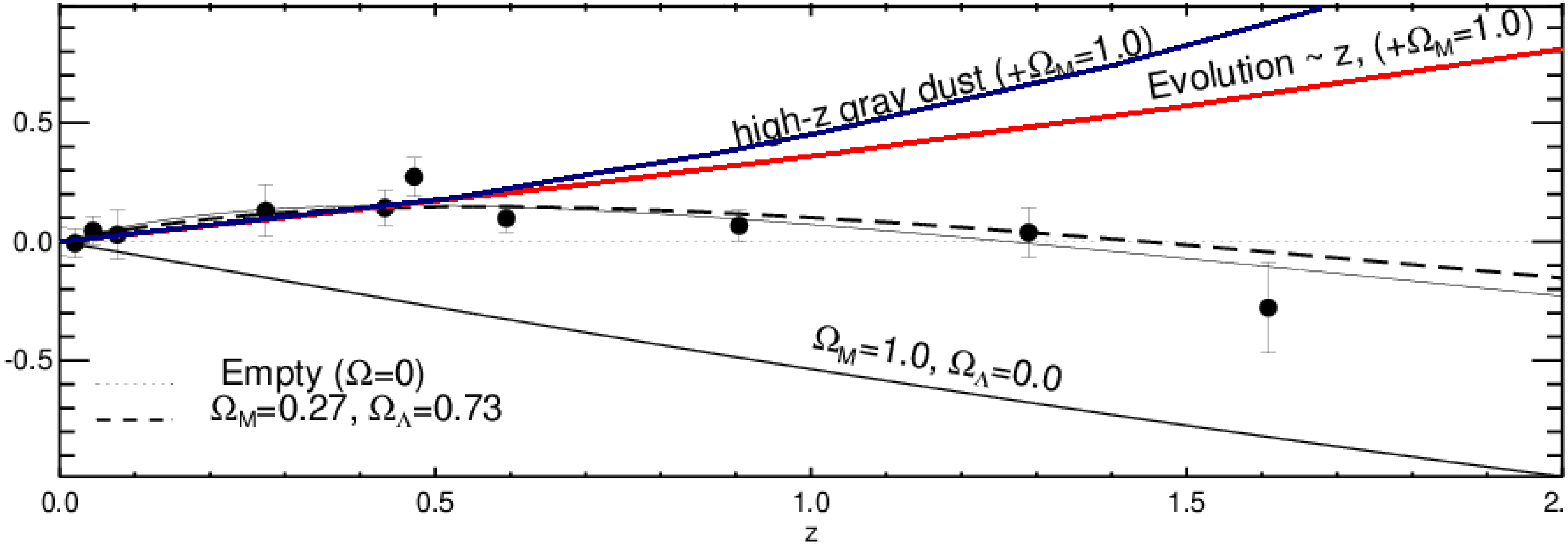
Dimmer?



Riess et al., 2004, ApJ, 607, 665

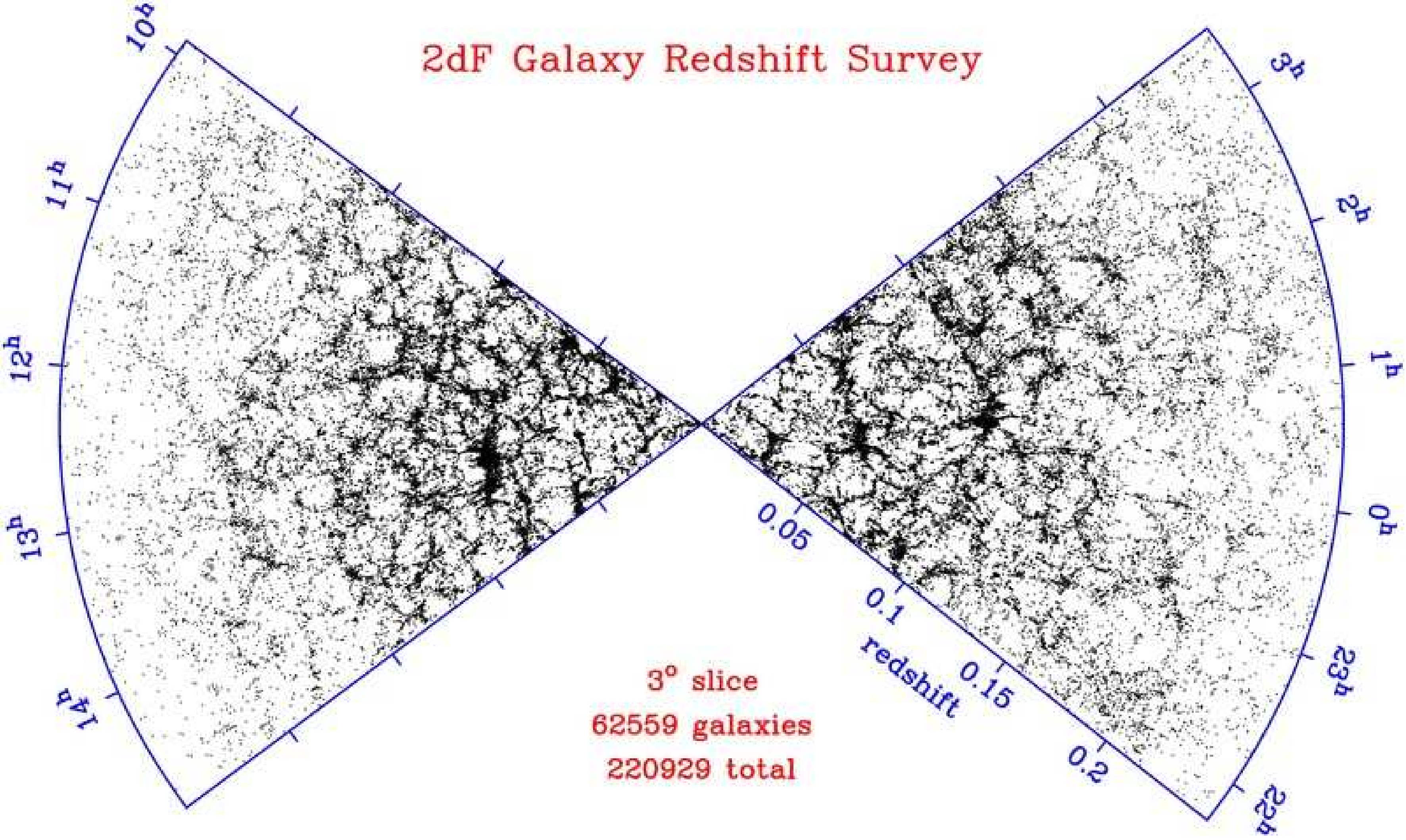
More remote?

$$\Delta m = m - m^{emp} = 5\log\frac{D_L}{D_L^{emp}},$$

$$\Delta m > 0 \rightarrow D_L > D_L^{emp} \rightarrow \text{acceleration?}$$

$$\Delta m < 0 \rightarrow D_L < D_L^{emp} \rightarrow \text{deceleration?}$$

Real Universe



Lemaître–Tolman model

$$ds^2 = c^2 dt^2 - \frac{R,_r^2(r,t)}{1+2E(r)}\, dr^2 - R^2(t,r)\left(d\theta^2 + \sin^2\theta d\phi^2\right),$$

FLRW limit:

$$ds^2 = c^2 dt^2 - \frac{a^2(t)}{1-kr^2}\, dr^2 - a^2(t) r^2 \left(d\theta^2 + \sin^2\theta d\phi^2\right).$$

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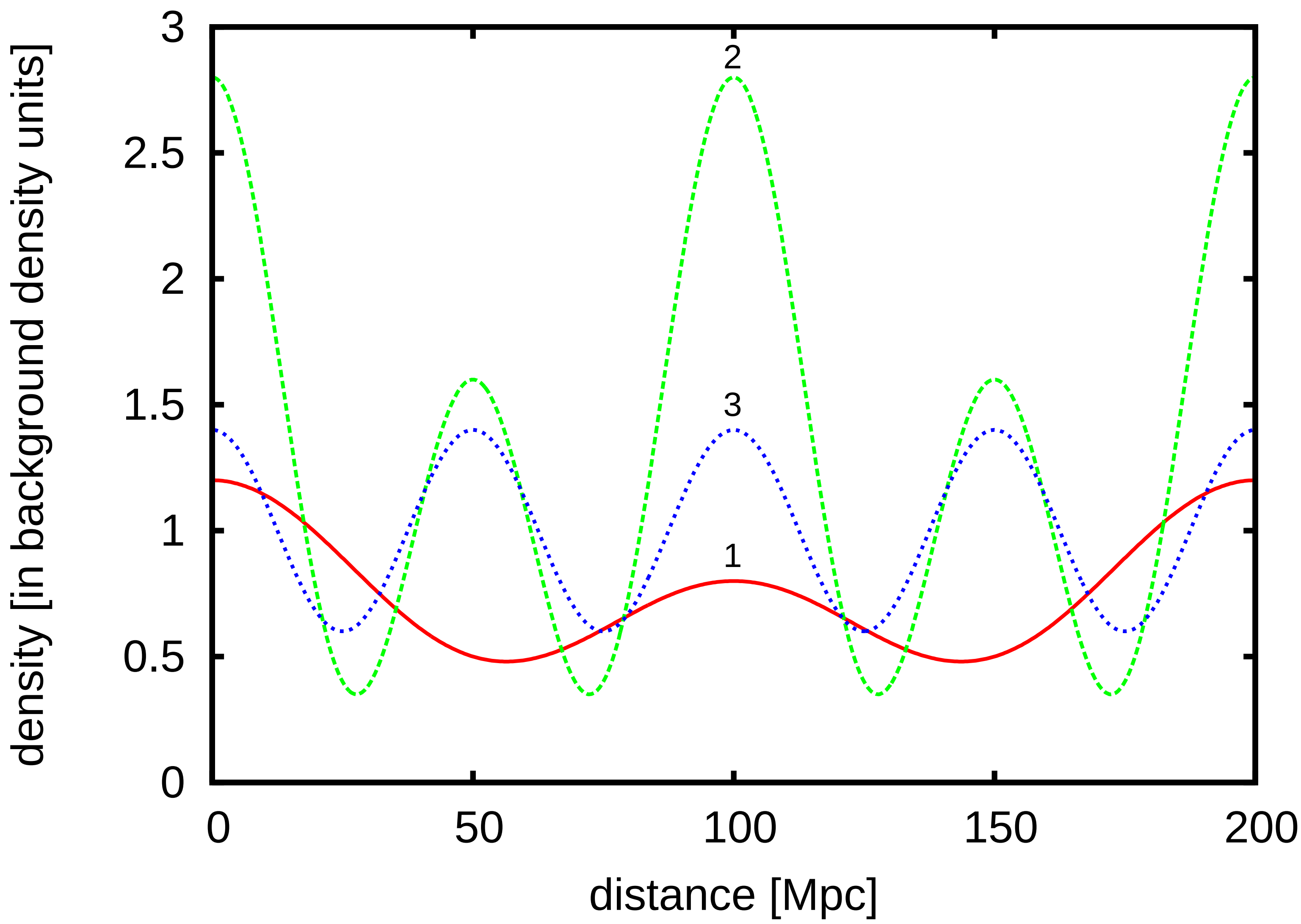
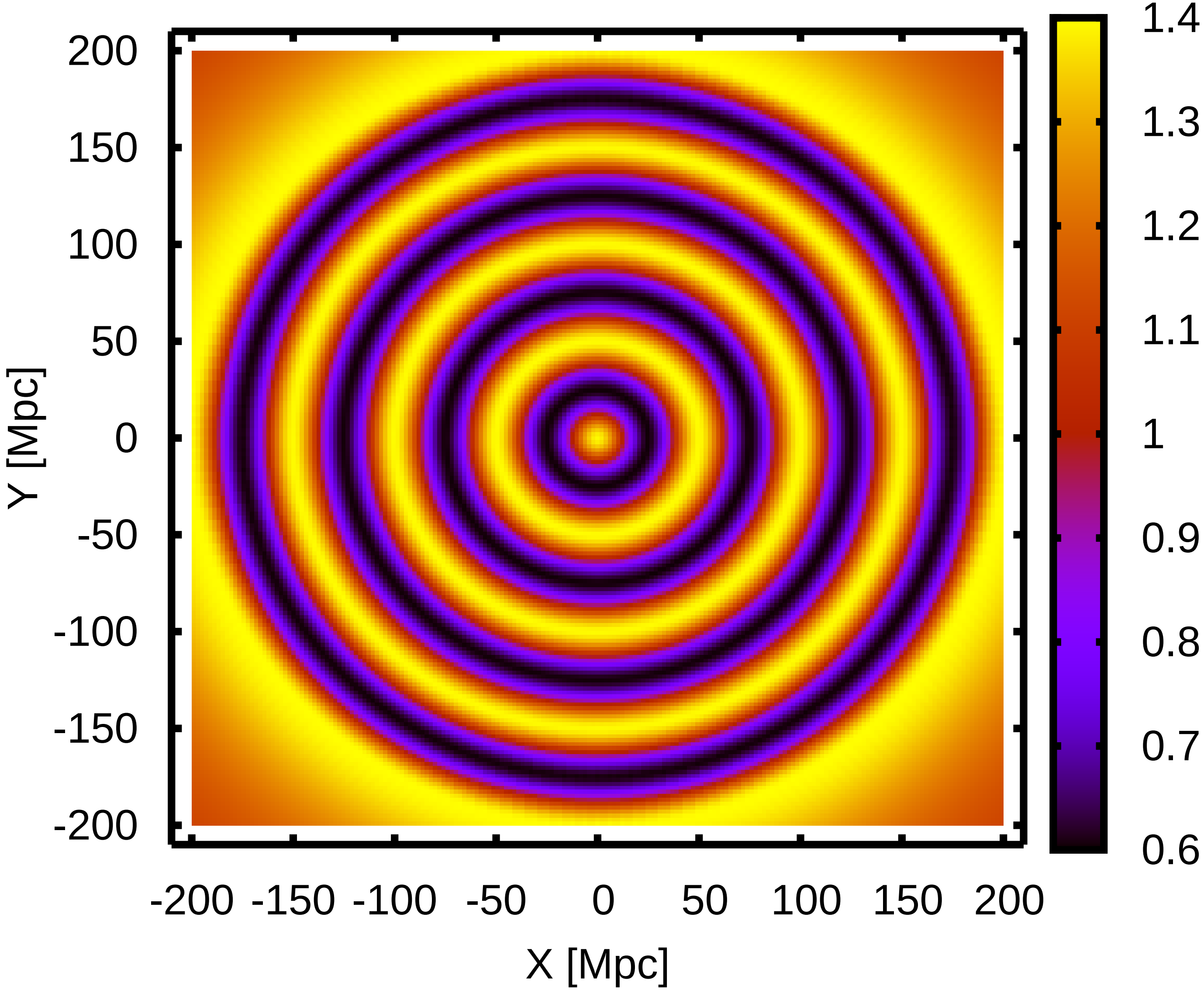
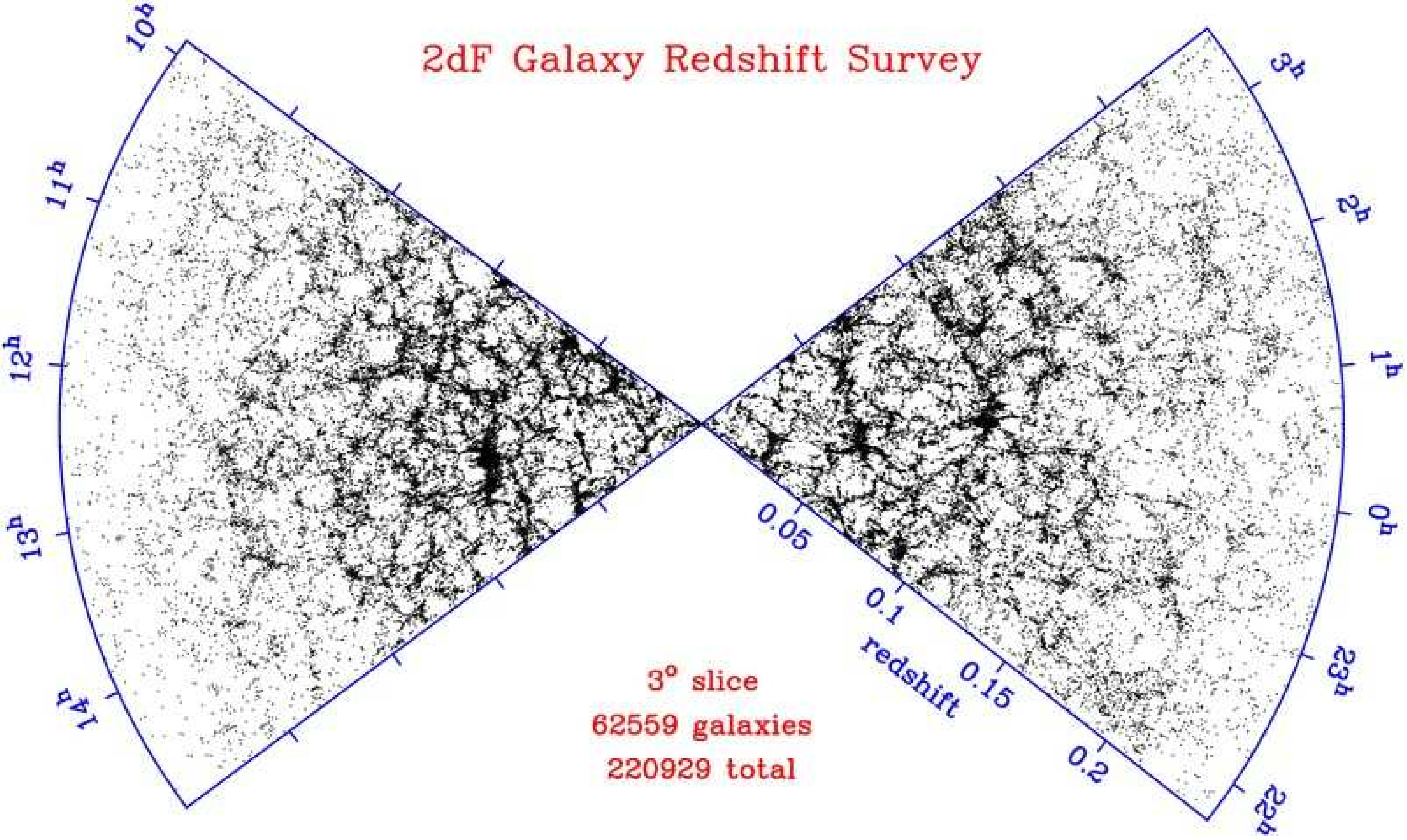
Density distribution



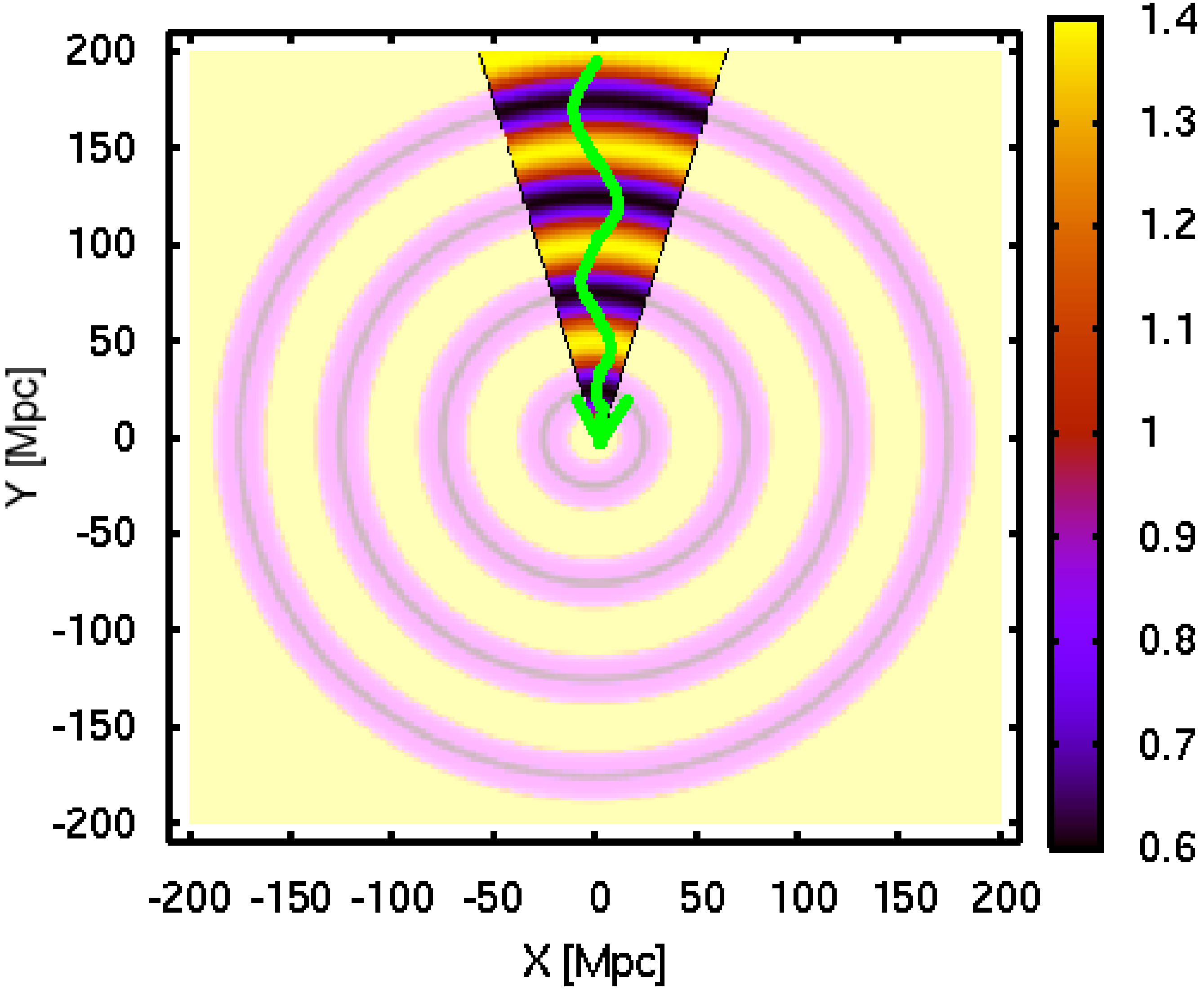
Lemaître–Tolman universe



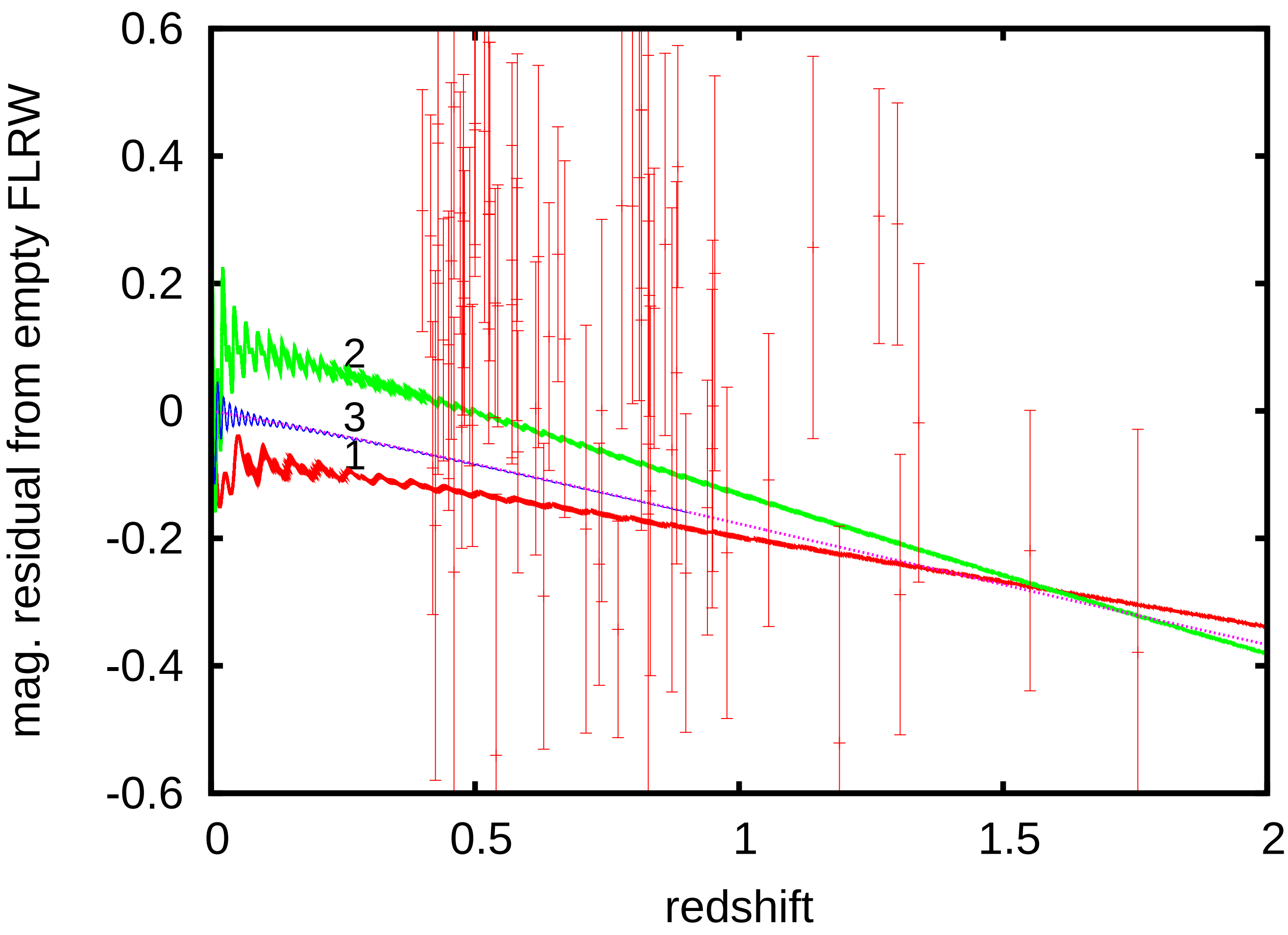
Real Universe



Light propagation

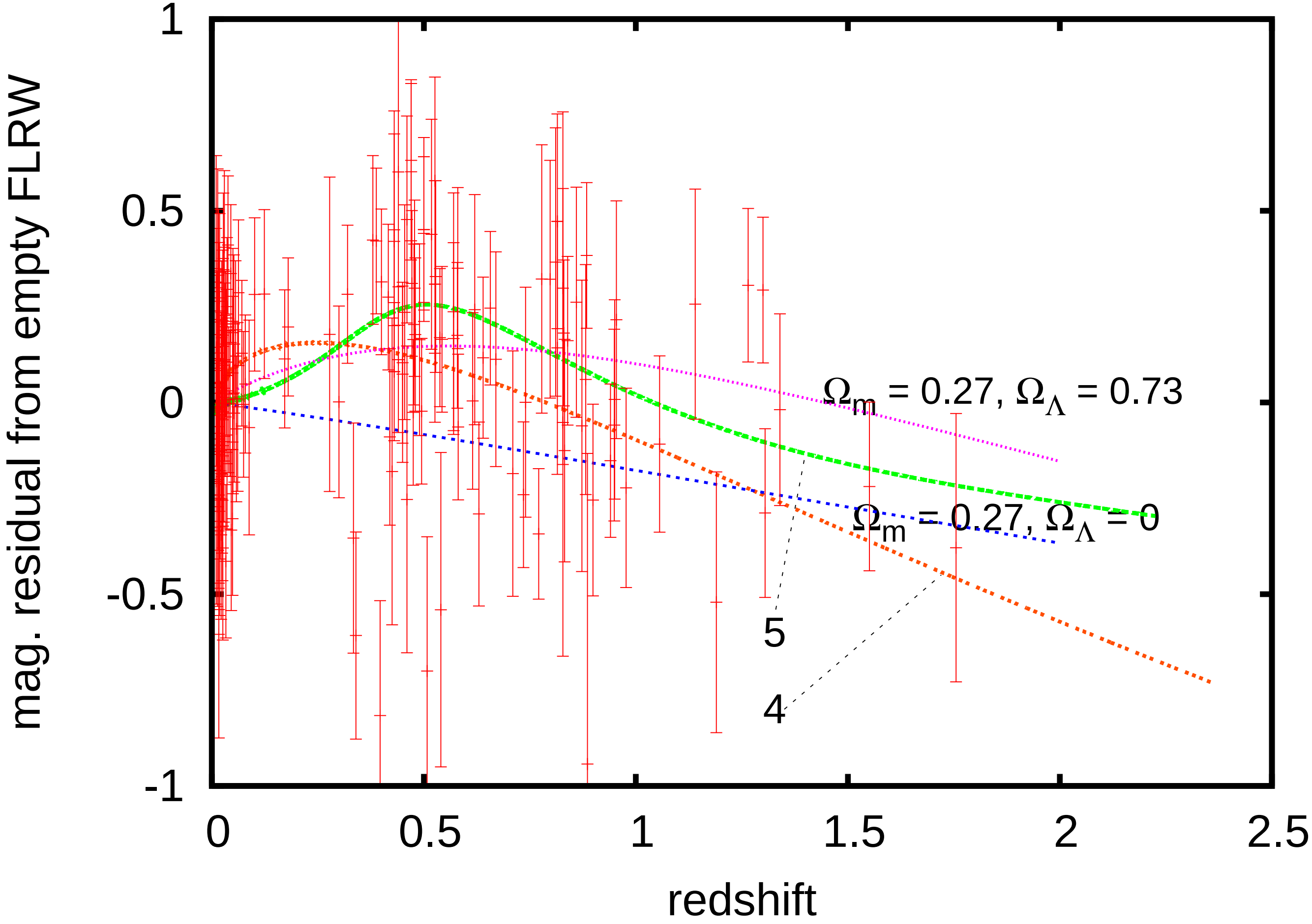


$$\Omega_{mat} = 0.27,\ \Omega_\Lambda = 0$$



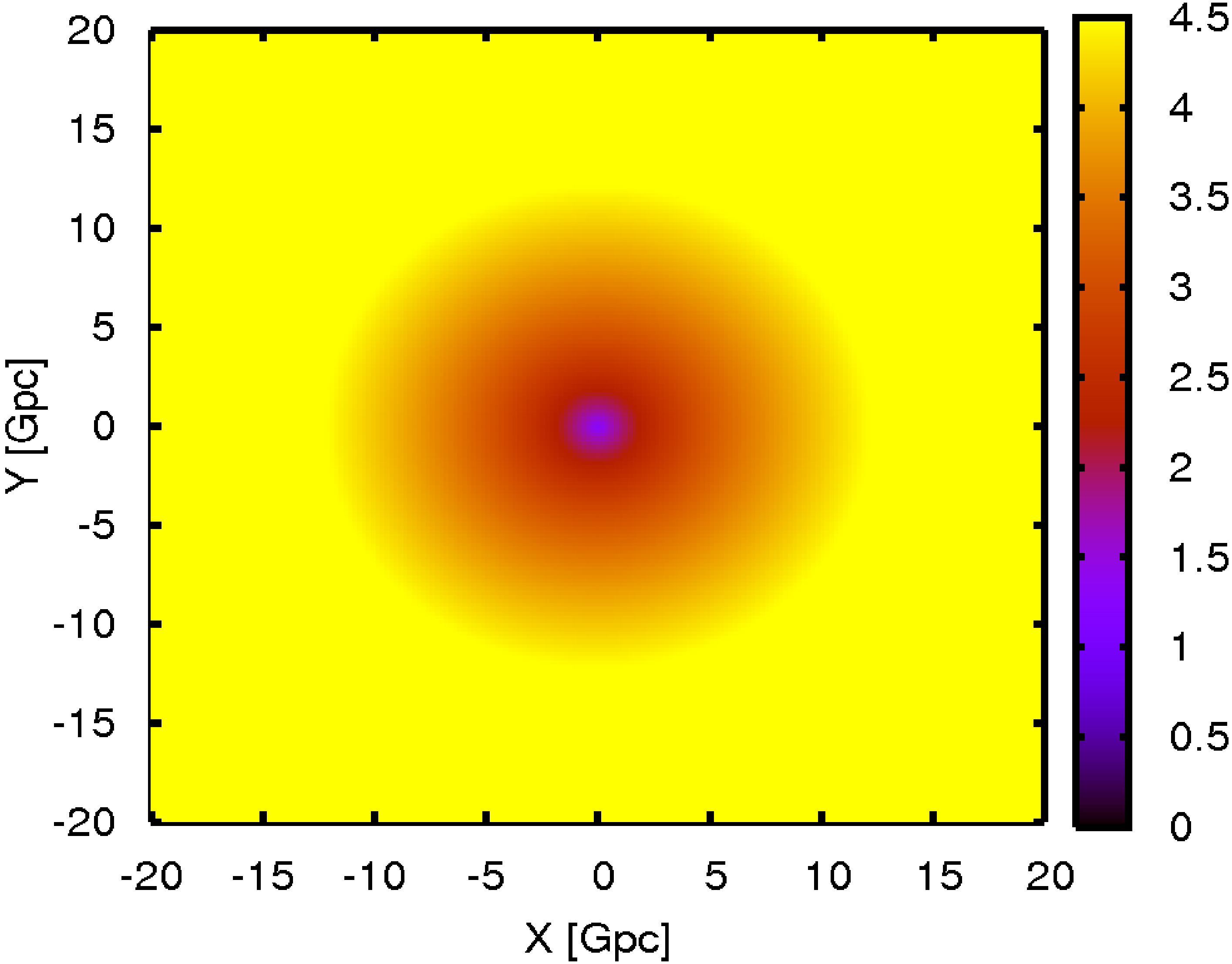
model	χ^2_{NDF}
1	2.05
2	1.46
3	1.62

Fitting the observations ($\Lambda = 0$)



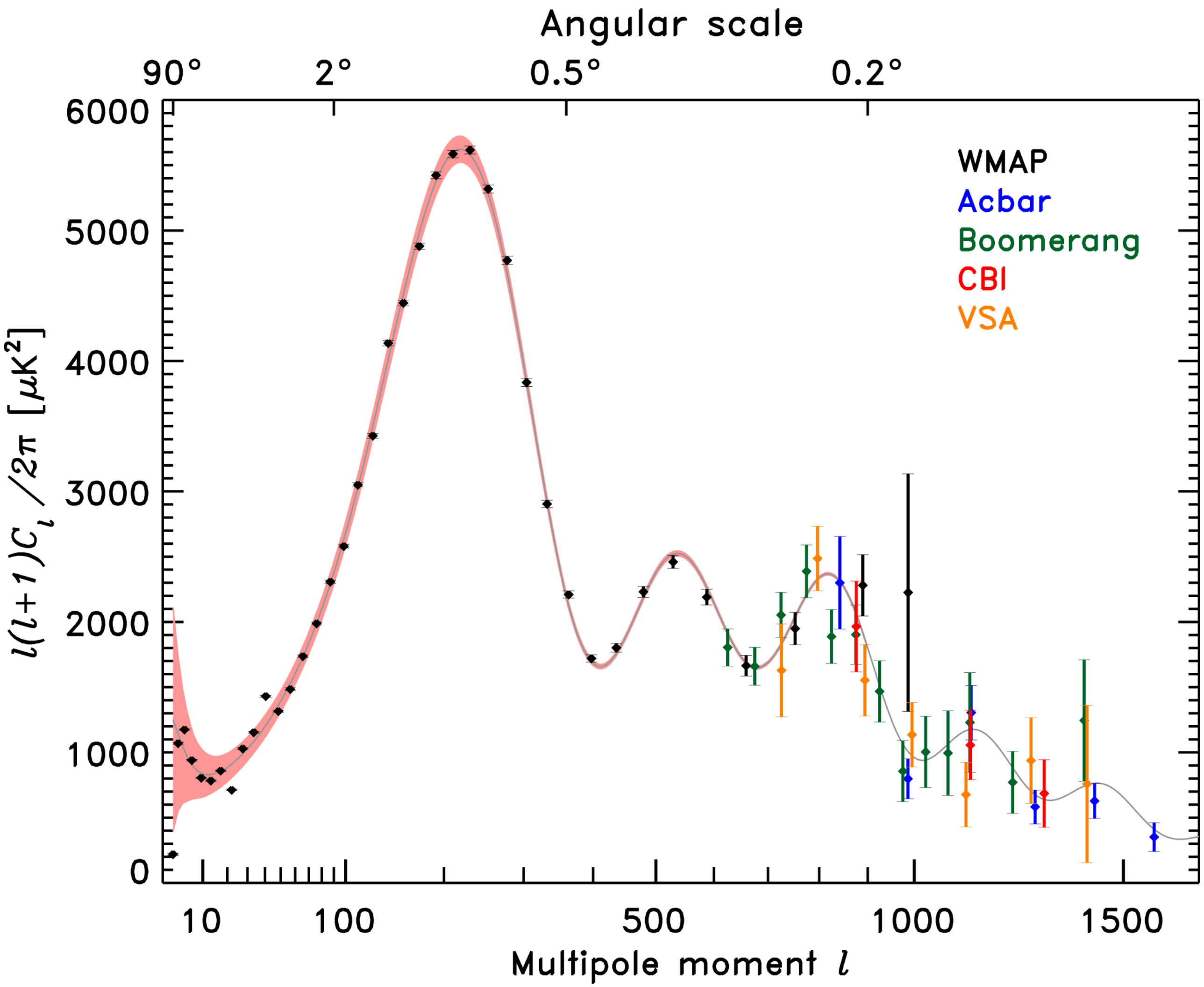
model	χ^2_{NDF}
4	1.19
5	1.15
ΛCDM	1.14
HIP	1.59

Model 4



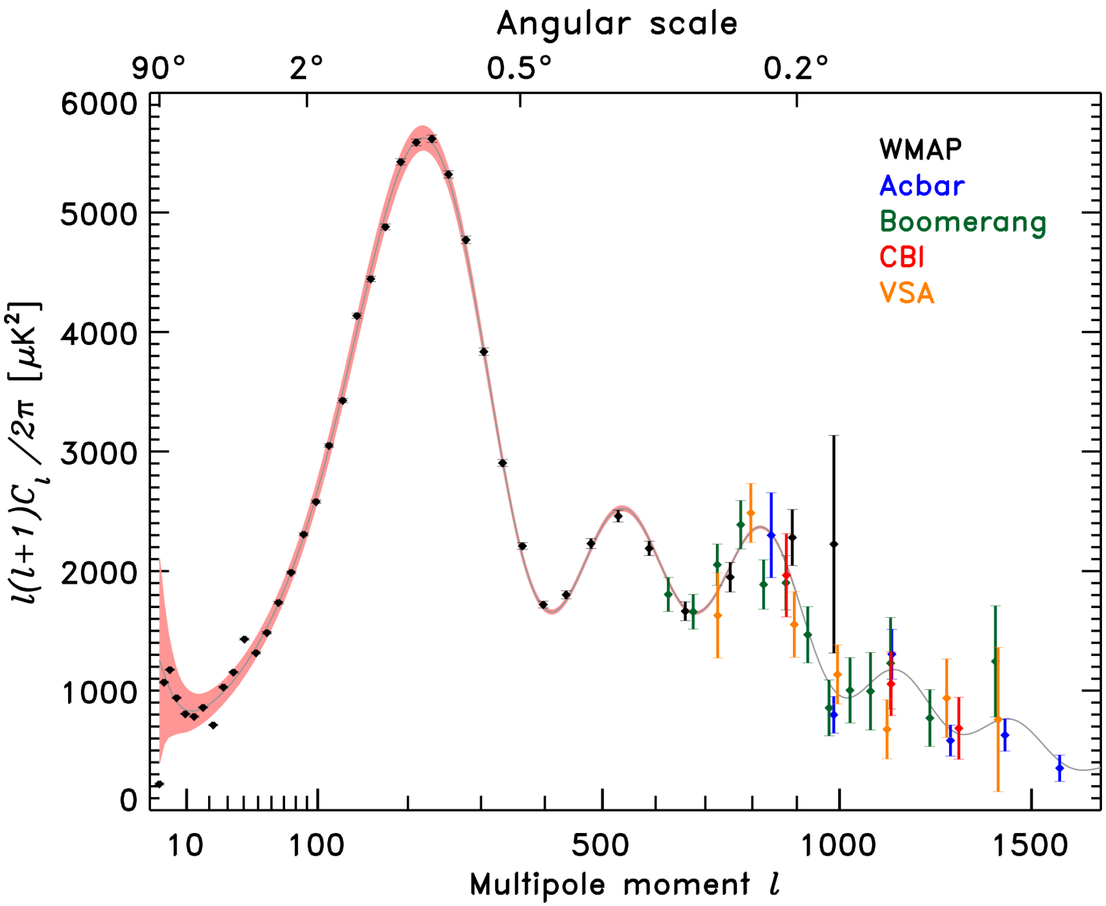
20
15
10
5
0
-5
-10
-15
-20
Y [Gpc]
-20 -15 -10 -5 0 5 10 15 20
X [Gpc]
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0

CMB



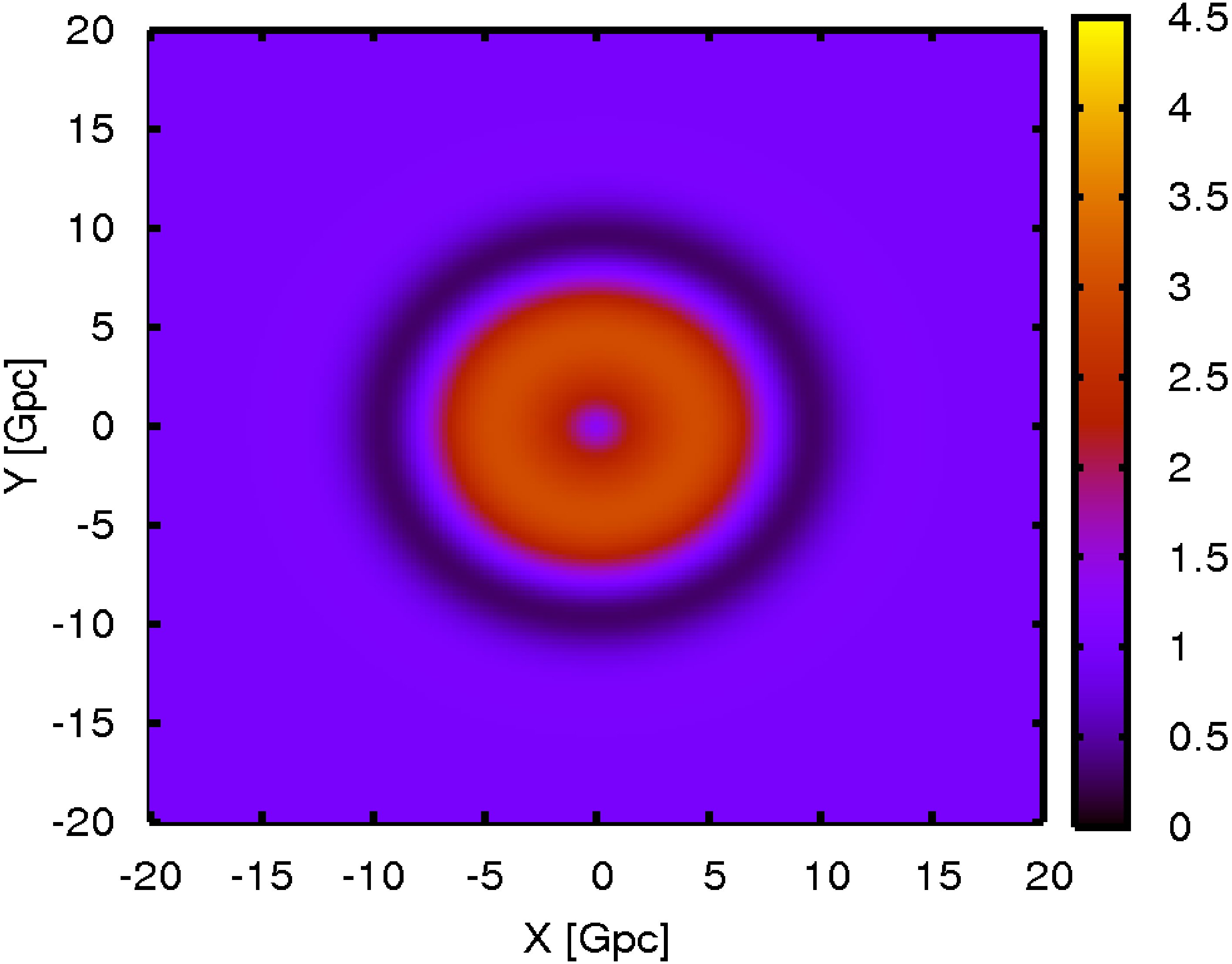
Angular scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi$ [μK^2]
WMAP
Acbar
Boomerang
CBI
VSA
10
100
500
1000
1500
Multipole moment l

CMB

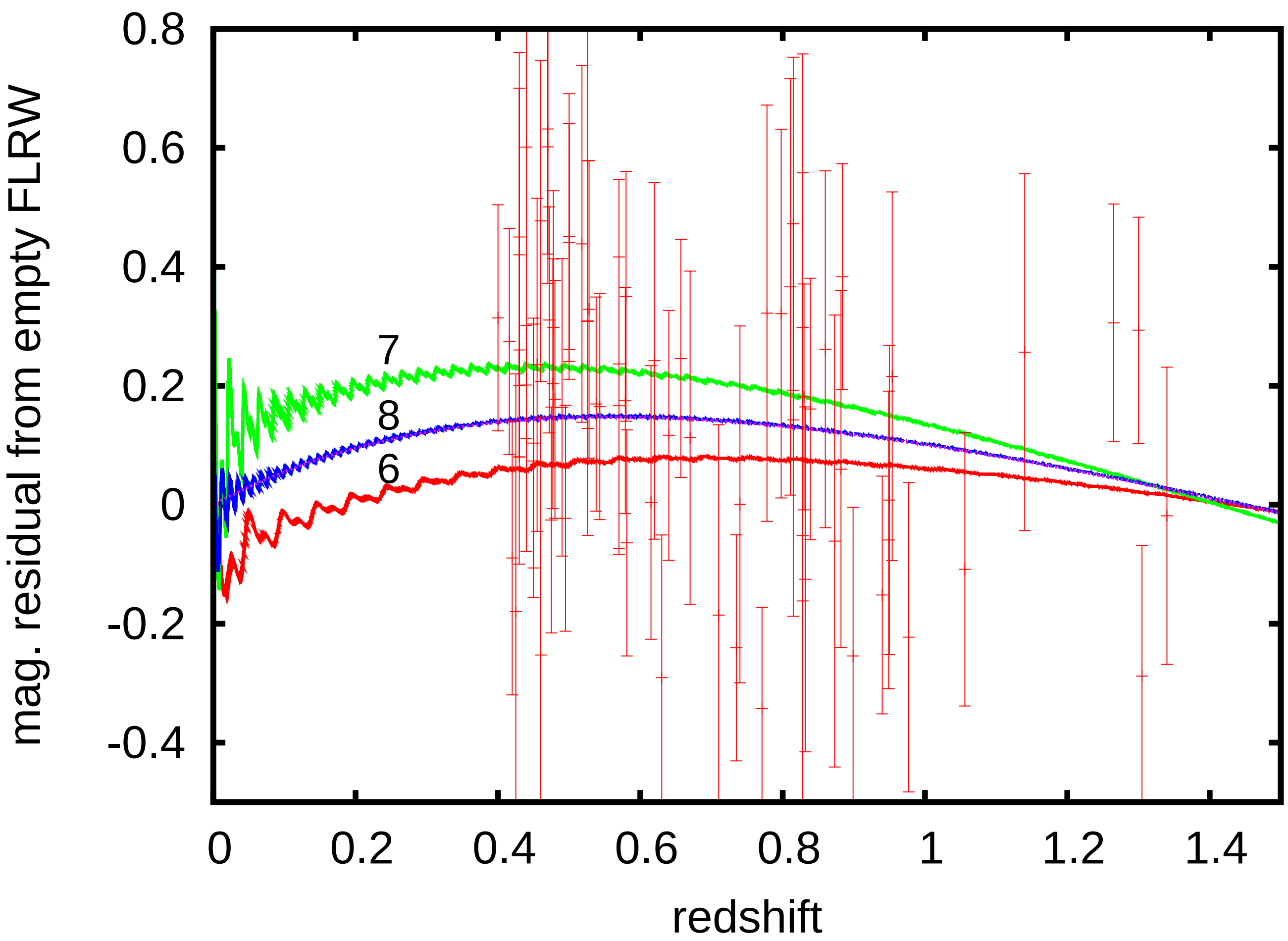


$$\mathrm{d}s^2 = c^2\mathrm{d}t^2 - \frac{R_{,r}^{\,2}(r,t)}{1+2E(r)}\,\mathrm{d}r^2 - R^2(t,r)\left(\mathrm{d}\theta^2 + \sin^2\theta\,\mathrm{d}\phi^2\right),$$

Fitting Sn & CMB



Cosmological constant



model	χ^2_{NDF}
6	1.35
7	1.26
8	1.14

Conclusions

- density inhomogeneities can mimic acceleration,
- cosmological constant needed,
- density inhomogeneities might partly explain the scatter in the residual Hubble diagram.

Thank you

Lemaître–Tolman equations

$$4\pi\rho(t,r) = \frac{\mathcal{M}'(r)}{R^2(t,r)R'(t,r)},$$

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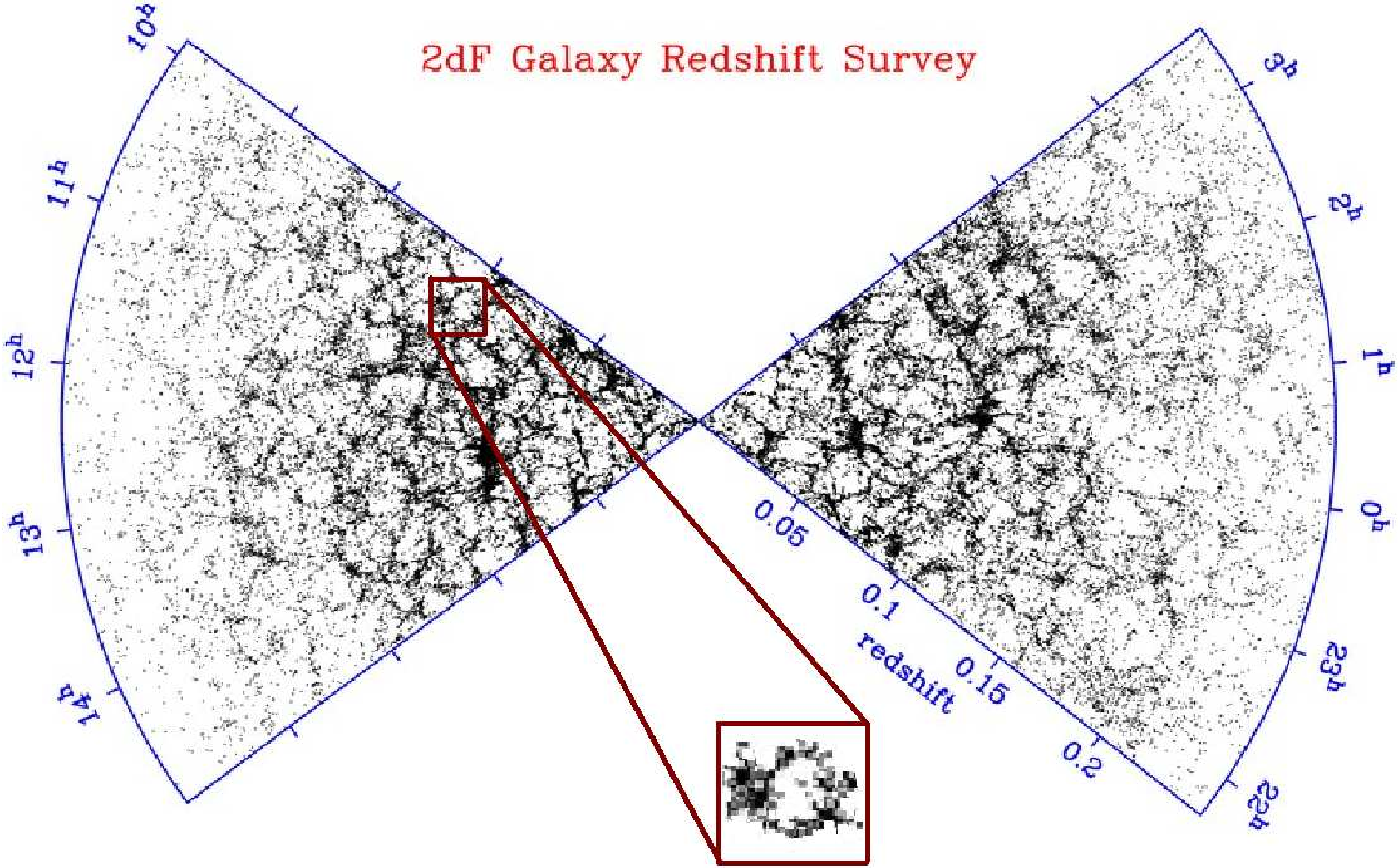
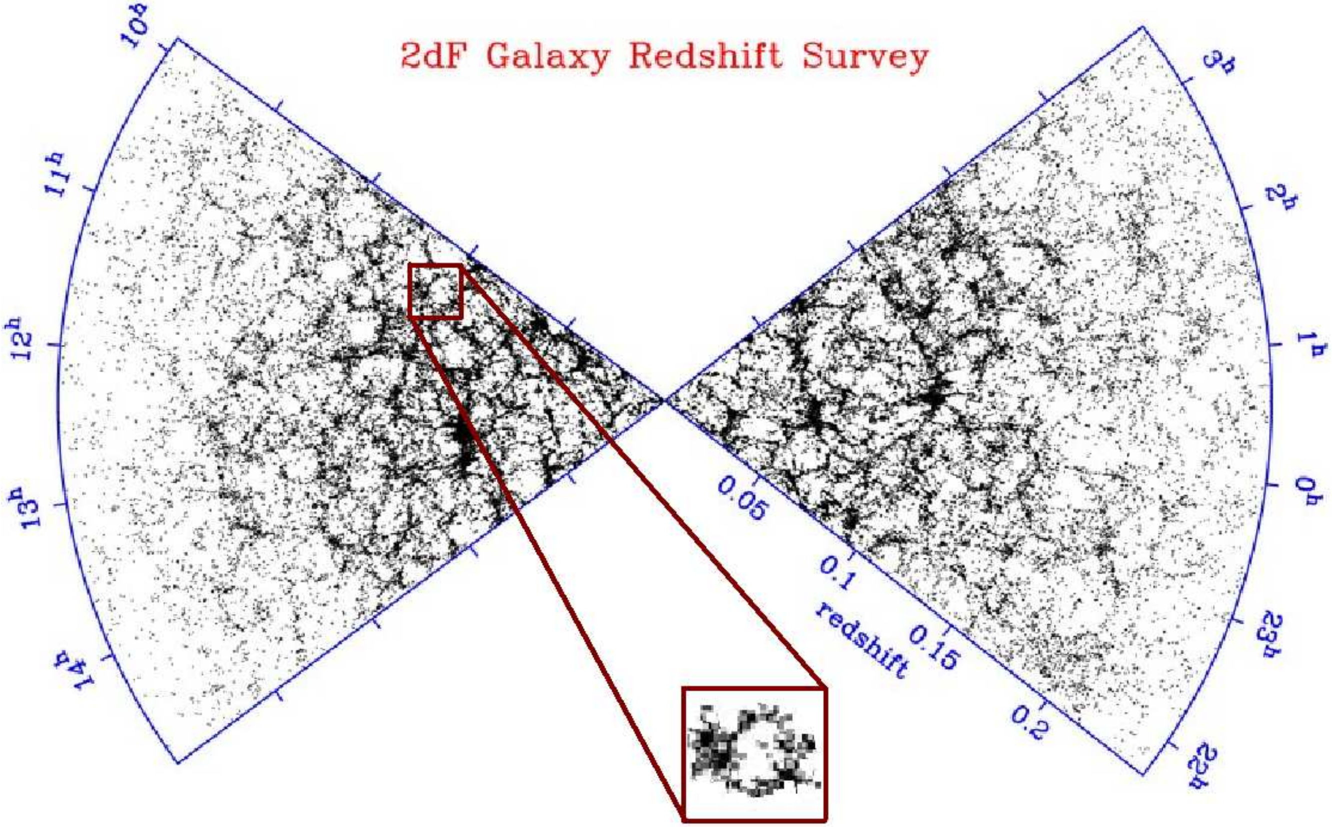
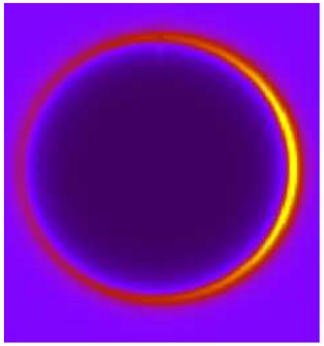
Models of single structure



Multi–Szekeresa universe





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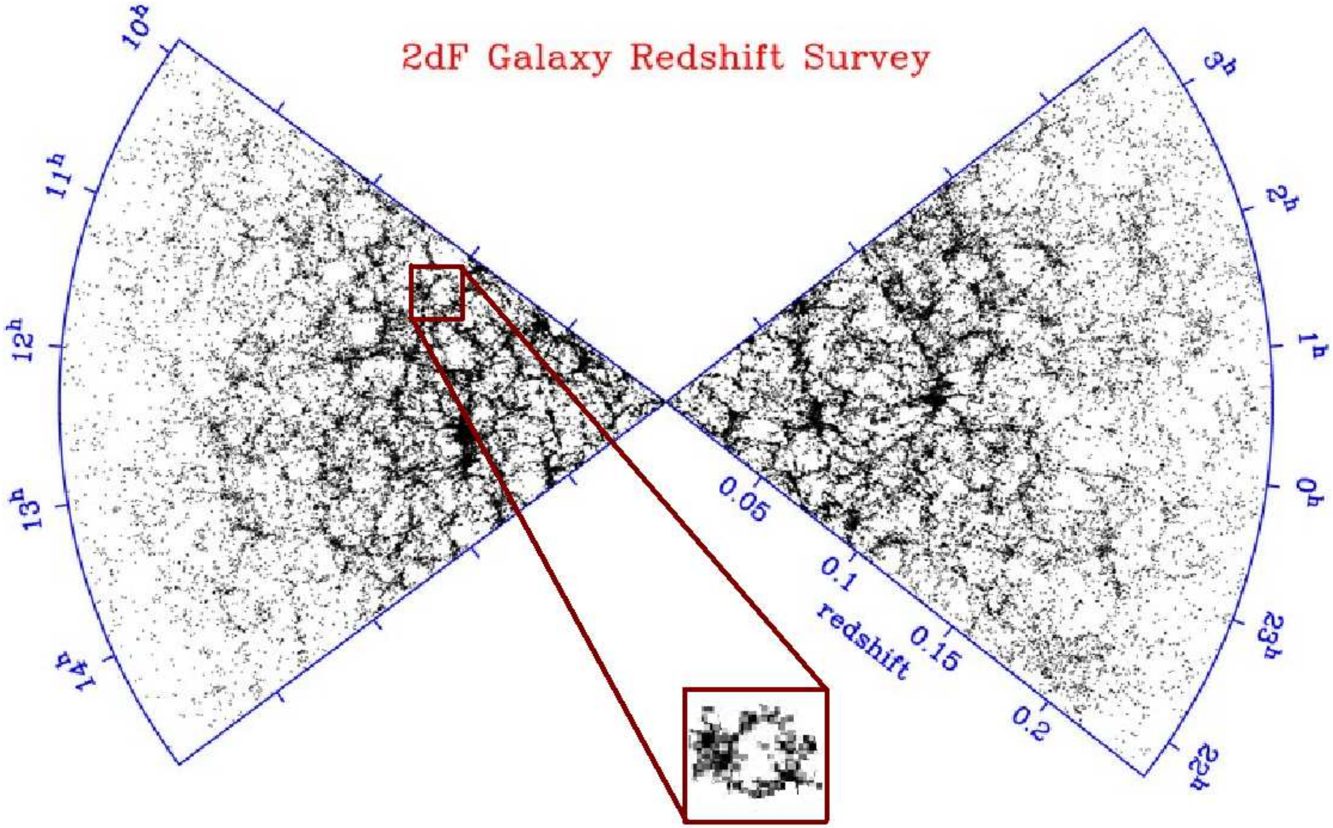

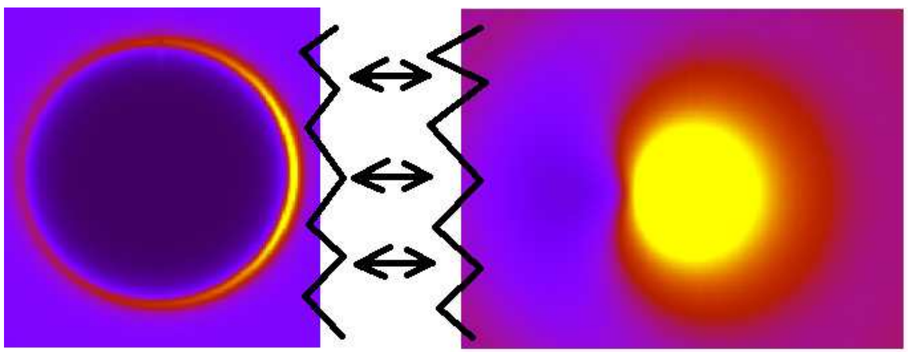

CMB temperature fluctuations