Voids in ΛCDM: Effects on Density Parameters

Arnaud de Lavallaz
with M. Fairbairn

King's College London

4th UniverseNet School

Lecce | Università del Salento

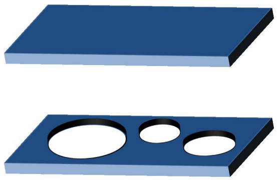
September 2010

Outline

Large Holes in Our Universe

'Standard' cosmological model:
homogeneous and isotropic
→ Good explanation of observations

Swiss-Cheese Universe:
inhomogeneities in matter distribution
→ More realistic at smaller scales



Main aim:

- Build a Swiss-Cheese model embedded in ΛCDM universe
- Study the effects of the voids on the density parameters Ω_m and Ω_Λ

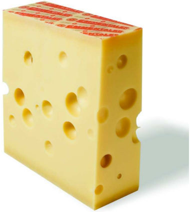
Radial Inhomogeneities

Model based on Lemaître-Tolman-Bondi (LTB) metric:

- spherically symmetric solution of Einstein's equations
- only dust (pressureless matter)
- similar to Einstein-de Sitter, but with radial inhomogeneities

Construction of our model:

- 'Cheese' = usual **FRW solution** (spatially flat)
- 'Holes' = **LTB solution**



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Analytical Considerations

LTB metric can be written as (comoving coordinates) [1]:

$$ds^2 = -dt^2 + S^2(r,t)dr^2 + R^2(r,t)(d\theta^2 + sin^2\theta d\phi^2)$$

with the following constraints:

$$S^2(r,t) = \frac{R'^2(r,t)}{1+2E(r)},$$

$$\frac{1}{2}\dot{R}^2 - \frac{GM(r)}{R(r,t)} - \frac{1}{3}\Lambda R^2 = E(r),$$

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

Parameters and Initial Conditions

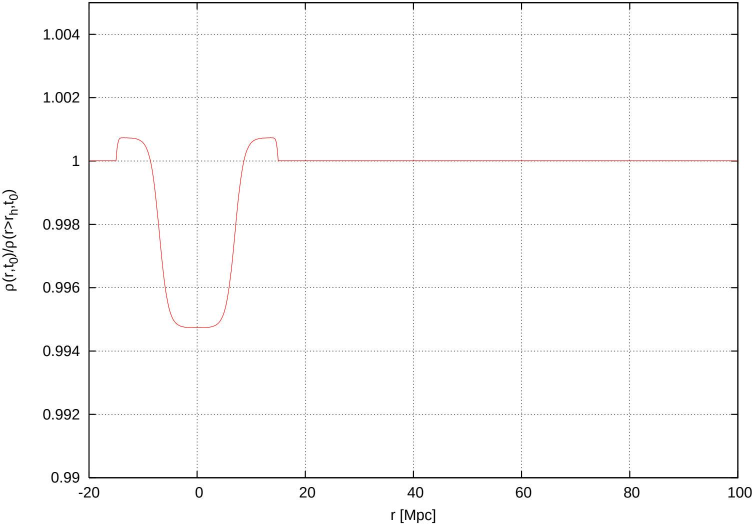
Functions $E(r)$ and $M(r)$ are left arbitrary in LTB model:

- $E(r) \sim$ **spatial curvature**, depending on $M(r)$
  $E(r) = \frac{1}{2}\frac{H_{LTB}^2 a_{LTB}^2}{c^2}\left(r^2 - \frac{3}{4\pi}\frac{M(r)}{r\rho_m}\right)$
  where $H_{LTB} = H(z_{LTB})$ and $a_{LTB} = a(z_{LTB})$, $z_{LTB} = 1100$
- $M(r) \sim$ mass inside sphere of comoving radial coordinate r, depending on the initial density contrast $\rho(r, t_0)$

Initial density contrast = Kostov's model [2]:

$$\rho(r, t_0) = \bar{\rho}(t_0)\left\{A_1 + A_2 tanh\left[\alpha\left(r - r_1\right)\right] - A_3 tanh\left[\beta\left(r - r_2\right)\right]\right\}$$

Parameters and Initial Conditions



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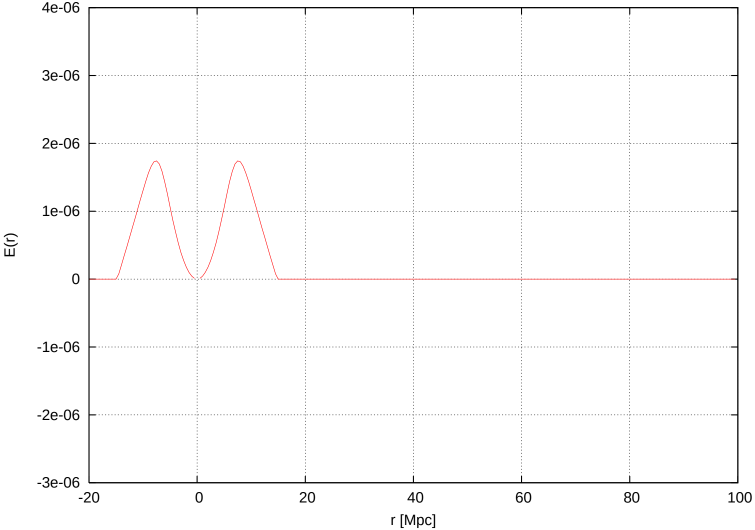
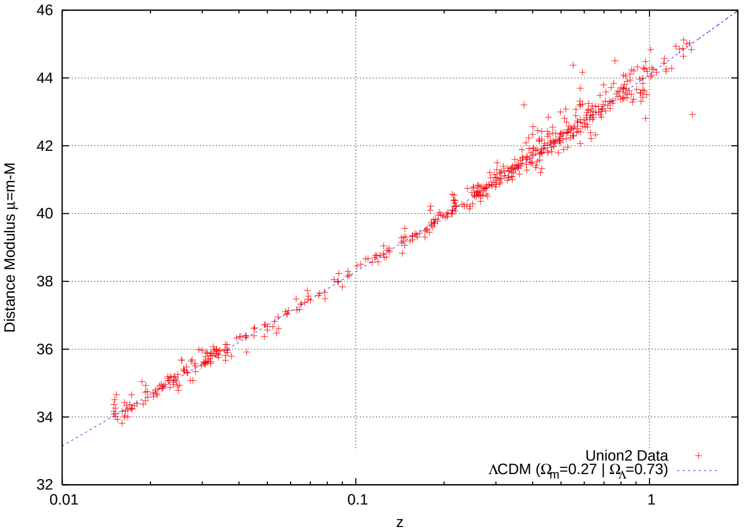


Fitting SN Ia Data (Union2)



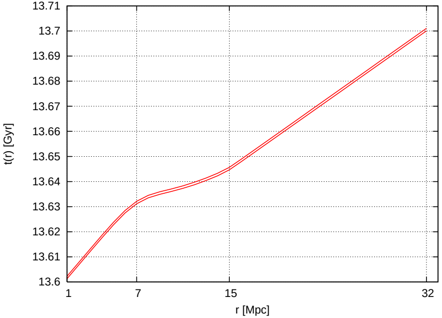
Simulations: Obtaining Redshifts

Computation process (1/2):

1. Creating look-up tables for $M(r)$ and $R(r, t)$
2. Setting initial conditions (r_{in} and t_{in})
3. Sending **first photon** $\rightarrow t_{now}$
   Calculating distance source-observer r_{obs}
4. Sending **second photon** from $t_{in} + \Delta t_{in} \rightarrow r_{obs}$, integrating

   $$t(r) = R'(r,t)/\left[c(1+2E(r))\right]^{1/2}$$

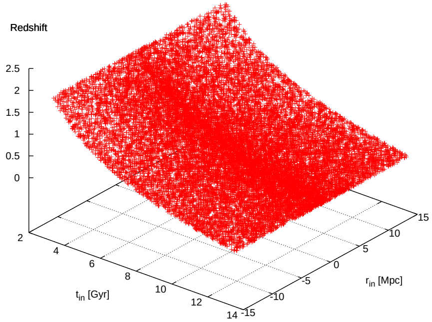
   where $R'(r,t) = \partial R(r,t)/\partial r$
   and obtaining $t(r_{obs})$



Simulations: Calculating Distance Modulus μ

Computation process (2/2):

1. Calculating Δt at t_{now}
   $\Delta t = t(r_{obs}) - t_{now}$
2. Obtaining redshift
   $z(r_{in}, t_{in}) = \Delta t / \Delta t_{in} - 1$
3. Calculating **distance modulus**
   $\mu = 5 \cdot log_{10}(dL/10\text{pc})$,
   with luminosity distance
   $dL = a_0 r_{obs}(1+z)$



Random Initial Positions of Sources

Our plan:

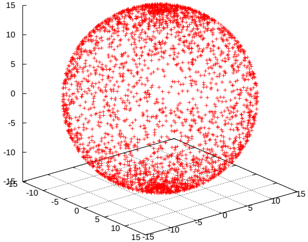
- Study the redshift of sources situated in the 'walls' (overdense regions)
- Consider many (r_{in}, t_{in}) in order to construct Hubble diagram

Avoid arbitrary choice $\Rightarrow$ Statistical treatment

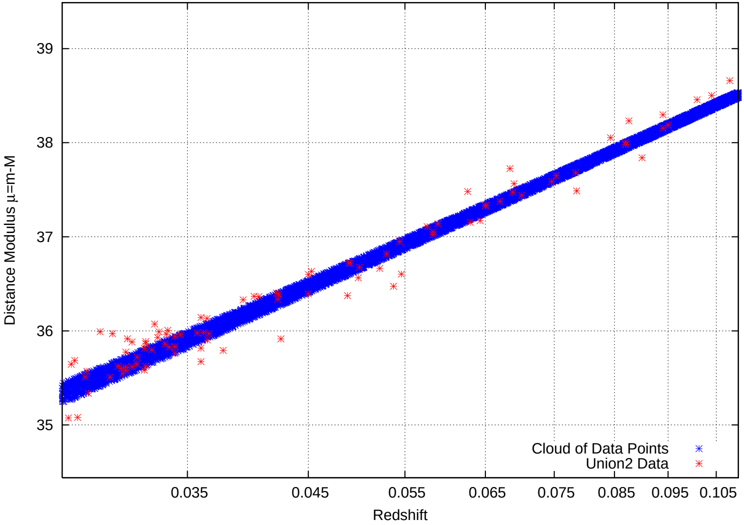
Distribution of sources $\sim$ Density distribution

Transition 3-D bubble $\rightarrow$ 2-D profile

$\Rightarrow$ Obtaining **clouds of data** for many (r_{in}, t_{in})



Taking Account of Random Initial Positions



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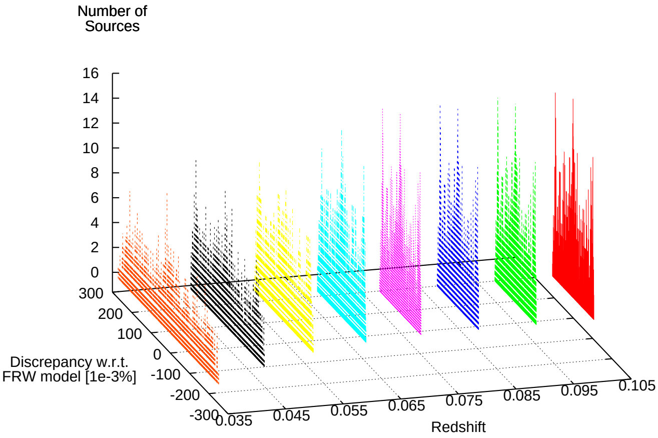
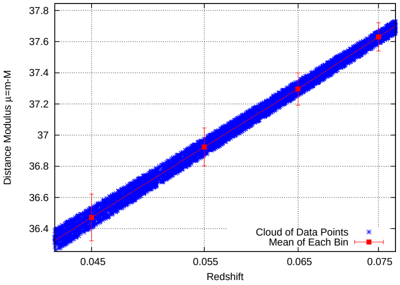


Evaluating Effects on Density Parameters

Fitting simulations to observations:

- Calculating **means** and standard deviations
- Comparing to SCP "Union2" SN Ia compilation [3] $\rightarrow$ 557 sources considered
- Adding systematic error on simulation redshift
- Obtaining χ^2 values for all sets $(\Omega_m, \Omega_\Lambda)$

Doing the same for FRW universes with similar $(\Omega_m, \Omega_\Lambda)$



Different Cosmologies Tested

Chosen initial geometry of the voids:

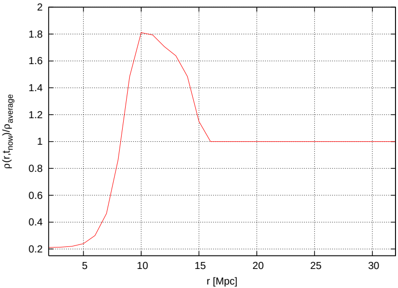
- $r_1 = 7$ Mpc, $r_2 = 15$ Mpc [4]
- Initial density contrast $A_1 = 0.997$
- **Final underdensity** (at t_{now}) $\approx$ 20% of average density [5]

Range of density parameters:

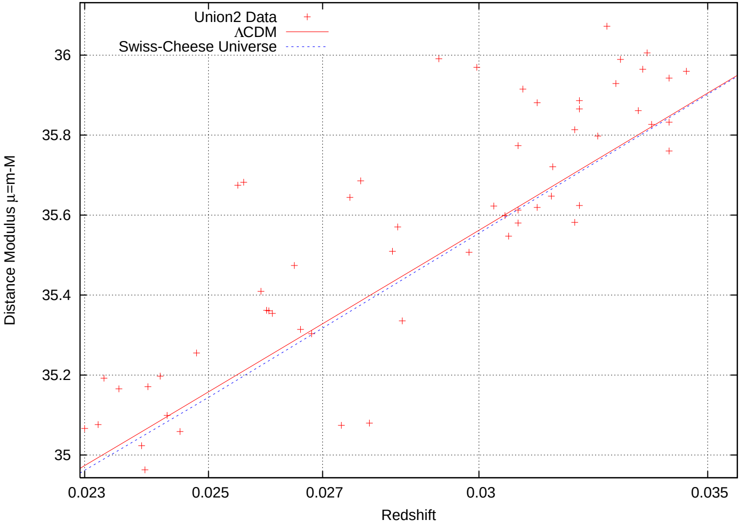
- $0.20 < \Omega_m < 0.40$
- $0.80 < \Omega_\Lambda < 0.60$

Different values of Hubble parameter:

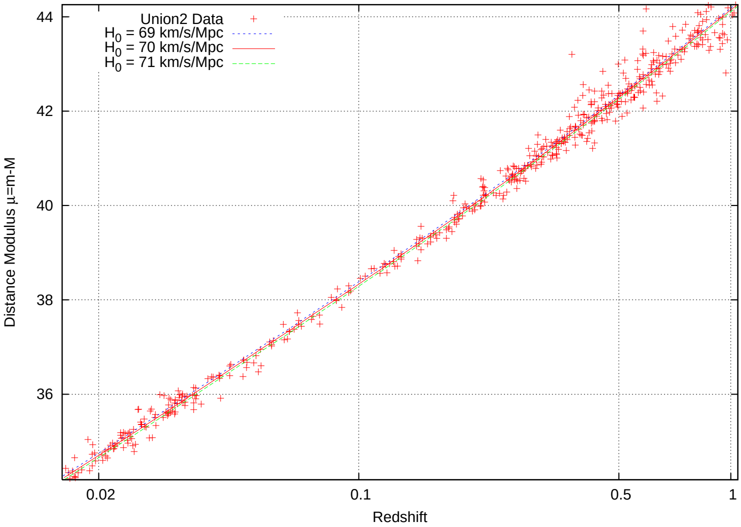
- $H_0 = 69\text{-}71$ km/s/Mpc



Global Shift from ΛCDM Solution



Influence of Parameter H_0



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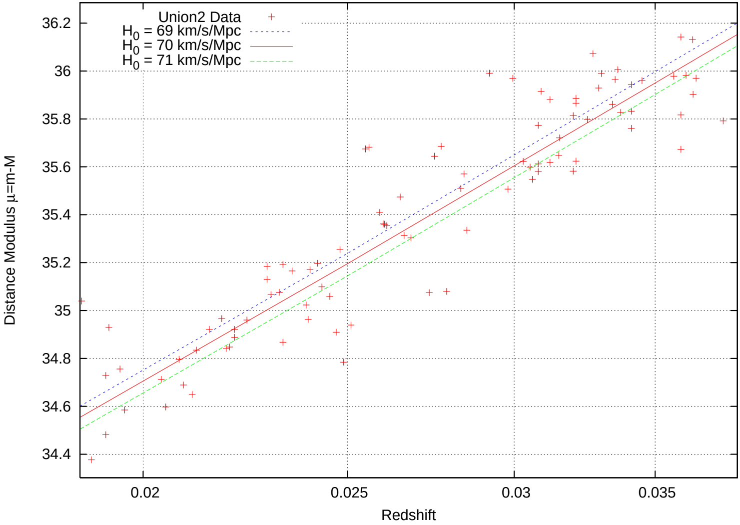
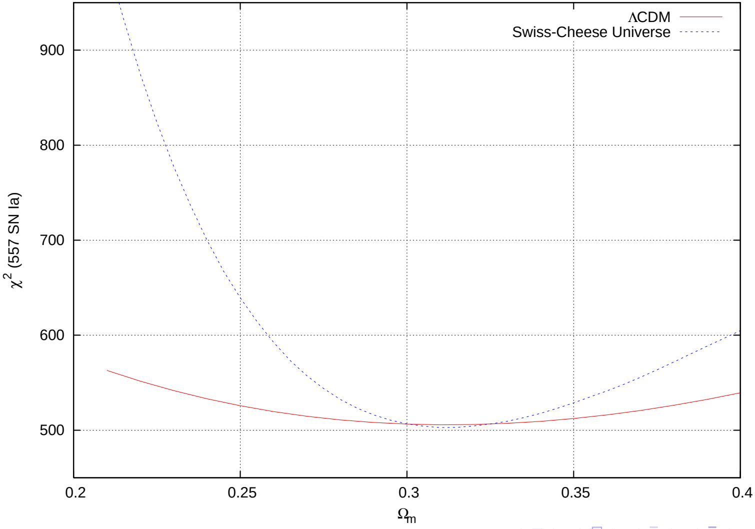
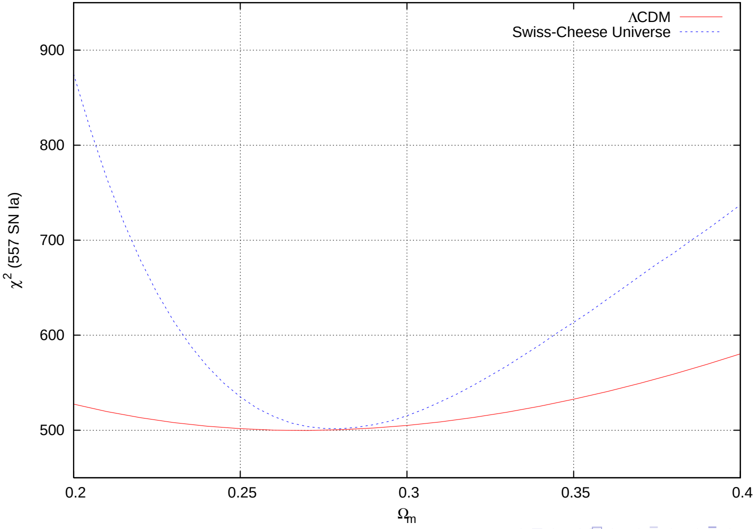


$H_0 = 69$ km/s/Mpc


ΛCDM
Swiss-Cheese Universe
900
800
700
600
500
χ^2 (557 SN Ia)
0.2
0.25
0.3
0.35
0.4
Ω_m

$H_0 = 70$ km/s/Mpc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Swiss-Cheese Universe
900
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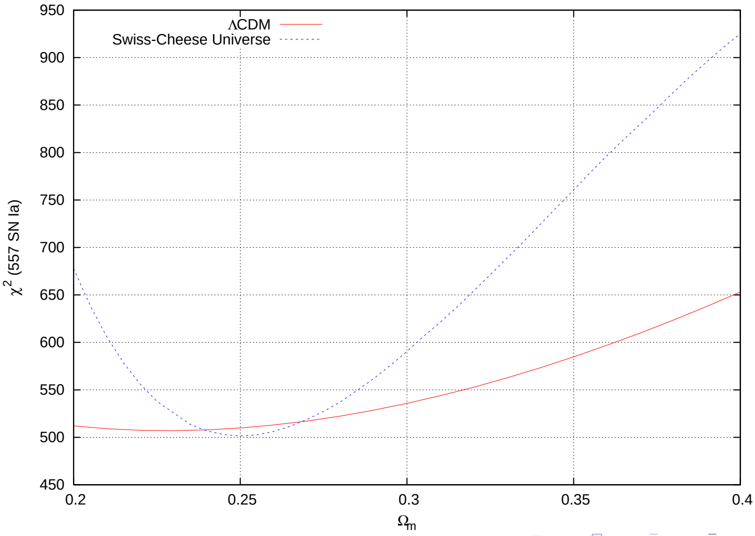
Ω_m

$H_0 = 71$ km/s/Mpc


ΛCDM
Swiss-Cheese Universe
χ2 (557 SN Ia)
Ωm
950
900
850
800
750
700
650
600
550
500
450
0.2
0.25
0.3
0.35
0.4

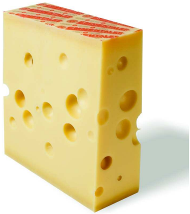
Wider Range of Cosmologies/Configurations

Conclusions:

- Swiss-Cheese universes cannot eliminate Λ
- **Realistic cosmologies** including voids are plausible
- Consistency with observations $\sim \Lambda$CDM

Next steps in our study:

- Investigate different geometries for the voids assuring **consistency with cosmological constraints**
- Widen range of density parameters and H_0
- Consolidate results with refined statistics



References

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2. V. Kostov, "Average luminosity distance in inhomogeneous universes", arXiv:0910.2611v3
3. R. Amanullah *et al.*, "Spectra and Light Curves of Six Type Ia Supernovae at 0.511<z<1.12 and Union2 Compilation", arXiv:1004.1711v1
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5. R. Van de Weygaert and E. Platen , "Cosmic Voids: Structure, Dynamics and Galaxies", arXiv:0912.2997v1
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Thank you for your attention!