Confronting Void Models with the CMB

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Outline

Why large-scale voids?

- We need to explain apparent acceleration seen in SNIa data
- ΛCDM explains acceleration, but generates cosmic coincidence problem - vacuum energy density is 120 orders of magnitude less than "natural" value, and yet not zero
- Local underdensity can explain SNIa data *without* dark energy -
  - $\Omega_m < 1$ inside the void, but $= 1$ outside
  - local Hubble rate is high, global rate is low
  - distant supernovae appear *dimmer* than expected
- Simplest models use a single spherically symmetric void with a Lemaitre-Tolman-Bondi metric

How do voids work?

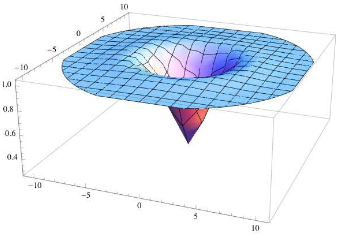
- LTB metric: $ds^2 = -c^2 dt^2 + \frac{A'^2(r,t)}{1+K(r)} dr^2 + A^2(r,t) d\Omega^2$
- Two Hubble rates: $H_T(r,t) \equiv \frac{\dot{A}}{A}$ and $H_L(r,t) \equiv \frac{\dot{A}'}{A'}$
- Obtain modified version of Friedmann equation -

$$H_T^2(r,t) = H_0^2(r) \left[\Omega_m(r) \left(\frac{A_0(r)}{A(r,t)} \right)^3 + \Omega_K(r) \left(\frac{A_0(r)}{A(r,t)} \right)^2 \right]$$

- Void profile specified by $\Omega_m(r)$ (or, equivalently, $K(r)$)
- For growing modes, bang time is homogeneous - and so Ω_m is the only free function

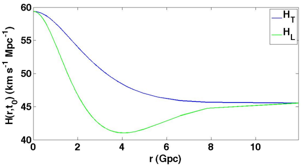
How do voids work?

Choose a density profile

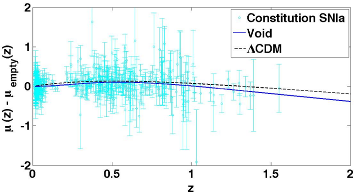


- Solve modified Friedmann equation numerically for A(r,t)
- Luminosity distance $D_L(z) = (1+z)^2 A(r,t)$

Hubble expansion rates



- Can get a very good fit to supernovae data:



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- ... but moving on ...
- Cannot (yet?) do perturbation theory in LTB metric, so cannot directly calculate CMB spectrum
- ... therefore we use equivalent EdS approach as a calculational tool to obtain power spectrum

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- Note: as the equivalent EdS universe matches at early times, it will differ at late times. In particular, $H_0^{EdS} \neq H_0^{LTB}$ and $T_0^{EdS} \neq T_0^{LTB}$
- Calculate H_0^{EdS} and T_0^{EdS} as inputs to `CAMB`

Can voids fit the CMB?

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- What if there are features in the primordial power?

Multiple Inflation

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- Theory embedded in a SUSY-breaking framework
- Inflaton gravitationally coupled to flat-direction fields

$$V(\phi, \psi) = V_0 - \frac{1}{2}m^2 H^2 \phi^2 + \frac{1}{2}\lambda H^2 \phi^2 \psi^2 - \frac{1}{2}\mu^2 H^2 \psi^2 + \gamma \psi^n$$

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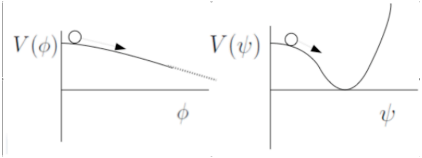

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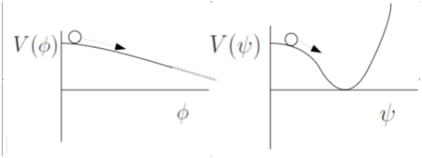

- Inflaton effective mass changes
- Fields with n =4, 6, 8, 10, 12, 16 exist in MSSM (Gerghetta et al, hep-ph/9510370)
- $n = 16$ and $n = 12$ are most important

Bump model

- Take two flat-direction fields, with $n = 16$ and $n = 12$, but with opposite couplings
- Fix most parameters at their natural values: $\mu^2_{16/12} = 3$, $\lambda_{12} = 1$, and allow only λ_{16} to vary
- Total 4 free parameters: H, λ_{16}, k_{16} and k_{12} (positions of transitions in k-space)
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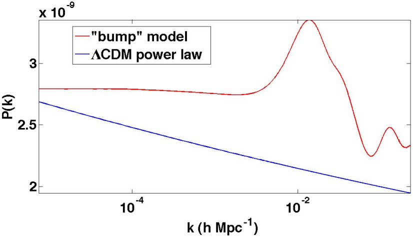
- Obtain primordial $P(k)$ with a "bump" feature and step down in power



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- Can extend study in future to include constraints from BAO, η_{10}, σ_8 etc.

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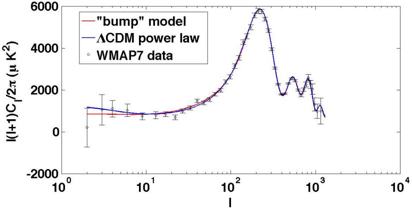

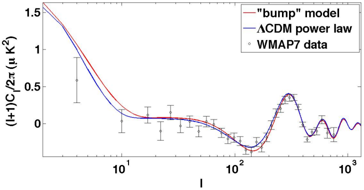

Datasets	#dof	$-\ln\mathcal{L}$	
		ΛCDM	Bump + void
CMB	1936	2892.5	-0.2
CMB + SN	2333	3109.3	-1.7
CMB + SN + $HST_{62\pm6}$	2334	3109.6	-1.7
CMB + SN + $HST_{72\pm8}$	2334	3109.4	-0.4
CMB + SN + $HST_{74\pm3}$	2334	3110.8	$+4.5$

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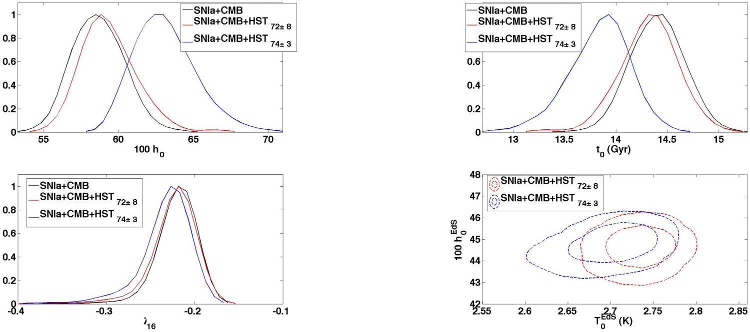

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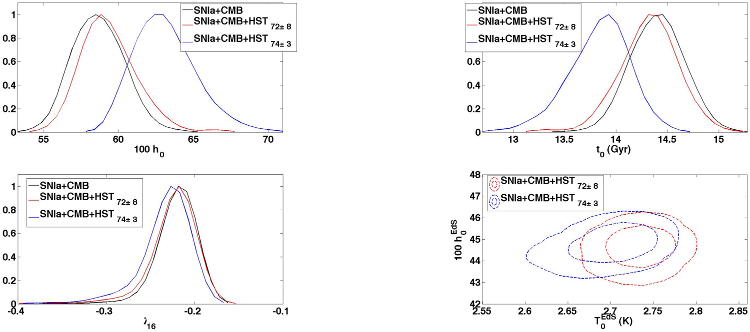

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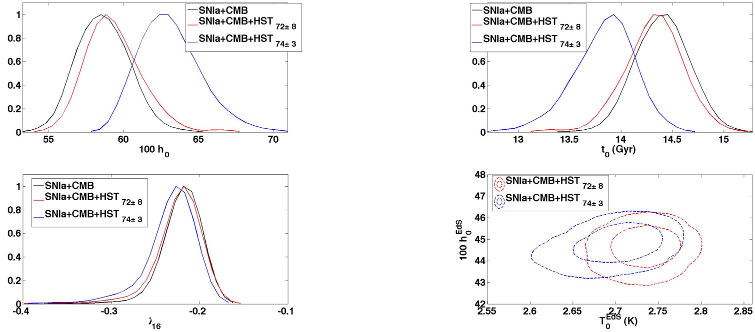

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- Parameters in inflaton potential have "natural" values (with caveats)

Summary

- We use a Gaussian void profile to fit SNIa data *without cosmological constant*
- We use a physically well-motivated model of inflation to generate a feature in primordial power
- The model with void and feature successfully fits WMAP7 data as well
- Unlike previous studies, we find reasonable values of H_0 and age of universe as well