Decisive tests of large-scale homogeneity

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Dark Energy and Homogeneity

The "concordance" model interpretation of cosmological data relies on assuming:

- Spatially homogeneous and isotropic FLRW background
- Theory of gravity is standard General Relativity

But the real Universe is inhomogeneous!

Modelling Inhomogeneity

Backreaction: Inhomogeneities modify the behaviour of the effective “background” model

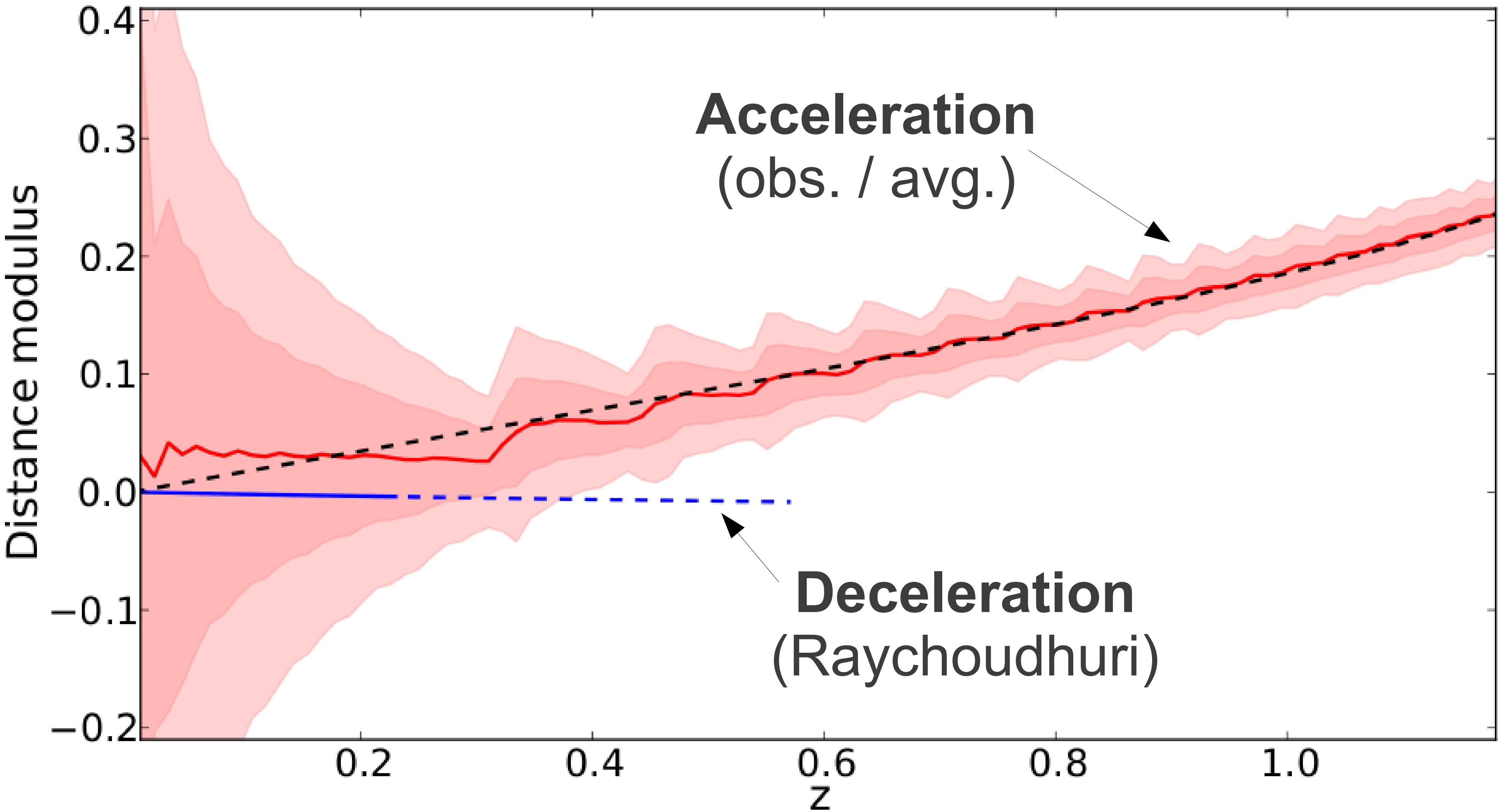
Are backreaction effects important? Theory says:

- Could be big (explains Λ), small (negligible), ...
- Size of effect is extremely model-dependent
- No fully-satisfactory inhomog. model yet exists

See CQG special issue for reviews:
http://iopscience.iop.org/0264-9381/28/16

Example:

Definition of acceleration becomes ambiguous



From Bull and Clifton 2012, arXiv:1203.4479

Example: Lemaitre-Tolman-Bondi
Inhomogeneous, isotropic, dust-only solution

$$ds^2 = dt^2 - \frac{a_2^2(r,t)}{1-k(r)r^2}dr^2 - a_1^2(r,t)r^2 d\Omega^2$$

Can fit supernova data by introducing spatial variations in density/expansion rate along LOS

2 arbitrary radial functional degrees of freedom

Fit other observables too (CMB, H_0...)

See Bull, Clifton, Ferreira 2012 and references therein:
Phys. Rev. D 85, 024002 (2012) / arXiv:1108.2222

Evidence for Homogeneity

- FLRW model fits observations very well

  (if you add an exotic fluid component)

- The observed CMB is almost isotropic

Implications of Isotropy

- Isotropy of the CMB about the worldline of every observer in a region → region is FLRW

Ehlers, Geren, Sachs (1968)

- Result is perturbatively stable

Stoeger, Maartens, Ellis (1995)

- We only see isotropy about ourselves

  → use Cosmological Principle

- See review by Maartens (arXiv:1104.1300)

Cosmological Principle

- <u>Assume</u> that our local conditions are the same as everywhere else (“not special”)

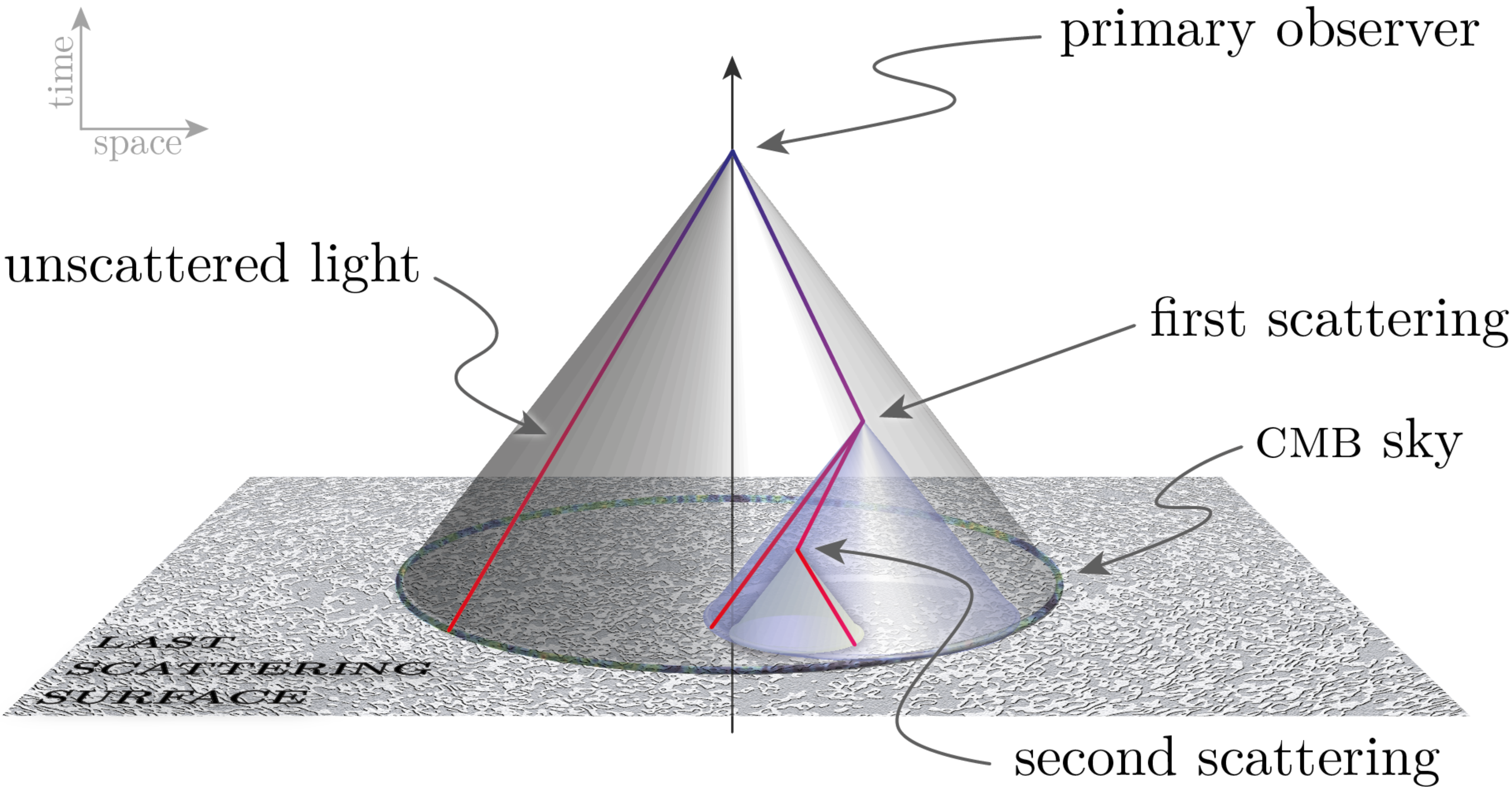
- Without the CP, require:
  - angular diameter distances
  - number counts
  - weak lensing
  - transverse velocities

(see Maartens 2011 and references therein)

Kinetic Sunyaev-Zel'dovich Effect

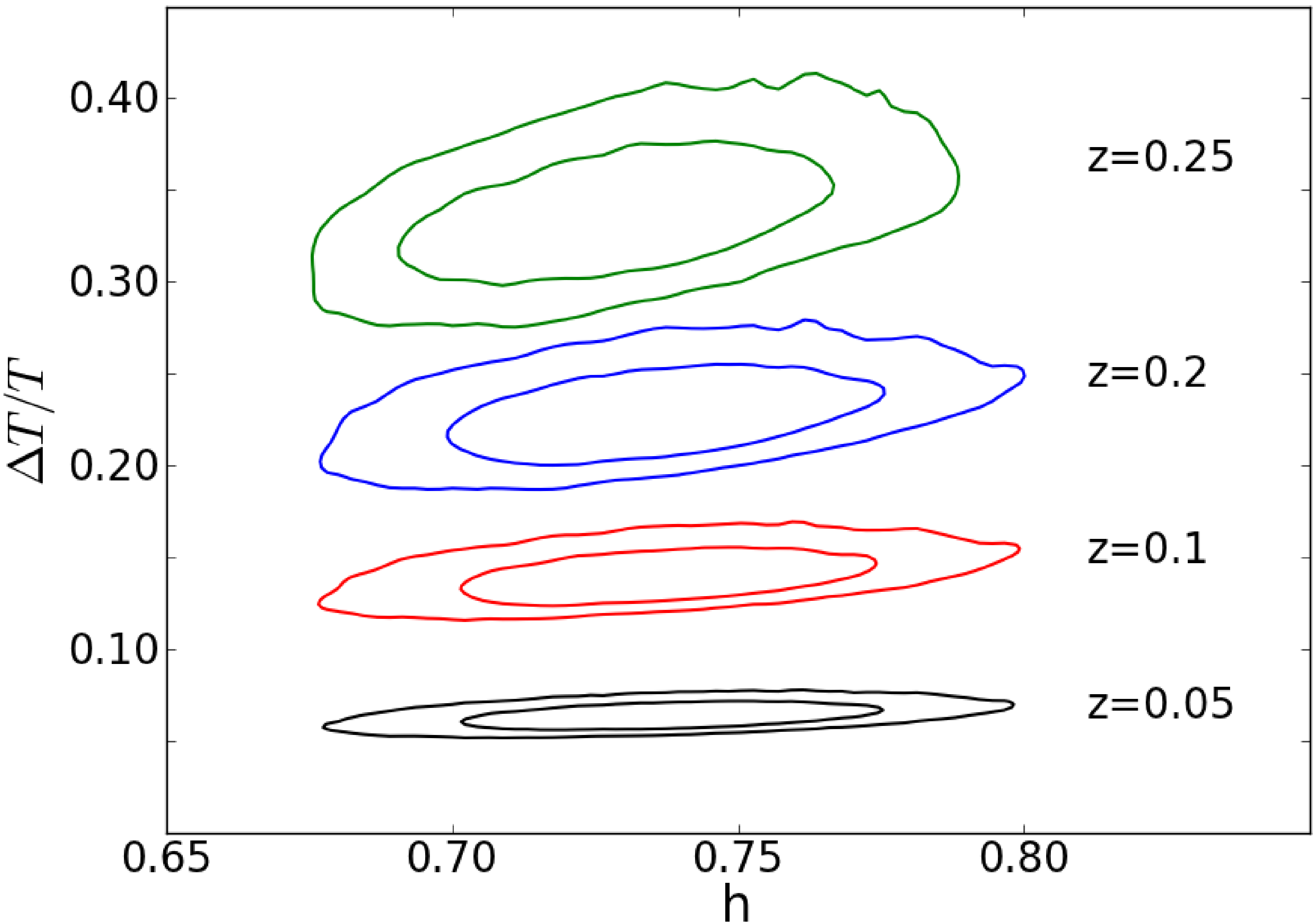
- **Sunyaev-Zel'dovich effect:** Hot cluster gas Compton-scatters CMB photons
- kSZ sensitive to dipole in CMB distribution (due to bulk velocity or intrinsic anisotropy)
- Use kSZ to measure anisotropy of the CMB about distant clusters (“CMB mirror”)
- Probing <u>inside</u> our past lightcone

Sunyaev and Zel'dovich 1980; Goodman 1995; Garcia-Bellido and Haugbolle 2008



From Clifton, Clarkson, Bull 2011 (arXiv:1111.3794)

LTB: Enormous kSZ signal!



From Bull, Clifton, Ferreira, Phys. Rev. D 85, 024002 (2012) / arXiv:1108.2222

Proof of Homogeneity?

- Relies on H_0 constraint
- Can get low kSZ signal for low H_0
- Still not necessarily isotropic in the whole spacetime region

  i.e. weaker than Ehlers-Geren-Sachs

Blackbody Distortions

- In a perfectly homogeneous region, a perfect blackbody CMB remains a blackbody after idealised scattering

Clifton, Clarkson, Bull, arXiv:1111.3794

- Conditions:
    - Non-zero electron density at every point
    - Only source of radiation is perfect blackbody CMB
    - Thermal SZ can be perfectly subtracted
    - At least two scatterings must occur
    - No perturbations!

Summary

- Inhomogeneities might affect our interpretation of cosmological data
- Isotropy about us not enough to prove FLRW!
- kSZ and its generalisation are powerful tests of homogeneity on large scales
- For details, see:
  - arXiv:1108.2222
  - arXiv:1111.3794
  - arXiv:1203.4479