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The Large Scale Structure Peak as a Comoving Standard Ruler

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Abstract. Estimates of the curvature parameters Ω_0 (density parameter) and λ_0 (cosmological constant) can be made geometrically by use of either a standard candle or a standard ruler. Just as supernovae of Type Ia appear to provide a good empirical standard candle, it now appears observationally justified to use the peak in the power spectrum of density perturbations at $L \approx 130 \pm 10 h^{-1}$ Mpc as an empirical standard rod. It will be shown that voids of this size are traced by quasars in a homogeneous catalogue near the South Galactic Pole at $z \sim 2$ and that the large scale structure peak of the catalogue constrains the value of Ω_0 to $0.1 < \Omega_0 < 0.45$ (68% confidence), independently of λ_0. Combination with the supernovae Ia data is sufficient to show that the observable Universe is almost flat. In other words, the combination of a standard ruler and a standard candle detected in two presently available data sets is sufficient to show that the Universe is nearly flat, *independently* of any microwave background data or any other data analyses.

5. Introduction

It is now well established that at the present epoch, i.e. at $z \sim 0$, galaxies are distributed in large scale structure in what may be termed walls, voids and filaments (e.g. de Lapparent, Geller & Huchra 1986). Observational evidence is also mounting (e.g. Broadhurst et al. 1990; Einasto et al. 1994; Baugh & Efstathiou 1993, 1994; Deng, Deng & Xia 1996; Gaztañaga & Baugh 1998; Einasto et al. 1997) that this structure has a characteristic scale at $L_{\mathrm{LSS}} \approx 130 \pm 10 h^{-1}$ Mpc near the peak in the power spectrum of density perturbations.

This power spectrum peak is a comoving scale, to which the bottom-up formation of galaxy or cluster dark matter haloes is not expected to have reached in a Hubble time. It is difficult to see how this *length* scale could be affected by evolution or by questions of bias, although the *amplitude* of the signal might be biased.

Hence, this scale provides what is potentially one of the most robust cosmic standard rulers, and has been applied previously in the redshift direction (Deng, Xiaoyang & Fang 1994; Broadhurst & Jaffe 2000).

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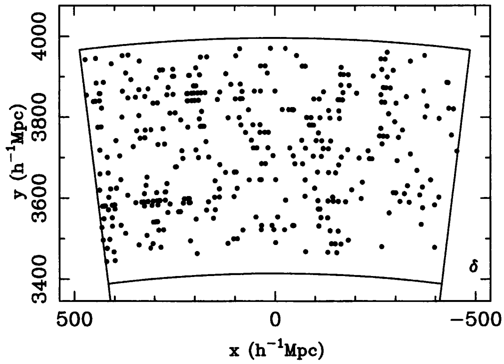

Figure 4. Wedge diagram for the $z \sim 2$ 'declination' subsample of the $z \sim 2$ Iovino et al. (1996) quasar catalogue, for $(\Omega_0 = 0.3, \lambda_0 = 0.7)$. Voids consistent with $L_{\rm LSS} = 130 \pm 10h^{-1}$ Mpc are clearly visible despite what appear to be redshift selection effects.

6. Analysis of a High Number Density, Homogeneous QSO Survey

To avoid redshift selection effects, Roukema & Mamon (2000) used only the *tangential* distribution of the homogeneous quasar catalogue of Iovino, Clowes & Shaver (1996) of $N \sim 1000$ quasars at $z \sim 2$.

Two-dimensional wedge diagrams (Fig. 1) and 1-D fourier analysis in the tangential direction clearly show that large scale structure exists among the quasars of the Iovino et al. (1996) catalogue at $z \sim 2$ at the expected scale, and that this provides a constraint in the (Ω_0, λ_0) plane.

Figs 6-8 of Roukema & Mamon (2000) show, by comparison with uniform random simulations, that the hypothesis of the $L_{\rm LSS}$ peak not existing in the tangential distribution of the Iovino et al. quasars is significantly rejected for low values of Ω_0, and by reversing the sign on one of the test conditions, high values of Ω_0 are also significantly rejected. (See the final two paragraphs of Section 3.1 of Roukema & Mamon for details.)

Since the possibility of no signal existing has been rejected, direct hypothesis testing is used in order to conservatively constrain the curvature parameters, avoiding the use of relative probabilities implied by techniques such as maximum likelihood estimation. Fig. 2 shows the levels at which various pairs (Ω_0, λ_0) can be rejected using this analysis.

The stronger constraint on the two parameters is that on Ω_0, i.e. $0.1 < \Omega_0 < 0.45$, independently of $\lambda_0 \in [0, 1]$ (Fig. 1).

This method and the supernova type Ia method (e.g. Perlmutter et al. 1999) both use *empirical standards* which are not quite understood theoretically, and are independent by

(i) choice of astrophysical object,

(ii) redshift range, and

(iii) standard ruler vs standard candle.

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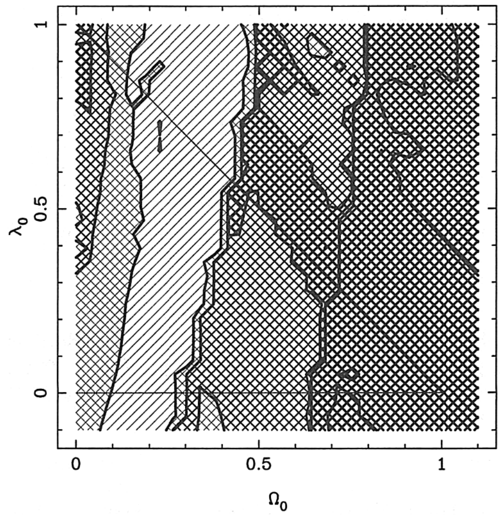

Figure 5. Confidence intervals for rejecting the hypothesis that the large scale structure peak occurs at $1/L_{\rm LSS}$, via a search for a local maximum in the 1-D fourier transforms of the tangential comoving length distributions of the quasar catalogue. Shading styles from pale to successively darker shadings represent rejections levels of $1-P > 0\%$, $1-P > 68\%$, $1-P > 95\%$ and $1-P > 99.7\%$.

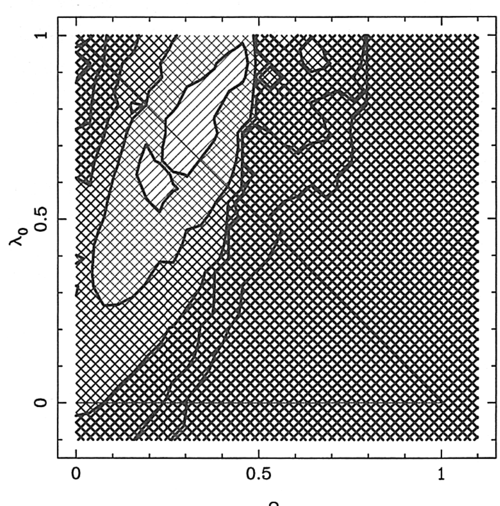

Figure 6. Confidence intervals from combining Fig. 2 with the relation $0.8\Omega_0 - 0.6\lambda_0 = -0.2 \pm 0.1$ from Perlmutter et al. (1999). Shading is as for Fig. 2.

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Combination of our result and that of Perlmutter et al. results in Fig. 3: $\Omega_0 + \lambda_0 = (1.00 \pm 0.11) + (1.57 \pm 0.11)(\lambda_0 - 0.7)$, $0.55 < \lambda_0 < 0.95$, (68% confidence limits).

Hence, the Universe is shown to satisfy an almost flat, perturbed FLRW model, *independently of any cosmic microwave background observations.*

7. Conclusion

This standard ruler should exist among any class of extragalactic objects formed from primordial density perturbations. Application to the new large quasar surveys of the 2 Degree Field survey and the Sloan Digital Sky Survey, combined with increased data sets of SNe Ia may result in estimates of (Ω_0, λ_0) to precisions of $\sim \pm 0.01$ if the noise decreases according to Poisson statistics.

This would provide as precise constraints as are hoped to be obtained from the MAP and Planck microwave background satellites.

Moreover, by use of tracer populations which are highly abundant and easily observable in the $0.5 < z < 1.0$ range, the $L_{\rm LSS}$ standard ruler technique should provide an $\Omega_0 - \lambda_0$ degeneracy relation which can double check the SNe Ia results.

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