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Constraints on Cosmological Models from Cosmic Flows

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1. Consistency of SMAC, SC, LP10k, ACIF and SNIa surveys

The SMAC cluster sample (Hudson et al. 1999), with a depth of $\sim 12000\,\mathrm{km\,s^{-1}}$, has a bulk velocity of $\sim 600\,\mathrm{km\,s^{-1}}$, with respect to the Cosmic Microwave Background (CMB) frame. Other surveys (Willick 1999, hereafter LP10k; Lauer & Postman 1994, hereafter ACIF) have also yielded large bulk motions on similarly large scales. Taken at face value, these results appear to be in conflict with bulk flows expected from favoured cosmological models. However, at the same time, other surveys (notably Dale et al. 1999, hereafter SC) have found rather small bulk motions on large scales. We have measured bulk flows from the above mentioned surveys plus SNIa (Riess et al. 1995) in a consistent way. The results are given in Table 1. The measurement errors are due to peculiar velocity errors. *Note that these are the errors typically quoted.* Based on these errors alone, there appears to be conflict between some of the surveys (e.g. SC vs SMAC).

Table 1. Bulk flows and consistency for large-scale surveys

Survey	Method	N	Depth	$\mathbf{V}$ km/s	l	b	Meas. error km/s	Samp. error km/s	P
SMAC	FP	56	6600	630	260	−1	200	183	0.659
SC	TF	63	8100	104	300	18	119	227	0.077
LP10k	TF	15	11100	1000	277	27	438	331	0.429
SNIa	SNIa	24	4000	444	276	−8	194	350	0.784
ACIF	BCG	119	8400	832	349	51	252	153	0.062
Combined	**Mixed**	**158**	**7455**	472	272	8	134		

Notes: Combined sample is SMAC+SC+LP10k+SNIa

All of these surveys are quite sparse, so small-scale ("internal") flows will not completely cancel, and will act as an extra source of noise in the bulk flow statistic. These "sampling errors" are typically not included in the error esti-

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mates. It is possible to allow for the sample geometry by assuming a power spectrum and calculating the appropriate window functions (Kaiser 1988; Watkins & Feldman 1995). Here we have assumed a ΛCDM model with parameters: $\Omega_m = 0.35$, $\Omega_\Lambda = 0.65$, $H_0 = 70$ km/s, $\Omega_b = 0.047$. In penultimate column of Table 1, we present sampling errors for the comparison between the bulk flow of the given survey compared to the bulk flow of all other surveys combined. Note that the sampling errors are comparable to or larger than the peculiar velocity errors. The last column indicates the probability that the bulk flows are consistent within the errors. **When sampling errors are included there is *no conflict* for any survey at the 2σ level.** The sample in poorest agreement is the ACIF survey of Lauer & Postman, but even there the difference is quite marginal (significant at only the 93% level). [1]

2. Constraints on Cosmological Models

The combined sample (excluding ACIF) yields a bulk flow of 422 ± 134 km/s toward $(l, b) = (272°, 8°)$, after correcting for "error-biasing". For the ΛCDM model used above, the expected rms value of the bulk flow, allowing for the sparse geometry of the combined sample, is $219\,\mathrm{km\,s^{-1}}$. **We conclude that the ΛCDM model is (marginally) acceptable**. It can be rejected at only the 94% CL. More generally, the bulk flow of the combined sample requires that $\Omega_{\mathrm{m}}^{(0.53-0.13\Omega_{\mathrm{m}})}\,\sigma_8 > 0.52$ at the 95% level, consistent with constraints from the abundance of rich clusters. This is also consistent with determinations from other peculiar velocity surveys (Zaroubi et al. 1997). If we allow the tilt n to vary, then the bulk flow of the combined sample yields the constraint $\Omega_{\mathrm{m}}\,h_{65}^{1.4}\,n^{1.7} > 0.37$ at the 95% CL.

References

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[1] However, it is expected that if the EFAR survey (Colless et al., astro-ph/0008418) had been included in this analysis, the consistency of SC would improve but that of ACIF would become worse.

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