Optimal ISW detection

Mona Frommert, Torsten A. Enßlin, and Francisco S. Kitaura

The integrated Sachs-Wolfe (ISW) effect is an imprint on the CMB created by the large-scale-structure (LSS), and hence it is strongly correlated with the latter. We present an optimal method for the detection of the integrated Sachs-Wolfe effect via cross-correlation of the cosmic microwave background with large-scale structure.

Standard method

- Compare the observed galaxy-temperature cross-correlation function $\hat{C}_l^{g,CMB} \equiv 1/(2l+1)\sum_{l,m}\mathrm{Re}(a_{lm}^{g}\bar{a}_{lm}^{CMB})$ to is theoretical prediction $C_l^{g,CMB} \equiv \langle a_{lm}^{g}\bar{a}_{lm}^{CMB}\rangle_{all}$, i.e. assume that $\hat{C}_l^{g,CMB}$ is Gaussian distributed around $C_l^{g,CMB}$ and estimate the amplitude of the latter using a maximum likelihood estimator.
- $C_l^{g,CMB}$ is by construction an ensemble average over all realisations of the universe, including the local matter distribution.

➔ ***Local variance*: the realisation of the matter distribution acts as a source of systematic noise in the estimate of the cross-correlation amplitude.** The local variance contributes about 11% to the total variance of the detected signal[1] (Fig. 1).

➔ The estimate of the amplitude is **biased** when averging over the realisations of the universe with the matter distribution held fixed.

➔ The **signal-to-noise ratio** for the estimate of the amplitude is[1]

$$\frac{S}{N}=\sqrt{\sum_{l=2}^{l_{max}}(2l+1)\frac{C_l^{ISW}}{C_l^{CMB}\oplus C_l^{ISW}}}$$

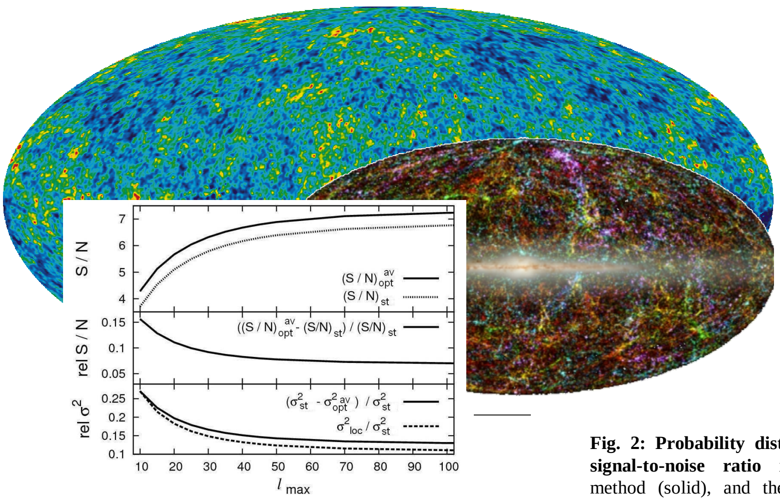


Fig. 1: **Top panel**: Comparison of the average[2] signal-to-noise-ratio of the optimal method (solid) with the signal-to-noise ratio of the standard method (dashed), versus the maximal multipole considered in the analysis.
Middle panel: relative improvement of the signal-to-noise ratio in the optimal method.
Bottom panel: Relative improvement of the variance of the detected signal in the optimal method as compared to the standard method (solid), and relative contribution of the local to the total variance in the standard method (dashed).[1]

Optimal method

- **Reduce the local variance by keeping the LSS fixed:**
- Create a Wiener filter reconstruction of the LSS from the galaxy data δ_g and obtain an ISW template T_{ISW} by projecting the reconstruction onto the sphere.
- Assume that the CMB is Gaussian distributed around this template,

$$P(T_{CMB}\,|\,\delta_g)=\frac{1}{\sqrt{|2\pi C|}}\exp\left[(T_{CMB}-T_{ISW})^t C(T_{CMB}-T_{ISW})\right],$$

and estimate the amplitude of the latter using a maximum likelihood estimator.

➔ The estimate of the amplitude is **unbiased** when averging over the realisations of the universe with the matter distribution held fixed.

➔ The **signal-to-noise ratio** for the estimate of the amplitude is[1]

$$\frac{S}{N}=\sqrt{\sum_{l=2}^{l_{max}}(2l+1)\frac{\hat{C}_l^{ISW}}{C_l^{CMB}\ominus C_l^{ISW}}}$$

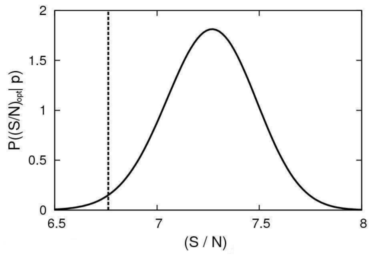
➔ The signal-to-noise ratio depends on the actual realisation of the matter distribution via the estimator $\hat{C}_l^{ISW}$. The probability distribution for the signal-to-noise ratio is shown in Fig. 2.

➔ The **average[2] signal-to-noise ratio is increased by ~7%** in the optimal method (Fig. 1).

➔ Can use the above probability distribution for **cosmological parameter constraints** from the joint CMB- and LSS-data, which includes the small coupling between the datasets, introduced by the ISW:

$$P(T_{CMB},\delta_g)=P(T_{CMB}\,|\,\delta_g)P(\delta_g)$$

Fig. 2: Probability distribution of the signal-to-noise ratio in the optimal method (solid), and the signal-to-noise ratio of the standard method (dashed) for comparison.[1]



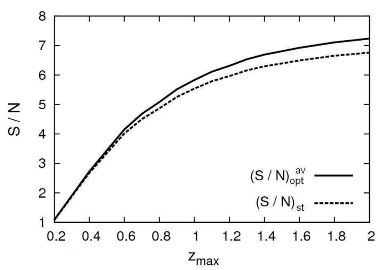


Fig..3: Dependence of the signal-to-noise ratio on the survey depth: Average[2] signal-to-noise ratio of the optimal method (solid) and signal-to-noise ratio of the standard method (dashed) versus the limiting redshift of the survey.

[1] We assume an ideal LSS survey without shot-noise that goes out to redshift ~ 2.
[2] Here 'average' denotes an ensemble average over all possible realisations of the universe, including the realisation of the matter distribution.

Reference: *Frommert et al, MNRAS in press, astro-ph/0807.0464*

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