Probing Dark Sector perturbations with the ISW effect

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Modified DE/MG perturbation eqs.

$$\dot{\delta} = -(1+w)\left(-k^2\theta^s + \frac{\dot{h}}{2}\right) - 3\mathcal{H}w\Gamma$$

$$\dot{\theta}^s = -\mathcal{H}(1-3w)\theta^s - \frac{w}{1+w}\left(\delta + \Gamma - \frac{2}{3}\Pi^s\right)$$
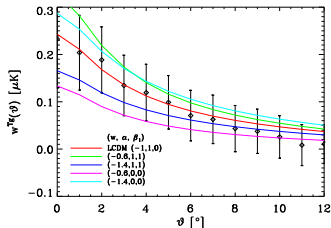
Anis. stress $\Pi^s = 0$, entropy pert. $w\Gamma$

$$w\Gamma = (\alpha - w)\Big[\delta - 3\mathcal{H}(1+w)\beta_1\Theta^s$$

$$-\frac{3\mathcal{H}(1+w)\beta_2}{2k^2 - 6(\dot{\mathcal{H}} - \mathcal{H}^2)}\dot{h} + \frac{3\mathcal{H}(1+w)(1-\beta_1-\beta_2)}{6\ddot{\mathcal{H}} + 6\mathcal{H}^3 - 18\mathcal{H}\dot{\mathcal{H}} + 2k^2\mathcal{H}}\ddot{h}\Big]$$
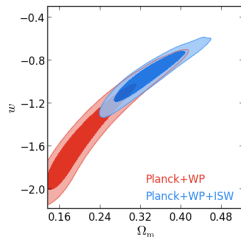
new parameters: α, β_1, β_2

ISW probes $\dot{\Phi} + \dot{\Psi}$, galaxies probe Φ

T-gal. & gal.-gal. correl. fcns. from: Planck + 2MASS, SDSS gal., SDSS LRG, NVSS, HEAO and SDSS QSO

Example: T-gal.-CCF (data: Planck + NVSS)

wCDM ($\alpha = 1$, $\beta_1 = 1$, $\beta_2 = 0$)