Expansion history & *f*(*R*) modified gravity

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based on M. Fairbairn & SR arXiv:astro-ph/0701900

The $1/R$ model

- Add inverse curvature term to Einstein-Hilbert action to get late time acceleration

$$S = \frac{M_{Pl}^2}{2}\int d^4x\sqrt{-g}\left(R - \frac{\mu^4}{R}\right) + \int d^4x\sqrt{-g}\mathcal{L}_M$$

- $\frac{\delta S}{\delta g_{\mu\nu}} = 0 \quad \Rightarrow$ new Einstein equations

- Assume spatially flat FLRW-metric⇒new Friedman eq

$$3H^2 - \frac{\mu^4}{12(\dot{H}+2H^2)^3}\left(2H\ddot{H} + 15H^2\dot{H} + 2\dot{H}^2 + 6H^4\right) = \frac{\rho_M}{M_{Pl}^2}$$

- Complicated!

Conformal transformation

- Go from matter frame to Einstein frame for $f(R)$ action

$$\tilde{g}_{\mu\nu} = p g_{\mu\nu}, \quad \frac{\partial f}{\partial R} \equiv p \equiv \exp\left(\sqrt{2/3}\sigma\right)$$

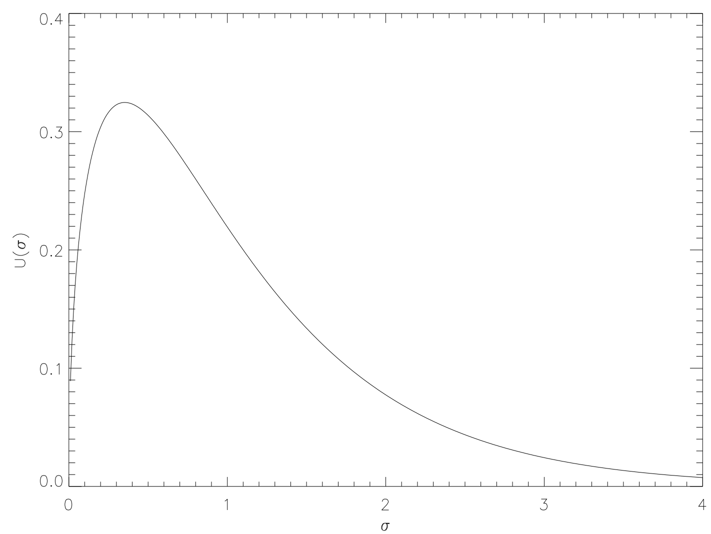
- New degrees of freedom now represented by effective scalar field σ in potential $V(\sigma)=(Rp-f)/2p$

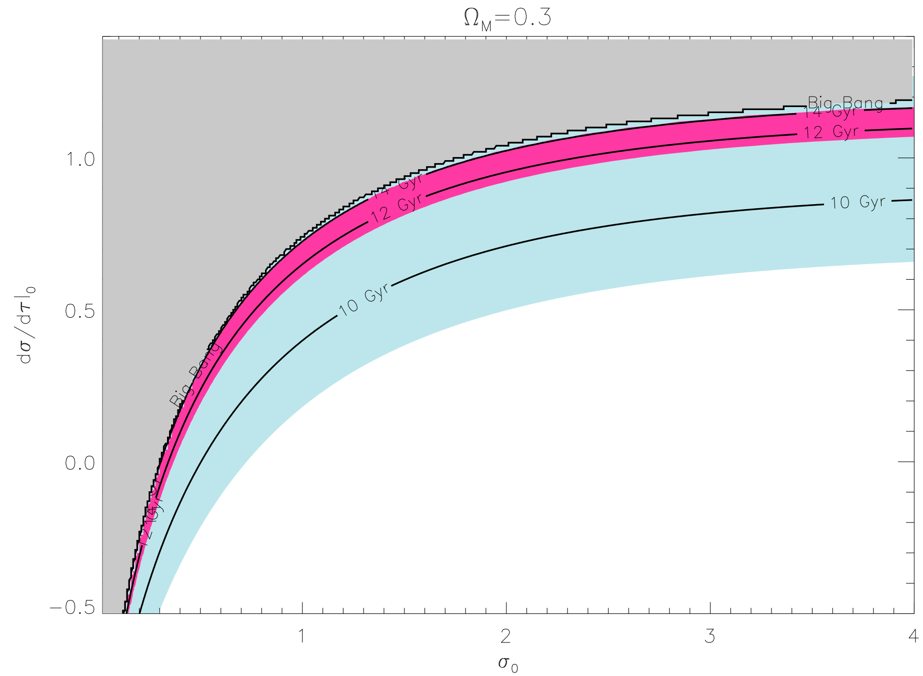
- Equations of motion look simpler and more familiar!

$$\tilde{R}_{\mu\nu} - \frac{1}{2}\tilde{R}\tilde{g}_{\mu\nu} = (\nabla_\mu\sigma)\nabla_\nu\sigma - \frac{1}{2}\tilde{g}_{\mu\nu}\tilde{g}^{\alpha\beta}(\nabla_\alpha\sigma)\nabla_\beta\sigma - V(\sigma)\tilde{g}_{\mu\nu} + \frac{T_{\mu\nu}}{M_{Pl}^2}$$

Hubble expansion in 1/R

- Solve EOM in Einstein frame and transform back to matter frame to get $H(z)/H_0$
- Free parameters: μ, Ω_M, σ_0, $\left.\frac{\partial\sigma}{\partial\tau}\right|_0$
- Need $\int \frac{dz}{H(z)/H_0}$ to calculate luminosity & angular distances

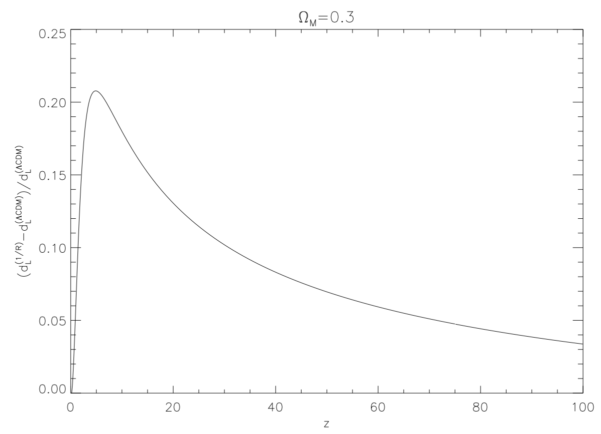


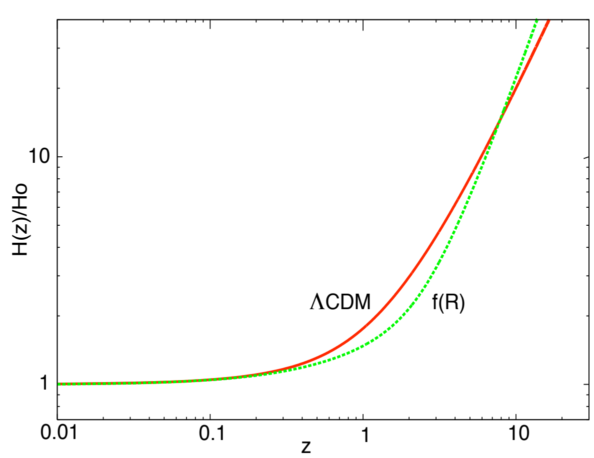


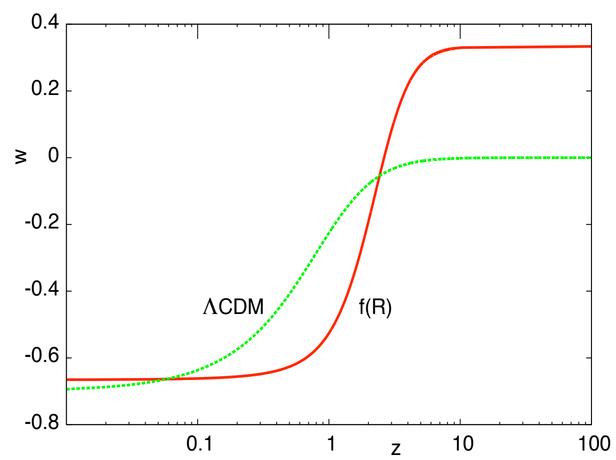
How to rule out the model?

- Peak difference from ΛCDM at z~5 - no observations

- Perturbation growth? Nucleosynthesis? ...?





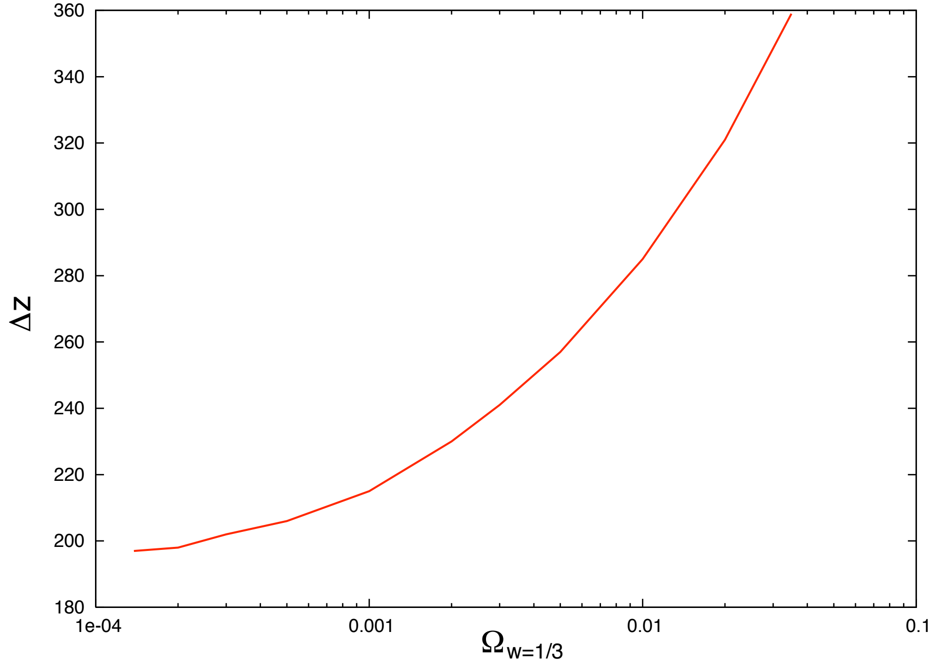


- Feature of best fit 1/R models: effective radiation domination more recently

Thickness of LSS!

- Know $\Omega_\gamma \sim 10^{-4}$ from temperature of CMB
- Best fit $1/R$ at high redshift corresponds to $\Omega_{w=1/3} \sim 0.034$
- Calculate thickness of last scattering surface (changing radiation density without changing temperature) using

$$\frac{dx_e}{dz} = \frac{1}{H(1+z)}\left[\alpha n_p x_e^2 - \beta(1-x_e)\exp\left(-\frac{B_1 - B_2}{kT}\right)\right] C$$



- Compare with WMAP value Δz=195±2
- Our value: Δz~350
- $1/R$ ruled out!

Conclusion & outlook

- We have put cosmological constraints on the simplest $f(R)$ modified gravity model that can give dark energy
- $1/R$ solutions that fit supernova data give rise to a radiation-like expansion at high redshifts and can be ruled out in a simple way using the thickness of the LSS
- Could $f(R)$ models that are gravitationally stable at high curvatures and in better agreement with solar system tests explain cosmological data?