On the implementation of the spherical collapse model

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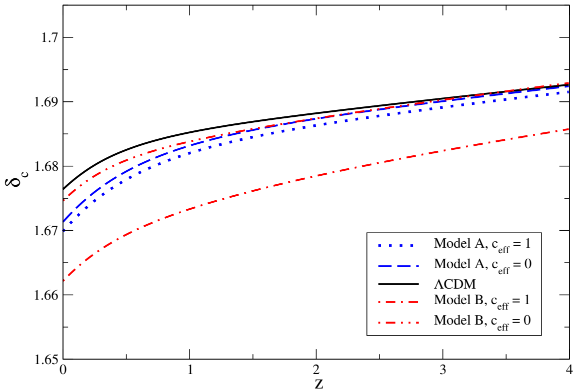
Outline

Theoretical motivations

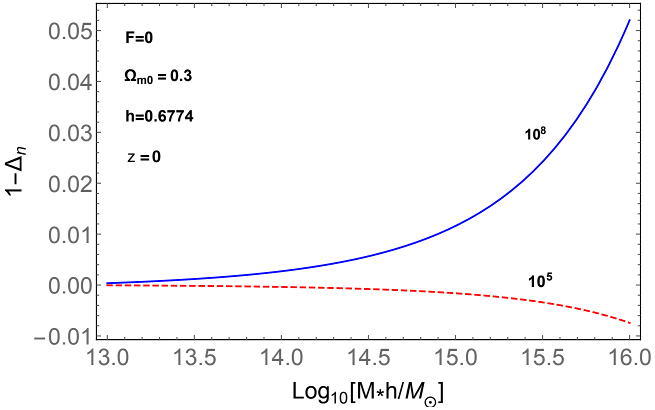
- The SCM is important for non-linear evolution of structures
- It is the main ingredient for the mass function (MF)
- The MF is used for the halo model
- The MF is sensitive to cosmology

Personal motivation



Batista & **FP**, 2013

Personal motivation



Herrera, Waga, Jorás, 2017

Spherical collapse model

- It follows the evolution of the overdense sphere
- Characterised by 4 parameters: $a_{\rm ta}$, ζ, $\delta_{\rm c}$, $\Delta_{\rm V}$

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- Two different approaches
  1. Evolution of the radius of the sphere
  2. Evolution of the overdensity (hydrodynamical approach)

Two equations, for the scale factor and for the radius

$$
\begin{aligned}
\dot{x} &= \sqrt{\frac{\omega}{x} + \lambda x^2 g(x) + (1-\omega-\lambda)} \\
\ddot{y} &= -\frac{\omega\zeta}{2y^2} - \frac{1+3w(x)}{2}\lambda g(x) y
\end{aligned}
$$

ζ and a_{ta} to be determined

Hydrodynamics

Continuity Equation

$$\dot{\delta} + (1 + \delta)\theta = 0$$

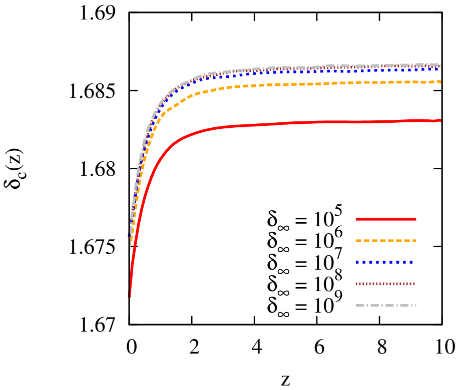
Euler Equation

$$\dot{\theta} + 2H\theta + \frac{1}{3}\theta^2 + \sigma^2 - \omega^2 + \frac{1}{a^2}\nabla^2\psi = 0$$

Poisson Equation

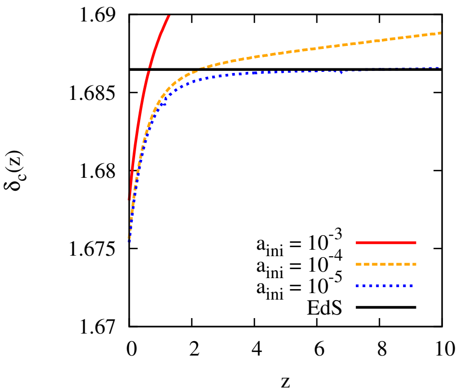
$$\nabla^2\psi = 4\pi G a^2 \bar{\rho}\delta$$

Numerical Infinity



FP, Meyer, Bartelmann, in preparation

Initial time



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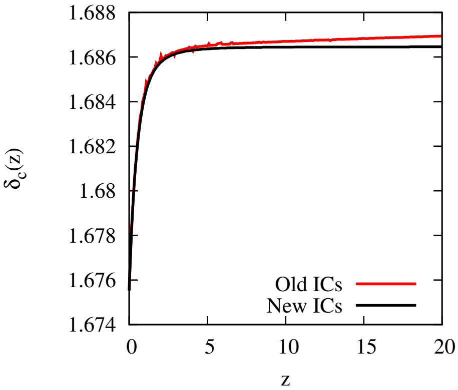
New ICs

1. Estimation of an initial slope at $a_{\rm ini} = 10^{-5}$
2. Given an arbitrary initial overdensity $\delta_{\rm ini} = 1$, $a_{\rm ini}$ is scaled by the quantity $\delta(a_{\rm c})/\delta(1)$
3. New estimation of the initial slope at the new $a_{\rm ini}$ and determination of $\delta_{\rm ini}$ leading to the collapse at $a = a_{\rm c}$
4. Refinement of $\delta_{\rm ini}$ via a Newton-Raphson method
5. Once $\delta_{\rm ini}$ has been found, linear (non-linear) differential equations are started with appropiate initial conditions: a linear (non-linear) relation is used to relate $\tilde{\theta}$ and δ
6. $\delta_{\rm ini}$ is now held fixed, but $a_{\rm ini}$ decreases with increasing collapse redshift $z_{\rm c}$

Results: evolution of δ_c



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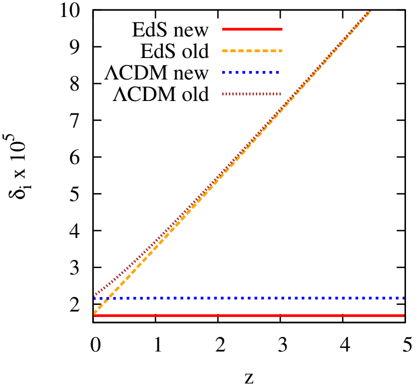
Results: ICs



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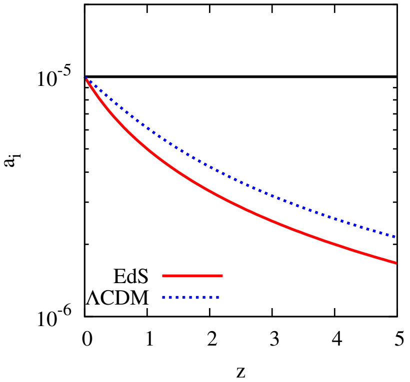

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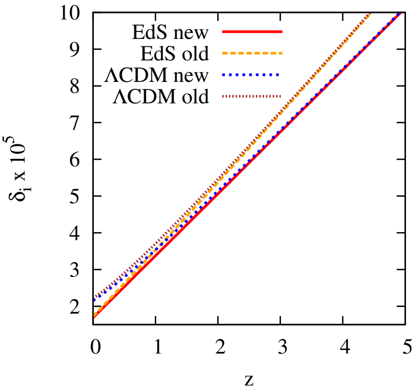

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Conclusions

- The new implementation provides stable and smooth results
- Analytic results are exactly matched
- $\delta_{\rm c}$ is now bounded
- Easily adapted to more general models
- Tested with several dark energy models