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Abstract.

Contents

1 Introduction

2 Modification of Gravity: nDGP

2.1 Background

Here we take the same background as ΛCDM or equivalently we consider an artificial dark energy fluid which cancels out the effect of modified gravity in the background level and as a result we see ΛCDM background. This is motivated since we can precisely compare the effect of modified gravity model with standard theory at the perturbation level.

2.2 Perturbations

We use the Newtonian flag of Gevolution and modify the Poisson equation as following

$$\nabla \Psi_N = 4\pi G a^2 \Big(1 + \frac{\Delta G_{\text{eff}}}{G}\Big)\, \delta\rho \tag{2.1}$$

For the normal branch of DGP (https://arxiv.org/pdf/1602.02154.pdf)

$$\frac{\Delta G_{\text{eff}}}{G} = \frac{1}{3\beta(a)} \tag{2.2}$$

where,

$$\beta(a) = 1 + \frac{4}{3} H r_c \Big(1 + \frac{A}{2H^2}\Big) \tag{2.3}$$

$A = \ddot{a}/a = \dot{H} + H^2$ and $\Omega_{rc} = \frac{1}{4H_0^2 r_c^2}$, changing time to conformal time as following,

$$H = \frac{\mathcal{H}}{a}, \qquad \dot{H} = \frac{-\mathcal{H}^2 + \mathcal{H}'}{a^2} \tag{2.4}$$

so,

$$\frac{A}{2H^2} = \frac{\dot{H} + H^2}{2H^2} = \frac{\mathcal{H}'}{2\mathcal{H}^2} \tag{2.5}$$

Substituting the values we get

$$\beta(a) = 1 + \frac{2\mathcal{H}(a)}{3\mathcal{H}_0 a\sqrt{\Omega_{rc}}}\Big(1 + \frac{\mathcal{H}'}{2\mathcal{H}^2}\Big) \tag{2.6}$$

Or probably better to write in terms of r_c ,

$$\beta(a) = 1 + \frac{4}{3a}\frac{\mathcal{H}}{\mathcal{H}_0}\mathcal{H}_0 r_c\Big(1 + \frac{\mathcal{H}'}{2\mathcal{H}^2}\Big) \tag{2.7}$$

Here like what is done in the reference in table 7 we assume different strength of modification $H_0 r_c$ and read Ω_{rc} from that. The GR case is recovered when $r_c \to \infty$, we also take $\mathcal{H}_0 r_c = 0.5$, $\mathcal{H}_0 r_c = 1.2$ and $\mathcal{H}_0 r_c = 5.6$. Specifically we can write,

$$\mathcal{H}_0 r_c = 0.5 \longrightarrow \Omega_{rc} = 1.0000 \tag{2.8}$$

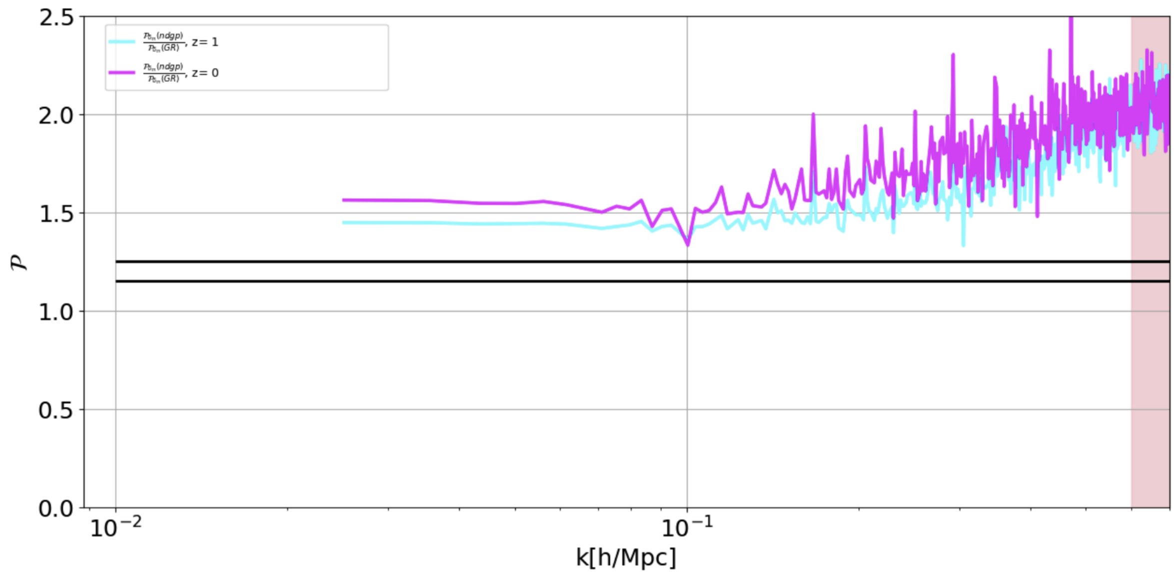
$$\mathcal{H}_0 r_c = 1.2 \longrightarrow \Omega_{rc} = 0.1736 \tag{2.9}$$

$$\mathcal{H}_0 r_c = 0.5 \longrightarrow \Omega_{rc} = 0.0079 \tag{2.10}$$

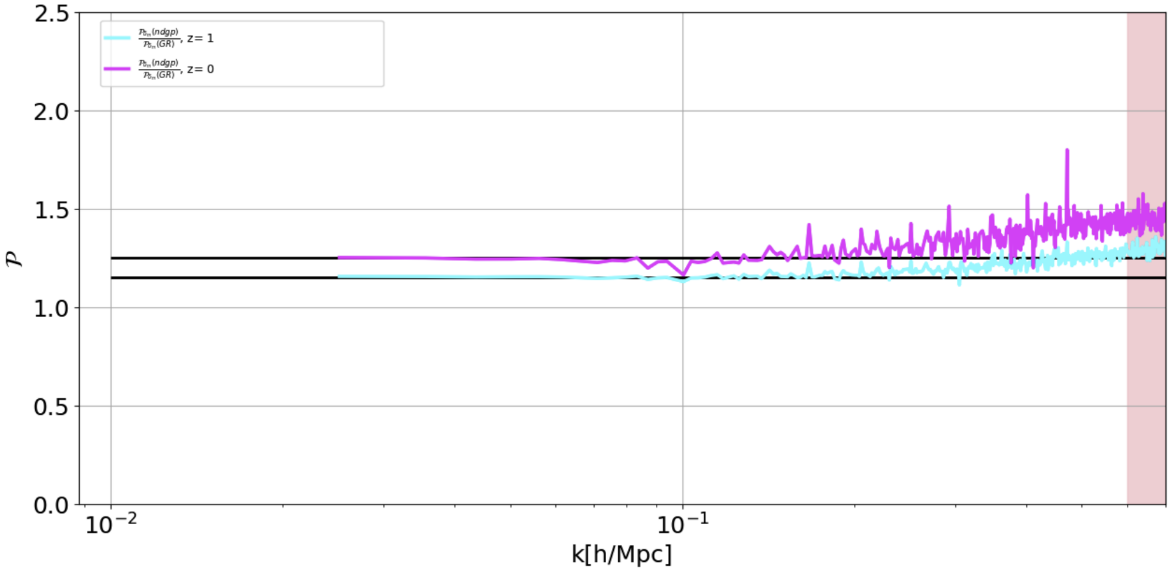
So in the Gevolution we need to compute $\mathcal{H}'$ and modify the Poisson equation. It is important to fix the cosmological parameters and also σ_8 is different for each model! First we thought it means that we need to obtain A_s corresponds to the relevant σ_8 for each set of parameters, so we used BBKS transfer function and integration over that to obtain relevant A_s. The $C++$ code is available in github. The relevant A_s reads as following,

```
 # A_s values for LCDM model in Table.7 of arxiv:1602.02154
#sigma(8) = 0.800 (LCDM)      ---> A_s =2.20630e-9  BBKS transfer function integration
#sigma(8) = 0.896 (H0rc=0.5) ---> A_s =2.76930e-9  BBKS transfer function integration
#sigma(8) = 0.849 (H0rc=1.2) ---> A_s =2.48530e-9  BBKS transfer function integration
#sigma(8) = 0.812 (H0rc=5.6) ---> A_s =2.26990e-9  BBKS transfer function integration
```

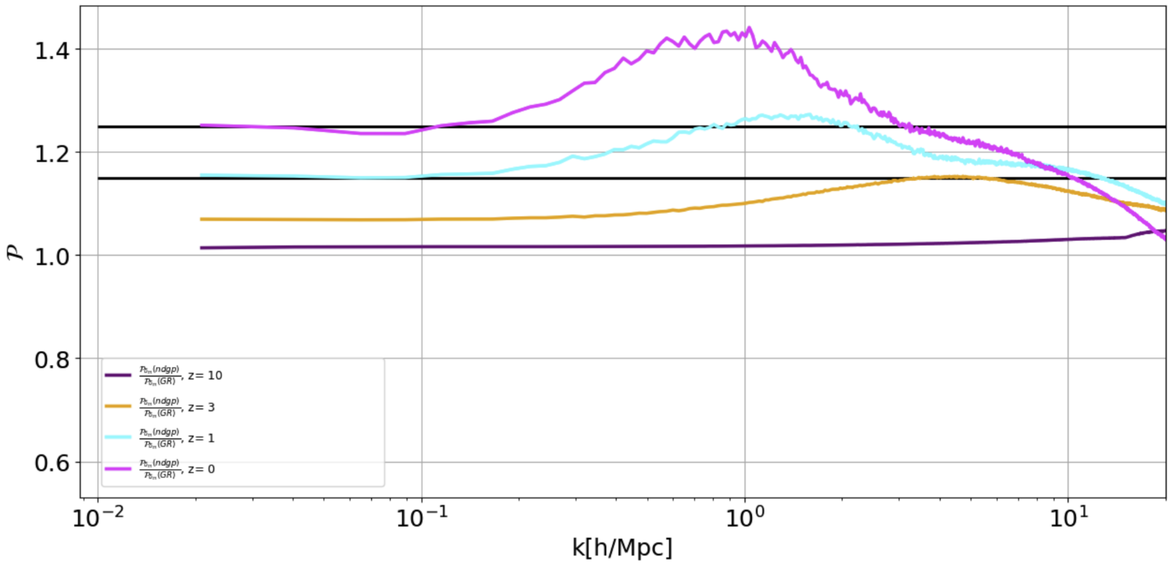
But what we get did not match to the paper results as following,



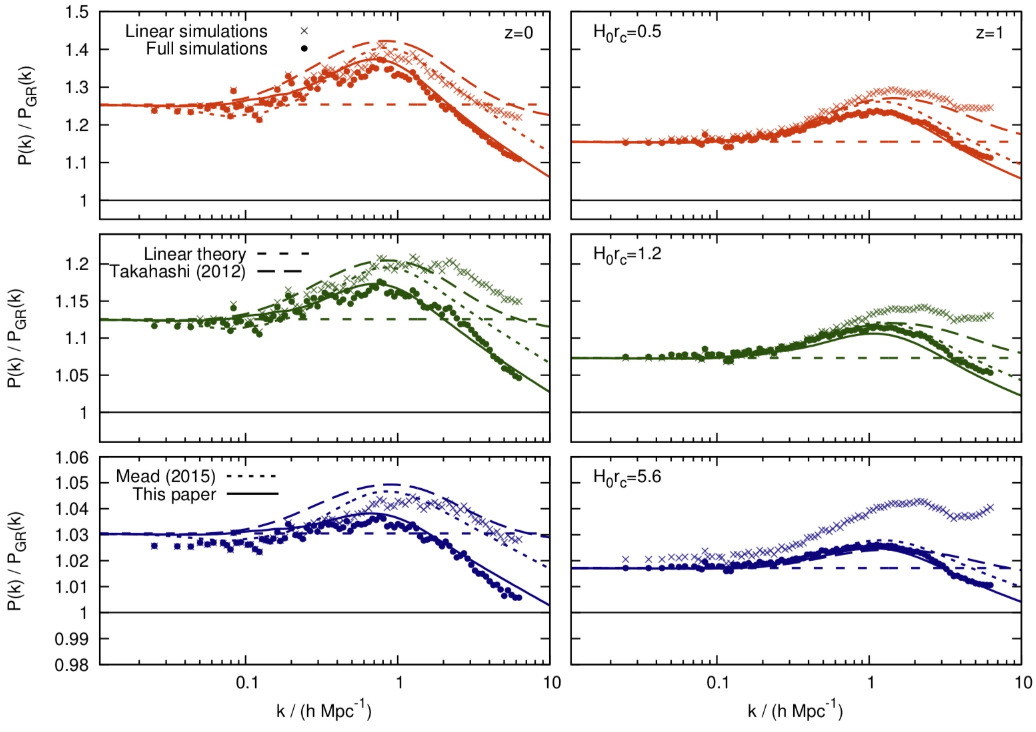
So we found out the meaning of different σ_8 comes from just because of different Poisson equation, or modification because of nDGP, which shows itself in the power spectrum and at the end σ_8 or A_s, so now we run for the same cosmological parameters and look at the results,



And because of mode coupling at non-linear regime, we get different grows of perturbations at different scales which is clear in the high-resolution run,



Compared to the paper result seems correct.



3 Screening mechanism

Now we are going to add screening to the previous results. We follow the same procedure as https://arxiv.org/abs/0911.5178 and https://arxiv.org/pdf/1703.00879.pdf. Basically because of gravity modification due to scalar field we can write,

$$\Psi = \Psi_N + \varphi/2 \tag{3.1}$$

where,

$$\nabla^2 \Psi_N = 4\pi G a^2 \delta\rho \tag{3.2}$$

$$\nabla^2 \varphi = 8\pi a^2 \Delta G(\frac{R}{R_*})\delta\rho \tag{3.3}$$

The modified Poisson equation is written,

$$\nabla^2 \Psi = 4\pi G a^2 \big(1 + \frac{\Delta G}{G}\big)\delta\rho \tag{3.4}$$

For the nDGP model ΔG reads,

$$\frac{\Delta G}{G} = \frac{2}{3\beta(a)} \frac{\sqrt{1+x^{-3}} - 1}{x^{-3}} \tag{3.5}$$

R_* the Vainstein radius is,

$$R_* = \Big(\frac{16 G \delta M r_c^2}{9\beta^2}\Big) \tag{3.6}$$

Moreover,

$$\delta M = 4\pi \delta\rho R^3/3 \tag{3.7}$$

and $x = \frac{R}{R_*}$, putting everything together gives,

$$\epsilon = x^{-3} = \Big(\frac{R_*}{R}\Big)^3 = \frac{8\mathcal{H}_0^2 r_c^2}{9\beta^2}\Omega_m(a)\delta = \frac{8\mathcal{H}_0^2 r_c^2}{9\beta^2}\Omega_{m,0}a^{-3}\delta \tag{3.8}$$

$$\frac{\Delta G}{G} = \frac{2}{3\beta}\frac{\sqrt{1+\epsilon}-1}{\epsilon} \tag{3.9}$$

$$\nabla^2\Psi = 4\pi G a^2\big(1+\frac{\Delta G}{G}\big)\delta\rho \tag{3.10}$$

In Gevolution we just need to define ϵ to implement it into the modified Poisson equation, and β is defined as before,

$$\beta(a) = 1 + \frac{4}{3a}\frac{\mathcal{H}}{\mathcal{H}_0}\mathcal{H}_0 r_c\Big(1+\frac{\mathcal{H}'}{2\mathcal{H}^2}\Big) \tag{3.11}$$

Note that the β in the equation. 10 of https://arxiv.org/pdf/0911.5178.pdf and equation. 48 of https://arxiv.org/pdf/1602.02154.pdf are the same.

3.1 Gevolution

The tricky part to implement in Gevolution is how we read δ_m in Gevolution.
First note that in Gevolution $T_0^0(gev) = -a^3 T_0^0 = -a^3\big(\bar{\rho}+\delta\rho\big)$ and by definition $M_{pl}^2 = 1/8\pi G$ Moreover we have we have the following identities,

$$\Omega_m = \frac{\rho_m(a)}{\rho_{crit}(a)} = \frac{a^2\bar{\rho}_m(a)}{3M_{pl}^2\mathcal{H}^2} \tag{3.12}$$

$$\rho_{crit} = \frac{3M_{pl}^2\mathcal{H}^2}{a^2} \tag{3.13}$$

$$\rho_{crit}^0 = \frac{3M_{pl}^2\mathcal{H}_0^2}{a_0^2} = 1 \tag{3.14}$$

$\rho_{crit}^0 = 1$ in Gevolution, i.e. $\mathcal{H}_0 = H_0 = \frac{8\pi G}{3}$.
On the other hand, $\bar{T}_0^0(Gev) = a^3\bar{\rho}_m$, so we have,

$$a^3\bar{\rho}_m = a^3\frac{\bar{\rho}_m^0 a^{-3}}{\rho_{crit}^0}\rho_{crit}^0 = \Omega_m^0 \tag{3.15}$$

At the end we can write,

$$T_0^0(gev) = \Omega_m^0\Big(1+\delta_m\Big) = a^3\bar{\rho}_m\big(1+\delta_m\big) \tag{3.16}$$

3.2 Relativistic

So because of the notation in Gevolution, T_0^0 is the perturbation part plus background so,

$$\delta_m(gev) = \frac{T_0^0(gev) - \bar{T}_0^0(gev)}{\bar{T}_0^0(gev)} = \frac{\text{source}(x) - a^3\bar{\rho}_m}{a^3\bar{\rho}_m} = \frac{\text{source}(x) - \Omega_m^0}{\Omega_m^0} \tag{3.17}$$

So $\delta\rho_m$ is exactly $T_0^0(gev)$ in Gevolution while it is rescaled by a^3. To compute ϵ in the code we need to use $\delta_m = \frac{T_0^0(gev)-\bar{T}_0^0(gev)}{\Omega_m^0}$. So basically having δ_m we can compute ϵ easily.
ϵ in Gevolution reads,

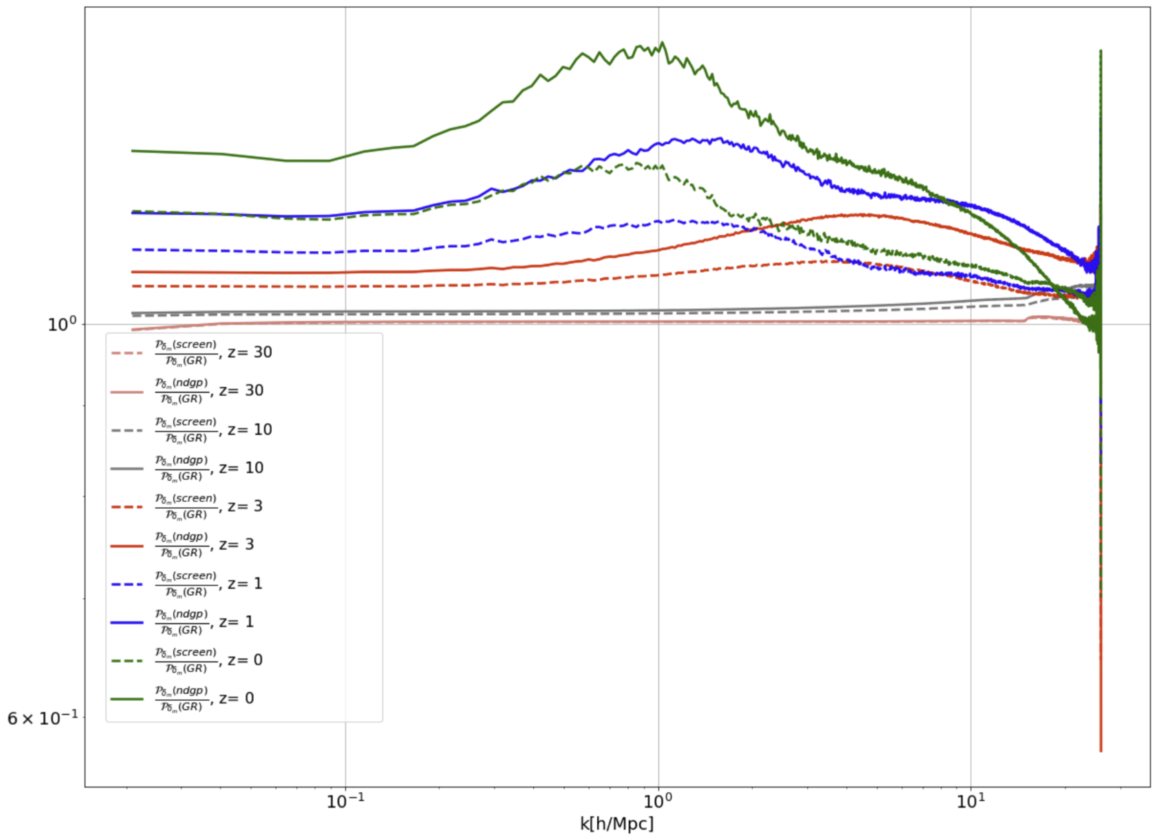
$$\epsilon = \frac{8\mathcal{H}_0^2 r_c^2}{9\beta^2}\Omega_{m,0}a^{-3}\delta_m = \frac{8\mathcal{H}_0^2 r_c^2}{9\beta^2}a^{-3}\Big(T_0^0(gev) - \bar{T}_0^0(gev)\Big) \tag{3.18}$$

3.3 Newtonian

In the Newtonian Gevolution we have "source(x)" which is actually $\bar{\rho}_m \delta_m = \Omega_m^0 \delta_m = \delta \rho_m$, so ϵ reads

$$\epsilon = \frac{8\mathcal{H}_0^2 r_c^2}{9\beta^2} \Omega_{m,0} a^{-3} \delta_m = \frac{8\mathcal{H}_0^2 r_c^2}{9\beta^2} \times \frac{\text{source}(x) - \Omega_m^0}{a^3} \tag{3.19}$$

The result is as following, in which we see an offset in the low wavenumbers,



4 f(R) gravity

We follow the same calculation as https://arxiv.org/pdf/0812.0545.pdf as following,

$$S = \int d^4x \sqrt{-g} \left(\frac{R + f(R)}{16\pi G} + \mathcal{L}_m \right)$$

$$f(R) = \underbrace{-16\pi G \rho_\Lambda}_{-2\Lambda} - \bar{R}_0 \frac{f_{R0}}{n} \left(\frac{\bar{R}_0}{R} \right)^n$$

for $n=1$ $\quad f(R) = -16\pi G \rho_\Lambda - f_{R0} \frac{\bar{R}_0^2}{R}$

$$\bar{R}_0 = \bar{R}(z=0)$$

$$f_{R0} = f_R(\bar{R}_0)$$

poisson eq: $\quad k^2 \psi(k) = -4\pi G \left(\frac{4}{3} - \frac{1}{3} \frac{\mu^2 a^2}{k^2 + \mu^2 a^2} \right) a^2 \delta\rho_m(k)$

$$\mu = \left(\frac{3 d f_R}{dR} \right)^{-1/2}$$

Also we can write: $\quad \underset{\substack{\text{Compton}\\\text{length}}}{\lambda^2} = \frac{1}{\mu^2} = -6 \frac{f_{R0}}{\bar{R}_0} \left(\frac{\bar{R}_0}{\bar{R}} \right)^3$

$$\bar{R} = 3H_0^2 \left(\Omega_m a^{-3} + 4\Omega_{vacuum} \right)$$

so we can write:

$$\lambda^2 = -6 \frac{f_{R0}}{3H_0^2 (\Omega_m + 4\Omega_{vacuum})} \left(\frac{1 + 4\Omega_{vacuum}/\Omega_m}{a^{-3} + 4\frac{\Omega_{vacuum}}{\Omega_m}} \right)^3$$

In order to implement it in gevolution.hpp we define a new function as following,

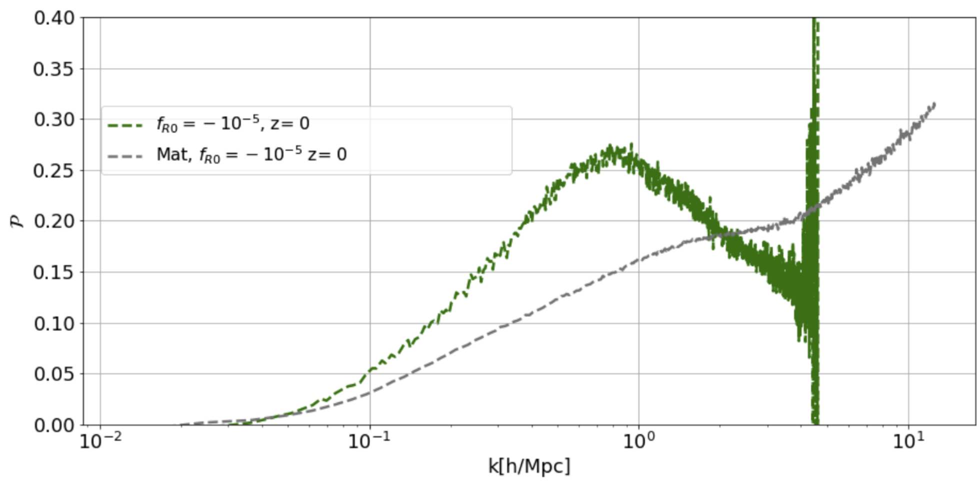
```
for (int i=0; i<iterations;i++)
{
void solveModifiedPoissonFT_fR(Field<Cplx> &
sourceFT, Field<Cplx> & potFT, Real coeff, const double fR0, const double a, const double H0 ,const double
Omega_m ,const double Omega_vacuum ,const Real modif = 0.)
{
        const int linesize = potFT.lattice().size(1);
        int i;
        Real * gridk2;
        Real * sinc;
        rKSite k(potFT.lattice());
  double R_bar = 3. *H0*H0*(Omega_m/a/a/a + 4.*Omega_vacuum);  //Ricci scalar Bg
  double R0_bar = 3. *H0*H0*(Omega_m + 4.*Omega_vacuum);  //Ricci scalar at z=0 Bg
  double f_R_coeff;
  double lambda_squared =  (-6. * fR0/(3.*H0*H0 * (Omega_m+4.*Omega_vacuum))) *
  pow((Omega_m+4.*Omega_vacuum)/(Omega_m/a/a/a + 4.*Omega_vacuum),3);
   //compton length and =1/mu
  double mu = sqrt(1./lambda_squared);
  double k2;
  // double f_R_modif;
  // f_R_modif

        gridk2 = (Real *) malloc(linesize * sizeof(Real));

        coeff /= -((long) linesize * (long) linesize * (long) linesize);

        for (i = 0; i < linesize; i++)
        {
                gridk2[i] = 2. * (Real) linesize * sin(M_PI * (Real) i / (Real) linesize);
                gridk2[i] *= gridk2[i];
        }

        k.first();
        if (k.coord(0) == 0 && k.coord(1) == 0 && k.coord(2) == 0)
        {
                if (modif == 0.)
                        potFT(k) = Cplx(0.,0.);
                else
                        potFT(k) = sourceFT(k) * coeff / modif;
                k.next();
        }

        for (; k.test(); k.next())
        {
    k2 = gridk2[k.coord(0)] + gridk2[k.coord(1)] + gridk2[k.coord(2)];
    f_R_coeff = 4./3. - (1./3.)*(a*a*mu*mu)/(k2 + mu*mu*a*a);
    potFT(k) = f_R_coeff * sourceFT(k) * coeff /
     (gridk2[k.coord(0)] + gridk2[k.coord(1)] + gridk2[k.coord(2)] + modif);
        }

        free(gridk2);
}
}
```

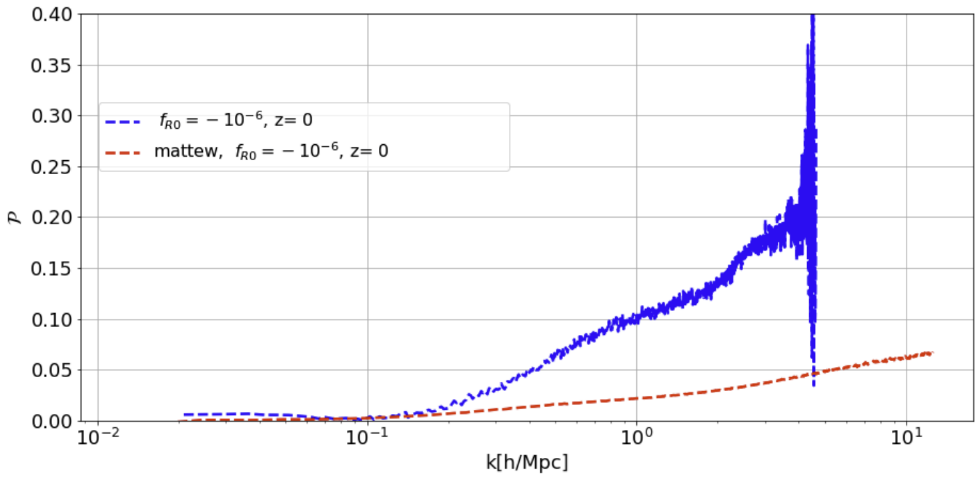
And in the main.cpp we have,

```
    if (sim.f_R_flag==0)
      {
```

```
        solveModifiedPoissonFT(scalarFT, scalarFT, fourpiG / a);  // Newton: phi update (k-space)
      }
      if (sim.f_R_flag==1)
      {
        solveModifiedPoissonFT_fR(scalarFT, scalarFT, fourpiG / a, cosmo.fR0, a, Hconf(1., fourpiG, cosmo) , cosmo.Omega_m , c
      }
```

Compared to the paper of Hu and Sawiscki, we get consistent results, but compared to Mattew's results which screening is also included, we have to add Chameleon screening.





4.1 Chameleon model

We use section 5.3 and 5.4 of 1608.00522, having,

$$\frac{\Delta G_{eff}}{G} = Bb\Big(\frac{y_h}{y_0}\Big)^a \Big\{\big[1 + (\frac{y_0}{y_h})^a\big]^{1/b} - 1\Big\} \tag{4.1}$$

4.2 General calculation

Having general α and w

$$p_2 = \frac{\Delta G}{G}, \quad p_3 = \frac{4-\alpha}{1-\alpha} = 7, \quad p_5 = -1, \quad p_6 = \frac{2}{3p_3} \tag{4.2}$$

$$p_7 = \frac{3}{\alpha - 4}, \quad p_4 = \Omega_m^{1/3}\Big[(\Omega_m + 4\Omega_L)^{1/(1-\alpha)}\frac{b}{3|f_{R0}|}\Big]^{1/p_3}, \quad B = \frac{\Delta G}{G}, \quad a = \frac{7b}{b-1}$$

$$\frac{\Delta G_{eff}}{G} = \frac{\Delta G}{G} b\Big(\frac{y_h}{y_0}\Big)^a \Big\{\big[1 + (\frac{y_0}{y_h})^a\big]^{1/b} - 1\Big\} \tag{4.3}$$

$$\begin{aligned} y_0 &= p_4 a^{p_5}\Big(2GH_0M_{vir}\Big)^{p_6}\Big(\frac{y_{env}}{y_h}\Big)^{p_7} \\ &= \Omega^{1/3}\Big[(\Omega_m + 4\Omega_L)^{1/(1-\alpha)}\frac{b}{3|f_{R0}|}\Big]^{1/p_3} a^{-1}\big(2GH_0M_{vir}\big)^{p_6}\Big(\frac{y_{env}}{y_h}\Big)^{p_7} \end{aligned} \tag{4.4}$$

Having $\epsilon = \Big(\frac{y_{env}}{y_h}\Big)^{p_7}$, $y_h = \big(\frac{\rho_m^h}{\bar{\rho}_m}\big)^{-1/3}$

$$\Big(\frac{y_h}{y_0}\Big)^3 = \frac{\bar{\rho}_m/\rho_m^h}{\Omega_m\Big[(\Omega_m + 4\Omega_L)^{-2}\frac{b}{3|f_{R_0}|}\Big]^{3/p_3} a^{-3}\big(2GH_0M_{vir}\big)^{3p_6}\epsilon^3} \tag{4.5}$$

$$\epsilon^{1/p_7} = \Big(\frac{y_{env}}{y_h}\Big) = \frac{\bar{\rho_m}/\rho_m^{\rm env}}{\bar{\rho}_m/\rho_m^h} = \frac{\rho_m^h}{\rho_m^{\rm env}} = \Big(\frac{\zeta_{env}}{\zeta_h}\Big)^3 \tag{4.6}$$

We need to have the following quantities,

$$M_{vir}, \alpha, b, \rho_m^h, \rho_m^{env}, |f_{R_0}| \tag{4.7}$$

We also assume that the background evolution is not affected, by modified gravity and screening (there is no backreaction). $2GH_0M_{vir}$ reads,

$$2GH_0M_{vir} = 2GH_0\frac{4}{3}\pi\zeta_h^3\rho^h = \zeta_h^3 H^2 H_0 \Delta_c \tag{4.8}$$

which we have used $\rho_m^h = \Delta_c\bar{\rho}_c = \frac{3H^2}{8\pi G}\Delta_c$. As a result, the following quantities should be given,

$$\zeta^h, \zeta^{env}, b, \alpha, w, \Delta_c \tag{4.9}$$

$\bar{\rho}_c$ is the critical density and Δ_c is a constant given by growth factor and cosmological elements.

Virial radius [edit]

The virial radius of a gravitationally bound astrophysical system is the radius within which the virial theorem applies. It is defined as the radius at which the density is equal to the crit
redshift of the system, multiplied by an overdensity constant Δ_c:

$$\rho(< r_{\rm vir}) = \Delta_c\rho_c(t) = \Delta_c\frac{3H^2(t)}{8\pi G},$$

where $\rho(< r_{\rm vir})$ is the halo's mean density within that radius, Δ_c is a constant, $\rho_c(t) = \frac{3H^2(t)}{8\pi G}$ is the critical density of the Universe, $H^2(t) = H_0^2[\Omega_r(1+z)^4 + \Omega_m(1+z)$
Hubble parameter, and $r_{\rm vir}$ is the virial radius.[1][2] The time dependence of the Hubble parameter indicates that the redshift of the system is important, as the Hubble parameter cha
parameter, referred to as the Hubble Constant H_0, is not the same as the Hubble parameter at an earlier time in the Universe's history, or in other words, at a different redshift. The

$$\Delta_c = 18\pi^2 + 82x - 39x^2,$$

where $x = \Omega(z) - 1$, $\Omega(z) = \frac{\Omega_0(1+z)^3}{E(z)^2}$, $\Omega_0 = \frac{8\pi G\rho_0}{3H_0^2}$, and $E(z) = \frac{H(z)}{H_0}$.[3][4] Since it depends on the density parameter Ω, its value depends on the cosmological mod
equals $18\pi^2 \approx 178$. This definition is not universal, however, as the exact value of Δ_c depends on the cosmology. In an Einstein-de Sitter model, it is assumed that the density par
$\Omega_m = 1$. Compare this to the currently accepted cosmological model for the Universe, ΛCDM model, where $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$; in this case, $\Delta_c \approx 100$. Nevertheless it is
purpose of using a common definition, and this is denoted as r_{200} for the virial radius and M_{200} for the virial mass. Using this convention, the mean density is given by

$$\rho(< r_{200}) = 200\rho_c(t) = 200\frac{3H^2(t)}{8\pi G}.$$

Other conventions for the overdensity constant include $\Delta_c = 500$, or $\Delta_c = 1000$, depending on the type of analysis being done, in which case the virial radius and virial mass is s

Also

$$\bar{\rho}_m/\rho_m^h = \frac{\bar{\rho}_m/\bar{\rho}_c}{\rho_m^h/\bar{\rho}_c} = \frac{\Omega_m^0 a^{-3}}{\Delta_c} \tag{4.10}$$

4.3 Choosing α, w

For Chameleon model in the screened regime, for the choice of $p_1 = b$ and having,

$$\begin{aligned}
&\alpha = \frac{1}{2}, \;\; w = 0 \\
&p_2 = \frac{\Delta G}{G}, \;\; p_3 = \frac{4-\alpha}{1-\alpha} = 7, \;\; p_5 = -1, \;\; p_6 = \frac{2}{21} \\
&p_7 = \frac{-6}{7}, \;\; p_4 = \Omega^{1/3}\Big[(\Omega_m + 4\Omega_L)\frac{b}{3|f_{R0}|}\Big]^{1/7}, \;\; B = \frac{\Delta G}{G}, \;\; a = \frac{7b}{b-1}
\end{aligned} \tag{4.11}$$

$$\frac{\Delta G_{eff}}{G} = \frac{\Delta G}{G} b\Big(\frac{y_h}{y_0}\Big)^{\frac{7b}{b-1}}\Big\{\big[1 + (\frac{y_0}{y_h})^{1/2}\big]^{1/b} - 1\Big\} \tag{4.12}$$

$$\begin{aligned}
y_0 &= p_4 a^{p_5}\Big(2GH_0M_{vir}\Big)^{p_6}\Big(\frac{y_{env}}{y_h}\Big)^{p_7} \\
&= \Omega_m^{1/3}\Big[(\Omega_m + 4\Omega_L)^{-2}\frac{b}{3|f_{R_0}|}\Big]^{\frac{1}{7}} a^{-1}\big(2GH_0M_{vir}\big)^{\frac{2}{21}}\Big(\frac{y_{env}}{y_h}\Big)^{\frac{-6}{7}}
\end{aligned} \tag{4.13}$$

Having $\epsilon = \Big(\frac{y_{env}}{y_h}\Big)^{-\frac{6}{7}}$, $y_h = \big(\frac{\rho_m^h}{\bar{\rho}_m}\big)^{-1/3}$

$$\Big(\frac{y_h}{y_0}\Big)^3 = \frac{\bar{\rho}_m/\rho_m^h}{\Omega_m\Big[(\Omega_m + 4\Omega_L)^{-2}\frac{b}{3|f_{R_0}|}\Big]^{3/7} a^{-3}\big(2GH_0M_{vir}\big)^{2/7}\epsilon^3} \tag{4.14}$$

$$\epsilon^{-7/2} = \Big(\frac{y_{env}}{y_h}\Big) = \frac{\bar{\rho_m}/\rho_m^{\rm env}}{\bar{\rho}_m/\rho_m^h} = \frac{\rho_m^h}{\rho_m^{\rm env}} \tag{4.15}$$

Taking $b = 6$, $\zeta_h = 1.5Mpc/h$, $\zeta_{env} = 5Mpc/h$ we have,

$$\epsilon = \Big(\frac{\zeta_{env}}{\zeta_h}\Big)^{-6/7} \tag{4.16}$$

Because, $\rho_m^h = M/\zeta_h^3$, $\rho_m^{env} = M/\zeta_{env}^3$.

4.3.1 Questions:

- I assumed background quantities (Ω_L, Ω_m) are at z=0!
- We still need to have ρ_m^h or δ_m^h, which I took $\delta_m^h = 200$ which is not necessarily true.
- What should we do exactly? should we first modify gravity by f(R) in Fourier space then go to real space and screen it?
- I think we have to use smoothing in Fourier/ real space to make the densities non-local, inorder to take into account the halos and environments statistically.
- Is it ok is to use $\frac{\rho_m^h}{\rho_m^{\rm env}} = \Big(\frac{\zeta_{env}}{\zeta_h}\Big)^3$, why?
- Should we take $2GH_0M_{vir}$ where $M_{vir}(z = 0)$? I assumed $M_{vir}(z)$!
- Do you agree with $\rho_m^h = \Delta_c\bar{\rho}_c = \frac{3H^2}{8\pi G}\Delta_c$ for all halos in average? Can we use it? - Also we did not use local density in this screening mechanism! I think something is wrong! It would be nice if we could use the local density information by smoothing or something!
- Also $\frac{\Delta G_{eff}}{G} = \frac{\Delta G}{G} b\Big(\frac{y_h}{y_0}\Big)^{\frac{7b}{b-1}}\Big\{\big[1 + (\frac{y_0}{y_h})^{1/2}\big]^{1/b} - 1\Big\}$ it is not clear what is $\frac{\Delta G}{G}$, is it ok to do f(R) in Fourier space then go back to real space and apply screening!
- Moreover, since we have screening for $\Delta G_{eff}/G$ not for G_{eff} in real space, we really need to have $\Delta G_{f(R)}/G$ in real space to apply the screening on top of it, while here at most we can have $(1 + \Delta G_{f(R)}/G) * \delta(k)$ then we don't know how to apply screening exactly!
- How to recover f(R) without screening? All the parameters equal to 1, does not work, because we have 1/b-1 in the denominator.

5 Implementation

Since the screening is defined in real space, while we have modified gravity (f(R)) in Fourier space, we first compute the m

The tricky part to implement in Gevolution is how we read δ_m in Gevolution.
First note that in Gevolution $T^0_0(gev) = -a^3 T^0_0 = -a^3\big(\bar{\rho} + \delta\rho\big)$ and by definition $M_{pl}^2 = 1/8\pi G$ Moreover we have we have the following identities,

$$\Omega_m = \frac{\rho_m(a)}{\rho_{crit}(a)} = \frac{a^2\bar{\rho}_m(a)}{3M_{pl}^2\mathcal{H}^2} \tag{5.1}$$

$$\rho_{crit} = \frac{3M_{pl}^2\mathcal{H}^2}{a^2} \tag{5.2}$$

$$\rho^0_{crit} = \frac{3M_{pl}^2\mathcal{H}_0^2}{a_0^2} = 1 \tag{5.3}$$

$\rho^0_{crit} = 1$ in Gevolution, i.e. $\mathcal{H}_0 = H_0 = \frac{8\pi G}{3}$.
On the other hand, $\bar{T}^0_0(Gev) = a^3\bar{\rho}_m$, so we have,

$$a^3\bar{\rho}_m = a^3\frac{\bar{\rho}^0_m a^{-3}}{\rho^0_{crit}}\rho^0_{crit} = \Omega^0_m \tag{5.4}$$

At the end we can write,

$$T^0_0(gev) = \Omega^0_m\Big(1 + \delta_m\Big) = a^3\bar{\rho}_m\big(1 + \delta_m\big) \tag{5.5}$$

So because of the notation in Gevolution, T^0_0 is the perturbation part plus background so,

$$\delta_m(gev) = \frac{T^0_0(gev) - \bar{T}^0_0(gev)}{\bar{T}^0_0(gev)} = \frac{\text{source}(x) - a^3\bar{\rho}_m}{a^3\bar{\rho}_m} = \frac{\text{source}(x) - \Omega^0_m}{\Omega^0_m} \tag{5.6}$$

So $\delta\rho_m$ is exactly $T^0_0(gev)$ in Gevolution while it is rescaled by a^3.

6 Conclusions

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References

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