example_notebook

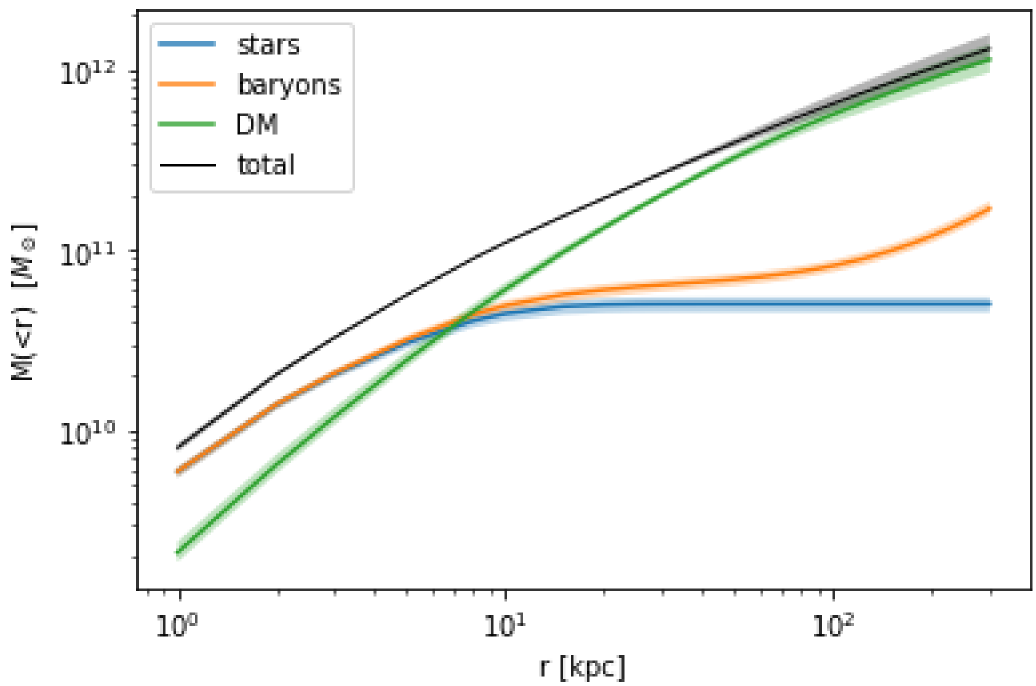
April 4, 2020

1 1) Read in the ASCII file containing the MW mass profile

[1]:
```
import numpy as np

data = np.loadtxt( "MW_enclosed_mass_profile.txt",  )

MW_r_vals = data[:,0]
MW_M_star = data[:,1:4]  # maxium likelihood value; 68% interval (lower and␣
↪upper bound)
MW_M_bar  = data[:,4:7]
MW_M_DM   = data[:,7:10]
MW_M_total= data[:,10:14]
```

[2]:
```
import matplotlib.pyplot as plt

plt.fill_between( MW_r_vals, MW_M_star[:,0]+MW_M_star[:,1], MW_M_star[:
↪,0]+MW_M_star[:,2], alpha=0.3 )
plt.loglog( MW_r_vals, MW_M_star[:,0], label="stars" )

plt.fill_between( MW_r_vals, MW_M_bar[:,0]+MW_M_bar[:,1], MW_M_bar[:
↪,0]+MW_M_bar[:,2], alpha=0.3 )
plt.loglog( MW_r_vals, MW_M_bar[:,0], label="baryons" )

plt.fill_between( MW_r_vals, MW_M_DM[:,0]+MW_M_DM[:,1], MW_M_DM[:,0]+MW_M_DM[:
↪,2], alpha=0.3 )
plt.loglog( MW_r_vals, MW_M_DM[:,0], label="DM" )

plt.fill_between( MW_r_vals, MW_M_total[:,0]+MW_M_total[:,1], MW_M_total[:
↪,0]+MW_M_total[:,2], fc='k', alpha=0.3 )
plt.loglog( MW_r_vals, MW_M_total[:,0], c="k", lw=1, label="total" )

plt.xlabel( "r [kpc]" )
plt.ylabel( r"M(<r)  $[M_\odot]$" )
plt.legend(  )
```

[2]:
```
<matplotlib.legend.Legend at 0x11035c050>
```



2 2) Calculate the contracted DM profile

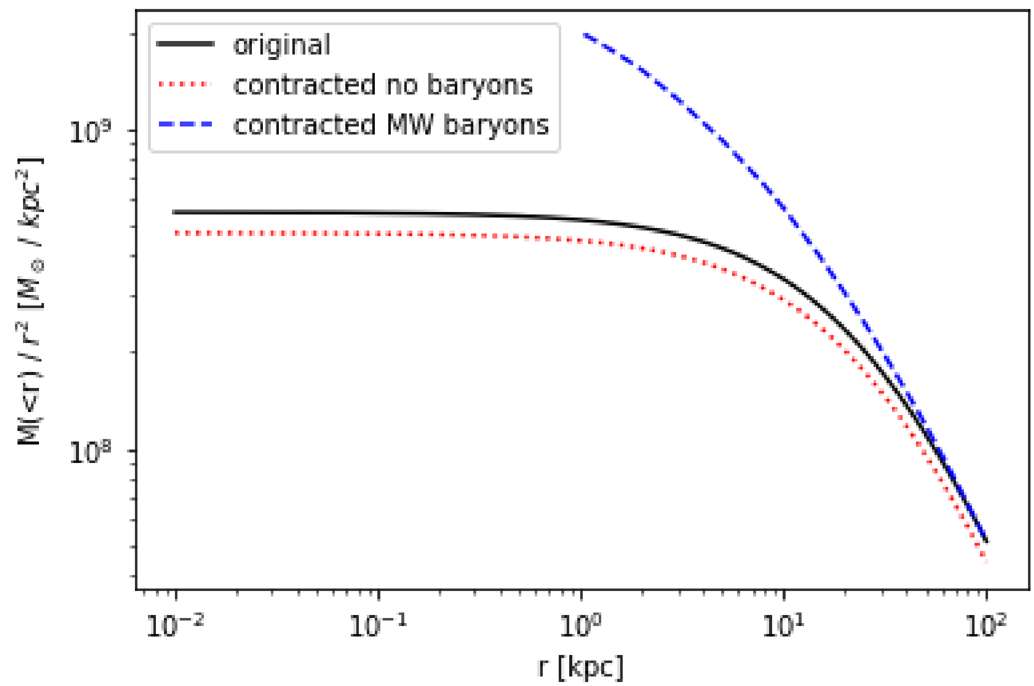
2.1 2.1) First for the DM enclosed mass

[3]:
```
# calculate the contracted mass profile for a 1.e12 halo assuming zero baryons

from Cautun20_contraction import contract_enclosed_mass, NFW_enclosed_mass
import numpy as np

r = np.logspace( -2, 2, 241 )
mass_total = NFW_enclosed_mass( r, M200=1.e12, conc=9 )       # total mass
f_bar      = 0.157    # cosmic baryon fraction
mass_DM    = mass_total * (1.-f_bar)   # DM mass
mass_bar   = 0.                        # no baryons
mass_DM_contracted = contract_enclosed_mass( mass_DM, mass_bar, f_bar=f_bar )
```

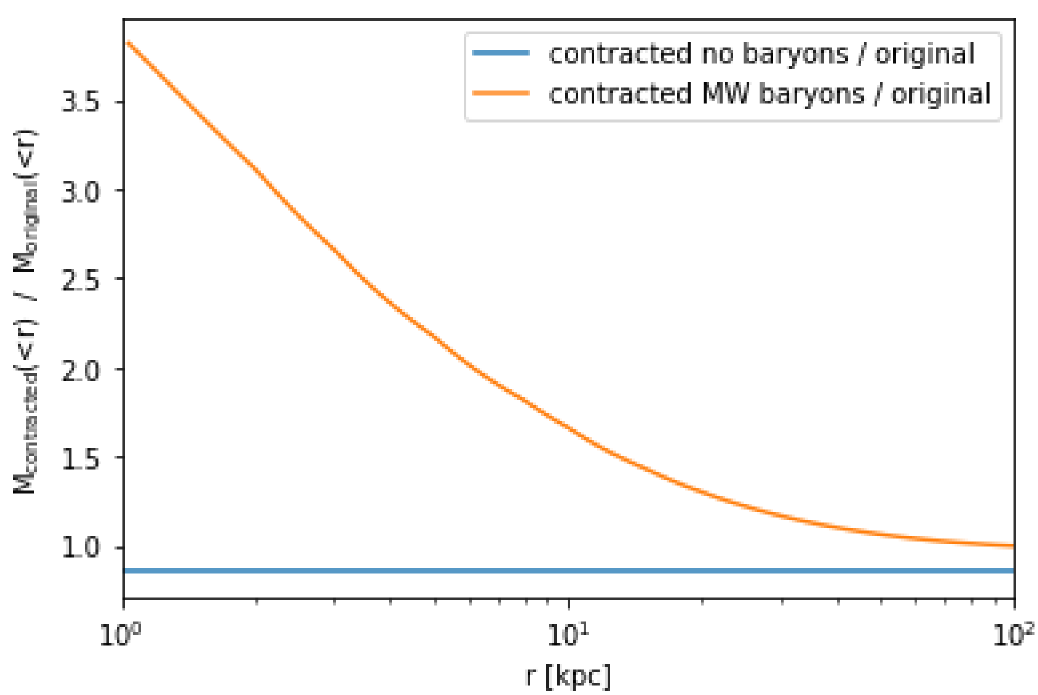
[4]:
```
# can calculate the profile of the same halo but using the MW baryonic␣
↪distribution
# for this to work, you need to have loaded the file containing the MW mass␣
↪profile

# first lets interpolates the DM enclosed mass to the radial distances␣
↪available for the MW data
```

```
mass_DM_2 = np.interp( MW_r_vals, r, mass_DM )
mass_bar_2 = np.interp( r, MW_r_vals, MW_M_bar[:,0] )

mass_DM_contracted_MW = contract_enclosed_mass( mass_DM_2, MW_M_bar[:,0],␣
↪f_bar=f_bar )
mass_DM_contracted_MW = contract_enclosed_mass( mass_DM, mass_bar_2,␣
↪f_bar=f_bar )

# The above calculation make senses only for r>1 kpc since the input file does␣
↪not contain mass values
# for lower distances, so, when plotting, we only show the range r > 1 kpc.
valid_MW = r > 1.
```

[7]:
```
# plot the enclosed mass (actually plots mass / r^2 to decrease the dynamical␣
↪range)
import matplotlib.pyplot as plt

plt.loglog( r, mass_DM / r**2, 'k-', label="original" )
plt.loglog( r, mass_DM_contracted / r**2, 'r:', label="contracted no baryons" )
plt.loglog( r[valid_MW], (mass_DM_contracted_MW / r**2)[valid_MW], 'b--',␣
↪label="contracted MW baryons" )

plt.xlabel( "r [kpc]" )
plt.ylabel( r"M(<r) / $r^2$ $[M_\odot \ / \ kpc^2]$" )
plt.legend()
plt.show()

plt.semilogx( r, mass_DM_contracted / mass_DM, label="contracted no baryons /␣
↪original" )
plt.semilogx( r[valid_MW], (mass_DM_contracted_MW / mass_DM)[valid_MW],␣
↪label="contracted MW baryons / original" )

plt.xlim( [1,100] )
plt.xlabel( "r [kpc]" )
plt.ylabel( r"M$_{\rm contracted}$(<r)  /  M$_{\rm original}$(<r)" )
plt.legend()
```



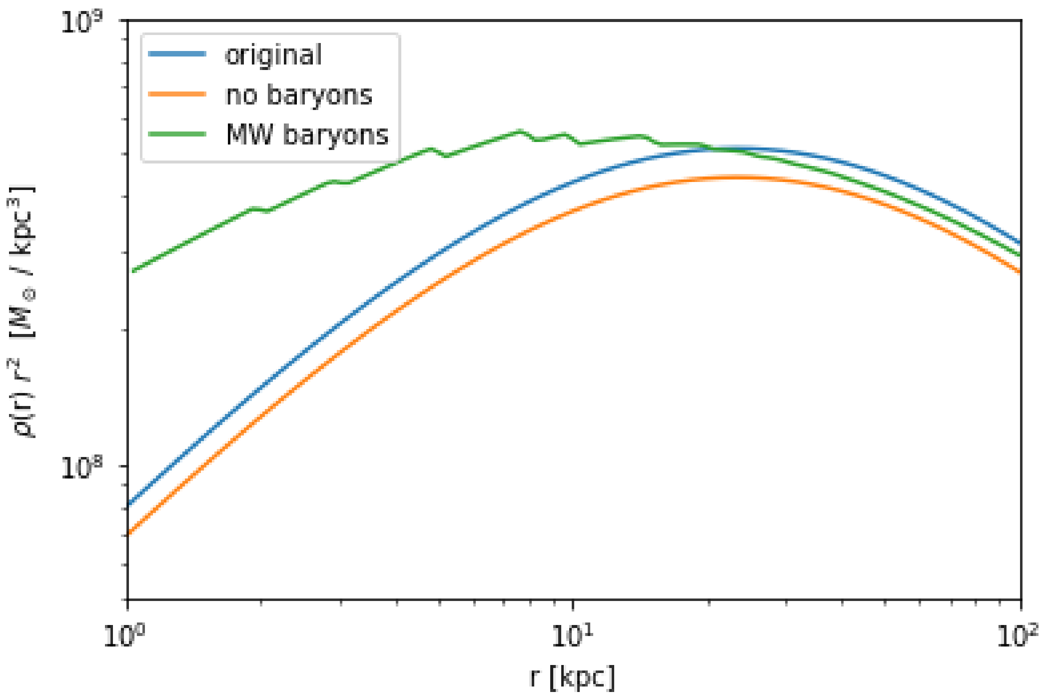
[7]: <matplotlib.legend.Legend at 0x115103a50>



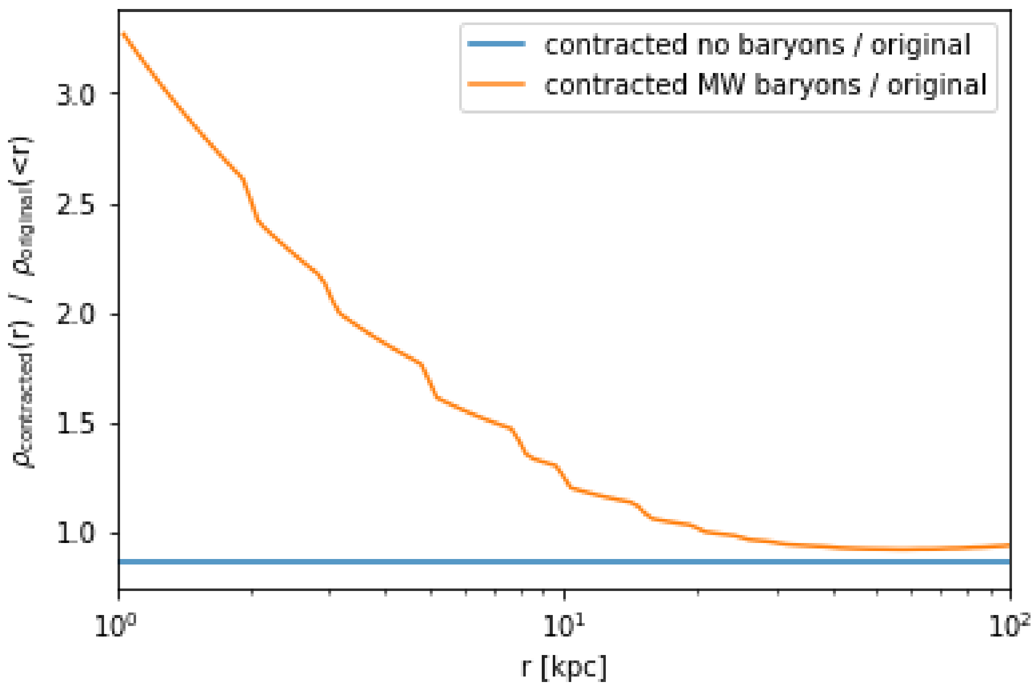
2.2 2.2) Second, for the DM density profile

[12]:
```
# apply the contraction to the density distribution
from Cautun20_contraction import contract_density, NFW_density,␣
 ↪density_from_enclosed_mass

# First apply to the case of zero baryons
# For this, we calculate the NFW radial density profile for the DM component␣
 ↪for the same
# halo used for the enclosed mass calculation.
density_NFW = NFW_density( r, M200=1.e12, conc=9 ) * (1.-f_bar)

# Note: the enclosed mass and the density need to match and be defined at the␣
 ↪same set of radial distances
density_DM_contracted = contract_density( density_NFW, 0., mass_DM=mass_DM,␣
 ↪mass_bar=mass_bar, f_bar=f_bar )


# Now apply to the MW baryonic distribution.
# For this, we need to calculate the baryonic density -- this is rather noisy␣
 ↪due to the
# small number of bins available in the input file and is shown here only for␣
 ↪illustration purposes.
den_bar_MW = density_from_enclosed_mass( r, mass_bar_2, r )
density_DM_contracted_MW = contract_density( density_NFW, den_bar_MW, \
                                            mass_DM=mass_DM, mass_bar=mass_bar_2,␣
 ↪f_bar=f_bar )


plt.loglog( r, density_NFW * r**2, label="original" )
plt.loglog( r, density_DM_contracted * r**2, label="no baryons" )
plt.loglog( r[valid_MW], (density_DM_contracted_MW * r**2)[valid_MW], label="MW␣
 ↪baryons" )

plt.xlim( [1,100] )
plt.ylim( [5.e7,1.e9] )
plt.xlabel( "r [kpc]" )
plt.ylabel( r"$\rho$(r) $r^2$  $[M_\odot \ / \ \rm{kpc}^3]$" )
plt.legend()
plt.show()

plt.semilogx( r, density_DM_contracted / density_NFW, label="contracted no␣
 ↪baryons / original" )
plt.semilogx( r[valid_MW], (density_DM_contracted_MW / density_NFW)[valid_MW], \
             label="contracted MW baryons / original" )

plt.xlim( [1,100] )
```

```
plt.xlabel( "r [kpc]" )
plt.ylabel( r"$\rho_{\rm contracted}$(r)  /  $\rho_{\rm original}$(<r)" )
plt.legend()
```



[12]: <matplotlib.legend.Legend at 0x115e4ba50>



3 3) Import the MW potential and use it in galpy

[13]:
```
# import the MW best fitting potential as determined by Cautun et al (2020)
from Cautun20_galpy_potential import Cautun20

# Can also import individual potentials: 4 components are available:
# 1) DM halo,
# 2) one component represneting all disks: stellar thin + thick, HI and␣
↪molecular gas disks
# 3) the stellar bulge
# 4) the CGM (i.e. hot gaseous halo)
Cautun_halo, Cautun_Discs, Cautun_Bulge, Cautun_cgm = Cautun20

# Can also import various spherically averaged masses and densities
# All these quanties are in internal galpy units!
# rspace - the (spherical) radial bins at which the quantities are defined
# rho_DM_contracted - the contracted DM density profile
# MassCum_DM_contracted - the enclosed DM mass for the contracted halo
# MassCum_bar - spherically averaged enclosed baryonic mass
# MassCum_DM_uncontracted - the enclosed DM mass before baryonic contraction
from Cautun20_galpy_potential import rspace, rho_DM_contracted,␣
↪MassCum_DM_contracted, MassCum_bar, MassCum_DM_uncontracted
```

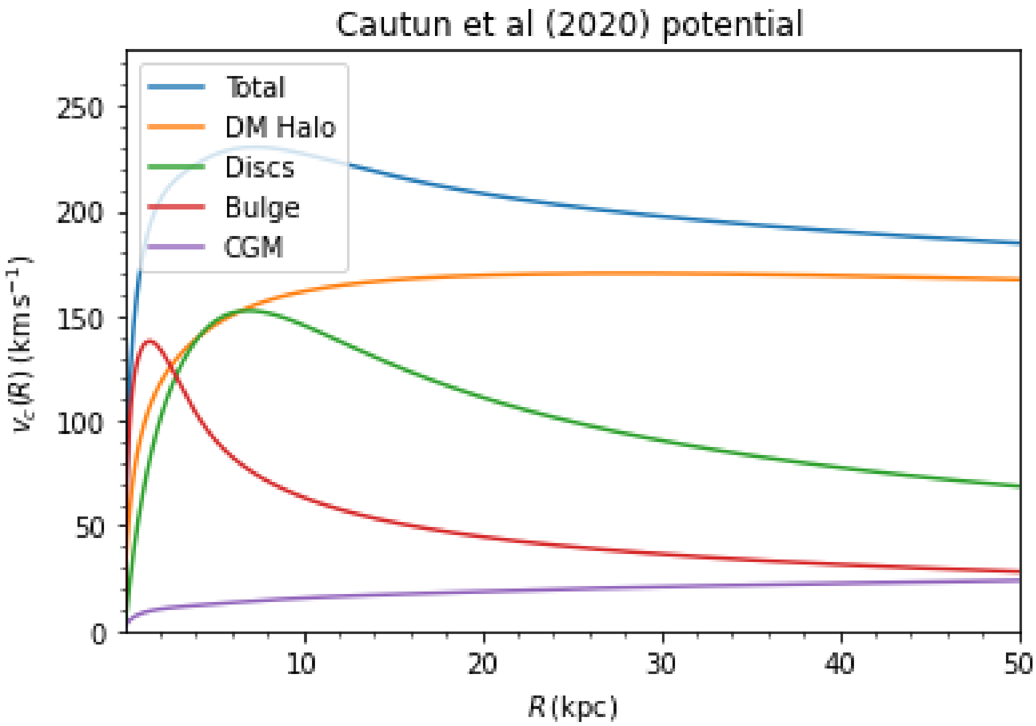
```python
import numpy as np
import matplotlib.pyplot as plt
```

galpyWarning: interppotential_c extension module not loaded, because
galpy_interppotential_c.cpython-37m-darwin.so image was not found

[14]:
```python
# Plot the rotation curve and the various components: DM halo, bulge, discs,␣
↪and CGM
from galpy.potential import plotRotcurve, vcirc

Rmax = 50 #100    # in units of R0
Rrange = [0.01,Rmax]


plt.figure()
plotRotcurve(     Cautun20, label='Total', Rrange=Rrange )
plotRotcurve(  Cautun_halo, label='DM Halo', Rrange=Rrange, overplot=True)
plotRotcurve( Cautun_Discs, label='Discs',  Rrange=Rrange, overplot=True)
plotRotcurve( Cautun_Bulge, label='Bulge', Rrange=Rrange, overplot=True)
plotRotcurve(   Cautun_cgm, label='CGM',   Rrange=Rrange, overplot=True)

plt.title('Cautun et al (2020) potential')
plt.legend()
```

[14]: <matplotlib.legend.Legend at 0x116750710>

<Figure size 432x288 with 0 Axes>

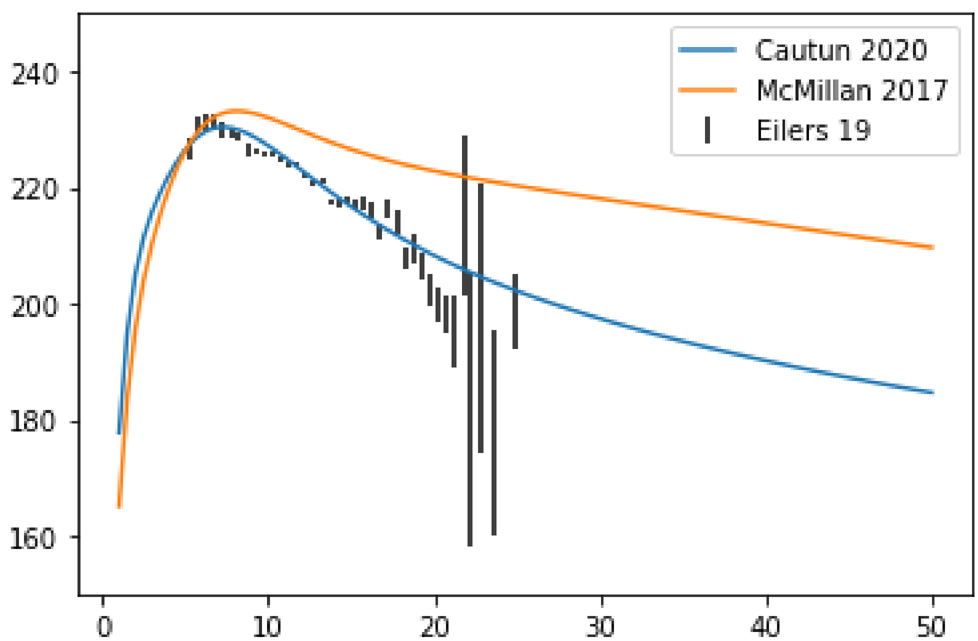


[15]:
```
# Compare the rotation curve with some recent data and with two other galpy␣
↪potentials
from galpy.potential.mwpotentials import MWPotential2014, McMillan17


# read the Eilers et al (2019) rotation curve data
MW_Vrot_data = np.loadtxt('MW_rotation_Eilers_2019.txt')
vdata_r    = MW_Vrot_data[:,0]
vdata_vc   = MW_Vrot_data[:,1]
vdata_vc_u = MW_Vrot_data[:,2]
vdata_vc_l = MW_Vrot_data[:,3]

# compare the various rotation curves with the data
R0 = 8.122    # Solar position in kpc
rvals  = np.linspace( 1., 50., 101 )  # kpc
plt.figure()

plt.errorbar( vdata_r, vdata_vc, yerr=[vdata_vc_l, vdata_vc_u], c='k',␣
↪label='Eilers 19', ls='', zorder=-1 )
plt.plot( rvals, vcirc( Cautun20, rvals/R0, 0 ), label='Cautun 2020' )
plt.plot( rvals, vcirc( McMillan17, rvals/R0, 0 ), label='McMillan 2017' )

if vcirc( MWPotential2014, 1, 0 ) < 200. :
```

```
    print( "Error loading the 'MWPotential2014' potential!" )
else:
    plt.plot( rvals, vcirc( MWPotential2014, rvals/R0, 0 ), label='Bovy 2015' )

# plotRotcurve(     Cautun20, label='Cautun 2020', Rrange=Rrange, overplot=True␣
 ↪)
# plotRotcurve( MWPotential2014, label='Bovy 2015', Rrange=Rrange,␣
 ↪overplot=True )
# plotRotcurve(     McMillan17, label='McMillan 2017', Rrange=Rrange,␣
 ↪overplot=True )

plt.ylim( [150,250] )
plt.legend()
```

```
galpyWarning: integratePlanarOrbit_c extension module not loaded, because
galpy_integrate_c.cpython-37m-darwin.so image was not found
galpyWarning: integrateFullOrbit_c extension module not loaded, because
galpy_integrate_c.cpython-37m-darwin.so image was not found
galpyWarning: integrateLinearOrbit_c extension module not loaded, because
galpy_integrate_c.cpython-37m-darwin.so image was not found
Error loading the 'MWPotential2014' potential!
```

[15]: <matplotlib.legend.Legend at 0x1175f9e90>



[ ]: