Modelando objetos autogravitantes

```
> restart:with(plots):
```

Definimos las constantes para adimensionalizar la ecuación

*r=R*r1 con R el radio exterior de la configuración y r1 una varible adimensional*

*P =P0*P1 con P0 la presión central de la configuración y P1 la función presión adimensional*

*rho = rho0*rho1 con rho0 la densidad central de la configuración y rho1 la función densidad adimensional*

*m = M*m1 con M la masa total de la configuración y m1 la función masa adimensional*

Las ecuaciones de estructura estelar para el caso newtoniano isótropo (http://eagle.phys.utk.edu/guidry/astro615/lectures/lecture_ch4.pdf) quedan como

```
> Ecuac1 := diff(P1(r1),r1) + GG*Delta1*m1(r1)*rho1/r1^2=0;
```

$$Ecuac1 := \frac{d}{dr1} P1(r1) + \frac{GG\, \Delta 1\, m1(r1)\, \rho 1}{r1^2} = 0 \quad (1)$$

```
> Ecuac2 := diff(m1(r1),r1) = Delta2*4*Pi*r1^2*rho1;
```

$$Ecuac2 := \frac{d}{dr1} m1(r1) = 4\, \Delta 2\, \pi\, r1^2\, \rho 1 \quad (2)$$

Estas ecuaciones de estructura son adimensionales y pueden integrarse numéricamente con

Delta1 := rho0*Mtot/(R*P0)

Delta2 := rho0*R^3/Mtot;

que utilizaremos más adelante

Ahora supongamos para este caso la ecuación polítropa

```
> EcEstado:= P1(r1) = K*rho1^gamma1;
```

$$EcEstado := P1(r1) = K\, \rho 1^{\gamma 1} \quad (3)$$

Adimensionalizamos y despejamos la densidad

```
> solrho:=solve(EcEstado,rho1);
```

$$solrho := e^{\frac{\ln\left(\frac{P1(r1)}{K}\right)}{\gamma 1}} \quad (4)$$

```
> rho1 := solrho;
```

$$\rho 1 := e^{\frac{\ln\left(\frac{P1(r1)}{K}\right)}{\gamma 1}} \quad (5)$$

Los parámetros de la ecuación politrópa

```
> K := 1.5; gamma1 := 4/3;
```

$$K := 1.5$$

$$\gamma 1 := \frac{4}{3} \quad (6)$$

Incorporemos las constantes que adimensionalizan las ecuaciones

```
> Delta1 := rho0*M/(R*P0);
```

$$\Delta 1 := \frac{\rho 0\, M}{R\, P0} \quad (7)$$

```
> Delta2 := rho0*R^3/M;
```

$$\Delta 2 := \frac{\rho 0\, R^3}{M} \tag{8}$$

y consideremos los parámetros solares en el sistema MKS

```
> RadioSol := 6.955*10^8;MasaSol := 1.98855*10^30;DensidadCentralSol
  := 1.622*10^5;PresionCentralSol := 2.5*10^16;
```

$$RadioSol := 6.955000000\ 10^{8}$$

$$MasaSol := 1.988550000\ 10^{30}$$

$$DensidadCentralSol := 1.62200000\ 10^{5}$$

$$PresionCentralSol := 2.500000000\ 10^{16} \tag{9}$$

y la constante gravitacional MKS

```
> GG:= 6.674*10^(-11); cc := 299792458;
```

$$GG := 6.674000000\ 10^{-11}$$

$$cc := 299792458 \tag{10}$$

Las constantes para el Sol que se usaron para adimensionalizar

```
> M:=MasaSol;
  R:=RadioSol;
  P0:=PresionCentralSol;
  rho0:=DensidadCentralSol;
```

$$M := 1.988550000\ 10^{30}$$

$$R := 6.955000000\ 10^{8}$$

$$P0 := 2.500000000\ 10^{16}$$

$$\rho 0 := 1.62200000\ 10^{5} \tag{11}$$

Las ecuaciones de estructura para el caso newtoniana isótropo serán

```
> simplify(Ecuac1);
```

$$\frac{\left(\frac{d}{dr1} P1(r1)\right) r1^2 + 0.9134146656\, m1(r1)\, P1(r1)^{3/4}}{r1^2} = 0 \tag{12}$$

```
> simplify(Ecuac2);
```

$$\frac{d}{dr1} m1(r1) = 254.4176034\, r1^2\, P1(r1)^{3/4} \tag{13}$$

y los parámetros de ejecución

```
> r0 := 10^(-4); ifinal:= 100; infinito := 10^(20):
```

$$r0 := \frac{1}{10000}$$

$$ifinal := 100 \tag{14}$$

Se plantea la integración del sistema de ecuaciones de estructura y se varía la condición inicial para la presión central.

```
> for i from 0 to ifinal do
  # se define el sistema de ecuaciones
  SistemaPm := {Ecuac1, Ecuac2, P1(r0)= 5*i+1, m1(r0)=0.}:
  funcionesPm := {P1(r1),m1(r1)}:
  #Se integra el sistema de ecuaciones para condiciones iniciales
```

```
variables en la presión
solucion:= dsolve(SistemaPm,funcionesPm,numeric,events=[[P1(r1)=10^
(-14),halt]],output=listprocedure):
#solucion:= dsolve(SistemaPm,funcionesPm,numeric,output=
listprocedure):
# se almancena los valores resultados de la integración
radio := rhs(solucion[1]):presion := rhs(solucion[2]):masa := rhs
(solucion[3]):
# se captura el último valor de la masa, generando una queja del
sistema que desantendemos
masaTotal[i]:=masa(infinito):RadioExt[i]:=radio(infinito): Pnula[i]
:=presion(infinito):
# a partir del valor de la presión central se calcula el densidad
central
rhoCentral[i]:= evalf(subs(P1(r1)=presion(r0),rho1));
end do:
```

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event #1 triggered a halt
Warning, cannot evaluate the solution further right of .19572333, 
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event #1 triggered a halt
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Warning, cannot evaluate the solution further right of .19519351, event #1 triggered a halt
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Warning, cannot evaluate the solution further right of .19467004, event #1 triggered a halt
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Warning, cannot evaluate the solution further right of .19118689, event #1 triggered a halt
Warning, cannot evaluate the solution further right of .19118689, event #1 triggered a halt
```

Grafico los valores para puntos rhoCentral, masa total

```
> puntosMasarho0:= {seq([rhoCentral[i],masaTotal[i]],i=1..ifinal)}:
> pointplot(puntosMasarho0, labels=[ "rhoCentral/rhocentralSol",
  "M/Msol"], labeldirections = ["horizontal", "vertical"]);
```

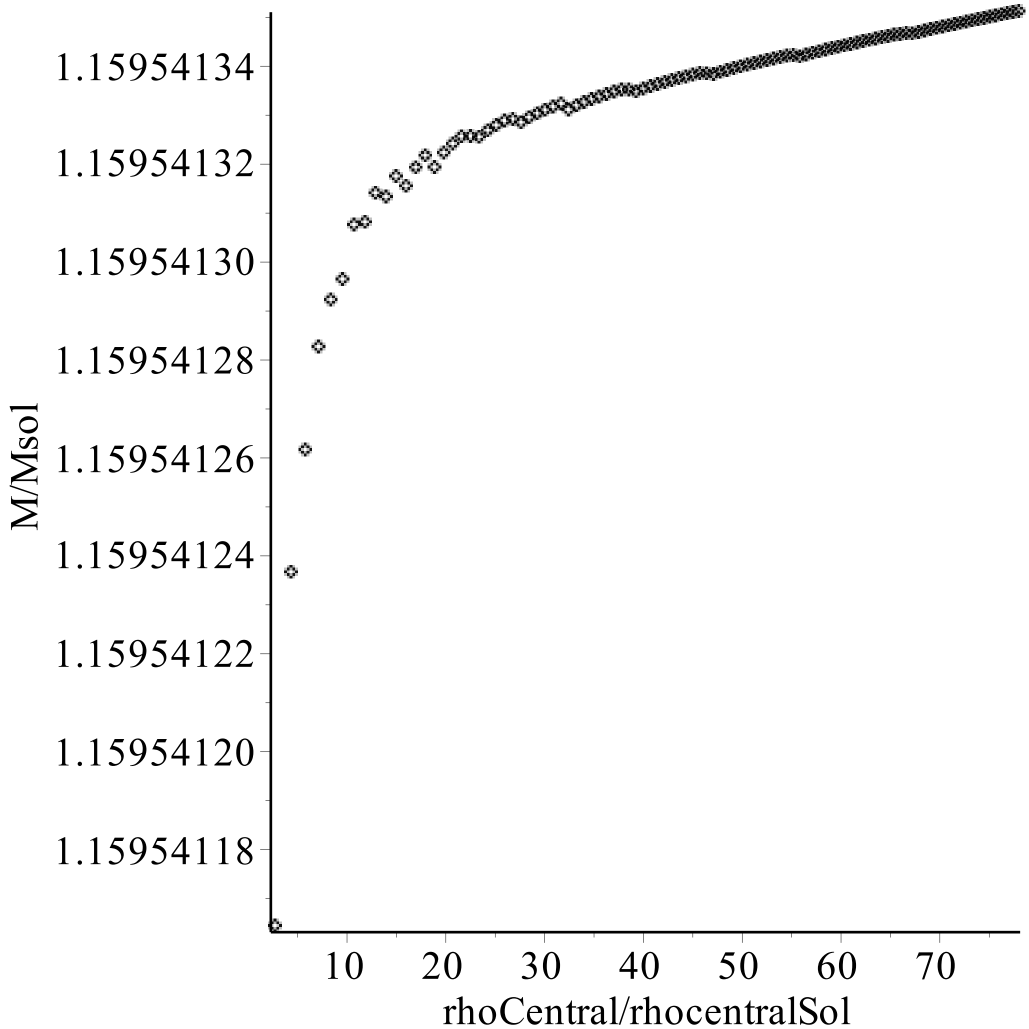
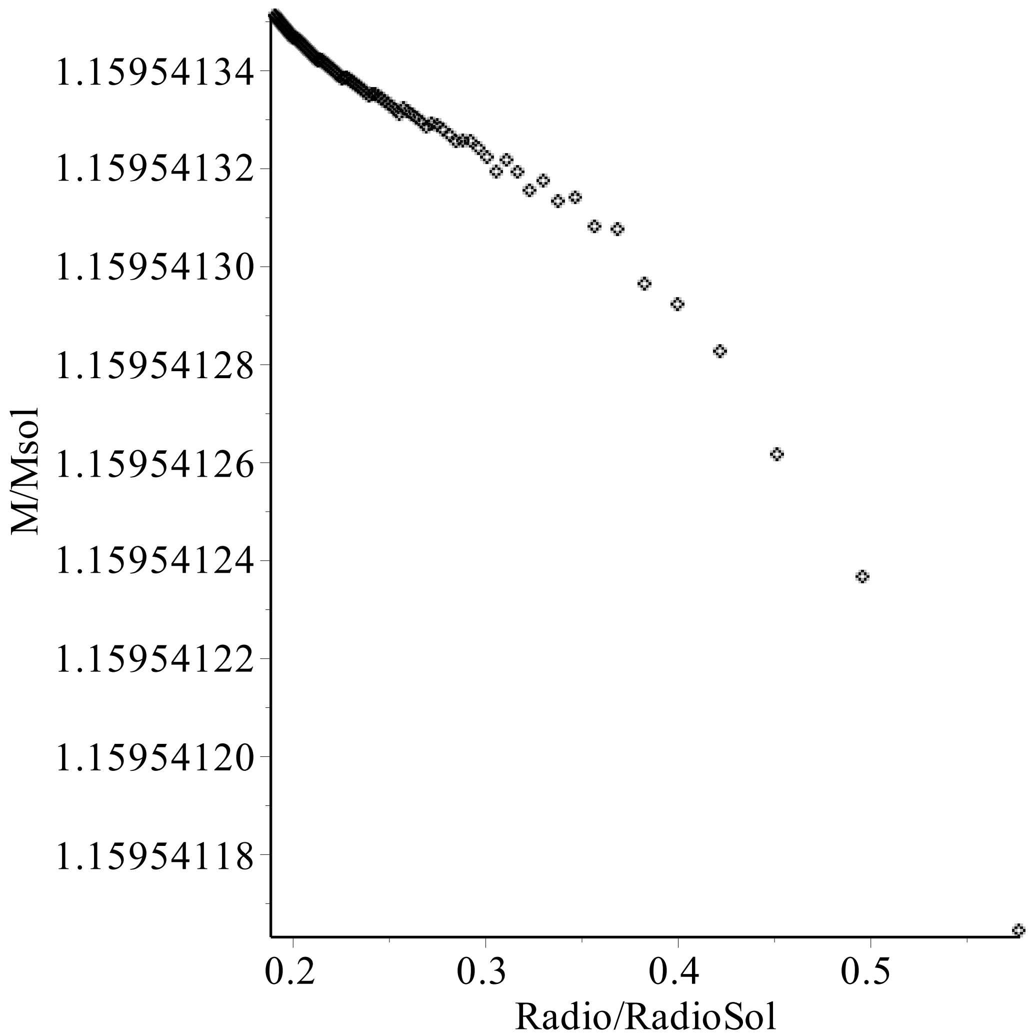


Grafico los puntos Radio exterior, masa total

```
> puntosMasaRadio:= {seq([RadioExt[i],masaTotal[i]],i=1..ifinal)}:
> pointplot(puntosMasaRadio,labels=[ "Radio/RadioSol", "M/Msol"],
  labeldirections = ["horizontal", "vertical"]);
```


1.15954134
1.15954132
1.15954130
1.15954128
1.15954126
1.15954124
1.15954122
1.15954120
1.15954118
M/Msol
0.2
0.3
0.4
0.5
Radio/RadioSol