Energy balance in ICMEs

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Thermodynamics first law in case of ICME, assuming adiabatic process, is

$$\Delta K + \Delta U = W_g + W_D + W_e \qquad (1)$$

ΔU and W_e are uncoupled from other terms, and then we could make two equations from equation (1).

First one is

$$\Delta K = W_g + W_D \qquad (2)$$

From this equation we obtain ICME velocity

And the second one is

$$\Delta U = W_e \qquad (3)$$

From this equation we obtain ICME temperature

Equation (2)

$$\Delta K = W_g + W_D \qquad (2)$$

in explicit form is

$$\frac{1}{2}mV^2 = -GM_S m\left(\frac{1}{r_0} - \frac{1}{r}\right) - \frac{1}{2}m\left[\left\{V_{R0}\exp\left[\frac{3}{2(2p-1)m}\rho_0 C_D A_0 r_0^{2-2p}\left(r_0^{2p-1} - r^{2p-1}\right)\right] + V_{SW}\right\}^2 - V_0^2\right]$$

And solving for V

$$V = \frac{2}{\mathrm{m}}\left[-2GM_S\left(\frac{1}{r_0} - \frac{1}{r}\right) - \frac{1}{2}m\left[\left\{V_{R0}\exp\left[\frac{3}{2(2p-1)m}\rho_0 C_D A_0 r_0^{2-2p}\left(r_0^{2p-1} - r^{2p-1}\right)\right] + V_{SW}\right\}^2 - V_0^2\right]\right]^{1/2}$$

Equation (3)

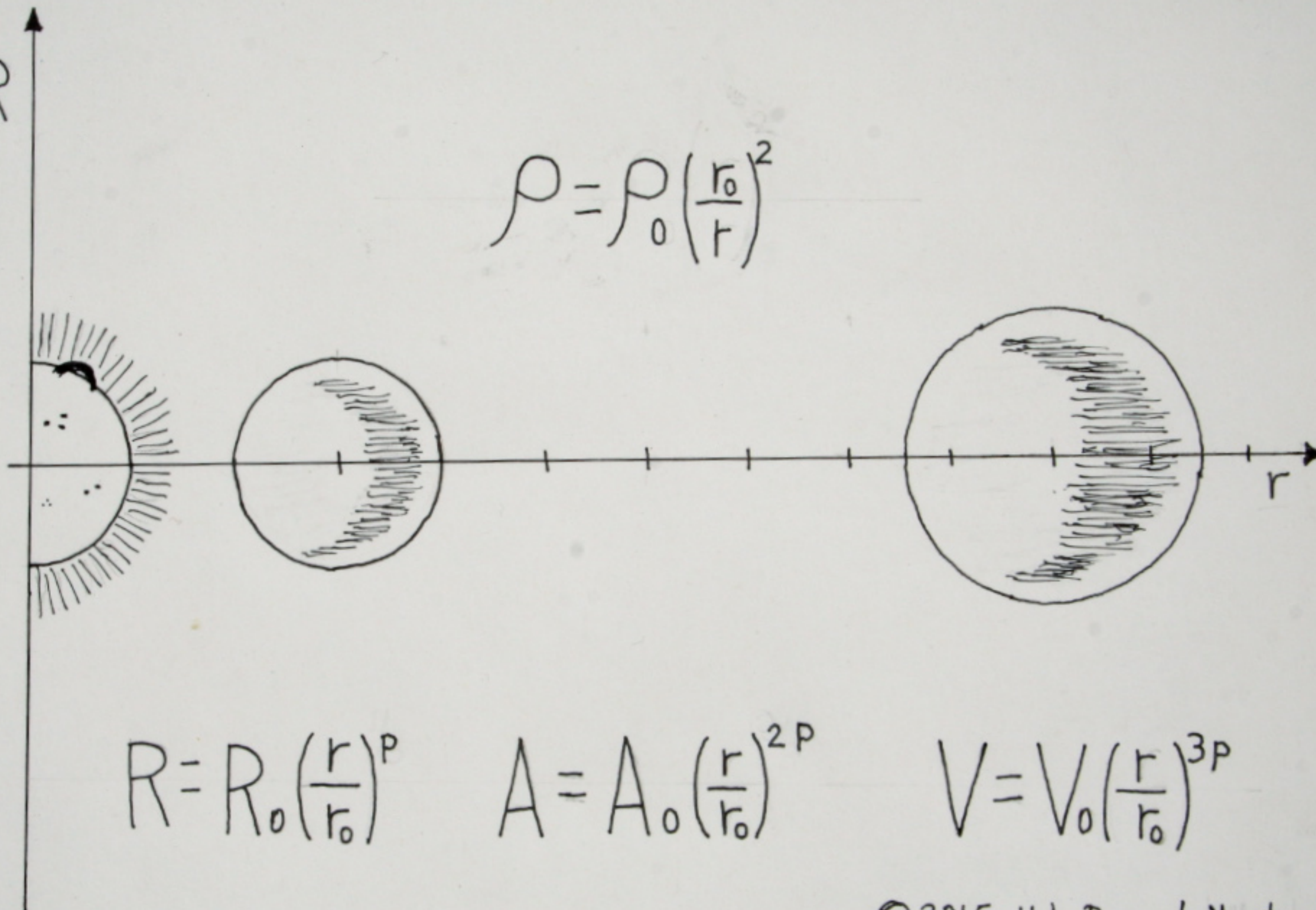
$$\nabla U = W_e \tag{3}$$

in explicit form, assuming ideal gas, is:

$$\frac{3}{2}NR(T - T_0) = -3NRT\left(\frac{r}{r_0}\right)^p$$

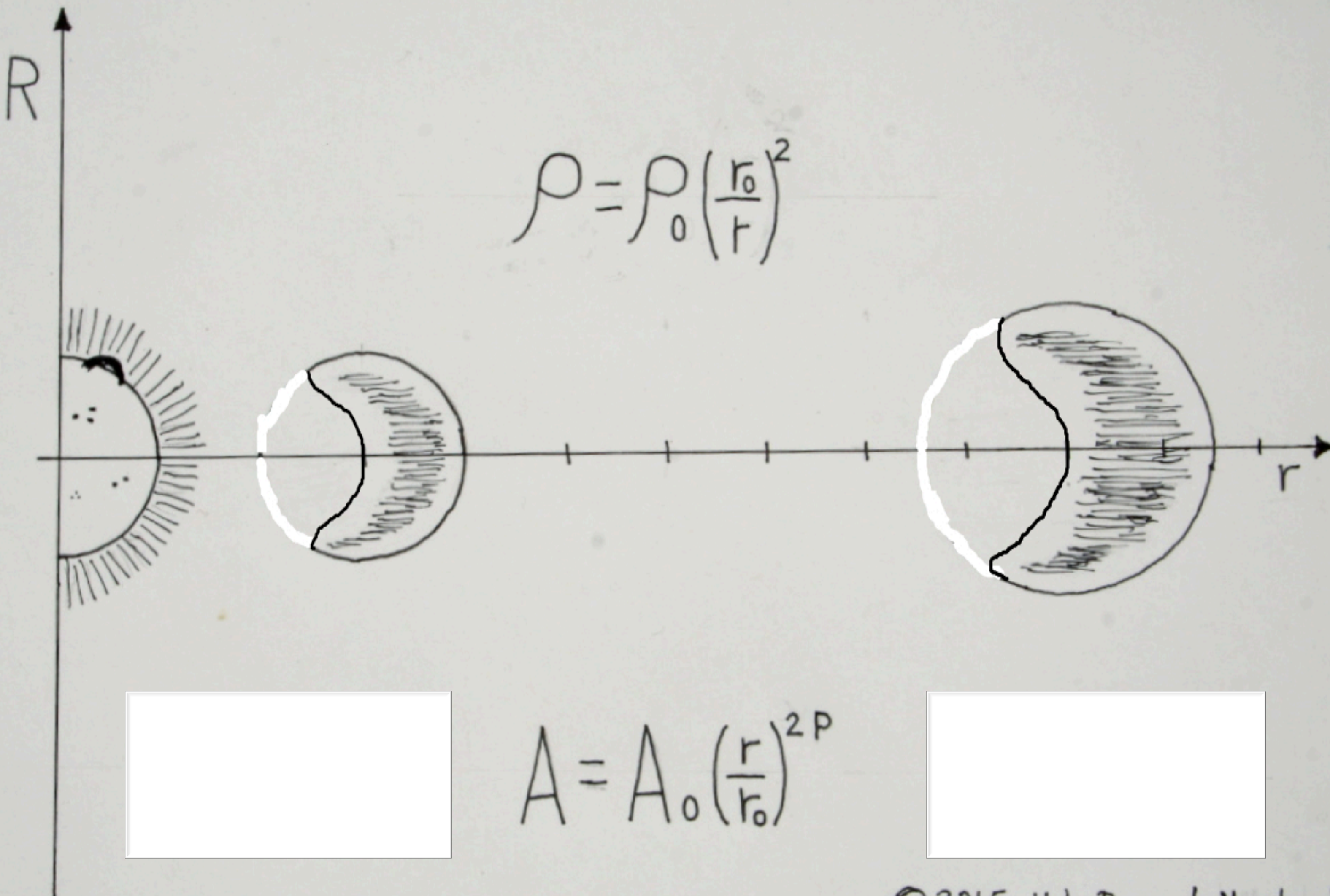
Solving for temperature we have:

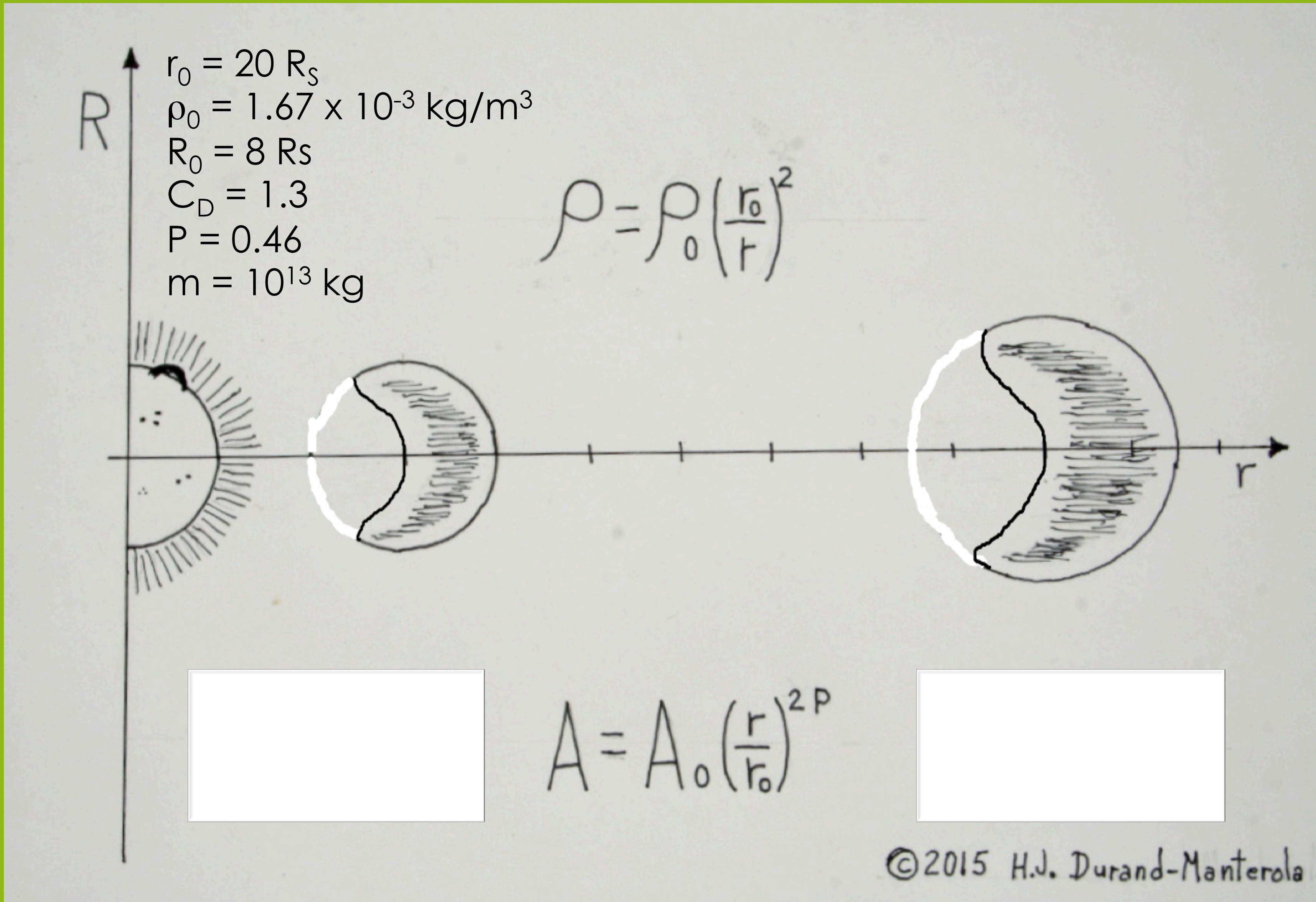
$$T = \frac{T_0}{1 + \frac{2}{3}ln\left(\frac{r}{r_0}\right)^p}$$



$$\rho = \rho_0 \left(\frac{r_0}{r}\right)^2$$

$$R = R_0 \left(\frac{r}{r_0}\right)^p \qquad A = A_0 \left(\frac{r}{r_0}\right)^{2p} \qquad V = V_0 \left(\frac{r}{r_0}\right)^{3p}$$


R
$\rho = \rho_0 \left(\frac{r_0}{r}\right)^2$
r
$A = A_0 \left(\frac{r}{r_0}\right)^{2P}$


R
r0 = 20 RS
ρ0 = 1.67 x 10-3 kg/m3
R0 = 8 Rs
CD = 1.3
P = 0.46
m = 1013 kg
ρ = ρ0 (r0/r)2
r
A = A0 (r/r0)2P
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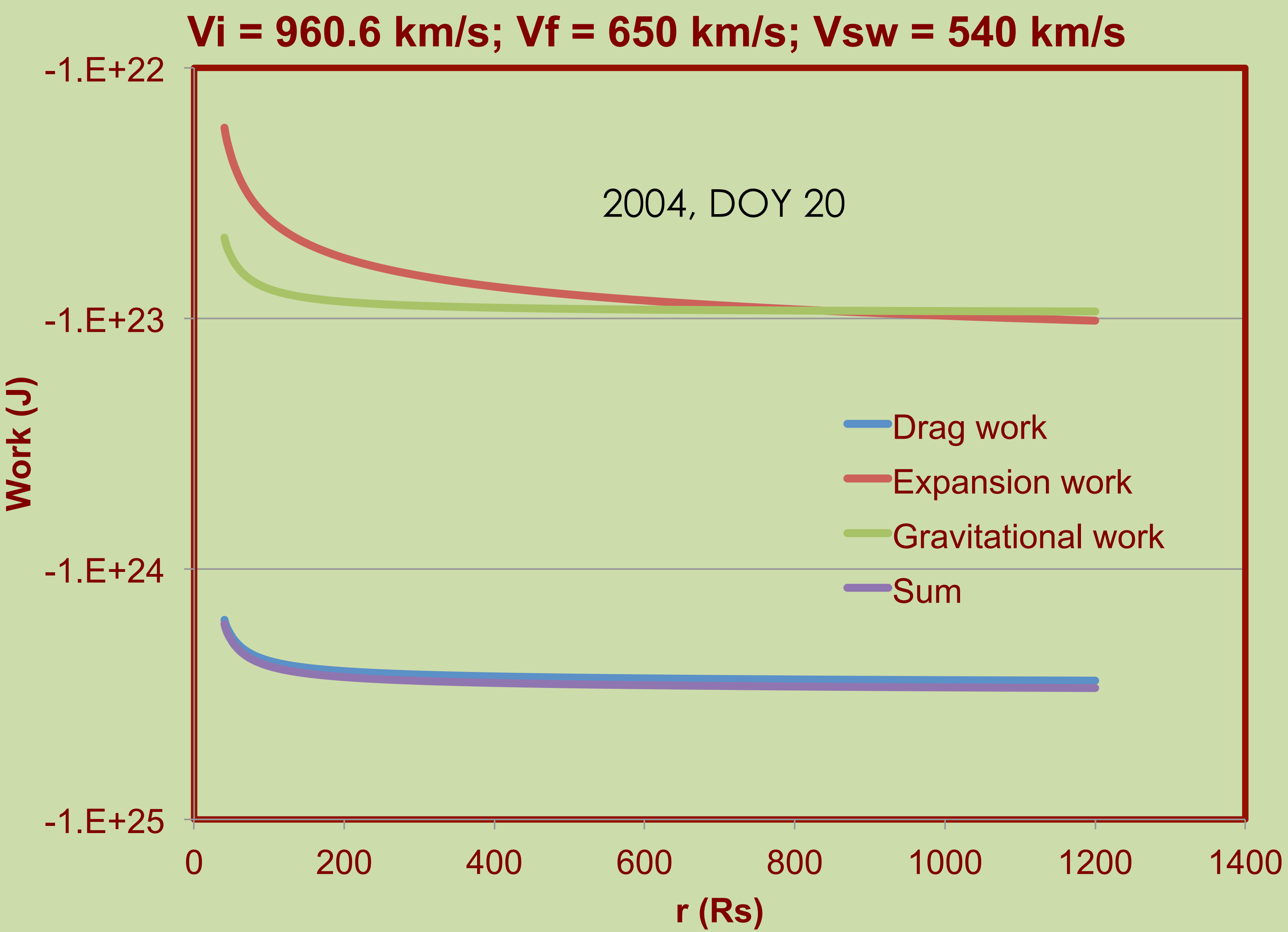
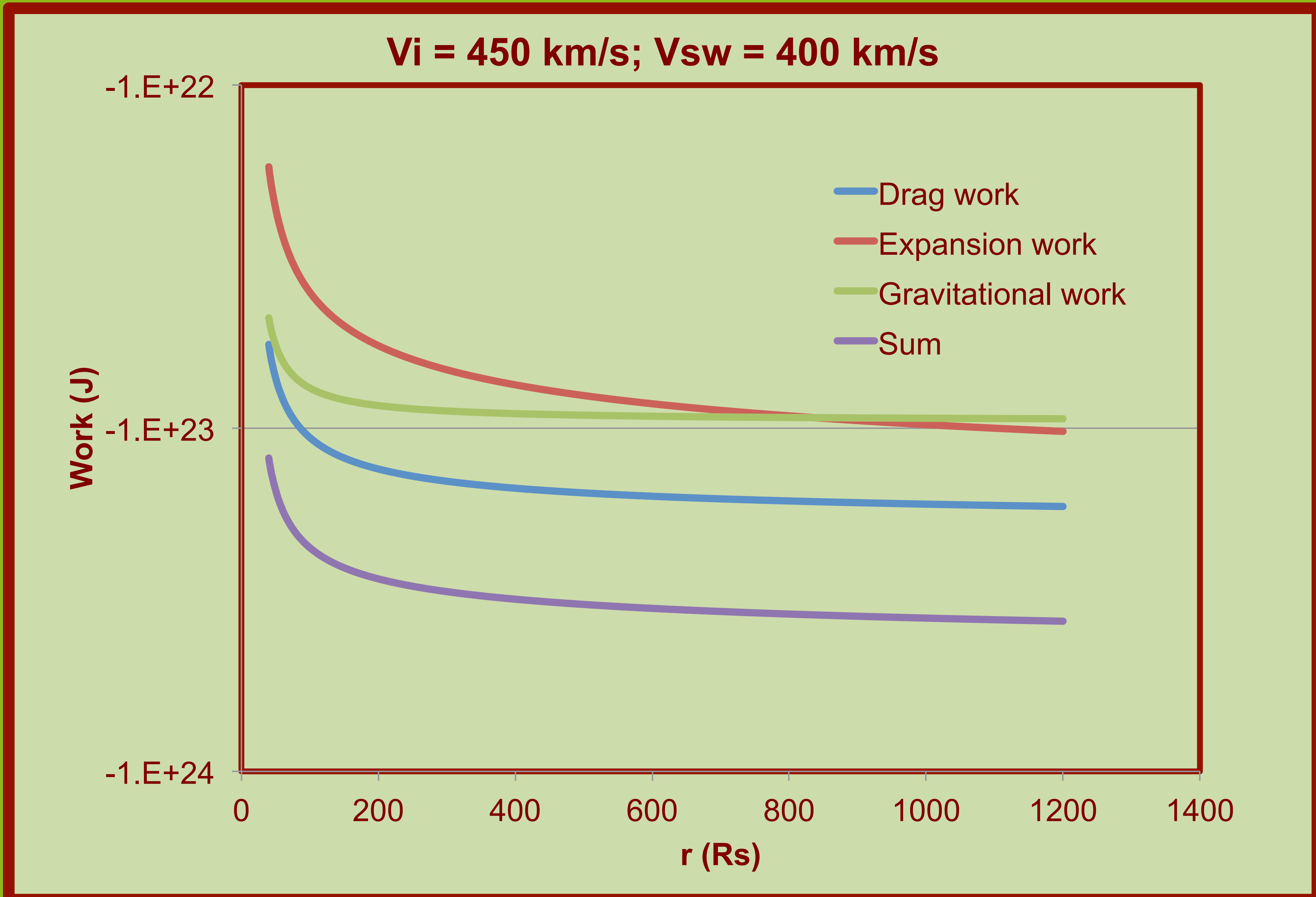
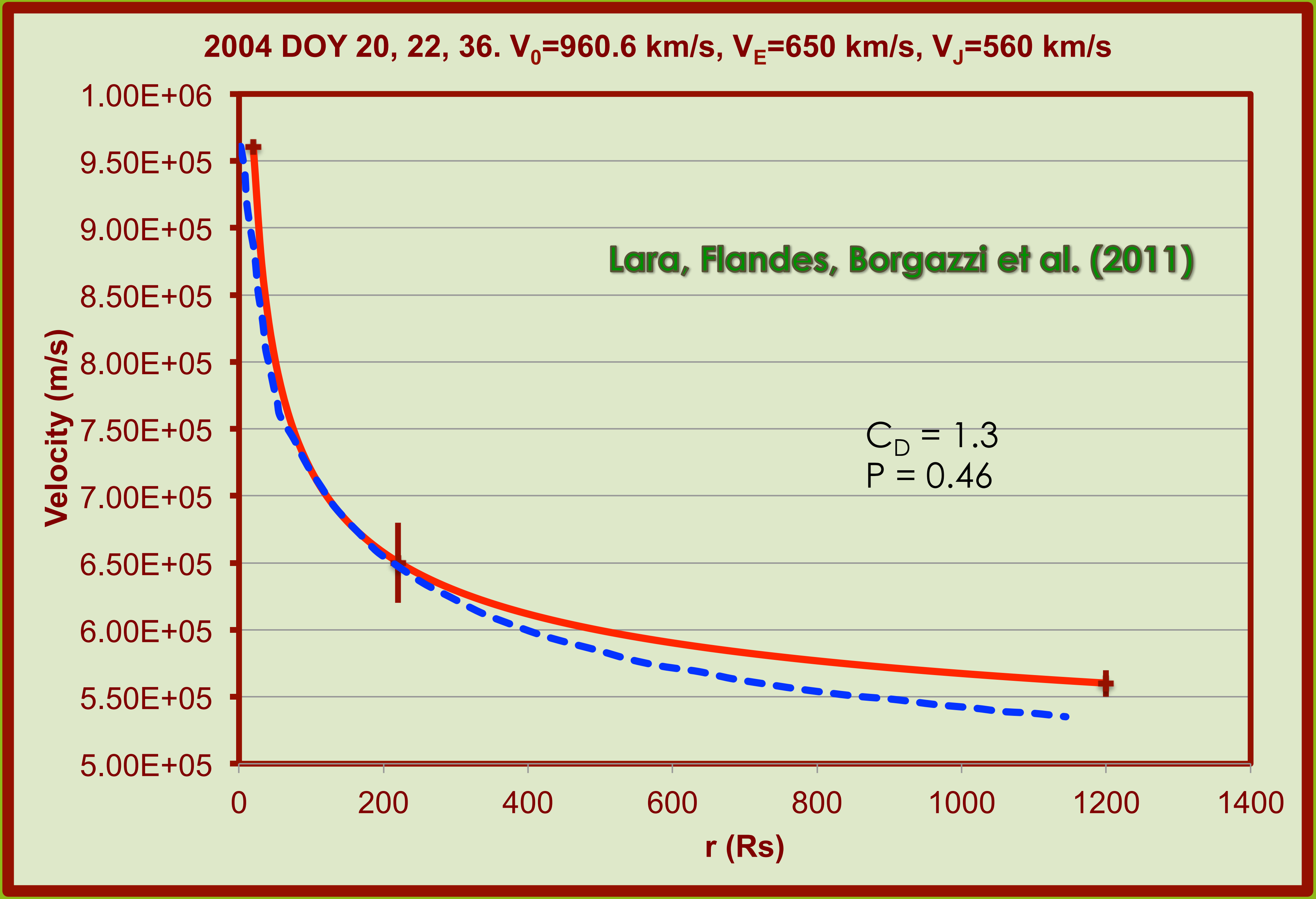
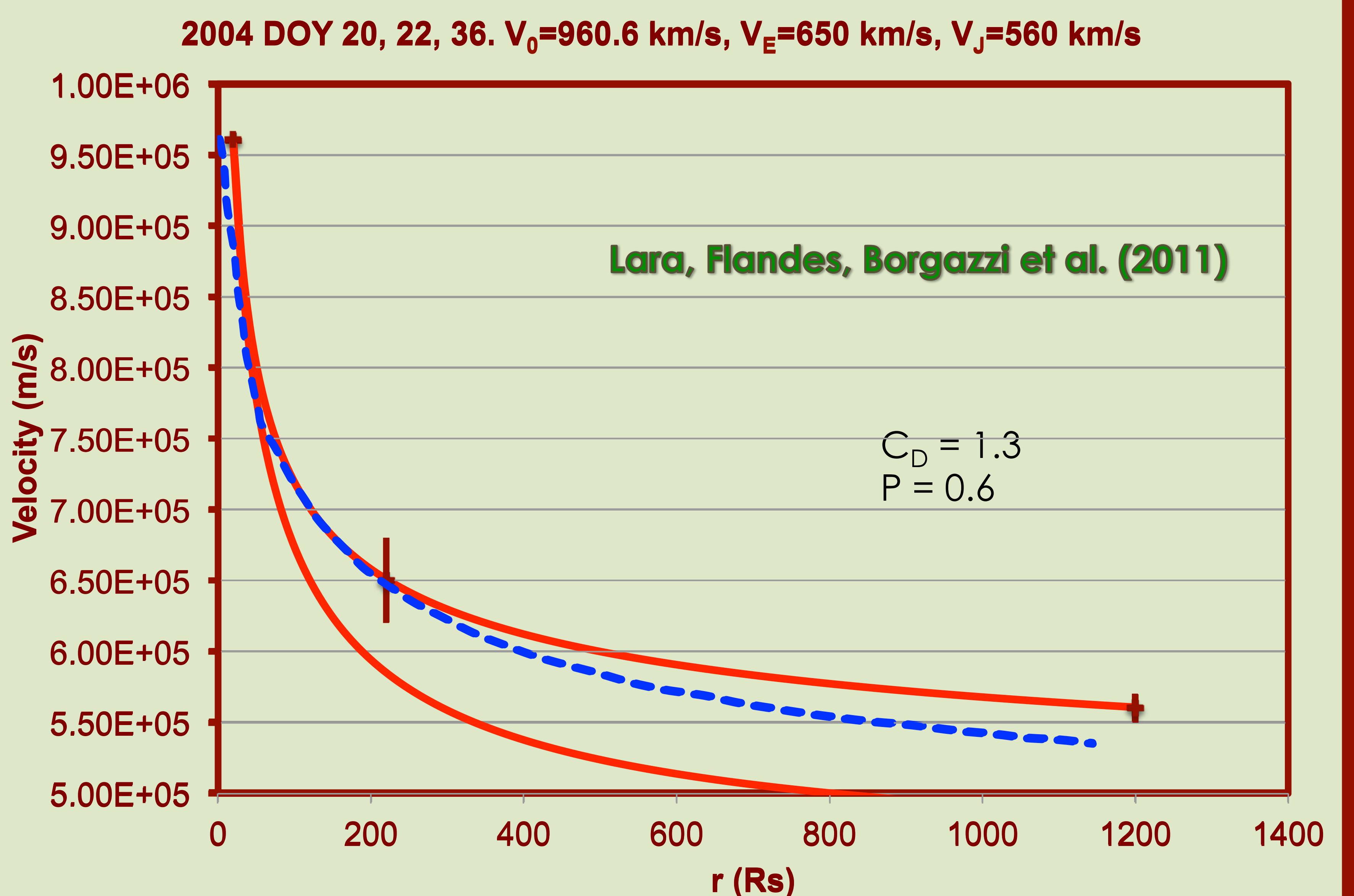

Vi = 960.6 km/s; Vf = 650 km/s; Vsw = 540 km/s
2004, DOY 20
-1.E+22
-1.E+23
-1.E+24
-1.E+25
Work (J)
0
200
400
600
800
1000
1200
1400
r (Rs)
Drag work
Expansion work
Gravitational work
Sum

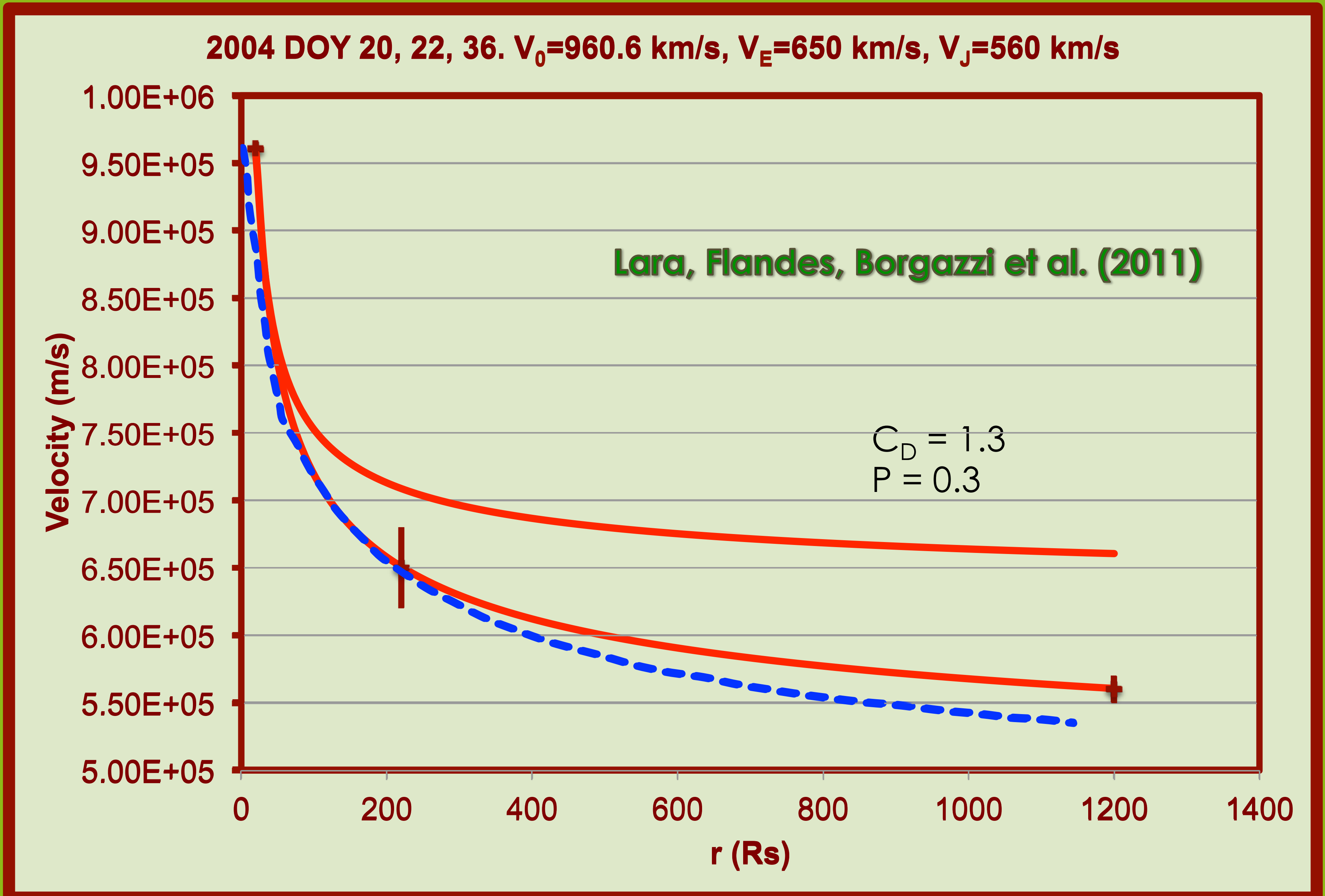

Vi = 450 km/s; Vsw = 400 km/s
-1.E+22
-1.E+23
-1.E+24
Work (J)
Drag work
Expansion work
Gravitational work
Sum
0
200
400
600
800
1000
1200
1400
r (Rs)



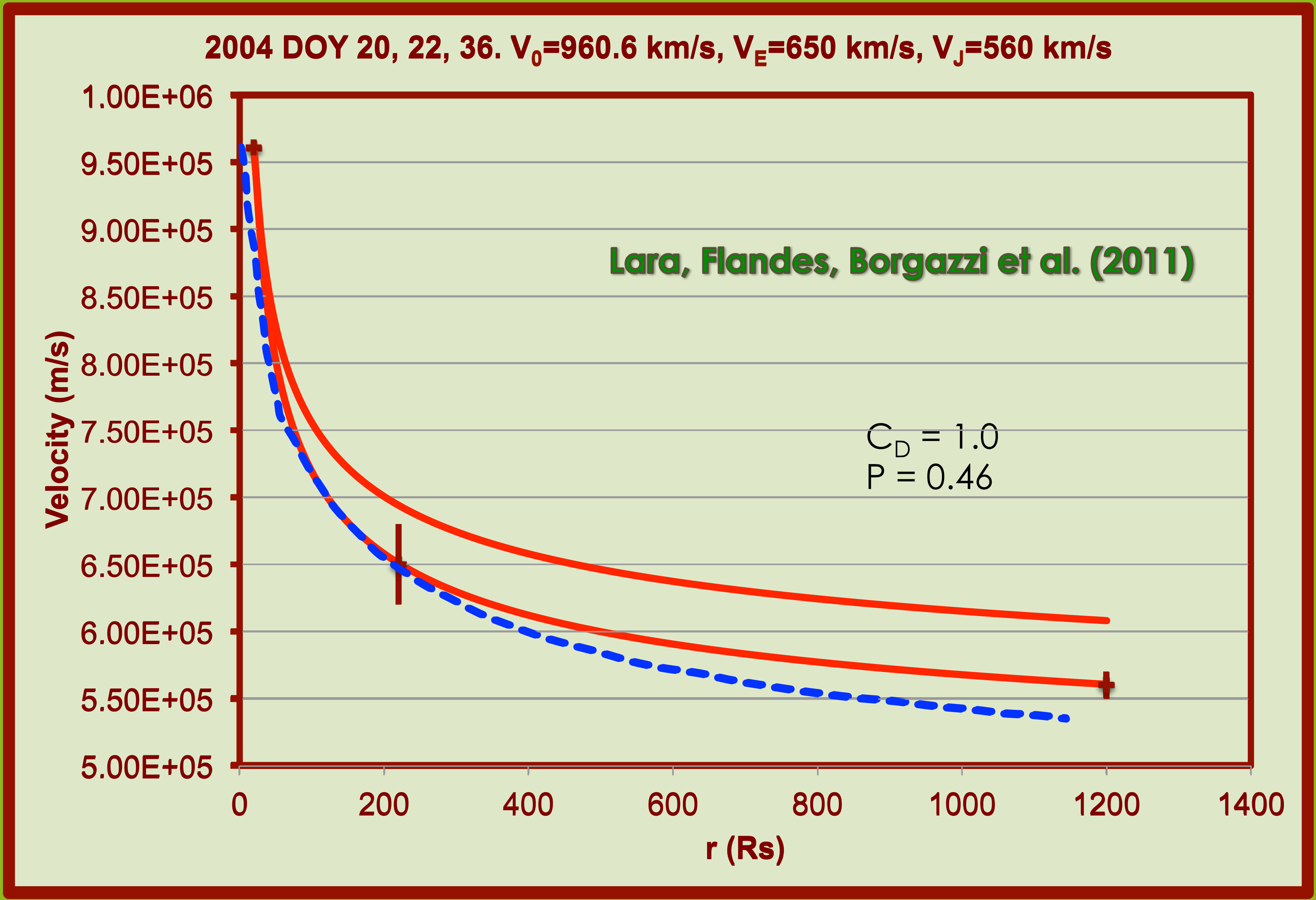
2004 DOY 20, 22, 36. V0=960.6 km/s, VE=650 km/s, VJ=560 km/s
Lara, Flandes, Borgazzi et al. (2011)
CD = 1.3
P = 0.46
Velocity (m/s)
1.00E+06
9.50E+05
9.00E+05
8.50E+05
8.00E+05
7.50E+05
7.00E+05
6.50E+05
6.00E+05
5.50E+05
5.00E+05
0
200
400
600
800
1000
1200
1400
r (Rs)



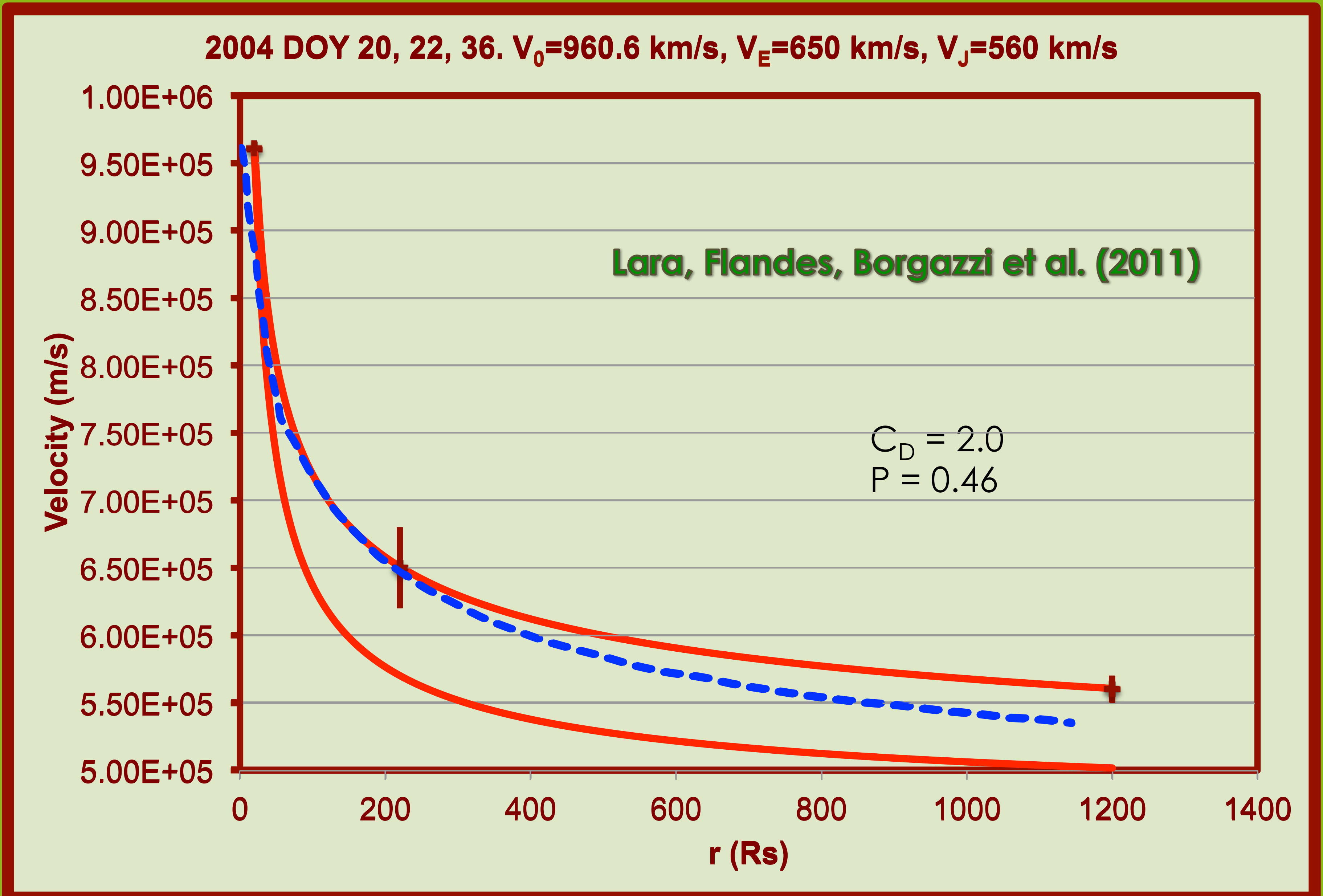
2004 DOY 20, 22, 36. V0=960.6 km/s, VE=650 km/s, VJ=560 km/s
1.00E+06
9.50E+05
9.00E+05
8.50E+05
8.00E+05
7.50E+05
7.00E+05
6.50E+05
6.00E+05
5.50E+05
5.00E+05
Velocity (m/s)
0
200
400
600
800
1000
1200
1400
r (Rs)
Lara, Flandes, Borgazzi et al. (2011)
CD = 1.3
P = 0.6



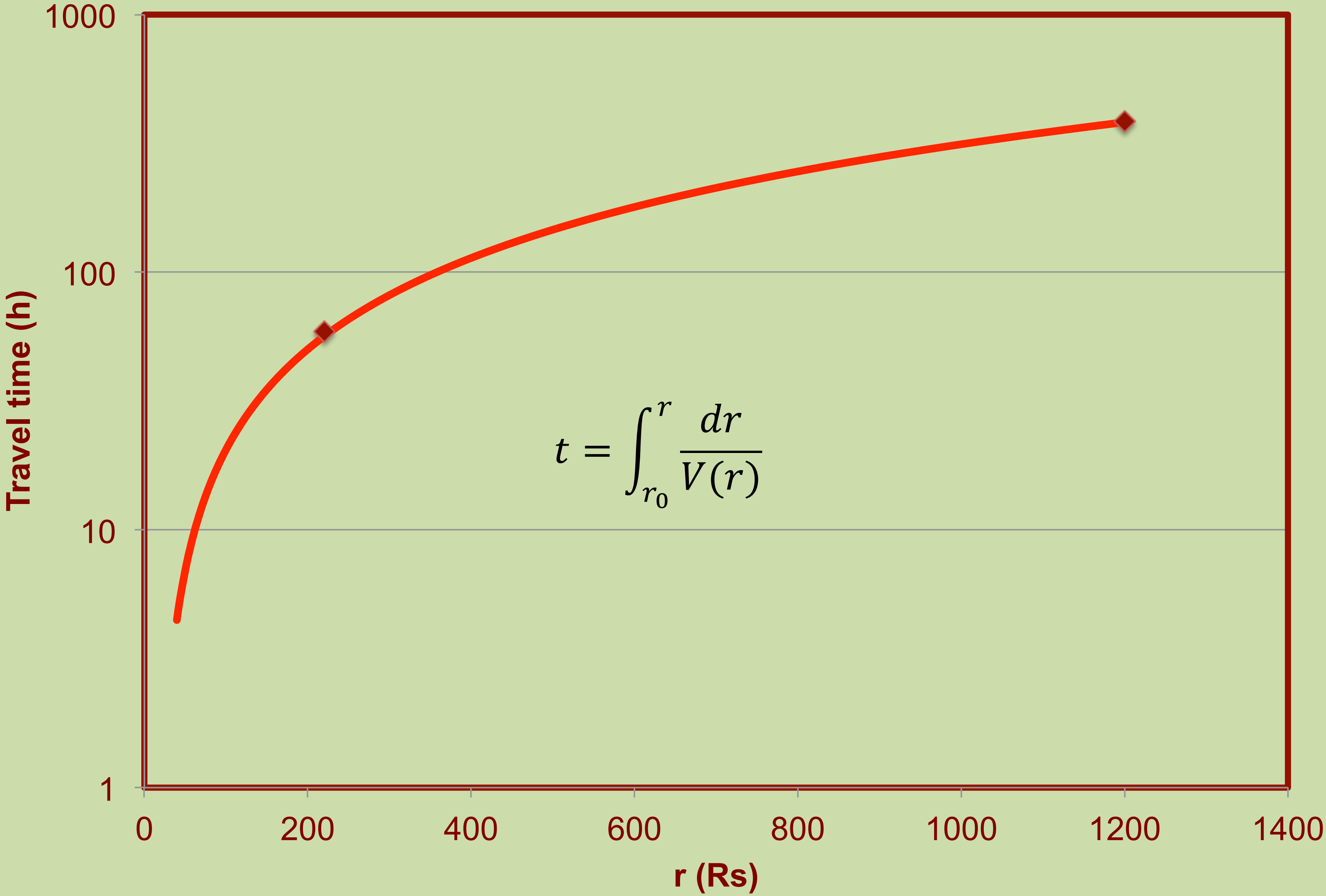
2004 DOY 20, 22, 36. V0=960.6 km/s, VE=650 km/s, VJ=560 km/s
1.00E+06
9.50E+05
9.00E+05
8.50E+05
8.00E+05
7.50E+05
7.00E+05
6.50E+05
6.00E+05
5.50E+05
5.00E+05
Velocity (m/s)
Lara, Flandes, Borgazzi et al. (2011)
CD = 1.3
P = 0.3
0
200
400
600
800
1000
1200
1400
r (Rs)



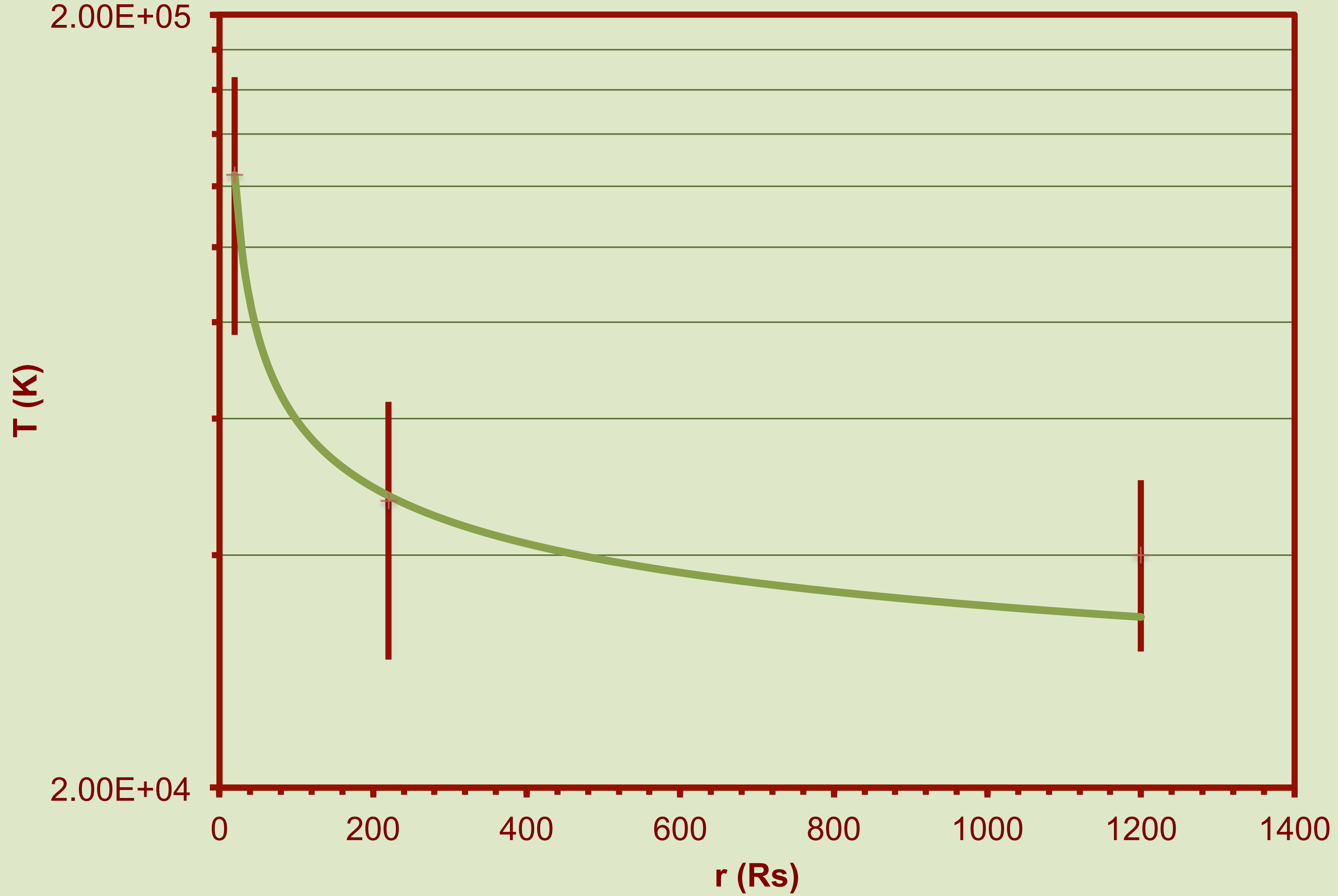
2004 DOY 20, 22, 36. V0=960.6 km/s, VE=650 km/s, VJ=560 km/s
Lara, Flandes, Borgazzi et al. (2011)
CD = 1.0
P = 0.46
Velocity (m/s)
1.00E+06
9.50E+05
9.00E+05
8.50E+05
8.00E+05
7.50E+05
7.00E+05
6.50E+05
6.00E+05
5.50E+05
5.00E+05
0
200
400
600
800
1000
1200
1400
r (Rs)



2004 DOY 20, 22, 36. V0=960.6 km/s, VE=650 km/s, VJ=560 km/s
Lara, Flandes, Borgazzi et al. (2011)
CD = 2.0
P = 0.46
Velocity (m/s)
1.00E+06
9.50E+05
9.00E+05
8.50E+05
8.00E+05
7.50E+05
7.00E+05
6.50E+05
6.00E+05
5.50E+05
5.00E+05
0
200
400
600
800
1000
1200
1400
r (Rs)



1000
100
10
1
Travel time (h)
$t = \int_{r_0}^{r} \frac{dr}{V(r)}$
0
200
400
600
800
1000
1200
1400
r (Rs)



2.00E+05
2.00E+04
T (K)
0
200
400
600
800
1000
1200
1400
r (Rs)

Conclusions:

These are preliminary results but the model is promising

Future work

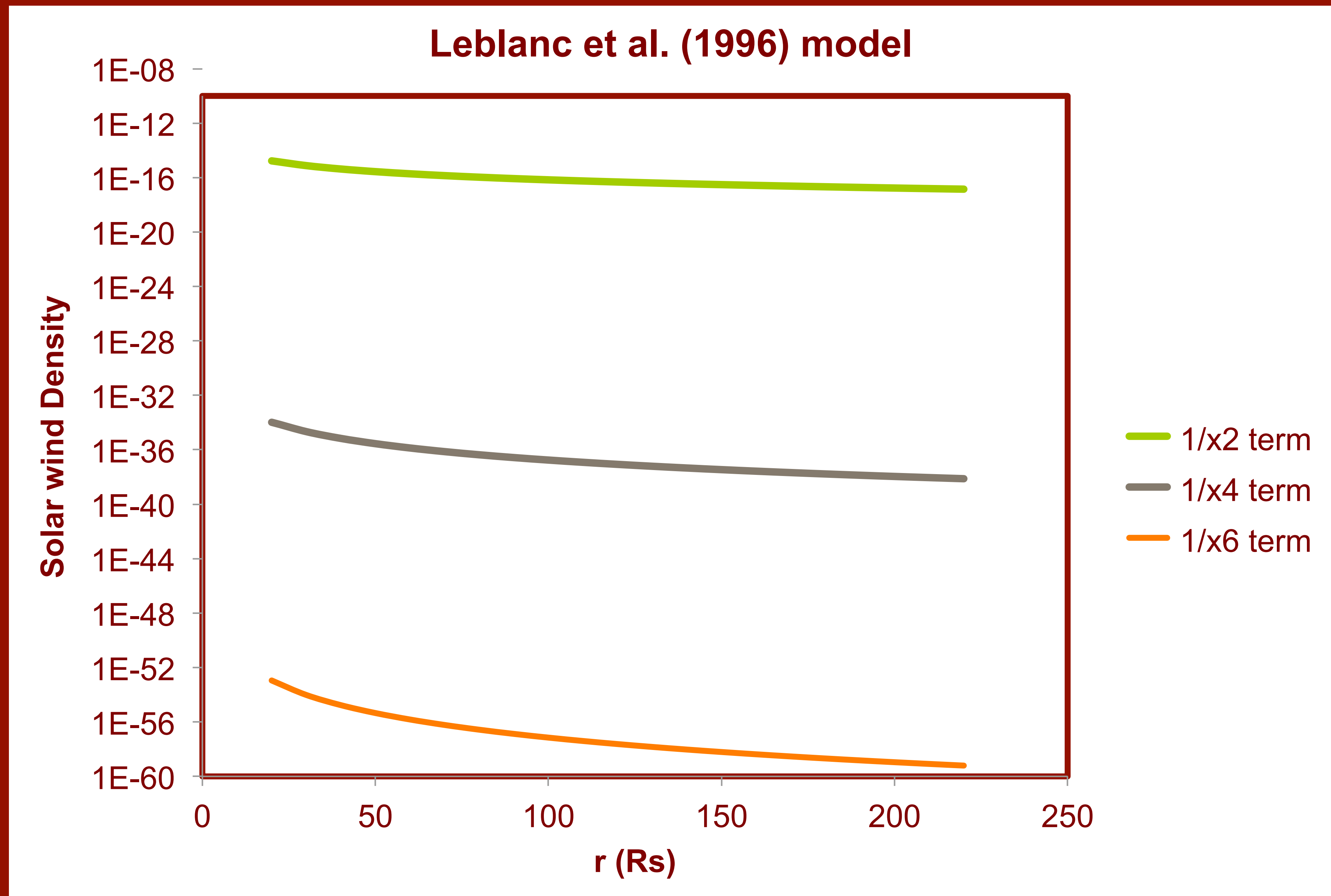
a) Compare with more data

b) Compare with data of Ulysses

c) Compare with other models

d) Add magnetic energy

Thanks for your attention



Leblanc et al. (1996) model
Solar wind Density
1E-08
1E-12
1E-16
1E-20
1E-24
1E-28
1E-32
1E-36
1E-40
1E-44
1E-48
1E-52
1E-56
1E-60
0
50
100
150
200
250
r (Rs)
1/x2 term
1/x4 term
1/x6 term

$$F_D = \frac{1}{2}\rho V_R^2 A\ C_D$$

$$C_D = \frac{F_D}{\frac{1}{2}\rho V_R^2 A}$$