Contents

1 Introduction

In this letter we examined the energy distribution for model A (run 143), and compared our result with Ohlmann's [2]

2 parameter comparison

In the following table, we listed the initial parameters used by our simulation and Ohlmann's simulation

Quantity	Our Simulation (Run 143, model A)	Ohlmann's Simulation [2]
Mass primary core(M_1)	0.369 $M_\odot$	0.38 $M_\odot$
Mass Envelope gas (M_g)	1.597 $M_\odot$	1.60 $M_\odot$
Mass Red Giant Total (M_{rg})	1.956 $M_\odot$	1.98 $M_\odot$
Mass Secondary core (M_2)	0.978 $M_\odot$	0.99 $M_\odot$
Co-rotation (percentage)	0	95%
Radius of envelope (RG) (R_g)	$48.1R_\odot$	Unspecified ($\approx 49\ R_\odot$[1])
Initial separation between cores (a_0)	49 $R_\odot$	49 $R_\odot$
Box side length (R)	1150 $R_\odot$	$3.3 * 10^{14}$ cm ($\approx 4744.78\ R_\odot$)
Softening radius (r_s)	2.4 $R_\odot \rightarrow$ 1.2 $R_\odot$	$7.3 * 10^{10}$ cm ($\approx 1.0\ R_\odot$)
Ambient density (ρ_a)	$6.67 * 10^{-9}$ g cm^{-3}	10^{-16} g cm^{-3}
Ambient pressure (P_a)	$1.01 * 10^5$ dyn cm^{-2}	Unspecified

As can be seen from the table, the initial values of our simulation is pretty close to those used by Ohlmann.

3 Theory

In this section we present the theory of different kinds of energies. For this project, we consider the system as a classical system.

3.1 Kinetic energy

The kinetic energy of two particles with mass m_1, m_2 in a two-body problem is given by

$$T_p = \frac{1}{2} m_1 \overrightarrow{v_1}^2 + \frac{1}{2} m_2 \overrightarrow{v_2}^2 = \frac{1}{2} \mu \overrightarrow{v}^2 \tag{1}$$

where

$$\mu = \frac{m_1 m_2}{m_1 + m_2} \quad \text{and} \quad \overrightarrow{v} = \overrightarrow{v_1} - \overrightarrow{v_2} \tag{2}$$

The Kinetic energy of gas is dependent on the location of the gas. Therefore we need to find the kinetic energy of gas at each location and integrate over its volume. Therefore

$$T_g = \frac{1}{2} \int_V \rho(\overrightarrow{r}) v(\overrightarrow{r})^2 dV \tag{3}$$

3.2 Internal energy

The thermal energy of a fluid is

$$E_{\text{int}} = \frac{1}{\gamma - 1} \int_V P(\overrightarrow{r}) dV \tag{4}$$

where γ is the adiabatic index

3.3 potential energy

The potential energy between two particles in Newtonian mechanics is

$$U_p = -G\frac{m_1 m_2}{|\overrightarrow{x_1} - \overrightarrow{x_2}|} = -G\frac{m_1 m_2}{|\overrightarrow{r_{12}}|} \tag{5}$$

To find the potential energy of the gas itself, We can find the potential due to gas as a function of location $\Phi(\overrightarrow{r})$ and multiply that by the density of the gas at that location. The potential energy is given by

$$U_g = \frac{1}{2}\int_V \Phi(\overrightarrow{r})\rho(\overrightarrow{r})dV \tag{6}$$

The potential energy between gas and particle can be obtained by taking the gravatational potential due to the particle $\Phi_p(r_g)$, mutiply by gas density and sum over all space

$$U_{p,g} = \int_V \Phi_p(\overrightarrow{r_g})\rho(\overrightarrow{r_g})dV \tag{7}$$

where r_1 is the location of m_1

4 Method

Energy of a system can be divided into three categories: kinetic energy, potential Energy and internal energy. We will present them one-by-one

4.1 Kinetic energy

The kinetic energy is composed of by the kinetic energy of the cores and the kinetic energy of the gas. In our simulation, the gas was treated as a fluid, so we will use equation for fluid dynamics to calculate the energy of the system.
The kinetic energy of the cores is given by the Newtonian kinetic energy

$$T_c = \frac{1}{2}m_c v_c^2 \tag{8}$$

And the gas kinetic energy density is given by

$$\mathscr{E}_{g-kin} = \frac{1}{2}\rho_g v_g^2 \tag{9}$$

And we sum it over the box to get the total kinetic energy f the gas.
Total kinetic energy is given by

$$T_{tot} = T_{c(1)} + T_{c(2)} + \int \mathscr{E}_g dV \tag{10}$$

4.2 Internal energy

Due to the lack of a sub-grid model, the internal energies of the cores are both zeros. Therefore the only component of internal energy is the internal energy of the gas (envelope)
By setup, the simulation output the sum of kinetic energy and internal energy. Therefore a quick way to calculate the internal energy is to use the output energy E_{output} subtract the kinetic energy

$$I_{tot} = I_{gas} = E_{output} - T_{gas} \tag{11}$$

4.3 Potential energy

The potential energy is the most tricky one. The potential energy is divided into three sub-catagories: core-core potential energy, gas-self potential energy and core-gas potential energy. Softening radius also effect the way we calculate the potential energy, which we will be discuss in more detail later
Because the cores never enter the softening radius of each other, the potential energy between the cores is given by the Newtonian potential energy

$$U_c = -G\frac{M_1 M_2}{r_{12}} \tag{12}$$

To compute the gas-self potential energy, we can use directly the output of the simulation. In the output, we have the potential due to gas as a function of a radius $\Phi_g(r)$. To obtain the potential energy, we only need to find the potential energy density and integrate over the entire box. The energy density and potential energy of gas-self gravity is given by

$$\mathscr{E}_{g-pot}dV = \frac{1}{2}\rho\Phi_g(r)dV \qquad \text{and} \qquad U_g = \int \mathscr{E}_{g-pot}dV \tag{13}$$

The final term to consider for potential energy is the gas-partial potential energy. Because of the existance of softening radius, the potential energy doesn't go as $-G\frac{Mm}{r^2}$ inside the softening radius. Therefore we need to divide into two regions: outside the softening radius and inside the softening radius.
Outside the softening radius, the gravitational potential due to the cores is given by

$$\Phi_{c,out}(r) = -G\frac{M}{r} \tag{14}$$

Inside the softening radius, we have two regions of refinement: region 1: between $0.5r_{\text{soft}}$ and r_{soft}; region 2: inside $0.5r_{\text{soft}}$ [6]
Now define a normalization factor for the distance from the core $\overrightarrow{\mathbf{r}}$

$$u = \frac{|\overrightarrow{\mathbf{r}}|}{|\overrightarrow{\mathbf{r_{soft}}}|} \tag{15}$$

In region 1, define spline 1, the modify term for gravitational potential in region 1 as

$$S_1 = -\frac{16}{3}u^3 + \frac{48}{5}u^5 - \frac{32}{5}u^6 + \frac{14}{5}u \tag{16}$$

In region, define spline 2, the modify term for gravitational potential in region 2 as

$$S_2 = -\frac{1}{15} - \frac{32}{3}u^3 + 16u^4 - \frac{48}{5}u^5 + \frac{32}{15}u^6 + \frac{48}{15}u \tag{17}$$

And by region, we define our gravitational potential by the cores as

$$\Phi_c = \begin{cases} \Phi_{c,out} & r_{\text{soft}} \leq r \\ \Phi_{c,out} \times S_1 & 0.5\ r_{\text{soft}} \leq r < r_{\text{soft}} \\ \Phi_{c,out} \times S_2 & r \leq 0.5\text{r}_{\text{soft}} \end{cases} \tag{18}$$

Using same logic as previous calculation, the potential energy between the gas and cores is given by

$$U_{gc} = \int \rho_g \Phi_c dV \tag{19}$$

And total potential energy is the sum of all three terms

$$U_{tot} = U_c + U_g + U_{gc} \tag{20}$$

4.4 Total energy

With kinetic energy, internal energy and potential energy being calculated, we can now determine the total energy of the system

$$E_{tot} = T_{tot} + U_{tot} + I_{tot} \tag{21}$$

Note that when E_{tot} is greater than zero, the *system* will become unbound. Because the cores clearly bounds to each other, unless the energy of the gas overwhelms the energy of the core, we expect that the total energy to be negative.

5 Reduced Resolution data

5.1 Time dependence of energy

We present here result from our simulation and result provided by Ohlmann's paper

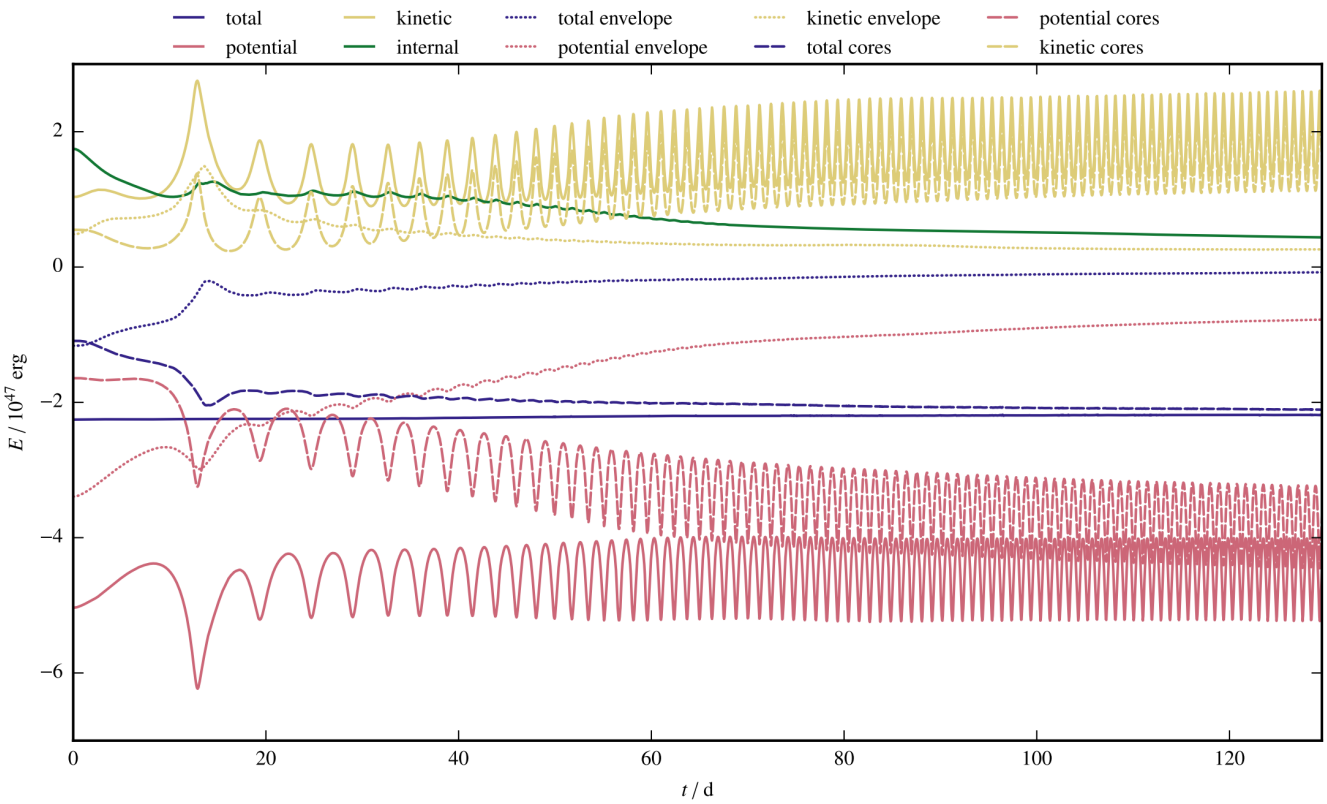

Figure 1: Energy diagram provided by Ohlmann's paper, note that in his simulation the simulation time goes to 120 days, whereas in the next figure, our simulation only goes to 40 days.[2]

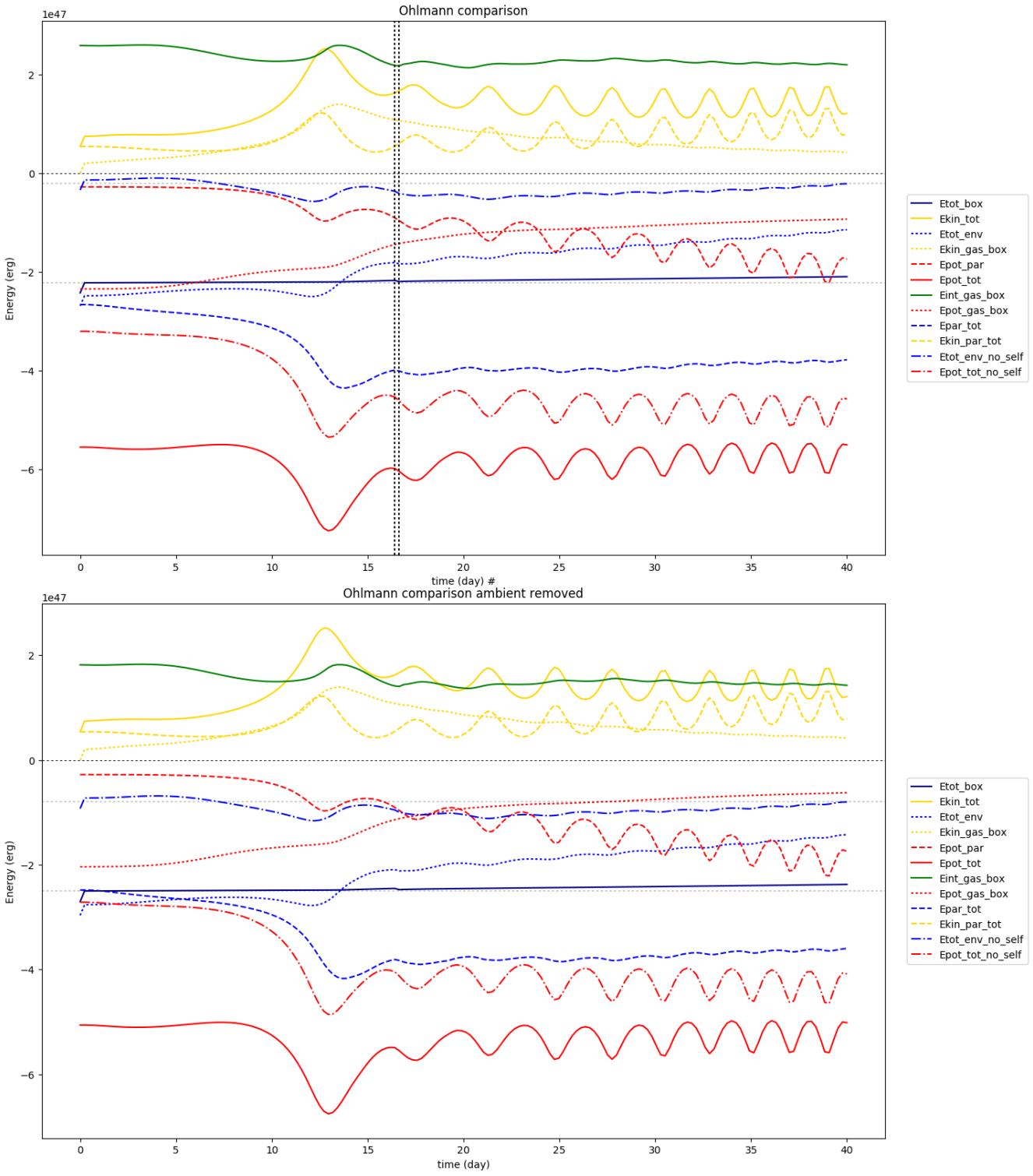

Figure 2: Energy diagram from our simulation. The figures are energy plots from our simulation, the upper panel is the original data, the lower panel is the data with ambient energy removed. Note that due to computational reasons, we use the first frame as approximation to all frames, and assumes that the effect is a constant. "no_self" denotes that self-gravity is excluded from calculation. Equations to calculate some terms are shown in appendix A, Because this two are messy, a plot with less lines is shown in appendix B. That includes what we now believe to be "most correct"

It's been noted that the ambient medium has an non-negligible mass and pressure. The total mass of the ambient medium is $M_{amb} = 6.67 * 10^{-9} * (8 * 10^{13})^3 = 3.41 * 10^{33}\text{g} = 1.717 M_\odot$, more then half of the mass of the RG and secondary combined!
The total energy changes by $3.28 * 10^{46}$erg (-12.1%). If we take into account the fact that the solfening radius is reduced by a half during the simulation, the total energy change will be $3.44 * 10^{46}$erg. (-12.7%)
To estimate the effect of ambient medium on the evolution, one of the method is to estimate the initial total energy of the ambient and subtract that from the energy of the gas. Because in the first frame, the ambient medium is not moving ($v = 0$ and $T_{amb} = 0$), we only need to consider potential energy and internal energy. In the first frame, the density and pressure of the ambient material are both constants through out, therefore the internal energy of the material is given by

$$E_{\text{int, amb}} = \frac{3}{2}PV = \frac{3}{2} * 10^5 * (8 * 10^{13})^3 = 7.68 * 10^{46}\text{erg} \tag{22}$$

The potential energy of the self-gravity of the material is

$$U_{amb} = \int_L^H \int_L^H \int_L^H \int_L^H \int_L^H \int_L^H -G \frac{\rho^2}{\sqrt{(x-x_0)^2 + (y-y_0)^2 + (z-z_0)^2}} dx dy dz dx_0 dy_0 dz_0 \tag{23}$$

where $L = -4 * 10^{13}$ and $H = 4 * 10^{13}$, the boundaries of the box.
This equation is too computational intensive to solve, therefore I believe we can consider the following.
The self-gravity potential will be less than a sphere that exactly fit in the box, and will be greater than a sphere that can exactly contain the box. Then, the limits are simply

$$U_{lim} = -\frac{3}{5}\frac{GM^2}{R} \quad \longrightarrow \quad U_{\text{upper}} = -1.17 * 10^{46}\text{erg} \quad \text{and} \quad U_{\text{lower}} = -6.74 * 10^{45}\text{erg} \tag{24}$$

This value appears to be less significant than the internal energy.
And the potential energy between the ambient material and the cores are

$$U_{\text{amb, core}} = \int_L^H \int_L^H \int_L^H -G \frac{\rho m_c}{\sqrt{(x-x_c)^2 + (y-y_c)^2 + (z-z_c)^2}} dx dy dz \tag{25}$$

And the values are ##### $U_{amb,core2}$ is crashing when I try to calculate it... So I calculate the value if the second core is at the center#####

$$U_{\text{amb, core1}} = -4.97375 * 10^{45}\text{erg} \quad \text{and} \quad U_{\text{amb, core2}} = -1.31825 * 10^{46}\text{erg} \tag{26}$$

Another term that we need to consider is the gravitational interaction between the ambient material and the actual gas in the box. To calculate this potential, we need to integrate over our actual gas (which is no longer a perfect sphere after the first frame) and integrate over the whole box. This calculation is again too computational intensive, but because the gas is concentrated in the center of the box, we can approximate it to a point particle at the location of its center of mass. With this approximation, the gravitational potential that we found is

$$U_{amb,gas} \approx \int_L^H \int_L^H \int_L^H -G \frac{\rho m_{gas}}{\sqrt{(x-x_g)^2 + (y-y_g)^2 + (z-z_g)^2}} dx dy dz = -2.1526 * 10^{46}\text{erg} \tag{27}$$

Note that this approximation breaks down after the first few frames, but we use this value to generate the plot.
To estimate the effect of ambient material to the envelope evolution, we have to take into account that the gas "wasted" some energy to push the ambient outward. There are two terms to consider: work acting against ambient pressure and work acting against ambient gravity.
First consider work acting against pressure. Approximate the initial position of the gas are all around the center region, assuming that the pressure doesn't change during the simulation (As we checked, the pressure changes by less than $2\times$) and assuming that the ambient medium has been pushed to a sphere with radius half the box width (This is an overestimate of the distance), we have energy used equal to

$$E_{\text{push-bound}} = P_0 * \int_0^{4*10^{13}} 4\pi r^2 dr = 1.34 * 10^{46}\text{erg} \tag{28}$$

In the simulation, the gas tends to be pushed to a sphere radius $3*10^{13}$ cm from the center. In this case, the energy dissipated is

$$E_{\text{push-3e13}} = P_0 * \int_0^{3*10^{13}} 4\pi r^2 dr = 0.565 * 10^{46}\text{erg} \tag{29}$$

Now consider work against gravity. Assuming that the rest of the mass (the stars) are located at the center with a constant mass, the gravitational potential to move a layer thick dr of ambient at the radius r is given by

$$\mathscr{E}_{\text{push-grav}} dr = G\frac{\rho 4\pi r^2 dr}{r} - G\frac{\rho 4\pi r^2 dr}{r_{\text{final}}} = 4\pi G\rho\Big(r - \frac{r^2}{r_{\text{final}}}\Big)dr \tag{30}$$

Then, to move everything inside radius $3 * 10^{13}$ cm to that radius, we need energy equal to

$$E_{\text{push-grav}} = 8.38596 * 10^{11}\text{erg} \tag{31}$$

This is an estimate of the energy used. In practice the ambient is accelerated to a non-zero velocity, meaning the gas has some kinetic energy. But unless the velocity is large (which is not likely), the energy will keep on this order of magnitude and be negligible comparing to those in orders of magnitude 10^{46}.
From the calculation, we can estimate that the total potential energy by the ambient gas is around $-0.4 * 10^{47}$ erg, and that the total energy of the ambient is dominated by the internal energy. The range of total energy of ambient gas is between $2.4 * 10^{46}$erg and $3.2 * 10^{46}$erg.
The final envelope total energy (excluding self-gravity) is $-8 * 10^{46}$ erg. If we add the work "wasted" by the gas, the final envelope total energy will become $-6.66 * 10^{46}$ erg.

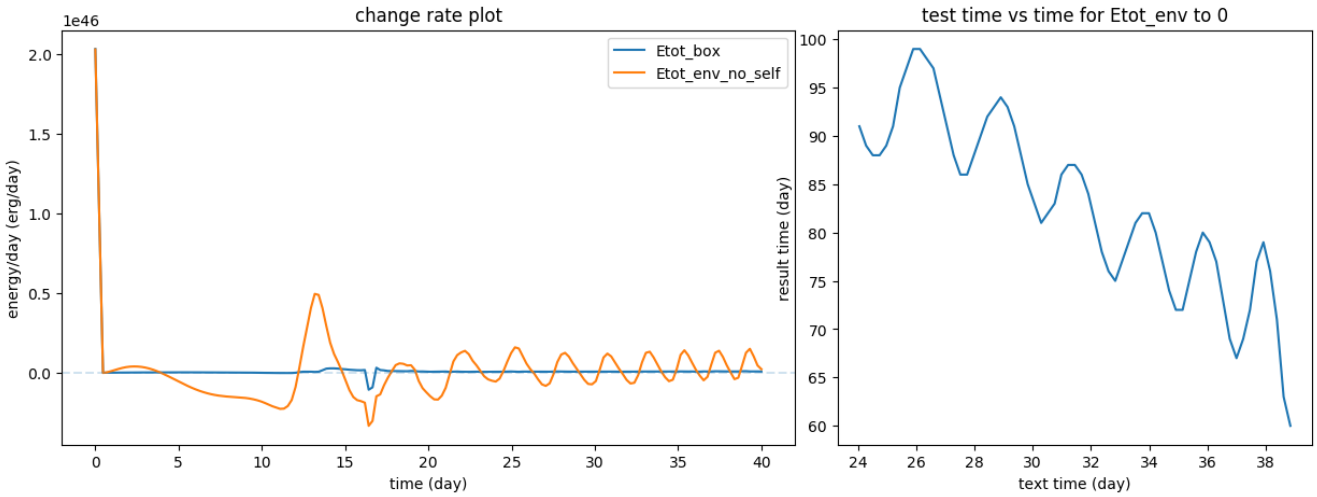

Figure 3: Left is the gradient of total energy and Etot_env_no_self. Right is the estimated time for Etot_env_no_self to go to zero vs the number of test data points that we take from the end of $\text{Etot}_e nv_n o_s elf$

It appears, from the preceding figures, that the acceleration is majorly above zero, meaning energy is mainly increasing. The figure to the right appears that the shorter we take, the faster it will be for the value to go to zero.

5.2 Spacial dependence of energy

5.2.1 Normalized energy figures

The following figures shows the normalized energy function. The function used to normalize the function is

$$N_{\mathbf{r}} = \frac{E_{\mathbf{r}}}{\max(|KE + E_{\text{int}}|, |PE_{\text{gas\_par}}|)} \tag{32}$$

where E_r is the total energy as a function of radius excluding the gas-self potential energy.

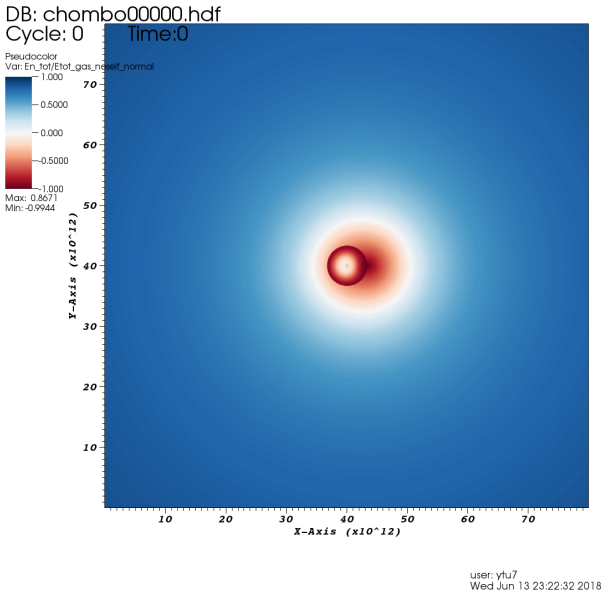

Figure 4: Initial energy distribution in x-y plane

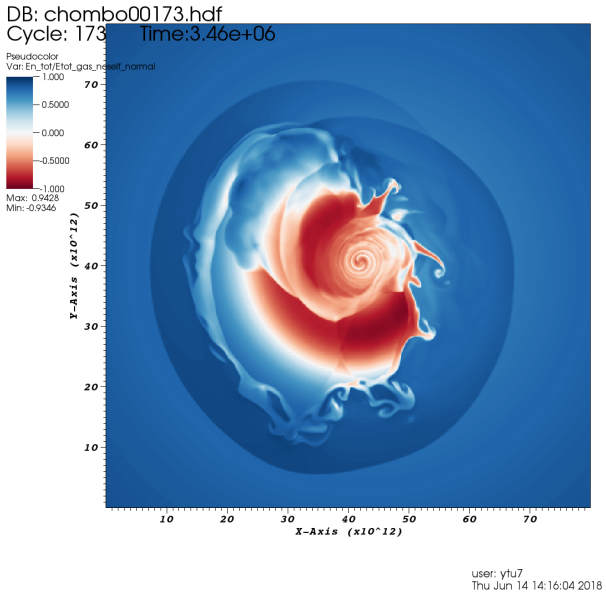

Figure 5: Final energy distribution in x-y plane

0.5

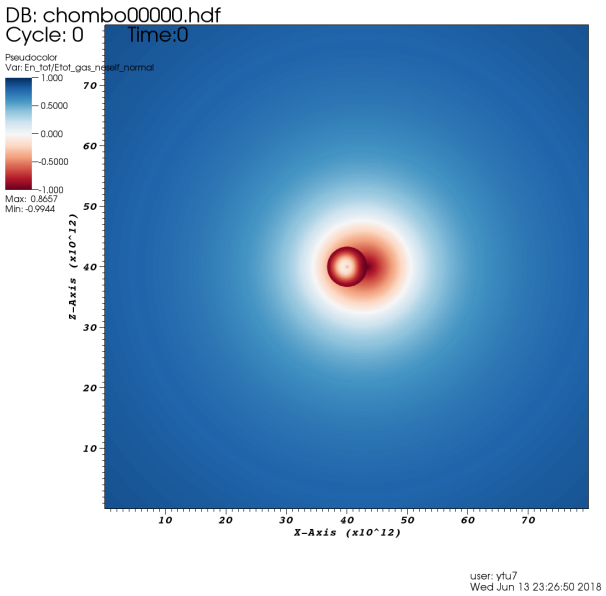

Figure 6: Initial energy distribution in x-z plane

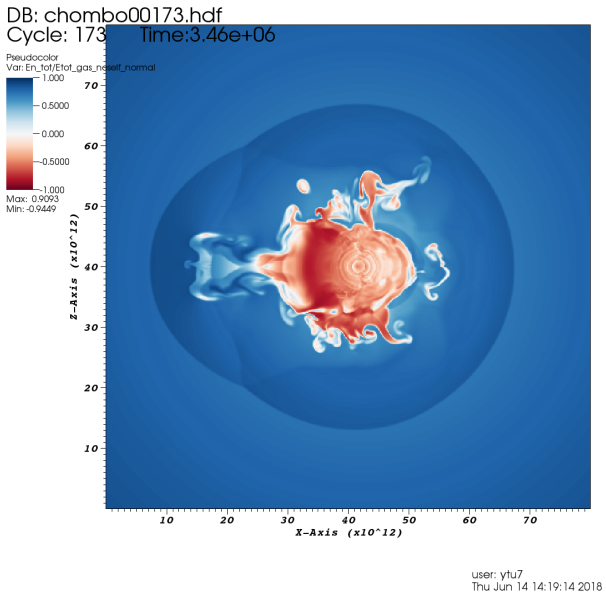

Figure 7: Final energy distribution in x-z plane

0.5

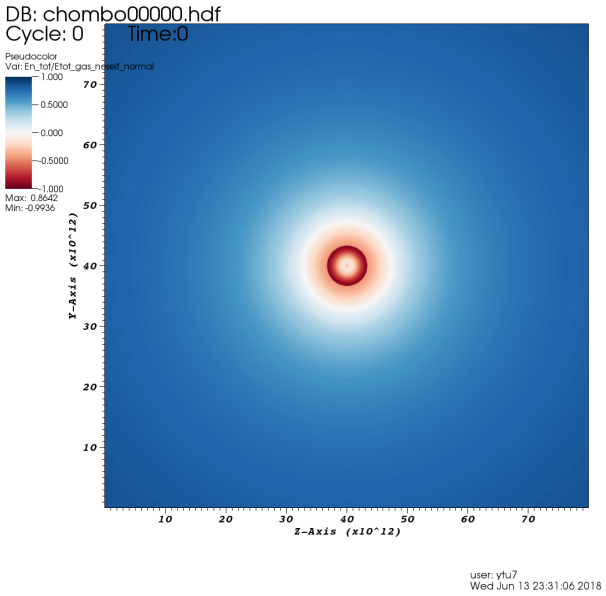

Figure 8: Initial energy distribution in y-z plane

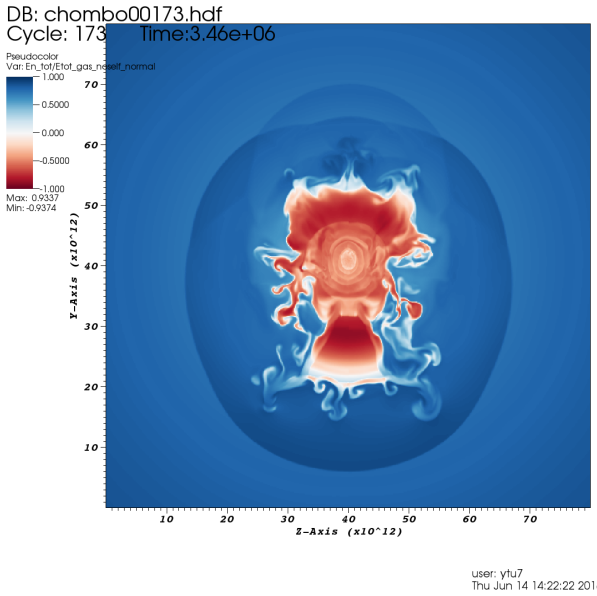

Figure 9: Initial energy distribution in x-y plane

0.5

The result gives us the sign of the gas and the difference between the positive energies and negative energies. The actual values of energy is distributed widely, so this is the way for us to understand the spacial distribution.
In figure 5, we see that the clear spiral structure. There are actually material with escape velocity keep ejected from the neighborhood of the cores, and they interact with the surrounding material losing some energy. Some earlier figures show that there can be an "onion" ring structure suggesting that unbound and bound gas form layer structure.
It is also worth noticing the initial ambient material is unbound.
I have plots for all frames in all three direction for normalized and original data. It would be informative to see some of the evolution. Though putting 174 frames in this Latex file is impossible..

5.3 Radial Energy distribution

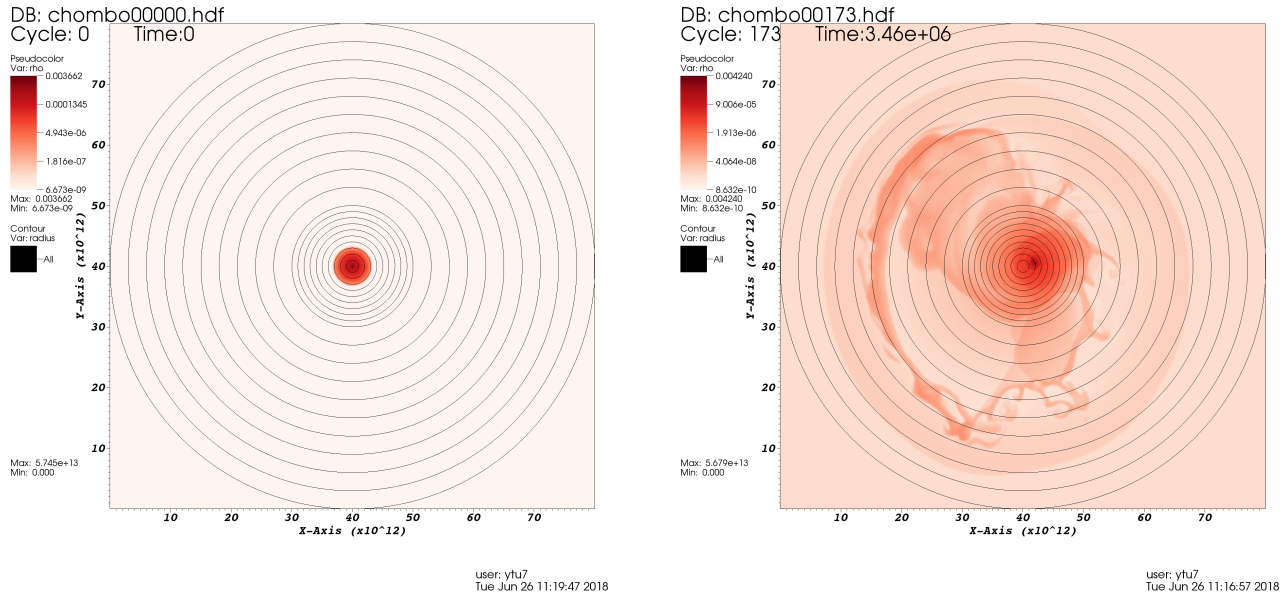

Figure 10: contours showing the radial shells that are presented next

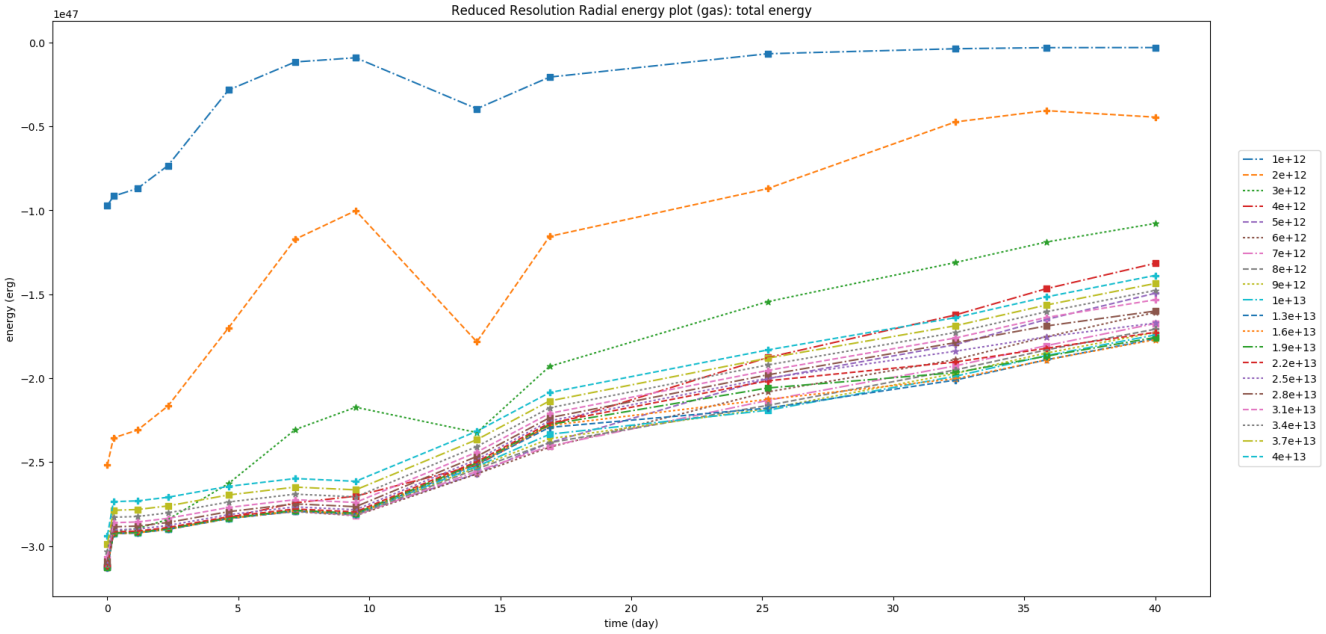

Figure 11: total energy distribution as a function of radius and time. The curves are cumulative: The outer radius includes all in the smaller radius.

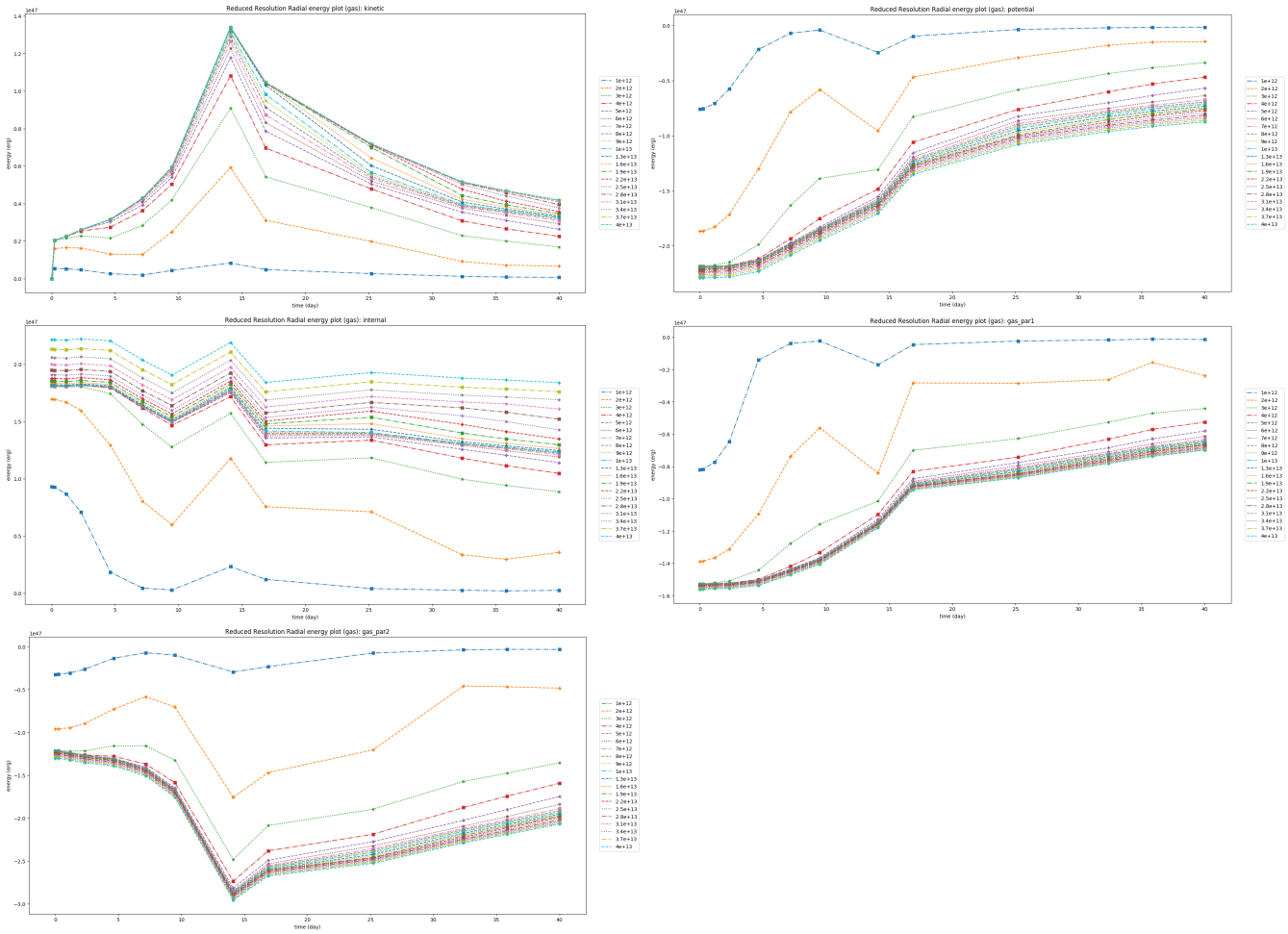

Figure 12: components for total energy as a function of radius and time. upper left: kinetic, upper right: potential; middle left: internal; middle right: gas and particle 1 potential; bottom left: gas and particle 2 potential.

These figures are radial distribution of energy for reduced resolution data set. Because the program is too computationally intensive, I only collected data from several frames where something interesting seems to be happening according to mass radial distribution plot (see later). The data points are marked on the figure. The blue line is the inner-most, and other lines move out respectively.

It appears that the energy is somewhat concentrated in the most central region. The potential energy and kinetic energy doesn't increase too much by moving outward a lot (10 lines). The ambient medium doesn't seem to have a lot of energy as the center do.
The most central region doesn't seems to have too much energy, however, the regions near the center $2e13$ to $3e13$ seems to be where energy concentrates. This also agrees with radial pseudocolor plot presented earlier.

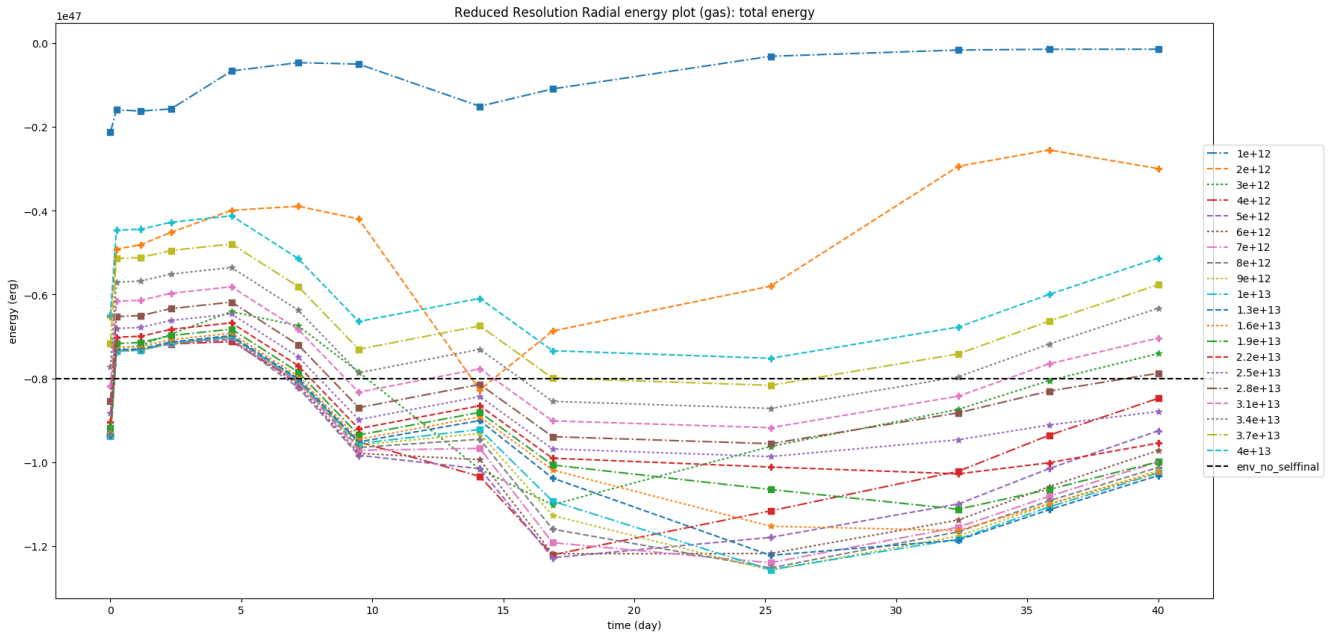

Figure 13: Same figure as previous one but with self-gravity removed. The horizontal black dahsed line is the final value of Etot_env_corrected_no_self in Ohlmann comparison figure. 2

5.4 Mass

5.4.1 Mass evolution

In this subsection we examine the mass evolution of the system

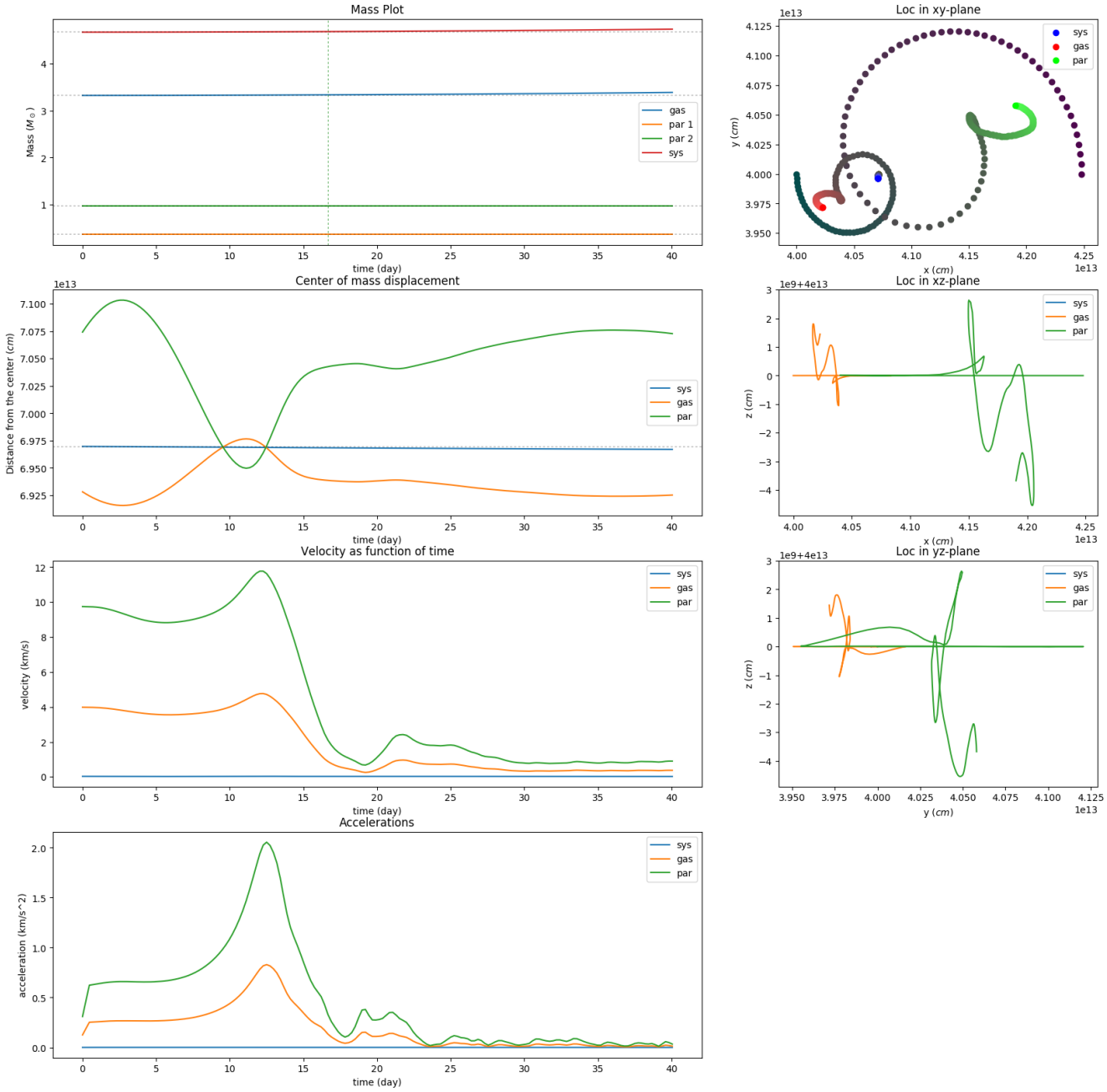

Figure 14: Mass evolution, the velocity and acceleration are scalars. They are the absolute value of the velocity/acceleration at that particular time

From the preceding figure, we can see that the total mass is relatively well-conserved. The initial mass is 4.66 $M_\odot$ and final mass is 4.73 $M_\odot$. The mass change fraction is $\frac{M_f - M_i}{M_i} = 1.38\%$. Counter-intuitively, the system is

actually gaining mass rather than losing mass, which explains why the system is gaining energy.
The total change in mass is equal to $0.06426 M_{\odot}$ over 40 days, which would require a mass change rate $0.0016 M_{\odot}$/ day on average, or $3.697 * 10^{25} g/s$

5.4.2 Unbound Mass

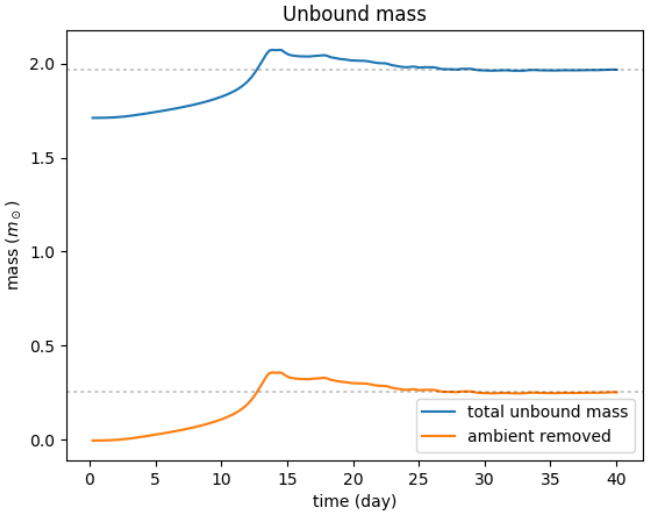

Figure 15: Amount of unbounded mass as a function of time

From the figure, it appears that the amount of mass unbound is increasing and then level off. The final total unbound mass is $1.96 M_{\odot}$ (59.37% of gas + medium) and the final unbound envelope (removing ambient) is $0.25 M_{\odot}$ (15% of gas only). The maximum unbounded envelope is $0.35 M_{\odot}$. The maximum seems to be reached when the secondary orbit around the primary exactly once (frame 57, 58 or 59, see appendix)
It appears that from this figure not much mass in the end gets unbound. Probably because most energy was taken away by some mass that was scattered at the beginning of the evolution. This would require further analysis on the distribution of mass and cross check with the energy plots.

5.4.3 Radial mass distribution

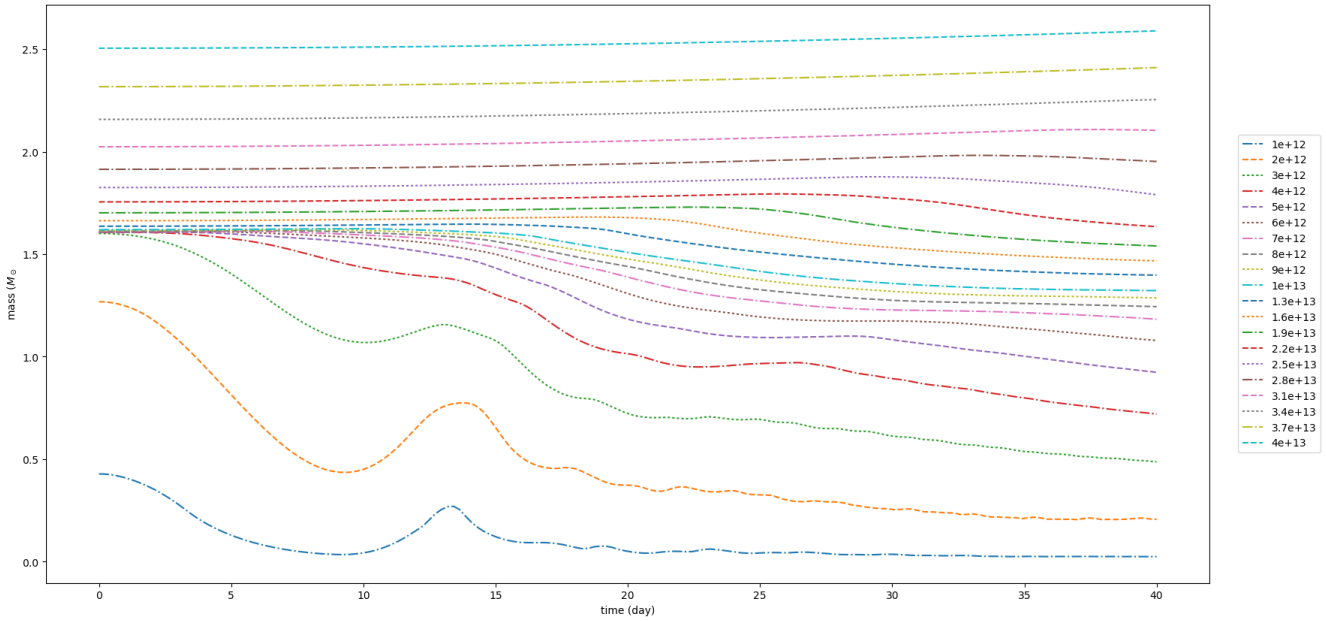

Figure 16: plot of mass inside a certain radius. The lines are cumulative so outer radius are further. The 10th line, the light blue line in the middle marks the transition between radius differ by 1e12 and by 3e12

In this figure, it appears that mass is transferring from the central region to the more outer regions. It looks like the mass was first concentrated inside radius $3 * 10^{12}$cm, which is expected because it's inside the RG. Later it transported to a region between $8 * 10^{12}$cm and $2.5 * 10^{13}$cm. However, it is interesting to notice that the top-most line is actually increasing. The top-most line denotes the ball exactly fit in the box. This increase meaning that there are material in-flowing into this boundary, part of which maybe due to inflow from boundary. It is likely that, if simulation were run longer, that the mass become concentrated around the middle region ($8 * 10^{12}$cm and $2.5 * 10^{13}$cm).

Luke said that there are inflow at the middle of the boundaries and outflow at the corners. It maybe worth to check these. It appears that this is true because the upper most curve here clearly changes more than the previous total mass curve.

5.5 Flux through boundary

5.5.1 Mass flux through boundary

To find the mass flux through the boundary, we use the following equation

$$\Phi_m = \int \rho_m v_m dA \tag{33}$$

where ρ_m is the density of mass at the boundary, v_m is the velocity of mass at the boundary and dA is the amount of area that a certain amount of mass pass through.
It should be noted that we are using simulation, meaning our dA is the area of a side of the grid. The method to perform this calculation is still developing, however it maybe logical to believe that the boundary grid is uniformally distributed. This subsection will require further investigation on the validity of the data, but I believe so far all logic sounds.
The process is used to find area of each mesh grid (dA)
Assuming that the grid are uniformally distributed so that each grid cell contribute to the total area for the same amount, then we can use the total area over the amount of cells on that level to get the area for each cell.

$$A_e = \frac{A_{\text{tot}}}{N} = \frac{(8 * 10^{13})^2}{262144} = 2.44 * 10^{22}\text{cm}^2 \tag{34}$$

And we multiply this to all values obtained from VISiT
I am not sure this process is actually necessary.

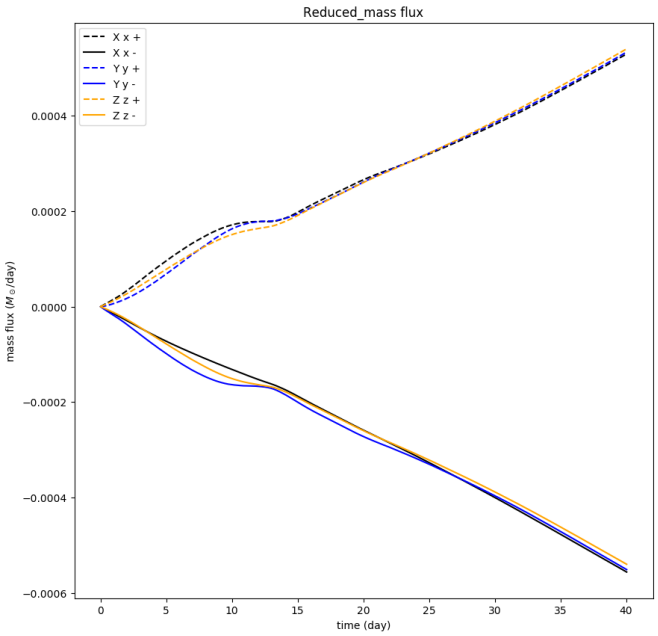

Figure 17: The mass flux through each edge in units g/s. Capital letters denote the plane, lower case letters and the + or - denote the 'positive' direction of velocity (into the box). i.e. if the flux is positive at +, it is coming into the box, or if the flux is negative at -, it is also coming into the box

Note that in this figure three of the cures are negative. That is because the material is traveling in the negative direction. However, because they are at the maximum end of axis, the material is actually coming into the box.
It appears from this figure that the amount of mass getting into the box is actually increasing. An approximation for calculating all mass coming into the box is by assuming that for all time between two frames, the rate is the same as the preceding frame. Then, the value would be $\Delta M_{\text{tot}} = 1.28 * 10^{32} g \approx 0.064 M_\odot$

5.5.2 Energy flux through boundary

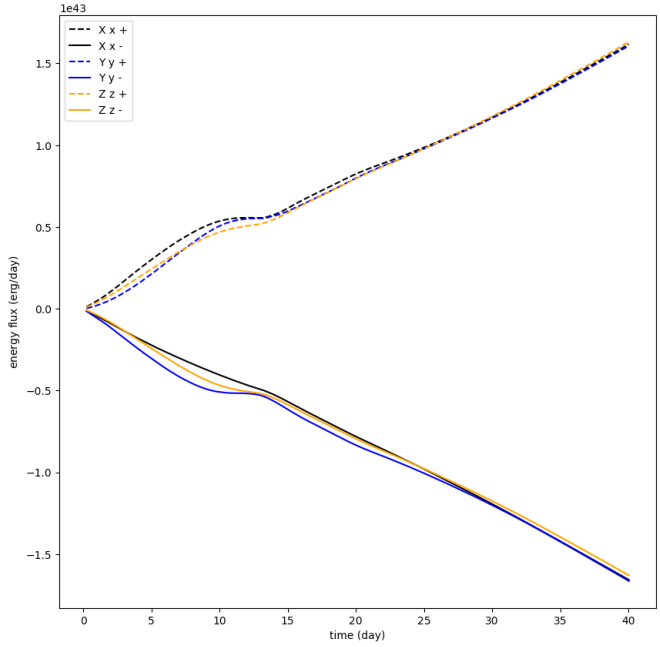

Figure 18: The energy flux through the boundaries. The notations are the same as the mass figure.

The energy plot looks nearly identical to the mass plot, meaning the mass getting into the box has similar energy throughout the simulation.
The cumulative energy inflow is $1.99 * 10^{45}$erg, which is less than the increase in total energy Is it possible for all these entering mass have velocities directed to the center such that it inpedes the ejection more?

6 Original data

6.1 Time dependence of energy (TO BE DONE)

6.2 Spacial dependence of energy (TO BE DONE)

6.2.1 Normalized energy figures (TO BE DONE)

6.3 Mass (TO BE DONE)

6.3.1 Mass evolution

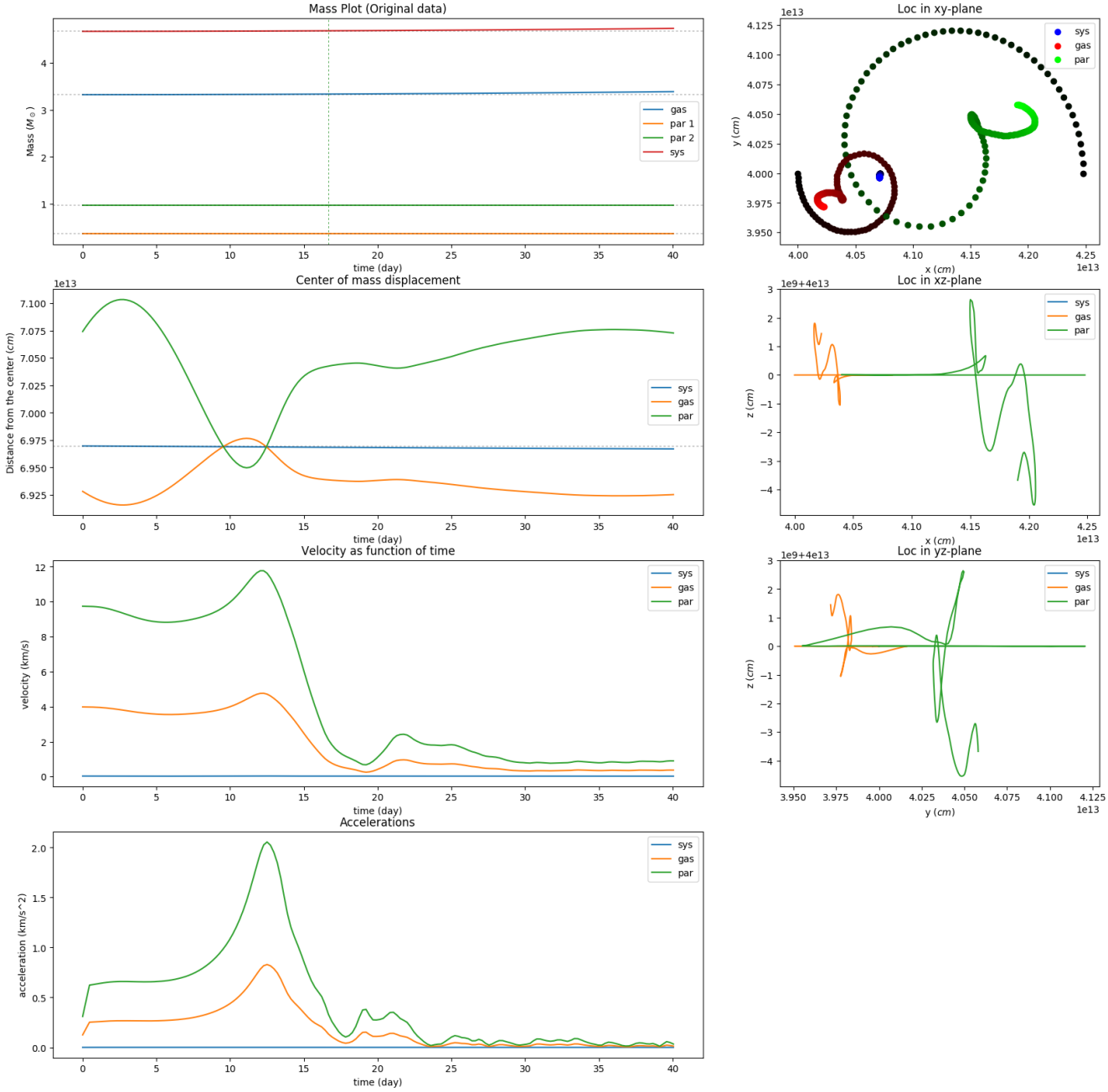

Figure 19: The figure with data from the original data set.

The mass evolution of the original data seems also relatively well. The system initial mass is $4.66M_\odot$, final mass is $4.73M_\odot$. This data is extremely similar to that of the reduced resolution. The deviation is less than $1.7 * 10^{-6}\%$ for initial mass and 0% (No deviation at all) for final mass.
The mass change is $0.064M_\odot$, which is 1.4% of the original mass. This data is again very similar to that in the reduced resolution one.
The final velocity of the particle center of mass is 0.899km/s. And the final acceleration of the particle CM is 0.033km/s^2
It is interesting to notice that the initial mass of the gas obtained from calculation is different from that obtained from the python file. The deviation is about $0.018M_\odot$
The data here was double-checked.

6.3.2 Unbound Mass (TO BE DONE)

6.3.3 Radial mass distribution (TO BE DONE)

6.4 Flux through boundary

6.4.1 Mass flux through boundary

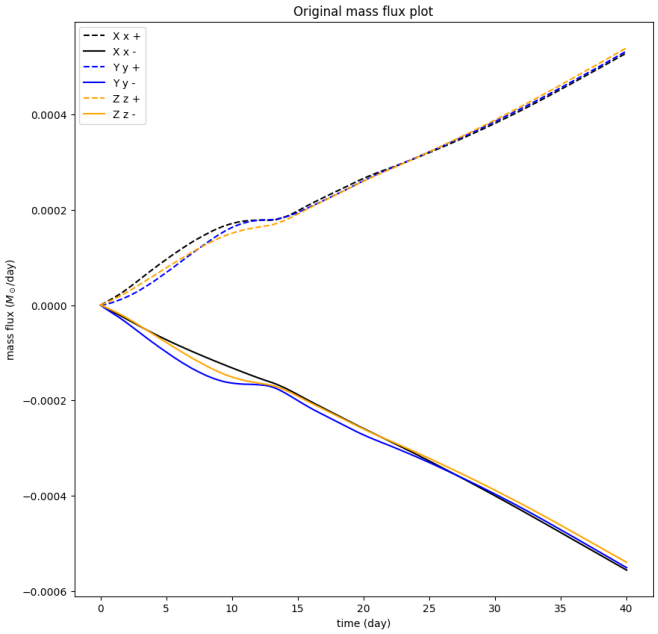

Figure 20: The figure is plotted with original data. The mass flux through each edge in units g/s. Capital letters denote the plane, lower case letters and the + or - denote the 'positive' direction of velocity (into the box). i.e. if the flux is positive at +, it is coming into the box, or if the flux is negative at -, it is also coming into the box

This figure looks not that different from the reduced resolution one. However, it appears that less mass is flowing into the boundary. The total mass change is $\Delta M = 1.28 * 10^{32}\text{g} = 0.064M_\odot$ (Mass of the sun is more accurate), about the same as the reduced one.
This data also mostly agrees with the total mass change data (Deviates by 0.03%).

6.4.2 Energy flux through boundary (TO BE DONE)

7 Ideas

7.1 Roche Lobe Overflow

During binary star interaction, a phase that usually meet by people is the Roche Lobe Overflow. In this phase, material from one star get transported onto the other.
The idea here is whether Roche Lobe Overflow phase can bring extra energy to the ejection of common envelope. Most of the energy in this phase comes from the decay of orbital energy. (Assuming that such overflow doesn't drive fusion). Then we need to consider the energy released from the beginning of Roche Lobe Overflow to when the star plunge in.
When two stars reach Roche Lobe overflow, according to Eggleton [3], the radius of the red giant r_1 and the distance between the star A is given by

$$\frac{r_1}{A} = \frac{0.49 * q^{\frac{2}{3}}}{0.6 * q^{\frac{2}{3}} + \ln\left(1 + q^{\frac{1}{3}}\right)} \tag{35}$$

where $q = \frac{m_1}{m_2}$
Now, if we plug in the numbers from our simulation (Table 1), then we get

$$r_{roche} = A = 7.73737 * 10^{12}\text{cm} = 111.248 R_\odot \tag{36}$$

Consider the system evolves from this radius to the plunge in radius ($r_{in} = 49 R_\odot$), by assuming that the secondary reach "stable" orbit on each radius, we can estimate the energy by applying the Virial Theorem

$$E_{orb,Roche} = -G\frac{M_{rg}M_2}{2r_{in}} - \left(-G\frac{M_{rg}M_2}{2r_{roche}}\right) = -4.16507 * 10^{46}\text{erg} \tag{37}$$

If all these energy is transported into envelope, then the energy is about 2/3 of the energy required
A flaw of logic in this argument maybe there are mass transfer and mass lose in the process of the evolution.
I am not sure if the following is correct.. The overflow system can be a chaotic system that is hard to be modeled. The transfer rate is approximated by Paczy nski, B., Sienkiewicz, (1972). The simulation in macleod's paper has a really different value than ours and it's actually hard to tell how the system will behave if it finally reaches a system like ours..
We also need to take into account that because there are mass lose, the remaining energy may not be as large as we estimated. Some of the gas maybe ejected with high energies that takes away a lot of energy (need grounds for this argument).

References

[1] Luke Chamandy, Adam Frank, Eric G. Blackman, Jonathan Carrol-Nellenback, Baowei Liu, Yisheng Tu, Jason Nordhaus, Zhuo Chen and Bo Peng *Accretion in common envelope evolution.* MNRAS 000, 000-000(0000)

[2] Sebastian T. Ohlmann, Friedricj K. Röpke, Rüdiger Pakmor and Volker Springel *Hydrodynamic moving-mesh simulation of the common envelope phase in binary stellar systems.* The Astrophysical Journal Letters, 816:L9 (6pp), 2016 January 1

[3] Eggleton, P. P. *Approximations to the radii of Roche lobes.* The Astrophysical Journal. 268: 368. Bibcode:1983ApJ.268.368E

[4] Paczy nski, B., Sienkiewicz, R. *Evolution of close binaries.* 1972, AcA, 22, 73

[5] Andreas Büning and Hans Ritter *Numerical stability of mass transfer driven by Roche lobe overflow in close binaries.* Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, D–85741 Garching, Germany

[6] H *H.* H

8 Appendix

8.1 Appendix A: equation for figures

Ekin_par_tot = Ekin_par1 + Ekin_par2
Ekin_tot = Ekin_par2 + Ekin_par1 + Ekin_gas_box
Epot_tot = Epot_gas_par2_box + Epot_gas_par1_box + Epot_gas_box + Epot_par
Etot_env = Ekin_gas_box + Epot_gas_box + Eint_gas_box + Epot_gas_par1_box + Epot_gas_par2_box
Epar_tot = Ekin_par1 + Ekin_par2 + Epot_par + Epot_gas_par1_box + Epot_gas_par2_box
Epot_tot_no_self = Epot_gas_par2_box + Epot_gas_par1_box + Epot_par
Etot_env_no_self = Ekin_gas_box + Eint_gas_box + Epot_gas_par1_box + Epot_gas_par2_box

8.2 Appendix B: A more clean-up plot

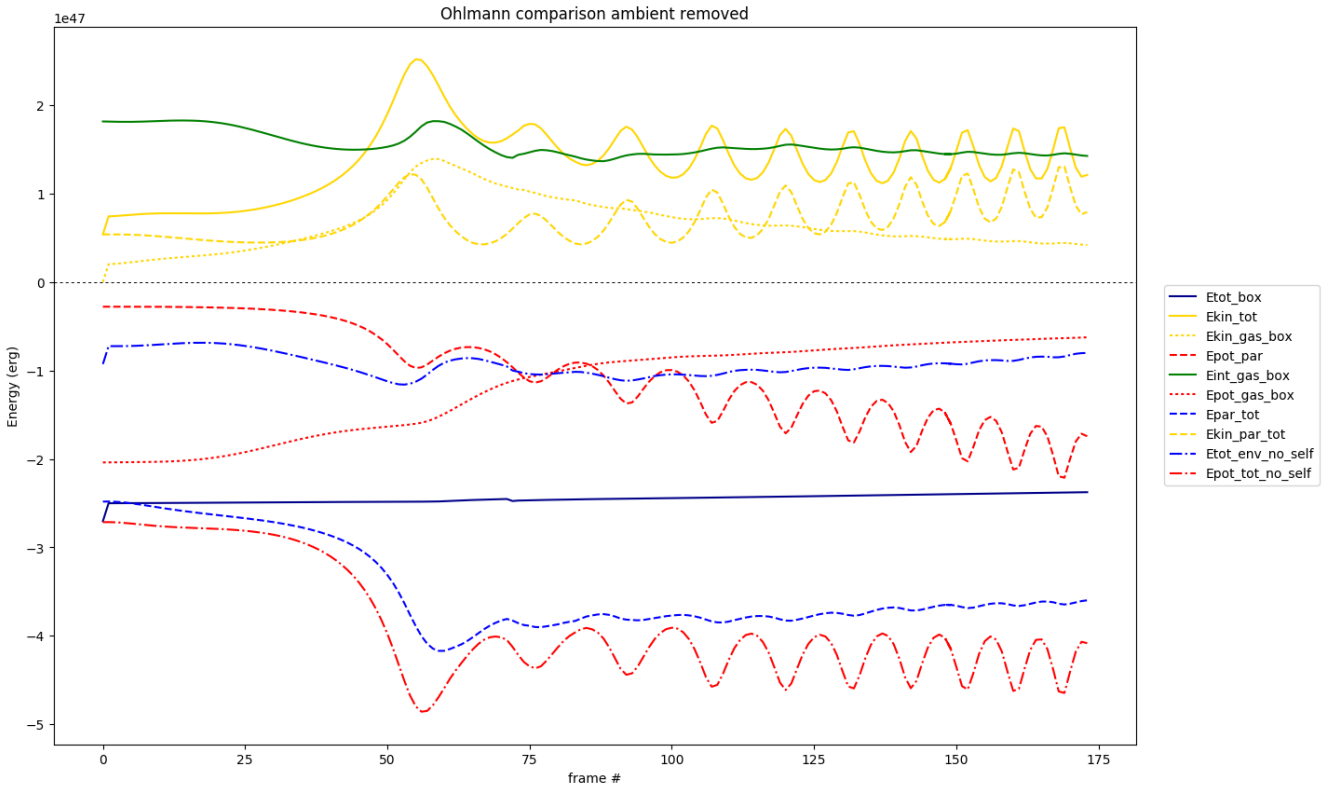

Figure 21: A more cleaned up plot of figure 2

8.3 Appendix C: supplementary: some other figures

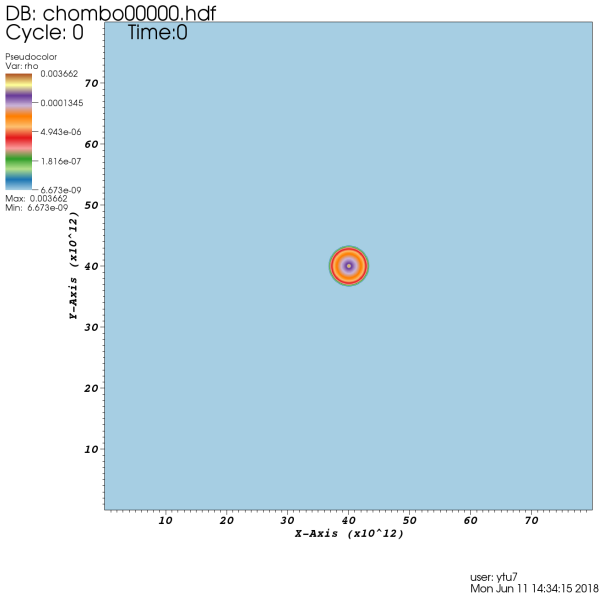

Figure 22: Density, frame 0, cut from z-axis

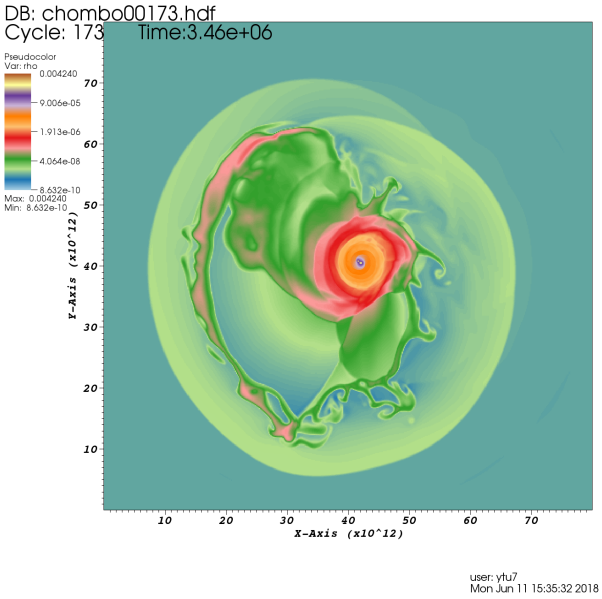

Figure 23: Density, frame last, cut from z-axis

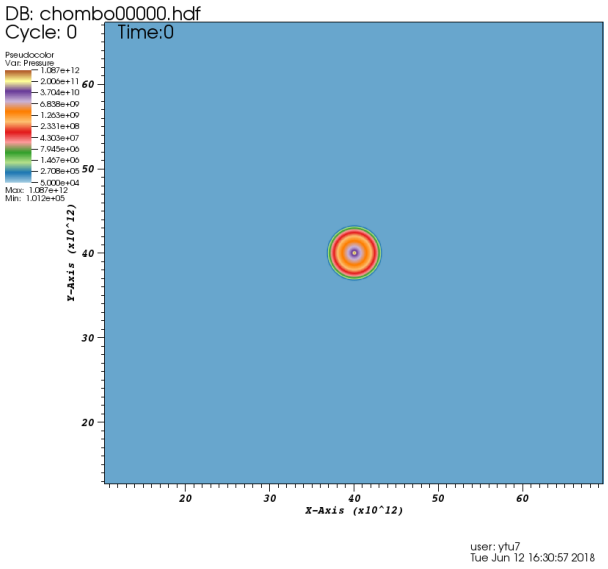

Figure 24: Pressure, frame 0, cut from z-axis

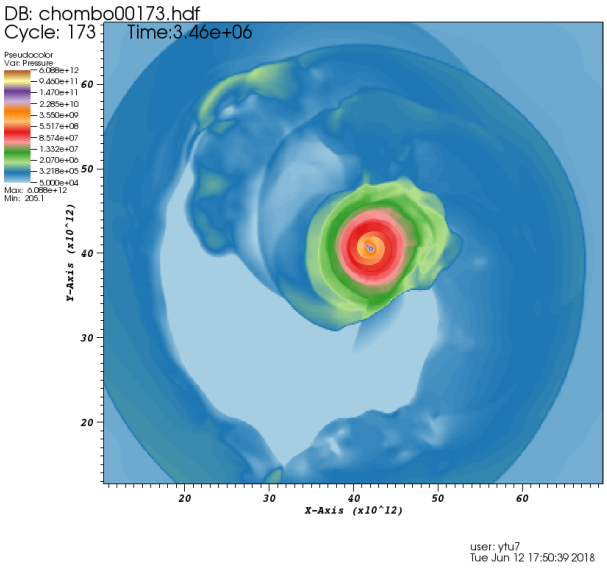

Figure 25: Pressure, frame last, cut from z-axis

8.4 Appendix D: Energy and Mass distribution frame 57-59