Contents

1 Introduction

2 Variables declaration

Variables	T_1	T_2	T_g	U_{12}	U_{1g}	U_{2g}	U_{gg}	J_g
Ekin_par1	✓							
Ekin_par2		✓						
Ekin_gas_box			✓					
Epot_par_self				✓				
Epot_gas_par1_box					✓			
Epot_gas_par2_box						✓		
Epot_gas_self_box							✓	
Eint_gas_box								✓
Epar_kin_tot	✓	✓						
Epar_pot_tot				✓	✓	✓		
Egas_pot_tot					✓	✓	✓	
Ekin_tot	✓	✓	✓					
Epot_tot				✓	✓	✓	✓	
Epar_tot_no_gp	✓	✓		✓				
Epar_tot	✓	✓		✓	✓	✓		
Egas_tot_no_gp			✓				✓	✓
Egas_tot			✓		✓	✓	✓	✓
Etot_box	✓	✓	✓	✓	✓	✓	✓	✓
Oh_Epar_kin_tot	✓	✓						
Oh_Eint_gas_box								✓
Oh_Epar_pot_tot				✓	×	✓		
Oh_Ekin_gas_box			✓					
Oh_Egas_pot_tot					×	✓	✓	
Oh_Ekin_tot	✓	✓	✓					
Oh_Epot_tot				✓	✓	✓	✓	
Oh_Epar_tot	✓	✓		✓	×	✓		
Oh_Egas_tot			✓		✓	×	✓	✓
Oh_Etot_box	✓	✓	✓	✓	✓	✓	✓	✓

Factors to consider

1. Ambient material (see Energy note)
2.

3 Figures

3.1 Ohlmann's energy

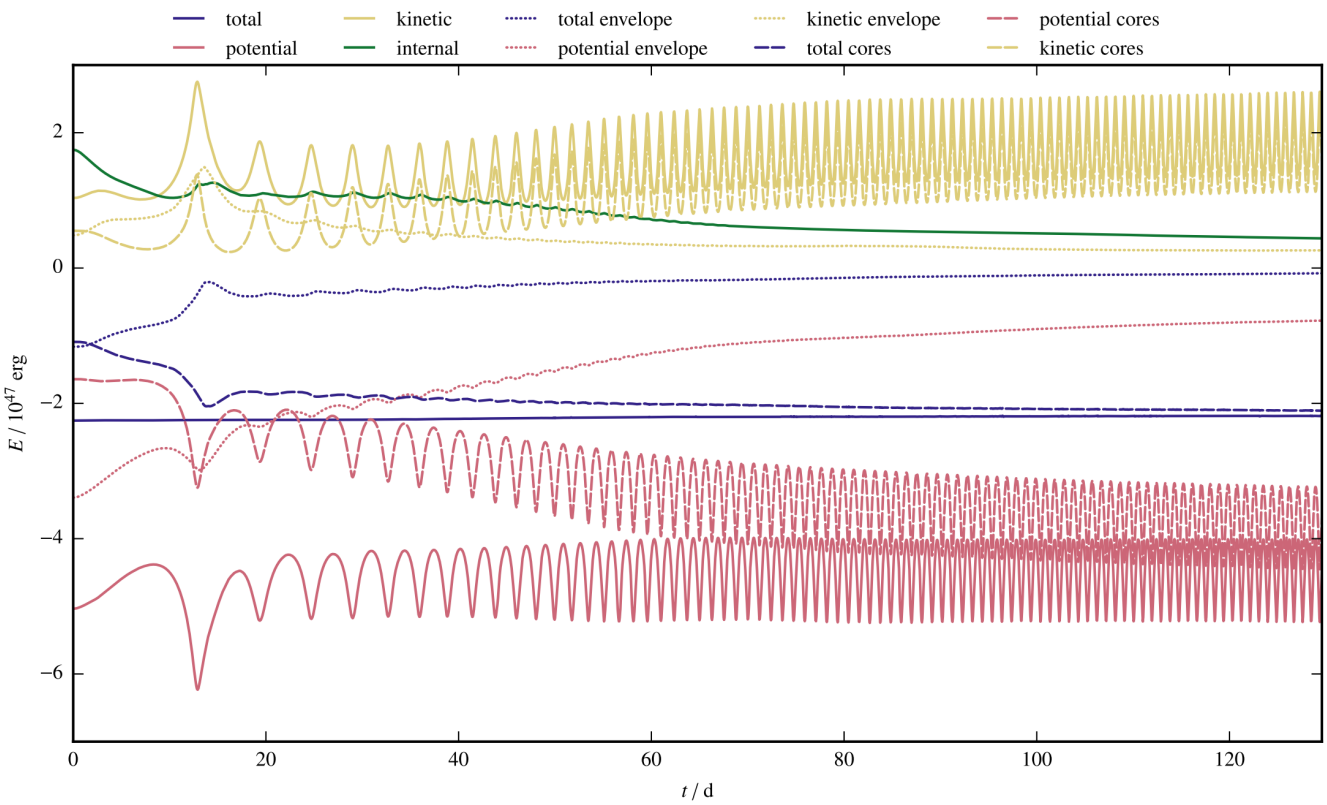

Figure 1: Caption

3.2 Ohlmann comparison; All curves with gas-particle potential energy KEPT

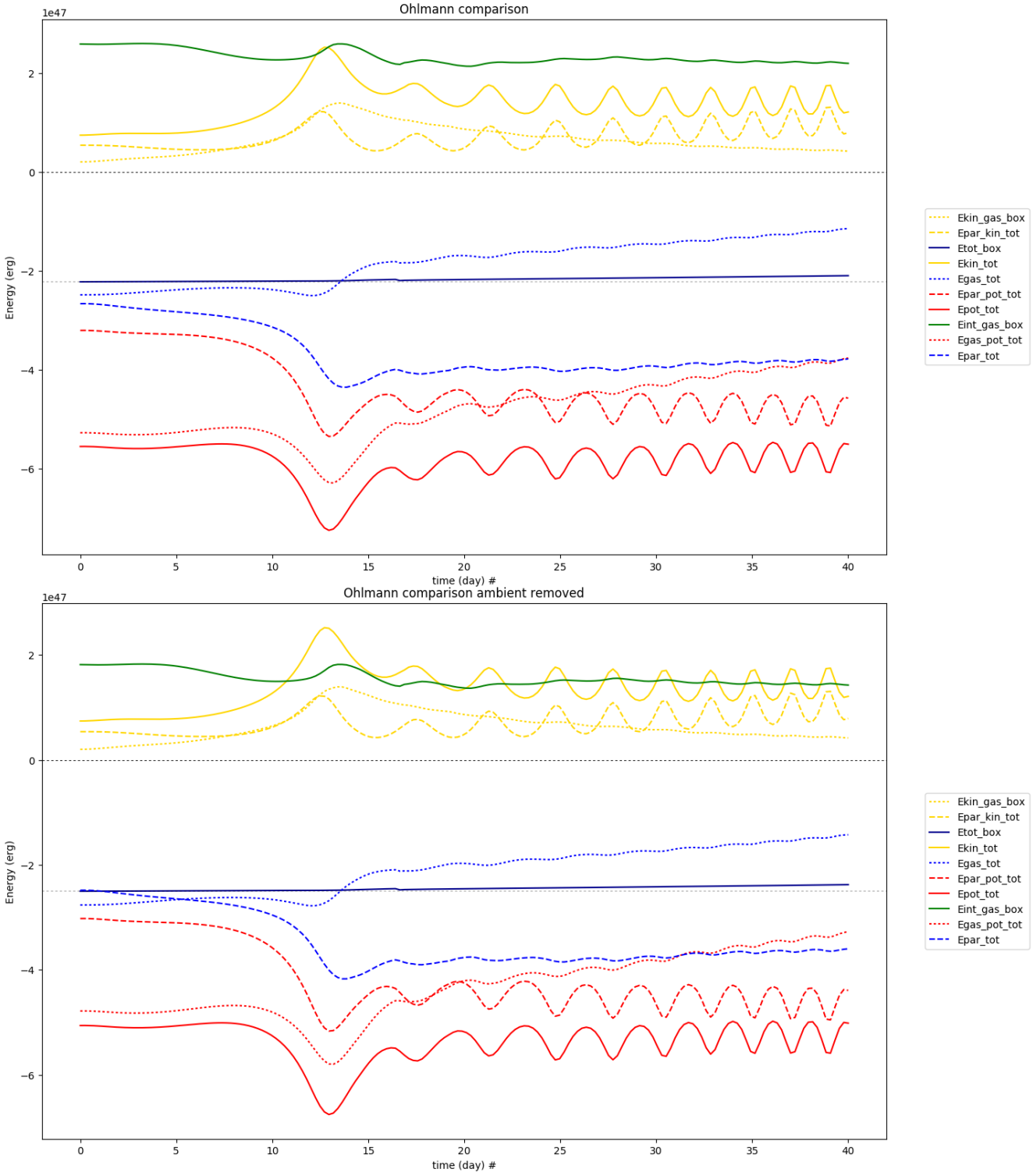

Figure 2: Caption

3.3 Ohlmann comparison; All curves with gas-particle potential energy REMOVED

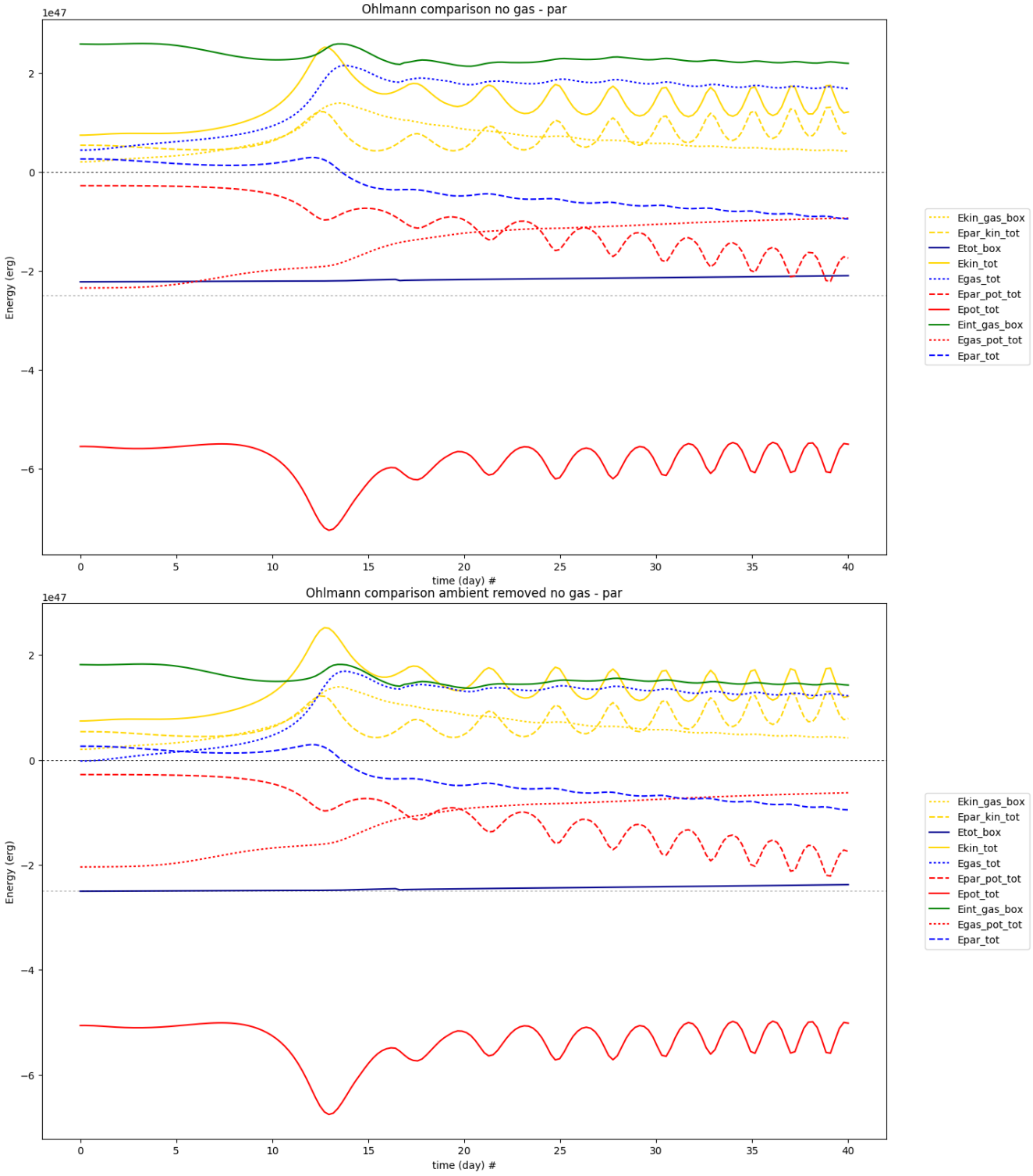

Figure 3: Caption

3.4 Original component of energy

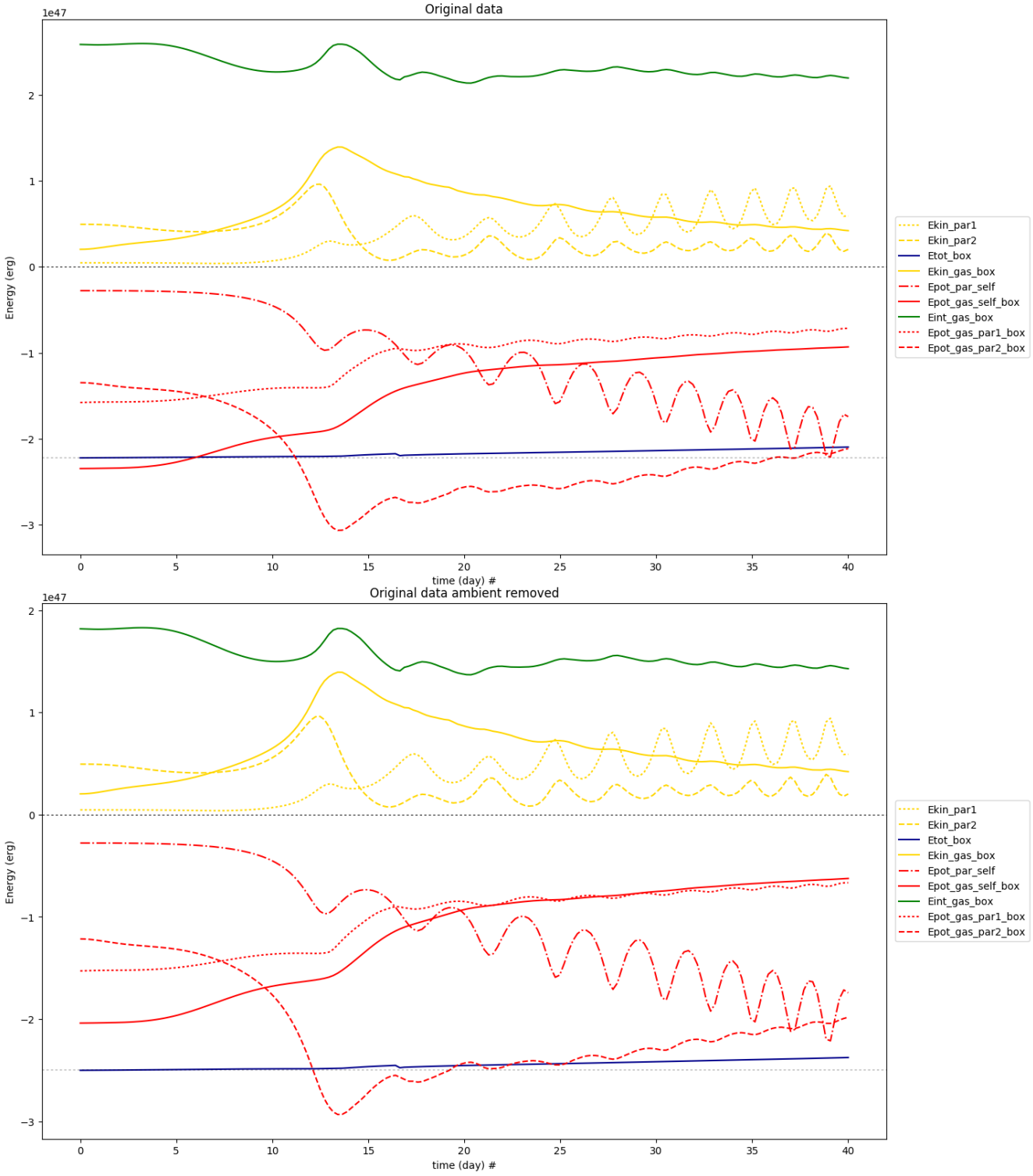

Figure 4: Original component of energy

3.5 Attempt to regenerate Ohlmann's plot

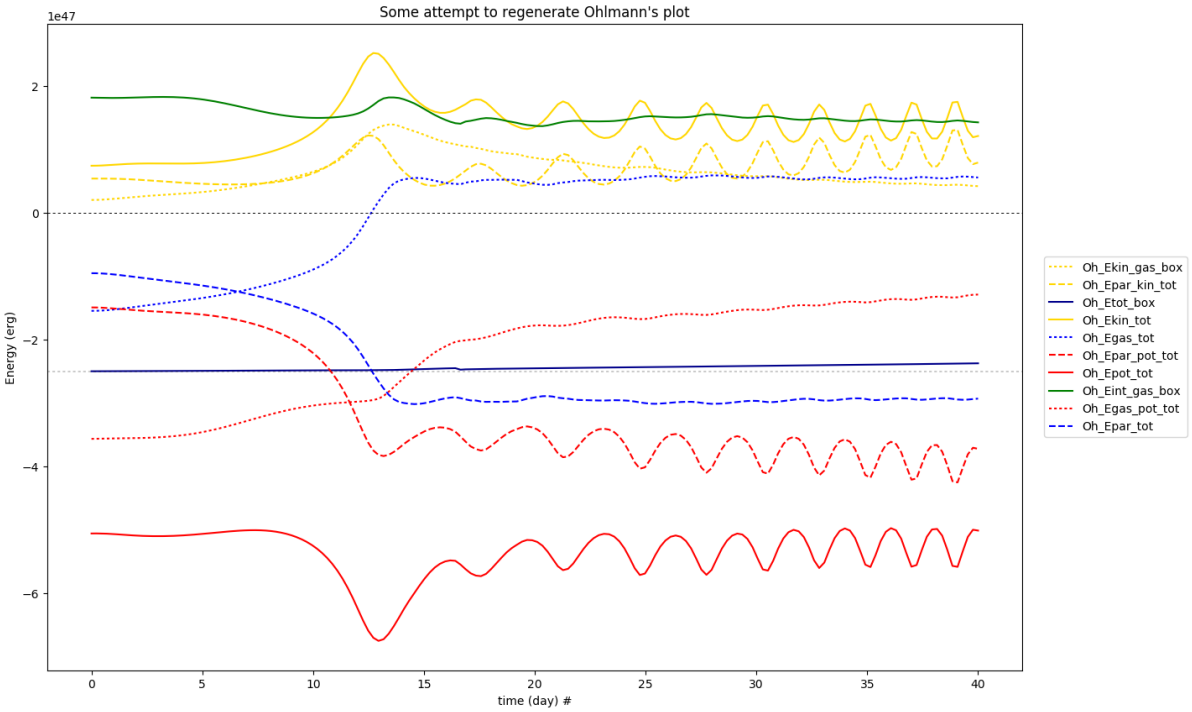

Figure 5: An attempt to regenerate Ohlmann's plot. The variable used is shown in the previous table

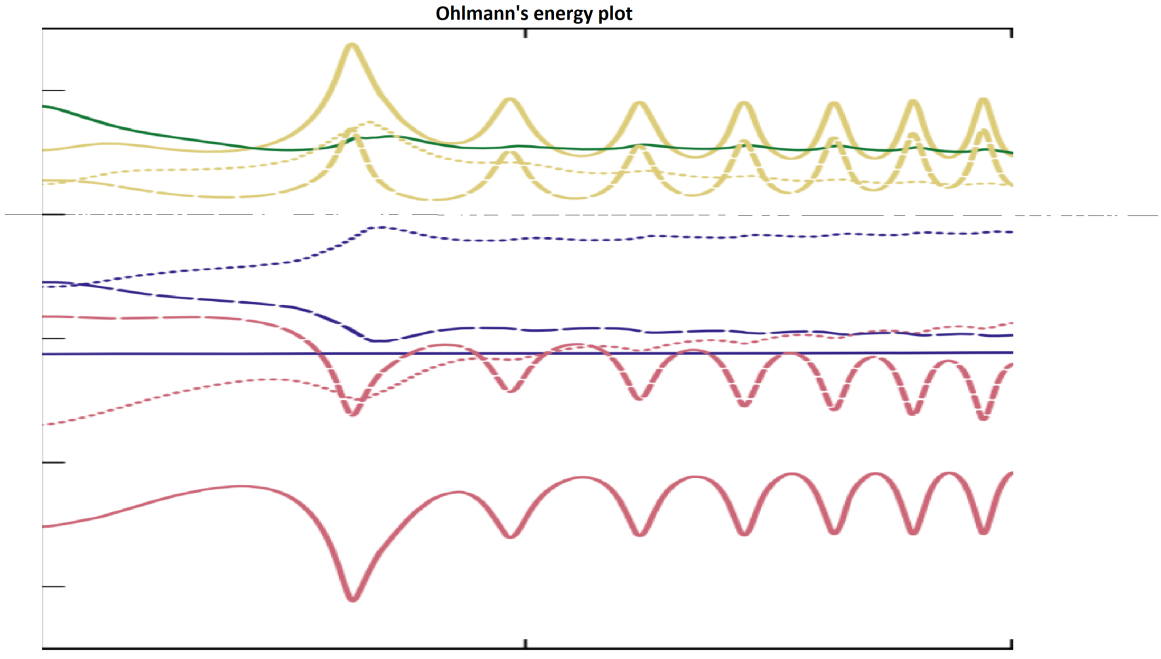

Figure 6: A stretched version of Ohlmann's plot so it's easier to compare, the broken dashed horizontal black line is 0

It is interesting to notice two pheonmeons in Ohlmann's plot

1. There is no curves in previous figures that corresponding to potential curves in Ohlmann's plot
2. The potential energy of particle is way lower than just the potential energy between the particle themselves

This figure above looks a lot similar to Ohlmanns. The differences are

1. Epar_pot_tot: The peaks after 17 days in our plot are much lower than those in Ohlmann's
2. Egas_pot_tot: There is a decrease in Ohlmann's plot at about 15 days that is not seen in our figure. Instead, in our figure, the curve seems only flatten out a little bit and rise again.
3. Epot_tot: our first minima is deeper than Ohlmann's. Though if we take into account that there is a rise at the beginning of Ohlmann's plot, the value can be similar.

Ohlmann used only gas-particle1 potential energy when calculating for gas potential; only used gas-particle potential energy when calculateing for particle potential. I think this may be the same problem Ivanova 13a equation 1. The binding energy may not be only come from the RG core but also from secondary (In our figure 2, the gas total decreased in the beginning and we believe that to be the fact that secondary suddenly plunge in and deeper the potential well with the primary.

3.6 Analysis

A pheonmenon maybe worth notice is in section 3.3 upper panel, the particle total energy curve is actually not always decreasing. Because all the ram pressure and gravitational drag, I would expect that the total energy of particle be always decreasing. The increase may be physical but also may be numerical.
The amount of increase if $2.636 * 10^{46}$erg, which is more than the increase in total energy. However, the excessive decrease is not accounted. So here it can be the problem.
Need information about time-step length. Each time the particle evolve it deviates from it's original trajectory a little bit, adding up may cause the issue. The time at which the particle are closer to each other (velocity larger) is different from the time at which the particles are far away from each other (velocity smaller). Accounting for this may explain the increase in total energy.

4 Some data

◦ For each component of energy, the change is listed following

Gas Internal energy	-3.9014123586e+46
Gas self potential energy	1.41469439603e+47
Gas kinetic energy	2.17424294543e+46
Particle self potential energy	-1.4648306805e+47
Particle 1 kinetic energy	5.4378211864e+46
Particle 2 kinetic energy	-2.91698634744e+46
Particle 1 - Gas potential energy	8.6256265717e+46
Particle 2 - Gas potential energy	-7.6660707836e+46

◦ Another analysis was done on the change in gas, particle energy.

1. $(U_{12} + T_1 + T_2)$ Particle total energy changes by -1.2127471966e+47
2. $(U_{gg} + T_g + J_g)$ Gas total energy changes by 1.24197745471e+47
3. $(U_{1g} + U_{2g})$ Gas-particle potential energy changes by 9.595557881e+45
4. total energy changes by 1.25185836925e+46

It looks like the energy of particle goes first into envelope, then energy from particle goes into gas-particle potential energy. It seems that particles are still loosing energy so more energy are expected to be liberated.

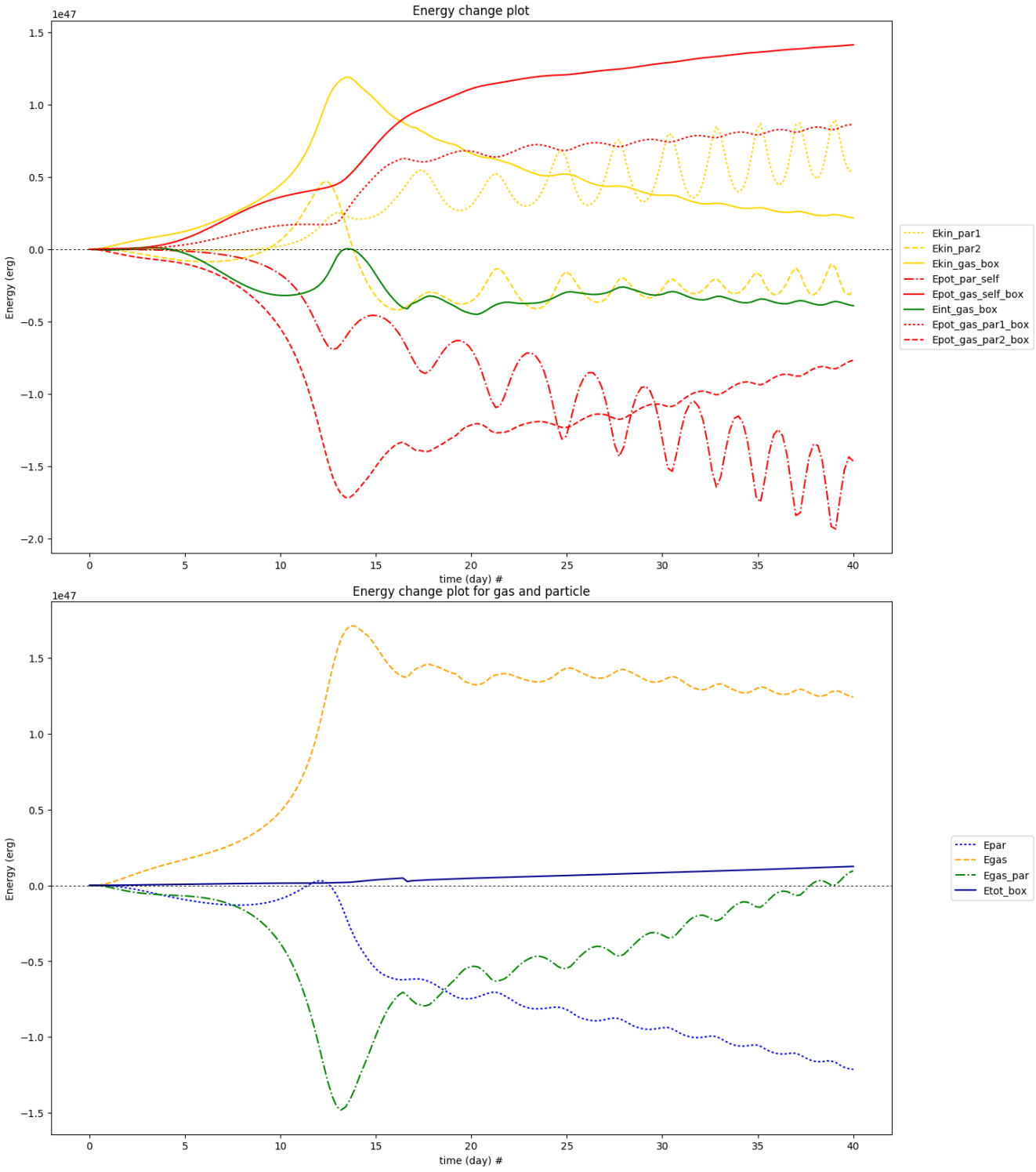

Figure 7: upper: change of energy for each component of energy; Lower: change of energy for particle and gas. The values plotted are the same as those shown above. Egas and Epar didn't include the gas-particle potential terms

4.1 Luke's value comparison

Description	Semi-analytic	Simulation	diff	agree?	note
Energy involving particle only					
Initial particle 1 kinetic energy	0.05	0.046	0.004	✓	
Initial particle 2 kinetic energy	0.49	0.494	-0.004	✓	
Initial particle kinetic energy	0.54	0.540	0.0	✓	
Initial inter-particle potential energy	-0.28	-0.278	-0.002	✓	
Final inter-particle potential energy	-1.95	-1.743	-0.2069	✓	(II)
Gas energy budget					
Initial envelope bulk kinetic energy	0.20	0.203	-0.003	✓	
Initial envelope internal energy	1.81	1.817	-0.0069	✓	(I)
Initial envelope particle 1 potential energy	-1.56	-1.529	-0.031	○	(I)
		1.534	*0.026*		*(VI)*
		1.501	0.059		(VII)
		1.513	*0.047*		*(VIII)*
Initial envelope particle 2 potential energy	-1.21	-1.216	0.006	✓	(I)
Env-par2 pot energy if par 2 at RG center	-4.14				
Initial envelope potential energy, self gravity	-2.13	-2.039	-0.0909	○	(I)
Initial ambient medium internal energy	0.77 (0.768)	0.768	0.002	✓	(V)
Initial ambient medium-particle 1 pot energy	-0.05 (-0.0497)	-0.025	-0.0243	×✓	(III)
Initial ambient medium-particle 2 pot energy	-0.13 (-0.138*)	-0.066	-0.072	×✓	(III)
Initial ambient medium envelope potential energy	-0.22 (-0.215)	???			
Initial ambient medium pot energy, self-grav	-0.09 (-0.0922)	-2.34			
Initial gas-particle 1 potential energy					
Initial gas-particle 2 potential energy					
Initial gas pot energy due to self-grav					
Initial envelope binding energy (< 0 = bound)					
RG core-env PE only	-1.56	-1.529	-0.0310	○	(I)
		1.534	*0.026*		*(VI)*
		1.501	0.059		(VII)
		1.513	*0.047*		*(VIII)*
RG core-env PE + intern	0.25	0.289	-0.0389	✓	(I)
RG core-env PE + Env-env PE + intern	-1.87	-1.750	-0.120	○	
RG core-env PE + intern + env bulk KE	0.46	0.492	-0.0319	○	
RG core-env PE + Env-env PE + intern + env bulk KE	-1.67	-1.548	-0.1219	○	(I)
RG core-env PE + Sec-env PE	-2.77	-2.744	-0.0259	✓	(I)
RG core-env PE + Sec-env PE + Env-env PE	-4.90	-4.784	-0.116	✓	(I)
RG core-env PE + Sec-env PE + intern	-0.96	-0.926	-0.0339	✓	(I)
RG core-env PE + Sec-env PE + intern + env bulk KE	-0.76	-0.724	-0.036	✓	(I)
RG core-env PE + sec-env PE + Env-env PE + intern	-3.09	-2.966	-0.1239	○	
ANS + env bulk KE	-2.89	-2.763	-0.1270	○	
As above but with secondary at center of RG	-5.82	N/A			
Liberated from change in orbital energy					
Ivanova et al. (2013) eq (3) RHS					
Initial orbital energy	-0.75	-1.494	0.744	×✓	(IV)
Final orbital energy	-0.97	-1.743	0.773	×✓	(IV)
Initial orbital energy of particle only	-0.14	-0.278	0.138	×✓	(IV)
By particles only	0.83	1.465	-0.6350	×✓	(IV)

The notes are listed velow

I) The simulation values are calculated using the data from simulation and subtract the value in parenthesis in Semi-analytic column. The calculation of these values are in Energy note.

II) The difference in r_{final} caused the problem. The particles are in elliptical orbits, and it's hard to define a r_{final} for elliptical orbit

III) The simulation calue reported cut areas within radius $3.35 * 10^{12}$, whereas in calculation all areas are included. This is a calculation independent of other calculations.

IV) They are differ by about a factor of two because the simulation value didn't account for kinetic energy. However, for final orbital energy, the particle is in elliptical orbit, so Virial Theorem doesn't work in this case (not a factor of 2)

V) This value is actually term E in chombo file. Because we know E_kin in the first frame is 0 in the file (disregard our correction), $E = E_{int}$

VI) This value is computed with a pseudo-integral way. I split each ring up into 5000 smaller ring and add them up. Cutting the ring 5000 times gets a similar value as cutting 1000 times ($-1.534e47$). Therefore this value is believable.

VII) Considering the effect of softening radius. Softening radius actually made the situation worse. The effect maybe accounted by the central region.

VIII) Considering the effect of softening radius, calculated using pseudo-integrate with each ring cut into 5000 pieces.

5 Time step analysis

It is believed that the time step may cause the increase in energy since the particles and gas goes along the tangential trajectory instead of their original trajectory, resulting in an increase in potential energy and decrease in kinetic energy. Whether this energy change could explain the energy shift is what's been looked at in this section.
Because the general equation of motion for a two-body problem is not yet solved (I got a system of two coupled non-linear differential equation that I don't think I could solve..). A sub-simulation using only the particle maybe the next best way to study this effect.
This simulation is ran only for two particles, which are mass 1 and mass 2 in run 143. The initial conditions are taken directly from each Chombo file. The particles are assumed only interact through gravity, and because this computation will be too computationally intensive if we include the gas, this simulation doesn't take the effect of gas into account.
For each Chombo file, I take the locations and velocities of the particles and use them as the intial condition for my two-body simulation. Then I determined the time-step in original run 143 simulation is 712.4 s. This would be the time step for run B. To determine the effect of time-step, I have a second run (run A) that use time step 1000000 times smaller.
Frame 1 the deviation between energy $(T + U)$ is $2 * 10^{37}$, Given higher the velocity the larger the effect, I believe the result may be significant