Results of the fifth project simulation

G2
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During last week, the ‘PSL week’, we attended a class in Astrophysics. Amazingly, the teachers used **exactly the numerical simulation that we were working on** to visualize the formation of planetesimals.

Planetesimals are the result of a 100 km wide aggregation of mm-size silicates called chondrules that bind together in the interstellar dust. These planetesimals then collide with each other to become planets as we know them !

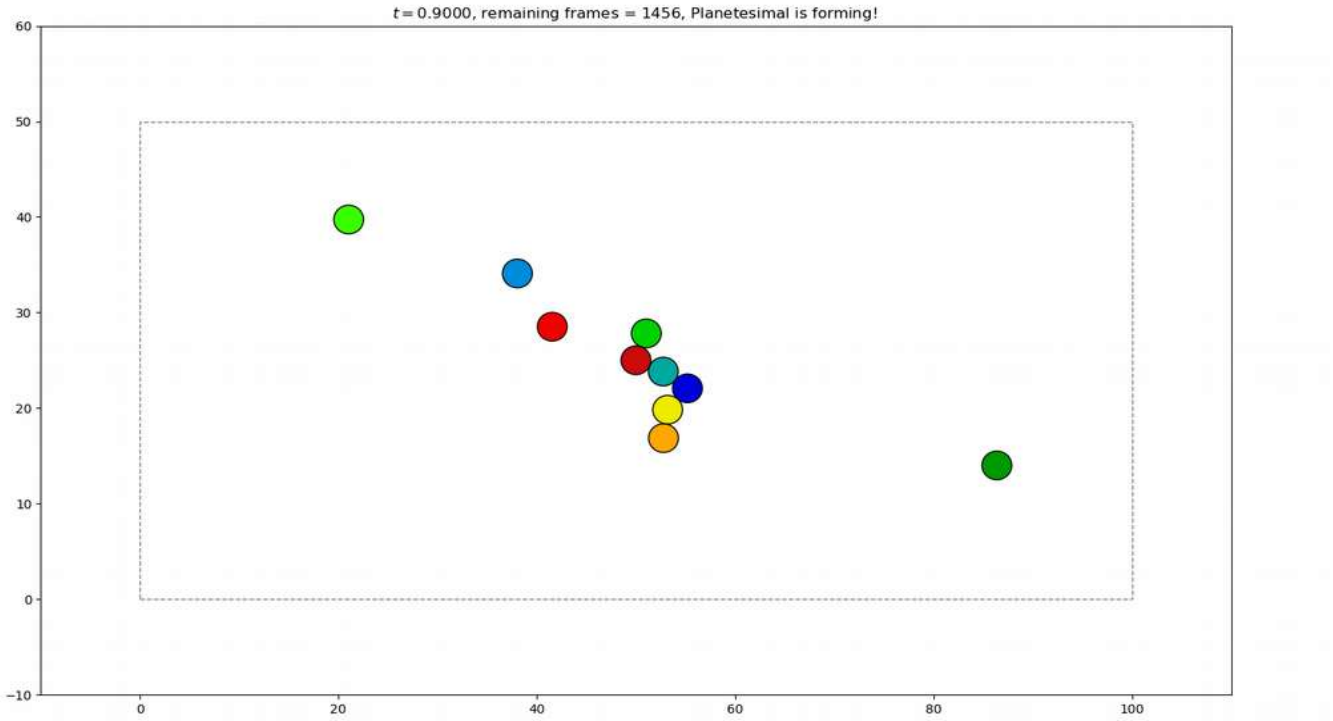
In the first step of a planetesimal formation, the particles collide with a heavier particule and aggregate together to form fractals: « Aggregation of solid grains would not generally produce spherical particles, but irregular shapes with variable density. Such bodies are fractals. » (https://adsabs.harvard.edu/pdf/1997LPI....28.1517W). This **is the first step of our simulation**.
Once the aggregate is massive enough, it scatters away new particles. The Russian physicist Safronov(https://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?bibcode=1980M%26P....22...63G&db_key=AST&page_ind=0&data_type=GIF&type=SCREEN_VIEW&classic=YES) demonstrated this in 1972 with the Safronov number :

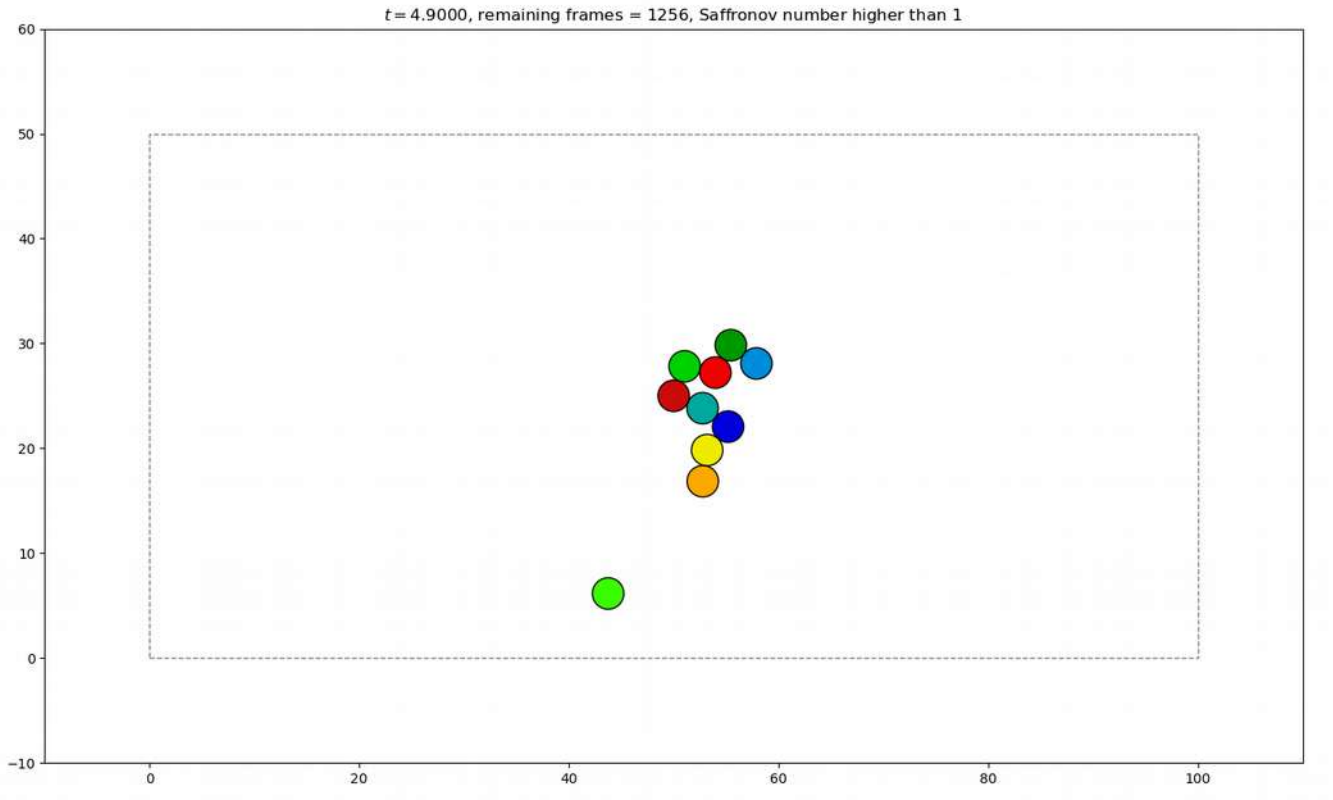
$$\theta = \frac{Ve^2}{2\,Vo^2}$$

Where Ve is the escape velocity of the planetesimal and Vo is the orbital velocity. When $\theta > 1$, which means that Ve is high enough, which means that the aggregate is massive enough, then no new particle can stick to the fractal ! This **is the last step of our simulation**.

Therefore, we can consider that this simulation is the simplified version of our home origin ! (home being planet Earth) That’s pretty beautiful.

- Let’s run the simulation for just 10 particles. The size of the box is 100x50.
  Beware of the title that tells you when you go from a planetesimal formation to a $\theta > 1$ situation.
  We put kb = 100 000 (very high, so that it goes very fast, because for 100 particles the simulation takes much longer).

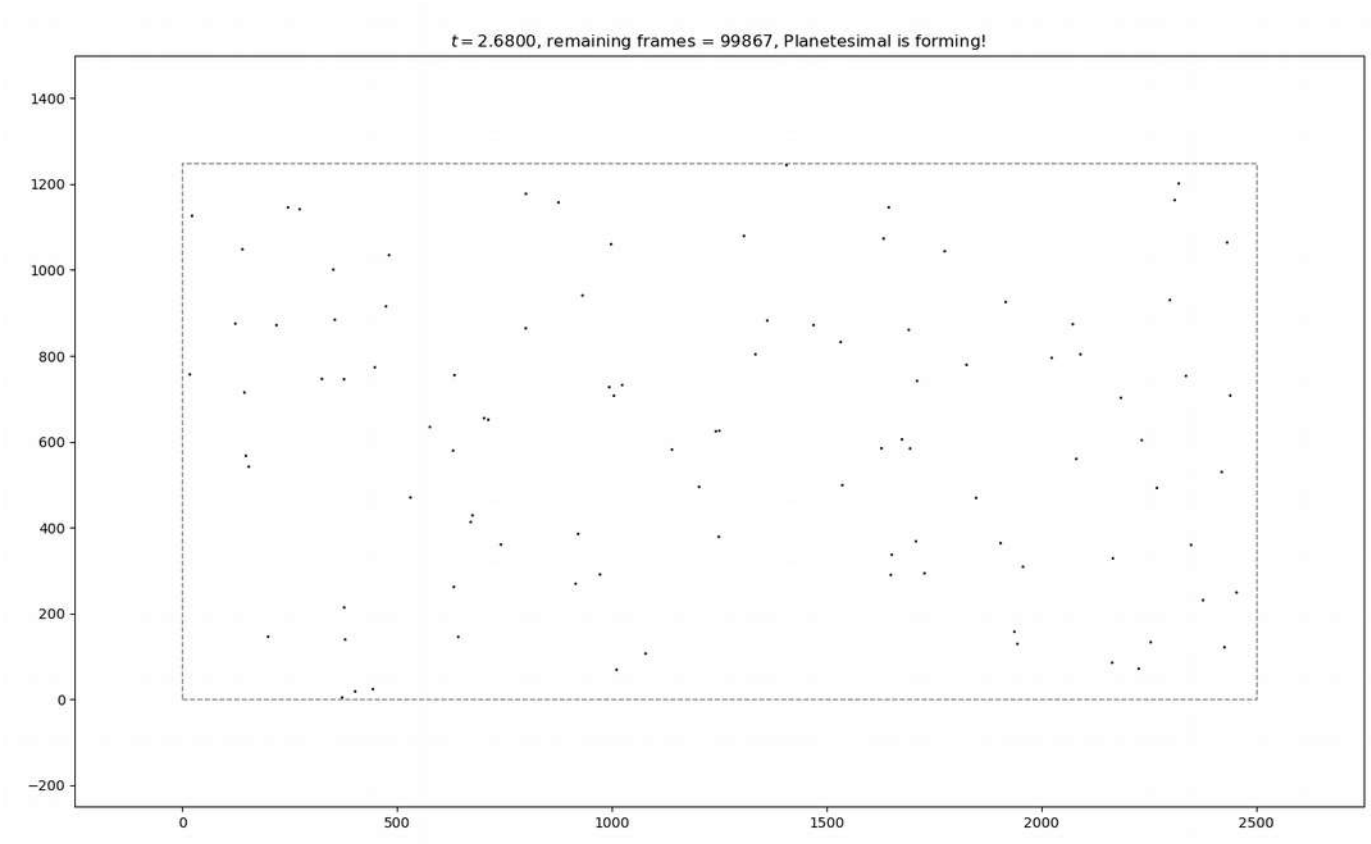




In less than 5 seconds we have a Safronov number greater than 1. The blue particle will indefinitely hit the aggregate without aggregating.
We cannot observe a great fractal because the number of particles is too low. We only observe a w-form branch of the supposed fractal. Let's try with more monomers to find out if we get a nice fractal !

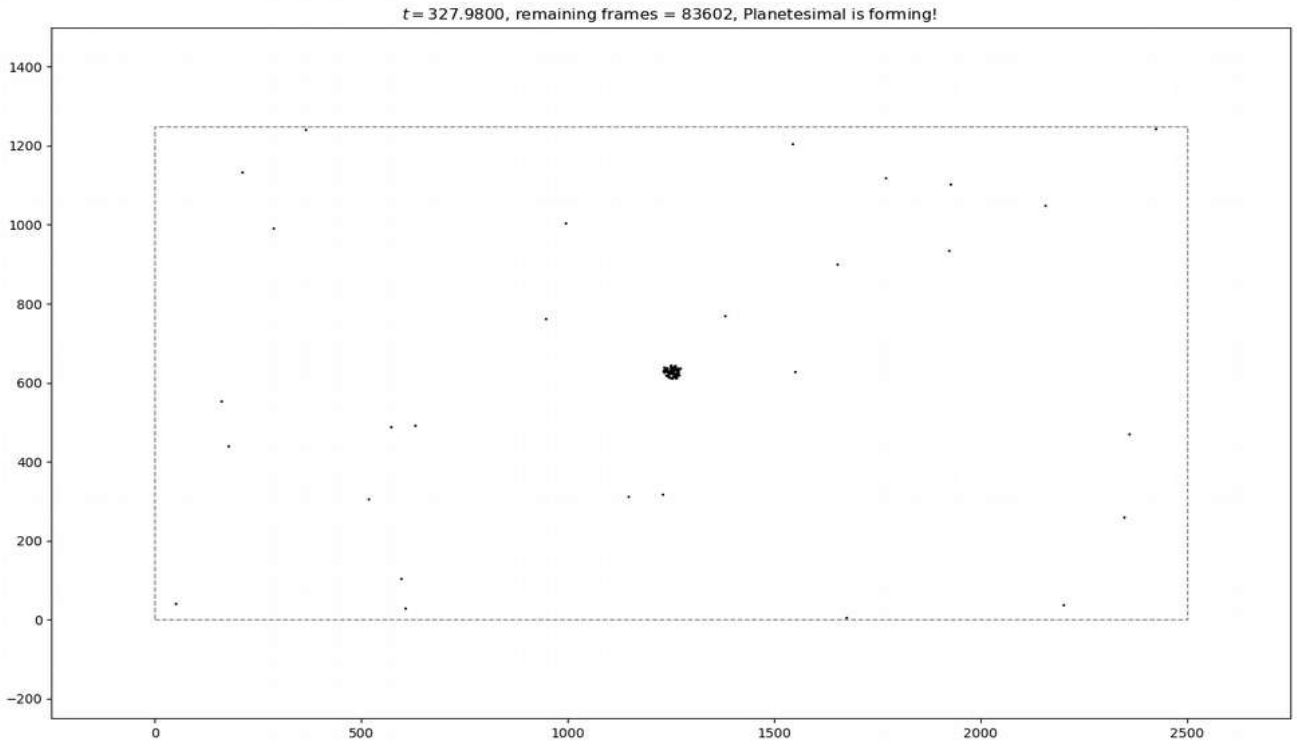
- Now let’s try for 100 particles. For that many particles, the simulation box size had to be heavily increased. Actually, the **number of particles is not linearly correlated to the size of the box**.
  If it was linear, 100 particles would just need a 1000x500 size box (multiply the 10-particule box by 10). But the simulation **wouldn’t run for any box size inferior to** 2500x1250 !! So the simulation needs more and more space when the number of monomers increases. And this with **highly non linear** dependance.

After 2 seconds :



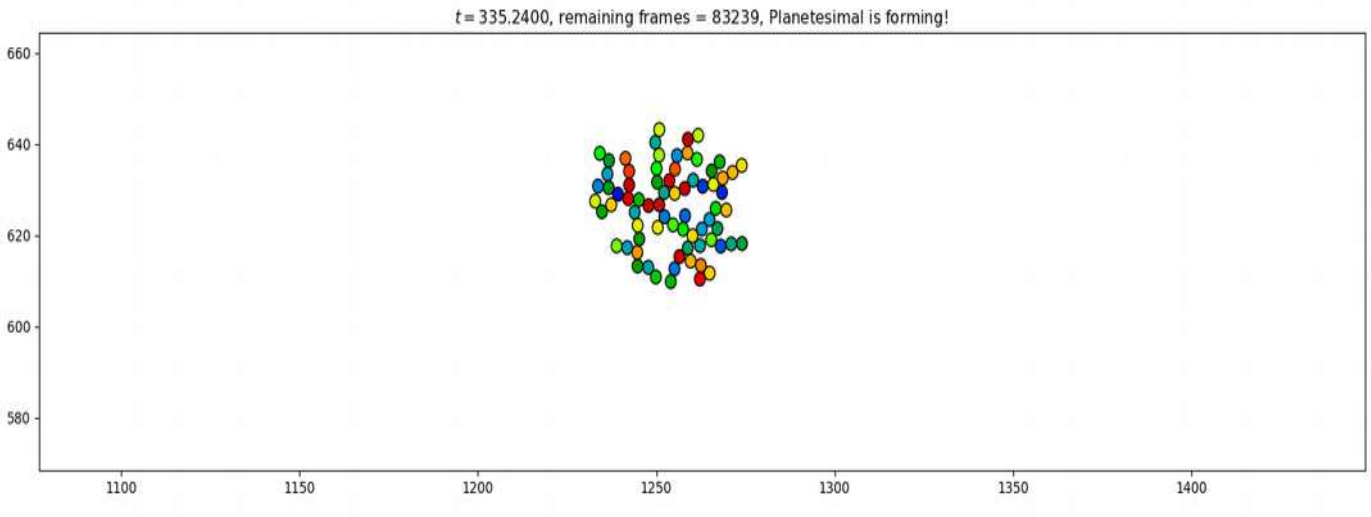
The silicates are scattered all over the place.

After 327 seconds :



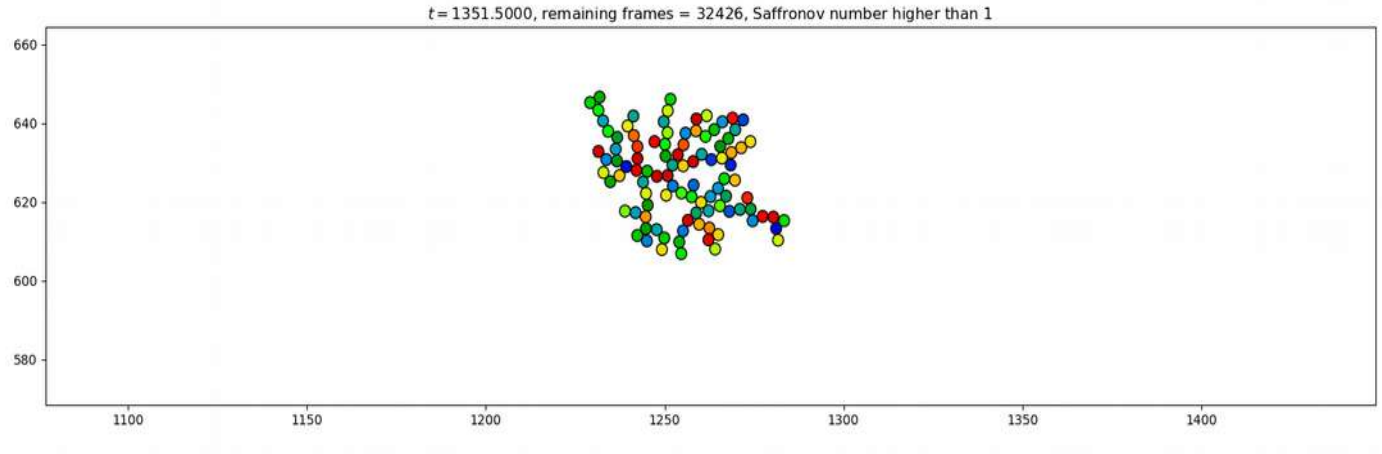
From afar, we may think that a homogeneous large particle is rising from the interparticle collisions. This was the error of the first simulations of Weidenschilling in 1980 (see https://adsabs.harvard.edu/pdf/1997LPI....28.1517W). In reality, physicists understood that the bodies forming weren't of equal density : they were fractals !

With our simulation, we can see this by zooming in :



We can observe this beautiful fractal, origin of planets ! The ramified branches are very clear here unlike the 10 particles simulation where we got only one branch. This is due to the higher number of particles giving a higher probability to hit the central particle from different directions. So our fractal hypothesis is confirmed in this case !

Finally, our simulation gave the final fractal (with no particles hitting it anymore) after more than 1300 seconds ! That's more than 20 minutes. Indeed the extra space allowed to the 100 silicates makes collisions less likely to happen and therefore longer to get to $\theta > 1$.



Here, any particle that would hit the fractal would immediately bounce onto it without aggregating.

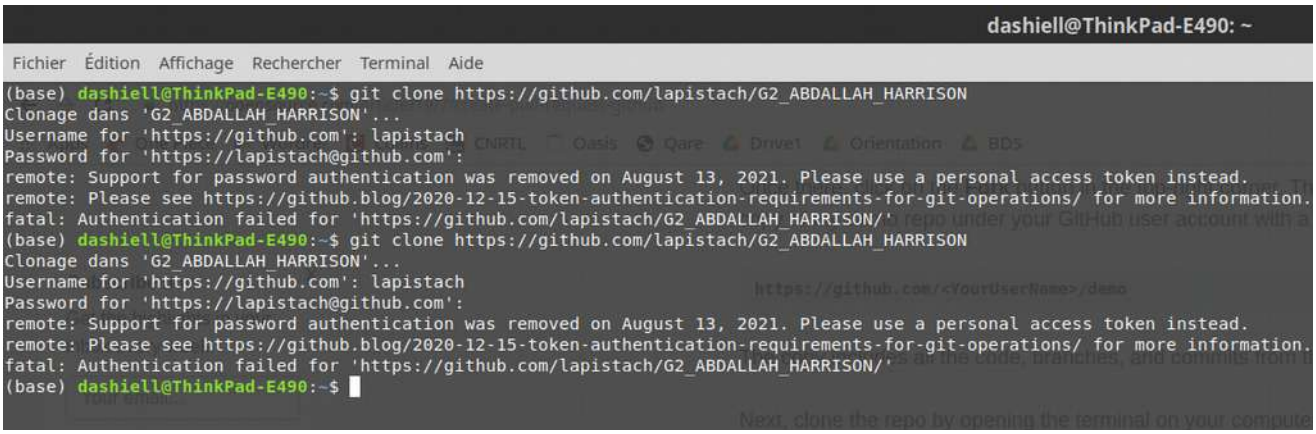
Conclusion

We saw through this class that numerical simulation in constant steps is all about organizing the order of the events. And it can get quite tricky if you don't pay attention to what happens before what. We have spent a lot of time on the code and still couldn't solve the problem of our code crashing each time we put an other number than 10 monomers in. We even had to ask for someone else's code to do the 100 particles simulation (although we changed the title on it!).
Finally we can say that analysing this simulation through planetesimal formation was quite fun, especially when we saw that it was the same simulation as our Astrophysics teacher's one during PSL week !

(See Annexe for explanation of github problems, if you want…)

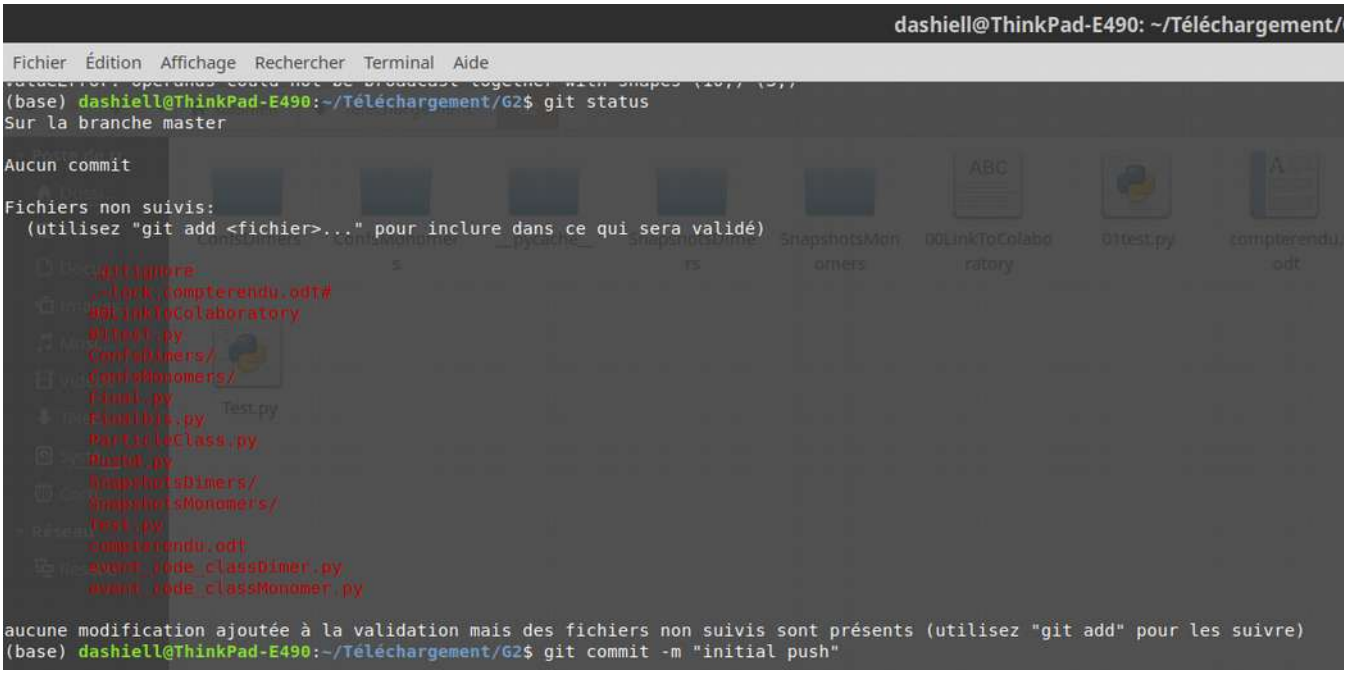
Annexe : Why couldn’t we push on github ?

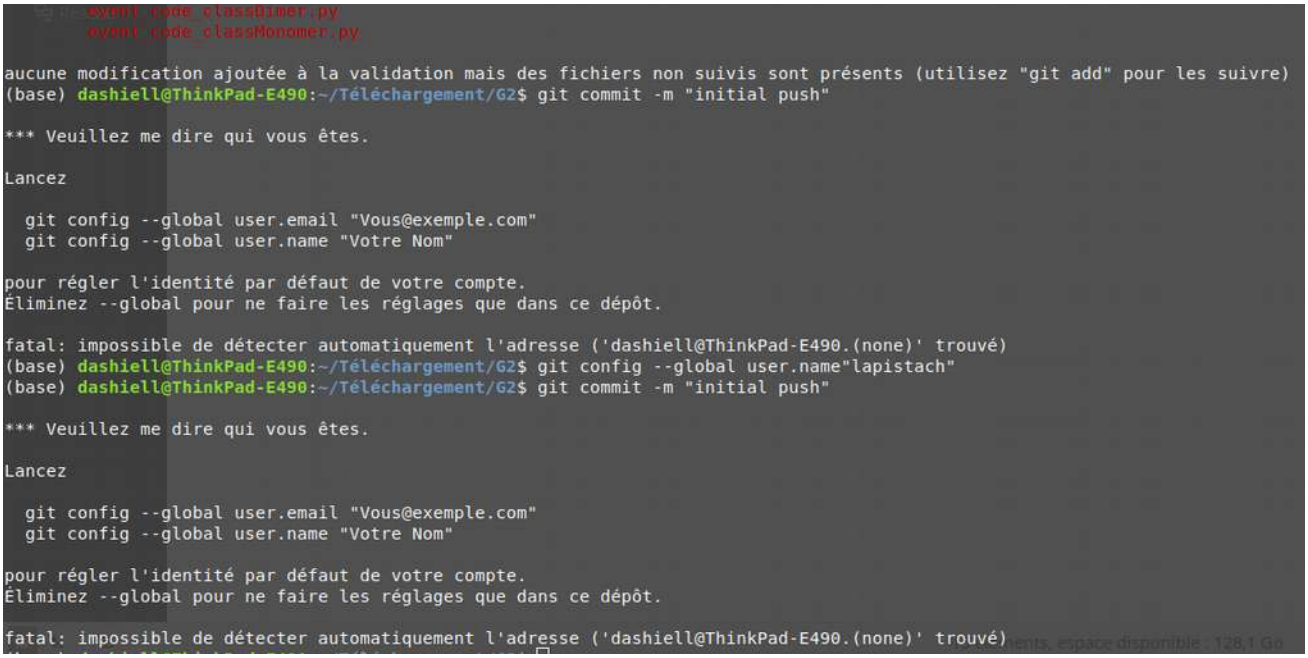
I followed a tutorial on the internet to pull and push on github. However, I must’ve done something wrong in the beginning, because after forking your project, I tried to clone it and didn’t succeed :



This was after creating a git deposit. My password would just not work although I am 100 percent positive that it is the good password (I tried it on github to verify multiple times).

Later I tried this as well :





So I just couldn’t clone the project, therefore I couldn’t pull it. Consequently, I couldn’t push it… Since I wasn’t very acquainted with github, I had firstly tried to push the project that I had downloaded (not pulled but downloaded) but of course this didn’t work either.
I asked for help around me but nobody could find the problem so I just gave up on that one and put the pushes in new repositories in public mode so that you can see our progression.

I would like to add that I tried the tutorial with another document (the one of the tutorial) and I succeeded to pull and push. I suppose that I initially did something wrong blocking me from pulling and pushing this project in particular. Sorry…