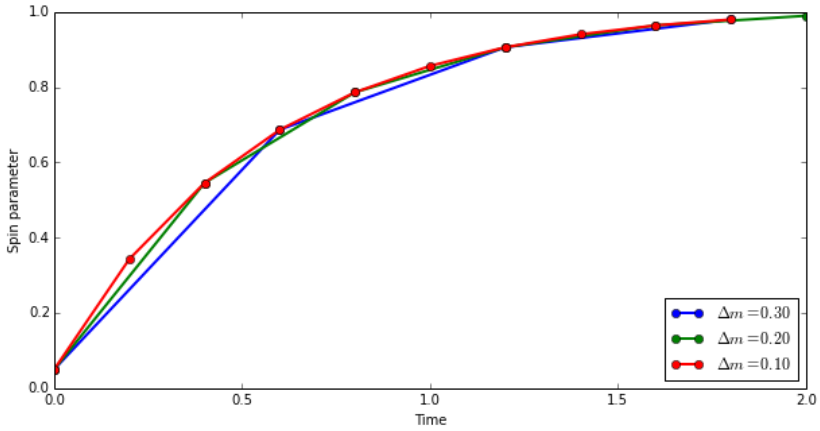
Things to discuss

1 Bondi Accretion

Is Bondi accretion physically consistent with the disk model I am using for spin evolution? Is there some possible way to implement other accretion model?

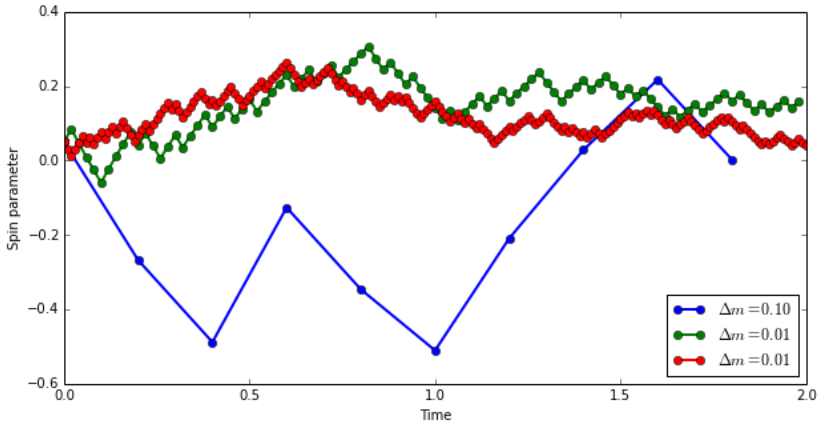
2 Mass interval in spin parameter evolution

Checking dependence on mass per accretion episode in equation of spin evolution. The solution given by (Bardeen, 1970) is exact as any interval gives the same solution. However, this cannot be randomly chosen in the code as there is a probability of spin-flip in both, the chaotic and prolonged mode.

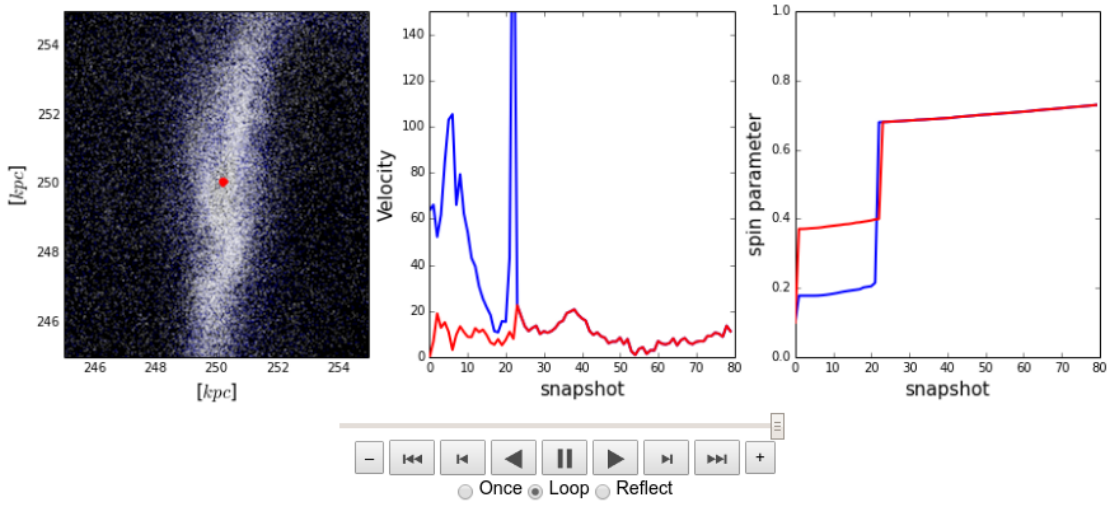


3 Recoil speed

The recoil velocity after a merger is already working, however there is some issues regarding the way the two black holes approach to each other. Using the repositioning scheme, sometimes both BHs are forced to be in the same position at the same time, which makes the code crash. Using the drag-force as an approximation of dynamical friction is much better, however as it depends linearly on the speed of the BH, the kick is quickly compensated. This

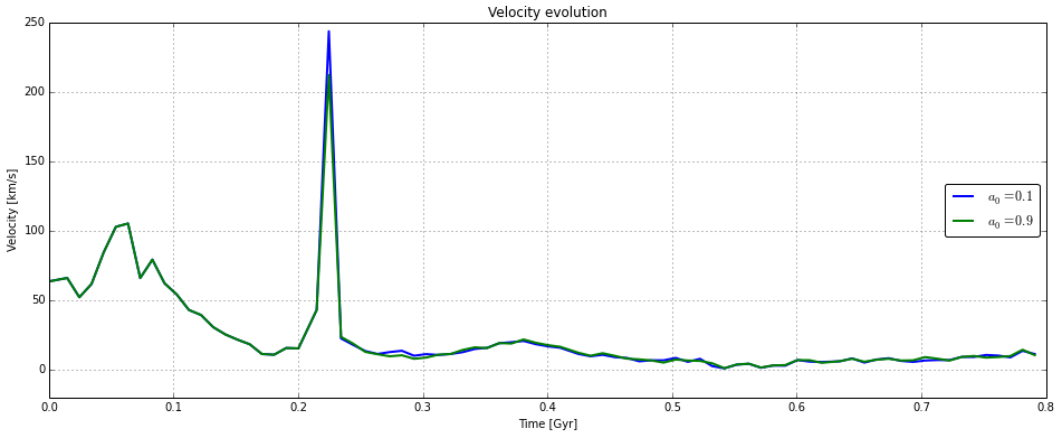


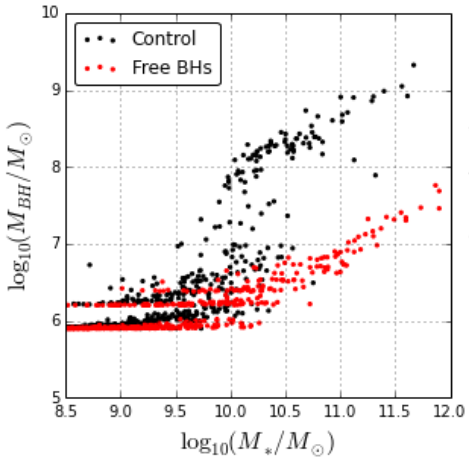
would be different with the Chandrasekhar formula, as the faster the BH goes, the fewer stars with a higher speed to slow it down.

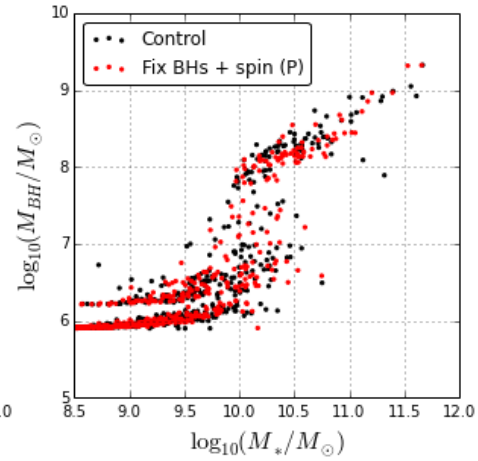


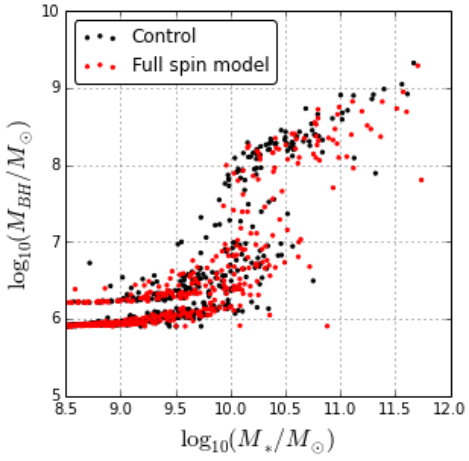
4 BH mass relation

I have run four different simulations. The control one with the fiducial model which serves as a control run. Second, the same fiducial model, but freeing the BHs from the potential centre. The BHmass-Stellar mass is not reproduced at all as the BHs wander around low density regions, thereby decreasing their accretion rates. The third run is the same fiducial model, but introducing spin evolution. The results are basically the same as the spin module (without recoils) doesn't have any effect on the physics. Finally, the last run implements the full spin model, including recoils. However, in order to avoid numerical crashes, the drag-force dynamical friction is implemented. The BH mass relation is reproduced, but it seems to be more spread out. The resolution of the simulation is low though.


Velocity evolution
Velocity [km/s]
Time [Gyr]
$a_0 = 0.1$
$a_0 = 0.9$

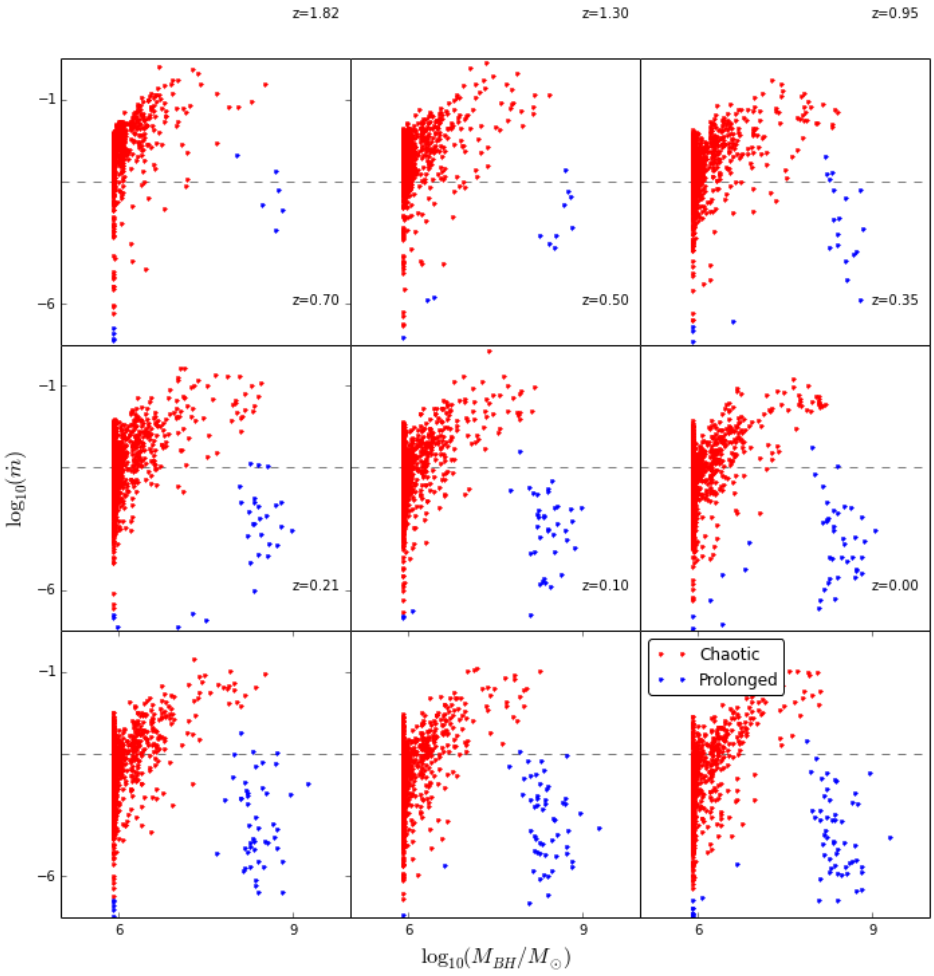

Control
Free BHs
$\log_{10}(M_{BH}/M_\odot)$
$\log_{10}(M_*/M_\odot)$


Control
Fix BHs + spin (P)
$\log_{10}(M_{BH}/M_\odot)$
$\log_{10}(M_*/M_\odot)$

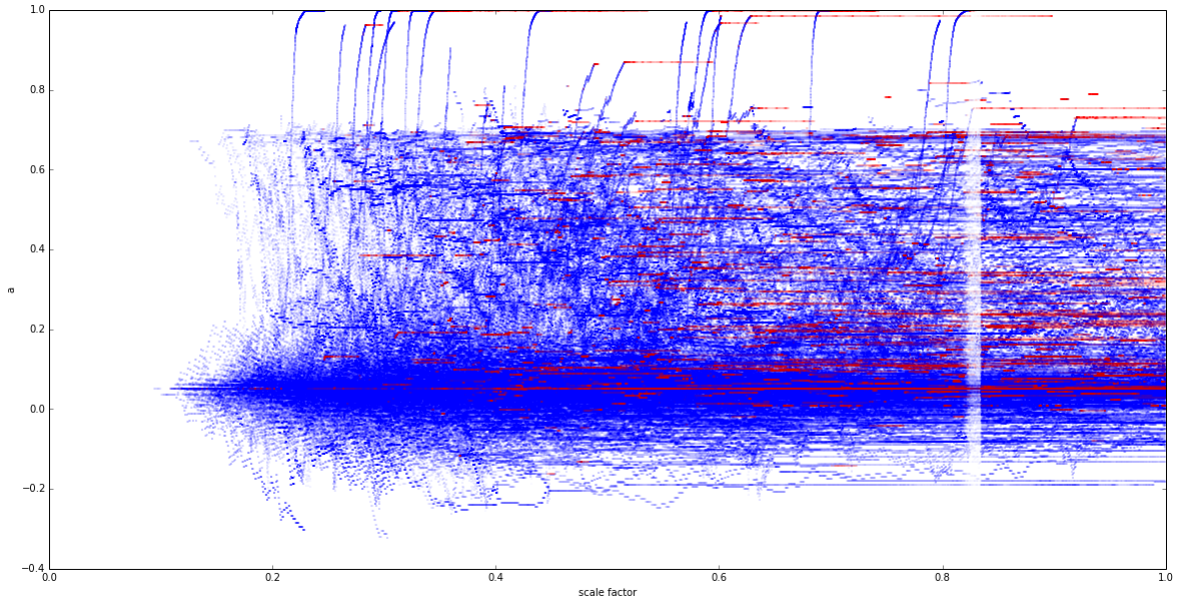

Control
Full spin model
$\log_{10}(M_{BH}/M_\odot)$
$\log_{10}(M_*/M_\odot)$

5 Transition between chaotic and prolonged modes

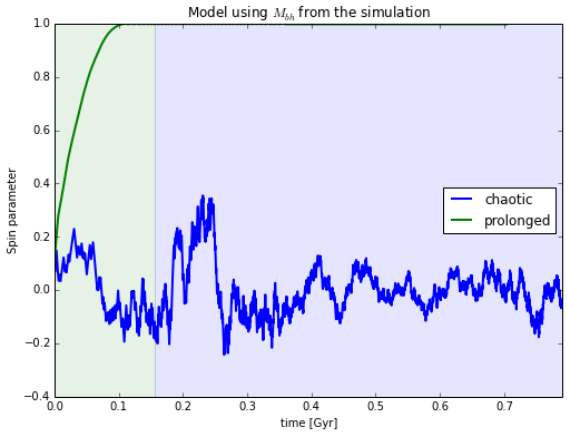
Right now I implemented in the code a switch of spin model using the same mass-dependent criterion for the quasar or radio mode. However, there seem to be a issue with this. The transition to the radio mode (prolonged spin mode) from the quasar mode (chaotic spin mode) seems to happen a bit late, where the mass accretion rate is too low that the spin is basically not evolving during the prolonged mode.

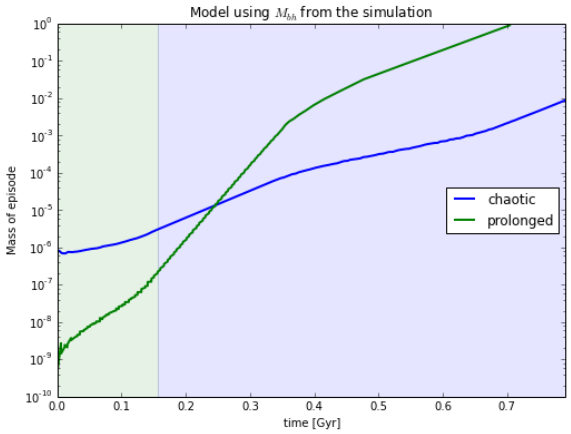


The high spin values reached in the chaotic mode are a result of a bug in the code, where I was using a value for the spin of the disk computed with the formula of the prolonged mode, yielding to high values and then the randomization of the direction of angular momentum was lost, pointing always pointing in the direction of the BH's spin. I am running a new simulation where this is corrected. Presumably only low to middle spin values will be observed. The coalescence of black holes is another mechanism to raise the spin value.



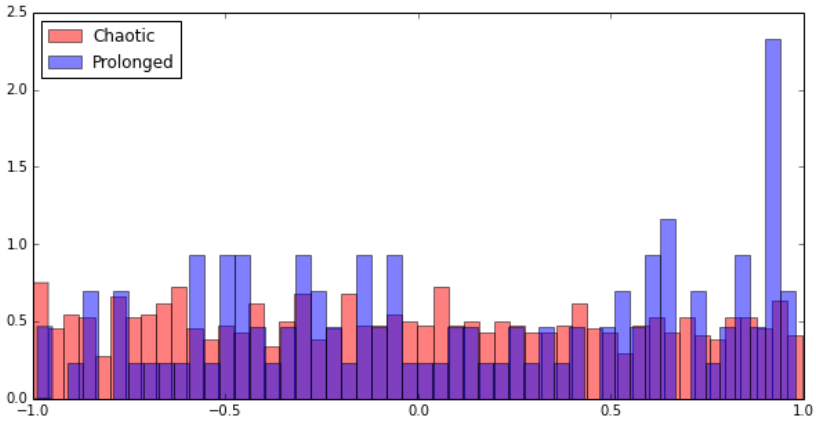
It is perhaps a better idea to apply a new criterion where the mass per episode in both modes are compared. So, whatever value is the smallest, the respective mode will be implemented. This has physical sense as the amount of mass accreted from self-gravitating disk should be smaller than whole mass inside the warped region. The question remaining should be whether to apply this only to the spin, or also extending it to the definition of the quasar/radio mode transition.

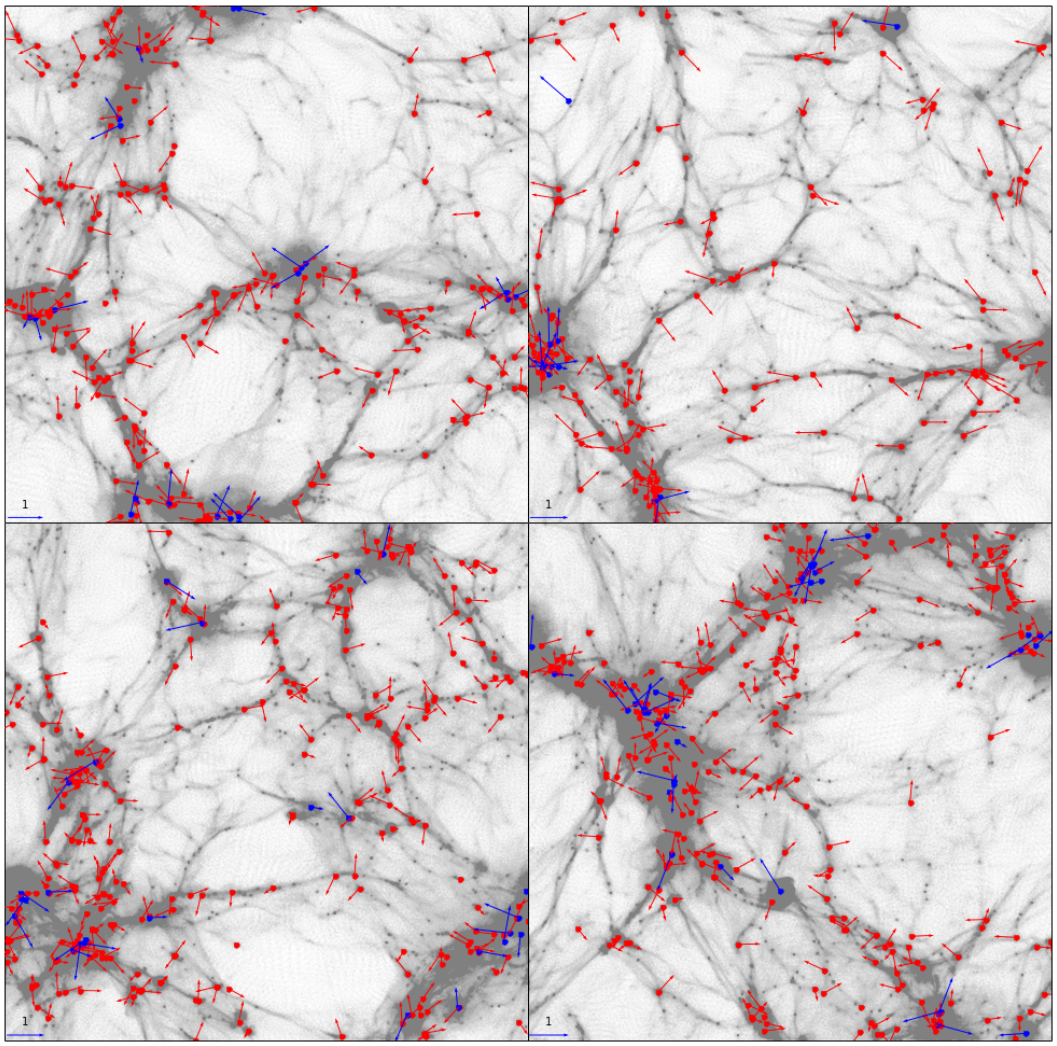




6 Spin alignment

I also was trying to study spin alignment as I am able to model direction evolution. At the moment it makes no much sense as the prolonged mode, where the BH's tend to align to the angular momentum of the neighbouring gas cells, is not properly working for all the BHs. However, it is interesting to verify that there is a tendency toward alignment.


Chaotic
Prolonged
2.5
2.0
1.5
1.0
0.5
0.0
−1.0
−0.5
0.0
0.5
1.0



7 Future work

- Further tests of the model.
- Original idea. Study dynamical friction and recoil velocities. This would require to focus on a more realistic dynamical friction treatment.
- Spin model itself. Study the spin evolution and the transition between modes. Maybe we can explore a new criterion based on the mass per episode.
- As an extension of the previous item, we can study spin-depended accretion efficiencies. This may have effects on the BH feedback and more interestingly, on the growth of seeds.
- An idea I was discussing with Rainer, which is about using the spin model along with his module of jet emissions. For example the jet can be applied in the direction of the spin, and it can also be another mechanism of spin evolution as the jet power comes from rotational energy of the BH.
- Considering this, it might be interesting to study large-scale alignment of spin (jets) with galaxies and their environment. To this purpose, we can use Jaime's code for calculating the Tweb/Vweb of cosmological simulations.