Research Proposal : Evolution of the MW/M31 Super Massive Black hole throughout the Merger Sequence (prior to final coalescence)

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1 INTRODUCTION

We shall first define the proposed topic : We would be simulating the mass of Super Massive Black Hole(SMBH) of M31 and M33 using the M-σ relationship for galaxies. In this relationship M stands for Mass of SMBH present at the center of the galaxy and σ represents the stellar velocity dispersion (1) of the galaxy bulge particles (concentrated at the center) . The topic matters to our current understanding because, first of all this relation helps us to measure the mass of SMBH in distant galaxies which is otherwise not possible by direct observation. The presence of this relation also establishes the fact that black hole affects the properties of the galaxies. As earlier it was thought that as SMBH have a low gravitational potential compared to the host galaxy so, it shouldn't influence galaxy formation in any way. However, as this relation relates the black hole mass to the velocity dispersion of the galaxy, which is itself a intrinsic property of a galaxy, this lead the astronomical society to believe that SMBH directly influences galaxy formation. Our current understanding of the topic is that scientists have agreed that indeed M-σ gives a good estimate of SMBH mass as, the SMBH mass of several nearby galaxies have been computed and that agrees with the measurement by other methods(3). Moreover, the following equation governs the M-σ relation (5) :

$$M = M_{sun} \times 10^8 \times A \left(\frac{\sigma}{200Kms^{-1}}\right)^{\alpha} \quad (1)$$

In equation 1 , many different models predict different values of A and σ . According to the recent studies the value for A is around 1.9 and value for alpha is around 5. Scientists are studying different models of how SMBH influences the evolution of the host galaxy.The most prevailing model is the active galactic wind feedback model. The outflows generated from the accretion disc of these SMBH can play a important role in the galaxy formation by affecting its star formation rate amongst many causes. The current open research questions in the field are those pertaining to the accuracy of this relation. Although quite a few SMBH measurements have been verified by this relation, but still we don't have enough sample space to conclude that this relation applies to all the galaxies in general. Moreover, not all galaxies have their SMBH at their center so, does the M-σ relation works on these galaxies? Moreover, M-σ doesn't do well on lower and high regimes. For example : M-σ predicts the SMBH mass for NGC 1277(4) to be equal to $2.5 \times 10^5 M_{sun}$, however the actual mass is grater by a factor of 7. So, testing the M-σ relation on lower and high end of SMBH masses. Also, on a bigger picture the M-σ relation can help us answer the famous puzzle, that what came first : SMBH or the host galaxy?

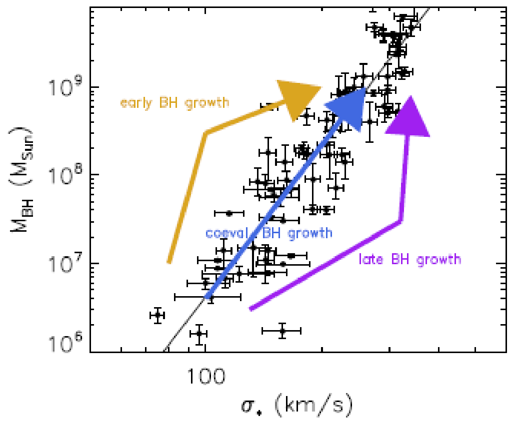

Figure 1. This figure (2) displays the evolution of black hole mass in accordance with the $M - \sigma$ relation. It explores the growth of black hole with respect to the galaxy bulge.

Figure 1 serves as the motivation for my project.

2 PROPOSAL

The specific question I am going to answer are : I would explore the validity of M-σ relation . I would study the relation before and during the merger of MW and M31 and see whether the mass of the SMBH of the two galaxies change throughout the merger sequence. Also, would the velocity dispersion of the combined bulge indicate that the mass of the resulting SMBH is just the sum of the two black holes masses or is it different than that? We would also study how to calculate the velocity dispersion, as velocity dispersion depends on the component of velocity that lies along the line of sight of the observer. So, we would calculate velocity dispersion in all 3 different directions (x,y,z) and put them into equation 1 and see whether we get same SMBH mass at each snapshot or not. Overall I would have two plots, one would be the time evolution of velocity dispersion and other would be the time evolution of the SMBH.

Now, here I would like to describe the way I would approach the problem.

Main idea is to use the simulation data, to find dispersion velocity at every snapshot of time and then plot Mass of SMBH using the M-σ relation. Here I shall present the detailed procedure.

1 We need to calculate the velocity dispersion of the bulge particles at each snapshot of time. We cannot use all the bulge particles, because, only the bulge particles near to center are involved in the M-σ relation. So, for that we need to find the effective radius (R_e of MW and M31 at each snapshot of time.

2 To find (R_e we will use the COM code developed in the homework where we plot the bulge mass profile as a function of radius. From this we will calculate the radius that contains half the total bulge mass.

3 Now, we would index all the bulge particles that lie within (R_e . Now, for each of these particles we have the x, y, and z component of velocity. So we shall compute the velocity dispersion that is the standard deviation in x, y and z separately for each of these particles. For example for x direction : we make an array that contains v_x of the selected particles. Now we use the stdev() in built function to find the standard deviation of the array. We follow the same procedure for v_y and v_z

4 We need to be careful during when the merger starts and during the merger, a snow we cannot treat MW and M31 as two separate entities. So, first of all we need to find the snapshot of time when merger starts using the orbital separation code we developed. From this snapshot onwards, we need to find the effective radii of the remnant. So, now would have a single value for velocity dispersion in x direction for the remnant contrary to two values before the merger as, then we were treating MW and M31 to be separate entities.

5 Now, at each snapshot, for each galaxy we shall plot the velocity dispersion with time for x, y and z components on a single graph

6 If the velocity dispersion is isotropic, then we can choose one of the velocity dispersion array and plug that into :

$$M = M_{sun} \times 10^8 \times 1.9 \left(\frac{\sigma}{200 Kms^{-1}}\right)^5 \tag{2}$$

to find the SMBH mass for M31 and M33 respectively. if velocity dispersion is not isotropic , then we would find SMBH mass using equation 2 using all three components separately, and try to ponder over the difference.

7 So, we would plot the SMBH mass trajectory with respect to time for MW and M31 on the same plot.

8 Now, at the time of merger, we would observe the behaviour of the black hole trajectories and see whether during merger the trajectories are just adding up or something else happens.

We shall have these two figures as shown in figure 2 as our result (here I am assuming that we get an isotropic velocity dispersion, else, we would have 3 set of figures, one for each direction).

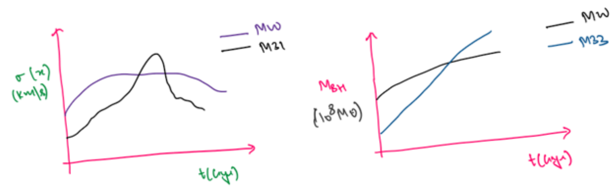

Figure 2. a) Diagram on the left displays that we would be plotting the time evolution of velocity dispersion with respect to time. In this figure we are plotting the x component. We have to make plots for y and z as well if, the velocity dispersion is not isotropic. b.) The figure on the right , displays the time evolution of SMBH for M31 and M33 . These are example plots and not to scale. Here I am just demonstrating the plots that I would be working upon in my project

Our hypothesis is that, the SMBH mass of the remnant would be less than the sum of the SMBH masses just before the merger because, during galaxy merger, black holes of the galaxies also merge and such an event is so luminous that they loose energy in form of gravitational radiation[(6)]. So, the gravitational potential energy of the black holes is carried away by the gravitational waves, and hence the merged back hole, has lesser total mass than expected. So, we shall see, whether the $M - \sigma$ relation confirms this or not.

REFERENCES

[1] Warren R Brown, Margaret J Geller, Scott J Kenyon, and Antonaldo Diaferio. Velocity dispersion profile of the milky way halo. *The Astronomical Journal*, 139(1):59, 2009.

[2] Kayhan Gültekin, Douglas O Richstone, Karl Gebhardt, Tod R Lauer, Scott Tremaine, Monique C Aller, Ralf Bender, Alan Dressler, SM Faber, Alexei V Filippenko, et al. The m–σ and m–l relations in galactic bulges, and determinations of their intrinsic scatter. *The Astrophysical Journal*, 698(1):198, 2009.

[3] Teruaki Suyama and So Okano. Testing time evolution of mass distribution of black hole mergers. *Astrophysics and Space Science*, 368(1):5, 2023.

[4] Ignacio Trujillo, Anna Ferré-Mateu, Marc Balcells, Alexandre Vazdekis, and Patricia Sánchez-Blázquez. Ngc 1277: a massive compact relic galaxy in the nearby universe. *The Astrophysical Journal Letters*, 780(2):L20, 2013.

[5] Kastytis Zubovas and Andrew R King. The m-σ relation between supermassive black holes and their host galaxies. *General Relativity and Gravitation*, 51(5):65, 2019.

[6] Simon F Portegies Zwart and Stephen LW McMillan. Black hole mergers in the universe. *The Astrophysical Journal*, 528(1):L17, 1999.