Paper II: A Fundamental Relation Between Supermassive Black Holes and Their Host Galaxies

Background:

Supermassive black holes (SMBHs) exist in the centers of most galaxies, including our own. These black holes are 10^6-10^9 times the mass of the Sun. There are many smaller black holes (1-100 times the mass of the Sun) that populate galaxies. These “stellar mass” black holes are the remnants of dead stars. Stars more massive than our sun (about 8 or more times as massive) will end their life by having their cores (the place where all the fusion happens) collapse under their own gravity. This collapse is what causes the rest of the star to explode in an event called a *supernova*. The collapsed core is all that is left behind, but now it is a black hole. All of the mass has collapsed into a singularity.

The boundary of a black hole is the *event horizon.* This represents the radius around the singularity where the *escape velocity* is equal to the speed of light. Nothing in the Universe travels faster than light, so beyond the event horizon nothing can escape the black hole’s gravity, not even light (hence “black”).

How these SMBHs came about is still a mystery. It is very unlikely that they were created the same way as stellar mass black holes. It would likely take longer than the age of the Universe to accumulate that much mass from such small initial masses! So, where these back holes came from and how they grew to be so large is an area of active research. Remember that these SMBHs exist within galaxies, so it is likely that the growth of a SMBH is related to the evolution of their host galaxy. How exactly the two are connected is still largely unknown. To find answers, we look for physical relationships between a galaxy and its central black hole.

After reading this paper, answer the following questions:

1) Explain the point of figures 1 and 2. What are they plotting and why did they plot it?
2) The authors use two different sets of data, “A” and “B”. What is the difference between them? The authors say that some of the black hole data is unreliable. What is their rationale for this?
3) At the end of Section 3, the authors talk about how their newfound relation could just be due to dynamics. Why would this make the result less interesting?
4) How do the authors refute the above idea that their results “simply reflect the influence of the BH on stellar kinematics”? **Hint**: This is a hard one... think about how gravity works. It goes as the *inverse of the distance squared*. That means that the *gravitational influence* of any object drops off rapidly with distance.

Glossary:

<u>Absolute Luminosity</u>: How bright an object actually is, i.e. the rate it is emitting photons.

<u>Aperture</u>: Essentially this is what the observers define as the extent of the galaxy.

<u>Bulge</u>: This is a region of *Spiral galaxies* (see below) located in the central regions. Unlike the rest of the disk, within which stars follow nice, orderly orbits, the bulge stars are more ‘messy’. The bulge is spherical, which means the orbits are more random in their direction and inclination (like an *elliptical galaxy* -- see below)

<u>Elliptical/Early-type Galaxies</u>: These galaxies are spherical in nature. They don’t have much gas and they mainly have older stars in them. They also tend to be more massive. The orbits of stars in these galaxies tend to be random, happening in all directions, inclinations, and eccentricities.

<u>Extinction/Absorption</u>: Dust and gas within both their host galaxies and our own galaxy before they come to earth, so the light we see is not all the light that is emitted. Correcting for these effects is important.

<u>Hubble type/T-type</u>: These are just different ways of categorizing the *morphology* of galaxies (i.e. are how spiral or elliptical-like they are).

<u>Lenticular Galaxy</u>: intermediate between a *spiral* and an *elliptical* galaxy.

<u>$M_\odot$</u> : A unit of mass called “solar masses”, or “number of times the mass of the sun”.

<u>Parsec</u>: A unit of distance. It is equal to about 3.26 light years.

<u>Radial Velocity</u>: Here, this refers to velocity toward/away from the center of a galaxy.

<u>RMS</u>: “Root mean squared”; This is just the square root of the average of the square of a value, x; $\sqrt{(< x^2 >)}$ (the $< ... >$ = average/mean). This is often used as a way of defining the magnitude of a varying quantity.

<u>Spiral/Disk/Late-type Galaxies</u>: These galaxies are disk galaxies like our own. They tend to have spiral arms and a lot of gas, dust, and active star formation. They tend to have a mixture of old and young stellar populations. Stars in the disk are orderly, in that the all have orbits with similar inclinations and directions (hence, why the form a “disk”)

<u>Velocity dispersion</u>: This is essentially a measure of the randomness of orbits. A higher velocity dispersion means you have a higher variety of orbits -- less ordered, more “spherical”.