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Chapter 1

Introduction

There is a super massive black hole (SMBH) at the center of galaxies. It resides in the bulge of its host galaxy. These SMBHs have a mass $M_\bullet \sim 10^6 - 10^{10} M_\odot$, expressed in solar masses. Similar to galaxy formation, not much is known about the formation of these SMBHs. Additionally the evolution of the bulge and the respective SMBH is not well understood either. To get new insights into the formation and evolution, one can investigate the correlation between the properties of the SMBH and their host galaxies, especially the bulges. The bulge is large enough not to be under the direct gravitational influence of the SMBH, so any correlations must be caused by either evolution or formation. The most important property of a black hole is its mass, so that will the studied property be. One can find a close relation between the black hole mass and the stellar velocity dispersion, the luminosity and the mass of the bulge. These will the properties be discussed in this literature review. There are formation and evolution models trying to reproduce these correlations. One such evolution model will be discussed. Lou and Jiang proposed a modell describing the bulge as a self similar, polytropic quasi-static fluid with self gravity and spherical symmetry.

Chapter 2

bulge relations

2.1 bulge stellar velocity dispersion

- dispersion is the (statistical) scatter
- (figure)
- linear in double logarithmic plot
- $M_\bullet \propto \sigma_e^\beta$
  - bulges $\beta = 3.86 \pm 0.71$
  - pseudo bulges $\beta = 5.63 \pm 0.86$
- tightest relation, scatter
  - early types $\epsilon = 0.38 \pm 0.04 dex$
  - late types $\epsilon = 0.53 \pm 0.14 dex$
- other sources find similar relations in all three parameters

2.2 bulge luminosity

- much more biases compared to velocity dispersion
- correction for
  - dependency on hubble constant
  - dust attenuation in the bulges of disc galaxies
  - mis-classification of lenticular galaxies as ellipticals
- (figure)

- $M_\bullet - L_{i,bulge}$ relation slightly less tight, larger scatter
- no dependency on morphological type or nuclear activity

2.3 bulge mass

- the connection to bulge luminosity suggests a linear dependency on bulge mass
- (figure)
- more scattering than the stellar velocity dispersion
- expected: one additional fitting parameter (radius)
- but less than bulge luminosity
- still no dependency on morphological type or nuclear activity

2.4 Linear Combinations of Parameters

- one might expect, that the correlations depend on more than one parameter
- that would lead to a reduced scatter and improved accuracy
- no combination offers a significant improvement
- there is a direct correlation between bulge mass and luminosity expected, so the correlation of these two with SMBH mass is no new.

Chapter 3

Self similar, polytropic quasi-static fluid

After earlier studies of the dynamics of self similar polytropic fluids, Lou and Wang found a quasi-static solution which approaches singular polytropic spheres at infinity. These models have been used to study proto star formation, formation of compact stellar objects, galaxy clusters as well as other stellar and galactic phenomena. Lou and Jiang used this solution to describe the bulge and its central SMBH.

For their model, they adopted a few simplifications. First they assumed that the bulge age is large, so the fluid is continously relaxed. Secondly the stars are described as a stellar fluid and the interstellar medium is merged into said fluid, because of negligible mass. Thirdly small scale structures like the AGNs and the disc around the SMBH are ignored.

With these assumptions they described the bulge as a general polytropic fluid, where the stellar velocity dispersion leads to pressure counteracting the self gravitation. To solve the hydrodynamic equations a self-similar transformation was used. The solution is dependent on to scaling indices K and n and the polytropic index γ.

To see the desired correlation, one has to compute the two properties. Because the mean stellar dispersion results in a pressure, one can derive it from the found solution for the pressure. To find the mass of the SMBH one computes the enclosed mass in a sphere with a given radius by integrating the density, which is also found as a solution of the hydrodynamic equations. This mass is then compared to the mass needed to produce a Schwarzschild radius. The intersection of these two is the mass of the black hole.

Ultimately Lou and Jiang found the relation $M_\bullet \propto \sigma^{1/(1-n)}$ with $2/3 < n < 1$ for positive mass. Different galaxies are described by a different K value. This model can reproduce the empirical relation between black hole mass and stellar velocity dispersion for bulges, which leads to a fixed n. With a given n one can derive other relations, for example between black hole mass and bulge mass, again reproducing empirical data.

One can try to describe pseudo bulges with this model and get the correct velocity dispersion relation. This leads to a different n and therefore a different bulge mass relation. This contradicts empirical data, because this relation is independent on morphology. The is not a flaw in the model, because one assumes spherical symmetry and pseudo bulges are no spheres and might have significant substructures.