Physics 781 Term Report:

Bulges, Black Holes, and Cores:

A Review of the $M_{BH} - \sigma$ and $M_{BH} - M_{bulge}$ Relation in Theory & Observation

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1 Introduction

when one examines the structure and evolution of a galaxy, at first glance it would seem that the central supermassive black hole (SMBH) would play a minimal role in the larger observable properties of the galaxy. On both mass and length scales, the SMBH is small compared to the galaxy as a whole. For a typical Milky-Way type galaxy, the SMBH mass is 4 orders of magnitude less than the total baryonic mass of the galaxy ($4 * 10^6 M_\odot$ vs $6 * 10^{10} M\odot$). The Schwartzchild radius of this black hole is even further from the scale of the galaxy, falling 11 orders of magnitude smaller than the disk radius ($4*10^{-7}$pc vs. 25kpc). Recent developments have shown, however, for the spheroidal bulge component of disk galaxies, the mass of this SMBH has a tight correllation with the large scale properties of the bulge, most notably the total bulge mass and the velocity dispersion of stars within the disk. Upon a more thorough examination of the physical processes governing this system, and the history of its evolution, it should become clear to the reader that this is neither particularly mysterious nor is it truly something that should be unexpected. Despite this, there still remains some uncertainty regarding the precise nature of these (hence refered to as the $M_{BH} - M_{bulge}$ and $M_{BH} - \sigma$) relations. In this paper, I hope to guide the reader to an understanding of the theory behind these observations, as well as the current state of knowledge on the topic.

2 Background & Observations

Simply by looking at night sky from a southern location, one can deduce that the Milky Way galaxy is densest in a region lying in the constellation Saggitarius. Kapteyn was able to determine, roughly a century ago, that the shape of our galaxy was that of a disk, and that our sun roughly halway along the radius of this disk. Close examination of the core region, Sgr A, has until relatively recently, been difficult due optically thick obscuring dust. With the advent of long wavelength astronomy, it has become possible to directly image stars and gas within the galactic core. It has been known from infrared observations since Genzel & Townes 1987 that the core radius of the galaxy is extremely compact, with current estimates placing it at ≈ 0.5pc in radius (Merrit 2010). Warm gas and dust have also been observed in infrared and radio wavelengths at higher densities in this core region.

2.1 A Central, Supermassive Black Hole

Within the core region of Sgr A exists a bright radio and hard X-ray emitter, Sgr A*. X-ray observations of this source have constrained it to being highly compact, and extremely hot ($10^8 - 10^{10}$K). This observation points towards a highly energetic source within the core. This source explained originally by two competing models: a driving SMBH, heating gas through accretion, or a particularly violent and compact region of starburst activity. The X-ray emission observed within this core region constrained the mass of the black hole only very loosely ($M_{BH} > 100M_\odot$) if starburst activity and UV heating of the gas was the source of the gas heating. The starburst model truly fails in the face of one important datum: the enclosed mass of the core. By examining the rotation curve of stars and gas very close to the core, the mass enclosed by that core was able to be determined, as is shown in figure NUM. As is clear from the figure, the SMBH model is a perfect fit for the observed rotation curve. In addition to this, the densities for the core are so large that there is no configuration of stars that could be long lived at that density. Currently, the SMBH hypothesis is the consensus view of the dark mass at the galactic center.

The SMBH hypothesis explaining the central dark mass of the Milky Way was an attractive answer for another group of astronomers working on a separate question: quasars. The extremely high luminosity (on the order of $10^{13} L\odot$) of these objects was a mystery for a number of years, and hinted at a driving engine far more energetic than any stellar effects could account for. As the physics of black hole accretion developed, it was realized that accretion onto a SMBH could easily produce the luminosity of quasars. As quasars were hypothesized as the early stages of modern disk galaxies, the existence of an SMBH in the Milky Way was taken as further confirmation of the SMBH accretion model of quasar emission. Further evidence of both the quasar connection and the SMBH hypothesis was found in the form of radio variability in the form of rapid flares in radio intensity coming from Sgr A*, corresponding to the accretion of stars or dense clouds.

2.2 Extragalactic SMBHs

Regardless of what the Copernican principle might tell us, the existence of a SMBH within the Milky Way is insufficient evidence for any sort of universal relationship between disk galaxies and SMBHs. In the decades following the discovery of the Milky Way SMBH, gas and stellar dynamical observations were made of nearby disk galaxies, and in a number of these galaxies, similar mass distributions were found to that of our own galaxy. Both gas and stellar velocity distributions in the inner few parsecs of numerous disk galaxies, including our two nearest disk neighbours M31 and M33, suggested the presence of a SMBH within them. It is now believed that the majority of disk galaxies contain a SMBH at their core (Magorrian et al. 1997 places the fraction at 97% for early-type galaxies).

2.3 The $M_{BH} - M_{bulge}$ and $M_{BH} - \sigma$ Relations

We are used to seeing relations between masses and velocity distributions before in the form of the Tully-Fisher and Faber-Jackson relations for galaxies (though in these cases, it is an indirect measure of stellar mass through their luminosity). This should not come as much of a suprise to us, since the Virial Theorem tells us there must be a relation between the kinetic energy and the enclosed mass. In the case of galactic spheroids, a similar relation is observed between the total bulge mass, the stellar velocity dispersion σ within the bulge, and the mass of the black hole. By measuring the mass of the central dark object (the SMBH) through velocity dispersions at very small radii and the mass of the bulge through dispersions at larger radii, a number of studies (Magorrian et al. 1997, Ford et al. 1997, and others) found that the SMBH and bulge masses were fairly well correlated, with a M_{BH} between $2 * 10^{-3} M_{bulge}$ and $6 * 10^{-3} M_{bulge}$. Observers, as one might imagine, also found a correlation between

3 Theory

While observations have done an excellent job of showing the *existence* of the $M_{BH} - \sigma$ relation, they leave open the obvious question as to the nature of this relation, namely how and why it arises. The first major attempt to answer this question was presented in Silk & Rees 1998, with a coevolution model. This model starts from rather simple assumptions. First, they assume that some primoridal gas clouds collapse to form

4 Recent Developments

5 Conclusion

References

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