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 ($M_{BH} > 100 M_\odot$) 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.

2.2 Extragalactic SMBHs

2.3 The $M_{BH} - \sigma$ Relation

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.

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.

4 Recent Developments

5 Conclusion

References

1. *Exploring the unusually high black hole-to-bulge mass ratios in NGC4342 and NGC4291: the asynchronous growth of bulges and black holes* Bogdan et al., submitted to ApJ, retrieved via arXiv 2012

2. *The Distribution of Stars and Stellar Remnants at the Galactic Center* Merritt, ApJ 718, 2010

3. *The Supermassive Black Hole at the Galactic Center* Melia & Falcke, ARAA 39, 2001

4. *Quasars and Galaxy Formation* Silk & Rees, A&A 331, 1998.

5. *Inward Bound – The Search for Supermassive Black Holes in Galaxtic Nuclei* Kormendy & Richstone, ARAA 33, 1995

6. *Physical Conditions, Dynamics, and Mass Distribution in the Center of the Galaxy* Genzel & Townes, ARAA 25, 1987