Supermassive Black Holes

Course 689 Presentation

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A Fundamental Relation Between Supermassive Black Holes and their host Galaxies[1]

Laura Ferrarese, David Merritt

(Published August 2000)

Beyond the Bulge: A Fundamental Relation Between Supermassive Black Holes and Dark Matter Halos

Laura Ferrarese

(Published October 2002)

Note 1: 1501 citations to date

Outline of the Presentation

- M_{BH} and σ_c relation (Ferrarese & Merritt 2000)
- M_{BH} and M_{DM} relation (Ferrarese 2002)
- M_{BH} and M_{tot} relation using gravitational lensing data (Bandara et al 2009)
- Possible explanations of $M_{BH} - M_{tot}$ relation

σ_c : Velocity dispersion at central bulge
$M_{DM} \approx M_{tot}$

M_{BH} versus Bulge Central Velocity Dispersion

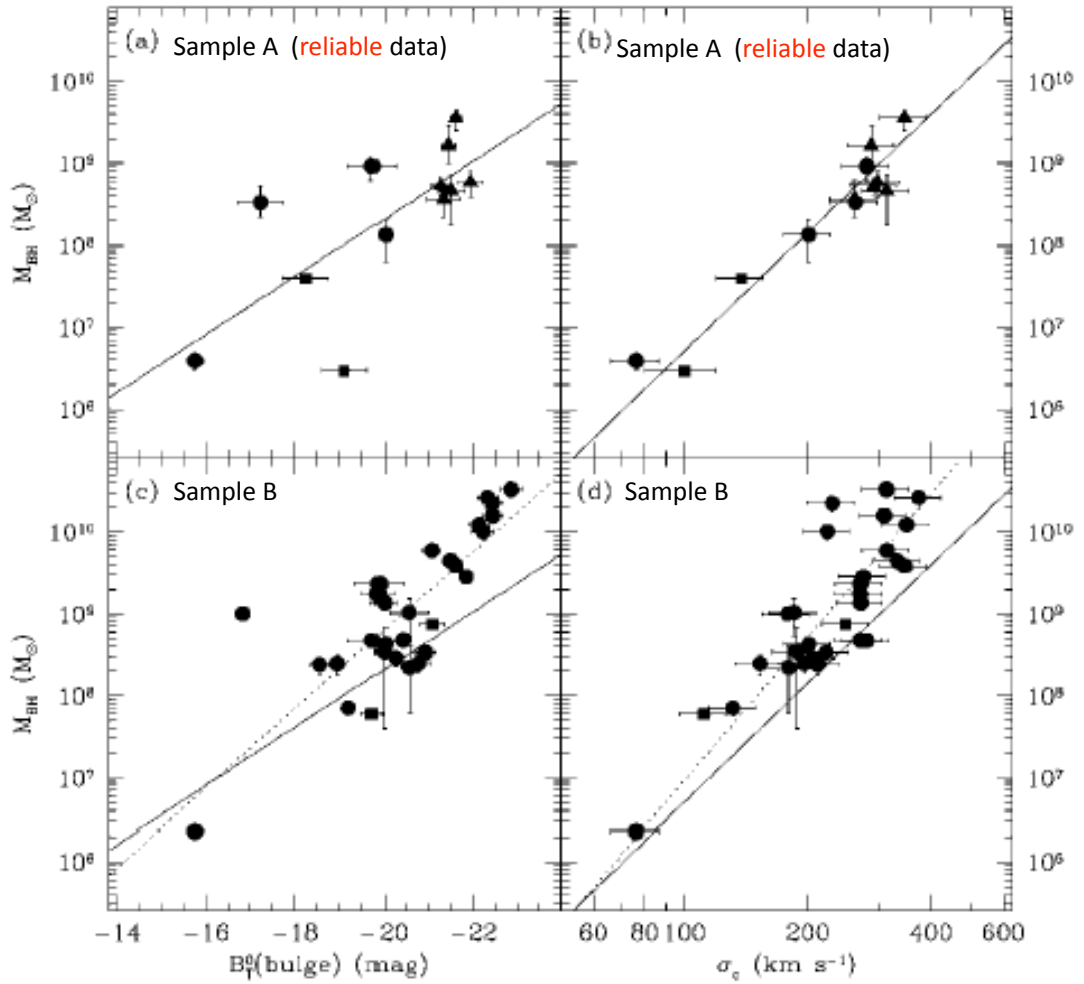
(Ferrarese & Merritt 2000)

- First study of the relation between M_{BH} and the stellar velocity dispersion of the host galaxy.
- Two group samples of galaxies:
  - Group A: Reliable M_{BH} estimates including MW , NGC 4525, and 10 galaxies from HST observations.
  - Group B: Less accurate M_{BH} data from ground based observations of stellar kinematics.

MW : motion of stars in Sagittarius A
NGC 4525 : water maser

Correlation between M_{BH} and Bulge Central Velocity Dispersion σ_c

M_{BH} versus Bulge Absolute Blue Luminosity (Left)

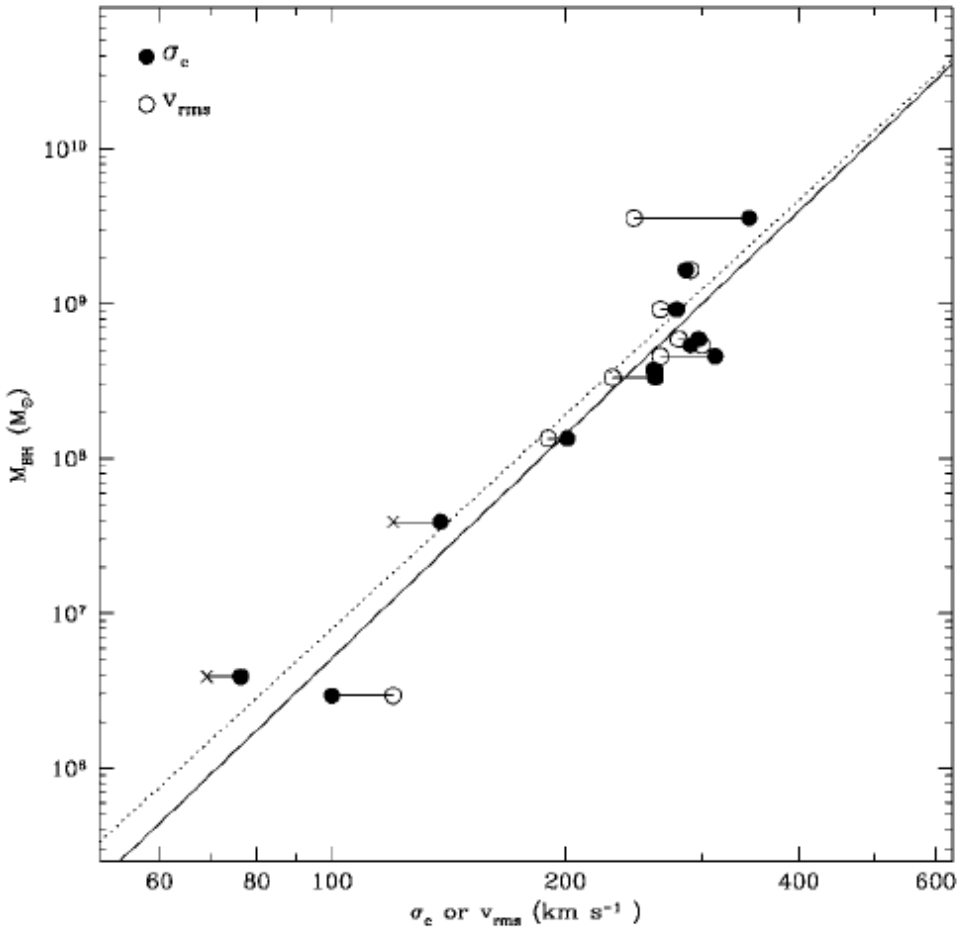


M_{BH} versus σ_c (Right)

Strong M_{BH} - σ_c correlation; weaker M_{BH} - luminosity correlation. Indication of stronger relation with M_{tot} not just baryons.

Strong Correlation between M_{BH} and V_{rms}

(V_{rms} measured at $r_e/4$)



M_{BH} versus V_{rms} (open circles, dashed line).

M_{BH} versus Bulge Central Velocity Dispersion (filled circles, solid line)

Since $R(V_{rms})$ ≈ R_{BH}, the $M_{BH} - V_{rms}$ relation is not caused by the influence of the BH on stellar kinematics.

r_e : effective radius, include half image light

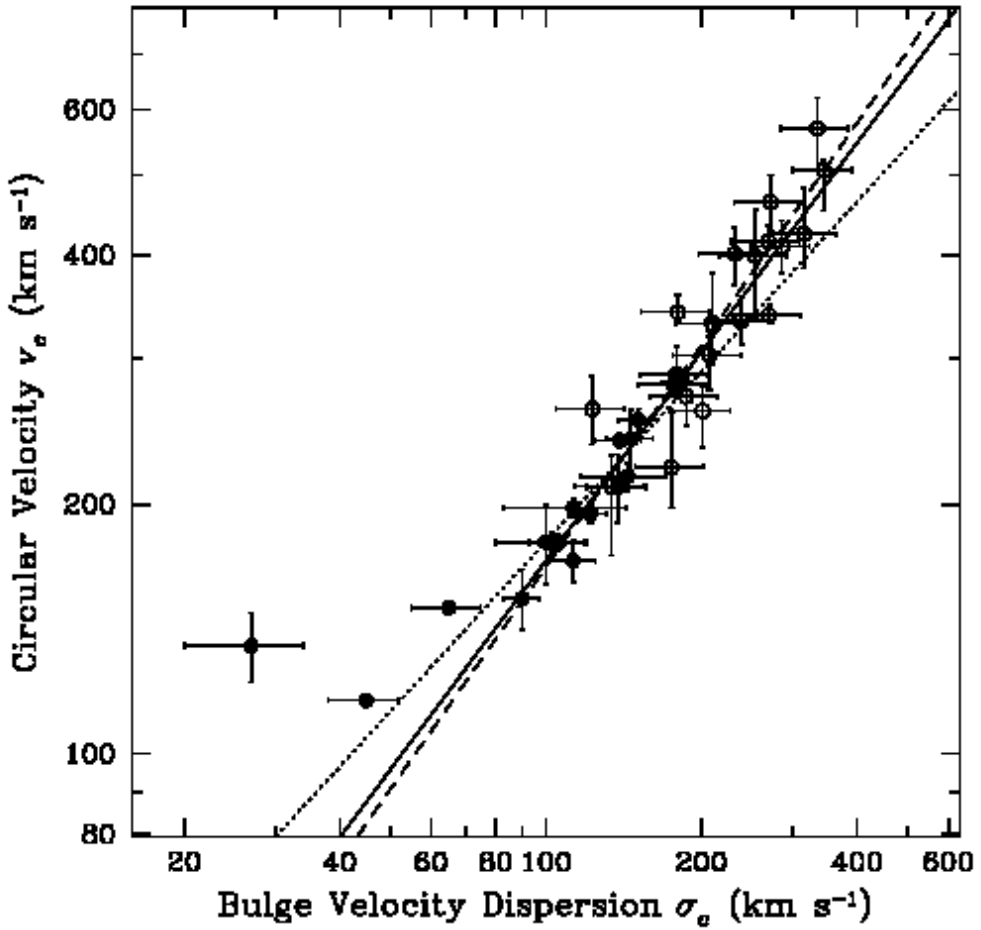
Circular velocity V_c - σ_c Relation

(Ferrarese June,2002)

V_c is measured beyond R_{25} where the rotation curve is flat.

$R(V_c) > R(V_{rms})$ ≈ $R(\sigma_c)$

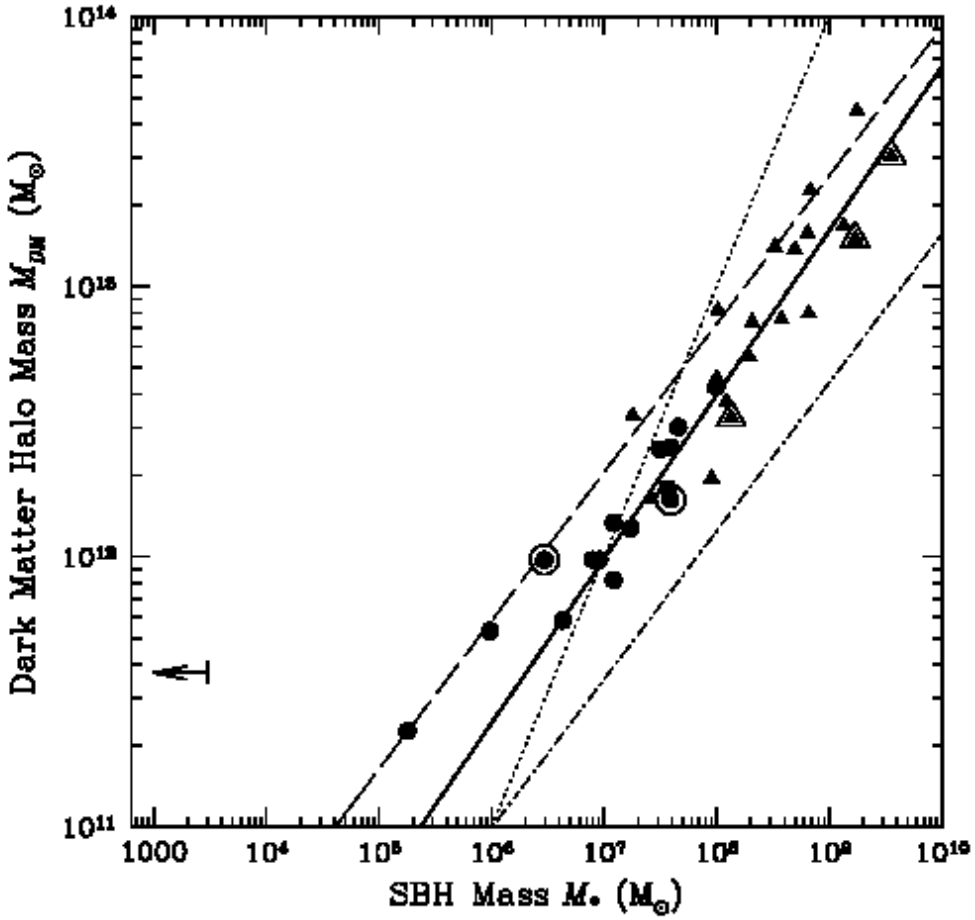
V_c is determined by M_{DM}



The V_c - σ_c Relation provides the link between M_{BH} and M_{DM} .

The M_{BH} and M_{DM} Relation

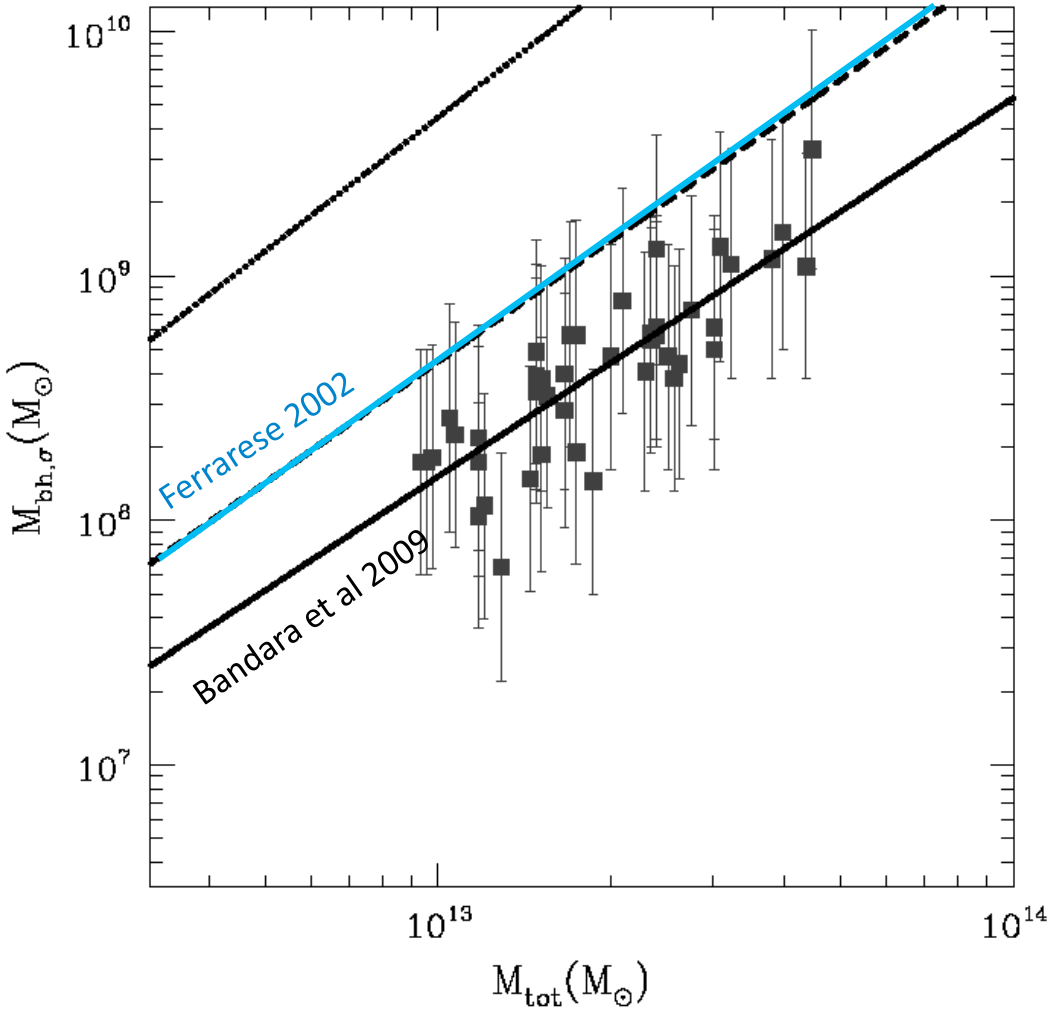
(Ferrarese June,2002)



The M_{BH} - M_{DM} Relation is obtained by converting V_c into M_{DM} .

The $M_{BH} - M_{tot}$ Relation by Gravitational Lensing

(Bandara et al 2009)



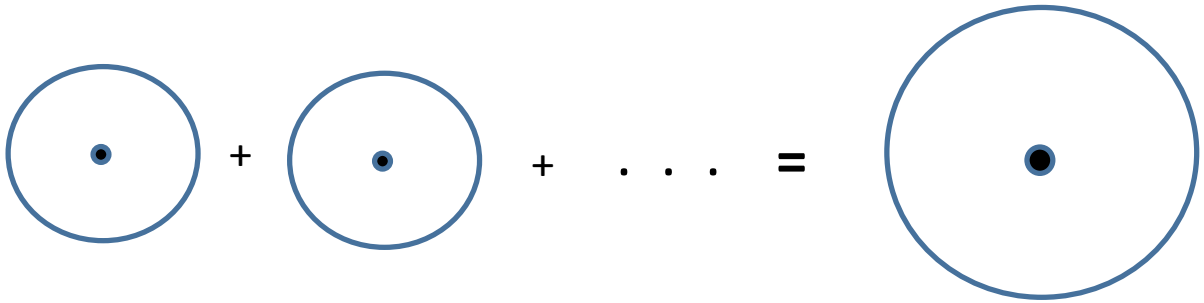
Gravitational lensing provides a more robust method to determine M_{tot} .
No conversion of velocity to mass required.

How does the entire galaxy know what is

the mass of the BH at the center?

Possible Explanation : Building Blocks Idea

- The first objects formed in the universe were not stars.
- Larger number of identical building blocks merged and formed into a galaxy. They provided seed black holes to coalesce into a single, massive black hole in the center of the galaxy.



Richstone et al, 1997, 189th Meeting of the American Astronomical Society.

Can explain the $M_{BH} - M_{tot}$ relation.
Need to explain how the identical building blocks were formed.

Possible **Explanation** : Quasar, AGN Idea

- Radiation from the accretion disk applies pressure to the in-falling particles.
- Silk & Rees 1998 and king 2003 were able to calculate σ_c for a given BH mass.

$$M_{BH} \propto \sigma_c^{5} \text{ (Silk \& Rees)}$$

$$M_{BH} \propto \sigma_c^{4} \text{ (King)}$$

Obtain the $M_{BH} - \sigma_c$ relation, not the $M_{BH} - M_{tot}$ relation.

An Engineer's view : Servo loop

- In order to build the $M_{BH} - M_{tot}$ relation need to have
  - Communications (between BH and rest of the system)
  - Feedback (able to add or reduce mass from the BH)

There is no efficient way to remove matter from a BH.
The Servo Loop idea does not work.

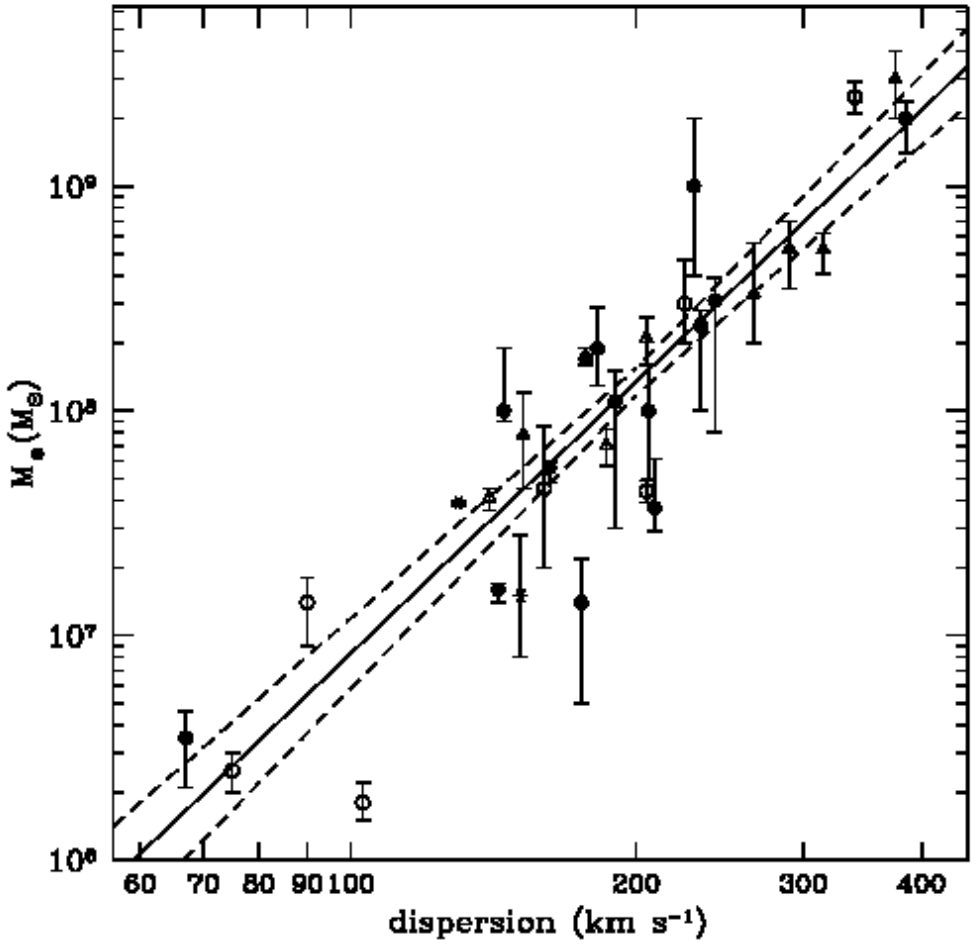
Summary

- Ferrarese & Merritt 2000 was the pioneer work to point out the M_{BH} - σ_c relation.
- The relation was expanded to link with M_{tot} by Ferrarese in 2002.
- More observations including gravitational lensing confirm the $M_{BH} – M_{tot}$ relation.
- There is no satisfactory explanation of the relation other than observations as of today.

$$\mathbf{M_{BH} – \sigma_c \; – V_{rms} – V_c – \; M_{tot}}$$

Backup Slides

More Results on M_{BH} and Velocity Dispersion Relation



Tremaine April,2002