A model for the black hole mass and halo mass correlation

Course 689 Final Presentation

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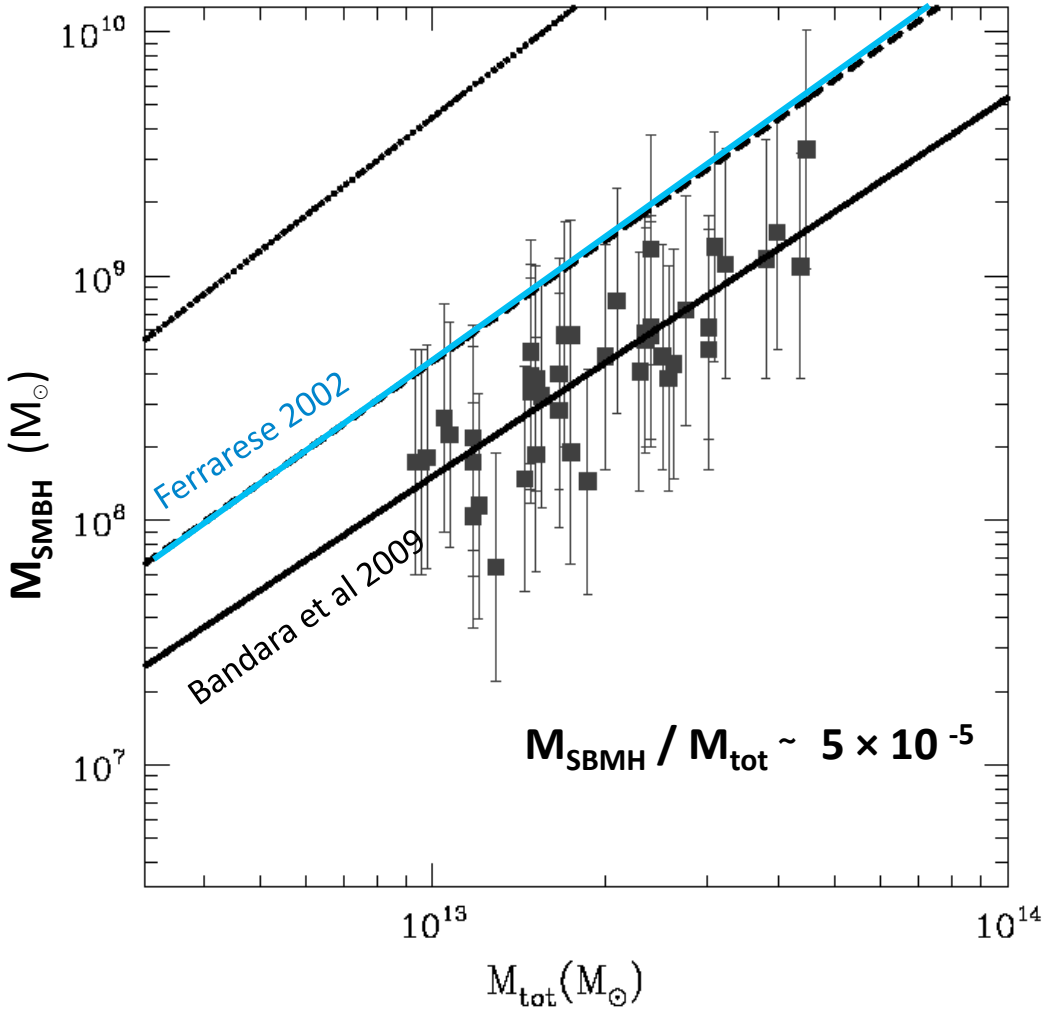
Second part presentation.
First part Nov 5, 2009.

Strong $M_{SMBH} - M_{tot}$ Relation



Ferrareses : Circular velocity at flat rotation curve

Bandara : Gravitational lensing

The $M_{SMBH} - M_{tot}$ relation is verified by two independent methods.

How does the entire galaxy know what is

the mass of the SMBH at the center?

An Engineer's view : Servo loop

- **If there is no initial relation** between M_{SMBH} and M_{tot} , to build the universal $M_{SMBH} - M_{tot}$ relation there needs to be
  - Communications (between SMBH and rest of the system)
  - Feedback (able to add or reduce mass from the SMBH)
- There is no efficient way to remove matter from a BH. The servo loop idea does not work.

The $M_{SMBH} - M_{tot}$ relation must be set at the early stage of a galaxy.

Universal DM Halo Density Profile

- Gravitational force is scale invariant

→ Universal mass density profile (NFW)

$$\rho(r) \propto \frac{1}{\left(\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2}$$

with a scale length r_s determined by the total mass M_{tot} (or $r_s \propto M_{tot}^{\Upsilon}$) .

The Newtonian force $F \propto \frac{M}{r^2}$ is scale invariant.

Unique property of Universal Profile

- The ratio of the mass inside the **same scaled length** to the total mass is the same for different mass DM halos.

$$\frac{m(< r_{scaled})}{m_{tot}} = \frac{M(< r_{scaled})}{M_{tot}}$$

Universal relation for M (r_{scaled}) to M_{tot} ratio.

SMBH at the DM halo Center

- **If there is a black hole** at the center, it can be viewed as a delta density function at **r** = 0.

  $\rho(r) \propto \delta(\mathbf{r})$, for $|\mathbf{r}| \ll r_s$,

  or $\rho(r) = M_{SMBH}\, \delta(\mathbf{r})$.

- In order to meet the universal profile condition,

  $M_{SMBH} \propto M_{tot}$.

A BH behaves similarly to weakly interacting dark matter particles. It will Virialize with dark matter particles.

How Does a SMBH Develop at the center?

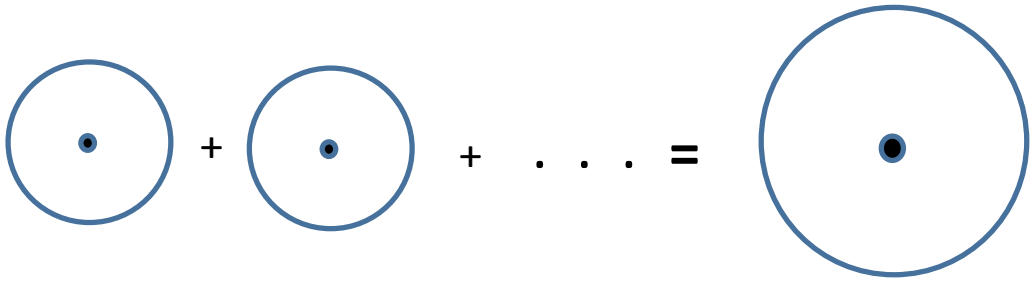
- At the early universe, the primordial gas was first able to cool and collapse into dark matter mini-halos.
- The first stars were very massive (~ 100 $M_{\odot}$), owing to the limited cooling properties of primordial gas.
- After the main sequence lifetime, the first stars collapsed to BH's.

The mini-halos with BH's (collapased from the first stars) are the initial building blocks of galaxies.

How Does a SMBH Develop at the center?

(continued)

- DM halos form hierarchically. Small halos form first and merge into bigger halos.
- Larger number of identical building blocks merge and form into a galaxy. They provide seed black holes to coalesce into a single, massive black hole in the center of the galaxy.



The mass of the SMBH at the center is always proportional to M_{tot}.

Building Block M_{BH} to M_{Halo} ratio

- In a CDM flat cosmology, primordial gas with $M_b \sim 10^6\ M_\odot$ would be collapsing from 3– σ fluctuations.[1]
- Assuming only one black hole of mass $m_\bullet \sim 100\ M_\odot$ in each mini-halo[1],

$$\mathbf{M_{BH} / M_{Halo}} = m_\bullet / (M_b + M_{DM}) \sim \mathbf{1.5 \times 10^{-5}}$$

Note 1: Johnson et al 2008, Spolyar et al 2009

$$(M_b : M_{DM} = 15\% : 85\%)$$

$$\mathbf{M_{SMBH} / M_{tot}} \sim \mathbf{5 \times 10^{-5}}$$ (Bandara, Ferrareses)

The building block M_{BH} to M_{Halo} ratio is the same order of magnitude as the observed M_{SMBH} to M_{tot} ratio.

Summary

- The massive first stars collapsed into BH's at the early universe.
- The BH's behave similarly to weakly interacting DM particles.
- They virialize with DM particles and sink to the center of the DM halo to form a massive BH.
- The peak of BH's merging activity leads to the quasar stage of a galaxy ($z = 2 \sim 4$).
- The gas accreted by the SMBH at late stages ($z<1$) is insignificant (< 5% in mass)*.

* Stated as "radio mode" in Croton, 2006
Presented by Sharon on Nov 12, 2009

Conclusion

The M_{SMBH} and M_{tot} correlation is probably established by the building blocks (mini-halos with first star BH's) at the early universe.

Further Question

How does the M_{SMBH} to M_{tot} ratio evolve with time according to this model?

Increase? decrease? or remain constant?