Local Scaling Relations of Super-Massive Black Holes: Origin, Evolution, Consequences

FRANCESCO SHANKAR

WHAT I WILL DISCUSS:

Local Scaling Relations:
Slopes, Breaks, Scatters, BHMF

Semi-empirical Models:
Accretion, Clustering, z-Evol.

More Advanced Models:
Mergers vs secular models

See talk by Michaela Hirschmann for further insights into models!!

Reviews available: Shankar 09; Shankar 13
Local Scaling Relations: Slopes, Breaks, Scatters, BHMF
The «Magorrian» relation: $M_{\text{BH}} - M_{\text{bulge}}$

Marconi-Hunt 03
Haering-Rix 04:
Slope about unity, normalization about $10^{-3}$
Sample of about 30 Galx, bulge masses from NIR (MH) or dynamical (HR) scatter $< 0.3$ dex!!

See also Sani+11, Beifiori+12, and many, many others
The «Magorrian» relation today?

Scott et al. 2013
Graham 2012
sample of 75 galx;
bulge masses from
K-band corr.;
slope from 2.2 to 1,
scatter from 0.9
to 0.47!!
Is this real? On more general grounds:

BUT see Läsker et al. 2014!! Kormendy & Ho 13
Is there a correlation with disc?

BUT see Läsker et al. 2014!!

Kormendy & Ho 13
Scatter always ranging within 0.3-0.5 dex.

First study differential: possible evidence for decrease at high masses, still unsecure and only in Mbulge!

McConnell+Ma 13
Is there a correlation with DM halo?
Several caveats: scatter, relations, variables, color change, bulge fractions, methodology, etc…

How many SMBH? How Massive?

\[ \Phi(L) \rightarrow \Phi(L_{\text{bulge}}) \rightarrow M_{\text{BH}} - L_{\text{bulge}} \rightarrow \Phi(M_{\text{BH}}) \rightarrow \Phi(\sigma) \rightarrow M_{\text{BH}} - \sigma \]
Different «populations»:
Pseudo bulges, nuclear
Star clusters, ....
Though mainly affecting
(again!) low masses

See talks by Hirschmann, (seed BHs) by Haardt
Semi-Empirical Models: Accretion, Clustering, Redshift Evolution
The Continuity Equation

\[
\frac{\partial n(M_{BH}, t)}{\partial t} = - \frac{\partial}{\partial M_{BH}} \left[ \langle \frac{dM}{dt} (M_{BH}, t) \rangle n(M_{BH}, t) \right] + \frac{dS}{dt}_{in} - \frac{dS}{dt}_{out}
\]

Accretion Term: proportional to \( P(\lambda, M_{BH}, t)/\)radiative efficiency; The sum of all active BHs must give you the observed AGN LF!

Merger Term: at the rate implied by hierarchical mergers of DM haloes

Main references: Cavaliere et al. (1971); Soltan (1982); Small & Blandford (1992); Salucci et al. (1999)
CONTINUITY EQUATION MODELS OF THE BH POPULATION

\[
\frac{\partial n(M_{BH}, t)}{\partial t} = - \frac{\partial}{\partial M_{BH}} \left[ \left\langle \dot{M}(M_{BH}, t) \right\rangle n(M_{BH}, t) + S_{in}(M_{BH}, t) - S_{out}(M_{BH}, t) \right]
\]

Marconi+04; Yu&Lu04; FS+04,09,13
Same evolution as in SFR, with Magorrian ratio!

Marconi+04; Merloni+04; Hopkins+07; Silverman+08; Zhang+09; FS+09
A step further: correlating SSFR to Specific BH growth!

$\frac{L_X}{L_{IR}} = 0.01$

$\dot{M}_{BH}/\dot{M}_* = 10^{-3}$

$10^{10}$ - $10^{11}$ Stellar mass ($M_\odot$)

Mullaney+12

$<\frac{dM_{BH}}{dt}> / M_{BH}$ [yr$^{-1}$]

Log $M_{BH}$ [$M_\odot$]

$z = 0.3$, $z = 1.0$, $z = 2.0$, $z = 3.0$

FS+13

See Rodighiero’s Talk!
Most of the SFR in Discs at $z<1$ or so...
Same evolution as in SFR, with Magorrian ratio!

Marconi+04; Merloni+04; Hopkins+07; Silverman+08; Zhang+09; FS+09
Is there a correlation with disc?

Kormendy & Ho 13
Is the emergence of bars responsible for triggering AGN at low z?

Cheung+14; see also Cisternas+14
Semi-Empirical Models:
Accretion, Clustering, Redshift Evolution

Haiman&Hui01; Martini&Weinberg; Gilli+07; White+08; Shen 09; Wyithe & Loeb 10; Bonoli, FS+10; FS+10

See, e.g., talks by Allevato, Cappelluti, etc...
From BHMF to mapping with Dark Matter Haloes!

Rank Ordering: $\rightarrow$ median relation $M_{\text{star}}, M_{\text{BH}}$-Halo mass
SEEDING EACH HALO WITH A BH AND A GALAXY
If there is substantial scatter, many low mass haloes will enter the selection and lower the inferred clustering (bias)
WITH 0.4 dex scatter
Is there a correlation with DM halo?

Kormendy & Ho 13
Just the opposite at $z>3$: very large scatter and duty cycles require **limited scatter** $<0.3$ dex for luminous QSOs

White+08; see also Shen 09; Wyithe & Loeb 10; Bonoli, FS+10; FS+10
At $z>1$ steep slope close to $\sim V^5$ as expected from AGN feedback models!

while very weak correlation at $z<1$, in agreement with what measured?!?
A BASIC ABUNDANCE MATCHING MODEL IS BROADLY CONSISTENT WITH AT LEAST THE LARGE SCALE CLUSTERING OF QUASARS

CONROY & WHITE 13

see also Gilli+; Hickox+; Magliocchetti+ and many others...

SMALL AND LARGE SCALES INFORMS US ON THE RELATIVE PROBABILITIES FOR SATELLITES AND CENTRALS TO BE ACTIVE
Semi-Empirical Models: Accretion, Clustering, Redshift Evolution
See talks by, e.g., Vignali, Valiante, ...
In the Mbh-sigma nearly absent!

\[ M_{\text{BH}} - \sigma \propto (1 + z)^{0.33} \]

A redshift dependent 'Soltan argument'

FS, Bernardi, Haiman 09
Interestingly, when they repeat for stars they find significant positive Evolution, consistent with Merloni, Decarli....

Zhang, Lu, Yu 2012
And by direct measurements! Reliable???
More Advanced Models: Mergers vs secular accretion

(IMPACT ON SCALING RELATIONS)
In this model, ONLY mergers trigger BH growth!

Large scatter at low masses mainly because of inefficiency of mergers, closer to «seed» BH masses!
At the other extreme: Even with NO Accretion, ONLY mergers at the rate predicted by LCDM can already predict a linear relation!

Jahnke+Maccio 11
EFFECTS OF BH GROWTH IN SECULAR EVOLUTION?

MERGER MODELS TEND TO PRODUCE MORE SCATTER IN THE LOCAL UNIVERSE!

\[
\text{Log M} \quad \text{BH}
\]

\[
\text{Log M_{BULGE}}
\]

FS+12
SOME RECENT PROPOSALS FOR IN-SITU BH GROWTH: COLD FLOWS

"X-ray data show that ... AGN fueling modes at $z \sim 1.85$---whether violent disk instabilities or secular processes---are as efficient in smooth galaxies as they are in clumpy galaxies." Trump+14
WHAT I DISCUSSED:

Local Scaling Relations:
Possible breaks, high scatter

Accretion and Clustering:
Evol. w/ SFR, evolving scatter

Evolution with redshift:
Yes Mbh/Mstar, NO Mbh/sigma

Galaxy co-evolution:
Triggering by mergers favoured