Constrains on the Evolution of Supermassive Black Holes

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Host: Matteo Viel
Today’s Menu

- Intro: Things you should know
- A simple framework: Our work
- Observational constraints: Our results
- Final remarks: What did we learn?
1. Supermassive Black Holes at the centres of massive galaxies.

Credit: Andrea Ghez (UCLA)
2. Supermassive Black Holes correlated with host galaxies!

Credit: Tim Jones (UT Austin)
3. Quasars: Distant galaxies with extremely luminous nuclei --> progenitors of today's massive galaxies
4. **Quasars:** Supermassive Black Holes having dinner!

--> progenitors of today’s **dormant** SMBHs
But how do we feed the monster?

Credit: John Biretta (STScI)

Credit: Hayden Planetarium
5. **Galaxy mergers**: an efficient way to feed the black hole (trigger quasar activity)

Credit: Jorge Moreno (SISSA/Hopkins Obs)

Credit: Steven Beckwith (STScI/HST)

Credit: Andrew Wilson (Maryland/STScI/Chandra)
Merging galaxies $\xrightarrow{\text{---}}$ Quasars

Credit: John Bahcall (IAS) & Mike Disney (Wales)
Quasars in “relaxed” galaxies

--> features due to a recent merger!

Credit: Gabriella Canalizo (UCR) & Nicola Bennert (UCSB)
Galaxy Merger $\rightarrow$ Quasar $\rightarrow$ Supermassive Black Hole

Credit: Andrea Zezas (Crete/NASA/CXC/DSS)
Supermassive Black Holes at galaxy centres

Quasars: SMBHs accreting gas

Galaxy Mergers $\rightarrow$ Quasar Activation

Galaxy Formation $\leftrightarrow$ Black Hole Evolution

Simple Picture:
Galaxy Mergers $\rightarrow$ Quasars $\rightarrow$ SMBHs
II. How do we model all this?
Method I: Hydro simulations

Credit: T.J. Cox (Carnegie), Phil Hopkins (UC Berkeley), etc.

See also: Works by di Matteo et. al., Schaye et. al., deBuhr et. al., Mayer et. al., etc.
Method II: Semi-Analytic Models

See also: Works by Croton, de Lucia, et. al., Volonteri et. al., Granato, Cook et. al., Monaco, Fontanot et. al., etc.

Credit: Andrew Benson (Caltech)
Method III: Analytic Models (our work!)

See also: Works by Wyithe & Loeb, Granato, Lapi, Danese et. al., Scannapieco & Oh, etc.

Halo merger rate Quasar light curve
Method III: Analytic Models (our work!)

Halo merger rate

Quasar light curve

See also: Works by Wyithe & Loeb, Granato, Lapi, Danese et. al., Scannapieco & Oh, etc.
Method III: Analytic Models (*our work!*)

See also: Works by Wyithe & Loeb, Granato, Lapi, Danese et al., Scannapieco & Oh, etc.
Halo Mass Function

Number of haloes of mass $m$ per unit volume

Sheth-Tormen fit

Halo mass

Many tiny haloes

Few massive haloes

Credit: Moreno et al. (2009)
Halo Merger Rate

Halo merger rate per unit volume

\[ \xi = m'/m \]

\[ \xi = m'/m \]

Mass ratio

Credit: Fakhouri & Ma (2008)

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Universal Merger Rate / Halo

Many minor mergers

Few major mergers

Merger rate per unit halo per unit volume

\[ B / n \]

Mass ratio

Credit: Fakhouri & Ma (2008)
Merger Rate Evolution

Major merger rate per unit volume

Redshift

$\text{Log M_{\text{HALO}}/M_\odot h^{-1} = 11}$
$\text{Log M_{\text{HALO}}/M_\odot h^{-1} = 12}$
$\text{Log M_{\text{HALO}}/M_\odot h^{-1} = 13}$

Credit: Fakhouri & Ma (2008)
So far

1st Ingredient: Analytic Merger Rate:

\[ B = \left( \frac{B}{n} \right) \times n \]

- Few **major** mergers, many **minor** mergers
- Massive haloes form **late**, tiny ones form **early**

2nd Ingredient:

- The Light Curve!
The Light Curve

Ascending phase

Peak

Descending phase

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A simple model

\[ F_{\text{rad}} = F_{\text{grav}} \]

\[ \rightarrow L_{\text{Edd}} \propto M_{\text{BH}} \]

\[ L = \lambda L_{\text{Edd}} \]

Eddington Ratio

\[ L \propto M_{\text{BH}} \]
A simple model

\[ L = \epsilon M_{\text{infall}} c^2 \]

\[ L \propto \dot{M}_{\text{BH}} \]

\[ (1 - \epsilon) M_{\text{infall}} \]
The Ascending Phase

\[ L \propto M_{\text{BH}} \]
\[ L \propto \dot{M}_{\text{BH}} \]

\[ \rightarrow M_{\text{BH}} \propto \dot{M}_{\text{BH}} \]

\[ M_{\text{BH}}(t), L(t) \propto \exp\left(\frac{t}{t_{\text{ef}}}\right) \]
The Peak

Outflows

(Masked) Jet

AGN

NCG 4261

Credit: Ford & Tsvetanov (1998)
Self Regulation (AGN Feedback)

\[ L_{\text{peak}} \propto M_{\text{Halo}}^{5/3} (1 + z)^{5/2} \]

The Descending Phase

\[ L \propto t^{-\alpha} \]

\[ \alpha = \alpha(M_{\text{Halo}}) \]
So far

The Light Curve:

Ascending phase: exponential growth

Peak: self-regulated

Descending phase: mass-dependent
Science Goals:

1. Luminosity Function at all redshifts
2. Clustering at all redshifts

Formidable Task!
Only major mergers: \( \xi = m'/m \geq 1/4 \)

Range of host halo masses:

\[
10^{11.5} M_\odot < M_{\text{Halo}} < 10^{13} M_\odot
\]

Short time delays:

\[
M_{\text{BH, seed}} = \frac{M_{\text{BH, peak}}}{\mu_{\text{BH}}}
\]

\( t_{\text{delay}} \) is fixed

\[
t_{\text{delay}} = t_{\text{peak}} - t_{\text{triggering}}
\]
The Luminosity Function
The Luminosity Function

Bright end Works!
The Luminosity Function

Not enough faint AGNs

Bright end Works!
The Luminosity Function

Not enough faint AGNs

Too many faint AGNs

Bright end Works!
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Bright end Works!

New prediction!
Quasar Clustering (the bias)
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Very biased bright quasars!
Alternative Models

- Smaller halo host masses?
- Long-lived quasars?
  - Massive BH seeds?
  - Super-Eddington Accretion?
- Include minor mergers / secular agents?
- Additional Help:
  - X-ray Counts
  - Black Hole Mass Function
Testing models with small host haloes

At low $z$: we cannot tell!!
Testing models with small host haloes

At very low $z$: small host model ruled out!!

$z = 0.1$
Testing long-lived Models

$z = 2.2$

Long-delay model

At intermediate $z$: we cannot tell!
At high $z$: long-delay model ruled out!!

$t_{\text{delay}} \lesssim 100$ Myr
Faint & Bright Quasars at High z

CUT model:

Data cannot tell!!

\[ z = 3.2 \]

No descending phase!

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CUT model:

Very massive hosts OR no descending phase (CUT) preferred!

\[ z = 3.2 \]

CUT model:

No descending phase!
All BHs (Shankar & Ferrarese, 2009)

BHs in early types (Sheth et. al., 2003 + Tundo et. al. 2007)

Major mergers --> BHs in early type
Minor mergers --> not enough for all BHs
Summary: Data Constrains

- **Low z bias** --> Quasars live in massive hosts

- **High z bias** --> Quasars have short lives!
  \[ t_{\text{delay}} \lesssim 100 \text{ Myr} \]

- **High z X-ray counts**
  --> Quasars in massive hosts
  *OR* No descending phase (CUT)

- **BH mass function:**
  --> **Major** mergers \(\rightarrow\) early types
  --> **Minor** mergers: not enough
IV. Things you should take home...

- **Picture:** Galaxy Mergers $\rightarrow$ Quasars $\rightarrow$ SMBHs

- **Analytic framework:**
  1. Halo major merger rate
  2. Quasar light curves

- **Observations:** Quasars: short lives & massive hosts
  Major mergers $\rightarrow$ BHs in early types

- **Puzzles:** small BHs in late types, faint low-z AGNs
  $\rightarrow$ secular processes?
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Thank you! Any questions?