Constrains on the Evolution of Supermassive Black Holes

Jorge Moreno (Sissa)

November 24, 2010 (INAF-OAT)

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- David Weinberg (Ohio State)
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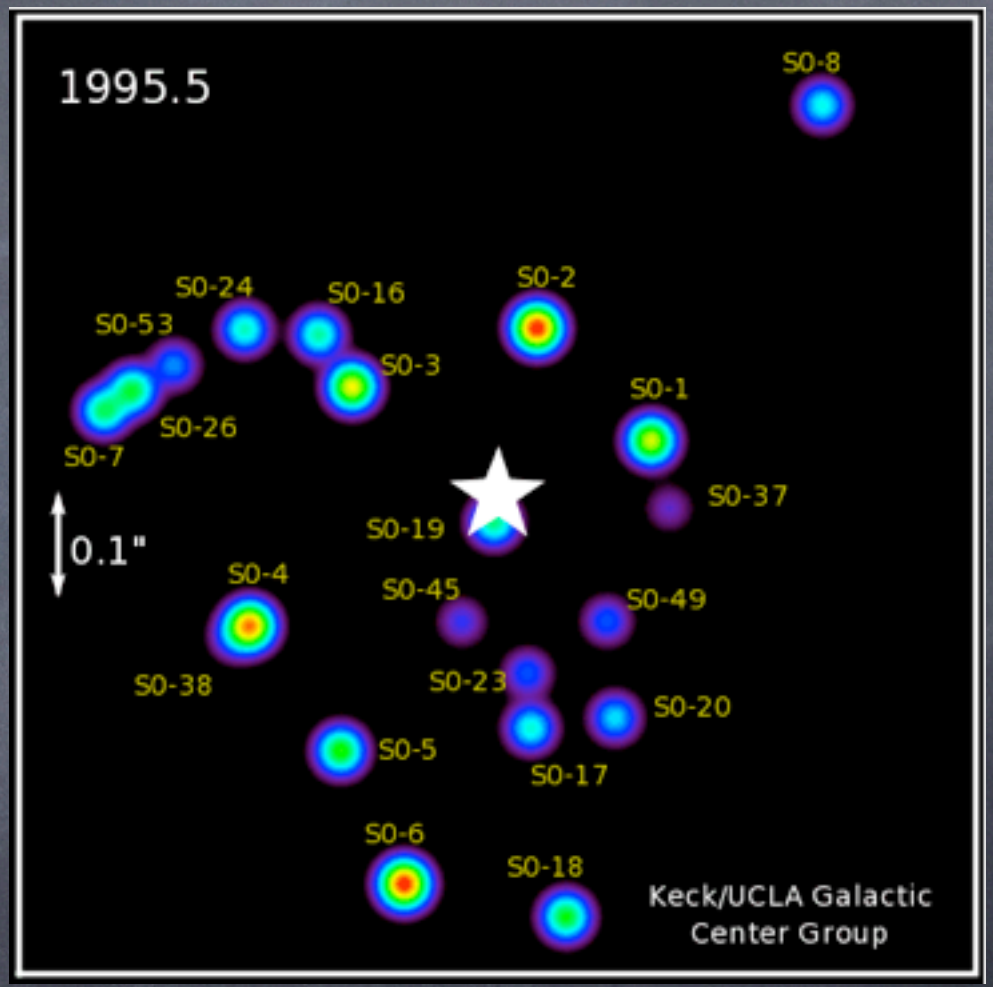
Today's Menu

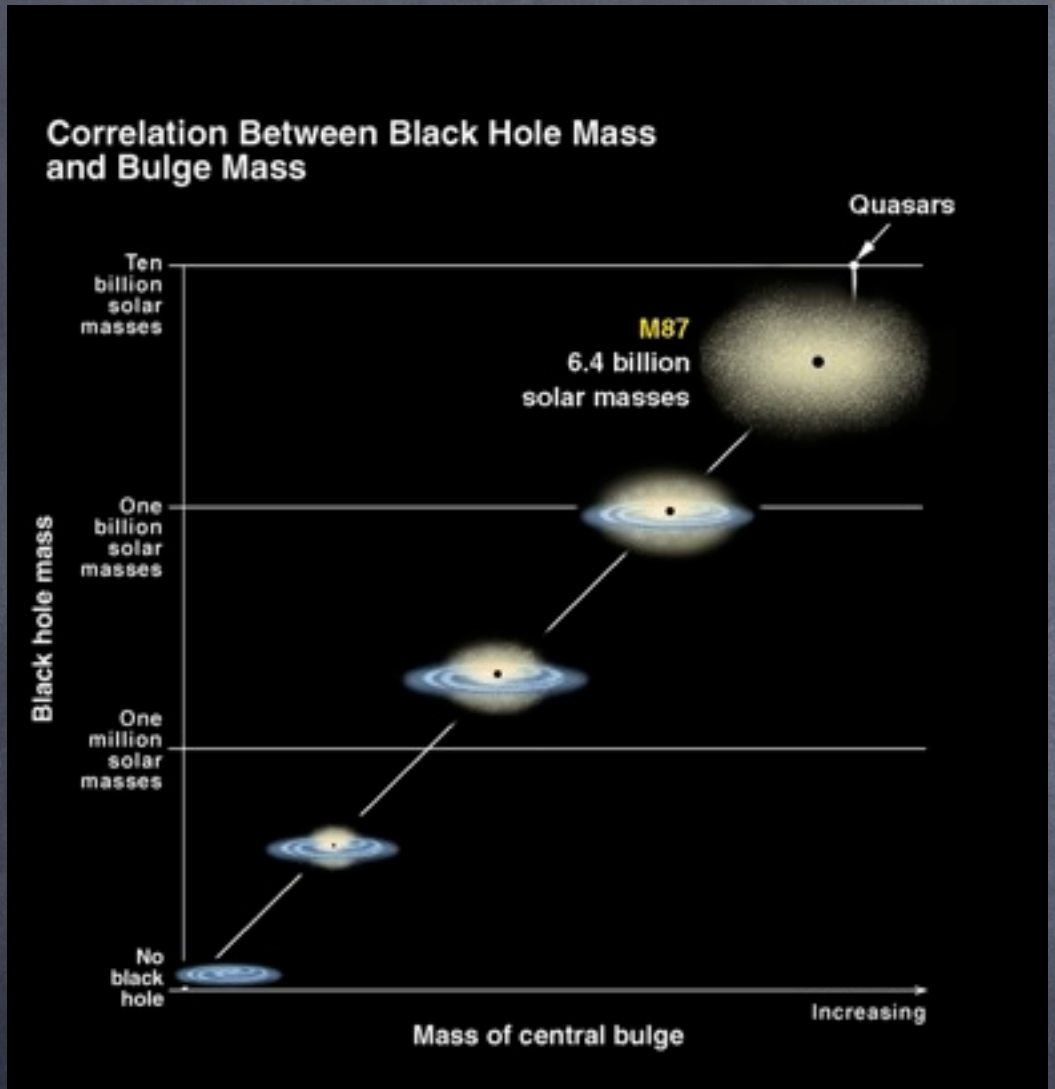
- Intro: Things you should know
- A simple framework: Our work
- Observational constrains: Our results
- Final remarks: What did we learn?

I. Intro: Stuff you should know...

1. Supermassive Black Holes at the centres of massive galaxies.



Credit: Andrea Ghez (UCLA)

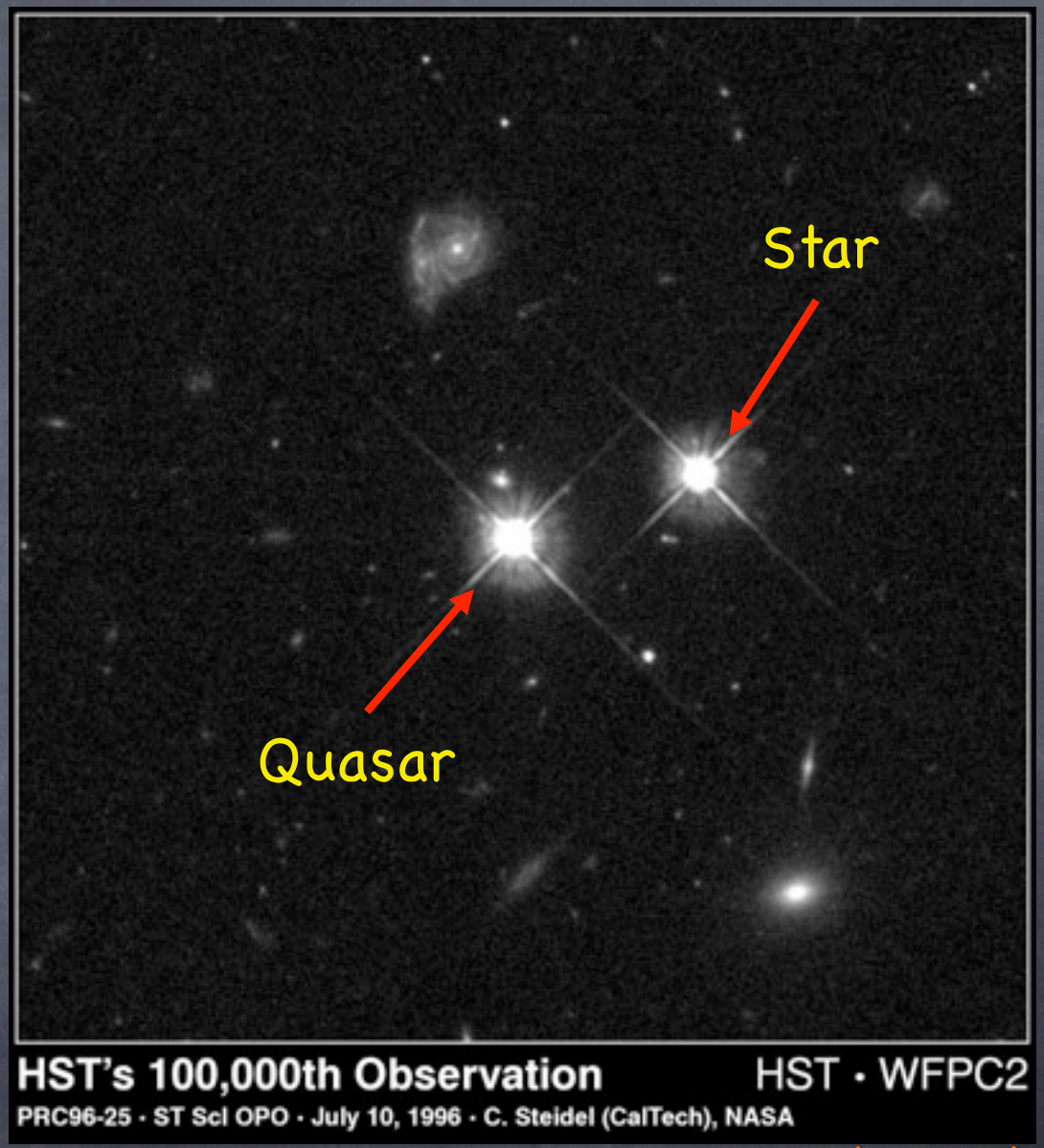


Credit: Tim Jones (UT Austin)

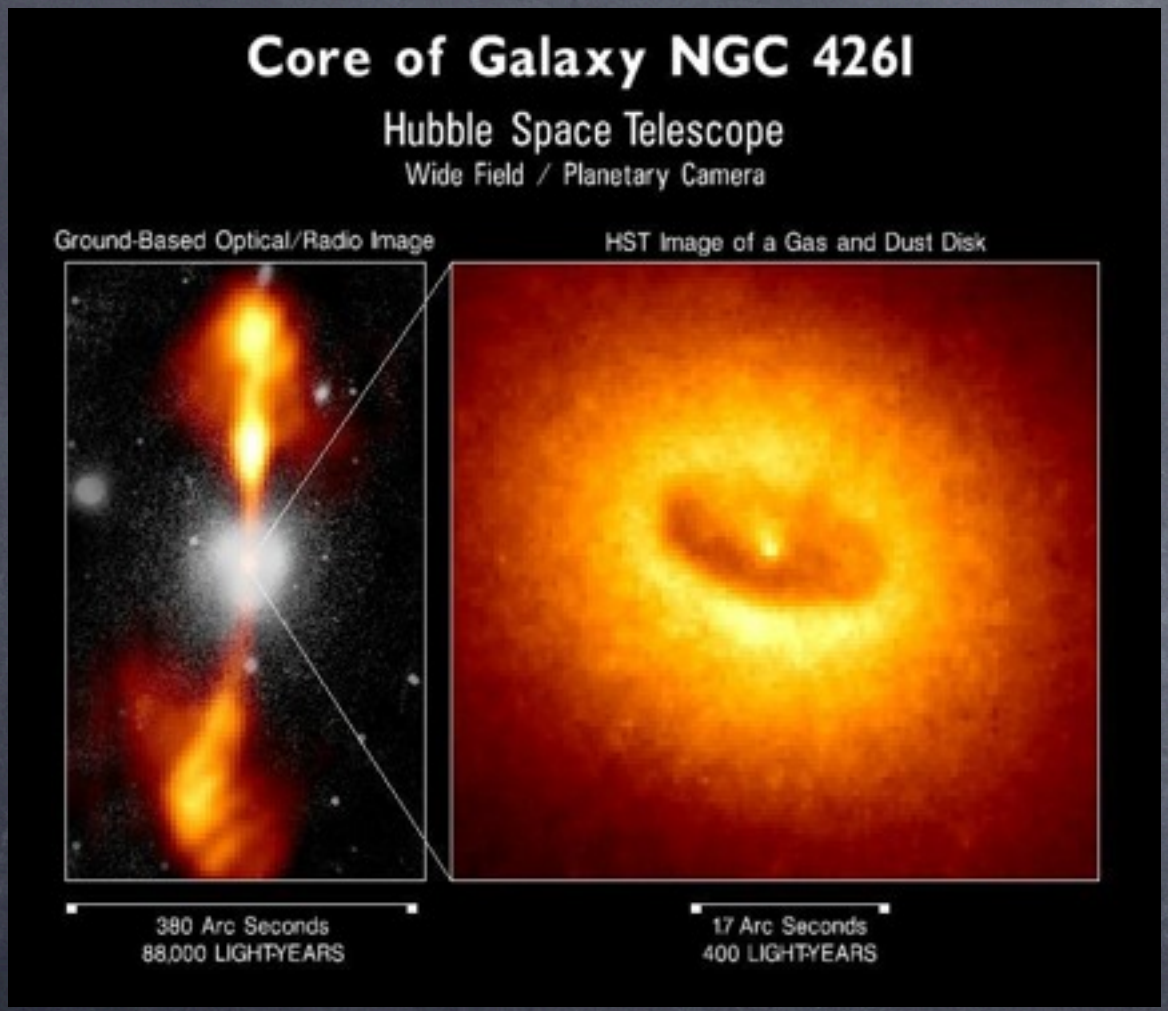
2. Supermassive Black Holes correlated with host galaxies!

3. Quasars:
Distant galaxies with extremely luminous nuclei

--> progenitors of today's massive galaxies



Credit: Charles Steidel (Caltech)



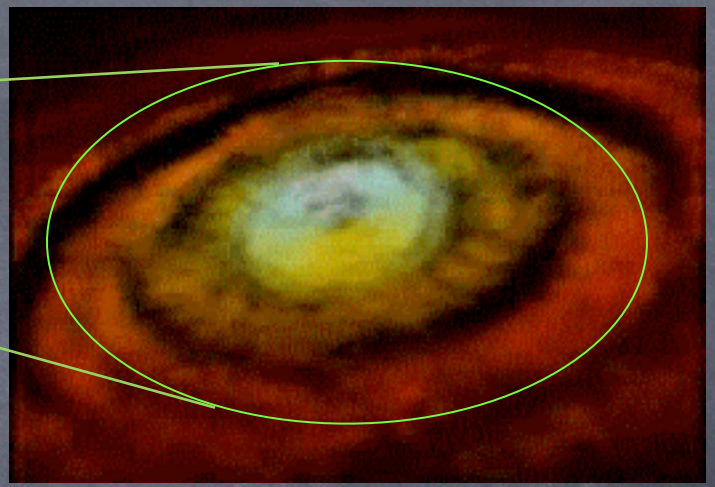
Credit: Walter Jaffe (Leiden/JHU/STScI/NASA)

4. Quasars: Supermassive Black Holes having dinner!

--> progenitors of today's dormant SMBHs

But how do we feed the monster?

Credit: John Biretta (STScI)



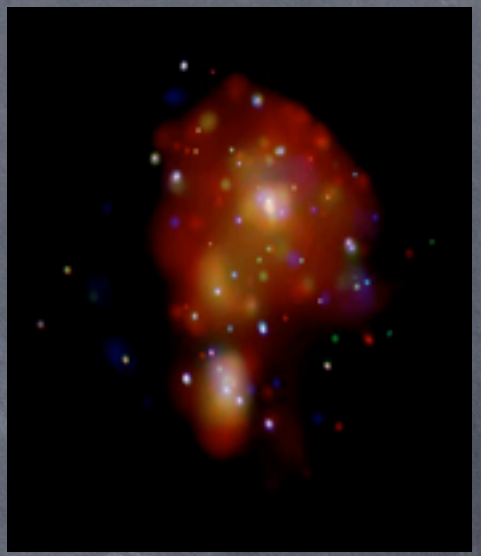
Credit: Hayden Planetarium

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

Credit: Jorge Moreno (SISSA/Hopkins Obs)

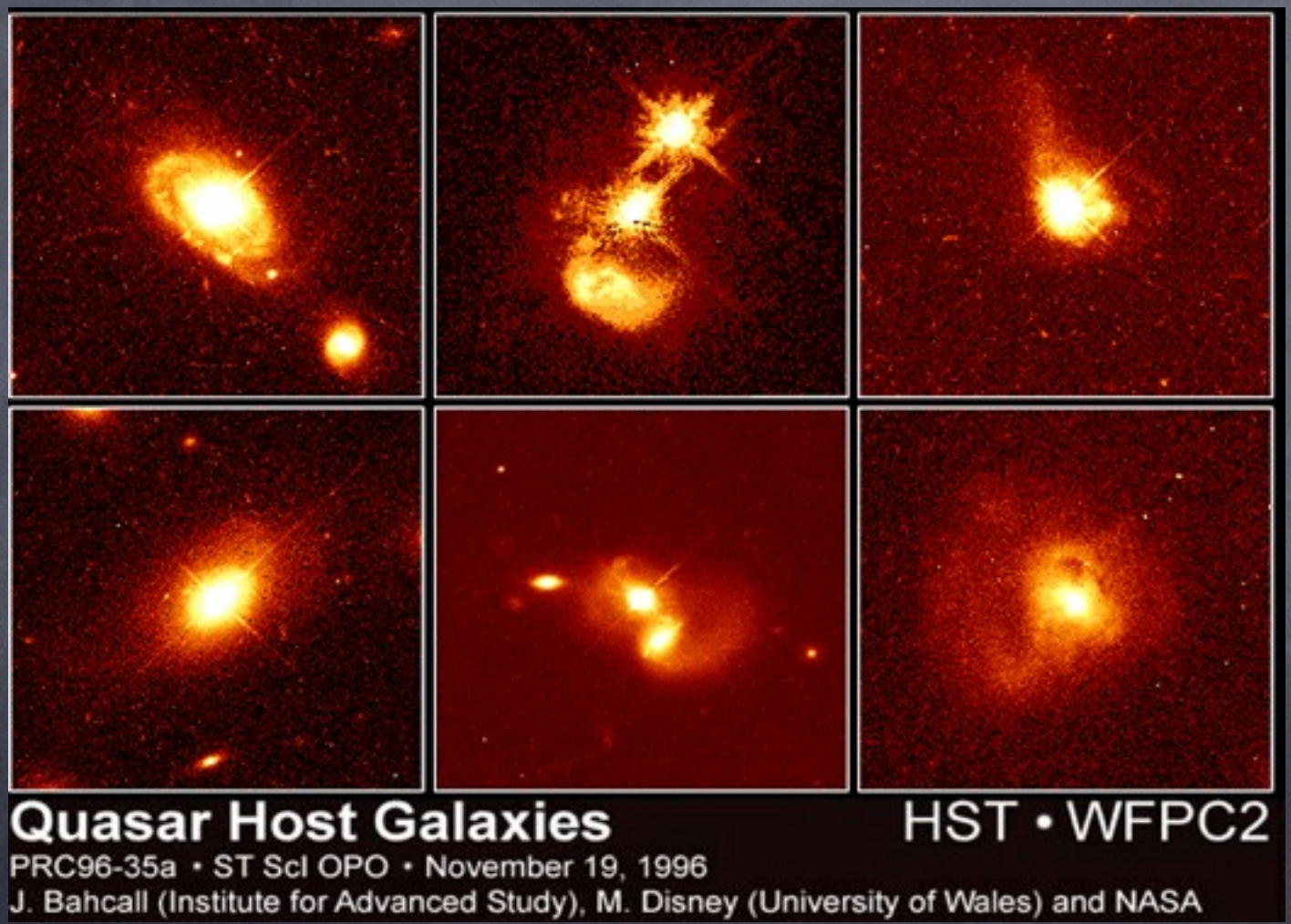
M51

Credit: Steven Beckwith (STScI/HST)



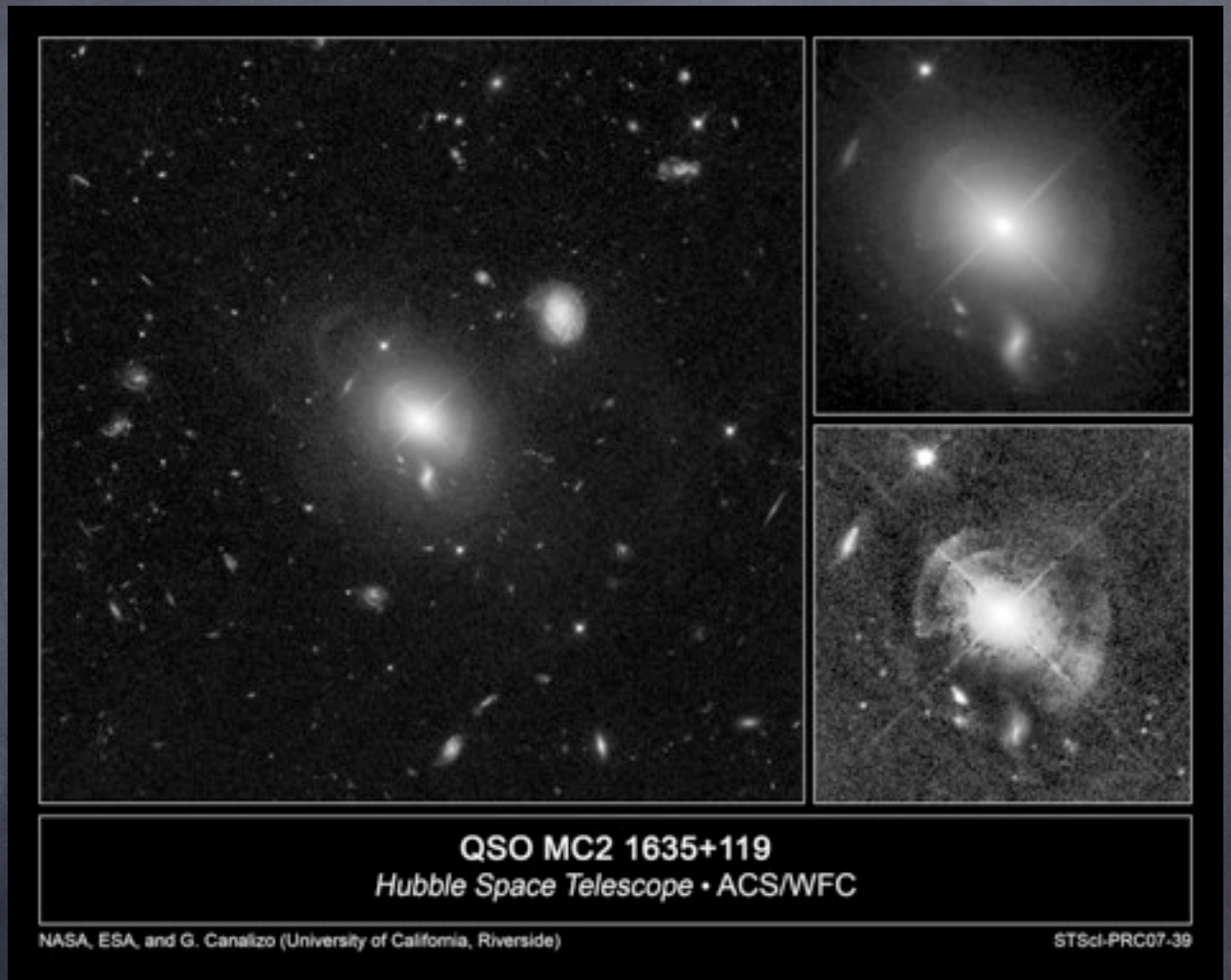
Credit: Andrew Wilson (Maryland/STScI/Chandra)

Merging galaxies <--> Quasars

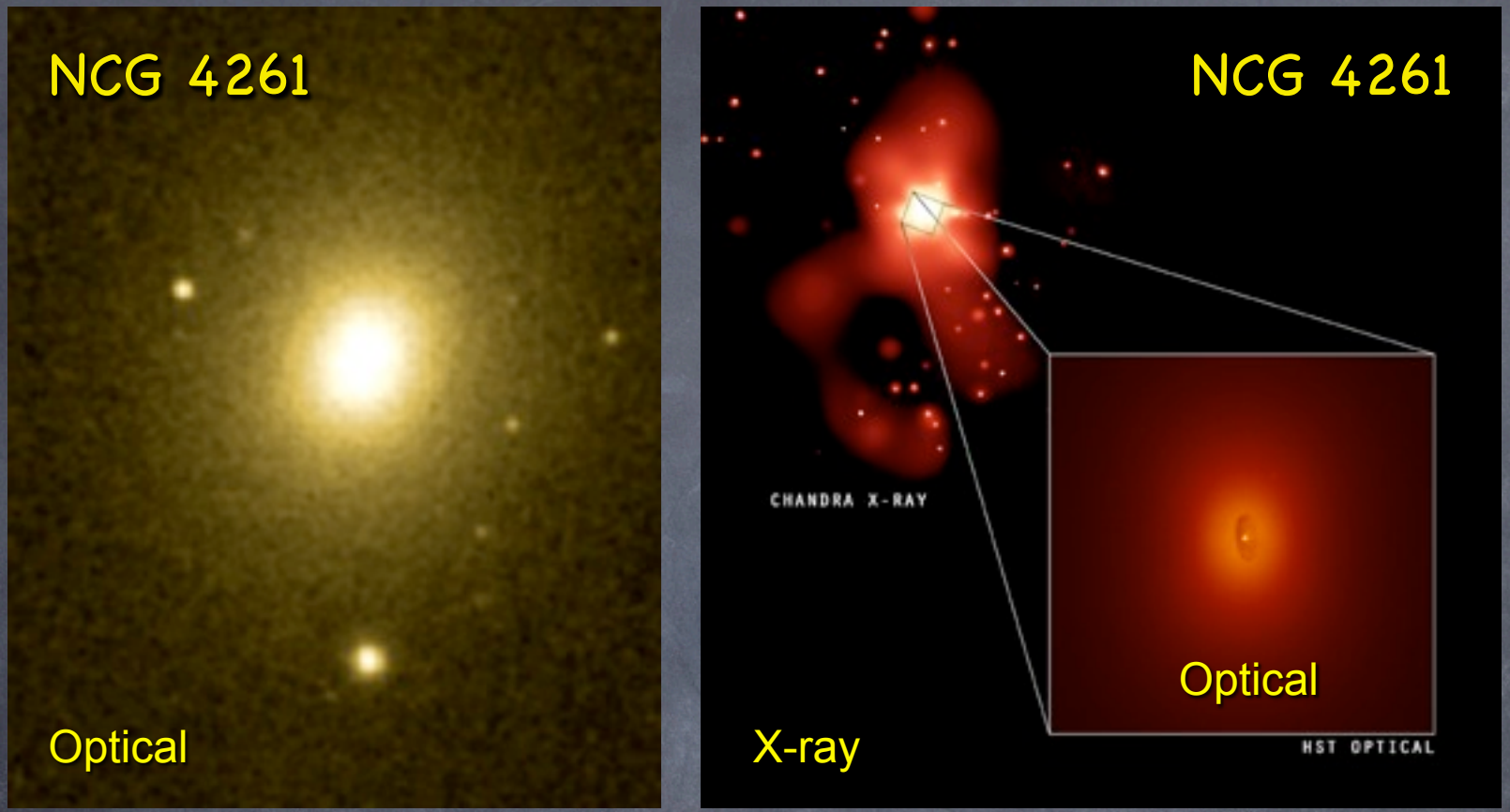


Credit: John Bahcall (IAS) & Mike Disney (Wales)

Quasars in "relaxed" galaxies
--> features due to a recent merger!



Credit: Gabriella Canalizo (UCR) & Nicola Bennert (UCSB)



Credit: Andrea Zezas (Crete/NASA/CXC/DSS)

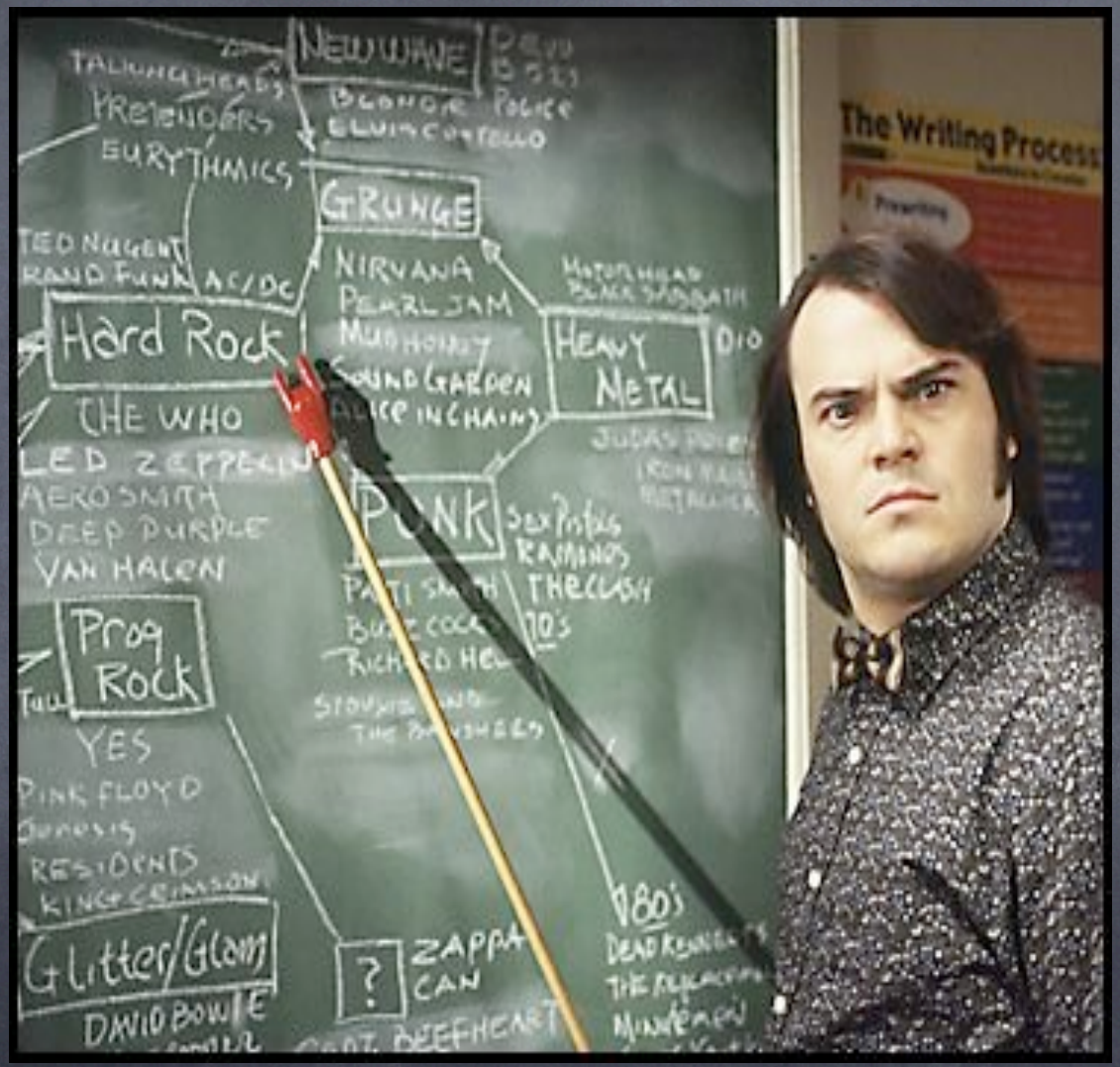
Galaxy Merger --> Quasar
--> Supermassive Black Hole

So far

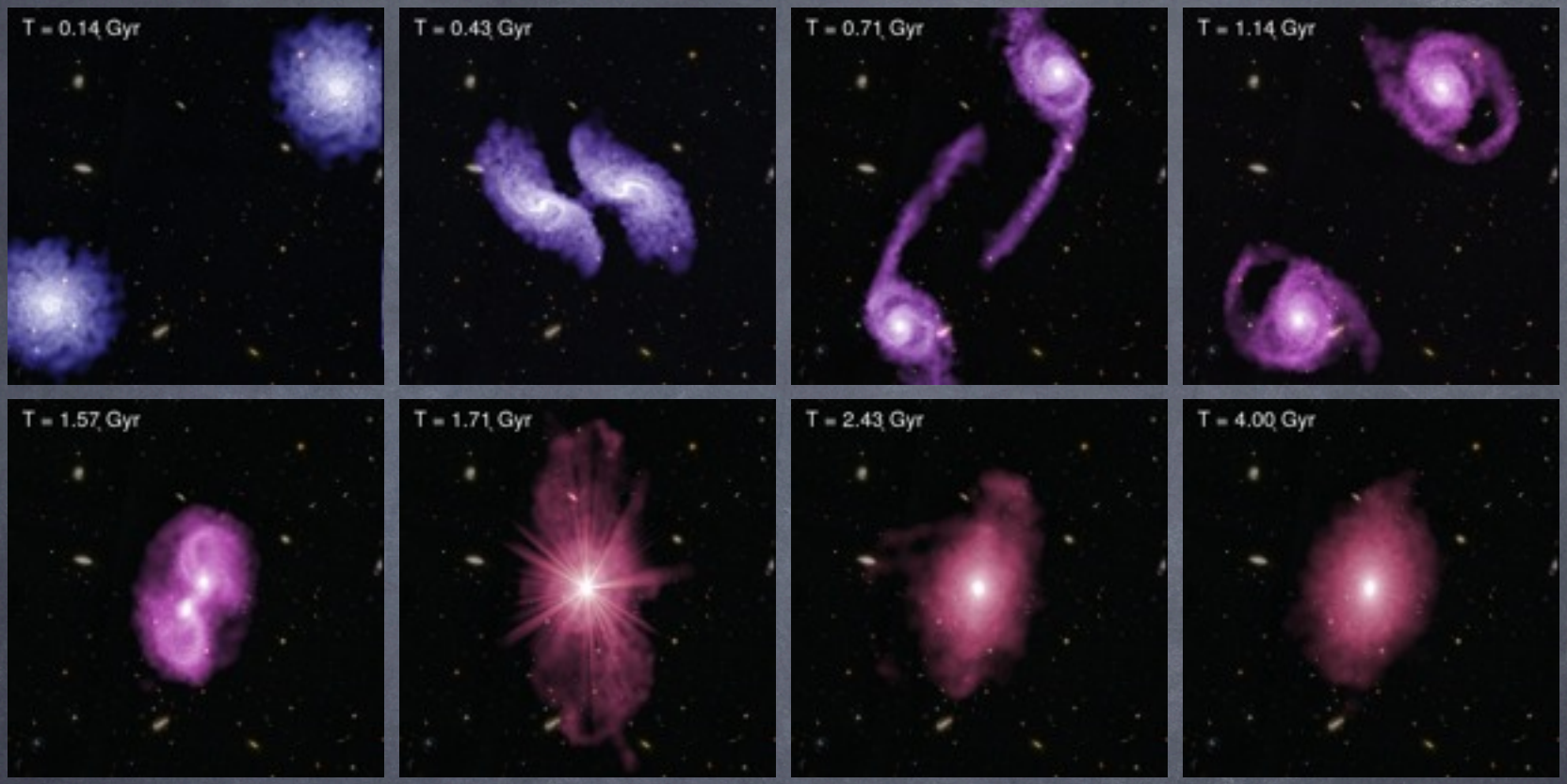
- Supermassive Black Holes at galaxy centres
- Quasars: SMBHs accreting gas
- Galaxy Mergers --> Quasar Activation
- Galaxy Formation <--> Black Hole Evolution

- Simple Picture:
  Galaxy Mergers --> Quasars --> SMBHs

II. How do we model all this?



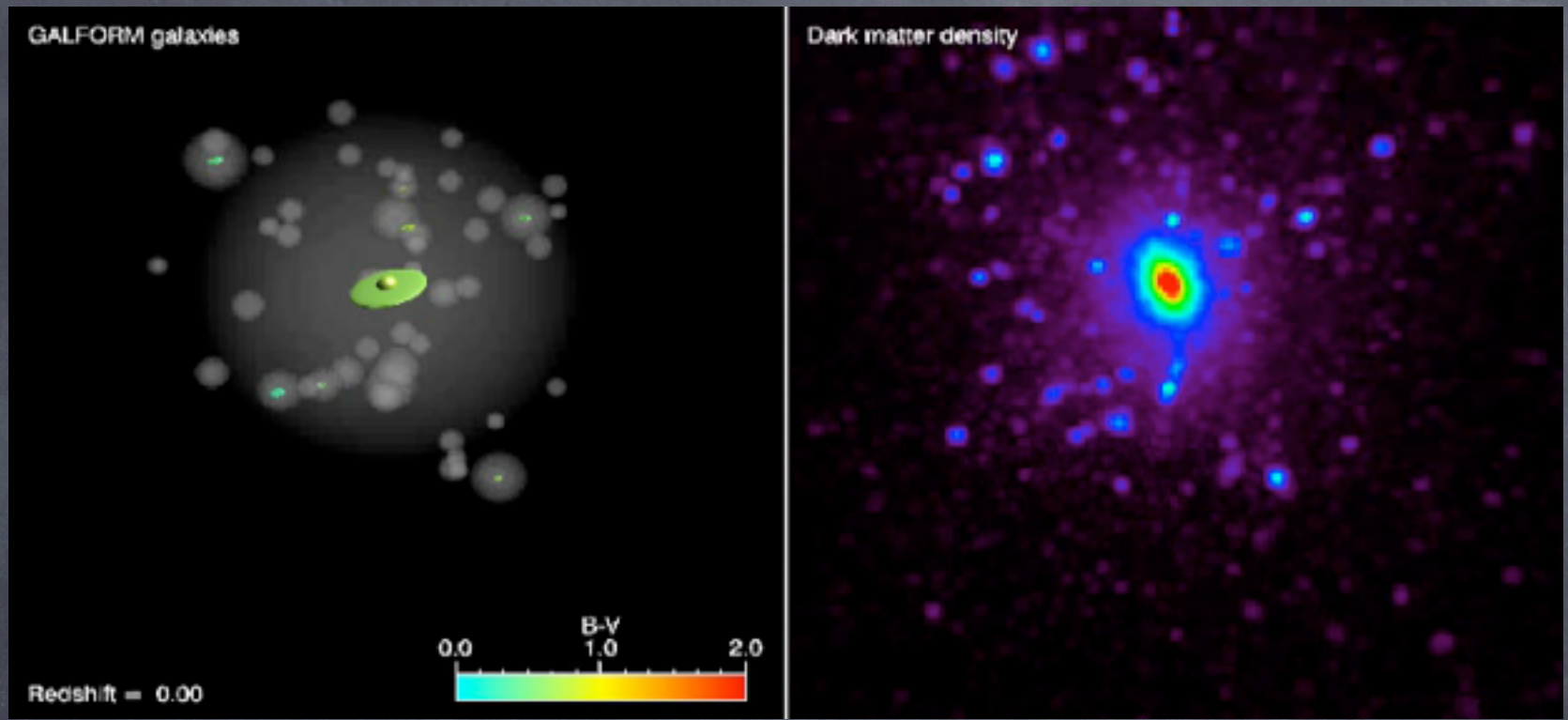
Method I: Hydro simulations



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.

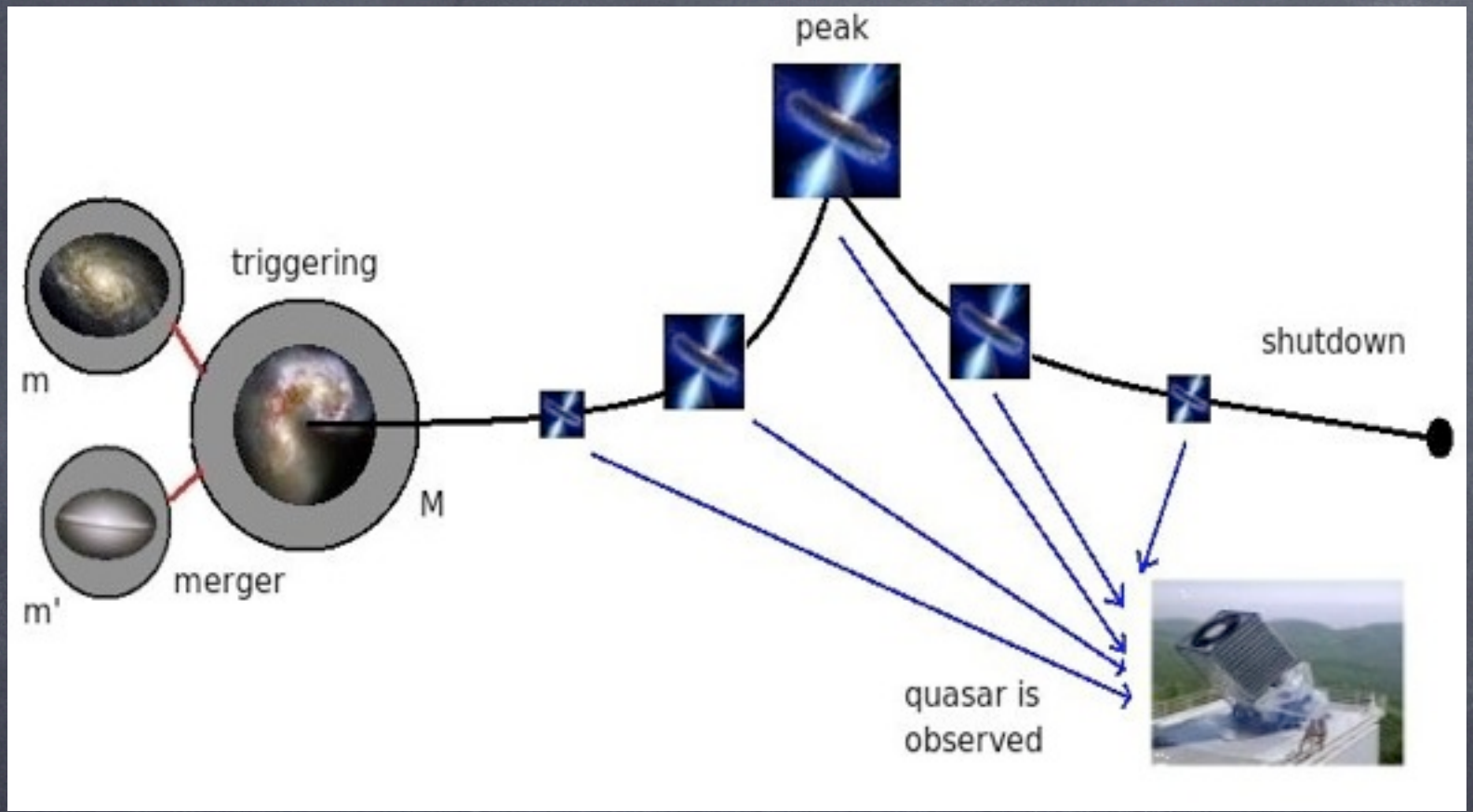
Method II: Semi-Analytic Models



Credit: Andrew Benson (Caltech)

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

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.

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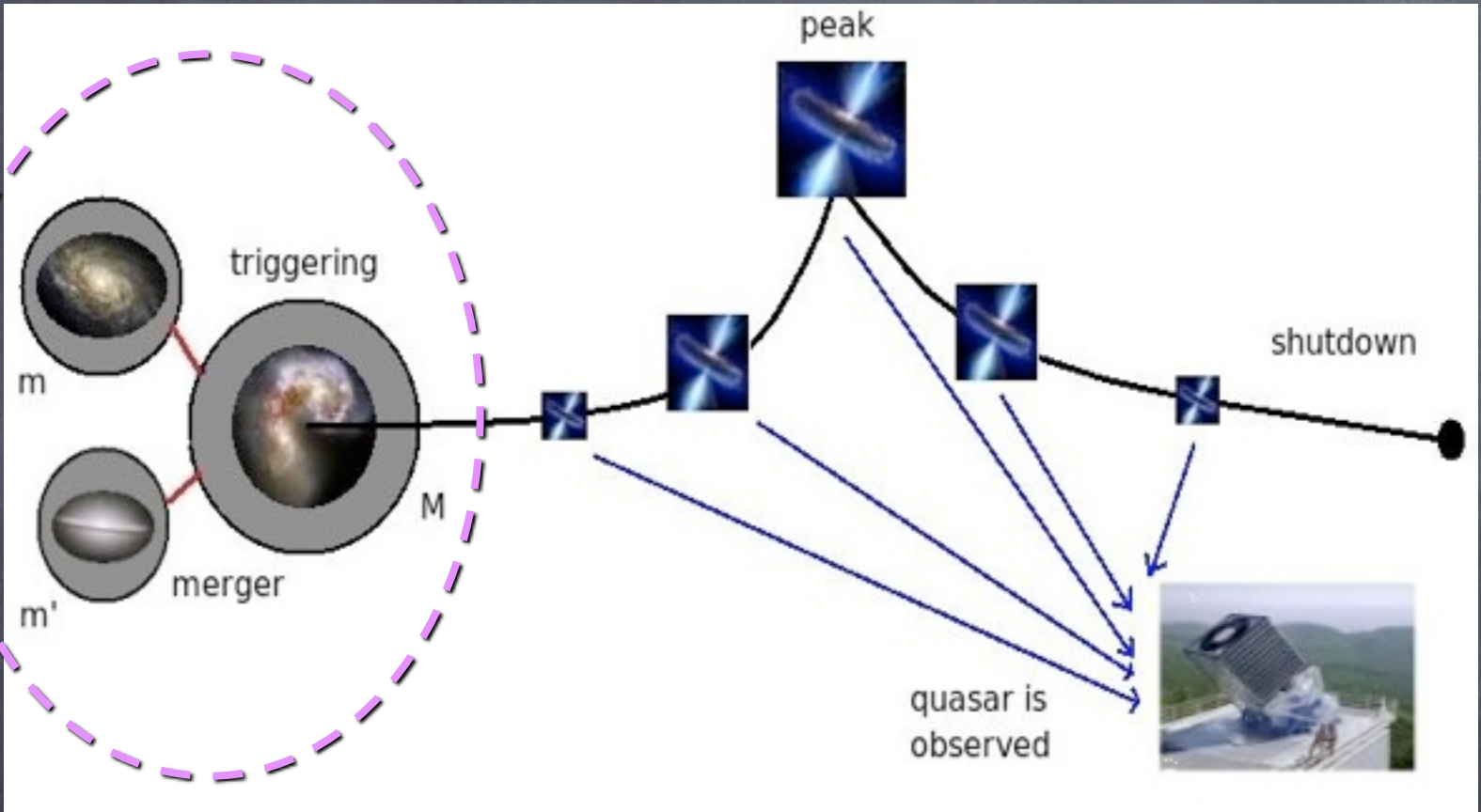

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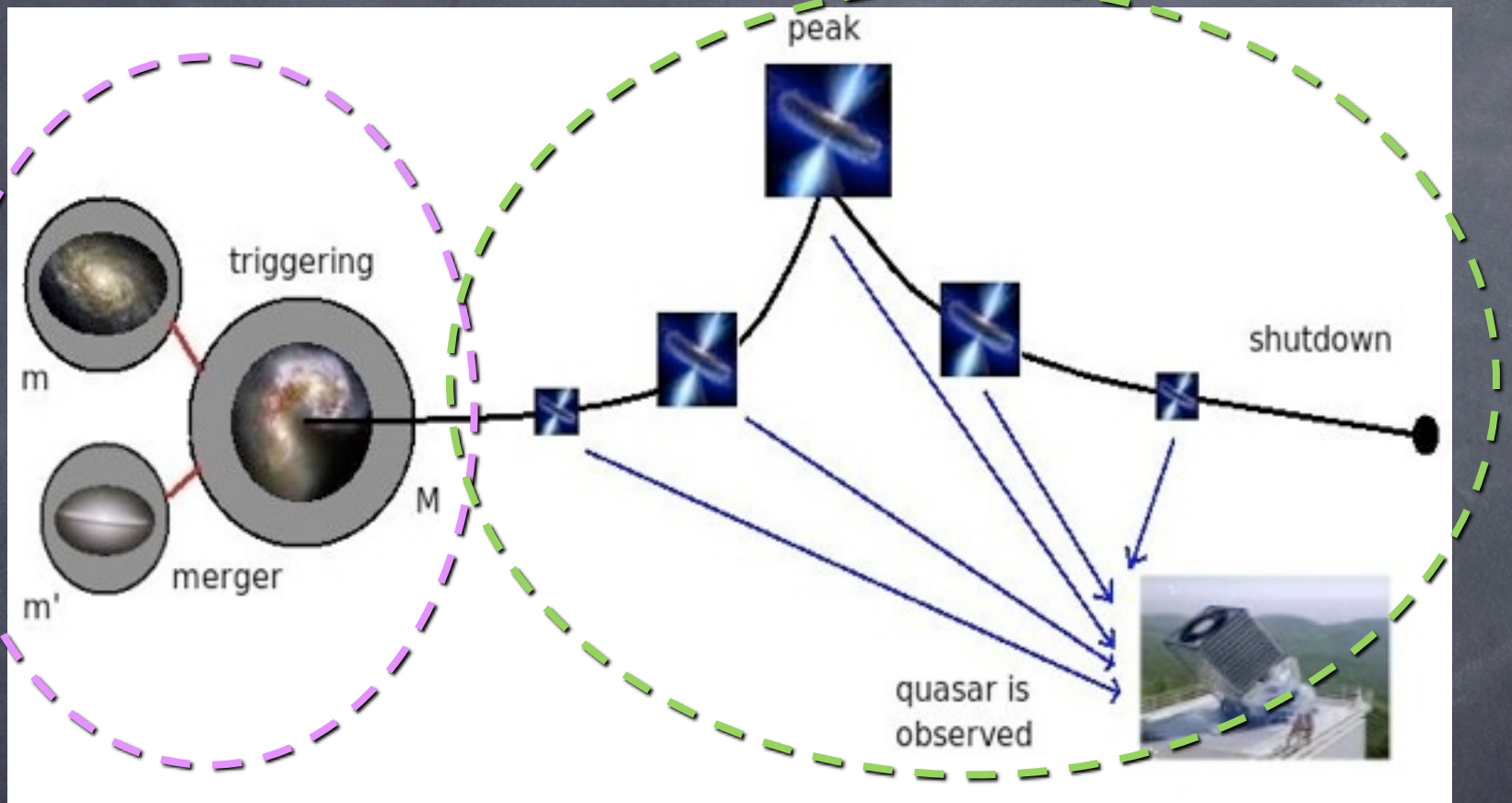

Halo merger rate

Quasar light curve

See also: Works by Wyithe & Loeb,
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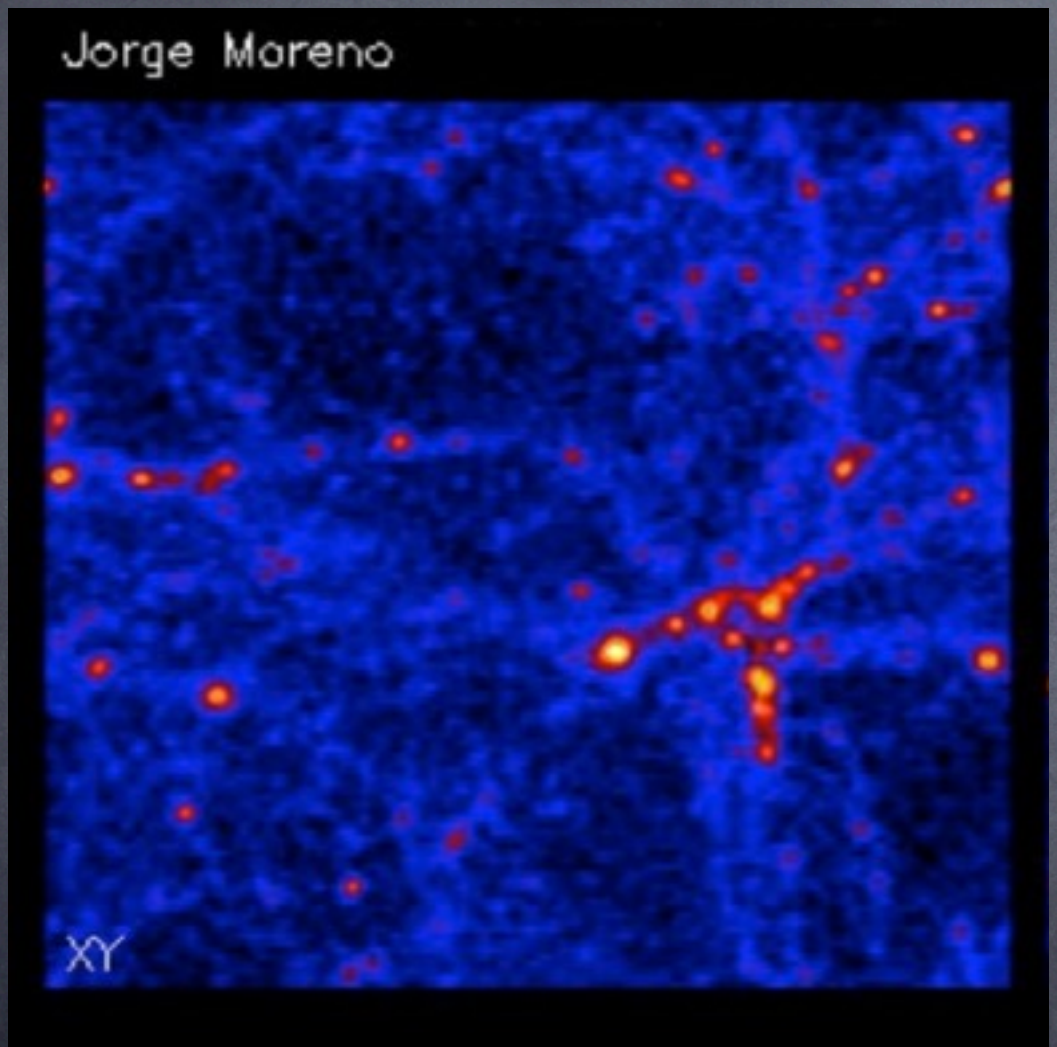
Cosmological Simulations --> Halo Growth



Credit: Jorge Moreno (SISSA/Gadget-2)

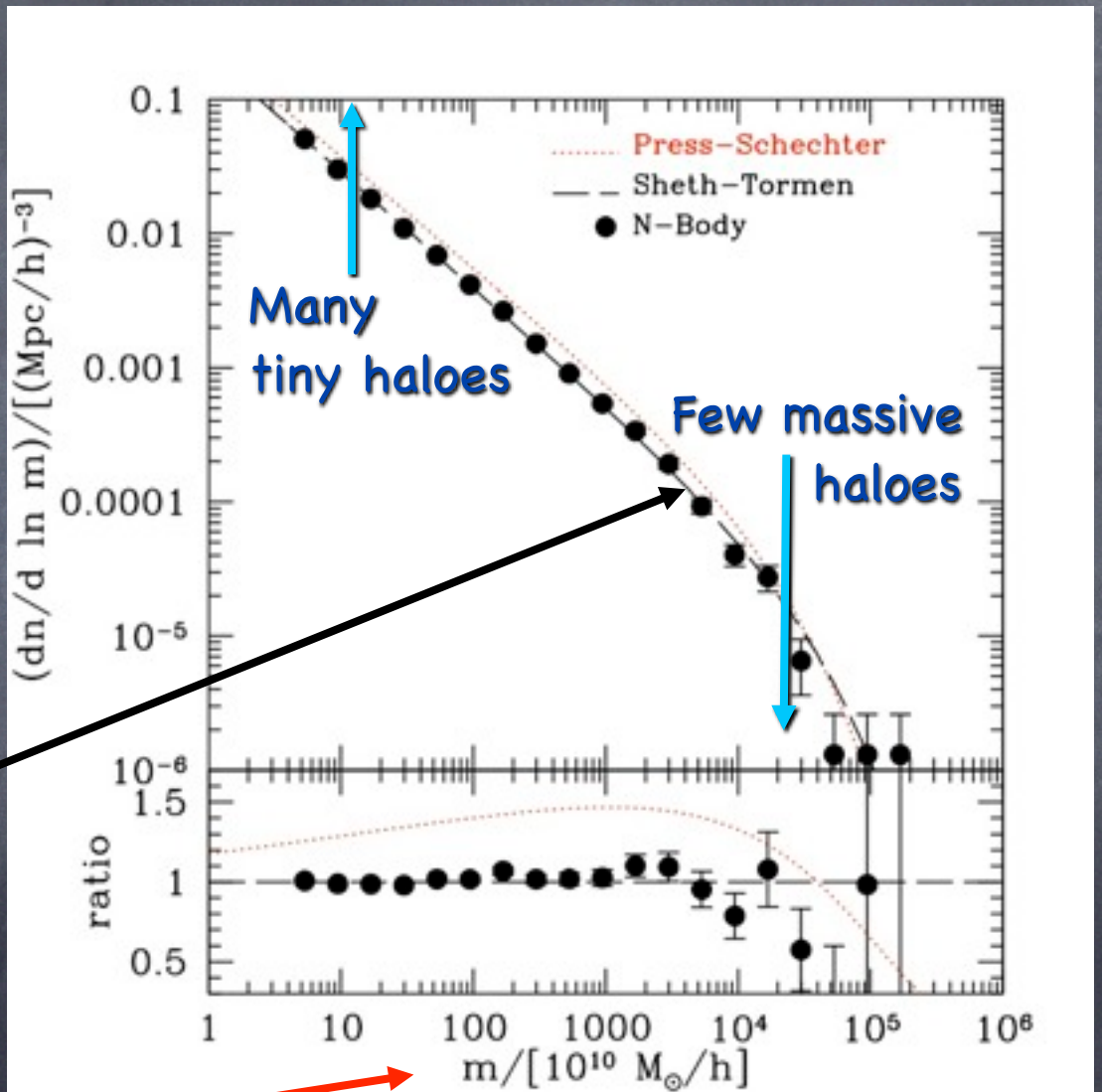
Merger Histories

Halo Mass Function

Halo Merger Rate

Halo Mass Function

Number of haloes of mass m per unit volume



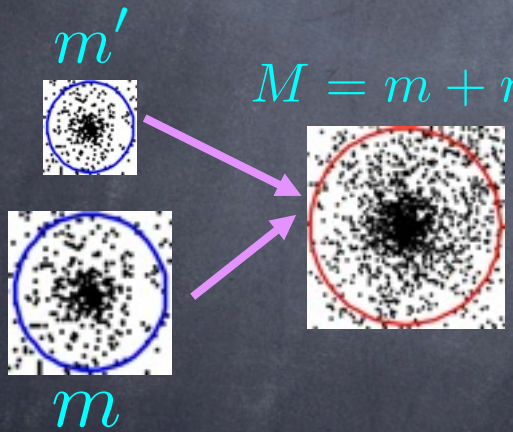
Sheth-Tormen fit

Halo mass

Credit: Moreno et. al. (2009)

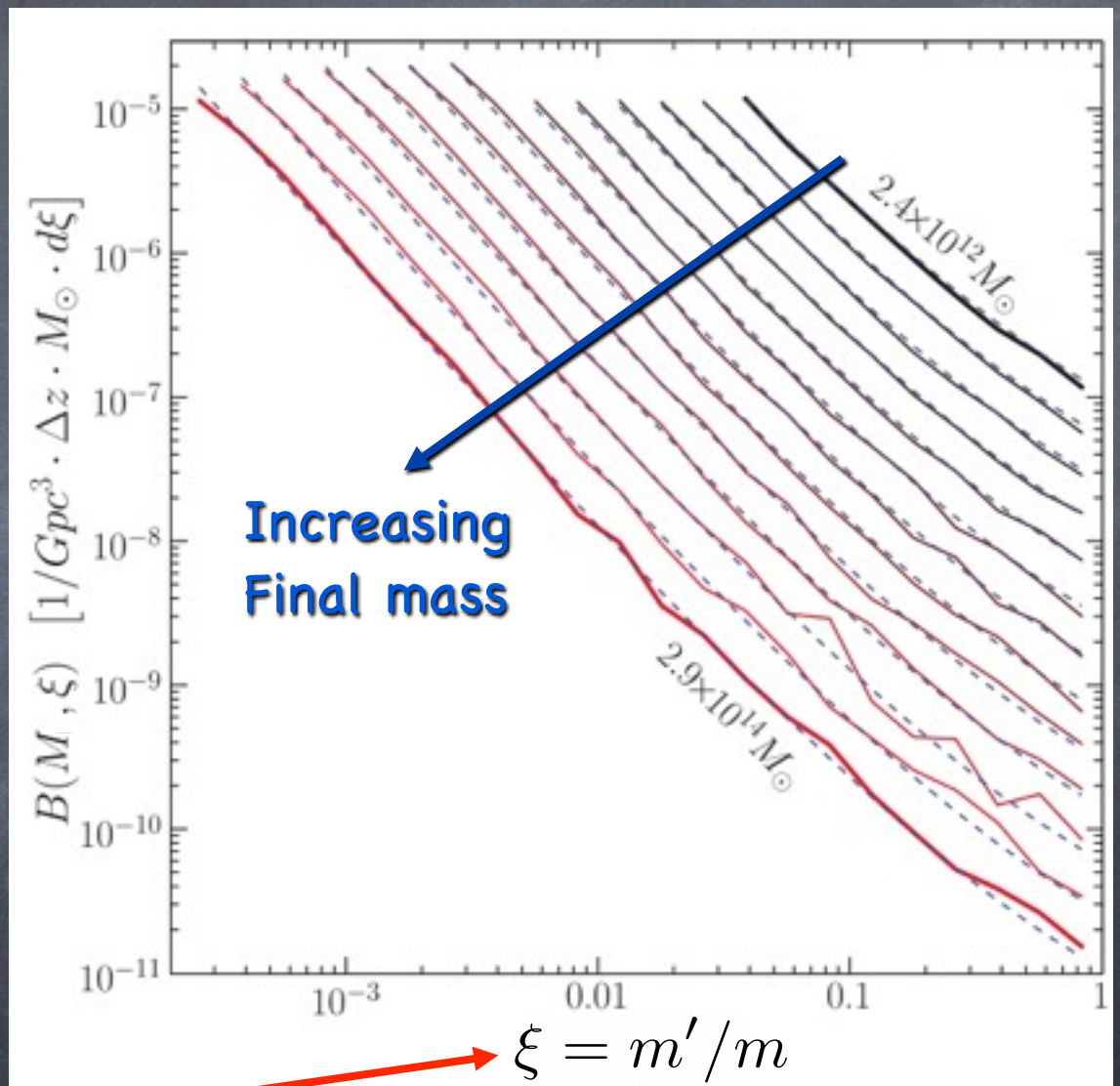
Halo Merger Rate

Halo merger rate per unit volume



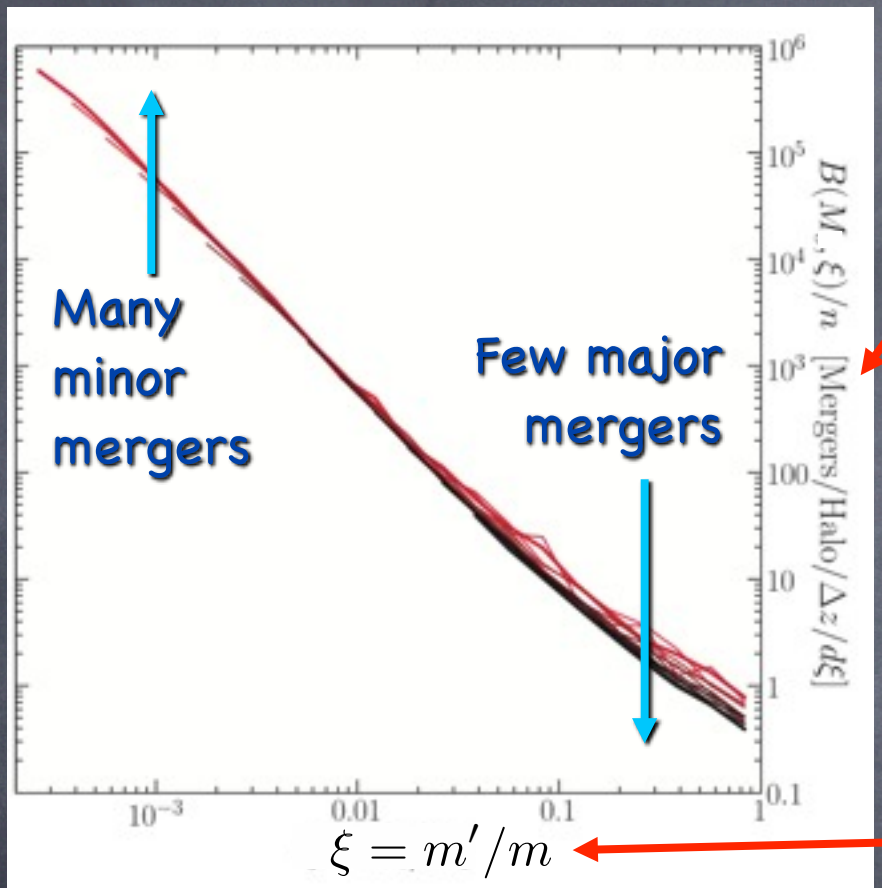
$$\xi = m'/m$$

Mass ratio



Credit: Fakhouri & Ma (2008)

Universal Merger Rate / Halo

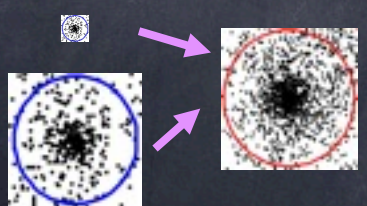


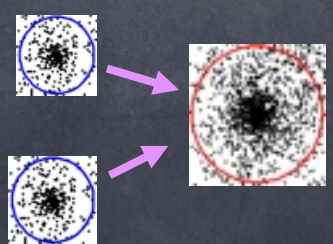
Merger rate per unit halo per unit volume

$$B/n$$

Mass ratio

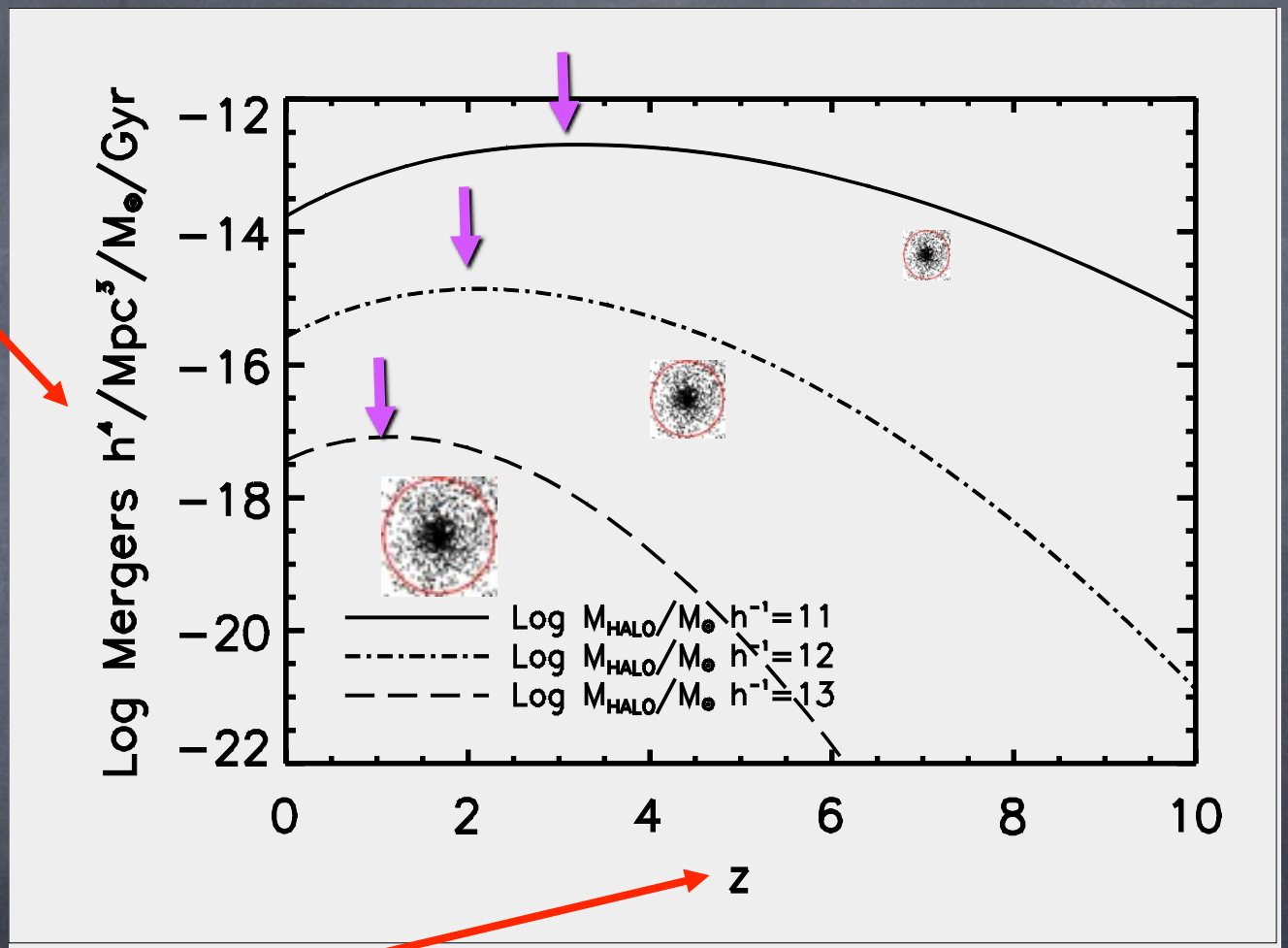
Credit: Fakhouri & Ma (2008)





Merger Rate Evolution

Major merger rate per unit volume



Credit: Fakhouri & Ma (2008)

Redshift

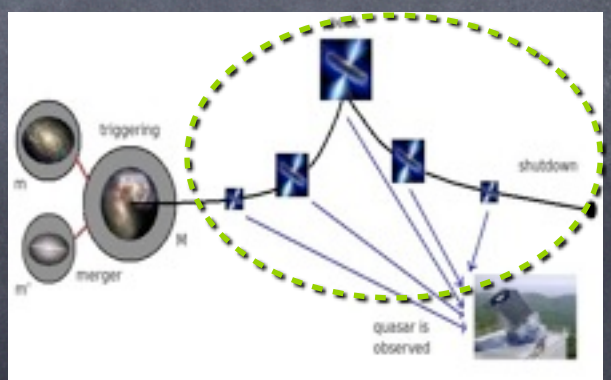
So far

- 1st Ingredient:
  Analytic Merger Rate:

$$B = (B/n) \times n$$

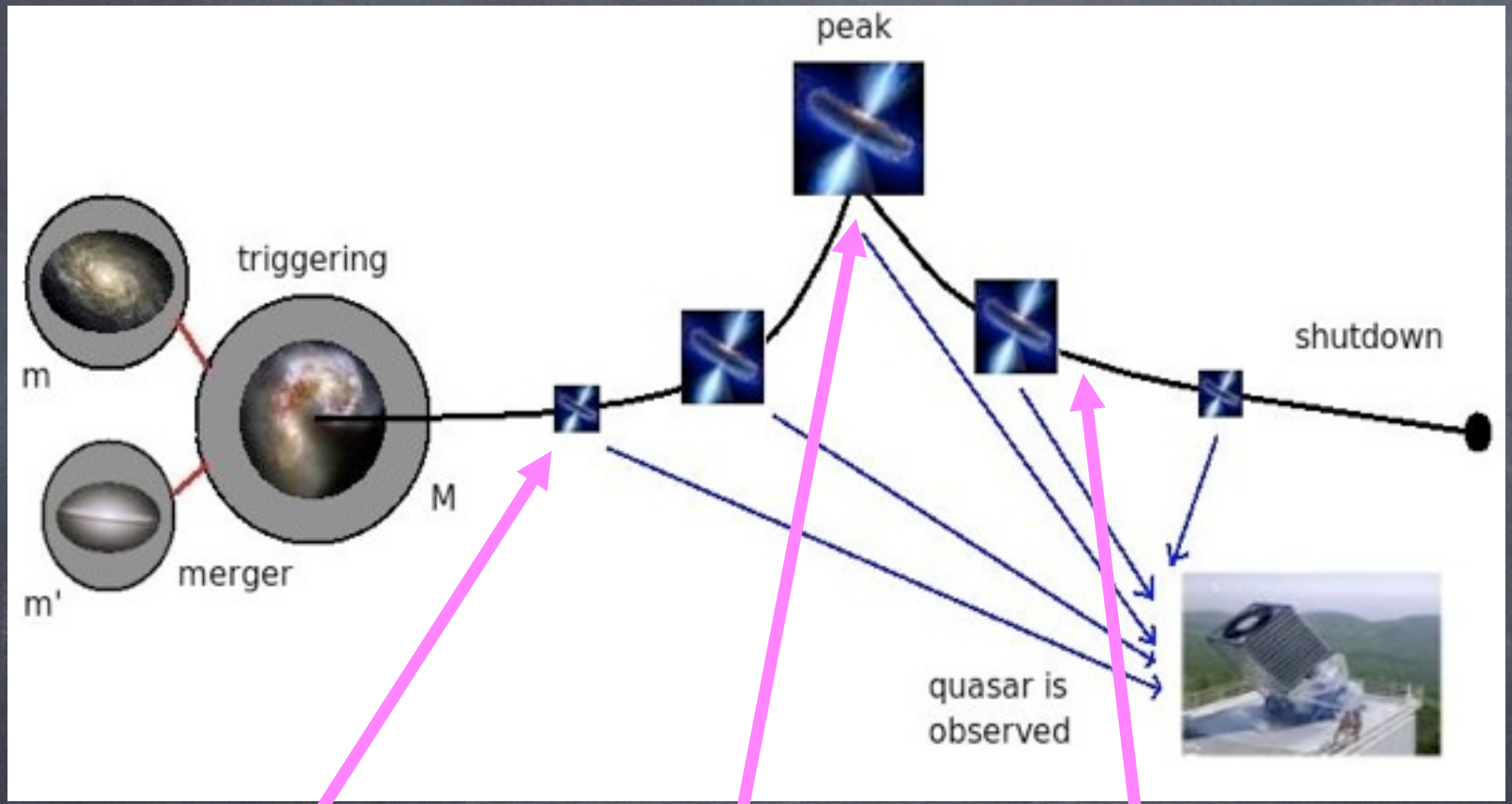
Fakhouri-Ma Sheth-Tormen

- 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

A simple model

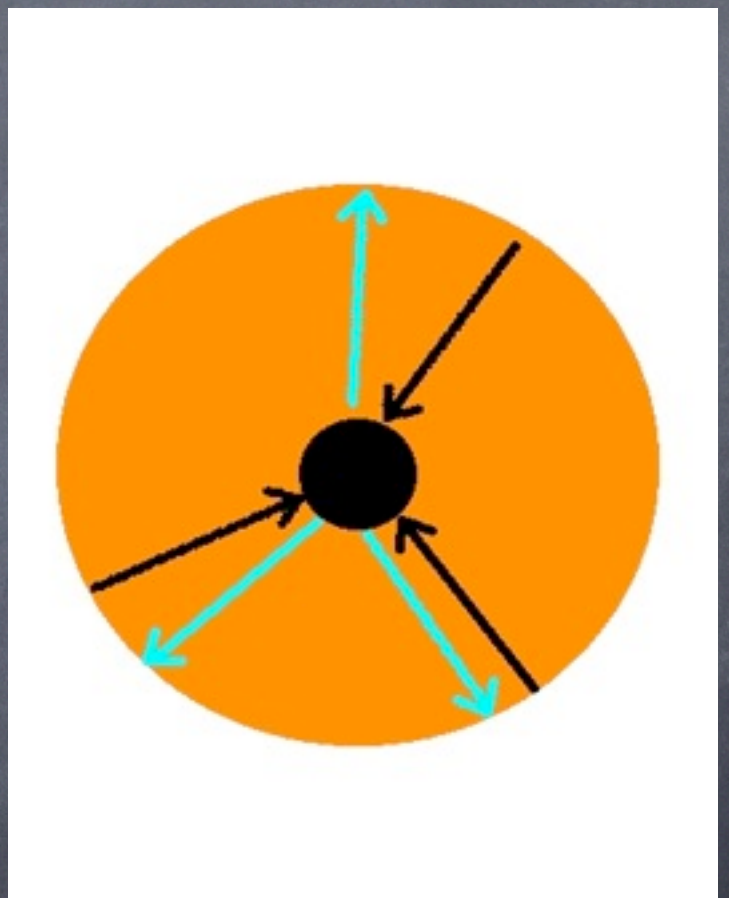
$$F_{\rm rad} = F_{\rm grav}$$

$$\rightarrow L_{\rm Edd} \propto M_{\rm BH}$$

$$L = \lambda L_{\rm Edd}$$

Eddington Ratio

$$\boxed{L \propto M_{\rm BH}}$$



A simple model

$M_{\rm infall}$

$$L = \epsilon \dot{M}_{\rm infall} c^2$$

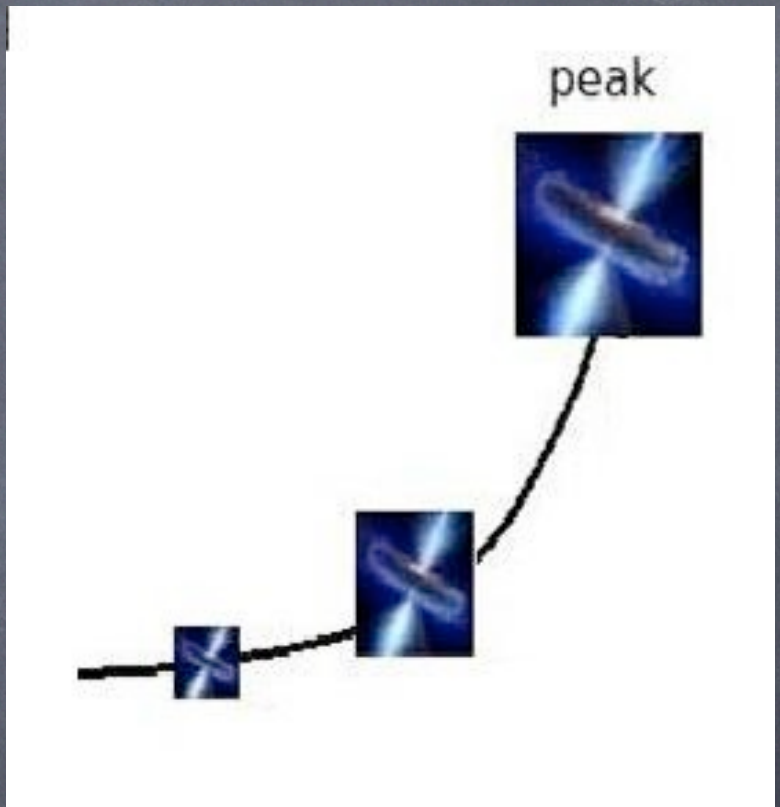
Radiative Efficiency

$$\boxed{L \propto \dot{M}_{\rm BH}}$$

The Ascending Phase

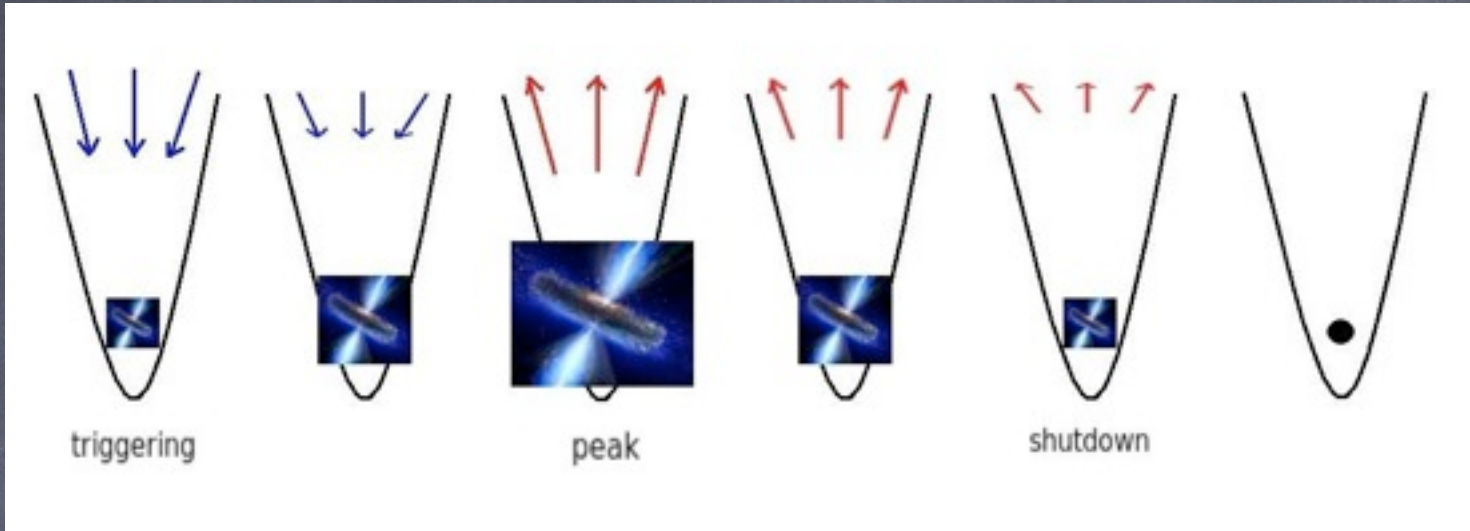
$$L \propto M_{\rm BH}$$
$$L \propto \dot{M}_{\rm BH}$$

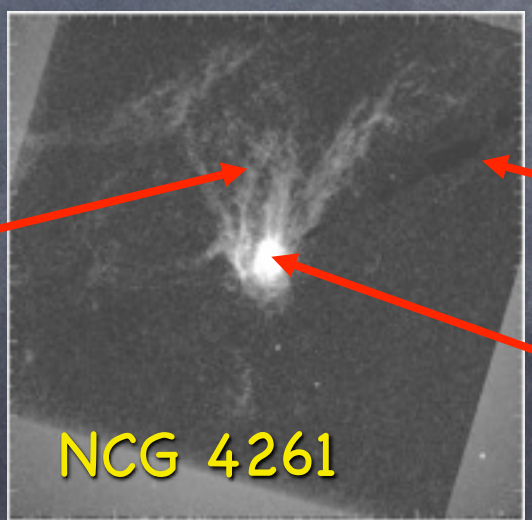
$$\rightarrow M_{\rm BH} \propto \dot{M}_{\rm BH}$$



$$\boxed{M_{\rm BH}(t), L(t) \propto \exp(t/t_{\rm ef})}$$

The Peak





Credit: Ford & Tsvetanov (1998)

Self Regulation (AGN Feedback)

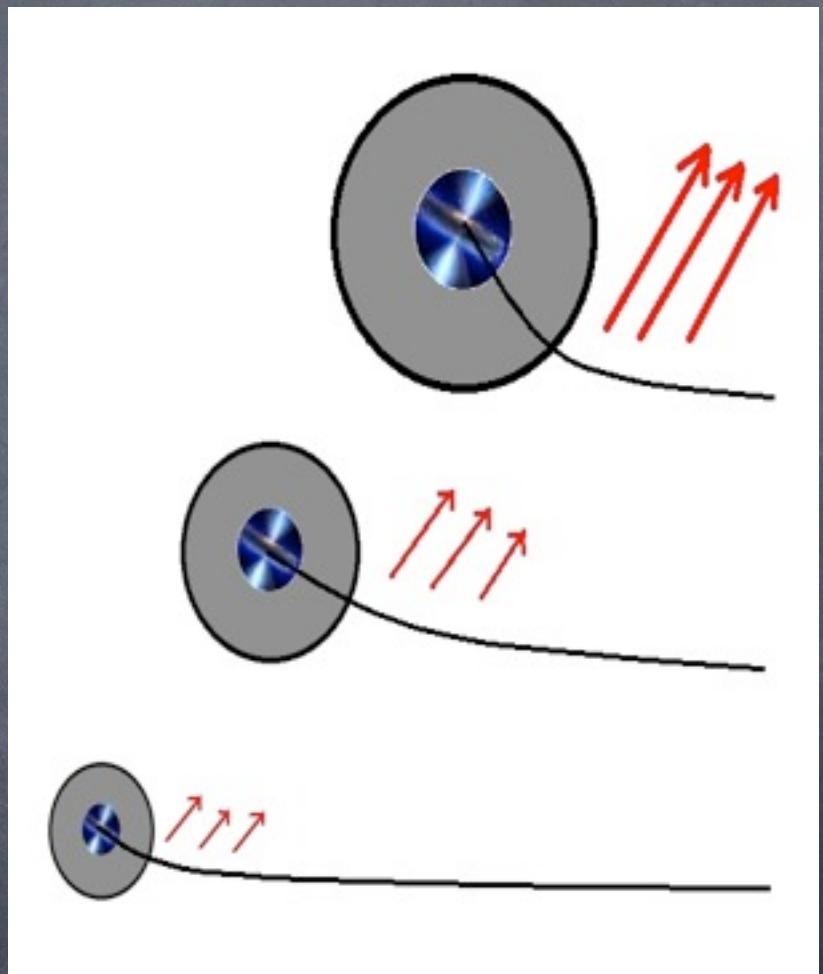
$$L_{\rm peak} \propto M_{\rm Halo}^{5/3}(1+z)^{5/2}$$

Wyithe & Loeb (2003)

The Descending Phase

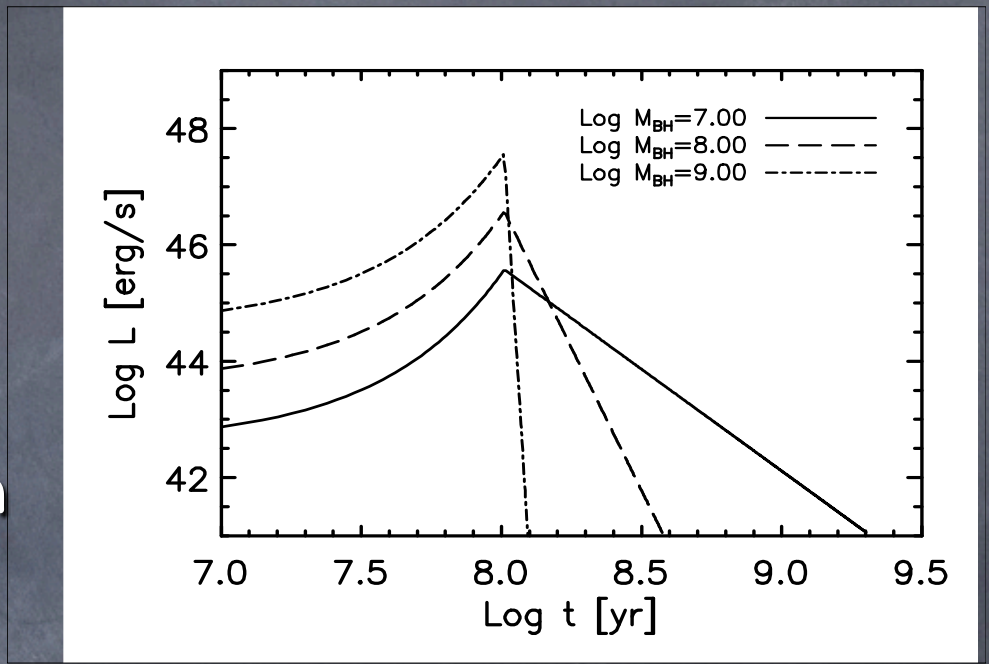
$$L \propto t^{-\alpha}$$

$$\alpha = \alpha(M_{\mathrm{Halo}})$$



So far

- The Light Curve:



- Ascending phase:
  exponential growth
- Peak:
  self-regulated
- Descending phase:
  mass-dependent

III. Results

- Science Goals:

1. Luminosity Function

   at all redshifts

2. Clustering

   at all redshifts

Formidable Task!

Reference Model

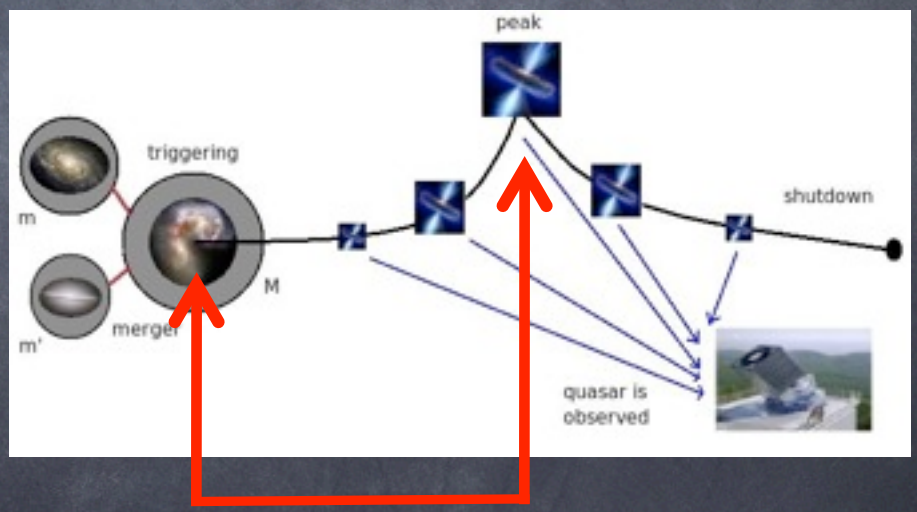
- Only major mergers: $\xi = m'/m \geq 1/4$
- Range of host halo masses:

$$10^{11.5} M_\odot < M_{\rm Halo} < 10^{13} M_\odot$$

- Short time delays:

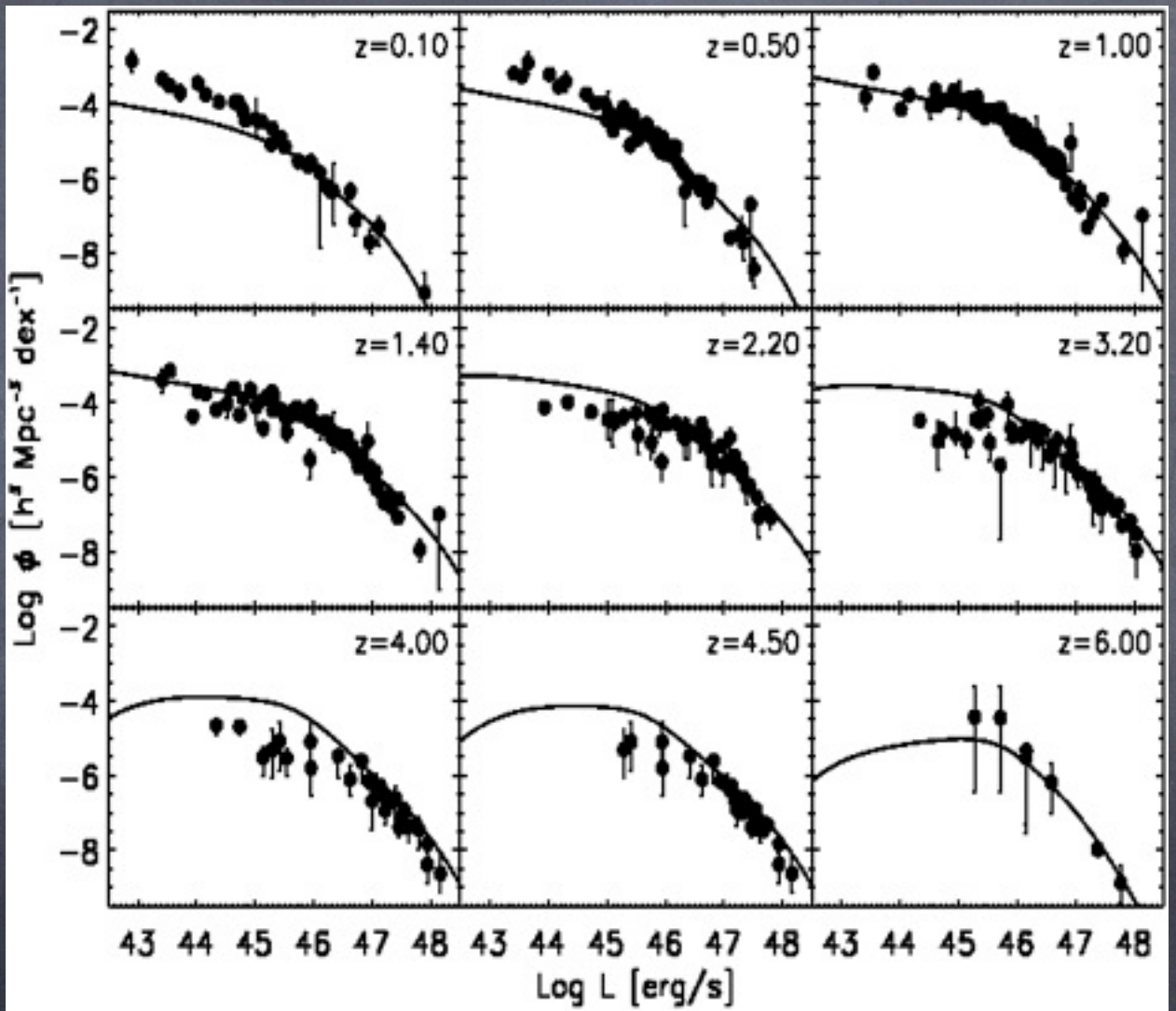
$$M_{\rm BH,\,seed} = \frac{M_{\rm BH,\,peak}}{\mu_{\rm BH}}$$

$$\rightarrow t_{\rm delay} \text{ is fixed}$$

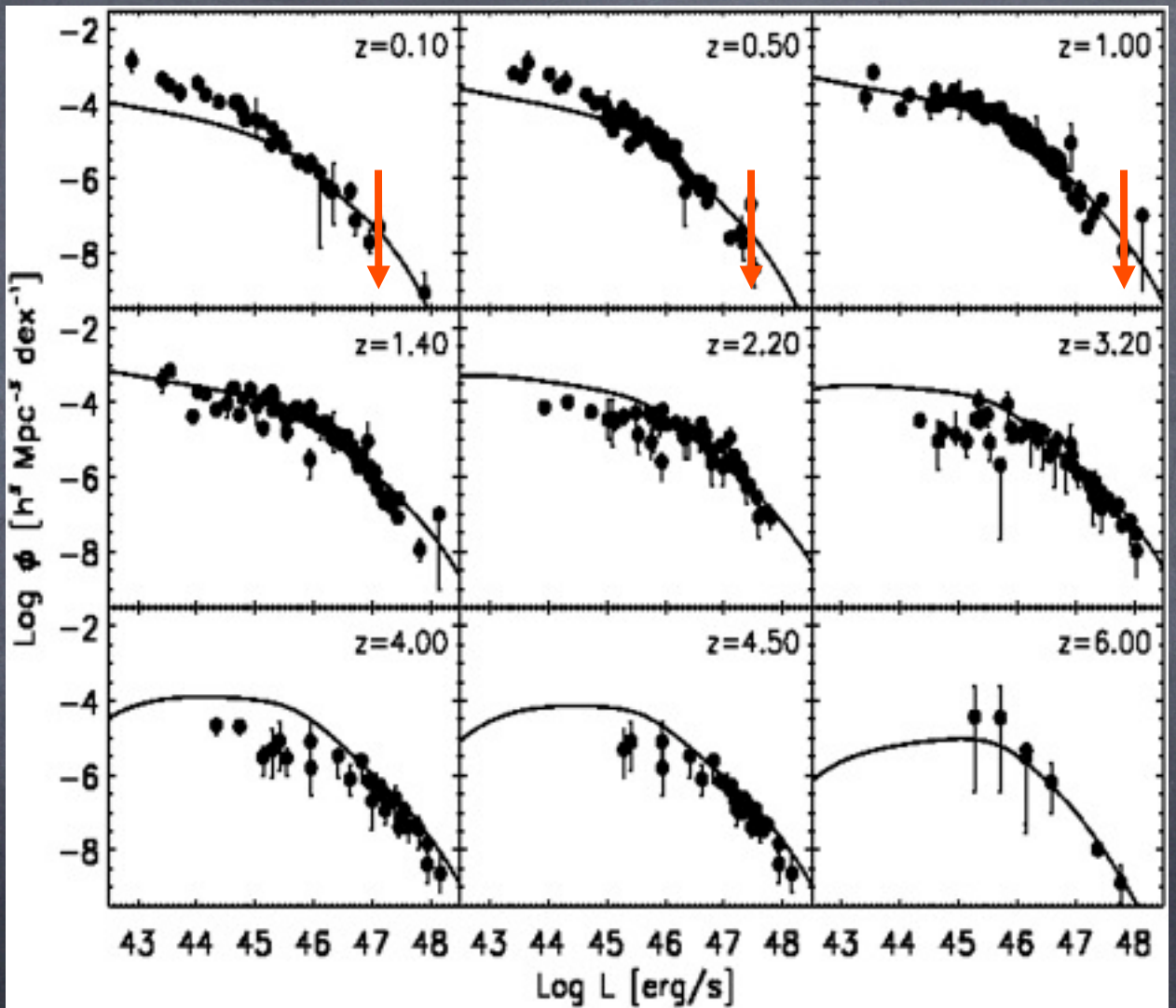


$$t_{\rm delay} = t_{\rm peak} - t_{\rm triggering}$$

The Luminosity Function



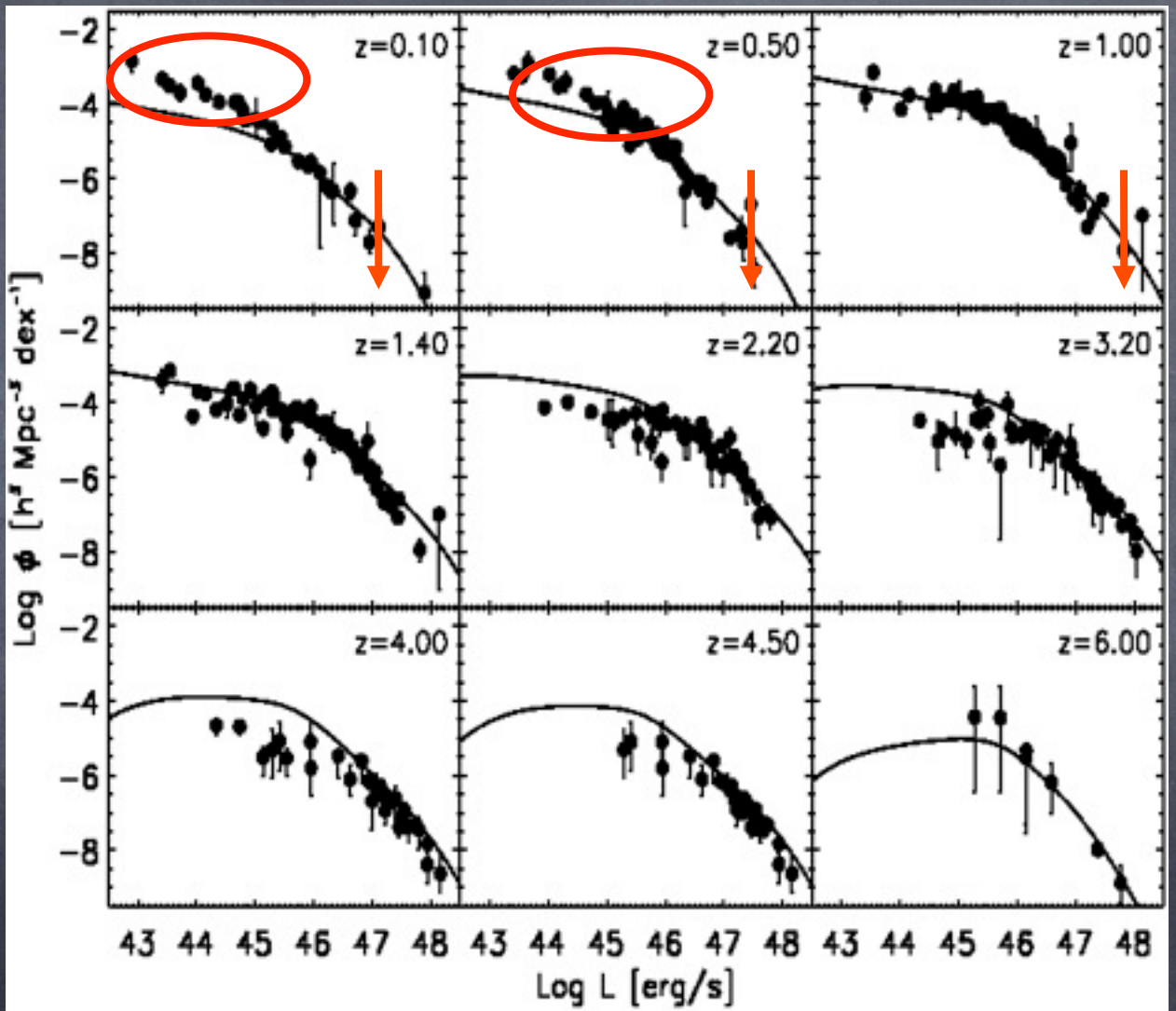
The Luminosity Function



Bright end Works!

The Luminosity Function

Not enough faint AGNs



Bright end Works!

The Luminosity Function

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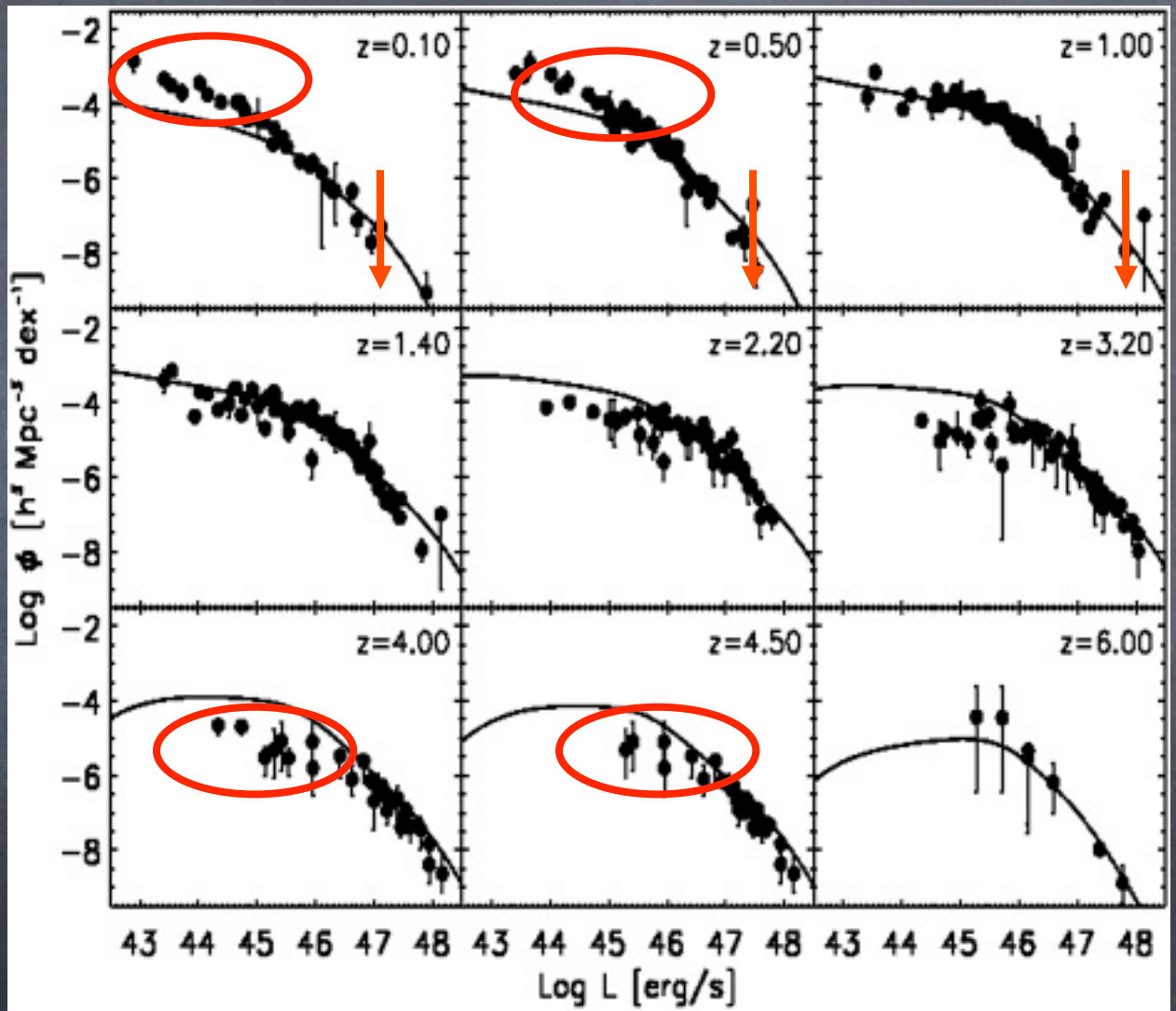
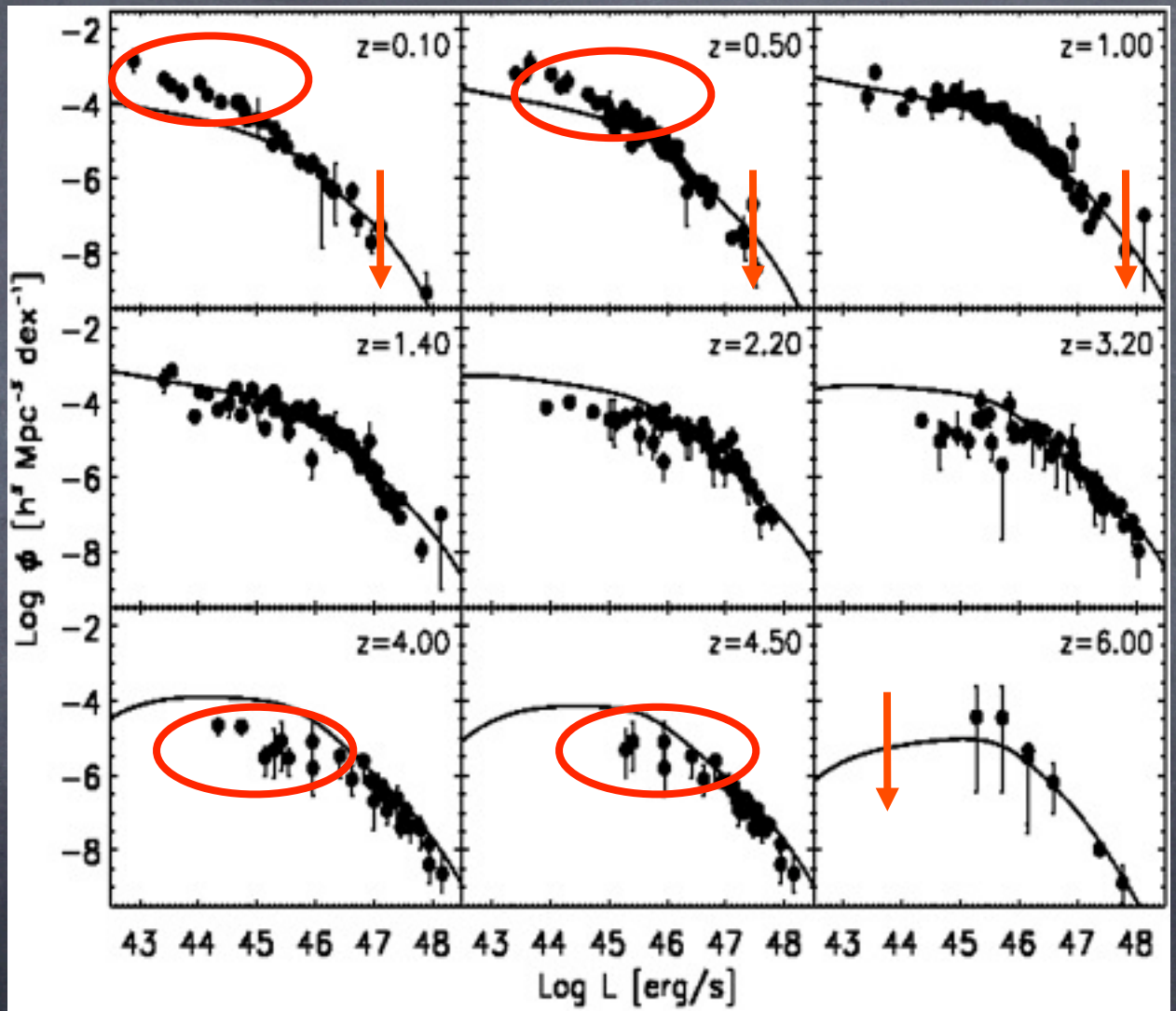


Too many faint AGNs

Bright end Works!

The Luminosity Function

Not enough faint AGNs

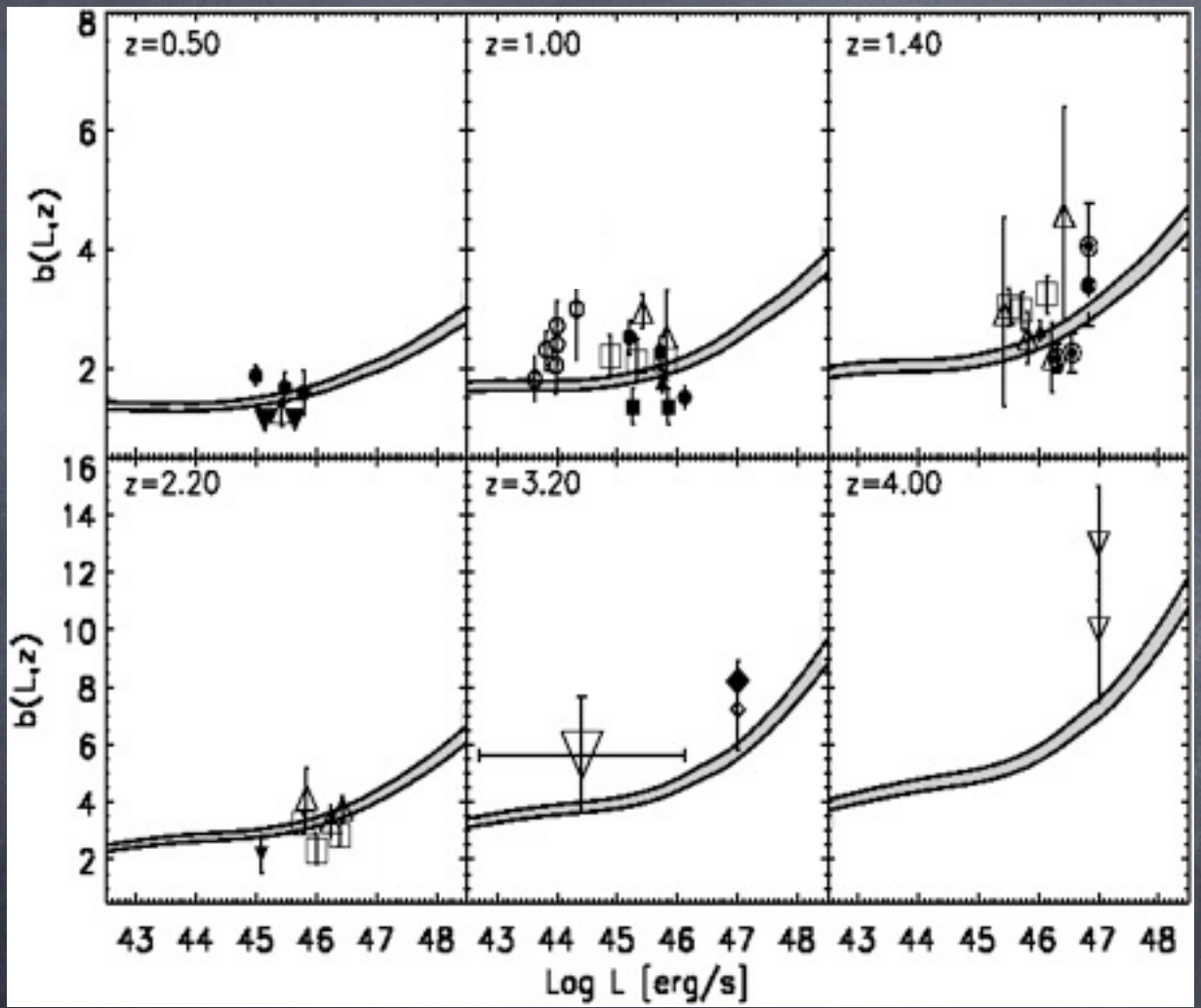


Bright end Works!

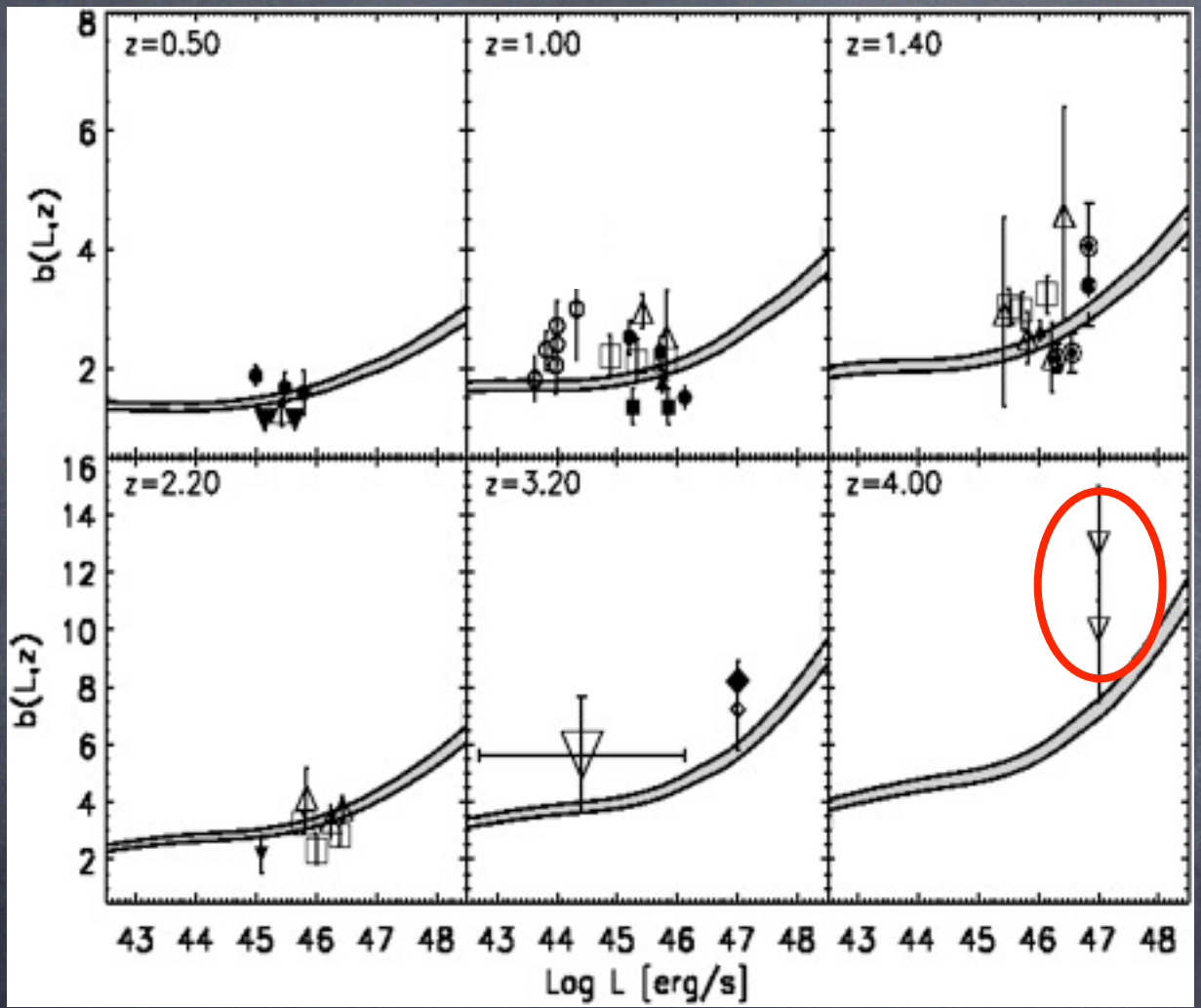
Too many faint AGNs

New prediction!

Quasar Clustering (the bias)



Quasar Clustering (the bias)

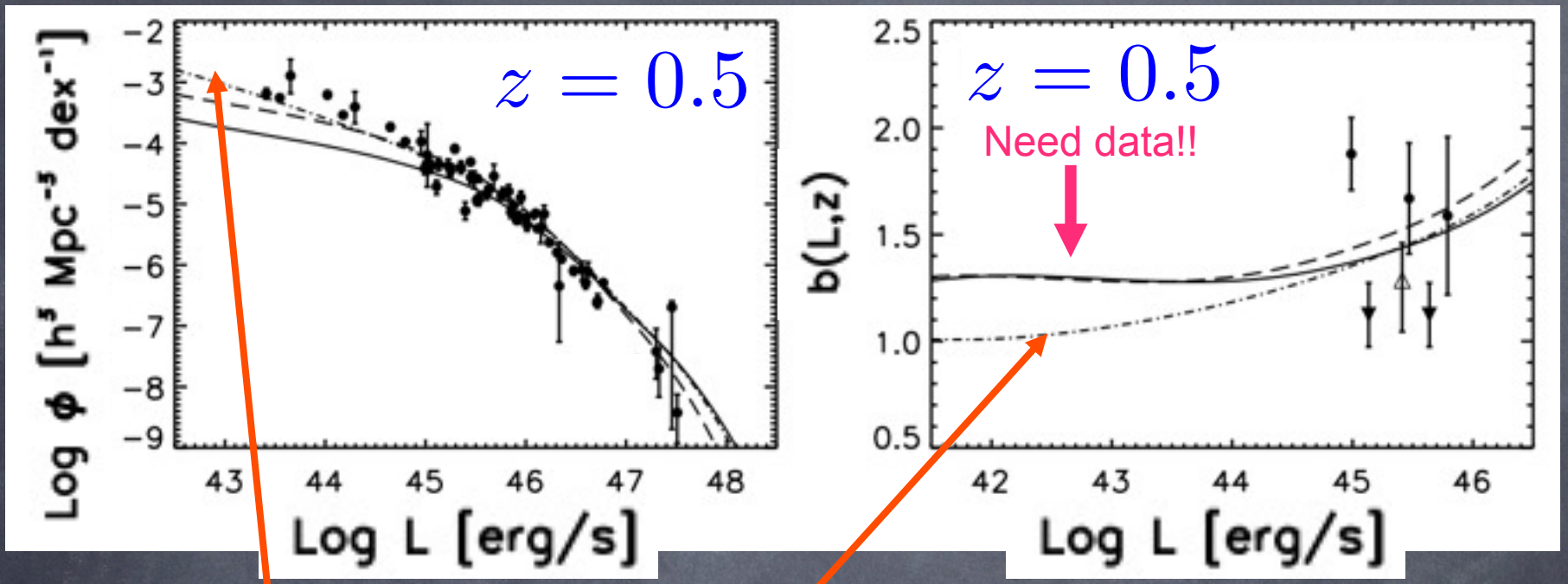


Very biased bright quasars!

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

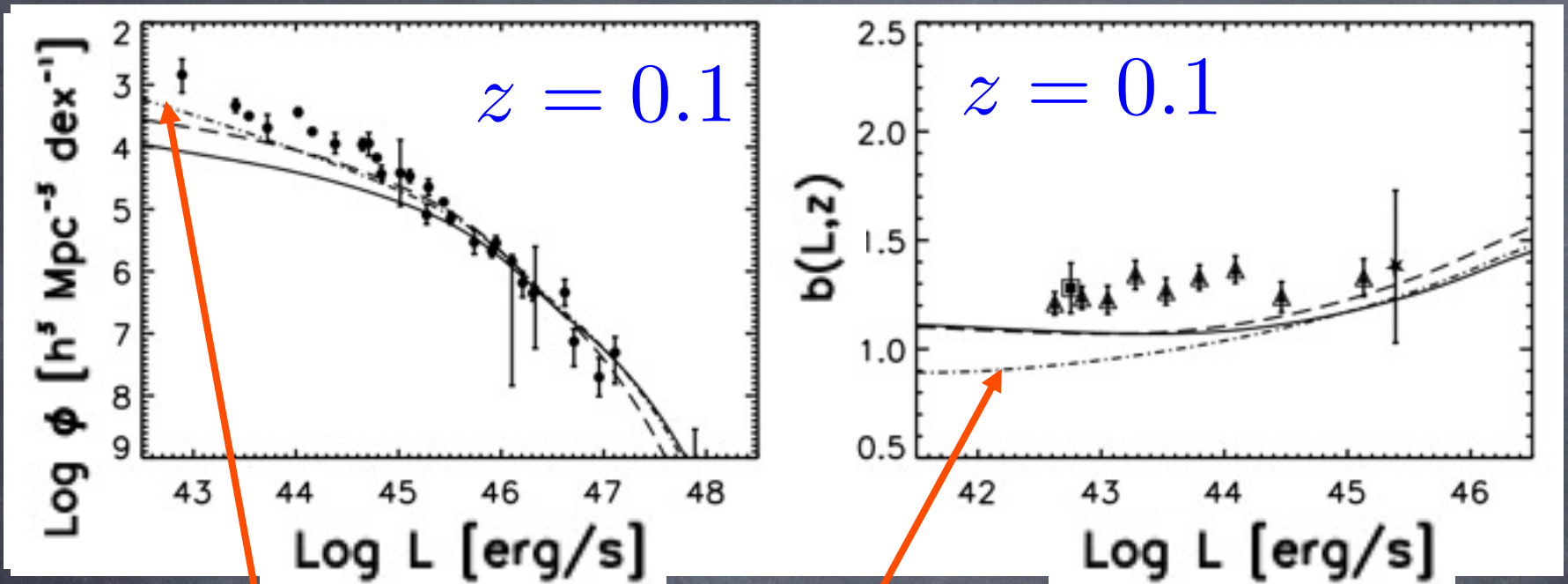
Testing models with small host haloes



Small host model

At low z: we cannot tell!!

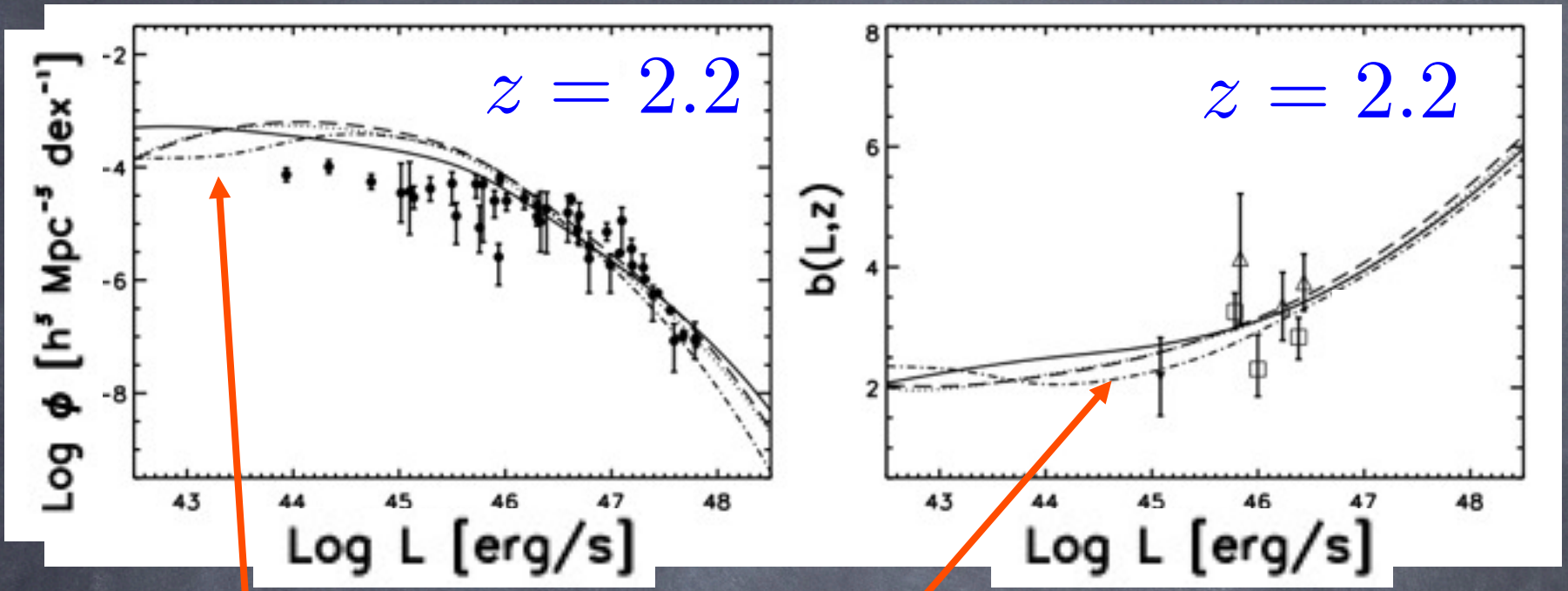
Testing models with small host haloes



Small host model

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

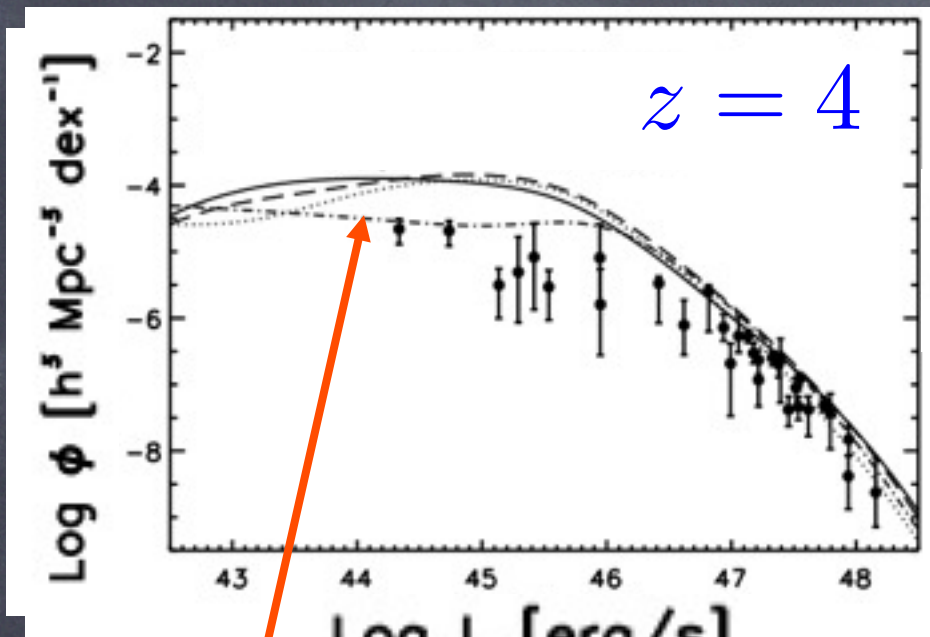
Testing long-lived Models

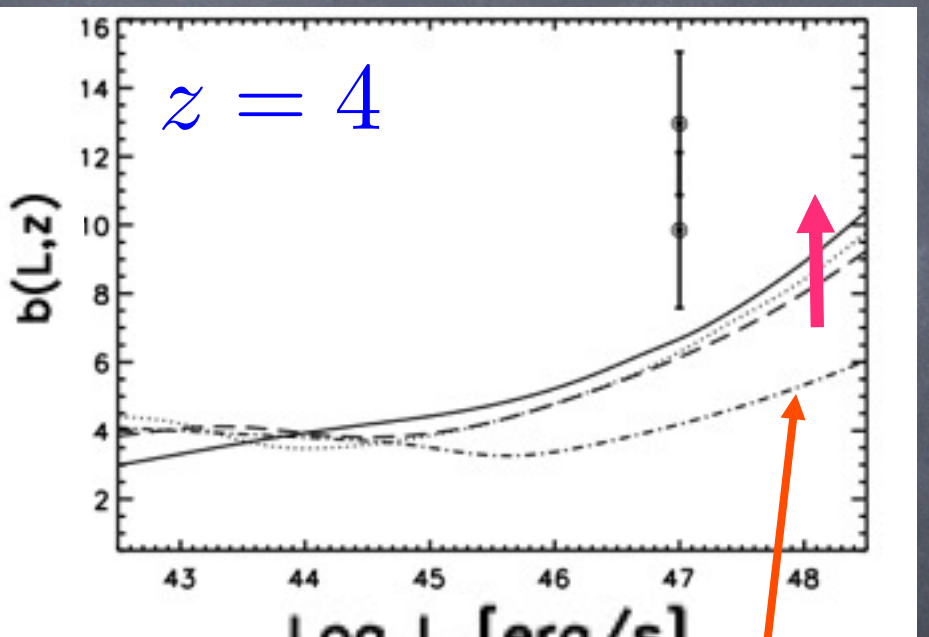


Long-delay model

At intermediate z: we cannot tell!

Testing long-lived Models





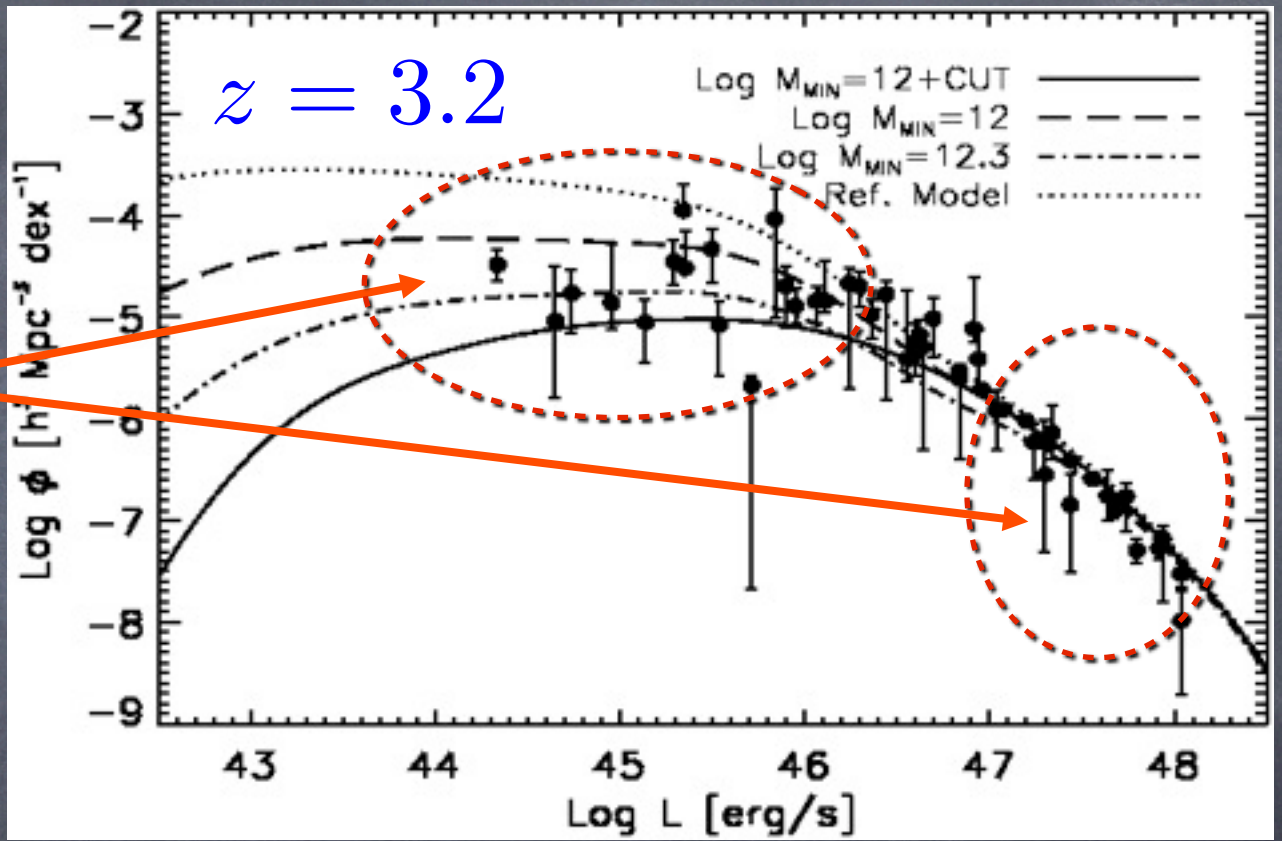
Long-delay model

At high z: long-delay model ruled out!!

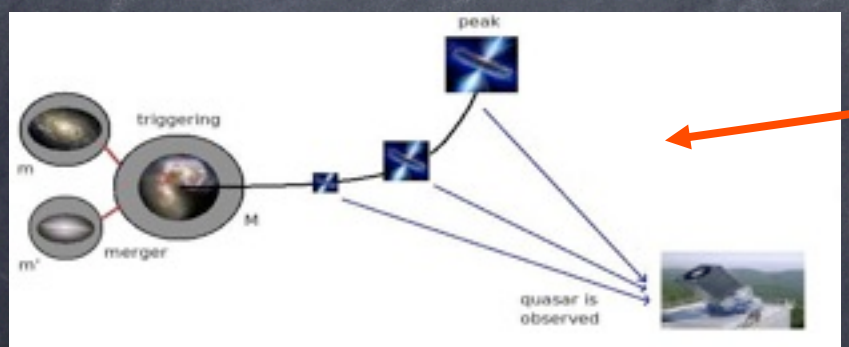
$t_{\rm delay} \lesssim 100\,{\rm Myr}$

Faint & Bright Quasars at High z

Data cannot tell!!

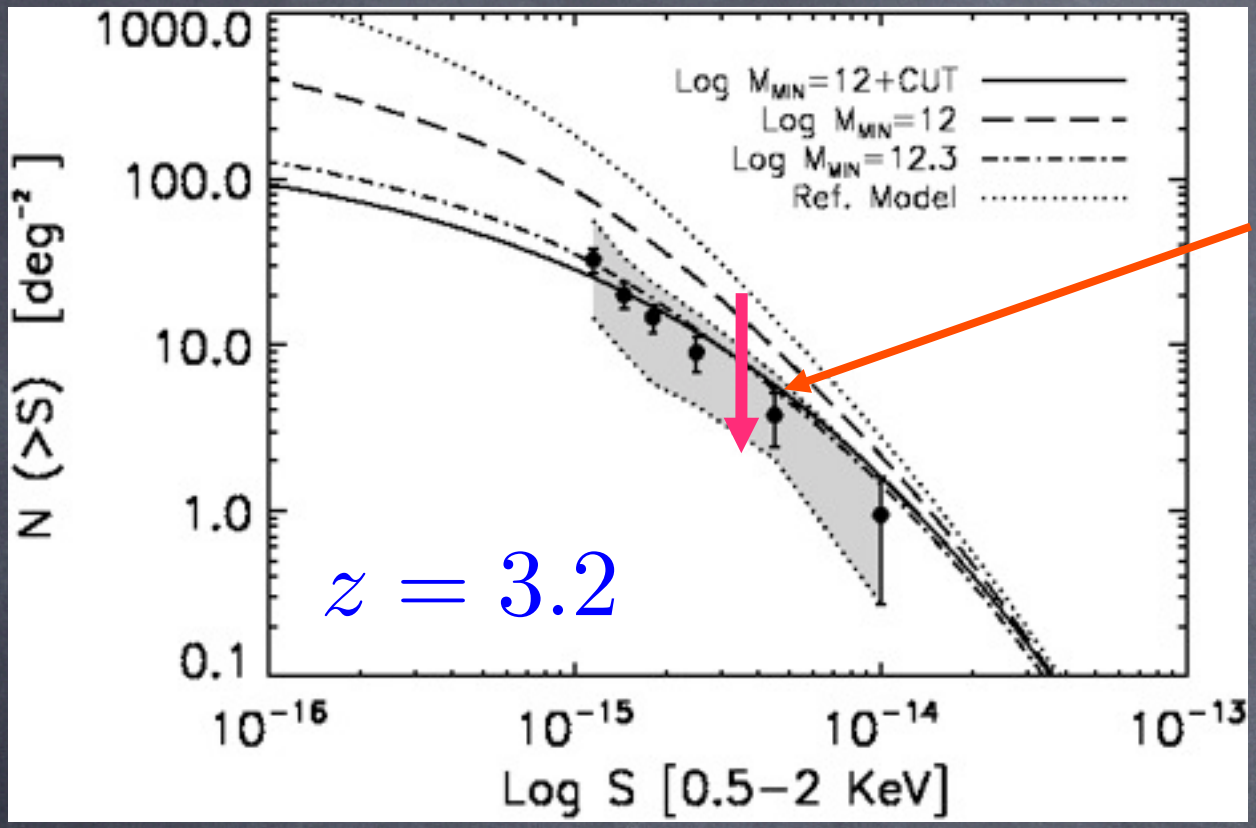


CUT model:



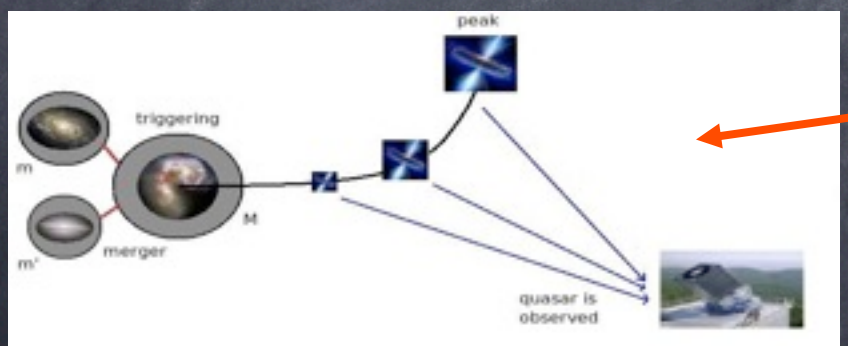
No descending phase!

X-ray Counts at High z



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

CUT model:

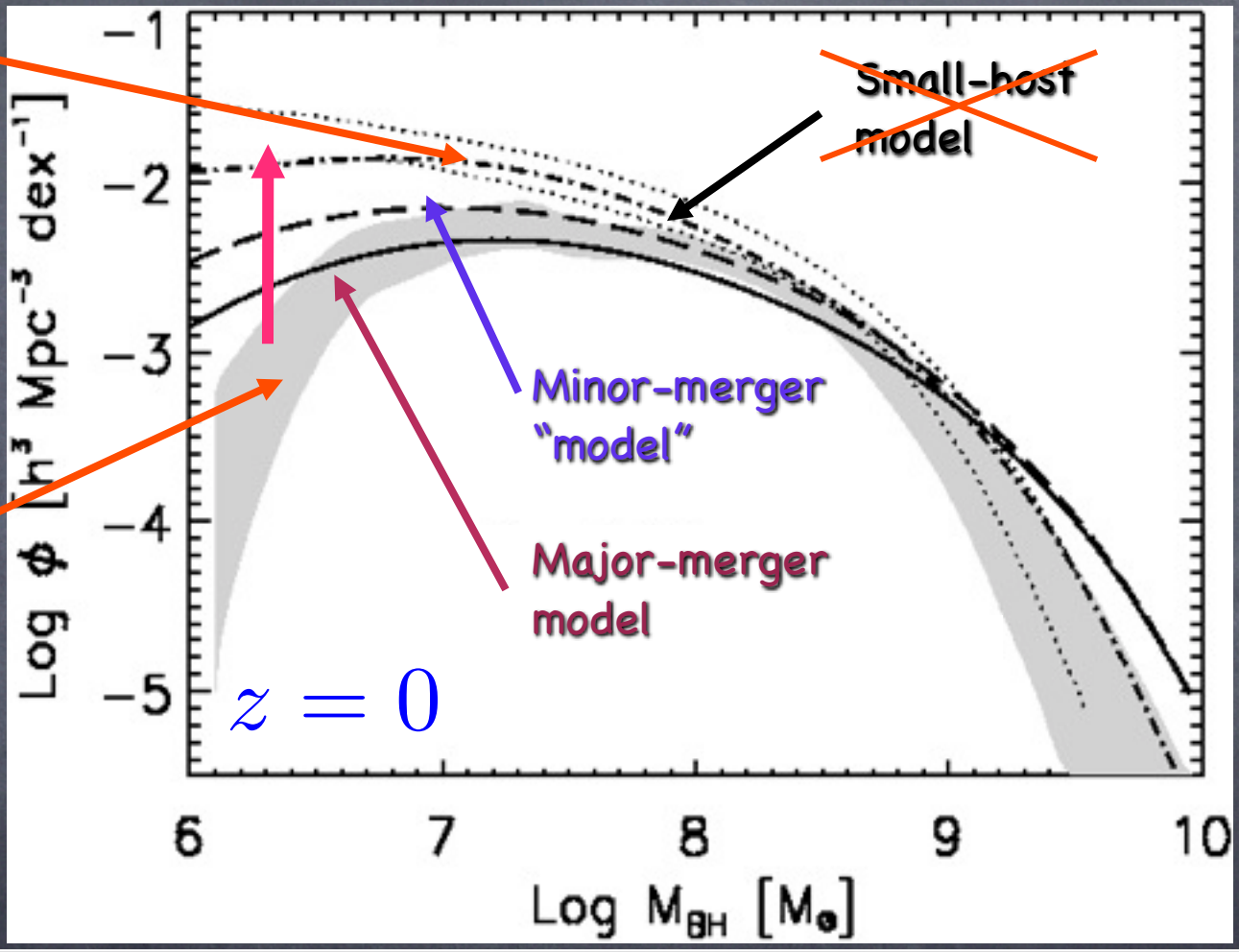


No descending phase!

Local Black Hole Mass Function

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!

$$t_{\rm delay} \lesssim 100\,{\rm Myr}$$

- High z X-ray counts

  --> Quasars in massive hosts

  OR No descending phase (CUT)
- BH mass function:

  --> Major mergers -> early types

  --> Minor mergers: not enough

IV. Things you should take home...

- Picture: Galaxy Mergers -> Quasars -> SMBHs
- Analytic framework: 1. Halo major merger rate
  2. Quasar light curves
- Observations: Quasars: short lives & massive hosts
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- Puzzles: small BHs in late types, faint low-z AGNs
  ---> secular processes?

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Thank you! Any questions?