Do halo mergers trigger quasars?

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Acknowledgments

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Acknowledgments

Hosts:

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And…

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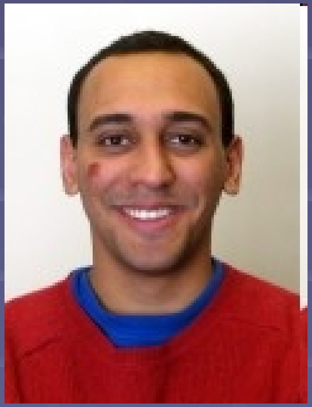
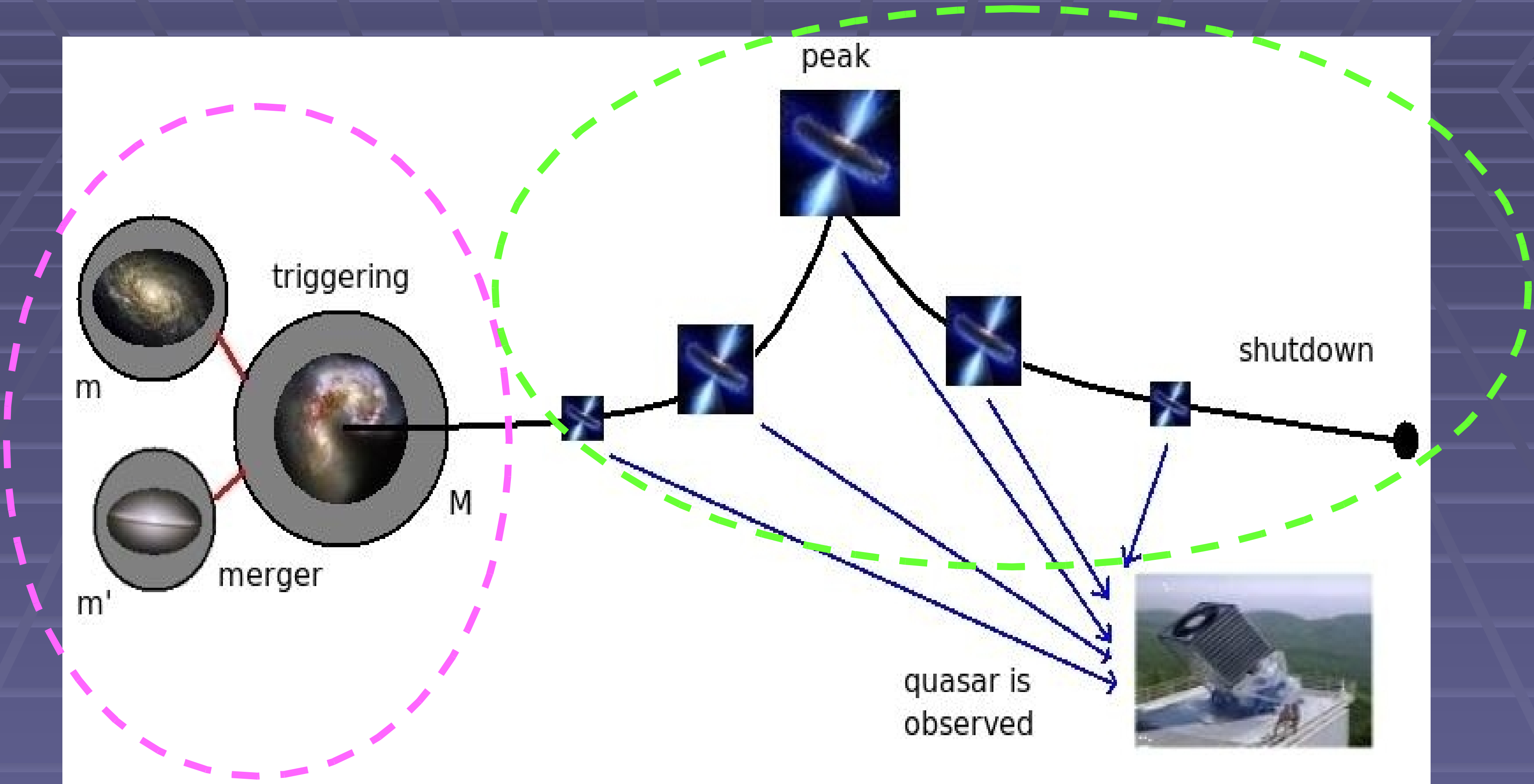


Onsi Fakhouri

The basic picture:



Halo merger rate

Quasar light curve

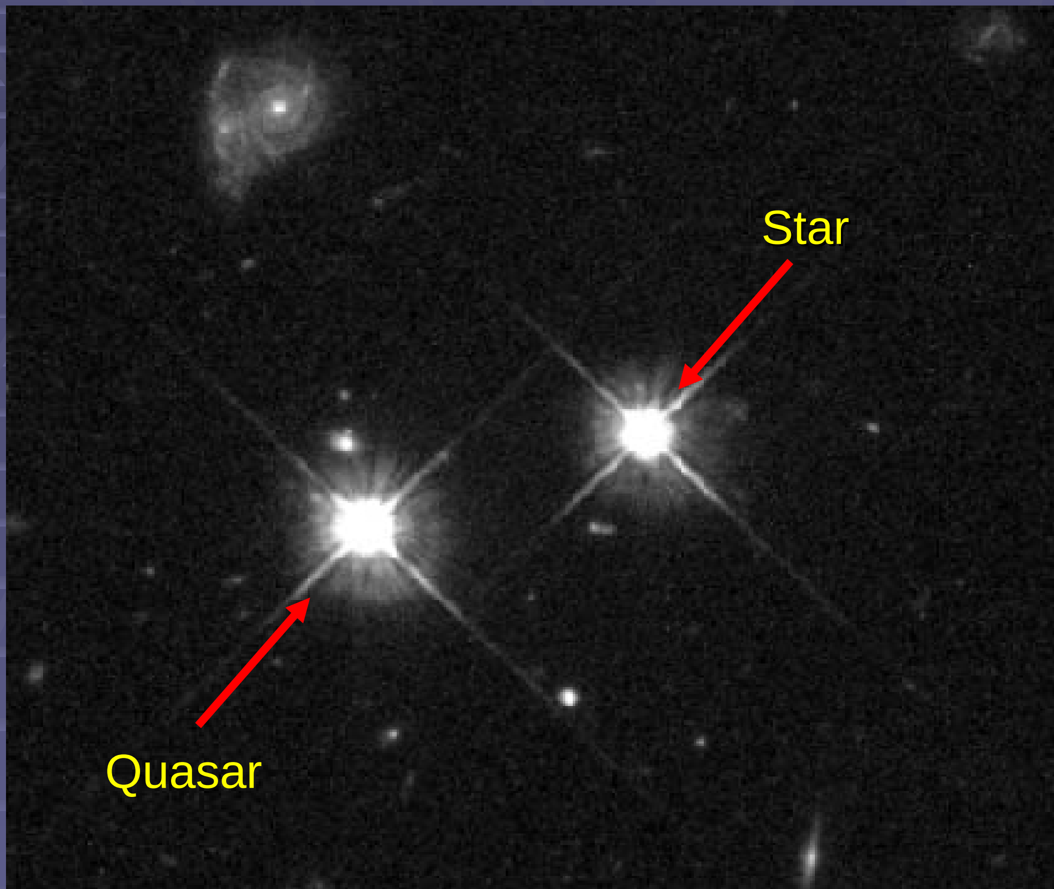
Today's menu:

- Background
- The excursion set theory
- → Halo merger rate
- Self-regulated growth
- → The light curve
- Observational tests

  → luminosity function

  → bias
- Future work and conclusions

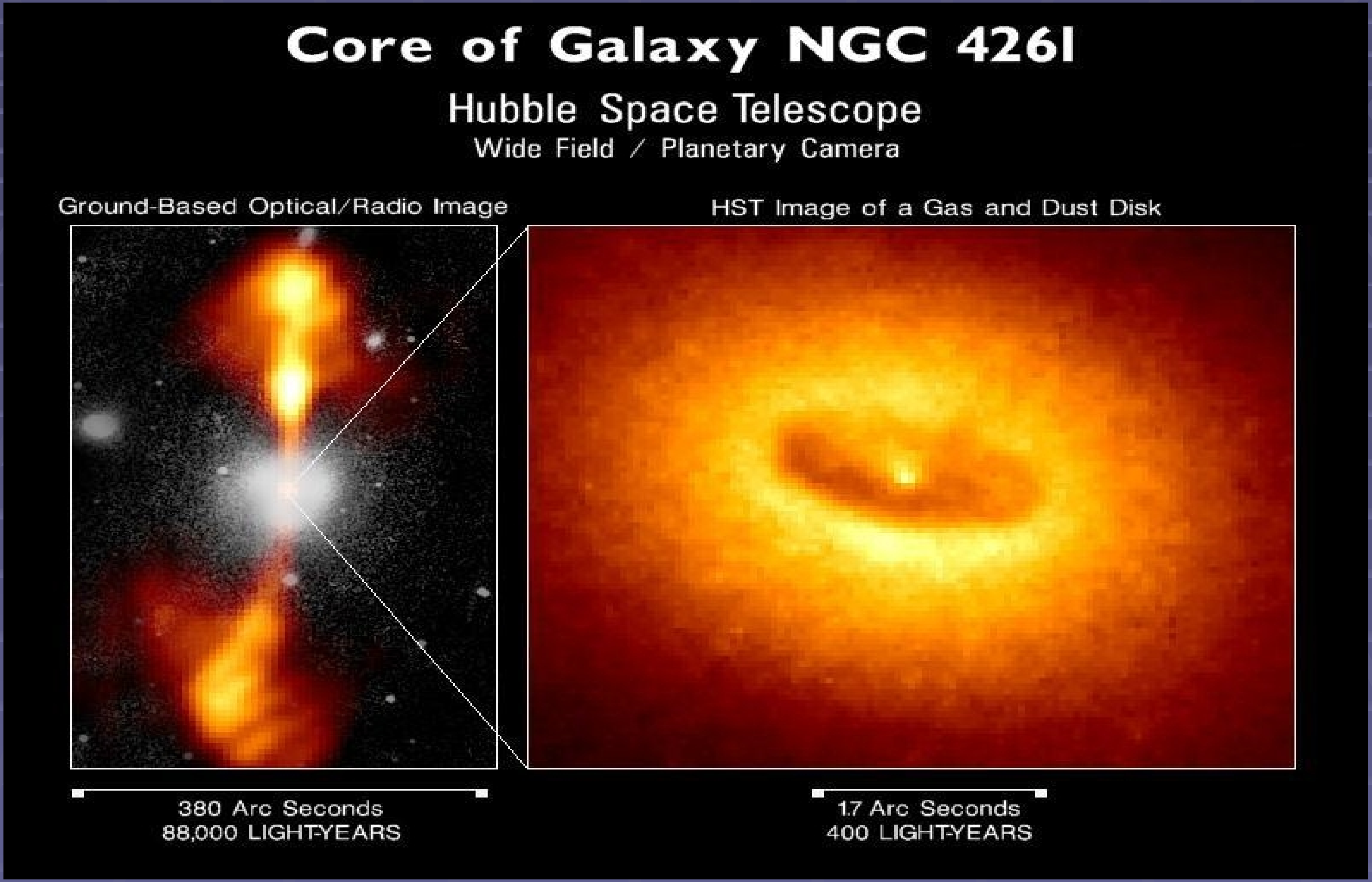
I. Introduction



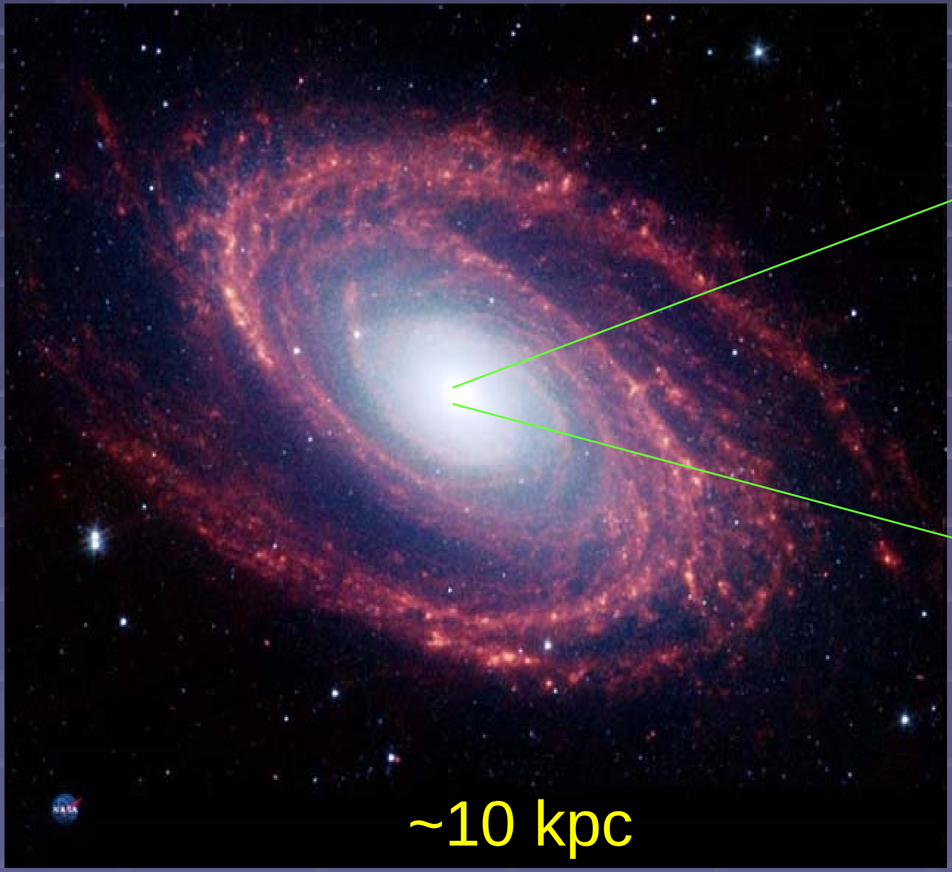
3C 273

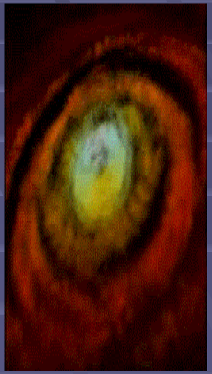
Maarten Schmidt (1963)

Supermassive Black Holes!



…but how do we feed the beast?



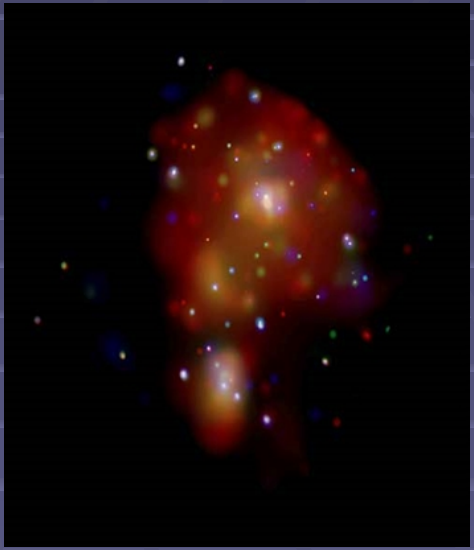


< 1 pc

…mergers, mergers, mergers

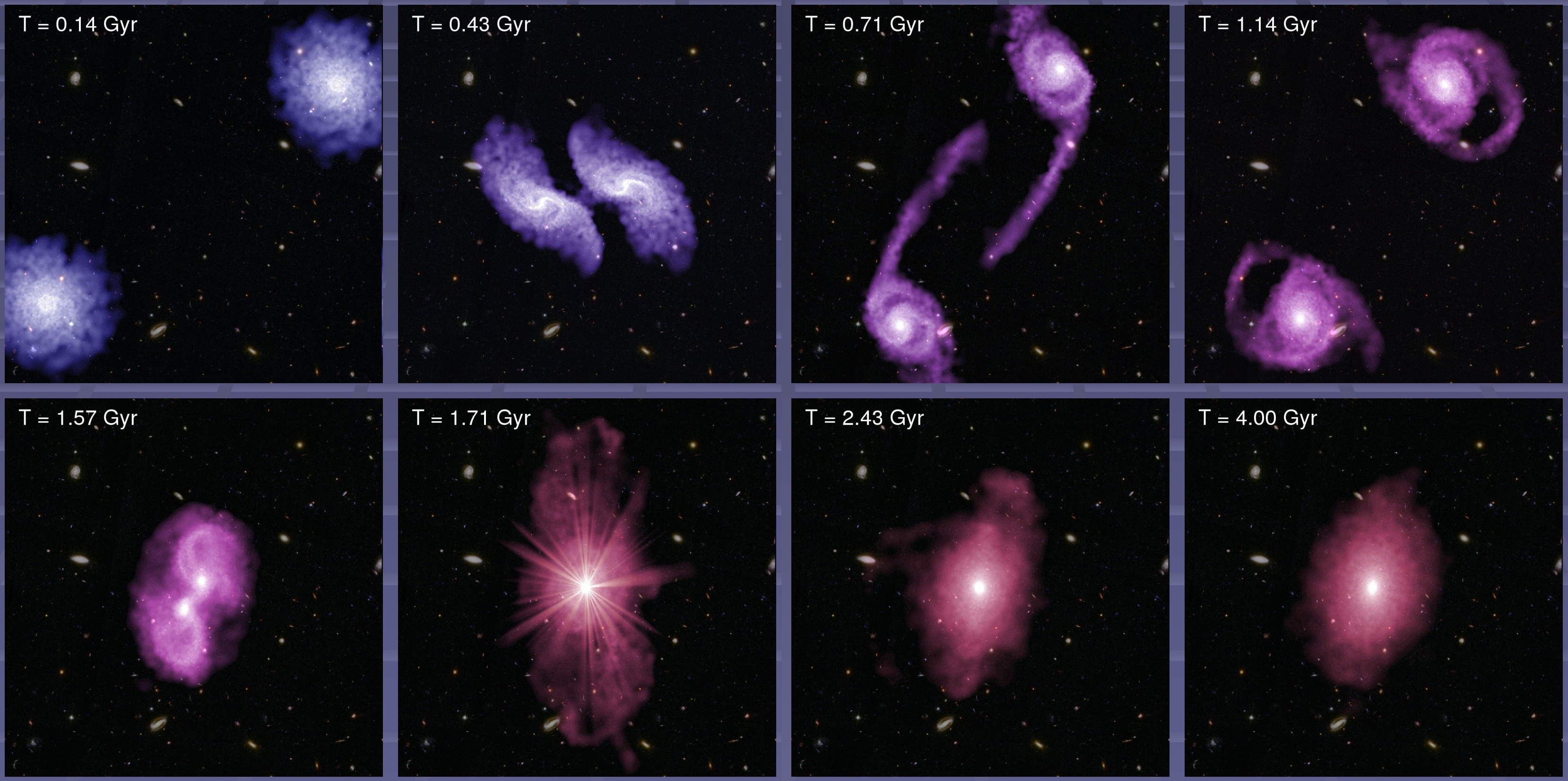
Credit: J. Moreno

Credit: S. Beckwith (STScI, HST)



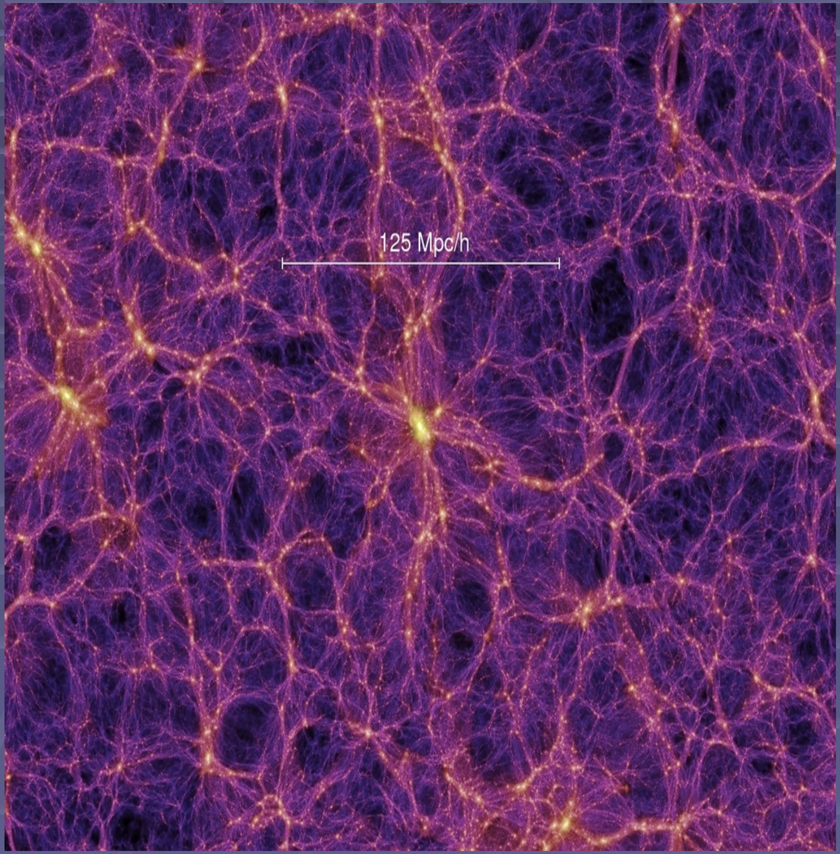
Credit: A. Wilson (Chandra)

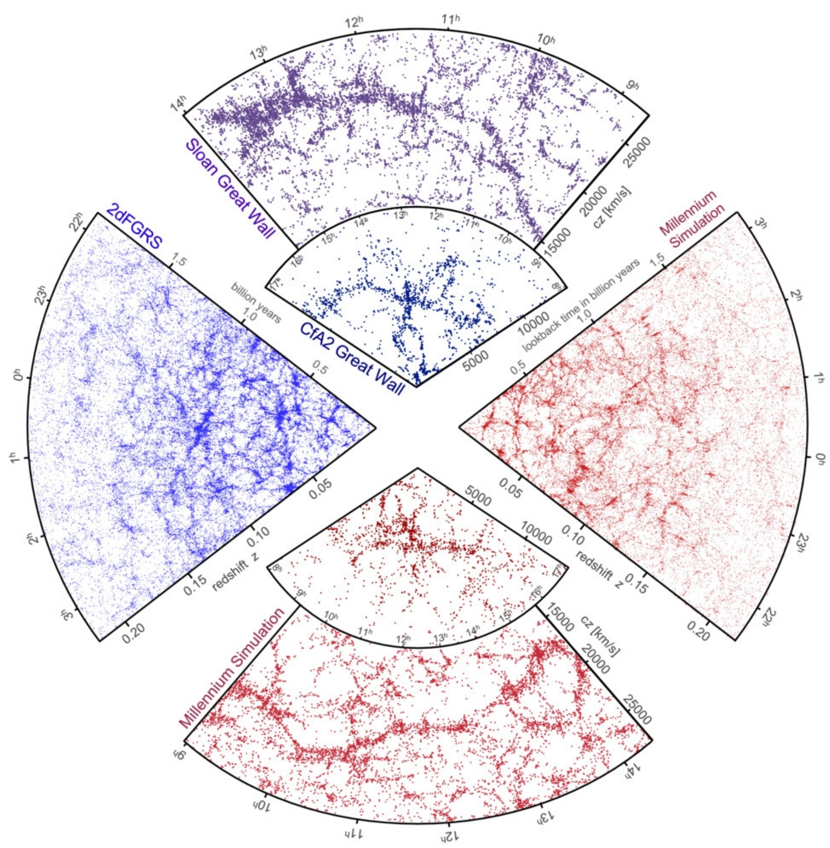
Simulations of galaxy mergers



Credit: T. J. Cox

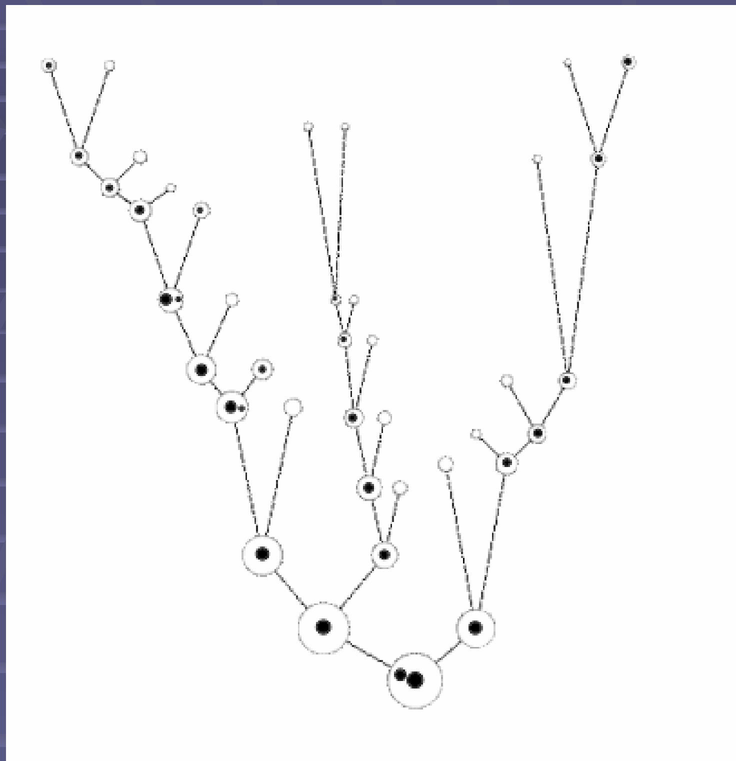
Cosmological simulations

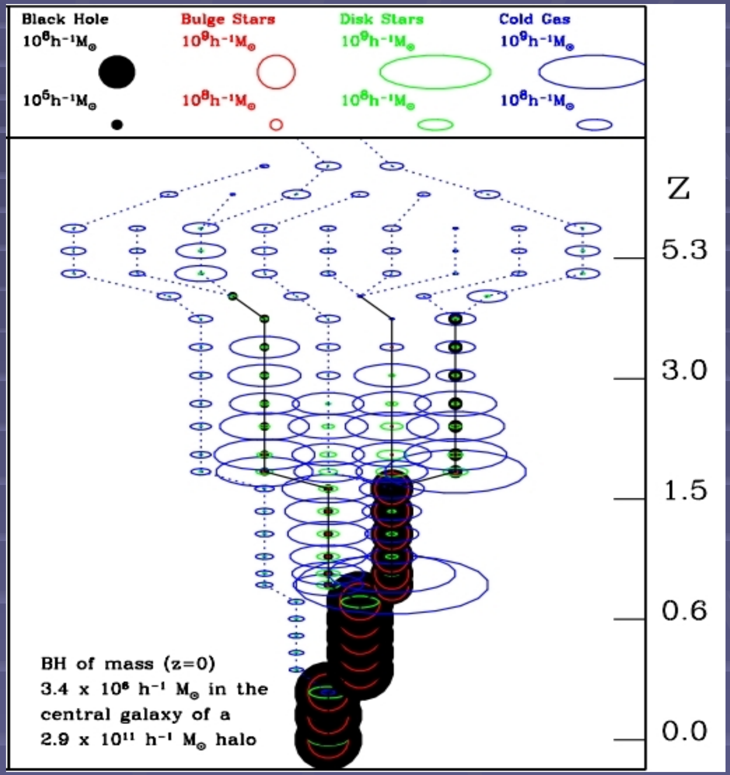




Credit: Volker Springel

Merger history trees





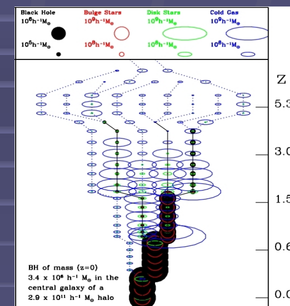
Credit: Marta Volonteri

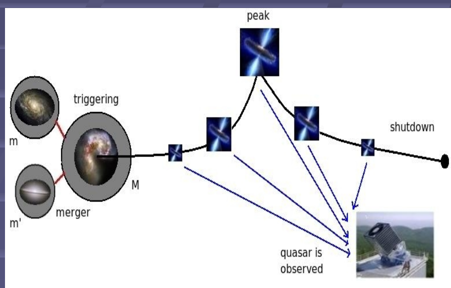
Credit: Rowena Malbon

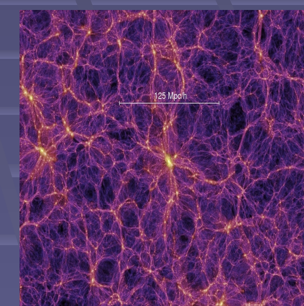
(See also Moreno et. al., 2008)

Analytic model

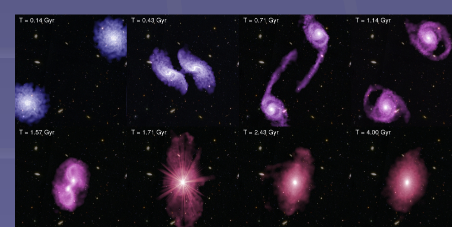
Other methods







See also:
Wyithe & Loeb (2003, 2002)
Haiman & Loeb (1998)

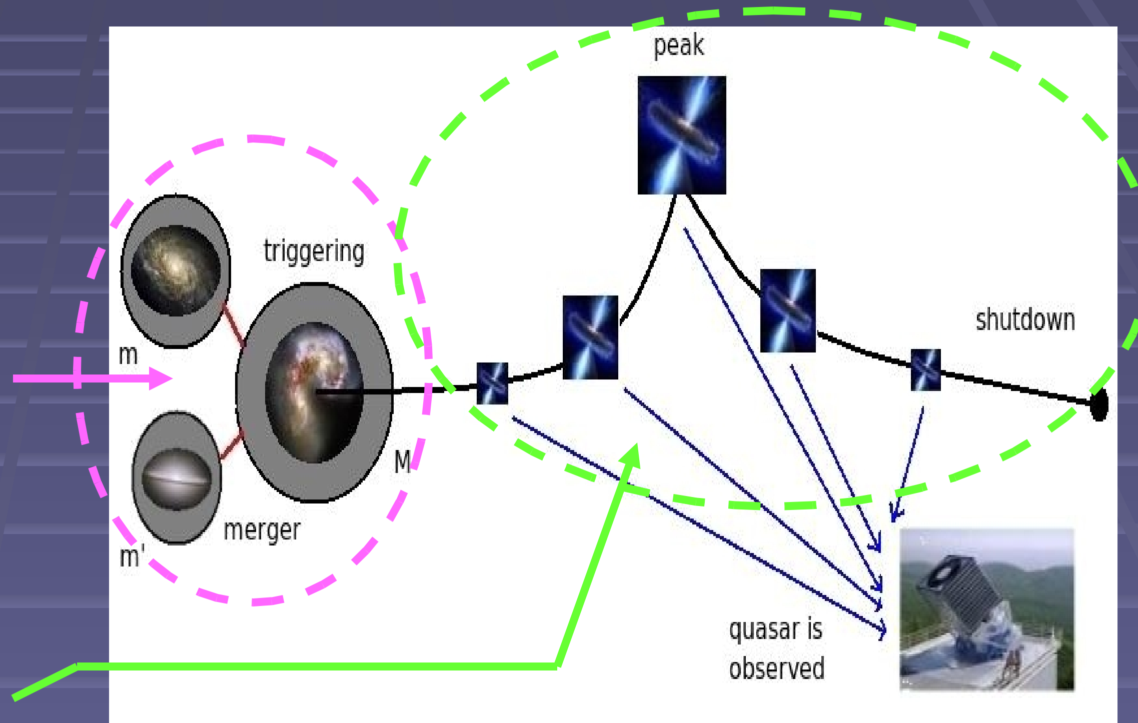


Our model

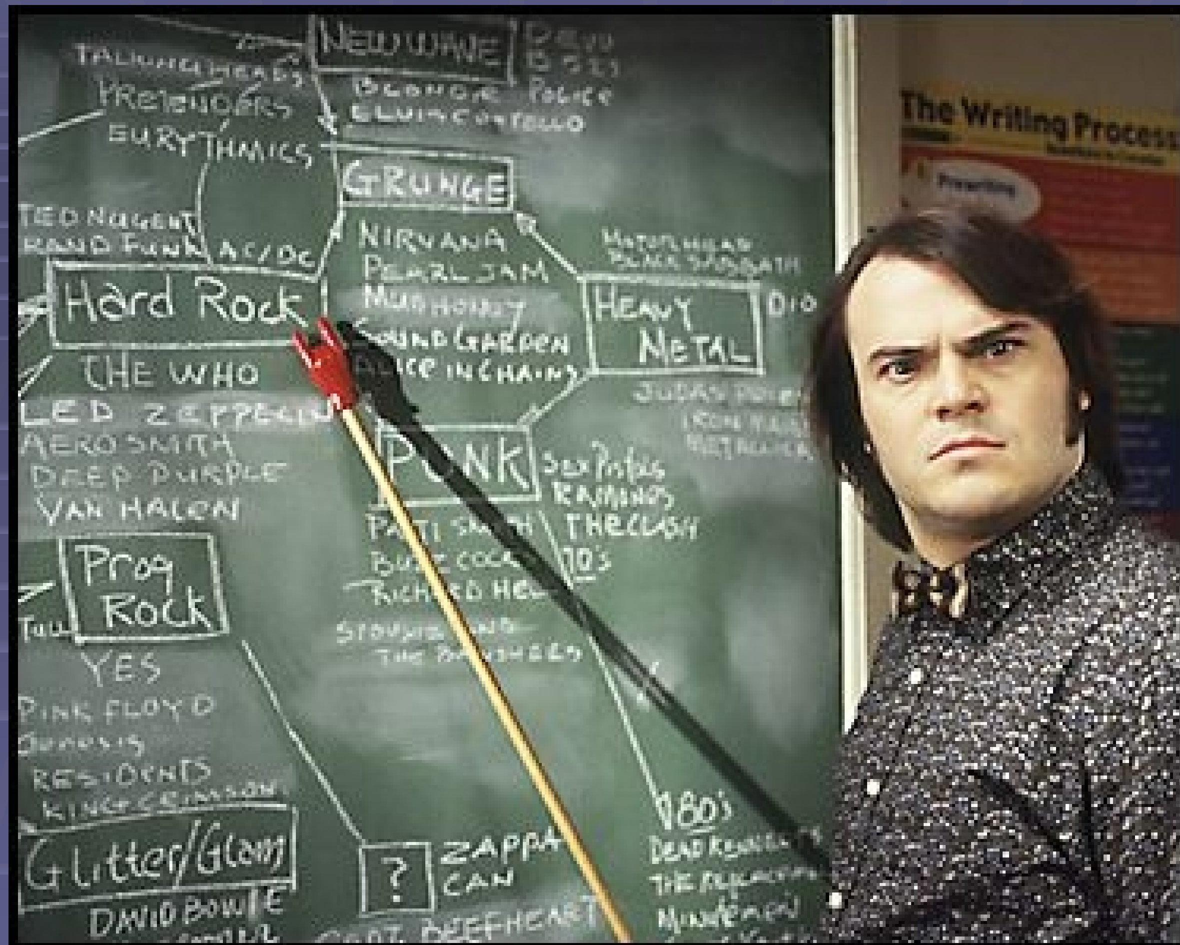
- <u>Key ingredients:</u>

  - Merger rate

  - Light curve

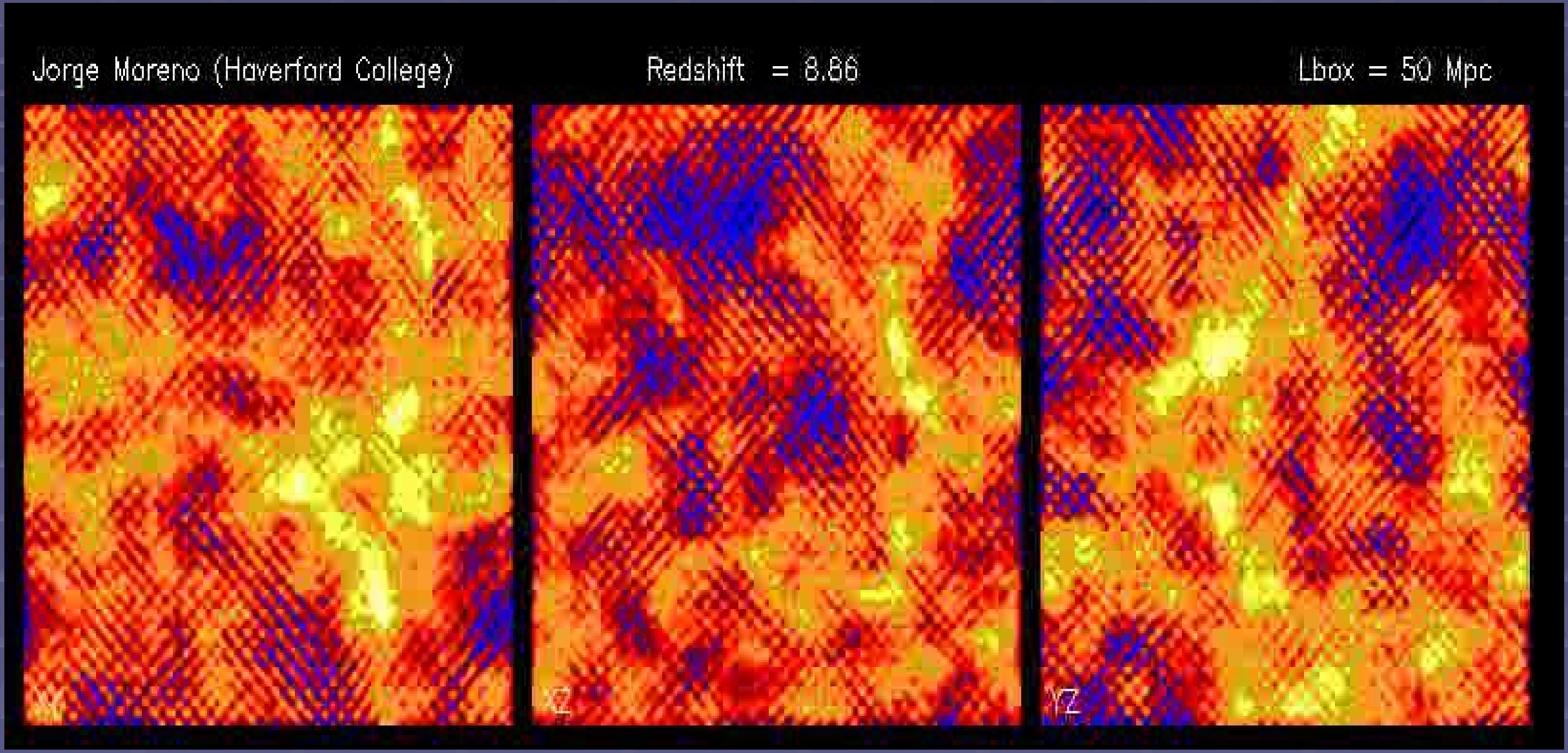


II. Excursion set theory



Aim: the halo merger rate!!

Cosmic capitalism

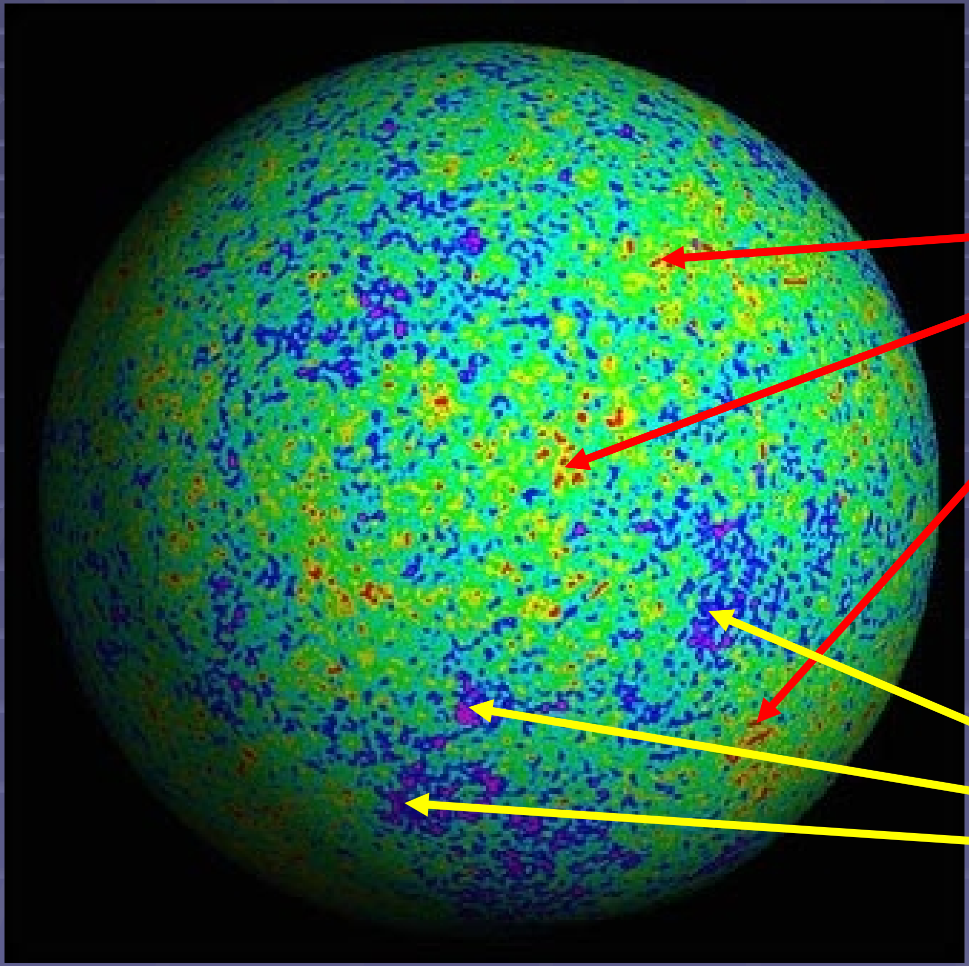


Credit: J. Moreno

Smooth (linear) → clumpy (nonlinear)

Initial density fluctuations

$\rho = \text{density}$ $\bar{\rho} = \text{mean density}$



Overdense regions

$$\rho > \bar{\rho}$$

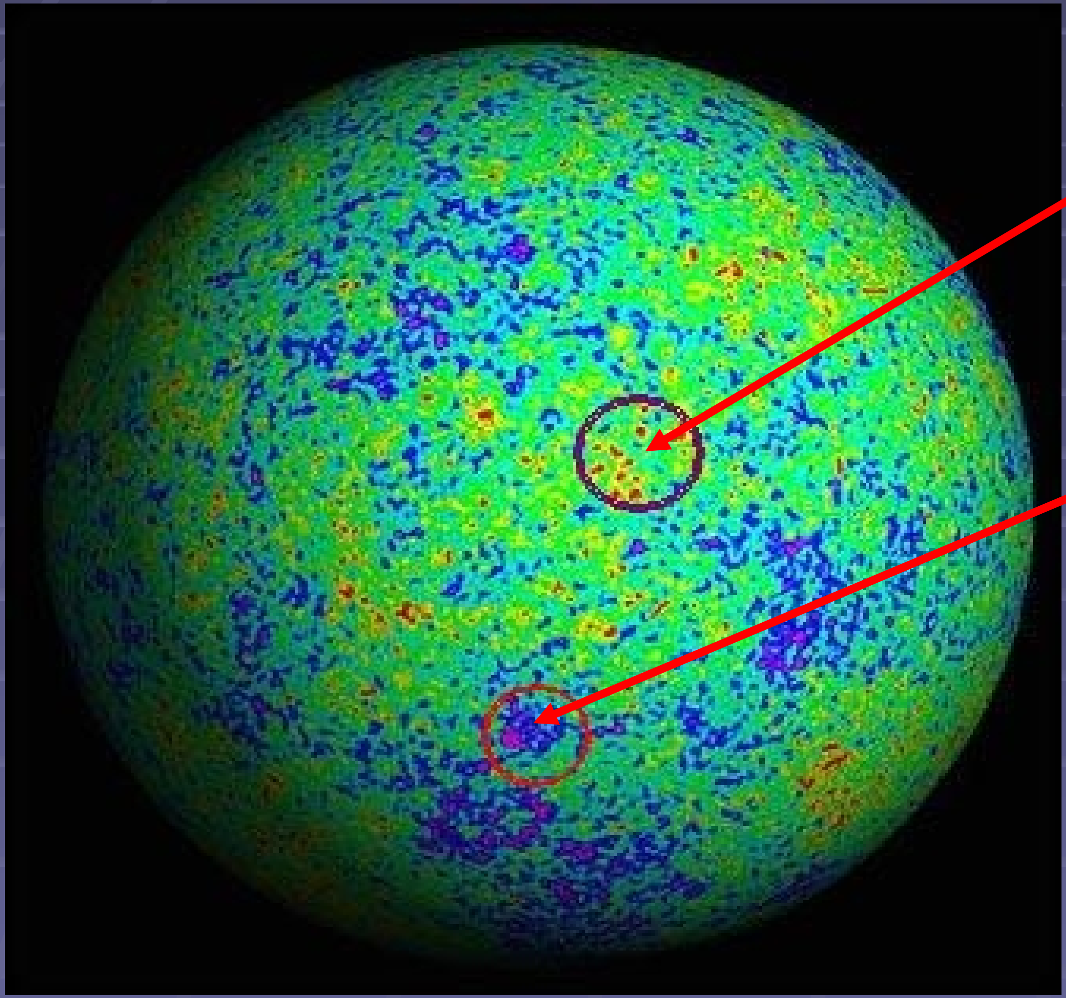
Underdense regions

$$\rho < \bar{\rho}$$

Gravitational collapse

δ = overdensity = $\rho - \bar{\rho}$

δ_c = critical density



$\delta > \delta_c$

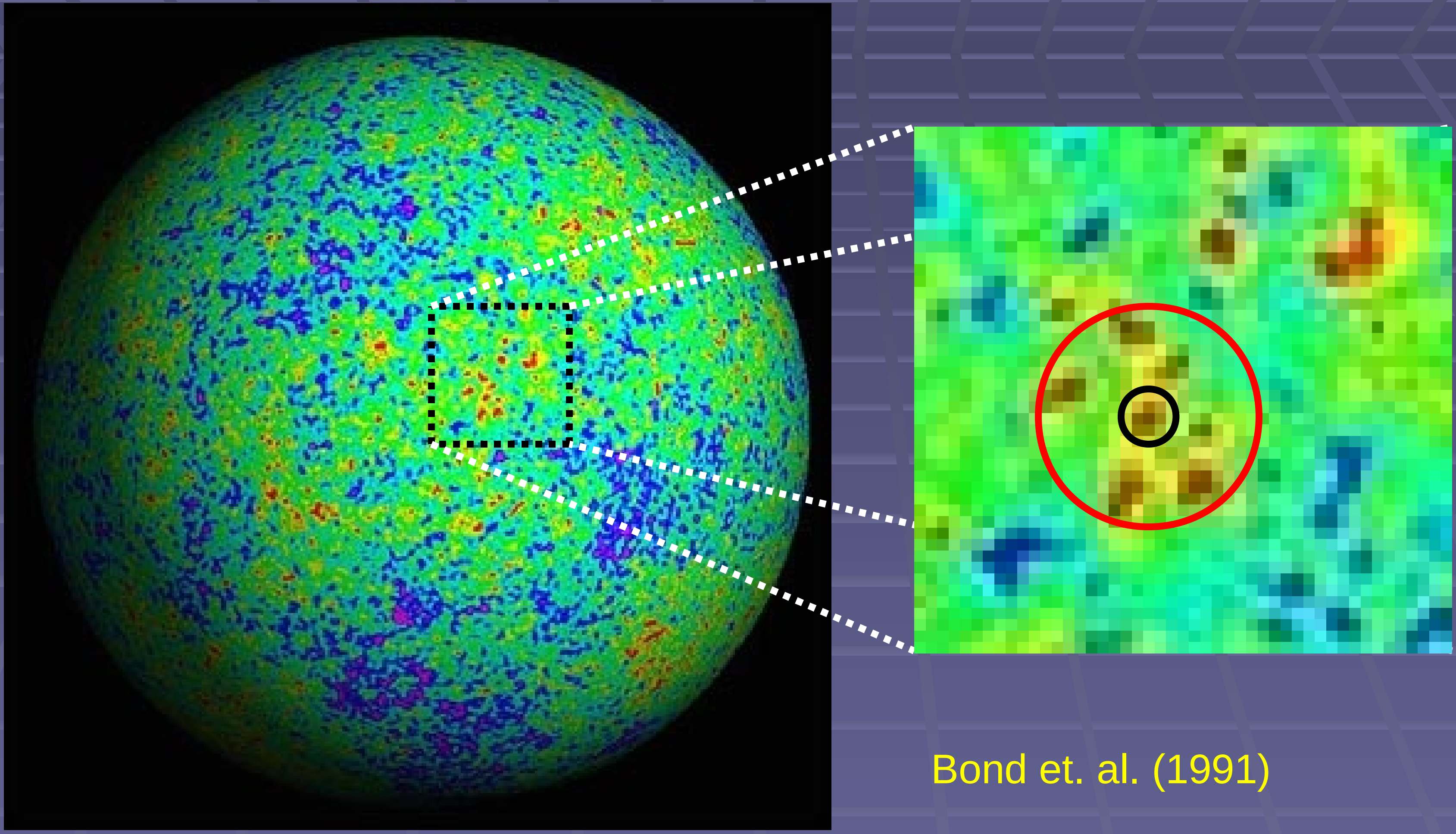
(dense enough)

$\delta < \delta_c$

(not dense enough)

Press Schechter (1974)

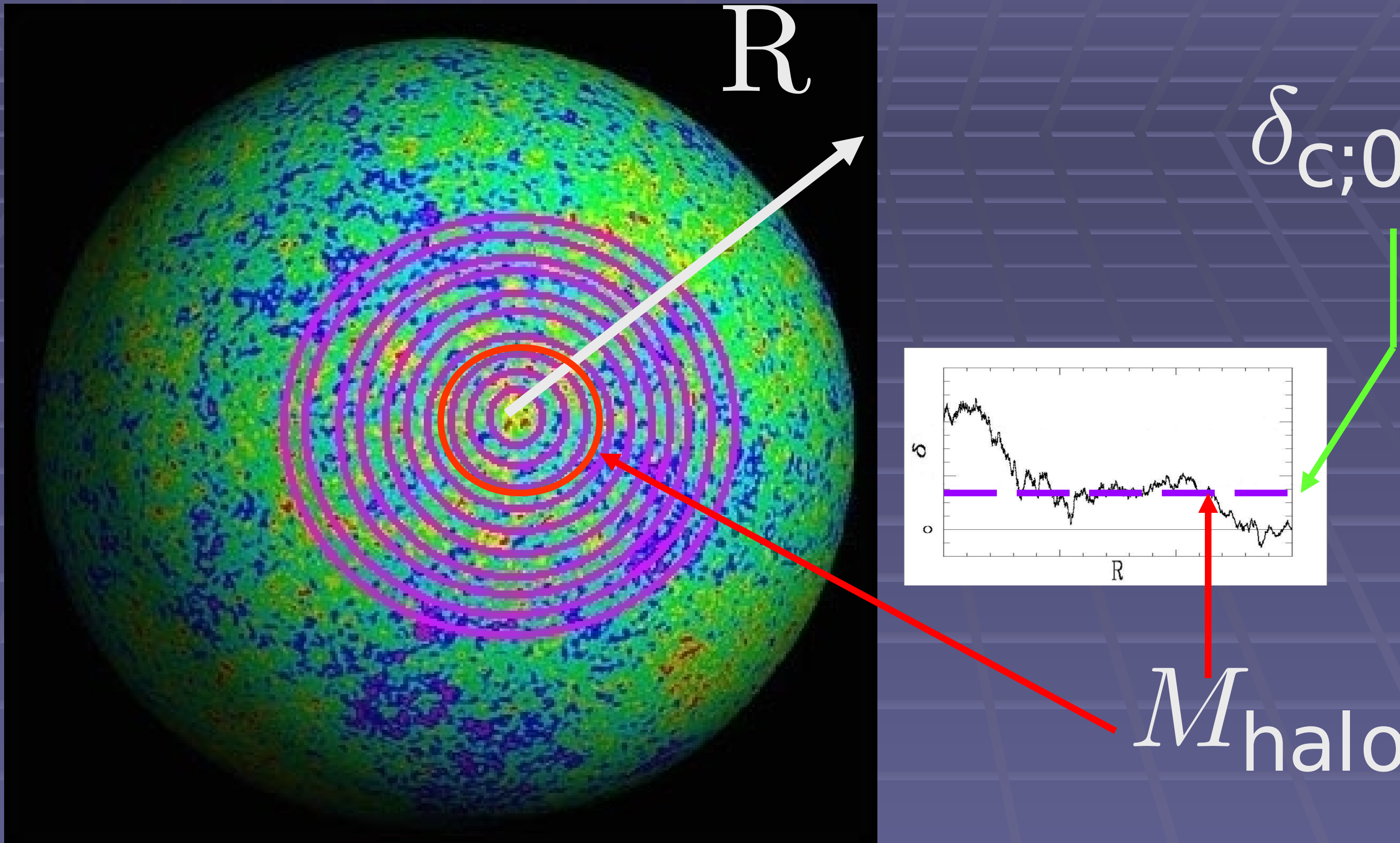
Cloud-in-cloud problem



Bond et. al. (1991)

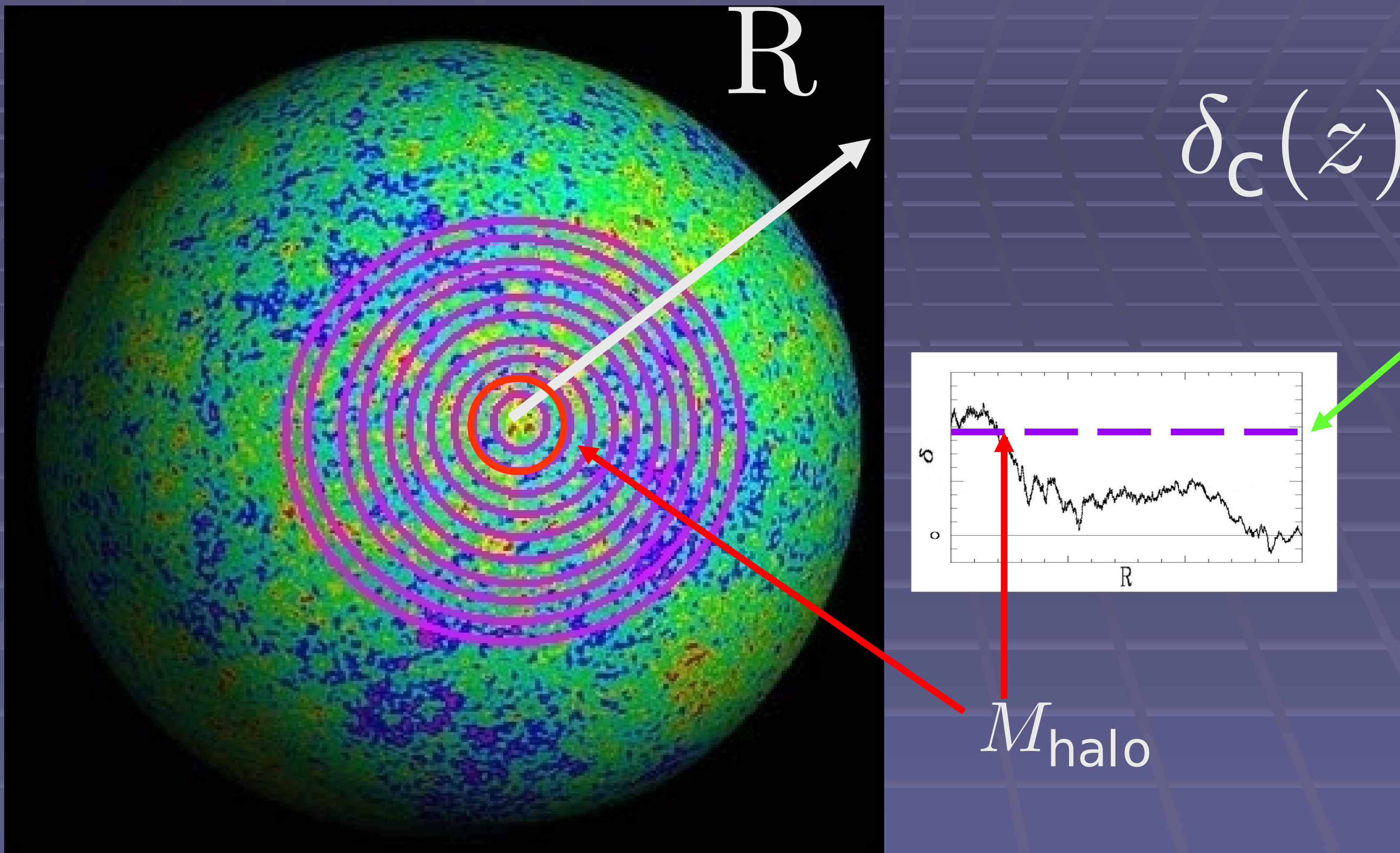
Cloud-in-cloud problem

Random walk model



Bond et. al. (1991)

Random walk model



Bond et. al. (1991)

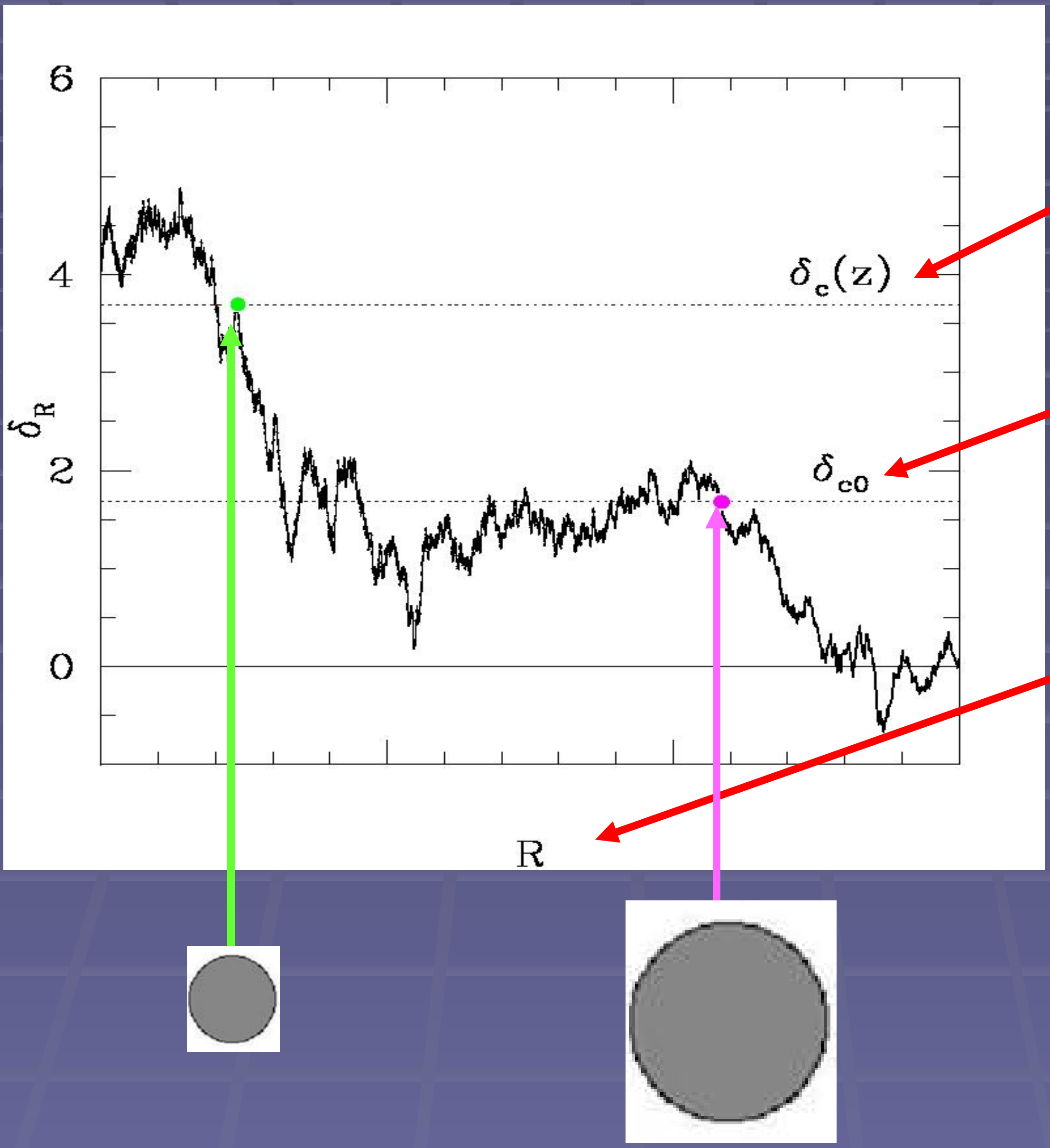
Spherical collapse: $\delta_c = \delta_c(t)$

Over density

Collapse in the past

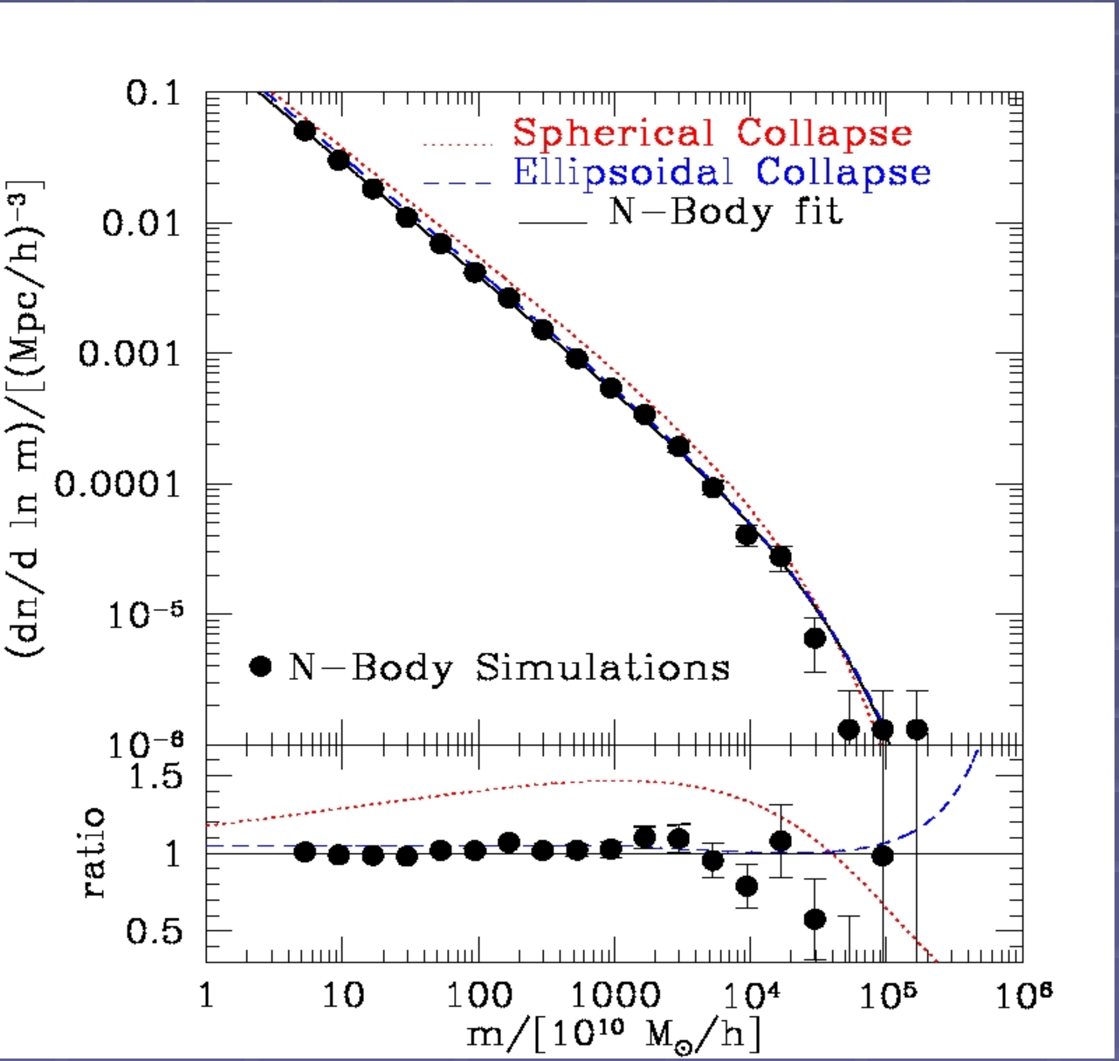
Collapse today

Scale → mass!



Halo mass function

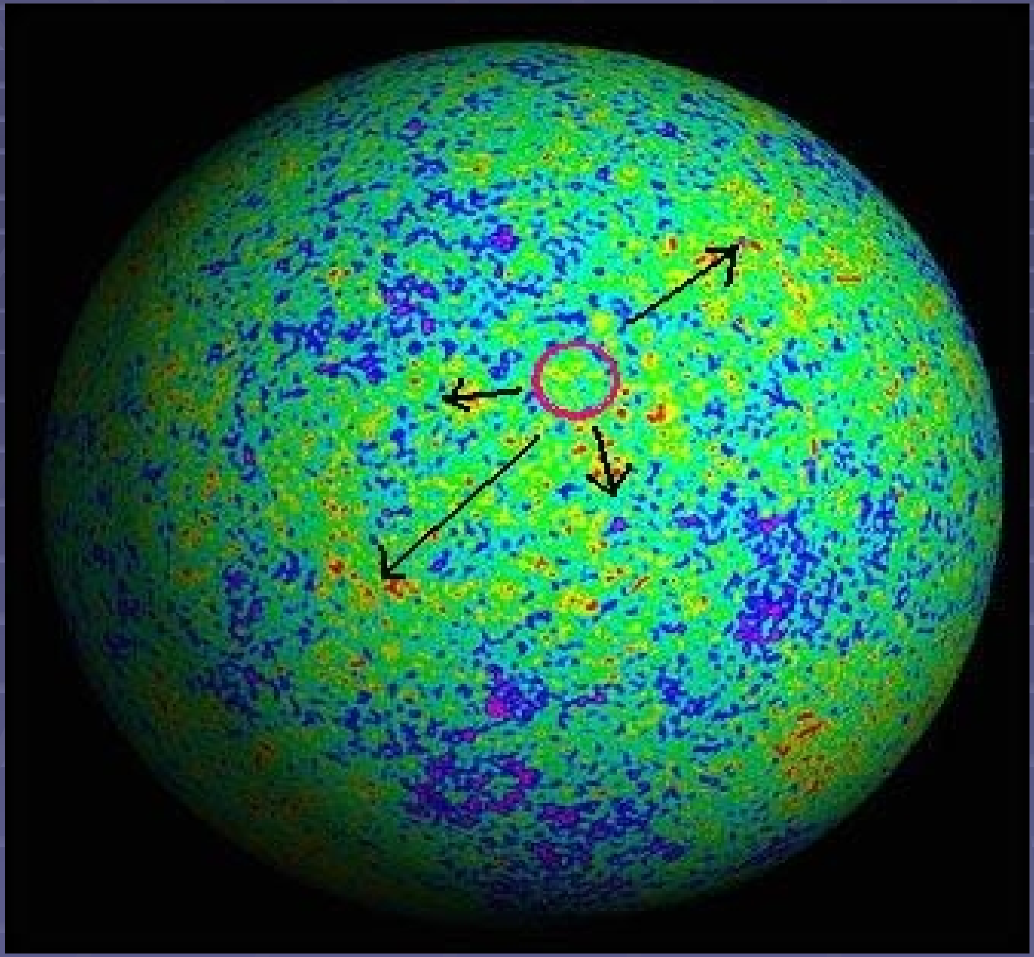
m-halos / volume



Halo mass

(Moreno et. al. 2009)

Ellipsoidal collapse: $\delta_c(t) \longrightarrow \delta_c(R,t)$



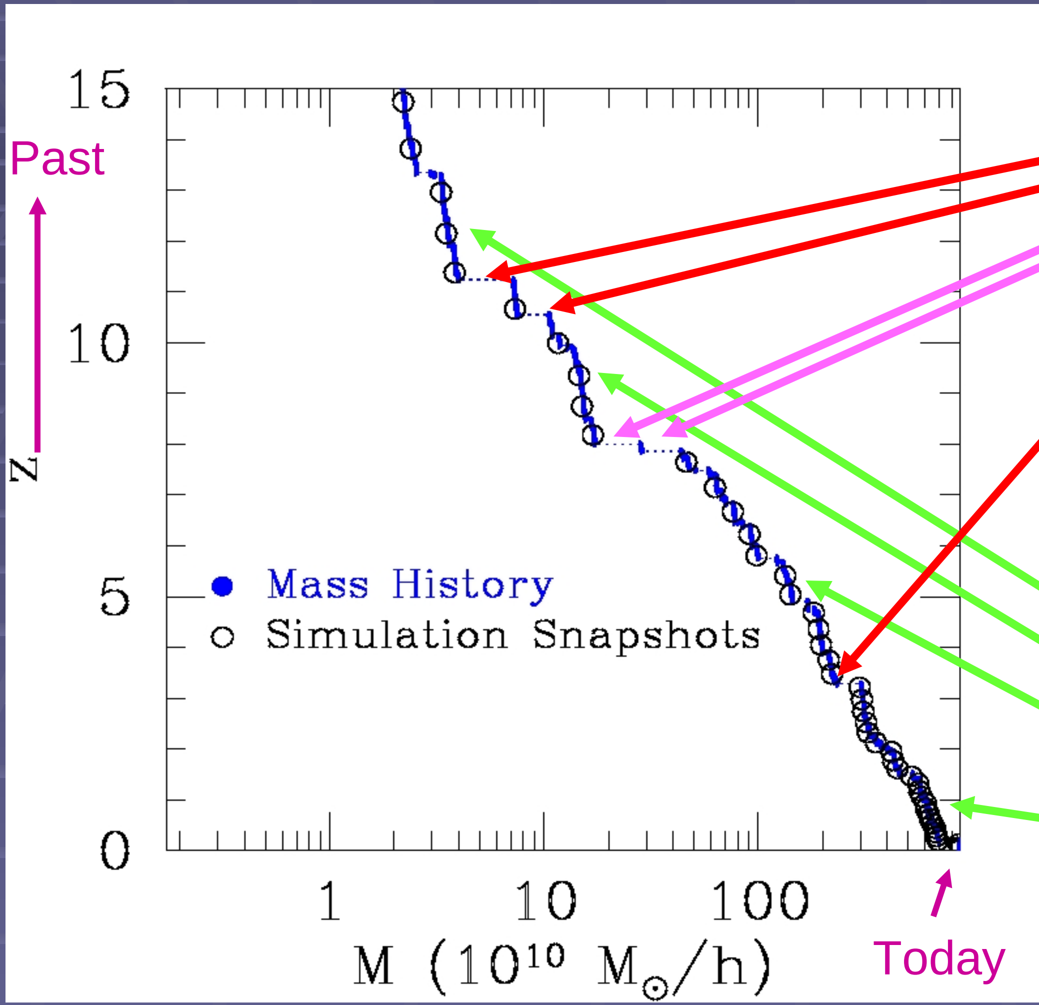
$R \rightarrow \delta$

$R \rightarrow \delta$

Shear matters!

Sheth, Mo & Tormen (2001)

Halo mass histories

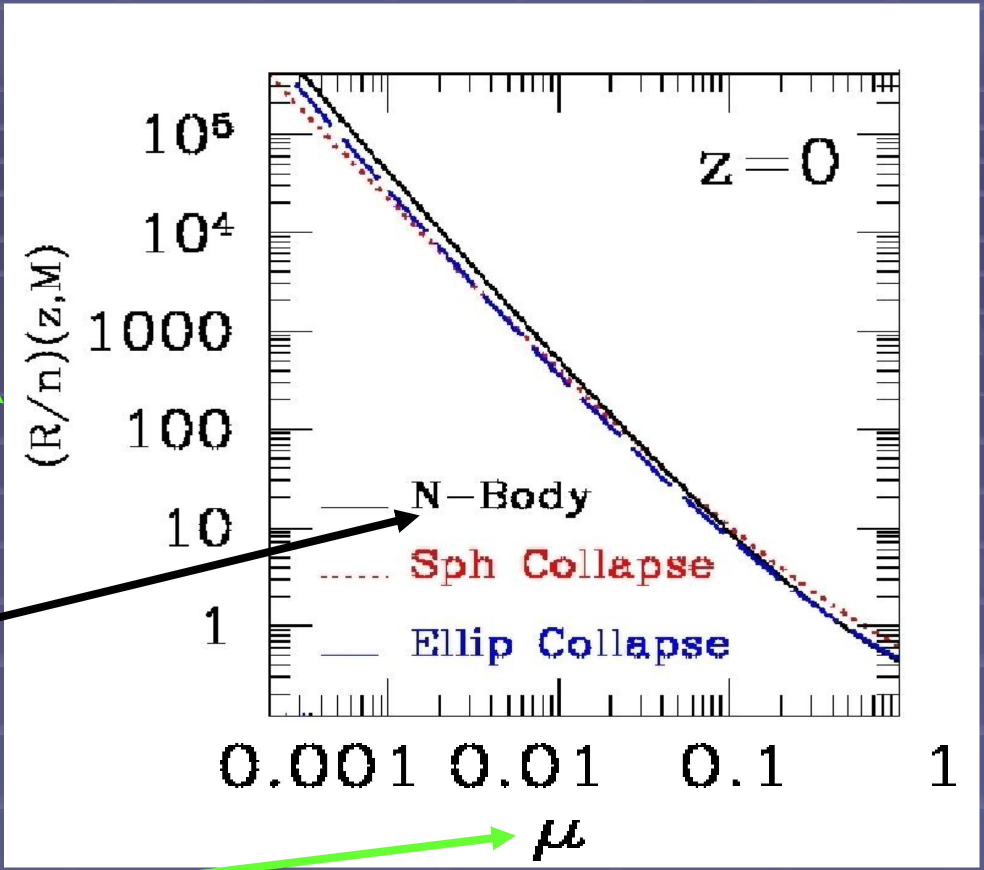


Major mergers

Smooth accretion

Analytic merger rates

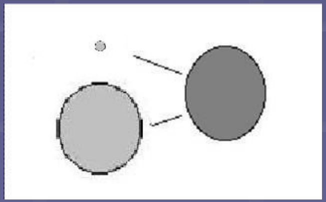
mergers
/ # M-halos

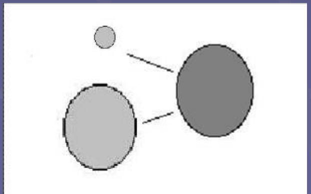


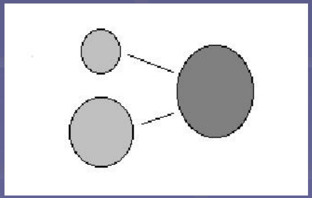
Fakhouri & Ma (2007)

Mass ratio of merging haloes

μ = m/(M-m)

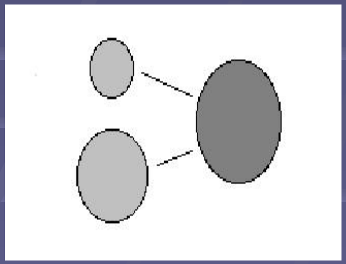






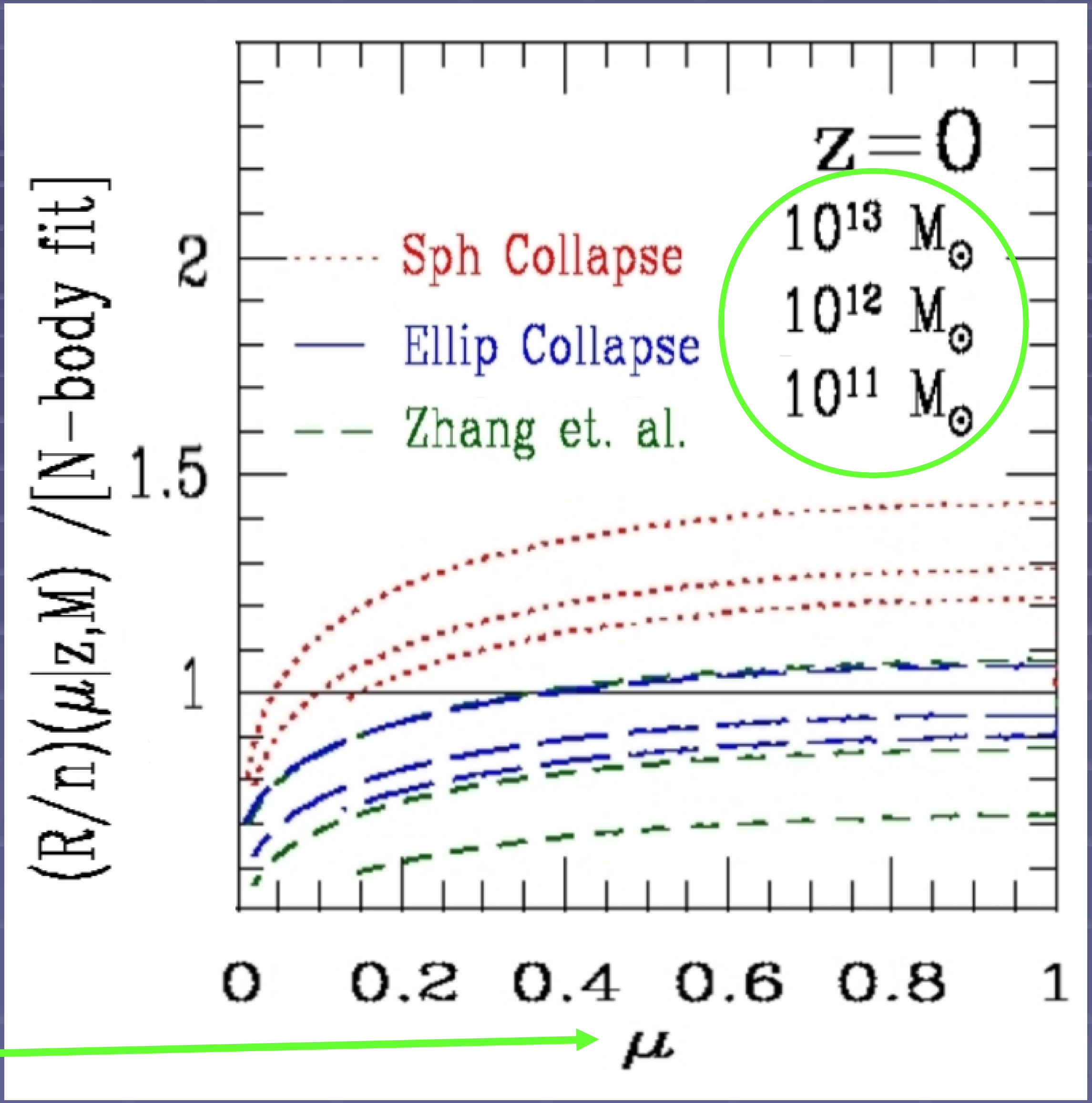
…a closer comparison

(R/n) modulo fit to Millennium



μ = m/(M-m)

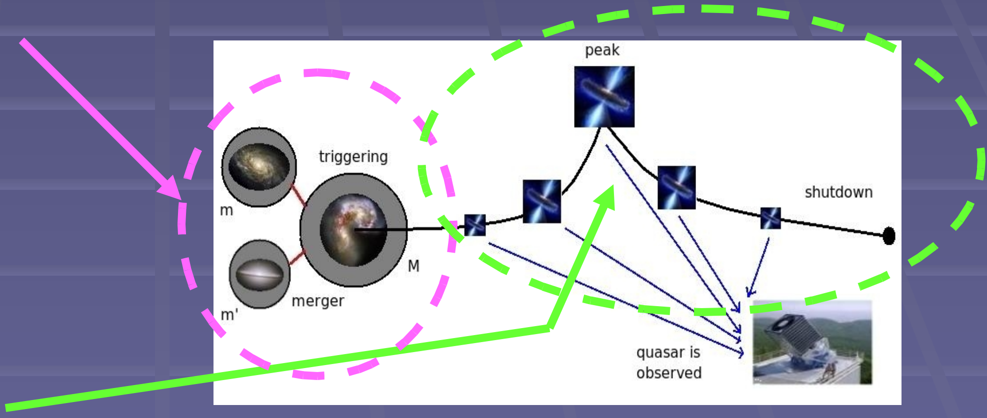
Mass ratio of merging haloes



So far:

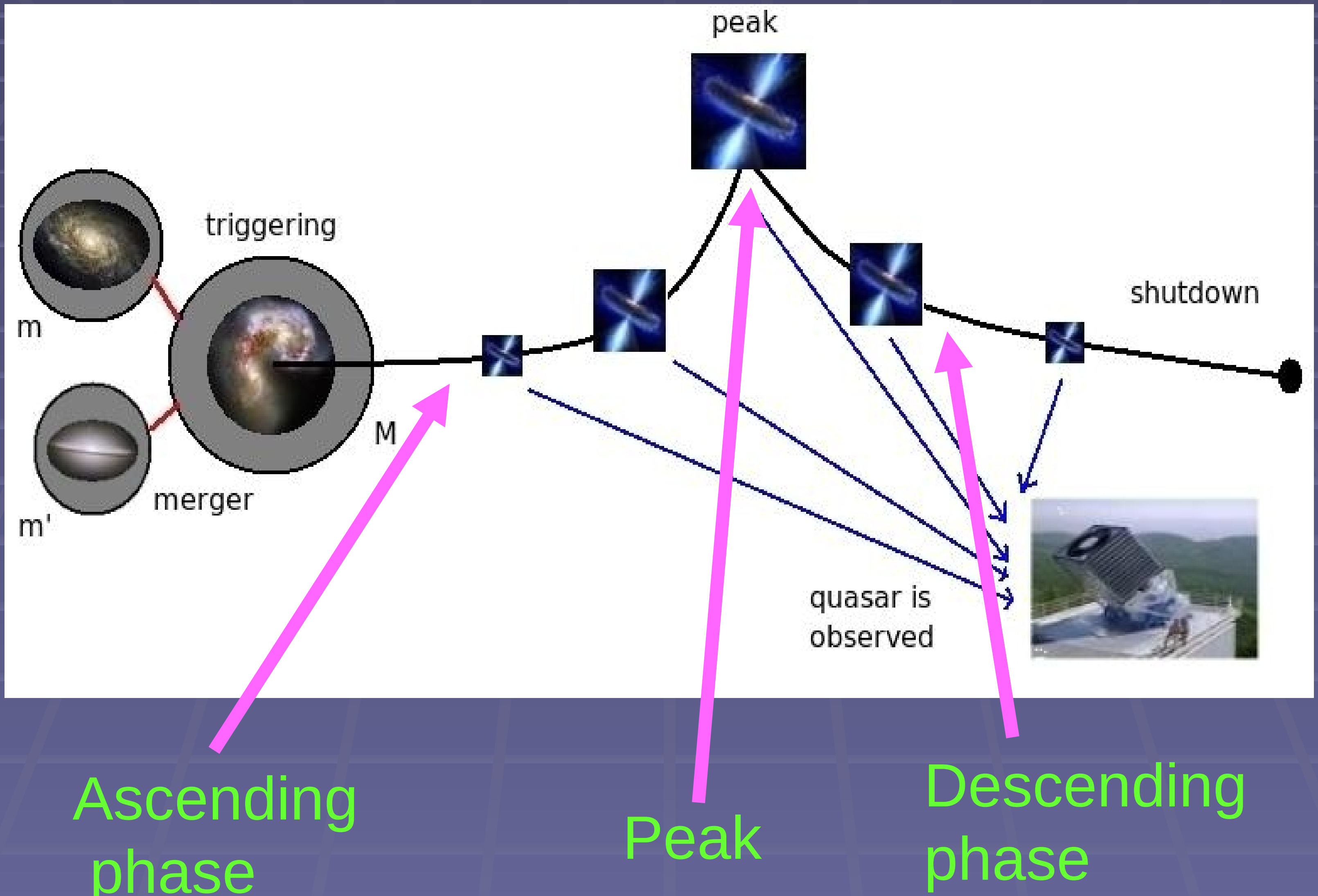
- Excursion set theory:
  - Random walks!
  - Halo abundance
  - Merger history
  - Ellipsoidal collapse → more accurate!
  - Merger rate!

- … still need:
  - Light curve!



III. The light curve

Recall…



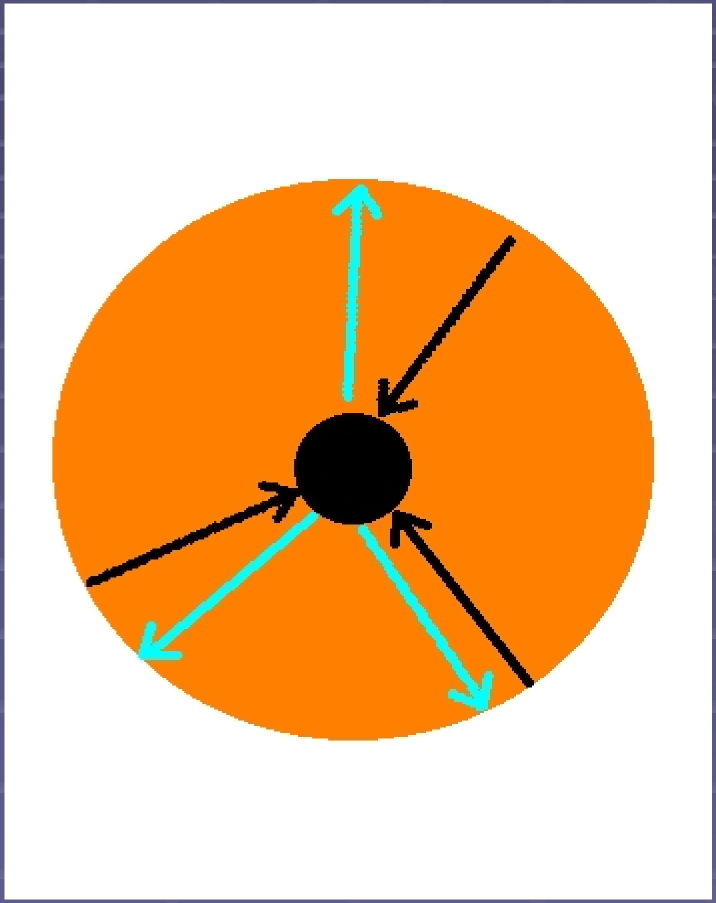
Simple picture

$$\vec{F}_{\mathrm{grav}} = \vec{F}_{\mathrm{rad}}$$

$$L_{\mathrm{Edd}} \propto M_2$$

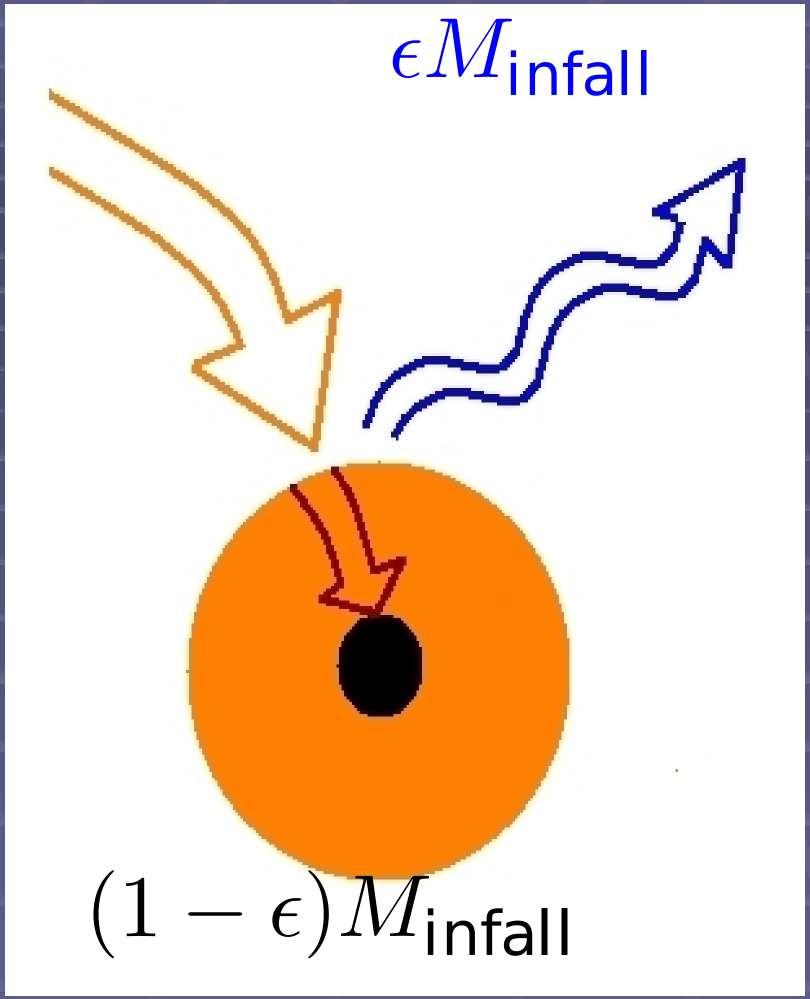
$$L = \lambda L_{\mathrm{Edd}}$$

$$\boxed{L \propto M_2}$$



$\lambda = \text{Eddington ratio}$

$$M_{\text{infall}}$$



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

$$L \propto \dot{M}_2$$

$\epsilon =$ Radiative efficiency

Ascending phase

$$L \propto M_2$$

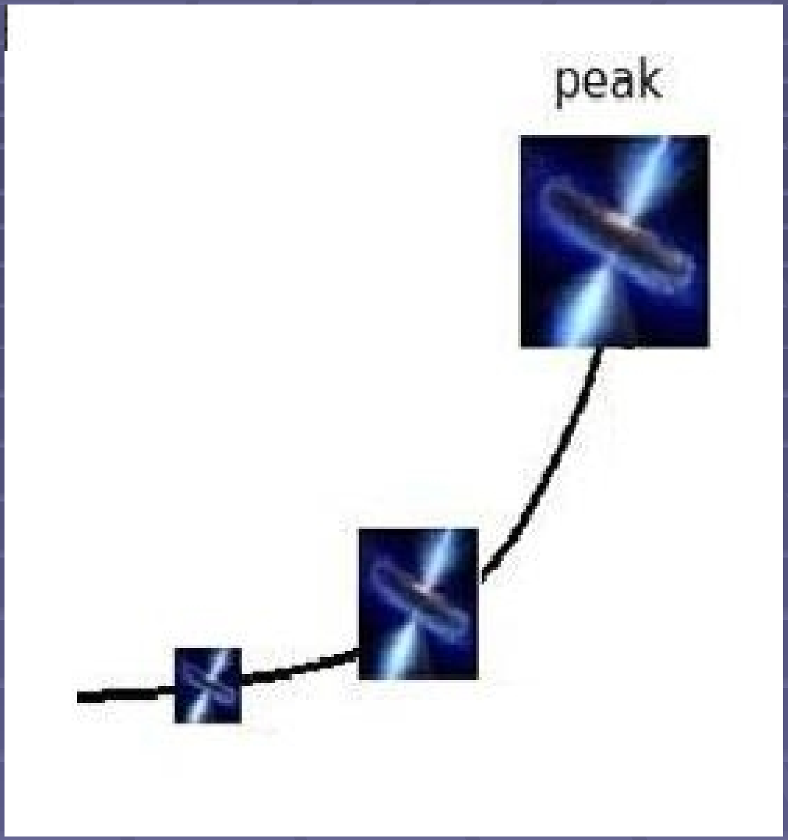
$$L \propto \dot{M}_2$$

$$\downarrow$$

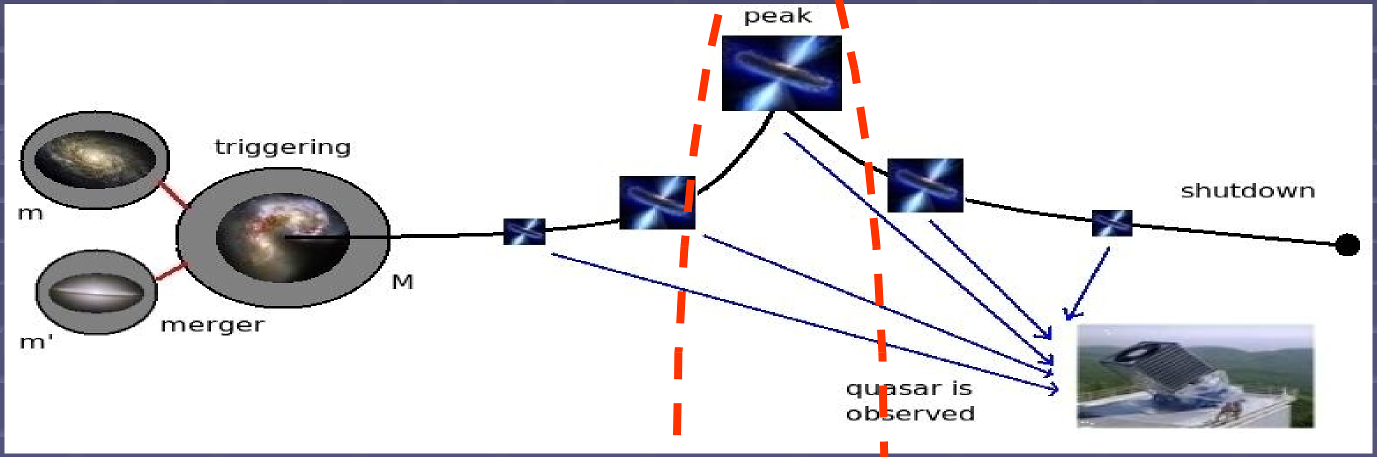
$$M_2 \propto \dot{M}_2$$

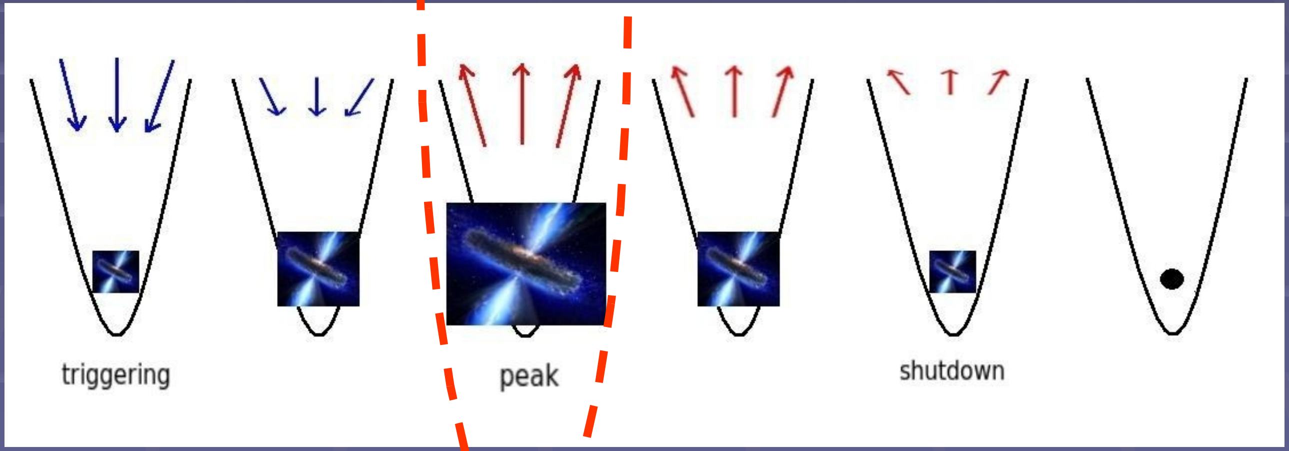
$$\downarrow$$

$$L(t),\ M_2(t) \propto \exp(t/t_e)$$



How does the beast kill itself?





Self-regulation: $M_2 \leftrightarrow M_{halo}$

Self-regulation

$$M_\bullet \propto M_{\rm halo}^{5/3}(1+z)^{5/2+\gamma}$$

Self-regulation

$$M_2 \propto M_{\rm halo}^{5=3}(1+z)^{5=2+°}$$

Simple argument: (See Wyithe & Loeb, 2002 & 2003)

$$M_2 \propto L \propto E/t$$

$E \propto M v_{\rm c}^2$ → $E/t \propto (M/r) v_{\rm c}^3$ → $L \propto v_{\rm c}^5$

$t \propto r/v_{\rm c}$ ↗

$v_{\rm c}^2 \propto M/r$ → $L \propto v_{\rm c}^5$

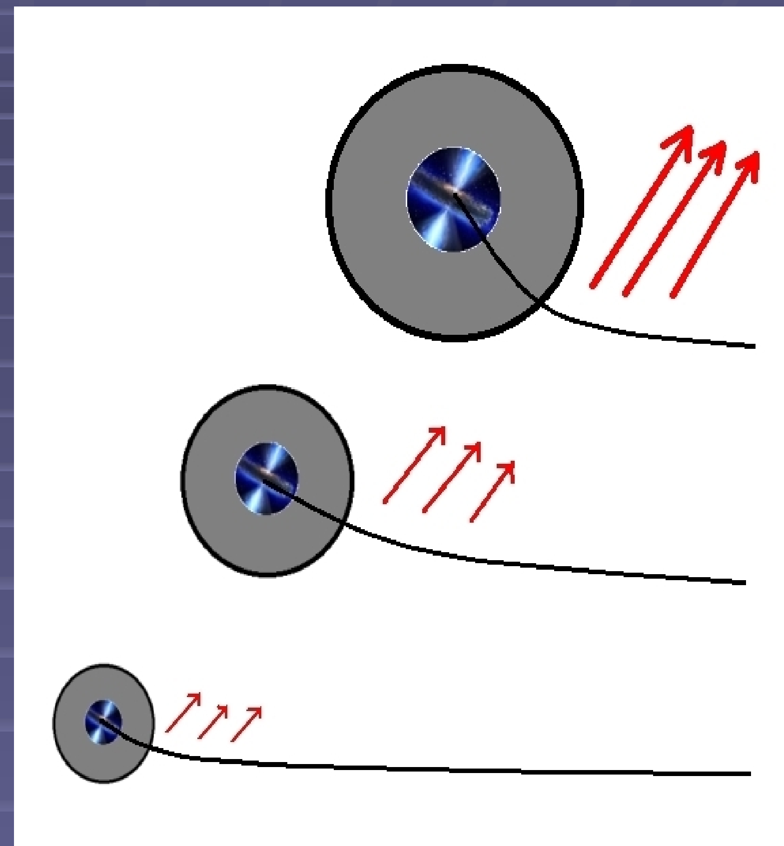
$v_{\rm c}^2 \propto M^{2=3}(1+z)$

$L \propto v_{\rm c}^5$ and $v_{\rm c}^2 \propto M^{2=3}(1+z)$ →

$$M_2 \propto M^{5=3}(1+z)^{5=2}$$

Descending phase

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



<u>See also:</u>
Hopkins & Hernquist (2008)
Yu & Lu (2008)

<u>Here:</u>

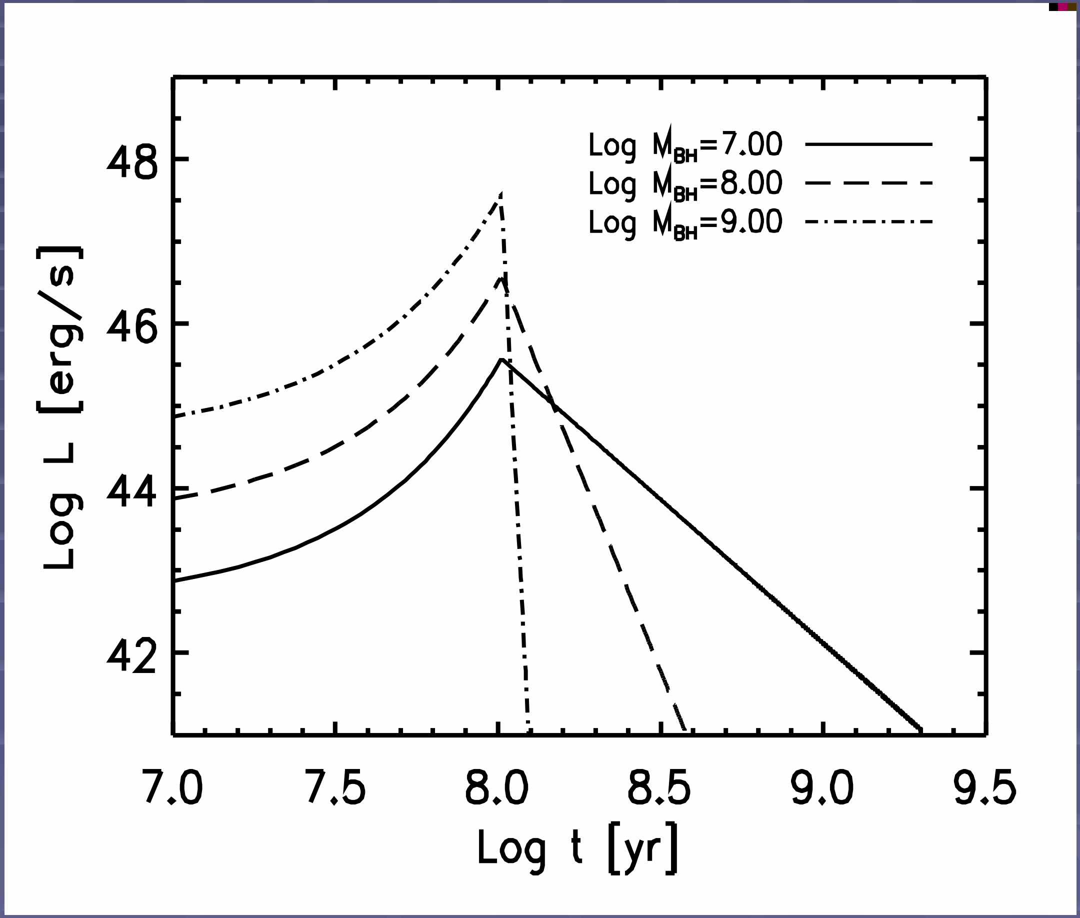
$$\alpha = \alpha(M_{\text{halo}})$$

$$\log \alpha \propto M_{\text{halo}}^{\beta}, \; \beta > 0$$

Summary: the light curve:

- Ascending phase:
  Exponentially
  increasing
- Peak:
  controlled by
- Descending phase:
  power law
  stronger decay for massive haloes!

$M_2 \leftrightarrow M_{\text{halo}}$



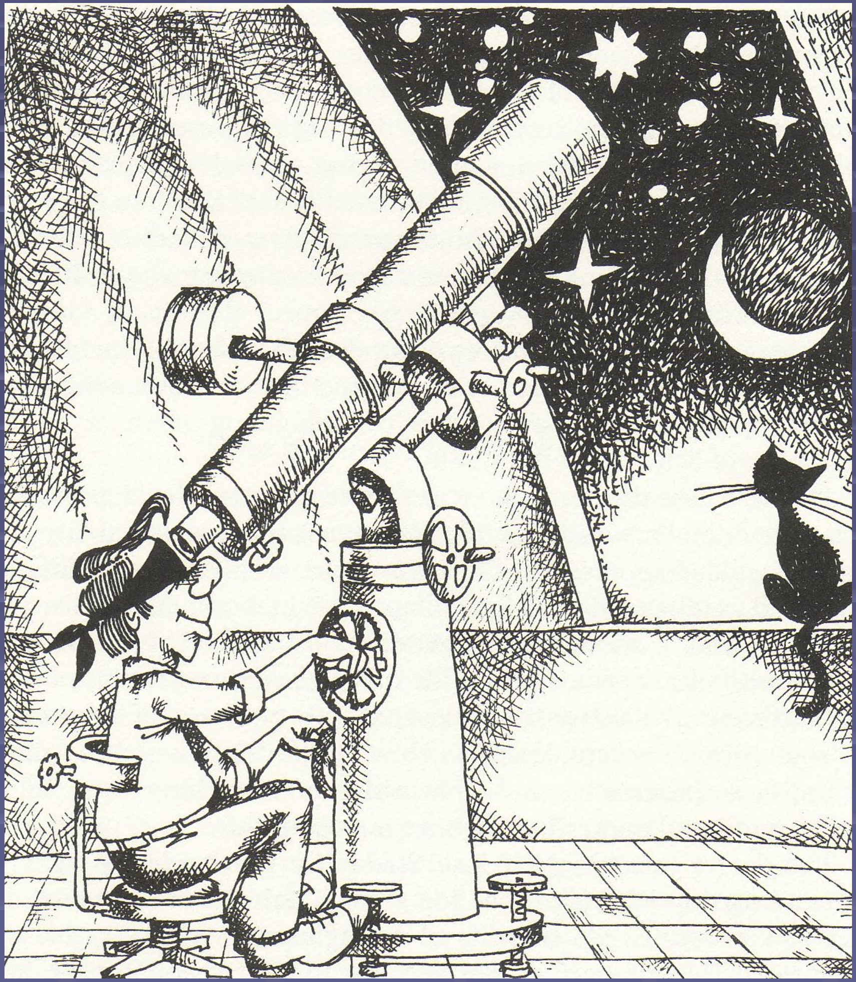
IV. Results

- Science goals:

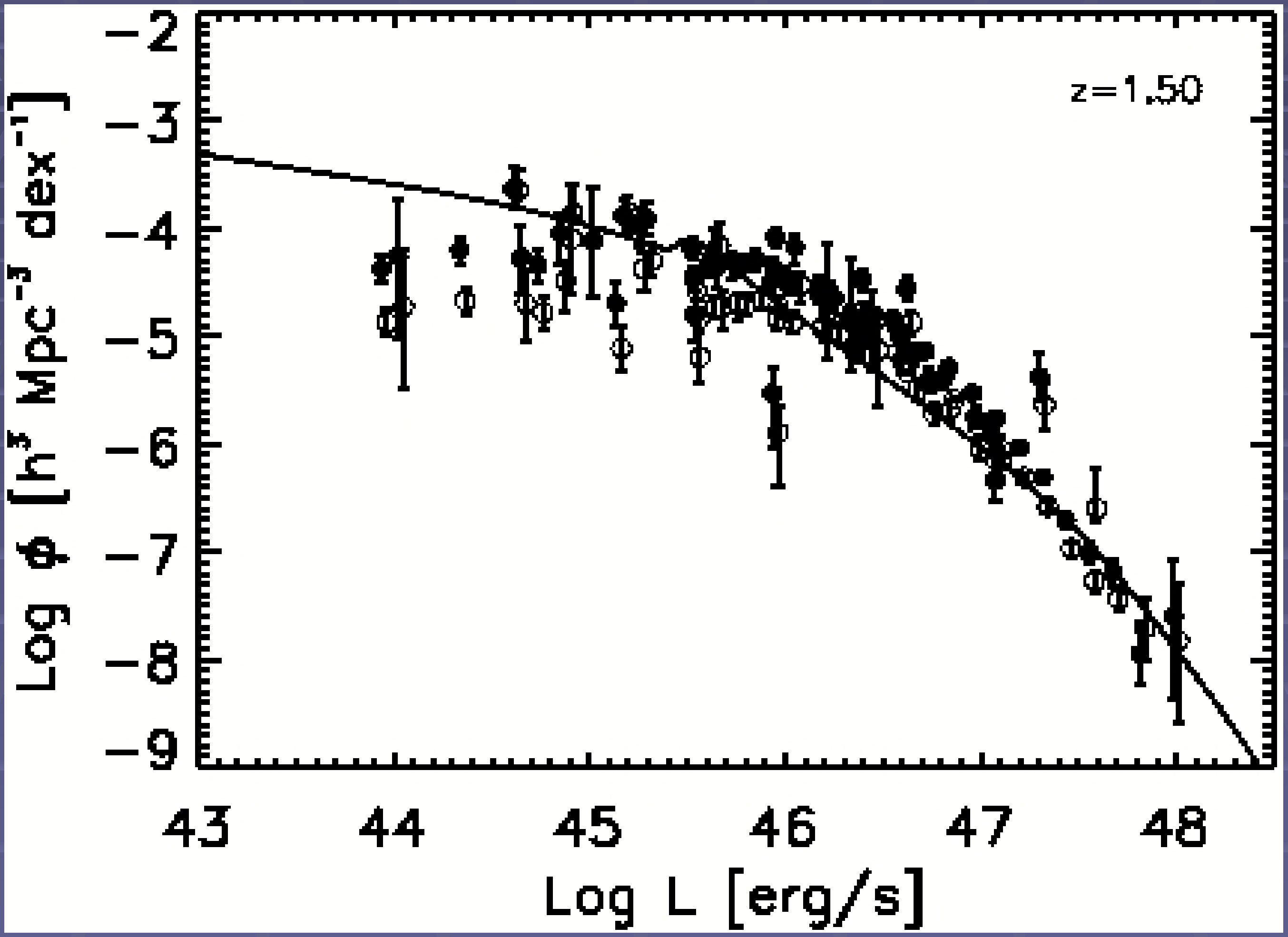
  - Luminosity function at all z.

  - Quasar clustering at all z.

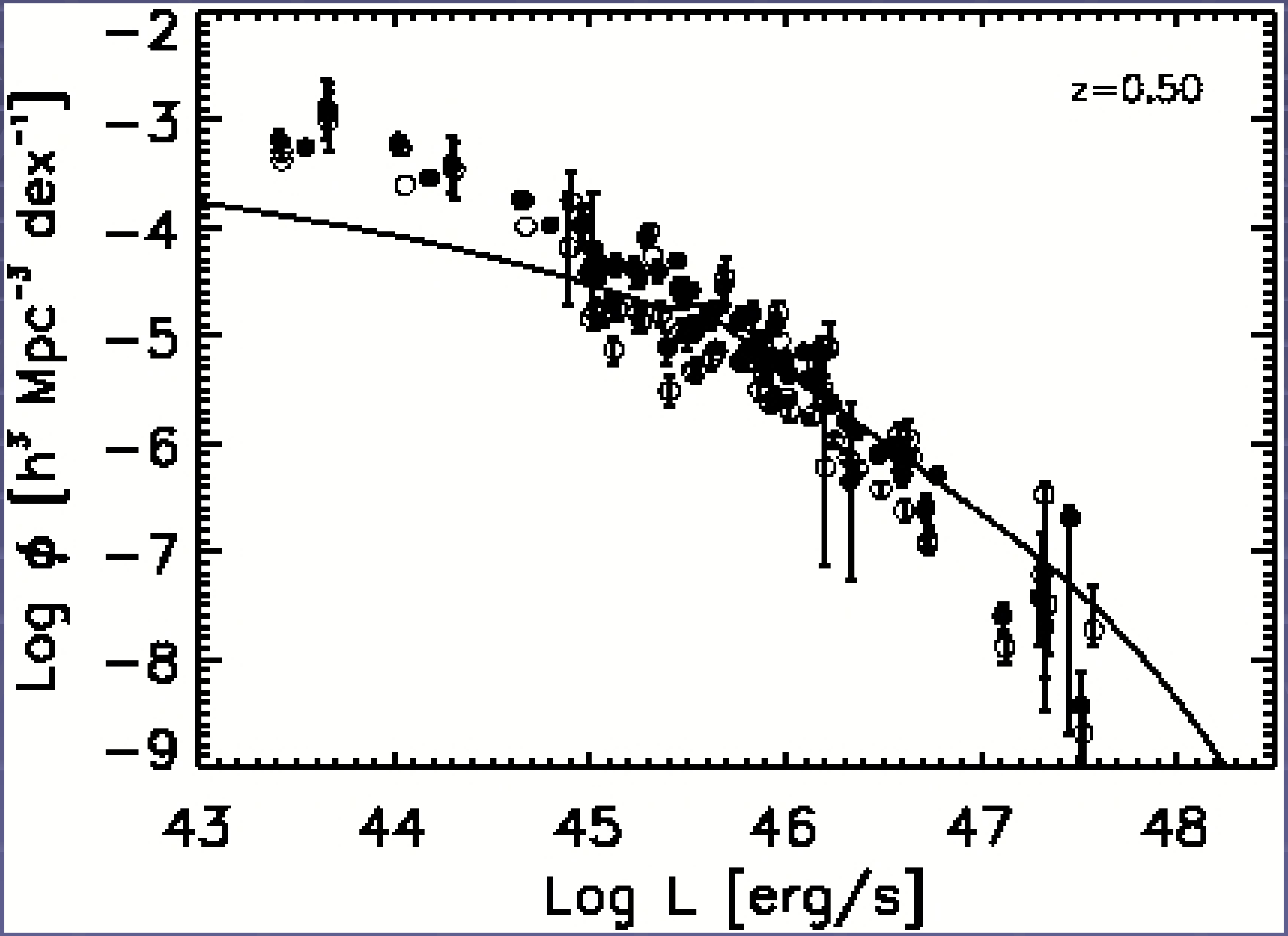
→ ***formidable task!!***



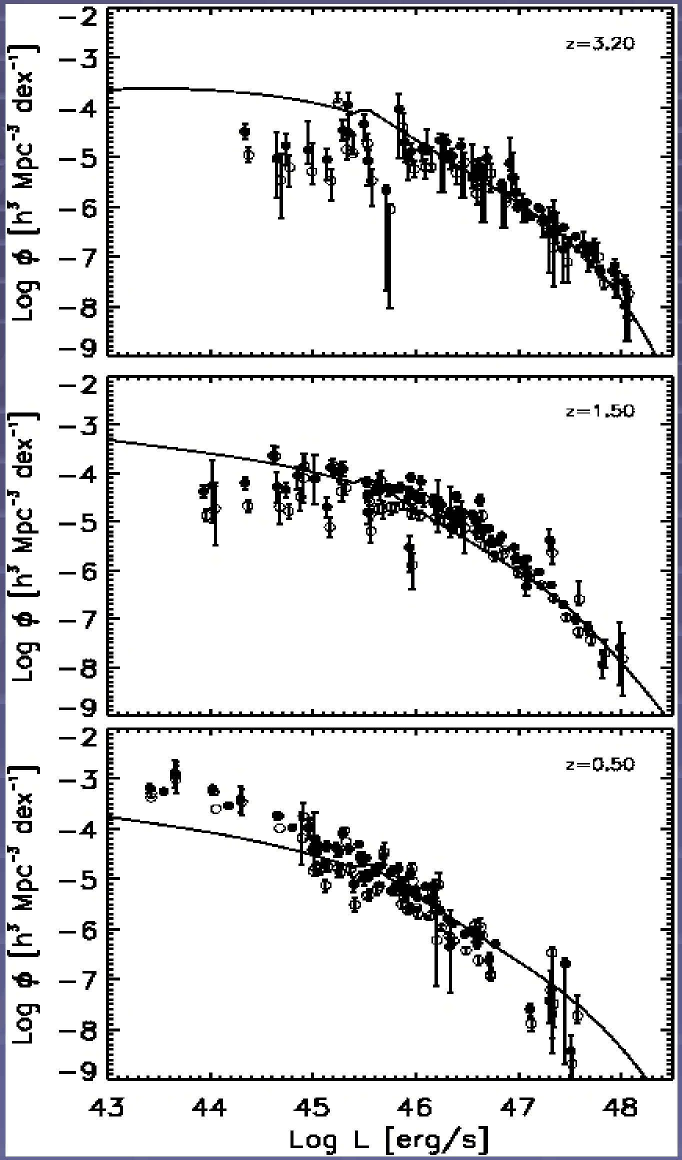
The luminosity function

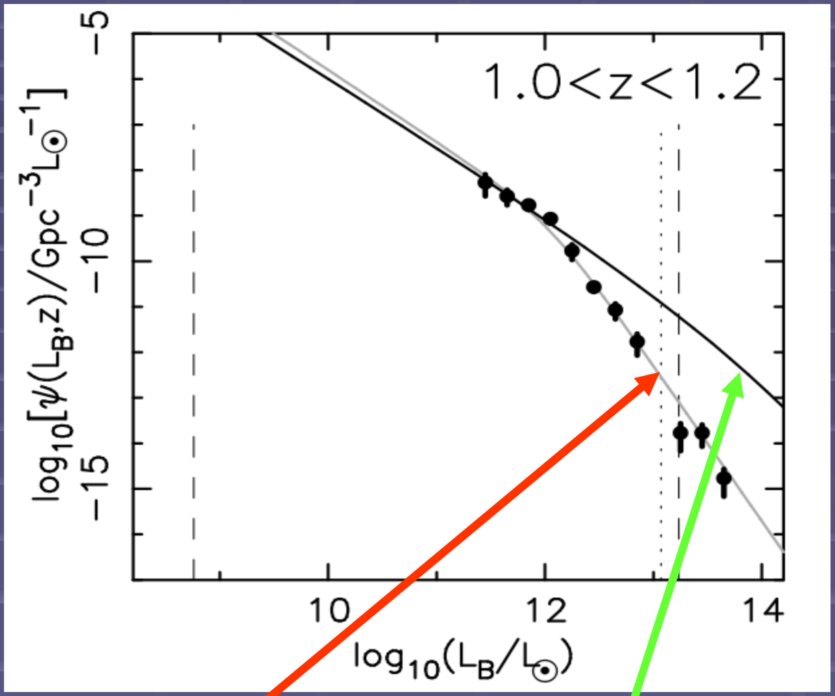


The luminosity function



Comparison: luminosity function

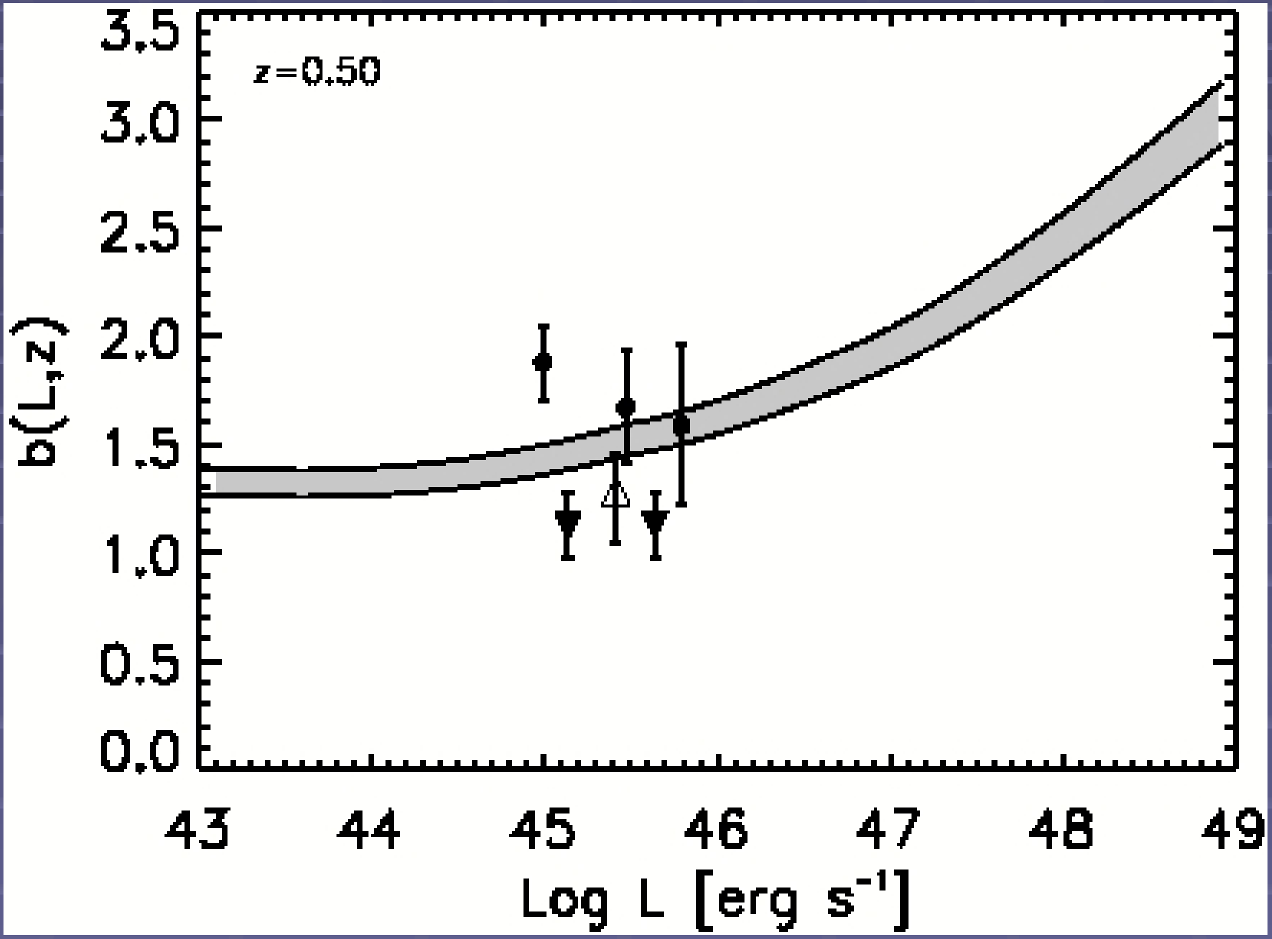




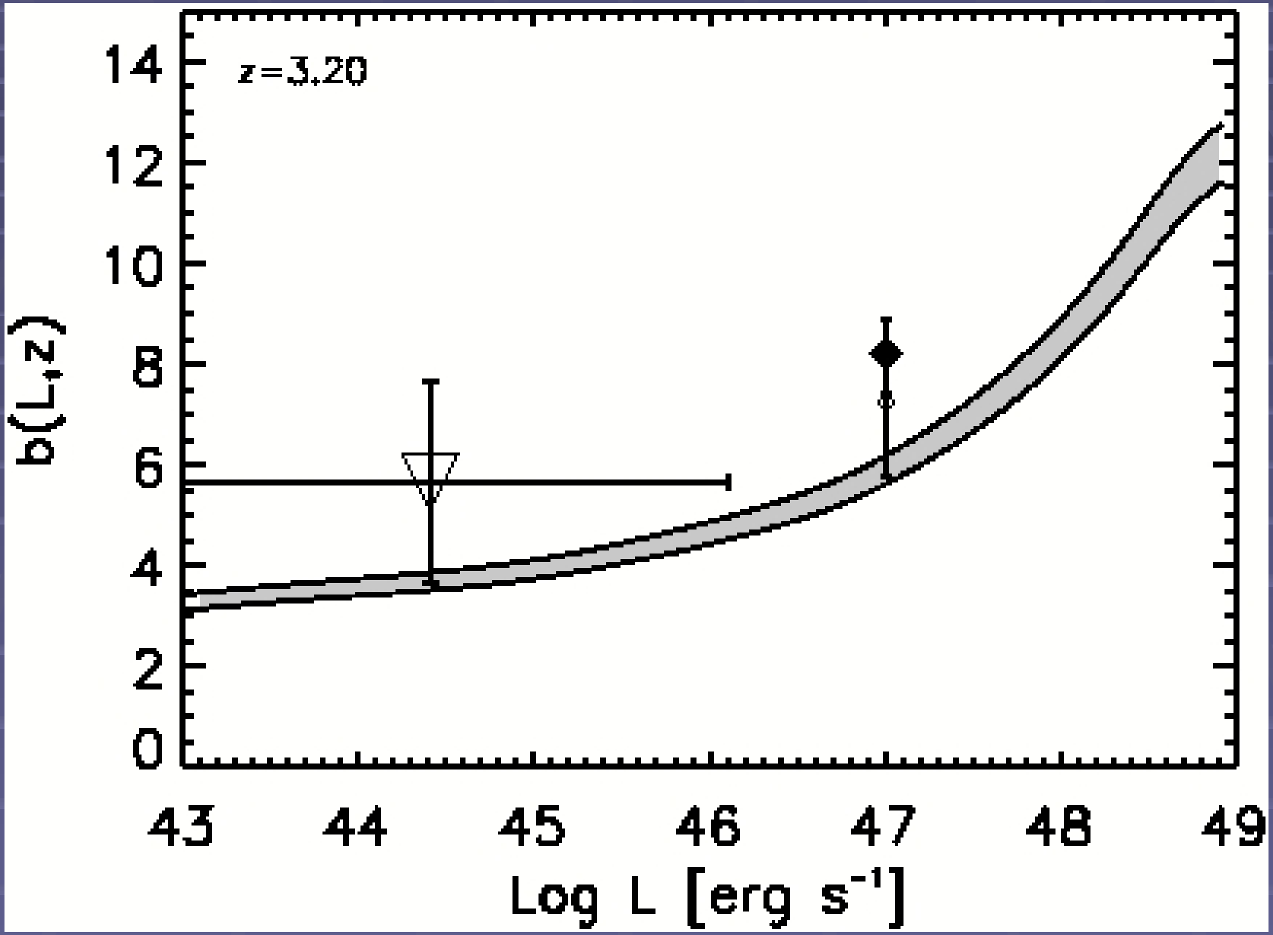
Boyle (2000) fit to data

Wyithe & Loeb (2003) model

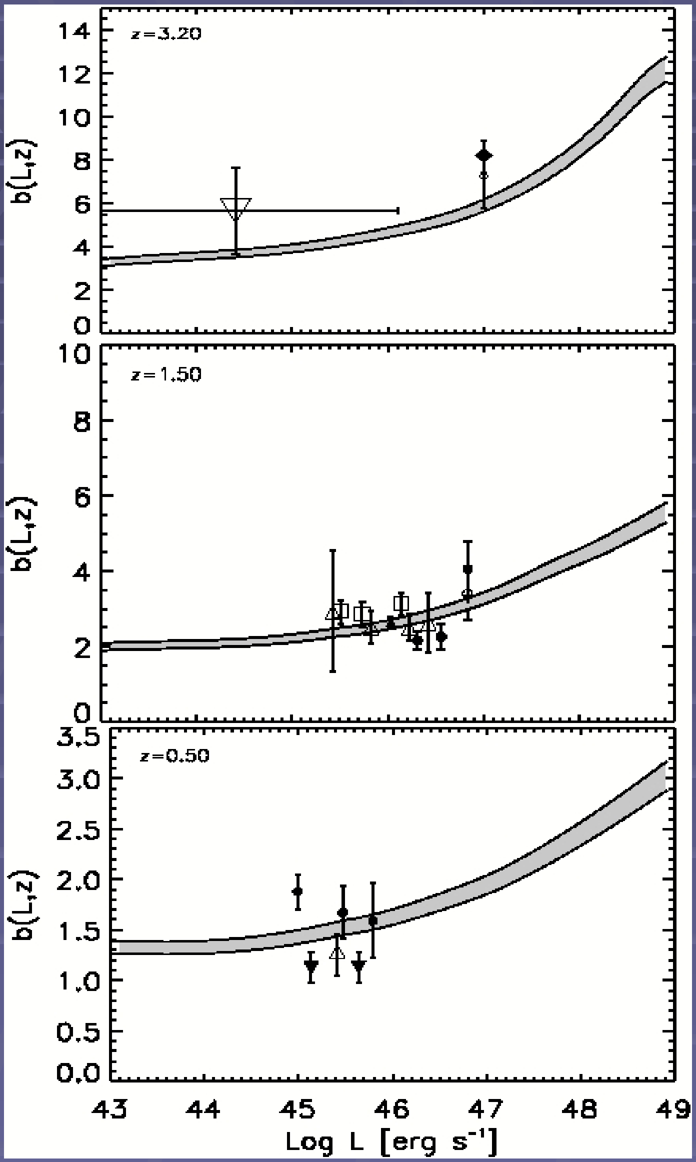
Quasar clustering

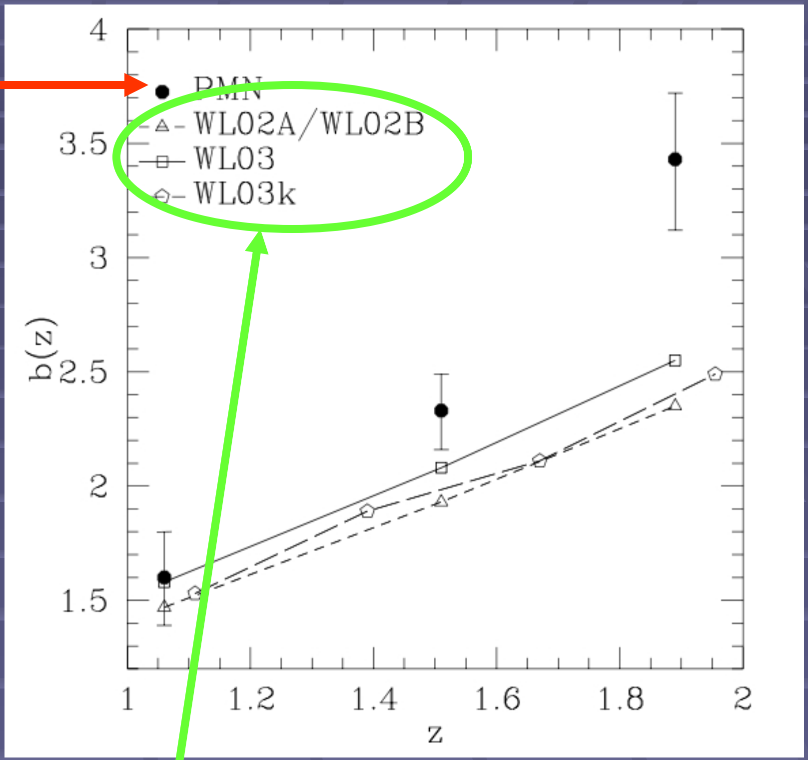


Quasar clustering



Comparison: bias



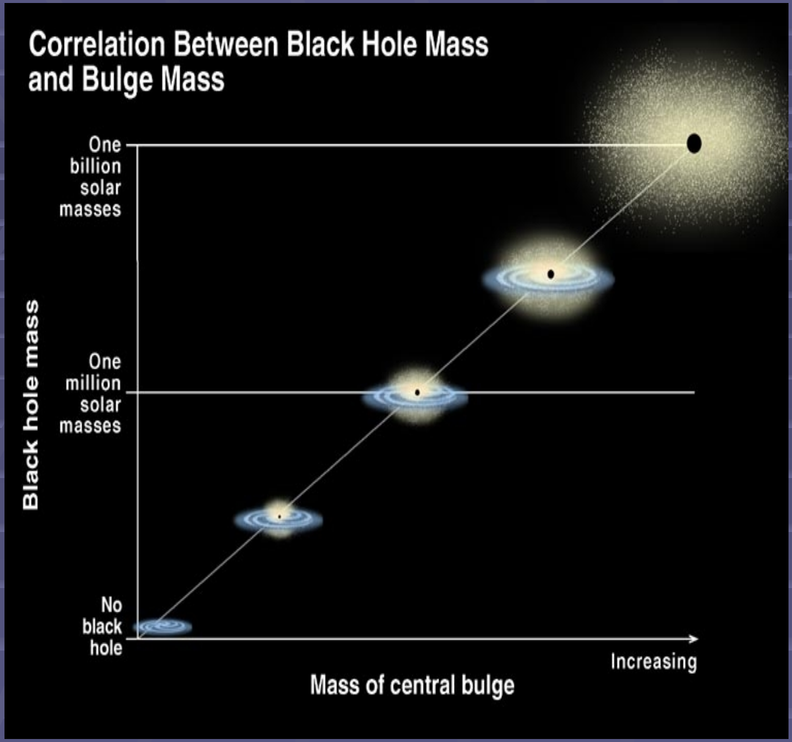


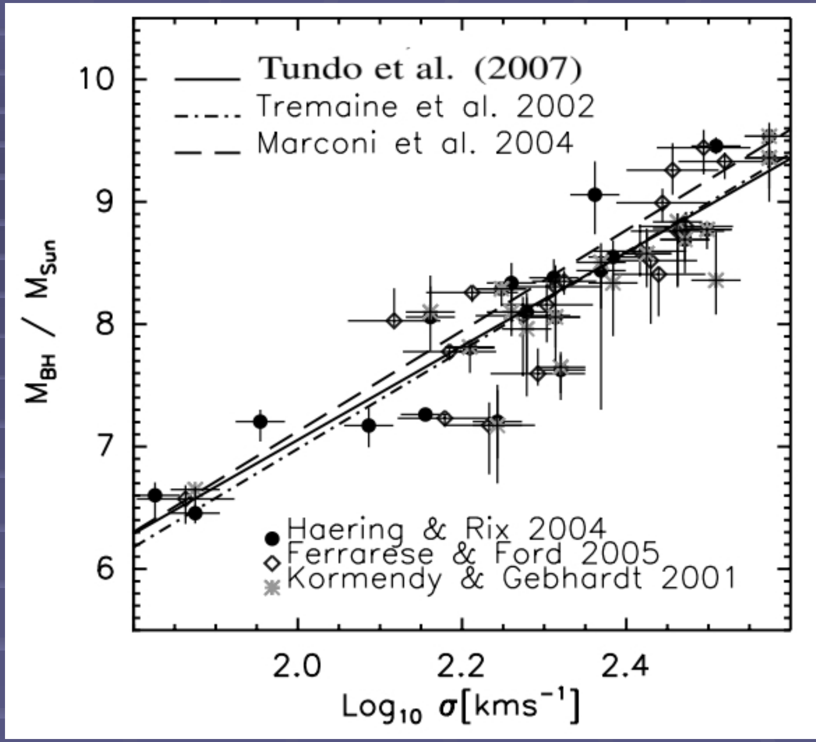
Credit: Marulli et al. (2006)

Previous models

Observations

V. Future research



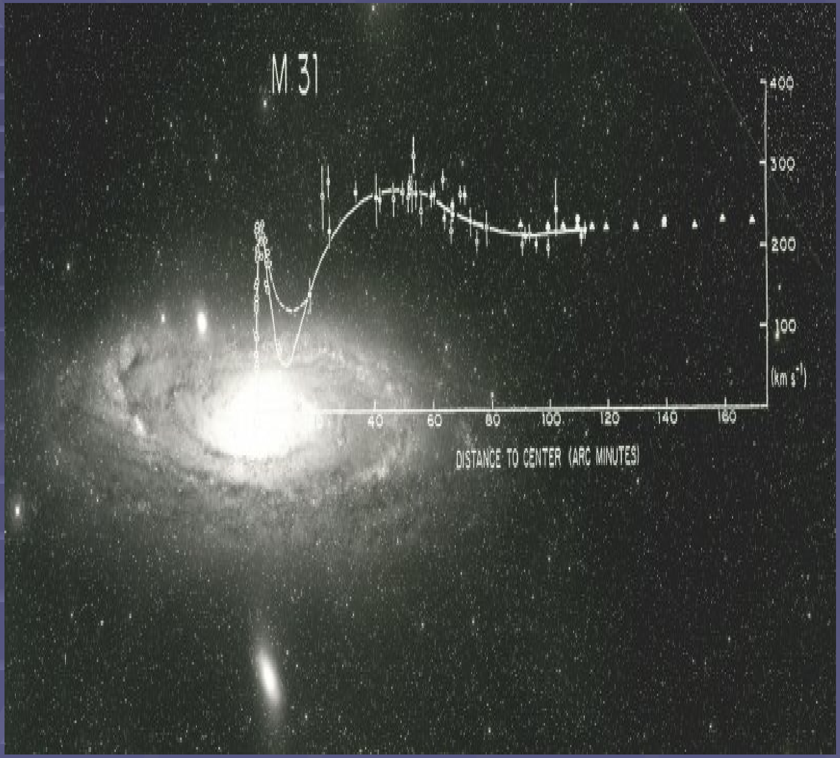


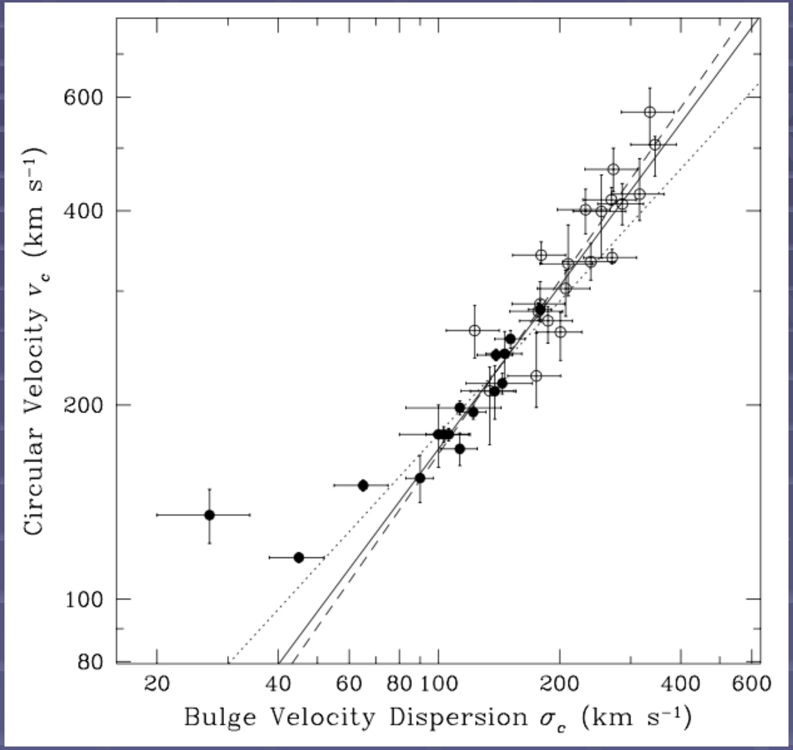
Credit: Yuri Beletski

Credit: Elena Tundo

$$M_2 \longleftrightarrow \sigma$$

More scaling relations!





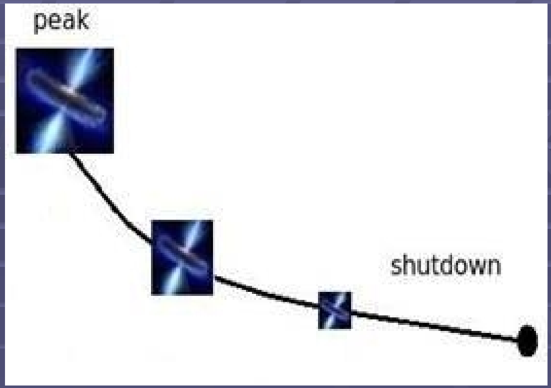
Credit: Vera Rubin

Credit: Laura Ferrarese

$$\sigma \longleftrightarrow v_c$$

Black hole - Halo relation

$M_2 \leftrightarrow M_{\text{halo}}$ (at the peak)



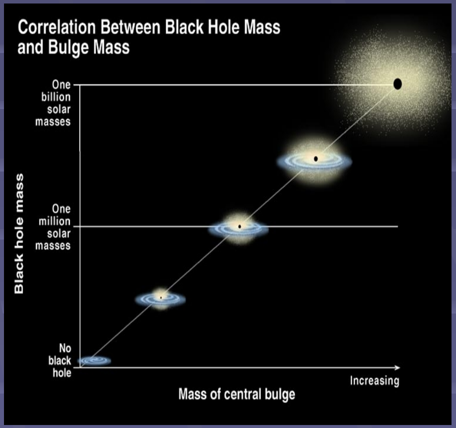
$M_2 \leftrightarrow M_{\text{halo}}$ (at shutdown)

$M_{\text{halo}} \leftrightarrow v_{\text{vir}}$

$v_{\text{vir}} \leftrightarrow v_{\text{c}}$

$v_{\text{c}} \leftrightarrow \sigma$

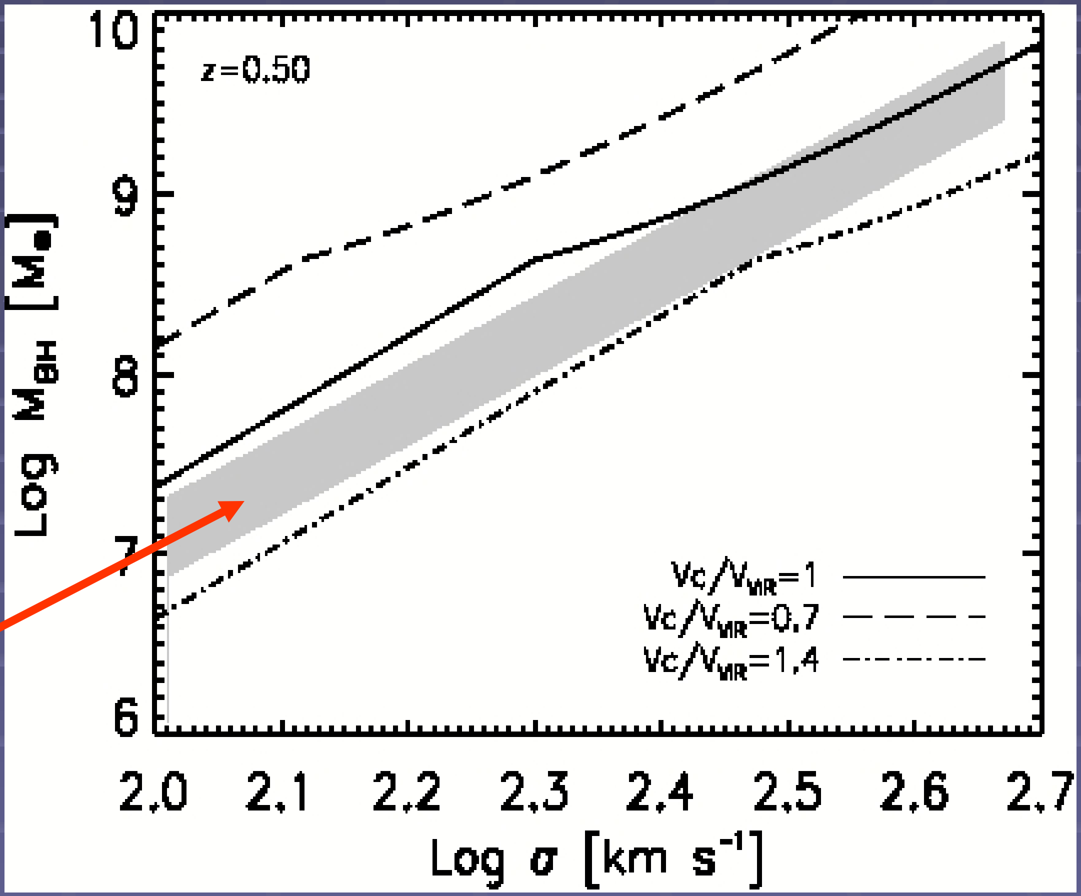
$\sigma \leftrightarrow M_2$



...or

$$M_2 \leftrightarrow \sigma$$

Preliminary results



Local
$M_2 \leftrightarrow \sigma$

VI. Final remarks

- Model:
  -Halo major mergers → quasars!
  -Very simple model (6 parameters!)

- Observational constraints:
  - Luminosity function
  - Quasar bias
  - Local $M_2 \leftrightarrow \sigma$ (?)

Thank you!!

Any questions??

- Paradigm shifts:
  -Merger rate: ellipsoidal collapse
  -Light curve peak: $M_2 \leftrightarrow M_{\mathrm{halo}}$
  -Faster shutdown for massive haloes!!