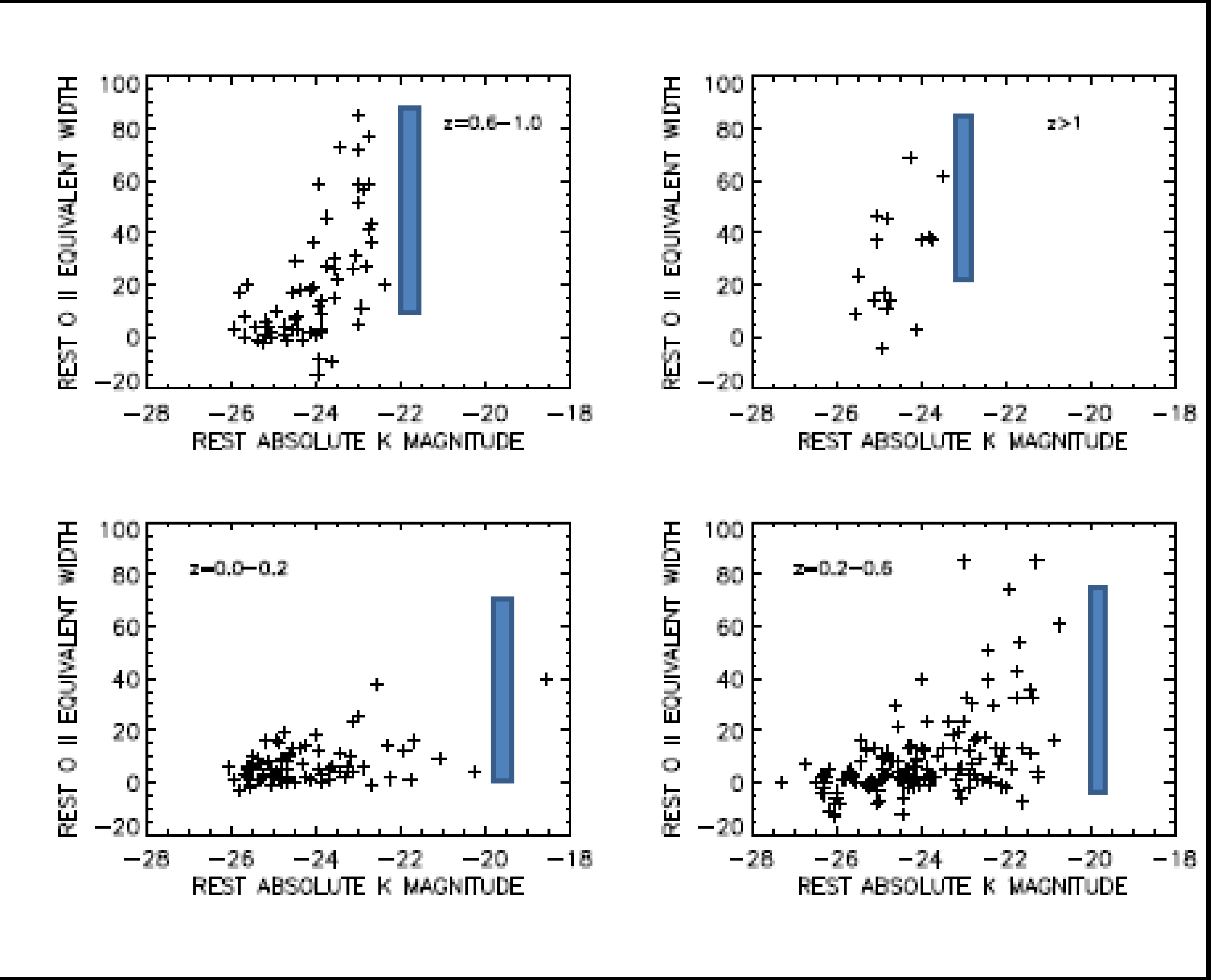
Feedback From Supermassive Black Holes: Theoretical Overview

Yale Computational Cosmology Seminar Series

10/27/2009

The Missing Piece (Feedback from AGN)

- ❑AGN feedback serves as non-Gravitational heating mechanism in clusters
  - ❑Gas is blown out from the center of the cluster
  - ❑Steepening the L_X-T relation
- ❑Lack of cooling flow
  - ❑AGN heating compensates the cooling or in other words decreases the cooling rate
- ❑Cosmic Downsizing
  - ❑Feedback from AGNs doesn’t allow gas to cool
  - ❑Shuts up star formation
  - ❑AGN luminosity function peaks between redshifts 2 and 3



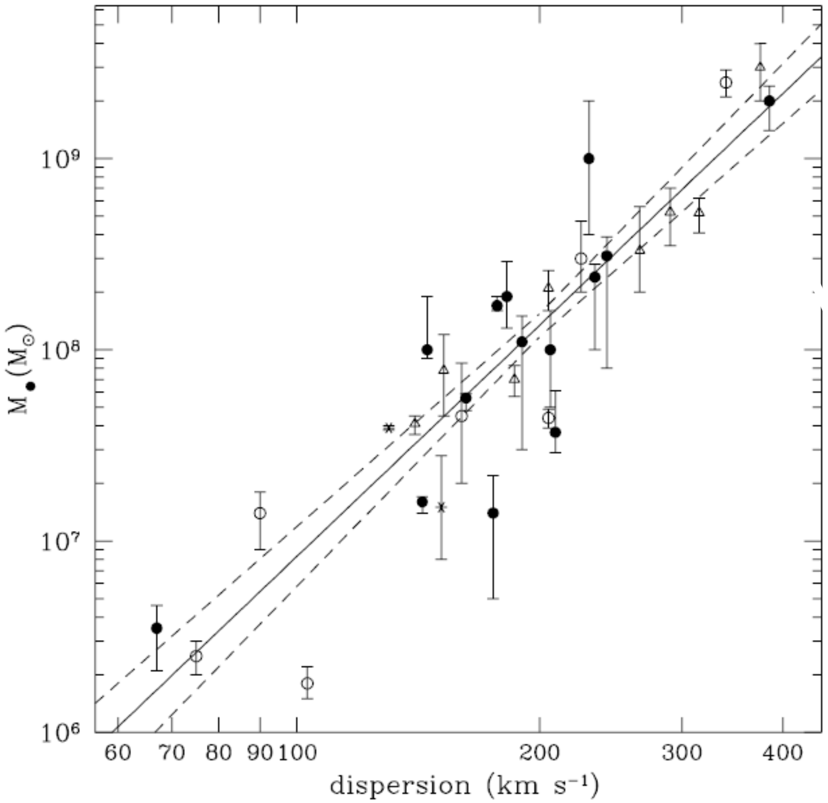
Cowie et al. 1996

❑Star-formation rate [OII] equivalent width is plotted as a function of stellar mass of the galaxy.

❑Massive galaxies are forming stars at higher redshift

Implication of downsizing of galaxy population

Tremaine et al. 2002



- Correlation between black-hole masses and velocity dispersions for the galaxies.
- The dashed lines show the 1σ limits on the best-fit correlation

Two classes of AGN : Radio Loud AGNs
: Radio quiet AGNs

❑**Radio Loud mostly operates in the form of mechanical feedback**
(Jets; common in galaxy clusters)

- Geometrically thick, radiatively inefficient, low accretion phases of the black hole
- Mechanical Pdv work

❑**Radio quiet operates mostly in the form of thermal feedback**
(radiative feedback)

- Geometrically thin, radiatively efficient, rapid accretion phases of a black hole
- Coupling unknown

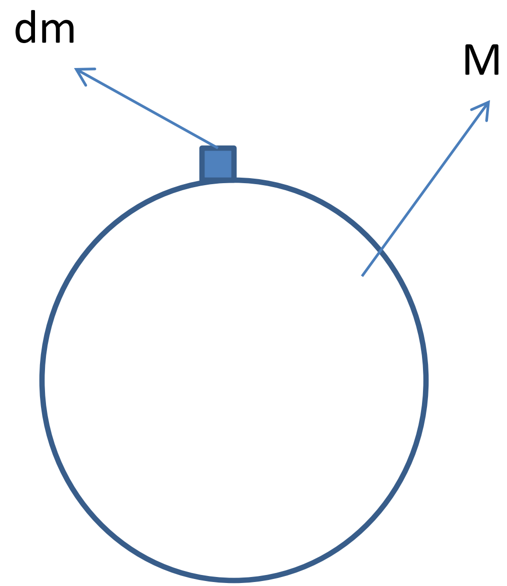
Quasar winds host mechanical outflow through winds

Hydrostatic Equilibrium

- Consider a self-gravitating system of gas (a star for example) where gravity is trying to collapse inward and pressure tries to stop the collapse.
- The equilibrium condition that is created in a self gravitating system due to the interplay between Pressure and gravity is called **Hydrostatic Equilibrium**

Gravitational Force
GdmM/r^2

Pressure gradient
= dP/dr



In equilibrium

$$\frac{dP}{dr} = -\rho g$$

Eddington Limit

- **Eddington Luminosity is defined as the maximum radiative luminosity a body can have to maintain hydrostatic equilibrium**

- **At high temperature radiation pressure dominates and thus the condition of hydrostatic equilibrium gives**

See Lecture Notes

$$\boxed{L_{Edd} = \frac{4\pi G c \mu m_p M}{\sigma_T}}$$

$L_{EDD} = 1.38\text{x}10^{38}\ (M/M_{sun})$ ergs/s

The Eddington luminosity is the maximum luminosity beyond which radiation pressure prevents gas accretion.

Radiatively Efficient
(Quasar Mode)

$$\frac{L_{Edd}}{c^2} = \frac{dM_{Edd}}{dt}$$

$$> 0.01\dot{M}_{Edd}$$

$$< 0.01\dot{M}_{Edd}$$

Radiatively Inefficient
(Jet Mode)

Radiative efficiency quoted in units of Eddington

Question

What is the Eddington Luminosity of the Sun??

Can you tell about the radiative efficiency of the Sun?

Hint: Think about the Solar luminosity

0.00001

Pathways of AGN Feedback

(Elvis 1994)

1. Radiation
(could be important in the early evolutionary phase)
2. **Relativistic Jets** (common in radio loud AGNs)
3. **Non-Relativistic Winds**
(commonly seen in Broad Absorption Line Quasars)

1. Theoretical models try to model one or the other mode of feedback
2. Observationally 2 and 3 are established.
3. A theoretical model should try to address the universality of modes of feedback

Semi-Analytic Model of Black Hole Feedback

Feedback from Black Hole

- ❑ Co Evolution of black holes with host galaxies.
- ❑ Interaction with the ICM , IGM

Wyithe & Loeb 2002, 2003; Scannapieco & Oh 2004. Also see Menci et al. 2005

1.Why is the Black Hole Mass Correlated with Velocity dispersions?

2. Can we reproduce the Observed Luminosity Functions of active galaxies?

3. Can we reproduce Cosmic Downsizing?

4.Do we solve the Cooling Flow Problem

Key Ingredients of the model

1. Some process that triggers feedback

mergers at high redshift can disrupt the quasar

disturbances in the accretion disc

2.Number density of Quasars

3.The amount of feedback energy

(determined by regulatory growth)

4. How does the feedback energy couples with the gas?

5. Dynamics of the outflow ? (which path??)

(Sedov-Taylor kind of Blast Wave, kinetic feedback)

Following a merger a black hole shines at a fraction of its Eddington Luminosity and returns a fraction of its mass energy to the surrounding gas

Self-Regulatory Growth

Wyithe & Loeb (2002, 2003)

The black hole growth is stopped once the feedback energy from the black hole is greater than the gravitational binding energy of the galactic gas

$$E_B = (1/2)\frac{\Omega_b}{\Omega_m} M_{halo} v_c^2,$$

$$E_f = \eta L_{EDD} F_q t_{dyn}.$$

$$t_{dyn} = \frac{0.035 r_{vir}}{v_c}$$

Mo, Mao & White 1998

$$
\begin{aligned}
v_c &= 245 \left(\frac{M_{halo}}{10^{12} M_\odot}\right)^{1/3} (\zeta(z))^{1/6} \left(\frac{1+z}{3}\right)^{1/2} km/s \\
\zeta(z) &= \left[\left(\frac{\Omega_m}{\Omega_m^z}\right)\left(\frac{\Delta_c}{18\pi^2}\right)\right] \\
\Omega_m^z &= [1 + (\frac{\Omega_\Lambda}{\Omega_m})(1+z)^{-3}]^{-1} \\
\Delta_c &= 18\pi^2 + 82d - 39d^2 \\
d &= \Omega_m^z - 1
\end{aligned}
$$

$$
M_{BH} = 1.9 \times 10^8 M_\odot \left(\frac{\eta F_q}{0.07}\right)\left(\frac{v_c}{350 km/s}\right)^5
$$

Barkana & Loeb 2001; Bryan & Norman 1998

Ferrarese 2002

$$log_{10}\left(\frac{v_c}{300kms^{-1}}\right) = (0.84 \pm 0.09) log_{10}\left(\frac{\sigma}{200kms^{-1}}\right) + (0.55 + 0.19)$$

(0.84±0.09)x5=4.20±0.45

$$M_{BH} = (1.66 \pm 0.32) \times 10^8 M_\odot \left(\frac{\sigma}{200kms^{-1}}\right)^{4.58 \pm 0.52}.$$

Normalisation depends on the feedback fraction

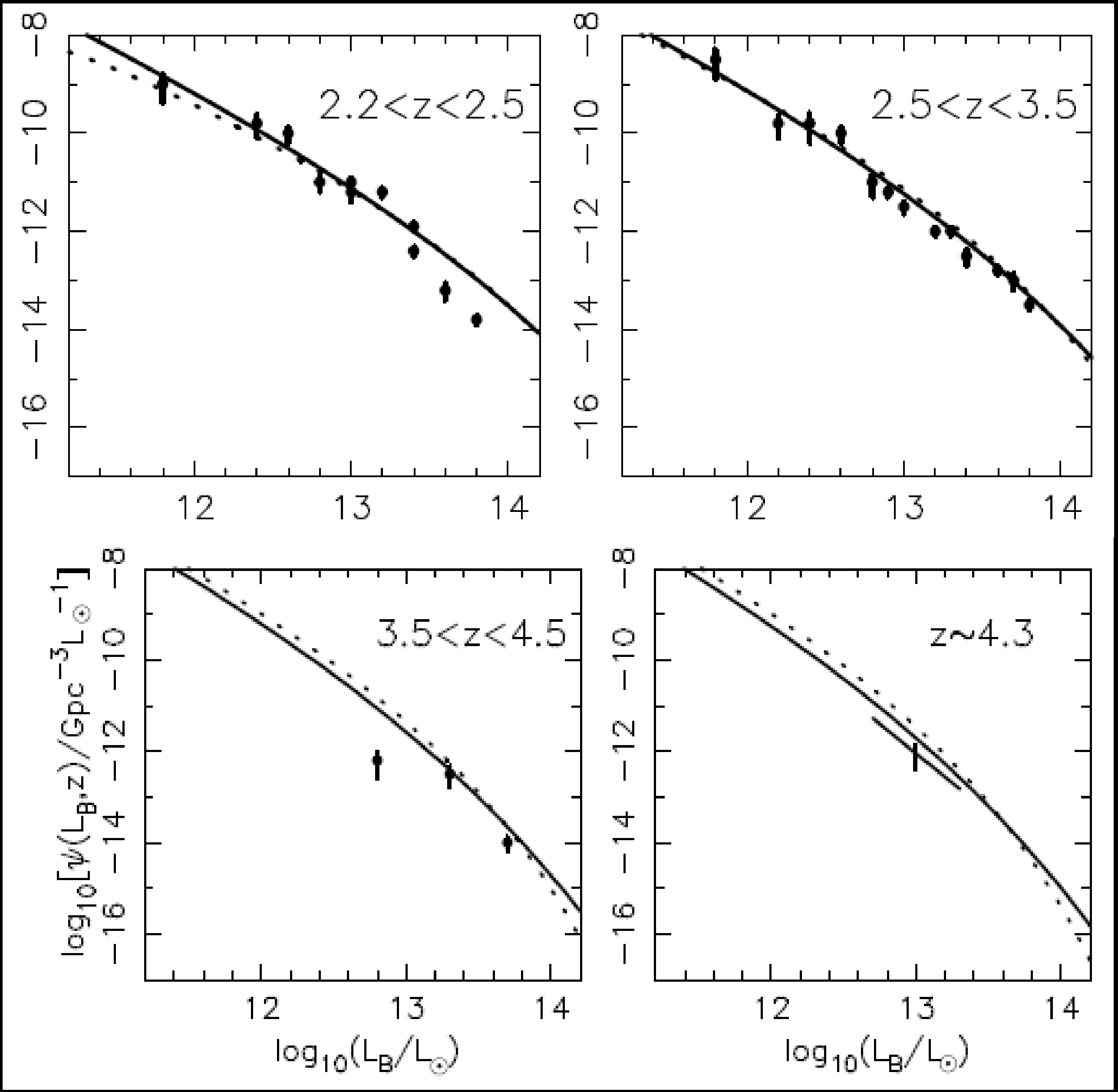
The Quasar Luminosity Functions

Haiman & Loeb 1998; Wyithe & Loeb 2003

- ❑Use the Press-Schechter (1974) Formalism (see Zheng Zheng's talk)
- ❑Quasar Luminosity function derived on the basis of halo formation rate
- ❑Modified Version (Derived from Merger Rate)

$$\Psi(L_B, z) = \int_z^{\infty} dz' \int_{\epsilon M_{min}}^{\infty} dM_{bh} \frac{d^2 n_{bh}}{dM_{bh} dz'} \times \delta[L_B - M_{bh} f(t_z - t')]$$

See Lecture Notes



Wyithe & Loeb 2003

Sedov-Taylor Model of Energy Outflow

Scannapieco & Oh 2004

The Sedov-Taylor model describes a point like (instantaneous) explosion in an uniform medium

See Shu 1992; Chatterjee thesis

$$r_{sh} = r_0 (Et^2/\rho_1)^{1/5}$$

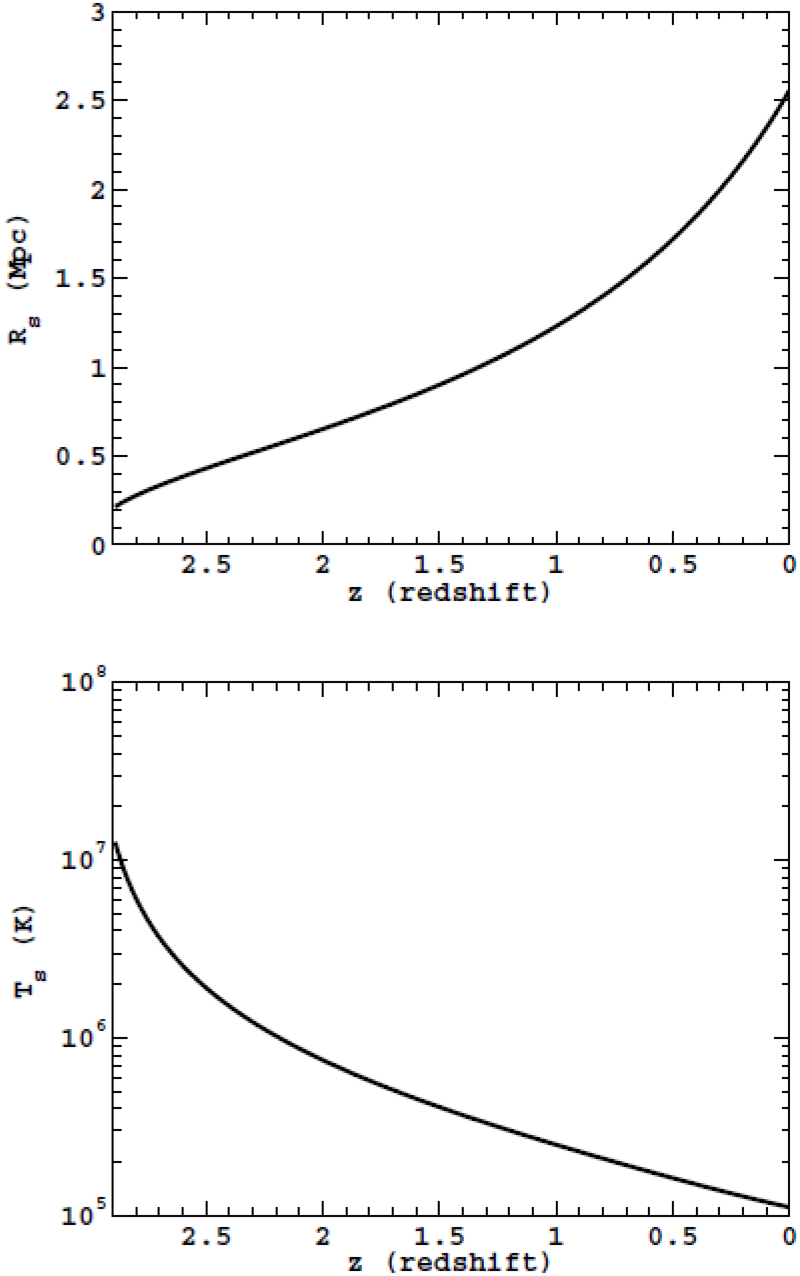
$$U_{sh} = \frac{dr_{sh}}{dt} = \frac{2}{5}\frac{r_{sh}}{t}$$

$$R_s = r_{sh} = 1.7 E_{60}^{1/5} \delta_s^{-1/5} (1+z)^{-3/5} t_{\rm Gyr}^{2/5} \ {\rm Mpc}$$

$$v_{sh} = U_{sh} = 1500 R_s^{-3/2} E_{60}^{1/2} \delta_s^{-1/2} (1+z)^{-3/2} \ {\rm km s^{-1}}$$

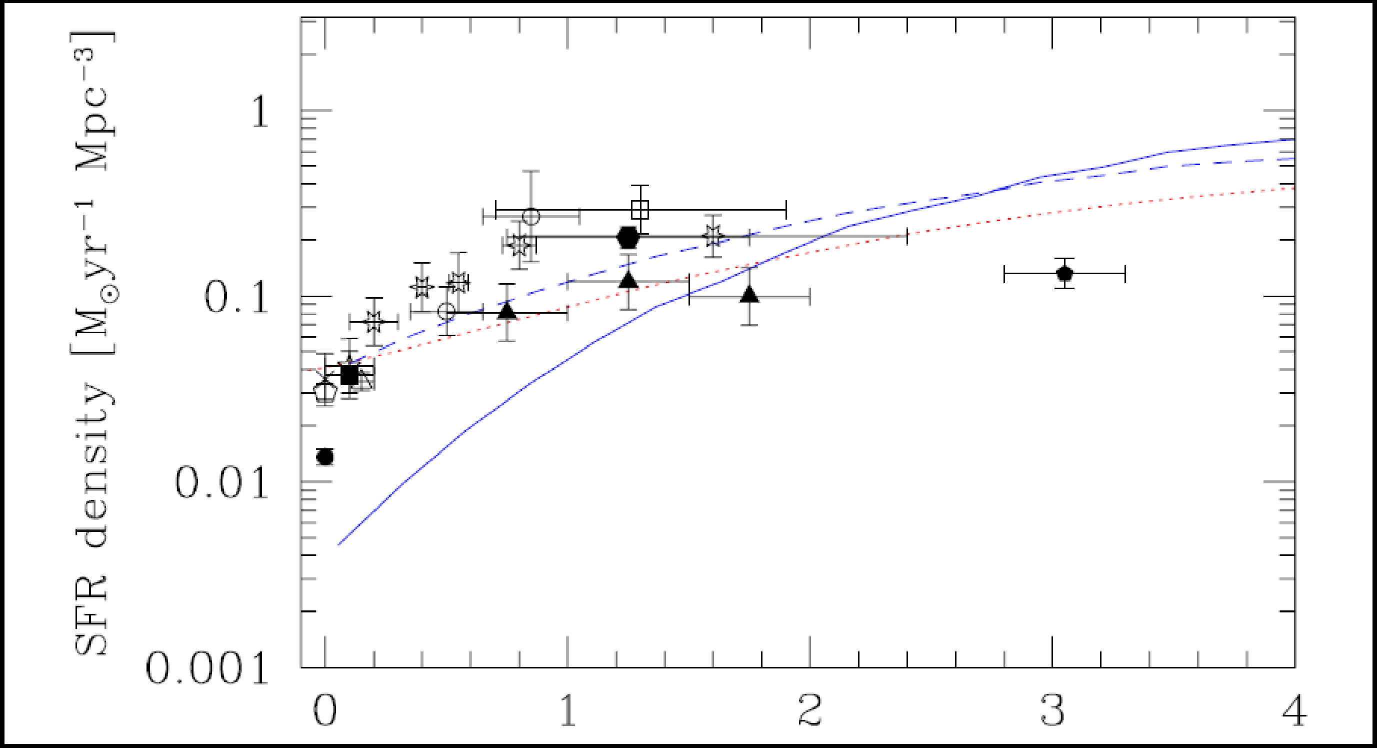
$$S = 1.8 \times 10^4 E_{60} \delta_s^{-5/3} (1+z)^{-5} \left(\frac{R_s}{1\,{\rm Mpc}}\right)^{-3}$$

This adds excess entropy into the system



Chatterjee:Thesis

- The excess entropy modifies the cooling time
- There is a critical entropy created in the system where the cooling time gets higher than Hubble time.
- Gas that is heated above critical entropy never cools.
- Using this prescription they compute the fraction of objects whose formation is suppressed by heating of quasar outflows.
- Compute the star formation rate and compare with observations.



See Scannapieco & Oh 2004 for references

Pros and Cons of the model

❑There are several free parameters which can be tuned to produce agreements with observations. Particularly with the star formation observation
❑A Sedov Taylor model is not an accurate description
❑ Doesn't describe the jet mode or the radiative mode
❑Yet pretty accurate and close to the observed properties of quasars. Physical arguments provided for explaining observation

Feedback From Supermassive Black Holes: Numerical Simulations

11/10/2009