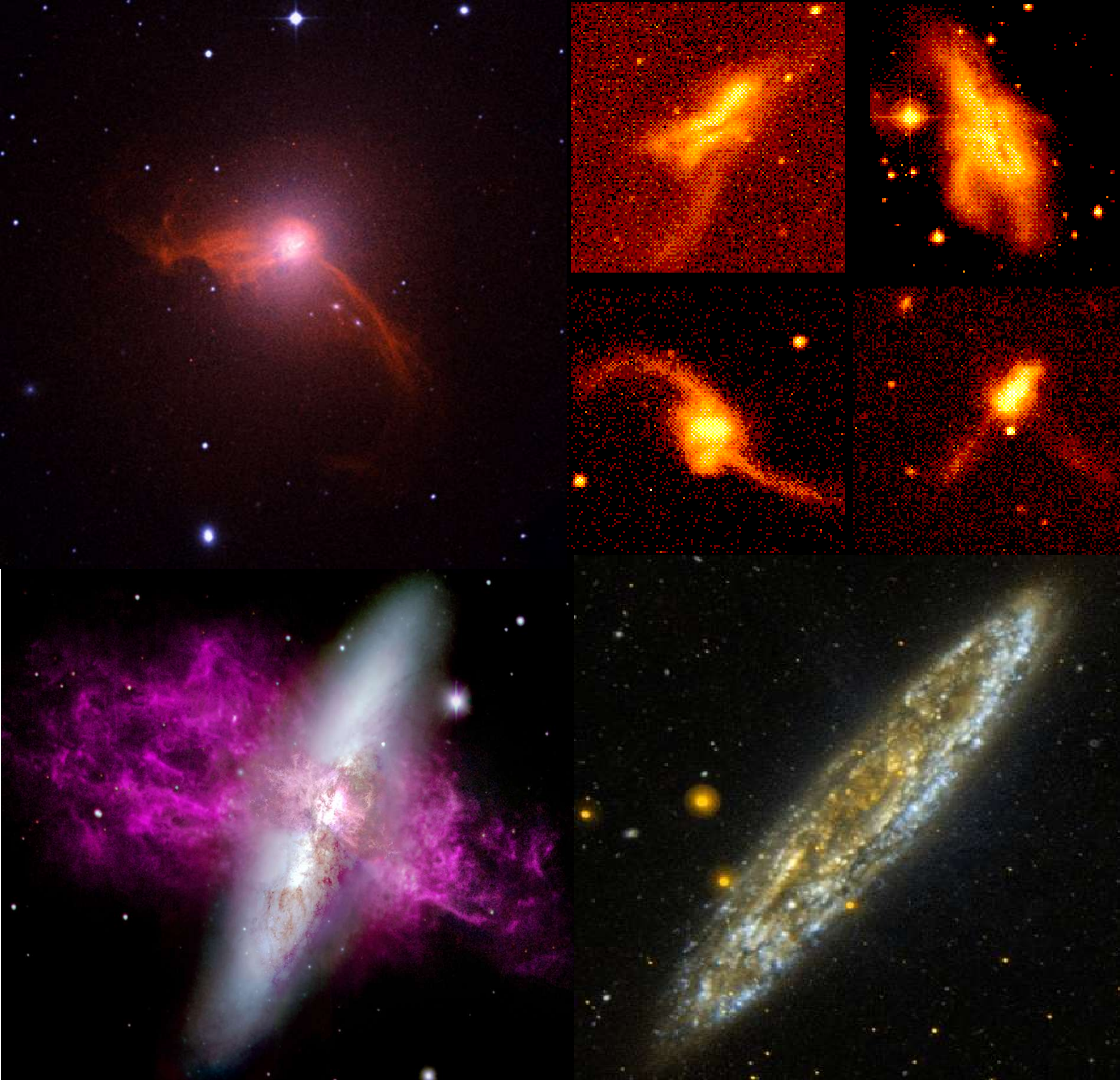
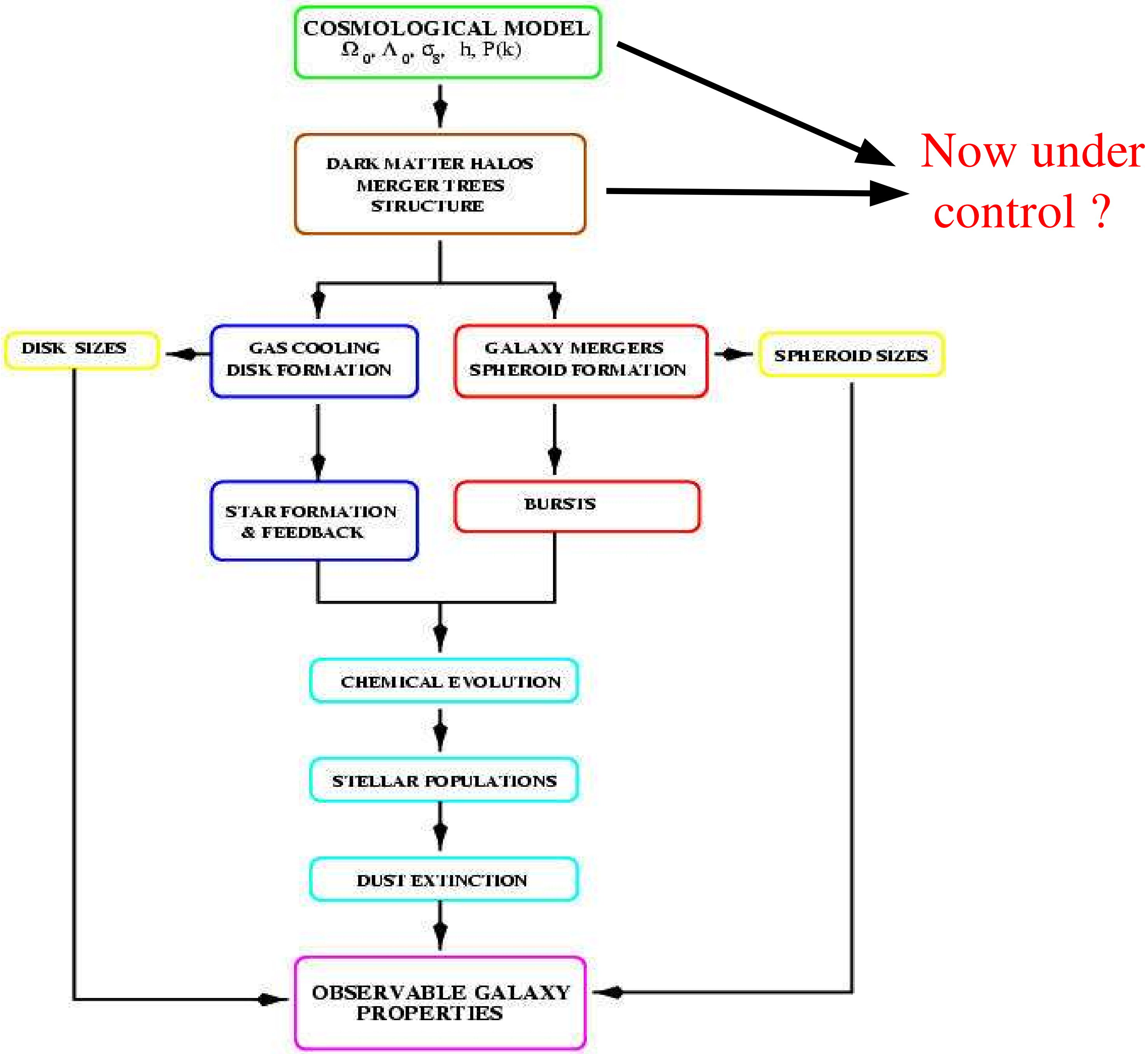


Which physical processes control massive galaxy formation ?

theoretical assumptions versus observational evidence

HIERARCHICAL GALAXY FORMATION



Cole, Lacey, Baugh & Frenk, 2000, MNRAS, 319, 168.

The Cooling of GAS

REGIME I: Cooling time of gas in the halo is short (cooling radius lies outside the virial radius):

gas accretion is regulated by the INFALL of new material onto the galaxy. This is the regime of "cold accretion".

REGIME II: Cooling time of gas in the halo is long (cooling radius lies inside the virial radius):

a quasi-static atmosphere of hot gas forms and the cooling rate is regulated by radiative losses near the cooling radius. This is the "cooling flow" regime.

e.g. White & Frenk 1991

Benson et al 2000

Table 2. Measured rotation velocity and predicted gas temperature for the galaxies in our sample.

Name	V_c (km s^{-1})[a]	T_{vir} (keV)[b]
NGC 2841	317 ± 2	0.287 ± 0.004
NGC 4594	358 ± 4	0.366 ± 0.009
NGC 5529	277 ± 3	0.219 ± 0.005

[a] Calculated from H I linewidths using the expression given in Tully & Fouqué (1985).
[b] As defined by White & Frenk (1991).

Current theories of galaxy formation predict that giant spiral galaxies are embedded in a reservoir of hot gas. Estimates of the X-ray luminosity emitted in the cooling region are of the order of 10^42 erg/s.

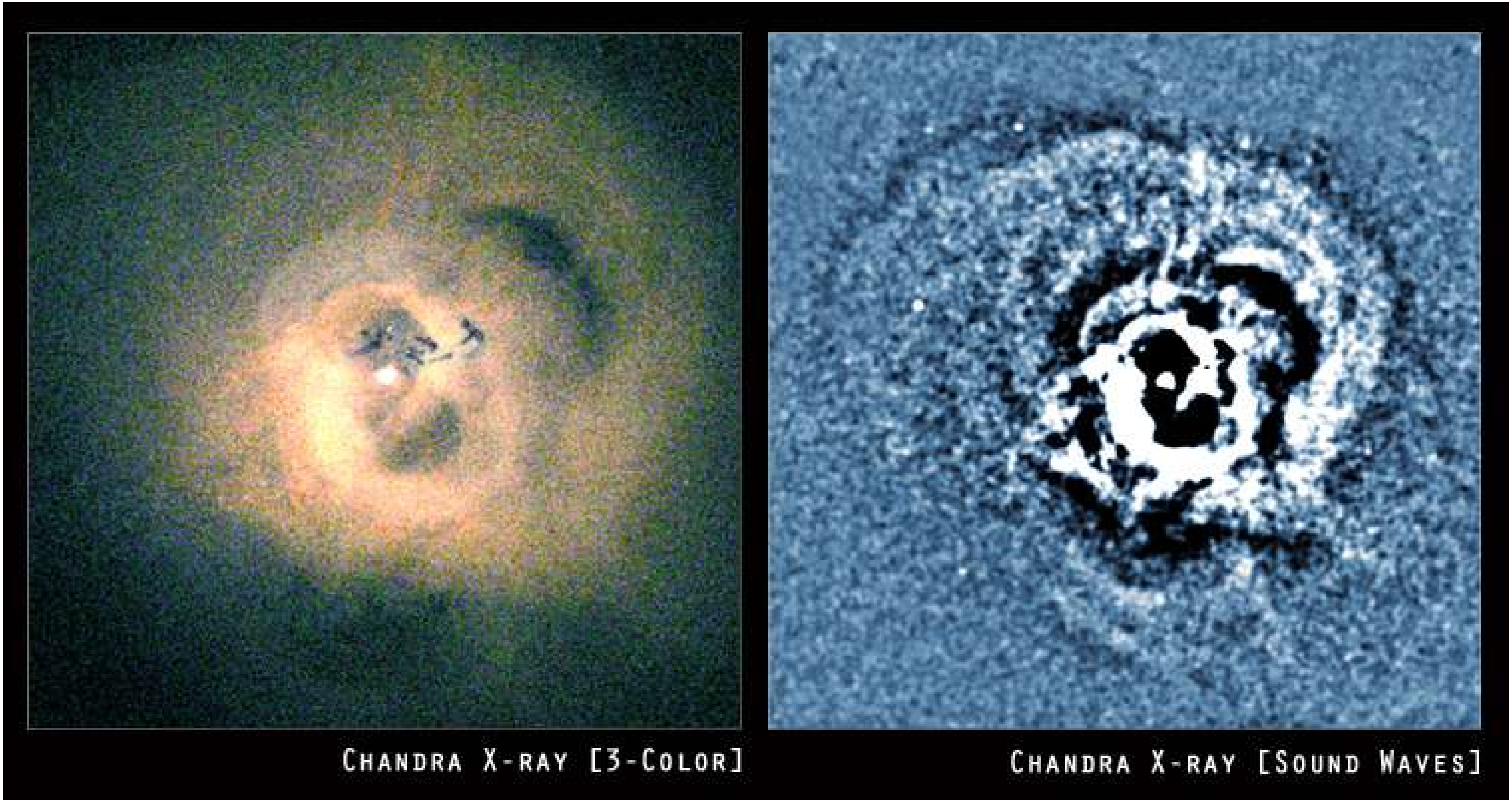
Thus, the true luminosity lies well below the theoretical prediction

A larger data set is needed to explore this important problem further

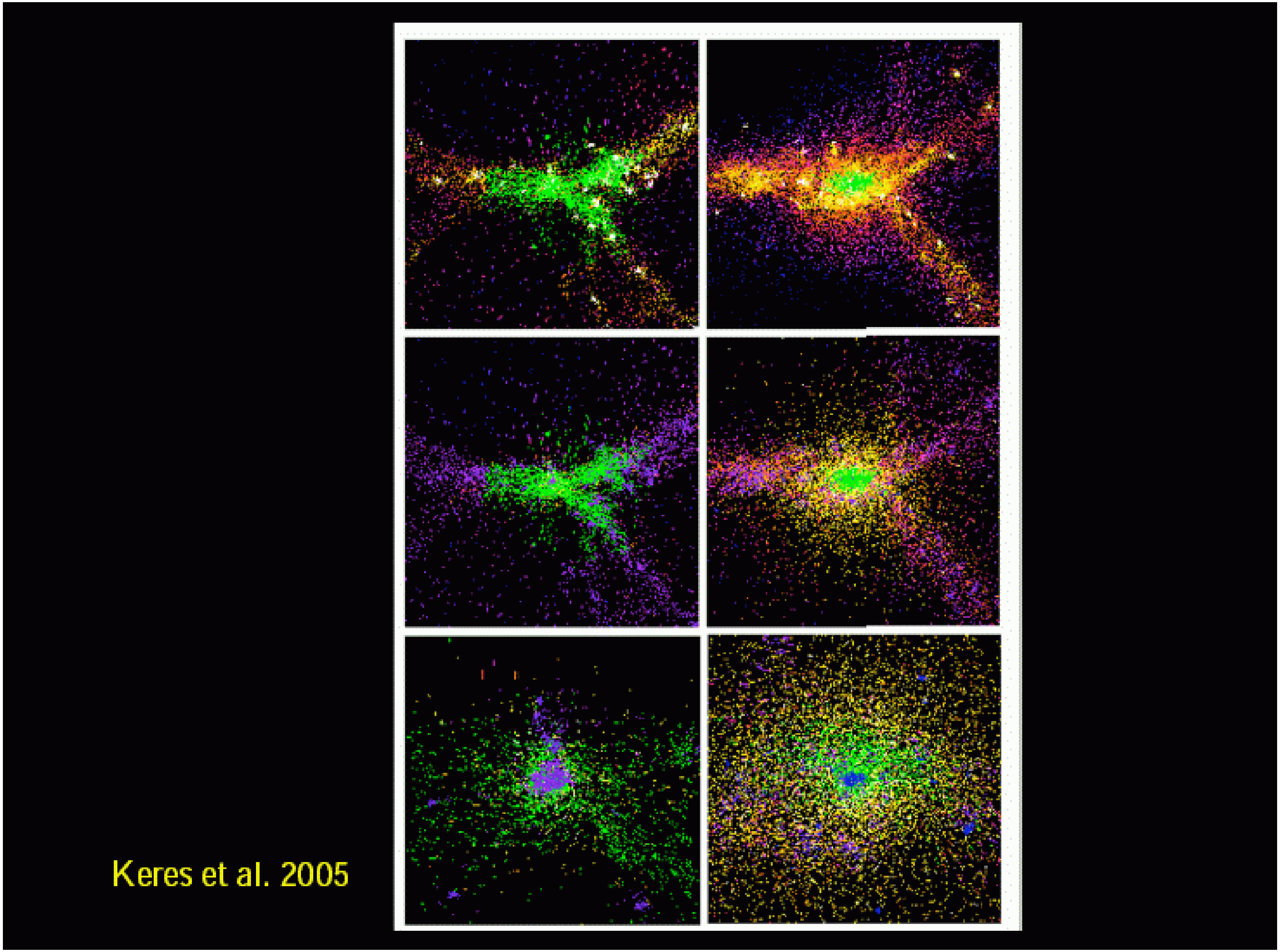
Galaxy	Bg. corr. flux (ring 1) (10^{-14} erg cm^{-2} s^{-1})	Bg. corr. flux (ring 2) (10^{-14} erg cm^{-2} s^{-1})	Bolometric L_X (ring 1) (10^{41} erg s^{-1})	Bolometric L_X (ring2) (10^{41} erg s^{-1})
NGC 2841	5.62 ± 10.33	22.90 ± 19.87	0.03 ± 0.06	0.16 ± 0.13
NGC 4594	17.96 ± 11.33	14.21 ± 22.40	0.44 ± 0.28	0.34 ± 0.54
NGC 5529	5.91 ± 10.03	-2.28 ± 19.22	0.78 ± 1.34	-0.29 ± 2.48

Claimed detection in NGC 5746a: Kristian et al 2006

In clusters, radio AGN can be seen to be heating the gas.
BUT is this the universal solution? Does this form of feedback apply in ALL massive halos??



Cold Accretion as studied in SPH simulations



Cold Accretion in SPH Simulations

Basic Results:

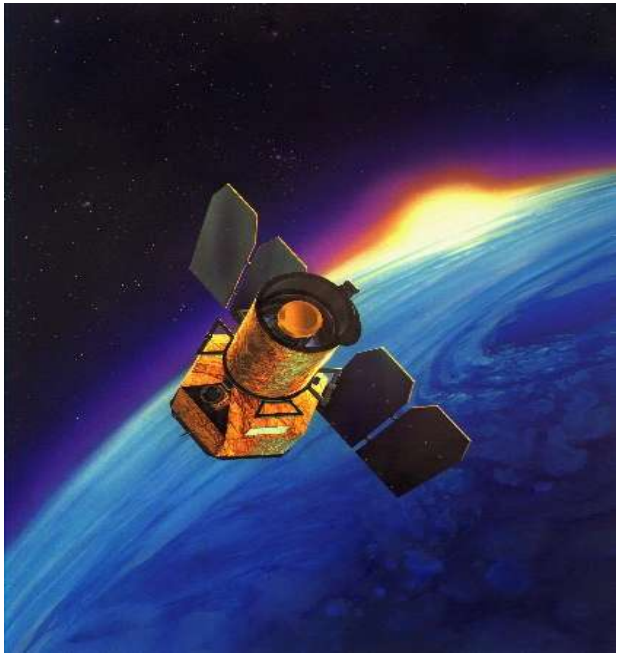
- Bimodal T_{max} distribution. 50% of gas accreted by galaxies never heats above 2.5×10^5 K.
- Cold accretion follows filamentary structures.
- Dominates below $M_{gal} \sim 2 \times 10^{10}\ M_{sun}$, $M_{halo} \sim 5 \times 10^{11}\ M_{sun}$
- Cold and hot modes co-exist in transition range.
- Transition mass is affected by UV background.

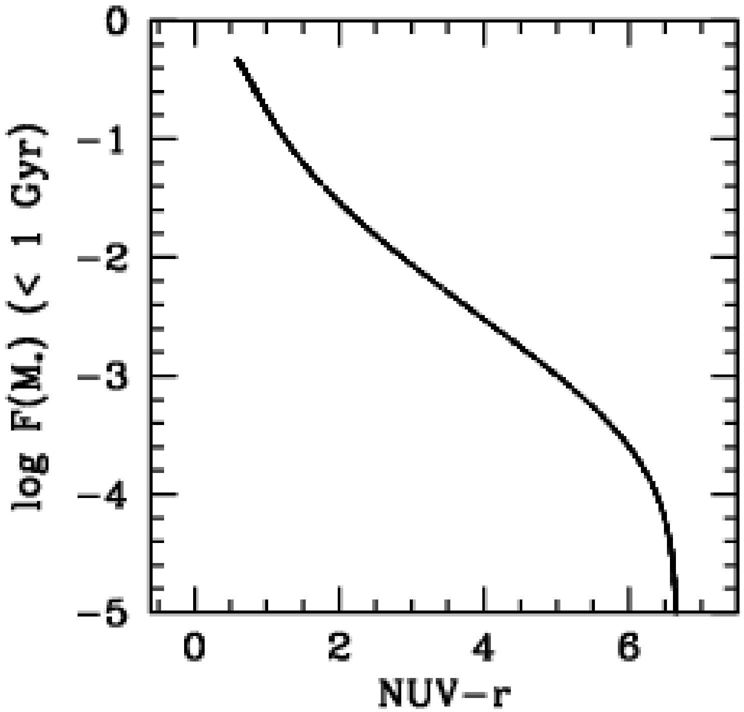
Observational problem: cold accretion very difficult to study with present radio telescopes. **Need Square Kilometer Array!!**

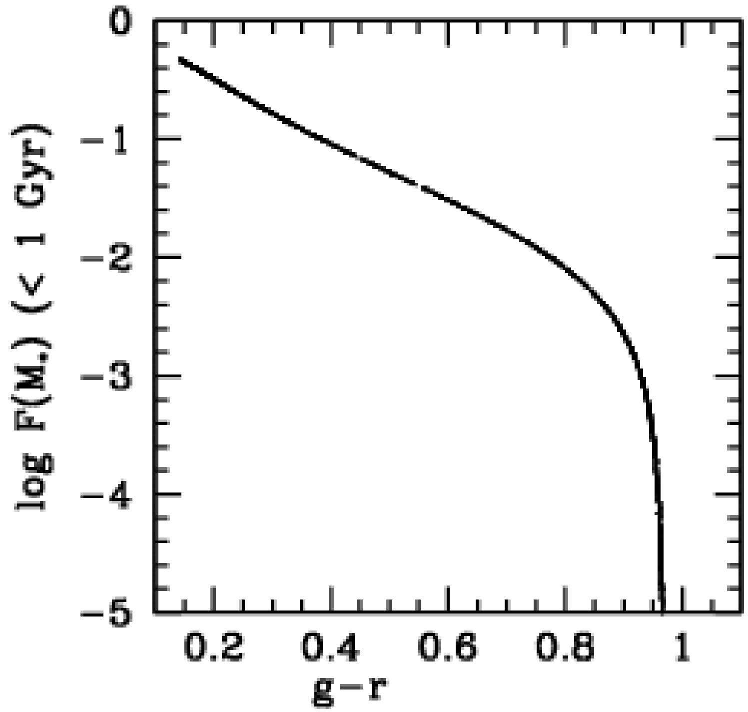
BUT IN THE MEANTIME:

Press release 2005: GALEX discovers “invisible” spiral arms around a galaxy previously believed to be early-type

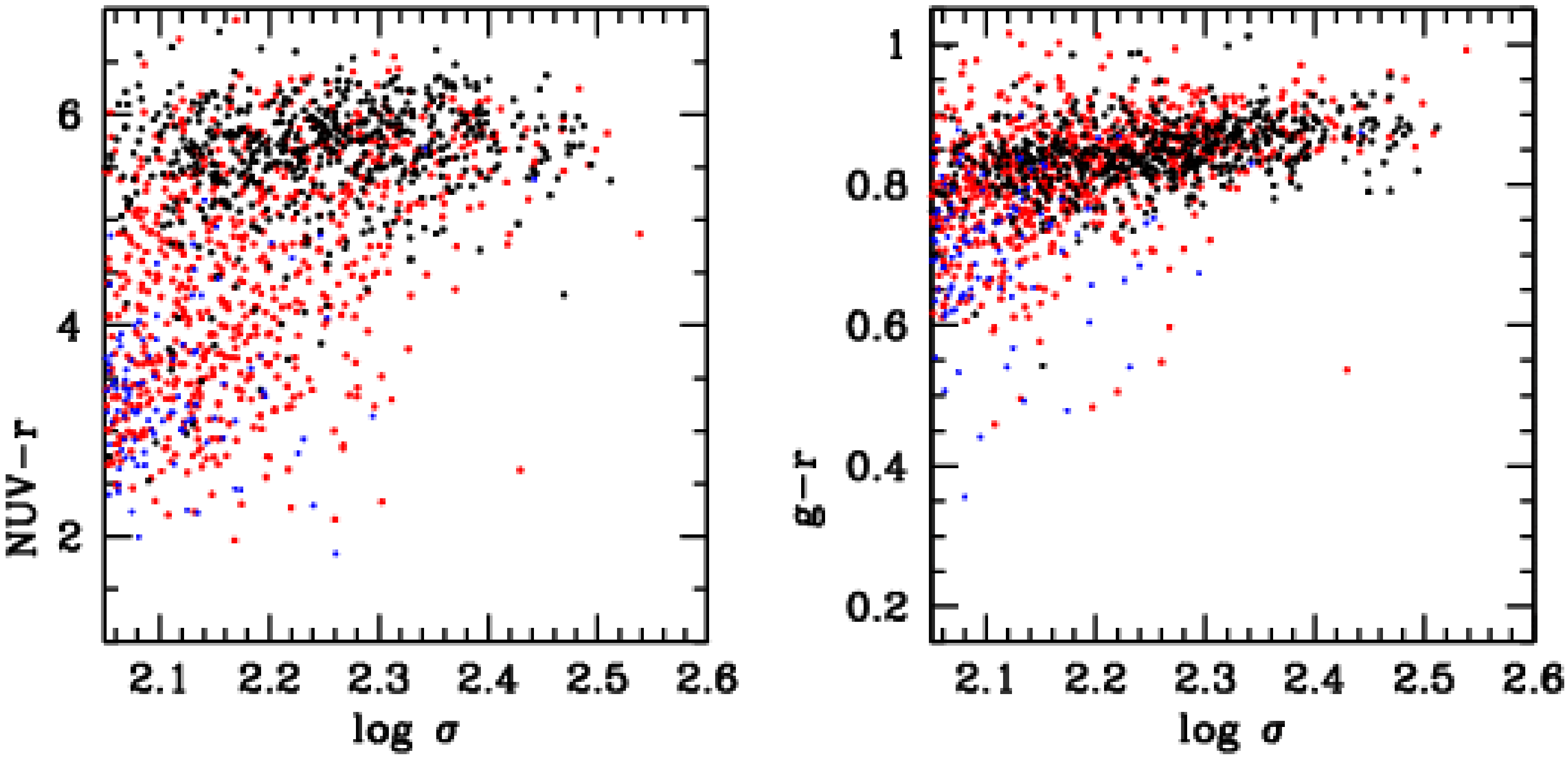
The UV offers greatly enhanced sensitivity to low rates of residual star formation, **but in the absence of dust**





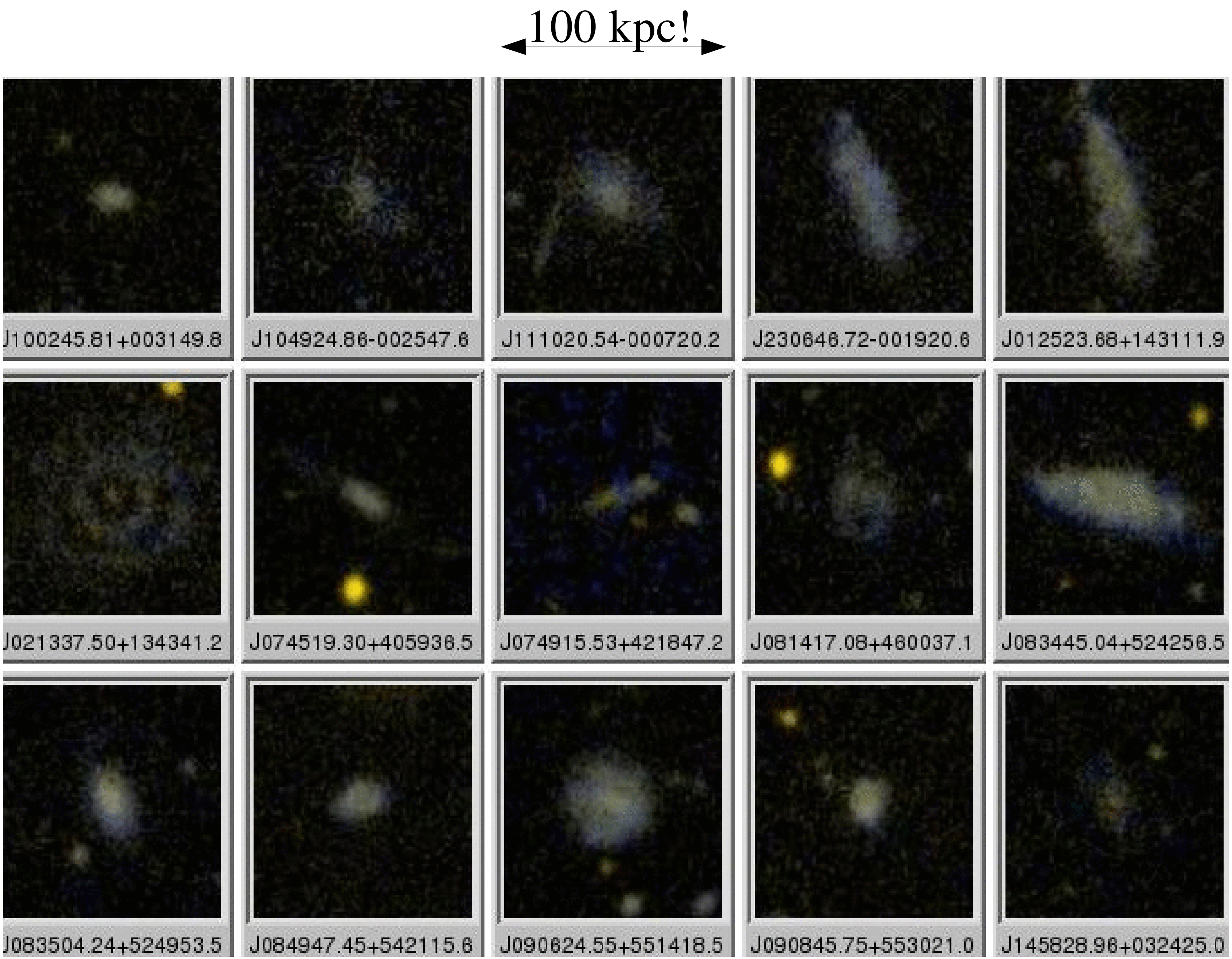


Surprise: Massive, bulge-dominated galaxies exhibit much more scatter in their UV/optical colours. Almost all the UV-bright systems are classified as AGN (by their emission lines).

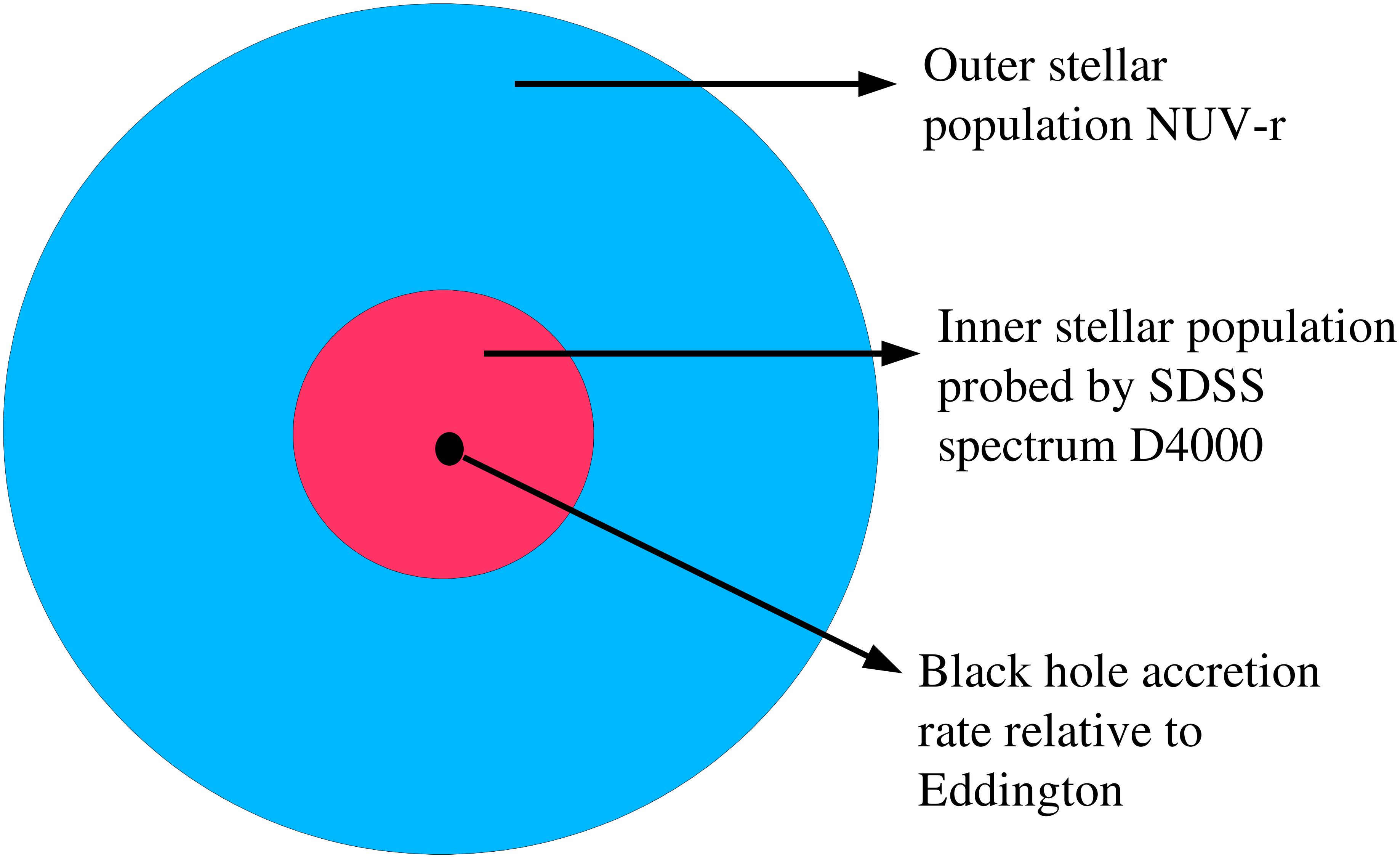


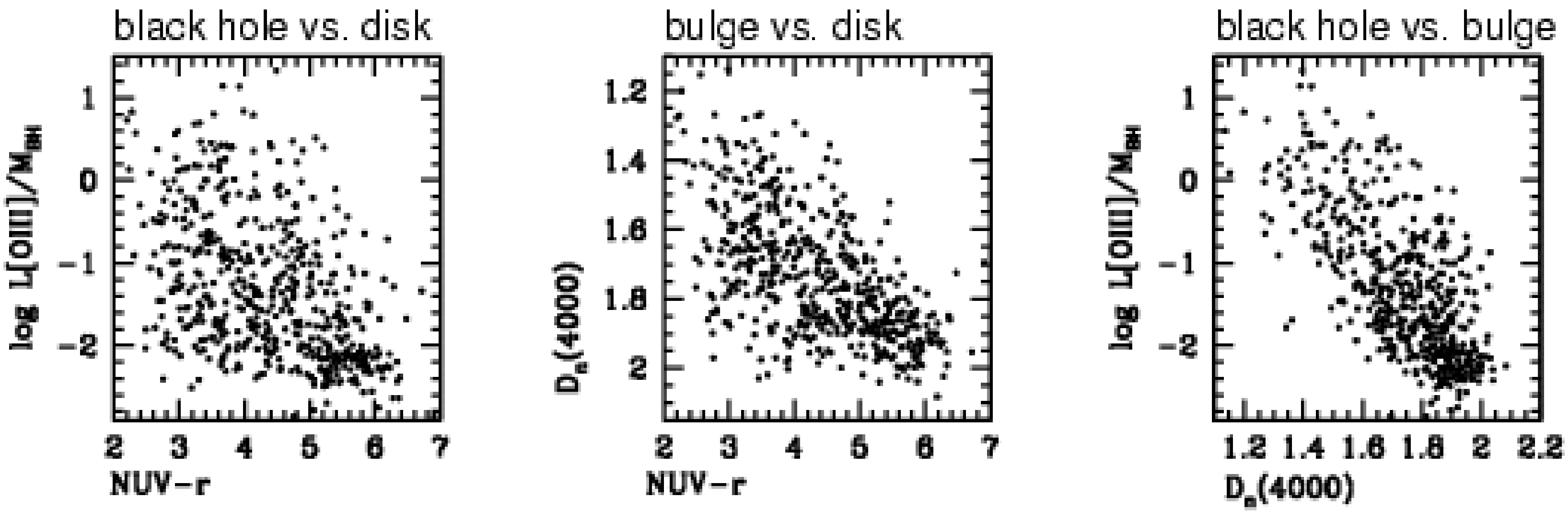
Kauffmann,Heckman + GALEX science team 2006

The UV light is almost always coming from an extended disk



What is the relation between the UV bright outer “disk” and the AGN??





ANSWER:

The UV bright outer stellar population is a NECESSARY BUT NOT SUFFICIENT condition for bulge and black hole growth.

Star formation (and presumably gas) in the bulge is a NECESSARY **AND** SUFFICIENT consition for black hole growth.

STAR FORMATION: For local galaxies, our bedrock is the Schmidt/Kennicutt law, e.g. Springel et al calibrate their multi-phase ISM model to recover the Kennicutt relation

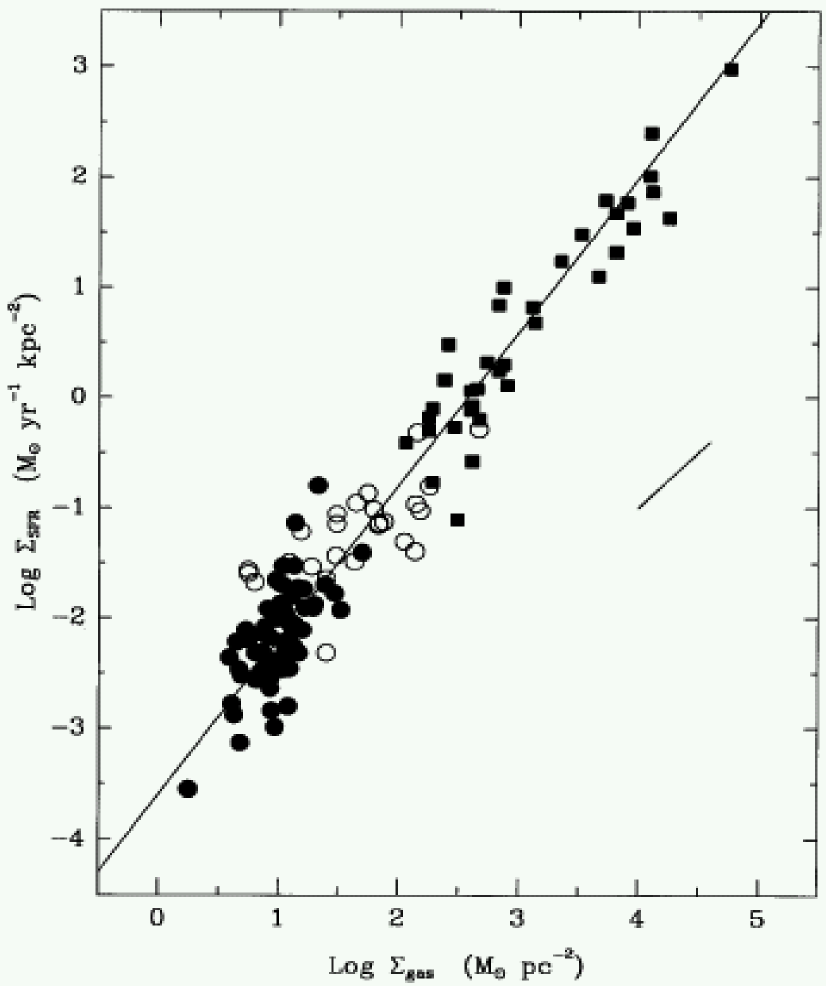


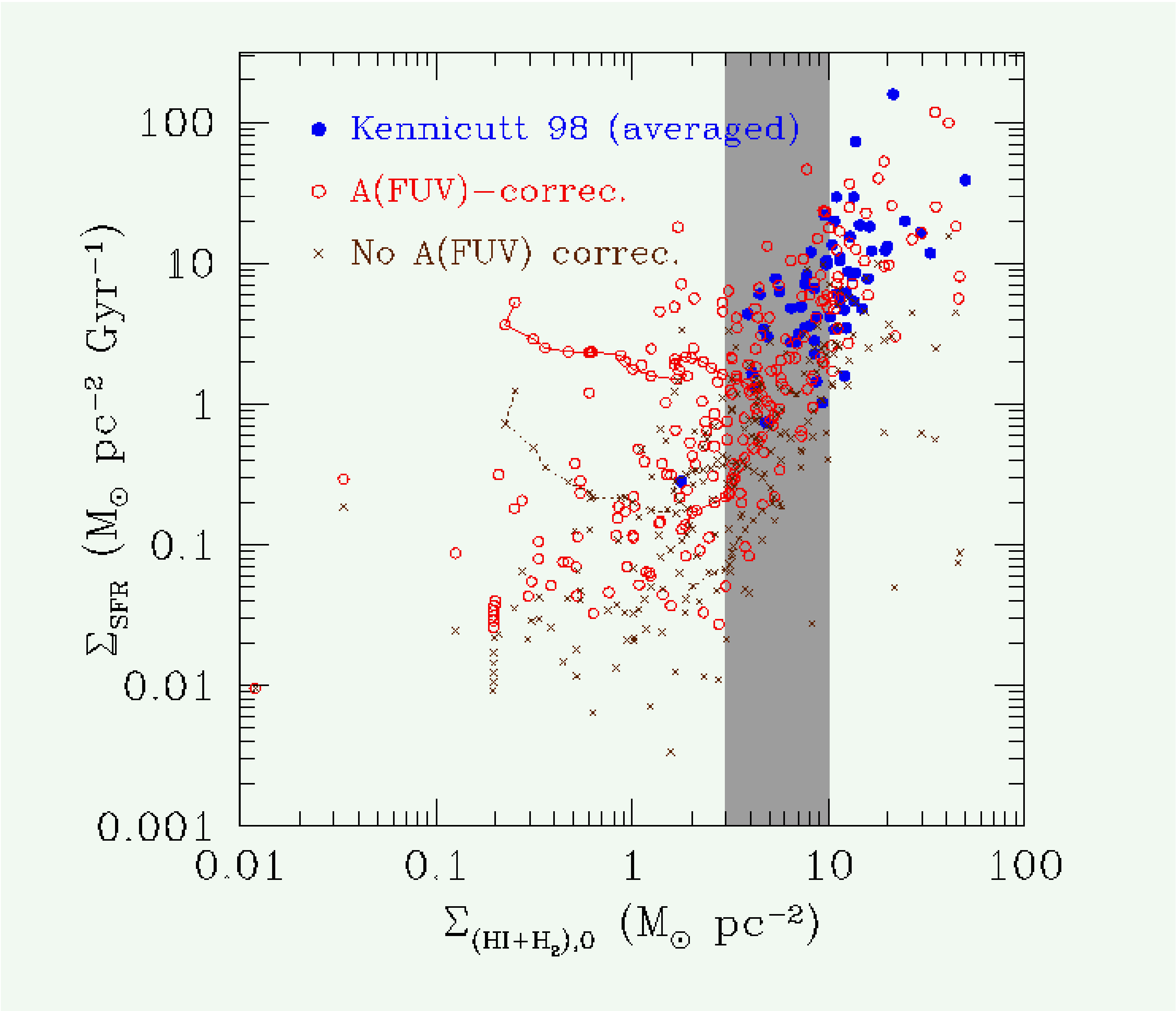
FIG. 6.—Composite star formation law for the normal disk (*filled circles*) and starburst (*squares*) samples. Open circles show the SFRs and gas densities for the centers of the normal disk galaxies. The line is a least-squares fit with index $N = 1.40$. The short, diagonal line shows the effect of changing the scaling radius by a factor of 2.

Questions:

1) What about at high redshifts? (need information about gas to answer this fundamental issue!)

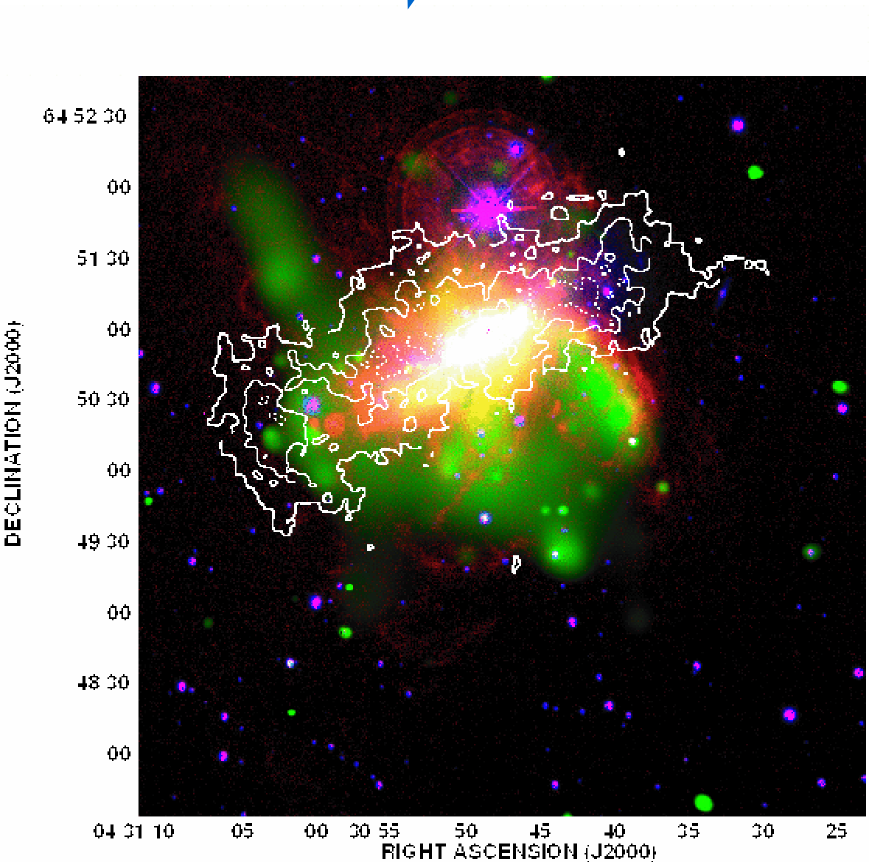
2) Do star formation thresholds really exist?

New analysis of GALEX XUV disks by Boissier et al 2006



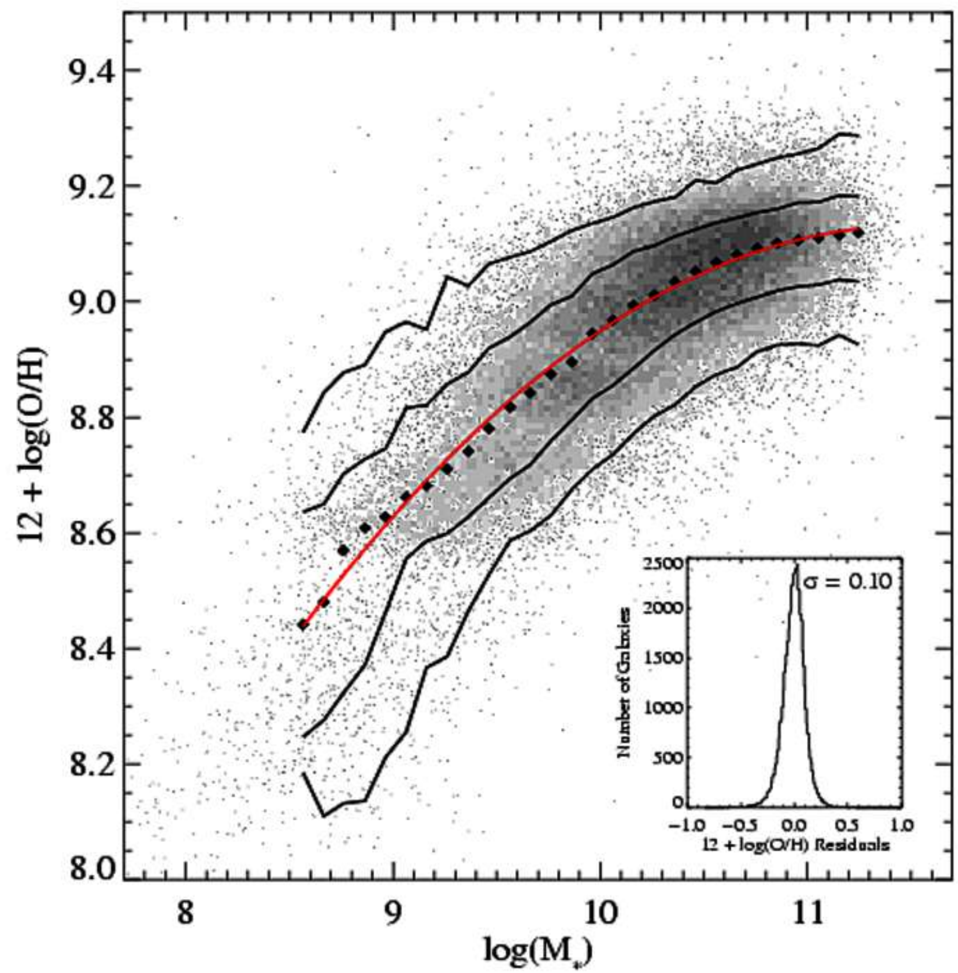
SN FEEDBACK

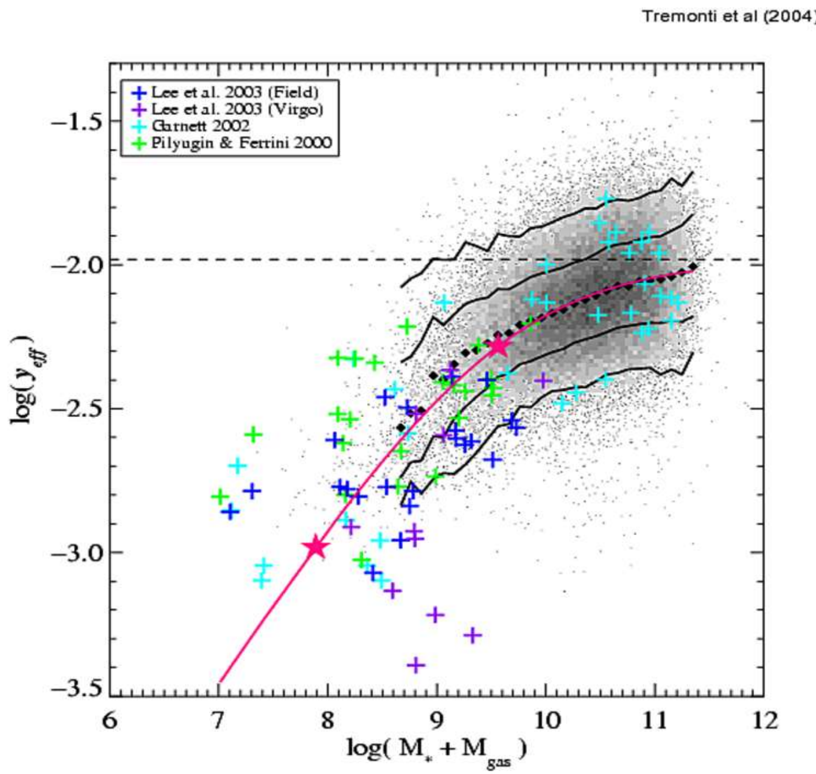
Can we use **THIS** model plus **THIS** relation to infer the total amount of metals that have been ejected from galaxies? This has important implications for the formation of massive galaxies: cooling rates are very sensitive to Z.

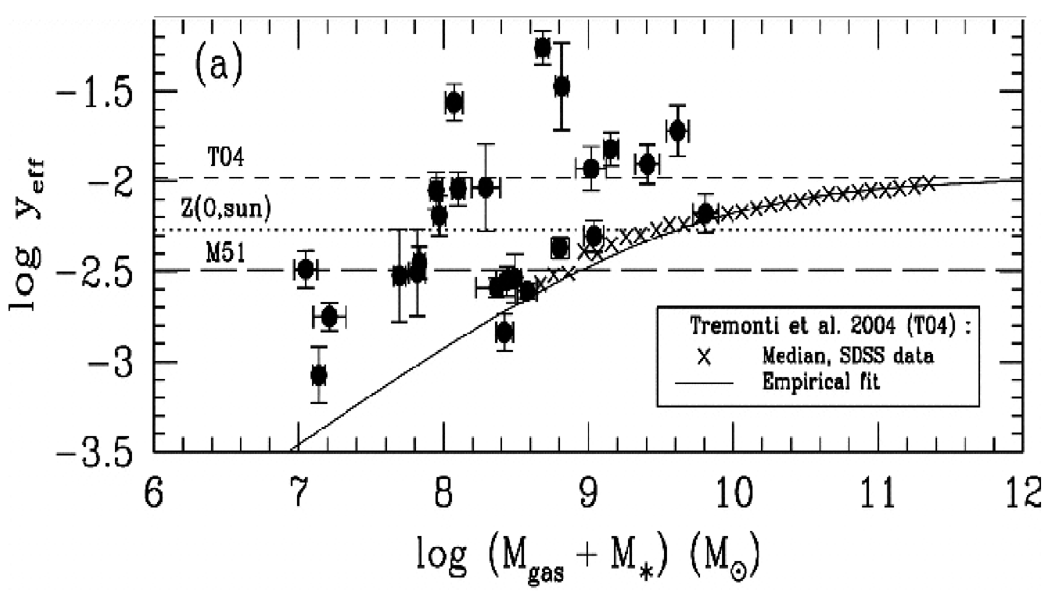


From Crystal Martin

Tremonti et al (2004)





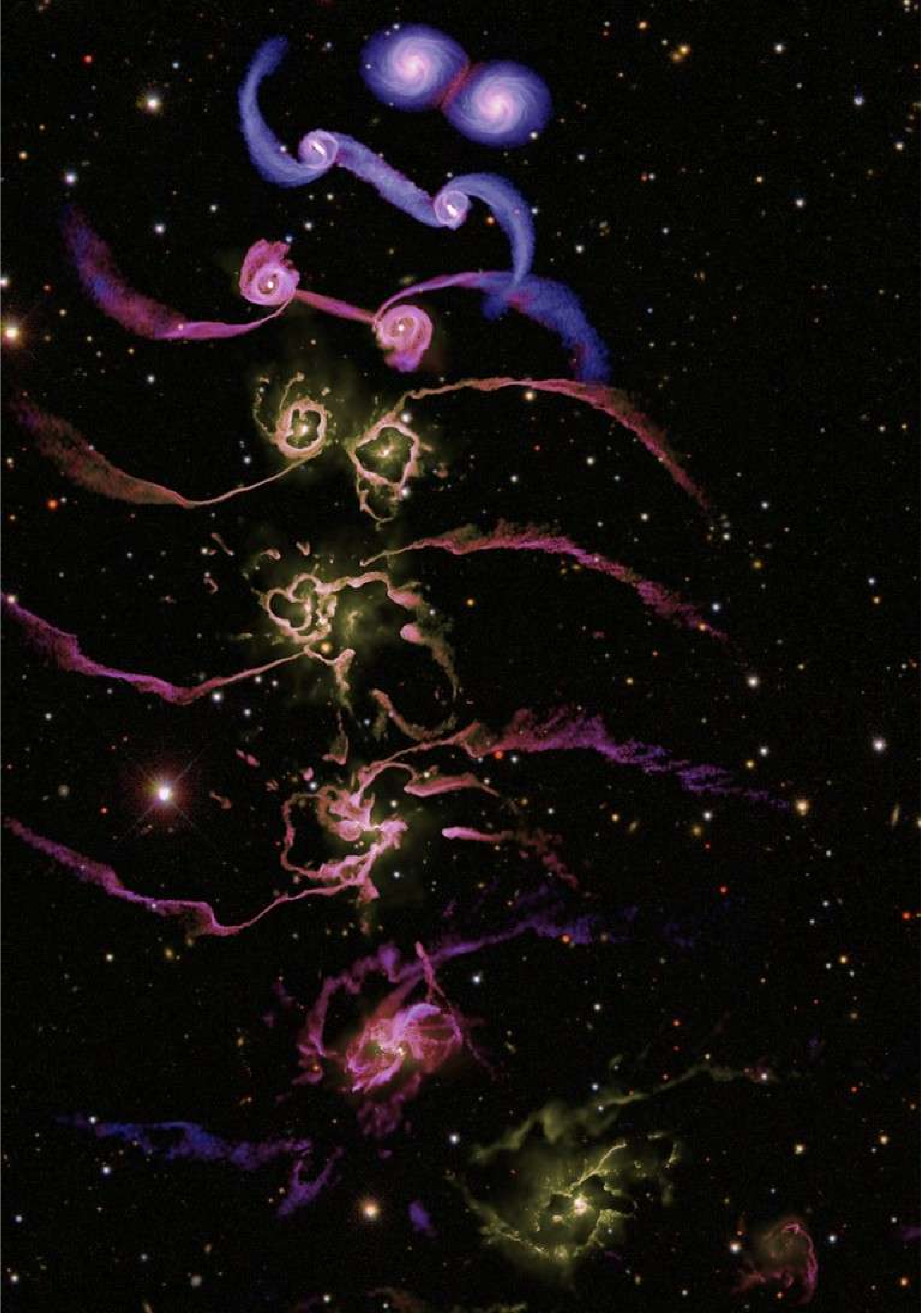


Problem not yet solved?

Tremonti et al (2004) claim to show that the effective yield decreases at low stellar masses, implying that metals have been ejected.

Lee et al (2006) find higher values and bigger scatter for their sample of dwarfs.

Observational roadblock: information about total **gas mass** for COMPLETE samples!



BULGES AND BLACK HOLES

Does the bulk of black hole growth in the Universe occur during major mergers?

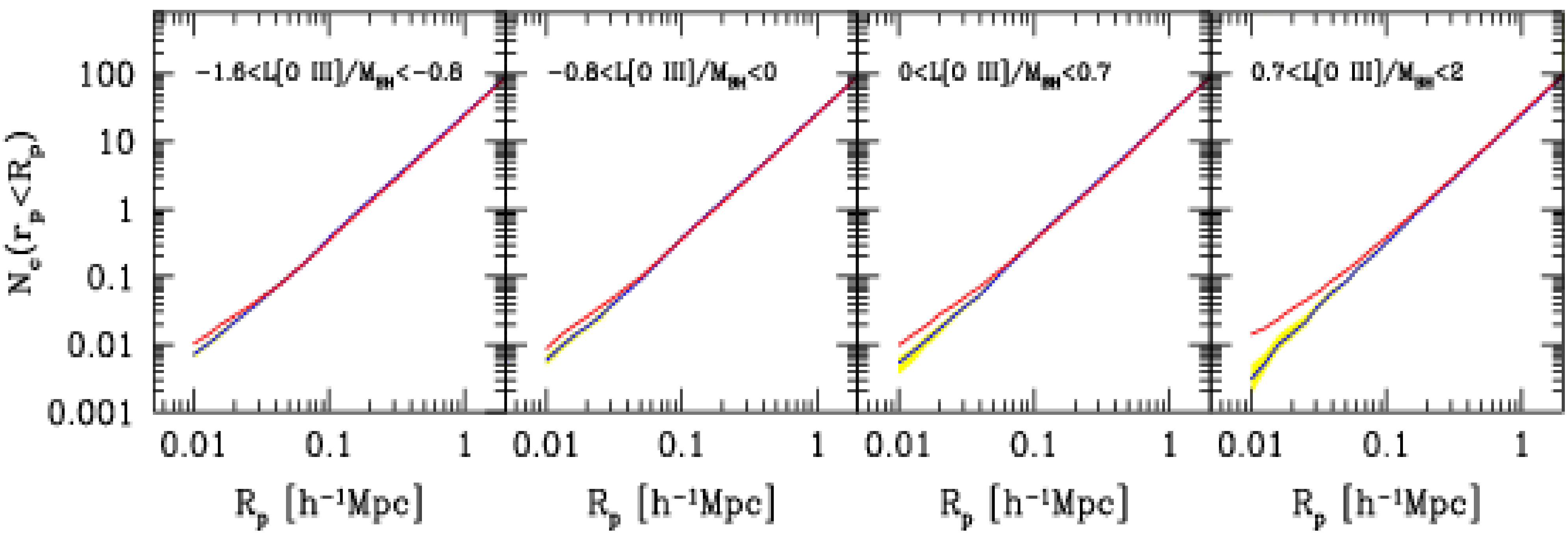
(subtitle: is the movie correct?)

In the nearby Universe, most studies have found that there is no convincing link between optical AGN activity and major mergers.

What about at higher redshift??

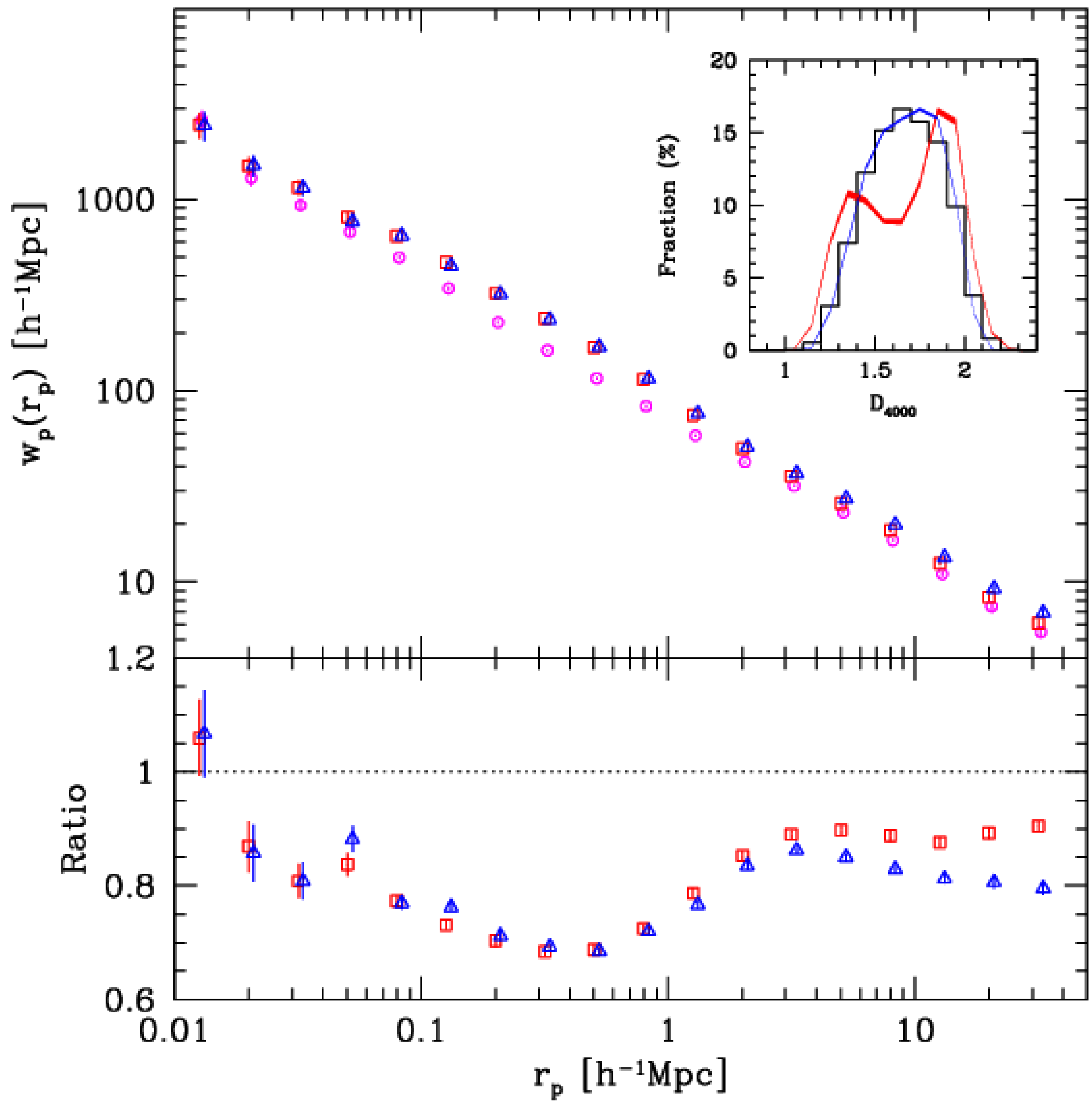
Springel, Di Matteo, Hernquist 2005

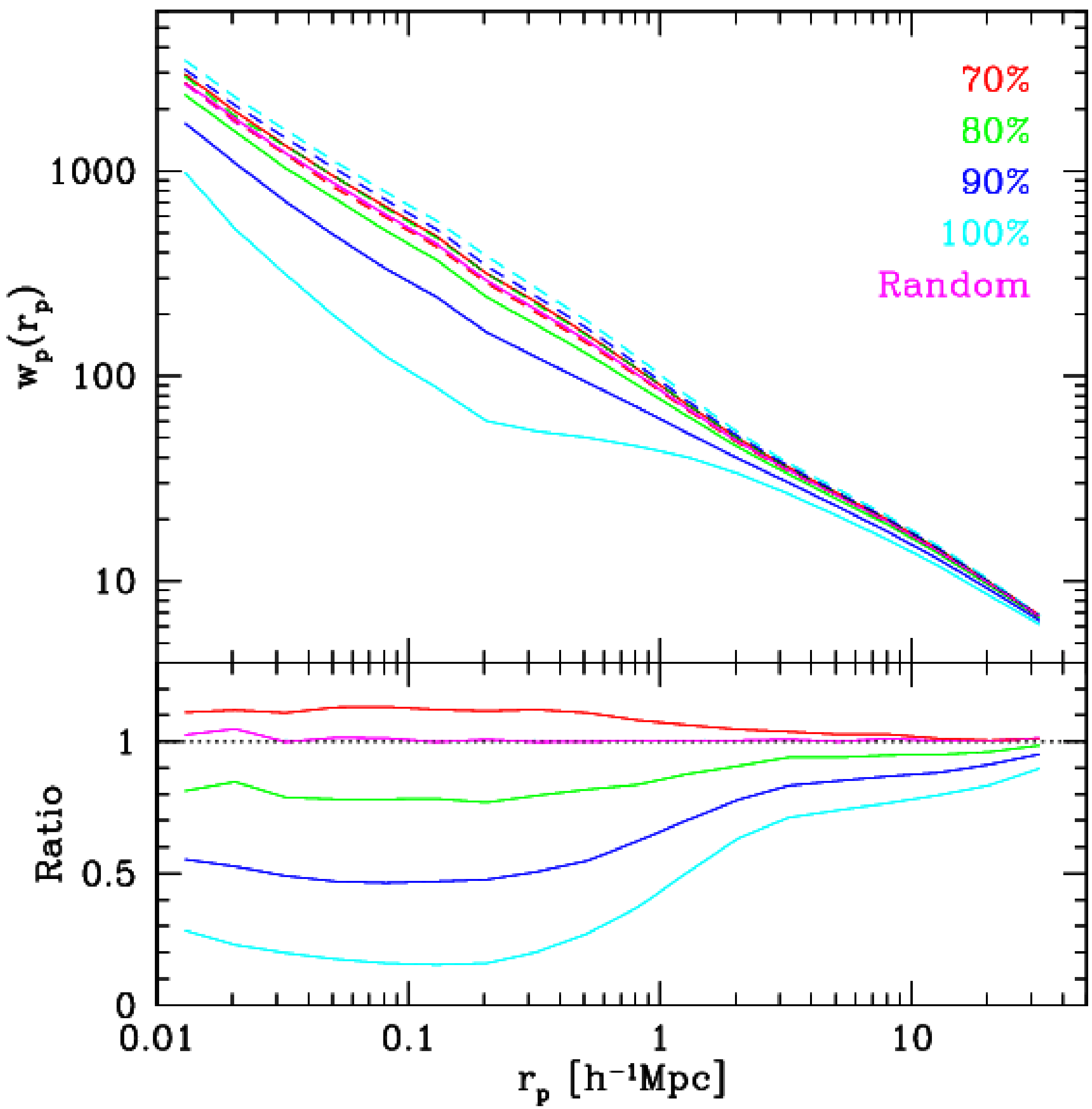
Counts around AGN in bins of accretion rate



Cheng Li et al 2006

The most striking result from the clustering analysis is that AGN exhibit a DEFICIENCY of neigbours on scales between 0.1 and 1 Mpc compared to the control sample.

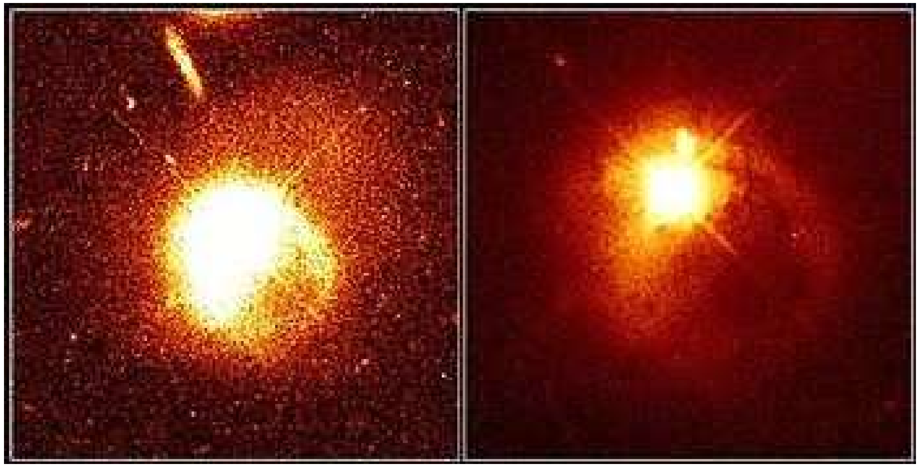


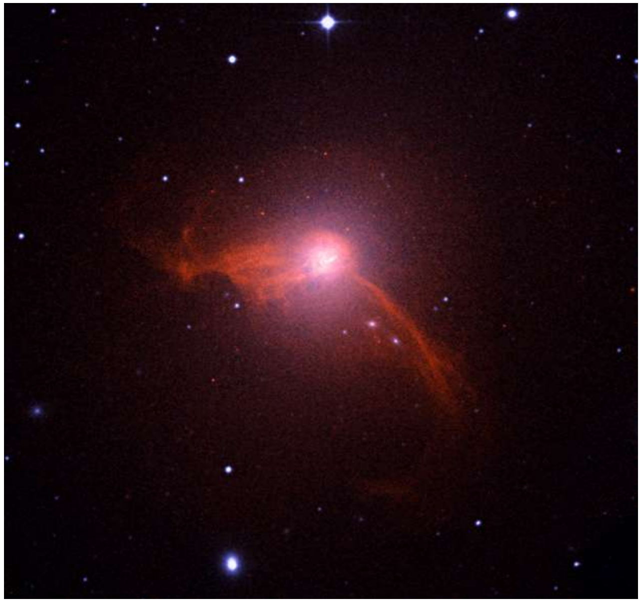


We show (see Li et al 2006) that this result is consistent with a model in which AGN are preferentially located at the centres of their own dark matter halos;

this is consistent with the idea that **gas cooling/ cold gas accretion** plays a vital role in maintaining ongoing AGN activity in galaxies. A violent trigger (e.g. major mergers) may not be required in order to produce substantial black hole growth....

Are there separate and distinct "quasar" and "radio" modes of AGN activity? If so, which mode has more influence on the evolution of massive galaxies?

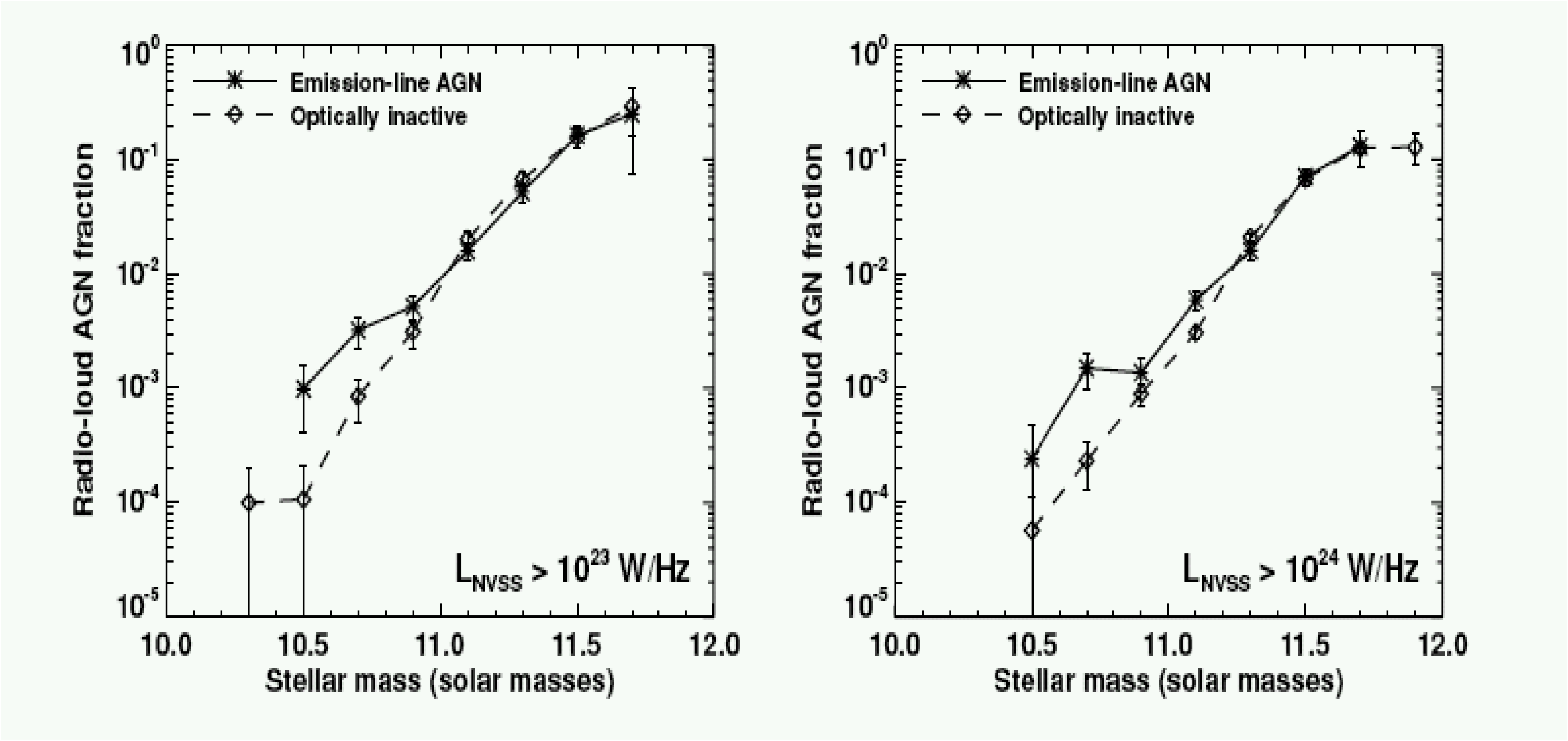


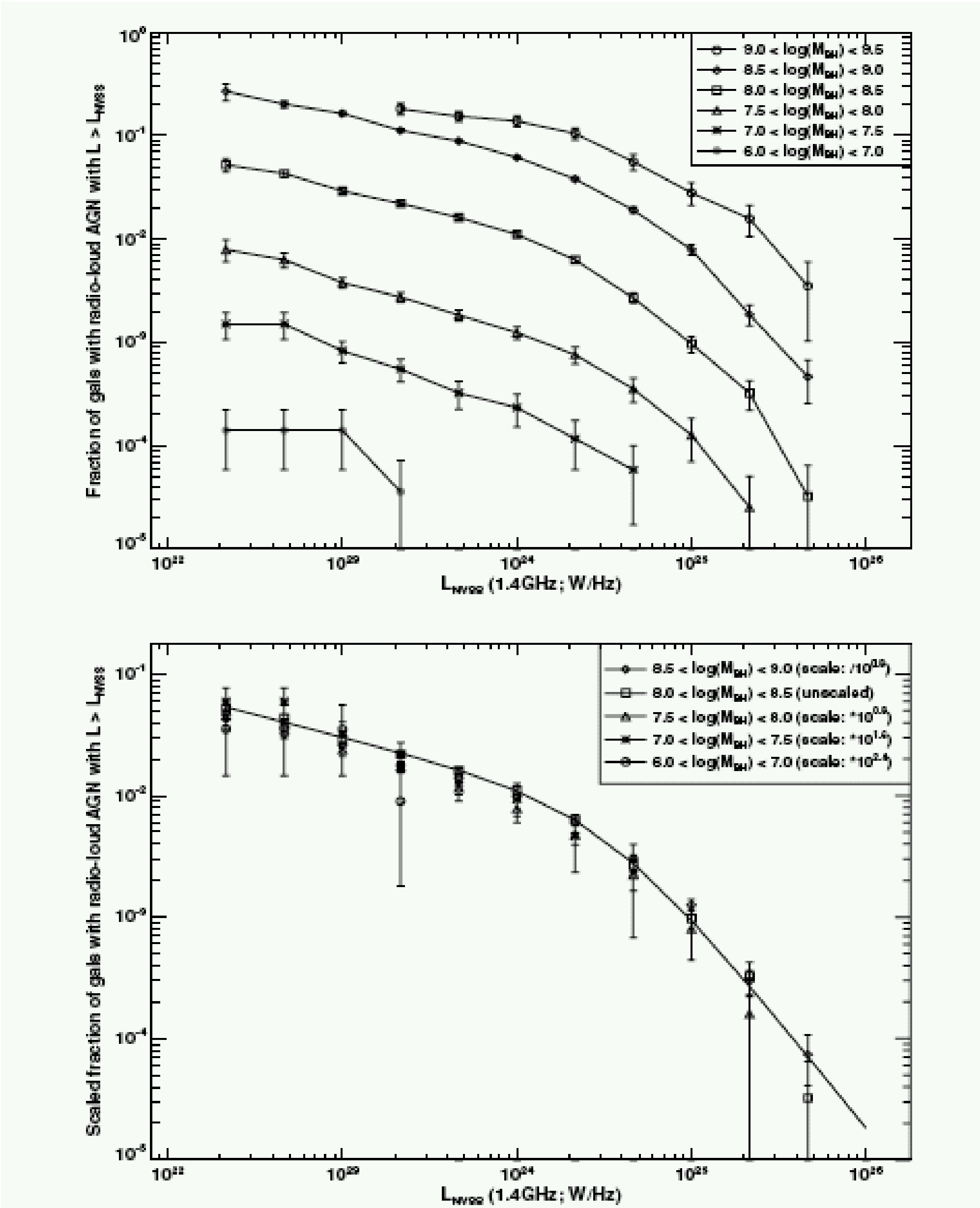


Croton et al 2006; radio AGN feedback is instrumental in explaining colour bimodality

Hopkins et al 2005;2006a,b,c,d,e,f,g,h: quasar mode rules!

Best et al (2005) have shown that in the Local Universe, the radio and optical AGN are **INDEPENDENT** physical phenomena.

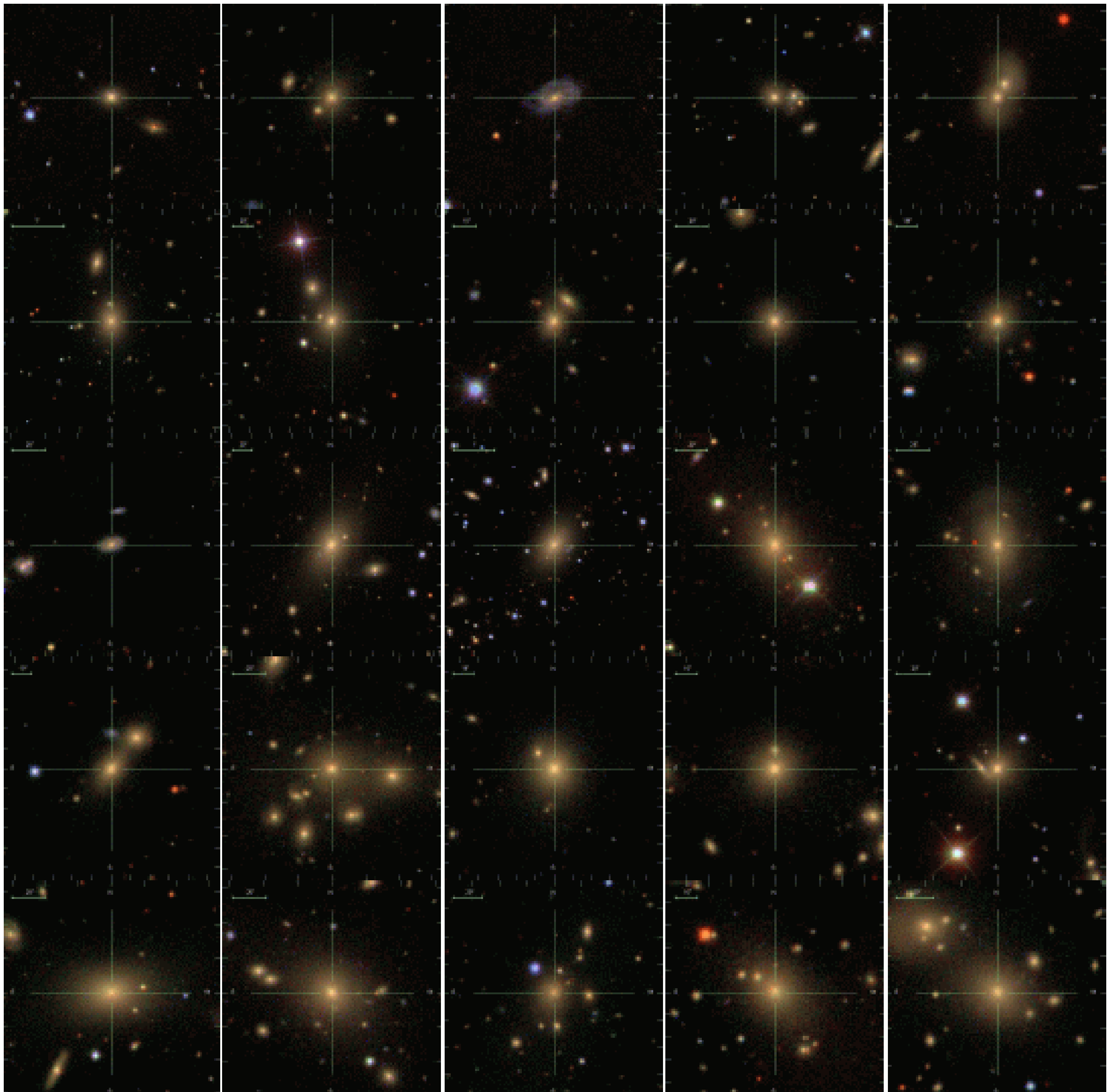




The **probability** that a galaxy is radio-loud is a strongly increasing function of black hole mass.

However, the **distribution** of radio luminosities is **independent** of black hole mass.

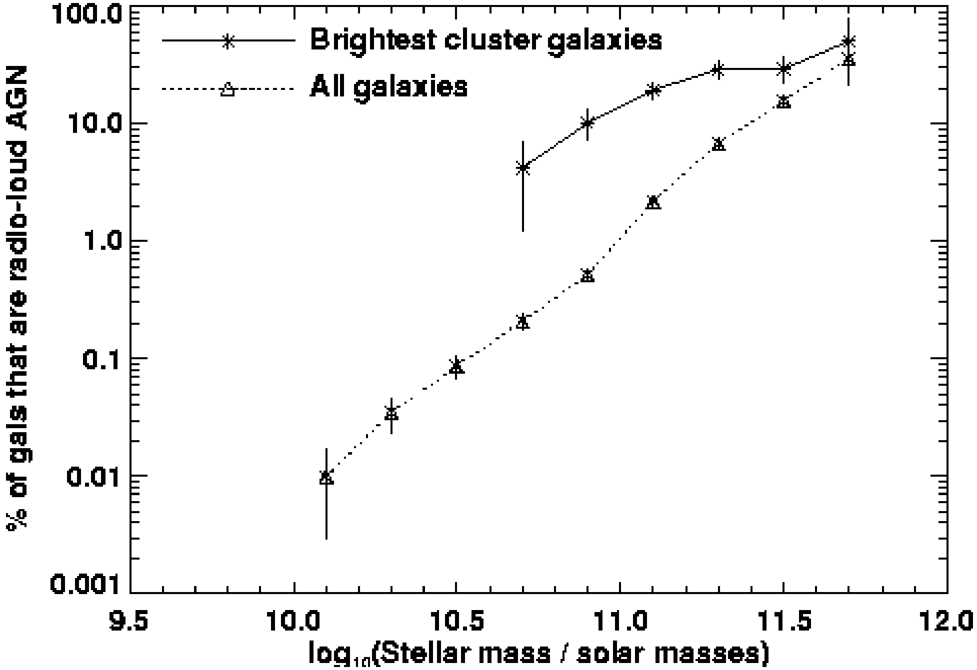
This work has now been extended to a sample of 625 brightest group and cluster galaxies from the SDSS



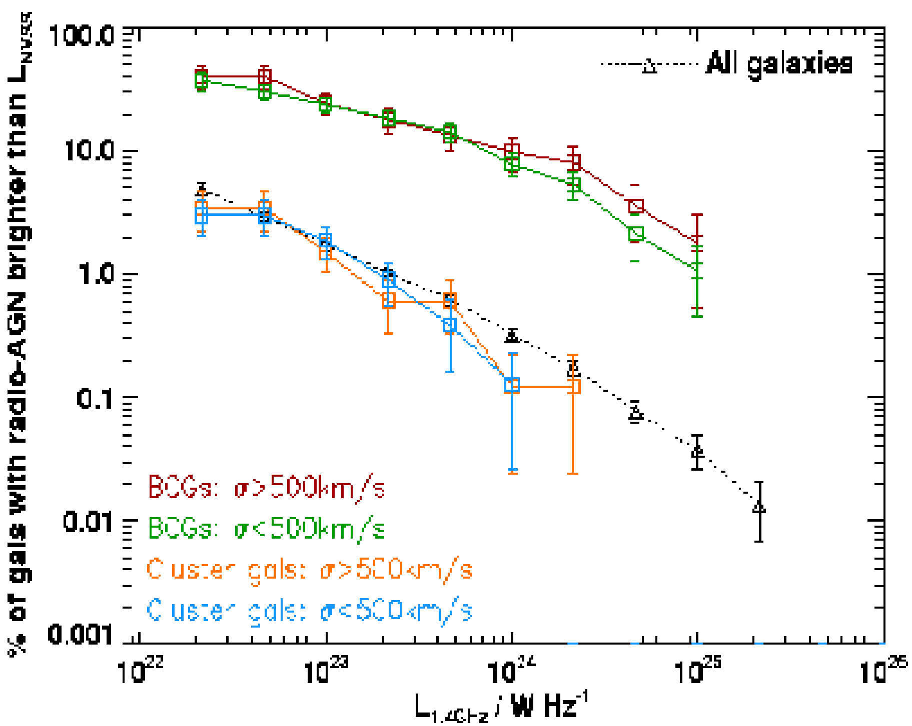
Von der Linden et al 2006 (Paper I)

Best et al 2006 (Paper II)

Out on astro-ph next week.



The fraction of radio loud AGN is significantly boosted in central group and cluster galaxies relative to field galaxies of the same mass.



However, the **distribution** of radio luminosities is always the same!!

Best et al compute the time-averaged heating rate associated with radio AGN as a function of dark matter halo mass, and ask whether this can balance cooling.

ANSWER: not simultaneously in dark matter halos of all masses.

If it works in clusters, the groups will be **over-heated**...

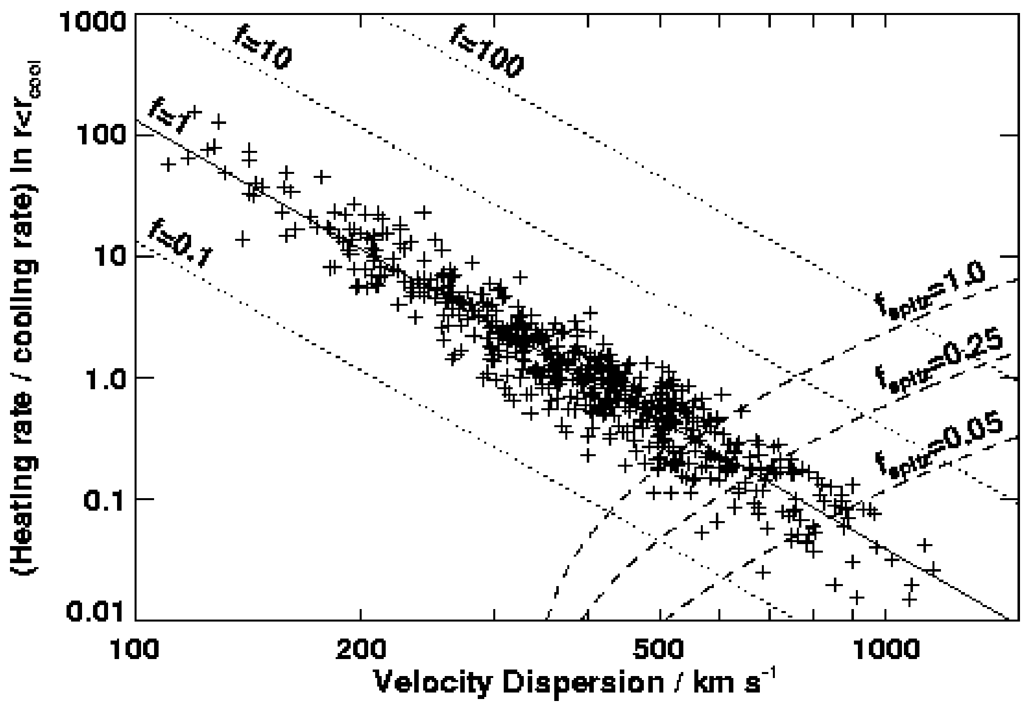


Figure 14. The data points show the ratio of the time–averaged heating rate associated with radio–loud AGN activity of all galaxies within the cooling radius, assuming $f = 1$ in Equation 4, to the radiative cooling losses within the cooling radius, as a function of cluster velocity dispersion. The solid line through these points,

So what is going on at high redshifts?

Radio galaxies at redshift 2

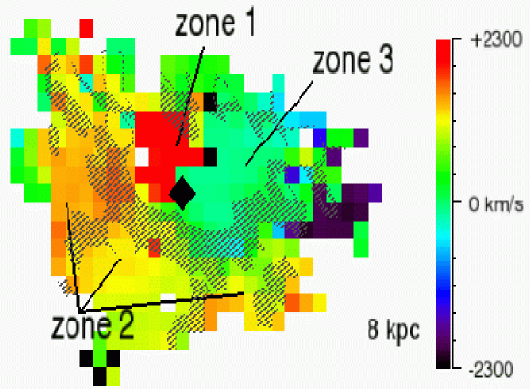
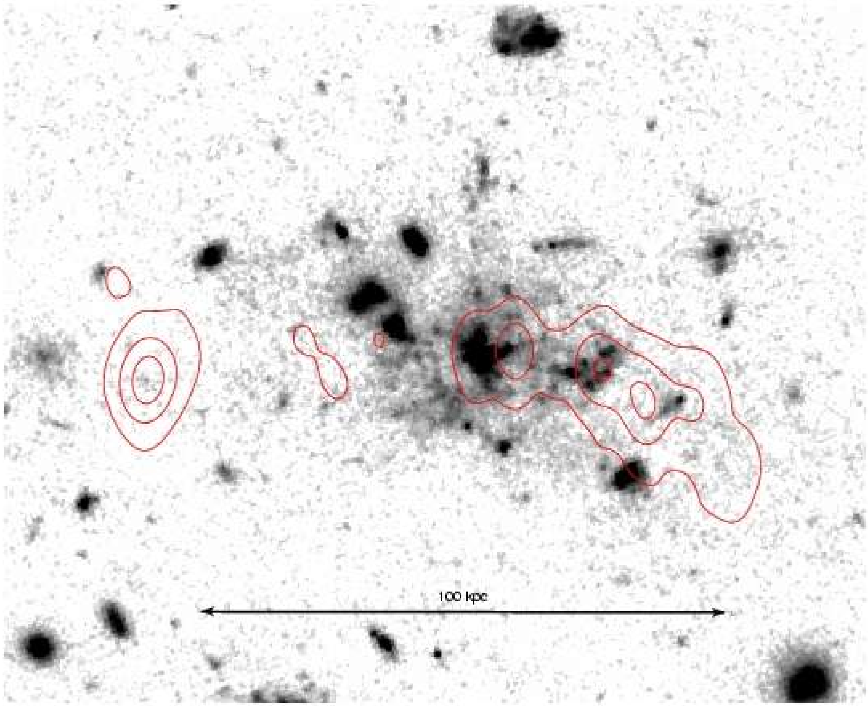


Fig. 3.— The map of relative velocities observed in MRC1138-262 from fitting the [OIII]λ5007 emission line. North is up, east to the left. The zero velocity is defined to be that of the highest surface brightness [OIII]λ5007 line emission. The coding is given in the color bar and the units are km s^{-1}. The hatched area shows the "ring" of broad (FWHM$\geq$ 1400 km s^{-1}) emission lines around zones 1 and 2. The diamond indicates the position of the AGN.



Outflow? Nesvadba et al 2006

Infall? Miley et al 2006