Hydrodynamical and gravitational effects on elliptical galaxies in galaxy clusters

- Ram-pressure stripping effects on the growth of SMBH and AGN feedback. (arXiv:1003.1108)
- Dynamically interacting radio galaxies and their AGN feedback effects.

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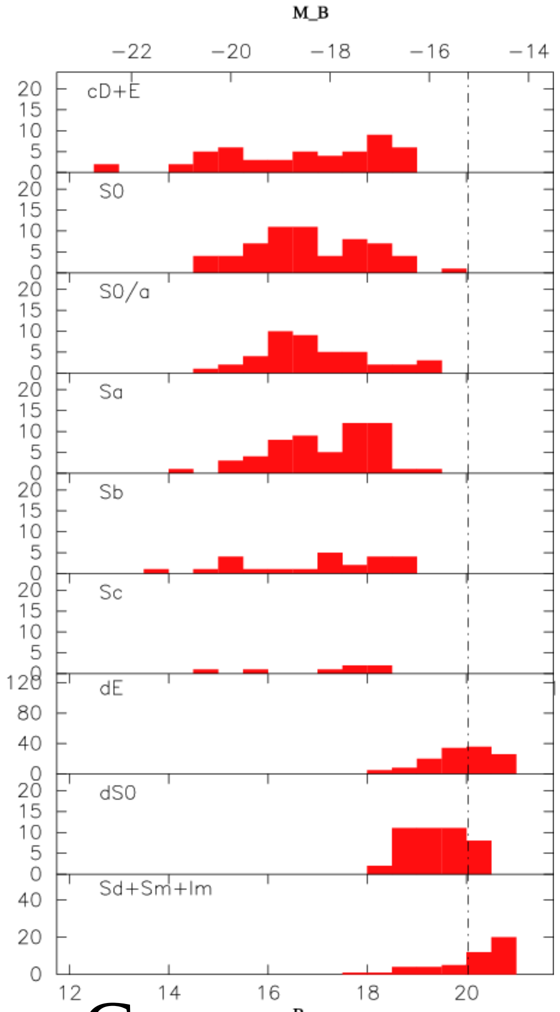
I. Ram-pressure stripping and AGN feedback

- SMBHs have strong correlations with various properties of elliptical galaxies.

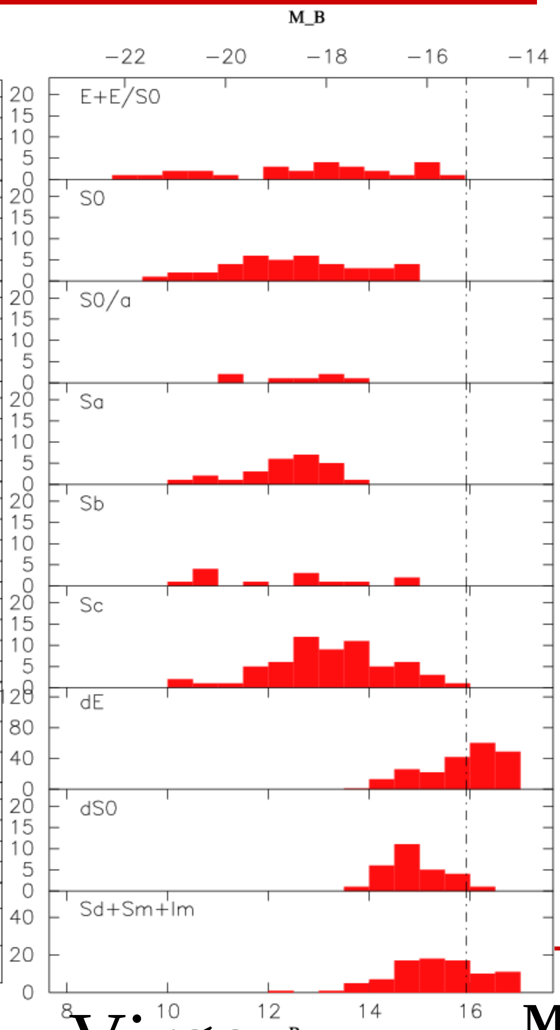
- Local environment can affect galaxy evolution by mergers, ram-pressure stripping, tidal stripping, etc.

Q. How does galaxy environment such as gas stripping alter co-evolution of the SMBH and its host galaxy?

Observations show…

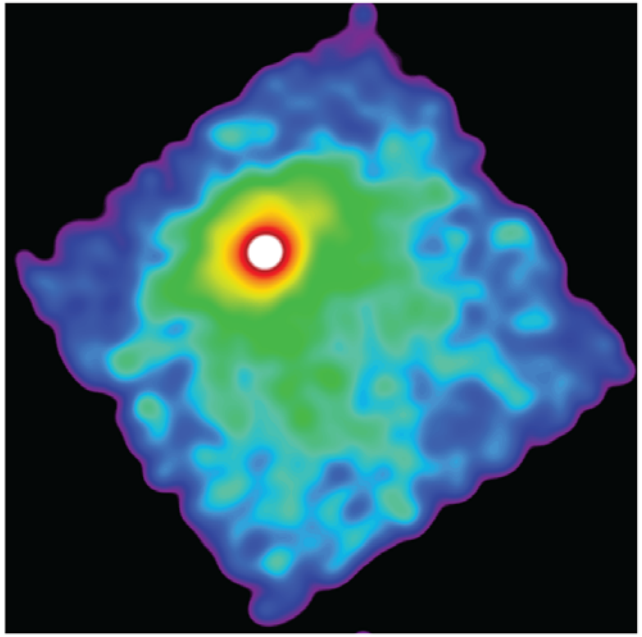


Coma



Virgo

Michard & Andreon 08



NGC 7619, Kim et al. 08

AGN feedback effects

- Both radiative and mechanical feedback effects are included with different truncation radii in 1D simulations. (Luca et al. 10, Shin et al. 10, and Novak et al. 10)

$$L_{\rm BH} = \epsilon_{\rm EM} \dot{M}_{\rm BH} c^2$$

$$\epsilon_{\rm EM} = \epsilon_0 \frac{A\dot{m}}{1 + A\dot{m}},$$

$$\dot{m} = \dot{M}_{\rm BH}/\dot{M}_{\rm Edd}$$

$$\epsilon_0 = 0.1$$

(10% radiative conversion in quasar-mode accretion)

$$L_{\rm dw} = \epsilon_{\rm w} \dot{M}_{\rm BH} c^2 + \epsilon_{\rm II} c^2 (1 - f_{\rm rem,h}) \frac{M_{\rm dh*}}{\tau_{*\rm h}}$$

$$\epsilon_{\rm w} \equiv \frac{3\epsilon_{\rm w}^{\rm M}}{4} \frac{l}{1 + 0.25 l}$$

$$l \equiv \frac{L_{\rm BH}}{L_{\rm Edd}} = \frac{A\dot{m}^2}{1 + A\dot{m}}$$

$$\epsilon_{\rm w}^{\rm M} = 3 \times 10^{-4}$$

$$\eta_{\rm w} \equiv \frac{3\eta_{\rm w}^{\rm M}}{4} \frac{l}{1 + 0.25 l} \qquad \eta_{\rm w}^{\rm M} = 1800 \epsilon_{\rm w}^{\rm M}$$

(mass loss coupling to the feedback efficiency)

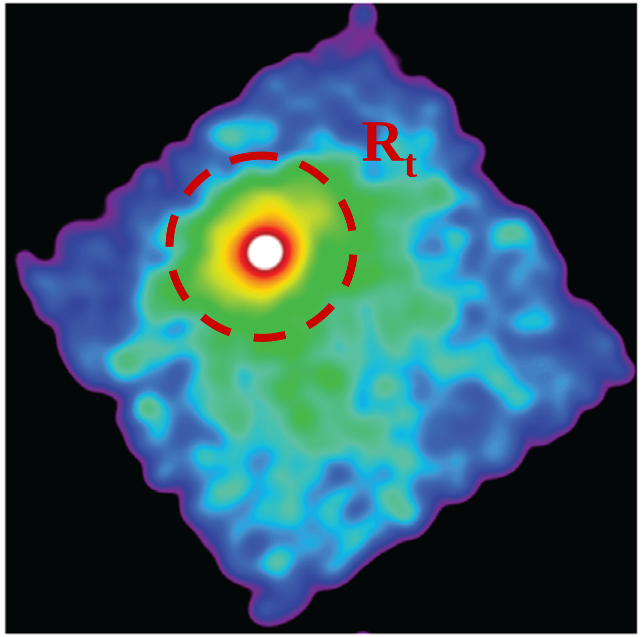
Radiative energy

Mechanical energy

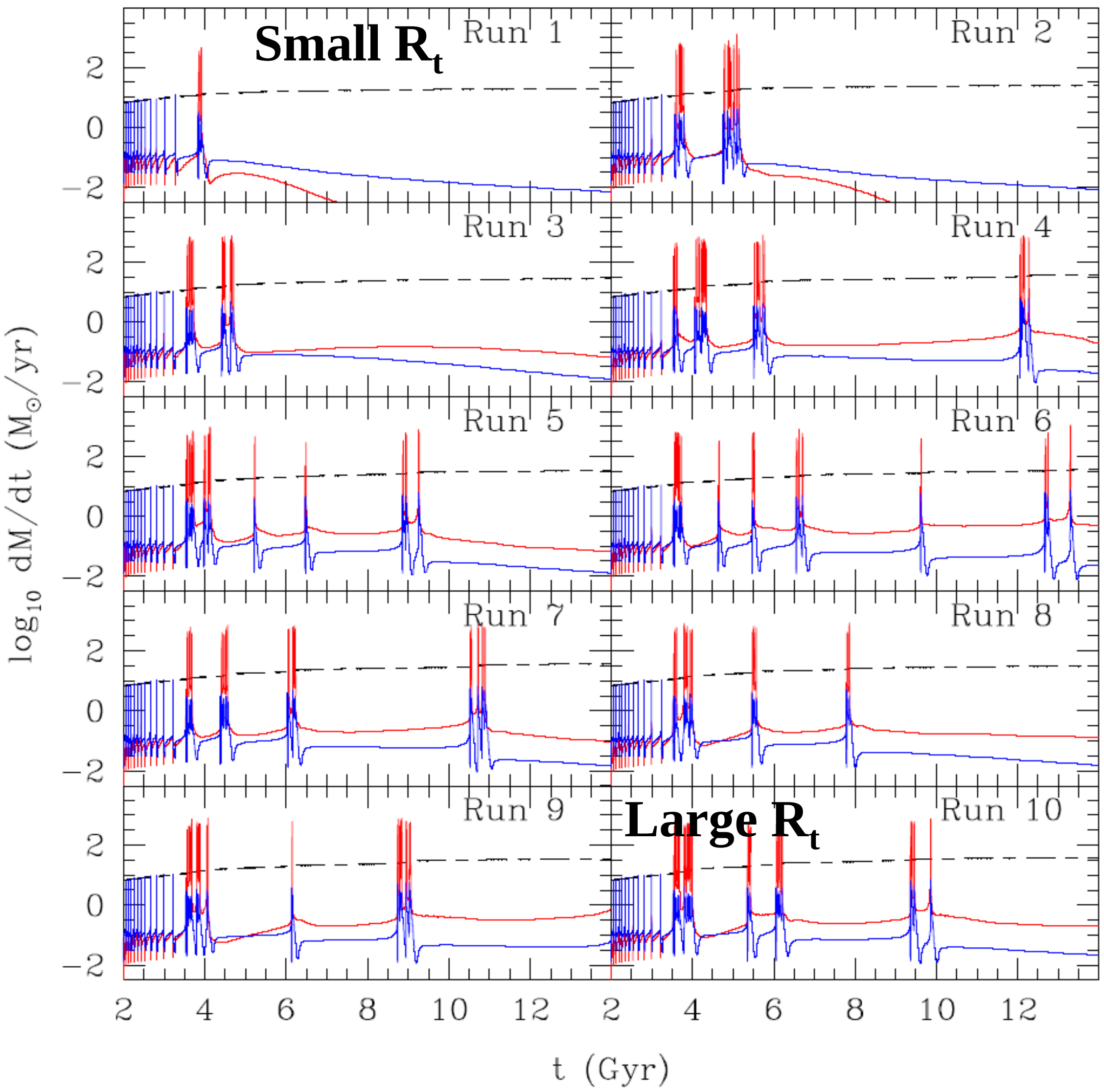
Truncation radius (R_t)

- Beyond the truncation radius gas escapes out from the galaxy.
- The small truncation radius represents strong gas stripping.
- The truncation radii do not change as a function of time.

Run	Radius (kpc)	Run	Radius (kpc)
1	51.4	6	239.7
2	88.5	7	287.3
3	127.2	8	344.4
4	166.9	9	377.0
5	218.9	10	412.8



NGC 7619, Kim et al. 2008



Classical cooling flow scenario : cooling flow should be continuously suppressed.

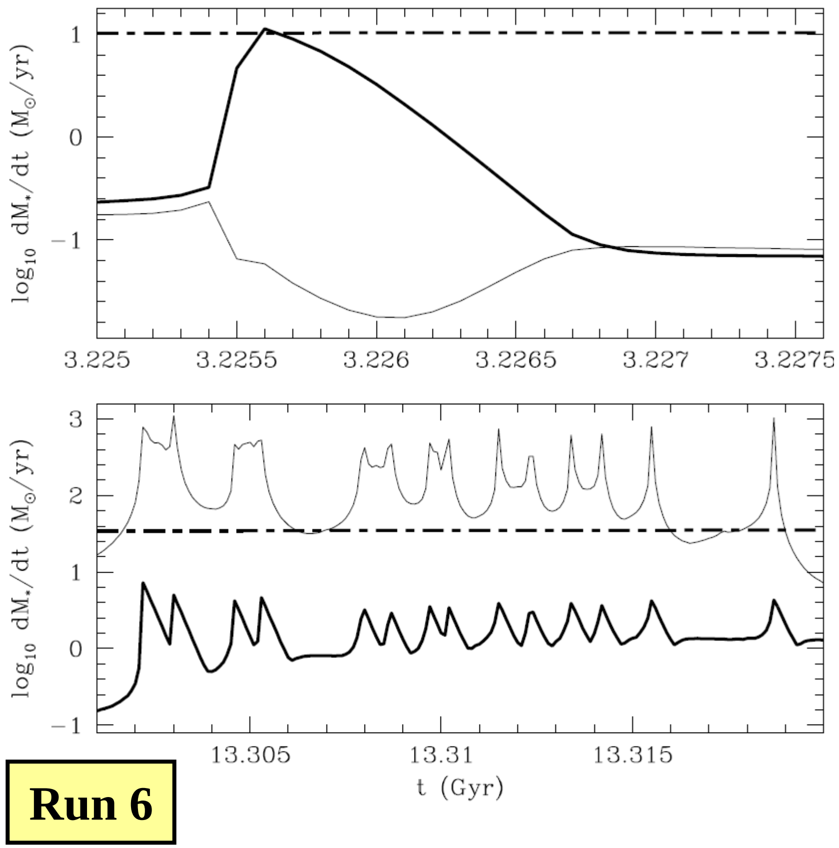
vs.

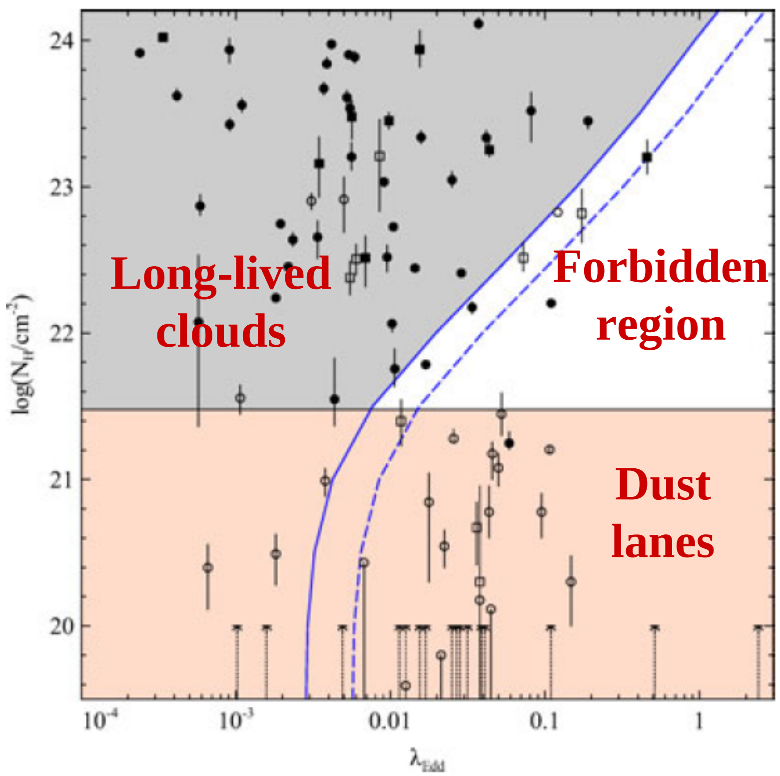
Intermittent cooling flow scenario (e.g. Salomé et al. 2006) : cooling flow can be recovered and then re-suppressed for a moment.

BH accretion rate : blue solid line
SFR : red solid line
Eddington accretion rate : dashed line

Evolution of dominating feedback modes

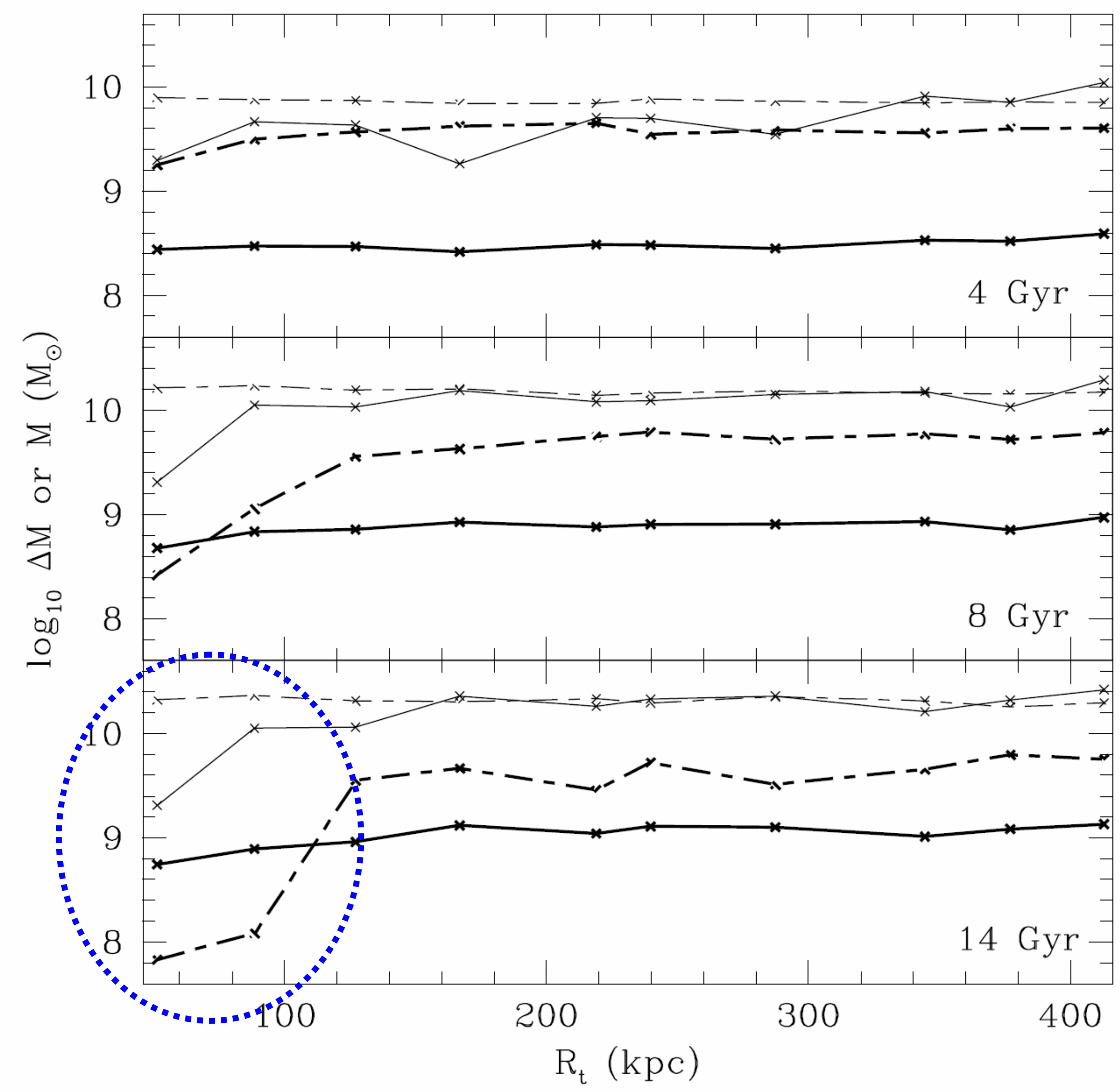
BH accretion rate : thick solid line
SFR : thin solid line
Eddington accretion rate : dashed line





(Fabian et al. 2009)

Late SMBH accretion rate is significantly lower than Eddington accretion rate because of radiative feedback mode.



ΔM_{BH} (*thick solid line*)

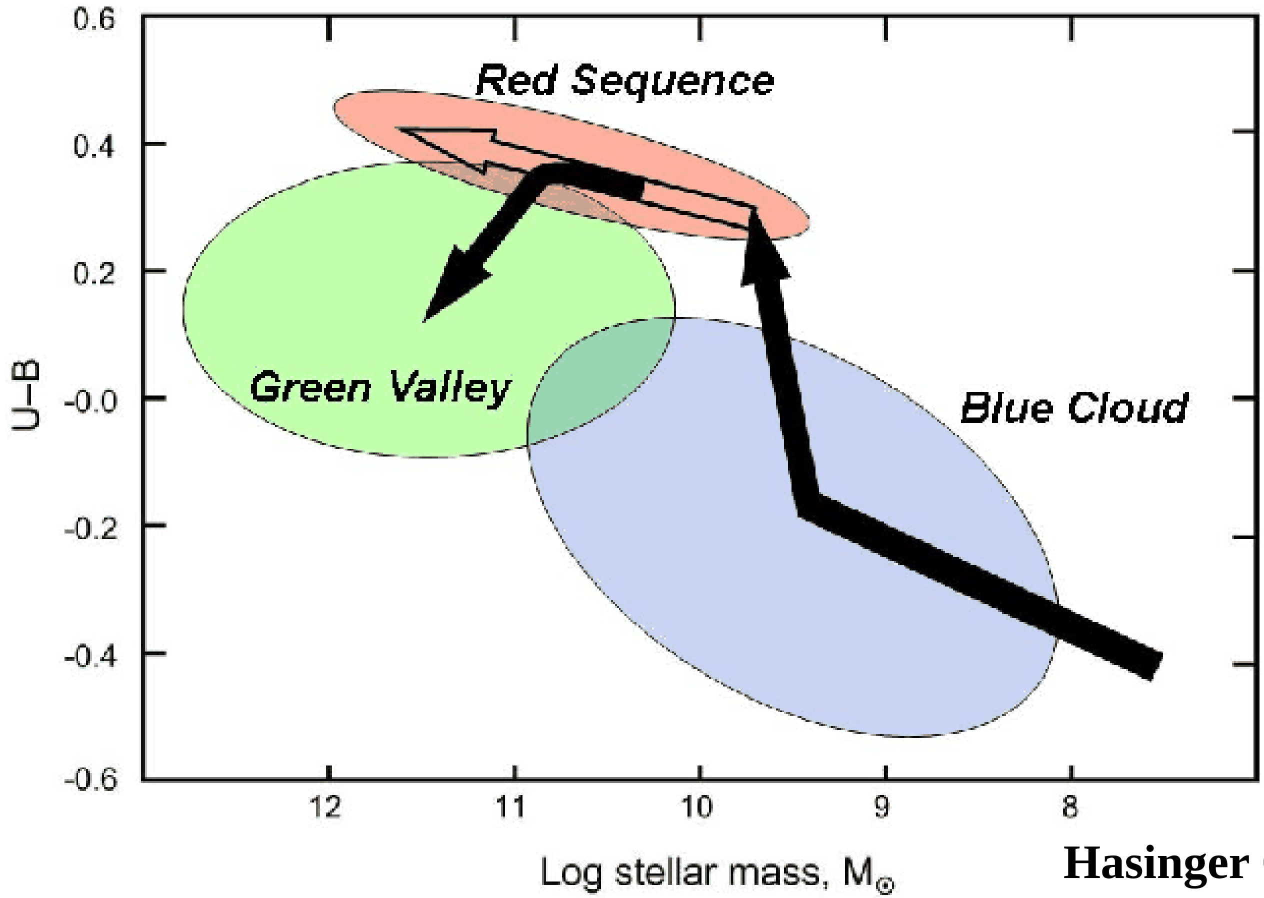
ΔM_* (*thin solid line*)

X-ray emitting hot gas (*thick short-long dashed line*)

outflowing gas (*thin short-long dashed line*)

Dispersions in scaling relationships between satellite and central galaxies exist if satellites have experienced substantial gas stripping.

Resurrection of SF and SMBH accretion



Hasinger 08

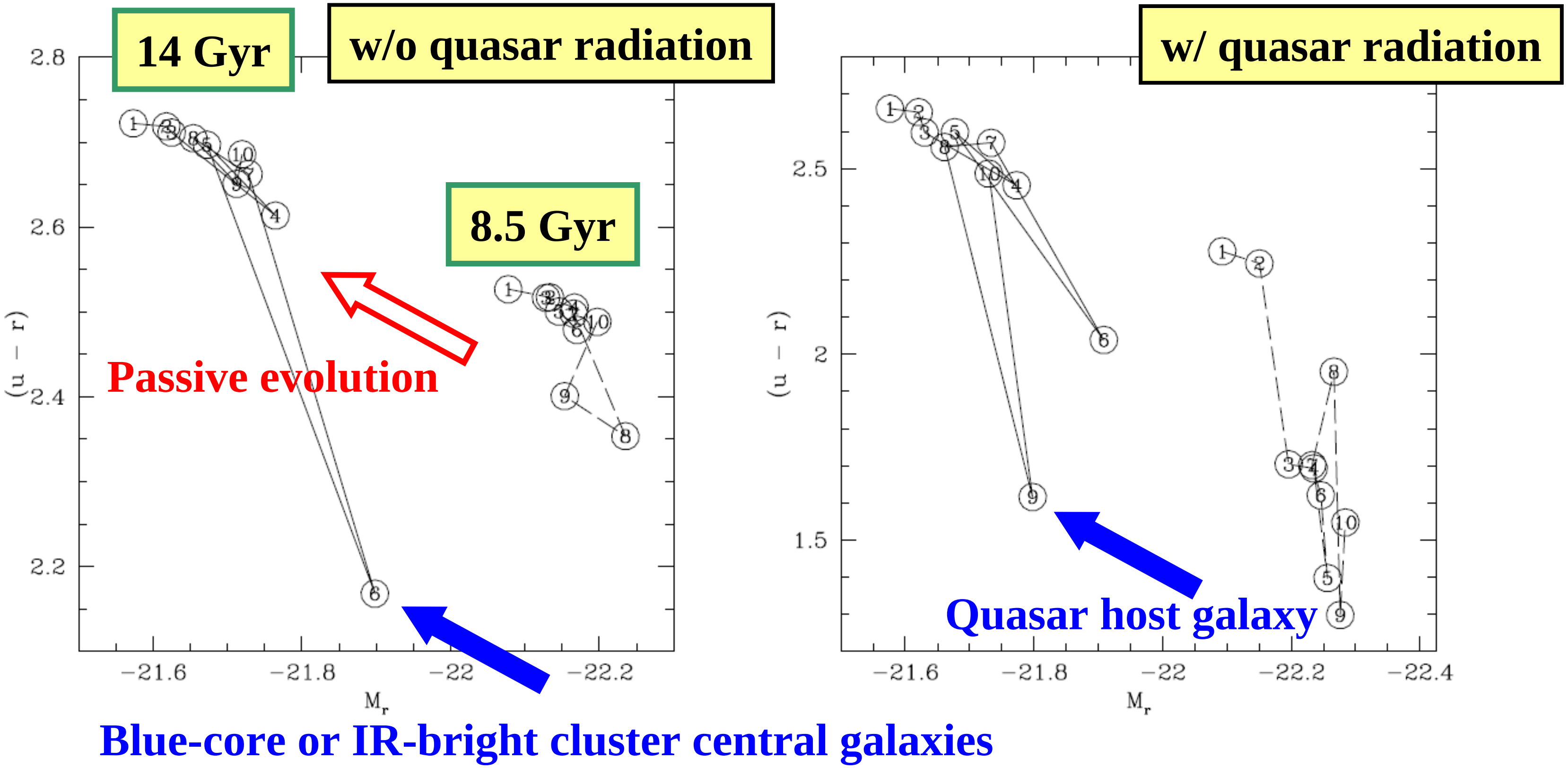


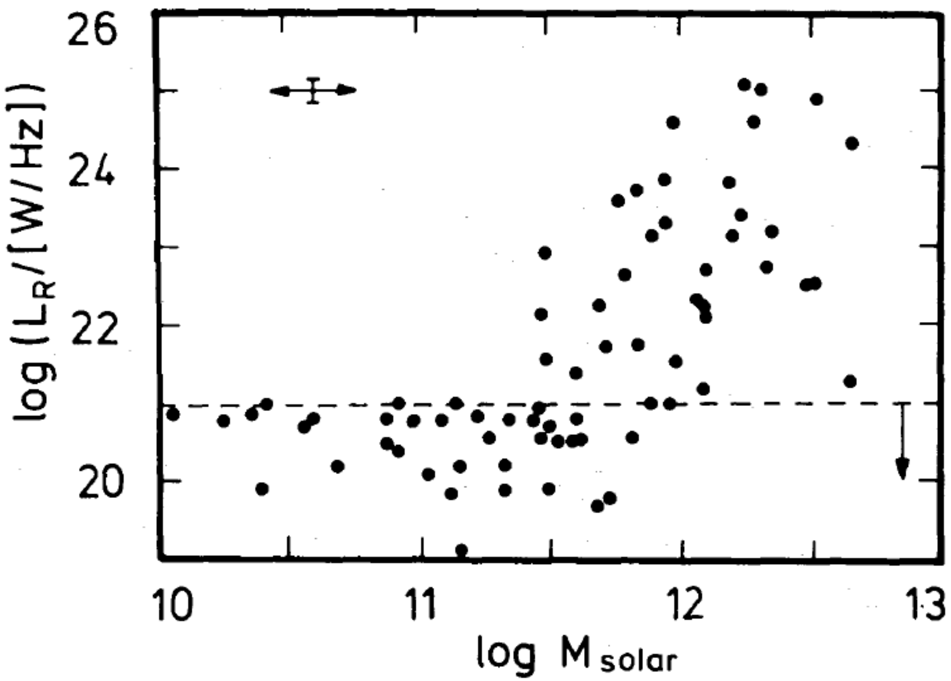
Figure 2.9: Color-magnitude diagram at 8.5 (*dashed line*) and 14 (*solid line*) Gyr without the optical radiation from the SMBH (*left*) and with it (*right*). From the star formation history of each run, we retrieve the synthesized spectra by using the BC03 model (Bruzual & Charlot, 2003). The effects from dust extinction are not considered in the construction of spectra. The numbers in circles represent the name of the run. The dashed and solid lines describe the results at 8.5 and 14 Gyr. The included quasar spectrum is a luminosity-scaled spectrum of type-I quasar (Vanden Berk et al., 2001).

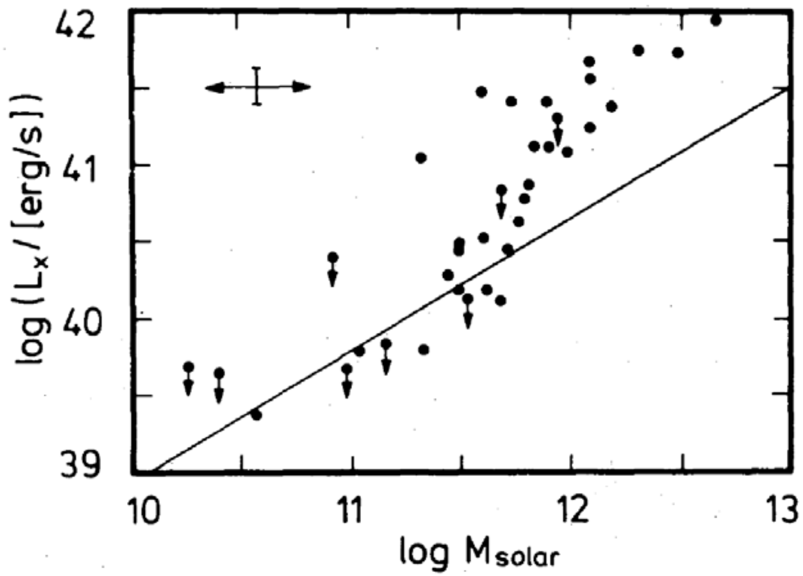
Implications

- **BH mass – stellar mass ratio can have dispersions by environmental effects.**
- **Metals stripped from satellites or minor galaxies can contribute the enrichment of ICM efficiently.**
- **Satellite galaxies experiencing gas stripping are redder than central galaxies.**
- **At high redshifts, AGN is more common and efficient in IGM enrichment than at low redshifts (Koulouridis & Plionis 10).**
- **At high redshifts, radiative AGN feedback is more effective than at low redshifts.**

II. Dynamically interacting radio galaxies and their AGN feedback effects

- Radio-mode AGNs are found in massive elliptical galaxies in dense environments with luminous X-ray emitting gas halos.

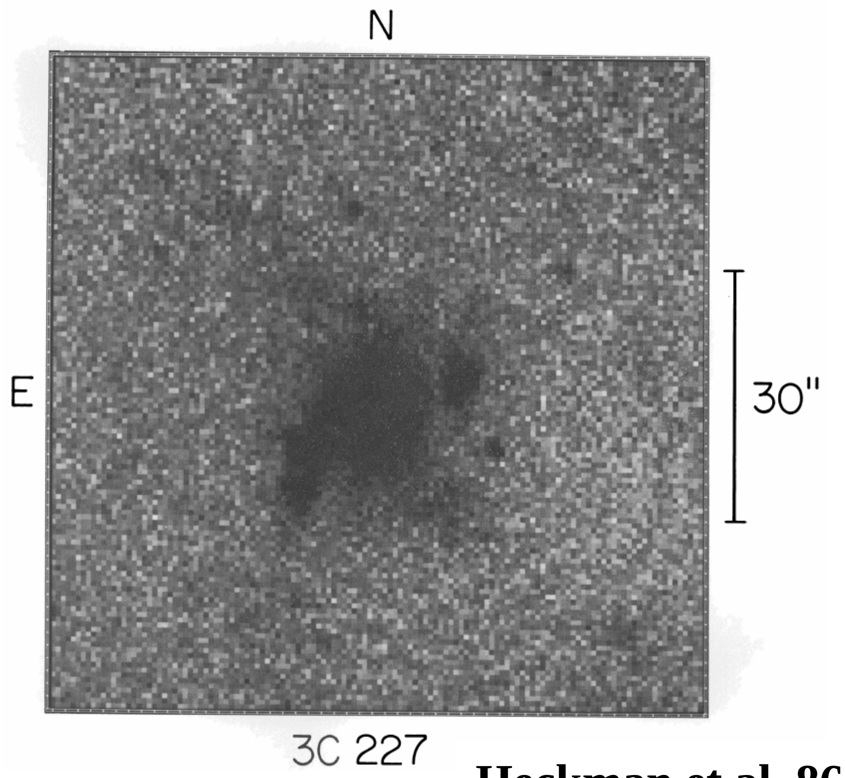




Bender et al. 89 (Kormendy et al. 09)

Dynamical interaction …

- Very powerful radio sources seem to be associated with disturbed galaxies (Heckman et al. 86).
- Dry mergers seem to produce core elliptical galaxies, i.e. massive elliptical galaxies.



Heckman et al. 86

Q. How does dynamical interaction by dry mergers affect radio-mode AGN activity in dense environments?

Simulations with FLASH3

- Fiducial model
  - $M_{BH}=10^9$, $M_* = 10^{12}$, $M_{DM}=10^{13}$ M_{solar}.
  - Hydrodynamics with cooling.
  - AMR with 11 or 12 refinement levels with the smallest cell size 0.4 or 0.2 kpc.
  - Simulation continues up to 2 - 3 Gyr.
- Three satellits orbits of e ~ 0.2, 0.6, and 0.8 with $M_{total}=2x10^{11}$ M_{solar}.
- Two initial gas profiles of positive and negative temperature gradients.
- Stochastic AGN models.