Feedback
flows of gas, energy and momentum in and out of galaxies

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a part of the course *Formation and Evolution of Galaxies*

Feedback

accretion

outflow

Feedback is of great importance for the appearance of a galaxy. It is directly related to

- star formation activity
- dynamics/morphology

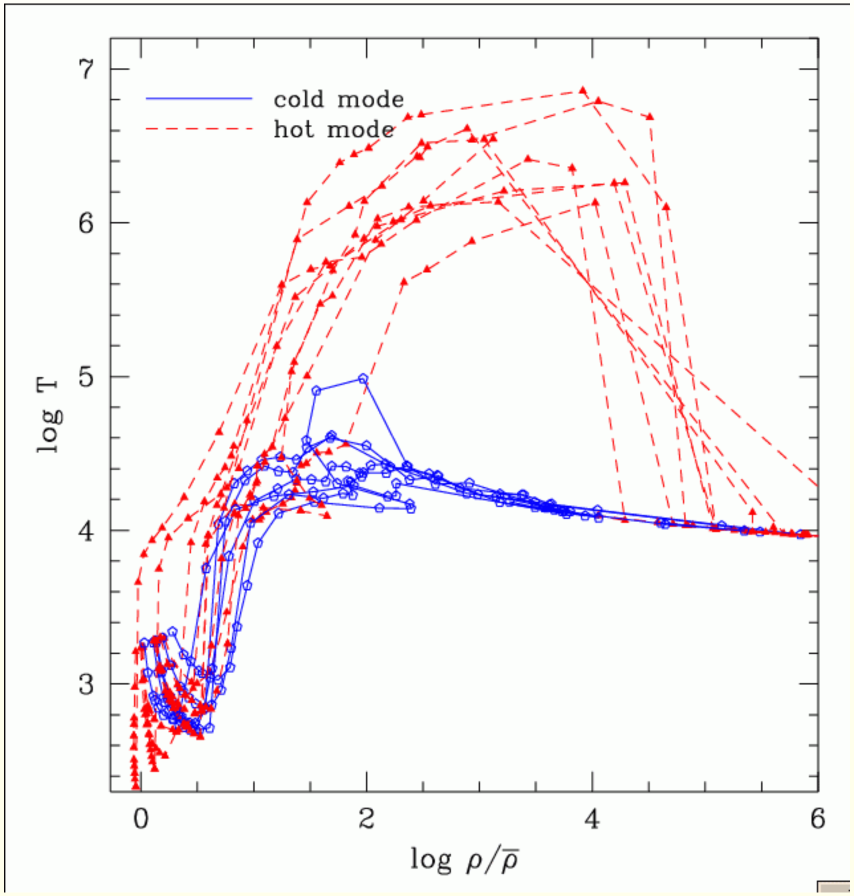
Observational difference:

- high mass ("normal") galaxies
  - lots of gas, star formation regions
  - high luminosity
- low mass galaxies (dwarfs)
  - no gas, only (old) stars
  - faint

Dwarfs are more common than massive galaxies. They are a much better tracer of the underlying (dark) matter distribution.

Gas accretion (1)

Massive galaxies ($M_{\rm baryon} > \sim 10^{10.3}$ or $M_{\rm halo} > \sim 10^{11.4}$) accrete gas mostly in the so-called *hot mode*, dwarf galaxies mostly in the *cold mode* (Keres et al. 2004).

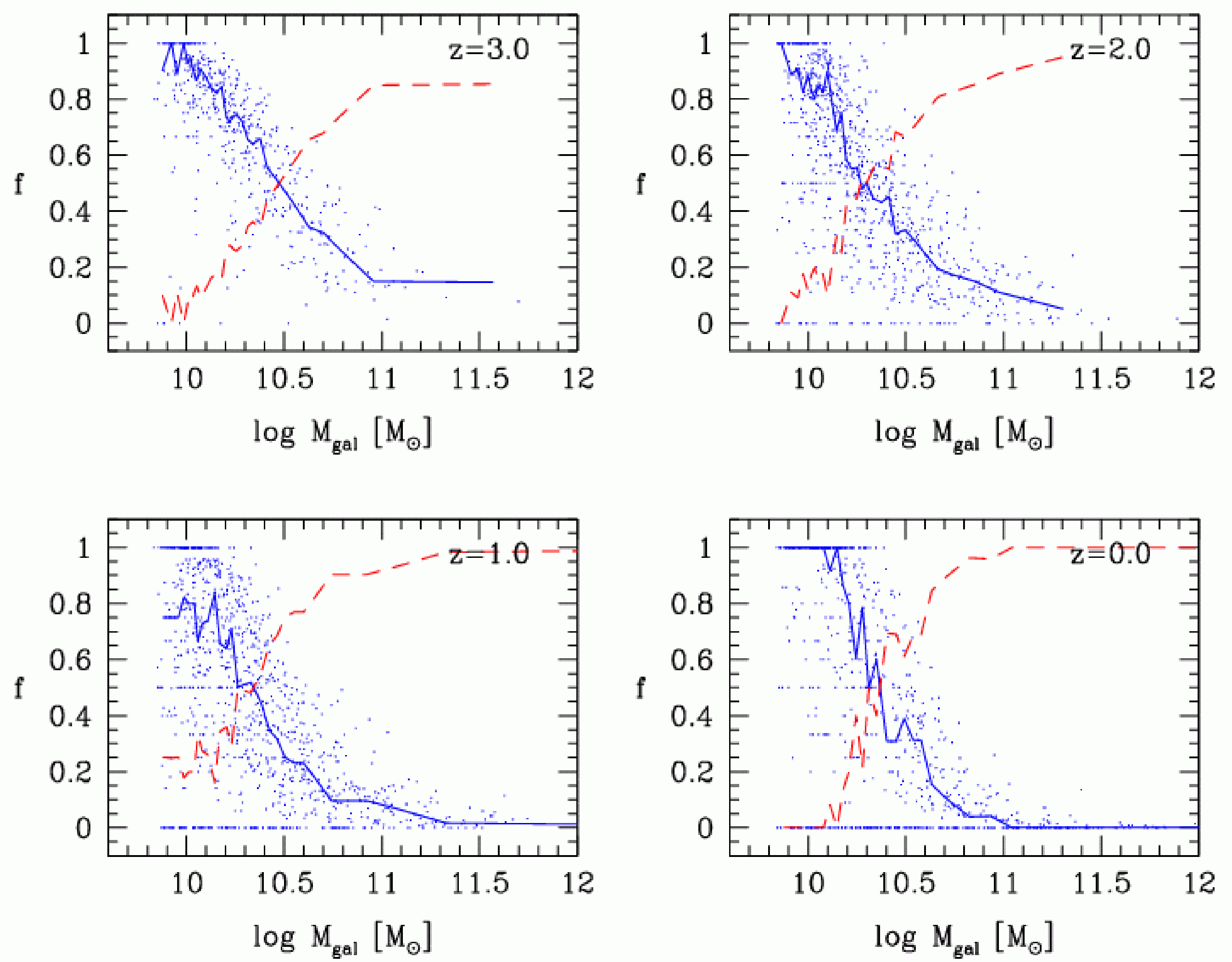


A number of particles is followed from z = 7 to z = 3. Half go through the hot phase, the other half (the cold mode particles) never get shock-heated to above log T = 5.4.

Gas accretion (2)

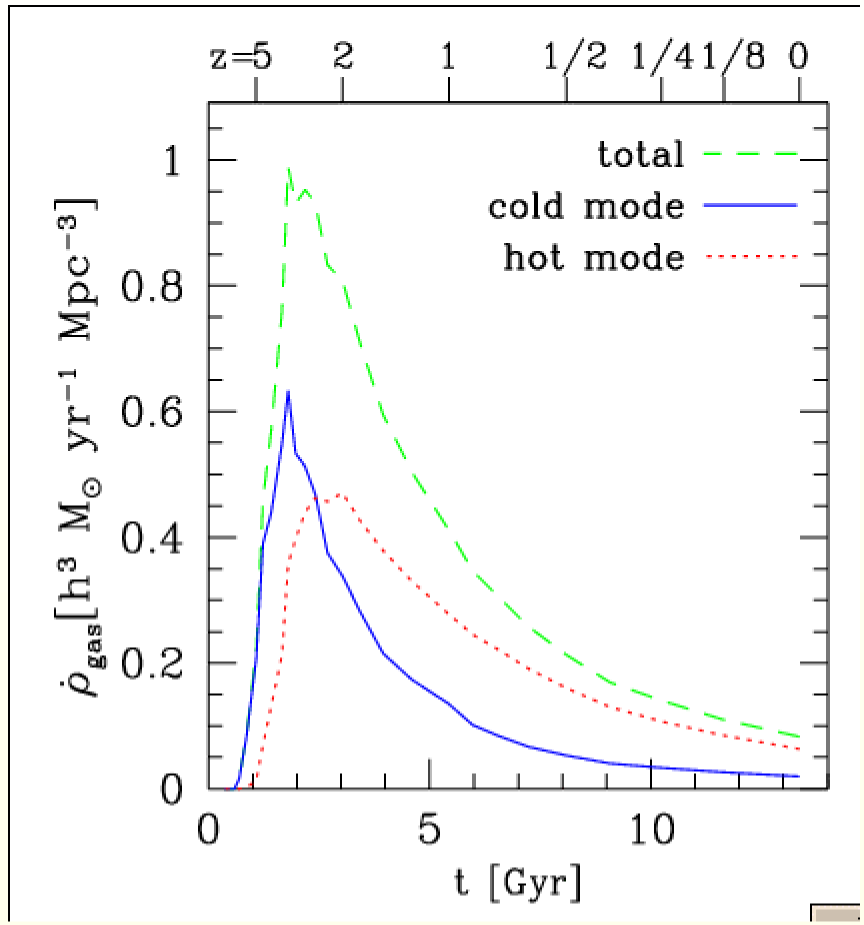
Blue solid line:
fraction cold mode;
red dashed line:
hot mode.

Equivalence of
cold and hot mode
always at $M_{\rm gal} = 10^{10.3}$
from z = 2.0.



Gas accretion (3)

Redshift history of the fractions of cold and hot accretion. At high z, when galaxies are not really massive yet, the cold mode dominates. At an age of ~ 2.5 Gyr, the hot mode takes over.



Outflow (1)

Energy produced by supernovae can expel gas, whenever $E_{SN} > \frac{1}{2} M_g V^2$

i.e.: the SNe must be able to provide the kinetic energy for the expelled gas.

E_{SN} depends on:

- rate of energy input into supernova remnants (star formation rate)
- efficiency of energy transfer to gas (evolution of SNR)
- the time it takes for individual SNRs to overlap (SFR + evolution of SNR)

Dekel & Silk (1986) find a *critical virial velocity* of ~ 100 km/s. This critical velocity divides galaxies into two classes: those who retain their gas and those who lose their gas.

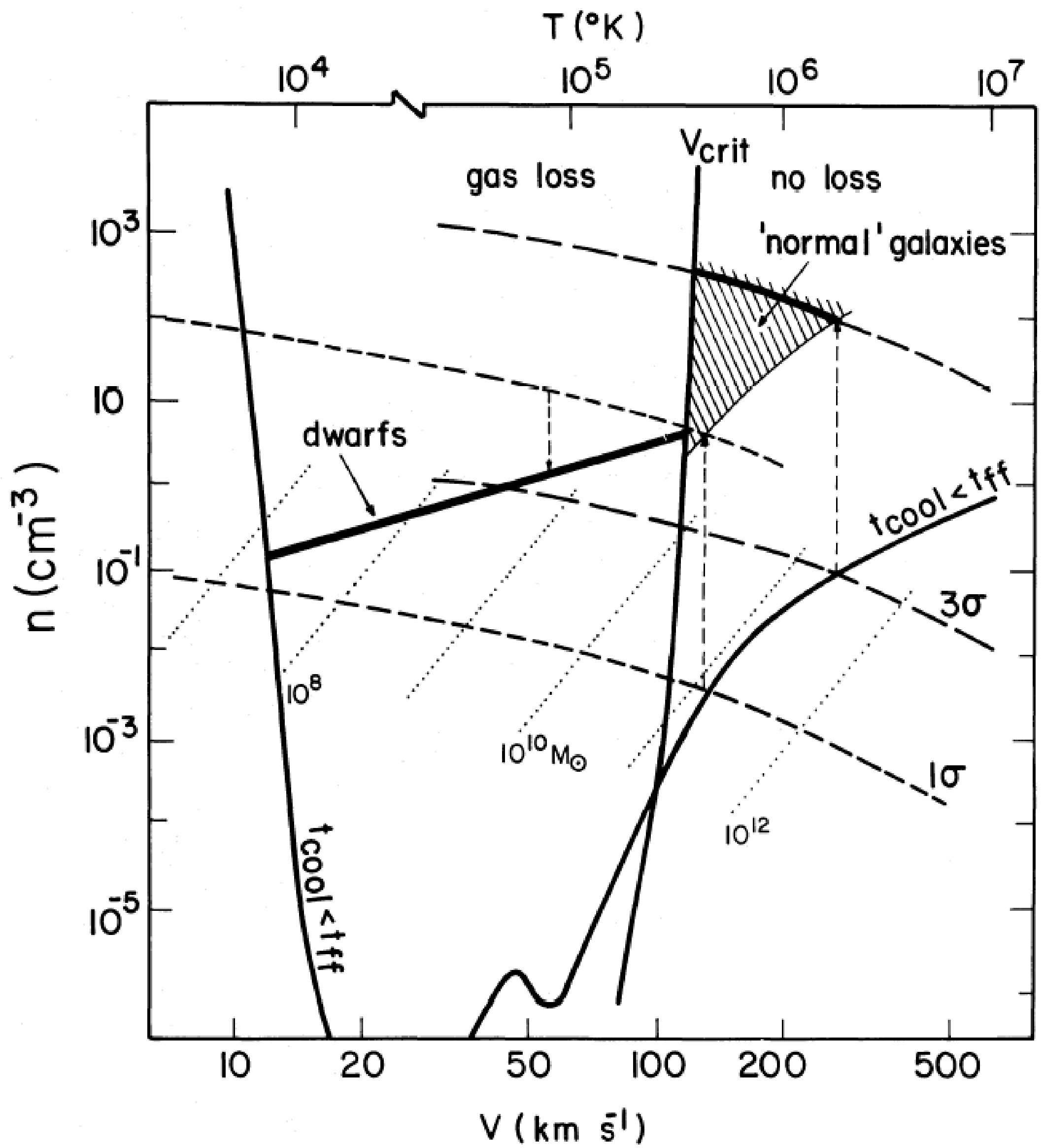
Outflow (2)

Gas number density against virial velocity (from Dekel & Silk, 1986).

Gas clouds can only contract to form stars and galaxies if $t_{cool} < t_{ff}$.

Dwarfs contract from 1 sigma fluctuations, 'normal' galaxies from higher sigma fluctuations.

If V (N.B.: $V^2 \propto \Phi_{grav}$) is smaller than the critical velocity, all of the gas can be blown out of the proto-galaxy by the energy of SNRs.



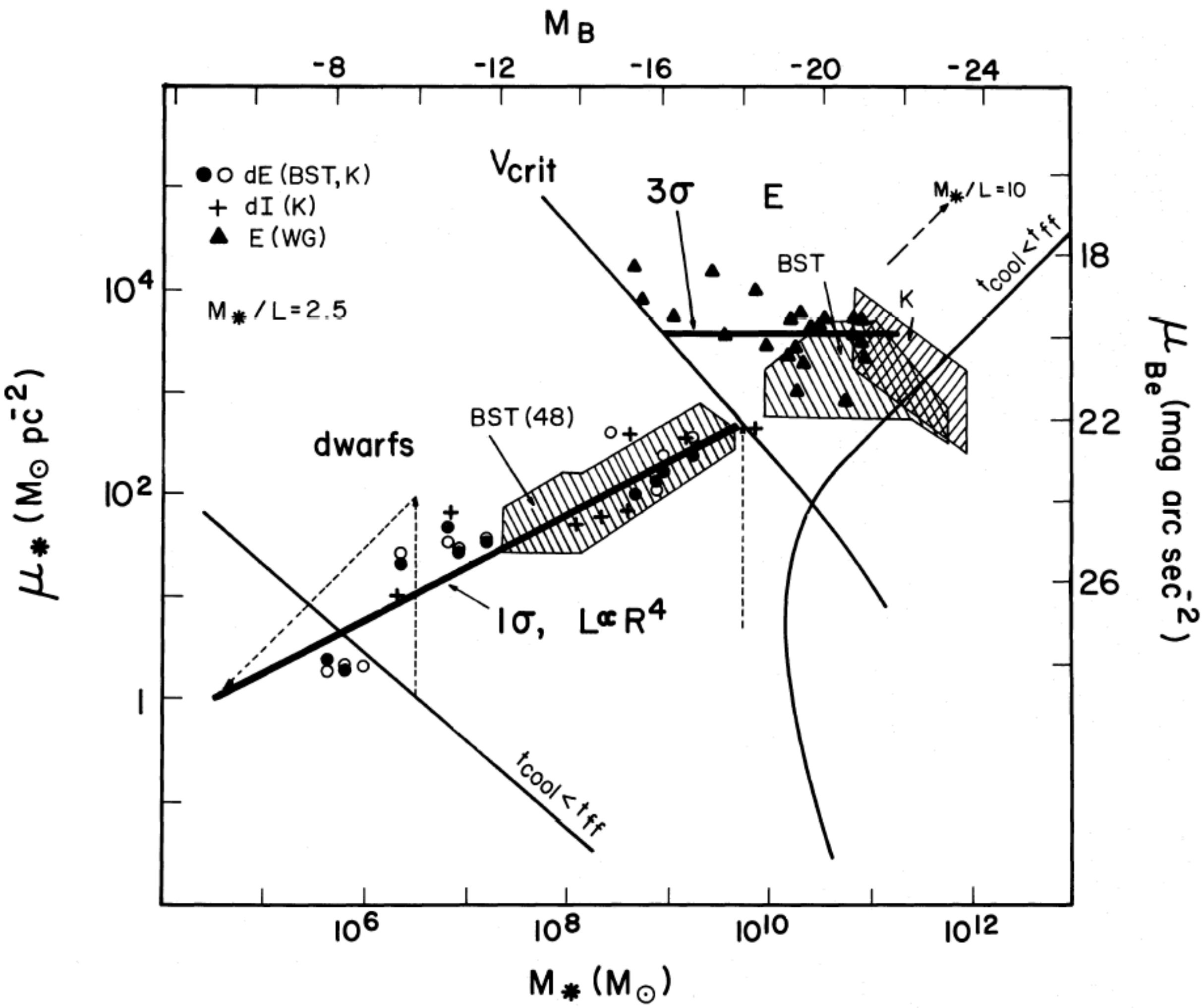
Outflow (3)

Surface brightness vs. luminosity.

Modeled quantities: bottom and left axes.

Observable quantities: top and right axes.

The observations match the model.



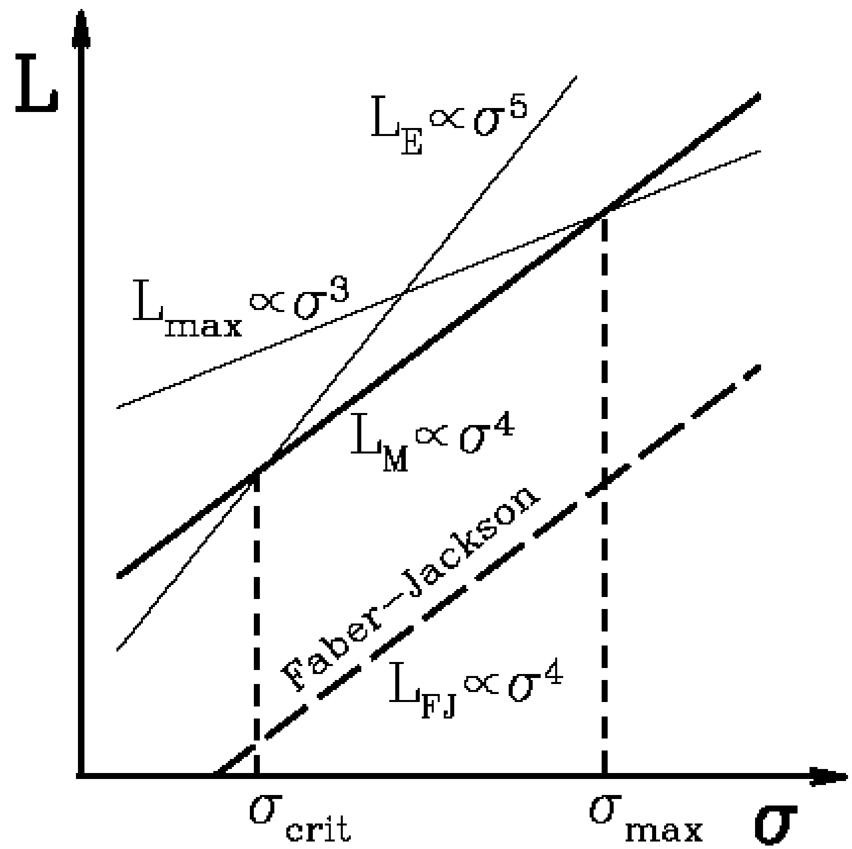
Outflow (4)

Murray et al. (2005), analytical considerations:

Besides the energy-driven winds, momentum-driven winds can occur, dependent on the total luminosity *L* of the galaxy. If *L* exceeds $L_M = \frac{4cf_g}{G}\sigma^4$, all gas will move outwards and we end up with a diffuse dwarf galaxy.

Murray et al. claim this to be the explanation for the Faber-Jackson relation: $L_{FJ} \propto \sigma^4$

When the velocity dispersion is between its critical and maximum value, any $L > L_M$ will blow out all of the gas, stop star formation and the growth of the galaxy mass.



Outflow (5)

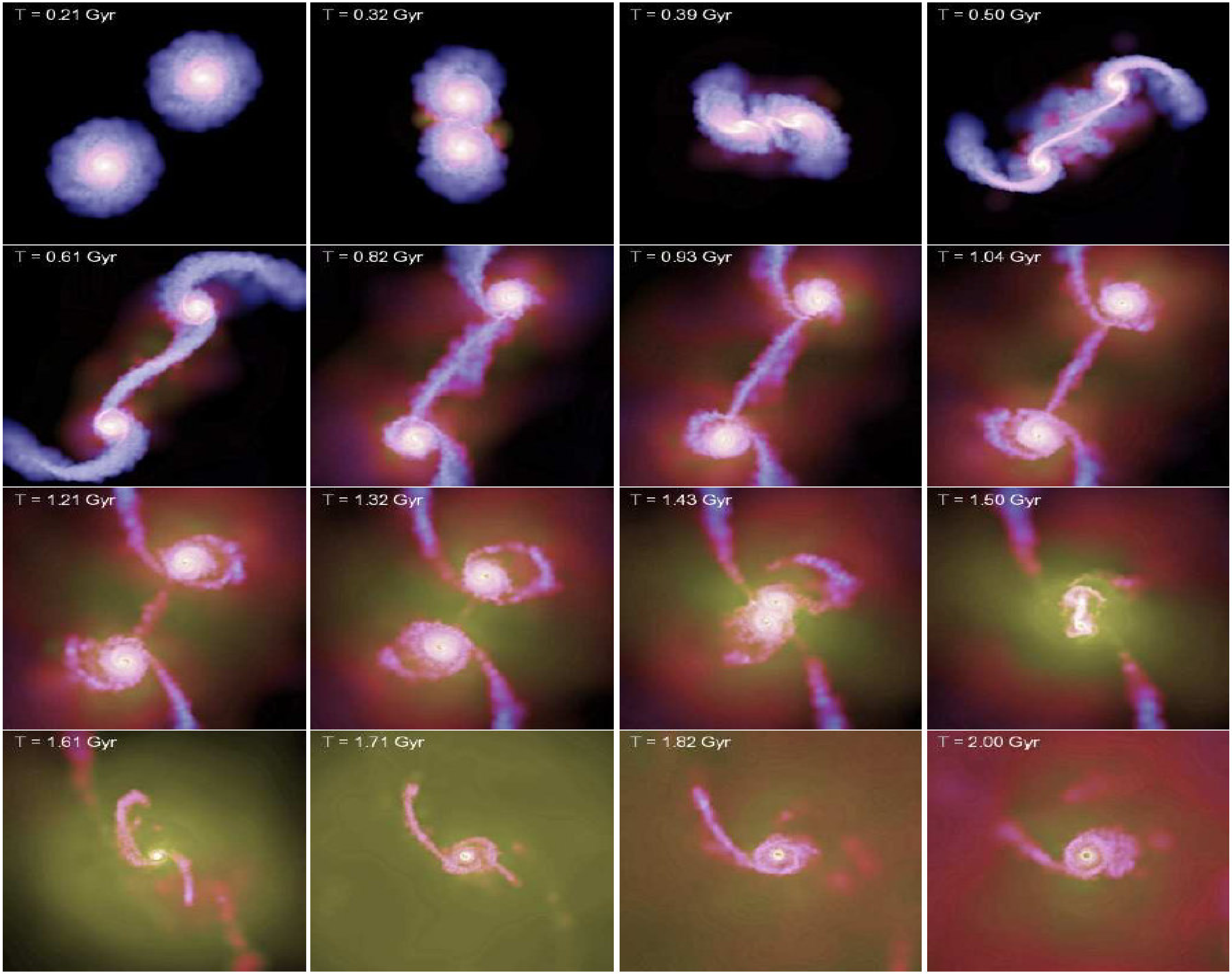
Numerical simulation of galaxy-galaxy merger by Di Matteo et al. (2005), including:

- radiative cooling
- star formation phyics
- black hole growth
- energetic feedback from SNe
- accretion onto black hole
- gravitational dynamics of gas, stars and dark matter

Shows that the presence of black holes in the merging galaxies leads to:

- a star formation burst
- strong gas flow into the galaxies, feeding the black holes
- Quasar energy pushing all of the gas out of the merging system.

(stopping SF and setting the BH mass)


T = 0.21 Gyr
T = 0.32 Gyr
T = 0.39 Gyr
T = 0.50 Gyr
T = 0.61 Gyr
T = 0.82 Gyr
T = 0.93 Gyr
T = 1.04 Gyr
T = 1.21 Gyr
T = 1.32 Gyr
T = 1.43 Gyr
T = 1.50 Gyr
T = 1.61 Gyr
T = 1.71 Gyr
T = 1.82 Gyr
T = 2.00 Gyr