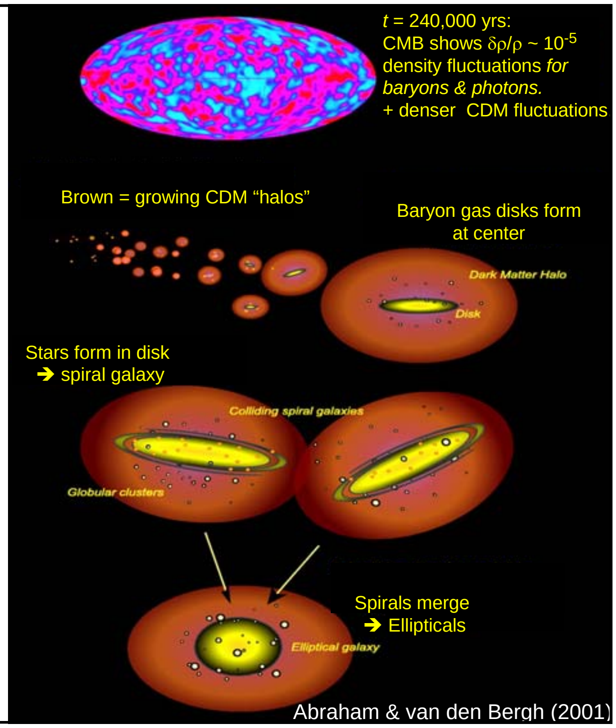
Basic idea behind galaxy formation - objects start small and grow by merging

Do galaxies form this way?

Does star formation occur before, during or after mass assembly?

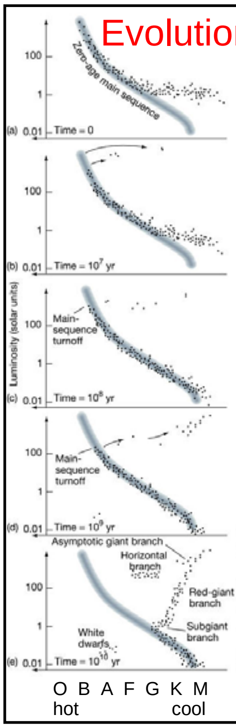
When and how do Hubble Types form?



Evolution of galaxy spectrum over cosmic time.

From AST 208: Magnitudes…

$m_a - m_b = a - b = 2.5 \log(F_b / F_a)$



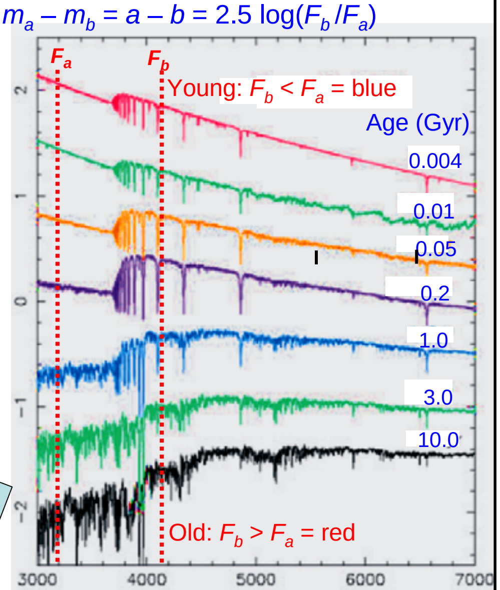
AST 208 lab exercise (?)

Star cluster age dating.

Hot, massive stars evolve off main sequence rapidly.

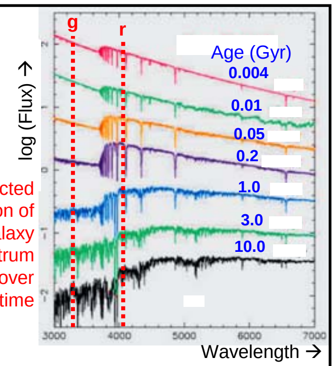
Cool, low mass stars take a long time.

Combined spectrum of whole galaxy

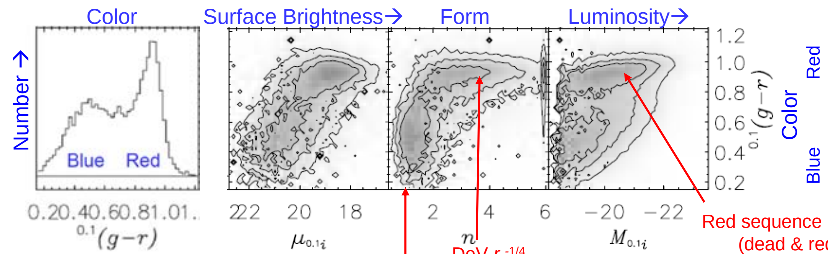


A large sample of galaxies

- SDSS (Sloan Digital Sky Survey)
  - 10^6 targets, mostly galaxies,
    - selected for spectroscopy
  - 10^4 deg^2 of sky
  - $m_r < 17.8$ mag



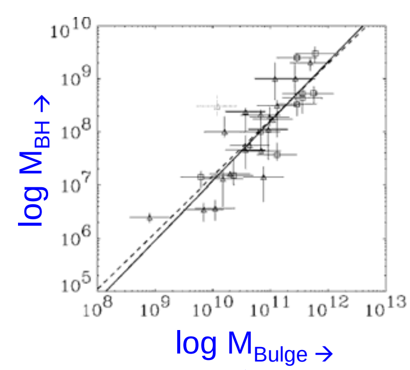
- 115,000 SDSS galaxies:



Blanton et al. 2005, ApJ, 629, 143

The Role of AGN in Galaxy Formation

- All massive galaxies contain massive black holes.
- $M_{Black\ Hole} \propto M_{Bulge}$
  - ➔ cause & effect



From stellar velocity dispersion + virial theorem.

$$M \propto \frac{v^2 R}{G}$$

- AGN feedback
  - Mass accretion rate is governed by
    - radiation pressure (Eddington limit)
    - and/or energy in jets/winds.
  - Limits size of galaxy.
  - Also operates on scale of galaxy cluster.

The Cooling Flow Problem

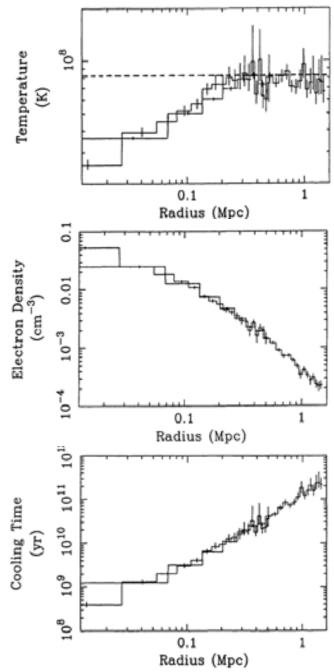
Bremsstrahlung emission from X-ray emitting gas in clusters and E galaxies:

$$\mathcal{L}_{vol} \propto n_e^2 T^{1/2}$$

$$t_{cool} = \frac{3 n_e k T}{\mathcal{L}_{vol}} \propto \frac{T^{1/2}}{n_e}$$

Coma cluster homework problem:
$T_e = 7\text{x}10^7$ K and R =1.5 Mpc
➔ $n_e = 5.5\text{x}10^{-5}$ cm^{-3}, $t_{cool} = 10^{12}$ yrs.

- Dense central regions should cool rapidly ($t_{\rm cool} < 1$ Gyr).
- Should cause inward mass flow
  - Some is observed
    - cD galaxies at cluster centers.
  - But not nearly enough inflow is observed.



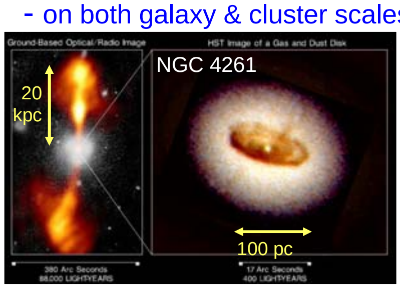
Abell 478 galaxy cluster

The Cooling Flow Problem

The Solution:

AGN feedback heats gas.

- on both galaxy & cluster scales.



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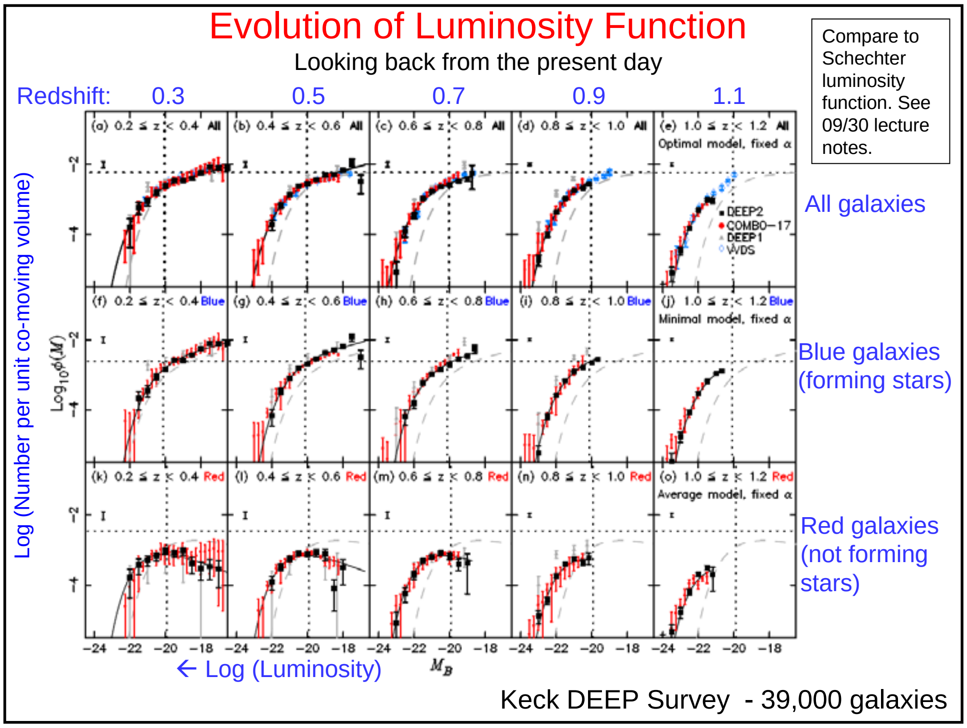
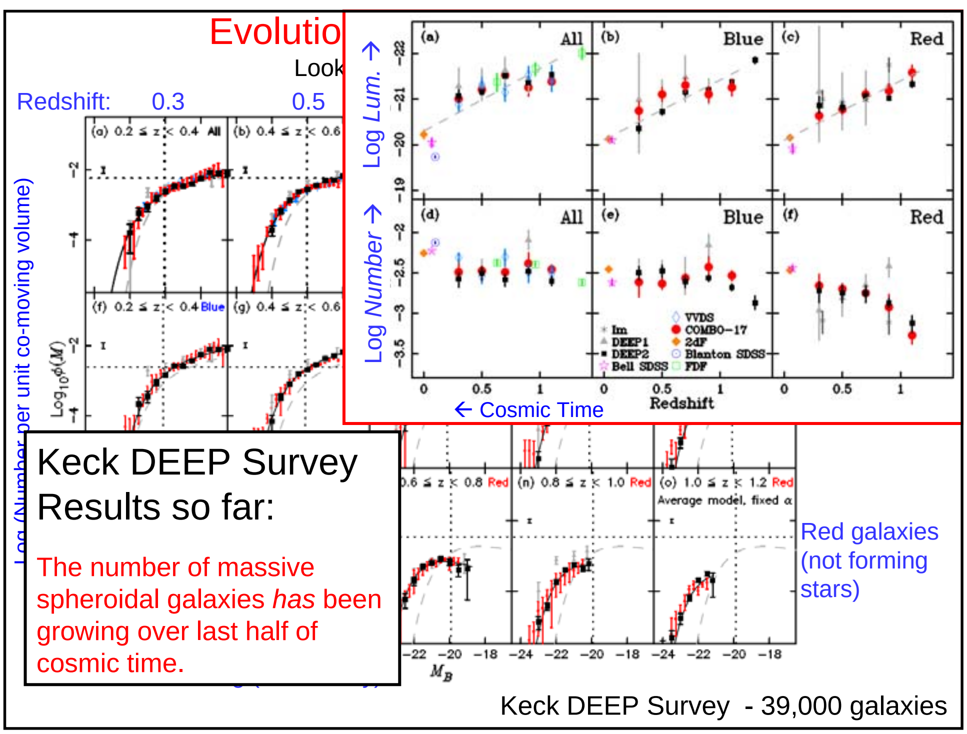

Evolution of Luminosity Function
Looking back from the present day
Redshift: 0.3 0.5 0.7 0.9 1.1
Compare to Schechter luminosity function. See 09/30 lecture notes.
All galaxies
Blue galaxies (forming stars)
Red galaxies (not forming stars)
Log (Number per unit co-moving volume)
← Log (Luminosity)
Keck DEEP Survey - 39,000 galaxies


Evolutio
Redshift: 0.3 0.5
Log Lum. →
Log Number →
← Cosmic Time
Redshift
Keck DEEP Survey
Results so far:
The number of massive spheroidal galaxies *has* been growing over last half of cosmic time.
Red galaxies (not forming stars)
Keck DEEP Survey - 39,000 galaxies

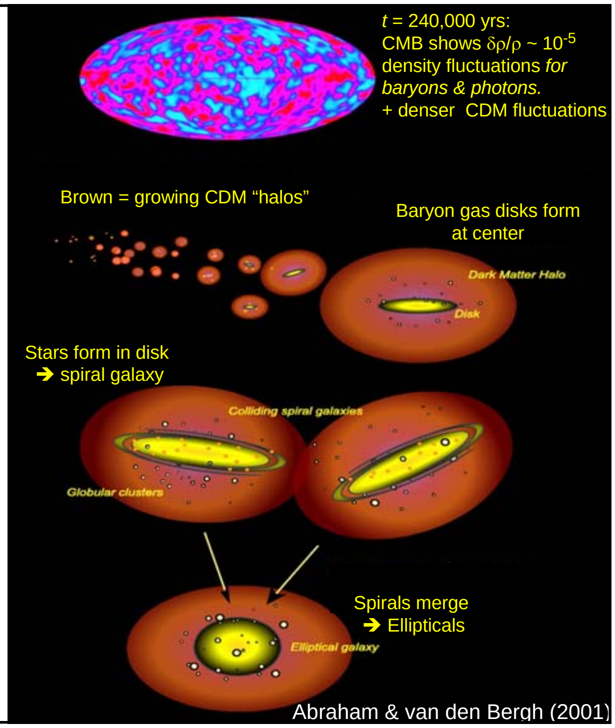
Basic idea behind galaxy formation - objects start small and grow by merging.

We see:

- Smaller galaxies back when $t \sim$ 1-7 Gyr. (with caveats)
- Increase in space density of large galaxies since $t \sim$ 7 Gyr = 1/2 current age. (with caveats)
- Lower Spiral/Elliptical ratio in cluster centers.
- Mergers.

But…

- Not enough very low-mass galaxies at current time ➔ SN winds??
- Many E galaxies ended star formation by $t \sim$ 7 Gyr ➔ AGN feedback.



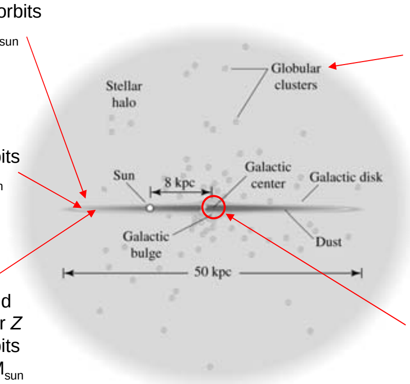
Abraham & van den Bergh (2001)

Formation of the Milky Way

Thick Disk
- ~10 Gyr old
- moderately low Z (metallicity)
- elongated orbits
- 0.3×10^{10} M_{sun}

Thin Disk
- ~8 Gyr
- solar Z
- circular orbits
- 6×10^{10} M_{sun}

Gas Disk
- < 10 Gyr old
- above solar Z
- circular orbits
- 0.5×10^{10} M_{sun}



[CO fig 24.6]
+ [CO Tbl 24.1]

Stellar Halo
- 11-13 Gyr old
  - horizontal branch
- very low Z (metallicity)
- elongated orbits
- 0.3×10^{10} M_{sun}

Nuclear Bulge
- 0.2 - 10 Gyr old
  - age-flatness correlation
- high Z (metallicity)
- elongated orbits
  - but much smaller than for halo stars
- 1×10^{10} M_{sun}

+ dark matter halo
> 230 kpc radius
~ 200×10^{10} M_{sun}