Cosmological formation of elliptical galaxies*

Thorsten Naab & Jeremiah P. Ostriker

(Munich, Princeton)

T.Naab (USM), P. Johannson (USM), J.P. Ostriker (Princeton),G.Efstahiou (Cambridge)

ASTRO-PH/0512235

Massive Galaxies over Cosmic Time II
Nov. 1-3, 2006
Tucson, AZ

Formation & evolution of elliptical galaxies

- How do elliptical galaxies form and evolve?
- All ellipticals have old metal-rich stellar populations with $z_{form}>2$ making up 3/4 of all stars (Ellis, Bell, Thomas etc.)
- Follow tight scaling relations (CM, FP, etc.)
- Most massive ellipticals formed earlier and on shorter timescales (e.g. Thomas et al. 2005)
- Total stellar mass in elliptical galaxies grows since z=1 which is only not caused by star formation or fading of bright blue galaxies (Bell et al., 2004, Drory et al . 2004, Conselice et al. 2005, Faber et al. 2006, Brown et al. 2006)
- Ongoing assembly of stars by gas poor (dry) mergers. (van Dokkum et al. 2005, Tran et al. 2005, Bell, Naab, McIntosh et al. 2006, McIntosh et al. 2006)

Cosmological simulations of massive field galaxies

- Few published simulations at reasonable resolution (e.g. Meza et al. 2003, Mori & Umemura 2006)
- Pick isolated massive field halos from cosmological dark matter only simulation □
- Three $M_*(10^{11}M_{solar})$ galaxies re-simulated individually at higher resolution with gas, star formation (cooling, no SN/AGN feedback) using GADGET 2 (Springel 2005)
- Resolution study with 40^3, 50^3, 100^3, and 200^3 particles in gas and dark matter, respectively
- At highest resolution (200^3): $M_{star} = 1.3 * 10^5 M_{solar}$□
- Photometric and kinematic properties of the galaxies analysed at z=0

The cosmological formation of an elliptical galaxy

Zur Anzeige wird der QuickTime™
Dekompressor „YUV420 codec“
benötigt.

Zur Anzeige wird der QuickTime™
Dekompressor „YUV420 codec“
benötigt.

Gas

Red: $T > 10^6$ K
Yellow: $10^4 < T < 10^6$ K
Blue: $T < 10^4$ K

Stars

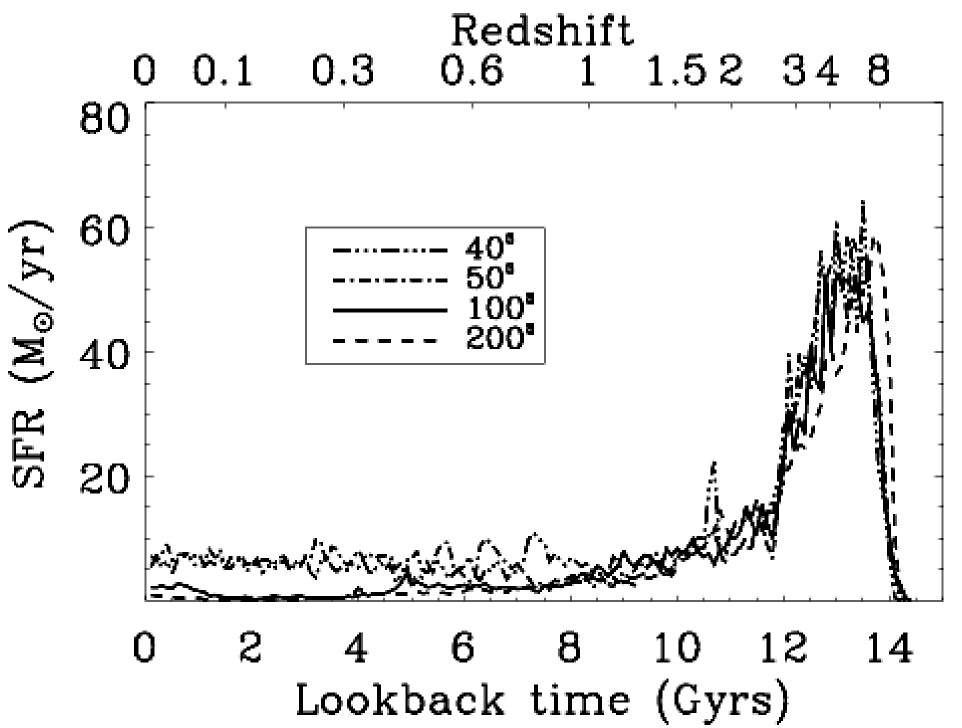
Blue: age < 1Gyr
Yellow: 1Gyr < age < 5 Gyrs
Orange: age > 5 Gyrs

Naab, Johansson, Ostriker & Efstathiou 2006

Star formation rate and numerical resolution

Temperature grows with time despite presence of cooling and absence of feedback

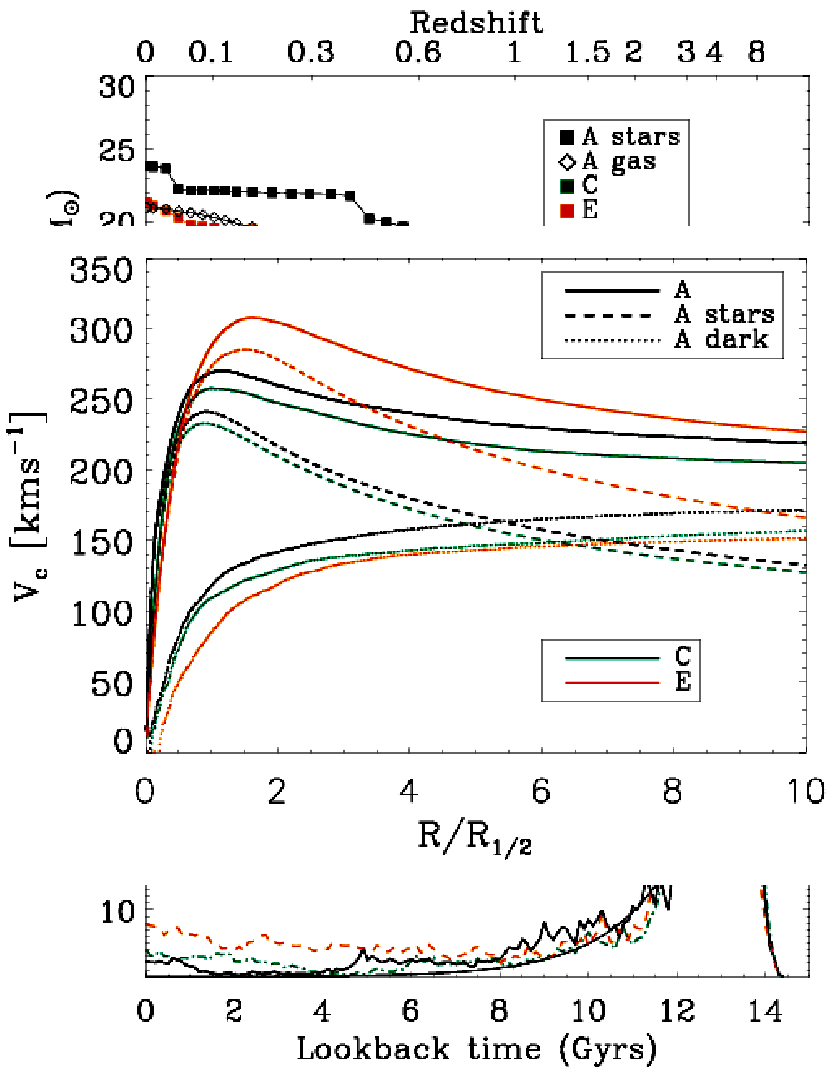
At higher resolution late cold gas infall and star formaiton is reduced



$2.5 * 10^{12}\ M_{solar}$ halo

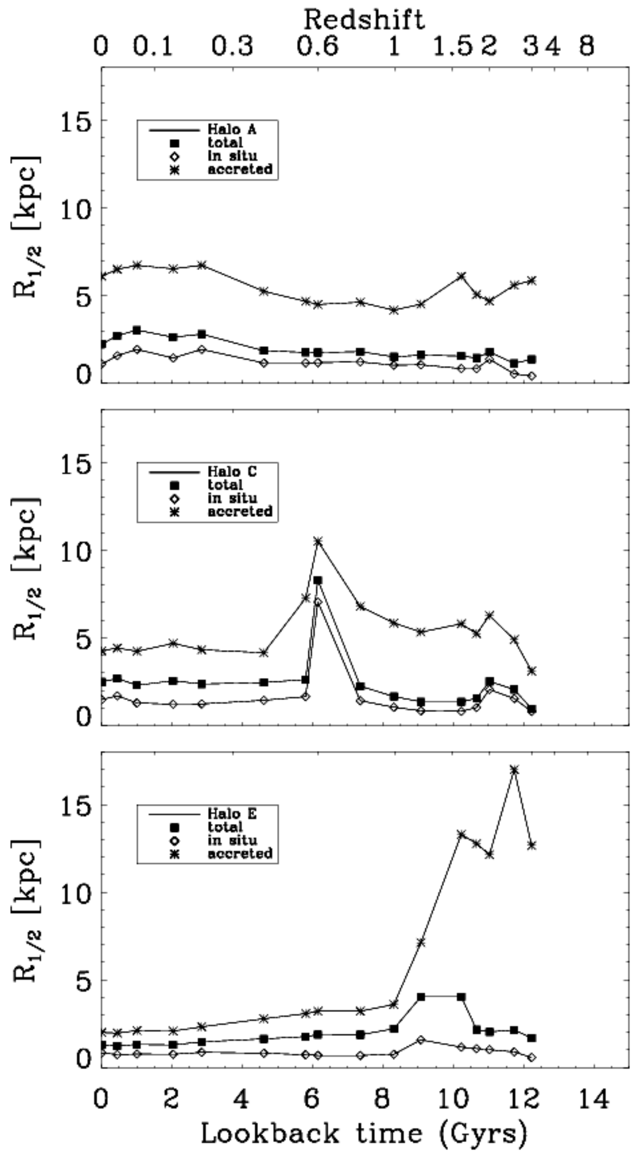
- High redshift star formation weakly affected
- Higher resolution alone results in lower present day SFRs
- Infalling cold gas is more effectively stripped and heated (see e.g. Agertz et al. 2006)
- High resolution galaxies have smaller present day stellar masses at similar virial masses
- Hot gas halo forms an is sustained by compression and shock heating (see e.g. Dekel & Birnboim 2006)
- Heating time is shorter than cooling time for this halo

Assembly history of three halos at 100^3



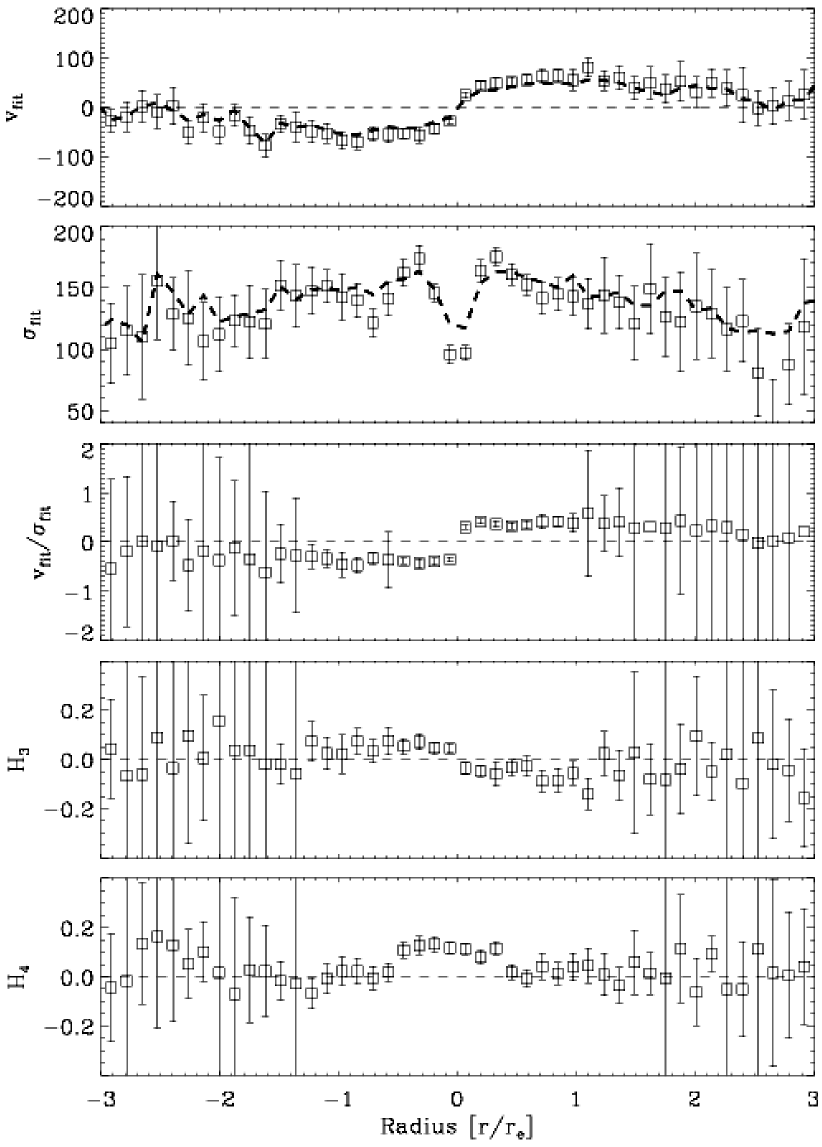
- Halo spin grows during merger/accretion event
- A & C with low present day SFRs, E with high SFR
- Early star formation exponential with τ = 1.5 Gyrs
- Properties similar to z=2 galaxies (see Pettini et al.)
- All galaxies have similar present day stellar masses and mean stellar ages of 9 - 11Gyrs and reasonable mass profiles

In situ star formation vs. accretion



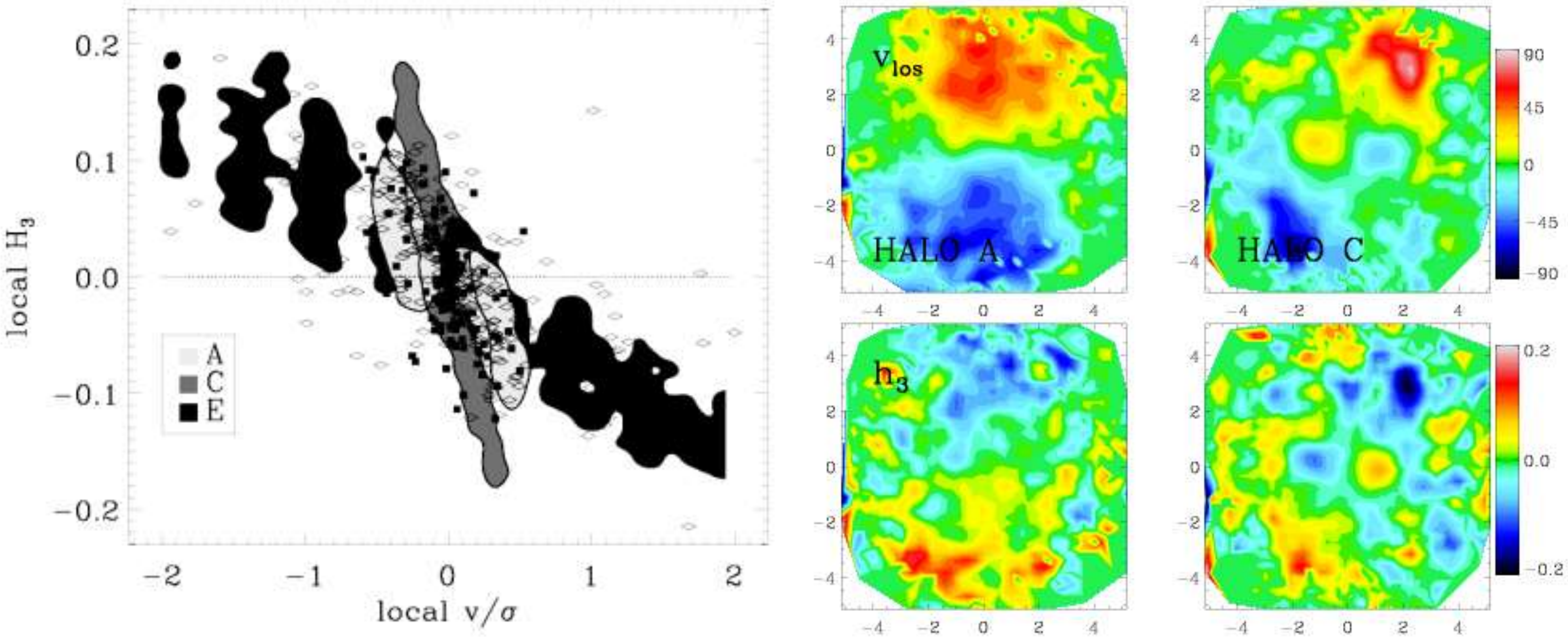
- Early assembly for is dominated by in situ star formation
- For A & C late assembly is dominated by accretion of stars (with respect to the more massive progennitor)
- Late assembly of C is dominated by in situ star formation
- Accreted stars assemble at larger radii (Trujilo et al. 2006)
- Late assembly either dominated by stellar accretion (early-type) or gas inflow (later-type)

Observables….



- Galaxy A has assembled 80% of its mass at z=1 and resembles observed evolved galaxies (R-K=4.6, I-K=3.2, no dust)
- One component surface brightness profiles for A & C
- Full analysis of the LOSVD: negative h_3 (Naab et al. 2006), central dispersion dip

Observables….



- All galaxies are disky and rotating, with asymmetric LOSVDs comparable to intermediate ellipticals
- Observed features like h_3-v/σ anti-correlation, KDC
- Galaxy A & C fall on the FP, slightly blueward the CM-relation, galaxy A (200^3) falls right on the CM-relation

Conclusions

•Higher numerical resolution can reduce late infall of cold gas and star formation in simulated galaxies

•Efficient gas heating during the formation of early-type halos, reducing further infall of cold gas, additional energy sources are not vital to make reasonable ellipticals ☐

•Simulations did not include additional feedback from SN or AGN

•2 out of 3 simulated galaxies have kinematic and photometric properties in good agreement with present day elliptical galaxies

•Early-type galaxies grow in mass and size by stellar mergers/accretion☐

to do… more statistics, high res. simulations of higher mass galaxies, high redshift properties, detailed impact of stellar/AGN feedback, detailed study of compression and shock heating is coming up… ☐