Current Picture: Hierarchical Galaxy formation

Galaxies don't assemble monolithically, but rather from the agglomeration of many small units — it takes a village of little monoliths to make a big one.

Early density field a Gaussian random mess of little density fluctuations. Many of these things collapse first, then merge to form bigger halos

This is what is seen in structure formation simulations

timing	CMB
$z \approx 30$	little dark matter halos form
$z \approx 10$	first baryons fall into little halos; reionize universe
	Galaxies merge continuously
$z \approx 2$	First big galaxies begin to emerge
$z \approx 1$	Most merging done in ΛCDM (not in SCDM) continual, gradual accretion of DM onto outer edge of halo
$z \approx 0$	Small mergers continue, big ones become rare.

Generally satisfactory but

Hierarchical Galaxy Formation looks a lot like Monolithic Galaxy Formation if it happens fast enough

Hierarchical merging good at building bulges, lousy at preserving cold stellar disks

"bulge-less" galaxy problem
MW only suffered one substantial merger, a long time ago (thick disk)
→ unusual for ΛCDM

Necessary steps in galaxy formation

- dark matter halos form
- gas accreted by halos
- gas dissipates, forms disk — ADIABATIC COMPRESSION
- stars form in disks — FEEDBACK
- some merging occurs (SZ fragments)
- accretion tapers off ... ends?
- SFR tapers off
- subsequent merging/accretion events (rare?)

Important events in galaxy formation

$t \approx 3 \times 10^5$ yr	Baryons decouple from CMB photons
First $\sim \frac{1}{2}$ Gyr	Dark matter halos grow Baryons fall into DM halos A few stars form during collapse: stellar halo
$t \approx 1$ Gyr	Gas settles into rotating disk (dissipational collapse) Stars start to form in gas disk
$t \approx$ a few Gyr	: Further mass accretion. Thick disk formation
$t \approx 9$ Gyr	Sun forms
	other, lesser mass accretions
$t \approx 13.5$ Gyr	present

2 things happen during disk formation to alter DM halos

Adiabatic contraction (see Keynote slides)

As baryons dissipate, they sink to the center of the potential well and drag some DM with them. If the process is gradual enough, this contraction can be modeled as adiabatic.
[This approximation appears to be better than it should be even in hierarchical simulations – Choi et al]

DM becomes denser in center, fluffier further out.

Details matter. Most commonly used "Blumenthal" algorithm is WRONG

Feedback

Fresh energy input by sources formed in the galaxy can, in principle, somewhat counteract compression by putting energy into the surroundings. Gas is heated and perhaps expelled, perhaps dragging dark matter with it.

Important energy sources:

BIG galaxies – AGN thought to matter at high mass end
SMALL galaxies – SN " " " " low " "
– stellar winds "

Feedback is invoked in a hand-waving way to solve many problems

Feedback type

AGN – supermassive black holes

Star formation
- Supernovae
- stellar winds
- radiation pressure

Exotic
- High mass X-ray binaries