The separate formation of different galaxy components

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Overview:

- Galaxy properties and morphologies
- Main galaxy components: bulges and disks
- A “simple” case: the formation of lenticular (S0) galaxies
- Summary
Normal Spiral Galaxy
Barred Spiral Galaxy

Barred Galaxy NGC 1365
(VLT UT1 + FORS1)
Elliptical Galaxy
Lenticular (S0) Galaxies
Irregular Galaxies

Small Magellanic Cloud

Large Magellanic Cloud

M82
Hubble Morphological Classification System

- Ellipticals: E0, E4, E7, S0 or SB0 (Lenticular galaxy)
- Normal spirals: Sa, Sb, Sc
- Barred spirals: SBa, SBb, SBc
- Irregulars
Photometric Bulge-Disk Decomposition

Christlein & Zabludoff 2004
How do S0s form?
Photometric Bulge-Disk Decomposition

- Bulges growing?
- Disks fading?
- Different progenitors?
Morphology-Density Relation at $z \sim 0$

Hubble & Humason (1931)
Dressler (1980)
Distant clusters: HST data
At $z \sim 0$
(Present time)
Many S0s in clusters
Few Spirals in clusters

At $0.36 < z < 0.6$
(~5 Billion years ago)
Many Spirals in clusters
Few S0s in clusters

ESO Distant Clusters Survey (EDisCS)
Desai et al. (2007)
(cf. Dressler et al. 1997)
Evolution of disks in clusters

- Possible mechanisms:
  - ram-pressure stripping
    - of gas halo (Bekki et al. 2002)
    - of disk gas (Quilis et al. 2000)
  - galaxy-galaxy interactions
    - harassment (Moore et al. 1998)
    - mergers (Bekki 1998)
  - cluster tidal field (Bekki 1999)
Cluster Formation (Cold Dark Matter Cosmogony)
Galaxy falling into Virgo cluster

Cardiff Numerical Simulations Group (2009)
Ram Pressure:

Gas disk interacting with hot intracluster medium

Cardiff Numerical Simulations Group (2009)

Quilis, Moore & Bower (2000)
Tully-Fisher relation for low-z Spirals

Pierce & Tully 1992
Evolution of a Fading Disc Galaxy
Other Formation Mechanisms

Mergers?

Gas-Rich Collapse?

Gas-Poor Collapse?

Something Complete Different?
factor of 3
S0 Tully-Fisher offsets vs. age

Bedregal, Aragón-Salamanca, Merrifield & Cardiel 2007
Prediction: Maximum Tully-Fisher offset for S0s

\[ \Delta M_B \text{(max)} \sim -2.5 \text{mag} \]
Bedregal, Aragón-Salamanca & Merrifield 2006
Globular Clusters in the Milky Way

Diagram showing the structure of the Milky Way galaxy, indicating the Sun's position in the Galactic nucleus, and the distribution of globular clusters in the Halo.
Evolution of a Fading Galaxy

$S_N \propto \frac{N_{\text{globulars}}}{L_{\text{galaxy}}}$
GC Specific Frequency vs. Galaxy Colours

Aragón-Salamanca, Bedregal & Merrifield 2006
Spectral Bulge-Disk Decomposition

Johnston et al. 2012
Spectral Bulge-Disk Decomposition

NGC1375

Bulge Spectrum

Disc Spectrum

Hβ, Mg triplet

Normalized Flux

Wavelength (Å)
Spectral Bulge-Disk Decomposition

Johnston et al. 2014
Spectral Bulge-Disk Decomposition

Johnston et al. 2014
Origin of the Young Bulge Stellar Populations

- Bulge and disc stellar populations show a correlation
- The offset shows bulges have enhanced Fe-enrichment
  - Fe-enriched disc gas dumped in the central regions, until a final SF event created the young bulge stellar populations and quenched all star formation
Separate star-formation history of Bulge and Disk

1. Disc undergoes continuous SF until quenching begins.

2. During quenching, Fe-enriched gas is dumped in the central regions.

3. Bulge undergoes a final SF event, using up the dumped disc gas and truncating all SF in the galaxy.

4. After all SF has been quenched, the spiral galaxy transforms into an S0.
Summary

- Bulges and disks are two distinct galaxy components.
- They have very different properties → their formation mechanisms must be different.
- S0s provide direct evidence of the separate evolution of bulges and disks.
- Lenticular (S0) galaxies are the descendents of spiral galaxies that stopped forming stars in the last few billion years.
  - Star formation ceased in the disk first, and the disk faded.
  - The last star-formation episode took place in the bulge, increasing its stellar mass/luminosity. It used gas pre-processed in the disk.