The University of Nottingham

The separate formation of different galaxy components

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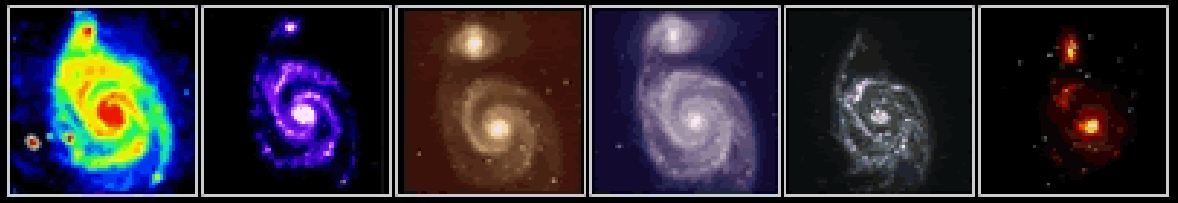

Overview:

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

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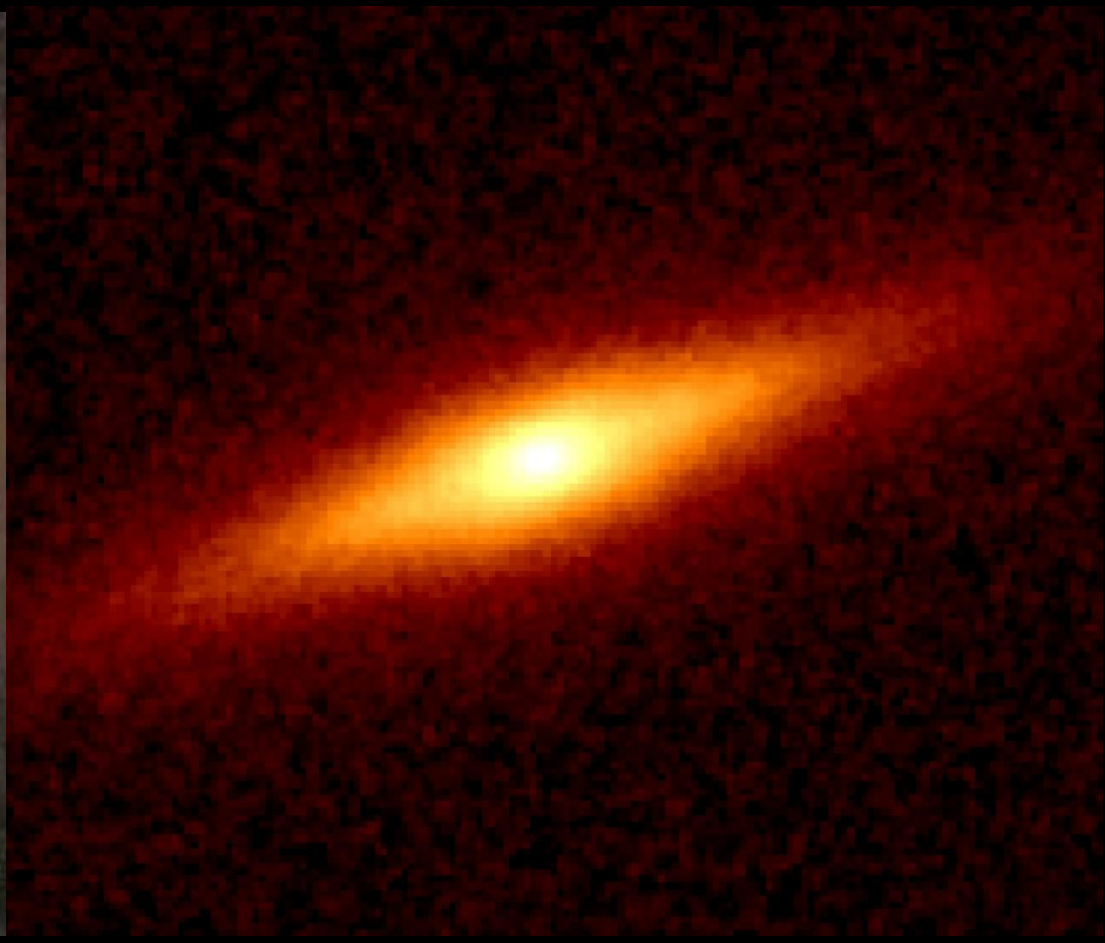
Photo by David Malin

Normal Spiral Galaxy

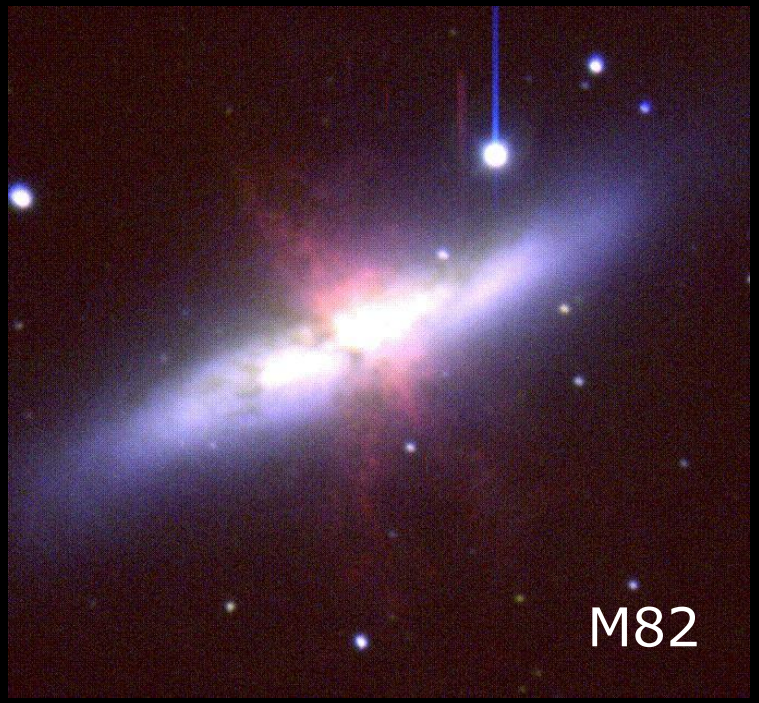
Barred Spiral Galaxy

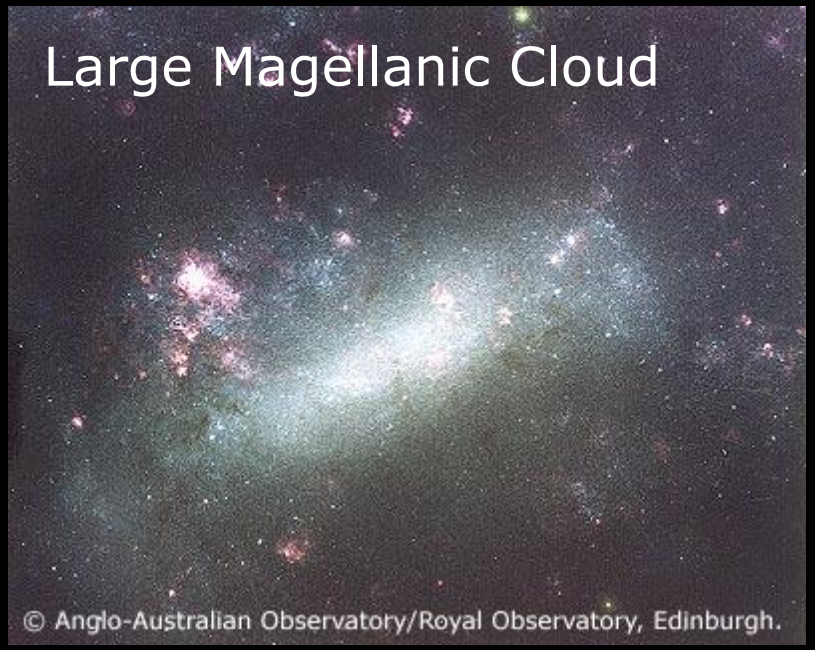
Elliptical Galaxy

Lenticular (S0) Galaxies

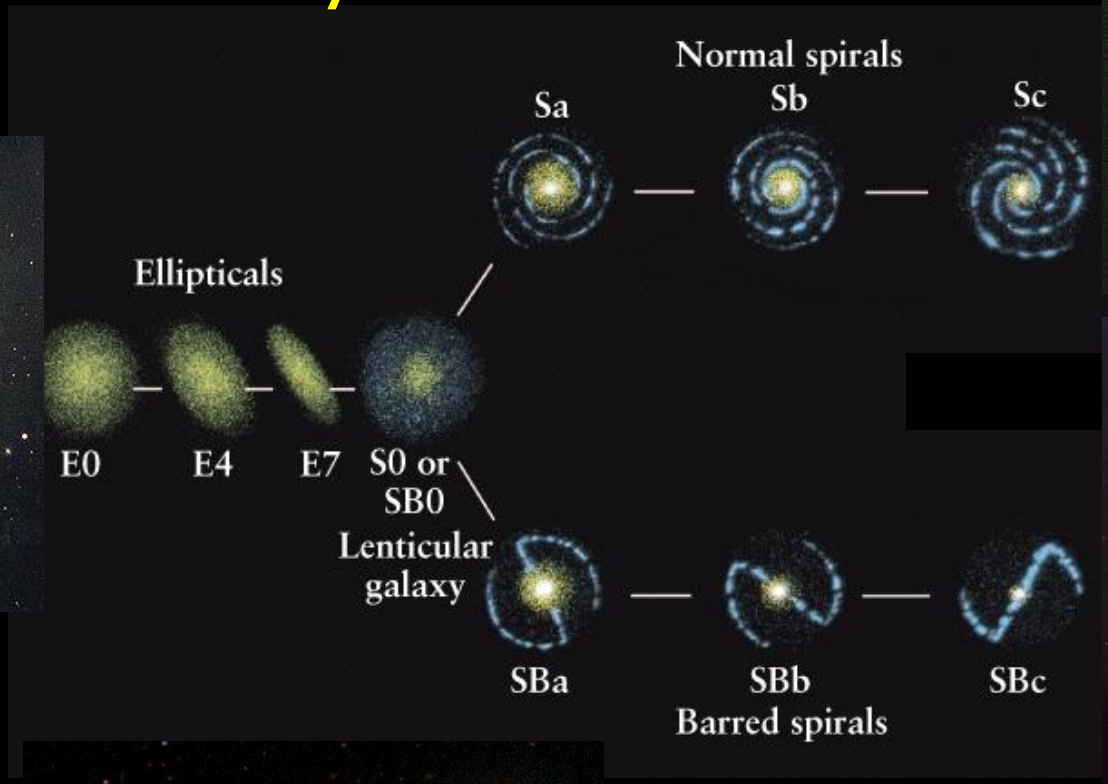


Irregular Galaxies



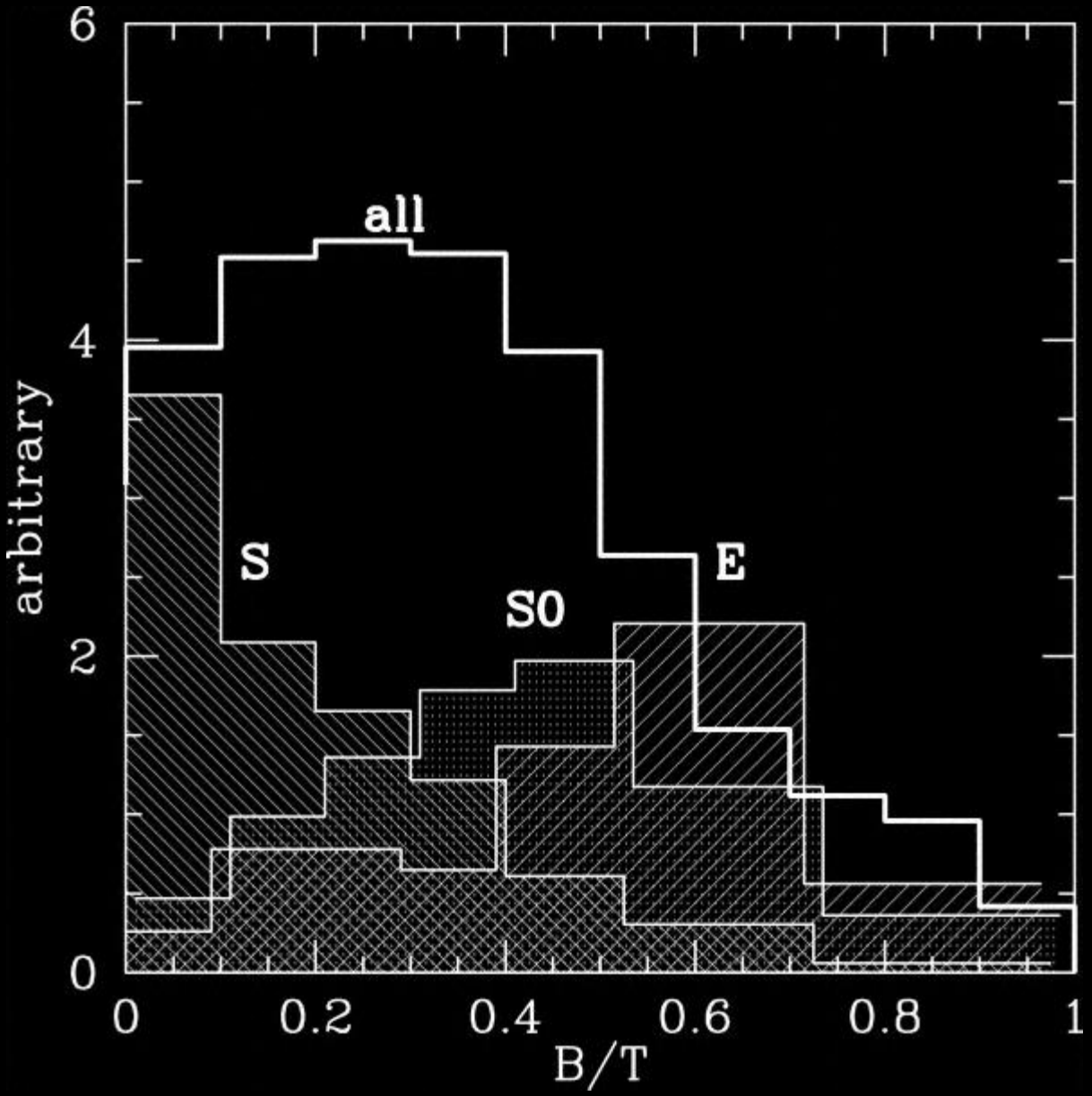


Hubble Morphological Classification System



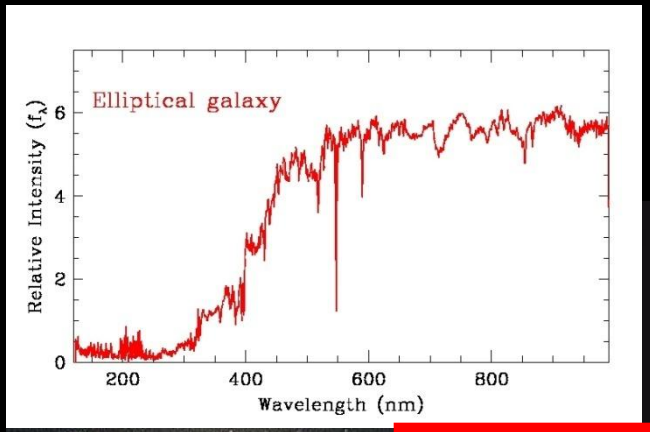
Irregulars

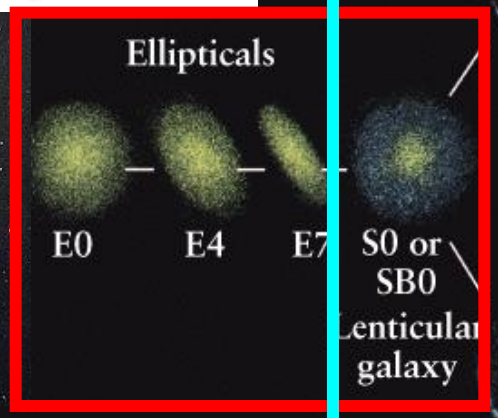
Photometric Bulge-Disk Decomposition

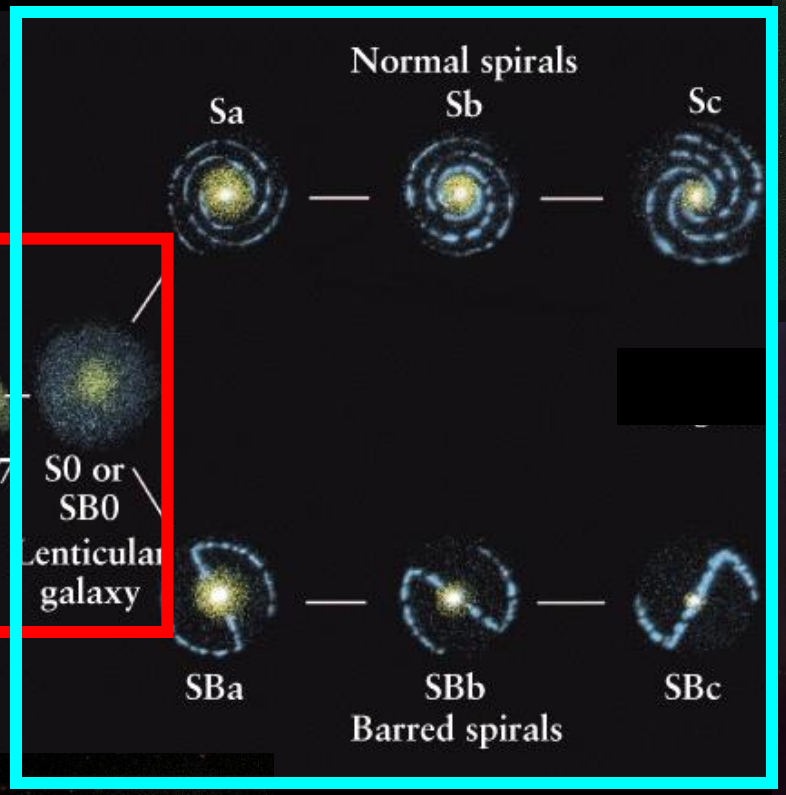


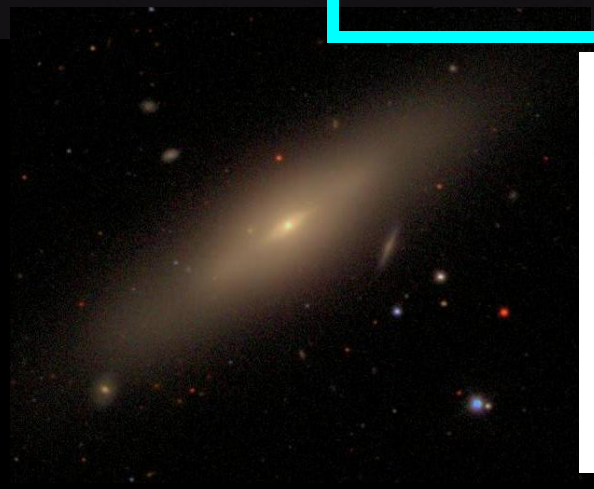
Christlein & Zabludoff 2004

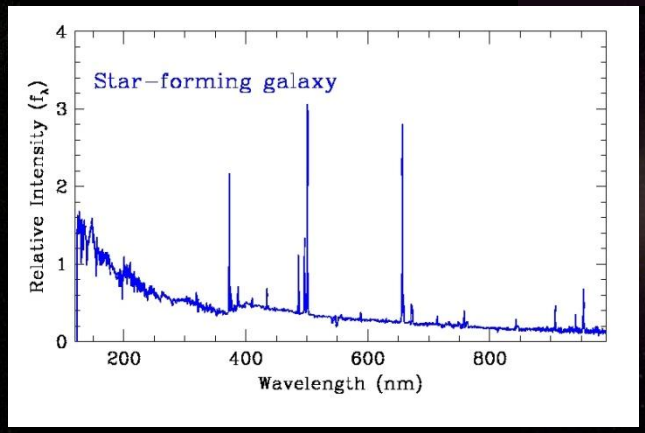
How do S0s form?



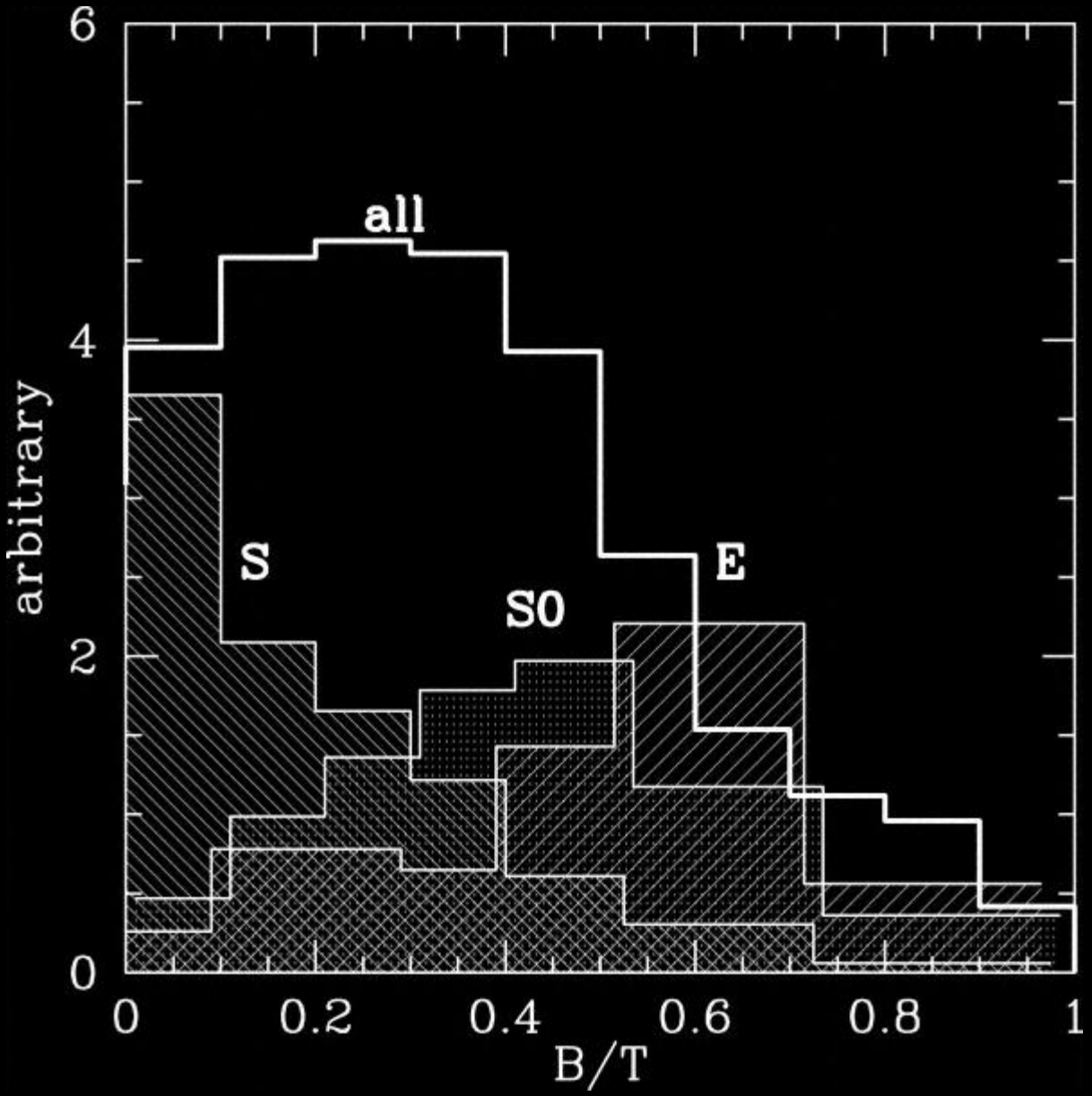








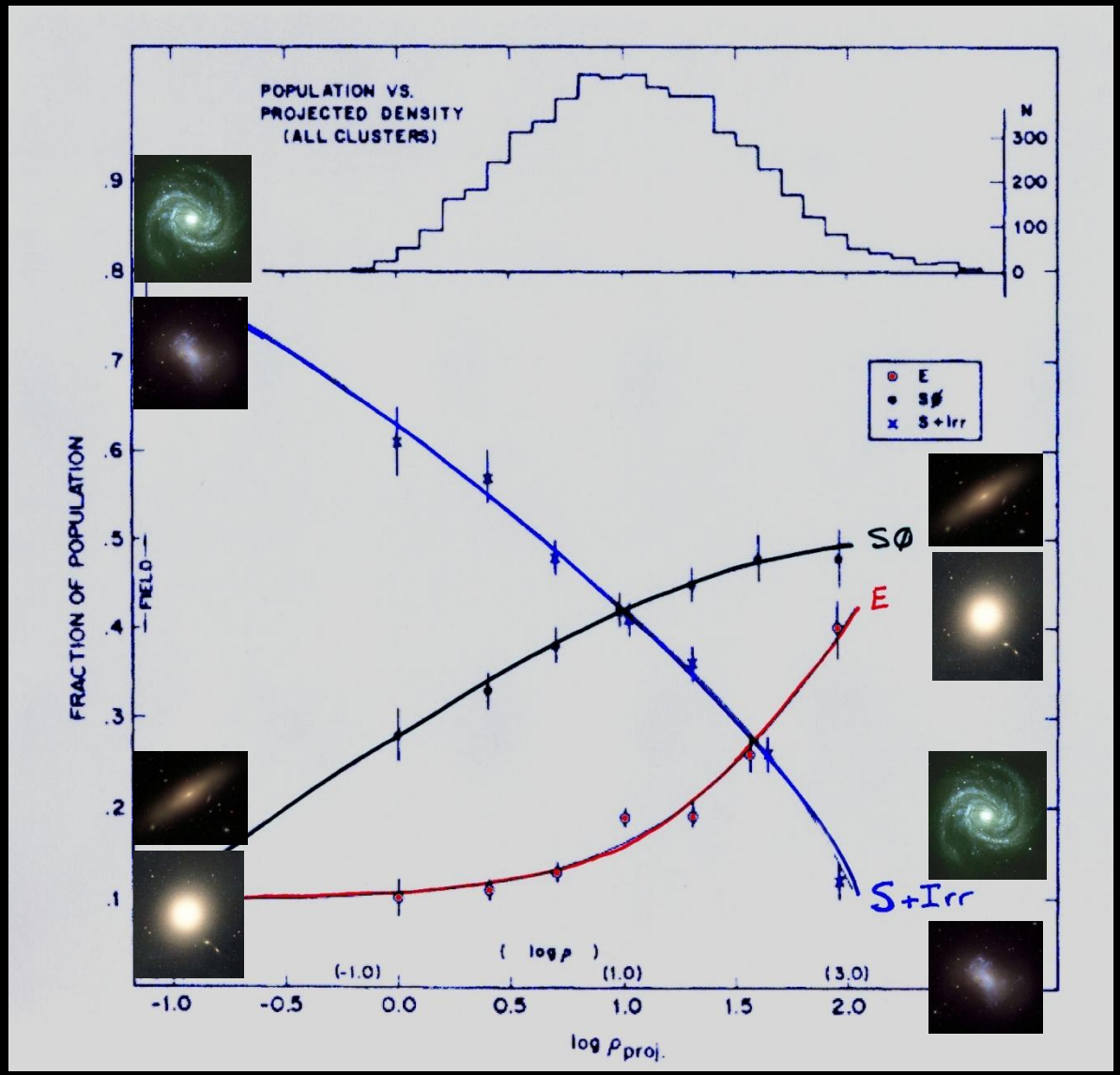
Photometric Bulge-Disk Decomposition



- Bulges growing?
- Disks fading?
- Different progenitors?

Christlein & Zabludoff 2004

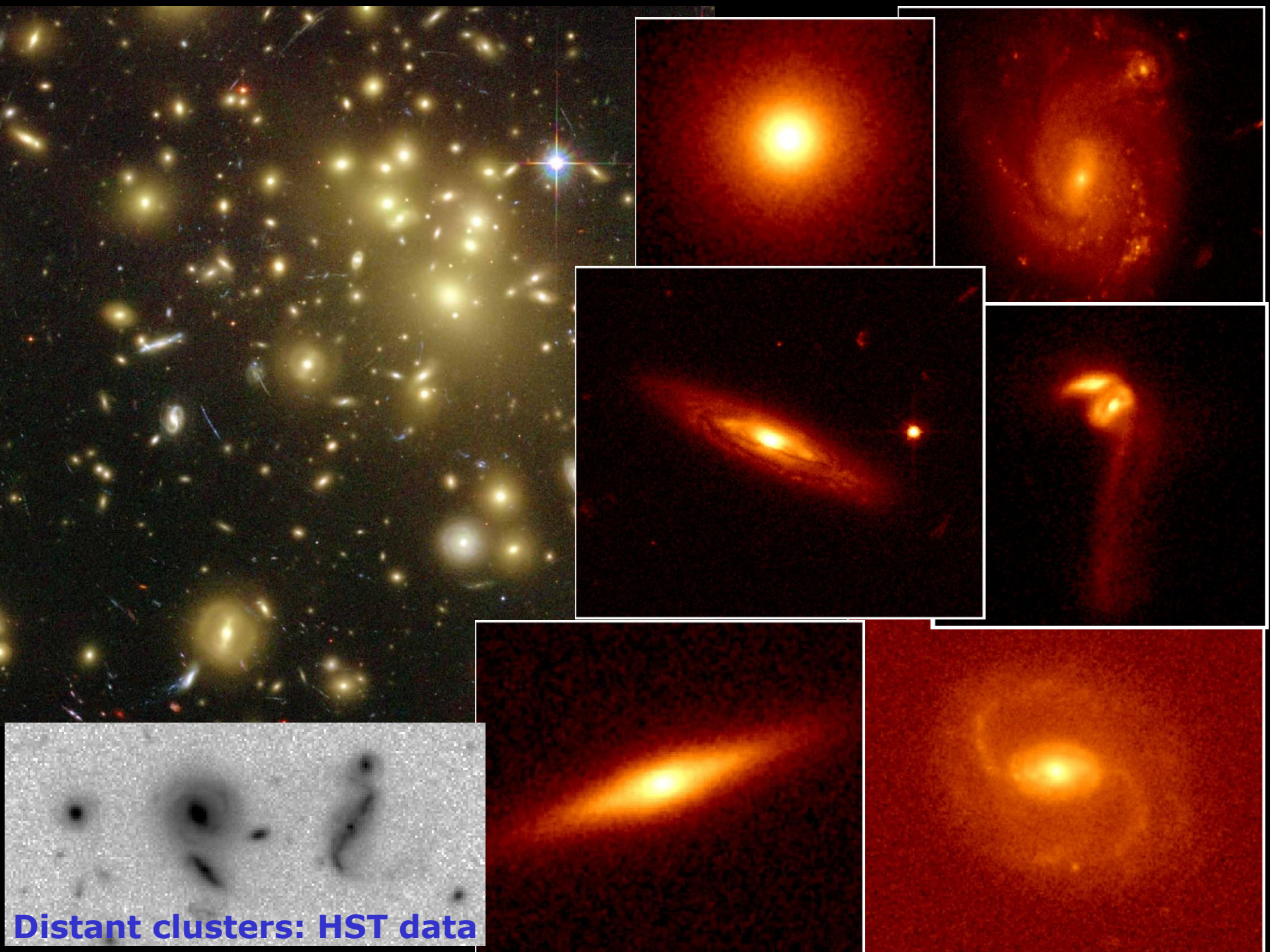
Morphology-Density Relation at z~0



Density

Hubble & Humason (1931)

Dressler (1980)

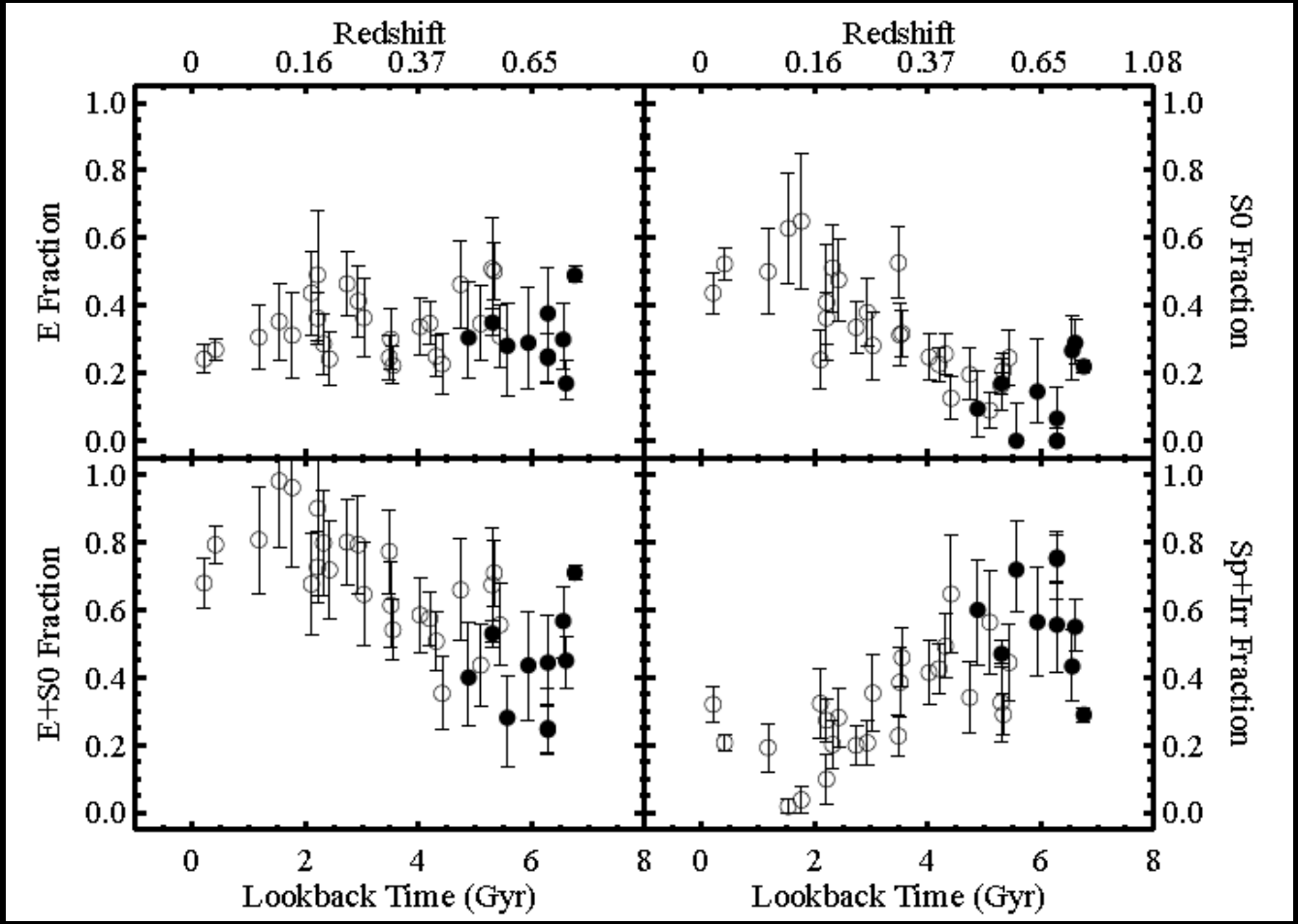

Distant clusters: HST data

At z~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



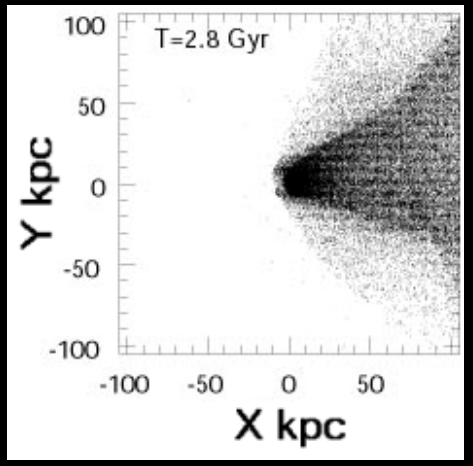
ESO Distant Clusters Survey (EDisCS)

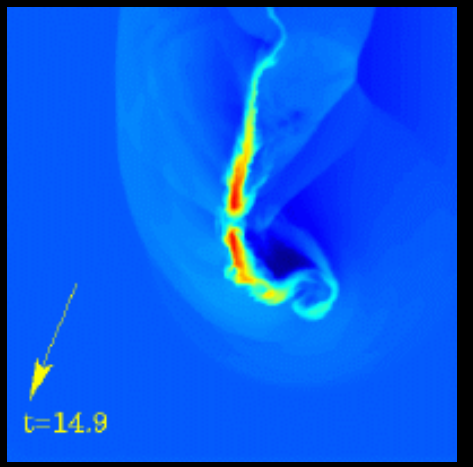
Desai et al. (2007)

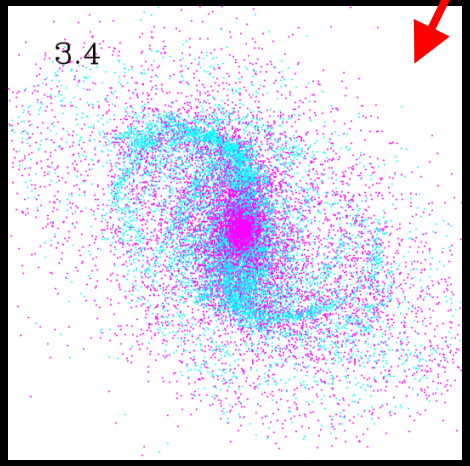
(cf. Dressler et al. 1997)

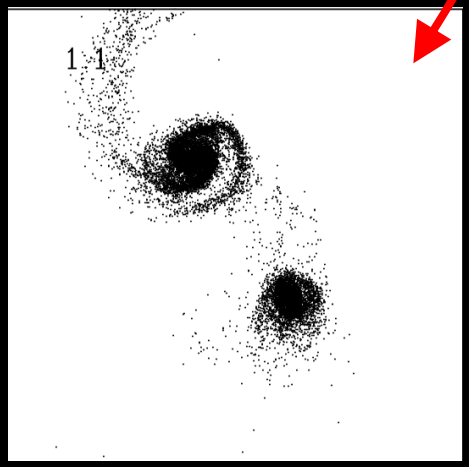
Evolution of disks in clusters

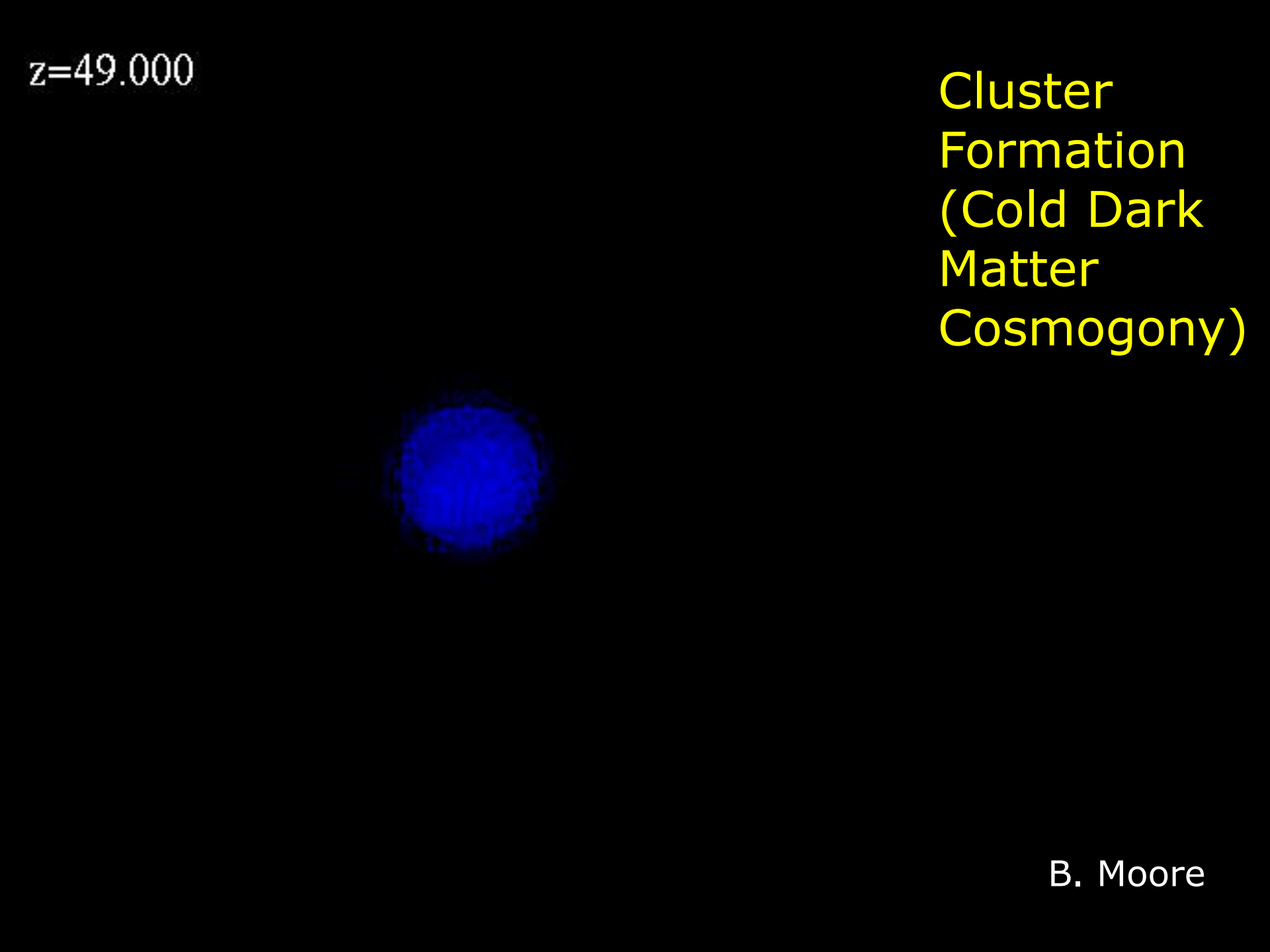
- Possible mechanisms:
  - ram-pressure stripping
    - of gas halo (Bekki et al. 2002)
    - of disk gas (Quilis et al. 2000)
  - galaxy-galaxy interactions
    - harassment (Moore et al. 1998)
    - mergers (Bekki 1998)
  - cluster tidal field (Bekki 1999)





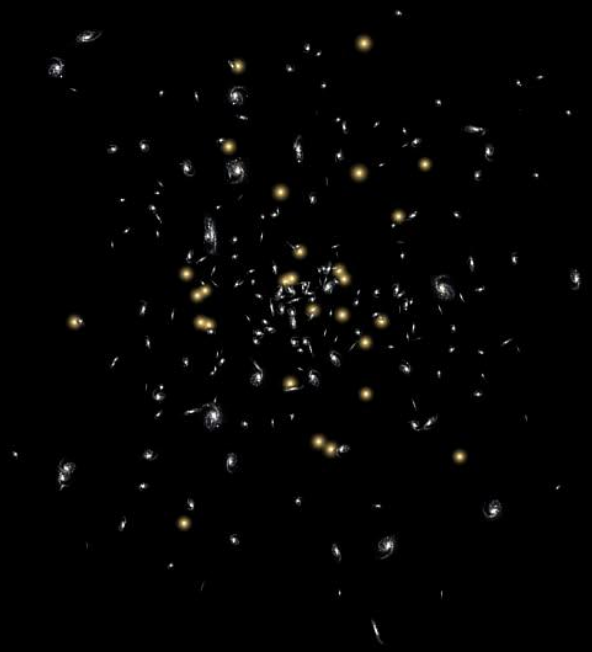


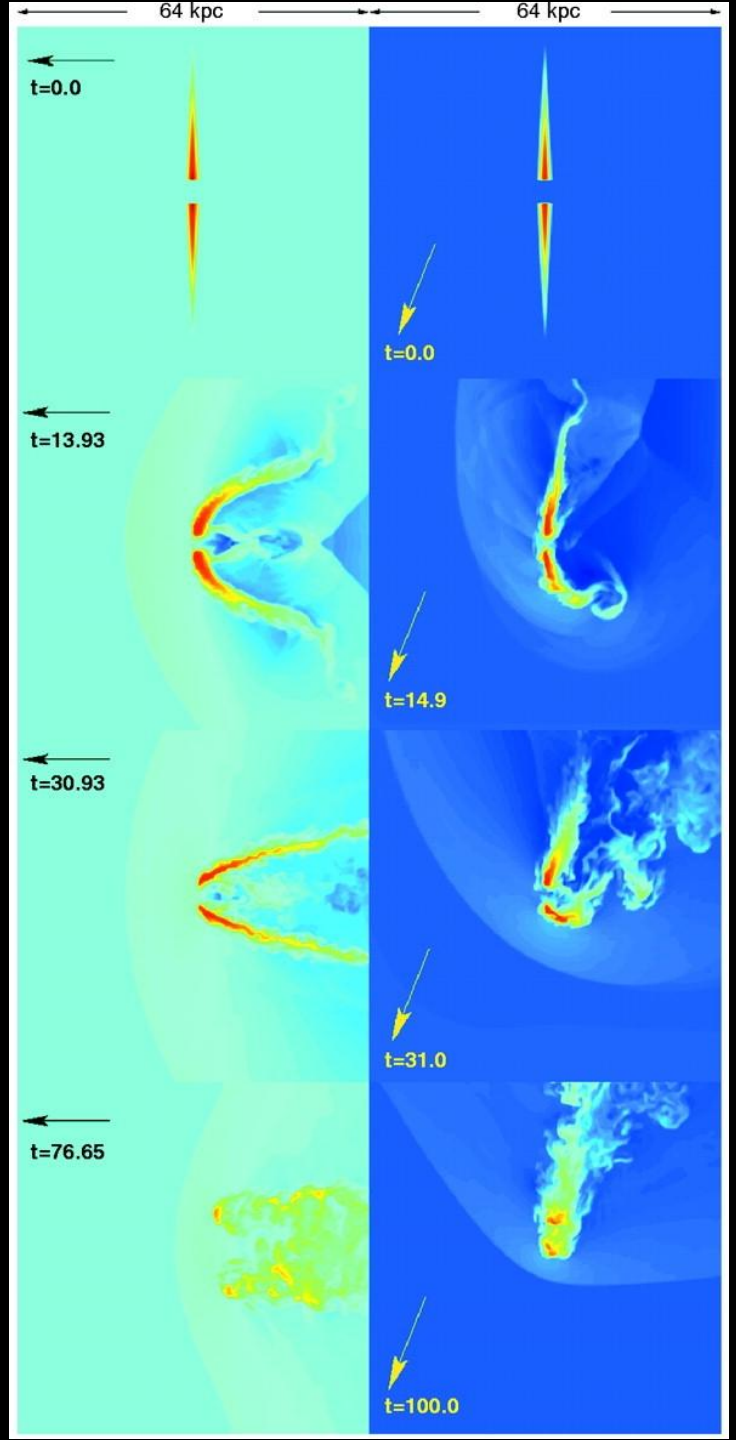



z=49.000
Cluster Formation (Cold Dark Matter Cosmogony)
B. Moore

Galaxy falling into Virgo cluster

Cardiff Numerical Simulations Group (2009)





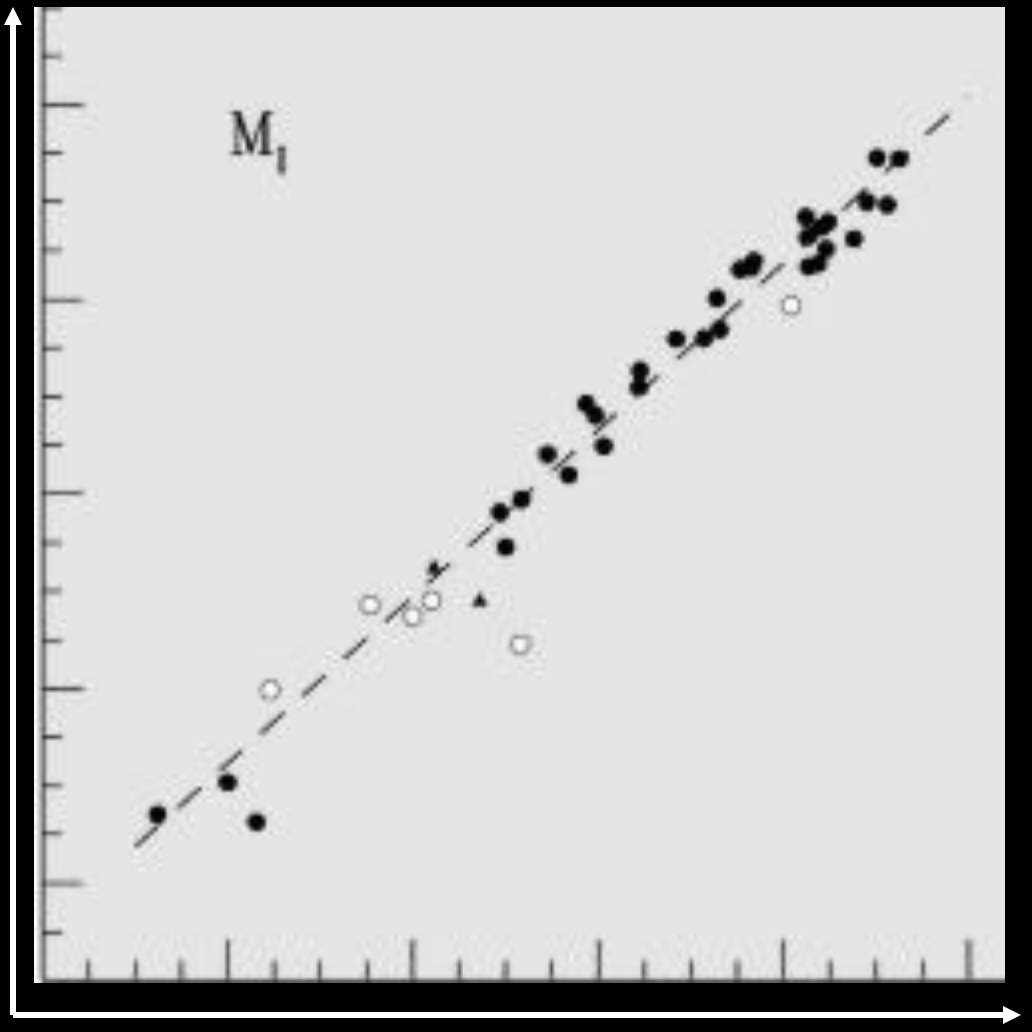
Ram Pressure:

Gas disk interacting with hot intracluster medium

Cardiff Numerical Simulations Group (2009)

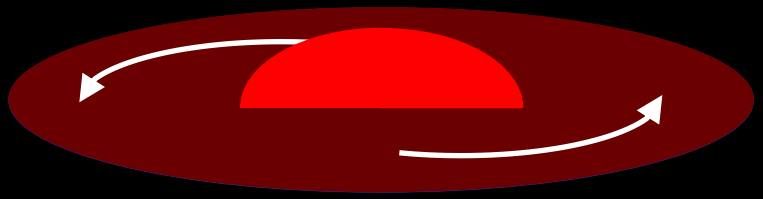
Quilis, Moore & Bower (2000)

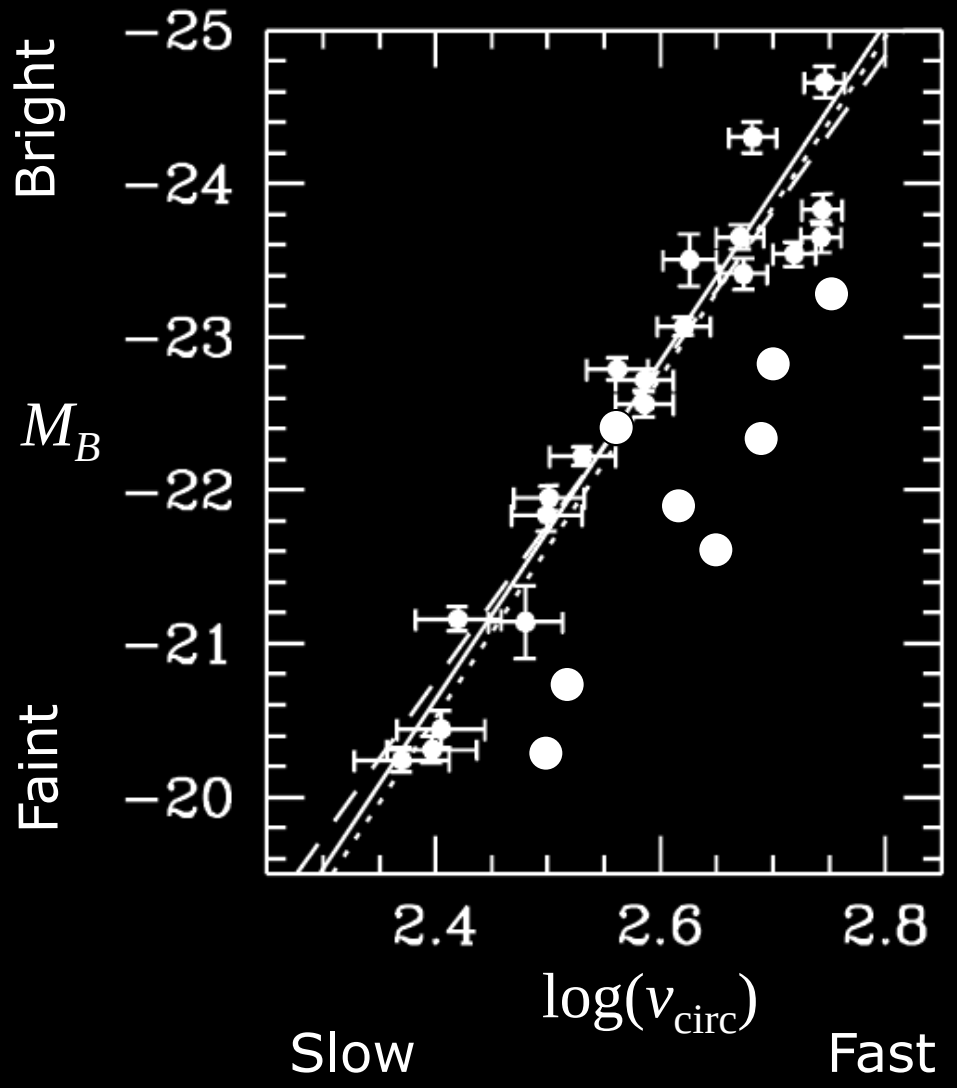
Tully-Fisher relation for low-z Spirals



Pierce & Tully 1992

Evolution of a Fading Disc Galaxy





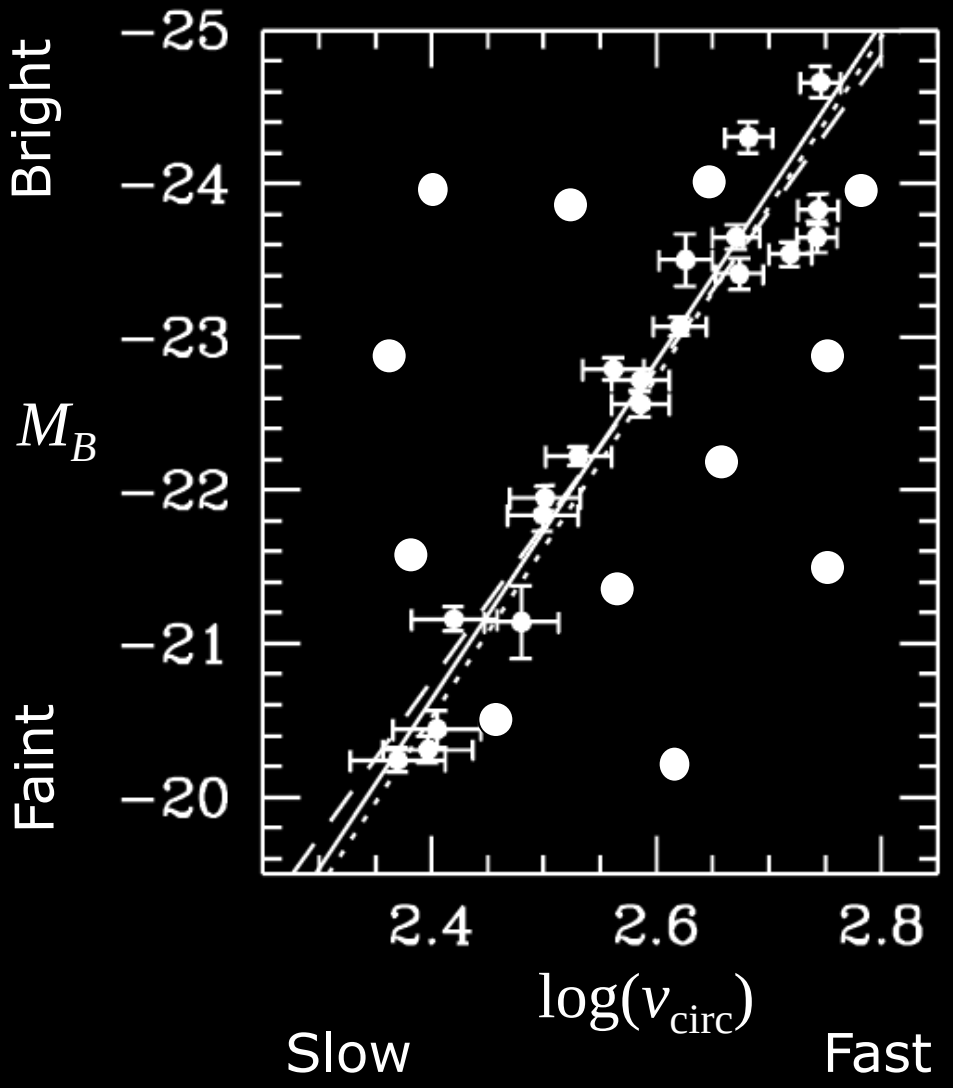
Other Formation Mechanisms

Mergers?

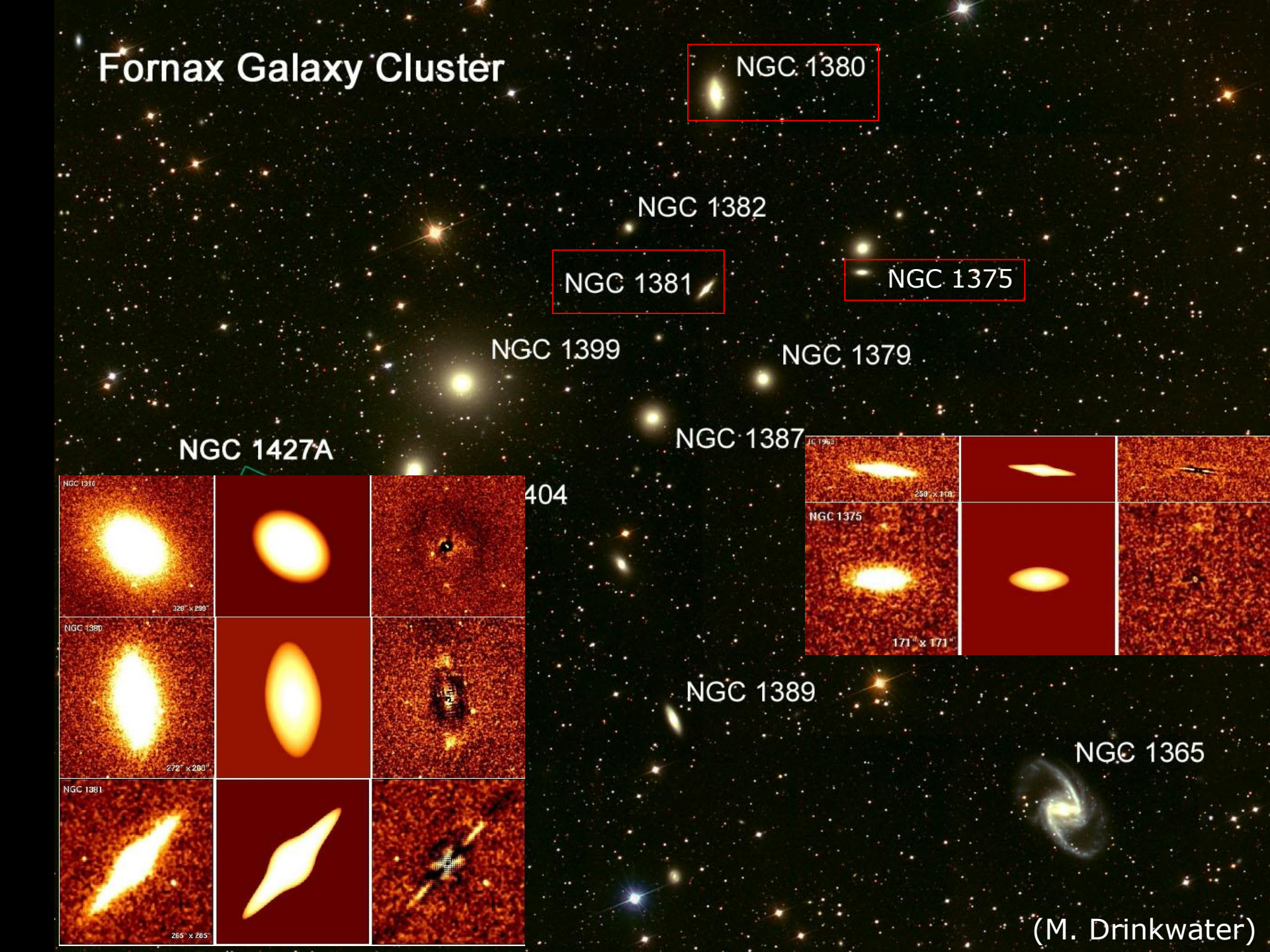
Gas-Rich Collapse?

Gas-Poor Collapse?

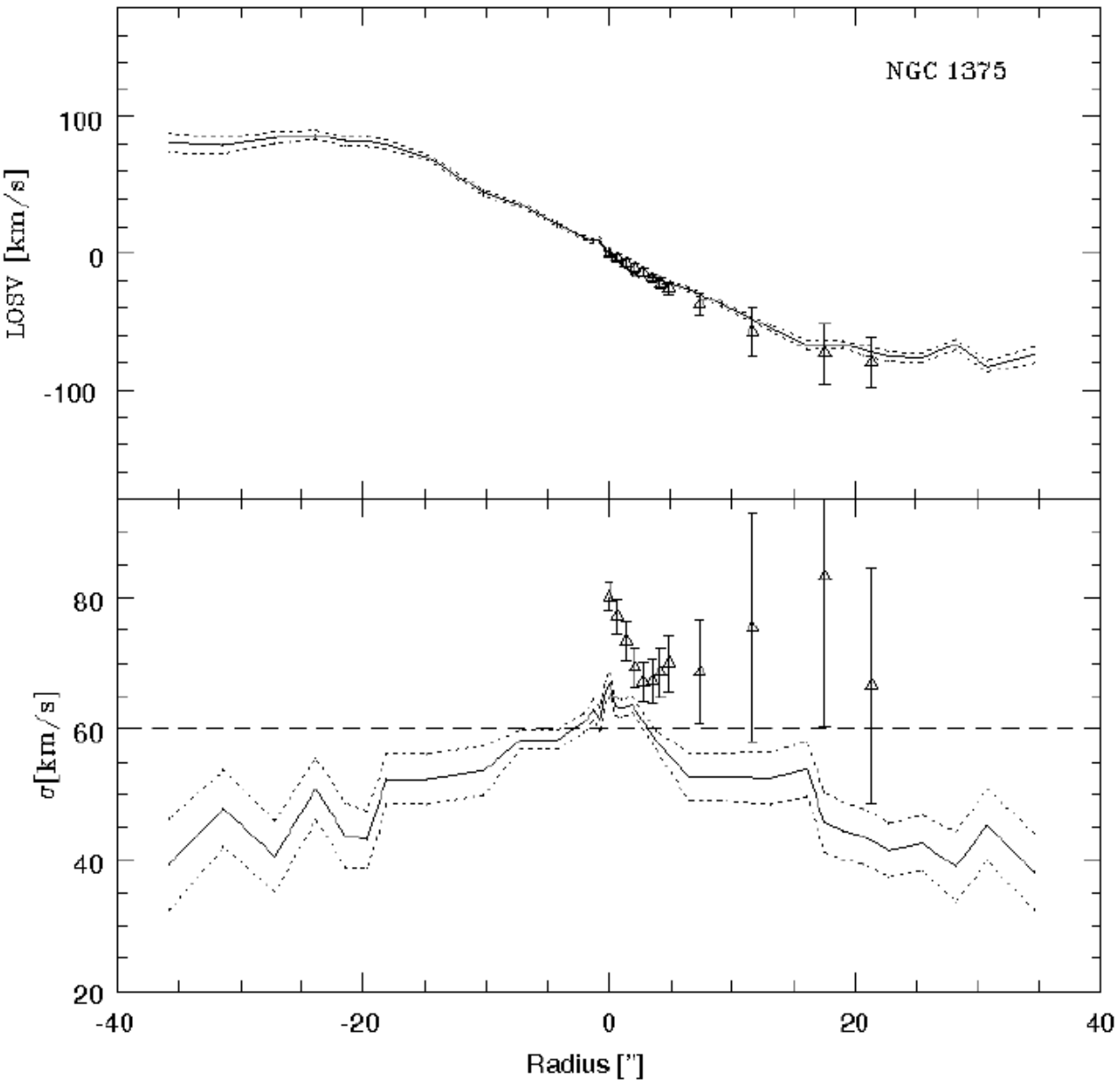
Something
Complete Different?



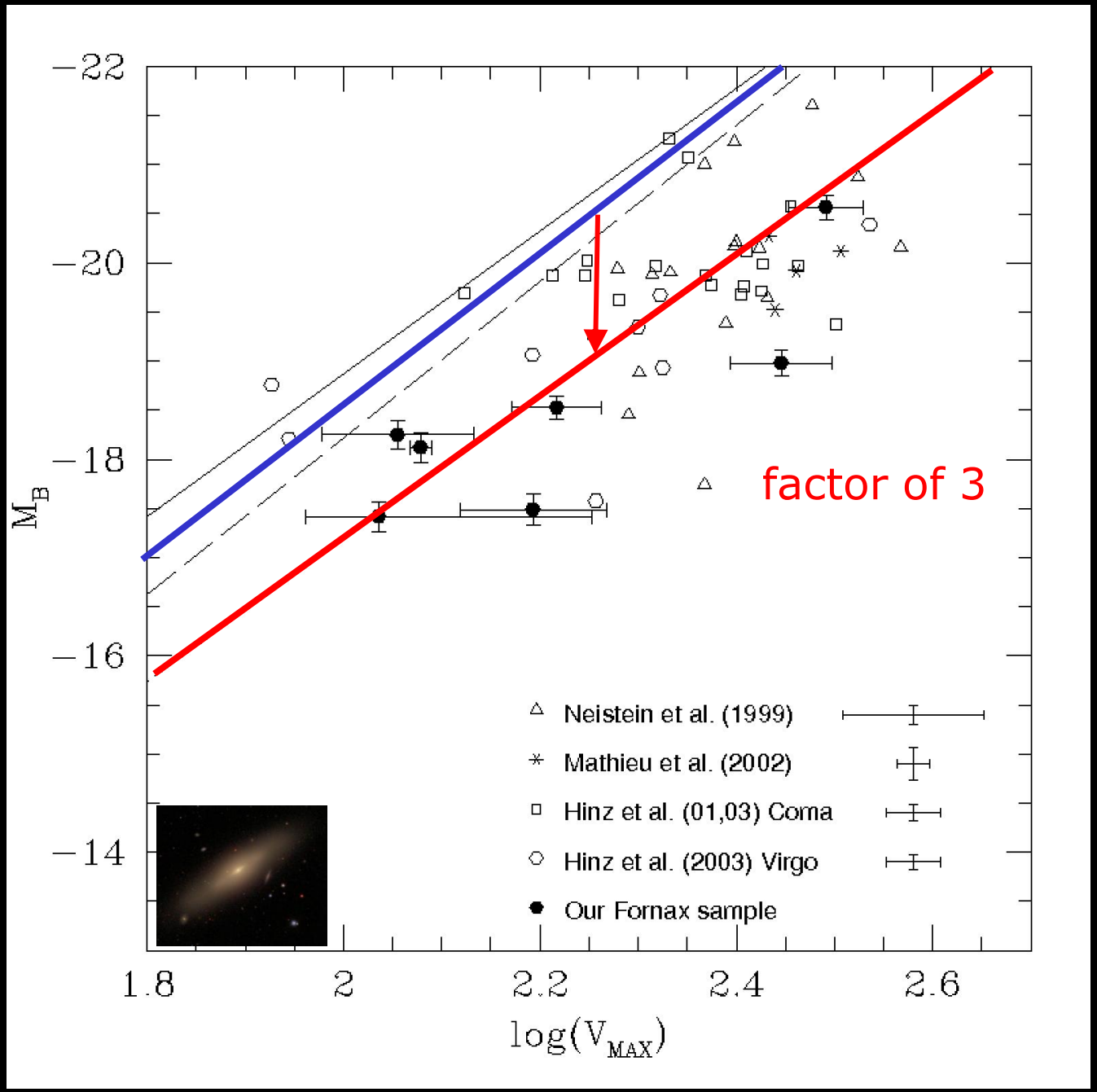
Fornax Galaxy Cluster



(M. Drinkwater)



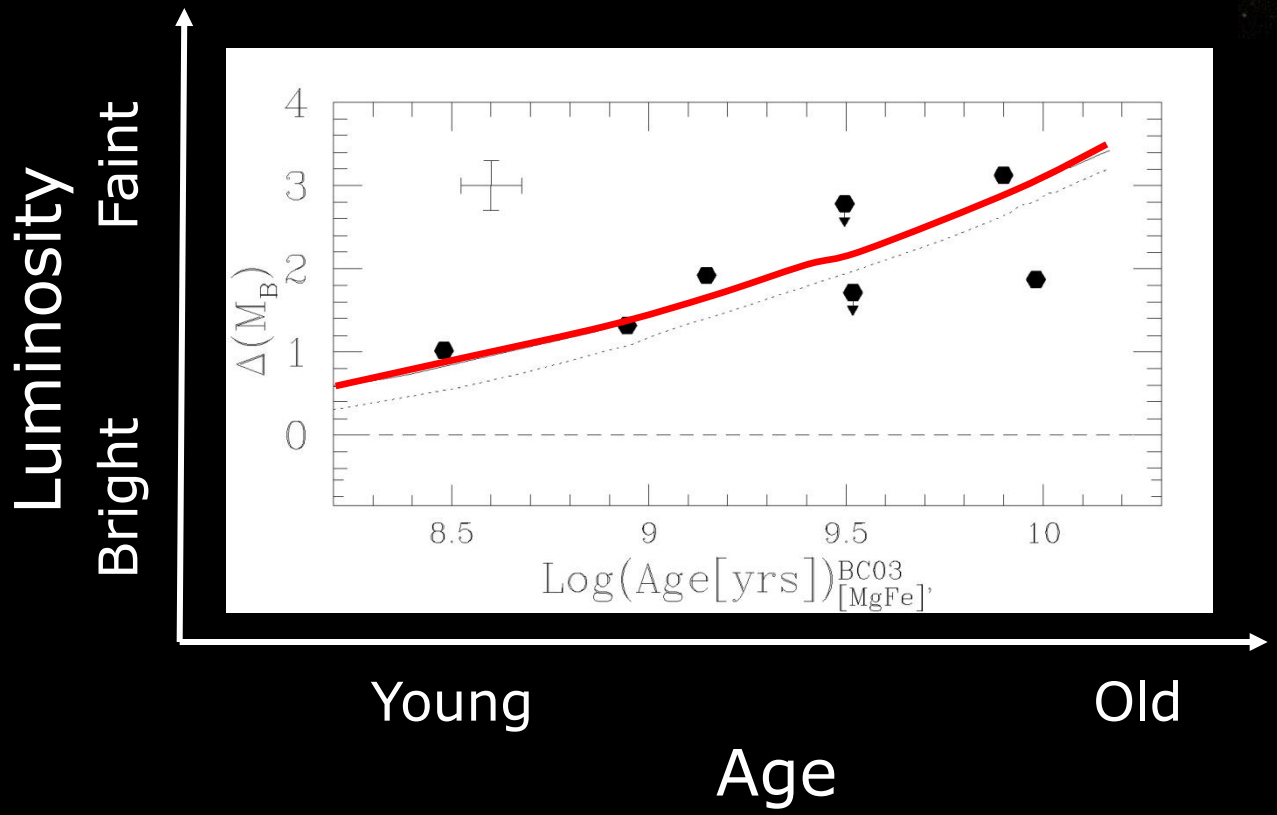
Bedregal, Aragón-Salamanca & Merrifield 2006



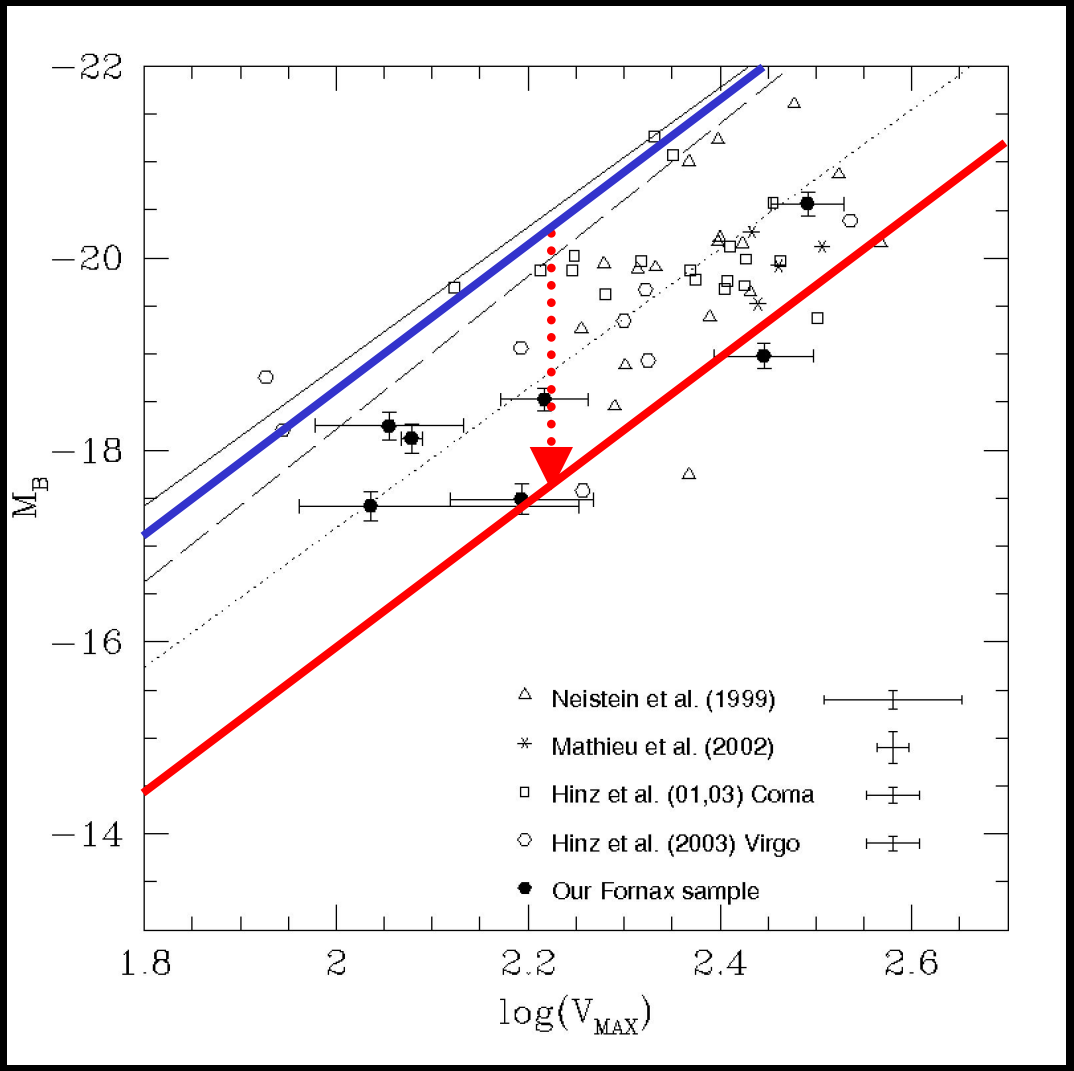
Bedregal, Aragón-Salamanca & Merrifield 2006

S0 Tully-Fisher offsets vs. age

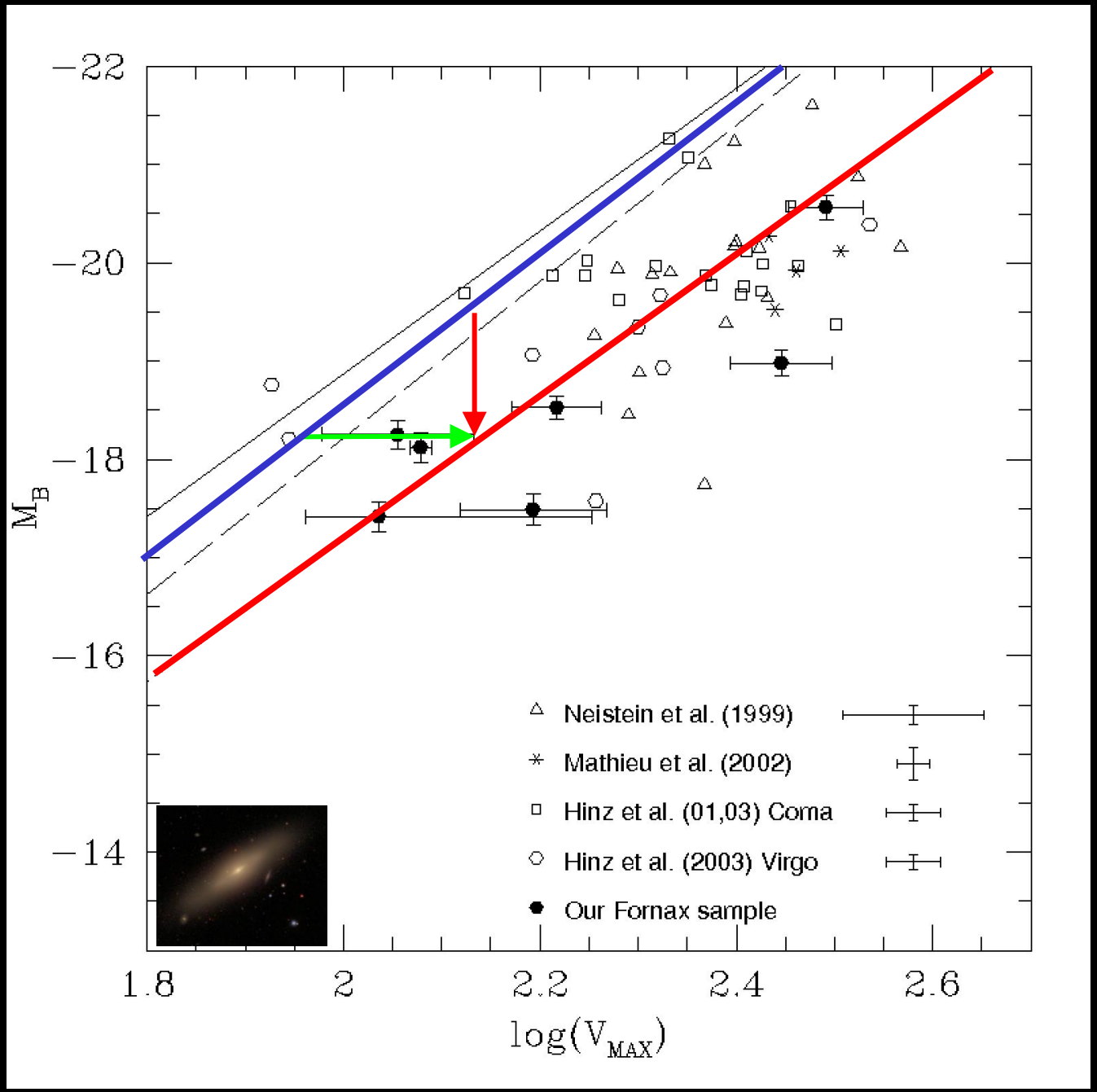
Bedregal, Aragón-Salamanca,
Merrifield & Cardiel 2007



Prediction:
Maximum Tully-Fisher offset for S0s



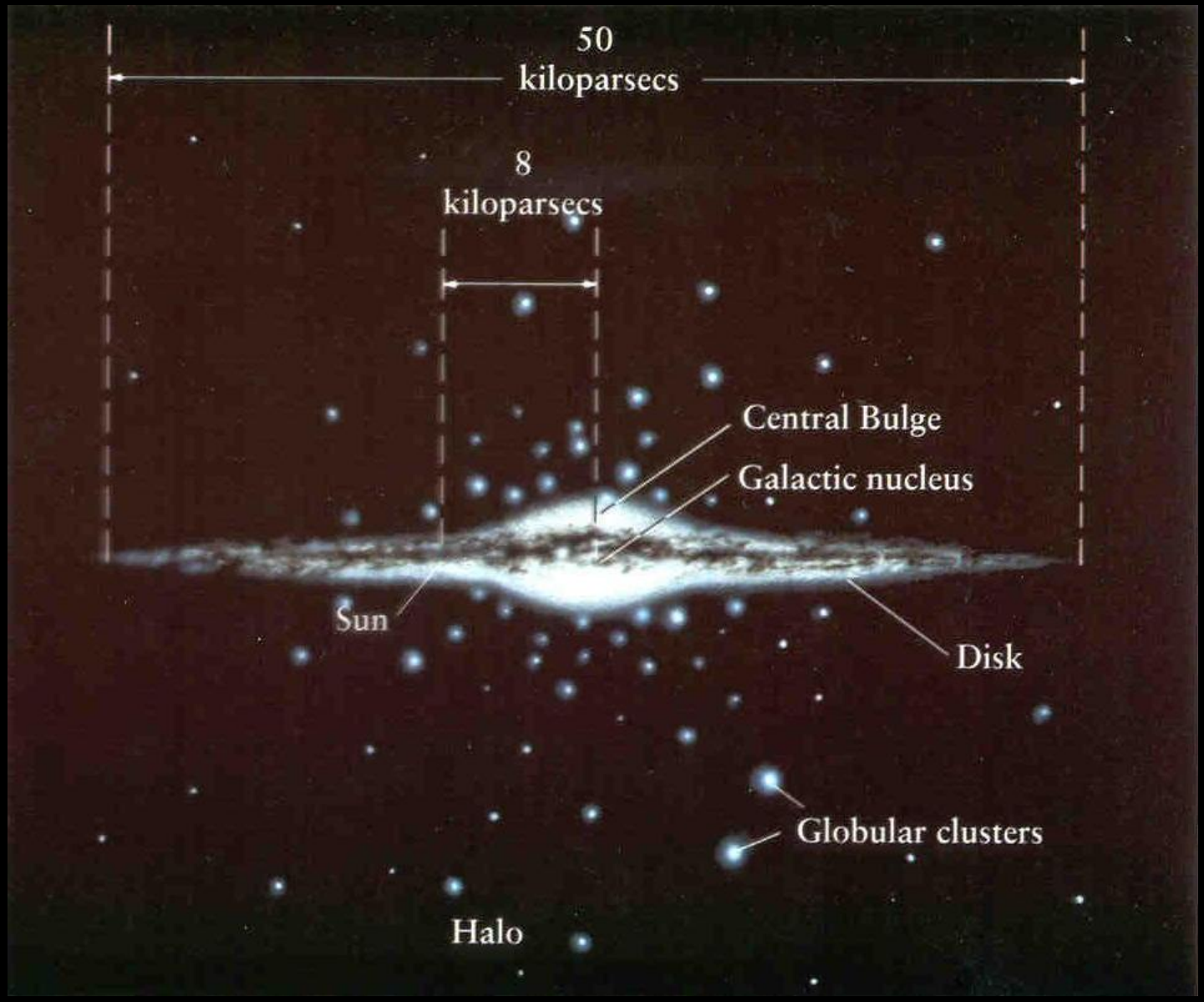
$\Delta M_B(max) \sim -2.5mag$



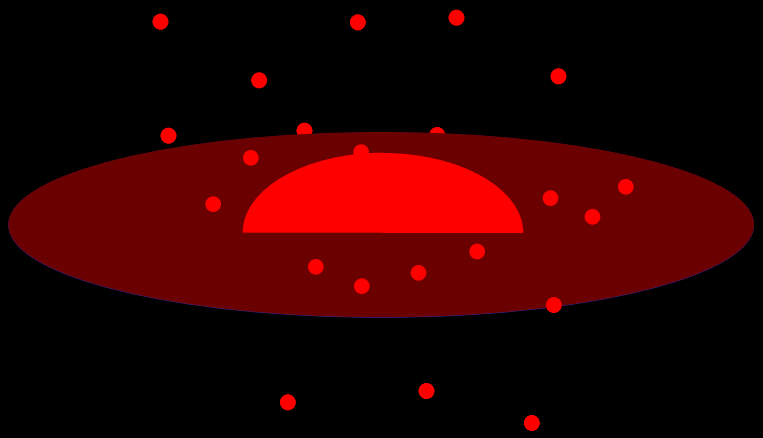
Bedregal, Aragón-Salamanca & Merrifield 2006

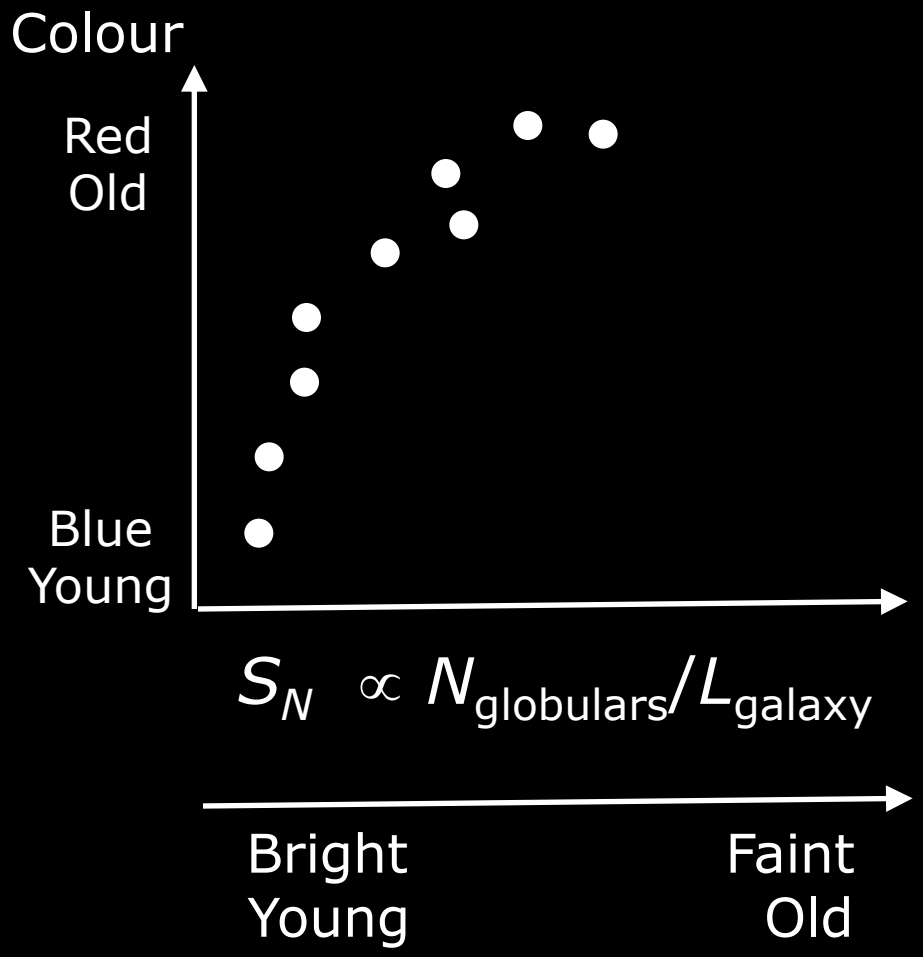
Globular Cluster M13

Globular Clusters in the Milky Way

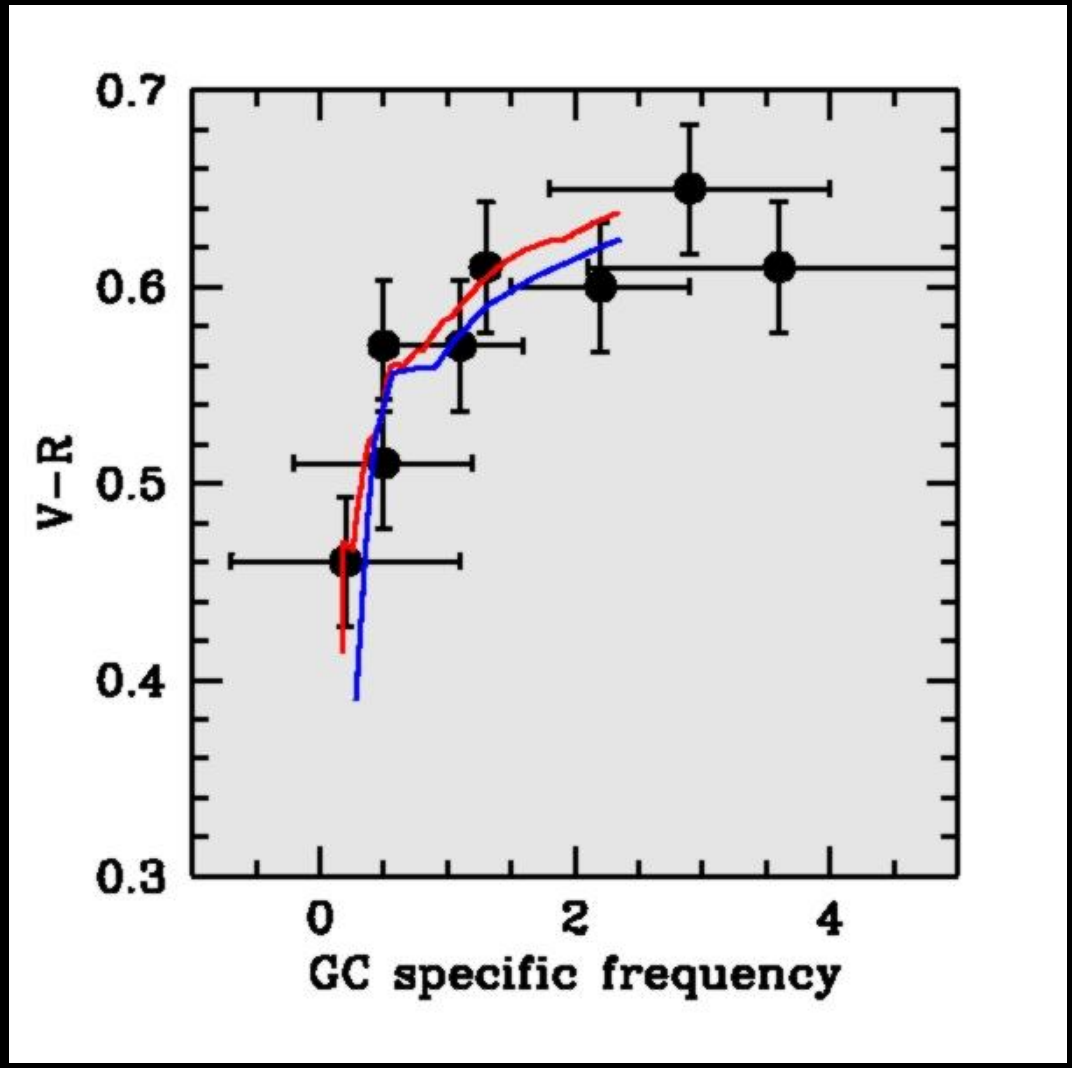


Evolution of a Fading Galaxy





GC Specific Frequency vs. Galaxy Colours



Red
Old

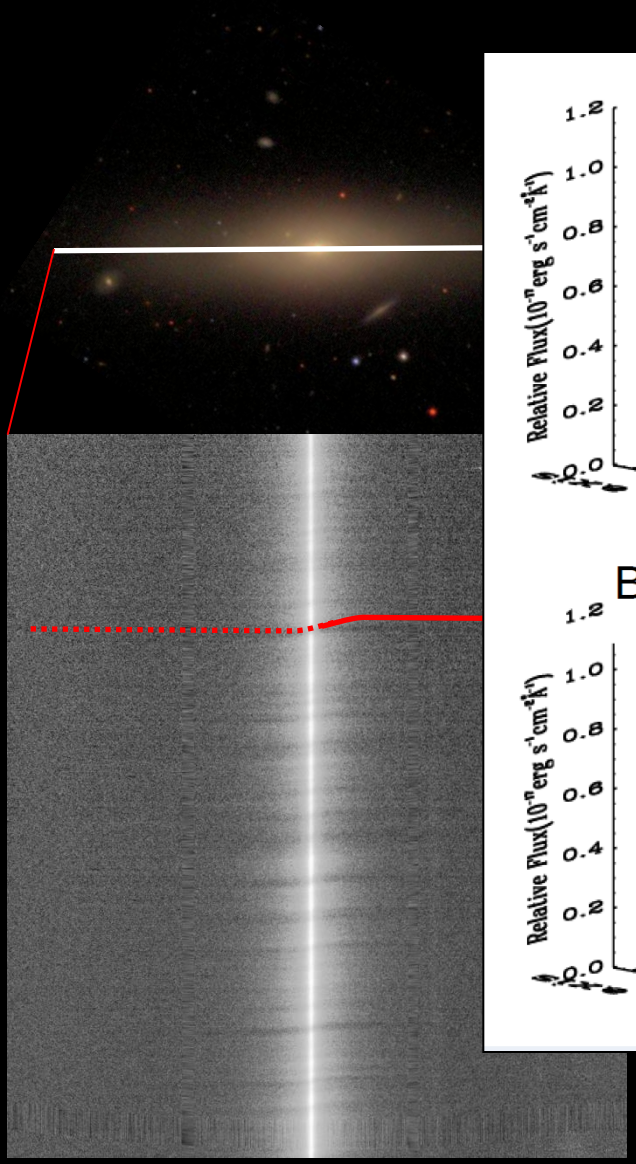
Blue
Young

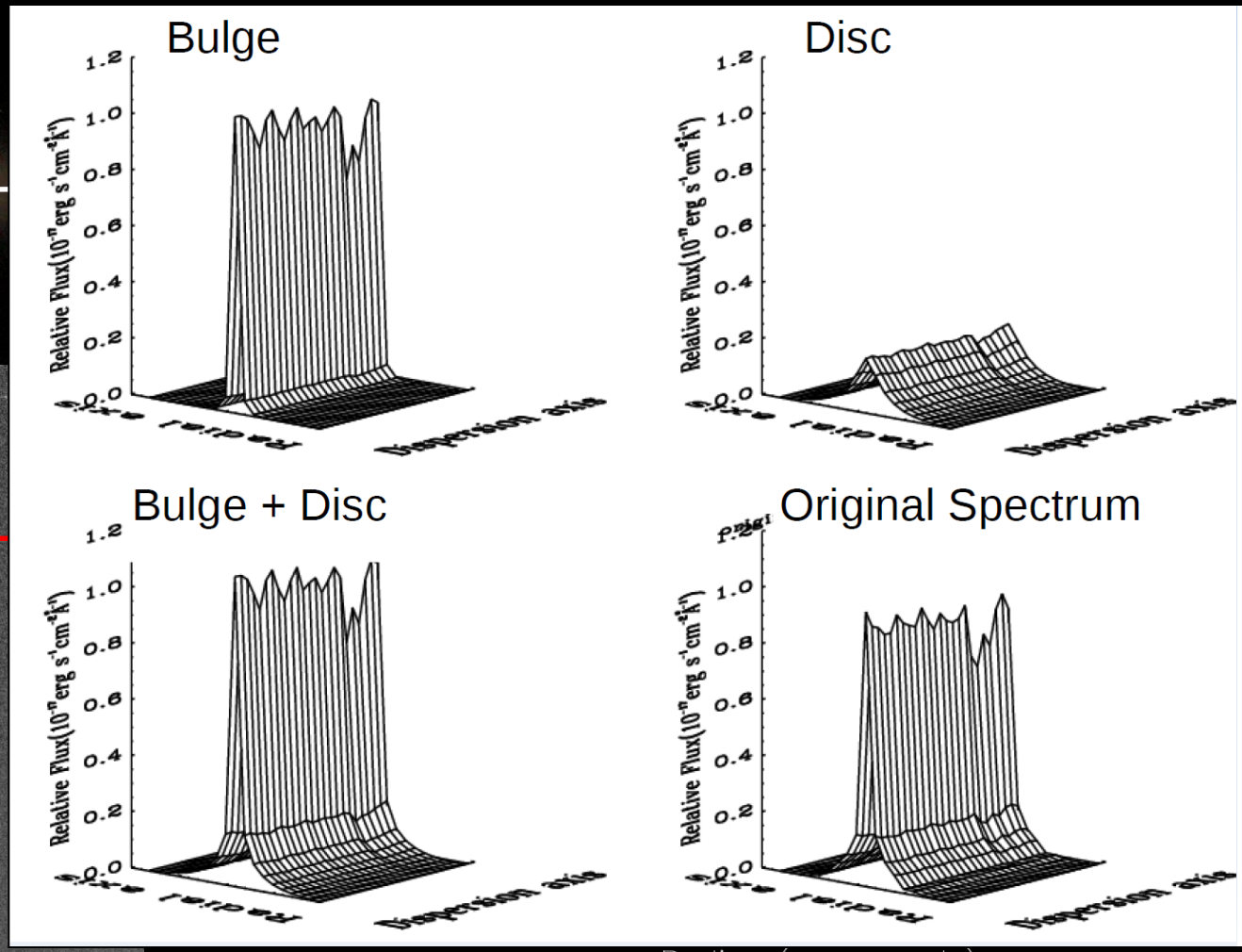
Bright
Young

Faint
Old

Aragón-Salamanca, Bedregal & Merrifield 2006

Spectral Bulge-Disk Decomposition

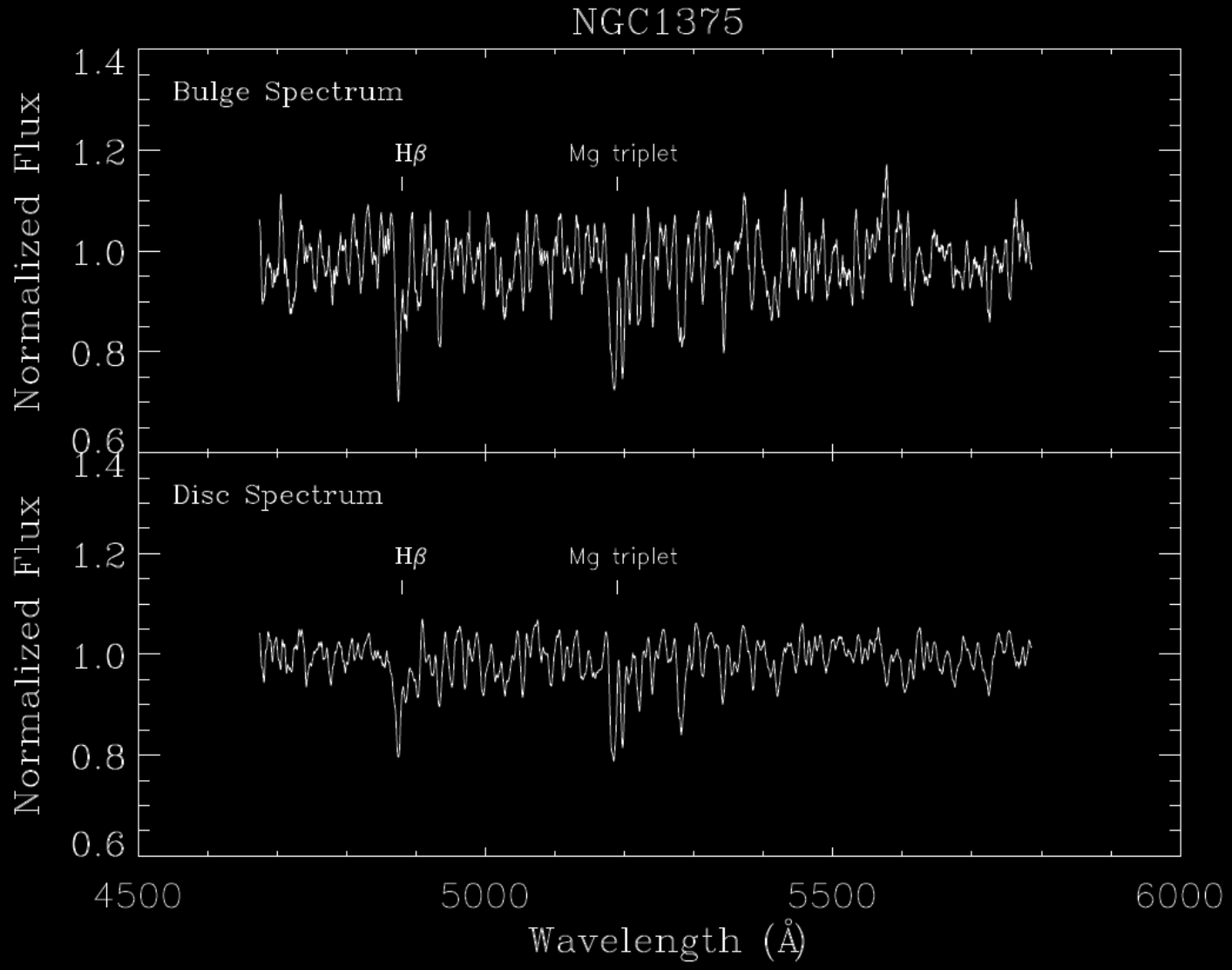




Radius (arcseconds)

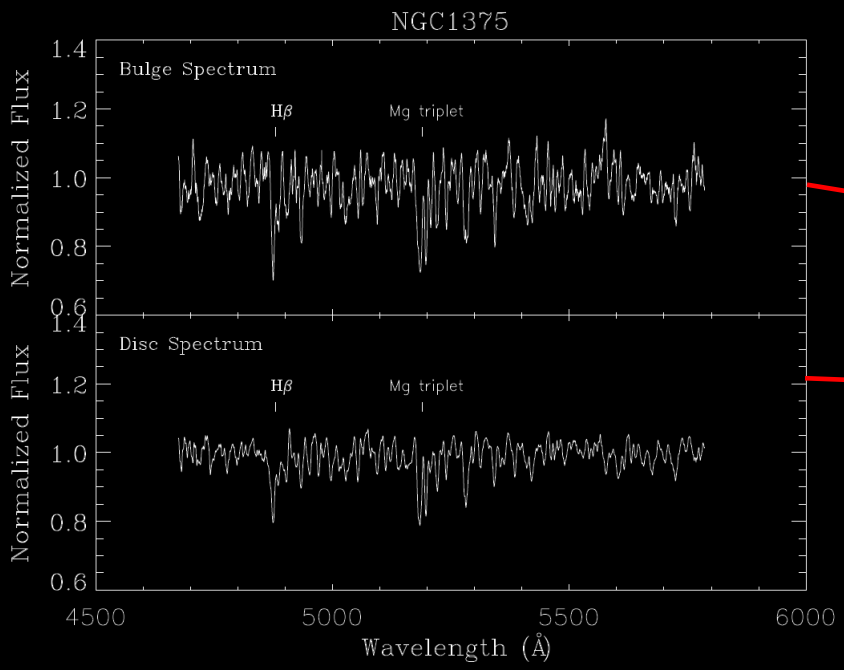
Johnston et al. 2012

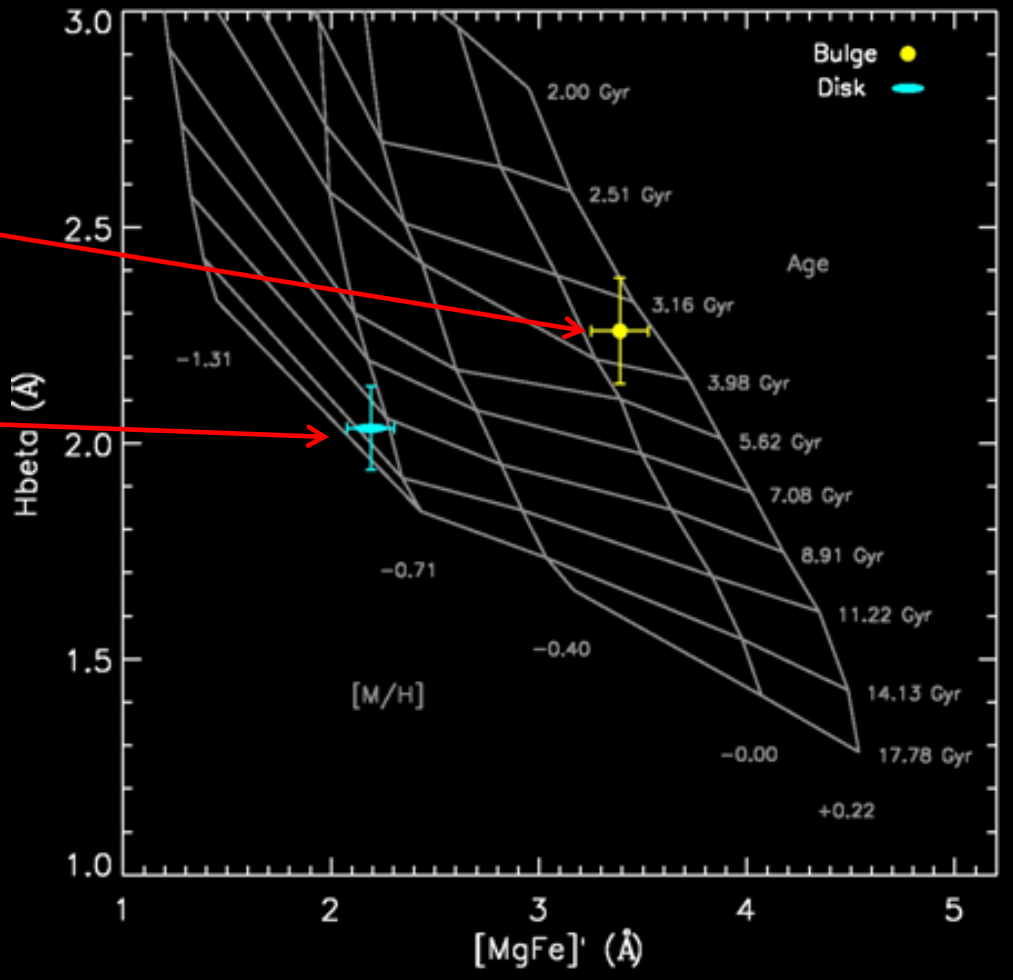
Spectral Bulge-Disk Decomposition



Johnston et al. 2012

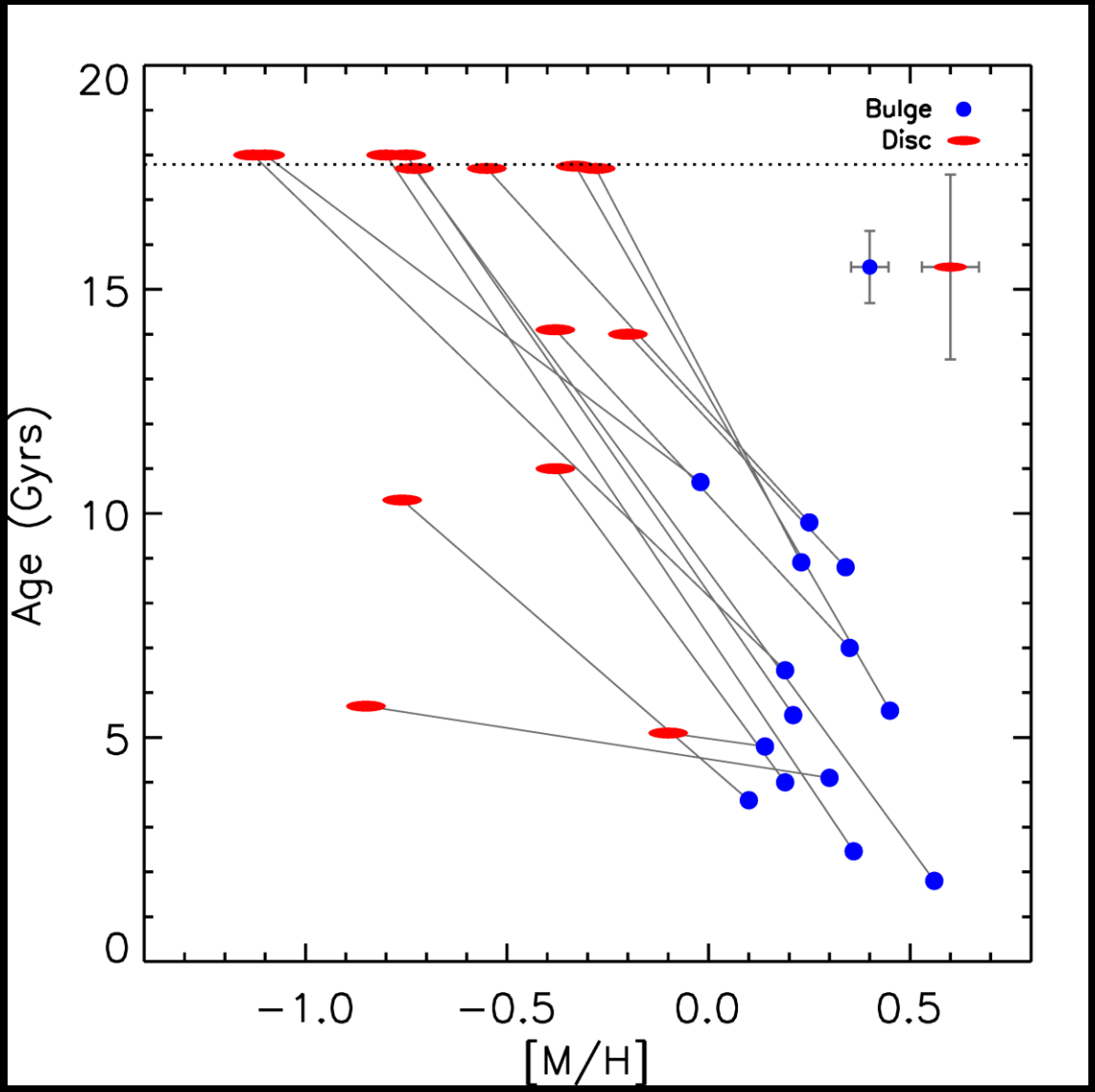
Spectral Bulge-Disk Decomposition



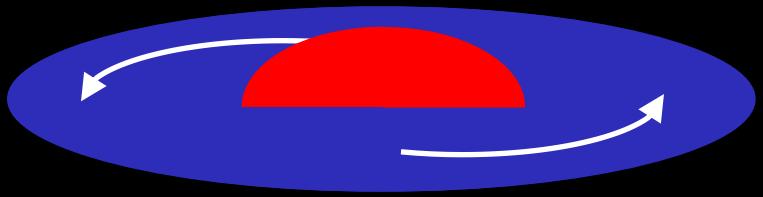


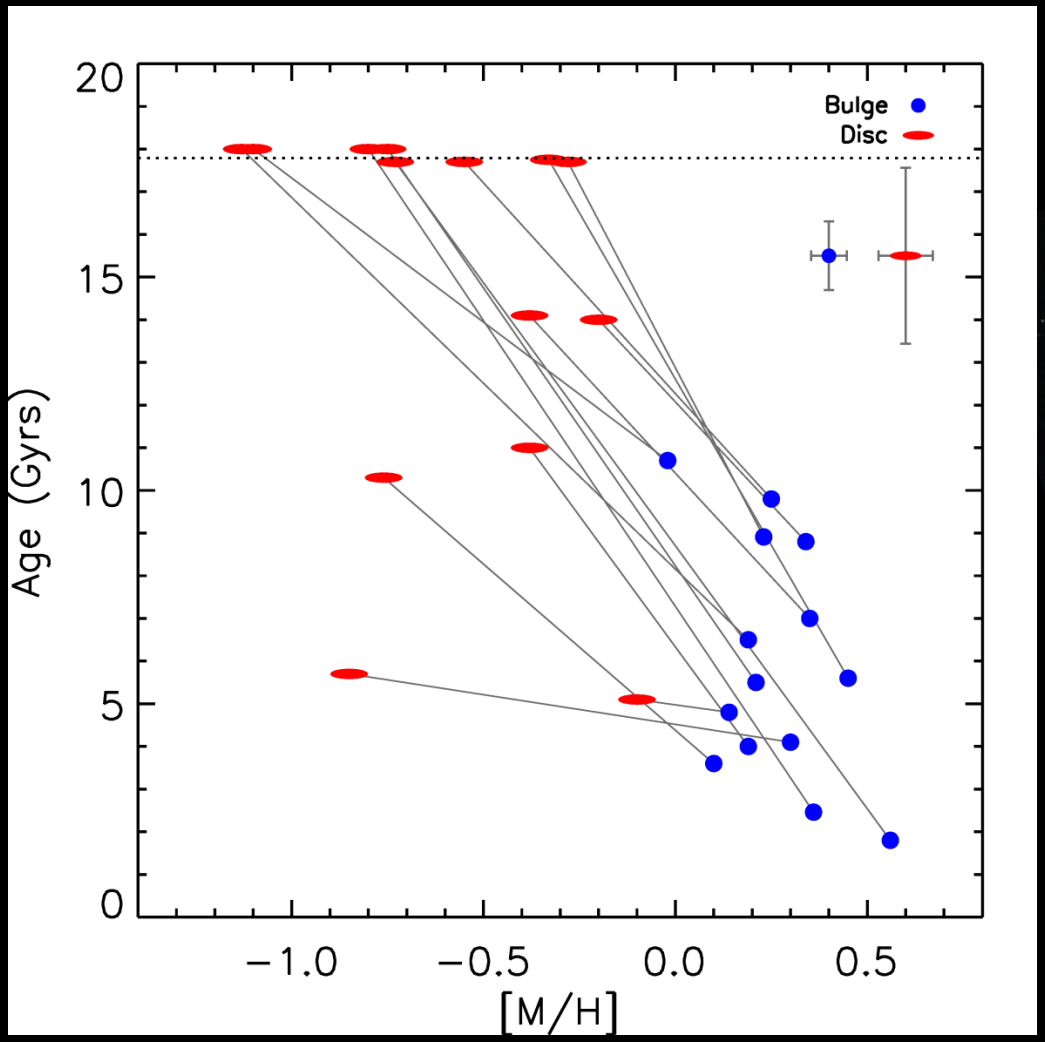
Johnston et al. 2014

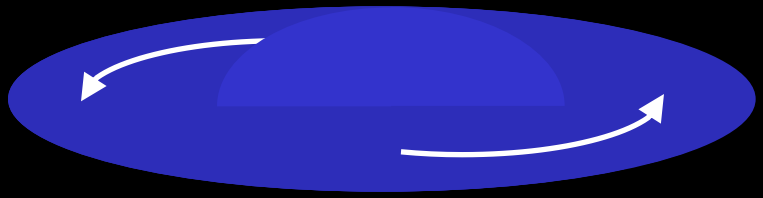
Spectral Bulge-Disk Decomposition

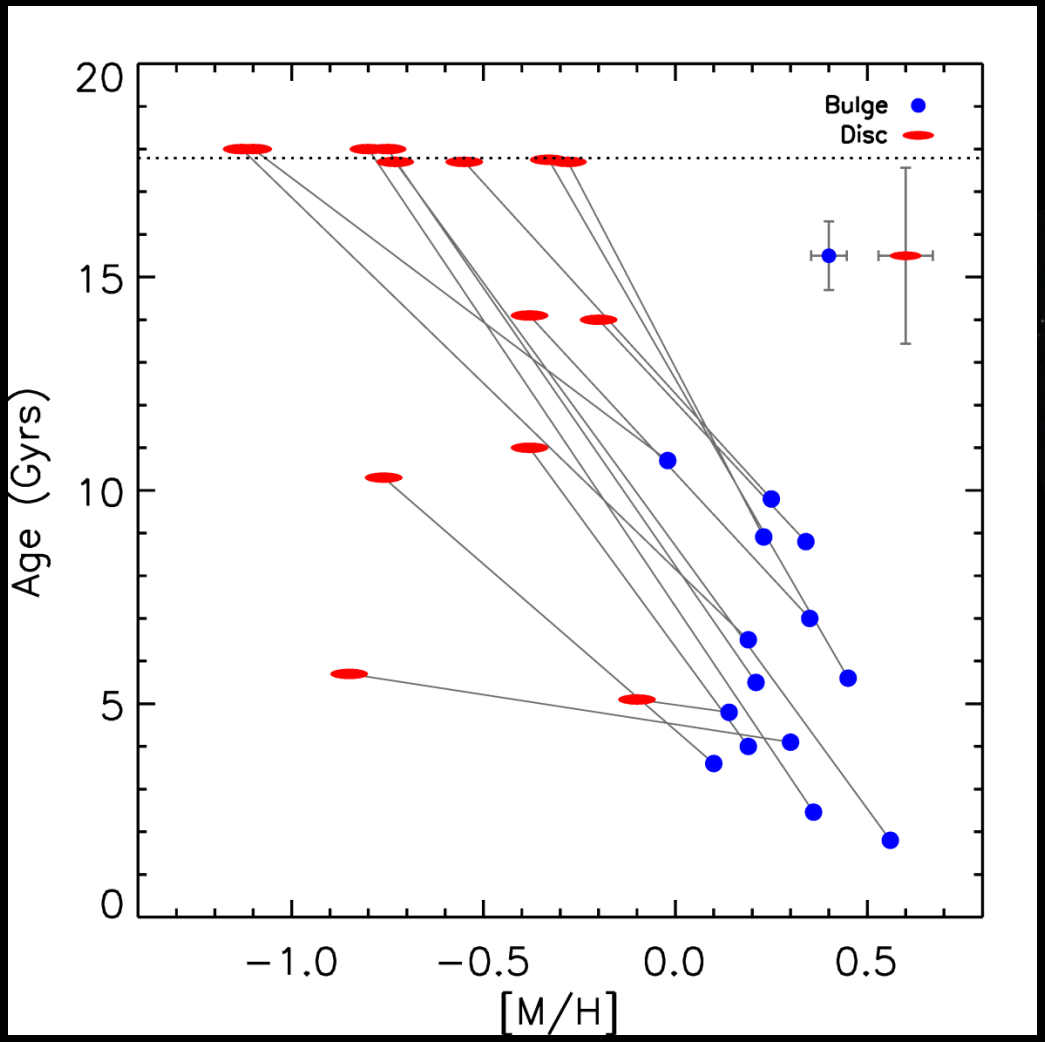


Johnston et al. 2014




Bulge
Disc
20
15
10
5
0
Age (Gyrs)
−1.0
−0.5
0.0
0.5
[M/H]




Bulge
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−1.0
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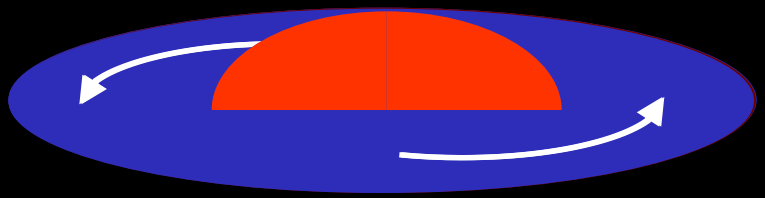
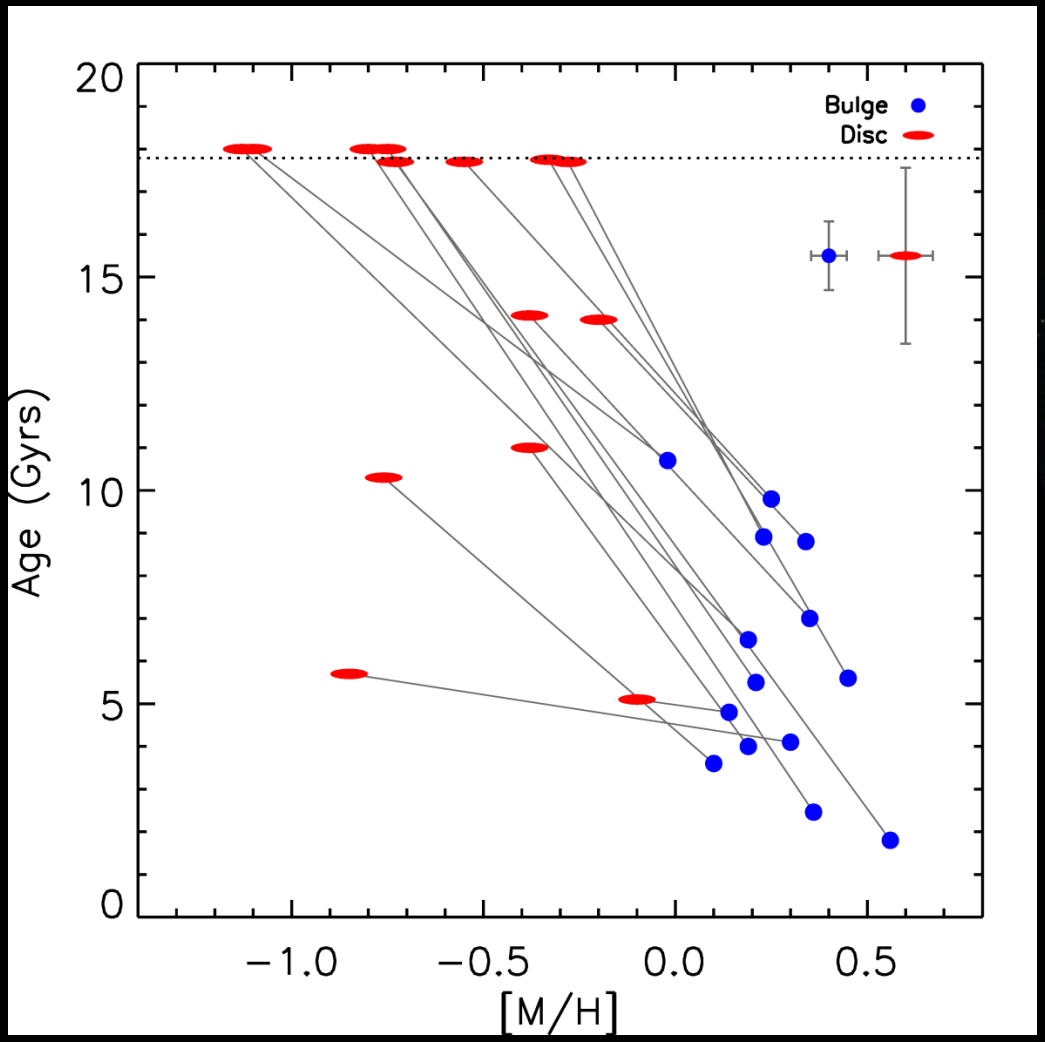
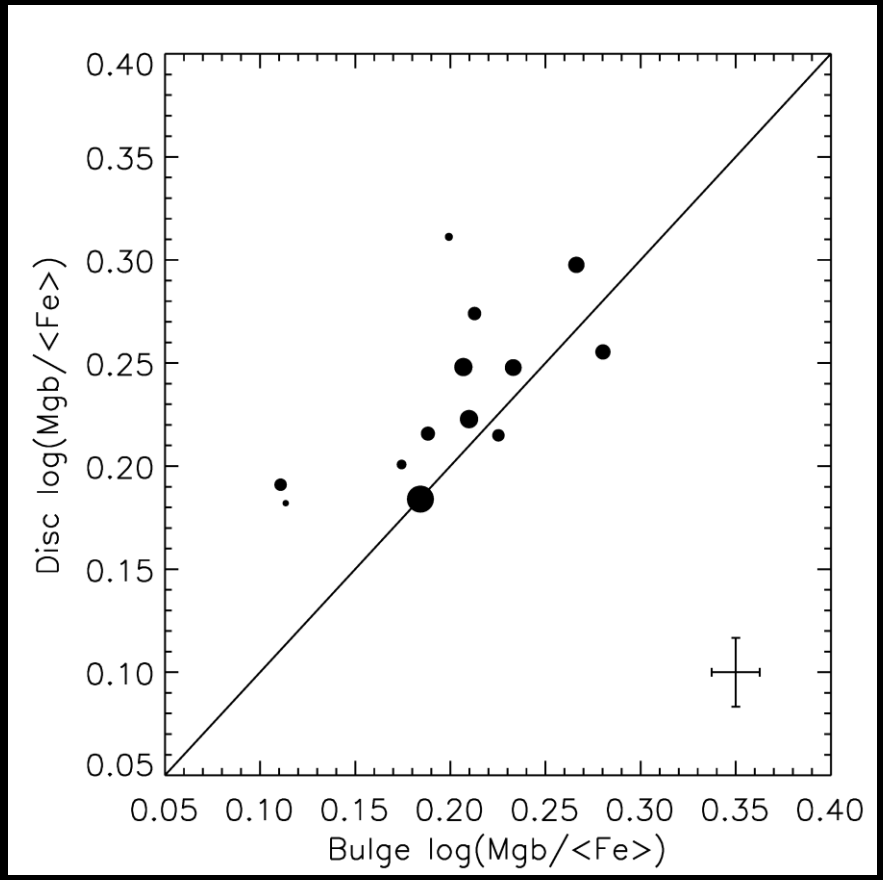
0.5
[M/H]




Bulge
Disc
20
15
10
5
0
Age (Gyrs)
−1.0
−0.5
0.0
0.5
[M/H]

Origin of the Young Bulge Stellar Populations

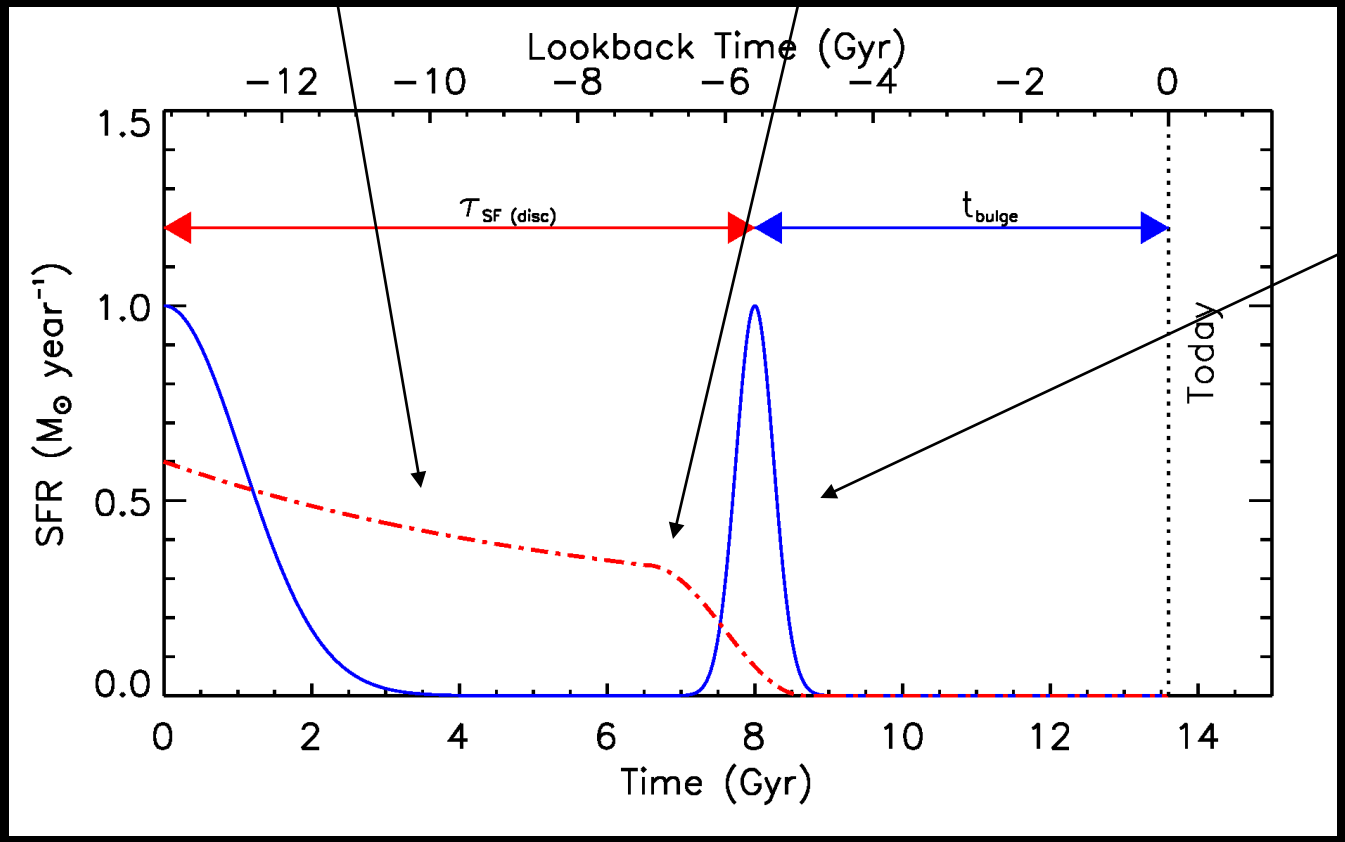
- Bulge and disc stellar populations show a correlation
- The offset shows bulges have enhanced Fe-enrichment
  - Fe-enriched disc gas dumped in the central regions, until a final SF event created the young bulge stellar populations and quenched all star formation



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.