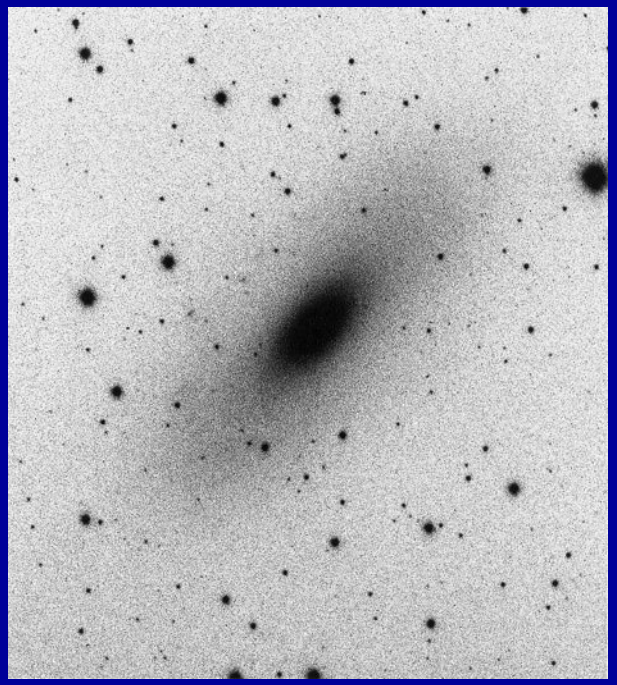
S0 Galaxies



Guest lecturer: Sheila Kannappan

AST358

March 30, 2006

Definition

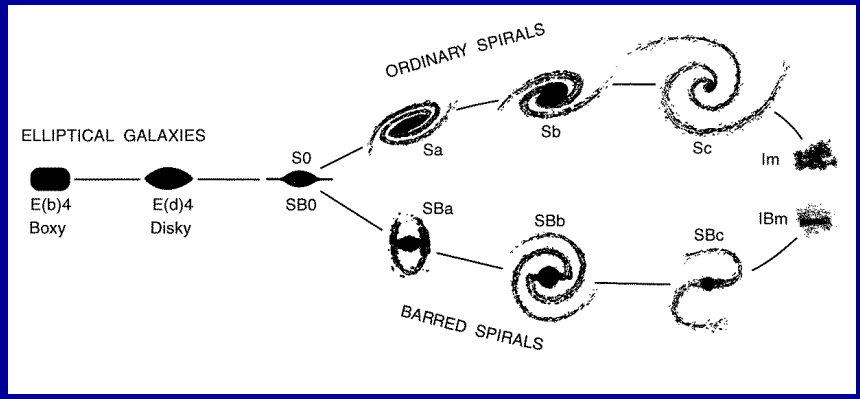
"The main feature of a spiral or S0 galaxy is its conspicuous extended stellar disk…. Spiral galaxies are distinguished from S0 systems by the multi-armed spiral pattern in the disk." – Sparke & Gallagher, p. 172

Caveat: Bulgeless spiral systems exist, but bulgeless systems with no spiral structure are never classified as S0 galaxies even if they have smooth disks.

Textbook characteristics of S0s

(Table 5.1, p. 204, Sparke & Gallagher)

- arms absent ← defining characteristic
- red color
- few young stars
- minimal star formation
- little gas
- massive (0.5-3x10^{11} M_{sun})
- dense environments (p. 34)
- high central surface brightness/ large bulge (p. 181) (second defining characteristic?)



Kormendy & Bender 1996

S0 S0 SB0

Bars can be present.

The Parallel Sequences Alternative

THE ASTROPHYSICAL JOURNAL, 206:883–887, 1976 June 15

A NEW CLASSIFICATION SYSTEM FOR GALAXIES*

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Received 1975 October 6

ABSTRACT

1) A new galaxy classification system is proposed in which normal spirals and lenticulars form parallel sequences within which "early" and "late" systems are distinguished by means of their disk-to-bulge ratios.
2) A sequence of "anemic spirals," which occur most frequently in rich clusters, is found to have characteristics that are intermediate between those of vigorous gas-rich normal spirals and gas-poor systems of type S0.
3) The differences between normal spirals (Sa-Sb-Sc), anemic spirals (Aa–Ab–Ac), and lenticulars (S0a–S0b–S0c) are tentatively interpreted in terms of the influence of environment on the evolution of flattened galaxies.

Subject heading: galaxies: structure

I. WHY A NEW CLASSIFICATION SYSTEM IS NEEDED

Current thinking on galaxy classification has its roots in the classical paper of Hubble (1926). Much of the simple beauty of the classification scheme proposed in that paper was lost when Hubble (1936) introduced a more or less hypothetical transitional stage, which he called type S0, *between* elliptical and spiral galaxies. The subsequent evolution of this S0 classification type in the hands of Hubble and Sandage is described in *The Hubble Atlas of Galaxies* (Sandage 1961).

In attempting to apply the Hubble-Sandage system to the classification of galaxies I have, for many years,

galaxies such as NGC 4866 (*Hubble Atlas*, p. 11) which have a very small nuclear bulge. The only feature common to all of these diverse types of objects is that star formation is not proceeding very vigorously.

c) Effects of Luminosity

The Hubble (1936) classification system for spirals was defined in terms of supergiant galaxies. This bias of the Hubble system has, to some extent, been overcome by van den Bergh (1960*a*, *b*, *c*), who extended the original Hubble classification scheme to include the effects of differing galaxy luminosity.

S0s can have small bulges.

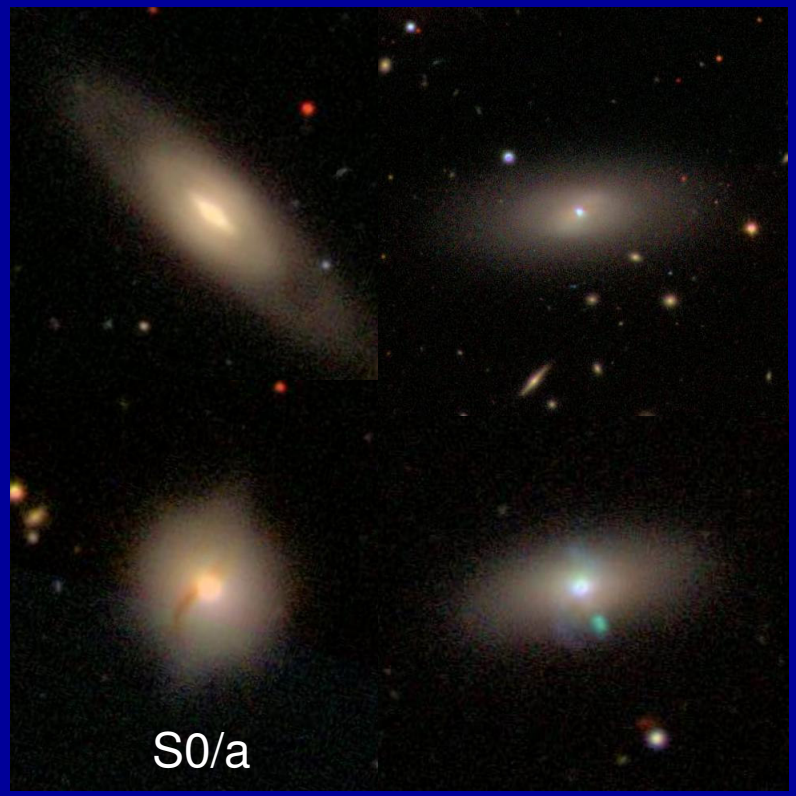
KEY: eliminate bulge size from S0 classification (van den Bergh 1976)

1) A new galaxy classification system is proposed in which normal spirals and lenticulars form parallel sequences within which "early" and "late" systems are distinguished by means of their disk-to-bulge ratios.
2) A sequence of "anemic spirals," which occur most frequently in rich clusters, is found to have characteristics that are intermediate between those of vigorous gas-rich normal spirals and gas-poor systems of type S0.
3) The differences between normal spirals (Sa-Sb-Sc), anemic spirals (Aa–Ab–Ac), and lenticulars (S0a–S0b–S0c) are tentatively interpreted in terms of the influence of environment on the evolution of flattened galaxies.

Sliding definitions

- arms absent ← defining characteristic
- red color
- few young stars
- minimal star formation
- little gas
- massive (0.5-3x10^{11} M_{sun})
- dense environments (p. 34)
- high central surface brightness/ large bulge (p. 181) (second defining characteristic?)

ALL of these have at times been used to “identify” S0s, but reality is complex…

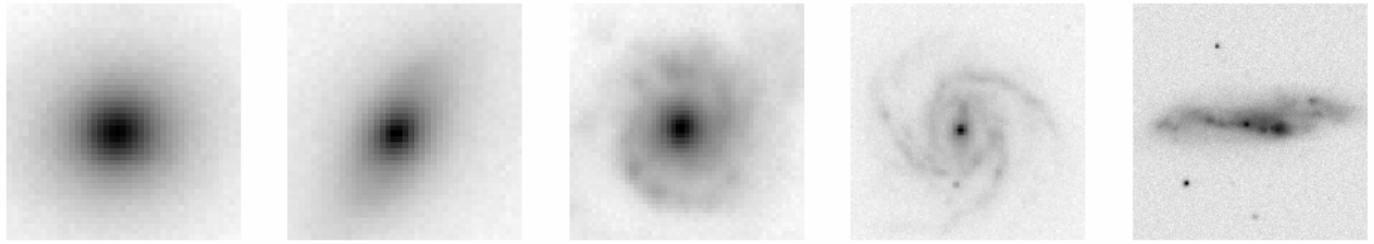


Why S0s matter

1) Abundant – approx. 20% of all galaxies

NEARBY FIELD GALAXY SURVEY

Relative Luminosity	Ellipticals	S0 and S0/a	Early Spirals	Late Spirals	Irregulars
10,000	4	2	2	7	1
1,000	9	13	16	14	
100	3	11	15	26	6
10	1	11	5	19	19
1		3		1	8



Morphological Type

Kannappan and NFGS team

Why S0s matter

2) many ways to form

Cluster/group processes:

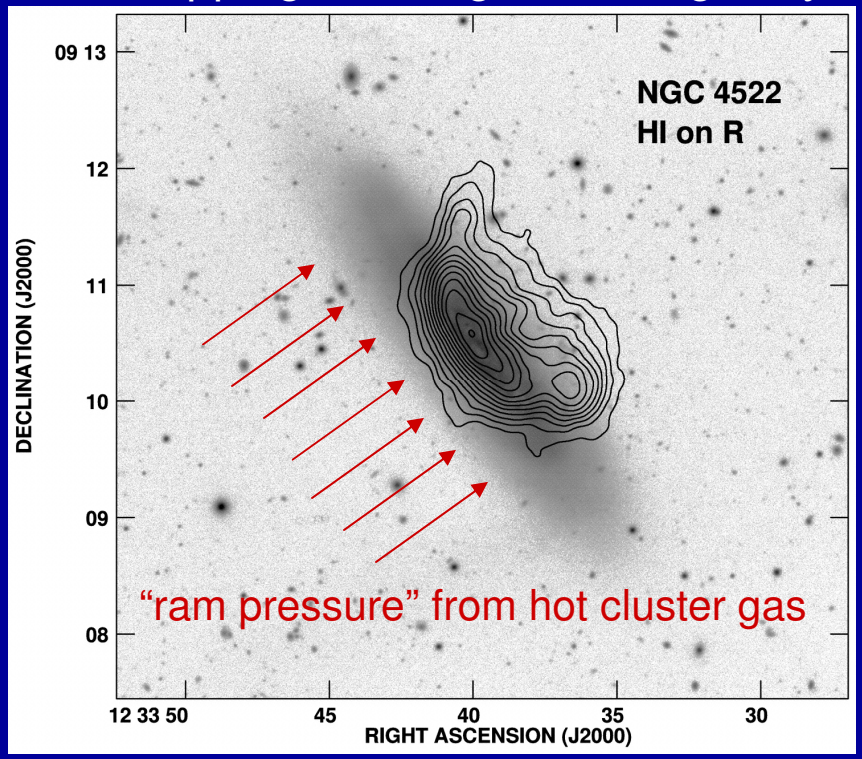
- gas loss (stripping)
- strangulation (lost cold gas supply)
* galaxy harassment

Group/field processes:

* minor mergers
* gas-rich major mergers
- disk growth over E/S0

* = can increase bulge:disk ratio

Gas stripping in a Virgo cluster galaxy

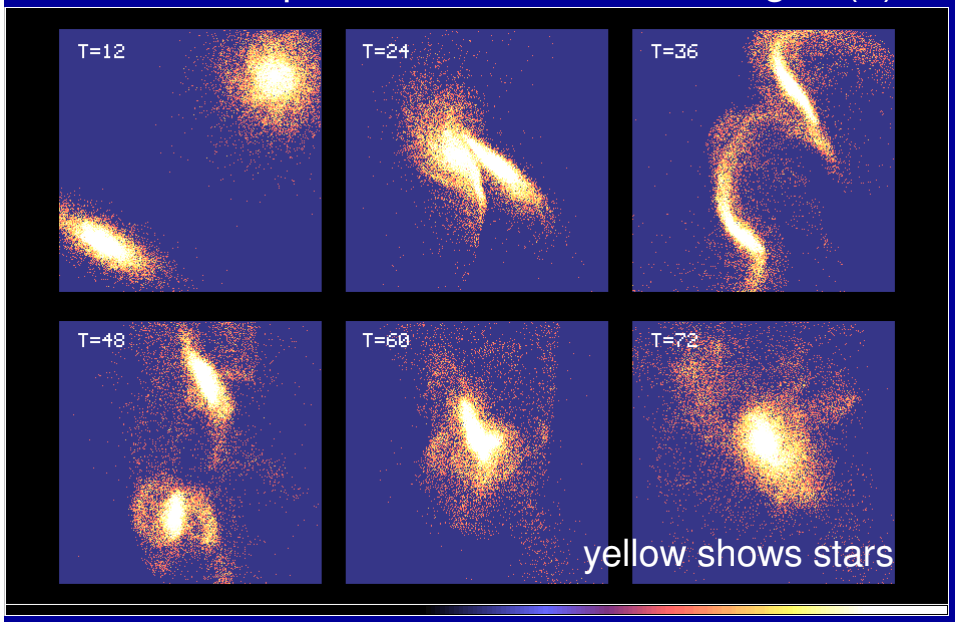


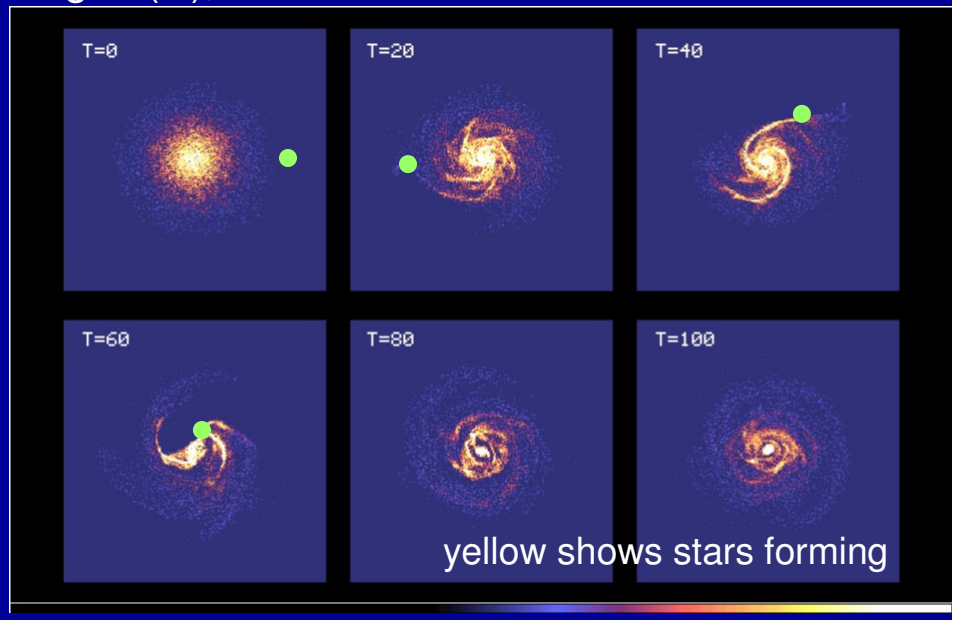
Kenney et al 2004

What happens when galaxies interact?

1. Stars rearrange into spheroids (bulges, E/S0s)
2. Gas flows to center, get burst of star formation

Computer simulations with no gas (L) & with gas (R), C. Mihos 1999 & 1994



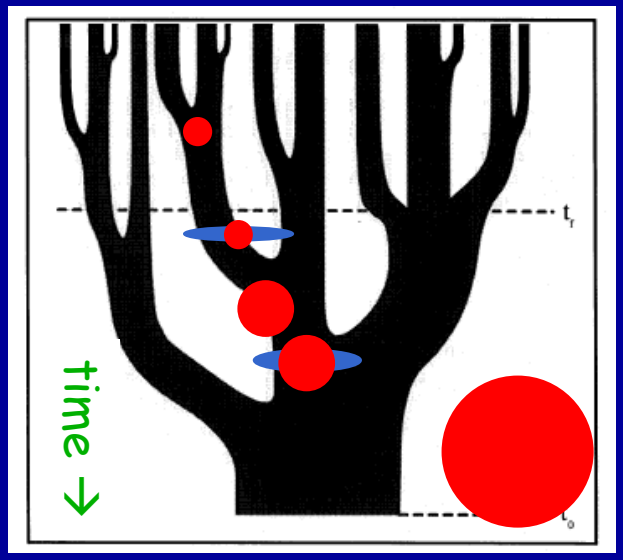


MAJOR MERGER (1:1) ➔ E

MINOR MERGER (10:1) ➔ bulge growth

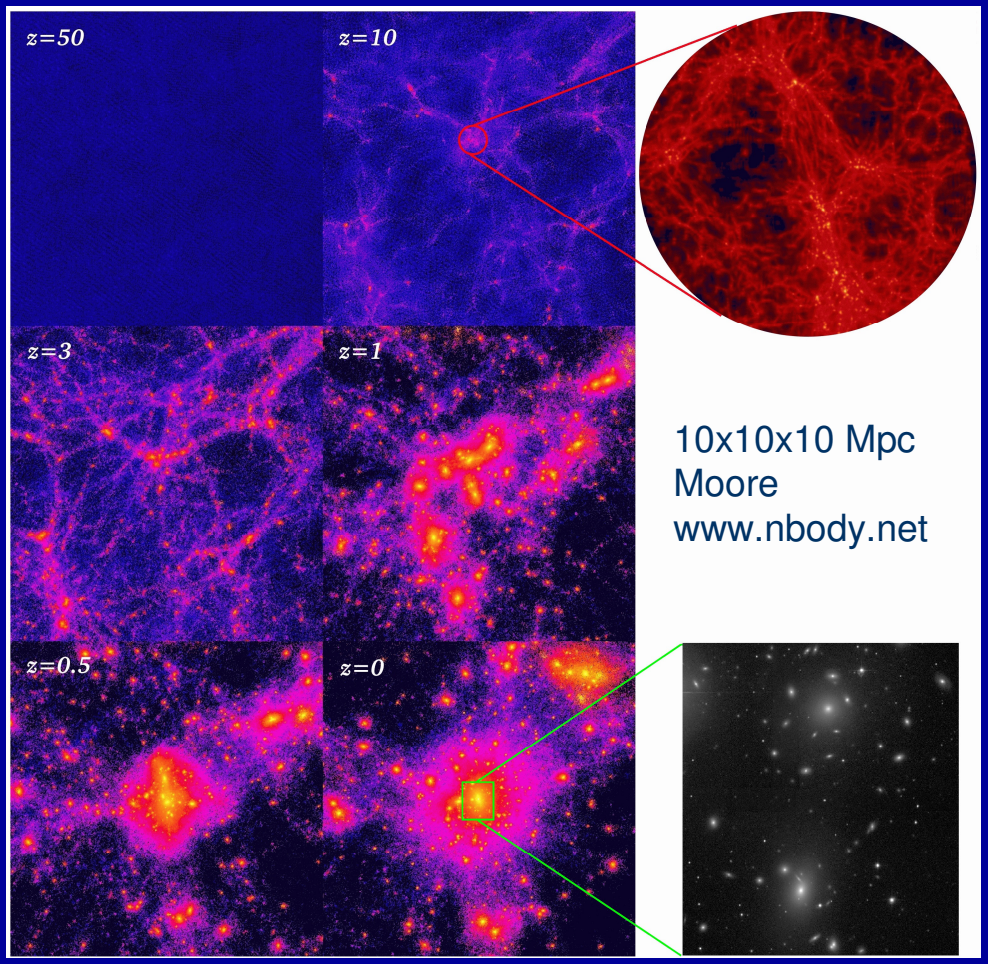
S0s can form in unequal mass mergers (e.g. 3:1, 5:1)
as well as gas-rich major mergers.

Hierarchical Galaxy Formation



Lacey & Cole 1993

repeated small interactions in dense environments ➔ "harassment"



10x10x10 Mpc
Moore
www.nbody.net

Question

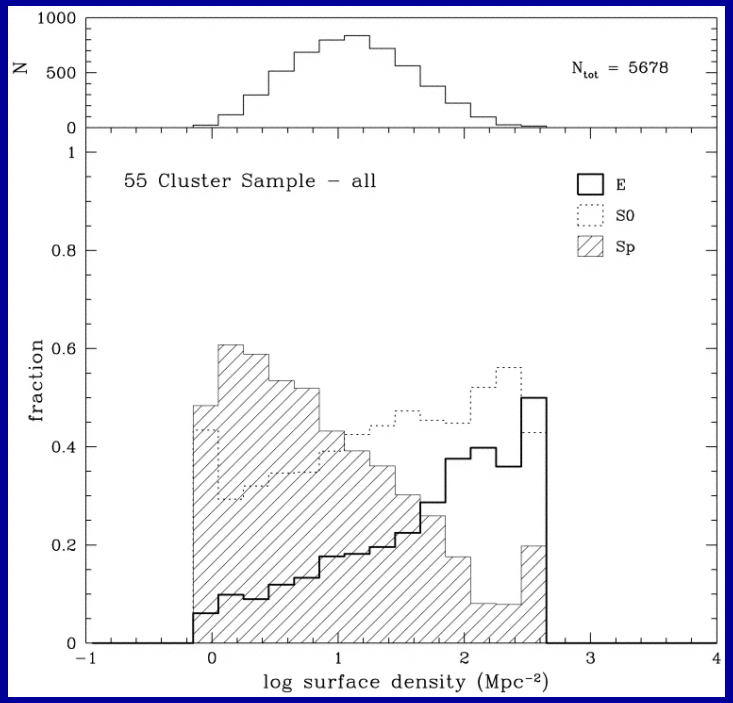
Which classification scenario (original Hubble sequence, parallel sequences) is more consistent with:

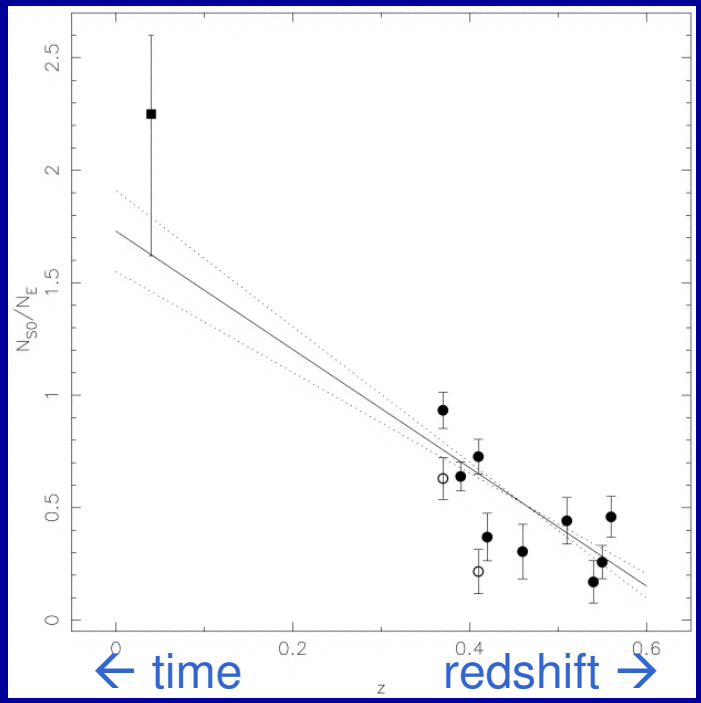
Cluster/group processes:	
•gas loss (stripping)	parallel
•strangulation (lost cold gas supply)	parallel
*galaxy harassment	mix of both
Group/field processes:	
*minor mergers	mix of both
*gas-rich major mergers	original
•disk growth over E/S0	mix of both

* = can increase bulge:disk ratio

The morphology-density relation

- E/S0 galaxies more common in denser environments (Dressler 1980)
- S0:E fraction in clusters may increase with cosmic time (disputed)





Dressler et al 1997

Which scenario(s) best explain these results?

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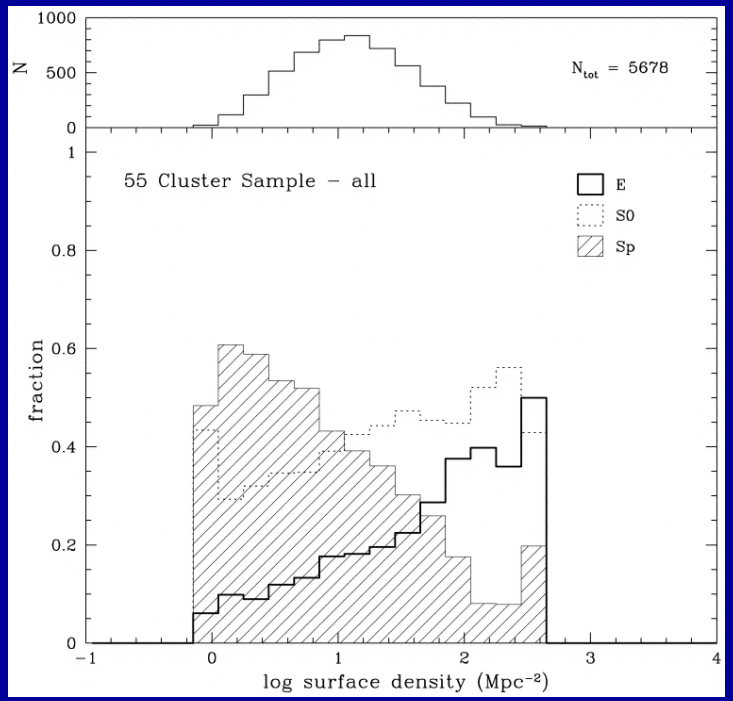

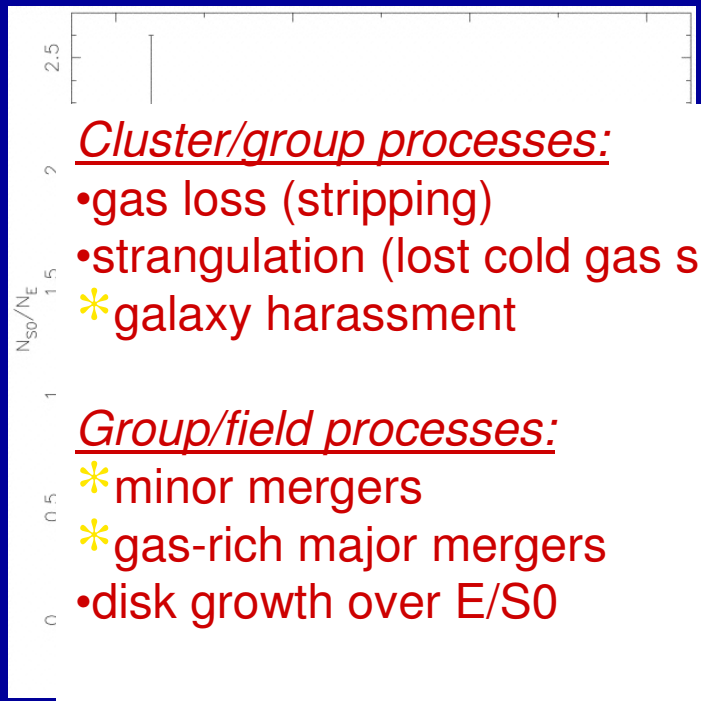

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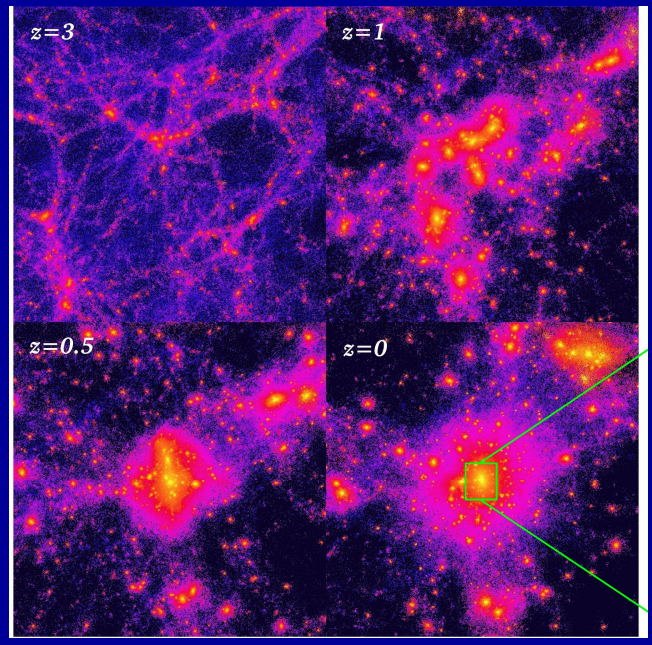
Which scenario(s) best explain these results?

Difficulty making Es: mergers don't happen in clusters

"If two disk galaxies pass by one another at the high speeds typical of rich galaxy clusters, they are unlikely to slow each other enough to become a bound pair." p.227, Sparke & Gallagher

Possible solution: morphology-density relation may not reflect cluster processes, but events that occurred in medium dense environments (e.g., groups) destined to merge into clusters.

This is widely accepted for Es, more controversial for S0s.



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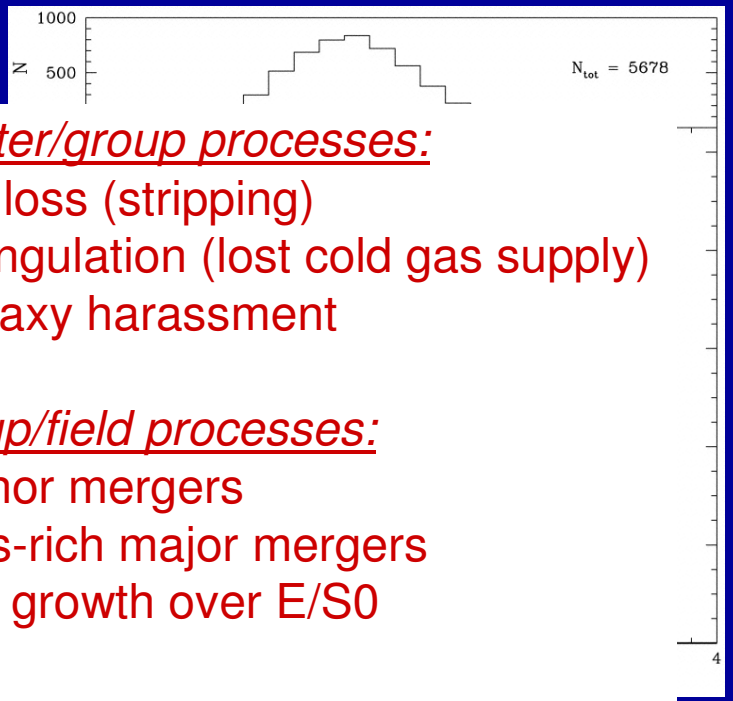

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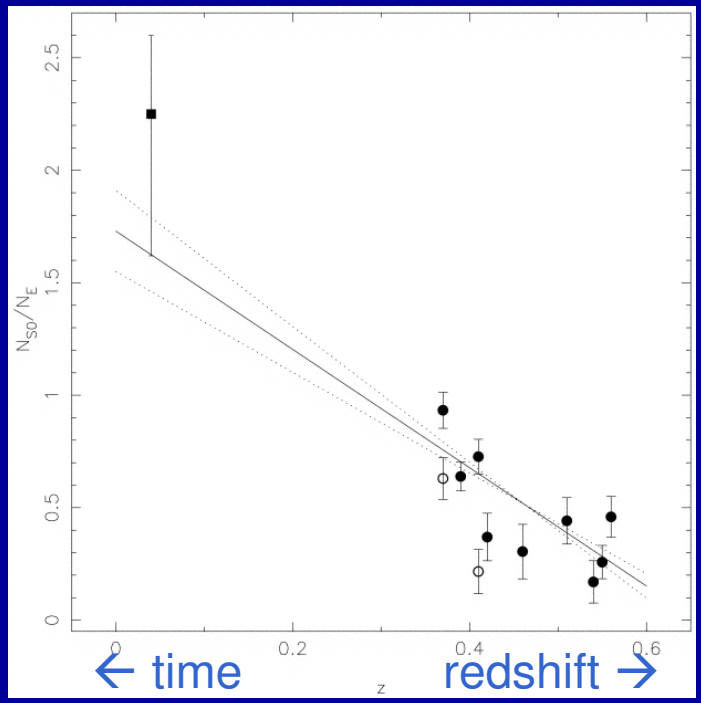

Dressler et al 1997

Which scenario(s) best explain these results?

What's wrong with sliding definitions?

textbook characteristics

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- red color
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explanations

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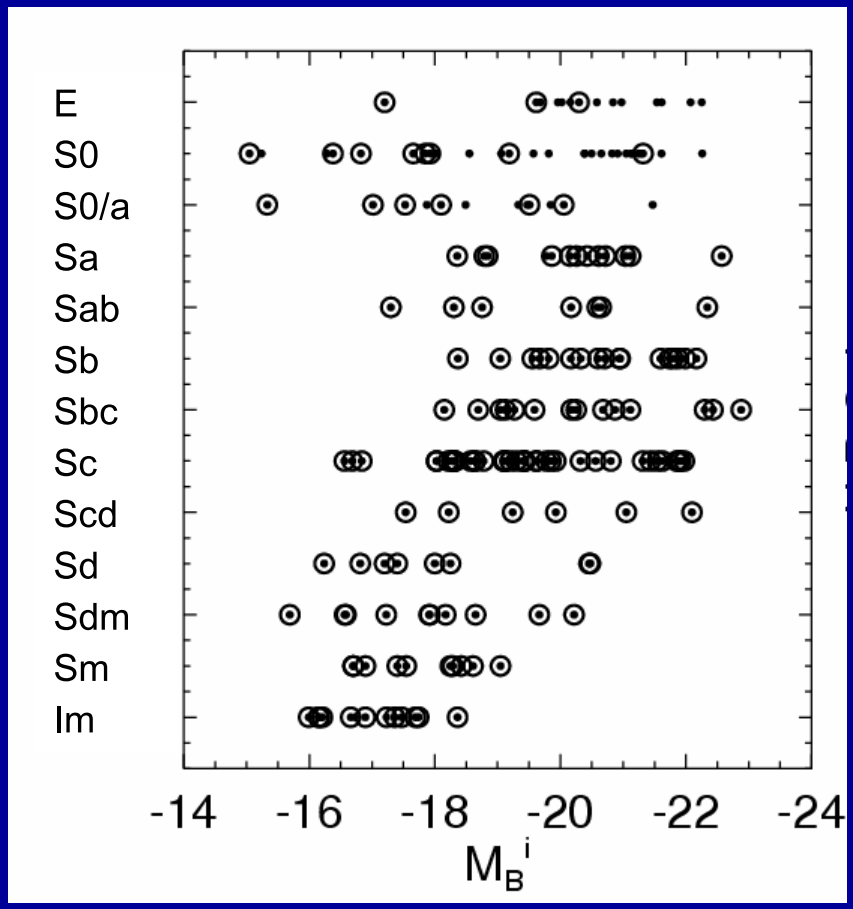
Danger of building in the answer! Just saw there are lots of low-mass S0s (NFGS figure, Sparke & Gallagher Fig. 5.6), plus S0s in moderate density environments (Dressler figure)… are there gas-rich/blue/star-forming S0s?

Rethinking S0s

(1) Many S0s have substantial gas.



Kannappan et al. 2006

Nearby Field Galaxy Survey:

Circled galaxies show strong, spatially extended emission from ionized gas.

HI gas fractions for low-luminosity S0s often 10-30% by mass.

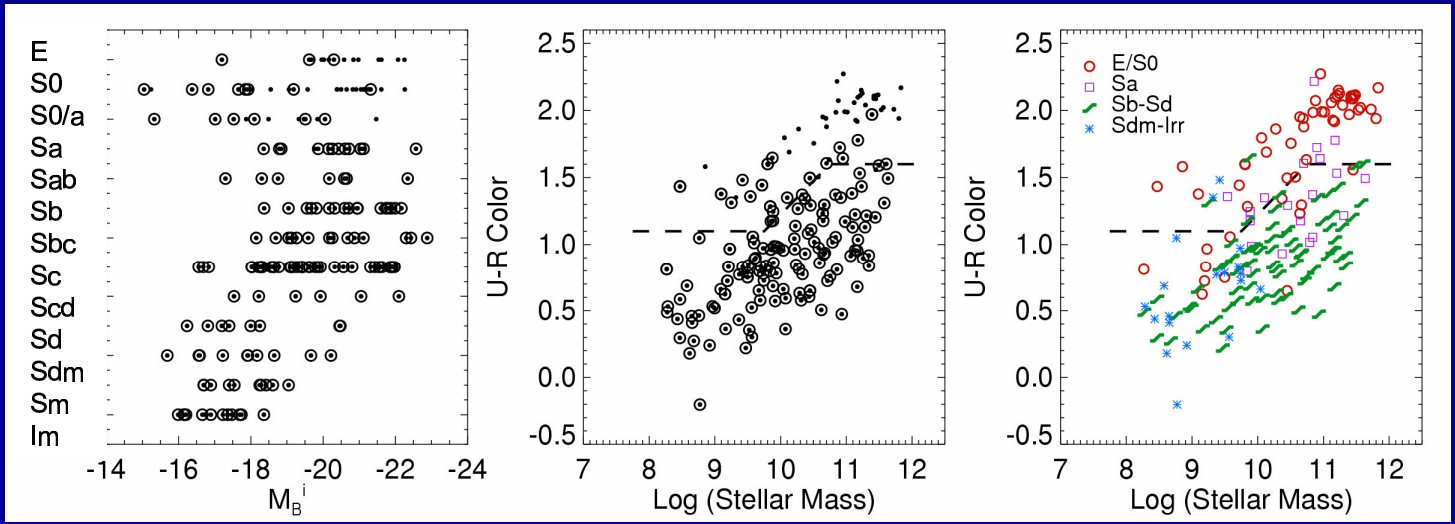
Rethinking S0s

(2) Many S0s are blue/star-forming.

Kannappan et al. 2006

How did we miss this???

Malmquist bias ➔ tendency to study bright galaxies



Nearby Field Galaxy Survey, Kannappan et al. 2006

Re-plot galaxy distribution in terms of color and mass:

gas-rich/blue S0s appear below galaxy (stellar) masses of ~10^{10}-10^{11} M_{sun}

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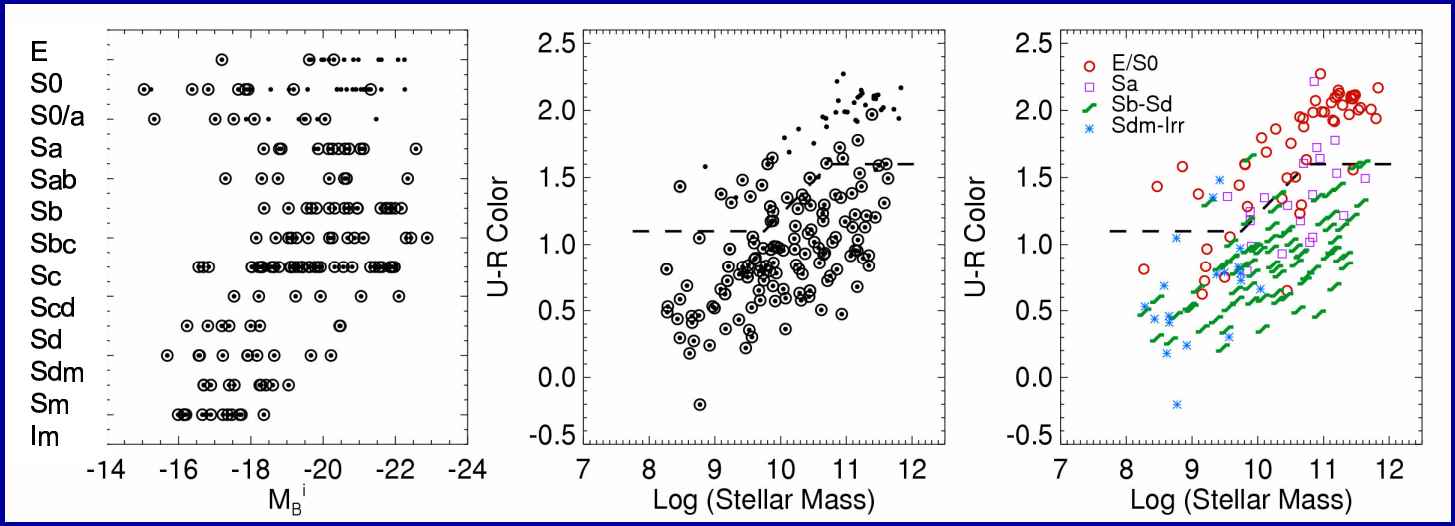
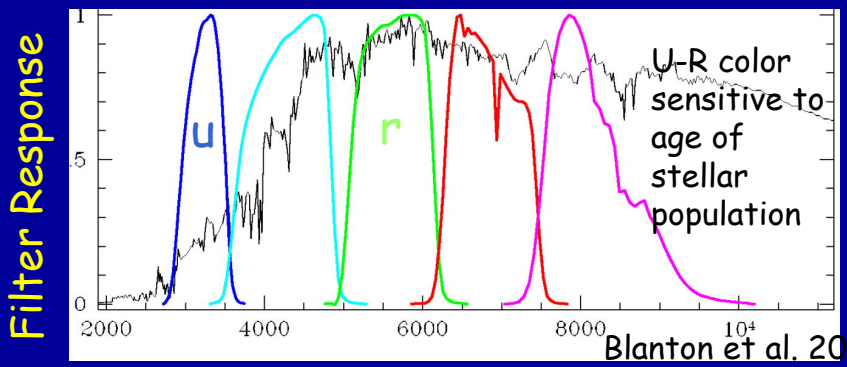
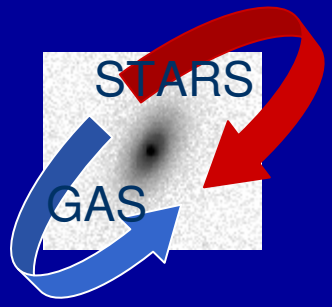


Aside: galaxies tend to show a bimodal division in U-R color (clearer in bigger surveys).



Blanton et al. 2003

Disk growth in E/S0s? [new research – not established!]



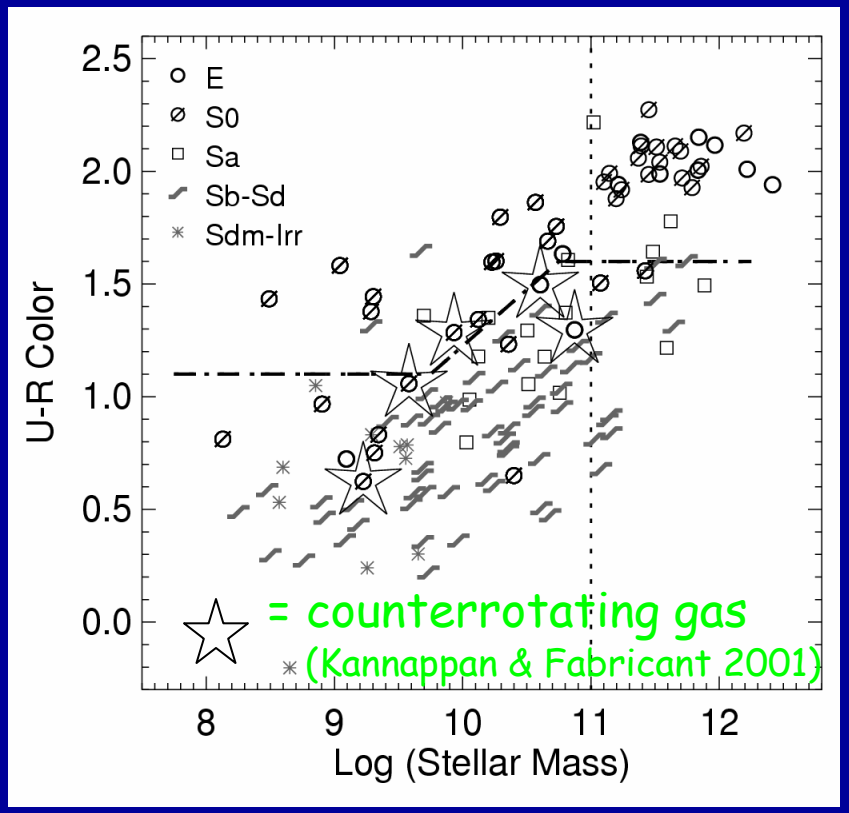
Previously known: polar rings and counterrotating gas are common for S0 and disky E galaxies.

Recently learned: these phenomena are associated with *blue* S0s (and disky Es).

Two interpretations for blueness:

→ recent merger remnants

→ young, growing disks



Kannappan et al 2006

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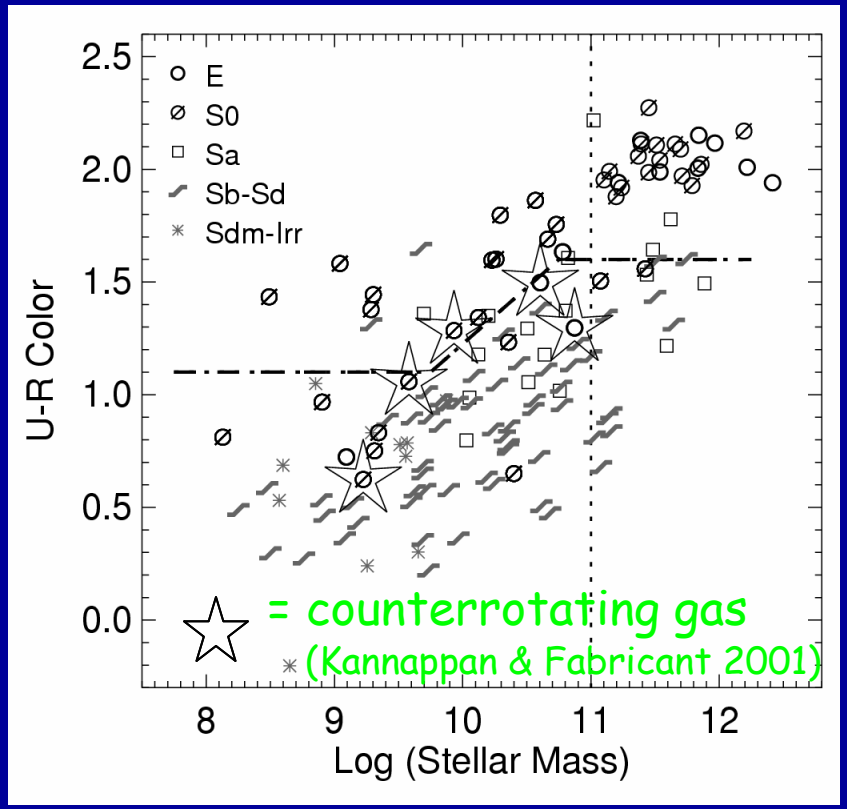
Previously known: rare to find two counterrotating populations of stars in S0s (Kuijken et al 1996)

New result: counterrotating stars likely in most of our counterrotating gas systems – this supports a disk (re)growth scenario



Kannappan et al 2006

work with former UT astro major Jocelly Guie

Wrap-up on S0s

textbook characteristics

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- red color
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1) S0s are abundant and form in many ways.
2) Textbook characteristics are most correct for high-mass S0s.
3) Neither classification system fully captures how S0s relate to other galaxy types.

Opportunity!