
Secular Processes and Galaxy Evolution
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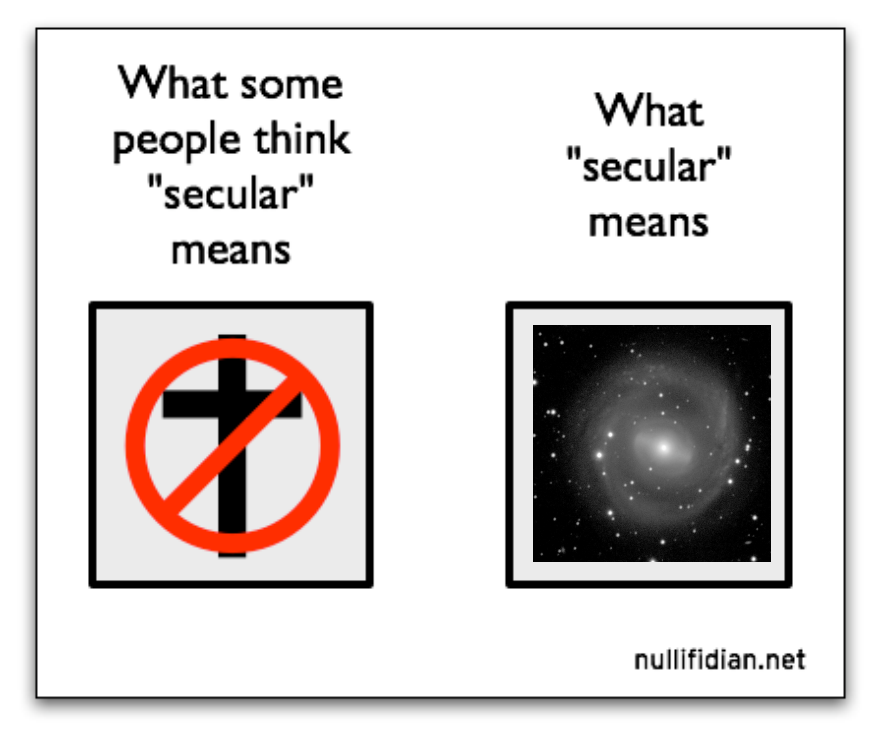
GALAXY ZOO

Secular Evolution

OED: (Definition #7)

Secular: *In scientific use, of process of change: Having a period of enormous length; continuing through long ages.* (i.e. a slow process)

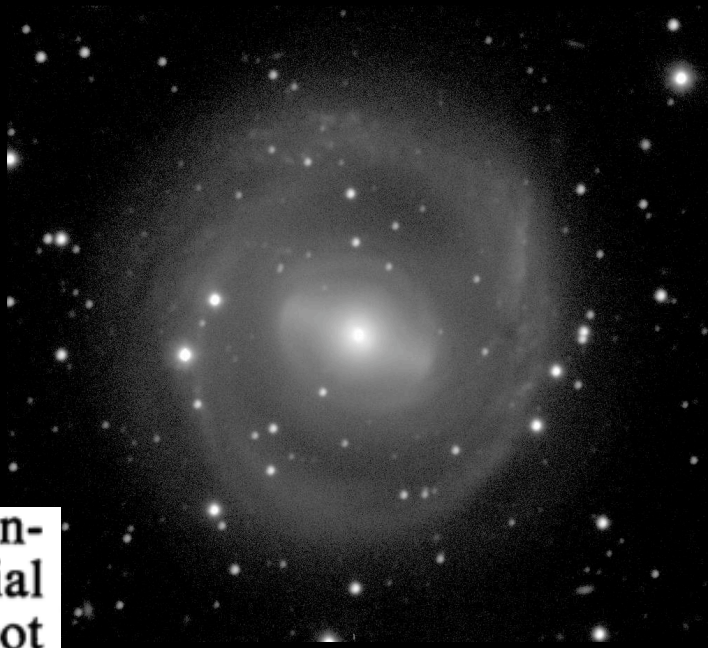


Secular Evolution in Galaxies

Early(est?) use in extragalactic astronomy:

"A morphological survey of bar, lens, and ring components in galaxies: Secular evolution in galaxy structure"

- Kormendy 1979 (ApJ 227, 714)



Since a bar creates a large, non-axisymmetric distortion in the gravitational potential field, with which other stars can interact, a not surprising conclusion will be that secular evolution plays a major role in changing galaxy structure.

Duus and Freeman (1975) have suggested that inner rings are manufactured out of disk material rearranged by the bar. One of the main suggestions of this paper is that secular evolution processes may generally be important in galaxies.

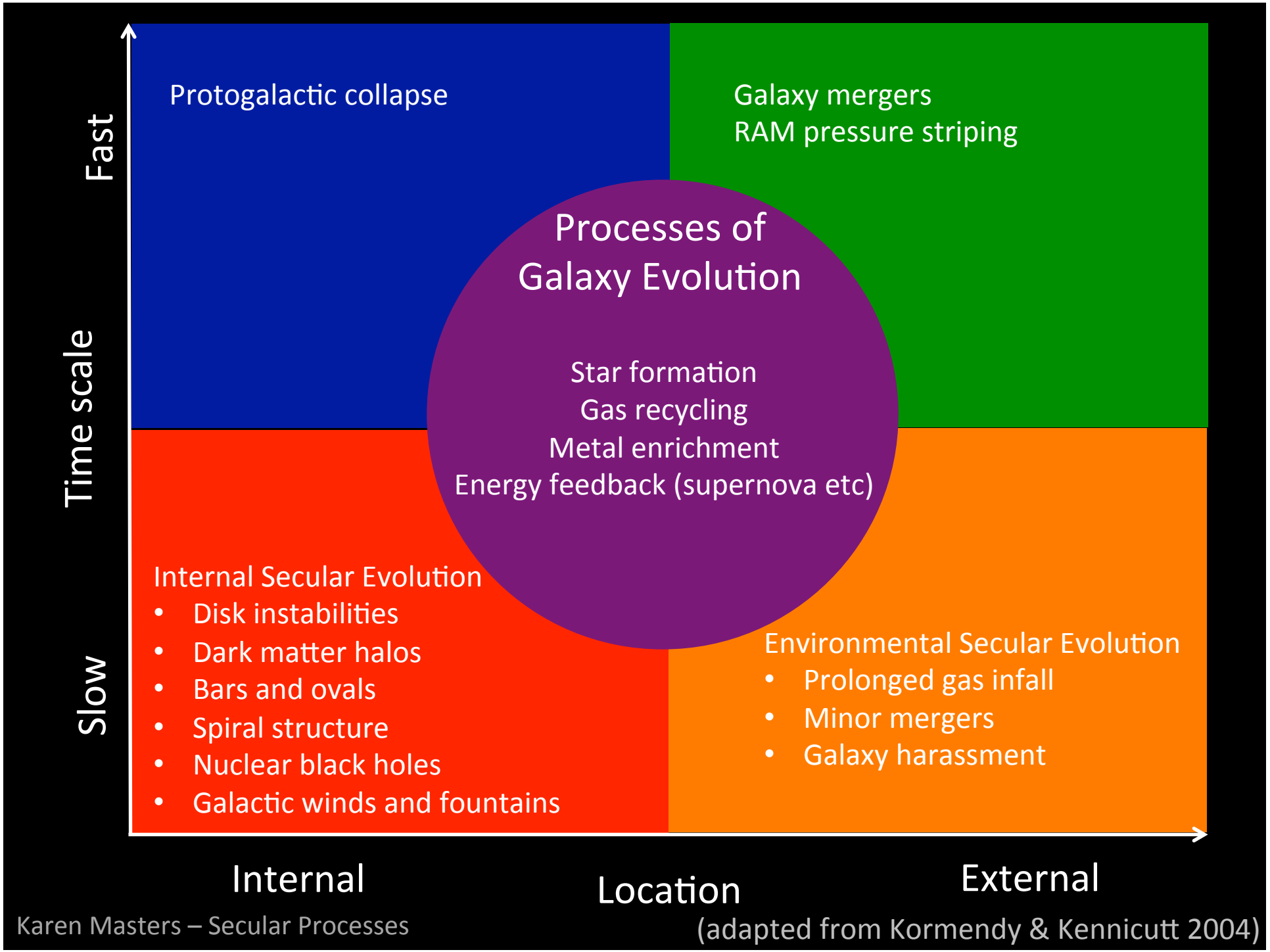
Secular Evolution in Galaxies

Common usage (in extragalactic astronomy):

- slow internal evolution (redistribution of material because of bars, or spirals)
- slow external evolution (ie. slow accretion of gas; harassment/strangulation).

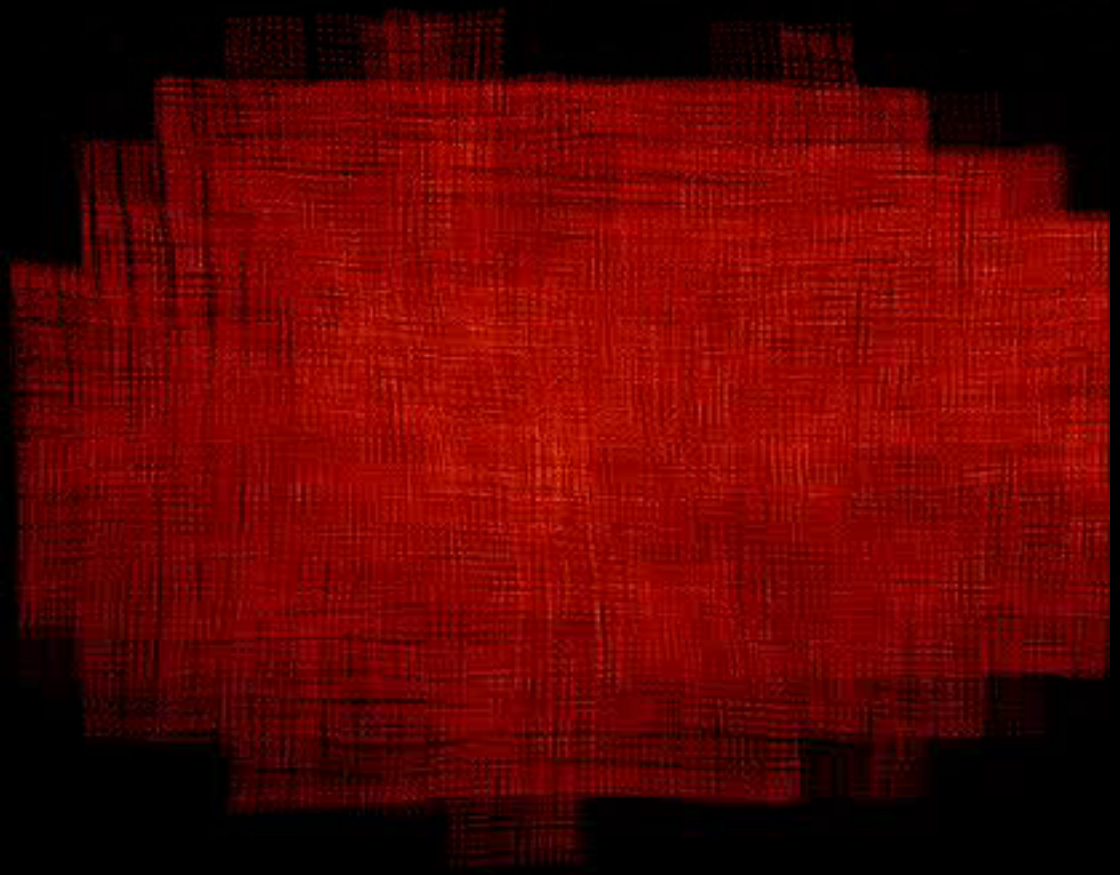
Contrast:

- (fast) mergers, ram pressure stripping etc.



(adapted from Kormendy & Kennicutt 2004)

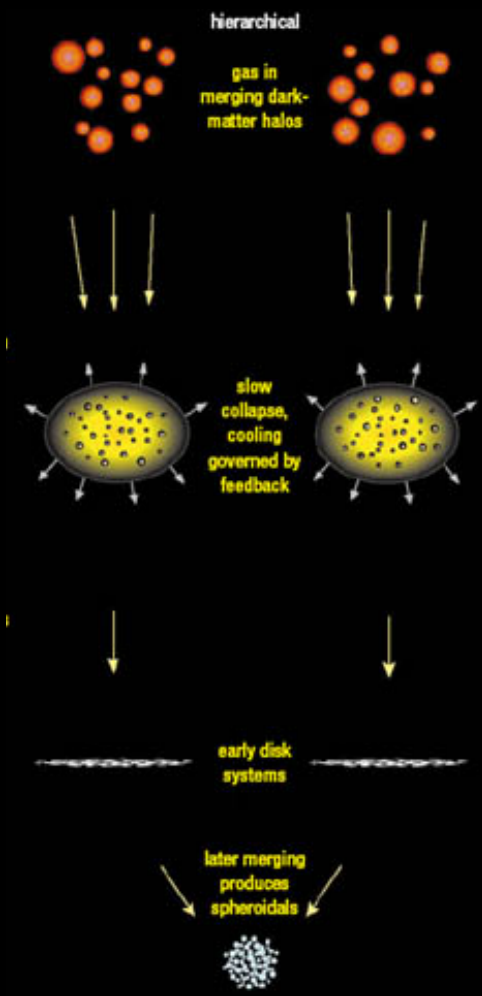
Hierarchical galaxy evolution



Hierarchical galaxy evolution

"Galaxies evolve mostly through merging"
– a dynamically fast, non-secular process…..

Most work in galaxy evolution in last 30 years on these processes…



Is secular evolution important?

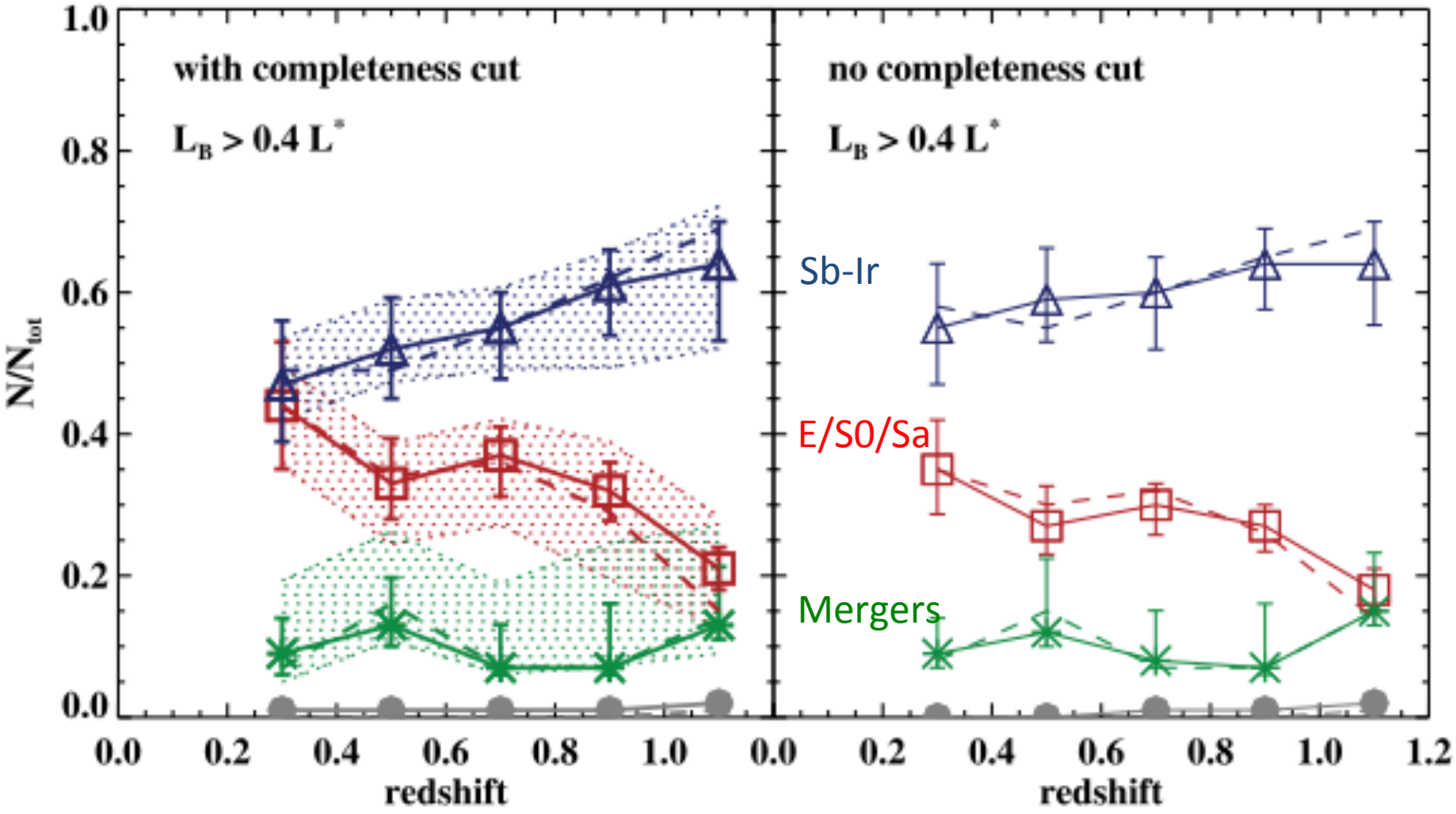
Hierarchical merging can't explain everything

Merging clearly occurs, but is it the dominant process for galaxy evolution?

- Really thin disks
- Really late type spirals (>15% bulgeless)

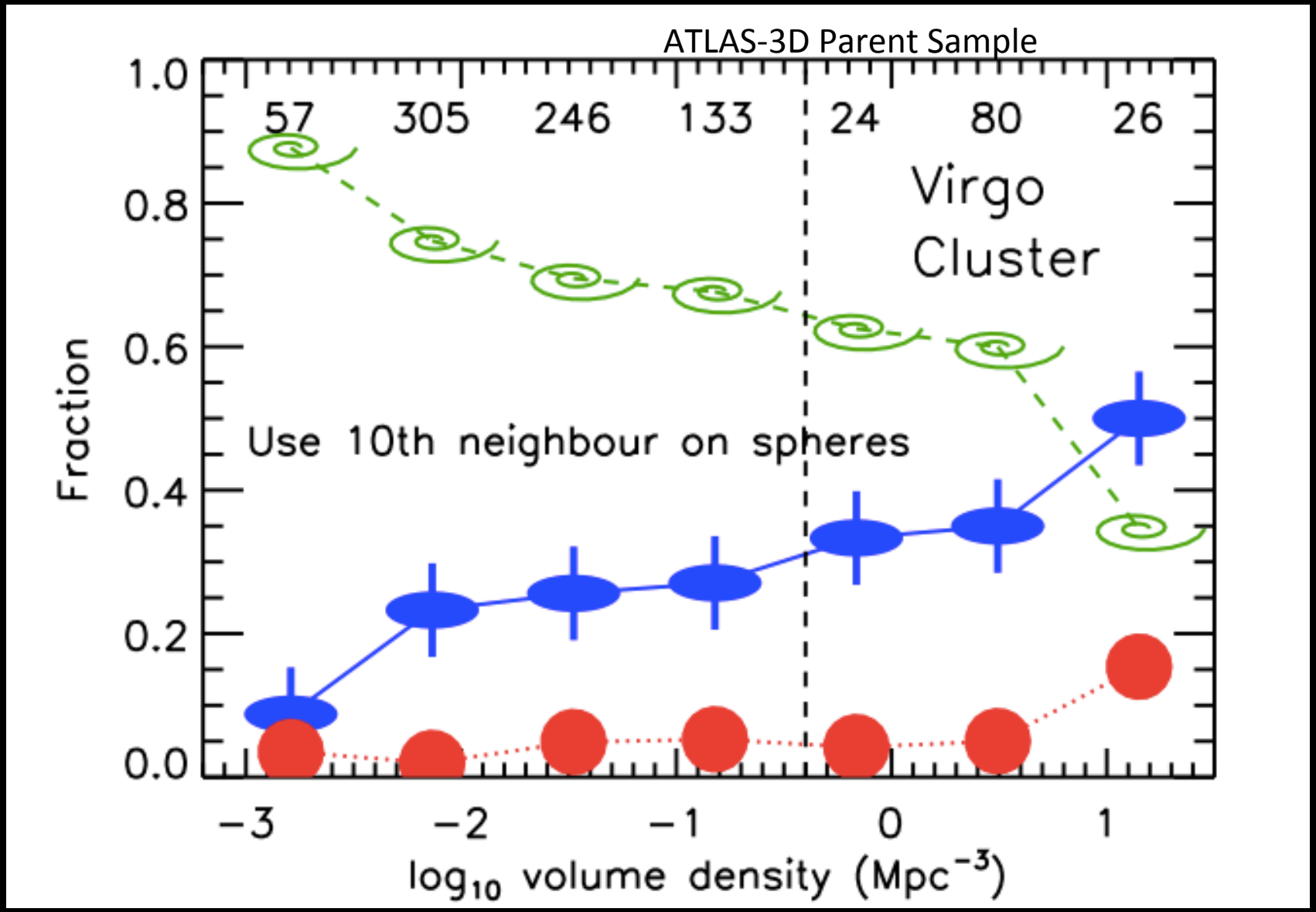
- Major mergers are rare:
  - Local merger fraction 1-3% of (Darg et al. 2010)
  - Massive galaxies ($M>10^{10}$ Msun) have few mergers after z~1 (Conselice et al. 2008)
  - Last major merger of Milky Way ~10 Gyrs

Most galaxies are discs

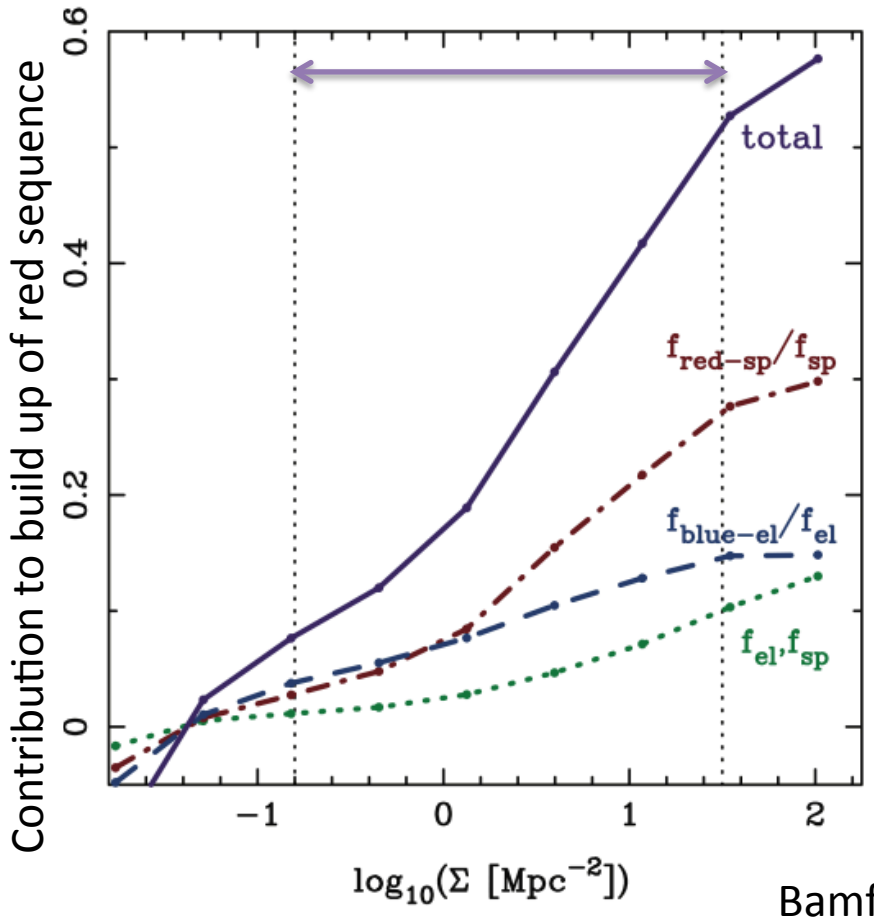


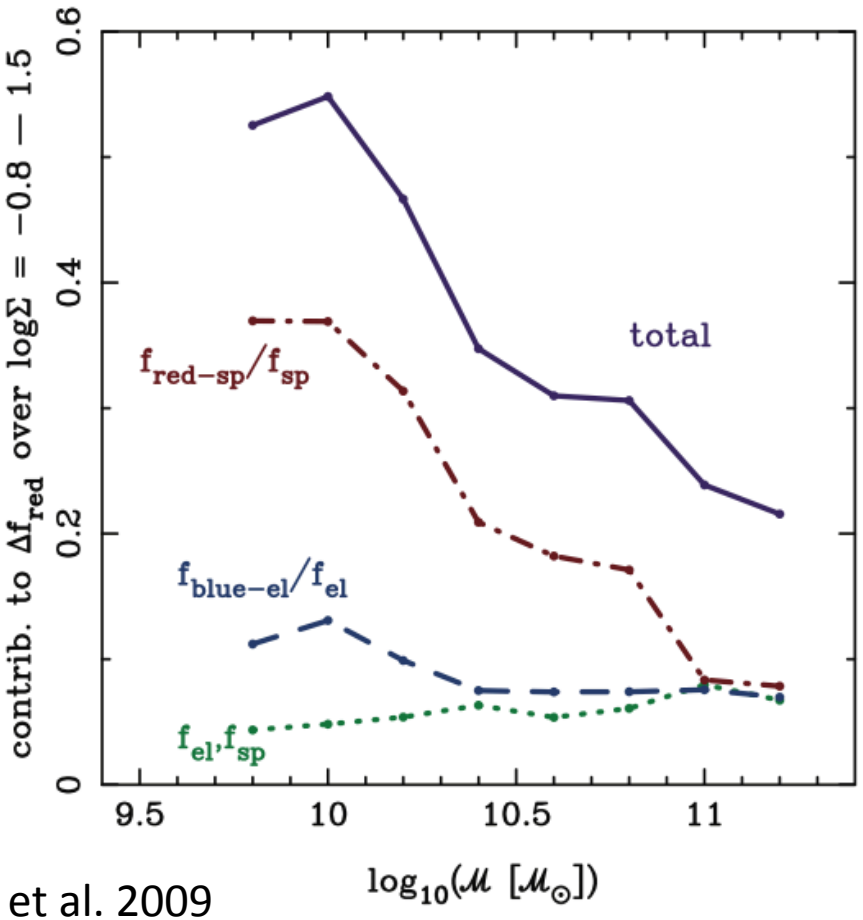
Lotz et al. 2008

Most early-types rotate



Build up of red sequence is mostly due to spirals turning red…





Bamford et al. 2009

Local Density

Stellar Mass

See Bundy et al. 2010 for build up with z

Entering the Secular Era…

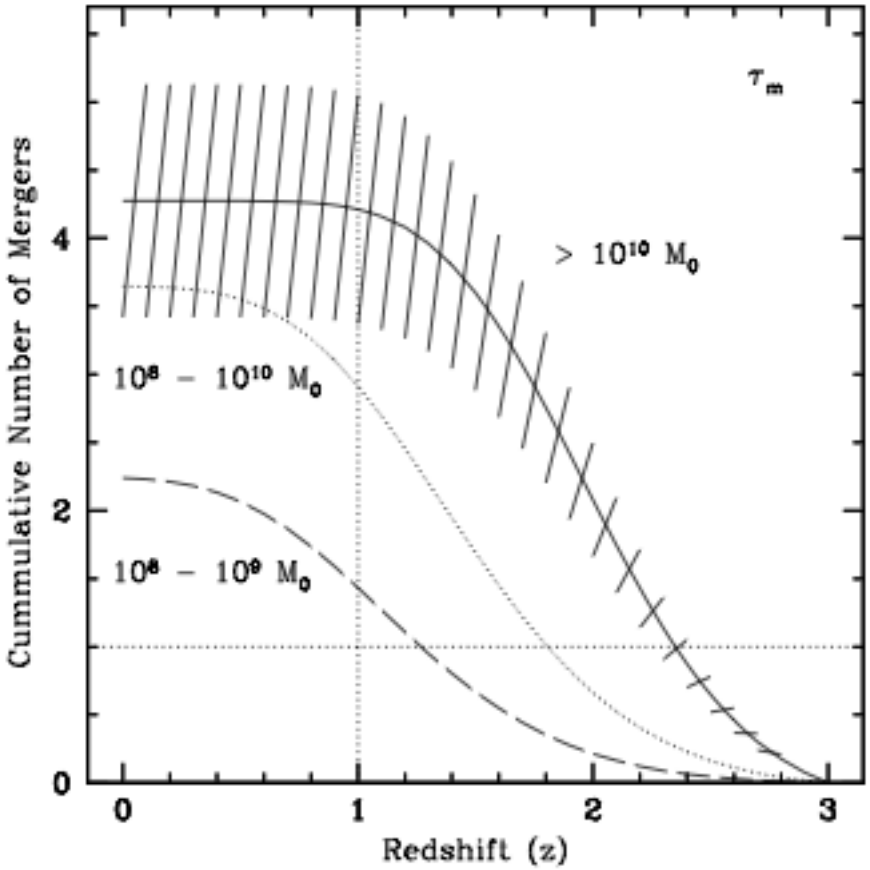
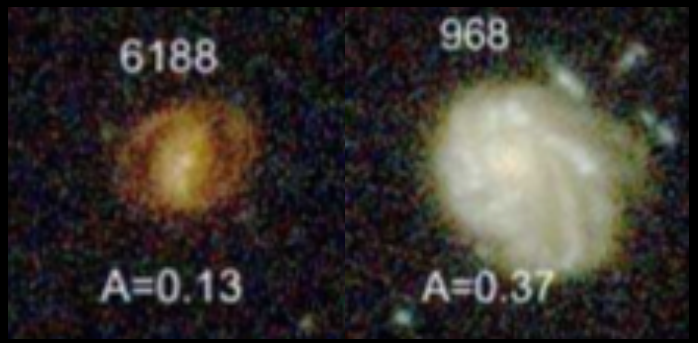


Figure 16. The cumulative number of major mergers for galaxies of various masses as a function of redshift. These cumulative mergers begin at $z = 3$. The error range for the $M_* > 10^{10}\,M_\odot$ galaxies is shown. In total, the most massive galaxies have a larger number of total galaxy mergers than the lower mass systems.

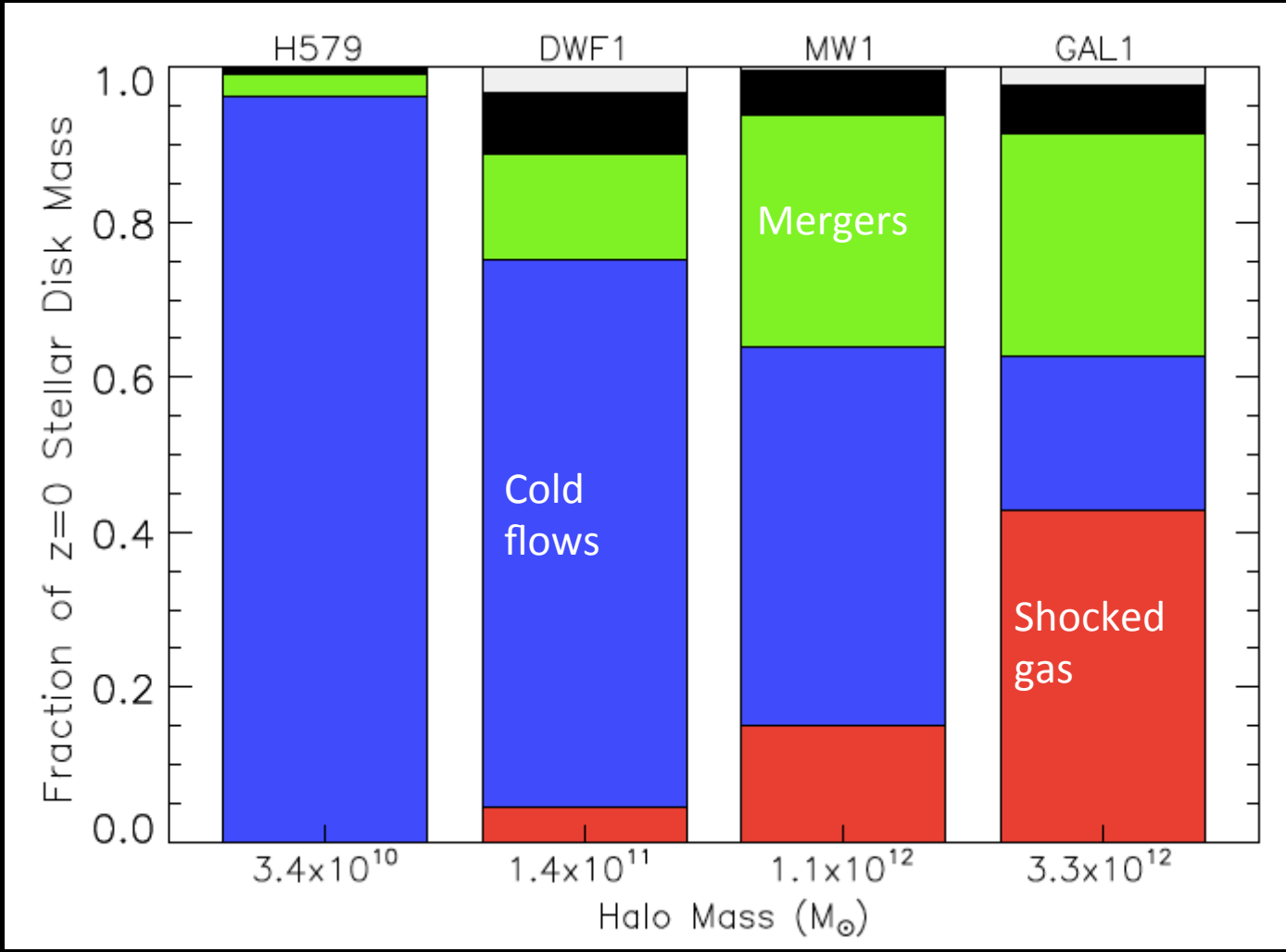
Last major merger of Milky Way – 10-12 Gyrs ago (Gilmore et al. 2002)



Conselice et al. 2008 – number of mergers (based on CAS on HUDF)

- very few major mergers at z<1

External Secular Processes



Brook et al. 2009

Four example galaxies chosen to have last major merger at z>1.5

Processess of Internal Secular Evolution

- Angular momentum transfer by
  - Spiral arms
  - Bars
- Disk heating (thickening)
- Growth of bars
- Growth of pseudobulges

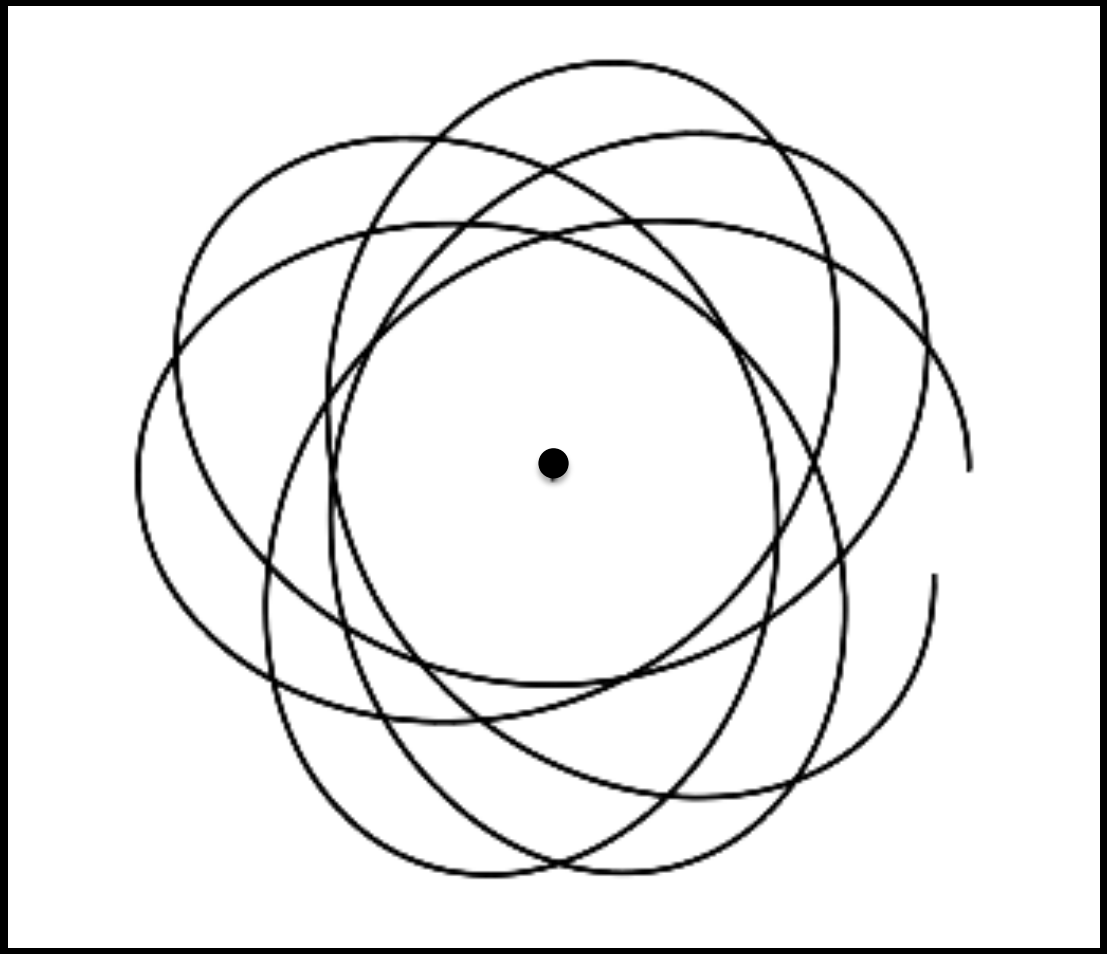
General dynamical principles

- Galaxies are self gravitating systems (stars, gas, DM floating around together in space)

- Self gravitating systems have negative specific energy
  - Can lower energy by increasing central density and flinging away the edges
- So discs spread in radius
  - Inner parts shrink
  - Outer parts grow

M101 imaged by Mike Hyde

Stellar Orbits



Non closing rosettes (spirograph pattern)

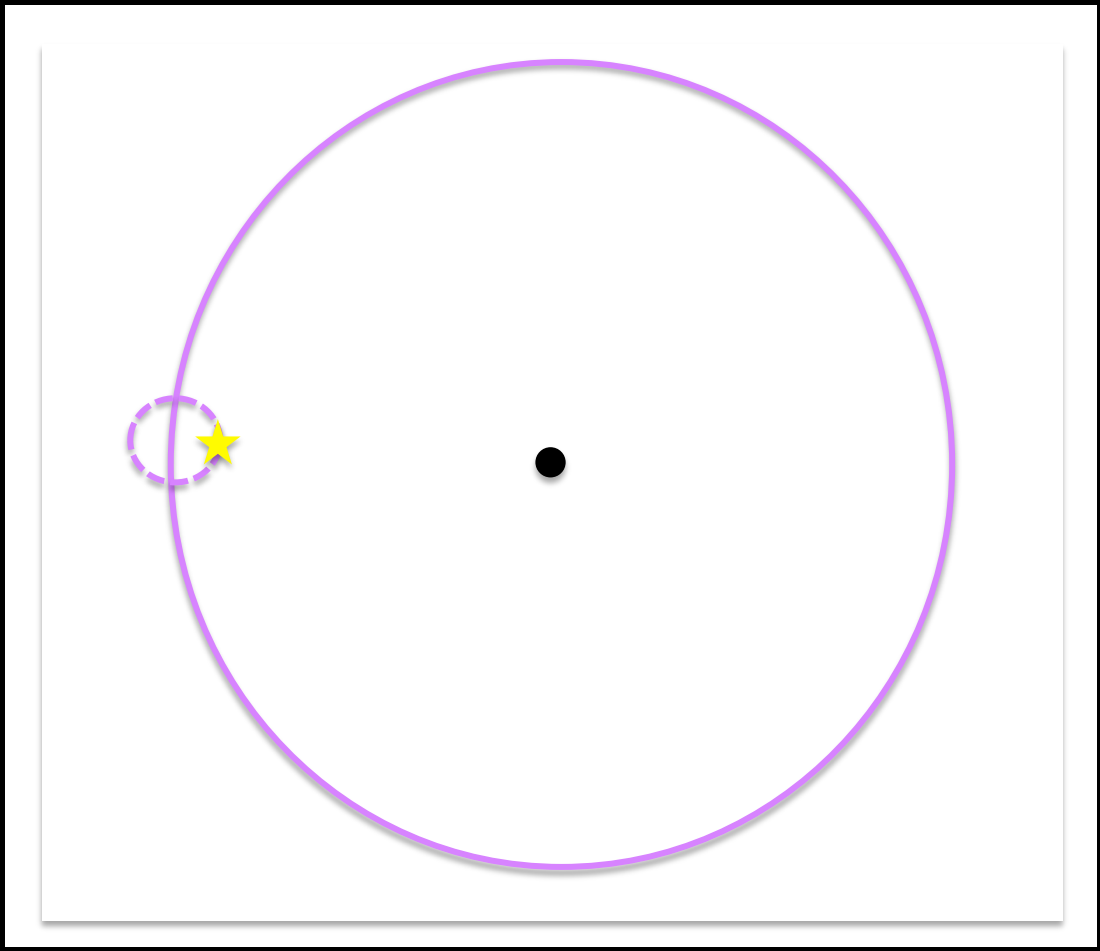
or:

- epicycles around a "guiding centre" which has a fixed angular velocity (Ω_ϕ)

or:

- in the rotating frame: radial oscillations with period Ω_R

Stellar Orbits



Non closing rosettes (spirograph pattern)

or:

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or:

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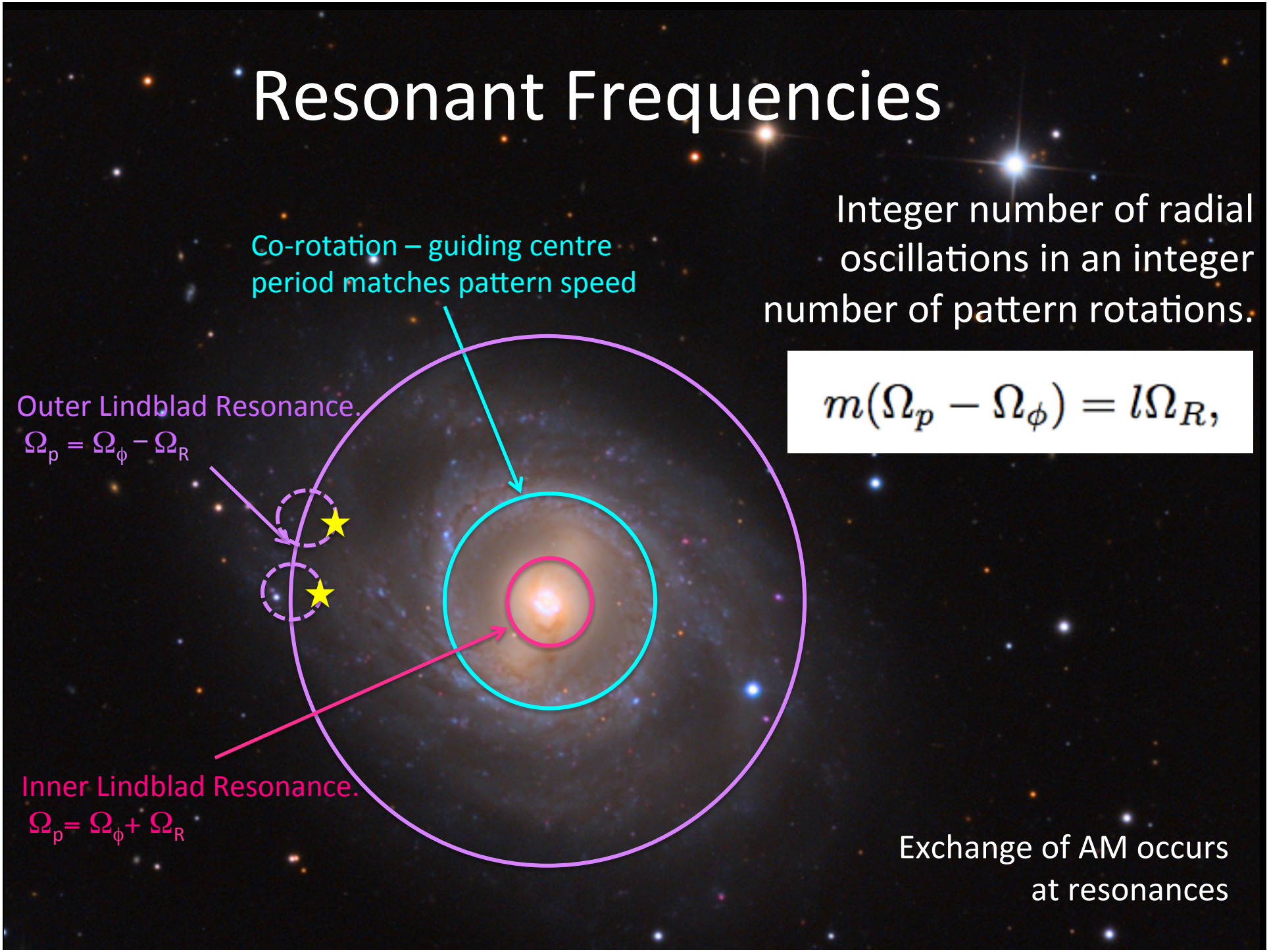
Resonant Frequencies

Integer number of radial oscillations in an integer number of pattern rotations.

$$m(\Omega_p - \Omega_\phi) = l\Omega_R,$$

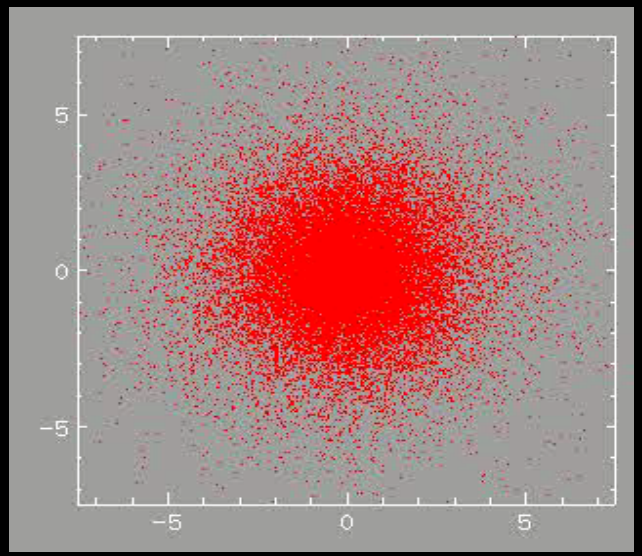


Exchange of AM occurs at resonances

Galactic Bars

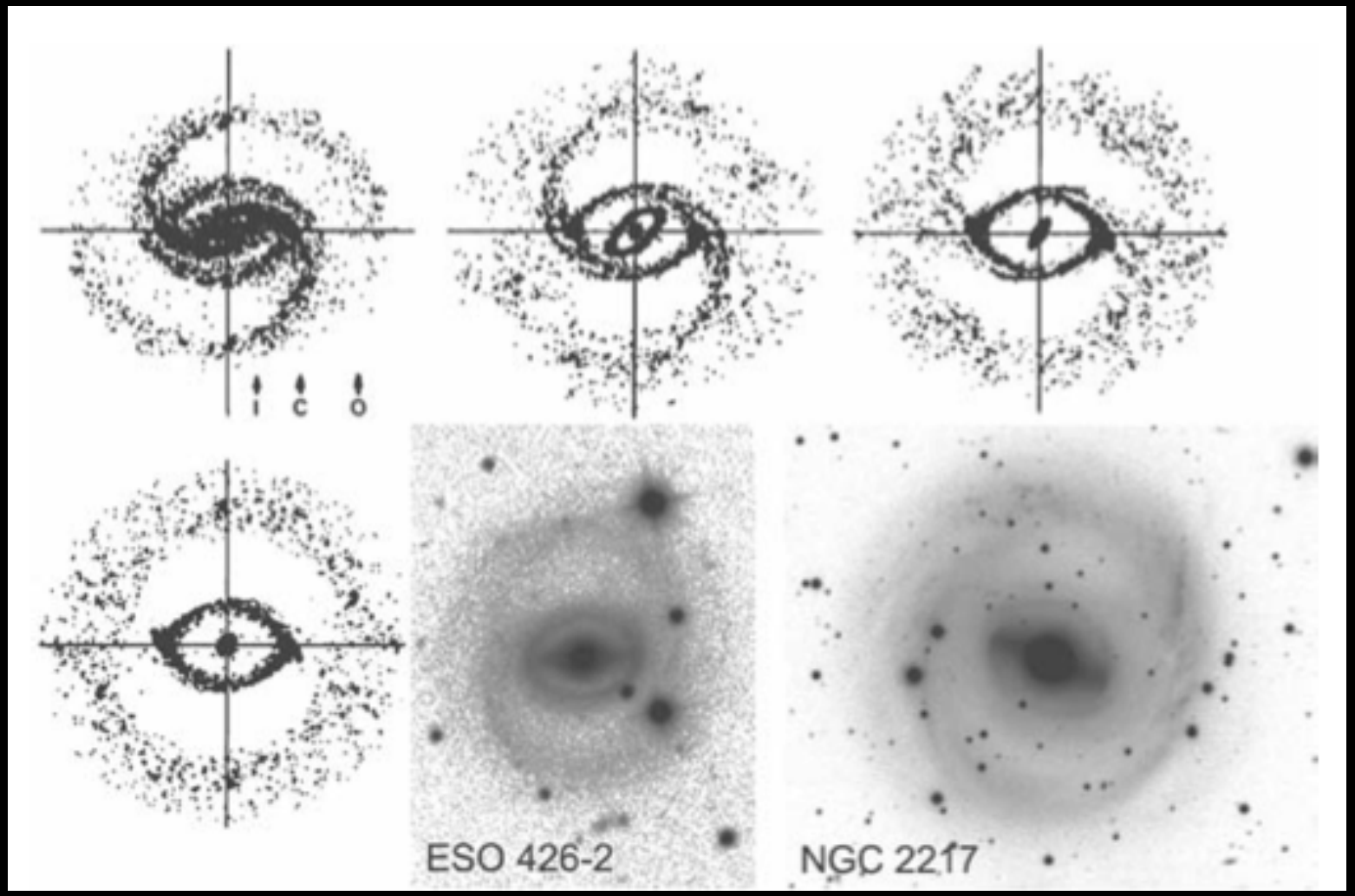
Forming a bar is easy - they are natural way to stabilize a self gravitating disc

- why do some disc galaxies not have them…..?



Sellwood, 2010 "Dynamics of Disks and Warps" (astroph/1006.4855)

Response of Gas to Resonances



Gas moves ~ 1kpc per Gyr.

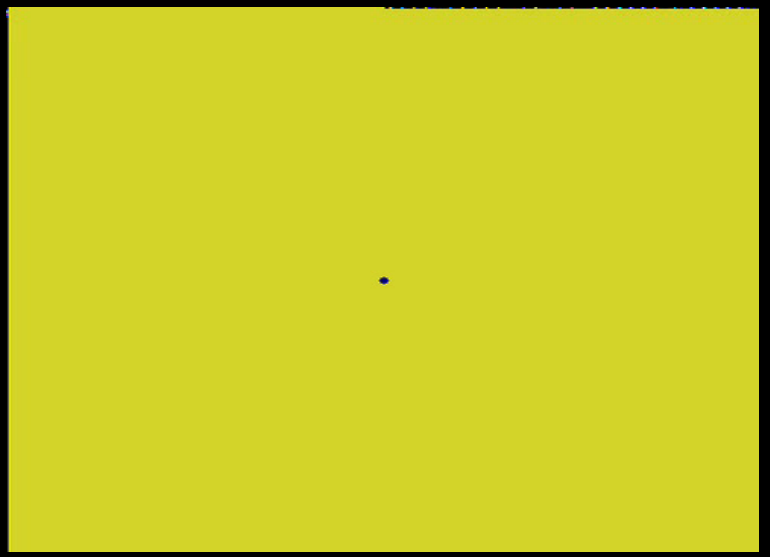
Athanassoula (1992)

Any non-axisymmetry can do this – just longer timescales.

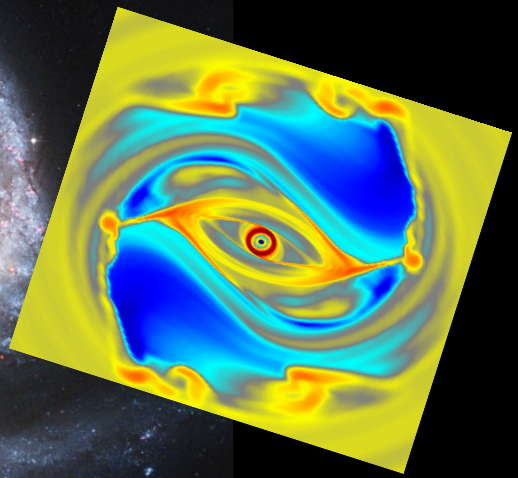
Figure 5, Kormendy & Kennicutt 2004

Bar evolution

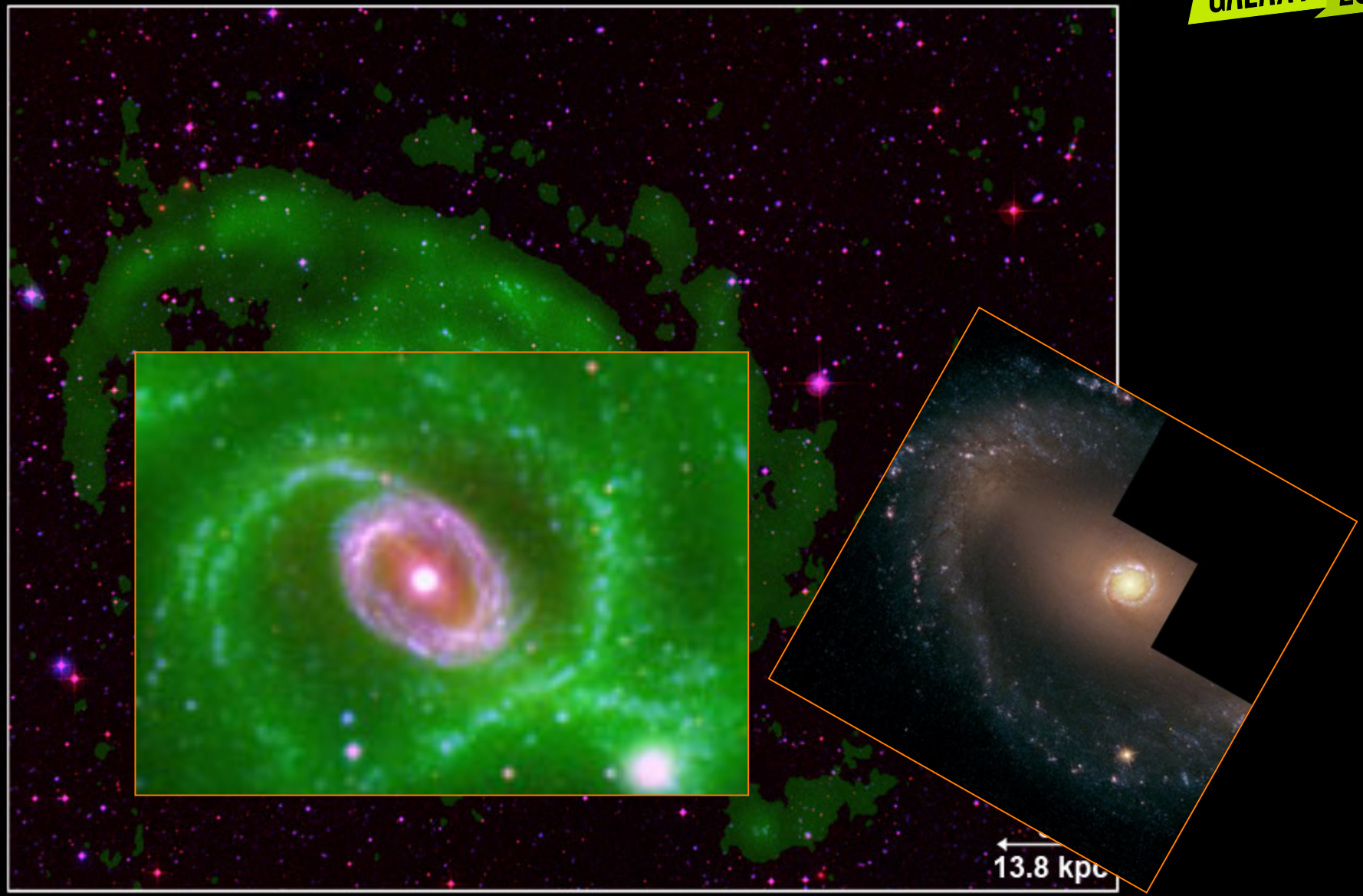
- Bars enable exchange of angular momentum -> they move material around…
  - growing central concentrations (pseudo-bulges)
  - sparking central star formation
  - feeding AGN?
  - using up gas more quickly?
  - limiting external in fall of gas (beyond co-rotation)



James Stone (Princeton)



Galaxy Pair NGC 1512 / NGC 1510



NUV (GALEX, blue) + H I (ATCA, green) + R (DSS, red) + MIR (Spitzer, luminosity on NGC 1512 center)
Optical image shows the stellar distribution. Near ultraviolet image traces the star forming regions.
The H I image is the neutral gas component, the data are from the LVHIS (*The Local Volume HI Survey*) project.

Ángel R. López-Sánchez & Bärbel Koribalski
CSIRO / Australia Telescope National Facility

CSIRO

Evidence for Secular Processes

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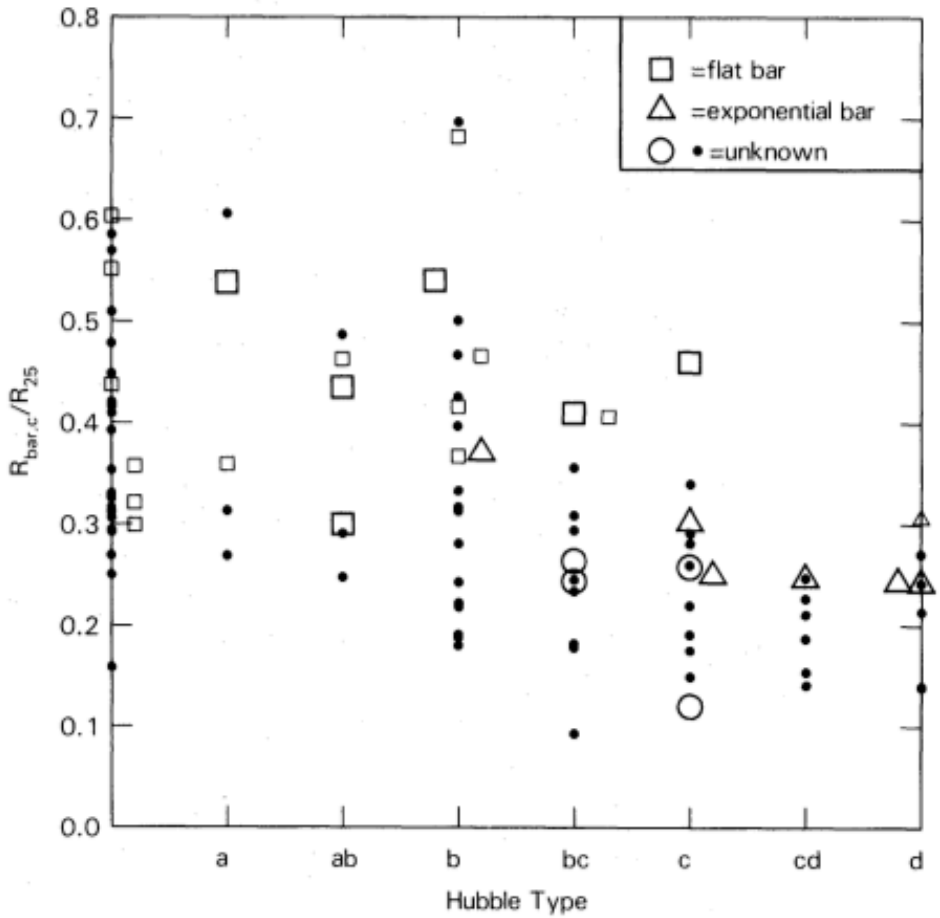


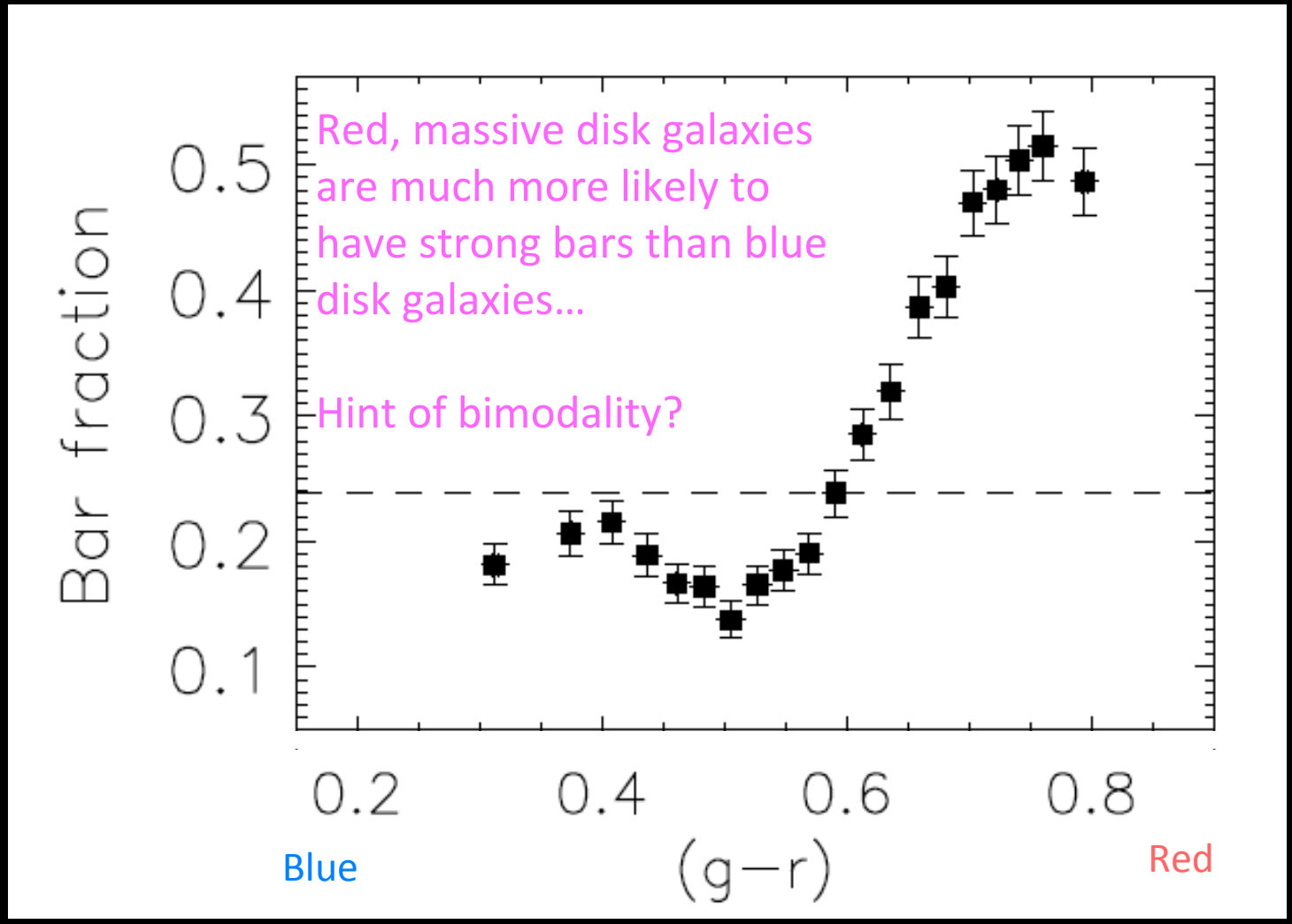
FIG. 4.—The ratio of the inclination-corrected bar radius to R_{25} is shown plotted against the galaxy Hubble type. Large squares and triangles are for galaxies in our survey; small squares and triangles are for SB galaxies in other published sources (see Table 3). Open circles represent our survey galaxies with unknown bar types, and small filled circles are for the additional SB galaxies in Kormendy (1979).

Elmegreen & Elmegreen 1985

Earlier type spirals have longer bars

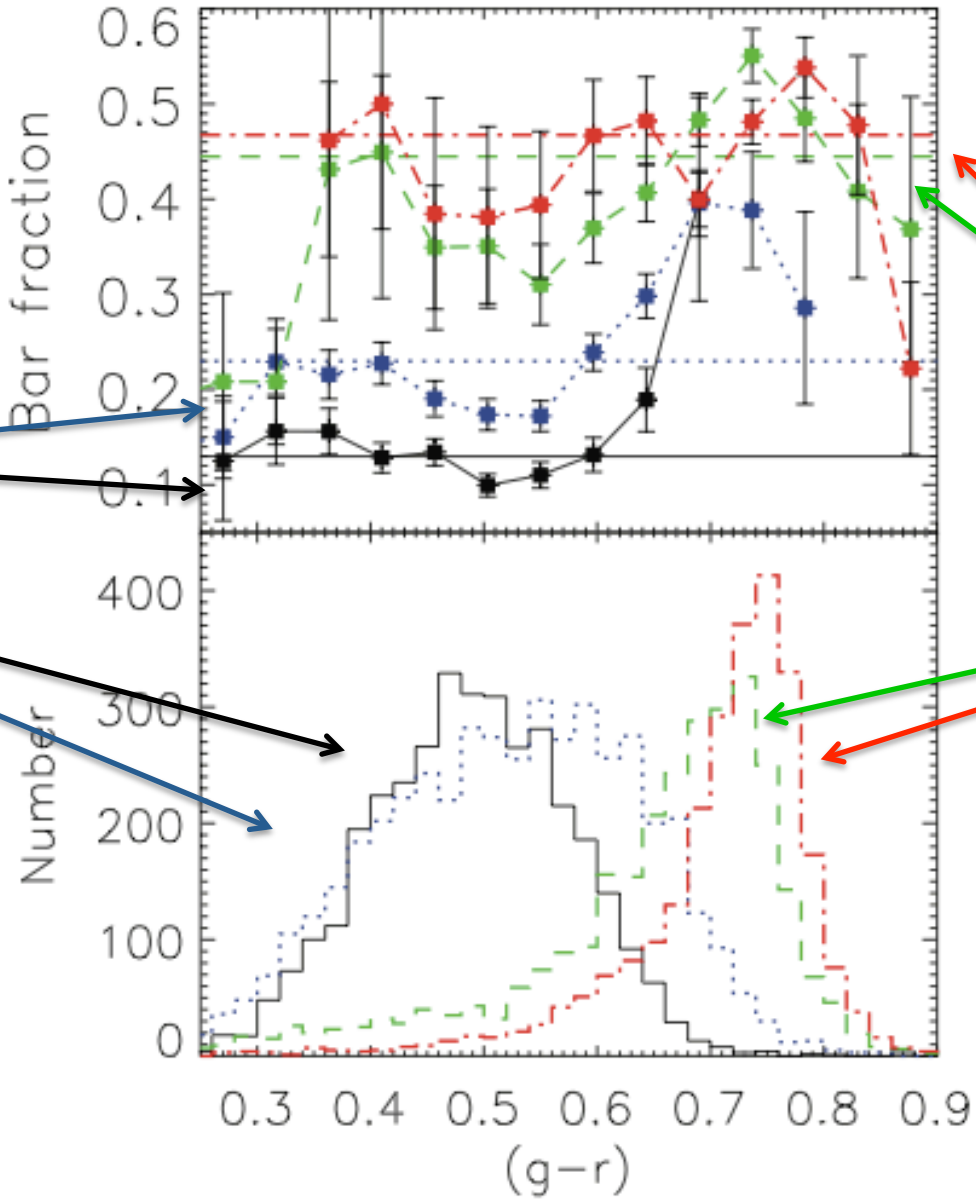
Bars get longer as they age and make disc galaxies grow bulges…..

Barred Red Spirals in Galaxy Zoo



Masters et al. 2010 (MNRAS 405, 783)
Masters et al. 2011 (MNRAS 411, 2026)
(Also seen in RC3; Nair & Abraham 2010; Giordani et al. 2010)

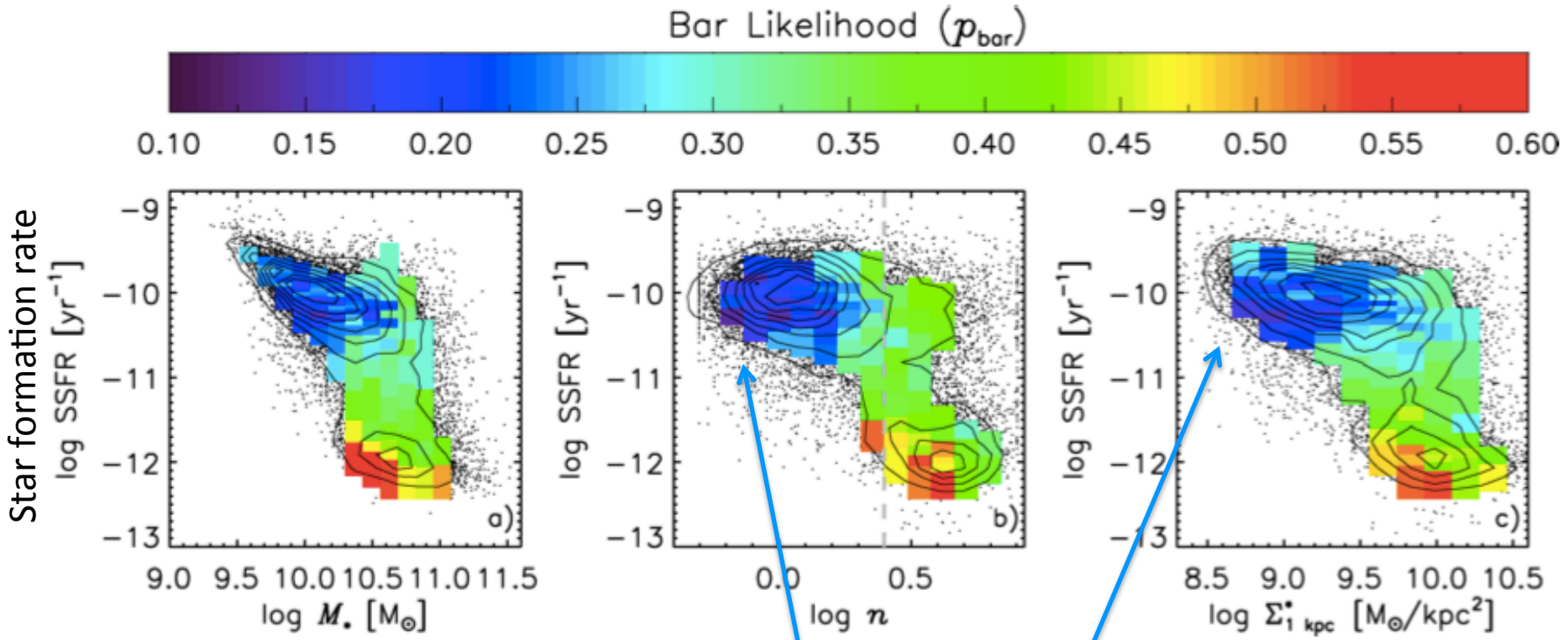
Correlation with Bulge Size



Disc dominated - low bar fraction except where very red

Bulge dominated - high bar fraction at all colours

Evidence for Secular Processes



Stellar mass

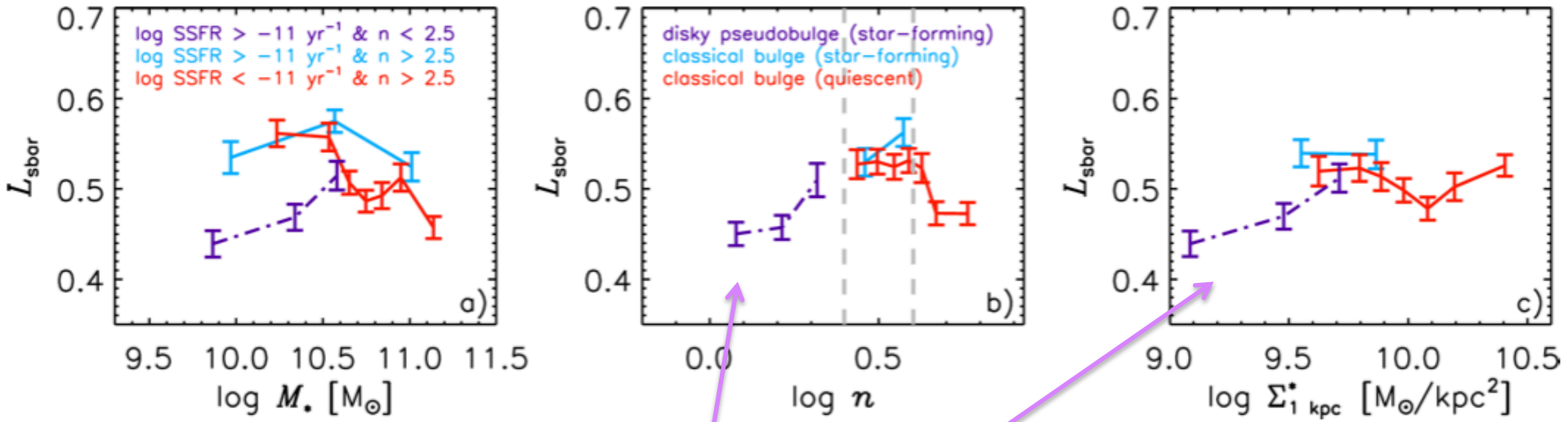
Sersic Index (bulge)

Central stellar density

Secular evolution?

Cheung et al. (submitted)

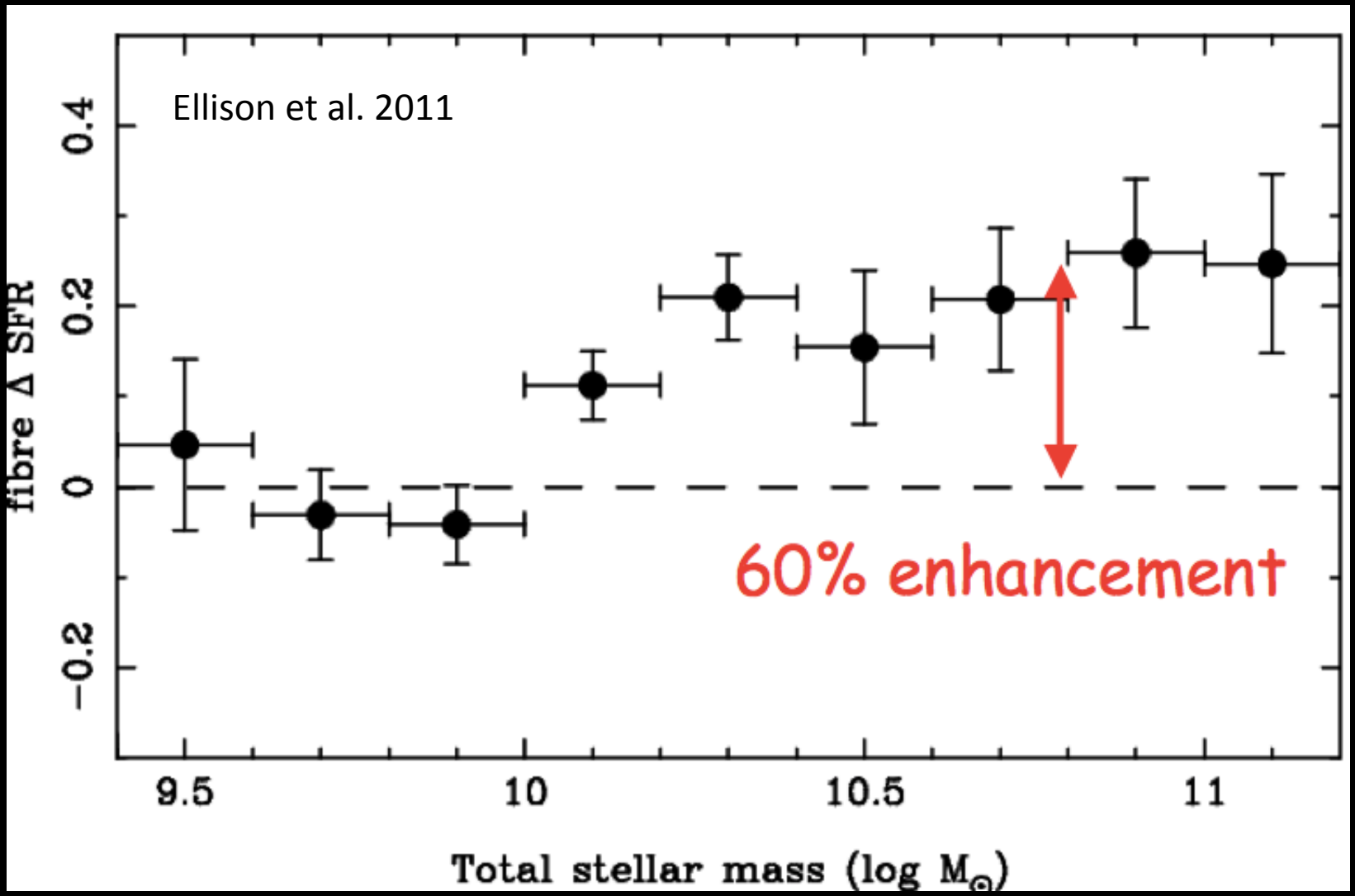
Evidence for Secular Processes



Cheung et al. (submitted)
Bar length as a proxy for age

More massive central concentrations the older the bar

Bars Affecting Starformation

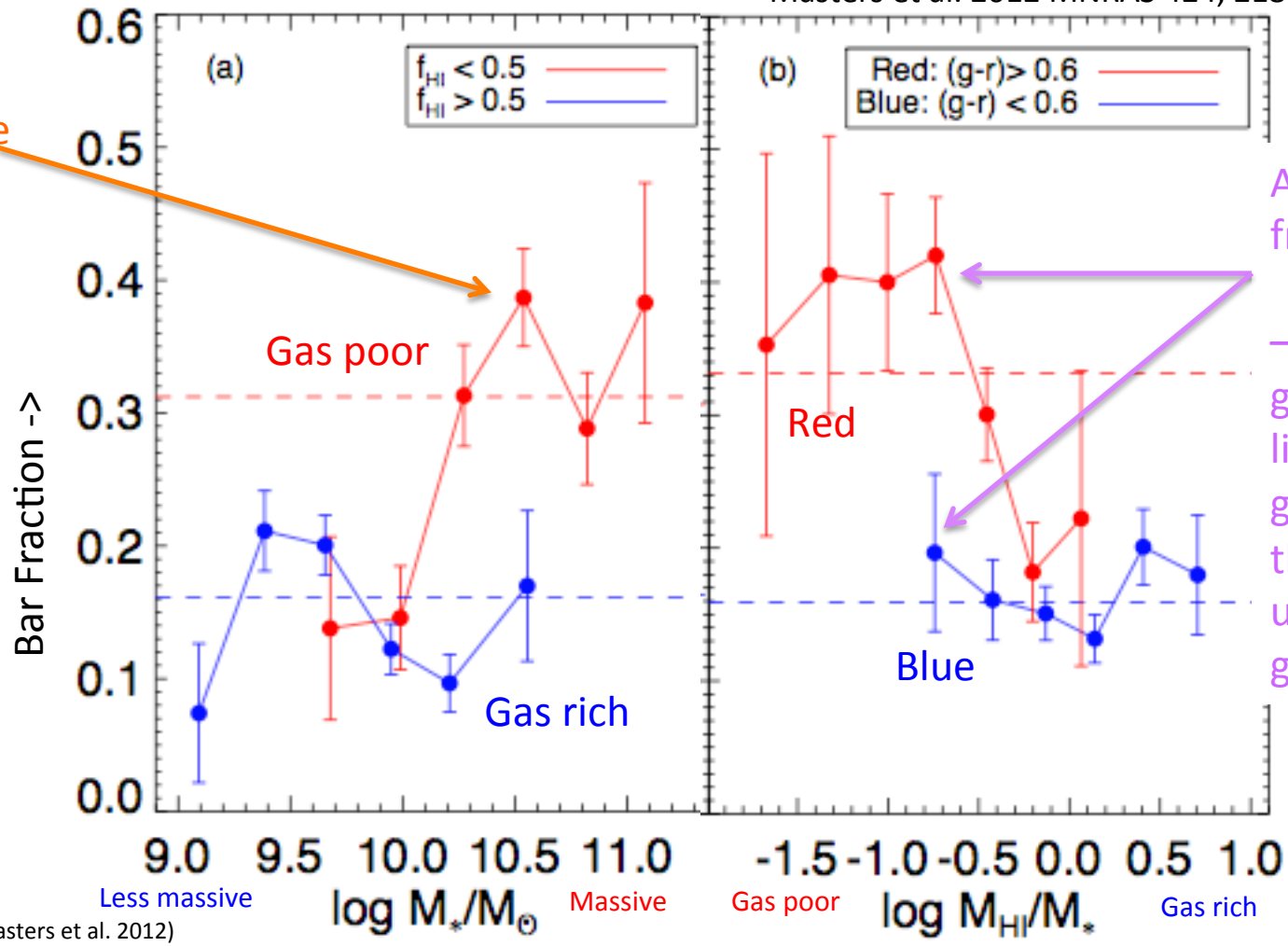


Bars affecting star formation?

At fixed M_{star}

– gas poor galaxies more likely to have bar than gas rich

Masters et al. 2012 MNRAS 424, 2180



(Masters et al. 2012)

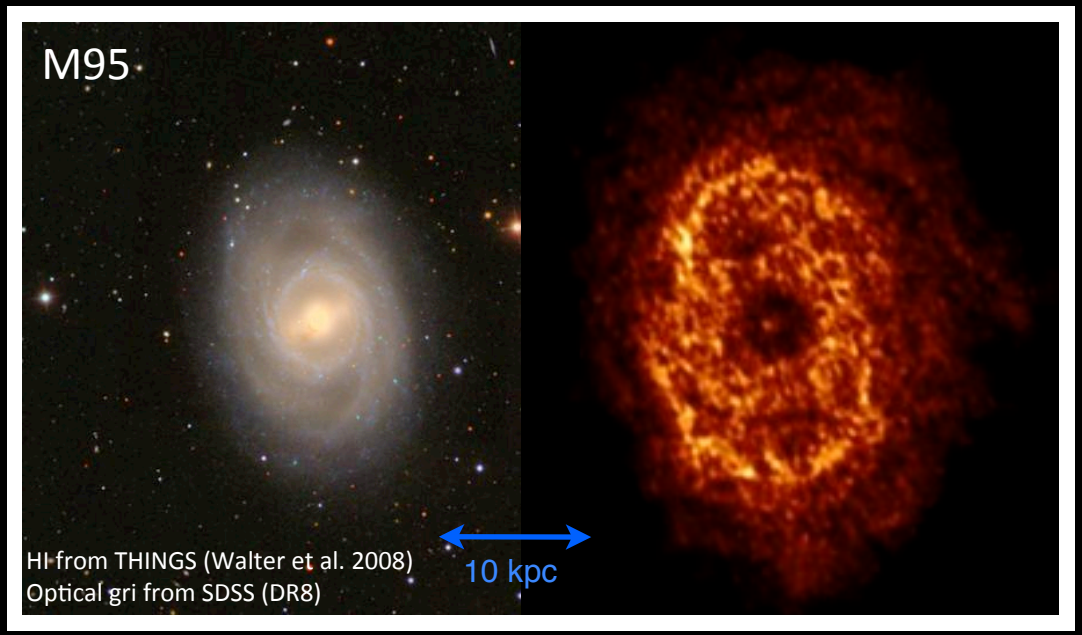
At fixed gas fraction

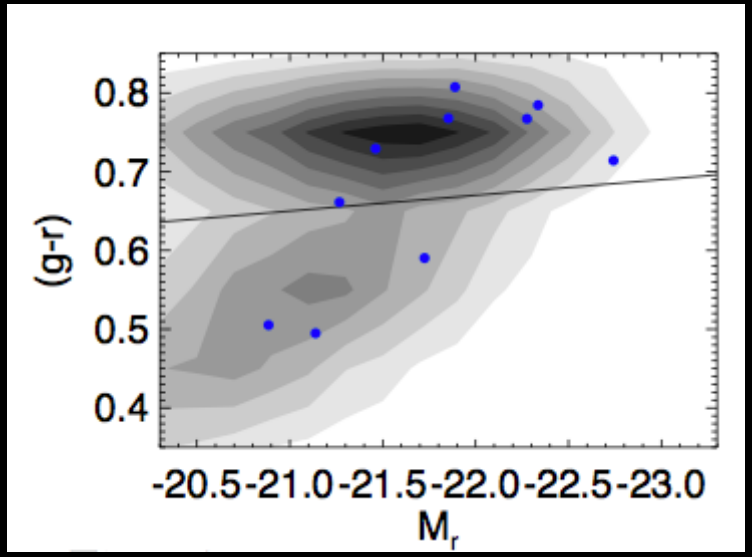
– barred galaxy more likely to be globally red than unbarred galaxy

Driven by gas (HI) content

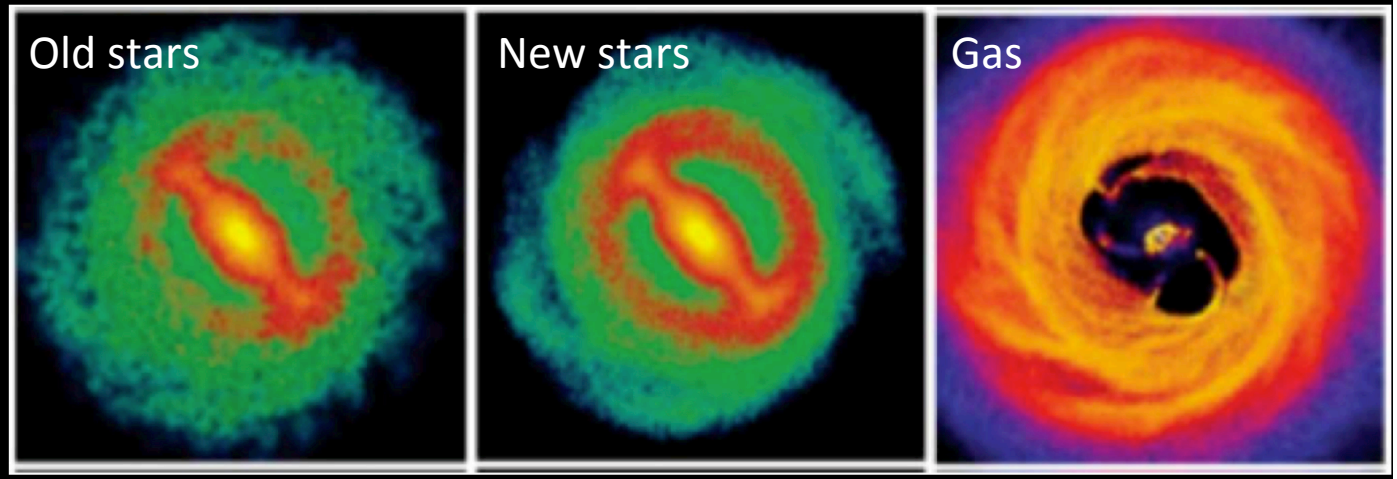
➔at fixed mass correlation with HI content persists

Bars in Gas Rich Spirals...



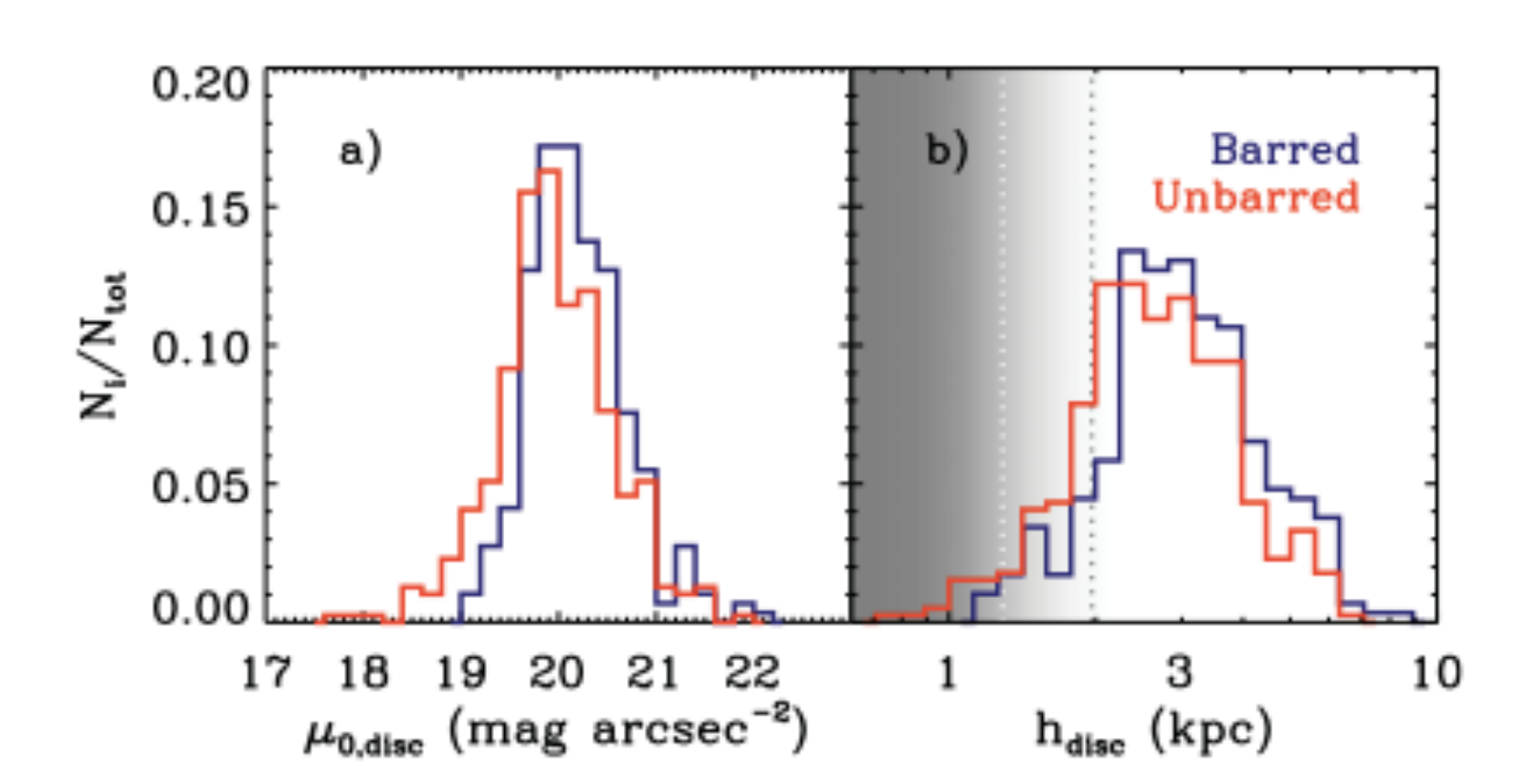


Resolved HI surveys for gas (VLA observations scheduled this autumn)



Simulation (Athanassoula et al. 2013)

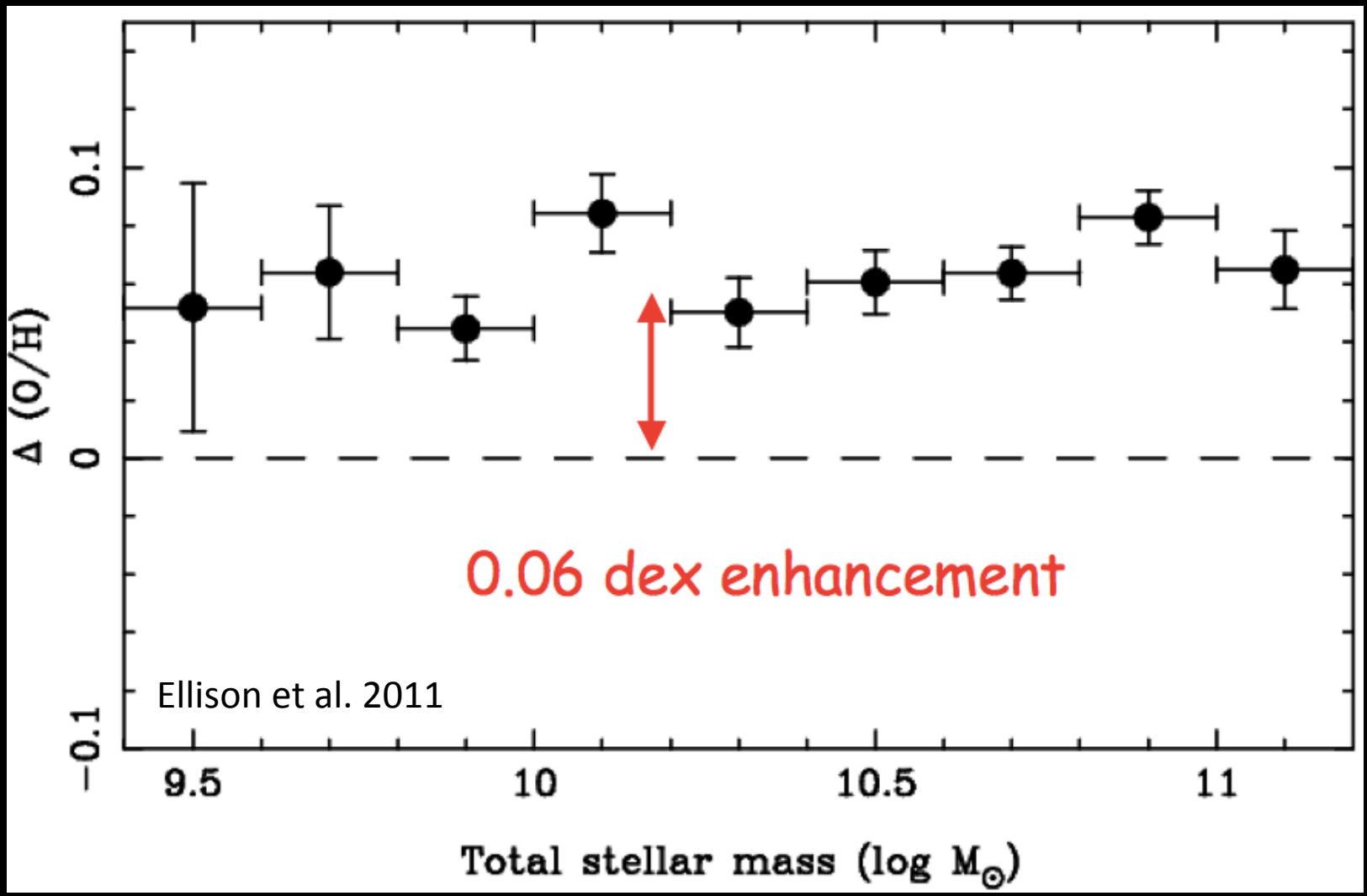
Bars Changing Disc Structure



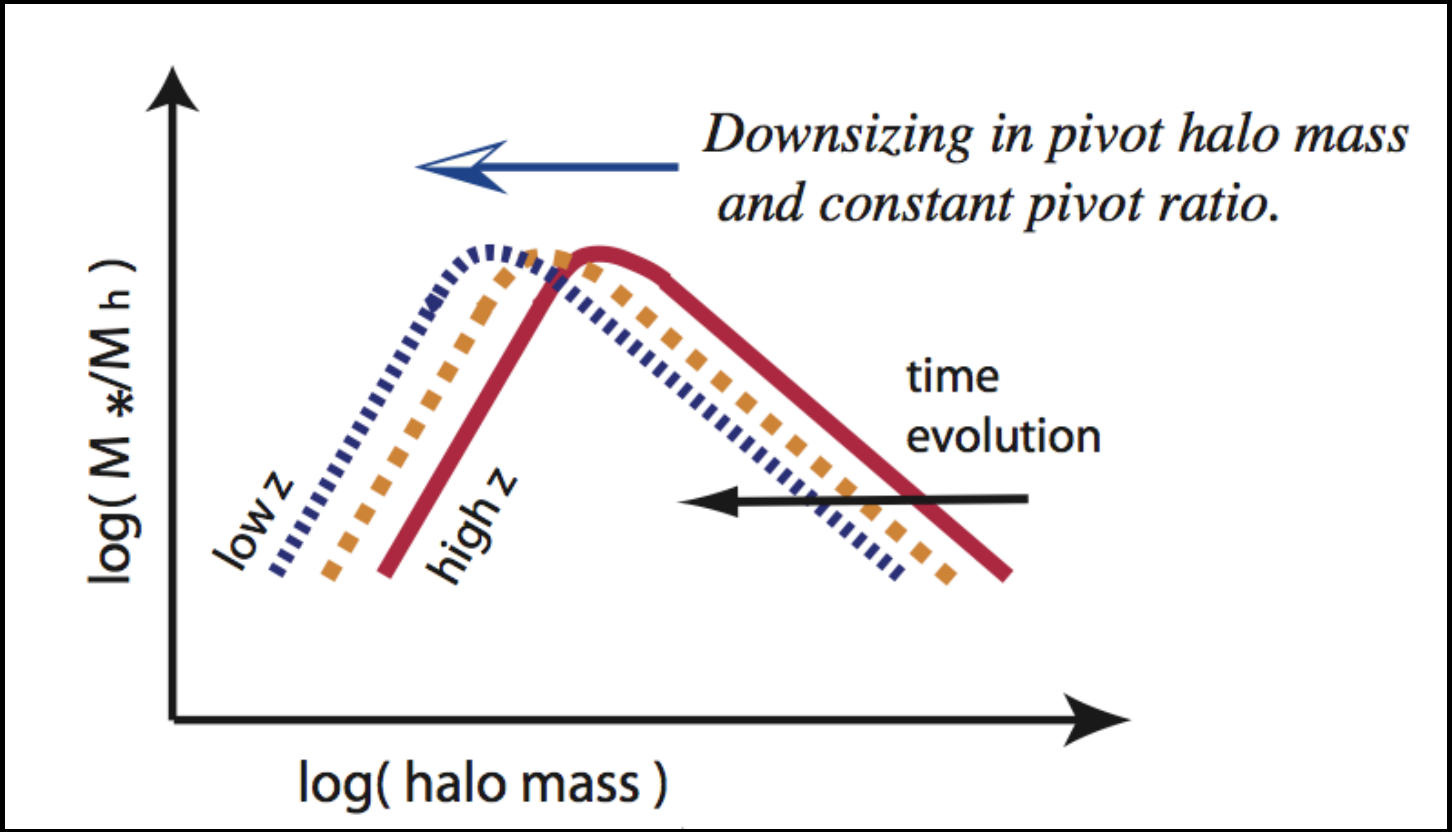
Fainter central surface brightness and longer scale lengths.

Sanchez-Janssen & Gadotti 2013

Changing Metallicity



Evidence for Secular Evolution?



Schematic of result from Leauthaud et al. (2012) based on weak lensing halo masses in COSMOS field.

Star formation quenching at constant $M_\star/M_h$ (not fixed M_h or $M_\star/M_{bulge}$)

Disk instabilities

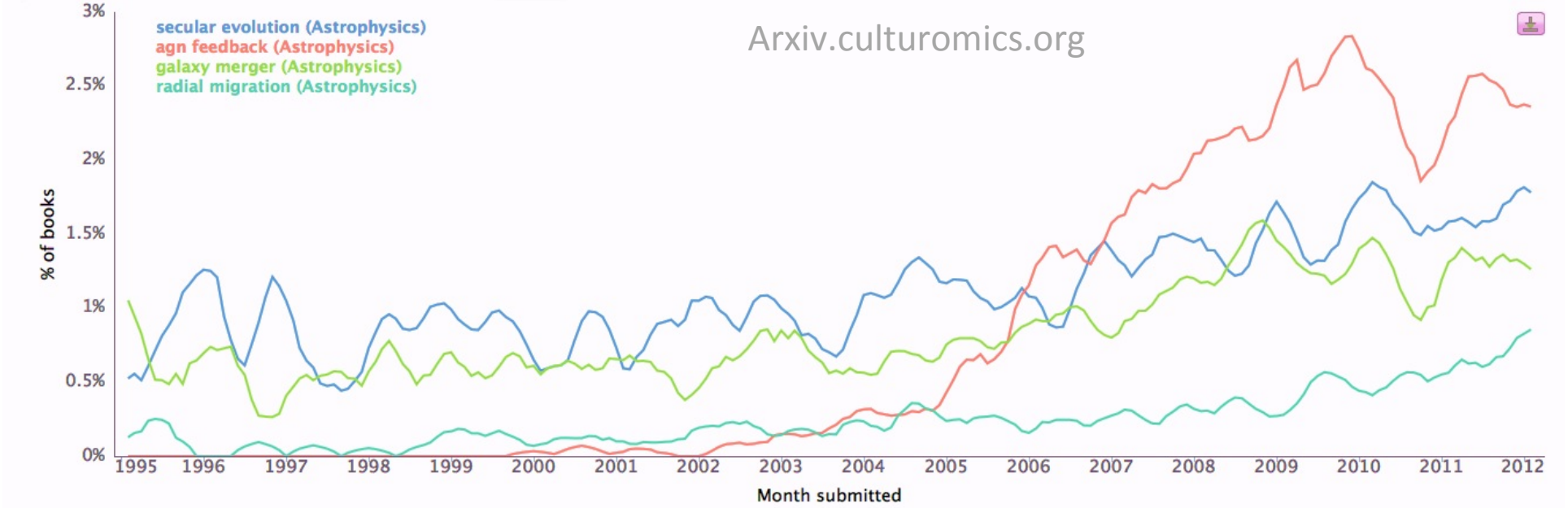
Classic disk stability criteria
(Efstathiou et al. 1982):

$$V_{\rm max}/(G_N M_{\rm disk}/r_{\rm disk})^{0.5} \leqslant 1,$$

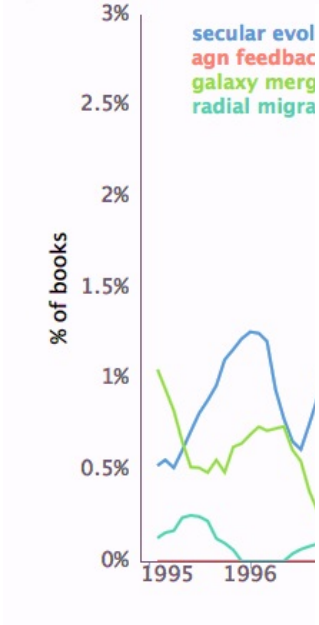
Could disc instabilities contribute to global star formation quenching in disc galaxies?

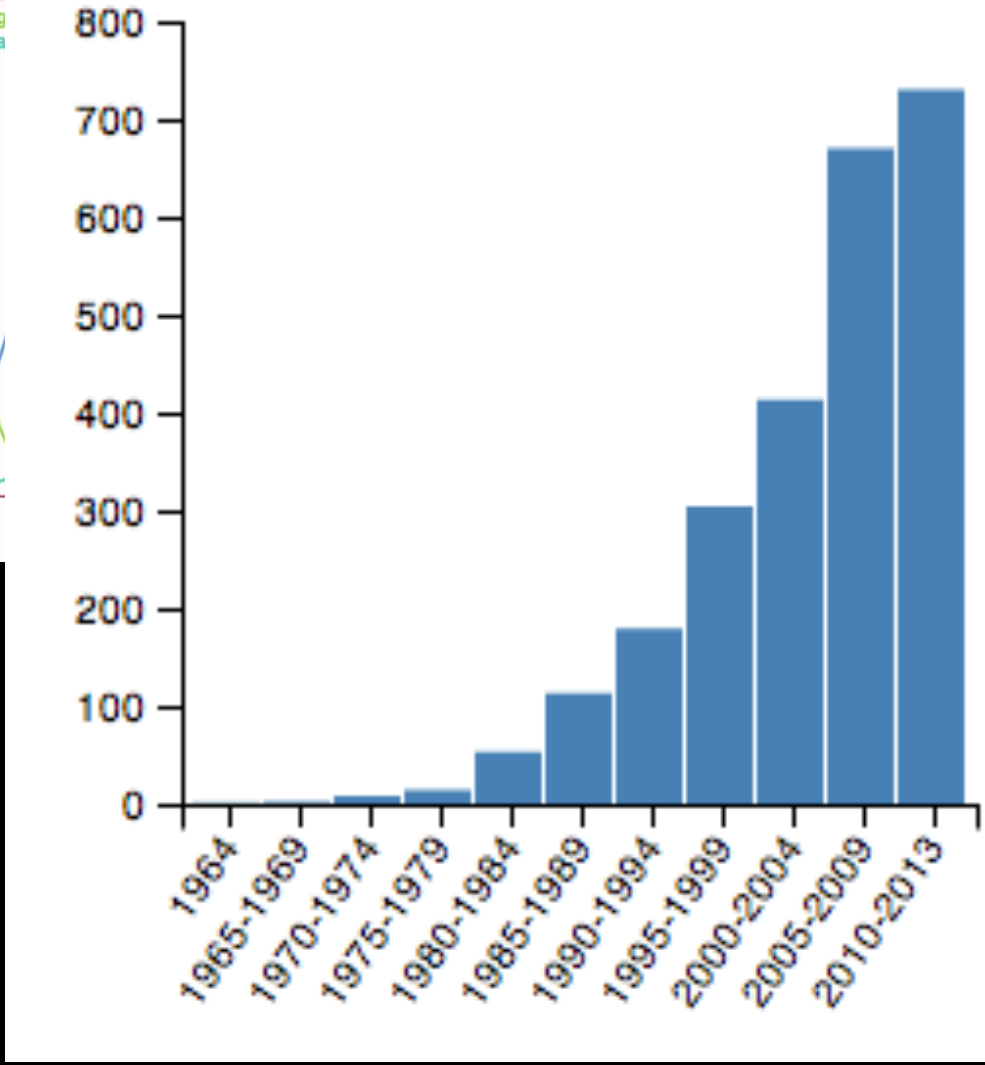

“Every galaxy is dynamically evolving”
- Kormendy & Kennicutt 2004

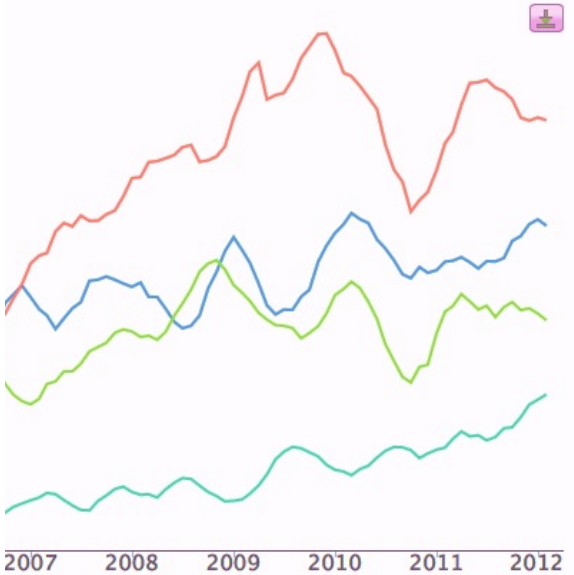
The Future is Secular…



The Future is Secular…







Adslabs.org (search on "secular evolution" galaxies

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