Bar formation in simulated disk galaxies

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Introduction

There are many studies about formation and evolution of barred galaxies using dynamical simulations, but very few using cosmological simulations

Studies with cosmological simulations

Scannapieco et al. (2012) → Study properties of 2 barred galaxies at z=0
Kraljic et al. (2012) → Study 33 disc galaxies in cosmological halos
Algorry et al. (2014) → Study the formation of a counter-rotating bar
Okamoto et al (2015) → Study the evolution of two barred galaxies
Goz et al. (2015) → Study the properties and instability criterion of two barred galaxies at two different resolutions.

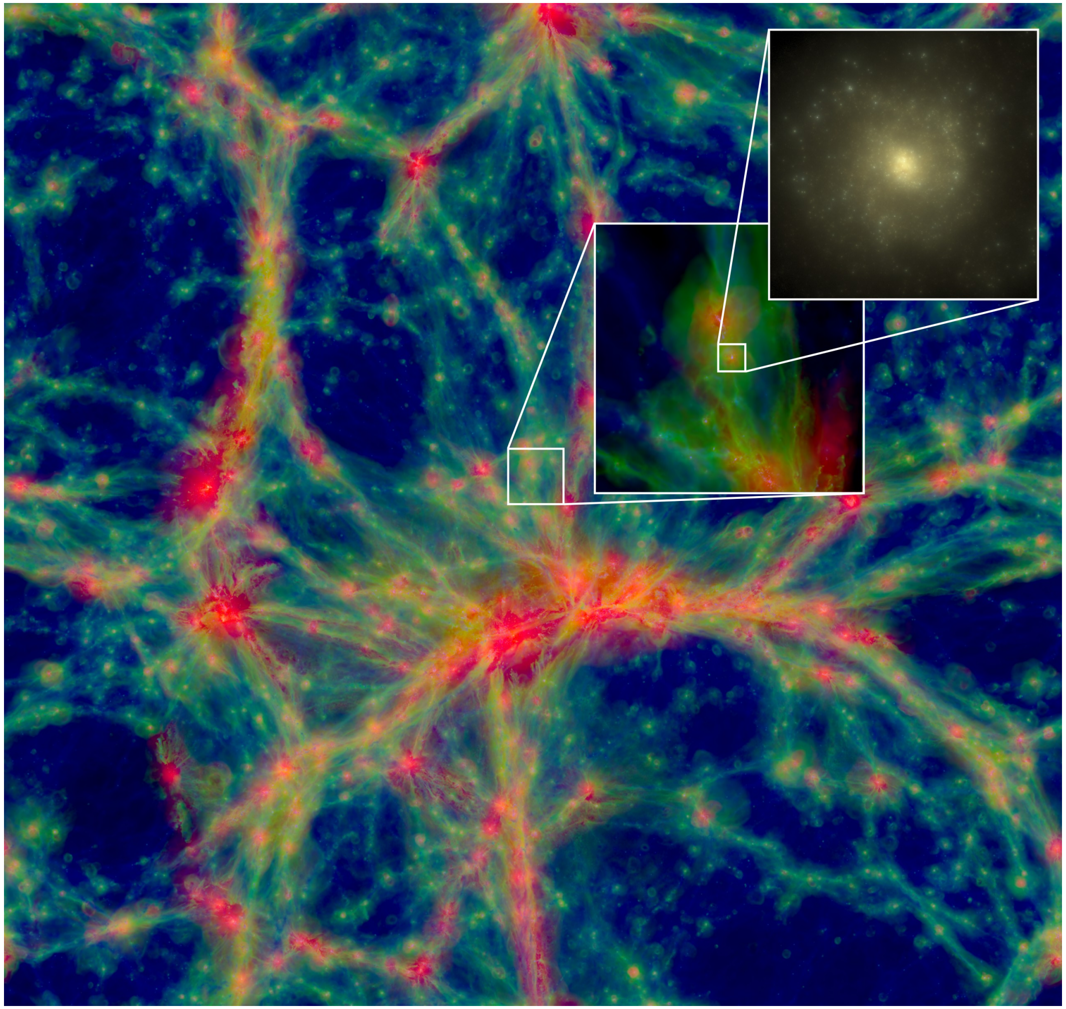
EAGLE simulations

EAGLE (Evolution and Assembly of GaLaxies and their Environments).

EAGLE set of N-body cosmological hydrodynamical simulations aimed at understanding how galaxies form and evolve.

GADGET3 code

100Mpc



Resolución
Mgas=1.81 x 10^6 Msun
Mdrk =9.70 x 10^6 Msun

Dark matter
Gas
Stars
Black holes

Schaye et al. 2014

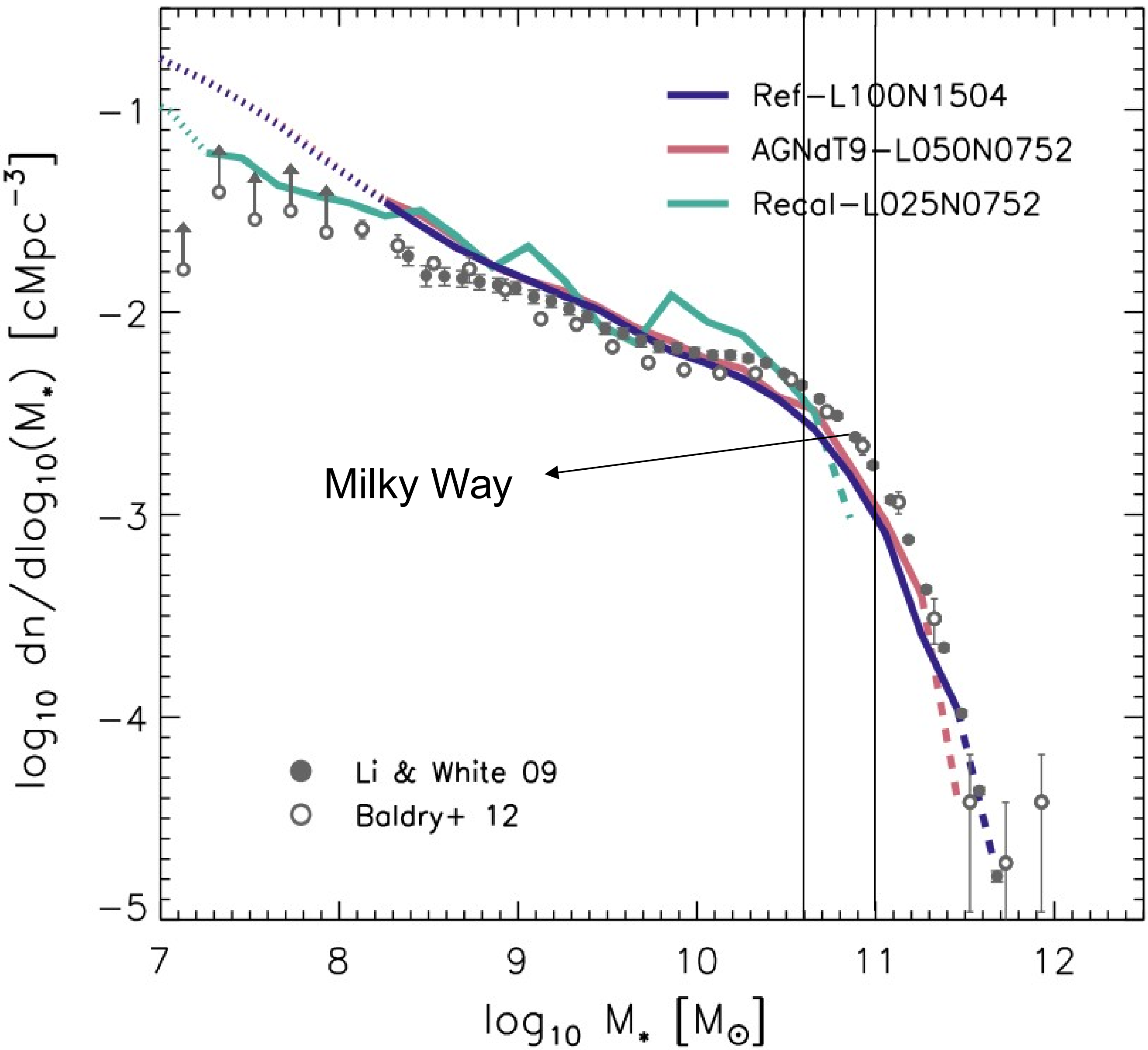
EAGLE simulations

Schaye et al. 2014

Good estimation of the galaxy stellar mass function

Sample selection
10.6 < log(Mgal) < 11.

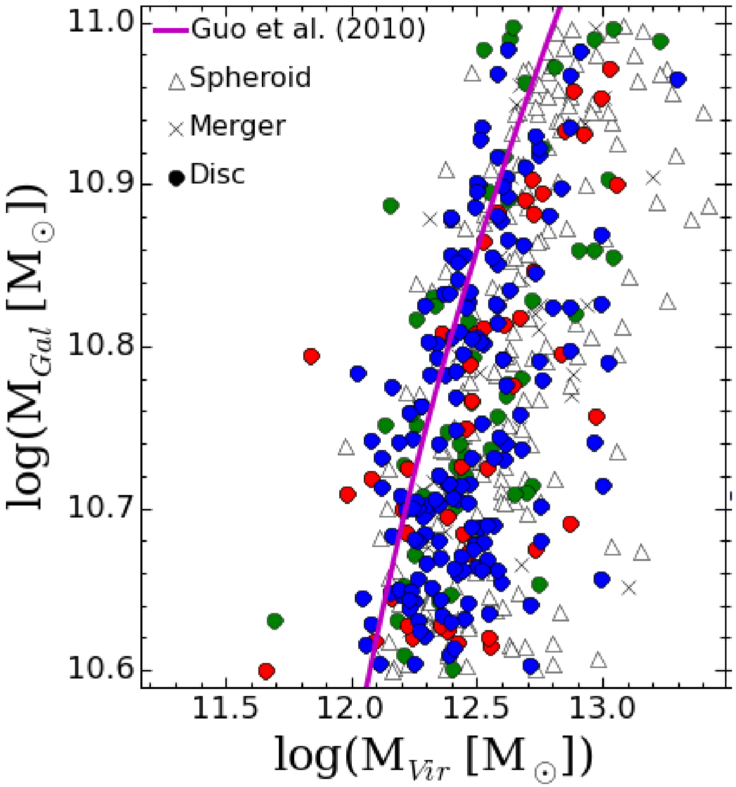
Stellar mass function



Sample Selection

269 disc galaxies

Stellar Mass

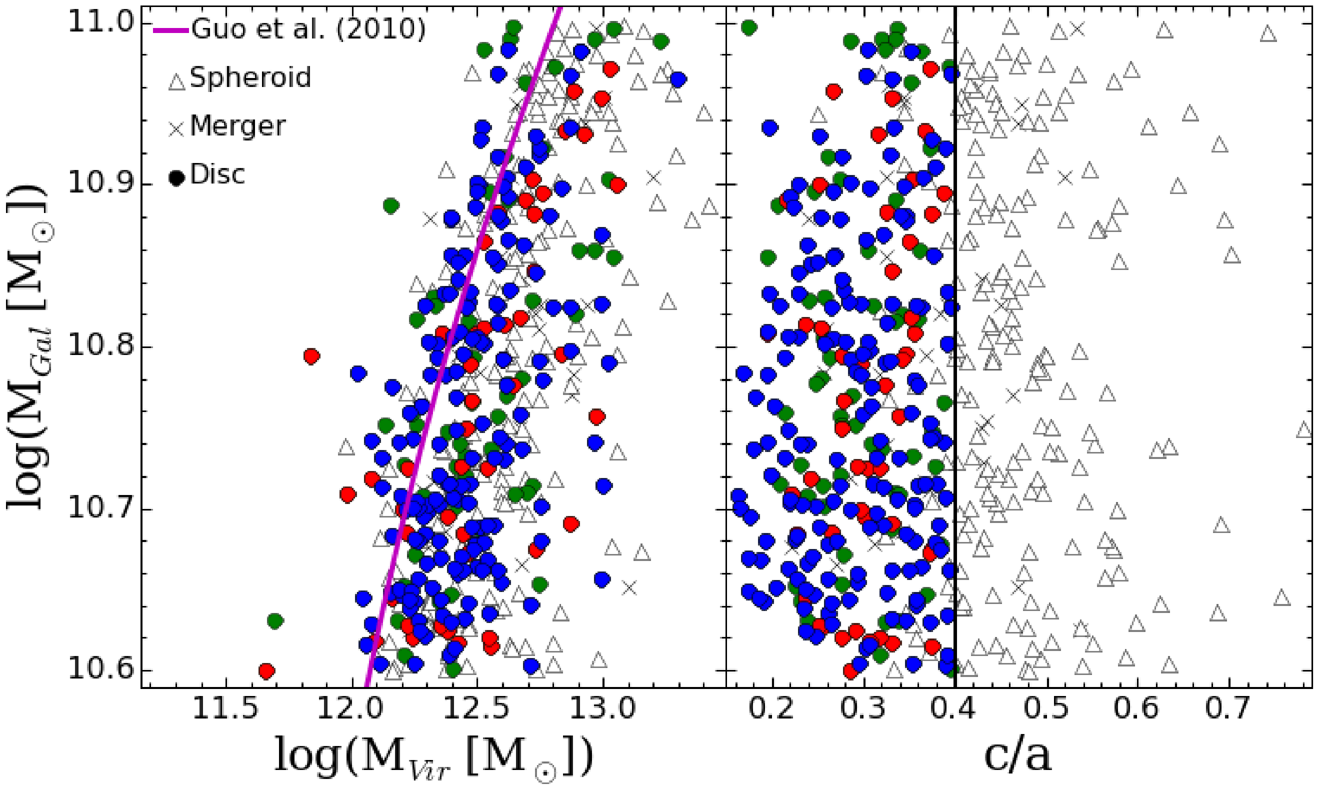


Virial Mass

Sample Selection

269 disc galaxies

Stellar Mass



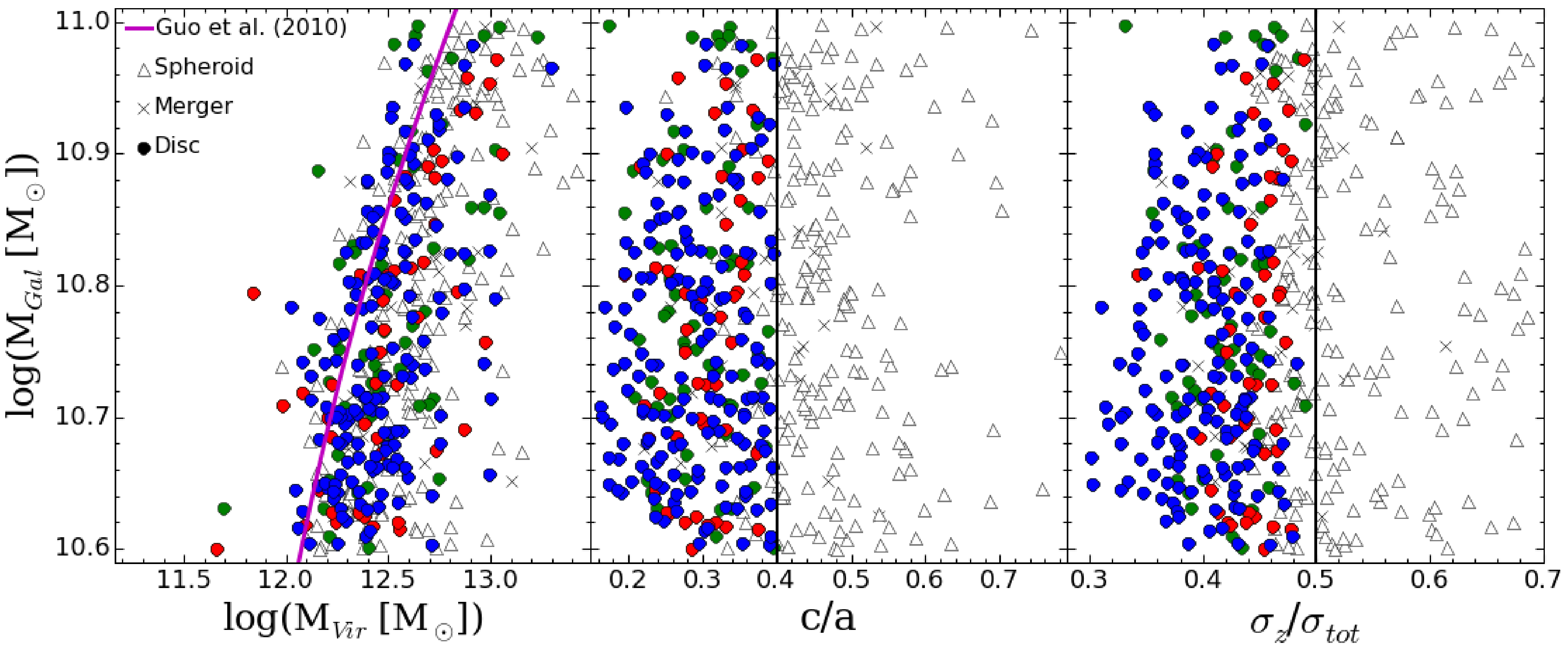
Virial Mass

Ratio between minor and major inertia axis.

Sample Selection

269 disc galaxies

Stellar Mass



Virial Mass

Ratio between minor and major inertia axis.

Ratio between z-direction and total velocity dispertion

Bar strength

Fourier components of the bi-dimensional mass distribution

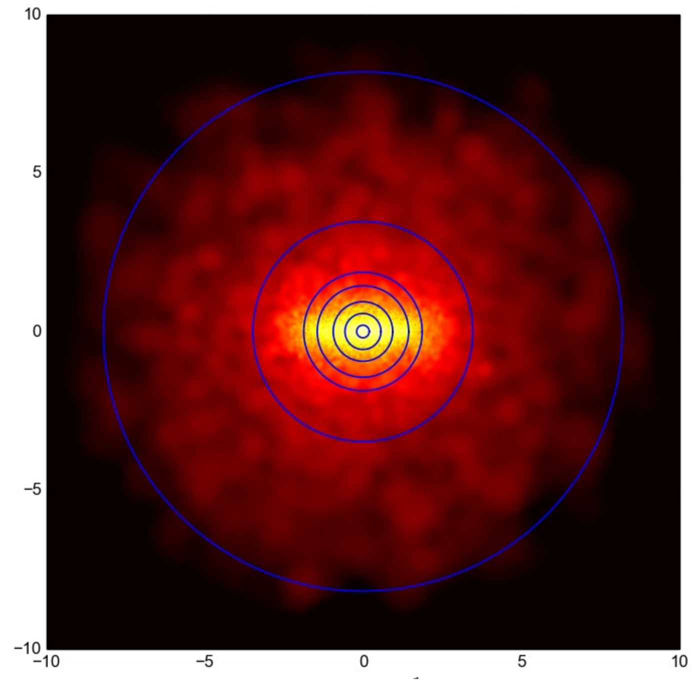
i) Face-on view of the galaxy
ii) We divide in circular bins
iii) We calculate:

$$a_0(R) = \sum_{i=0}^{N_R} m_i$$

$$a_2(R) = \sum_{i=0}^{N_R} m_i \; cos(2\theta_i)$$

$$b_2(R) = \sum_{i=0}^{N_R} m_i \; sen(2\theta_i)$$

Y [kpc h^{-1}]



X [kpc h^{-1}]

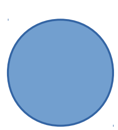
Face-on view of the galaxy

m_i = mass of the particle i
θ_i = azimuthal angle of the particle i
R= Cylindrical radius

$$A_2(R) = \frac{\sqrt{a_2^2 + b_2^2}}{a_0}$$

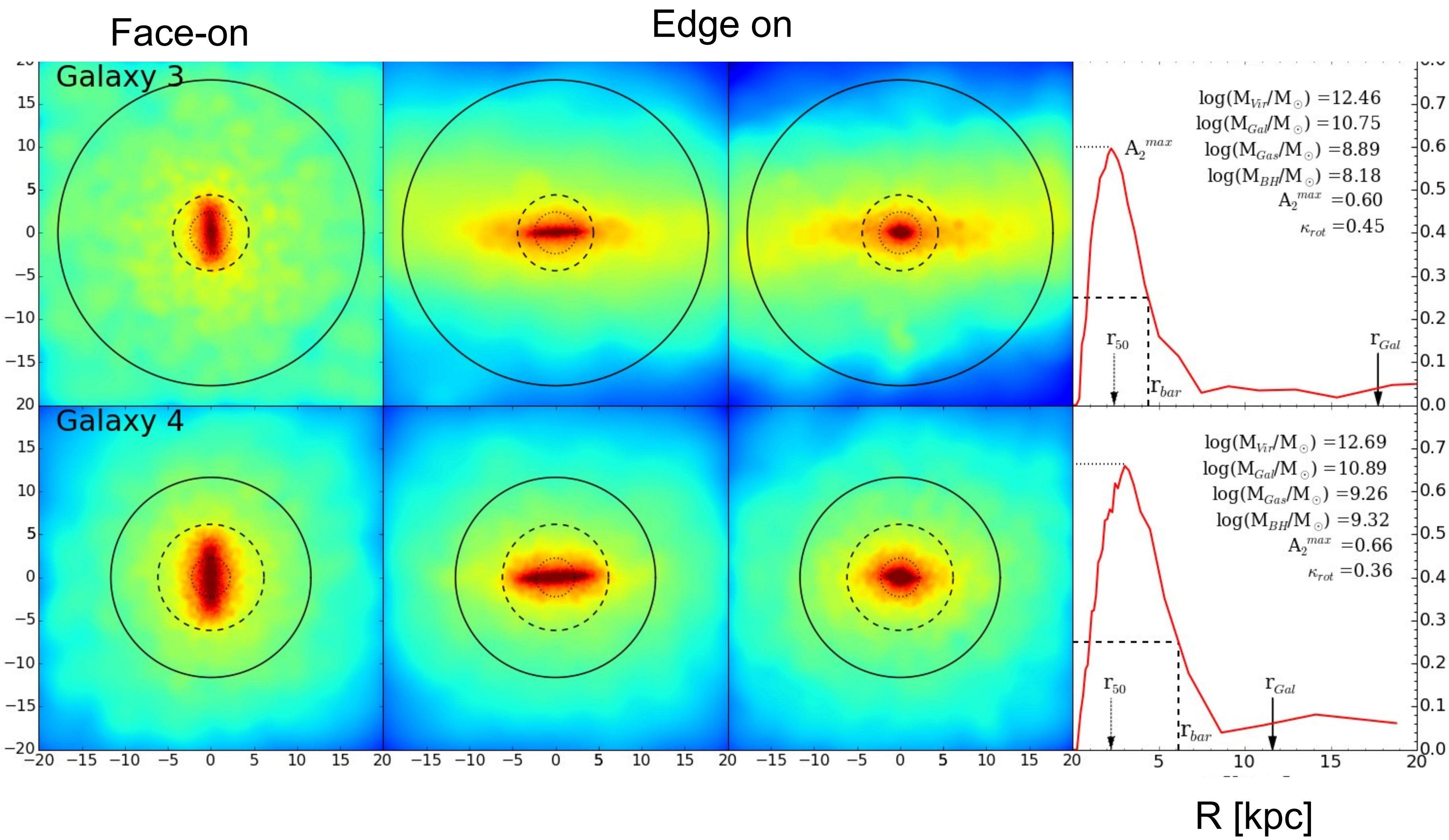
$A_2 = 1$ ———

$A_2 = 0$

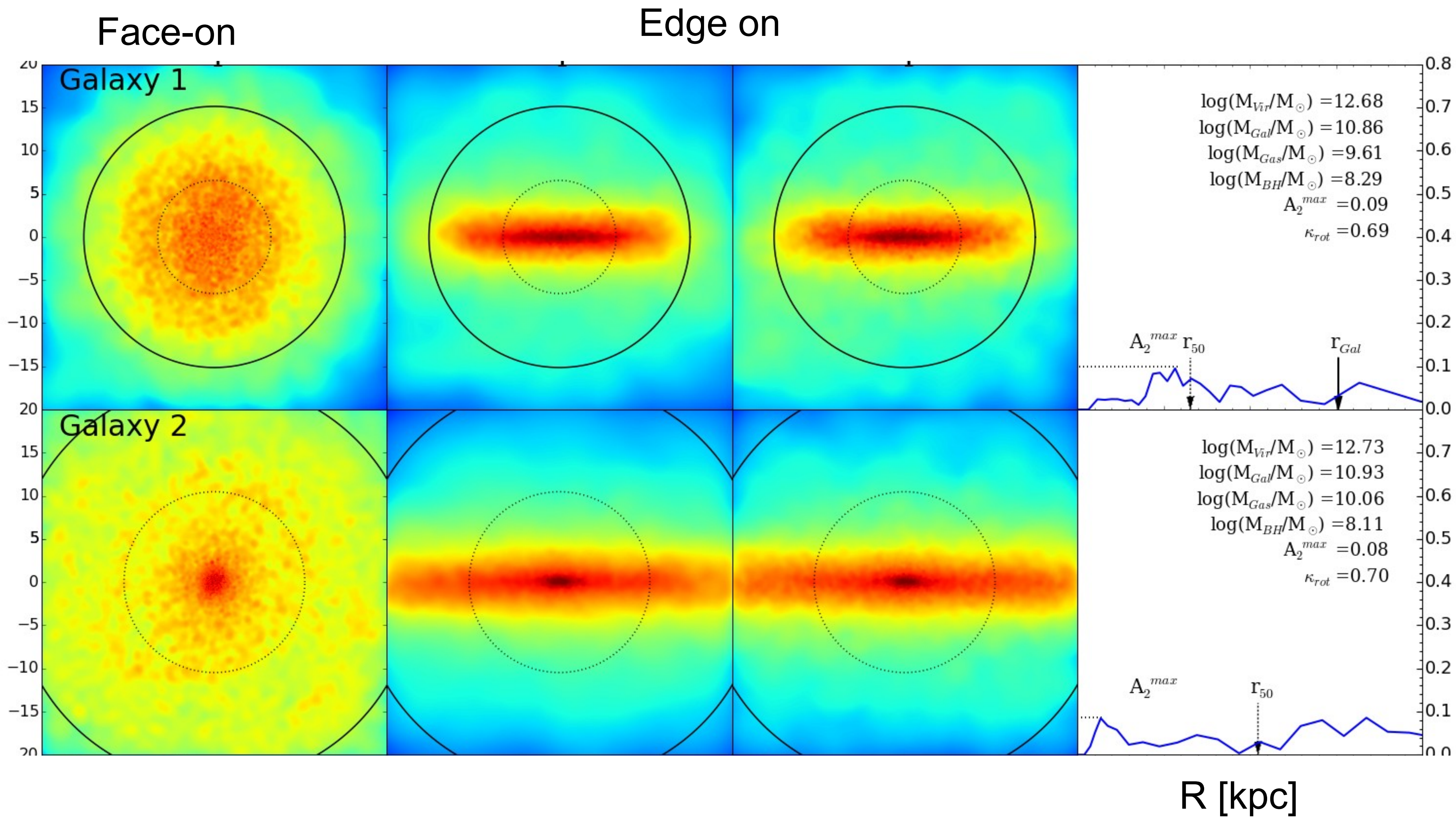


(Athanassoula et. al. 2013)

Examples of strong barred disk galaxies



Example unbarred disk galaxies

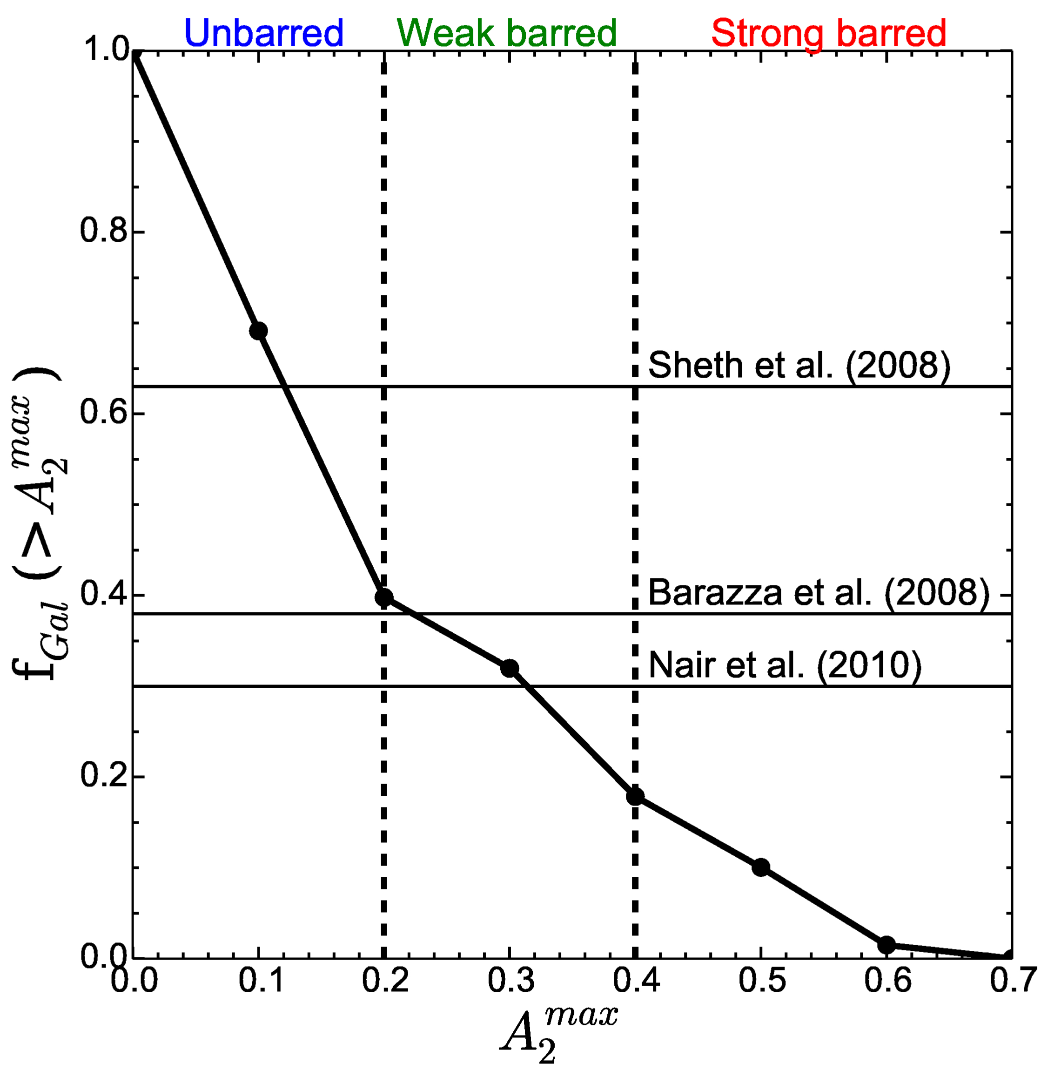


3 groups of galaxies

Strong barred galaxies	$A_2^{max} > 0.4$
Weak barred galaxies	$0.2 < A_2^{max} < 0.4$
Unbarred galaxies	$A_2^{max} < 0.2$

Fraction of galaxies with A_2^{max} larger than a certain value

48 strong barred galaxies
59 weak barred galaxies
162 unbarred galaxies



Comparison with observational data

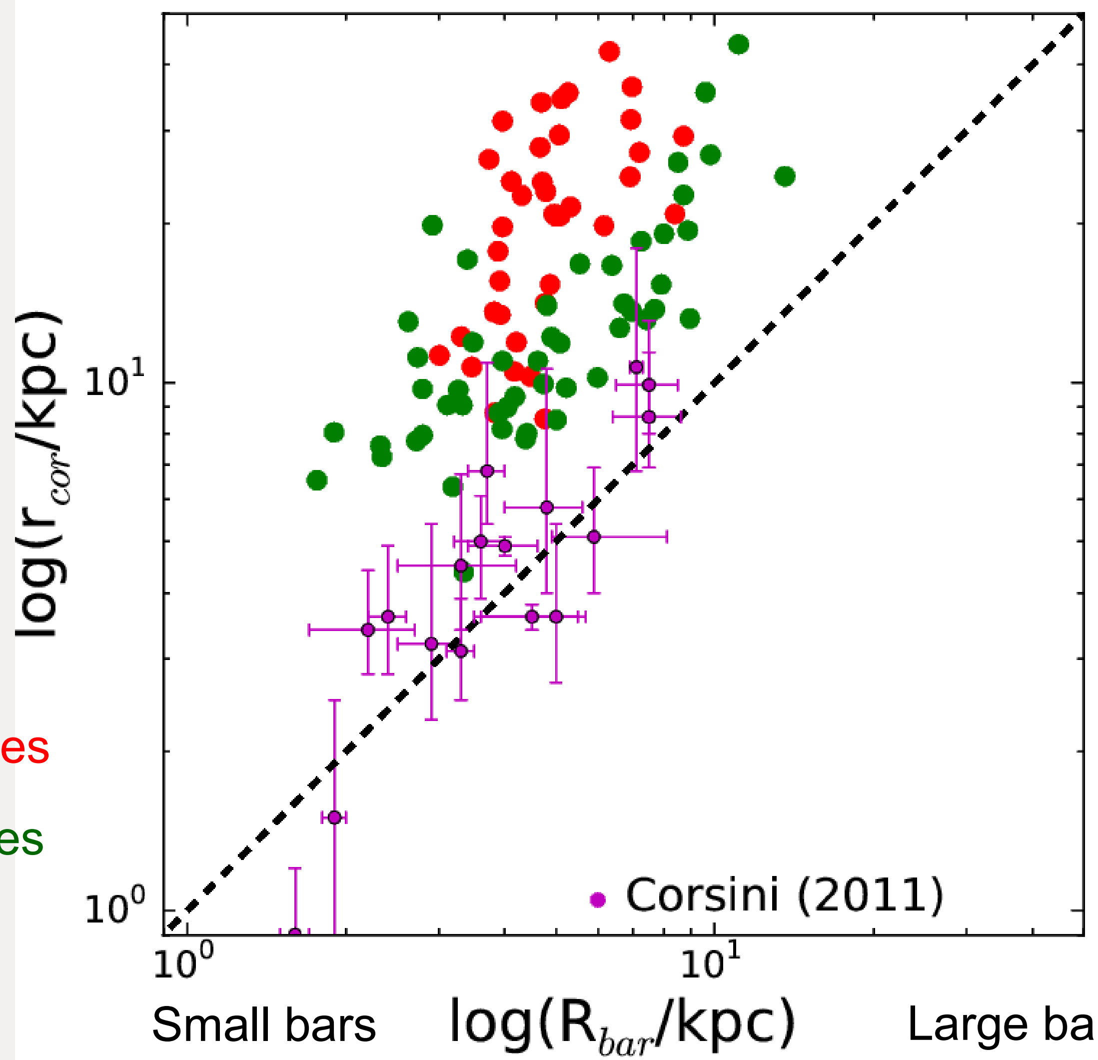
The larger the corotation radius is, the slower the bar will be

Corotation radius

Strong barred galaxies

Weak barred galaxies

Observational data



Slow bars

Fast bars

Small bars

Large bars

Size of the bars

A_2^{max} vs Rotational kinetic energy

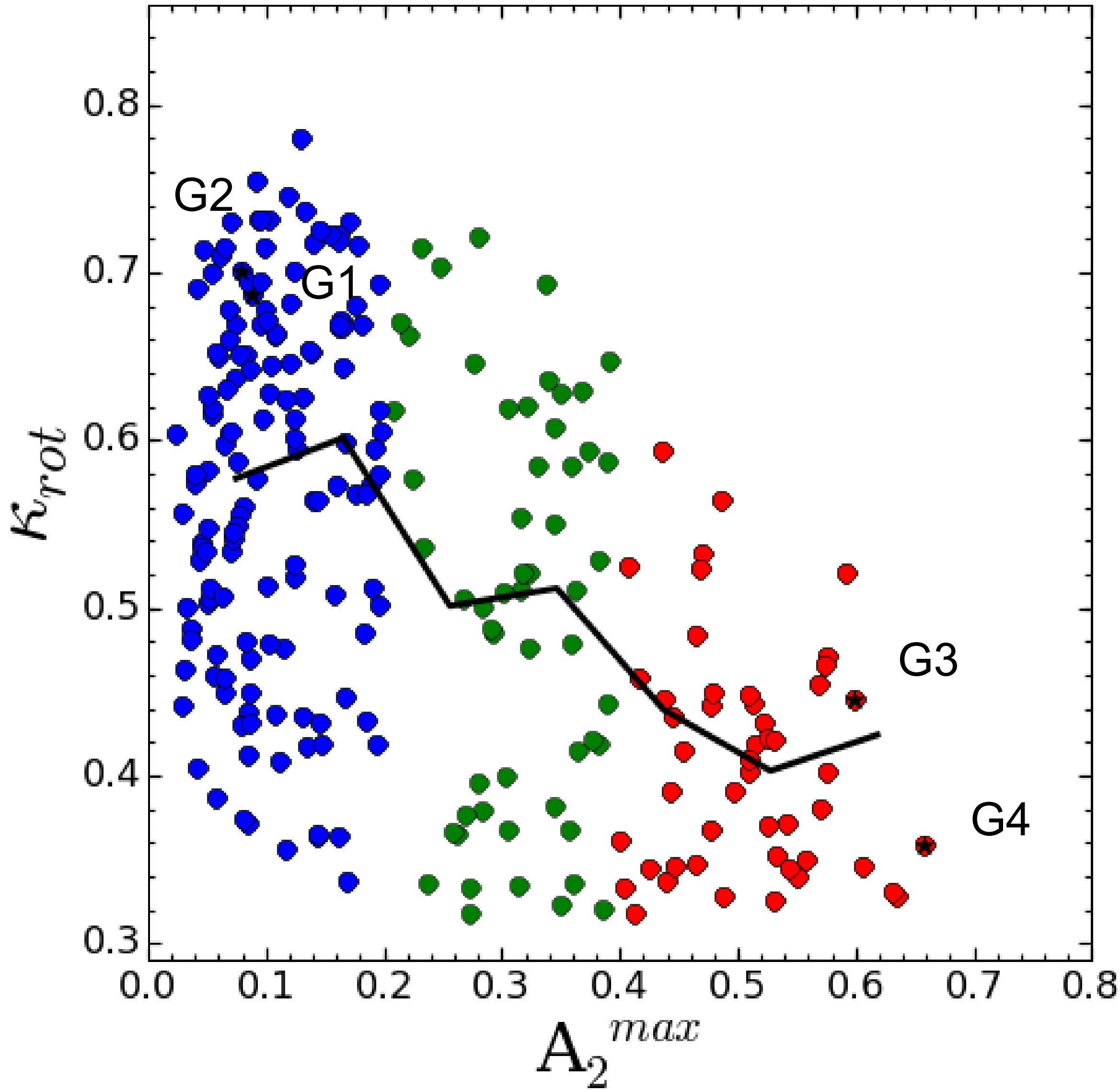
$\kappa_{rot} = K_{rot}/K_{total}$

K=kinetic energy

K_{rot}=Rotational kinetic energy

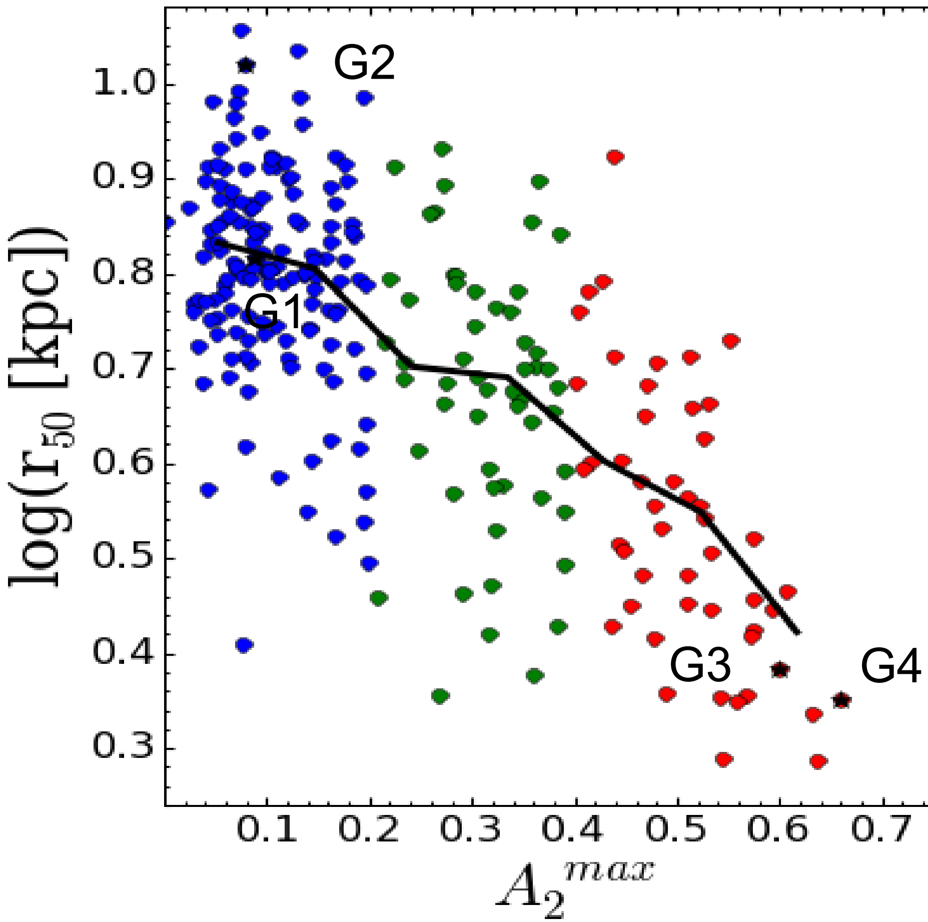
Rotating systems

Non- rotating systems



A_2^{max} vs half mass radius

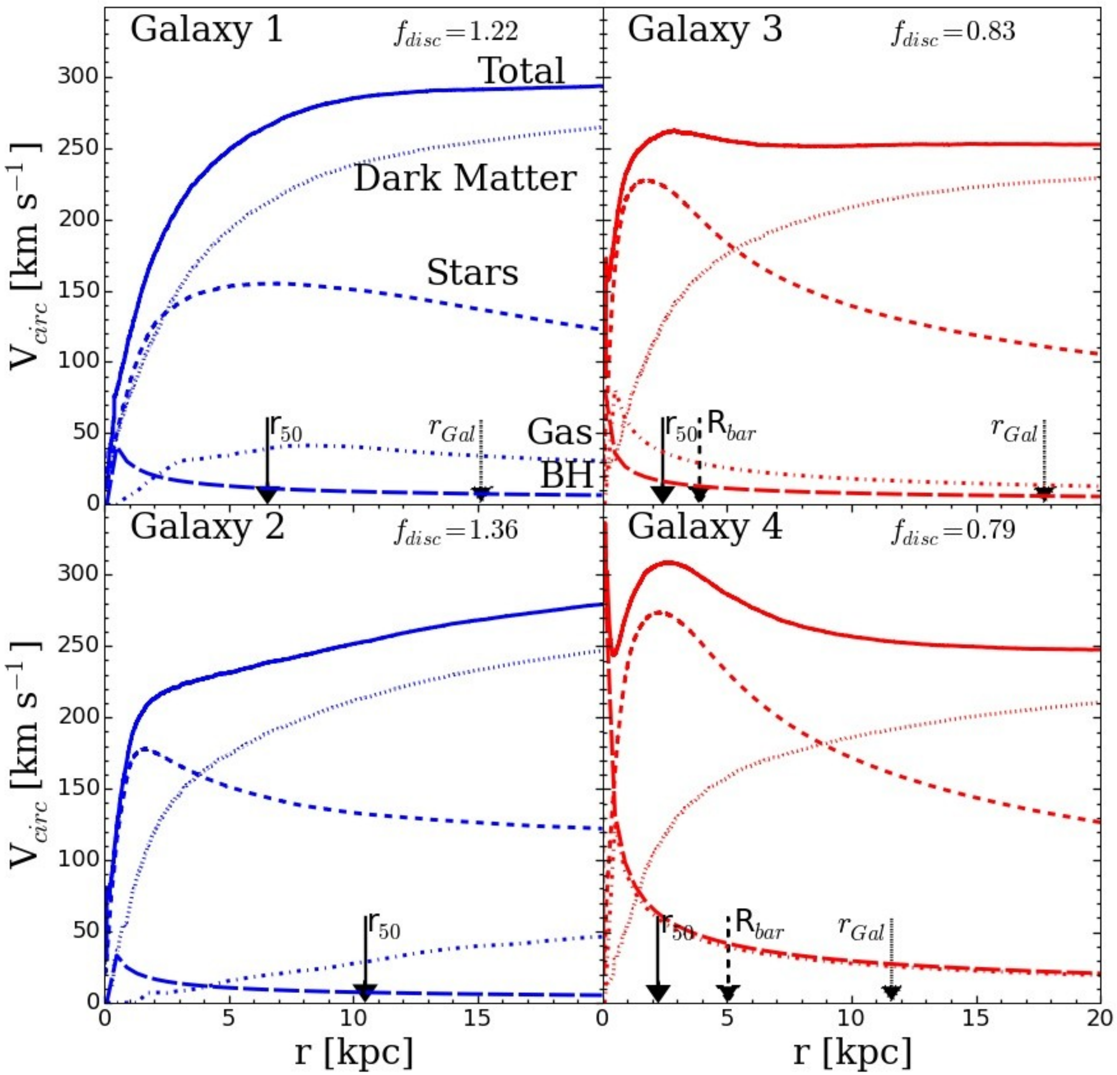
r_{50} of unbarred galaxies is twice larger than r_{50} of strong barred galaxies



Circular velocity profiles of the examples

$$V_{circ} = \sqrt{\frac{GM}{r}}$$

Unbarred galaxies Strong barred galaxies



$$f_{disc} = \frac{V_c(r_{50})}{\sqrt{GM_{disc}/r_{50}}},$$

How important is the stellar disc respect to the total in the inner region.

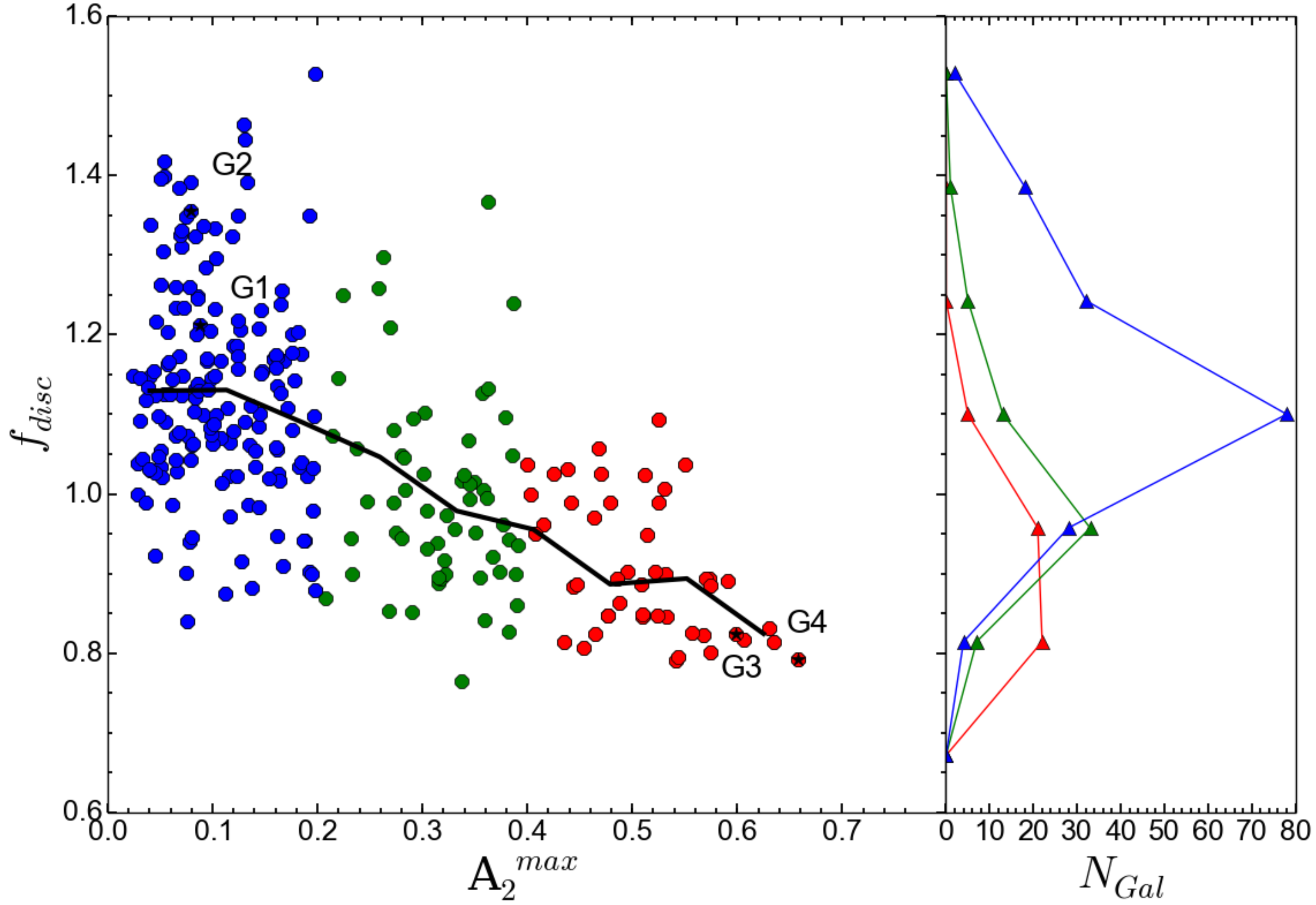
Efstathiou et al. (1982)

$f_{disc} < 1.1$ for unstable discs

$f_{disc} > 1.1$ for stable discs

Instability criterion based on Efstathiou (1982)

How important is the stellar disc respect to the total in the inner region.

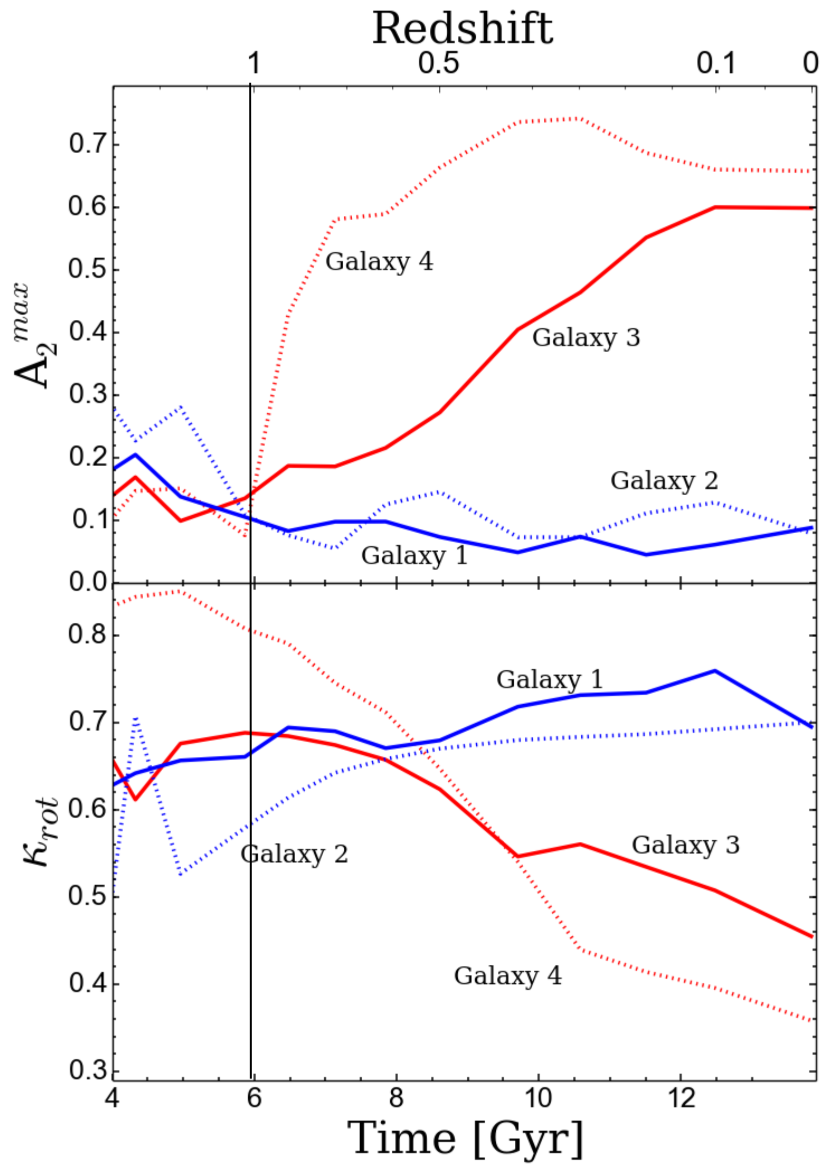


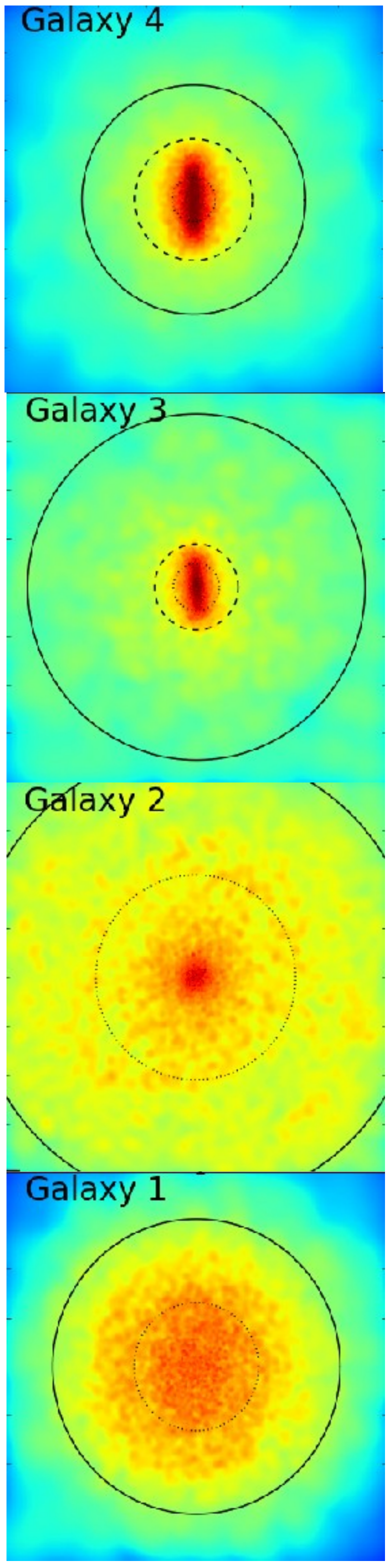
Temporal evolution of A_2^{max} and κ_{rot}

Bar strength

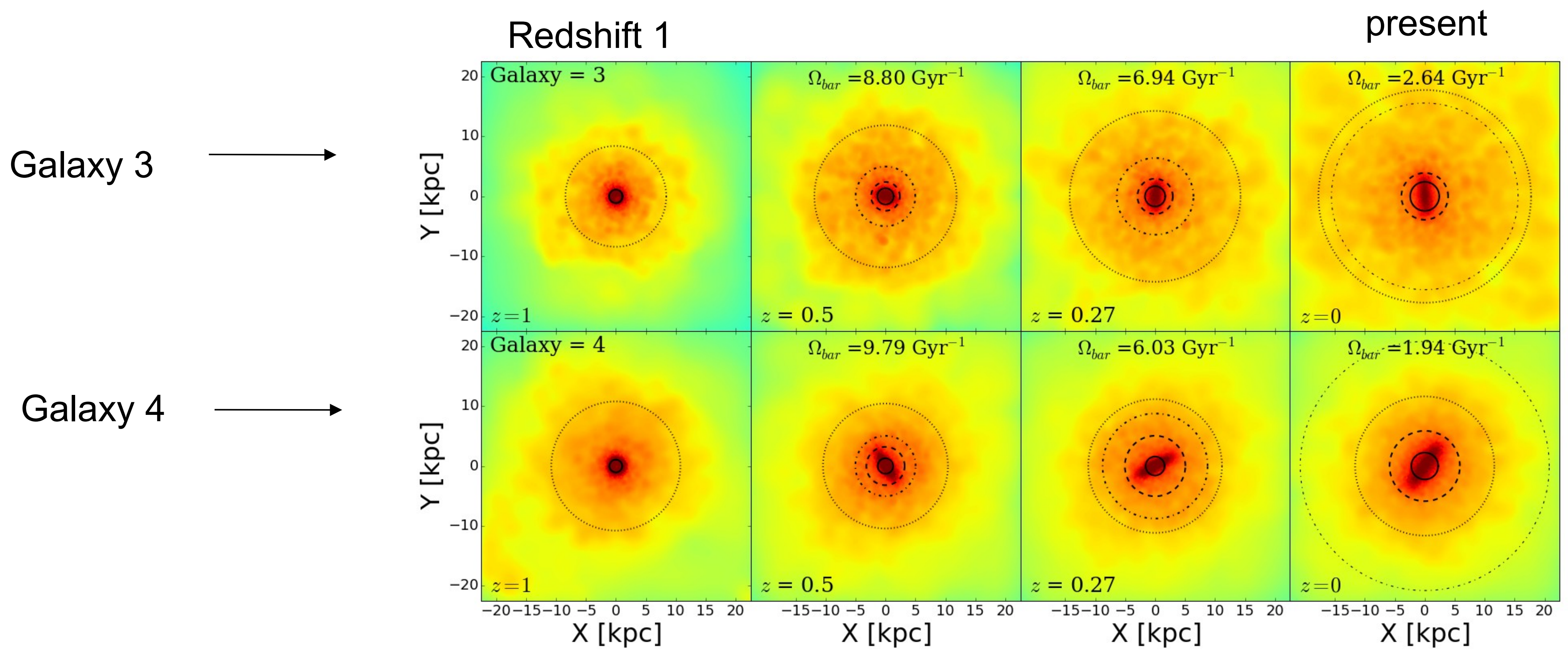
The four example are unbarred galaxies at z= 1.

Rotational kinetic energy





Evolution of the two strong barred galaxies

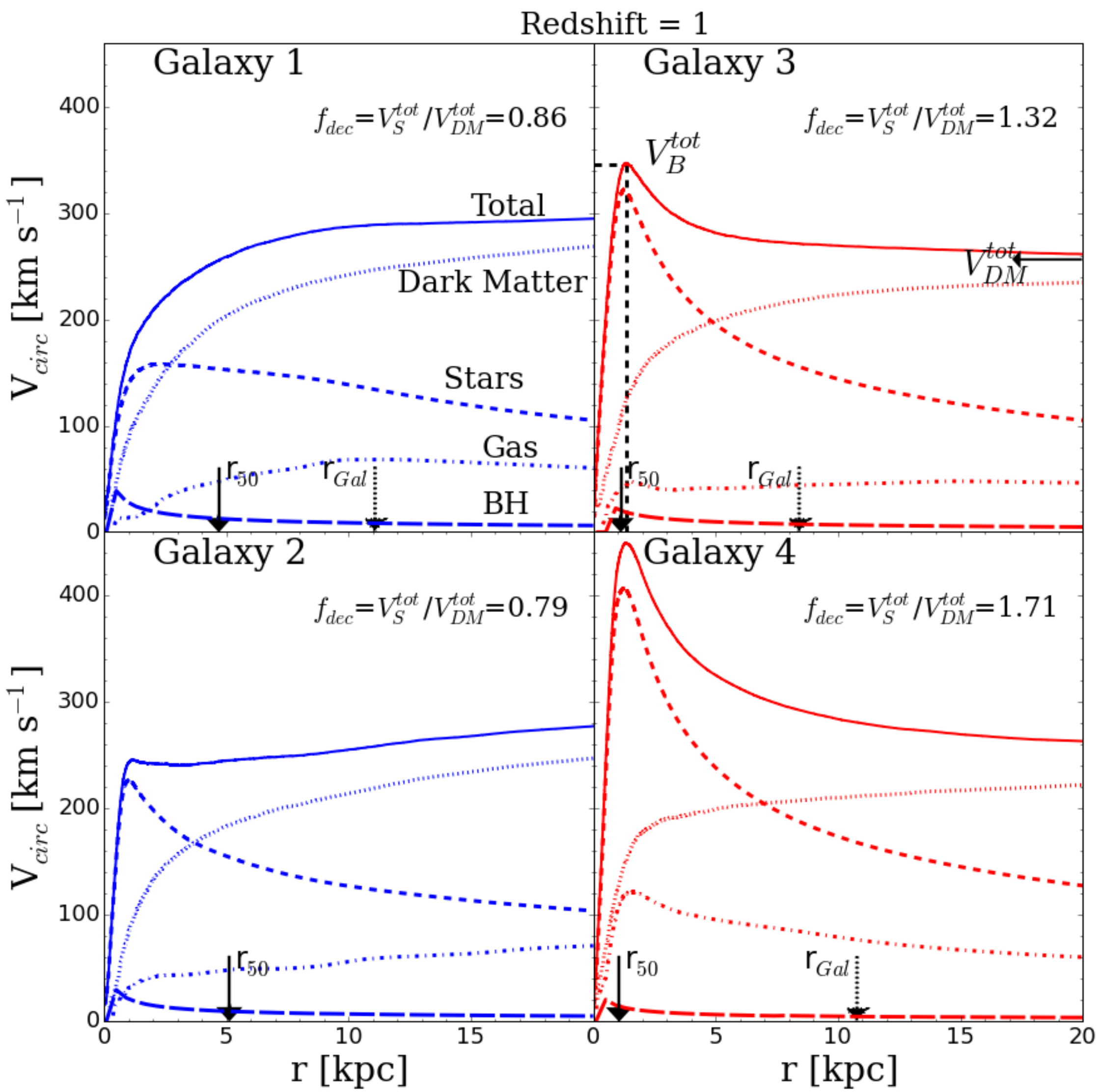


Circular velocity profiles of the 4 examples

Redshift z=1

$$V_{circ} = \sqrt{\frac{GM}{r}}$$

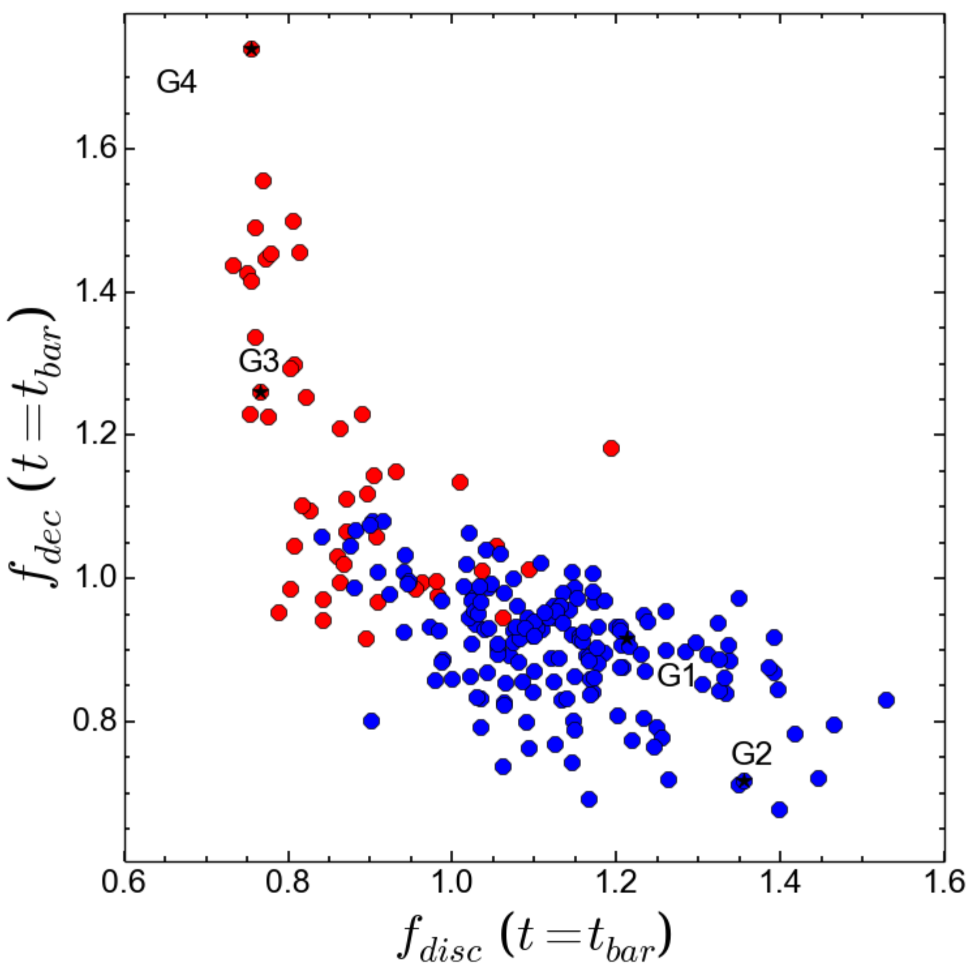
$$f_{dec} = V_S^{tot} / V_{DM}^{tot}$$



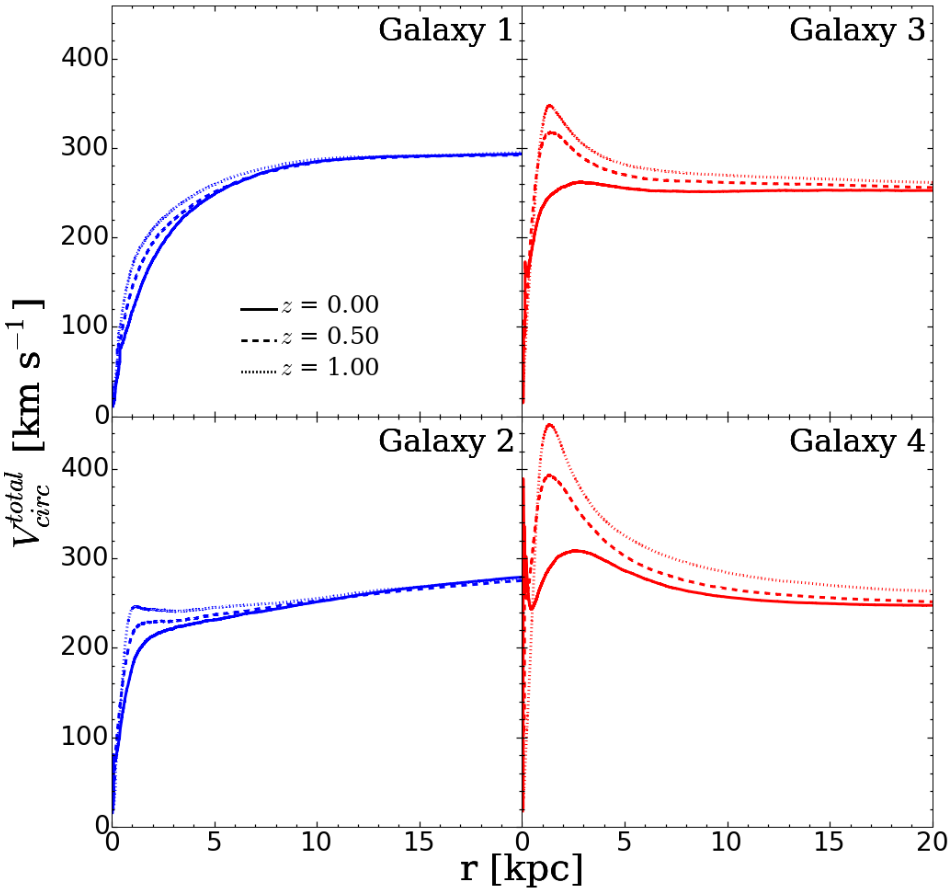
$f_{dec} > 1$ declining circular velocity profile

$f_{dec} < 1$ rising circular velocity profile

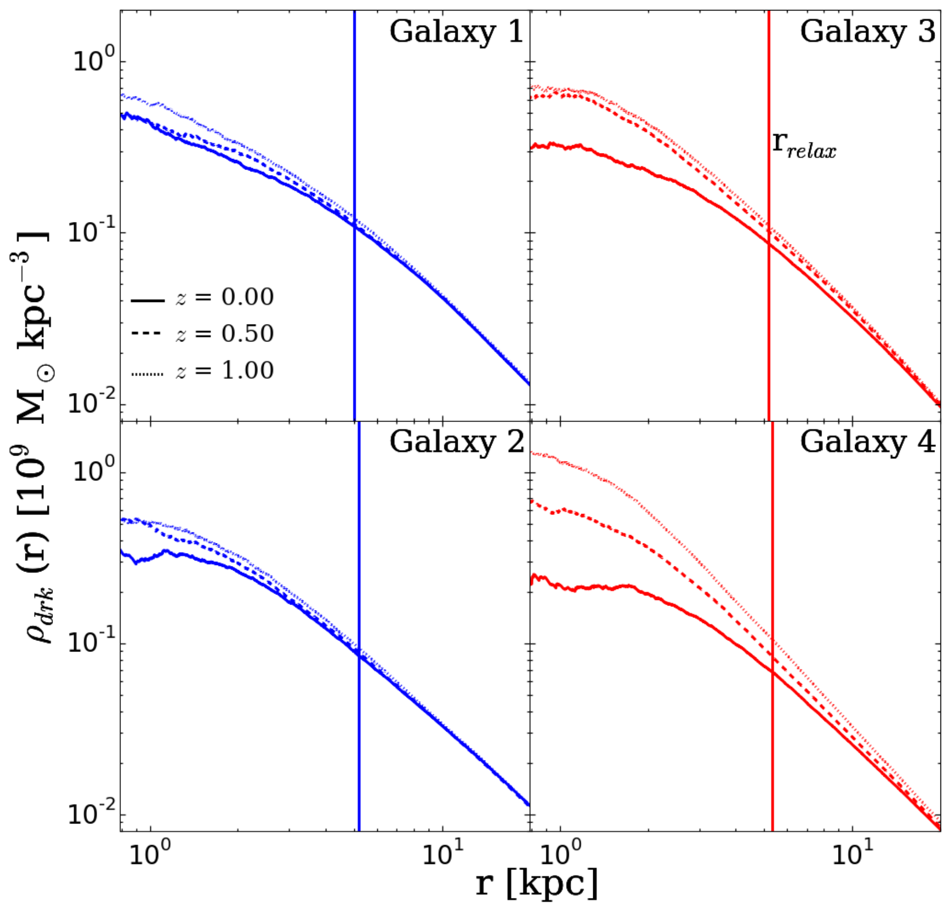
Time $t = t_{bar}$ is the more recent time when the galaxy take values of A_2^{max} <0.25.
If this time is lower than 5Gyr ⟶ t_{bar} =5 Gyr



Circular velocity profile evolution

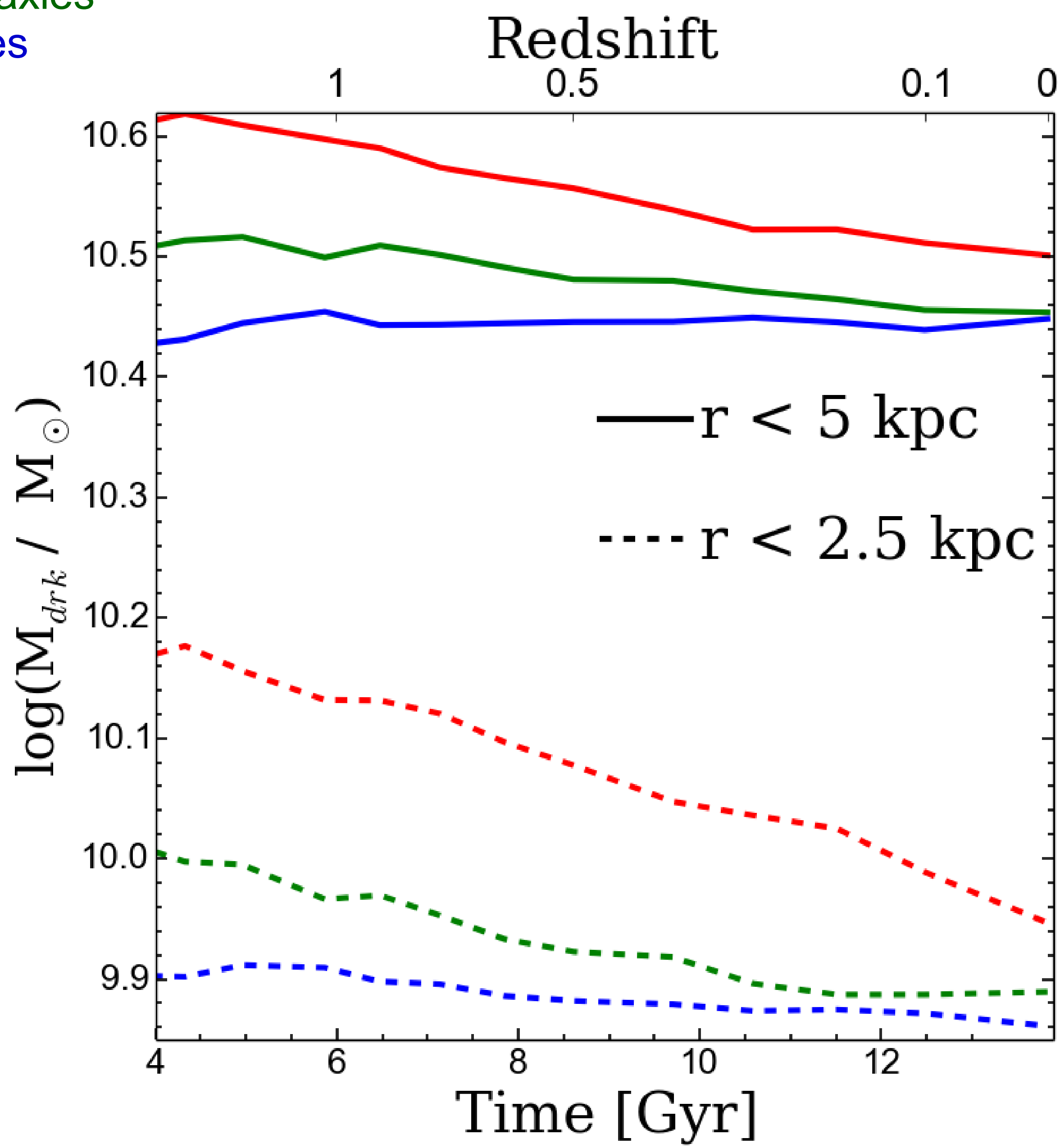


Dark matter profile evolution



Evolution of the medians of the dark matter

Strong barred galaxies
Weak barred galaxies
Unbarred galaxies



Conclusions

Barred galaxies are present in approximately 40% of the disc galaxies of the sample

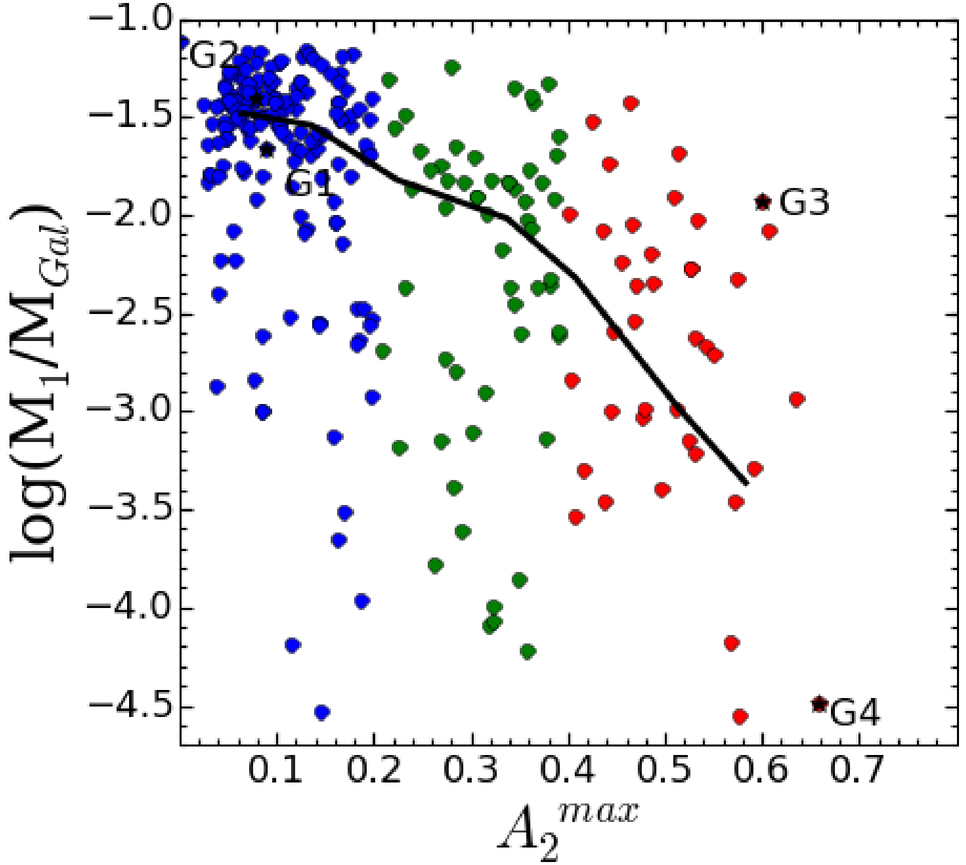
Good correlation between bar strength and rotational kinetic energy and half mass radius

We expand the Efstathiou (1982) instability criterion based on how are the total contribution circular velocity profiles of the sample

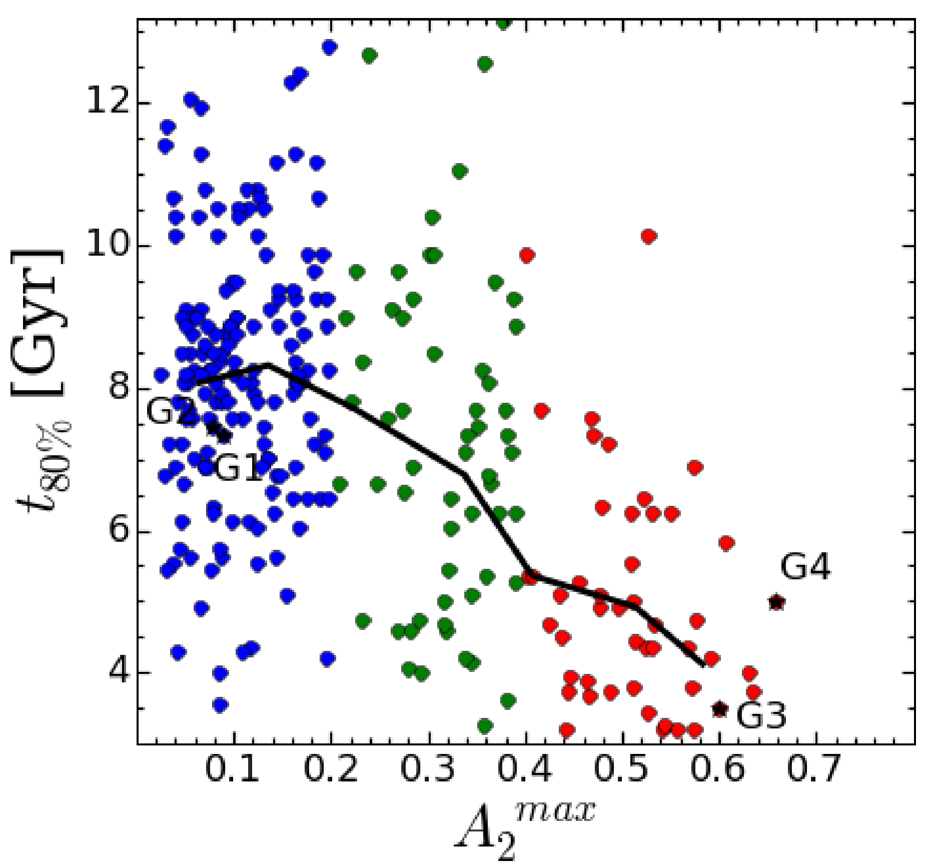
Bar growth along time

Barred galaxies transfer their rotational energy to the dark matter halo.

A_2^{max} vs normalized stellar mass formed in the last Gyr



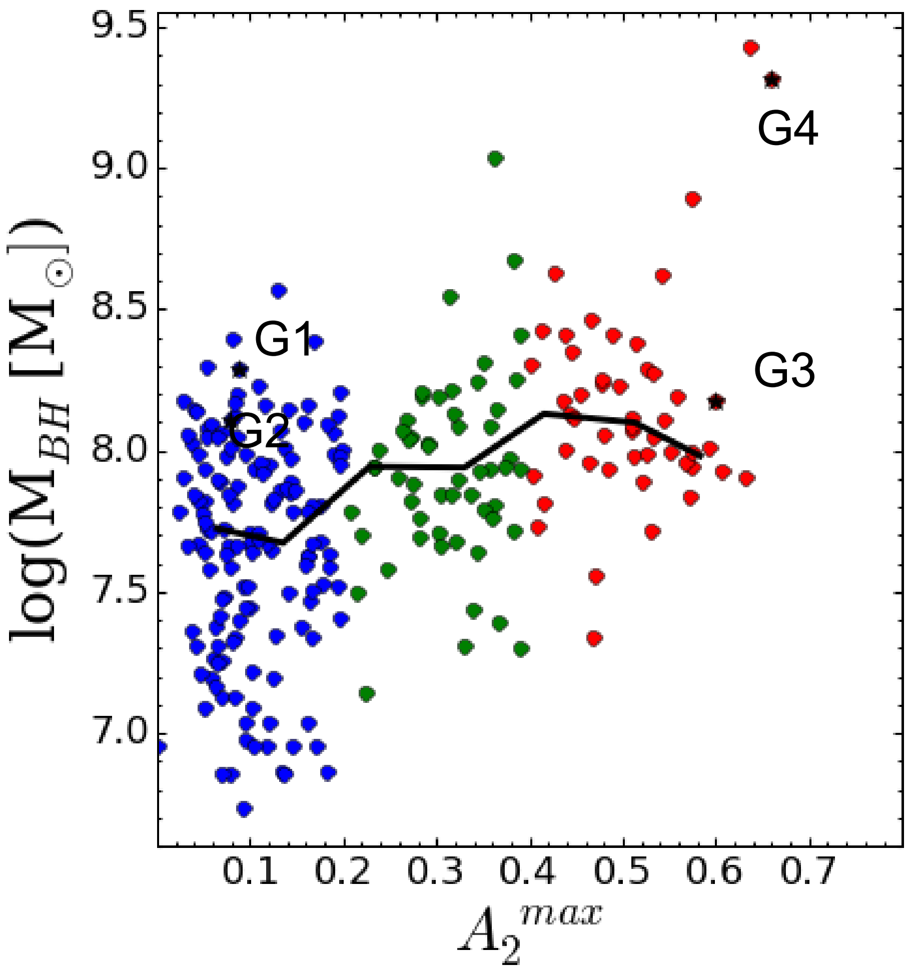
A_2^{max} vs time when the galaxy formed the 80% of its present day stellar mass



A_2^{max} vs Supermassive black

Galaxias con barras tienden a tener agujeros negros un pocos mas grandes y menos cantidad de gas

A_2^{max} vs supermassive black hole mass



A_2^{max} vs gaseous mass