Bar formation and evolution: What do they depend on?

Lia Athanassoula

LAM/AMU/DAGAL/S4G

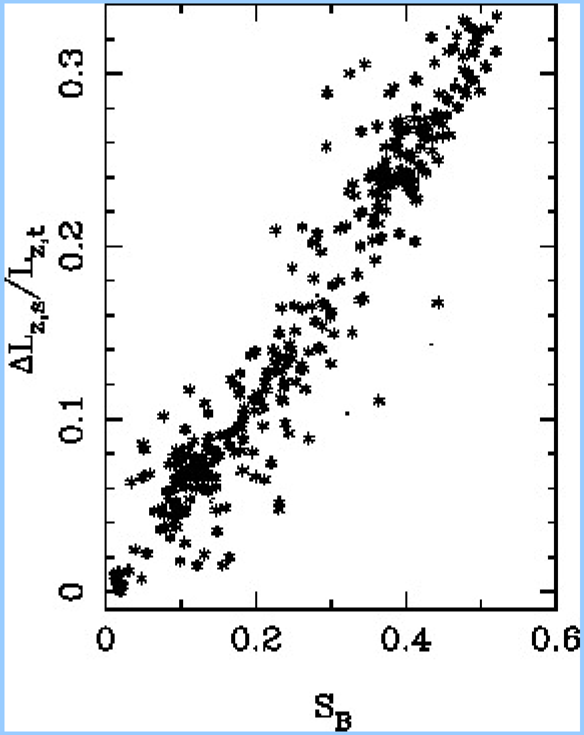
Angular momentum exchange drives the evolution in barred galaxies

Emitters : (material at near-resonance in the) inner disc
Absorbers : (material at near-resonance in the) halo and outer disc

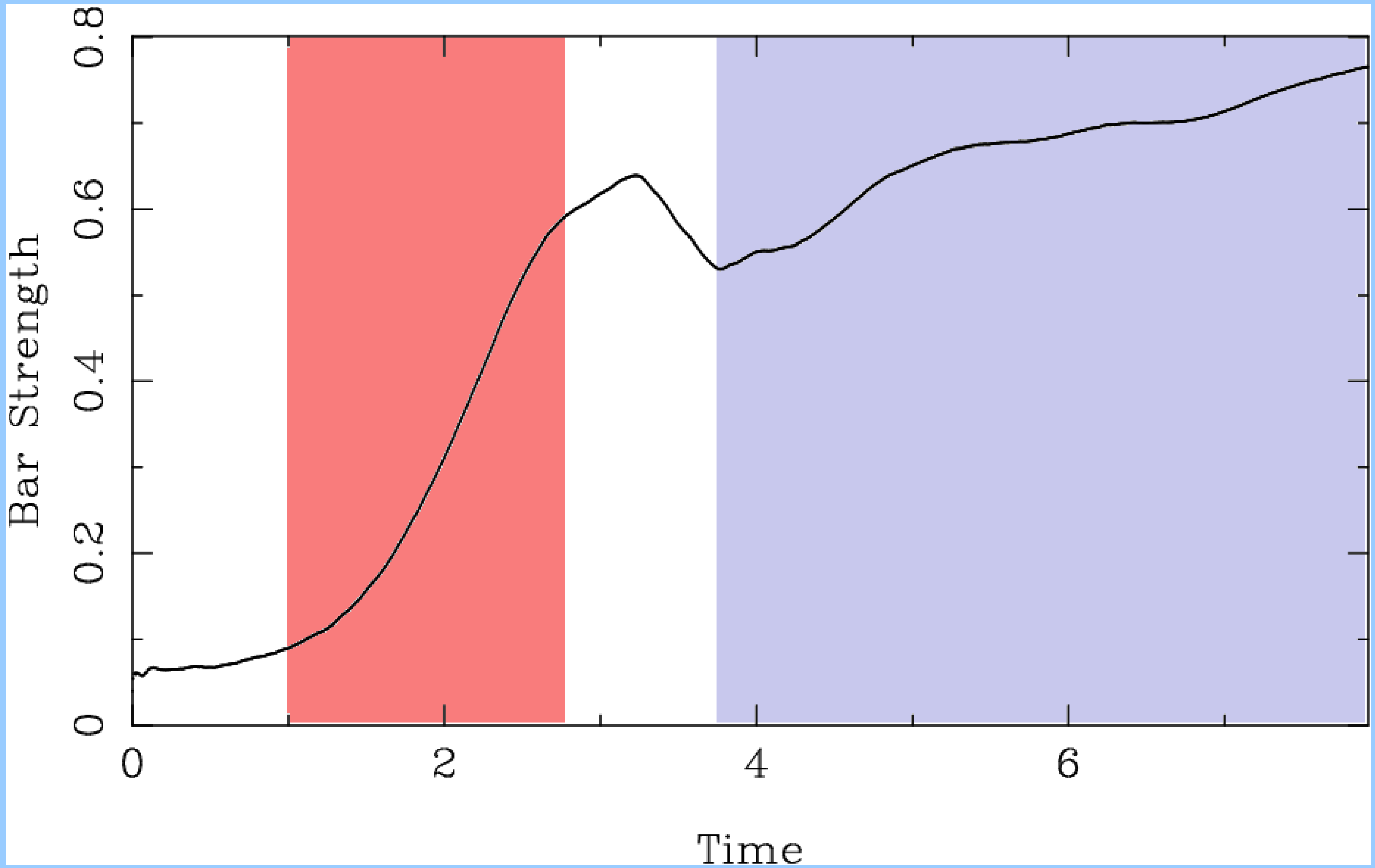
More angular momentum redistribution should lead to stronger bars and to stronger decrease of their pattern speed

Simulations show that the strength of the bar correlates well with the amount of angular momentum exchanged

Both for the disc and the halo, there is more angular momentum gained/lost at a given resonance if :
- the density is higher there
- the resonant material is colder



Athanassoula 2013 = EA03



Bar growth

Secular evolution

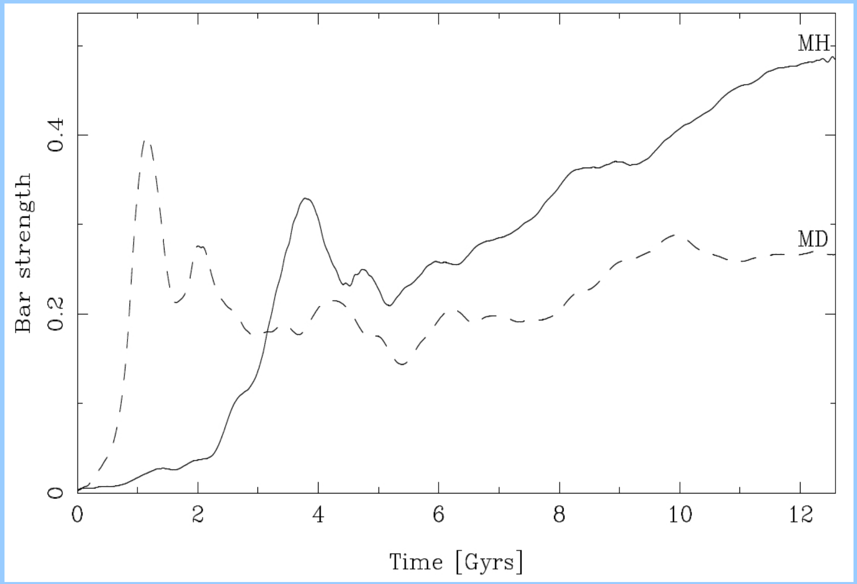
Bar formation

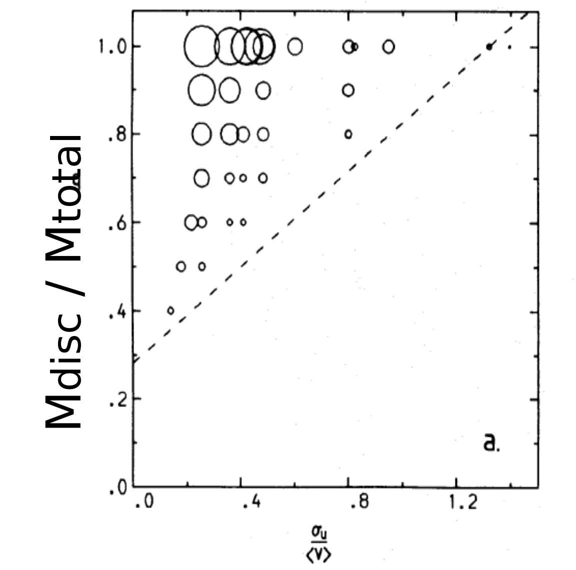
Bar evolution

Effect of halo mass on bar formation and evolution: duality

Haloes slow down bar formation

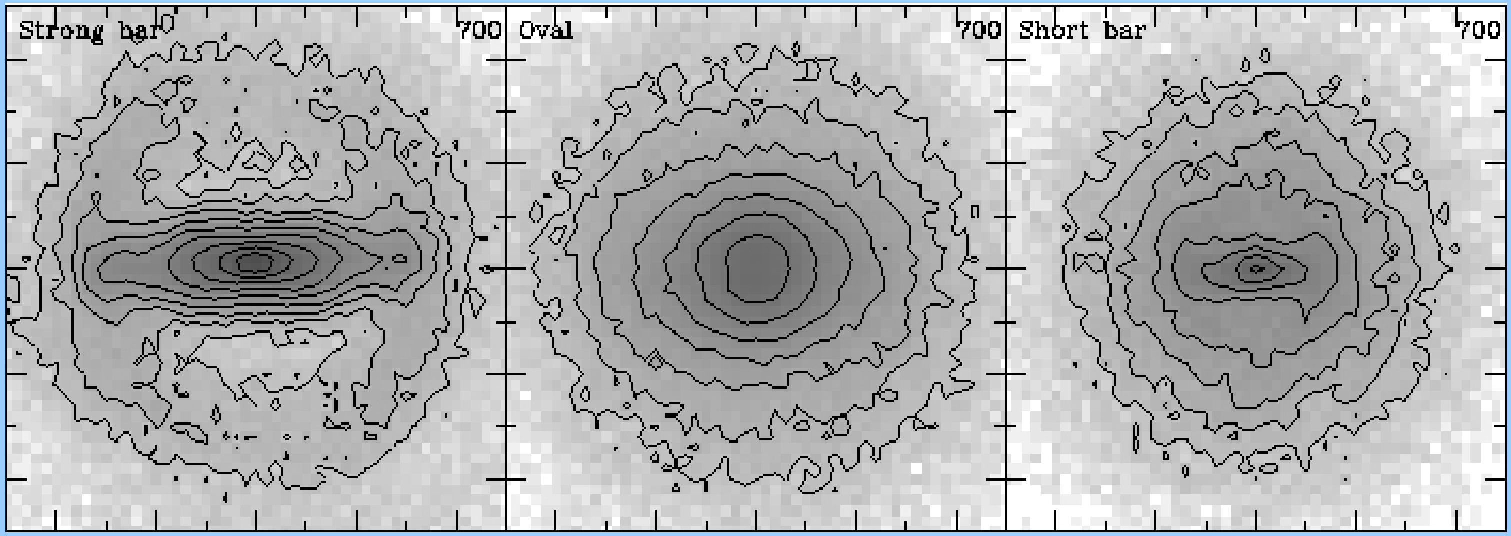
EA02





EA & Sellwood 86
EA03

But haloes make bars strong (secular, nonlinear evolution)

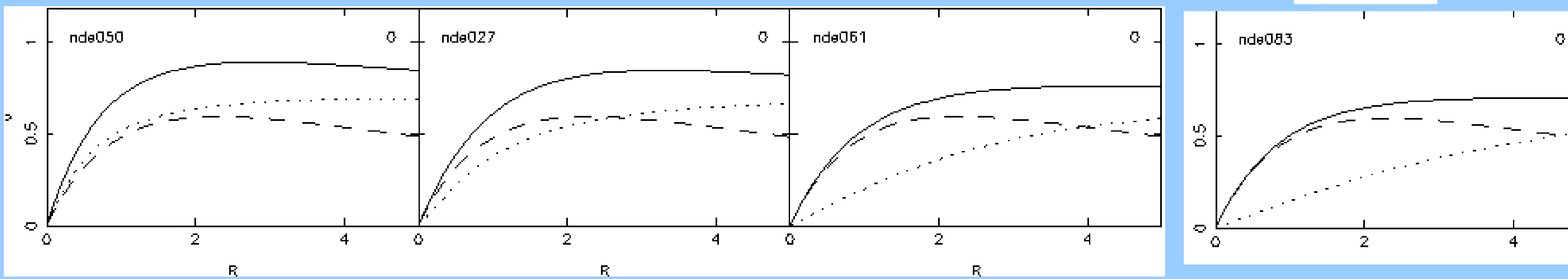


EA03

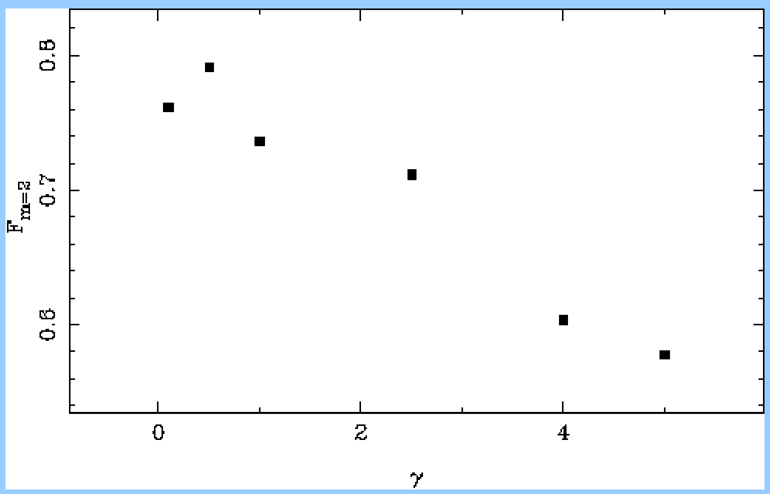
A series of haloes with different mass in the regions of the main resonance

EA & Misiriotis 02, EA 03

$\gamma = 0.5$ $\gamma = 1.$ $\gamma = 2.5$ $\gamma = 4.$

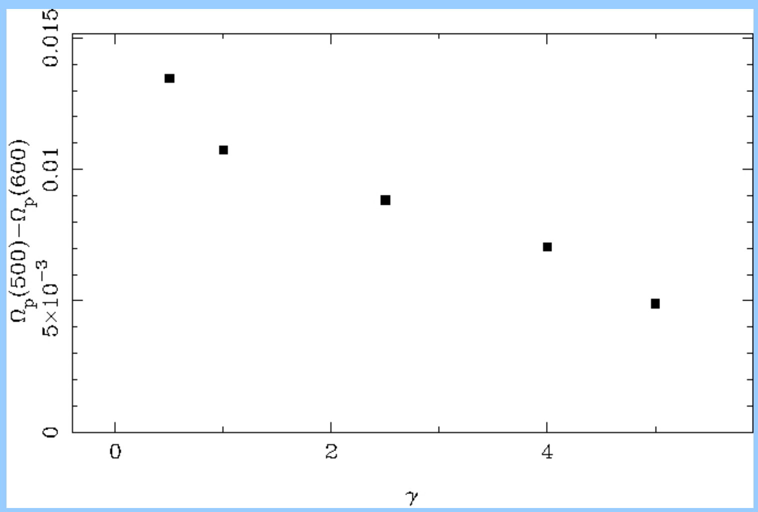


Bar strength



Halo core radius

Pattern speed drop



Halo core radius

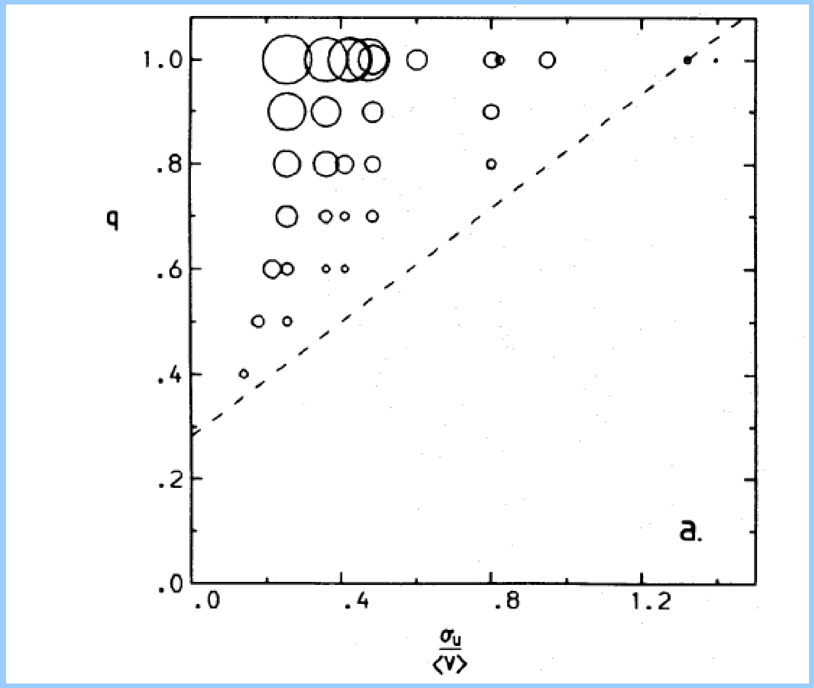
More concentrated haloes have more mass at resonances and thus can absorb more angular momentum. The bar will emit more angular momentum and grow stronger.

Influence of the disc velocity dispersion

Bar formation phase

Bars form later in hot discs

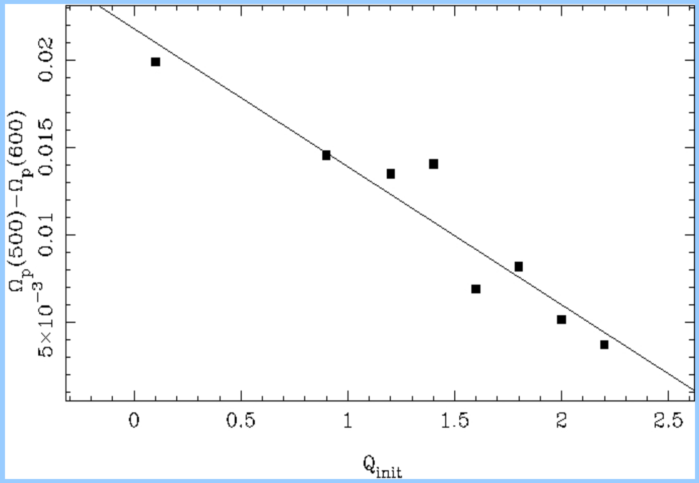
EA & Sellwood 1986



Secular evolution phase

Bars in hotter discs slow down less

Pattern speed drop



Q

EA03

and they are weaker (oval-like)

EA83
EA03

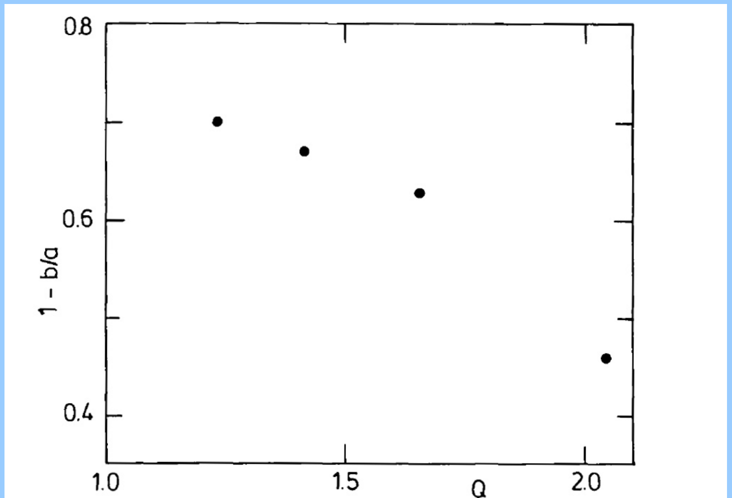
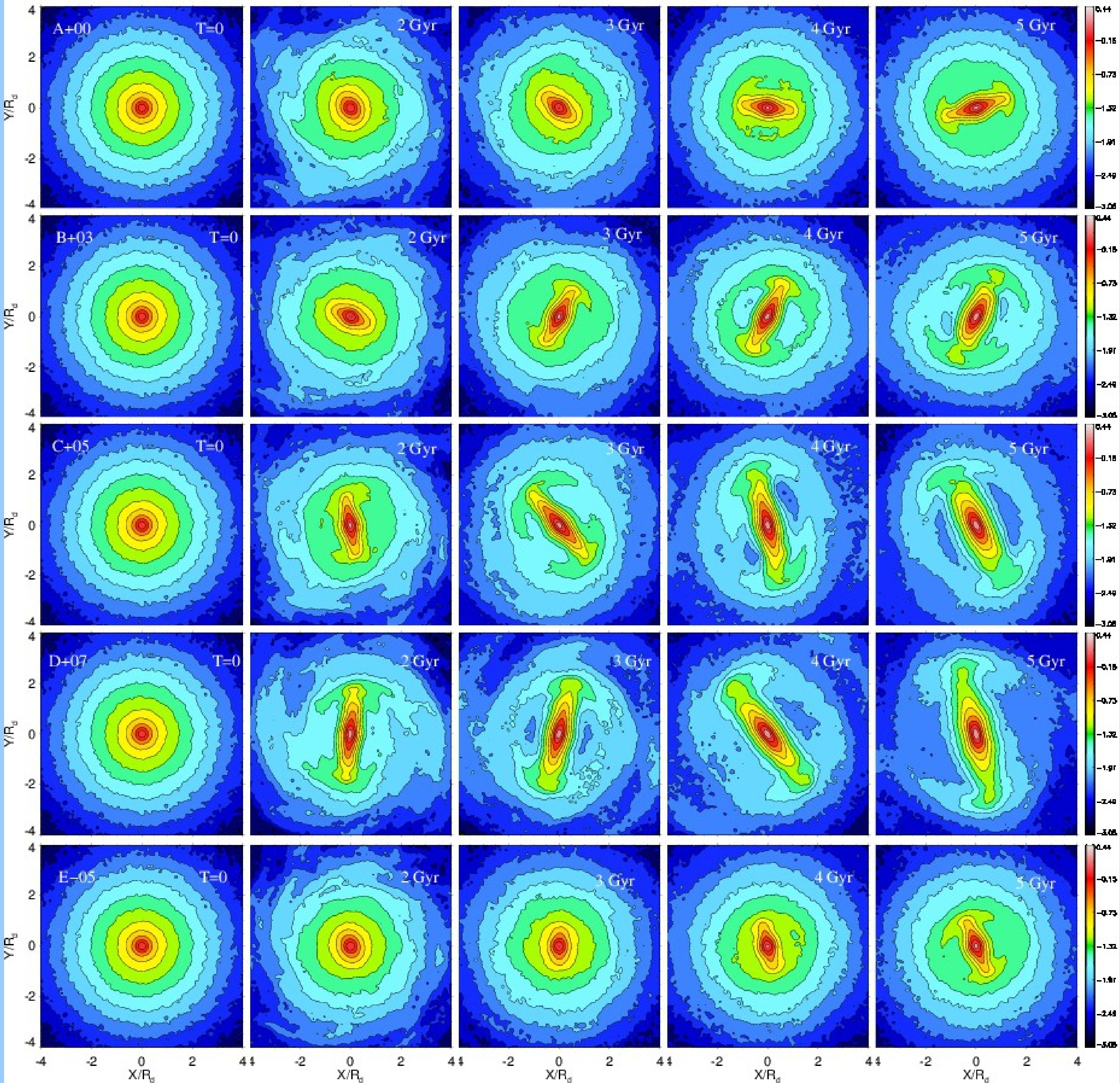


Figure 4. Mean eccentricity of the bar isodensities as a function of the mean mass averaged Q.



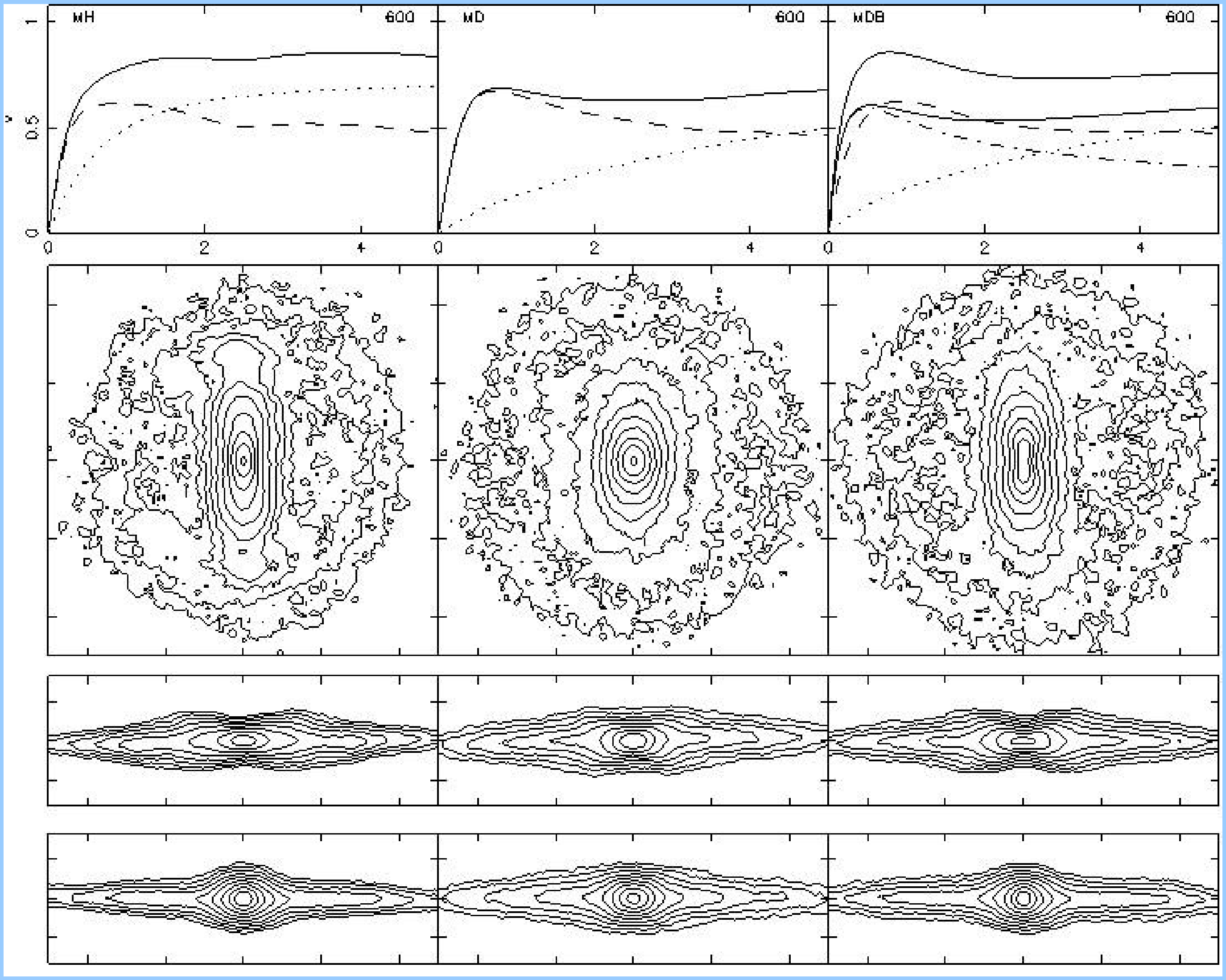
HALO
ROTATION
AND
COUNTER-
ROTATION

Weinberg 85
EA 96
Debattista &
Sellwood 00
Saha & Naab 13

Saha &
Naab 2013

A classical bulge

EA & Misiriotis 02
EA 03

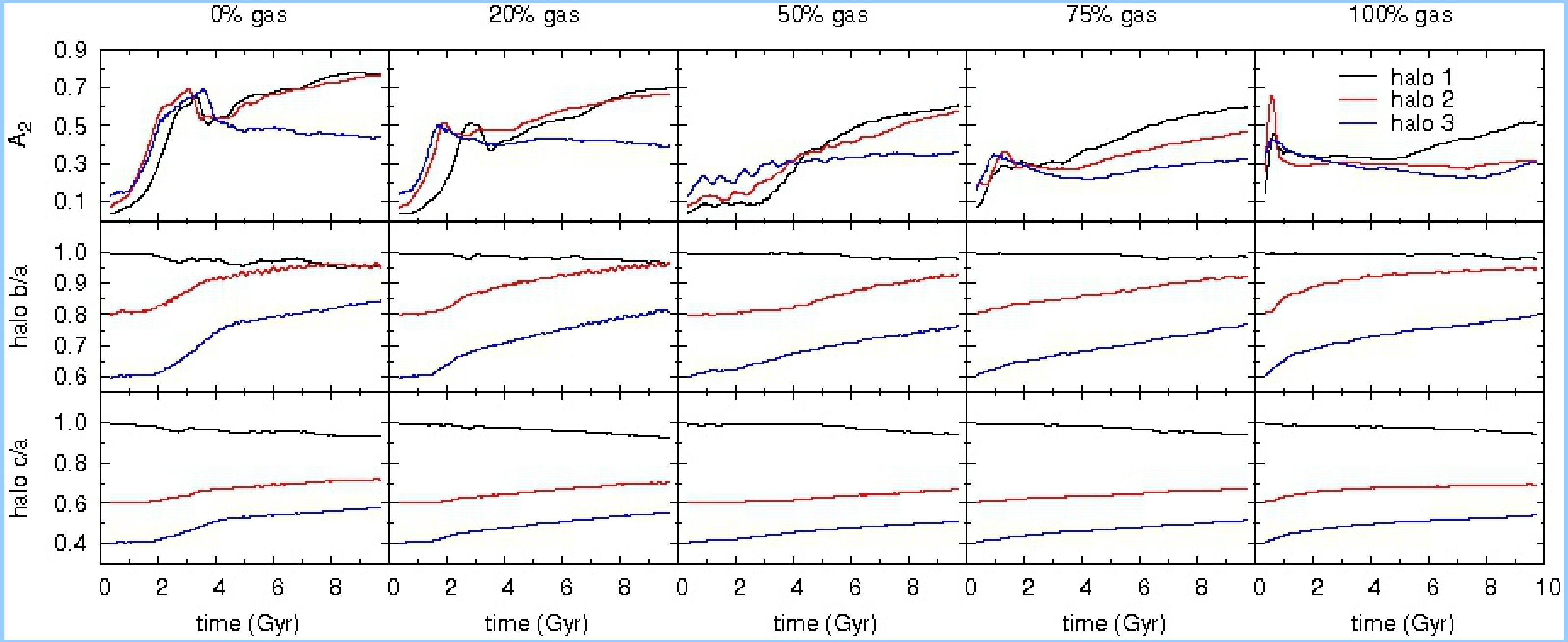


BULGES/HALOES

Classical bulges slow down bar formation

In the secular evolution regime they help bars grow stronger

The effect of halo shape: duality again



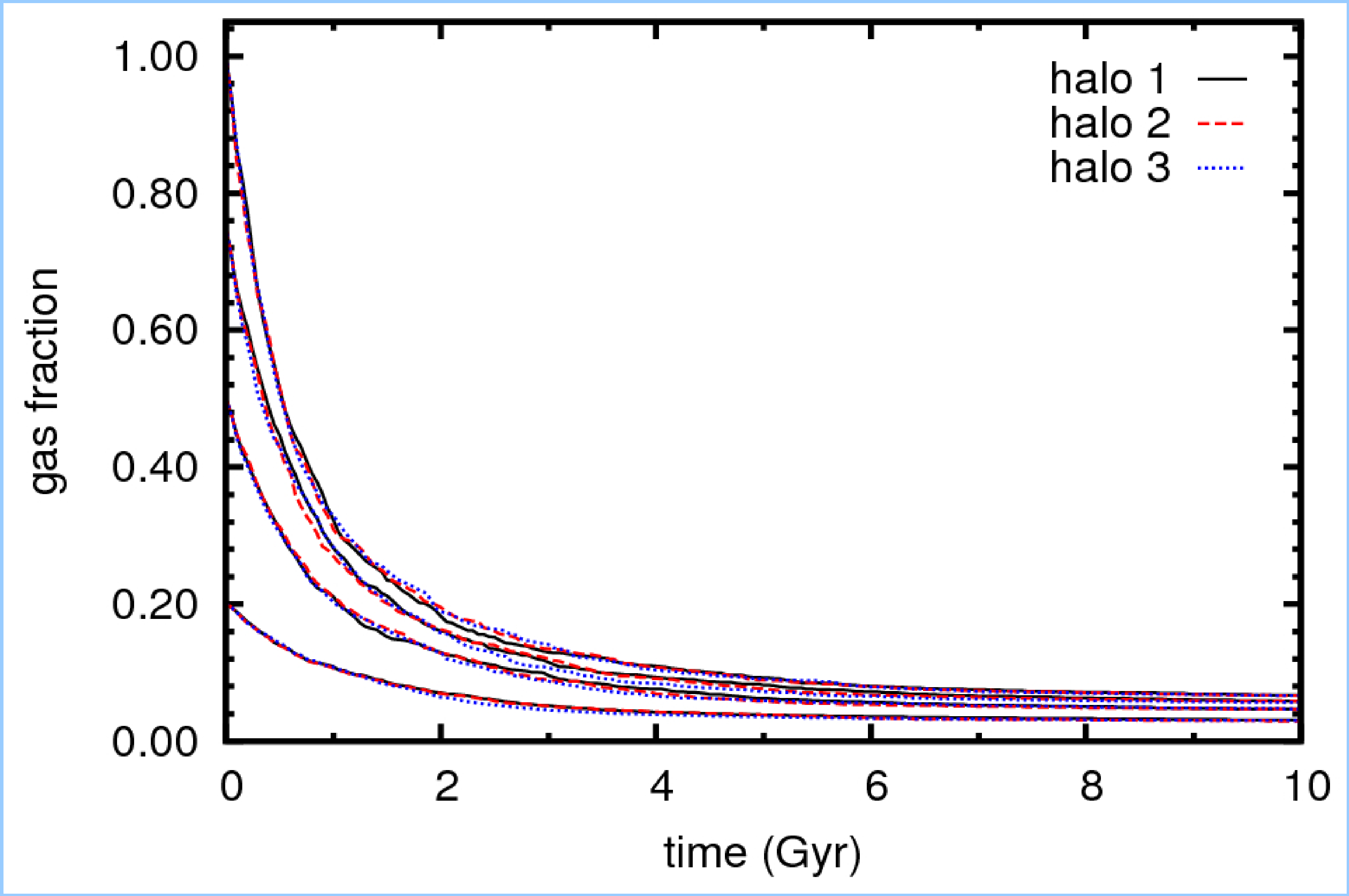
Driving by the triaxial halo:

Bar formation phase:
The bar forms faster in a triaxial halo

Secular evolution stages:
Less secular growth

Sufficient triaxiality can stop the secular evolution

EA, Machado, Rodionov 13 = AMR13

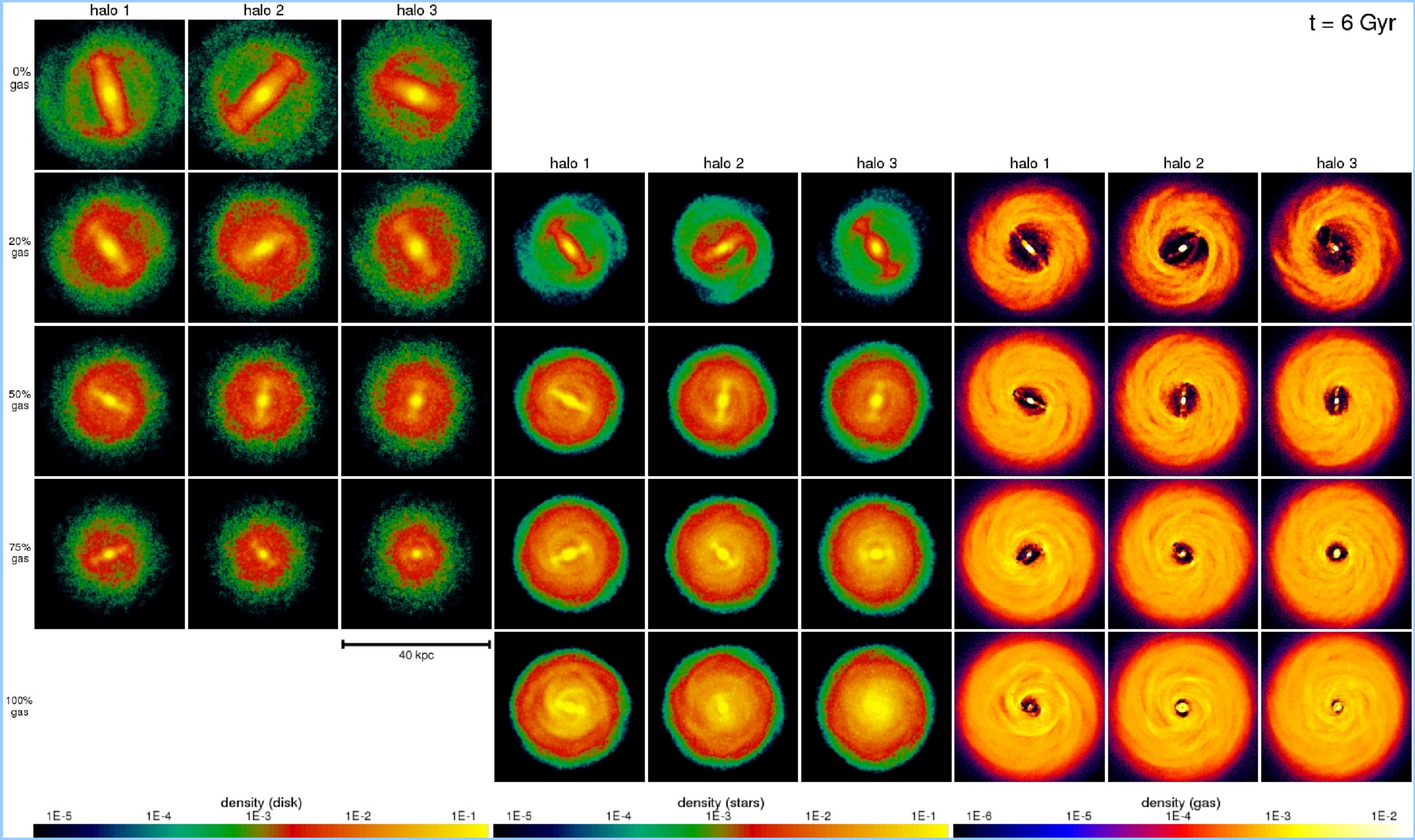

halo 1
halo 2
halo 3
1.00
0.80
0.60
0.40
0.20
0.00
gas fraction
0
2
4
6
8
10
time (Gyr)

AMR13

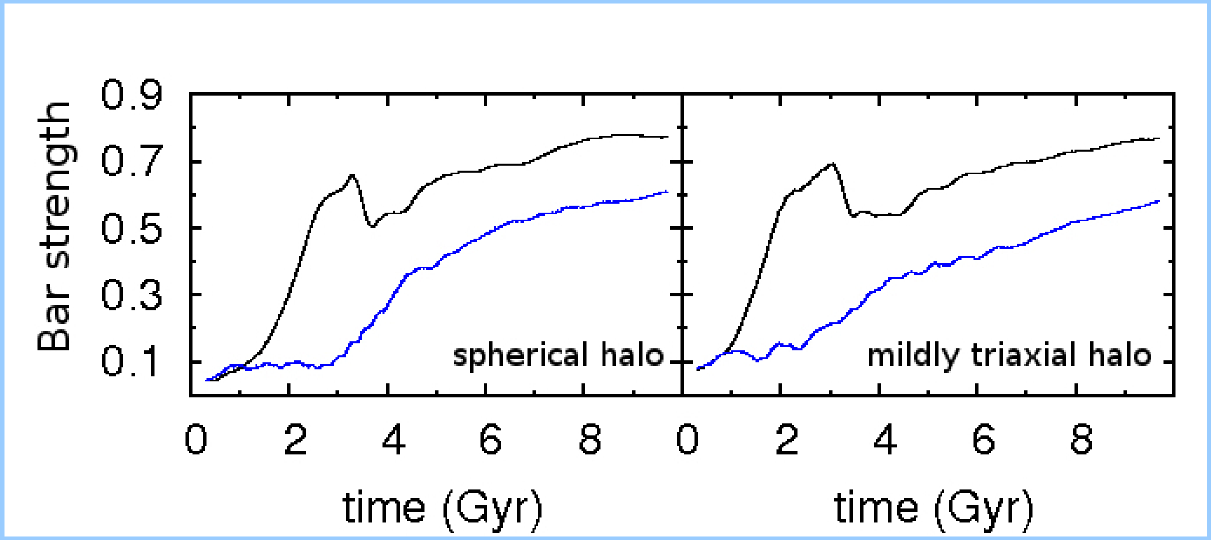
A gaseous component

AMR13

t > 6 Gyrs　　t < 6 Gyrs　　Gas



Gas slows down bar formation in two ways:



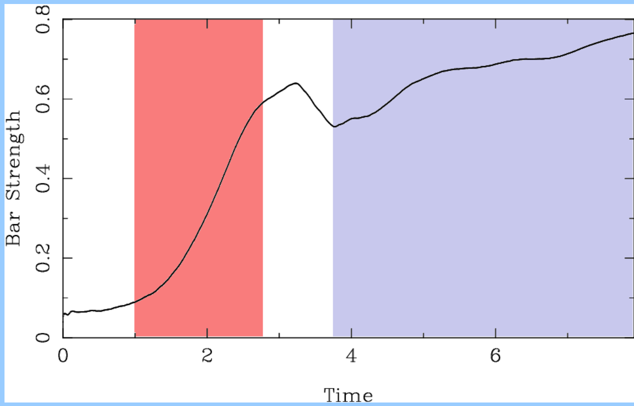
AMR13

Bars are stronger in gas poor than in gas rich cases

Black line: 0% gas
Blue line: Initially 50% of disc mass in gas, drop with time to 5%

Bar formation stage

Relatively heavy haloes (M_h/M_t) slows down
Hot discs slows down
Halo triaxiality speeds up
Increased gas fraction slows down
Presence of a thick disc component slows down



What makes bars stronger (secular evolution part)

Maximum angular momentum redistribution, i.e:

Considerable halo and/or bulge contribution stronger
Cold discs stronger
Velocity distribution function in halo stronger/weaker
Halo triaxiality weaker
Gas poor discs stronger
Absence of a CMC stronger

Note: This list is NOT complete
Some of these can not be applied concurrently

The slowing-down of the bar due the halo

Fast bars ===> 1 < R_{CR}/a_B < 1.4 -- 1.5

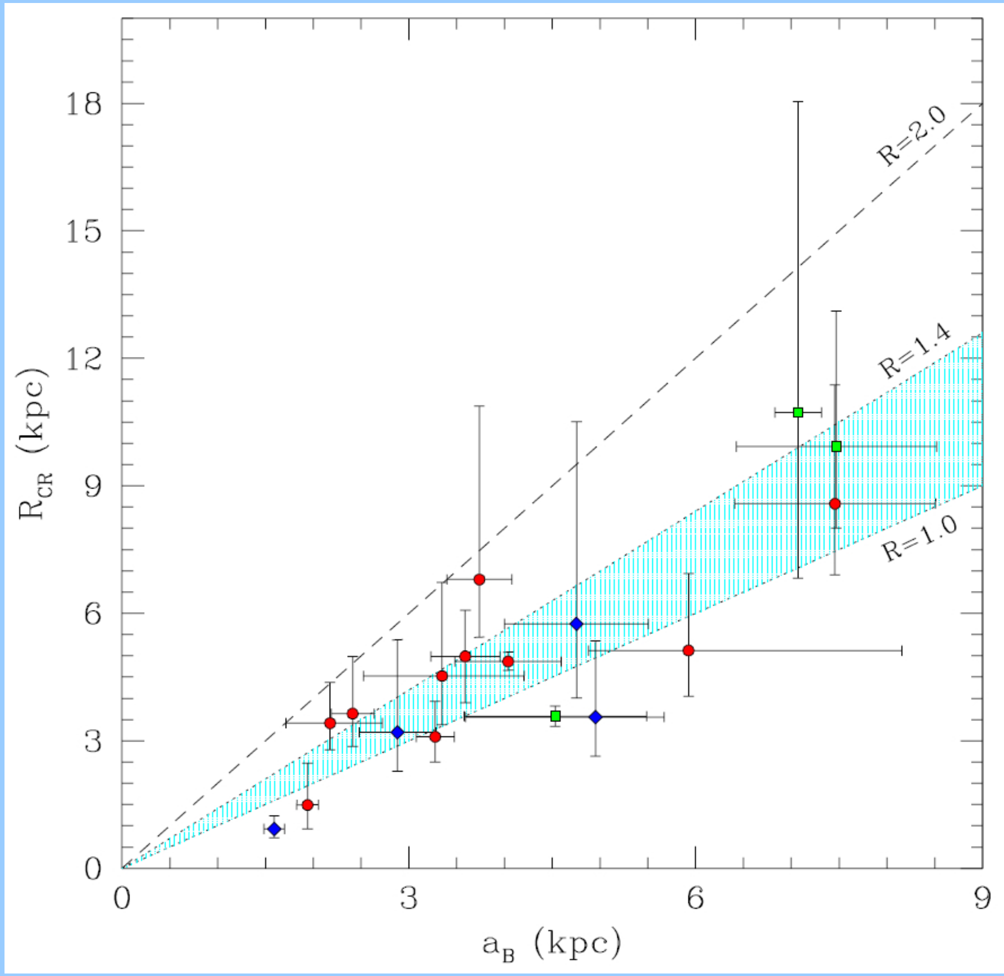
Constraints on this value

Morphology:

Shape of dust lanes from gas flow simulations (EA 92)
1. < Ratio < 1.4

Other morphological features (Rautiainen, Salo, Laurikainen 05, 08)

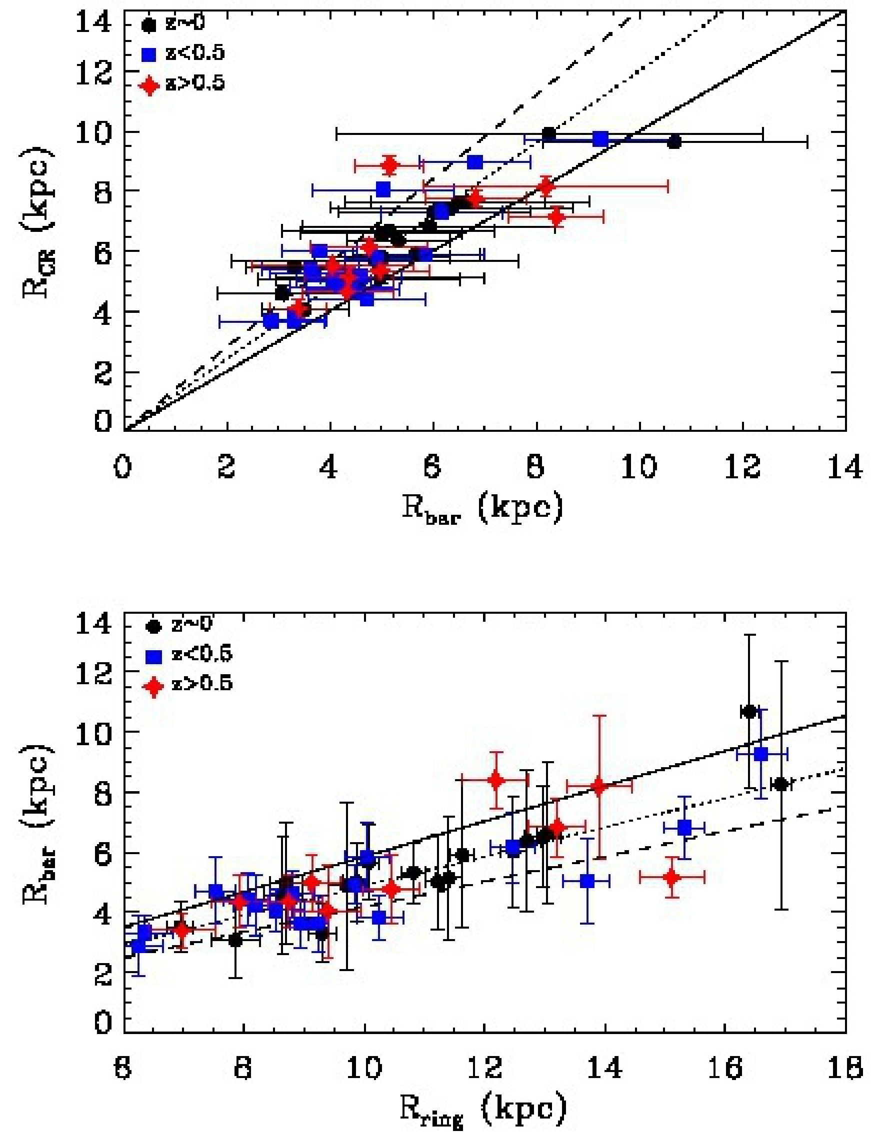
Tremaine-Weinberg (1984) method on galaxies. Compilation by Corsini 2008, from papers by Aguerri, Corsini, Debattista, Mendez-Abreu.. etc



Perez, Aguerri, Mendez-Abreu 12

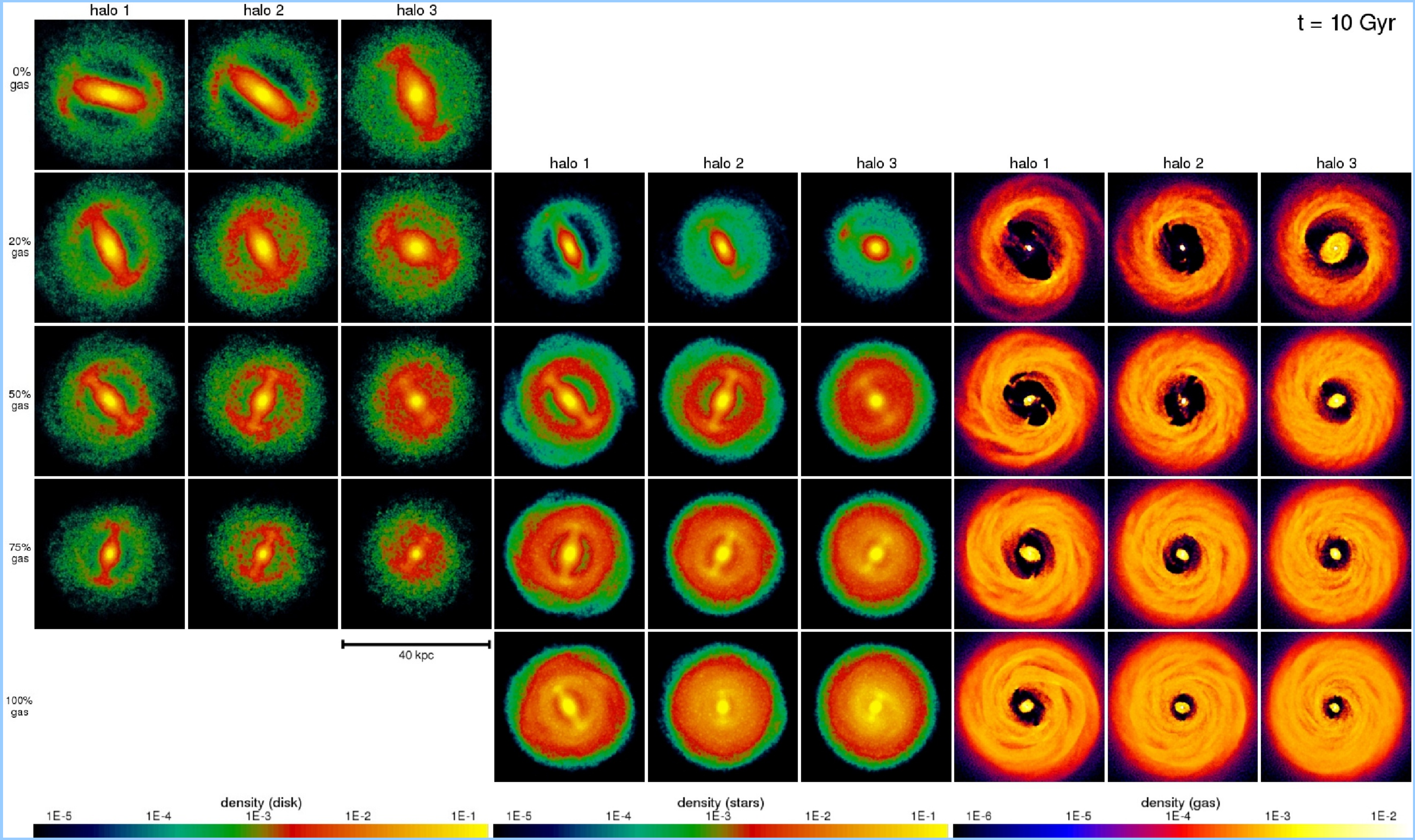
No kinematics, corotation radius determined by morphology (position of outer rings). Allows much bigger samples, but introduces bigger error bars

z=0 black
z<0.5 blue
z>0.5 red



AMR13

All have the same halo !!!

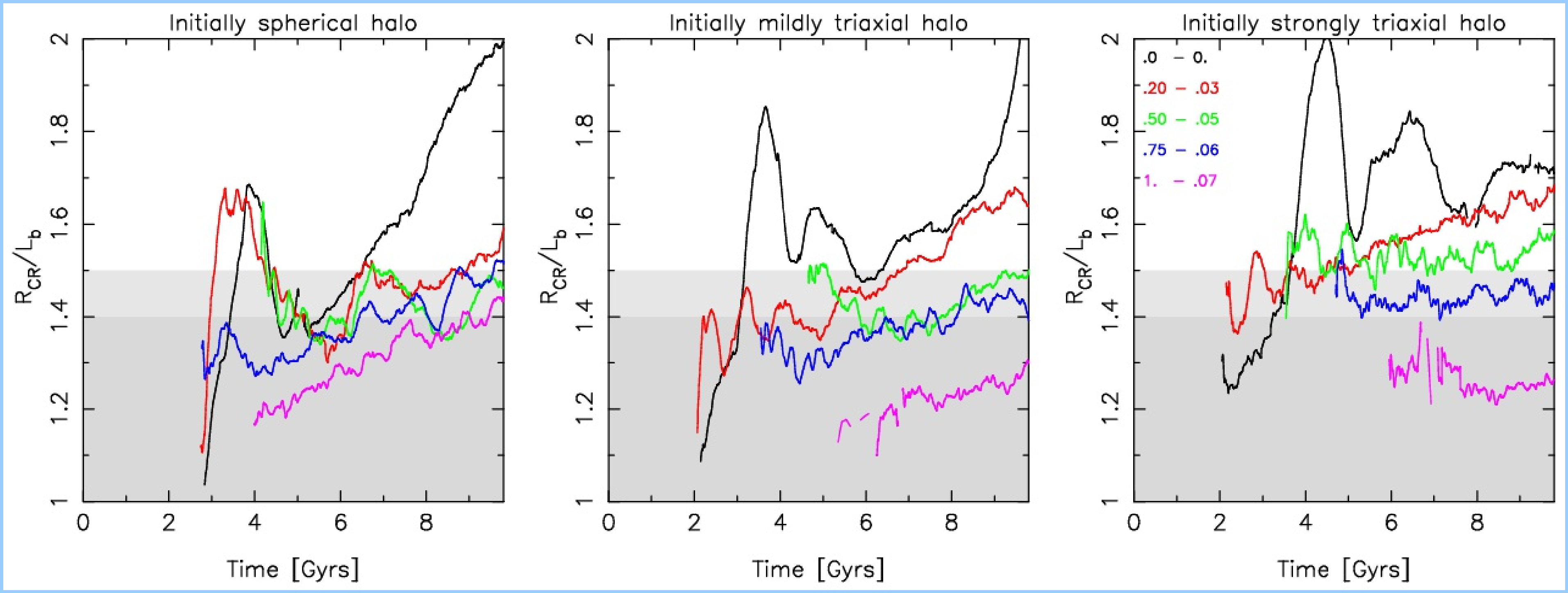


Initially spherical halo

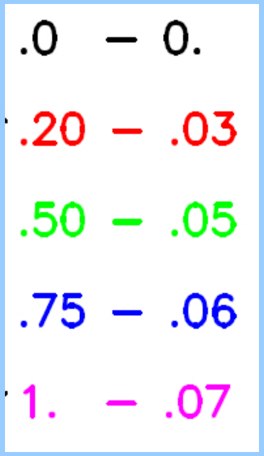
Initially triaxial halo

Initially strongly triaxial halo

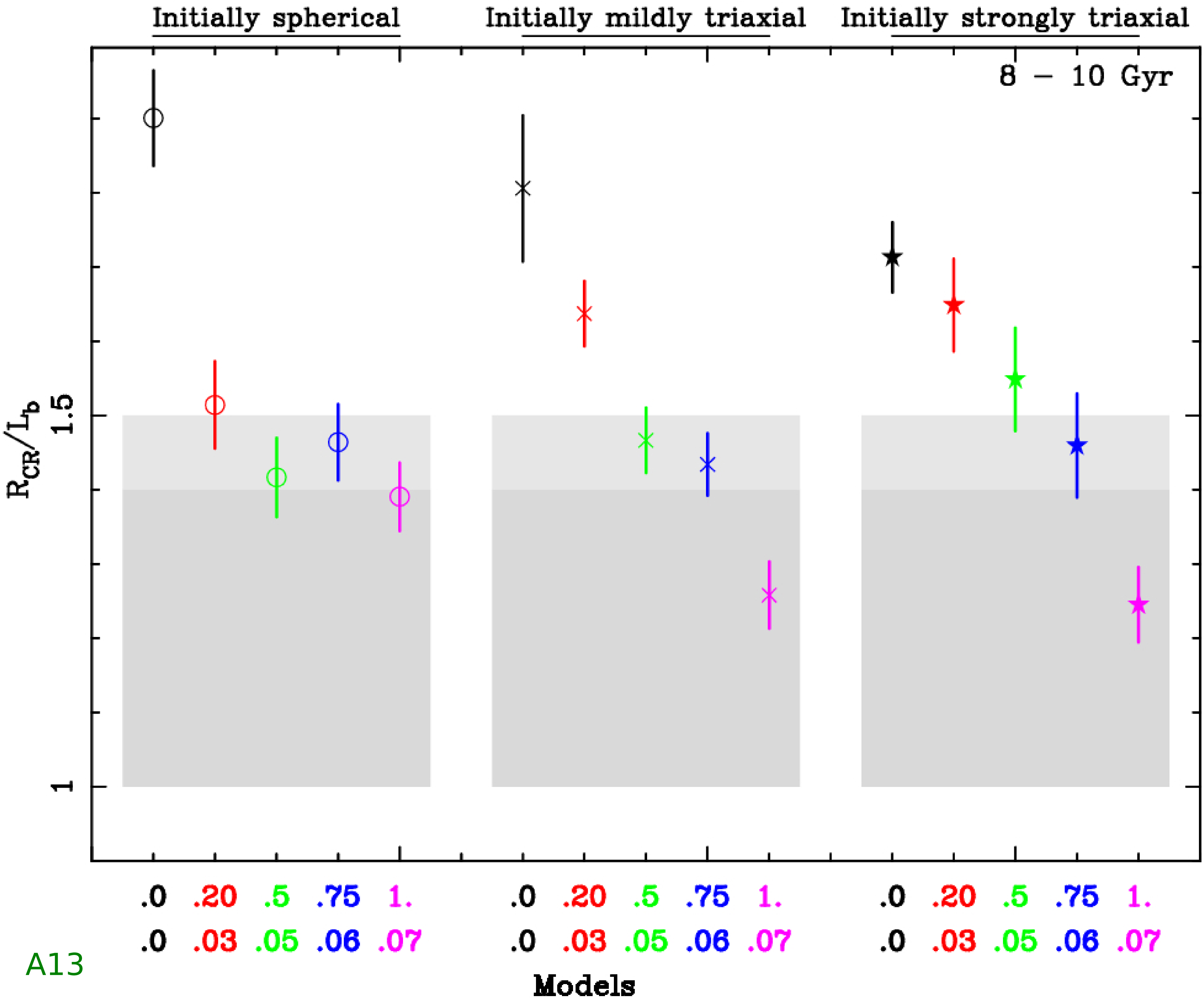
Rcorotation/Barlength



Time

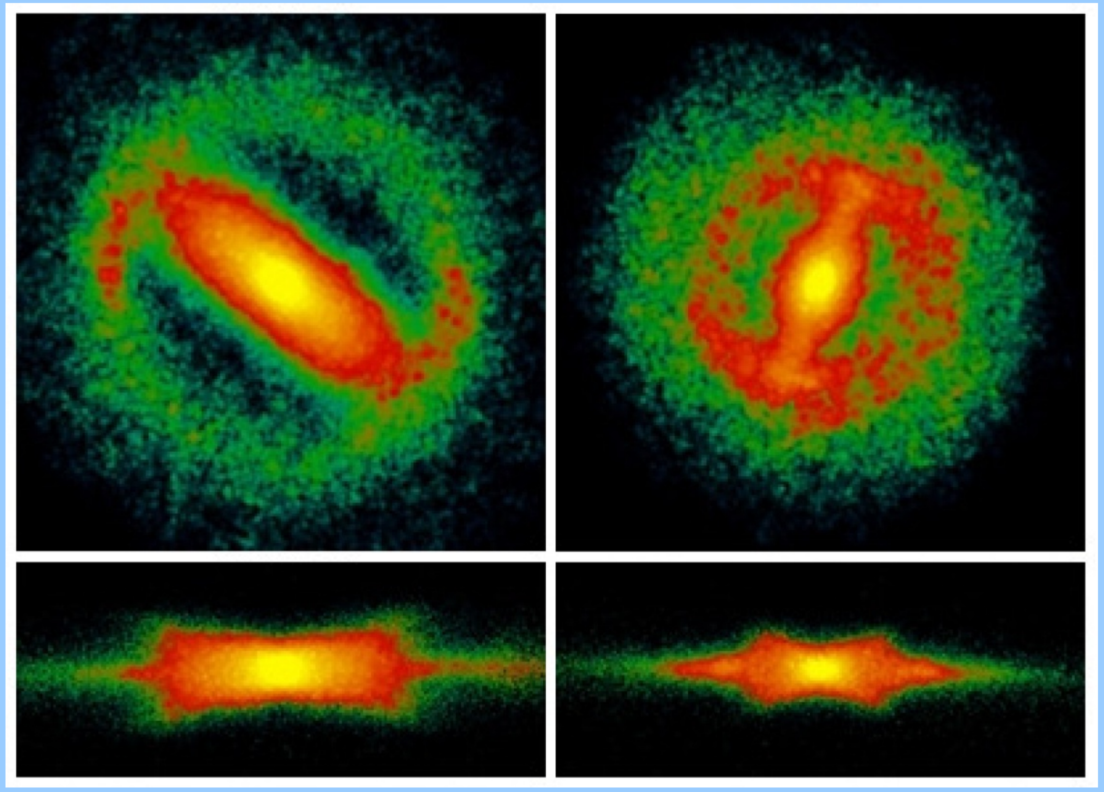


Athanassoula 13



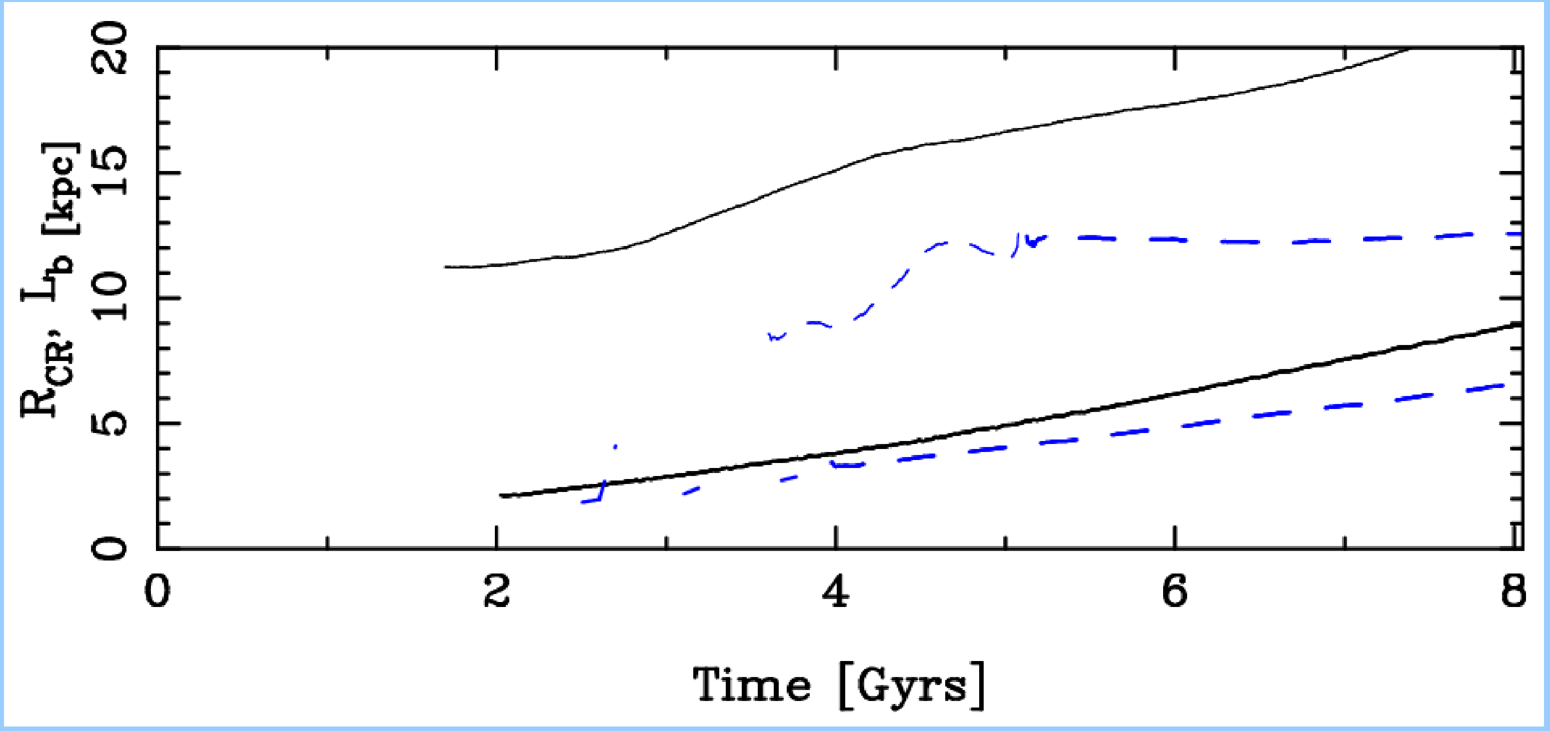
Initially spherical
Initially mildly triaxial
Initially strongly triaxial
8 – 10 Gyr
R_{CR}/L_b
1.5
1
.0 .20 .5 .75 1.
.0 .03 .05 .06 .07
.0 .20 .5 .75 1.
.0 .03 .05 .06 .07
.0 .20 .5 .75 1.
.0 .03 .05 .06 .07
Models

A13



What about bar length?

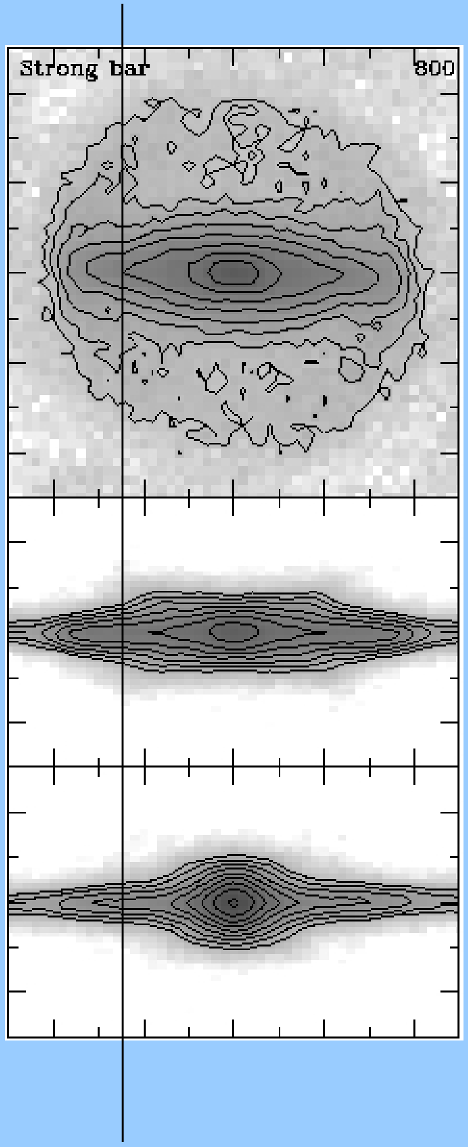
AMR13



A13

Orbital structure theory: peanuts are shorter than bars

Pfenniger 84; Skokos, Patsis, EA 02; Patsis, Skokos, EA 02

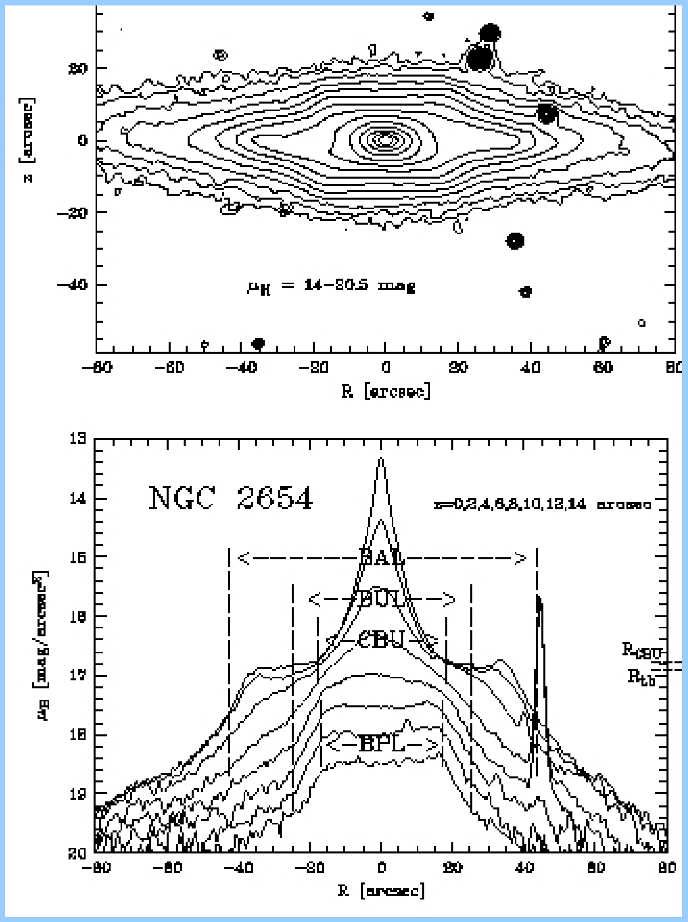


Simulations :

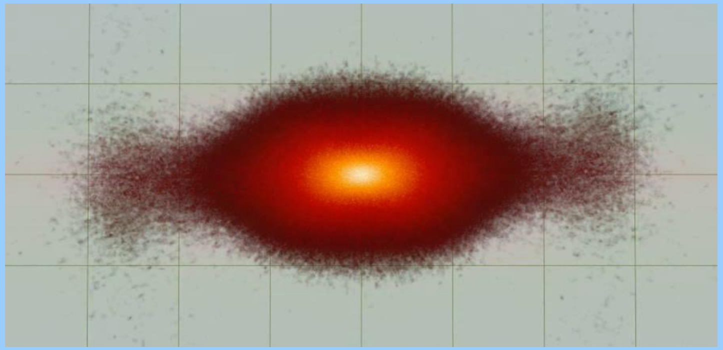
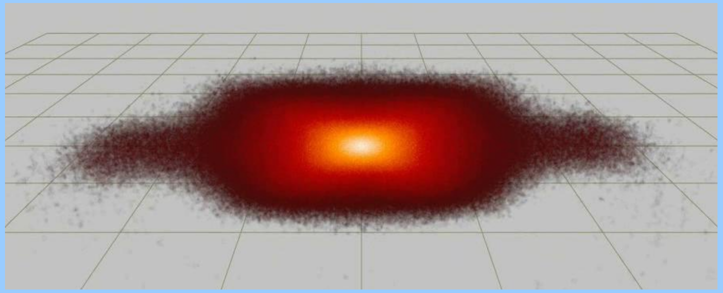
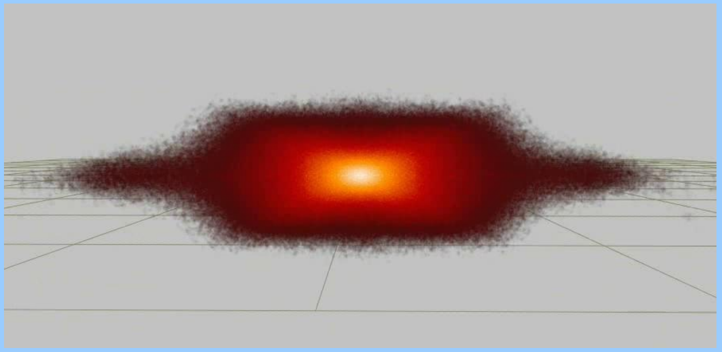
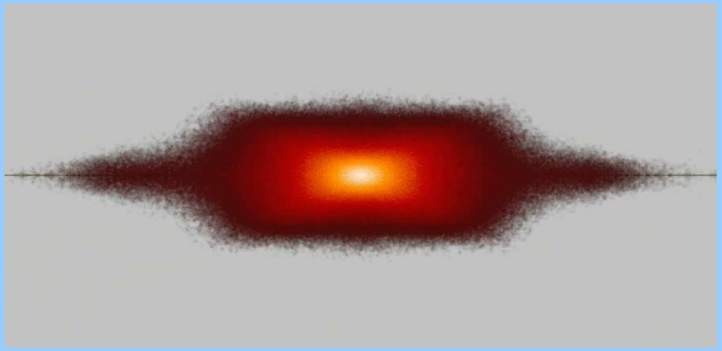
Athanassoula and Misiriotis 2002

Athanassoula 05

Athanassoula and Beaton 2006

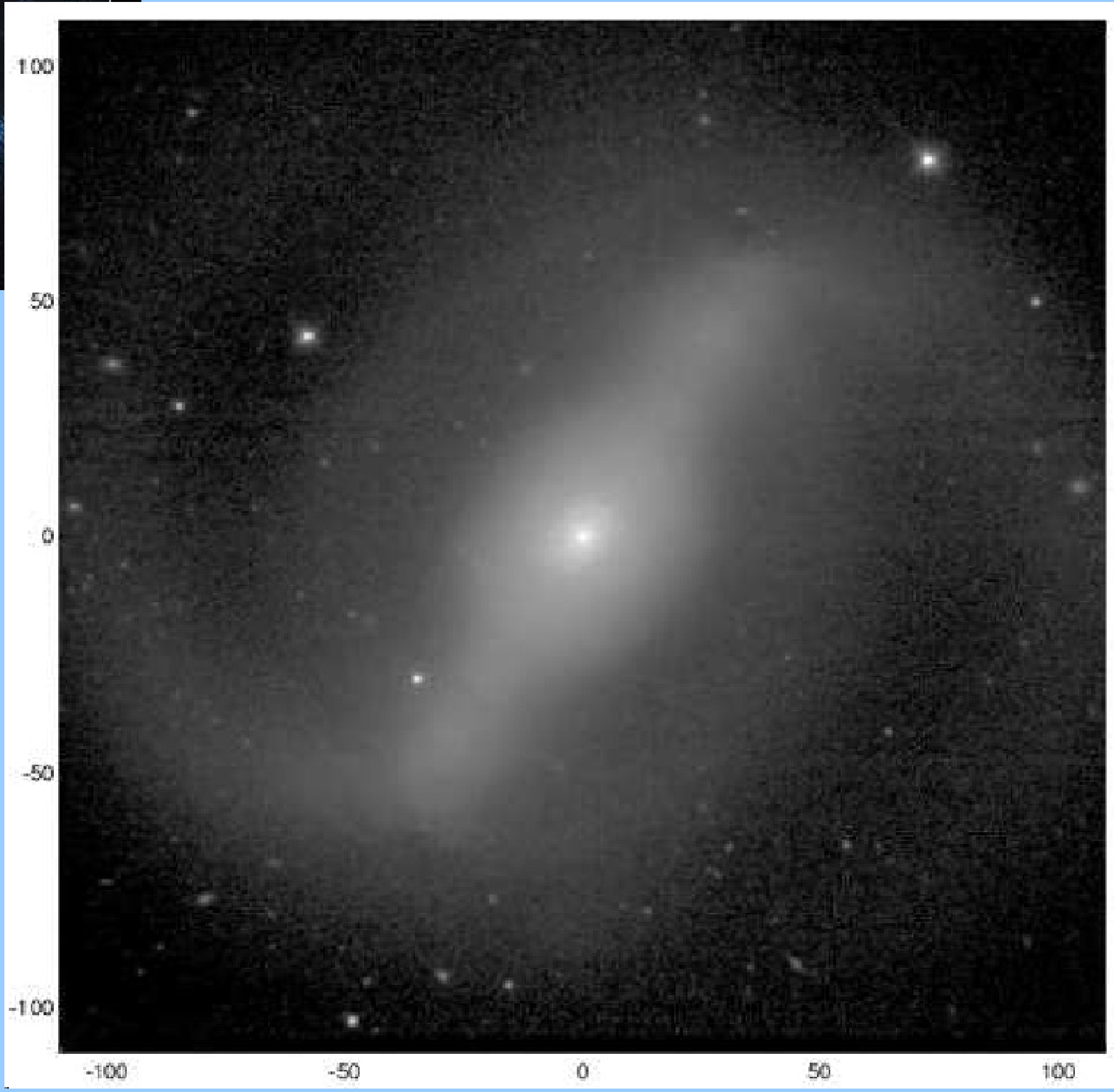


Lutticke, Dettmar and Pohlen, 2000
Bureau, Aronica, EA et al 2006

For a full movie see
http://lam.oamp.fr/research/dynamique-des-galaxies/
scientific-results/milky-way/bar-bulge/how-many-bars-in-mw

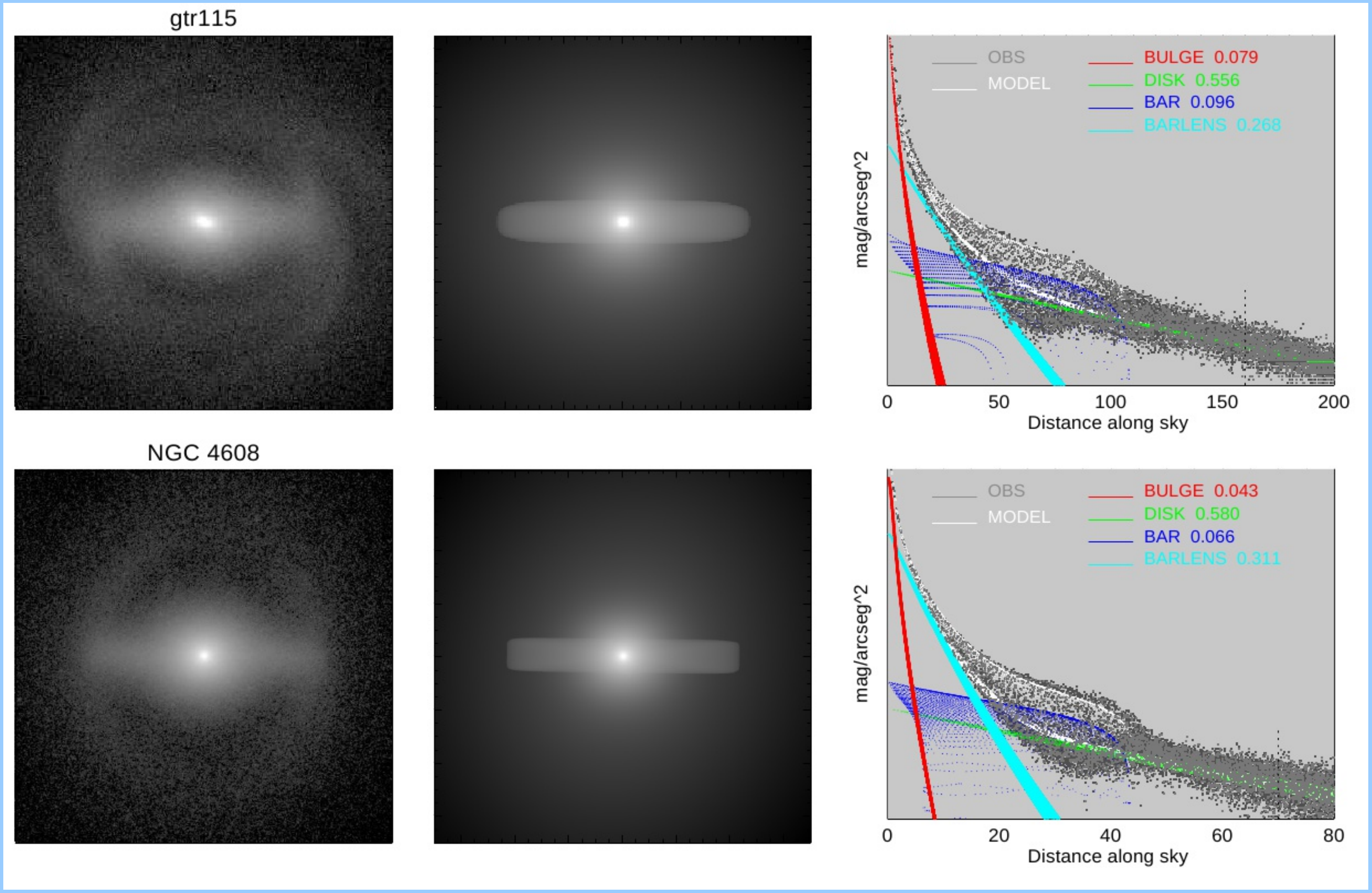
In external galaxies



Barlens component
(see talk of E. Laurikainen)

NGC 4314
NIRSOS
Laurikainen et al

Comparing observations and simulations: decompositions

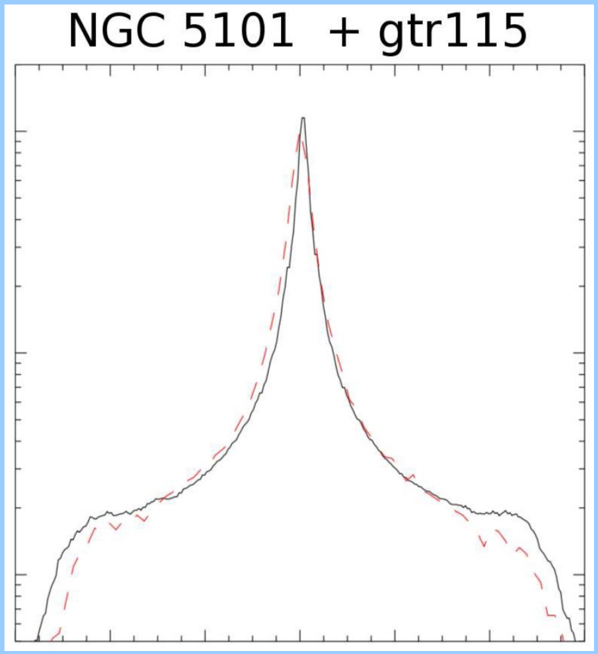


EA, Laurikainen et al 13

Comparing observations and simulations

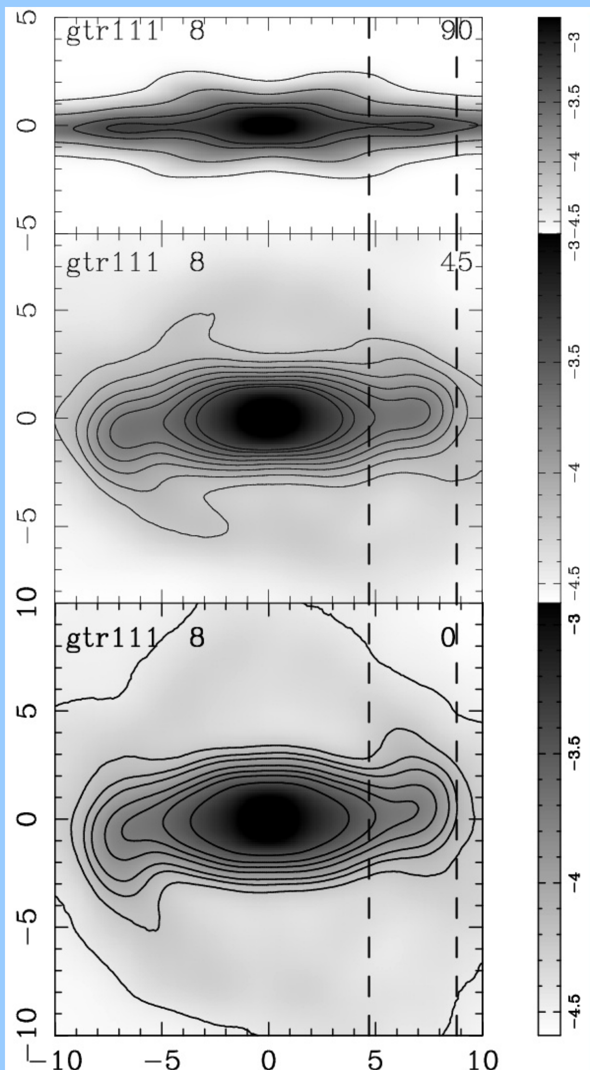
– Similar range of axial ratios (shapes) and of mass ratios

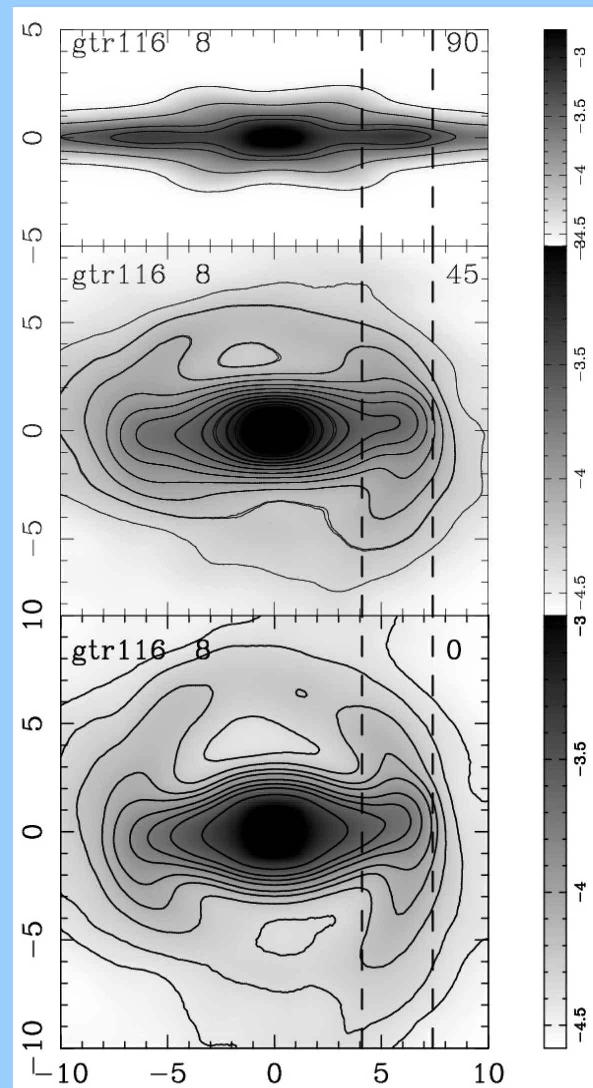
– Profile similarity

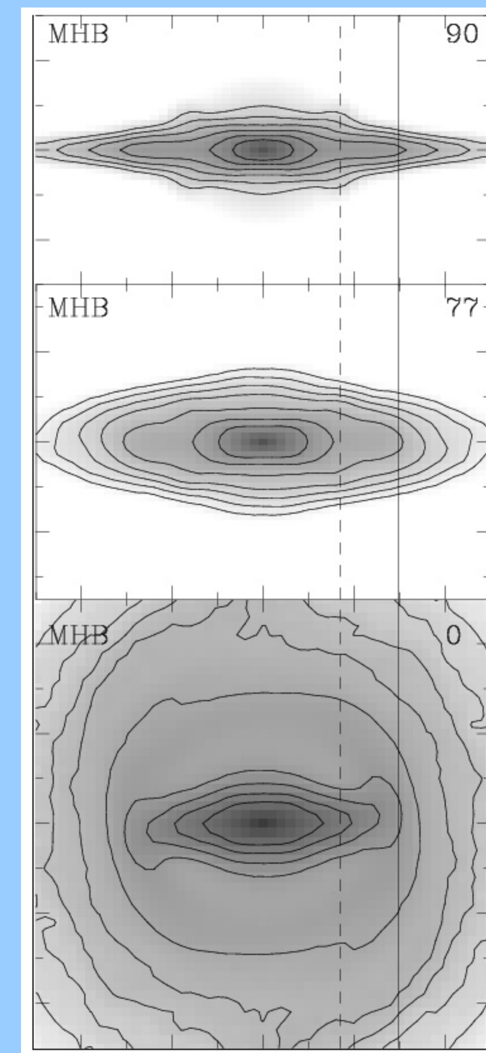


EA, Laurikainen et al 13

So what is the barlens component?

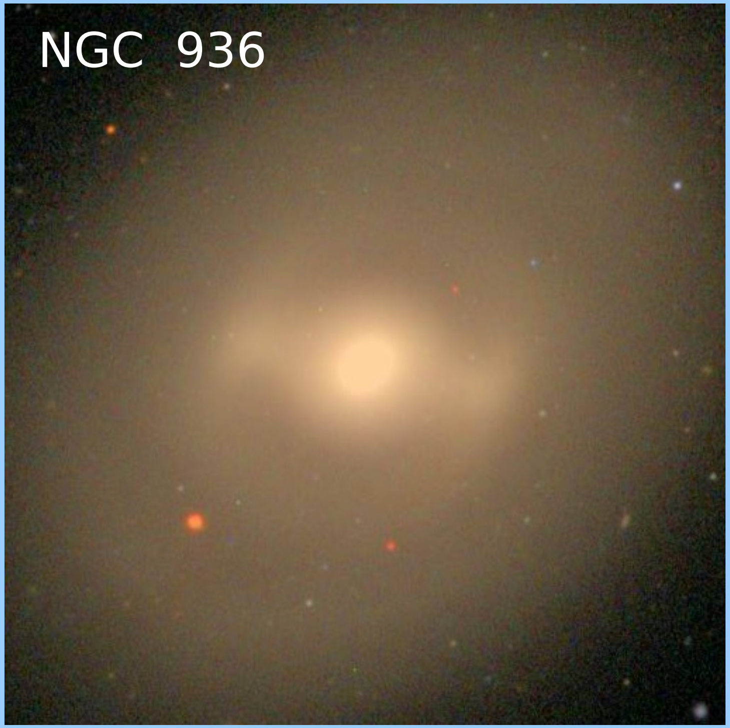


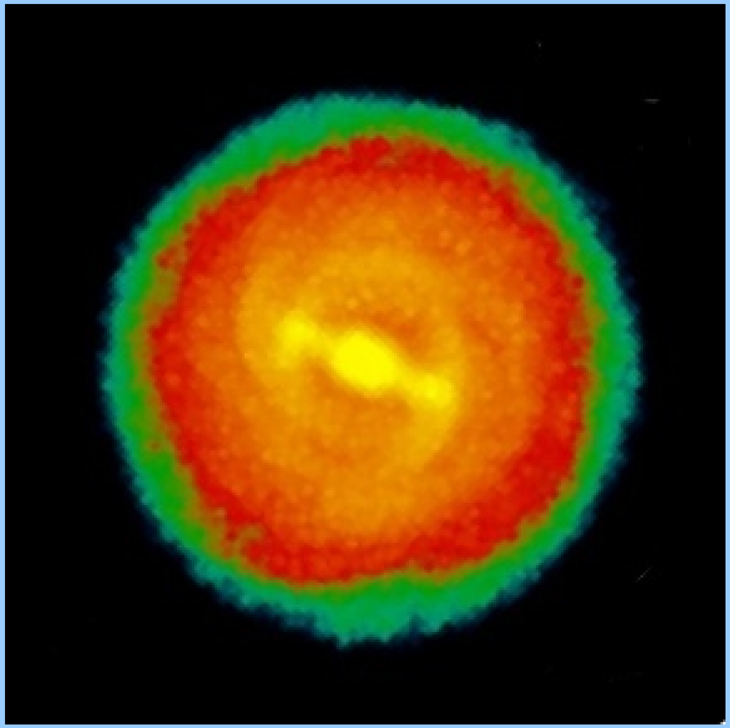




EA, Laurikainen et al

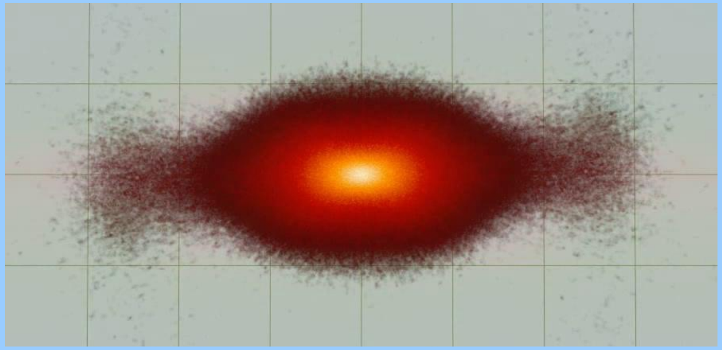
A barlens may masquerade as a classical bulge

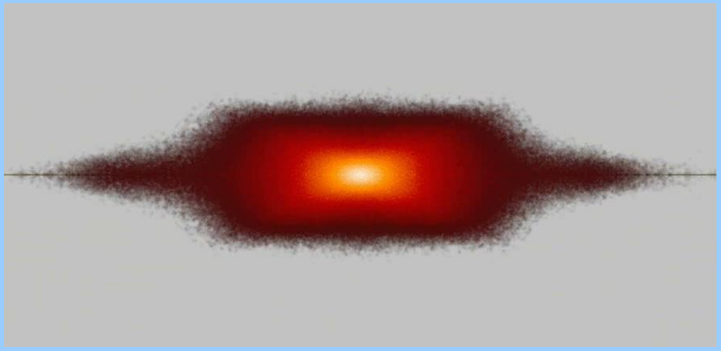


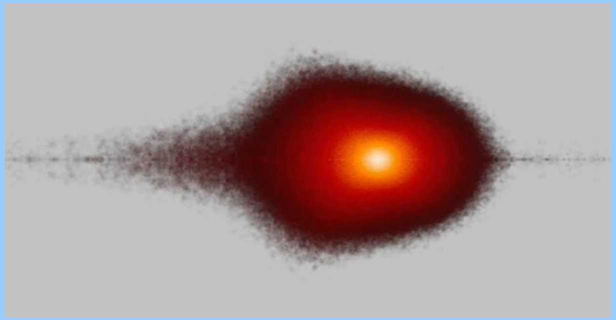


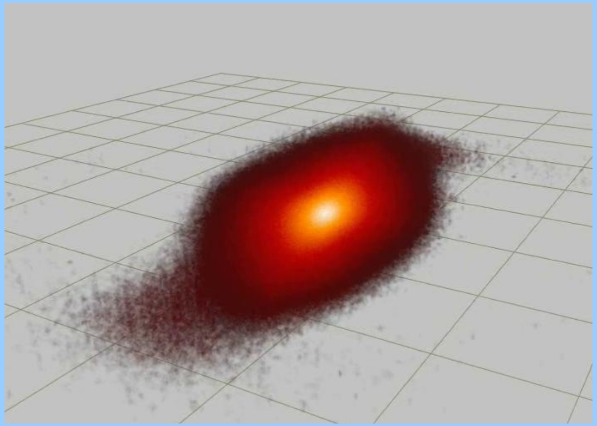
- Morphology/photometry alone will not be sufficient
- Need kinematics and modelling

EA, Laurikainen et al 13





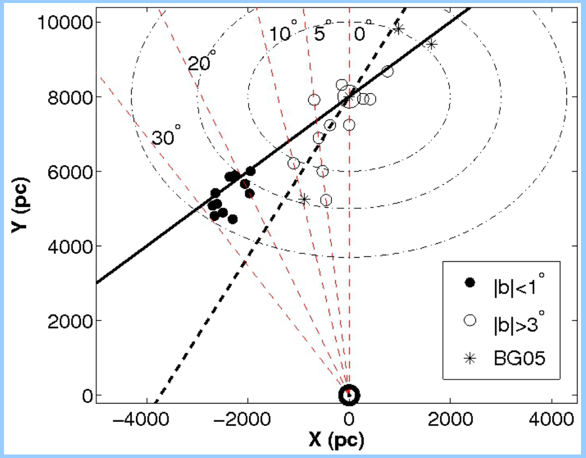




Milky Way

How are the COBE/DIRBE bar and the Long bar related?
Clue: Long bar is vertically very thin, COBE/DIRBE bar is very thick.

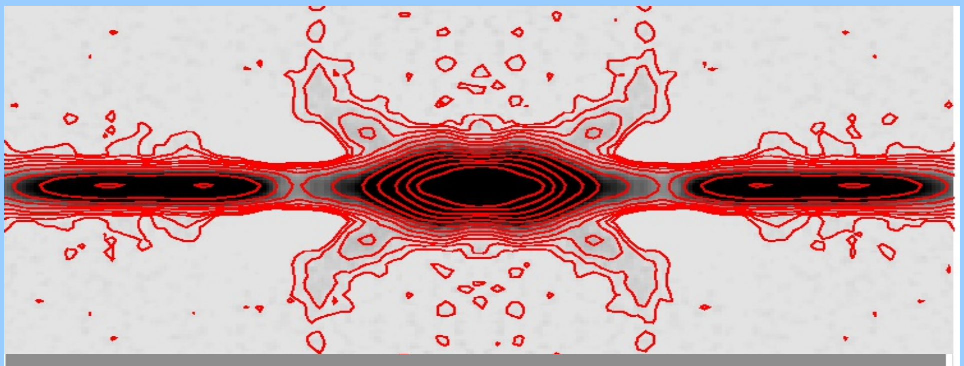
Athanassoula (2006): There is a single bar of which the COBE/DIRBE bar is the boxy/peanut part and the Long bar is the thin outer parts. Tested by Cabrera-Lavers et al (2007).



See also Romero-Gomez et al (2011) and Martinez-Valpuesta and Gerhard (2011)

For a full movie see
http://lam.oamp.fr/research/dynamique-des-galaxies/scientific-results/milky-way/bar-bulge/how-many-bars-in-mw

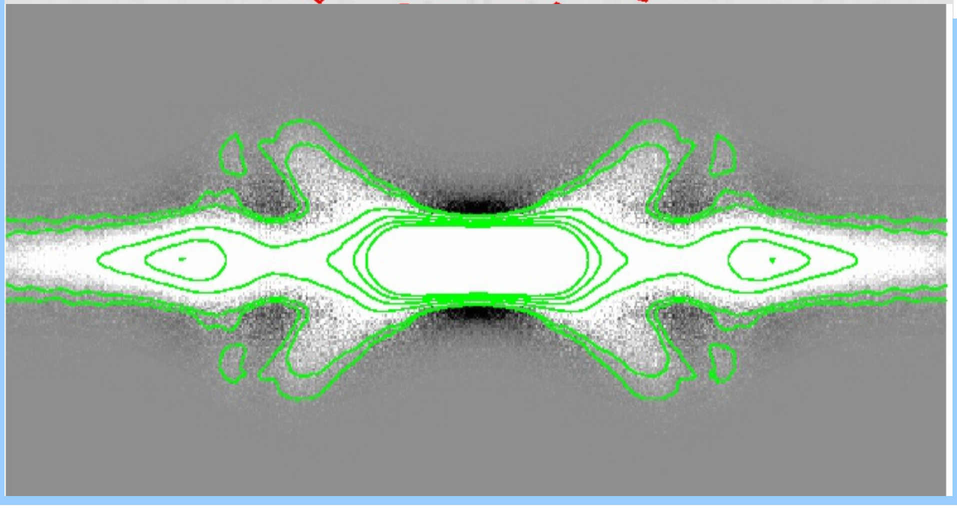
X shapes



NGC 4710 unsharp masked

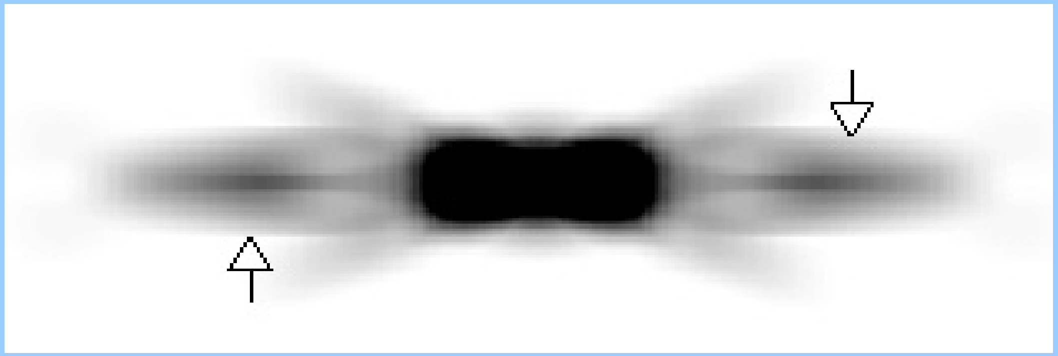
Aronica, EA, Bureau et al 2003

Bureau, Aronica, EA et al 2006



N-body simulation

Athanassoula (2005)



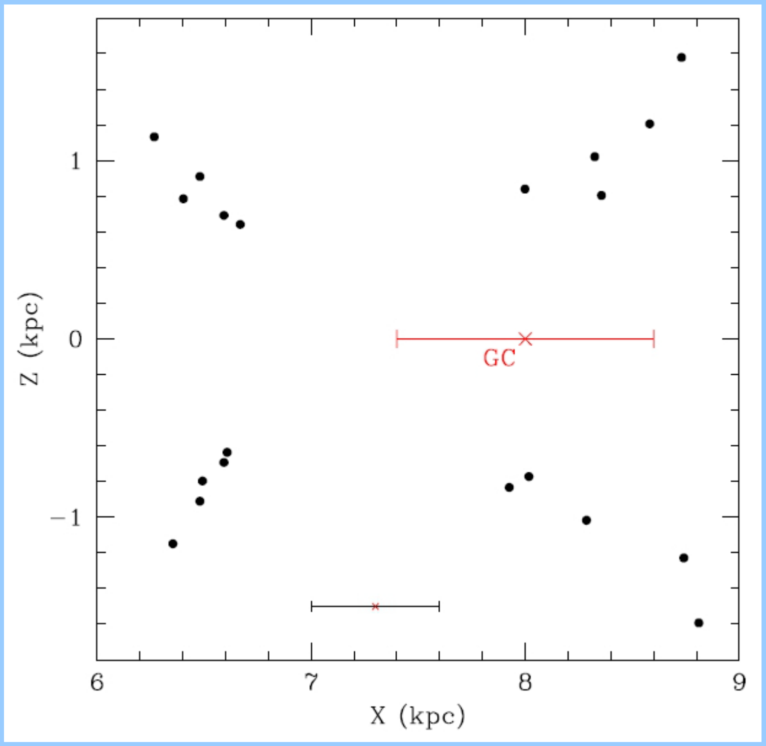
3-D periodic orbit calculation

Patsis, Skokos and EA (2002)

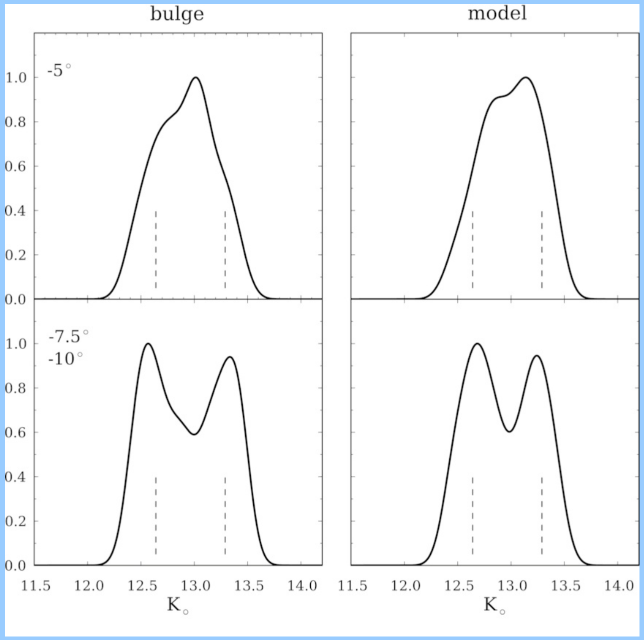
McWilliam & Zoccali 2010

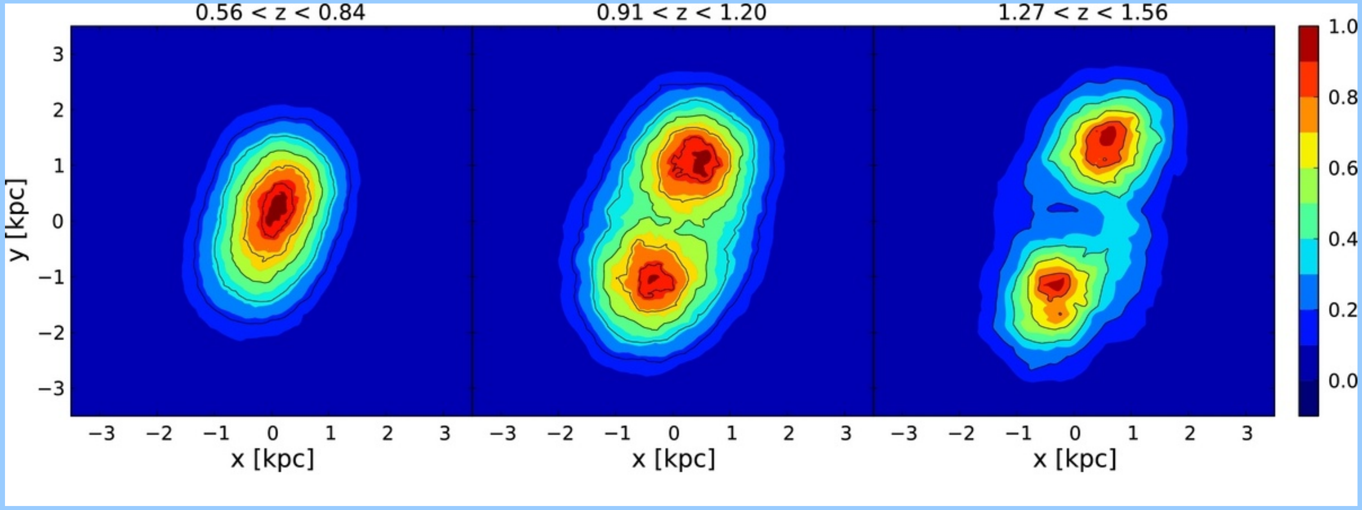
Nataf et al 2010

etc



ARGOS: Ness et al 2012, 2013a, 2013b





The end