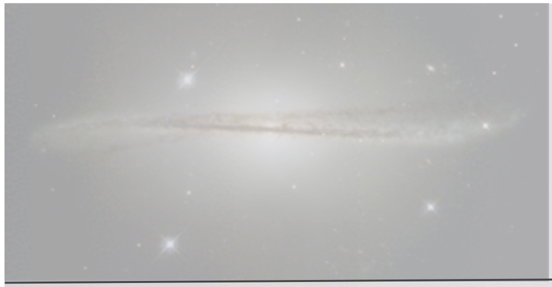

Secular evolution and the the origin of the double exponential profile

Patricia Sánchez-Blázquez

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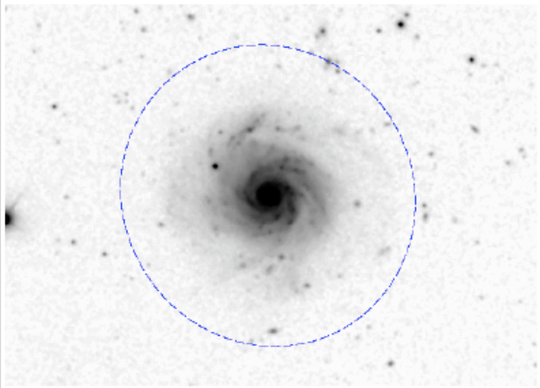
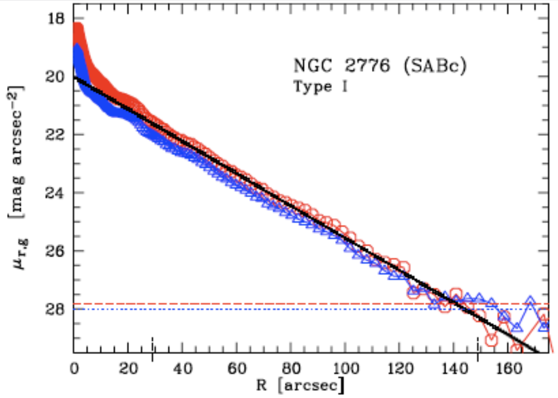
Universidad Autónoma de Madrid

B. Gibson, C. Brook, S. Courty, P. Ocvirk, I. Perez

Profiles types

Pohlen & Trujillo 2006





"Exponential"

← Type I

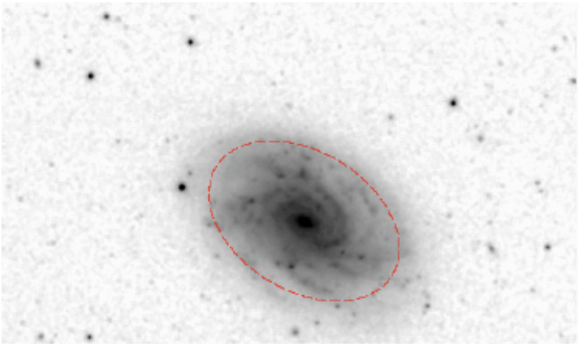
10%

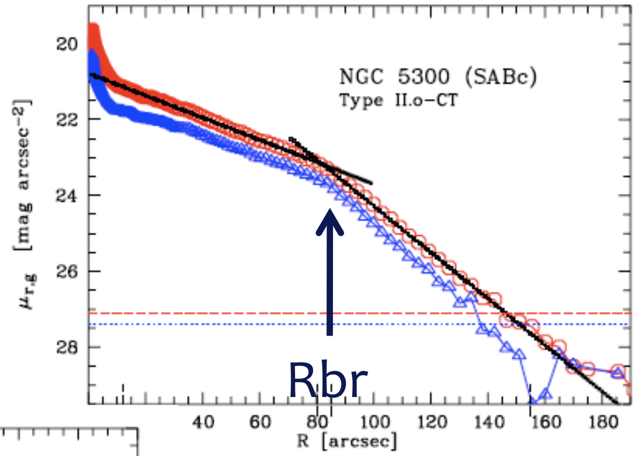
"Truncated"

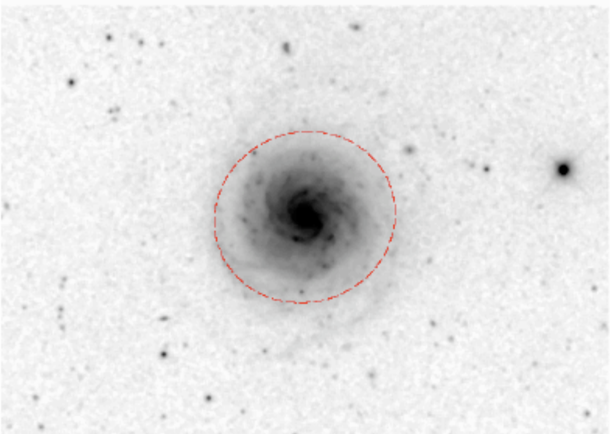
Type II →

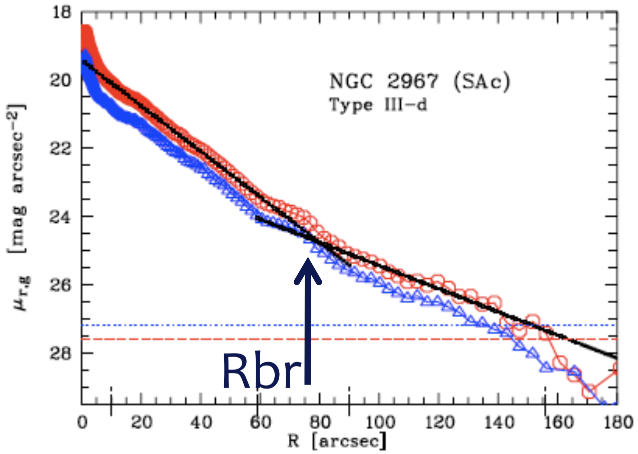
60%

<Rbr>≈1.5-4.5 rs









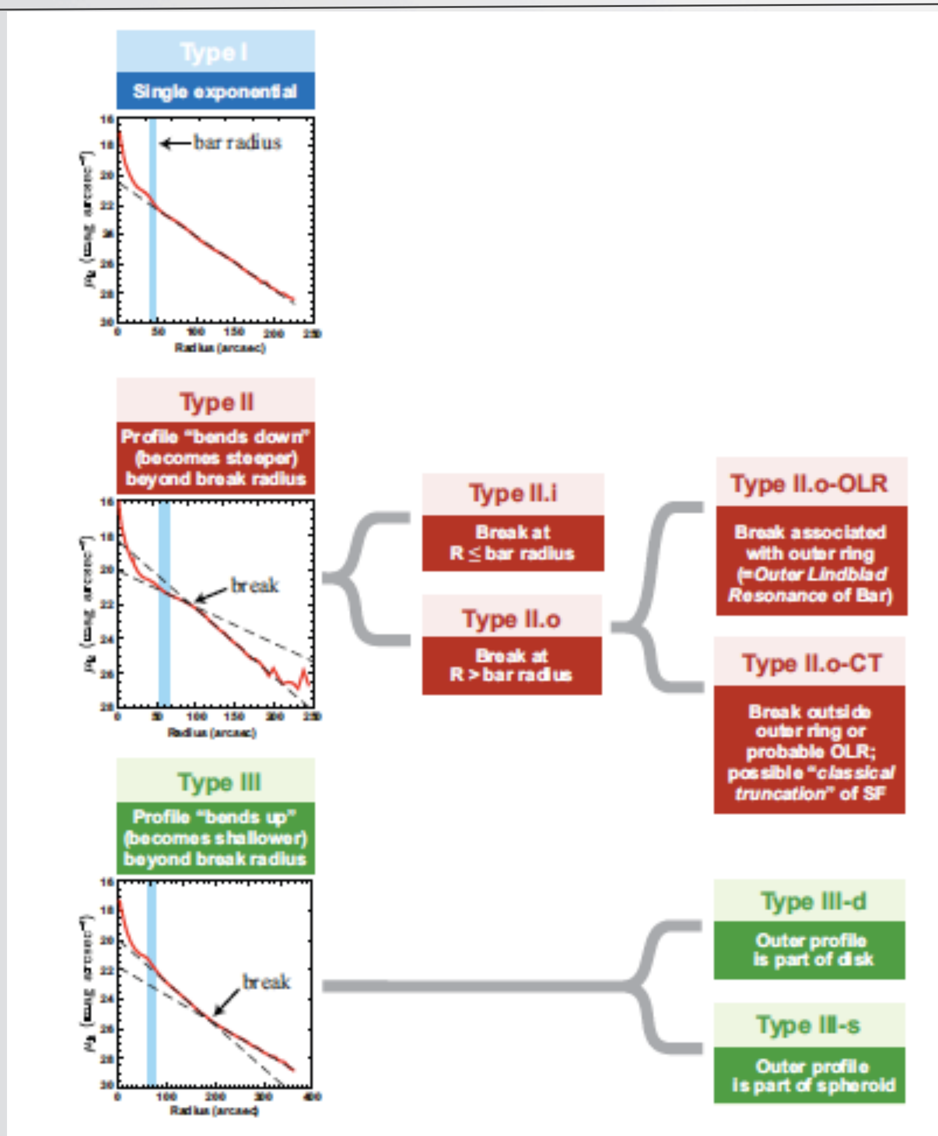
"Anti-truncated"

← Type III

30%

<Rbr>≈4.0-6.0 rs

It gets more complicated...



Erwin et al. 2007

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Possible mechanisms

Star formation threshold (Kennicutt 1989; Fall & Efstathiou 1980; Elmegreen & Parravano 1994; Schaye 2004)

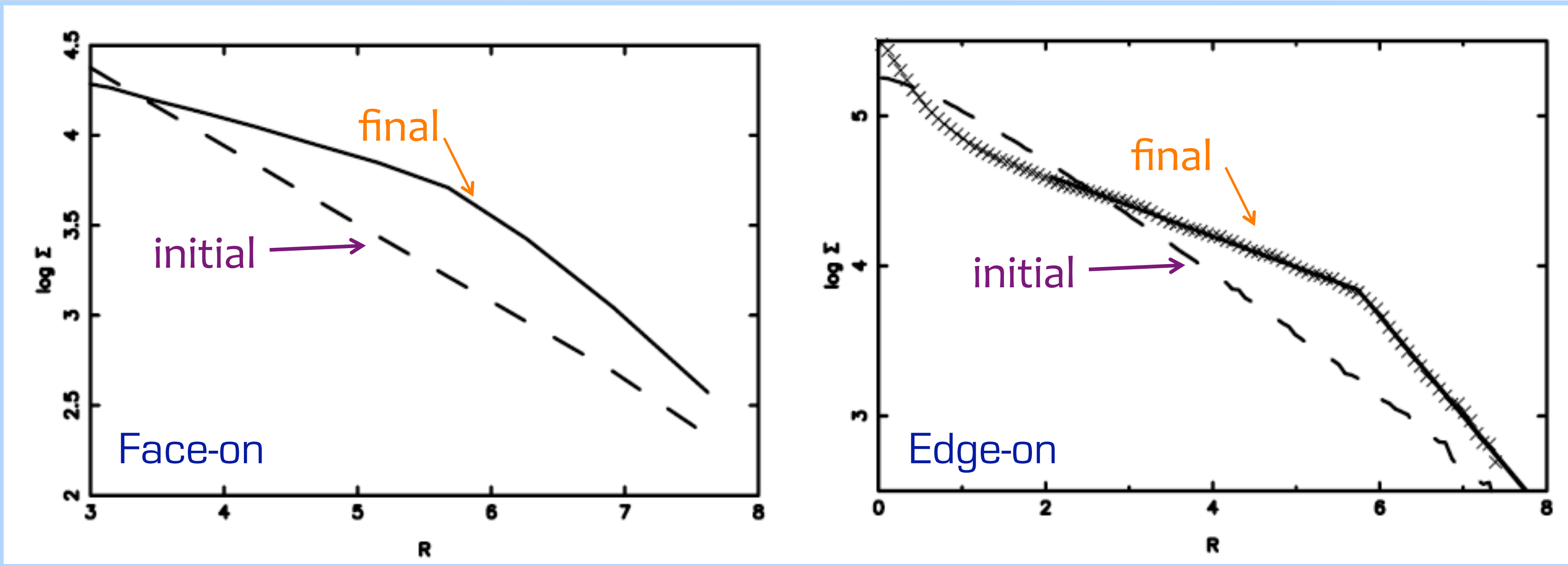
(the break would be located where the density of the gas is lower than the critical value for star formation)

Angular momentum conservations (van der Kruit 1987) or angular momentum cutoff in the cooling gas (van der Bosch 2001)

(if AM redistribution does not occur in the disk the collapse of a Mestel sphere gives an exponential disk with a cuttoff at 4.5 rs . Also the position of the breaks can reflect the maximum angular momentum of the baryonic material that has been able to cool)

Redistribution of AM

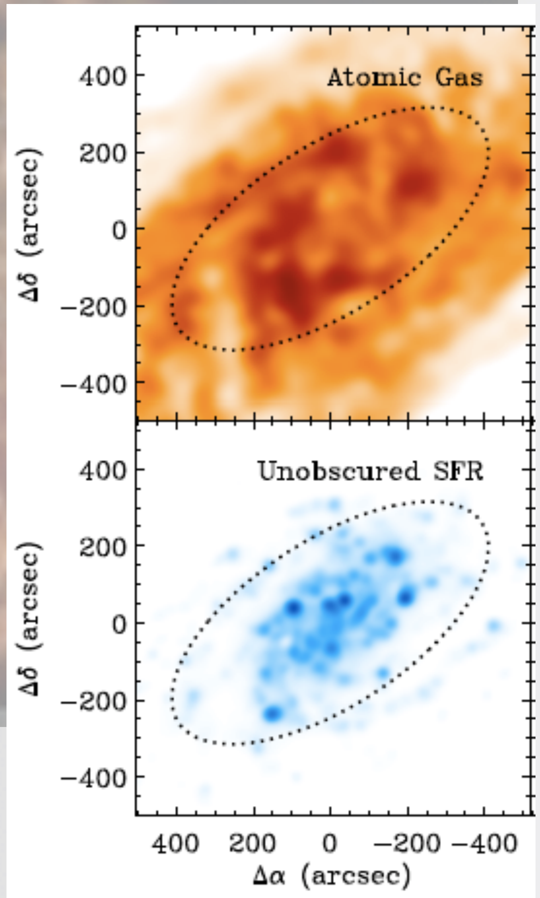
N-body simulations



Debattista et al. (2006)

See also Foyle et al. (2008)

Extended gas disks



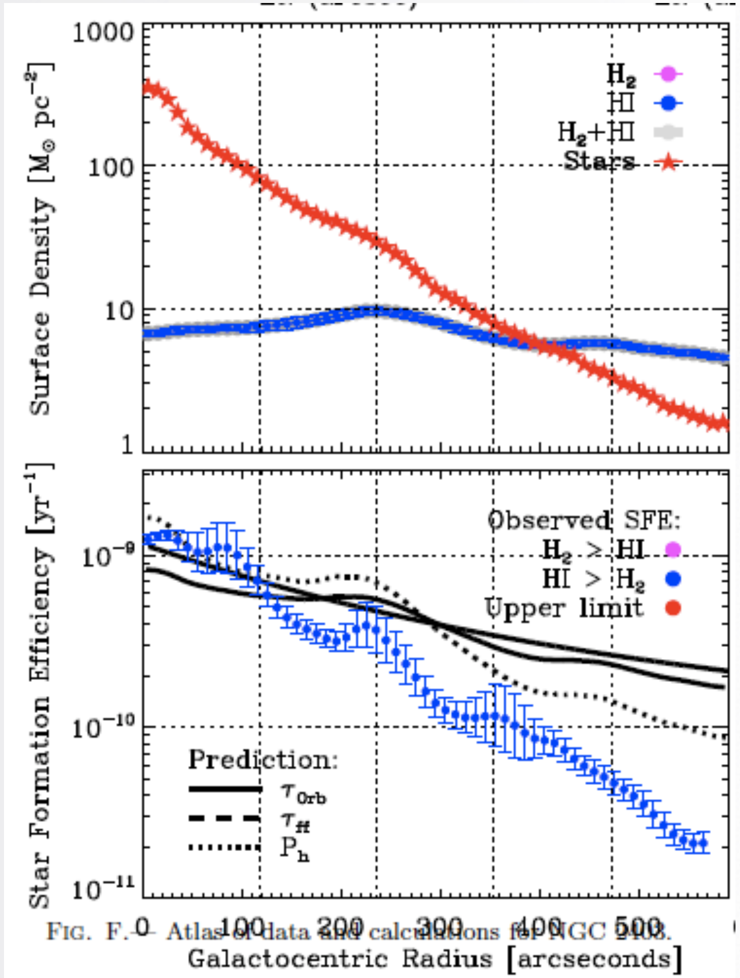
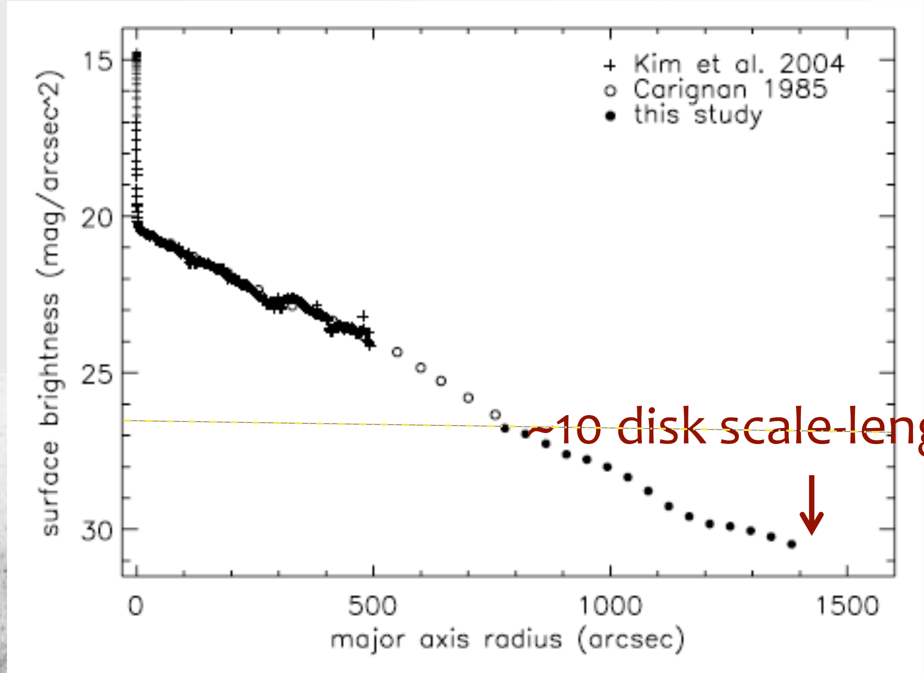


FIG. F. Atlas of data and calculations for NGC 2403.

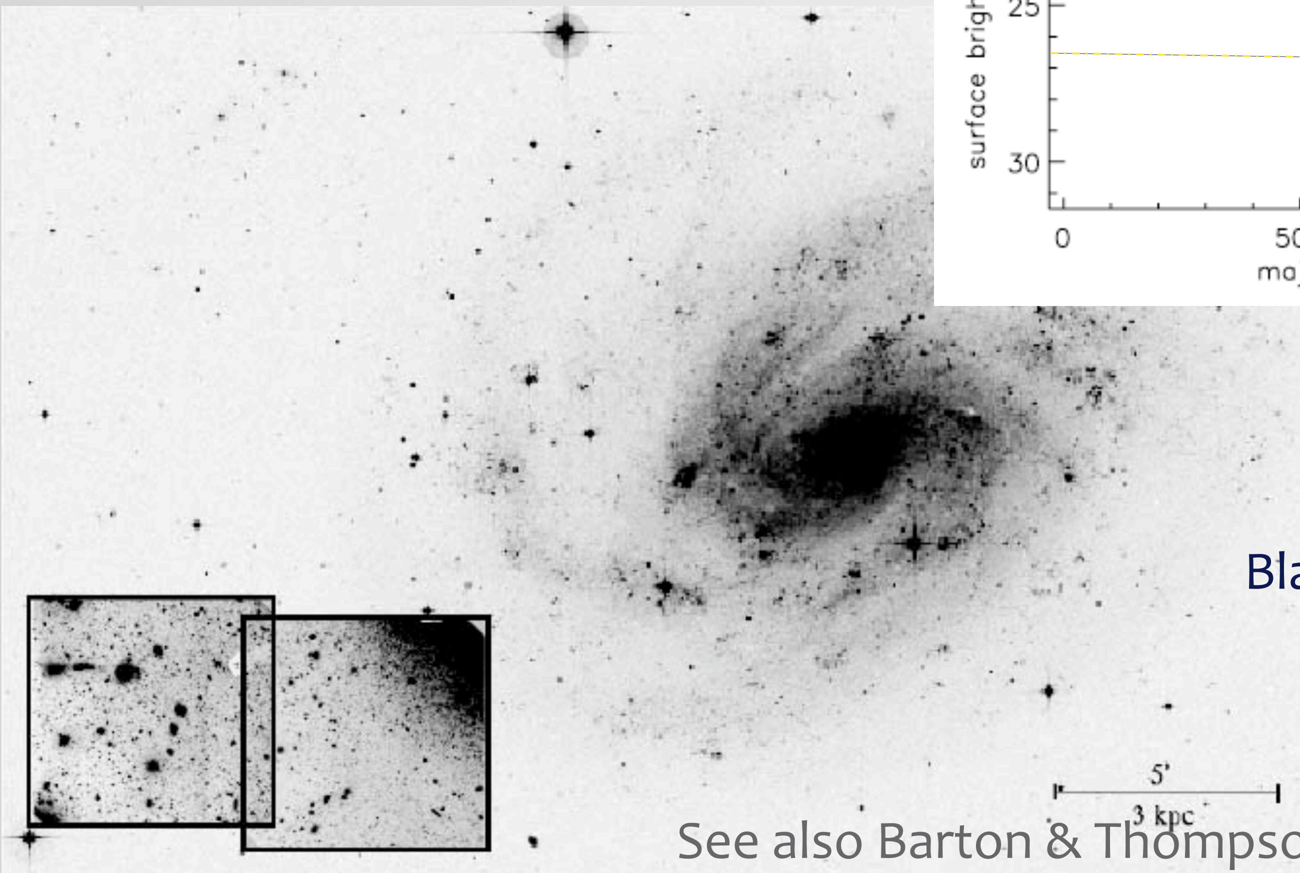
Leroy et al. (2006)

Not all galaxies show breaks

NGC 300



Stellar densities
0.01 $M_{\odot}/pc^2$

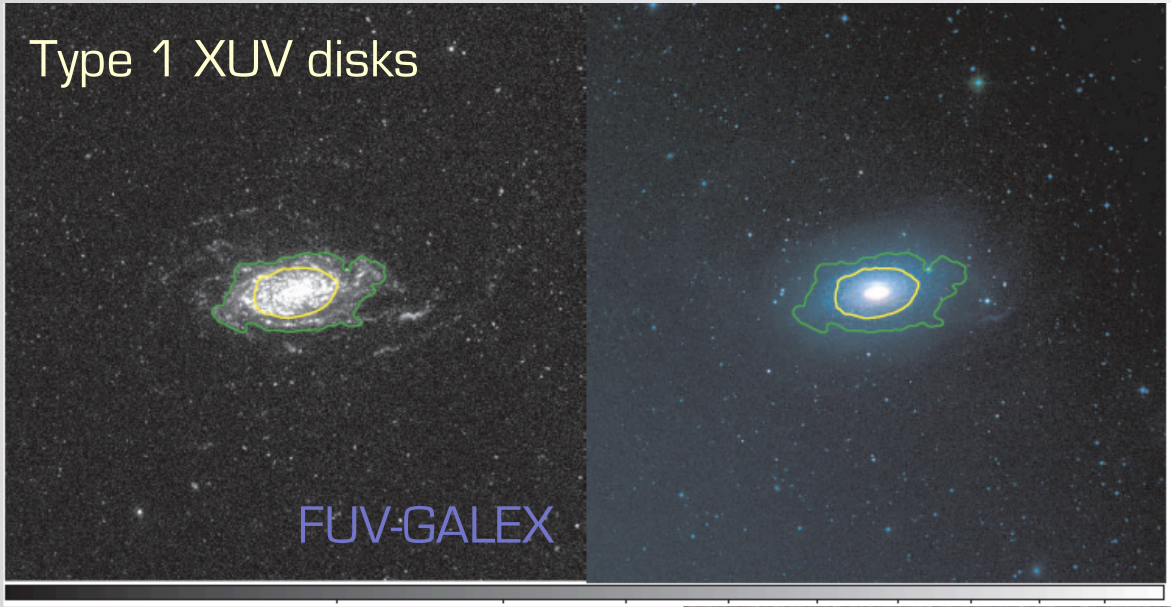


Bland-Hawthorn et al. (2005)

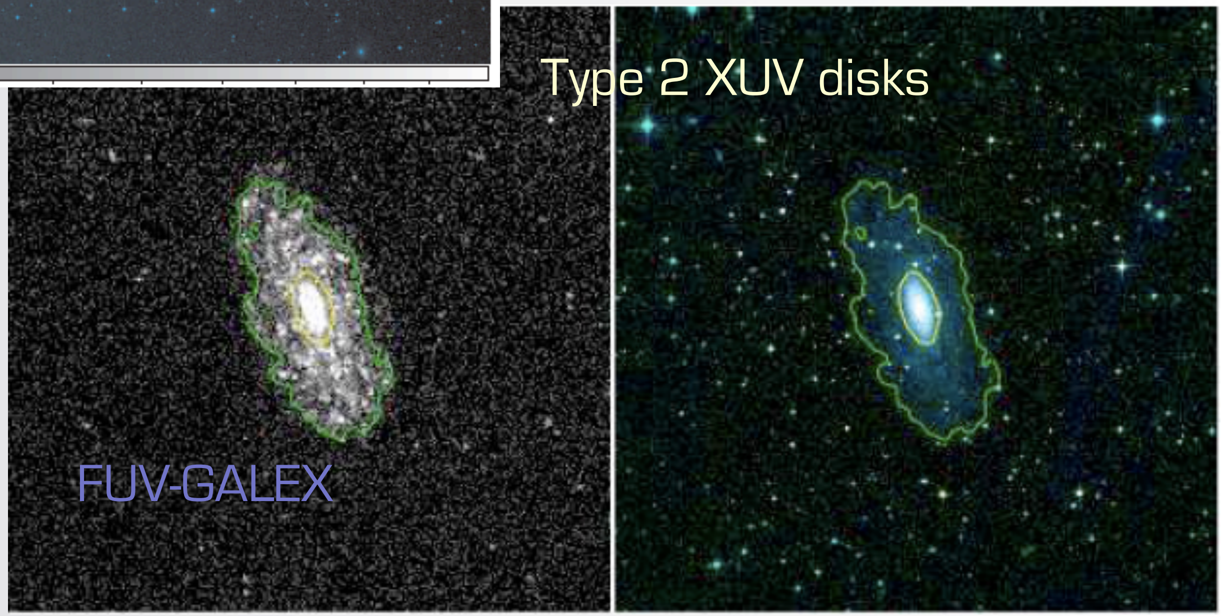
See also Barton & Thompson 1997; Weiner et al. 2001

Observational facts

Davidge (2003); Ferguson et al. (1998); Thilker et al. (2005, 2007), Zaritsky & Christlein 2007

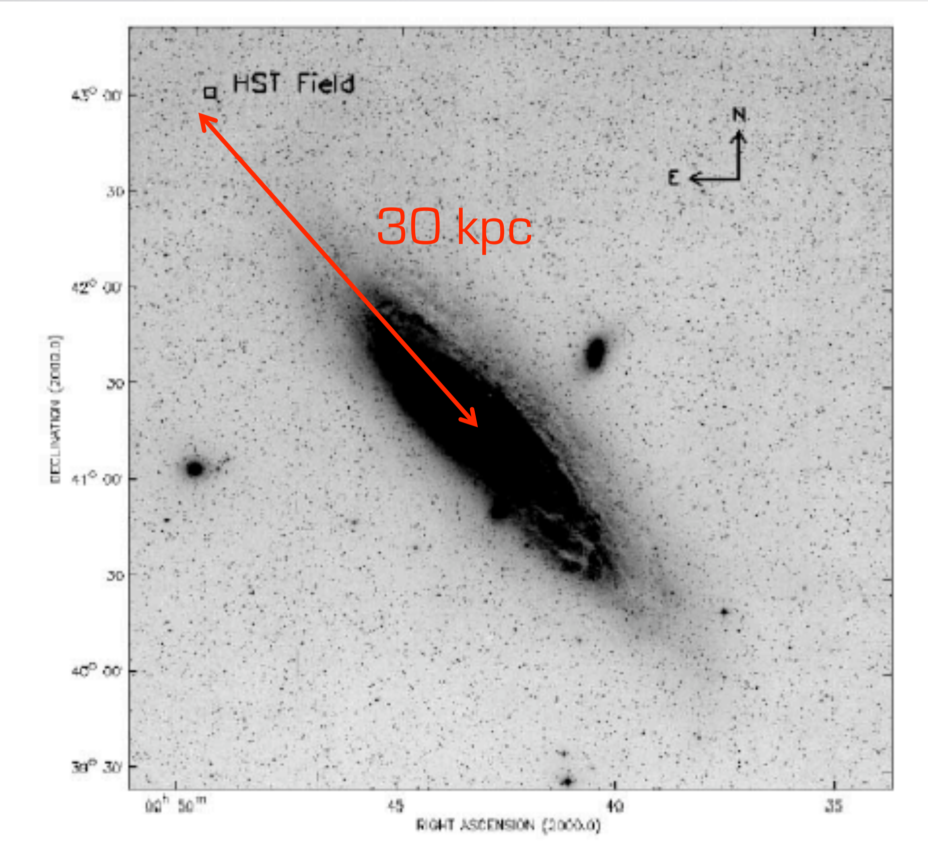


There is recent star formation in the outskirts of the disks, at densities beyond the threshold



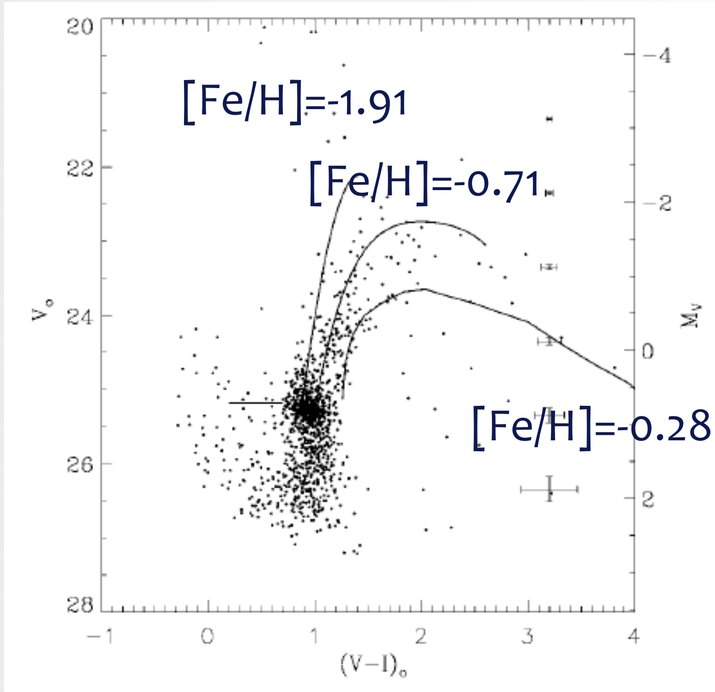
30% of disk galaxies show UV emission out to 2-3 times the optical radius

Stellar populations in the outskirts



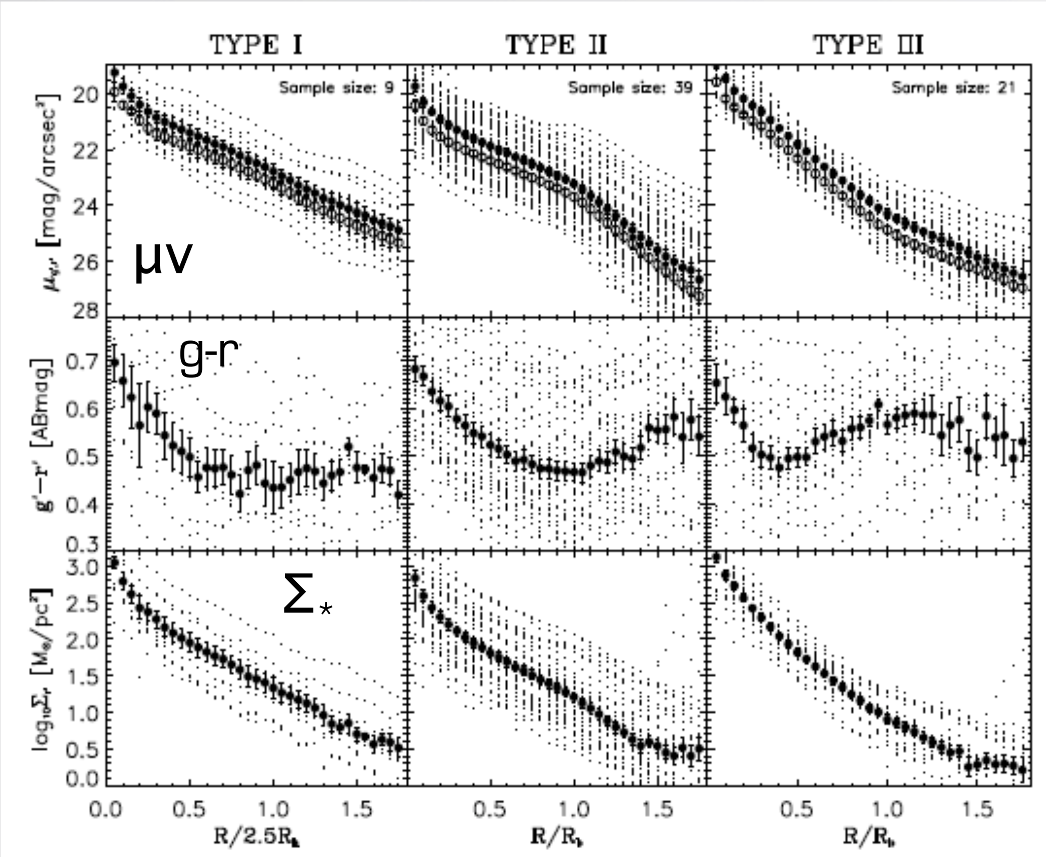
Ferguson & Jonhson (2001)

Mean metallicity [Fe/H] ≈ −0.7 and
Age > 8 Gyr



Davidge (2003, 2006, 2007), Baker et al. (2007); Ferguson et al. (2007)

Observational facts

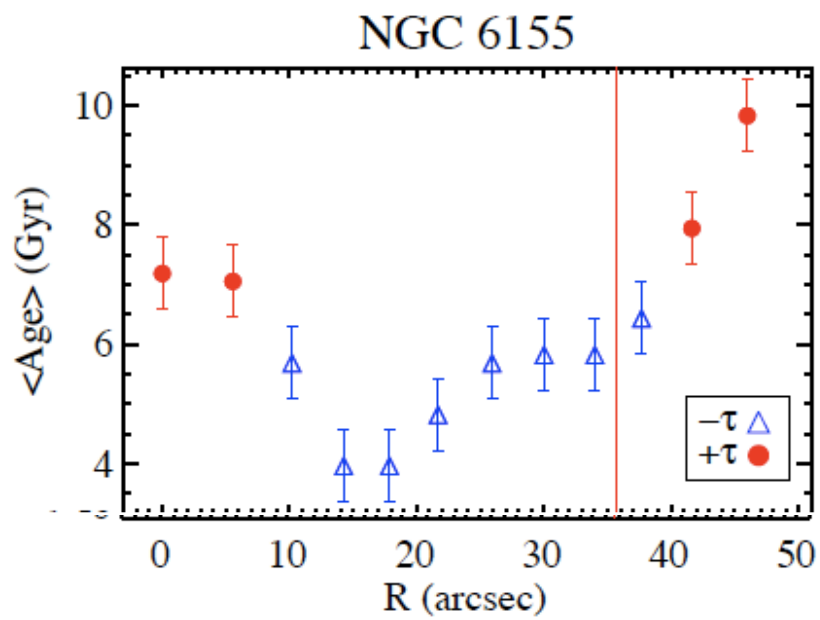


Minimum in the colour profile at the break position (type II)

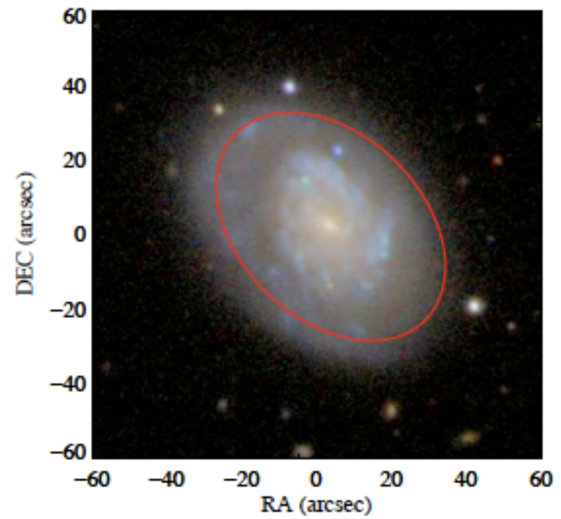
No break in the surface mass density

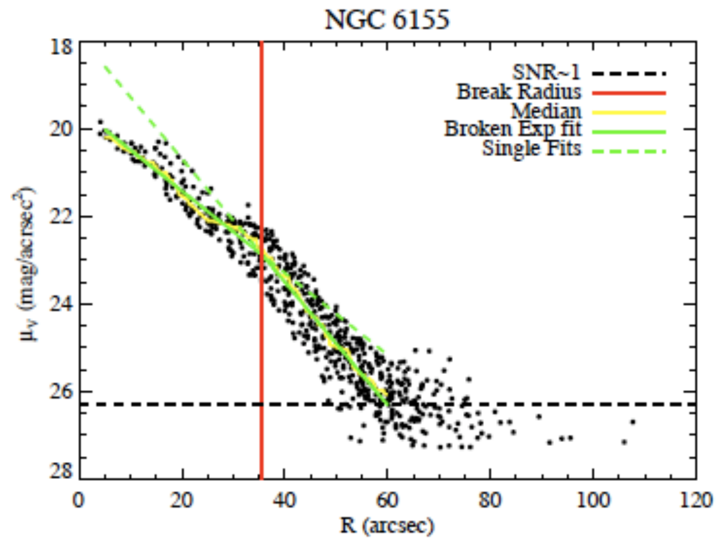
Bakos, Trujillo & Pohlen 2008

Observational facts

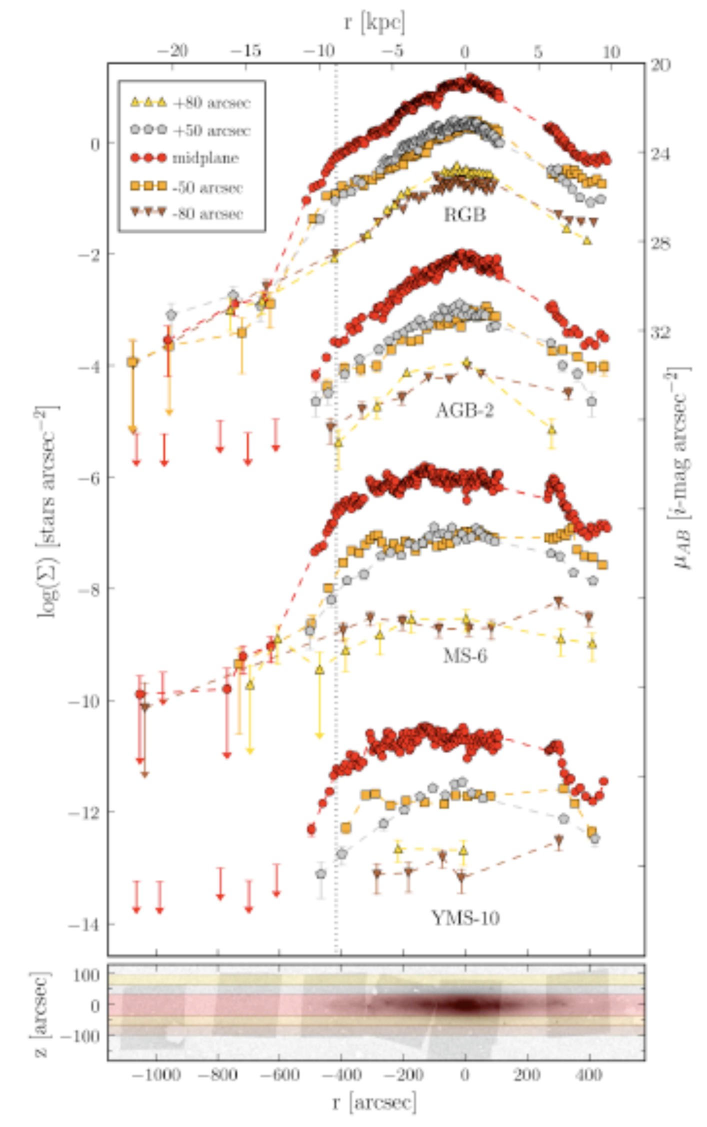


Yoachim, Rŏskar & Debattista (2010)

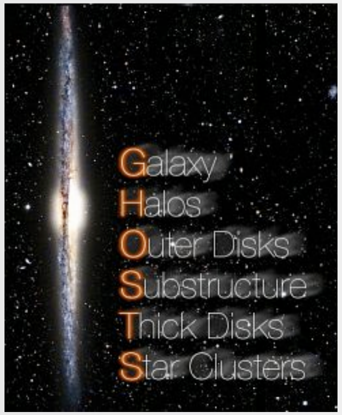


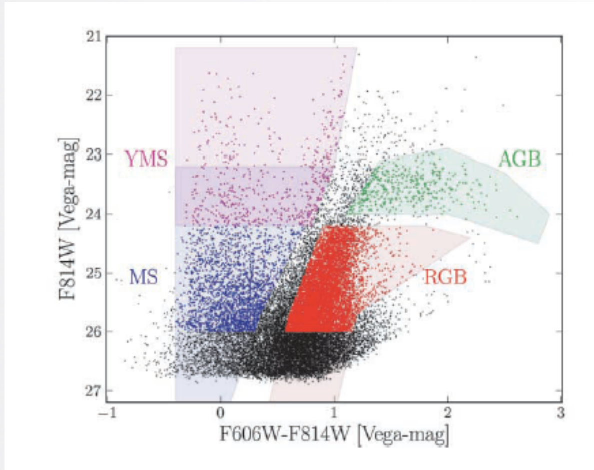


Observational facts



NGC 4244 (de Jong et al. 2007)





The position of the break does not depend on age of the stars and get shallower with distance from the mid-plane

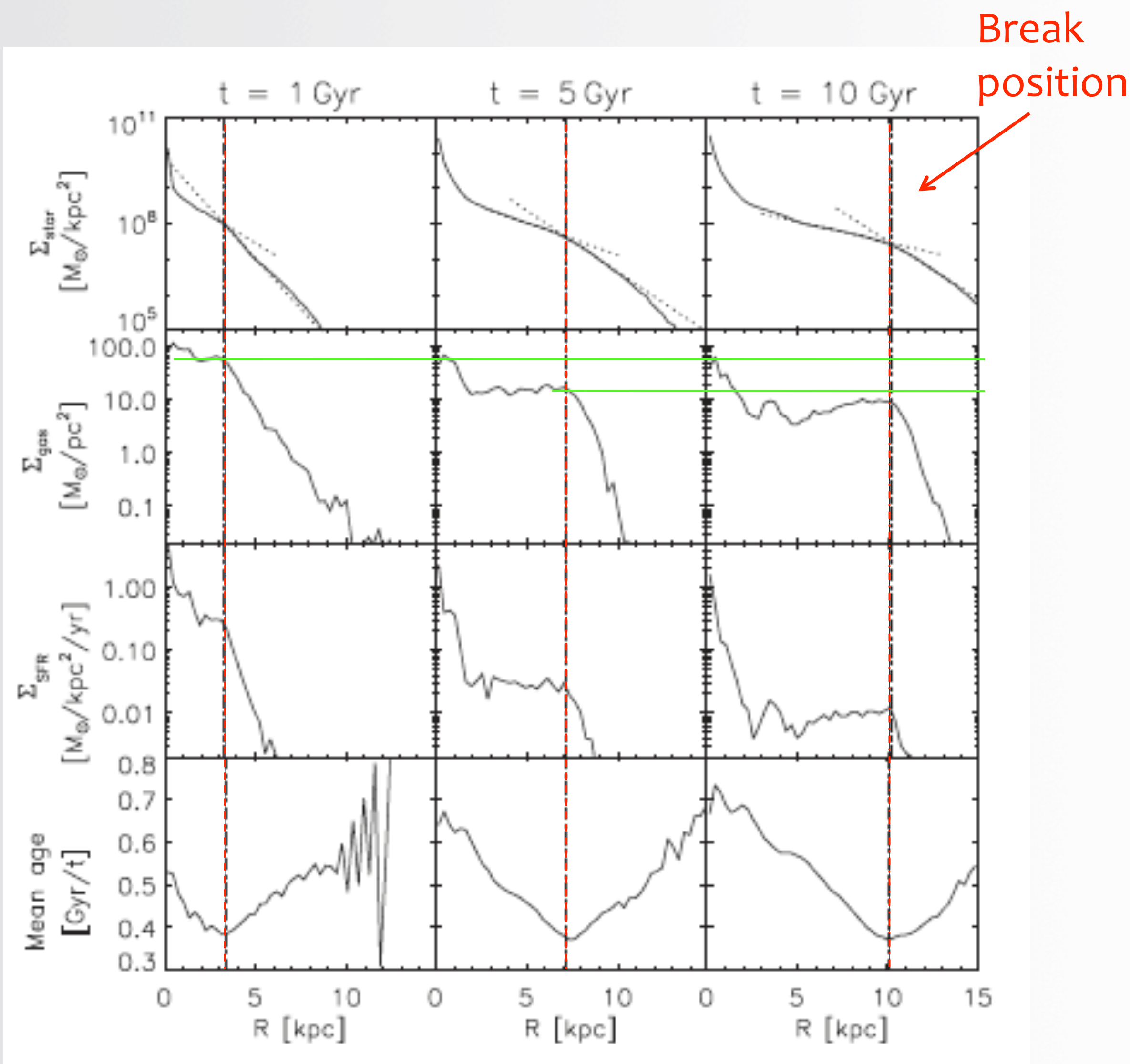
De Jong et al. (2007): " *it is very unlikely that truncations are caused by a star formation threshold alone: the threshold would have to keep the same radial position from less than 100 Myr to 10 Gyr ago."*

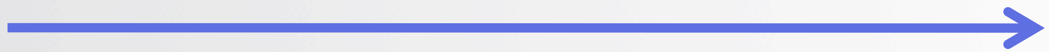
Double exponential profiles

Breaks appear at different gas surface density

Double exponentials are naturally explaining due to secular evolution

Age profile shows a U-shape as the one observed

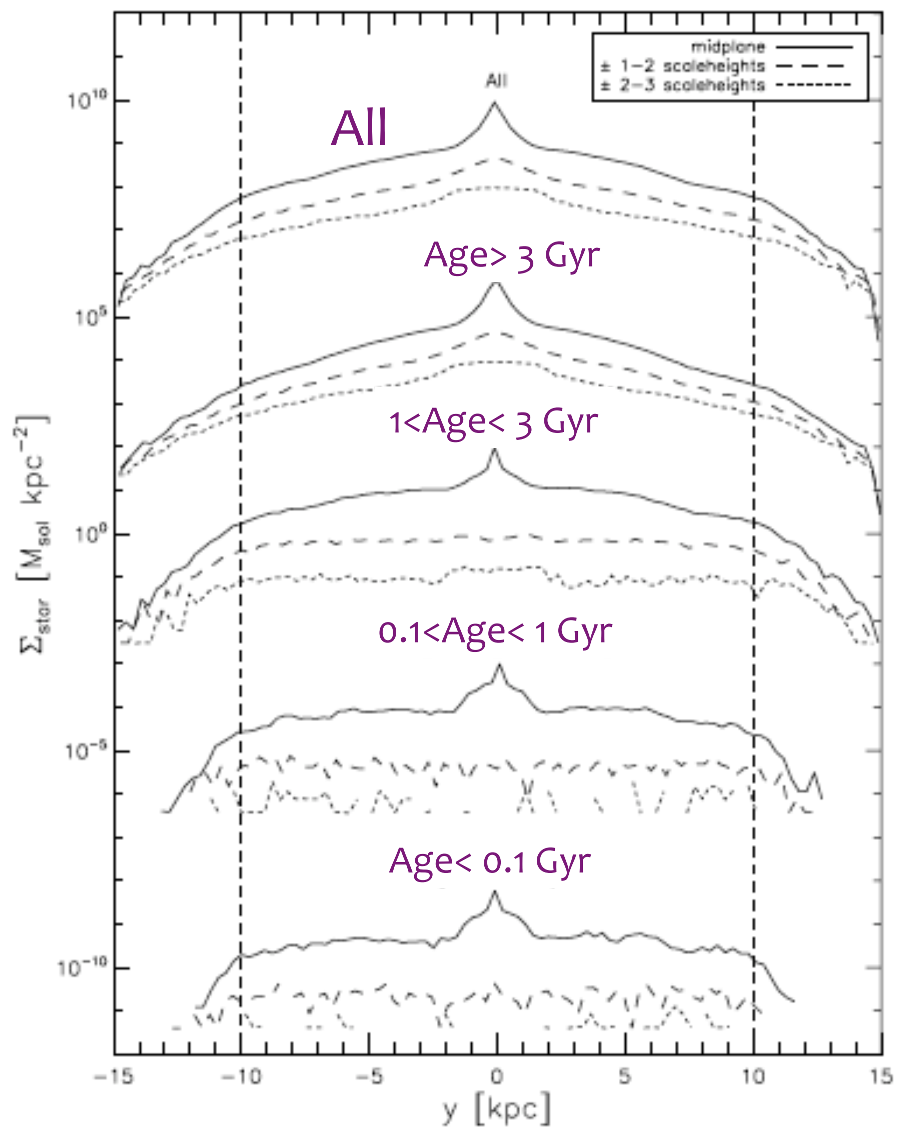




Rŏskar et al. 2008a

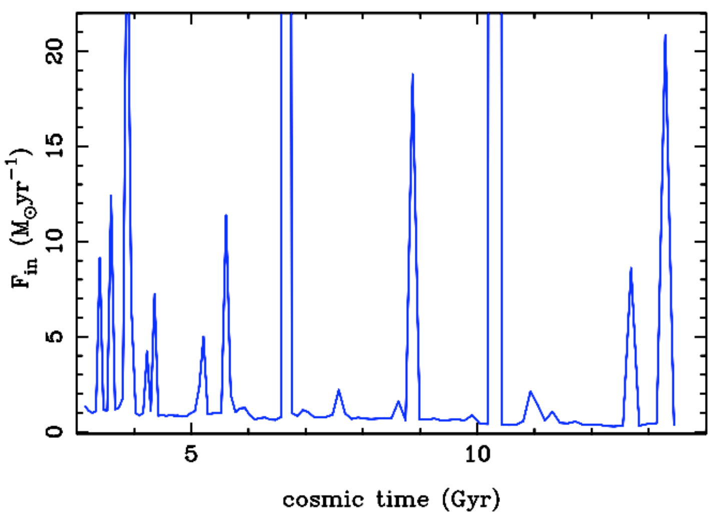
Break position is the for stars of different ages

Secular evolution is fundamental to explain the observed characteristics of the disk outskirts



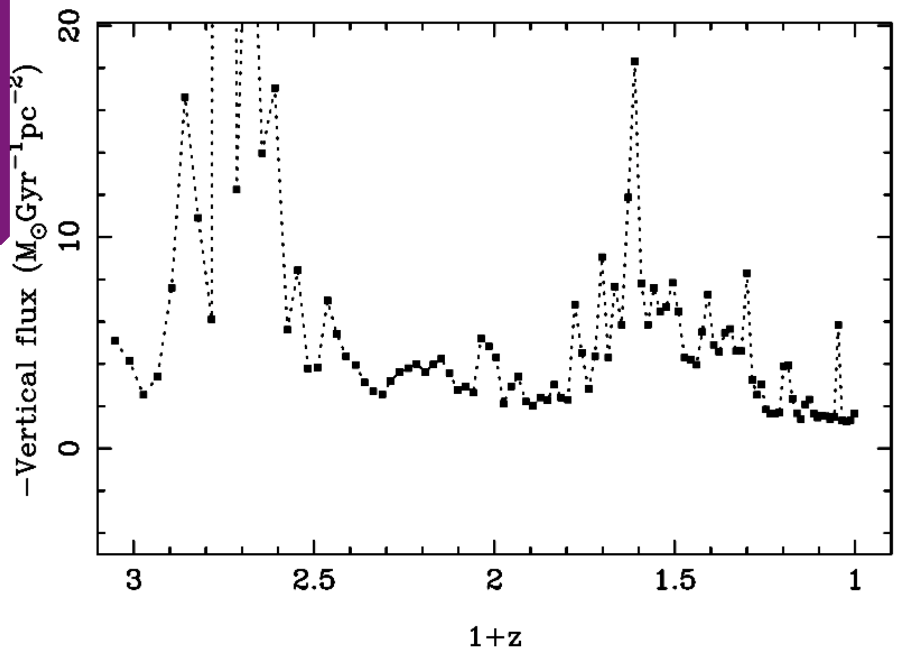
Rŏskar et al. (2008a)

Gas Accretion History (it's not smooth)



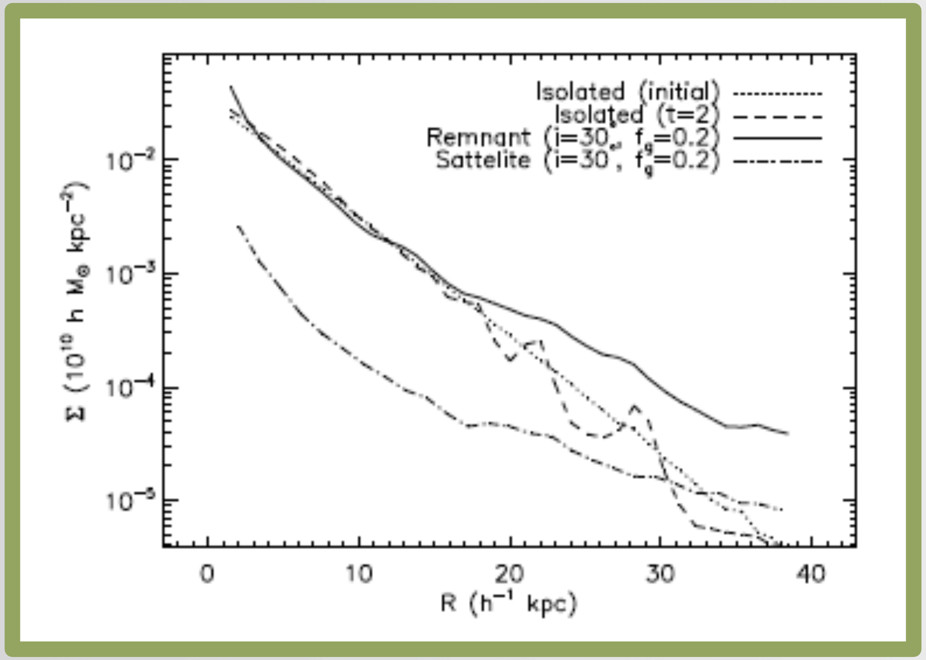
→ gas flux at R=30 kpc

vertical gas flux at z=6 kpc →



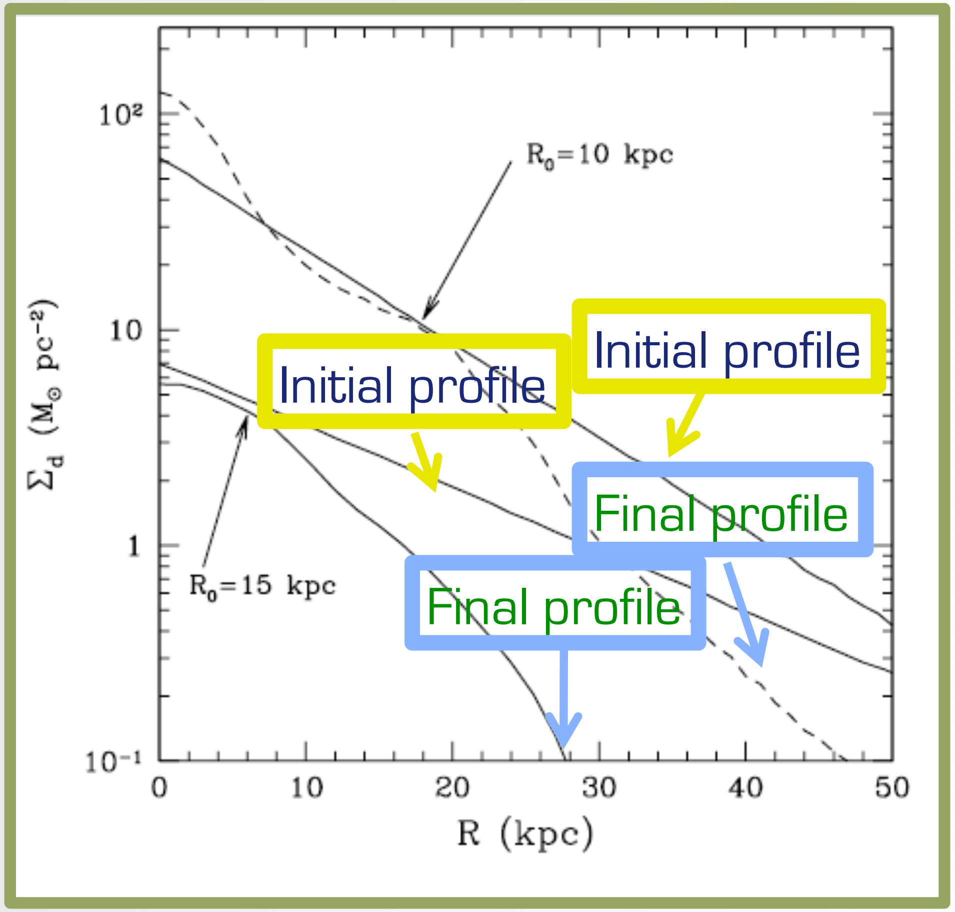
Courty et al. (in prep.)

Effects of interactions



Younger et al. (2007)

Redistribution of AM due to accreted satellites can produce Type III profiles



Gnedin (2003) (see also Kazantzidis et al.)

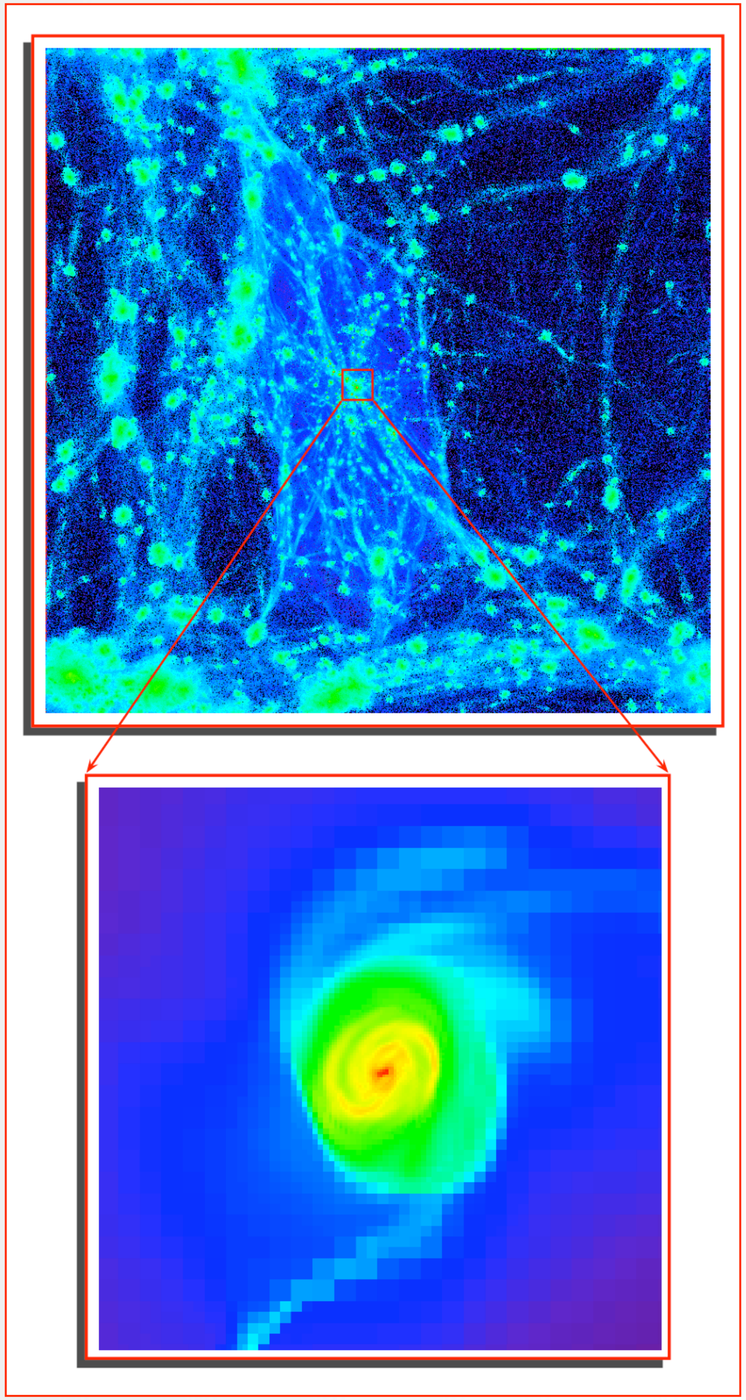
Tidal stripping by galaxy interactions can create Type II profiles

What We Did...

Using RAMSES (Teyssier 2005)

- parent cosmological dark matter simulation from *Projet Horizon*
- select halo *randomly*
- "zoom"-style re-simulation w/7 more levels w/baryonic physics (res = 400pc; $10^6\ M_\odot$) including star formation, blast-wave SN feedback parametrisation, chemical enrichment, UV background, metal dependent cooling, etc..
- repeat (touch on just 2 here, 1 of which was simulated with and without a polytropic equation of state ISM formalism)

Abadi et al (2003); Governato et al (2004,2007); Okamoto et al (2005,2008); Bailin et al (2005)



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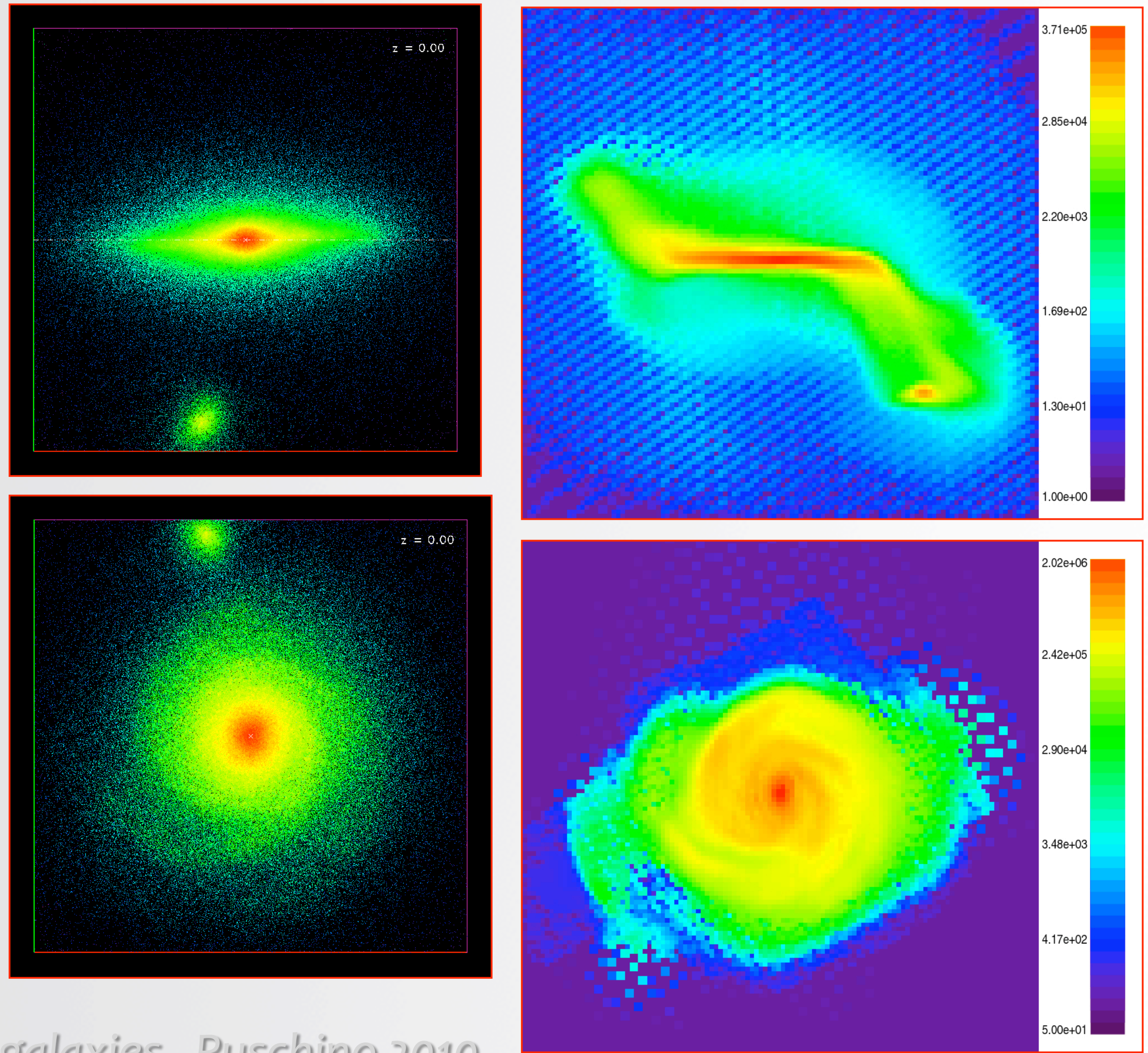
Basic characteristics

$M_{dyn}=7.6\times10^{11}M_{\odot}$

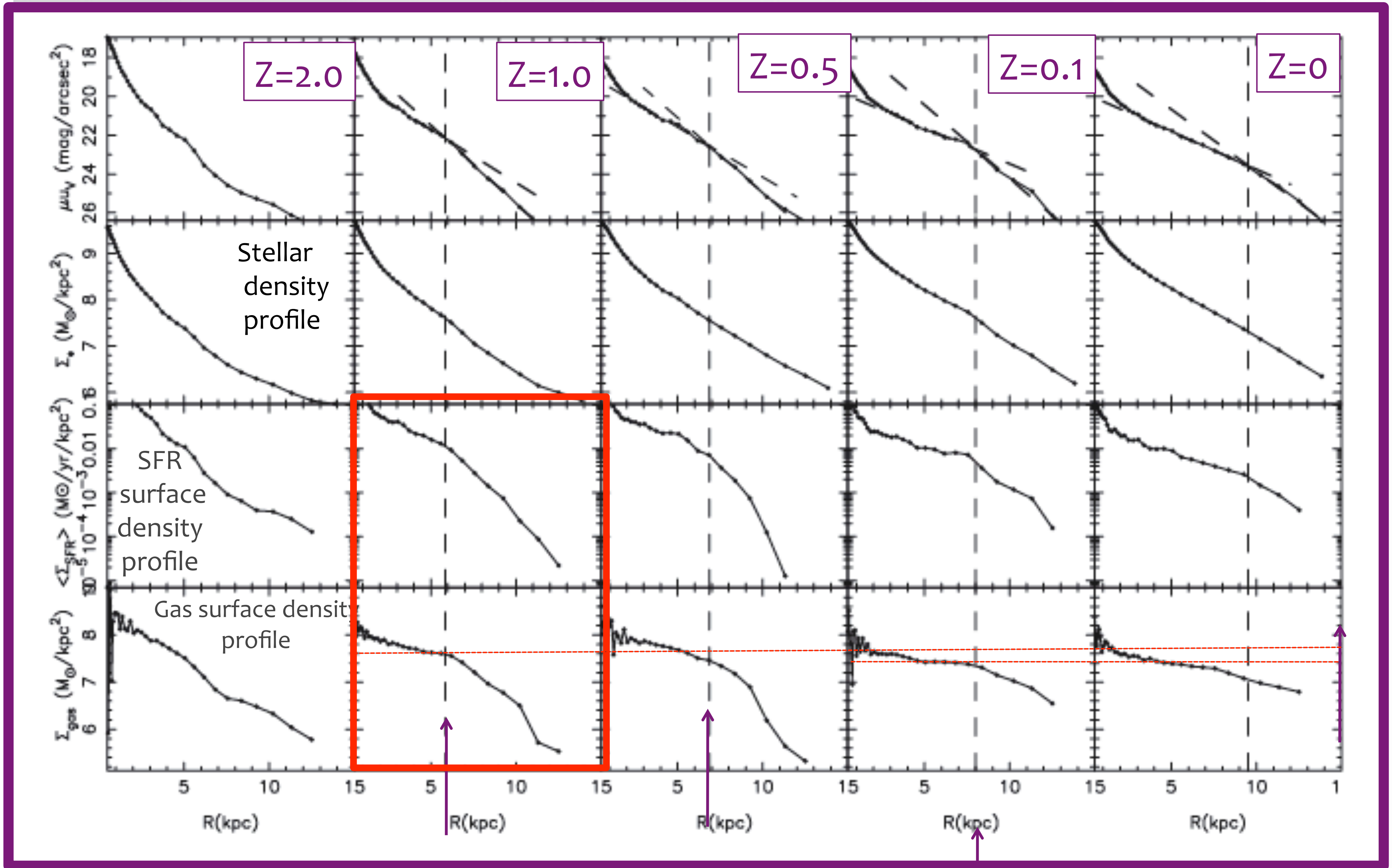
rs=3.2 kpc

B/D=0.4



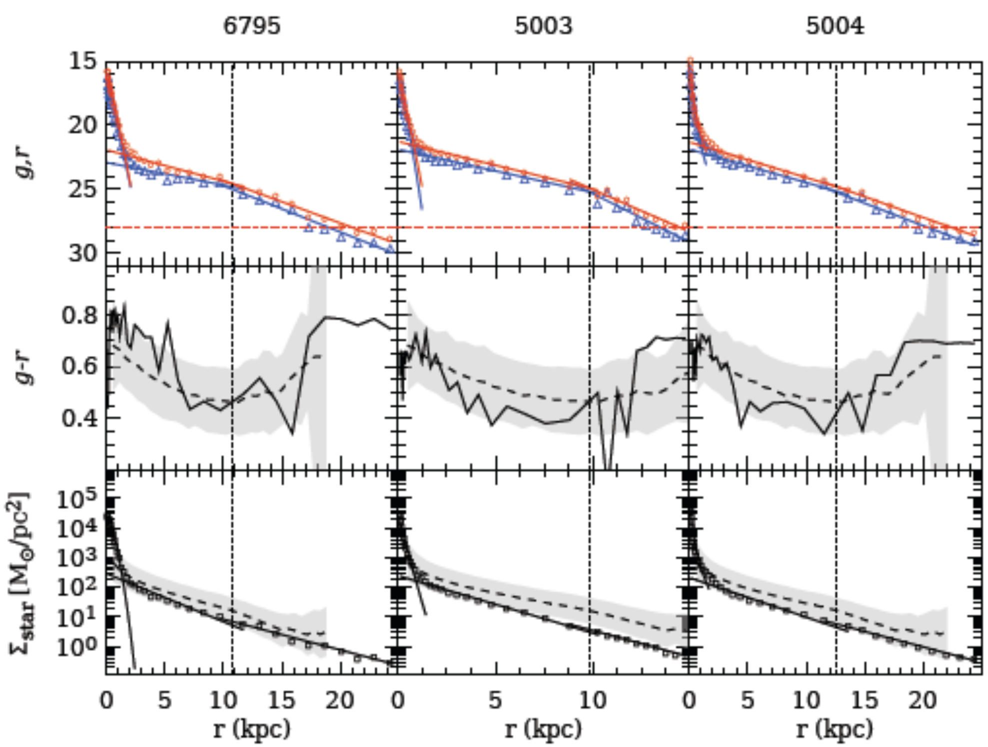
Sánchez-Blázquez et al. (2009)

Evolution of the light and density profiles

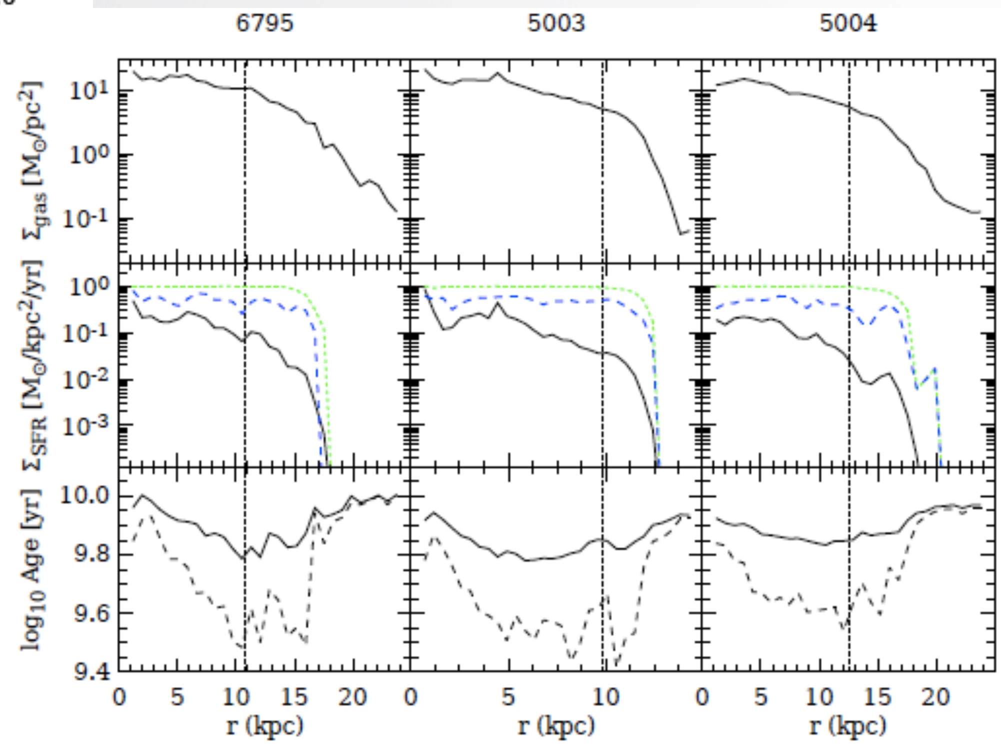


Position of the break

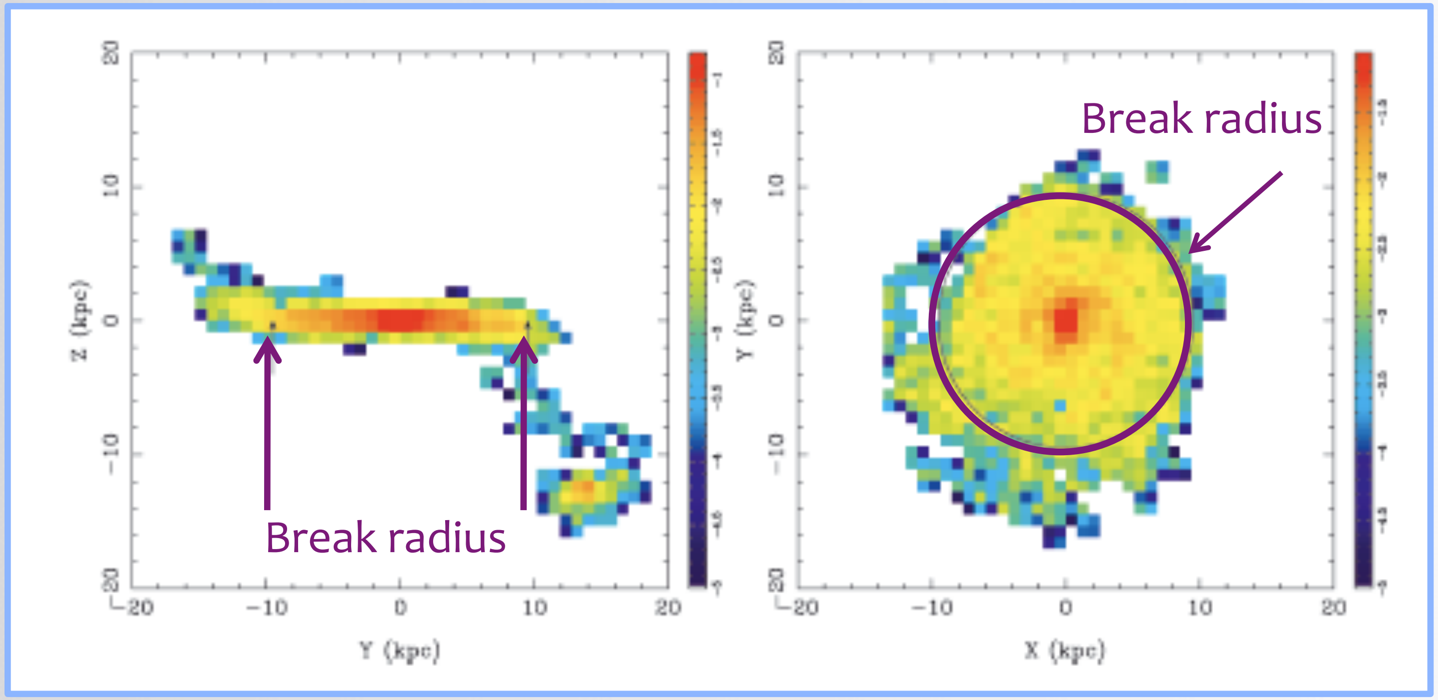
PSB et al. (2009)



Martinez-Serrano et al. (2009)



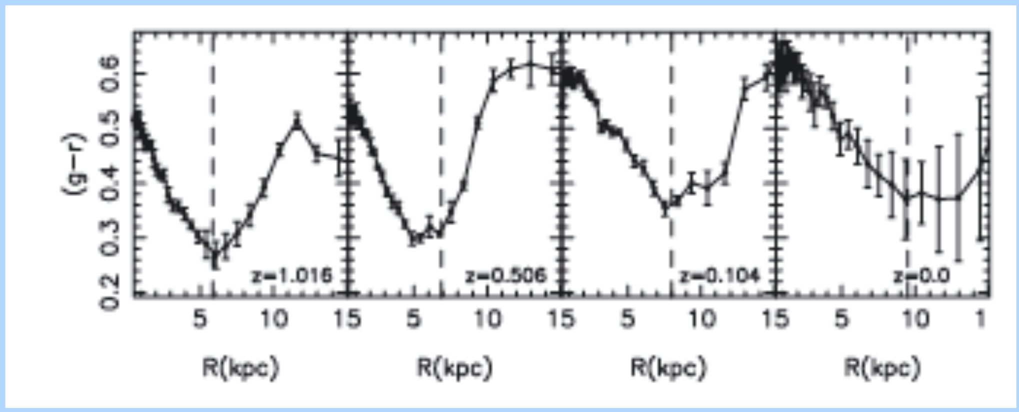
SFR maps



Sánchez-Blázquez et al. (2009)

Observational facts

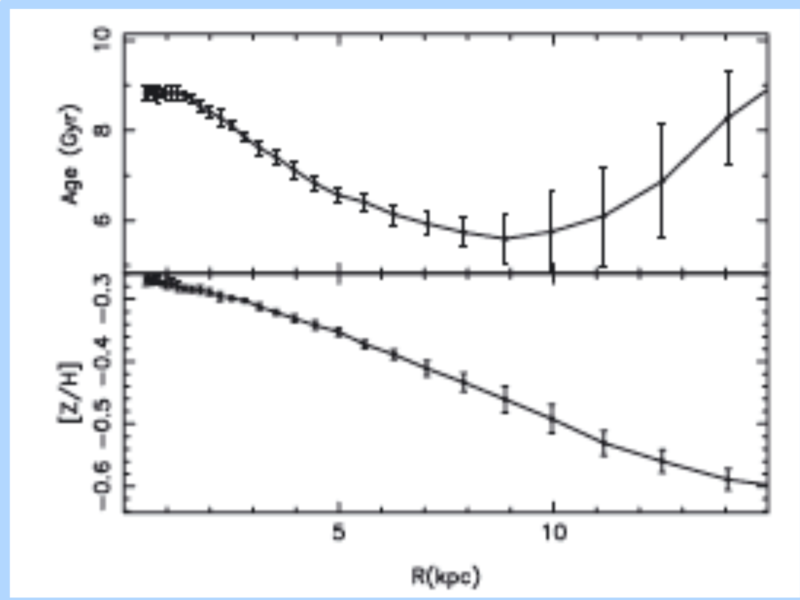
The colour profile show a U-shaped profile with the minimum at the position of the break



← Colour profile

Age profile →

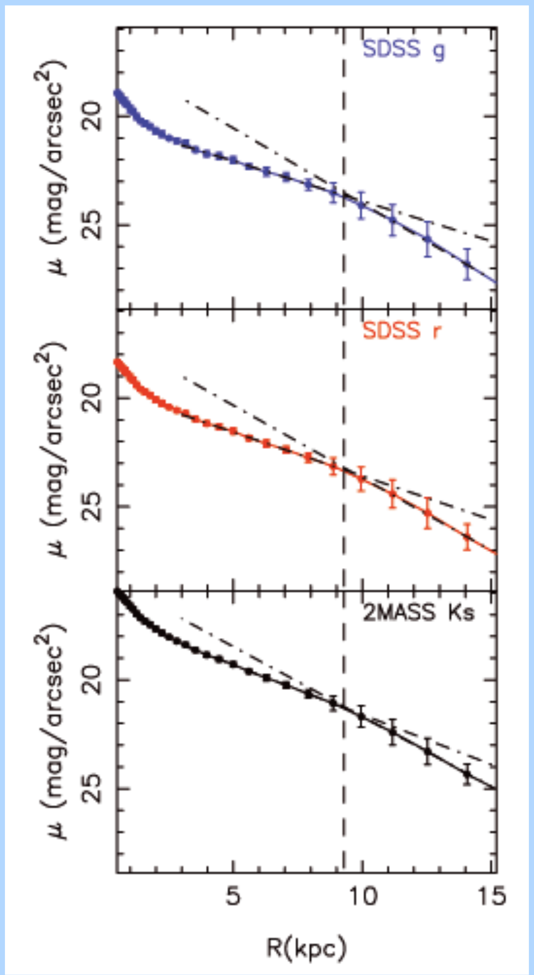
[Z/H] profile →



Sánchez-Blázquez et al. (2009)

Observational facts

The position of the break is independent of the photometric band although the break is shallower in the redder bandpasses



Sánchez-Blázquez et al. (2009)

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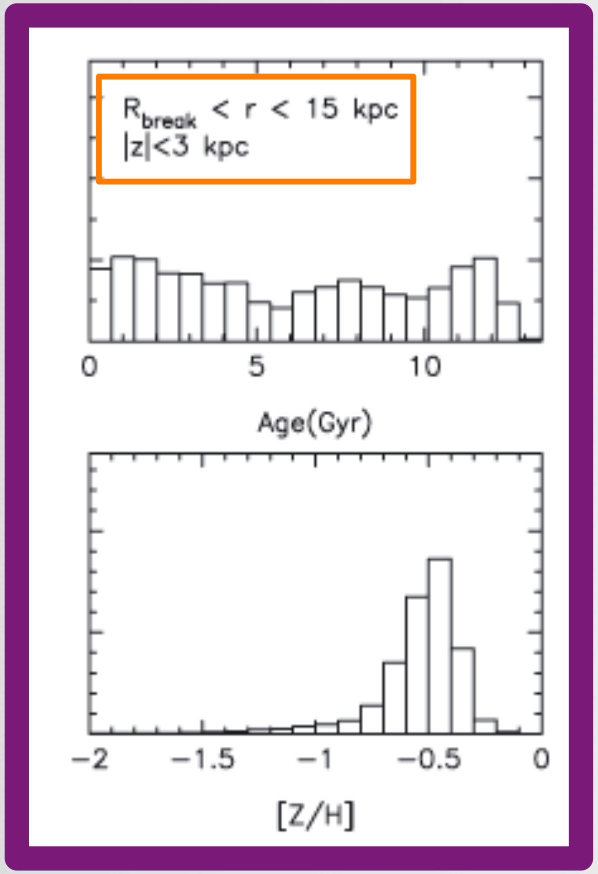
Age and metallicity distribution in the outskirts



Significant fraction of stars have ages above 8 Gyr
The peak of the metallicity is quite high.

Sánchez-Blázquez et al. (2009)

UAM
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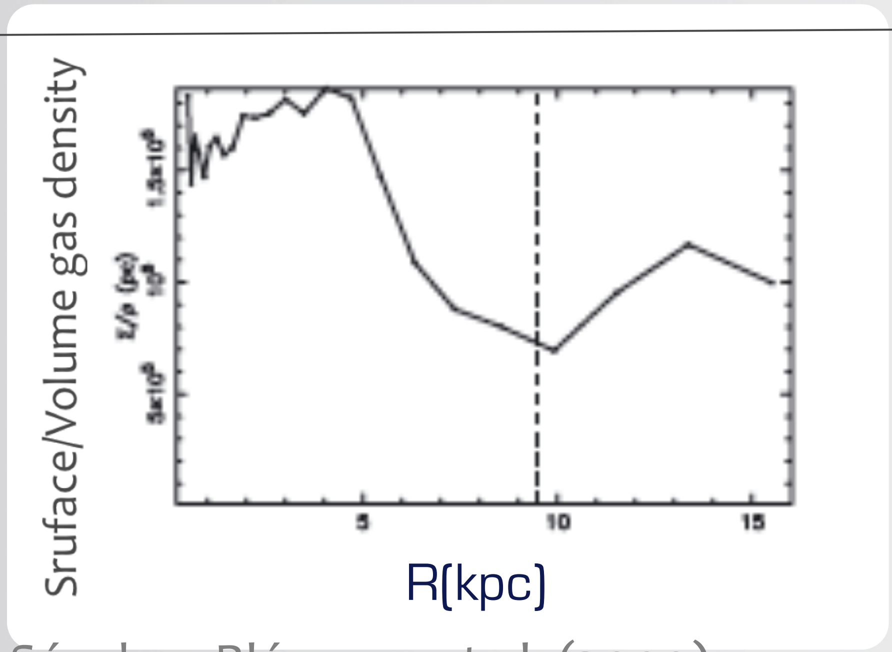
DE MADRID

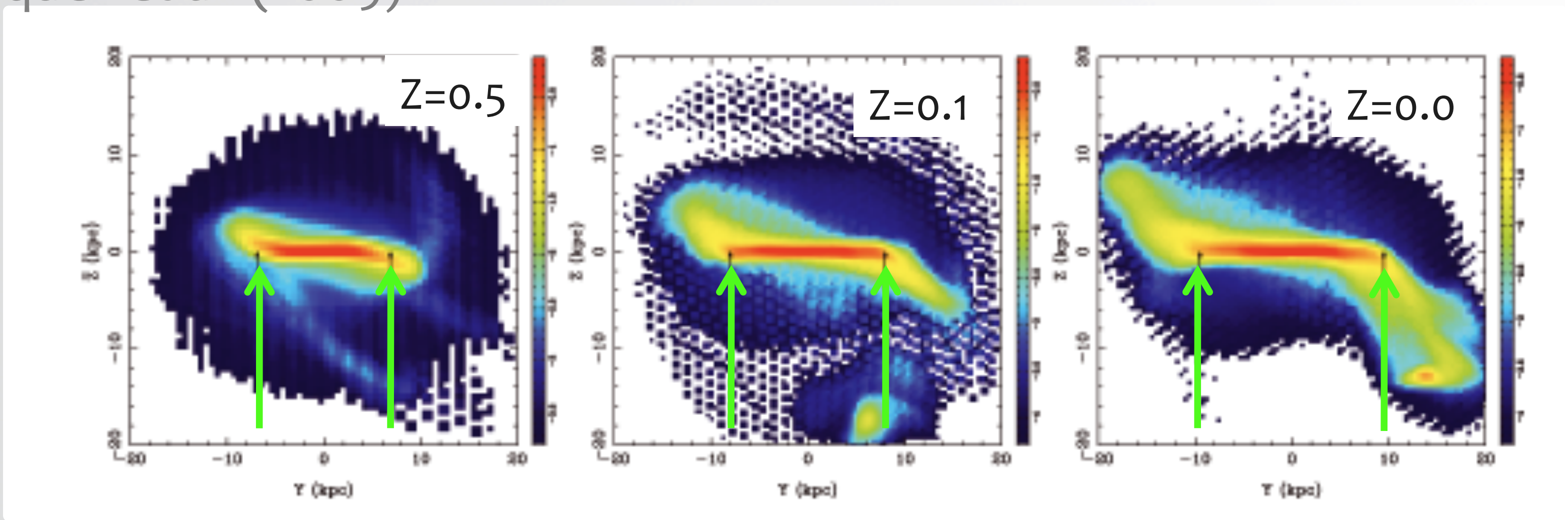
Ultimate reason for the break

It is only one simulation!



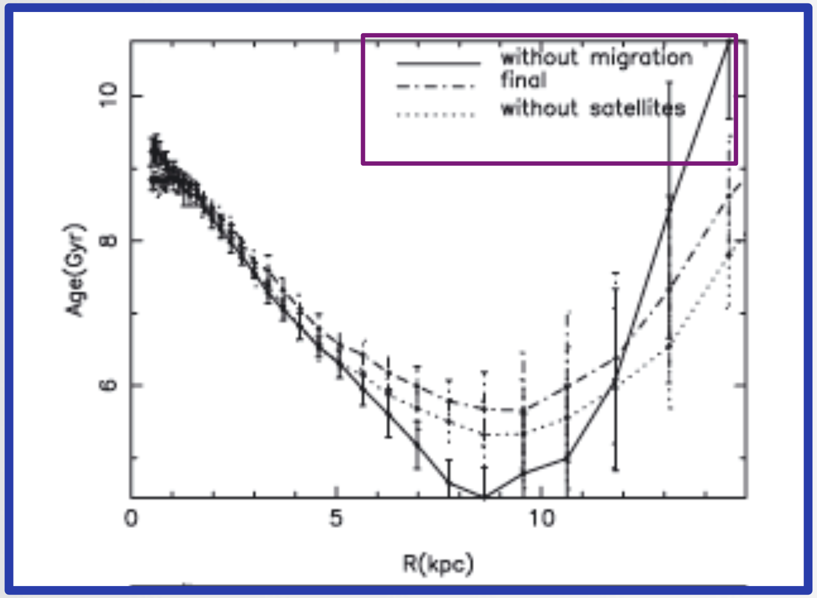
Sánchez-Blázquez et al. (2009)

Drops in the surface density of the gas at the onset of a warp have been observed in several galaxies Józsa 2007; García-Ruiz et al. 2002)



Main differences with idealised simulations

Age profile

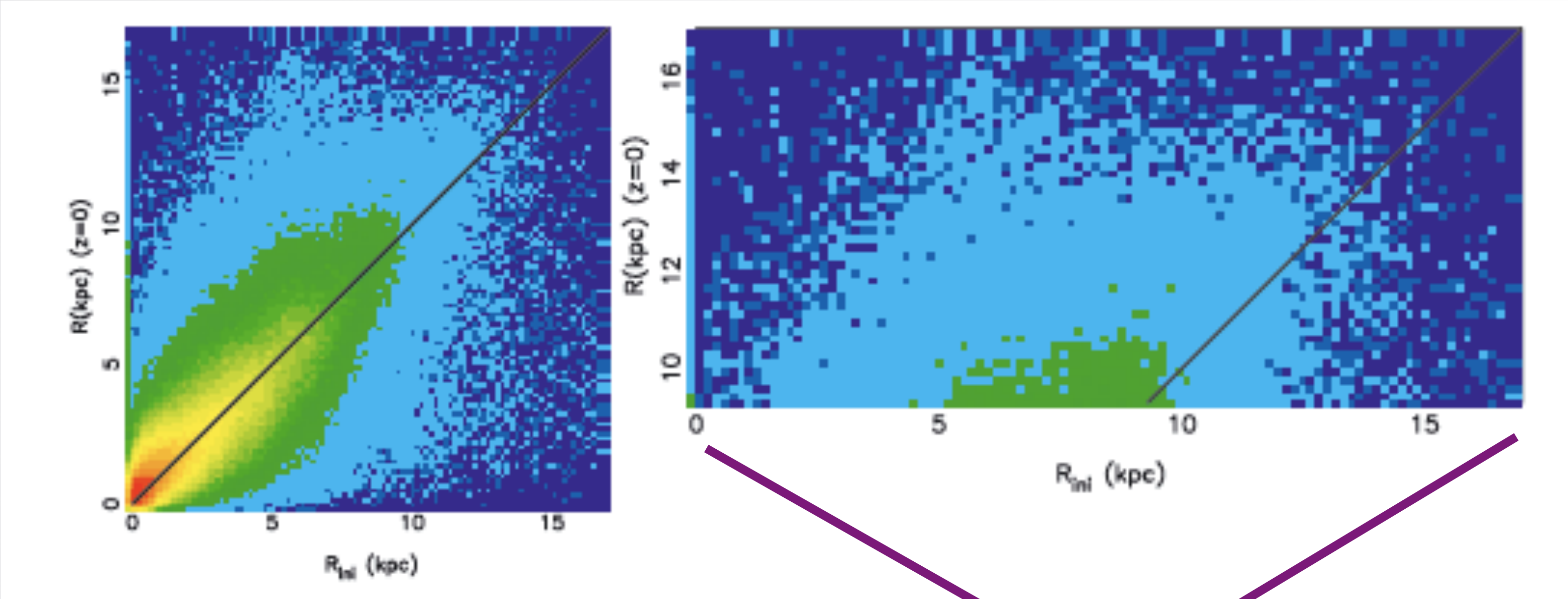


Sánchez-Blázquez et al. (2009)

Radial Migration

All stars

Stars outside the break radius



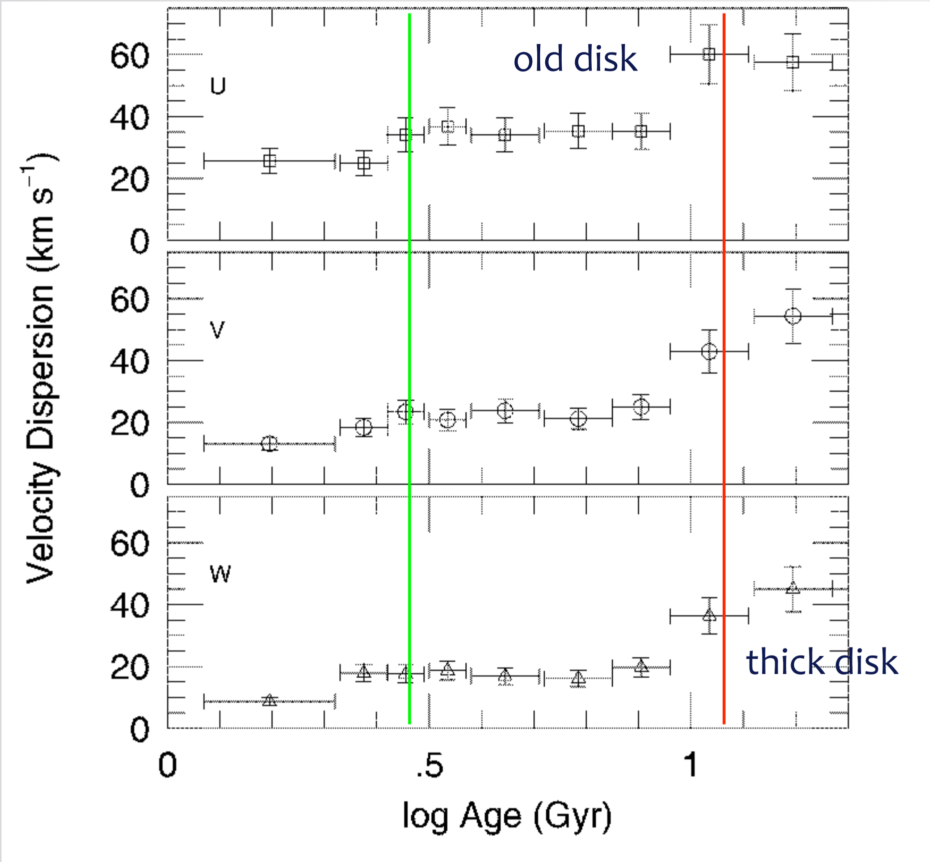
57% formed inside the R_{break}

21% formed *in situ*

22% formed at r> 15 kpc (including satellites)

$<|R_{final}-R_{inicial}|>_{disk\ stars}$=1.7 kpc, while for those r>15 kpc $<|R_{final}-R_{inicial}|>$=3.4 kpc

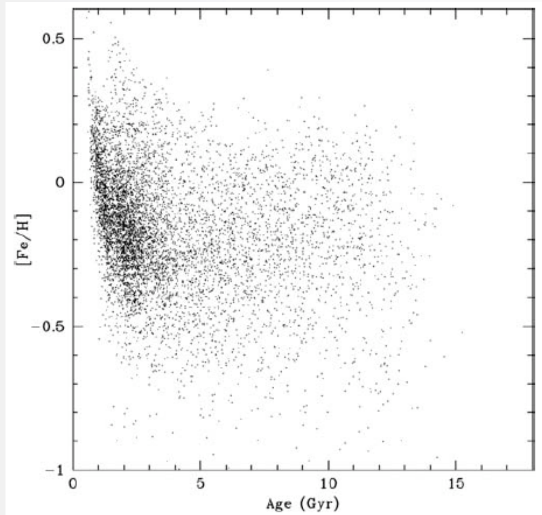
Heating in the MW



Freeman 1991; Edvardsson et al 1993; Quillen & Garnett 2000

$$\Delta \simeq \sqrt{2}\sigma_u/\kappa,$$

For old stars near the sun,
1.3 kpc



Nordstrom et al. (2004)

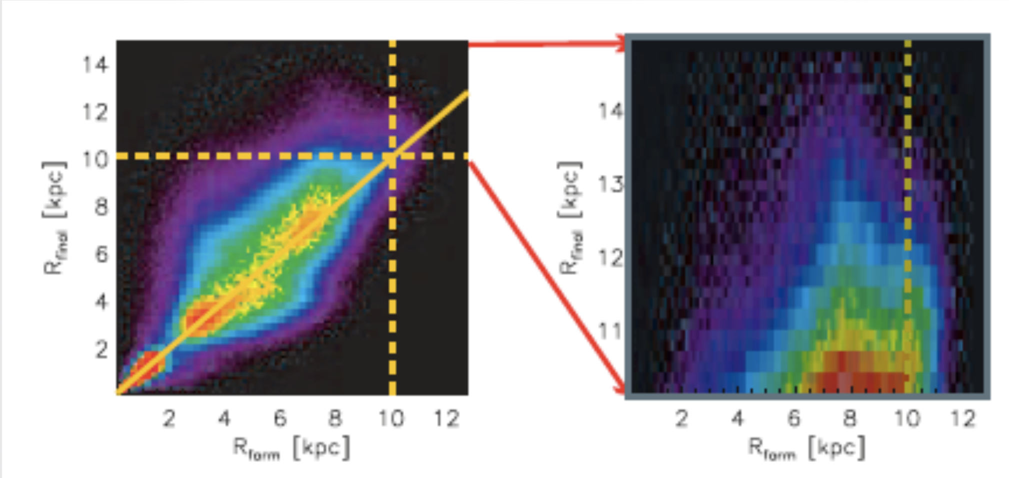
Radial migration

Sellwood & Binney (2002)

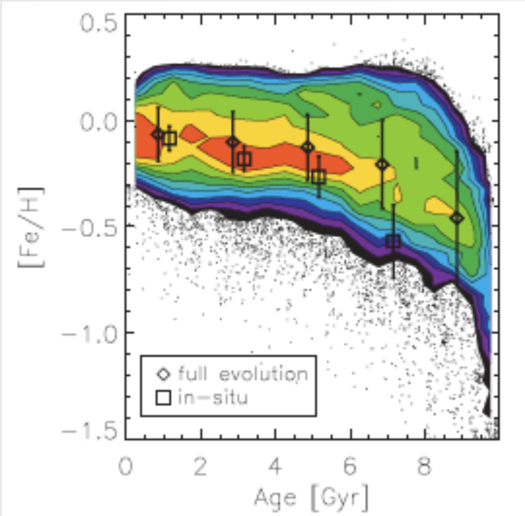
Transient spiral arms

Minchev et al. (2009)

Spiral-bar interaction



Roskar et al. (2008a)

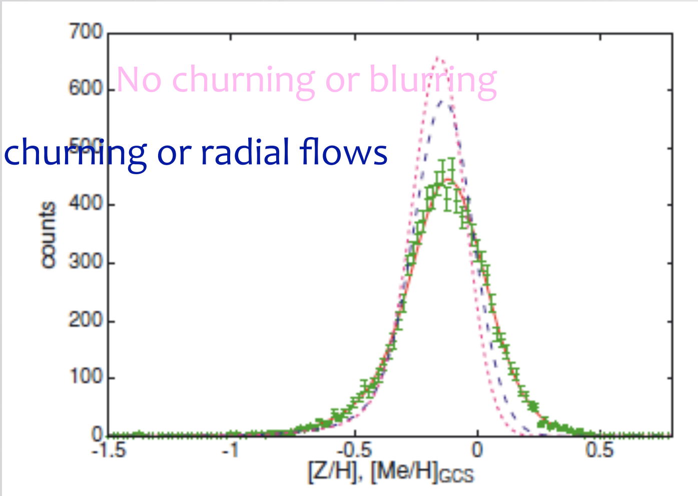


Roskar et al. (2008b)

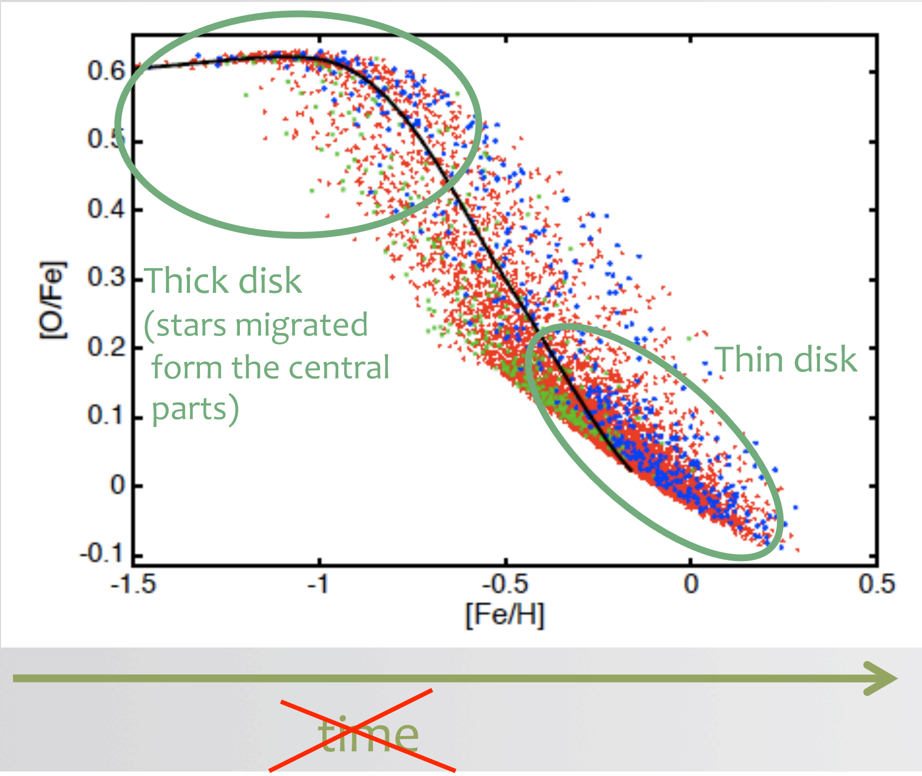
80% of star in the outskirts are In nearly circular orbits

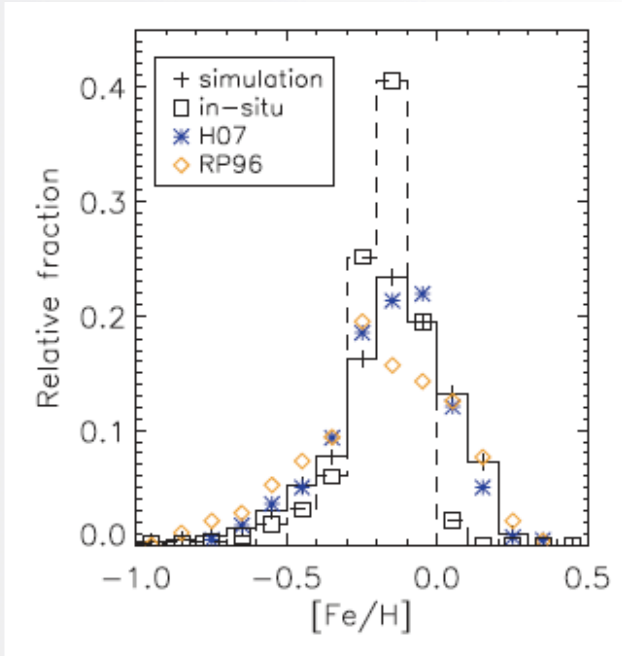
The mean radial excursion of stars in the outskirts is 3.7 kpc while the mean epicyclic radius is only 2 kpc

Consequences of secular evolution



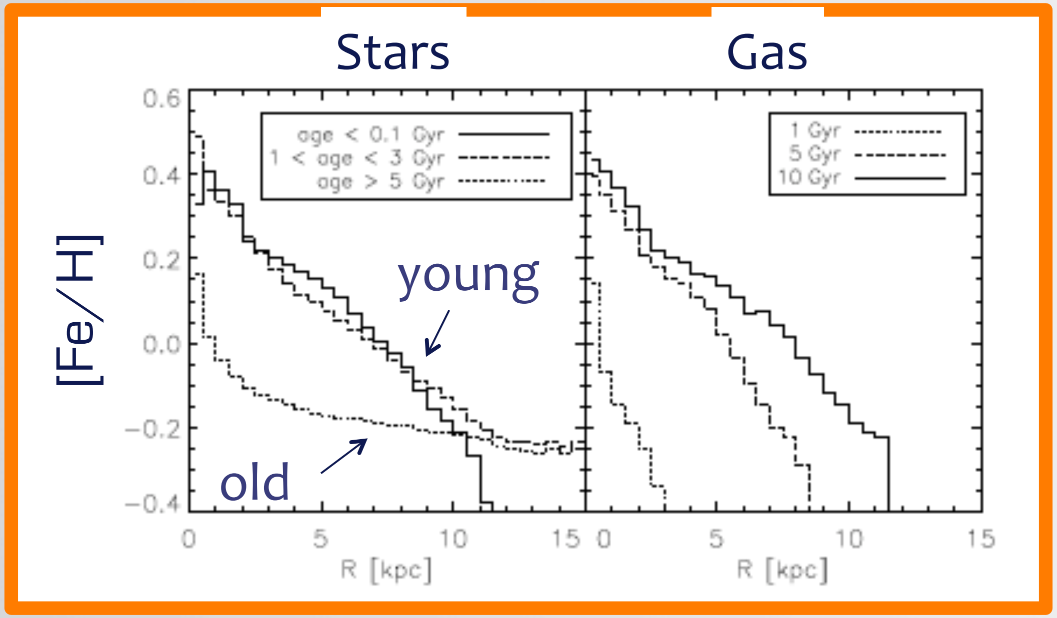
Schönrich & Binney (2009)





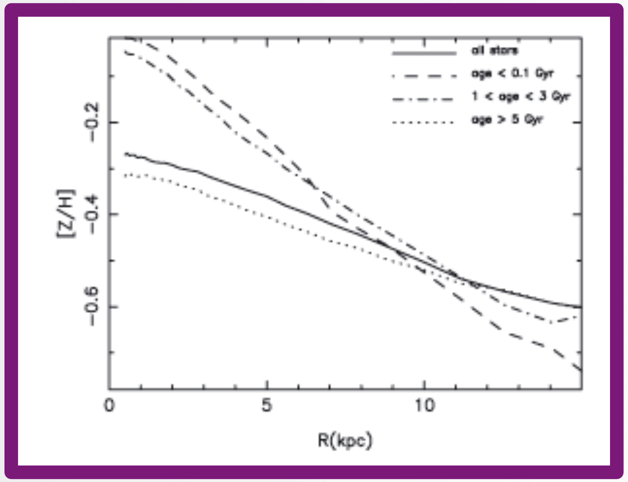
Rŏskar et al (2008b)

Consequences of secular evolution

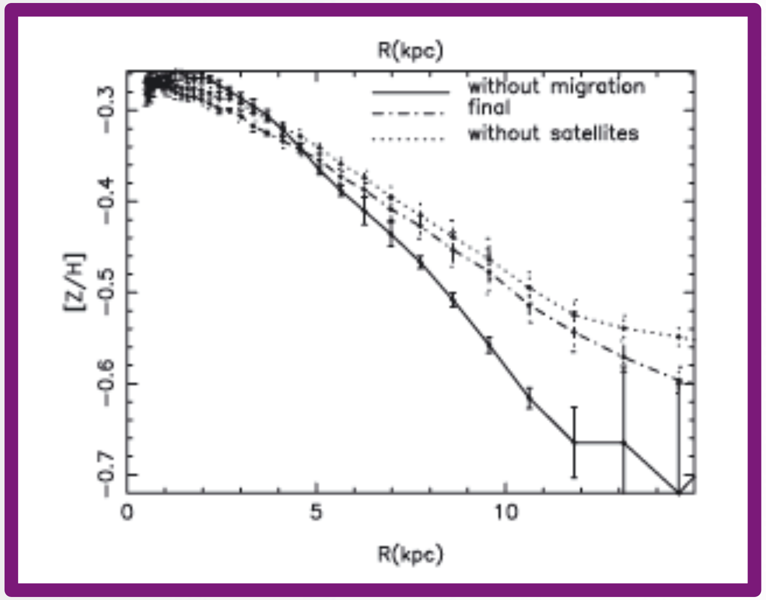


Roskar et al. (2008b)

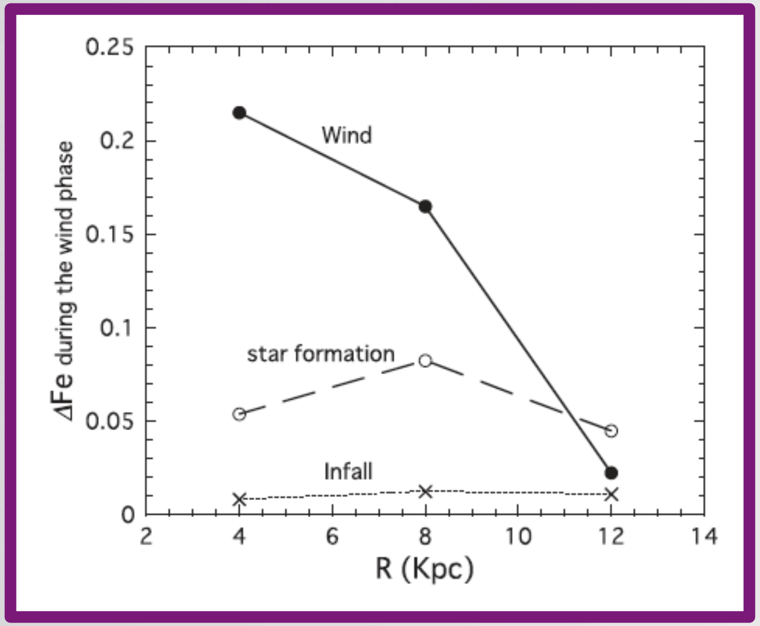
Flattening of the metallicity gradients with time



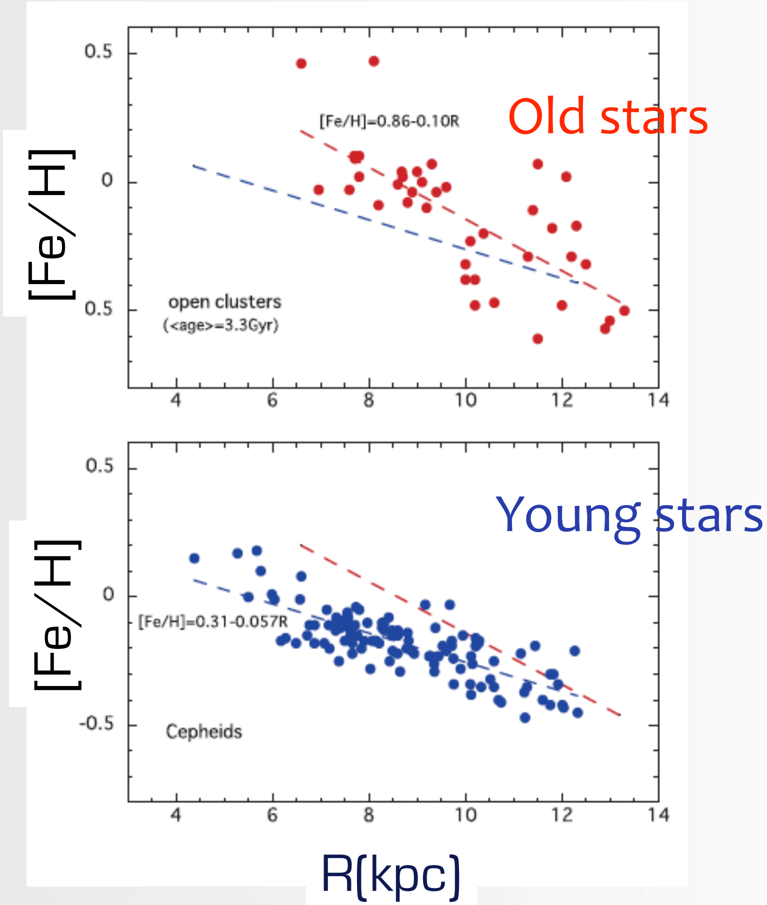
PSB et al. (2009)



Observational tests: Evolution of the metallicity gradients

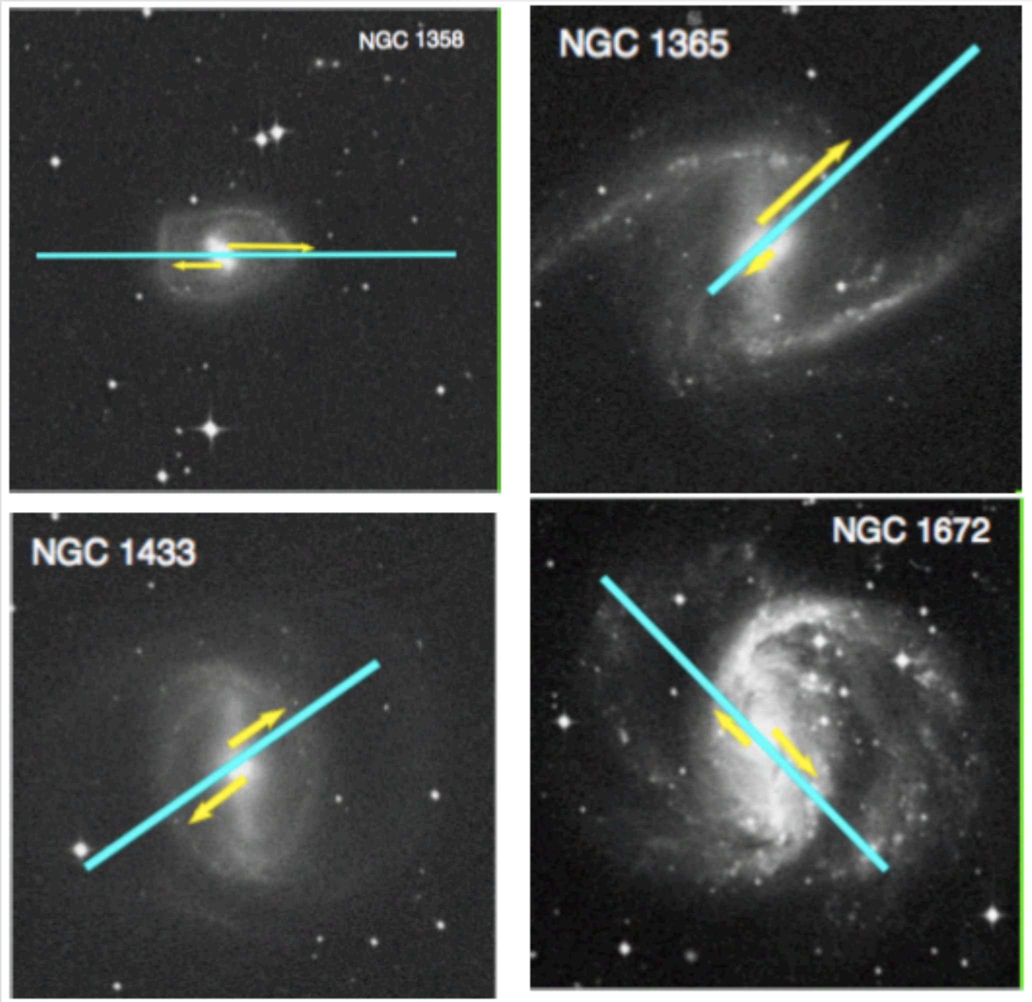


Wind+Infall model



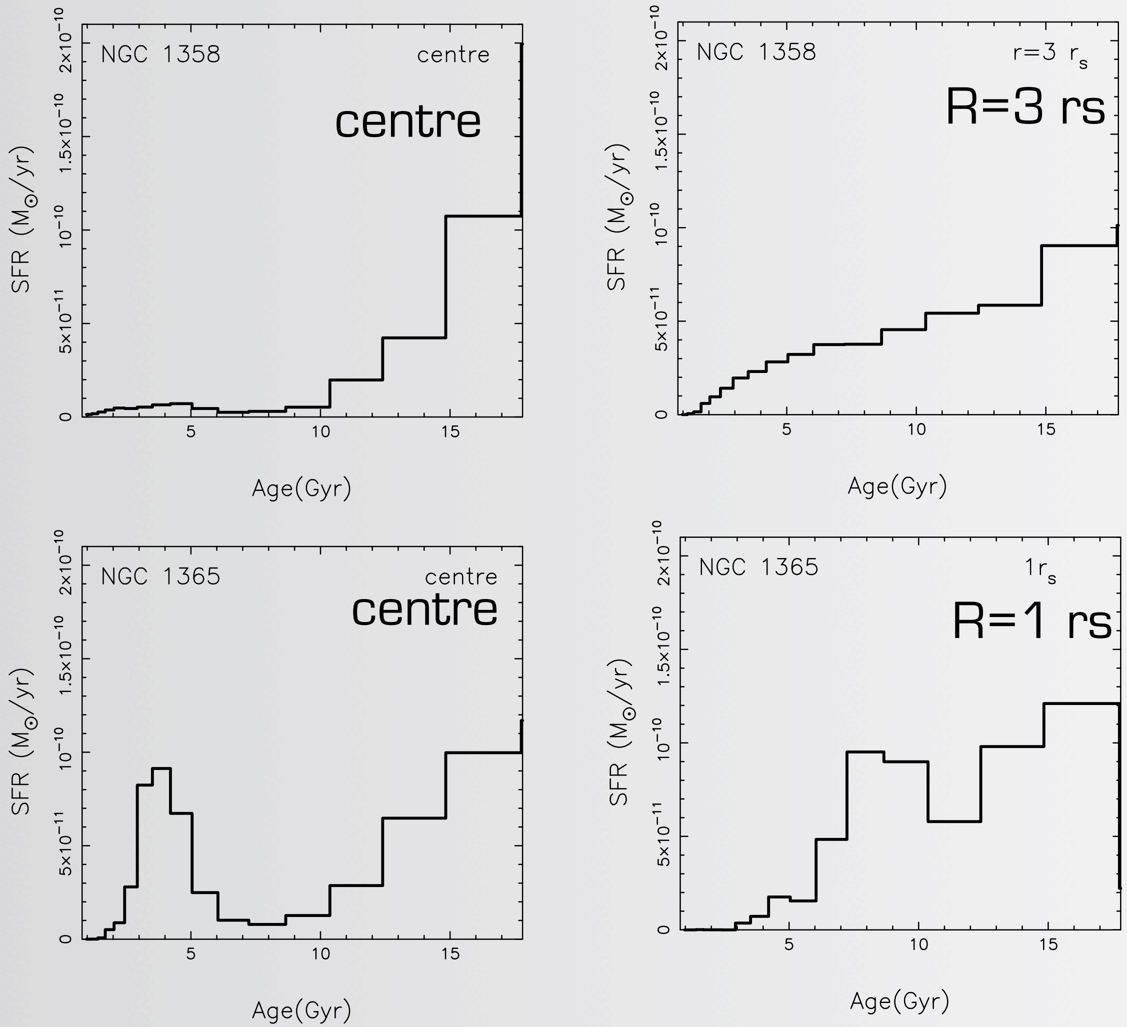
Tjusimoto et al. (2010) (see also Friel et al. 2002; Chen et al. 2003; Daflon & Cunha 2004; Magrinin et al. 2009; Maciel et al. 2003, 2006, 2007)

Observations of disc galaxies



Sánchez-Blázquez et al. (2010, in prep)

Star formation Histories: examples

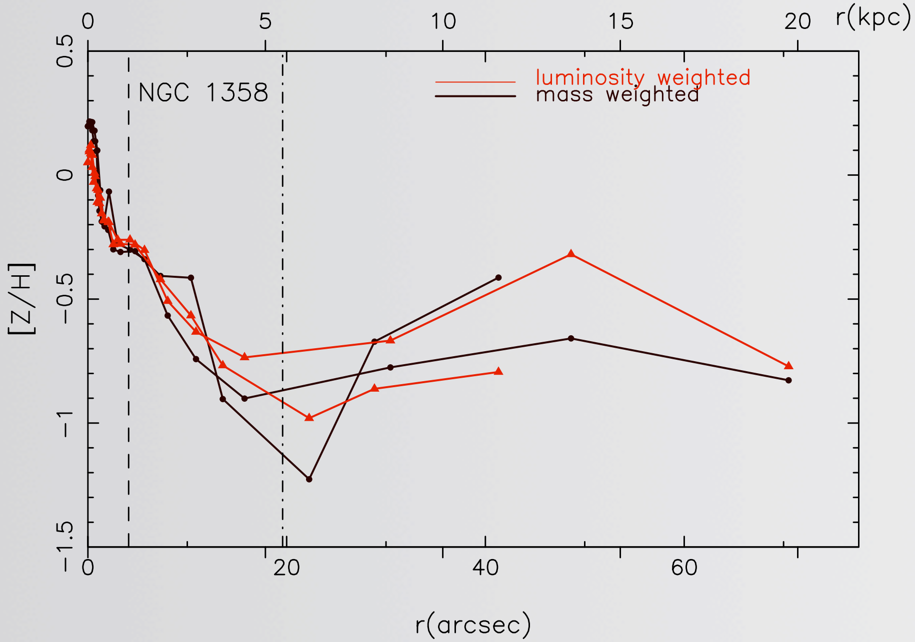


STECKMAP
(Ocvirk et al. (2006ab)

SFR[$M_\odot$/yr]

http://astro.u-strasbg.fr/~ocvirk/STECKMAP

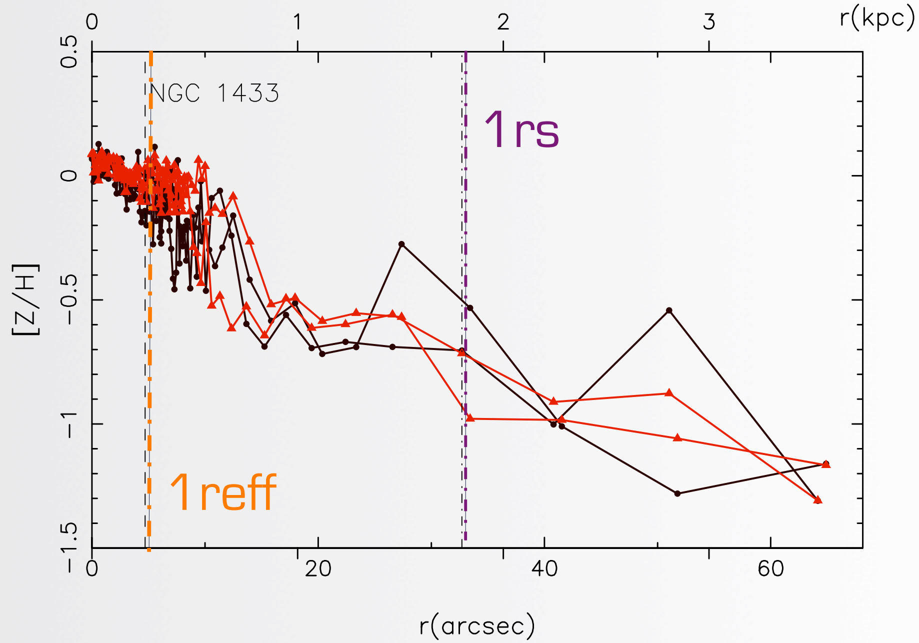
Mass and Luminosity-weighted [Z/H] gradients



Luminosity weighted: more sensitive to young populations

Mass weighted: more sensitive to old stars

Metallicity gradient does not seem to evolve



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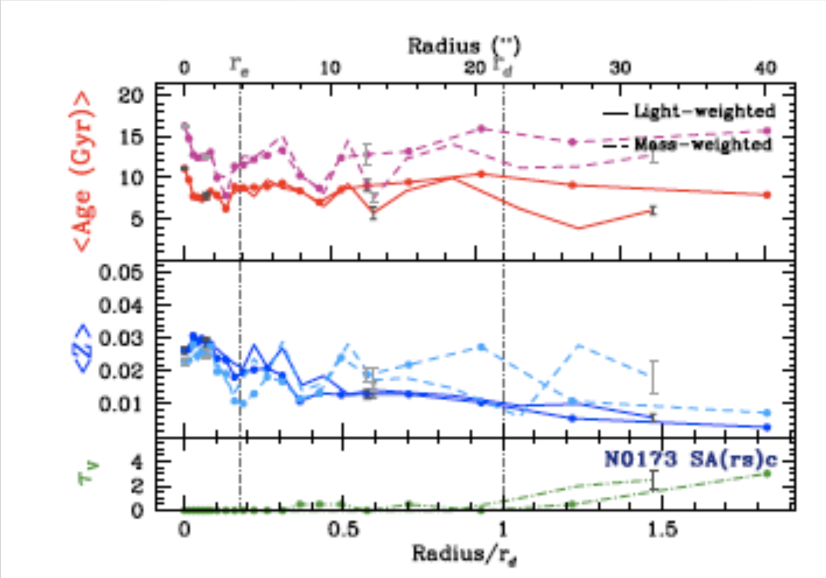
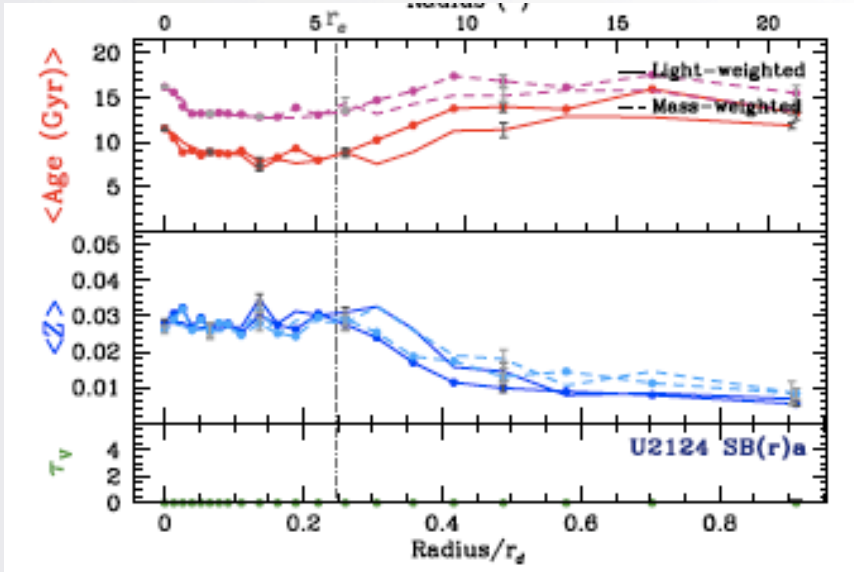
Mass and luminosity-weighted metallicity gradients



MacArthur et al. (2009)



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Summary

- The origin of the outer disk structures remains a puzzle but secular evolution processes seem to be necessary to explain some observational results.

- Combination of both, idealised, high resolution simulations with fully cosmological simulations are necessary to understand the physical processes affecting the surface brightness profiles of disk galaxies. Statistical samples of simulations will help up us to understand the ultimate causes of the break.

- Stellar population studies (abundances gradients) are fundamental to understand the secular evolution in disk galaxies. Evolution of the metallicity gradient with time may give a definitive test for the mixing mechanisms.