The outer structure of disc galaxies

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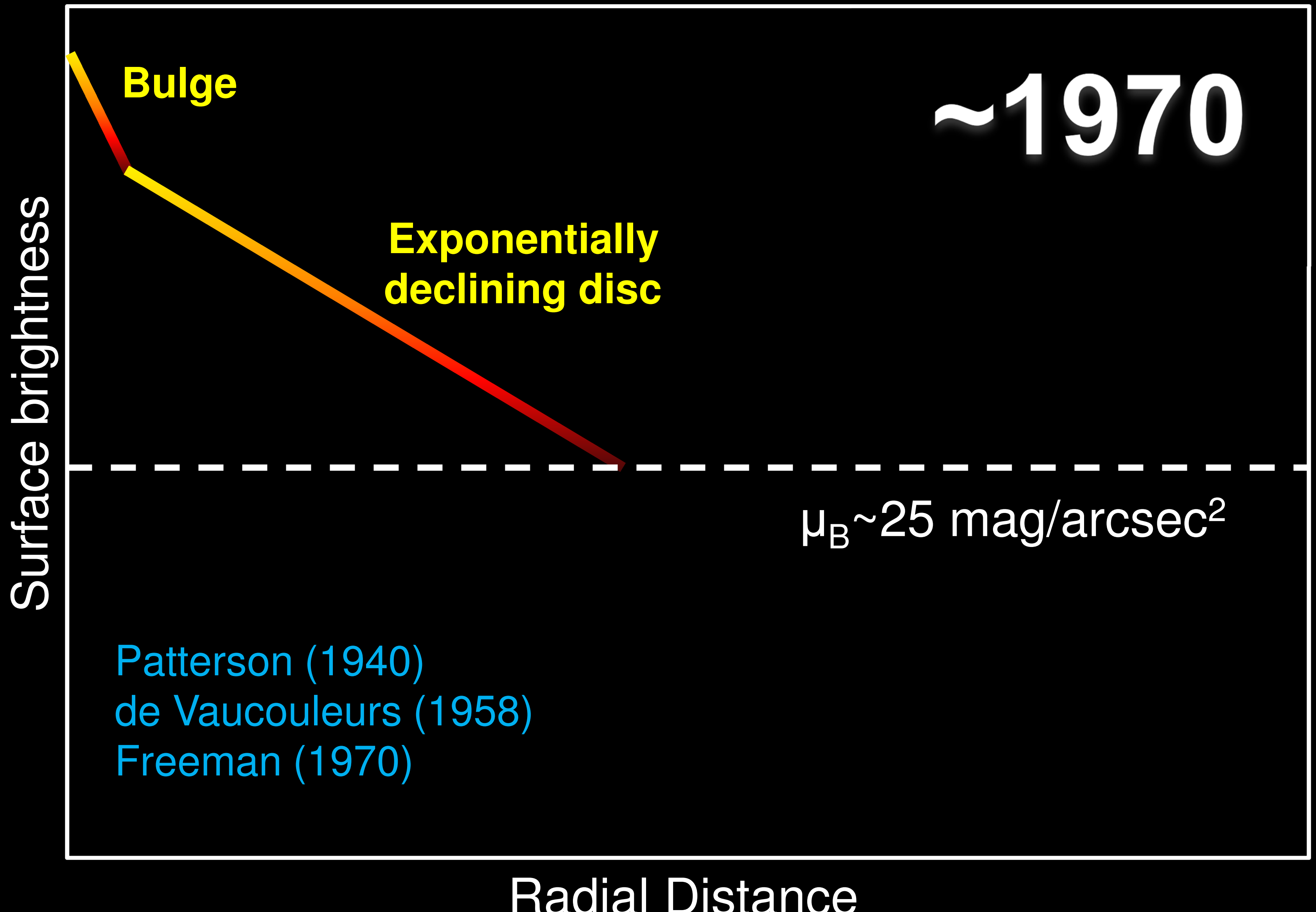
The shape of the disc galaxies: a simplified history



Patterson (1940)
de Vaucouleurs (1958)
Freeman (1970)

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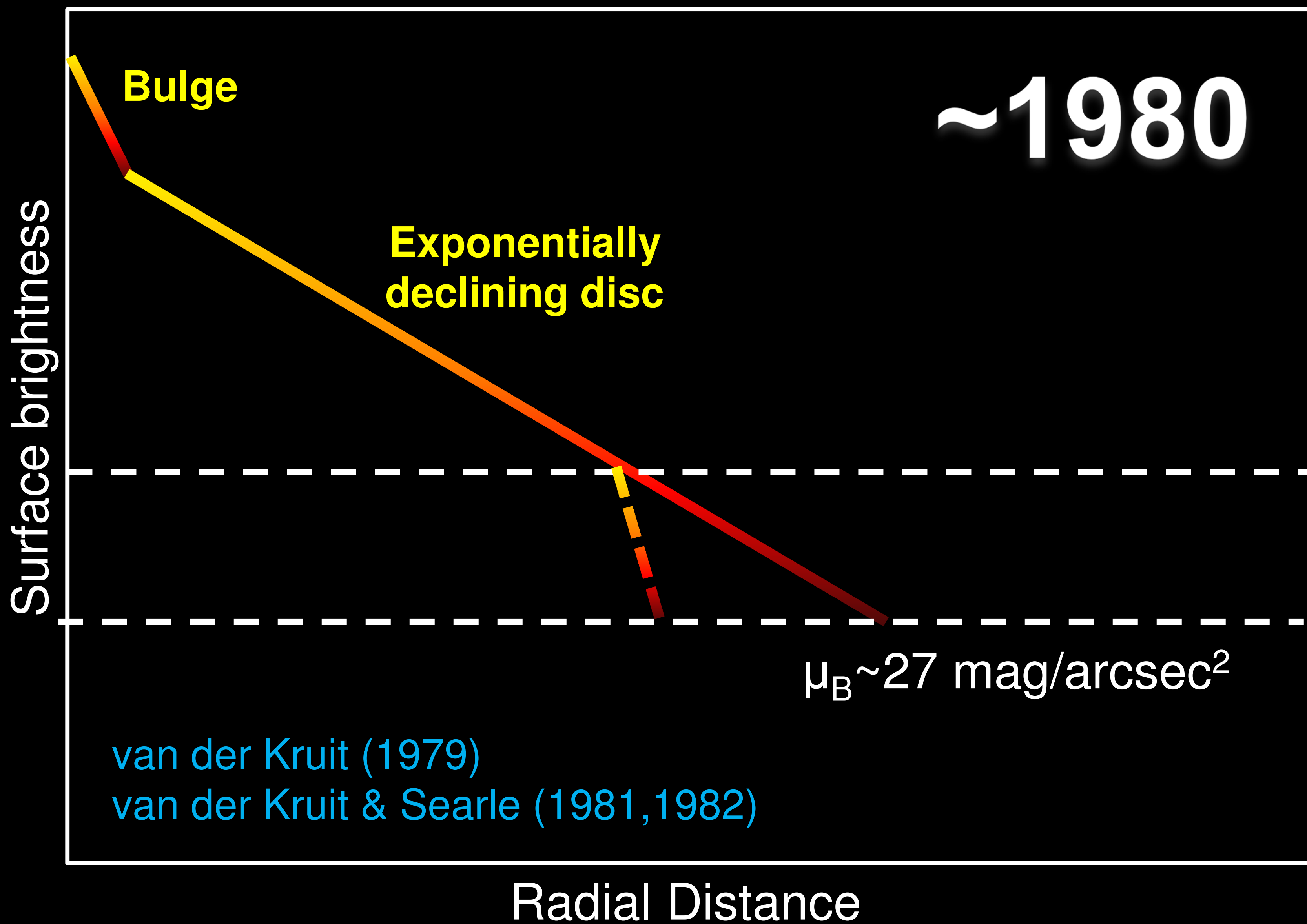

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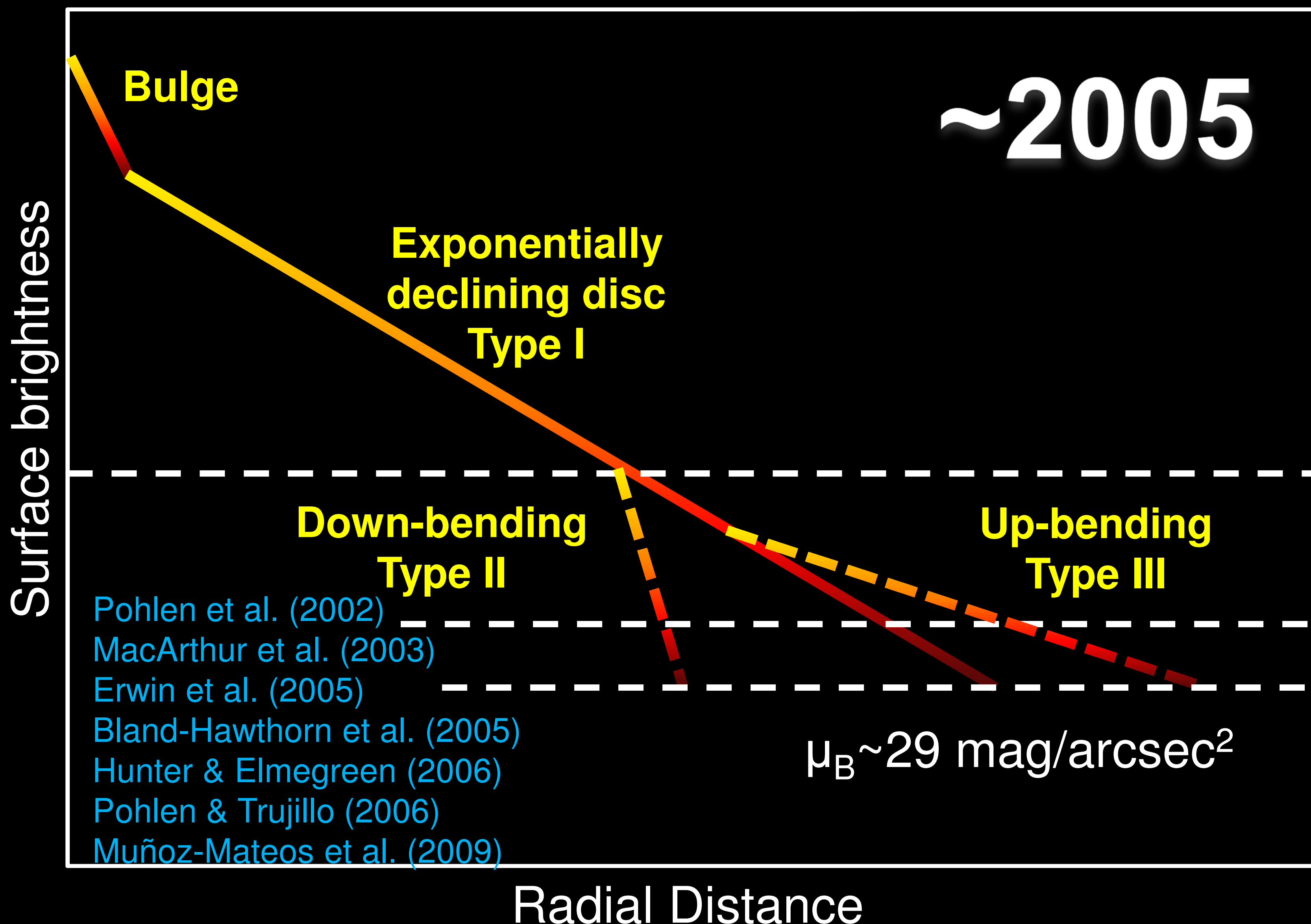

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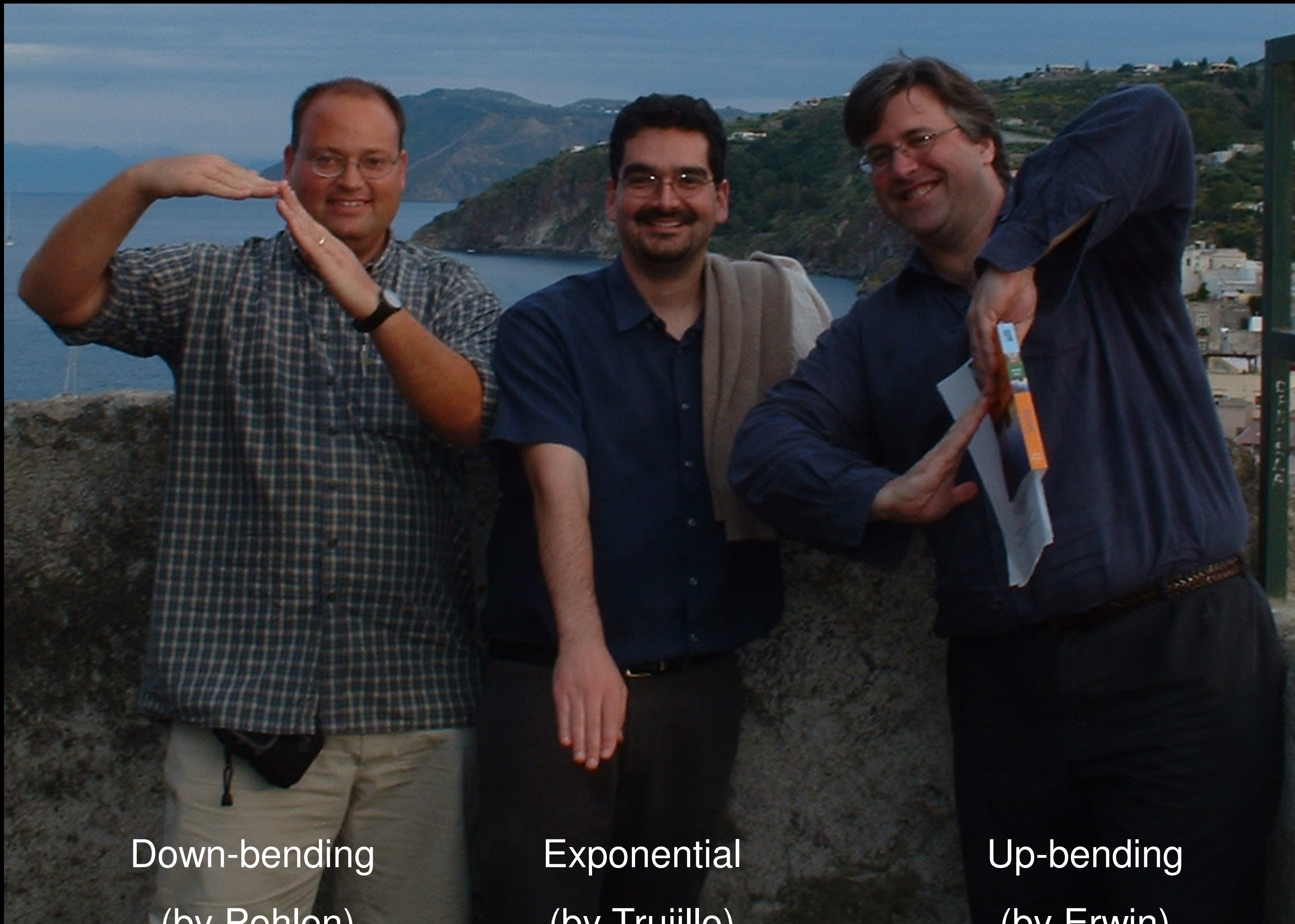
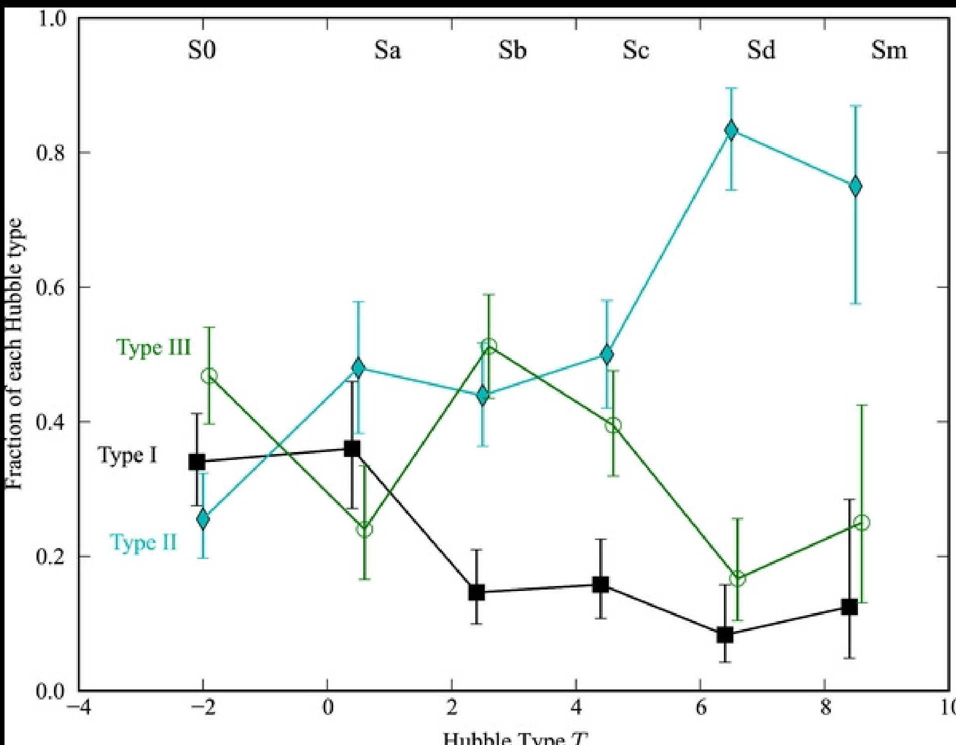
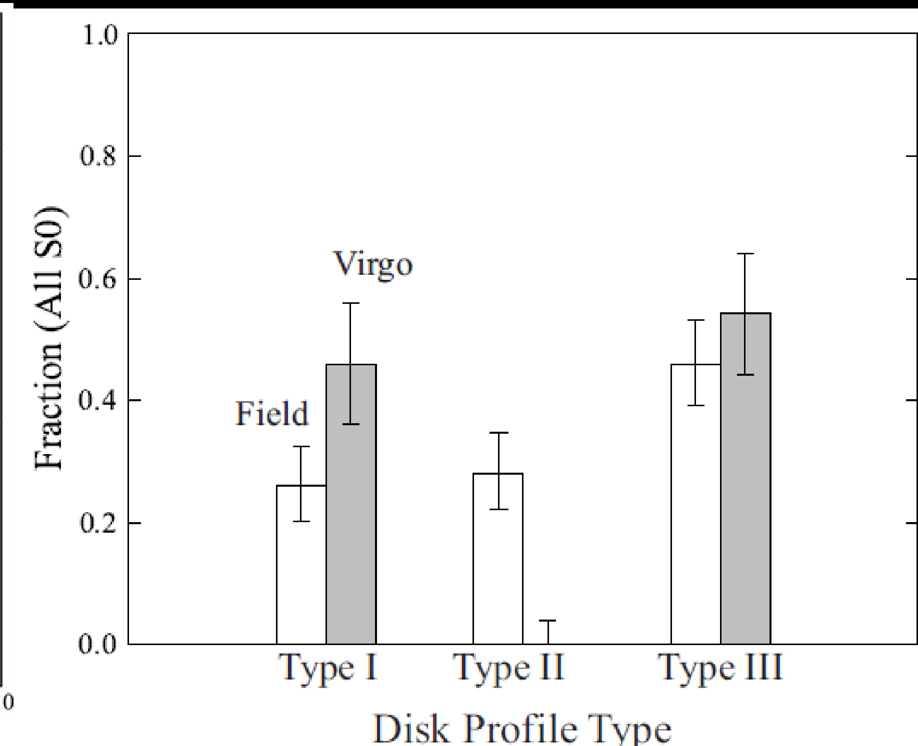


The shape of the disc galaxies: a simplified history

Breaks vs Galaxy Morphology

Breaks vs Environment



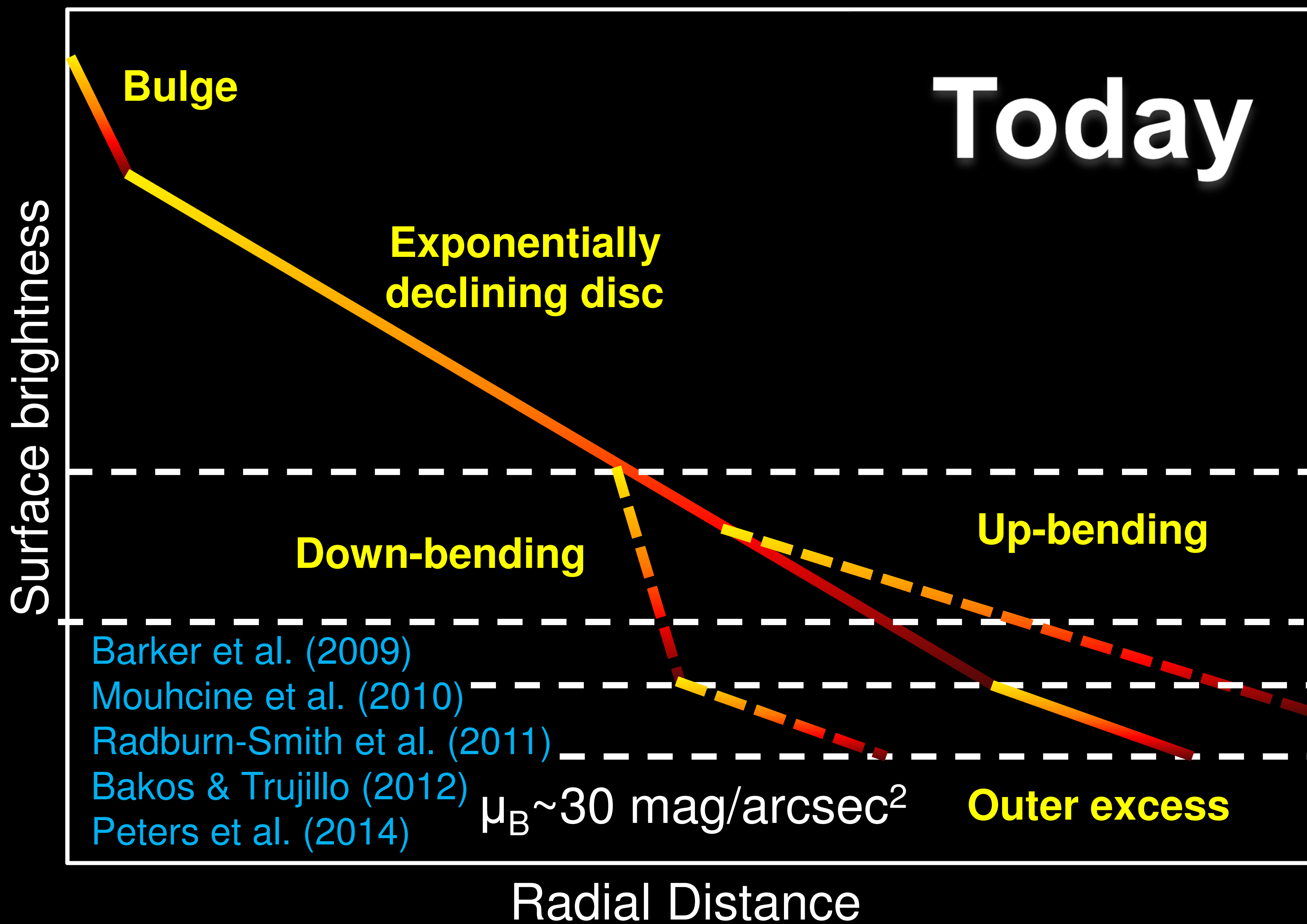


e.g. Gutiérrez et al. (2011)

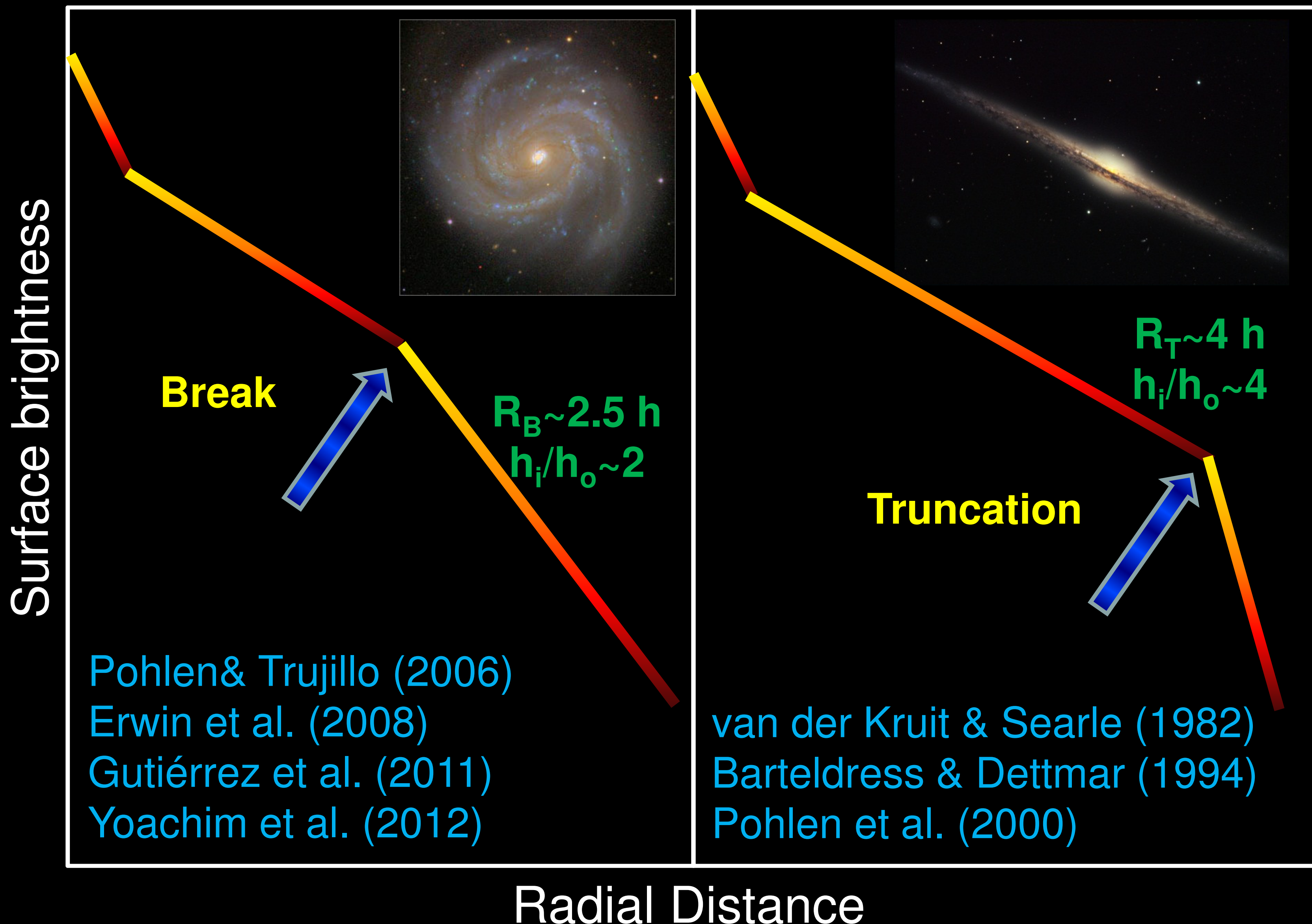
Erwin et al. (2012); Maltby et al. (2012):

Roediger et al. (2012)

The shape of the disc galaxies: a simplified history

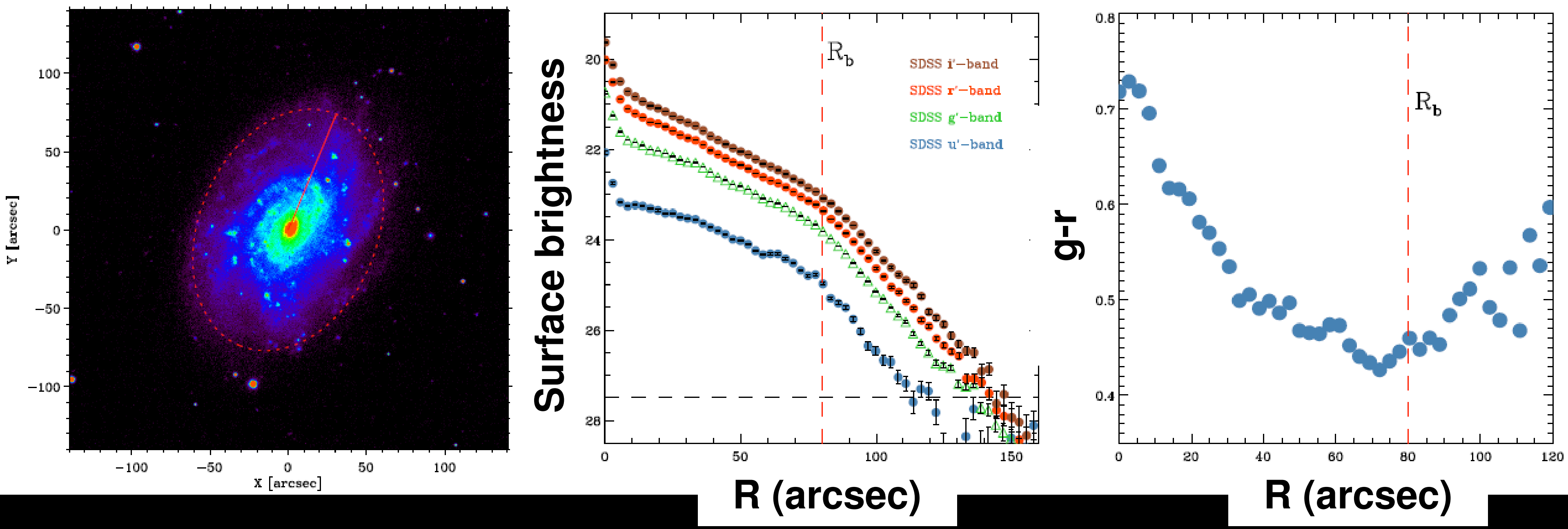


Differences in edge-on and face-on views



How do we organize all this mess?

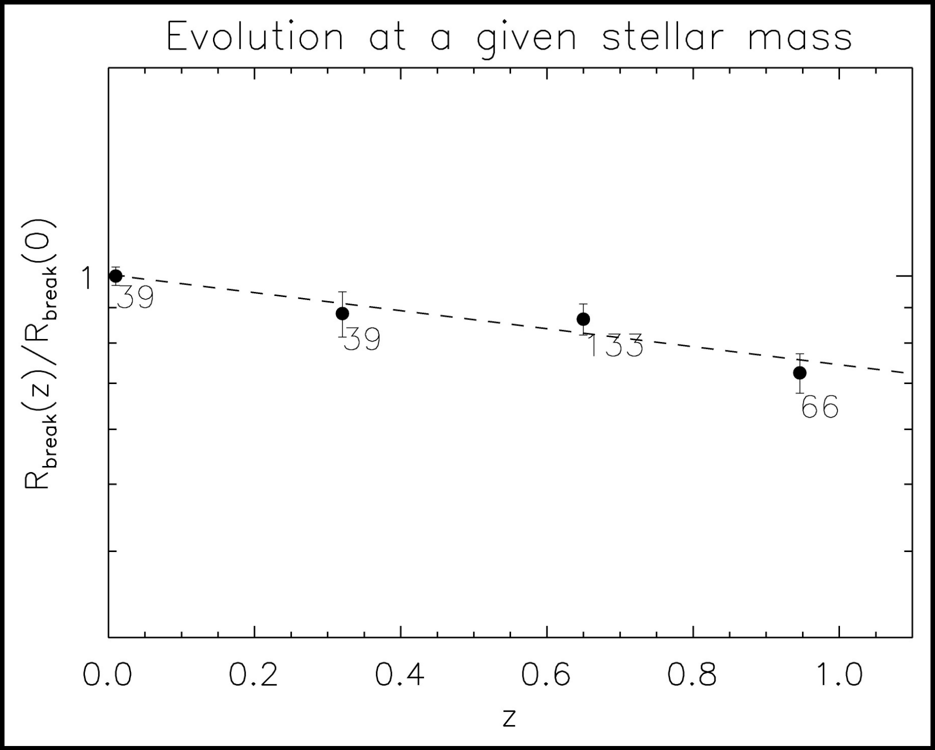
What are the breaks?

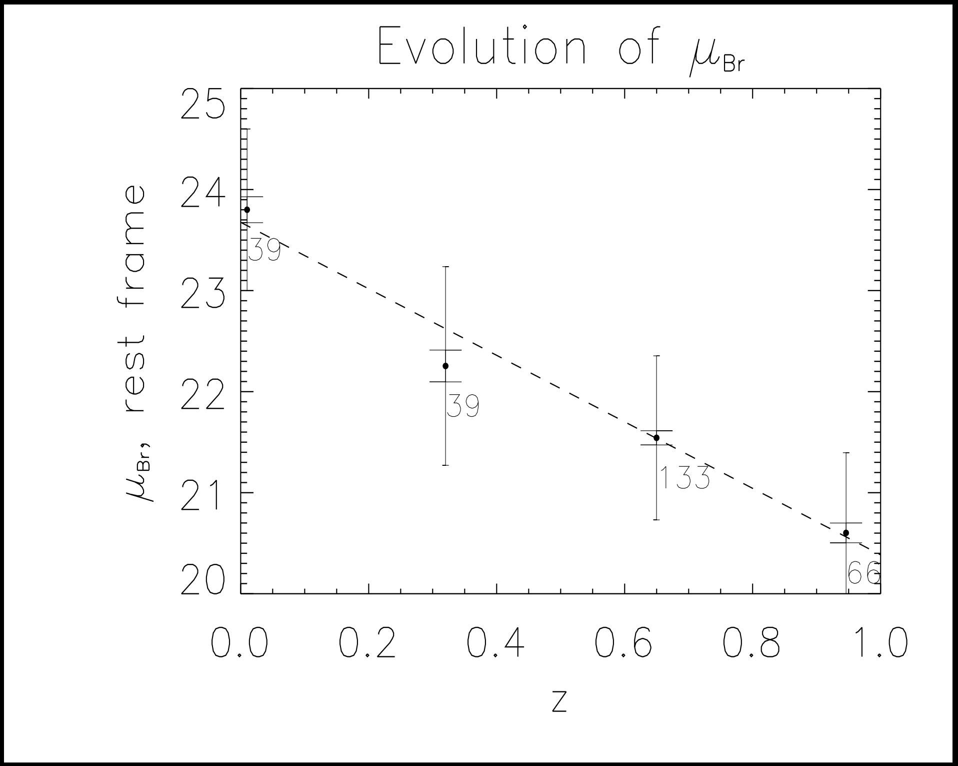


Observational constraints at low z

1. Present in ~60% of low-inclined late-type spirals Pohlen & Trujillo (2006)
2. Appear at ~9 kpc (μ_r~23.5 mag/arcsec^2) Pohlen & Trujillo (2006)
3. U-shaped color profiles at the break Azzollini+ (2008a); Bakos+ (2008)
4. The strength of the break decreases towards longer wavelenghts/older populations (Radburn-Smith et al. 2012)

What are the breaks?





Observational constraints at high z

1. Breaks have been found since z~1 Perez (2004); Trujillo & Pohlen (2005)
2. ΔR_{break}=1.3±0.1; $\Delta\mu_{break}$=3.3±0.2 mag/arcsec^2 since z~1 Azzollini+ (2008b)

What are the breaks?

Summary:

1. Breaks are associated to changes on the stellar populations at the break position (e.g. Yoachim et al. 2010; 2012)

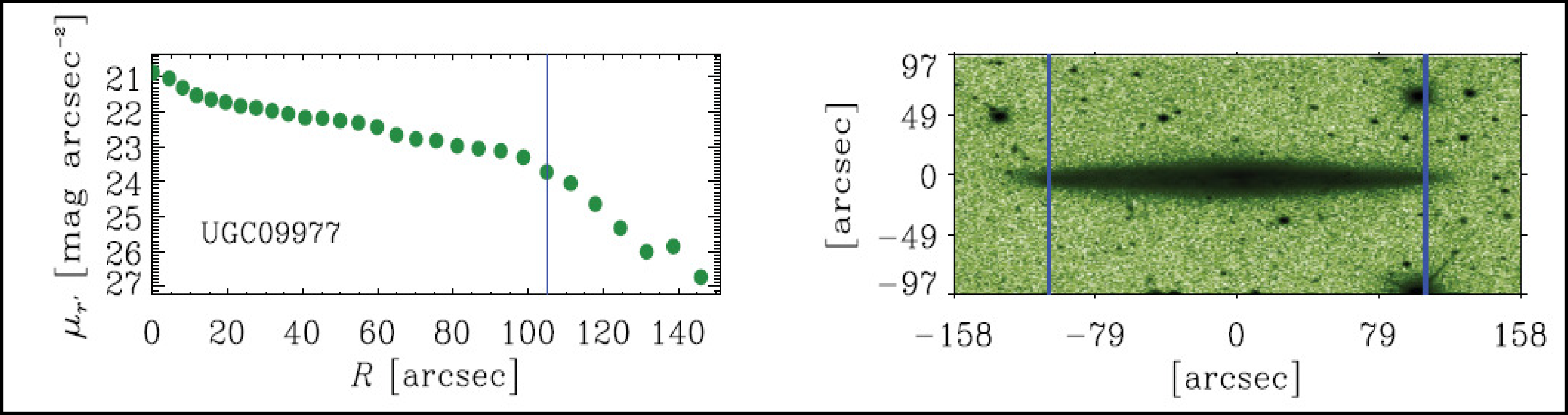
2. No strongly related to drops in the number density of stars (e.g. Bakos et al. 2008)

3. The physical mechanism is under debate:

a) Star formation thresholds + stellar migration + hierarchical mass aggregations + interactions with their environment (Roskar et al. 2008; Foyle et al. 2008; Sánchez Blázquez et al. 2009; Martínez Serrano et al . 2009)

b) Resonances produced by strong bars+ stellar migration (Debattista et al. 2006; Minchev et al. 2012; Muñoz-Mateos et al. 2013)

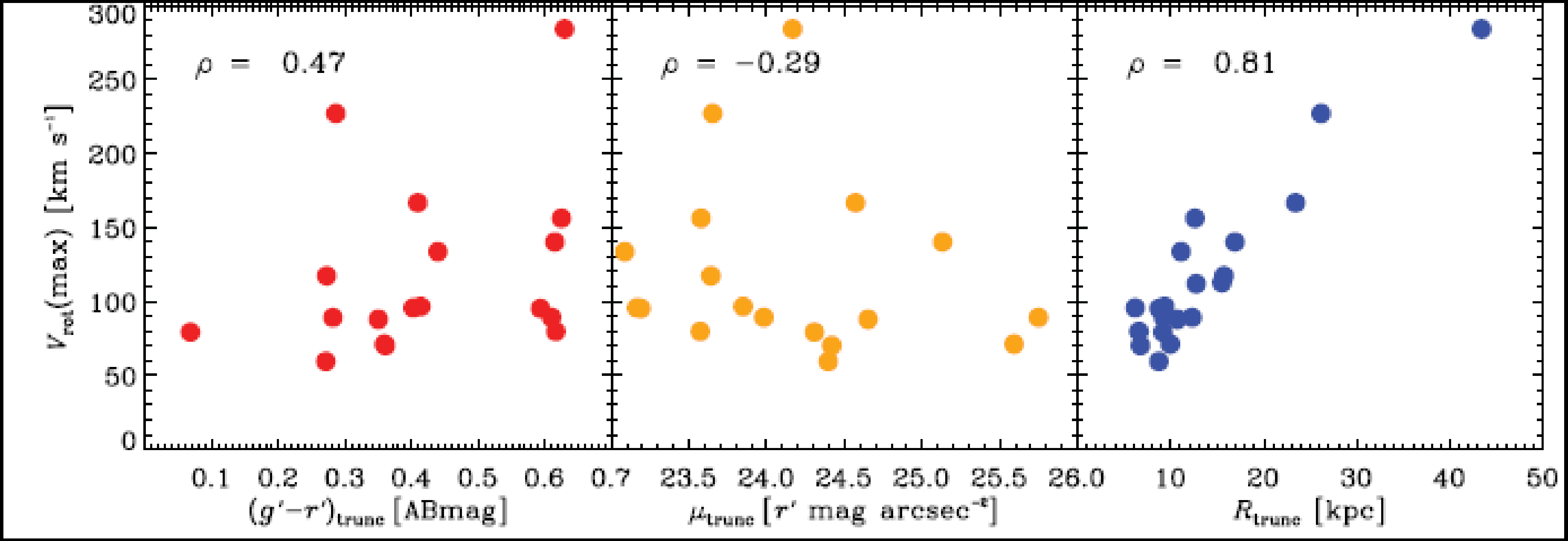
What are the truncations?



Observational constraints

1. Found only in edge-on orientations ; sharper feature than breaks
2. Appear at ~14 kpc (μ_r~24 mag/arcsec^2) e.g. de Jong et al. (2007)
3. Connected to the appearance of warps of neutral hydrogen van der Kruit (2007)

What are the truncations?



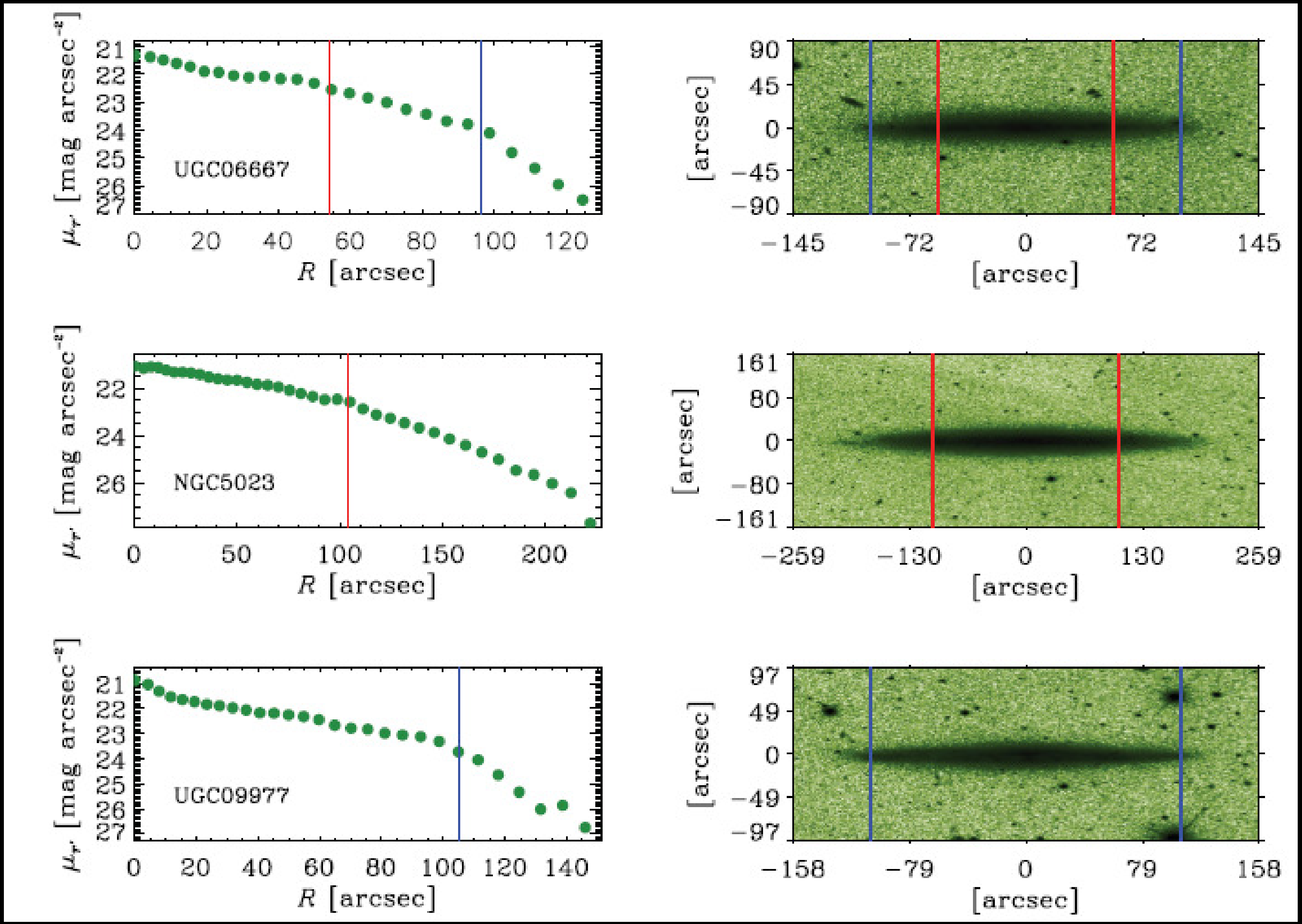
Summary:

1. Connected to a real drop in the number density of stars (e.g. de Jong et al. 2007; Florido et al. 2007)
2. Unclear whether there are changes in the stellar populations (the dust effect is severe in edge-on orientation)
3. The physical mechanism associated to the phenomena seems to be connected with the maximum angular momentum of the disc

Do breaks and truncations appear at the same time on the galaxies?

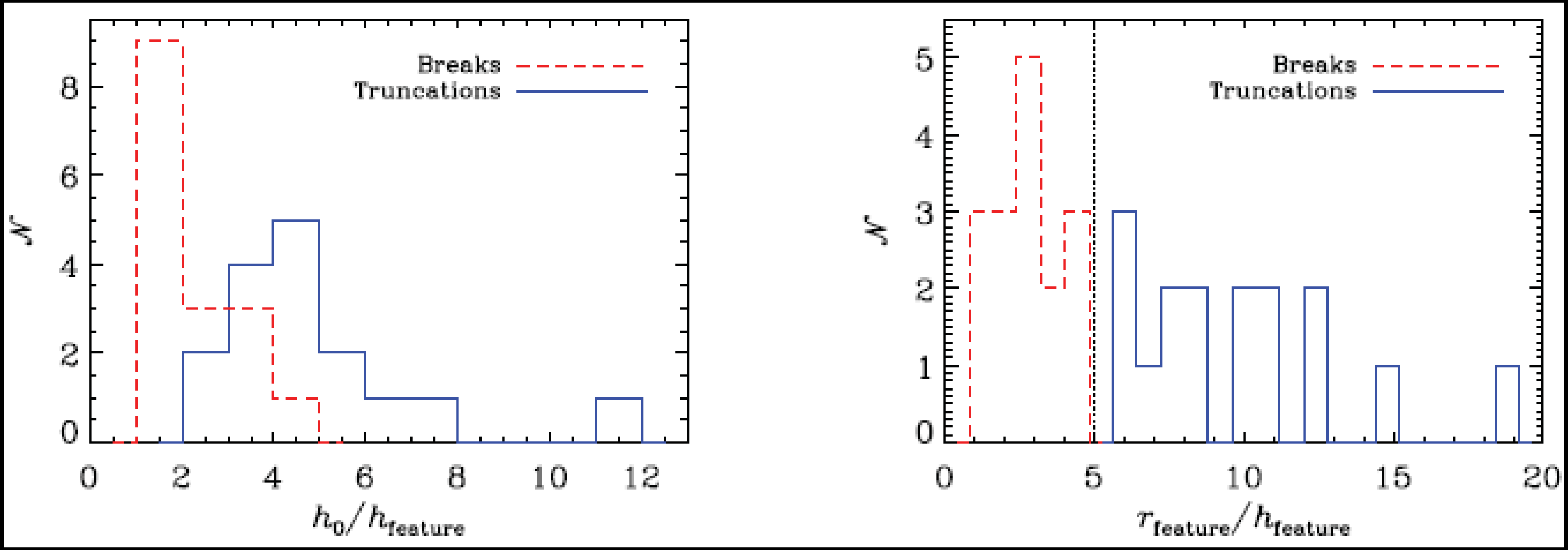
Yes, they have been found in edge-on orientations…

Martín-Navarro et al. (2012)



Do breaks and truncations appear at the same time on the galaxies?

Breaks and truncations are different phenomena…

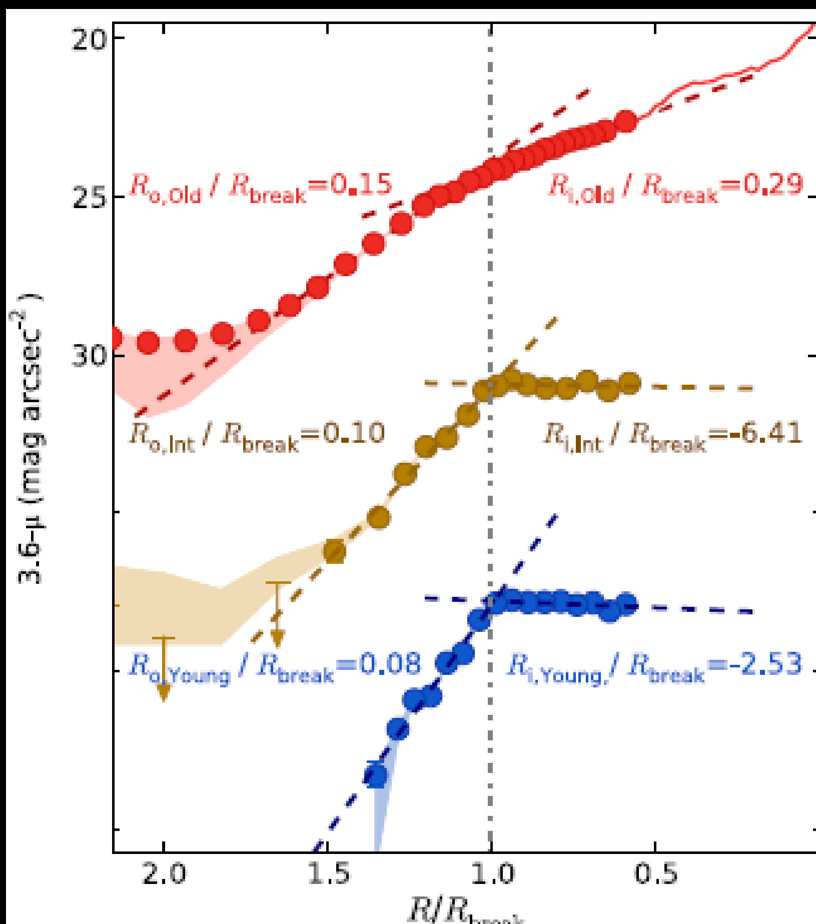


Martín-Navarro et al. (2012)

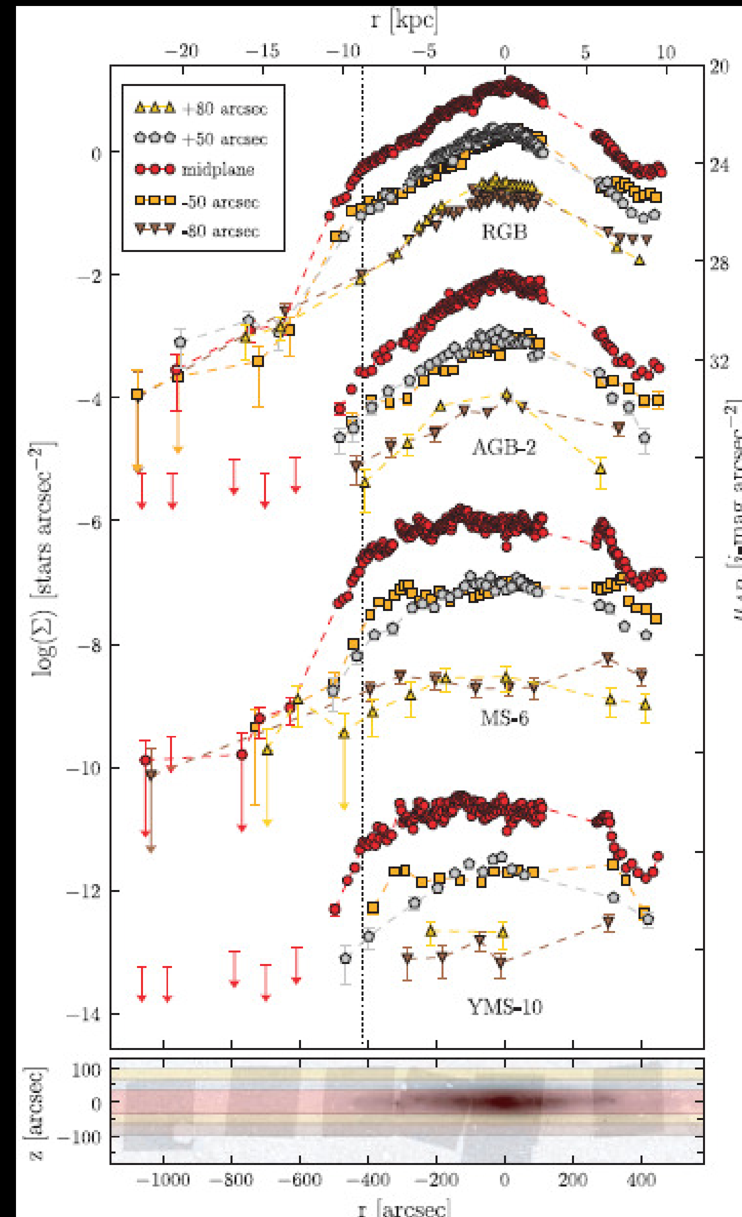
Do breaks and truncations appear at the same time on the galaxies?

Breaks and truncations are different phenomena…

NGC7793; Face-On



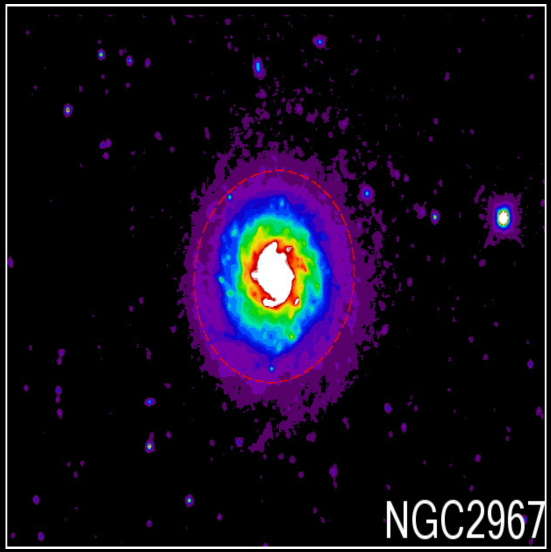
Radburn-Smith et al. (2012)

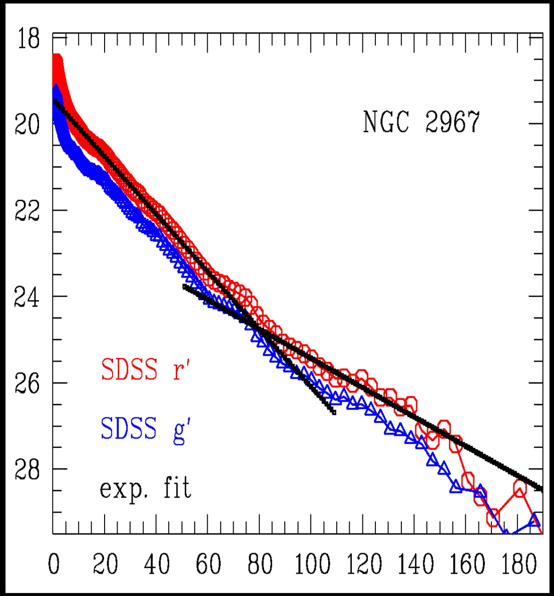


NGC4244; Edge-on

De Jong et al. (2007)

What is the up-bending phenomenon?





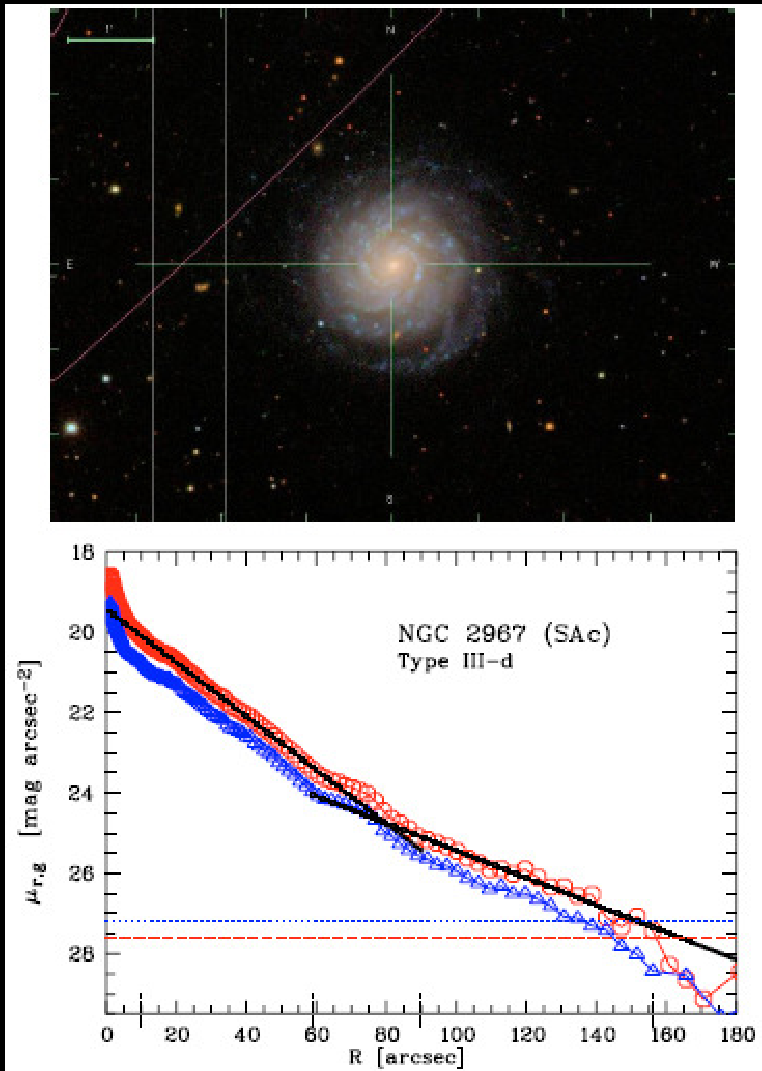
Observational constraints

1. Present in ~40% of low-inclined early-type spirals but only ~20% in late-type Pohlen & Trujillo (2006); Erwin et al. (2007)

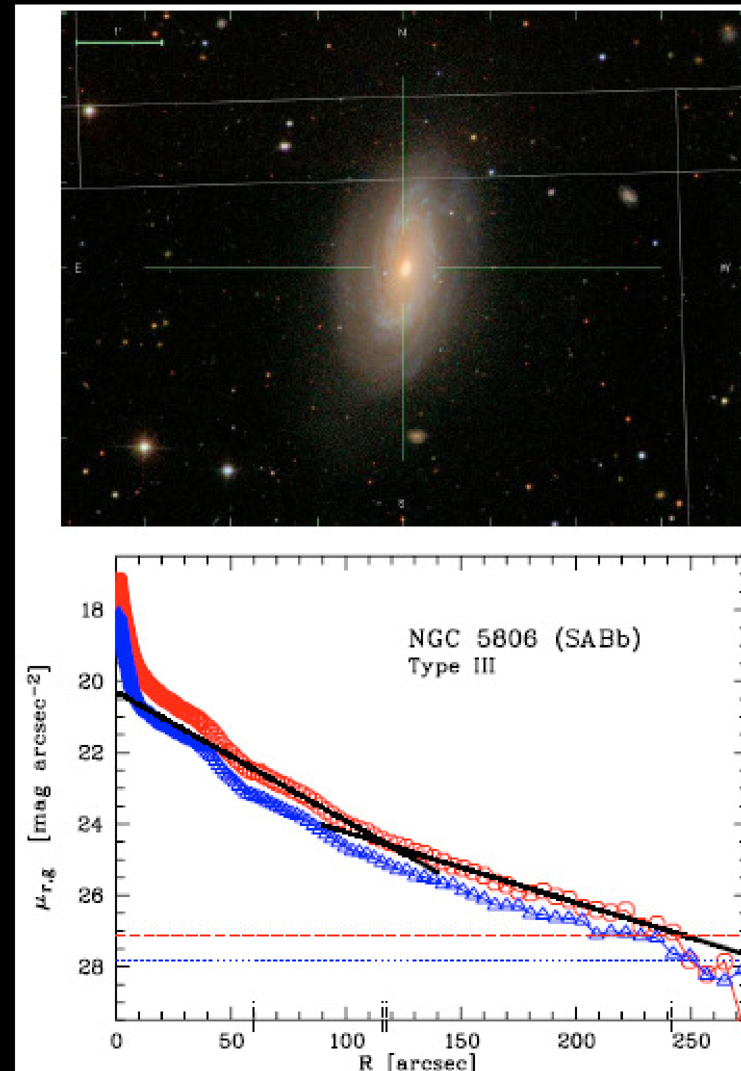
2. Appear at ~10 kpc (μ_r~25 mag/arcsec^2) Pohlen & Trujillo (2006)

What is the up-bending phenomenon?

Up-bendings appear in 2 flavours:



Disk-like



Spheroid-like

What is the up-bending phenomenon?

Summary:

1. Up-bending is connected to activity in the outer parts:

a) Disk-like upbending: interactions with other galaxies triggering outer star formation? (Elmegreen & Hunter 2006)

b) Spheroid-like upbending: minor merging/smooth gas accretion? (Younger et al. 2007; Kazantzidis et al. 2009; Minchev et al. 2012)

Legitimate question: Are these up-bendings bright stellar haloes?

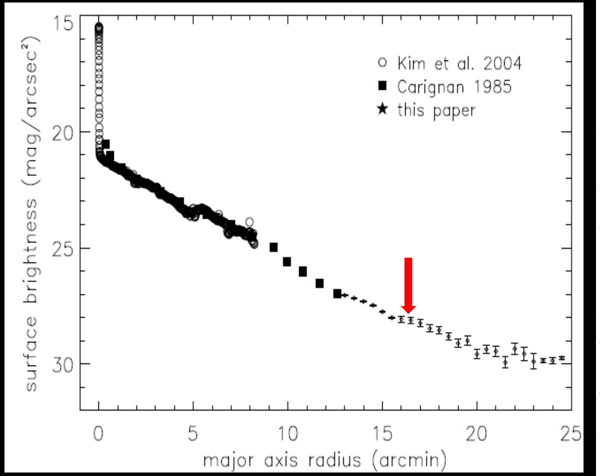
What is the "outer excess"?

Independently of the disk type: pure exponential, breaks, truncations, inclinations… there is an outer excess of light

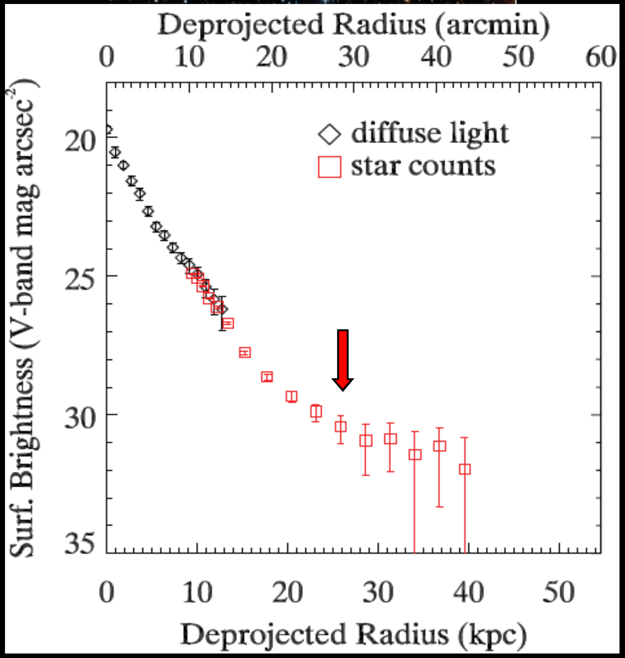
NGC0300; -18.1 mag

NGC2403; -19.4 mag

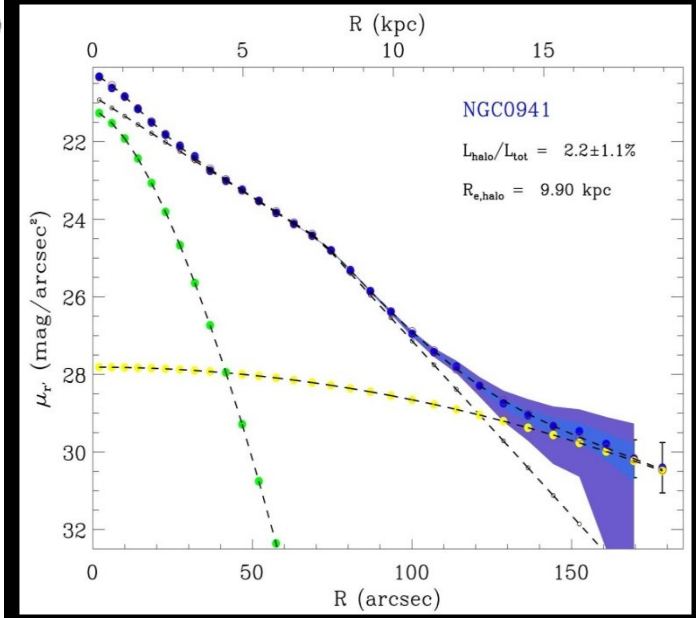
NGC0941; -19.1 mag



Vlajic et al. (2009)



Barker et al. (2012)



Bakos & Trujillo (2012)

What is the "outer excess"?

The outer excess of light seems to be the stellar halo…

Observational constraints at low z:

1. The excess of light appears at R>20 kpc

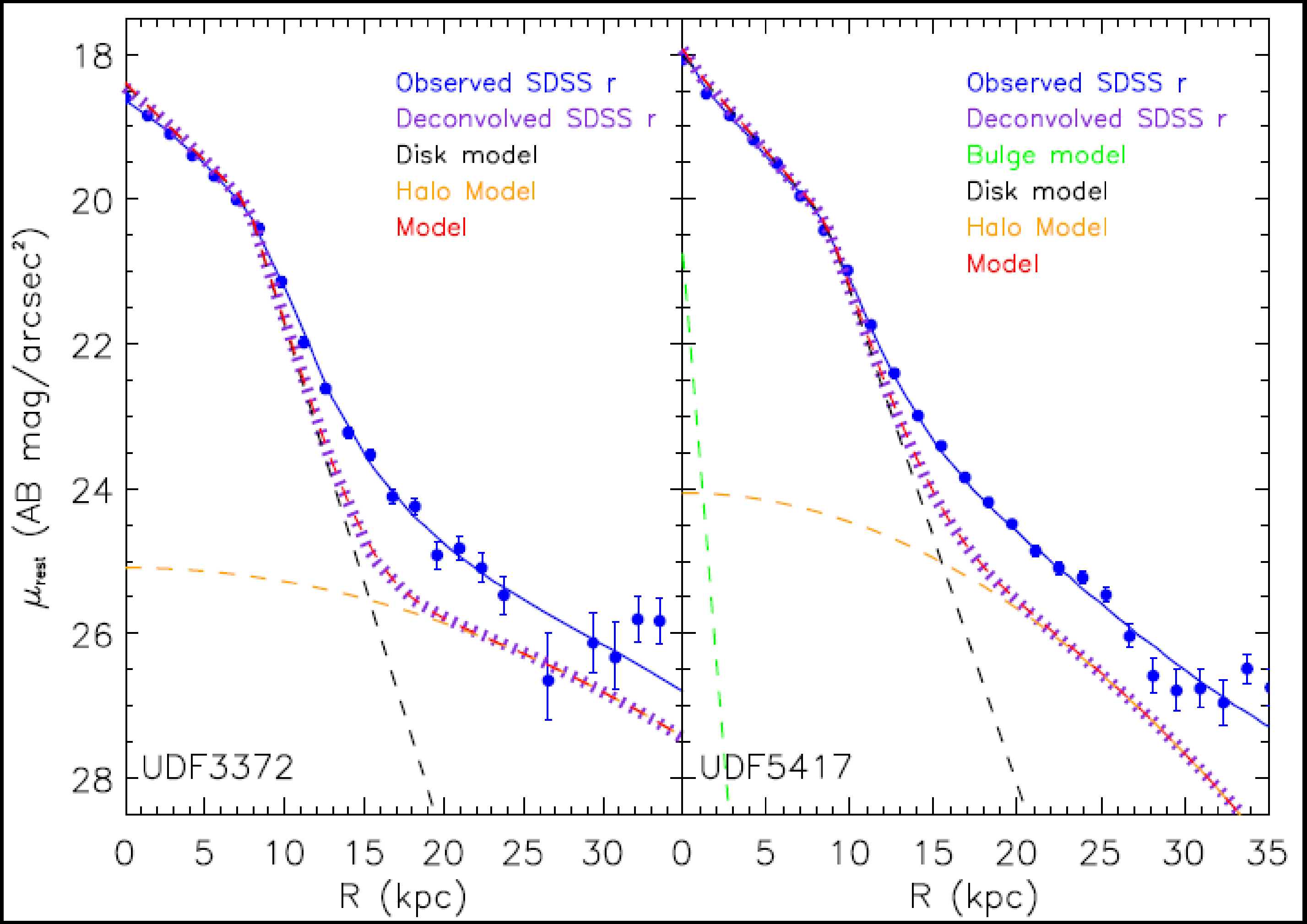
2. Very faint surface brightness μ_r>28 mag/arcsec^2

Wu et al. (2002); Jablonka et al. (2010); Barker et al. (2012); Bakos & Trujillo (2012)

What is the “outer excess”?

Observational constraints at high z:

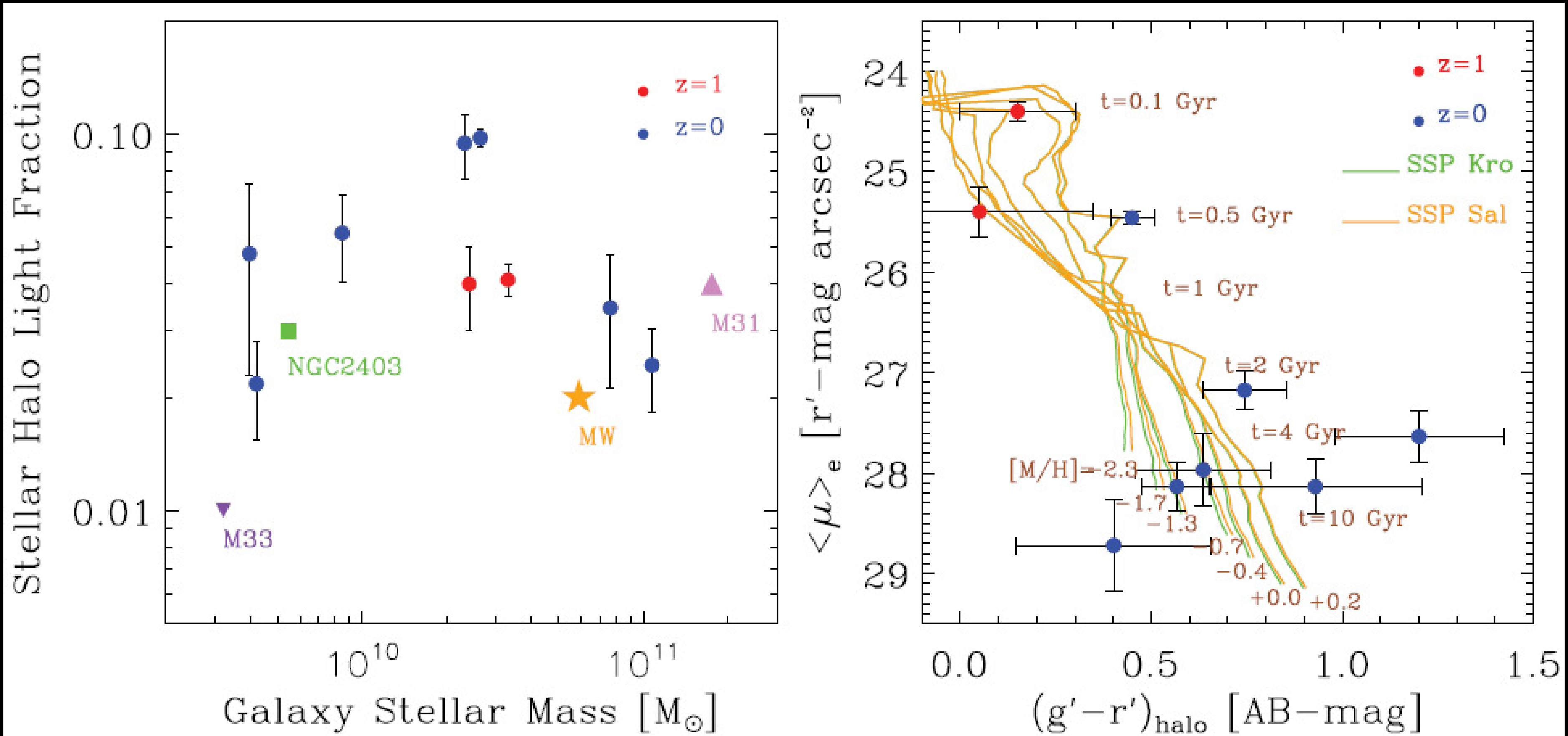
1. Stellar halos probed now at z~1 Trujillo & Bakos (2013)



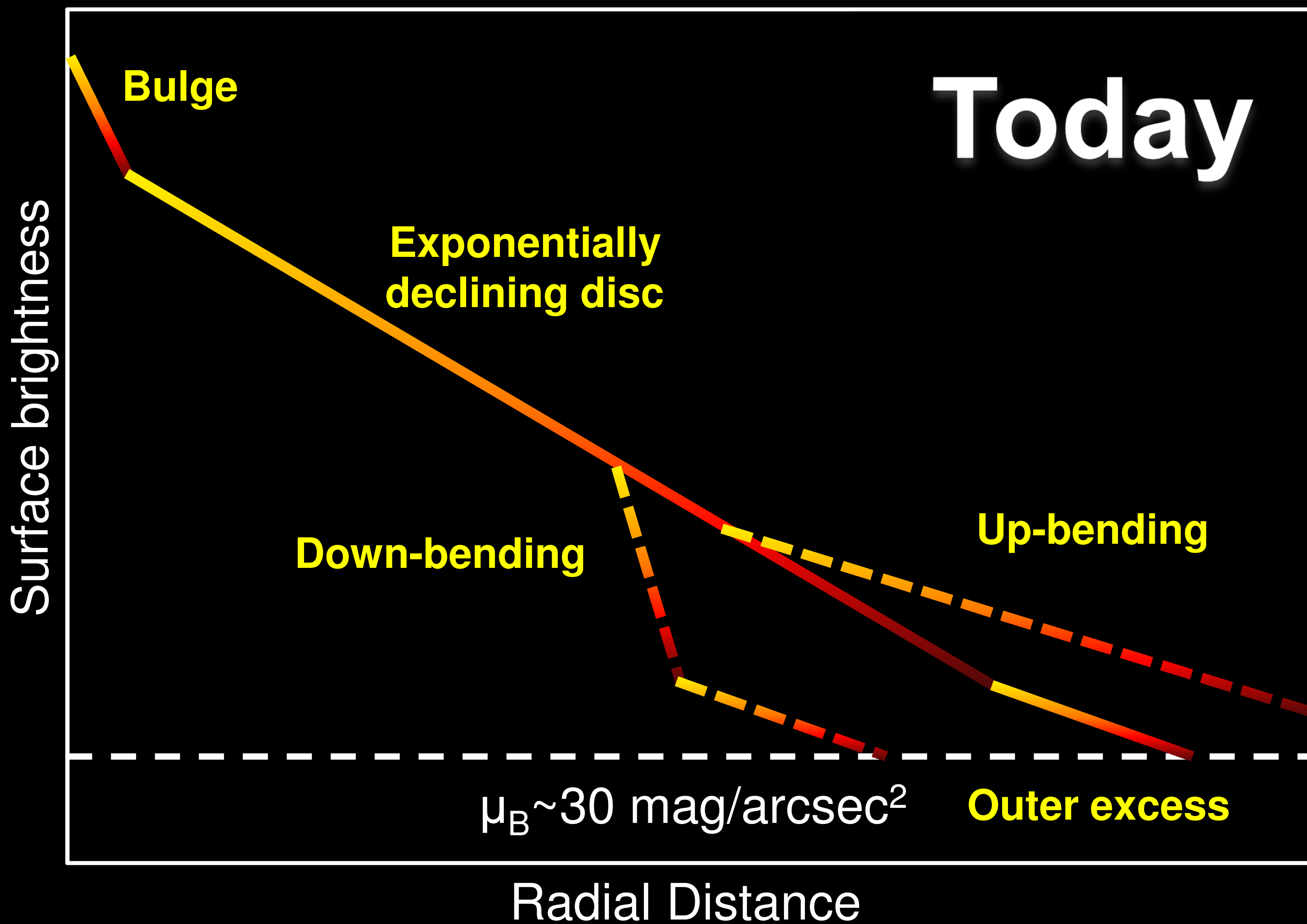
What is the “outer excess”?

Observational constraints at high z:

1. Stellar halos passively evolving since z~1 Trujillo & Bakos (2013)



Can we put all this into the same context?



Towards a unified framework: breaks+truncations+stellar haloes

Martín-Navarro et al. (2014)

Hypothesis:

1. The outer excess is a universal phenomenon caused by the emergence of the stellar halo:

a) It should be universally found in face-on and edge-on orientations
b) It should be more prominent in more massive disks
c) In case of a recent merger: could be the responsible of the up-bendings

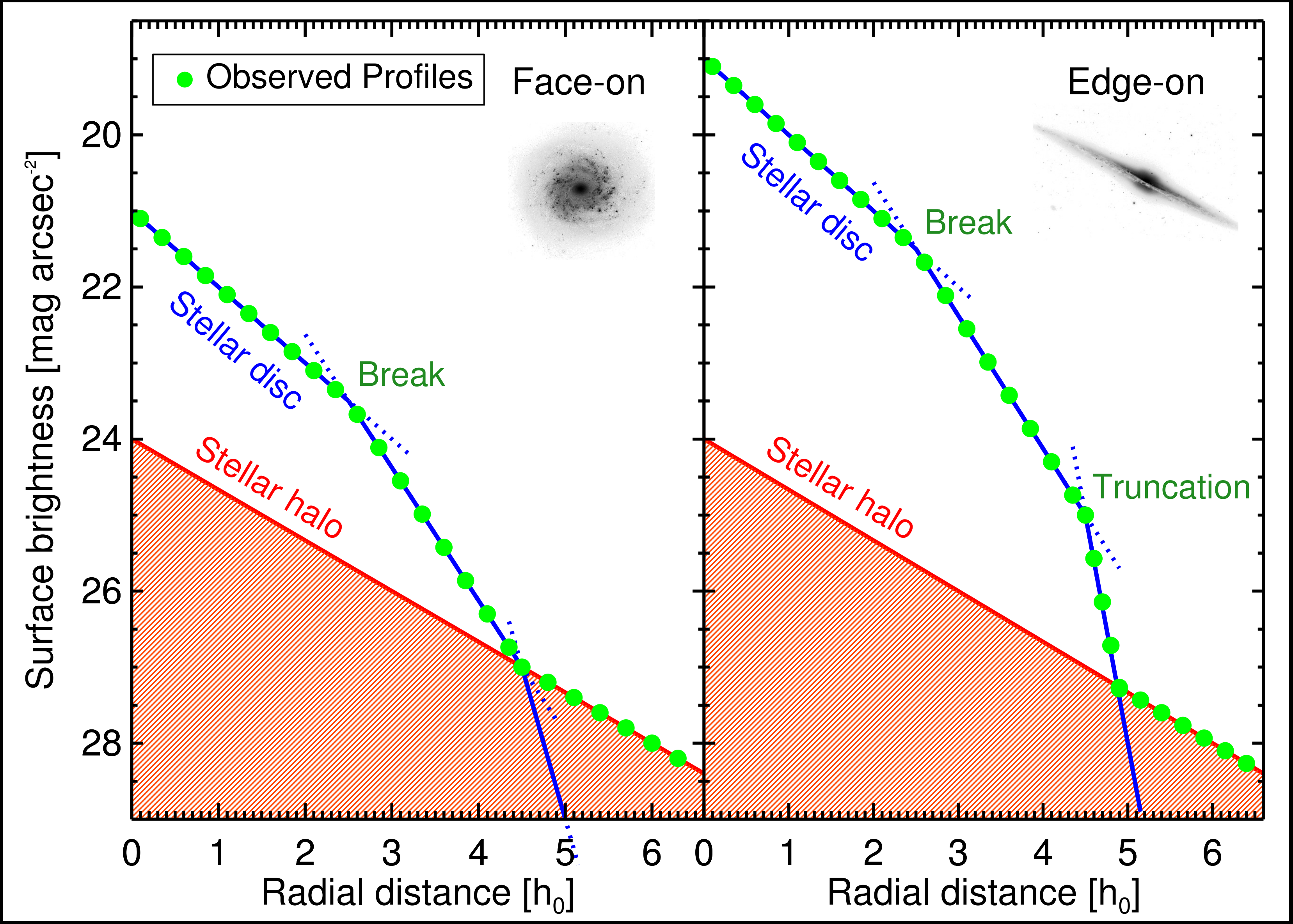
2. The truncations are a universal phenomenon

a) It should be seen more easily in edge-on orientations
b) It should be outshined by the stellar halo light in face-on orientations

3. The down-bending breaks are non-universal phenomenon

a) It should appear on galaxies with enough amount of gas

Towards a unified framework: breaks+truncations+stellar haloes



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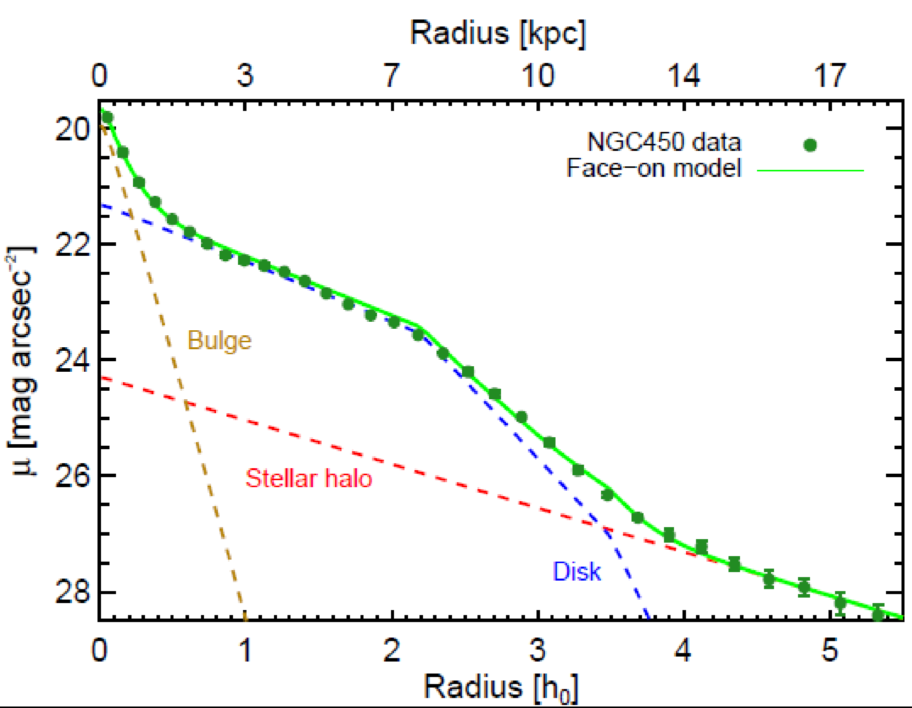
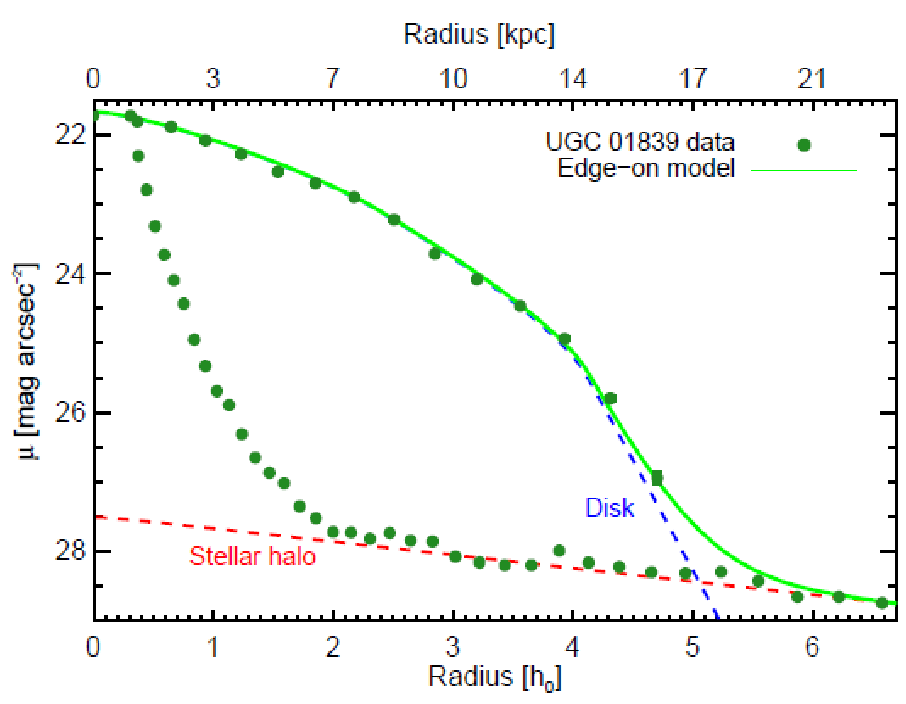
Towards a unified framework: breaks+truncations+stellar haloes





Martín-Navarro et al. (2014)

Conclusions

1. The outer structure of disc galaxies is rich

a) Three different behaviors:
   pure exponential, down-bending and up-bending
b) Universal excess of light in the outer regions: the stellar halo
c) We are approaching to an unified understanding of the variety of observations

2. The outer structure of disc galaxies is in place at least since z~1

3. The outermost disc structure could be ultimately beyond our scrutiny due to the stellar halo light

Towards an unified model: breaks+truncations+stellar haloes