(Outer) Rings and Breaks in Disk Galaxy Profiles

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Radial Surface-Brightness Profiles of Galaxy Disks

Type I:
Single-exponential
(Freeman 1970)

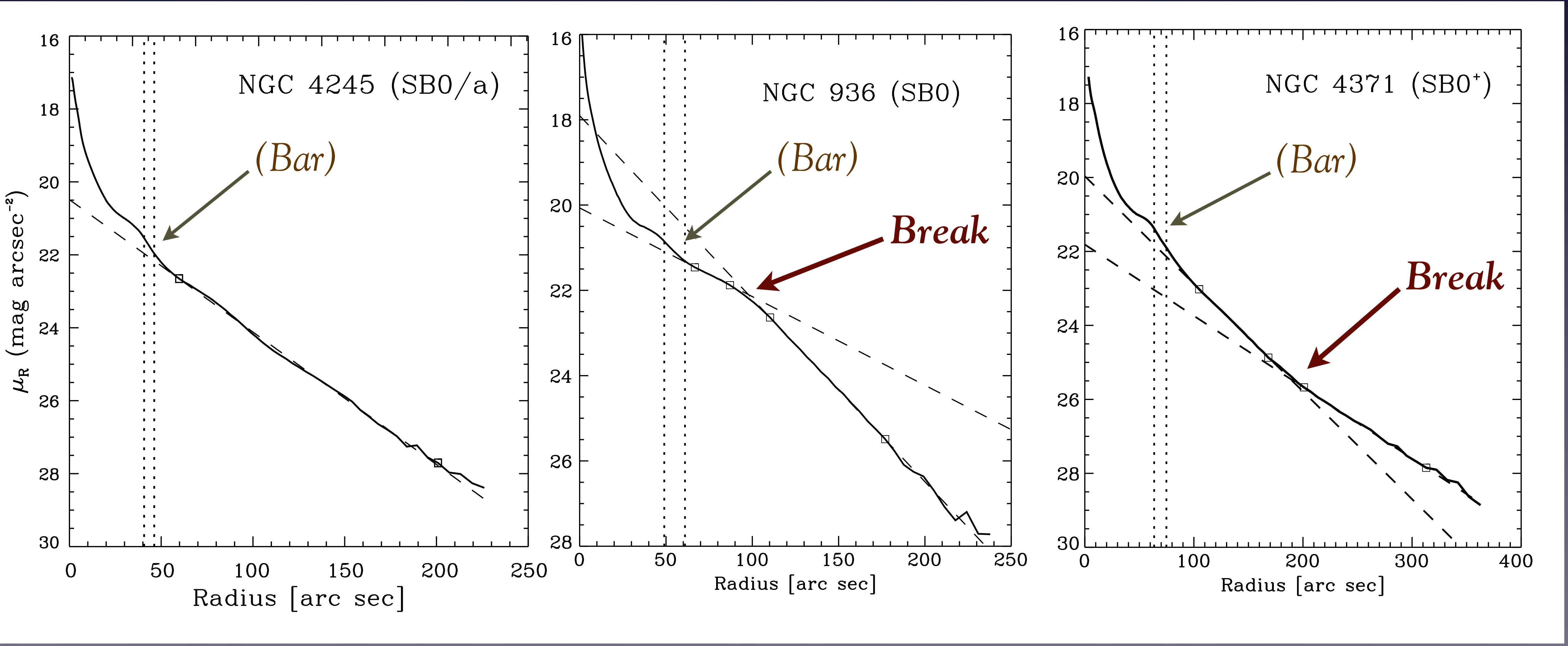
Type II:
includes "Truncations"
(Freeman 1970; van der Kruit & Searle 1981)

Type III:
"Antitruncations"
(Erwin+2005)

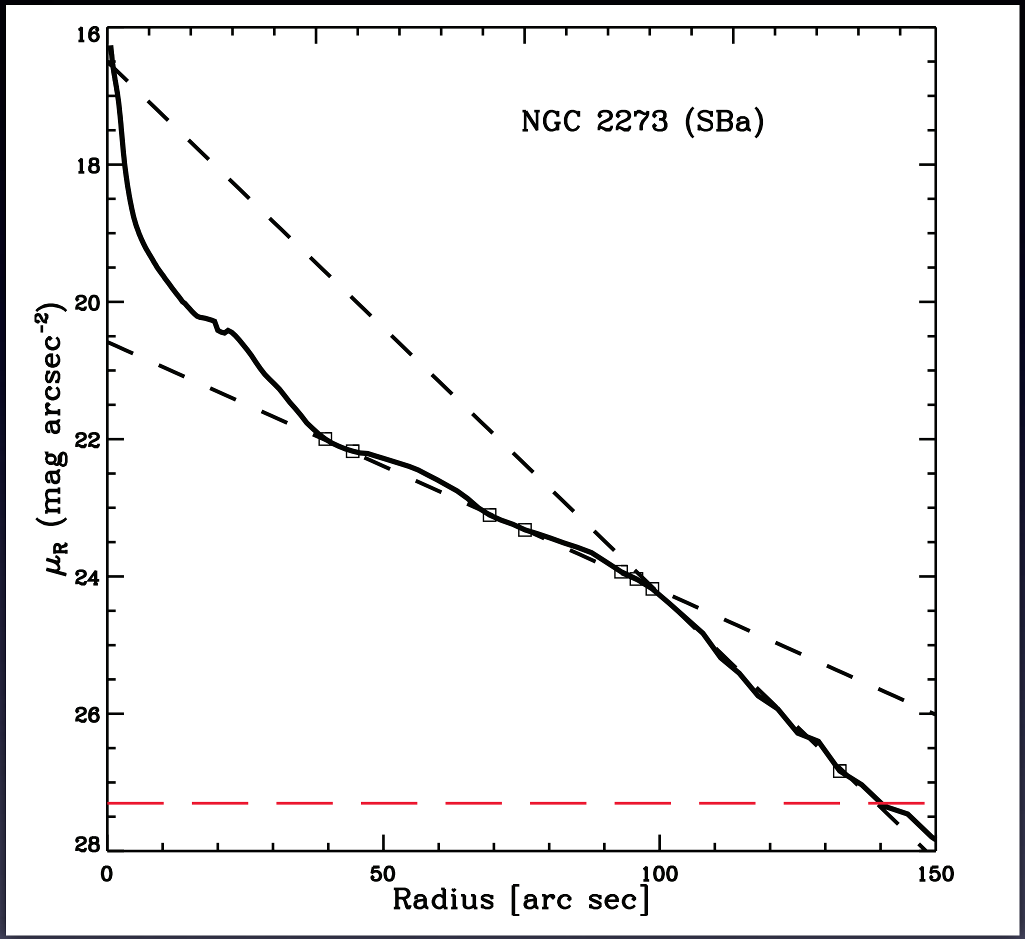
No Break

"Downbending" Break

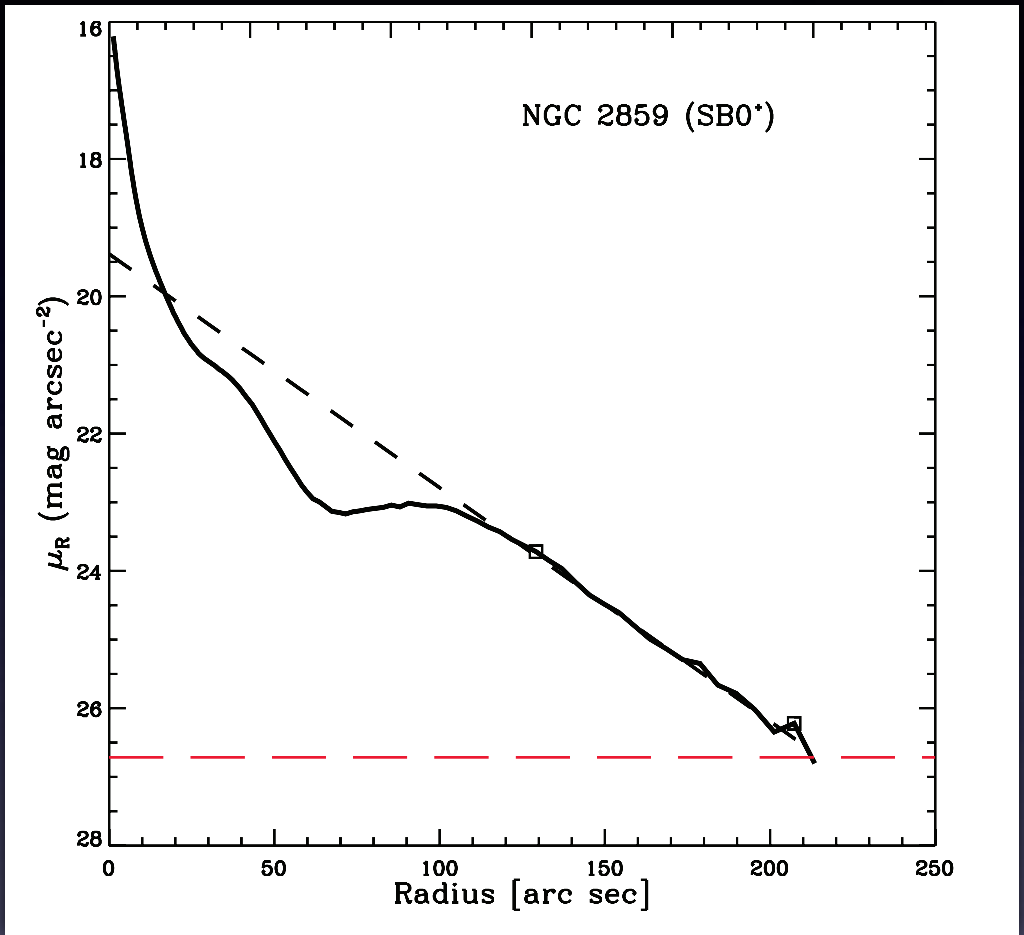
"Upbending" Break



What Do We Mean by "Break"?



Broken exponential



Inner non-exponential zone

1. Two extended exponential zones in disk with transition between them (the break in "broken exponential")

2. Where outer exponential gives way to *deficit* relative to its inward extrapolation (inner region may not be exponential!)

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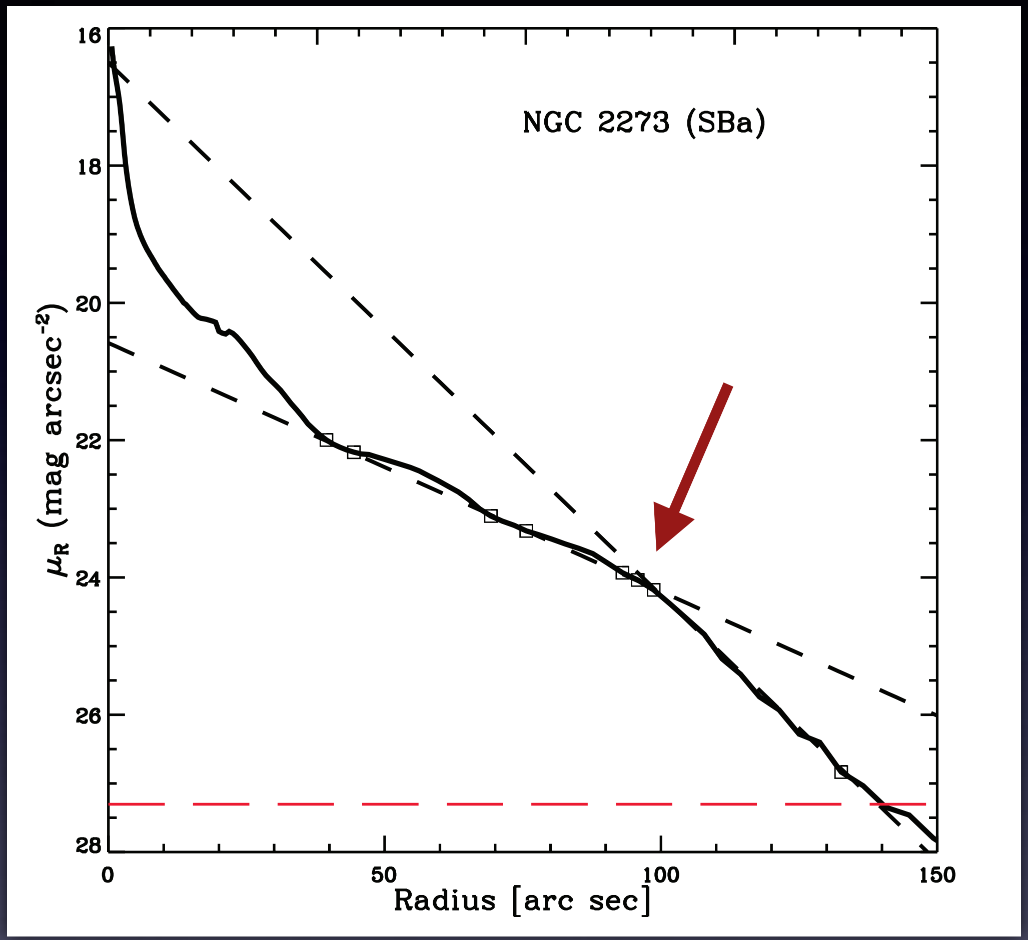

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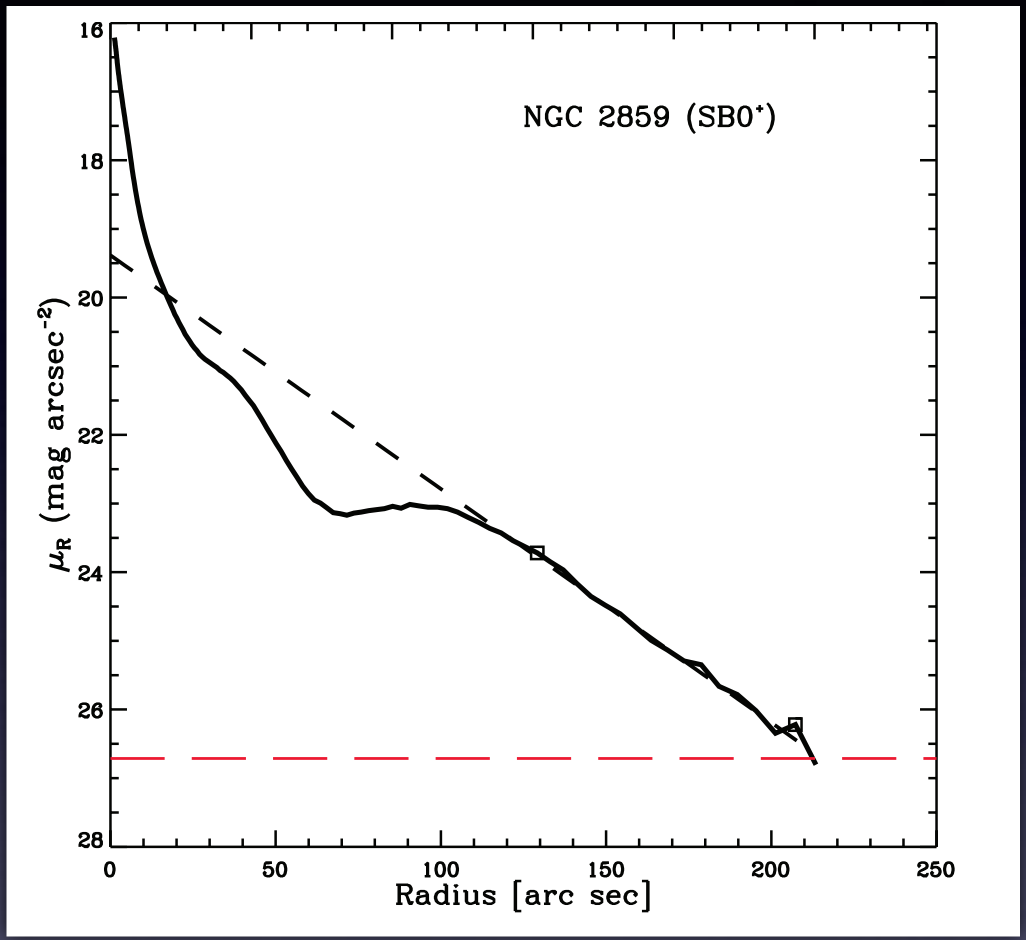

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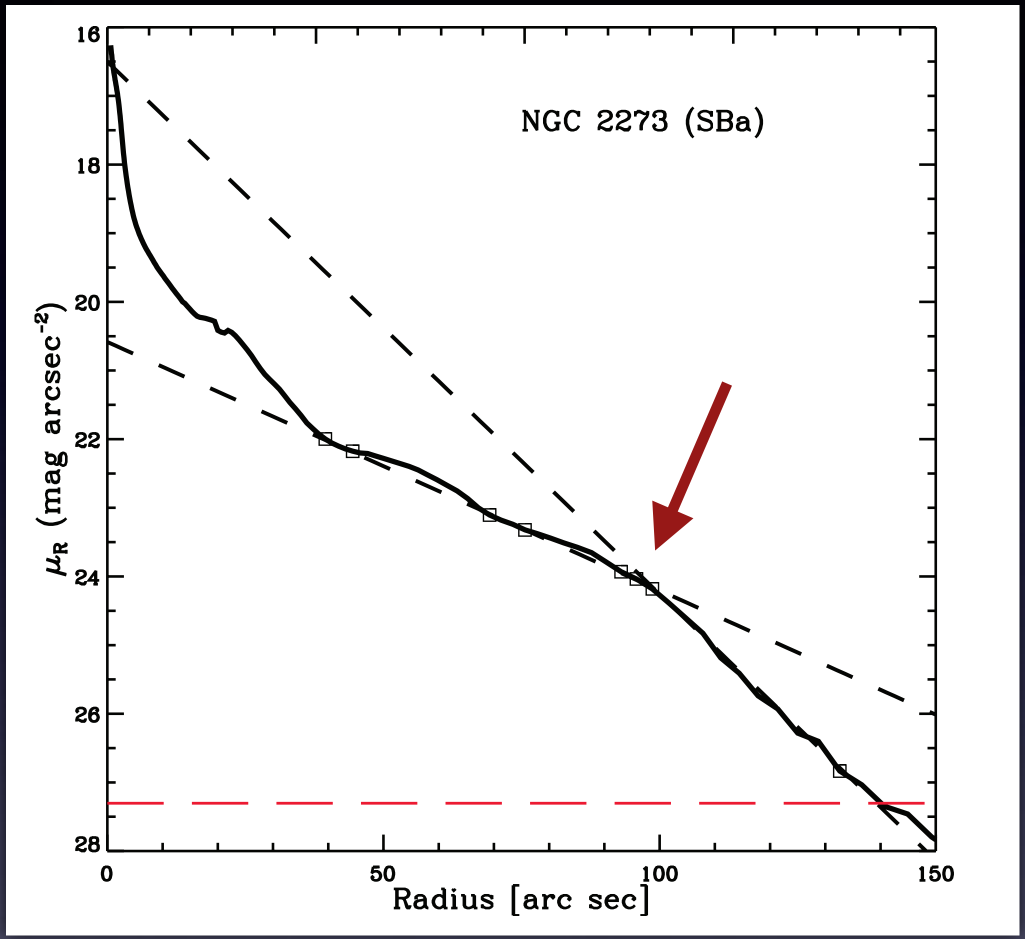

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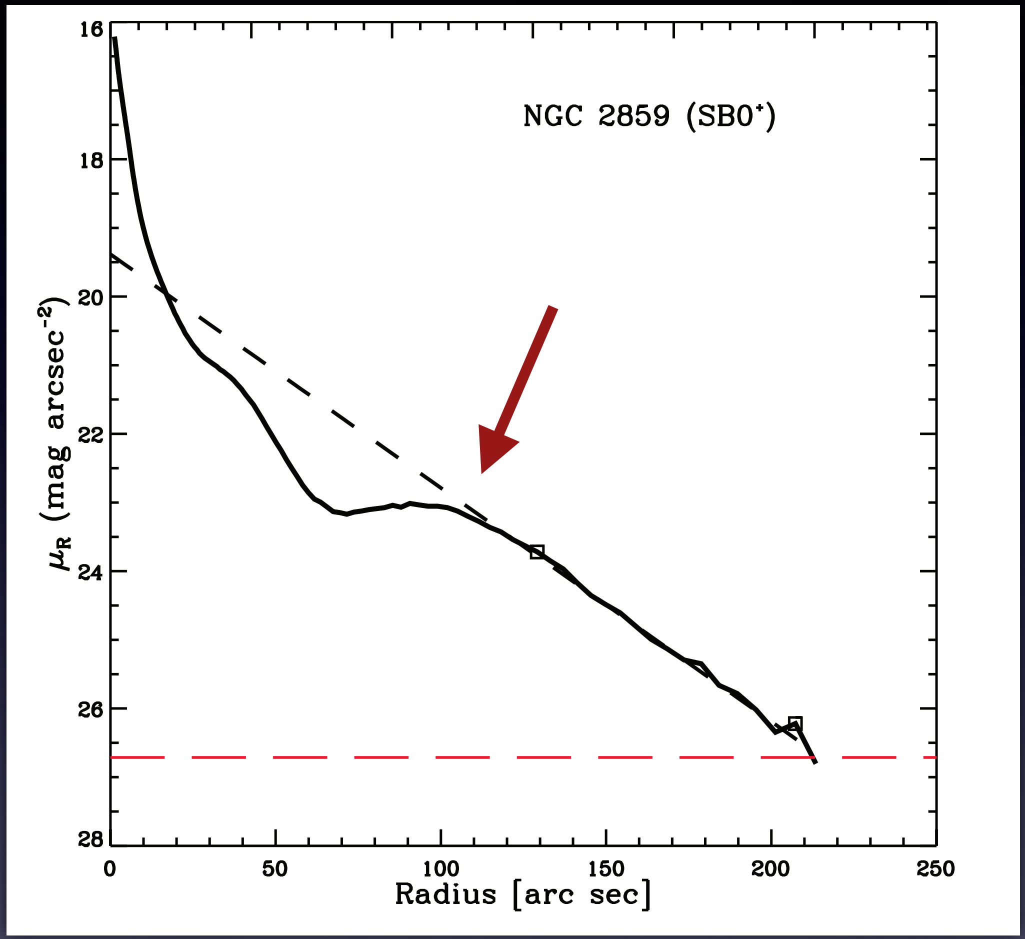

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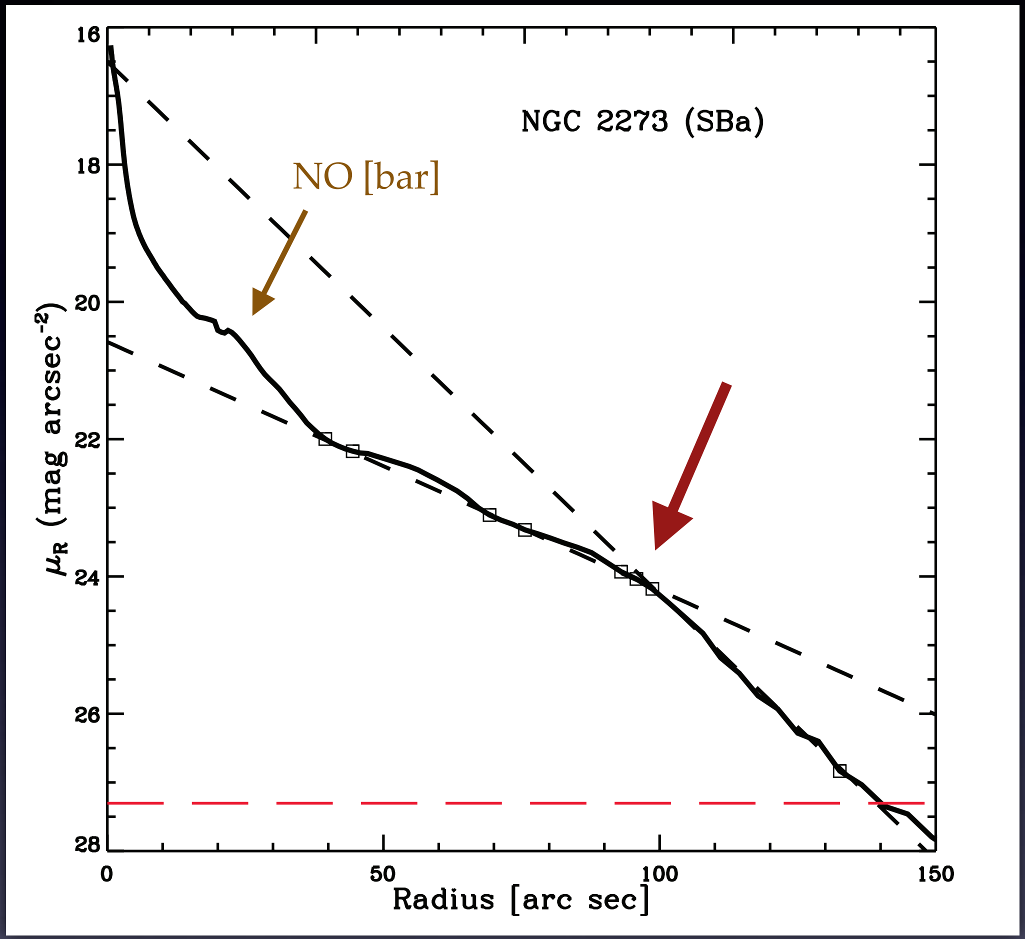

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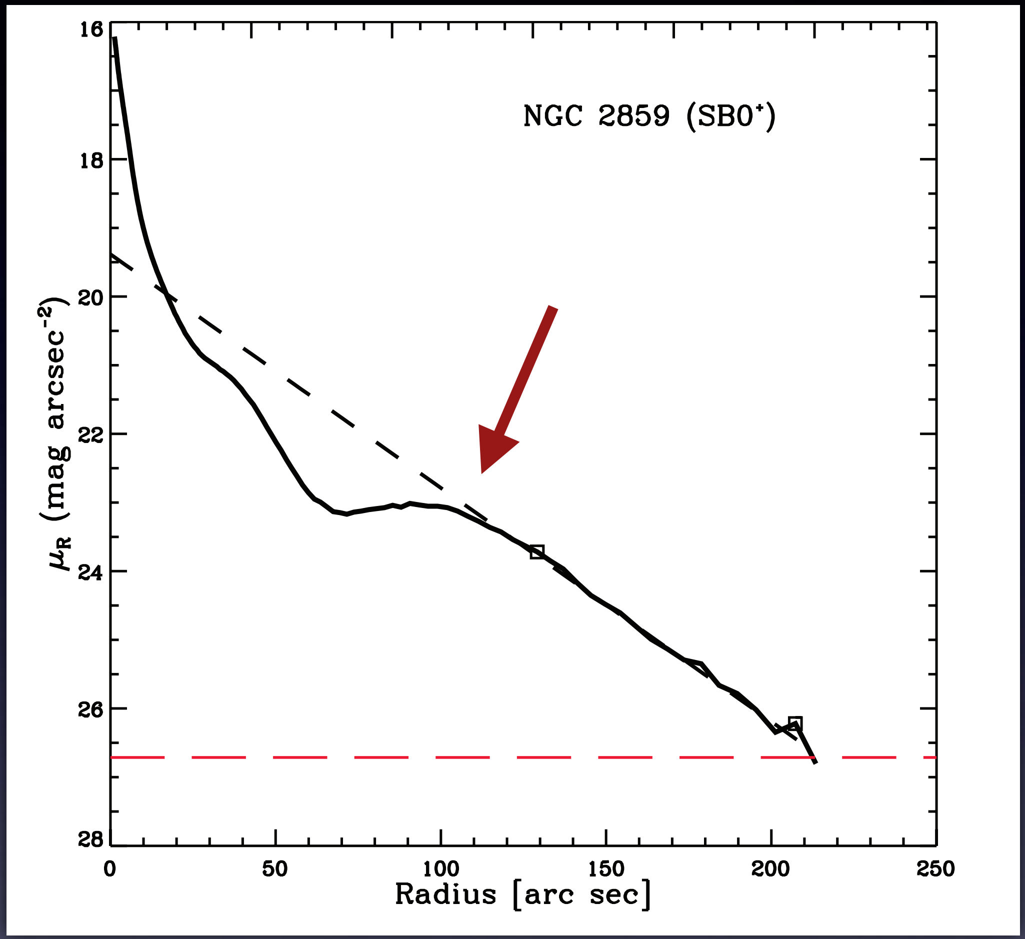

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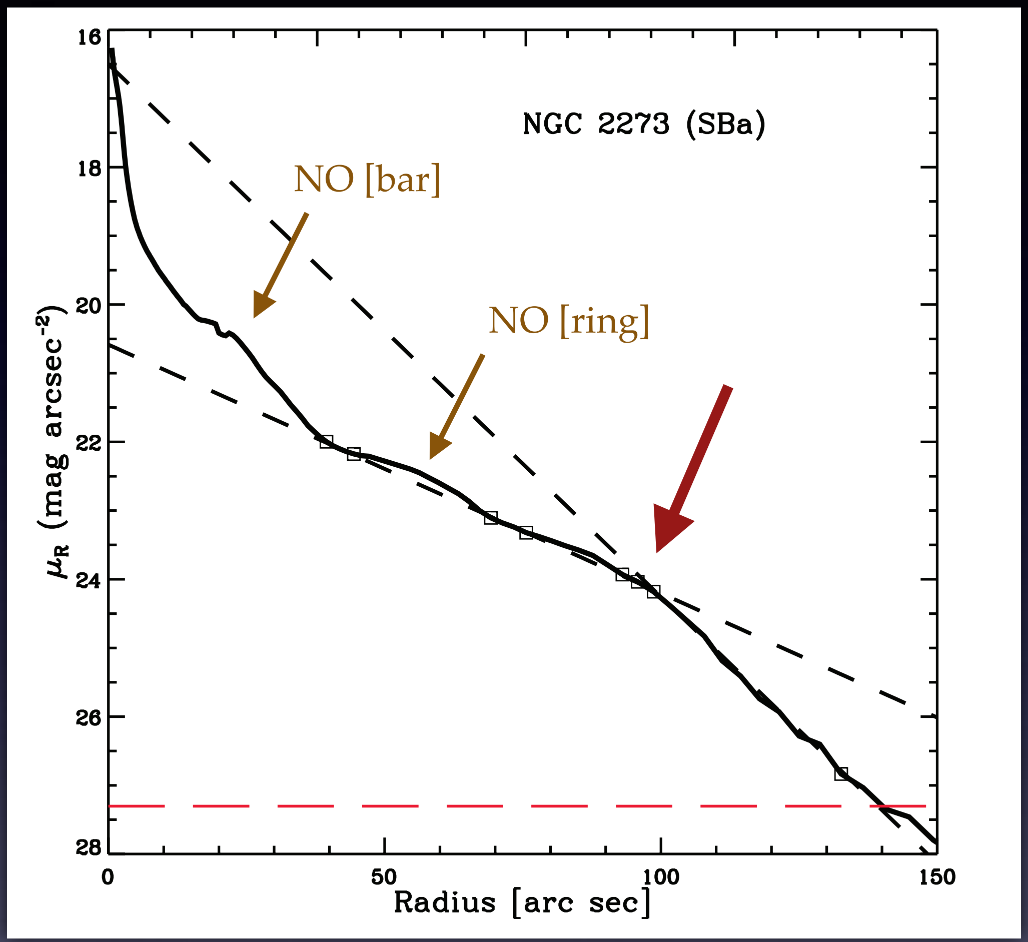

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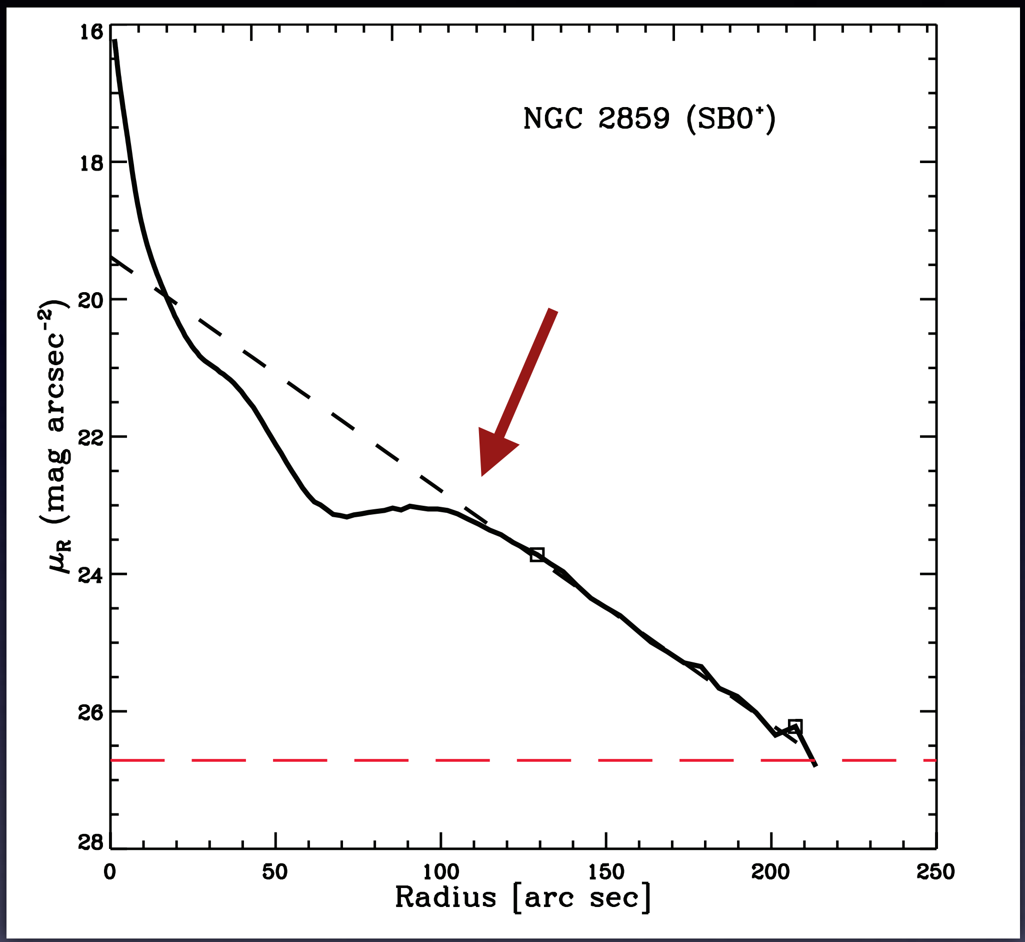

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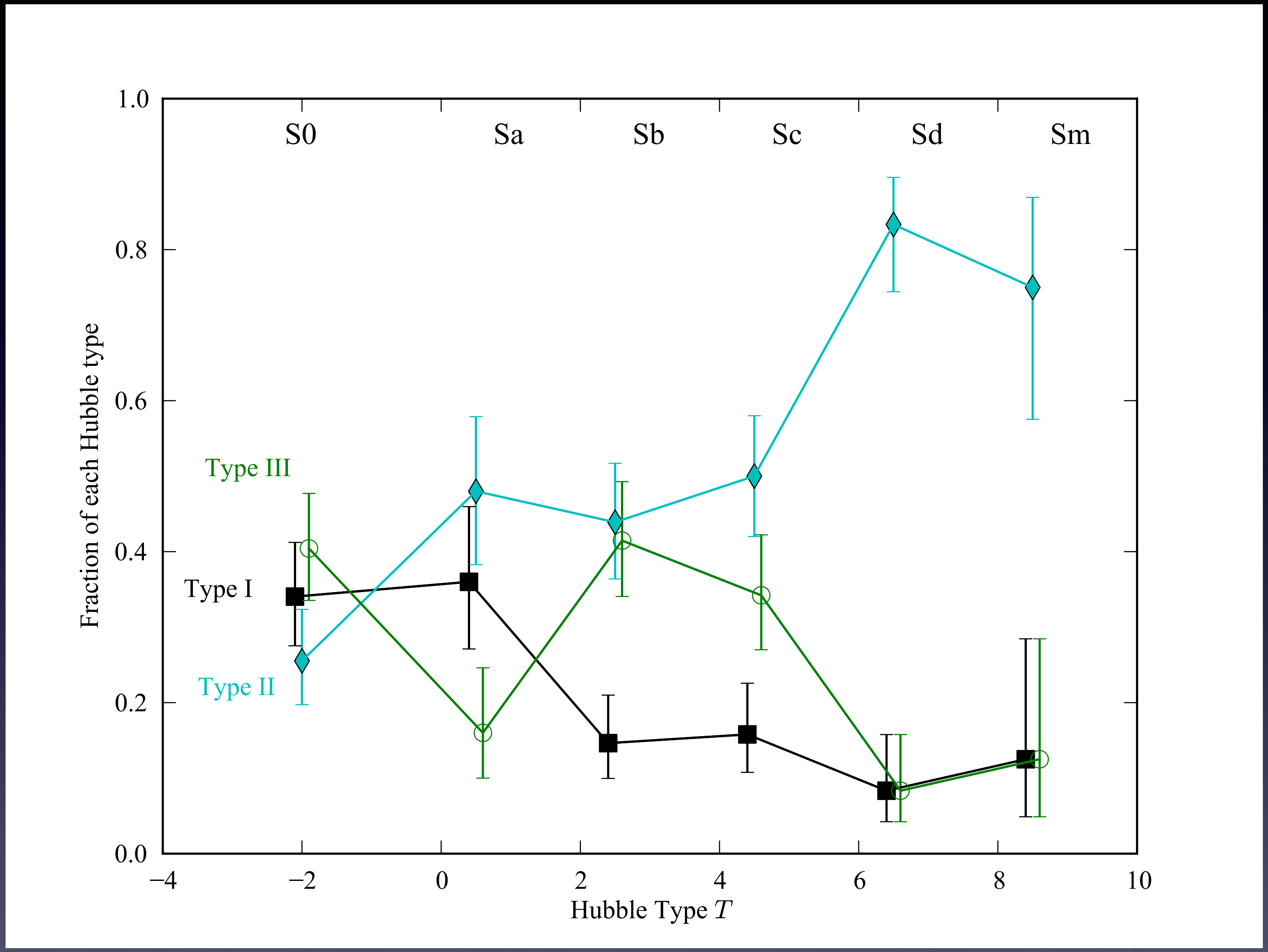
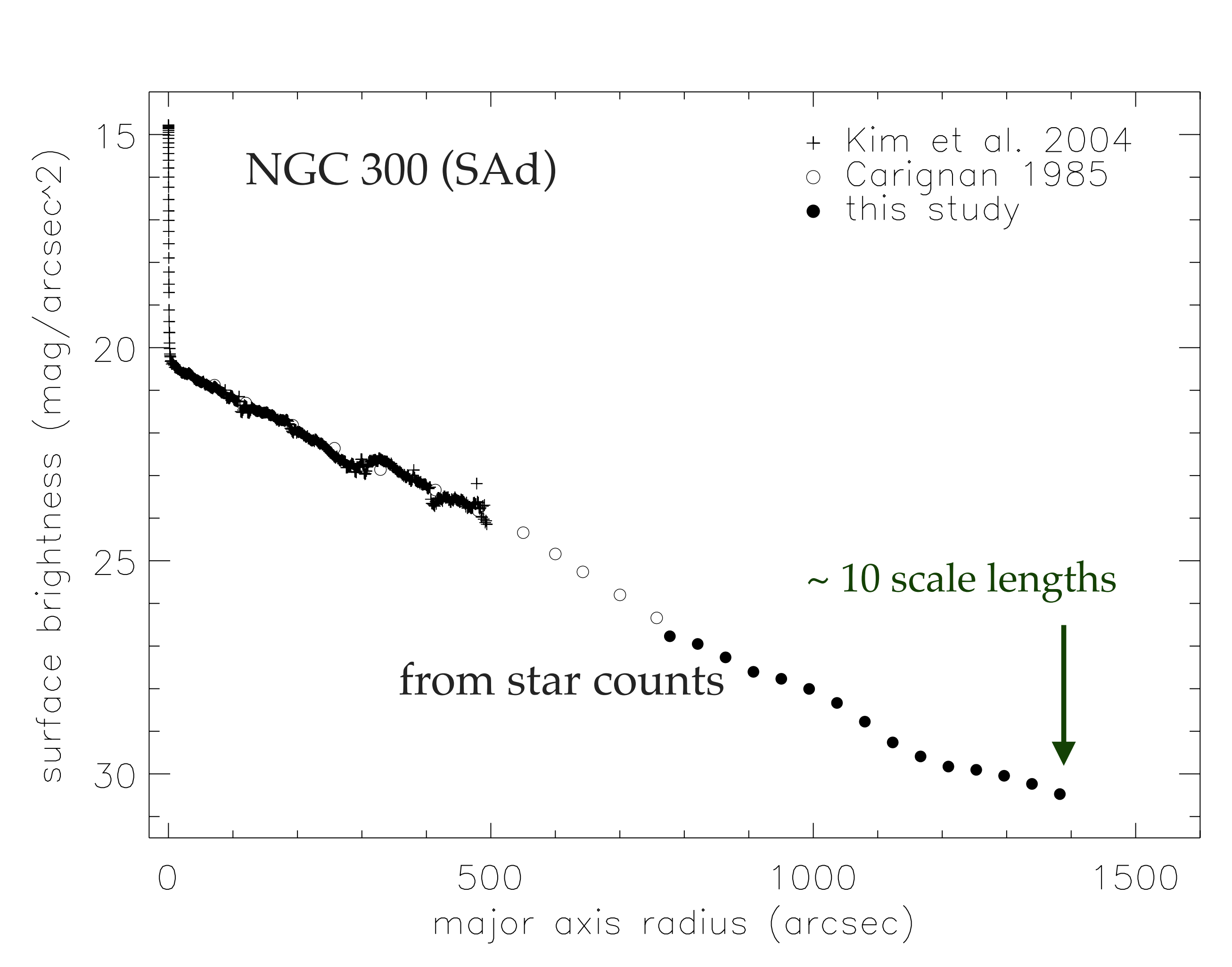
Profile Types vs Hubble Type



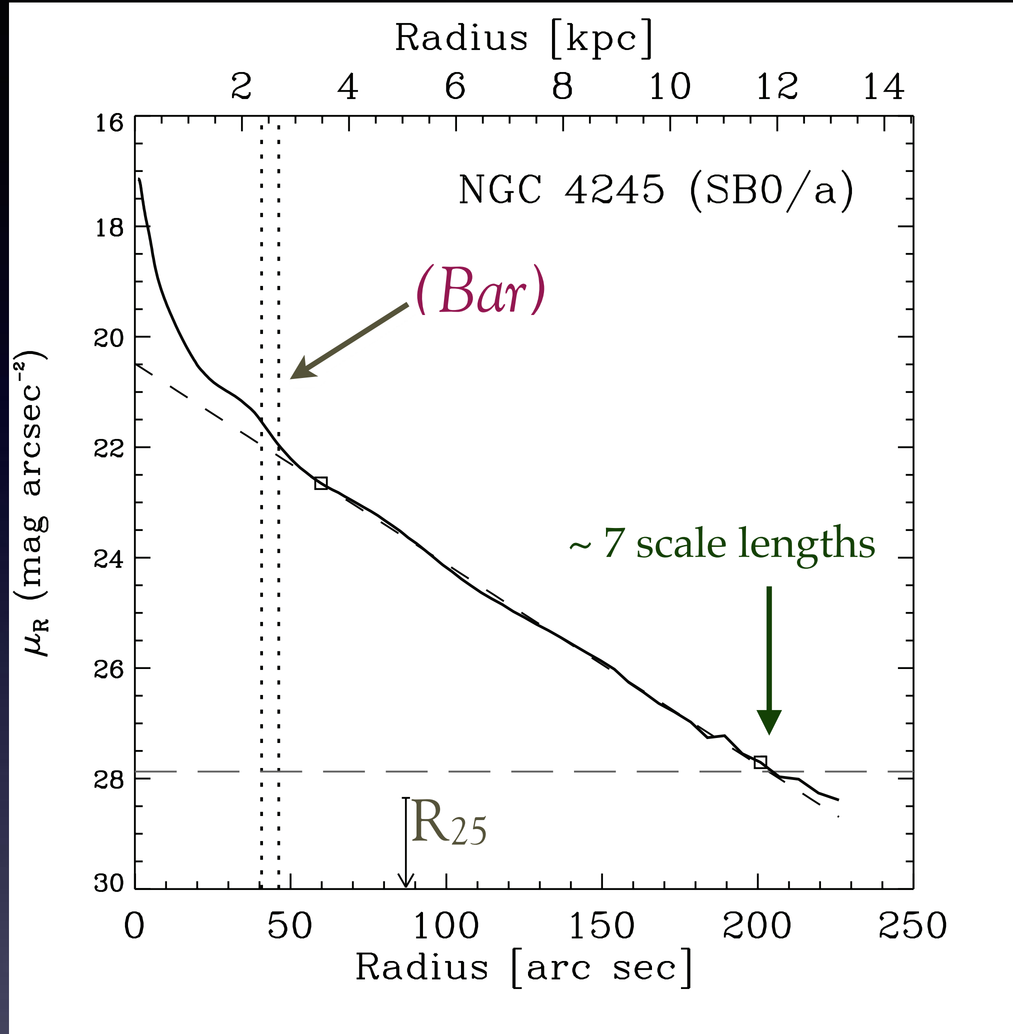
Gutiérrez+2011 (incl. data from Pohlen & Trujillo 2006, Erwin+2008)

Type I favor early types; late-type spirals are predominately Type II
Similar results found with S4G data by Muñoz-Mateos+2013
(Laine+2016 find high Type I fraction in late types – missing Type III due to SB limits?)
Late-type dwarfs (Sm, Im, BCDs): Herrmann+2013 find 8%, 61%, 16% for Types I, II, III

Type I (No Break): Simplest Case



Bland-Hawthorn+2005



Erwin+2008

Classic single-exponential disk (e.g., Freeman 1970)

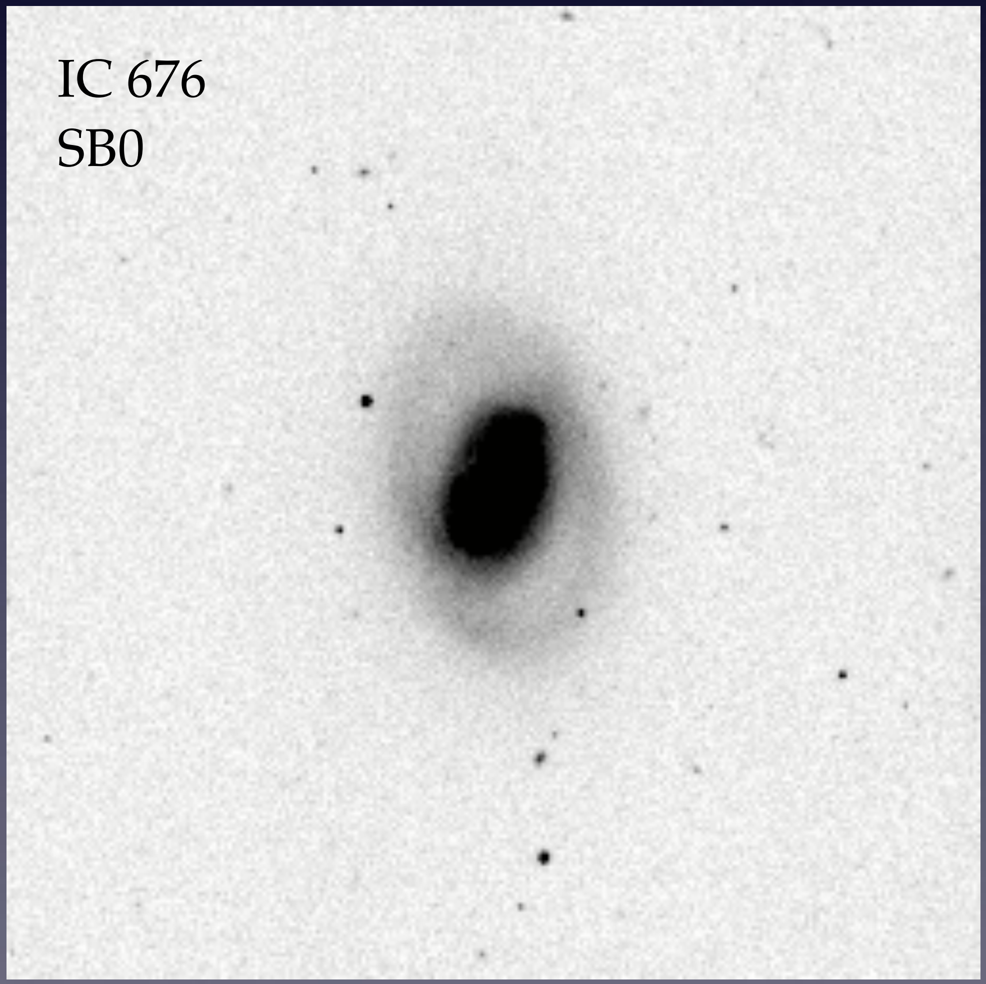
21% of local bright (M_B < -18.4) S0–Sm galaxies; most common in S0–Sa

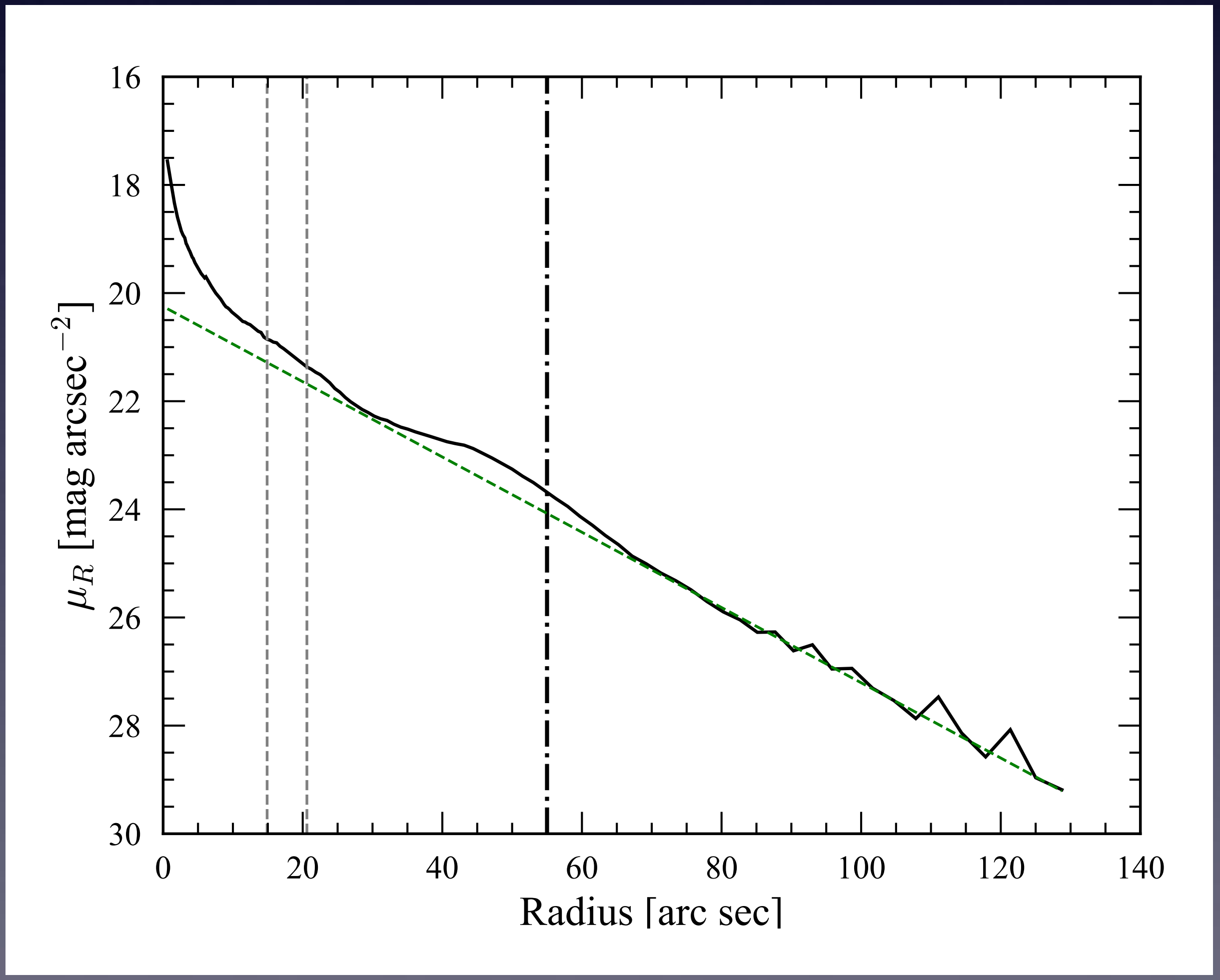
Some, at least, are quite extended: no breaks visible out to limits of ~ 8.5 scale lengths (Barton & Thompson 1997; Hunter+2011) and even 10–11 scale lengths (Weiner et al. 2001; Bland-Hawthorn et al. 2005; Vlajic et al. 2011)

Rings and Type I Profiles

Yes, rings are found in Type I profiles

43±8% of Type I profiles in S0–Sb have outer rings





Outer ring identifications and sizes mostly from Comerón+2014

Type II Breaks and Outer Rings

Rings as False Breaks

Warning: Outer rings can potentially create the illusion of breaks in profiles, especially for edge-on galaxies (where we cannot see rings directly!) and shallow exposures

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Integration along line of sight through 3D models of disk with broken-exponential radial profile (black) and exponential disk + circular Gaussian ring (red), using Imfit [Erwin 2015; github.com/perwin/imfit]

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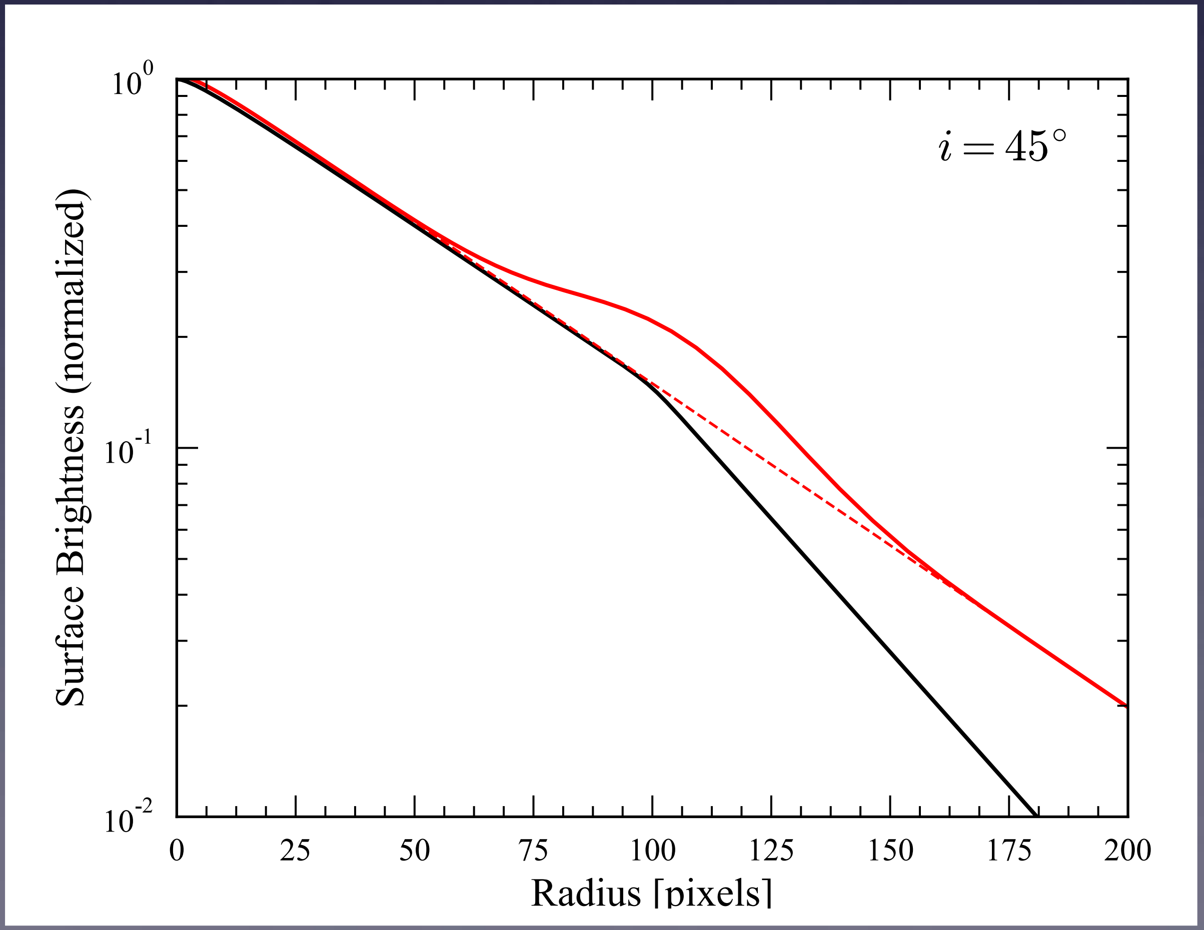

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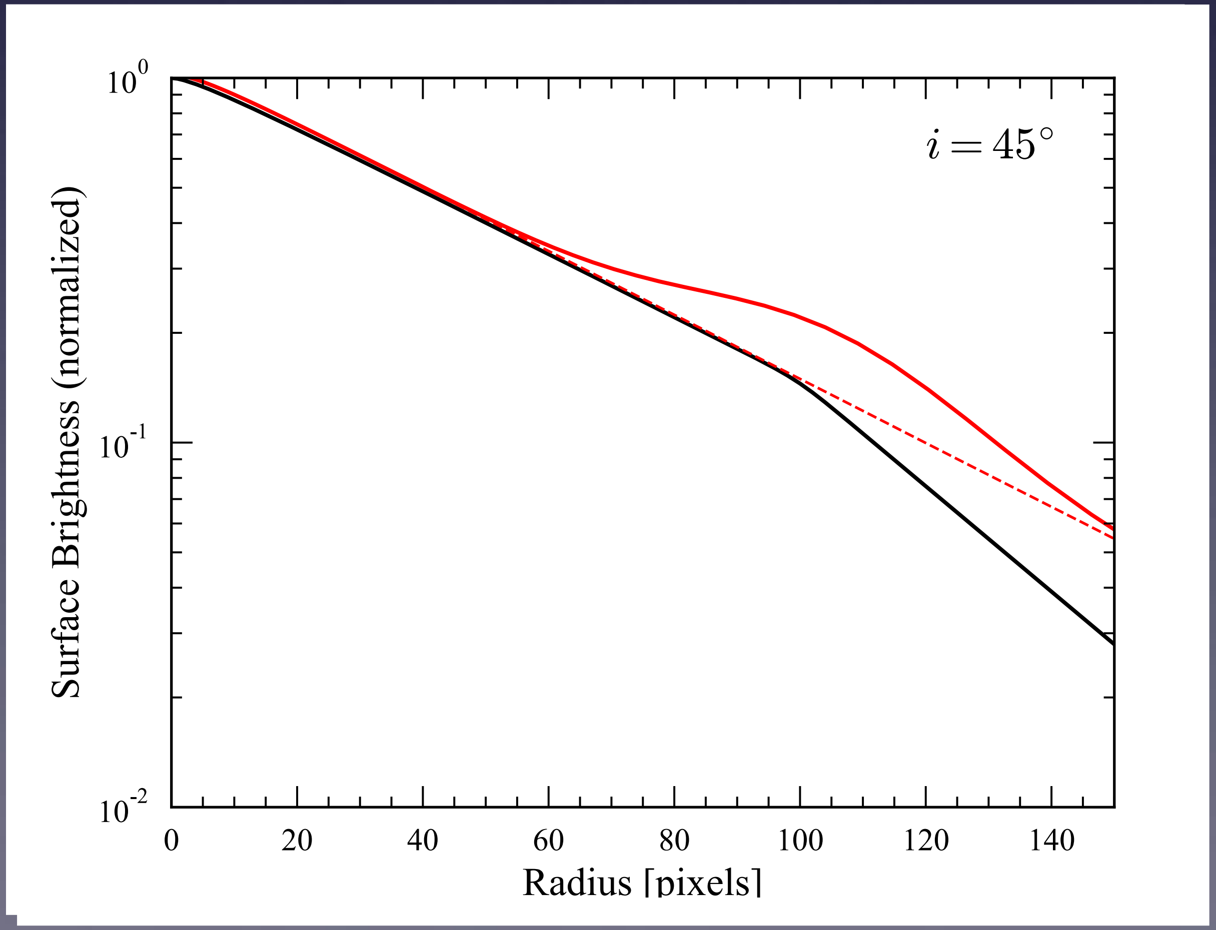

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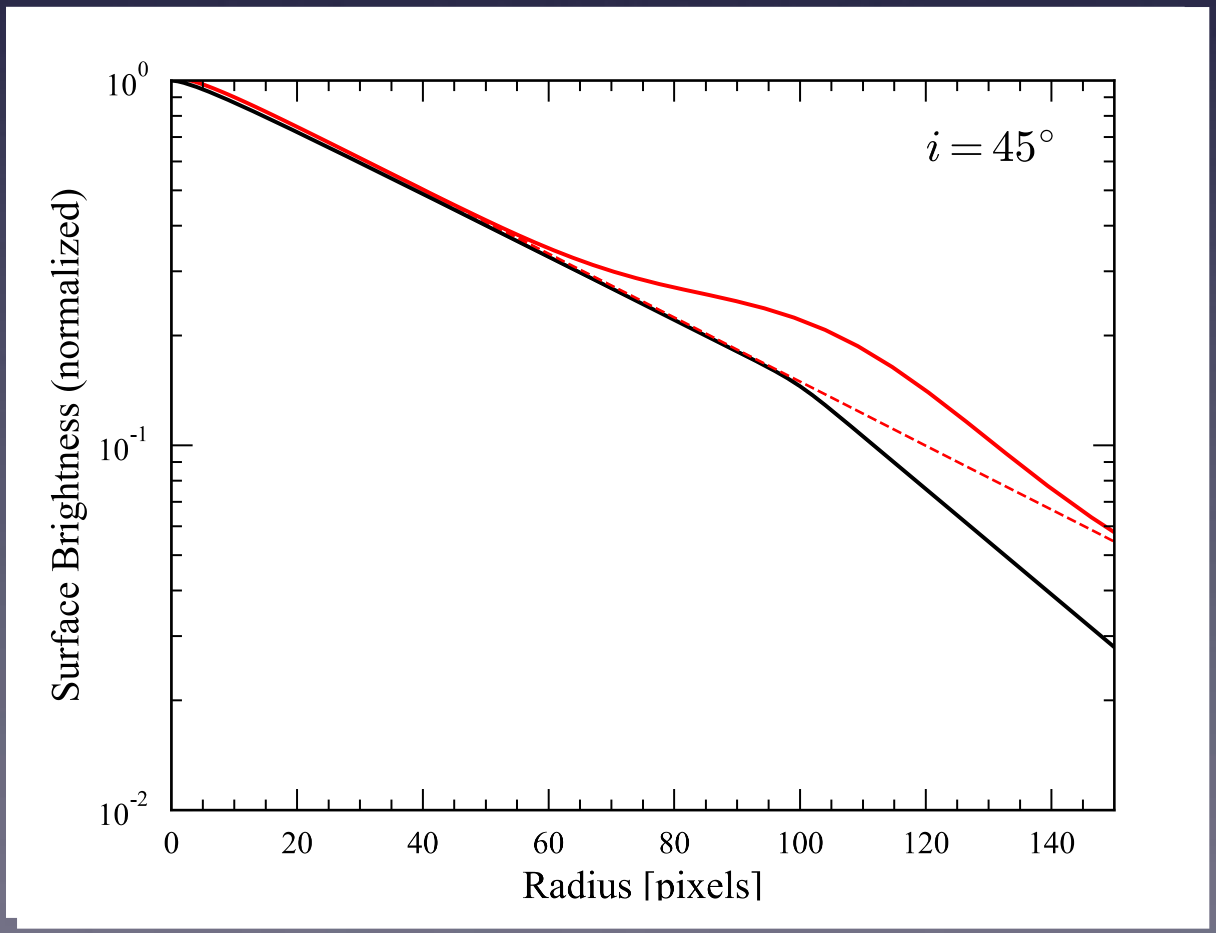

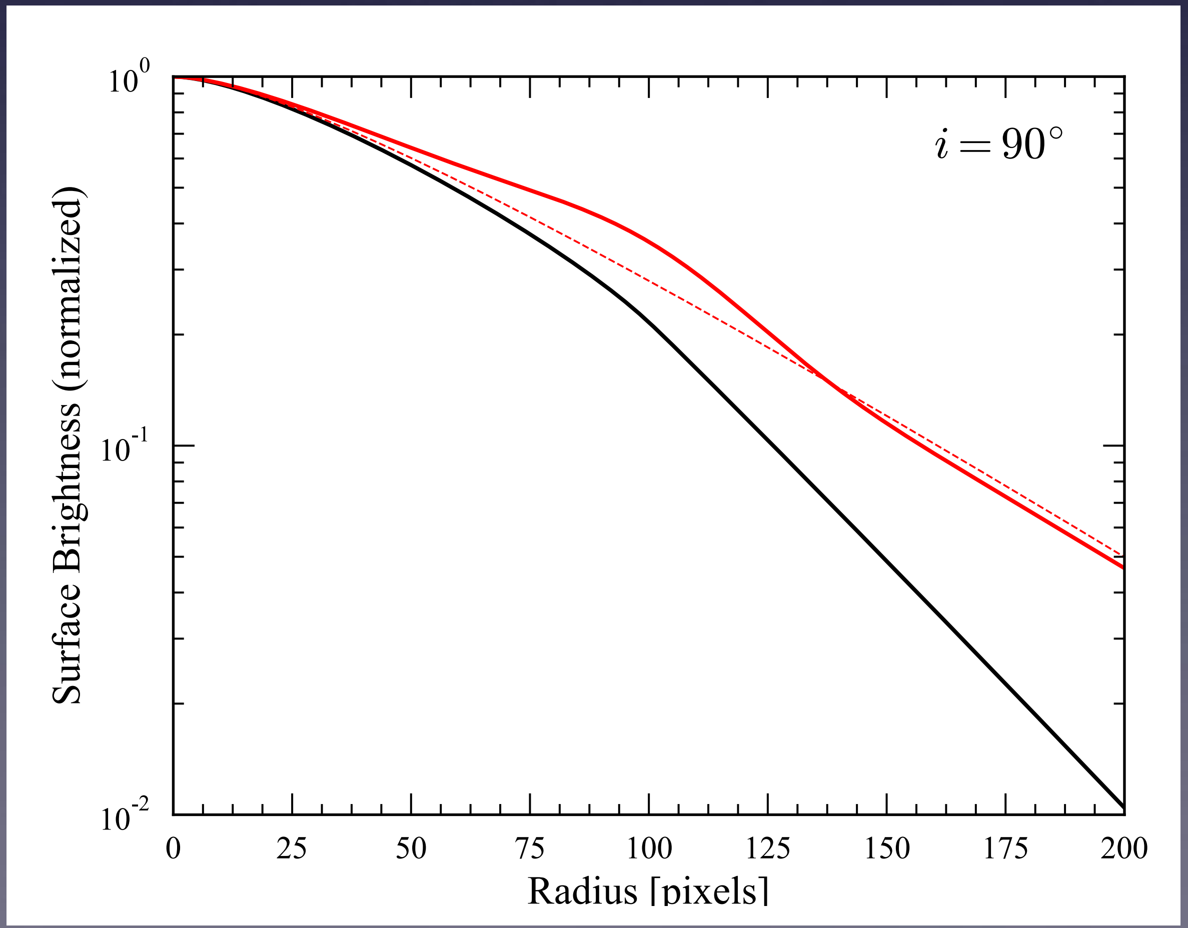

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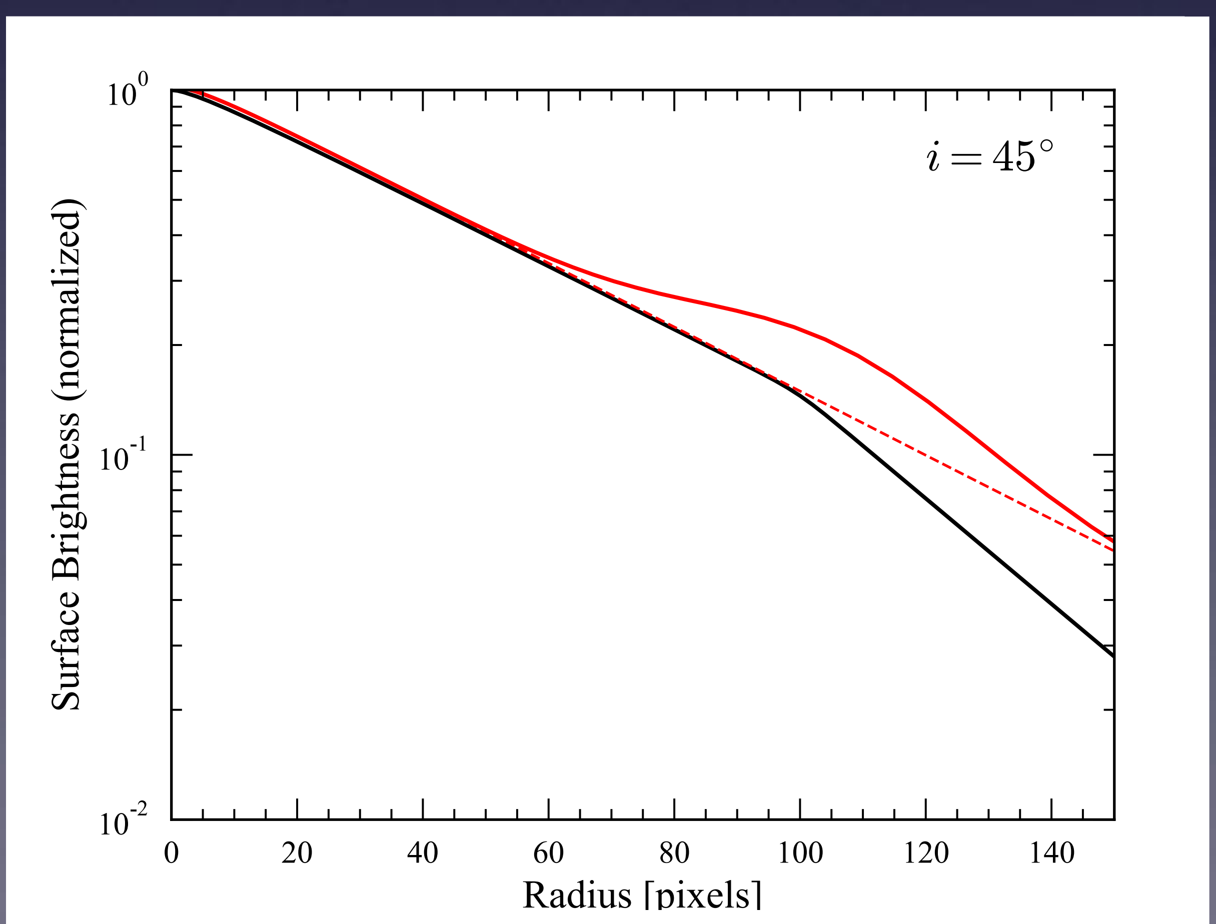

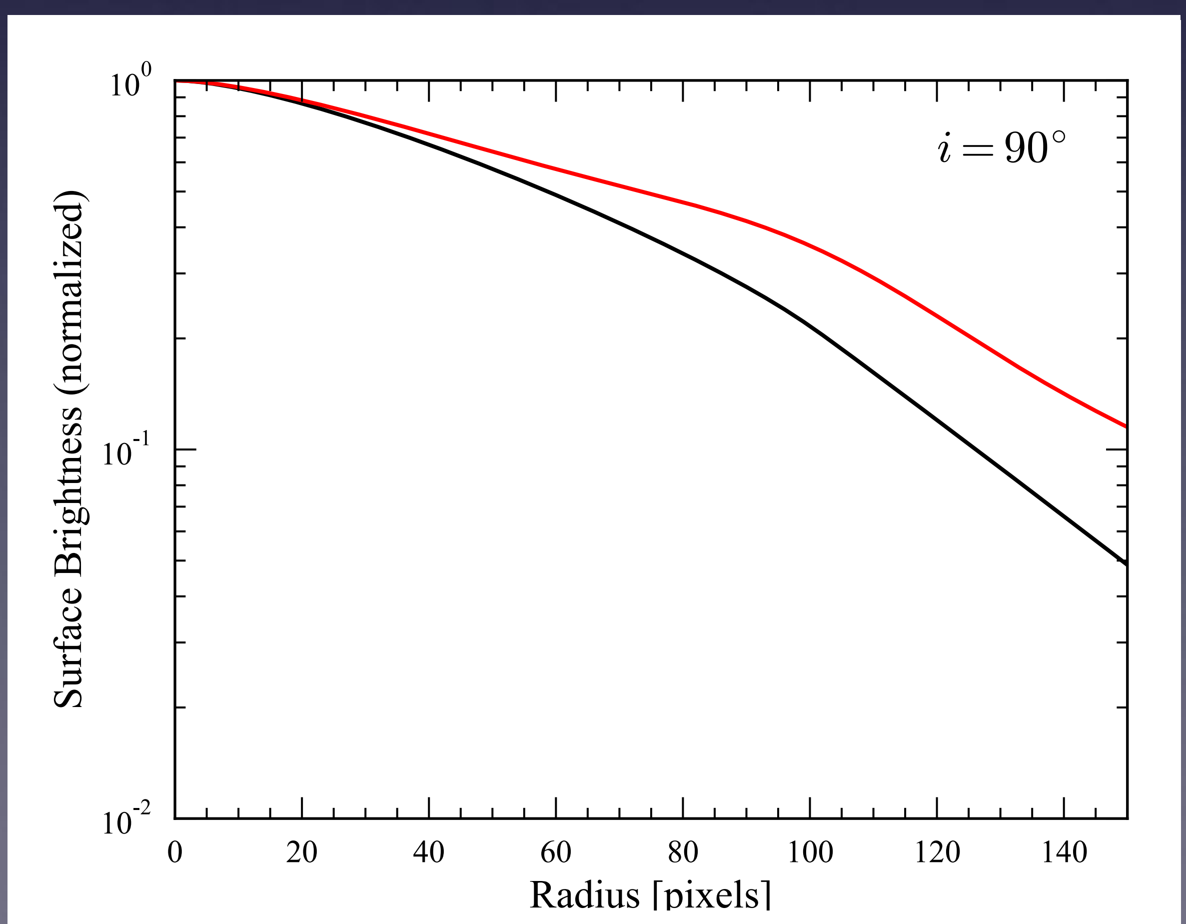

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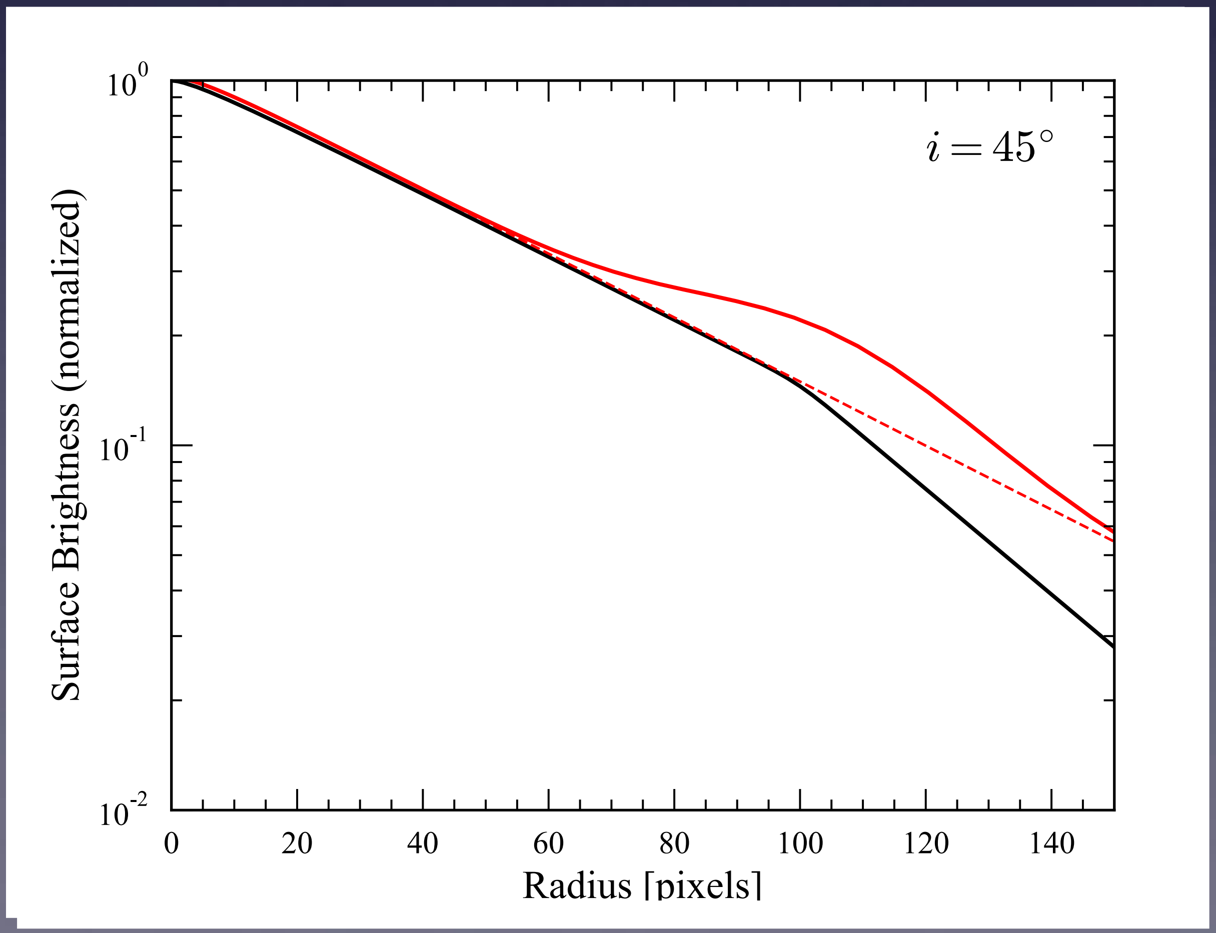
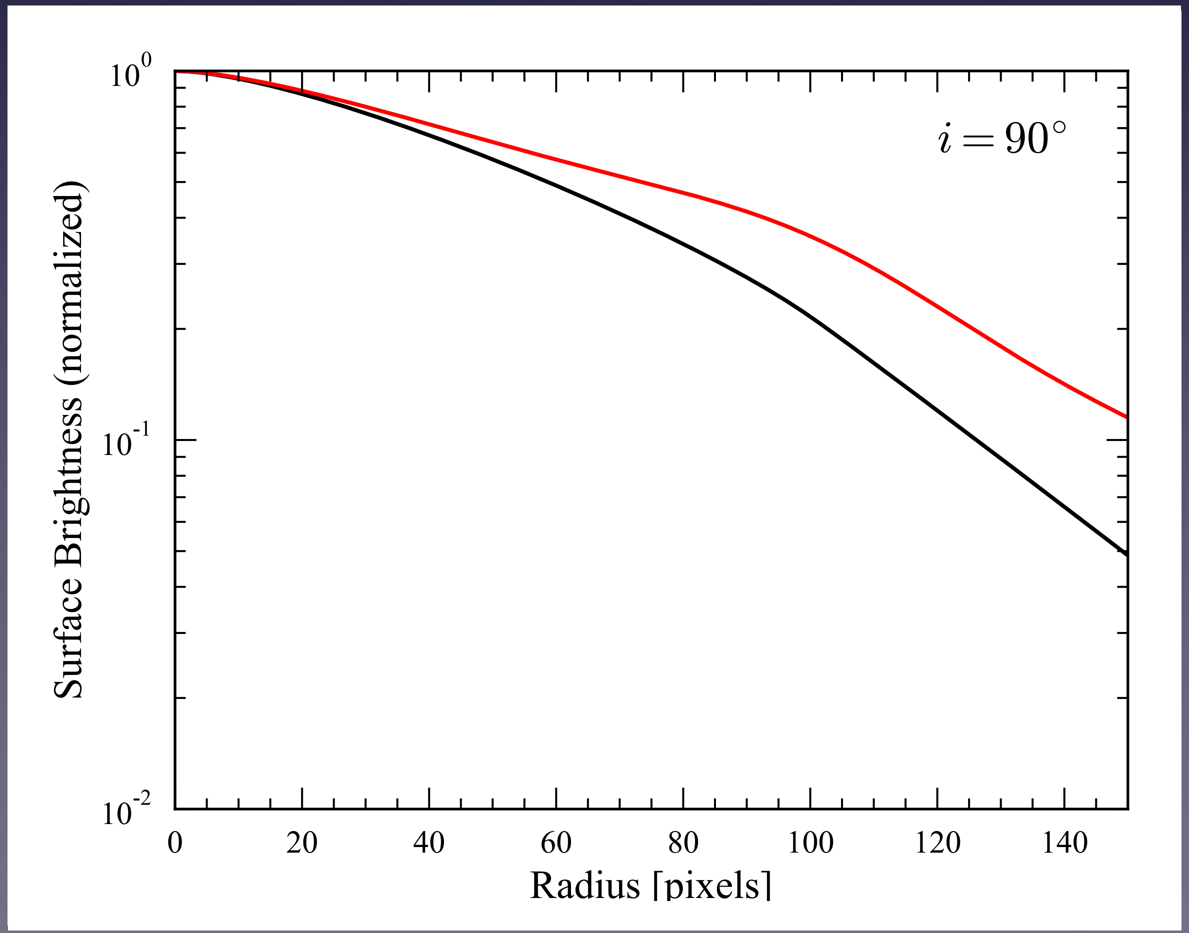
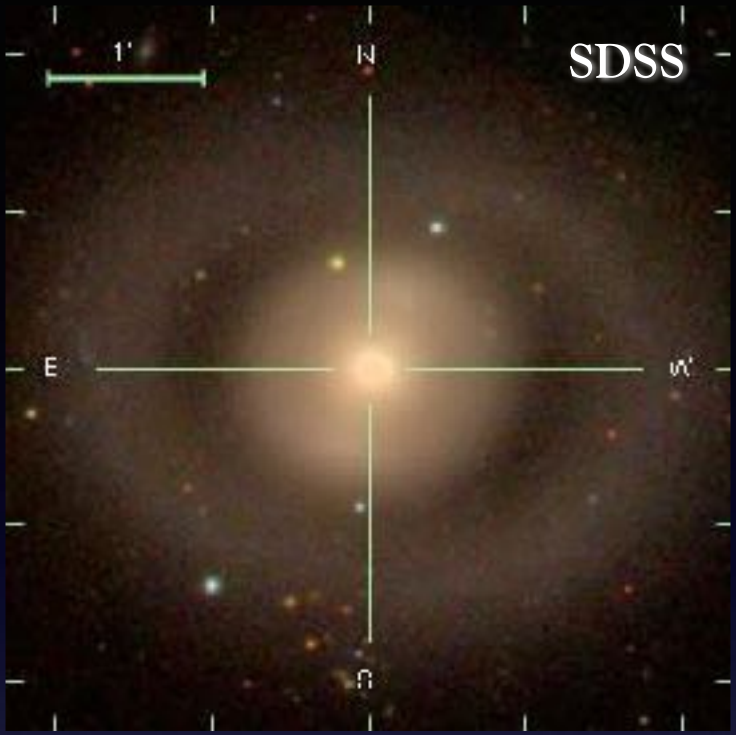
Suggestion: Look at low-to-moderate-inclination galaxies!

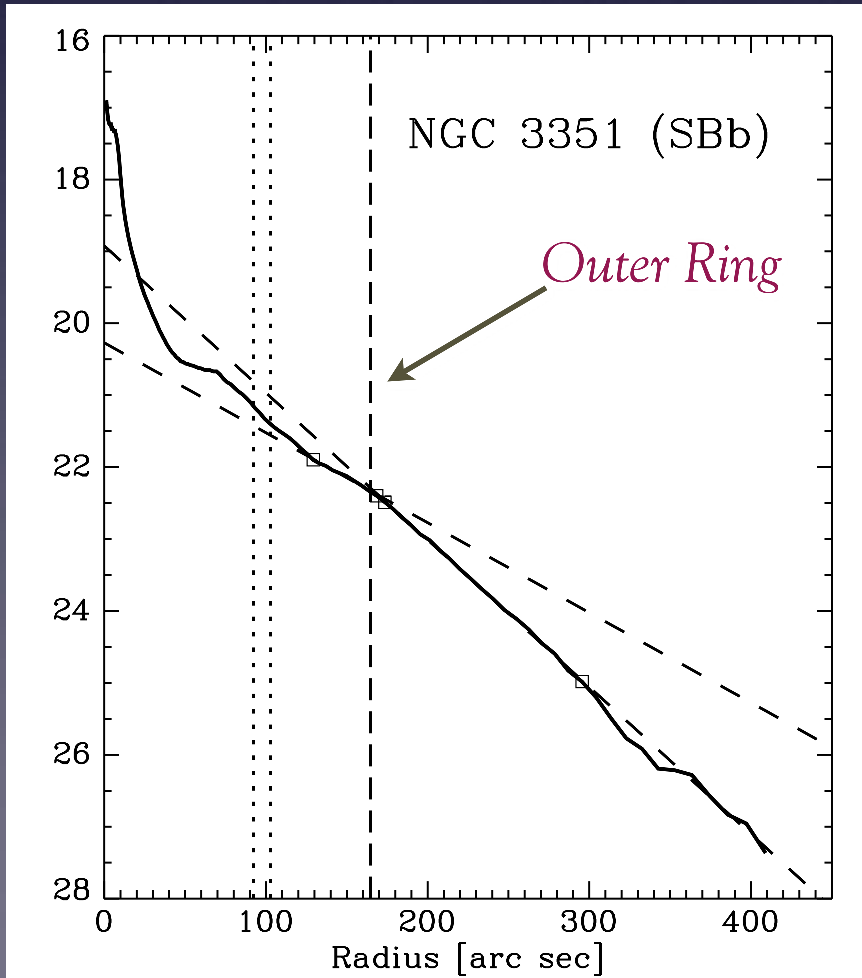




Type II breaks: Linked to Outer Rings (and Outer Lindblad Resonance?)



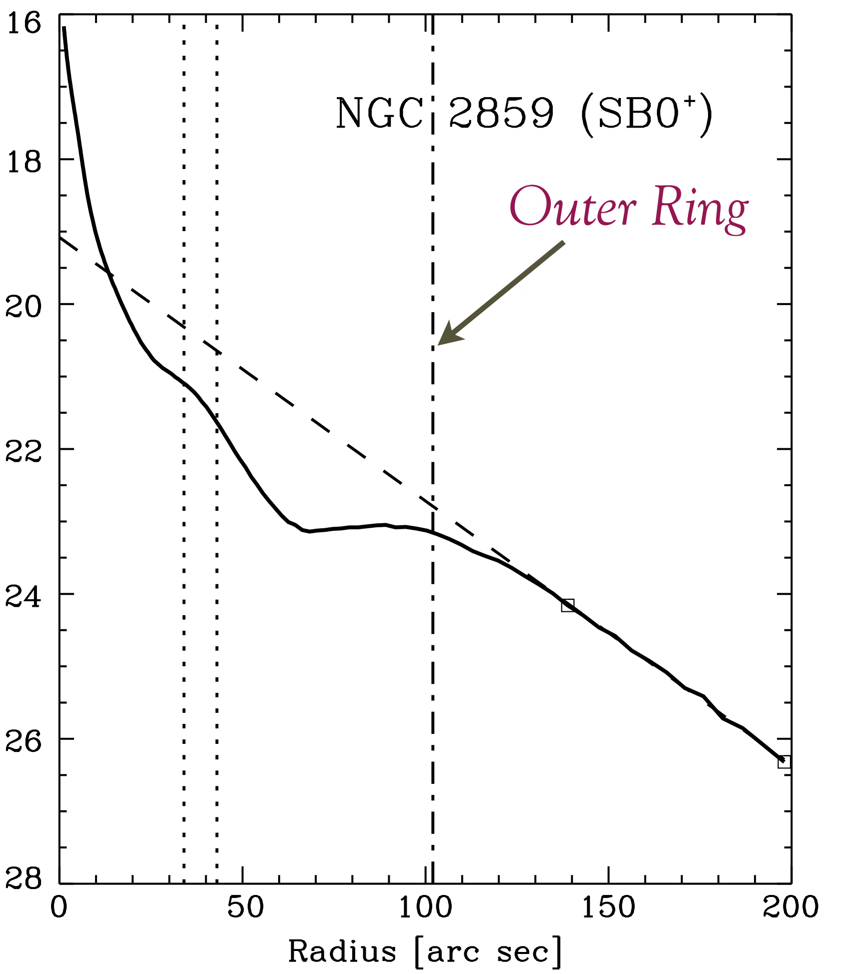
“Normal” Outer Rings



In ~ 45% of barred S0-Sb Type II profiles, break coincides with a visible outer ring.

Laine+14: 48% of S0–Sab Type II breaks correspond with outer rings/pseudorings/“ringlenses”

“Extreme” Outer Rings



As a Population

50±7% of Type II profiles in S0–Sb have outer rings

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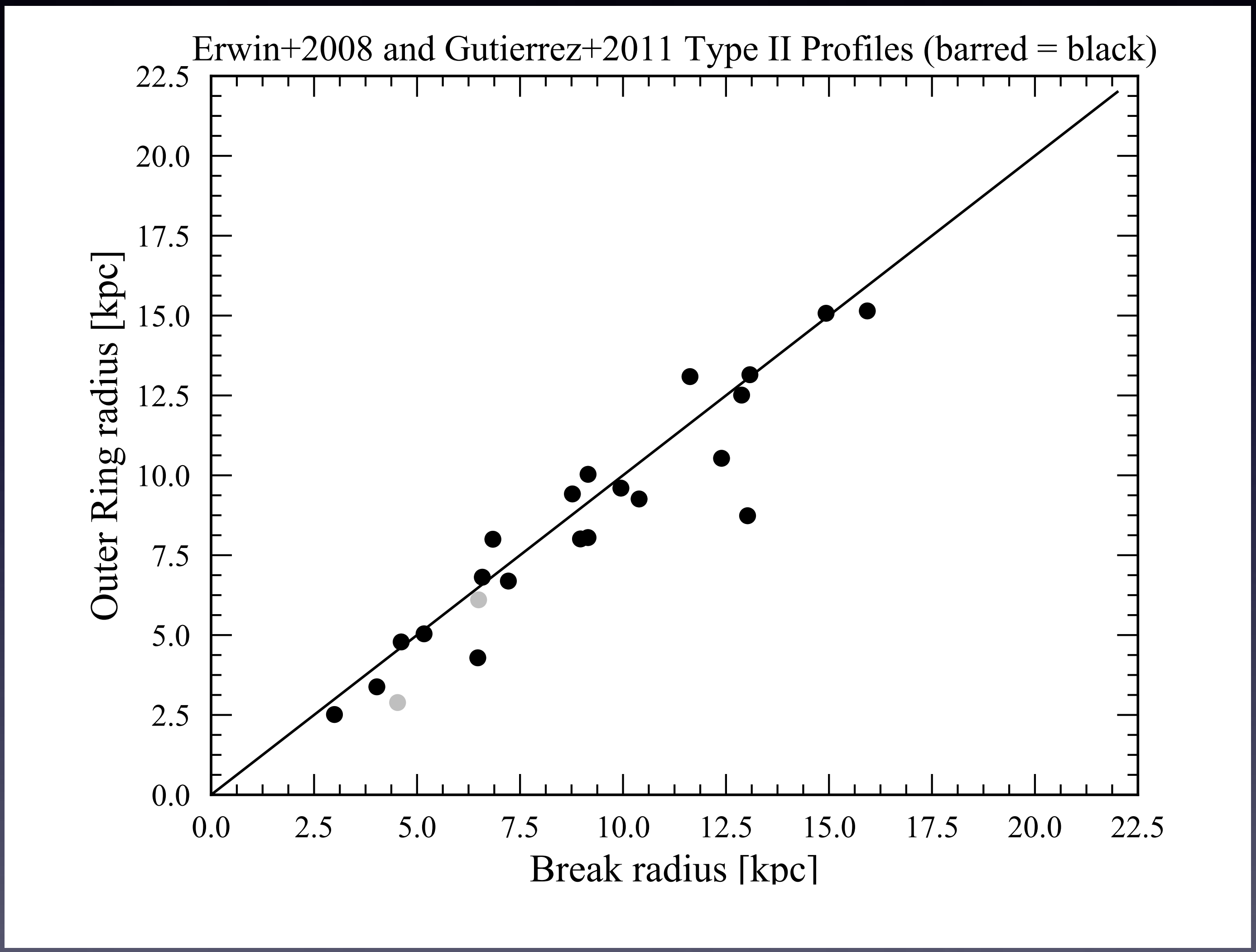

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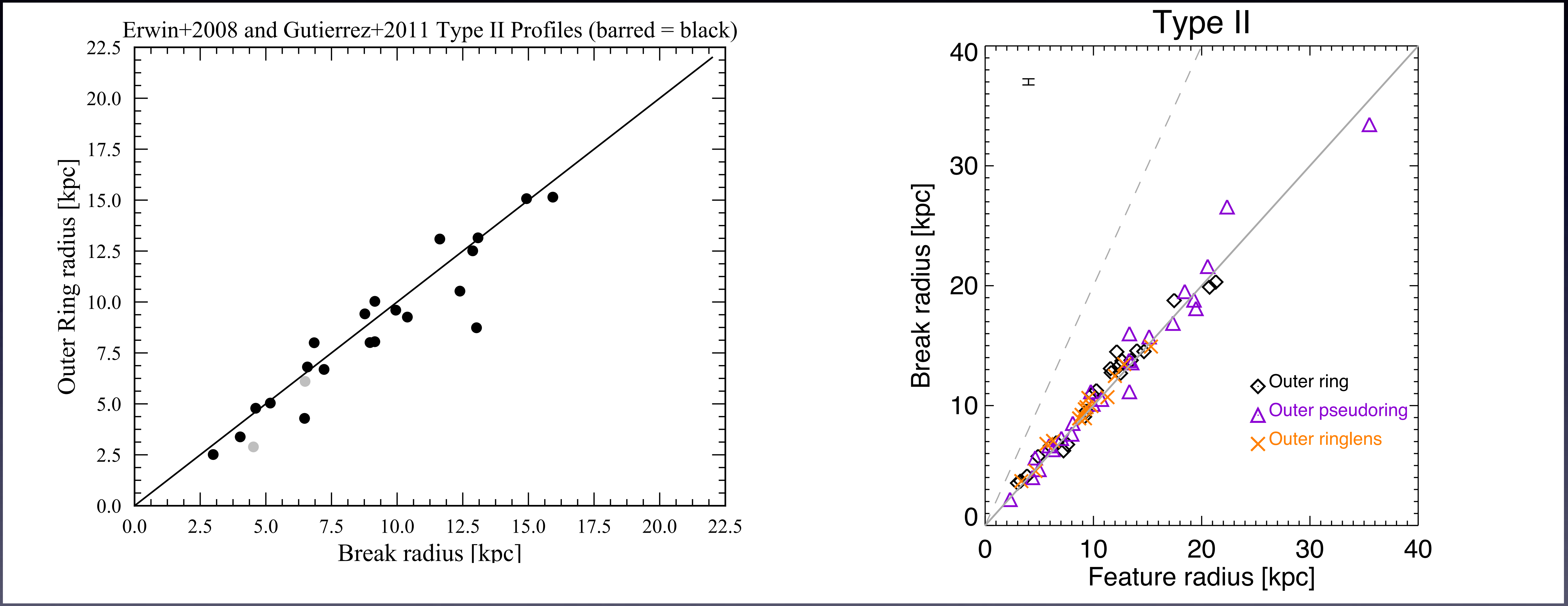

Laine+2014 (S4G)

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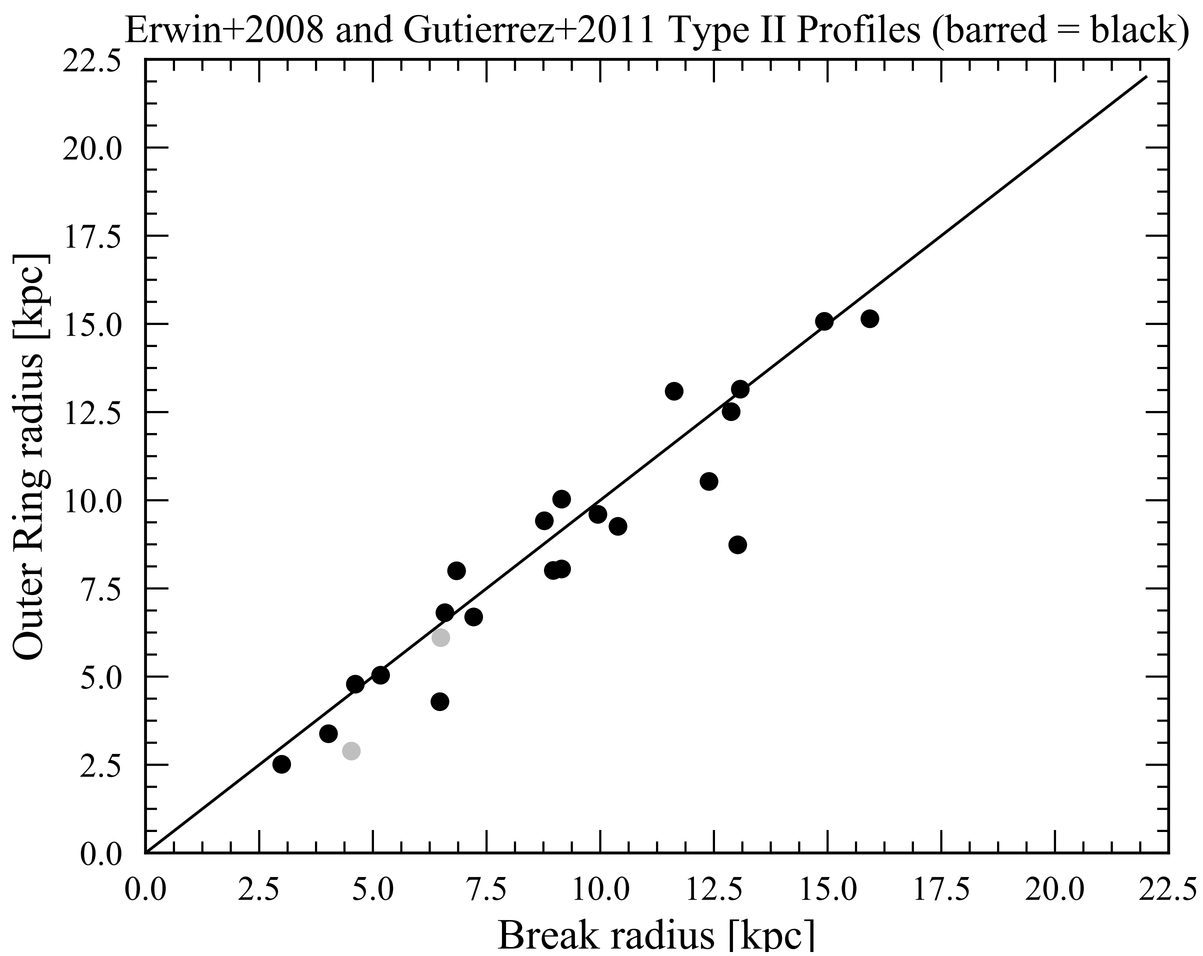

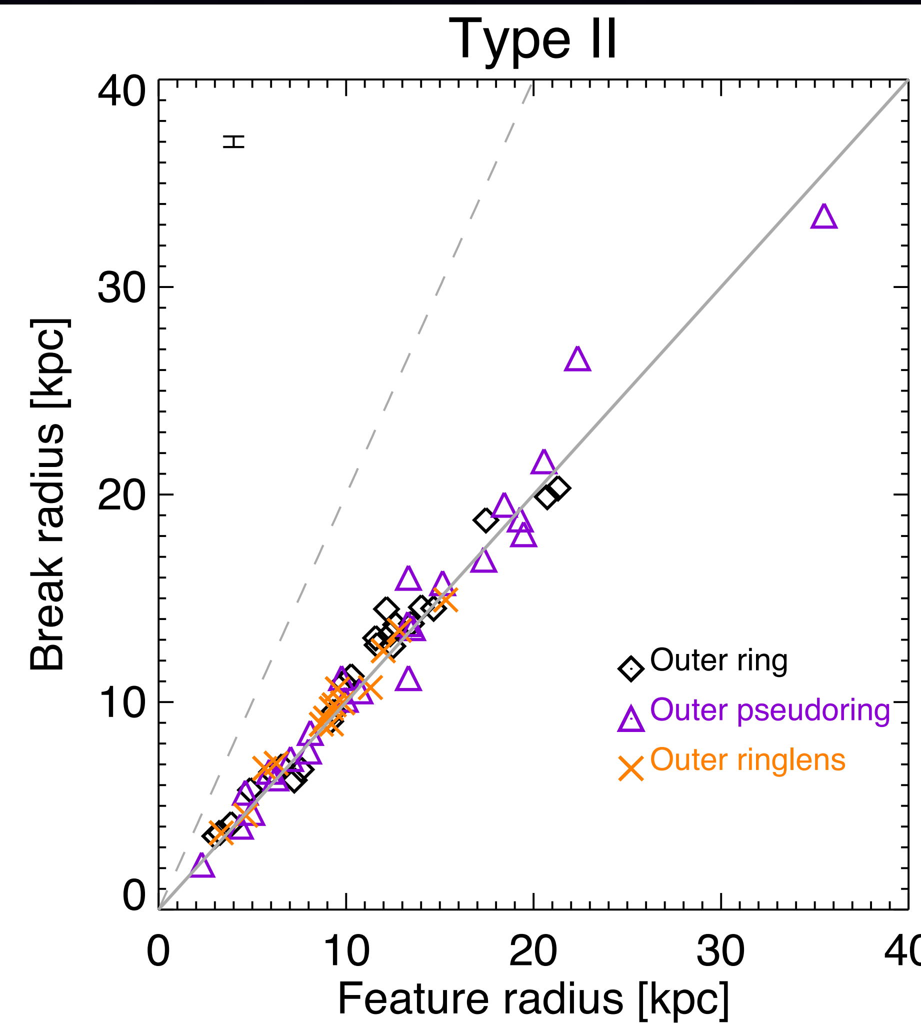

Laine+2014 (S4G)

Outer ring sizes strongly correlate with Type II breaks!

OLR Breaks and Faded Rings?

Hypothesis: most breaks in early-type disks are related to bar's OLR ("Type II-OLR" breaks; Erwin+2008) – even when there's no visible outer ring

Type II profiles without outer rings: ring is old / faded?

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Type II profiles without outer rings: ring is old / faded?

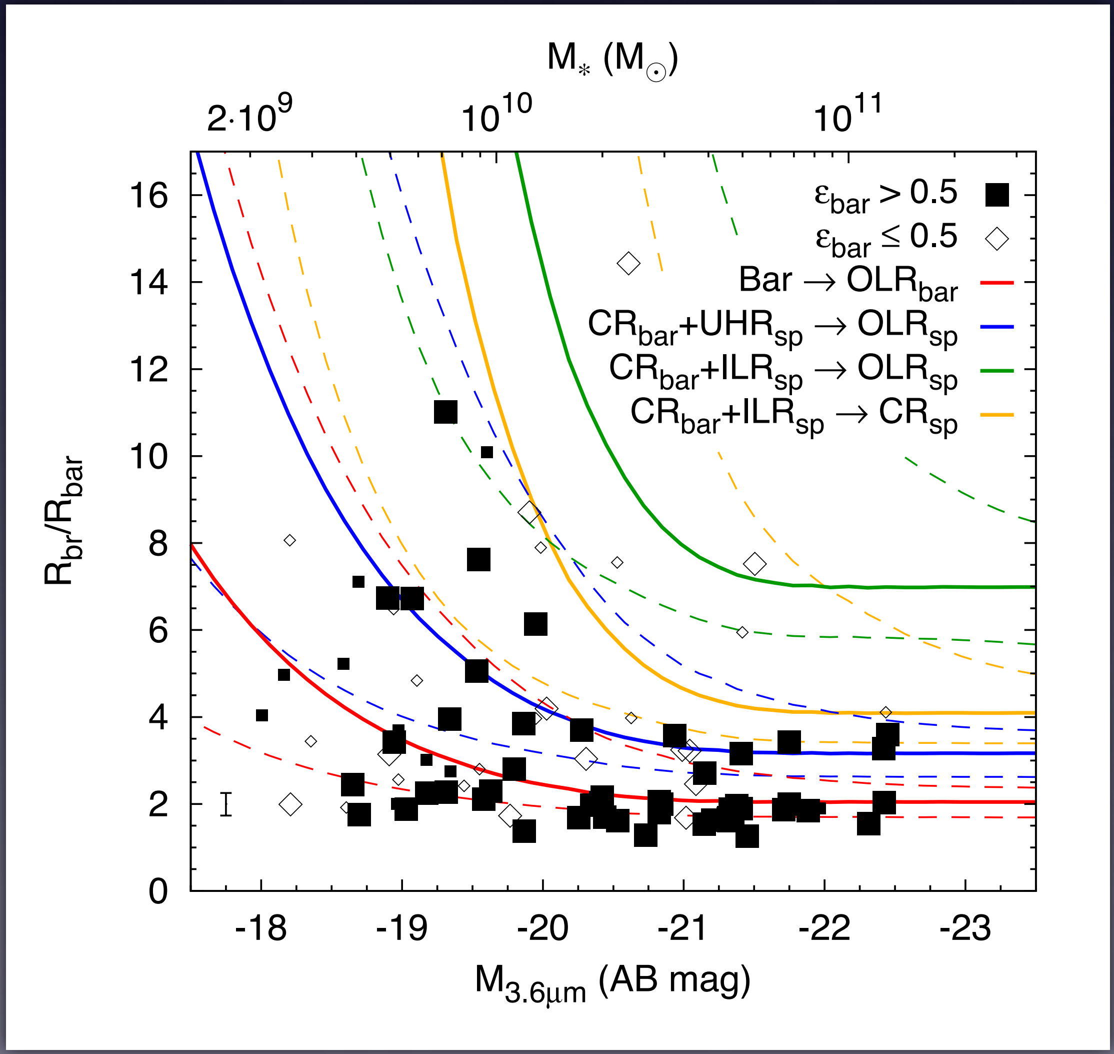
Muñoz-Mateos+2013 (S4G Spitzer IRAC)

R_brk is typically ~ 2 R_bar, consistent with bar OLR

(red curve: OLR assuming corotation at 1.2 R_bar + Leroy+2008 rotation curve as fn. of M_3.6)

BUT:

- some breaks are at ~ 3–4 R_bar – consistent with coupled spiral OLR; Debattista+2006?
- Some breaks in low-mass galaxies are very far out

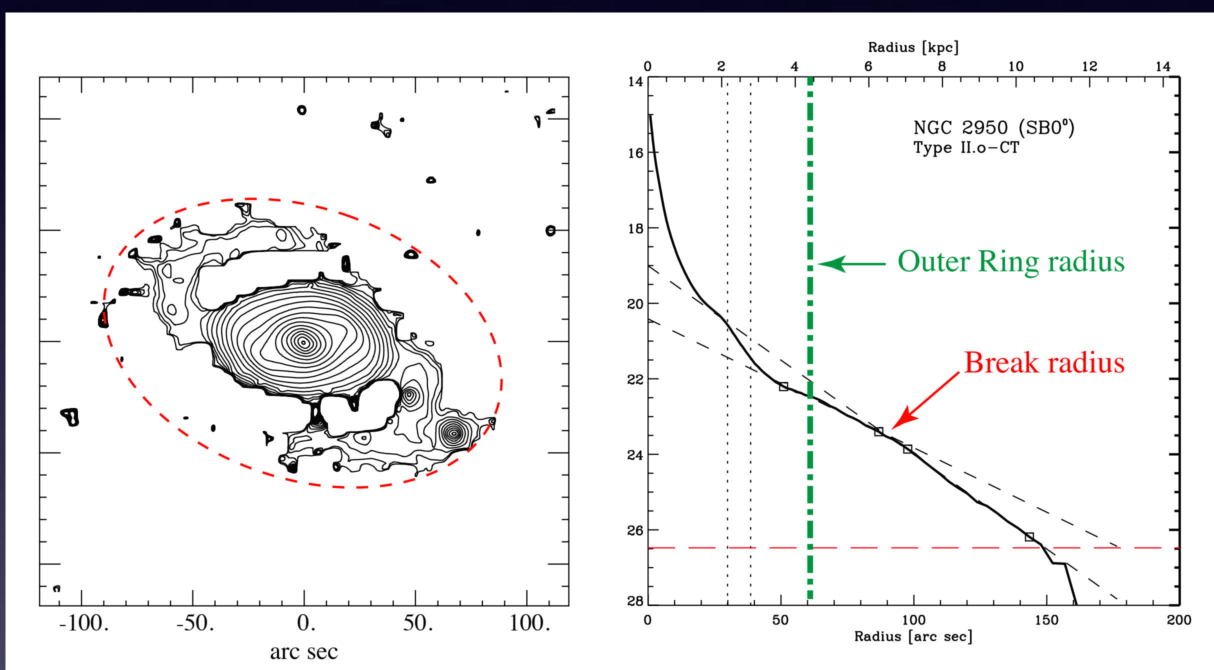


Exceptions!

- Type I profiles have outer ring without any breaks
- Type II breaks outside an outer ring
- Type II profiles without outer rings, *not* associated with bar OLR

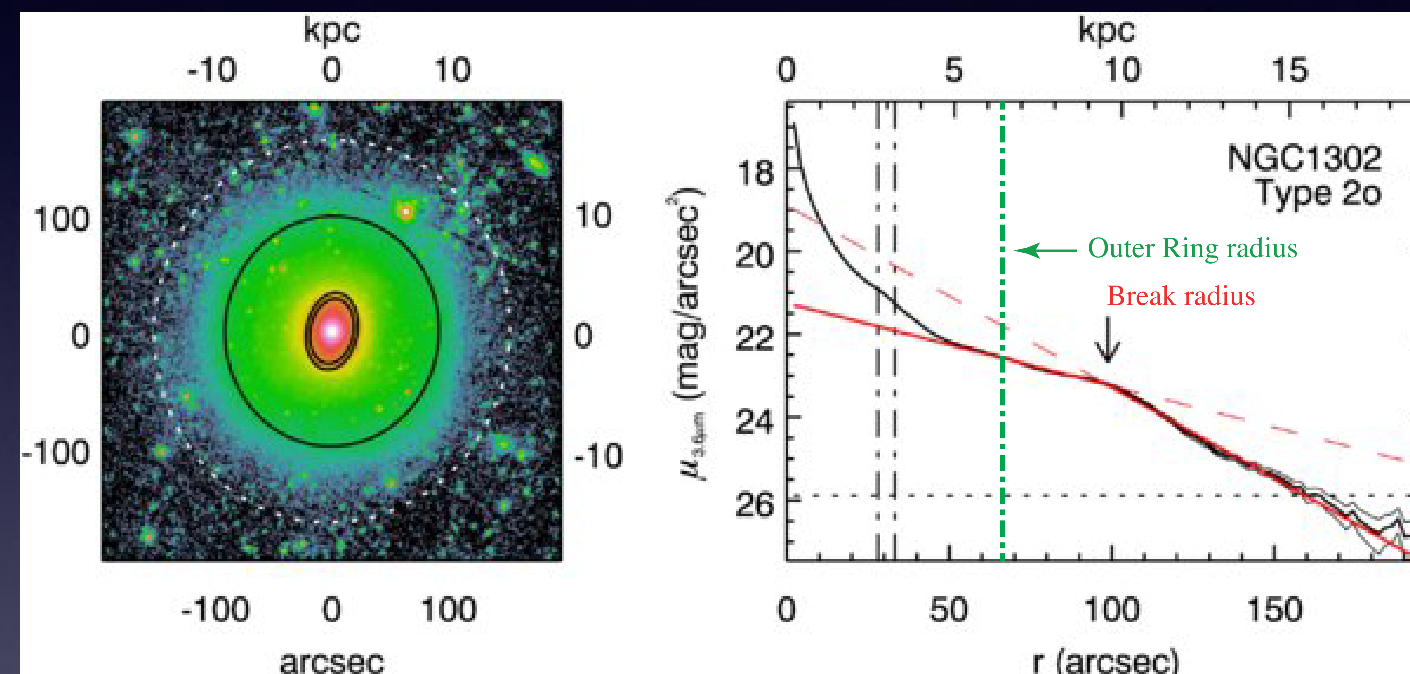
Exceptions: Type II Breaks *Outside* Rings

NGC 2950 (SB0)



Erwin+2008
(exponential disk model subtracted

NGC 1302 (SAB0)



Muñoz-Mateos+2013

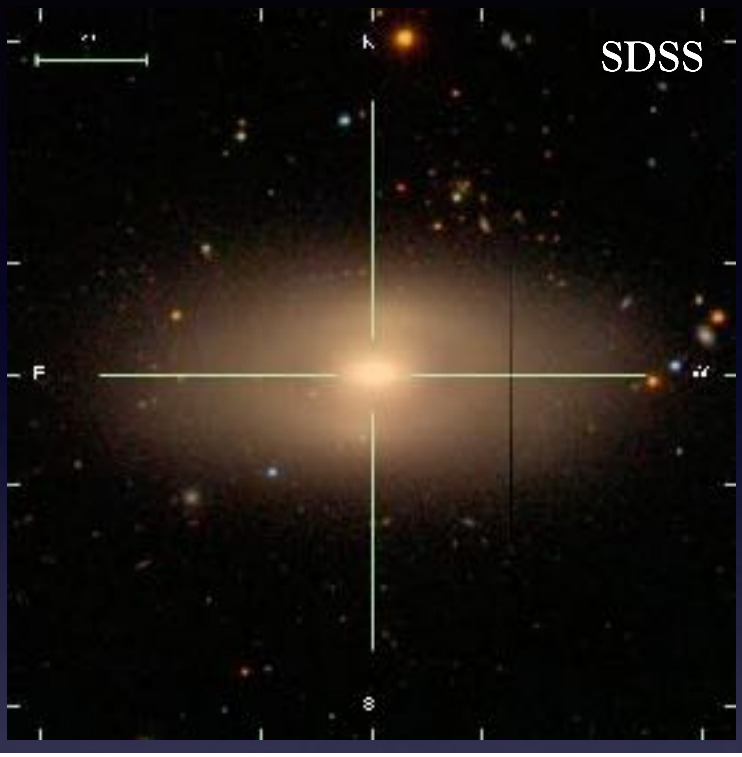
Some early-type barred galaxies with outer rings have Type II break radii *well outside* the ring

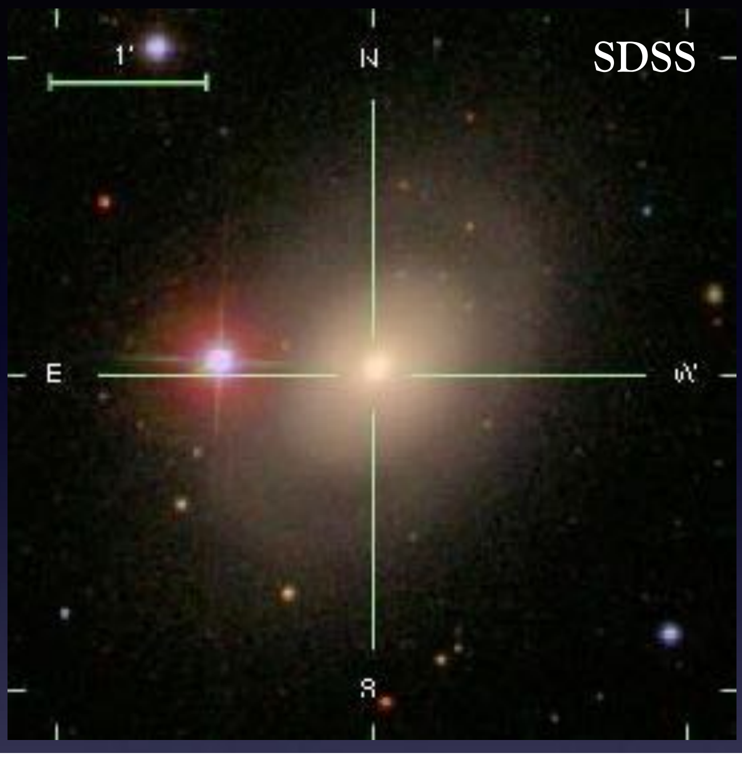
Exceptions: Type II Breaks *without* Rings

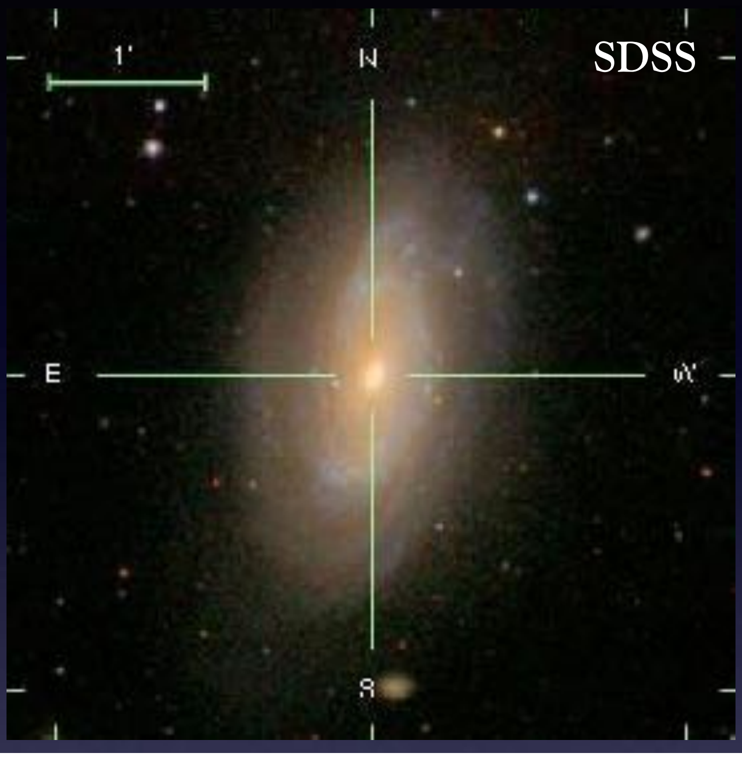
- The majority of low-mass, late-type (Sc and later) spirals and dwarfs have Type II profiles
- These galaxies, as a rule, do *not* have outer rings! (outer rings most frequent in S0–Sb)
  - Type II in > 50% of Sc–Sm, but OR in < 10%
- Breaks probably not connected with bar OLR
  - Truncation due to SF cutoff in disk + radial migration of stars?

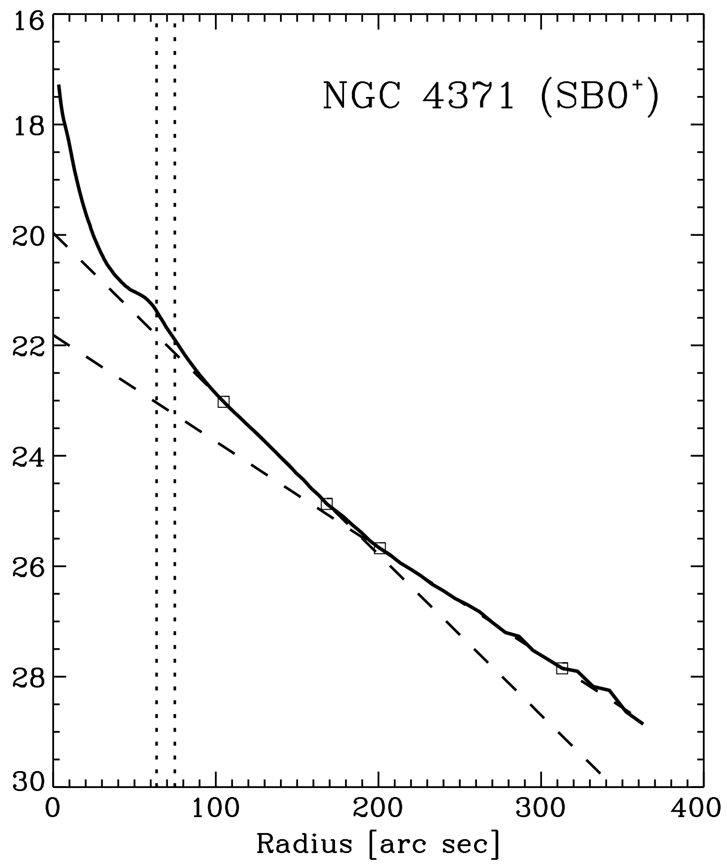
Type III ("Antitruncations")

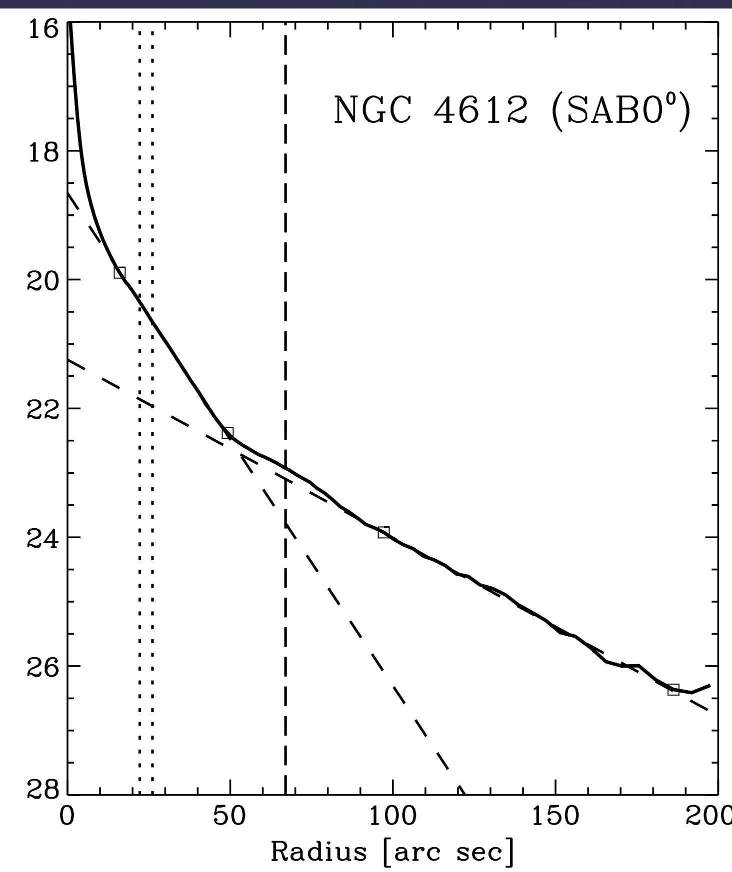
Erwin, Beckman, & Pohlen (2005, ApJL 626: L81)

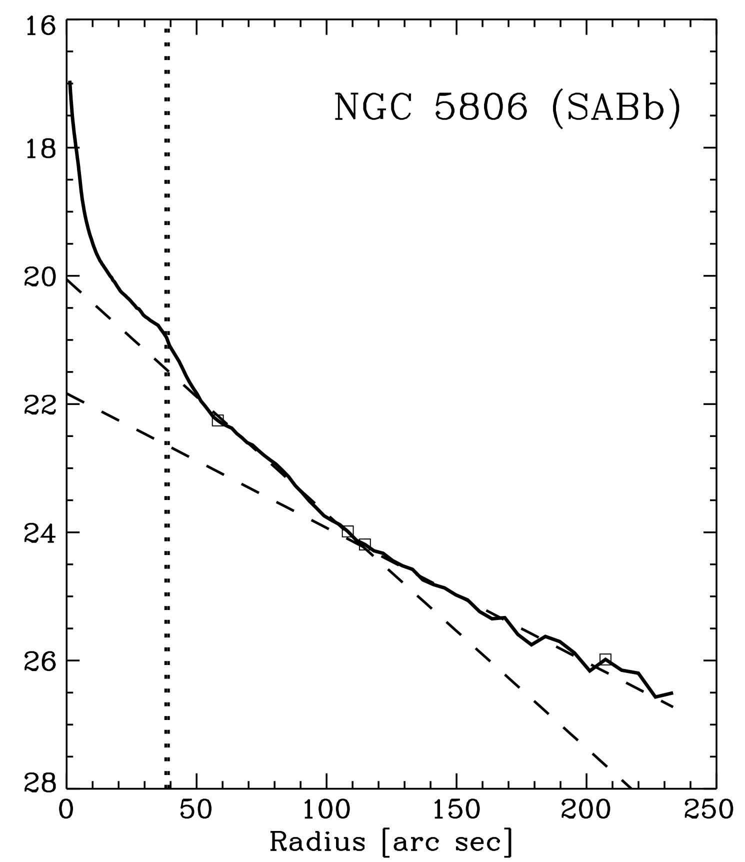












For some galaxies, outer excess light is from a rounder halo ("III-s") ...but for majority, it's still part of the disk ("III-d")

1. Inclined galaxies: outer isophotes ~ same ellipticity as inner disk.

2. Sharp transitions in profile: not sum of 2 exponentials, so prob. not outer bulge or halo light.

3. Spiral structure in outer disk.

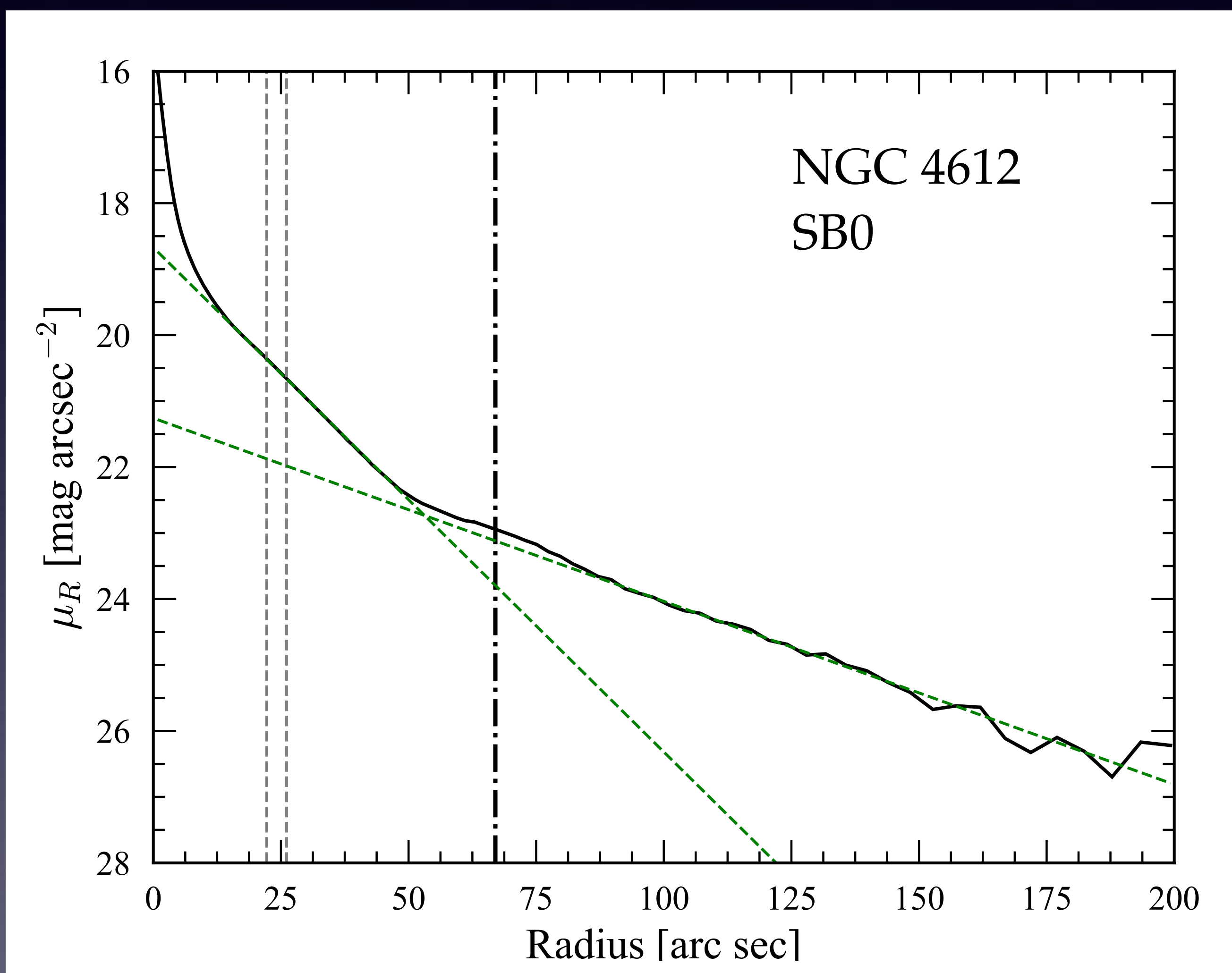
4. Antitruncation seen in *edge-on* disks by Pohlen+2007, Comerón+2012

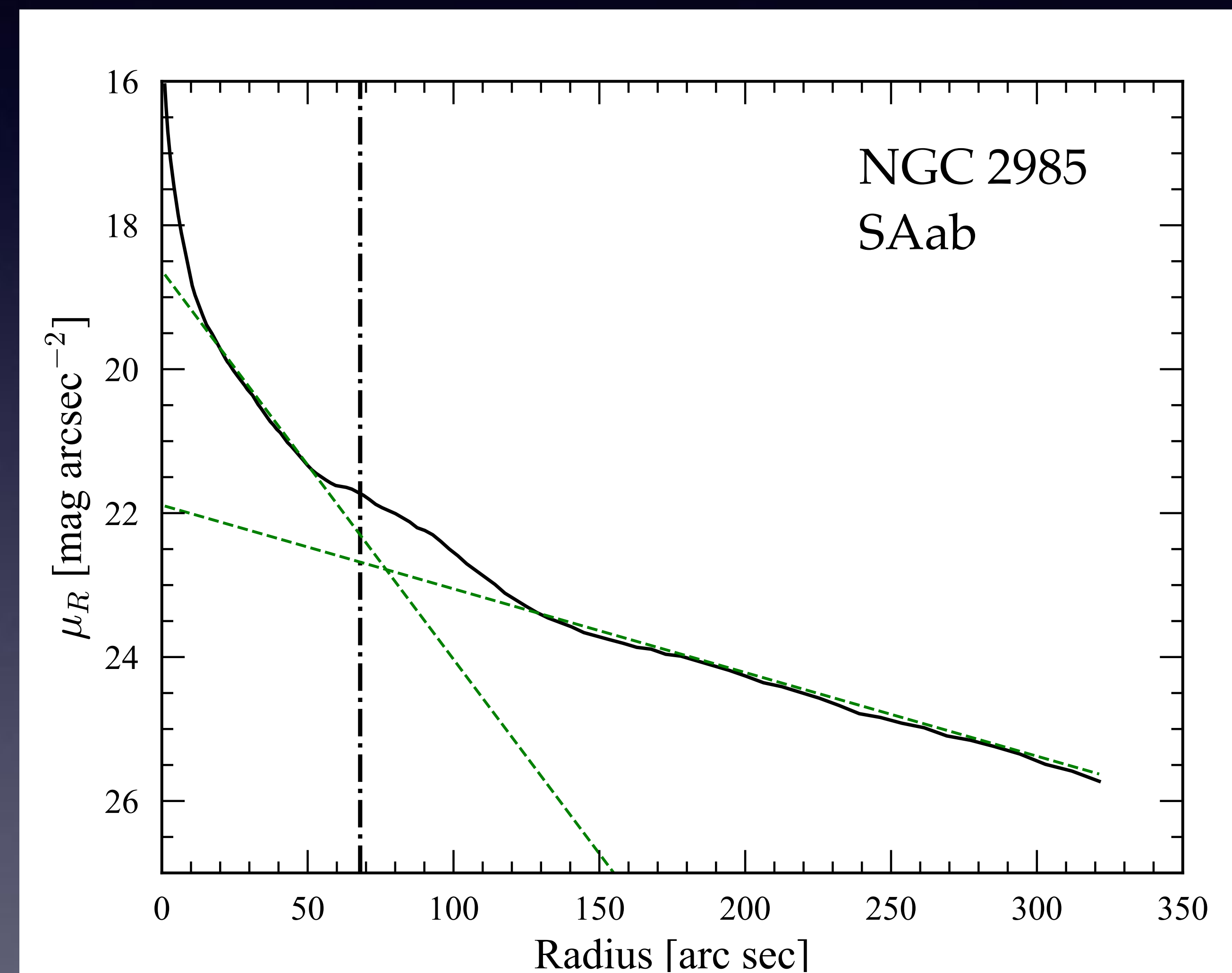
Erwin+2008/Gutiérrez+2011 S0–Sb galaxies with $i > 30°$:
S0: 47% of Type III are III-d
S0/a–Sb: 71% of Type III are III-d

Rings in Type III-d

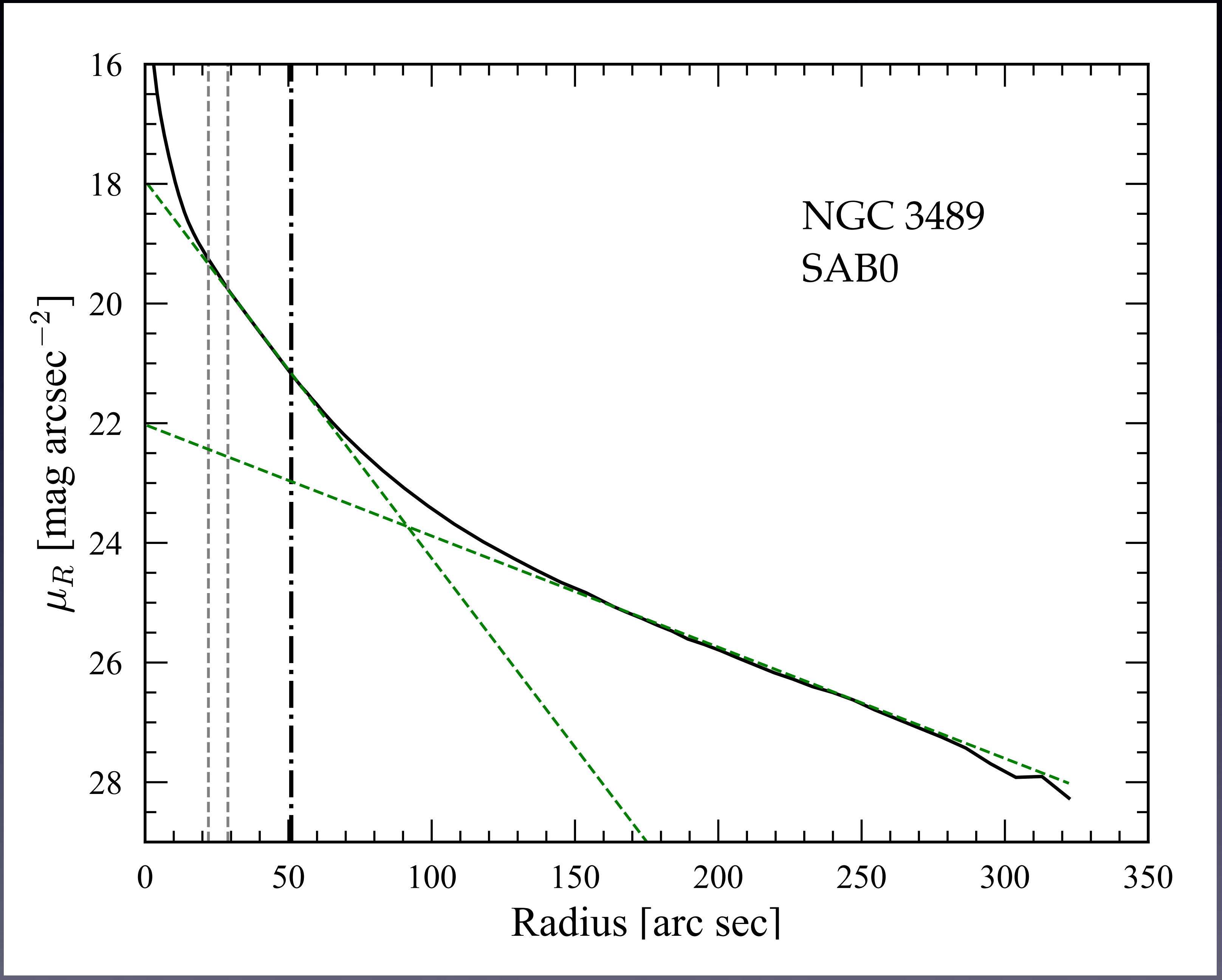
- Focus on Type III-d (assume Type III-s are basically Type I + outer spheroid)
- 54±9% of S0–Sb III-d have outer rings

Apparent Coincidences: Rings Associated with Breaks?

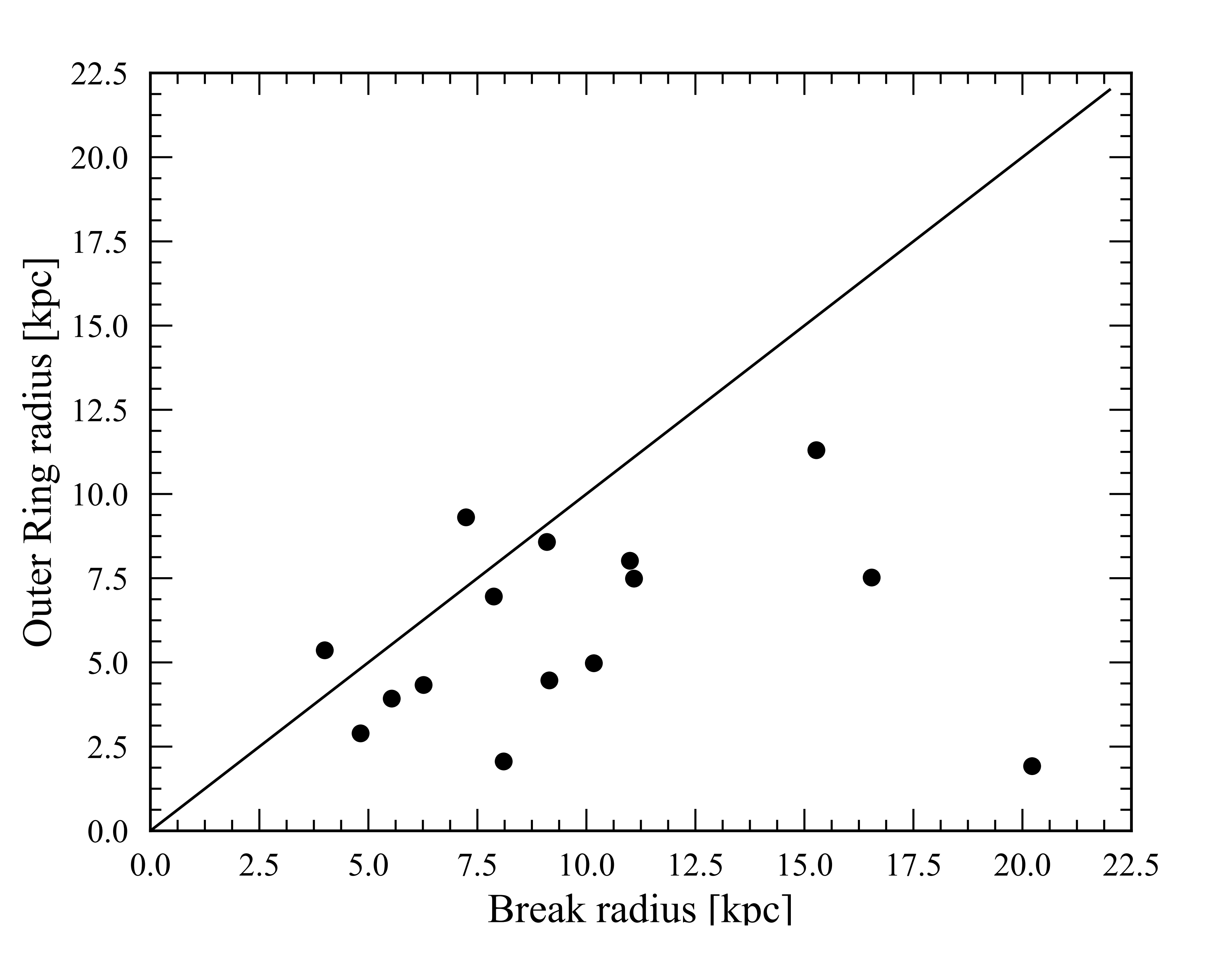




More Common: OR *inside* breaks



No General Correlation!



S0–Sb galaxies (Erwin+2008 & Gutierrez+2011)

Summary

- Outer rings are found in galaxies with all three types of disk profiles, with roughly equal frequency
- In almost all early-type (S0–Sb) galaxies with Type II profiles, if an outer ring exists, the break is *at* the ring, and sometimes the outer profile *is* the ring ("extreme outer rings")
- But in late-type spirals and dwarfs, outer rings are rare, while breaks are common and not associated with rings
- In galaxies with Type III profiles, outer rings are not linked to breaks
- We are missing theoretical models to explain this diversity