Unveiling the structure of barred galaxies with the S⁴G

Taehyun Kim (**S**eoul **N**ational **U**niversity)

& **S⁴G Team**

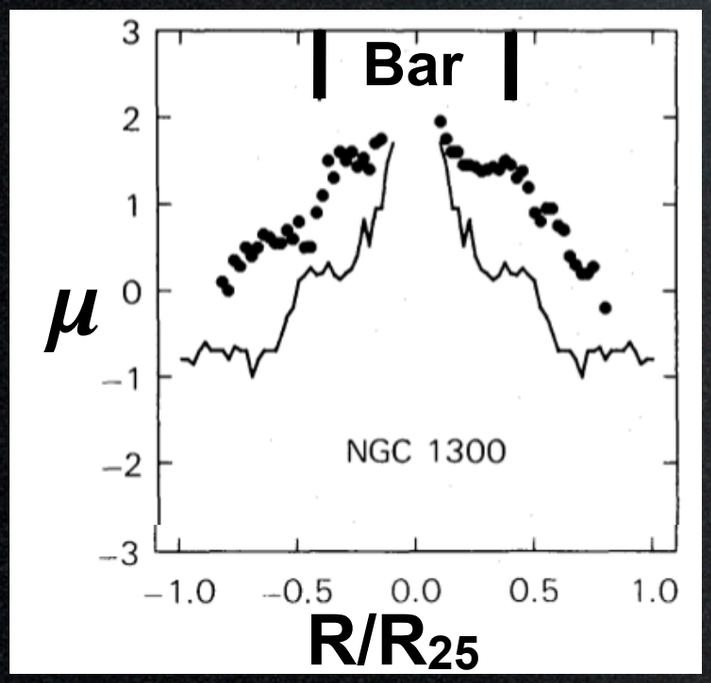
Kartik Sheth (NRAO), **Dimitri Gadotti** (ESO), **Myung Gyoon Lee** (SNU)

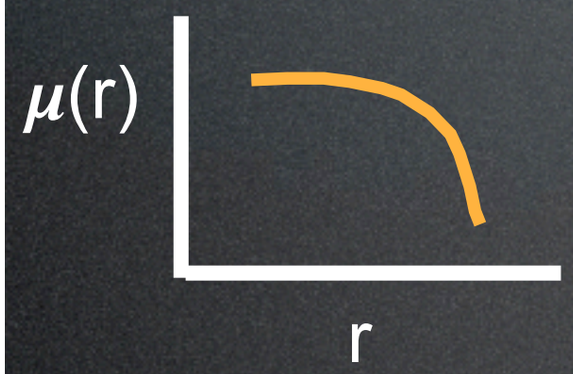
Light profile of bars

Hubble Heritage Team

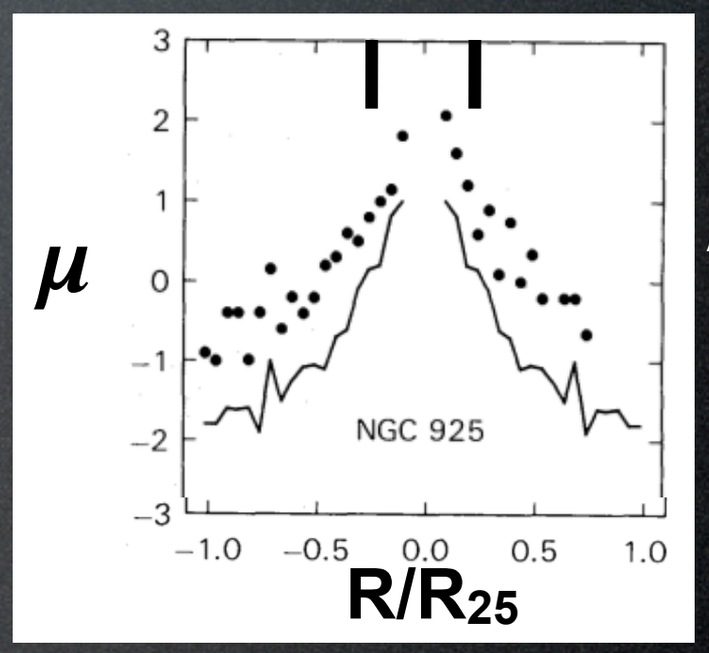
Mt. Lemmon SkyCenter

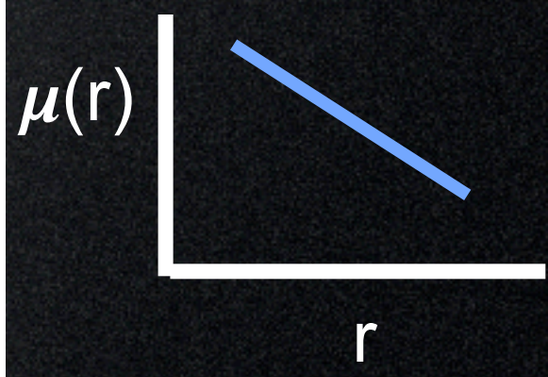
Flat surface brightness profile





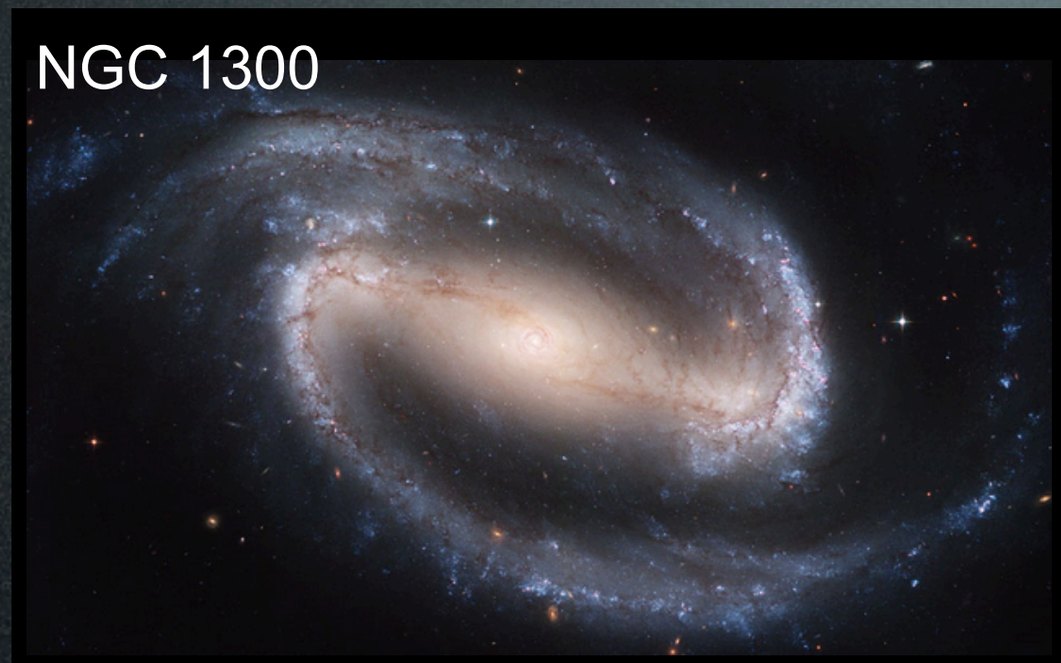
Exponential-like profile





Elmegreen & Elmegreen (1985), Elmegreen+(1996), ~30 Galaxies

Light profile of bars



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Mt. Lemmon SkyCenter

Flat surface brightness profile **Exponential**-like profile

Bars become **flat** as stars **trapped around x1 orbit** **(Athanassoula 2003)**

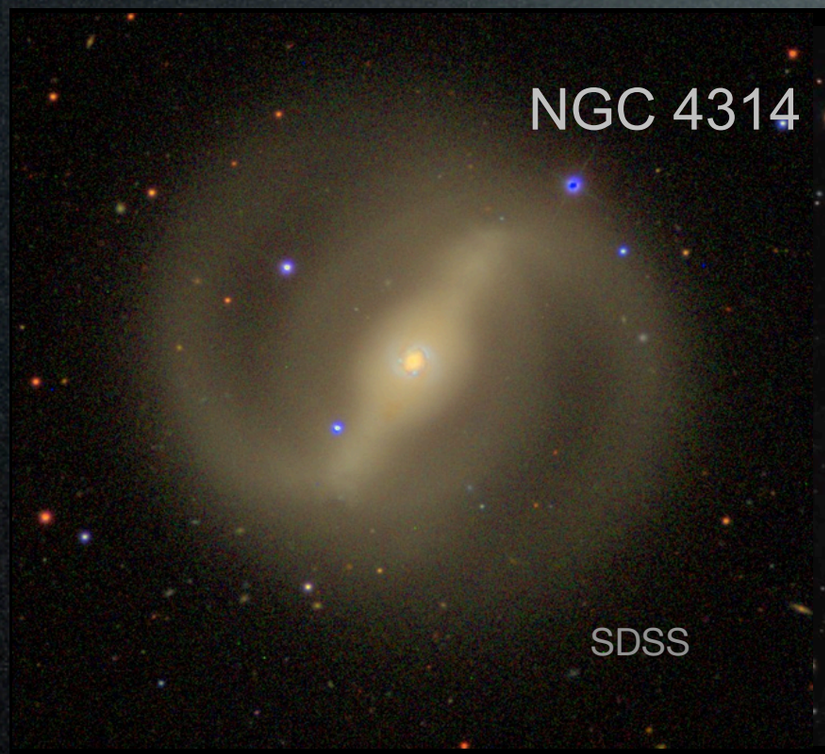
- Locations of resonances (ILRs), resonance crowding

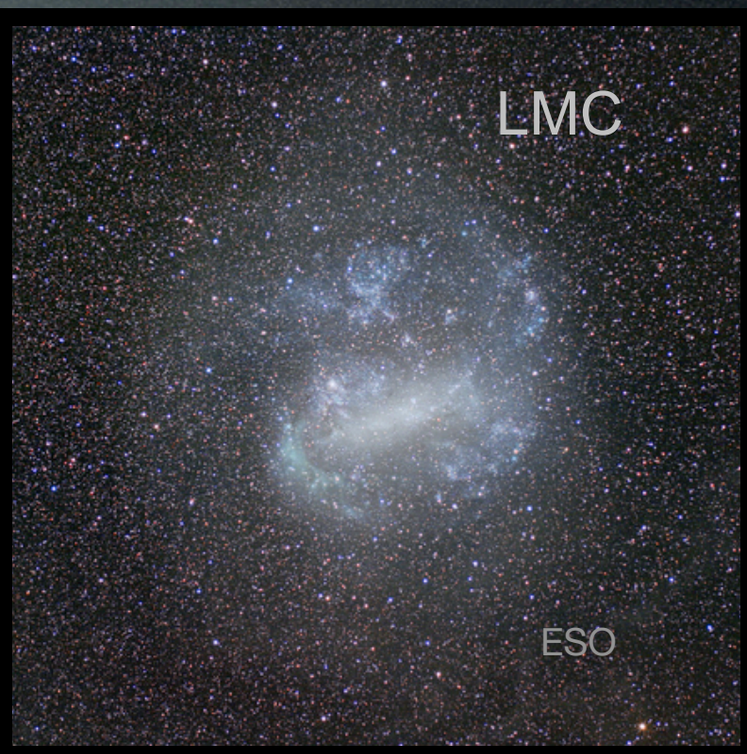
(Combes & Elmegreen 1993; Elmegreen et al. 1996)

μ

Quantifying bar profile to investigate evolution of bars

Shape of bars



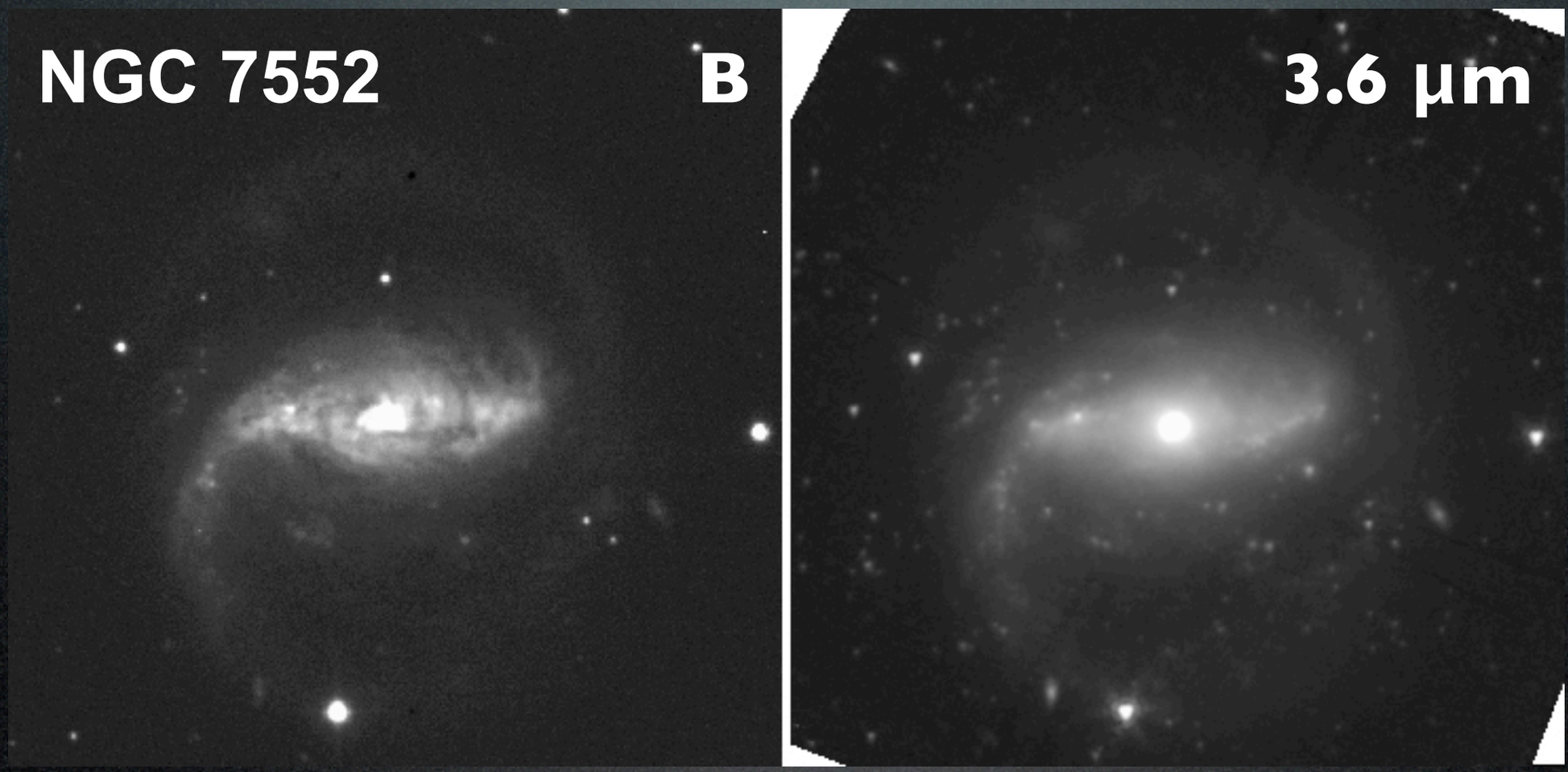


Bars are rectangular-shaped **(Athanassoula 1990, Gadotti 2011)**

Are bar shapes **different**?
Is there any disky bar?
Can these tell us about how bars formed?

The **S**pitzer **S**urvey of **S**tellar **S**tructure in **G**alaxies (**S^{4}G**, Sheth et al. 2010)

- Survey of ~**2,352** galaxies in **3.6 & 4.5 μm**

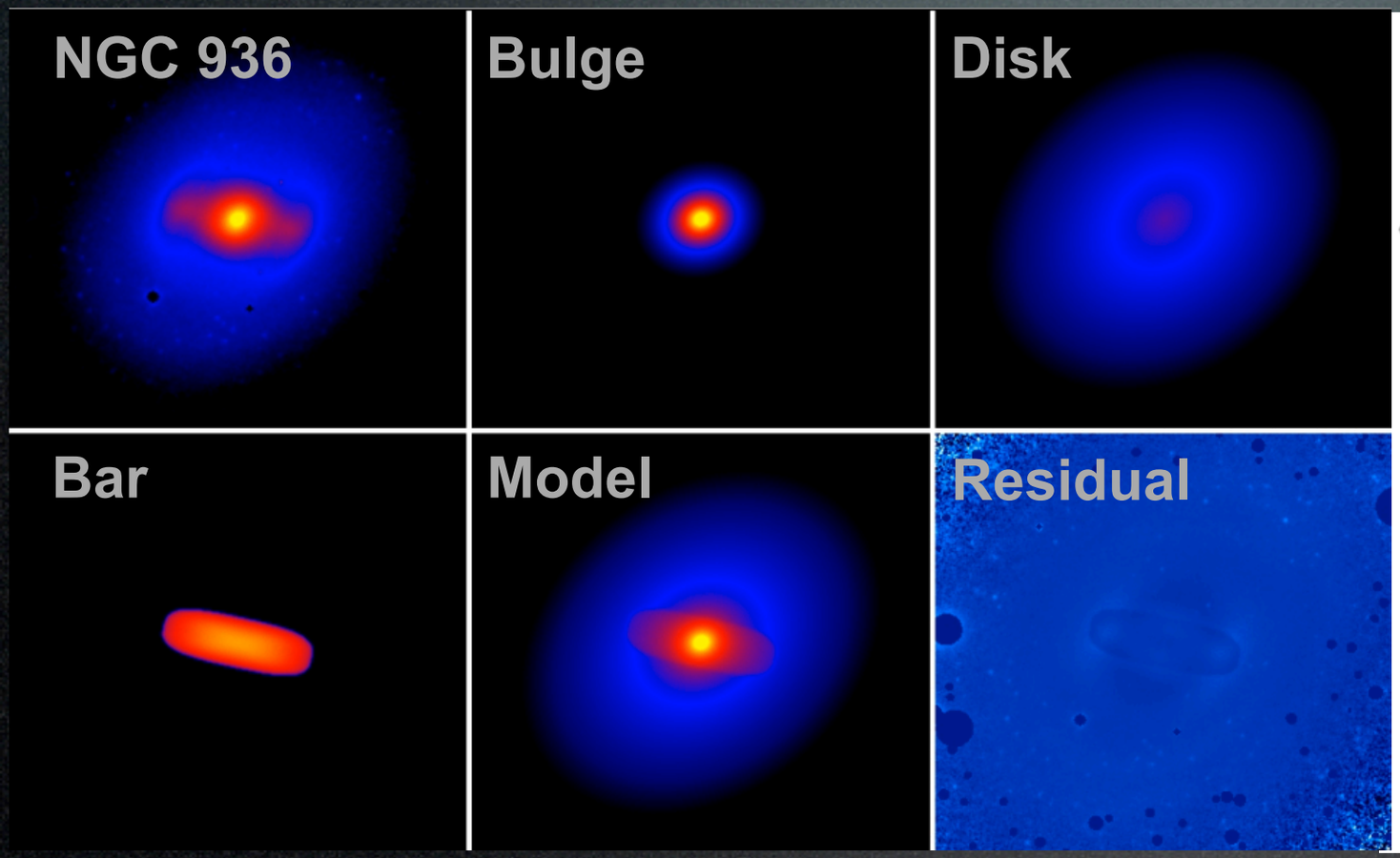


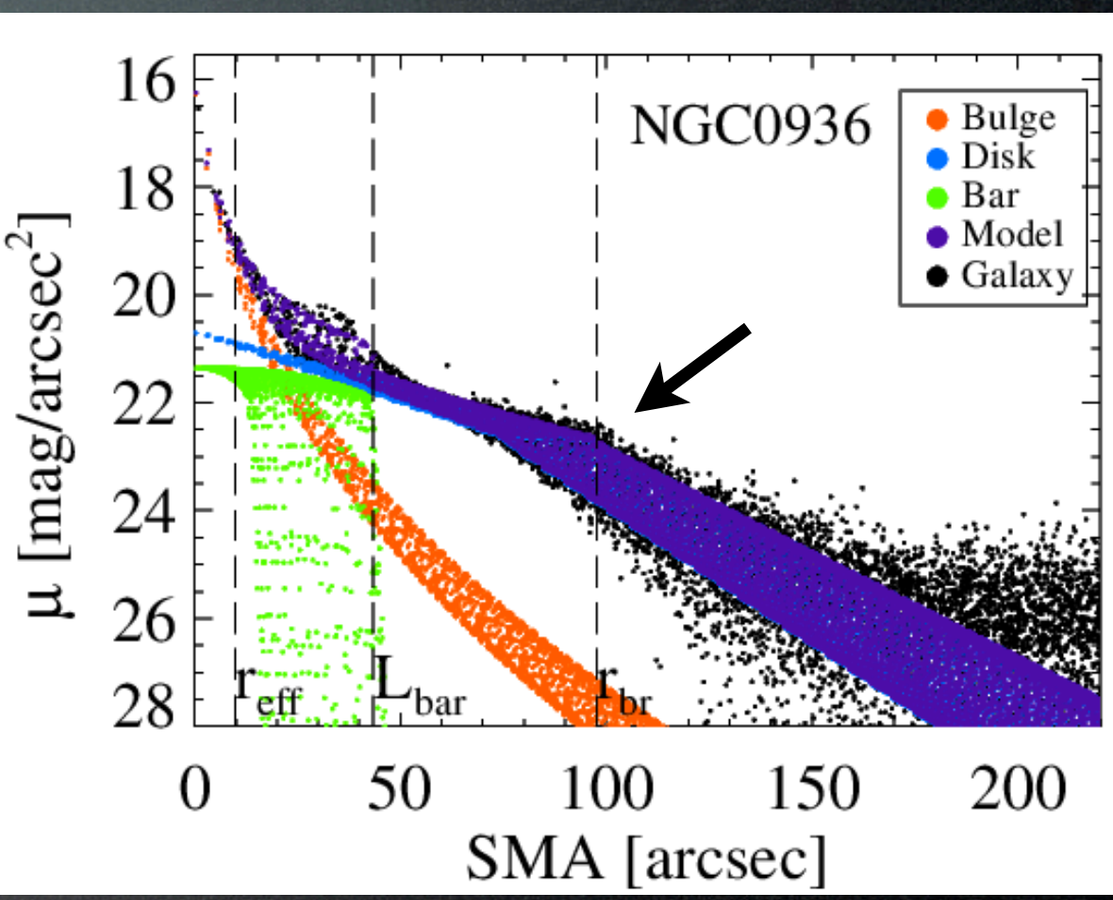
Structural parameters can be affected by **dust**
(e.g. Gadotti+10, Kelvin+12, Pastrav+13)

Data Analysis - 2D decomposition

BUDDA (**Bu**lge/**D**isk **D**ecomposition **A**nalysis, **de Souza+2004, Gadotti 2008**)

144 nearby barred galaxies ($M_{\star}=10^{9}\sim10^{11}M_{sun}$, SB0~SBdm)





Disk breaks are taken into account in our disk model fits

- **80%** of disk galaxies have a disk break (Gutierrez+11)

?

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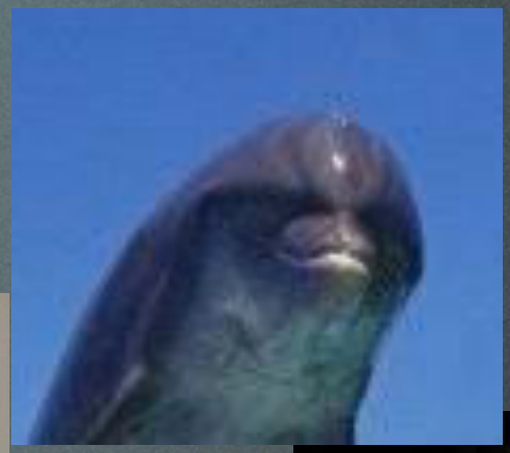

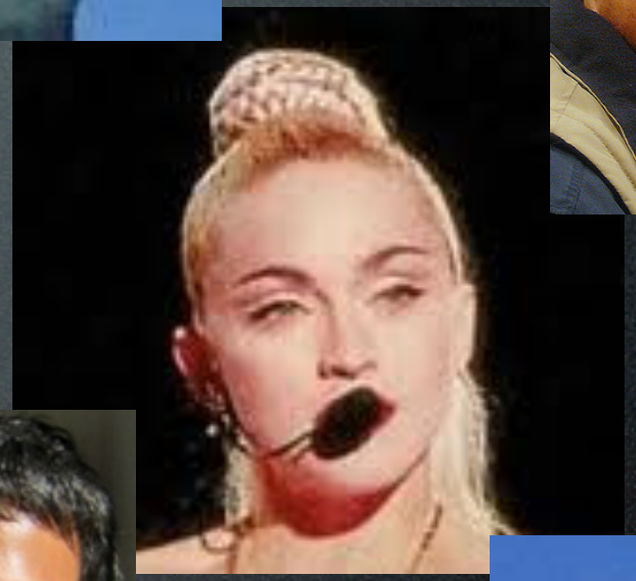

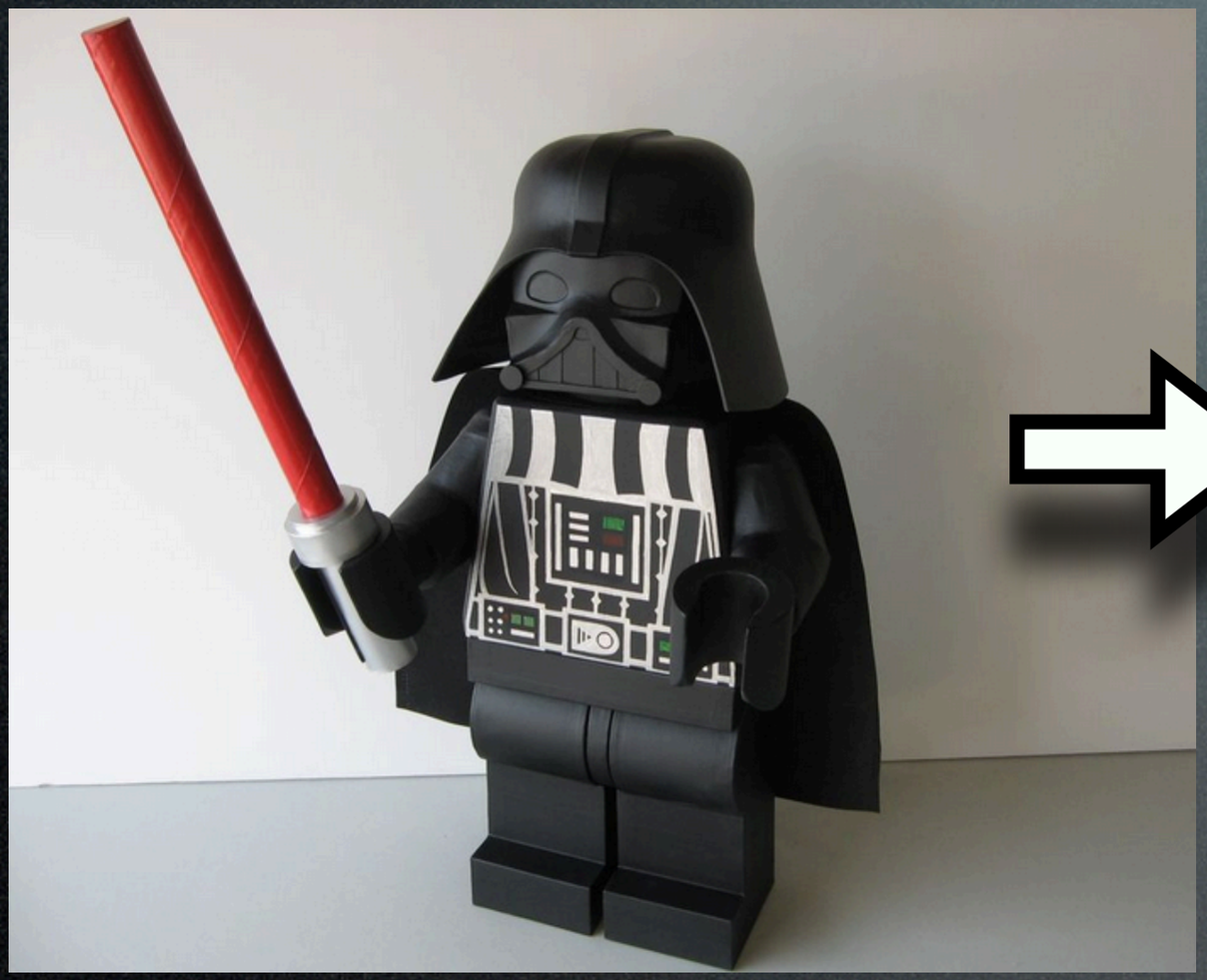

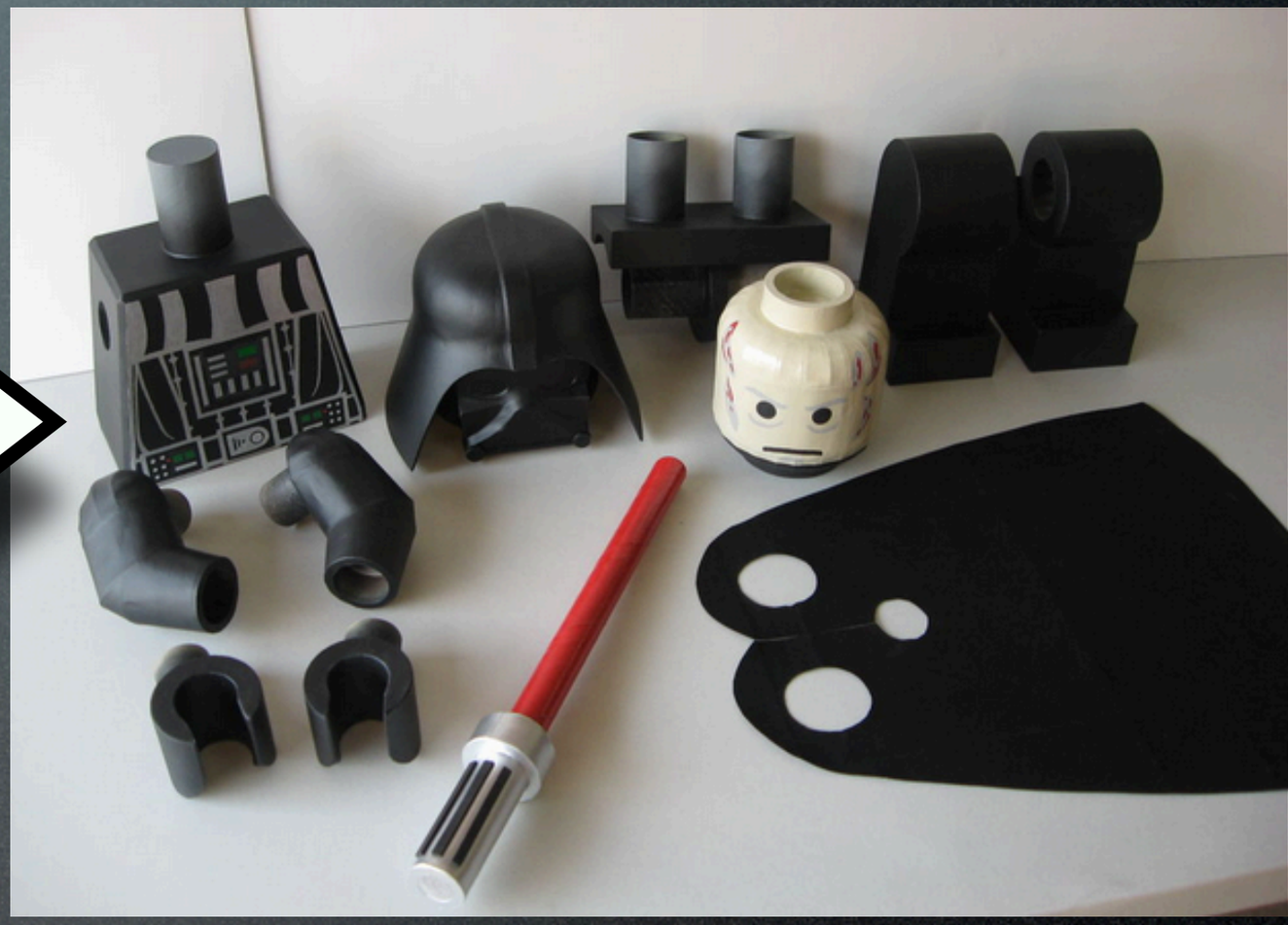

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Deconstructing!

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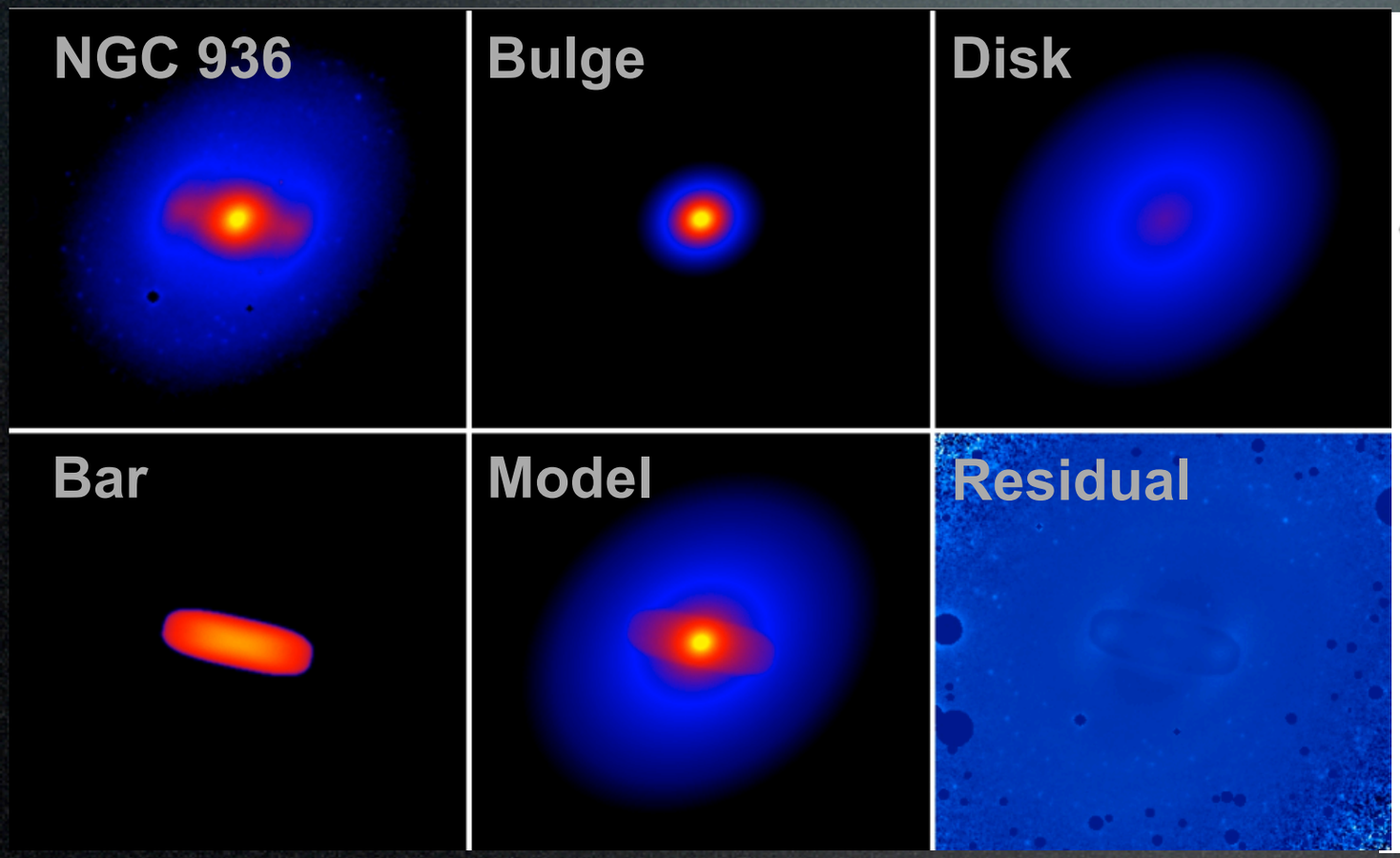

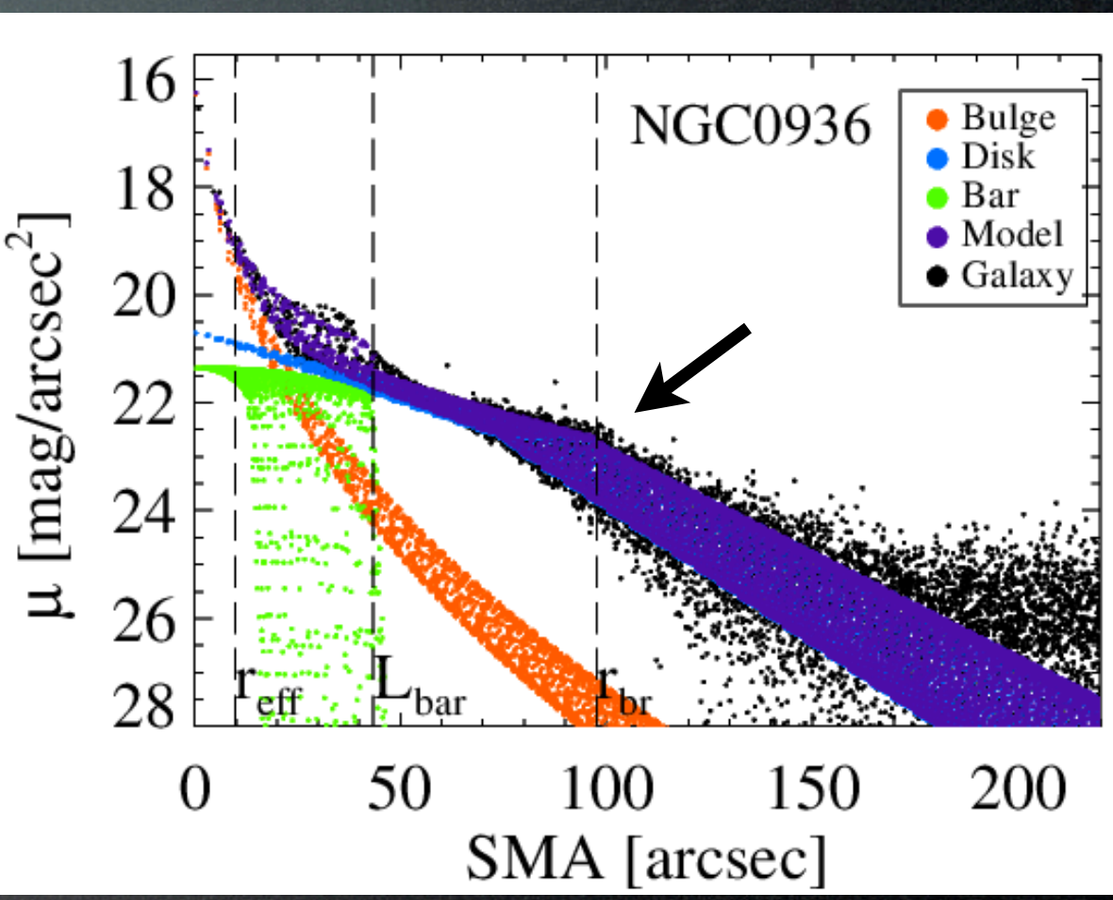

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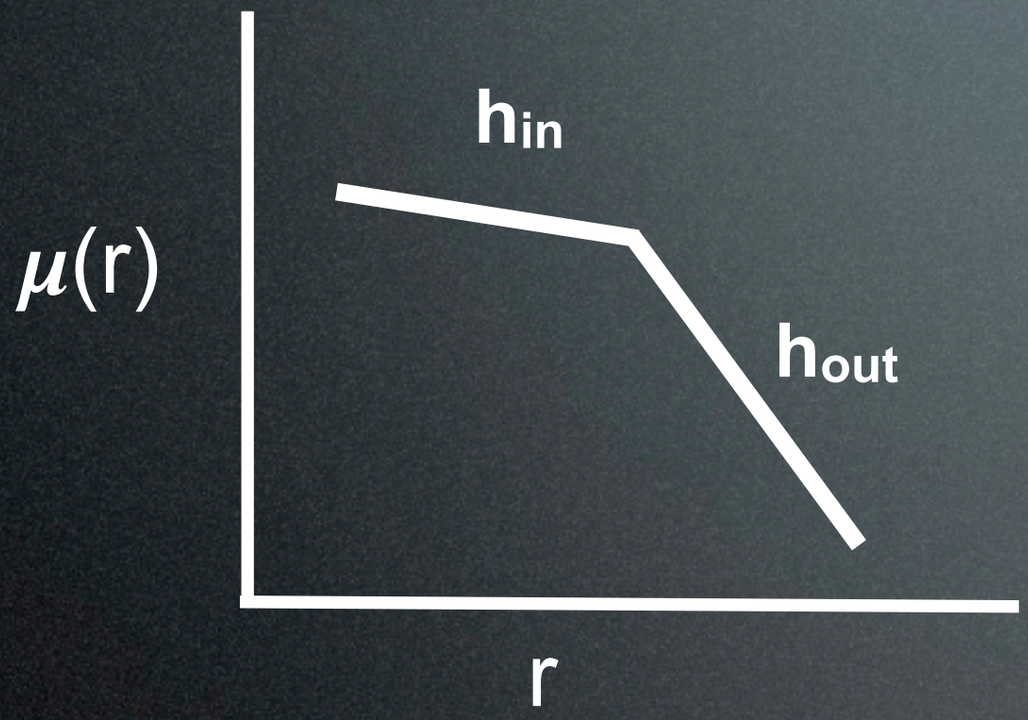
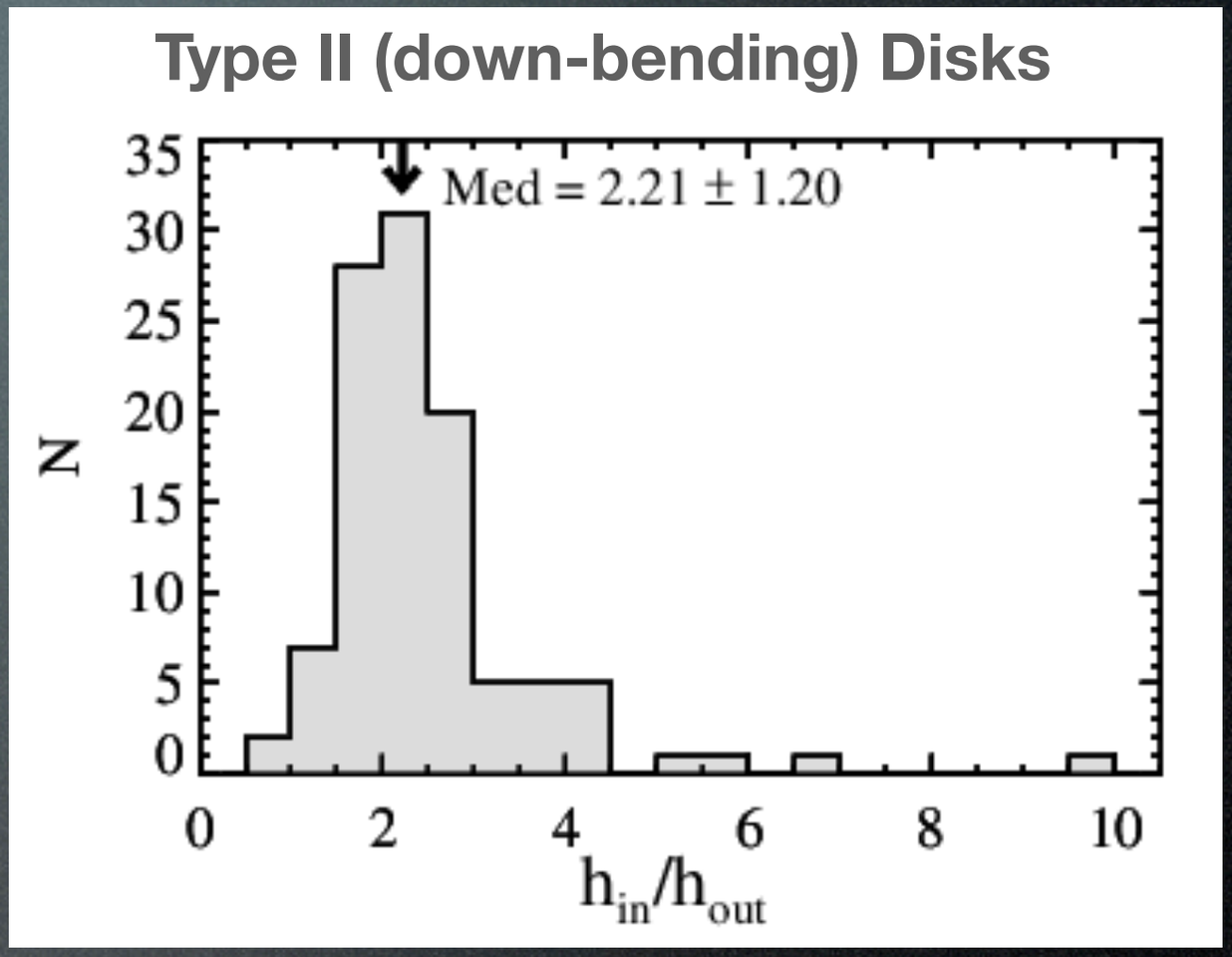
Importance of including disk breaks





Kim et al. (2013, ApJ, submitted)

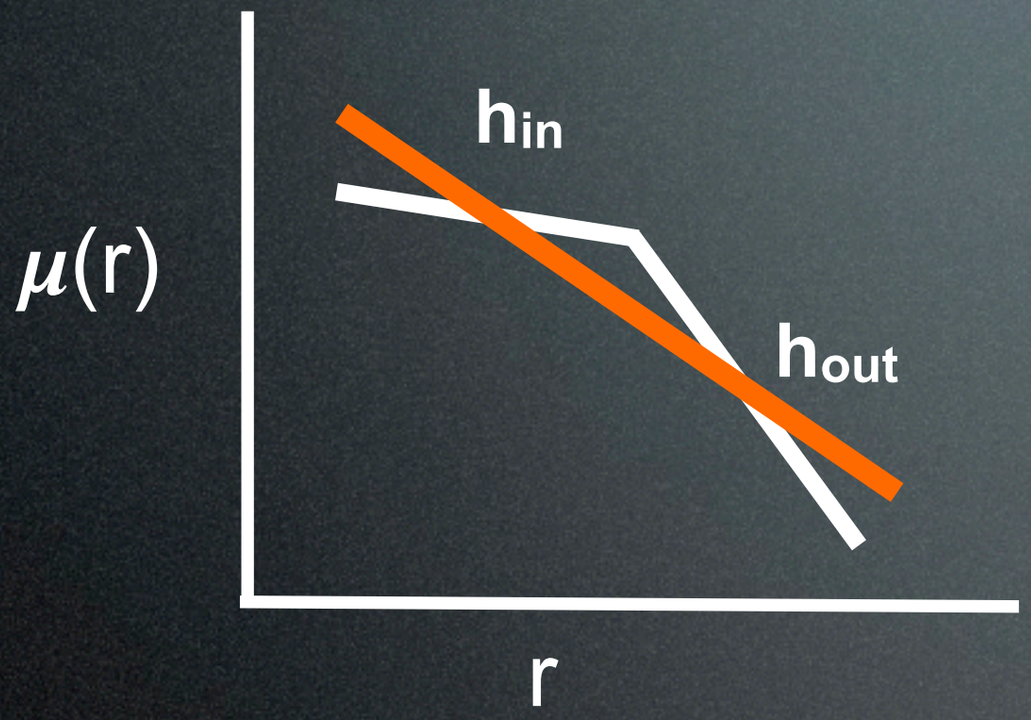
If disk break is not accounted for,

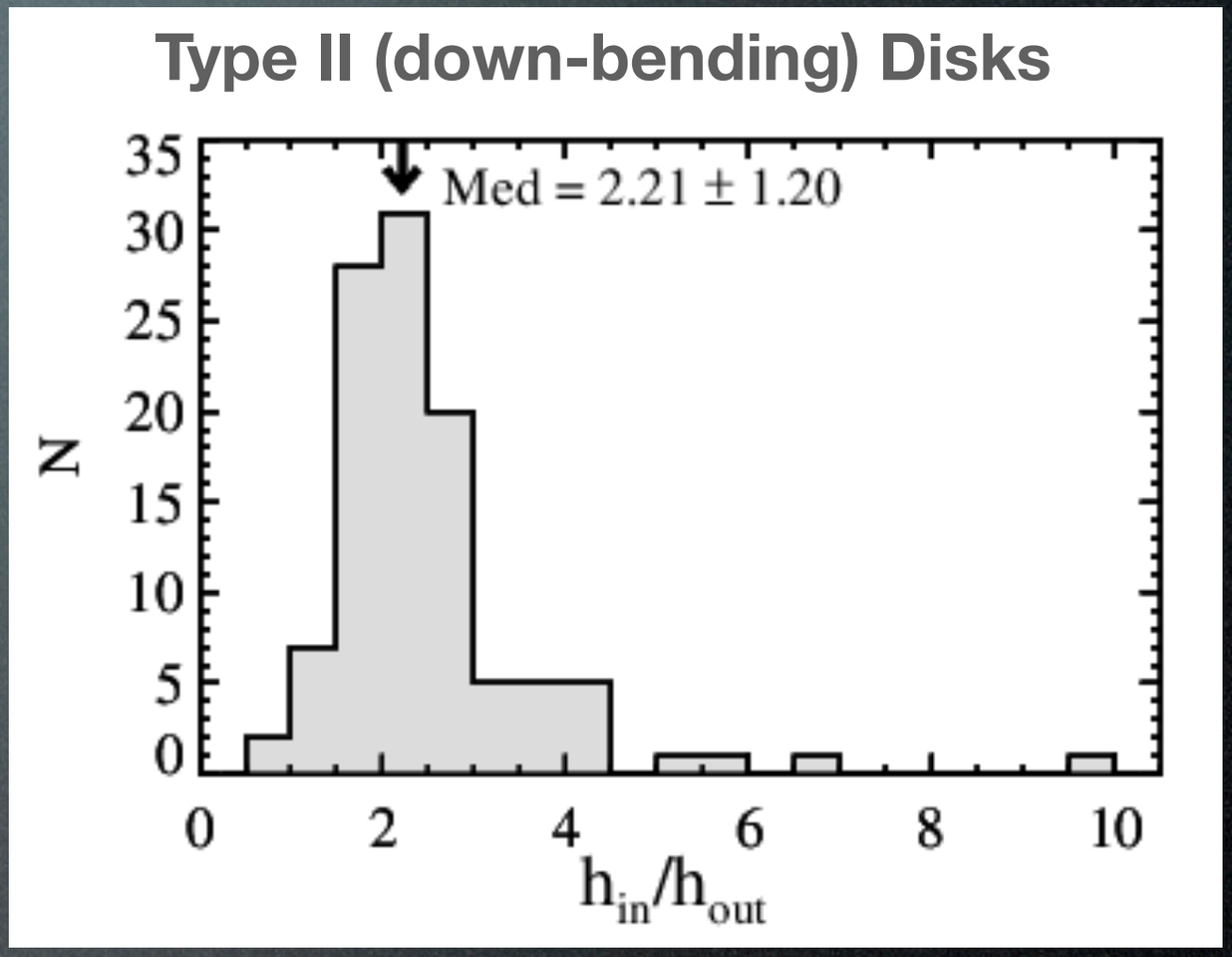
Disk Scale length changes by **~40%**
Bulge/Total is underestimated by **~10%**
Bar/Total is underestimated by **~20%**

Not including disk breaks strongly impacts model fits!

ex) Disk size evolution?

Importance of including disk breaks





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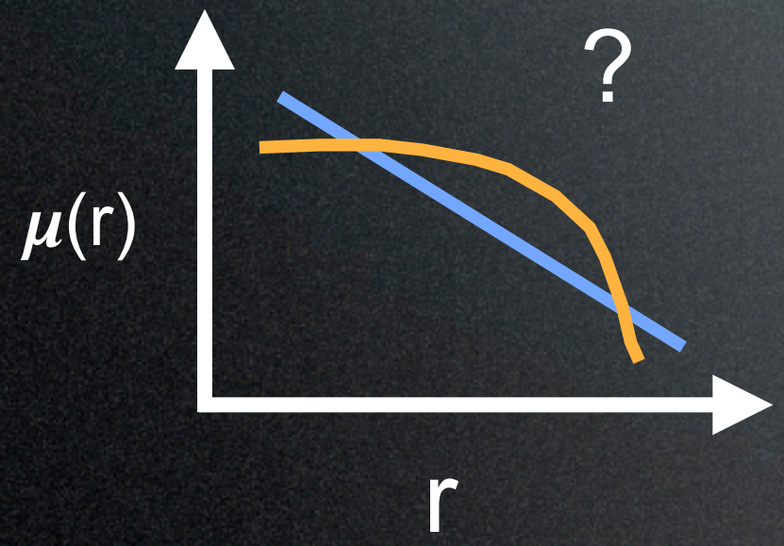
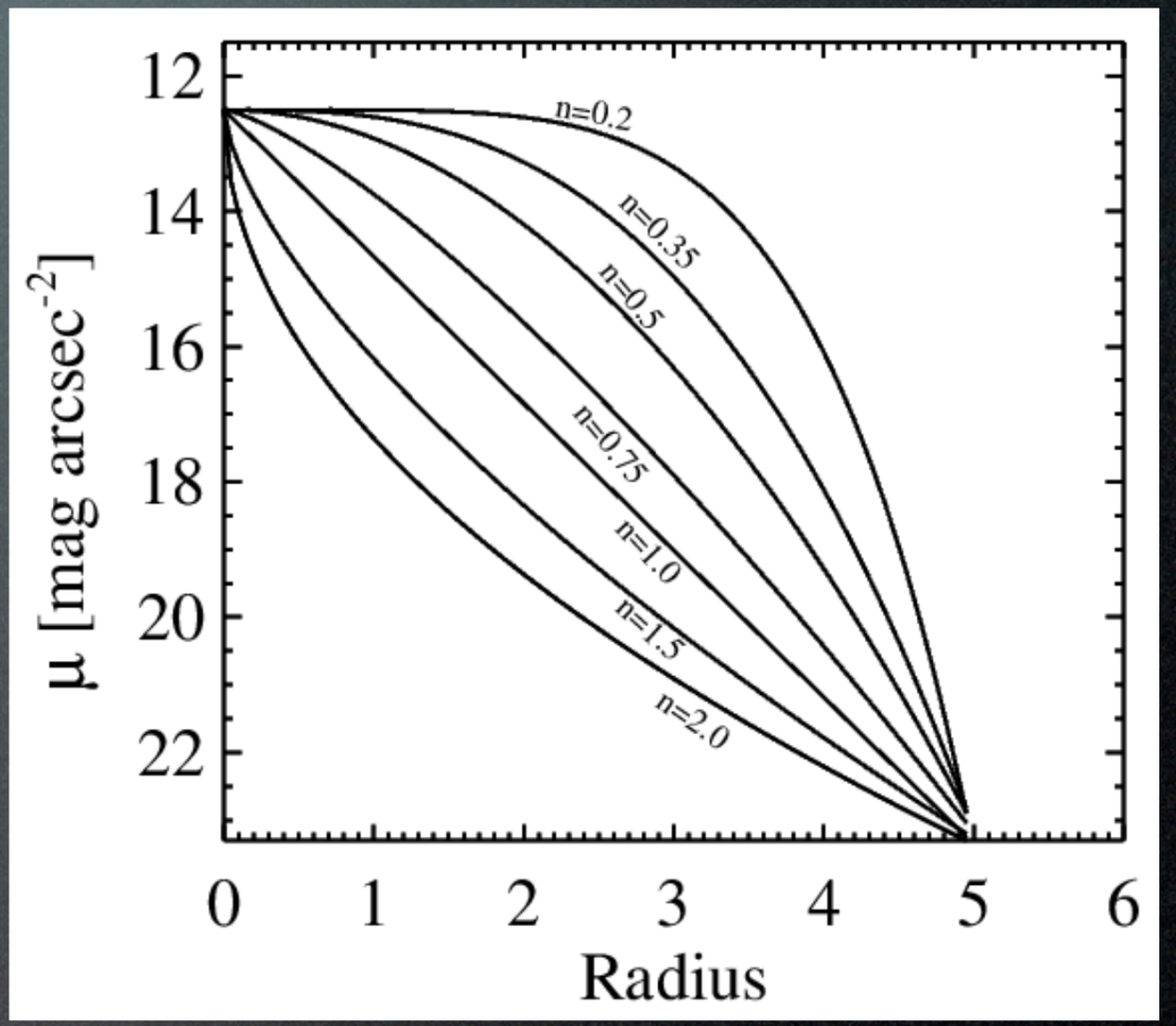
Light profile of bars

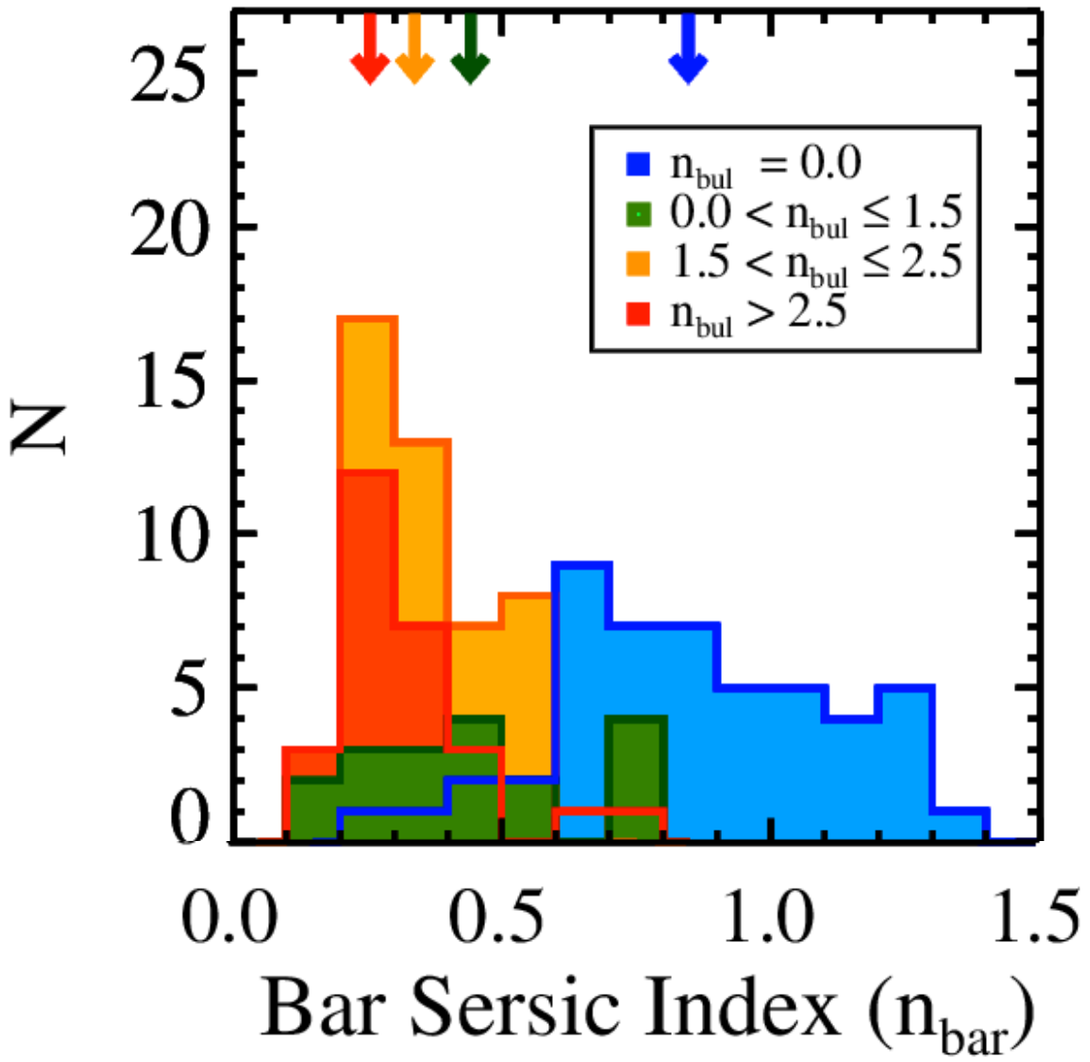


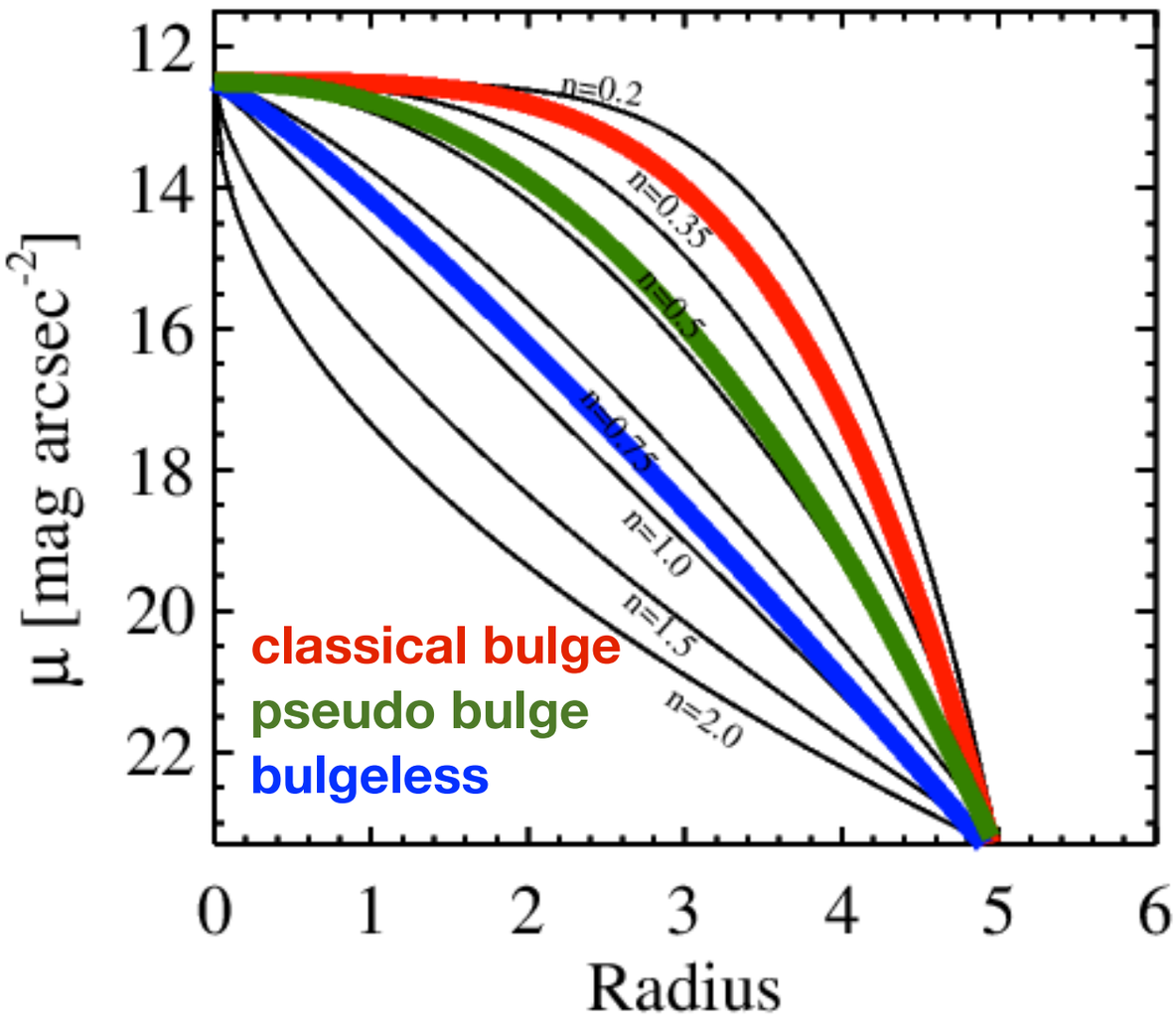


$$I(r) = I_{\text{eff}} \exp\left\{-b_n\left[\left(\frac{r}{r_{\text{eff}}}\right)^{1/n} - 1\right]\right\}$$

Sersic Profile (1963)

Light profile of bars





Bar profiles are related to the **presence/prominence** of a bulge.

- Galaxies with a bulge have flat bars
- Bulgeless galaxies have both flat and exponential bars.

Interpretation

- **Bar profile : an dynamical age indicator of the bar?**
  - **More evolved bars should be flatter**
    - longer time to trap stars into bar orbits
  - **Consistent with the COSMOS study** (Sheth et al. 2008)
    - more massive, redder, and bulge dominated disks formed their bars first (downsizing)
  - **Need to better understand conditions that turn a exponential profile into a flat profile**
    - What properties of the bar, disk, and galaxy make this process most efficient? (Gas? Triaxial halo? e.g., **Athanassoula et al. 2013**)

Outer shape of bars

Generalized ellipses (Athanassoula et al. 1990)

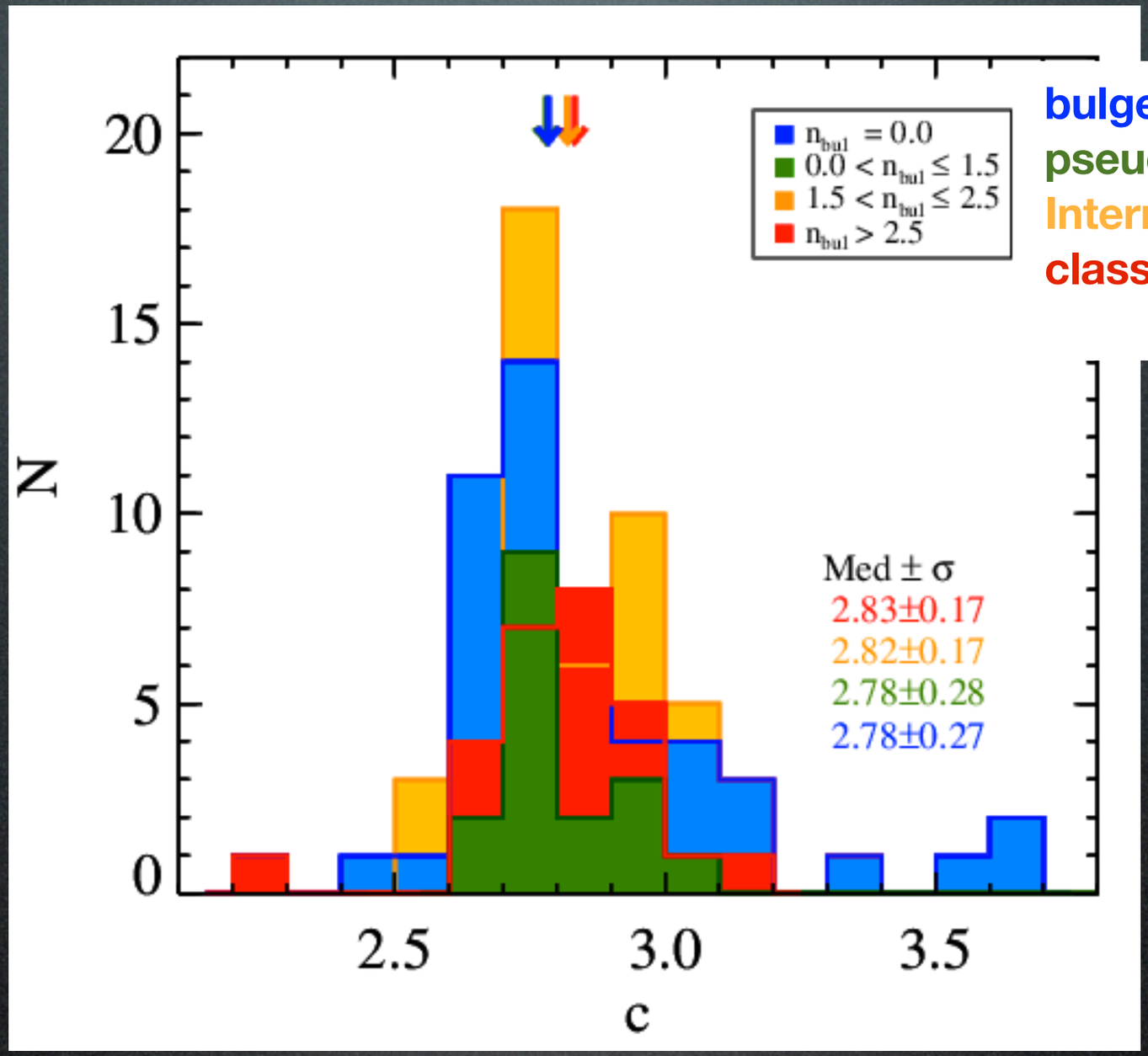
$$\left(\frac{|x|}{a}\right)^c + \left(\frac{|y|}{b}\right)^c = 1.$$

c: shape parameter

c<2 : Disky
c=2 : Ellipse
c>2 : Boxy

Different shapes of bar models

Bars are boxy!



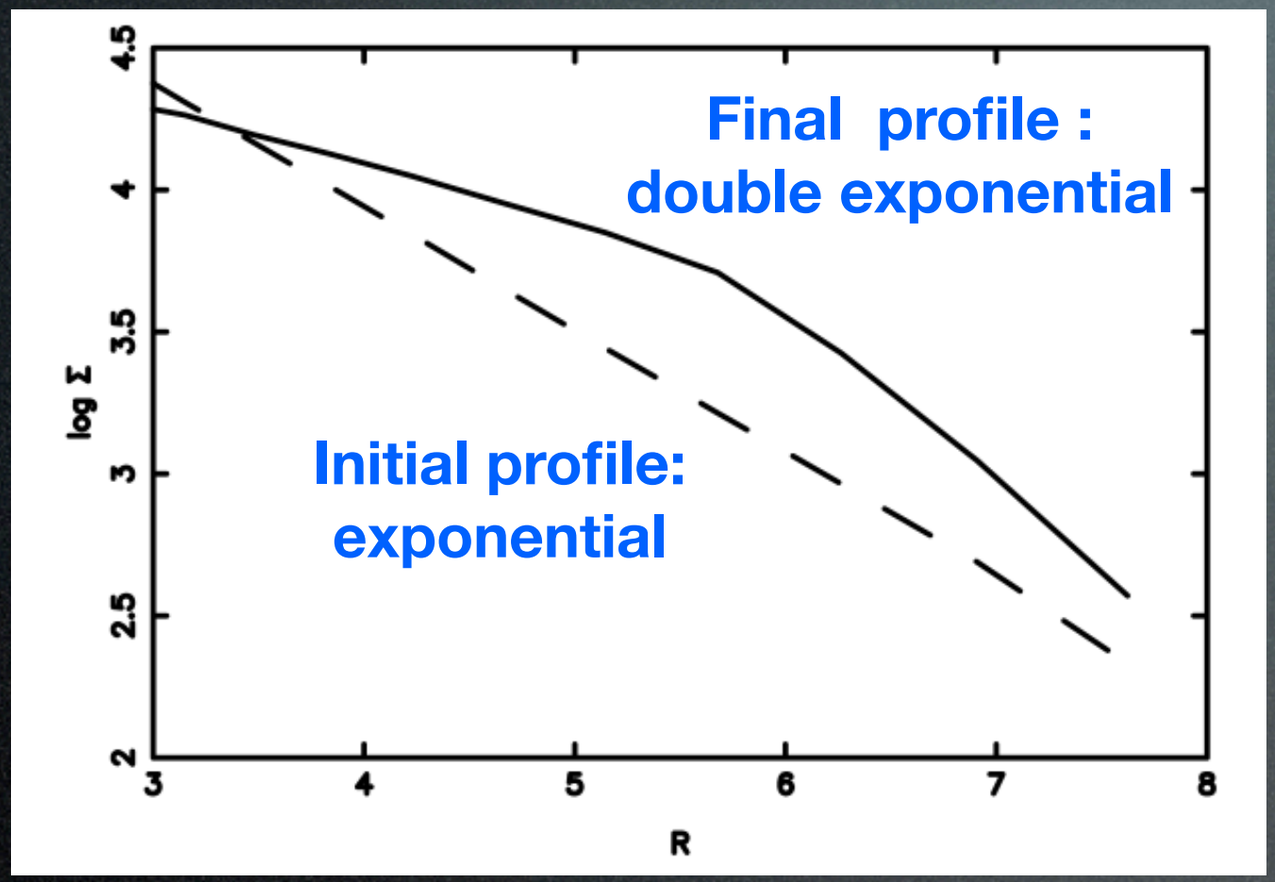
bulgeless
pseudo bulge
Intermediate bulge
classical bulge

c: shape parameter

Kim et al. (2014, in prep)

No significant differences in the shape of bars
Bars changes in profile while keeping their outer shapes boxy

Role of Bars - Induce disk break



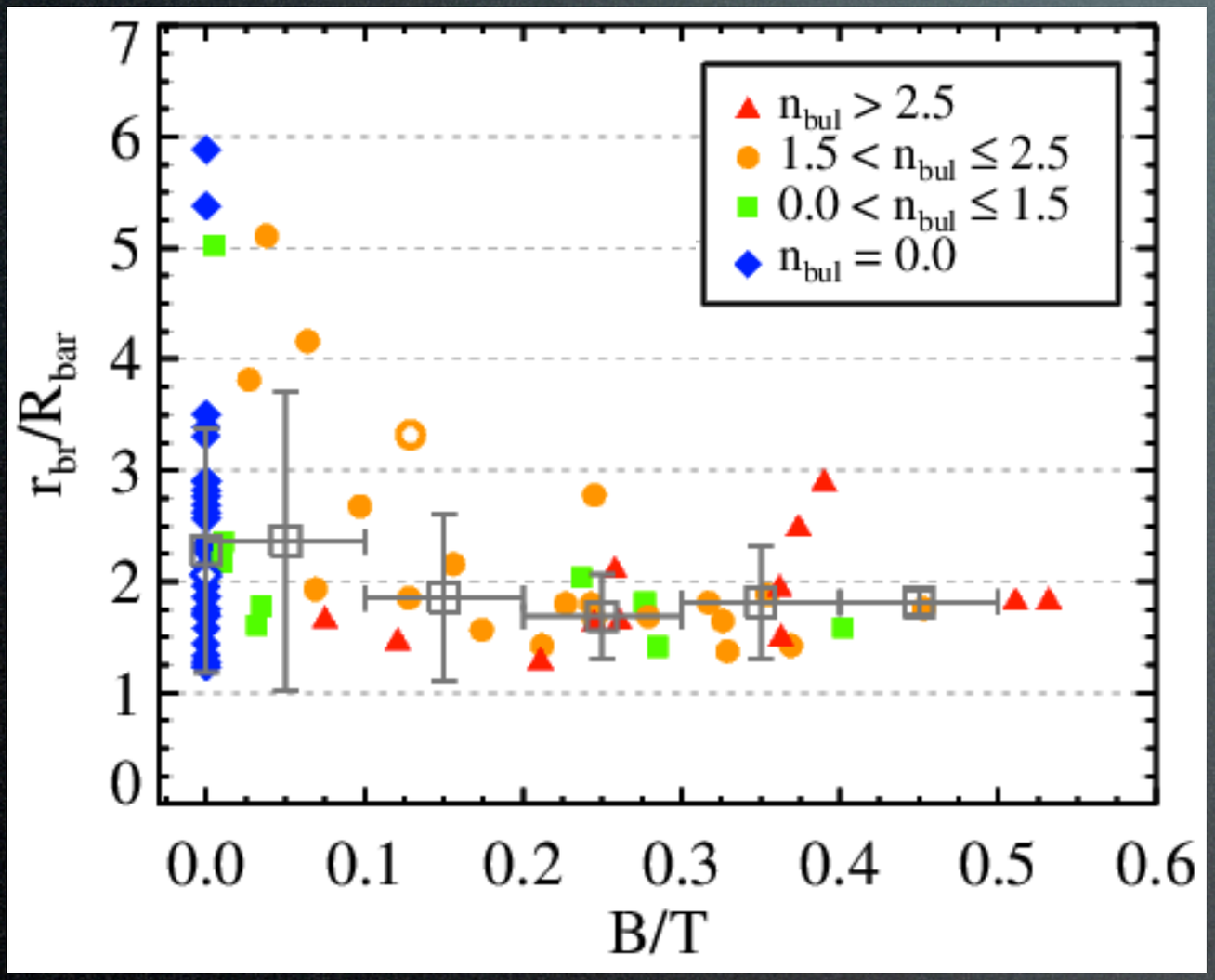
(Debattista et al. 2006)

Bars induce angular momentum redistribution

=> results in **disk break**

How are breaks related to bars?
Where do breaks happen?

Disk break



Galaxies with B/T> 0.1 :
r_{br}/R_{bar} ~2, related to bar OLR
(Schwarz 1981; Buta & Crocker 1991; Buta 1995)

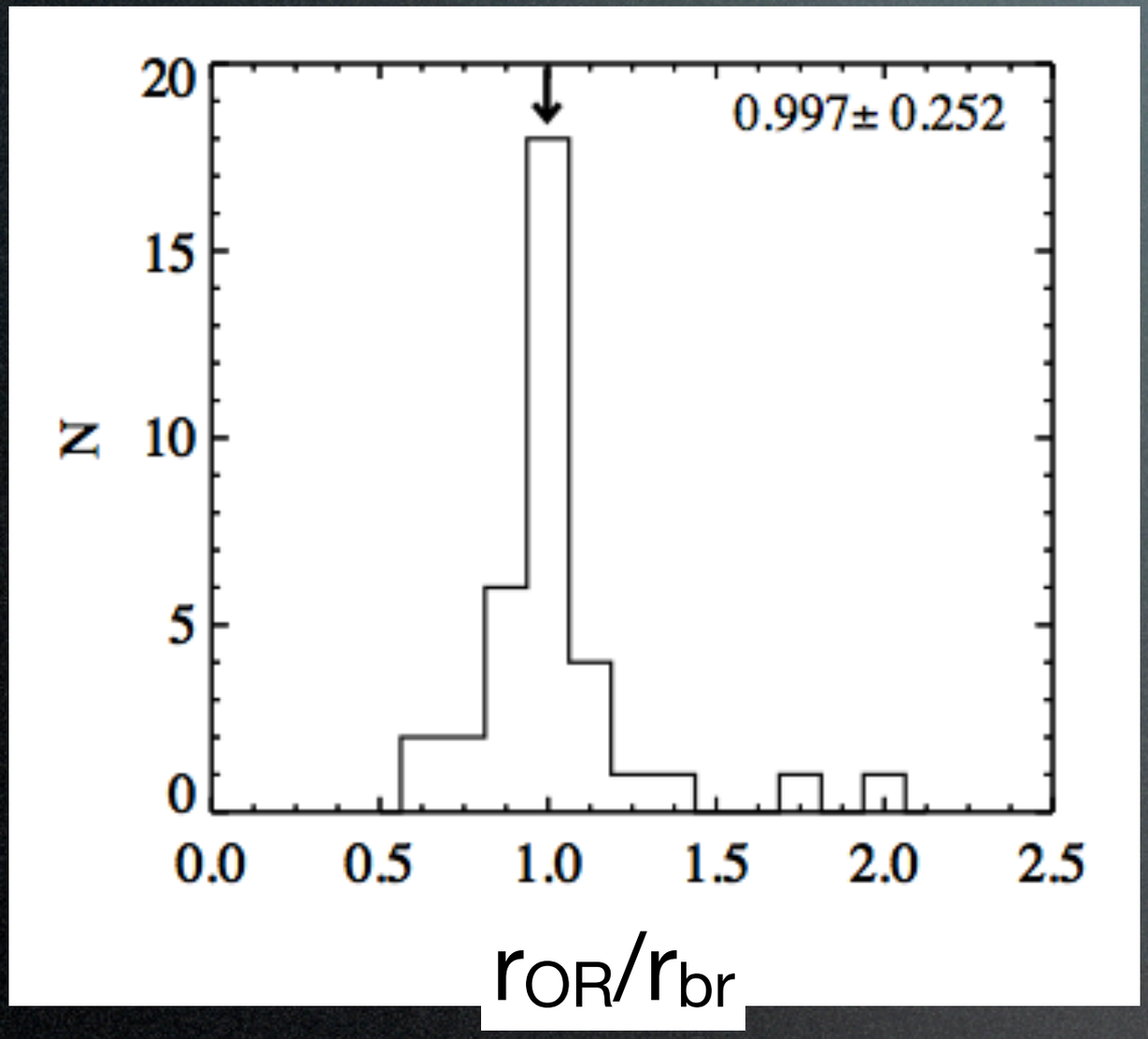
Galaxies with B/T< 0.1 :
- resonances may be coupled with spirals (Muñoz-Mateos+2013)

- r_{br} may be star formation threshold related.
(Kennicutt et al. 1989, Elmegreen et al. 2006)

r_{br} : break radius
R_{bar} : deprojected bar radius

Where do breaks arise?

Type II Disks with an outer ring



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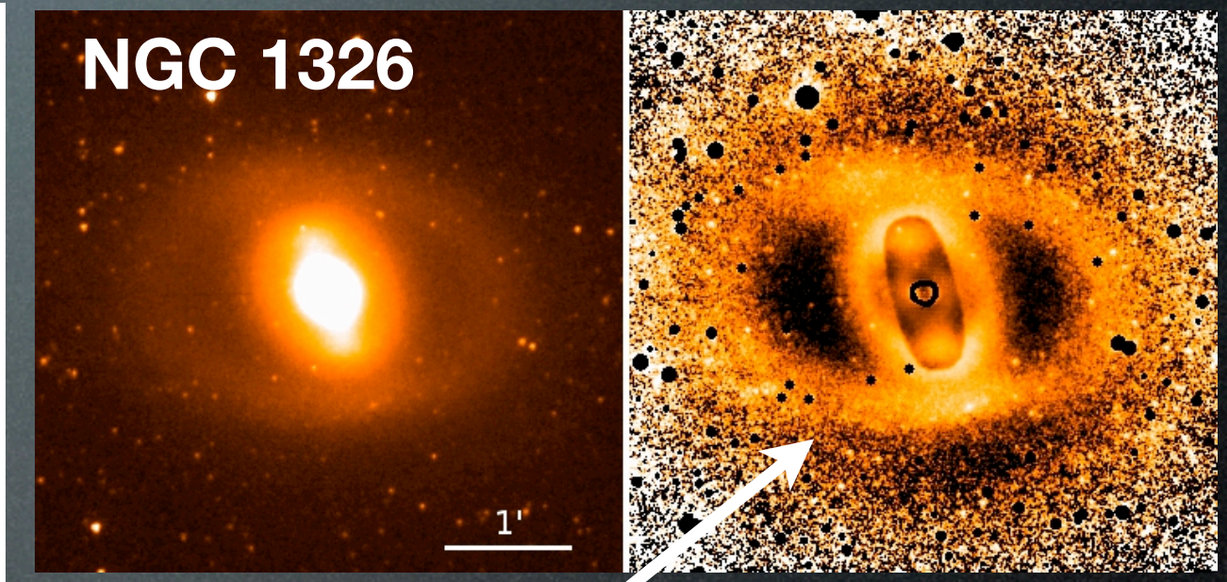

r_{OR}: outer ring radii from Comerón et al. (2013, A&A submitted)

r_{br} : break radii

86% of outer rings are in between $0.8 \times r_{br}$ and $1.2 \times r_{br}$

Disk breaks are at outer rings (~OLR of bars)

Let’s break disks!

Summary

* **Radial profile of bars** are related to the **presence of the bulge** - consistent with the downsizing of bar formation.

* Bar profiles change with **bulge properties** while **keeping their outermost shape boxy**.

* **Disk breaks** should be taken into account properly in the model fit.

* Breaks are related to the **OLR of the bar** for prominent bulge galaxies, and most disk breaks arise at the outer ring.
  - bar plays a role in setting **the position of break.**

Thank you!