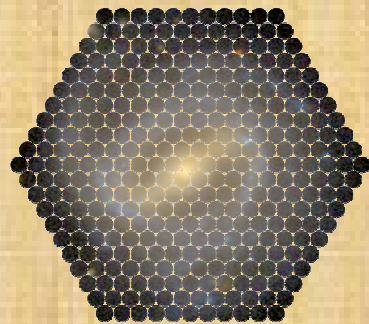


# DECONSTRUCTING EARLY-TYPE GALAXY BULGES



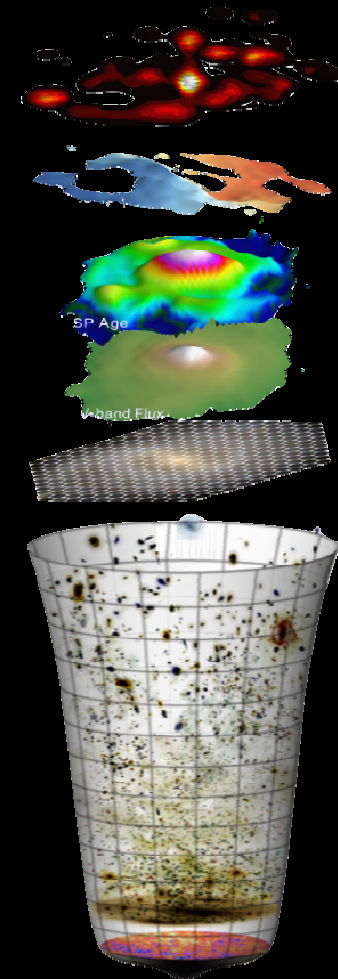
CALIFA Survey

Jairo Méndez Abreu



University of  
St Andrews

Santiago, ESO Headquarters, 20.11.13



Thanks are due to

T. Ruiz-Lara

A. De Lorenzo-Cáceres

J. Falcón-Barroso

J. A. L. Aguerri

& CALIFA TEAM

# (TWO OR) THREE TYPES OF BULGES

(Naively three different formation paths)

## ☞ Classical Bulges

Dissipative collapse of gas clouds *Eggen+62*

Coalescence of giant clumps in primordial discs

*Bournaud+07*

Satellite accretion during minor merging events

*Aguerri+01*

Galaxy mergers *Hopkins+10*

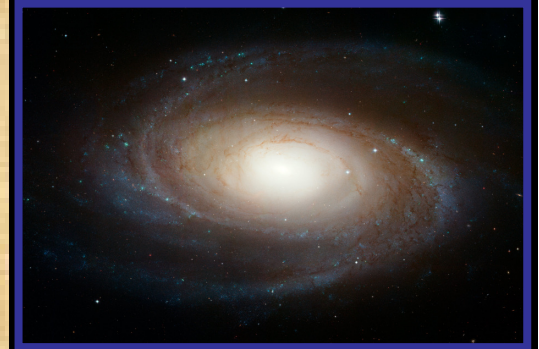
## ☞ Disk-like bulges (aka pseudobulges)

Secular processes driven by bars *Kormendy & Kennicutt 04;*

*Athanassoula05*

## ☞ Boxy-Peanut Bulges

Natural evolution of barred galaxies *Martinez-Valpuesta+06*



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*Athanassoula05*

## ∞ Boxy-Peanut Bulges

Natural evolution of barred galaxies *Martinez-Valpuesta+06*

Bulge  
demography  
helps  
us to  
understand  
Mass  
assembly  
in bulges

# PREVIOUS WORKS ON BULGE DEMOGRAPHY

∞ Driver+07 (see talk past Monday)

26% Classical Bulges 1.5% Disk-like bulges

∞ Gadotti09

25% Classical Bulges 3% Disk-like bulges

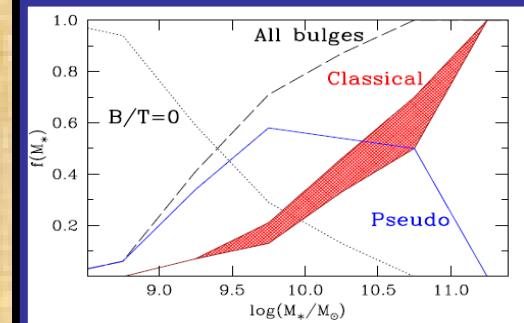
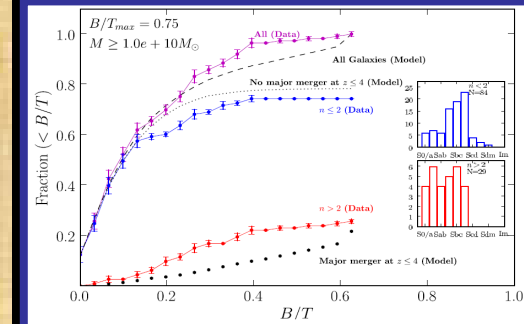
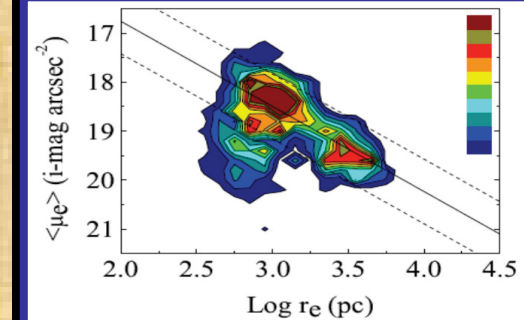
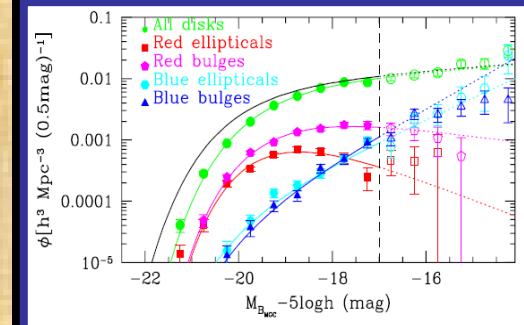
∞ Weinzirl+09

11%  $n > 2$  bulges 9%  $n < 2$

∞ Fisher&Drory11

Changing Classical vs. Pseudo Ratio with mass

Mainly based on photometric properties





# NEED FOR A WIDER VIEW

- ☞ Photometric properties in several bands
- ☞ Spatially resolved kinematics
- ☞ Spatially resolved stellar populations
- ☞ Spatially resolved gas properties
- ☞ Statistical samples



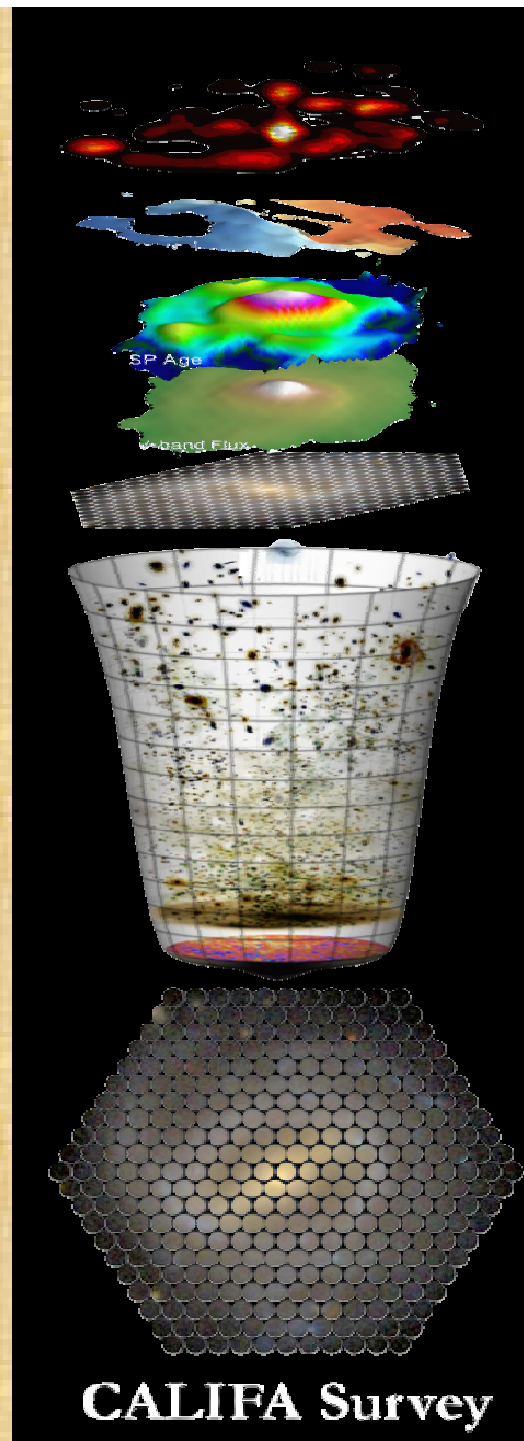
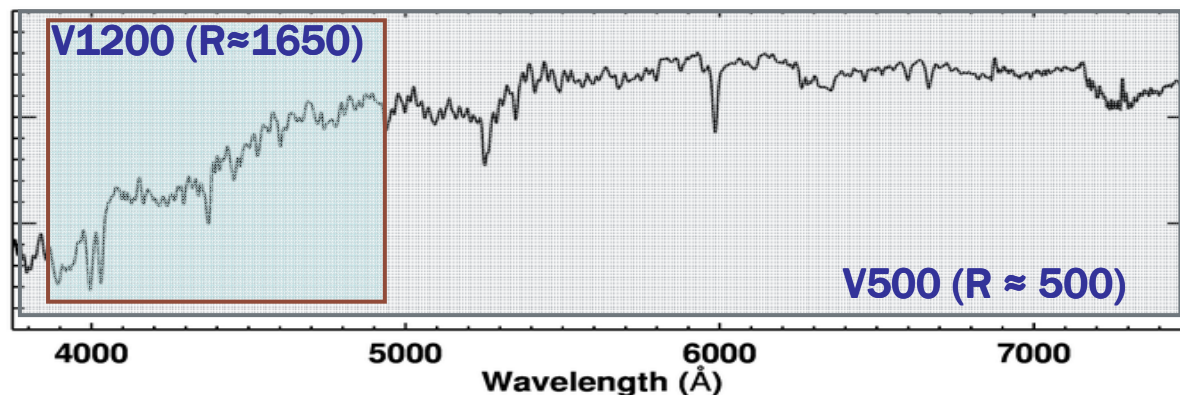
# THE CALIFA SURVEY

∞ The Calar Alto Legacy Integral Field Area (CALIFA) survey plans to observe a statistically well-defined sample of about 600 nearby galaxies by using the PMAS integral field spectrograph at the 3.5m telescope in Calar Alto observatory

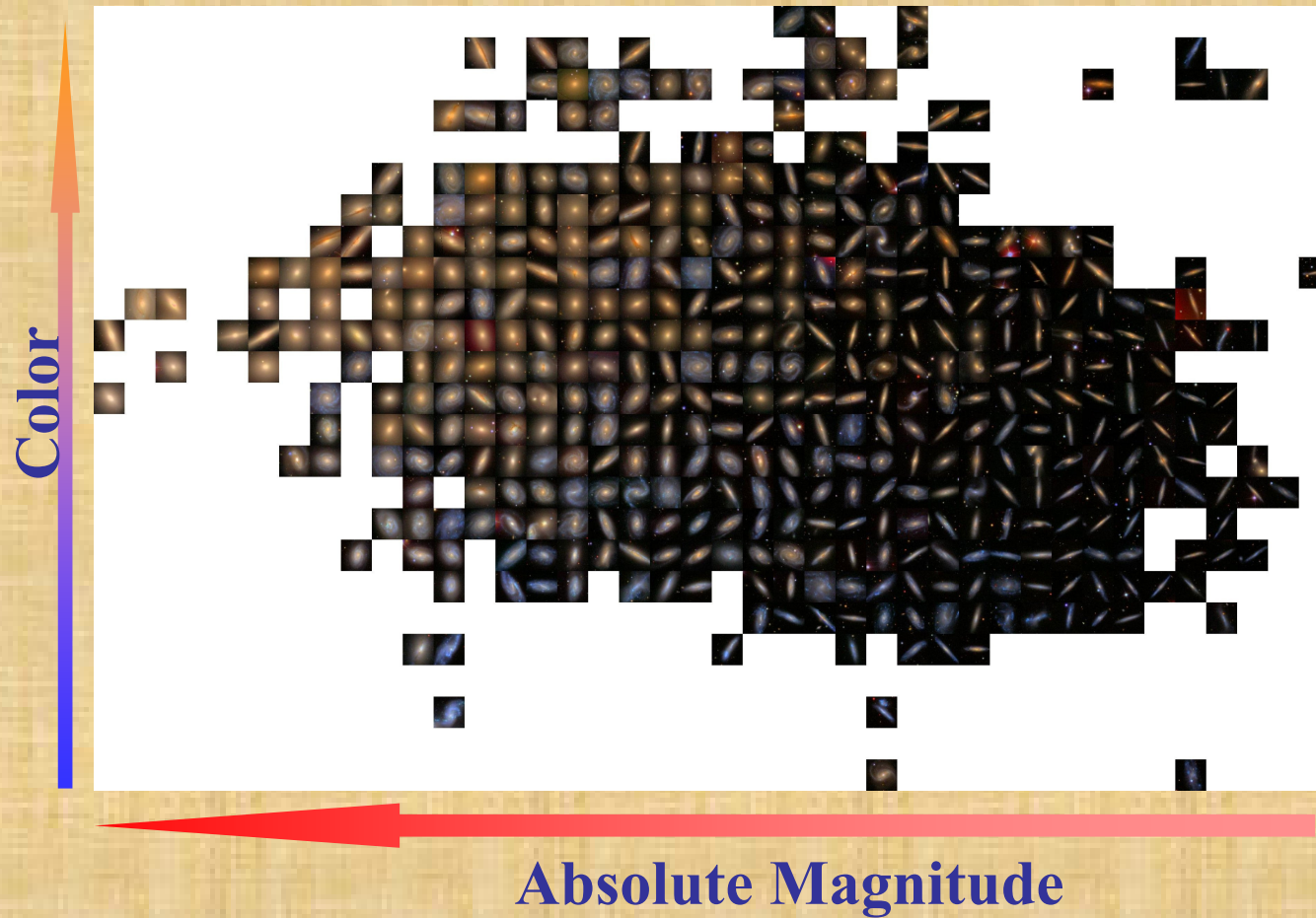
*Sánchez+12; Husemann+13*

∞ The main science goals of the survey

- Stellar population content, distribution of age and metallicity
- Distribution of ionized gas content
- Kinematic properties of both stars and gas



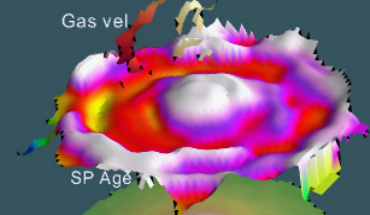
# CALIFA ANCILLARY DATA SDSS PHOTOMETRY



NGC 1349

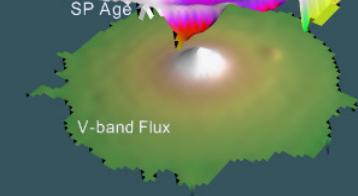


Gas vel

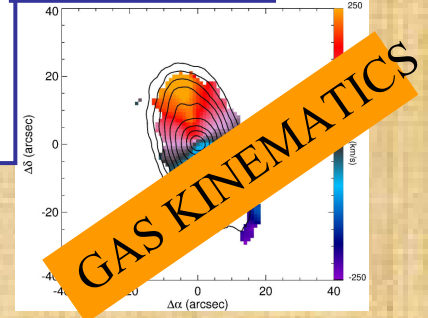
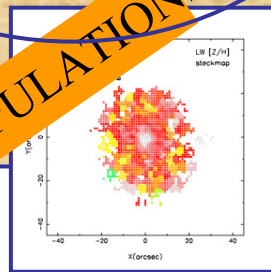
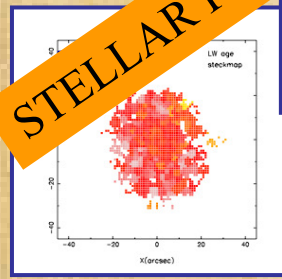
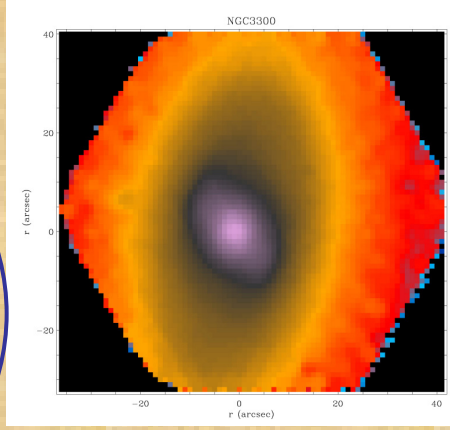
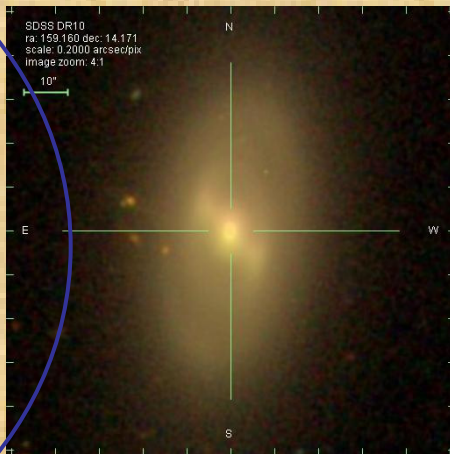
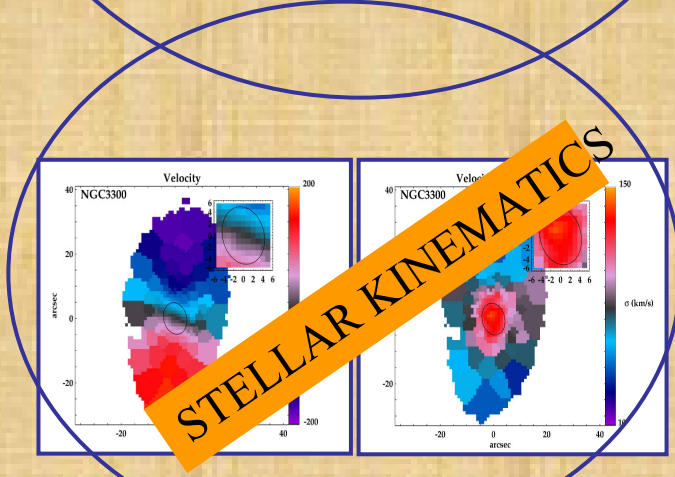
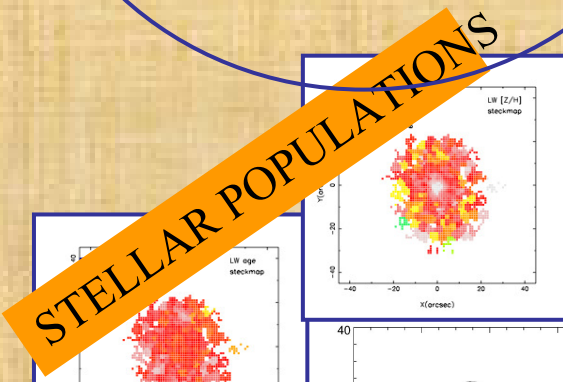
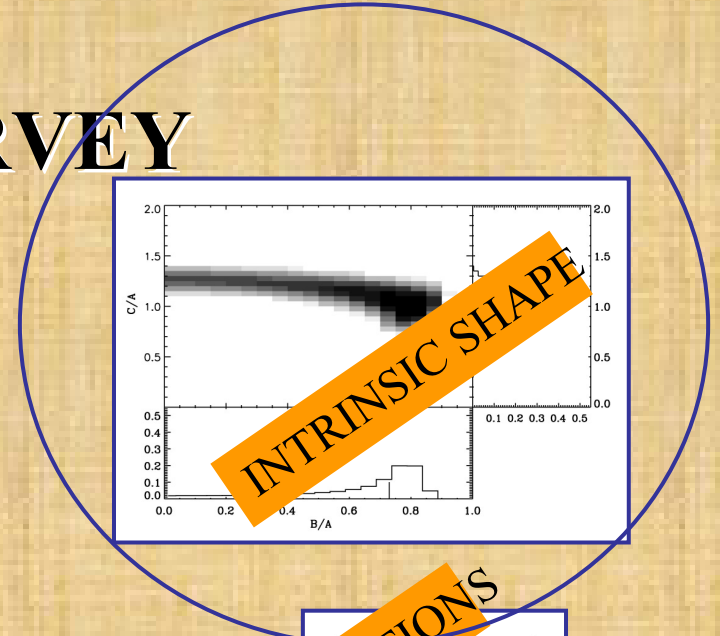
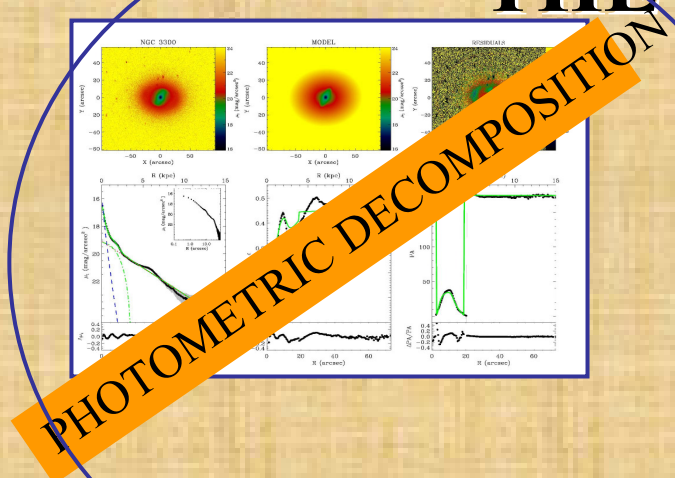


SP Age

V-band Flux



# WIDER VIEW OF BULGES USING THE CALIFA SURVEY





# BULGES IN THE CALIFA SURVEY

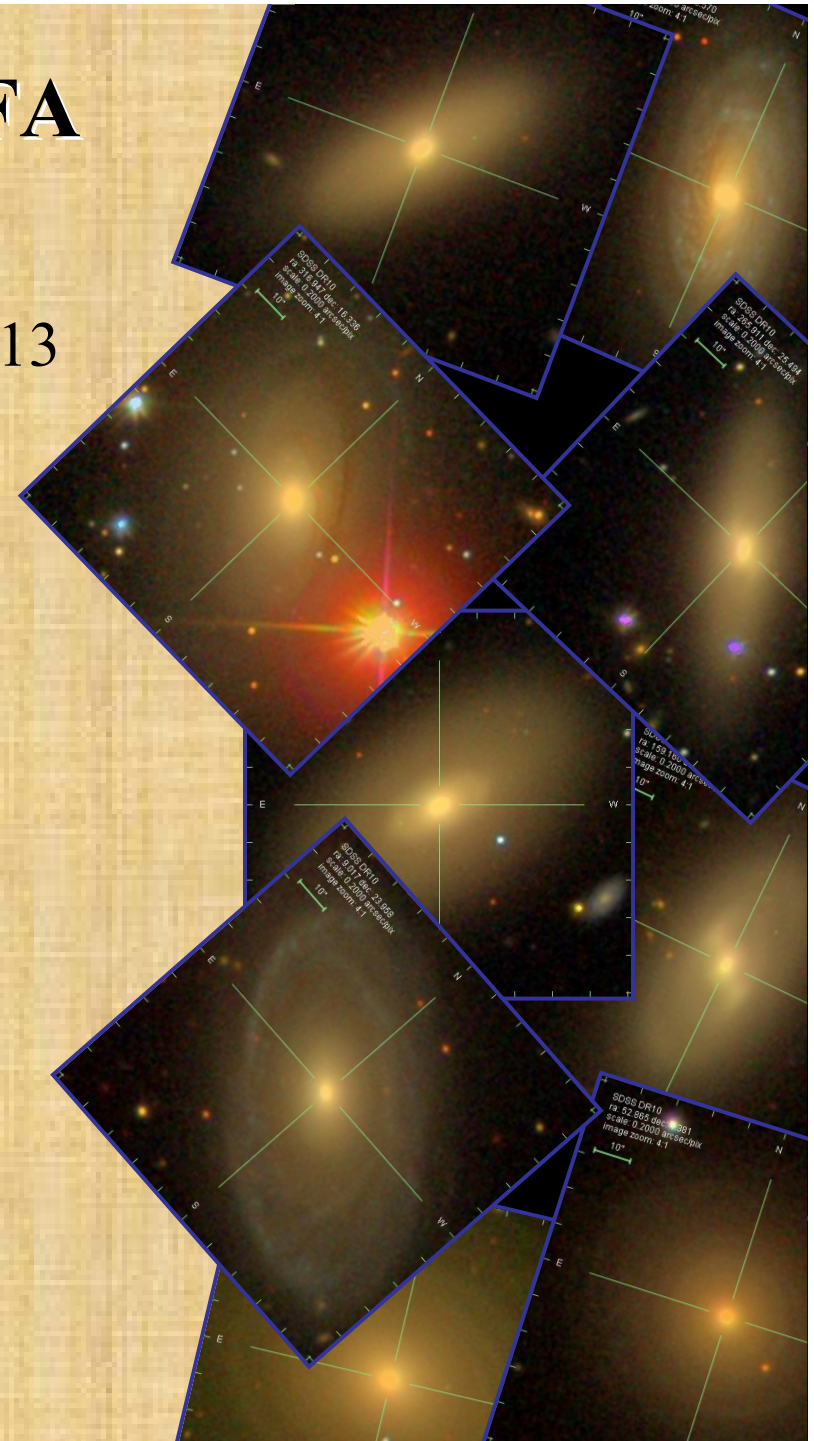
298 Galaxies observed until April 2013

154 Disk Galaxies (S0 to Sd)

27 Early type disks (S0-S0a)

Our preliminary sample

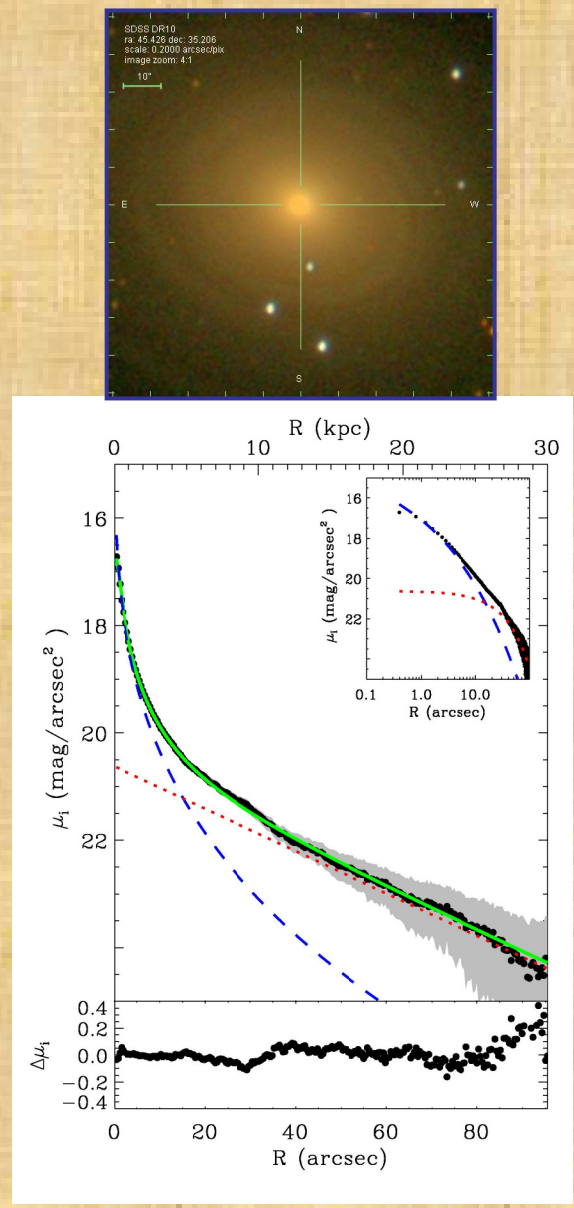
17 Moderate/Low Inclined S0-S0a





# SURFACE BRIGHTNESS PROFILES

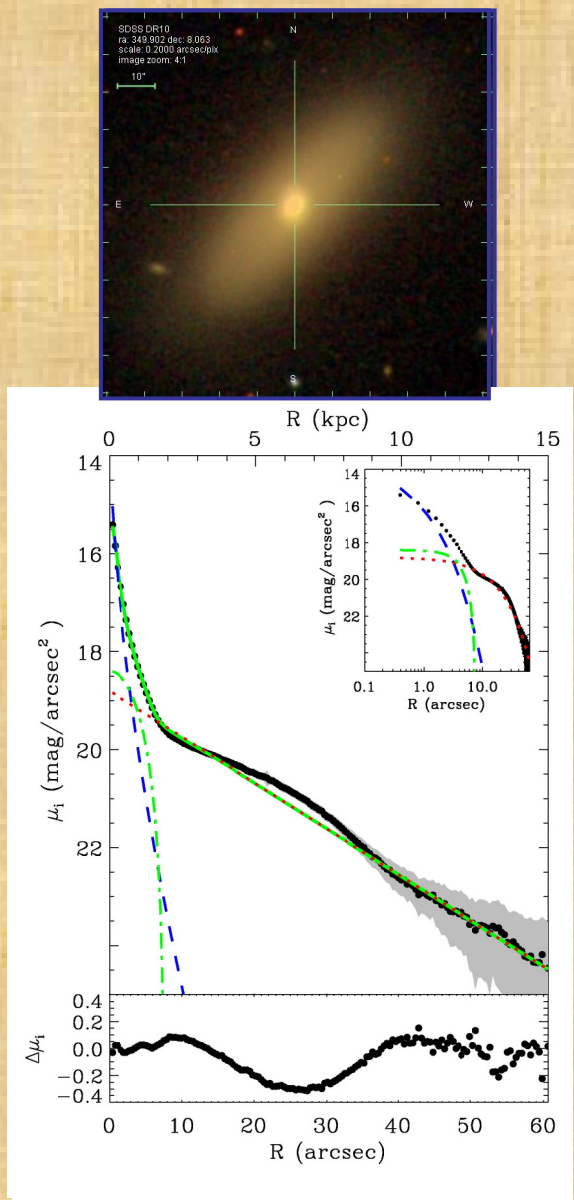
**BULGE+DISK**



Decomposition using three different bands: g, r, i  
*GASP2D Méndez-Abreu+08*

# SURFACE BRIGHTNESS PROFILES

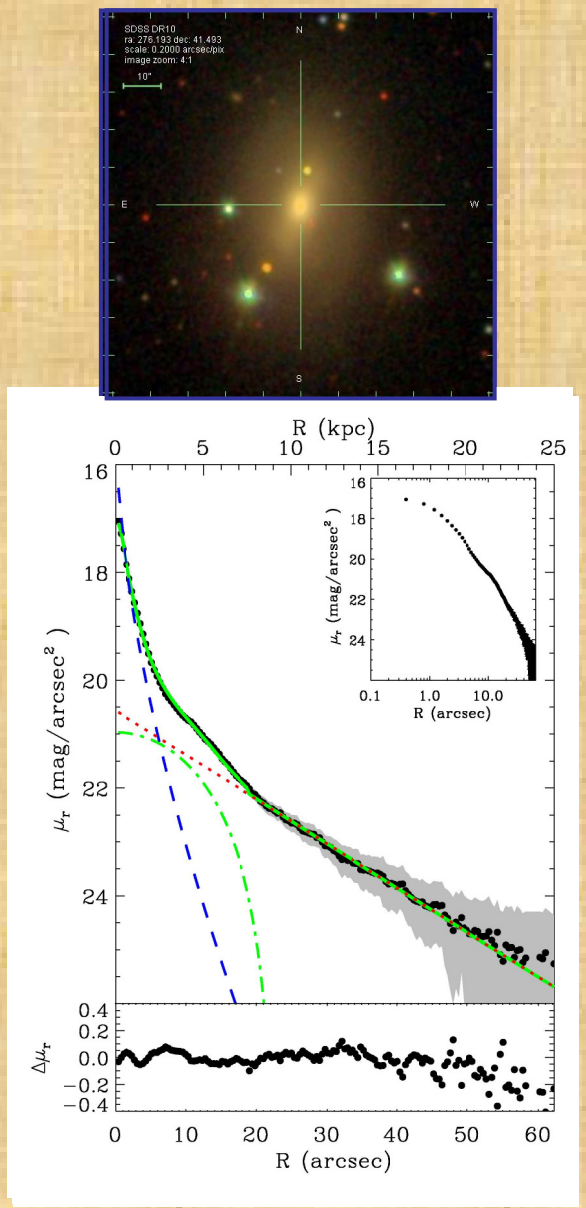
**BULGE+DISK+SMALL BAR**



Decomposition using three different bands: g, r, i  
*GASP2D Méndez-Abreu+08*

# SURFACE BRIGHTNESS PROFILES

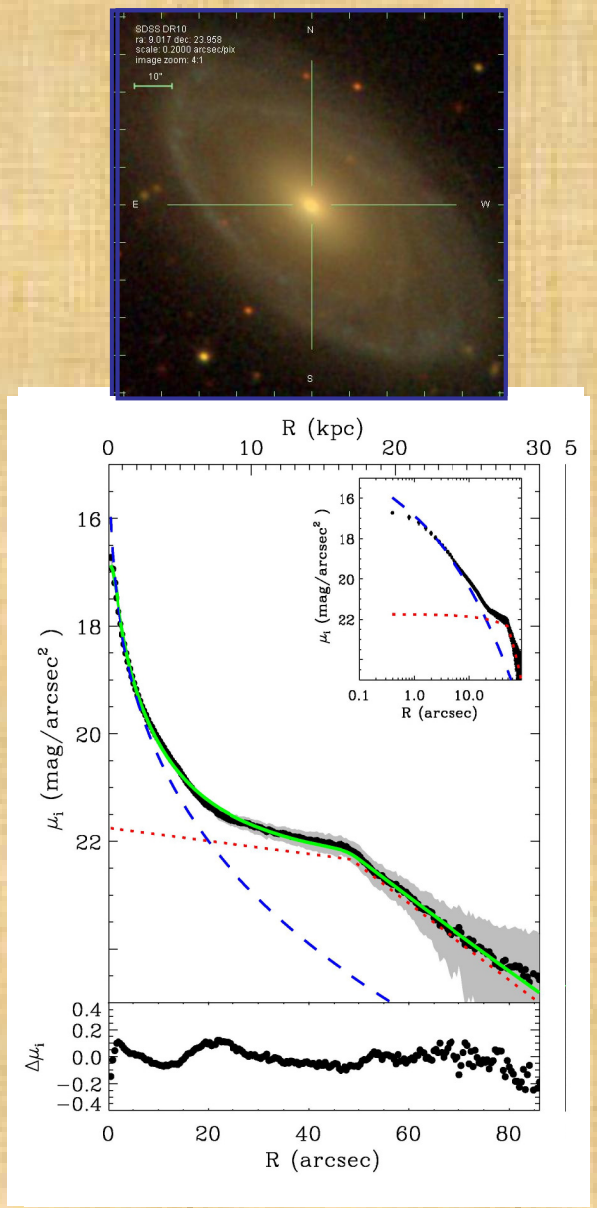
**BULGE+DISK+LARGE BAR**



Decomposition using three different bands: g, r, i  
*GASP2D Méndez-Abreu+08*

# SURFACE BRIGHTNESS PROFILES

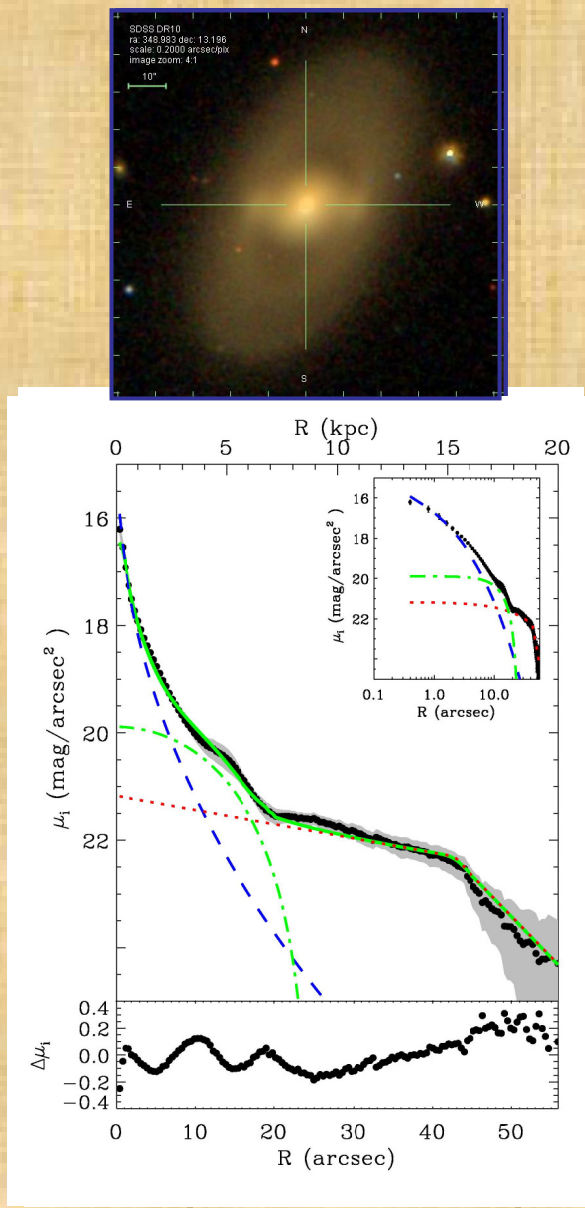
**BULGE+TRUNCATED DISK**



Decomposition using three different bands: g, r, i  
*GASP2D Méndez-Abreu+08*

# SURFACE BRIGHTNESS PROFILES

**BULGE+TRUNCATED DISK+LARGE BAR**



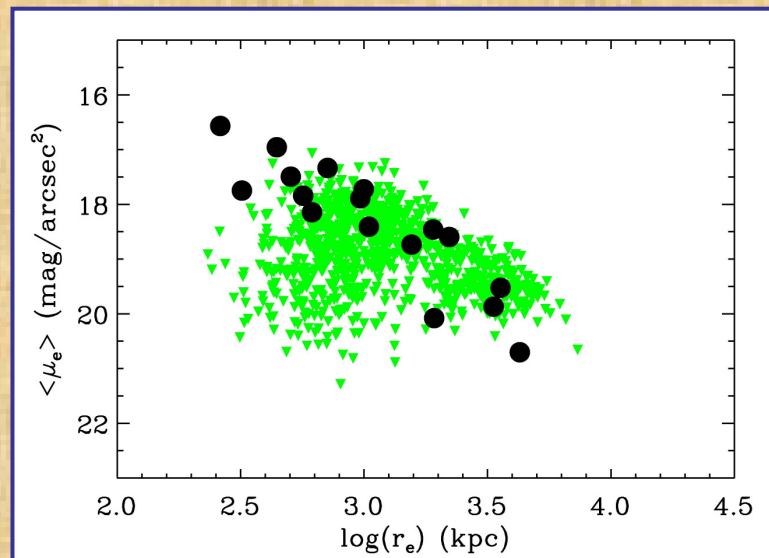
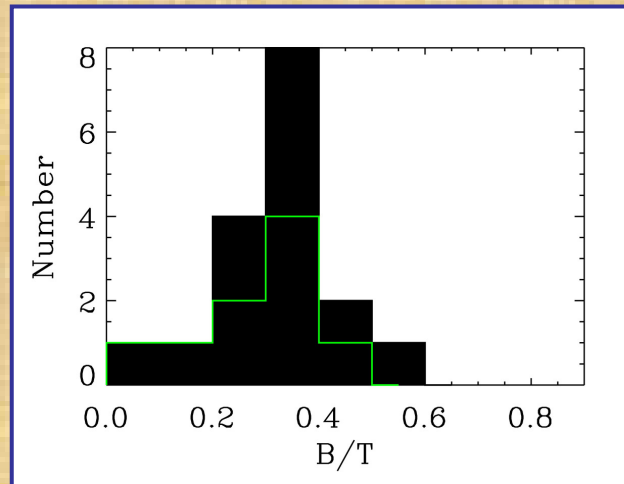
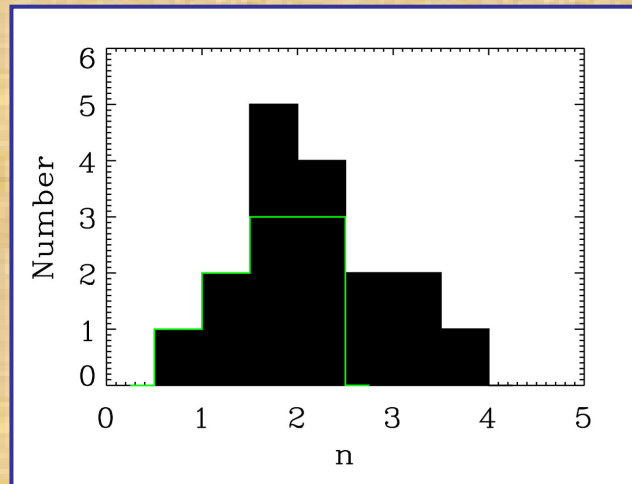
Decomposition using three different bands:  $g, r, i$   
*GASP2D Méndez-Abreu+08*



# SURFACE BRIGHTNESS PROFILES

*Careful  
photometric decompositions  
are needed!!!*

# BASIC PHOTOMETRIC PROPERTIES



∞ S0s span a wide range of  $n$  and  $B/T$   
*Laurikainen+07,+10*

∞  $n$  and  $B/T$  is lower for barred systems  
*Gadotti09*

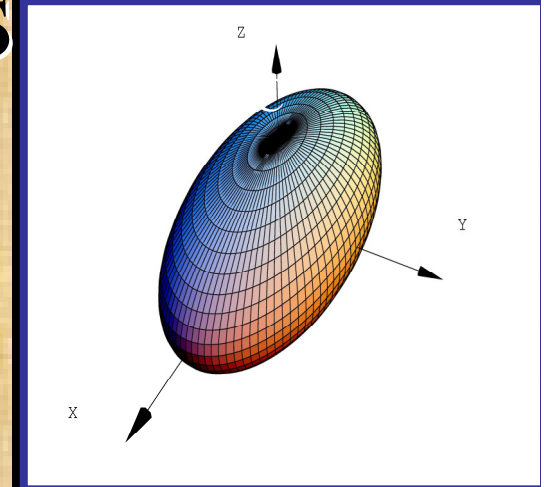
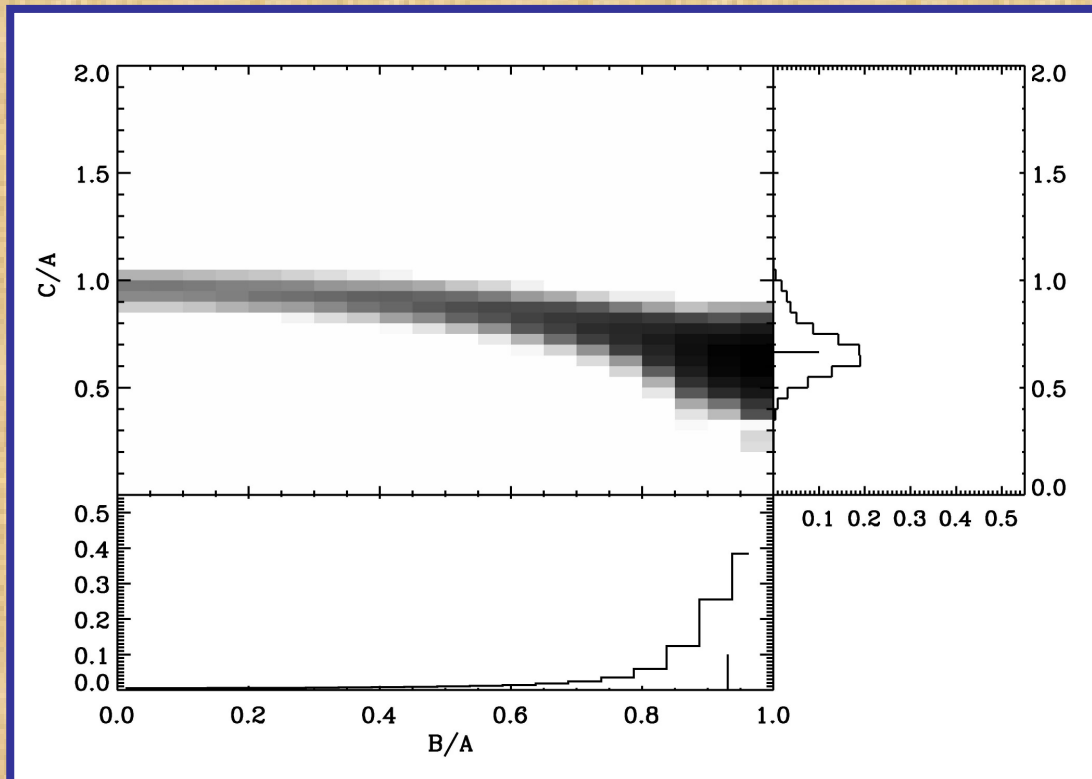
∞ S0s follows the main Kormendy relation  
*Gadotti09*

# INTRINSIC SHAPE OF BULGES

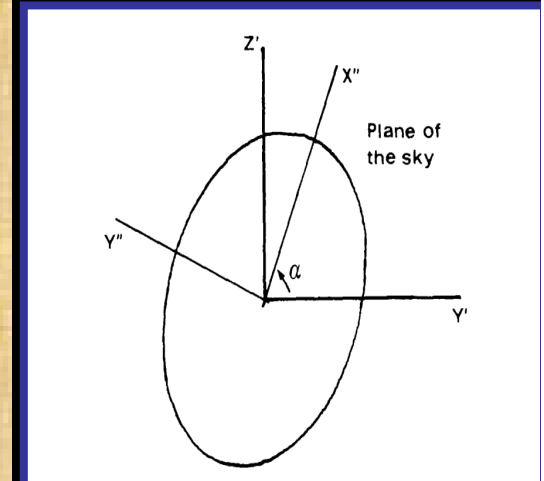
Based on Méndez-Abreu+08, 10

The intrinsic shape of bulges can be derived from the length of the apparent major and minor semi-axes of the bulge, twist angle between the apparent major axis of the bulge and the galaxy line of nodes, and galaxy inclination.

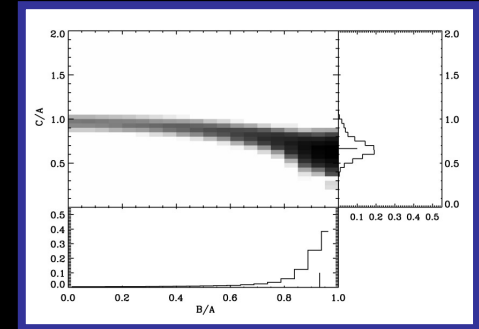
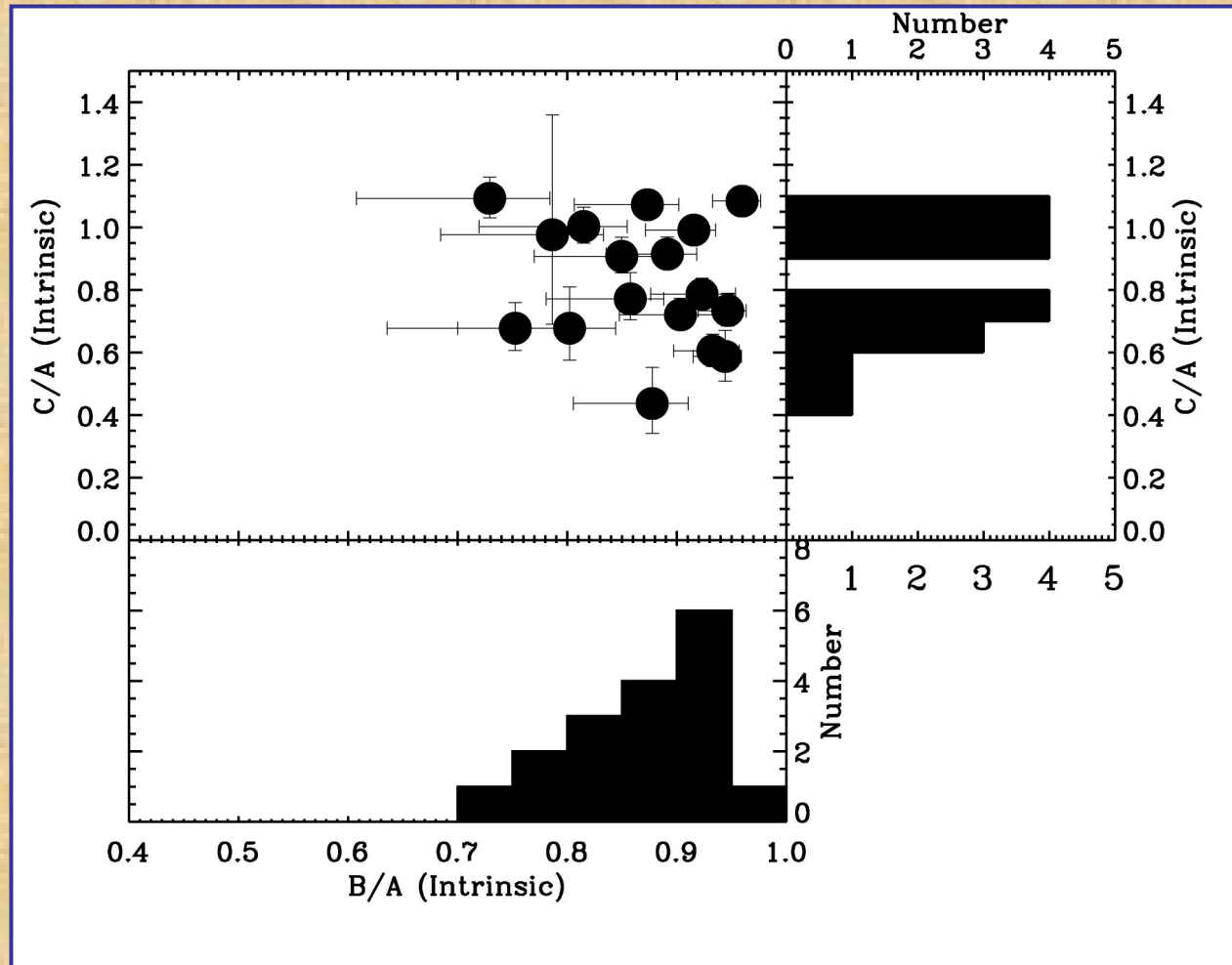
Taking into account the PDF  
of the intrinsic axis ratios  
and photometric errors



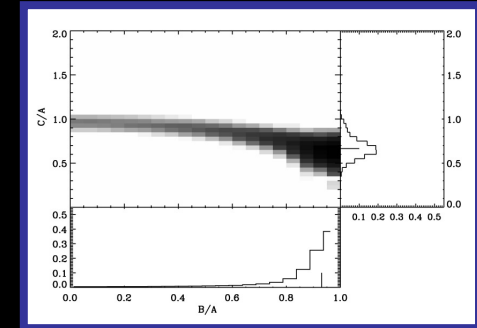
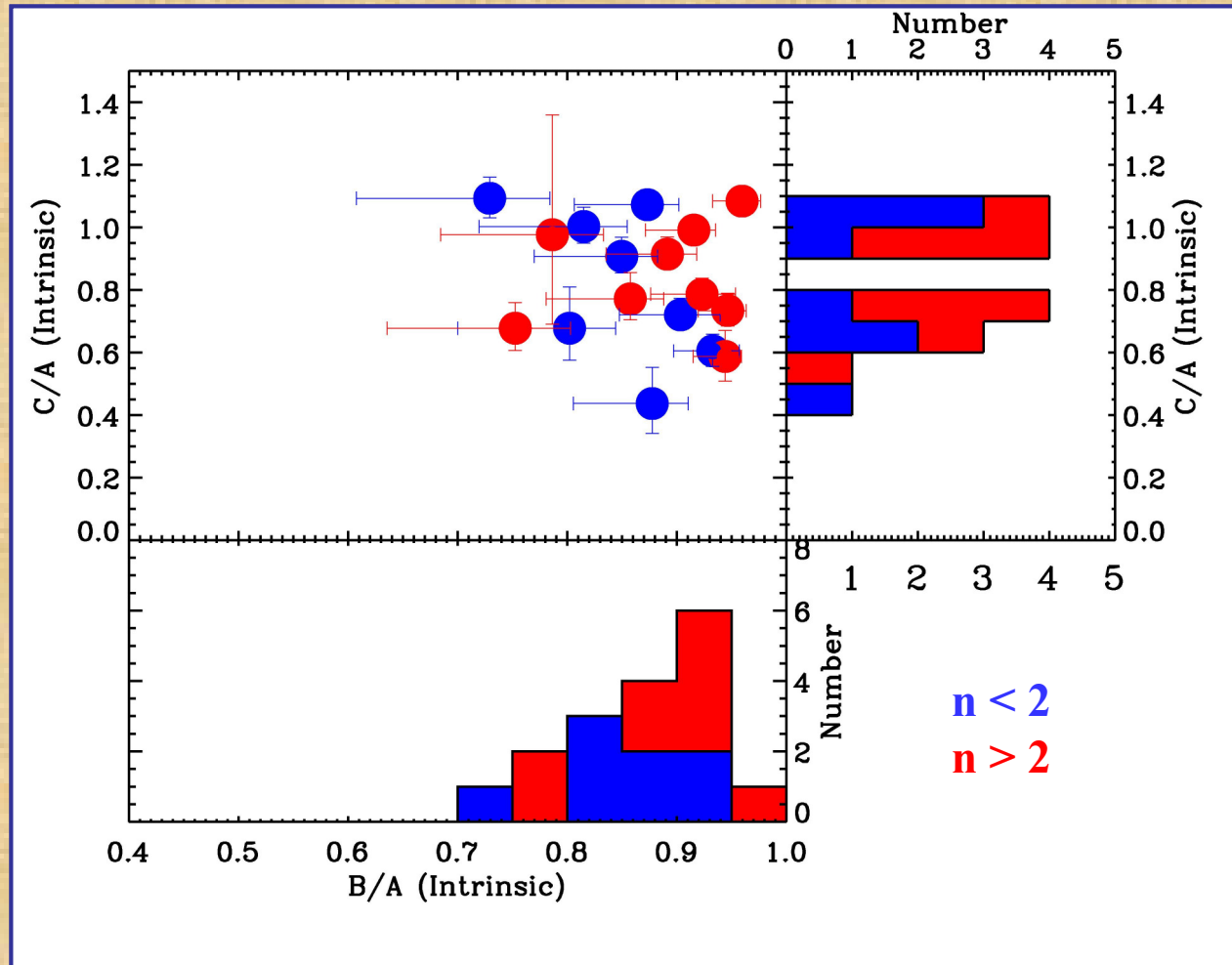
Line-of-sight



# INTRINSIC SHAPE OF BULGES

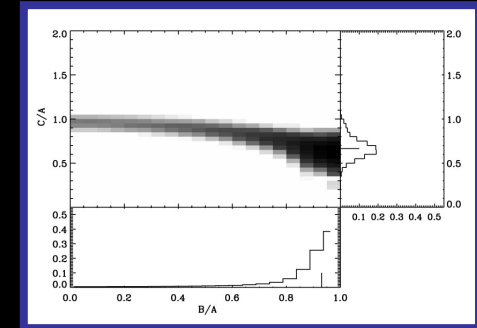
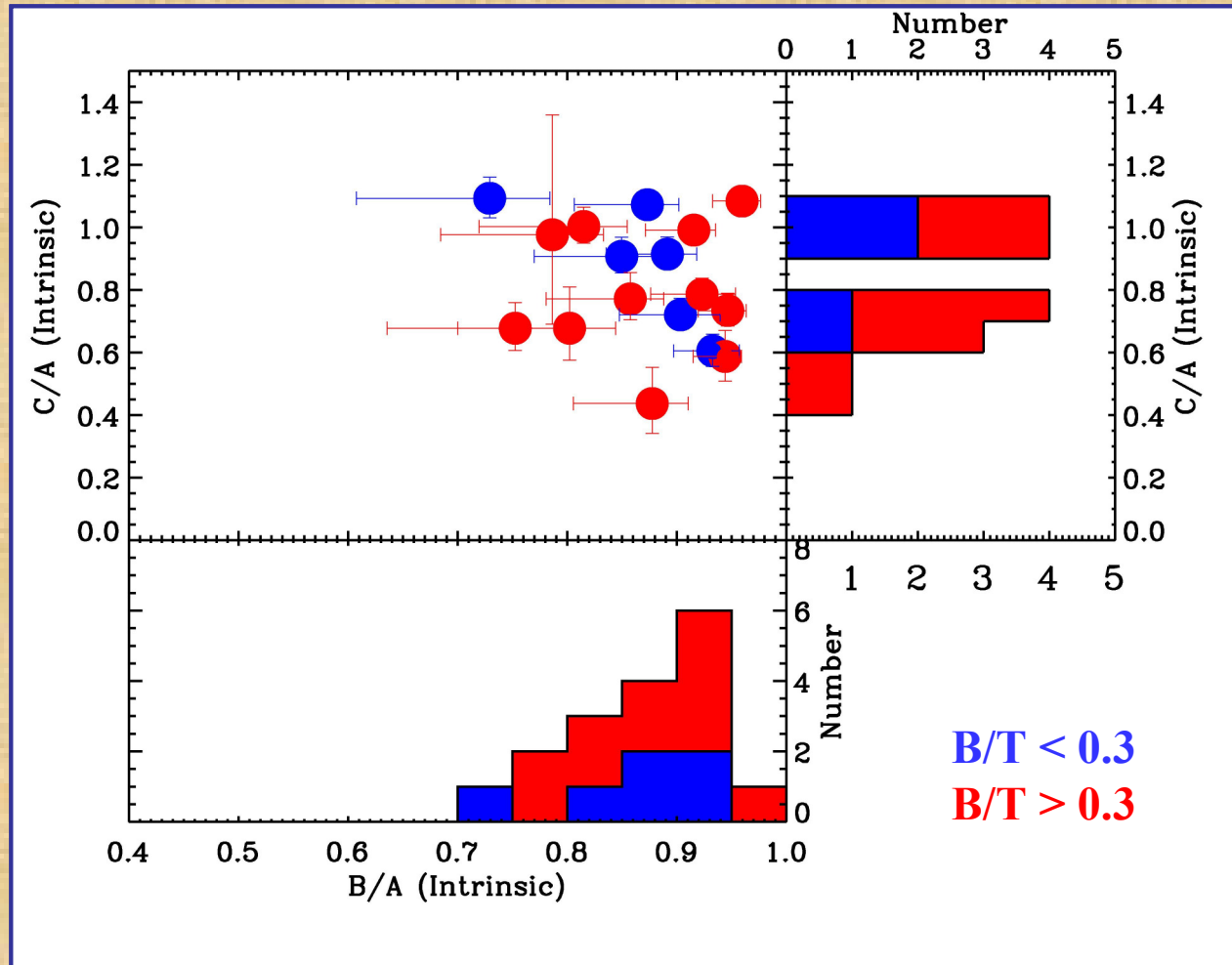


# INTRINSIC SHAPE OF BULGES

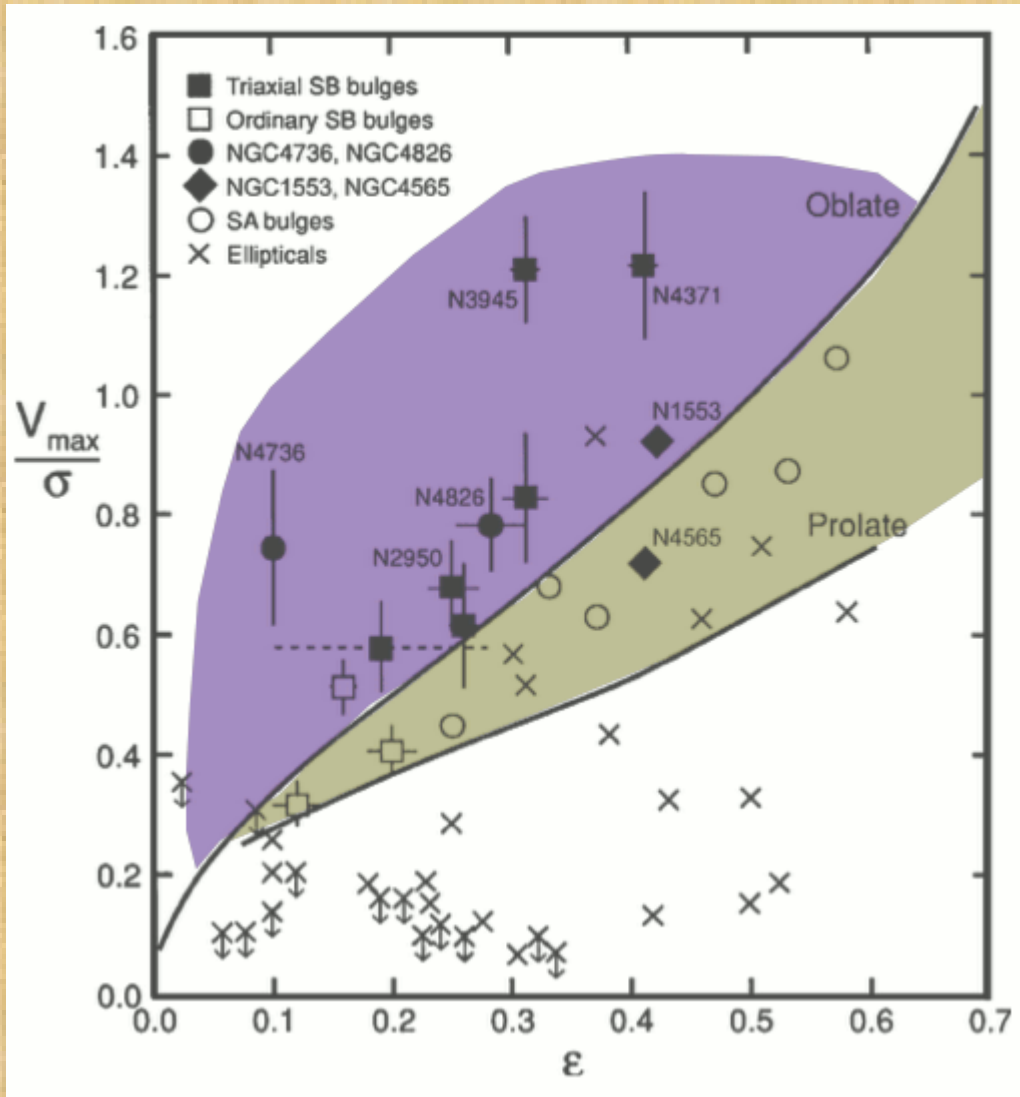




# INTRINSIC SHAPE OF BULGES



# STELLAR KINEMATICS



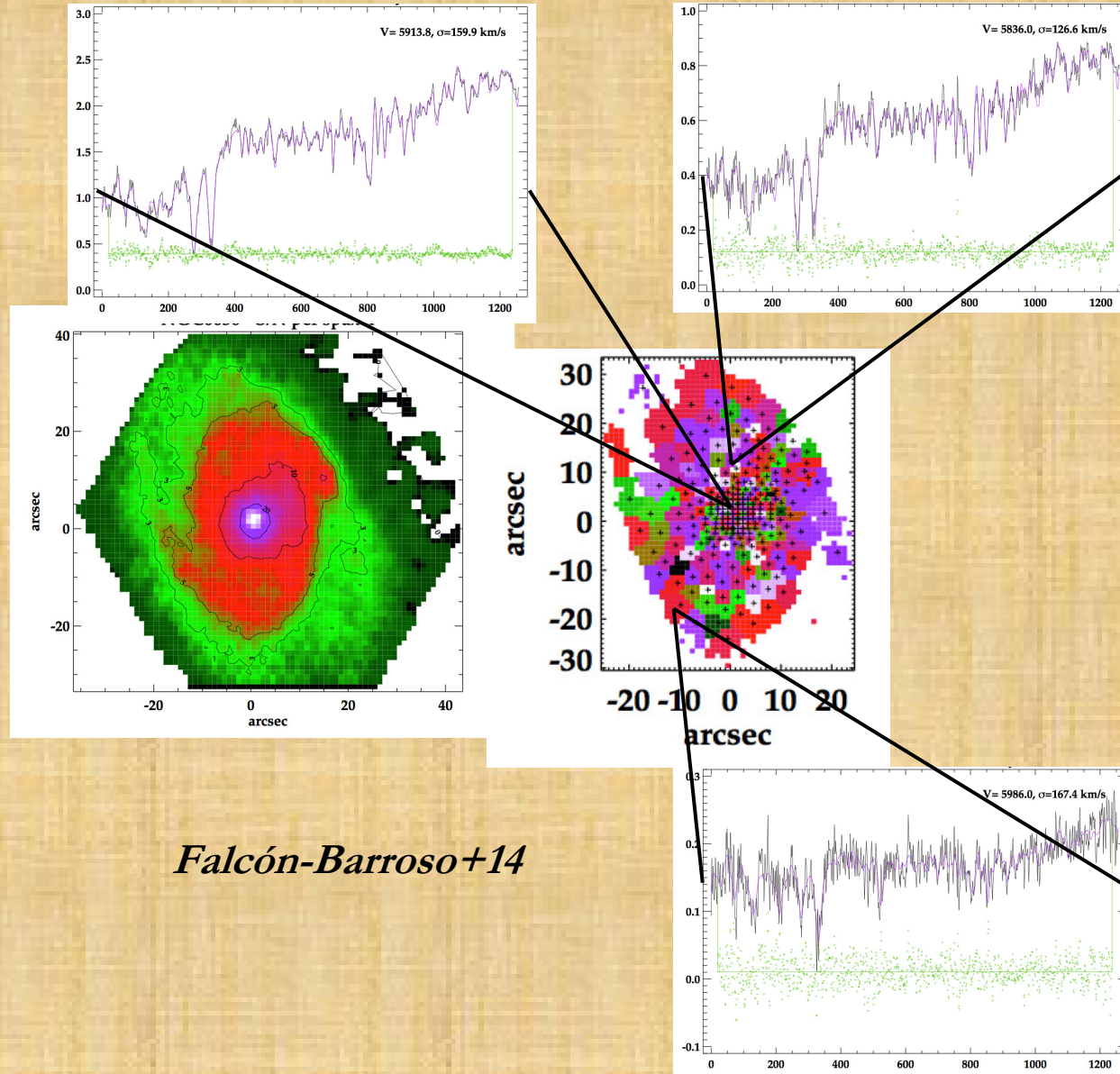
*Kormendy & Kennicutt 04*

By definition:

∞ Pseudobulges should resemble the kinematics of disks

∞ Classical bulges are expected to be dominated by random motions

# STELLAR KINEMATICS



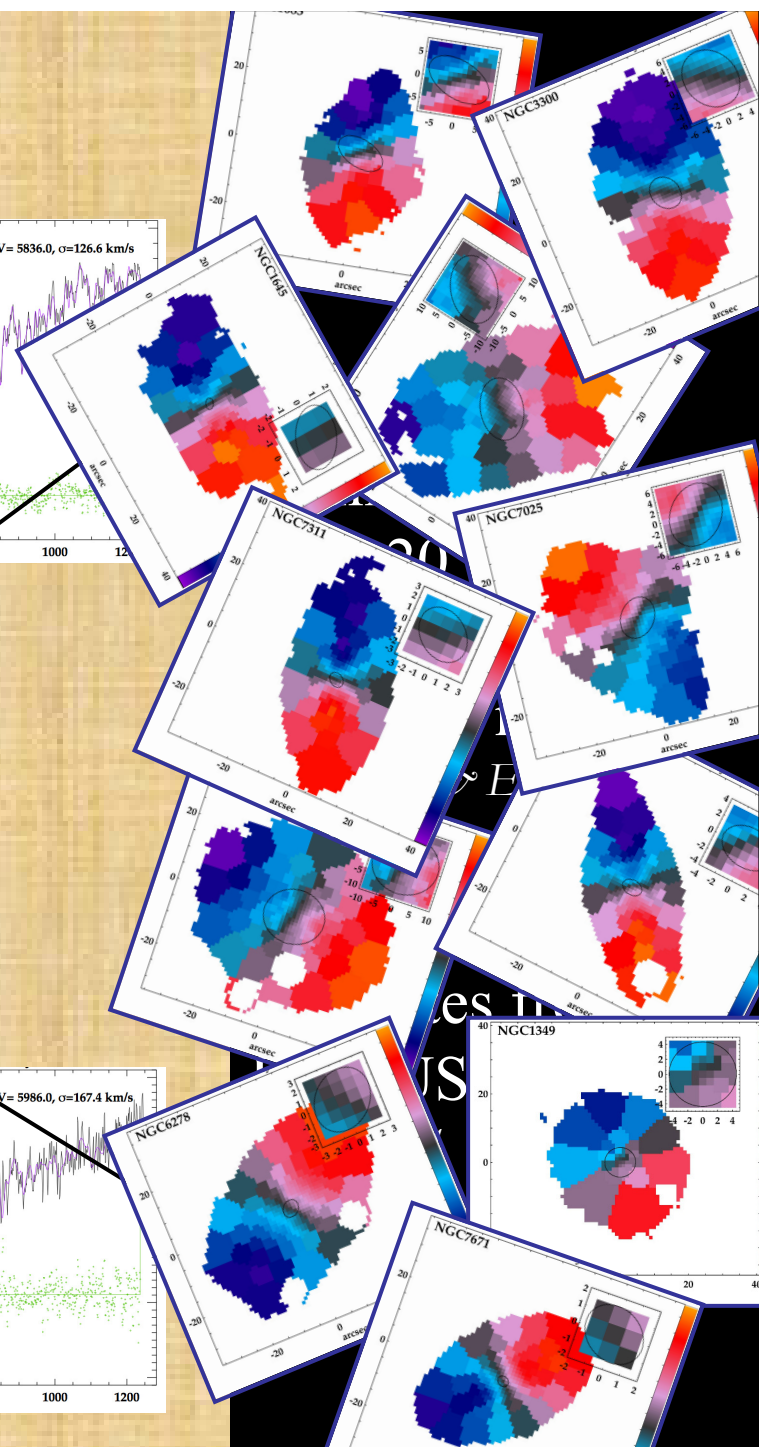
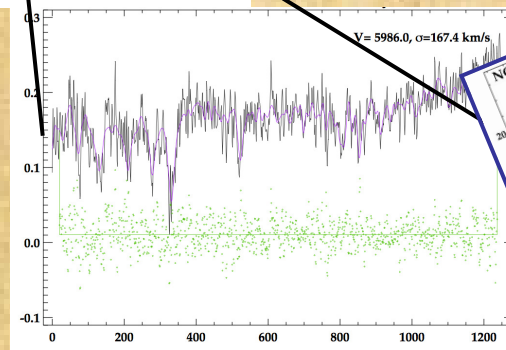
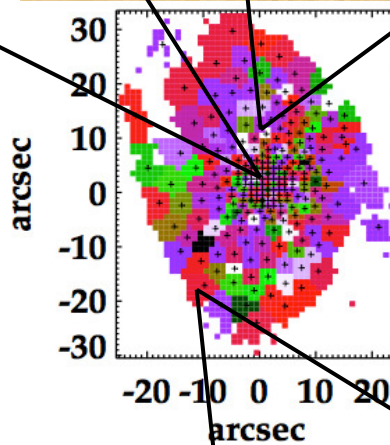
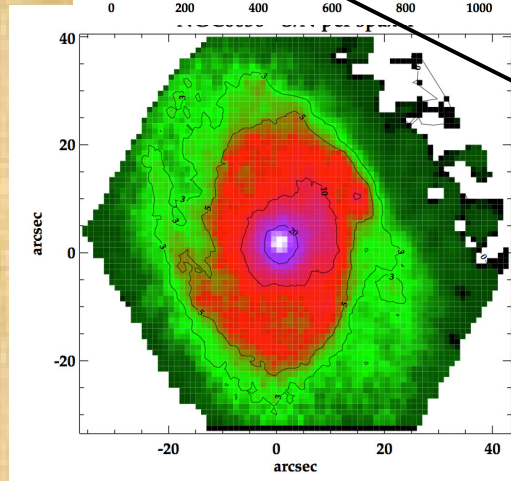
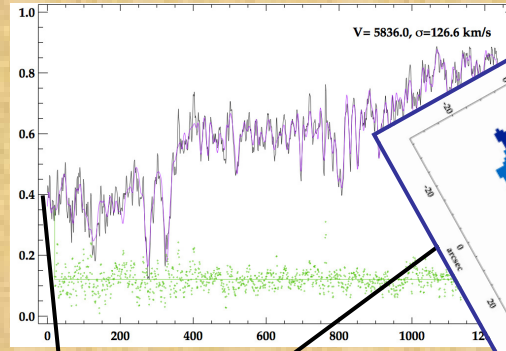
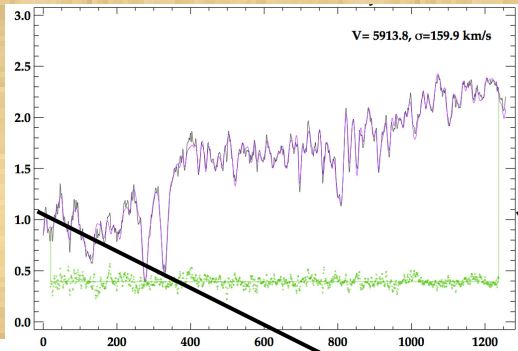
*Falc3n-Barroso+14*

∞ Voronoi  
binning minimum  
S/N=20

∞ pPXF method  
*Cappellari & Emsellem04*

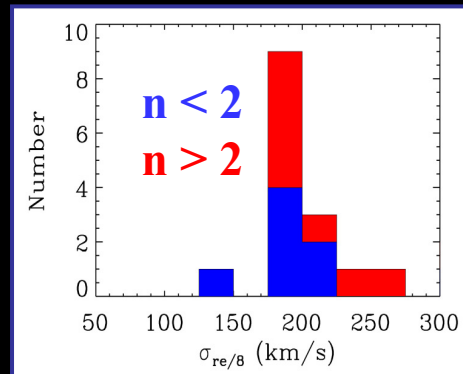
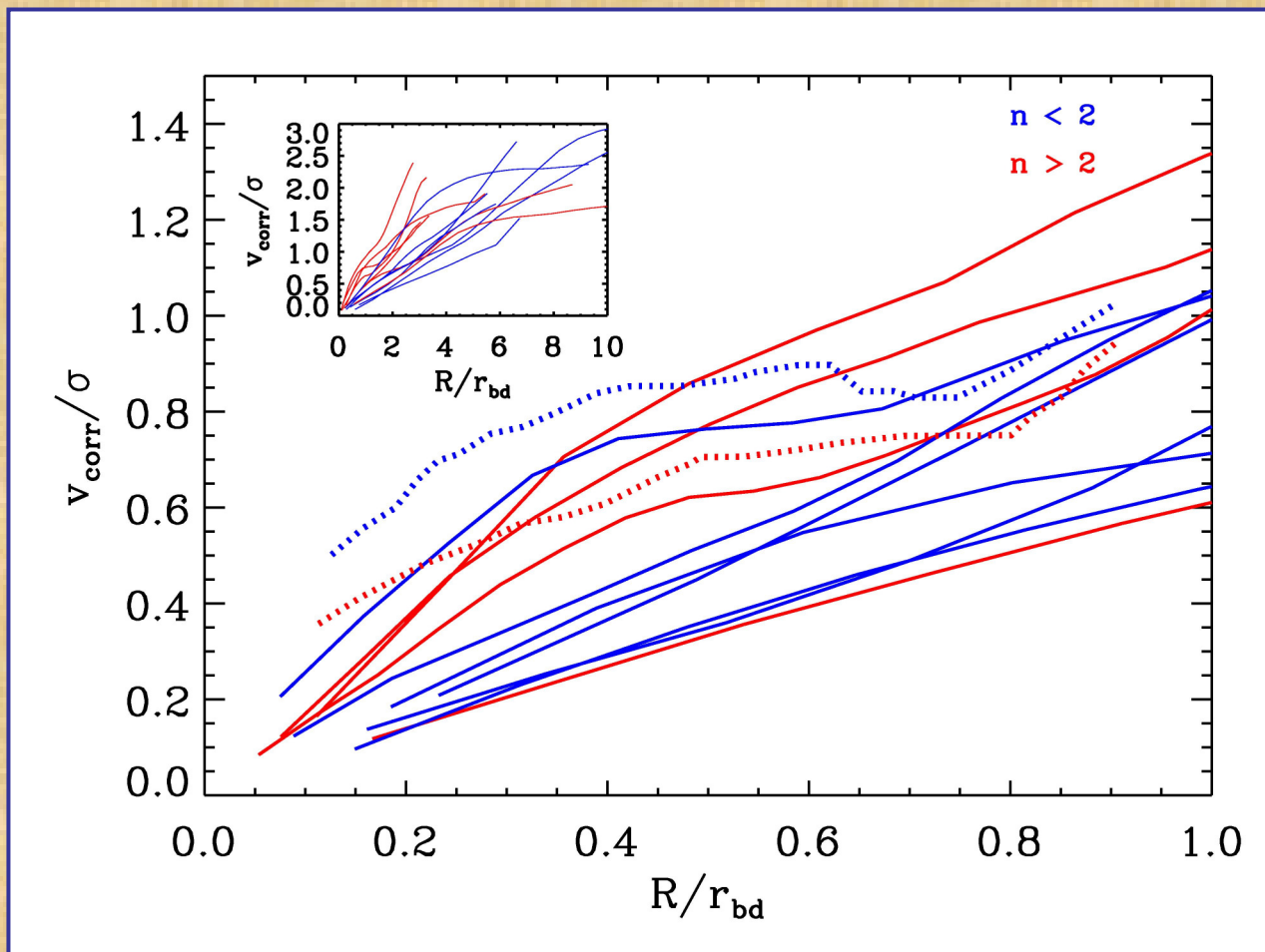
∞ Stellar  
templates from  
Indo-US library  
*Valdes+04*

# STELLAR KINEMATICS



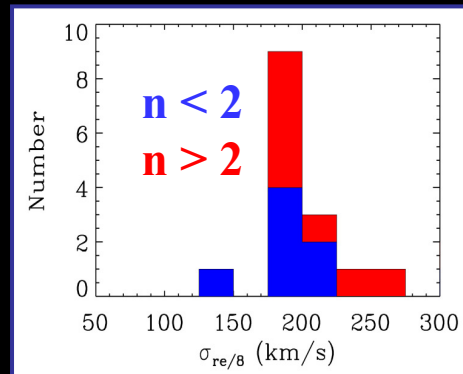
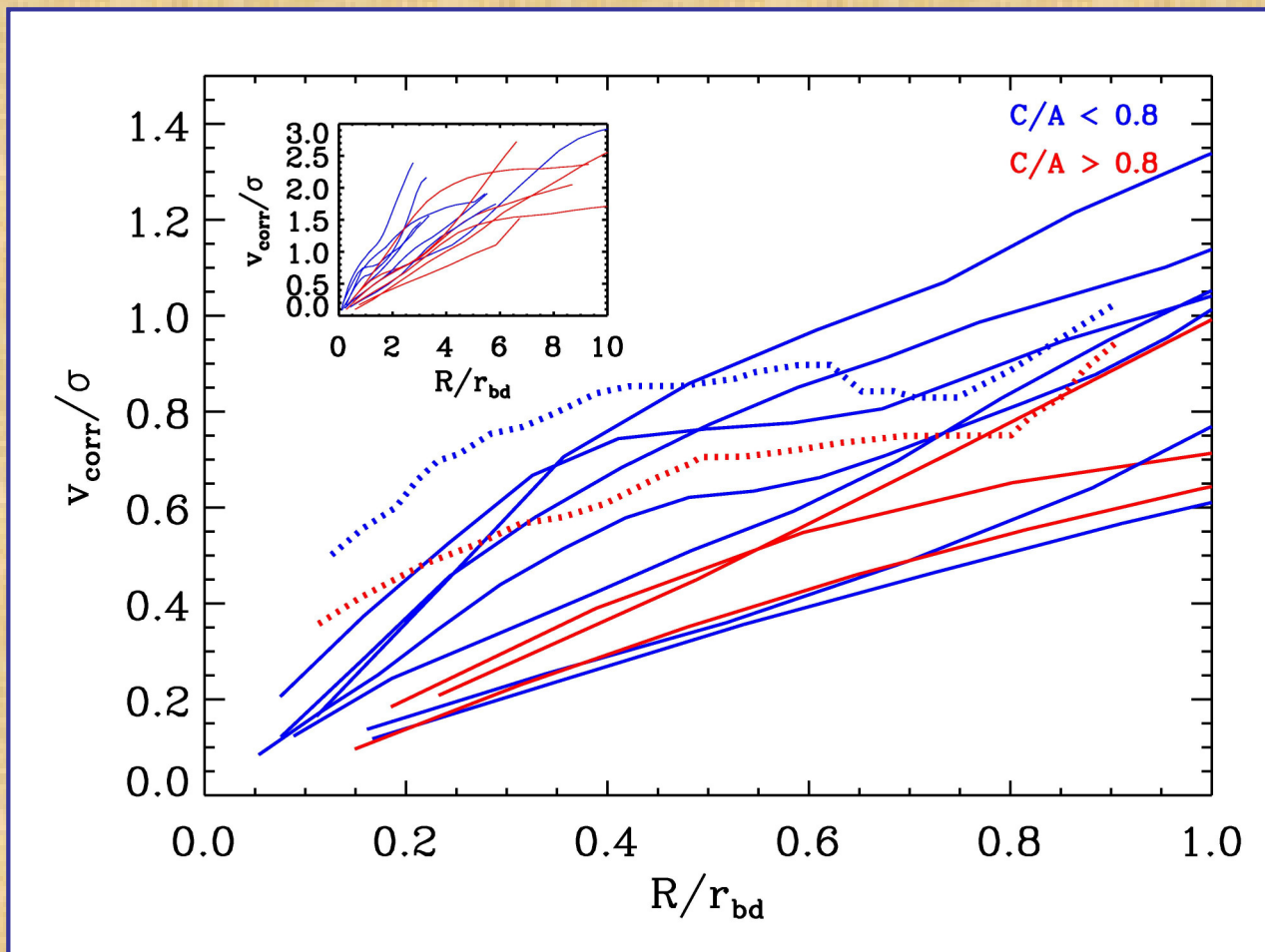
*Falcón-Barroso+14*

# STELLAR KINEMATICS

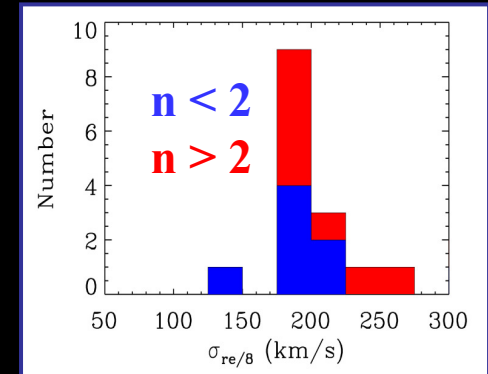
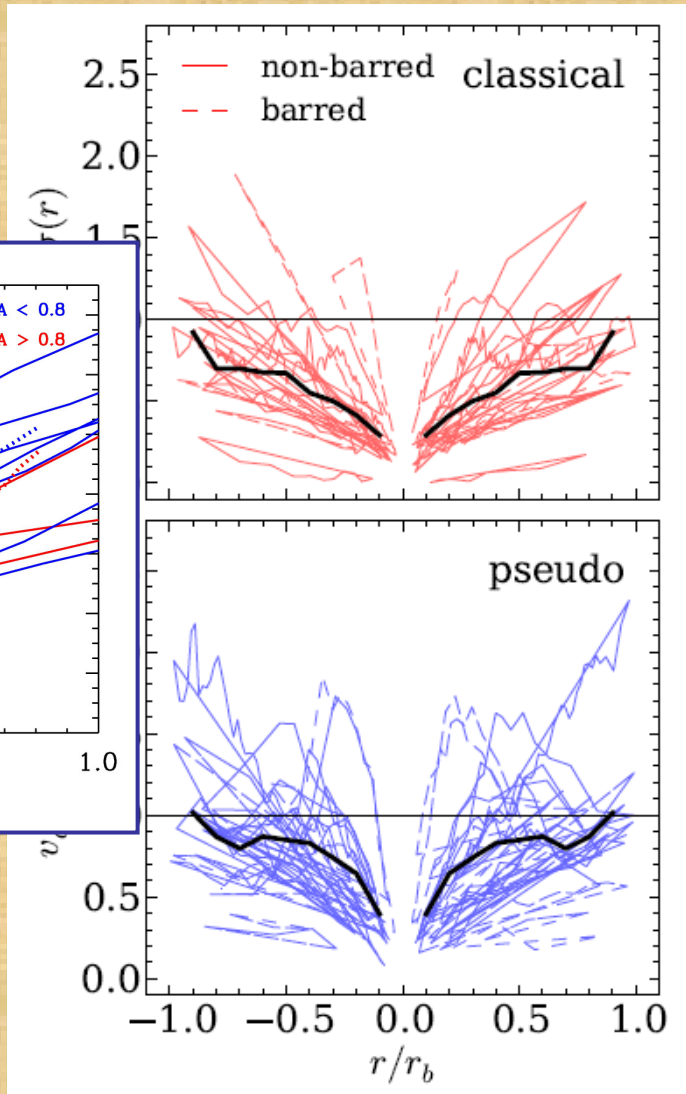
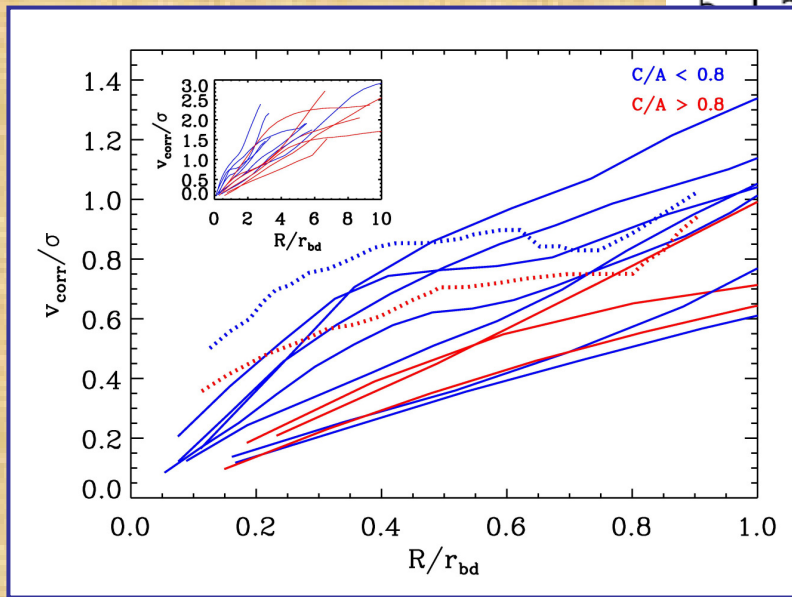




# STELLAR KINEMATICS



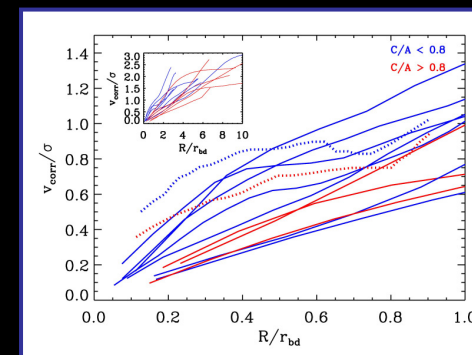
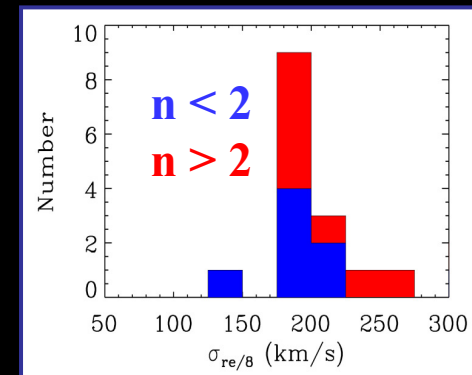
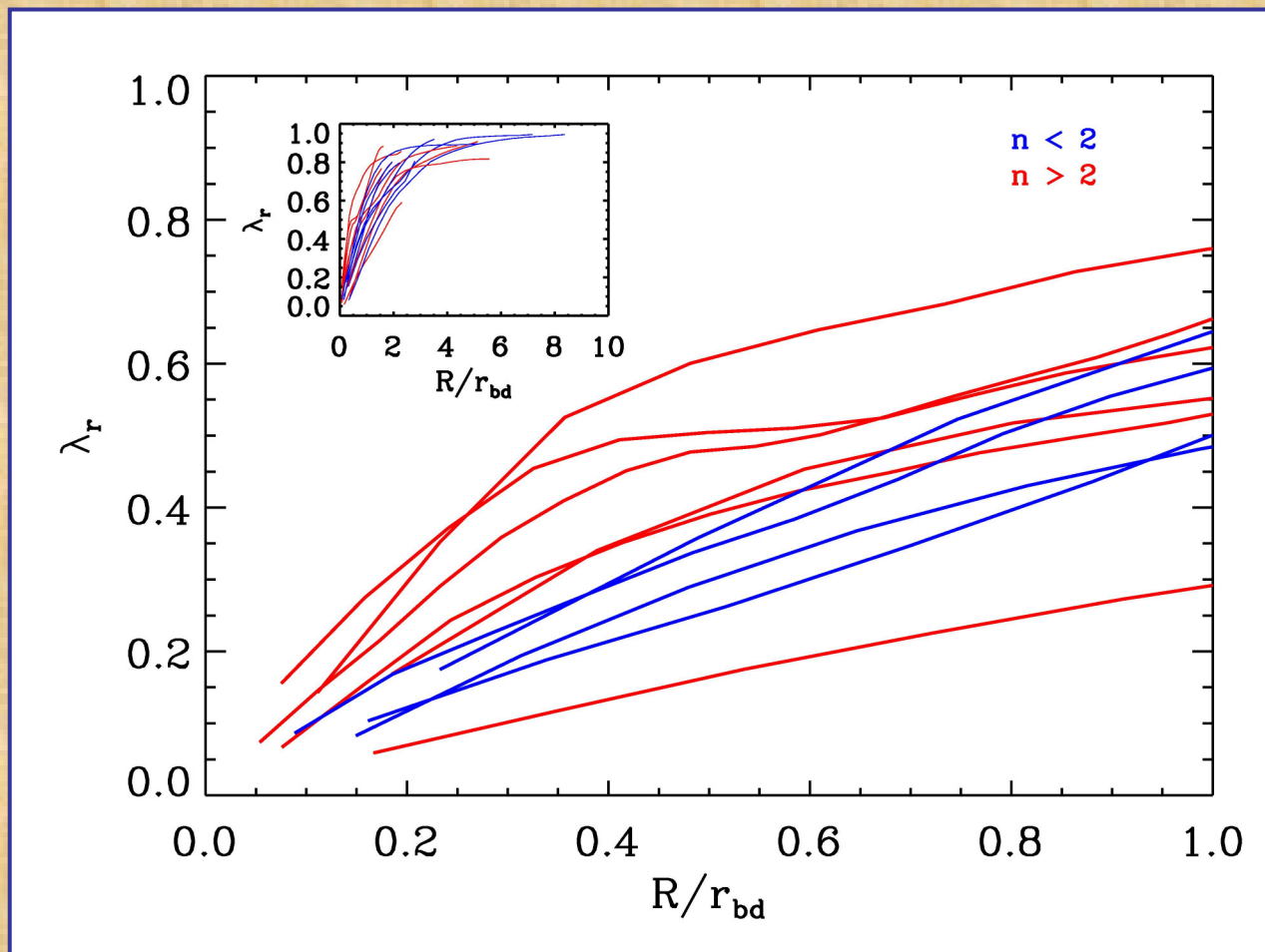
# STELLAR KINEMATICS



*Fabricius+12*

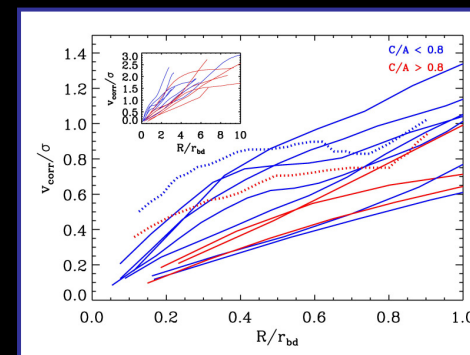
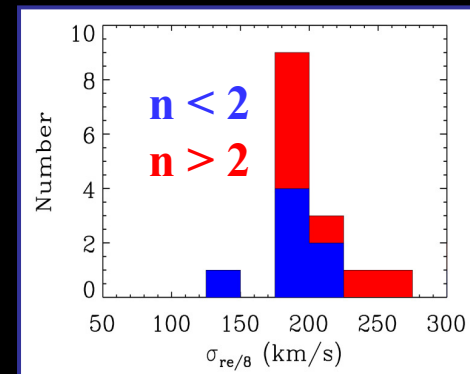
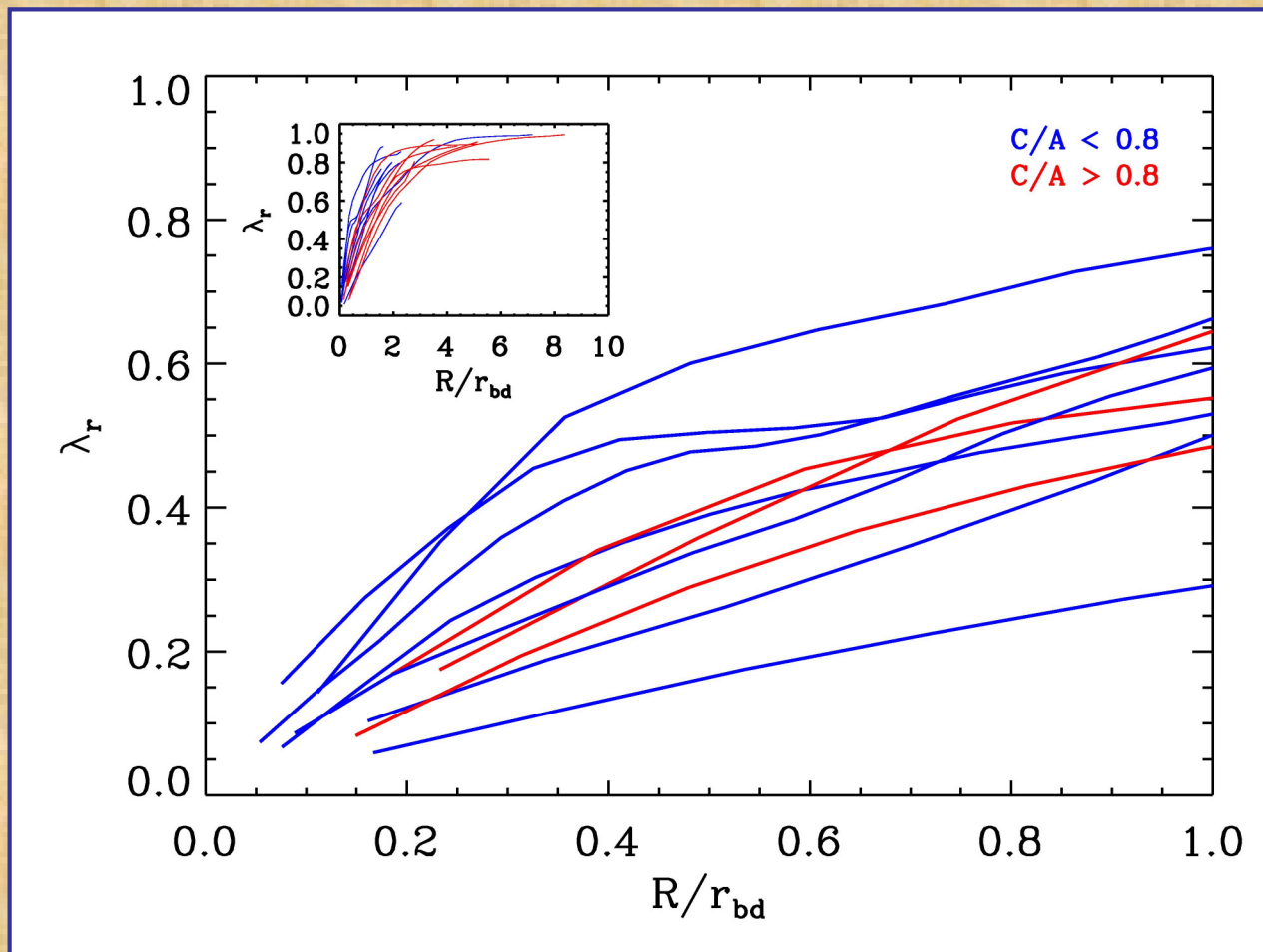
# STELLAR KINEMATICS

*Emsellem+07*



# STELLAR KINEMATICS

*Emsellem+07*



# CONCLUSIONS AND FUTURE WORK

- ✧ We have studied a sample of early-type bulges from the CALIFA survey
- ✧ Early-type bulges show a large variety of Sersic index, B/T, and intrinsic shapes
- ✧ Stellar kinematics do not seem to correlate with photometric quantities, but...
  - ✧ Only early-type galaxies
  - ✧ Yet small sample
- ✧ We will complete our analysis using the spatially resolved stellar populations and gas physical properties.