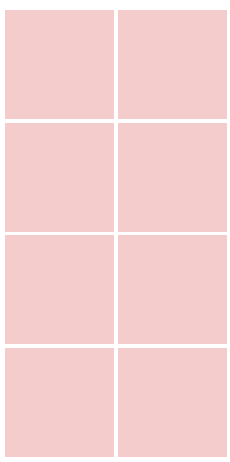


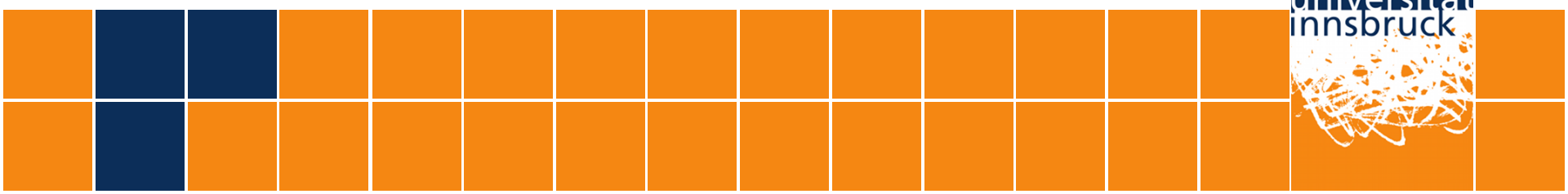
# Dividing the Local Galaxy Stellar Mass Function by **Morphology** and **Structure**



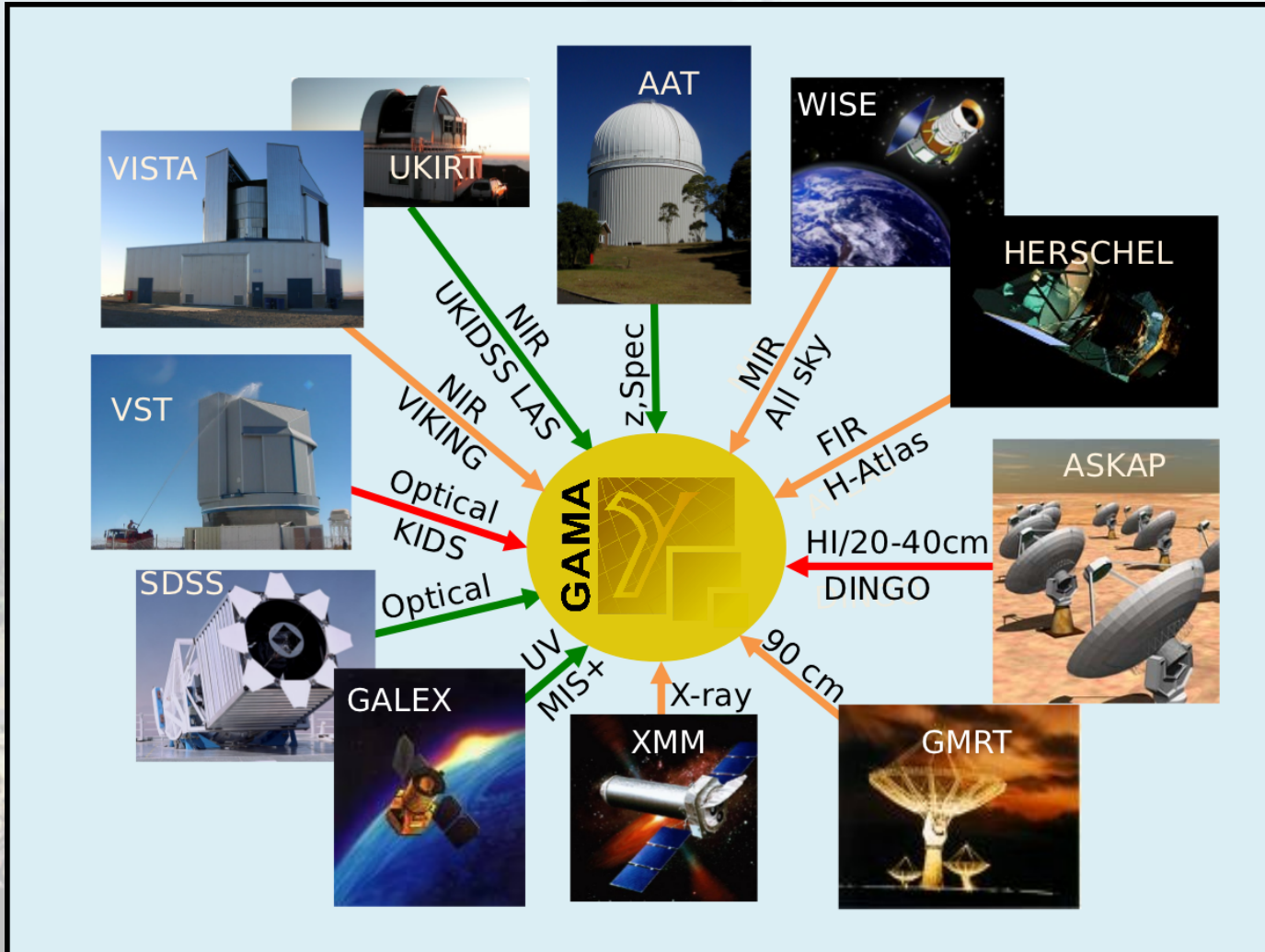
Lee Kelvin



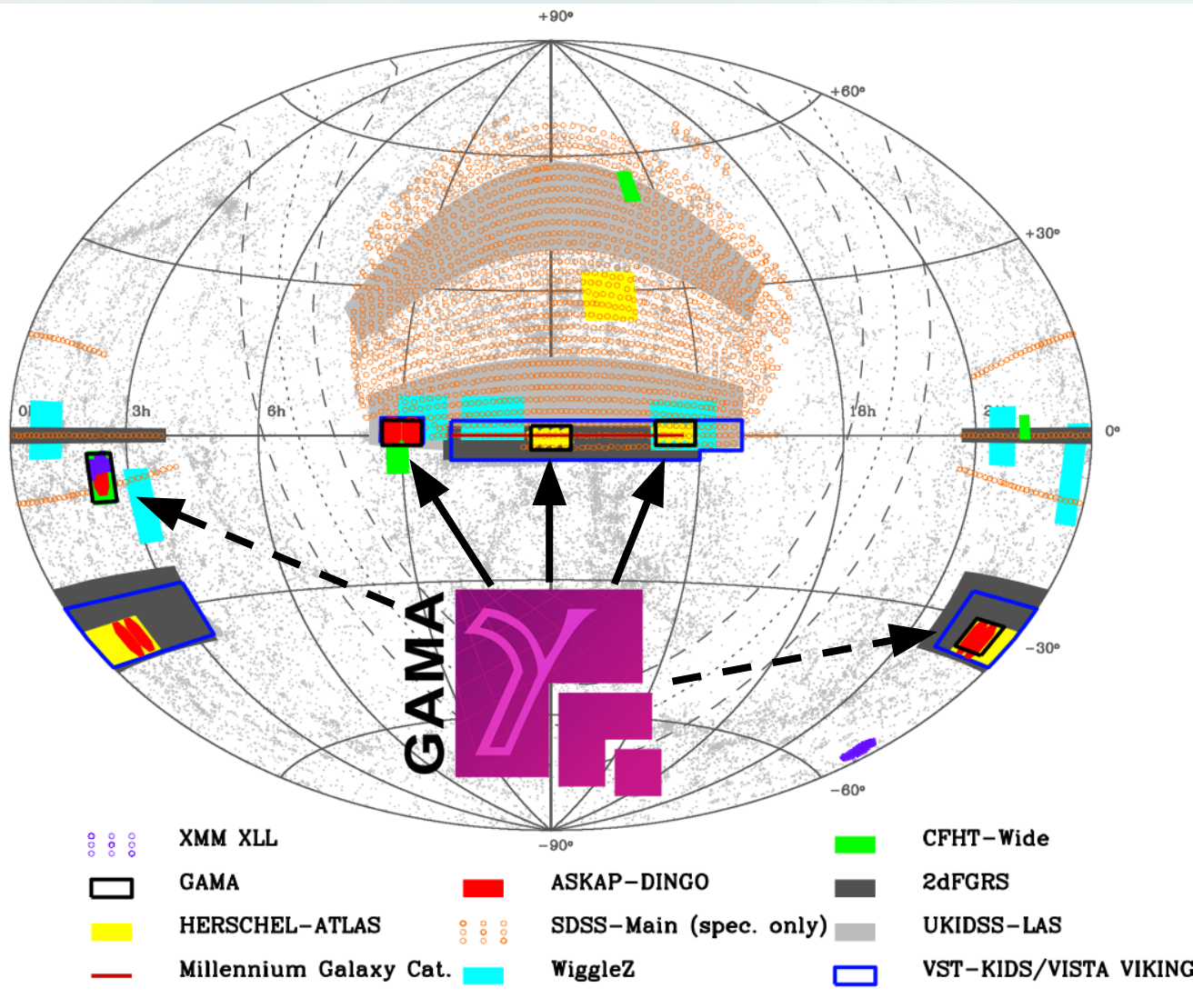
University of Innsbruck



# Galaxy and Mass Assembly



# GAMA Regions



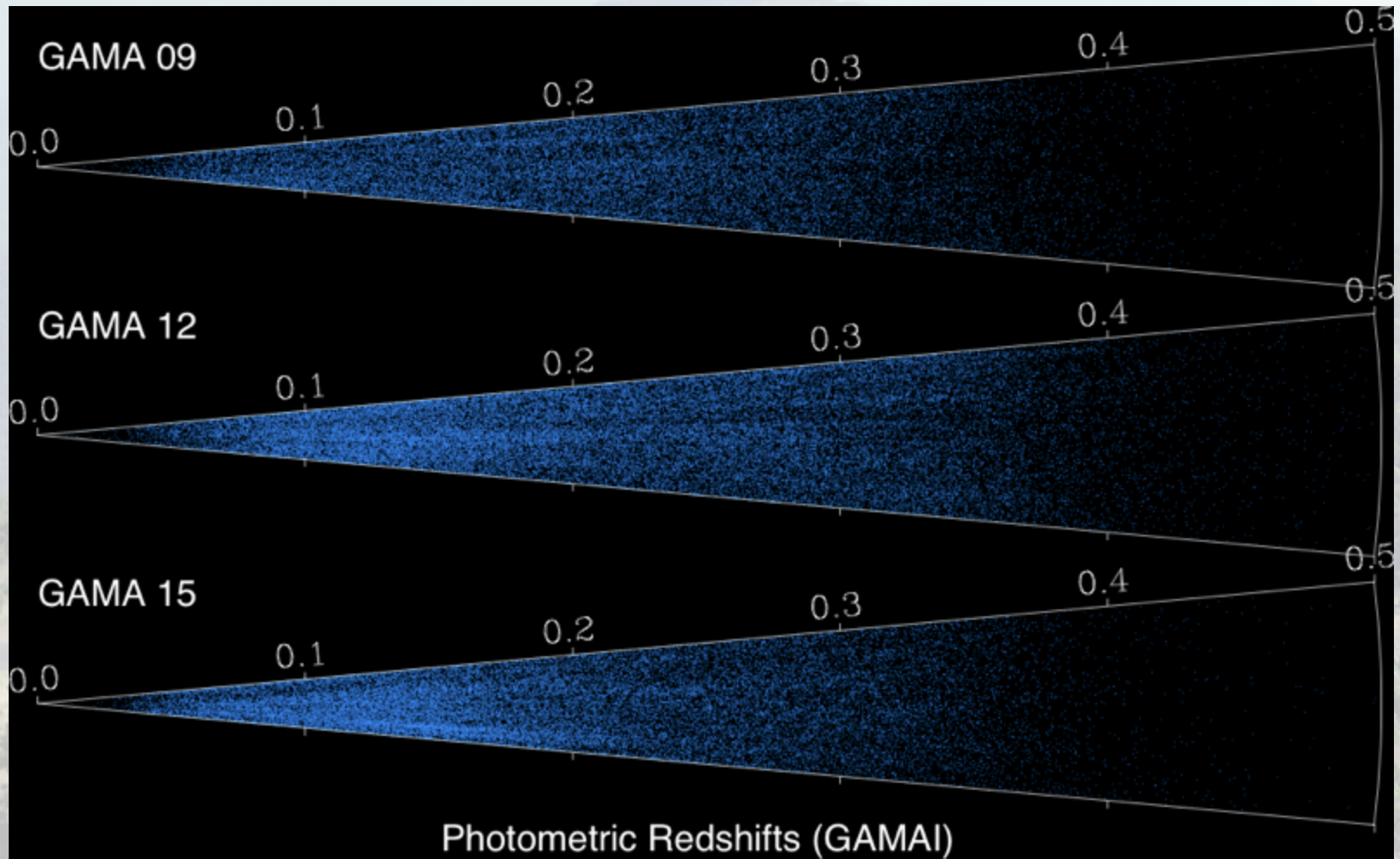
- ~340,000 gals
- $r < 19.8$  mag
- ~310 deg<sup>2</sup>
- 27 passbands

*"Study structure on scales of 1 kpc to 1 Mpc"*

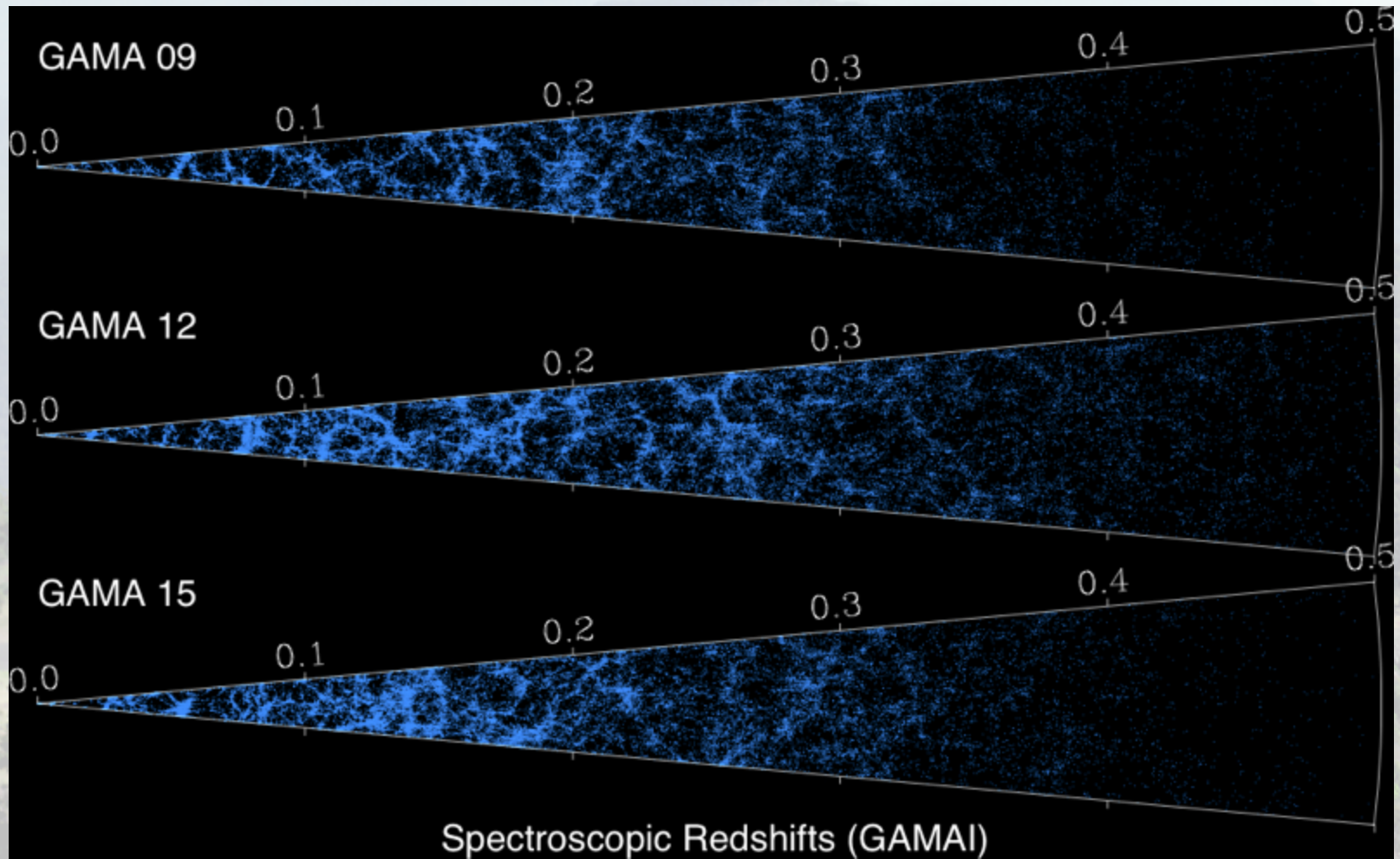
galaxy...

- clusters
- groups
- mergers
- structure

# GAMA: Photo-Redshifts...



# GAMA: Spectro-Redshifts



# GAMA: People (2012)



**GAMA SSAC**

- Ivan Baldry
- Steven Bamford
- Joss Bland-Hawthorn
- Sarah Brough (SC)
- Michael Brown
- Michael Drinkwater
- Simon Driver (PI)
- Andrew Hopkins (PI)
- Joe Liske (PM)
- Jon Loveday
- Martin Meyer
- Peder Norberg
- John Peacock
- Aaron Robotham (SC)
- Richard Tuffs

**GAMA Team members**

- Nicola Agius
- Mehmet Alpaslan
- Ellen Andrae
- Amanda Bauer
- Ewan Cameron
- John Ching
- Leonidas Christodoulou
- Matthew Colless
- Chris Conselice
- Scott Croom
- Nick Cross
- Tamara David
- Roberto De Propriis
- Jacinta Delhaize
- Simon Ellis
- Caroline Foster
- Alister Graham
- Meiert Grootes
- Madusha Gunawardhana
- David Hill
- Heath Jones
- Eelco van Kampen
- Lee Kelvin
- Maritza Lara-Lopez
- Angel Lopez-Sanchez
- Claudia Maraston
- Bob Nichol
- Seb Oliver
- Hannah Parkinson
- Steve Phillipps
- Kevin Pimbblet
- Cristina Popescu
- Matthew Prescott
- Rob Prcotor
- Isaac Roseboom
- Elaine Sadler
- Anne Sanson
- Rob Sharp
- Max Spolaor
- Oliver Steele
- Edward Taylor
- Daniel Thomas
- Jose Vazques Mata
- Dinuka Wikesinghe

**GAMA Consortium Members**

- ICC** Shaun Cole
- Carlos Frenk
- HATLAS** Loretta Duune
- Steve Eales
- CFHTLens** Catherine Heymans
- Mike Hudson
- Matt Jarvis
- GMRT** Konrad Kuijken
- KIDS** Barry Madore
- GALEX** Mark Seibert
- DINGO** Lister Staveley-Smith
- VIKING** Will Sutherland
- UKIDSS** Steve Warren
- XXM-XXL** Trevor Ponman

**GROUND-BASED FACILITIES:**

- AAT, Siding Springs
- SDSS, Apache Point
- VST, Paranal
- UKIRT, Mauna Kea
- VISTA, Paranal
- GMRT, Pune
- ASKAP, WA

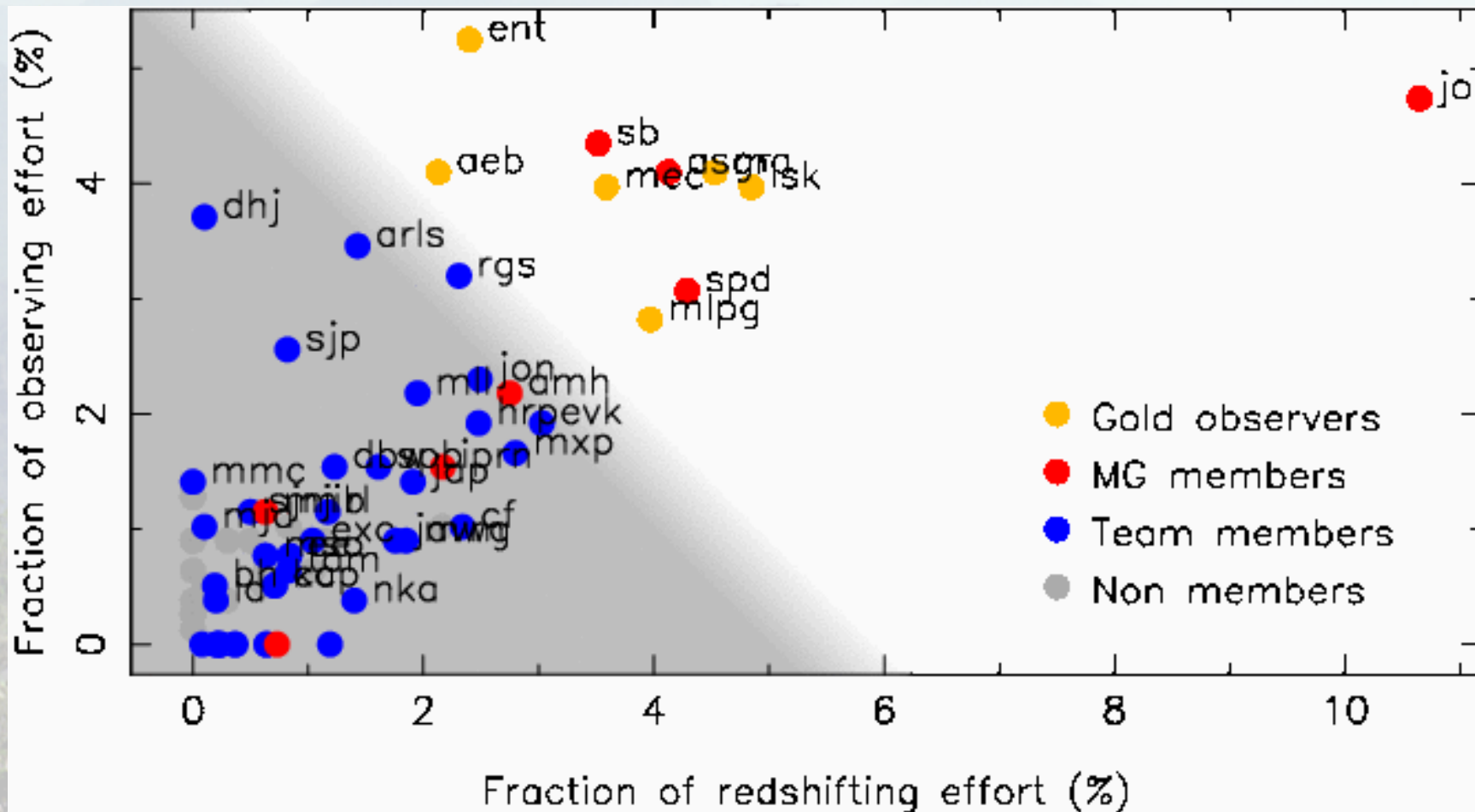
**SPACE MISSIONS**

- Herschel, L2
- GALEX, Earth Orbit
- WISE, Earth Orbit

# GAMA: People (2013)



# GAMA Redshifts



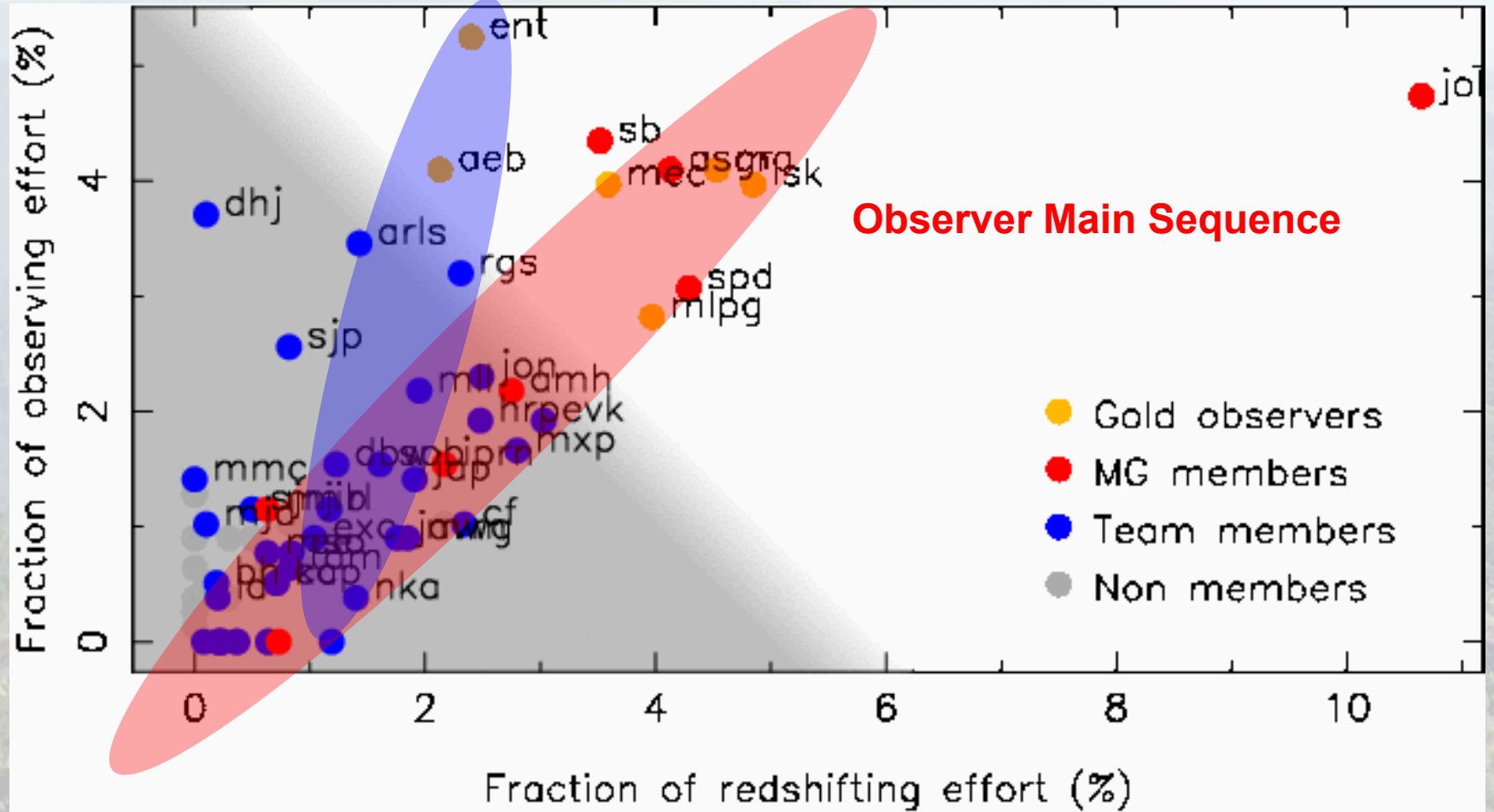
~250,000 spectroscopic redshifts

$$0 < z < 0.5$$



# GAMA Redshifts

Support Branch



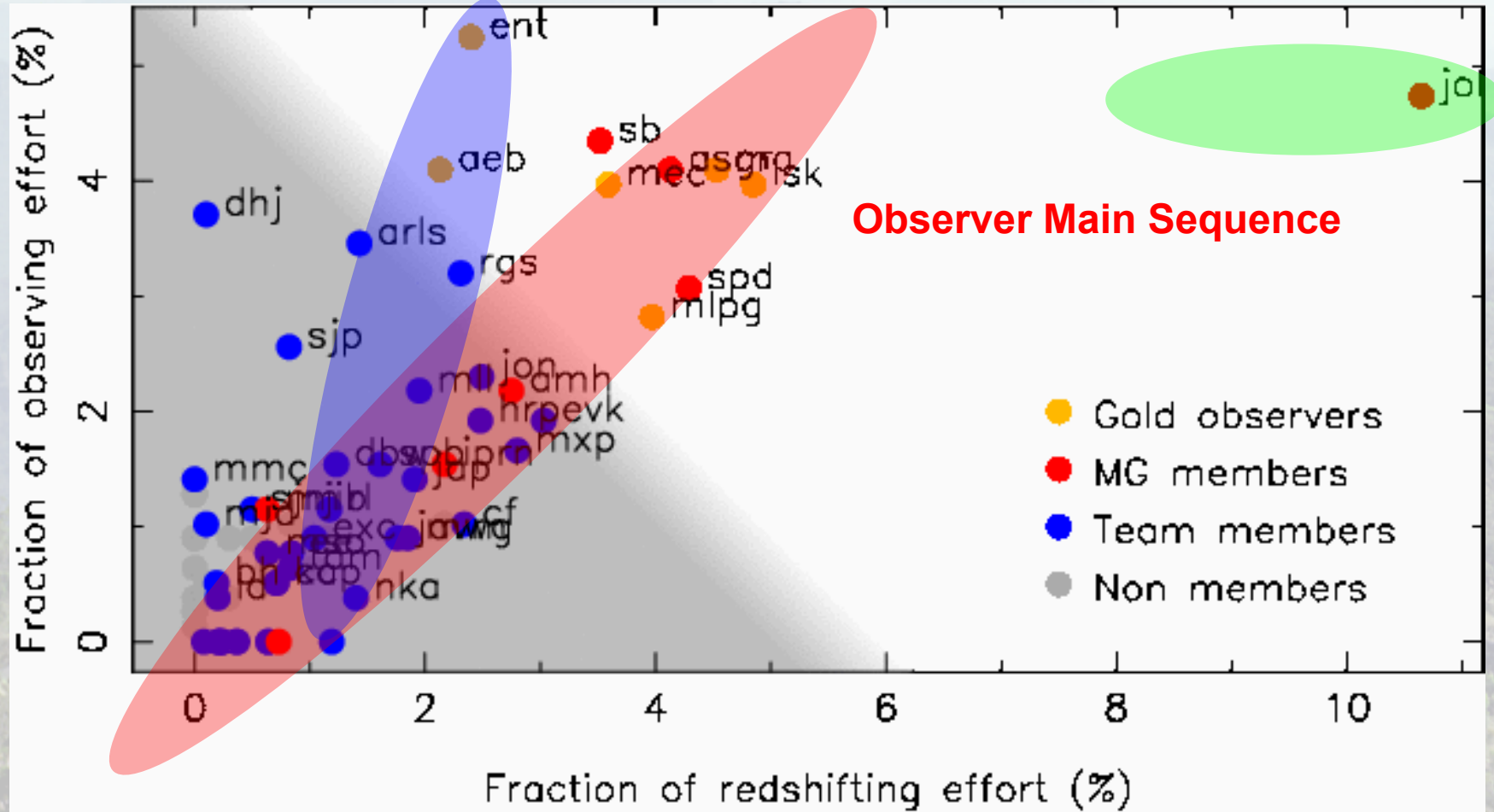
~250,000 spectroscopic redshifts

$0 < z < 0.5$

# GAMA Redshifts

Support Branch

Joe Liske Giant

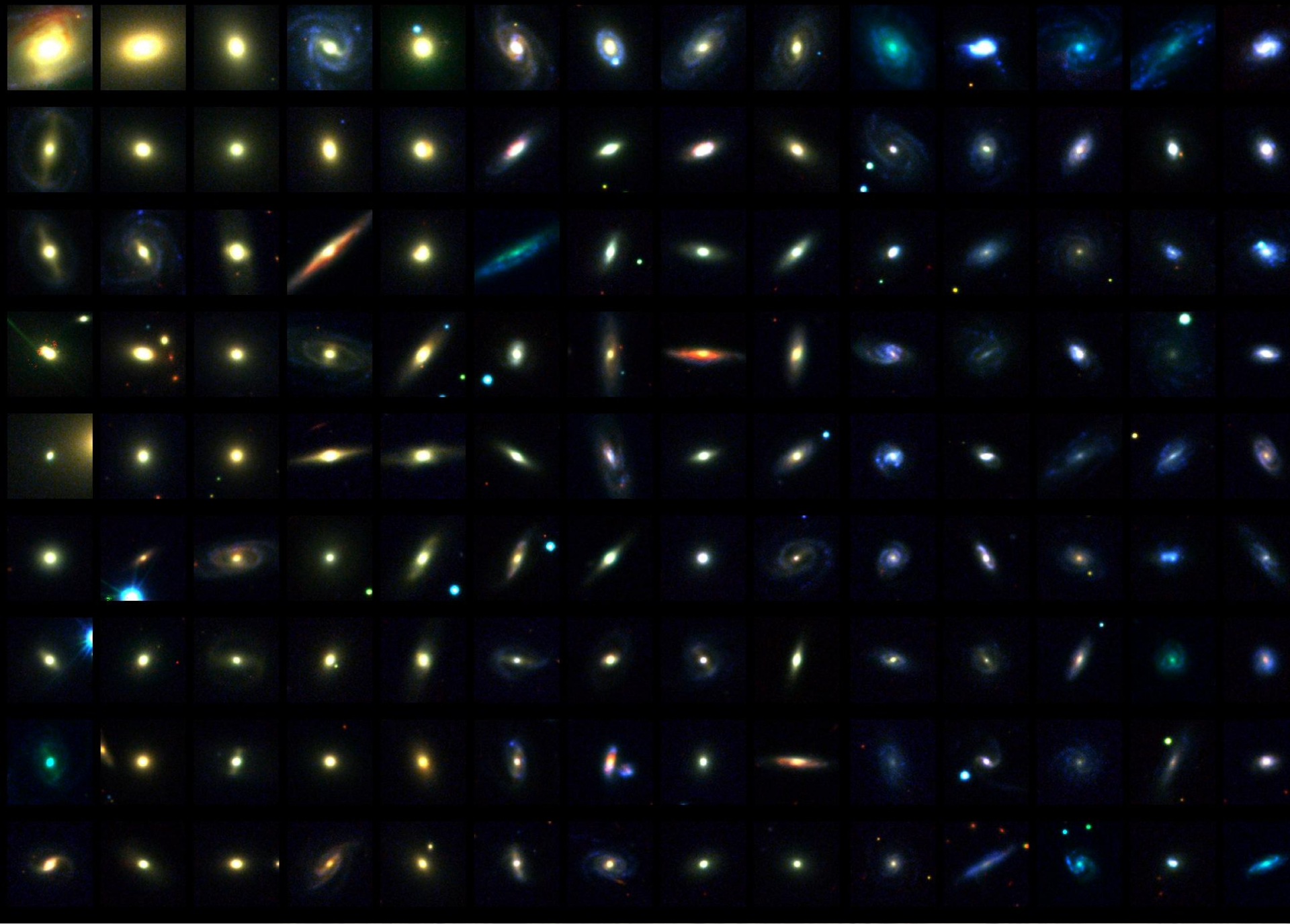


~250,000 spectroscopic redshifts

$$0 < z < 0.5$$

# GAMA: Equatorial Regions Done!



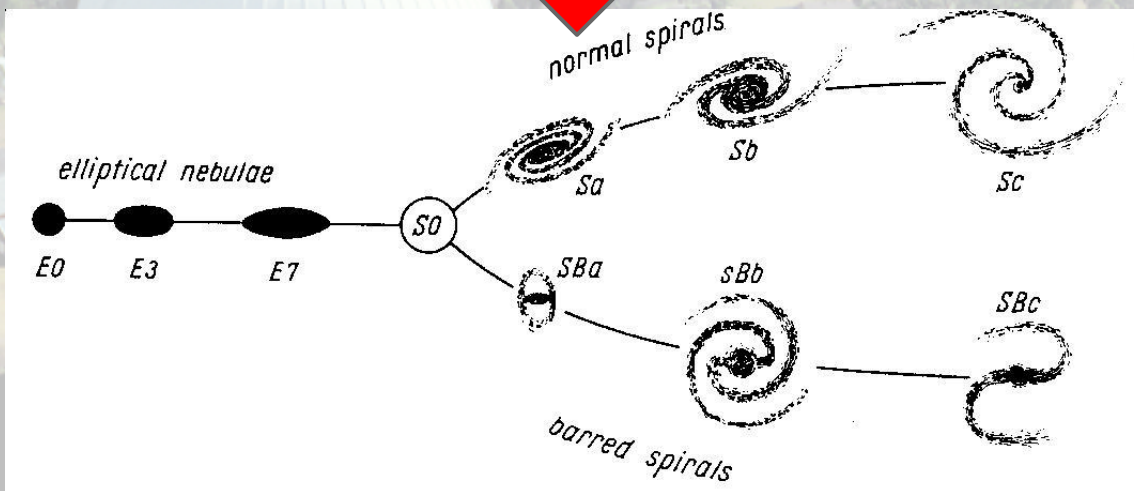
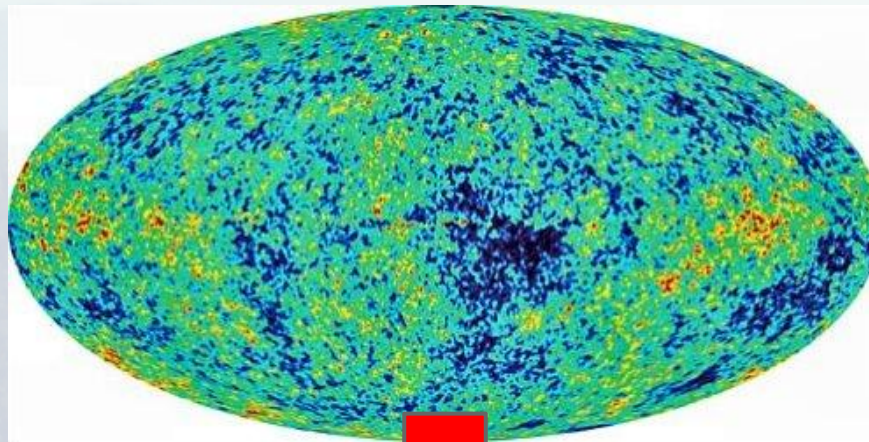


A large grid of galaxy images, each showing a different type of galaxy. The galaxies are arranged in a roughly 10x10 grid. The colors of the galaxies vary, including yellow, orange, red, green, blue, and cyan. The shapes also vary, from smooth, elliptical galaxies to irregular, clumpy galaxies, and from spiral galaxies to elliptical galaxies. The background is black, making the galaxies stand out.

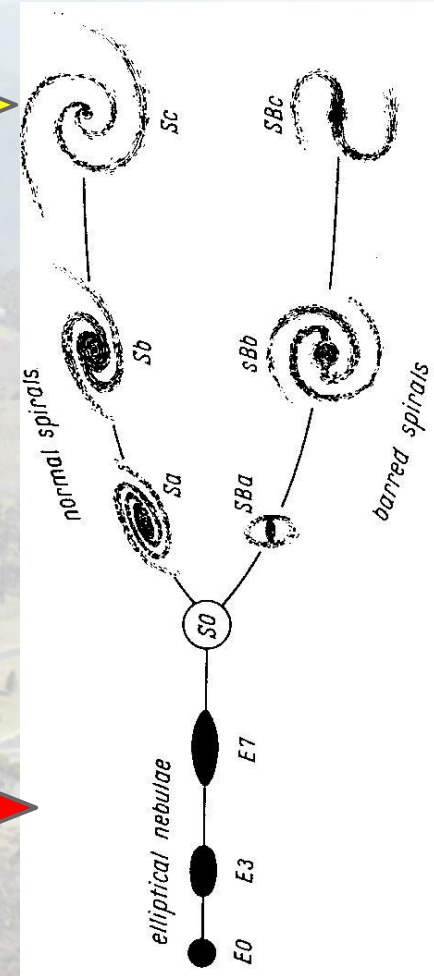
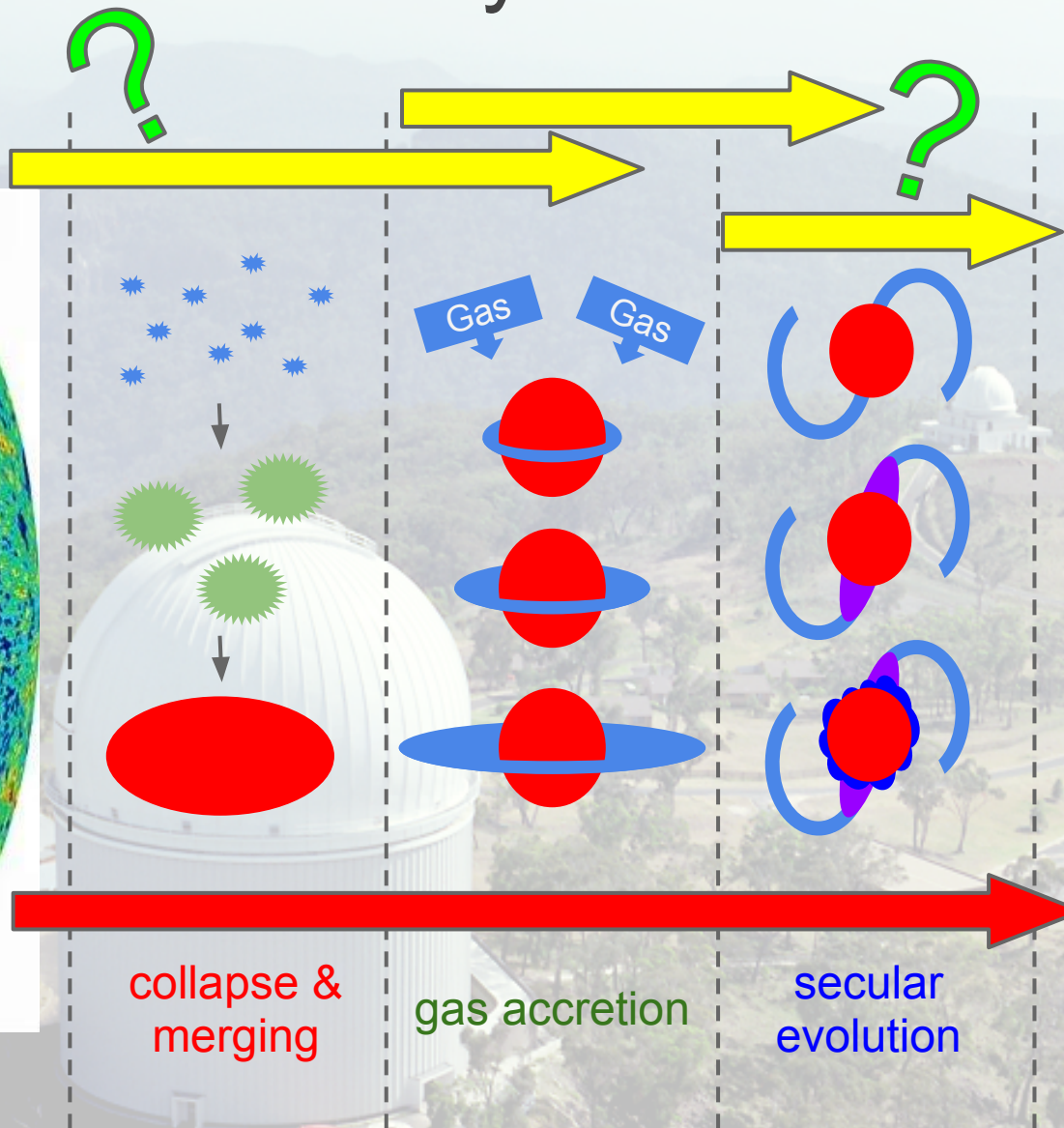
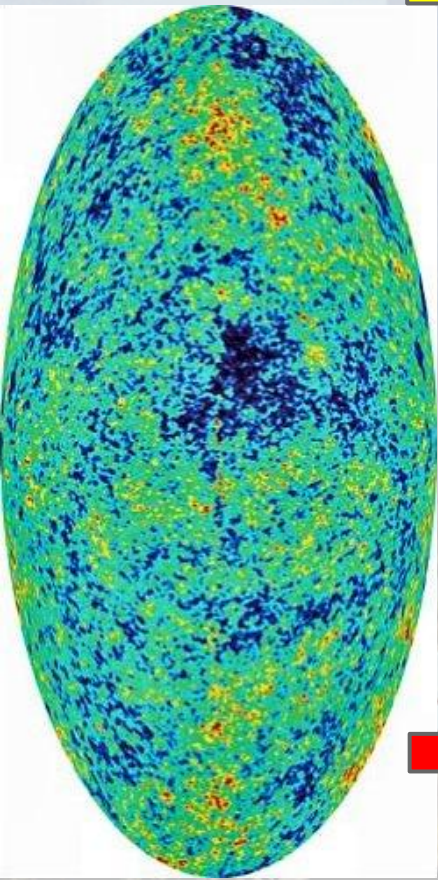
**How do these galaxies  
form and evolve?**

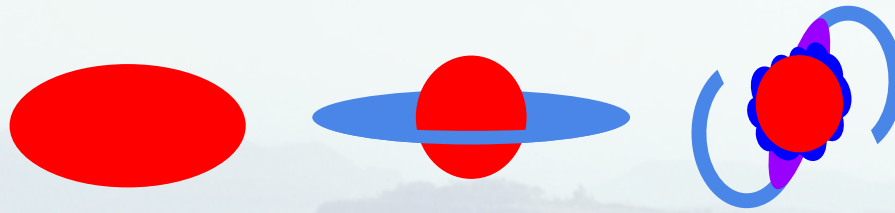
# How do galaxies form and evolve?

Motivation



# Evolutionary Mechanisms





Survey Data

Galaxy Modelling

Bulge-Disk

Global Trends with Wavelength

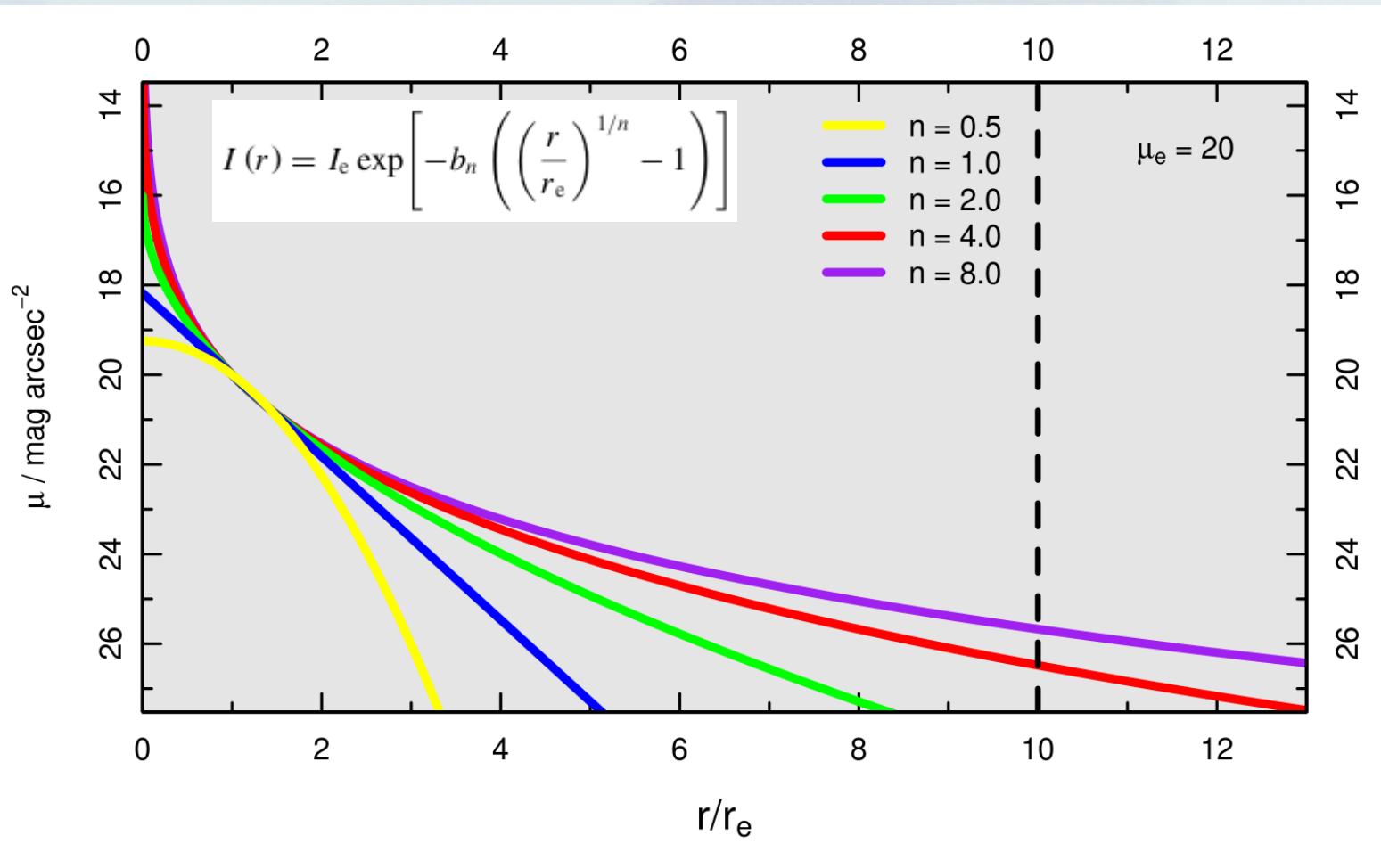
Morphological Classification

The Local Galaxy Luminosity/Mass Function

My PhD Thesis



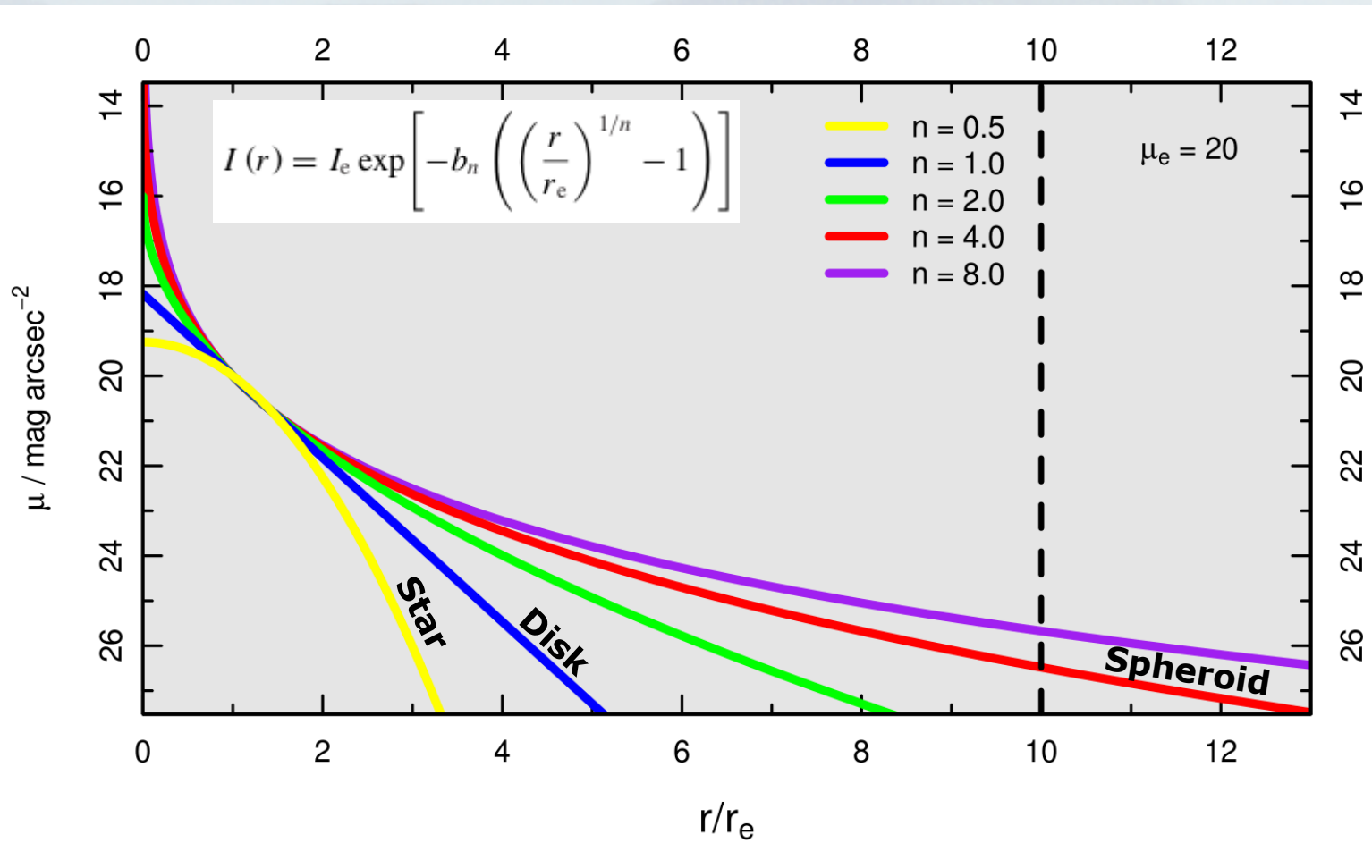
# Sérsic Profile



José Luis Sérsic

Models many different galaxy profile shapes

# Sérsic Profile

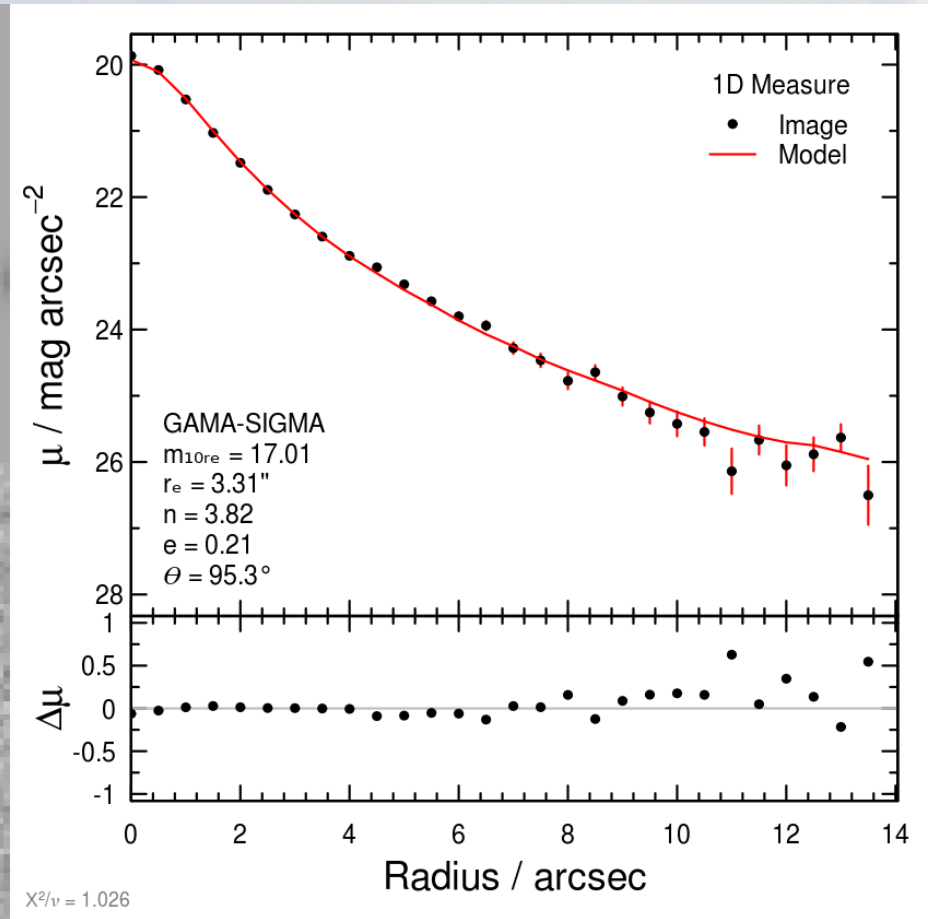
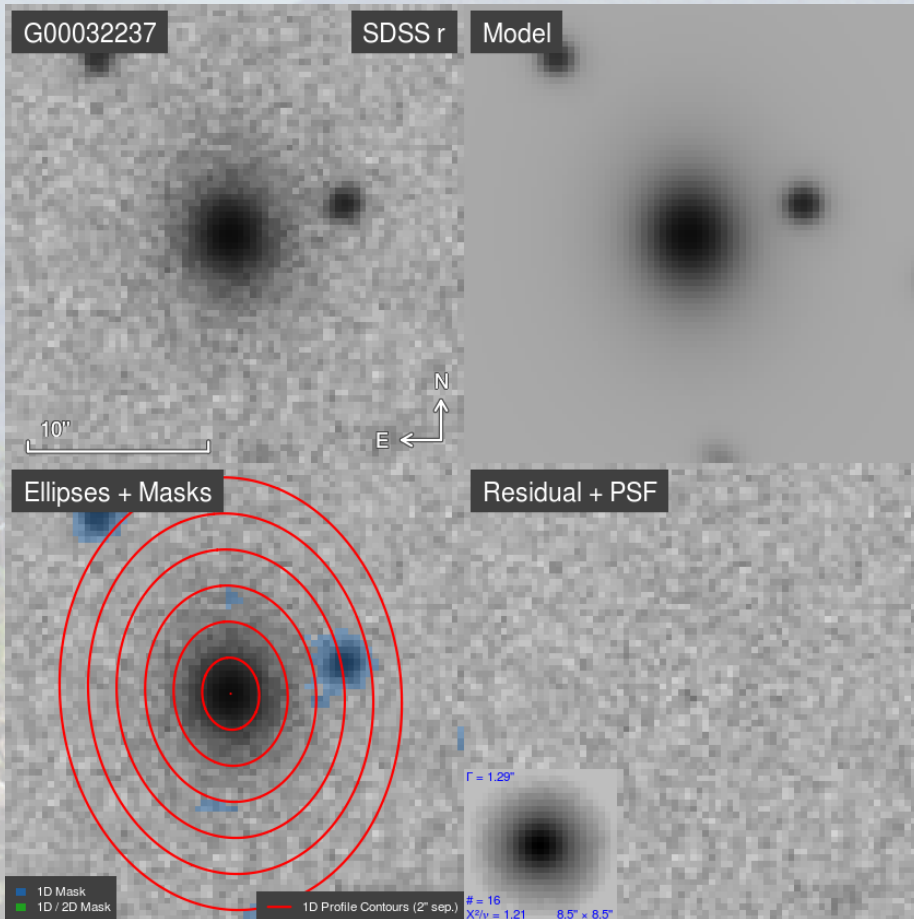


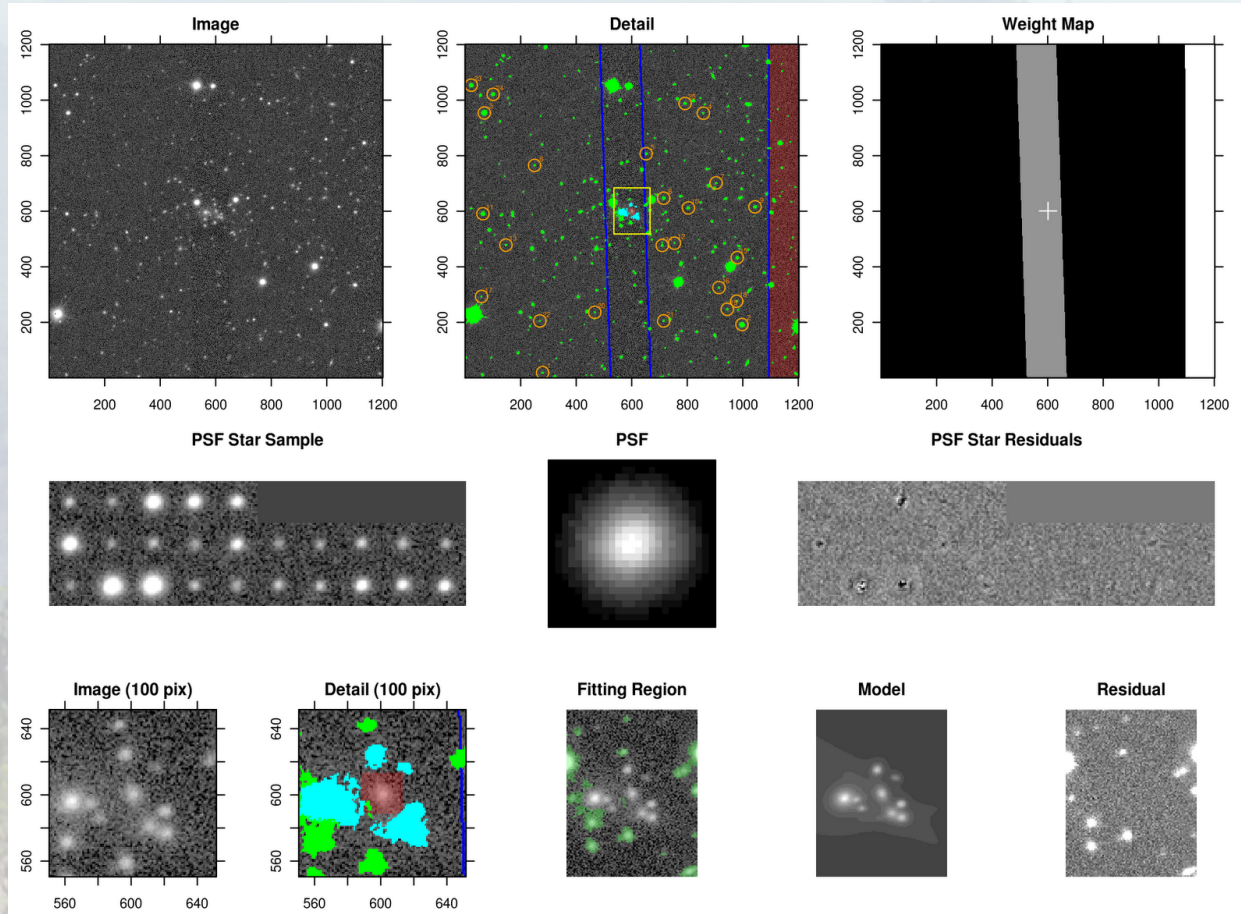
José Luis Sérsic

Models many different galaxy profile shapes

# Sérsic Modelling

$$I(r) = I_e \exp \left[ -b_n \left( \left( \frac{r}{r_e} \right)^{1/n} - 1 \right) \right]$$





Imaging & Pointing Data



Model Fit Parameters

SExtractor Bertin+ 1996  
 PSFEx Bertin 2011  
 GALFIT3 Peng+ 2010

[astro-staff.uibk.ac.at/~lee](http://astro-staff.uibk.ac.at/~lee)



**Achtung! The model does not always accurately represent the underlying image!**

# Mass-Limited Sample



Limits:

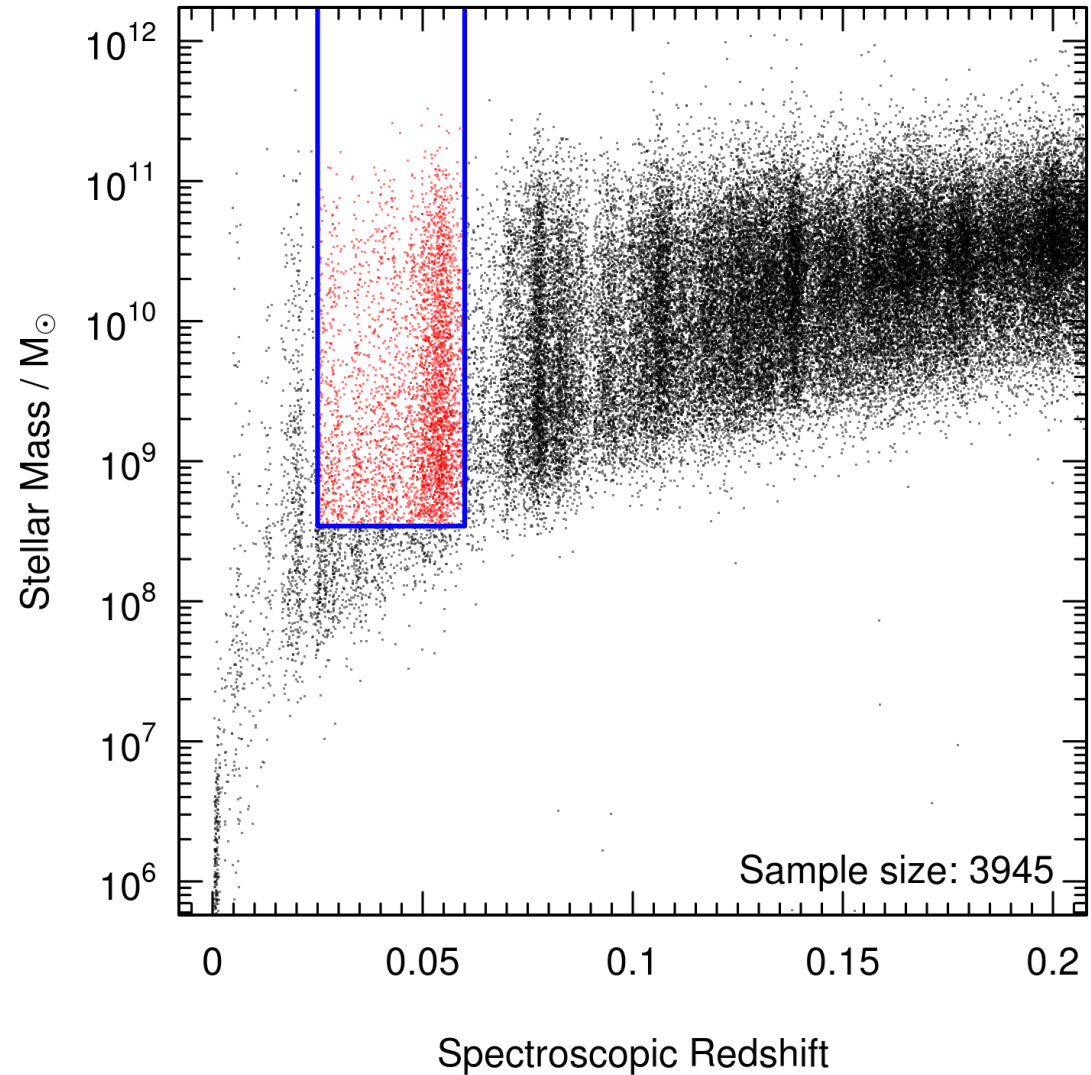
$$0.025 < z < 0.06$$

$$\log_{10} M > 8.537$$

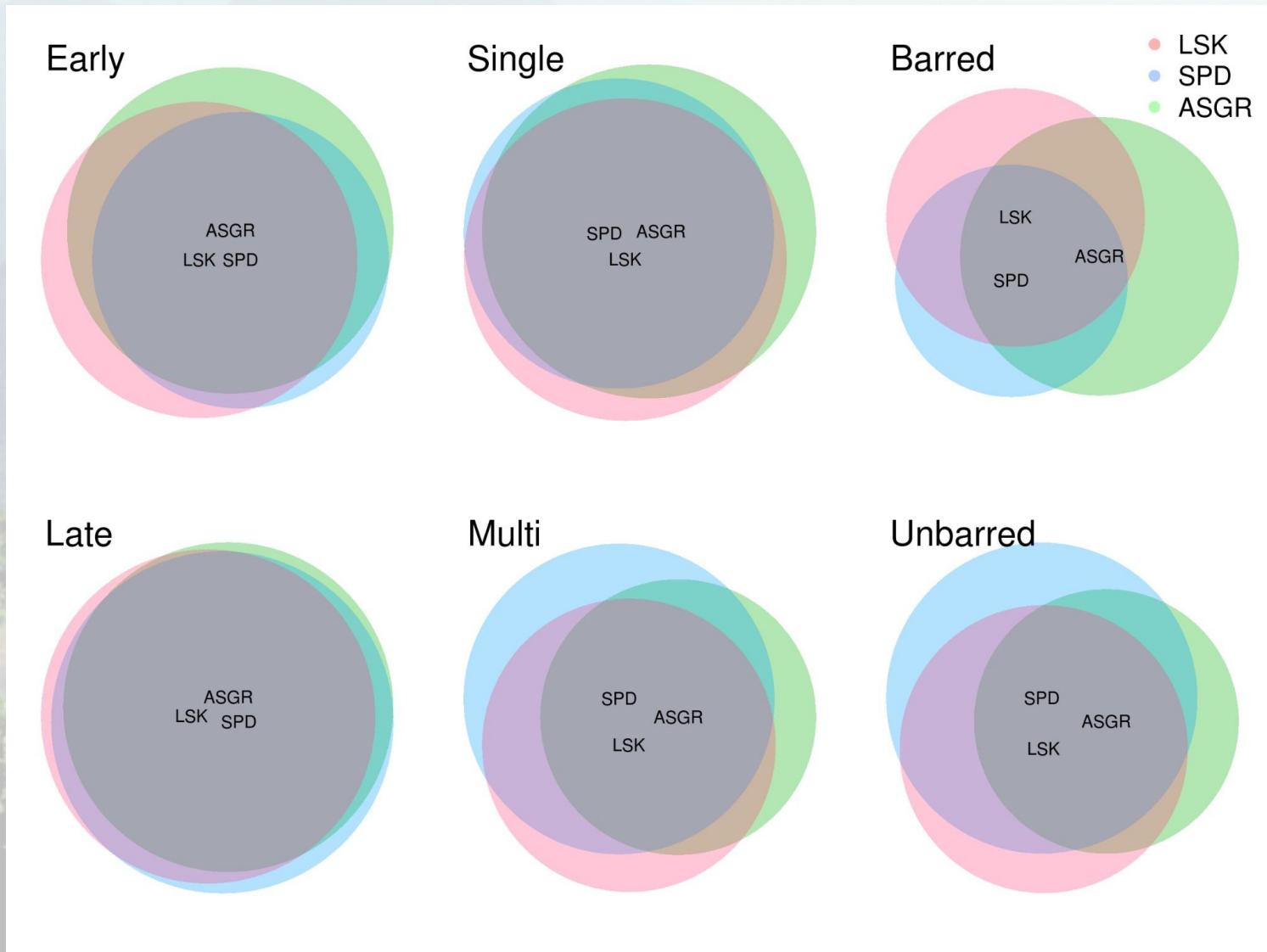
(Taylor et al., 2011)

Structural  
Decomposition:

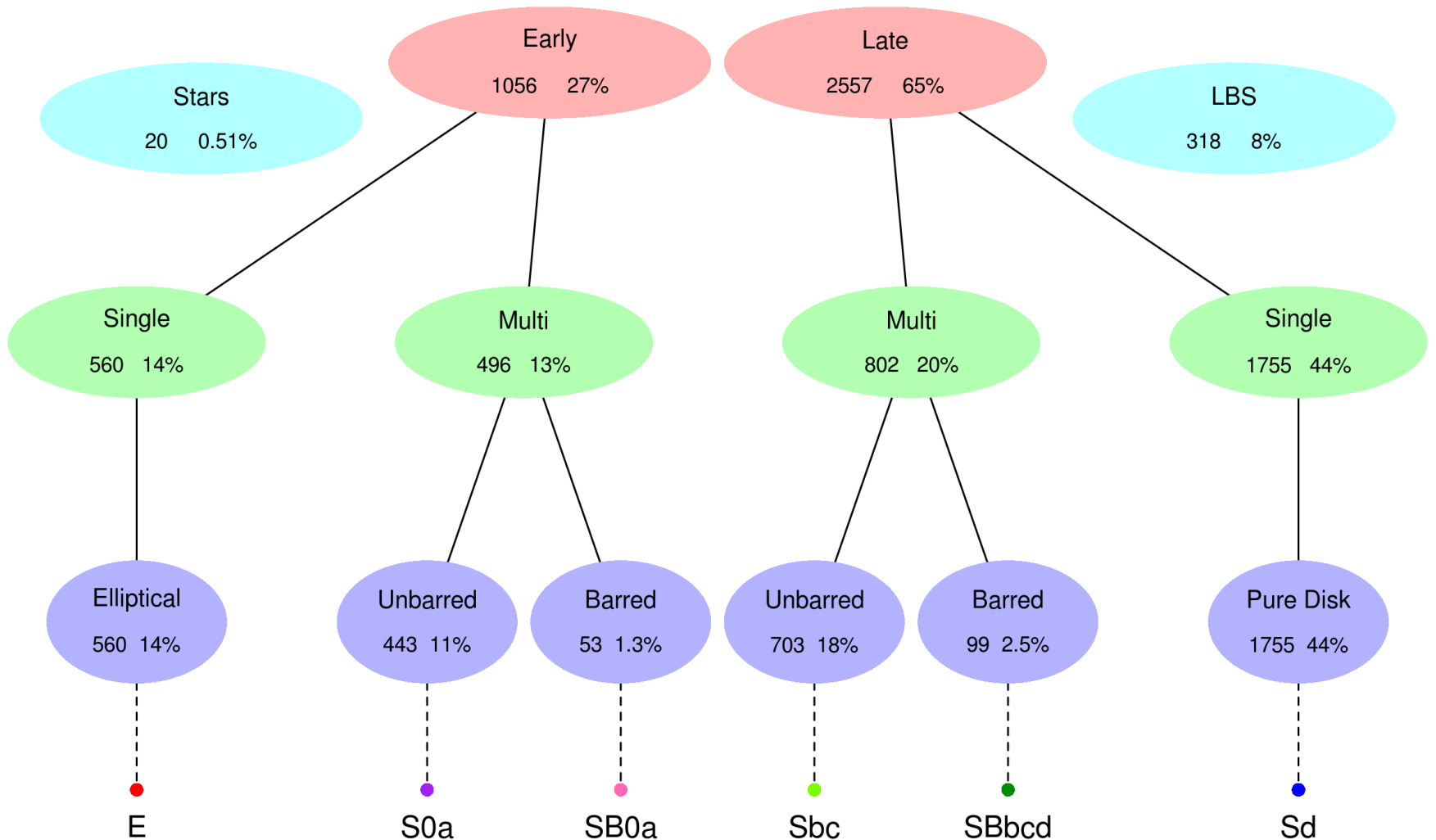
1. Morphological classification
2. Bulge-Disk decomposition



# Visual Classification

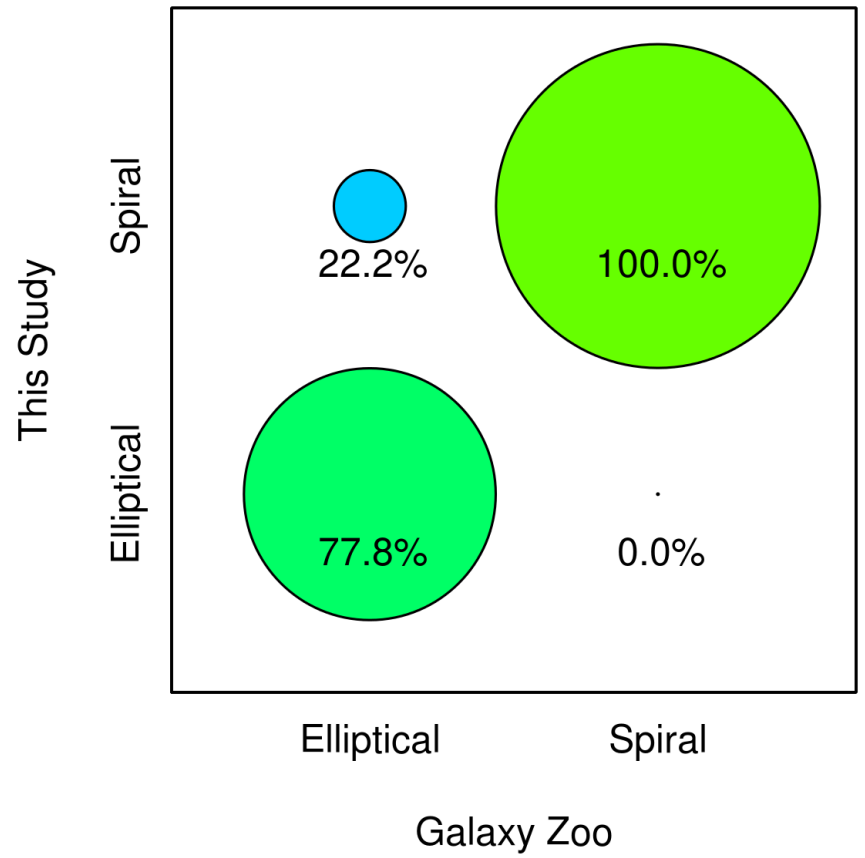
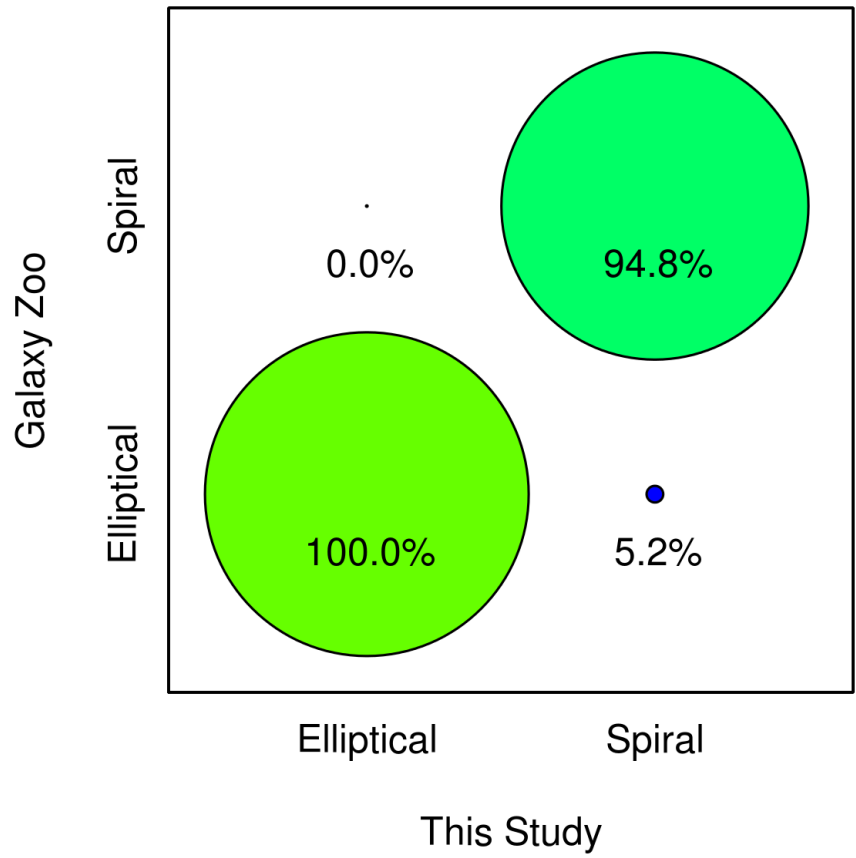


# Visual Classification





# Visual Classification



(Lintott et al., 2010)

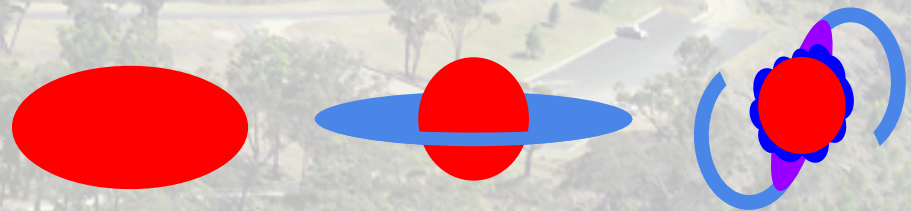
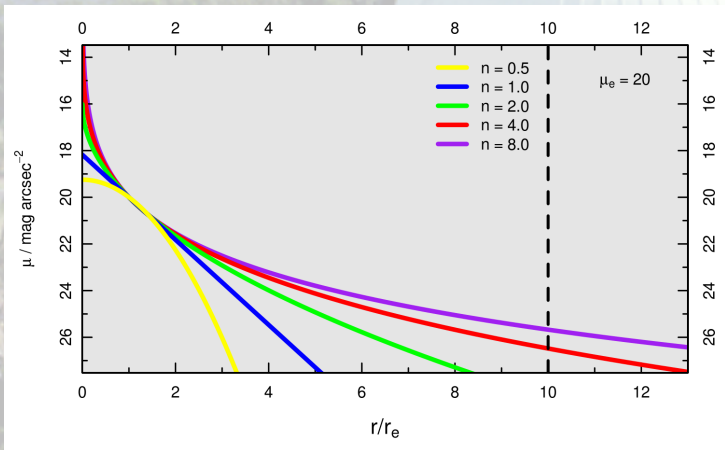
# Multi-Component Models

M01: Single-Sérsic

M02: De Vaucouleurs bulge + exponential disk

M03: Sérsic bulge + exponential disk

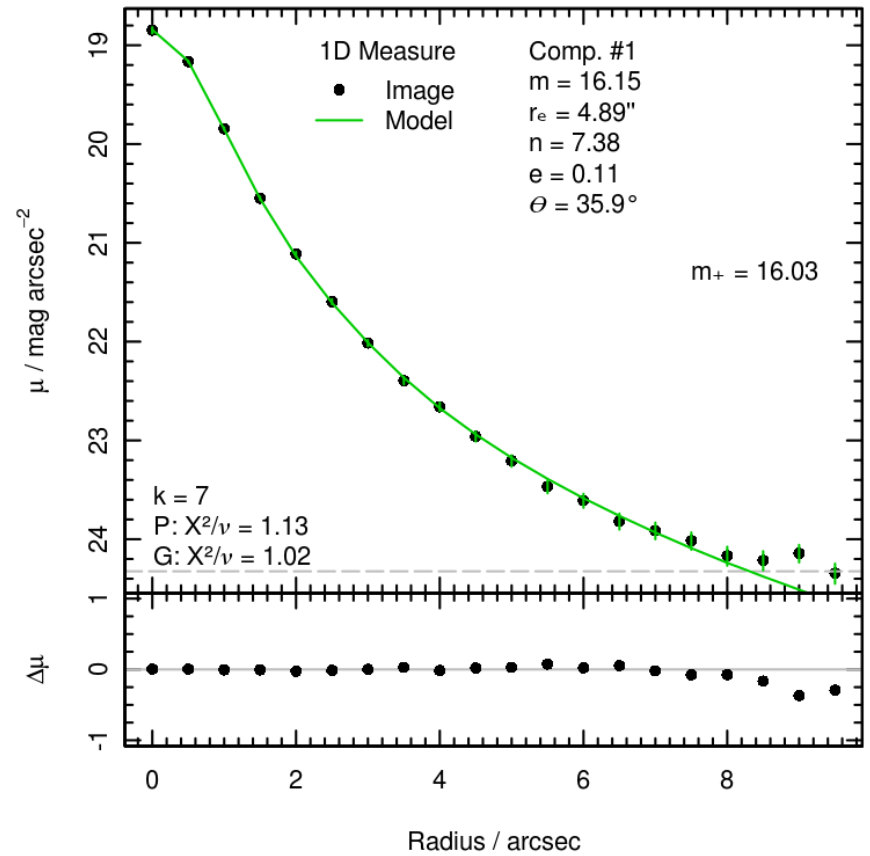
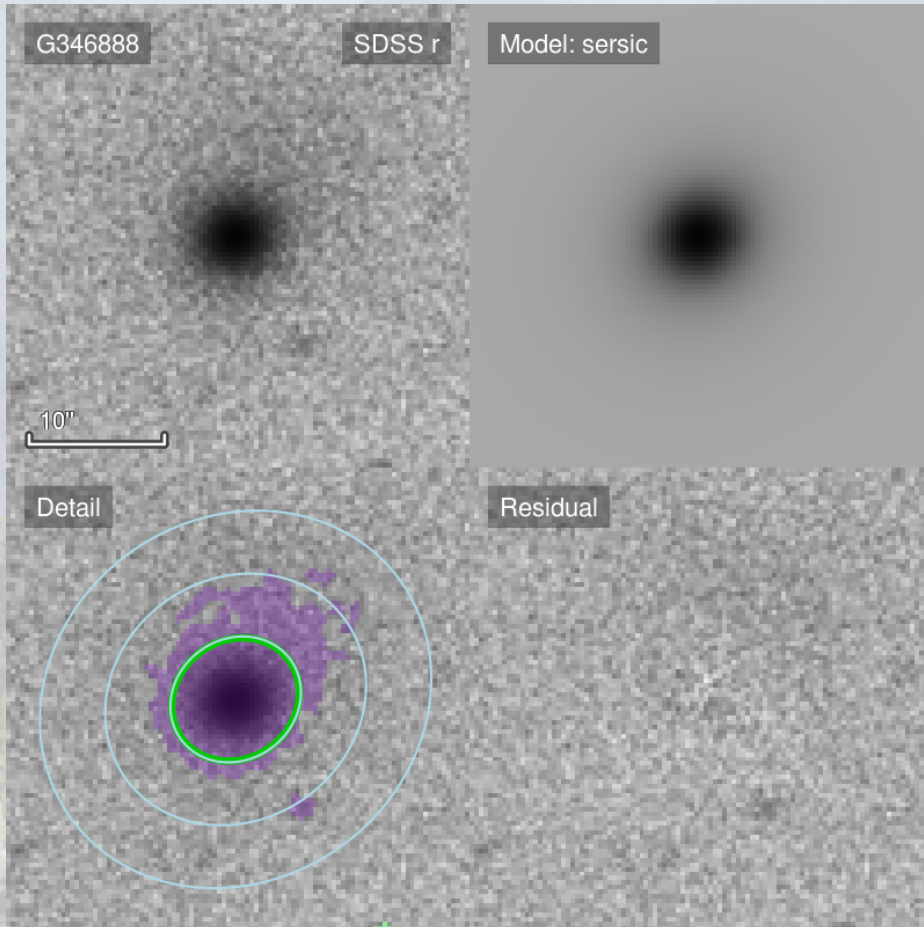
M04: Sérsic bulge + Sérsic disk



# Elliptical: G346888



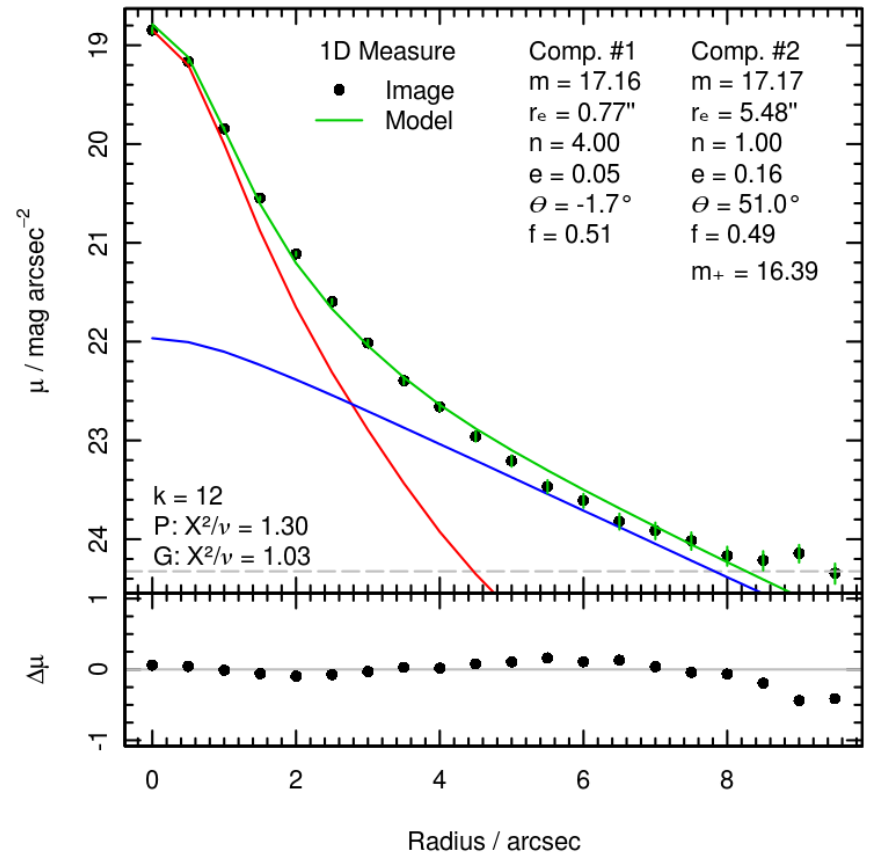
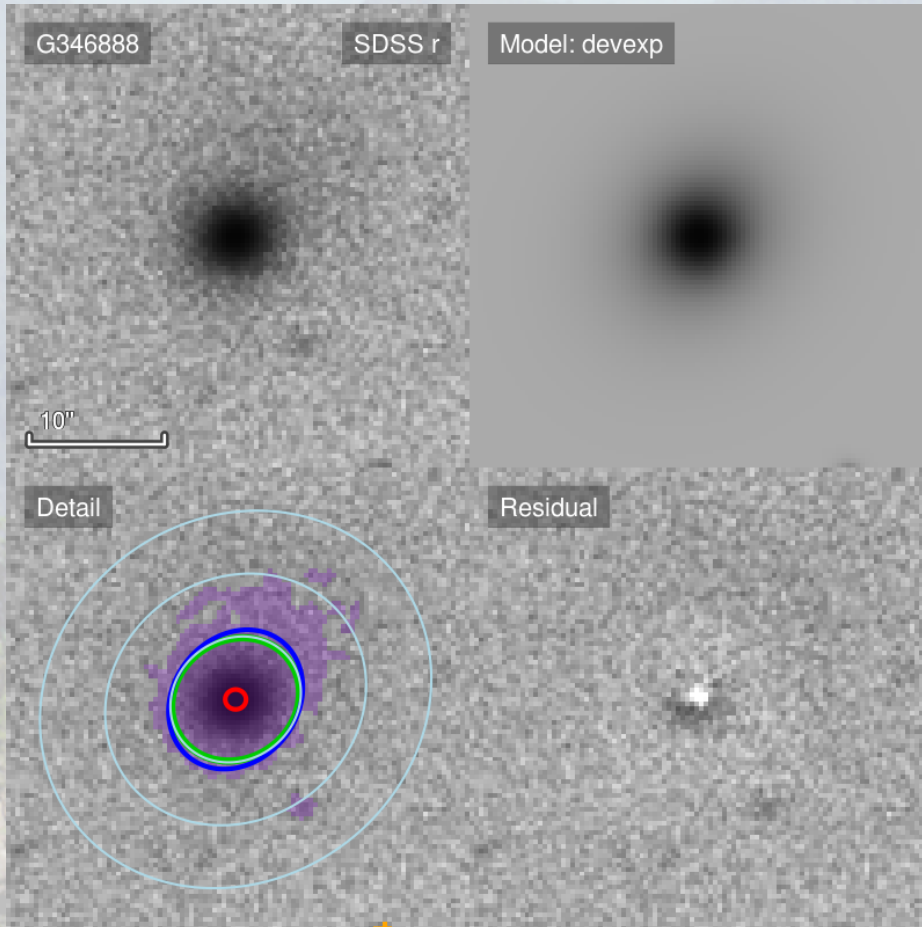
*M01: Single-Sérsic*



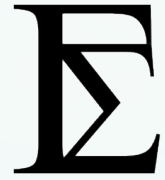
# Elliptical: G346888



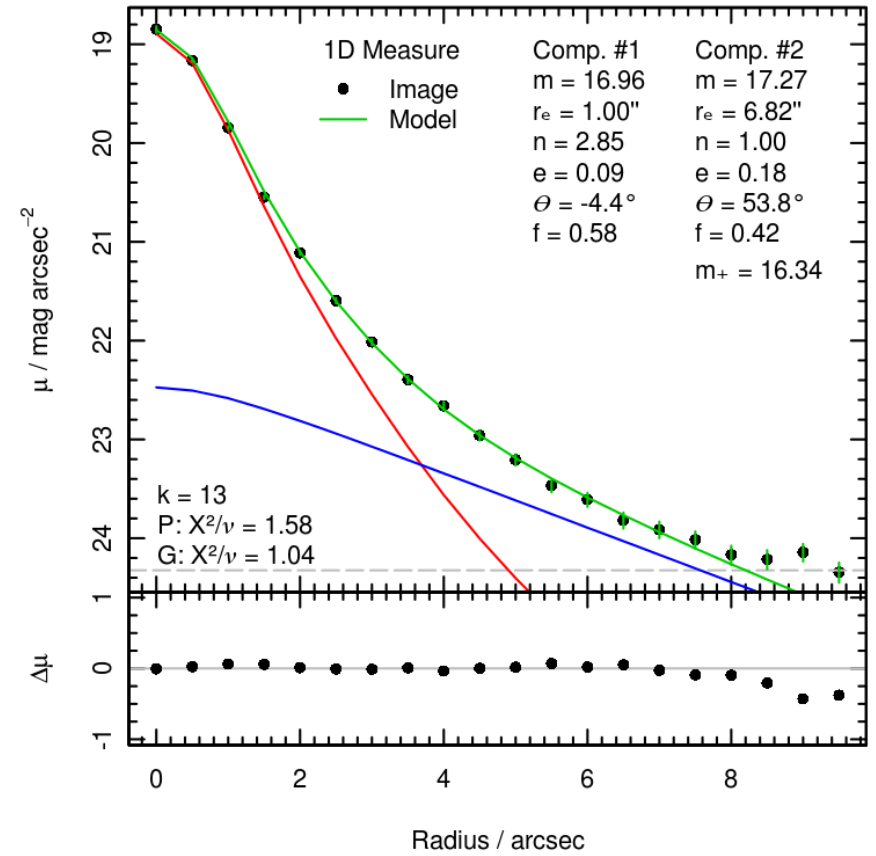
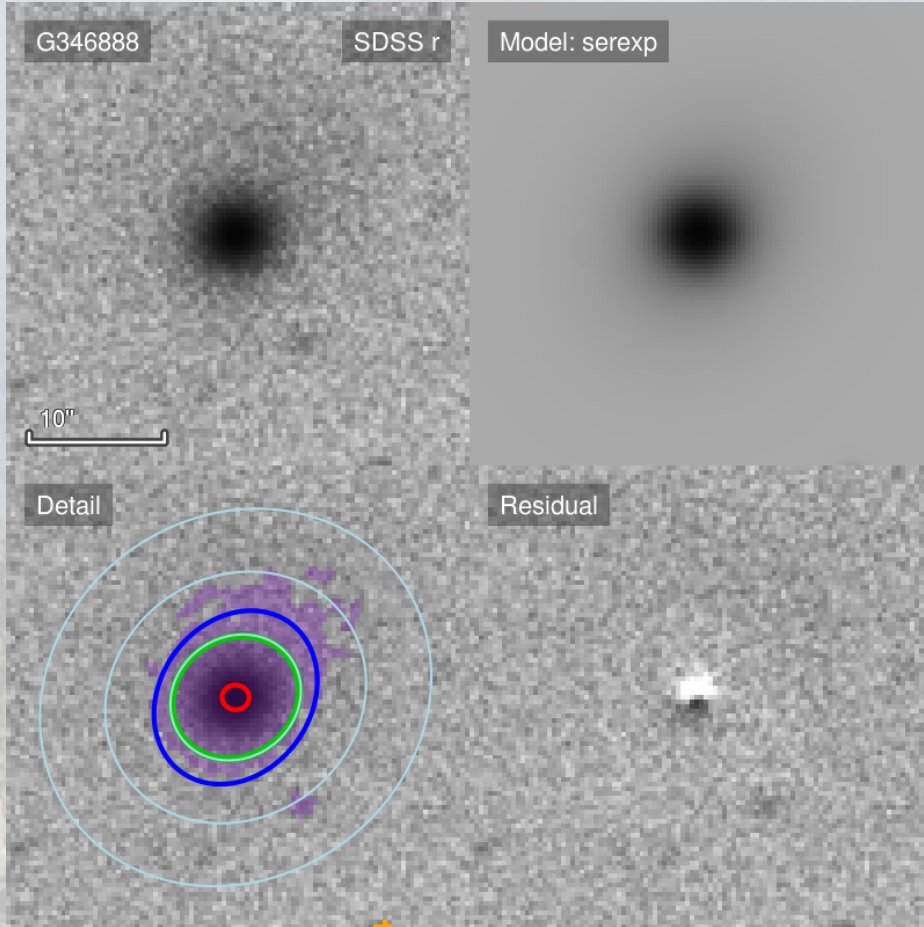
*M02: De Vaucouleurs bulge + exponential disk*



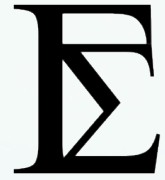
# Elliptical: G346888



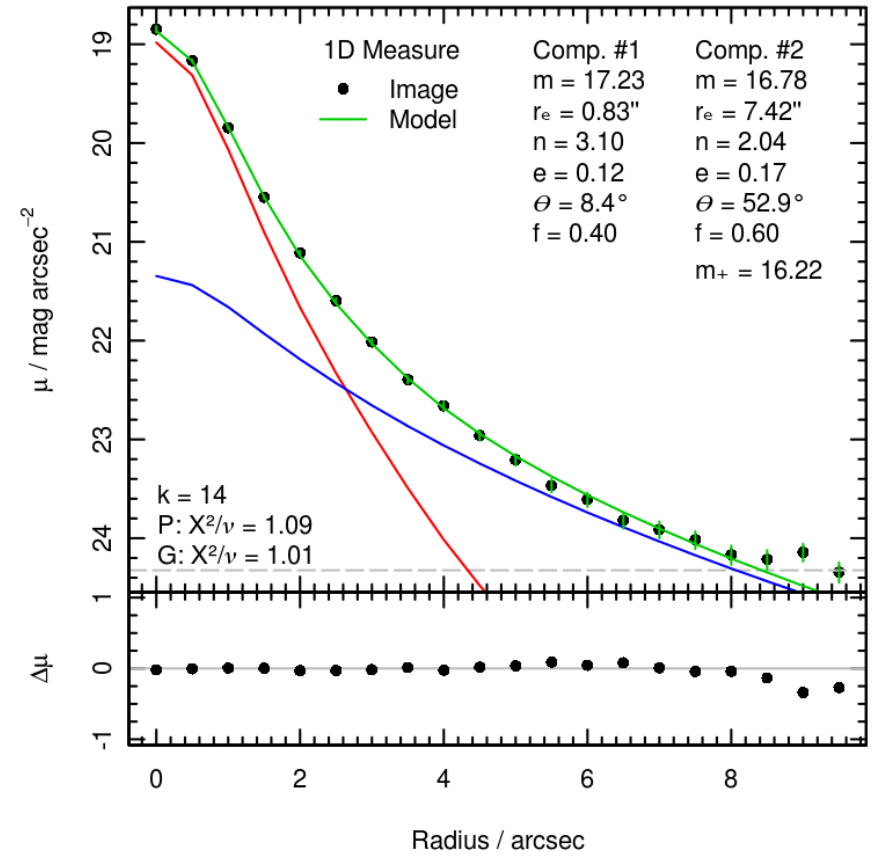
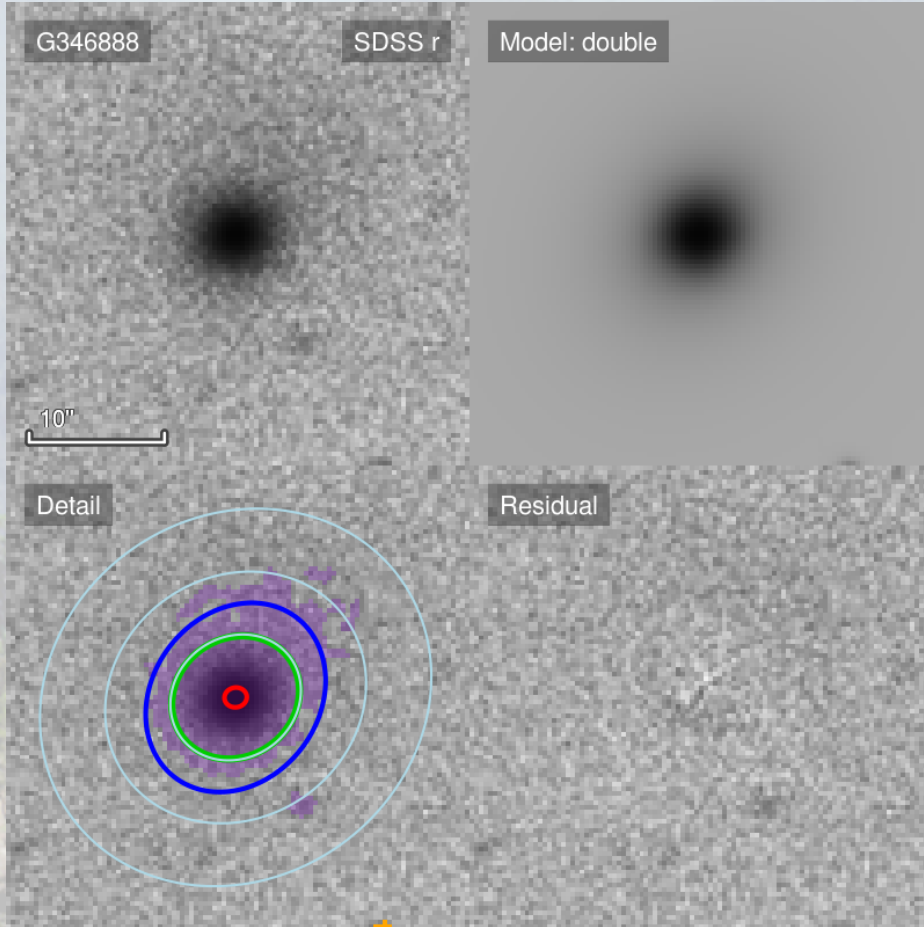
*M03: Sérsic bulge + exponential disk*



# Elliptical: G346888

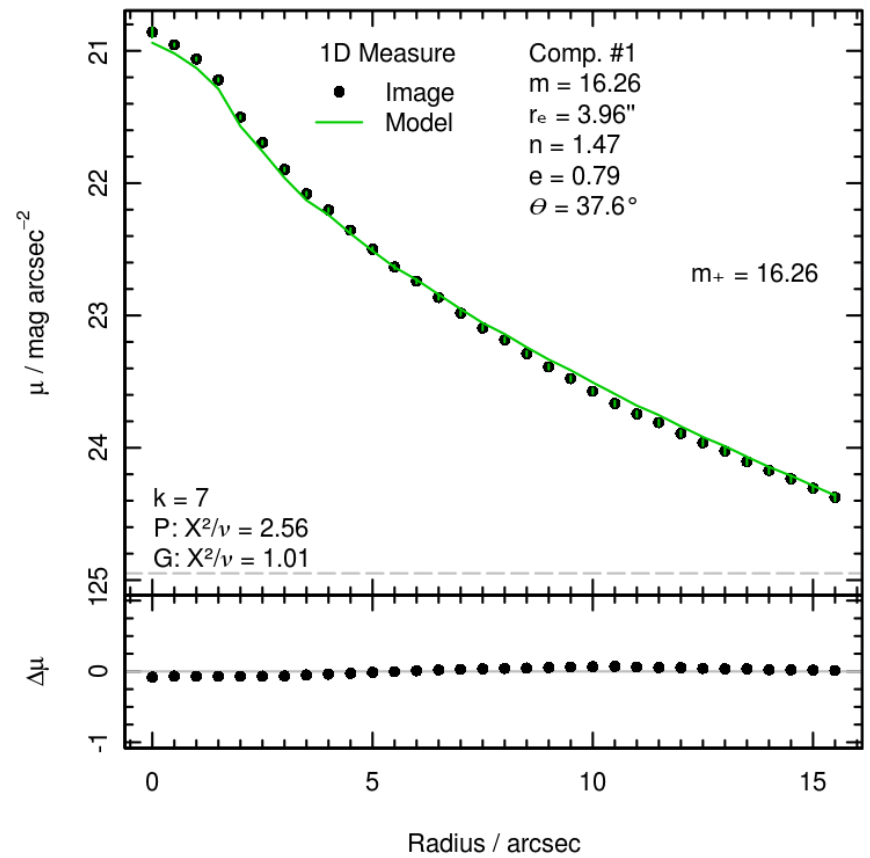
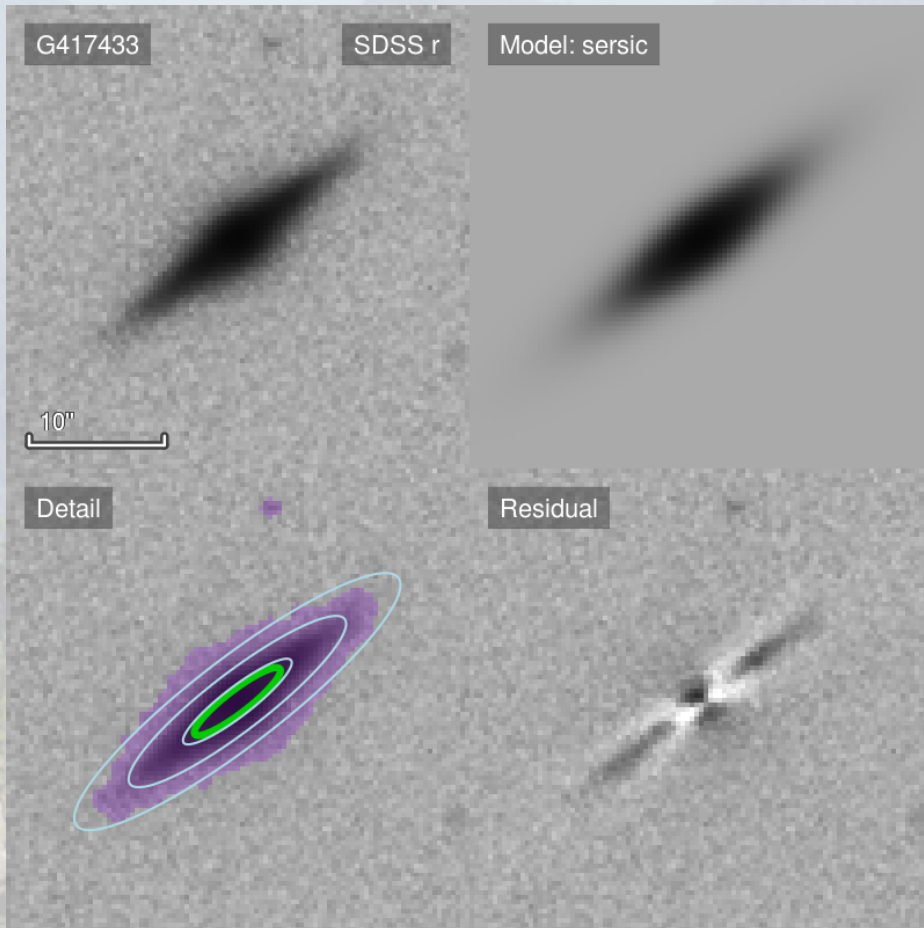


*M04: Sérsic bulge + Sérsic disk*



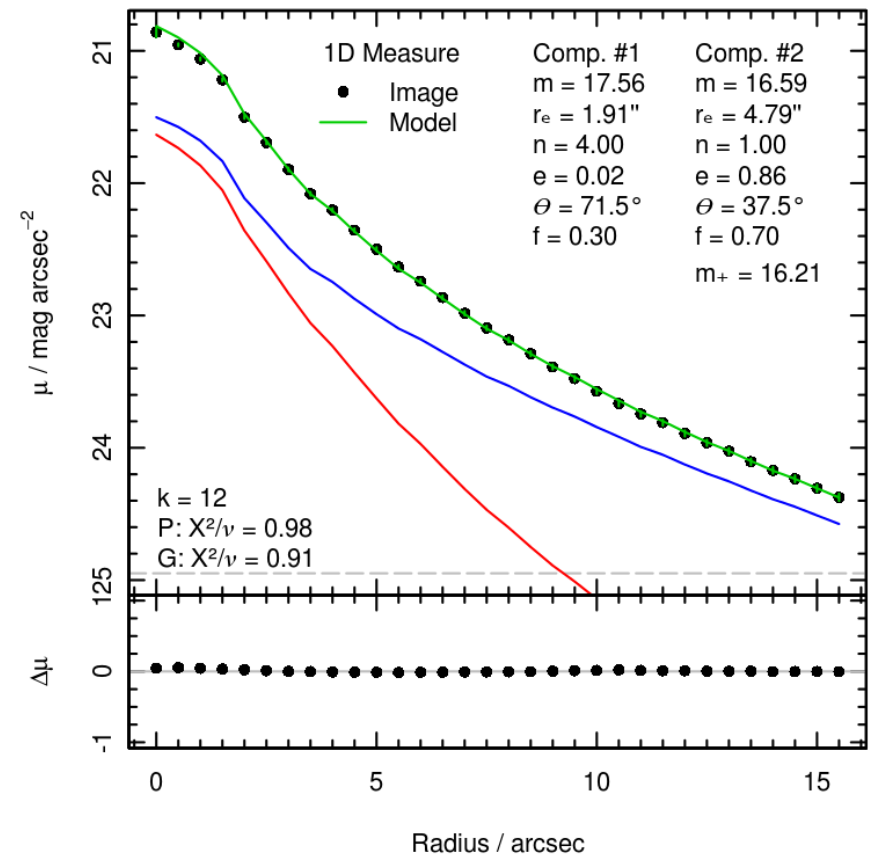
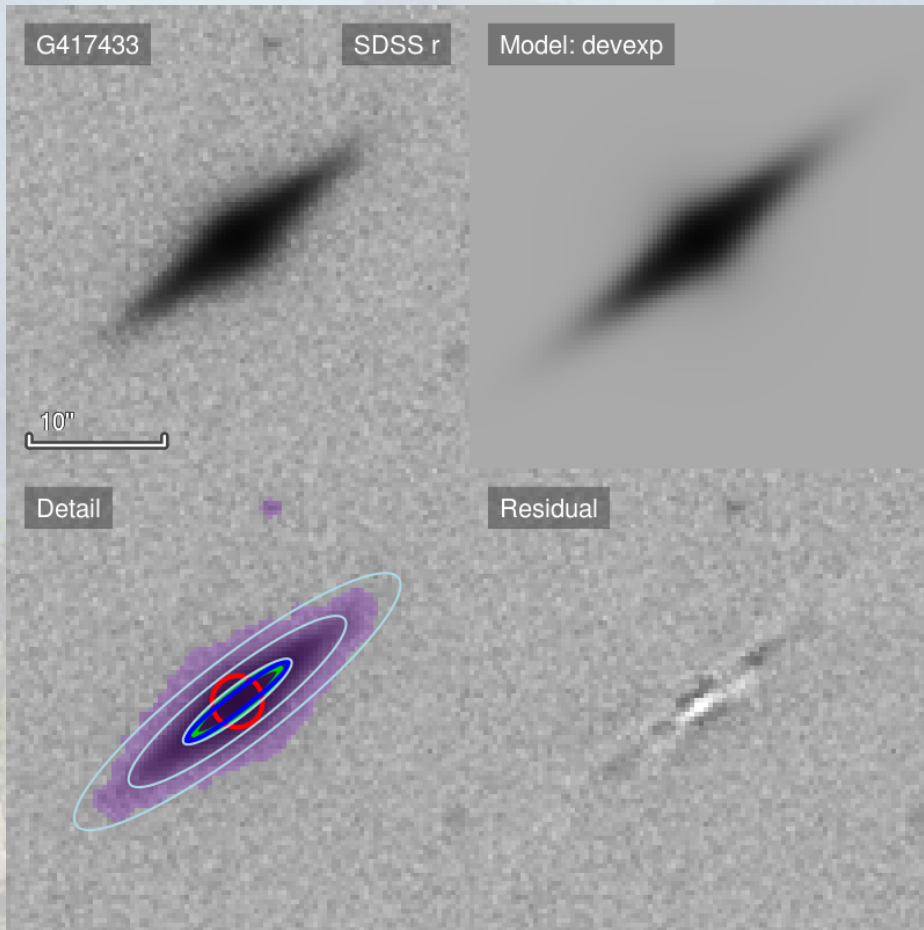
# S0a: G417433

*M01: Single-Sérsic*



# S0a: G417433

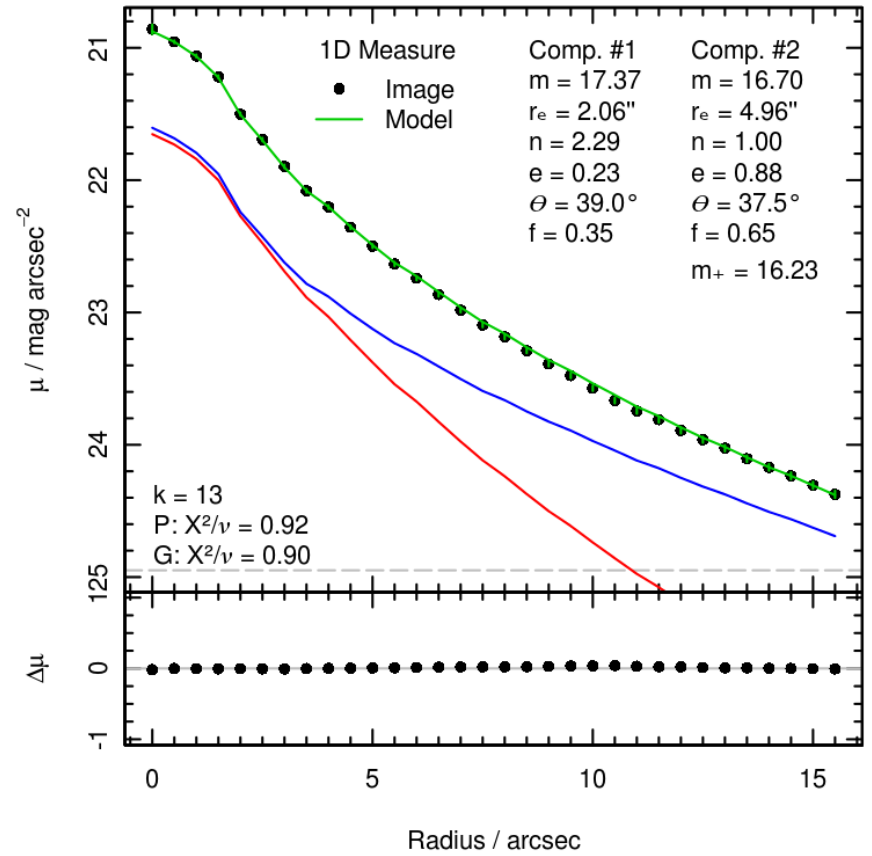
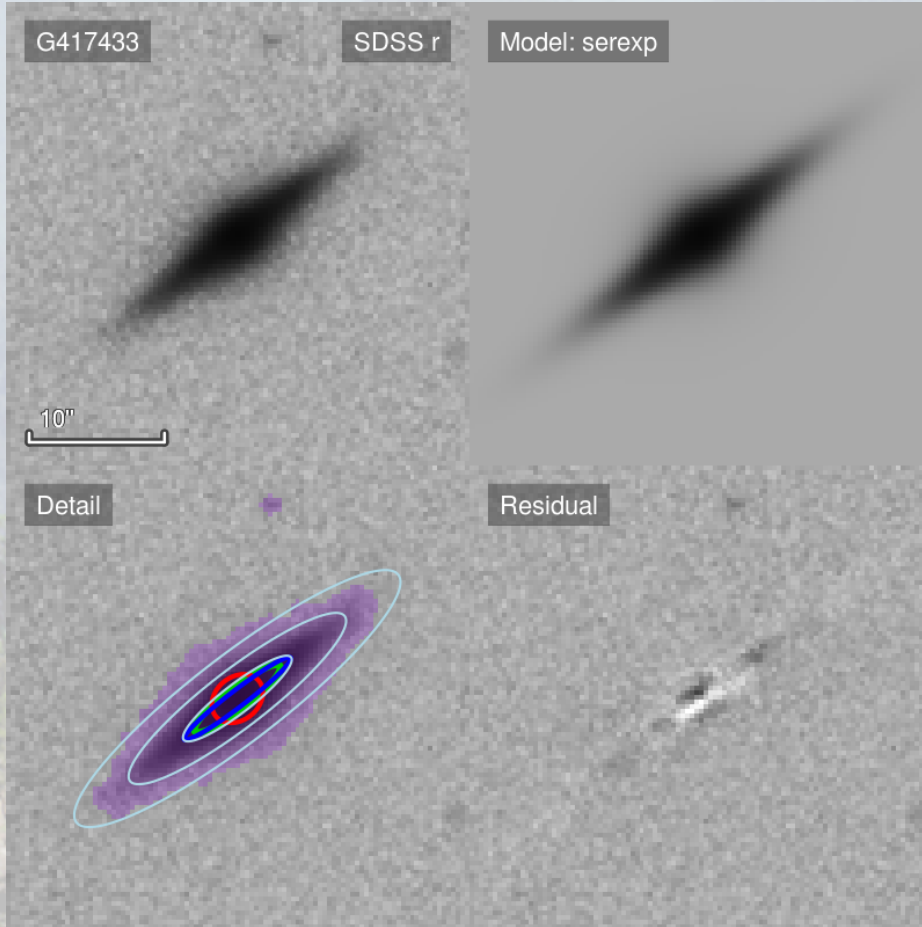
*M02: De Vaucouleurs bulge + exponential disk*





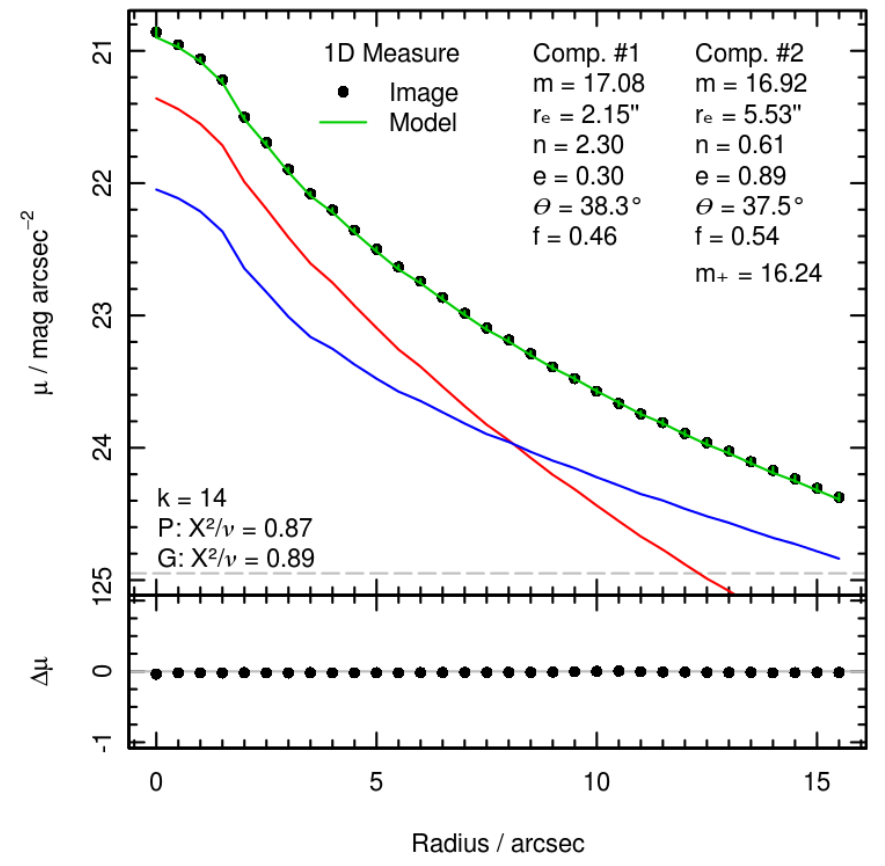
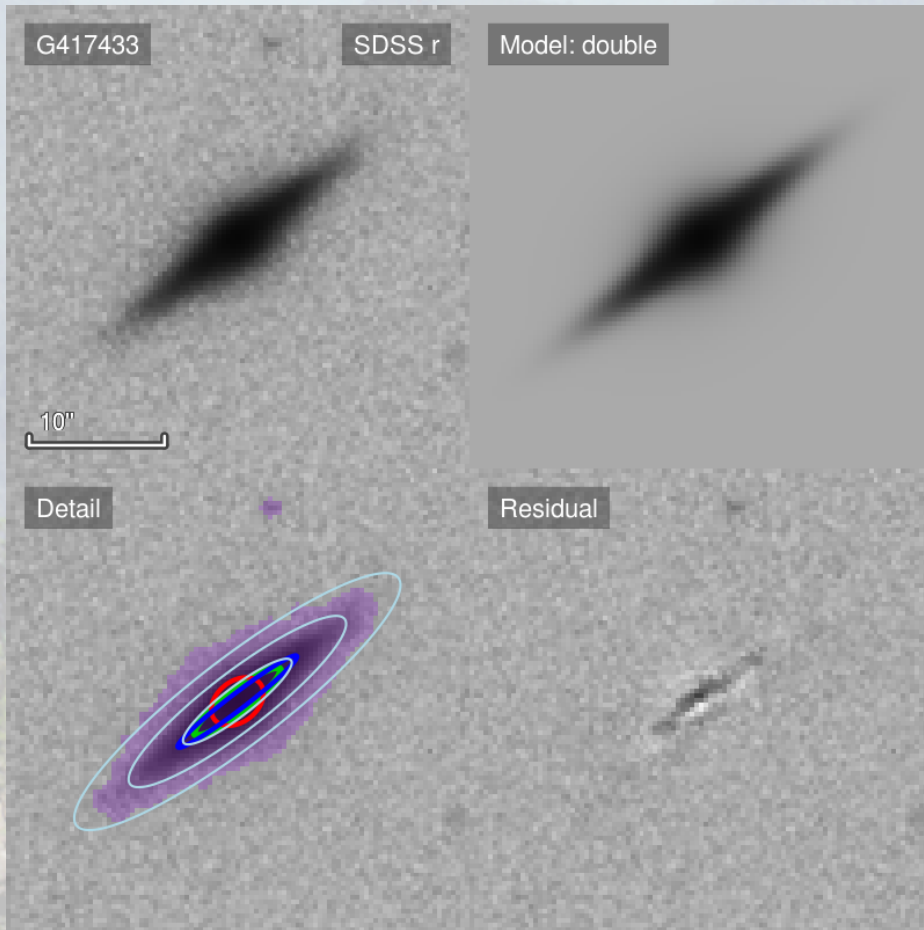
# S0a: G417433

*M03: Sérsic bulge + exponential disk*



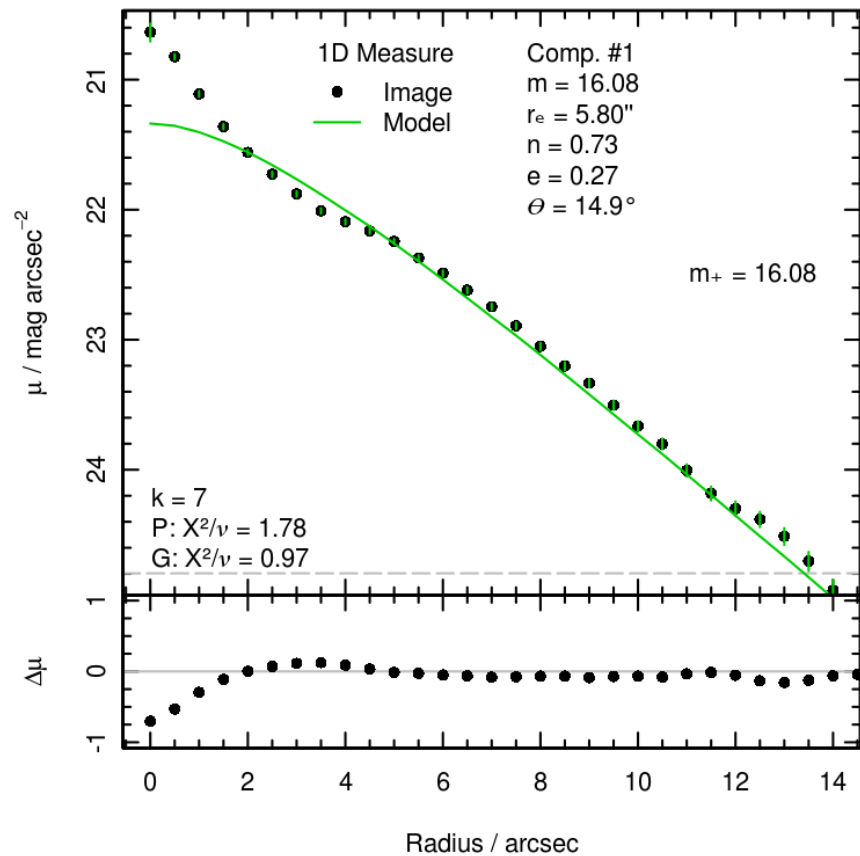
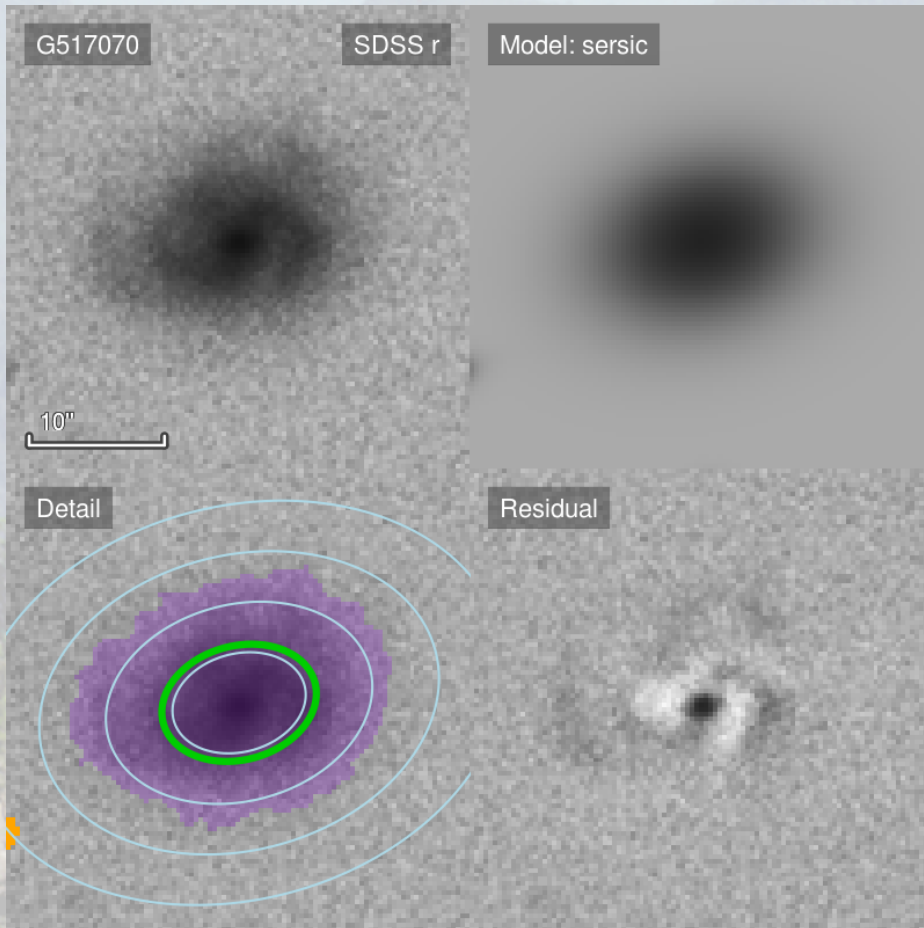
# S0a: G417433

*M04: Sérsic bulge + Sérsic disk*



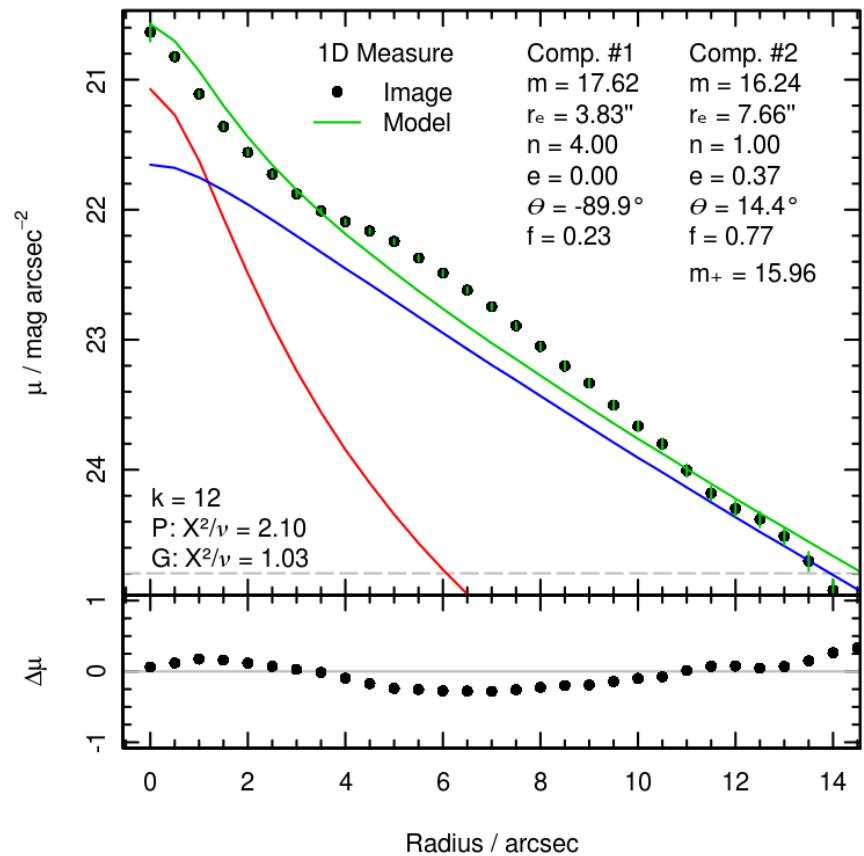
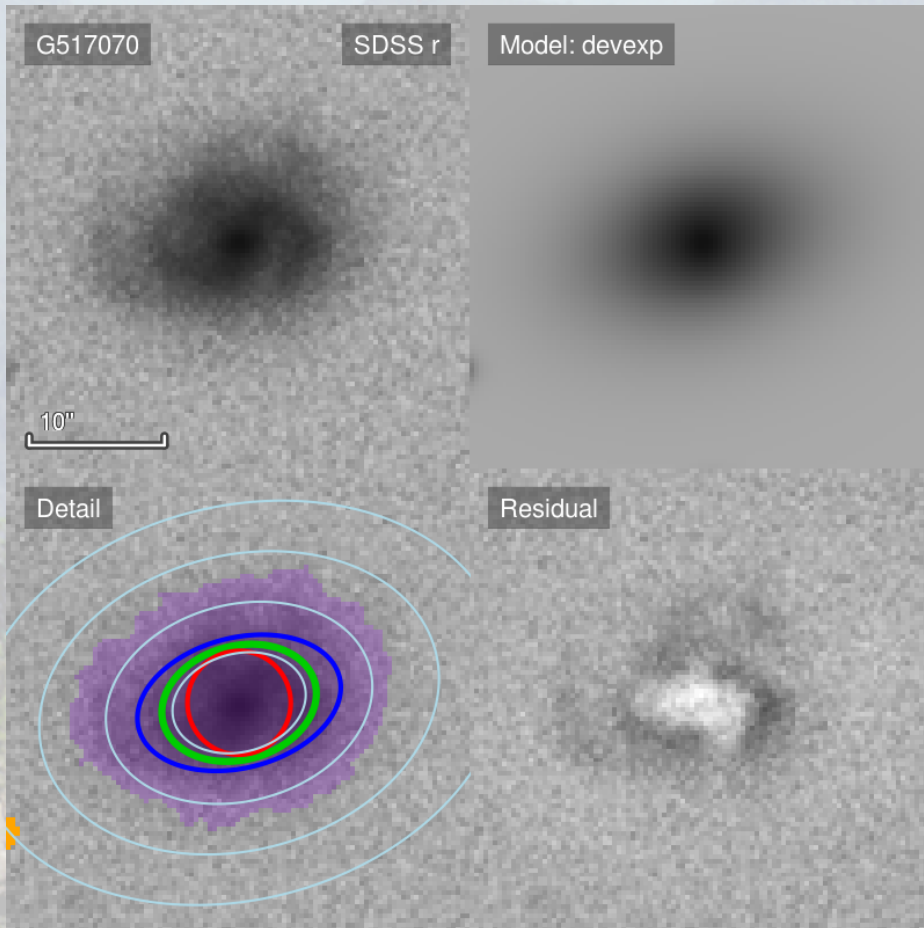
# SBbc: G517070

*M01: Single-Sérsic*



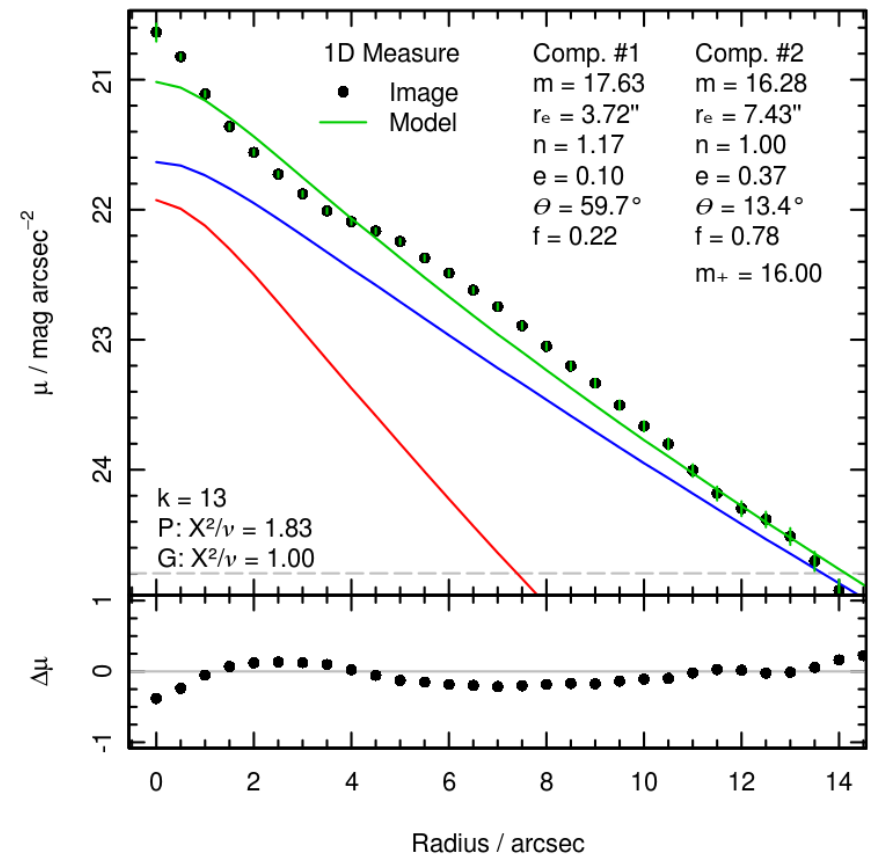
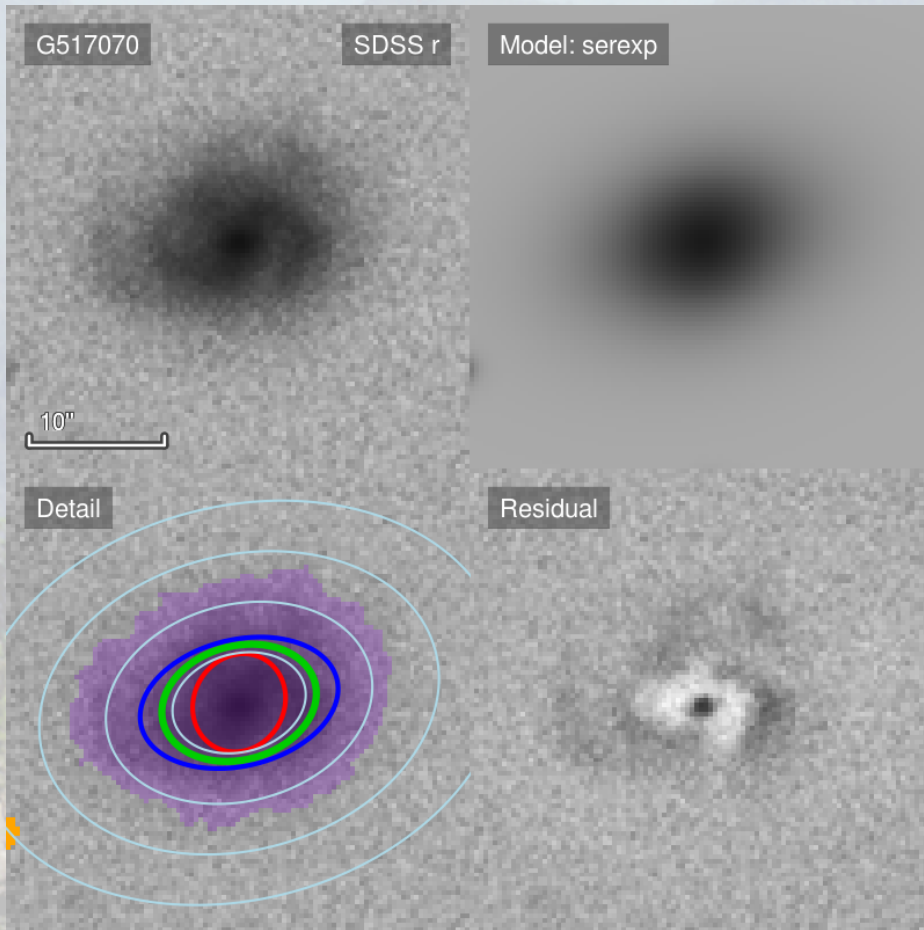
# SBbc: G517070

*M02: De Vaucouleurs bulge + exponential disk*



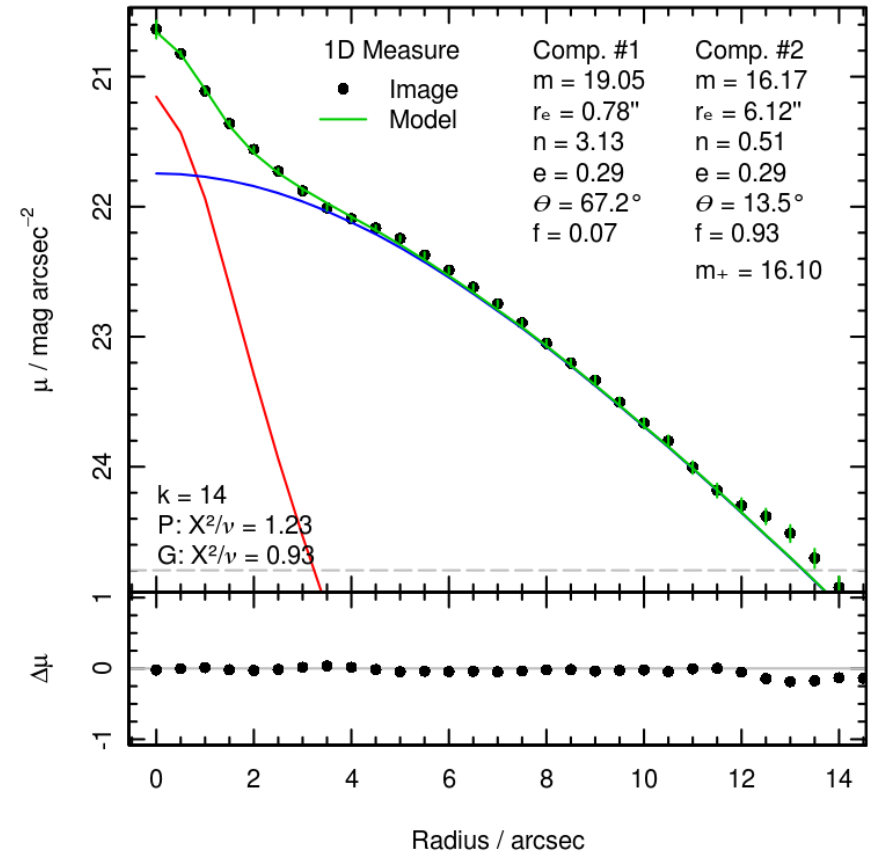
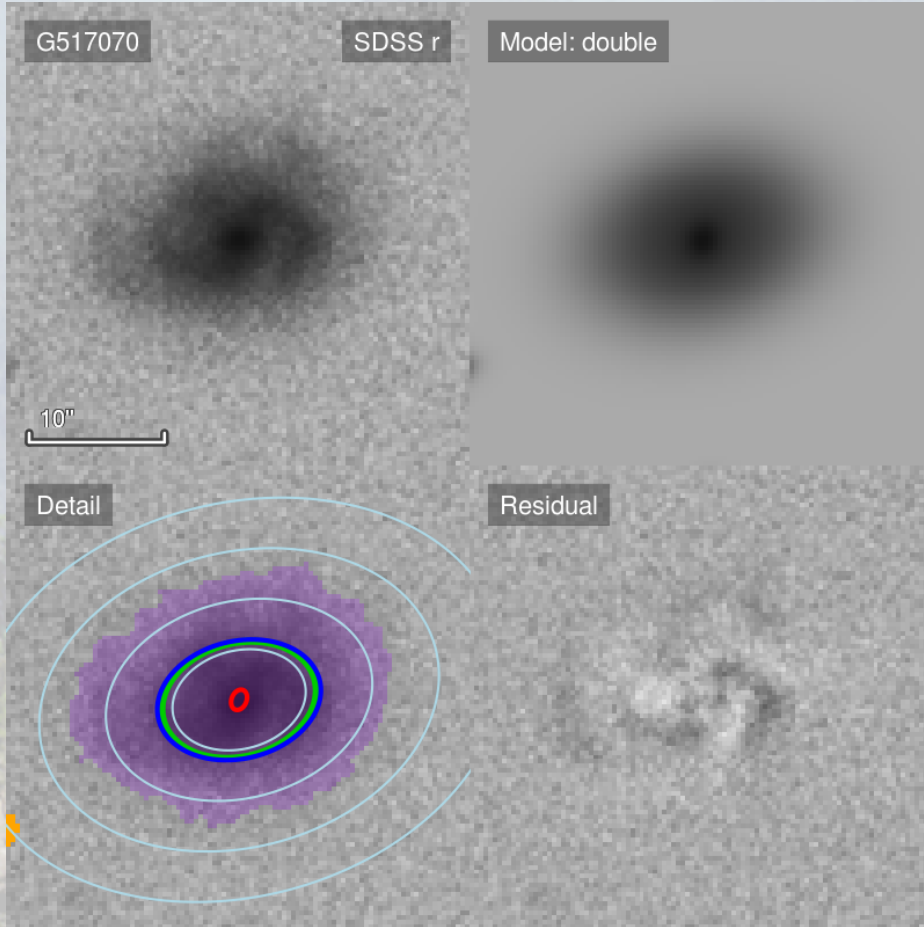
# SBbc: G517070

*M03: Sérsic bulge + exponential disk*



# SBbc: G517070

*M04: Sérsic bulge + Sérsic disk*



# Model Choice

How do we select the 'best' model?



How do we select the 'best' model?

Bayesian Information Criterion:

$$\text{BIC} = \chi^2 + k \cdot \ln(n)$$

$\chi^2$  total goodness of fit  
k number of free parameters  
n number of contributing pixels



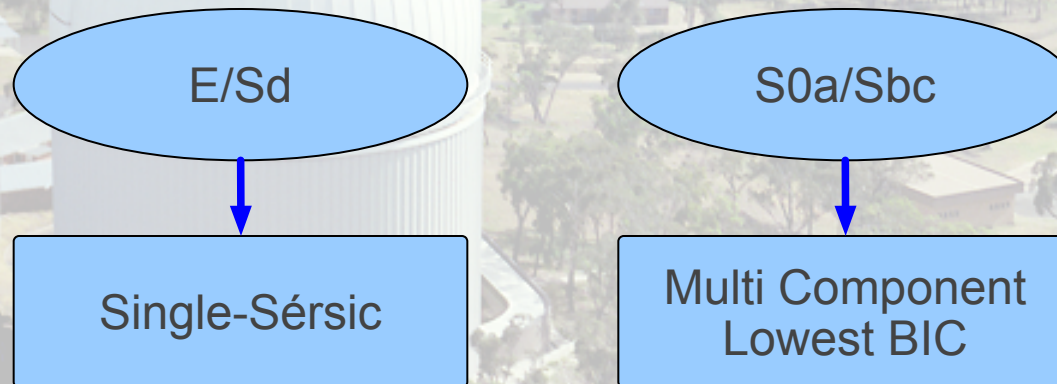
How do we select the 'best' model?

Bayesian Information Criterion:

$$\text{BIC} = \chi^2 + k \cdot \ln(n)$$

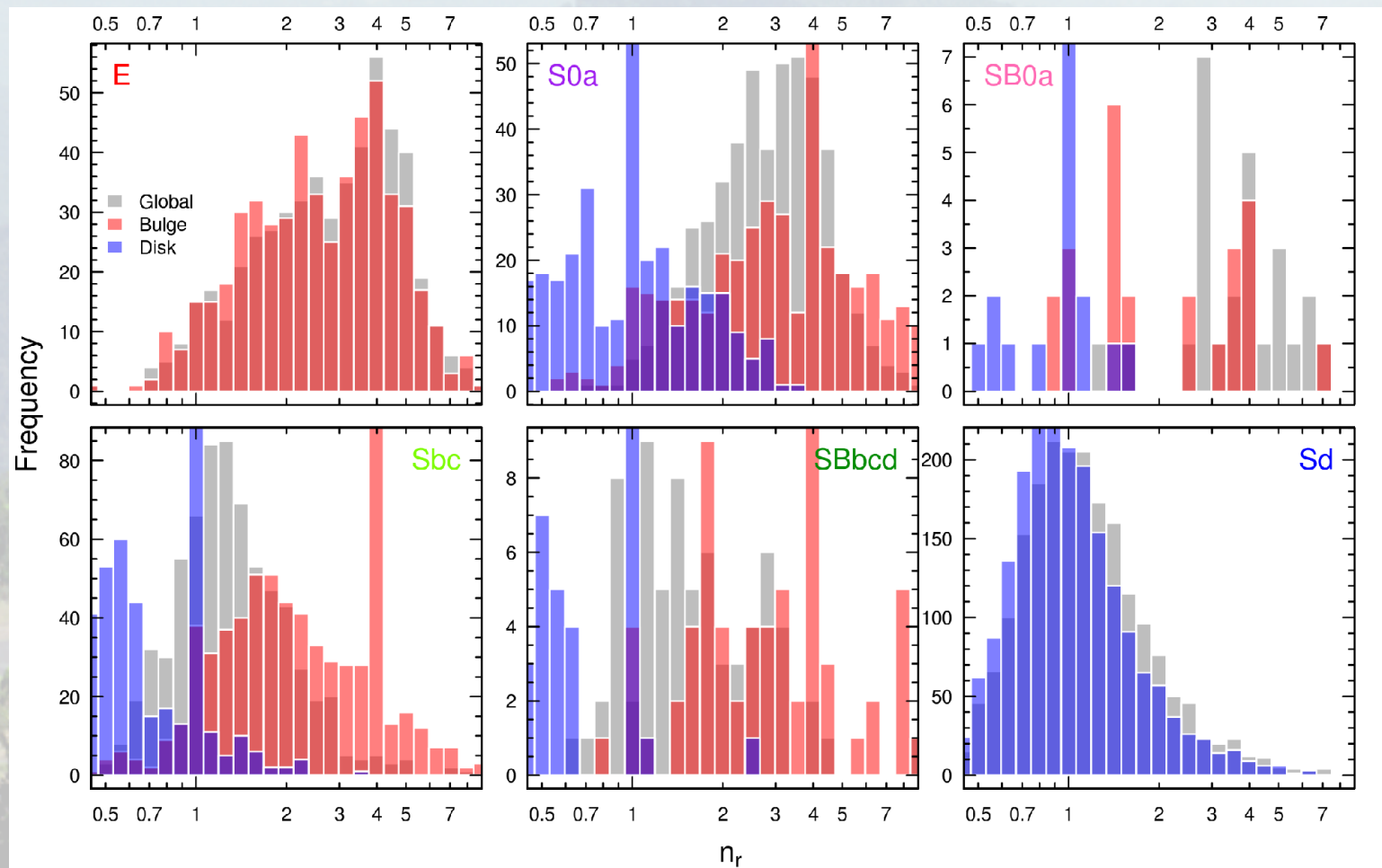
$\chi^2$  total goodness of fit  
k number of free parameters  
n number of contributing pixels

Use visual classifications as a guide:



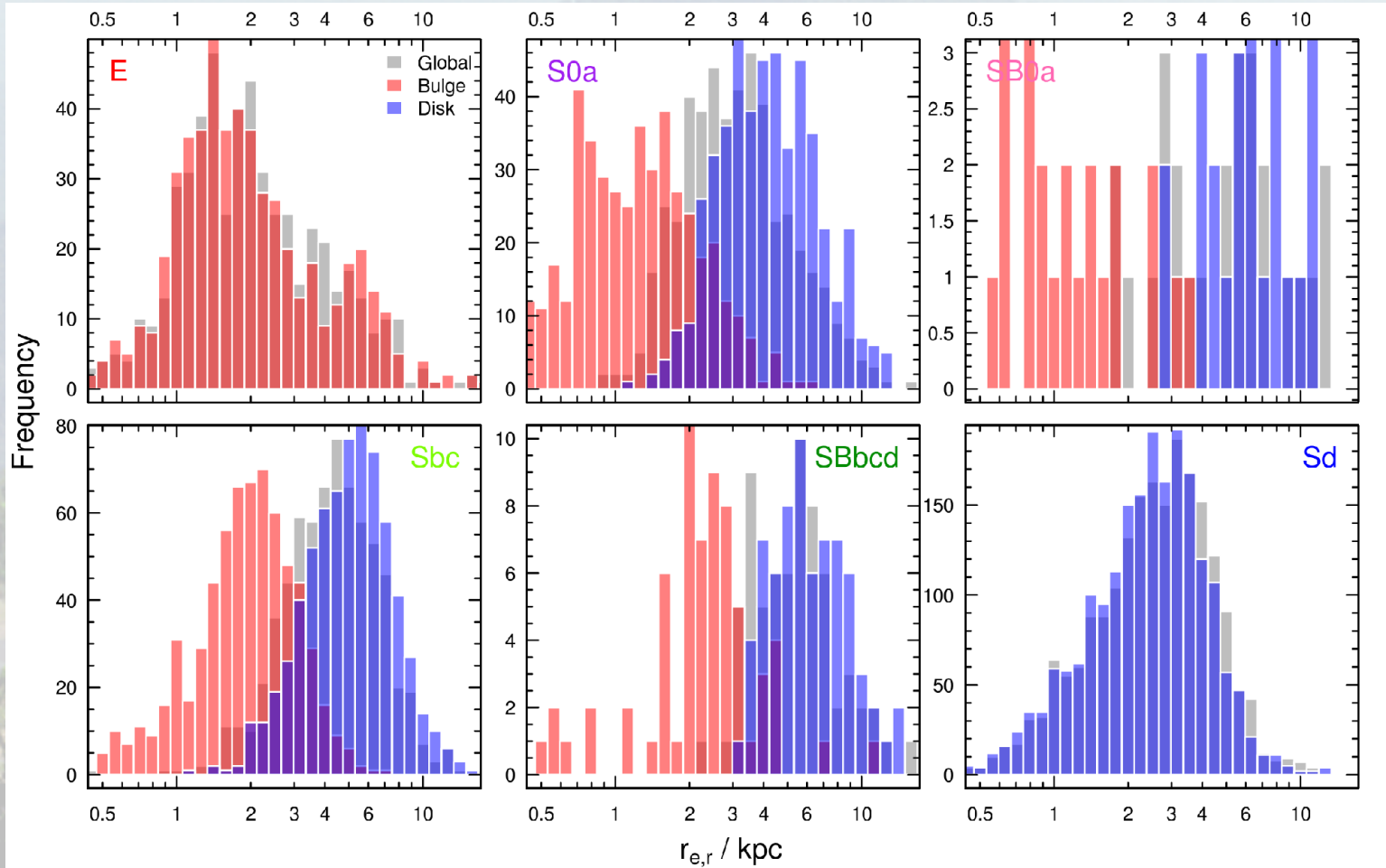
# Structural Results

## Sérsic Index



# Structural Results

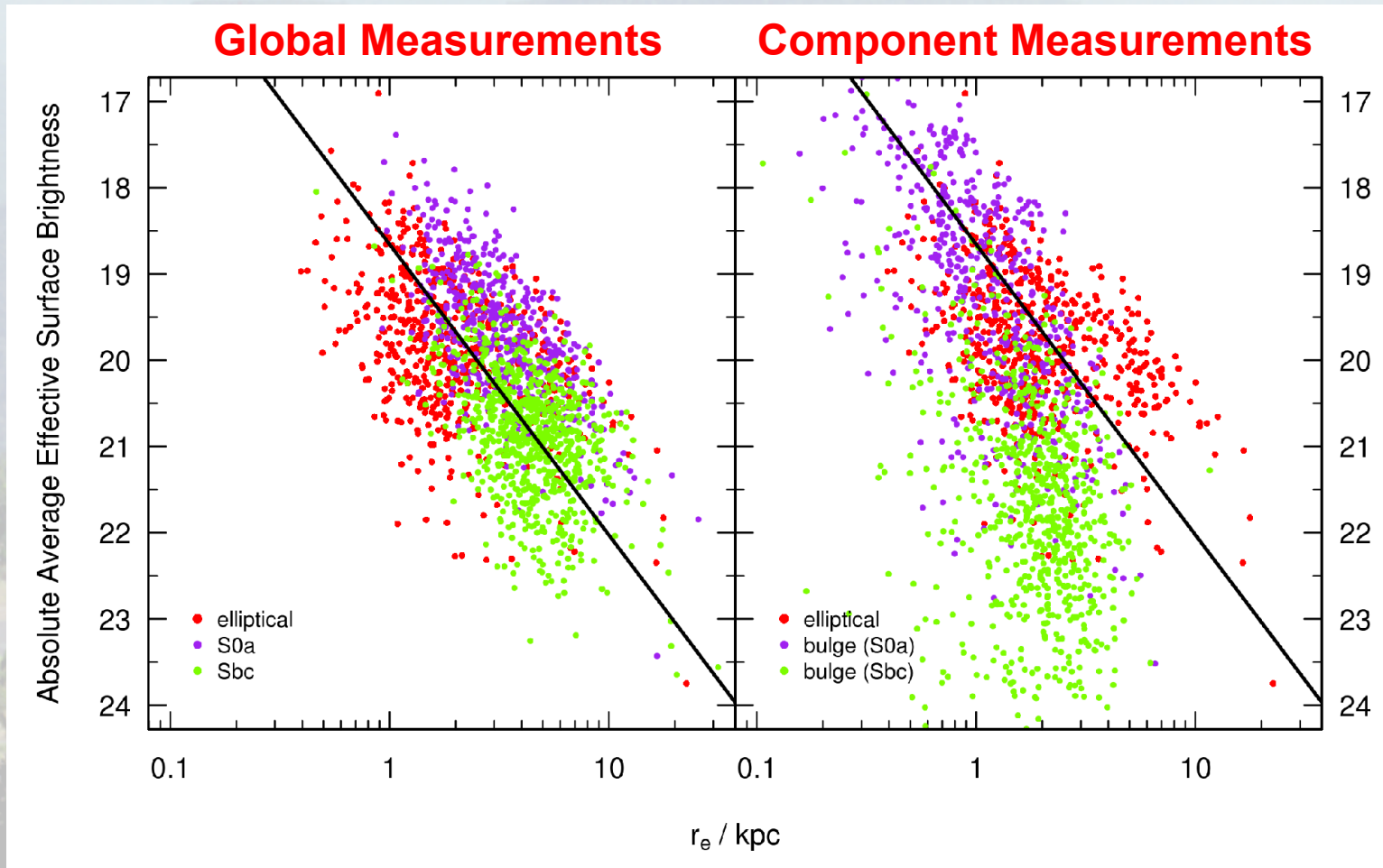
## Half-Light Radius



# Early/Late Type Bulges



## Kormendy Relation



# Quick Recap



3945 galaxies:  $0.025 < z < 0.06$ ;  $\log_{10} M > 8.537$

## Morphological Classification

Elliptical

S0a

Sbc

Sd

## Bulge-Disk Decomposition

Elliptical

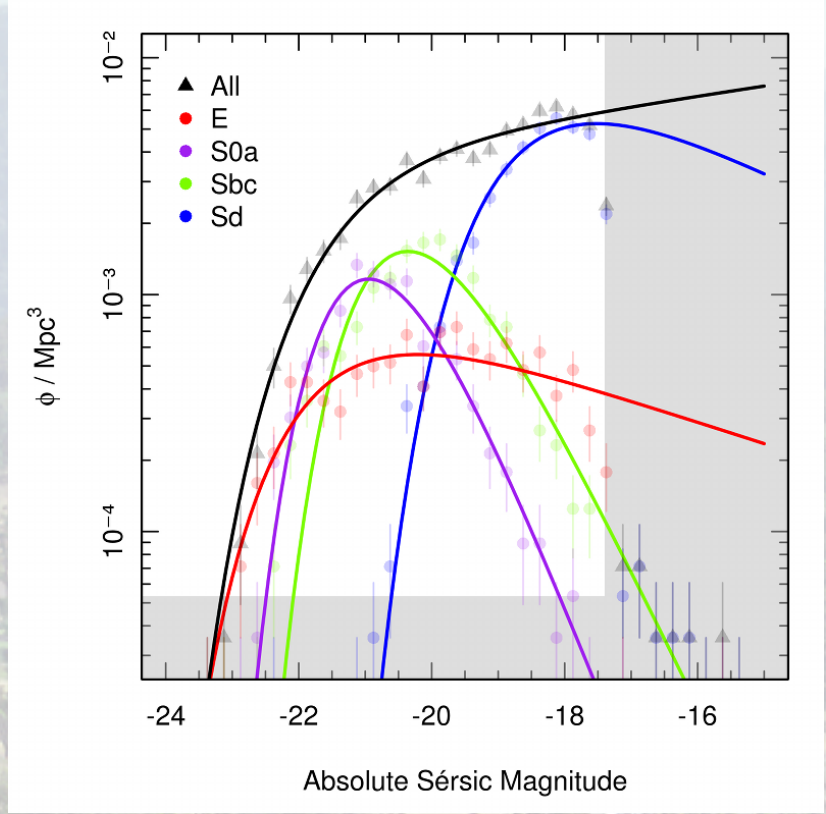
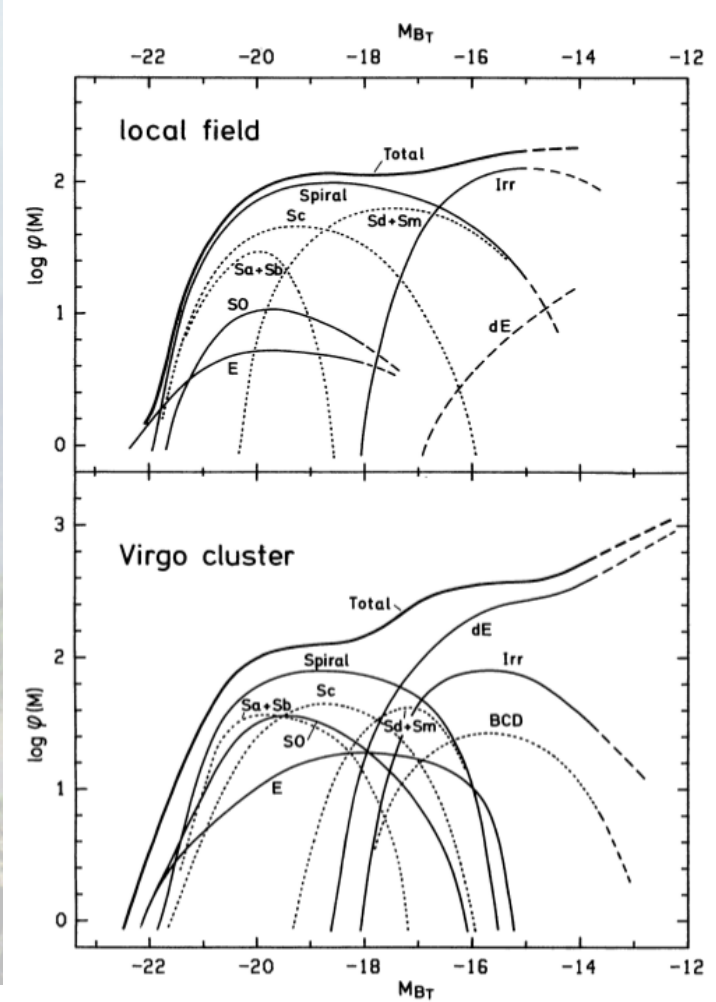
Classical Bulge

Pseudo-Bulge

Disk

redshifts, stellar masses, aperture-matched photometry, photometric corrections, structural information (size, inclination, position angle), environmental measures and group information

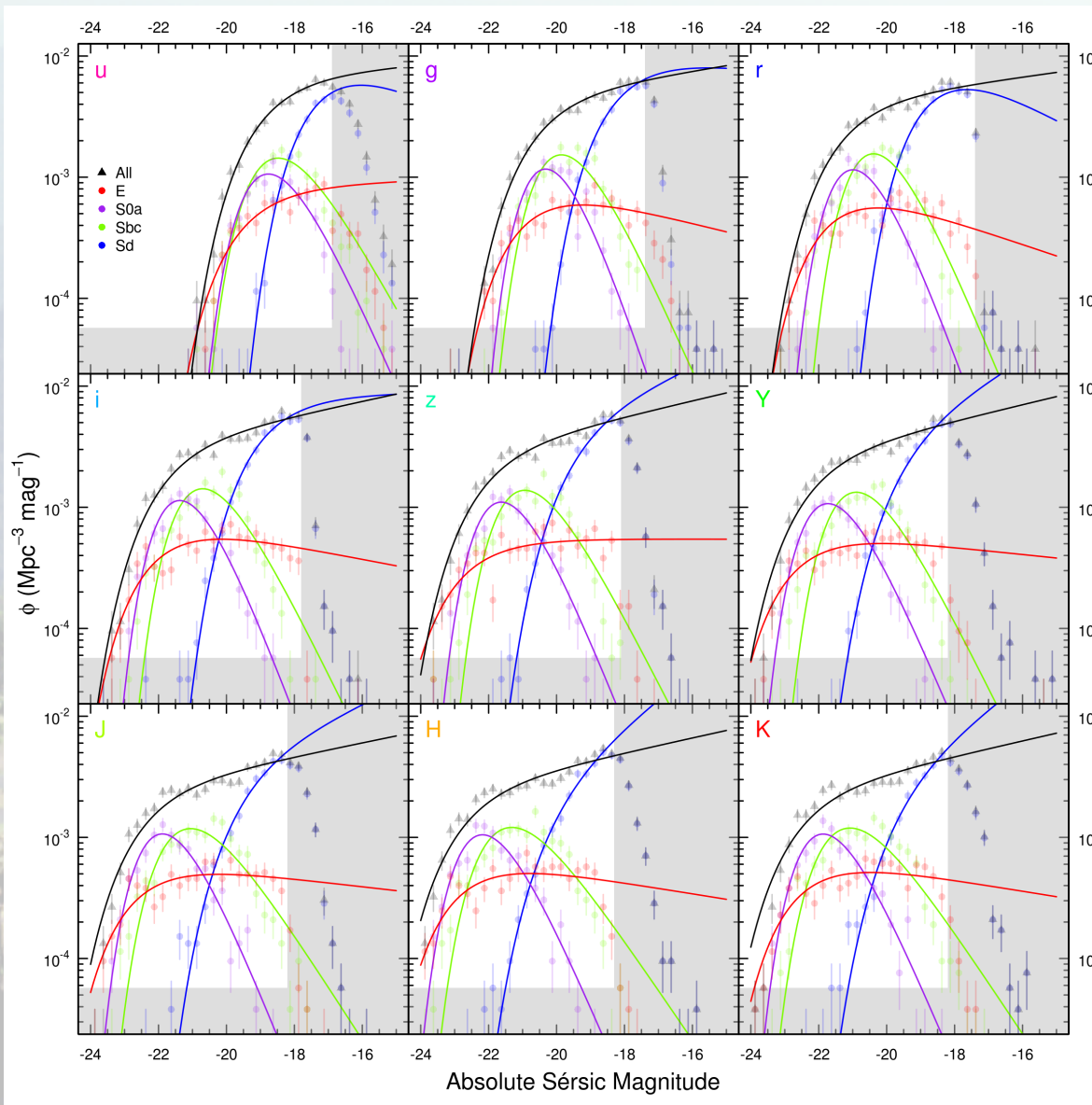
# Sérsic Luminosity Functions



$$\phi(L) dL = \phi^* \left(\frac{L}{L^*}\right)^\alpha \exp\left(-\frac{L}{L^*}\right) d\left(\frac{L}{L^*}\right)$$

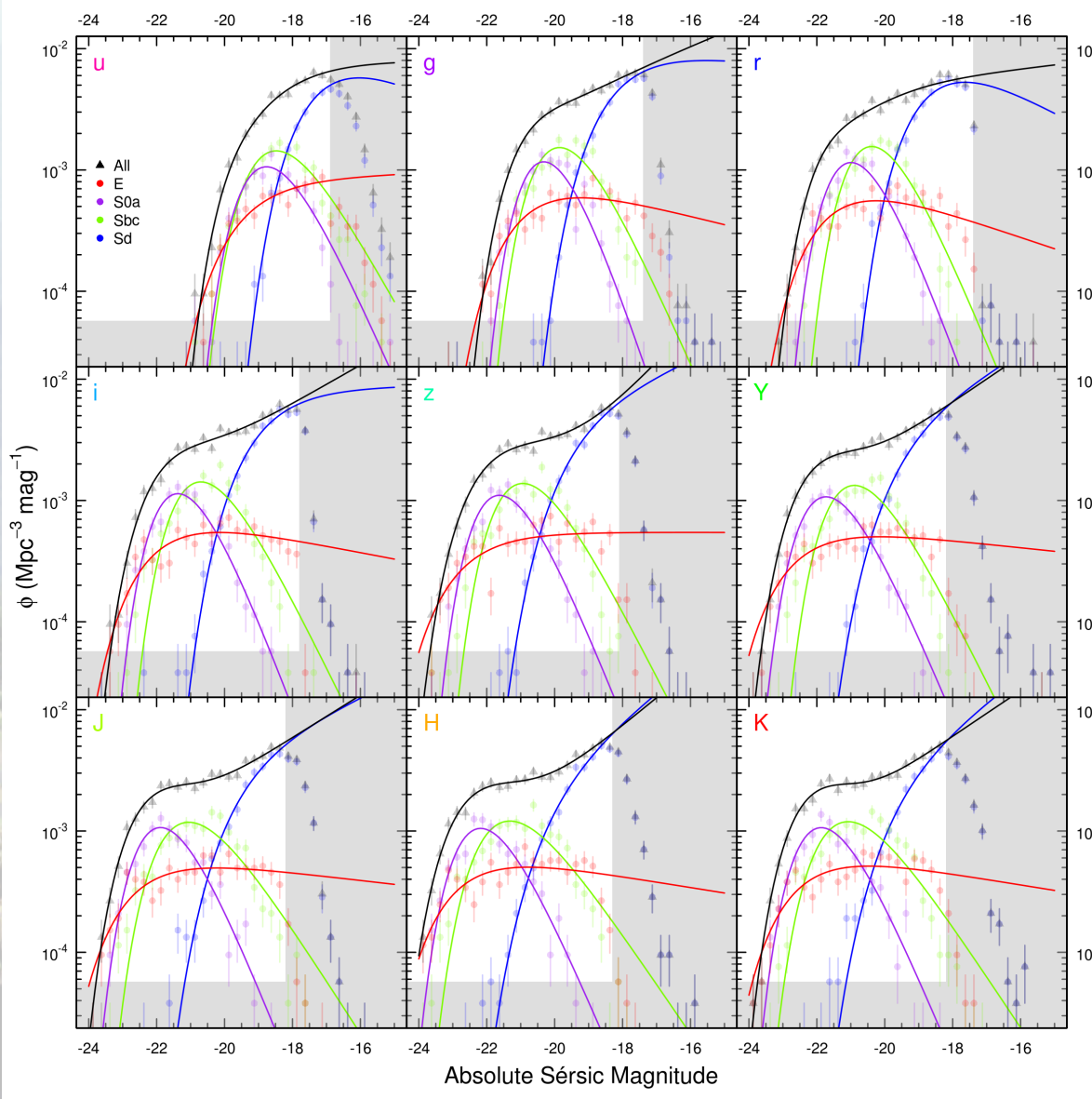
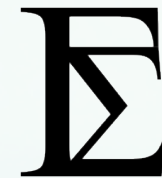
Binggeli et al., 1988

# Sérsic Luminosity Functions



Single-Schechter

# Sérsic Luminosity Functions



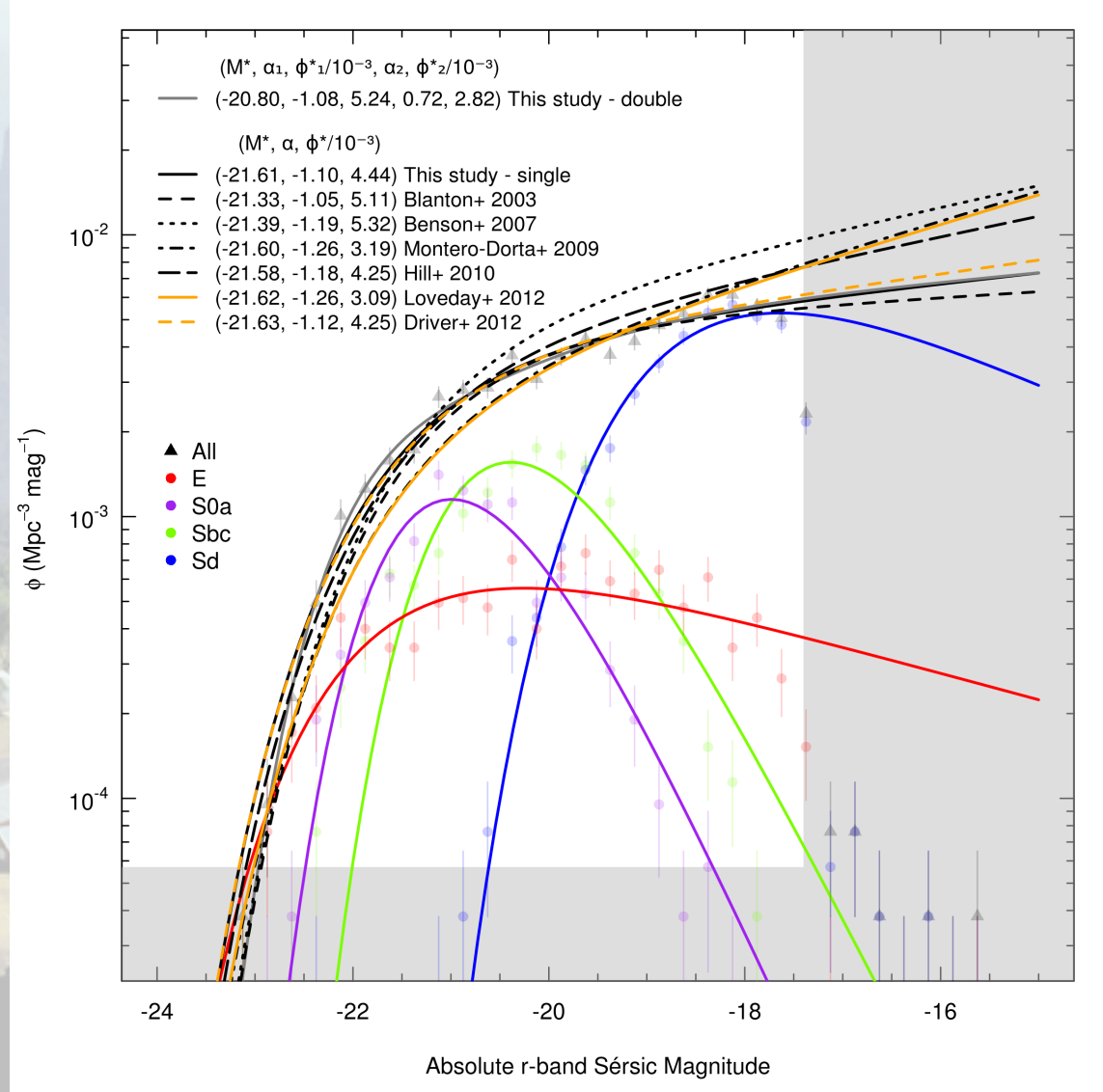
Double-Schechter

Test, e.g.:  
quenching of SF in  
galaxies

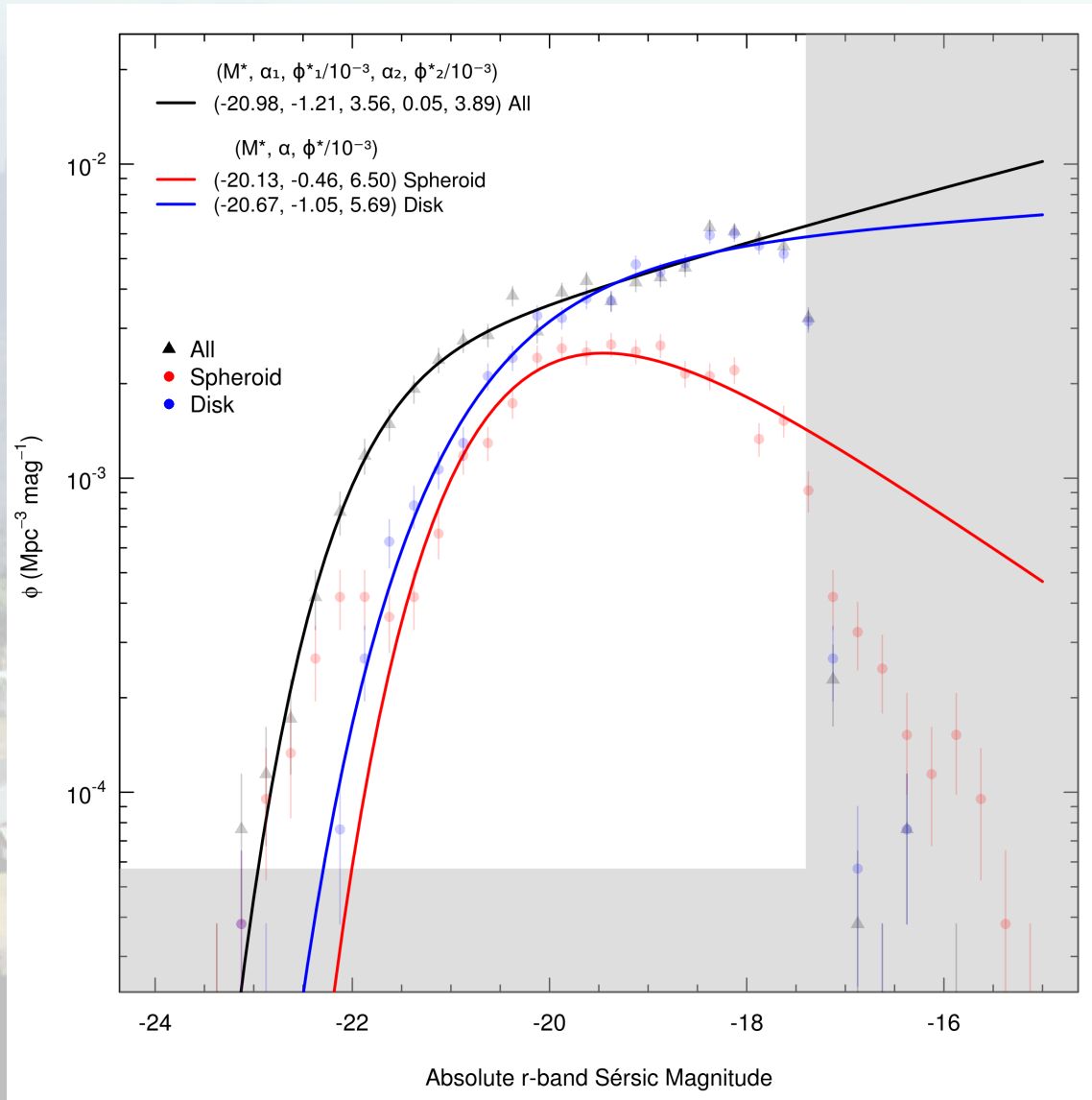
(Baldry et al., 2012)



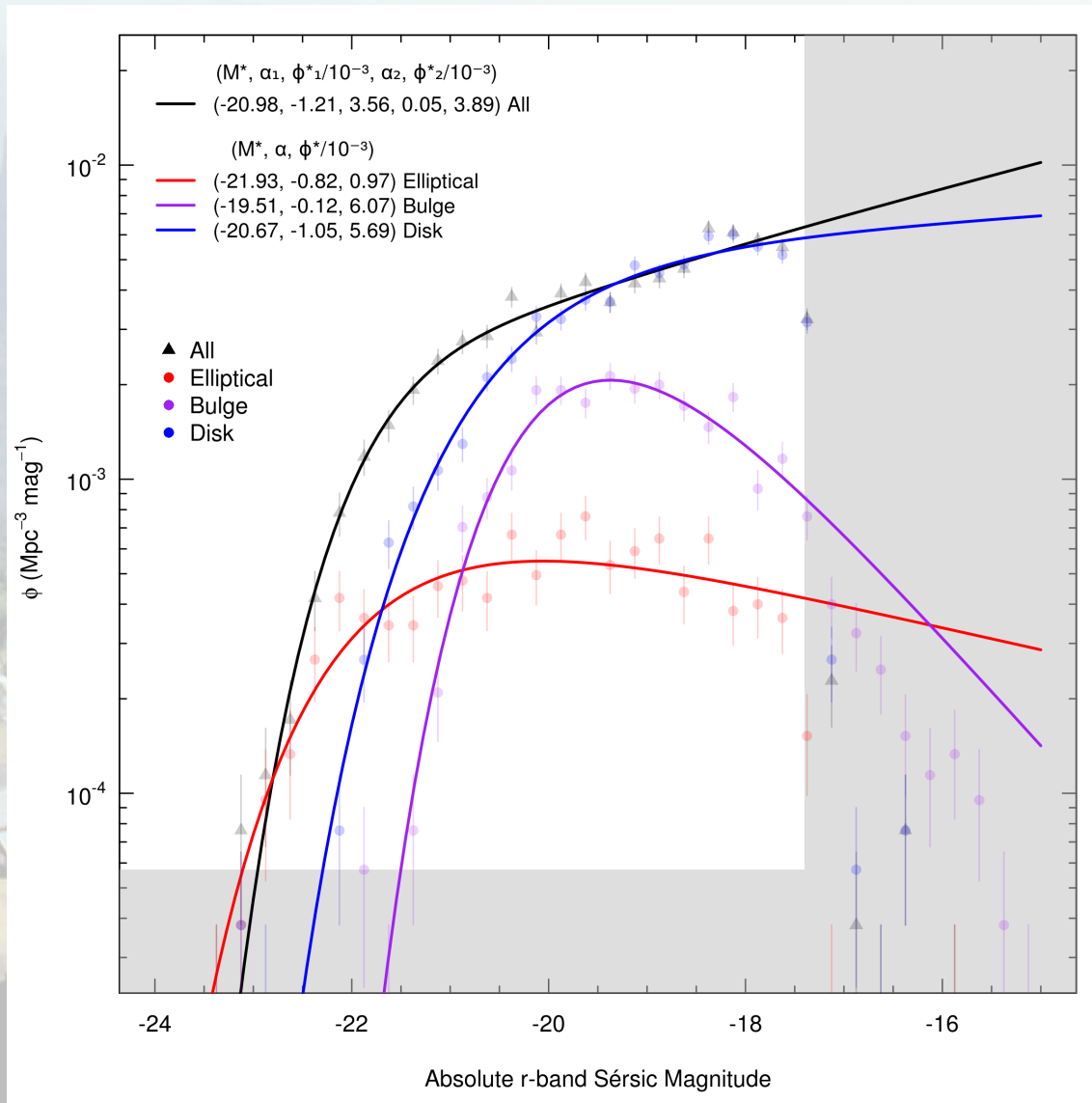
# Sérsic Luminosity Functions



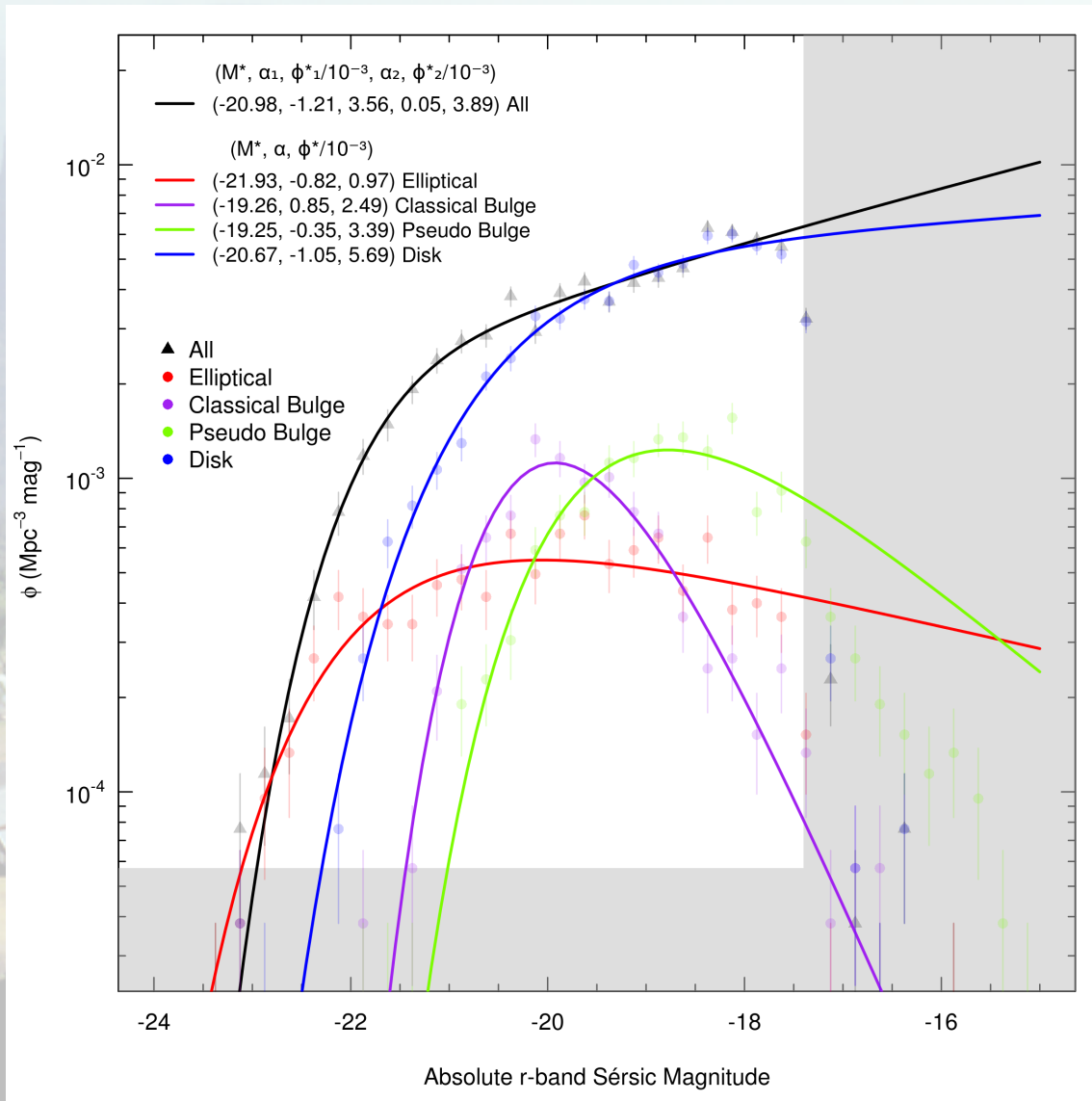
# Sérsic LF by Structure



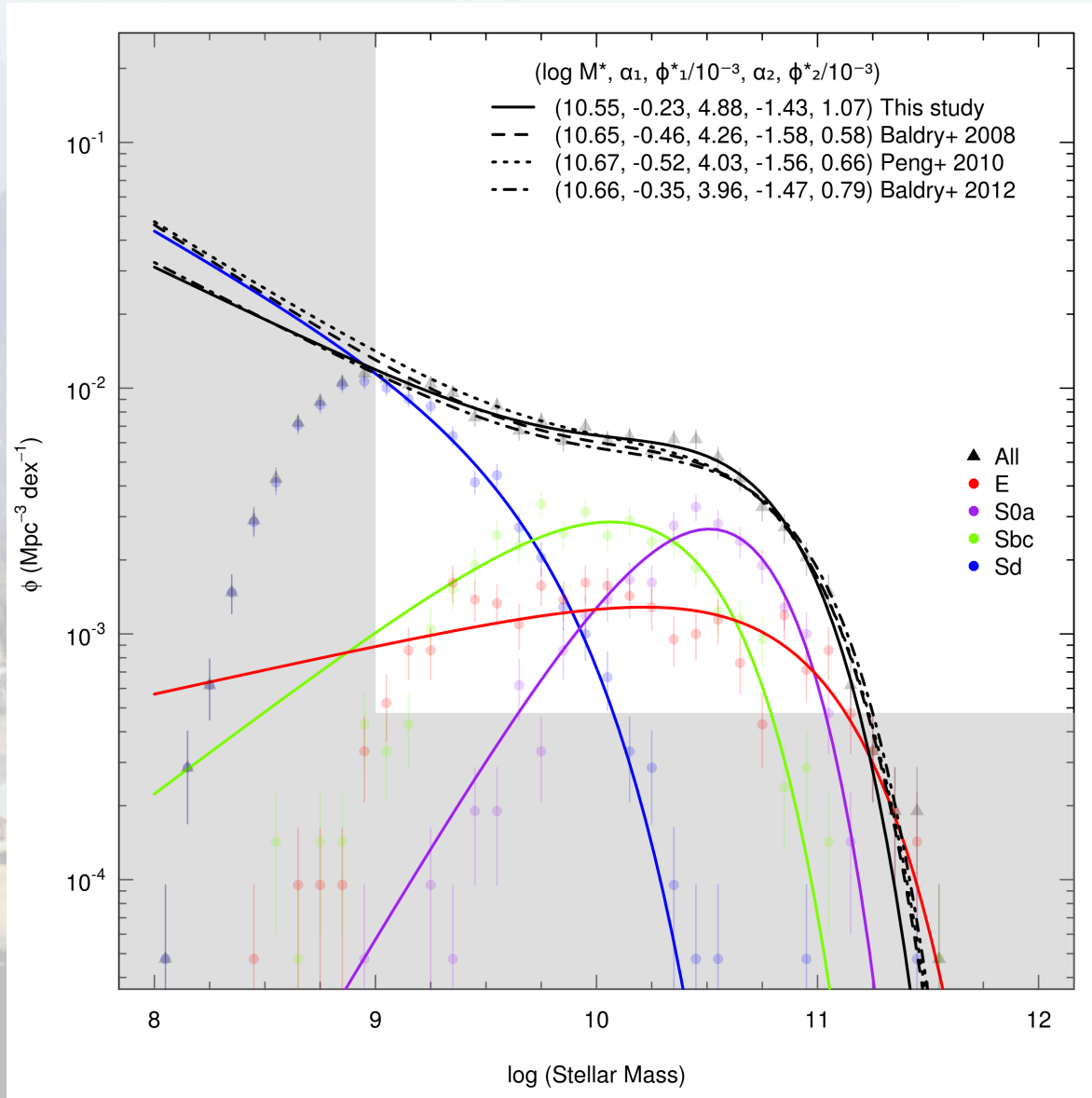
# Sérsic LF by Structure



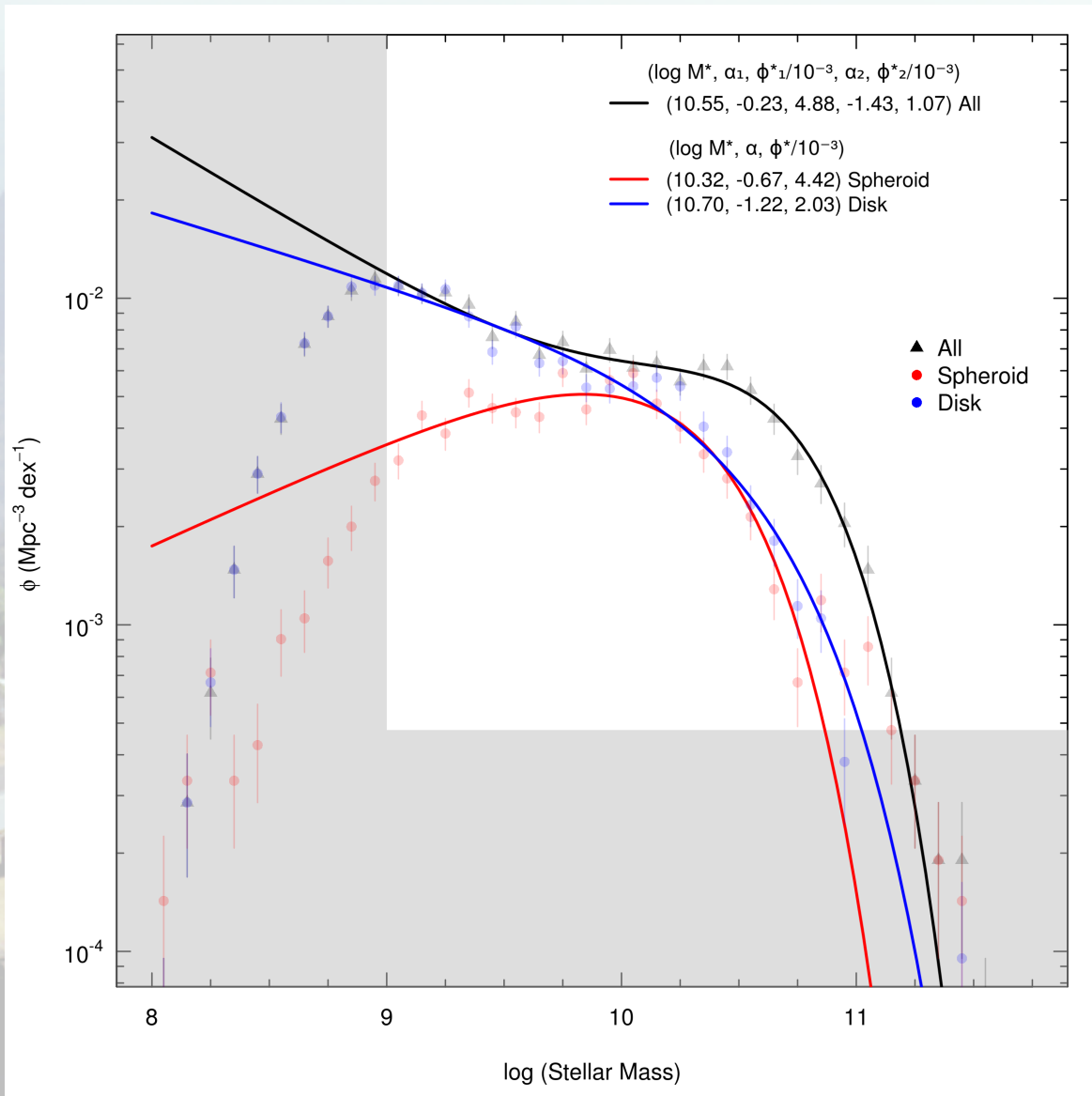
# Sérsic LF by Structure



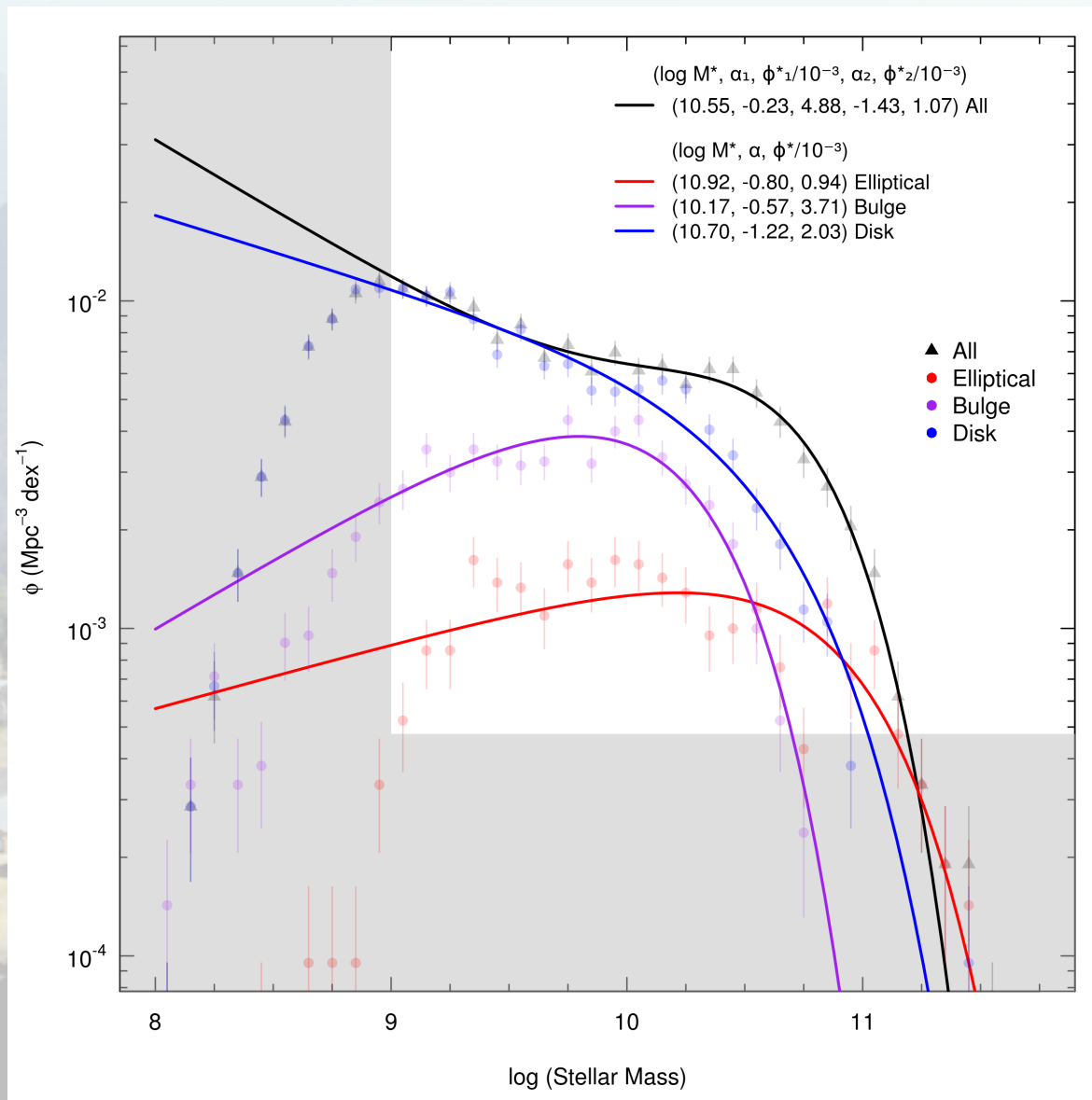
# Morphology Mass Function



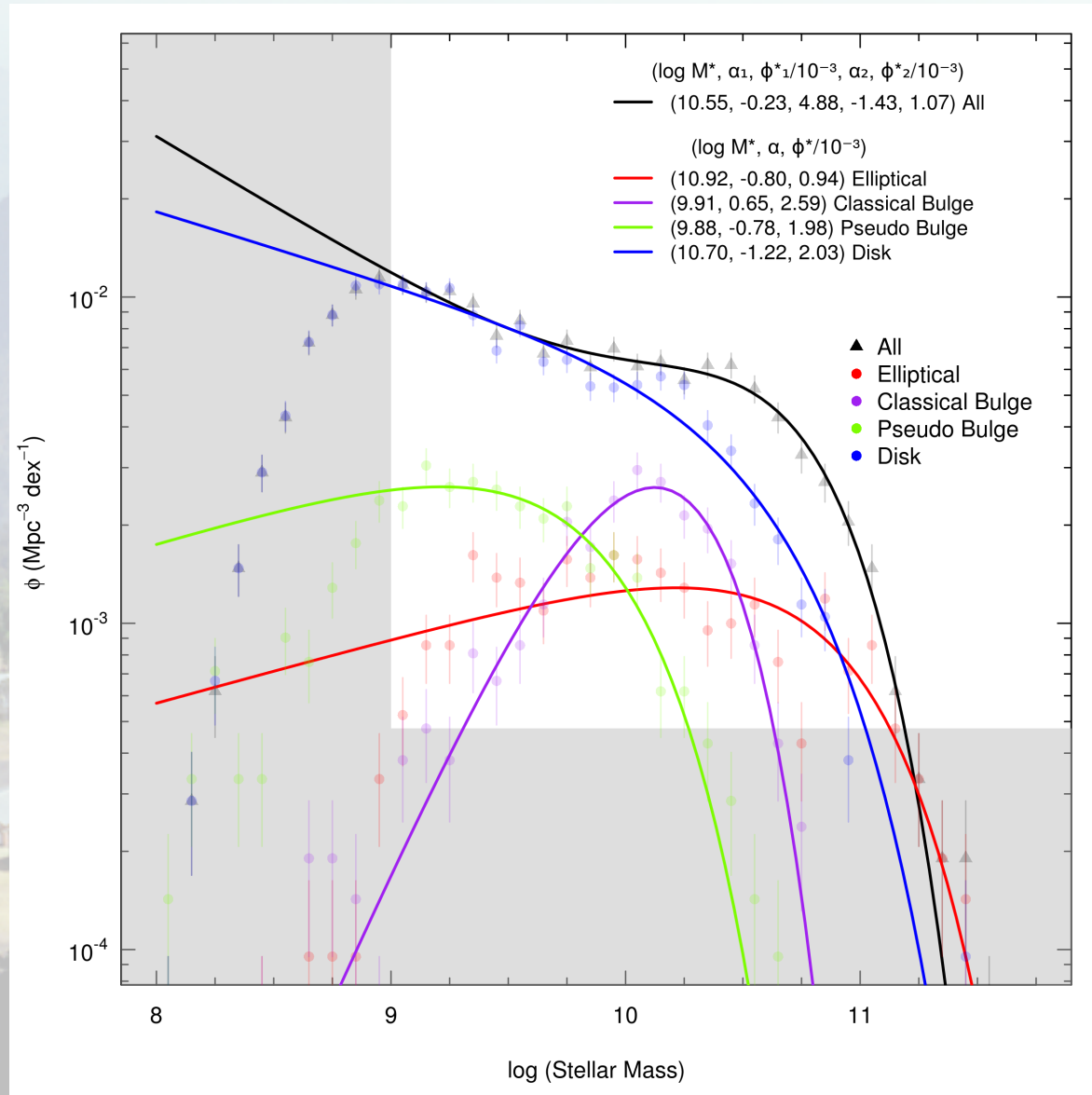
# Structural Mass Function



# Structural Mass Function

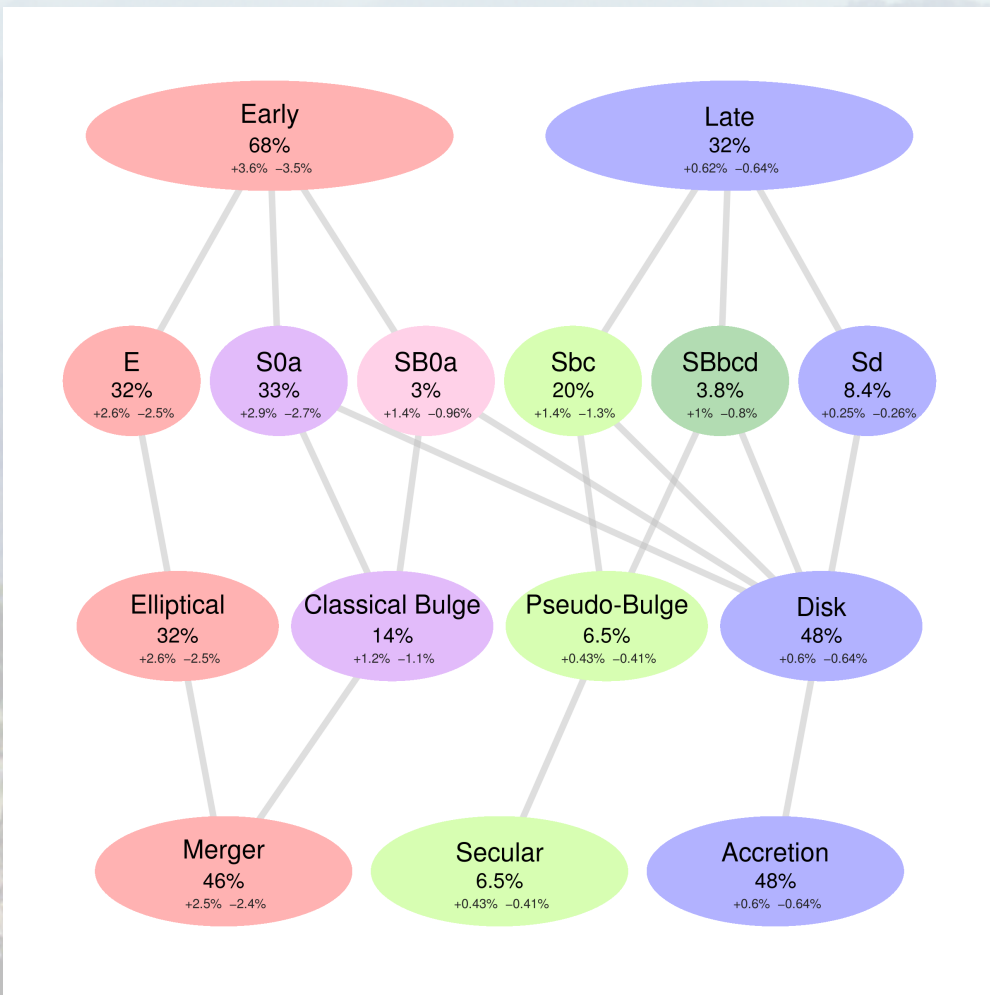


# Structural Mass Function





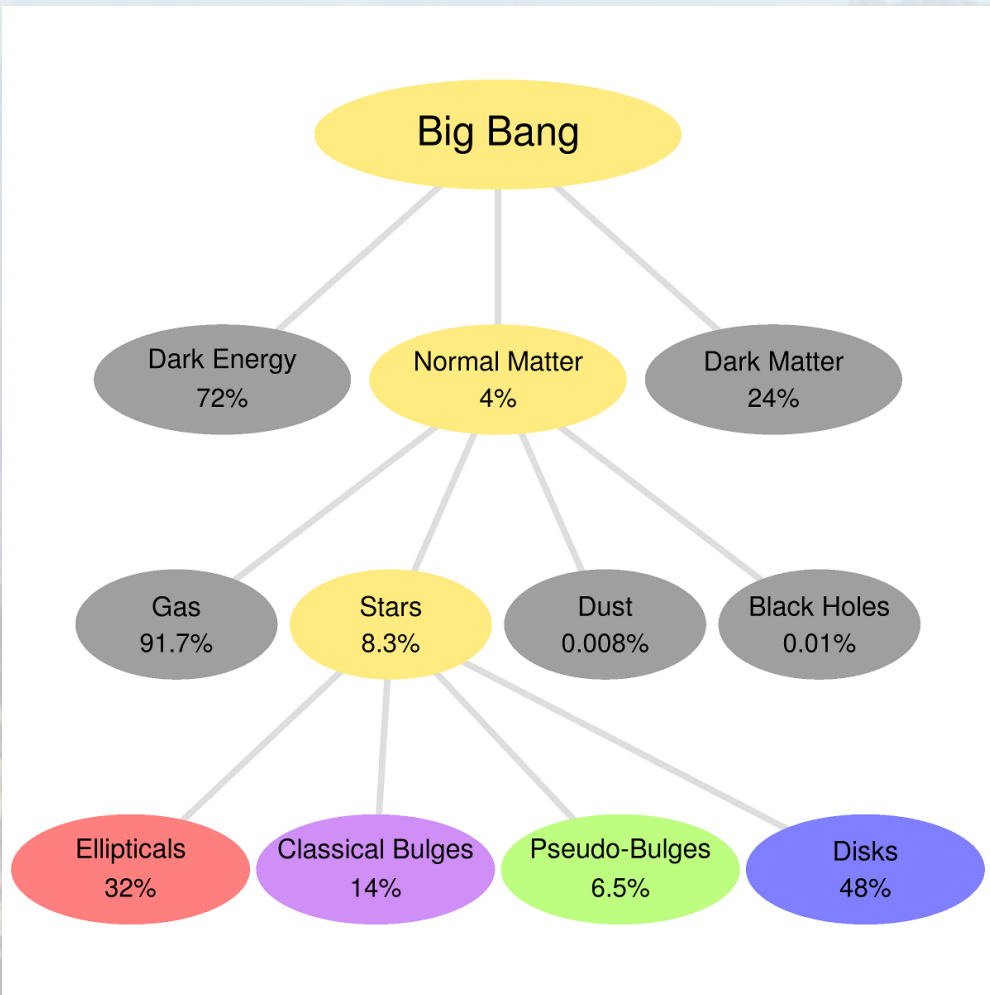
# Stellar Mass Breakdown



Mass in the local Universe:

- Hierarchical merging ~45.8%
- Gas accretion ~47.7%
- Secular evolution ~6.5%

# Stellar Mass Breakdown



Mass in the local Universe:

- Hierarchical merging ~45.8%
- Gas accretion ~47.7%
- Secular evolution ~6.5%

Automated, fast and robust **structural decomposition is essential** in order to model increasingly large galaxy datasets to a high level of accuracy.

**NIR wavelengths are preferred**, as they avoid the effects of dust attenuation and hence are able to 'see' more of the galaxy (but multi- $\lambda$  cannot be ignored).

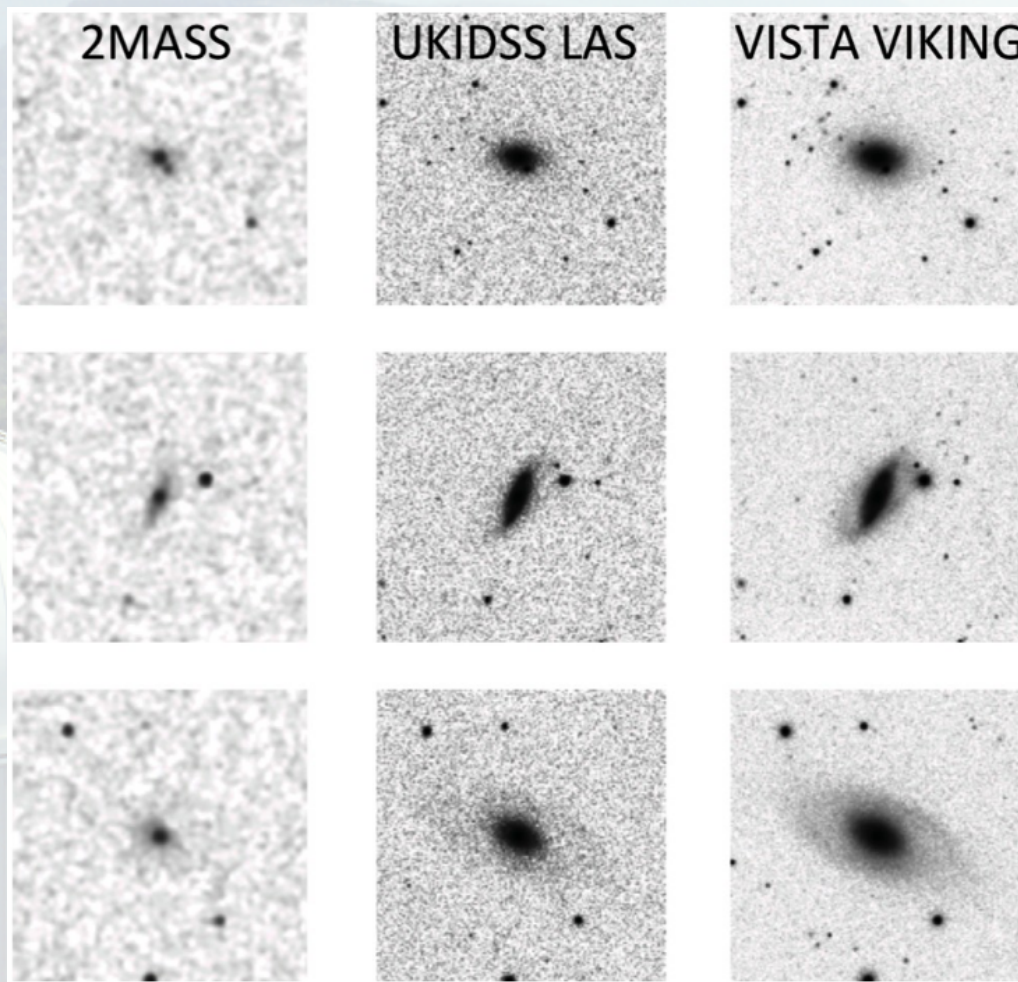
Early-type bulges are well described by the Kormendy relation, whereas late-type bulges do not follow this relation

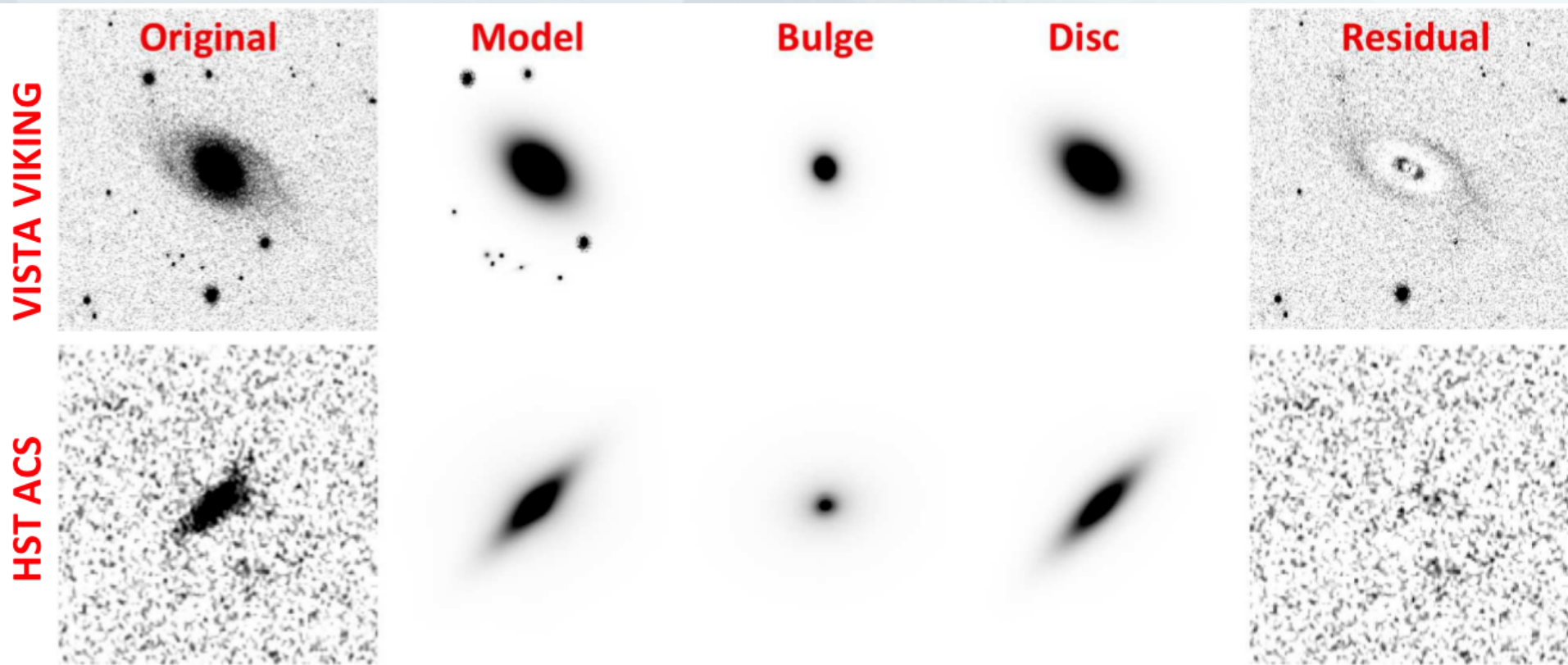
→ **early-type bulges ~ classical bulge**, **late-type bulges ~ pseudo-bulge**

The evolutionary processes of monolithic **collapse/merging** and gas **accretion** contribute roughly equal measures of stellar mass in the local universe.

**Secular evolutionary processes contribute ~6.5%** of the total stellar mass at  $z < 0.06$  through the creation of pseudo-bulges.

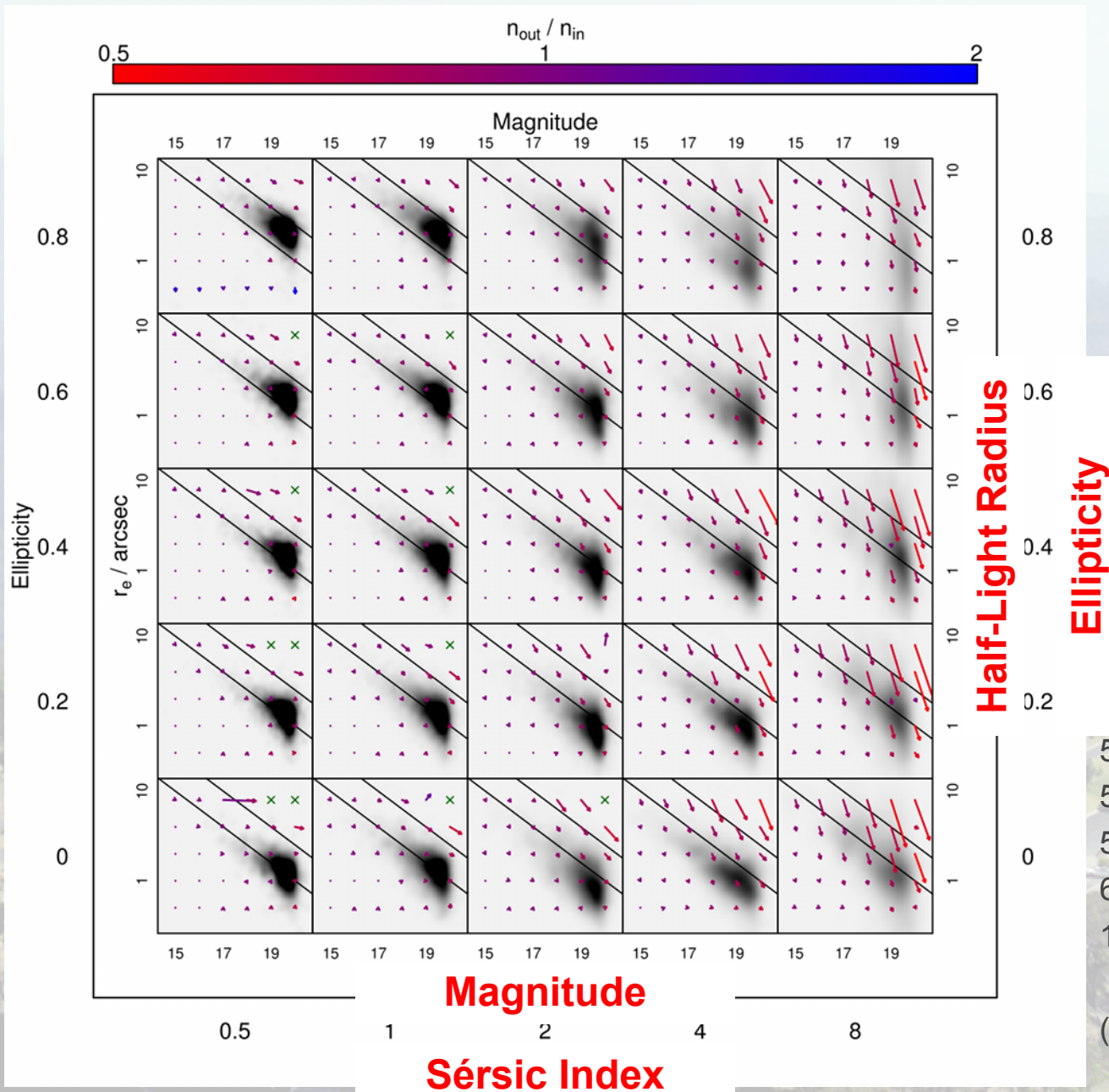
Significant improvements in structural measurements when moving from **previous-generation** to **current-generation** to **next-generation** survey data





Bulge-Disk decomposition essential for a full understanding of galaxy structure and mass breakdown

# Does SIGMA work?

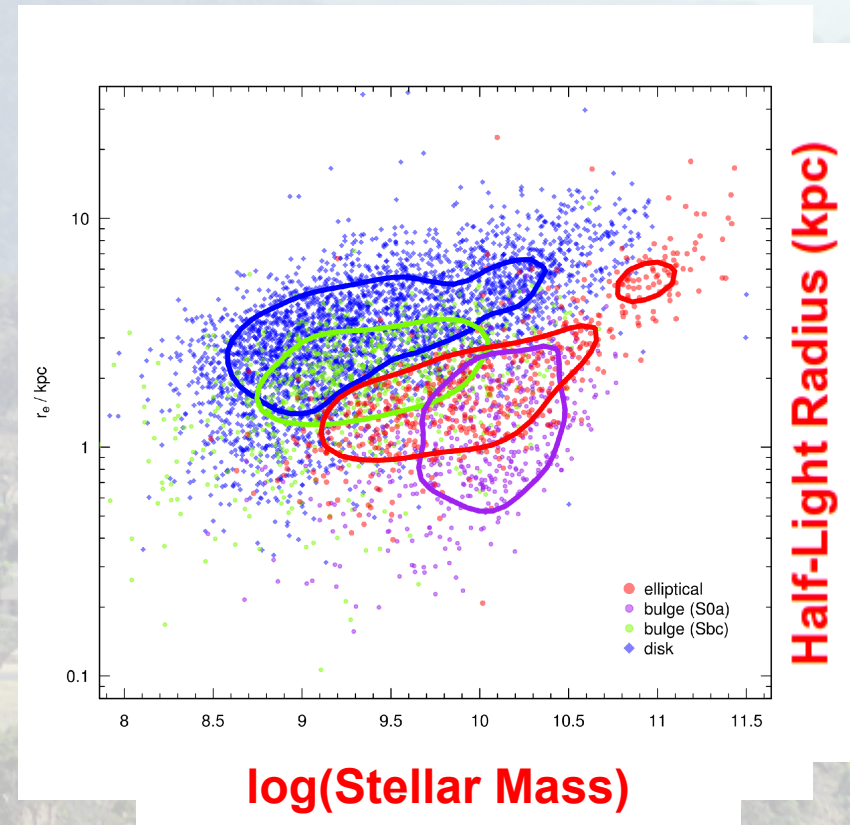
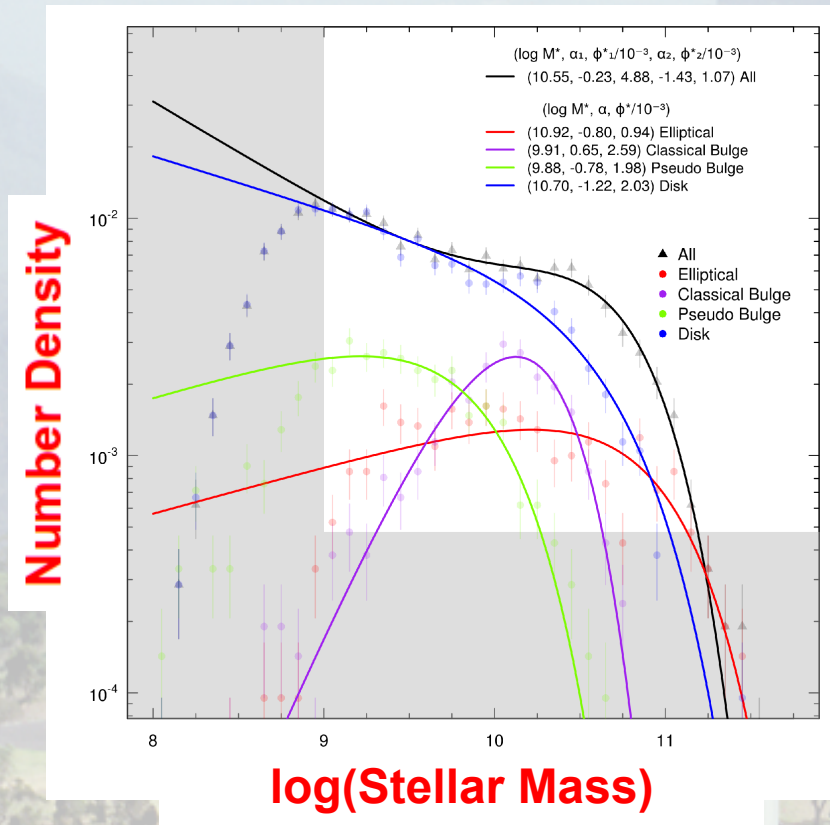


- 5 × Sérsic index
- 5 × Half-light rad
- 5 × Ellipticity
- 6 × Magnitude
- 100 × iterations
- = 75,000 models
- (~24h; 16 procs)

# Component Mass



Stellar Masses: Taylor 2011+



Ellipticals dominate at high-mass, disks at low-mass

Late-type bulges share more in common with disks than early-type bulges