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

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Galaxy and Mass Assembly
"Study structure on scales of 1 kpc to 1 Mpc"

- ~340,000 gals
- \( r < 19.8 \) mag
- ~310 deg\(^2\)
- 27 passbands

- clusters
- groups
- mergers
- structure
GAMA: People (2012)

GAMA SSAC
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Michael Brown
Michael Drinkwater
Simon Driver (PI)
Andrew Hopkins (PI)
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GMRT
KIDS
GALEX
DINGO
VIKING
UKIDSS
XMM-XXL
Herschel, L2
GALEX, Earth Orbit
WITE, Earth Orbit

GROUND-BASED FACILITIES:
AAO, Siding Springs
SDSS, Apache Point
VST, Paranal
UKIRT, Mauna Kea
VISTA, Paranal
GMRT, Pune
ASKAP, WA

SPACE MISSIONS

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~250,000 spectroscopic redshifts

0 < z < 0.5
GAMA Redshifts

~250,000 spectroscopic redshifts

0 < z < 0.5

Support Branch

Observer Main Sequence

Gold observers

MG members

Team members

Non members
GAMA Redshifts

~250,000 spectroscopic redshifts

0 < z < 0.5

Observer Main Sequence

Support Branch

Joe Liske Giant

Gold observers

MG members

Team members

Non members
How do these galaxies form and evolve?
How do galaxies form and evolve?
Evolutionary Mechanisms

collapse & merging

gas accretion

secular evolution
Survey Data

Galaxy Modelling

Global Trends with Wavelength

Morphological Classification

The Local Galaxy Luminosity/Mass Function

Bulge-Disk
Sérsic Profile

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

- \( n = 0.5 \)
- \( n = 1.0 \)
- \( n = 2.0 \)
- \( n = 4.0 \)
- \( n = 8.0 \)

\( \mu_e = 20 \)

Models many different galaxy profile shapes
Sérsic Profile

The Sérsic profile is a mathematical function used to model the surface brightness profiles of galaxies. It is given by the equation:

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

where:
- \( I(r) \) is the surface brightness at radius \( r \)
- \( I_e \) is the surface brightness at the effective radius \( r_e \)
- \( n \) is the Sérsic index, which determines the shape of the profile
- \( b_n \) is a parameter related to the Sérsic index

The Sérsic profile models many different galaxy profile shapes, including stars, disks, and spheroids. The parameter \( n \) controls the shape; higher values of \( n \) result in more round profiles, while lower values give more disk-like profiles. The effective radius \( r_e \) is a measure of the size of the galaxy. The figure shows how the profile changes with different values of \( n \), from 0.5 to 8.0.

José Luis Sérsic developed this model, which is widely used in astrophysics to describe the light distribution of galaxies.
Sérsic Modelling

\[ I(r) = I_e \exp \left[ -b_n \left( \left( \frac{r}{r_e} \right)^{1/n} - 1 \right) \right] \]
SIGMA
Structural Investigation of Galaxies via Model Analysis

Imaging & Pointing Data
400" x 400" cutout
Star identification
Empirical PSF
Galaxy detection
Sérsic modelling
Model self-check
Value added results

Model Fit Parameters

SExtractor
PSFEx
GALFIT3
Bertin+ 1996
Bertin 2011
Peng+ 2010
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Achtung! The model does not always accurately represent the underlying image!
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

Early

ASGR
LSK SPD

Single

SPD ASGR
LSK

Barred

LSK
SPD
ASGR

Late

ASGR
LSK SPD

Multi

SPD ASGR
LSK

Unbarred

SPD
LSK
ASGR
Visual Classification

Early
- Stars: 1056 (27%)
  - Single: 560 (14%)
    - Elliptical: 560 (14%)
  - Multi: 496 (13%)
- Late
  - LBS: 318 (8%)
  - Multi: 802 (20%)
  - Single: 1755 (44%)

Unbarred
- Barred: 703 (18%)
- SB0a: 53 (1.3%)
- S0a: 443 (11%)

Barred
- Barred: 99 (2.5%)
- Sbc: 703 (18%)

SBbcd
- Pure Disk: 1755 (44%)

Sd
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

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Elliptical: G346888

M02: De Vaucouleurs bulge + exponential disk

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Elliptical: G346888

M03: Sérsic bulge + exponential disk

1D Measure

- m = 16.96 (Comp. #1)
- r_e = 1.00''
- n = 2.85
- e = 0.09
- θ = -4.4°
- f = 0.58

- m = 17.27 (Comp. #2)
- r_e = 6.82''
- n = 1.00
- e = 0.18
- θ = 53.8°
- f = 0.42

μ / mag arcsec^2

k = 13
P: X^2/ν = 1.58
G: X^2/ν = 1.04

Δμ

Radius / arcsec

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S0a: G417433

M01: Single-Sérsic

1D Measure
- Image: m = 16.26
- Model: r_e = 3.96″
- n = 1.47
- e = 0.79
- θ = 37.6°

m_e = 16.26

k = 7
P: X^2/ν = 2.56
G: X^2/ν = 1.01

μ (mag arcsec^-2) vs. Radius / arcsec

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S0a: G417433

M02: De Vaucouleurs bulge + exponential disk

1D Measure

- \( m = 17.56 \)
- \( r_e = 1.91'' \)
- \( n = 4.00 \)
- \( e = 0.02 \)
- \( \theta = 71.5^\circ \)
- \( f = 0.30 \)

- \( m = 16.59 \)
- \( r_e = 4.79'' \)
- \( n = 1.00 \)
- \( e = 0.86 \)
- \( \theta = 37.5^\circ \)
- \( f = 0.70 \)

- \( m_a = 16.21 \)

Comp. #1

Comp. #2

\( k = 12 \)

\( P: X^2/\nu = 0.98 \)

\( G: X^2/\nu = 0.91 \)
S0a: G417433

M03: Sérnel bulge + exponential disk

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S0a: G417433

M04: Sérsic bulge + Sérsic disk

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SBbc: G517070

M01: Single-Sérsic

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SBbc: G517070

M02: De Vaucouleurs bulge + exponential disk
SBbc: G517070

M03: Sérsic bulge + exponential disk
SBbc: G517070

M04: Sérsic bulge + Sérsic disk

1D Measure
- Image
- Model

Comp. #1
- m = 19.05
- r_e = 0.78''
- n = 3.13
- e = 0.29
- θ = 67.2°
- f = 0.07
- m_+ = 16.10

Comp. #2
- m = 16.17
- r_e = 6.12''
- n = 0.51
- e = 0.29
- θ = 13.5°
- f = 0.93

G: X^2/ν = 0.93
P: X^2/ν = 1.23
k = 14

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Model Choice

How do we select the 'best' model?
Model Choice

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

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How do we select the 'best' model?

Bayesian Information Criterion:

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

Use visual classifications as a guide:

- E/Sd
  - Single-Sérsic
- S0a/Sbc
  - Multi Component
  - Lowest BIC

- x²: total goodness of fit
- k: number of free parameters
- n: number of contributing pixels
Structural Results

Sérsic Index

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Structural Results

Half-Light Radius

![Histograms showing the distribution of half-light radii for different galaxy types.](image)
Early/Late Type Bulges

Kormendy Relation

Global Measurements vs. Component Measurements

 absoloute average effective surface brightness

 $r_e / \text{kpc}$
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

Binggeli et al., 1988

\[ \phi(L) dL = \phi^* \left( \frac{L}{L^*} \right)^\alpha \exp \left( -\frac{L}{L^*} \right) d\left( \frac{L}{L^*} \right) \]
Sérsic Luminosity Functions

Single-Schechter
Sérsic Luminosity Functions

Double-Schechter Test, e.g.:
quenching of SF in galaxies

(Baldry et al., 2012)
Sérsic LF by Structure

\[ (M^*, \alpha_1, \phi^*/10^{-3}, \alpha_2, \phi^*/10^{-3}) \]

- (20.98, -1.21, 3.56, 0.05, 3.89) All

- (20.13, -0.46, 6.50) Spheroid

- (20.67, -1.05, 5.69) Disk

\[ \phi (Mpc^{-3} \text{ mag}^{-1}) \]

Absolute \( r \)-band Sérsic Magnitude

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Sérsic LF by Structure
Structural Mass Function

(log $M^*$, $\alpha_1$, $\phi^*/10^{-3}$, $\alpha_2$, $\phi^*/10^{-3}$)

(10.55, -0.23, 4.88, -1.43, 1.07) All

(log $M^*$, $\alpha$, $\phi^*/10^{-3}$)

(10.92, -0.80, 0.94) Elliptical

(9.91, 0.65, 2.59) Classical Bulge

(9.88, -0.78, 1.98) Pseudo Bulge

(10.70, -1.22, 2.03) Disk

$\phi$ (Mpc$^{-3}$ dex$^{-1}$)

8 9 10 11

log (Stellar Mass)
Stellar Mass Breakdown

Mass in the local Universe:
Hierarchical merging ~45.8%
Gas accretion ~47.7%
Secular evolution ~6.5%

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Stellar Mass Breakdown

Mass in the local Universe:
Hierarchical merging ~45.8%
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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-λ 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?

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Ellipticals dominate at high-mass, disks at low-mass
Late-type bulges share more in common with disks than early-type bulges