The Millennium Galaxy Catalogue: Bimodality, Dust and SMBHs

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1. Structural galaxy catalogues are here and more data coming (VST, VISTA)
   - The MGC = 10,095 galaxies with B/D decomposition

2. Two examples of breakthrough science from large scale galaxy structure (MGC)
   - Dust & disc opacity --> Cosmic dust & stellar mass densities
   - SMBH mass function --> Cosmic BH mass density

3. Galaxy bimodality
   - two components not two types
   - routine bulge-disc decomposition essential
   - optical to complex ==> near-IR (VISTA)

4. A blueprint for galaxy formation and evolution?
Limitations of SDSS & 2MASS

- Each has over 300 publications and each represents a remarkable advance in galaxy catalogues = remarkable achievements.
- But:
  - Shallow = missing galaxies and missing flux?
  - Low resolution images = unresolved/poorly resolved?
  - Circular photometry = muddles inclination information
  - Low completeness redshift coverage = biased?
- Why is structure important?
  - Galaxies are fundamentally multiple component systems, to decipher galaxy evolution we need to be able to disentangle these components: nuclei, bulges, pseudo-bulges, discs, (bars, rings, … etc)
- Still much left to be done at z=0
  - Mass function only known over 1/3 of range
The galaxy luminosity function at z=0

One third of the way there!

Space density of galaxies -->

Absolute magnitude --->

SDSS (Blanton et al 2005, estimated via extrapolation)
MGC (Driver et al 2005, data incomplete $M_B > -16$)
LSI (Karachentsev et al 2004, data incomplete $M_B > -16$)
Halo mass function
Best semi analytic model
Empirical fit

Current consensus
Proposed GAMA limit

✓
?
???
The MGC Team

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http://www.eso.org/~jliske/mgc/

INT WFC: 37 sq deg to B=26mag/s arcsec
~1 million galaxies

SDSS DR4: ugriz to B~25mag/sq arcsec

AAT 2dF: 10k zs to B=20 mag (96%)

GEMINI: zs for extreme-LSBGs (30%)

15 science papers in print/under review
MGC Bulge/disc decomposition

- 96% redshift completeness (AAT/GEMINI) to B=20.0 mag, Driver et al (2005)
- B(INT) + ugriz(SDSS) + zYJHK(UKIRT) imaging now complete.
- All data available from Friday 18th August online: http://www.eso.org/~jliske/mgc/
The Component Luminosity Functions


Stars = 11% $\Omega_b$
Bulges = 41%
Discs = 59%

DUST ATTENUATION?
Structure: Dust and SMBHs

1. Dust (Driver et al 2006)
   - By using inclination information we can derive mean disc opacity
   - Derive M* in 1-cos(i) intervals
   - Plot M* v 1-cos(i)
   - Fit attenuation-inclination with a dust model ==> OPACITY
   - Dust mass to light ratio + luminosity density ==> DUST DENSITY

2. SMBH Mass Function (Graham et al 2006)
   - Use bulge Sersic index Black Hole mass relation (Graham & Driver 2006)
   - Derive early and late=type SMBH mass function
   - Integrate to get ==> BLACK HOLE MASS DENSITY
Empirical dust attenuation in $B$

(a) Discs ($B/T < 0.5$)

(b) Bulges ($B/T < 0.5$)

DISCS

BULGES

Face-on extinction
Dust modelling

- We fit the Tuffs and Popescu dust model and derive: \( \tau_B = 3.8 \pm 0.7 \)
  
  \((\text{Popescu et al 2000; Tuffs et al 2004; Popescu et al 2005; Mollenhoff et al 2006})\)

- Model based on UV+ugrizJHK+Spitzer data of 6 nearby galaxies

- One free parameter = core dust density

- Face-on attenuation correction in \( B \): Discs = 0.20 mag; Bulges = 0.84 mag

- Total attenuation in \( B \): Discs = 0.2 - 1.1 mag; Bulges = 0.8 - 3.4 mag !!!

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**Diagram Details**

- **disk (B-band)**
  - \( \tau = 1 \)
  - \( \tau = 2 \)
  - \( \tau = 4 \)

- **Empirical Inclination dependent attenuation**
  - Derived face-on attenuation

- **M**
  - (DISC)
  - **magnitude**
  - **1 - \( \cos(i) \)**

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Dust corrected LFs!

- Bulge LD up 100%; Disc LD up 40%
- Bulge mass up 150%; Disc mass up 50%
- Similar results derived from scaling up face-on LFs + offsets

Can derive dust and stellar mass densities from
SMBH mass function

- Use Sersic index BH relation (Graham & Driver 2006) to predict BH masses (see Graham et al 2006):

- SMBH density = $5.1 \times 10^5 \, h^5 M.Mpc^{-3}$
Bimodality now seen in the Colour Sersic-index plane (Driver et al. 2006)

\[(u-r) - \log(n)\]


Bimodality in $(u-r)-\log(n)$

BLUE DIFFUSE

Bridging Pop'n ?

RED COMPACT

<- Number density
Stellar mass density ->

\[
\begin{array}{c}
\text{Number density} \\
\text{Stellar mass density}
\end{array}
\]
Two populations or two components?

- E/S0s
  - Bulge system
- Sabc
  - Bulge+Disks
- Sd/Irr
  - Disk systems

El (Old)
- Sa (Interm.)
- Sc (Young)
Two populations or two components?


Sabc (Sersic only fits)

No bridging population

Sabc (Bulge+Disk)

Exponential discs

Truncated discs

Bulges

BULGEBULGE

DISKBULGE

DECOMP'DECOMP'

No bridging
depopulation

Exponential discs

Truncated discs

Bulges
Two populations or two components?


Exponential discs
Truncated discs
Bulges

No bridging population

All (Sersic only fits)
All (Bulge+Disk)
Galaxy types vs components?

(z > 0.1)
- E/S0s (red)
- Sabc (red&blue)
- Sd/Irrs (blue)

(z < 0.1)
- Spheroids & Bulges
- Discs

Graphs showing distribution of galaxy components.
2 DISTINCT FORMATION MECHANISMS AND ERAs?

Collapse or rapid mergers?

Infall/splashack?

SFR

z = 1---2.5

z > 2

AGN
Summary

- Disks & bulges occupy distinct regions in the colour-structure plane
- Must entertain notion of bi(tri)-modal galaxy formation scenario?
  - Bulk of dark matter halo assembly at high-z (rapid) ???
  - Bulge formation via collapse of baryons + residual mergers (Bulge/AGN/SMBH trinity) $z > 2$ (Low mass blue spheroids suggest downsizing of bulge formation) ?
  - Disk formation through later splashback, accretion & infall ? (truncated disks still growing I.e., inside out formation) ???
- Must abandon HTF/global approach and routinely dismantle galaxies into their key components (bulges and discs)
- 20% of baryons in stars (almost half emergent B flux attenuated)
- 50% of stars in bulges 50% in discs
- Dust attenuation in B a big issue (bulges heavily attenuated)
  disks $0.2-1.1$ mag, bulges: $0.8 - 3.4$ mag ! $\tau_B \sim 3.8 \pm 0.7$
- Switch to near/far-IR now essential to overcome dust issues: GAMA
Galaxy And Matter Assembly

- 300 sq deg ugrizJHK sub-arcsec deep imaging and spectroscopic survey
- St Andrews (Driver), Edinburgh (Peacock), LJMU (Baldry), ESO (Liske)
- 4 tests of CDM structure plus generic galaxy resource on scale of SDSS
- Zero redshift benchmark for JWST (launch 2013)
Observe strong colour \((u-r)\) and structural \((\log n)\) bimodalities (Strateva et al 2001; Baldry et al 2004; Driver et al 2006)

OBSERVED DISTRIBUTIONS \((M_B < -16)\)
Observe strong colour \((u-r)\) and structural \((\log n)\) bimodalities (Strateva et al 2001; Baldry et al 2004; Driver et al 2006)

**VOLUME CORRECTED (NUMBER DENSITY)**

**Galaxy Bimodality**

- **RED**
- **BLUE**
- **COMPACT**
- **DIFFUSE**

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

\[
(u-r)_c \text{ (mag)}
\]

\[
\log(n)
\]
Observe strong colour \((u-r)\) and structural \((\log n)\) bimodalities (Strateva et al. 2001; Baldry et al. 2004; Driver et al. 2006)

**VOLUME CORRECTED (MASS DENSITY)**

**Galaxy Bimodality**

**Red**

**Blue**

**Compact**

**Diffuse**