Galaxy and Mass Assembly: Pitfalls and Progress

Simon Driver and the MGC & GAMA teams
University of St Andrews + Many

- 10 reasons why we’re struggling...
- Highlighting the issue of dust attenuation
- GAMA (going beyond SDSS, in progress)
10 reasons why we’re struggling

1. Global v component measurements?
2. The hierarchy of components?
3. Photometry (flux, size & component bias)
4. Incomplete sampling (dwarf pops, LSBGs)
5. Cosmic variance (dominates HDF etc)
6. SFH v stellar mas density (incompatible)
7. Photo-z v spectro-z (no substitute)
8. Wavelength bias (UV/opt./far-IR/radio divide)
9. Dust attenuation (1-3 mags in B !)
10. Disconnect with hierarchical-CDM
1. Global v component measures

- Bimodality, what does it mean?

![Graph showing bimodality in galaxies from MGC](image)
1. Global v component measures

(Driver et al. 2005)

(Allen et al. 2006)
Bulge formation
Dynamically hot phase
Rapid Collapse/merger
AGN/SMBH formation
QSO activity $z > 2$

Disc growth
Dynamical cool
Accretion &
Secular evolution
Star-form’ History $z < 2$
The cosmic star-formation history

- Bulge Formation
- Disc Growth
- Secular
- AGN Activity
- Look back TIME →

Hopkins & Beacom (2006)
THE HUBBLE DEEP FIELD CORE SAMPLE ($I < 26.0$)

$z$

0.19
0.44
0.54
0.64
0.74
0.87
0.97
1.03
1.14
1.24
1.41
1.61
1.76
2.05
2.57
3.59

Age ($z < 0.2$)

77%
58%
52%
48%
44%
39%
36%
35%
32%
30%
27%
24%
22%
19%
15%
10%

Simon Driver & Alberto Fernandez-Soto (UNSW)
I. Global v component measures

Spatial resolution crucial:

Ground-based limit: \( z < 0.15 \)

Space-based limit: None

Current space-based samples prone to Cosmic Variance & other issues, need space-based survey telescope: Euclid

(Kelvin et al, in prep)
2. The hierarchy of components?

What physical process is each linked to?

HOT?

COLD?
2. The hierarchy of components?

GALAXY

NUCLEUS
Core depletion
SMBH/CMC
Hot accretion

BULGE
Boxiness
Triaxiality
Collapse

P-BULGE
Bar
Secular

DISC
Truncation
Thick/Thin
Cold Accretion

What physical process is each linked too?
2. The hierarchy of components?

What physical process is each linked too?
2. The dark art of profiling...

(Cameron et al 2009)
3. Photometric bias

- Many systems in use:
  - Isophotally corrected: APM(2dFGRS)
  - Petrosian (circular): SDSS, UKIDSS
  - Kron (elliptical): MGC
  - Model (de Vauc v exponential): SDSS
  - Fitted Sersic: GAMA

- Suitable for multi-component systems?
  - Detection of disc dependent on bulge?

- Above only robust if Re,α above isophote
  - Missing discs in 2MASS/UKIDSS
  - Bias against LSBGs and HSBGs (i.e., dwarfs)
  - At high-z bias towards faint compact systems

- Detection AND Measurement bias
3. Photometric bias: Detection

(Cameron & Driver 2009)
3. Photometric bias: Measurement

(Cameron & Driver 2009)
3. Photometric bias: Systematic

(Cameron & Driver 2009)
3. Photometric bias: with redshift

(Cameron & Driver 2009)
4. Sample incompleteness
4. Sample incompleteness: BBD
4. Sample incompleteness: BBD

![Galaxy Samples Graph](image_url)
4. Sample incompleteness: LF
5. Cosmic variance

Distribution of L* galaxies to $z<0.1$ over 5000 sq deg
For 1 sq deg
Cosmic Var.
30% @ z=0.5
10% @ z=2.0

Reduces by root-n for n independent pointings.
More slowly for contiguous areas

(Driver 2009)
6. Photo-z versus spectro-z
6. Photo-z versus spectro-z
6. Phot-z v spectro-z: HDF analysis

(Cameron & Driver 2007)
Cosmic SFH + Univ. IMF = Cosmic SED

x2 discrepancy in stellar mass

Variable IMF
Incorrect SFH
Hidden SF at low-z

(Data: Hill et al submitted; Model: Wilkins et al, in prep)
7. SFH vs Stellar mass density
7. SFH v Stellar mass density
8. Wavelength bias
9. Dust attenuation
10. Disconnect with CDM

- Ben Moore’s talk?

- Dark Matter
  - Numerical galaxy
  - Observed galaxy

- Light
Dust: Recent (optical) papers

- Shao et al (2007)
- Choi et al (2007)
- Graham & Worthy (2008)
- Balin & Harris (2008)
- Unterborn & Ryden (2008)
- Padilla & Strauss (2008)
- Cho & Park (2009)
- Maller et al (2009)
- Ganda et al (2009)
- Masters et al (2009)
Dust: The MGC

- 36 sq deg equatorial strip
- B band only 1” + SDSS ugriz + UKIDSS YJHK
- 10,092 galaxies with B < 20 (resolved)
- 98% redshift complete (SDSS+AAT)
Dust: Bulge disc decompositions

- 10,092 galaxies via GIM2D (Allen et al 06)
- Verified via 1000 repeat observations
- Only resolved bulges used
Dust: \( L_F \propto \cos(i) \)

(Driver et al 2007)
Dust: cos(i) before and after

(Bulges $B_{MGC} < 18.5$ mag)

- After correction
- Before correction

(Discs $B_{MGC} < 19.0$ mag)

- After correction
- Before correction

(Driver et al 2007)
Dust: Bulge and disc attenuation

(Driver et al 2007)
Dust transformation?

1. Mid-type spiral falling into cluster (cos(i)=0.5):
   B=0.2, D=0.8, B/T=0.2, L=1.0, Blue
   Sc   (NB: cos(i)=0.0=Sa, cos(i)=1=Sd)

2. *destroy dust* (heating):
   B=0.6, D=1.2, B/T=0.3, L=1.8 Green
   Sab

3. Truncate star-formation in disc (stripping):
   B=0.6, D=0.8, B/T=0.4, L=1.4, Red
   Sa/S0

4. Further fading and harassment etc:
   B=0.6, D=0.6, B/T=0.5, L=1.2, Red
   S0a

5. Transformation from Sc-S0a purely by removing dust and switching off SF! it gets *earlier, redder* and *brighter* without dry mergers!
Dust: Impact on bulge & disc LF

(Driver et al 2007)
Dust: Impact on global LF

\[ \log \phi(h_{0.7}^3 \text{ Mpc}^{-3} [0.5\text{mag}]^{-1}) \]

-5 \log_{10} h_{0.7} \text{ (mag)}

-2

-6

-1.4

-21.5

-21

-20.5

-1

\( M_B \)

\( \alpha \)

-1.2

-1.4

(Driver et al 2008)
Dust: Wavelength dependence

(Driver et al 2008)
Dust: Mean photon escape fraction

(Driver et al 2008)
Dust: Balancing the energy budget

(Driver et al 2008)
Galaxy and Mass Assembly (GAMA)
GAMA: Science goals

- Generic galaxy database (150/500k systems)
- Halo Mass Function
- Stellar Mass Function
- Baryonic Mass Function
- Bulge-disc decomp to \( z < 0.1 \) (30k)
- Star-formation rates via UV, \( H_\alpha \), Far-IR
- All above versus environment, galaxy type, galaxy mass, and redshift (\( z < 0.5 \))
NGC891+weak AGN at z=0.1, 0.25, 0.5, 1.0
GAMA 48 sq deg, 1120z/sq deg
CFHTLS 9.3 sq deg
CFHTLS 5 sq deg

GAMA Spatial Resolution

GAMA Sensitivity
All (~250k):
General: GAMA ID : SDSS ID : z (heliocentric) : z quality
Flux: UV : optical : near-IR : mid-IR : far-IR : radio (20,rest-21,30,40,90cm)
Shape: CAS : Sersic index: half-light radii : b/a : PA in ugrizYJHK
Opacity: $\tau_{UV,ugriz,YJHK}$
Spectral features: Emission: H$\alpha$,H$\beta$,H$\gamma$,H$\delta$,OII,OIII,NII
Abs.: Dn4000,Ca4227,H$\alpha$,H$\beta$,H$\gamma$,H$\delta$,Mgb,Fe
SFR: UV : H$\alpha$ : far-IR : radio continuum
Fossil record: Age : SFH : element abundance
AGN: BPT diagnostics : type : strength : ionisation state
Dynamics: $\sigma_{spec}$ (GANDALF) : $W_{21}$ : HI line profile
Distances: Tully-Fisher : Faber-Jackson
Environment/Halo: Local density : group membership : group halo mass

GAMA spectrum, z=0.11
GANDALF Best Fit, $\sigma$=151km/s
GANDALF Emission lines (offset)
Residual
For $z<0.1$ ($\sim 30k$):

**Structural:** Bulge/Bar/Disc decomps. in $ugrizYJHK$ (GALFIT3)
- **Bulge:** Sersic index, half light radius, PA, ellipticity
- **Bar:** Sersic index, half light radius, scale-length
- **Disc:** Scalelength, PA, $b/a$

**SMBH Mass:** via $M-\sigma$, $M-L$, $M-n$ relations
GAMA Survey regions
GAMA Redshift Survey

• Aims to be 99% complete down to:
  • $r < 19.4$ (G09 / G15), 19.8 (G12)
  • $K_{AB} < 17.6$ (All)
  • $z < 18.2$ (All)

• High fidelity redshifts will be our first data product (100k so far)

• Full SWARPed images in ugrizYJHK (20GB per image) + GALEX
  • Common: gain/ zero point/ res (0.4” per pix).
  • Co-addition weight-maps also produced.

• Standalone SExtracted catalogues in each band.
• Aperture matched catalogues using $r$ and $K$ defined apertures.
AAT RESPONSIBLE FOR 35% OF ALL KNOWN REDSHIFTS
GAMA coverage to date

GAMA 09  GAMA12  GAMA15

Redshifts

SDSS

UKIDSS

GALEX

23 more nights next year to complete Equatorial regions
4. Sample incompleteness: LF
GAMA: $r$ band LF v SDSS

- G09 ($r < 19.4$)
- G12 ($r < 19.4$)
- G15 ($r < 19.4$)
- G12 ($r < 19.8$)
- G09+G12+G15 ($r < 19.4$)
- Fit ($M = -20.64$, $\alpha = -1.19$)
- SDSS (Blanton et al 2005)
GAMA: r band LF v SDSS
GAMA: r band LF v SDSS
GAMA: Stellar mass function

Required star-formation Efficiency:
GAMA: Halo Mass Function
GAMA: Group finding progress
Identified FoF Groups:
550 in G09
180 in SV
Robotham et al, in prep

Median velocity disp: 260 km/s
Quartiles: 511-123 km/s
GAMA: Cosmic variance

\[ \phi(M_{\pm0.5}) \, d(0.5 M) \] (diff.)

\[ \phi(M_{\pm0.5}) \, d(0.5 M) \] (cum. mm.)

Redshift

\( 0 \rightarrow 0.25 \)

\( 0.001 \rightarrow 0.01 \)
GAMA: SIGMA-GAMA

GAMA-SIGMA

The SIGMA code pieces together several widely used astronomical packages including the SWarp mosaicing tool (Bertin et al. 2002), the HEASARC package CFITSIO, Source Extractor (Bertin & Arnouts, 1996) and the IRAF STSDAS Ellipse routine. Beta versions of PSF Extractor (E. Bertin) and GALFIT 3.0 (C. Peng) are also used, and several self-made tools (bar detection; 1D Analysis) are utilised. SIGMA is built on the programming and scripting language R.

SDSS
UKIDSS

VST
VISTA

Zero Point Normalisation
Gain Correction
Sky Estimation & Subtraction

SWarp Mosaics
Detection & Selection
CFITSIO imcopy
Source Extractor

PSF Extractor
GALFIT 3.0
Model Analysis

IRAF Ellipse
1D Analysis

Model Choice

Galaxy Components
Case Study- G550582

FUV | NUV | u | g
---|---|---|---

r | i | z | Y

J | H | K
**Summary**

- **Multiple component systems (Bulge+disc+?):**
  - Implies two or more evolutionary modes?
  - How useful are global measurements (colour, SFR etc)?

- **Multi-constituent systems (Gas, stars, dust):**
  - Multi-wavelength approach essential

- **Severe biases in most datasets (including mine!):**
  - Photometry (Detection AND Measurement bias), bias towards faint compact systems
  - Cosmic variance: 10% at $10^6$Mpc$^3$
  - $e$, $k$ and now $d$-corrections (even in near-IR)

- **GAMA:**
  - Aiming for 500k galaxies over 500 sq deg (Herschel-Atlas Eq. & SGP regions)
  - Study of structure on 1kpc to 1Mpc scales to $z < 0.5$
  - Measurement of Halo Mass Function to $10^6 M_\odot$
  - Constrain feedback via HMF, BMF, and SMF
  - Direct measurement of galaxy merger rate via close pairs and asymmetry
  - Group finding completed in one 30 sq deg region (G09) to $z=0.5$
  - Total SED modeling (UV to far-IR)
  - Bulge-disc-bar decomposition for ~30k systems
  - First data release Dec 2009
  - High priority target regions for: GALEX, Herschel, VISTA, VST, GMRT, ASKAP, [X-Ray?]