Is structure the key to unlocking galaxy formation?

CDM Numerical models
CDM+Semi-analytics
Non-cosmo num. mod.
HR diagrams
G. Archaeology
Integrated spectra
Kinematics (SAURON)

NGC4565
The Millennium Galaxy Catalogue

UKIRT/LAS  8 nights

SDSS

INT/WFC  14 nights

AAT/AAΩ  15 nights + 2dFGRS

GEMINI/GMOS  3 nights

Near-IR (JHK)  

ugriz+z’s

B, morph
B/D decomp

z, spectra

z, LSBGs

MGC

STINGZ, LSBG

Z, LSBGS

SCIENCE

TNG  4 nights

NTT  3 nights

2.3m ANU  12 nights

INT/WFC
Galaxy bimodality

- BLUE DIFFUSE
- Bridging Pop’n ?
- RED COMPACT

<- Number density
Stellar mass density ->
Two populations or two components?

E/S0s
Spheroidal systems

Sabc
Bulge+Disks

Sd/Irr
Disk systems
GIM2D bulge/disc decompositions

- 96% redshift completeness (AAT/GEMINI) to B=20.0 mag, Driver et al (2005)
- B(INT) + ugriz(SDSS) + YJHK(UKIRT) imaging now 100% complete.
- All data available online: http://www.eso.org/~jliske/mgc/
Two pop’s or two components?

- Sersic only fits
- Bridging population
- DISK
- DECOMP’

- Exponential discs
- Blue

- Truncated discs
- Blue

- Spheroids
- Blue (pBulges?)

- Red

- Bulge+disc fits
- No bridging population

- ALL

- (u-r)_c (mag)

- log(n)

- (u-r)_c (mag)
Two distinct modes of evolution?

Structure more fundamental than colour.

COLD MODE

HOT MODE

z = >2

BULGE SMBHs AGN?

Fan et al

z = 1---2.5

SFR

SFRD/(M_☉ yr^-1 Mpc^-3)

log(M_☉):

9.0 - 10.2

10.2 - 10.8

10.8 - 11.5

redshift
The Component Luminosity Functions


DUST?

RED SPHEROIDS (Classical)
BLUE SPHEROIDS (pBulges+BEs ?)

DISCS (Exp. + Trunc)
Decomps unreliable

By mass:
E = 13% => HOT
rB = 26% => HOT
D = 58% => COLD
pB+BS = 3% => Secular+

Component LFs vs $\cos(i)$

NEARLY FACE-ON GALAXIES

Bulges  $0.1 < 1 - \cos(i) < 0.2$
Discs

REFERENCE LINE

$0.1 < 1 - \cos(i) < 0.2$

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

\[ M_r - 5 \log h \text{ (mag)} \]
Component LFs $v$ cos$(i)$

**Bulges** $0.2 < 1 - \cos(i) < 0.3$

**Discs**

![Graphs showing the distribution of galaxy components as a function of luminosity.](image-url)
Component LFs vs $\cos(i)$

Bulges $0.3 < 1 - \cos(i) < 0.4$

Discs

Graphs showing the distribution of luminosity functions for Bulges and Discs, with $\log \phi (h^{-1} \text{Mpc}^{-3} \text{mag}^{-1})$ vs $M_{r} - 5 \log h$ (mag) for $0.3 < 1 - \cos(i) < 0.4$. The graphs illustrate the variation in luminosity with inclination.
Component LFs v cos(i)

Bulges \[0.4 < 1 - \cos(i) < 0.5\] Discs
Component LFs $\nu \cos(i)$

Bulges $0.5 < 1 - \cos(i) < 0.6$  
Discs
Component LFs vs $\cos(i)$

Bulges: $0.6 < 1 - \cos(i) < 0.6$

Discs: $0.6 < 1 - \cos(i) < 0.7$

Graphs showing the log of the number density vs $M_{\text{host}} - 5 \log h$ for different ranges of $\cos(i)$.
Component LFs $\propto \cos(i)$

Bulges $0.7 < 1-\cos(i) < 0.8$  
Discs

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

$log \phi[h^3 Mpc^{-3} (0.5\text{mag})^{-1}]$
Component LFs v cos(i)

Bulges  $0.8 < 1 - \cos(i) < 0.9$  Discs
Component LFs vs $\cos(i)$

Bulges $0.9 < 1 - \cos(i) < 1.0$ Discs

\begin{align*}
\log \phi^{\text{h}^3 \text{Mpc}^{-3} (0.5\text{mag})^{-1}} & \\
\text{vs} \ M_v - 5\log h \text{ (mag)} & \\
\end{align*}
Empirical dust attenuation

BULGES SEVERELY ATTENUATED IN INCLINED SYSTEMS UP TO 2 MAG EX. FACE-ON CORRECTION!

Multiple component dust model required

Dust model previously calibrated to multi-\(\lambda\) NGC891
Leaving one free parameter (the face on central opacity)

disk (B-band)

- two dust-disk model; \(\tau = 3.8\)
- one dust-disk model; \(\tau = 1.0\)

Tuffs & Popescu model

\(\tau = 1\) model
(I.e., conventional wisdom)
Tuffs & Popescu 3 component dust model implies that discs are on average optically thick in the centres (τ=3.8) and predicts bulge trend.
Impact on global B band LF

I.E., ONLY 48% OF B-BAND PHOTONS ESCAPE INTO THE IGM

The Galaxy LF

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

\[
M_{B_{\text{mag}}} = \log_{10} h \ (\text{mag})
\]

- Ignoring dust
- Incl–only dust corr.
- Full dust corr.

0.8 mag
Photon escape fraction averaged over entire nearby galaxy population

Define a canonical galaxy in B, modify its B/T according to colours, integrate over cos(i)
The baryon budget: stars, dust & SMBHs

Big Bang

Dark Energy 72%

Dark Matter 24%

Normal Matter 4%

Gas 91.7%

Supermassive Black Holes 0.01%

Stars 8.3%

Stars in Discs 60%

Stars in Bulges 27%

Stars in Ellipticals 10%

Stars in Blue Spheroids 3%

Dust 0.008%
Component Stellar Mass Functions

The Stellar Mass Function (Components)

Log(Space density) vs. Log(Stellar Mass)

- DISCS
- SPHEROIDS
- Bulges and Ellipticals different
- Bulges and Ellipticals the same
- pBULGES/BS
The Stellar Mass Function (Components)

**DISCS**

**BULGES**

**ELLIPticals**

**pBULGES/BS**

The Same!

Except
Hubble type transformation ?!

1. MID-TYPE SPIRAL FALLING INTO CLUSTER (COS I=0.5):
   \[ B=0.2, \ D=0.8, \ B/T=0.2, \ L=1.0, \ \text{BLUE} \]
   SC  (NB: COS(I)=0.0=SA, COS(I)=1=SD)

2. DESTROY DUST (HEATING):
   \[ B=0.6, \ D=1.2, \ B/T=0.3, \ L=1.8 \ \text{GREEN} \]
   SAB

3. TRUNCATE STAR-FORMATION IN DISC (STRIPPING):
   \[ B=0.6, \ D=0.8, \ B/T=0.4, \ L=1.4, \ \text{RED} \]
   SA/S0

4. FURTHER FADING AND HARASSMENT ETC:
   \[ B=0.6, \ D=0.6, \ B/T=0.5, \ L=1.2, \ \text{RED} \]
   S0A

5. TRANSFORMATION FROM SC-S0 PURELY BY REMOVING DUST AND SWITCHING OFF SF! IT GETS REDDER AND BRIGHTER WITHOUT DRY MERGERS!
PIVOT BULGE & DISC SPECTRA BY ADJUSTING AGES UNTIL SUM = TOTAL INTEGRATED SPECTRA.
Work in progress

Top heavy IMF or incompleteness in near-IR surveys ???
Need MGC/UKIDSS
Summary

- **BIMODALITY DUE TO TWO COMPONENT NATURE OF GALAXIES (D06)**
  - STRUCTURE MORE FUNDAMENTAL THAN COLOUR: STRUCTURE=TRACER OF FORMATION
    - FAST/HOT MODE (COLLAPSE/RAPID MERGER) > SPHEROIDS/AGN/SMBHS/HIGH-[α/Fe], Z > 2
    - SLOW/COLD MODE (ACCRETION[LUMPY]) > DISCS BUILT SLOWLY IN FIELD Z < 2-3
- **STELLAR MASS IN EACH COMPONENT: (D07 APJL)**
  - DISCS = 60% INFALL MODE (HALF EXPONENTIAL, HALF TRUNCATED?, TRUNC’D BLUER)
  - SPHEROIDS = 37% COLLAPSE/MERGER MODE (ELLIPTICALS 10%, BULGES 27%)
  - PBULGES < 2% SECULAR MODE (ALSO SEE BLUE SPHEROIDS AT SIMILAR LEVEL)
- **MEAN DISC DUST OPACITY HIGH, BULGES OBSCURED BY 0.8–2.5 MAGS ! (D07)**
  - HTF AN ENVIRONMENTAL EFFECT OF IGM & ICM ?
    - IGM ALLOWS DISC CONSTRUCTION VIA INFALL, DUST PRODUCTION OBSCURES BULGES
    - ICM SHUTS DOWN SF AND DESTROYS DUST DIMINISHING DISC AND UNVEILING BULGE
  - REMOVING DUST MAKES A GALAXY REDDER AND BRIGHTER (DRY MERGERS NOT NEEDED ?)
- **COSMIC ENERGY BUDGET: LOST STARLIGHT=FAR-IR DUST EMISSION (D08)**
A blueprint for galaxy formation?

8+ GYRS
DM ASSEMBLY VIA RAPID MERGING
- MAJOR MERGERS DESTROY DISCS SO MUST END BEFORE 8GYRS (COINCIDENT WITH SECOND INFLATION?)

10+ GYRS
SPHEROID FORMATION VIA (PREDOMINANTLY) RAPID COLLAPSE
- 37% OF STELLAR MASS (SECONDARY MODE)
- MEAN AGE OF SPHEROIDS 10-13GYRS = AGN PEAK
- ALPHA-ENHANCEMENT = SHORT BURST (AGN MODERATED)
- COLLAPSE INHIBITED DURING DM ASSEMBLY => DOWNSIZING

8 GYRS
DISC GROWTH VIA INFALL/SPLASHBACK
- 60% OF STELLAR MASS (DOMINANT MODE)
- COUPLED WITH FALLING SFR
- MEAN AGE OF DISCS 8GYRS

0-8 GYRS
PSEUDO-BULGE GROWTH & MORPHOLOGICAL TRANS’S
- AGES UNCHANGED (MATERIAL JUST SHUFFLED)

BUT WHAT IS THE VARIANCE, ENVIRONMENTAL & HALO MASS DEPENDENCIES, AND WHAT ABOUT THE NEUTRAL GAS AND PLASMA?

NEED BARYON (ENERGY) BREAKDOWN FOR EACH GALAXY -> CAMA
Galaxy And Matter Assembly

- COMPREHENSIVE
  - 250 SQ DEGREES (5X50 SQ DEG. CHUNKS), 250K GALAXIES (25X MGC)

- GENERAL SCIENCE:
  - A STUDY OF STRUCTURE ON 1KPC-1MPC SCALES, WHERE BARYON PHYSICS CRUCIAL

- SPECIFIC GOALS:
  - THE CDM HALO MASS FUNCTION FROM GROUP VELOCITY DISPERSIONS
  - THE STELLAR MASS FUNCTION INTO THE INTERMEDIATE MASS REGIME
  - BUILDING TOTAL SEDS FOR GALAXIES AND THEIR COMPONENTS AT Z < 0.5

- GOING MASSIVELY MULTI-WAVELENGTH:
  - UV (GALEX)
  - OPTICAL: UGRI (VST, SDSS), SPECTRA (AAT)
  - NEAR-IR: ZYJHK (VISTA, UKIRT)
  - FAR-IR (HERSCHEL), SUB-MM SCUBA-II
  - RADIO: 21CM (ASKAP)

- OVERCOME SECONDARY STRUCTURAL ISSUES:
  - NUCLEI-BULGE-BAR-DISC-DISC TRUNCATION DECOMPOSITIONS

- DISENTANGLE ENVIRONMENTAL DEPENDENCIES
### WORKING GROUPS/HEADS

<table>
<thead>
<tr>
<th>SCIENCE</th>
<th>CATS</th>
<th>DATABASE</th>
<th>OBS</th>
<th>MOCKS</th>
<th>RADIO</th>
<th>SPEC. PIPE.</th>
<th>IMAGE. PIPE.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peacock (ROE)</td>
<td>Baldry (LJMU)</td>
<td>Liske (ESO)</td>
<td>Driver (PI, St And)</td>
<td>Norberg (ROE)</td>
<td>Hopkins (USyd)</td>
<td>Loveday (Sussex)</td>
<td>Bamford (Nott.)</td>
</tr>
</tbody>
</table>

### TEAM MEMBERS

- Bridges (AAO)
- Bland-Haw’n (U.Syd)
- Cameron (St And)
- Conselice (Nott.)
- Couch (Swin.)
- Croom (U.Syd)
- Cross (Edin.)
- Frenk (Durham)
- Graham (Swin)
- Hill (StA)
- Edmonson (Ports)
- Jones (AAO)
- Kuijken (Leiden)
- Lahav (UCL)
- Nichol (Ports.)
- Oliver (Sussex)
- Parkinson (Edin.)
- Phillipps (Bristol)
- Popescu (UCLan)
- Eales (Cardiff)
- Ellis (USyd)
- Prescott (LJMU)
- Proctor (Swin.)
- Sharp (AAO)
- Staveley-Smith (UWA)
- Sutherland (Camb.)
- Tuffs (MPIK)
- van Kampen (Innsbruck)
- Warren (Imperial)
- Dunne (Nottingham)

### TEAM AFFILIATIONS:

- UKIRT/LAS, VST/KIDS, VISTA/VIKING, HERSCHEL-ATLAS, DURHAM ICC

### WEBSITE:

[http://www.eso.org/~jliske/gama/](http://www.eso.org/~jliske/gama/)
Galaxy And Mass Assembly

- UKIRT/LAS: 28 nights
- AAT/AAΩ: 165 nights
- HERSCHEL: 150hrs
- VISTA/VIKING: 60 nights
- VST/KIDS: 96 nights
- GALEX: (25hrs)
- ASKAP: 1 year

- GAMA
  - NEAR-IR: z, spectra
  - FAR-IR
  - FUV/NUV
  - OPTICAL
  - HI

SCIENCE
GAMA DEEP

SUBARU/WFMOS

ALMA

JWST

SKA

MGC

GAMA

GAMA DEEP

SCIENCE

220 hours
HI and continuum coverage via ASKAP

- GAMA DEPTH AND AREA WELL MATCHED TO THE PROPOSED ASKAP DEEP.

GAMA 12h region
50 sq deg (4 x 12.5 deg)
20% completed

Predicted ASKAP redshift dist (scaled) (Johnston et al., 2008)
NGC891 spectrum at z=0.1 with weak AGN added
<table>
<thead>
<tr>
<th>Facility</th>
<th>Wavelength</th>
<th>Time</th>
<th>Depth</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAMA: AAT/AAΩ Spectra</td>
<td>165nights</td>
<td>r &lt; 19.8, K=17.0 mag</td>
<td>in progress</td>
<td></td>
</tr>
<tr>
<td>GAMA: UKIRT LAS Near-IR (YJHK)</td>
<td>35nights</td>
<td>Y=20.9, J=20.6, H=20.3, K=20.1</td>
<td>Done.</td>
<td></td>
</tr>
<tr>
<td>GAMA: VISTA VIKING Near-IR (YJHK)</td>
<td>75nights</td>
<td>Z=23.1, Y=22.3, J=22.1, K=21.1</td>
<td>Mar 09</td>
<td></td>
</tr>
<tr>
<td>GAMA: VST VST Optical (ugriz)</td>
<td>120nights</td>
<td>u=24.8, g=25.4, r=25.2, i=24.2</td>
<td>09/10?</td>
<td></td>
</tr>
<tr>
<td>GAMA: HERSCHEL ATLAS Far-IR</td>
<td>200hrs</td>
<td>110,170,250,350,500 microns</td>
<td>Aug 09</td>
<td></td>
</tr>
<tr>
<td>GAMA: HERSCHEL ATLAS Far-IR</td>
<td>67, 94, 45, 62, 53 mJy</td>
<td>Aug 09</td>
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<td>Aug 09</td>
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<td>GAMA: GALEX MIS+prop pending UV</td>
<td>25hrs+25hrs</td>
<td>NUV/FUV</td>
<td>2013?</td>
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Current CONE plot (80k z’s)

GAMA
GAMA Deep
2dFGRS
MGC
### A blueprint for galaxy formation?

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**But what is the variance, environmental & halo mass dependencies, and what about the neutral gas and plasma?**

**Need Baryon (energy, breakdown for each galaxy => GAMA**
GAMA = FIVE
4X12.5 DEG
CHUNKS
STARTED
01/08/08
G09=20% DONE
G12=20% DONE
G15=10% DONE
GAMA (full sample, variable depth)

GAMA (sample complete to $r < 19.8$)

ASKAP (strawman) projection

2dFGRS ($b < 19.45$)
The GAMA Stellar Mass fn

- GAMA (simulated)
- Bell et al. 2003 table 5
- Baldry et al. 2006 fig. 8
- New analysis using NYU–VAGC
- Cole et al. 2001 fig. 18
- Jones et al. 2006 table 4
The Global luminosity distribution

GAMA r LF $z < 0.1$ only
1/5 th of final dataset

$\phi(h^3\text{ Mpc}^{-3}\text{ mag}^{-1})$

$M_{r_{\text{GAMA}}} - 5\log(h) \text{ (mag)}$

Fit ($M = -20.84$, $\alpha = -1.17$)
SDSS (Blanton et al. 2005)