Deconstructing Galaxies

Why we need surveys of galactic components

Jochen Liske
The cosmological framework

- Observations of the CMB, SNIa, large scale structure, weak lensing, D/H, BAO, abundance of clusters, etc, are all found to be consistent (to the level of accuracy so far probed) with one another and with $\Lambda$CDM.

➔ The cosmological background model is now known (±10%)!

- Although the model is incomplete (nature of DM, DE, quantum-gravity?) any changes/additions are unlikely to significantly affect our understanding of galaxy formation and evolution.

⇒ From the point of view of galaxy evolution cosmology is solved.
What is the origin of present-day structures and their diversity?
Gravitational instability and hierarchical build-up

Initial density perturbations grow through gravitational attraction.

Hierarchical merging of smaller structures to form larger ones.

Linear growth

Collapse = decoupling from Hubble expansion

Gas cools through brems and recombination radiation

Luminous galaxy within a dark halo

Increased density region

Average region
Structure formation

CDM simulations: numerical solution of the coupled Boltzmann and Poisson equations through discretization as N-body system \[ \rightarrow \] excellent reproduction of the observed distribution of matter.

Hydrodynamics of baryons: can be included approximately \[ \rightarrow \] excellent reproduction of IGM properties. Problem: gas collapses to very high densities resulting in short timescales \[ \rightarrow \] cosmological simulations that resolve collapsed objects require an enormous dynamic range.

Makeshift solution: semi-analytical models = combination of the hierarchical structure formation process of CDM halos from simulations with analytical 'recipes' describing the physics of the baryons.
Structure formation

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Makeshift solution: semi-analytical models = combination of the hierarchical structure formation process of CDM halos from simulations with analytical 'recipes' describing the physics of the baryons.
Structure of the MVV pricing system?
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Evidence for non-intelligent design?
Galaxy formation and evolution?

- Afterglow Light Pattern 400,000 yrs.
- Dark Ages
- Development of Galaxies, Planets, etc.
- Dark Energy Accelerated Expansion
- Inflation
- Quantum Fluctuations
- 1st Stars about 400 million yrs.

Big Bang Expansion
13.7 billion years
How to approach galaxy formation and evolution?

Observations

Level of detail
Statistical power, completeness

Detailed investigations of individual galaxies

Large surveys of galaxy population(s)

Galaxy evolution
complex physics

Theory
(analytic, semi-analytic, numerical)
How to approach galaxy formation and evolution?

Galaxy evolution
- gravitational collapse
- gas hydrodynamics
- star formation
- feedback from SF
- feedback from AGN/BH
- interaction with environment
- ...

Observations
- Detailed investigations of individual galaxies
- Large surveys of galaxy population(s)
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How to approach galaxy formation and evolution?

Observed galaxy properties:
- gravitational collapse
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Observations:
- Large surveys of galaxy population(s)
- Detailed investigations of individual galaxies

Observational vs. theoretical methods:
- Observational: statistical power, completeness
- Theoretical: analytic, semi-analytic, numerical

Galaxy evolution:
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Theory

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- gravitational collapse
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Large surveys of galaxy population(s)
How to approach galaxy formation and evolution?

Most of today's stellar mass is in luminous giant galaxies. Their properties show significant diversity, which presumably reflects a corresponding diversity of formation and/or evolutionary mechanisms.

- **Luminosity / Mass**: giant ↔ dwarf
- **Morphology**
  - Hubble type: E1-7 ↔ S(B)abc ↔ Sd/Irr
  - Concentration/Asymmetry/Clumpiness
- **Stellar population**
  - Colour: blue ↔ red
  - Continuum type: young ↔ old, metal rich ↔ poor
  - PCA: SF ↔ non-SF
- **Structure**
  - Size
  - Surface brightness
  - Surface brightness profile type: exponential ↔ deVauc.
- **Dynamics**
  - rotating ↔ dynamically hot
How to approach galaxy formation and evolution?

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  - Surface brightness profile type
- Dynamics

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<th>Properties</th>
<th>Giant ↔ Dwarf</th>
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<tr>
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<td>Young ↔ Old, Metal rich ↔ Poor</td>
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How to approach galaxy formation and evolution?

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Different evolutionary processes(paths/modes):
- Gas accretion
- Major mergers
- Minor mergers
- 'Monolithic' collapse
- Secular evolution
- Harassment
- ...

Observationally, what is the best way to isolate, identify and investigate the various formation/evolutionary mechanisms?
The Millennium Galaxy Catalogue (MGC)

www.eso.org/~jliske/mgc

- Deep, wide-field B-band imaging survey using WFC/INT
- Area = 37.5 deg²
- Median seeing = 1.3 arcsec, pixel size = 0.33 arcsec
- $B_{\text{lim}} = 24 \text{ mag}$, $\mu_{\text{lim}} = 26 \text{ mag arcsec}^{-2}$
- Internal photometric accuracy = 0.03 mag
- $B$ + ugriz (SDSS) photometry
- Main sample: $B < 20 \text{ mag}$ (10,095 galaxies):
  - Structural parameters, morphological classification
  - MGCz = redshift survey (96% completeness)
- A $z=0$ reference point.
The Millennium Galaxy Catalogue

**MGC Core Team**
Simon Driver (St Andrews)
Joe Liske (ESO)
Alister Graham (Swinburne)
Ewan Cameron (St Andrews)
David Hill (St Andrews)
(Paul Allen)

**Collaborators**
Chris Conselice (Nottingham)
Roberto de Propris (CTIO)
Nick Cross (Edinburgh)
Simon Ellis (AAO)
Richard Tuffs (MPIfK)
Cristina Popescu (UCLAN)
Bimodality of the galaxy population

Bivariate colour-luminosity distribution

Observed number

Volume corrected
Bimodality of the galaxy population

Bivariate Sersic index-luminosity distribution

Observed number

Volume corrected
Bimodality of the galaxy population

Bimodality is not everywhere! Here: Surface brightness-luminosity distribution (BBD)
Although there is structure, there is no clear separation into two peaks.
Bimodality of the galaxy population

Bivariate Sersic index-colour distribution

Observed number

Volume corrected
Bimodality of the galaxy population

- Multivariate analyses involving luminosity, surface brightness, size, light concentration, asymmetry, Hubble classifications, colour, spectral classifications and star-formation indicators consistently indicate the existence of two, and only two, sub-groups.

- These are best separated in the colour-Sersic index plane.
Today's giant galaxies consist of two distinct components which contain almost all of their stellar mass:

- **Disk**
- **Bulge**

Bulges and disks differ in terms of:
- photometric structure
- dynamics
- stellar, gas and dust content.

---

**B/T**

- Disk only
- Disk + Bulge
- Bulge only (= elliptical)
Bimodality ↔ 2-component nature?

- B/T
- B/T

Hubble type

↓

location in colour log(n) plot

→ Good evidence that the bimodality is caused by the two-component nature of galaxies, i.e. by disks and spheroids.
Bimodality ↔ 2-component nature?

It's not that simple:
1. There are two types of bulges ('classical' and 'pseudo') and one of them is like a disk.
2. Disk properties correlate with type of bulge so that type of bulge predicts total galaxy properties.
   → Galaxy ≠ random bulge + random disk
Hierarchical galaxy formation

“Galaxies are assumed to form inside dark matter halos, and their subsequent evolution is controlled by the merging histories of the halos containing them.”

“We assume that disks form by cooling of gas initially in the halo.”

“In our model, the primary route by which bright elliptical galaxies and the bulge components of spiral galaxies form is through galaxy mergers.”

Cole et al. (2000)
Implications

• There are clear observational and theoretical motivations to consider:
  Galaxy types or classes
Implications

- There are clear observational and theoretical motivations to consider: Galaxy types or classes → Galaxy components

- i.e., we should decompose galaxies into their major constituents and investigate *their* properties, as opposed to 'global' ones.
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  Galaxy types or classes → Galaxy components

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- The disk-bulge view of galaxies is the most 'natural' language in which to confront models of galaxy formation and evolution with observations.
Implications

- There are clear observational and theoretical motivations to consider:
  - Galaxy types or classes
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- i.e., we should decompose galaxies into their major constituents and investigate their properties, as opposed to 'global' ones.
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Implications

- There are clear observational and theoretical motivations to consider: Galaxies of types or classes versus Galaxy components.

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Implications

- There are clear observational and theoretical motivations to consider:
  - i.e., we should decompose galaxies into their major constituents and investigate their properties, as opposed to 'global' ones.
  - The disk-bulge view of galaxies is the most 'natural' language in which to confront models of galaxy formation and evolution.

Critical issues for galaxy formation

- Origin of the bright and faint cutoffs in the luminosity function
- Relative prevalence of disks/spheroids -- violent/quiescent modes
- Sizes of disks and spheroids -- J evolution, merging
- Efficiency/IMF of star formation -- understanding down-sizing
- Efficiency of feedback -- heating/enrichment of galaxies/IGM
- Relation of SMBH growth to galaxy formation -- QSOs/starbursts

Interpretation of large multiwavelength datasets will require careful quantitative analysis using detailed physical models in the context of a standard structure formation paradigm.
Implications

• There are clear observational and theoretical motivations to consider:
  - Galaxy types or classes
  - Galaxy components

• i.e., we should decompose galaxies into their major constituents and investigate their properties, as opposed to 'global' ones.

• The disk-bulge view of galaxies is the most 'natural' language in which to confront models of galaxy formation and evolution with observations.

• To probe disk/bulge evolution requires high-quality data at both low and high z:
  - Deep
  - High resolution
  - Wide area

→ The MGC is an excellent place to start.
MGC bulge-disk decomposition

- Model: Sersic bulge + exponential disk → 12 parameters
- Careful PSF modelling → convolve model profile with seeing
- Used GIM2D (Simard et al. 2002)
- Applied to all 10,095 MGC galaxies with B < 20 mag ← largest available sample
MGC bulge-disk decomposition
MGC bulge-disk decomposition
MGC bulge-disk decomposition

Reproducability: comparison of parameters independently derived from duplicate observations of 702 galaxies in overlap regions between individual MGC fields.
The presence of 'second order' features can result in (apparently?) unphysical models: Spiral arms, irregular morphology, dust, SF regions, truncated disks, bars, rings, inner disks, unresolved central components (AGN, nuclear starburst), twisted isophotes, perturbed background, ...
MGC B-D decomposition: problems

Current 'solution':
Replace 'unphysical' fits with Sersic-only fits.

Better solutions needed:
• Faster algorithms to be able to explore a range of models.
• Longer wavelengths where irregularities are less pronounced.
Motivation for a new B-D decomp code

Fundamental problem: Speed ↔ Robustness

Difficult to achieve both at the same time and yet both are crucial for automated analysis of large samples (~10^6 galaxies).

Existing (public) codes: GALFIT (C. Peng) fast, flexible, not robust
GIM2D (L. Simard) slow, unflexible, robust

Solution: data compression and fitting of model to the compressed data:
MOPED (Heavens et al. 2000)

Data compression with respect to a given model:

Original data vector = 100 x 100 pixel

Compression

Length of new data vector = # of model parameters

With respect to the model the compression is lossless.

→ Massive speed-up of the exploration of the likelihood surface by x 10-1000.
Component bimodality

Composite galaxies
(1-component Sersic fits)

Galaxy components

Type I disks

Type II/III disks

Sersic Bulges
Component bimodality

Composite galaxies
(1-component Sersic fits)

Galaxy components

Type I disks

Type II/III disks

Sersic Bulges

Pseudo-bulges?
Two types of bulges?

Disks
Bulges
Two types of bulges?

Disks
Bulges

'classical' bulges
'pseudo' bulges
Probably a catch-all class!
Global SFH tells us WHEN the bulk of present-day stars were formed. What
structures did they assemble into? What is the relative importance of the formation
mechanisms associated with these structures?

Hopkins (2004)
Global SFH tells us WHEN the bulk of present-day stars were formed. What structures did they assemble into? What is the relative importance of the formation mechanisms associated with these structures?

Hopkins (2004)
Component luminosity functions

Luminosity density:
- Disks: 68%
- Spheroids: 32%
- Bulges: 19%
- Ellipticals: 13%
- Red bulges: 16%
- Blue bulges: 3%
- Red ellipticals: 10%
- Blue ellipticals: 3%
- Red spheroids: 26%
- Blue spheroids: 6%
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<td>Bulges</td>
<td>27%</td>
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<td>Ellipticals</td>
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<tr>
<td>Red bulges</td>
<td>26%</td>
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<tr>
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<td>2%</td>
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<tr>
<td>Red spheroids</td>
<td>39%</td>
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<tr>
<td>Blue spheroids</td>
<td>3%</td>
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</table>

Component luminosity functions
The luminosity-size relation of disks

• In hierarchical CDM models the angular momentum of disks is tightly coupled to the angular momentum of their halos → strong dependence of disk size on z.
• The angular momentum distribution of halos is a robust prediction of CDM models.
• (Problem: hydrodynamical sims produce disks that are far too small.)
• Barden et al. (2005) measure the L-R relation from GEMS/COMBO-17 data out z ~ 1.
• Comparing the local MGC relation with GEMS reveals an evolution ~1 mag arcsec$^{-2}$ out to z ~ 1.
• This appears to be consistent with hierarchical models. BUT: need to convert to stellar mass.
The luminosity-size relation of spheroids

- Monolithic collapse models: size evolution due to passive evolution of old stellar population.
- Hierarchical models: depends on details of merger statistics, i.e. frequency and properties of product of each type of merger.
- MGC/GEMS comparison:
  - L-R evolution consistent with passive evolution
  - Newly formed spheroids follow same L-R relation as older spheroids.

McIntosh et al. (2005)
The mass function of SMBH

- Feedback from SMBH is currently the favoured process to curtail SF in massive galaxies.
- The present-day mass function of SMBH tells how much material has been accreted in the past.
- Combined with the luminosity function of QSOs one can estimate their average efficiency.
- $M_{SMBH}$ not only correlates with $\sigma$ and $L_{\text{bulge}}$ but also with Sersic index.
- Use n-distribution to obtain mass function of SMBHs.

$\Omega_{SMBH} = (3.8 \pm 1.3) \times 10^{-6} \, h$

Graham et al. (2006)
What about dust?
What about dust?

- Dust in the disks of galaxies may severely affect all photometric measurements (mags, colours), stellar mass, size, morphology, SB profile...

- (Spheroids are assumed to be dust-free.)

- **To what extent does dust distort our view of galaxies?**

- The Holmberg test: disk galaxy properties as a function of inclination. Here: luminosity.

- Advantages of bulge-disk composition:
  - Enables the selection of pure disks, without any bulge components.
  - Improves estimation of inclination.
  - Enables the study of the effect of the dust in the disk on the bulge.

- Recent realisation in the survey community that this might be a problem: Shao et al. (2007), Driver et al. (2007), Choi et al. (2007), Unterborn & Ryden (2008), Driver et al. (2008), Padilla & Strauss (2008), Maller et al. (2008)
Disk LF versus inclination

Red dotted line: measured LF
Red solid line: corrected LF
Blue dashed line: face-on sample
Disk attenuation-inclination relation

0.8 mag!
Sanity check

- For randomly orientated disks (and no dust) the cos(i) distribution should be flat. Initially it's not!
- The empirical attenuation-inclination correction also successfully corrects the inclination distribution.
- Some residual incompleteness in the highest inclination bin remains.
Modeling the dust

Old stellar bulge:
\[ \eta(\lambda, R, z) = \eta_{\text{bulge}}(\lambda, 0, 0) \exp(-7.67 B^{1/4}) B^{-7/8}, \]
\[ B = \sqrt{R^2 + z^2 (a/b)^2} \]

Old stellar disk:
\[ \eta(\lambda, R, z) = \eta_{\text{disk}}(\lambda, 0, 0) \exp\left(-\frac{R}{h_{\text{disk}}} - \frac{|z|}{z_{\text{disk}}}\right) \]

Young stellar disk:
\[ \eta_{\text{tdisk}}(\lambda, R, z) = \eta_{\text{tdisk}}(\lambda, 0, 0) \exp\left(-\frac{R}{h_{\text{tdisk}}} - \frac{|z|}{z_{\text{tdisk}}}\right) \]

Dust disk associated with the old stellar disk:
\[ \kappa_{\text{ext}}(\lambda, R, z) = \kappa_{\text{ext}}(\lambda, 0, 0) \exp\left(-\frac{R}{h_{\text{d}} - \frac{|z|}{z_{\text{d}}}\right) \]

Dust disk associated with the young stellar disk:
\[ \kappa_{\text{ext}}(\lambda, R, z) = \kappa_{\text{ext}}(\lambda, 0, 0) \exp\left(-\frac{R}{h_{\text{tdisk}}} - |z|\right) \]

Based on UV+optical+NIR +Spitzer data of 6 very nearby galaxies.

Popescu et al. (2000)
Tuffs et al. (2004)
Modeling the dust

- The Popescu & Tuffs model has only one free parameter: the central face-on B-band optical depth.
- Best-fit $\tau_B^f = 3.8 \pm 0.7$
- Note: popular $\tau = 1$, one dust-disk models fail miserably!
Modeling the dust

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- Best-fit $\tau_B^f = 3.8 \pm 0.7$
- Note: popular $\tau = 1$ one dust-disk models fail miserably!

We now have a fully specified, empirically calibrated dust model. It provides us with:

- Residual face-on attenuation correction
- Dust mass
- Predictions of (property)-inclination relations
- Predictions for bulge and total galaxy
- Predictions at other wavelengths
Bulge LF versus inclination

Red dotted line: measured LF

Red solid line: corrected LF

Blue dashed line: face-on sample
Bulge attenuation-inclination relation

1 mag!
Bulge attenuation-inclination relation

Model prediction (not a fit)
Total attenuation

Face-on B-band disk attenuation = 0.2 mag
Face-on B-band bulge attenuation = 0.88 mag (!)
A model galaxy

No dust

B-band

K-band

face-on

i = 60°

edge-on
Corrected component LFs

Luminosity density:
Disks: up by 59%
Bulges: up by 230%!
Ellipticals: no change
Corrected component LFs

Stellar mass density:
- Disks: up by 16%
- Bulges: up by 38%
- Ellipticals: no change

Total: up by 19%

0.9 mag

0.3 mag
Corrected component LFs

Stellar mass density split:
Disks: \(58 \rightarrow 58\%\)
Bulges: \(26 \rightarrow 29\%\)
Ellipticals: \(13 \rightarrow 10.5\%\)
Blue spheroids: \(3 \rightarrow 2.5\%\)
The cosmic mass budget

- **Big Bang**
  - Dark Energy
    - 74%
  - Dark Matter
    - 22%
  - Gas
    - 85%
  - Baryonic Matter
    - 4%
    - Stars
      - 11.9%
      - Stars in Disks
        - 58%
      - Stars in Spheroids
        - 40%
    - Dust
      - 0.008%
    - Supermassive Black Holes
      - 0.01%?
    - Stars in Bulges
      - 73%
    - Stars in Ellipticals
      - 27%
The cosmic mass budget

Big Bang

- Dark Energy: 74%
- Gas: 85%
- Baryonic Matter: 4%
  - Stars: 11.9%
  - Dust: 0.008%
  - Supermassive Black Holes: 0.01%?
  - Lunch in the canteen: 0.1%?
- Stars in Disks: 58%
- Stars in Spheroids: 40%
- Stars in Bulges: 73%
- Stars in Ellipticals: 27%
Corrected total galaxy LF

Full dust correction increases the total luminosity density by 63%.

In other words:
Only 61% of B-band photons that are produced by stars actually escape into the IGM.

What about other wavelengths?
And what happens to the energy absorbed by the dust in the UV-optical?
Photon escape fractions

- Use dust model to calculate photon escape fraction averaged over all $\cos(i)$ as a function of $B/T$.
- Pick $B/T$ that corresponds to observed $B$-band escape fraction.
- Transform this $B/T$ to other wavelengths using mean bulge and disk colours.
- Using the dust model transform the $B/T$ to a corresponding photon escape fraction at each wavelength.
The cosmic SED
The cosmic SED

Energy of starlight absorbed by dust = Energy of FIR emission by dust

⇒ No room for dust heating by AGN!

\[(0.6 \pm 0.1) \times 10^{35} \text{ W Mpc}^{-3}\]

\[(0.7 \pm 0.2) \times 10^{35} \text{ W Mpc}^{-3}\]
The (immediate) future

The next generation of wide-field survey instruments + HST/ACS will provide datasets with an unprecedented combination of size, depth and resolution:

Low z:
- **KIDS** – VST ugri imaging survey over ~1000 deg$^2$ (approved ESO Public Survey)
  Compared to MGC: 2 x resolution, 1.5 mag deeper, 30 x area, 4 bands
- **VIKING** – KIDS NIR extension with VISTA (co-I, approved EPS)
- **GAMA** – Deep redshift survey with AAOmega over ~250 deg$^2$ (co-PI)

High z:
- **COSMOS** – 2 deg$^2$ ACS survey (largest HST survey ever, complete)
- **zCOSMOS** – VLT/VIMOS redshift survey for COSMOS (in progress)

→ Bulge/disk decomposition of ~2 x 10$^5$ galaxies with 0 < z < 1 from UV to NIR.
Galaxy And Mass Assembly (GAMA)

www.eso.org/~jliske/gama

- Spectroscopic component of a comprehensive, multi-wavelength, state-of-the-art survey of the local Universe, bringing together data from the latest generation of survey facilities.
- Spectroscopy from AAT/AAOmega
- 5 regions, \(\sim 250 \text{ deg}^2\), \(\sim 250K\) galaxies to \(r < 19.8\) mag + K-band selection
- Science goal: study of structure on 1 kpc – 1 Mpc scales
  - CDM halo mass function of groups and clusters from group velocity dispersion
  - Galaxy stellar mass function to Magellanic Cloud masses
  - Merger rate as a function of mass and mass ratio
  - Properties of galaxy components
GAMA facilities

UKIRT

VISTA

VST

AAT

HERSCHEL

ASKAP

Optical

NIR

Spec

FIR

HI

Science
# GAMA team and structure

## Working Groups and Heads

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<tr>
<th>Science</th>
<th>CATS</th>
<th>Database</th>
<th>OBS</th>
<th>Mocks</th>
<th>Radio</th>
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<td>Baldry (LJMU)</td>
<td>Liske (ESO)</td>
<td>Driver (St And)</td>
<td>Norberg (ROE)</td>
<td>Hopkins (USyd)</td>
<td>Loveday (Sussex)</td>
<td>Bamford (Portsmouth)</td>
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## Team Members

- Bland-Hawthorn (USyd)
- Couch (Swinburne)
- Eales (Cardiff)
- Frenk (Durham)
- Jones (AAO)
- Lahav (UCL)
- Parkinson (ROE)
- Prescott (LJMU)
- Staveley-Smith (UWA)
- Quinn (UWA)
- Cameron (St Andrews)
- Croom (U.Syd)
- Edmondson (Portsmouth)
- Graham (Swinburne)
- van Kampen (Salzburg)
- Nichol (Portsmouth)
- Phillipps (Bristol)
- Proctor (Swinburne)
- Sutherland (Camb.)
- Warren (Imperial)
- Conselice (Nottingham)
- Cross (ROE)
- Ellis (AAO)
- Hill (St Andrews)
- Kuijken (Leiden)
- Oliver (Sussex)
- Popescu (UCLan)
- Sharp (AAO)
- Tuffs (MPIA)
- 3 PDRAs pending

## Affiliated Consortia

- UKIRT/LAS, VST/KIDS, VISTA/VIKING, HERSCHEL-ATLAS, DURHAM ICC
GAMA in comparison
GAMA in comparison
GAMA survey regions
GAMA survey regions
Survey progress

- 66 nights allocated over 3 years (~1/2 of the nights required)
- 21/22 clear nights in March-April 2008
- 50-75 min exposures in dark/grey time
- 159 fields observed → all 3 GAMA I regions covered almost entirely at least once to variable depths (including a deep strip to r < 19.8 mag)
- All data reduced and redshifted
- 50,746 good quality redshifts at 96.6% (!) completeness
GAMA redshift cone

GAMA
GAMA Deep
2dFGRS
MGC
GAMA redshift distribution
GAMA example spectra
GAMA example spectra

Galaxy G00300337

- Original spectrum
- $S/N = 9.79$
- $z = 0.093$

- Bestfit galaxy template
- $\sigma = 325$ km/s

- Bestfit emission templates

Galaxy G00380740

- Original spectrum
- $S/N = 19.04$
- $z = 0.073$

- Bestfit galaxy template
- $\sigma = 148$ km/s

- Bestfit emission templates

Original spectrum - emission

Original spectrum - emission
GAMA example spectra

Galaxy G00214312

Original spectrum
S/N = 3.54
z = 0.24

Bestfit galaxy template
σ = 353 km/s
Bestfit emission templates

Original spectrum – emission

Galaxy G00375532

Original spectrum
S/N = 15.99
z = 0.029

Bestfit galaxy template
σ = 166 km/s
Bestfit emission templates

Original spectrum – emission
Quick-look science: SFR vs z
Quick-look science: colour bimodality vs z
Quick-look science: photo-z improvement
Quick-look science: photo-z improvement
Conclusions

• The distinction between galaxy disks and spheroids contains most of the variance of the galaxy population as a whole.

• The decomposition of galaxies from large, complete samples into their main stellar components provides a crucial tool for isolating, identifying and studying different formation and evolutionary mechanisms.

• Studying the evolution of disks and bulges [can | may be necessary to] discriminate between competing formation scenarios.

• Significant progress is imminent: VST, VISTA and HST will provide the data to construct x20 larger, x2 higher resolution, multi-wavelength databases of disk and bulge properties.

→ New technology enabling the birth of a new research area:
Survey-style quantitative morphology and galaxy bulge/disk evolution.