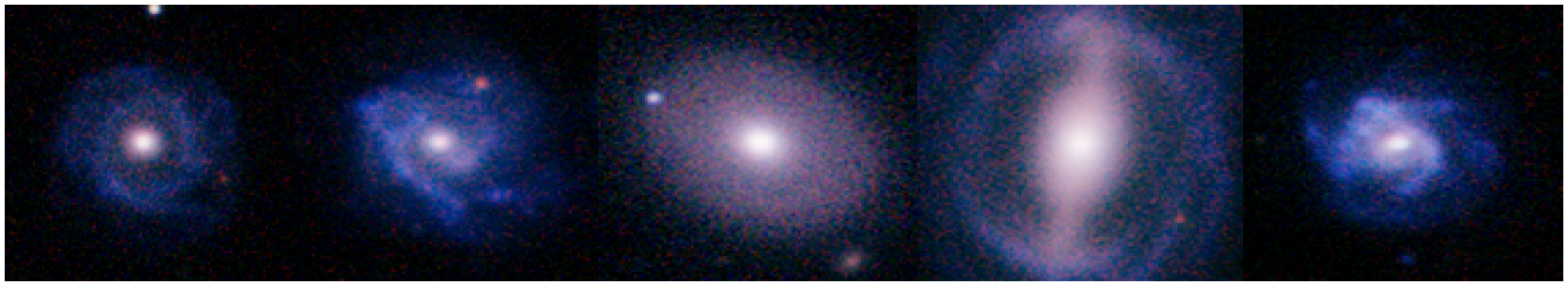
The Local Universe of Disk Galaxies: Energy, Mass, and Structure

Simon Driver

and

the GAMA team



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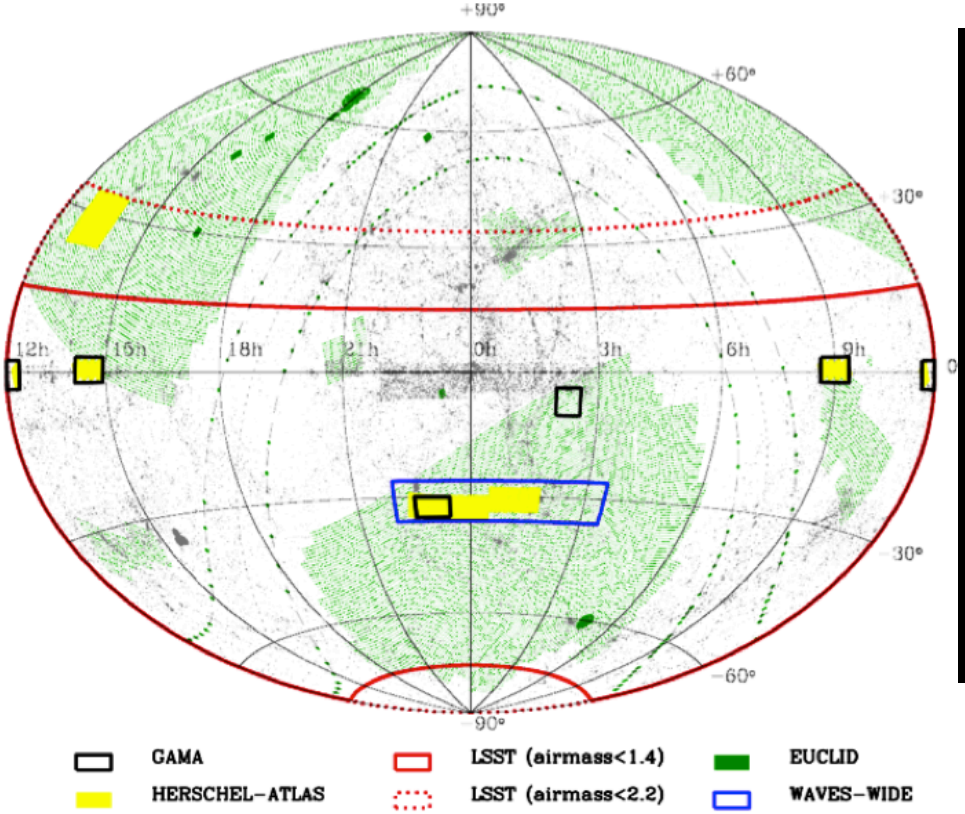
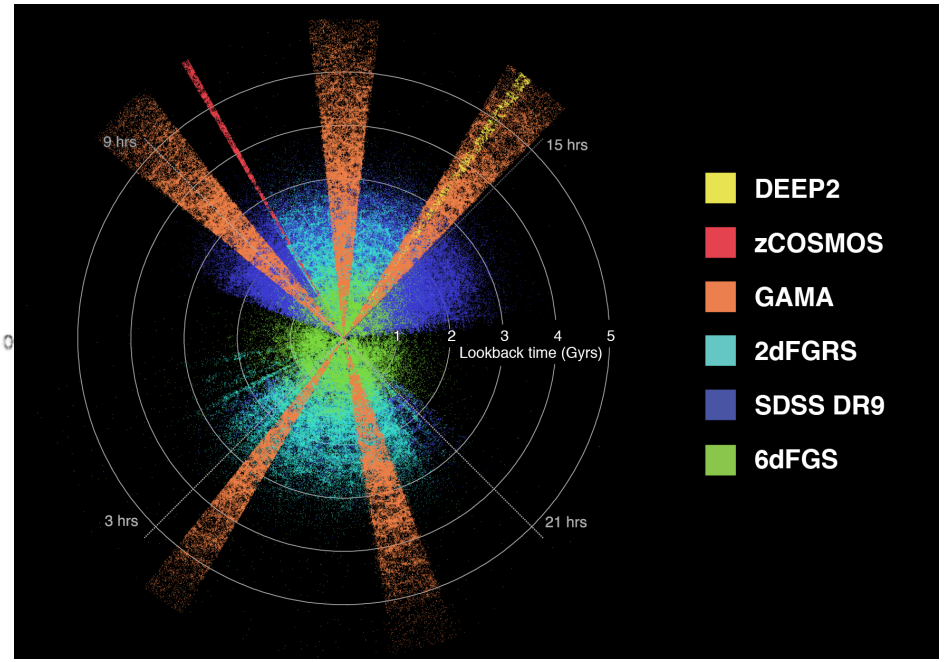
Overview

- Apologies to CALIFA, S^{4}G, KINGFISH etc
- Introduction to GAMA
  - The Panchromatic Data Release
  - The energy output of the nearby Universe
- The distribution of stellar mass:
  - by morphological type
  - the stellar mass budget
  - the dark art of bulge-disc decomposition
  - stellar mass breakdown by component
  - the mass-size relation of components
  - discs as self-regulating systems?
- Summary

GAMA

- A spectroscopic and *panchromatic* imaging survey of ~300,000 galaxies to r<19.8mag over 5 sky regions (230 sq deg)





- Building on the legacy of SDSS and 2dFGRS

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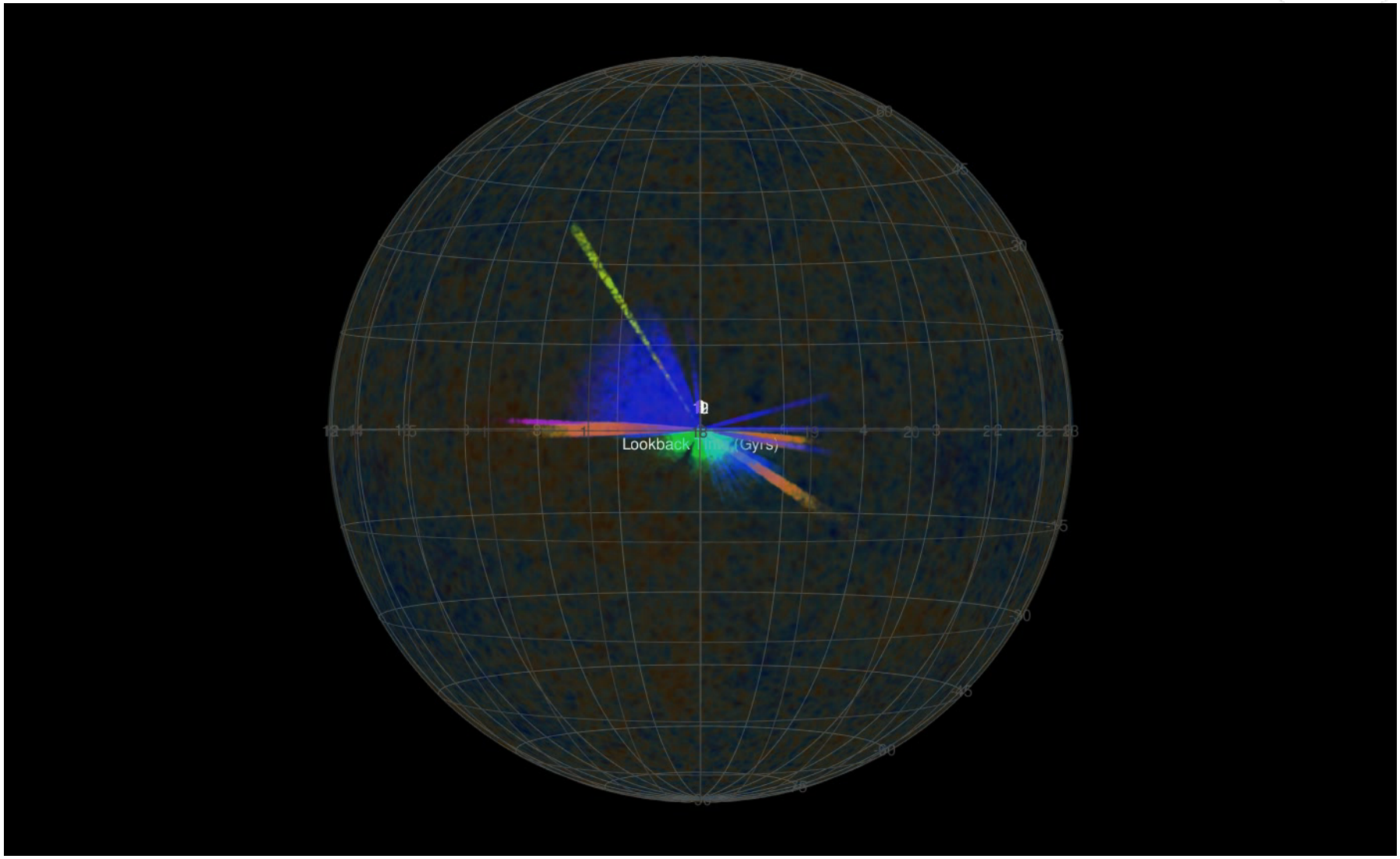
GAMA: Redshift surveys



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GAMA

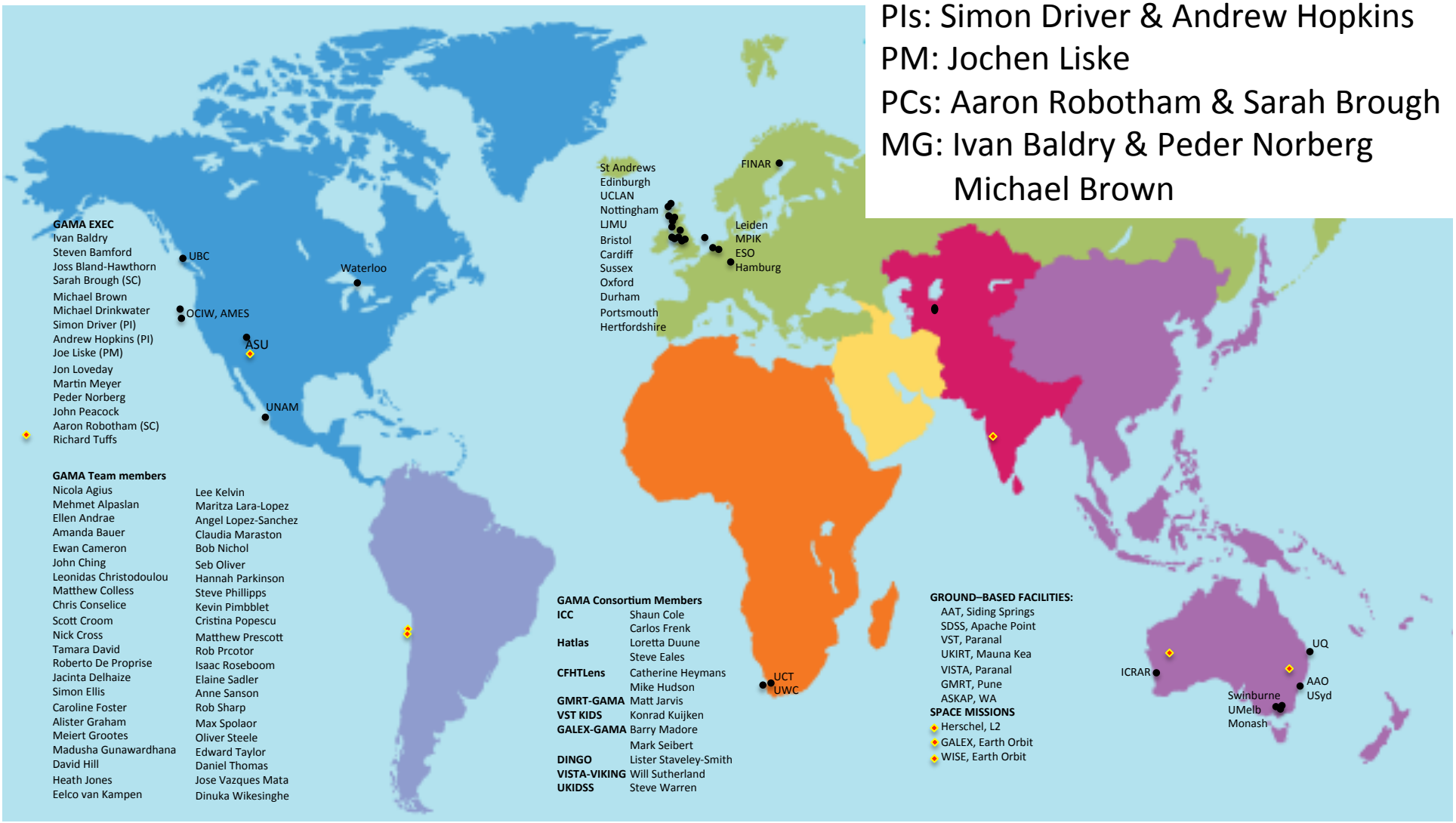
- Science motivation:
  - Tests of numerical, SA and hydro simulations through provision of complete and comprehensive database (e.g., Halo Mass Function)
  - The empirical measurement of mass, energy, and structure on 1kpc to 1Mpc scales and its recent evolution
- Unique selling points:
  - 2mag deeper than SDSS (r<19.8 mag, = 1120 galaxies/sq deg)
  - High spectroscopic completeness (98%, unbiased due to repeat visits)
  - Far-UV to far-IR coverage (available now)
  - Imminent 21cm, radio continuum and x-ray coverage (ASKAP, eROSITA)
  - Excellent database accessibility and functionality (SDSS-like)
  - High-order data products (e.g., bulge-disc decomposition, group catalogue, filament catalogue, stellar mass estimates, metallicities etc.)

Data Release 2 and Panchromatic Data Release available at: → gama-survey.org

The GAMA Team

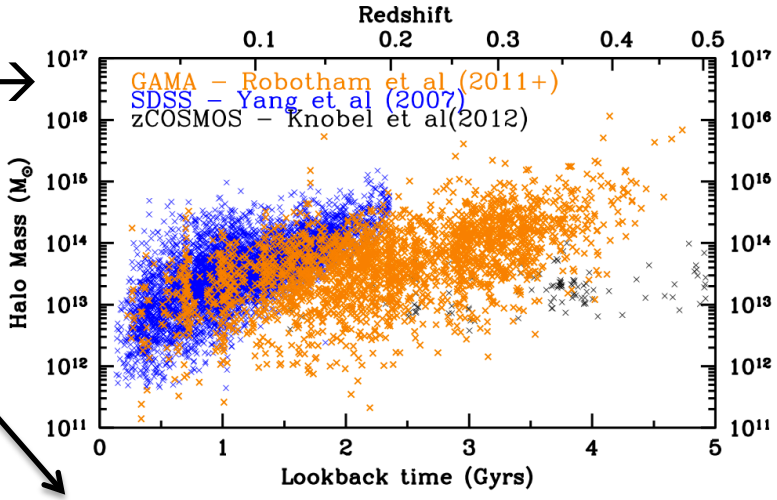
Team now includes: 97 scientists (including 14 PhD students) across 39 institutions, 4 continents

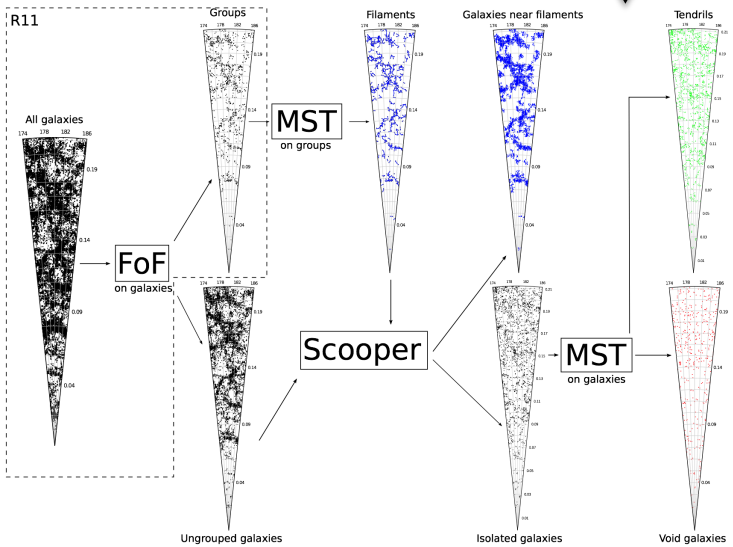
PIs: Simon Driver & Andrew Hopkins
PM: Jochen Liske
PCs: Aaron Robotham & Sarah Brough
MG: Ivan Baldry & Peder Norberg
Michael Brown



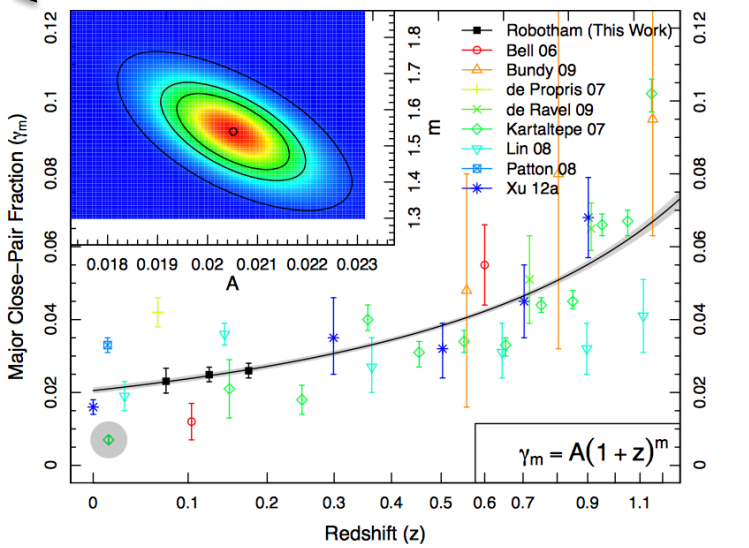
GAMA: Groups, pairs, filaments

- GAMA group catalogue (Robotham et al 2011) →
- Most complete group catalogue ever constructed (5000 groups with N>3)
- 20,000 pairs shows declining merger rate
- Allows measurement of dark matter mass filament, void and tendril catalogues





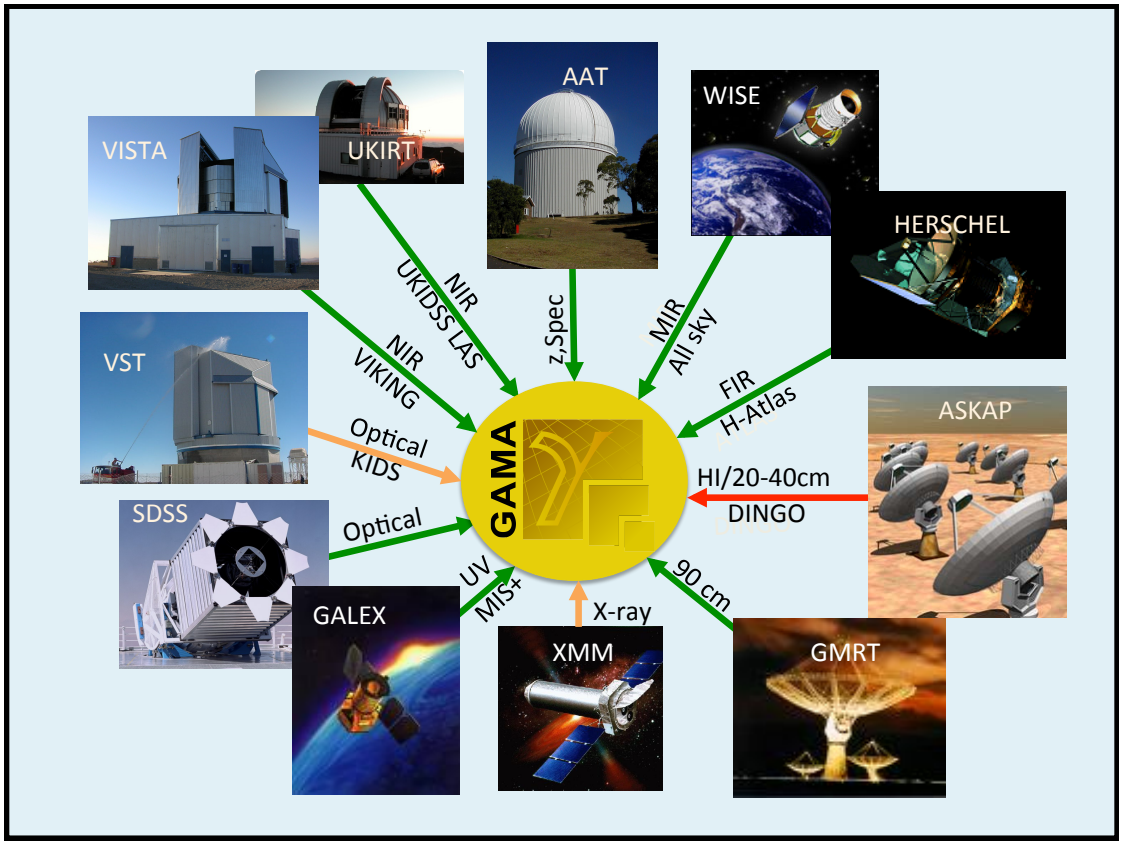
Alpaslan et al (2014a,b, 2015)



Robotham et al (2013, 2014)
Davies et al(2014, 2015)

GAMA: Panchromatic Data Release (PDR)

- *gama-psi.icrar.org*
- complete release of 21 band imaging for over 230 sq deg of sky
- catalogues to follow:
  - 21 band photometry
  - MAGPHYS analysis
  - structural decompositions
  - redshifts
  - line measurements
  - environment markers
- paper now on astro-ph
- radio data coming!



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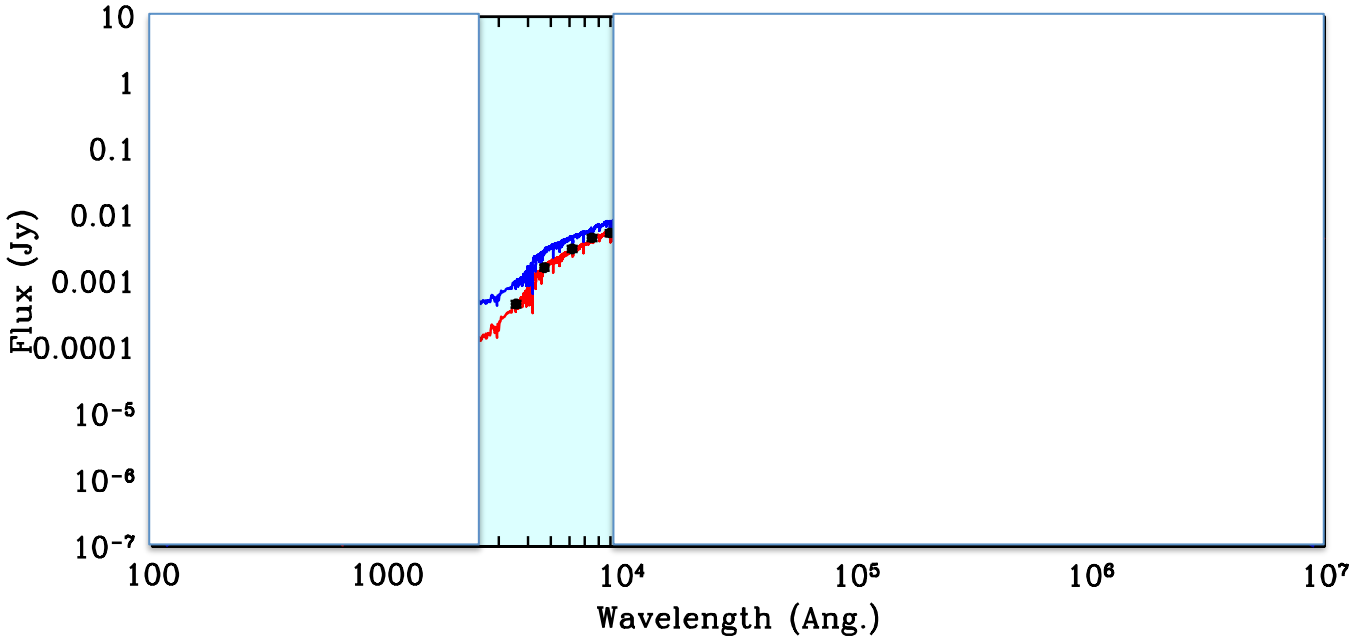
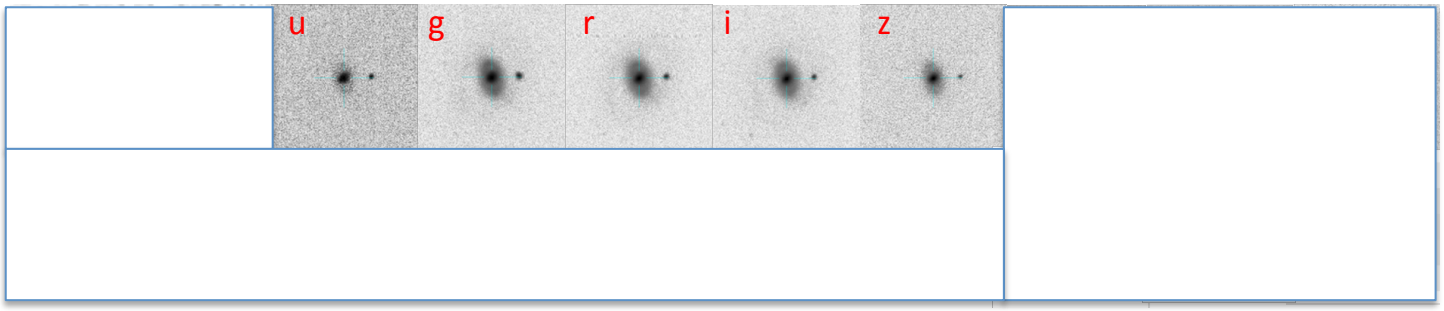
GAMA: optical only





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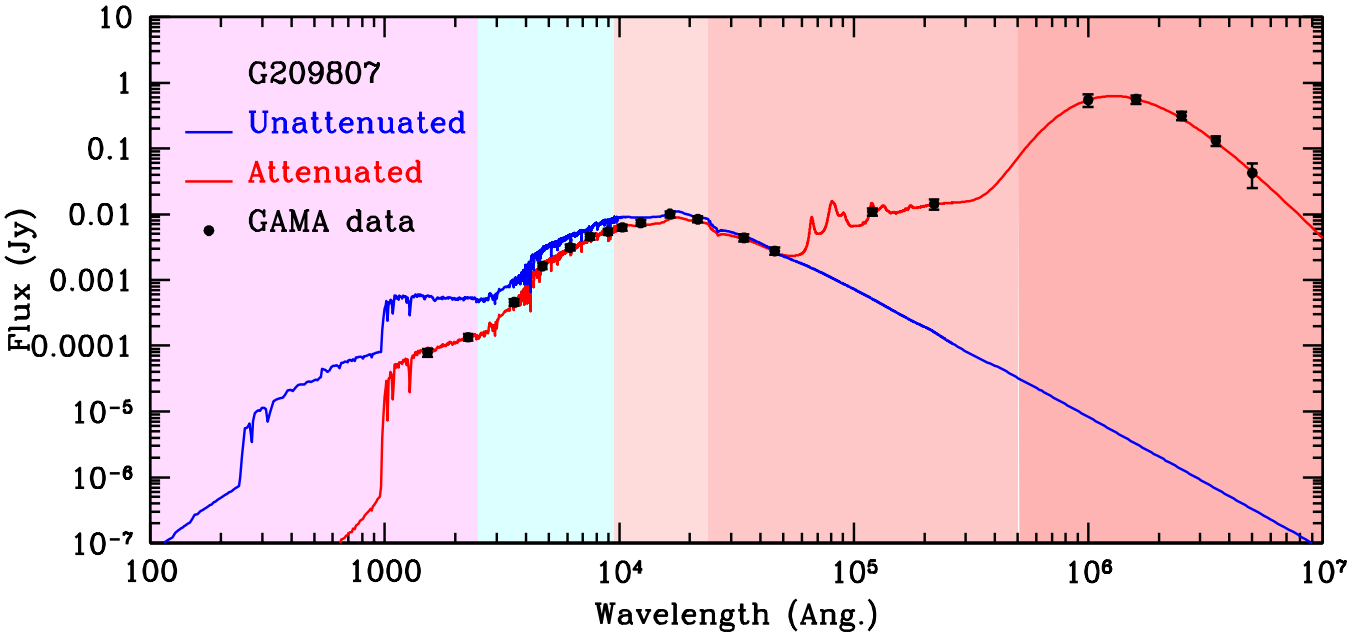
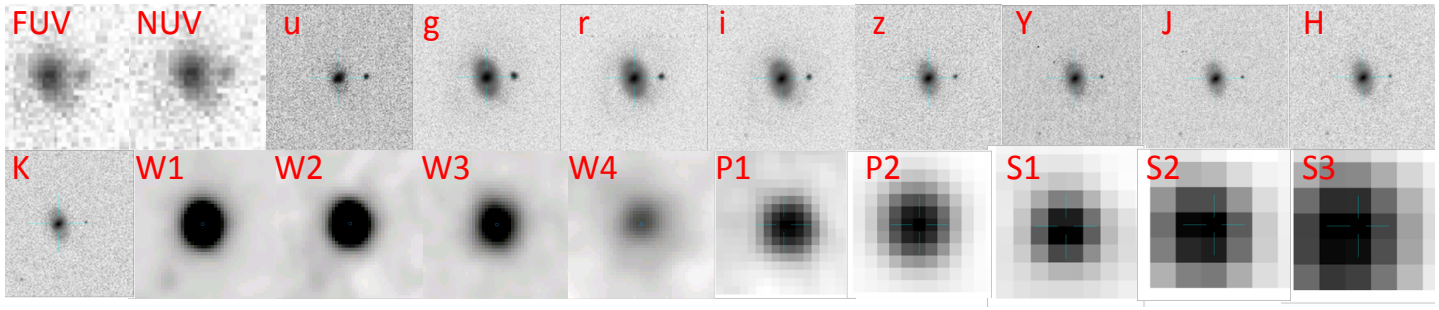
GAMA: multi-λ





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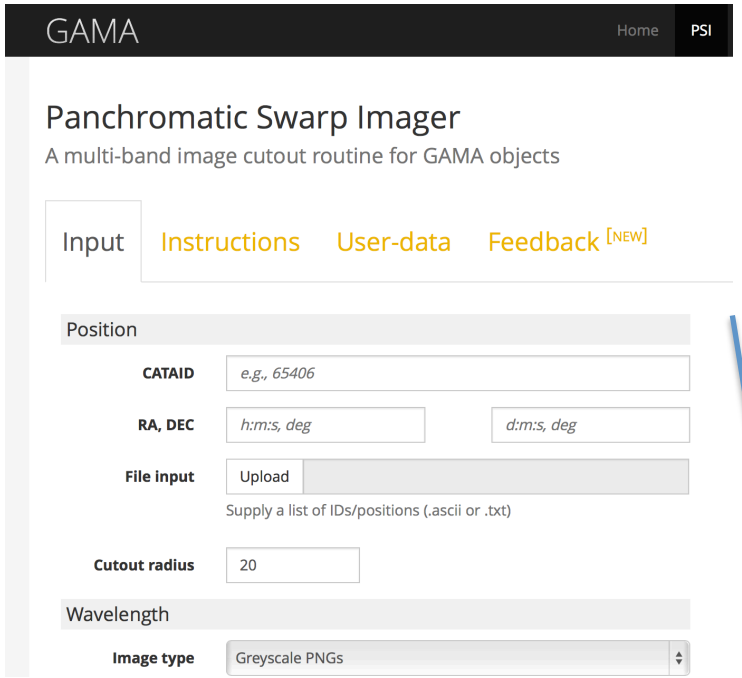
GAMA: PDR

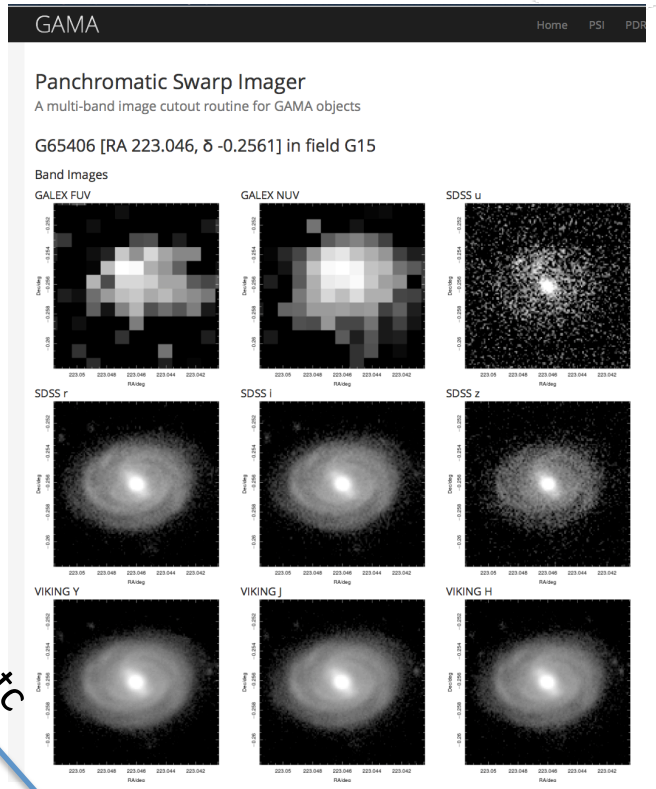
Simple interface (221,000 galaxies)

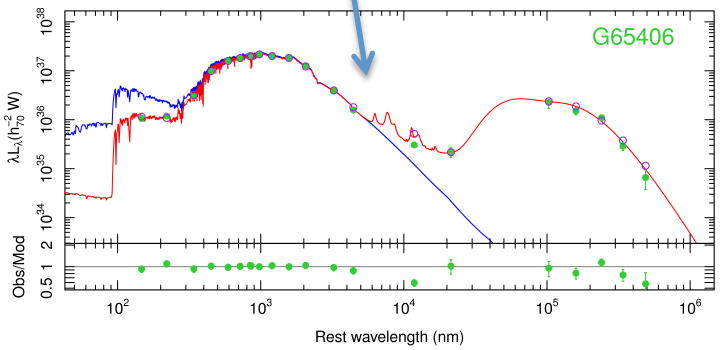


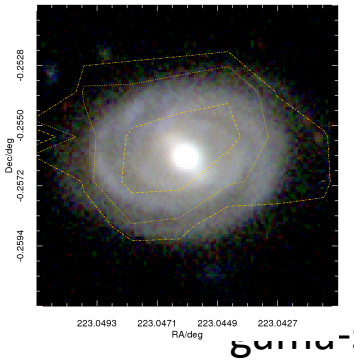
21 band images

Colour stamps/contours etc

MAGPHYS analysis







e.g., giH + Spire 250 contours

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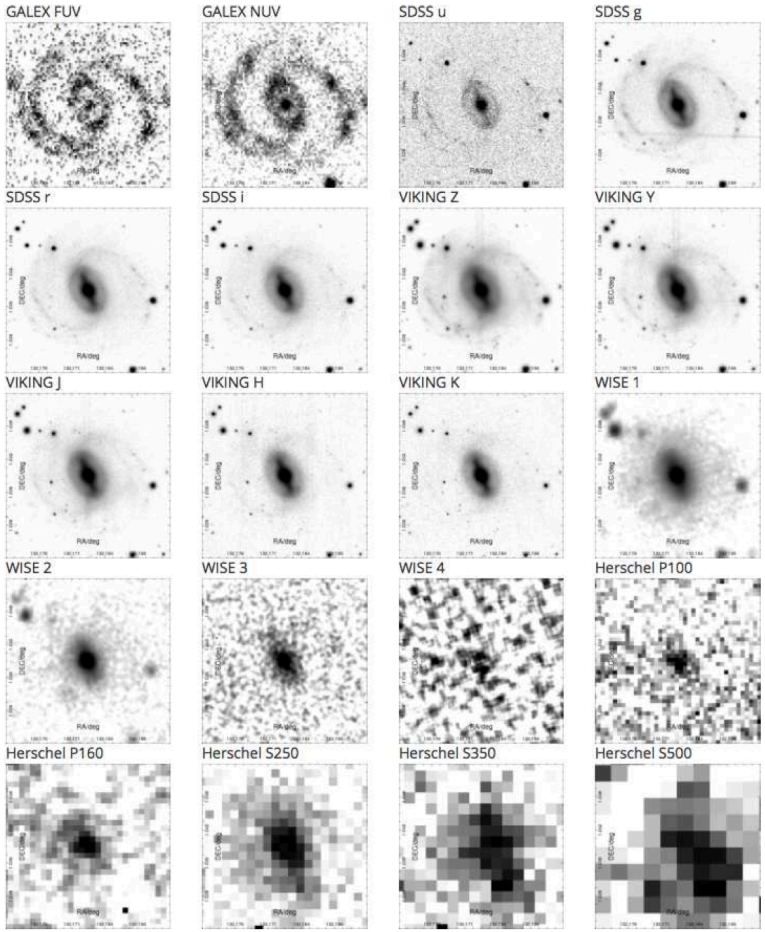
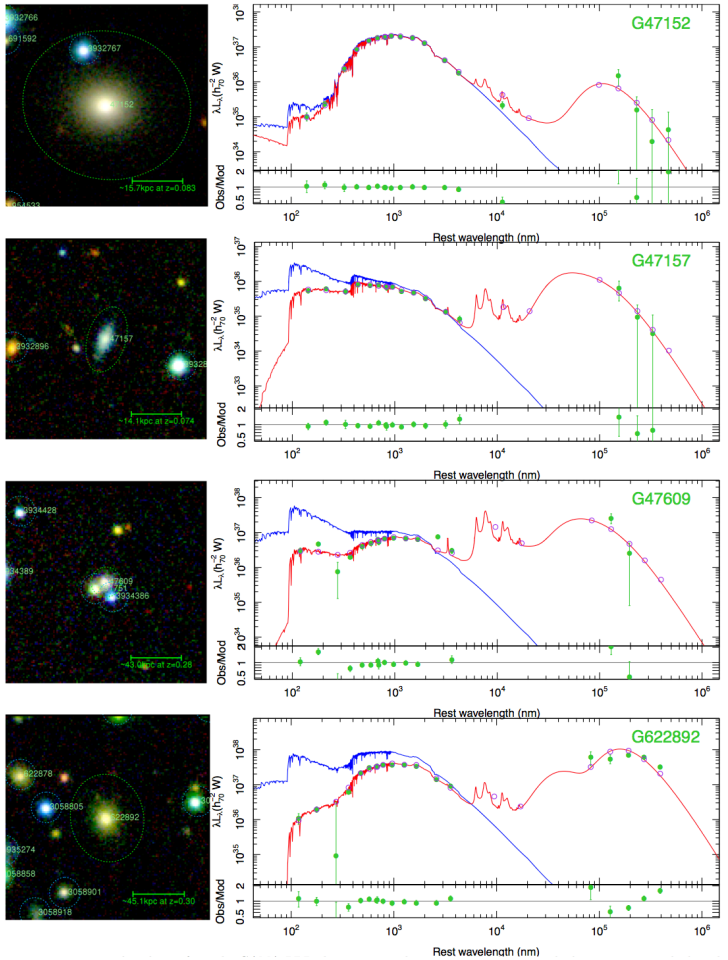
GAMA: PDF

21 band photometry plus MAGPHYS fits for 221,000 galaxies





Driver et al (2015, astro-ph/Today), gama-psi.icrar.org

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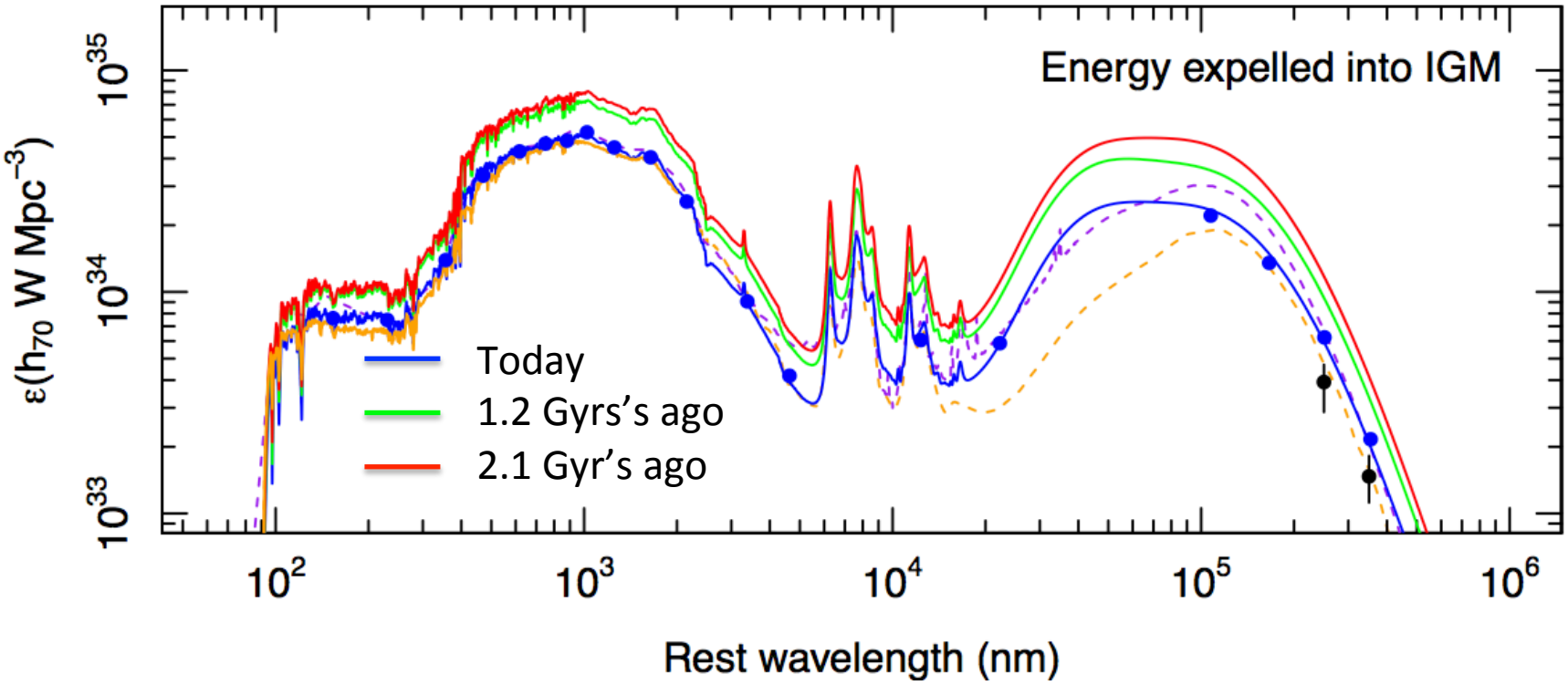
GAMA: Energy

- Use MAGPHYS to determine a fitting function for all 221k galaxies
- Sum the SEDs in volume slices to determine energy output v time.



- Observe energy decline over past 2Gyrs at all λ (Universe is fading away)

Driver et al (2015)

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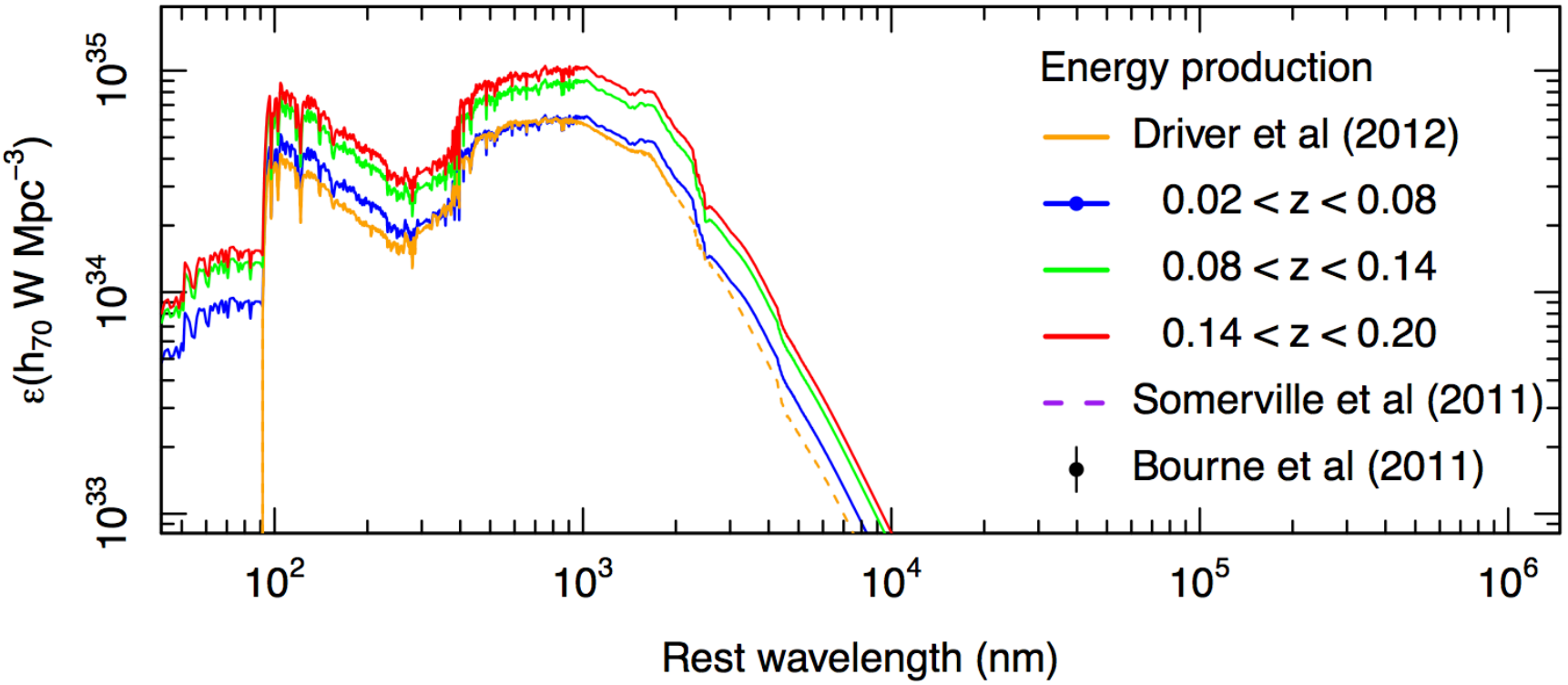


- Observe energy decline over past 2Gyrs at all λ (Universe is fading away)

Driver et al (2015)

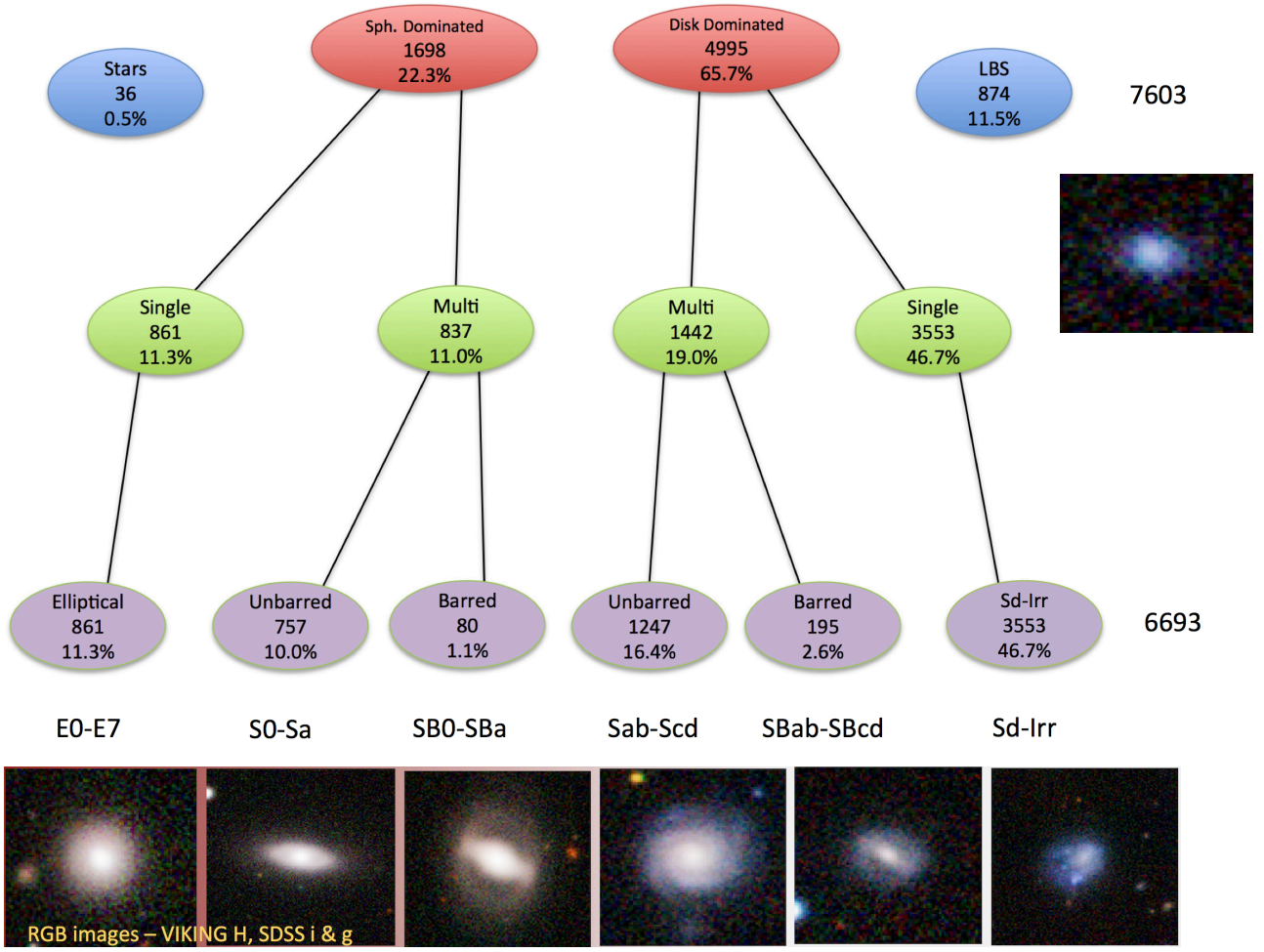
GAMA: Stellar mass

- The distribution of stellar mass in the Universe:
  - Following work in collaboration with Rebecca Lange and Amanda Moffett
  - Focus on distribution of stellar-mass in the nearby Universe, and the mass-size relation of galaxy components.

- Key questions:
  - In what population and component does most stellar mass reside?
  - Are there missing galaxy populations locally?
  - How does the energy output of the Universe vary with galaxy type?
  - Is division by component or galaxy type more fundamental?
  - Have galaxies formed via two distinct processes/epochs?

GAMA: Stellar Mass

- At z < 0.06 can reliably classify galaxies by type (7603 galaxies)



- See poster by Moffett et al, Sym. 319

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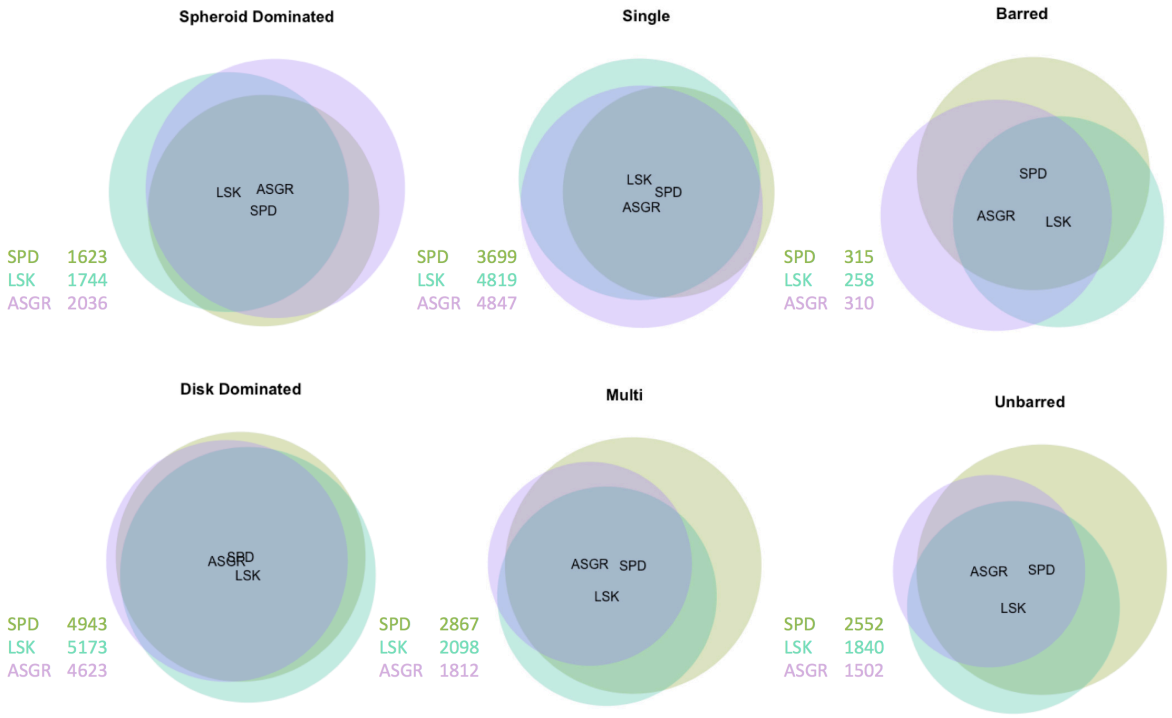

- See poster by Moffett et al, Sym. 319

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GAMA: Mass by type

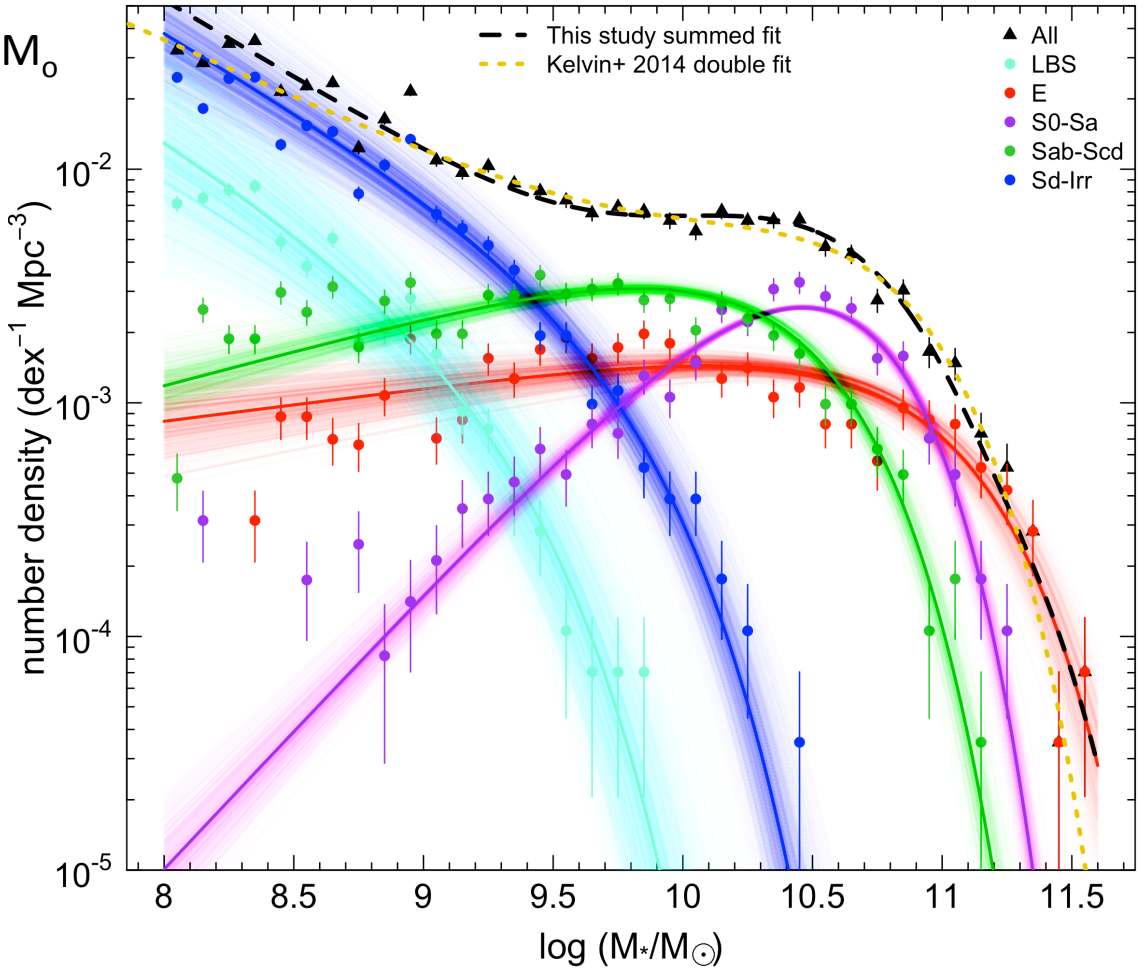
Stellar mass functions by type $10^8 M_o$

Ellipticals: 33%
S0-Sa: 34%
Sabc-Scd: 23%
Sd-Irr: 9%
LBS: 1%

Spheroid dominated: 72%
Disc dominated: 27%

Key features:

- Steep faint-end upturn
- Distinct ranges for each type
- Early-types bound
- Late-types unbound



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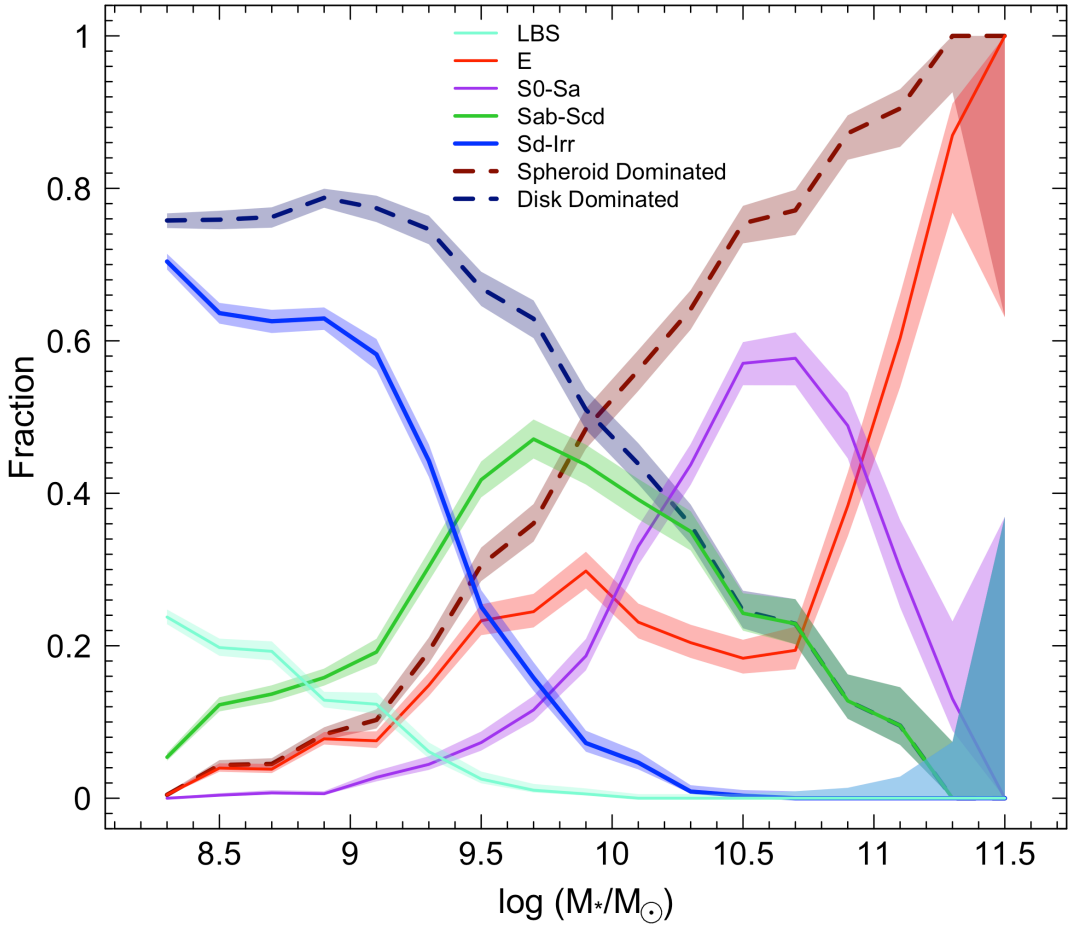

See poster by Moffett et al, Sym. 319

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GAMA: Mass density by type

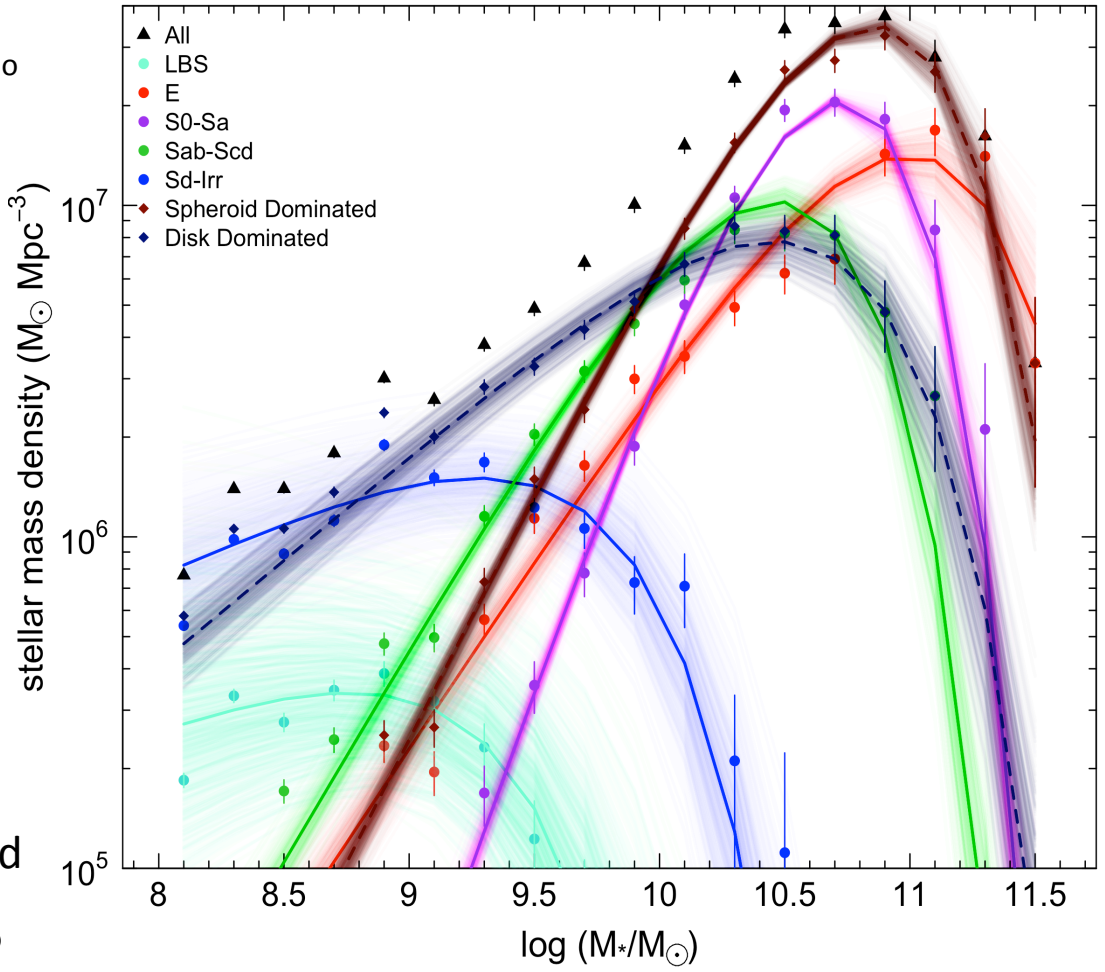
Stellar mass functions by type $10^8 M_o$

Ellipticals: 33%
S0-Sa: 34%
Sabc-Scd: 23%
Sd-Irr: 9% but almost flat!!
LBS: 1% but almost flat!!

Spheroid dominated: 72%
Disc dominated: 27%

Appears bounded but:

- LBS population elusive
- SB effects start at $10^{8.5} M_o$!
- However LG suggest bounded



But what about Spheroids and discs?
Which dominates the stellar mass budget?
See poster by Moffett et al, Sym. 319

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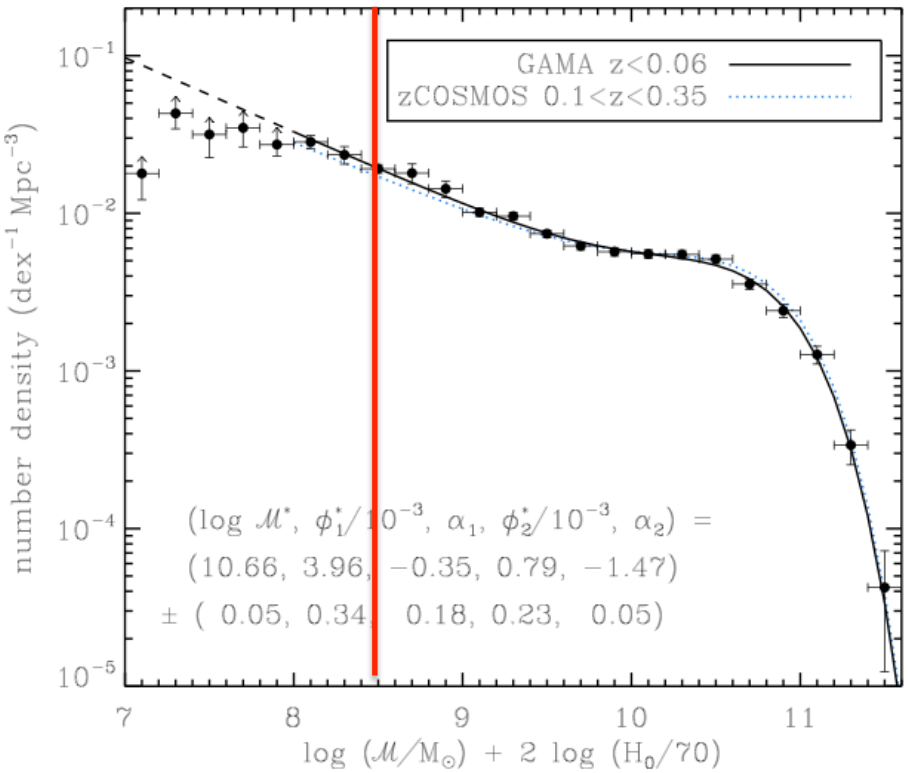
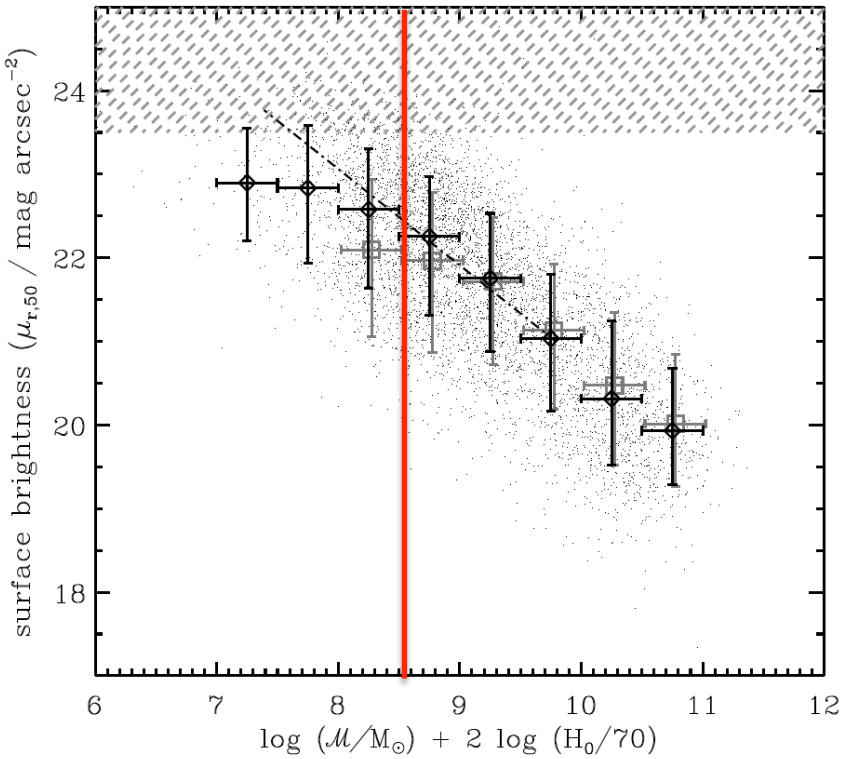
GAMA: LSBGs?

GALAXY STELLAR MASS FUNCTION ONLY KNOWN TO $10^{8.5}M_{\odot}$ AT z=0





Baldry et al (2013)

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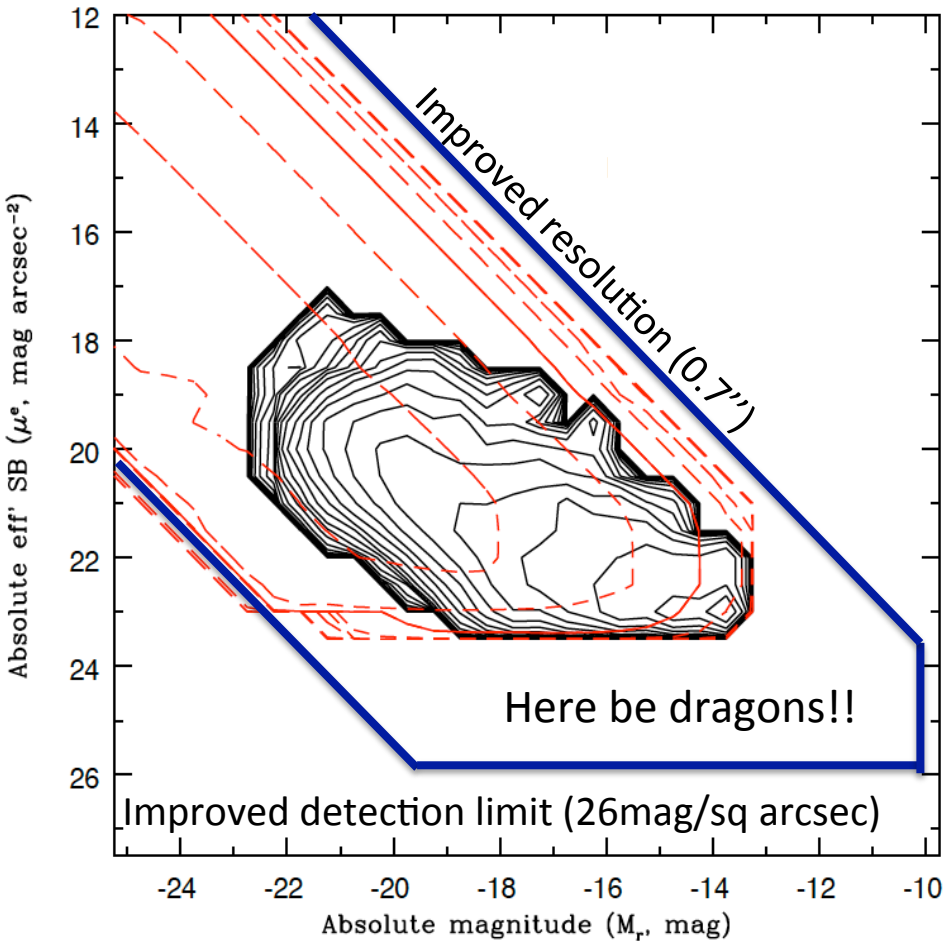
GAMA: LSBGs



The current constraint on the space density of galaxies is shown as contours with the selection boundaries for various volumes shown in red.

VST-KiDS will allow

- improved resolution
- improved surface brightness
- group refined photo-z's

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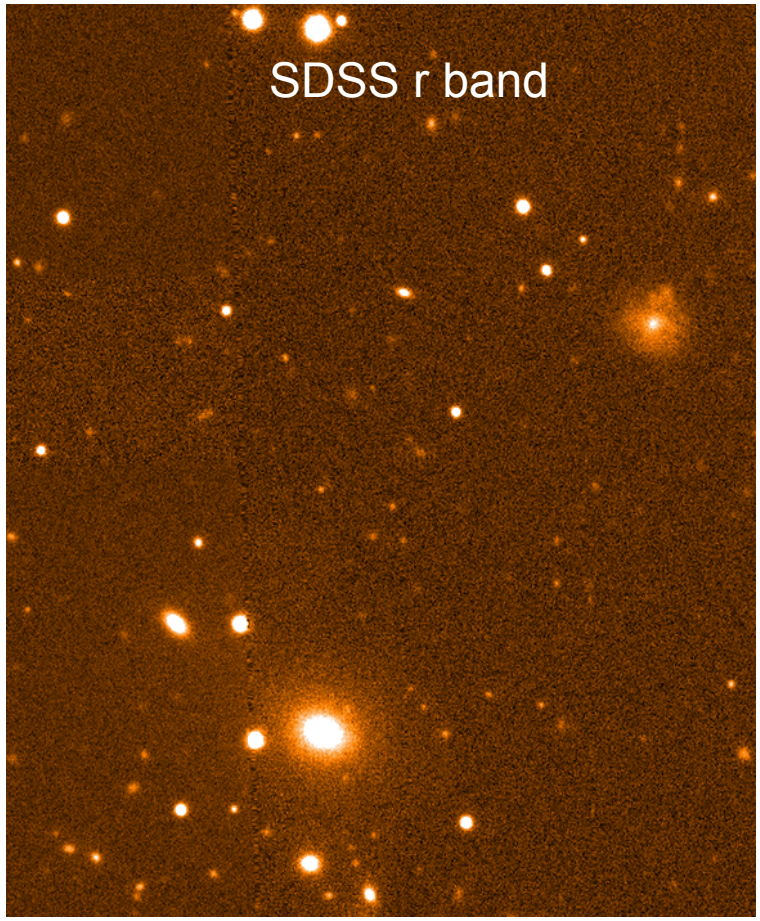
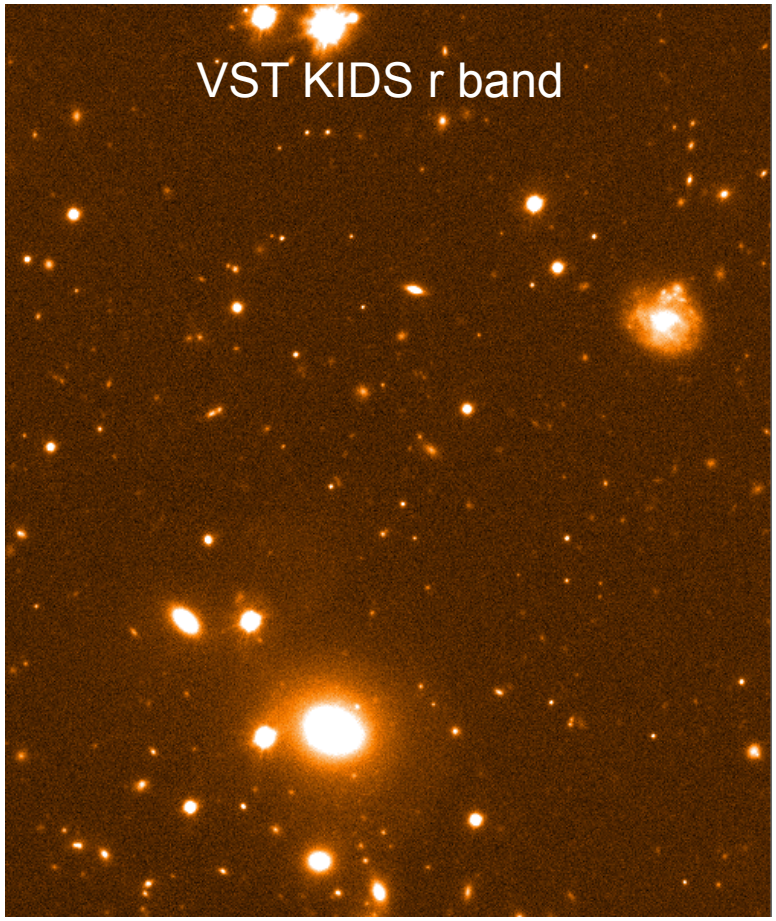
GAMA: LSBGs

Imaging resolution & depth
1.5” → 0.7”, r ~22 → r~24





Note the great work being done by DragonFly etc

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GAMA: components

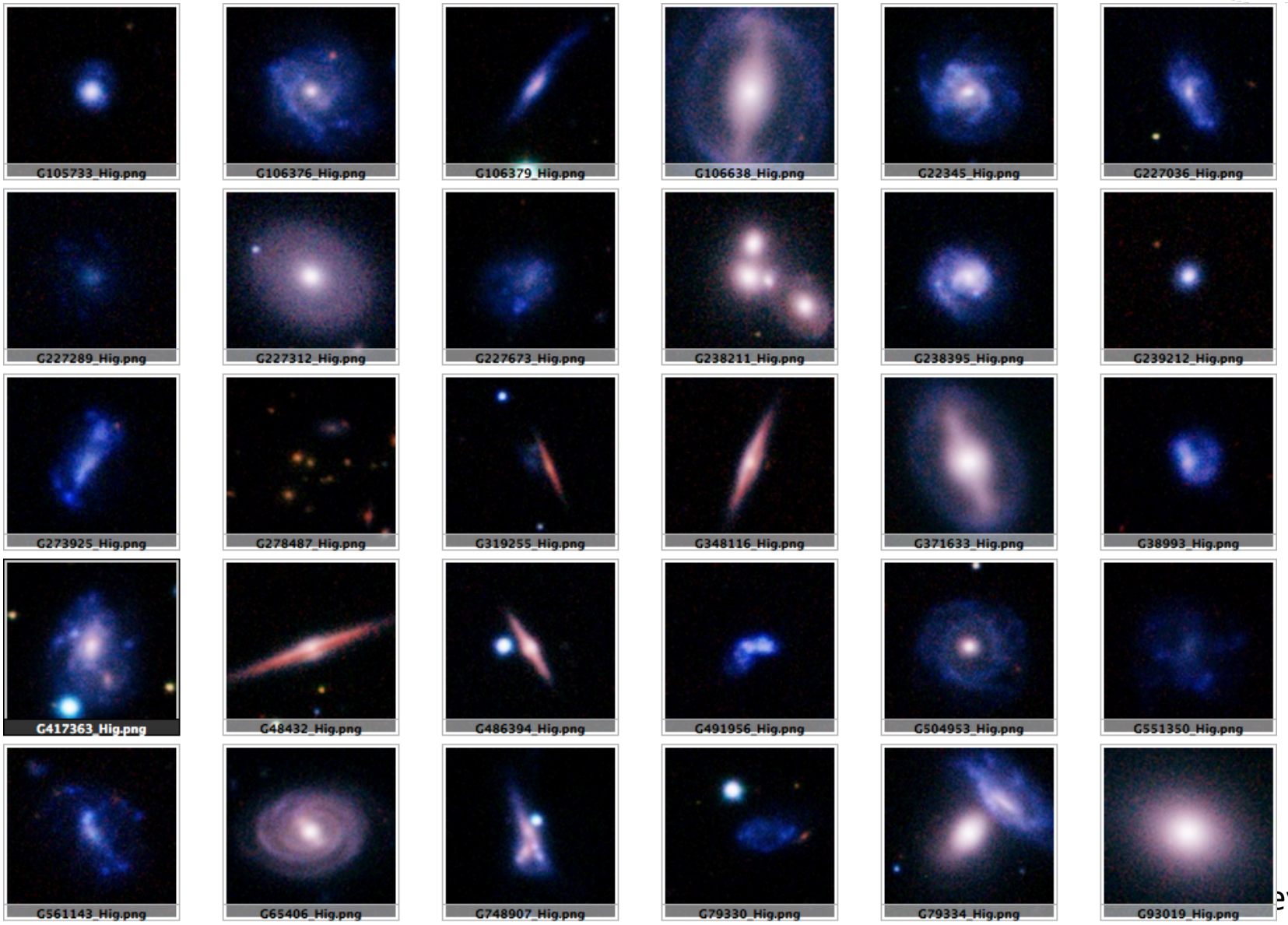
- Do galaxies come in two flavours or two components? (Driver et al 2013)

- z<0.1 folk generally agree two components:
  - dynamics (dynamically hot/pressure supported v dynamically cold/rotating)
  - stellar populations (α abundance, metallicities, ages)
  - Star-formation rates
  - Surface brightness profiles
  - Gas and dust content
  - SMBH-Bulge relations

- z>1 folk generally focus on blue v red because:
  - bulge-disc decomposition is extremely hard, (ask S^4G & CANDELS)
  - very high-z galaxies do not adhere to simple two-component mantra

- 0.1<z<1 a dearth of data (HST f.o.v. too small, need Euclid, WFIRST):
  - Fundamental need to bridge the low and high-z populations
  - Not a zone of significant focus but potentially fundamental to bridge this gap

Two-phase evolution



ey.org

Bulge-disc decomposition

Is anyone doing this right?

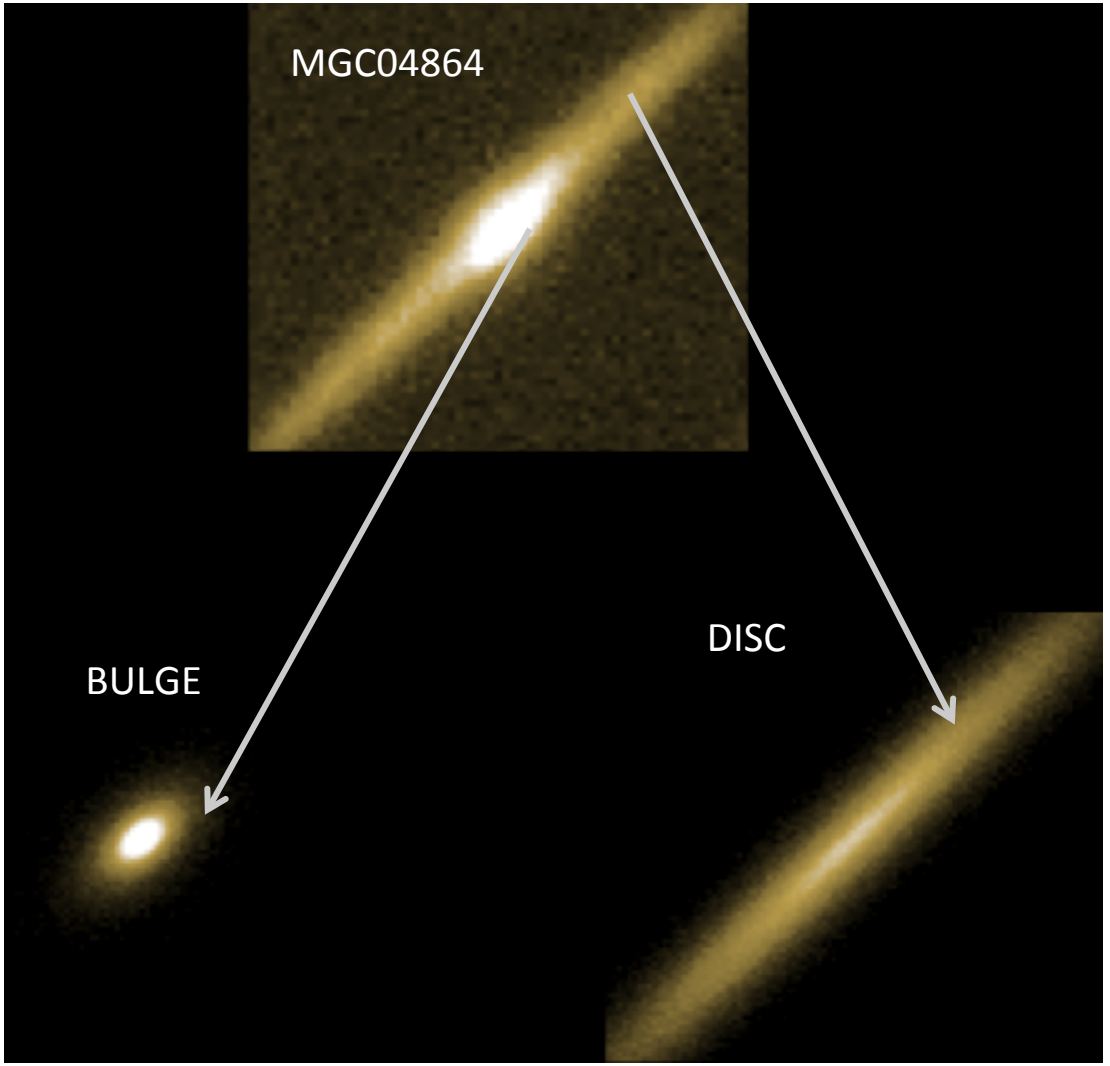
Probably S^{4}G closest

But how to move to fully automated process?

- GALFIT
- GIM2D
- BUDHA
- IMFIT
- <your code here>

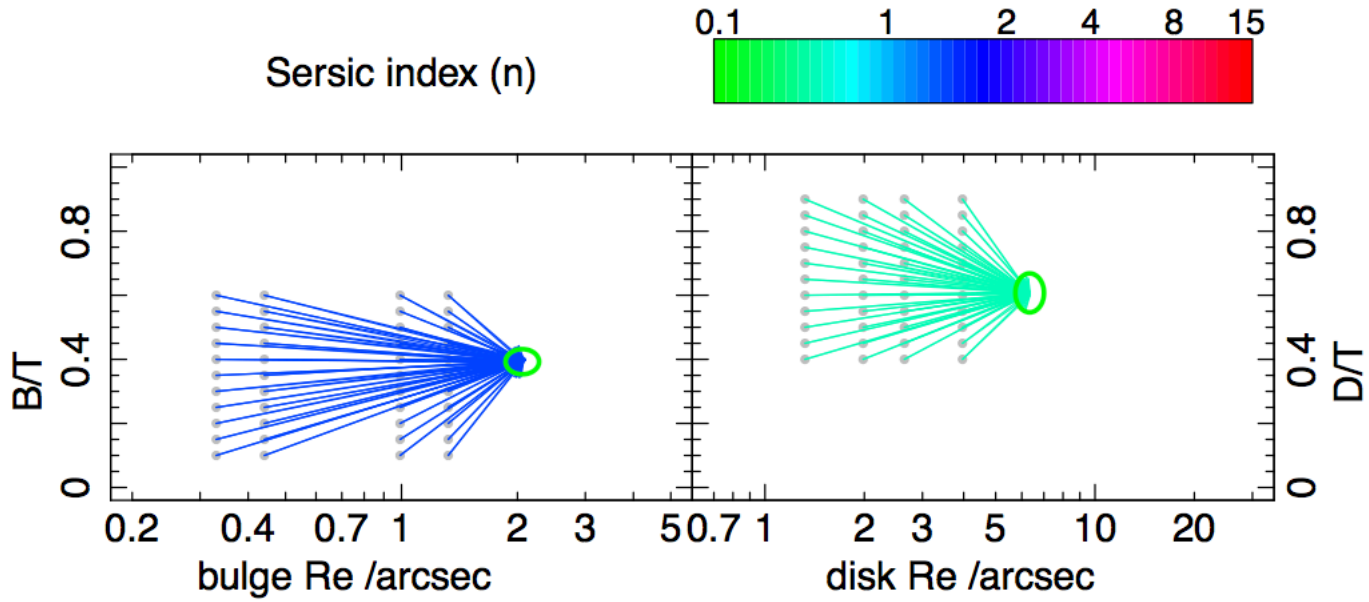
Typical 20-30% catastrophic failure rate

How many components
Multiple solutions
Initial conditions



GAMA: Bulge-disc decomposition

- GALFIT is the defacto code but has issues with initial conditions
- E.g., run galfit with a grid of B/T and size ratios and Sersic indicees.
- Ideally →



- Convergence!

Lange et al, in prep

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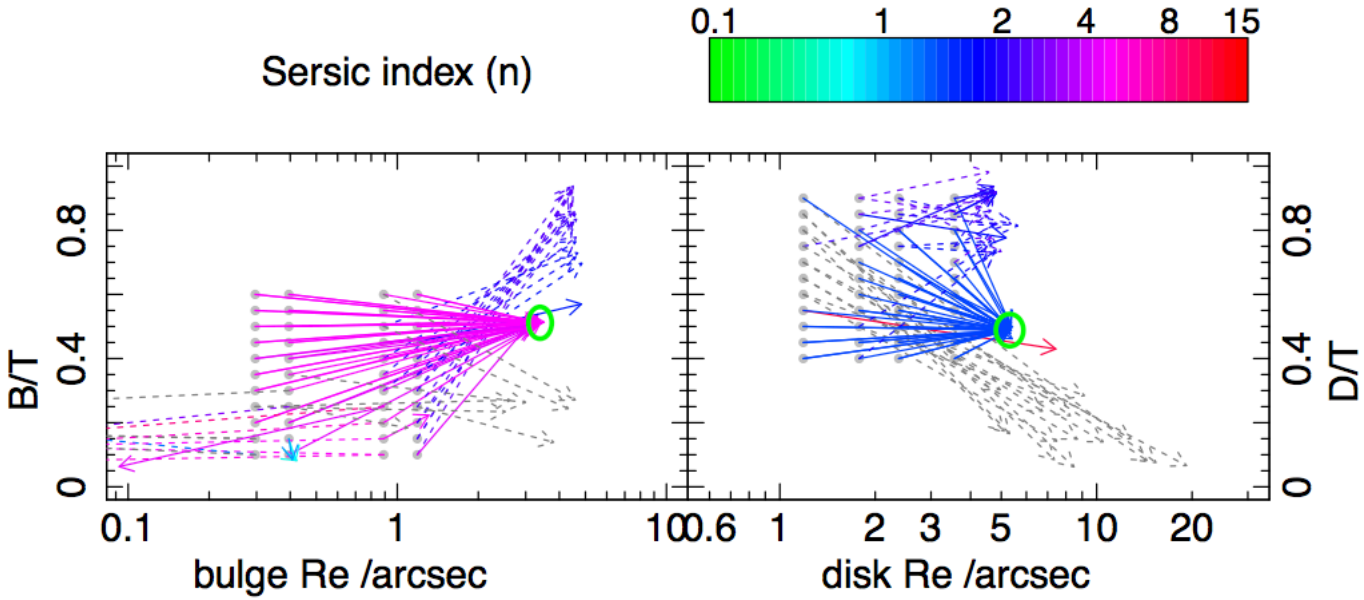
GAMA: Bulge-disc decomposition

- GALFIT is the defacto code but has issues with initial conditions
- E.g., run galfit with a grid of B/T and size ratios and Sersic indicees.
- In reality a significant fraction fails to converge →



- Partial convergence!

Lange et al, in prep

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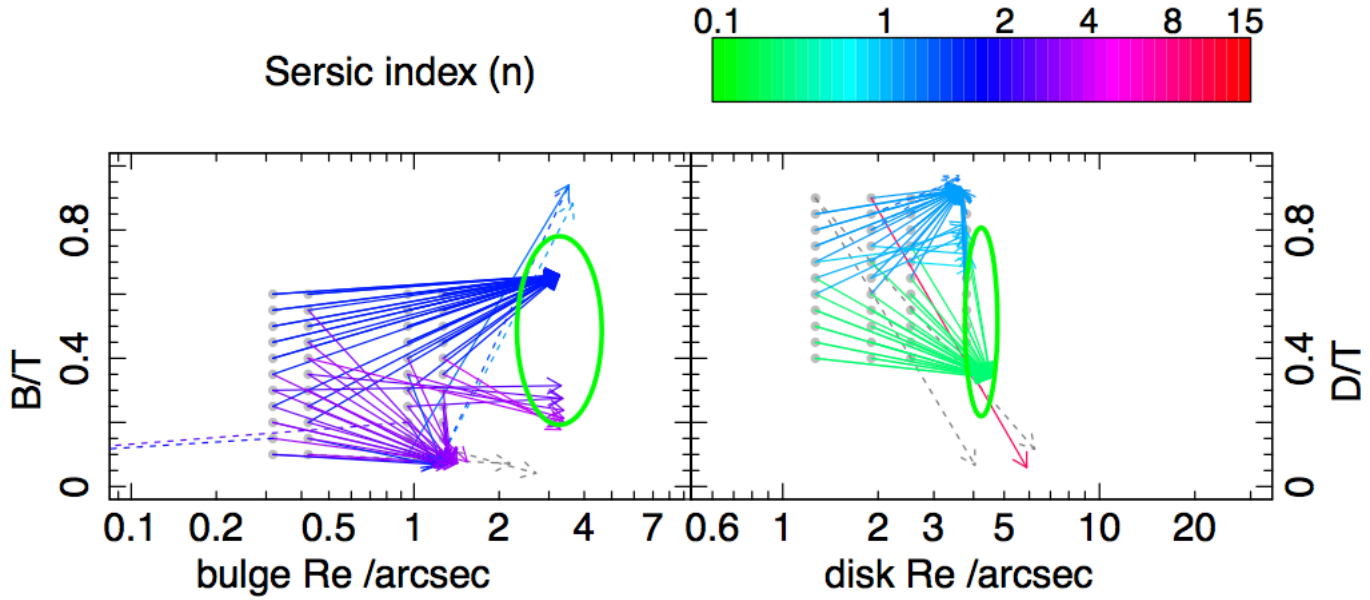
GAMA: Bulge-disc decomposition

- GALFIT is the defacto code but has issues with initial conditions
- E.g., run galfit with a grid of B/T and size ratios and Sersic indicees.
- and sometimes →



- Multiple solutions!

Lange et al, in prep

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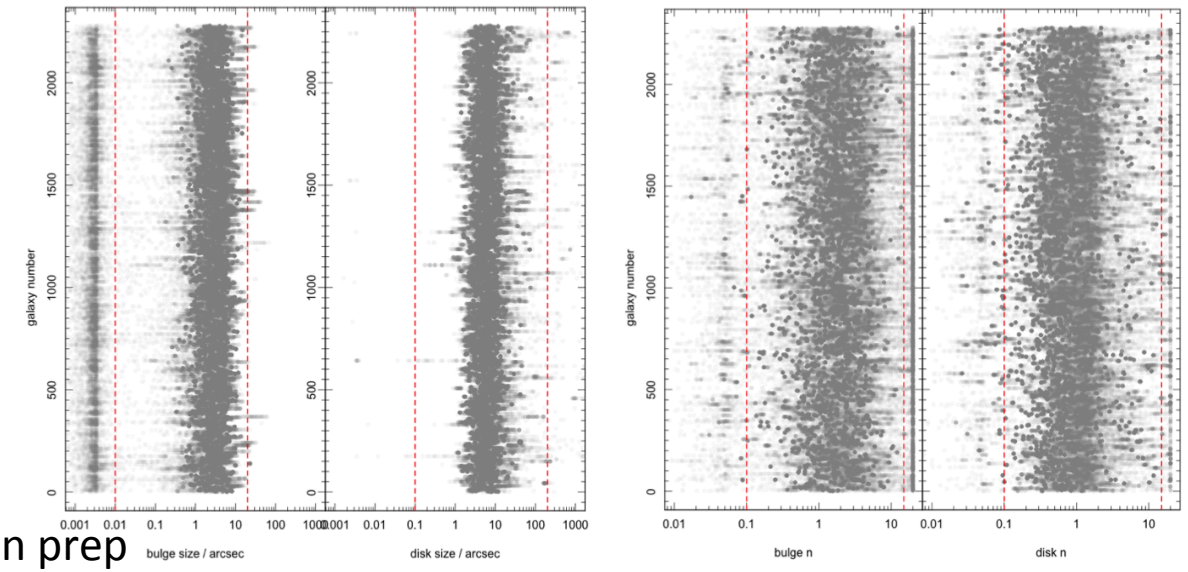
GAMA: Bulge-disc decomposition

- Our process:
  - Use eyeball classifications to determine if 1 or 2 component fit is needed (we tried AIC, BIC but outcomes not convincing)
  - Use a broad grid of initial conditions and run GALFIT (as previous slides)
  - Reject fits with extreme values (high-χ^2, n=0.01 or n=15 etc, R < 0.01'' etc)
  - Switch components when necessary (i.e., bulge Re > disc Re, $n_{bulge} < n_{disc}$)
  - Determine median values AND quantile ranges to obtain realistic errors



Lange et al, in prep

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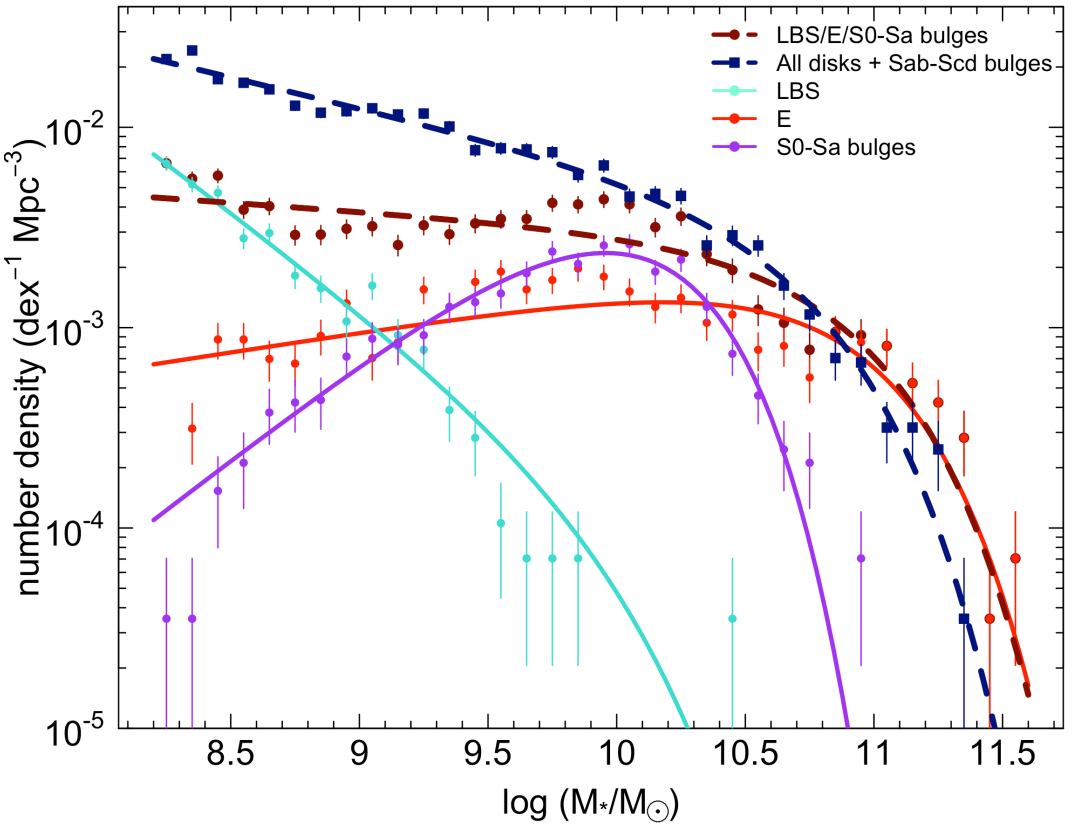
GAMA: Bulge-disc decomposition

Mass by component:

E:	34%
S0-Sa(bulge):	12%
Sab-Scd (bulge):	9.5%
S0-Sa (disc):	25.8%
Sab-Scd (disc):	12.2%
Sd-Irr:	5.0%
LBS:	1%
Spheroids:	46%
Discs:	53%



Two formation pathways of equal importance in terms of mass

But are Sab-Scd bulges really disc products?

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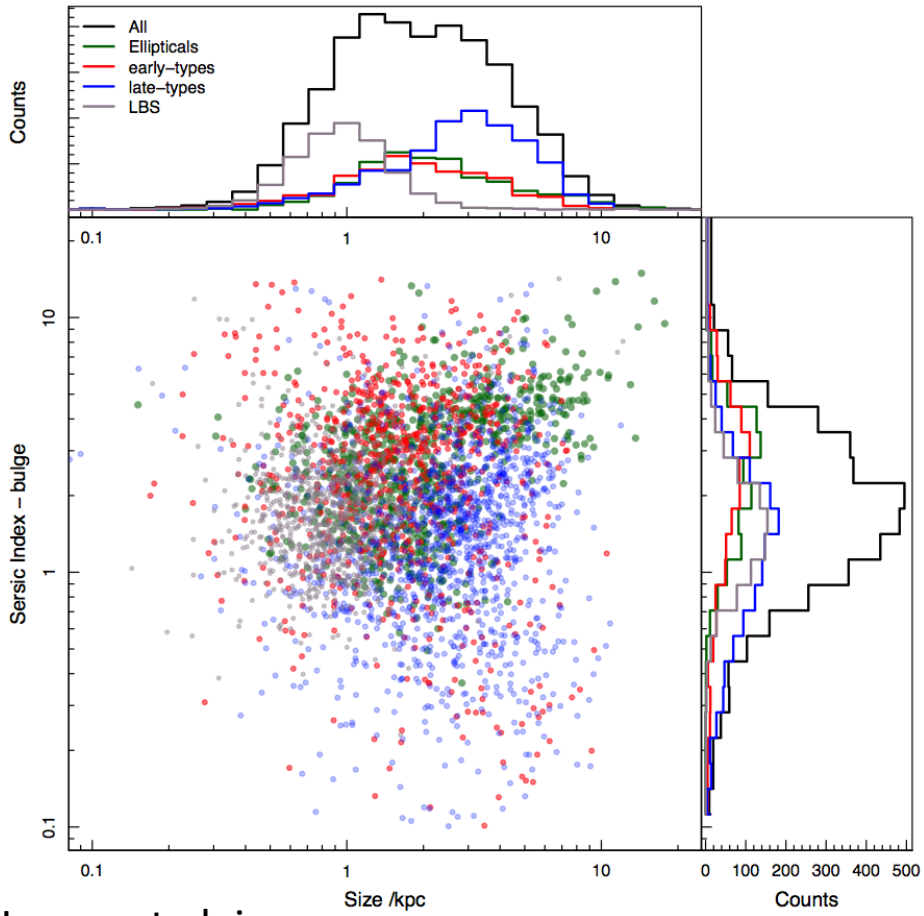
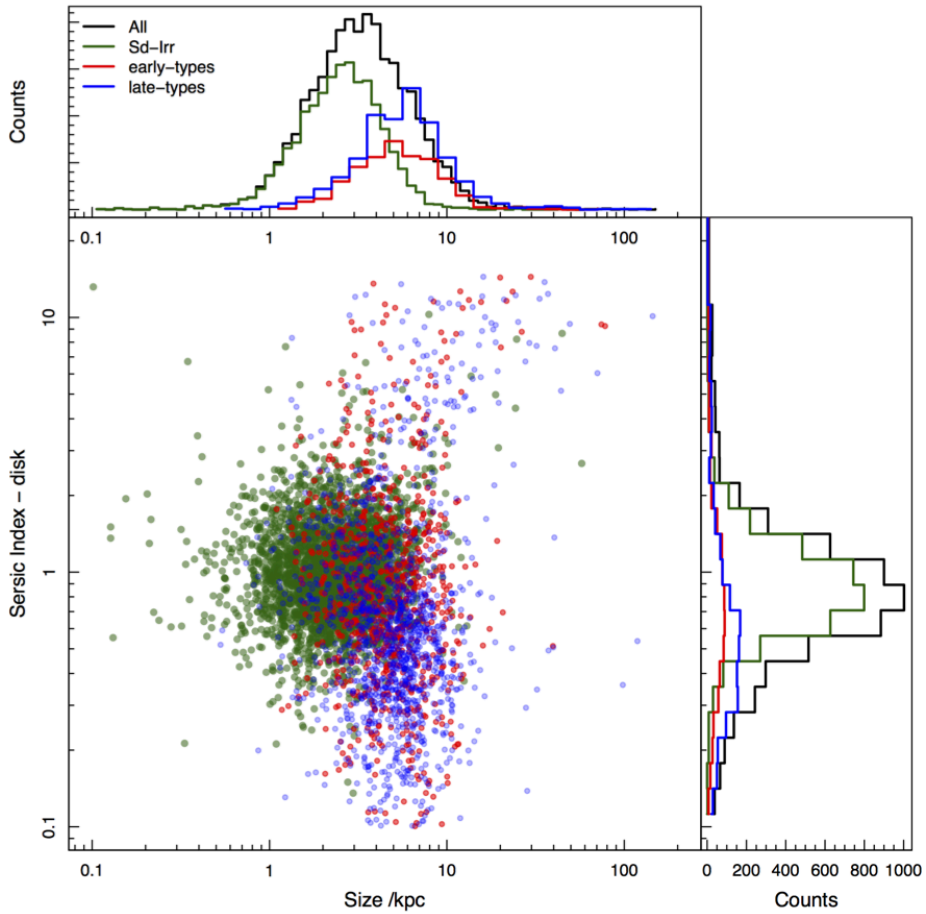
GAMA: components

Early-type bulges = Ellipticals
Late-type bulges more extended and lower Sersic index = pseudo-bulges?
Late-type discs = low n systems





Lange et al, in prep

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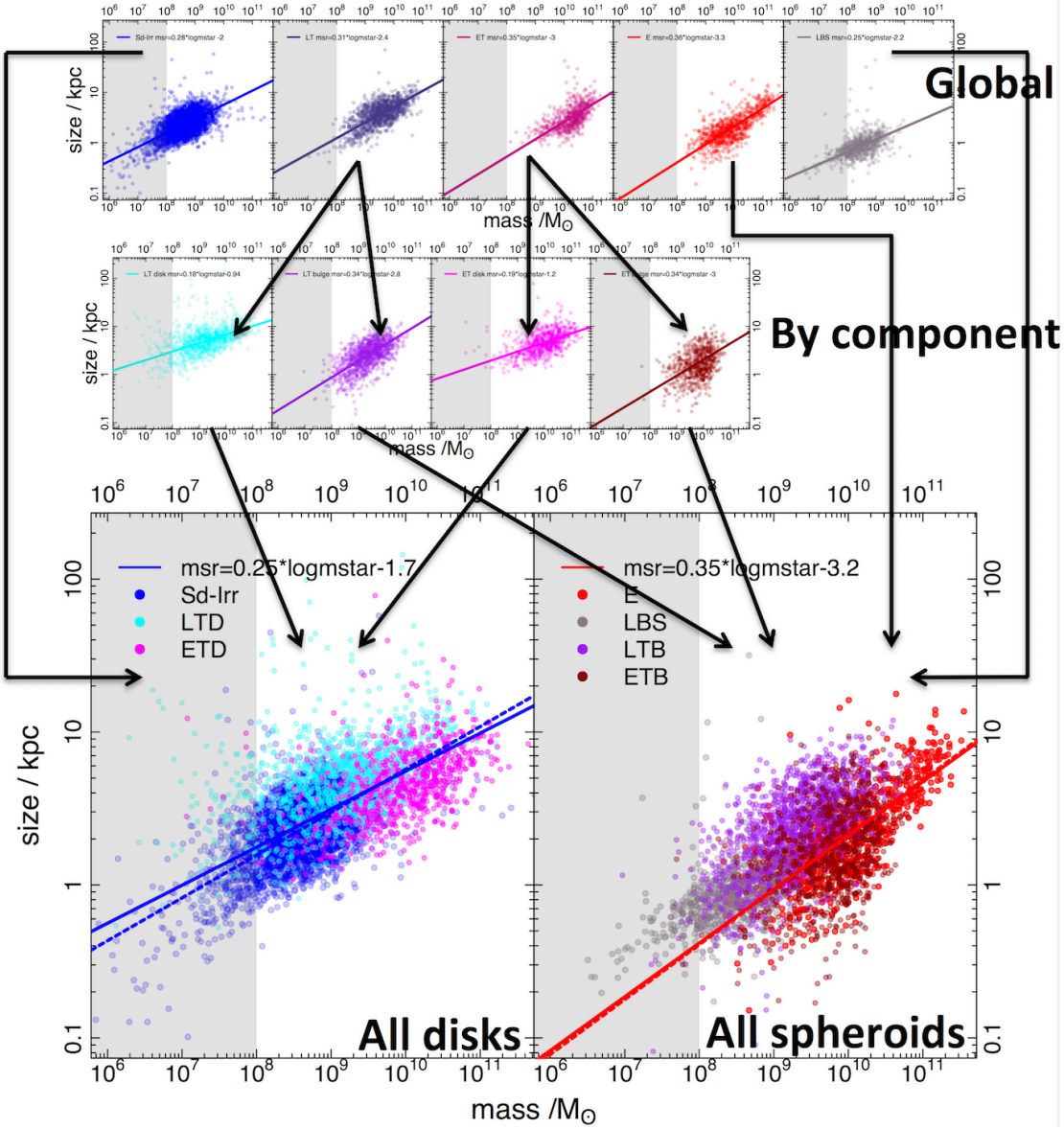
GAMA: Mass-size relations of distinct components

Preliminary, but:

Discs appear to follow a relatively well defined mass-size relation consistent with Sd/Irrs.

Late-type bulges follow more closely the disc relation
= pseudo-bulges? i.e., non-spheroid?



Lange et al, in prep

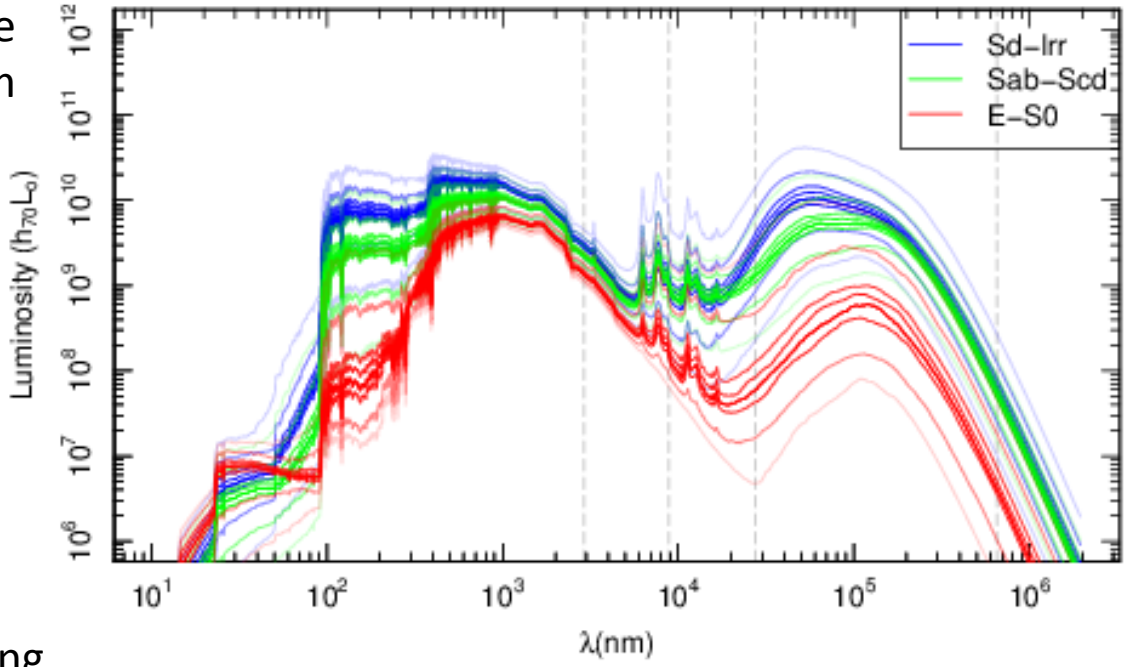
GAMA: energy by type

Energy output of mid and late-type spirals appear very consistent from far-UV to far-IR

Coupled with fairly tight M-R_e relations this suggests discs are effective self-regulating systems.

SF↑, SN rate increases, ISM and infalling gas heated, SF decreases.

SF↓, SN rate drops, ISM and infalling gas cools more efficiently, SF increases.

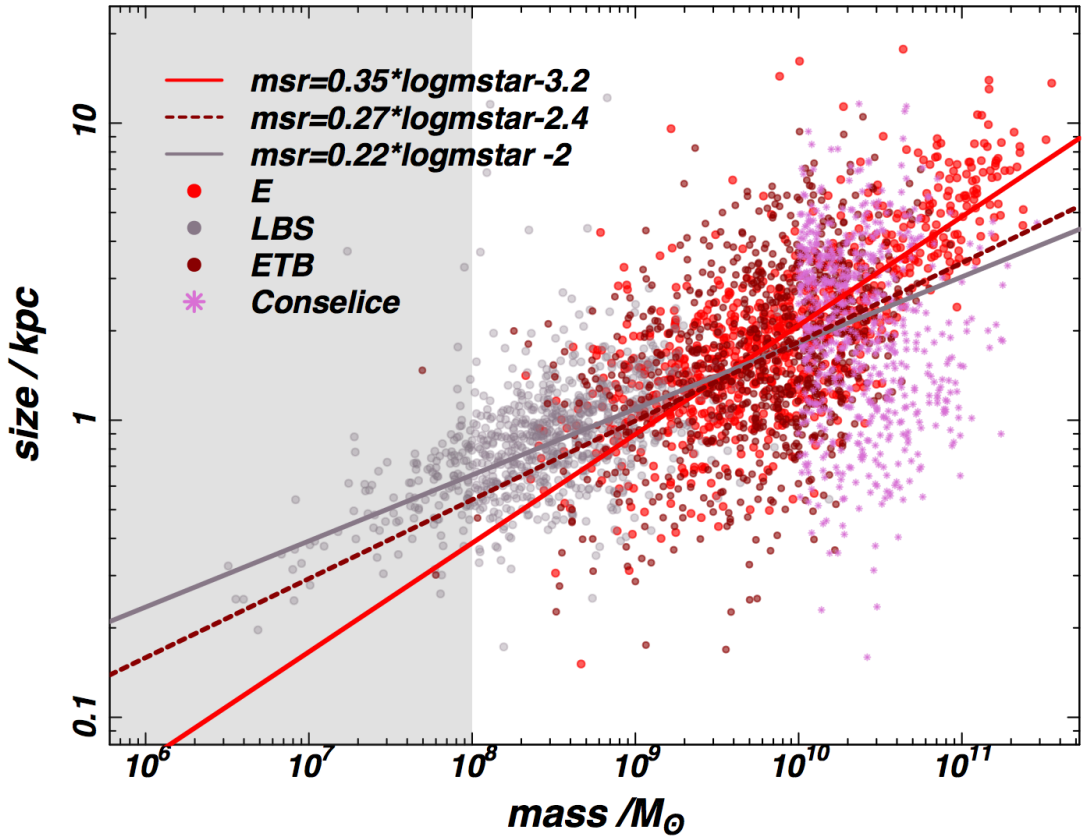


Driver et al (2015)

gama-survey.org

GAMA: components

High-z systems lie in similar region to today's spheroids (including bulges)
High-z systems = bulge-formation?



Lange et al, in prep

gama-survey.org

Summary

- GAMA data available for use (gama-survey.org and gama-psi.icrar.org)
- Observe energy decline from far-UV to far-IR over a 2Gyr baseline
  - the Universe is dying (merger rates, energy output, SFR)
- Stellar mass appears bounded:
  - Disc systems dominate at < $10^{10}M_o$
  - Disc systems dominate energy output at all wavelengths
  - little blue spheroids = mystery population (late starters, duty-cycle pop^n)
  - need deeper data to fully explore low-surface brightness Universe (e.g., DragonFly)
  - currently find stellar mass in spheroids = stellar mass in discs (two formation pathways?)
- Galaxies are two-component systems:
  - Bulge-disc decomposition is non-trivial (complex process but getting there)
  - Bulges of late-types are different to bulges of early-types (pseudo-bulges?)
  - Are discs the perfect self-regulating systems?
    - Discs of all types lie on a common mass-size relation
    - Discs have self-similar energy outputs (far-UV to far-IR)
  - Ellipticals, Bulges, and high-z systems lie on a similar M-R_e relation
  - Bulge formation z > 1.5, Disc formation z < 1.5 (see Driver et al 1998, 2013)
- WAVES survey is needed to bridge z<0.1 and z>1 Universe (wavesurvey.org)