The stellar mass functions of spheroids and discs

Simon Driver

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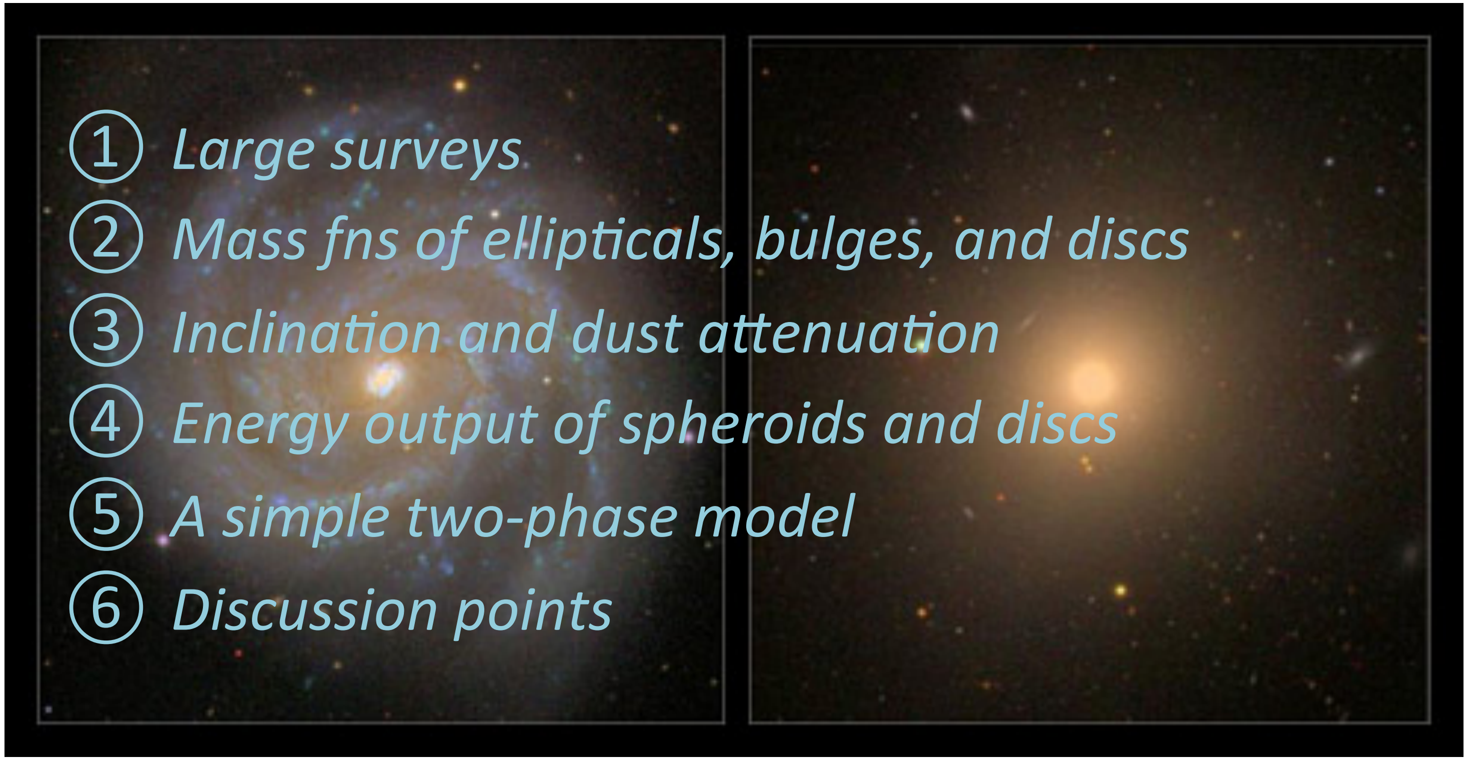
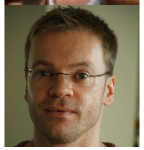


1. *Large surveys*
2. *Mass fns of ellipticals, bulges, and discs*
3. *Inclination and dust attenuation*
4. *Energy output of spheroids and discs*
5. *A simple two-phase model*
6. *Discussion points*

Key collaborators/contributors


Joe Liske (ESO)


Alister Graham (Swinburne)


Paul Allen (City)

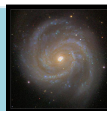

Lee Kelvin (Innsbruck)


Rebecca Lange (UWA)


Aaron Robotham (UWA)


Mehmet Alpaslan (St Andrews)

GAMA Team

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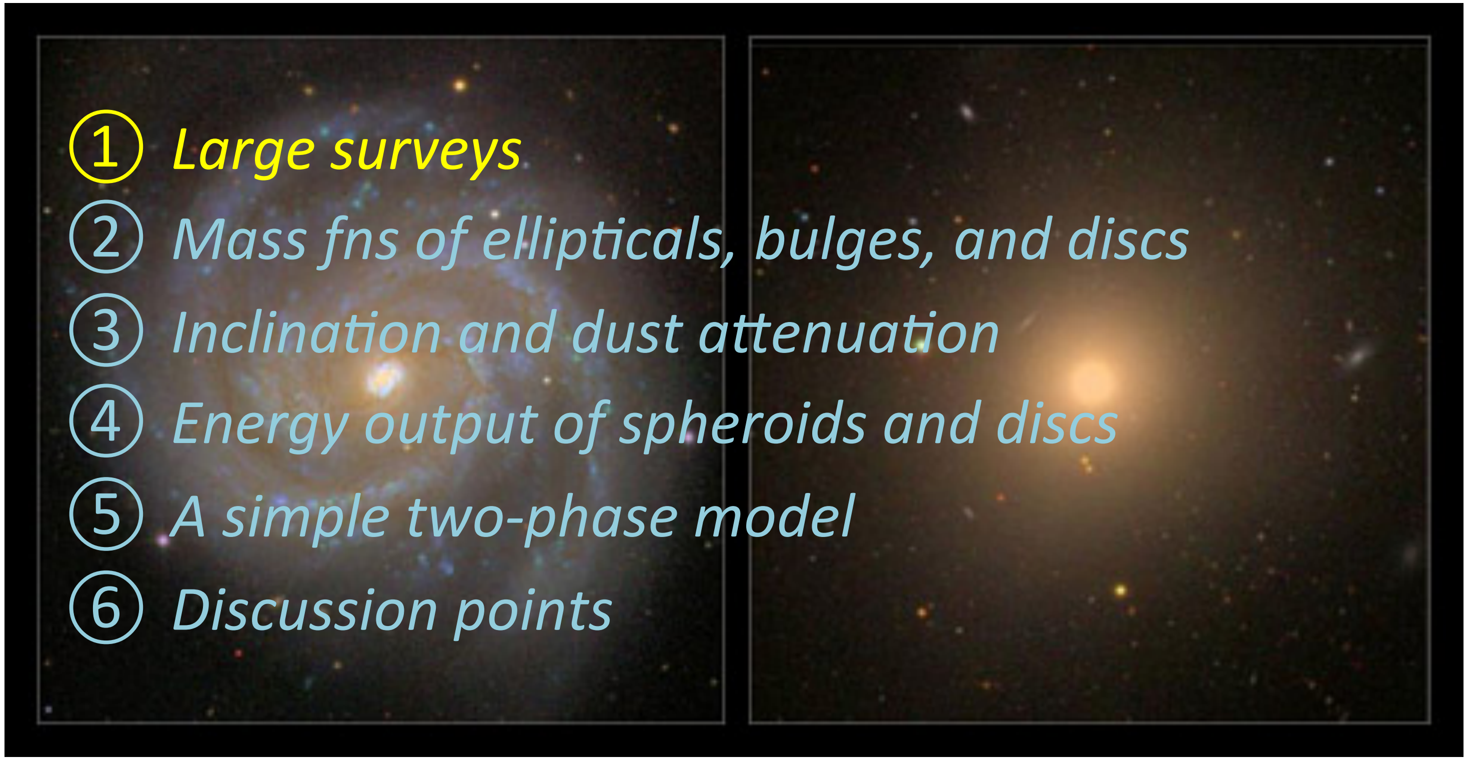

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Large Galaxy Surveys: SDSS, MGC, GAMA & WAVES
(with redshifts)

10k redshifts
uBgrizYJHK
B<20mag
1'' spatial res, 30 sq deg
http://www.eso.org/~jliske/mgc/
Liske et al (2003)

MGC
Millennium Galaxy Catalogue

250k redshifts
UV-Opt-IR-Radio
r<19.8mag
0.7'' spatial res, 250 sq deg
http://www.gama-survey.org/
Driver et al (2011)

GAMA

2million redshifts
UV-Opt-IR-Radio
r<22mag & phot-z
0.2'' spatial res, 1000 sq deg

WAVES

Survey footprints

10k redshifts
uBgrizYJHK
B<20mag
1'' spatial res, 30 sq deg
http://www.eso.org/~jliske/mgc/
Liske et al (2003)

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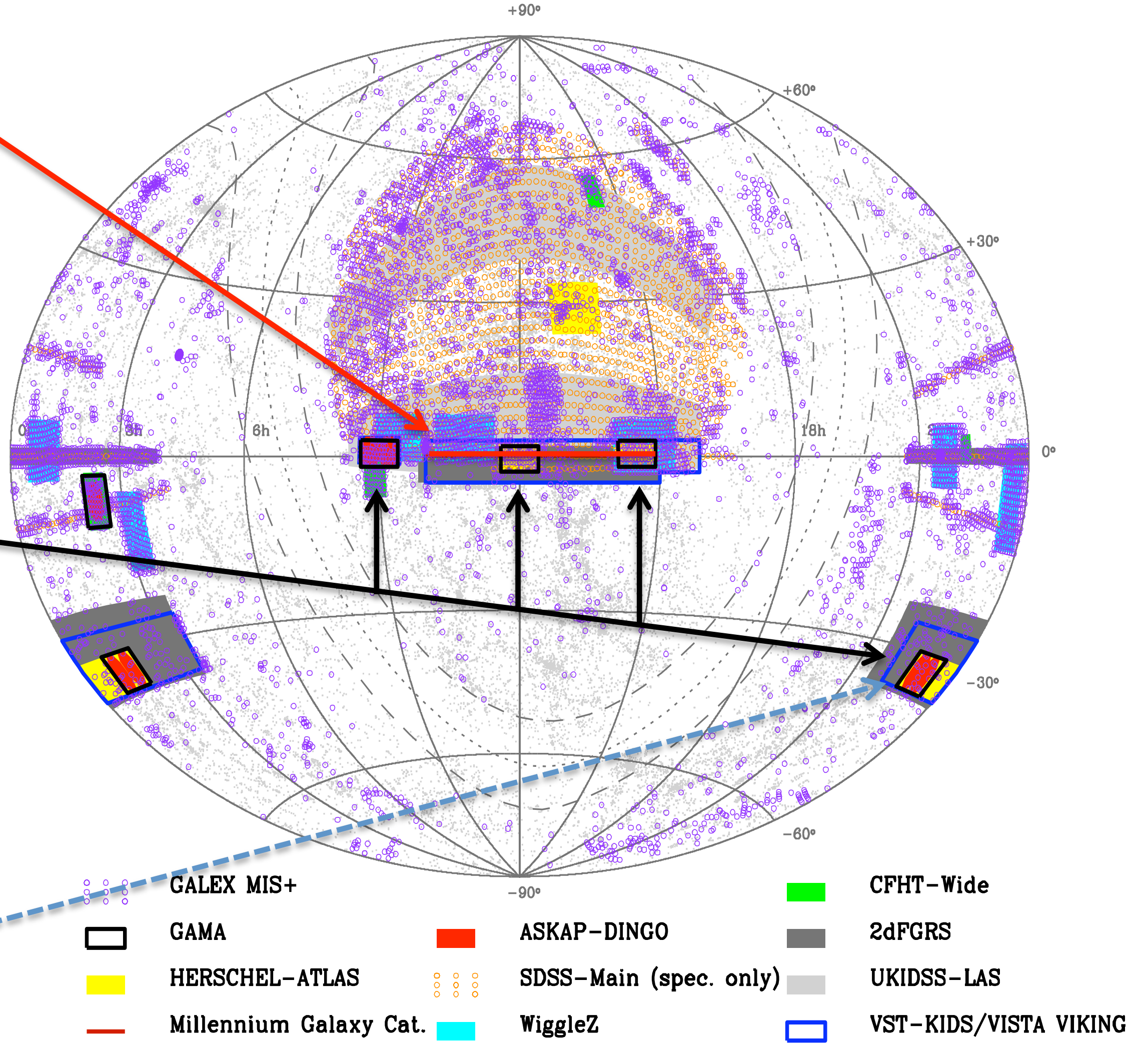


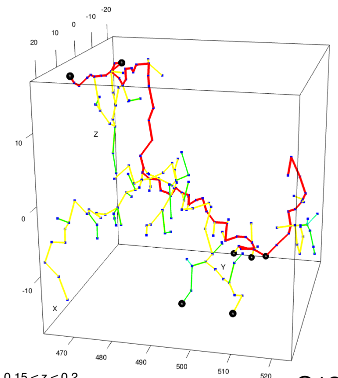
Structure on 1kpc to 100Mpc scales

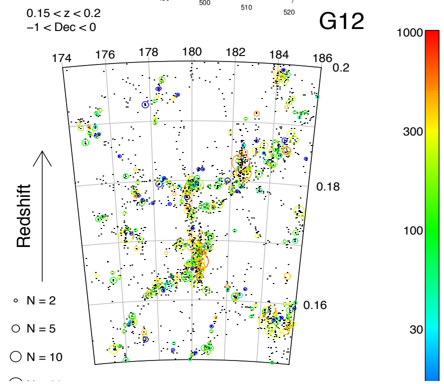
Cosmology:
- Driver & Robotham (2010), cosmic variance
- Blake et al (2013), growth of structure tracers
- Robotham et al (in prep), halo mass function

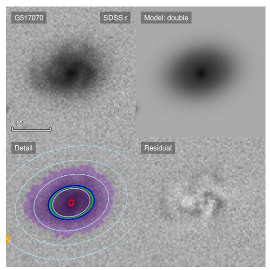
Filaments, tendrils and voids (1-100Mpc):
- Alpaslan et al (2013), 500 filaments
- Alpaslan et al (2013, submitted), Tendril discovery

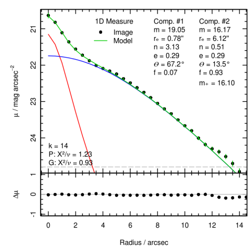
Galaxy groups (100kpc-1Mpc):
- Calvi, Poggianti & Vulcani (2011), 176 groups (PM2GC)
- Robotham et al (2011), 14k groups (G^3Cv1)
- Robotham et al (in prep), 24k groups (G^3Cv2)

Galaxy structure (~1-10kpc):
- Allen et al (2006), 10k GIM2D bulge-disc decomps
- Driver et al (2007), 10k GIM2D, bulge-disc mass densities
- Driver et al (2008), 10k GIM2D, dust attenuation
- Kelvin et al (2011), 150k Sersic profiles
- Kelvin et al (2013a,b), 3k Hubble type Mass Functions
- Kelvin et al (in prep), 3k GALFIT3 decomps
- Lange et al (in prep), z<0.1 bulge-disc mass-size relations
- Lange et al (in prep), 30k GALFIT3 decomps



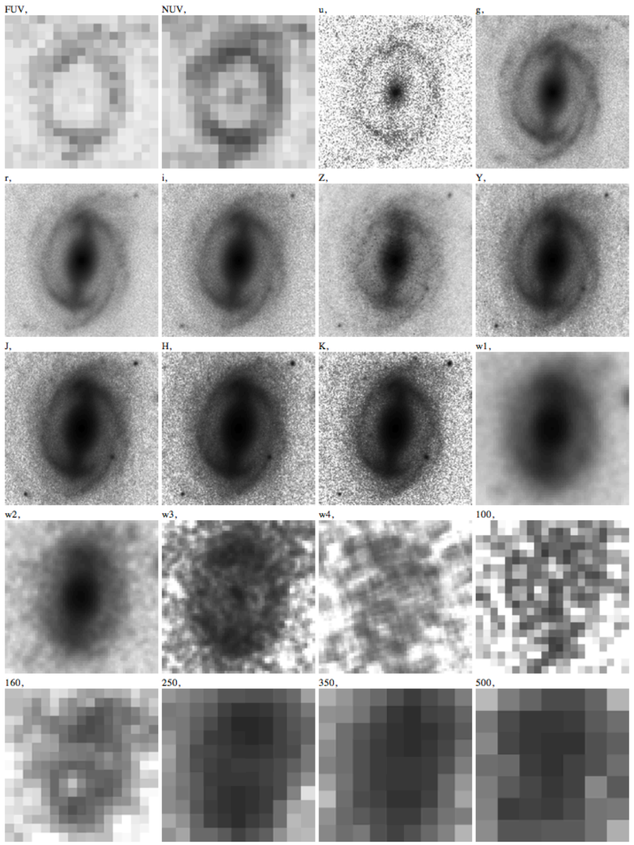


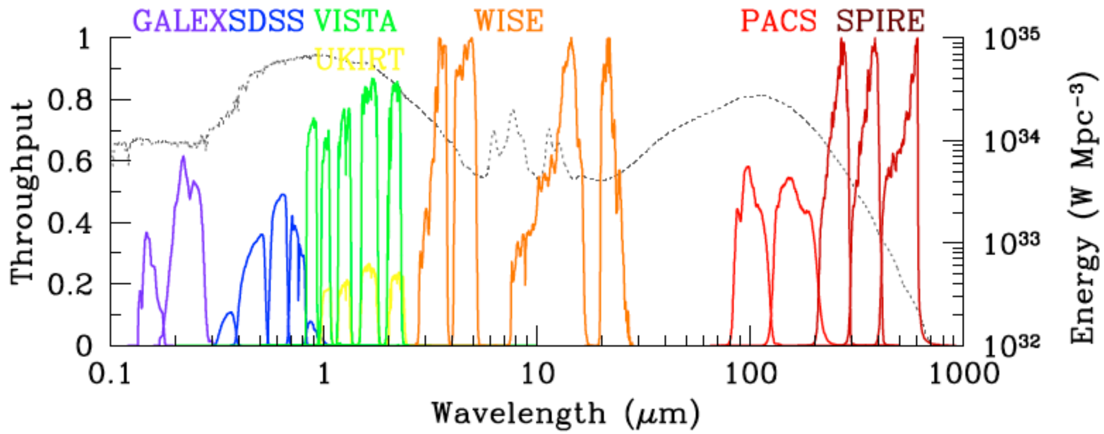


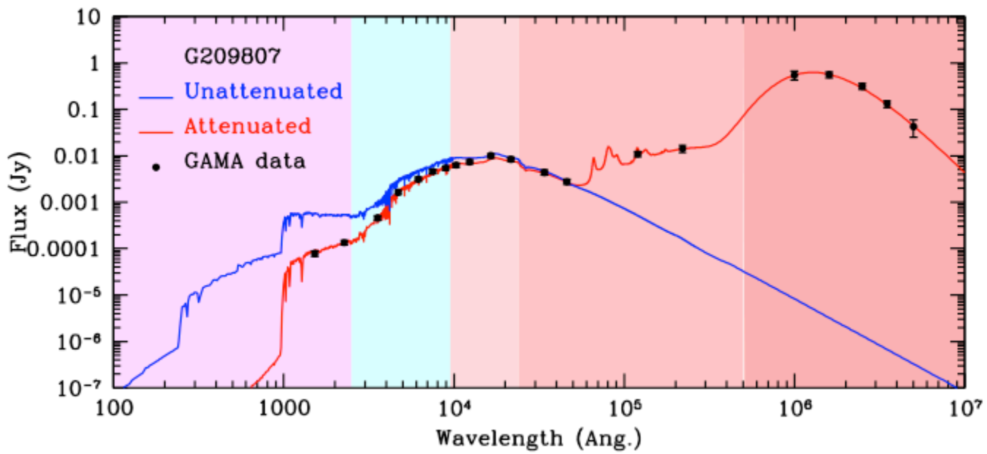


Energy output of galaxies

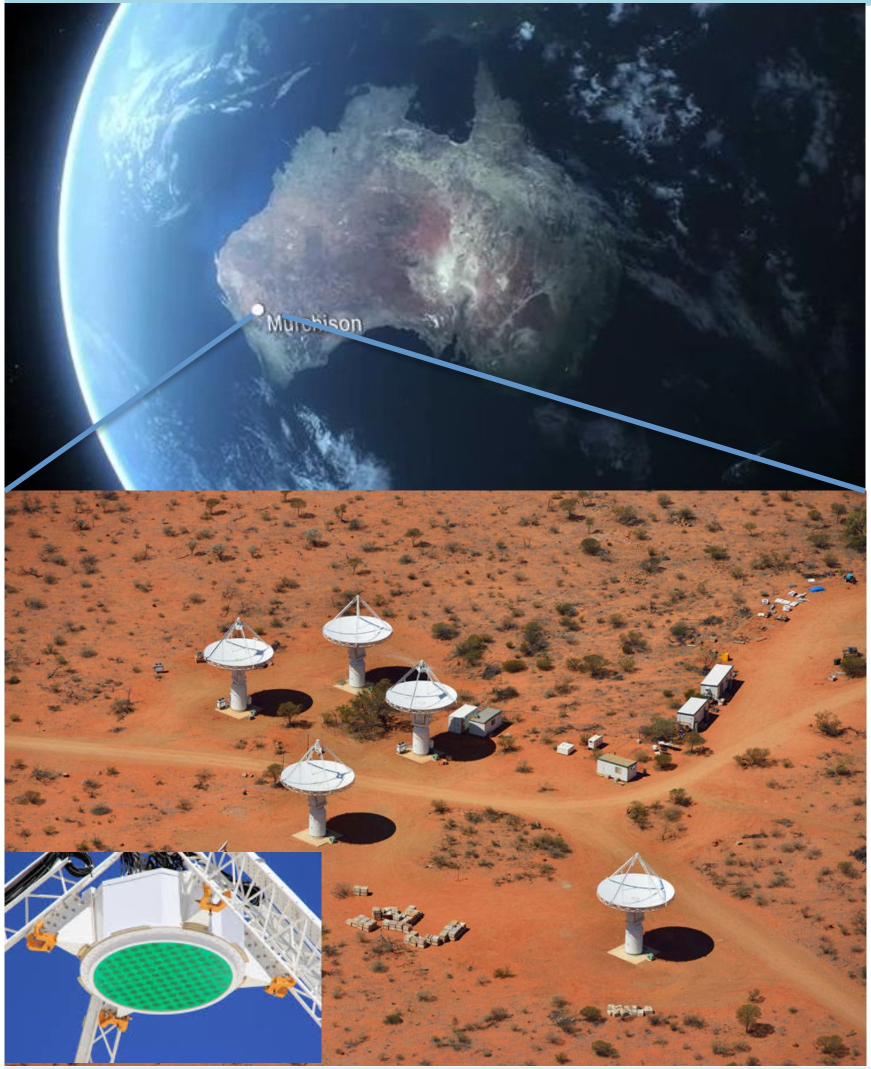
20 band photometry
FUV-Opt-NIR-MIR-FIR



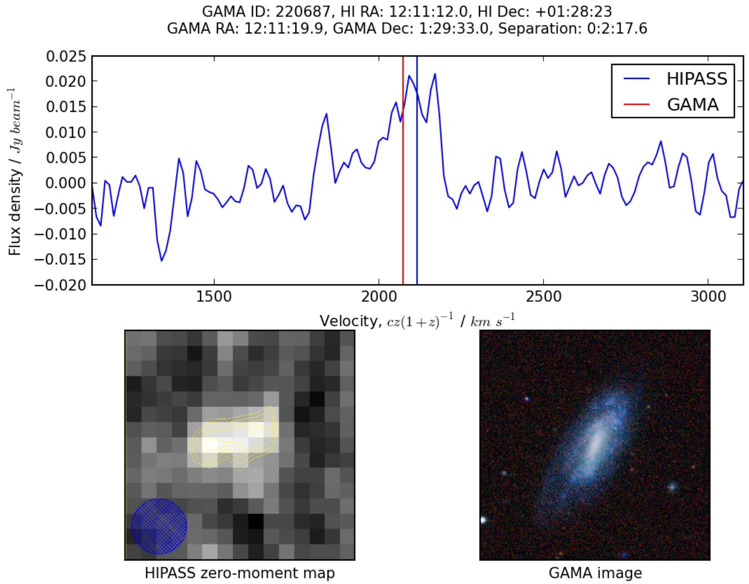




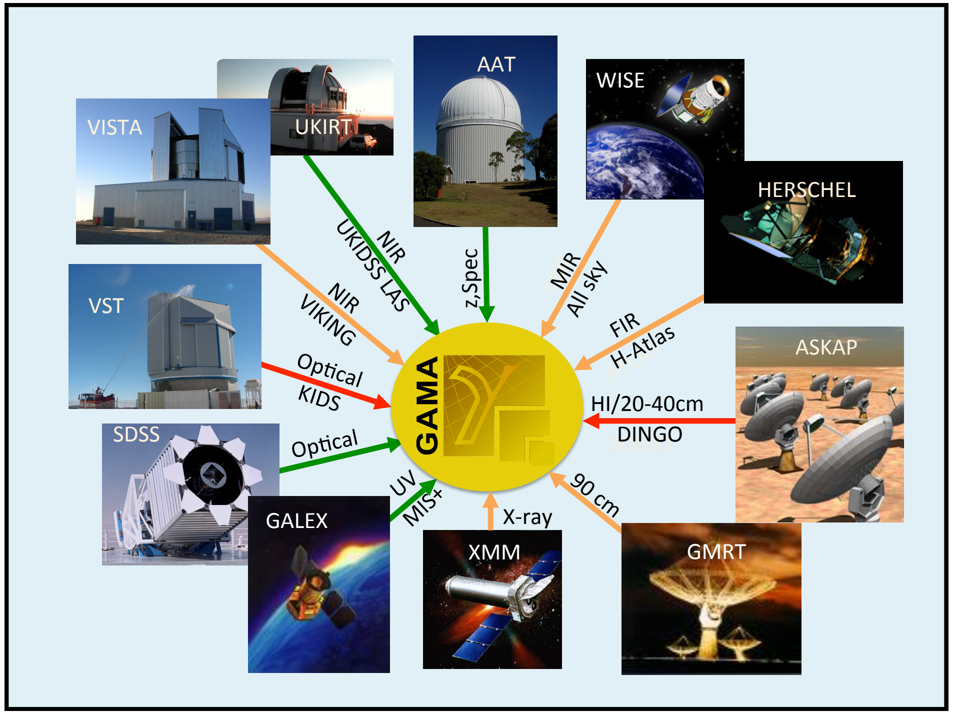
HI gas and dynamics via ASKAP

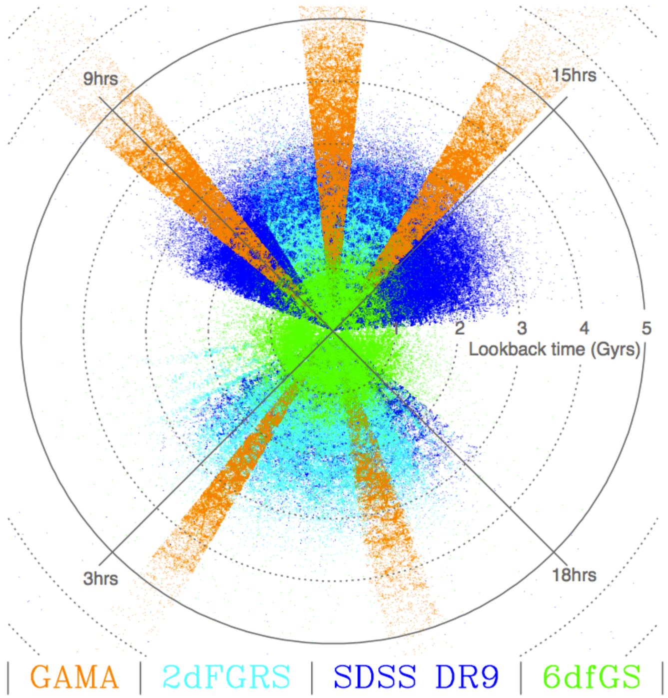


Australian-SKA Pathfinder
Thirty-six 12m antennas with phase array feeds
30 sq deg field of view
GAMA23 region primary deep target
Operations with 12 antennas comence Dec-2014
HI to z=0.45



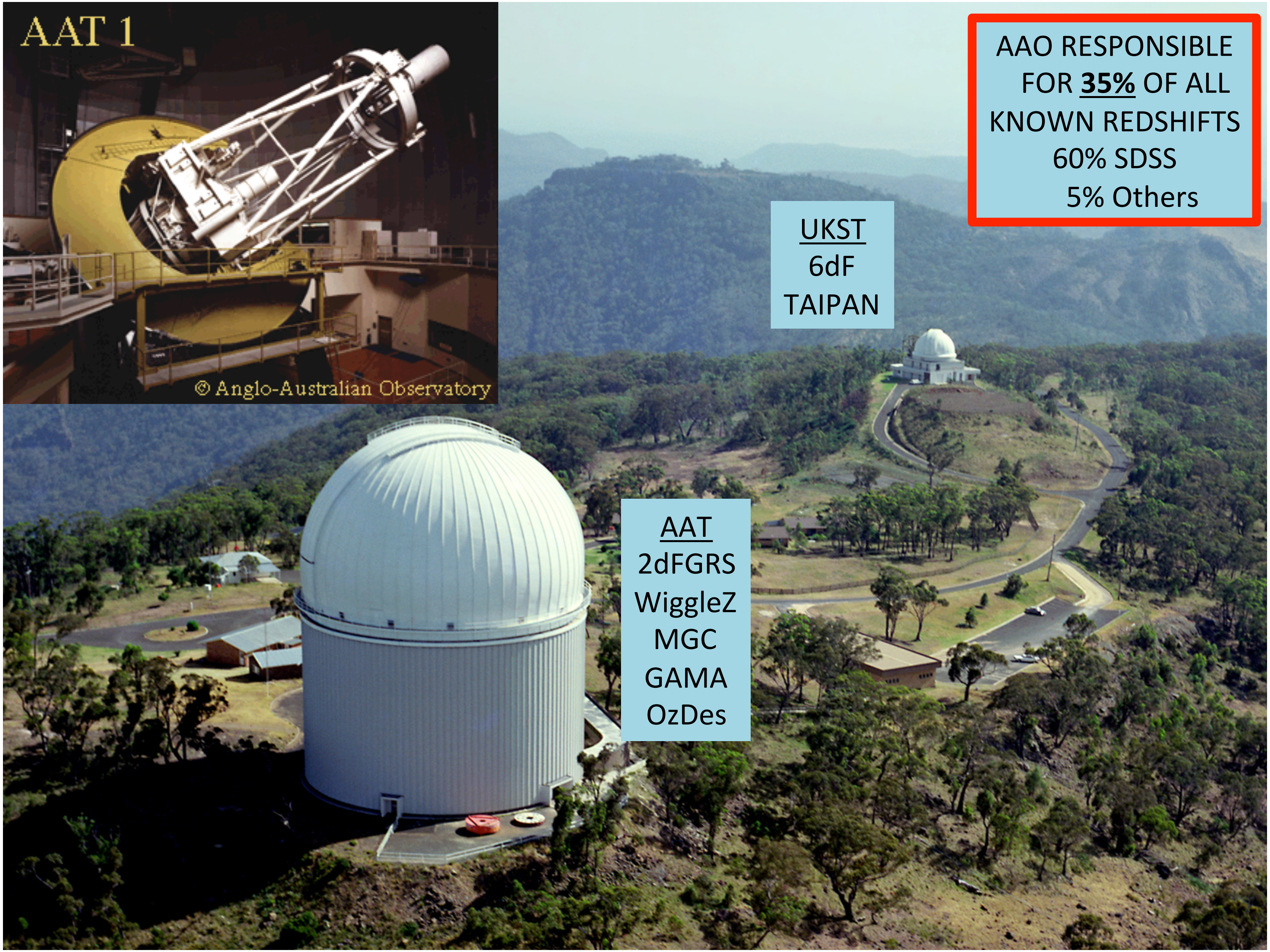
Galaxy And Mass Assembly (GAMA)



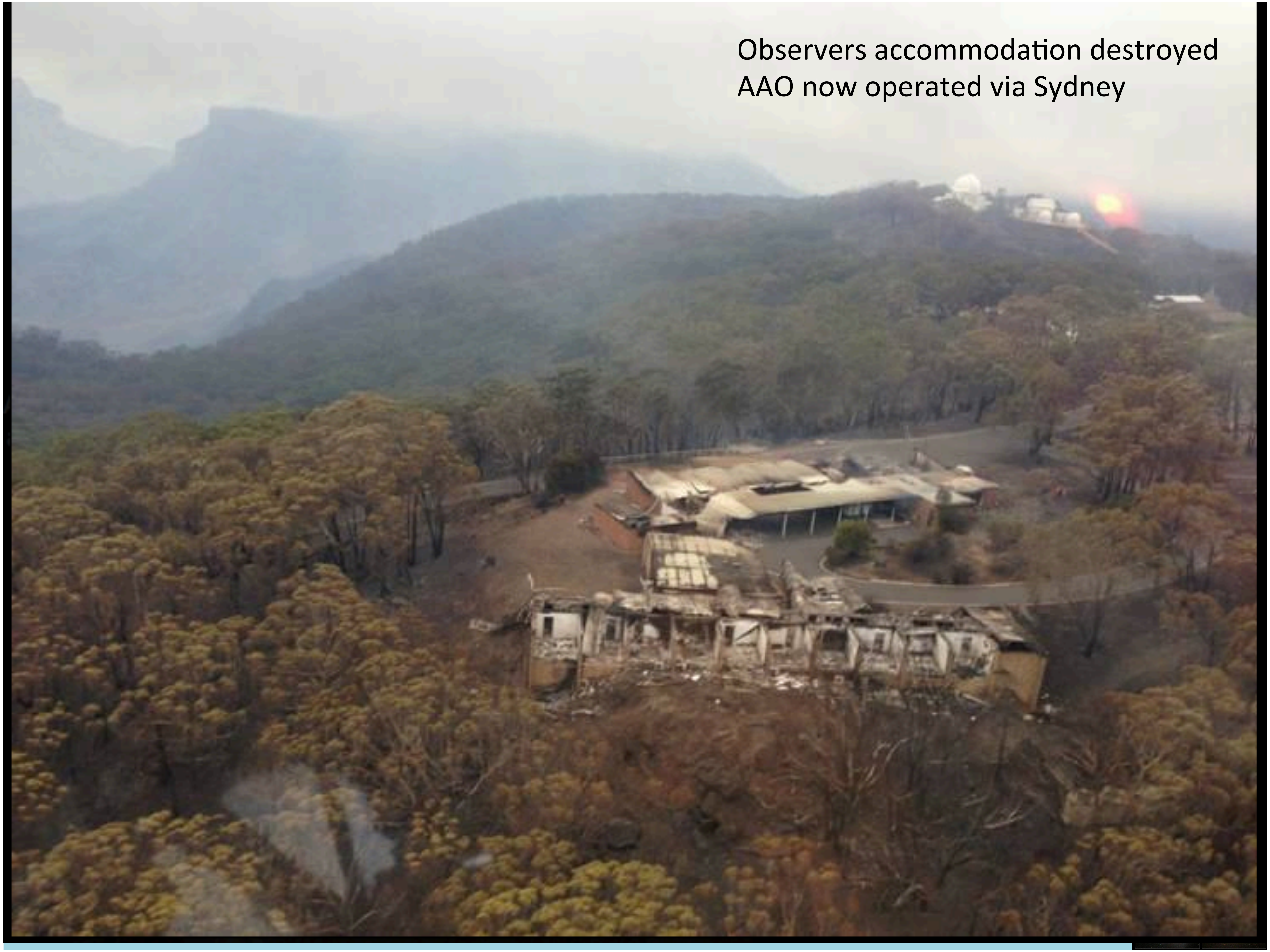


240,000 galaxies to r<19.8mag over four 60 sq deg (~98% complete, selected from SDSS)

- catalogue of 25,000 groups (halos) to $10^{12}M_o$
- 20 band photometry + gas (ASKAP) [GALEX+VST+VIKING+WISE+Herschel]
- structure on 1kpc to 100Mpc scales to z~0.2
- DR2 available via http://www.gama-survey.org/dr2/


AAT 1
© Anglo-Australian Observatory
AAO RESPONSIBLE
FOR 35% OF ALL
KNOWN REDSHIFTS
60% SDSS
5% Others
UKST
6dF
TAIPAN
AAT
2dFGRS
WiggleZ
MGC
GAMA
OzDes

January 2012 Bushfire: No significant damage to AAT
Operations resumed within 1 month


Observers accommodation destroyed
AAO now operated via Sydney

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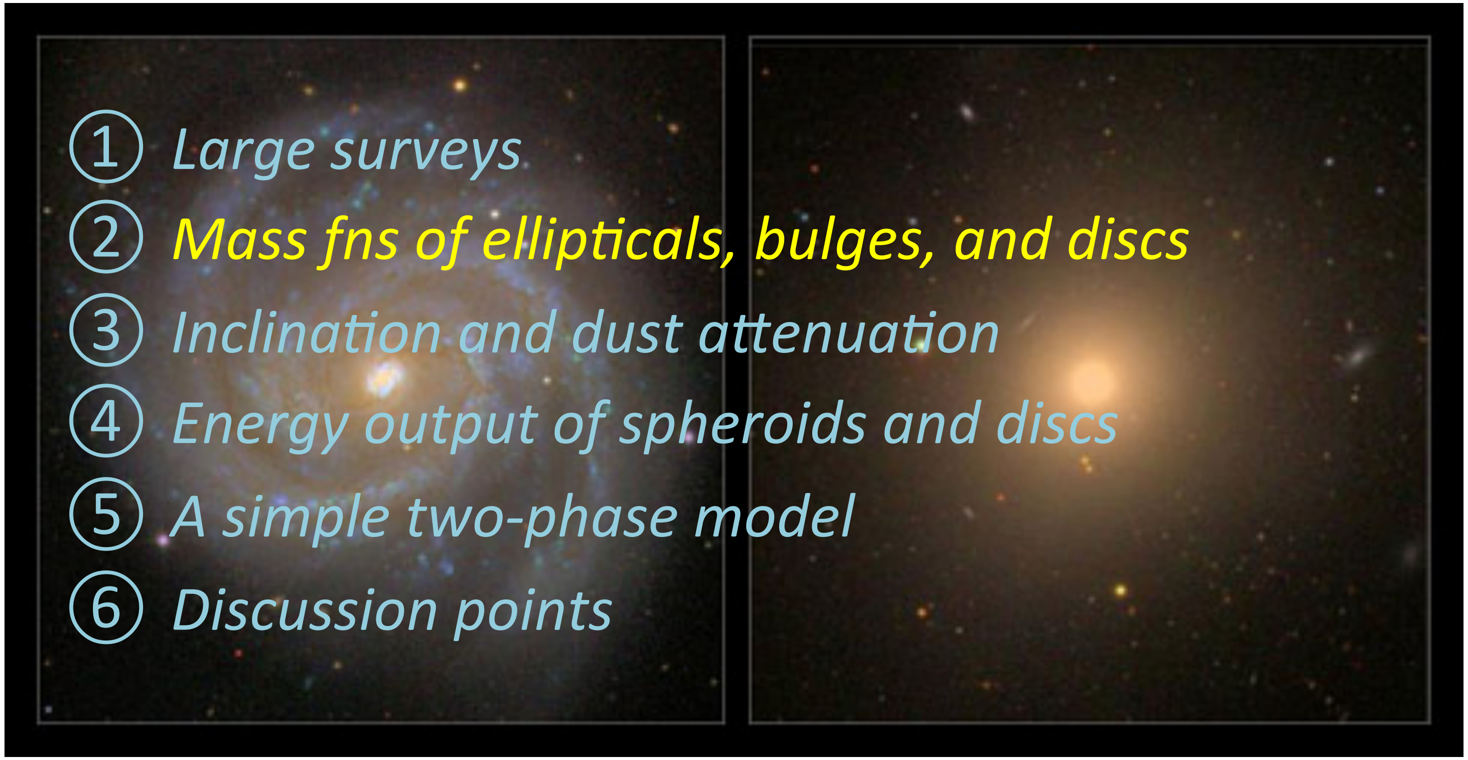
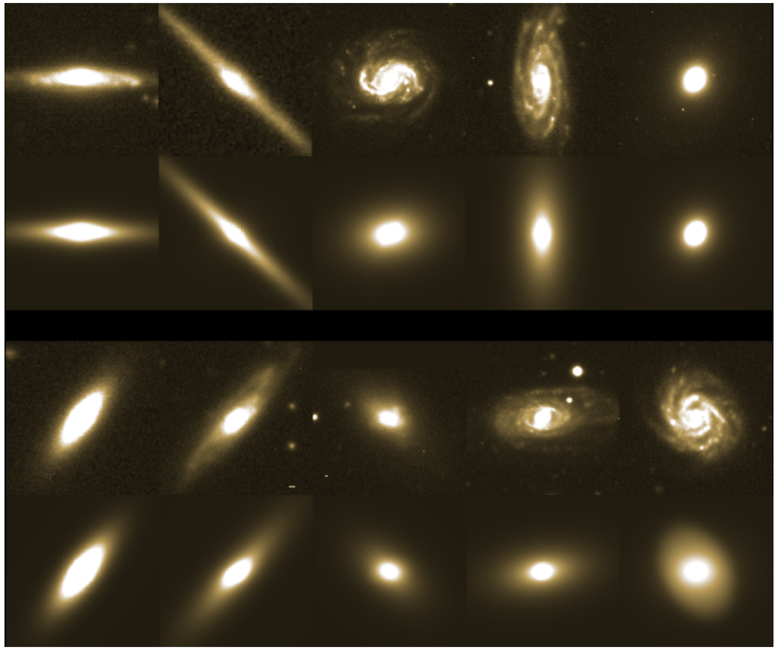
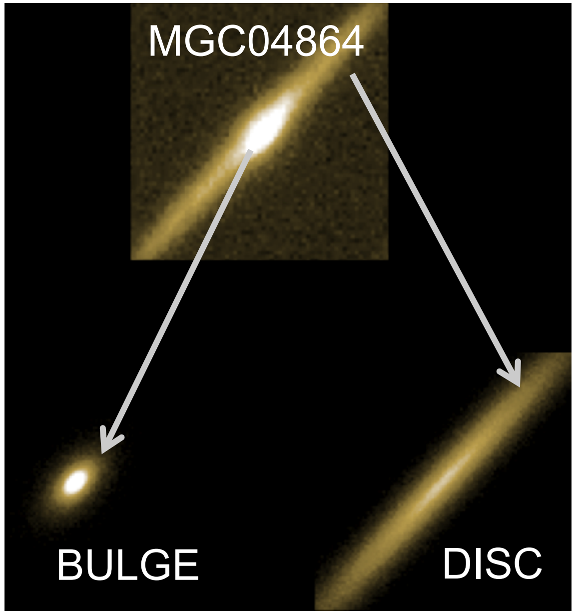


GIM2D bulge/disc decompositions

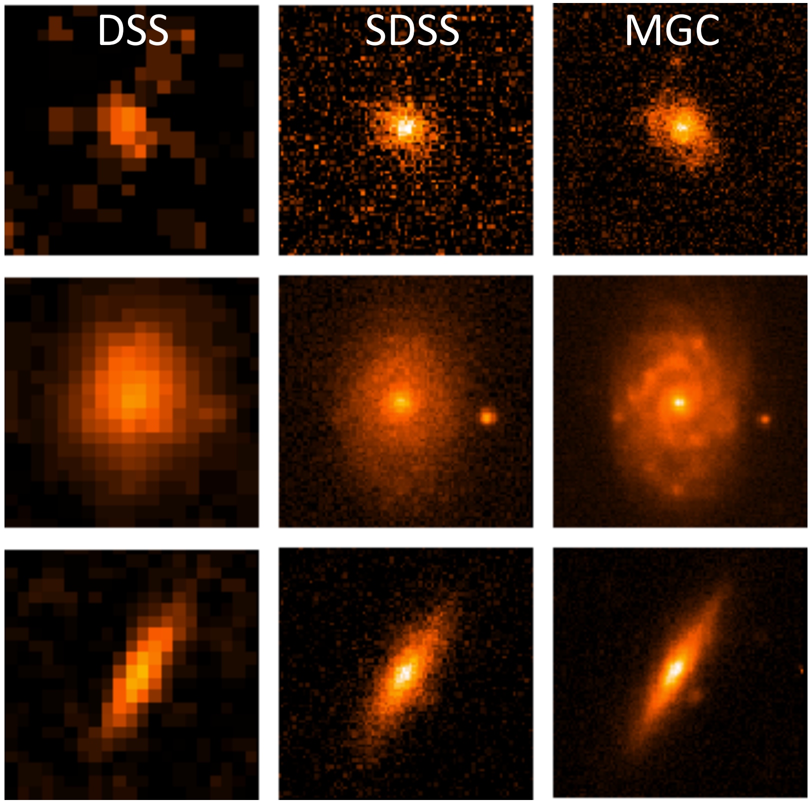
- Sersic+exponential profiles+PSF convolution via GIM2D, Simard et al (1998)
- 10,095 gals = largest available sample, Allen et al (2006) (robust/reproduceable)
- 96% redshift completeness (AAT/GEMINI) to B=20.0 mag, Driver et al (2005)
- B(INT) + ugriz(SDSS) + YJHK(UKIRT), Liske et al (2003), Hill et al (2009)
- All data available online: http://www.eso.org/~jliske/mgc/



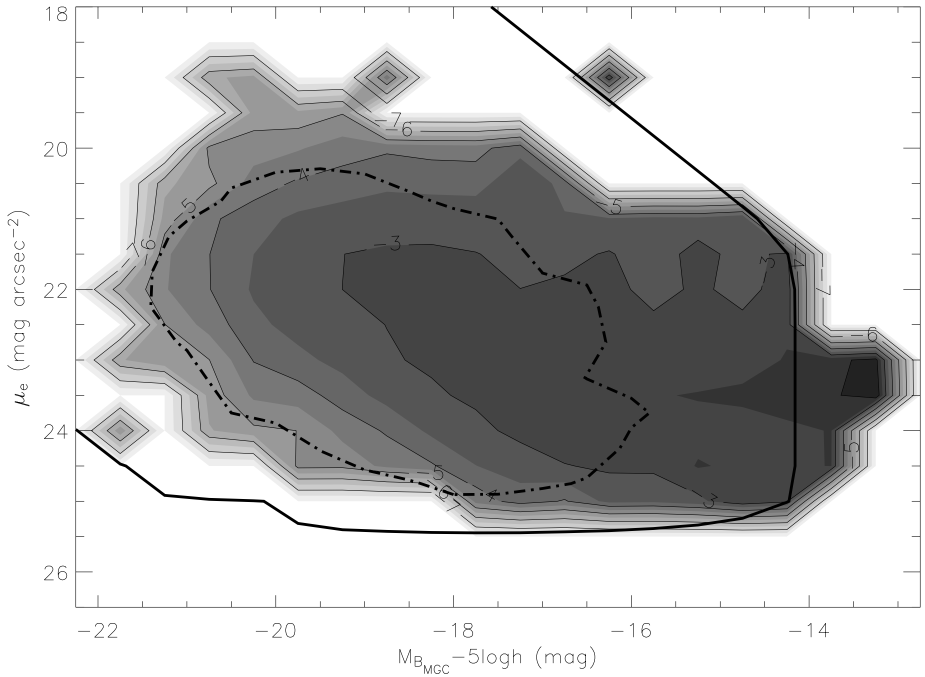


Advantage of MGC

Image quality: B-only, 1'' resolution



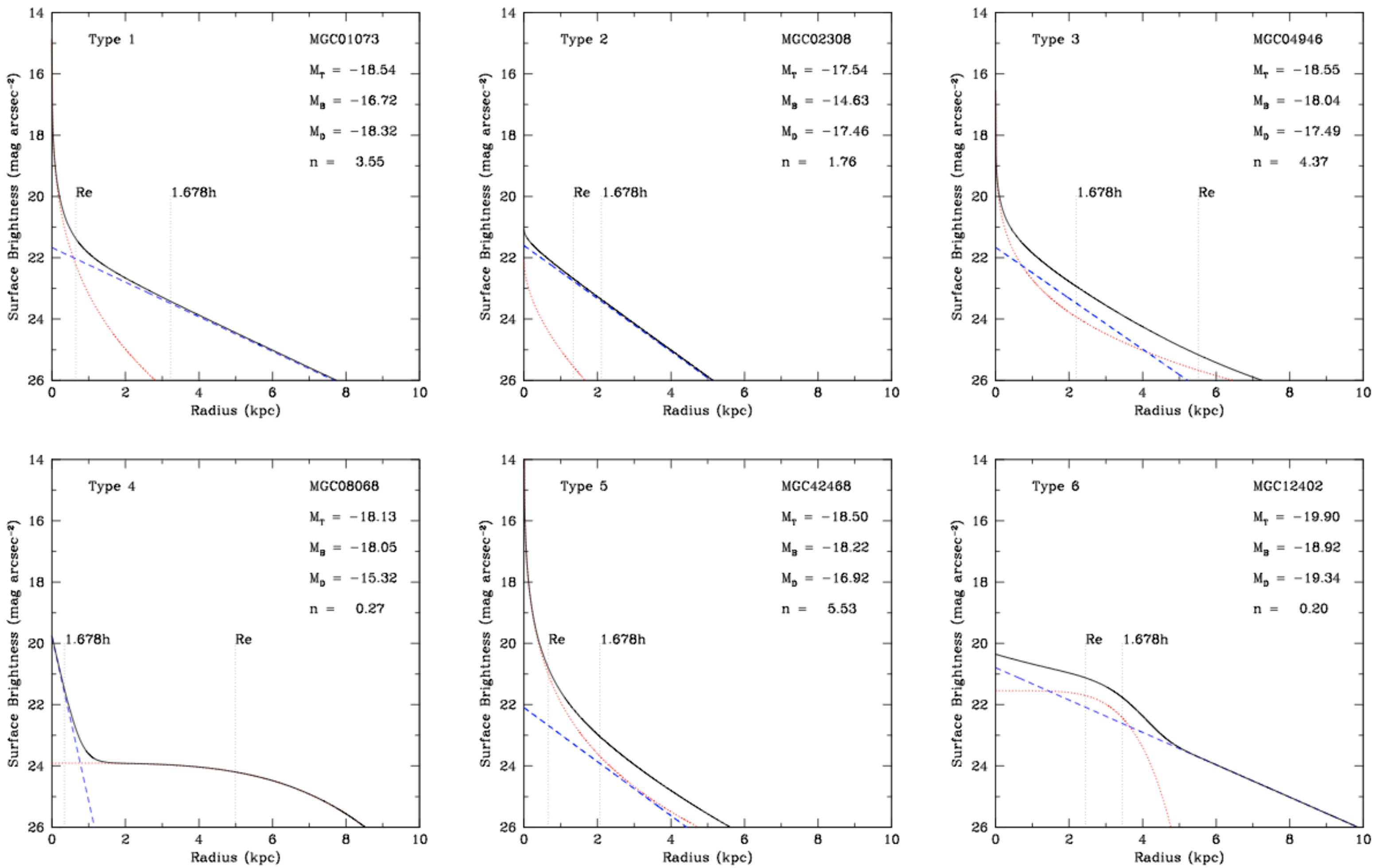
Surface brightness limit: 26 mag/sq arcsec



Still the best wide area imaging+z dataset about to be superseded by GAMA+VST: ugri, 0.7'', 26 mag/sq arcsec

Driver et al (2005)

The Logical Filter

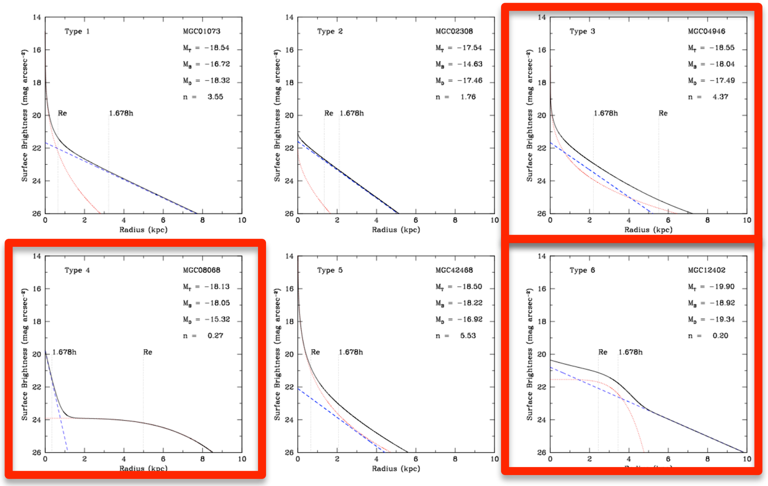


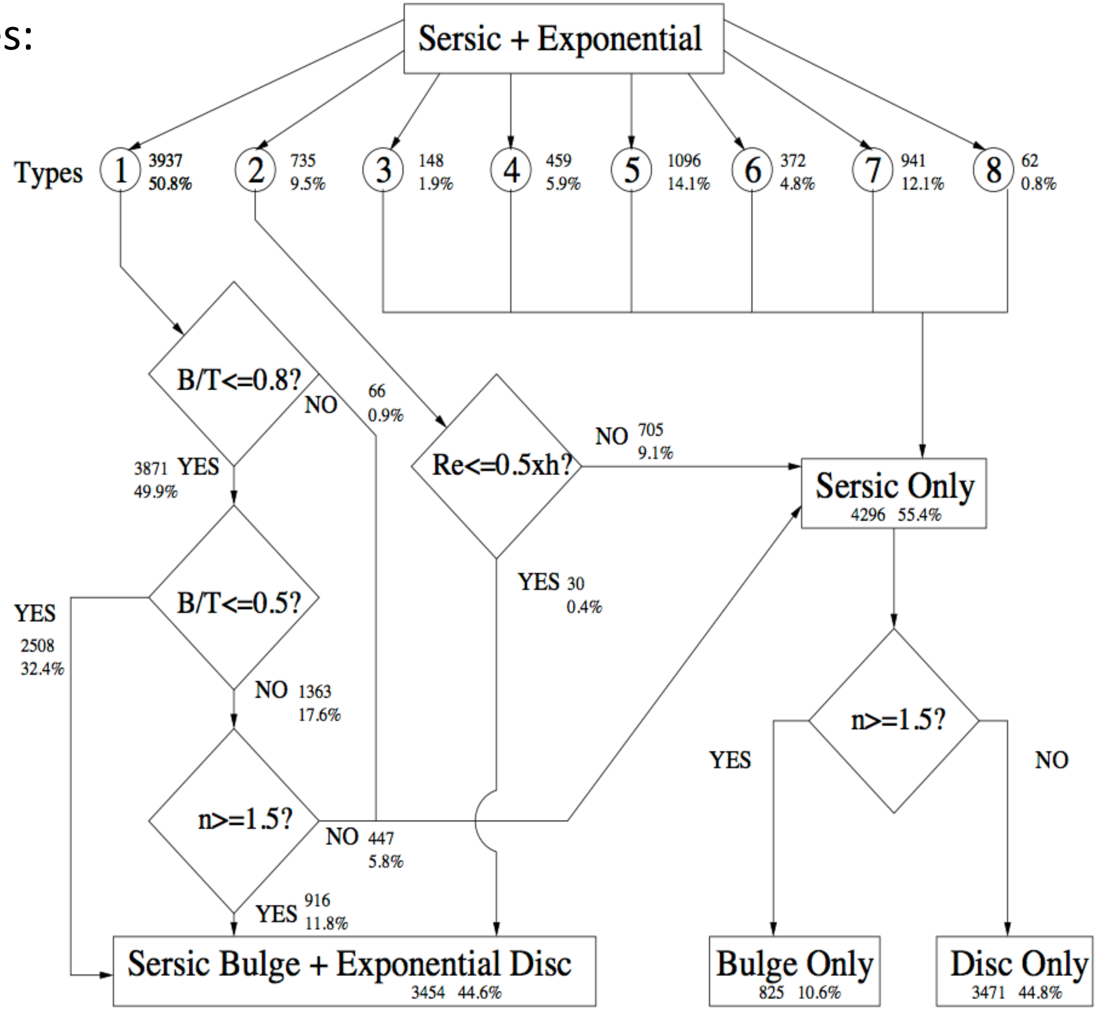
Allen et al (2006)

The Logical Filter

Identified 8 characterstic profile shapes:

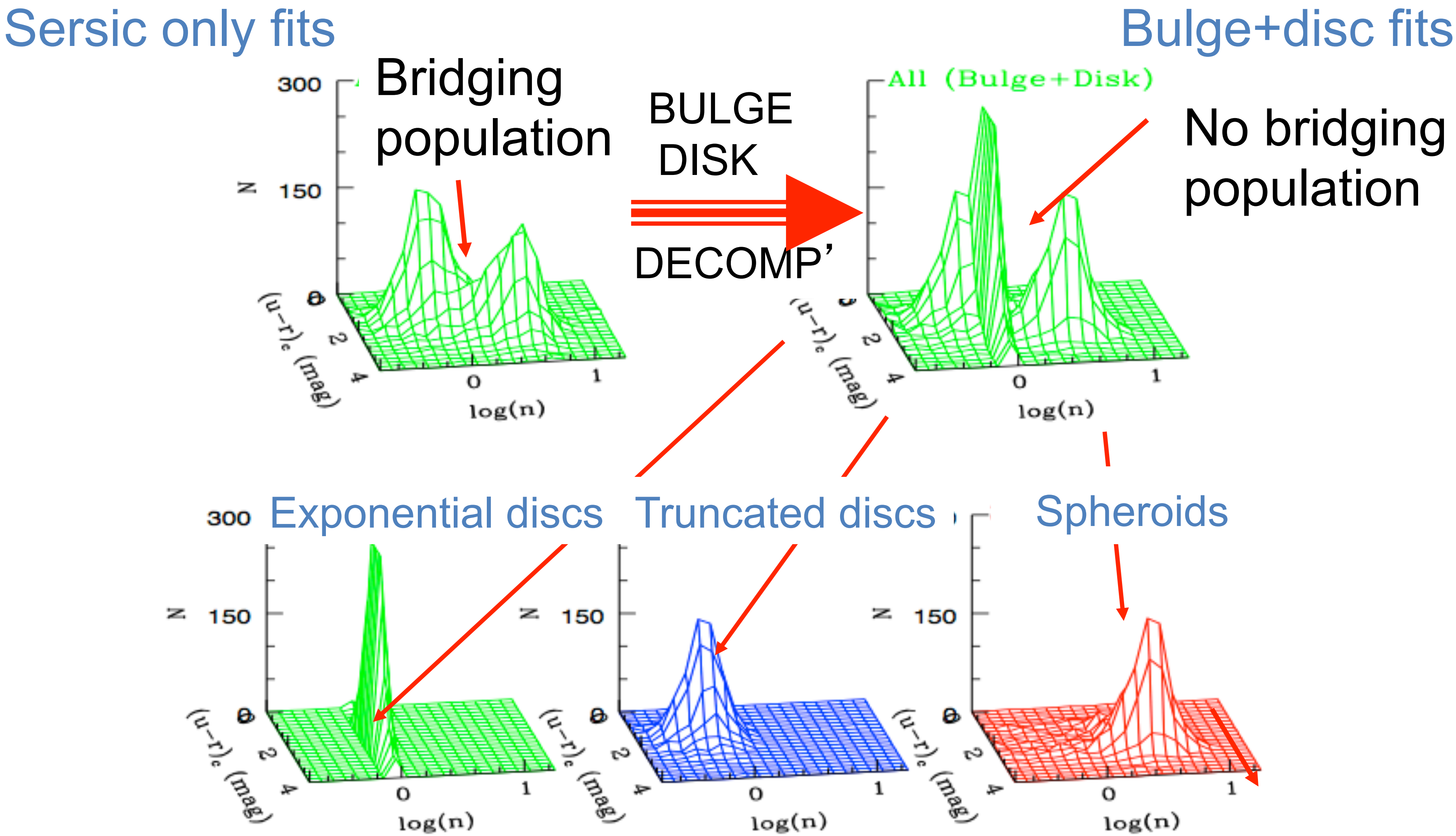
- Type 1 classic bulge+disc
- Type 2 suppressed bulge
- Type 3 inner & outer bulge
- Type 4 inverted
- Type 5 suppressed disc
- Type 6 inner & outer disc
- Type 7 spheroid only
- Type 8 disc only



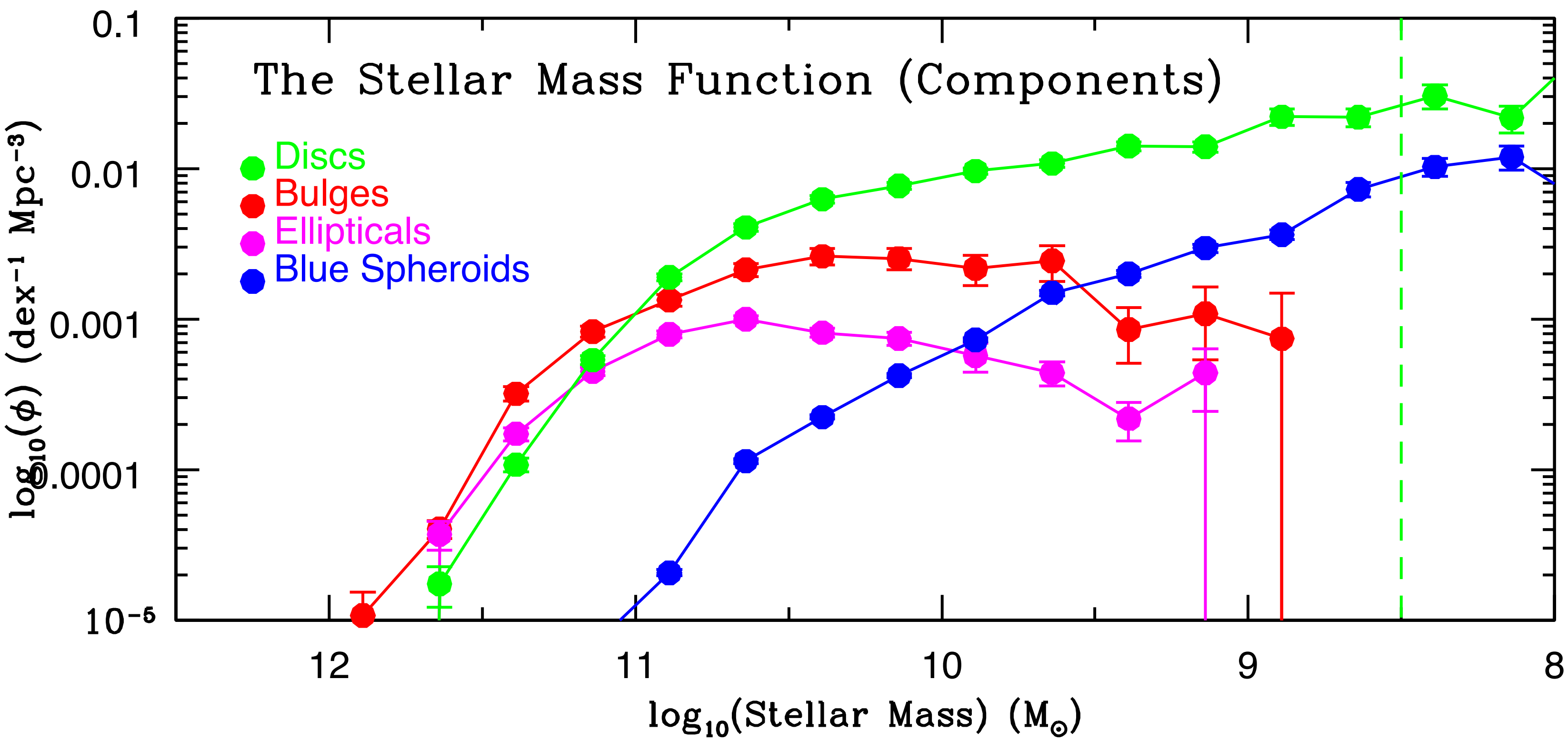


Allen et al (2006)

Two pop's or two components ?

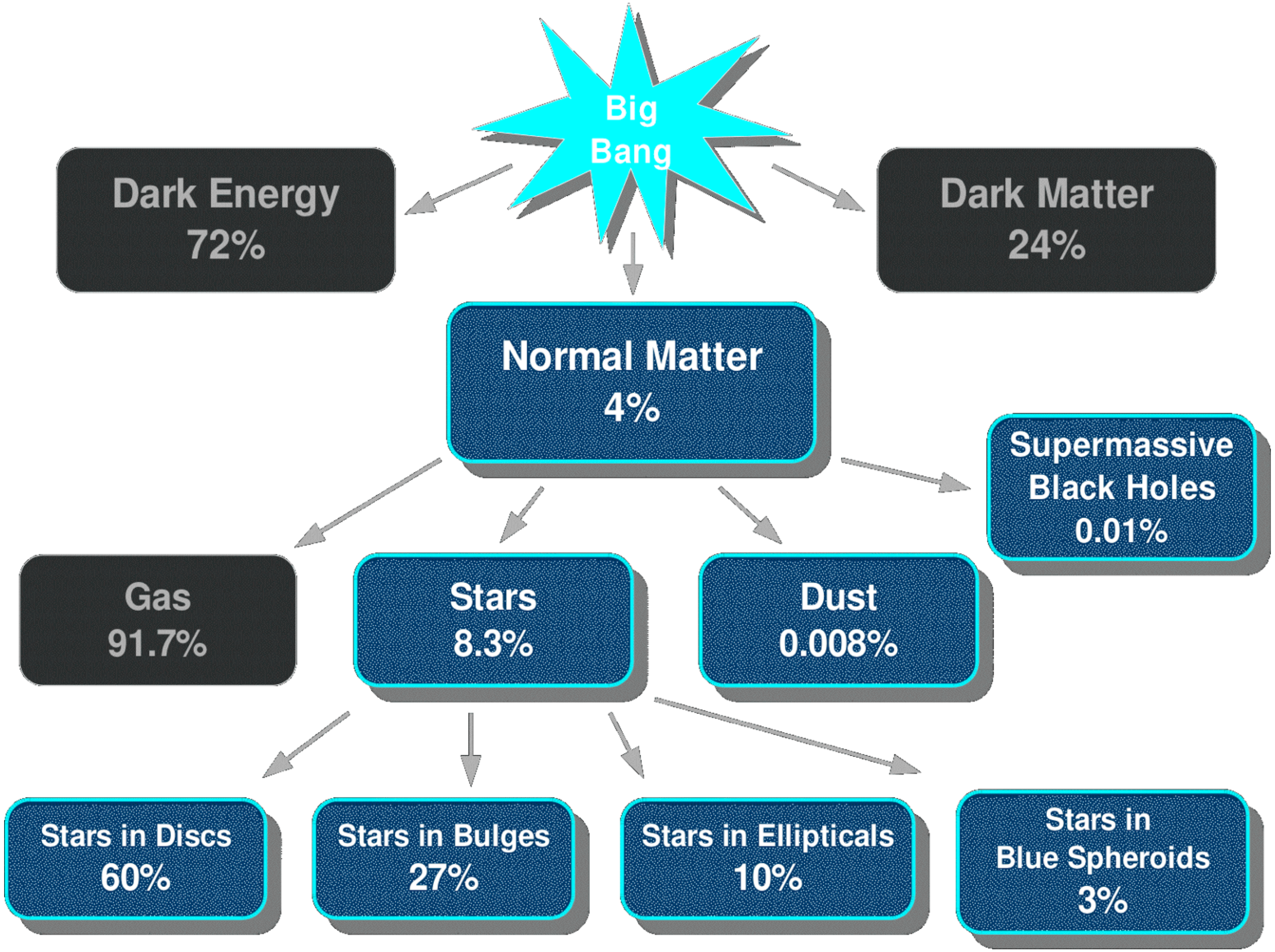


Stellar mass functions (dust corrected)



(c2008, unpublished)

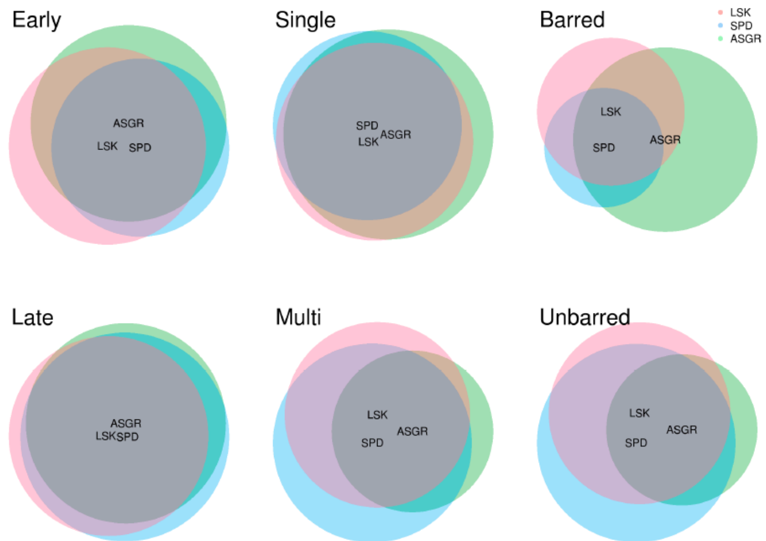
The baryon breakdown at z=0



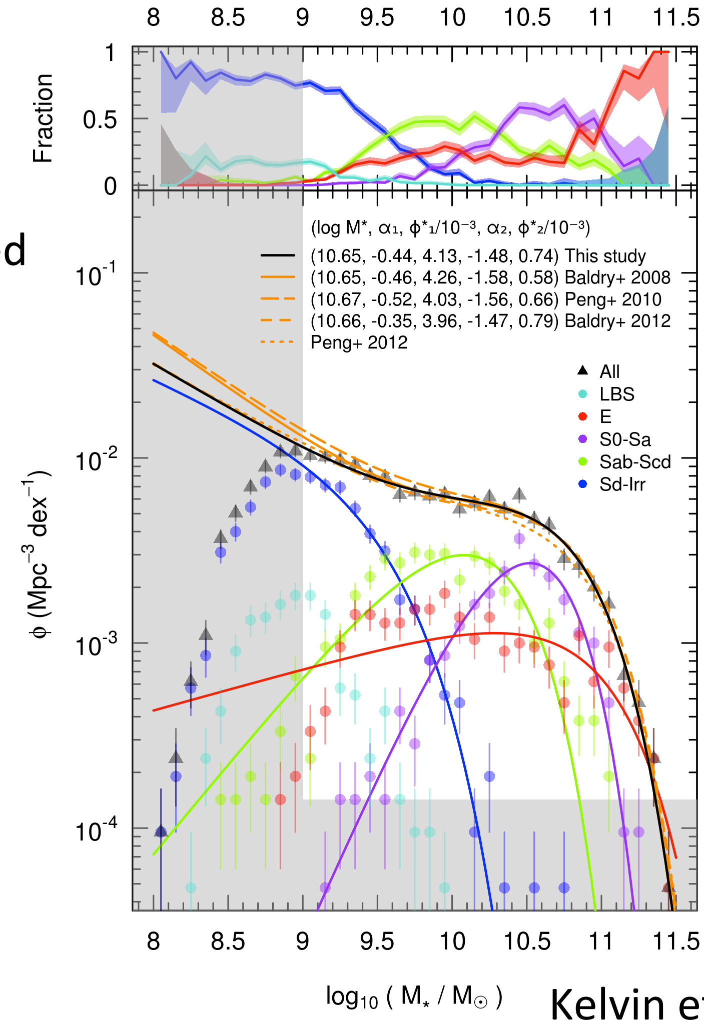
Mass functions by Hubble type

Selection:
- $0.025 < z < 0.06$ - similar to Gadotti (2009)
- Mass > $10^{9.5}$ - deeper than Gadotti (2009)
- 3000 systems only
- Will push deeper once VST KiDS data processed

Classification by eye (3 pairs!):



GALFIT3 profiling based on eye classifications



Kelvin et al (2013)

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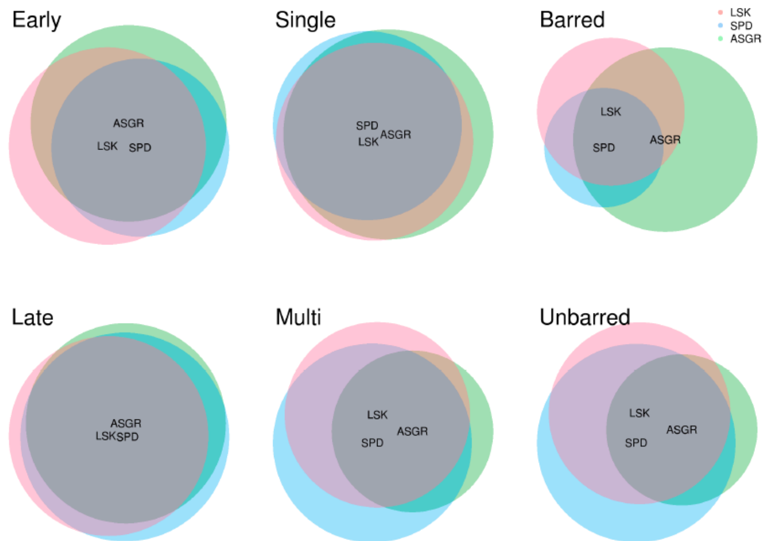
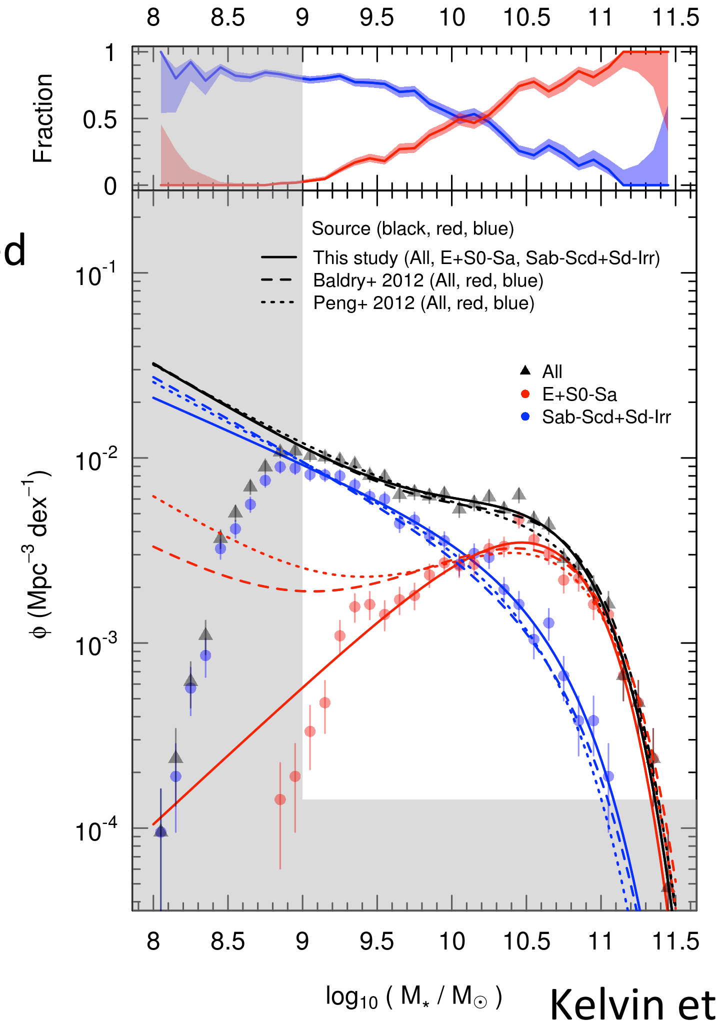
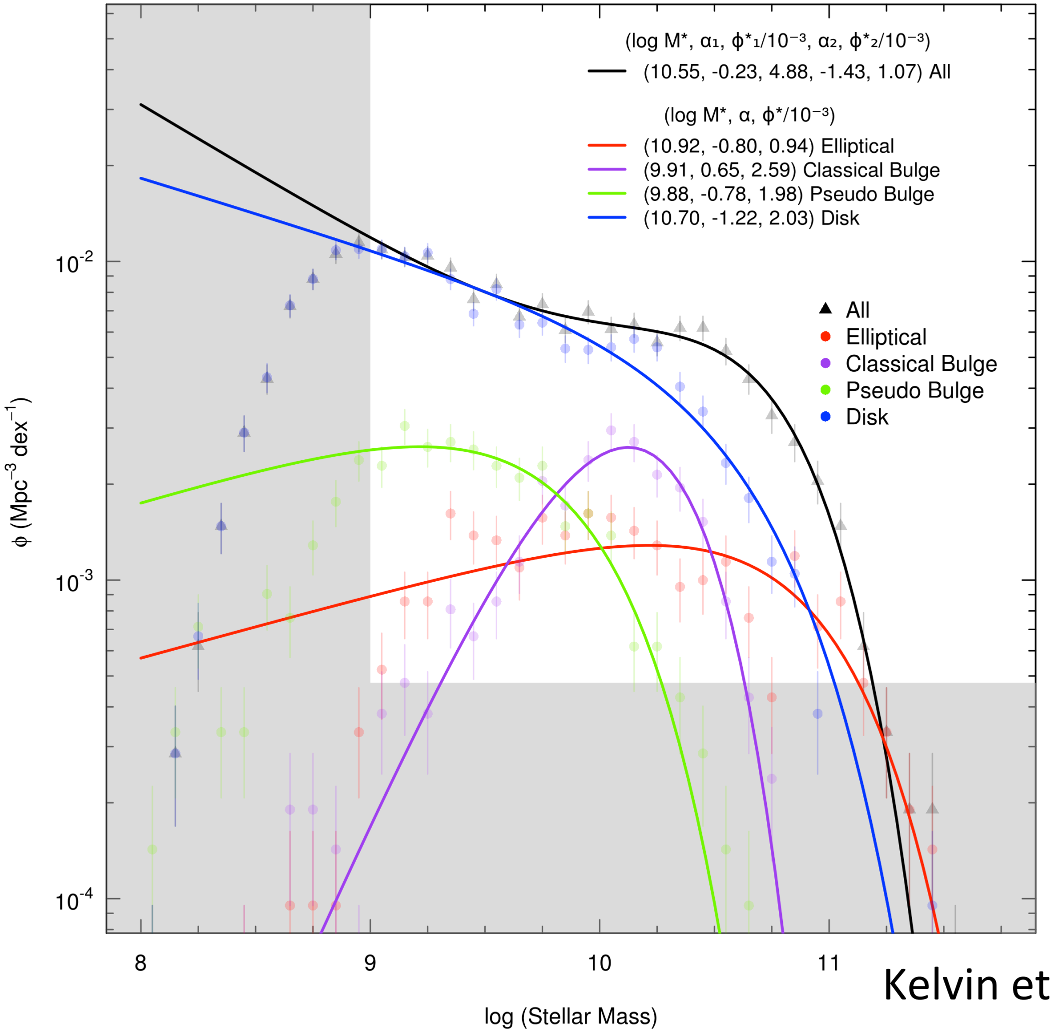


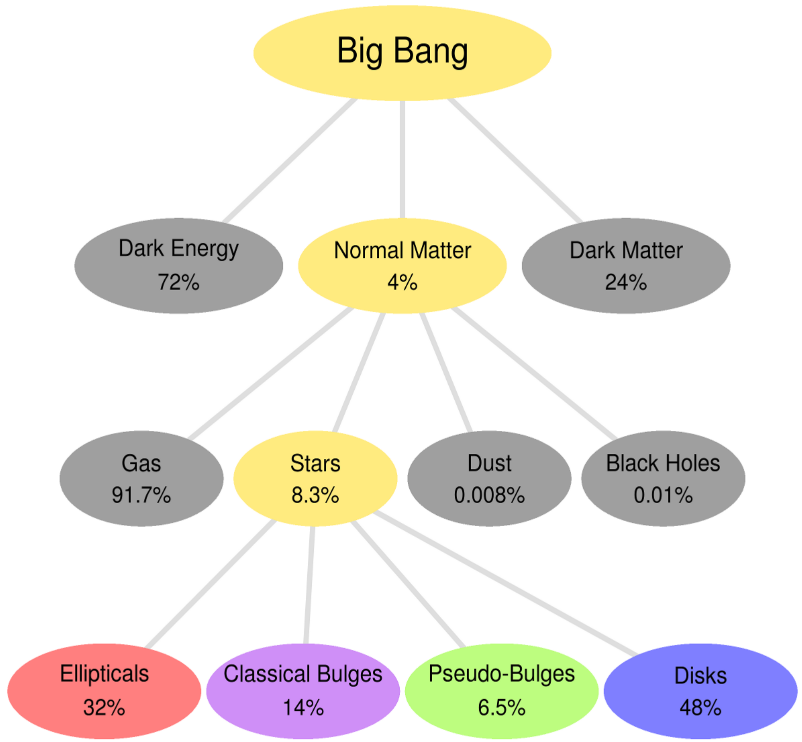
GALFIT3 profiling based on eye classifications



Kelvin et al (2013)

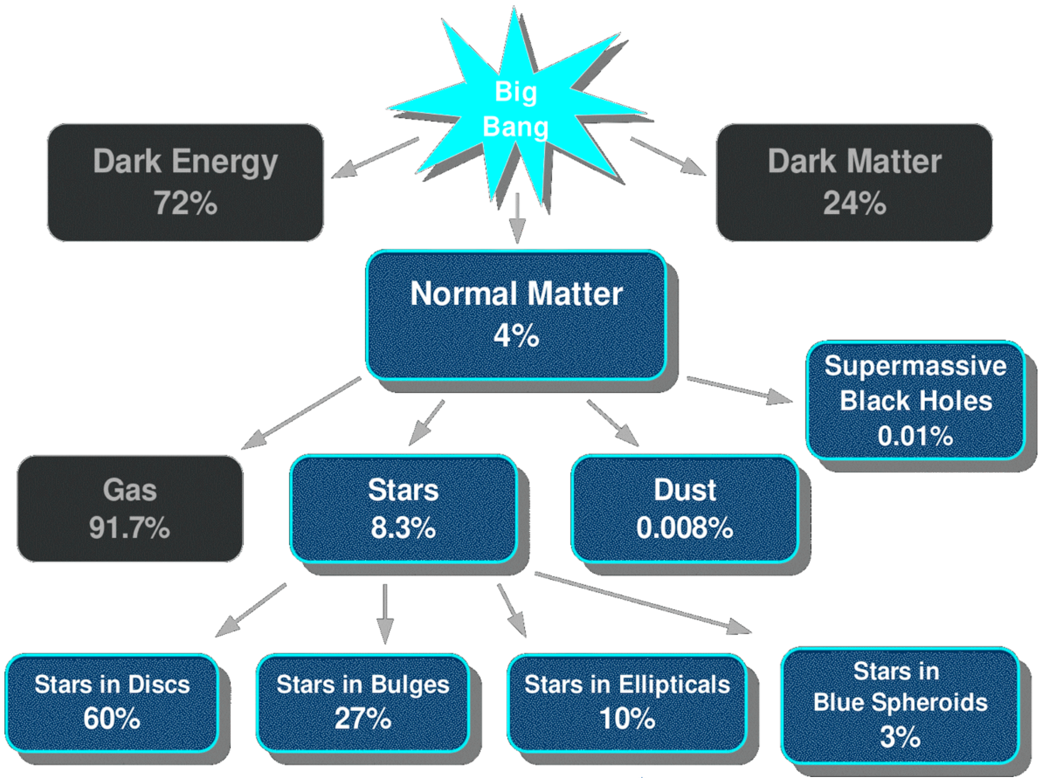
GALFIT3 Bulge-disc decompositions 3000 galaxies (0.025 < z < 0.06)

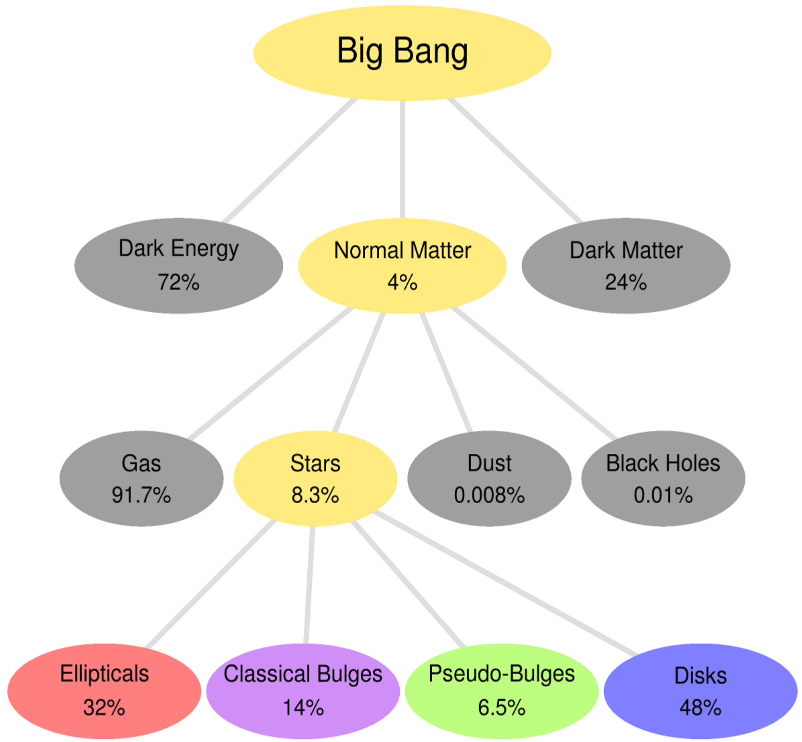




Kelvin et al (20143, PhD thesis), see talk on friday

Major discrepancy for Es!

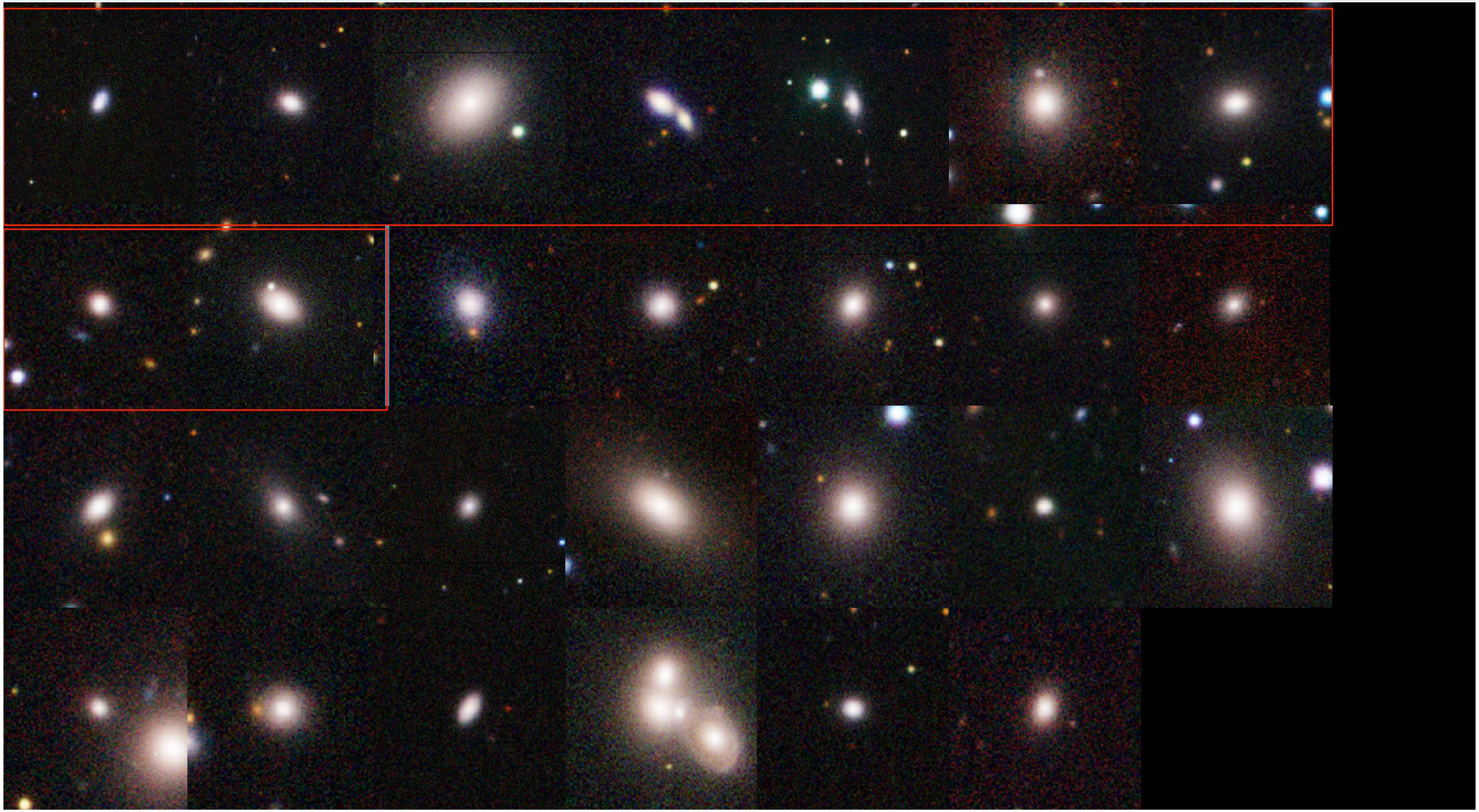




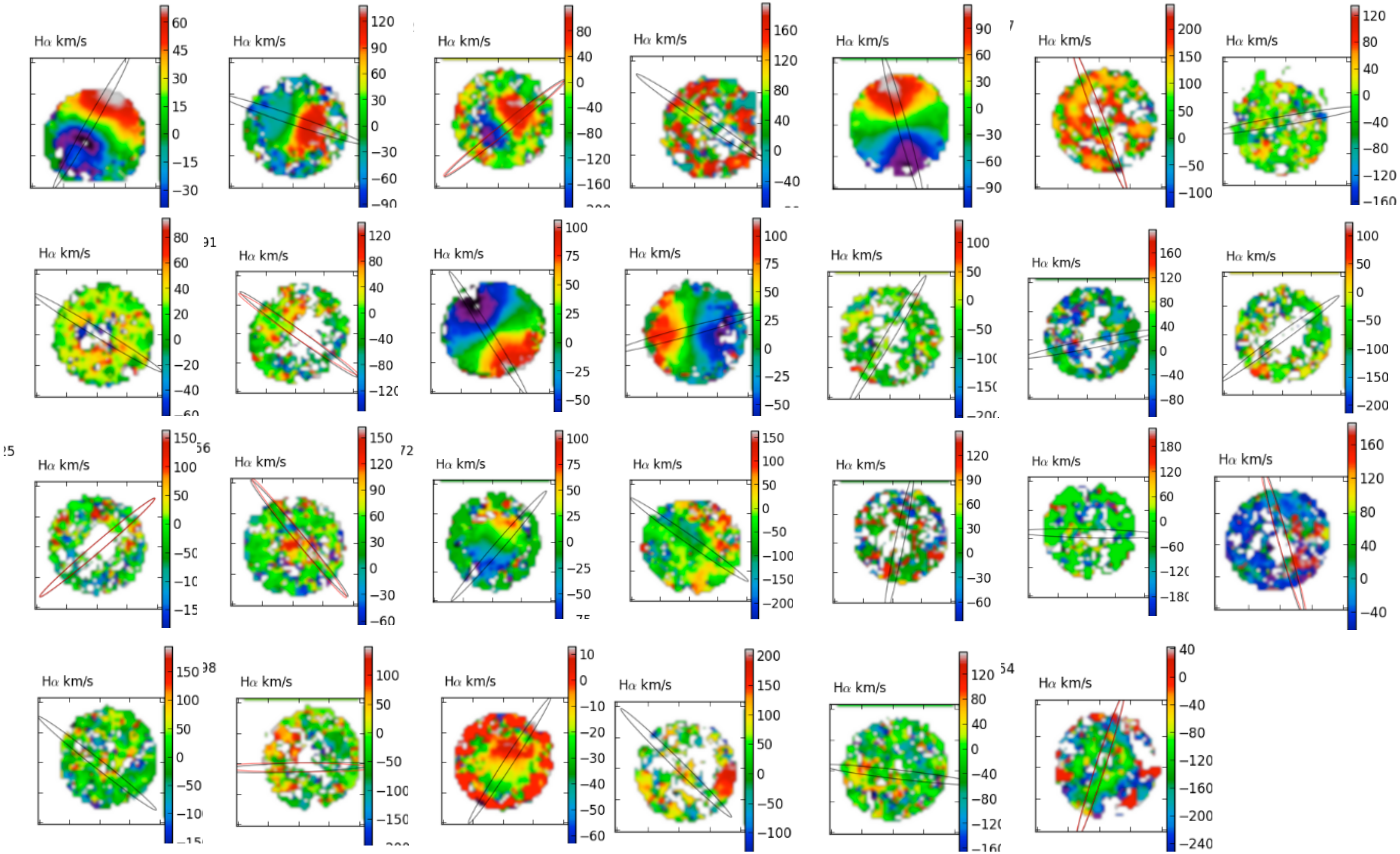
MGC: Driver et al (2008)
Selection by Sersic index > 2.5

GAMA: Kelvin et al (2013)
Selection by eye

Can we distinguish E's from S0's?

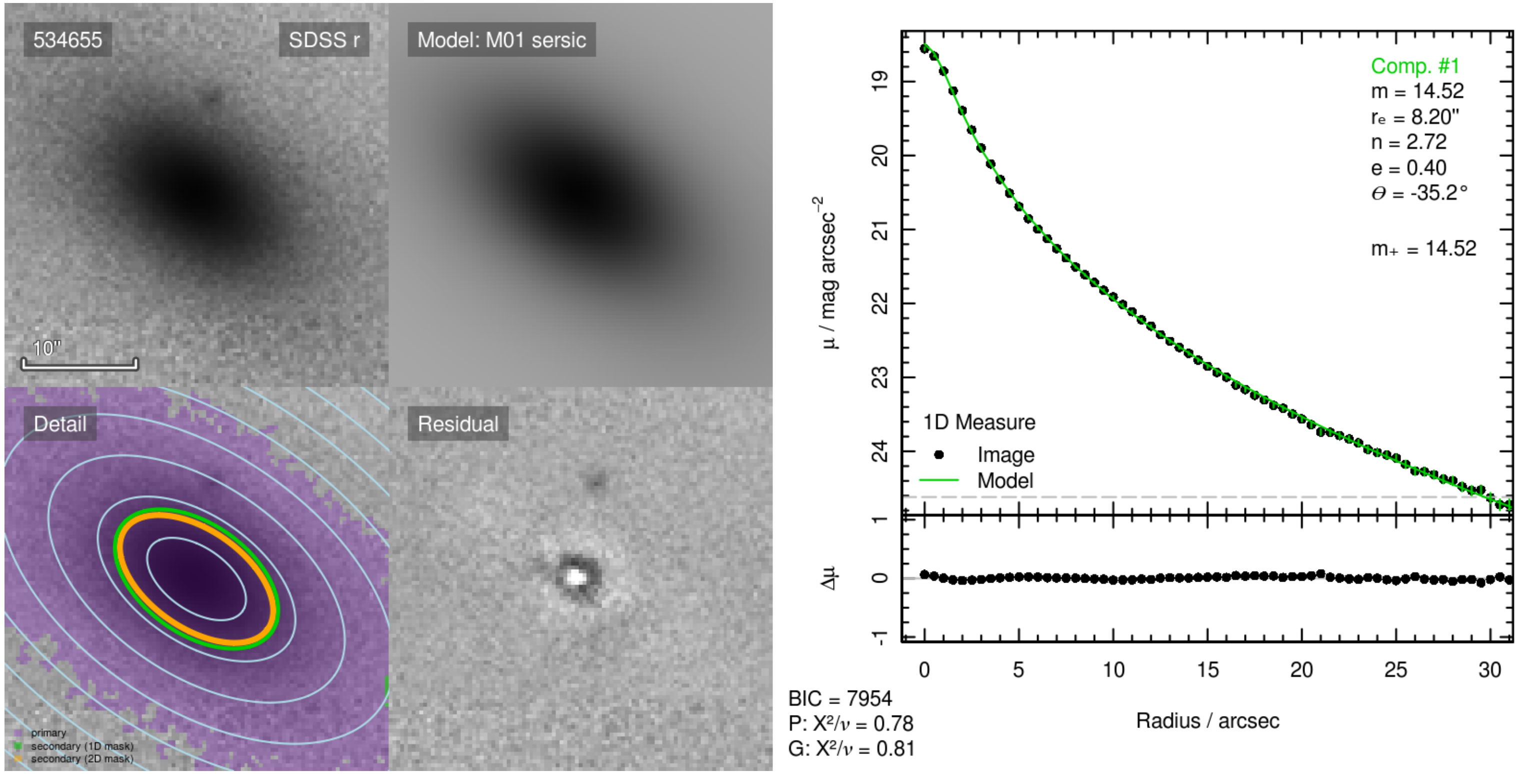


Can we distinguish E’s from S0’s?



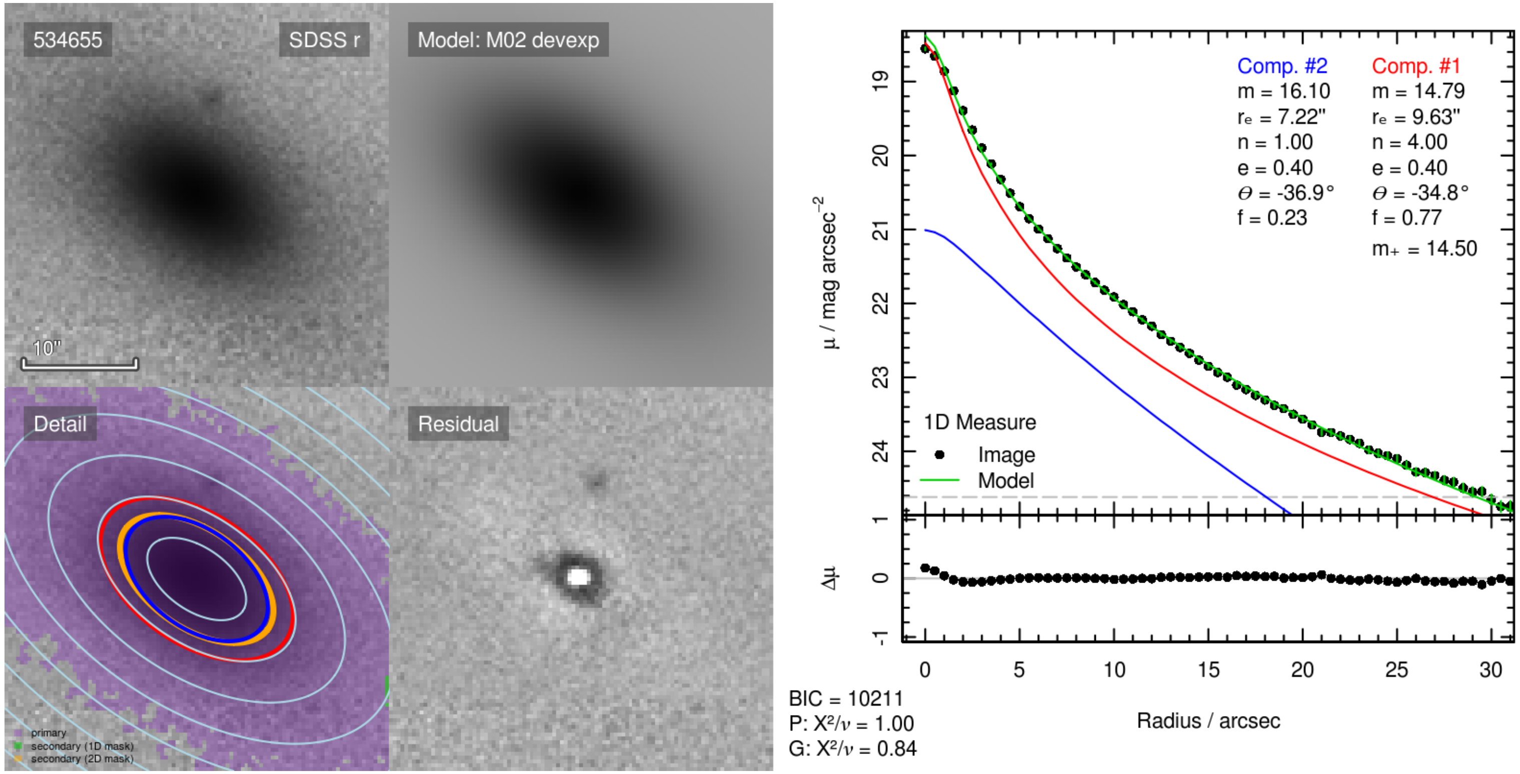
See Lisa Fogarty’s talk)

e.g., eyeball elliptical: G534655



$$\mathrm{BIC} = \chi^2 + k \cdot \ln(n)$$

e.g., eyeball elliptical: G534655



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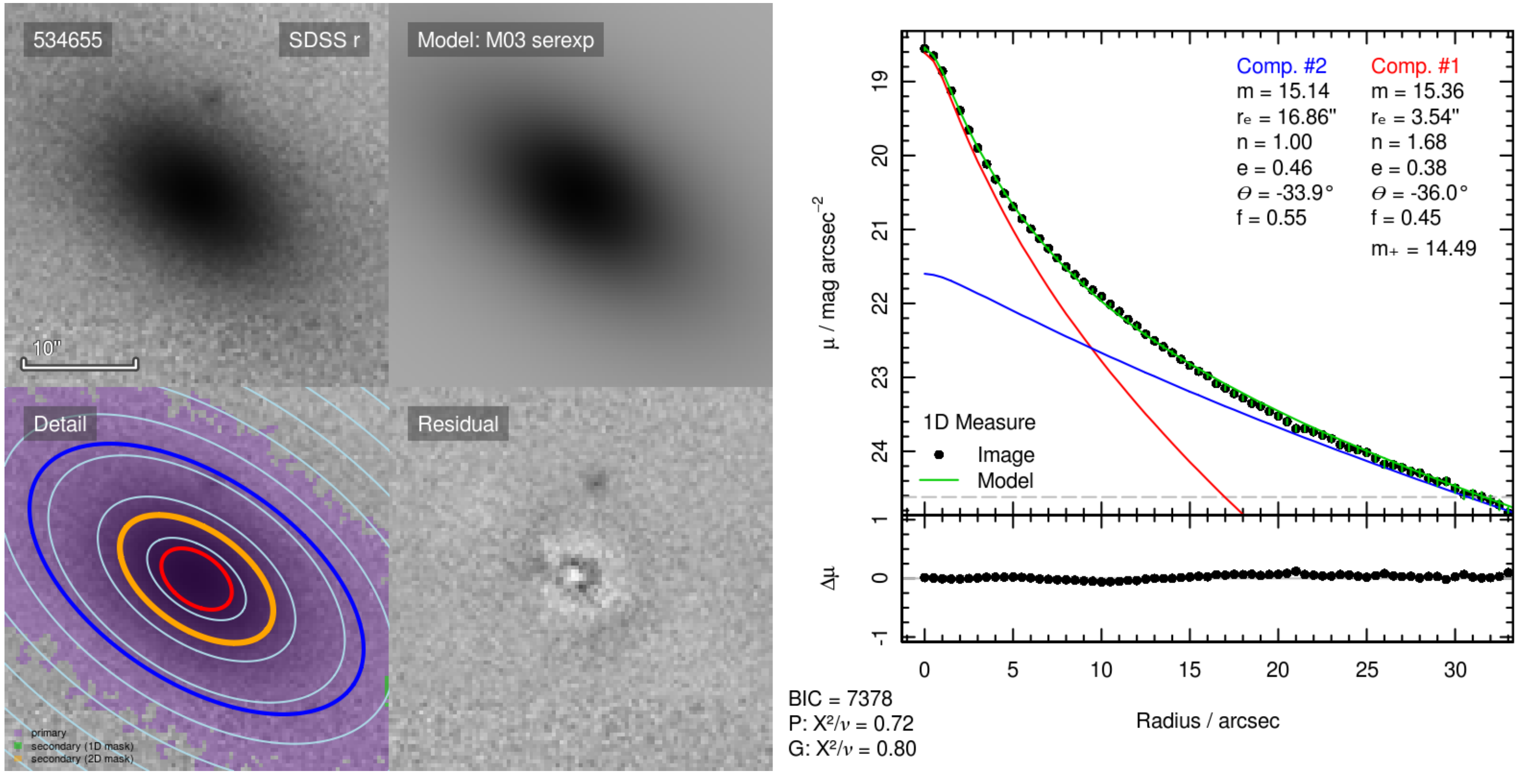

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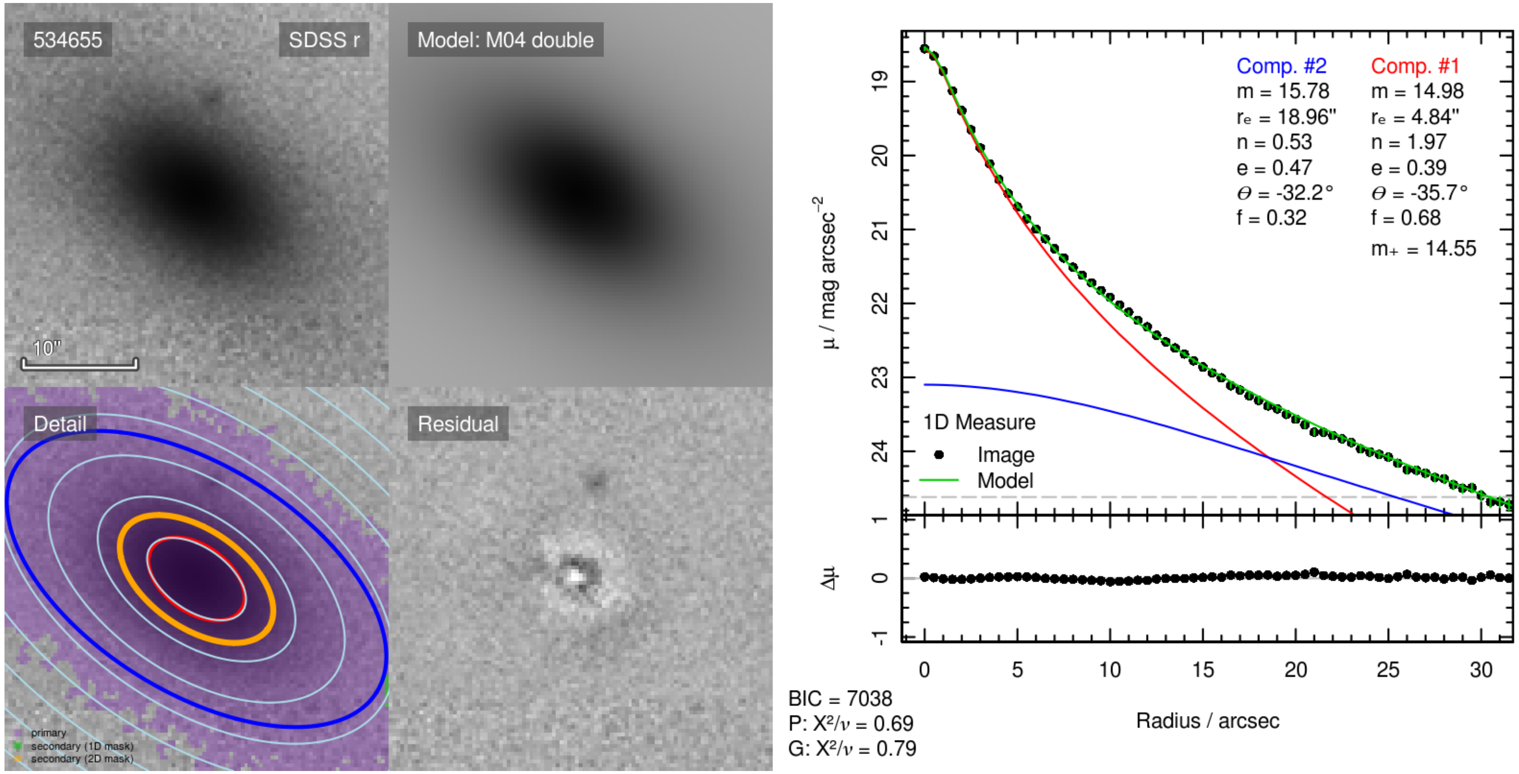
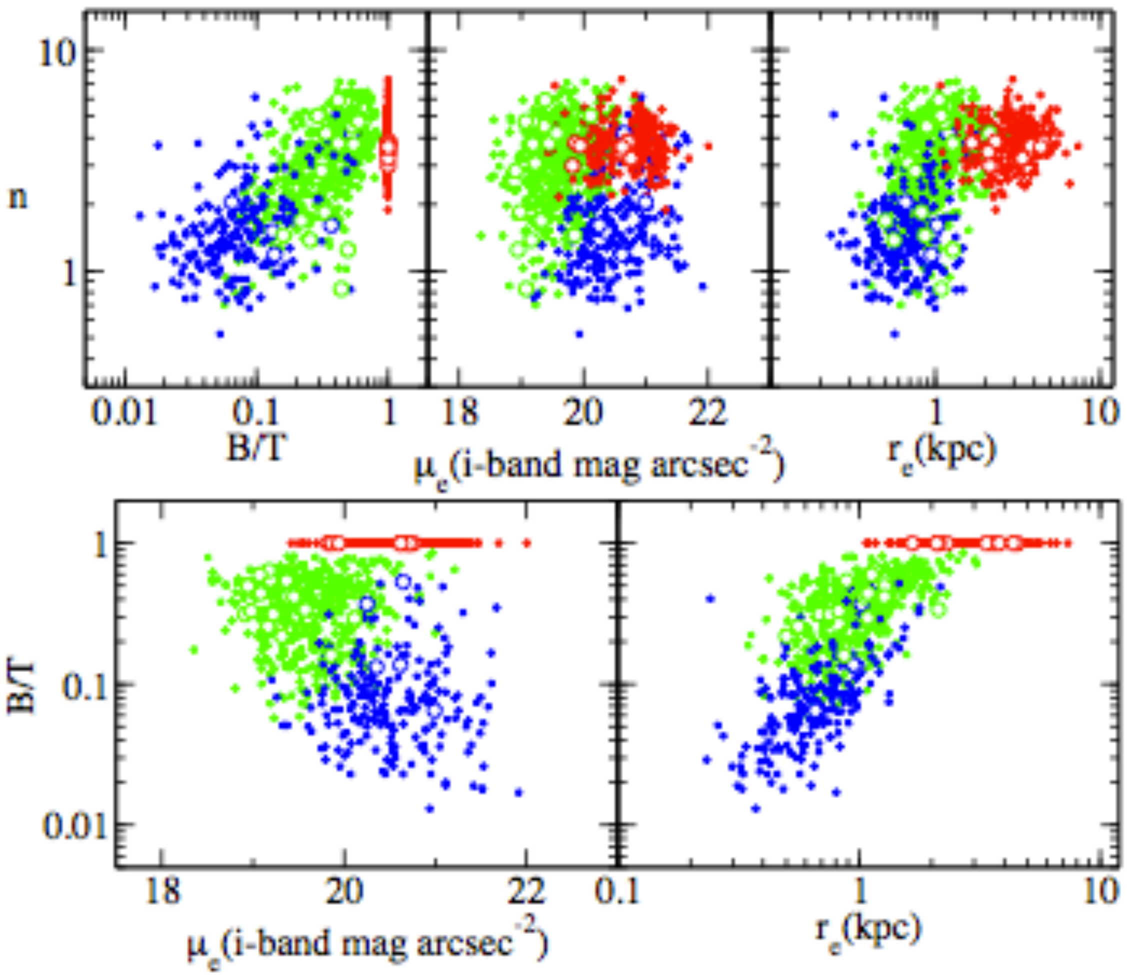


$$\mathrm{BIC} = \chi^2 + k \cdot \ln(n)$$

Elliptical, classical bulges and pseudo bulges

Ellipticals,
Classical bulges
Pseudo bulges
appear to lie
in distinct regions

Need high-S/N



Gadotti (2009)

Consensus on the stellar mass budget

- Driver et al (2008):

10% E, 27% bulges, 60% discs, 3% BS

- Gadotti (2009):

25% E, 20% cbulges, 5% pbulges+bars, 50% discs

- Tasca & White (2011):

50% discs   50% spheroids

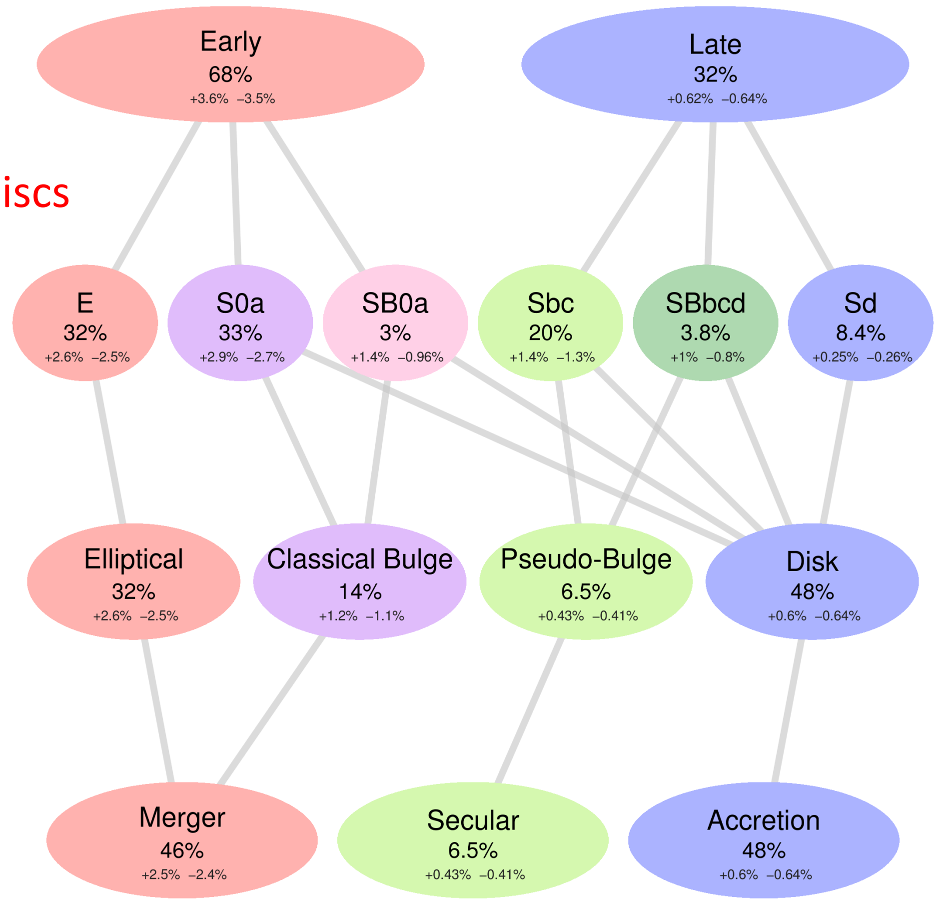
- Kelvin (2012, PhD)

32%E, 14% cbulges, 6.5% pbulges, 48% disc

Lets say 50:50

<u>Upper limit for bulges!</u>

<u>Lower limit for discs!</u>



Kelvin et al (2013, PhD thesis), see talk on friday

Numerical simulation merger tree

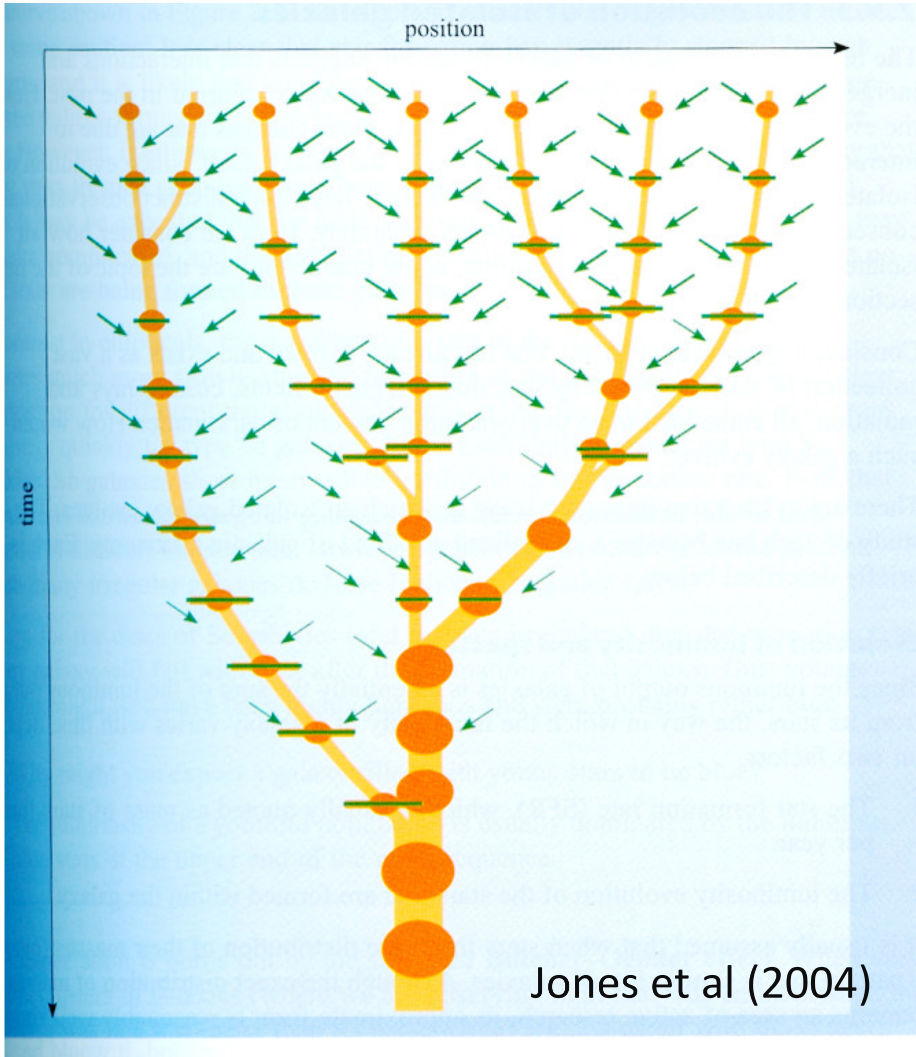
Discs and bulges form via two (or more) distinct process (dynamically hot v cold).

However mergers will convert both the bulge and disc mass into spheroids.

Some (gas) mass may be returned but stellar mass of disc and bulge both end up in bulge.

Ergo: z=0 spheroid mass is lower limit to stellar mass *formed* in spheroids.

Dominant process by which stars form is the disc formation process.



Jones et al (2004)

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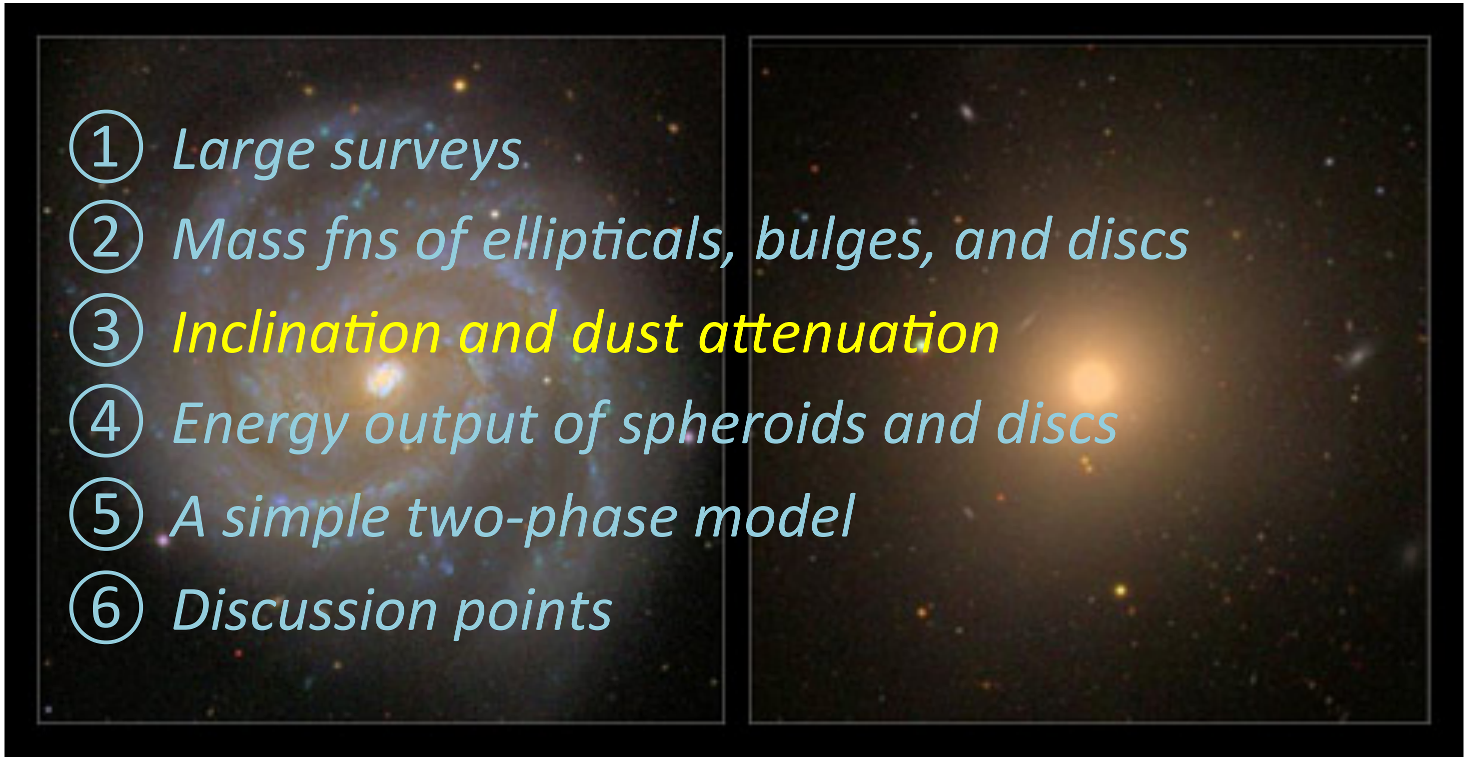
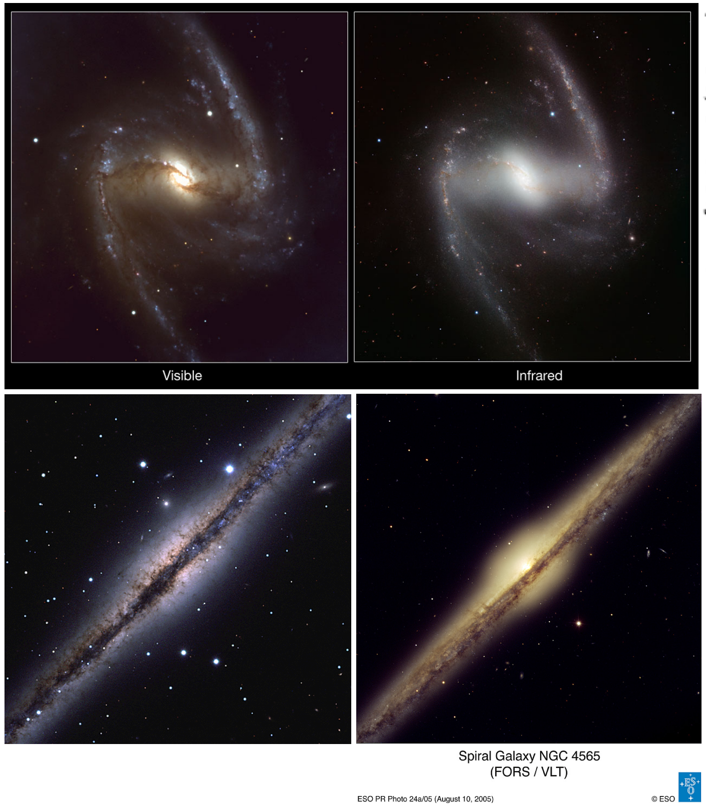
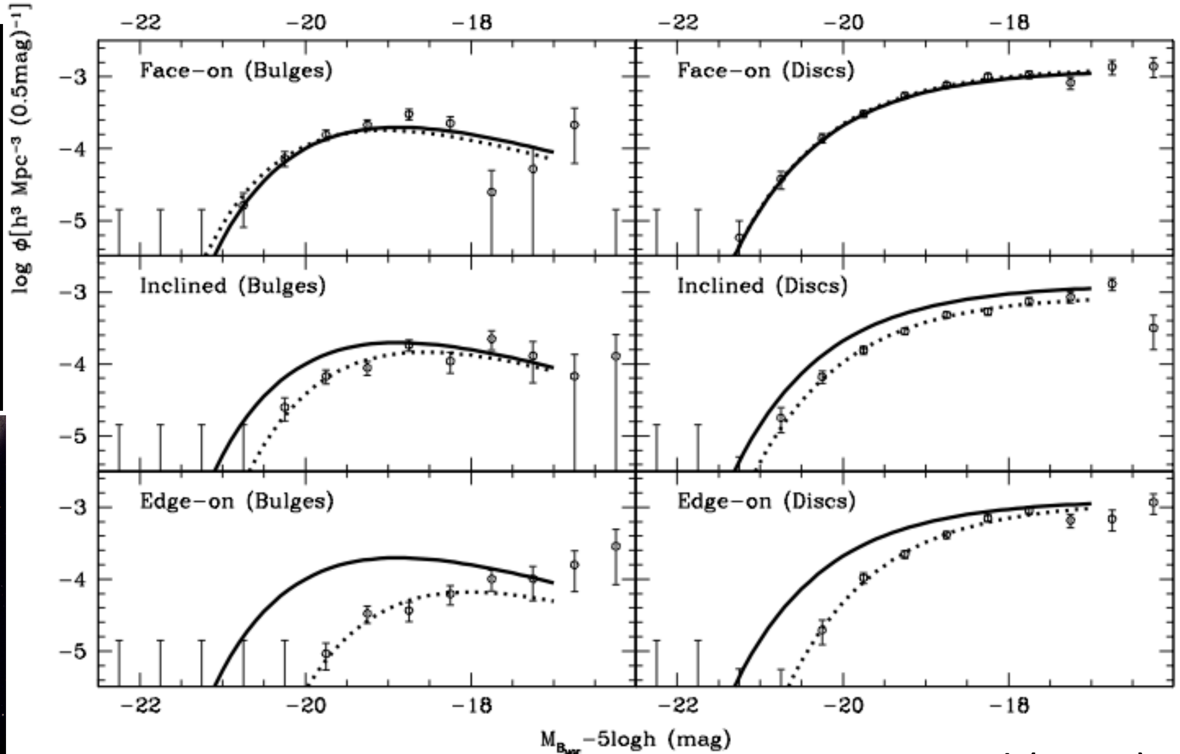


Bulge & disc luminosity functions

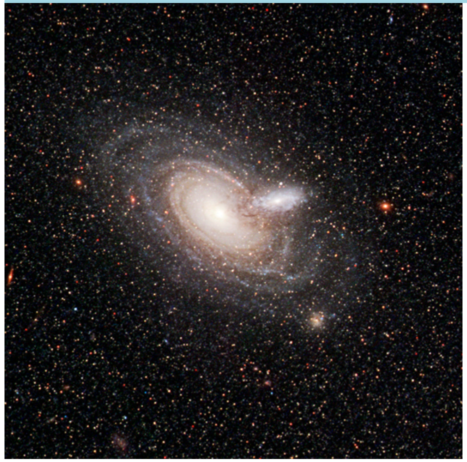
Bulge and disc luminosity functions versus inclination, no dust = no change

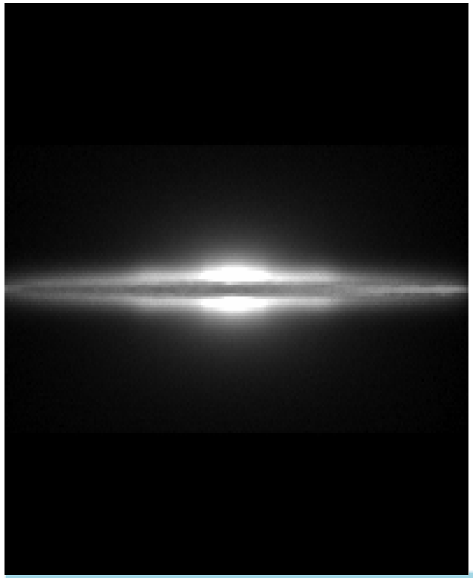


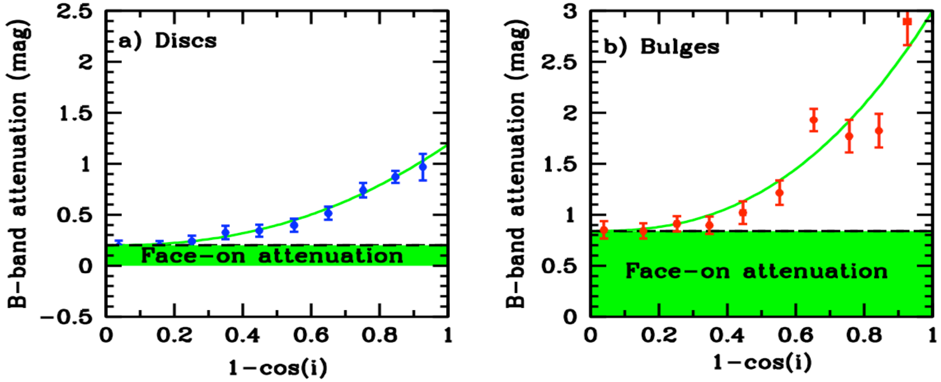


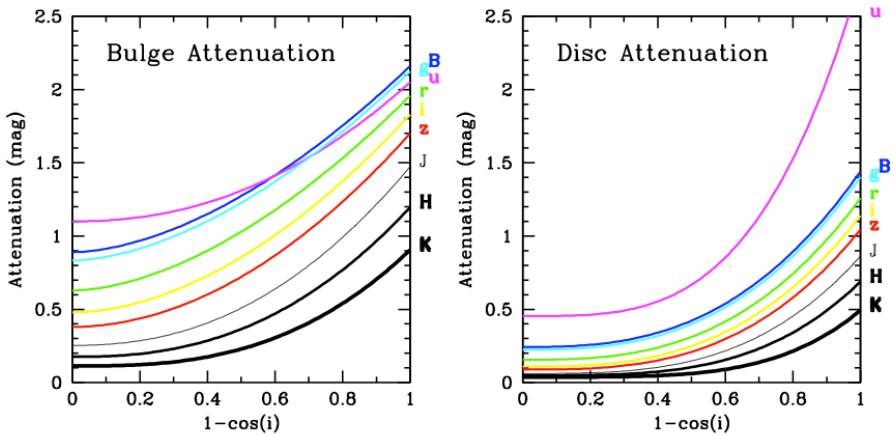
Driver et al (2007)

Dust attenuation



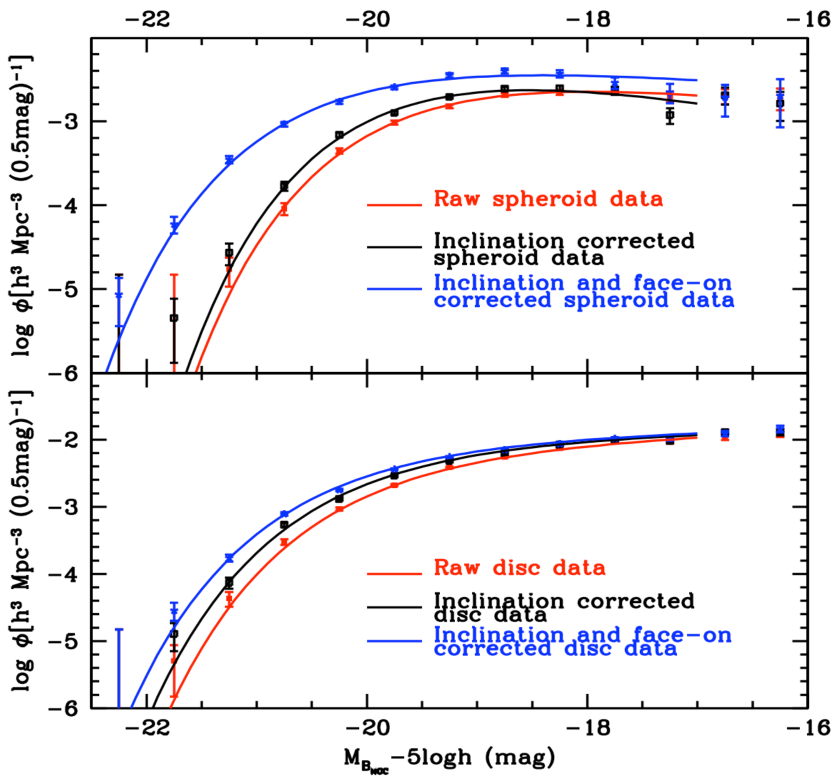




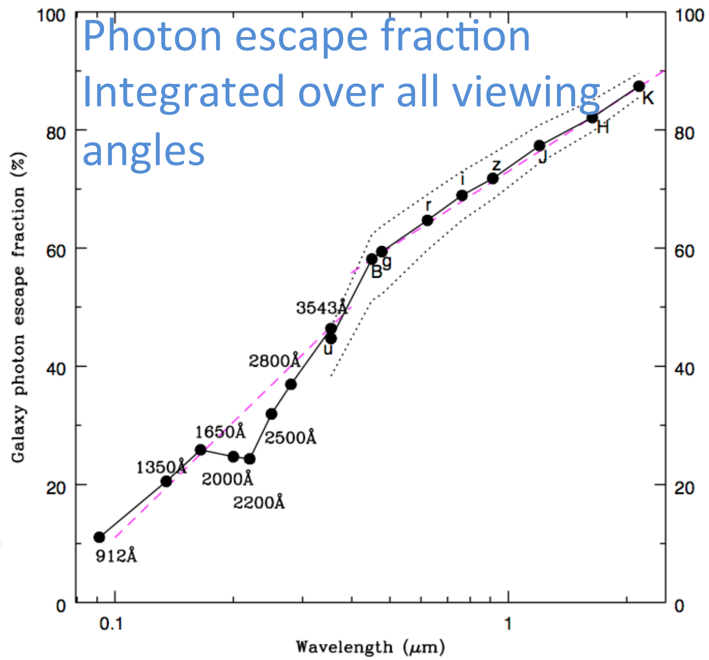


Dust models above from: Popescu et al (2000, 2011), Tuffs et al (2004) calibrated to MGC to determine <u>mean</u> opacity of $\tau_V = 3.4$!

Dust attenuation severe



Luminosity Function significantly affected by dust attenuation (Driver et al 2008)



Photon escape fraction:
50% of starlight is lost to dust
Driver et al (2008)

Dust: Recent (optical) papers

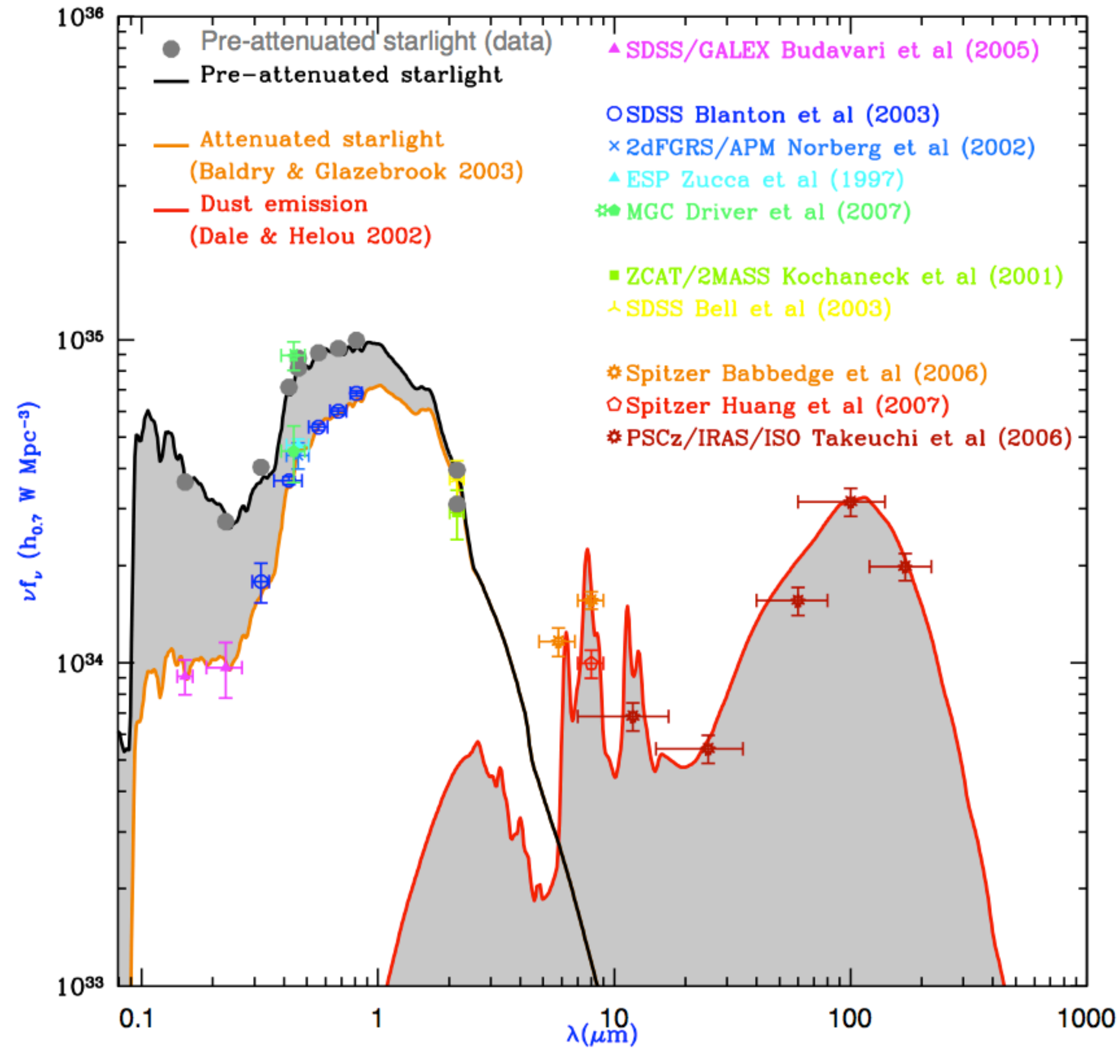
- Shao et al (2007)
- Choi et al (2007)
- Driver et al (2007, 2008)
- Graham & Worthy (2008)
- Balin & Harris (2008)
- Unterborn & Ryden (2008)
- Padilla & Strauss (2008)
- Cho & Park (2009)
- Maller et al (2009)
- Ganda et al (2009)
- Brice et al (2009)
- Masters et al (2009)
- Yip et al (2009)

Confirmation via far-IR

Starlight lost = far-IR emission

Little room for any AGN heating

Does this affect the mass estimates?

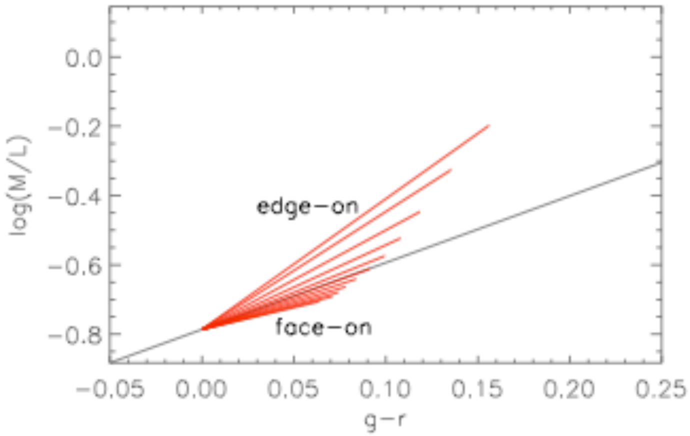


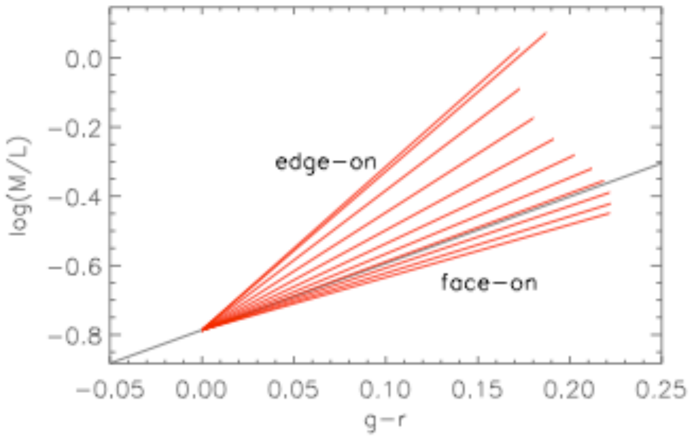
MGC
Millennium Galaxy Catalogue

Significant impact for edge-on systems

Table 1. Schechter function parameters for various galaxy samples with varying degrees of dust attenuation corrections.

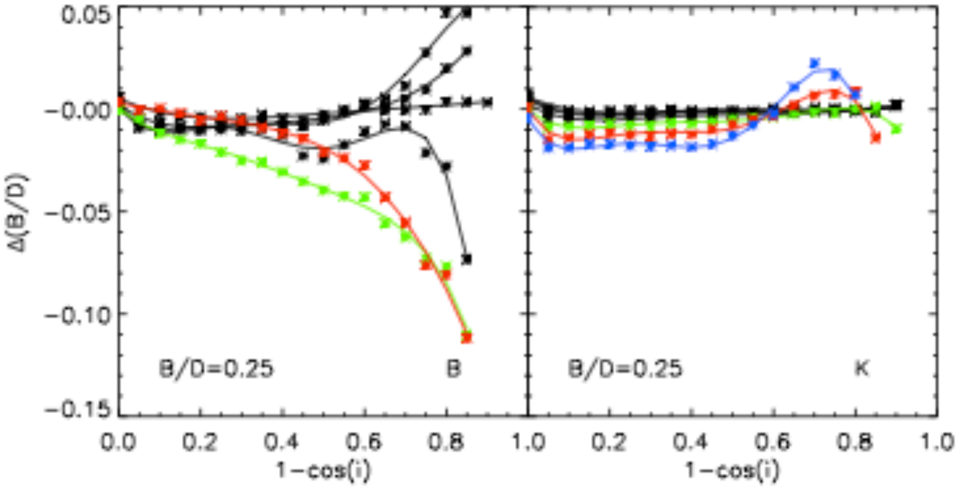
Component	$M^* - 5\log h$ (mag)	ρ^b ($10^8\,h\,M_\odot\,\mathrm{Mpc}^{-3}$)
Discs:		
uncorrected	–	3.8 ± 0.4^d
inclination corrected	–	$4.7(5.0)^c \pm 0.5^d$
inclination & face-on corrected	–	$4.1(4.4)^c \pm 0.3^d$
$3.33 \times (1 - \cos(i) < 0.3)$	–	5.3 ± 1.2^d
$3.33 \times (1 - \cos(i) < 0.3)$ & face-on corrected	–	4.7 ± 0.9^d
Bulges:		
uncorrected	–	1.6 ± 0.3^d
inclination corrected	–	$2.3(2.4)^c \pm 0.3^d$
inclination & face-on corrected	–	$2.1(2.2)^c \pm 0.2^d$
$1 - \cos(i) < 0.3$	–	2.7 ± 0.4^d
$1 - \cos(i) < 0.3$ & face-on corrected	–	2.1 ± 0.3^d
Spheroids (bulges + ellipticals)^e:		
uncorrected	–	2.4 ± 0.4^d
inclination corrected	–	$3.1(3.2)^c \pm 0.4^d$
inclination & face-on corrected	–	$2.9(3.0)^c \pm 0.3^d$
$3.33 \times (1 - \cos(i) < 0.3)$	–	3.5 ± 0.5^d
$3.33 \times (1 - \cos(i) < 0.3)$ & face-on corrected	–	2.9 ± 0.4^d
Ellipticals (no corrections)	–	0.8 ± 0.1^d

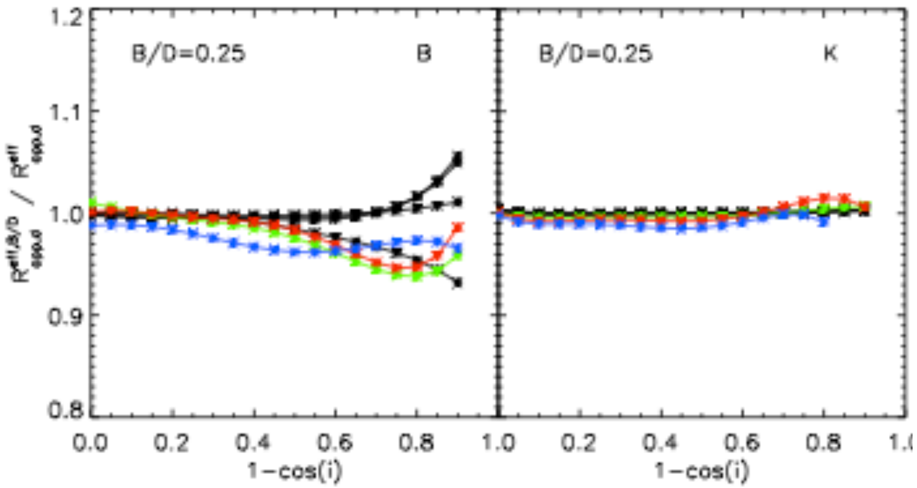


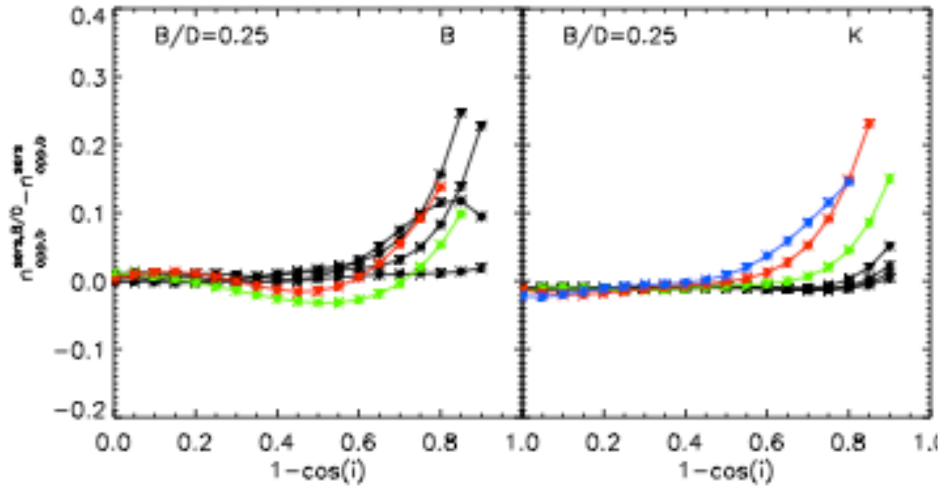


Net effect on ratios relatively minor (few %)

How dust affects structural params v inclination

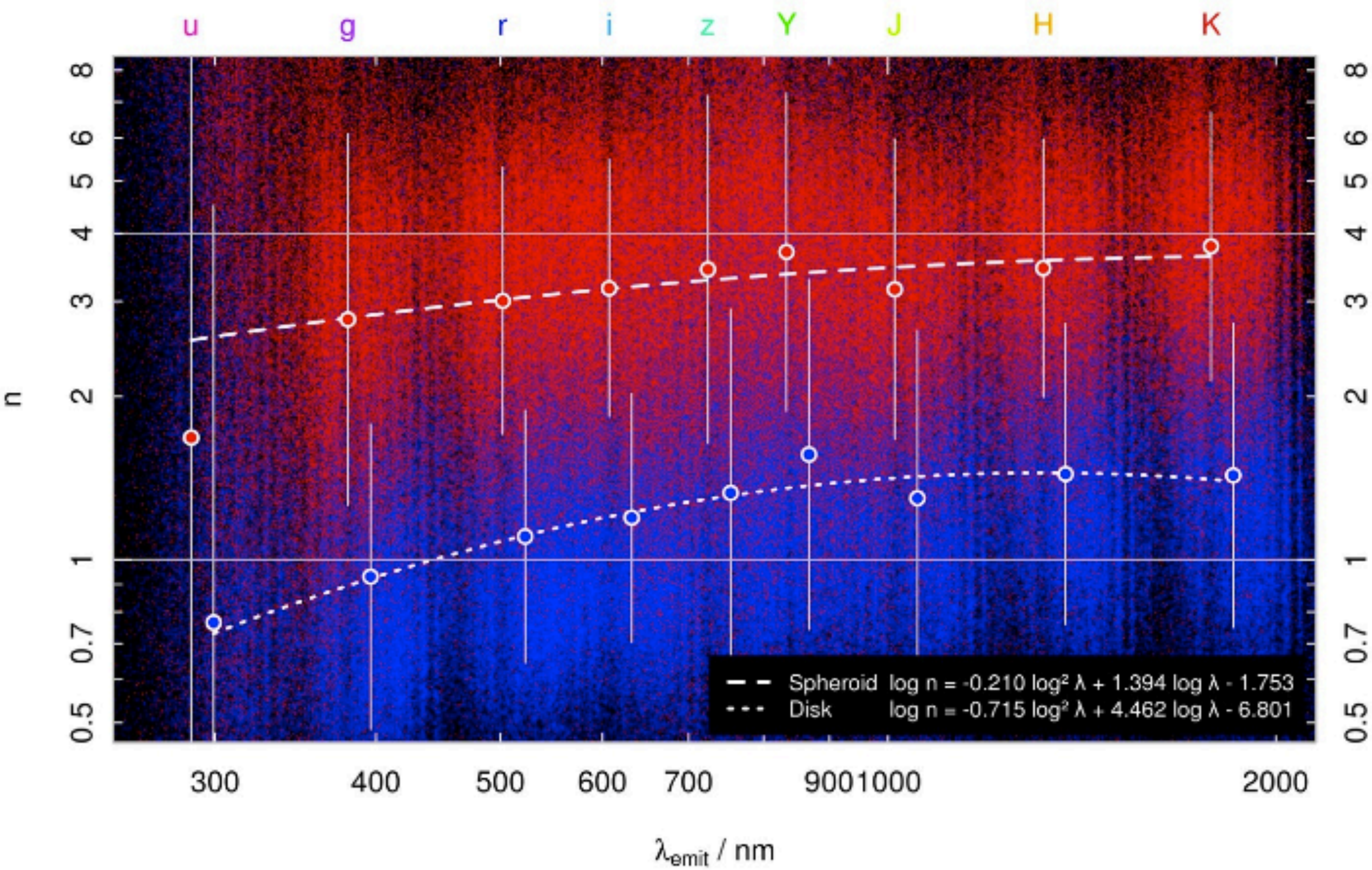






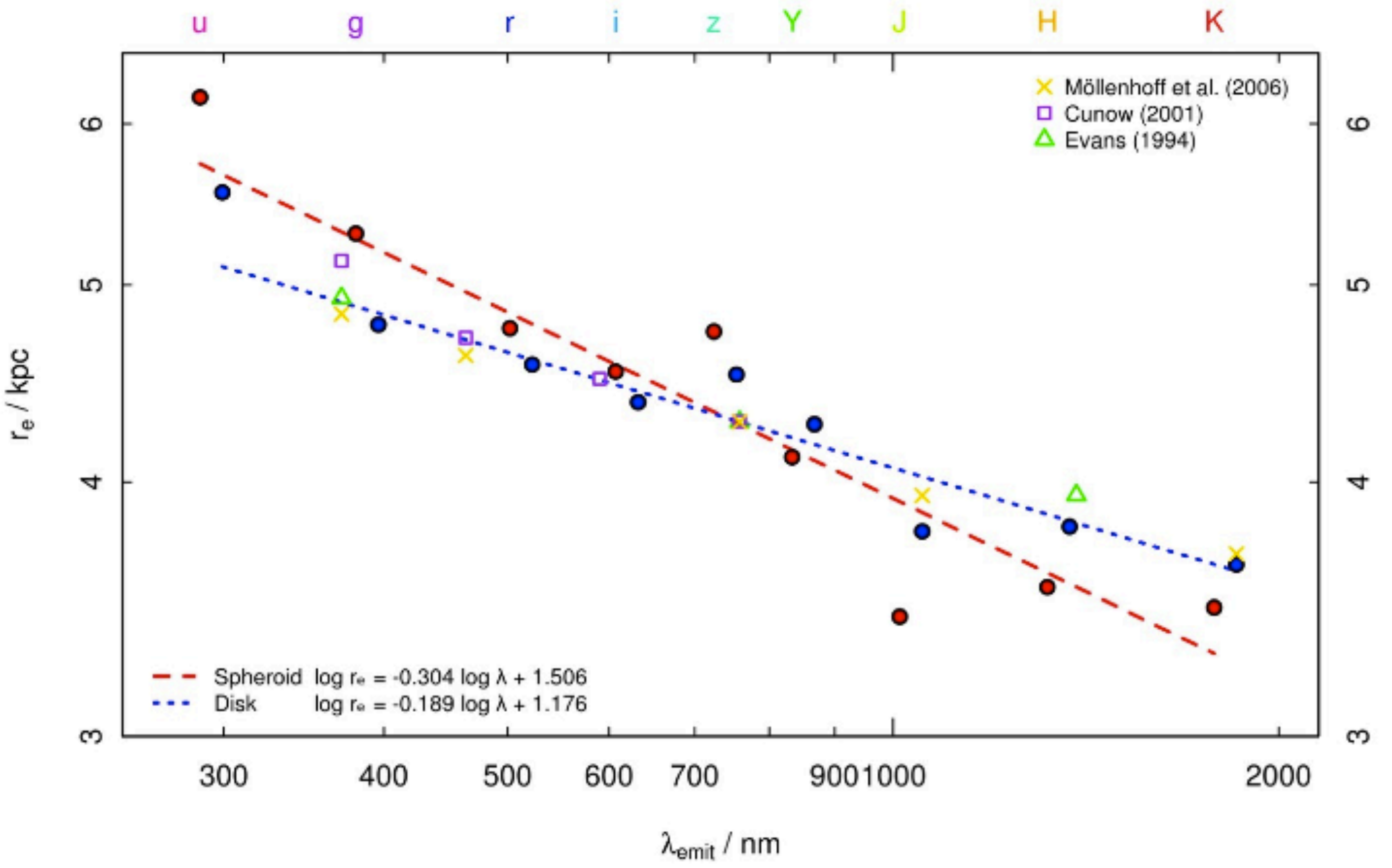
Pastrav et al (2013)
See also:
Mollenhoff, Popescu & Tuffs (2003)

Wavelength dependence of size and Sersic index?



Kelvin et al (2012); Hauβler et al (2013)

Wavelength dependence of size and Sersic index?



Kelvin et al (2012); Hauβler et al (2013)

The stellar mass functions of spheroids and discs

Simon Driver

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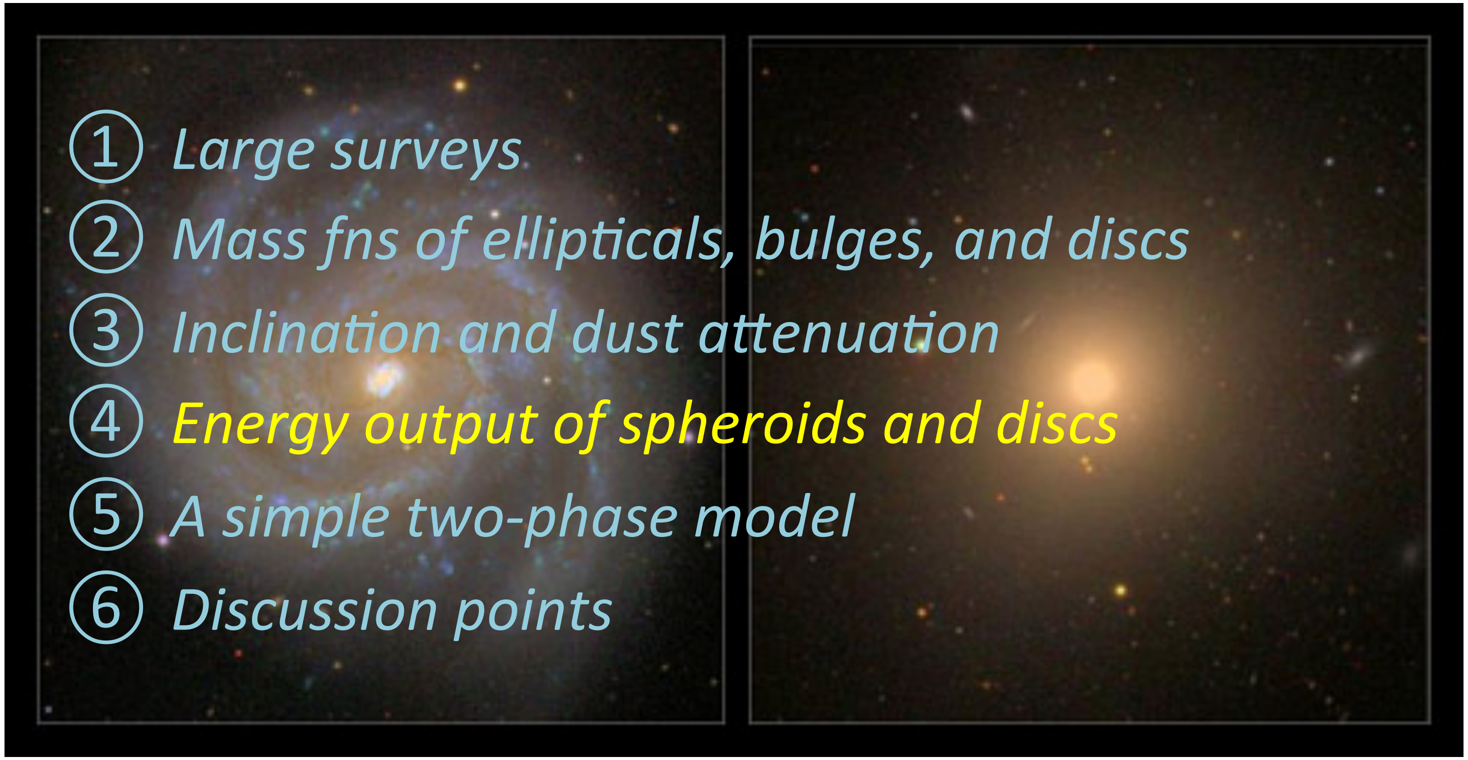


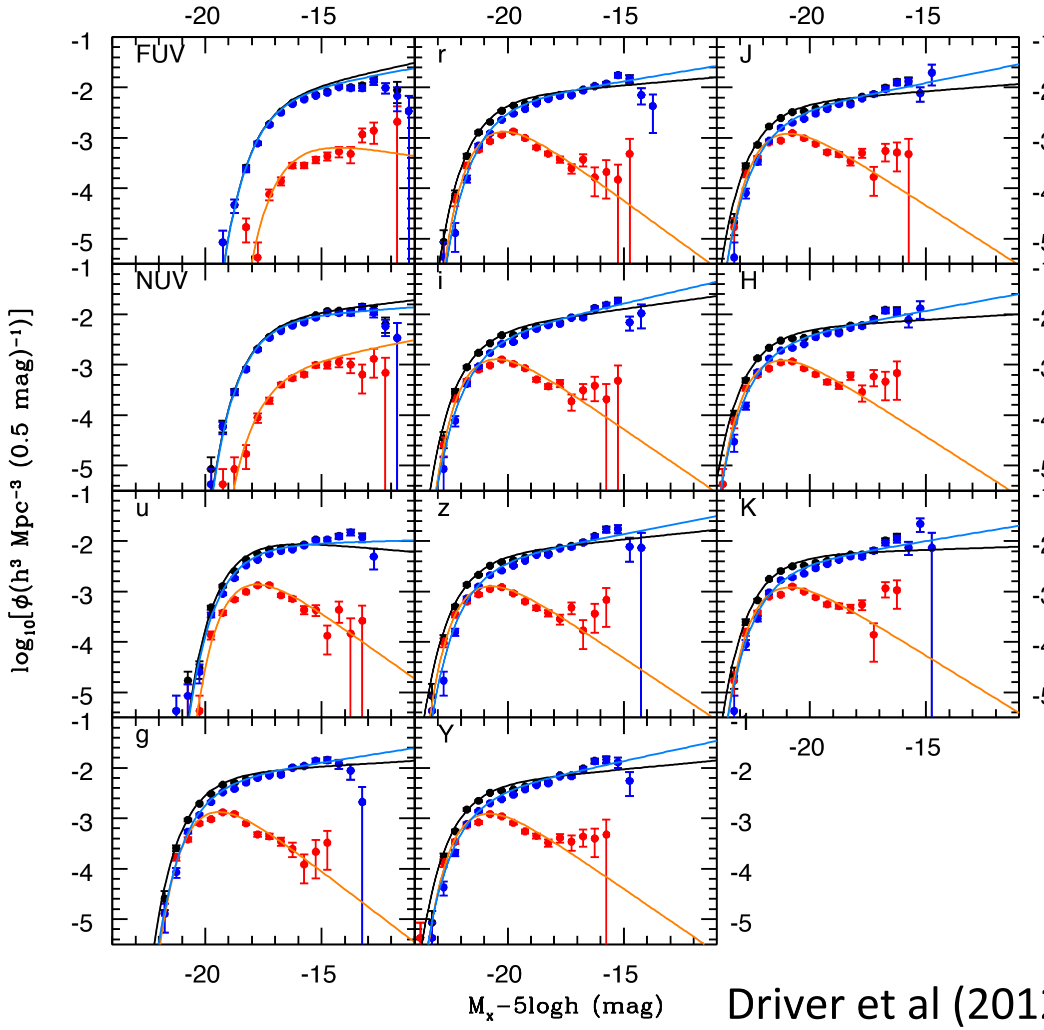
FUV-K LFs by morphological type

Can measure LFs of Elliptical and non-elliptical systems

Correct non-ellipticals for dust using MGC photon escape fraction

Integrate LFs to get luminotiy density

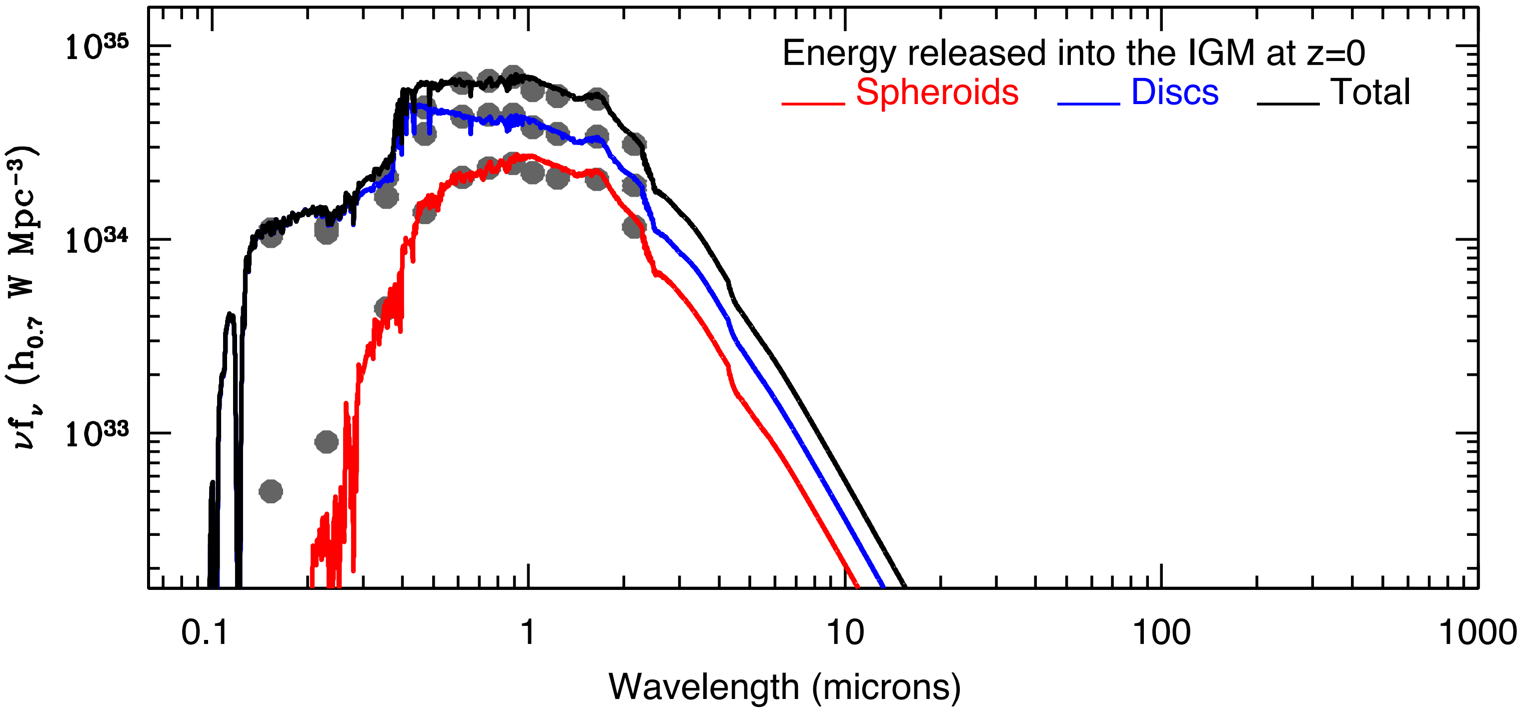
Observed energy output of the combined z=0 galaxy population



Driver et al (2012)

SED of Universe at z=0

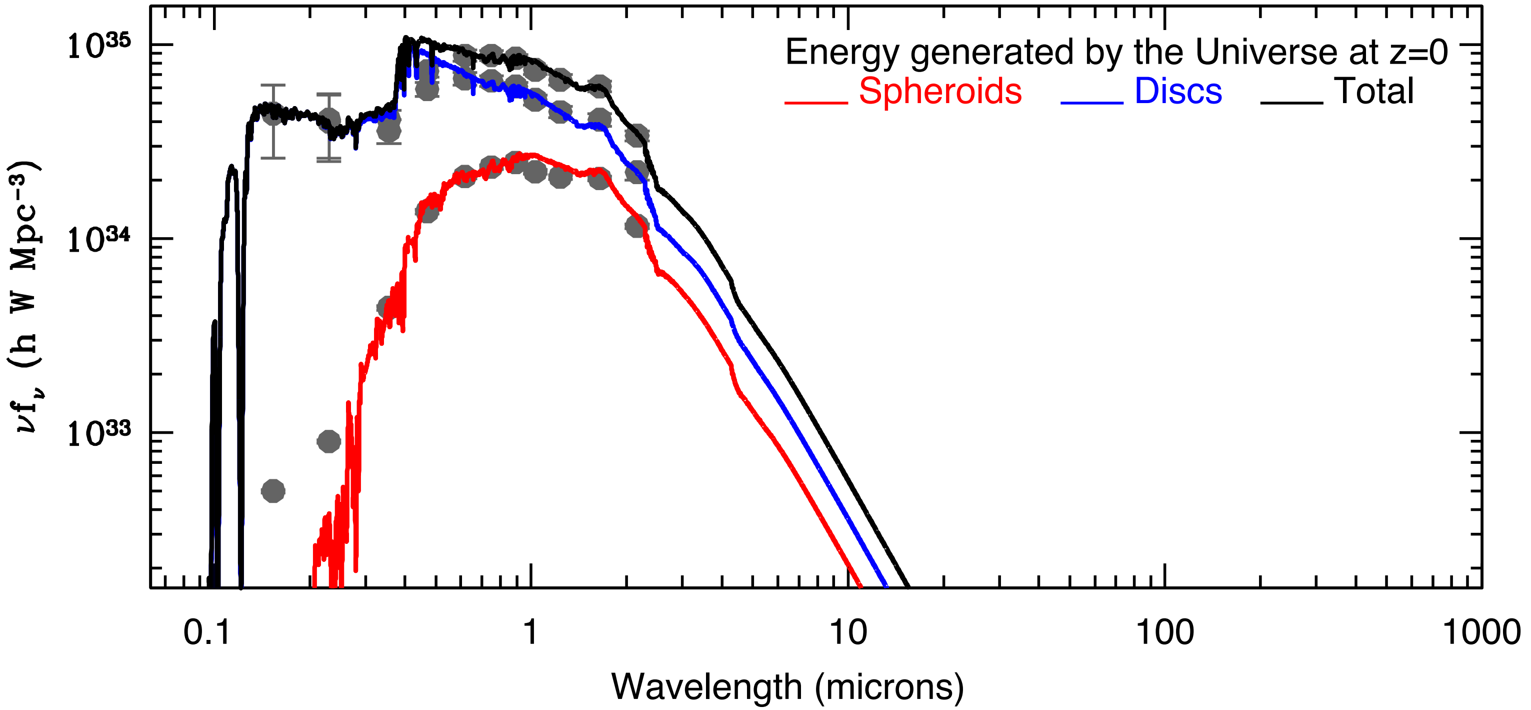
Attenuated spectrum for spheroids and discs



Driver et al (2012)

SED of Universe at z=0

Unattenuated spectrum for spheroids and discs

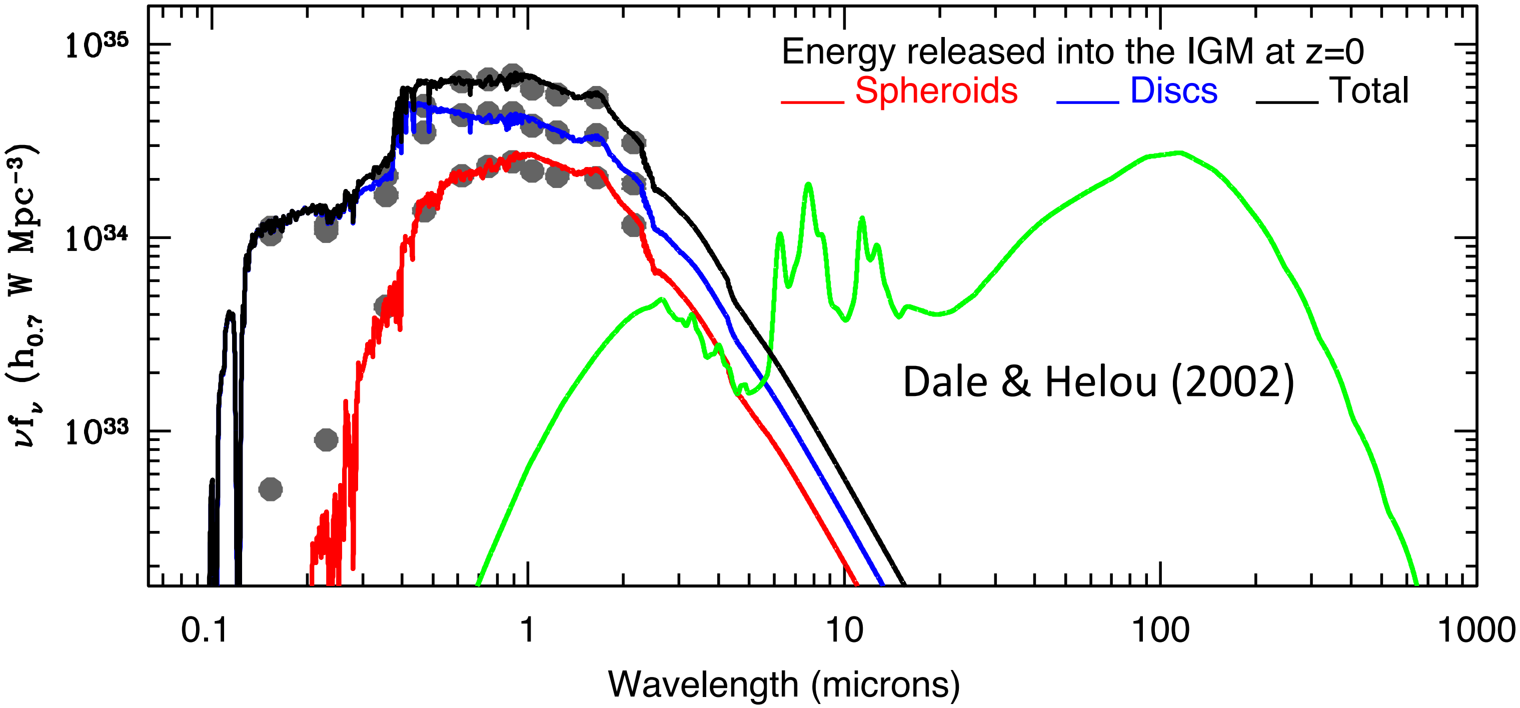


Using photon escape fraction from Driver et al (2008)

Driver et al (2012)

SED of Universe at z=0

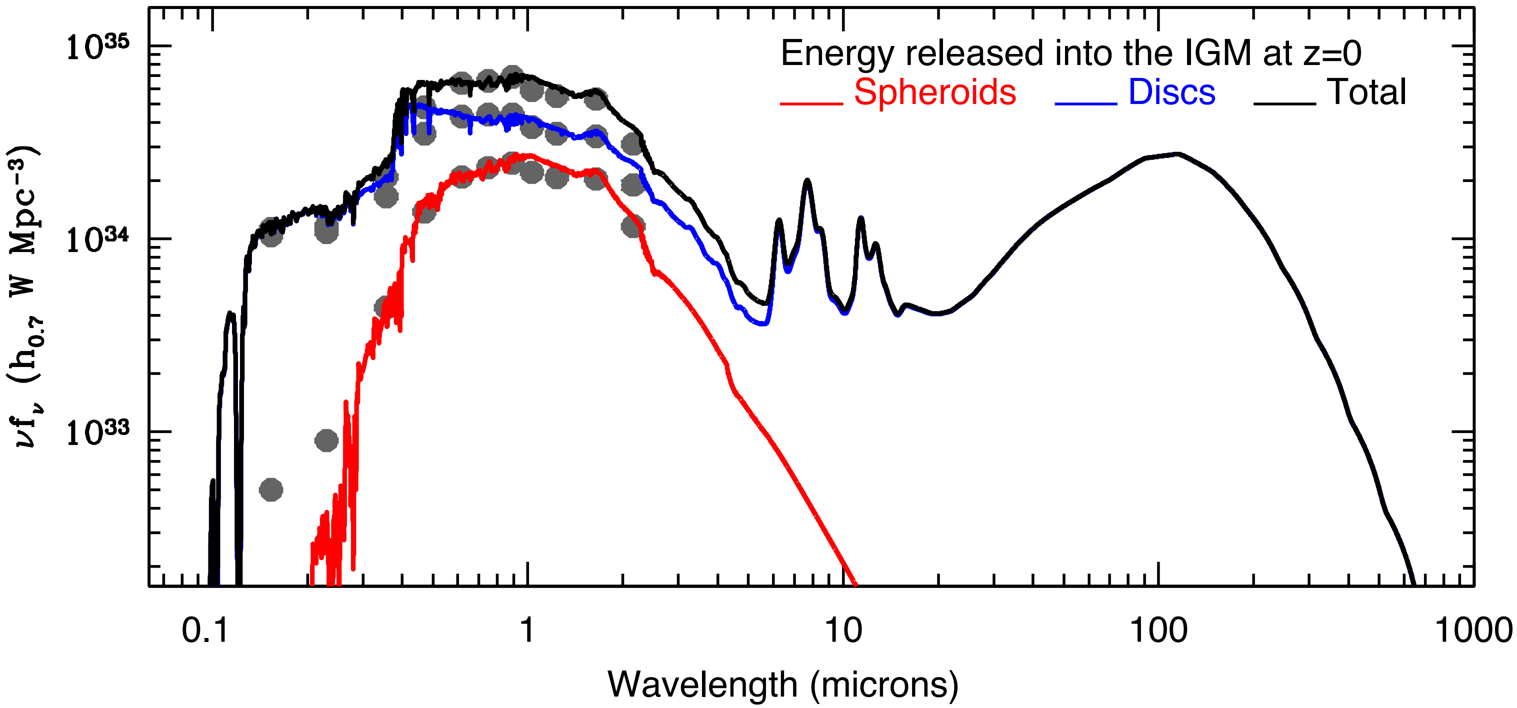
Missing energy transferred to dust



Driver et al (2012)

SED of Universe at z=0

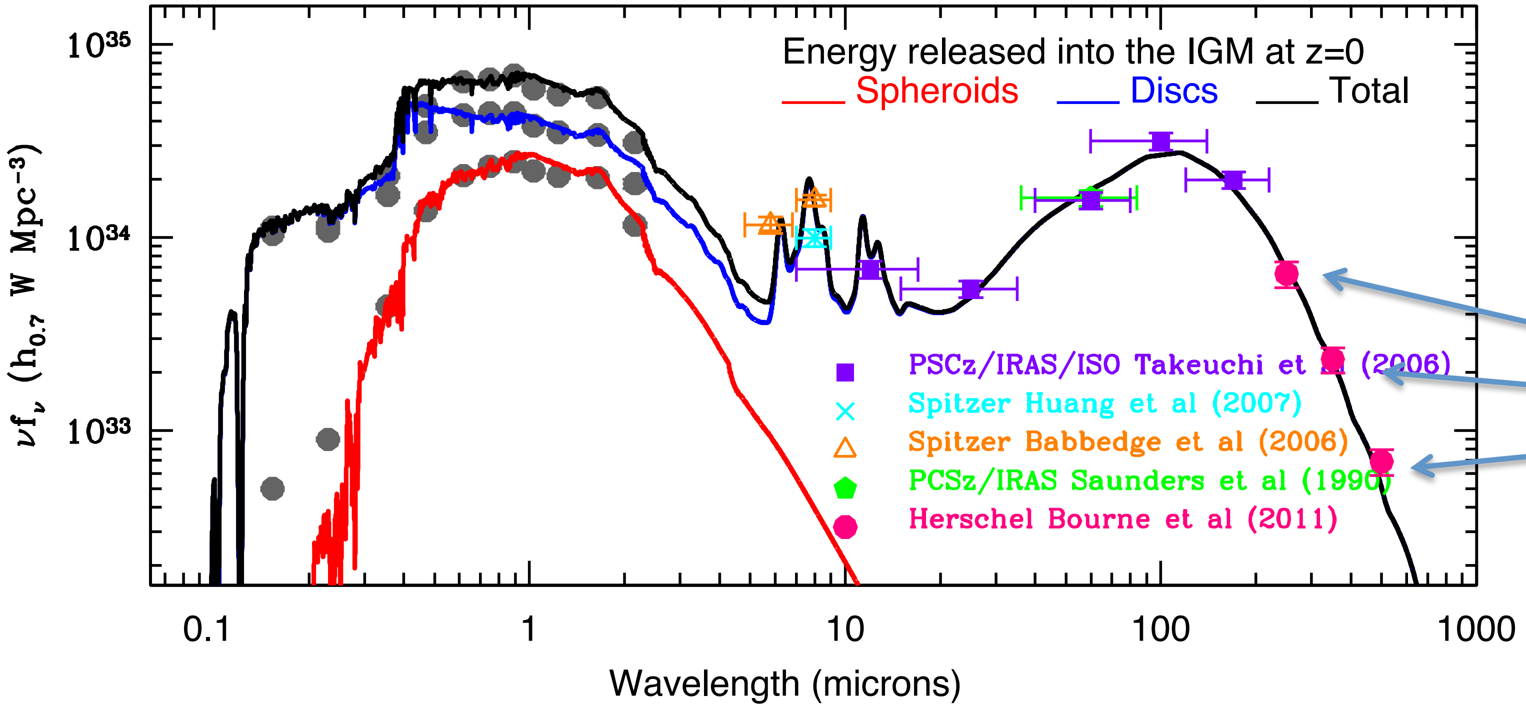
PREDICTED far-IR emission



Driver et al (2012)

SED of Universe at z=0

PREDICTION v FIR data



Driver et al (2012)

The stellar mass functions of spheroids and discs

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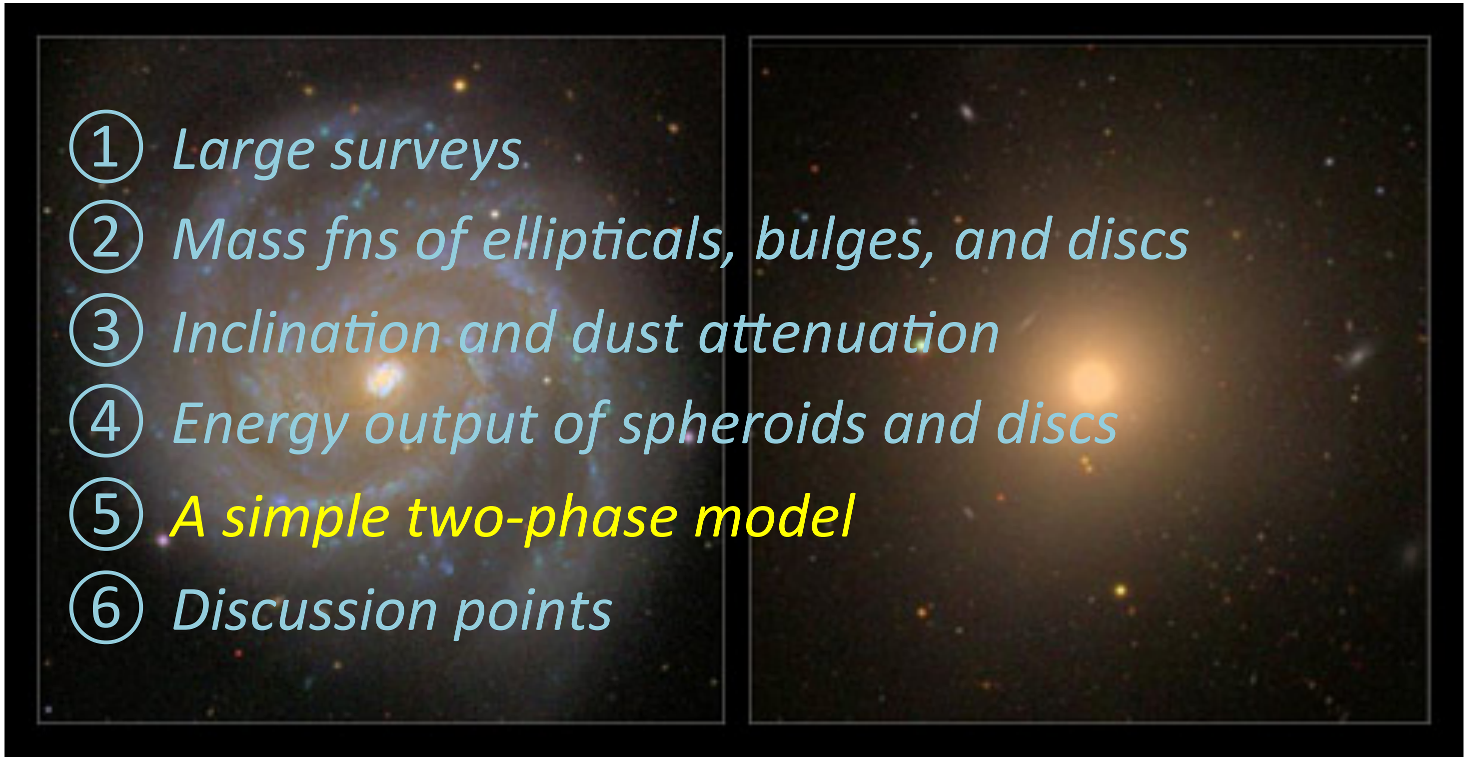
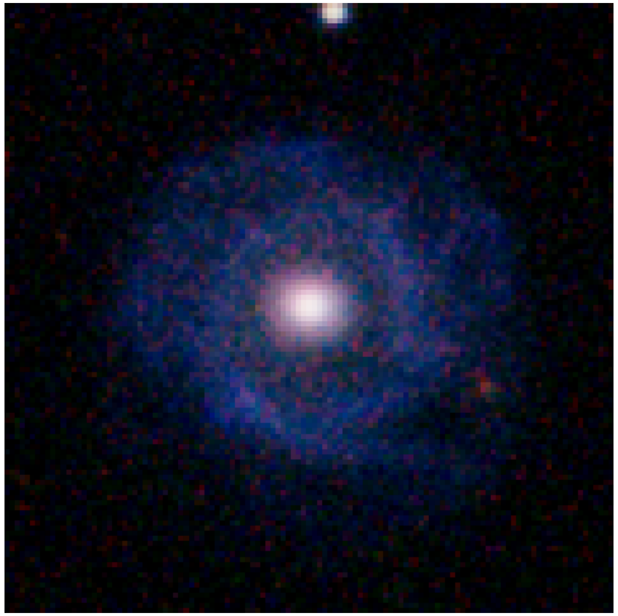


Spheroids & Discs?

Are there 2 distinct evolutionary modes?

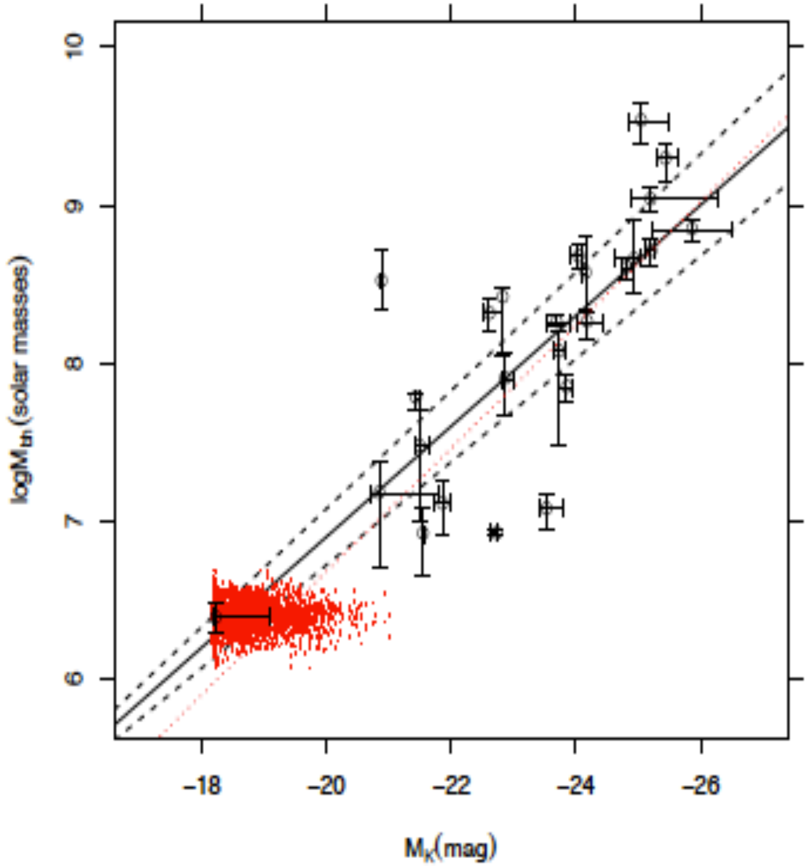
Hot mode → spheroids (collapse/mergers)

Cold mode → discs (accretion/gas infall)



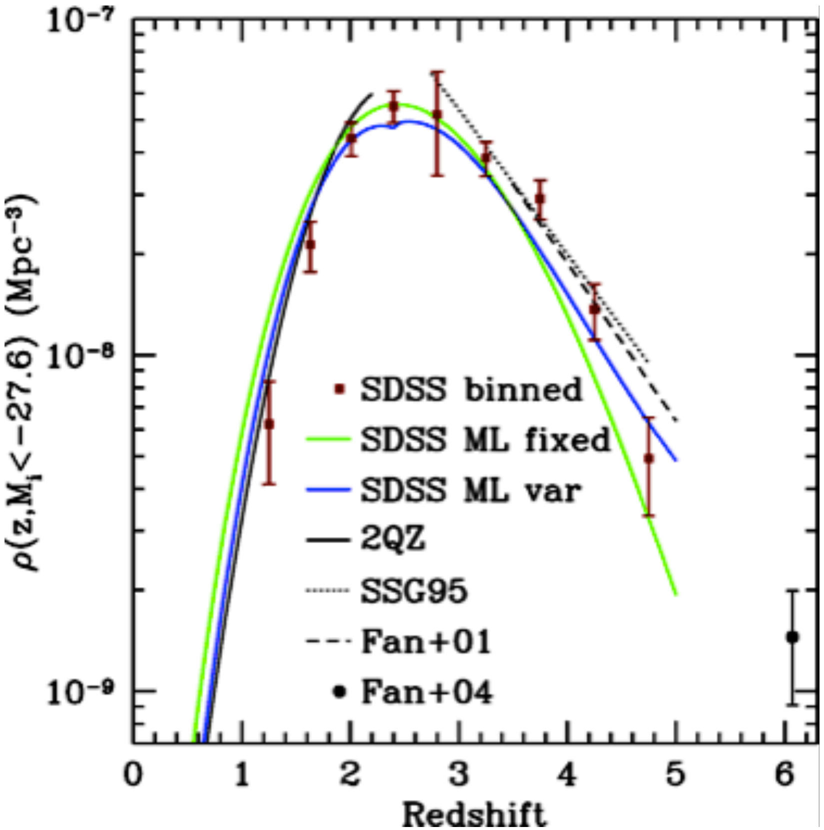
AGN and Spheroid formation

Magorian-Gebhardt relation



e.g., near-IR relation from Vika et al (2012)

AGN activity



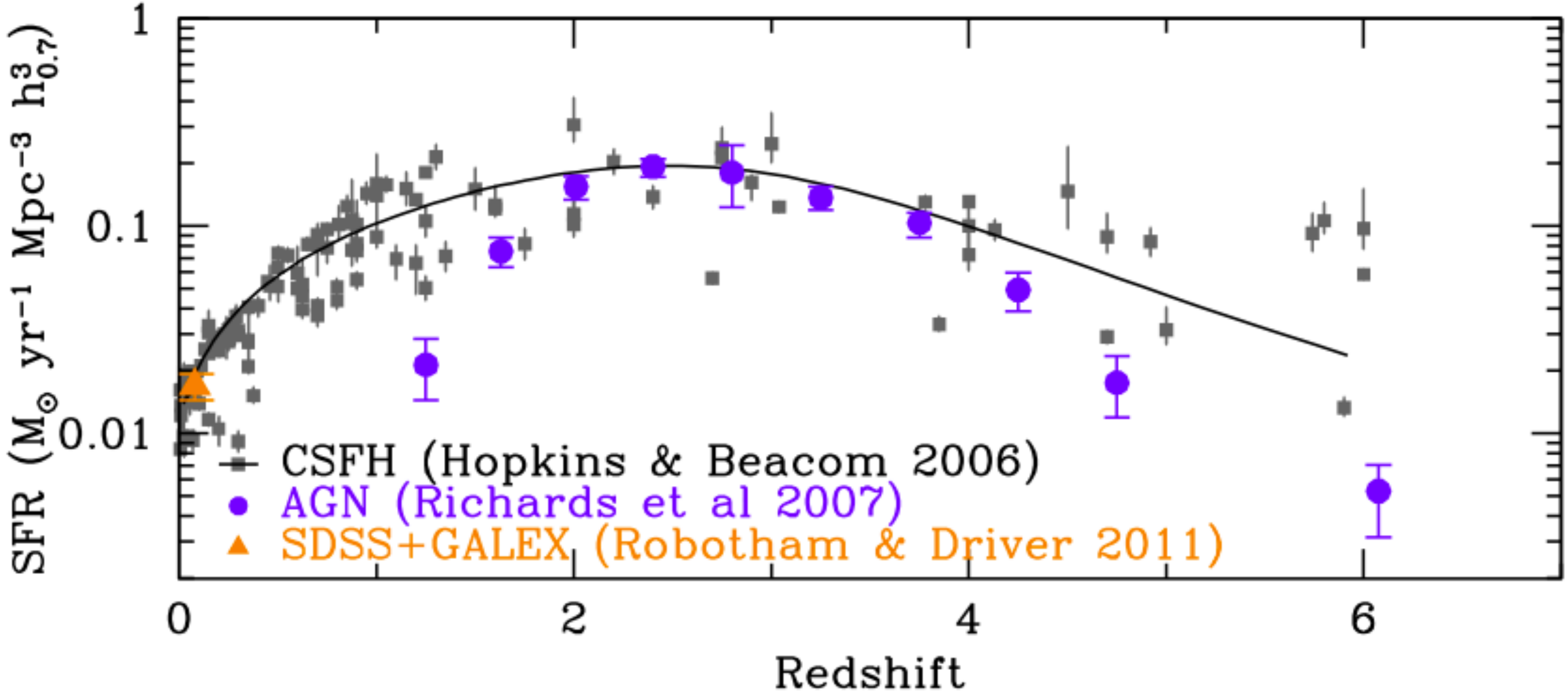
Richards et al (2007)

Two phase galaxy formation?

Axioms:

AGN activity traces spheroid formation (Richards et al 2007)

Spheroid formation dominates at high-z (Hopkins & Beacom (2006)



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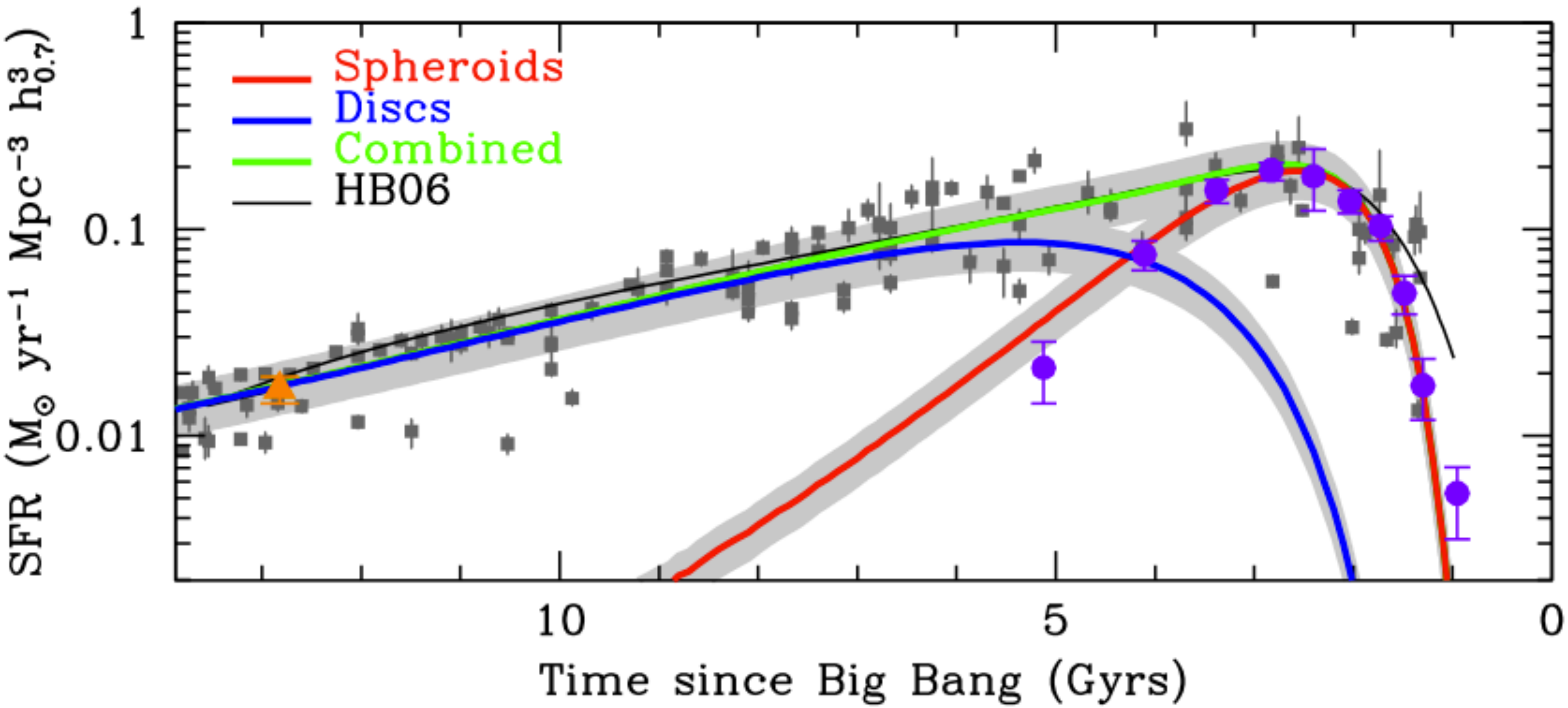
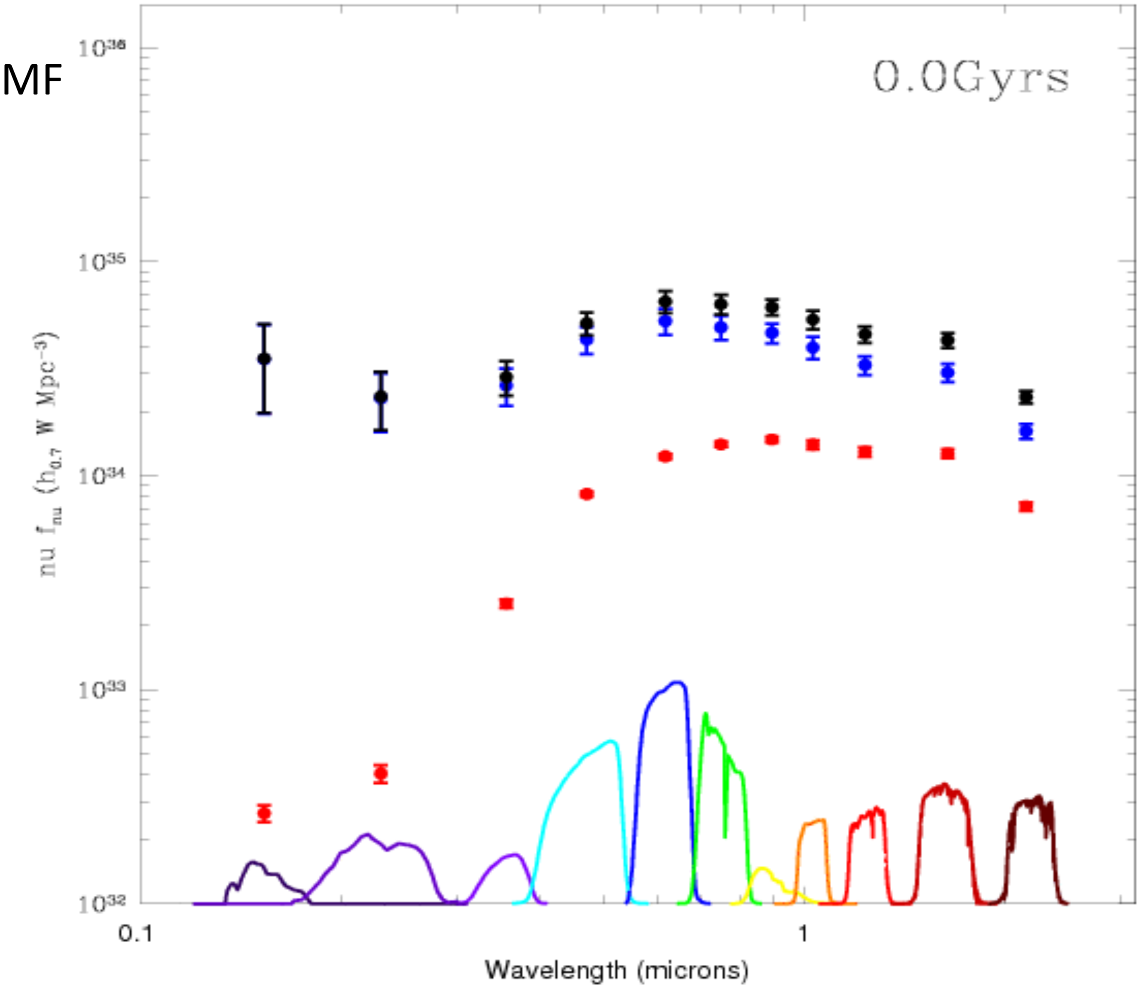


Two phase galaxy formation?

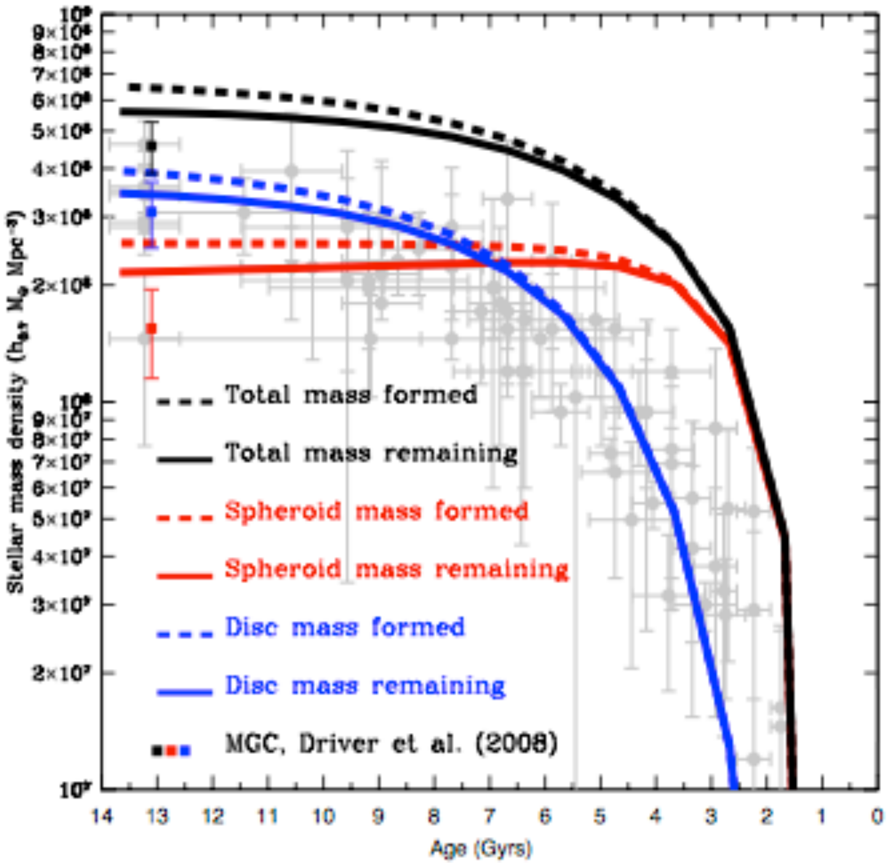
Baldry & Glazebrook IMF
PEGASE2.0
Z(t) 0->Local



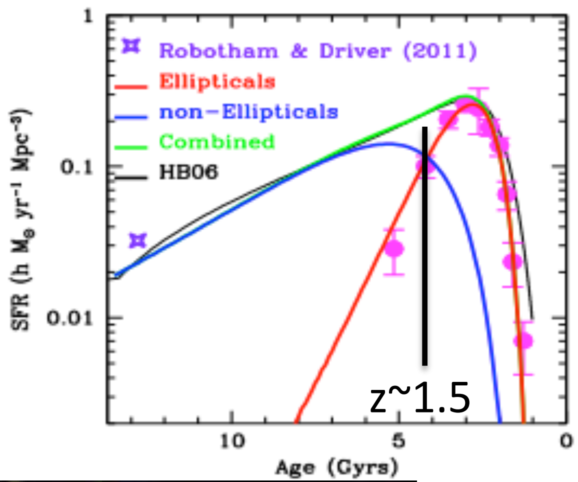
Driver et al (2013)

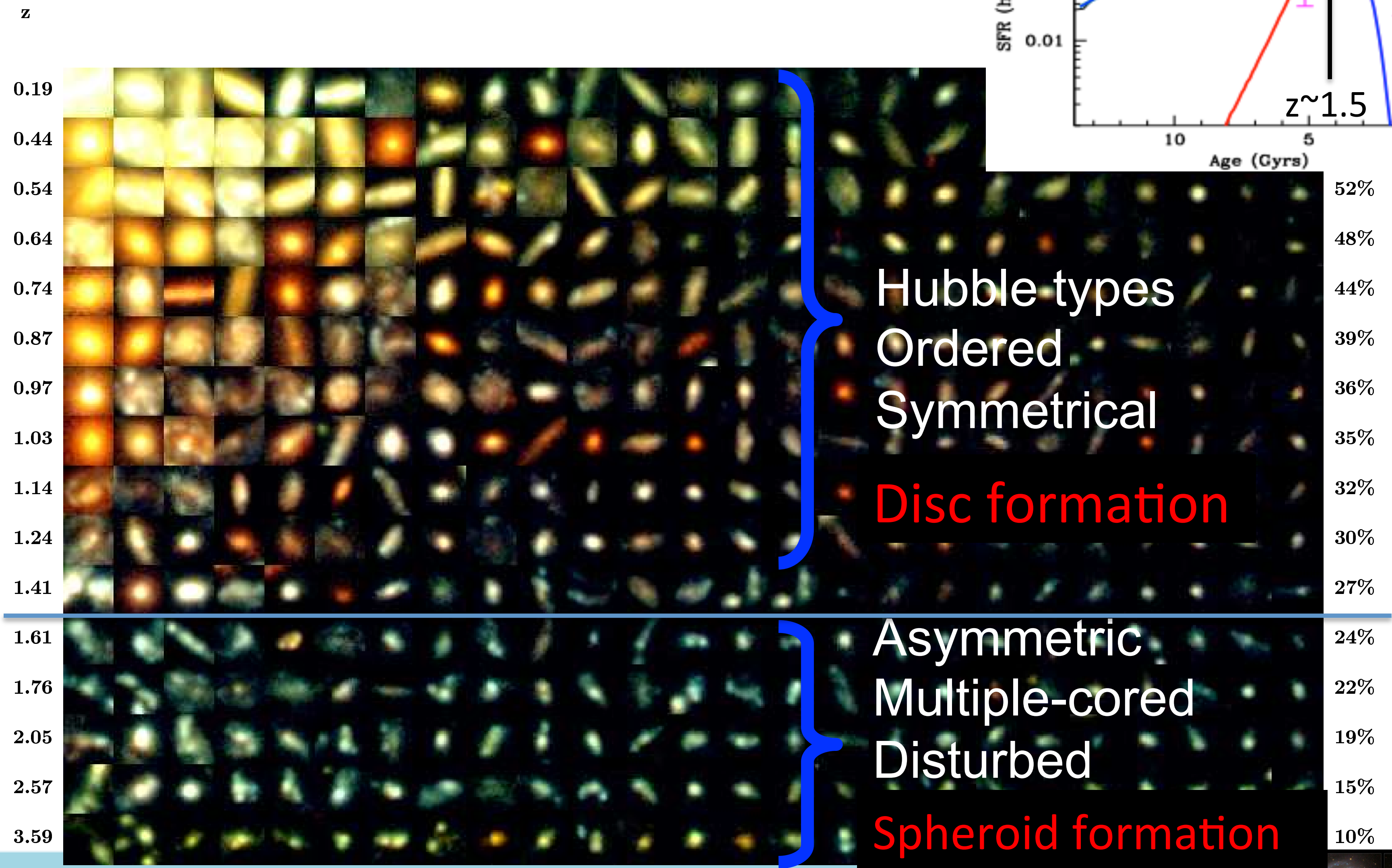
Prediction of bulge and disc mass

Mass prediction 50% too high (as for all models) but mass ratio agrees well with MGC i.e., 60%discs 40% spheroids



Implied transition redshift at z~1.5





Simon Driver & Alberto Fernandez-Soto (UNSW)

Galaxy Evolution ?

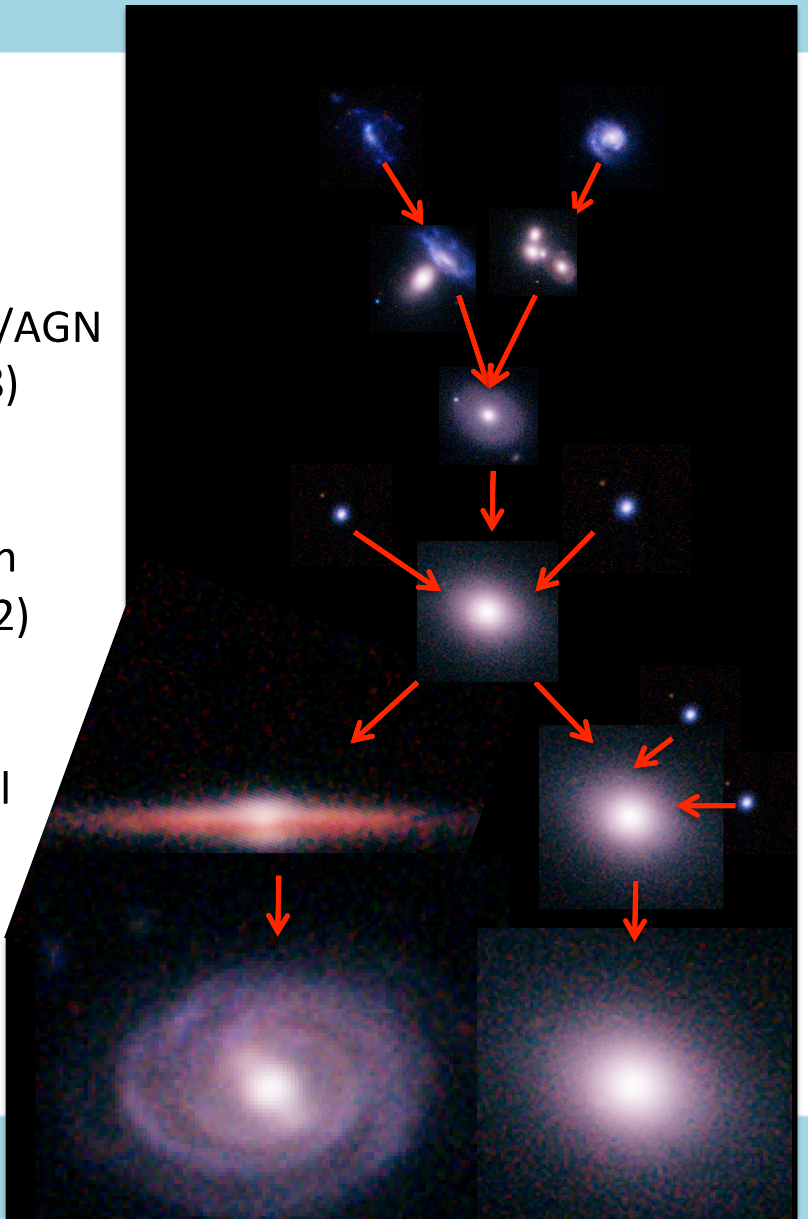
Collapse
(z<10+)

Mergers/AGN
(1 < z < 8)

Accretion
(1 < z < 2)

Gas Infall
(z<1)

Secular
(z<0.5)



Thick rotating discs
(proto-Spheroids)

Turbulent discs
(proto-Spheroids)

Compact spheroids

HOT
PHASE

Minor Merging

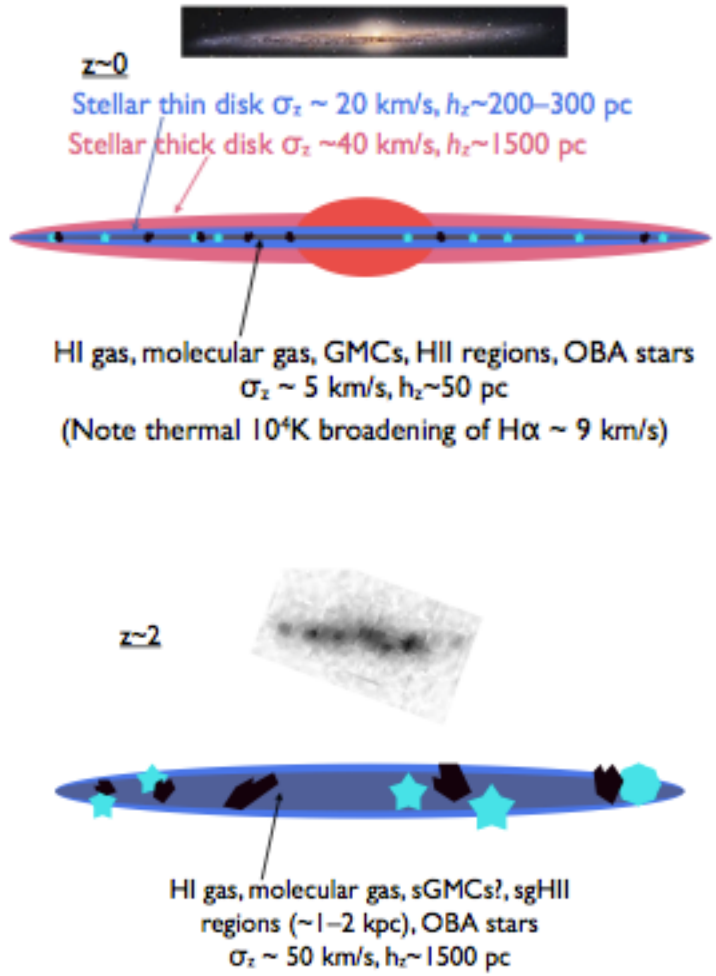
Dynamical Relaxation
Adiabatic expansion

COLD
PHASE

Evolution of structure →

What does a spheroid look like while forming?

- A. a perfect spheroid but blue (i.e., violent collapse)
- B. a thick turbulent disc (i.e., merger---> spheroid)
- C. a clumpy thick disc (i.e., clump migration--->spheroid)
- D. all of the above!
- E. none of the above!!



Figures from Glazebrook (2013)

What does a spheroid look like while forming?

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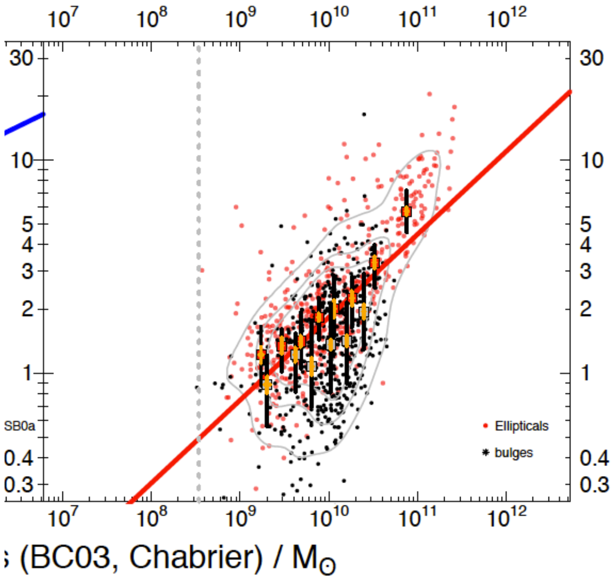
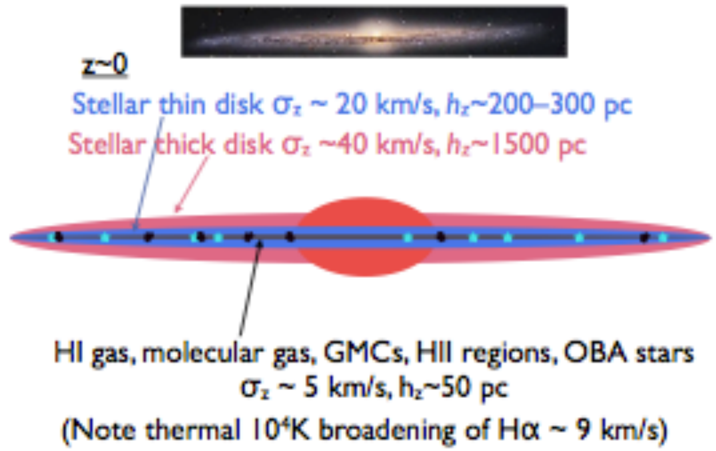
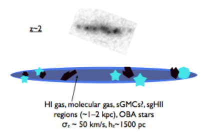




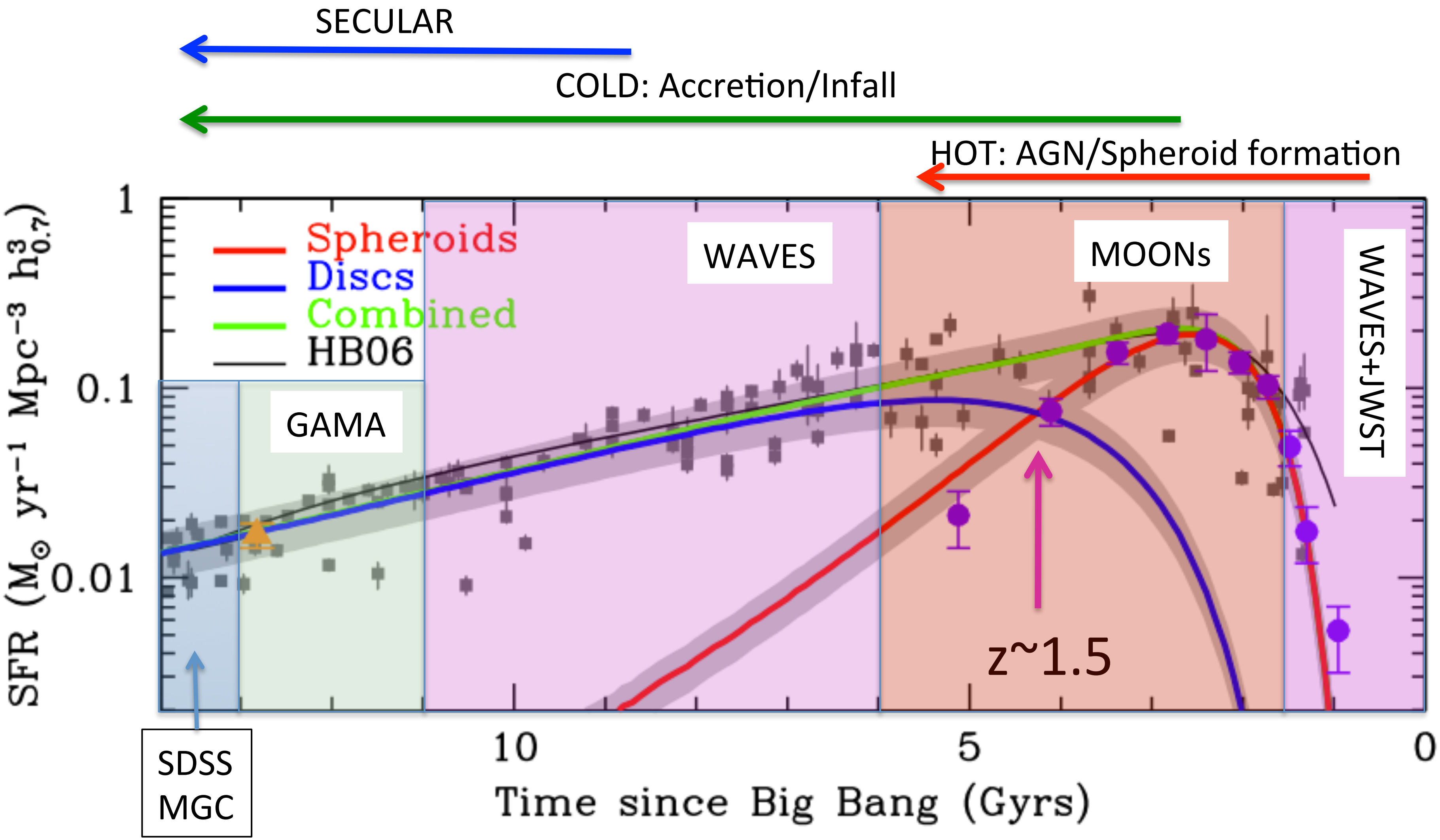
Likely not to look like Ellipticals as SFR is vigorous



Lange et al (see poster)

Figures from Glazebrook (2013)

Legacy surveys



The stellar mass functions of spheroids and discs

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1. *Large surveys*
2. *Mass fns of ellipticals, bulges, and discs*
3. *Inclination and dust attenuation*
4. *Energy output of spheroids and discs*
5. *A simple two-phase model*
6. *Discussion points*

Key issues

- Which components are primary and which are secondary?
  - Primary: Spheroids (Ellipticals and classical bulges), disc, nucleus?
  - Secondary: Pseudo-bulges, bars, rings?
- How do we decide how many components to fit?
  - AIC, BIC, reduced χ^2, eyeball over-ride?
  - Can we ever distinguish Es from S0s without dynamical info?
- Do we detect bulges or bulge complexes?
  - Sbc=pbulges, Sa=classical bulges, S0=both?
  - Sbc=pbulge dominant, Sa=classical bulge dominant, S0=either
- Structure is strongly wavelength and inclination dependent:
  - What wavelength do we fit in?
  - Simultaneous wavelength fitting: GALFIT-M/MEGAMORPH
  - Build stellar mass maps?