The Millennium Galaxy Catalogue: Bimodality, Dust and SMBHs

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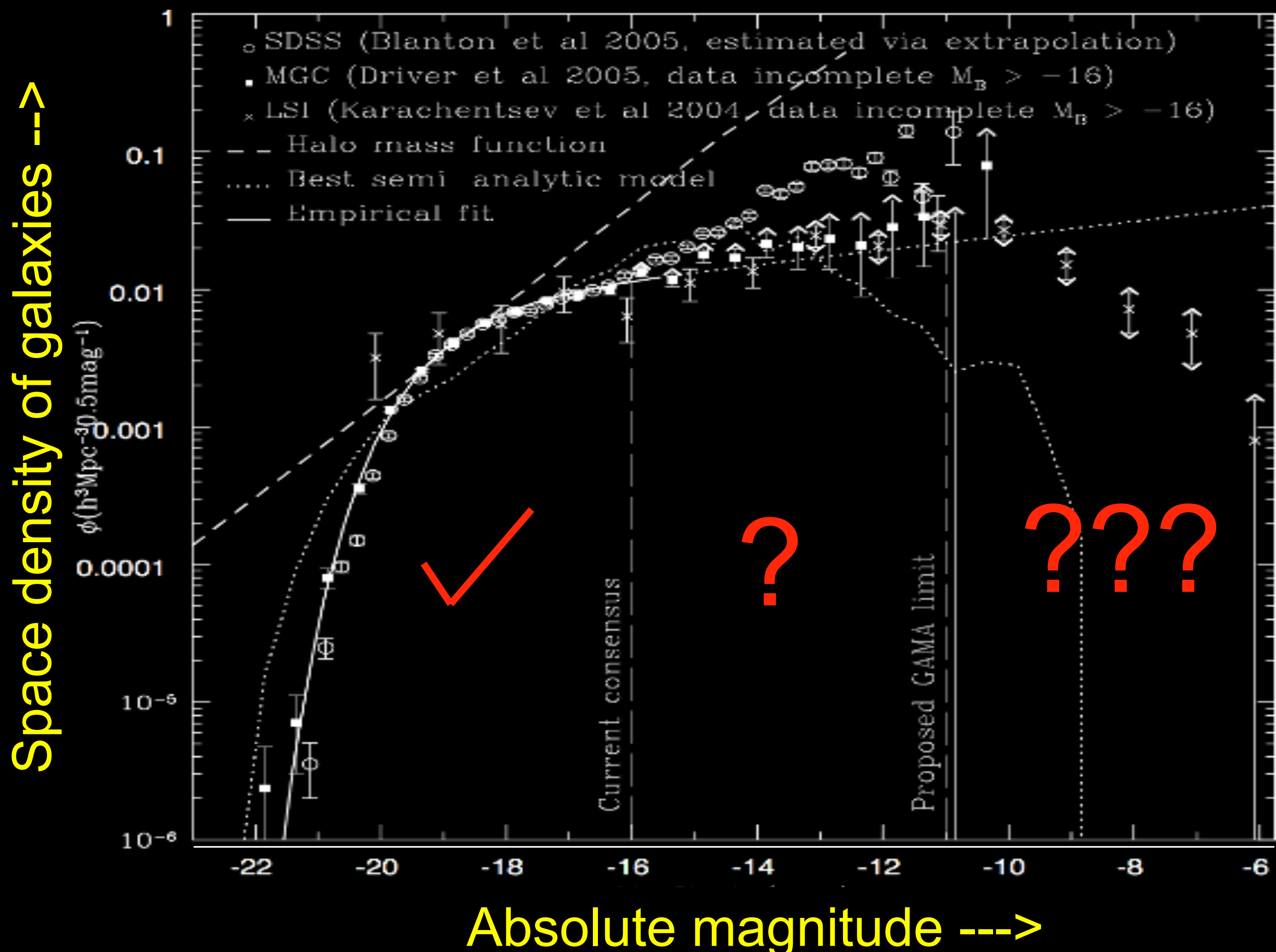
1. Structural galaxy catalogues are here and more data coming (VST, VISTA)
   - The MGC = 10,095 galaxies with B/D decomposition
2. Two examples of breakthrough science from large scale galaxy structure (MGC)
   - Dust & disc opacity --> Cosmic dust & stellar mass densities
   - SMBH mass function --> Cosmic BH mass density
3. Galaxy bimodality
   - two components not two types
   - routine bulge-disc decomposition essential
   - optical to complex ==> near-IR (VISTA)
4. A blueprint for galaxy formation and evolution ?

Limitations of SDSS & 2MASS

- Each has over 300 publications and each represents a remarkable advance in galaxy catalogues = remarkable achievements.
- But:
  - Shallow = missing galaxies and missing flux ?
  - Low resolution images = unresolved/poorly resolved ?
  - Circular photometry = muddles inclination information
  - Low completeness redshift coverage = biased ?
- Why is structure important ?
  - Galaxies are fundamentally multiple component systems, to decipher galaxy evolution we need to be able to disentangle these components: nuclei, bulges, pseudo-bulges, discs, (bars, rings, … etc)
- Still much left to be done at z=0
  - Mass function only known over 1/3 of range

The galaxy luminosity function at z=0

One third of the way there !



MGC
Millennium Galaxy Catalogue

Liske et al (2002); Cross et al (2003); Driver et al (2004)

INT WFC: 37 sq deg to B=26mag/s arcsec

~1 million galaxies

SDSS DR4: ugriz to B~25mag/sq arcsec

AAT 2dF: 10k zs to B=20 mag **(96%)**

GEMINI: zs for extreme-LSBGs (30%)

15 science papers in print/under review

The MGC Team

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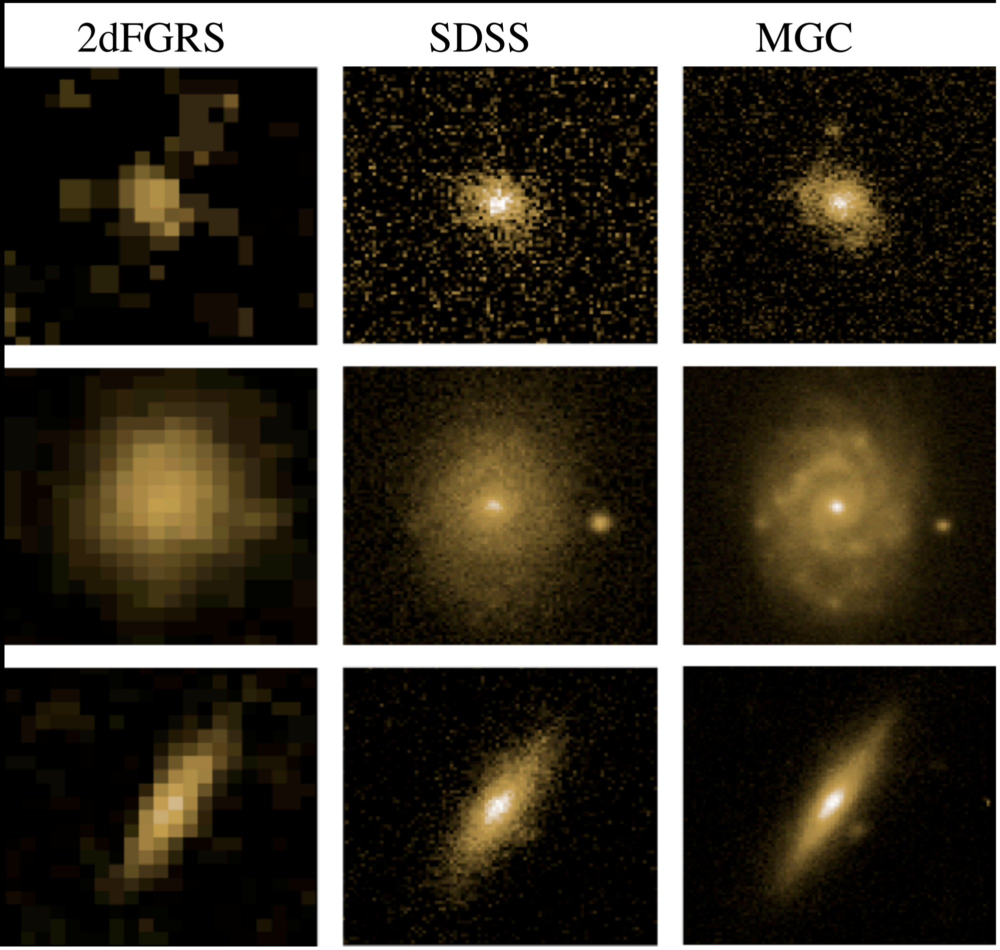
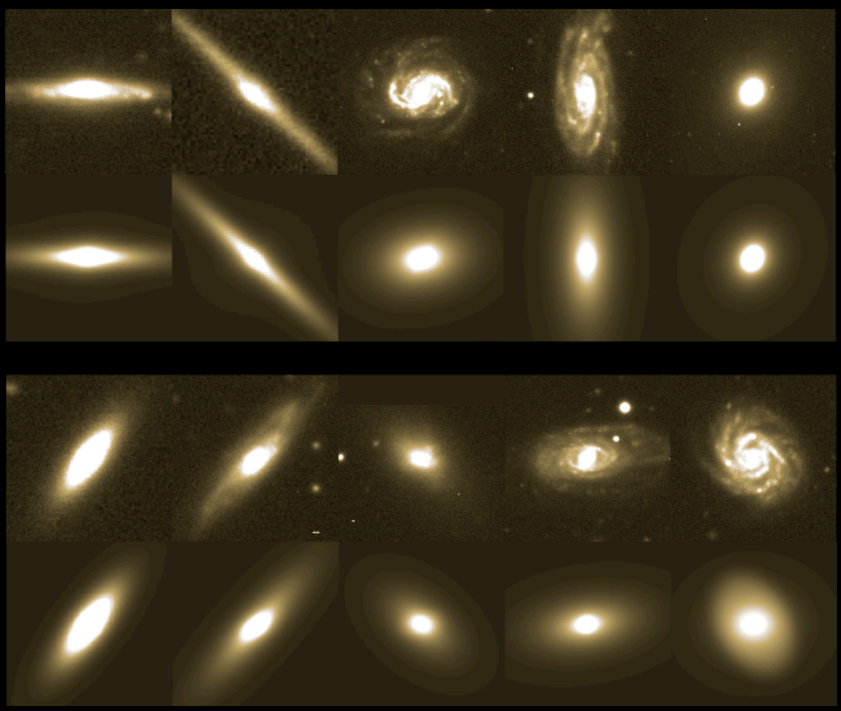
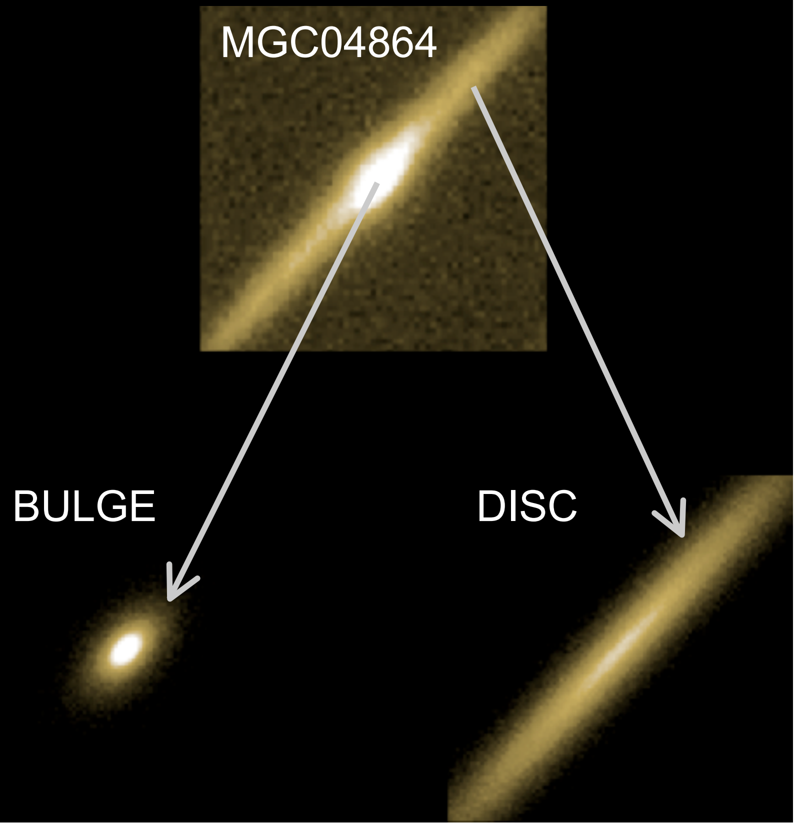
http://www.eso.org/~jliske/mgc/



MGC Bulge/disc decomposition

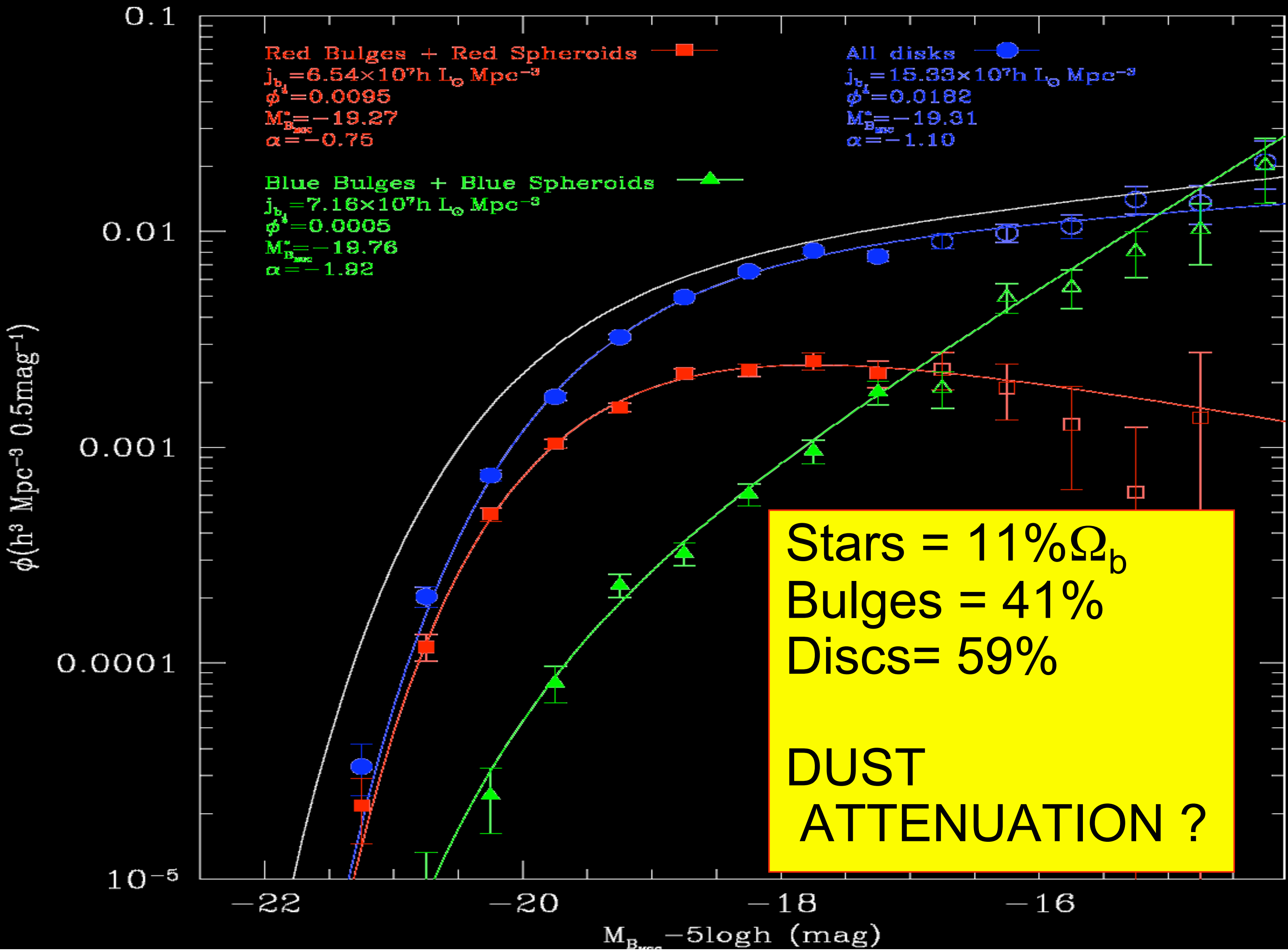
- Sersic+exponential profiles+PSF convolution via GIM2D, Simard et al (1998)
- 10,095 gals = largest available sample, Allen et al (2006)
- 96% redshift completeness (AAT/GEMINI) to B=20.0 mag, Driver et al (2005)
- B(INT) + ugriz(SDSS) + zYJHK(UKIRT) imaging now complete.
- All data available from Friday 18th August online: http://www.eso.org/~jliske/mgc/





The Component Luminosity Functions

Liske et al (2006), ApJL, submitted



Stars = 11% Ω_b
Bulges = 41%
Discs= 59%

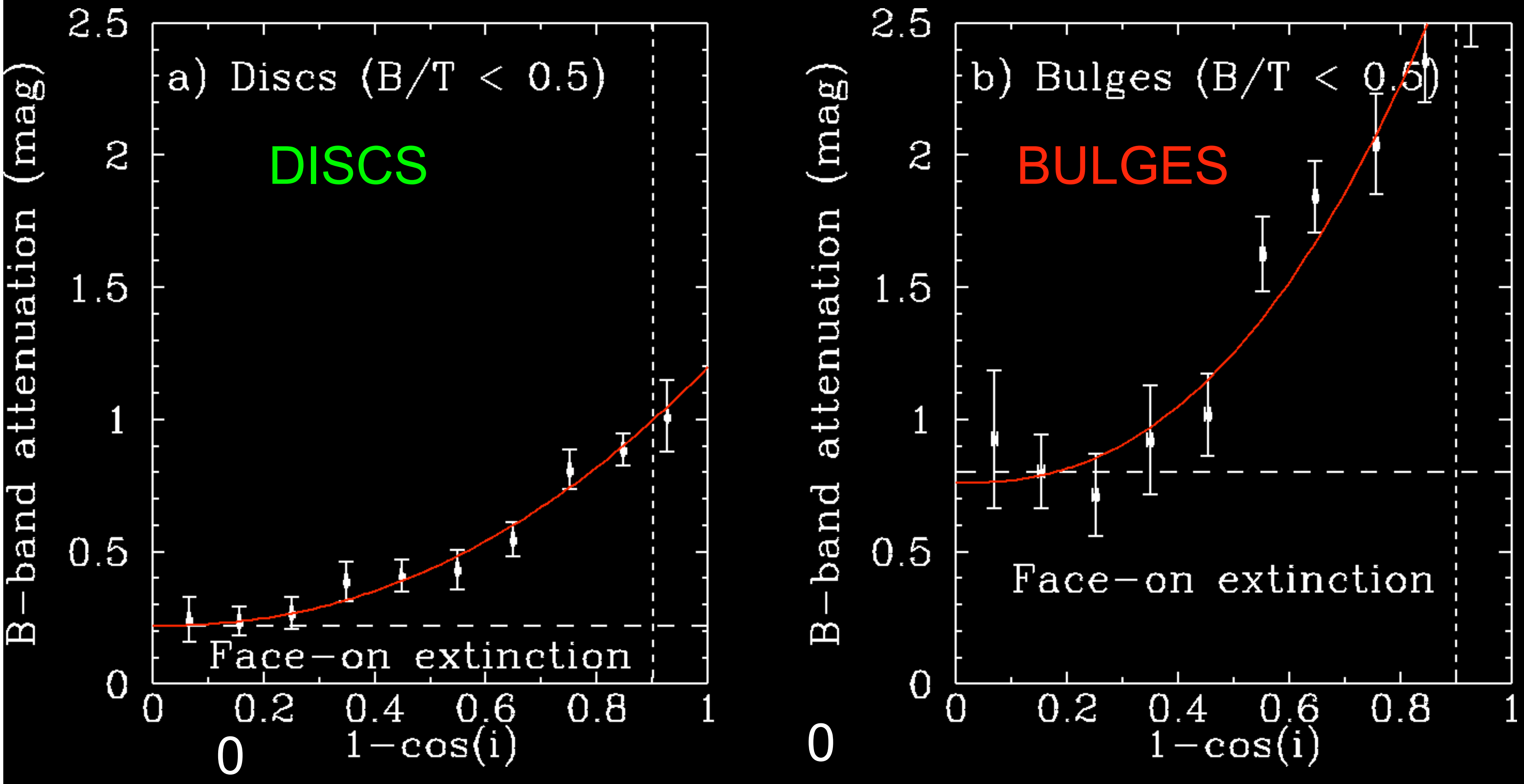
DUST
ATTENUATION ?

Structure: Dust and SMBHs

1. Dust (Driver et al 2006)
   - By using inclination information we can derive mean disc opacity
   - Derive M* in 1-cos(i) intervals
   - Plot M* v 1-cos(i)
   - Fit attenuation-inclination with a dust model ==> OPACITY
   - Dust mass to light ratio + luminosity density ==> DUST DENSITY

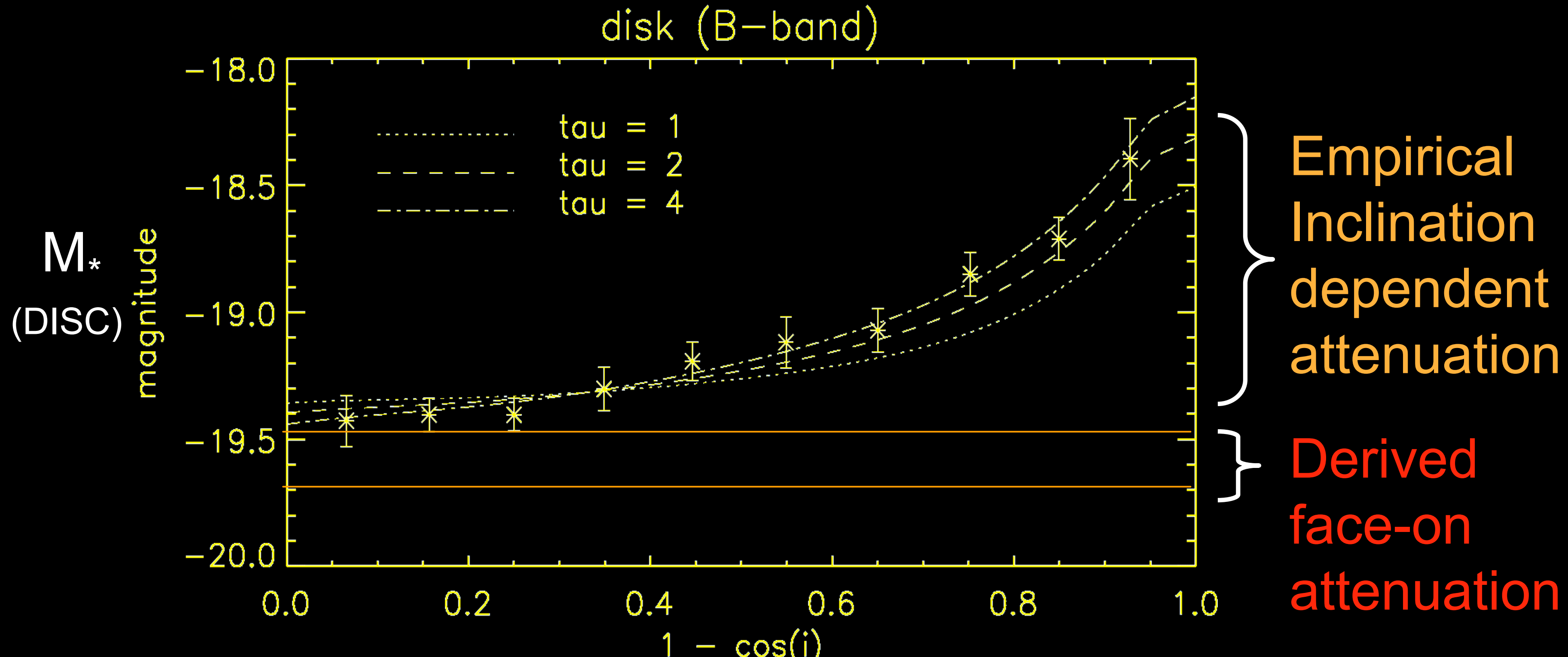
2. SMBH Mass Function (Graham et al 2006)
   - Use bulge Sersic index Black Hole mass relation (Graham & Driver 2006)
   - Derive early and late=type SMBH mass function
   - Integrate to get ==> BLACK HOLE MASS DENSITY

Empirical dust attenuation in B



Dust modelling

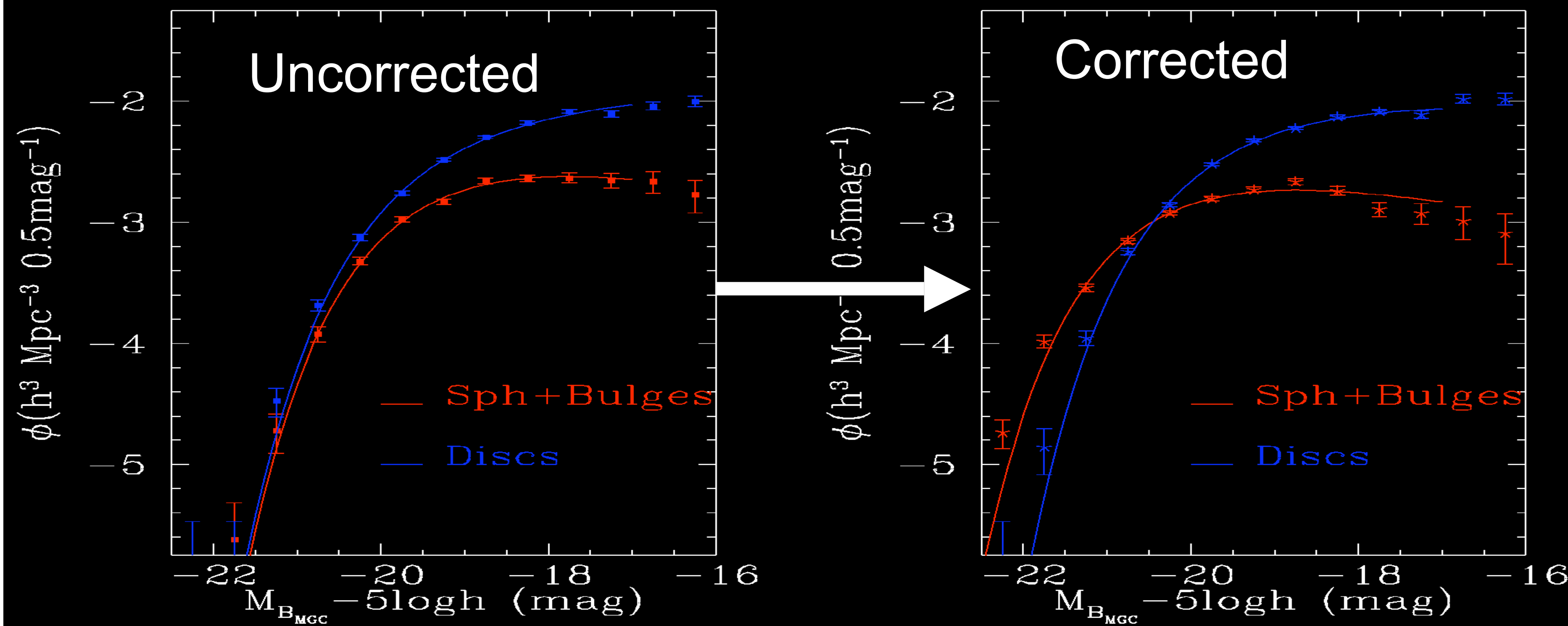
- We fit the Tuffs and Popescu dust model and derive: τ_B = 3.8 +/- 0.7
  (Popescu et al 2000; Tuffs et al 2004; Popescu et al 2005; Mollenhoff et a 2006)
- Model based on UV+ugrizJHK+Spitzer data of 6 nearby galaxies
- One free parameter = core dust density



- Face-on attenuation correction in B: Discs = 0.20 mag; Bulges = 0.84 mag
- Total attenuation in B: Discs = 0.2 - 1.1 mag; Bulges = 0.8 -3.4 mag !!!

Dust corrected LFs !

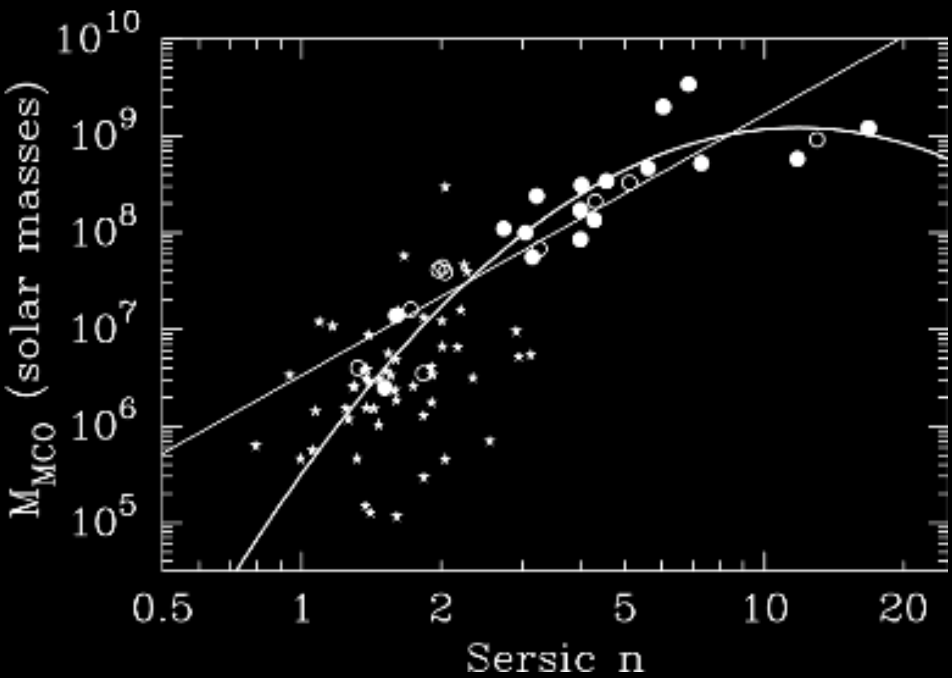
- Bulge LD up 100%; Disc LD up 40%
- Bulge mass up 150%; Disc mass up 50%
- Similar results derived from scaling up face-on LFs + offsets



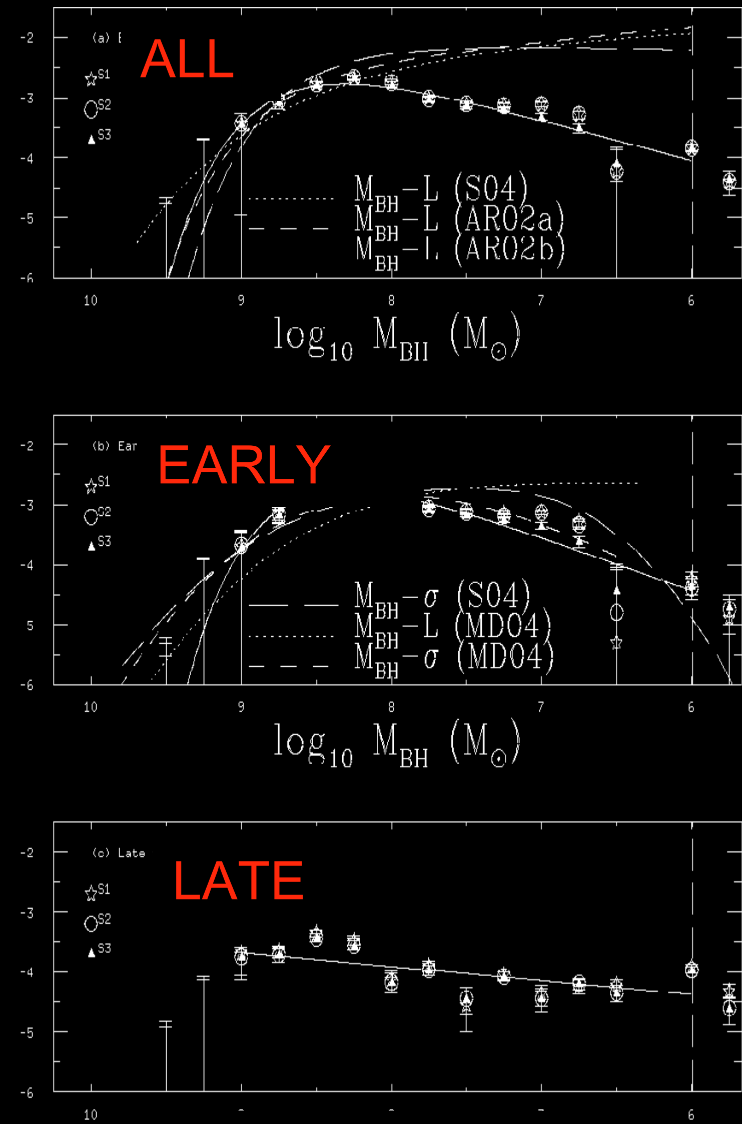
- Can derive dust and stellar mass densities from

SMBH mass function

- Use Sersic index BH relation (Grahan & Driver 2006) to predict BH masses (see Graham et al 2006):

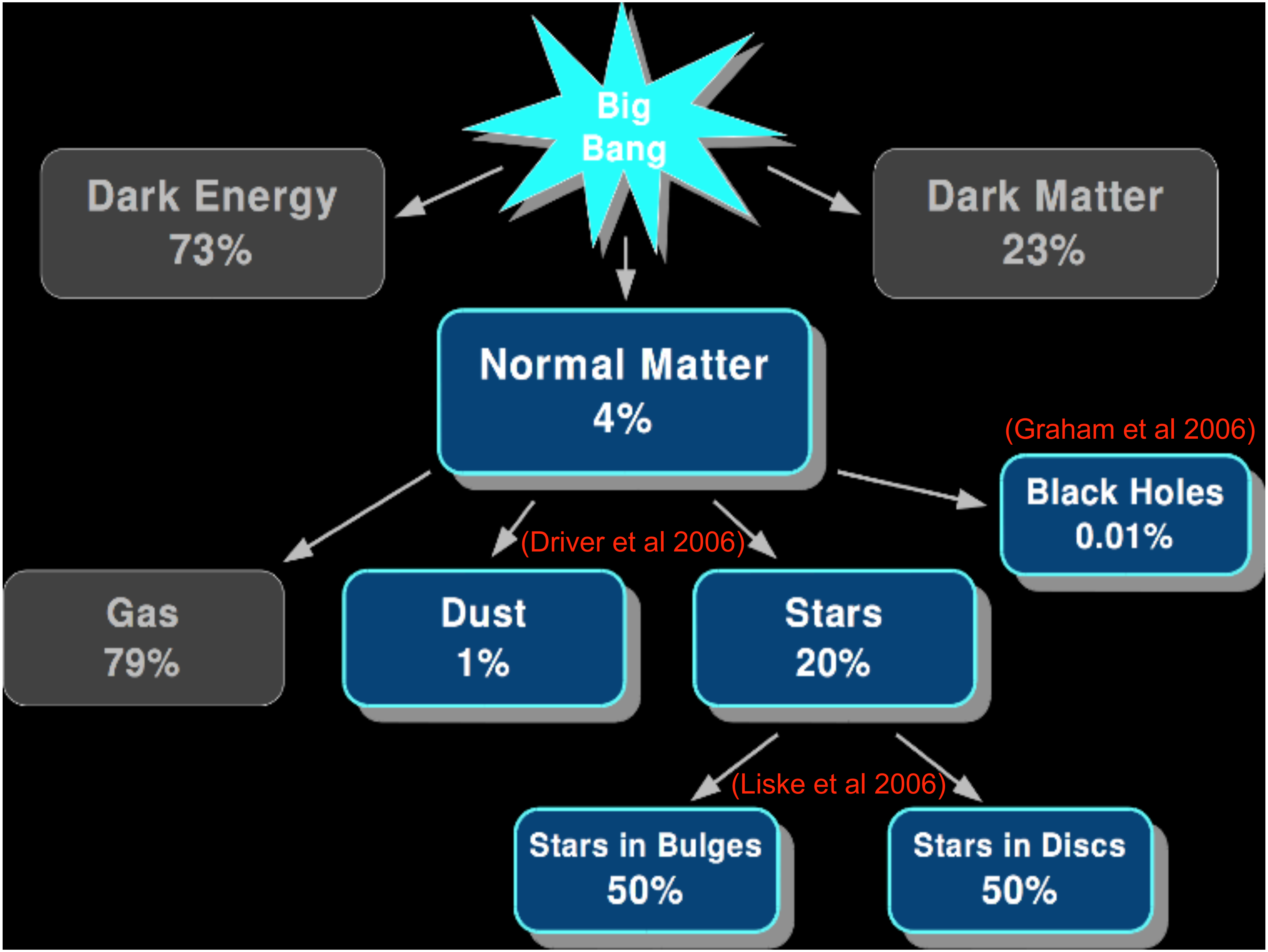


Log(Number density) -->



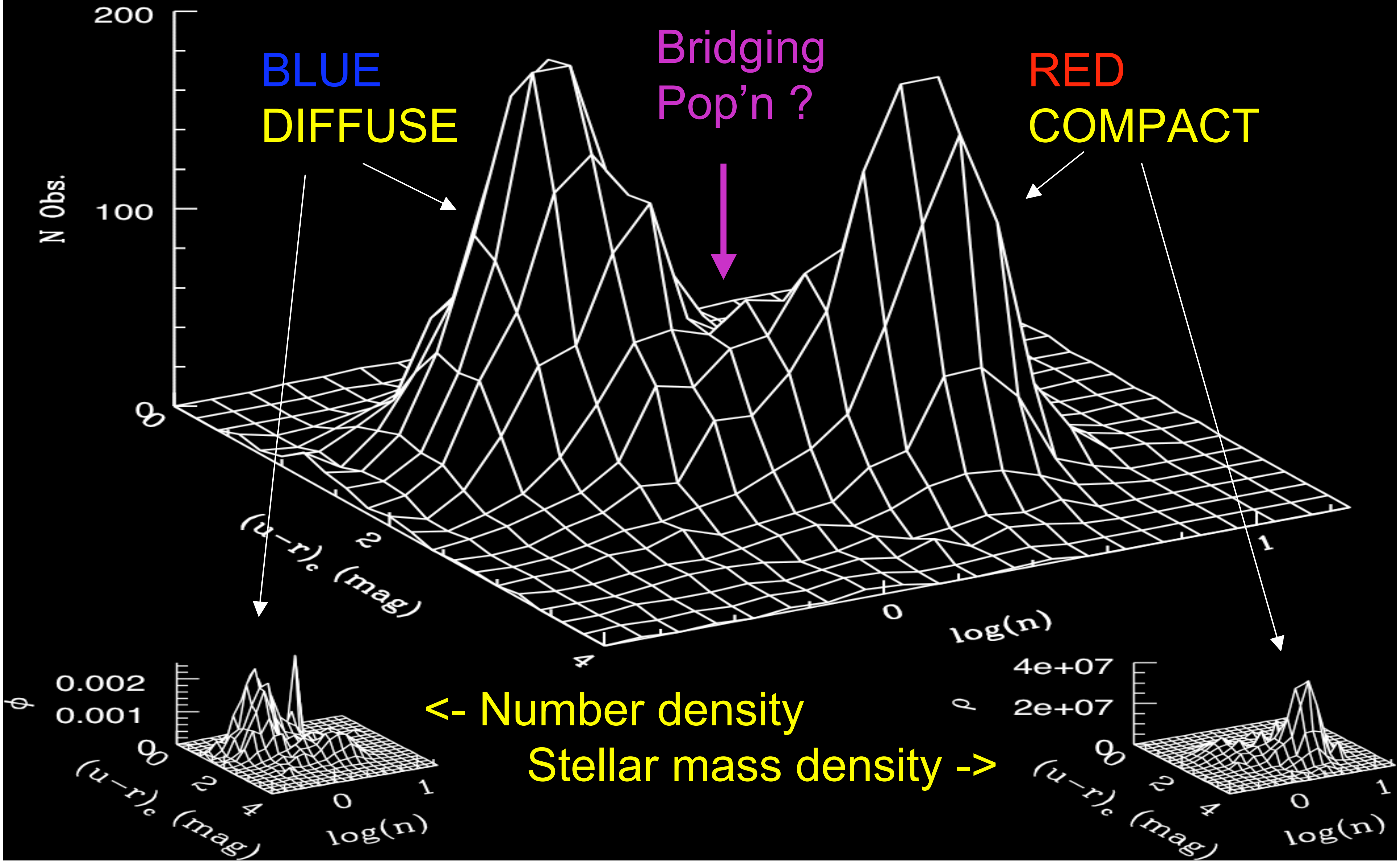
<-- Log(Mbh)

- SMBH density = $5.1\times10^5\ h^5 M.Mpc^{-3}$


Big Bang
Dark Energy 73%
Dark Matter 23%
Normal Matter 4%
(Graham et al 2006)
Black Holes 0.01%
(Driver et al 2006)
Gas 79%
Dust 1%
Stars 20%
(Liske et al 2006)
Stars in Bulges 50%
Stars in Discs 50%

Bimodality in (u-r)-log(n)

Driver et al, 2006, MNRAS, astro-ph/0602240



Two populations or two components ?

E/S0s

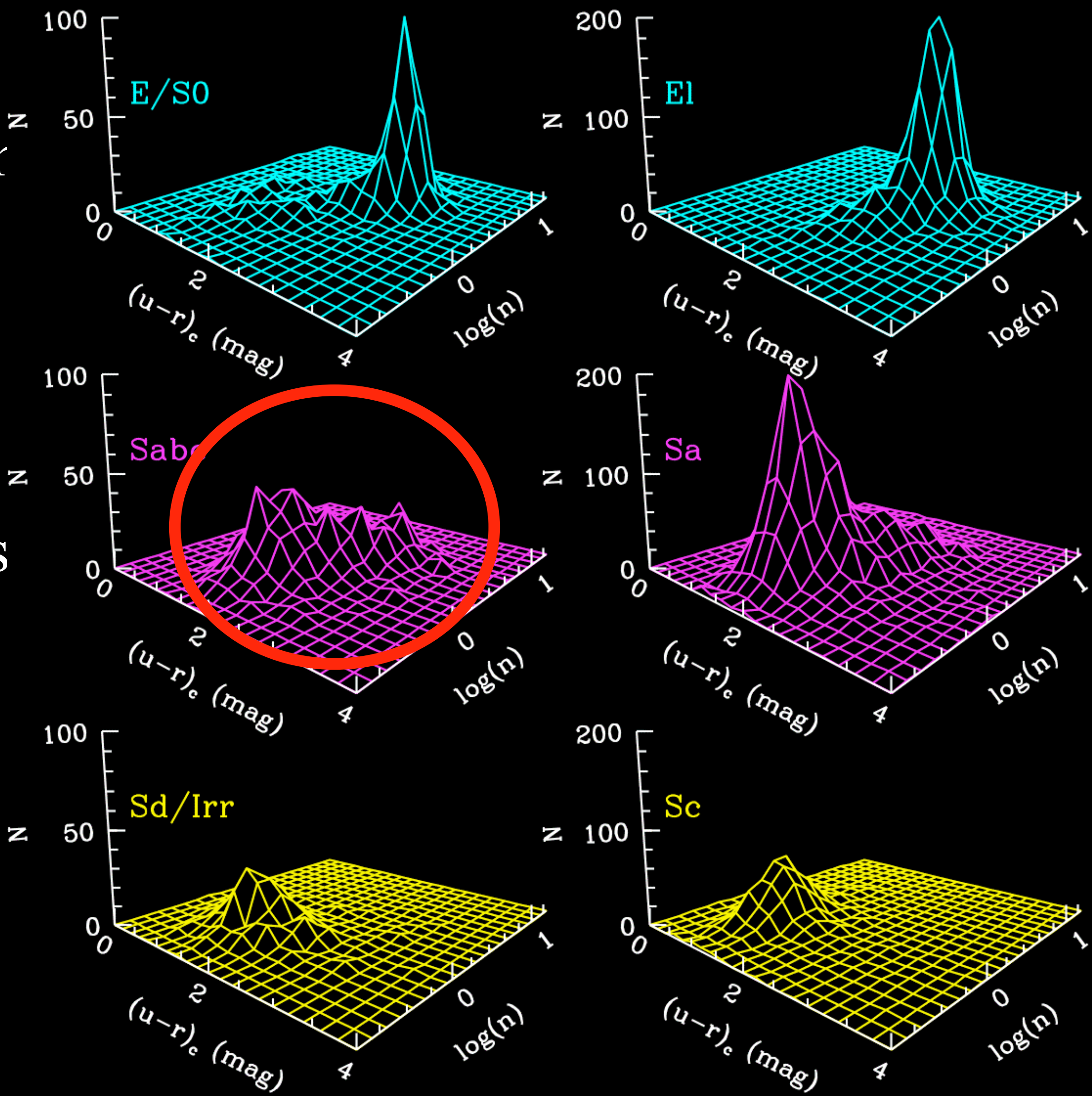
Bulge systen

Sabc

Bulge+Disks

Sd/Irr

Disk systems



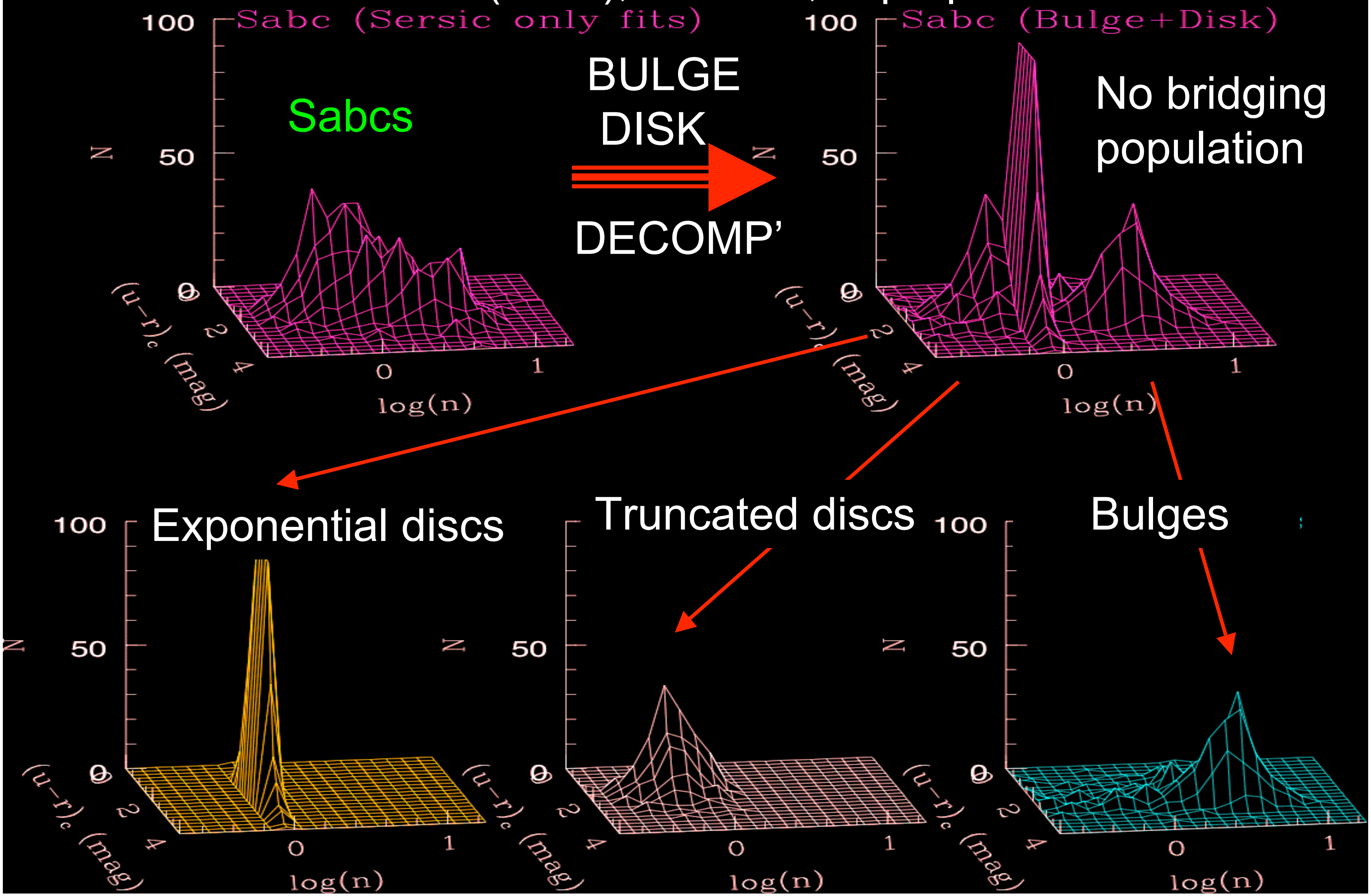
El(Old)

Sa(Interm.)

Sc(Young)

Two populations or two components ?

Driver et al (2006), MNRAS, in preparation



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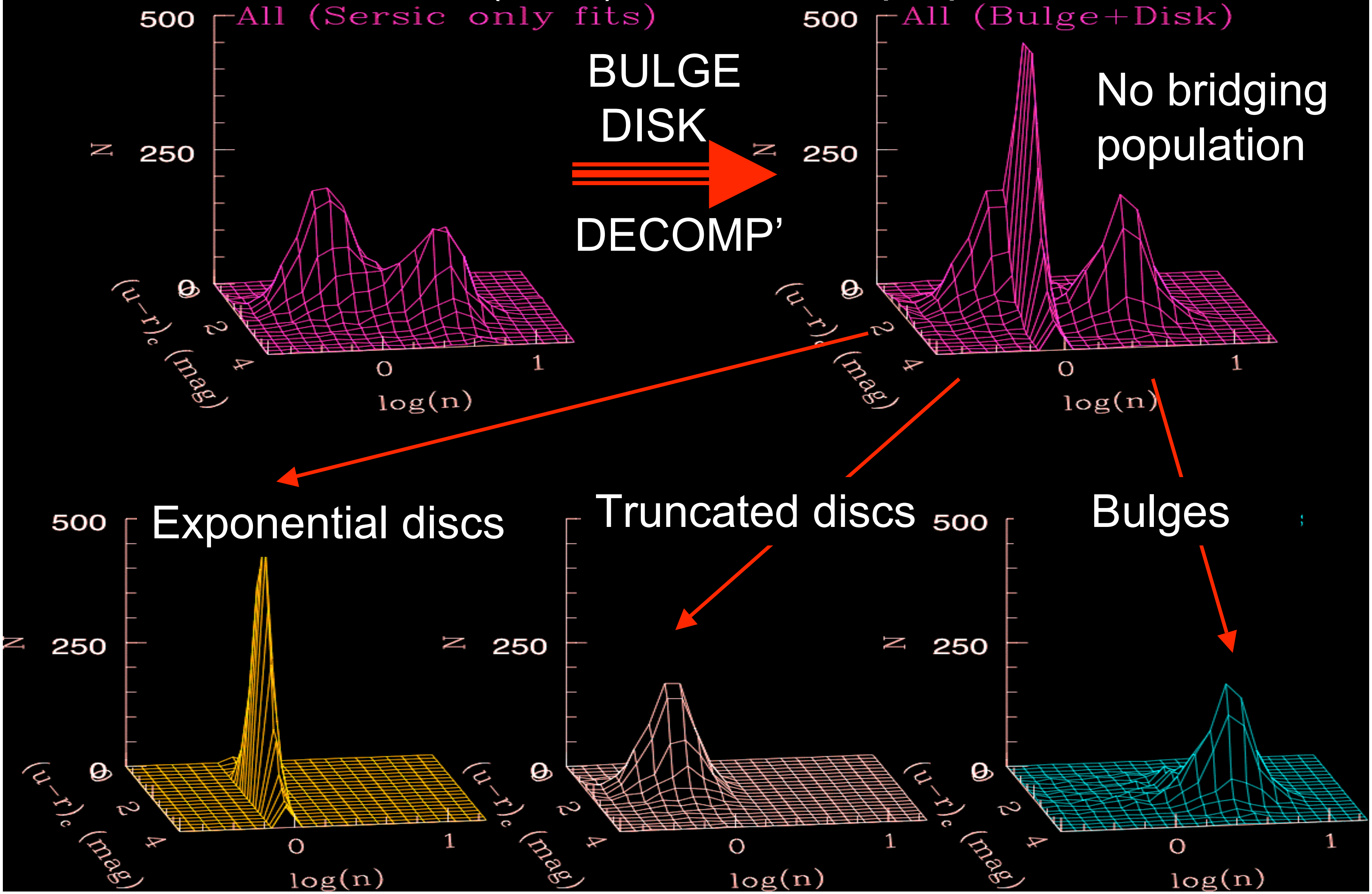
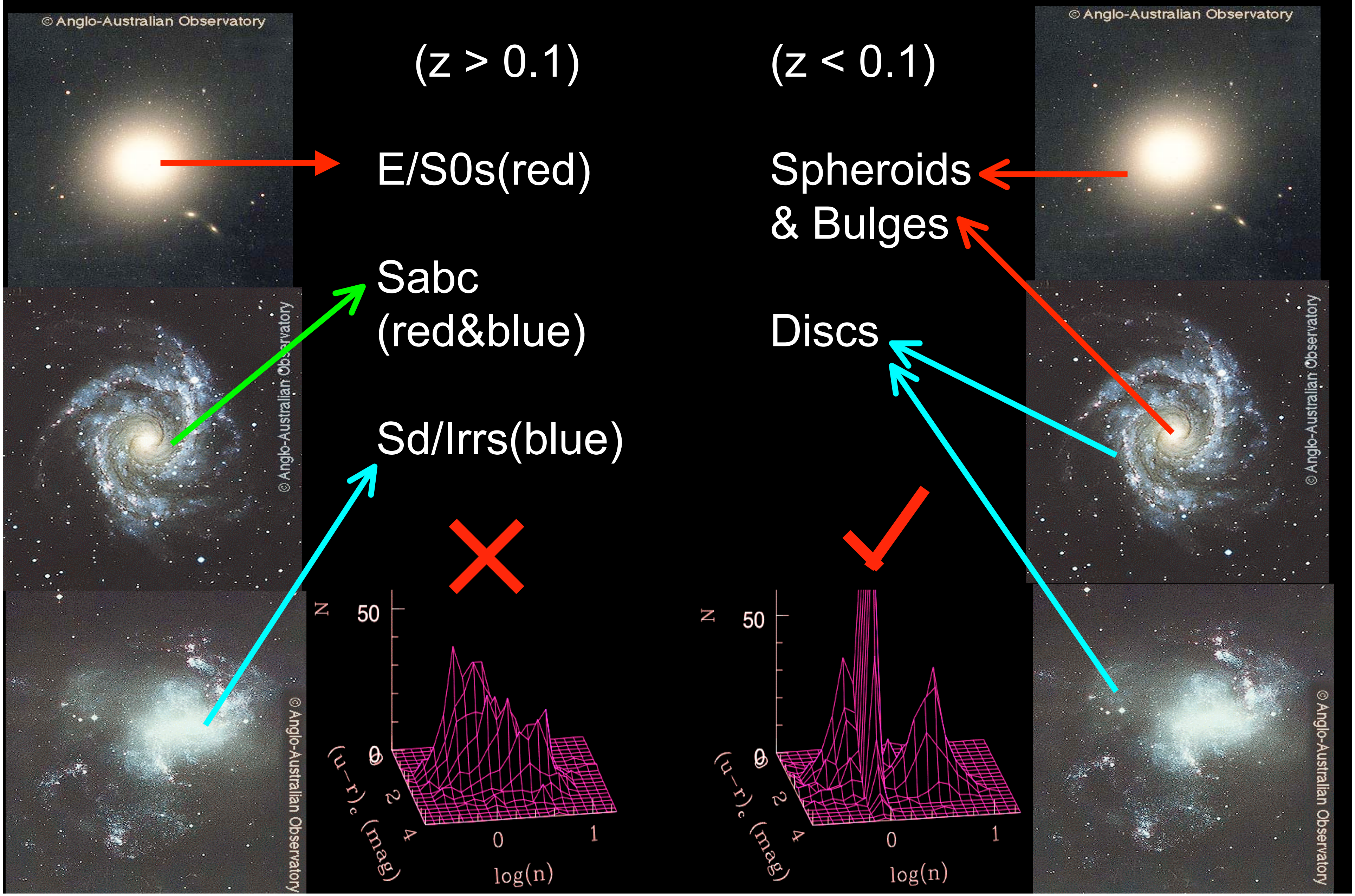
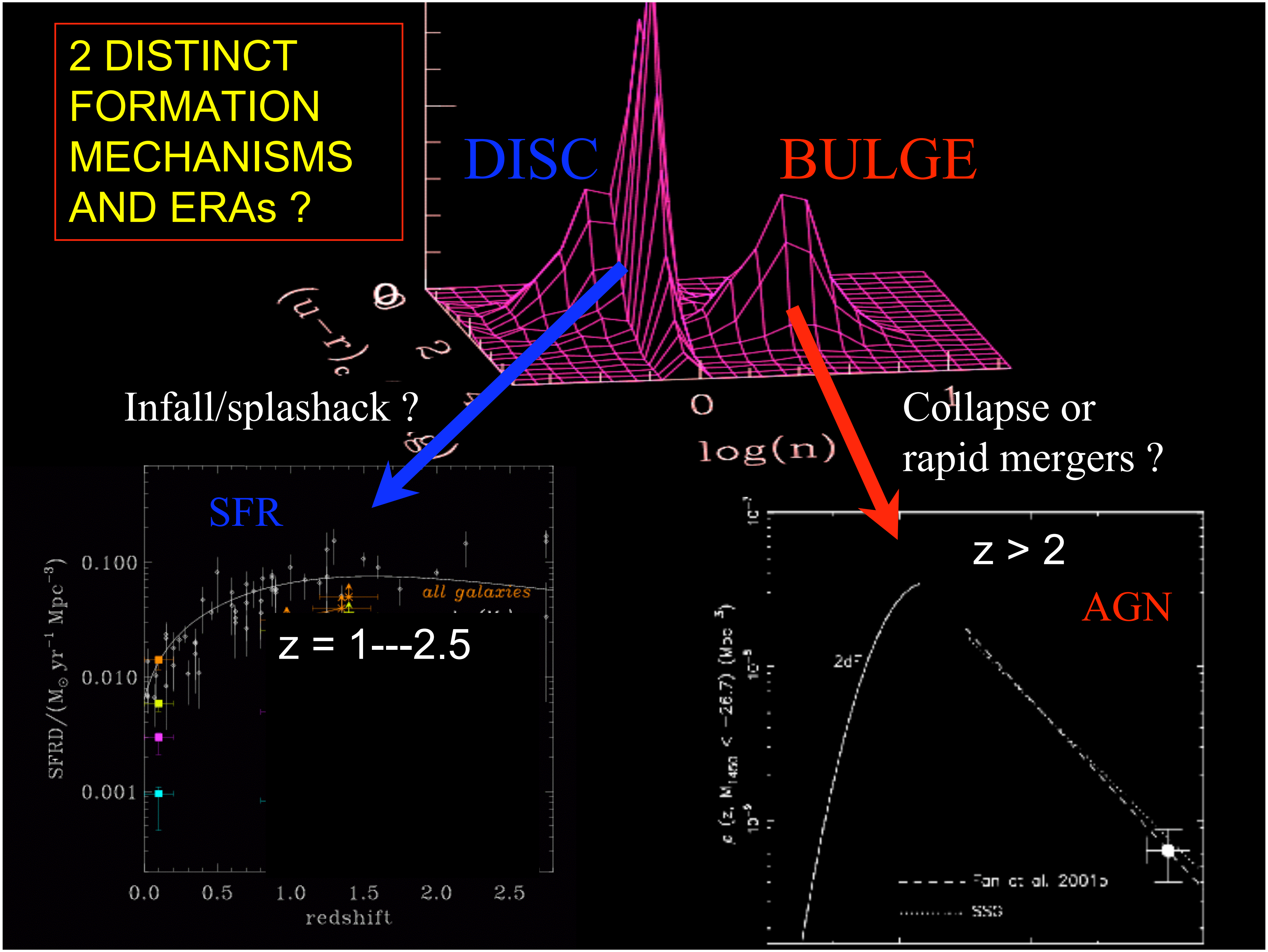


Galaxy types v components ?



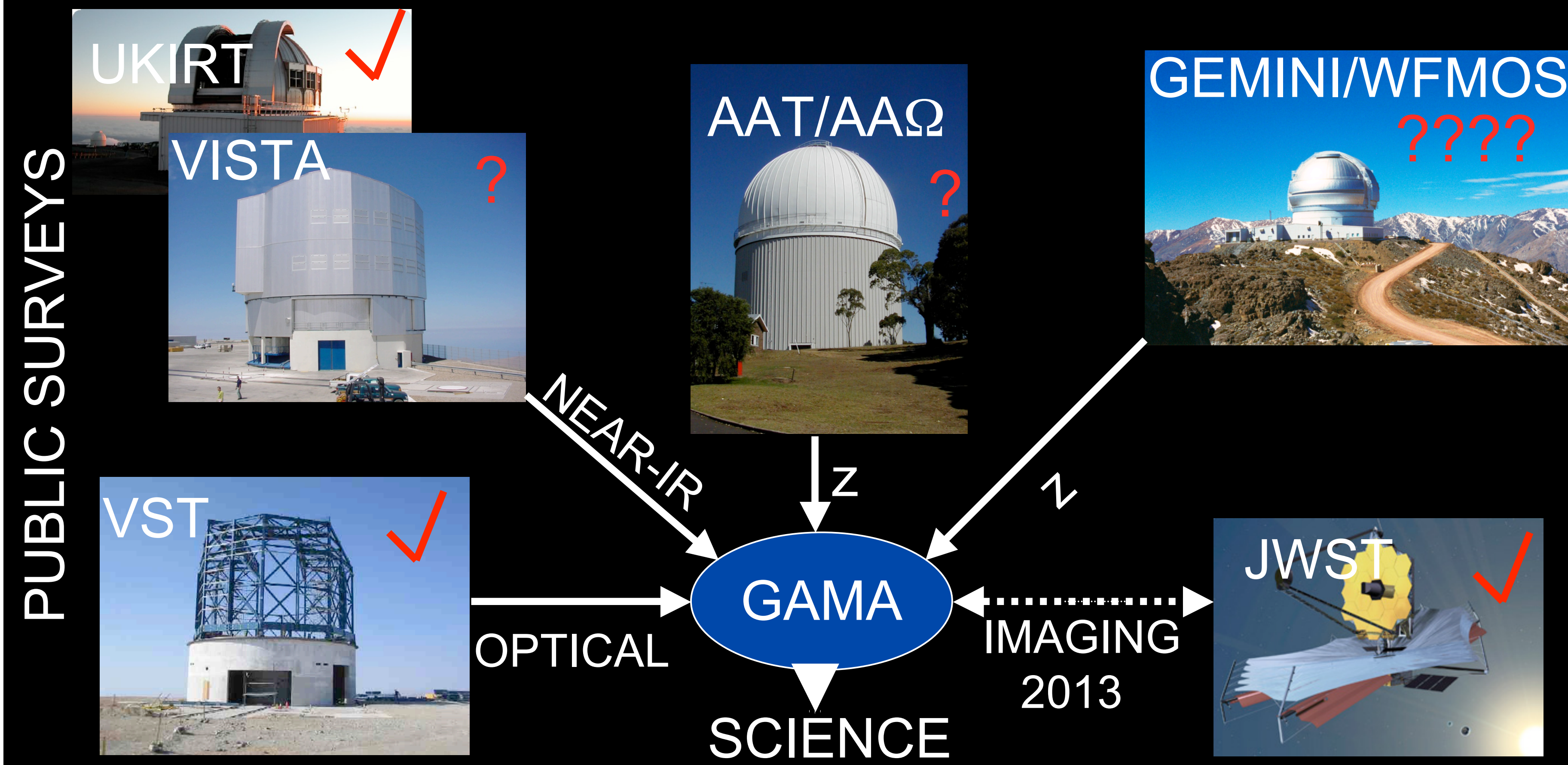

2 DISTINCT FORMATION MECHANISMS AND ERAs ?
DISC
BULGE
Infall/splashack ?
Collapse or rapid mergers ?
log(n)
SFR
z = 1---2.5
all galaxies
SFRD/(M⊙ yr⁻¹ Mpc⁻³)
0.100
0.010
0.001
0.0
0.5
1.0
1.5
2.0
2.5
redshift
z > 2
AGN
Fan et al. 2001b
SSG

Summary

- Disks & bulges occupy distinct regions in the colour-structure plane
- Must entertain notion of bi(tri)-modal galaxy formation scenario?
  - Bulk of dark matter halo assembly at high-z (rapid) ???
  - Bulge formation via collapse of baryons + residual mergers (Bulge/AGN/SMBH trinity) z > 2 (Low mass blue spheroids suggest downsizing of bulge formation) ?
  - Disk formation through later splashback, accretion & infall ? (truncated disks still growing I.e., inside out formation) ???
- Must abandon HTF/global approach and routinely dismantle galaxies into their key components (bulges and discs)
- 20% of baryons in stars (almost half emergent B flux attenuated)
- 50% of stars in bulges 50% in discs
- Dust attenuation in B a big issue (bulges heavily attenuated)
  disks 0.2-1.1 mag, bulges: 0.8 - 3.4 mag ! τ_B~3.8 +/- 0.7
- Switch to near/far-IR now essential to overcome dust issues: GAMA

Galaxy And Matter Assembly

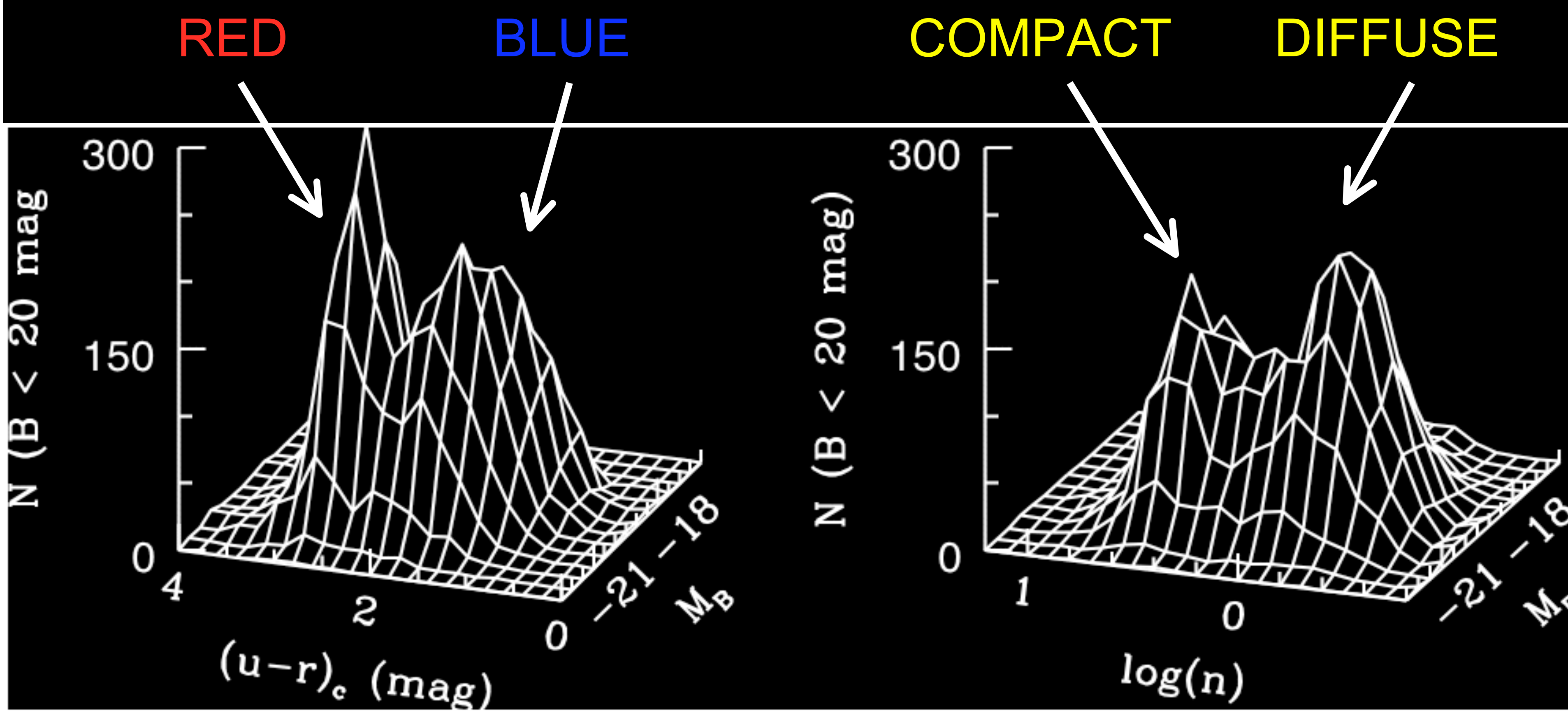
- **300 sq deg ugrizJHK sub-arcsec** deep imaging and spectroscopic survey
- St Andrews (Driver), Edinburgh (Peacock), LJMU (Baldry), ESO (Liske)
- 4 tests of CDM structure plus generic galaxy resource on scale of SDSS
- Zero redshift benchmark for JWST (launch 2013)



Galaxy Bimodality

Observe strong colour *(u-r)* and structural (log*n*) bimodalities (Strateva et al 2001; Baldry et al 2004; Driver et al 2006)

OBSERVED DISTRIBUTIONS (M_B < -16)



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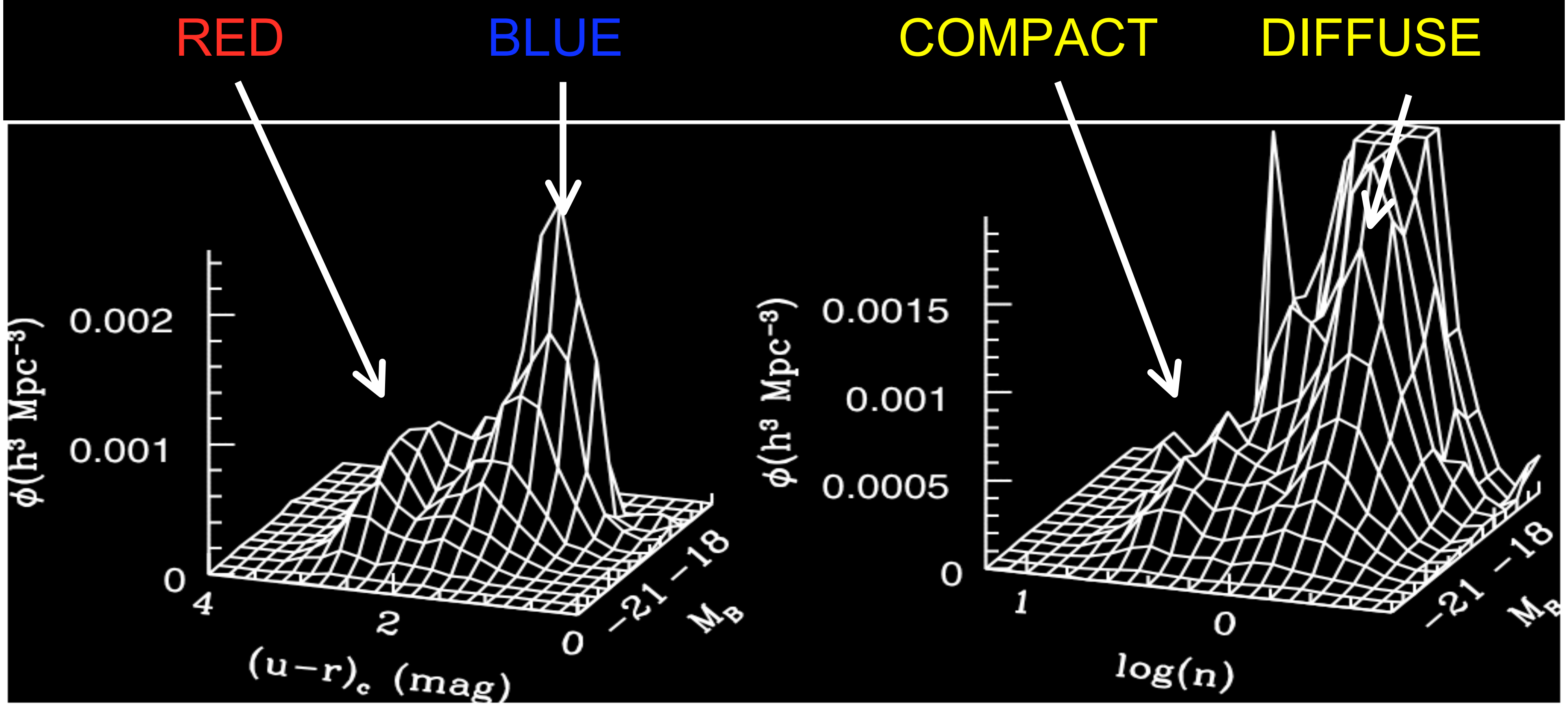
VOLUME CORRECTED (NUMBER DENSITY)



Galaxy Bimodality

Observe strong colour *(u-r)* and structural (log*n*) bimodalities (Strateva et al 2001; Baldry et al 2004; Driver et al 2006)

VOLUME CORRECTED (MASS DENSITY)