The Bivariate Brightness Distribution of the Millennium Galaxy Catalogue

Jochen Liske

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Nick Cross (JHU), Steve Phillipps (Bristol), Warrick Couch (UNSW)
Roberto De Propris (Bristol), Simon Ellis (AAO)

Why BBD?

- BBD = number density of galaxies as a joint function of luminosity and surface brightness

- Fundamental property of galaxy population:

  The idea is that L ⇔ M and ⇔ $\lambda = J E^{1/2} G^{-1} M_{halo}^{-5/2}$

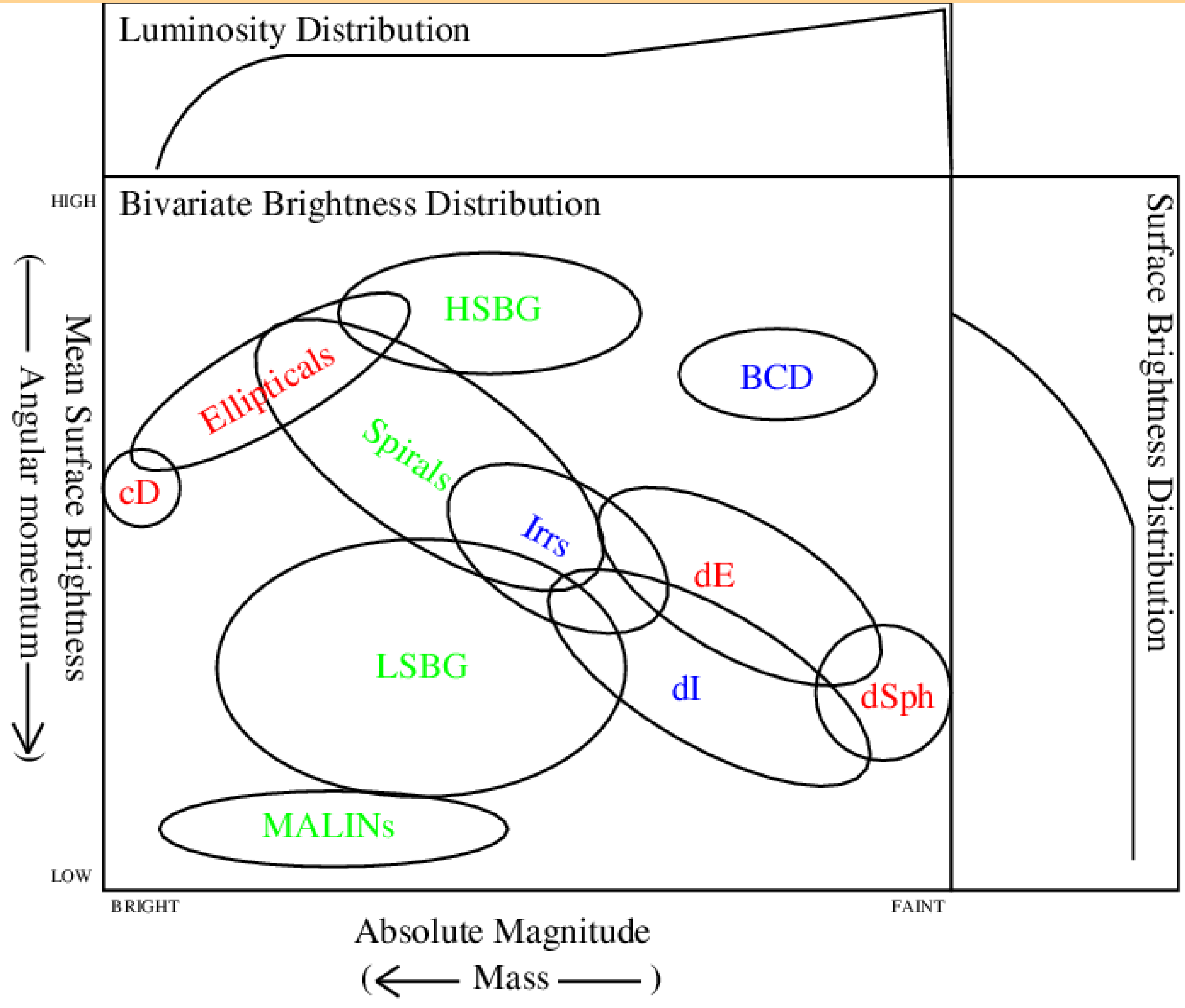
  (e.g. Dalcanton et al. 1997; Mo et al. 1998; Bell et al. 2003).

  The evolution of the mass and angular momentum distributions of dark matter halos can be predicted from simulations with some confidence (e.g. Bullock et al. 2001).

⇒ BBD should be a useful testbed for galaxy formation models.

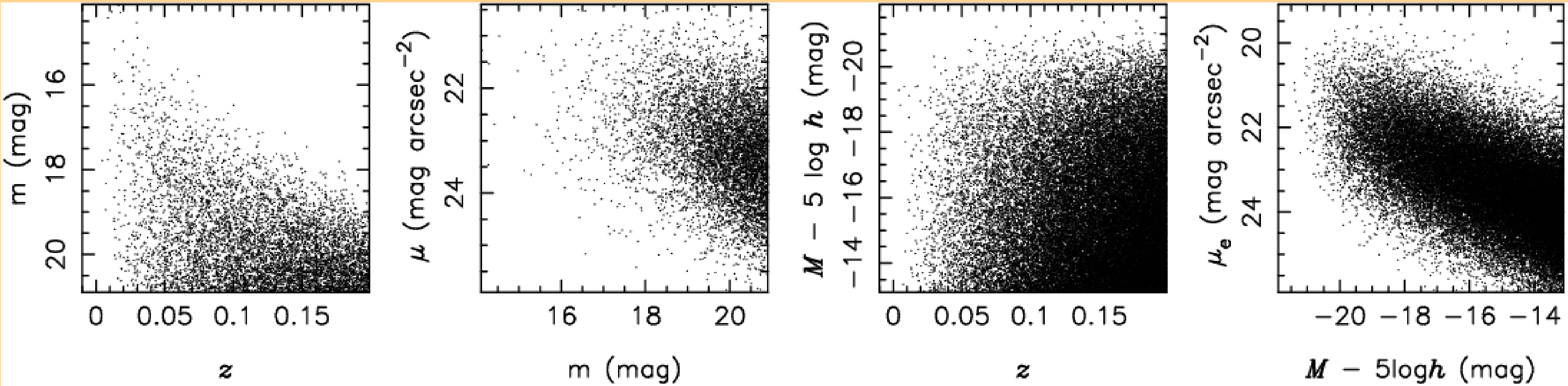
- Good starting point for studying multivariate distributions ('natural' extension of luminosity function) because it enforces consideration of most important selection effects (flux, size and surface brightness limits).

Why BBD?

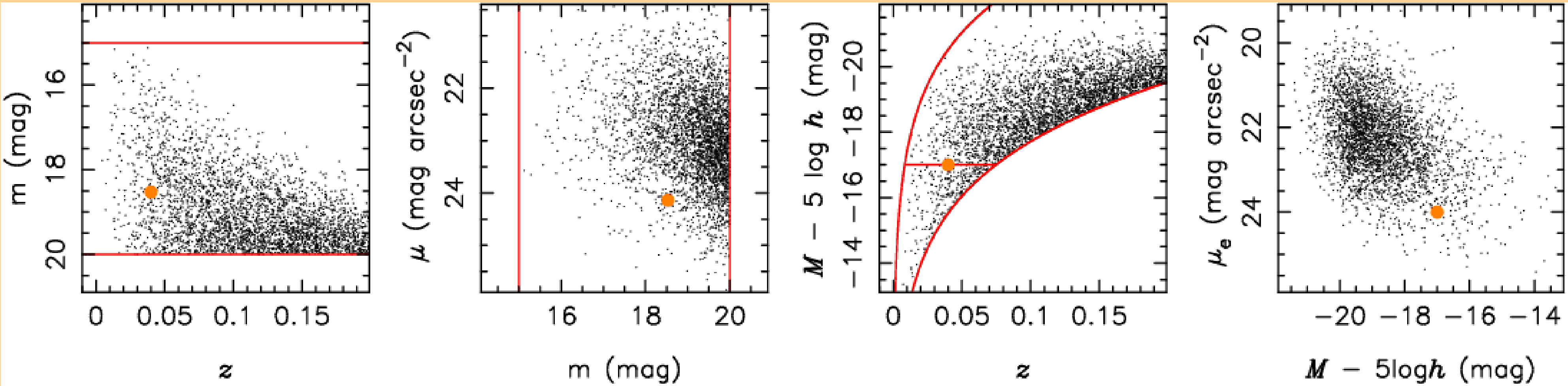


Luminosity Distribution
Bivariate Brightness Distribution
HIGH
LOW
Mean Surface Brightness
Angular momentum
HSBG
BCD
Ellipticals
cD
Spirals
Irrs
dE
LSBG
dI
dSph
MALINs
Surface Brightness Distribution
BRIGHT
FAINT
Absolute Magnitude
(Mass)

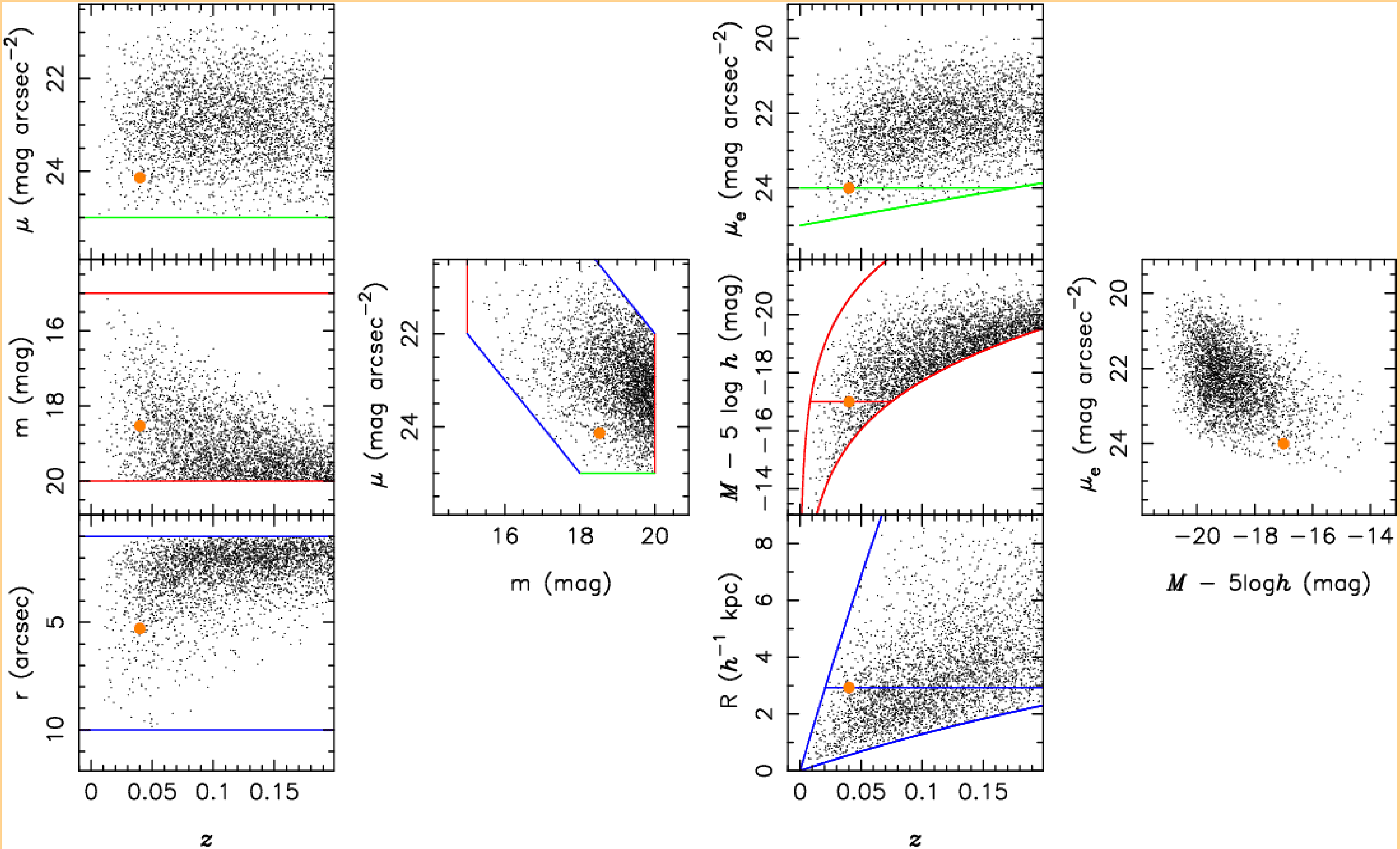
Selection effects



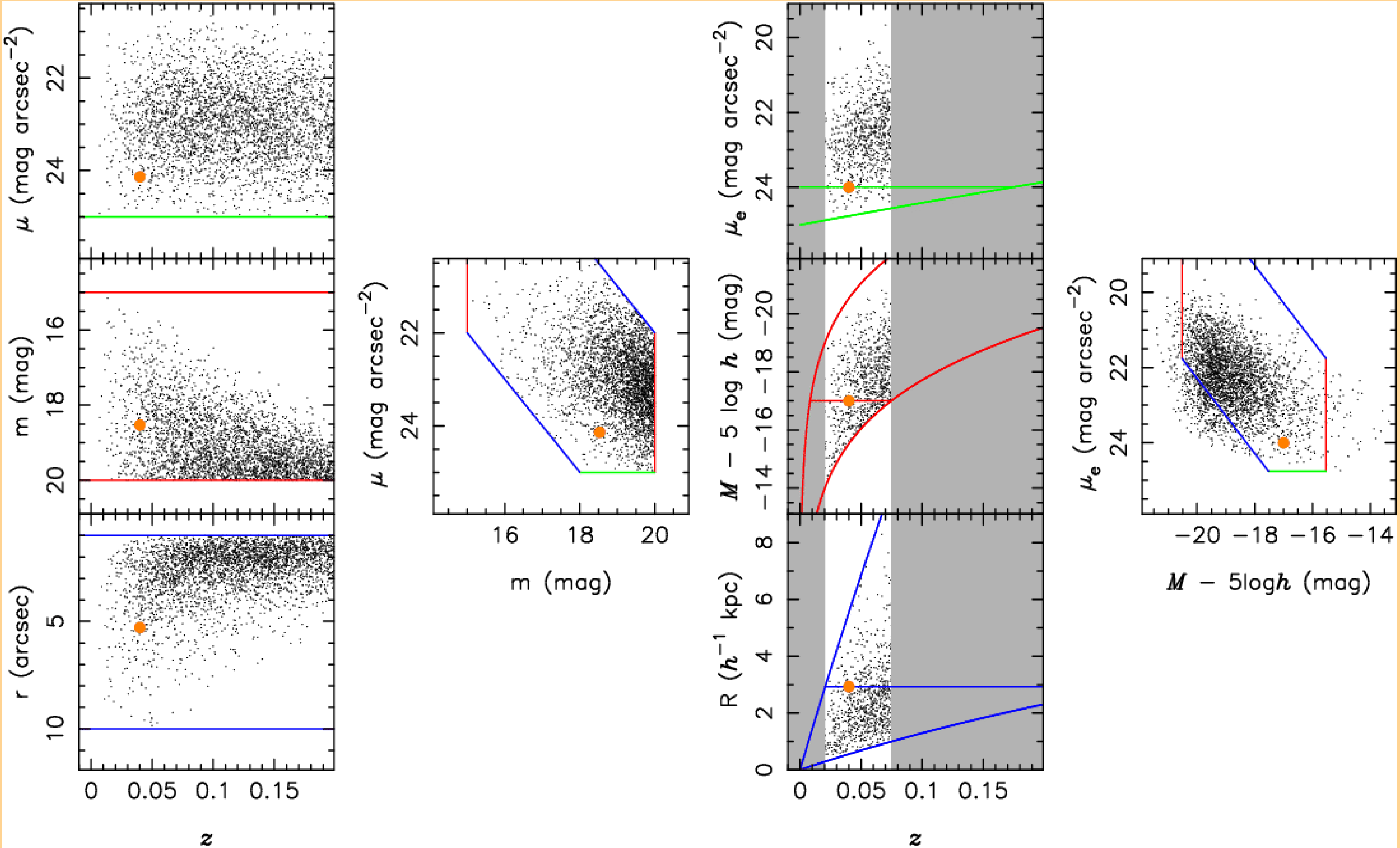
Selection effects



Selection effects



Selection effects

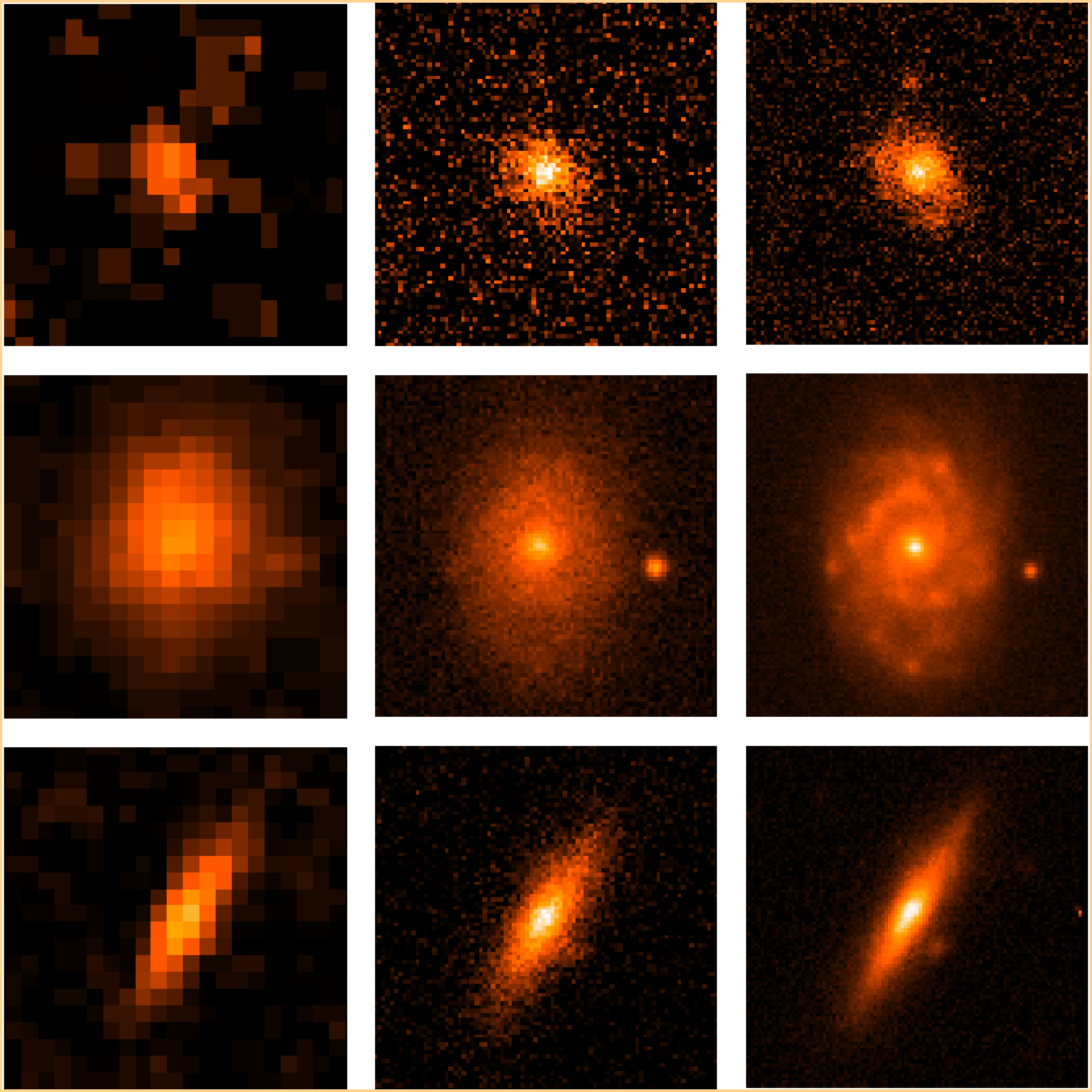


The Millennium Galaxy Catalogue (MGC)

www.eso.org/~jliske/mgc/

- Deep, wide-field B-band imaging survey using WFC/INT
- Area = 37.5 deg^2
- Median seeing = 1.3 arcsec pixel size = 0.333 arcsec
- B_{lim} = 24 mag μ_{lim} = 26 mag $arcsec^{-2}$
  internal photometric accuracy = 0.03 mag
- B + ugriz (SDSS) photometry
- Main sample: B < 20 mag (10,095 galaxies):
  - structural parameters (see talk by P. Allen)
  - redshifts

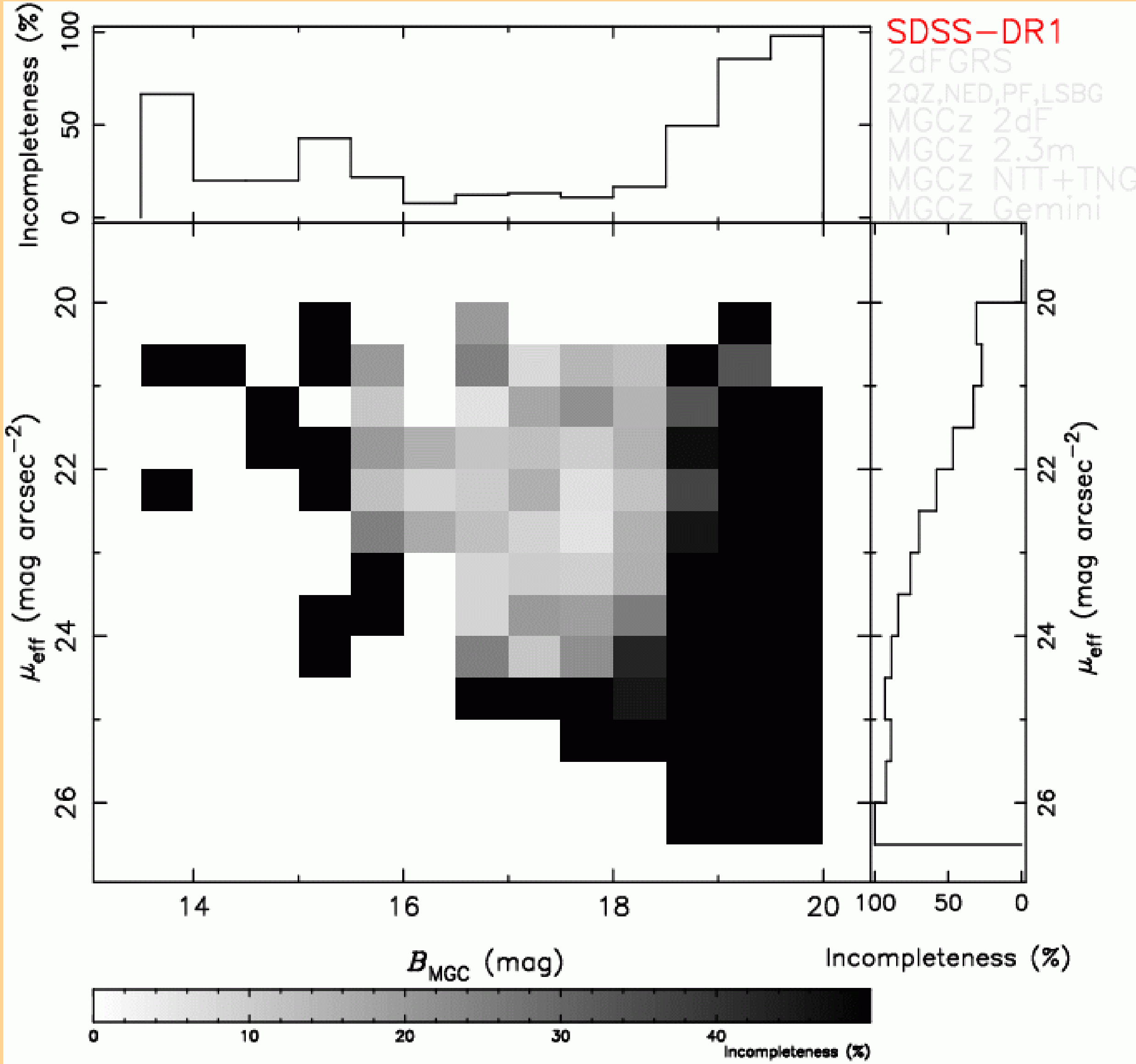
- Broad goal: provide *z*=0 description of the galaxy population for comparison with high-*z* observations and theory.



DSS
SDSS
MGC

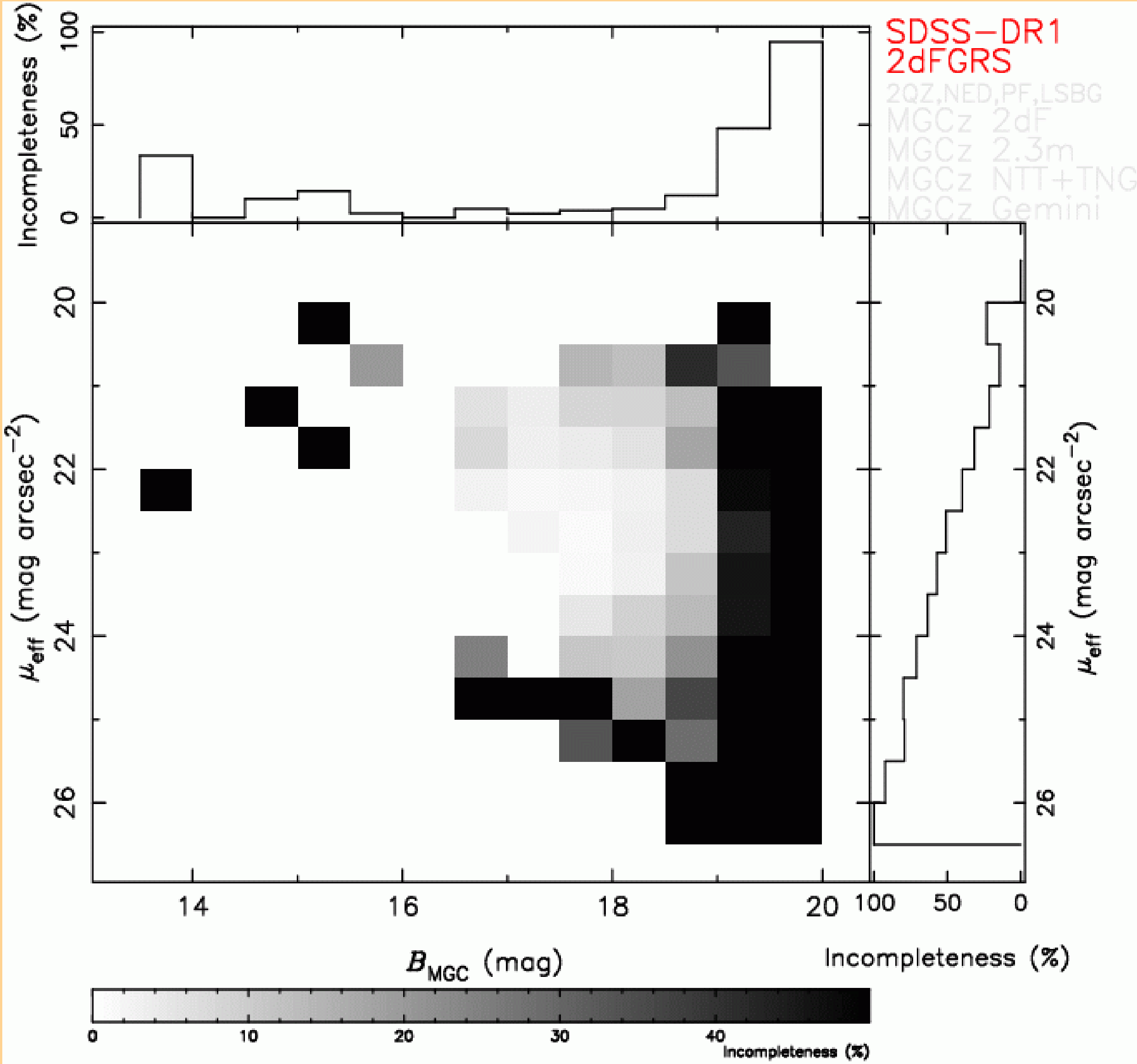
MGC redshift completeness

Survey	# of z's contributed
SDSS	1528



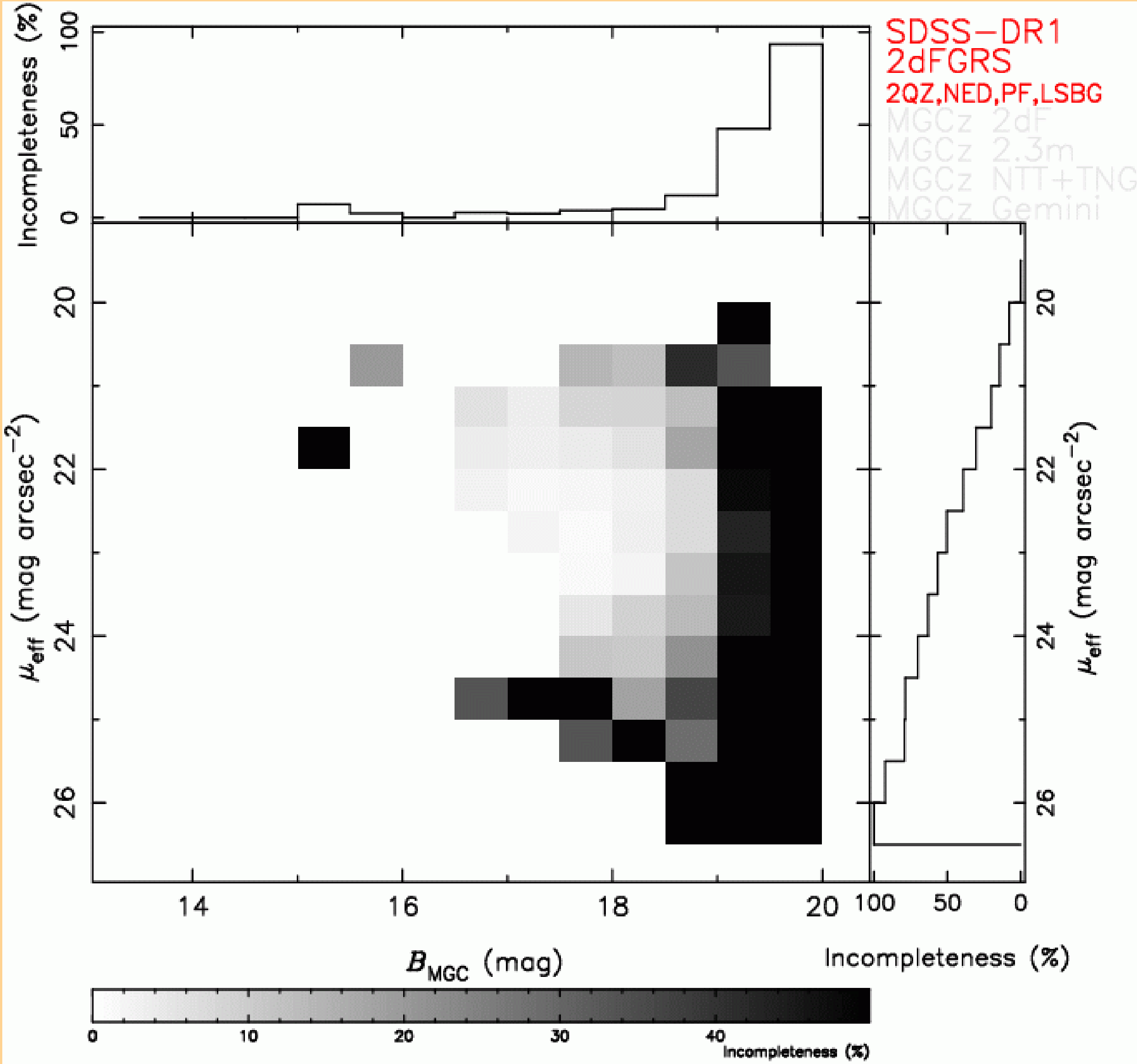
MGC redshift completeness

Survey	# of *z*'s contributed
SDSS	1528
2dFGRS	3152



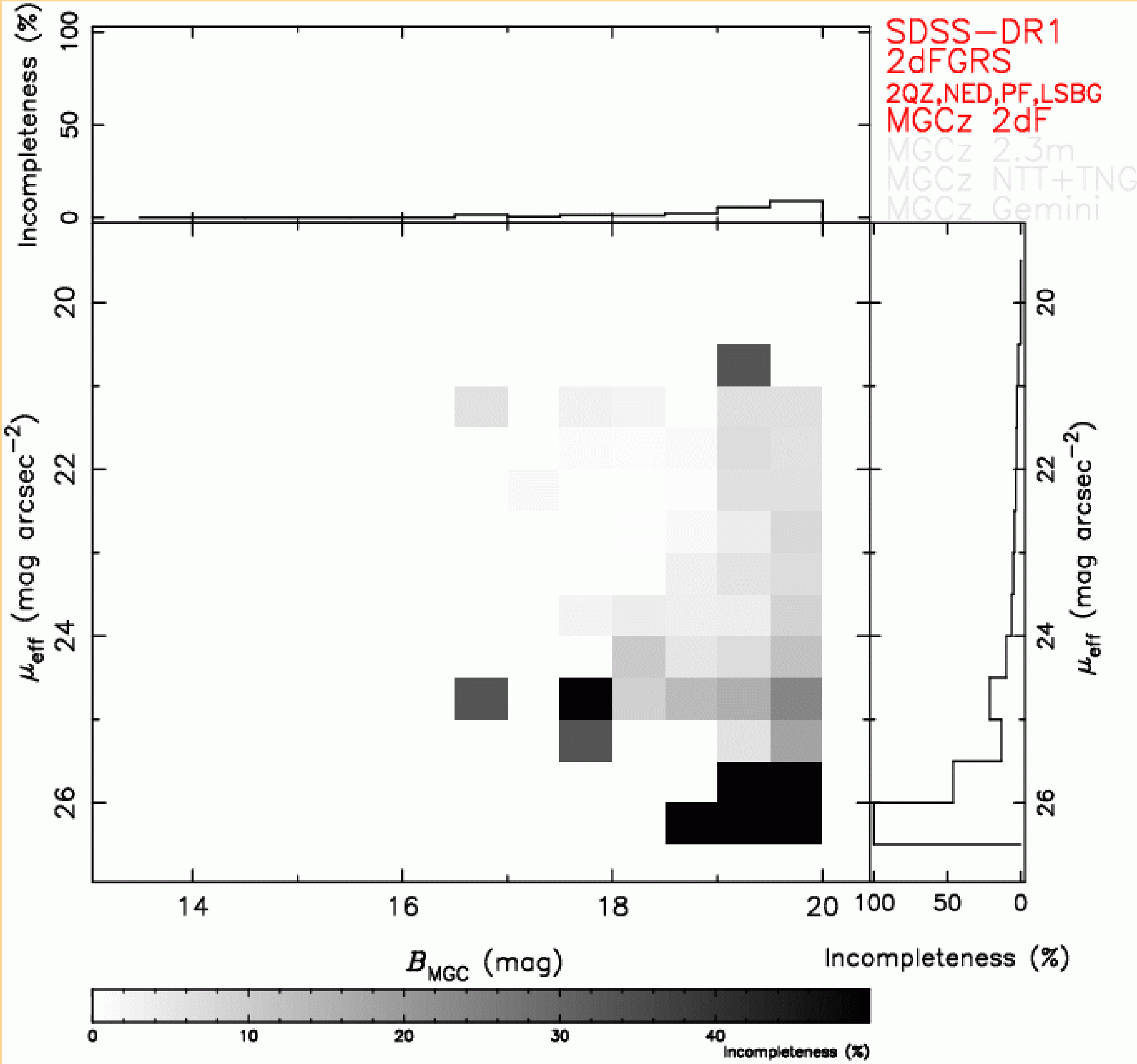
MGC redshift completeness

Survey	# of z's contributed
SDSS	1528
2dFGRS	3152
Other public	72



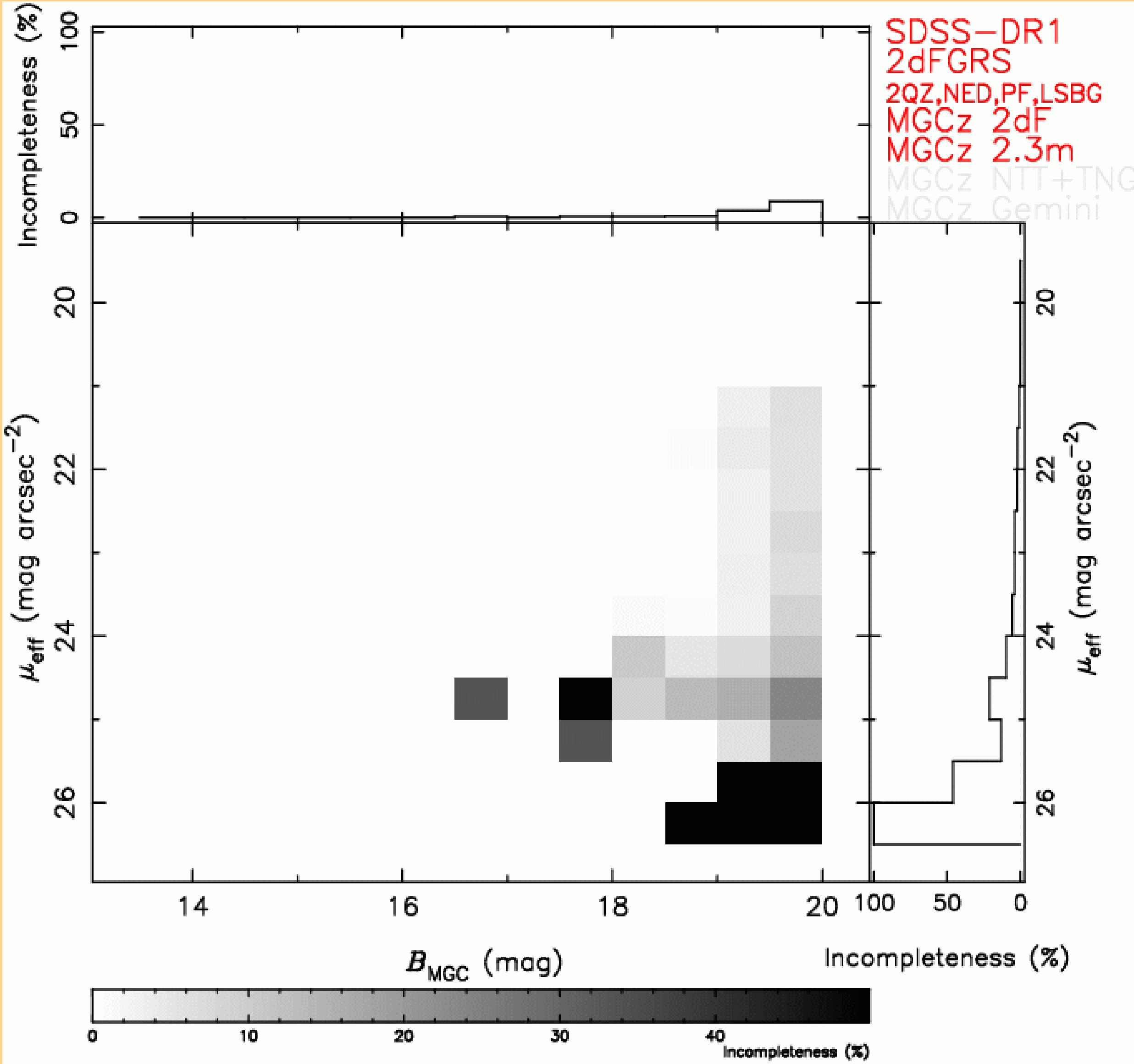
MGC redshift completeness

Survey	# of z's contributed
SDSS	1528
2dFGRS	3152
Other public	72
MGCz:	
2dF	4766



MGC redshift completeness

Survey	# of *z*'s contributed
SDSS	1528
2dFGRS	3152
Other public	72
MGCz:	
2dF	4766
ANU 2.3m	80



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SDSS	1528
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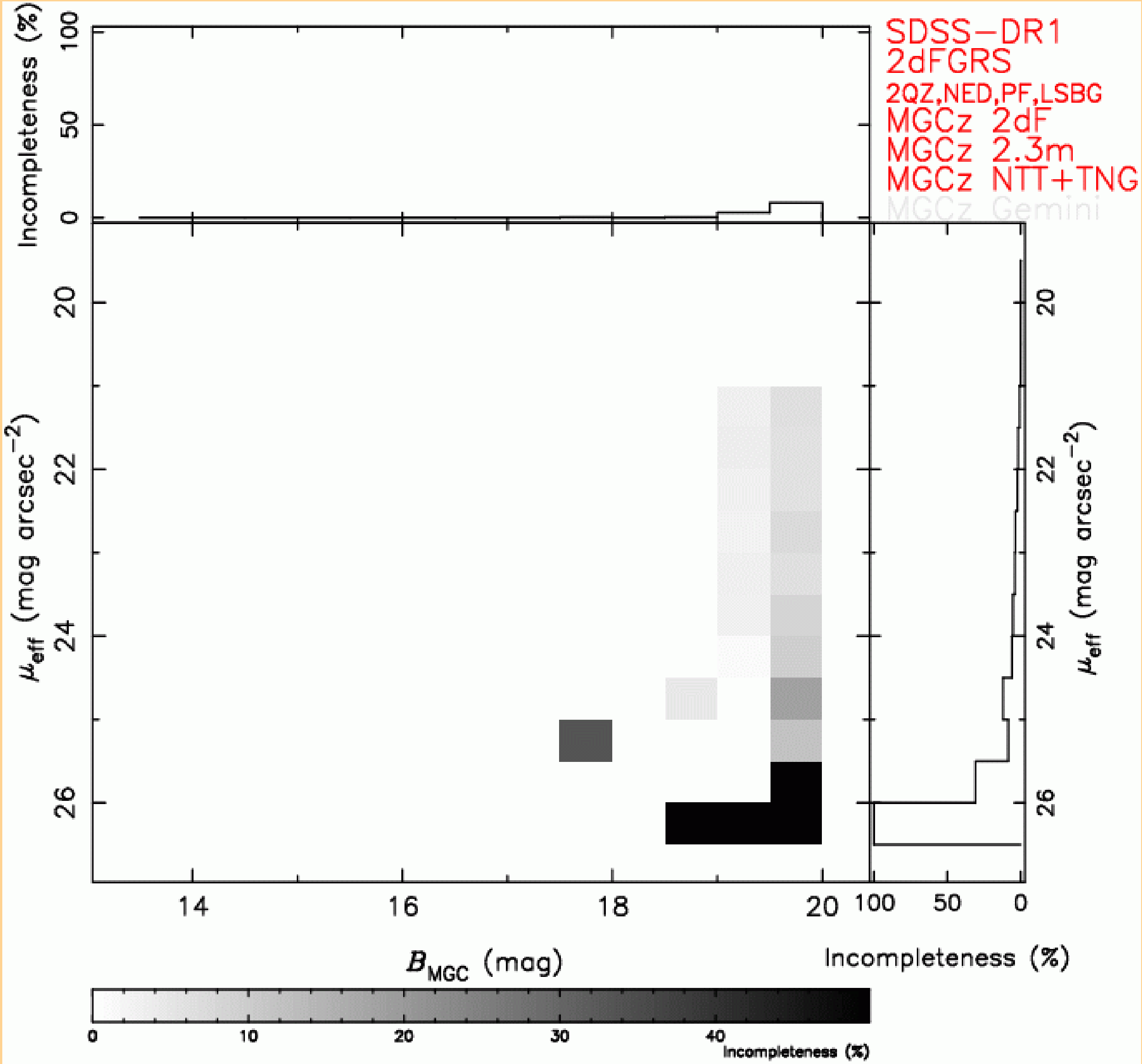
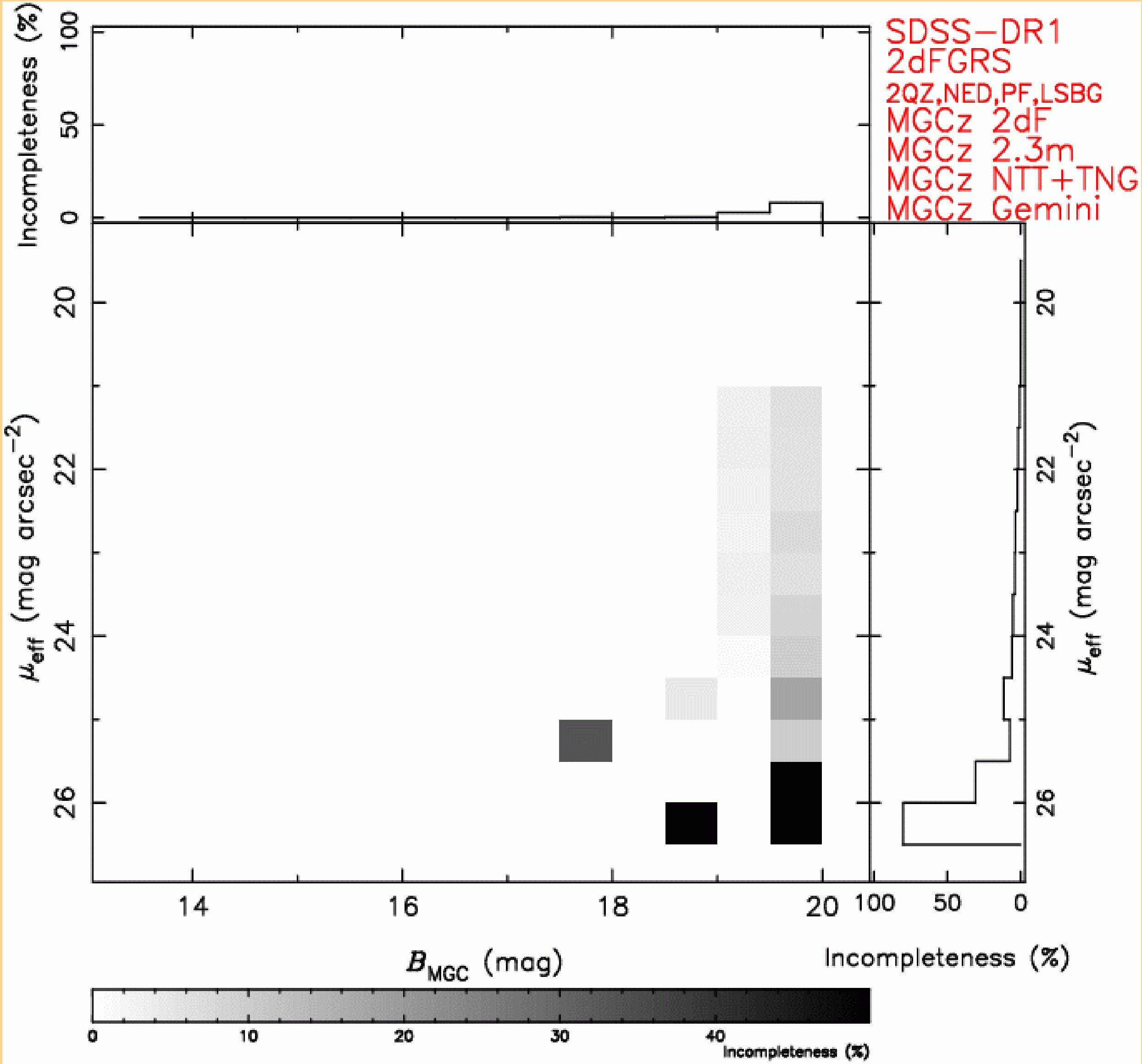
MGCz:	
2dF	4766
ANU 2.3m	80
NTT+TNG	94



MGC redshift completeness

Survey	# of *z*'s contributed
SDSS	1528
2dFGRS	3152
Other public	72
MGCz:	
2dF	4766
ANU 2.3m	80
NTT+TNG	94
Gemini	4



MGC redshift completeness

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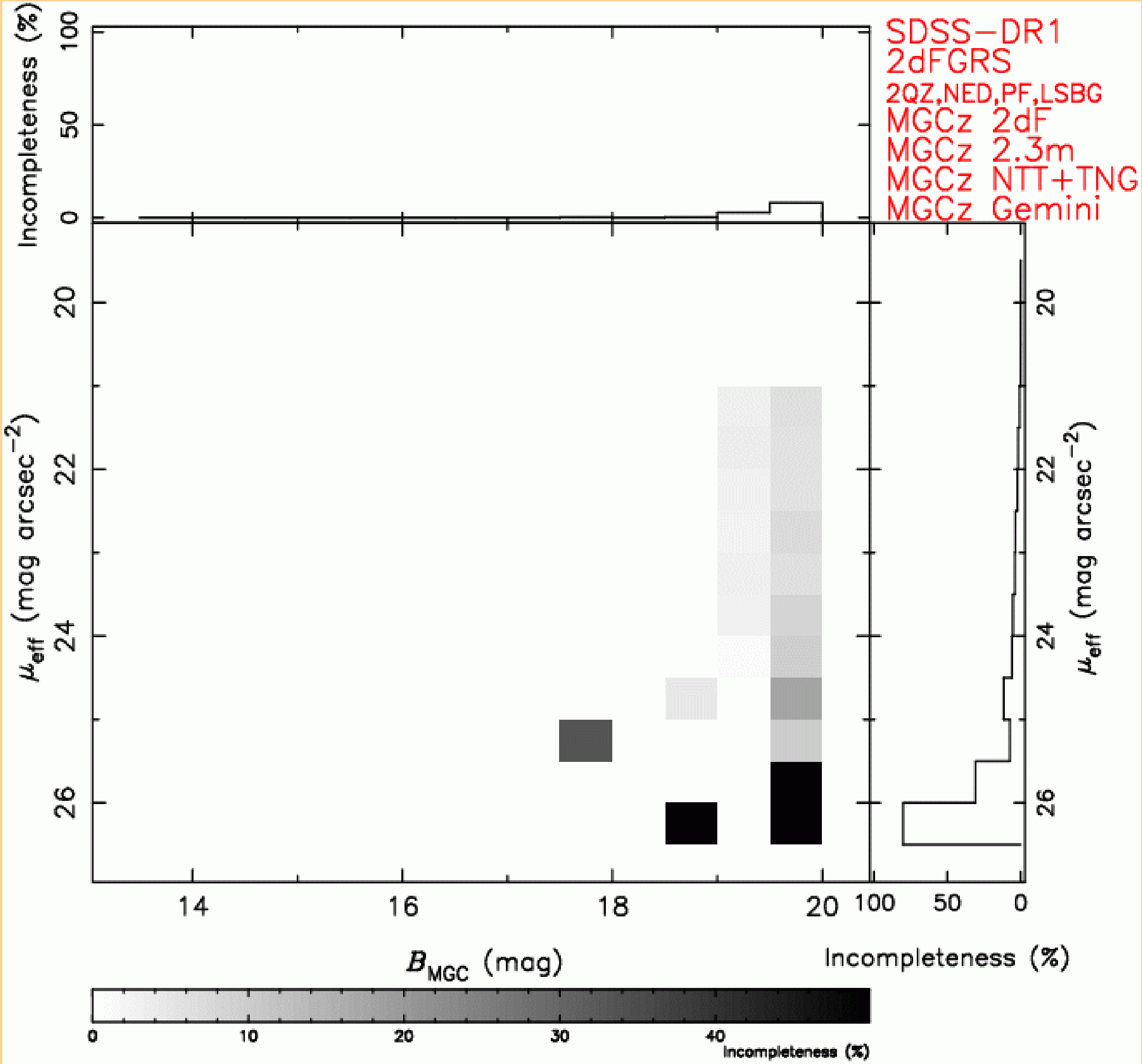
MGCz:	
2dF	4766
ANU 2.3m	80
NTT+TNG	94
Gemini	4
	9696

of 10,095 B < 20 galaxies.

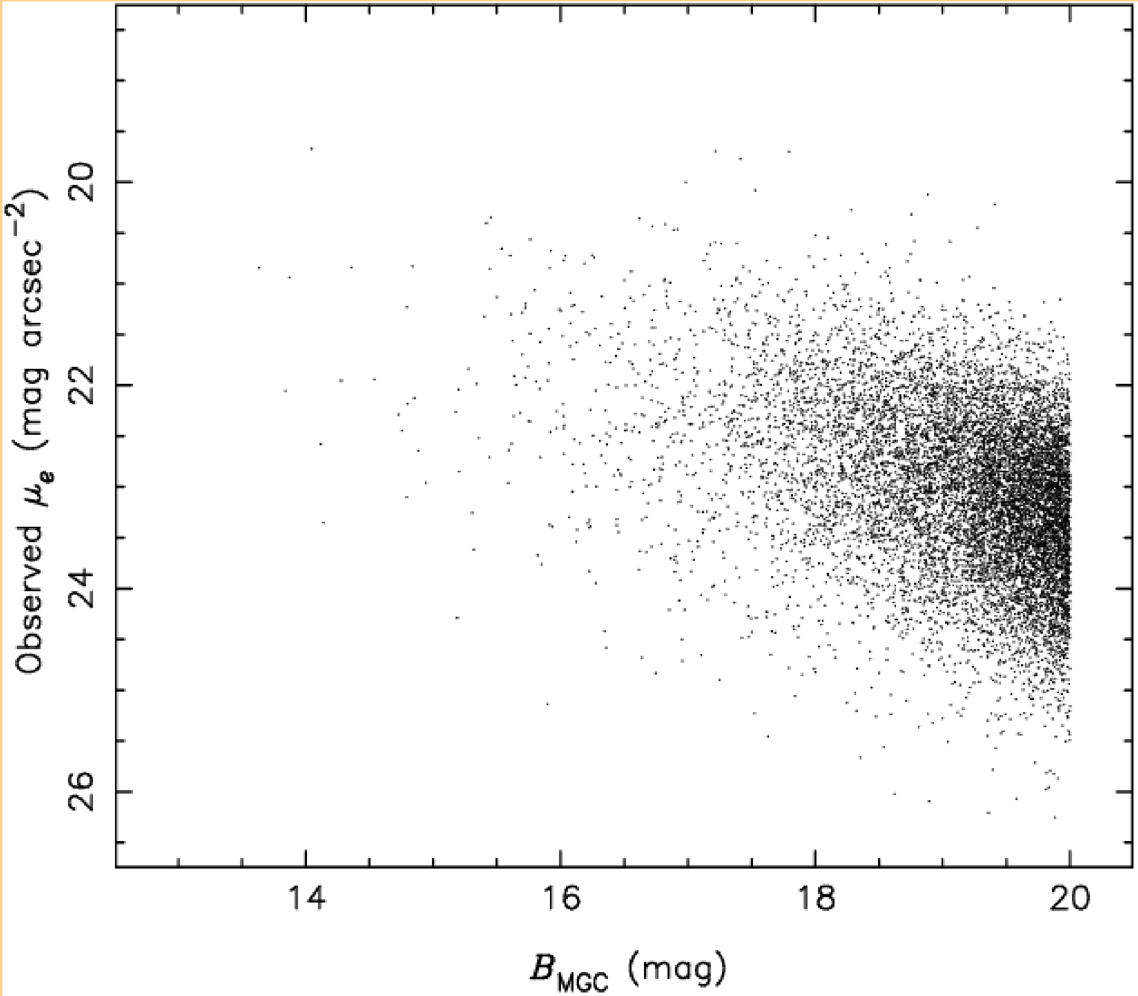
Overall completeness: 96.05 %

B <19.2 only: 99.79 %



Deriving the global BBD

- Measure HLR and effective SB



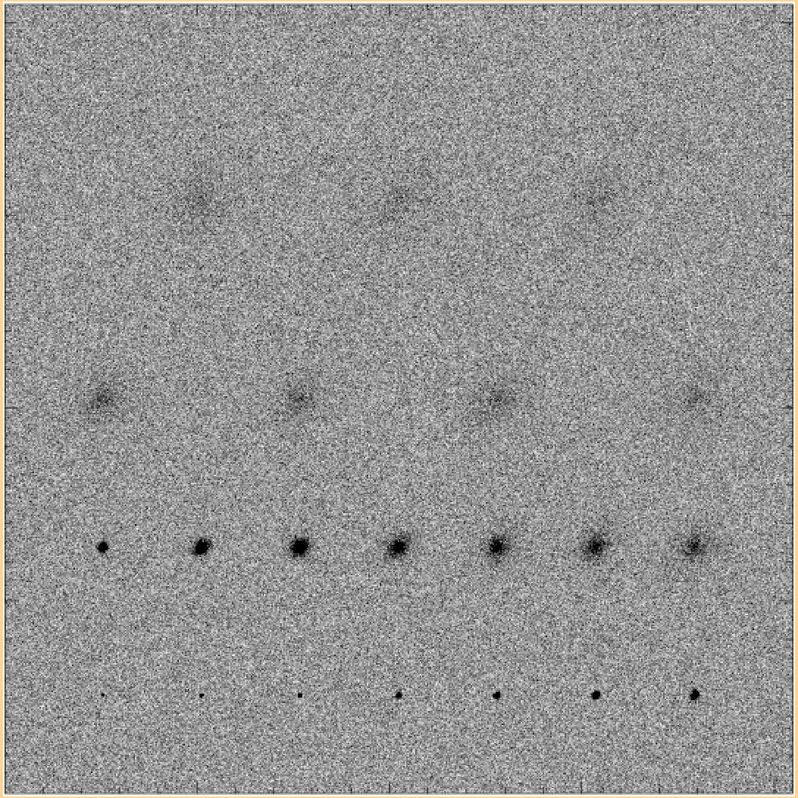
Deriving the global BBD

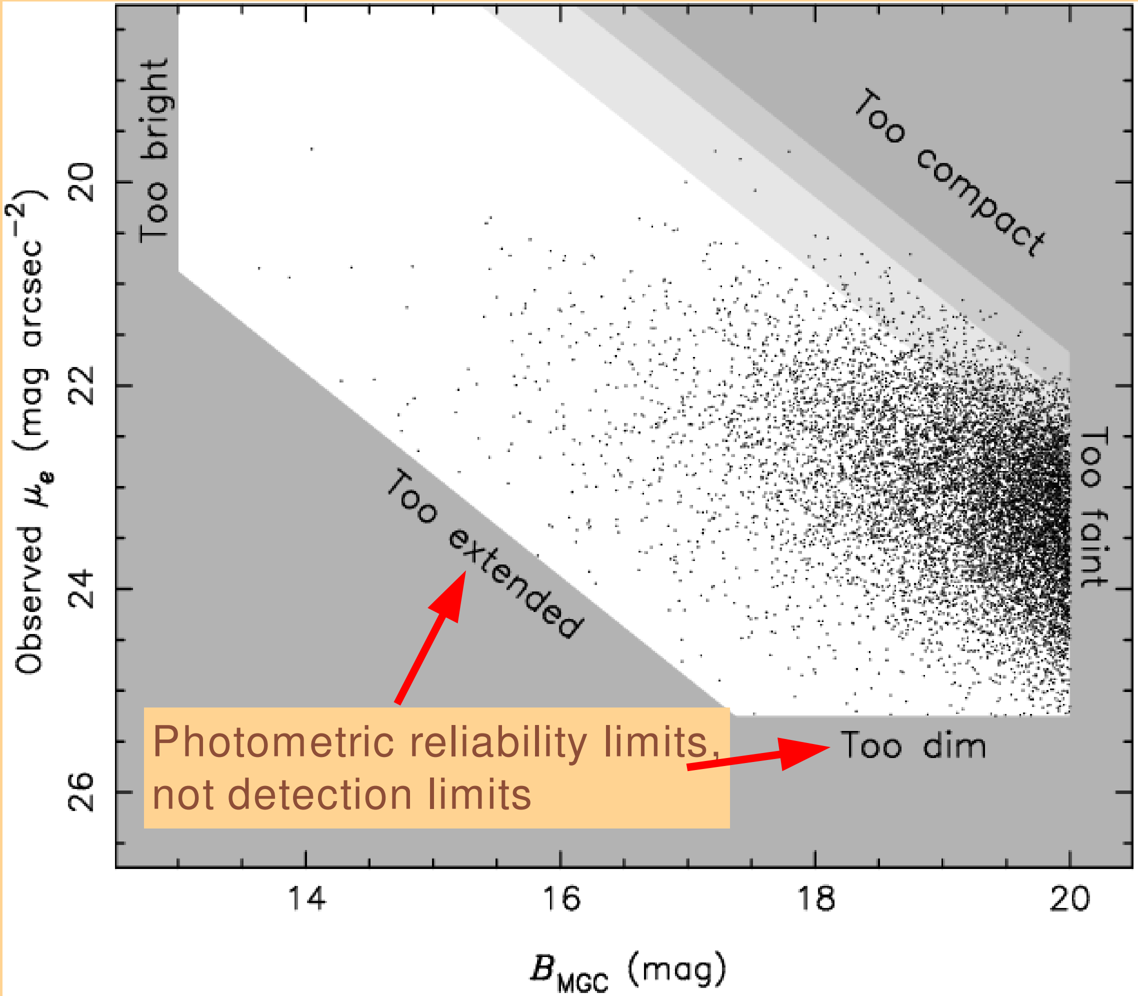
- Measure HLR and effective SB
- Determine selection limits:

  $13 < B < 20$ mag

  $0.6\,\Gamma + 0.31 < r < 15$ arcsec

  $\mu < 25.25$ mag arcsec^{-2}





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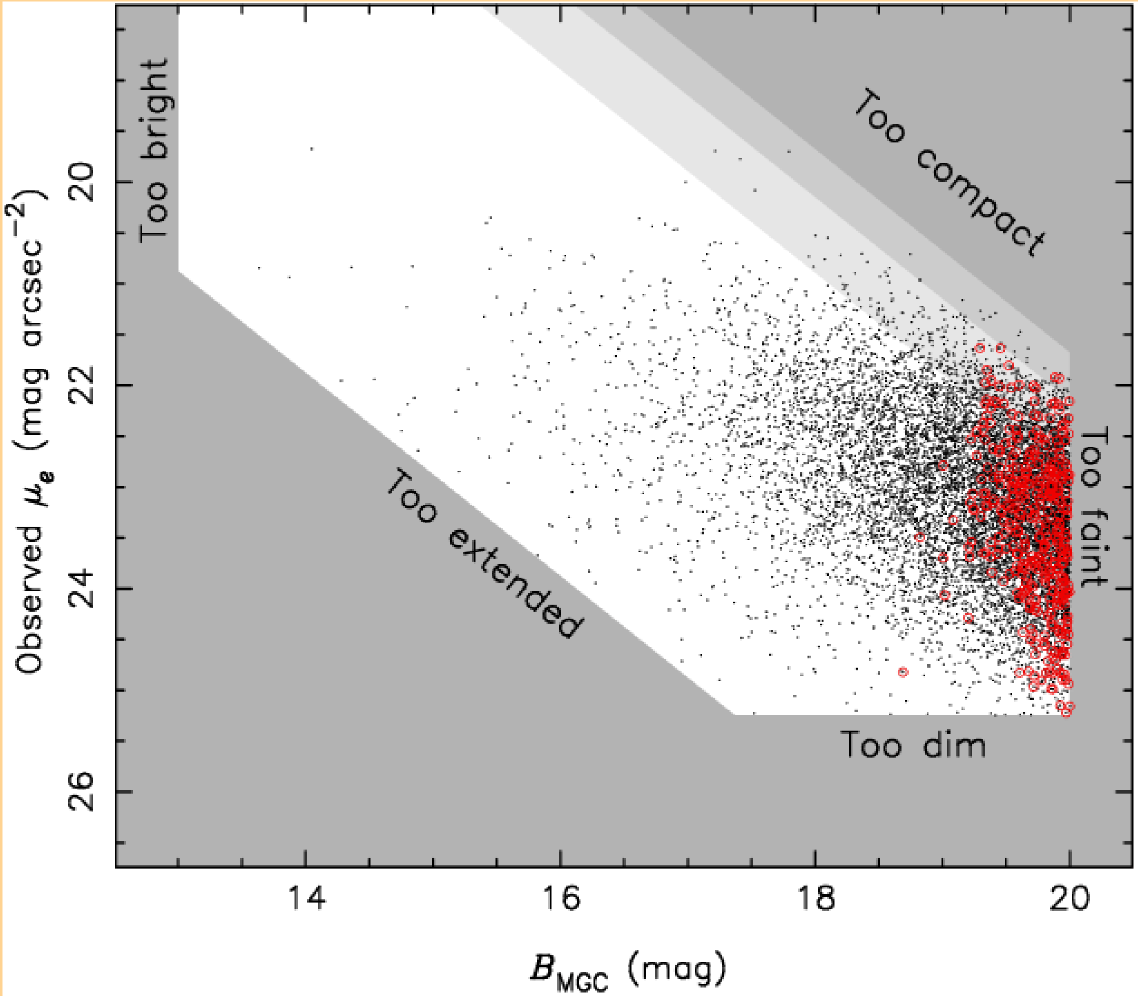
- B-μ dependent *z*-incompleteness weights



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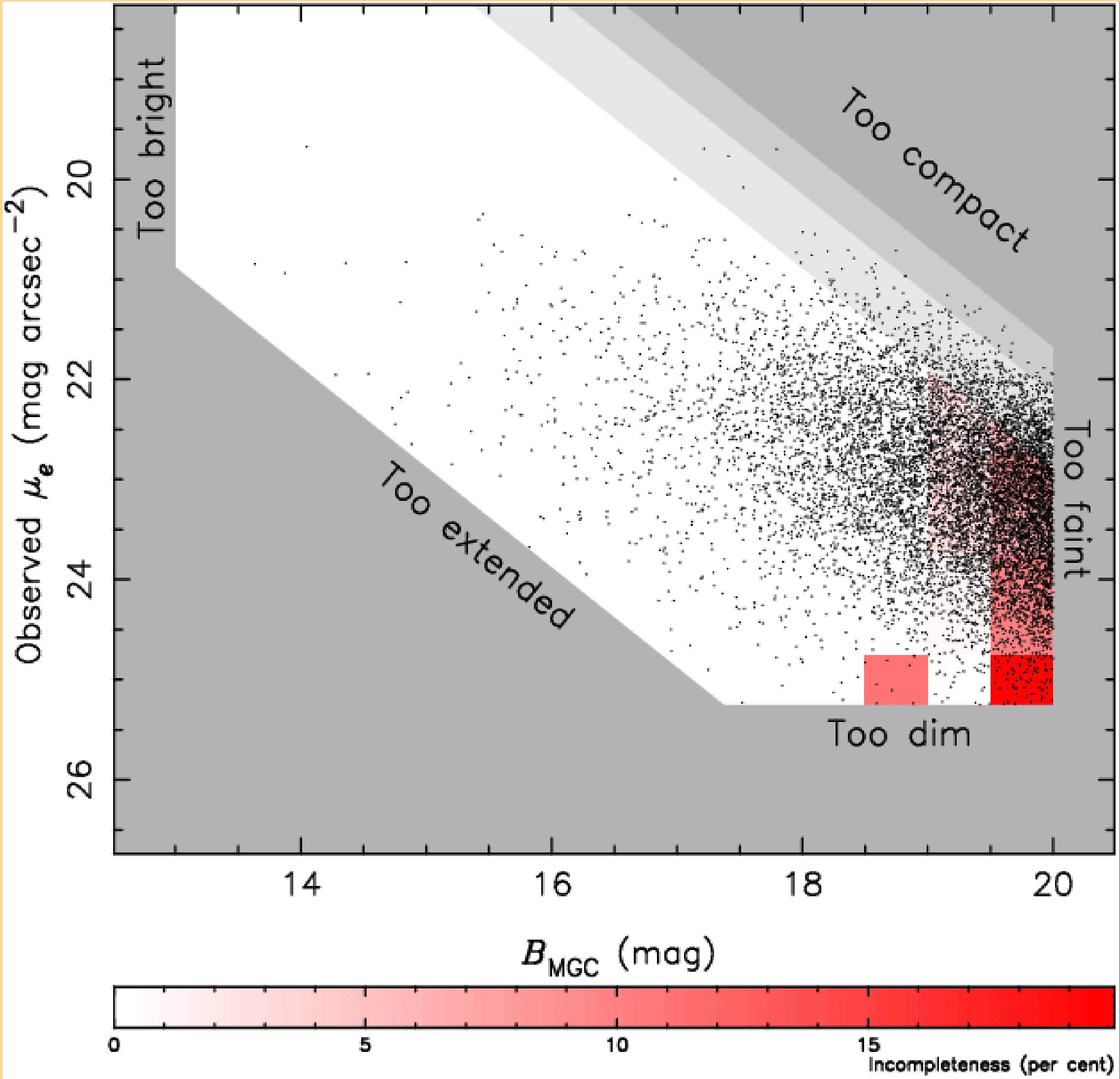

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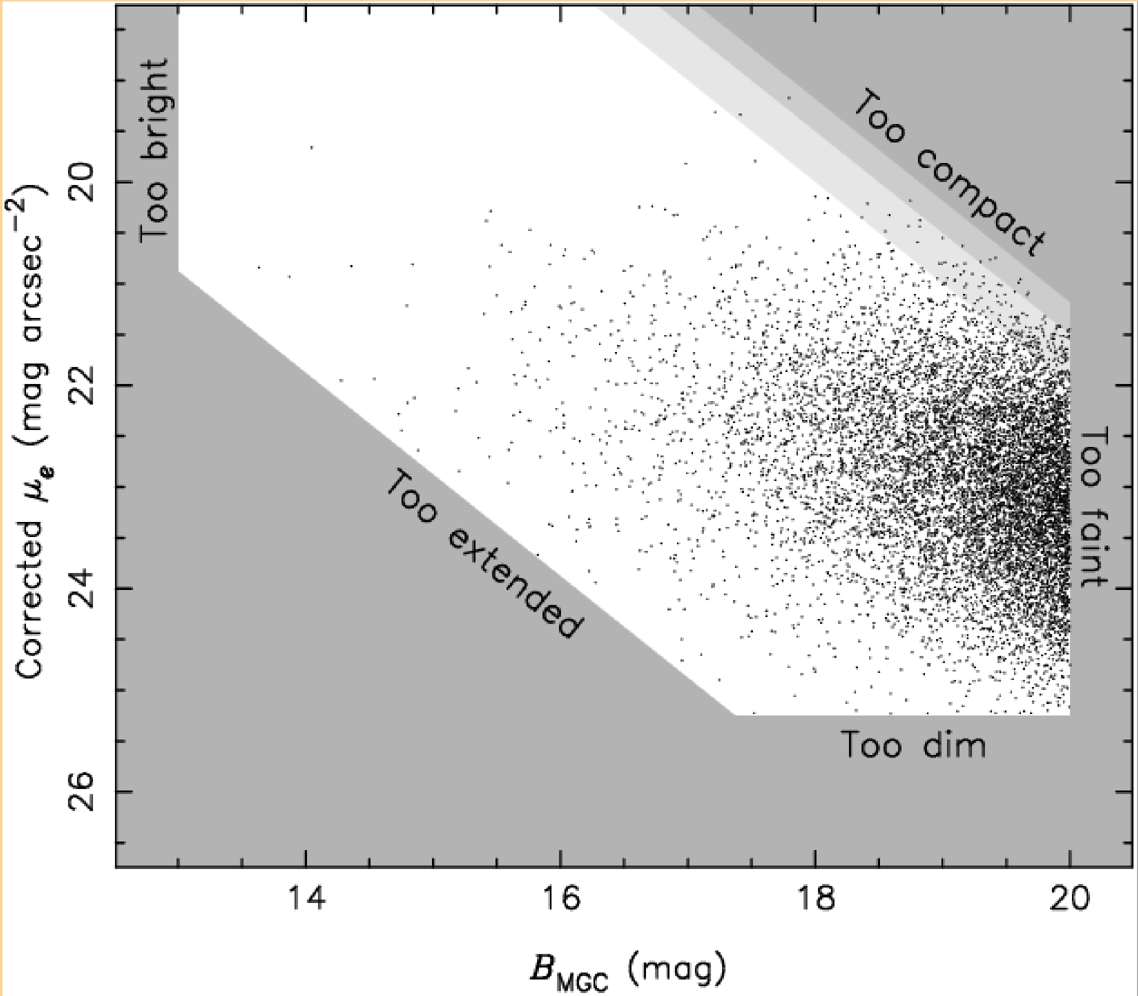
- B-μ dependent *z*-incompleteness weights
- Seeing correction: $r_0 = (r_{obs}^2 - 0.32\,\Gamma^2)^{1/2}$



Deriving the global BBD

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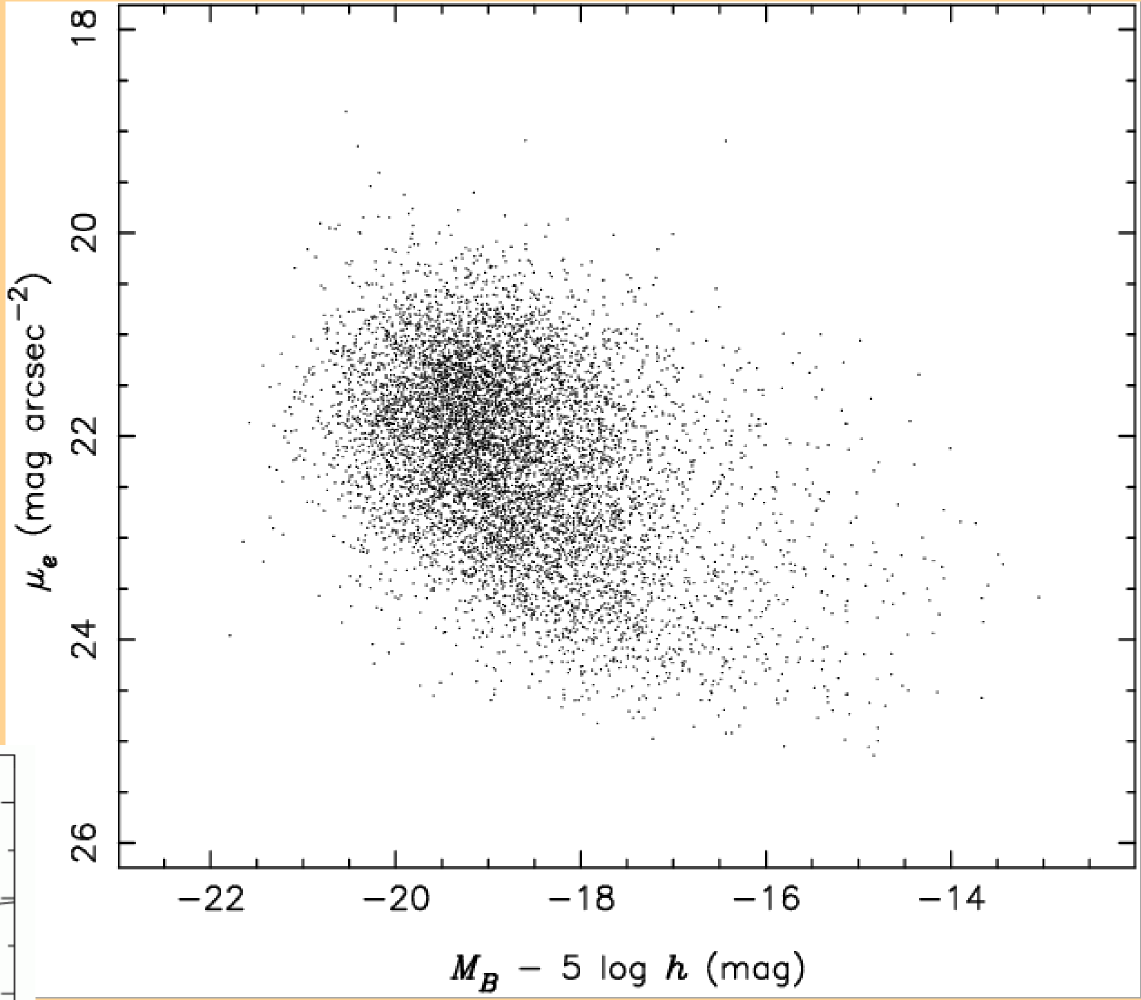
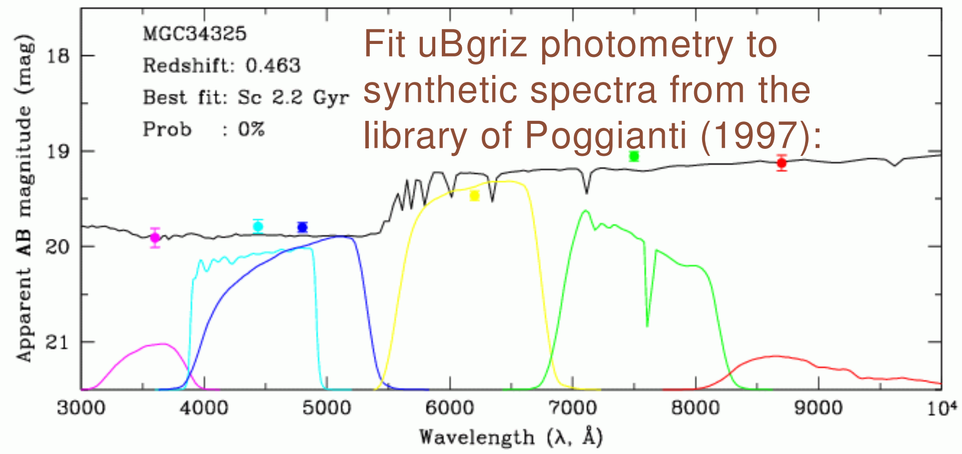
- Seeing correction: $r_0 = (r_{obs}^2 - 0.32\,\Gamma^2)^{1/2}$
- Convert to absolute parameters:
  - h = 1, $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$
  - $E(z) = 2.5 \log(1+z)^{-0.75}$
  - individual k-corrections



Fit uBgriz photometry to synthetic spectra from the library of Poggianti (1997):



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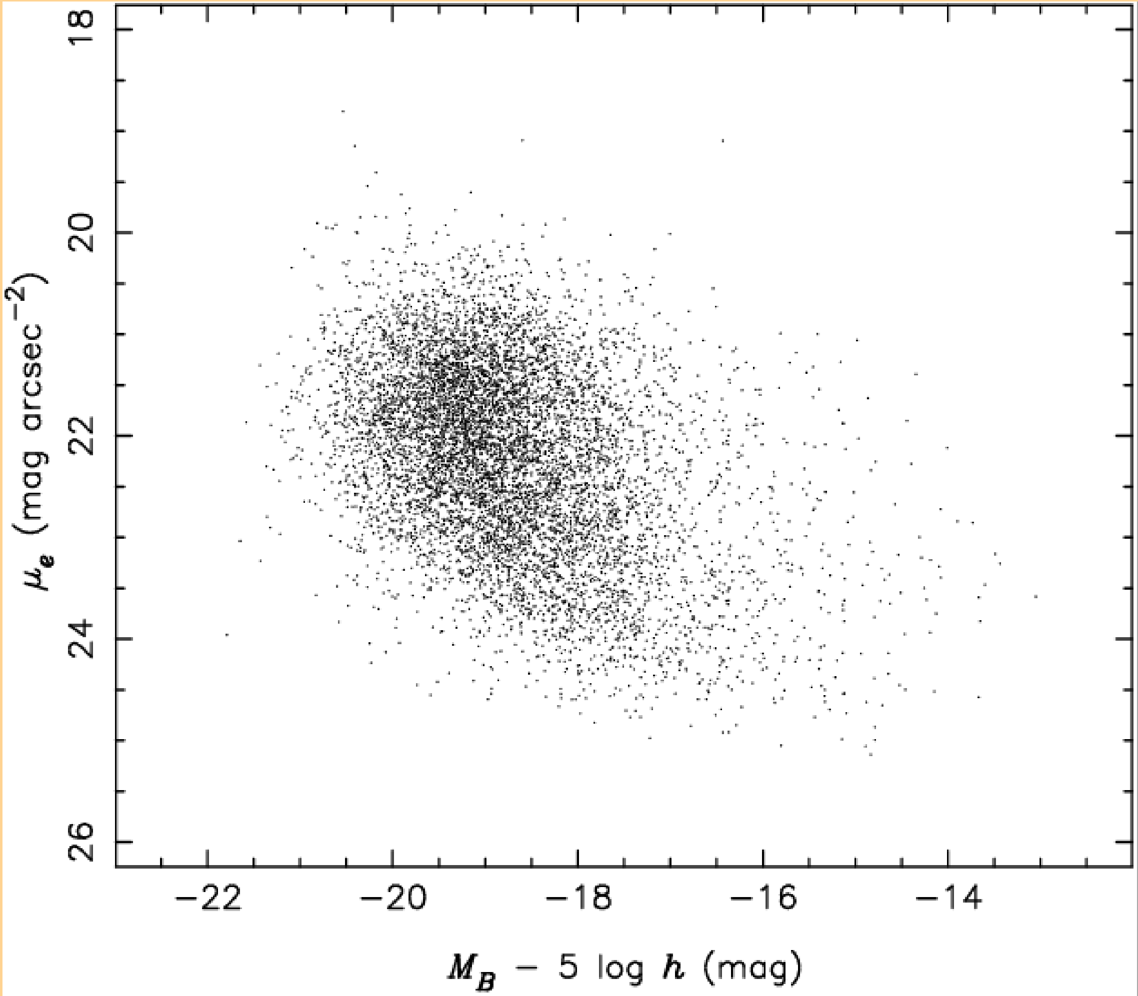
  - individual k-corrections
- Apply bivariate SWML:

$$\phi_{jk} = \frac{\sum_i^{Ngal} W_{ijk}}{\sum_i^{Ngal} \frac{H_{ijk}}{\sum\sum \phi_{lm} H_{ilm}}}$$

Weights (W_{ijk})

Visibility (H_{ijk})



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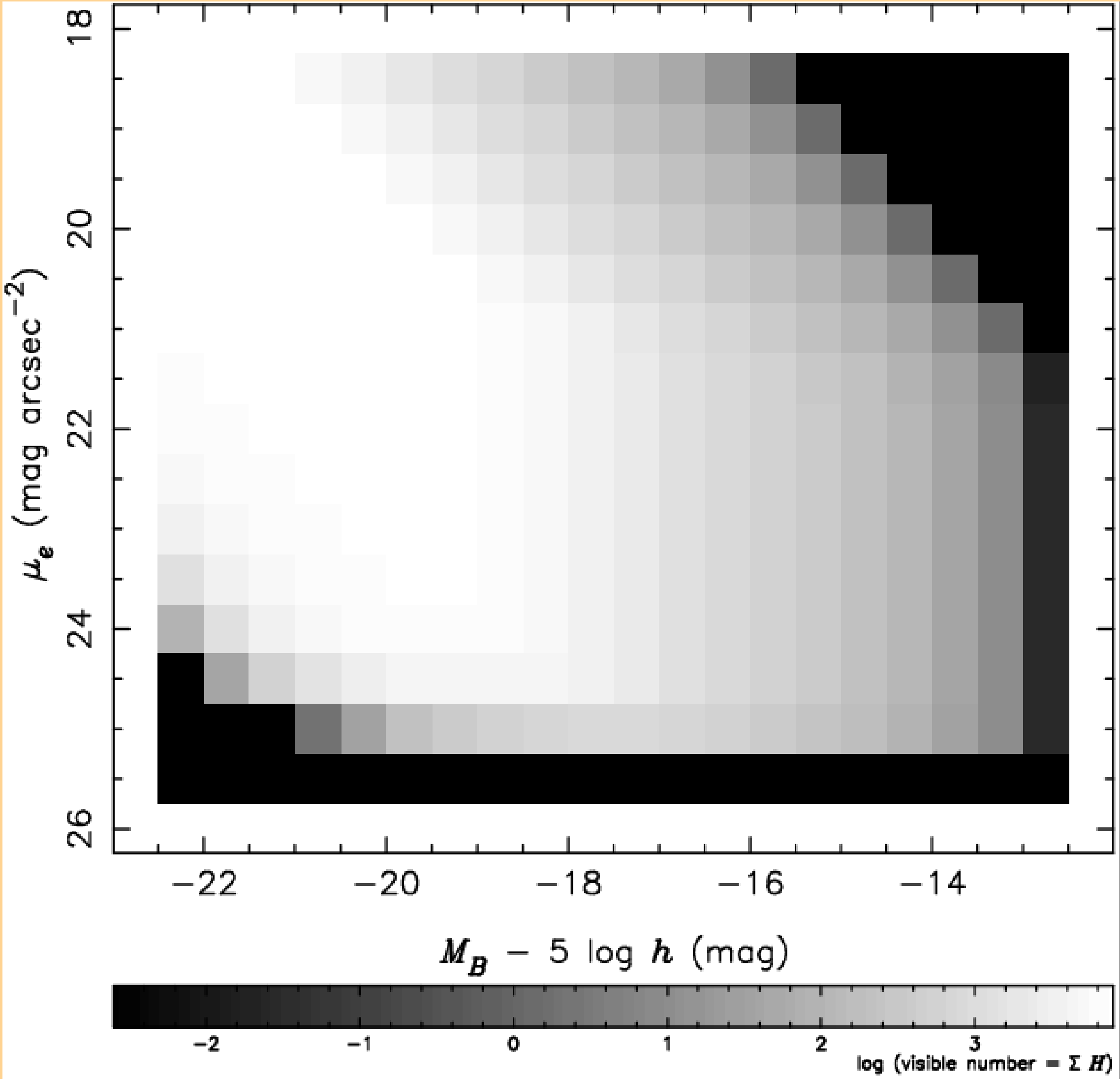
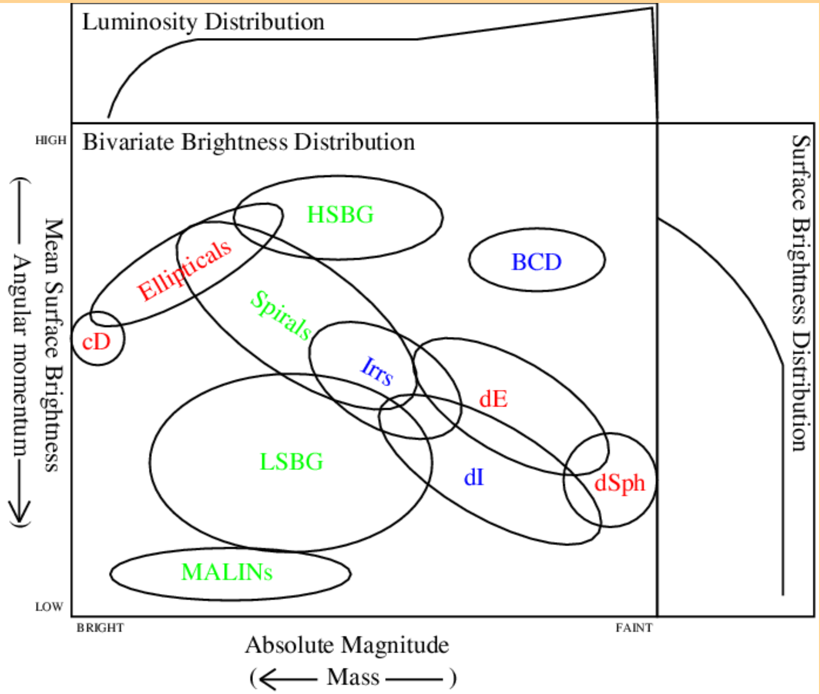
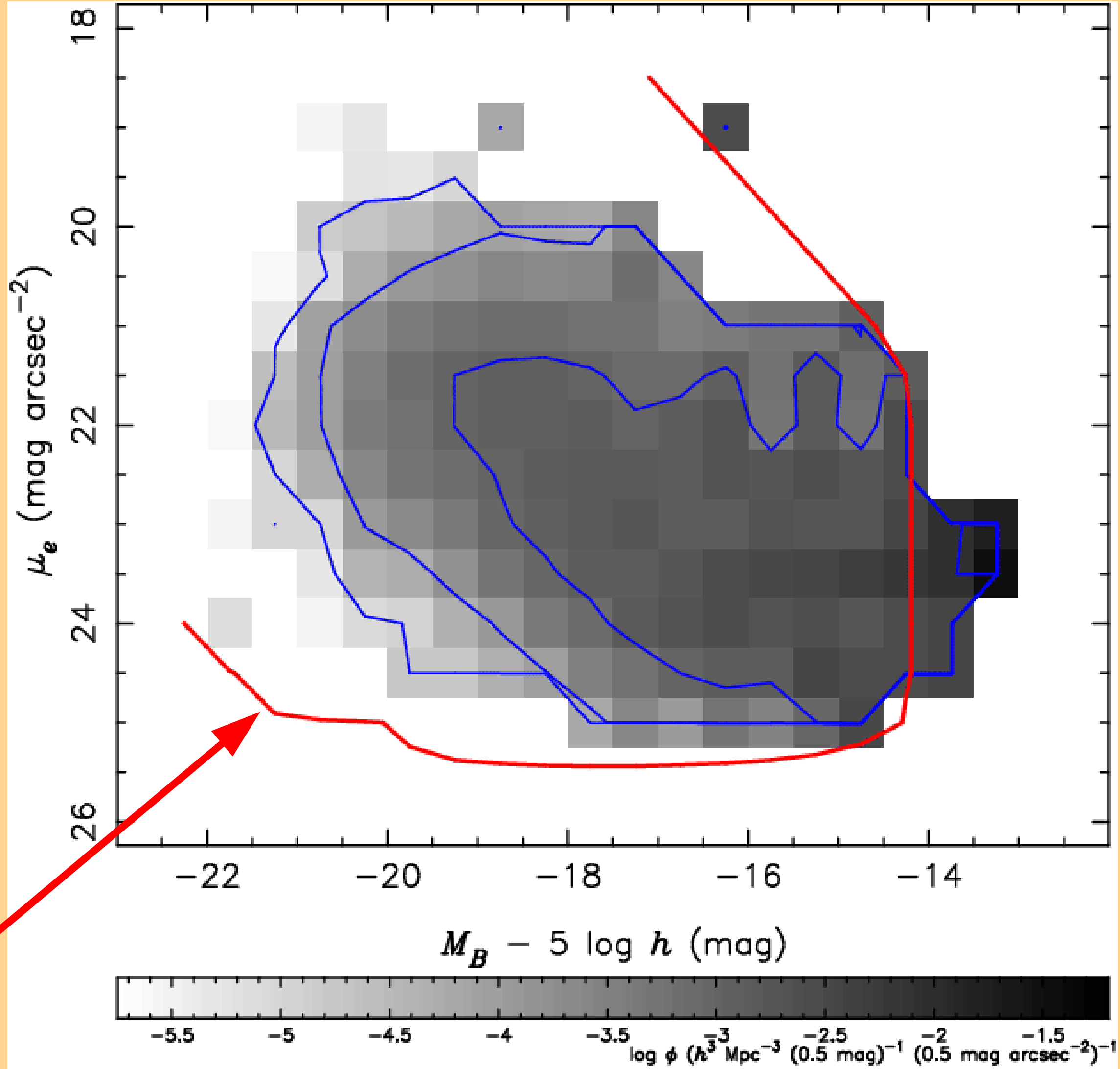


The final MGC global BBD

- Choloniewski function does not fit.
- LSB regime at $M_B > -17$ mag is still difficult!





'Selection limit' = region sampled by at least 100 galaxies ~ 1800 h^{-3} Mpc^3

MGC Millennium Galaxy Catalogue

SB distributions

- SB distributions are Gaussian, i.e. size distributions are log-normal.

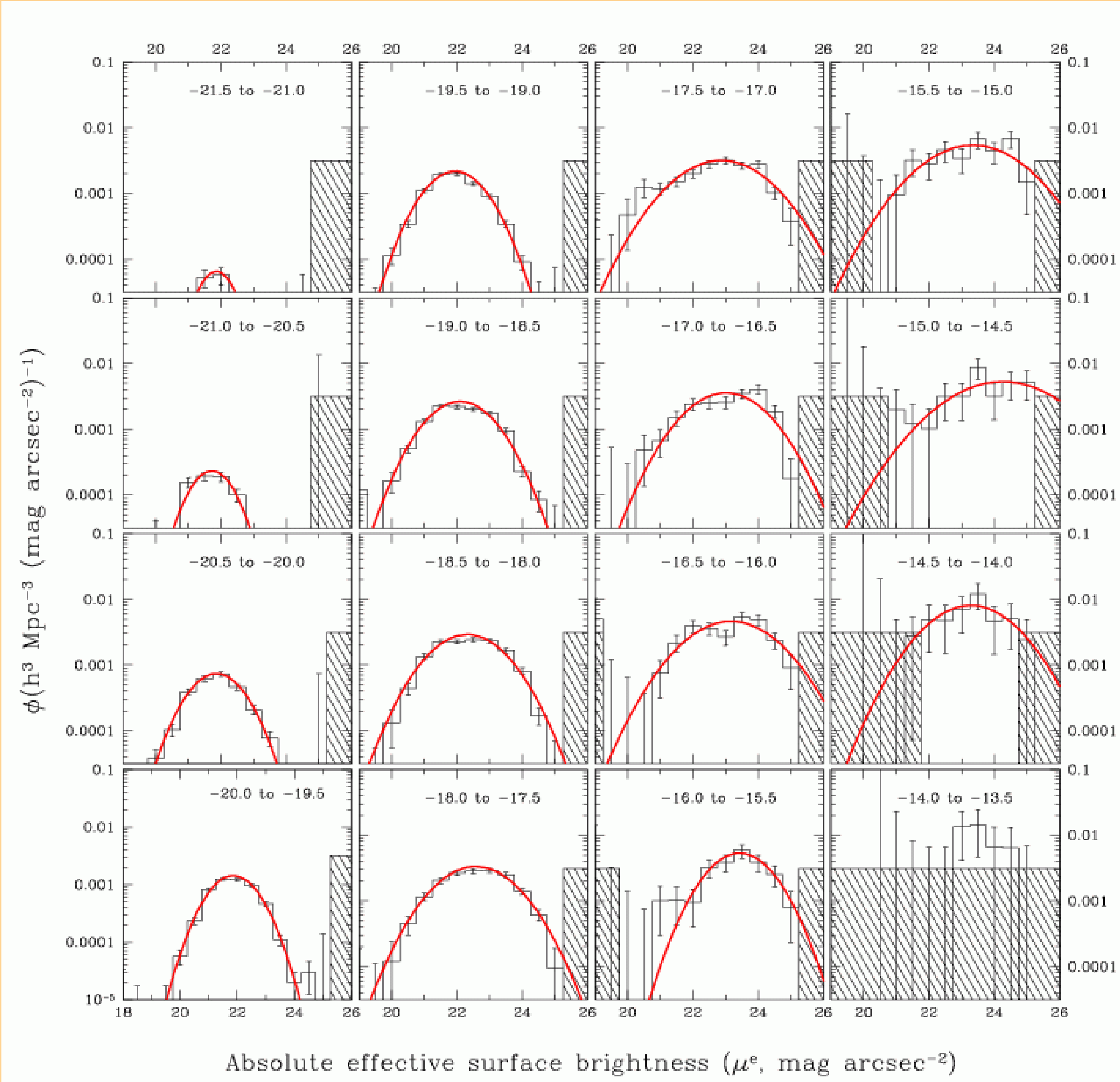
- μ^* constant with M to M < -19, then becomes fainter.

- Distribution broadens towards fainter M:

At M*: $\sigma_{\ln R} = 0.35$

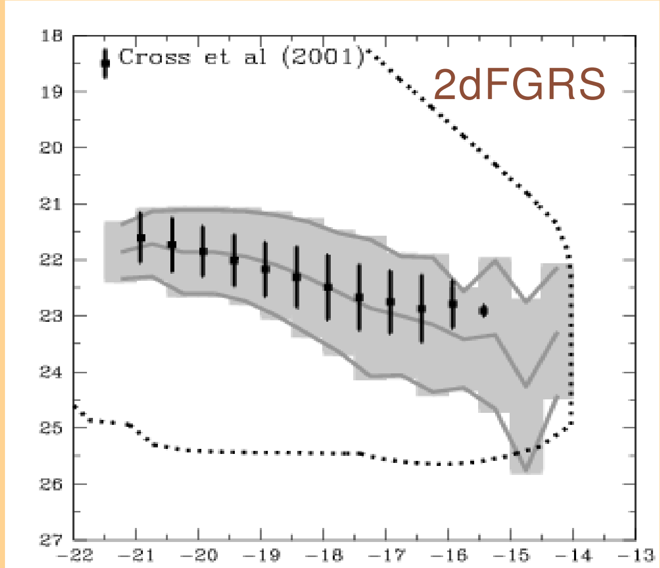
Fainter: $\sigma_{\ln R} = 0.5\text{-}0.7$

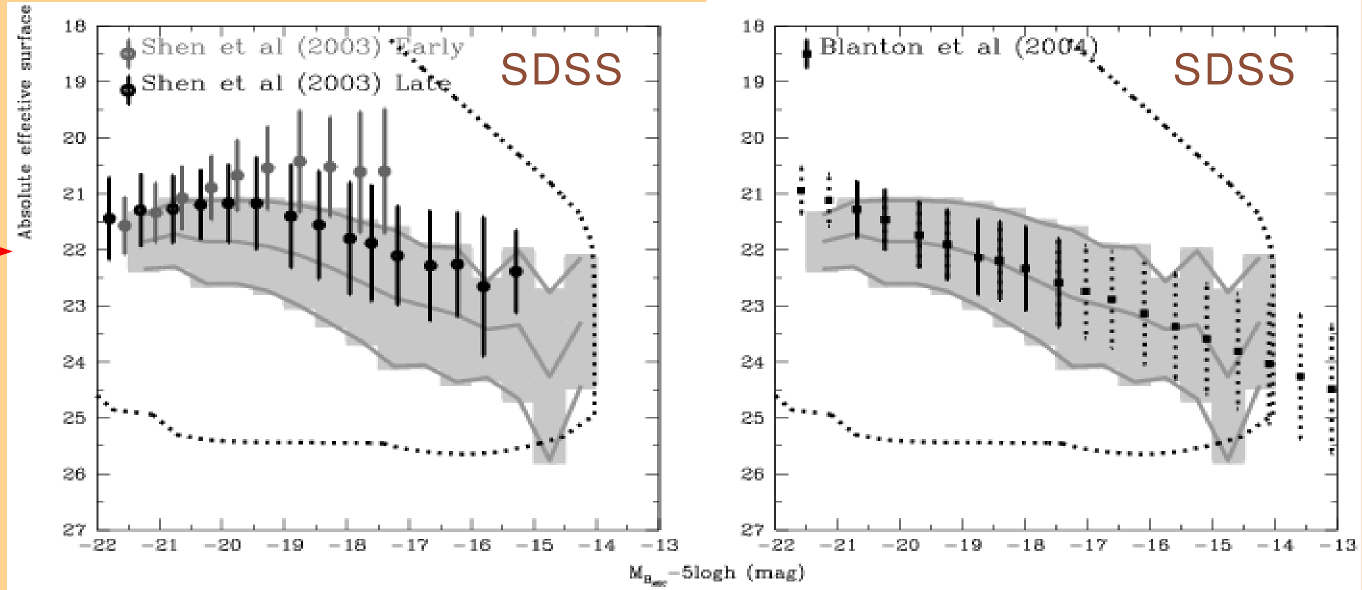
Simulations: $\sigma_{\ln R} = 0.56 \pm 0.04$, independent of mass (Bullock et al. 2001)



Comparison to other BBDs

- 2dFGRS: M-μ relation ok, σ too narrow. Due to low resolution and shallow SB limit?
- SDSS (Shen et al. 2003): Significant offset in M-μ relation of $\Delta\mu = 0.4$ mag arcsec^{-2}. Cannot explain this.
- SDDS (Blanton et al. 2005): M-μ relation ok, σ slightly too narrow. Due to circular apertures?





Problem? Used as z=0 point by e.g. Trujillo et al. 2004, Barden et al. 2005, Trujillo et al. 2005.

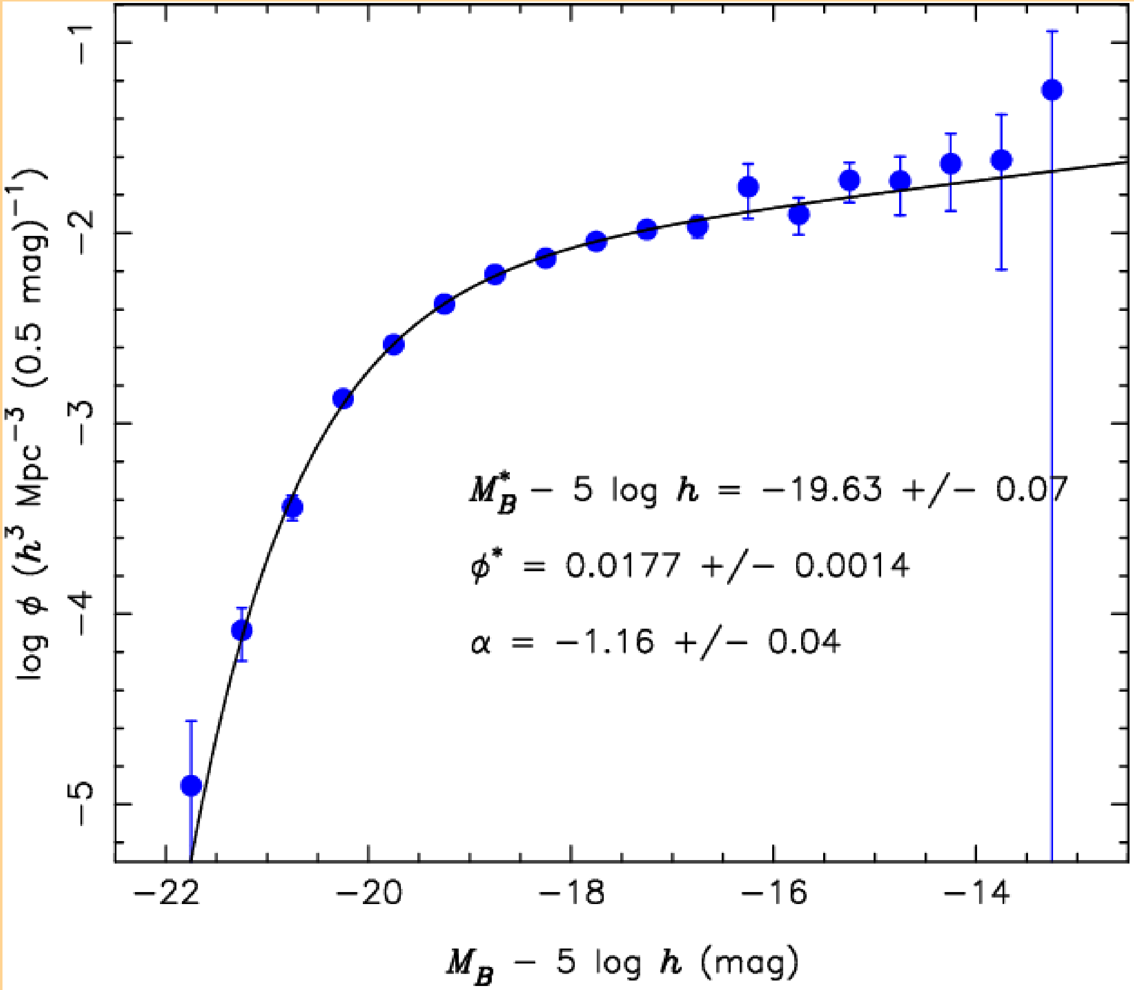
The MGC luminosity function

$0.013 < z < 0.18$

$13 < B < 20$ mag

$r_{min} = 0.6\,\Gamma + 0.31 < r < 15$ arcsec

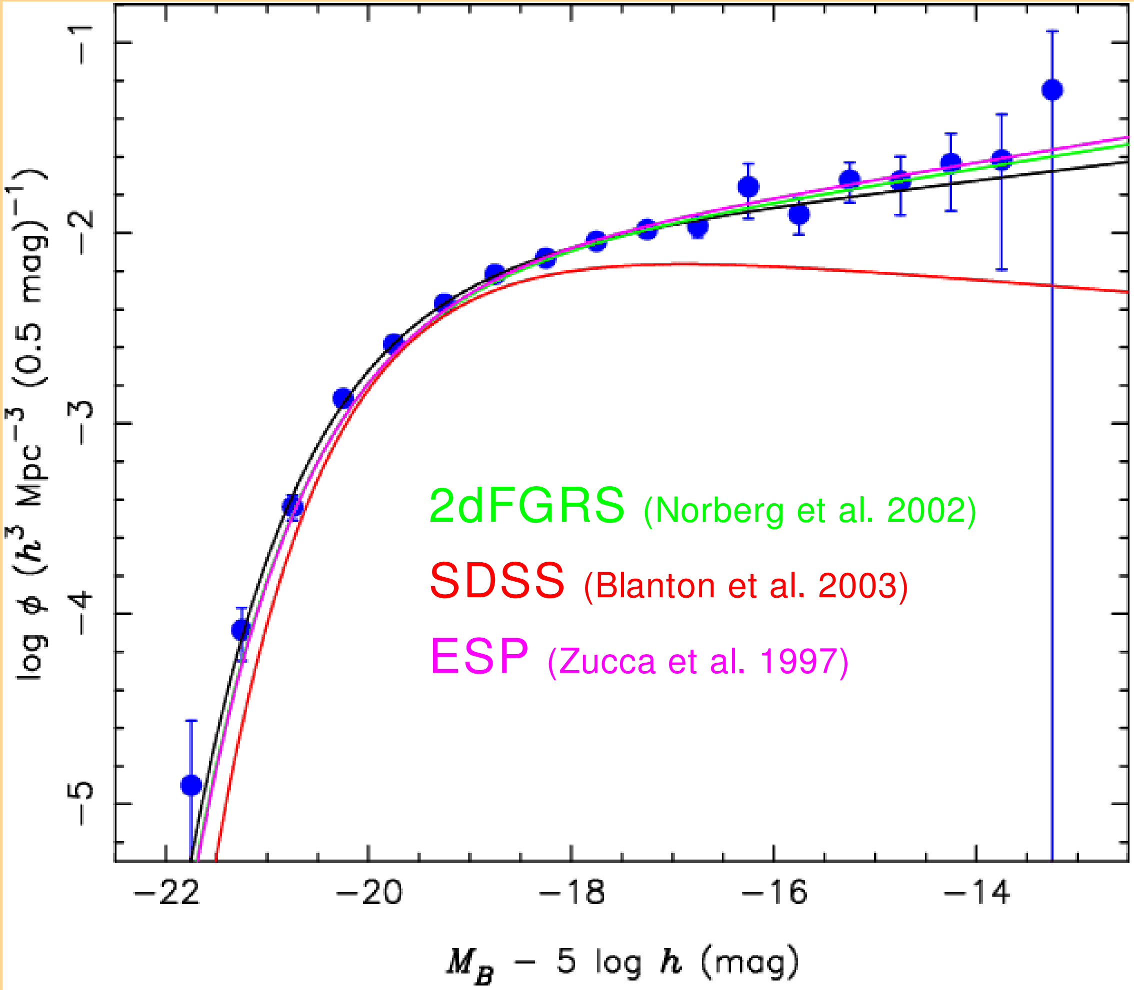
$\mu < 25.25$ mag arcsec^{-2}



Comparison to other LFs

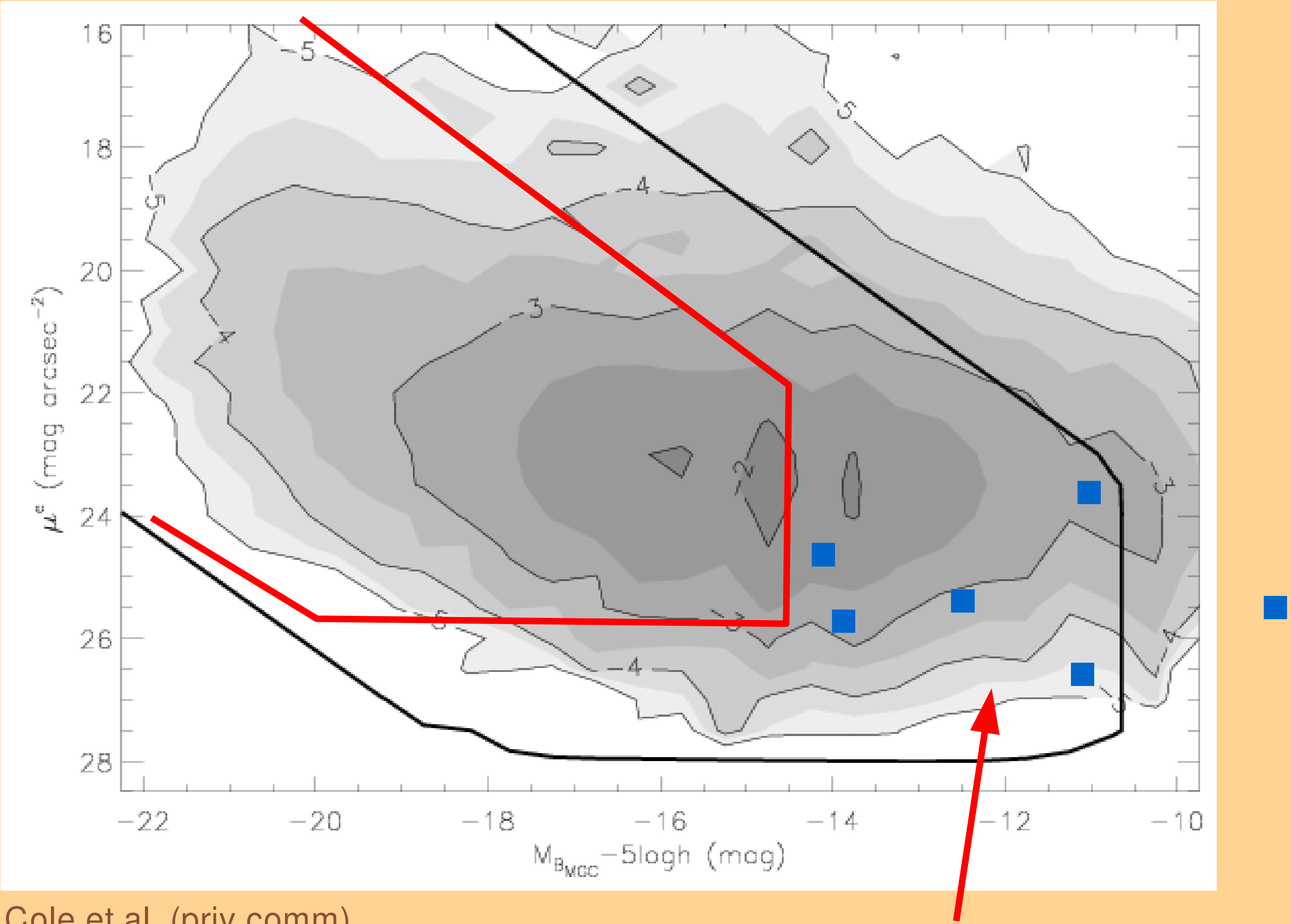
- Excellent agreement with 2dFGRS and ESP.

- SDSS: Too faint and faint-end too shallow.
NOT due to: - stronger evolution
- shallower SB limit
BUT: r-band selected but here we use the *g*-band LF.



Putting it into context

We are currently barely detecting the peak (in number) of the galaxy distribution. Almost all of the Local Group is currently 'off the plot'.



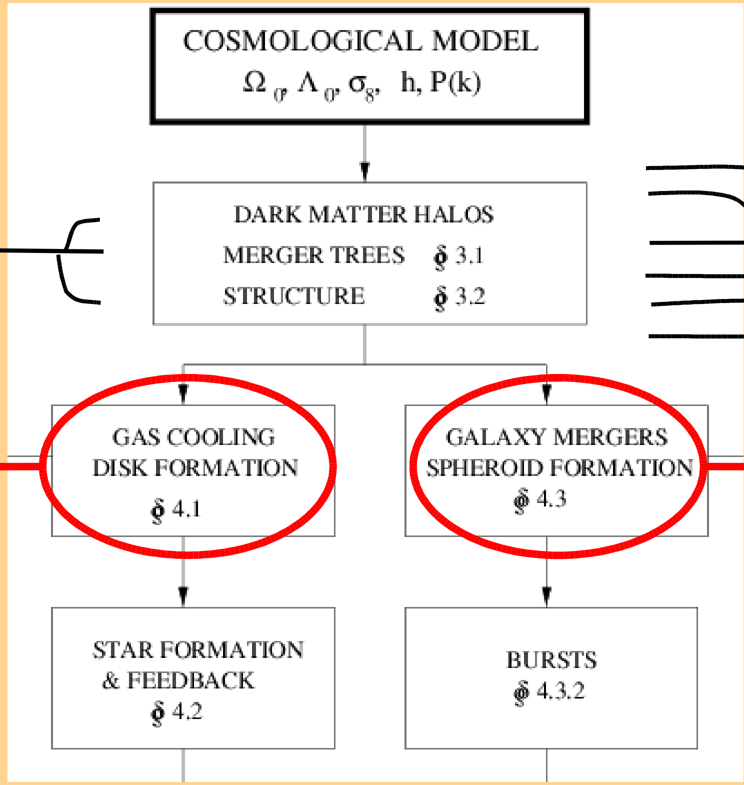
Cole et al. (priv comm)

Some Local Group members

Hierarchical Galaxy Formation

e.g. Cole et al., 2000, MNRAS, 319, 168

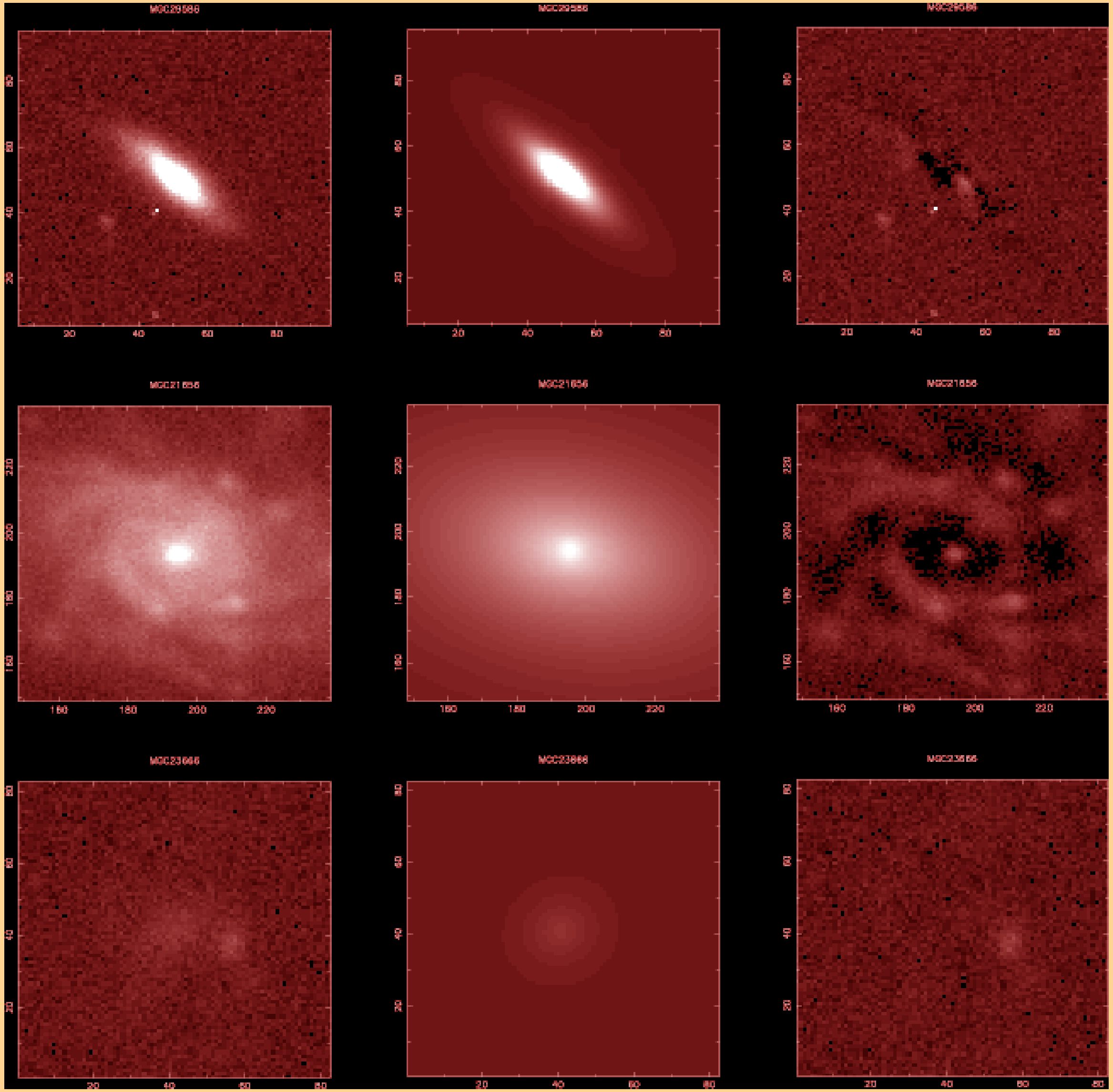
“Galaxies are assumed to form inside dark matter halos, and their subsequent evolution is controlled by the merging histories of the halos containing them.”



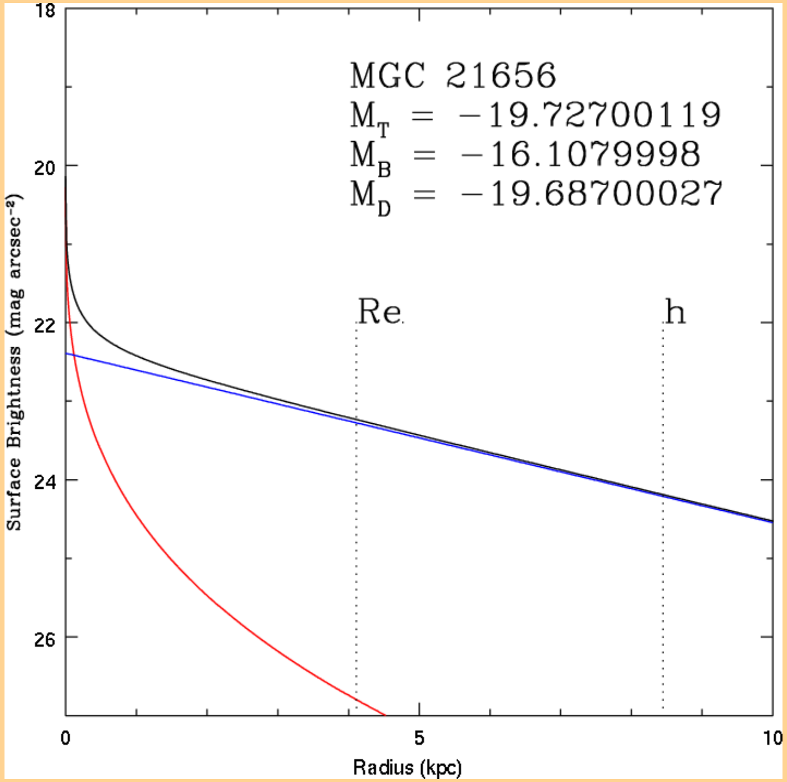
“We assume that disks form by cooling of gas initially in the halo.”

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

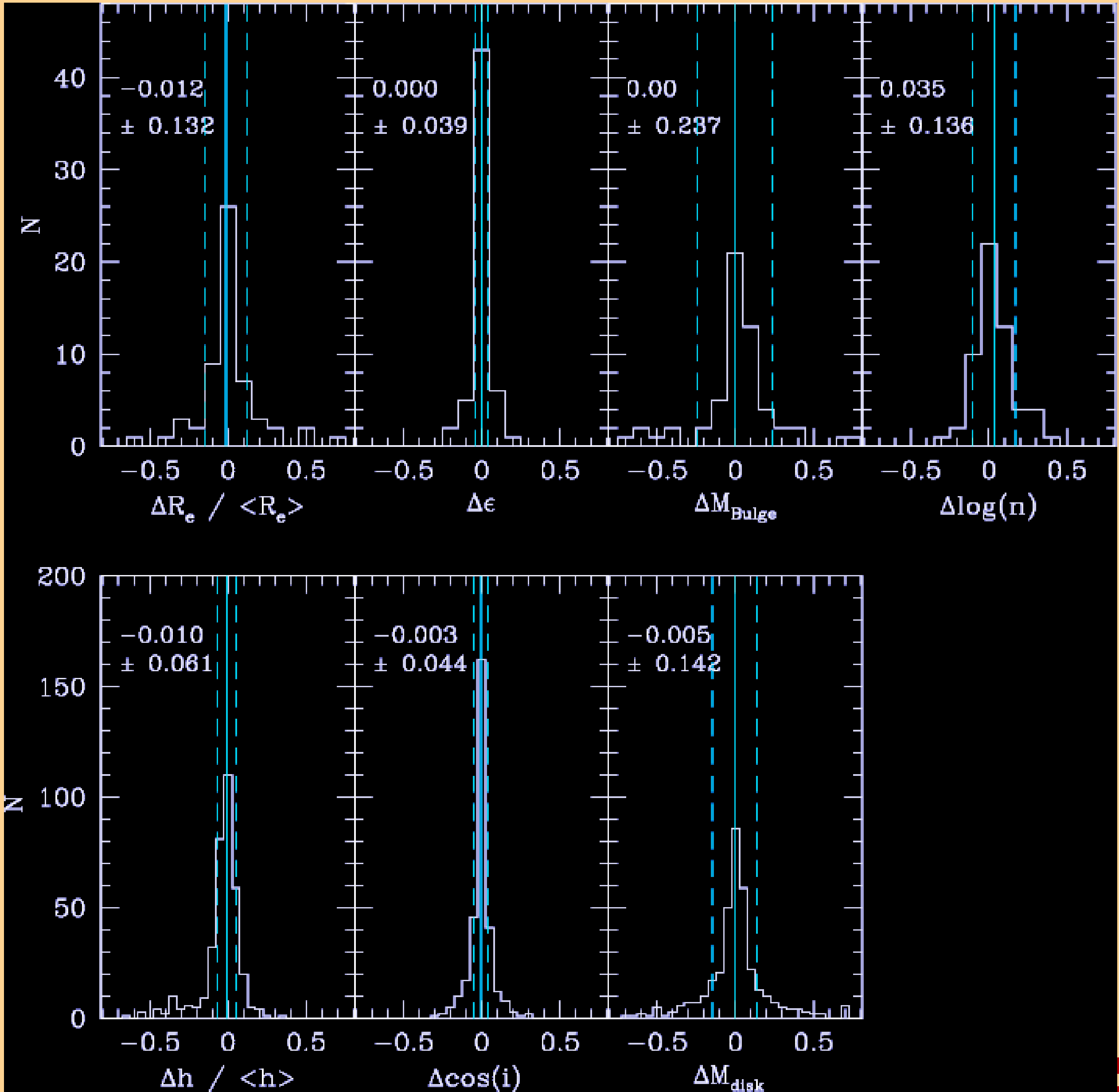
MGC Bulge/Disk decomposition



- See talk by Paul Allen this morning!
- Using GIM2D (Simard 1998).
- Sersic bulge + exponential disk fits (including PSF) for all 10,095 galaxies to B < 20 mag.

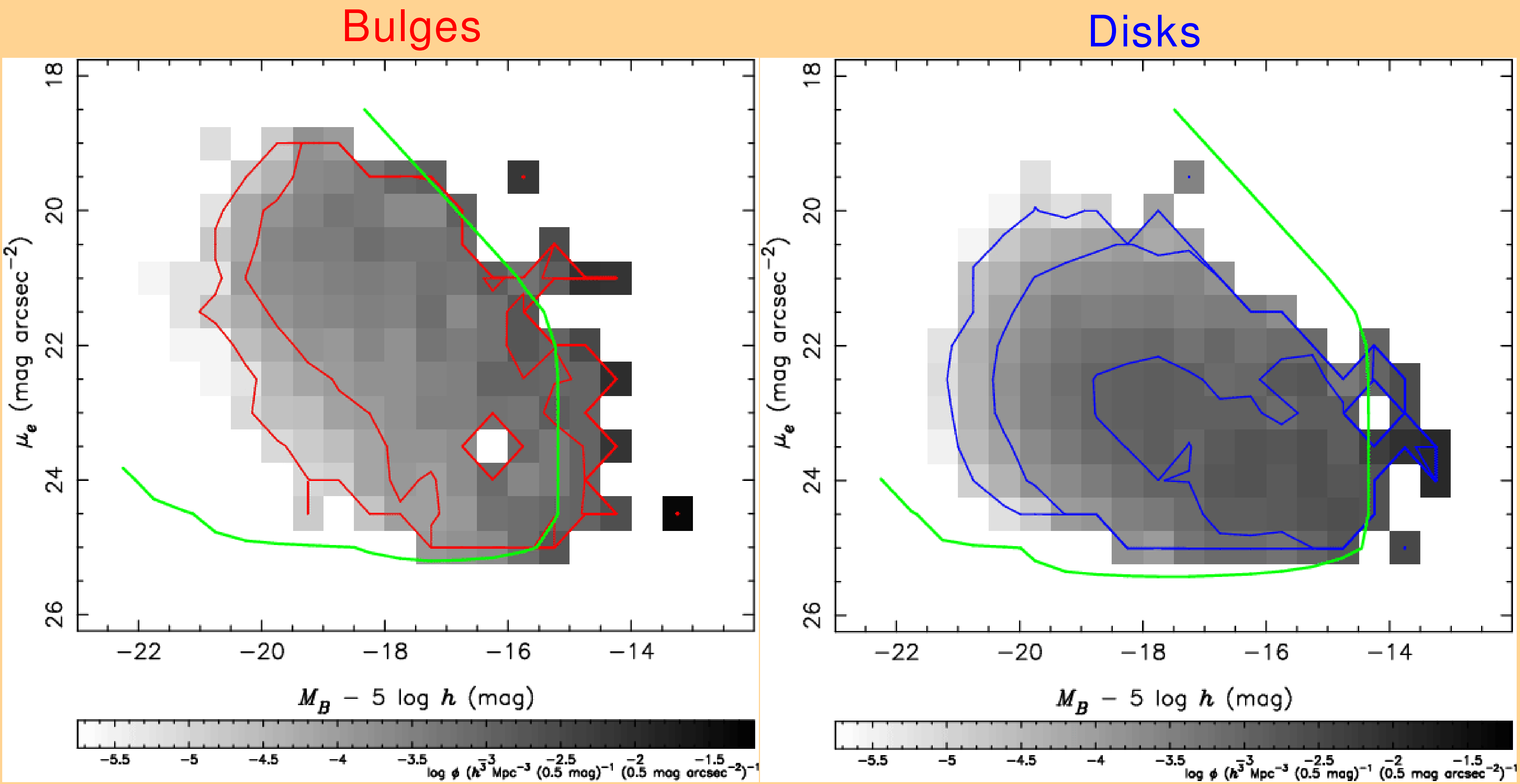


MGC Bulge/Disk decomposition



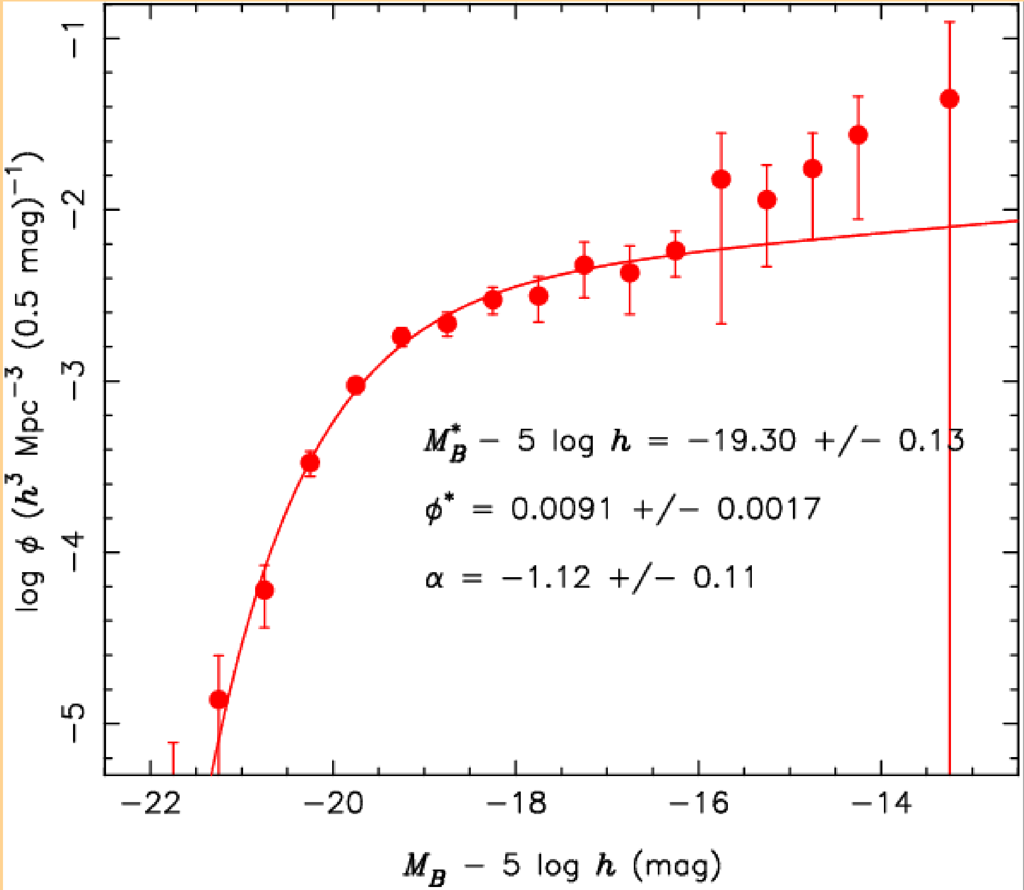
- See talk by Paul Allen this morning!
- Using GIM2D (Simard 1998).
- Sersic bulge + exponential disk fits (including PSF) for all 10,095 galaxies to B < 20 mag.
- Accuracy and limits of fitting procedure from duplicate observations 700 galaxies in regions of overlap between adjacent MGC fields.

The (preliminary) MGC Bulge/Disk BBDs

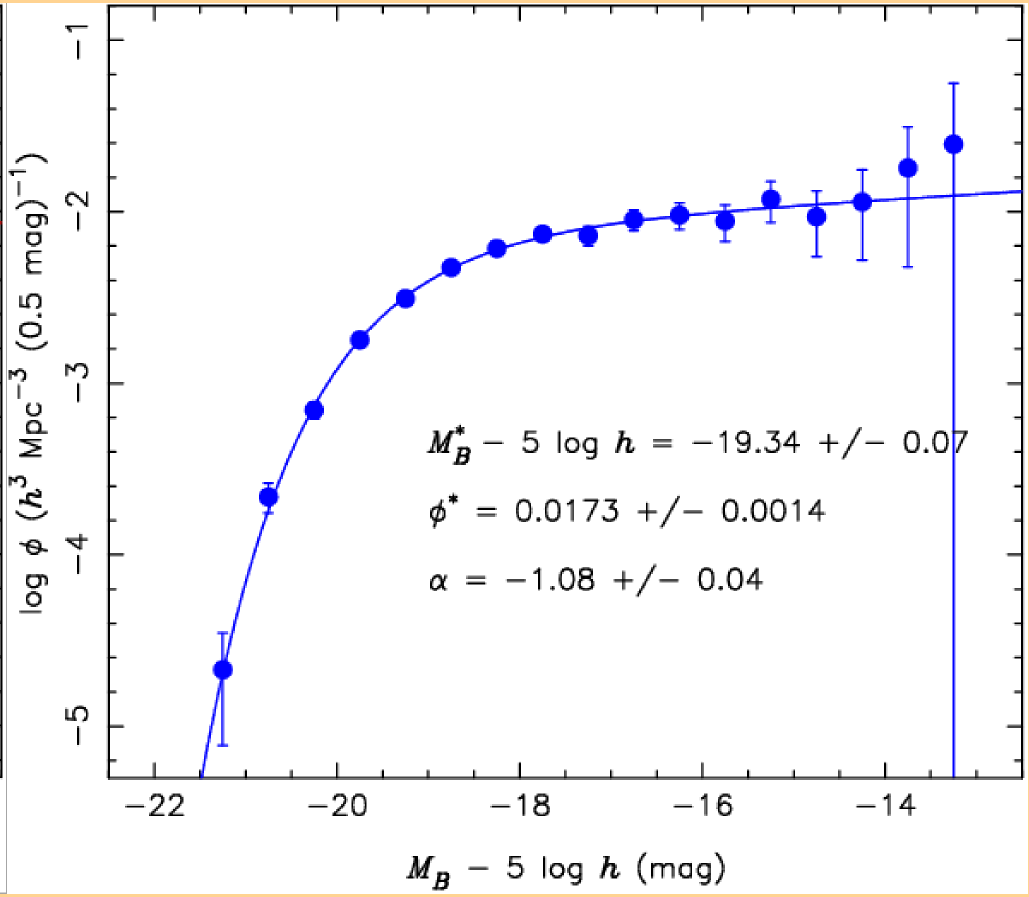


The (preliminary) MGC Bulge/Disk LFs

Bulges



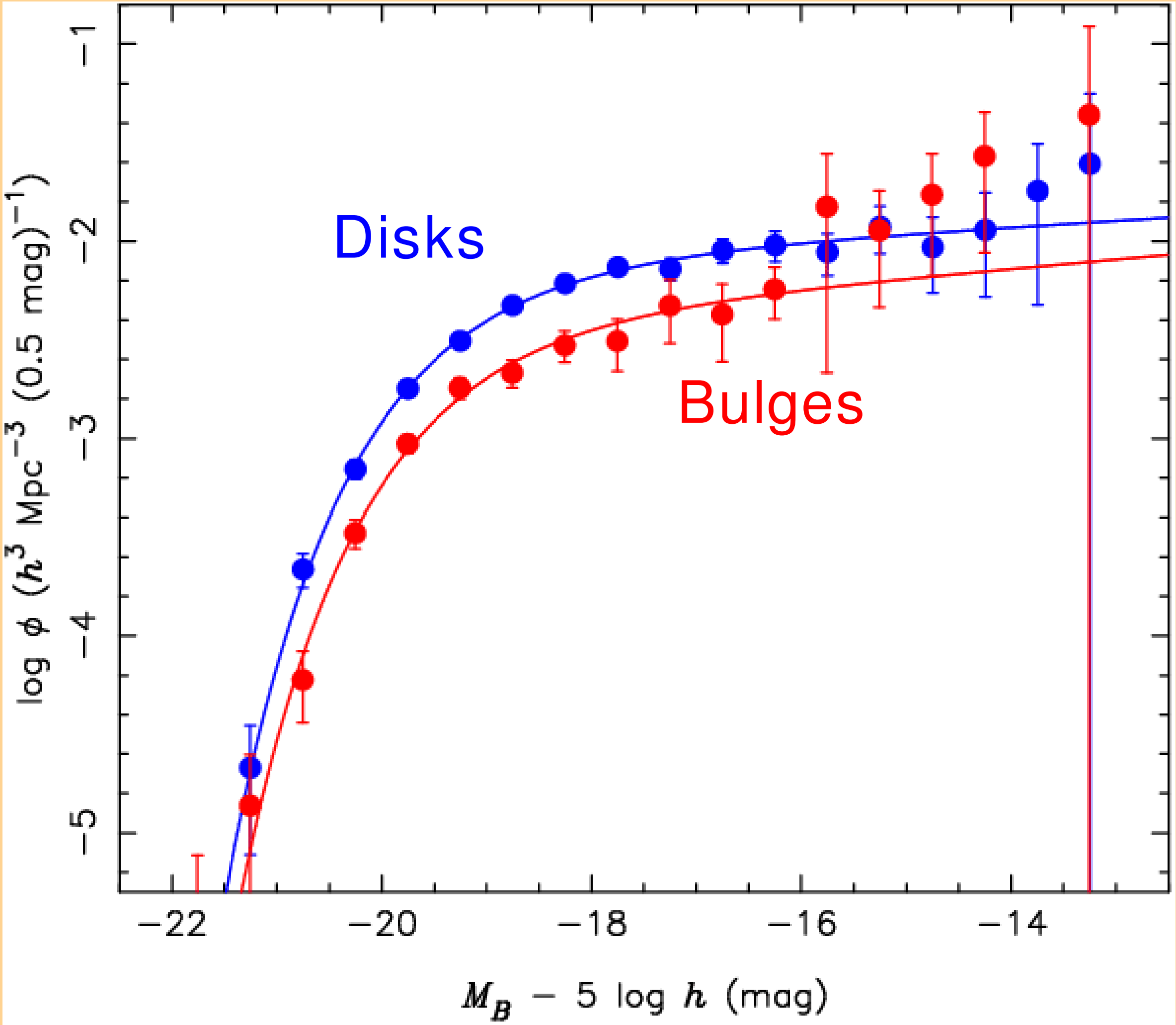
Disks



The (preliminary) MGC Bulge/Disk LFs

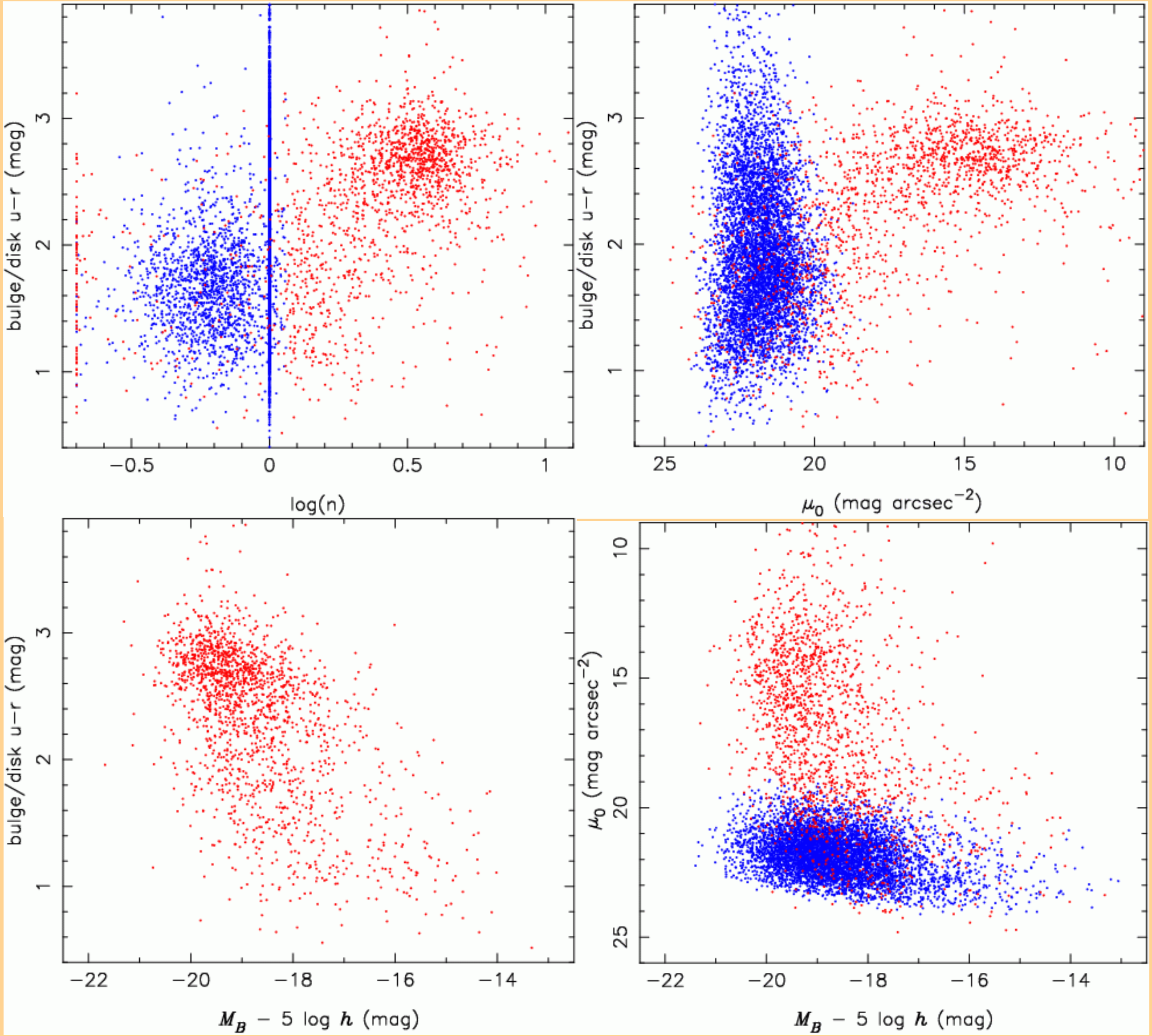
- Similar M*.
- $\phi^*_{bulge} = 0.5\ \phi^*_{disk}$
- Bulges show steep up-turn at M = -16 mag.

⇒ Two populations?



Two types of bulges?

Disks
Bulges



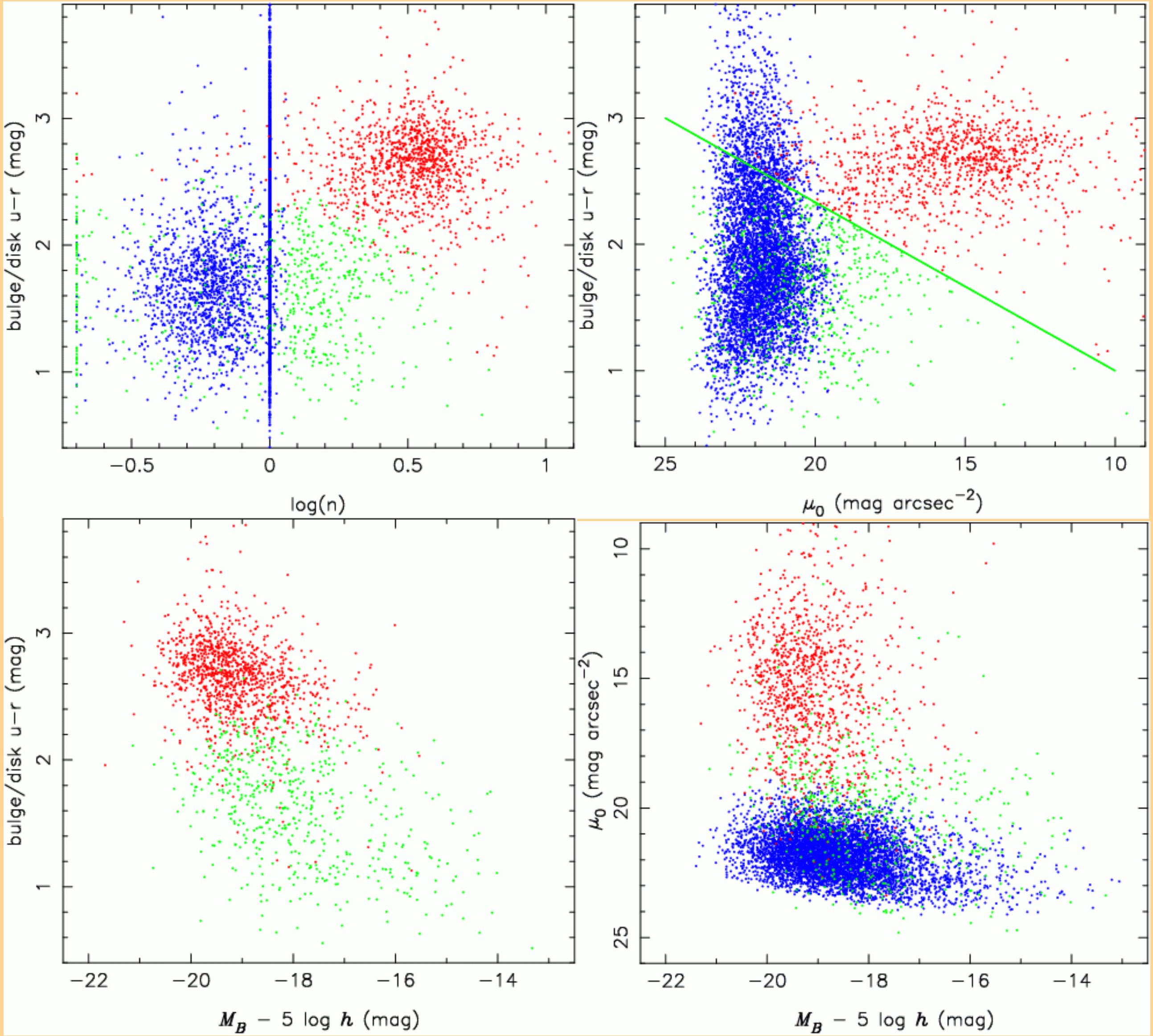
Two types of bulges?

Disks
Bulges

'real' bulges

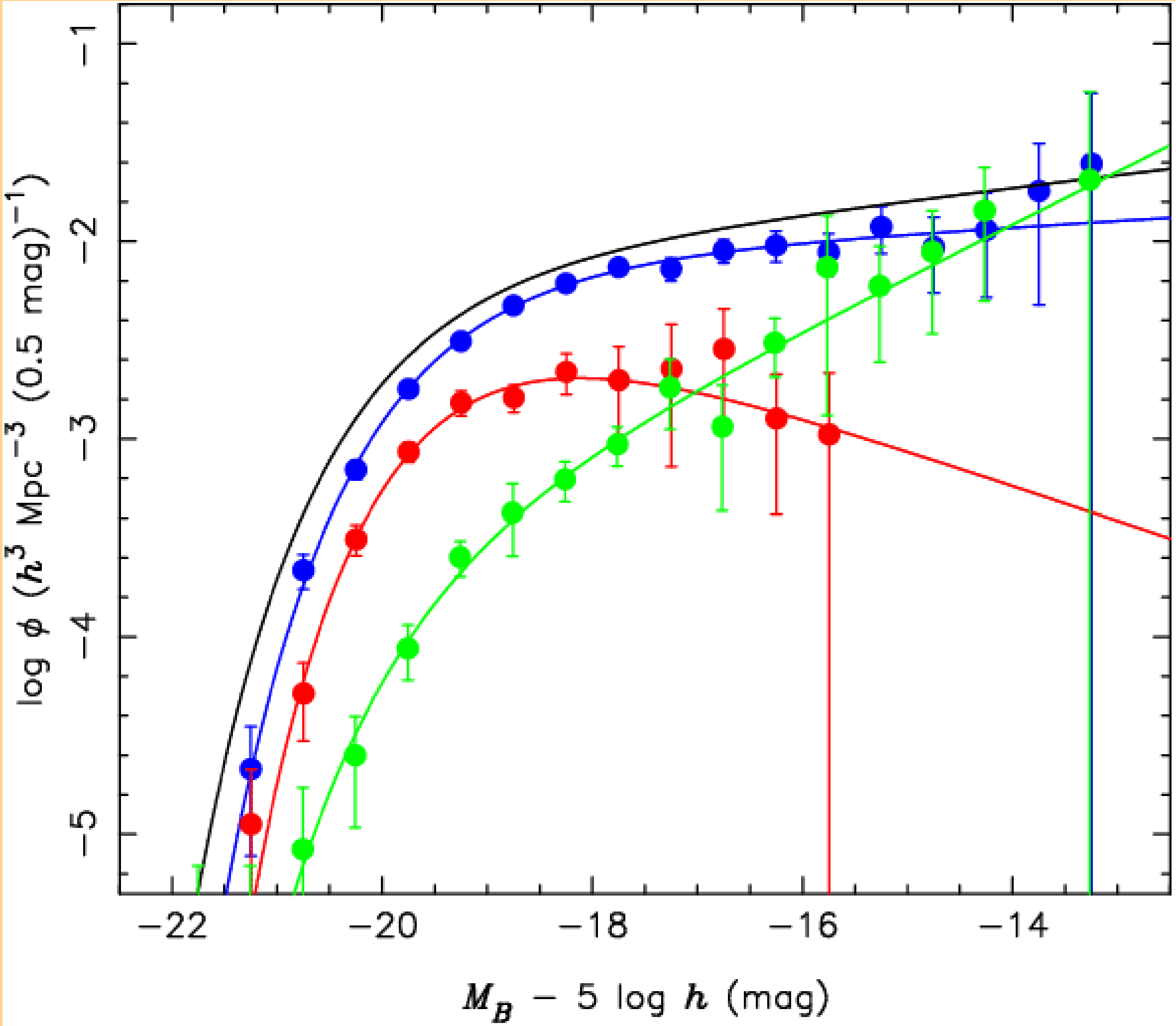
'pseudo' bulges

Probably a catch-all class!



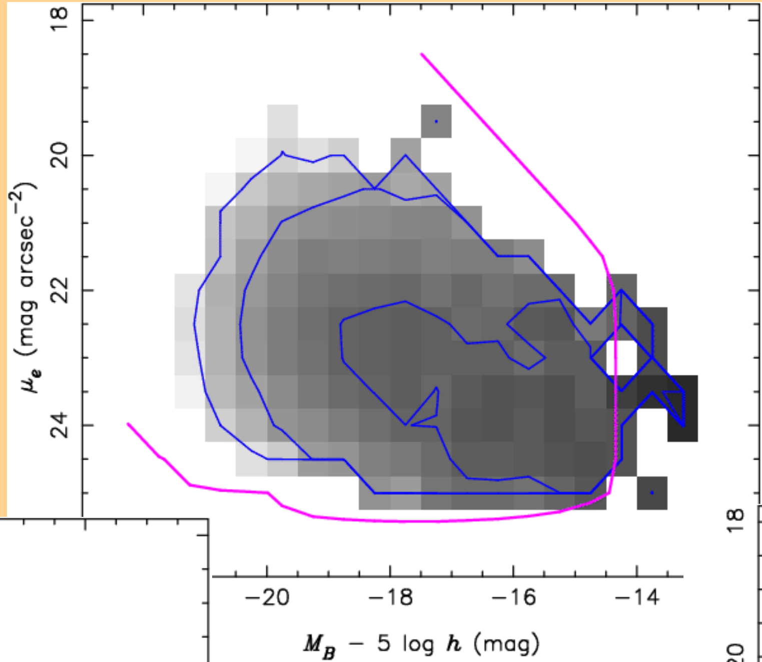
Structurally segregated LFs

Total
Disks
'Real' bulges
'Pseudo' bulges

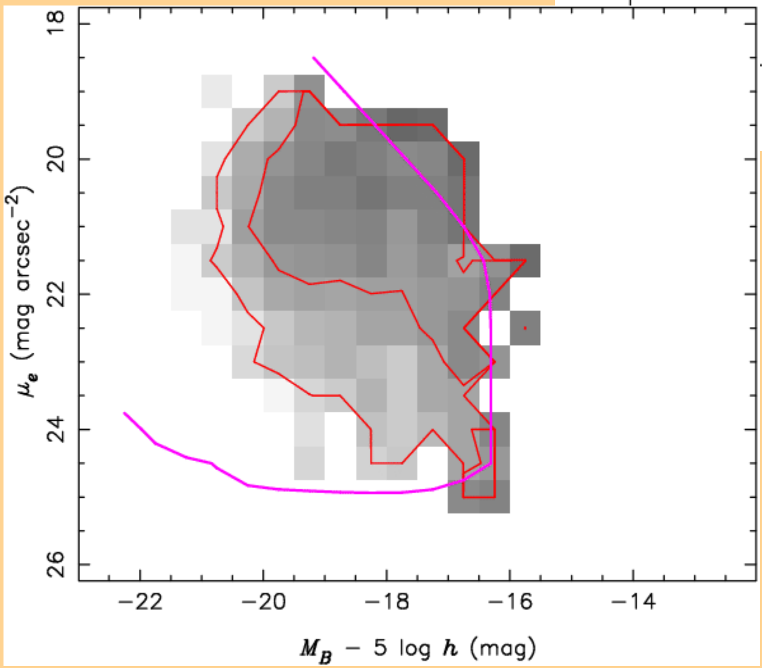


MGC Millennium Galaxy Catalogue

Structurally segregated BBDs

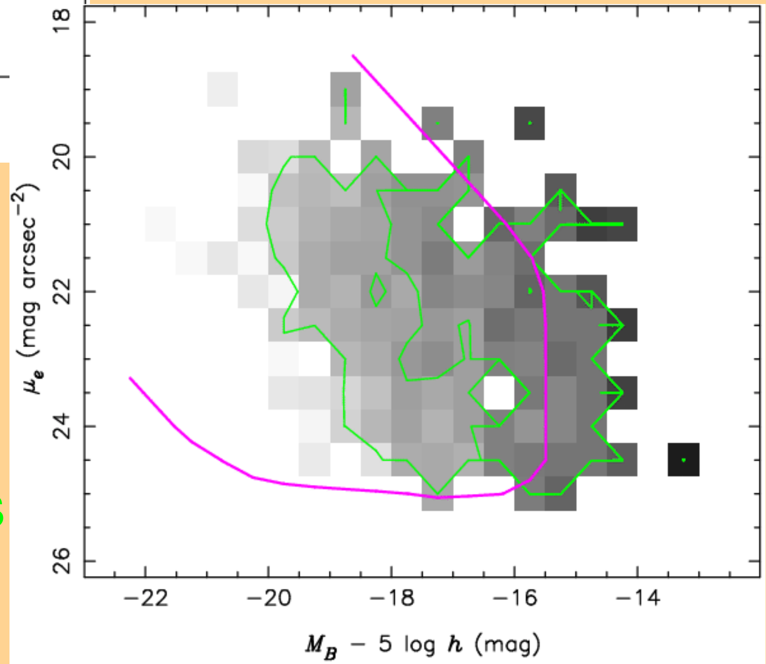


Disks



'Real' bulges

'Pseudo' bulges



Conclusions – Part I

- We have recovered the BBD from the MGC. The data and analysis feature:
  - Deep and high resolution imaging data.
  - Modelling of and accounting for photometric selection limits.
  - Seeing corrections to size measurements (no assumption of profile).
  - High spectroscopic completeness.
  - Incompleteness correction dependent on B and μ.
  - Individual k-corrections.
  - Joint M-μ SWML method incorporating selection limits.

- Significant differences in comparison to previous BBDs.
- μ^* constant as a function of M until M ~ -19, then decreases.
- σ_μ increases towards fainter M.
- Choloniewski function is not a good representation of the BBD.
- σ_μ too narrow for luminous systems compared to simulations.
- LF agrees well with previous studies $\Rightarrow$ SB selection effects not a big deal?
- $j_{bj} = (2.00 \pm 0.17) \times 10^8\ h\ L_{solar}\ Mpc^{-3}$

Conclusions – Part II

???

Future plans

- Improve construction of component BBDs.
- Is the distinction between 'real' and 'pseudo' bulges real/meaningful?
- Detailed comparison with GOODS and theory.
- Investigate the effects of dust (with Tuffs & Popescu).
- Obtain HI masses (with Zwaan) to investigate gas mass to light ratio across the BBD.
- Go deeper to push back selection limits in BBD and to survey those galaxies that dominate the local population (by number).
- Go to higher resolution to improve bulge/disk decomposition.

⇒ MGCII = deeper and higher resolution imaging (VST?)
+ deeper spectroscopy (AAΩ?).

- Go to longer wavelength (near-IR, VISTA?) to trace stellar mass and minimise dust effects.