The Millennium Galaxy Catalogue: Redshift zero revisited

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3rd June 2004, AAS Denver

Redshift Zero: Why ?

- Vital for the correct interpretation of Hubble Deep Fields
- Prelude to JWST (IDS Team Windhorst)
- Problems at home:
  - The local luminosity function
    - x2 Uncertainty at L* (conflict between 2dFGRS, SDSS1 & SDSS2)
    - The elusive faint-end and the space density of dwarf systems
  - Missing galaxies ?
    - Malin 1's, Crouching Giants, LSBGs etc
    - cEs, UCDs, CNELGs etc.
  - The Surface brightness distribution
    - Freeman's Law v Disney Conjecture
  - Quantitative galaxy morphology/classification

- The Millennium Galaxy Catalogue
- Managing selection bias
- The luminosity surface brightness plane (or luminosity-size plane)

Illustration: Selection Effects in the HDF

- Redshift = 0.3 --- 0.5
- Selection limits
  - m > 19 mag
  - m < 27 mag
  - r > 0.1"
  - r < 5"
  - μ < 27 mag/sq arcsec

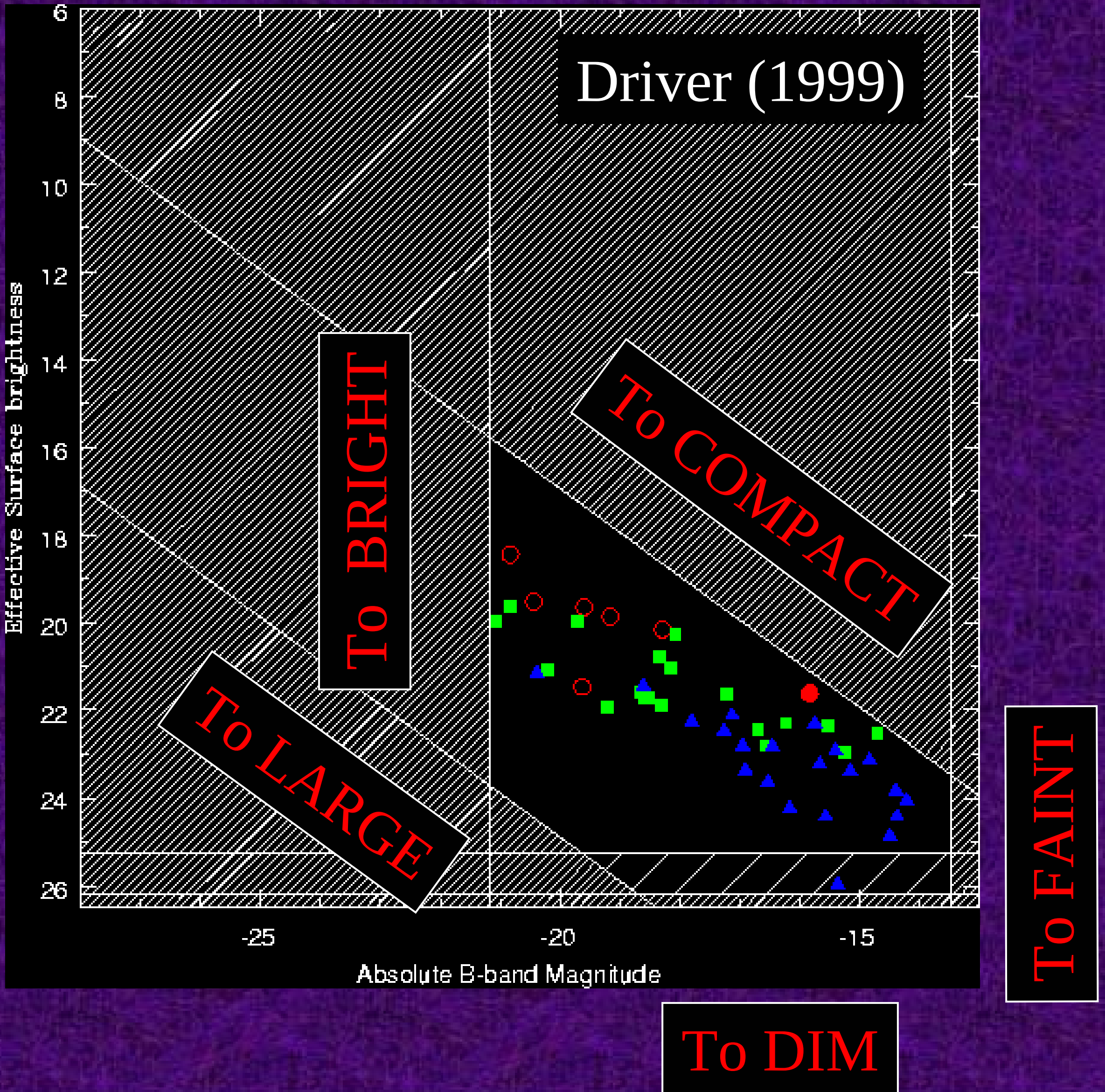


Illustration: Selection Effects in the HDF

- Redshift = 0.9 --- 1.1
- Selection limits
  - m > 19 mag
  - m < 27 mag
  - r > 0.1"
  - r < 5"
  - μ < 27 mag/sq arcsec

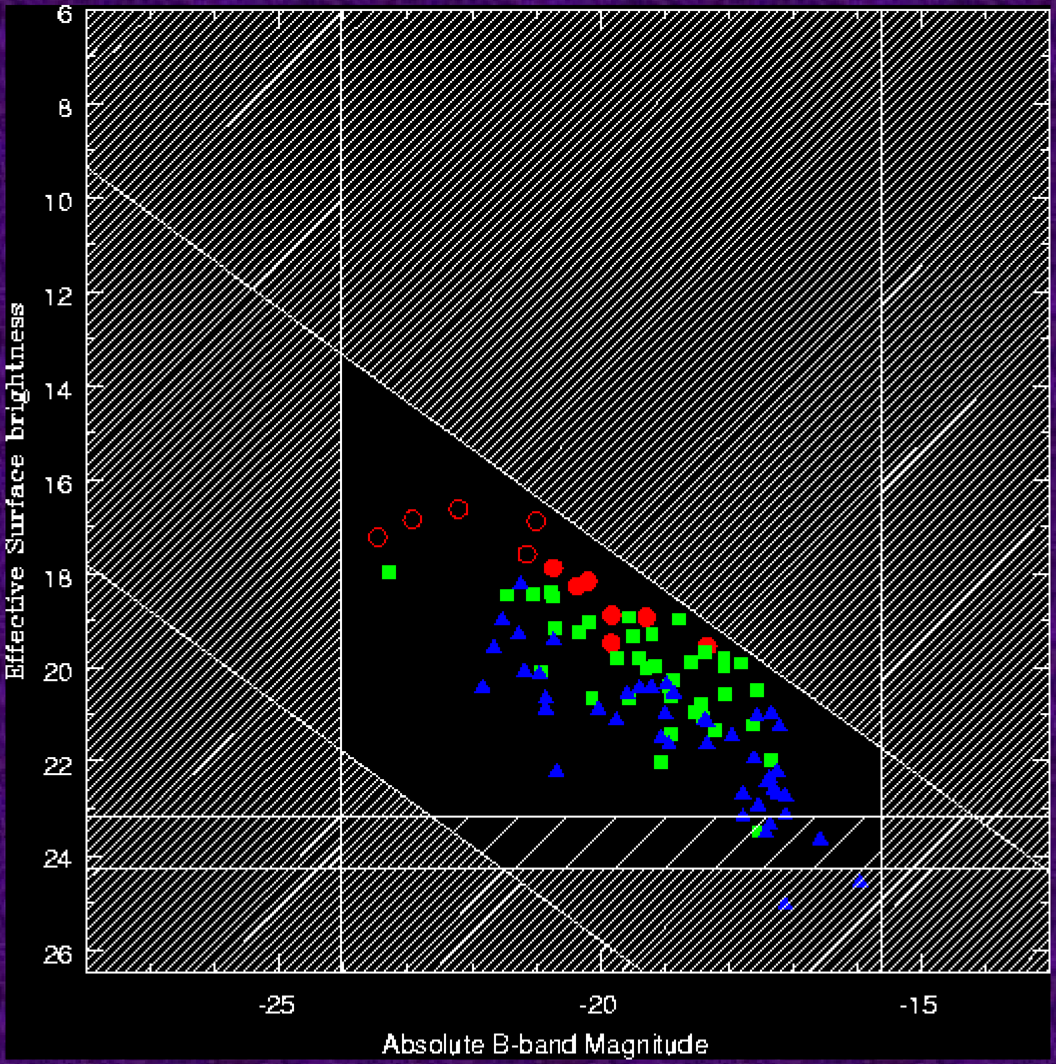
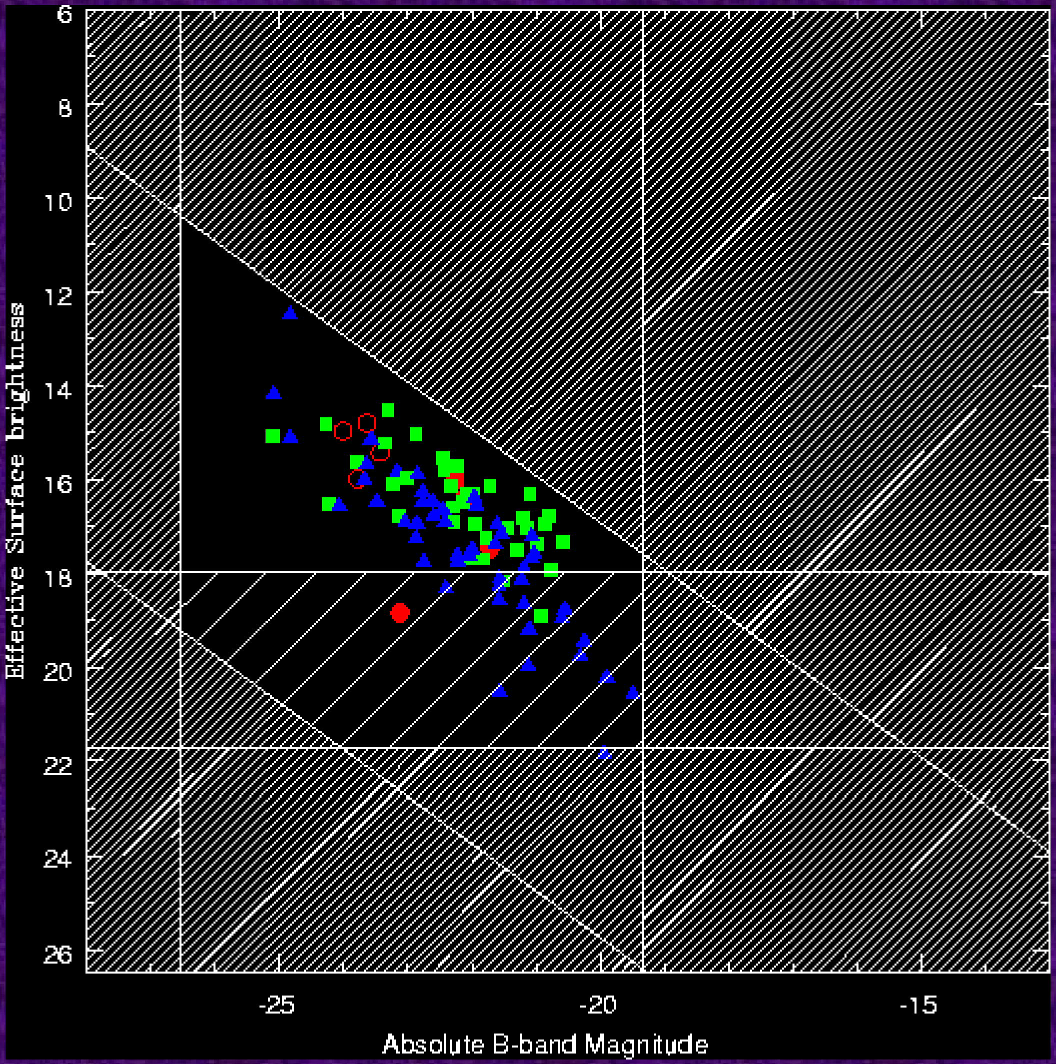


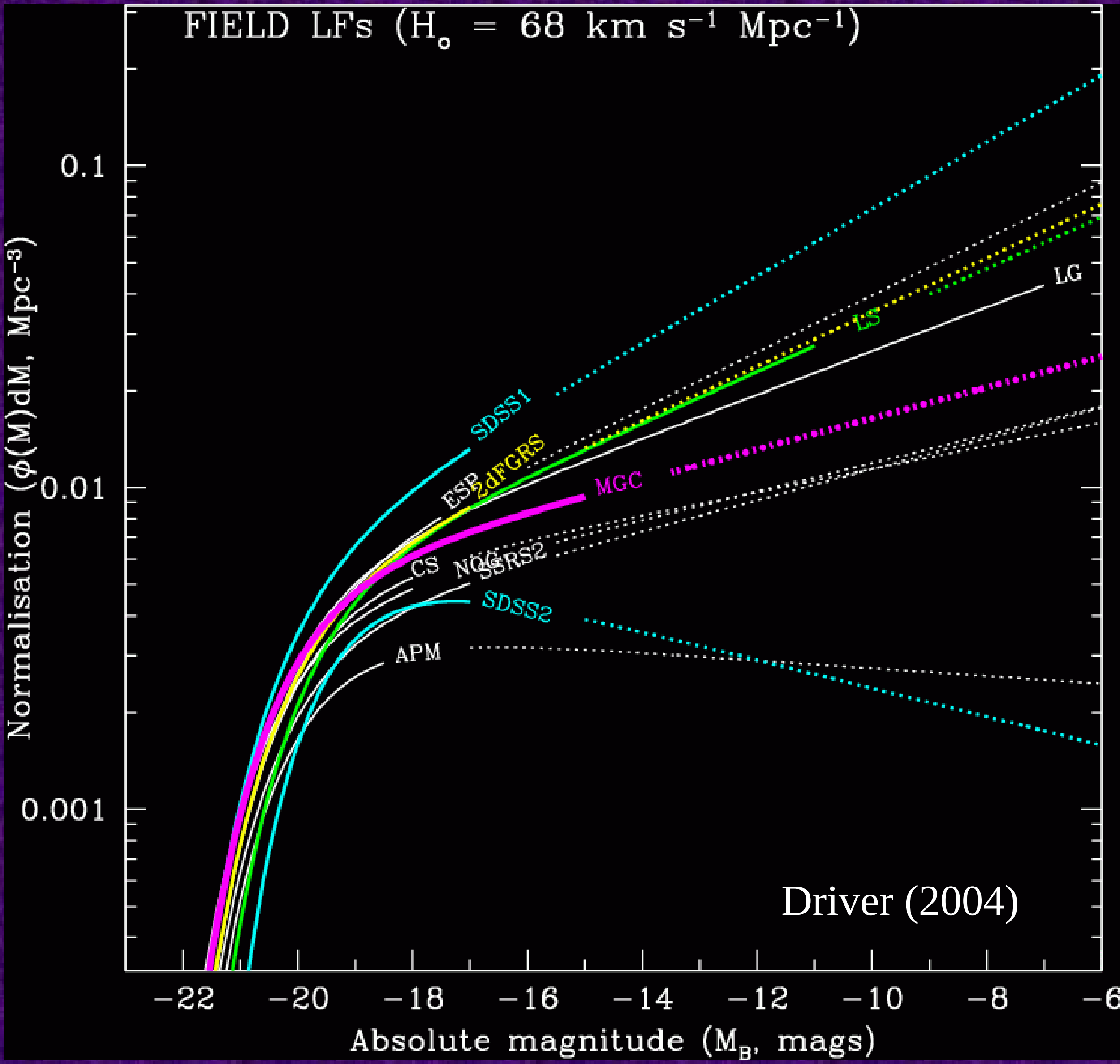
Illustration: Selection Effects in the HDF

- Redshift = 2.0 --- 3.25
- Selection limits
  - m > 19 mag
  - m < 27 mag
  - r > 0.1"
  - r < 5"
  - μ < 27 mag/sq arcsec

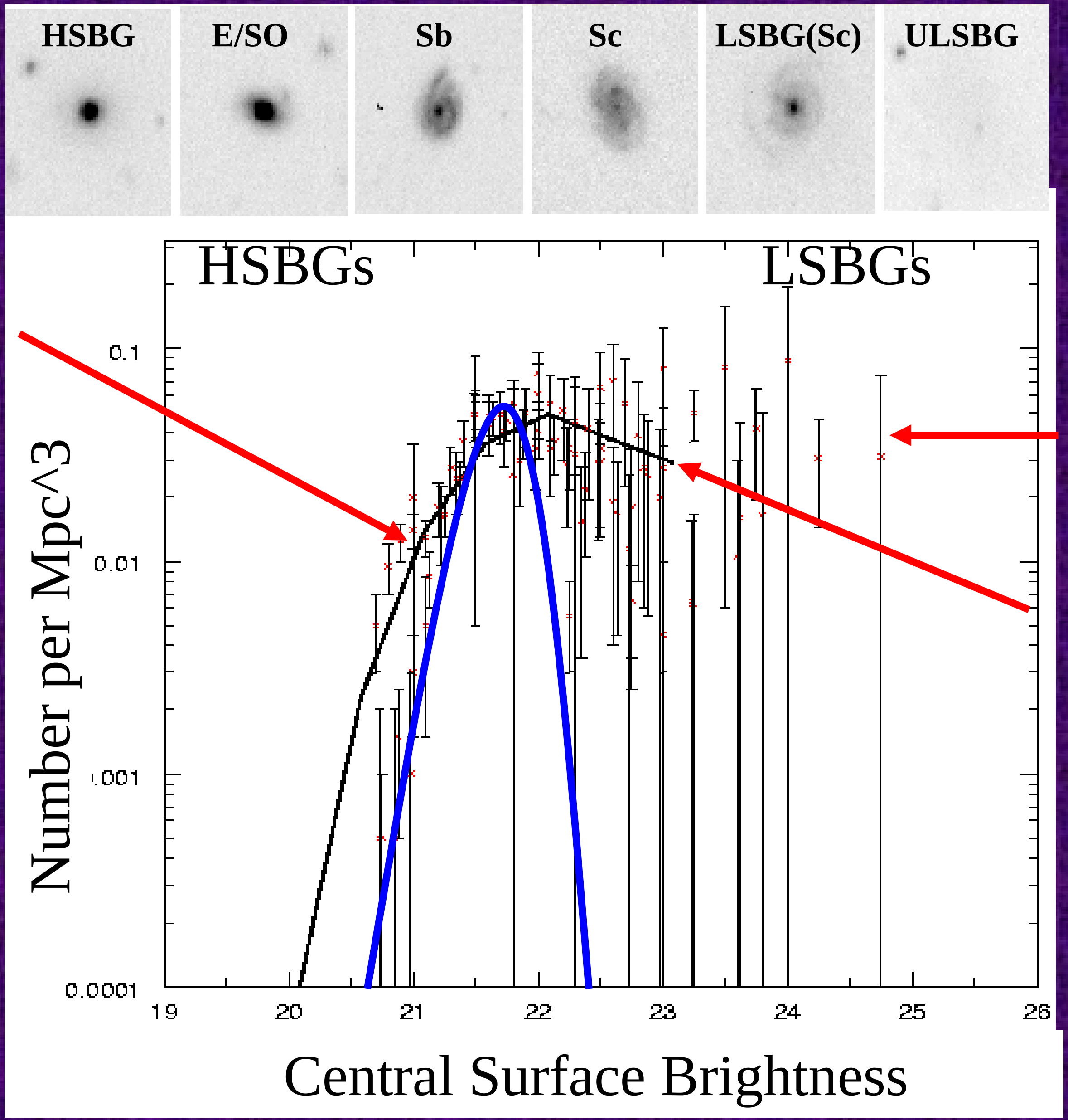


The Galaxy Luminosity Function

- No consensus
  - x2 uncertainty at M*
  - M > -16 unknown
- SDSS & 2dFGRS:
  - SDSS1 resolved
  - SDSS2 puzzling
- ESP & 2dFGRS OK
- LG best insight ? (~50 galaxies)
- MGC (see later)



The Galaxy Surface Brightness (Size) Distribution



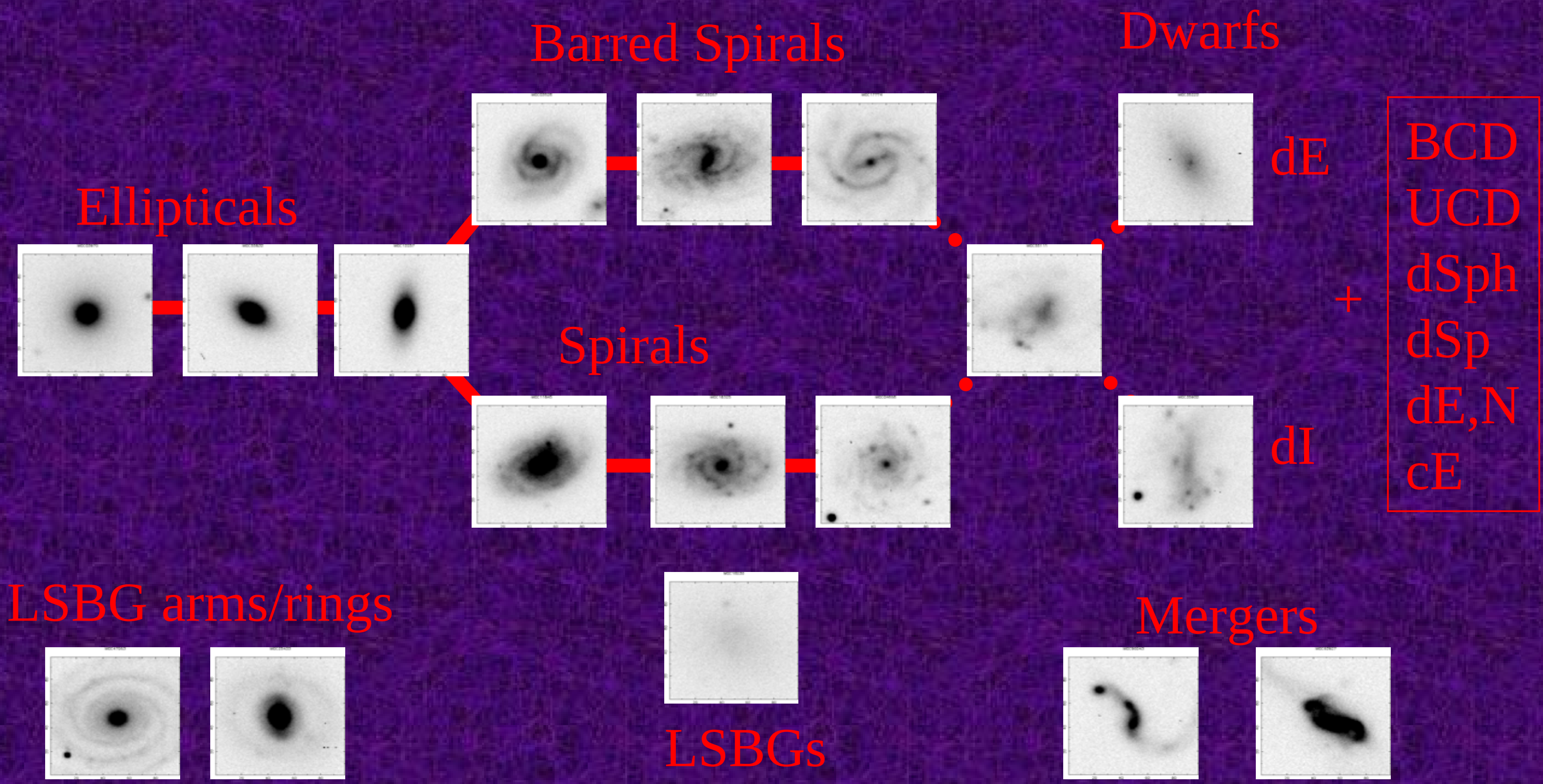
Freeman's Law 1970

Other (no z's)

2dFGRS (Cross et al 2001)

Galaxy Classification: The Hubble Tuning Fork

- The Hubble Tuning Fork is no-longer viable, with many types defying classification:



- Diversity implies multiple evolutionary paths (epochs)
- But how to incorporate this diversity into the modeling

Beyond The Galaxy Luminosity Function ?

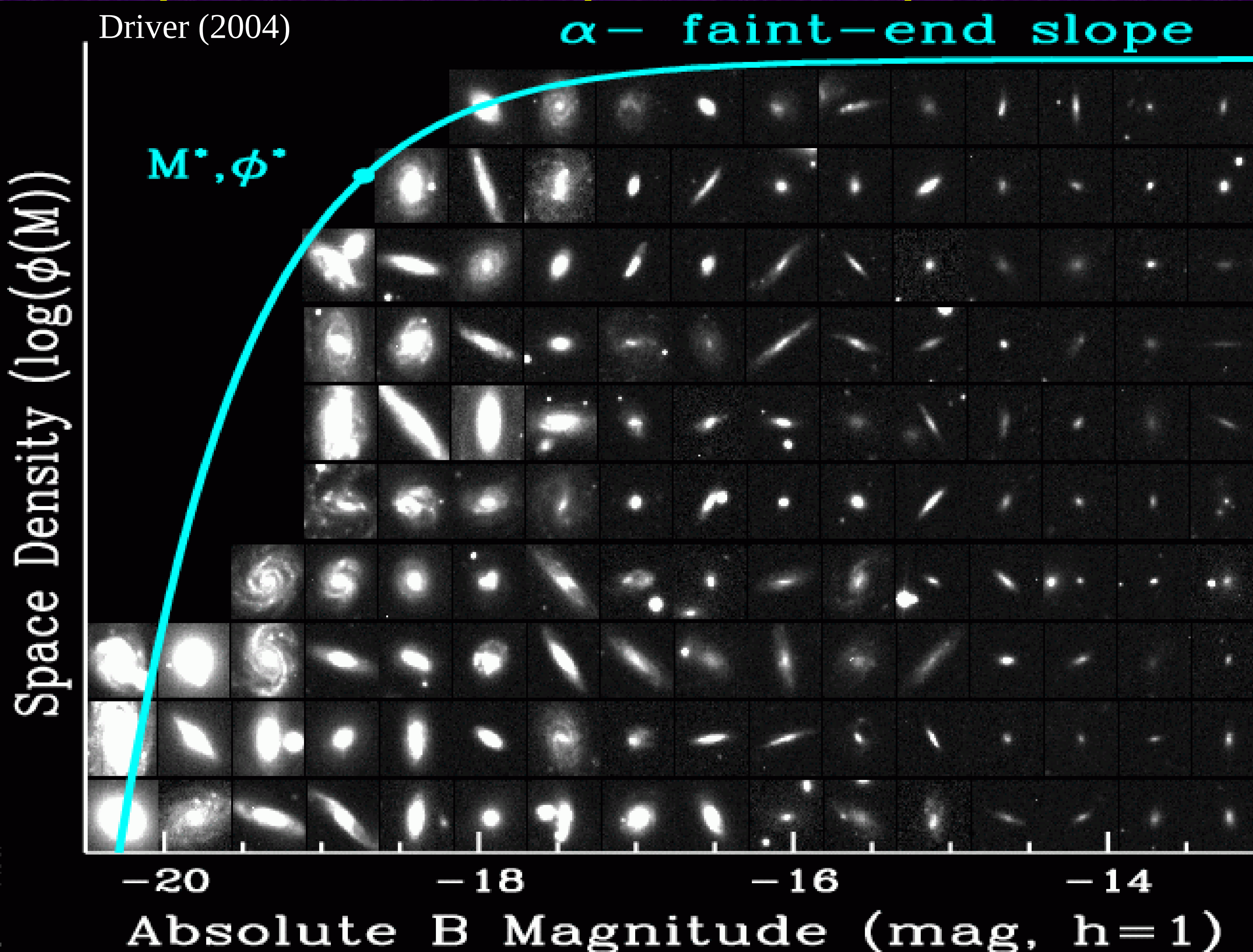
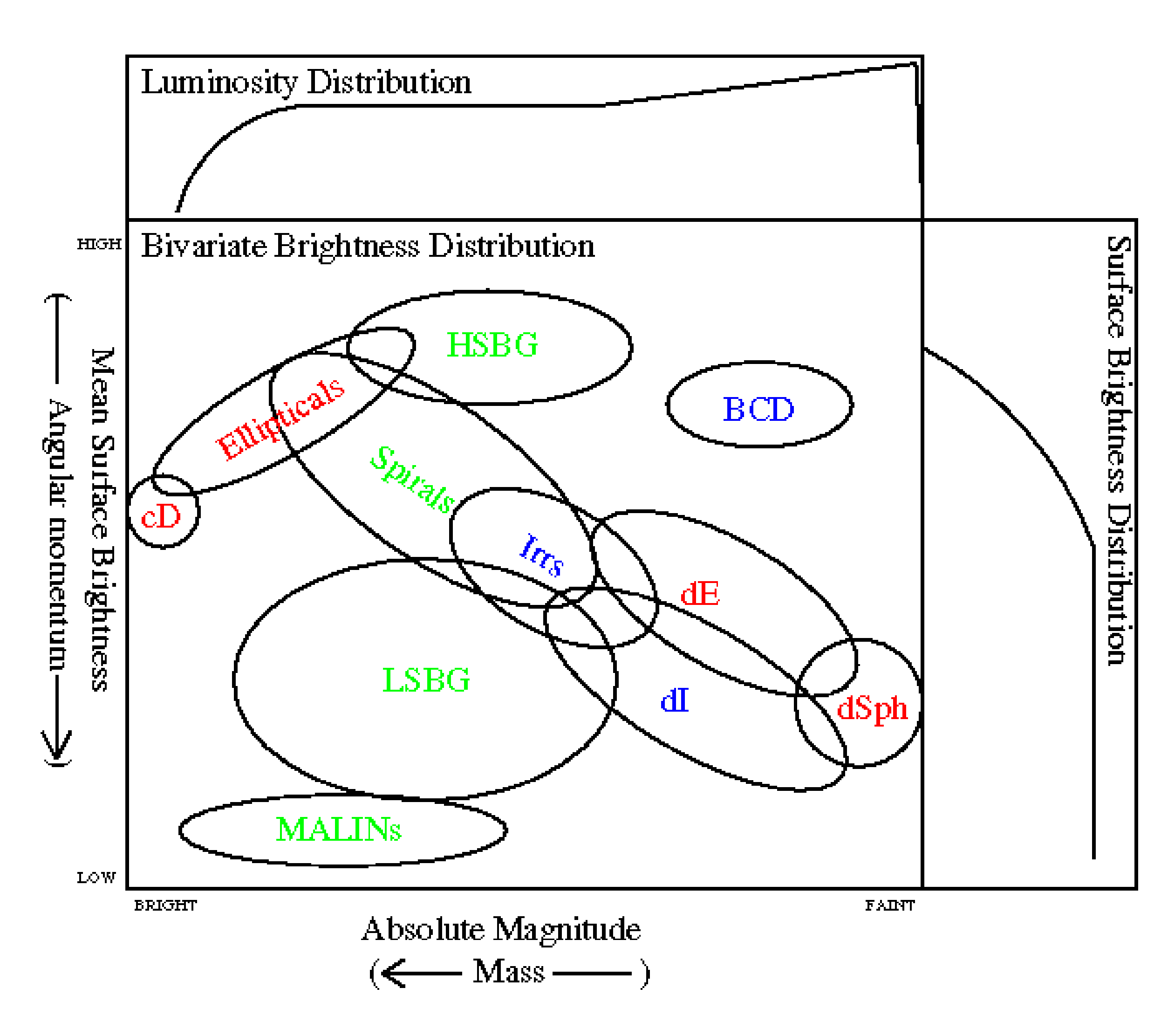


Figure 9. PLATE1: The Global Galaxy Luminosity Function (red line) condenses the available information of galaxies (images) into three crucial numbers: the characteristic luminosity (M^*); the absolute normalisation (ϕ^*); and the faint-end slope (α). Although the schechter parameterisation is more often that not a remarkably good fit, one cannot help but feel that too much important information may have been lost, for instance the sizes and bulge-to-total parameters.

The Luminosity-Surface Brightness Plane

- Combines all 3 representations
- Quantitative
  - Reproducible
  - Universal
- Theoretical basis
  - μ —–> λ (Spin)
  - L —–> M (Mass)



The Millennium Galaxy Catalogue

Driver(PI), Allen, (RSAA)
Liske (ESO), Cross (JHU), Phillipps (Bristol)

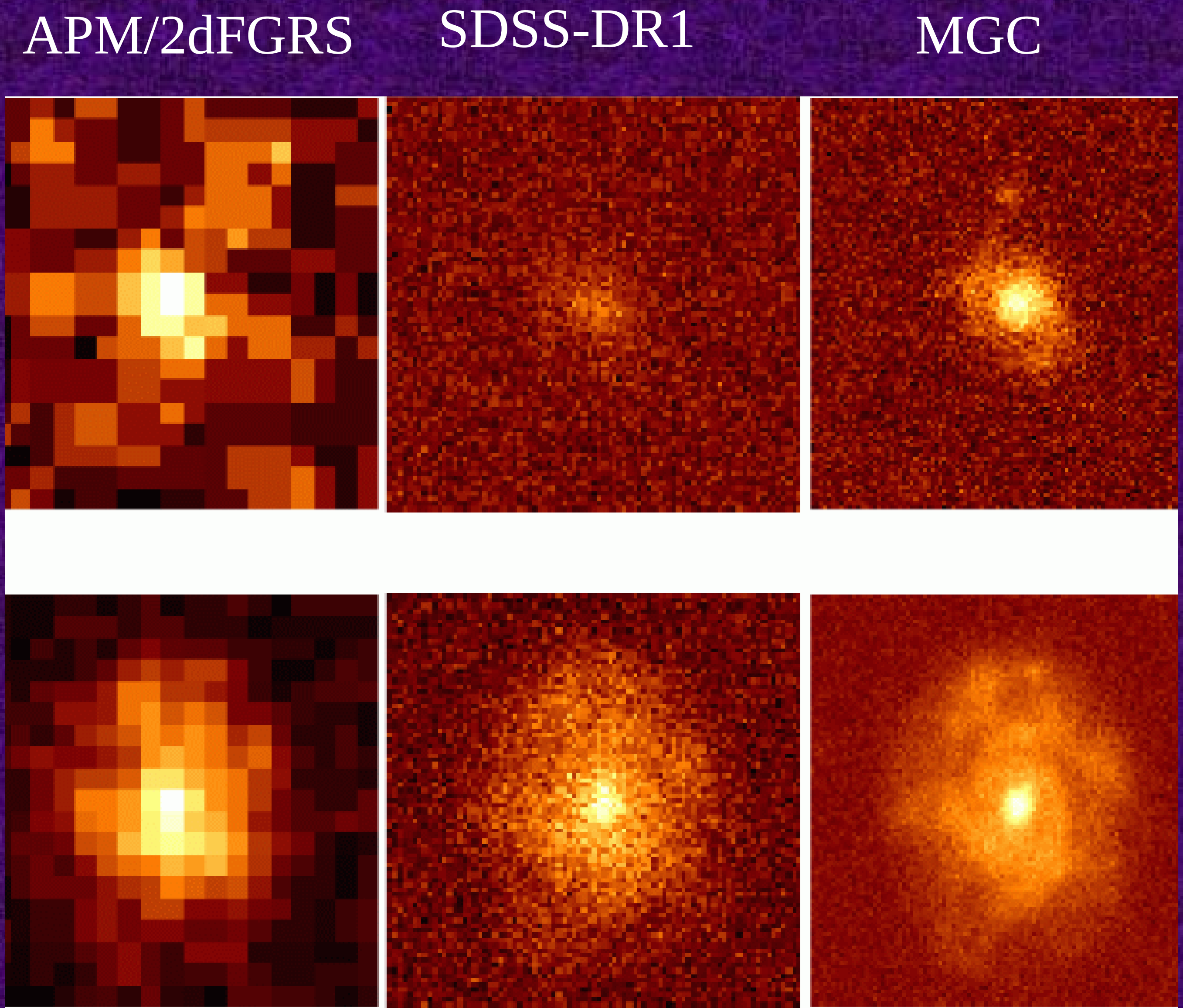
Aims:

- To revise local calibration data (in advance of ACS/GOODs and JWST)
- To manage selection effects throughout (observation, detection and analysis phases)
- To identify new meaningful ways to represent galaxies: The LSP and CD

Details:

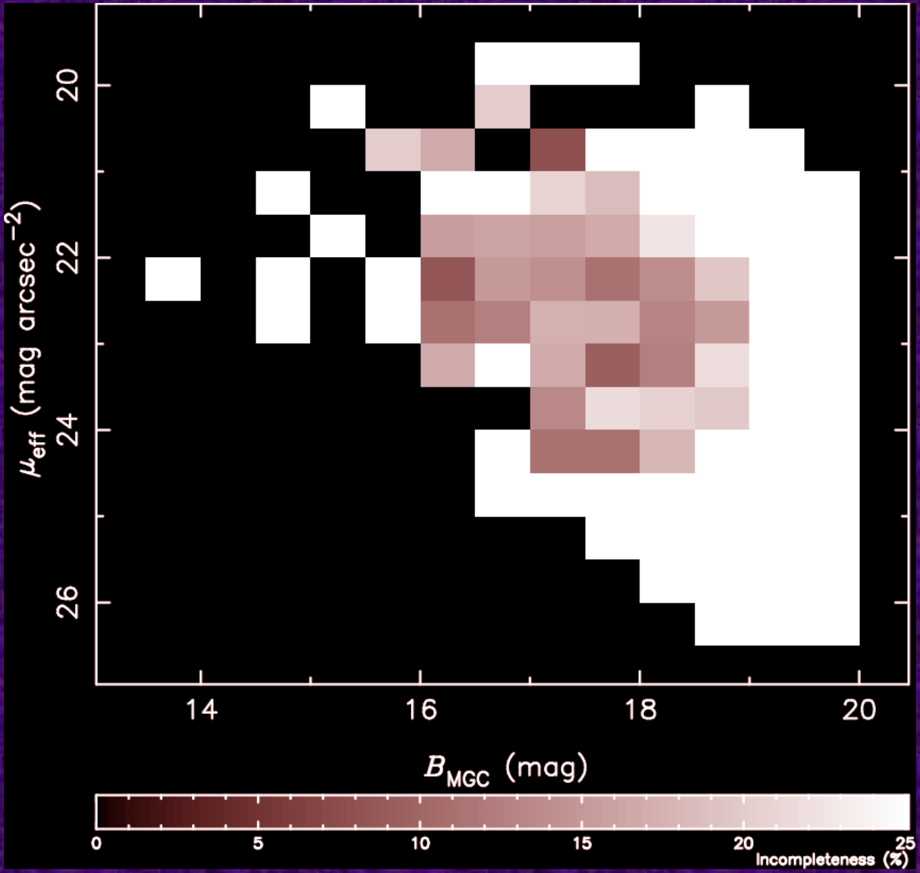
- Imaging INT/WFC + SDSS-DR1: *uBgriz*
  - 37 sq degrees along equatorial strip (0.5 x 75 deg)
  - Detection Limit μ(B limit) = 26 mags/sq arcsec
  - 10,065 resolved galaxies to B=20
  - All objects verified by eye
- Spectroscopy: 2dFGRS+SDSS-DR1+AAT/2dF, RSAA/2.3m, NTT, TNG, Gemini
  - Over 95% complete and aiming for 100%

MGC data quality v APM & SDSS



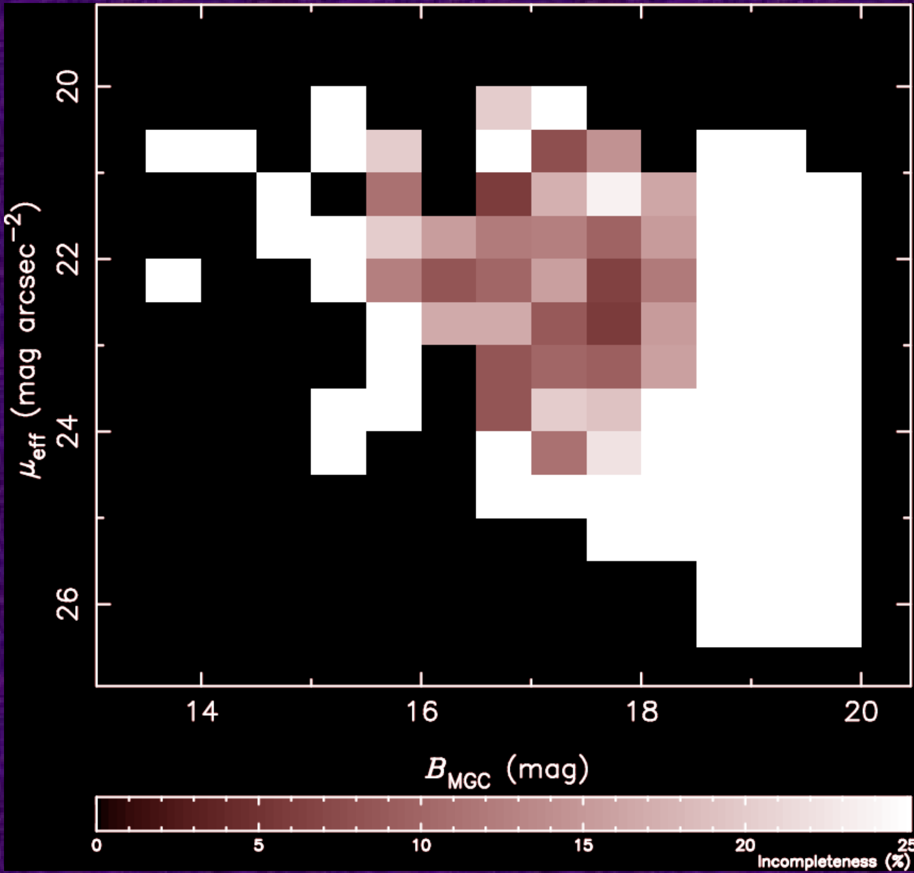
Spectroscopic Incompleteness

2dFGRS



Incompleteness (%)

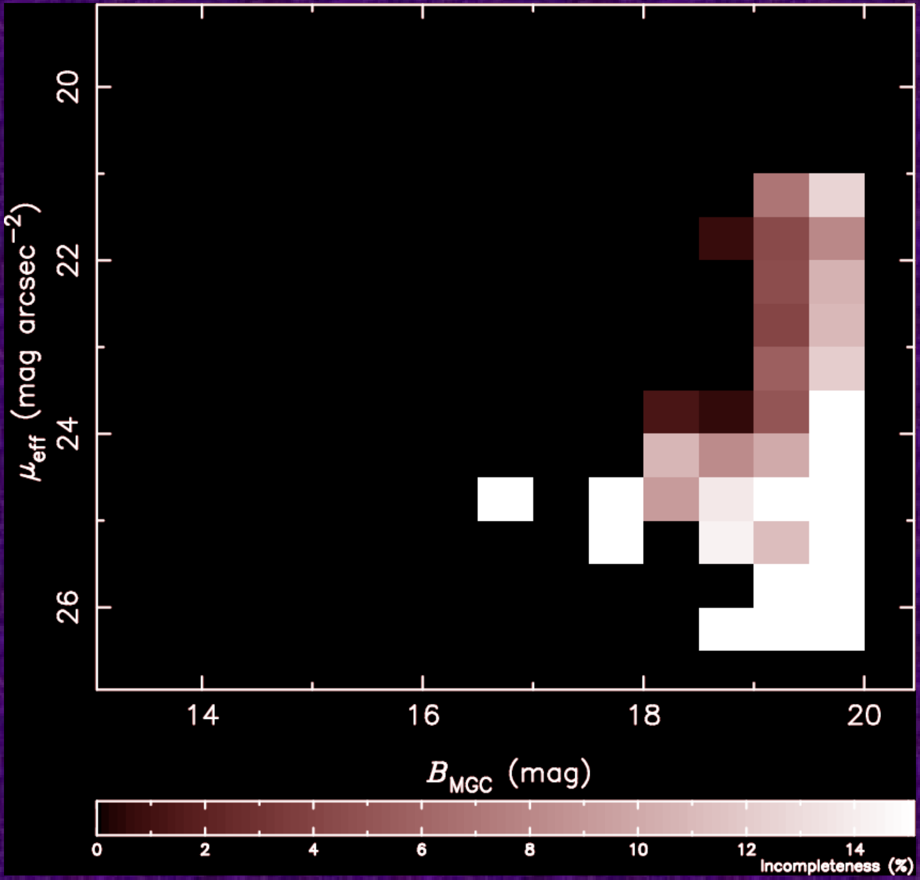
SDSS



Incompleteness (%)

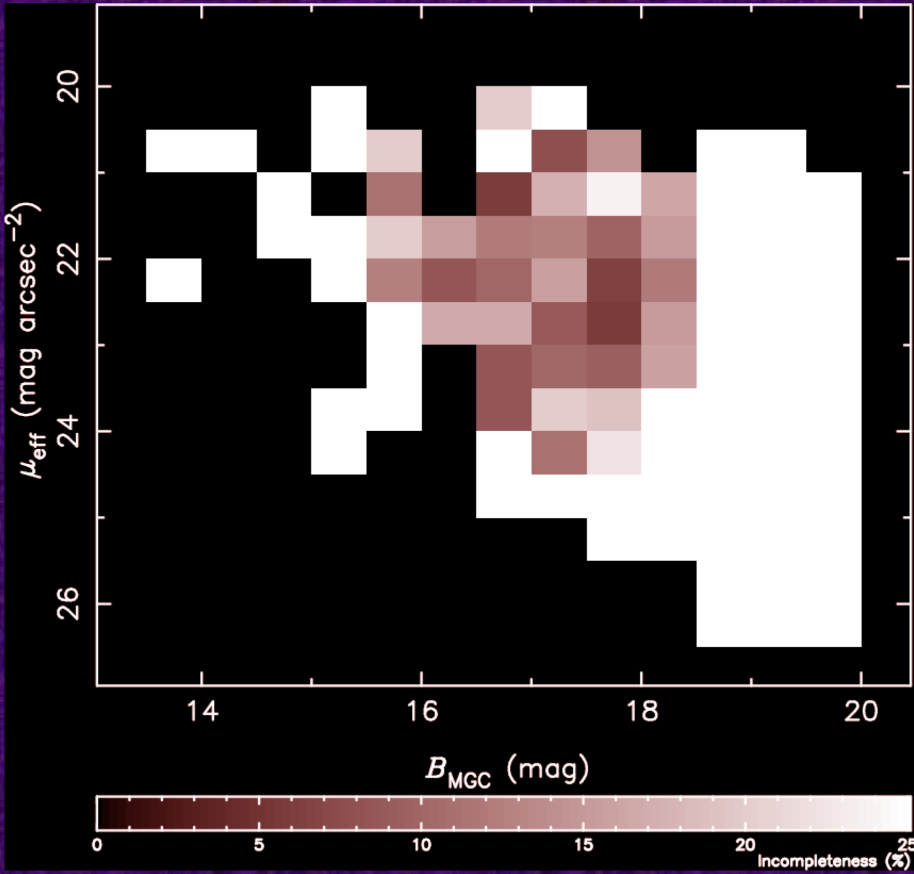
Spectroscopic Incompleteness

MGC

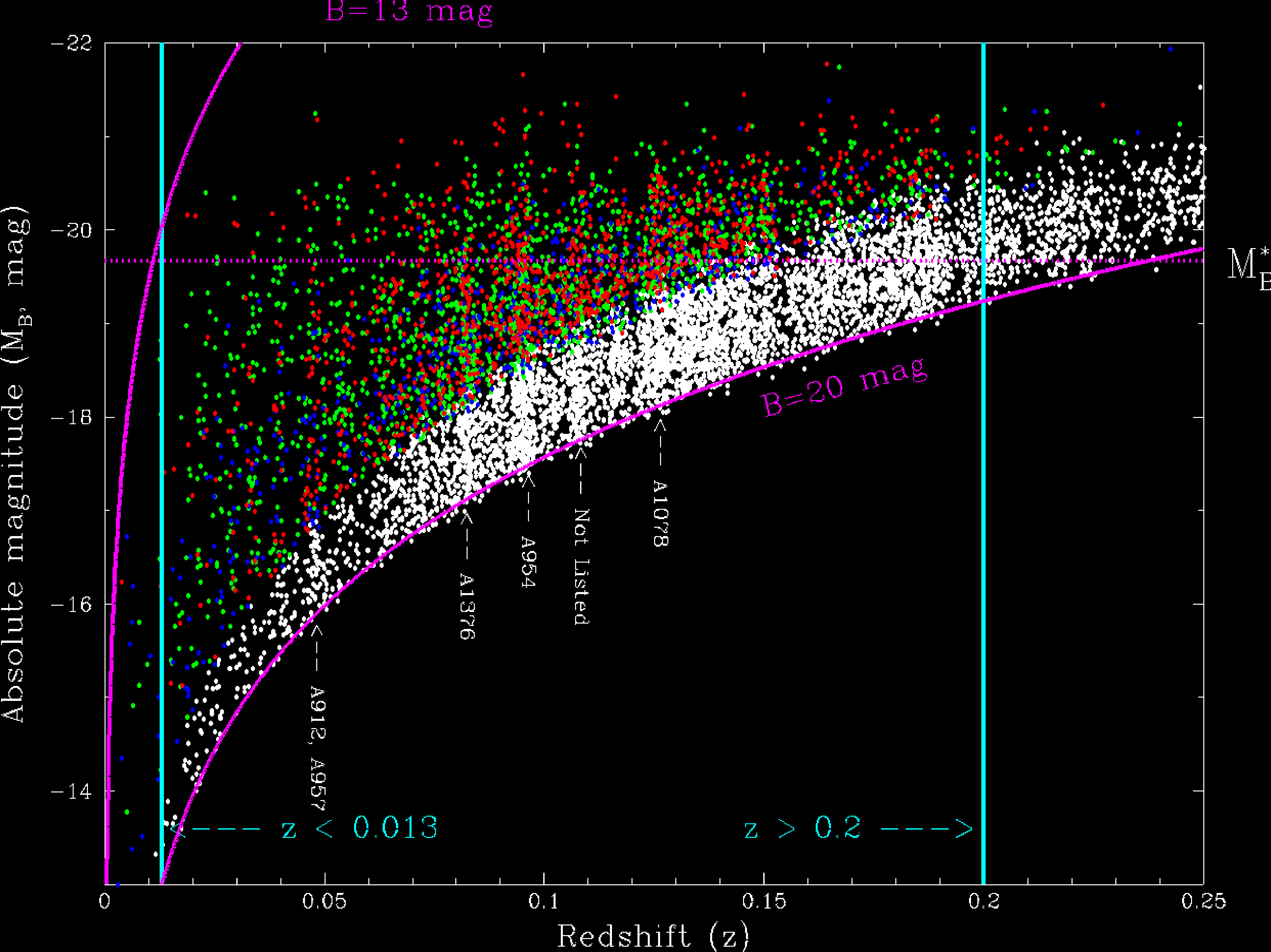


Incompleteness (%)

SDSS



Incompleteness (%)

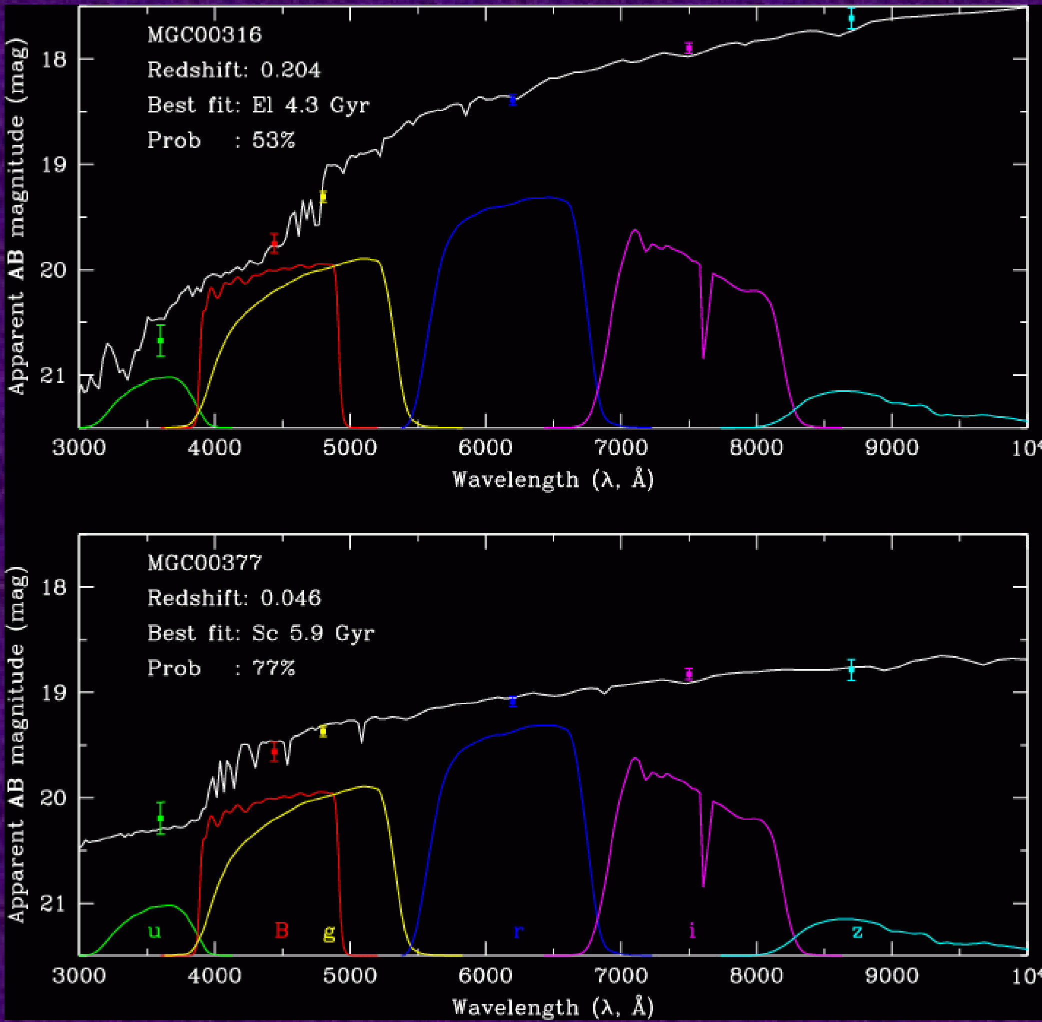


B=13 mag
B=20 mag
Absolute magnitude (M_B, mag)
Redshift (z)
M*_B
-22
-20
-18
-16
-14
0
0.05
0.1
0.15
0.2
0.25
<--- A912, A957
<--- A1376
<--- A954
<--- Not Listed
<--- A1078
<---- z < 0.013
z > 0.2 --->

Constructing the volume corrected LSP

- Ω=0.3,Λ=0.7,Ho=75 km/s/Mpc
- Kron magnitudes (uncorrected !)
- No inclination/dust correction
- Individual K(z)
  - k(z) derived for each galaxy from 27 synthetic templates (Poggianti 1998)
- E(z) currently fixed: $L \propto L_o(1+z)^{0.75}$
- z limits
  - z > 0.013 (local velocity field)
  - z < 0.2 (QSO contamination)
- Half-light radius measured directly
- Half-light radius seeing corrected (empirically via simulations)

$$r_{hlr^o} = \sqrt{r_{hlr}^2 - 0.33\Gamma^2}$$



- Effective surface brightness derived

$$\mu_{eff,i} = m_i + 2.5\log(2\pi r_{hlr^o,i}^2) - 10\log(1+z) - K_i(z) - E(z)$$

- Star-galaxy separation modelled

MGCz: 2D Step-Wise Maximum Likelihood

- SWML developed by Efstathiou, Ellis & Peterson (1988)
  - Robust to galaxy clustering
- 2D variant proposed by Sodré & Lahav (1993)
- 2D variant inclusive of selection effects Driver et al (2004)
  - Iteratively evaluate the solution of the Likelihood function:

$$\phi_{jk} = \frac{\sum_{i=1}^{N} W_{ijk}}{\sum_{i=1}^{N} [H_{ijk} / \sum_{i=1}^{J} \sum_{k=1}^{K} \phi_{jk}^{-} H_{ijk}]}$$

  - Wijk = weighting matrix to accommodate for redshift incompleteness (by L & Σ)
  - Hijk = 2D selection matrix incorporating the 5 selection limits
  - I=1,N objects (6324 galaxies)
  - J=1,J absolute magnitude bins (-23 to -11 mag)
  - K=1,K effective surface brightness bins (16 to 28 mag/sq arcsec)
  - ϕ^{-} = old space density values

Managing Selection Bias

- 5 key selection boundaries:
  - Maximum detectable luminosity (due to choice of pointing, B=13.0 mags)

$$M_{\text{bright}} = m_{\text{bright}} - 5\log d(z) - 25 - k(z) - E(z)$$

  - Minimum detectable luminosity (due to faint magnitude cut-off, B=20.0 mags)

$$M_{\text{faint}} = m_{\text{faint}} - 5\log d(z) - 25 - k(z) - E(z)$$

  - Maximum detectable surface brightness (due to background smoothing, r(max) = 15'')

$$\mu_{\text{high}} = M + 5\log d(z) + 25 + 2.5\log(2\pi r_{\min}^{2}) - 10\log(1+z)$$

  - Minimum detectable surface brightness (due to resolution, r(min) = 0.63 FWHM)

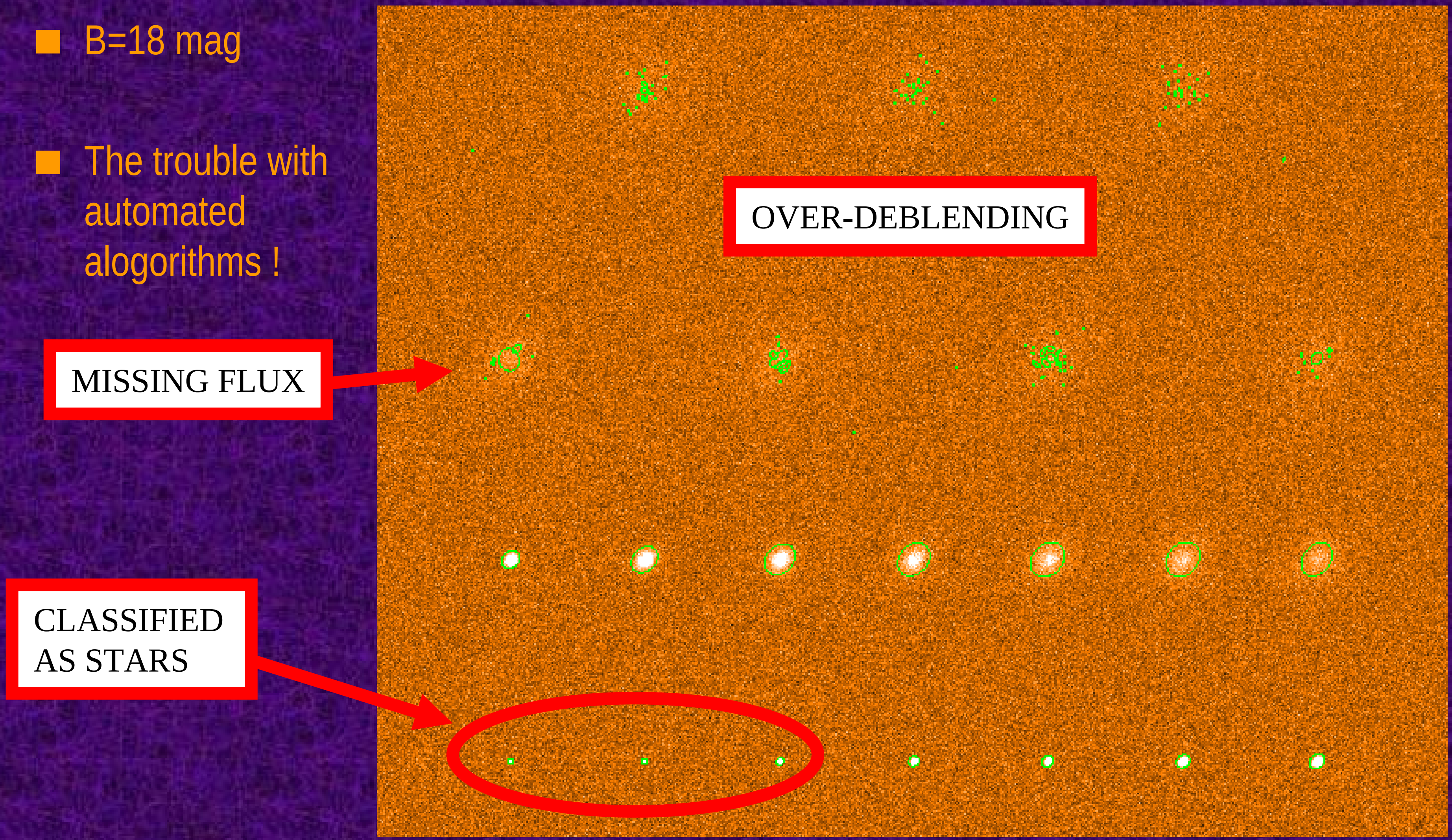
$$\mu_{\text{low}} = M + 5\log d(z) + 25 + 2.5\log(2\pi r_{\max}^{2}) - 10\log(1+z)$$

  - Minimum detectable surface brightness (due to detection isophote, μ = 26.0 mag sq arcsec)

$$\mu_{\text{low}} = \mu_{\text{lim}} - 10\log(1+z) - K(z) - E(z)$$

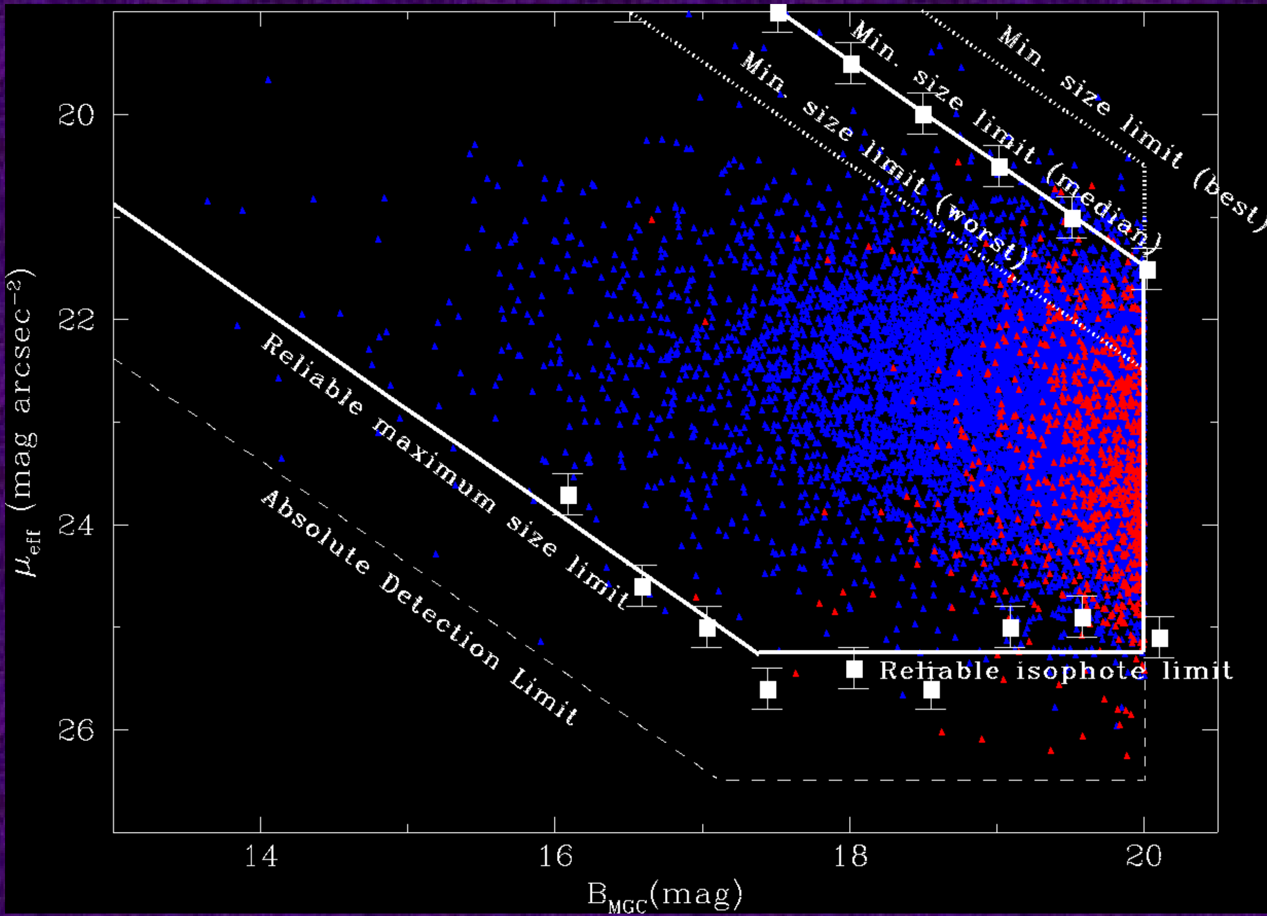
MGCz: Deriving the MGC Selection Limits

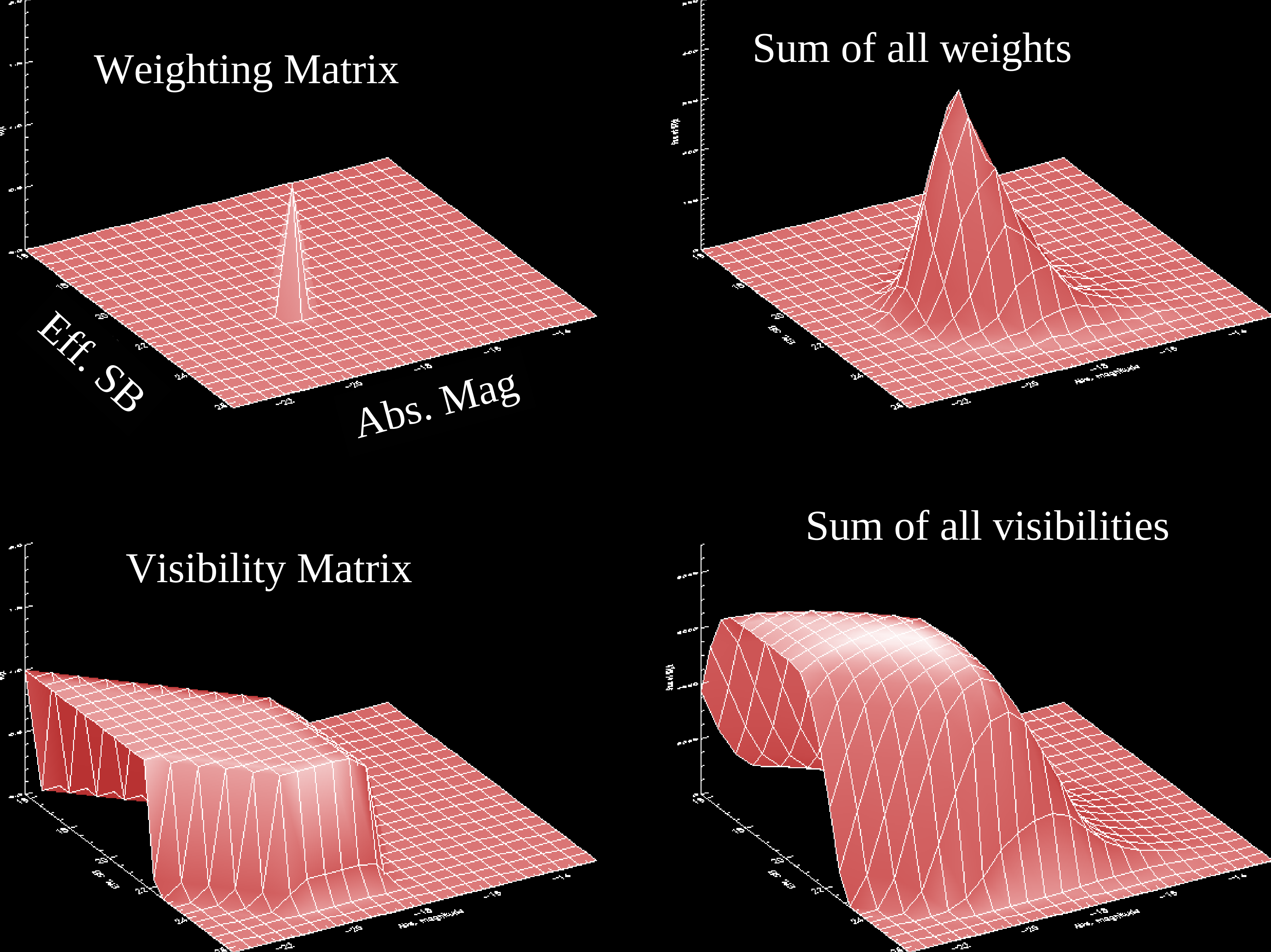
- B=18 mag
- The trouble with automated alogorithms !



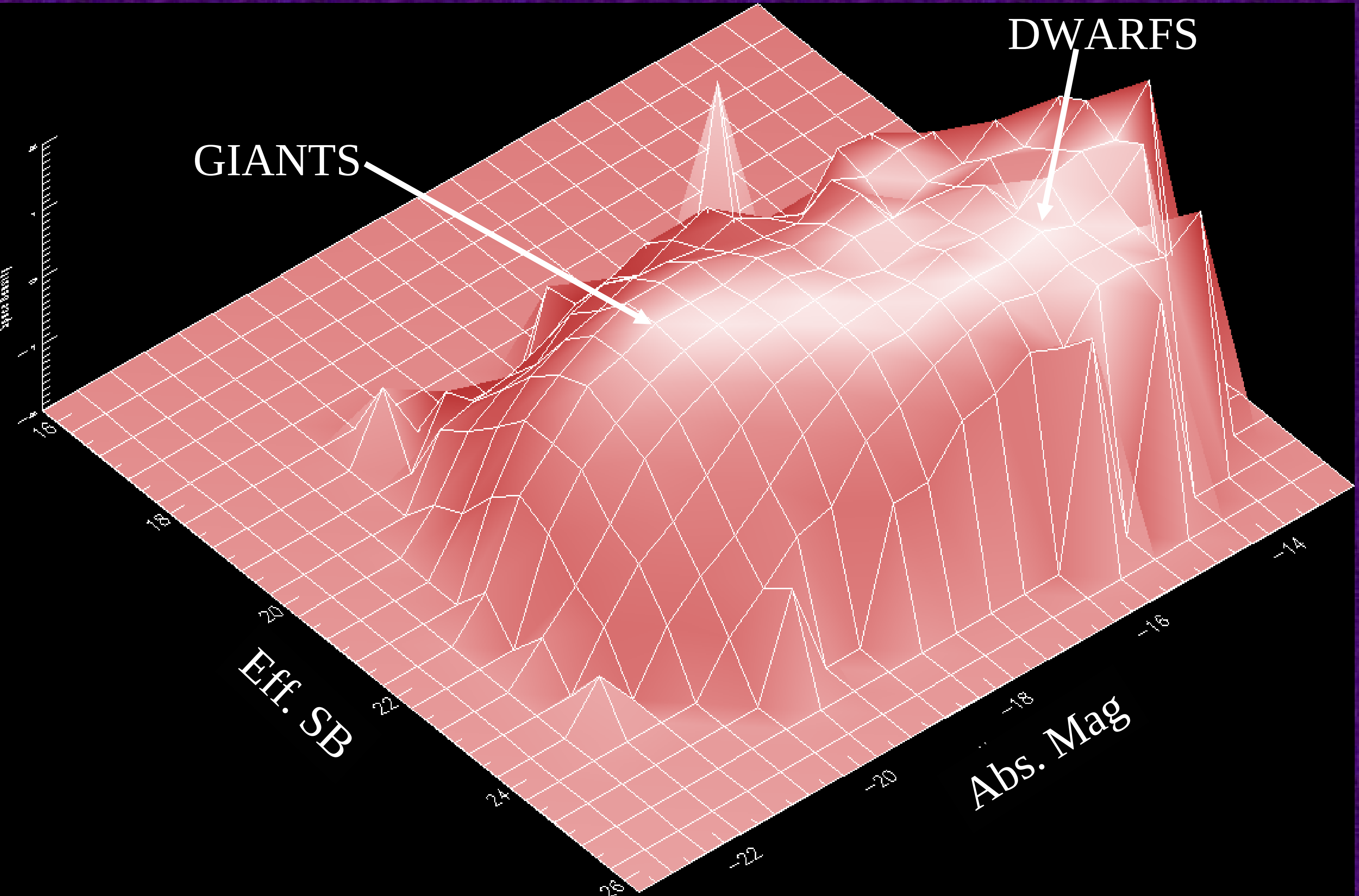
MGCz: Deriving the MGC Selection Limits

- Selection Limits derived from simulations.
- Detection Limits:
  - m=20.0 mag
  - μ=26.00 mag/sq arcsec
  - r(max) = 15''
  - r(min) = 0.63 FWHM
- Reliability Limits:
  - m=20 mag
  - μ = 25.25 mag/sq arcsec
  - r(max) = 25''
  - r(min)=0.63 FWHM

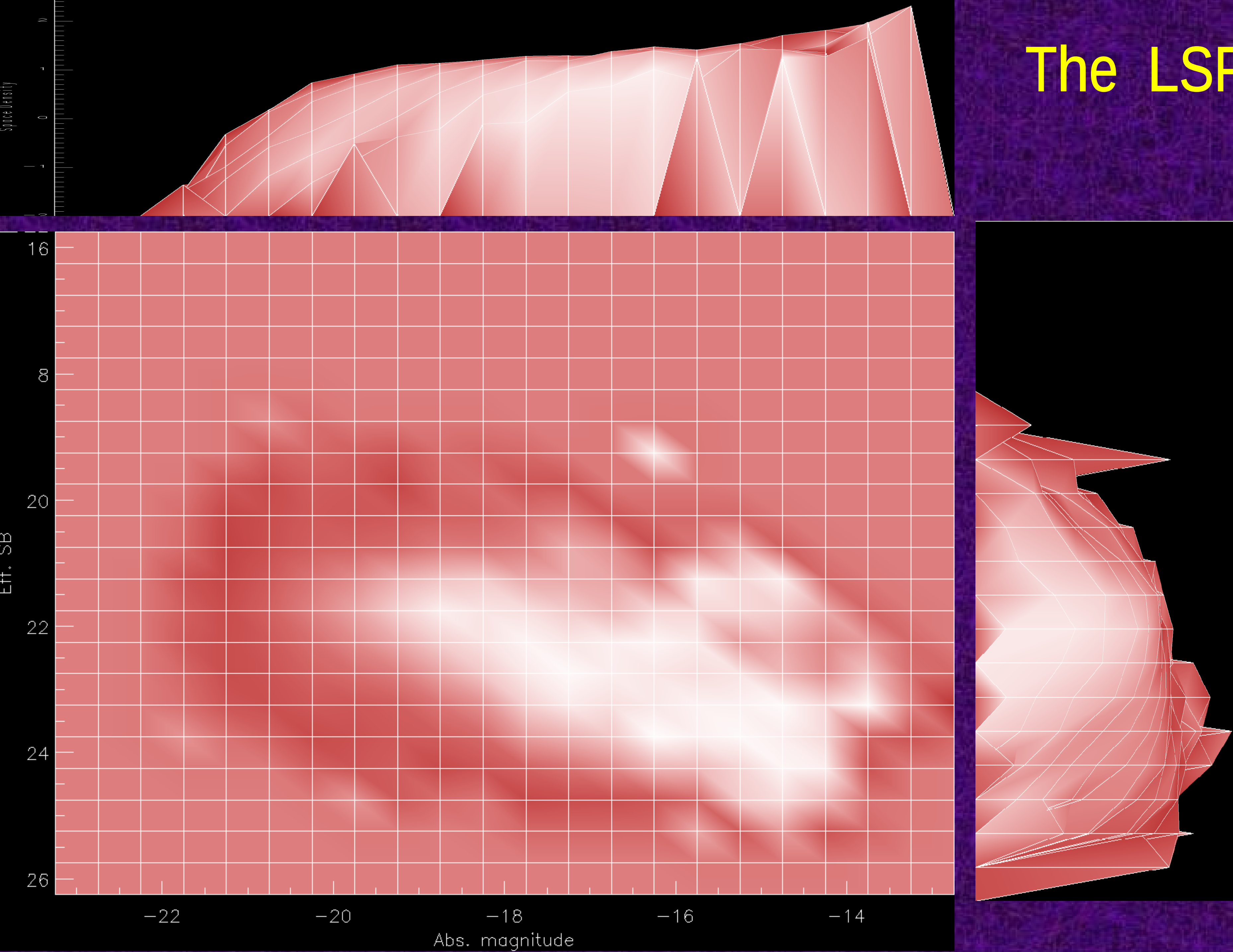



Weighting Matrix
Sum of all weights
Eff. SB
Abs. Mag
Visibility Matrix
Sum of all visibilities

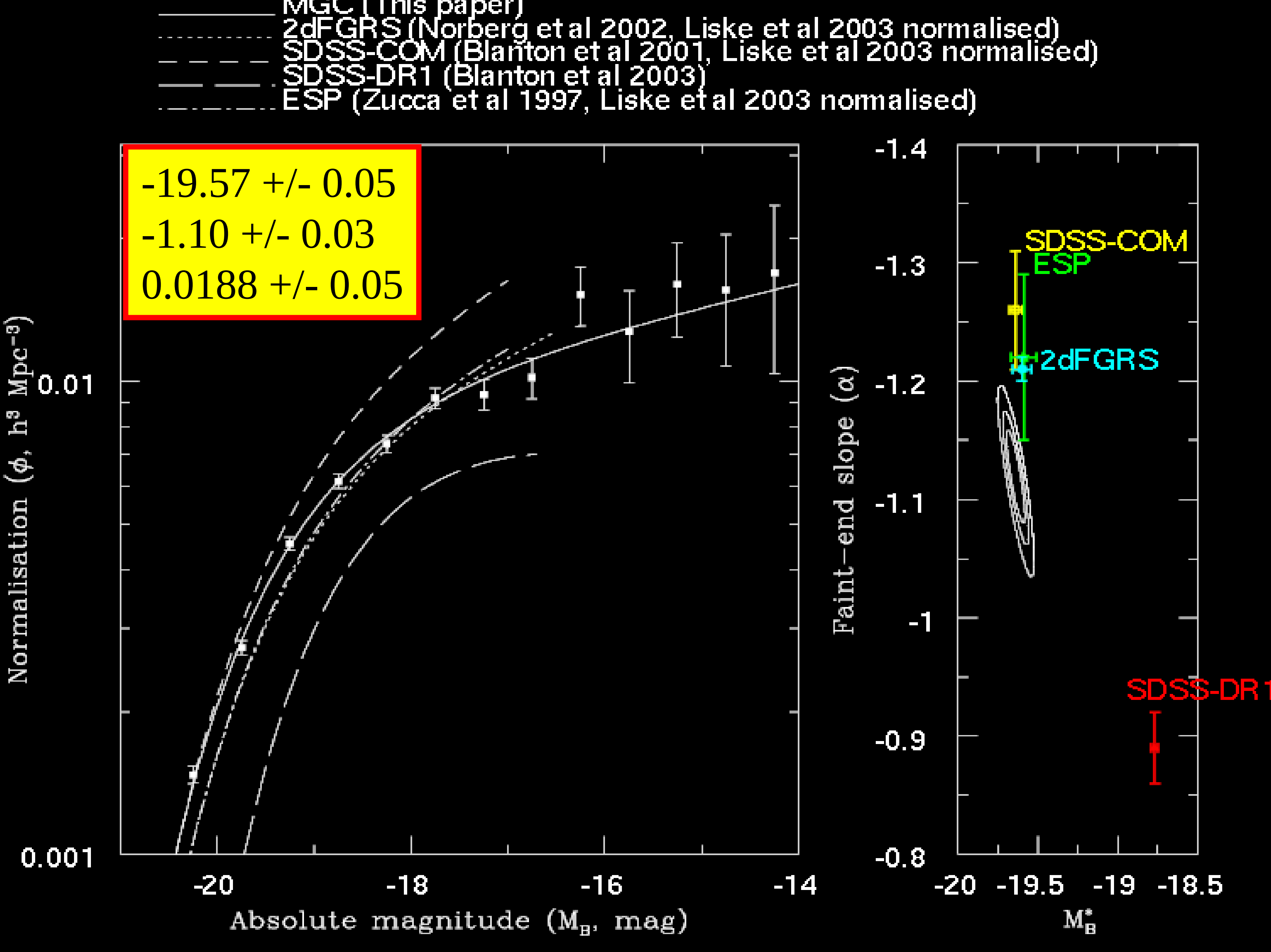
Joint Luminosity Surface Brightness Distr'n



The LSP



Space Density
Eff. SB
16
8
20
22
24
26
−22
−20
−18
−16
−14
Abs. magnitude



MGC (This paper)
2dFGRS (Norberg et al 2002, Liske et al 2003 normalised)
SDSS-COM (Blanton et al 2001, Liske et al 2003 normalised)
SDSS-DR1 (Blanton et al 2003)
ESP (Zucca et al 1997, Liske et al 2003 normalised)
-19.57 +/- 0.05
-1.10 +/- 0.03
0.0188 +/- 0.05
Normalisation (ϕ, h³ Mpc⁻³)
0.01
0.001
-20
-18
-16
-14
Absolute magnitude (M_B, mag)
Faint-end slope (α)
-1.4
-1.3
-1.2
-1.1
-1
-0.9
-0.8
SDSS-COM
ESP
2dFGRS
SDSS-DR1
-20
-19.5
-19
-18.5
M*_B

Schechter versus Cholienewski function

- Schechter (1976) proposed the now standard functional fit to the galaxy luminsity dist'n:

$$\phi(M) = 0.4\ln(10)\phi^{*}10^{0.4(M^{*}-M)(\alpha+1)}e^{-10^{0.4(M^{*}-M)}}$$

  - α = faint-end power-law
  - ϕ^* = normalisation point
  - M* = Characteristic turnover luminosity

- Cholienewski (1983) proposed a bivariate functional formal, essentially the Schechter function multiplied by a Gaussian in surface brightness:

$$\phi(M,\mu) = \frac{0.4\ln(10)}{\sqrt{2\pi}\sigma_{\mu_{eff}}}\phi^{*}10^{0.4(M^{*}-M)(\alpha+1)}e^{-10^{0.4(M^{*}-M)}}\exp[-\frac{1}{2}(\frac{\mu_e-\mu_e^{*}-\beta(M-M^{*})_e}{\sigma_{\mu_e}})^2]$$

  - α = faint-end power-law
  - ϕ^* = normalisation point
  - M* = Characteristic turnover luminosity

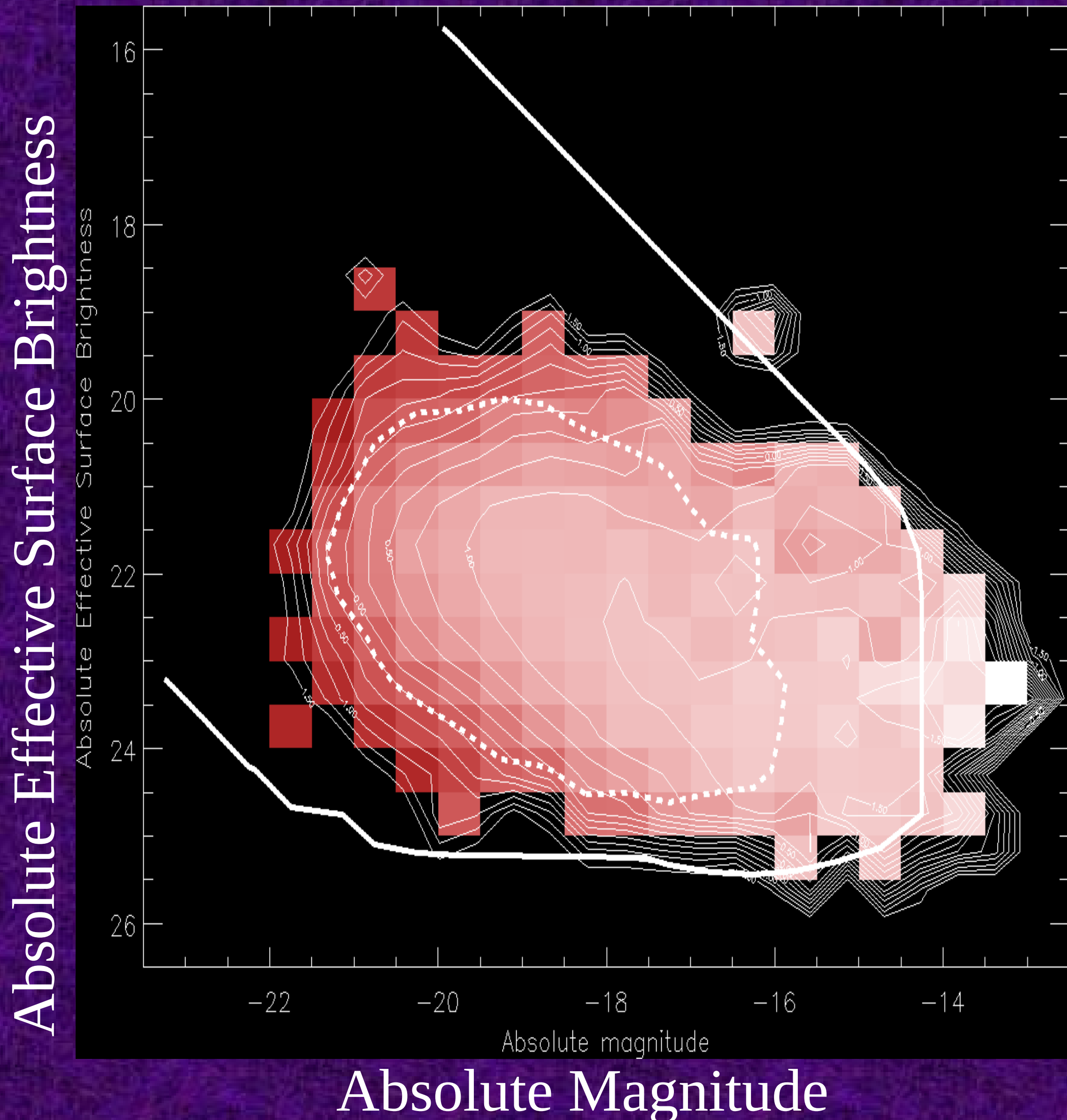
  } Identical to Schechter fn

  - μ^* = Characteristic surface brightness at M*
  - β = slope of luminosity surface brightness relation
  - σ = width of Gaussian distribution

  } Gaussian SB multiplier

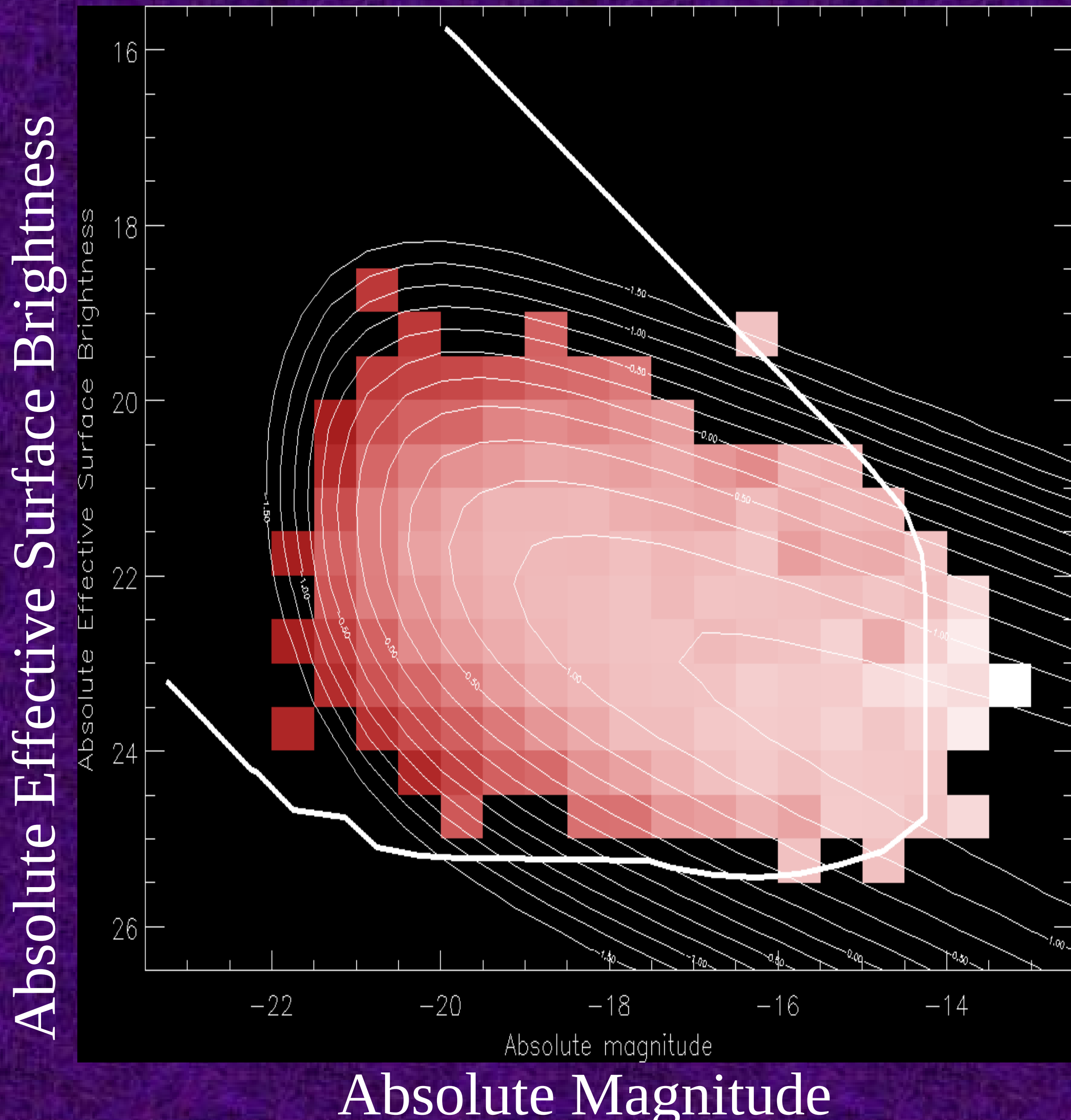
MGCz LSP in more detail

- Selection boundary is defined as the region sampled by at least 100 galaxies
- We see a clear L-Σ relation
- Not due to selection bias
- Clear decline in space density of low surface brightness giants
- Selection effects become severe for the dwarf population
- However to M < -15 LF is flat
  - Negligible contribution to:
    - Light
    - Mass
    - Faint Counts
- Evidence for the dwarf population diving into two or distribution broadening ?

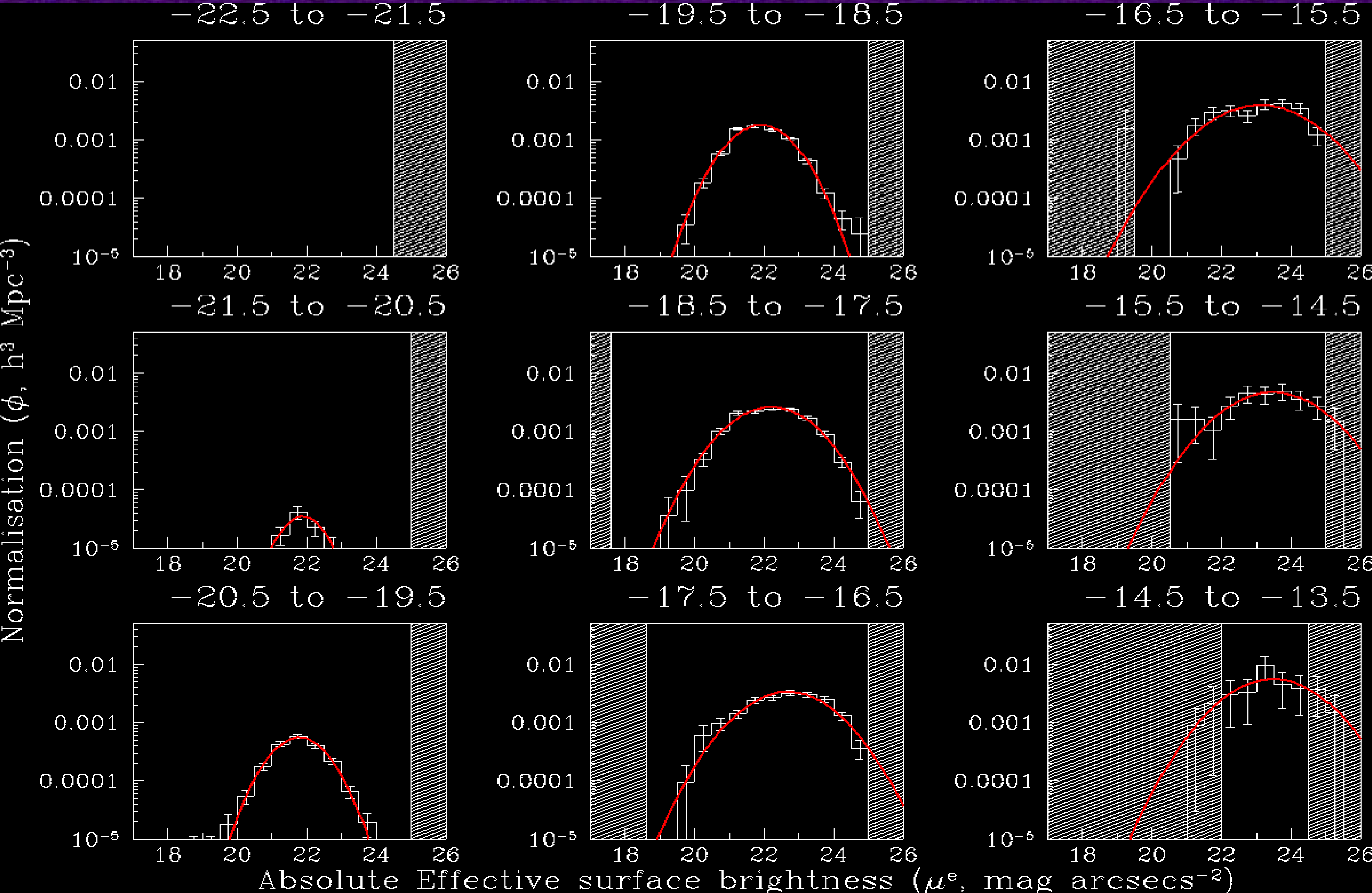


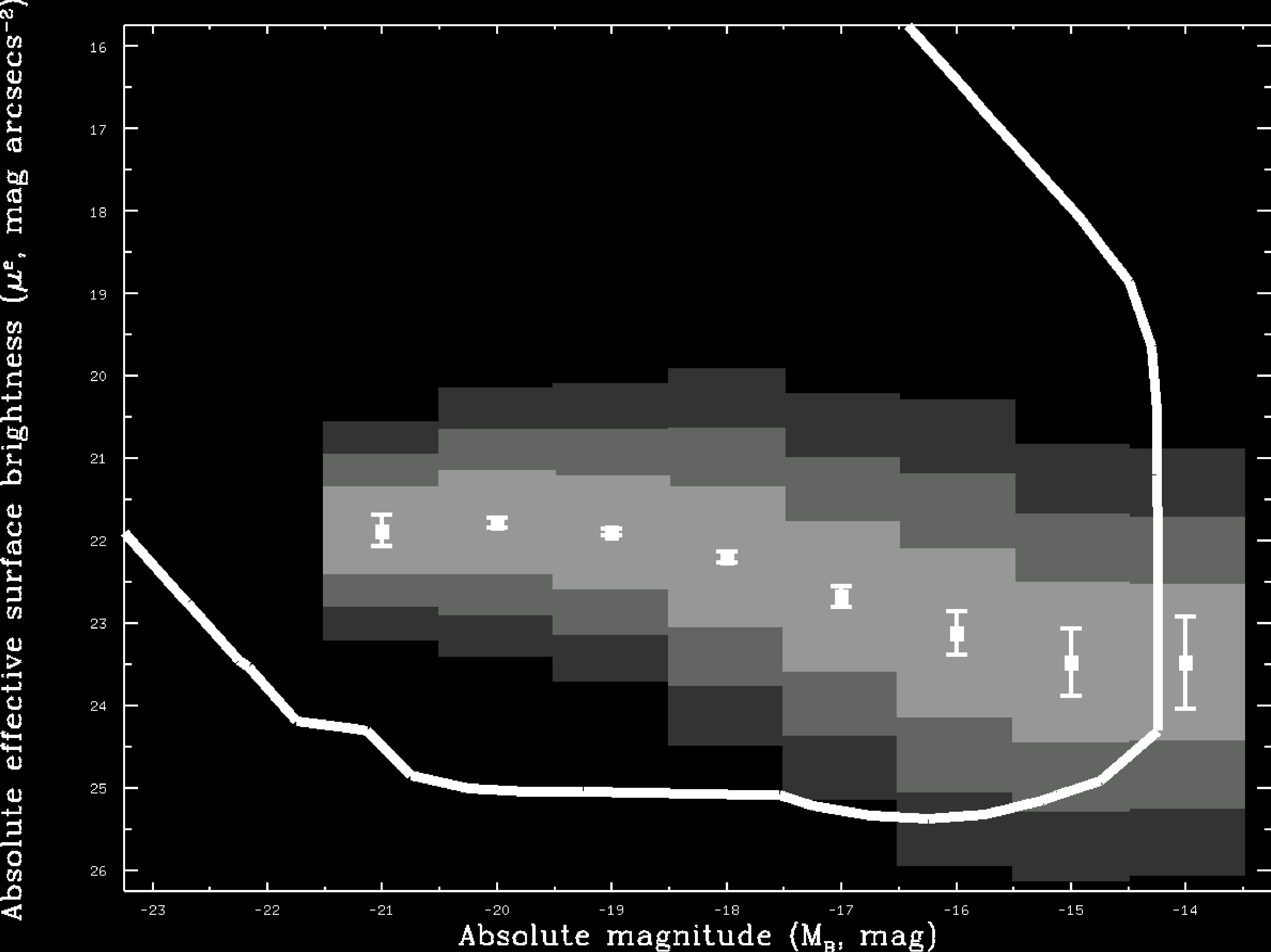
MGCz LSP:Chołoniewski Function ?

- Minimise via Ameoba algorithm
- Fit extremely poor (χ^2 =617/149)
- Two reasons:
  - Change in slope of L-Σ relation from giants to dwarfs
  - Broadening of SB distribution at faint mags
- Try simple Gaussian fits in dM intervals

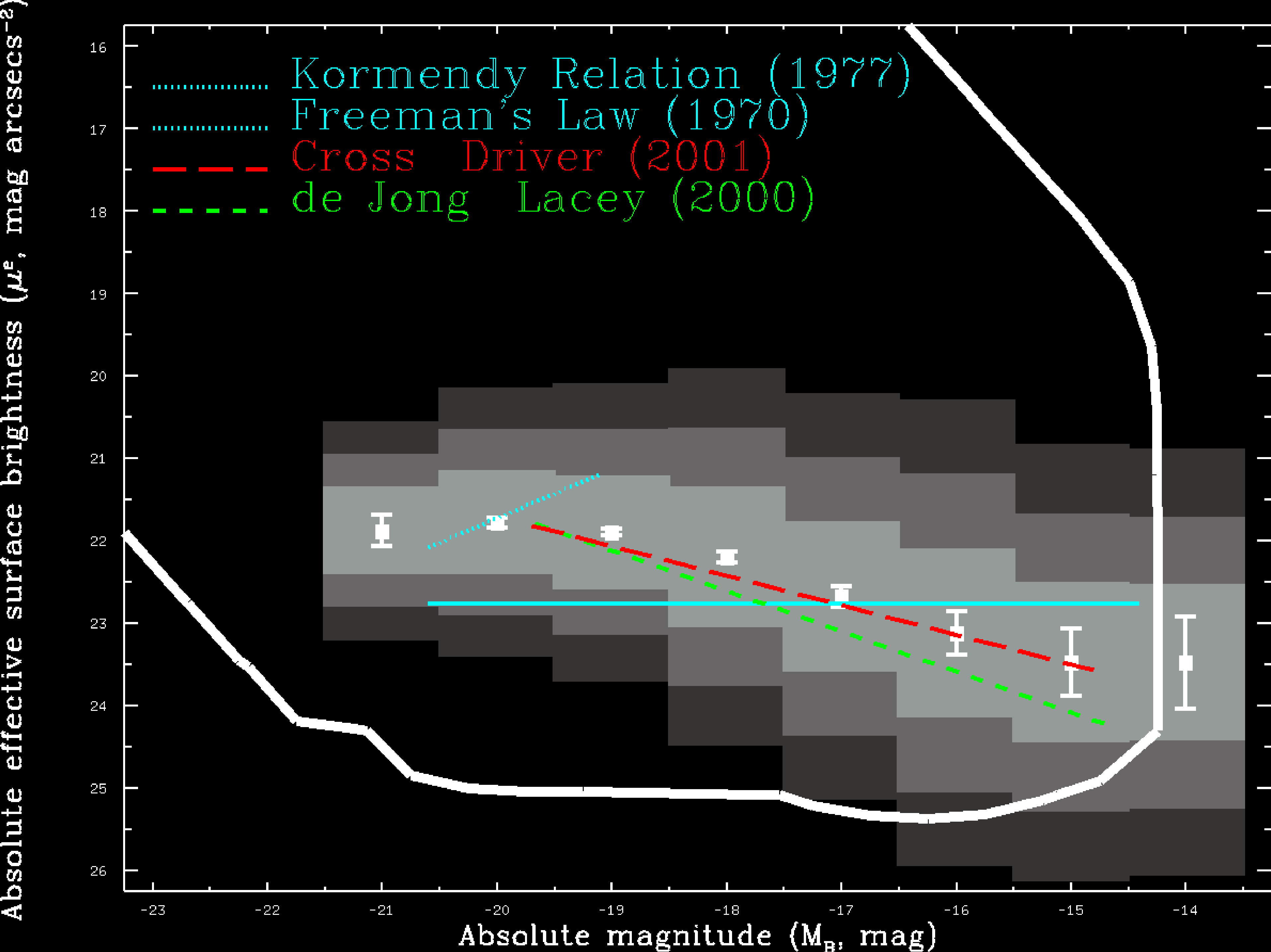


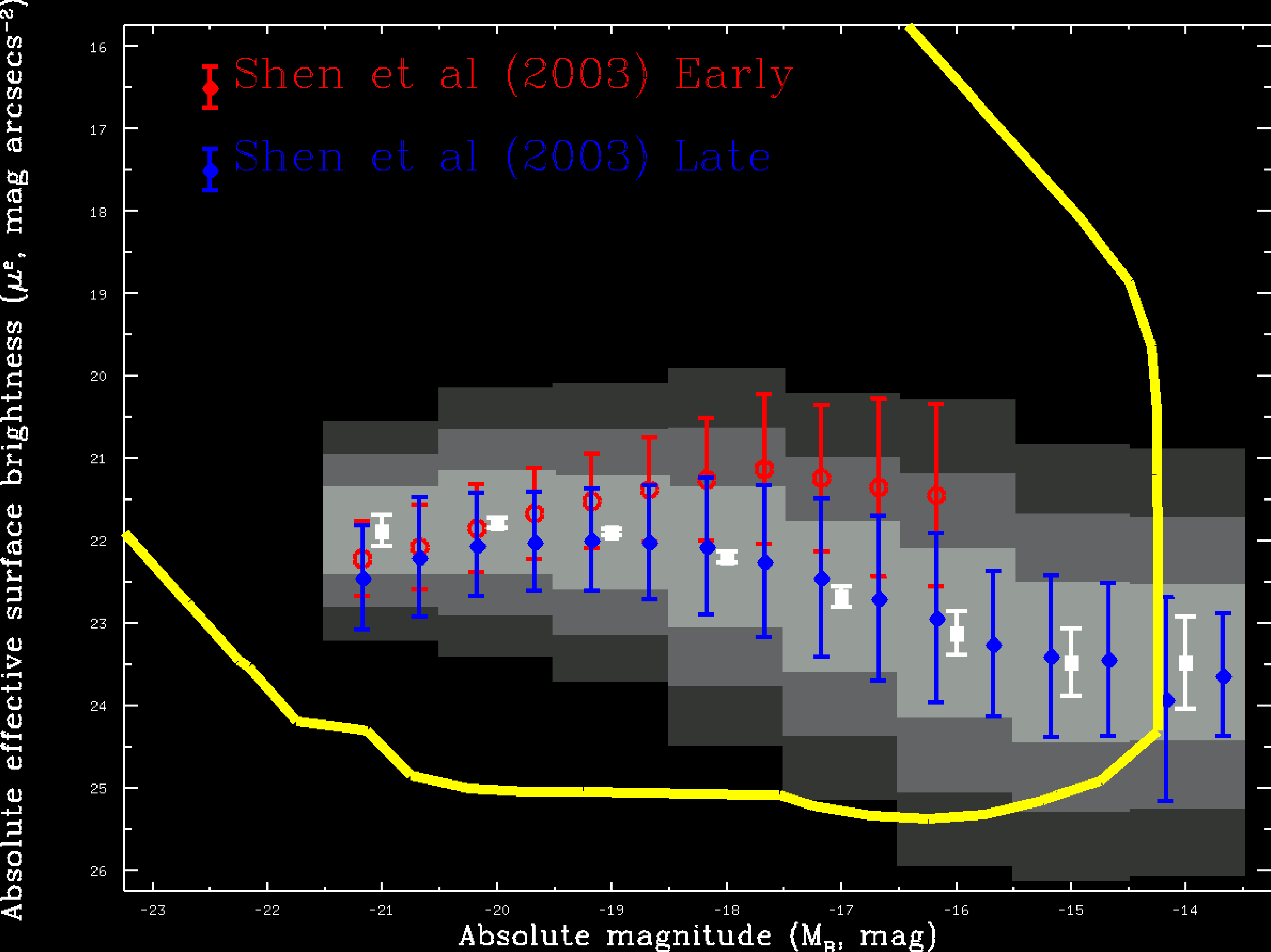
MGCz LSP: Gaussian SB fits





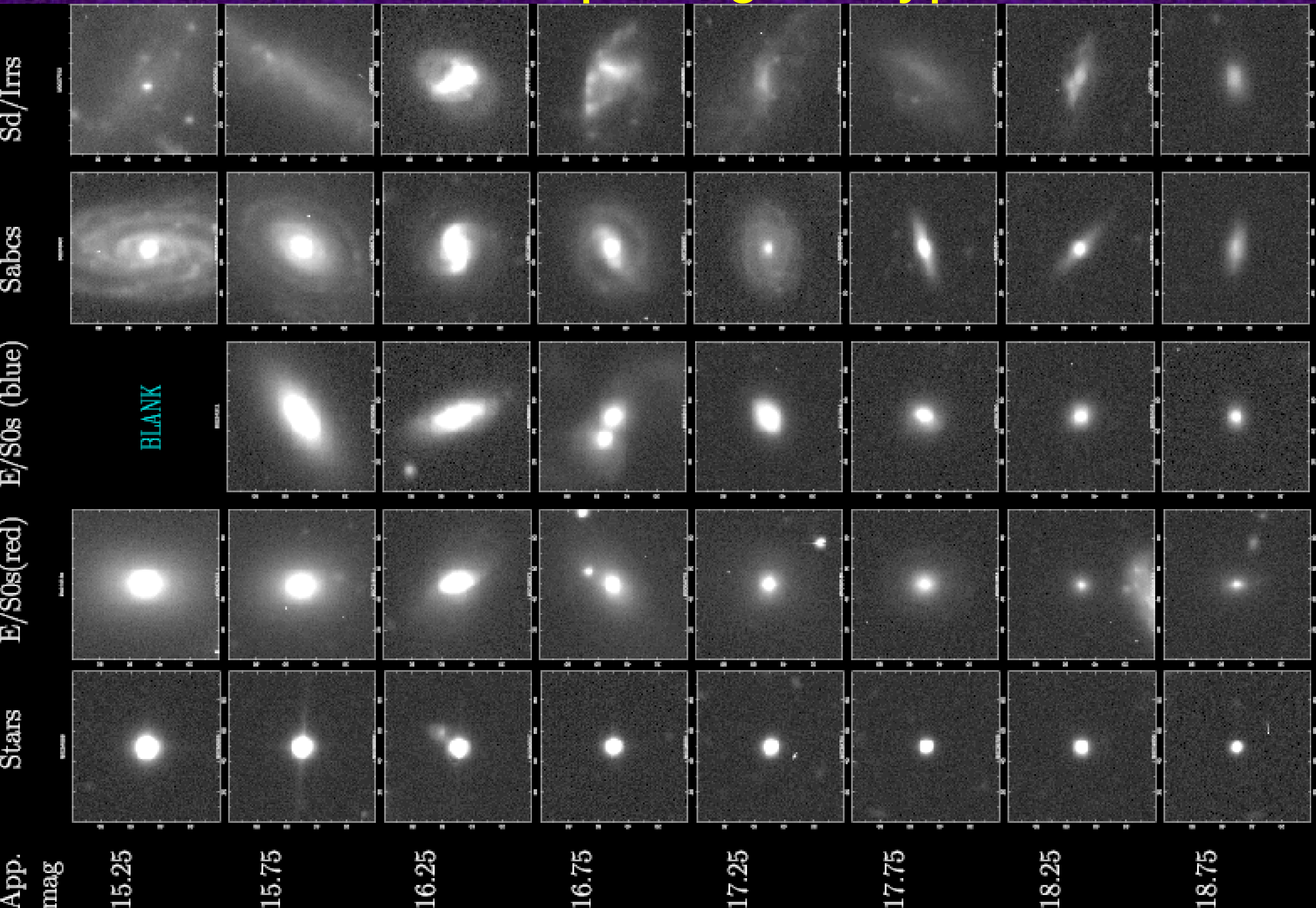
Absolute effective surface brightness (μ^e, mag arcsecs^{-2})
16
17
18
19
20
21
22
23
24
25
26
-23
-22
-21
-20
-19
-18
-17
-16
-15
-14
Absolute magnitude (M_B, mag)

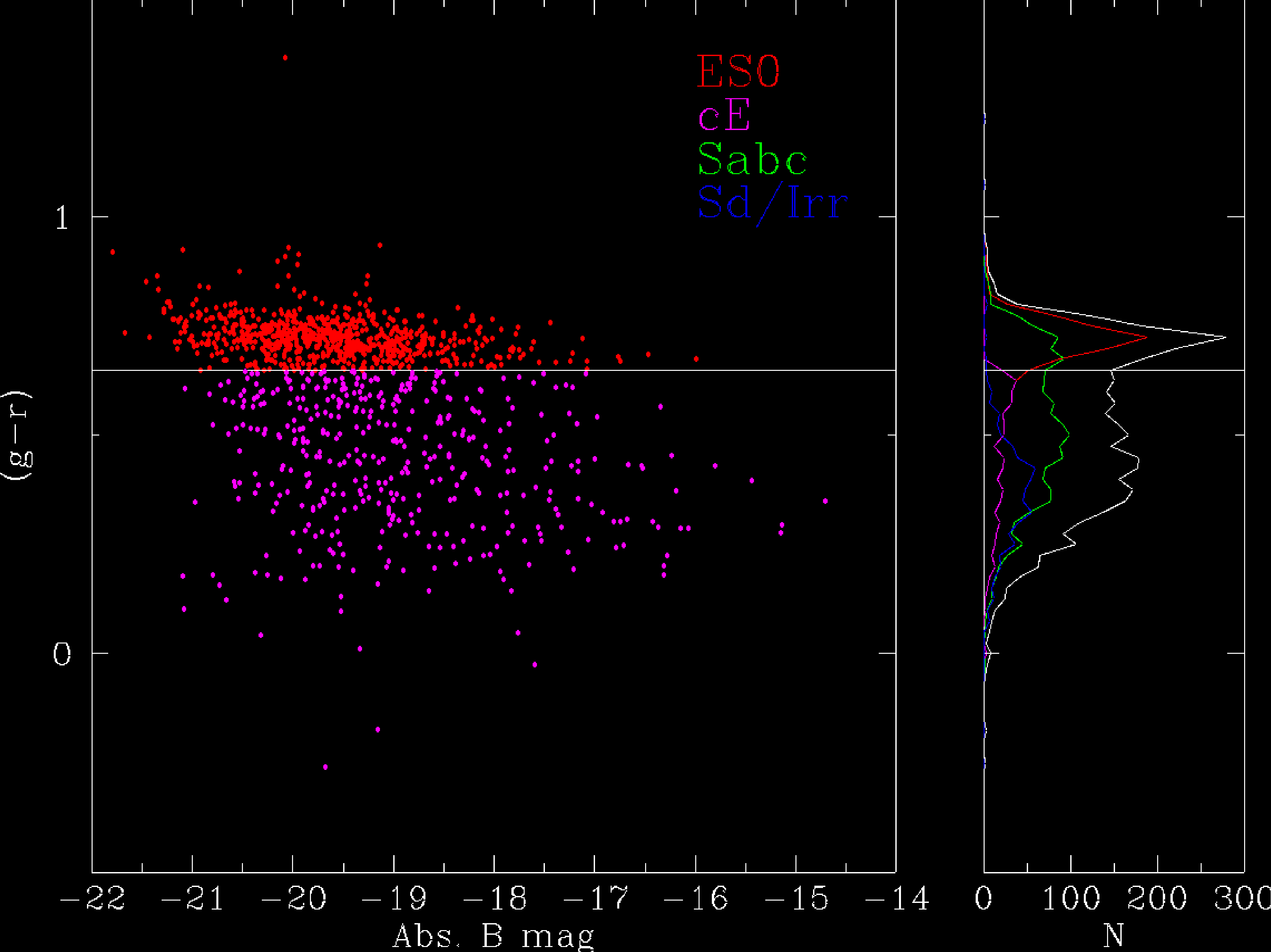

Kormendy Relation (1977)
Freeman's Law (1970)
Cross Driver (2001)
de Jong Lacey (2000)
Absolute effective surface brightness (μ^e, mag arcsecs^{-2})
Absolute magnitude (M_B, mag)
16
17
18
19
20
21
22
23
24
25
26
-23
-22
-21
-20
-19
-18
-17
-16
-15
-14



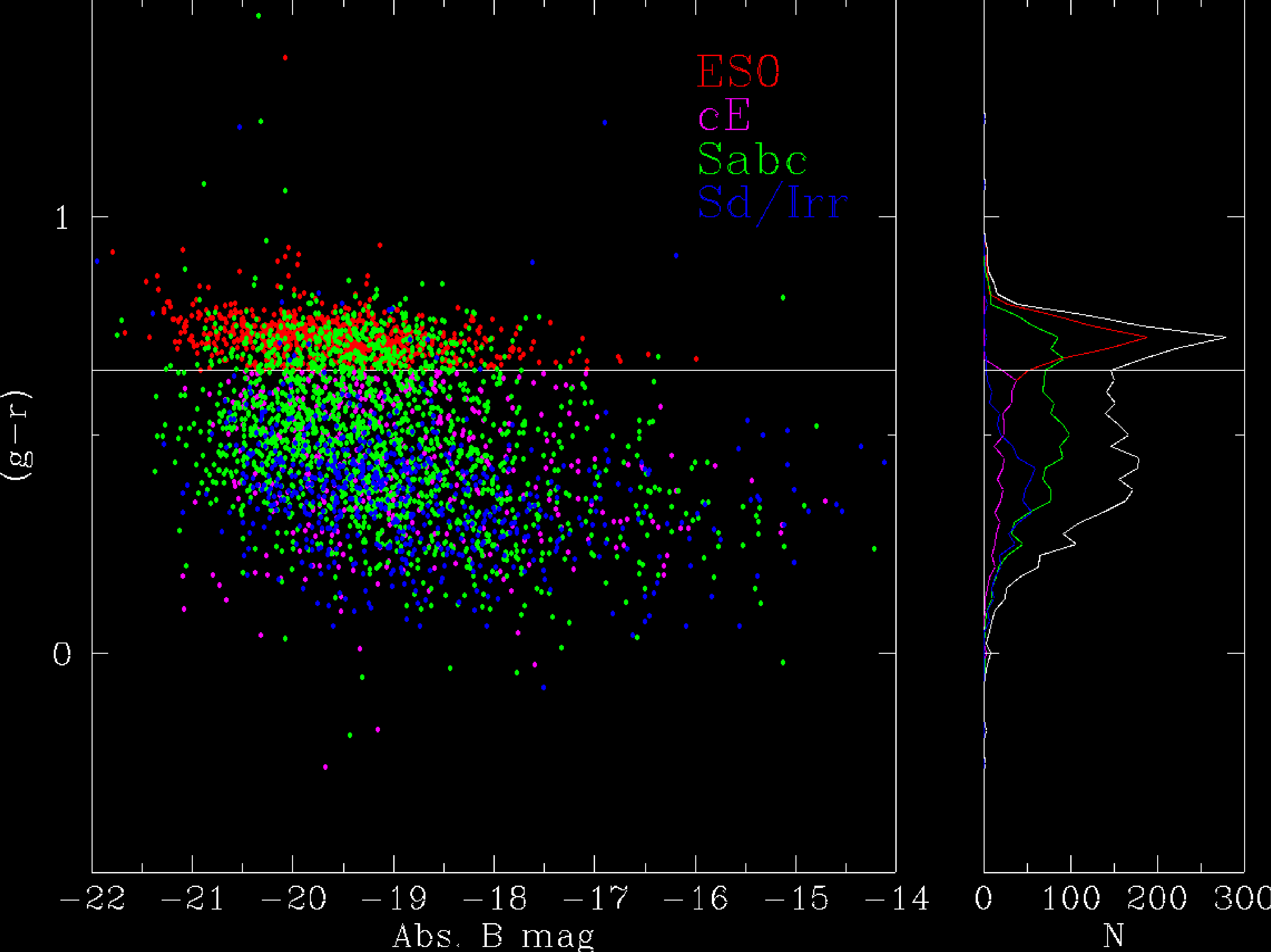
Shen et al (2003) Early
Shen et al (2003) Late
Absolute effective surface brightness (μ^e, mag arcsecs^{-2})
Absolute magnitude (M_B, mag)
16
17
18
19
20
21
22
23
24
25
26
-23
-22
-21
-20
-19
-18
-17
-16
-15
-14

MGC:Morphological Type

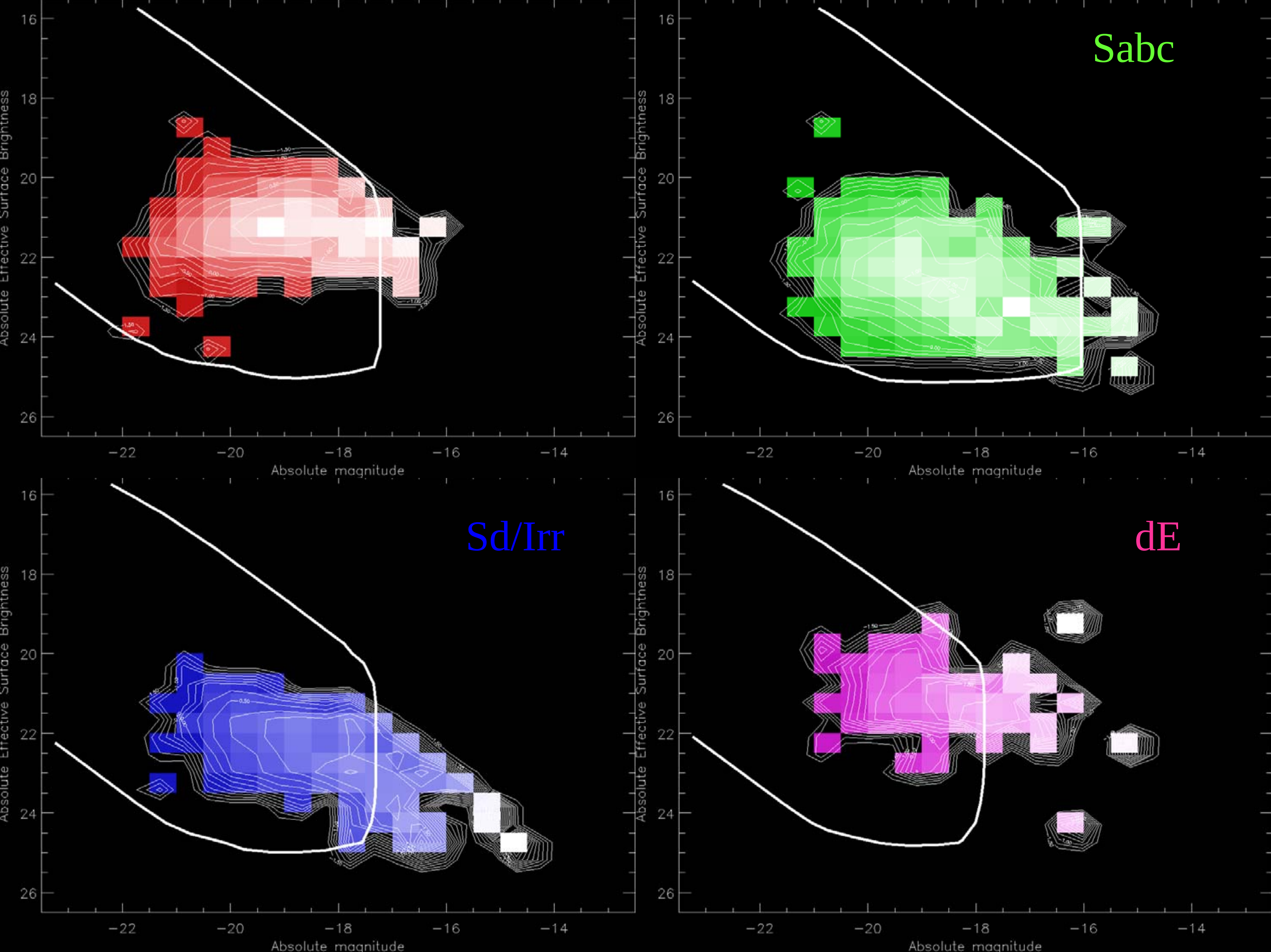


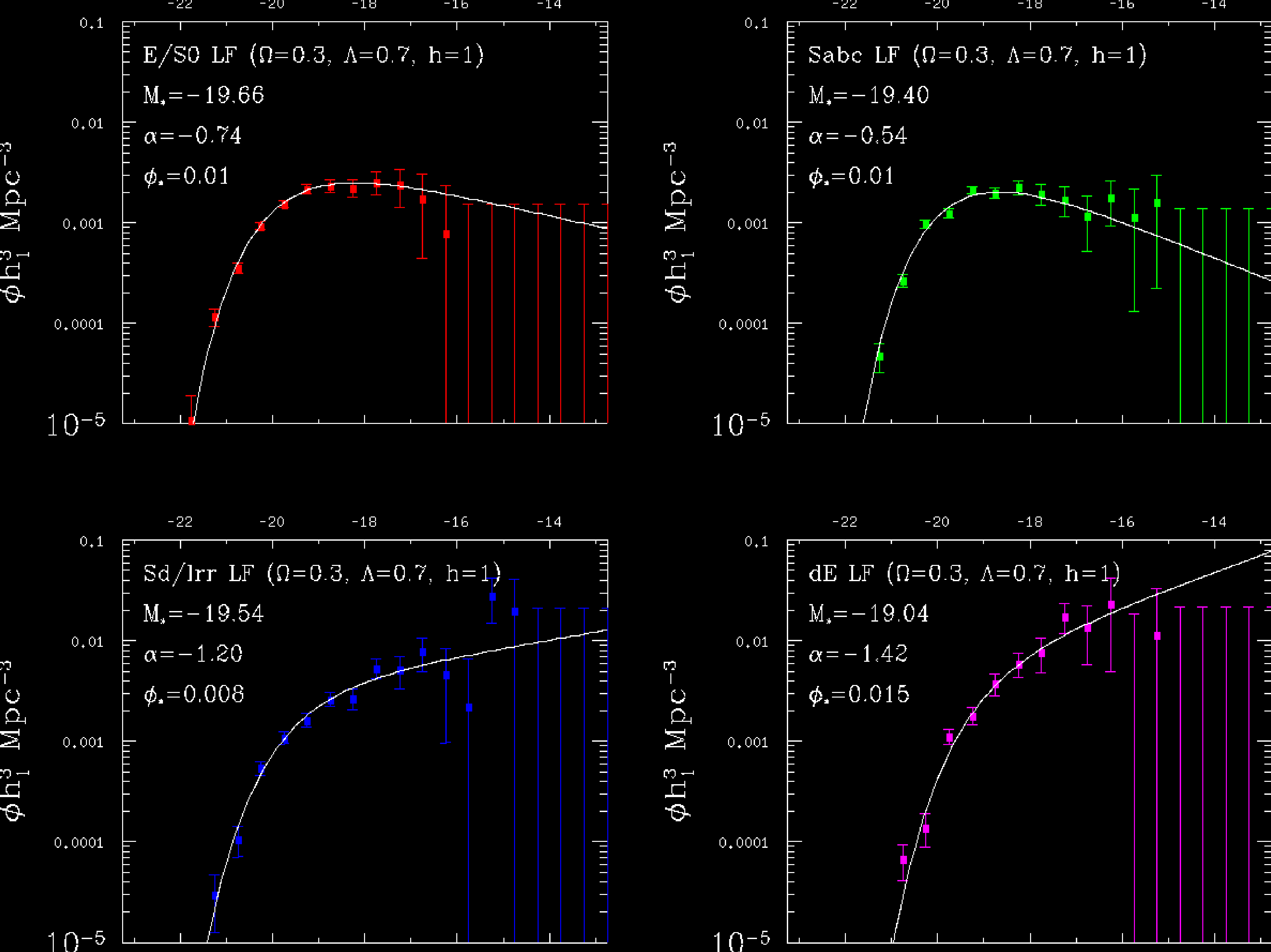


ES0
cE
Sabc
Sd/Irr
1
0
(g−r)
−22
−21
−20
−19
−18
−17
−16
−15
−14
Abs. B mag
0
100
200
300
N

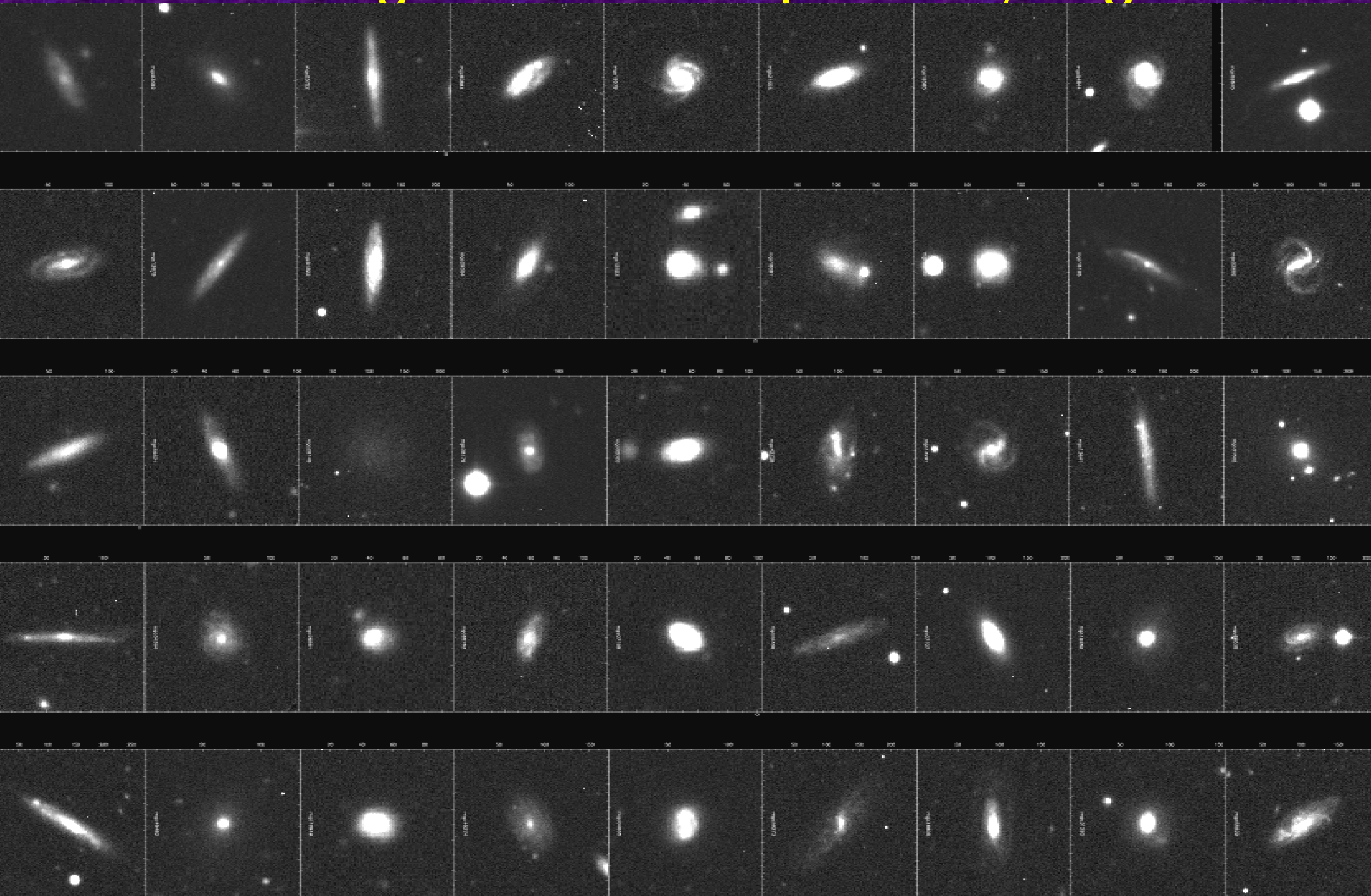


ES0
cE
Sabc
Sd/Irr
1
0
(g−r)
−22
−21
−20
−19
−18
−17
−16
−15
−14
Abs. B mag
0
100
200
300
N

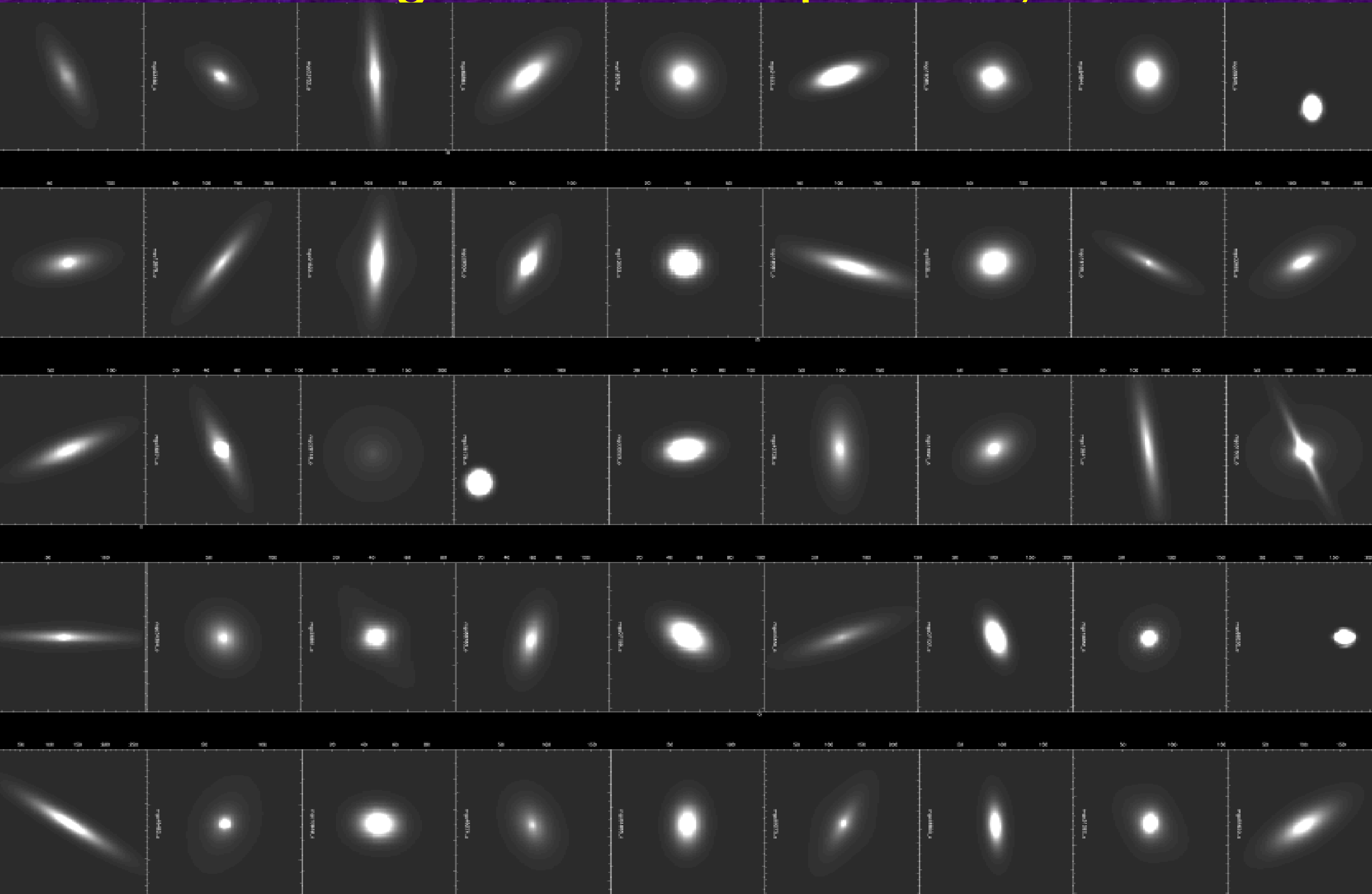

Sabc
Sd/Irr
dE
Absolute Effective Surface Brightness
Absolute magnitude

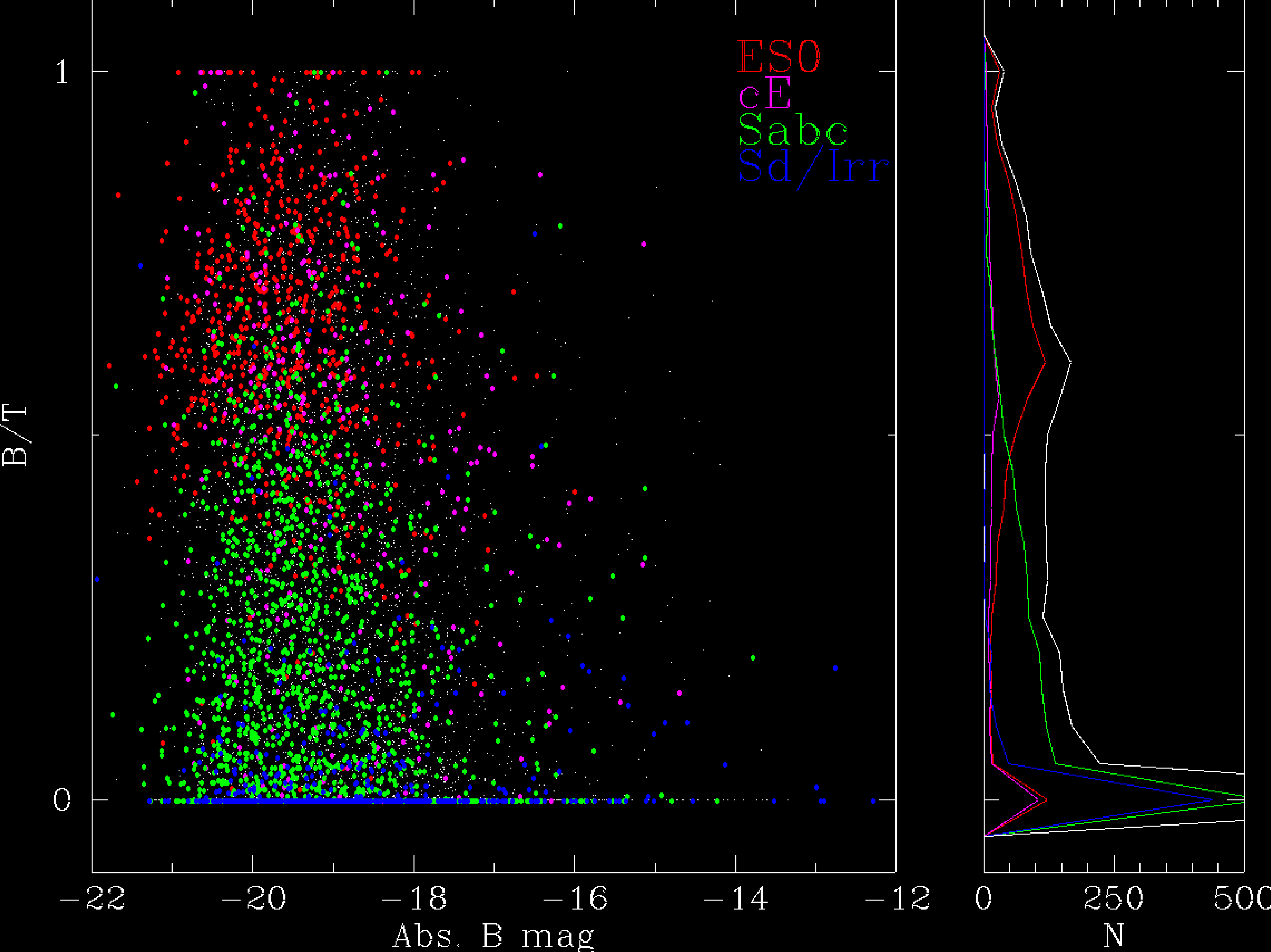

E/S0 LF (Ω=0.3, Λ=0.7, h=1)
M*=−19.66
α=−0.74
φ*=0.01
Sabc LF (Ω=0.3, Λ=0.7, h=1)
M*=−19.40
α=−0.54
φ*=0.01
Sd/Irr LF (Ω=0.3, Λ=0.7, h=1)
M*=−19.54
α=−1.20
φ*=0.008
dE LF (Ω=0.3, Λ=0.7, h=1)
M*=−19.04
α=−1.42
φ*=0.015
φh13 Mpc−3
0.1
0.01
0.001
0.0001
10−5
-22
-20
-18
-16
-14

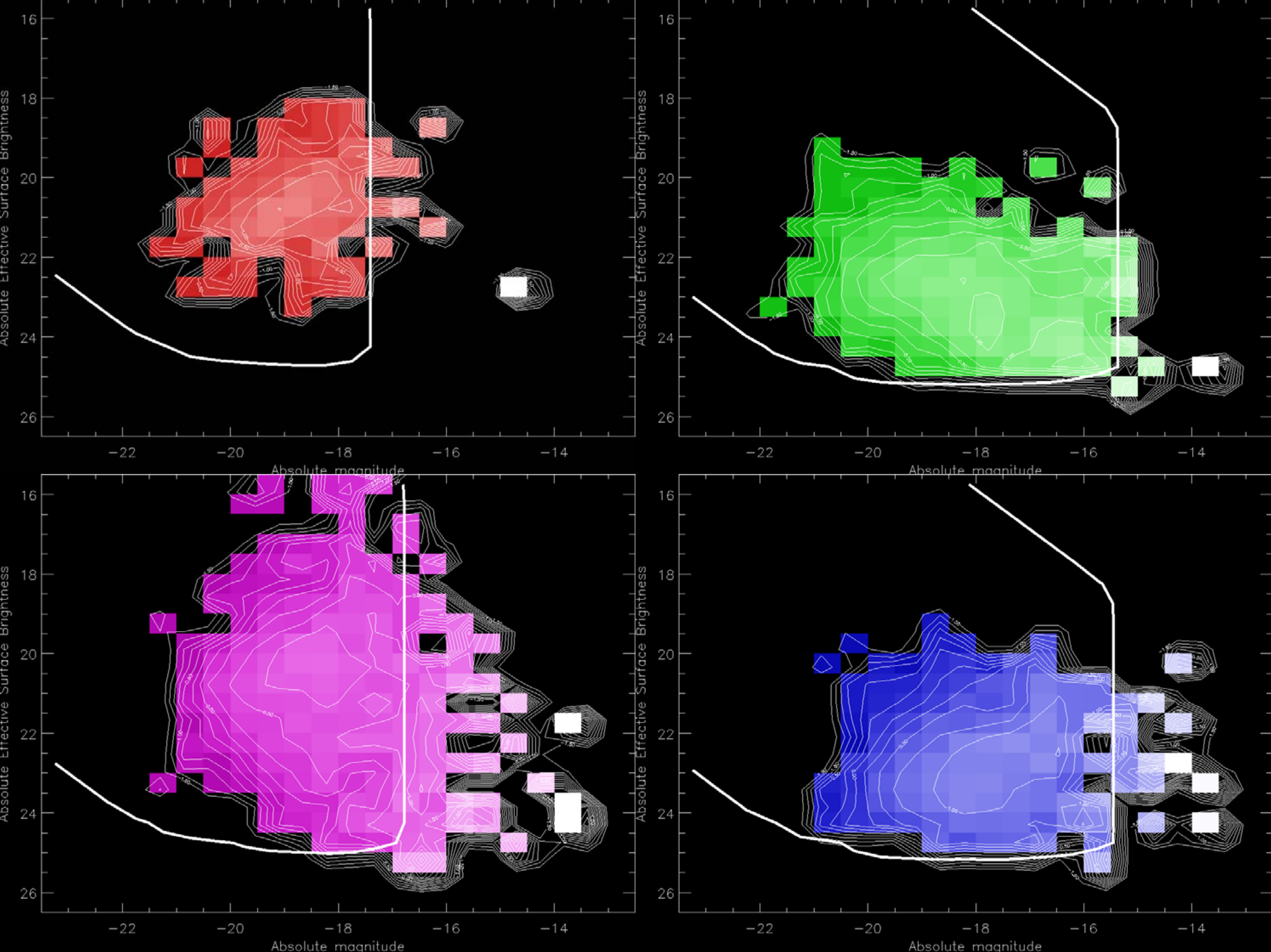
MGC: Bulge Disk Decomposition, originals



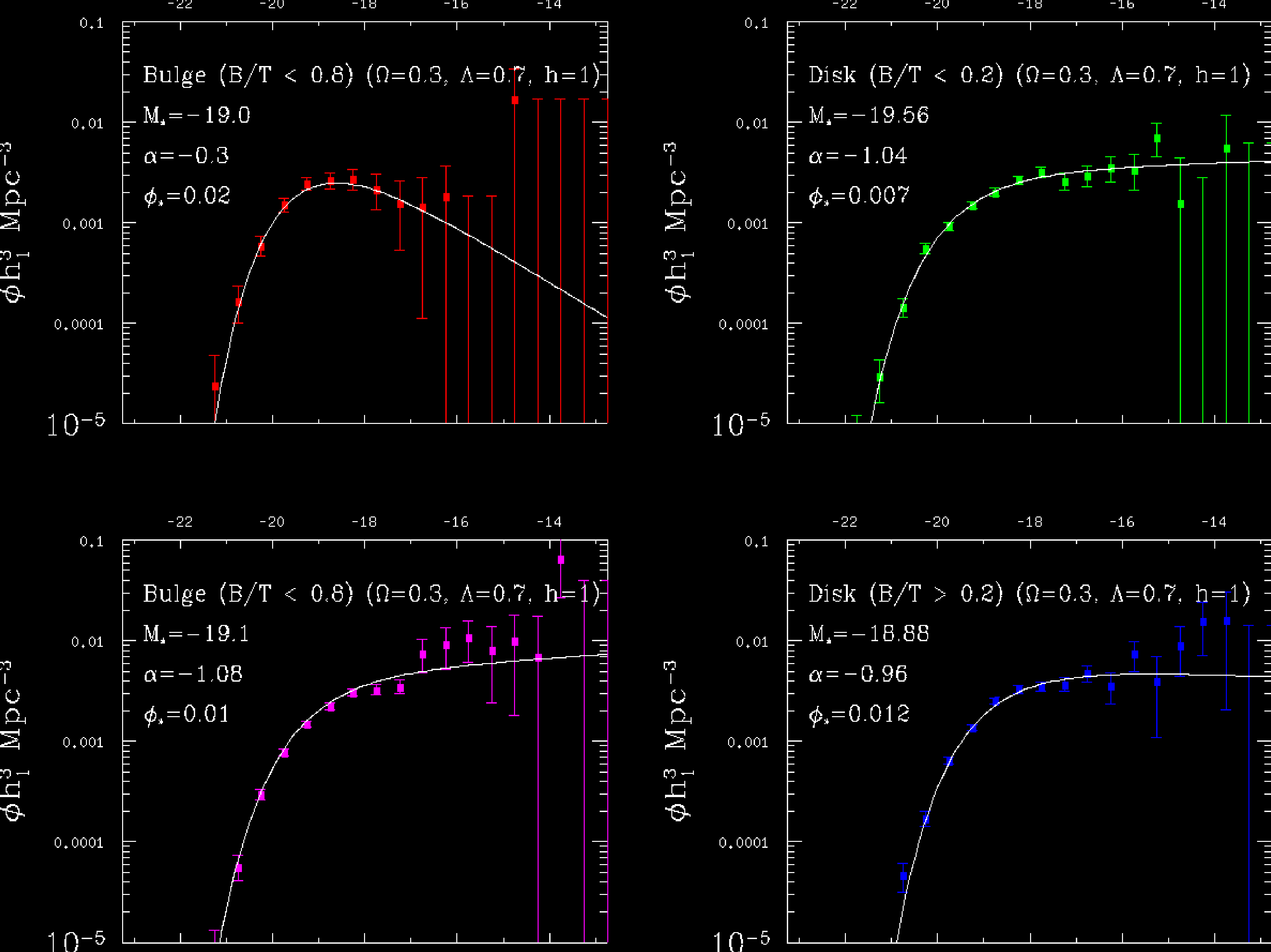
MGC: Bulge Disk Decomposition, models




ES0
cE
Sabc
Sd/Irr
1
0
B/T
−22
−20
−18
−16
−14
−12
Abs. B mag
0
250
500
N



Absolute Effective Surface Brightness
Absolute magnitude
16
18
20
22
24
26
-22
-20
-18
-16
-14


Bulge (B/T < 0.8) (Ω=0.3, Λ=0.7, h=1)
M*=−19.0
α=−0.3
φ*=0.02
Disk (B/T < 0.2) (Ω=0.3, Λ=0.7, h=1)
M*=−19.56
α=−1.04
φ*=0.007
Bulge (B/T < 0.8) (Ω=0.3, Λ=0.7, h=1)
M*=−19.1
α=−1.08
φ*=0.01
Disk (B/T > 0.2) (Ω=0.3, Λ=0.7, h=1)
M*=−18.88
α=−0.96
φ*=0.012
φh13 Mpc−3
-22
-20
-18
-16
-14
0.1
0.01
0.001
0.0001
10−5

Galaxy Formation: Connecting λ and Σ

- Fall & Efstathiou (1980), Dalcanton, Spergel & Summers (1997), Mo, Mao & White (1998), de Jong & Lacey (2000) all relate λ to either μ or r_d under varying assumptions

$$\lambda \propto r_d \qquad \Sigma_o \propto F M_{tot}^{1/3} \lambda^{-(2+6F)} \qquad \lambda \propto L^{1/6} \Sigma^{-1/2}$$

- All agree that at fixed Mass or Luminosity: $\lambda \propto \Sigma^{-1/2}$

- Hence surface brightness distribution should follow same distribution as Spin

- Currently we agree with the Gaussian form but find a much narrower distribution at M*

- Theory: $\sigma_\lambda \sim 0.5$ or $\sigma_\mu \sim 1.085$ in MGC we find 0.4 for giants and 0.9 for dwarfs

Galaxy Formation:The Spin Distribution

- Analytically and numerically (Barnes & Efstathiou 1987; Warren et al 1992; Eisenstein & Loeb 1995; Catelan & Theuns 1996) the distribution of spin angular momentum of collapsed haloes is lognormal distribution, I.e,:

4.3 The evolution of the spin parameter

Previous works have shown that the spin parameter λ, obtained from simulations, has a log-normal distribution (Barnes & Efstathiou 1987; Cole & Lacey 1996; van den Bosch 1998; Ryden 1998),

$$P(\lambda)d\lambda = \frac{1}{\sigma_\lambda\sqrt{2\pi}} exp\left(-\frac{ln^2(\lambda/\lambda_0)}{2\sigma_\lambda^2}\right)\frac{d\lambda}{\lambda} \quad (14)$$

which seems to be a universal result, independent of the cosmological model. In Fig. 7 we show the distribution of the spin parameter at $z = 0$ for the two catalogs considered here. An inspection of this plot confirms again that halos which have undergone important merger episodes have, on the average, a larger spin parameter and a wider distribution than those evolved by accretion only. We will return to this point later in this section.

If the halos of both samples are considered together, the parameters defining the distribution at $z = 0$ are: $\lambda_0 = 0.036$ and $\sigma_\lambda = 0.57$, in agreement with previous

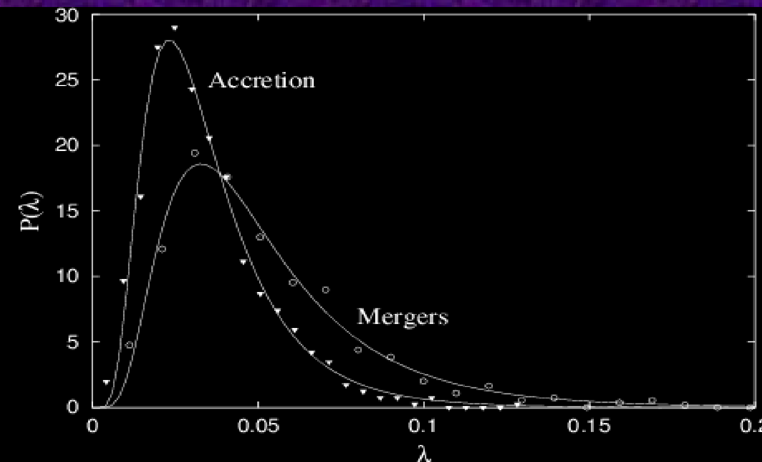


Figure 7. The distribution of the spin parameter for halos that grow by merger and those which grow by accretion at $z = 0$. The average spin parameter is higher for halos underwent merger events than for halos which have growth by accretion only.

Peirani et al 2004

- Typically: $0.03 < \langle\lambda\rangle < 0.05$ and $0.5 < \sigma < 0.7$
- E.g., Bullock et al (2001): $\langle\lambda\rangle = 0.042 \pm 0.006$ and $\sigma = 0.50 \pm 0.04$

Galaxy formation: Evolution of Spin

- Vitvitska et al (2003)
  - Major mergers can radically change λ
  - Minor mergers generally leave unchanged
  - λ damps with mass and time
  - gradually decreases

- Expect distribution of λ (Σ) ♦□ ♌♏ ♌❒□♋♎♏❒ ♐□❒ ●□⬧ ❍♋⬧⬧ ⬧⌧⬧♦♏❍⬧ ✍

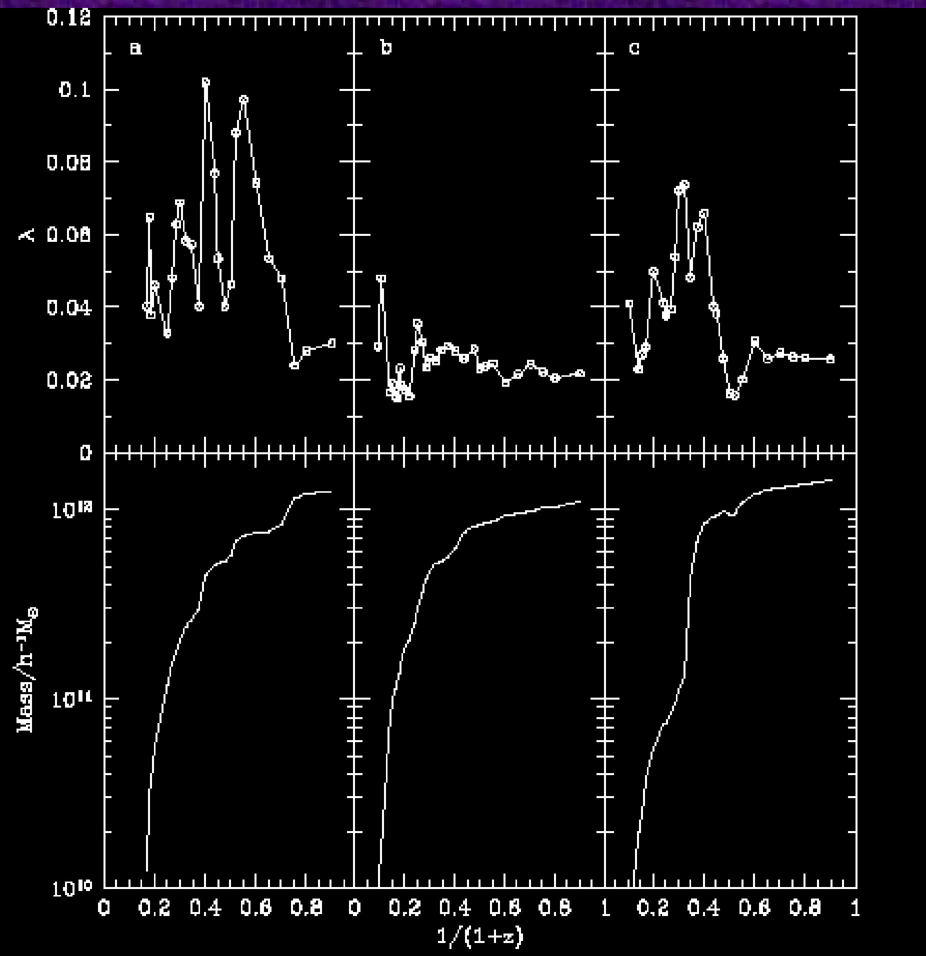


Figure 3. Mass accretion (lower panels) and spin parameter evolution (upper panels) of three galaxy-mass halos. Halos typically show fast mass growth at high redshift with rapid changes of spin parameter, followed by slower mass accretion with spin parameter usually declining. (From Vitvitska et al. 2002.)

Galaxy formation: Evolution of Spin

- Peirani et al (2004)
  - Mergers increase λ – Builds Bulges ?
  - Accretion decreases λ – 👌◆♓●♎⬧ 👎♓⬧&⬧ ✍
- Bulge dominated and disk dominated systems should have distinct SB distributions ?

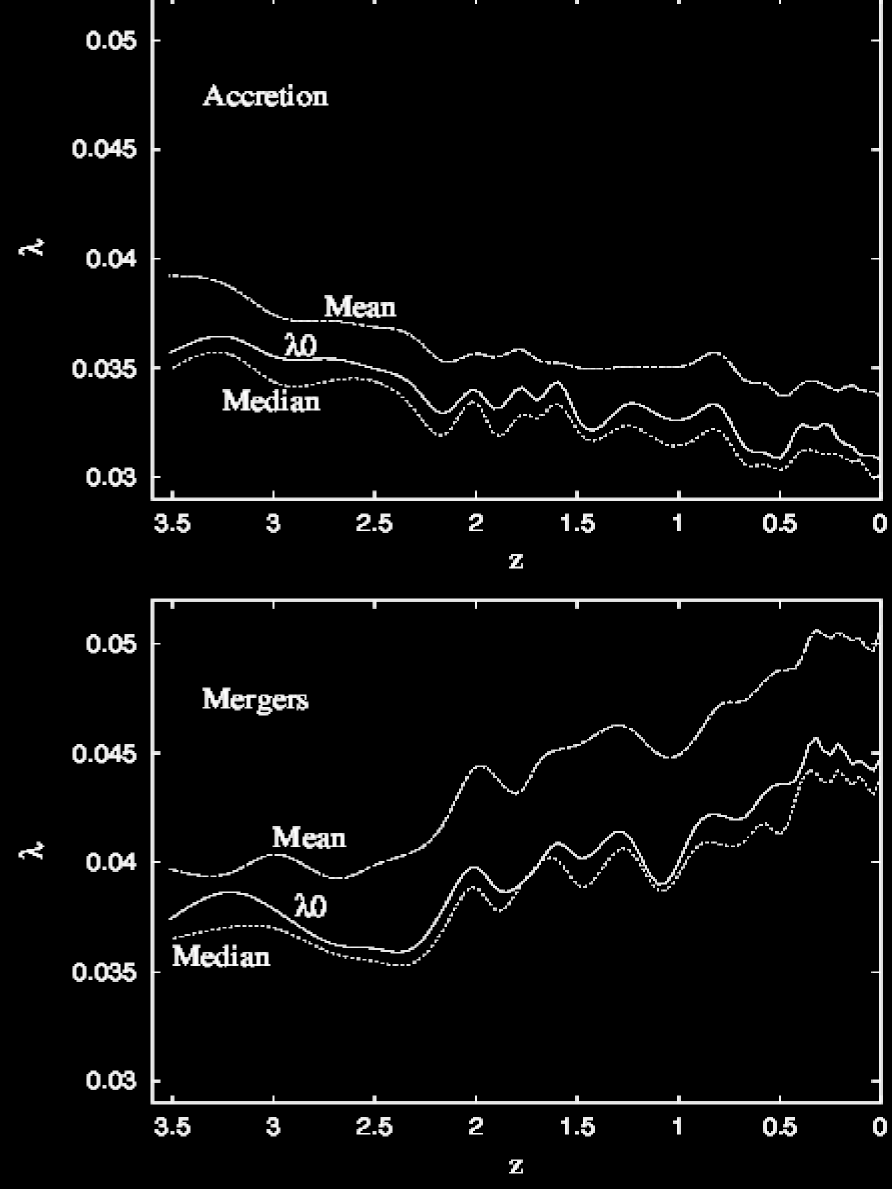


Figure 8. Panels from up to down: a) evolution of the spin parameter for all the halos (accretion + merger). Three statistical parameters are shown: the median, the mean and λ_0; evolution of the same parameters but for halos of the accreting catalog only (b) and for halos of the merger catalog (c).

Summary

- The MGC is providing a definitive z=0 galaxy benchmark
  - Overall LF:-19.57+/- 0.05, -1.10 +/- 0.03 0.0019+/-0.005
  - Morphological and structural LFs coming
- Exploration of the Luminosity Surface Brightness plane
  - Connection to theory ?
  - Tracking of selection effects
  - Measurement of Luminosity Surface Brightness relation
- Selection effects not critical at L*

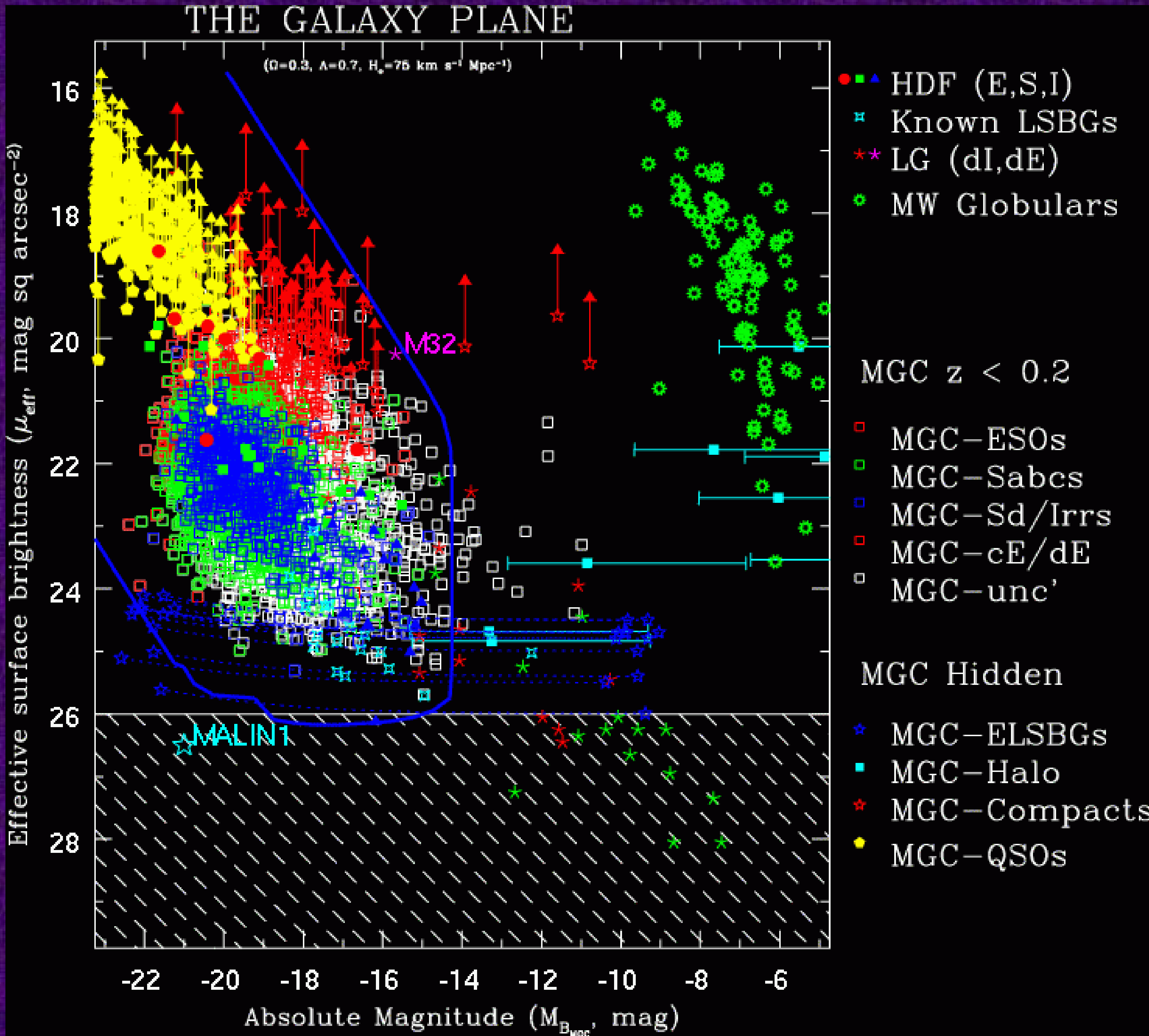
Summary

- Exploration of the Luminosity Surface Brightness Plane (or Luminosity Size plane)
- The Millennium Galaxy Catalogue: http://www.eso.org/~jliske/mgc/
- Surface brightness selection effects appear negligible at L*
- Selection effects become severe for the dwarf populations (both high and low SB)
- Surface brightness distribution at any M well described by a Gaussian distribution
- Surface brightness decreases either side of M*
- The Global Luminosity function (morphological and structural en route):
  - The MGC LF is slightly brighter, slightly flatter and has a slightly higher normalisation than 2dF resulting in a 7% increase in j (the B-band luminosity density)

-19.57+/-0.05, -1.10+/-0.03, 0.019+/-0.005

- Connection to theory/CDM ?
  - λ —> Σ ?
  - lnλ & Σ ♌□♦♒ ☝♋◆⬩⬩♓♋■ ♎♓⬩♦❒♓♌◆♦♓□■⬩ ⬩♓♦♒ ♍□❍□♋❒♋♌●♏ ♎♓⬩□♏❒⬩♓□■⬩
  - Bulge dominated and disk dominated systems exhibit distinct λ ♋■♎ Σ ♎♓⬩♦❒♓♌◆♦♓□■⬩
  - Low mass systems have broader λ & Σ ♎♓⬩♦❒♓♌◆♦♓□■⬩

MGC LSP


THE GALAXY PLANE
(Ω=0.3, Λ=0.7, H₀=75 km s⁻¹ Mpc⁻¹)
M32
MALIN1
Effective surface brightness (μeff, mag sq arcsec⁻²)
Absolute Magnitude (MBmgc, mag)
16
18
20
22
24
26
28
-22
-20
-18
-16
-14
-12
-10
-8
-6
HDF (E,S,I)
Known LSBGs
LG (dI,dE)
MW Globulars
MGC z < 0.2
MGC−ESOs
MGC−Sabcs
MGC−Sd/Irrs
MGC−cE/dE
MGC−unc'
MGC Hidden
MGC−ELSBGs
MGC−Halo
MGC−Compacts
MGC−QSOs

The LSP

- Existing data
  - HDF
  - 2dFGRS
  - SDSS
  - LG
- Current data reveals L-Σ relation
- Real or a selection bias ?

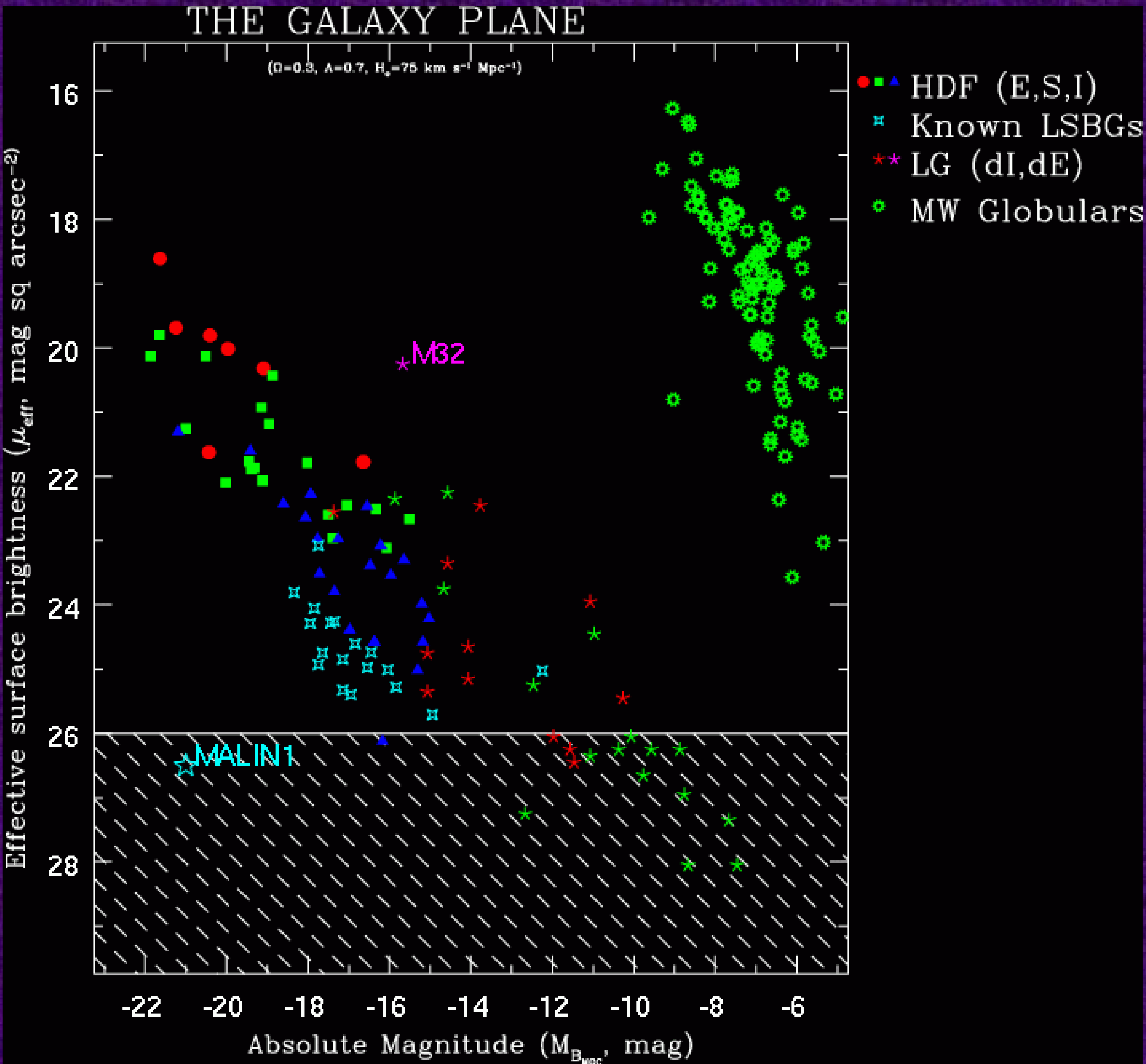
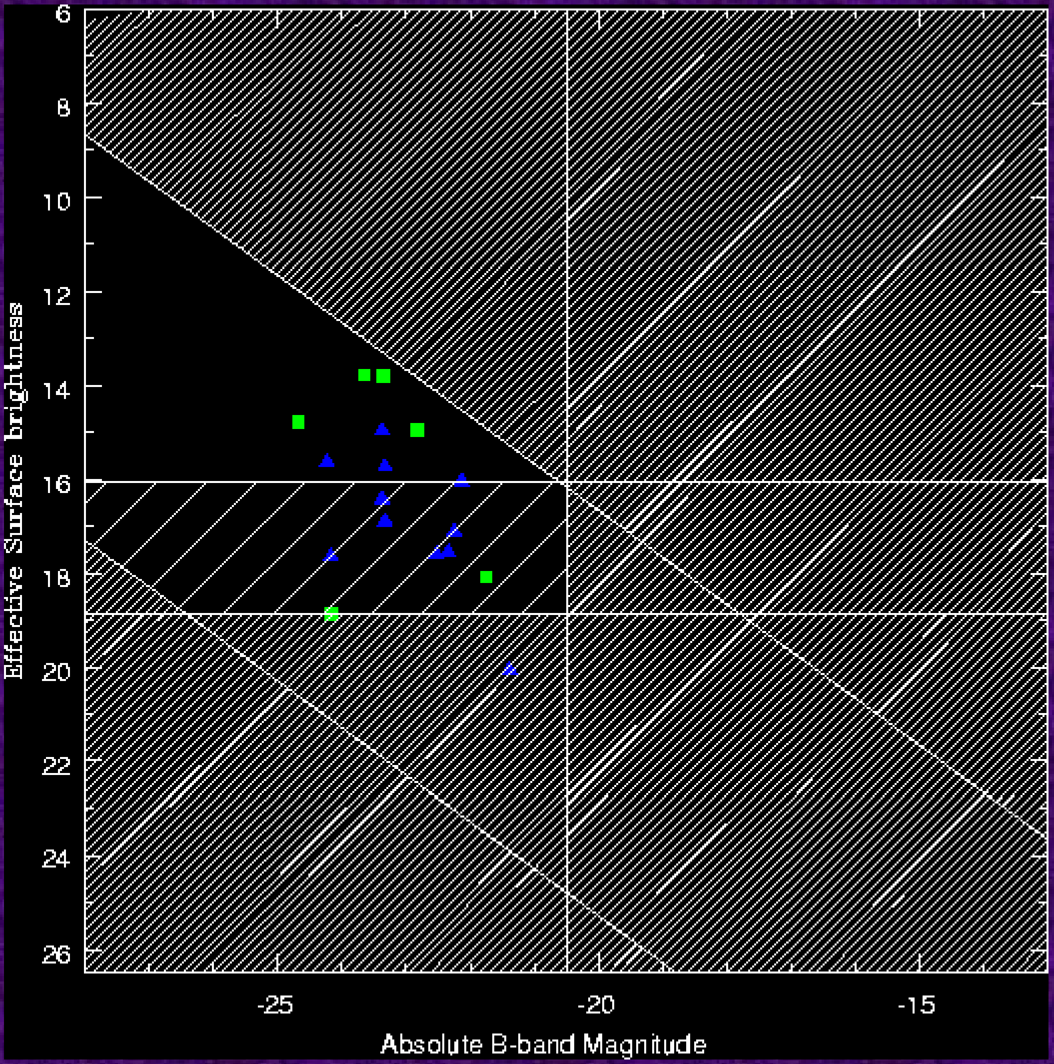


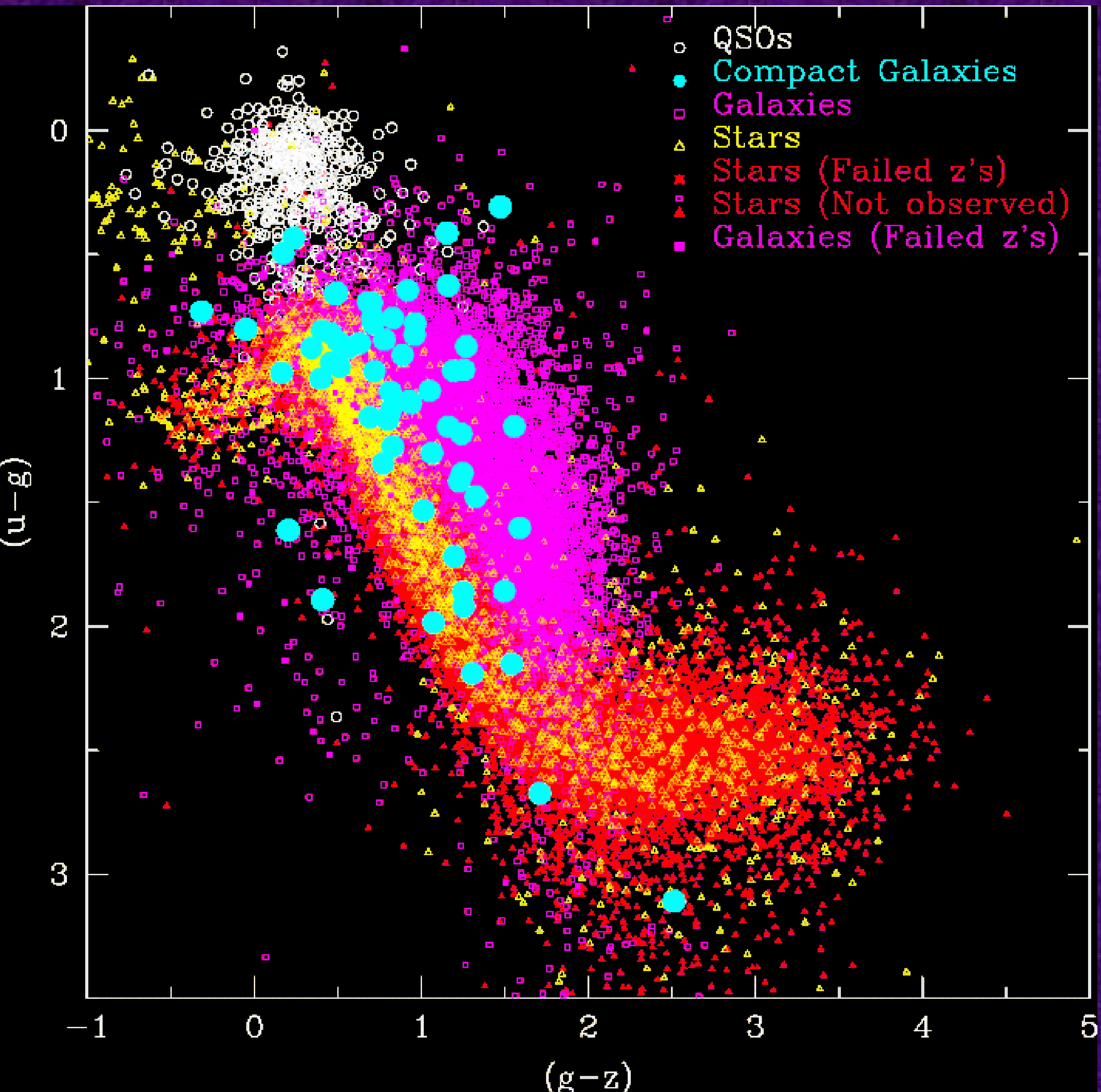
Illustration: Selection Effects in the HDF

- Redshift = 3.75 --- 4.25
- Selection limits
  - m > 19 mag
  - m < 27 mag
  - r > 0.1''
  - r < 5''
  - μ < 27 mag/sq arcsec



Health Warning: Not all surveys are equal !

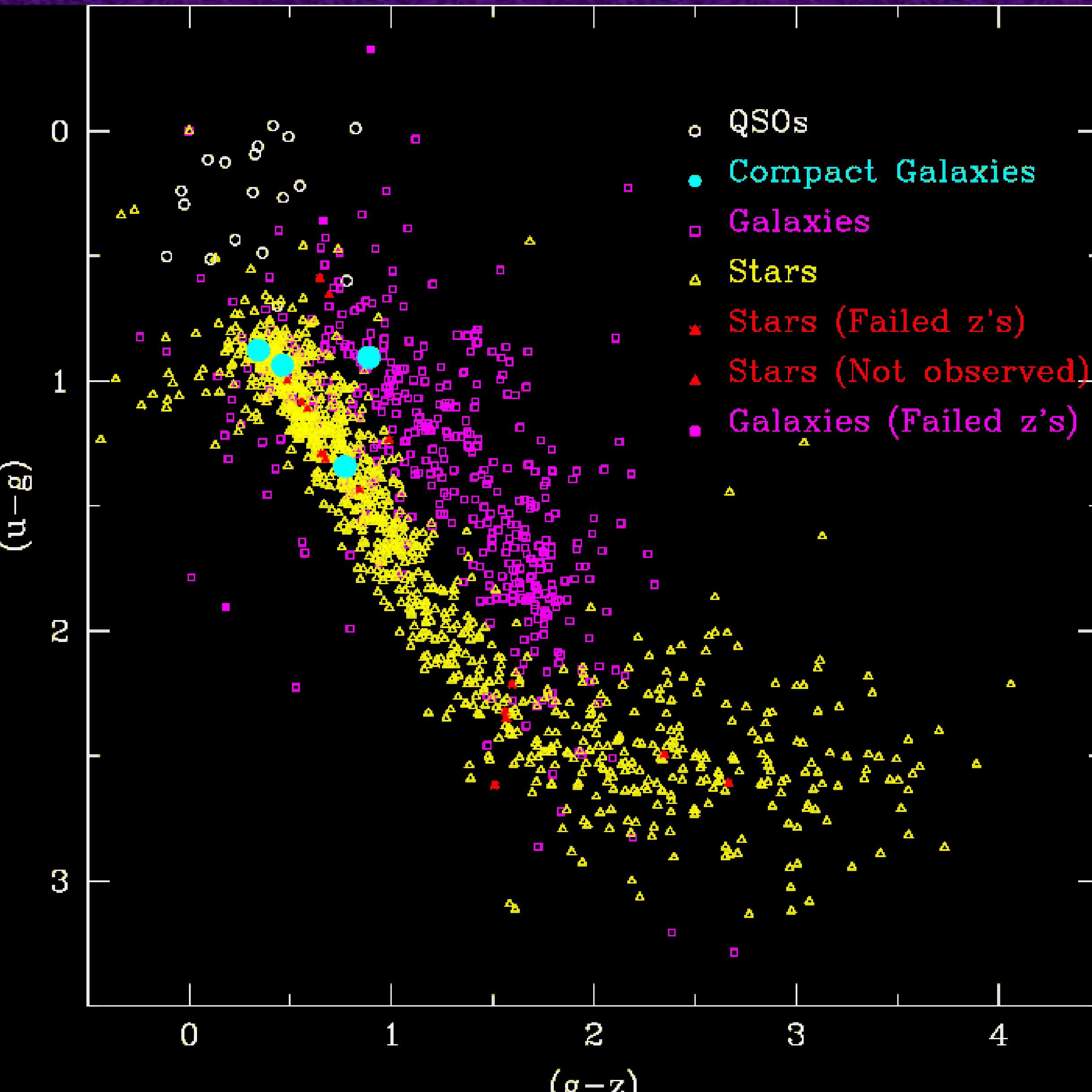
MGC: Looking for compact galaxies



So far all compacts are barely resolved distant galaxies:

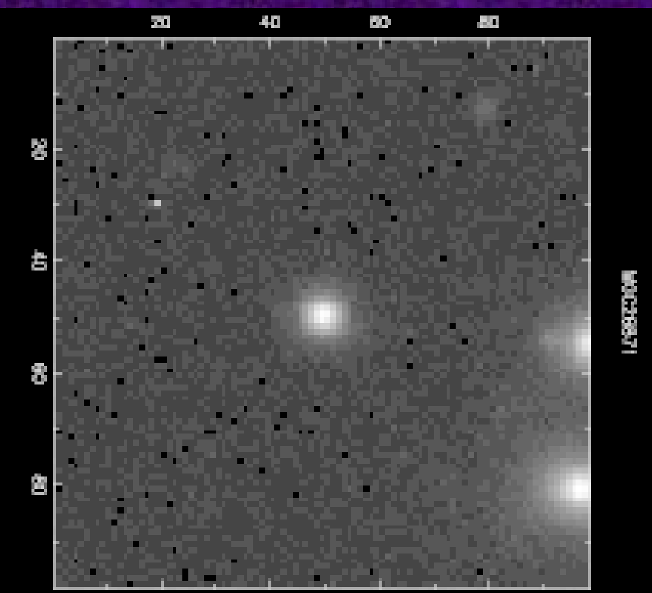
No hidden population of nearby compacts.

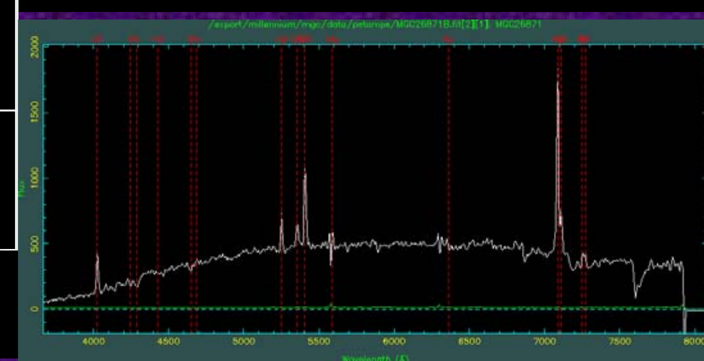
MGCz: The All Object Region



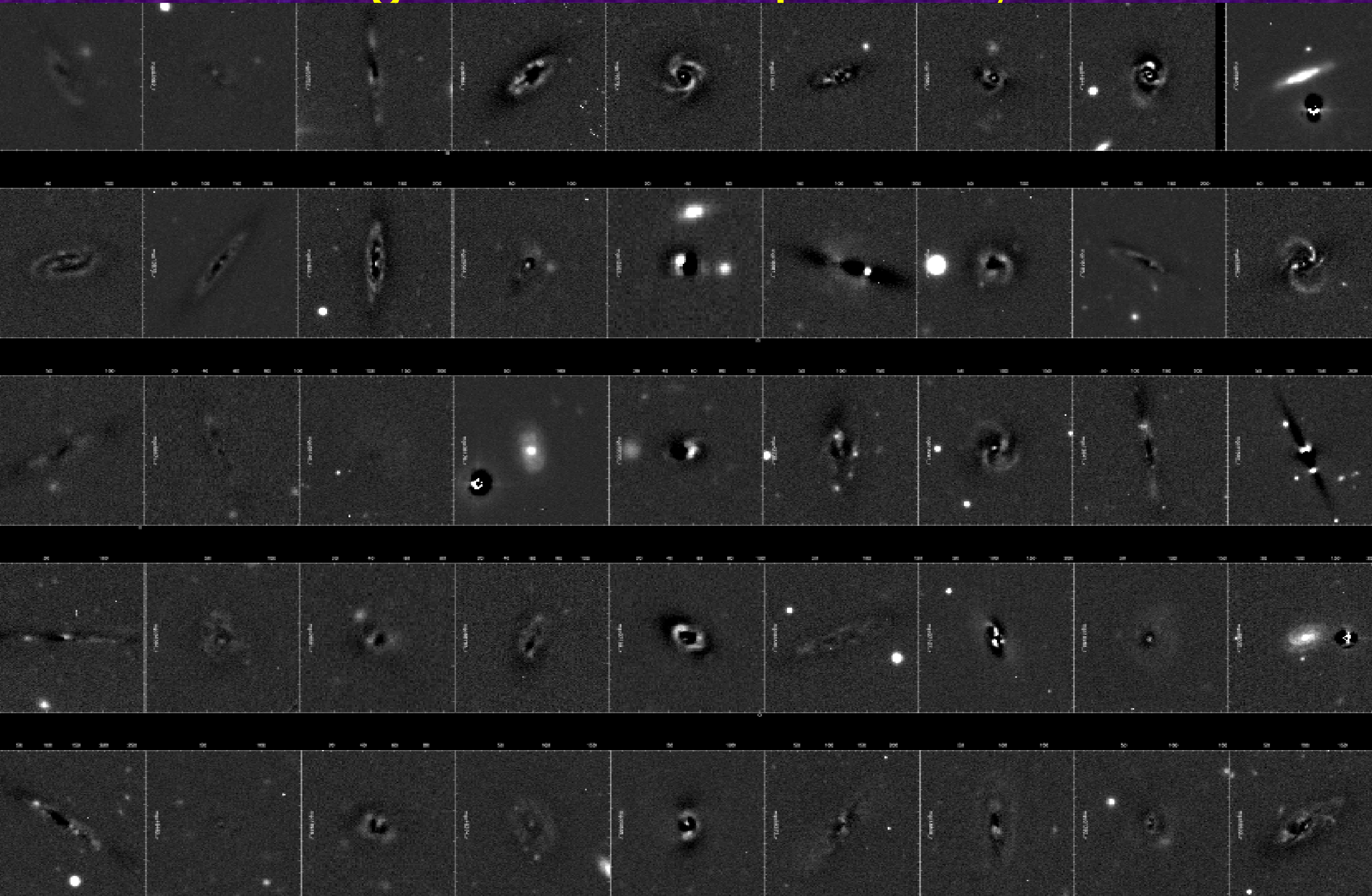
1 compact galaxy found (partially resolved)

Classification error





MGC: Bulge Disk Decomposition, residuals



Not to be outdone: MGC Merchandise

Merchandise List

Home > Merchandise > MGC Sweat Shirt Oxford

MGC Sweat Shirt Oxford

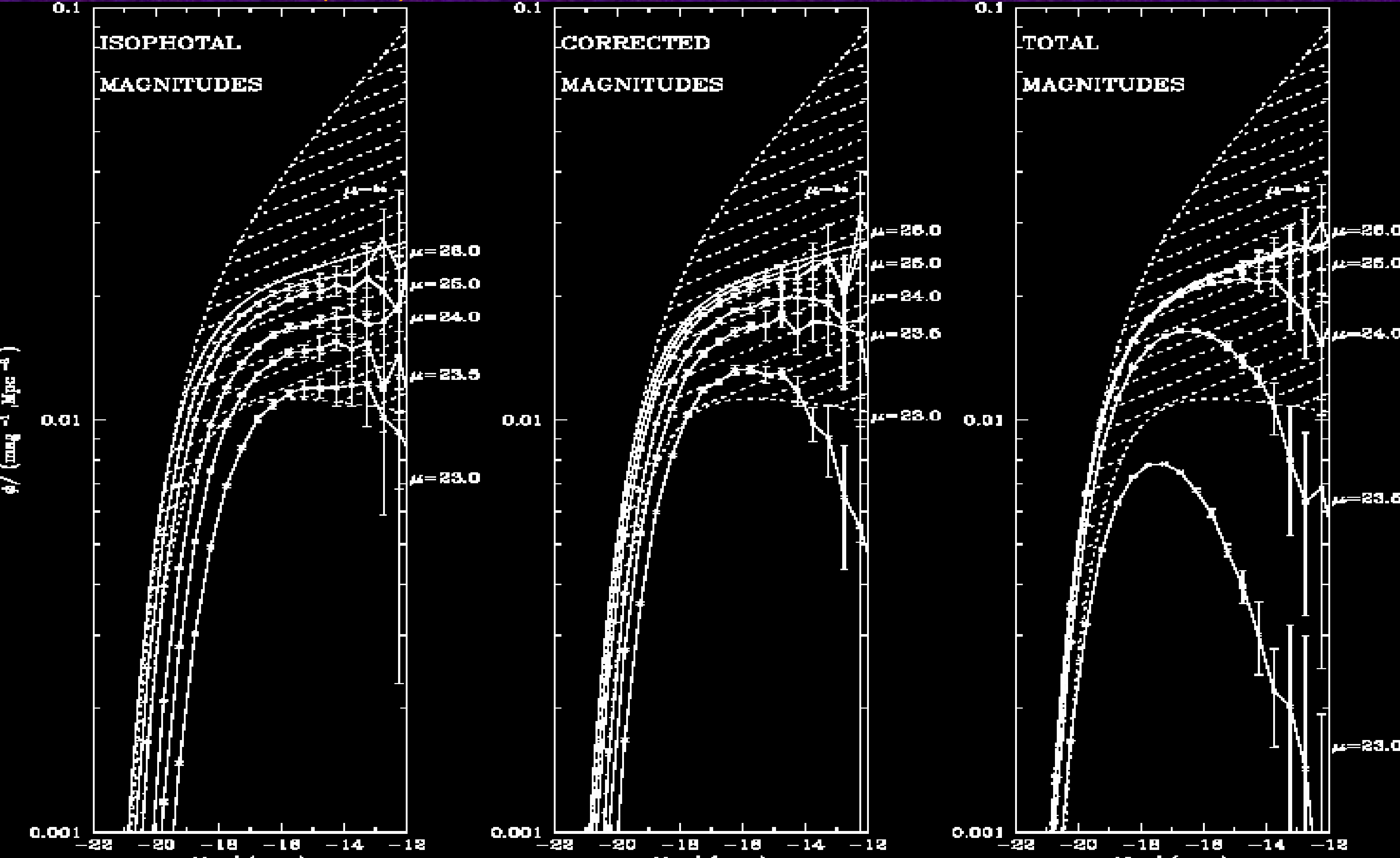
$39.99 - $40.99

SWEAT SHIRT OXFORD WITH BLK MGC AND WARRIORS FELT LETTERS

Style	Color	S	M	L	XL	XXL
Sweat Shirt	OXFORD	$39.99	$39.99	$39.99	$39.99	$40.99

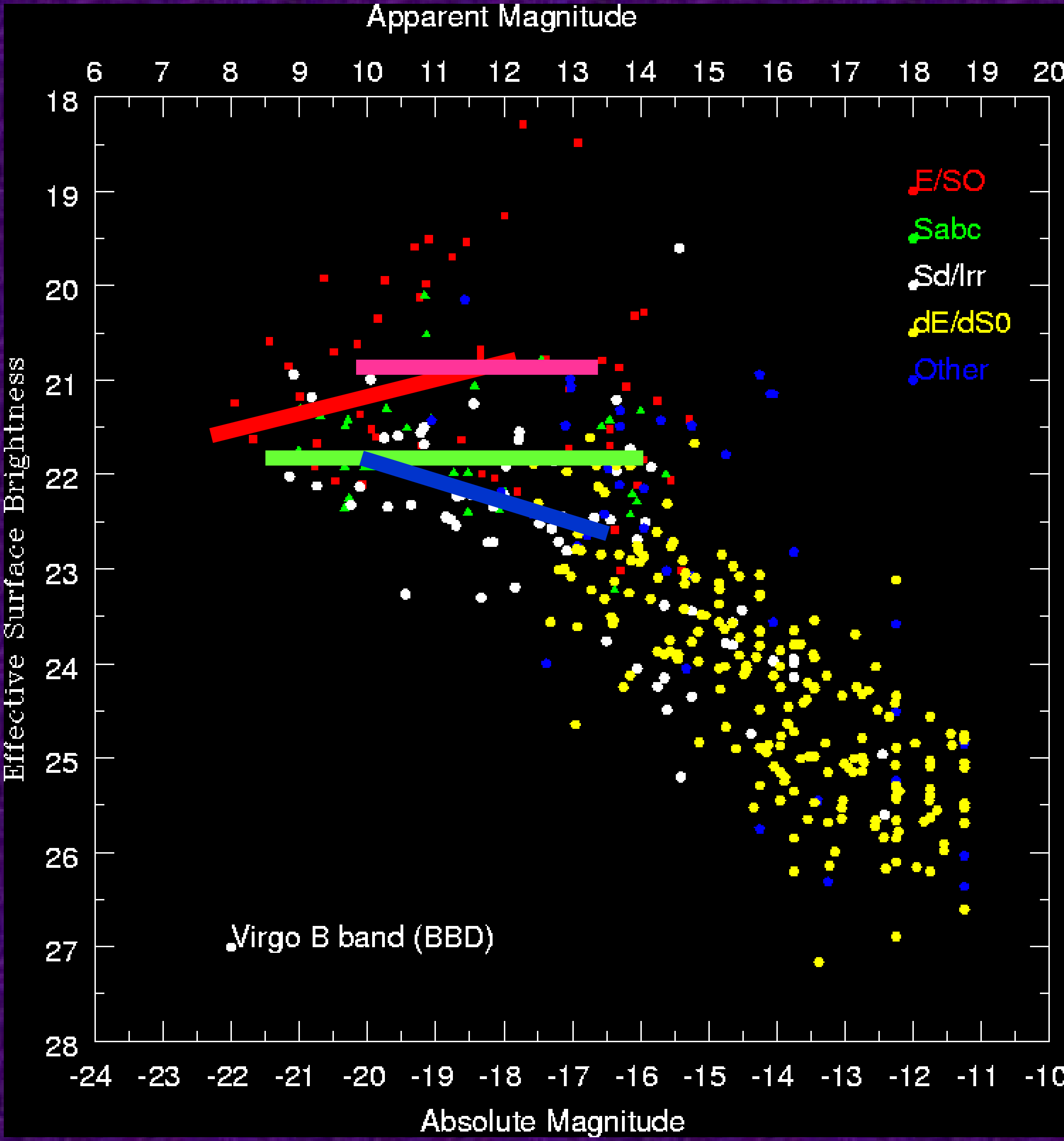
Surface Brightness Selection Bias

- Cross & Driver (2002)



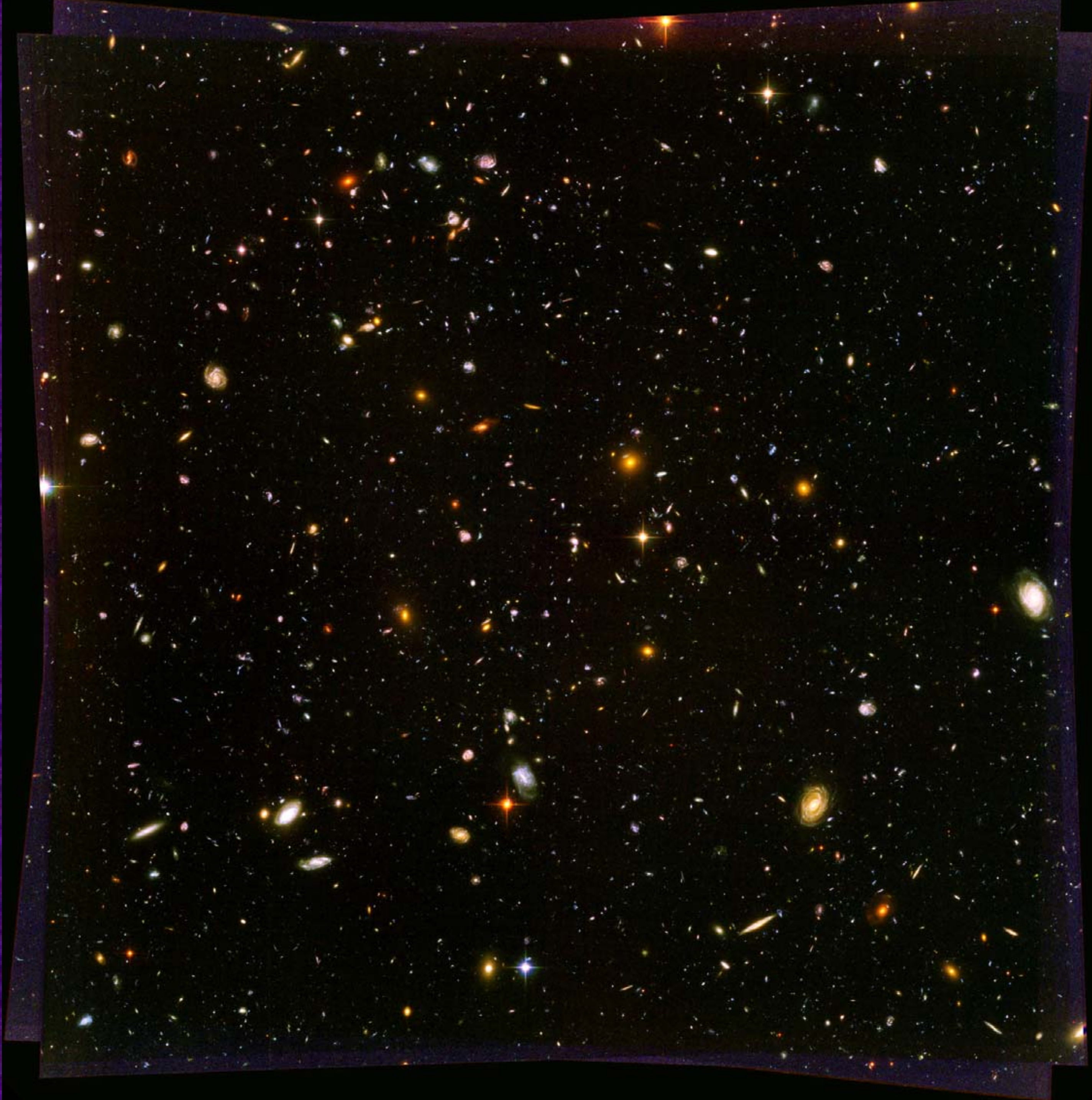
MGC compared to Virgo

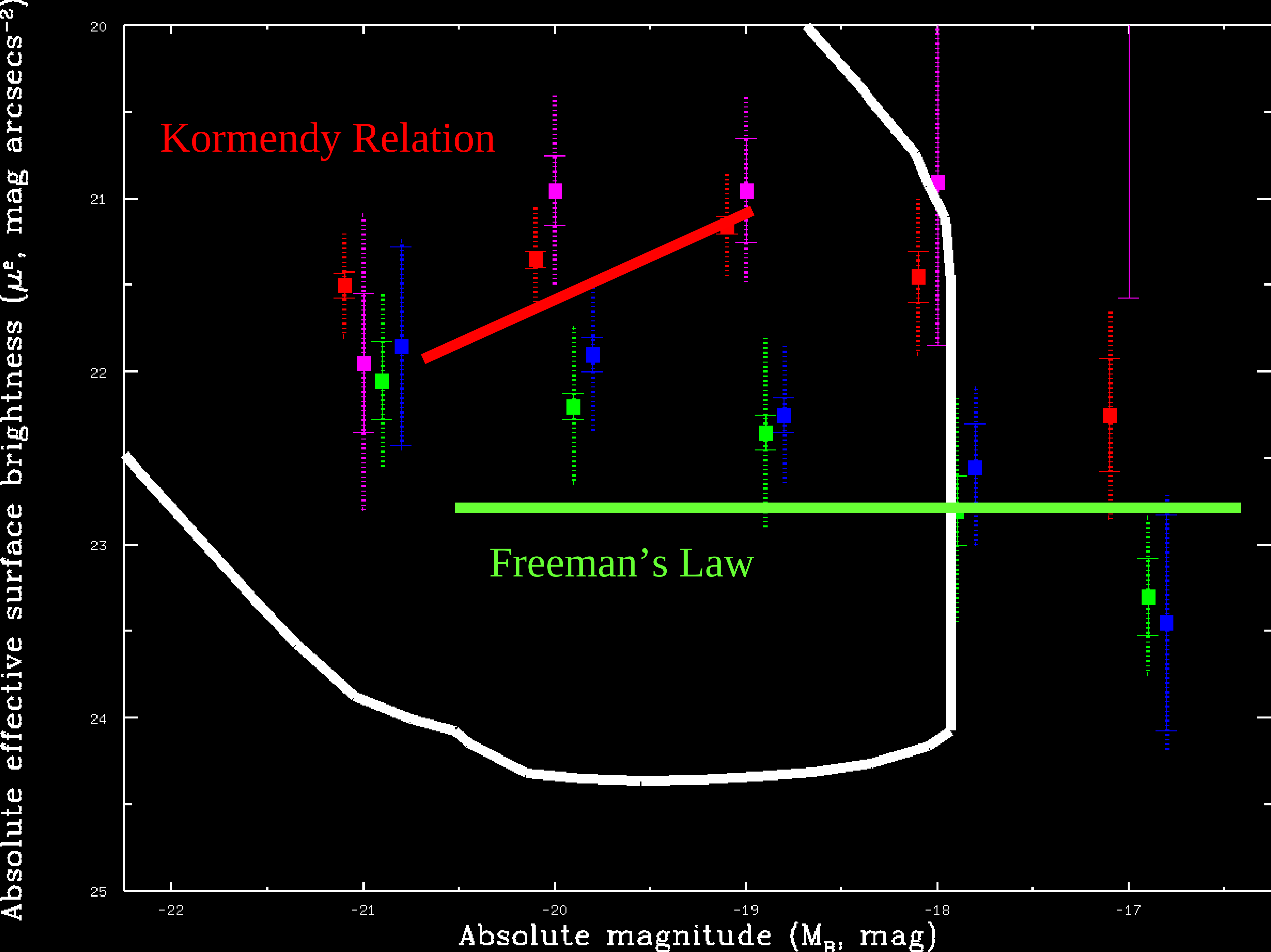
- .

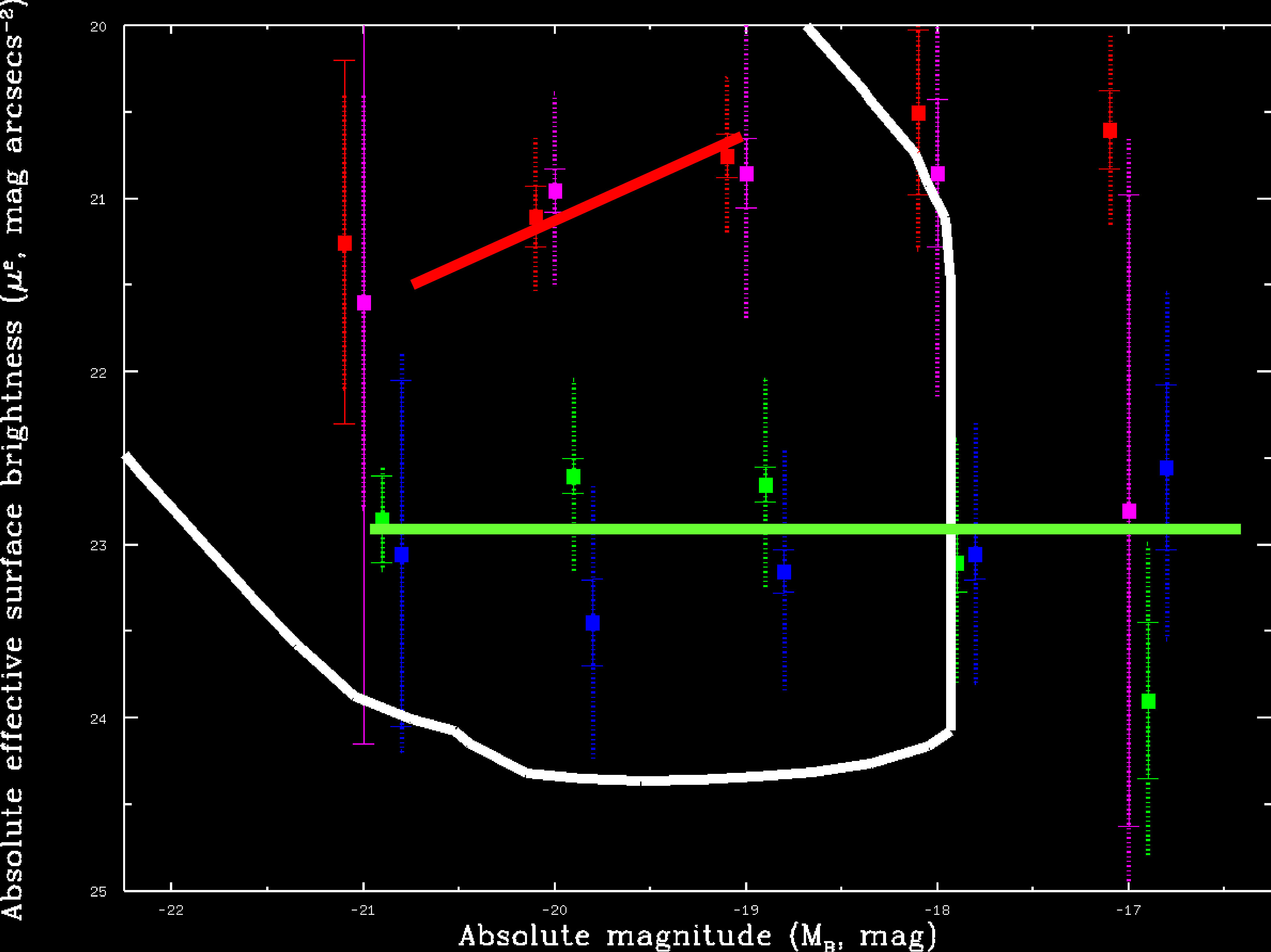


HST Ultra Deep Field

- Public data
  - 03:32:39.0
  - -27:47:29.1
- 412 orbits (AB):
  - B=28.7
  - V=29.0
  - i=29.0
  - z=28.4
- 60 candidate z > 6 objects
- 3.4' x 3.4'
- 0.03 arcsec/pixel
- One of the most expensive photos ever taken !

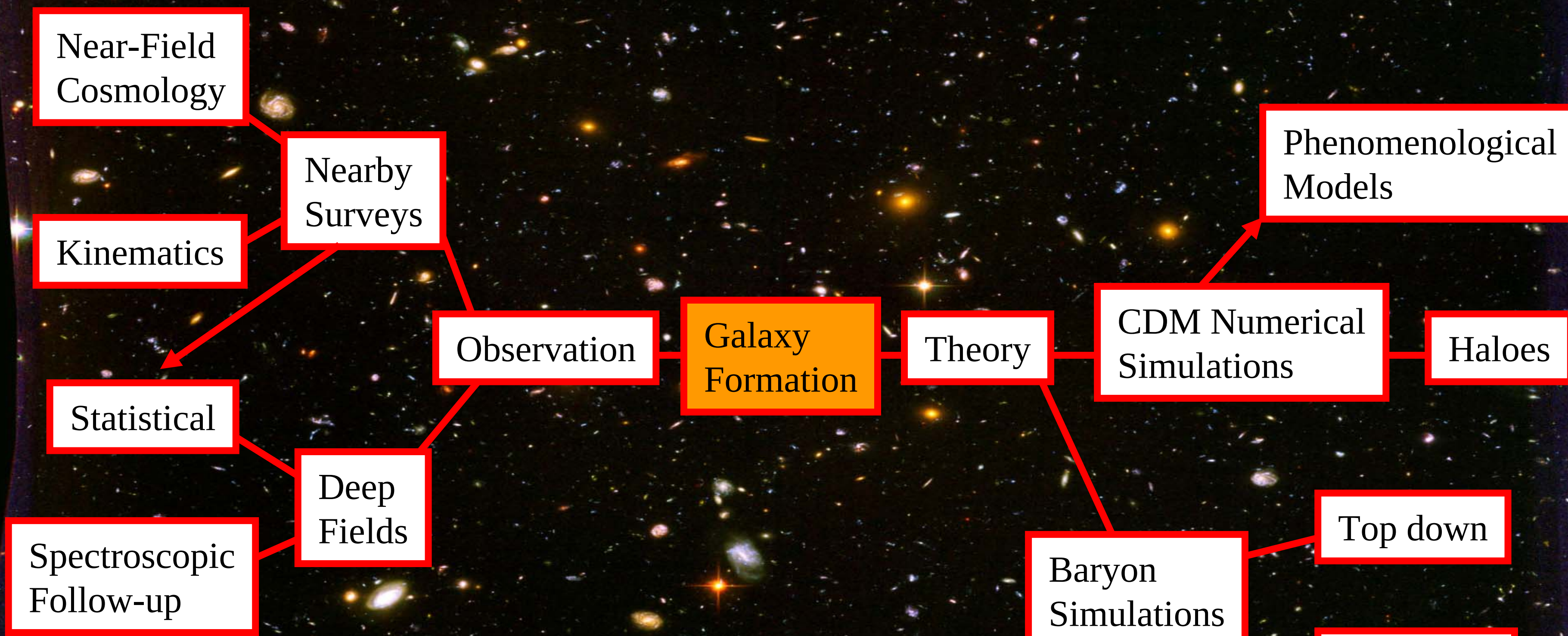



Kormendy Relation
Freeman's Law
Absolute effective surface brightness (μ^e, mag arcsecs^{-2})
20
21
22
23
24
25
-22
-21
-20
-19
-18
-17
Absolute magnitude (M_B, mag)



Absolute effective surface brightness (μ^e, mag arcsecs^{-2})
20
21
22
23
24
25
-22
-21
-20
-19
-18
-17
Absolute magnitude (M_B, mag)

Galaxy Formation: Overview



Physics of the L-Σ relation ?

$\lambda \alpha J |E|^{1/2} M^{-5/2} G^{-1}$ - The Dimensionless Spin Parameter (Peebles 1969)
[λ =1 = rotationally supported system, $\lambda \sim 0.03–0.12$]

$|E|^{1/2} \alpha \; v_c M_{tot}^{1/2}$ - Total Energy

$M_{tot} \alpha M_D$ - Disk/Halo mass

$M_D \alpha L^{\gamma}$ - Mass-to-light ratio (observed, here assume γ=1)

$L \alpha v_c^3$ - The Tully-Fisher relation (observed)

$J \alpha M_D v_c r_e$ - Angular-Momentum

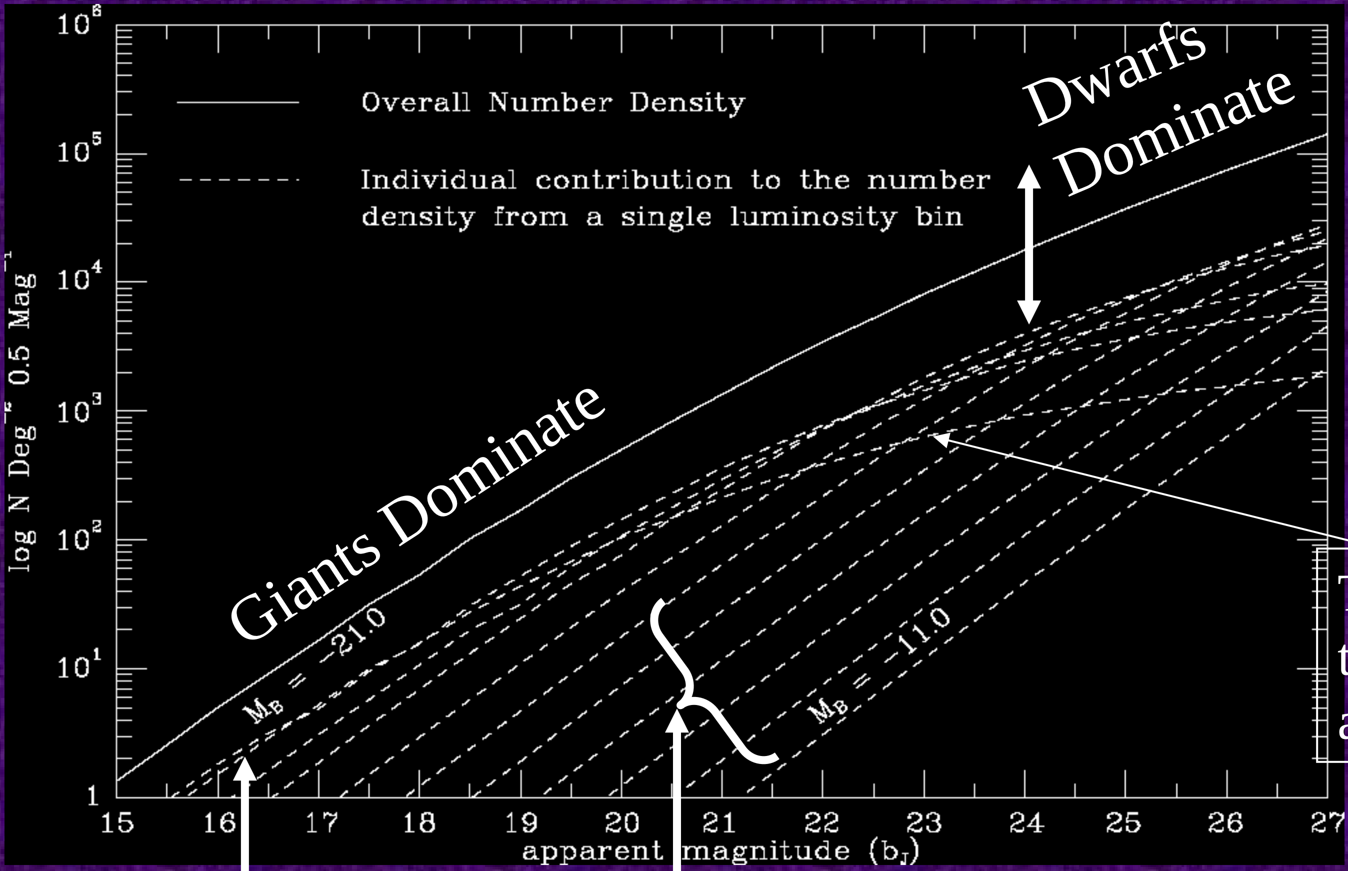
$\Sigma \alpha L r_e^{-2}$ - Surface Brightness

$\lambda \alpha L^{1/6} \Sigma^{-1/2}$ => $M \alpha 3 \mu_e$ (de Jong & Lacey 2000)

During merging individual λ's vary but the overall distribution should remain log Normal

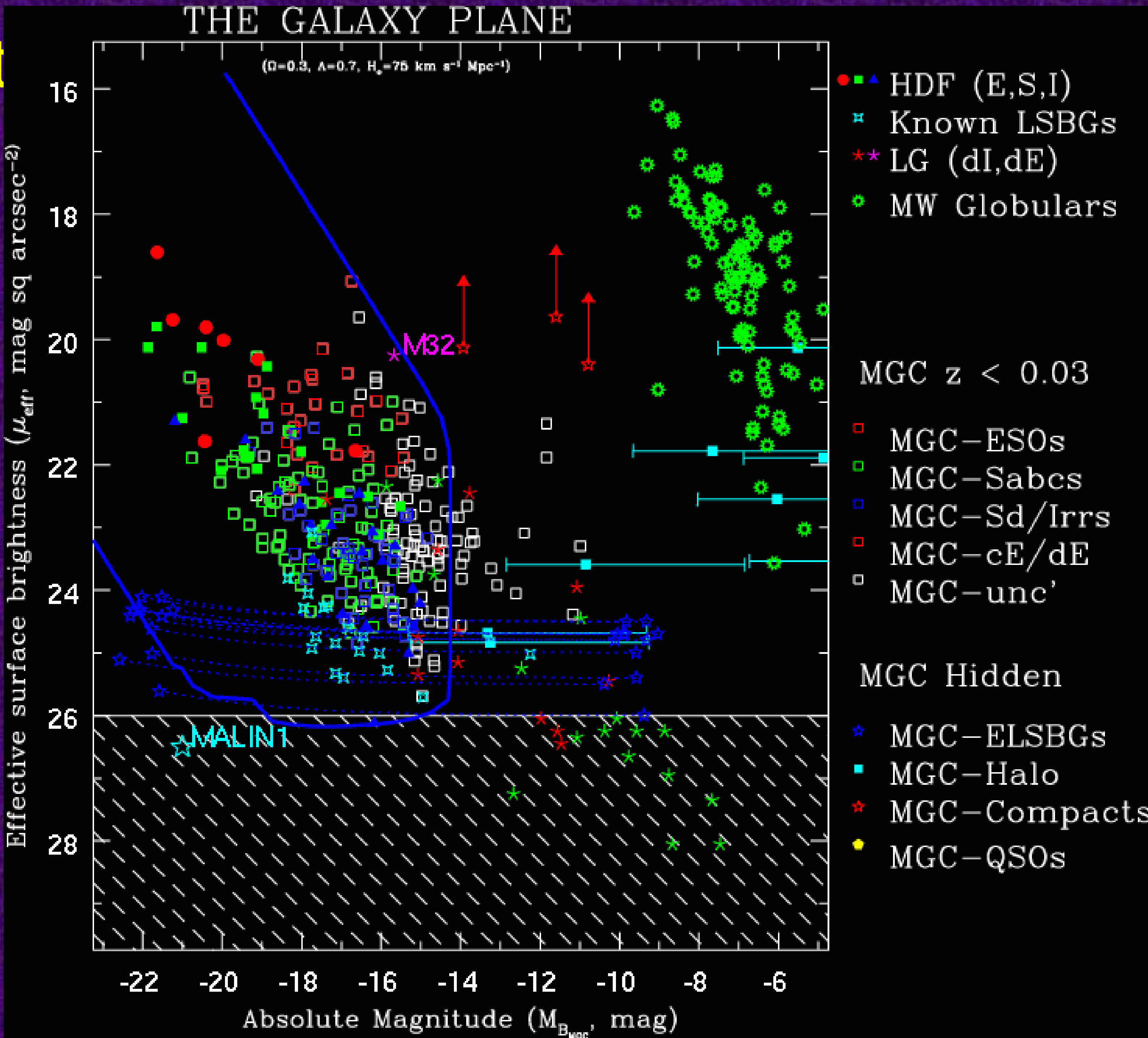
The impact of the faint-end at faint magnitudes

- The contribution of each luminosity class to the numbers of galaxies (α=1)



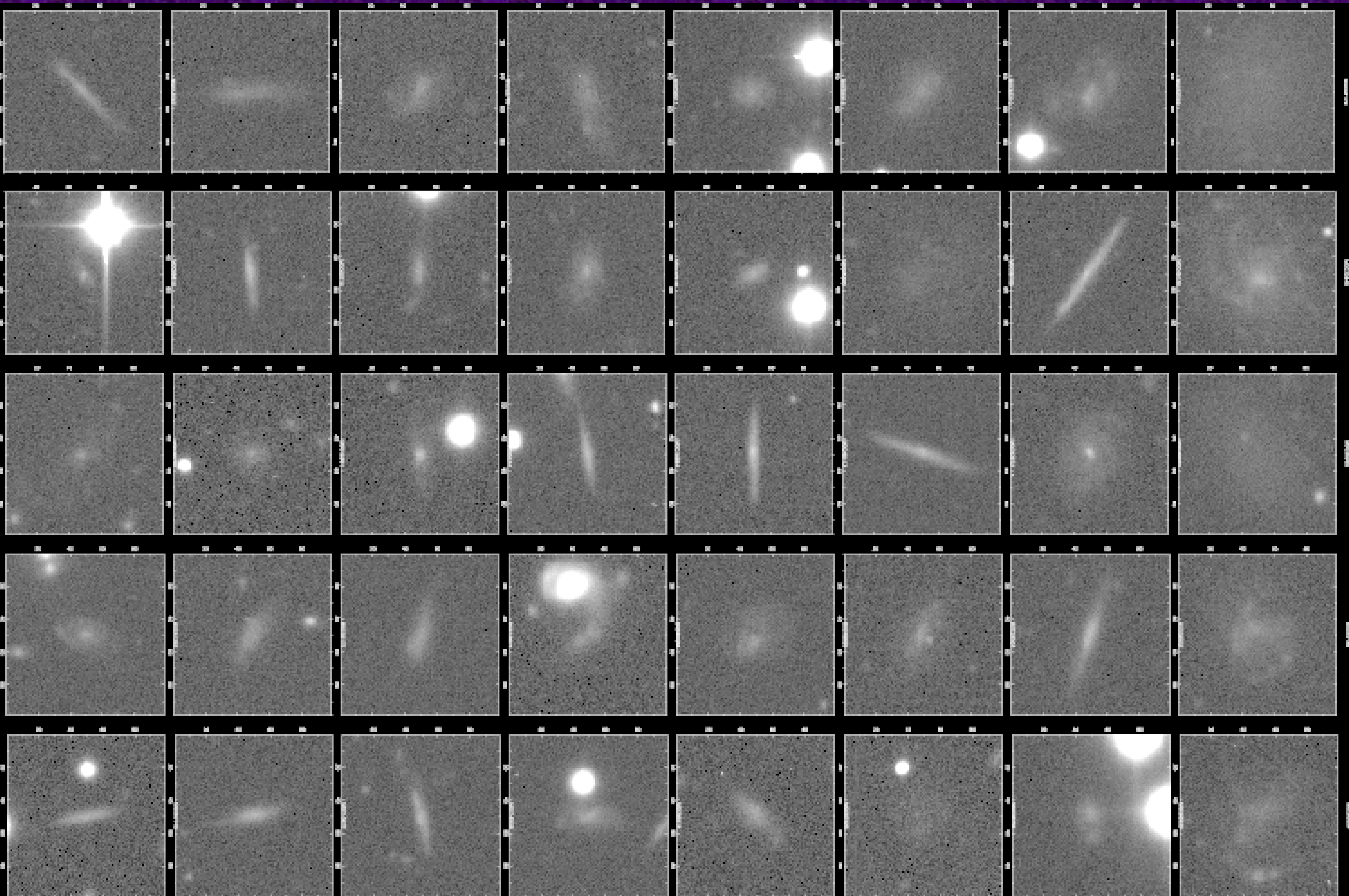
Driver et al (1995)

Current LSP



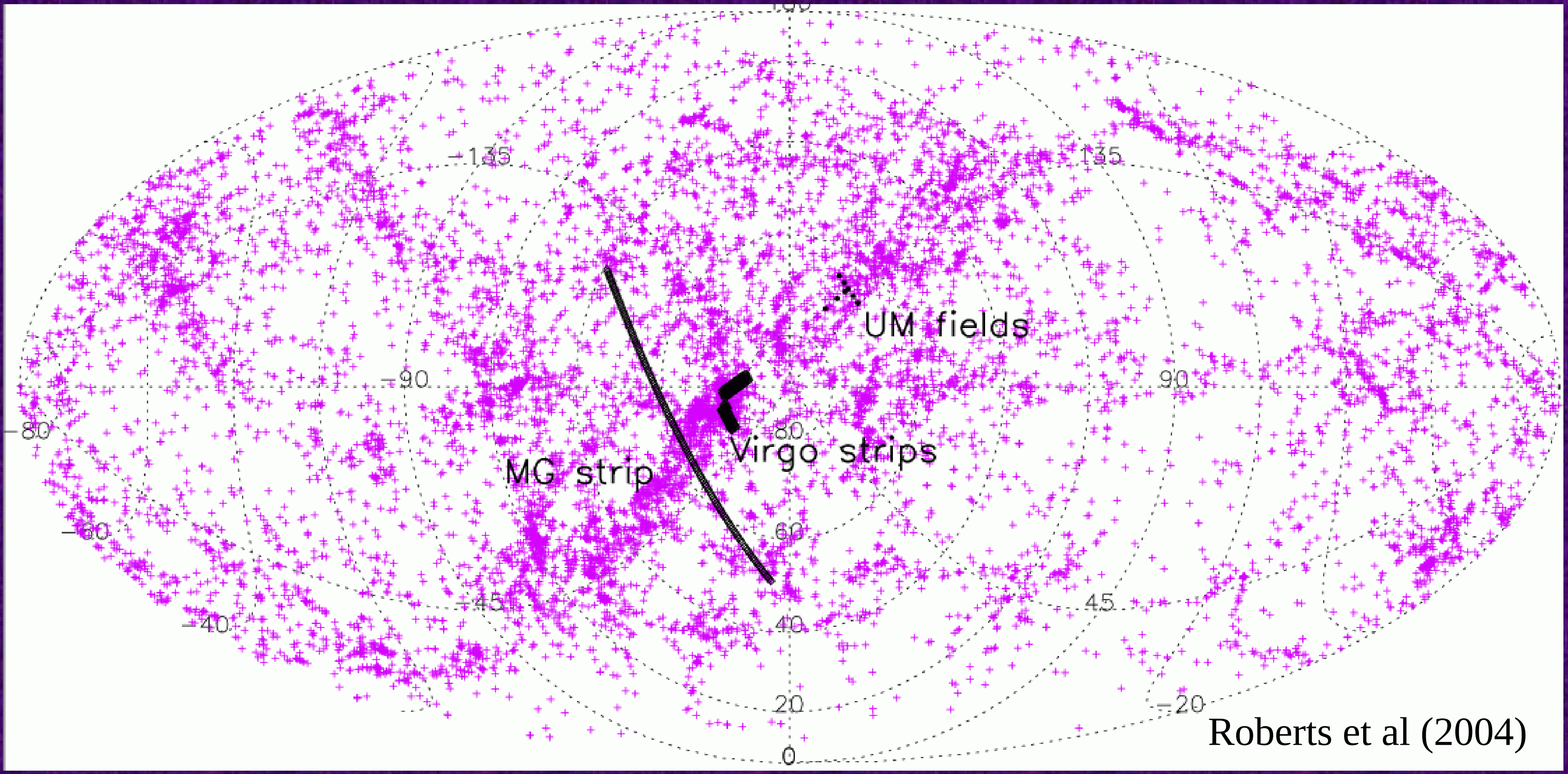
THE GALAXY PLANE
(Ω=0.3, Λ=0.7, H₀=75 km s⁻¹ Mpc⁻¹)
HDF (E,S,I)
Known LSBGs
LG (dI,dE)
MW Globulars
MGC z < 0.03
MGC−ESOs
MGC−Sabcs
MGC−Sd/Irrs
MGC−cE/dE
MGC−unc'
MGC Hidden
MGC−ELSBGs
MGC−Halo
MGC−Compacts
MGC−QSOs
M32
MALIN1
Effective surface brightness (μeff, mag sq arcsec⁻²)
Absolute Magnitude (MBmgc, mag)
16
18
20
22
24
26
28
-22
-20
-18
-16
-14
-12
-10
-8
-6

MGC: Low Surface Brightness Galaxies (no z's)



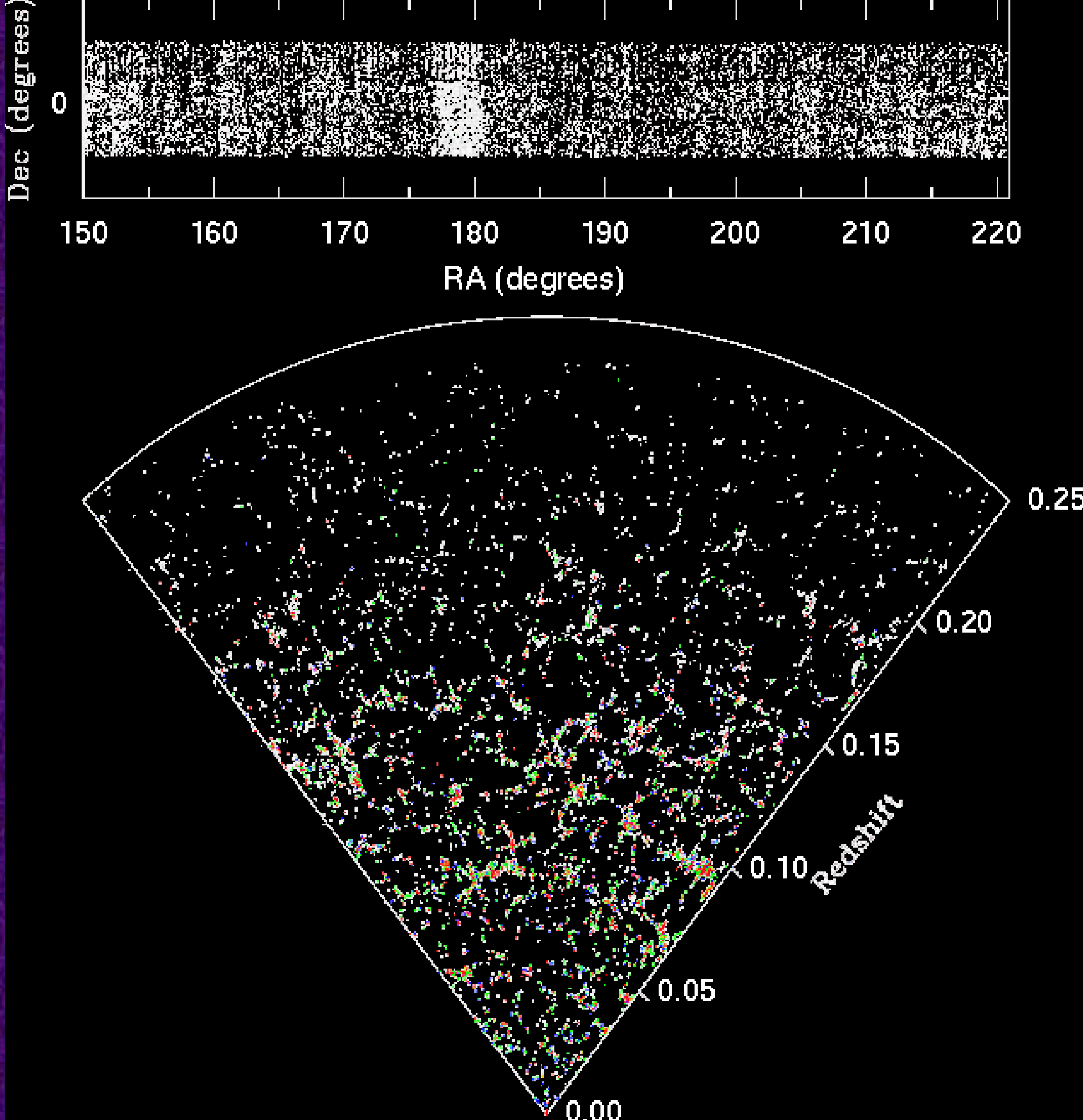
The Millennium Galaxy Catalogue

- Projection of MGC region looking down from North Galactic Pole
- Crosses show NED galaxies with v < 4500 km /s
- Northern Hemisphere "above/right" of MGC strip, Southern "below/left".



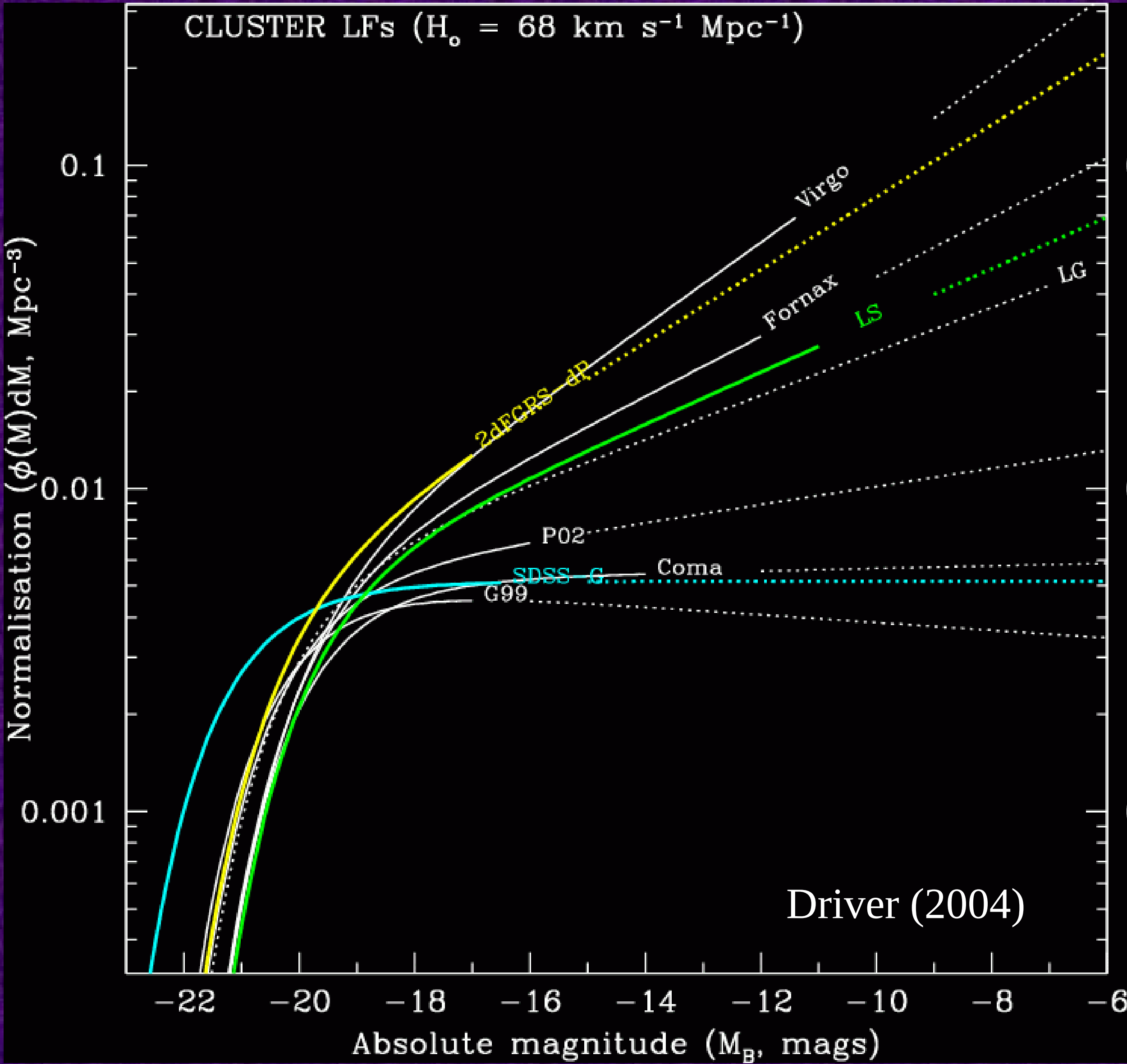
Roberts et al (2004)

MGC Cone Plot

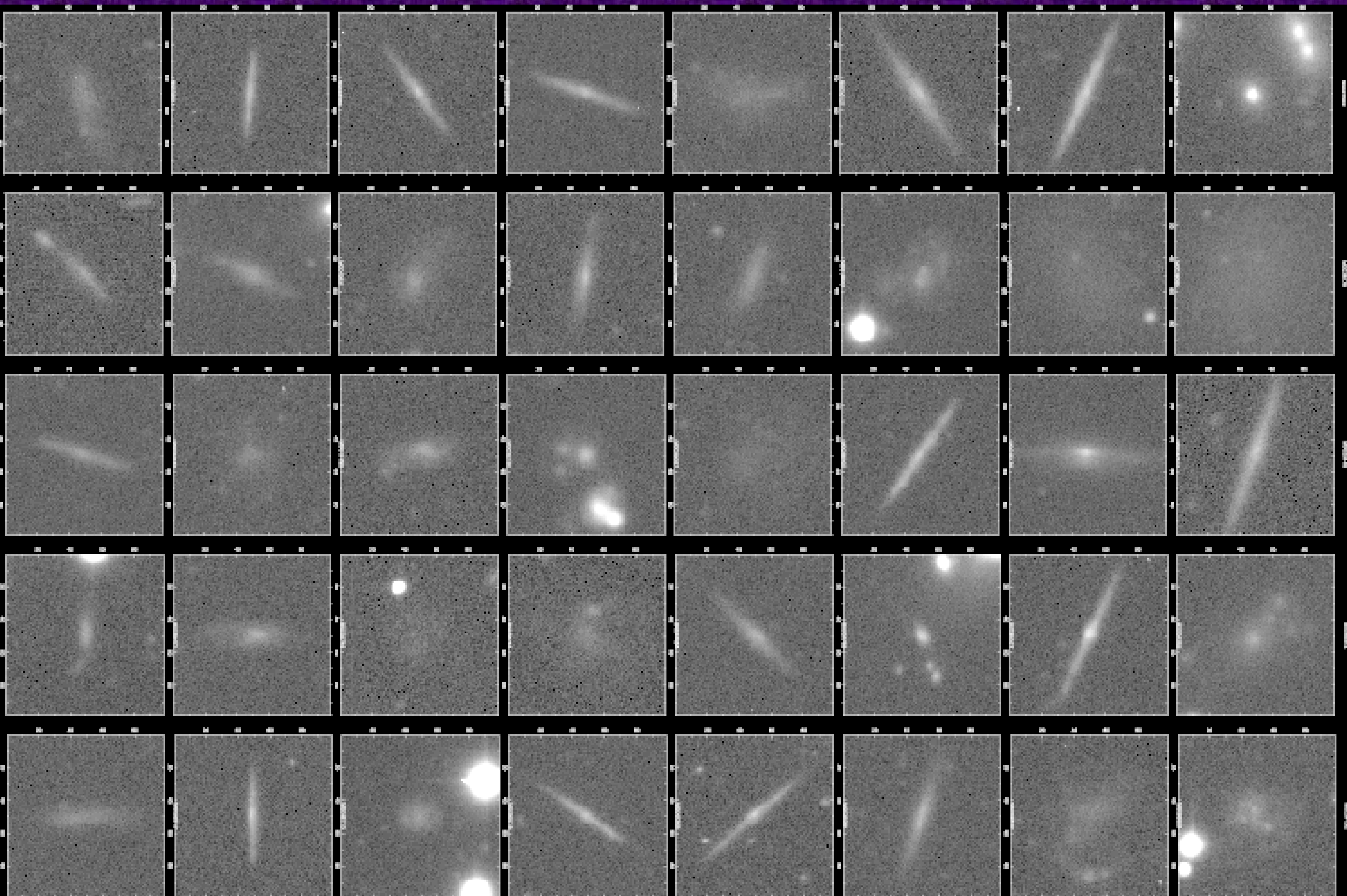


The Space Density of Galaxies

- Cluster surveys also show wide dispersion
- Cannot study environmental dependencies until systematic resolved
- SDSS ?

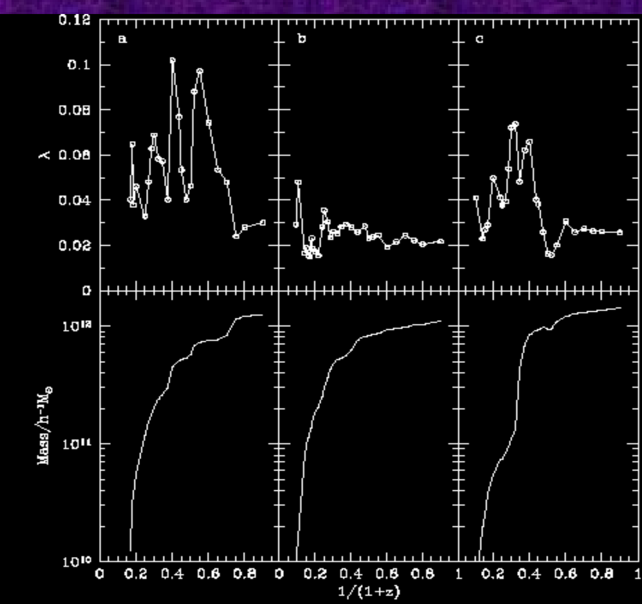


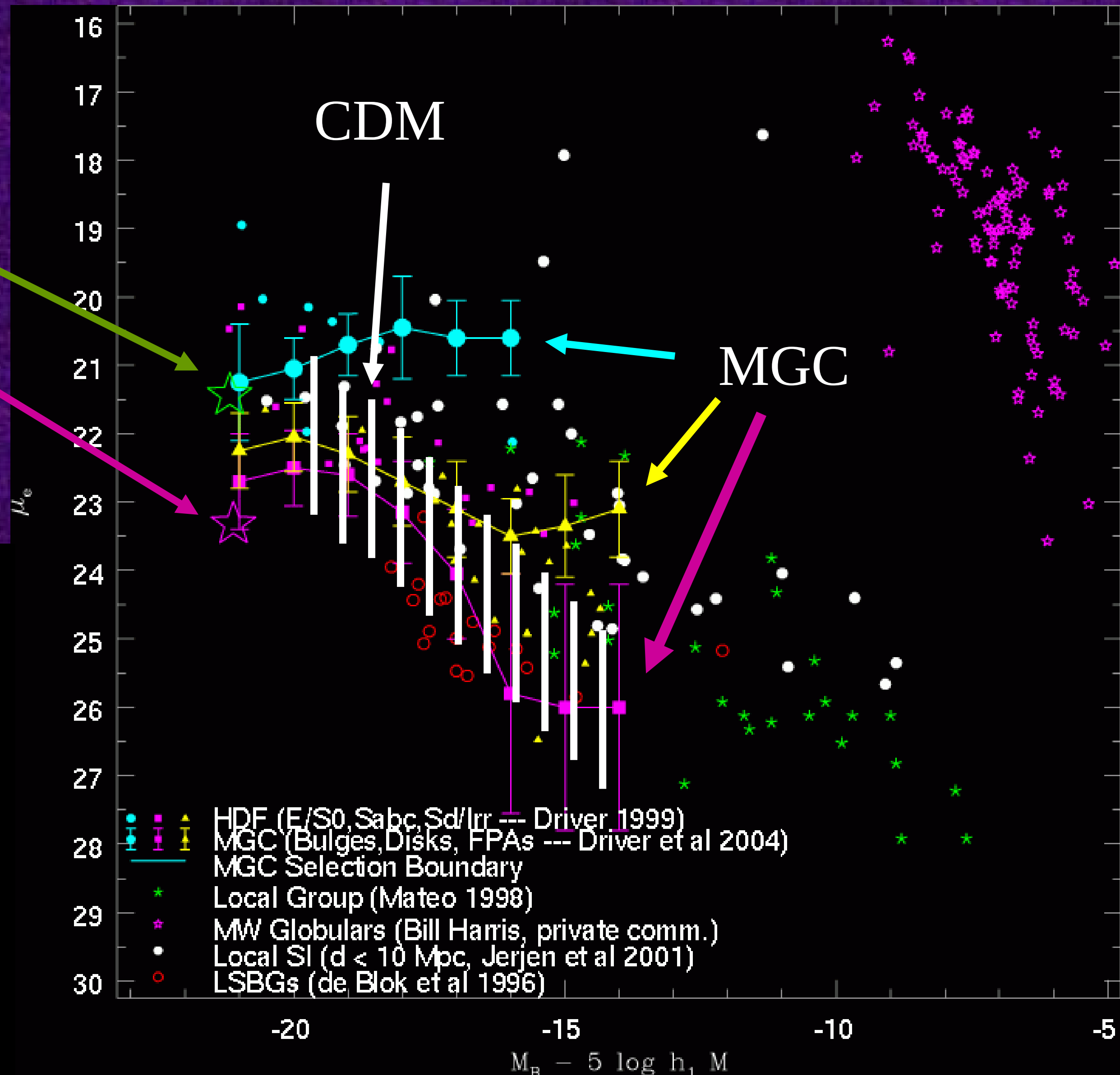
MGC:Low Surface Brightness Galaxies (z's)



Galaxy Formation: CDM and the LSP ?

- Steinmetz Inc.
  - Elliptical
  - Disk





The MGC Galaxy Luminosity Function

- New BBD-SWML methodology including:
  - ~10,000 galaxies to B=20 mag (Kron magnitudes, catalogue fully eyeballed)
  - Seeing corrected surface brightness measurements based on major axis half-light radii
  - Incompleteness corrections based on apparent magnitude & effective surface brightness
  - Tracking of 5 selection boundaries for each galaxy
  - Individual K-corrections derived from uBgriz photometry

Galaxy Formation: Phenomenological Models

- CDM Numerical simulations plus handful of known scaling relations (e.g., T-F) to allocate galaxies to haloes
- e.g., Rimes, van Kampen (2002)
  - Predicts bivariate μ v r dist'n

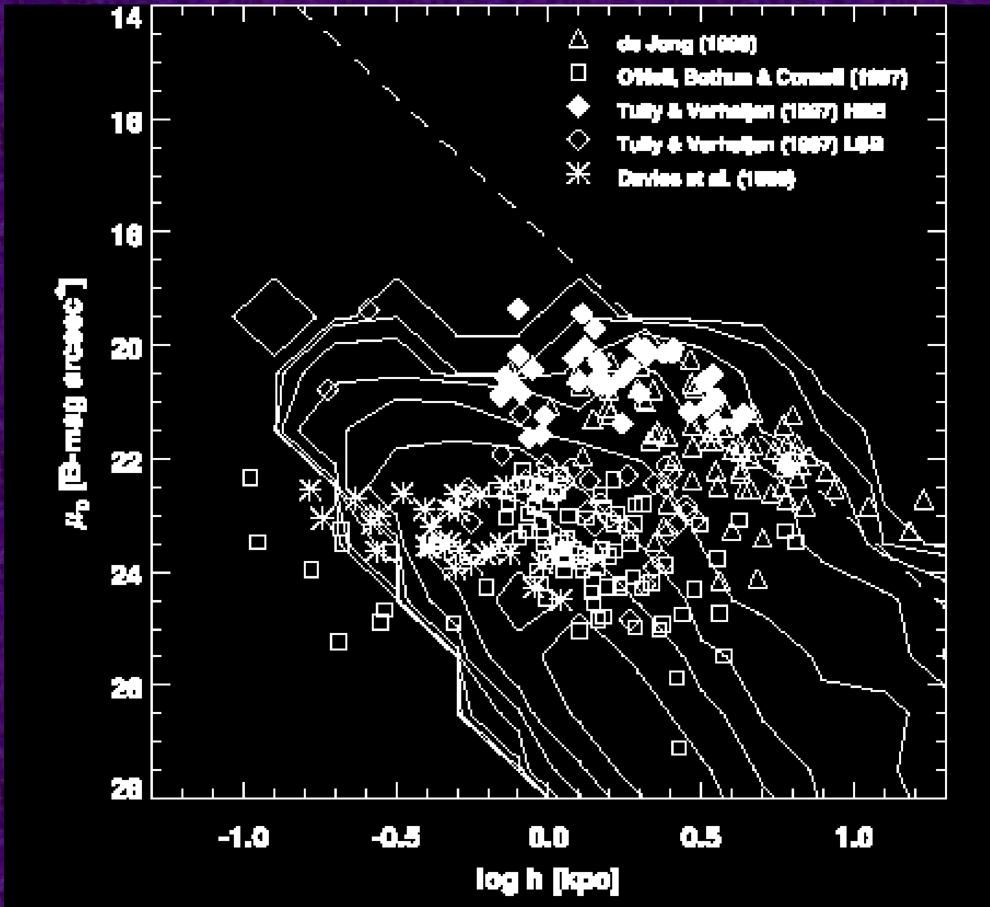


Fig. 1. Bivariate distribution of central disk surface-brightness against exponential scale length. Contours are the number density of galaxies as predicted by our model. The dashed line is the knee of the Schechter luminosity function.

The Luminosity-Surface Brightness Plane

- Also Luminosity-Size plane (US)
- Ferguson & Binggeli (1994) in Virgo
- Previous Measurements:
  - Driver (1999) - 50 galaxies from HDF at z=0.4, selection boundaries defined
  - de Jong & Lacey (2000) - Nearby Sdm galaxies, selection effects incorporated
  - Cross, [Driver] et al (2001) - 2dFGRS, selection effects modeled via visibility theory but APM
  - Driver & De Propris (2003) - Local group only 50 galaxies, ad hoc selection
  - Shen et al (2003) - SDSS study of 140,000 galaxies, selection effects ignored
- Pros:
  - Manages selection bias
  - Quantitative combination of HRF+LF+SBF into one scheme
  - Theoretical basis (see later)
  - Well established in cluster environments
- Cons:
  - Requires clearly defined selection limits
  - Requires a high completeness survey (imaging and spectroscopic)
  - Requires detailed consideration of all selection effects throughout