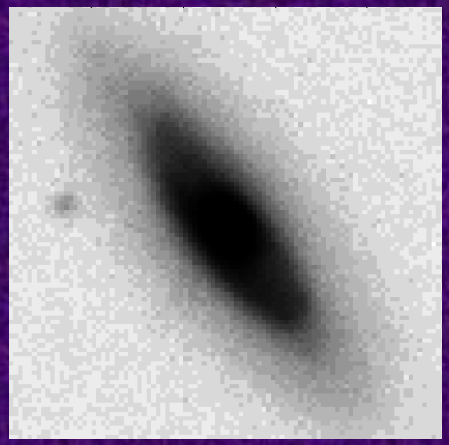
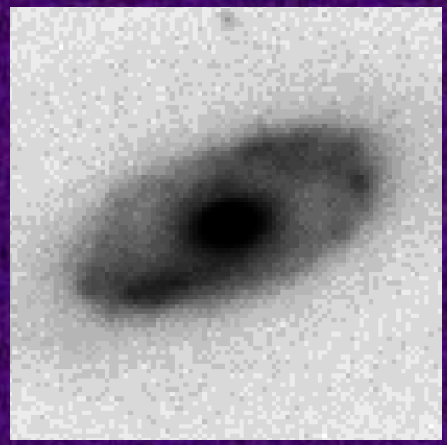
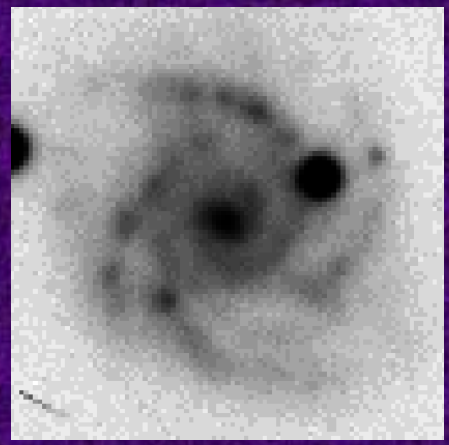
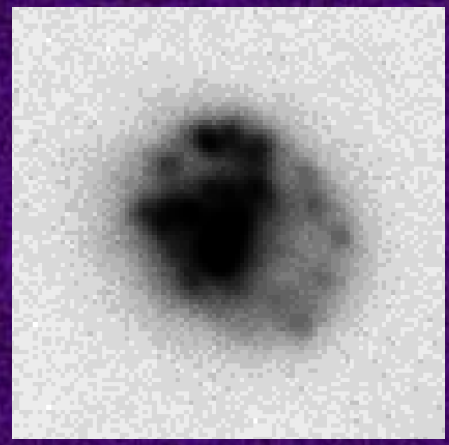
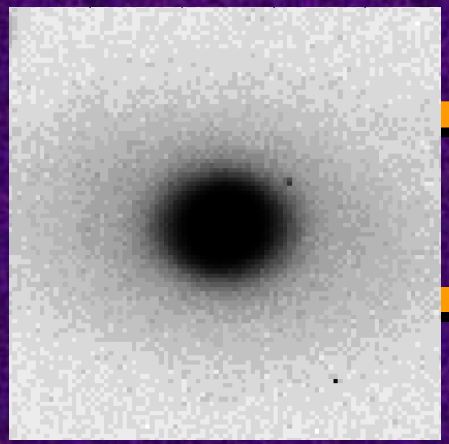
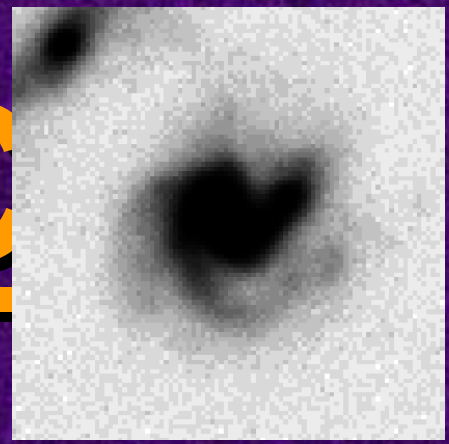







THE MGC

Simon Driver (RSAA)

David Lemon, Jochen Liske (St Andrews)

Nicholas Cross (JHU)

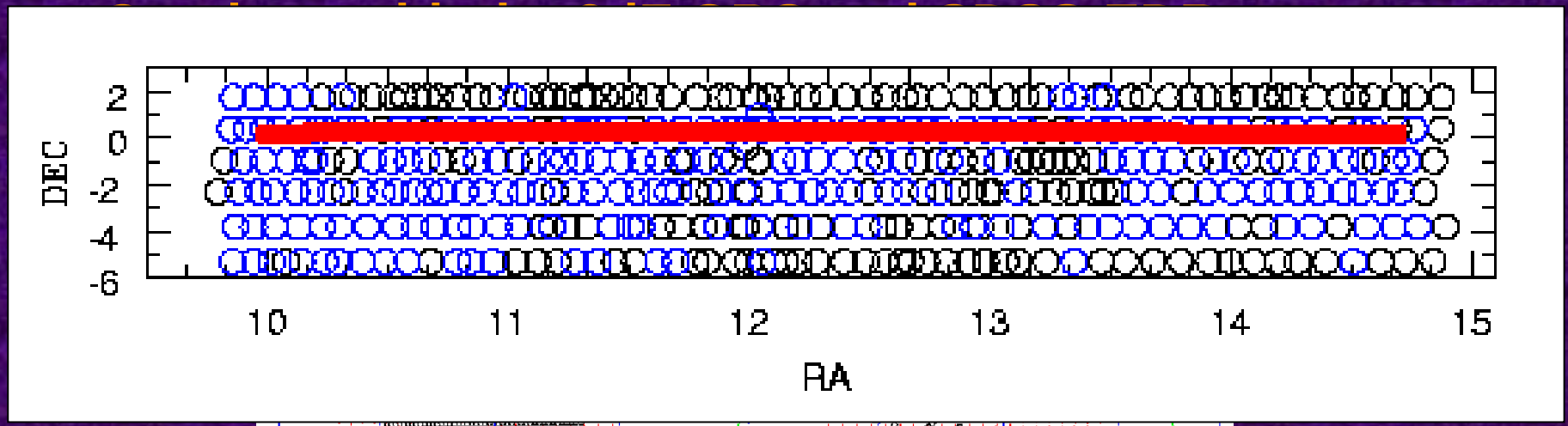
[Rogier Windhorst, Steve Odewahn, Seth Cohen (ASU)]

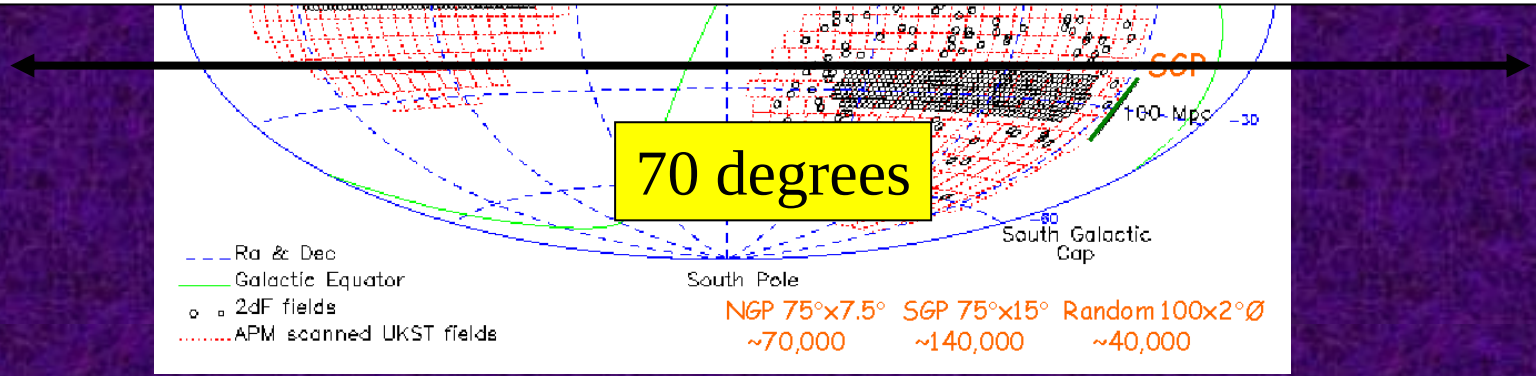
Overview

- **The Millennium Galaxy Catalogue - The MGC**
  - A *High Precision* Nearby Galaxy Catalogue - A Roll-Royce Survey
    - Observation, Reduction, Calibration (Photometric and Astrometric), Image Detection, Image Extraction, Contamination, Classification & Completeness
  - Preliminary Science Results:
    - Star-counts and the Galactic Halo
    - Calibration of 2dFGRS and SDSS-EDR
    - Missing Local Galaxy Populations ?
    - Precision Galaxy Counts $16 < B < 24$
      - Solving the Normalisation Problem
      - Measuring/Constraining the Local Luminosity Function
      - The Local Luminosity Density
      - The fraction of baryons in galaxies
  - Future work and the bigger picture:
    - The MGC-BRIGHT morphology and redshift campaign
    - Pushing beyond the nearby universe: HST BBPAR and GOODS surveys

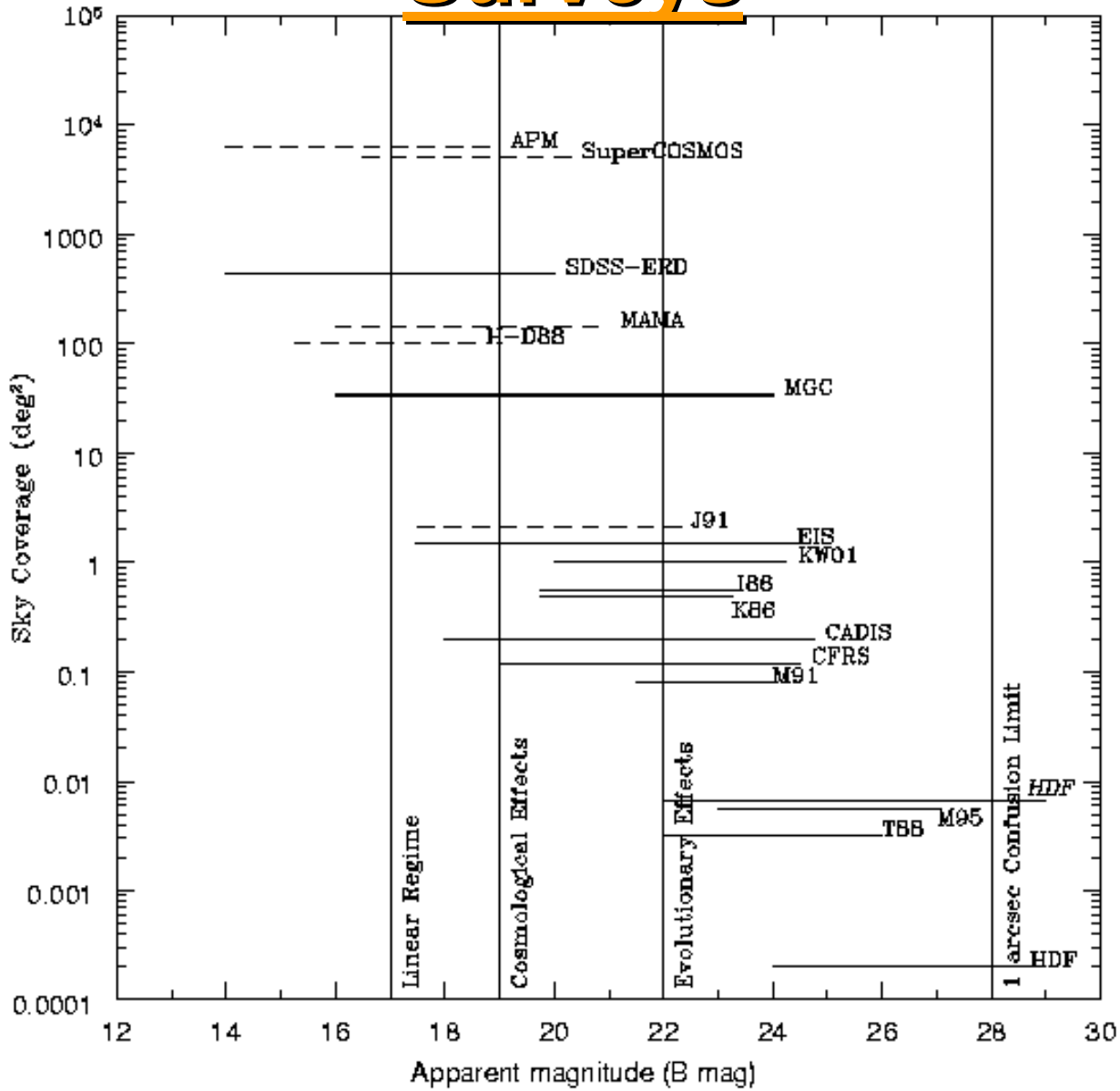
The Millennium Galaxy Catalogue

- A deep wide survey (36 sq deg, to μ_{lim}=26 mags/sq arcsec, B~24 mags)
- The Isaac Newton Telescope (2.5m) Wide Field Camera



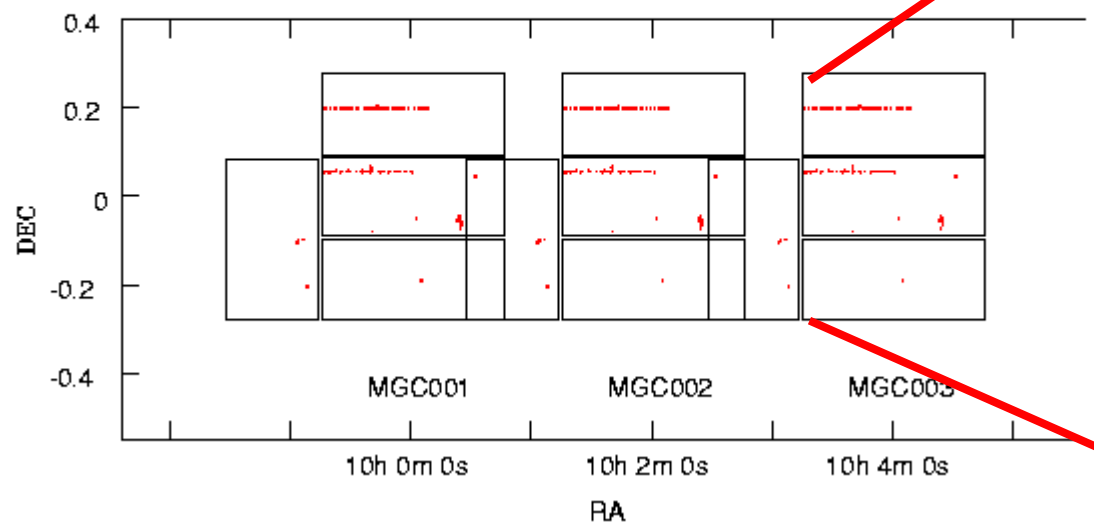


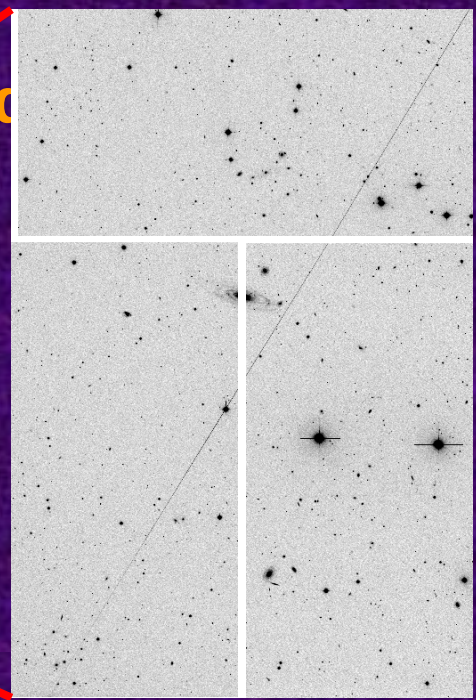
Comparison to other Imaging Surveys



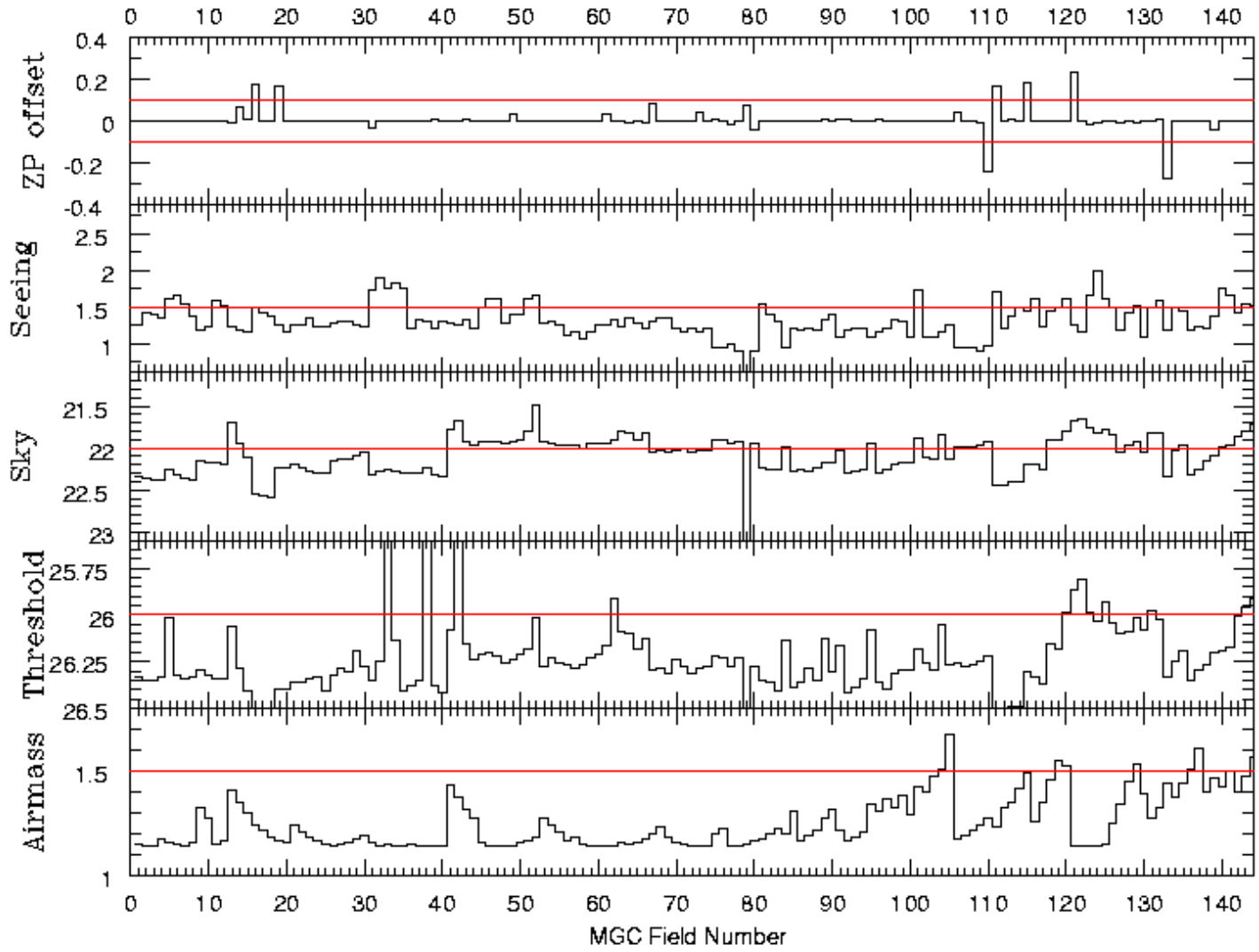
The WFC Footprint

- 144 overlapping pointings along zero dec (10h00m-14h50min)
- 576 individual 2048x4100 CCD images
- 0.33'' pixels, seeing FWHM ~ 1.3'', single 750 sec exposures
- B-band only (u,g,r,i,z from SDSS-EDR)
- Redshifts to B=19.45 from 2dFGRS and



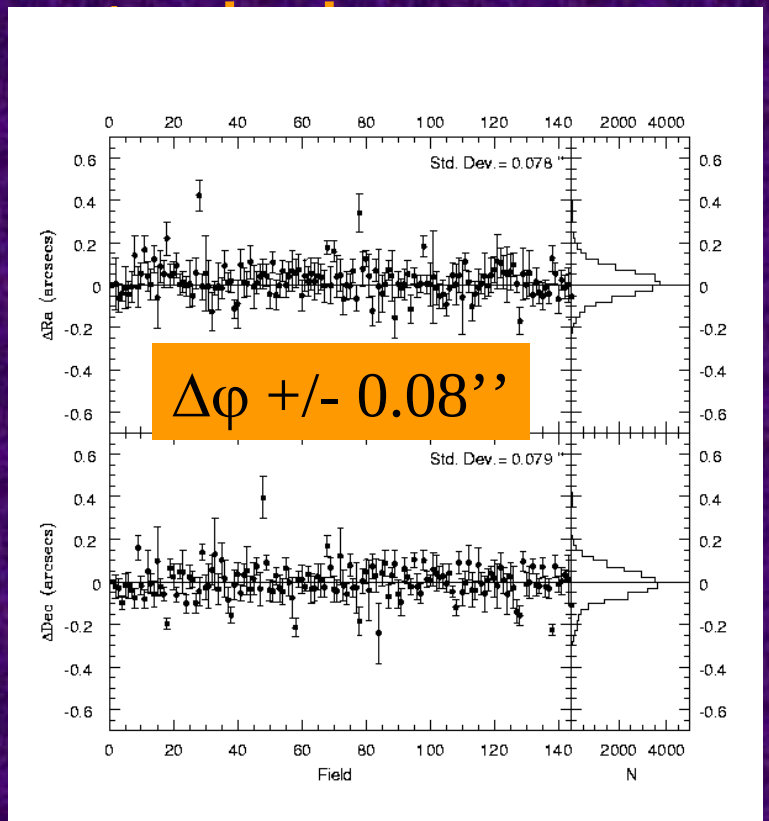


Data Quality



Calibration (Photometry and Astrometry)

- Every 10th field calibrated to Landolt Standards
- Data reduced via Cambridge WFSU pipeline
- Final astrometry calibrated to APM (Tycho-2)
- Final photometry via bootstrapping *between*



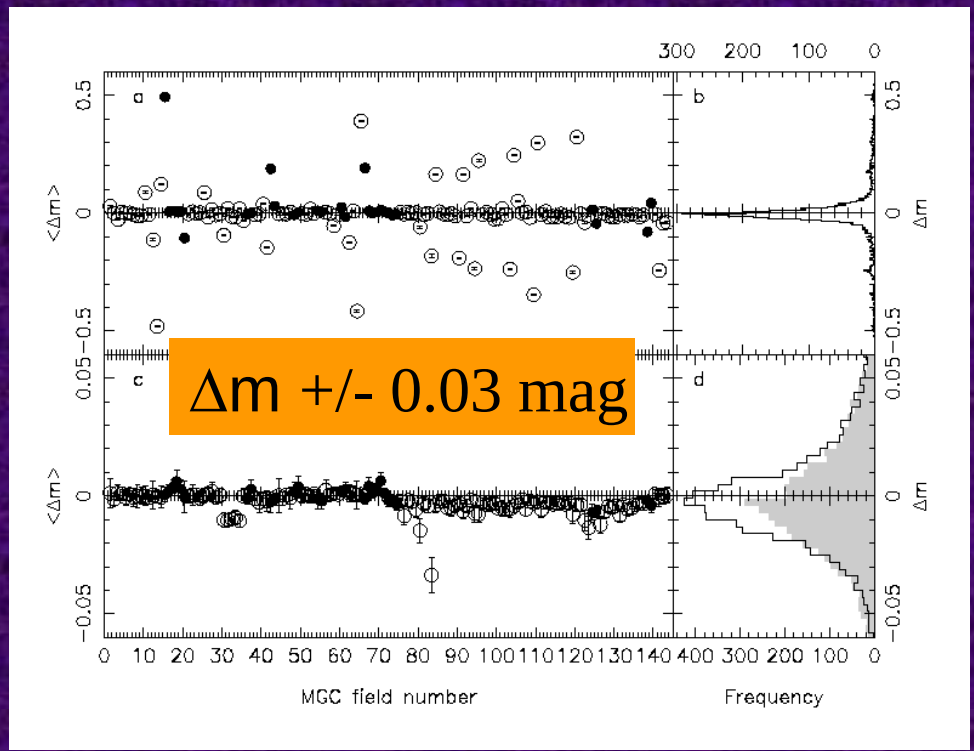
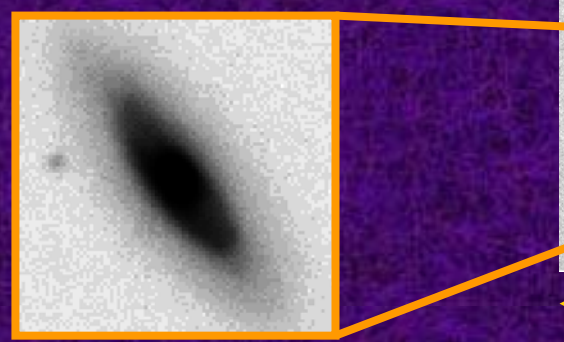


Image Detection and Analysis

- **Analysis Issues:**
  - Photometric Accuracy/Conditions
  - Background variations/light gradients
  - Bright stars
  - Object detection/deblending
  - Isophotal v total magnitudes
  - Star-galaxy separation
  - Completeness and Selection Biases



m=16th mag

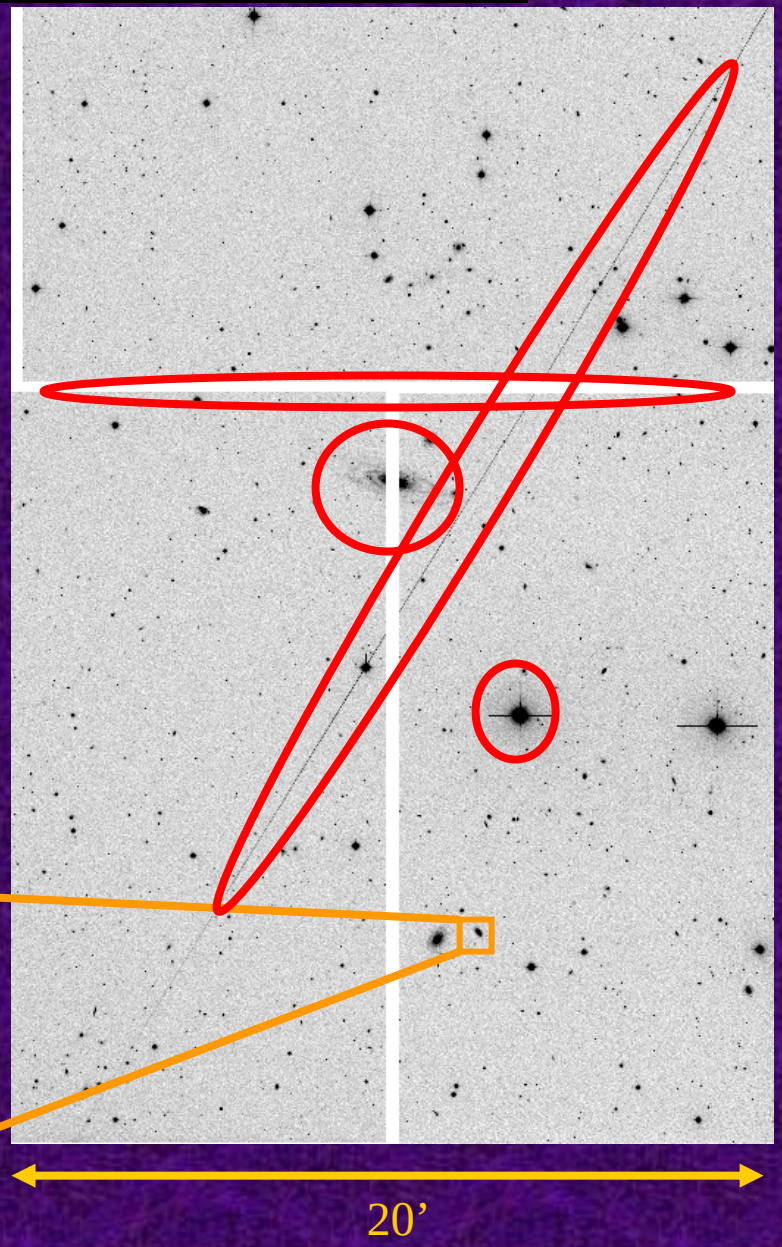
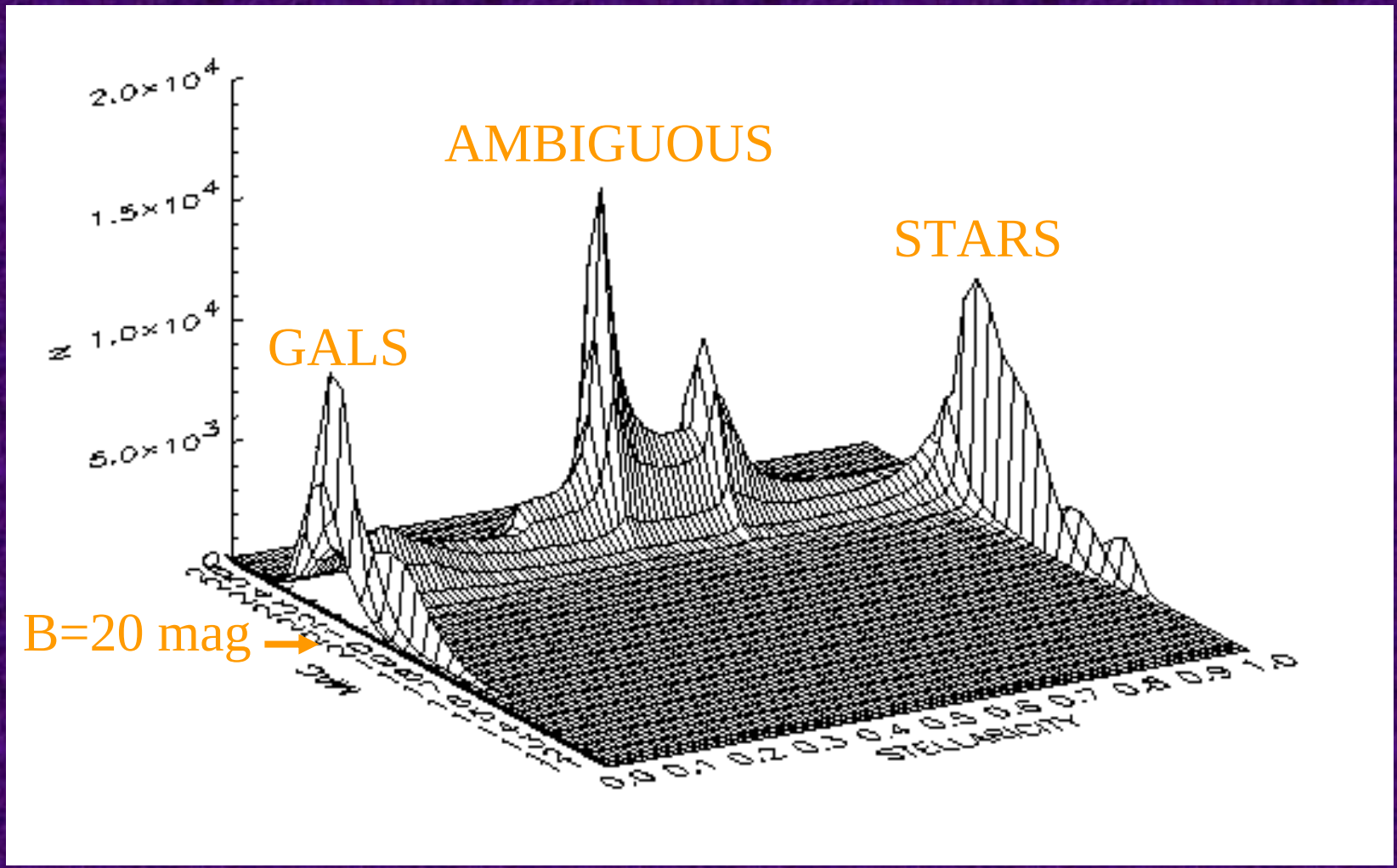


Image Extraction

- **Source Extractor:**
  - Objects identified from > 9 connect pixels above limiting isophote
  - *Constant* limiting isophote of 26 mags/sq/arcsec
  - Isophotal, Isophotally corrected and Kron magnitudes recorded
  - Extinction correction via Schlegel maps
  - Initial star-galaxy separation via inbuilt Artifical Neural Network
    - Stars/galaxies well defined upto B=20 mags
  - Overlap regions eliminated

- **Initial *first pass* catalogues:**
  - ~1.38 million objects detected to B=24 mags: MGC-FAINT
  - ~68,747 to B=20 mags (resolveable): MGC-BRIGHT
    - 56,294 stars
    - 12,453 galaxies

Star-galaxy separation



Viable to B ~ 21 mags,
For B > 21 mags use statistical method

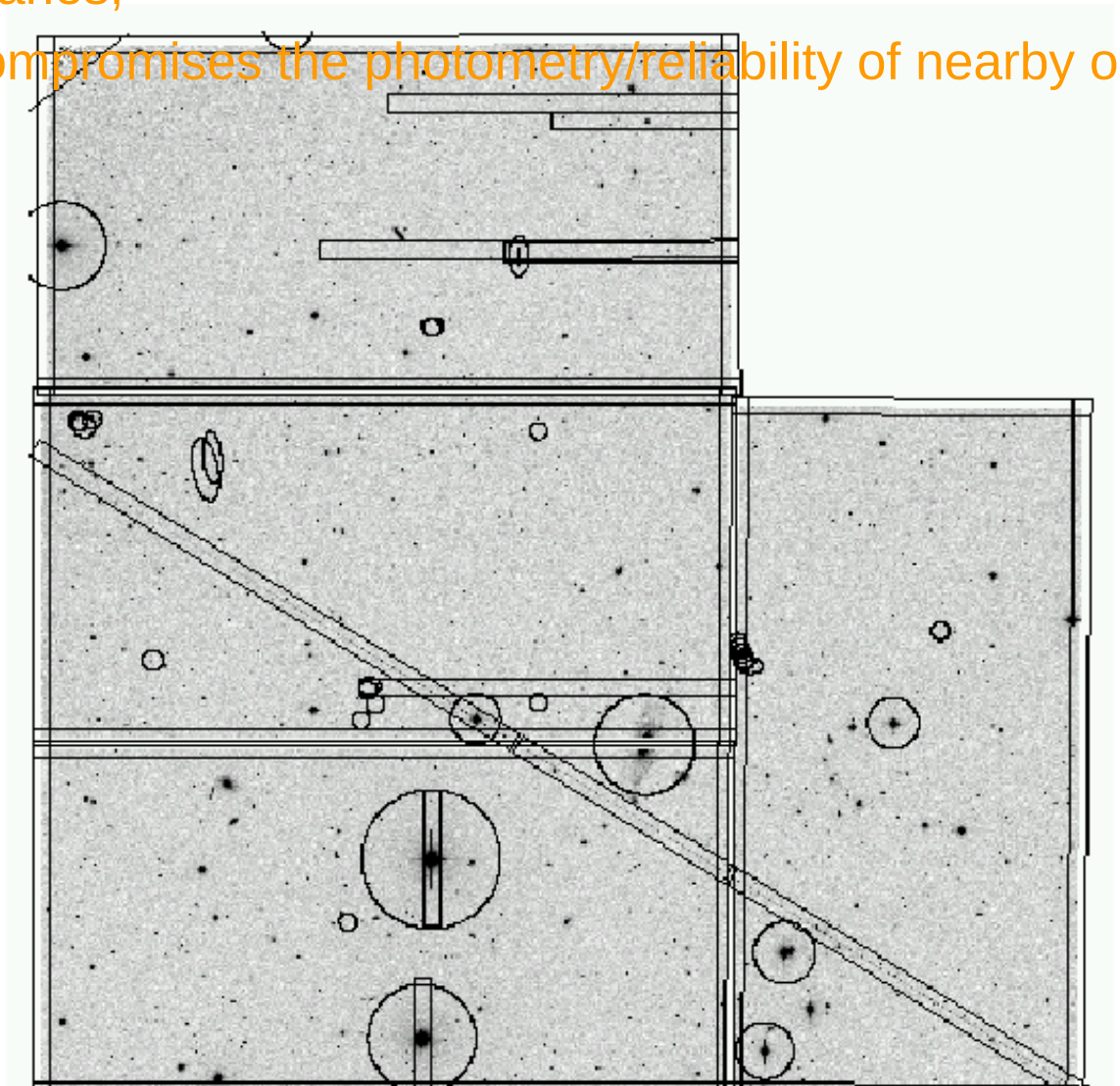
Eyeballing

- **All objects with B < 20 mag, stellaricity < 0.97 eyeballed !**
- **All objects with size < FWHM eyeballed !**
- **Object breakdown:**
  - 51,213 Stars
  - 11,808 Galaxies
  - 140 Erroneous deblends
  - 148 Asteroids
  - 162 Satellittes
  - 263 Diffraction spikes
  - 113 Extended cosmic rays
  - 3,027 Defects (hot pixels, bad columns)
  - 2,061 Noise detections
- **9.9 % contamination of stars !**
- **5.6% contamination of galaxies !**

Masking:

Bright stars, satellitte trails, dad columns, hot pixels, boundaries,

compromises the photometry/reliability of nearby objects

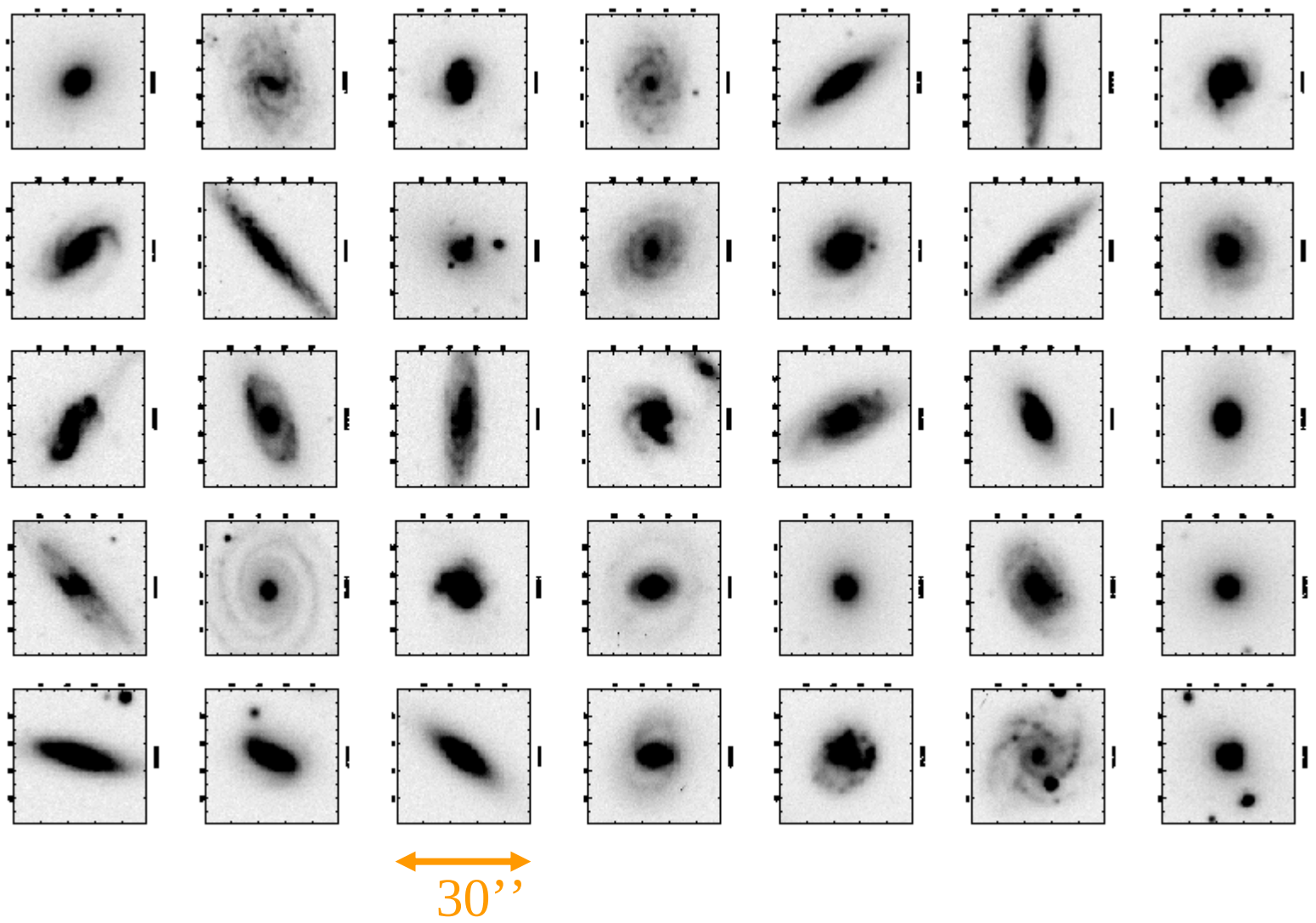


The Final Product: MGC-BRIGHT

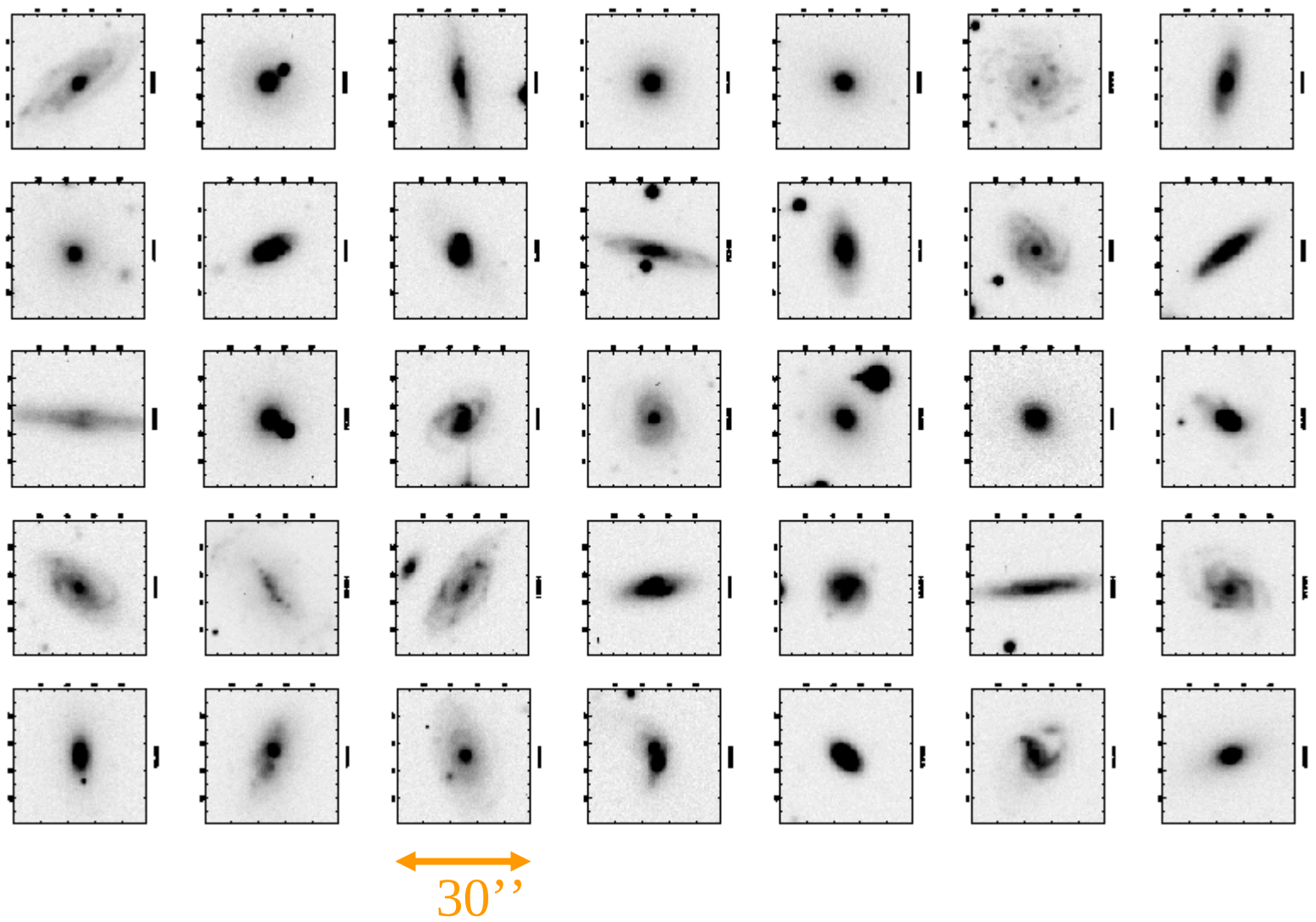
	Original	Eyeballed	Final
Area Covered	37.5 sq deg	37.5 sq deg	30.90 sq deg
No of Stars	56,294	51,213	41,235
No of Galaxies	12,453	11,808	9,837
No gals/sq deg	332	315	318

- ~10% contamination in automated galaxy catalogues
- Implications for APM and SDSS imaging catalogues.

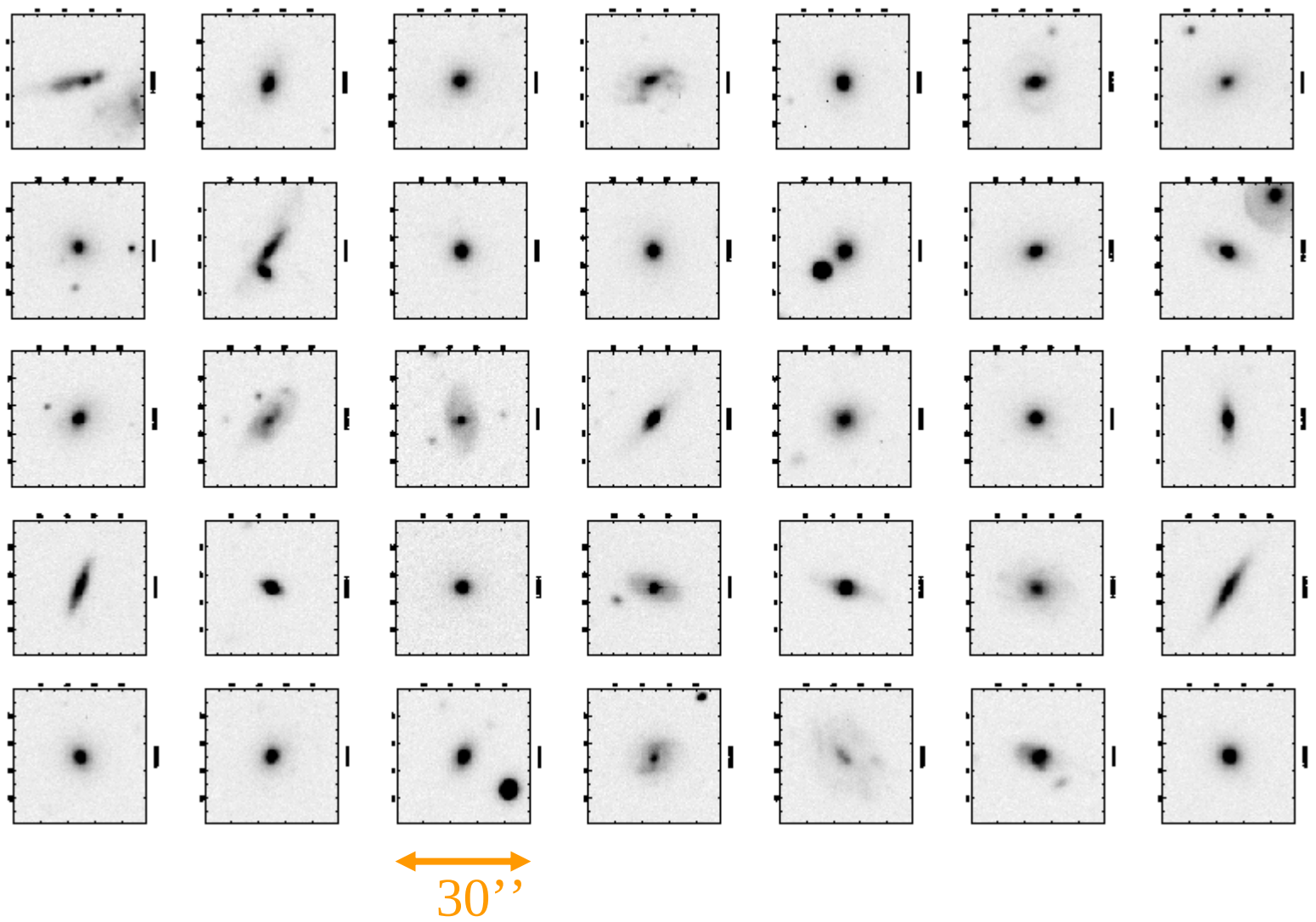
Final catalogues: 16th mag



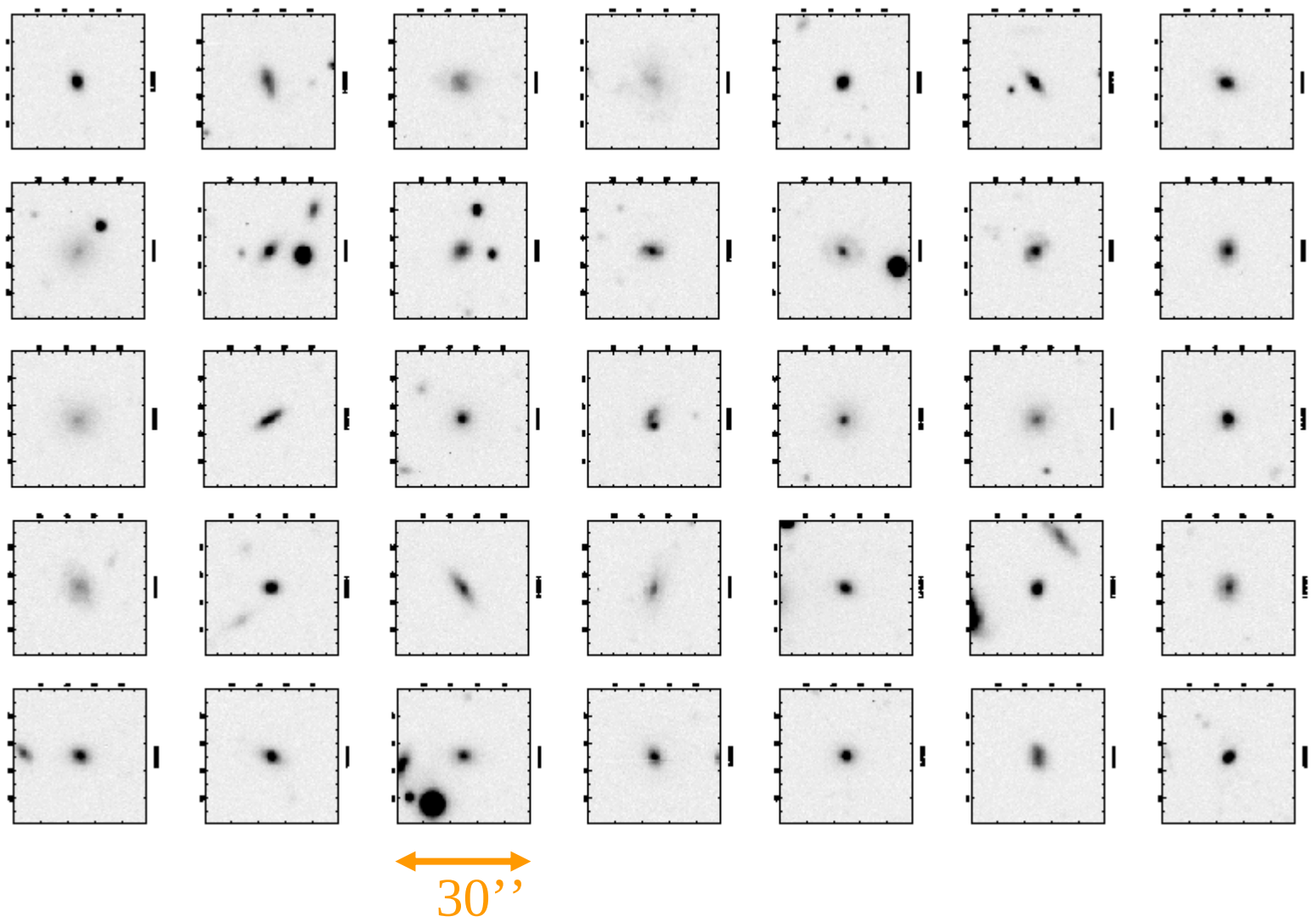
Final catalogues: 17th mag



Final catalogues: 18th mag

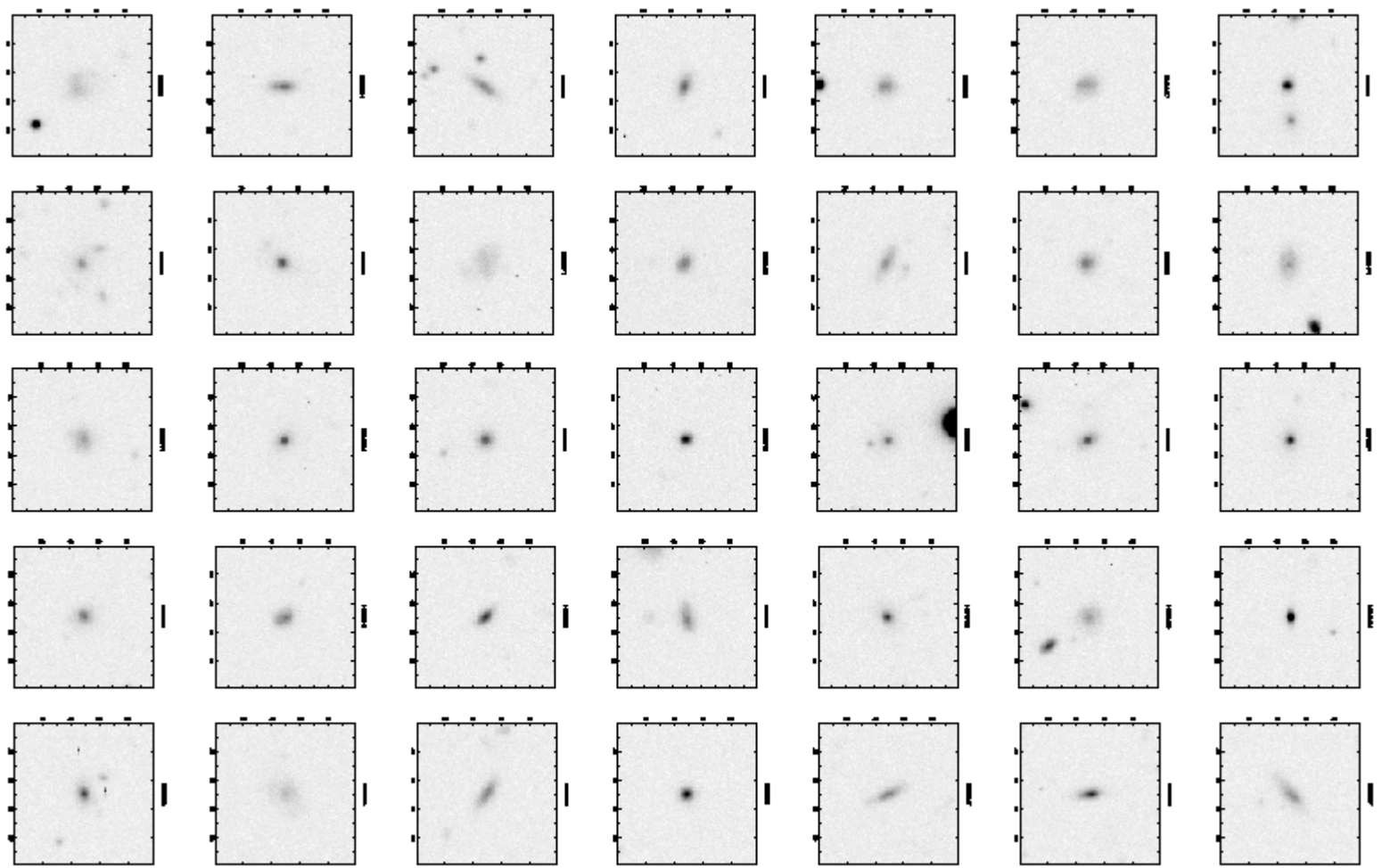


Final catalogues: 19th mag



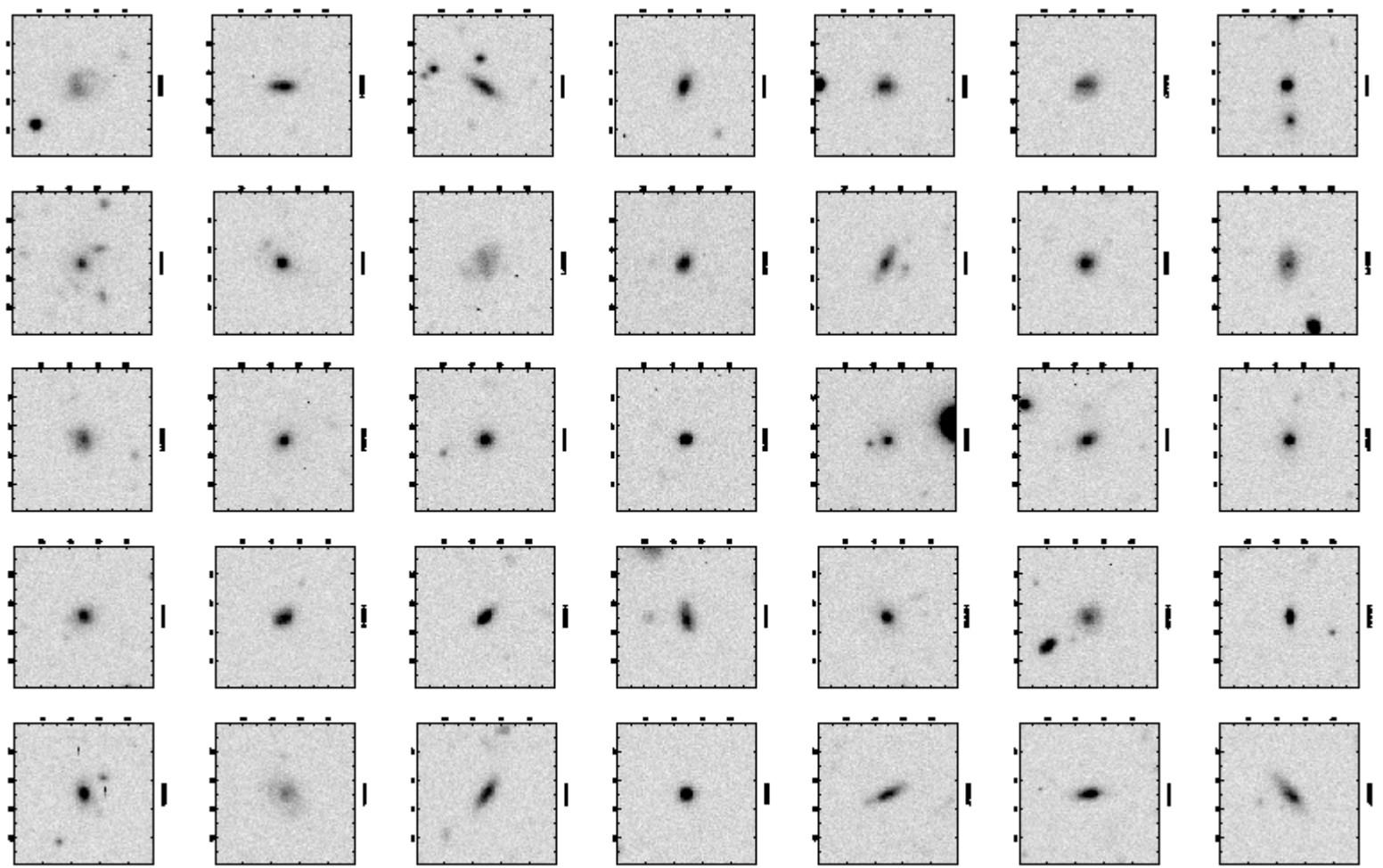
Final catalogues: 20th mag

(μ=22mags/sq')



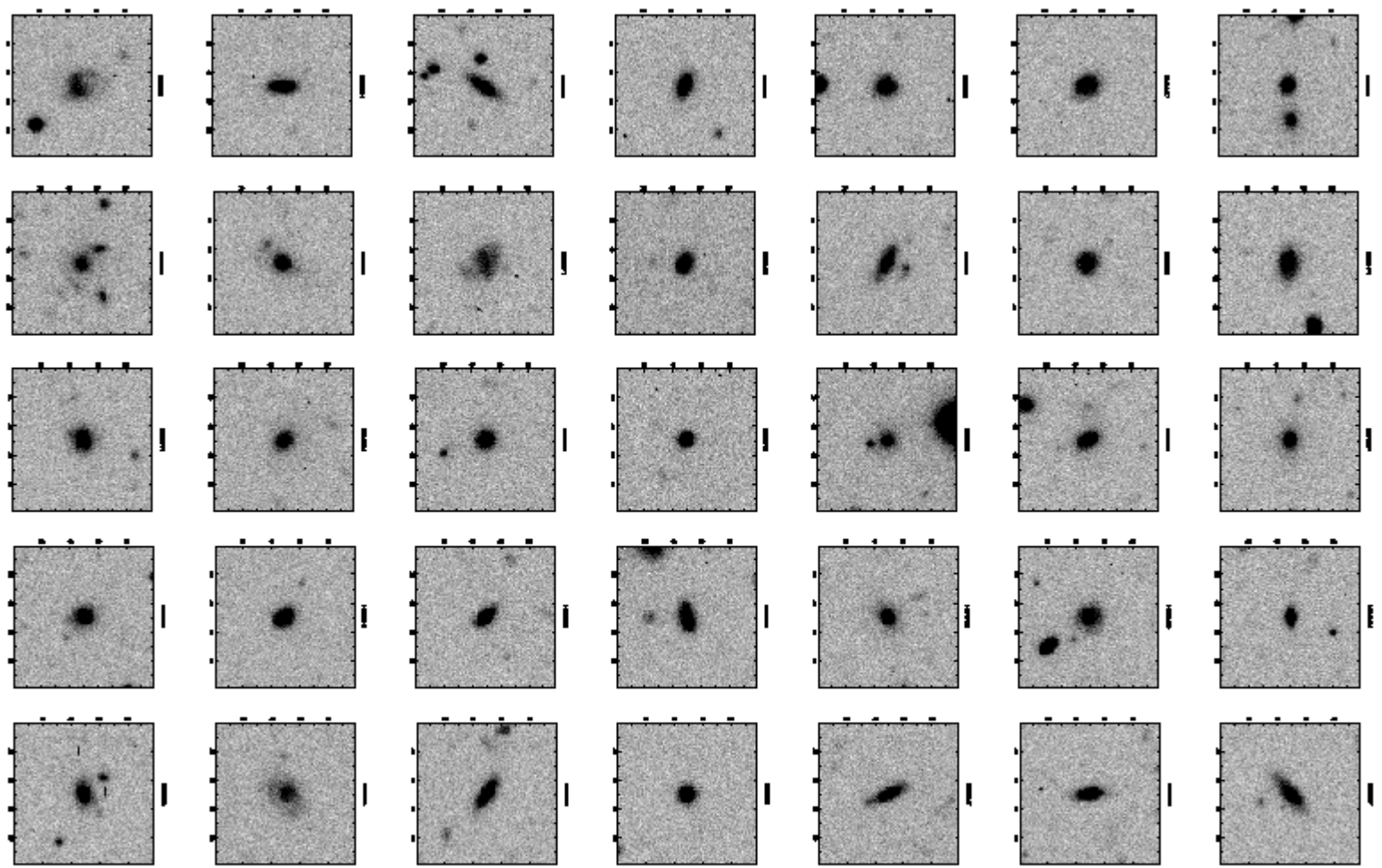
Final catalogues: 20th mag

(μ=23mags/sq')



Final catalogues: 20th mag

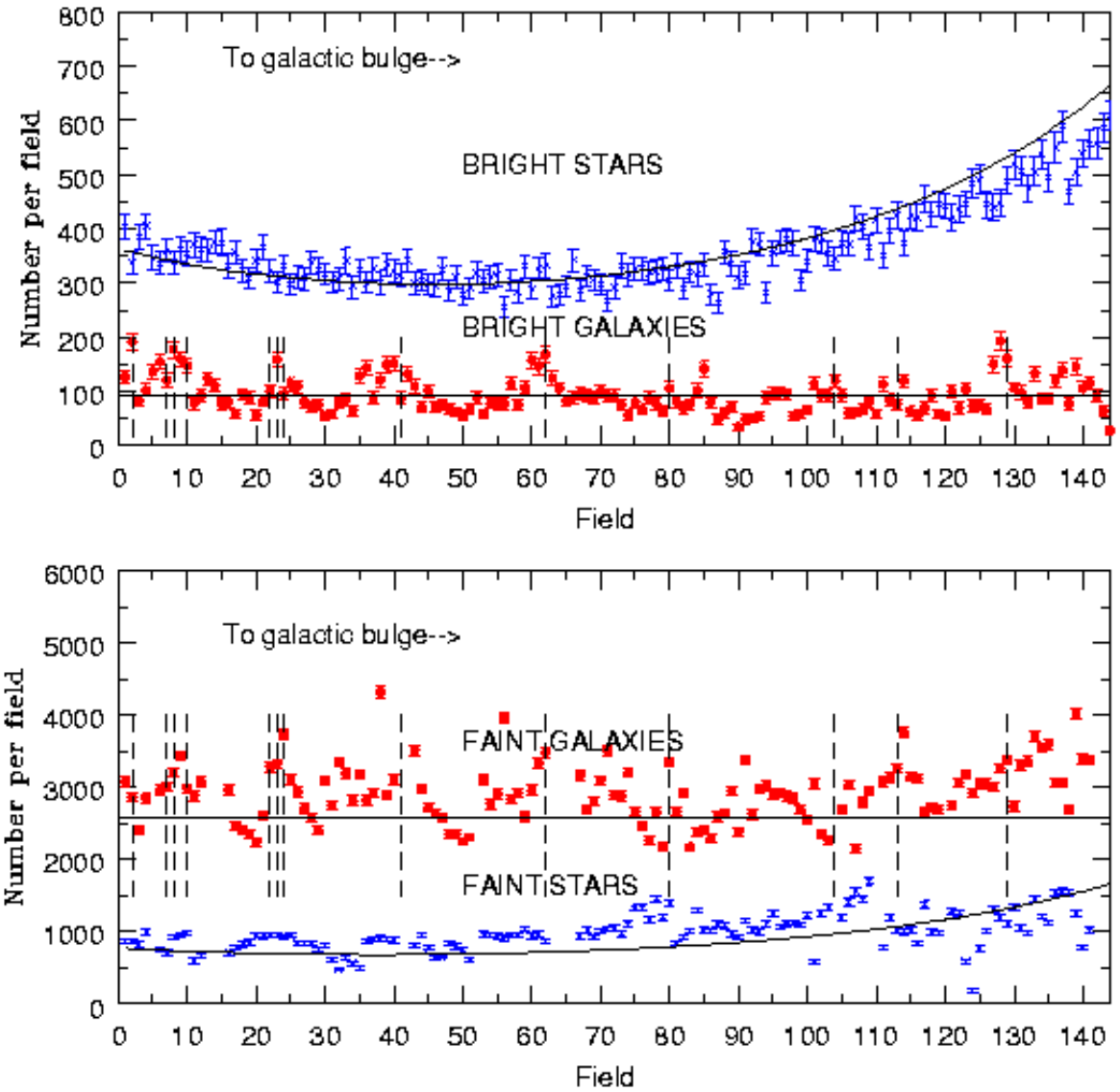
(μ=24mags/sq')



Preliminary MGC-BRIGHT Science:

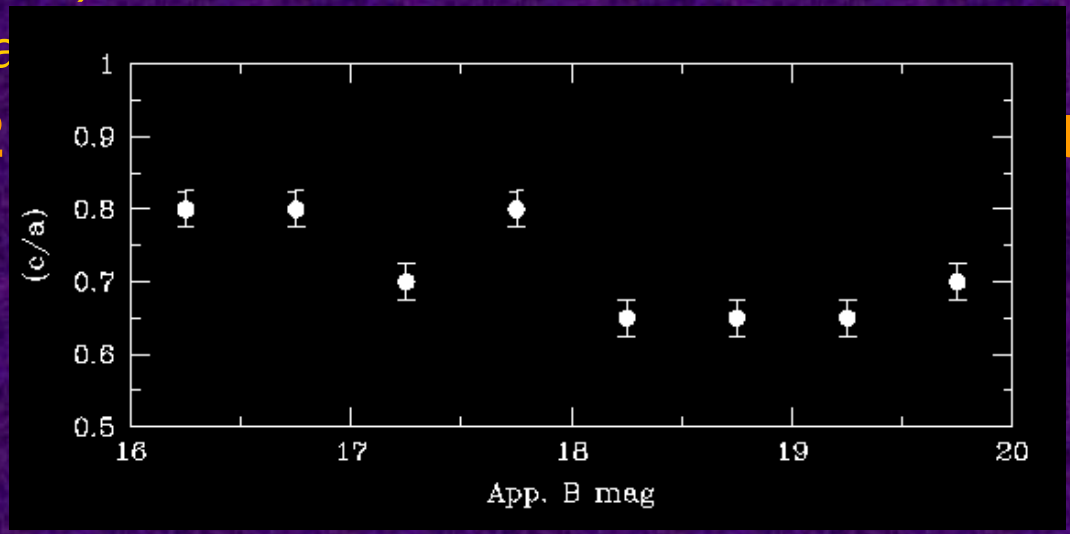
- **Star-counts and the Galactic Halo**
- **Photometric Accuracy and Completeness of 2dFGRS and SDSS-EDR**
- **Missing Local Galaxy Populations or not ?**
- **Precision Galaxy Counts 16 < B < 24**
  - Solving the Normalisation Problem
  - Measuring/Constraining the Local Luminosity Function
  - The Local Luminosity Density
  - The fraction of baryons in galaxies
- **Morphologies via ANN and Structural Analaysis via GIM2D**
  - Morphological counts
  - Morphological Luminosity Functions

Star and galaxy distributions



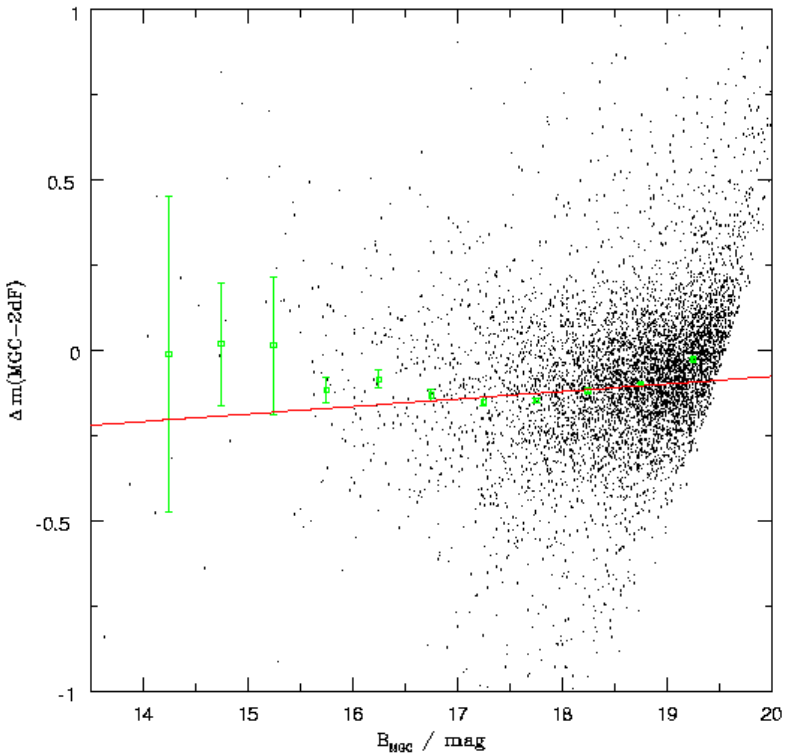
The Axial ratio of the Galactic Halo

- **Used Gilmore starcount model:**
  - Thin disk population (exponential scale length, height = 3.5kpc, 250pc)
  - Thick disk population (exponential scale length, height = 3.5kpc, 1300pc)
  - Spheriod population (de Vauc', effective radius= 2.67kpc, axis ratio=?)
  - Sola
- **Chi^2 tude bin:**

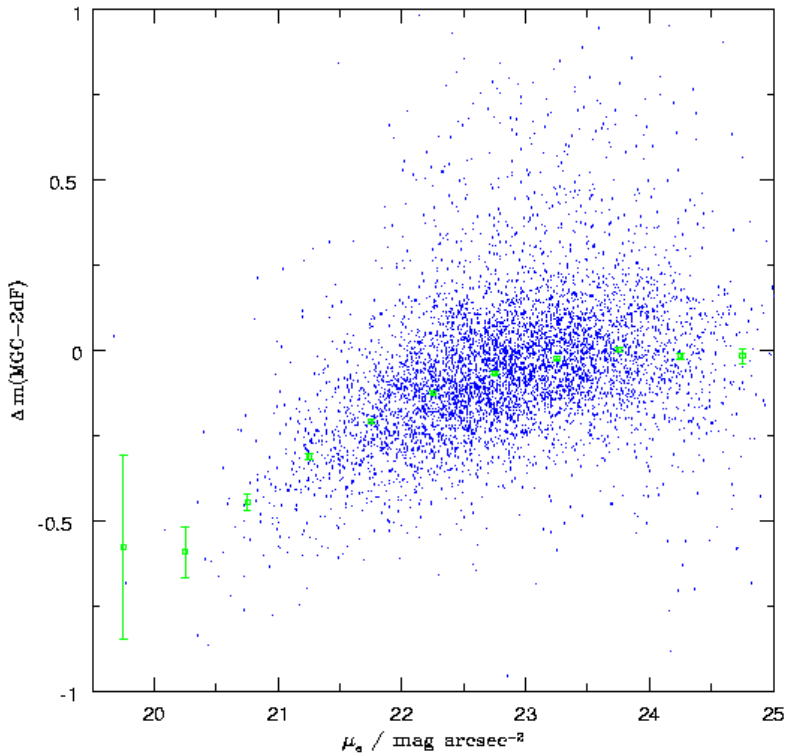


Photometric Accuracy of 2dFGRS

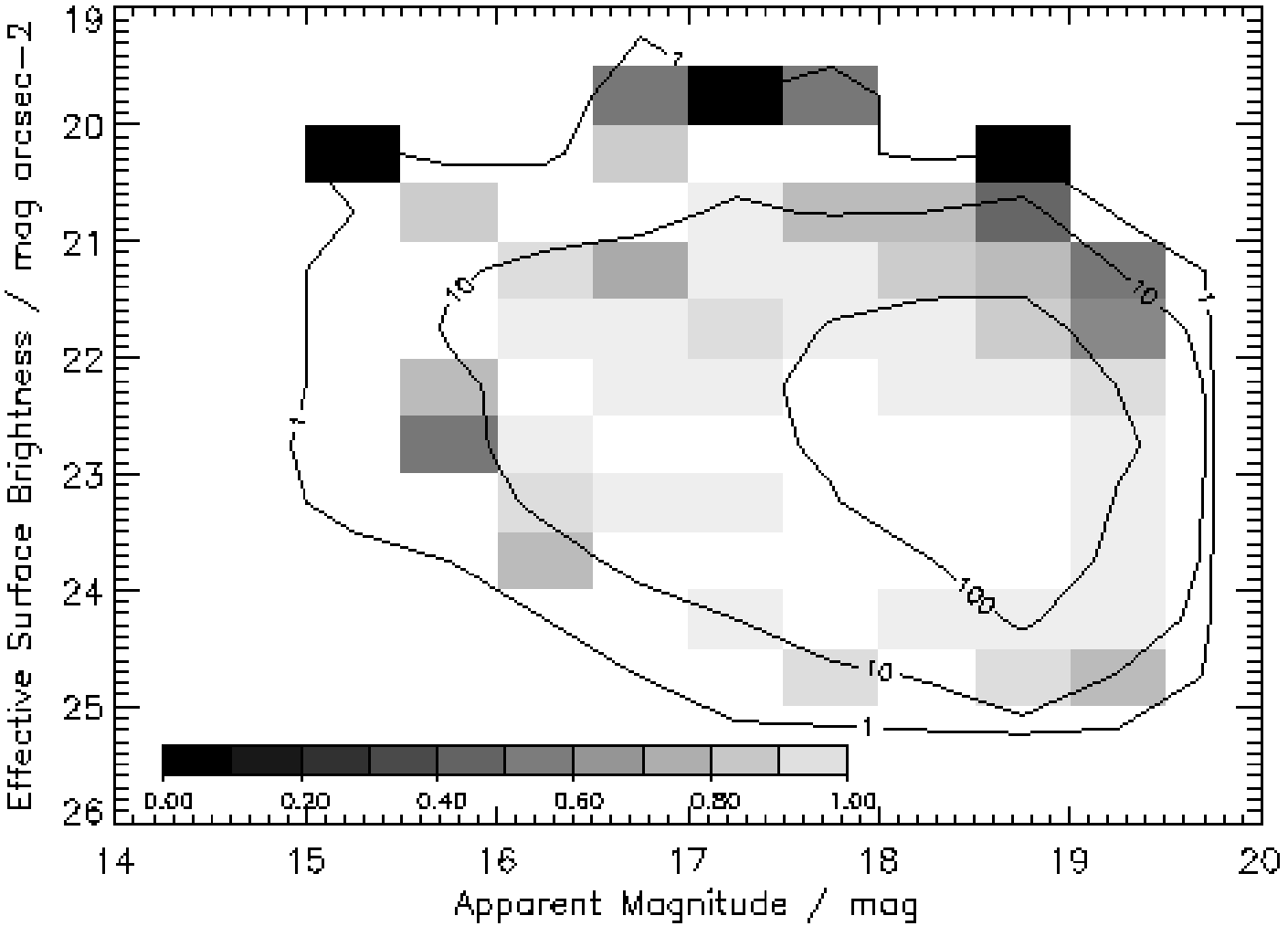
v magnitude



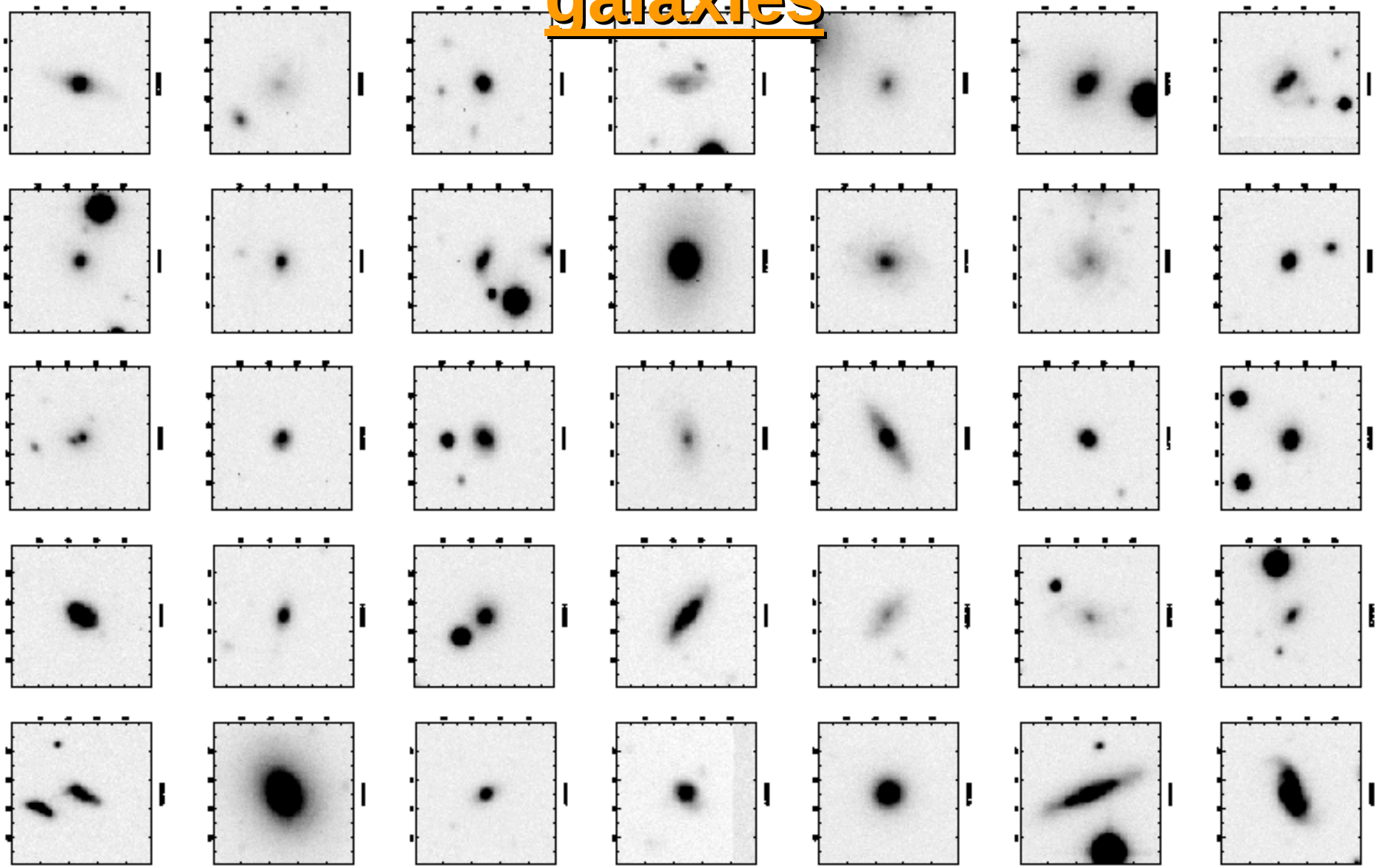
v surface brightness !



Completeness of the 2dFGRS ~ 93%

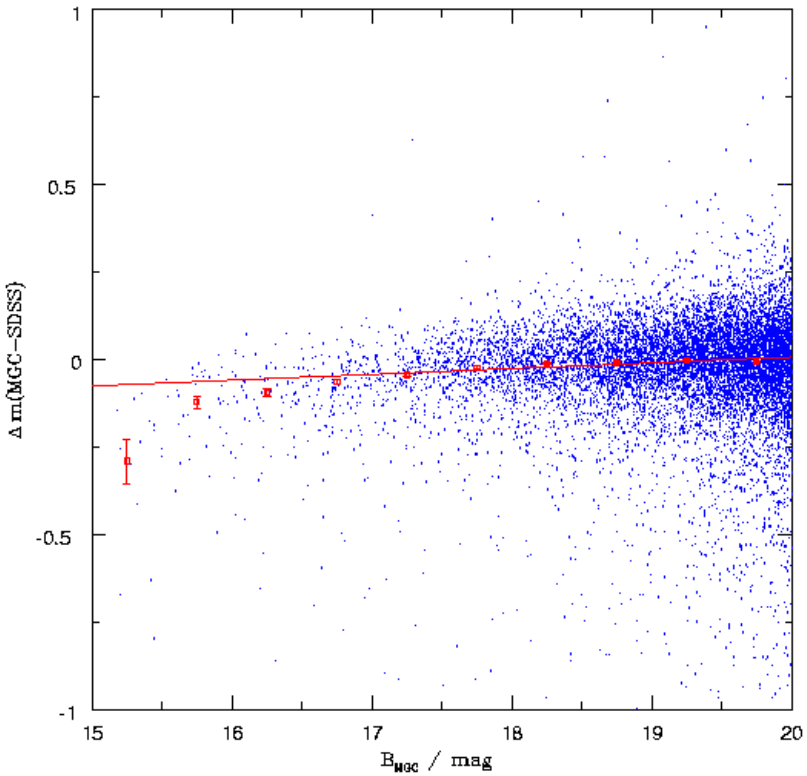


Examples of missing 2dFGRS galaxies

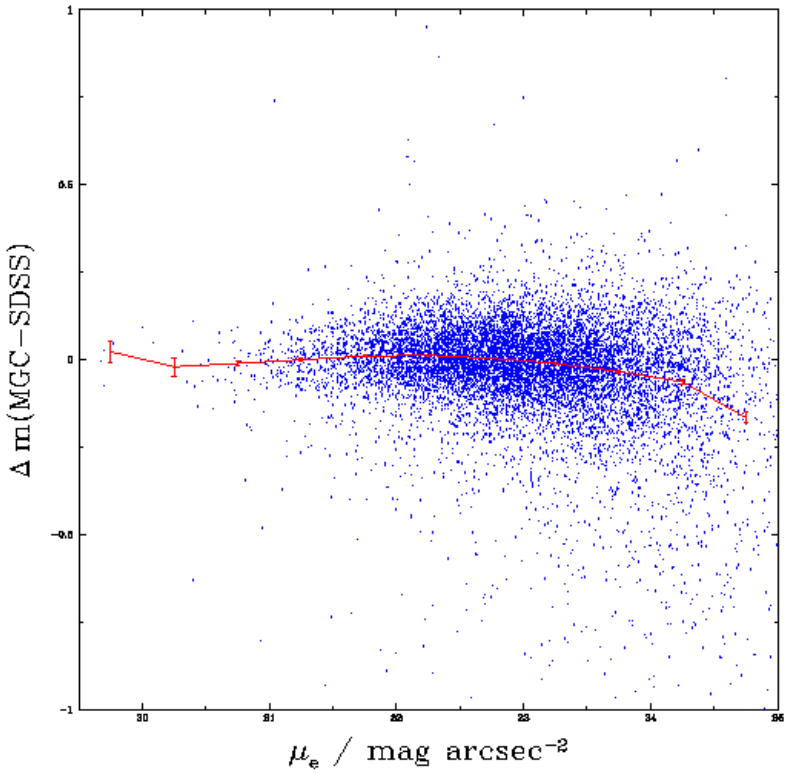


Photometric Accuracy of SDSS-EDR

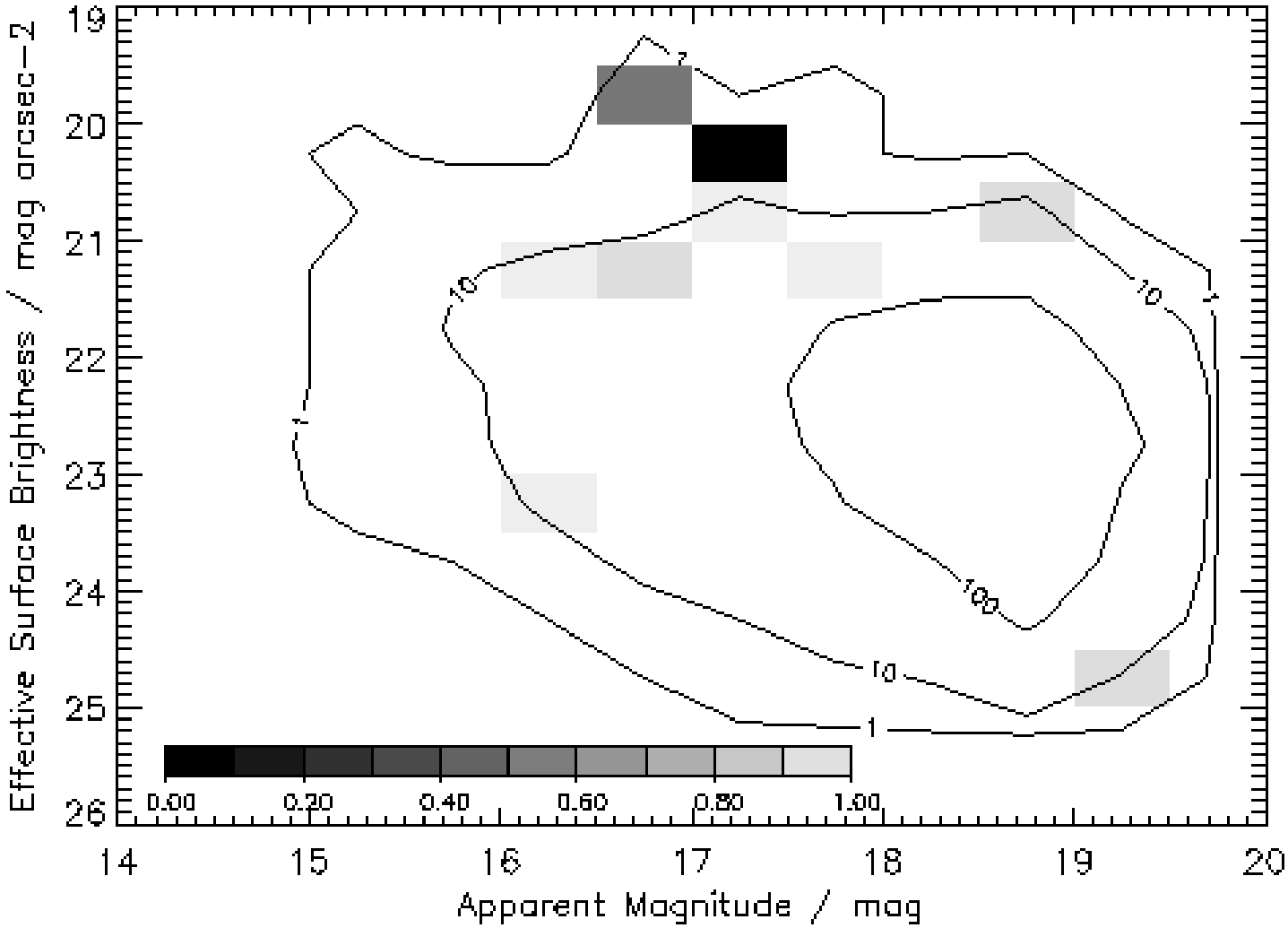
v magnitude



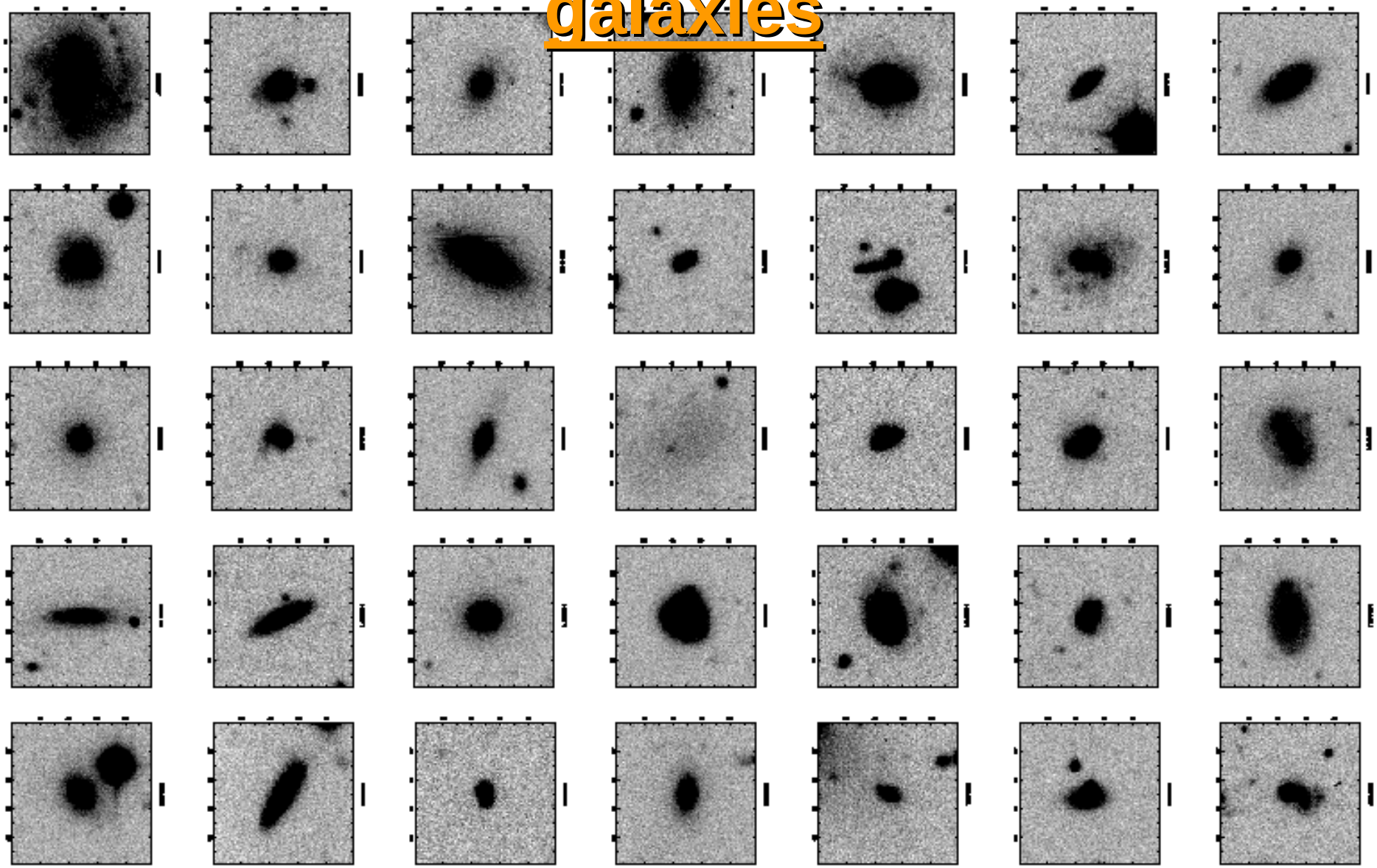
v surface brightness



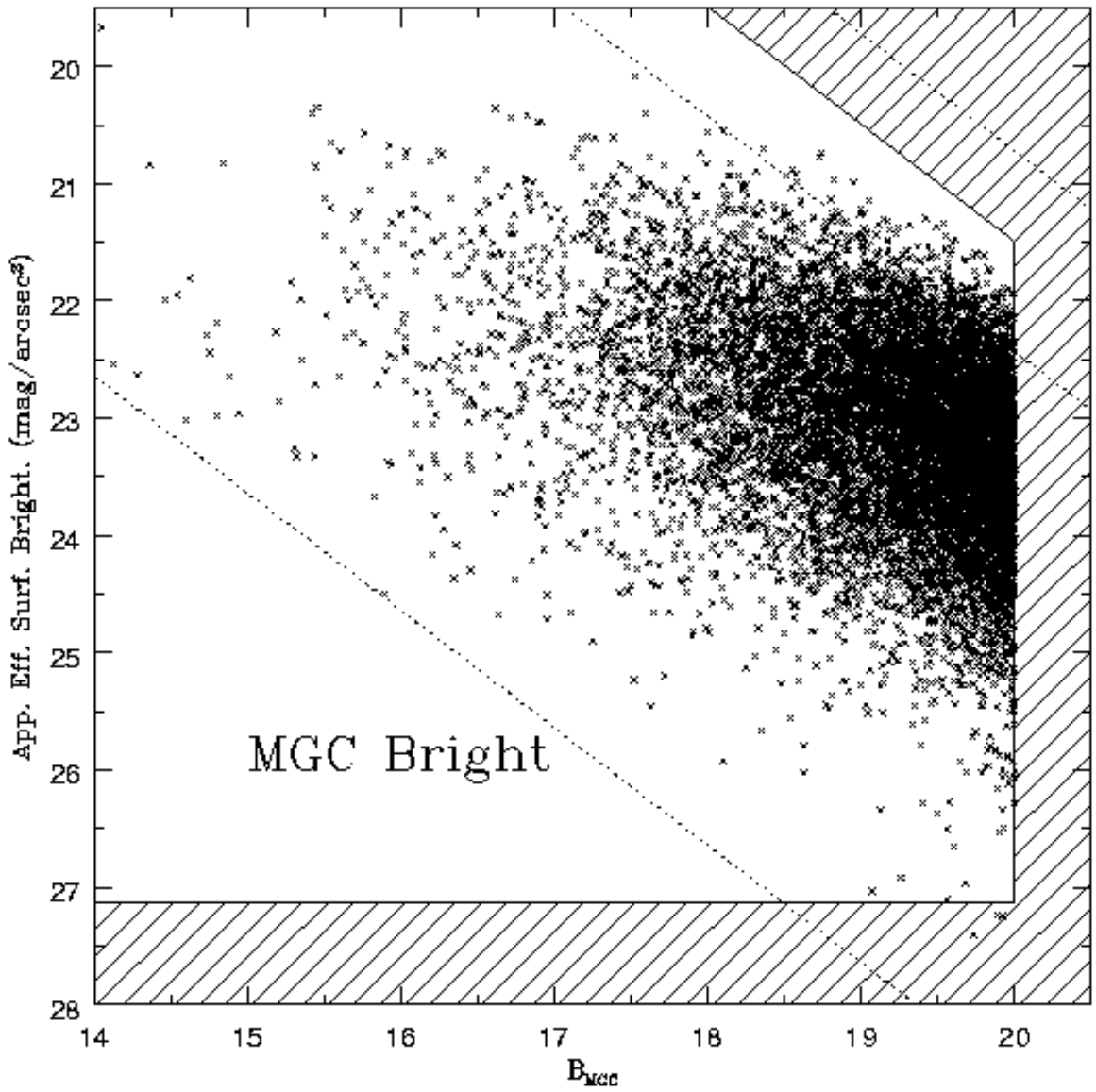
Completeness of the SDSS-EDR ~99%



Examples of missing SDSS-EDR galaxies

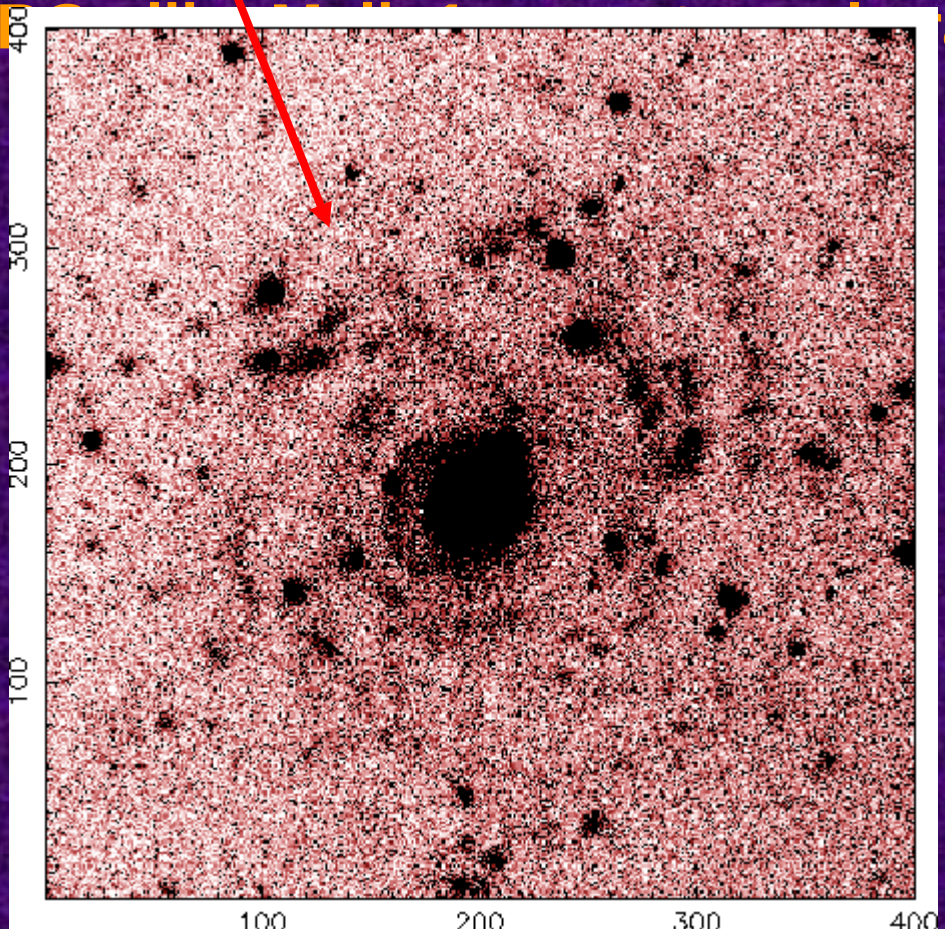


The MGC-BRIGHT Completeness



Missing galaxies

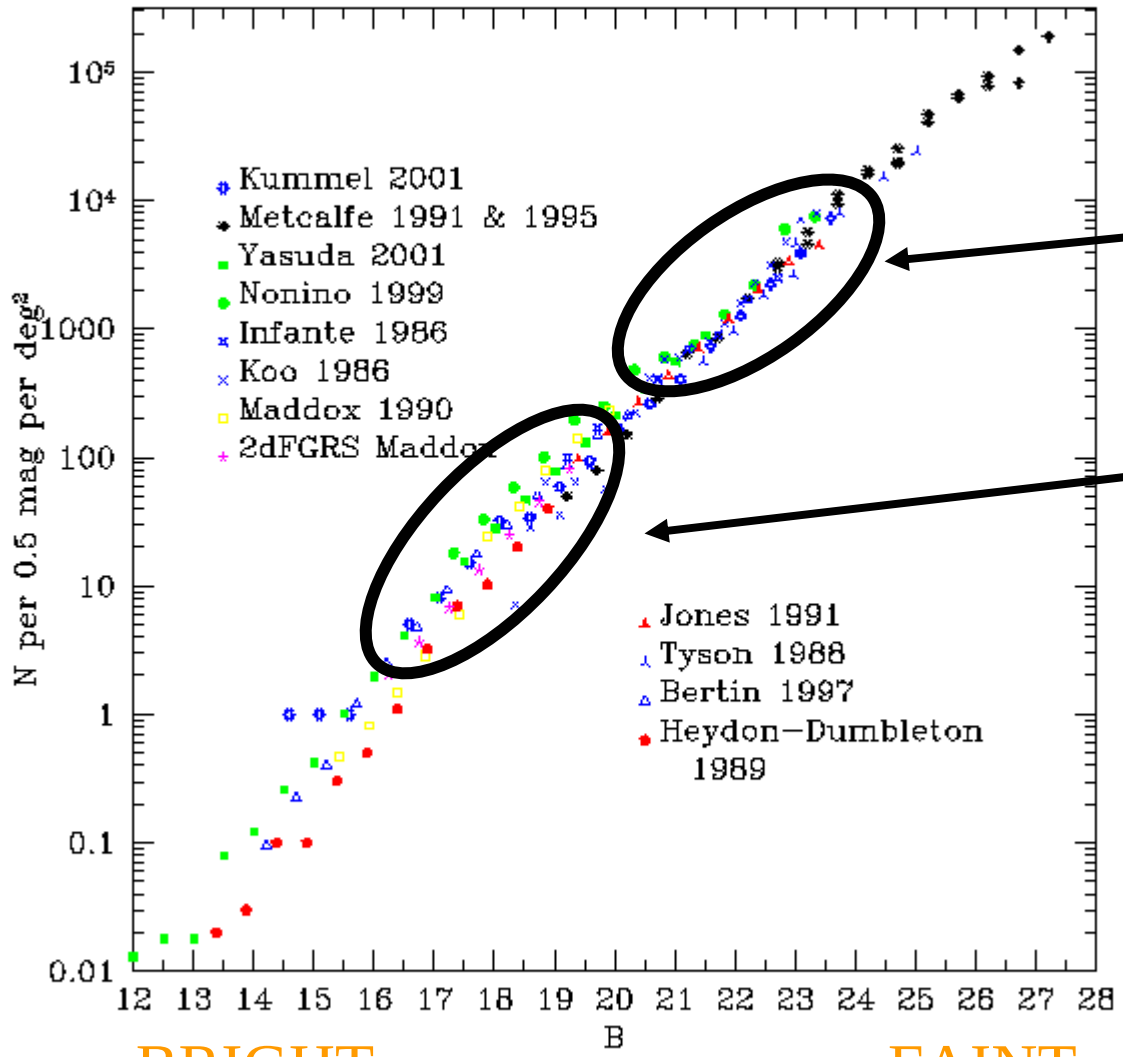
- Speculation of a missing population of Low Surface Brightness galaxies ruled out as no new population discovered
- Giant LSB [illegible] are (r.f HIPASS)



The Galaxy Number Count Plot

MANY

FEW



GOOD (CCD)

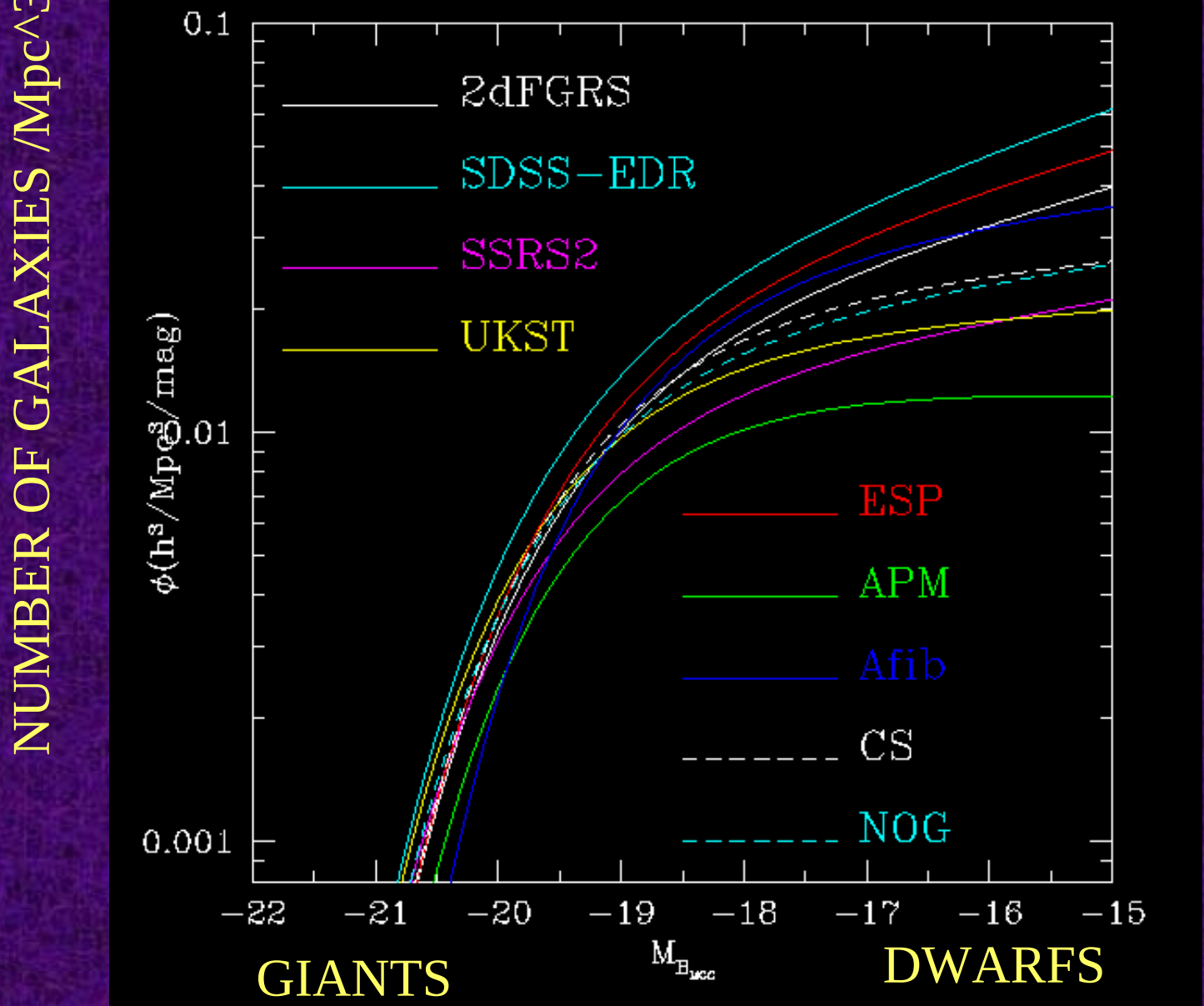
BAD (PHOTO)

BRIGHT (Nearby/Giant) → FAINT (Far/Dwarf)

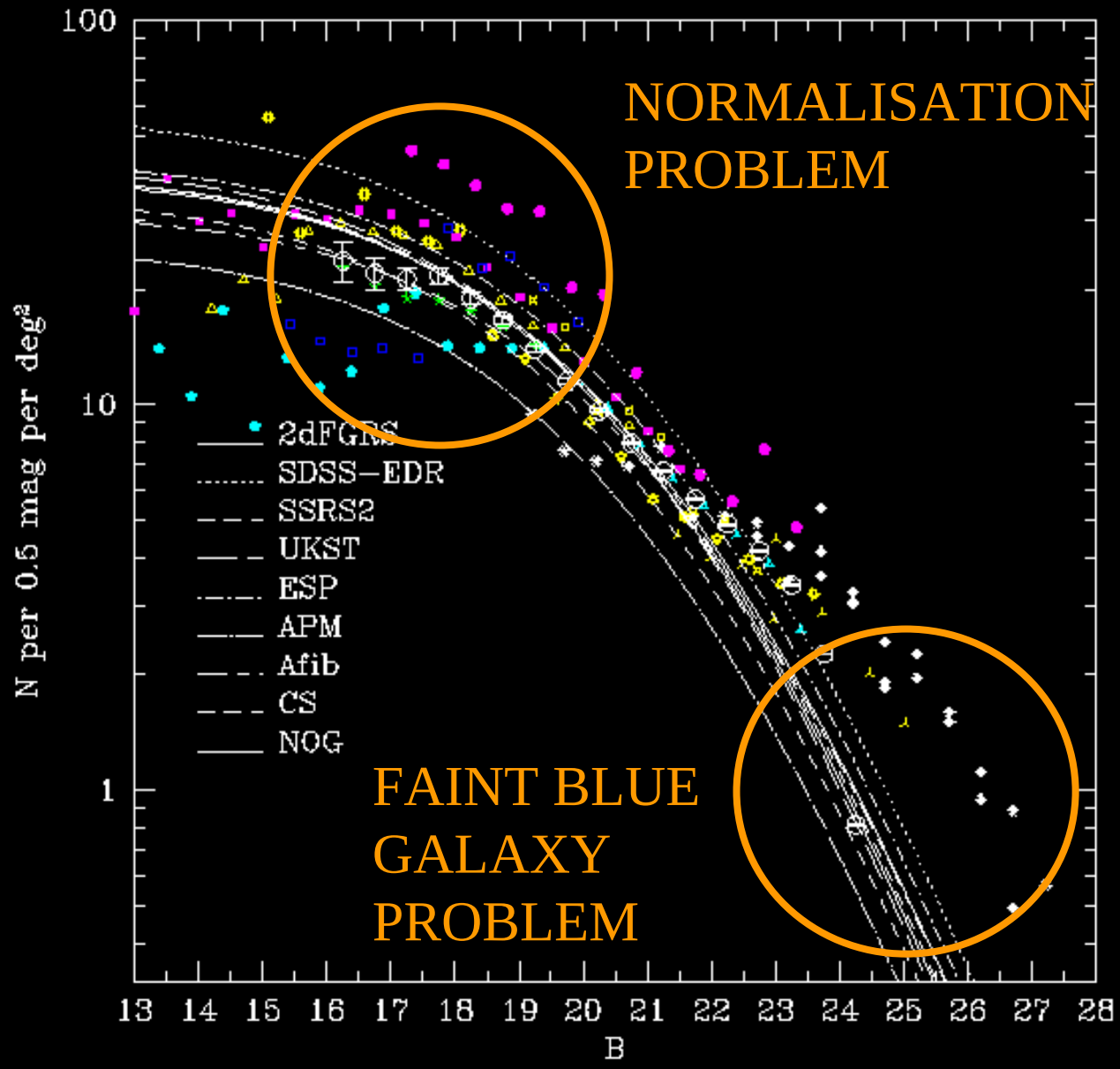
Modeling the Galaxy Counts

- **A prediction of the galaxy number counts depends upon:**
  - The Cosmological Model (Ω_M, Ω_Λ) ***0.3,0.7***
    - The Matter Density
    - The Cosmological Constant ***0.5,0.0***
  - The Evolution of the Population (β, γ)
    - Luminosity Evolution: $L \propto L_o(1+z)^\beta$
    - Number Evolution: $N \propto N_o(1+z)^\gamma$
  - The Space Density of Galaxies Locally (M_*, α, ϕ_*) ***BUT WHICH LF ???***
    - The Characteristic Luminosity
    - The Faint-end slope
    - $\varphi(M) = -0.9 \ln 2.5 \varphi(*) 10^{-0.4(M-M*)(\alpha-1)} e^{-10^{-0.4(M-M*)}} dM$
  - [The K-correction (K(z))]
- **7 parameters per evolutionary track (morphological type ?)**

Which Luminosity Function ?



Models v Observations



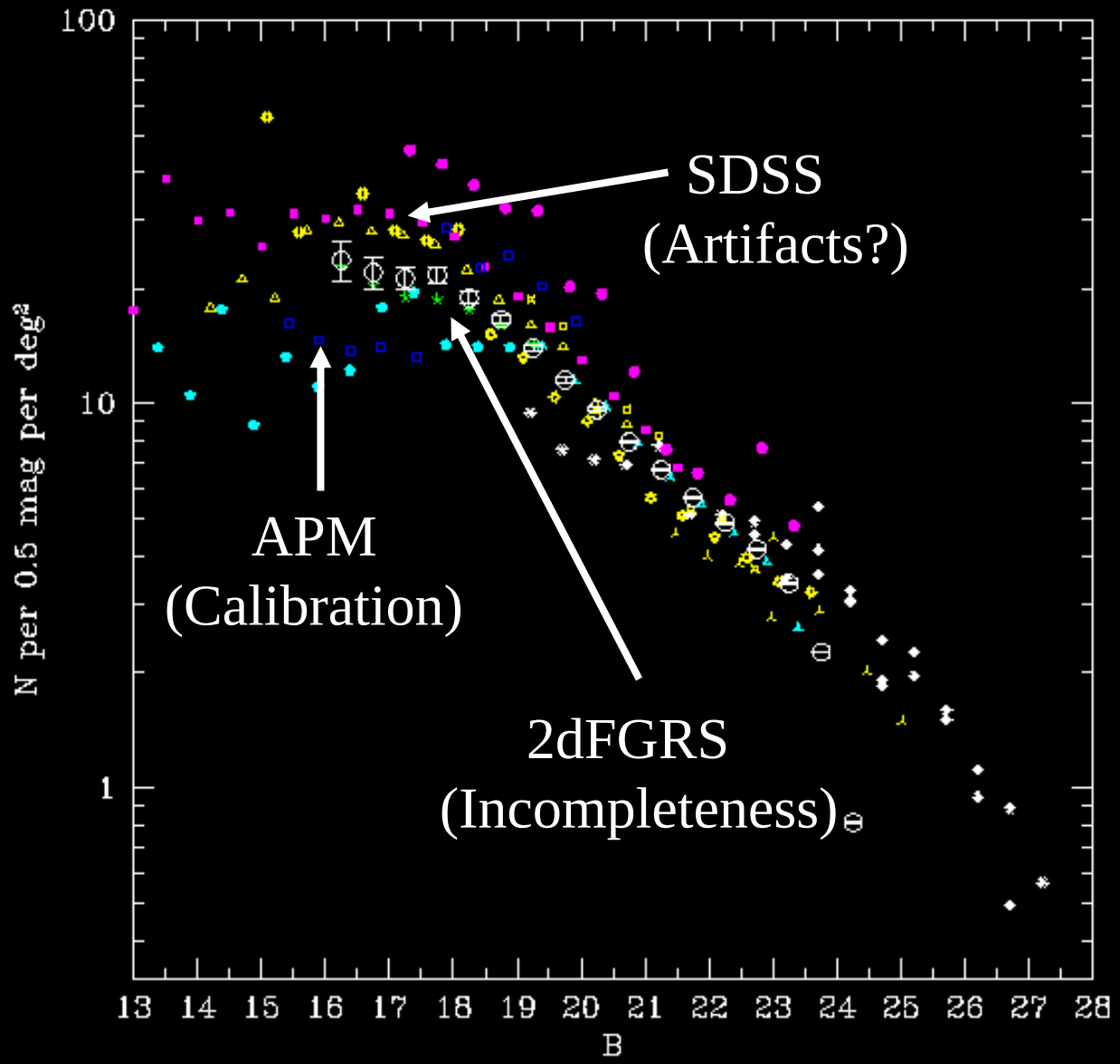
Problems

- **The Normalisation Problem : 3 possible solutions**
  - Substantial Nearby Large Scale Structure
  - Calibration errors
  - Incompleteness/Missing Galaxies

- **The Faint Blue Galaxy Problem : 3 possible solutions**
  - Wrong Cosmology => Cosmological Constant
  - Underestimated Evolution of the Galaxy Population
    - Low z formation
    - Delayed formation of a sub-class
  - Incomplete estimate of the nearby dwarf galaxy population

- **The Normalisation Problem is the more fundamental !**
  Require Nearby Precision Galaxy Counts

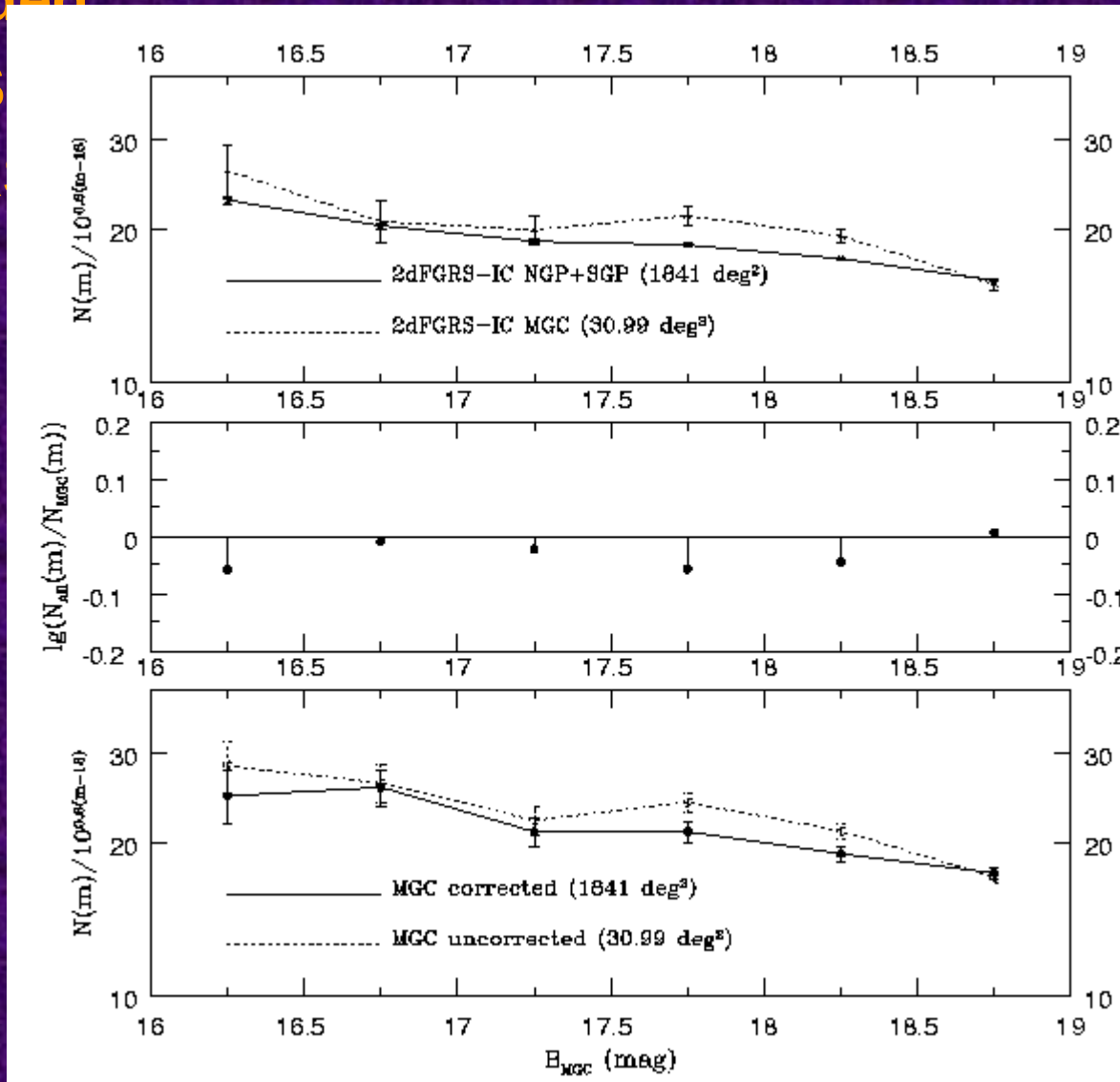
The Final MGC Galaxy Counts



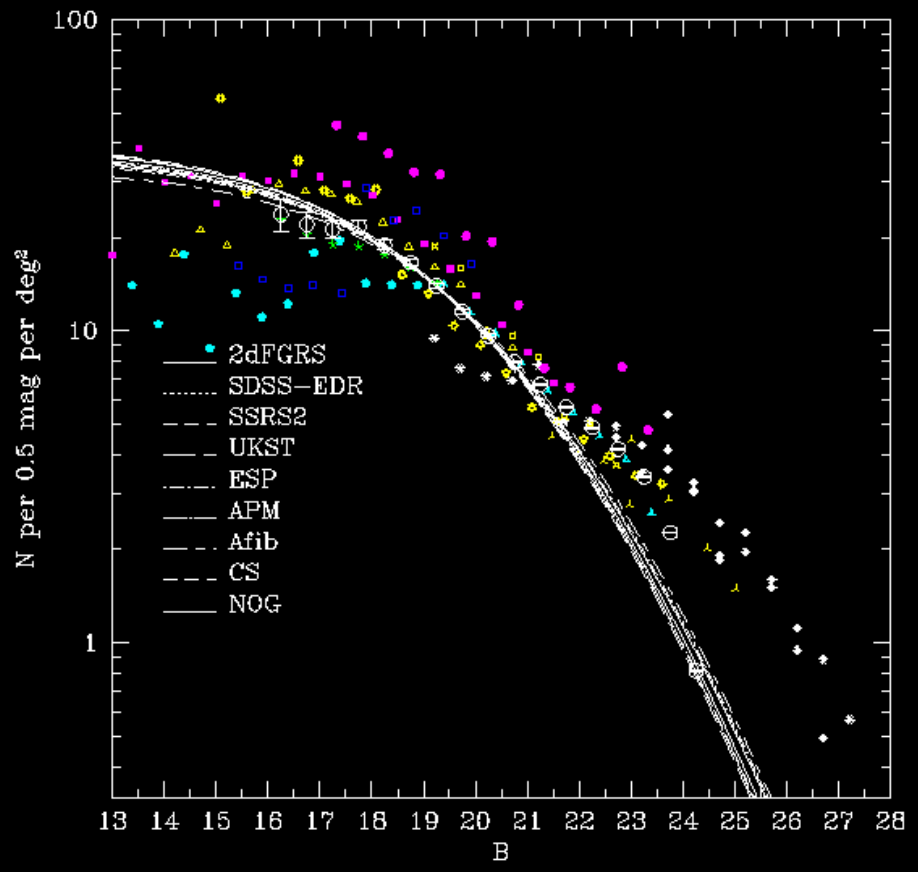
Large Scale Structure Correction for MGC

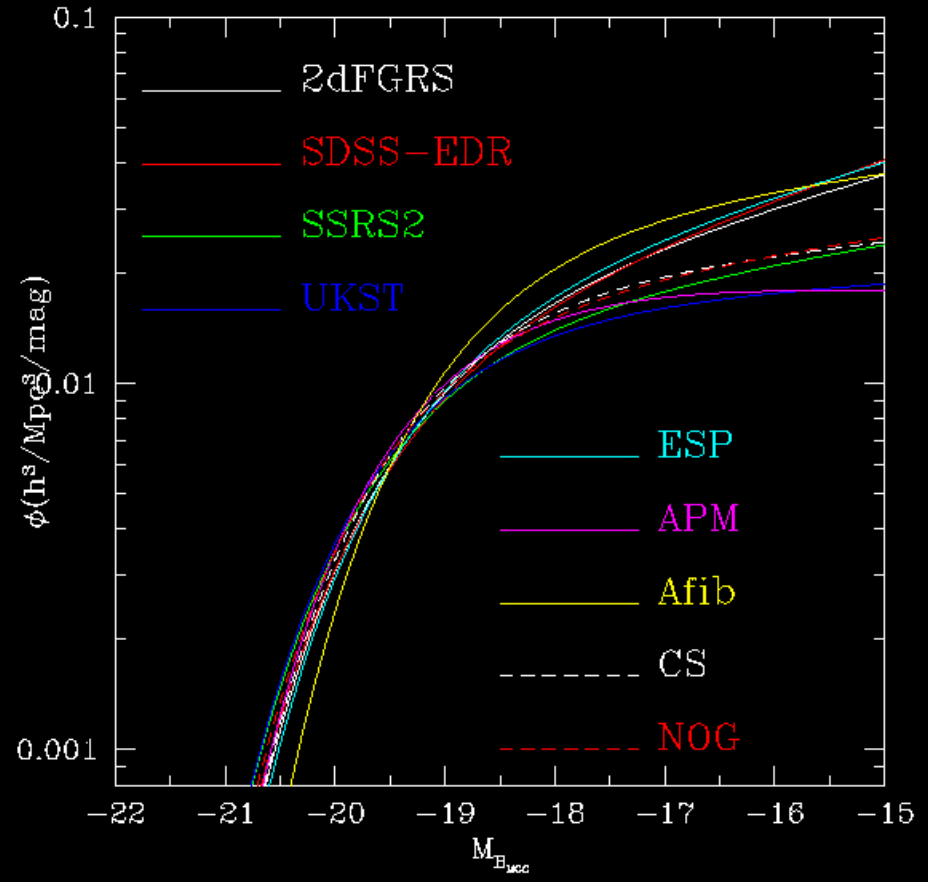
- MGC area = 31 sq deg
- Susceptible to LSS
- Can map to 2dFGRS
- Increases effective area to 1841 sq deg !

- Assumes NGP and SGP are not offset



Constraining the local LFs



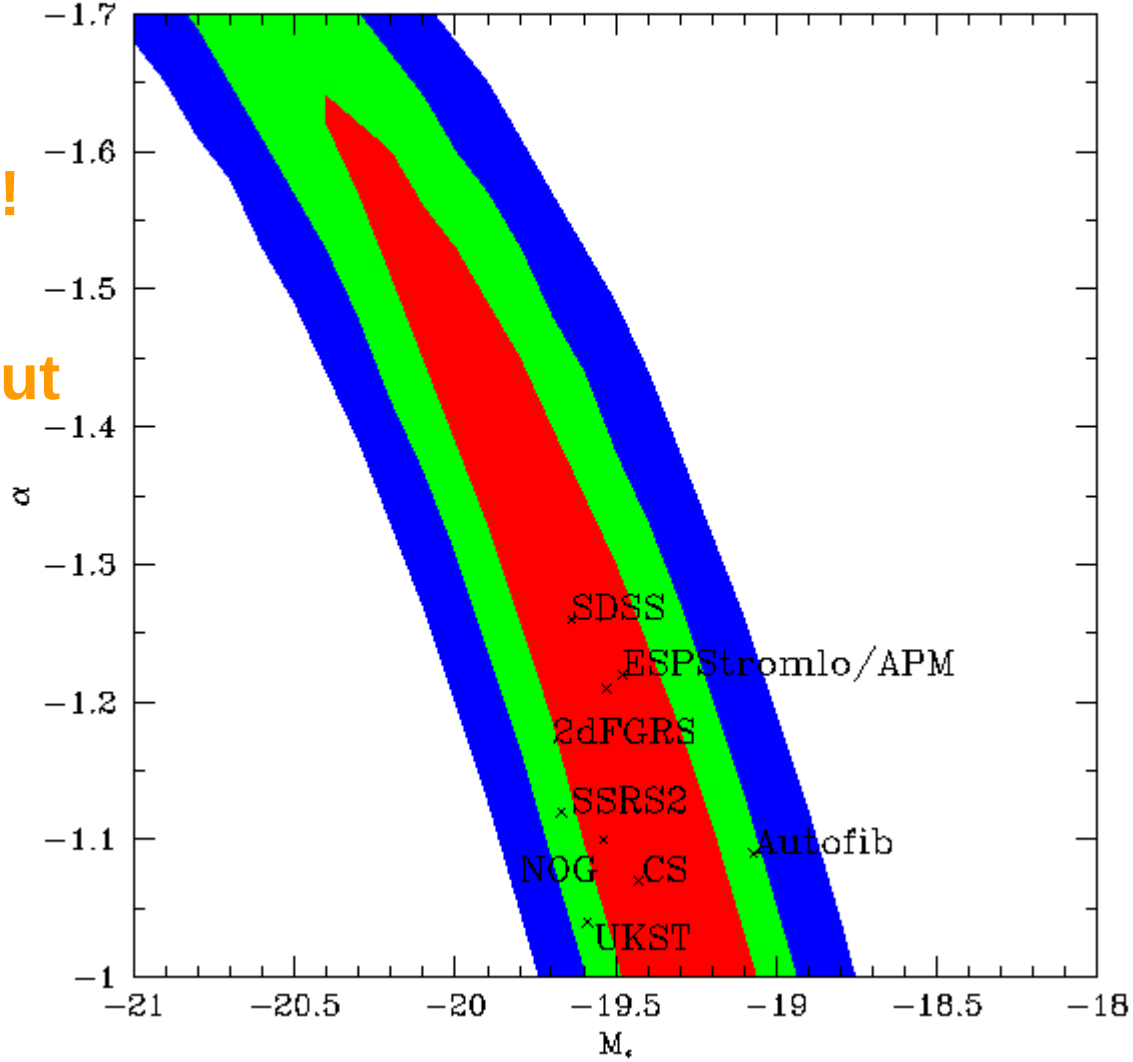


Derive local LF from counts alone ?

Use curvature of the galaxy counts to constrain the LF without a single z !

Constraint weak but consistent with z surveys

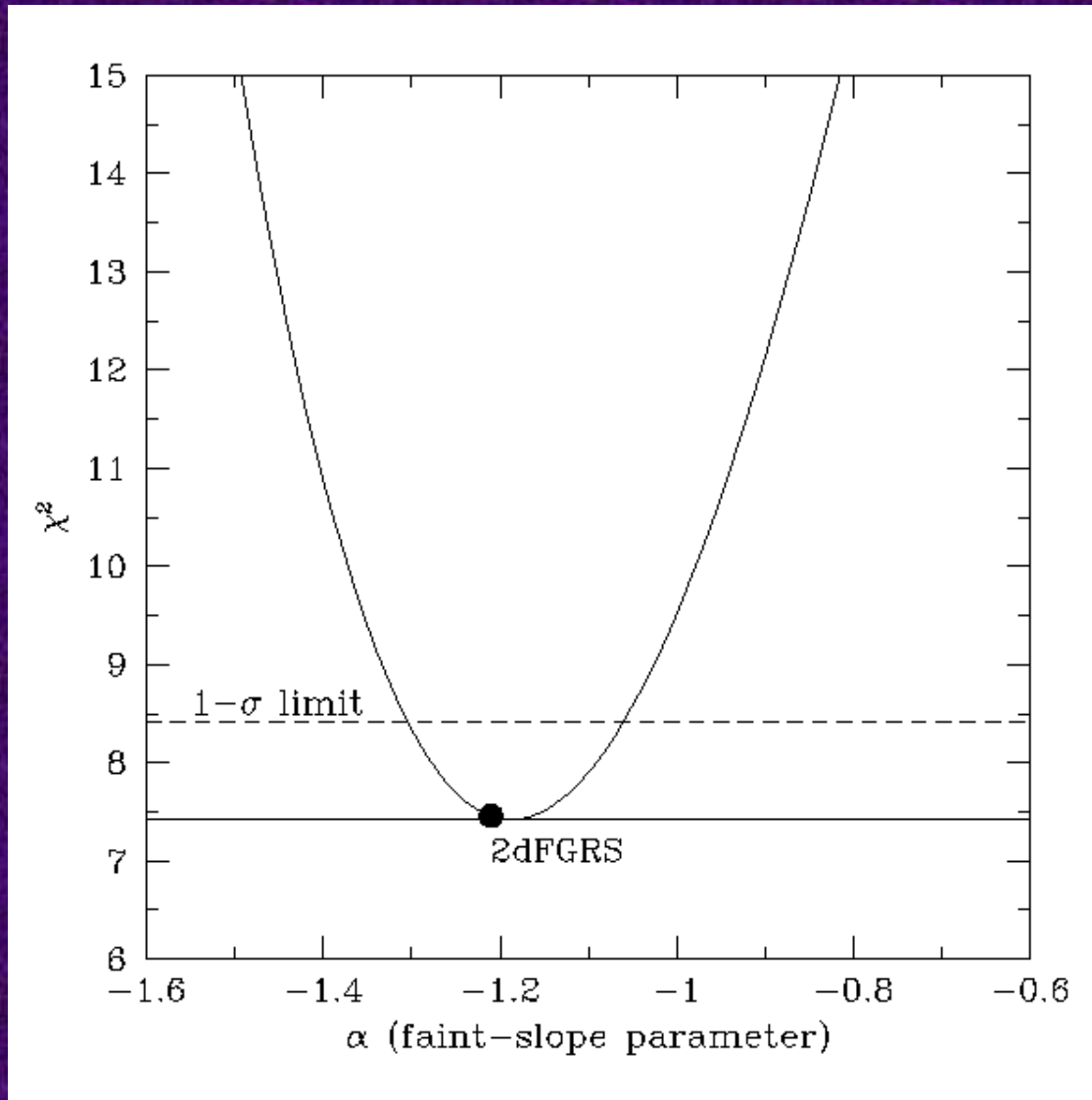
Now fix M* and constrain α



Constrain alpha only ?

α = -1.19+/-0.08

Important confirmation of α, as methodology is independent of the z incompleteness.



The generic local luminosity function

MGC M* = -19.53, α= -1.19, ϕ*=0.0159/Mpc^3 (h=1)

Errors in published LFs ϕ(*)'s (wrt MGC-BRIGHT+2dFGRS LSS corr)

2dFGRS	+1%	-	Incompleteness Correction
SDSS	+51%	-	Artifacts/Clustering
SSRS2	+13%	-	Zwicky magnitudes ?
Durham/UKST	+6%	-	???
ESP	+21%	-	???
MSO/APM	-32%	-	APM Calibration
Afib datasets ?	-5%	-	Combined

The Local Luminosity Density

- The Luminosity Density is given by $j = L(*)\phi(*)\Gamma(\alpha+2)$
- SURVEY OLD j (x10^8L$_\odot$/Mpc^3) REVISED j

SURVEY	OLD j (x10^8L$_\odot$/Mpc^3)	REVISED j
2dFGRS	1.90	1.77
SDSS	2.72	1.79
SSRS2	1.49	1.69
UKST	1.77	1.67
ESP	2.18	1.80
APM	1.14	1.67
Afib	1.74	1.82
CS	1.83	1.71
NOG	1.78	1.70
RANGE	1.14 - 2.72	1.67 - 1.80

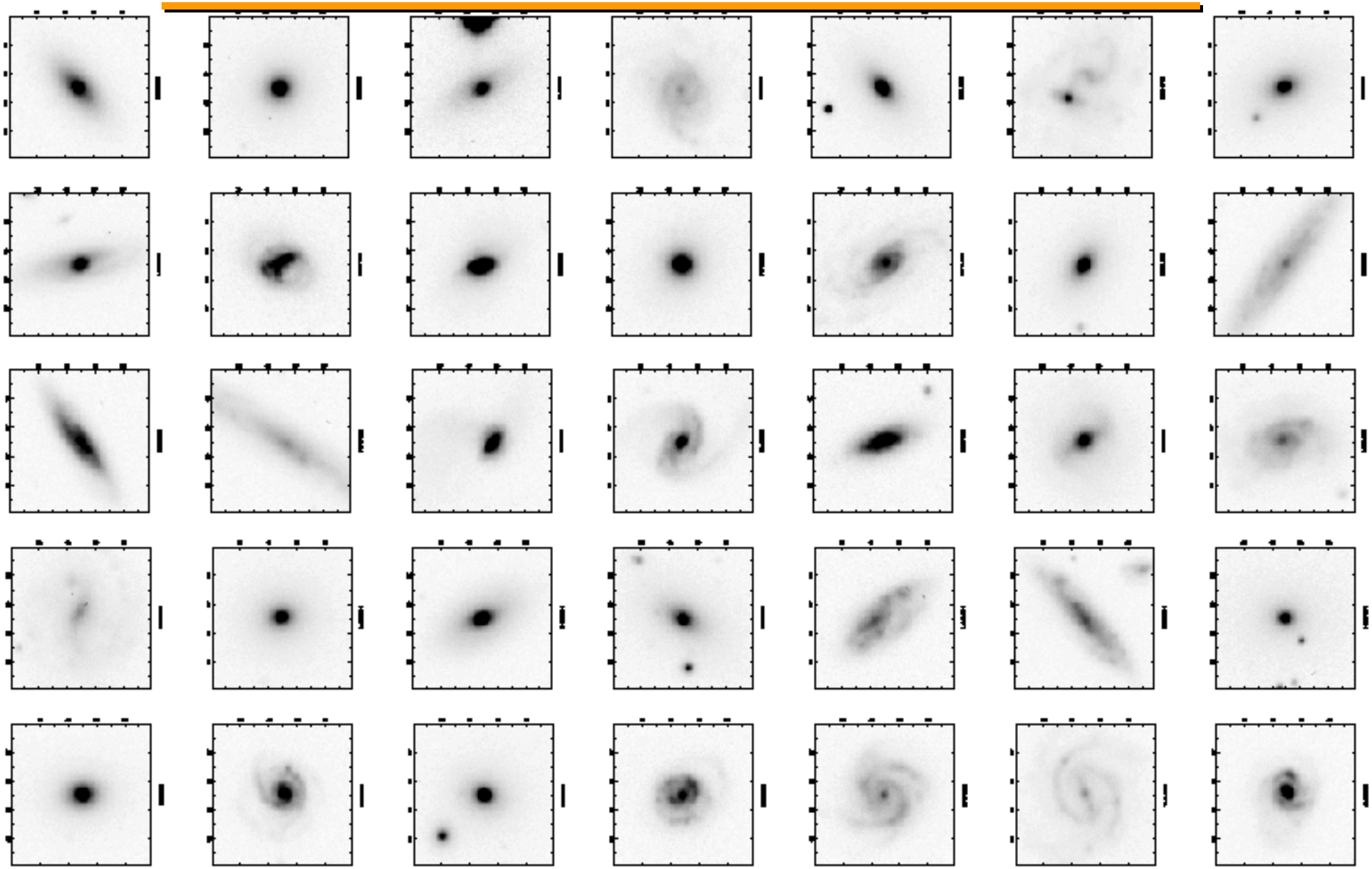
The Fraction of Baryons in Galaxies

- Luminosity density is derived from the local LF:
- The LD is related to the matter-densit $\Omega_{M,gals} = \left(\frac{M}{L}\right) j$
- Adopting a mean baryon mass-to-light ratio for galaxies => $\Omega_{M,gals}$
- From Big Bang Nucleosynthesis: $\Omega_{b,total} = 0.020h^2 +/- 0.002$
- Fraction of baryons in galaxies: $f_b\left(gals/total\right) = (3.30 +/- 0.05)\left(\frac{M_b}{L}\right)\% < 16.50\%$
- So where are the baryons ?

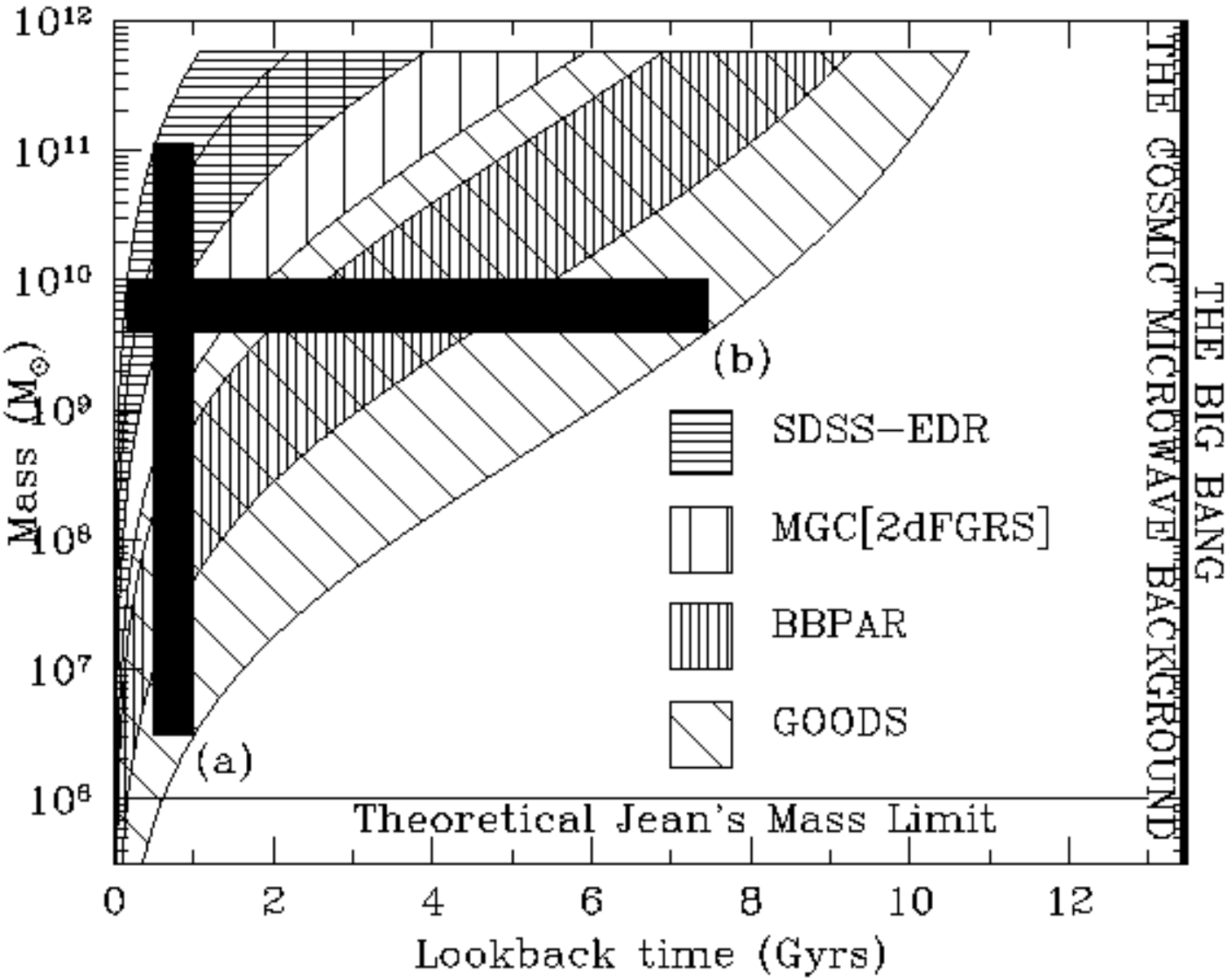
The longer term plan: Galaxy Morphology

- **The MGC is one component that will lead to constraints on:**
  - morphological evolution of galaxies via extraction of volume limited samples
  - galaxy luminosity/merger evolution from galaxy counts and N(z)s
  - Λ, by isolating the elliptical galaxies for which the uncertainties are less
- **The power and scope of combined surveys:**
  - Precision morphological galaxy counts from 16 < B < 28 mags
    - 16 < B < 20 - MGC-BRIGHT
    - 20 < B < 28 - Hubble Space Telescope (BBPAR/GOODS)
  - Plus the redshift distributions
    - 16 < B < 20 - 2dFGRS+SDSS+missing via AAT (~7300 so far 2500 to get).
    - 21 < B < 24 - BBPAR redshifts via GEMINI
    - 21 < B < 26 - Photometric redshifts for GOODS

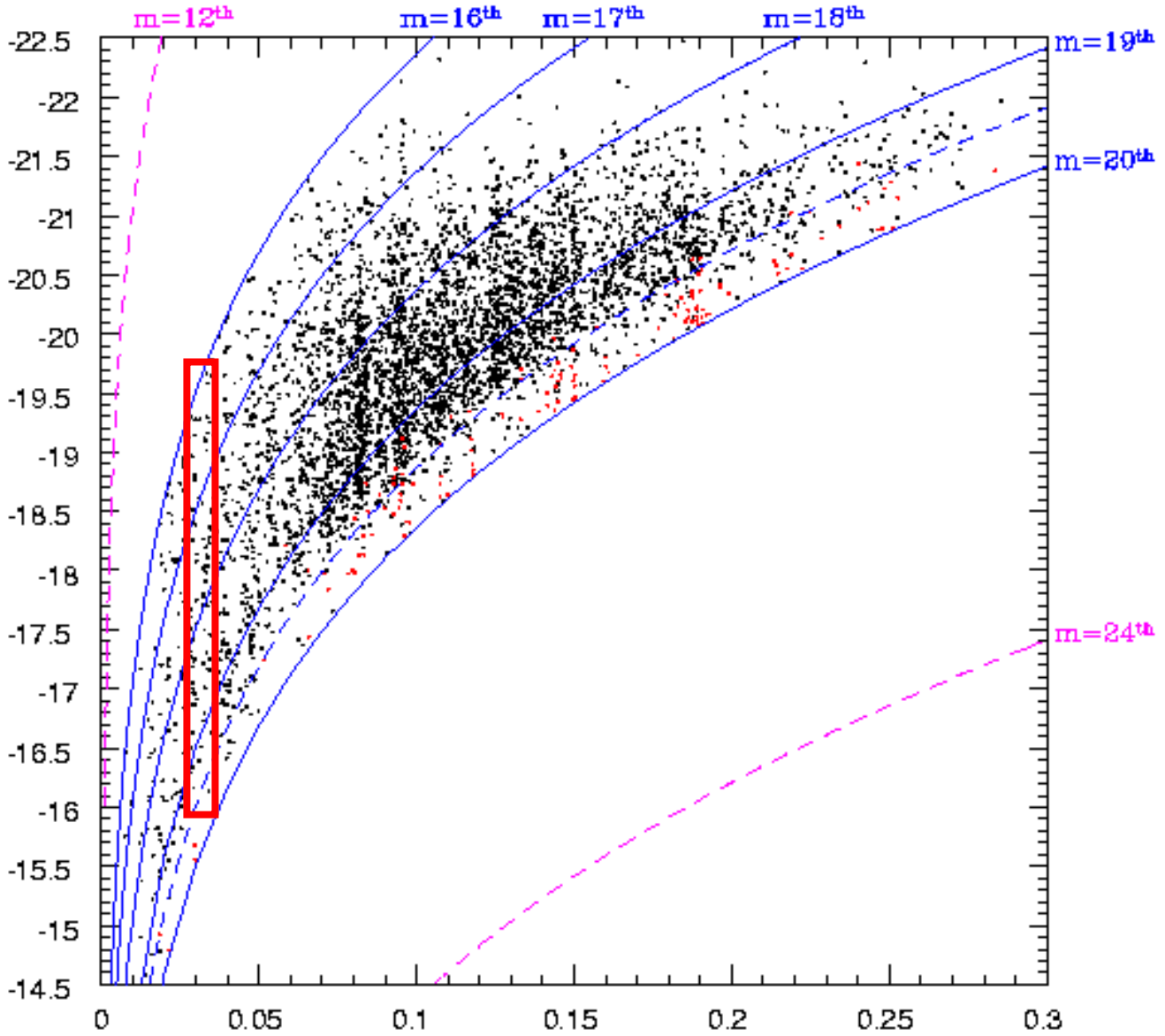
Galaxies are are not like stars !



The power of combined datasets



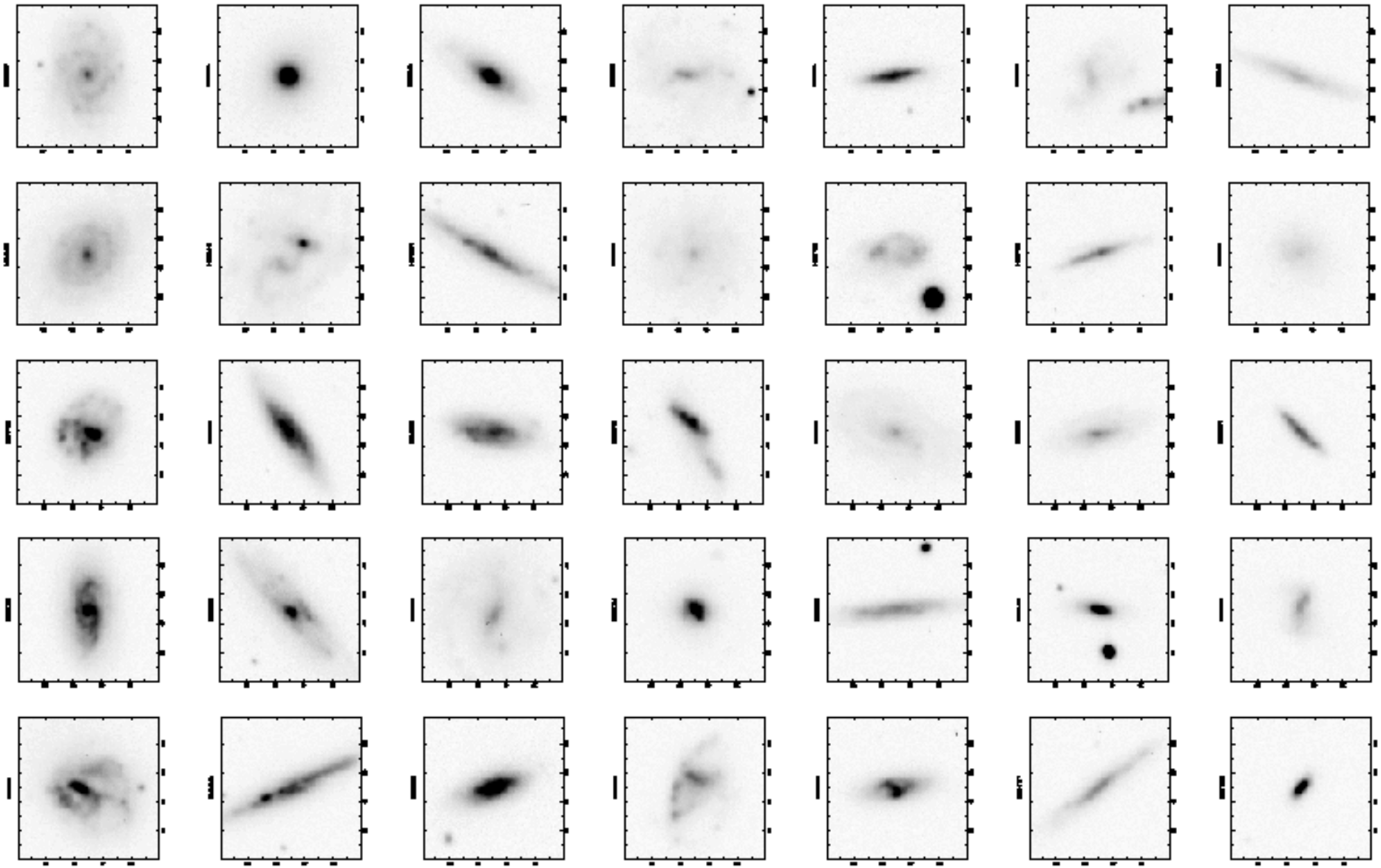
The MGC-BRIGHT z campaign



M>-19.75

Volume limited samples: z=0.03

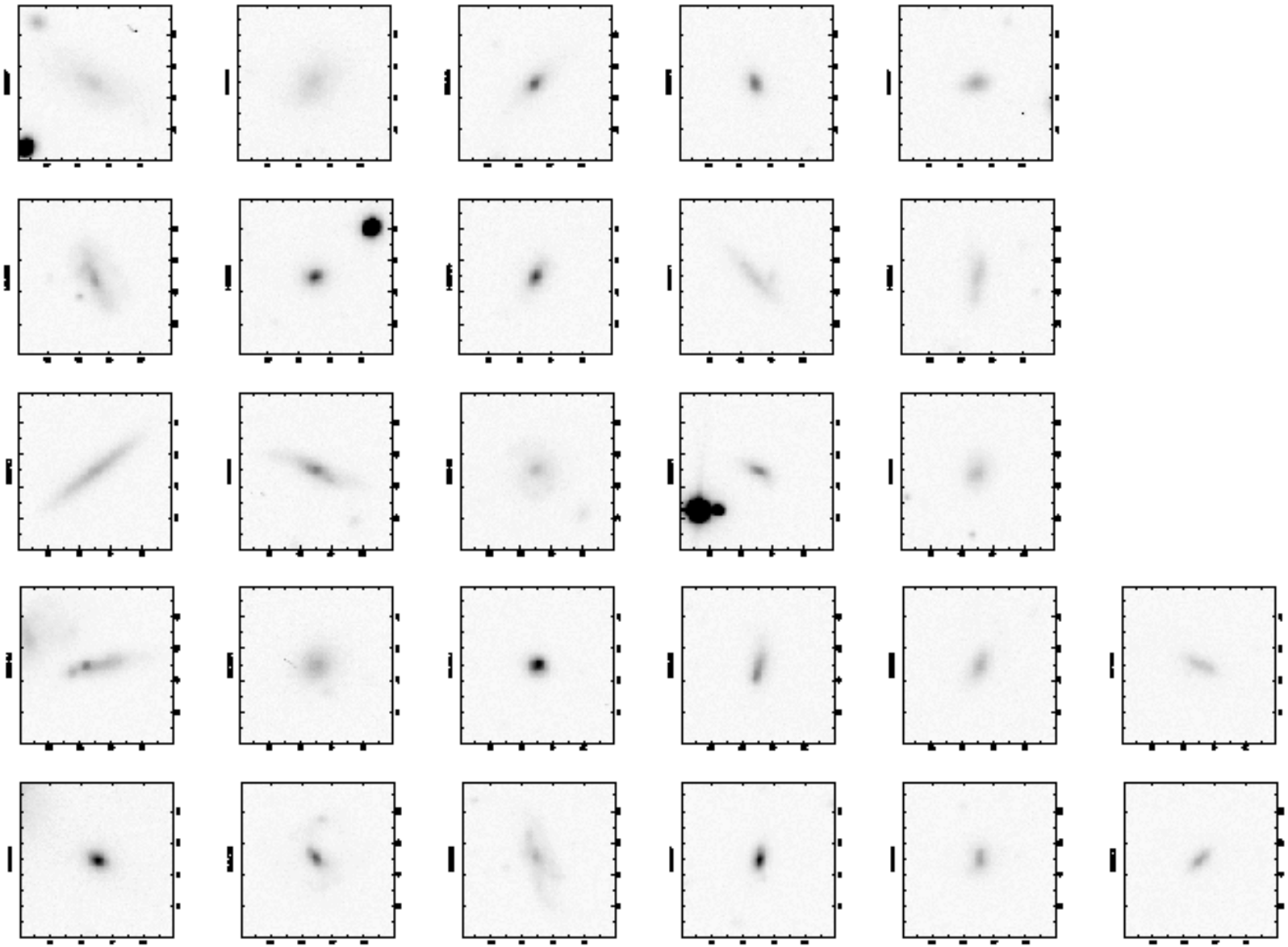
M<-17.5



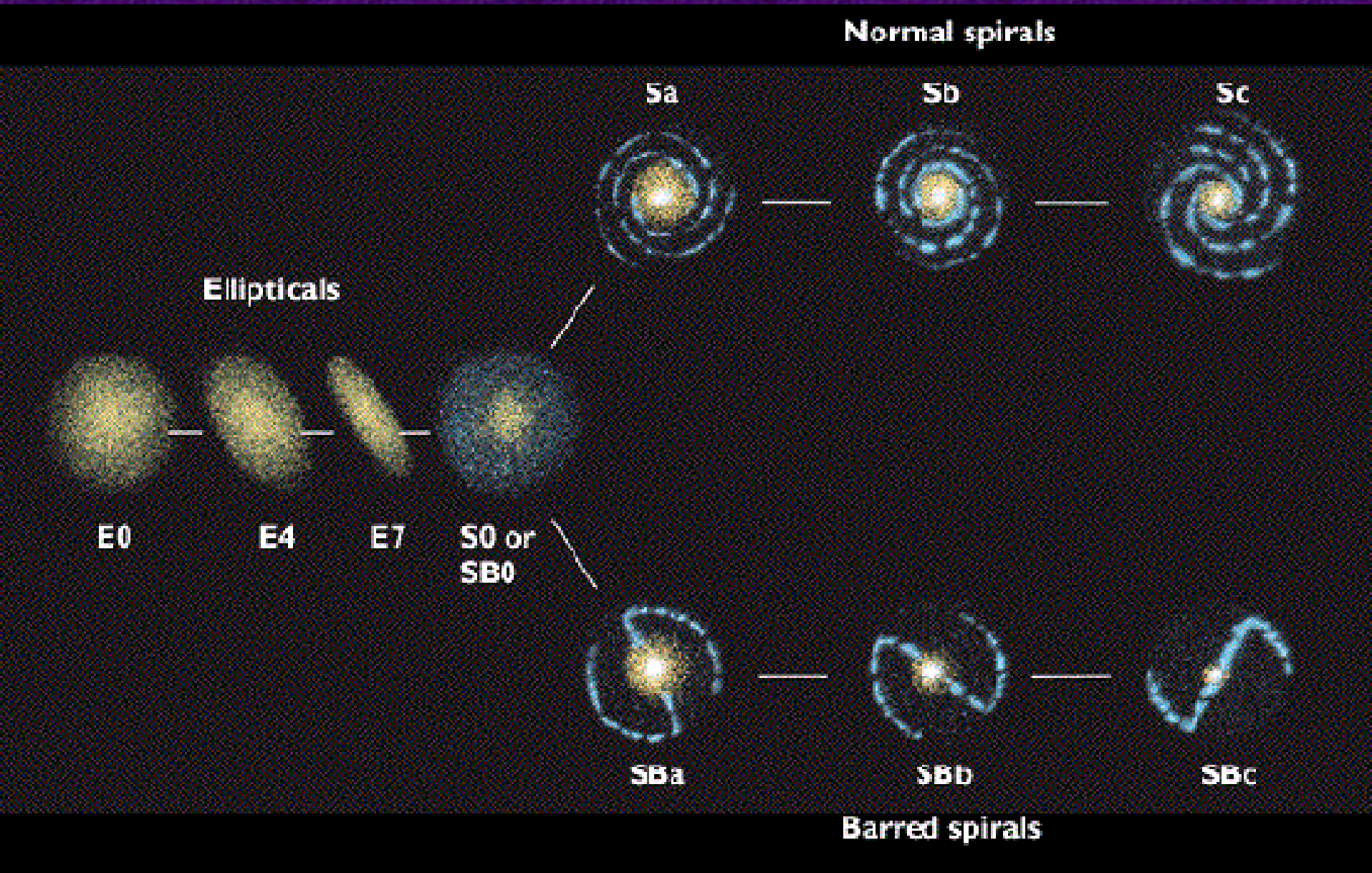
M>-17.5

Volume limited samples: z=0.03

M<-16

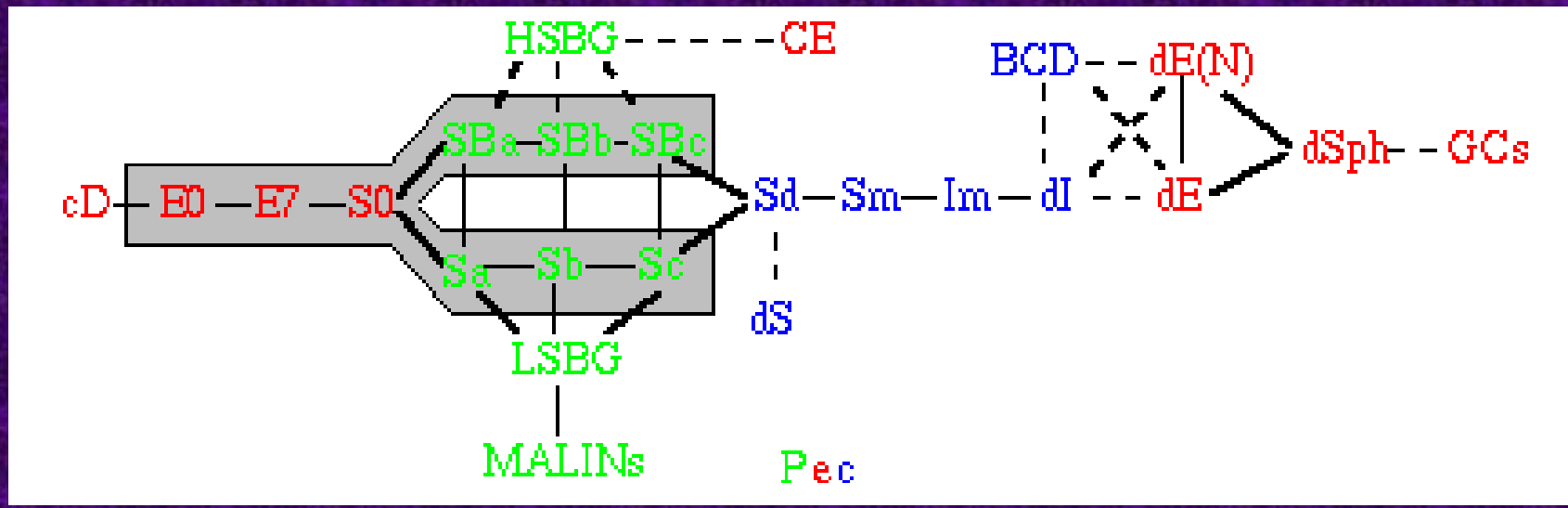


The Hubble Tuning Fork



The Hubble Tuning Fork Breakdown

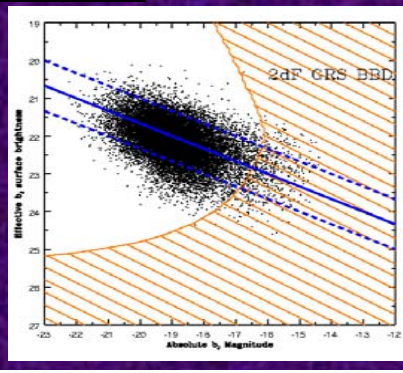
- **Numerous new galaxy types have been found which do not fit on the original Hubble tuning fork diagram**

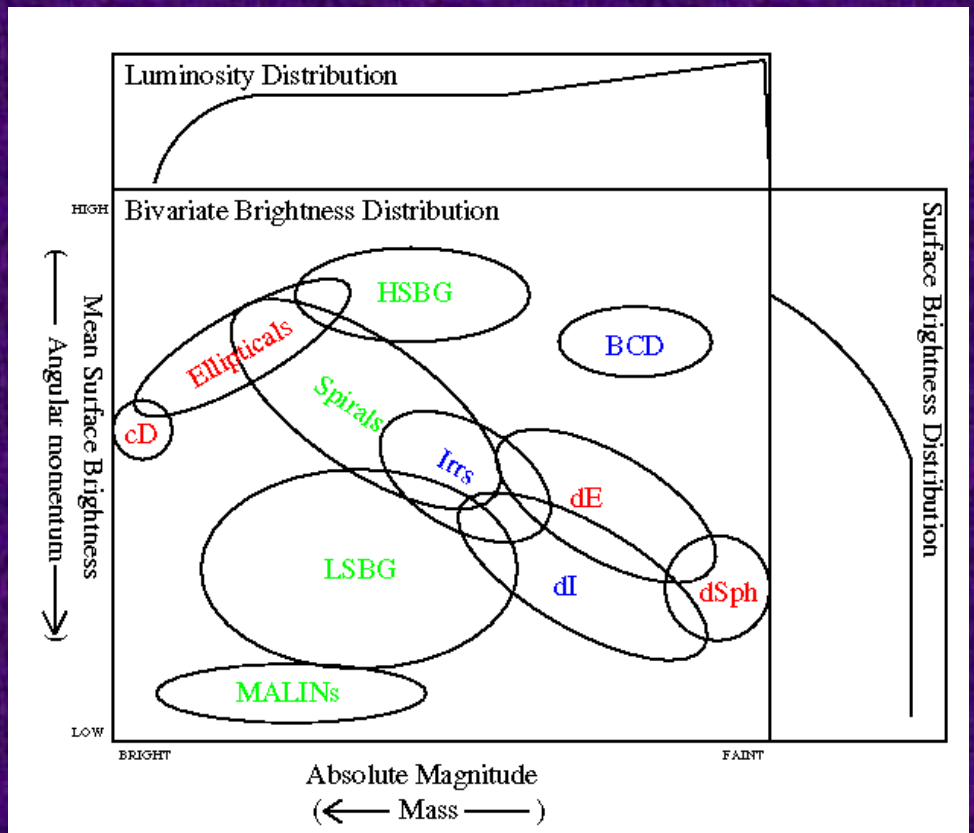


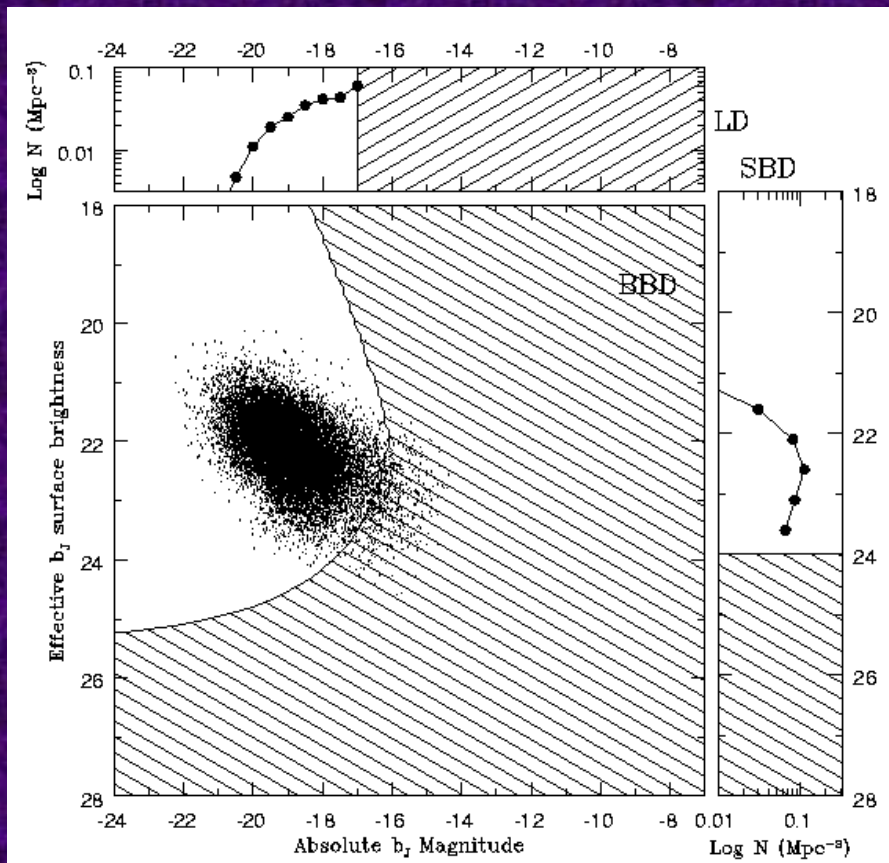
- **Other issues**
  - Subjective
  - No physical basis
  - Shoe-horning required

The BBD: A new methodology

- **Surface brightness versus magnitude**
  - Quantitative
  - Physical basis ? (SB -> ang. Mom., mag ~~-> mass~~)







The path to Λ

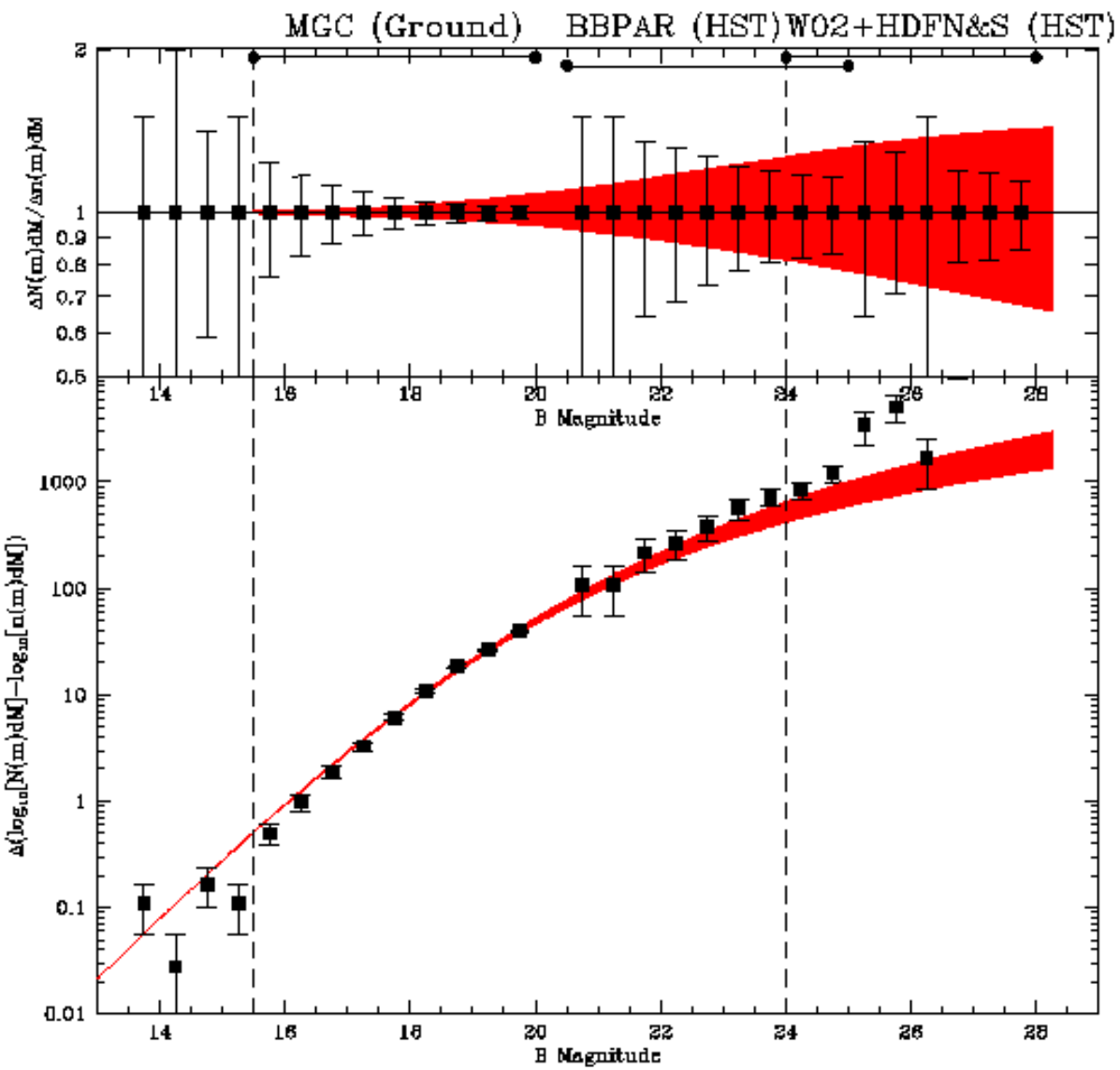
- **Isolate Elliptical galaxies:**
  - High surface brightness objects = easy to find and measure magnitudes for
  - Simple systems relative to spirals and irregulars = easy to classify
  - Old systems with low star-formation rates = minimal evolution
- **7 parameter model to predict N(m) and N(z) distributions:**
  - M*
  - α
  - $\phi(*)$
  - E(z)
  - K(z)
  - Ω_M

Can be measured locally from MGC-BRIGHT

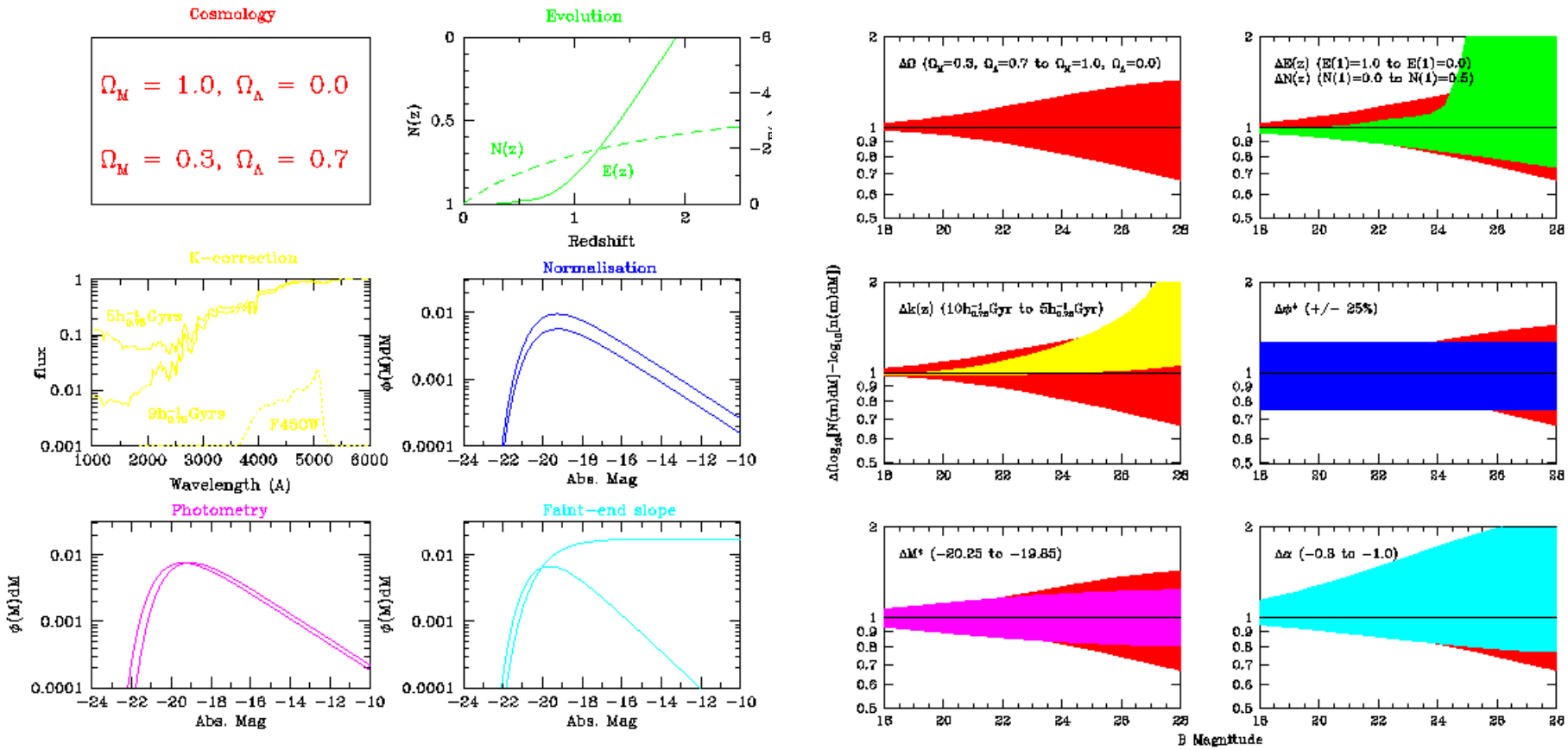
Adopt parameters from latest simulations

Solve via 2-parameter χ^2 minimisation

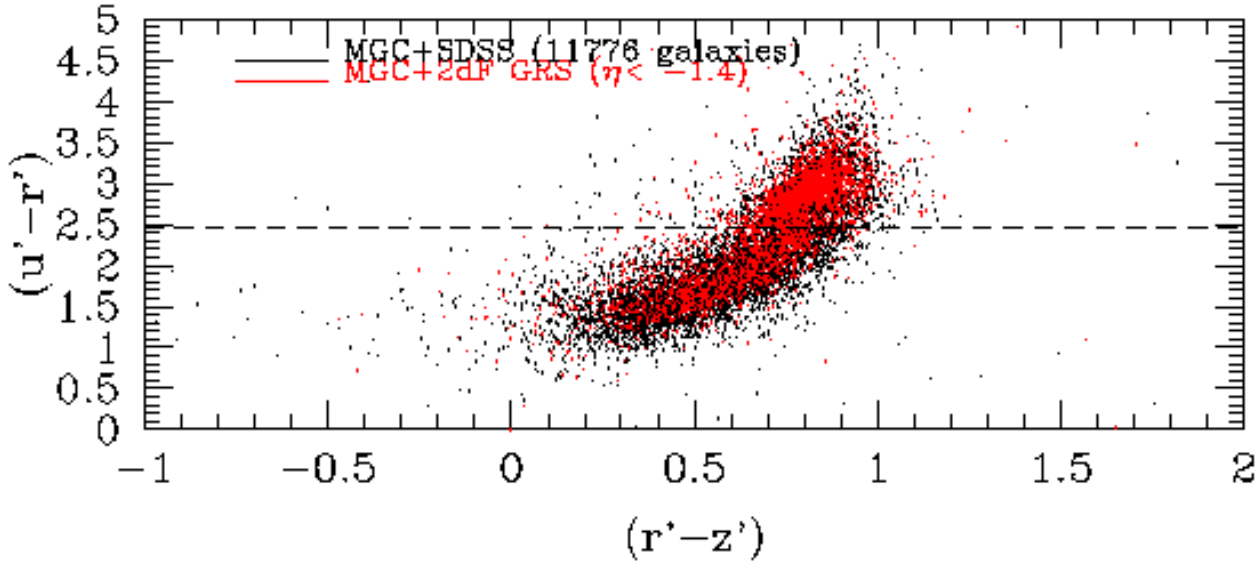
Elliptical Galaxy Counts

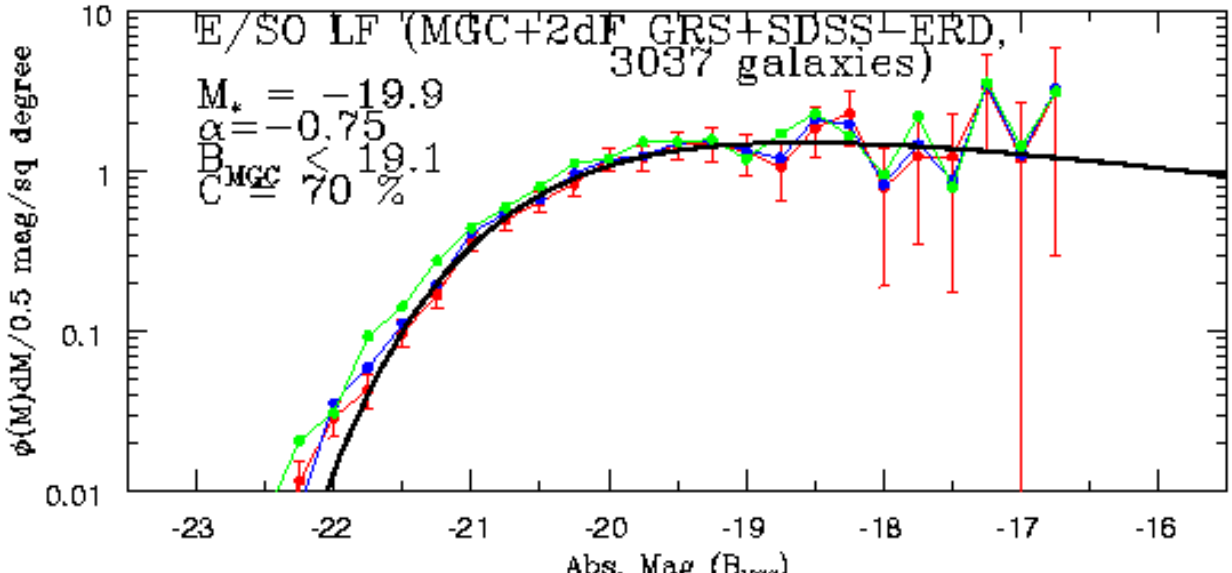


Uncertainties in Elliptical Number count models

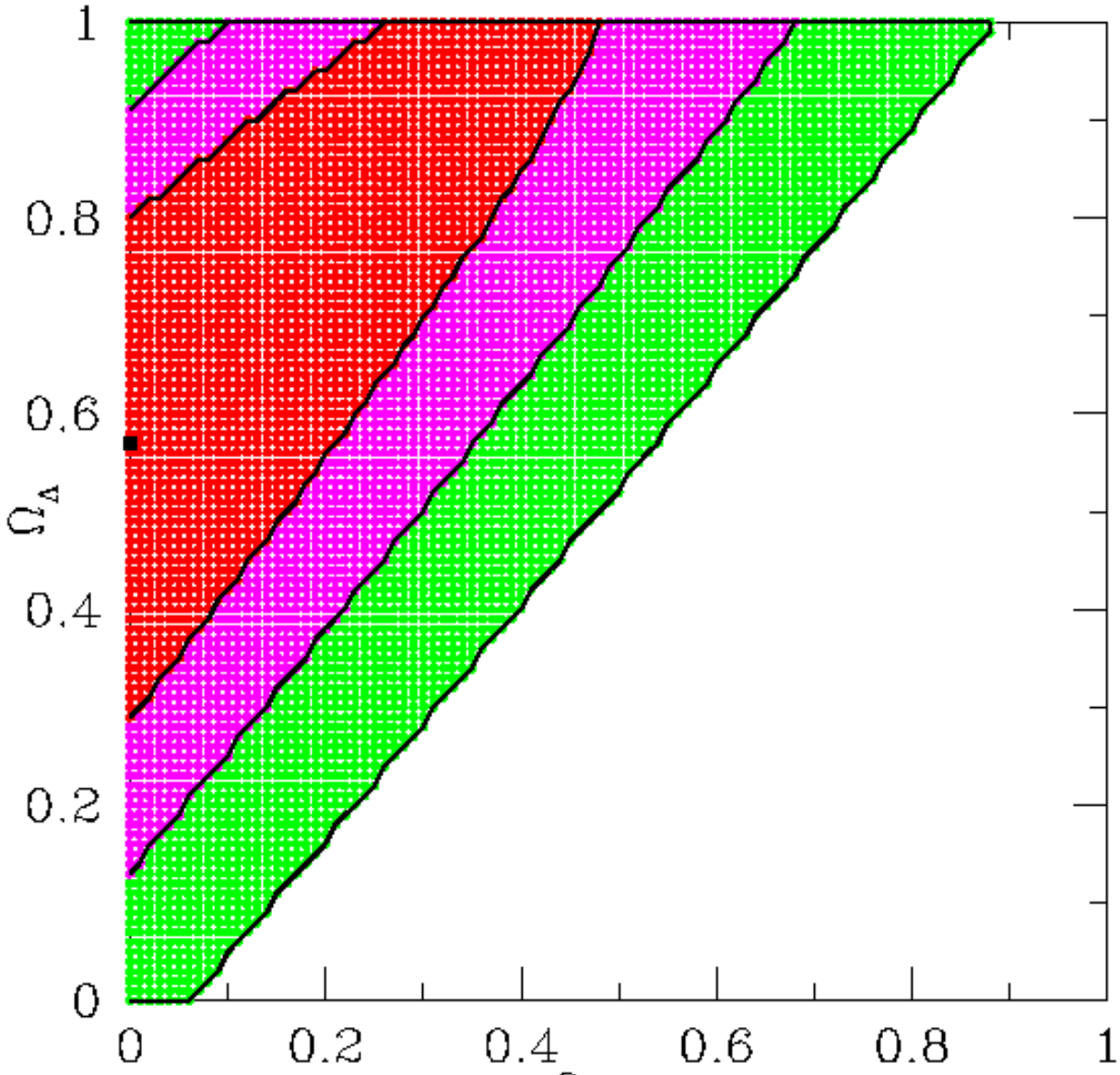


The Nearby Elliptical LF

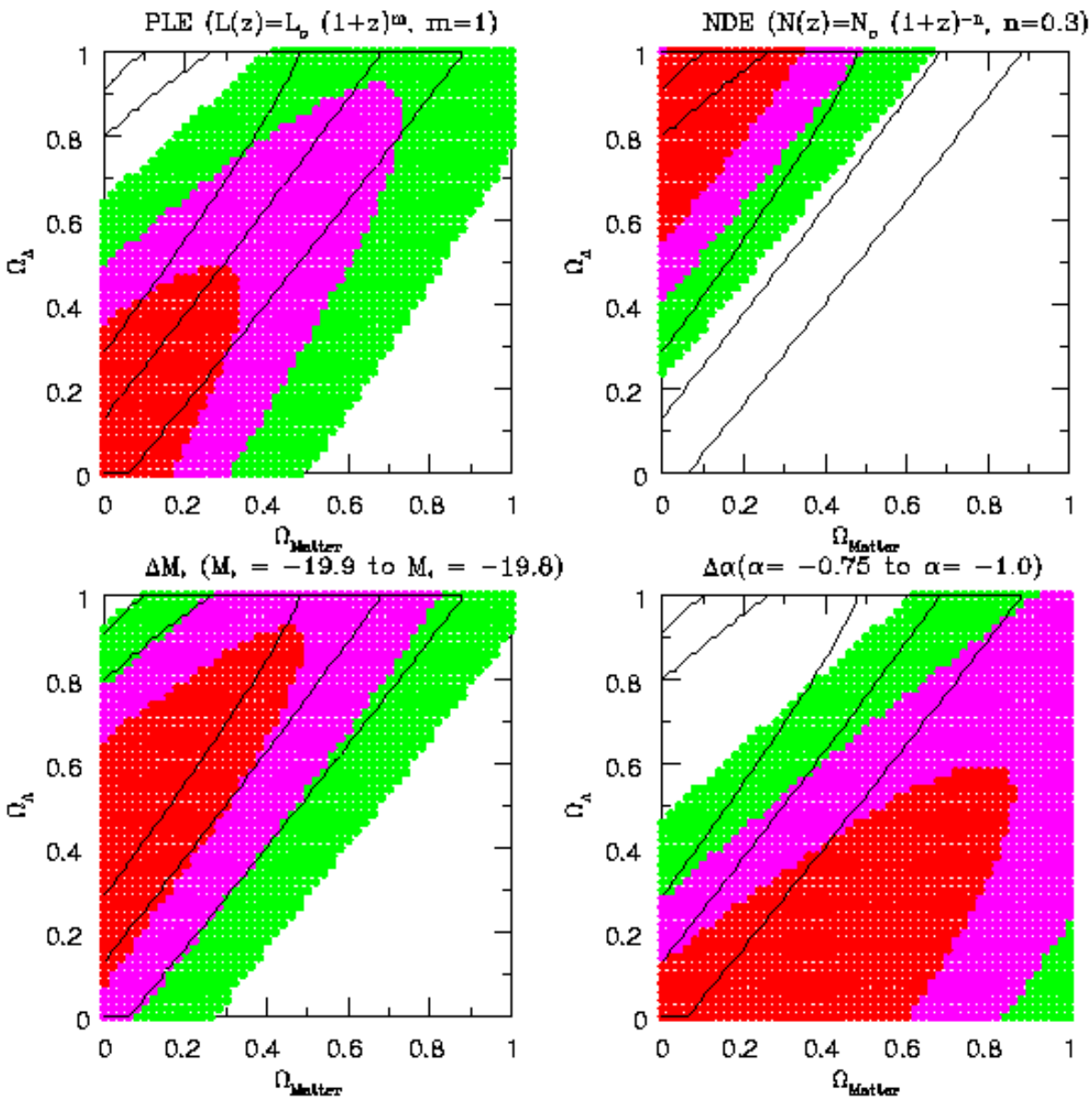




Current constraints from N(m) alone

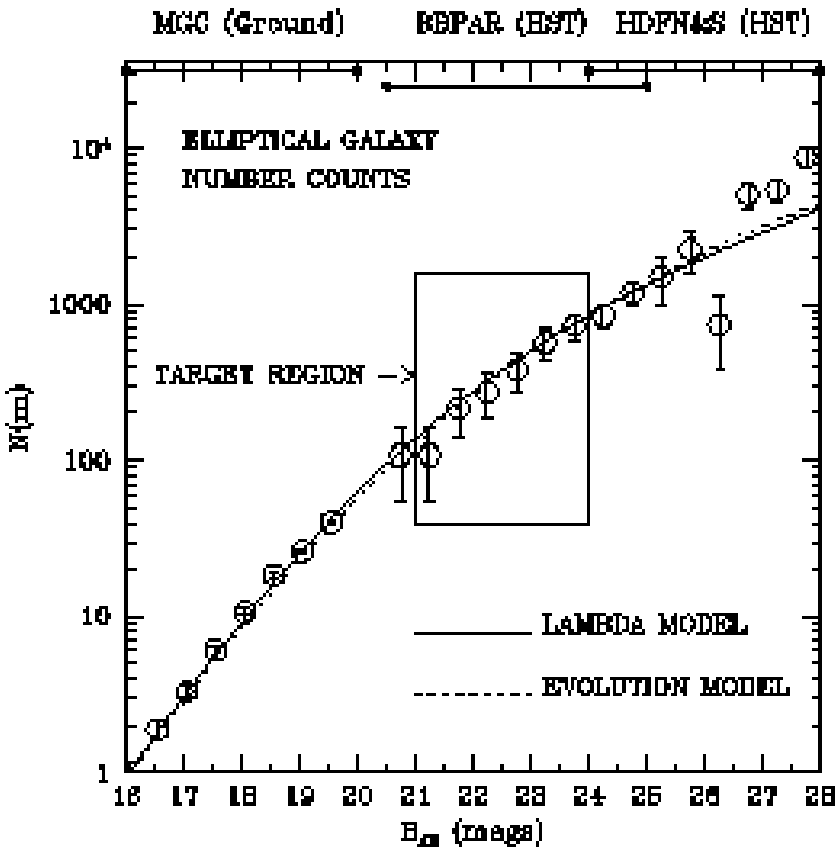


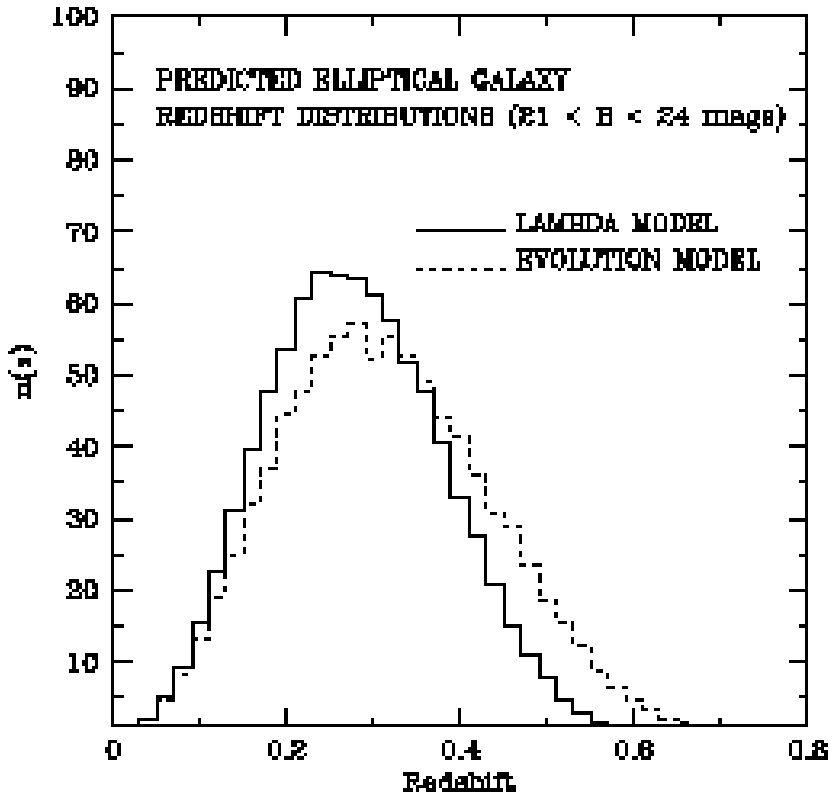
Incorporating the uncertainties



Need N(z) distributions to be viable:

- N(z)s help to break the evolution-Lambda degeneracy





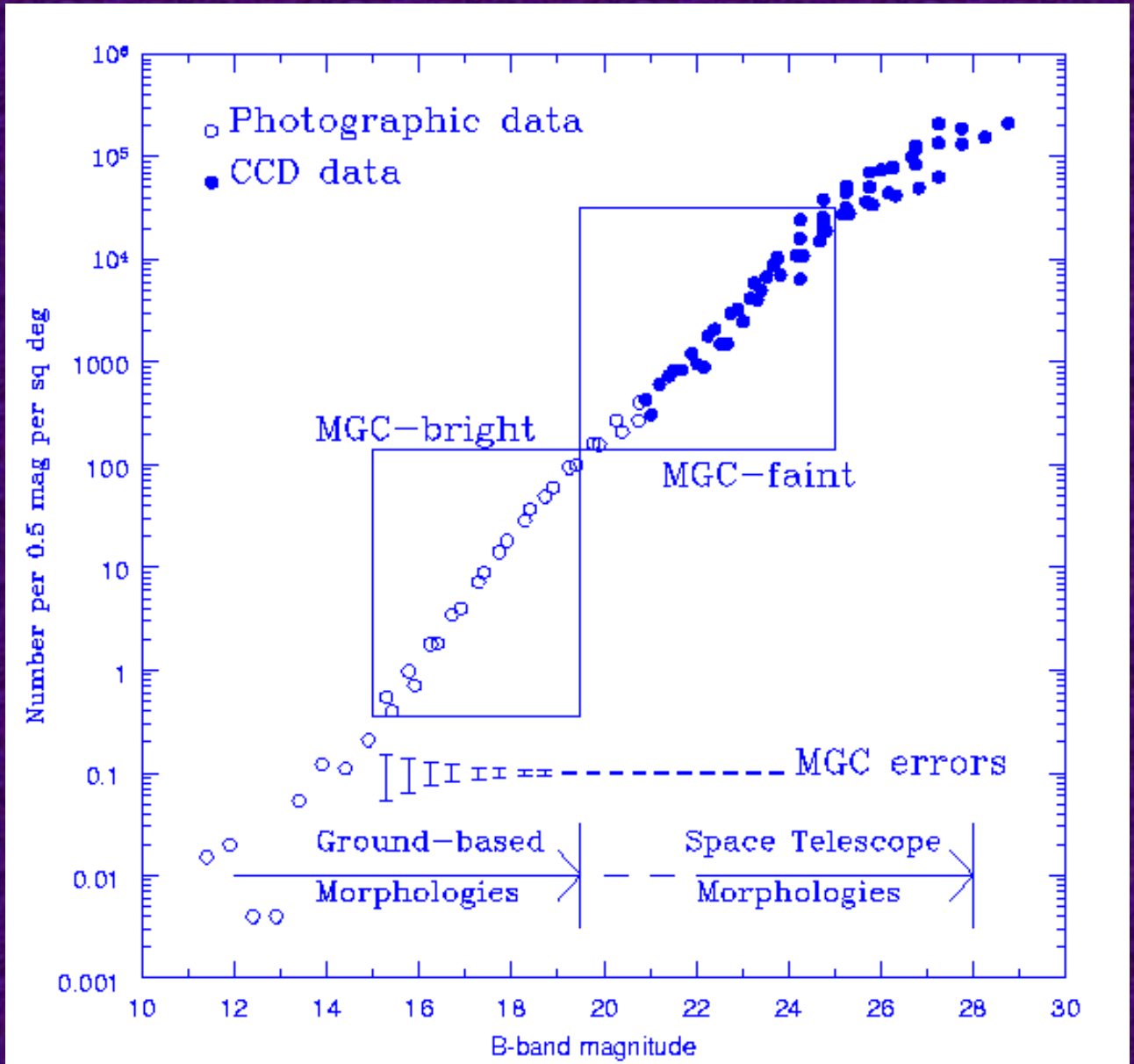
MGC Summary

- **MGC-BRIGHT = A Rolls-Royce local catalogue of ~10,000 galaxies**
- **z's for 7,000 galaxies to date (thanks to 2dFGRS+SDSS-EDR)**
- **u, B, g, r, i, z photometry (thanks to SDSS-EDR)**
- **Preliminary Results:**
  - Galactic Halo axis ratio (c/a)=0.60+/-0.05 (errors to improve)
  - No missing population of giant low surface brightness galaxies
  - No missing population of giant compact objects
  - 2dFGRS suffers ~8% incompleteness in the imaging survey
  - The 2dFGRS photometry is OK (~ +/- 0.2), but strong surface brightness bias
  - SDSS-EDR *may* suffer from a 10% contamination by artifacts
  - SDSS-EDR photometry is good (~+/- 0.1) with no surface brightness bias
  - The 2dFGRS LF provides the most reliable LF

Conclusions

- **The MGC-BRIGHT is re-calibrating our insight into the local universe**
- **Interpretation of faint galaxy counts and N(z)s is fundamentally flawed until local information is refined**
- **Morphology represents a new research avenue**
- **Elliptical counts *could* constrain Lambda, *if* other errors are minimal**
- **Lambda-evolution degeneracy broken via redshifts distributions**
- **With a revised local sample and N(z)s for HST samples we can:**
  - Simultaneously solve for Cosmology and Evolution
  - Determine the rate and level of the evolution of other types (spirals and irregulars)
- **In reality expect cosmology to be constrained via CMB**

MGC Scope


Photographic data
CCD data
MGC−bright
MGC−faint
MGC errors
Ground−based
Morphologies
Space Telescope
Morphologies
Number per 0.5 mag per sq deg
B-band magnitude
10⁶
10⁵
10⁴
1000
100
10
1
0.1
0.01
0.001
10
12
14
16
18
20
22
24
26
28
30

The End