The Millennium Galaxy Catalogue: Bimodality, Dust and Stellar Mass Functions

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(University of St Andrews)

1. The Millennium Galaxy Catalogue (MGC)
2. Galaxy Bimodality = spheroid+disc dichotomy
3. Overcoming dust attenuation in the B-band
4. The stellar mass functions: galaxies, spheroids, discs
5. Some conceptual thoughts on galaxy formation…
6. Galaxy And Matter Assembly (GAMA)

1.

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%)

18 science papers in print/under review

The MGC Team

Simon Driver (St Andrews)
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Paul Allen (ex-St Andrews)
Alister Graham (Swinburne)
Ewan Cameron (St Andrews)

MGC Collaborators

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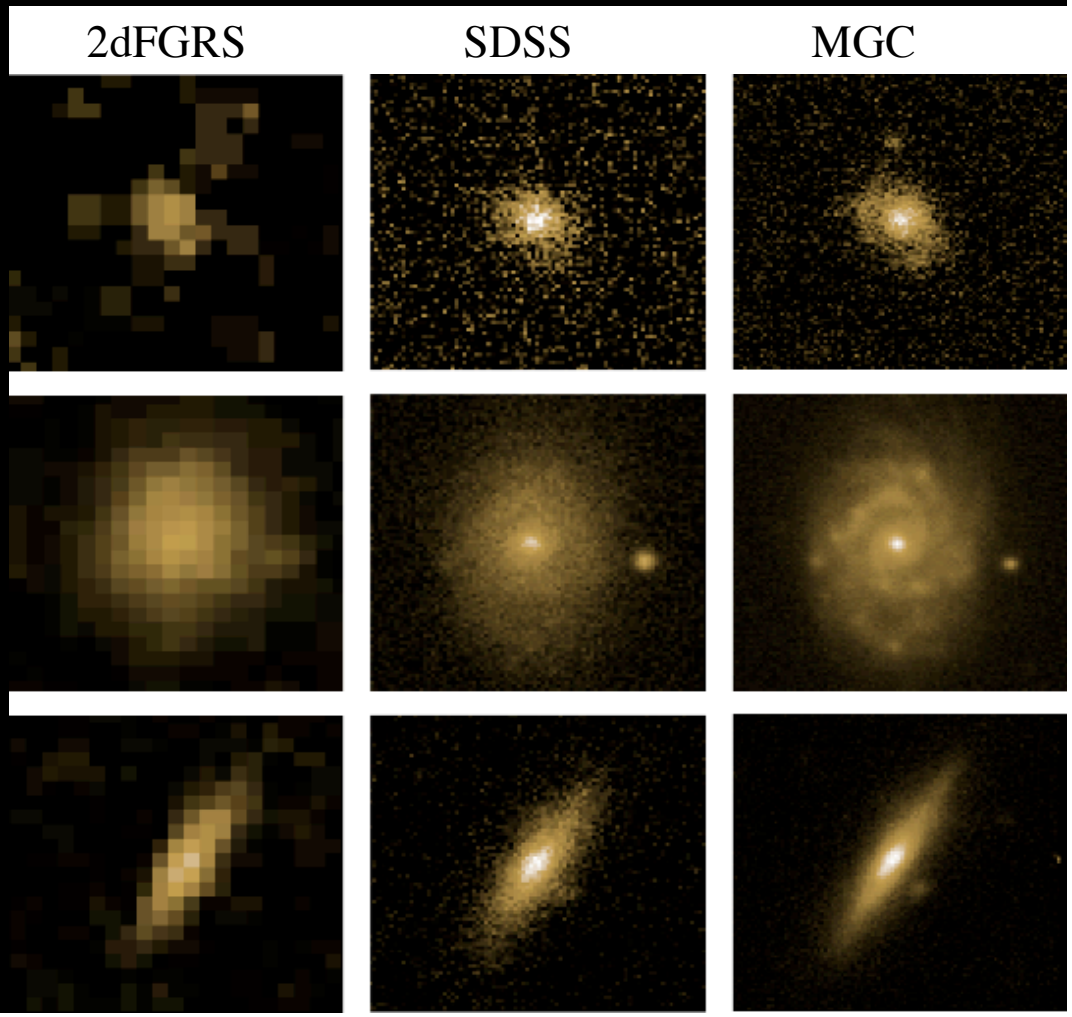
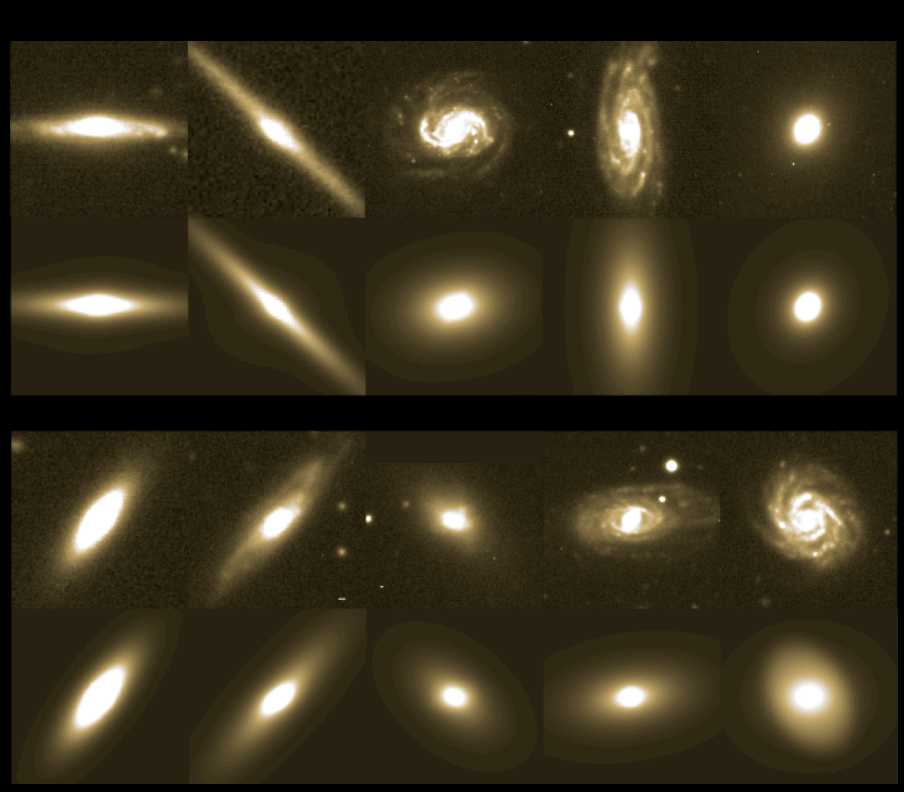
Nicholas Cross (ROE)
Roberto De Propris (CTIO)
Simon Ellis (AAO)
Richard Tuffs (MPIK)
Cristina Popescu (MPIK)

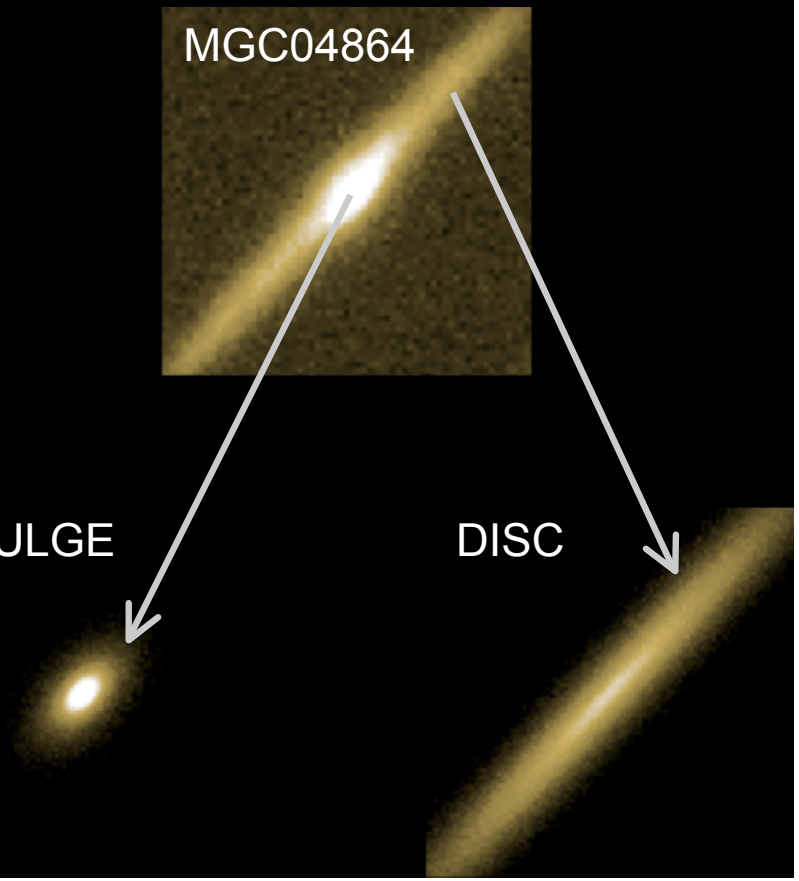
http://www.eso.org/~jliske/mgc/



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) + YJHK(UKIRT) imaging now 50% complete.
- All data available online: http://www.eso.org/~jliske/mgc/





HEALTH WARNING

TO RUN GIM2D: 1 MONTH

TO FIX BAD PROFILES: 2 YEARS+

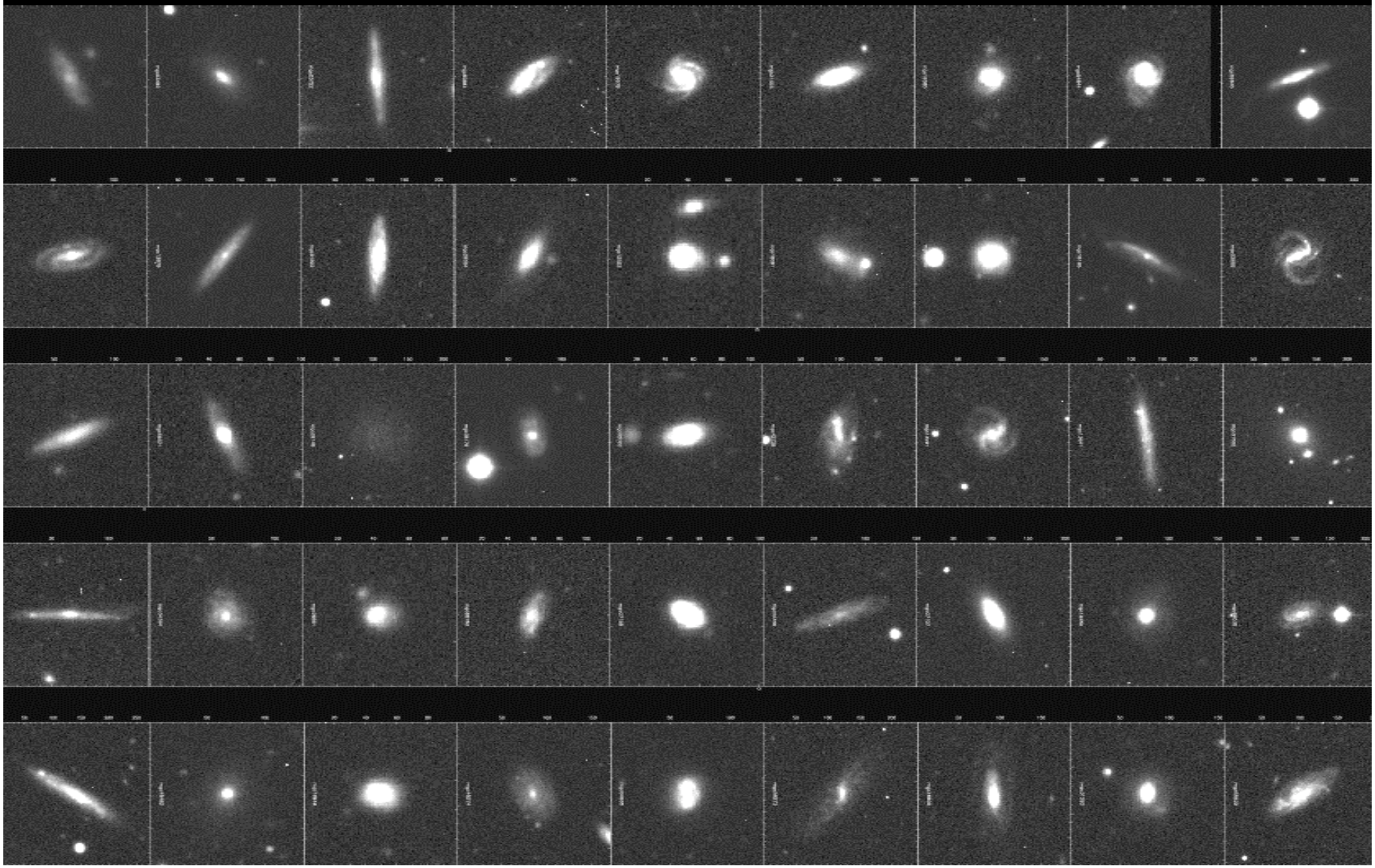
20% OF PROFILES HAD BAD MASKS

20% OF PROFILES TOTAL JUNK

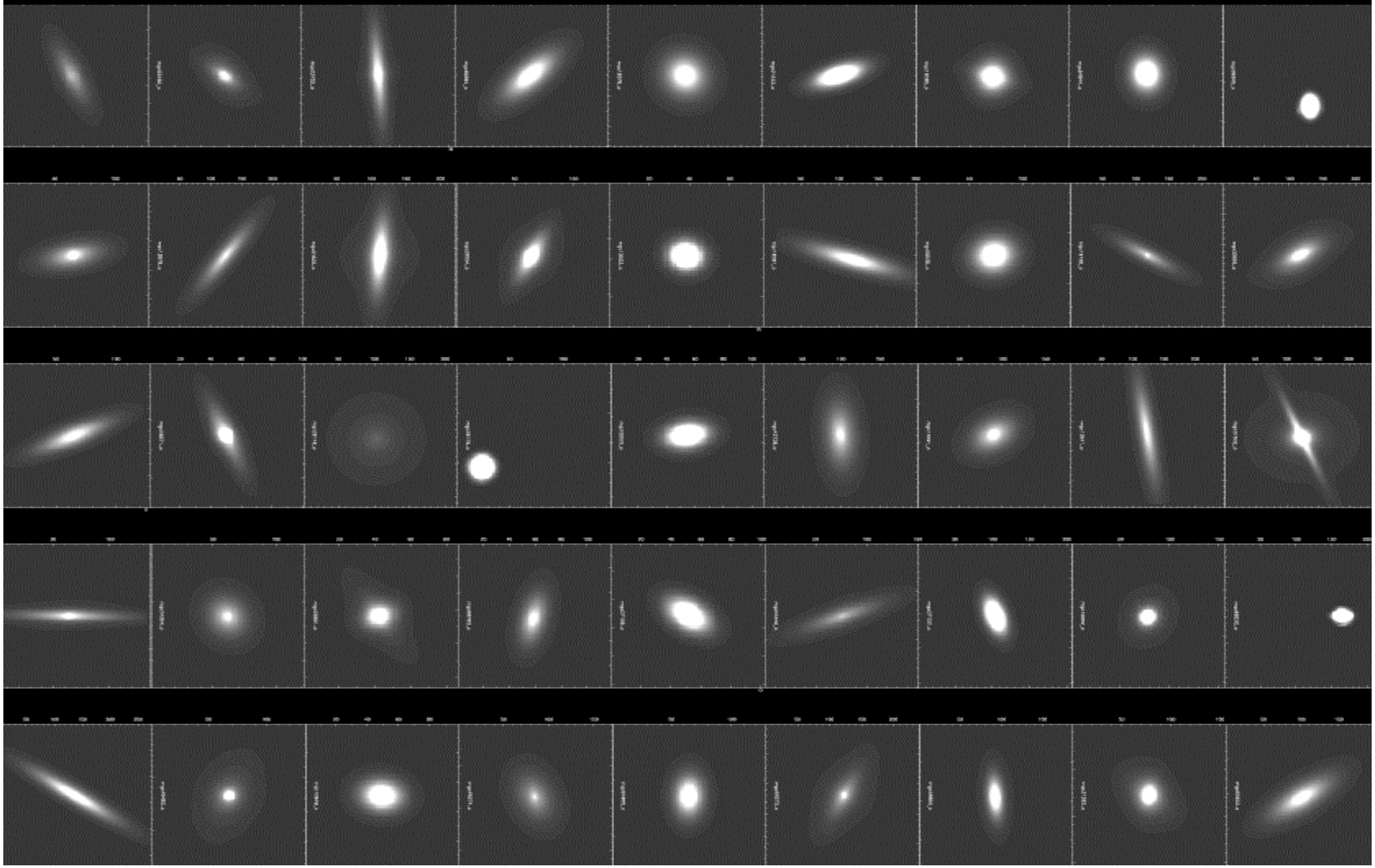
FAILURE RATE AFTER FIXING:10%

DO NOT BELIEVE AUTOMATED ALGORITHM OUTPUT
UNTIL AFTER DETAILED QUALITY CHECKS

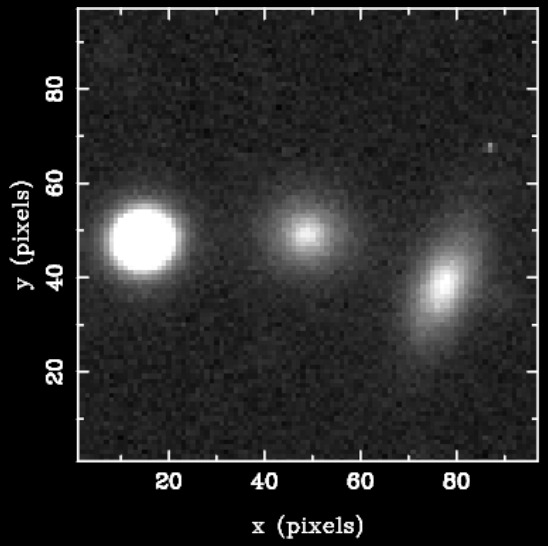
MGC: Bulge Disk Decomposition, originals

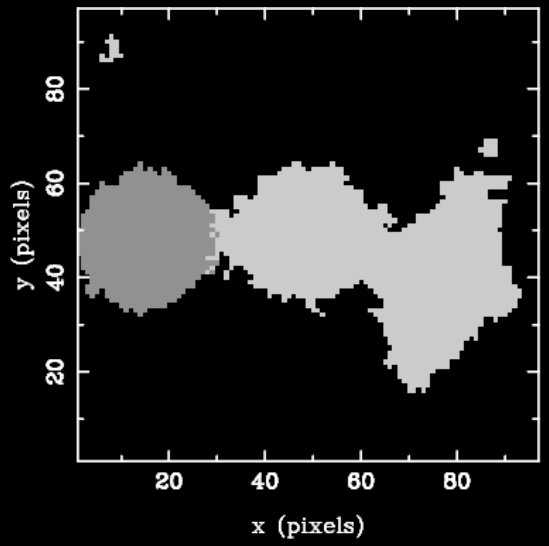


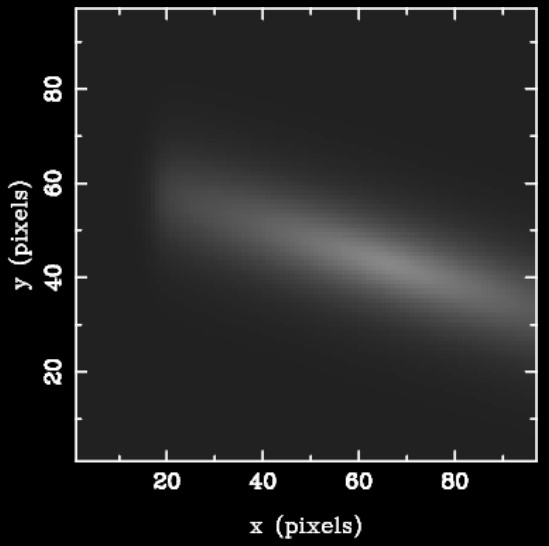
MGC: Bulge Disk Decomposition, models



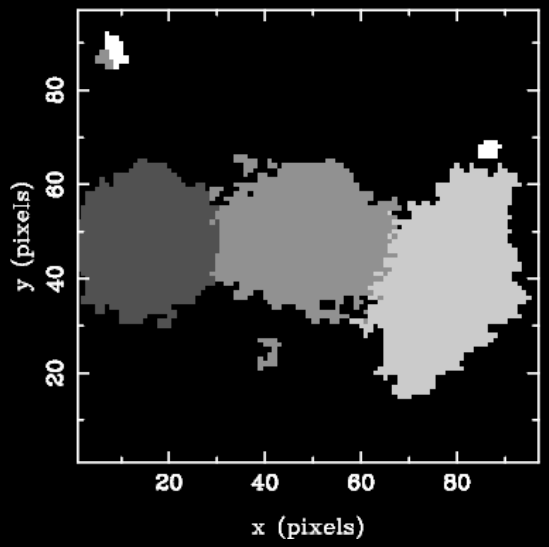
Example: Bad mask

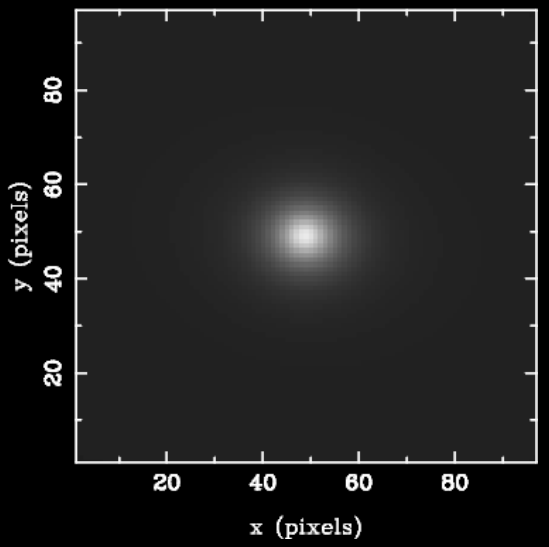




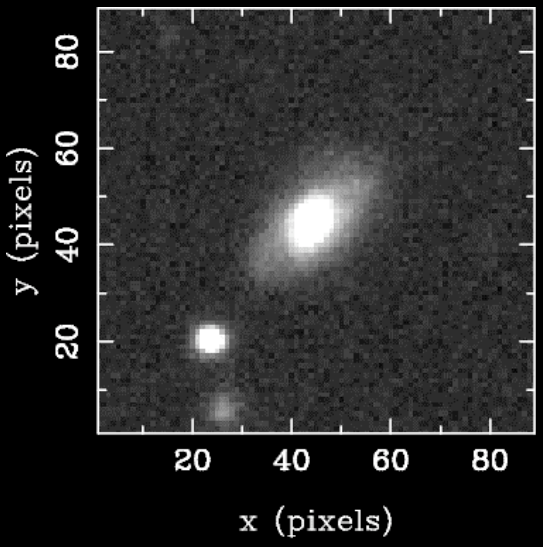


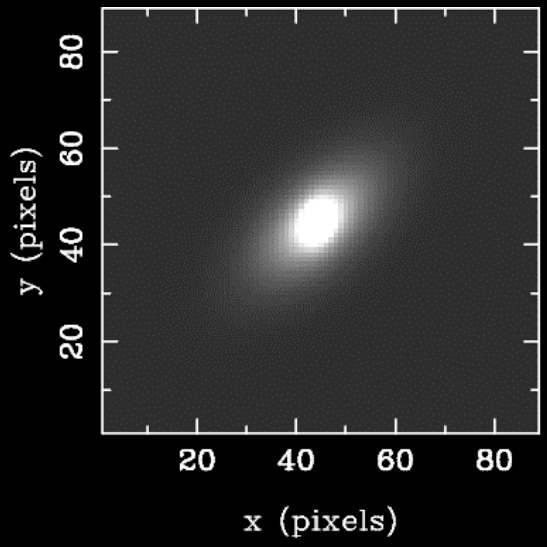
20 % of galaxies had bad masks and required fixing by hand !

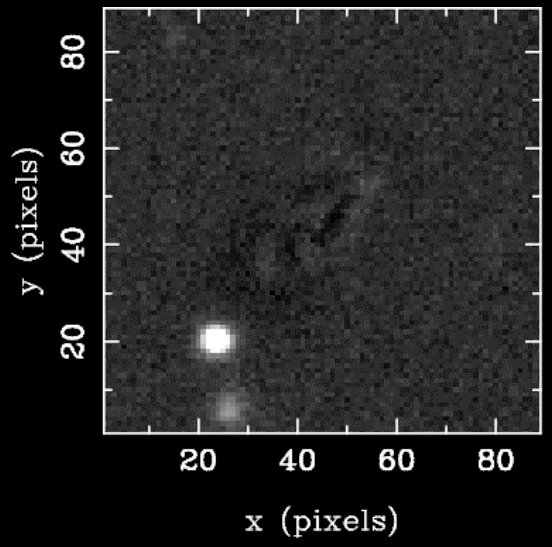


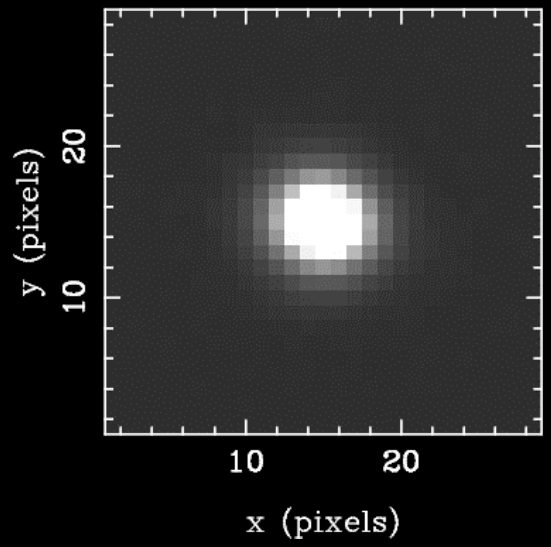


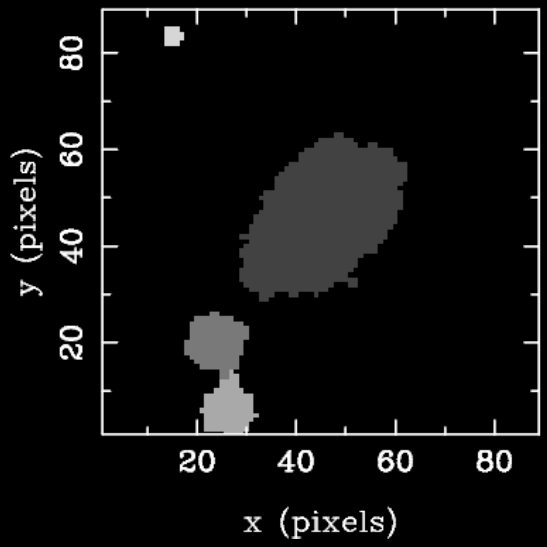
Example 1: MGC27301

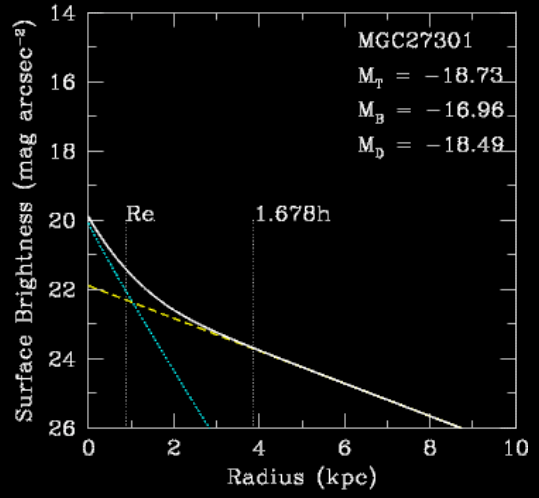












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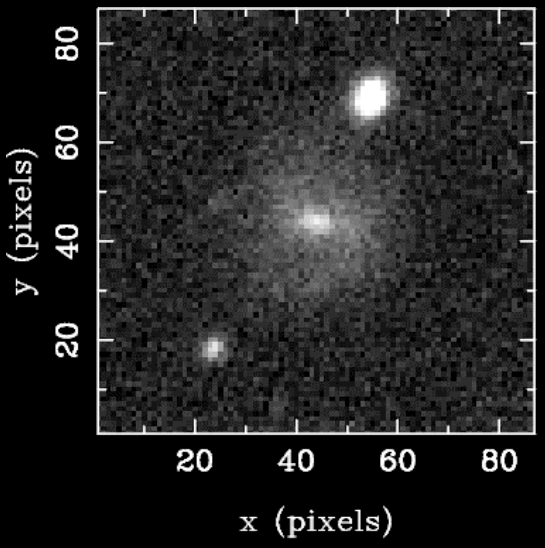
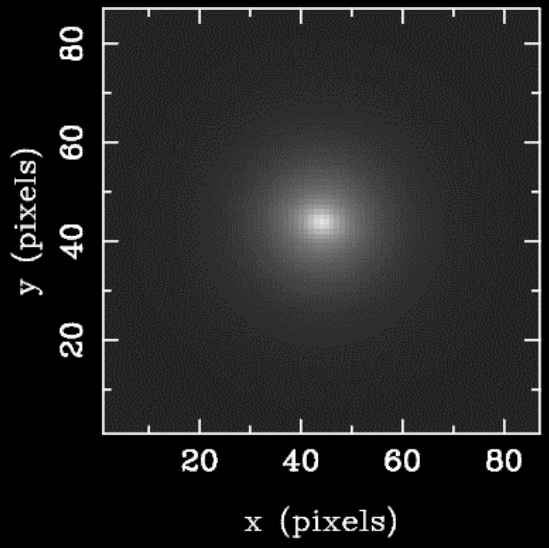
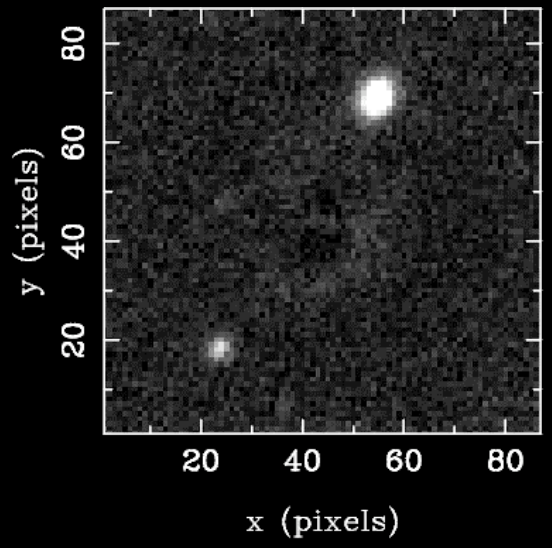
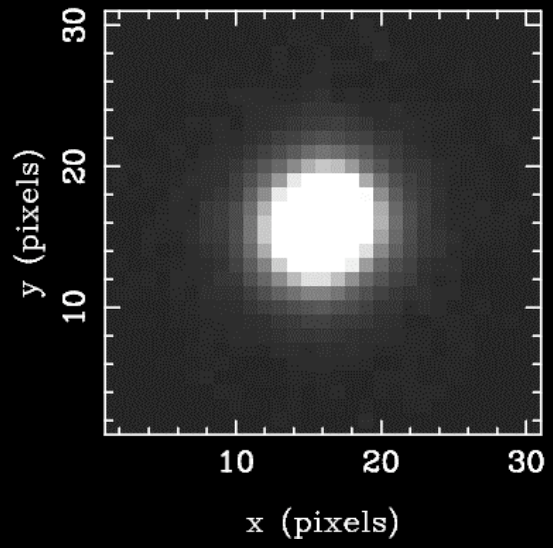
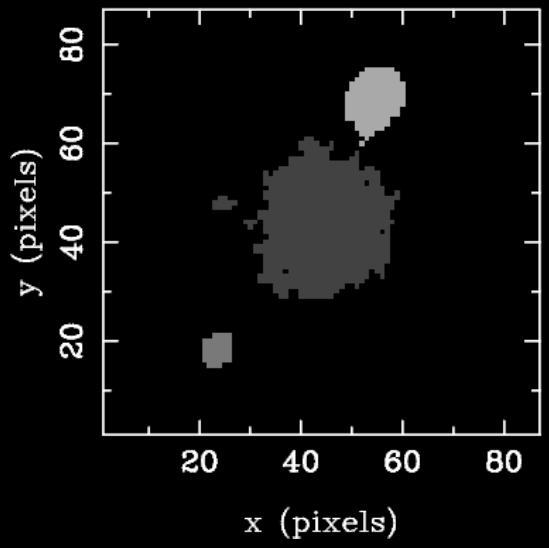
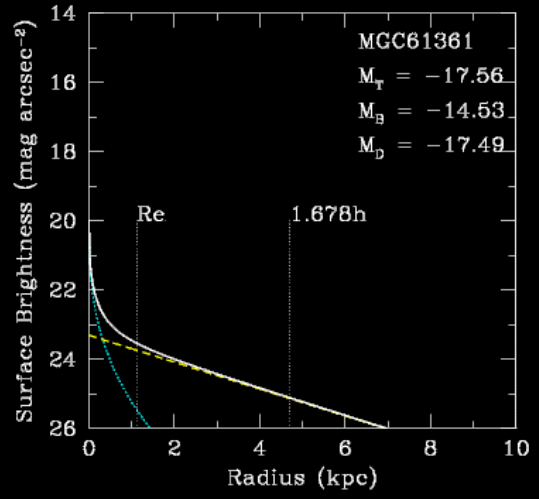




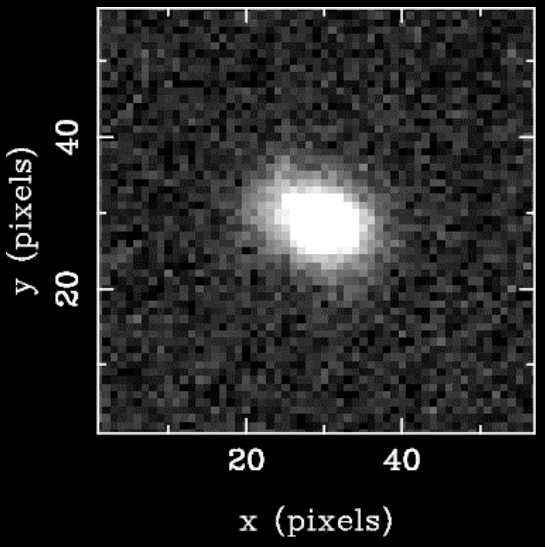


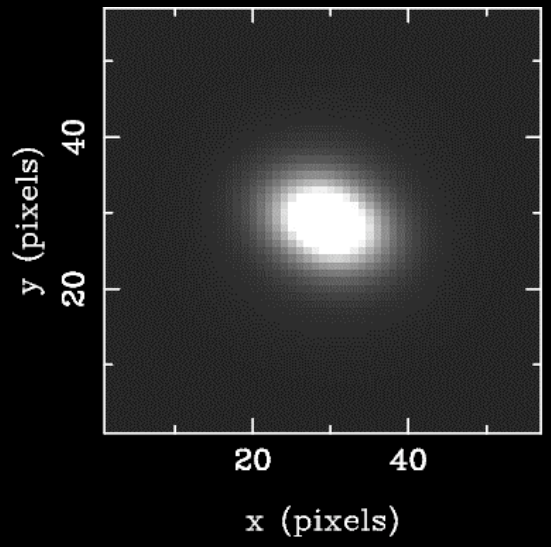


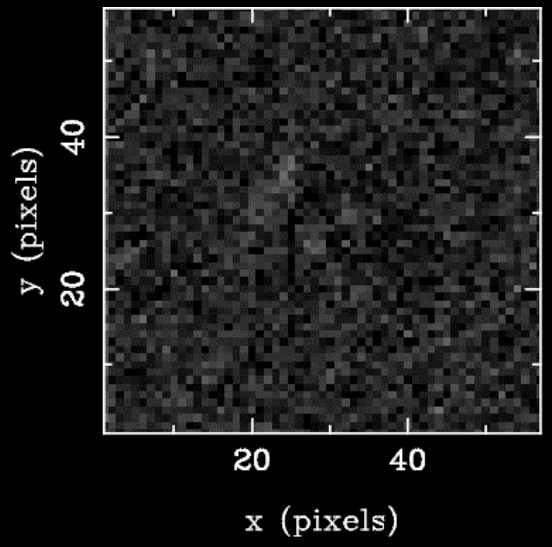


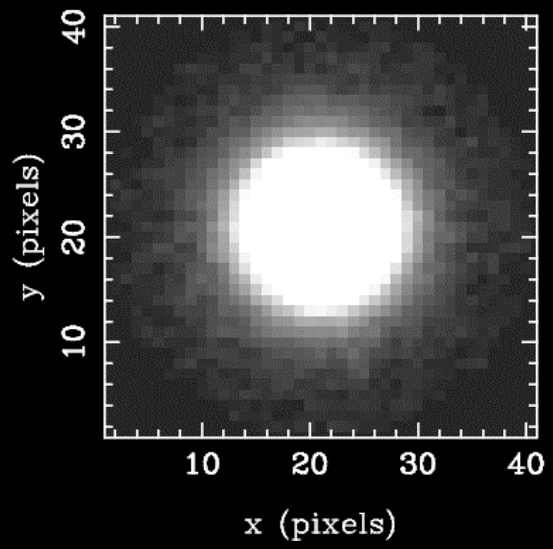


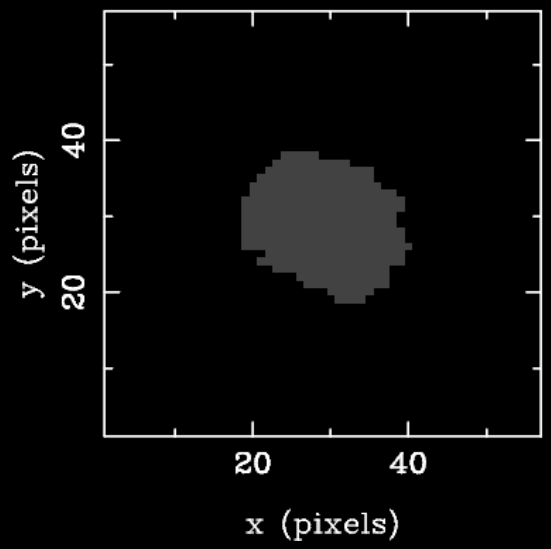
Example 3: MGC55593

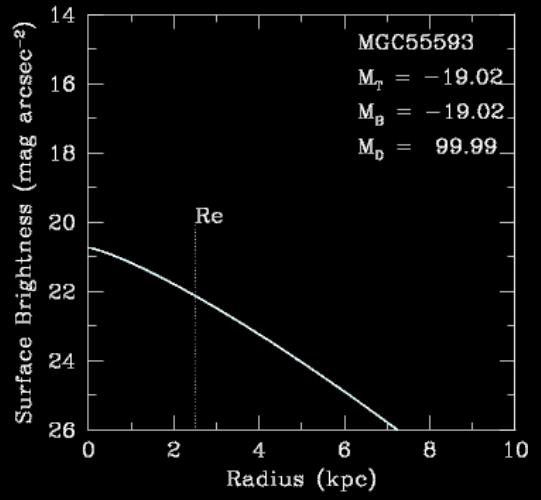






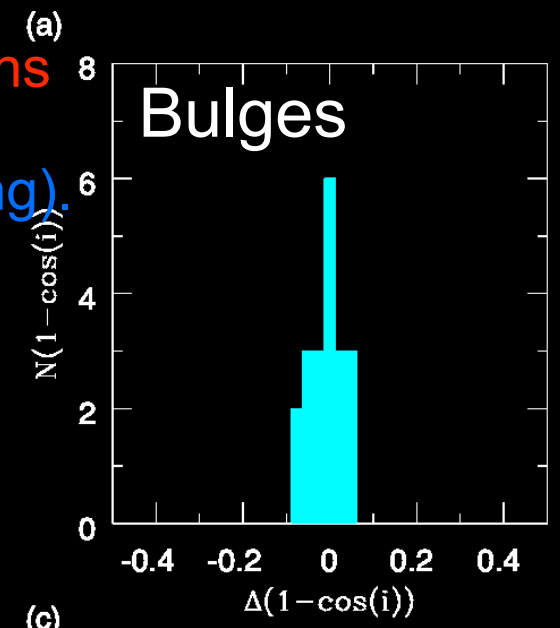


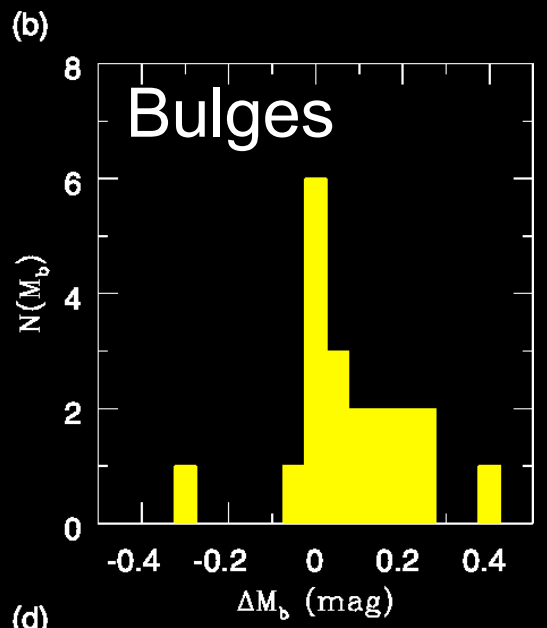


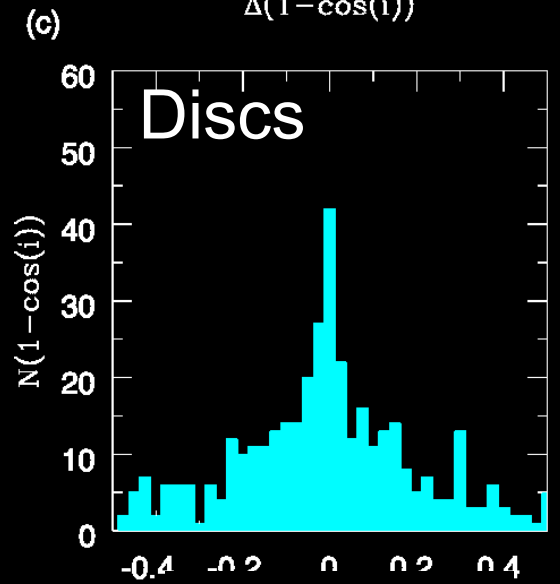


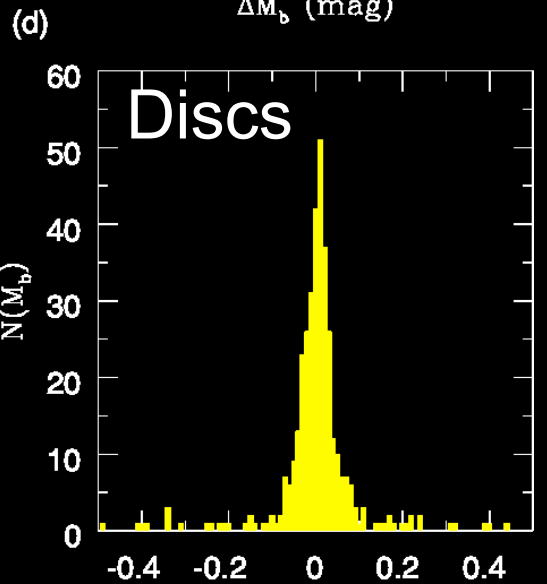
Sanity check via repeat obs.

- From 780 repeat observations we can test the structural reliability (after logical filtering).
- For final catalogue we find:
  - +/- 0.103 mag
  - +/- 0.132 in log(n)
  - +/- 0.047 in cos(i)
  - +/- 0.122 in R(HLR)
- For Sersic only cat we find:
  - +/- 0.036 mag
  - +/- 0.041 in log(n)
  - +/- 0.036 in R(HLR)







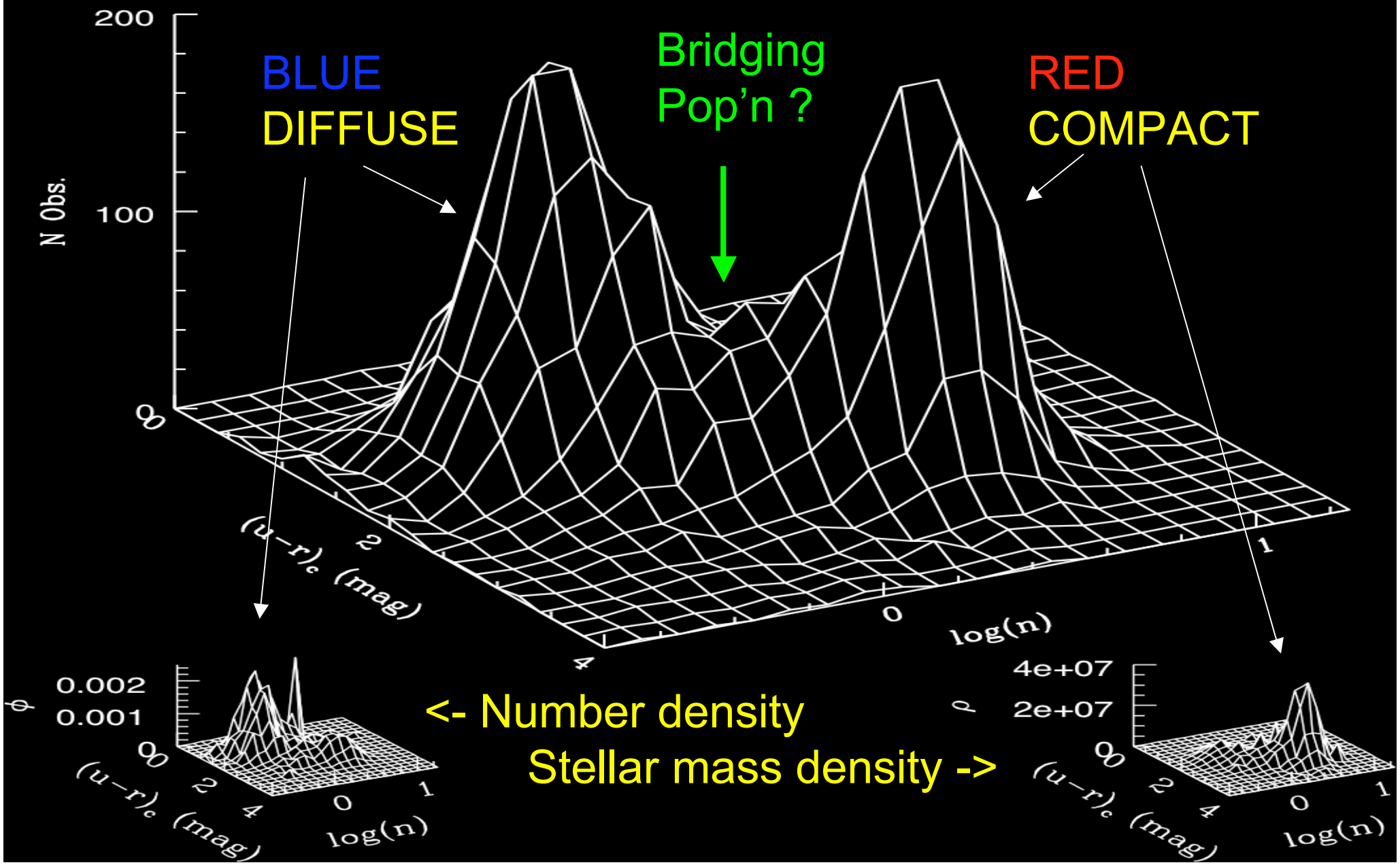


Δ[1-cos(i)]

ΔM (mag)

2. Galaxy bimodality in (u-r)-log(n)

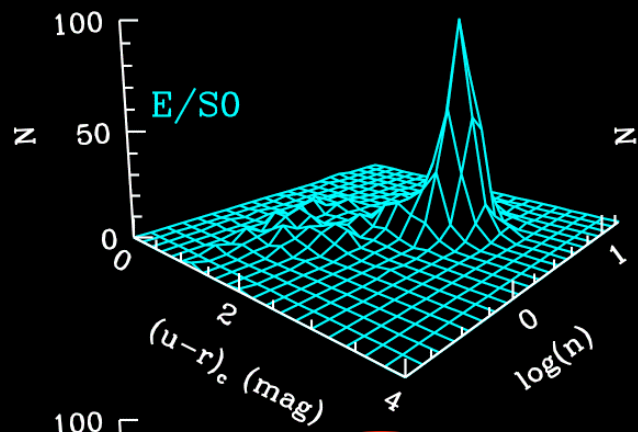
Driver et al, 2006, MNRAS, astro-ph/0602240

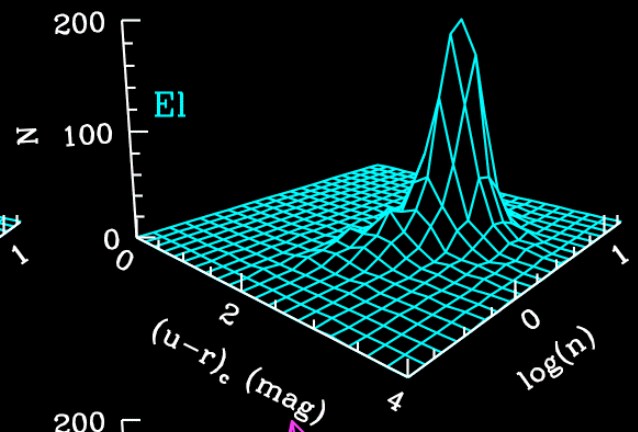


Two populations or two components ?

E/S0s

Spheroidal systems

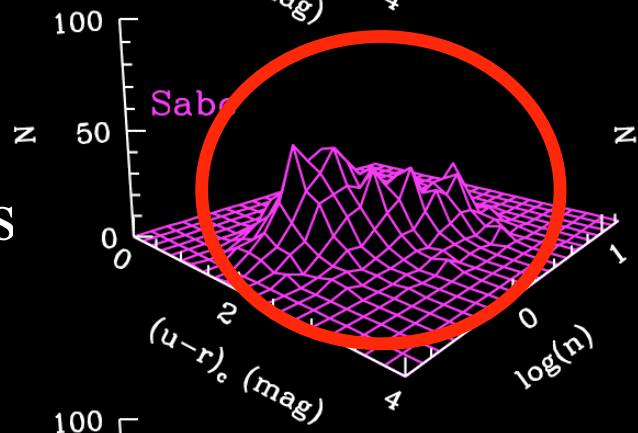


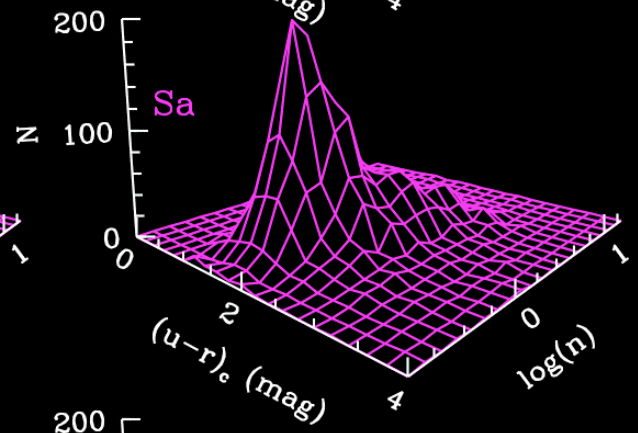


El(Old)

Sabc

Bulge+Disks

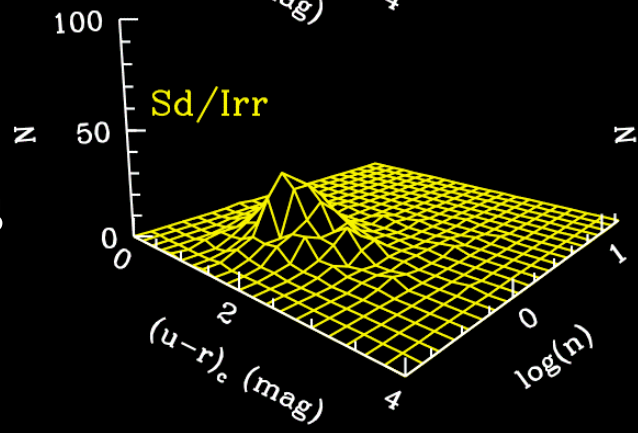


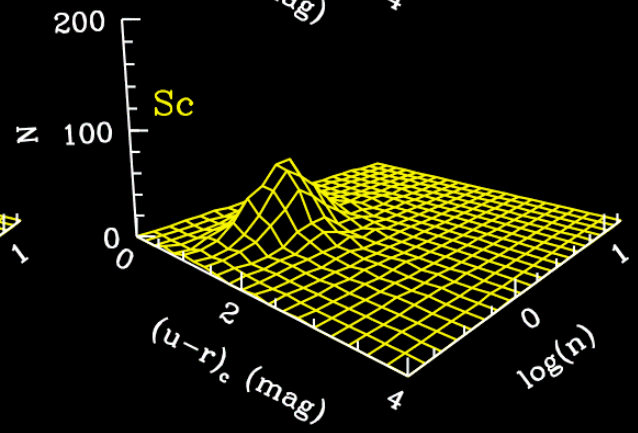


Sa(Interm.)

Sd/Irr

Disk systems

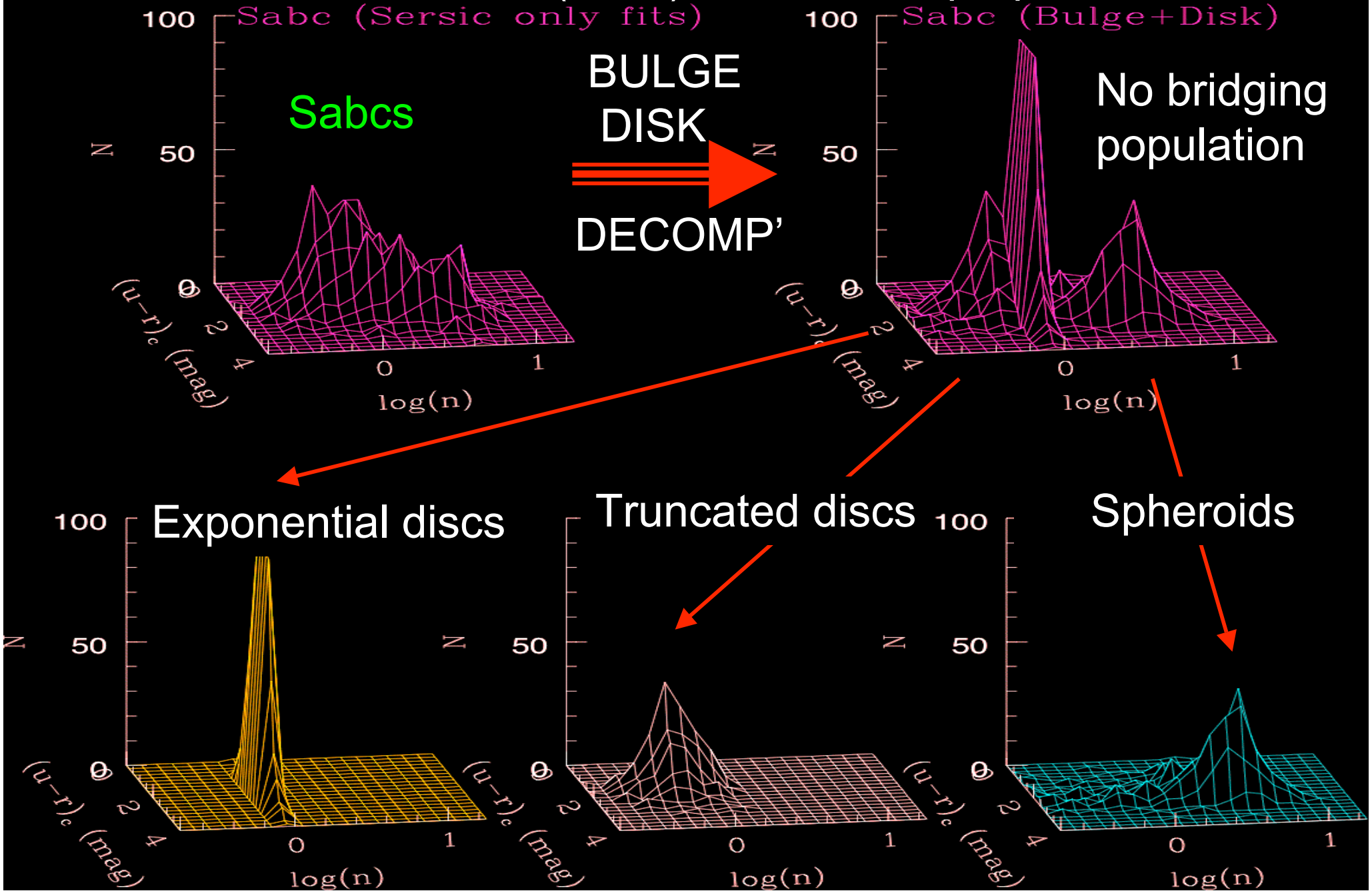




Sc(Young)

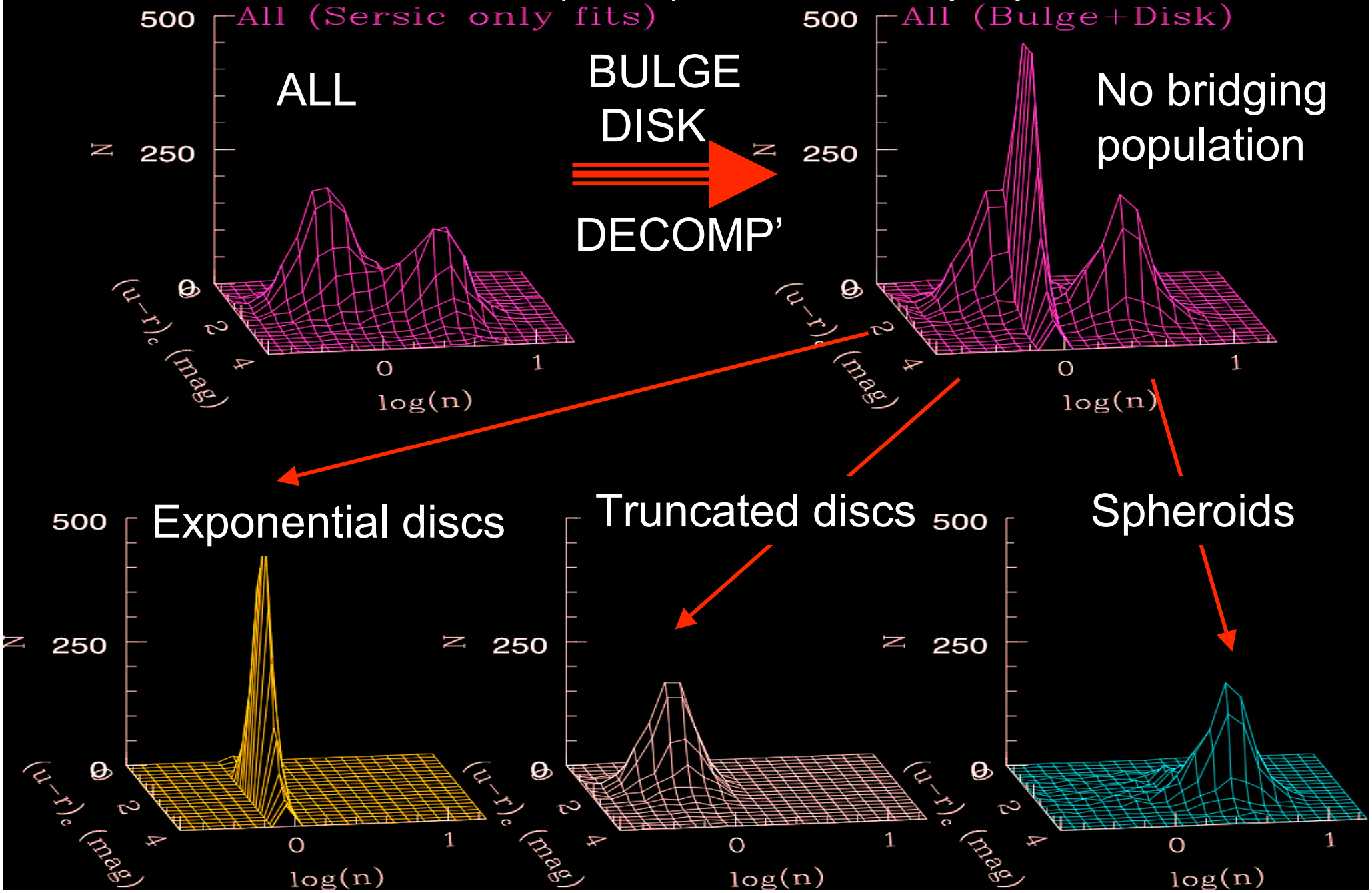
Two populations or two components ?

Cameron et al (2007), MNRAS, in preparation

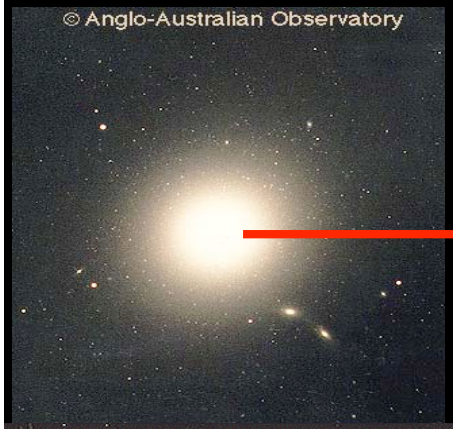


Two populations or two components ?

Cameron et al (2007), MNRAS, in preparation



Galaxy pops or galaxy components ?

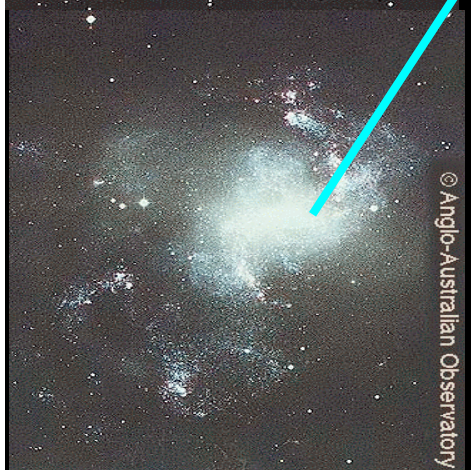


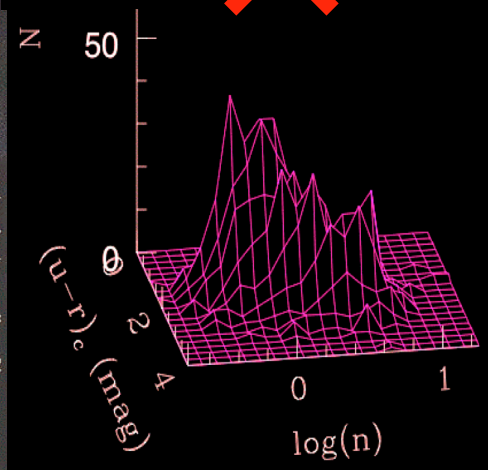
(z > 0.1)

E/S0s(red)

Sabc
(red&blue)

Sd/Irrs(blue)

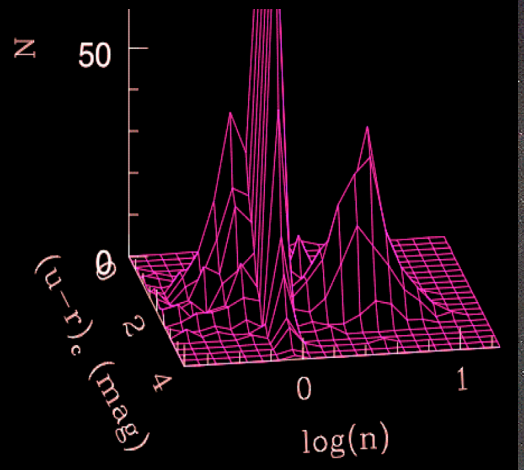




(z < 0.1)

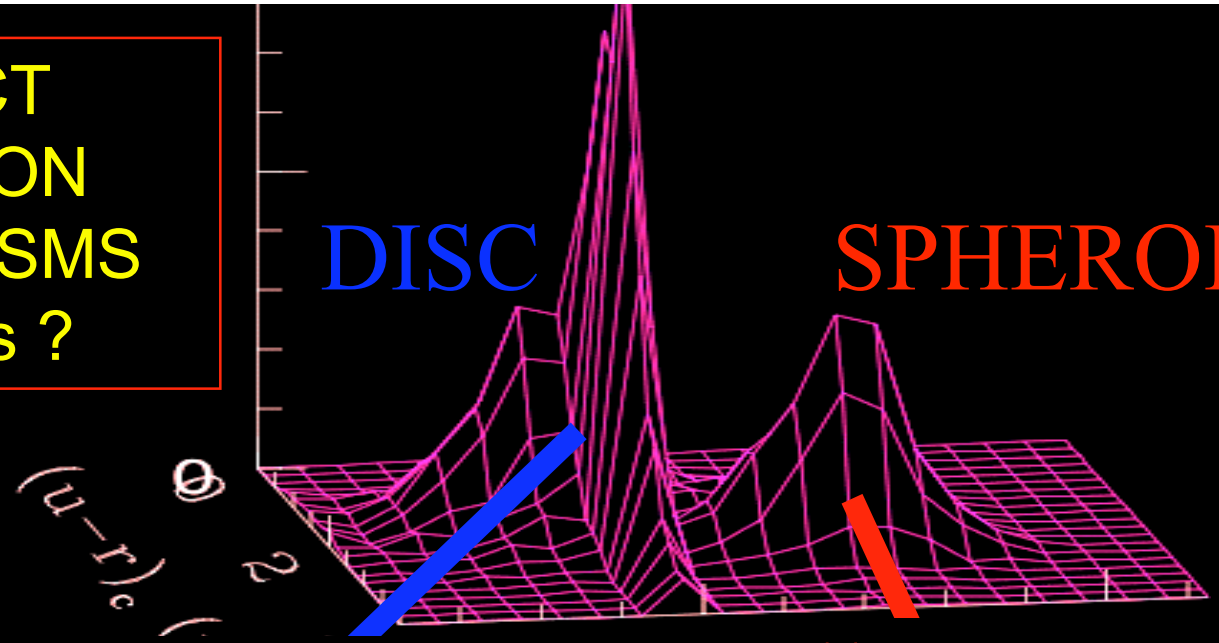
Ellipticals
& Bulges

Discs



2 DISTINCT FORMATION MECHANISMS AND ERAs ?

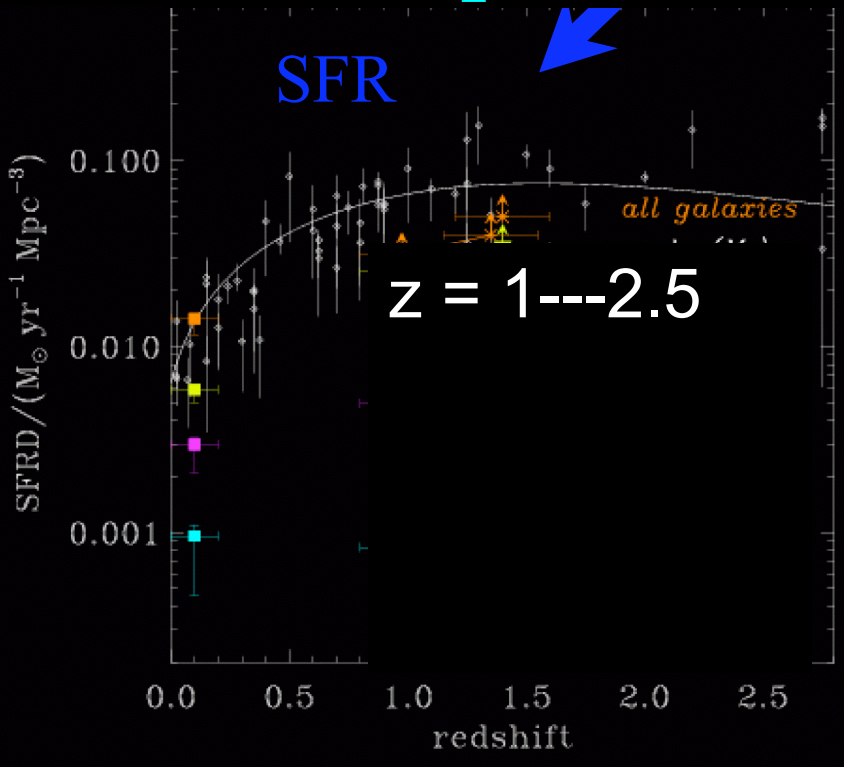
SFR
DUST ?



SMBHs
AGN ?

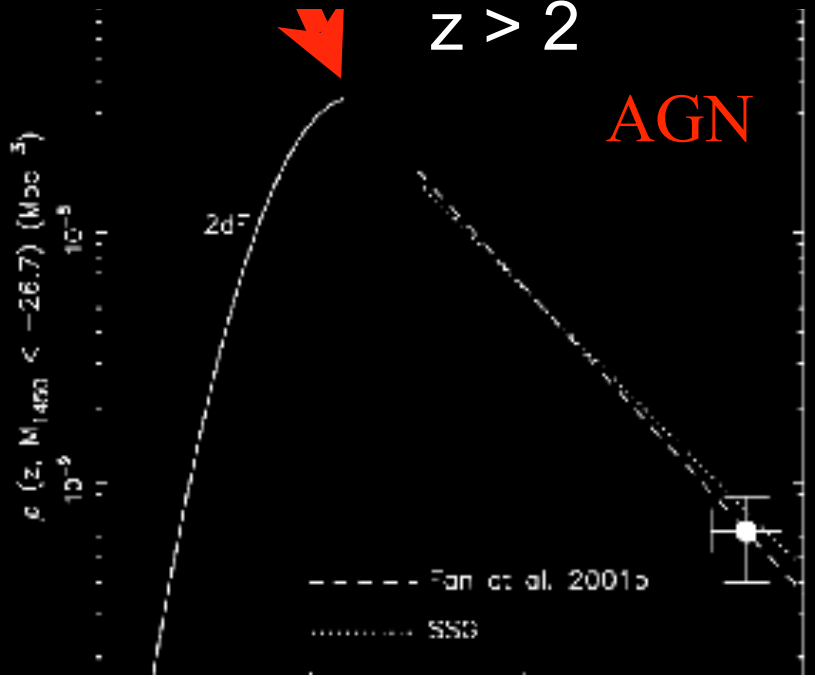
Infall/splashback ?

Collapse or rapid mergers ?



z > 2

AGN



3. Dust attenuation

IMAGE CREDIT AAO

Can we quantify the severity of dust attenuation ?

Yes!

Divide disc sample into inclination bins

Measure disk luminosity function in each bin

Plot M* v cos(i)

Can repeat for bulges using the disc inclination

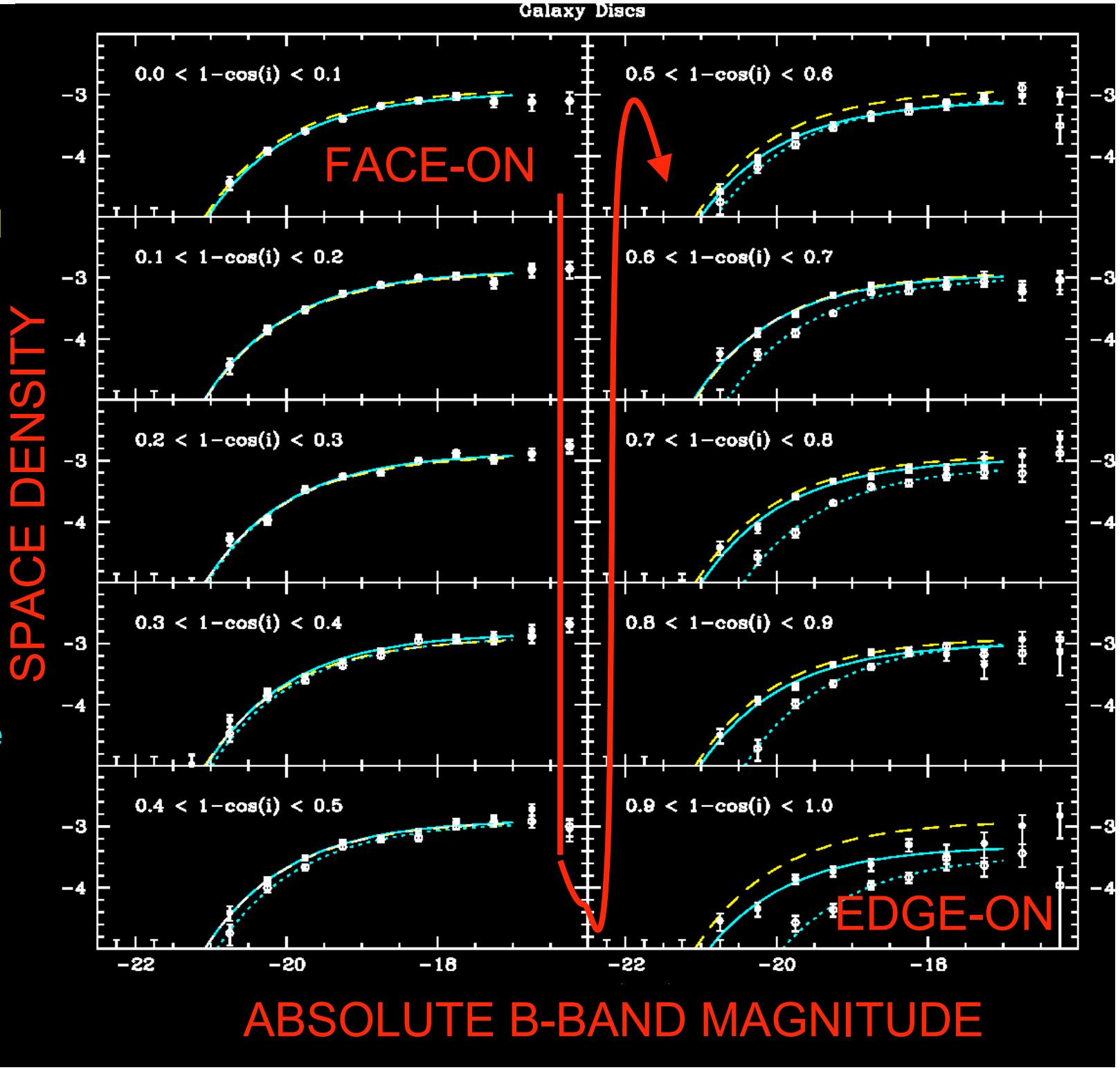
Reveals the inclination dependent component

DISCS:

Yellow dashed line = reference line

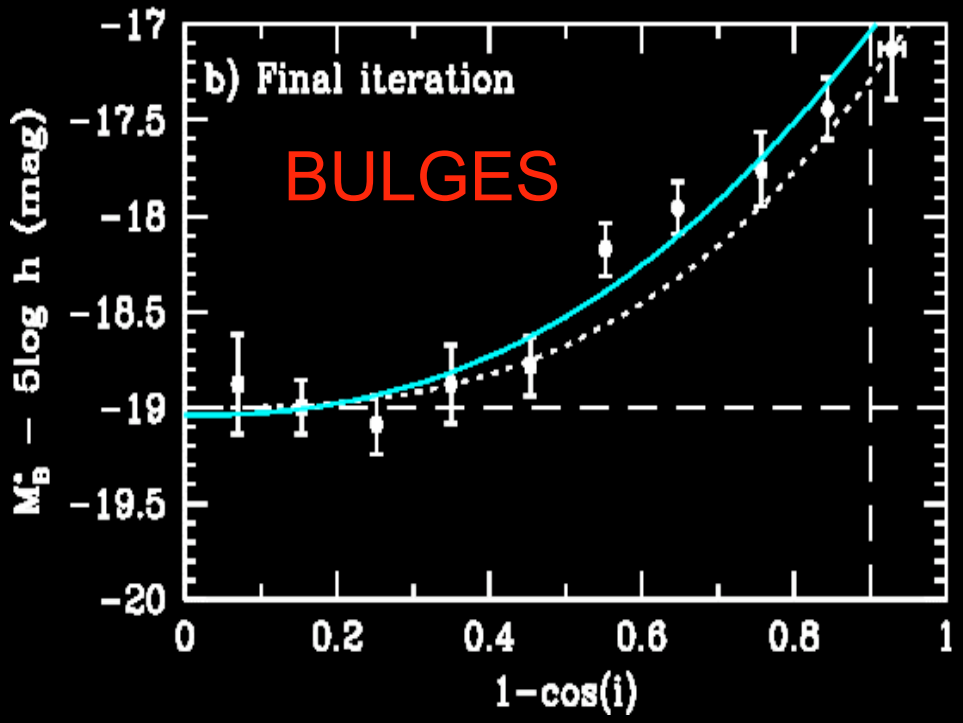
Cyan dotted line = original results

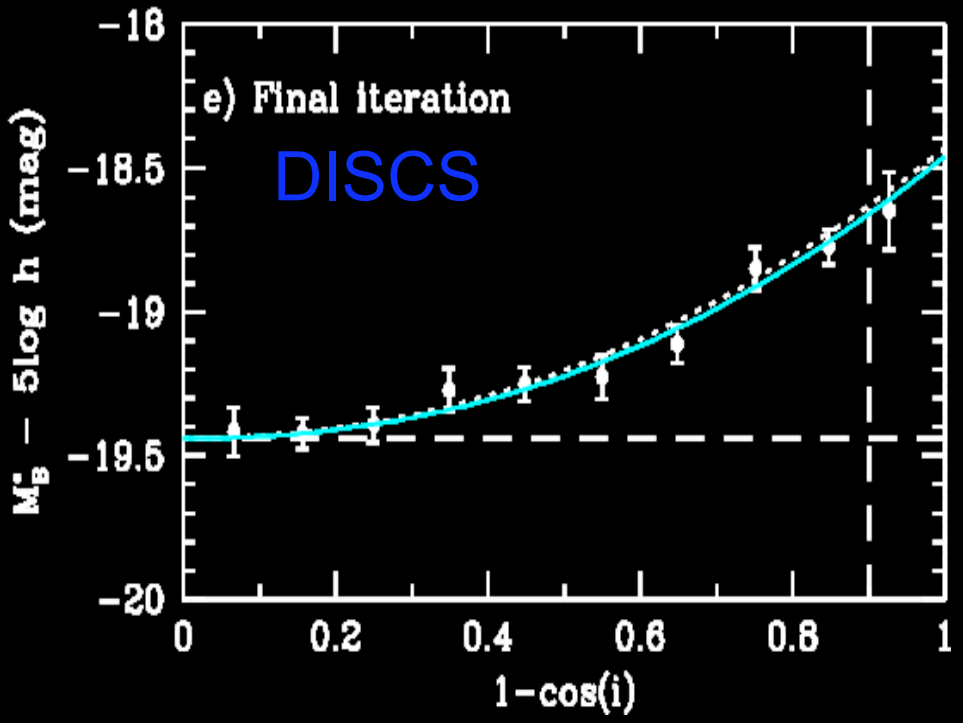
Cyan solid line = after correction



Purely empirical result

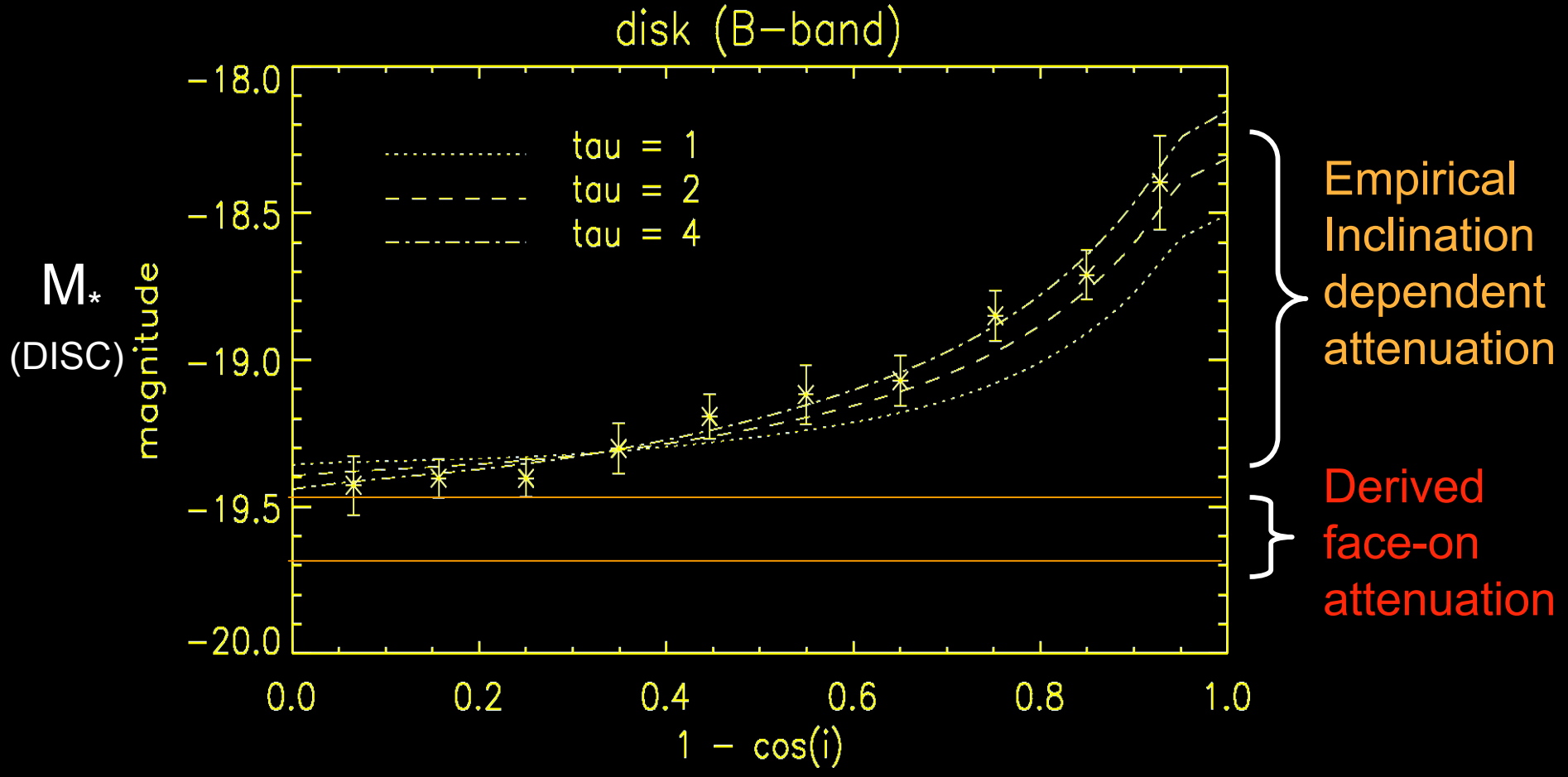
Bulges severely attenuated in inclined systems up to 2 mag + face-on correction !



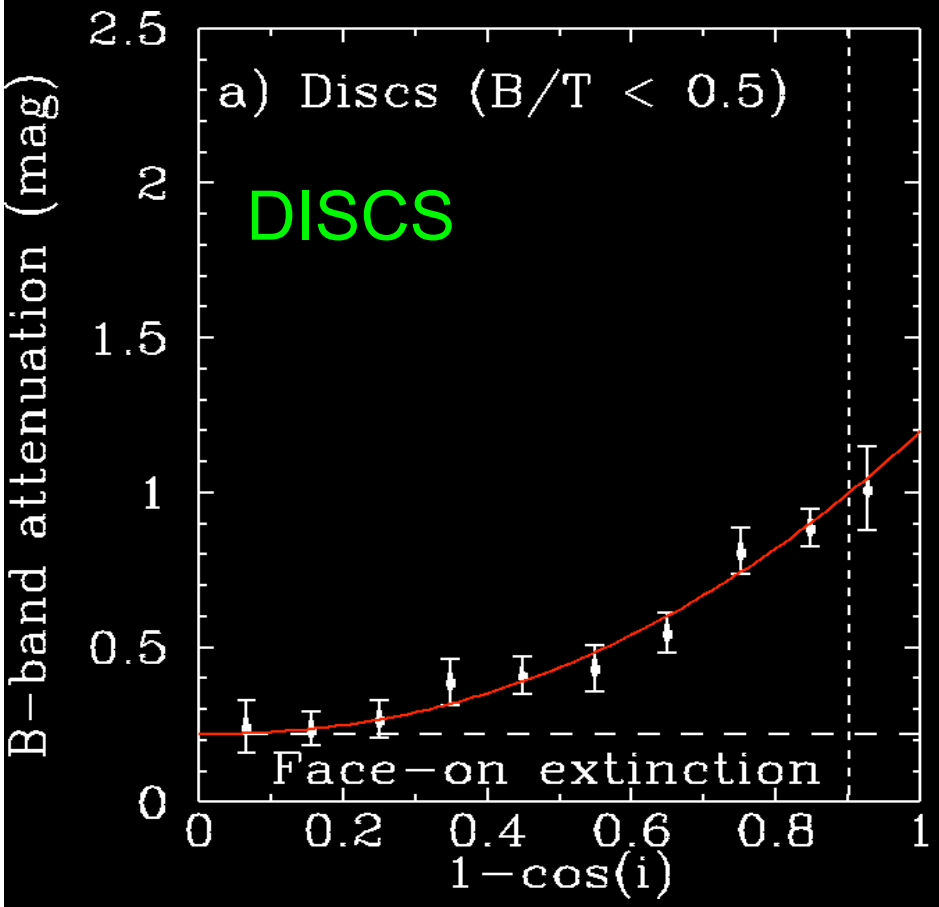


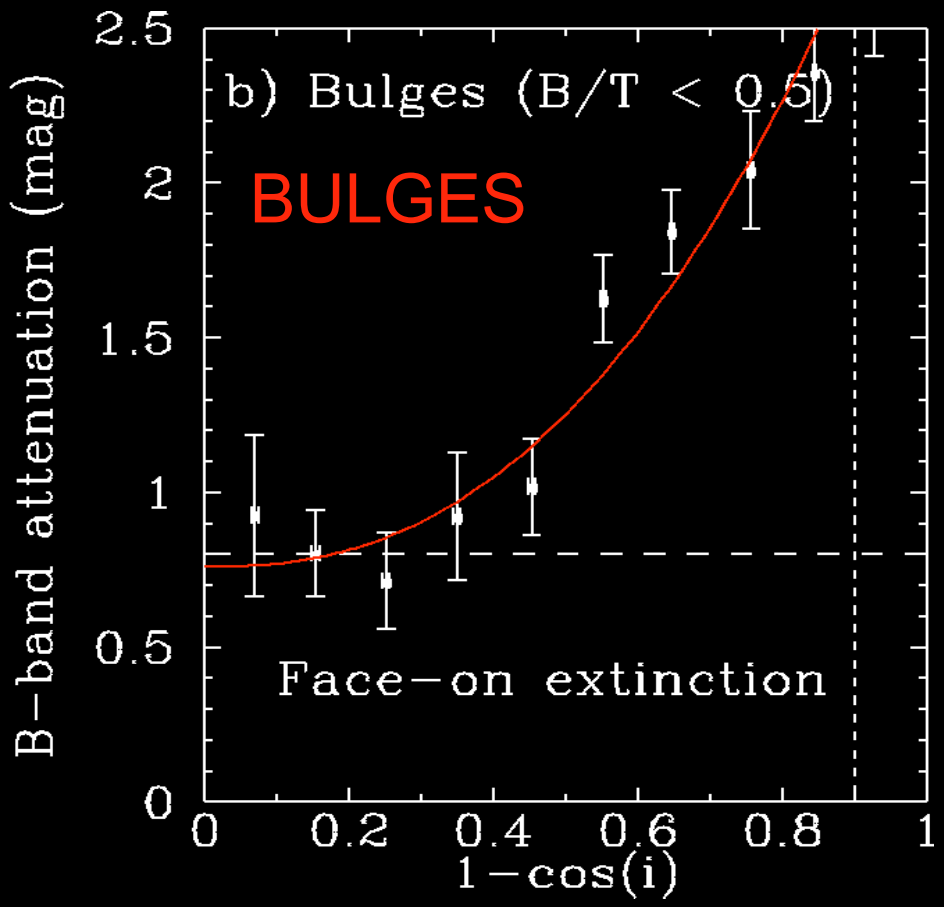
Dust modeling

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

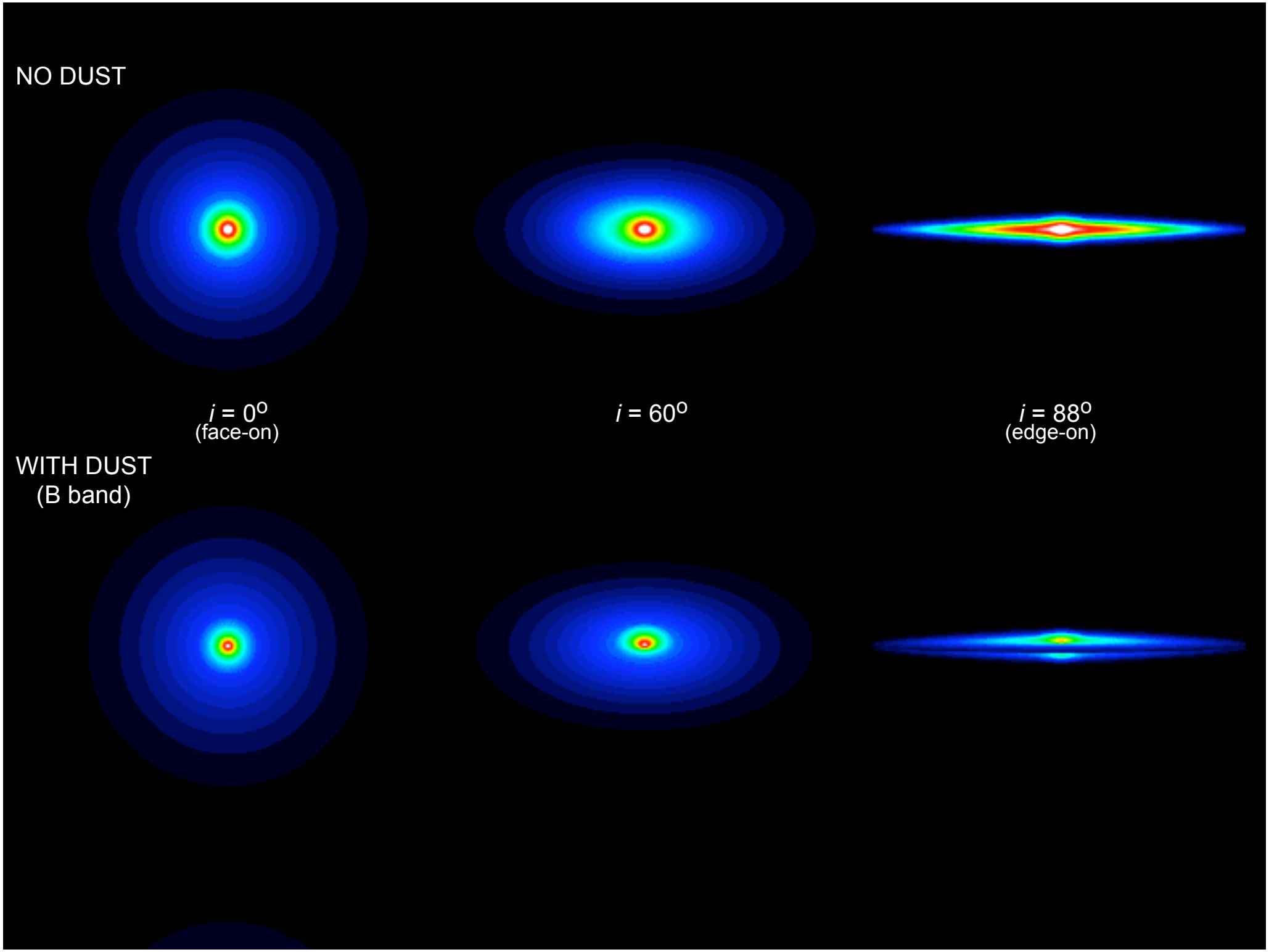


Dust Attenuation

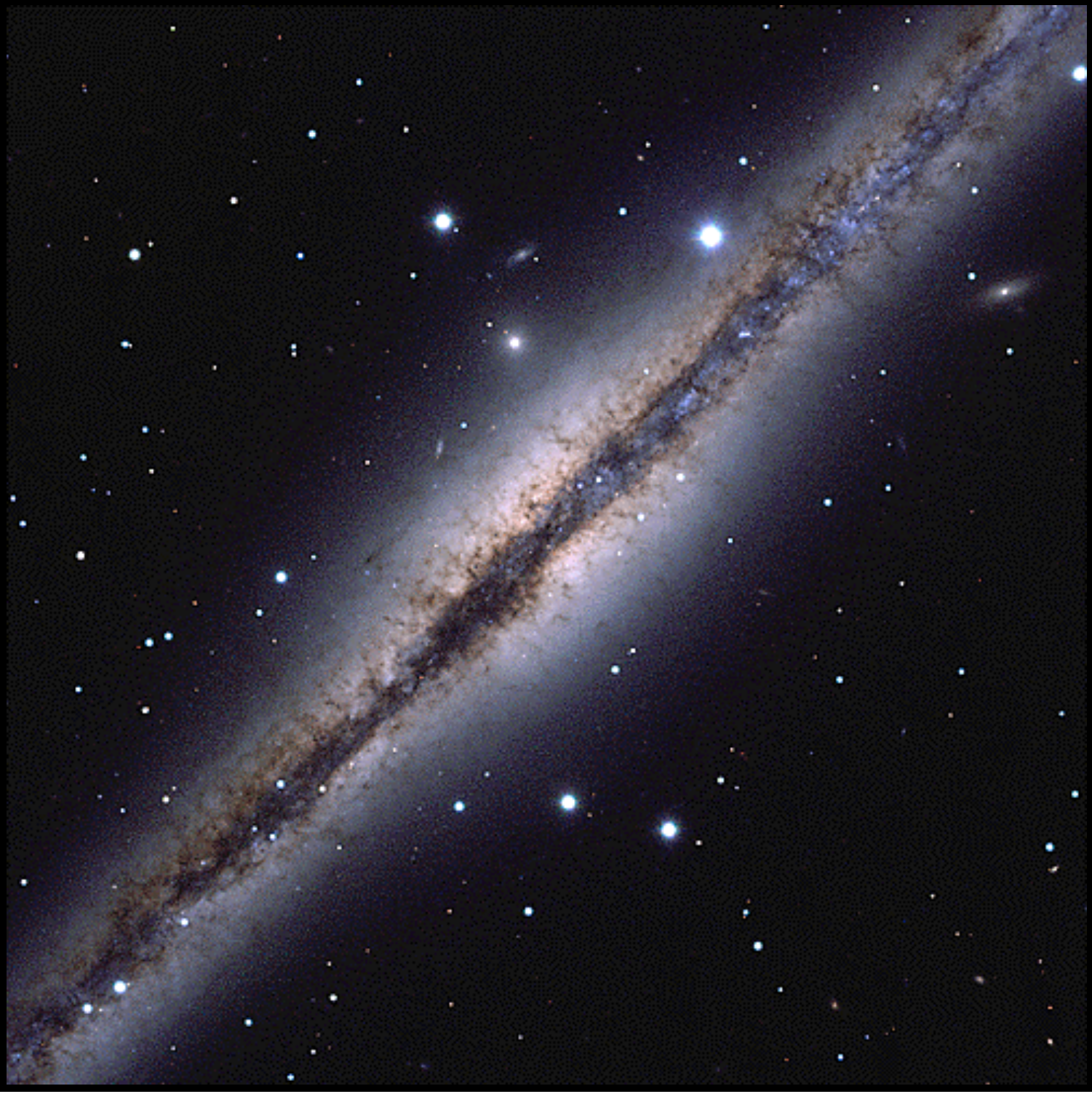




Model shows that discs are optically thick in the centre,
Hence *half* of bulge flux is attenuated in face-on systems
=0.75 mag, (as dust has thickness our value is 0.84).

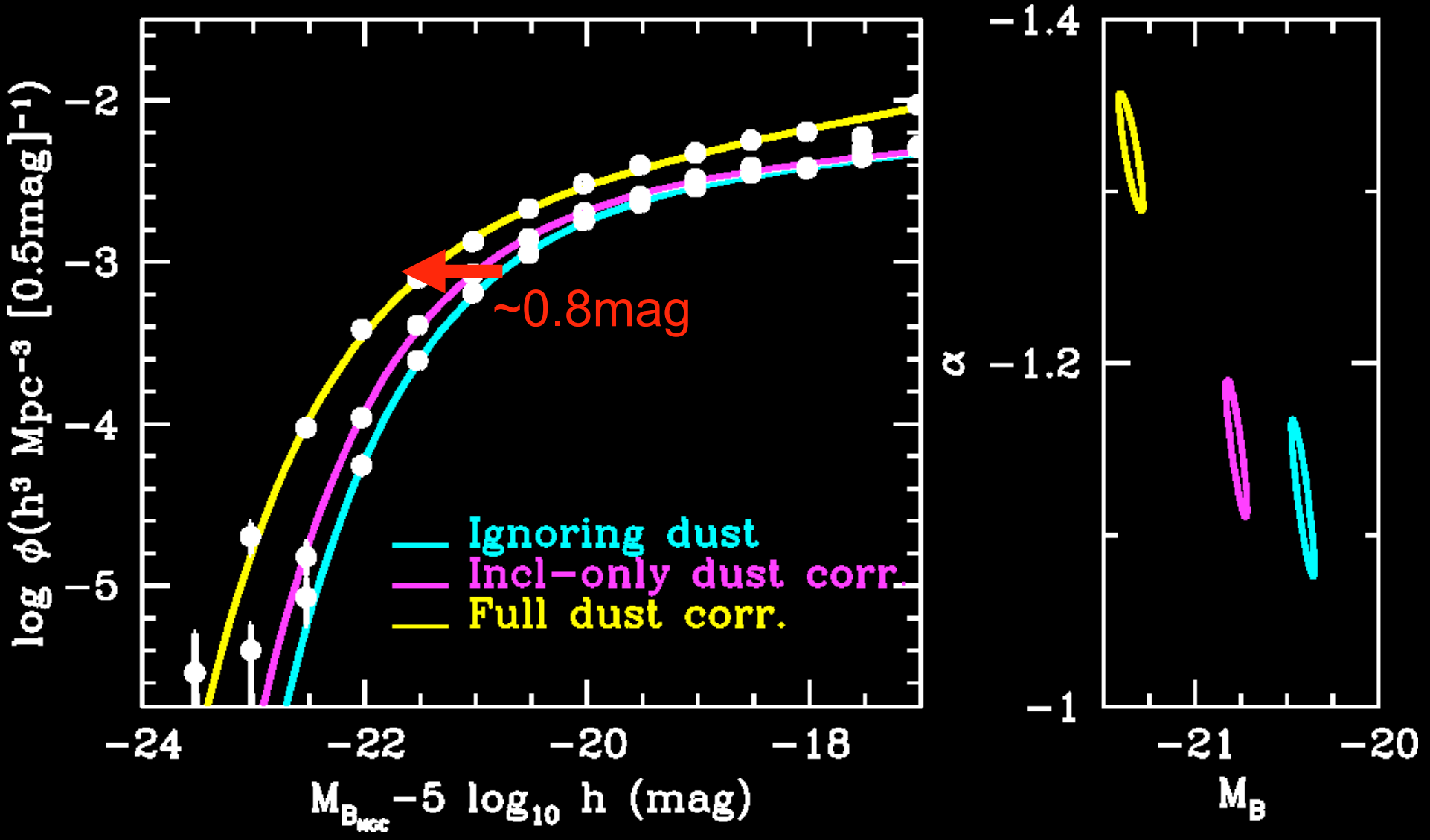

NO DUST
i = 0o
(face-on)
i = 60o
i = 88o
(edge-on)
WITH DUST
(B band)

NGC891



Impact of dust on global B LF

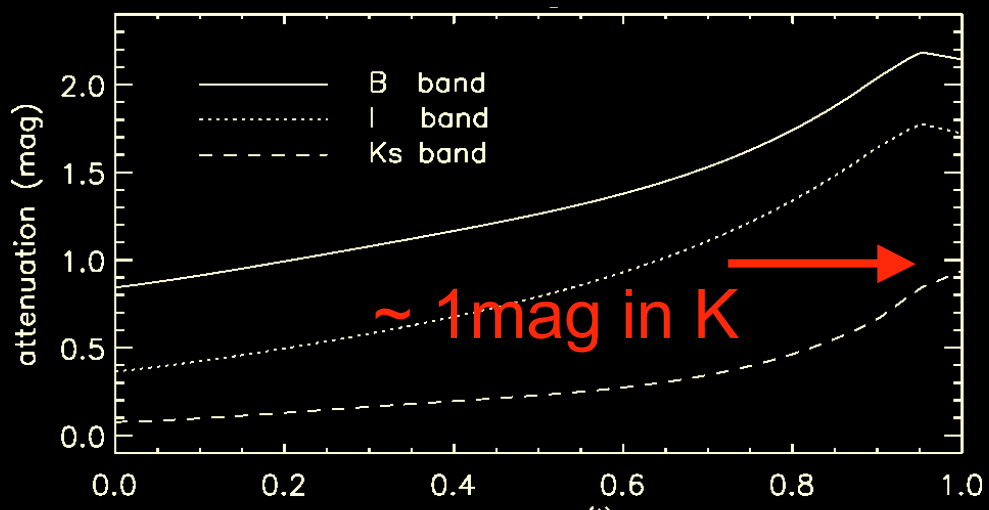
Luminosity density doubles, I.e., only 50% photons escape



Dust attenuation v wavelength

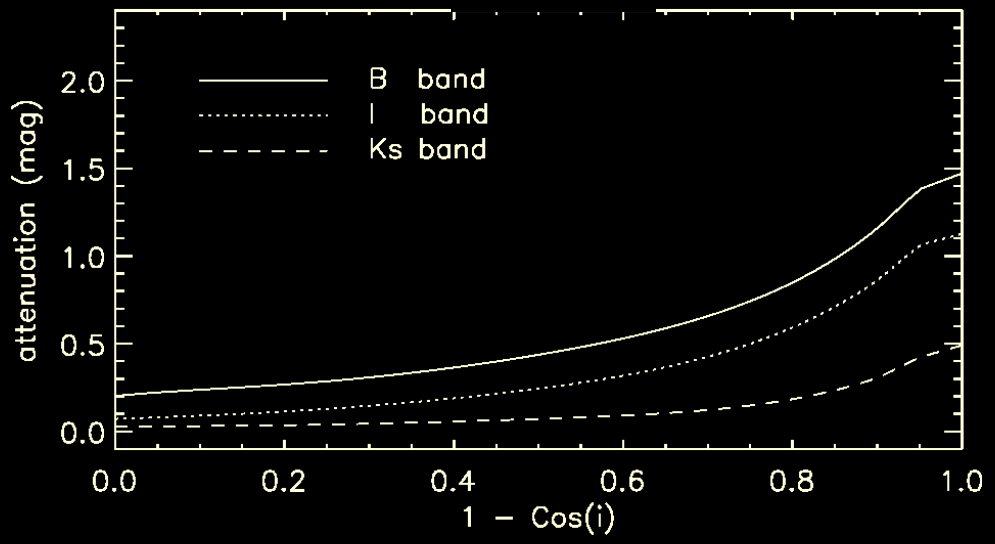
Dust still an issue even in K, but much better.

BULGE



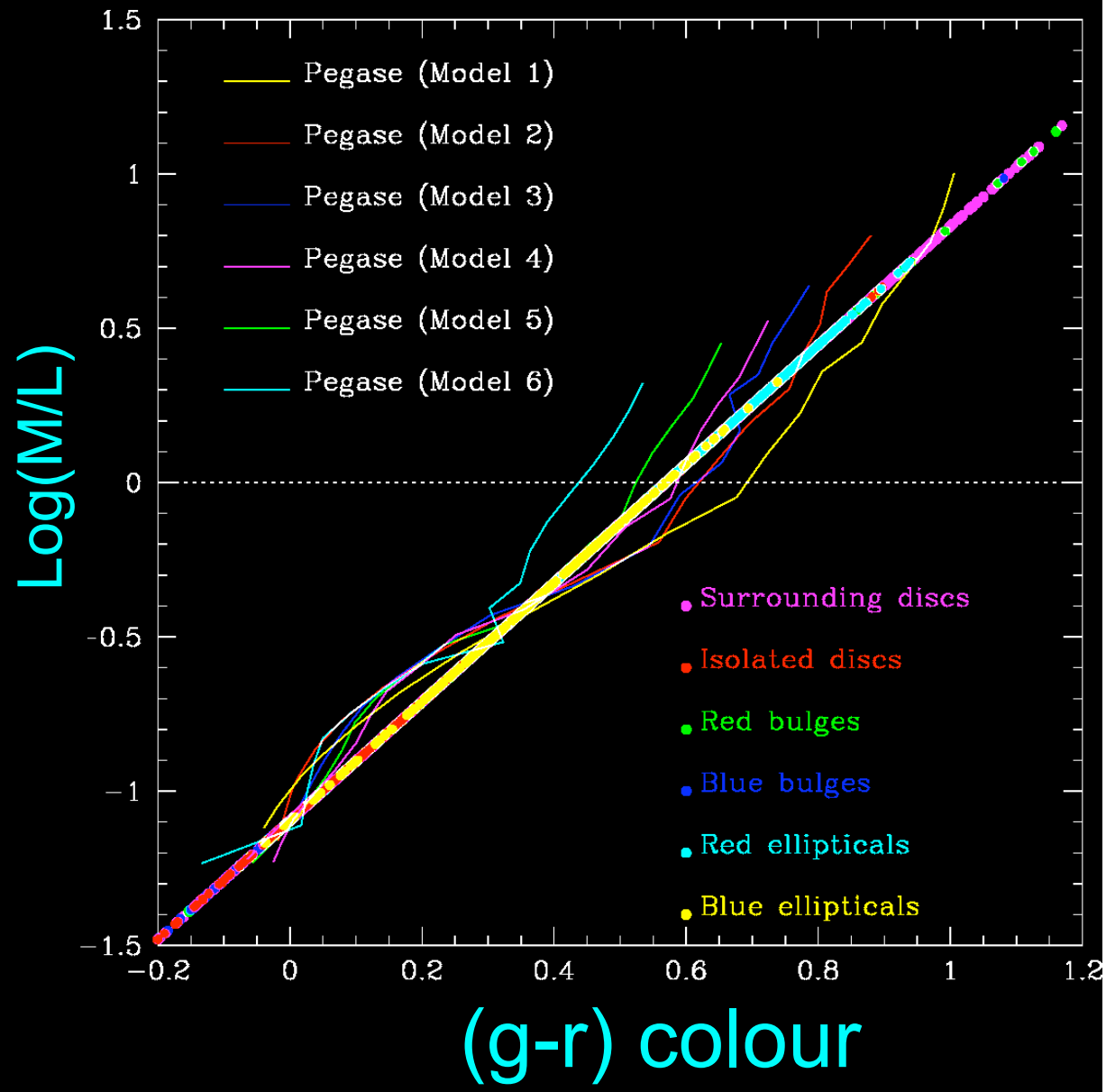
VISTA

FACE-ON DISC EDGE-ON



4. The stellar mass function

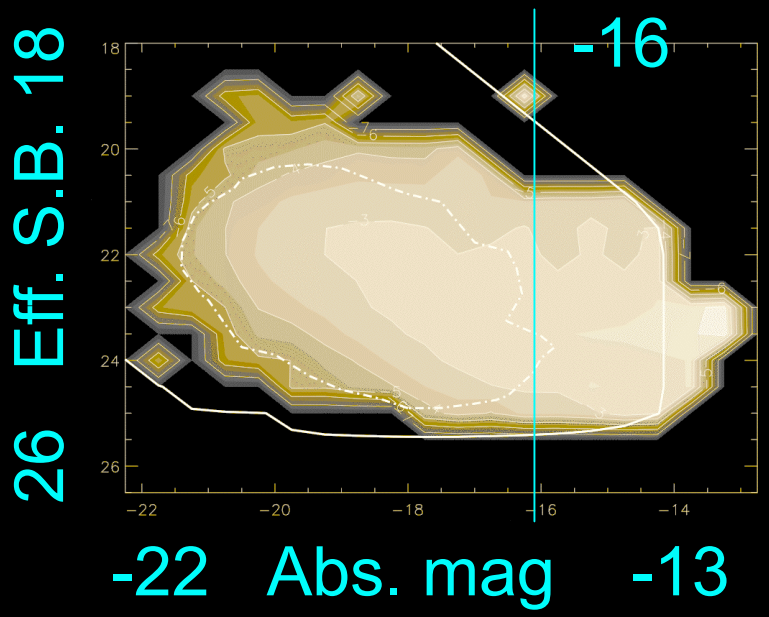
- More fundamental and more useful for comparisons to theory.
- (g-r) an OK predictor of M/L (Bell & de Jong 2001)

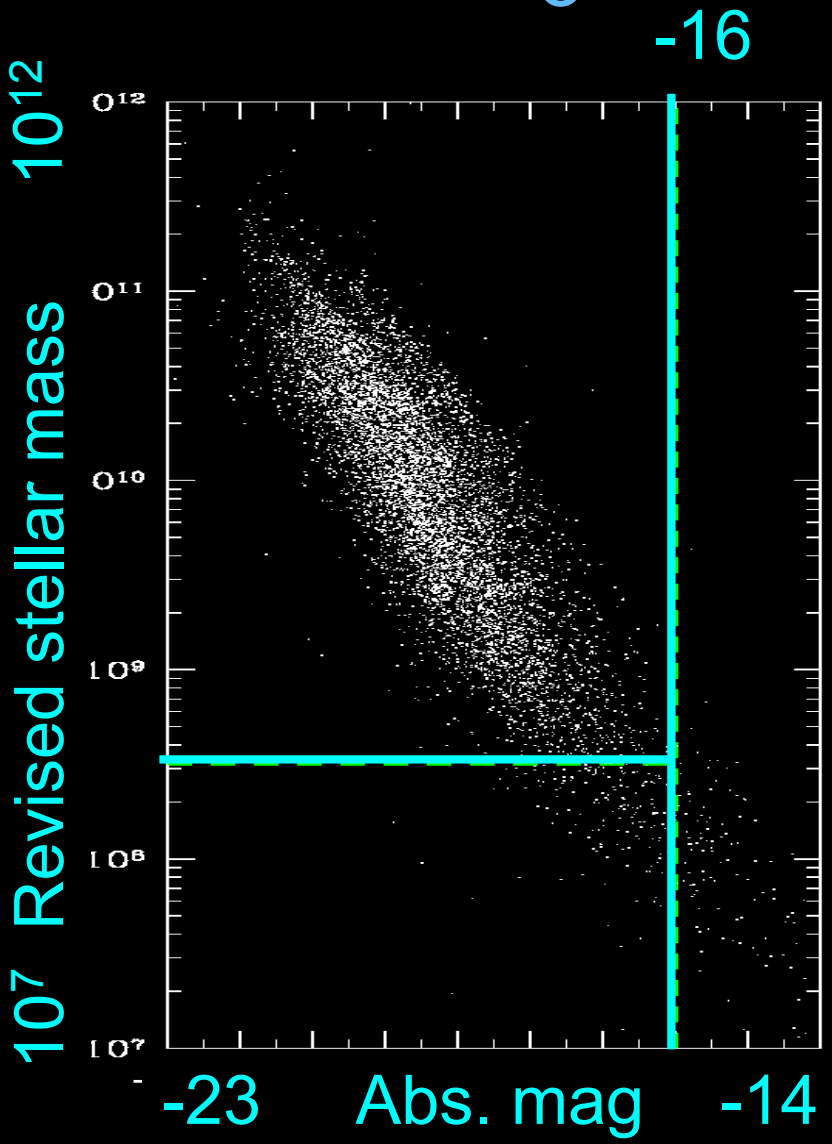


MGC mass limit = $10^{8.5}M_o$

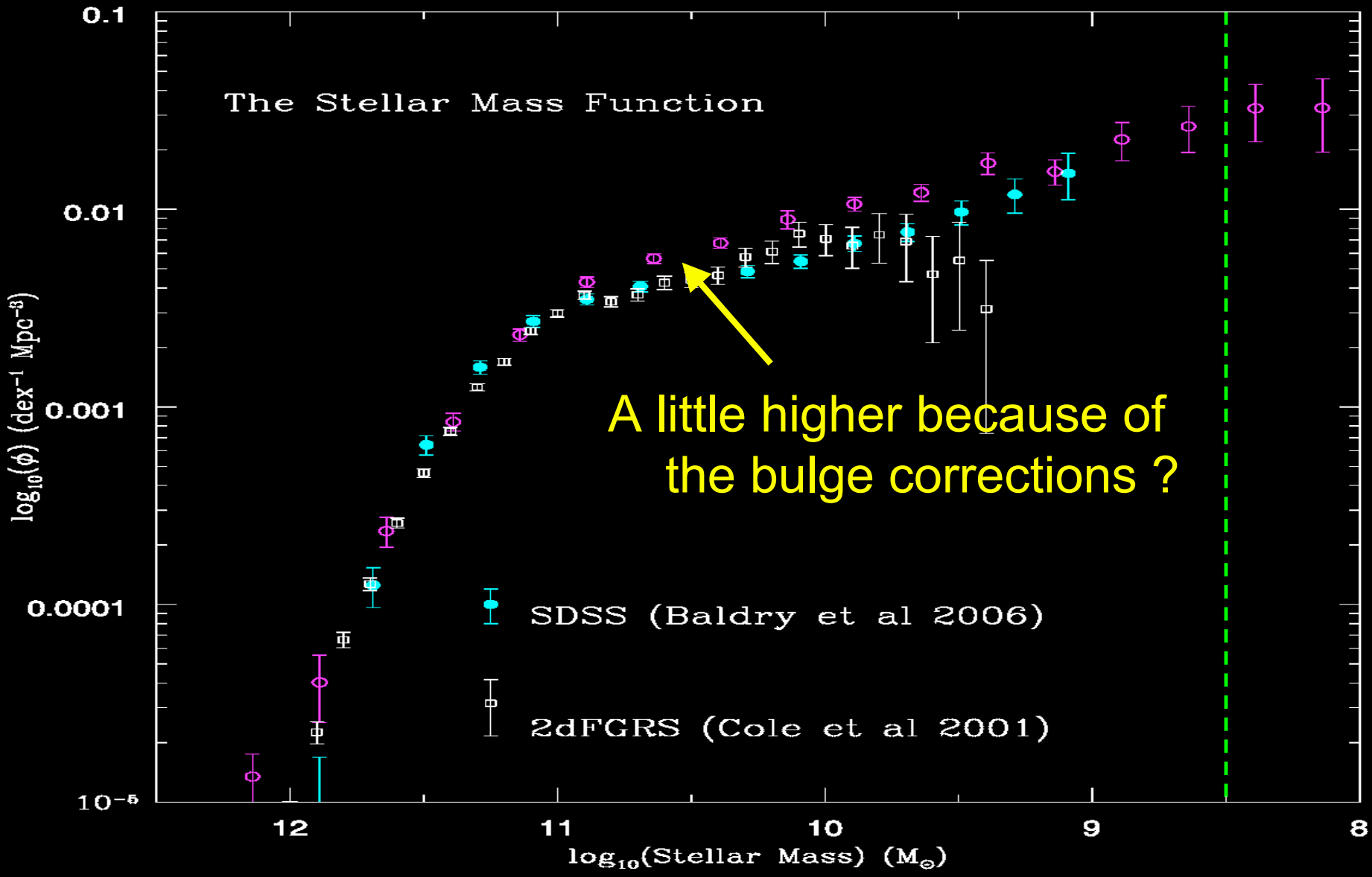
The MGC becomes incomplete to high and low surface brightness galaxies at M=-16 mag

(Driver et al 2005)

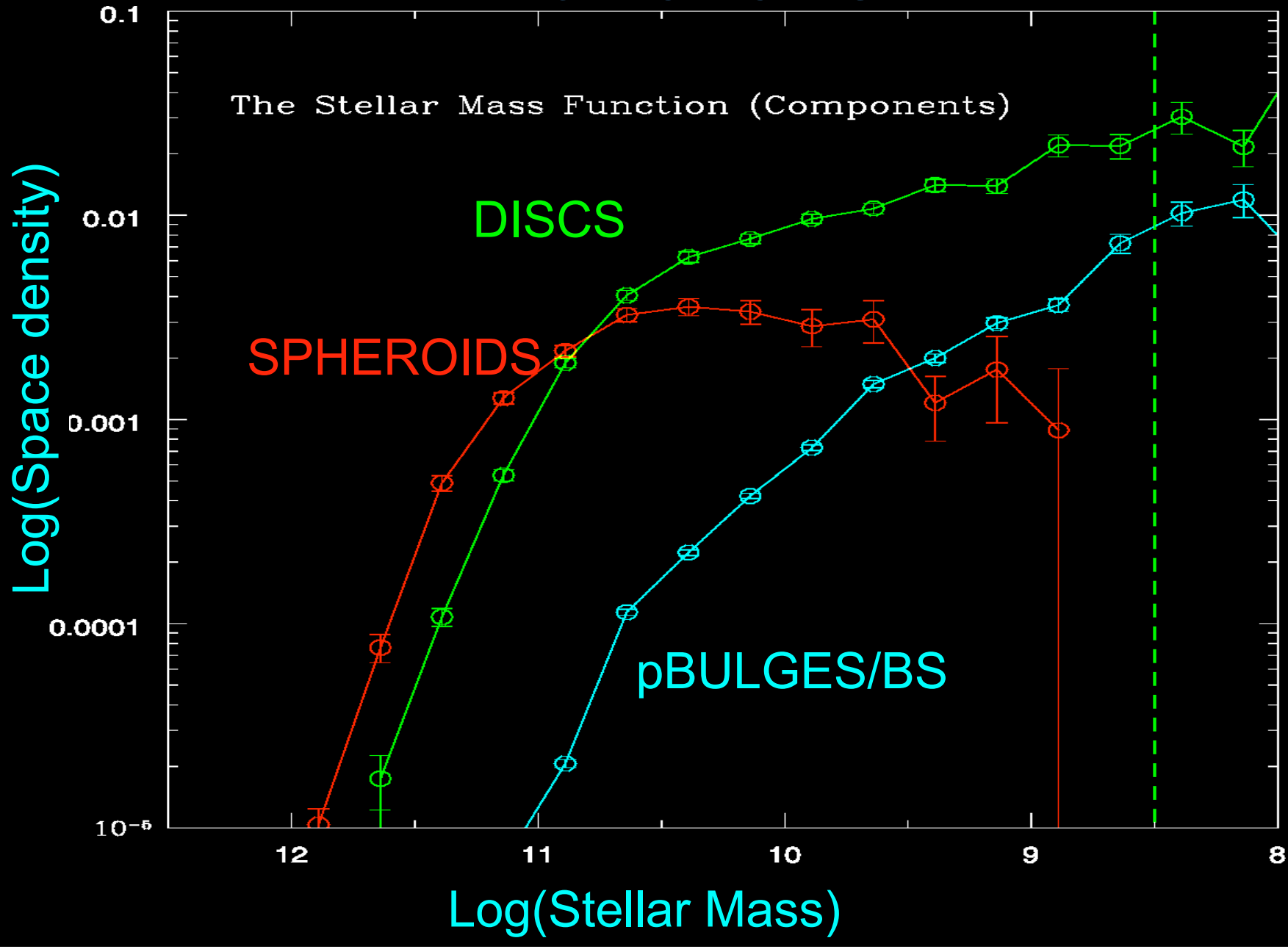




The MGC Stellar Mass Function



Component Stellar Mass Functions



5. Recipe for Galaxy Formation ?

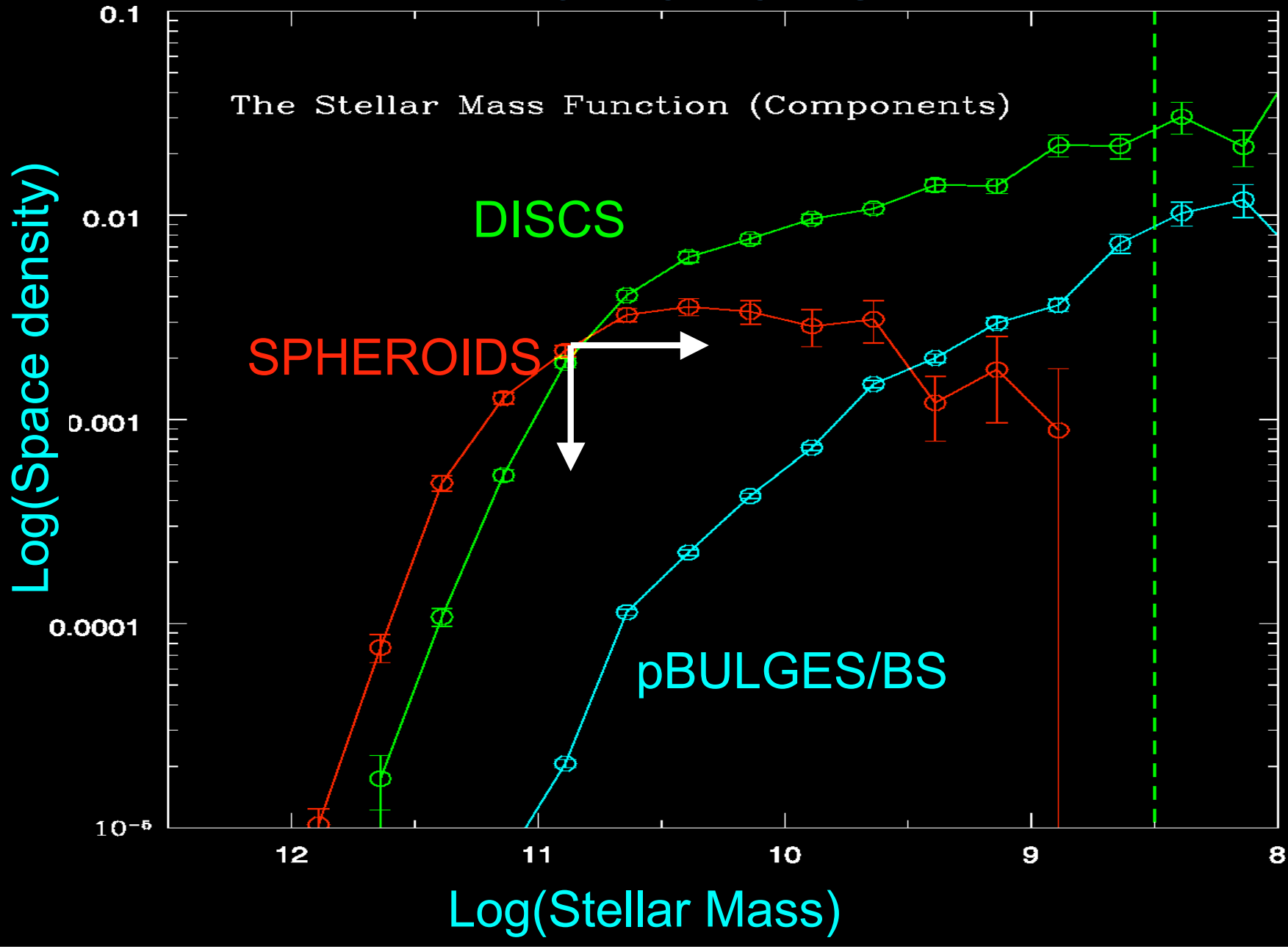
- Ingredients: Mechanisms:
  1. DM Halo ← Mergers
  2. Spheroid ← Mergers and/or Collapse (37%)
  3. Disc ← Infall/Accretion (60%)
- Environment and bimodality:
  - Dense: SF shutdown, dust destroyed, bulge easily seen, red disc = red sequence (Sa => S0)
  - Sparse: Gas infall, SF, dust formation, bulge obscurred, disc blue = blue sequence (Sa => Sc)
- SF+Dust help galaxies cross the divide quickly and without any morphological transformation (mergers not necessarily required).

Spheroid formation

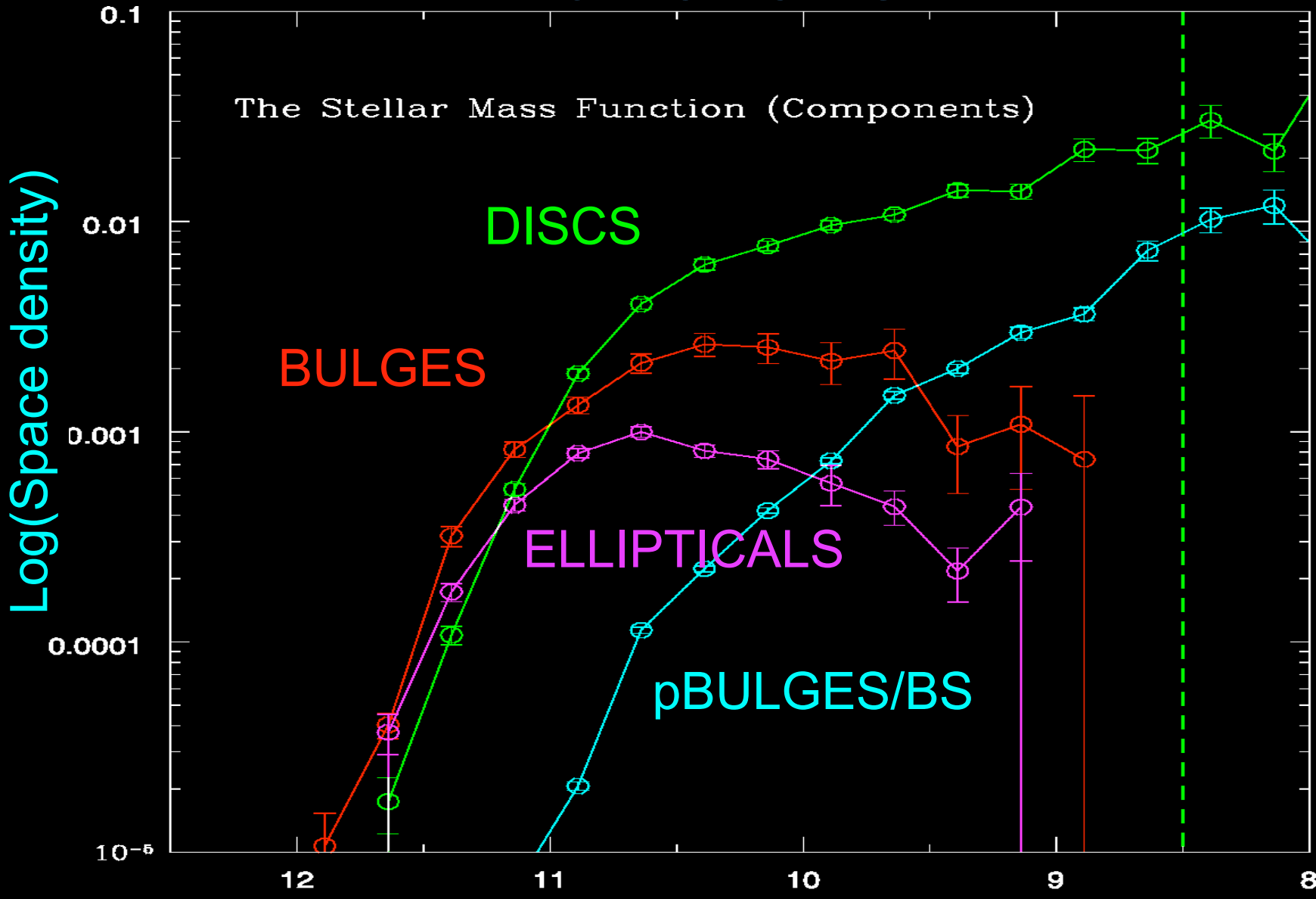
- Old population = early formation of stars
- [α/Fe]-enhanced = rapid formation (AGN feedback)
- SMBH-Bulge relation = formation coeval with peak of AGN activity, z>2.5
- No mini bulge-disc systems = mass regulation or downsizing with time

- Rapid merging or monolithic collapse ?
  - Merging: Elliptical SMF more massive than Bulge SMF
  - Collapse: Elliptical SMF = Bulge MF

Component Stellar Mass Functions



Component Stellar Mass Functions



The sequence of galaxy formation

Discs are fragile yet they contain 60% of stars by mass.

Ellipticals and bulge MFs overlap yet distinct environments.

⇒Low merger rate ?

Could the main phase of DM Halo assembly precede galaxy formation, i.e.,

DM assembly

Spheroid formation

Disc growth

???

or the initial halo mass function be shallow:

Critical to measure Halo Mass function directly => GAMA

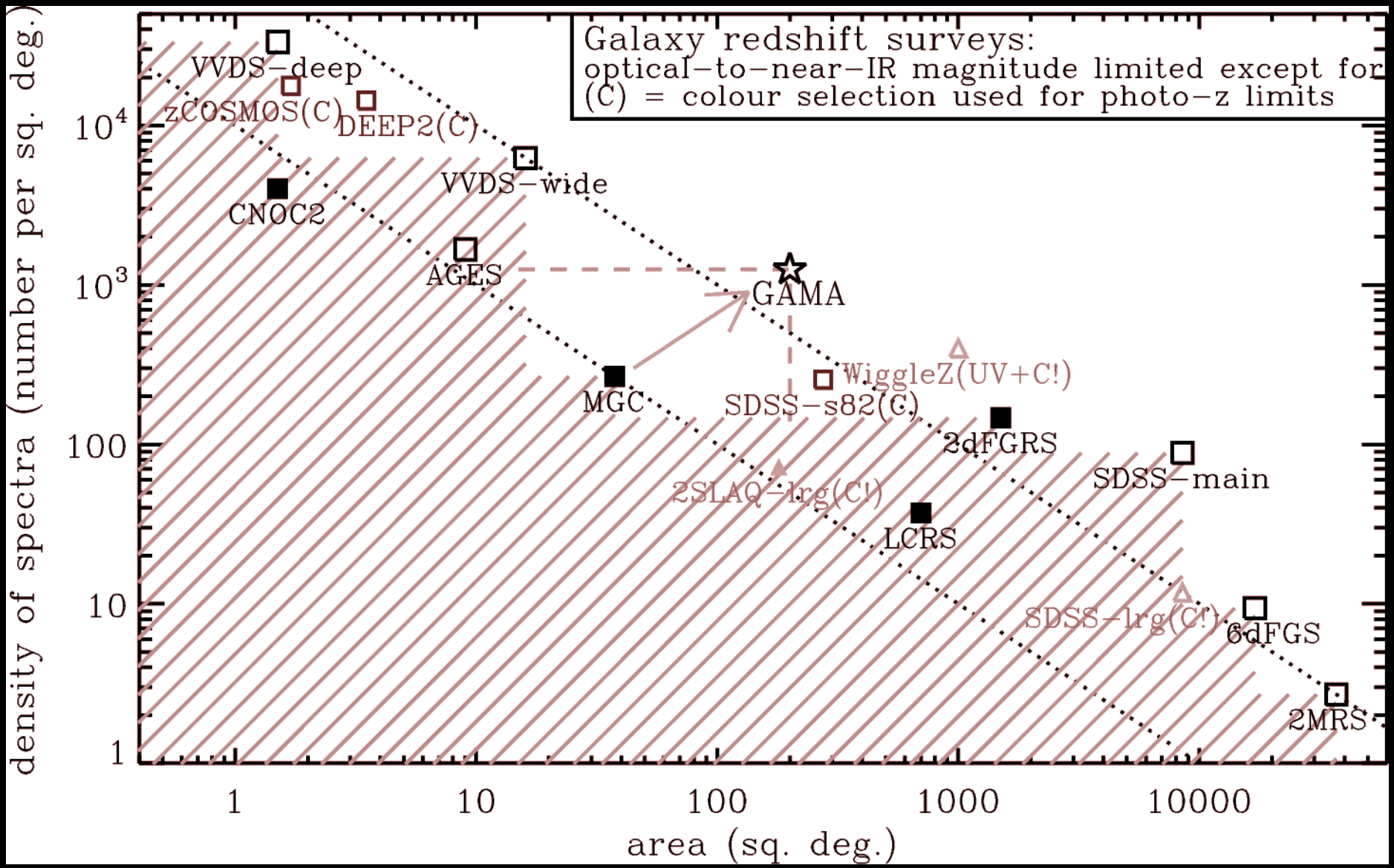
6. Galaxy And Matter Assembly

- PIs: Driver (St Andrews), Baldry (LJMU), Hopkins (Usyd), Liske (ESO), Nichol (Ports.), Norberg (Edin.), Peacock (Edin.) + 16 Co-Is

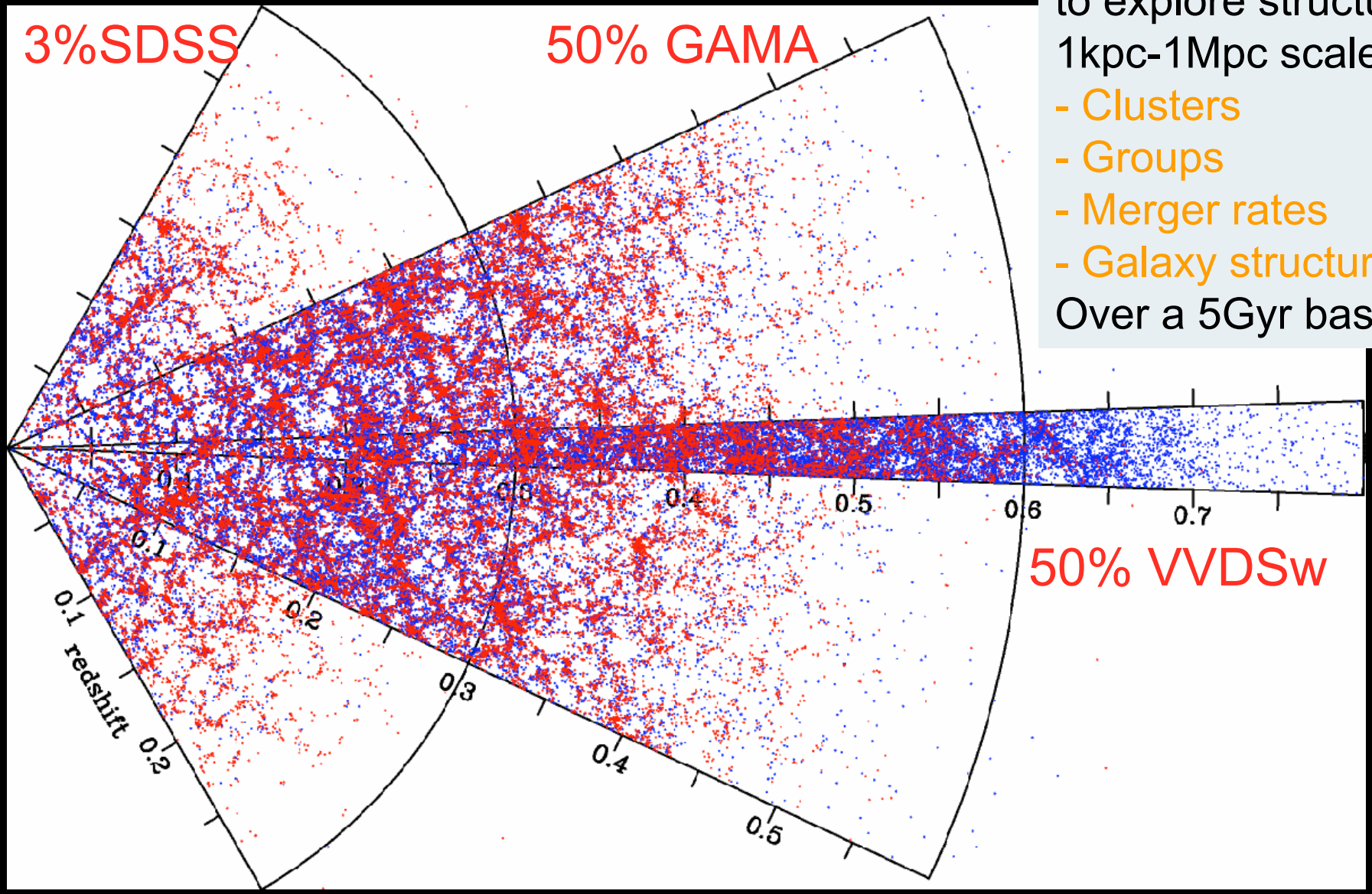
- Associated groups: UKIDSS LAS, VST KIDS, VISTA VIKING, ICC
- Building on success of the 2dFGRS, SDSS and MGC
- 200 sq degrees (2x100 sq deg. chunks each 4x25deg), 250k galaxies
- General science:
  - A study of structure on 1kpc-1Mpc scales, where baryon physics is critical
- Specific goals:
  - the CDM Halo mass function from group velocity dispersions
  - the stellar mass function into the dwarf regime
  - determine the galaxy merger rates as a function of mass ratio
- Provision of a SDSS/2MASS like public database incorporating:
  - Optical: ugri (VST), spectra (AAT)
  - Near-IR: ZYJHK (VISTA)
  - Radio: 21cm (xNTD, SKADS)

GAMA

GAMA: Survey comparison



GAMA: Cone plot

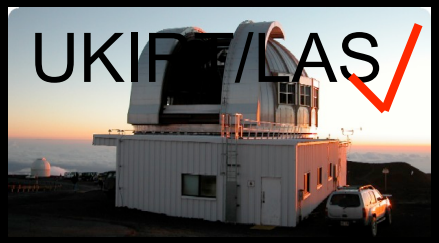


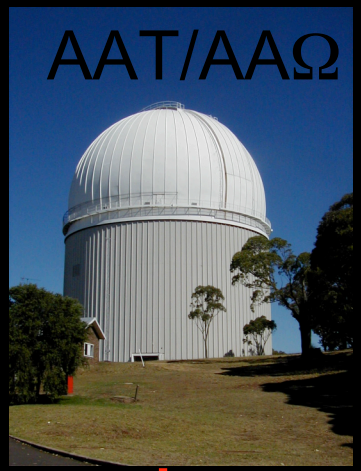
GAMA is designed to explore structure on 1kpc-1Mpc scales:

- Clusters
- Groups
- Merger rates
- Galaxy structure

Over a 5Gyr baseline

GAMA: Contributing Facilities





NEAR-IR

z, spectra

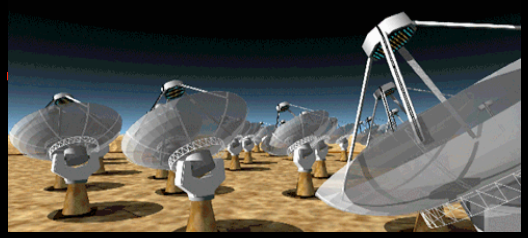
z, LSBGs

xNTD ?

OPTICAL
+ SDSS

GAMA

HI
2009

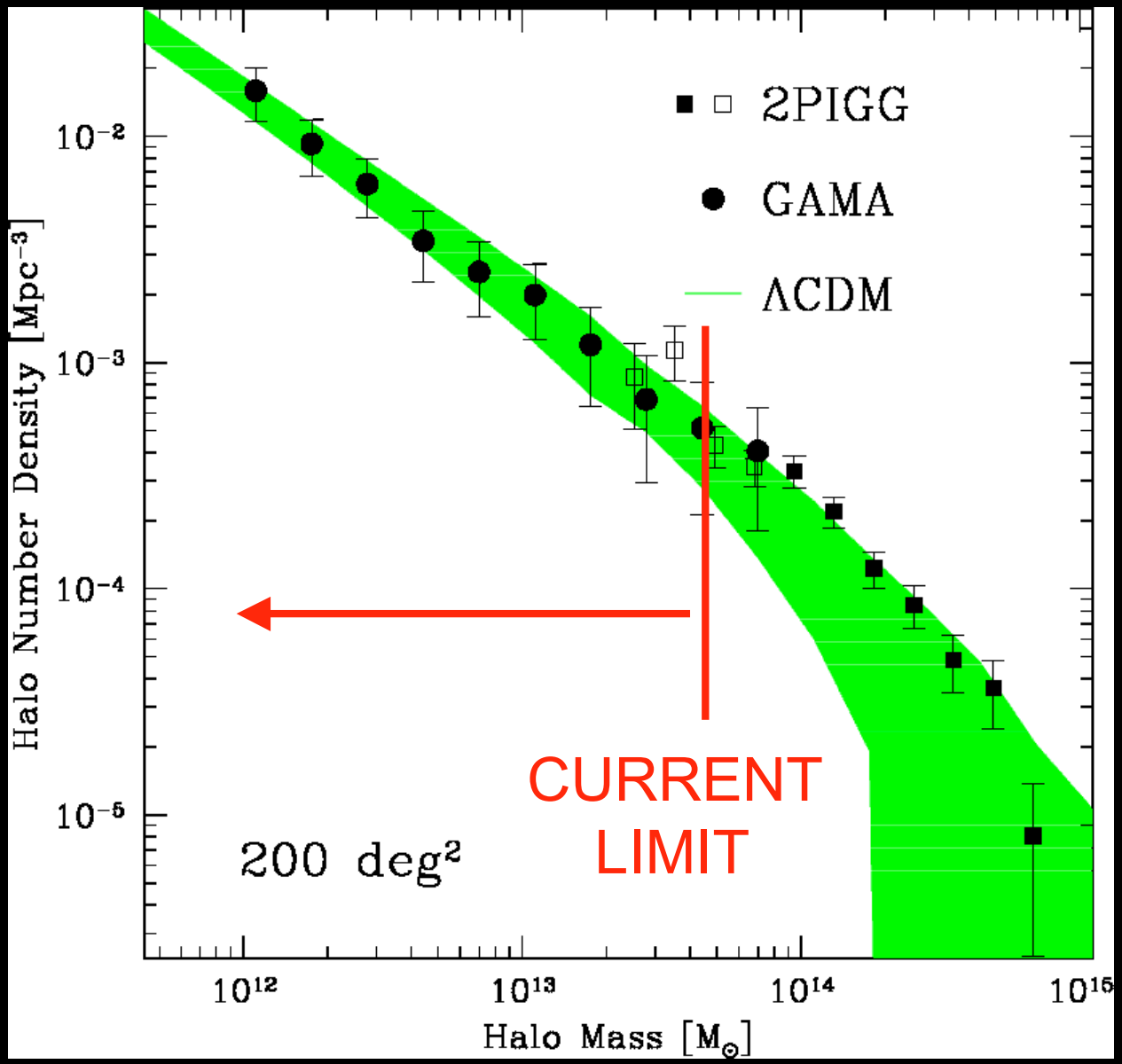


The CDM halo mass fn

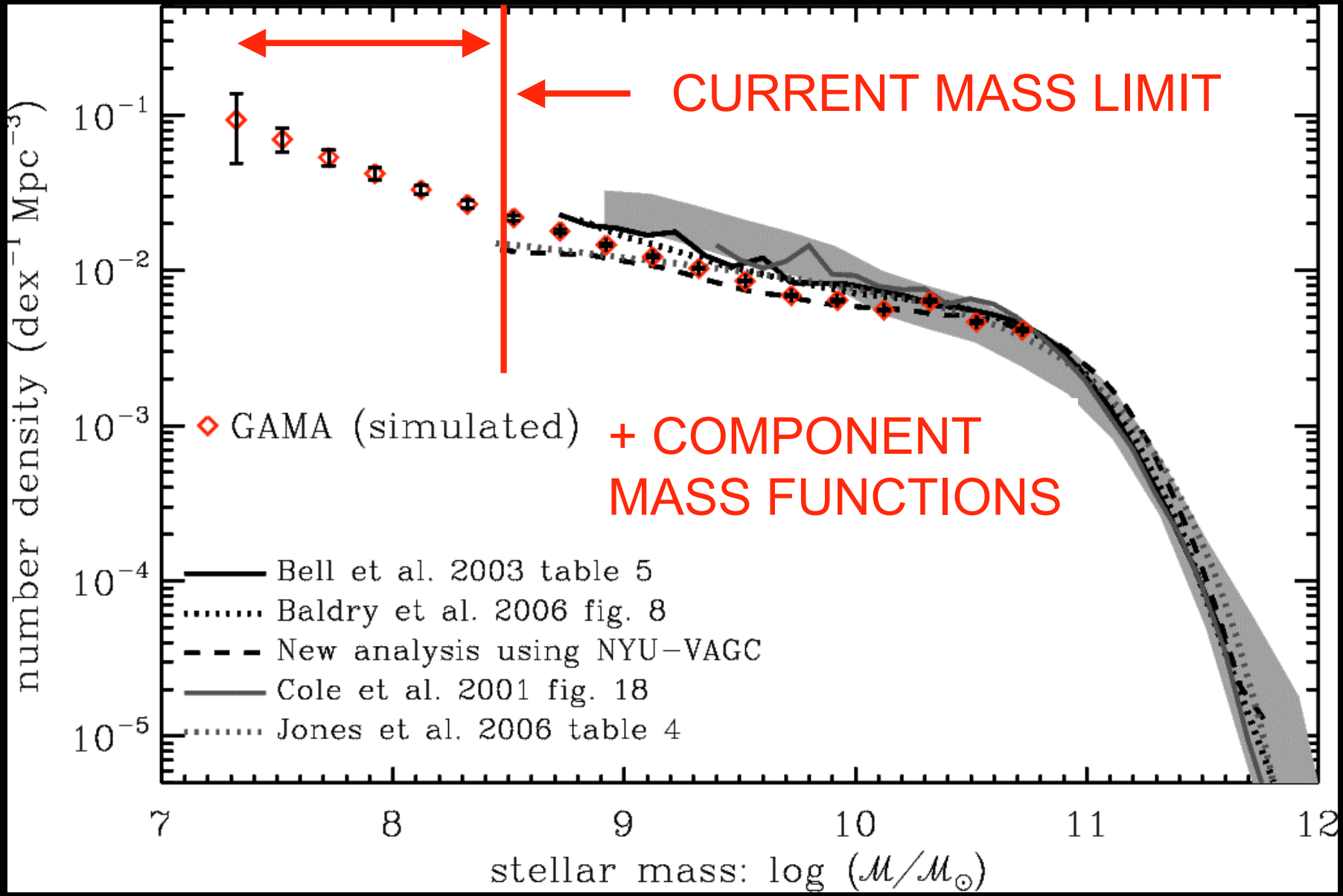
HALO MASS FUNCTION IS A ROBUST PREDICTION OF CDM (GREEN AREA)

CAN BE DIRECTLY MEASURED VIA GROUP VELOCITY DISPERSIONS (DATA)

GAMA WILL PROBE TWO ORDERS OF MAGNITUDE DEEPER THAN 2PIGG



The GAMA Stellar Mass fn



Summary

- Automated structural analysis is here but very messy: MGC
- Bimodality best explained by two components ***not*** multiple populations
- Must consider two distinct formation mechanisms:
  - Spheroid formation via collapse at $z > 2$ (37% stars by mass)
  - Disk formation through accretion & infall $z < 2$ (60% stars by mass)
- Dust attenuation in B severe, especially for bulges:
  - discs 0.2-1.1 mag, bulges: 0.8 - 3.4 mag !
- Need two tweaks to CDM to make all this work (conceptually)
  - DM halo assembly must precede spheroid formation
  - Require low mass spheroid formation to be inhibited
- GAMA survey about to commence to measure Halo mass function directly and study structure on 1Mpc to 1kpc scales: ugriZYJHK+HI