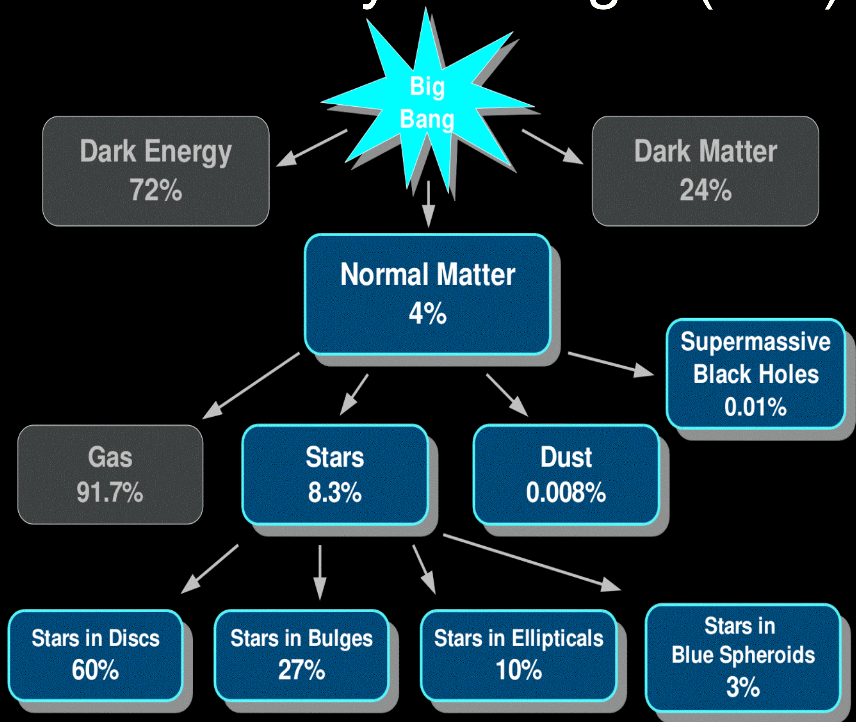
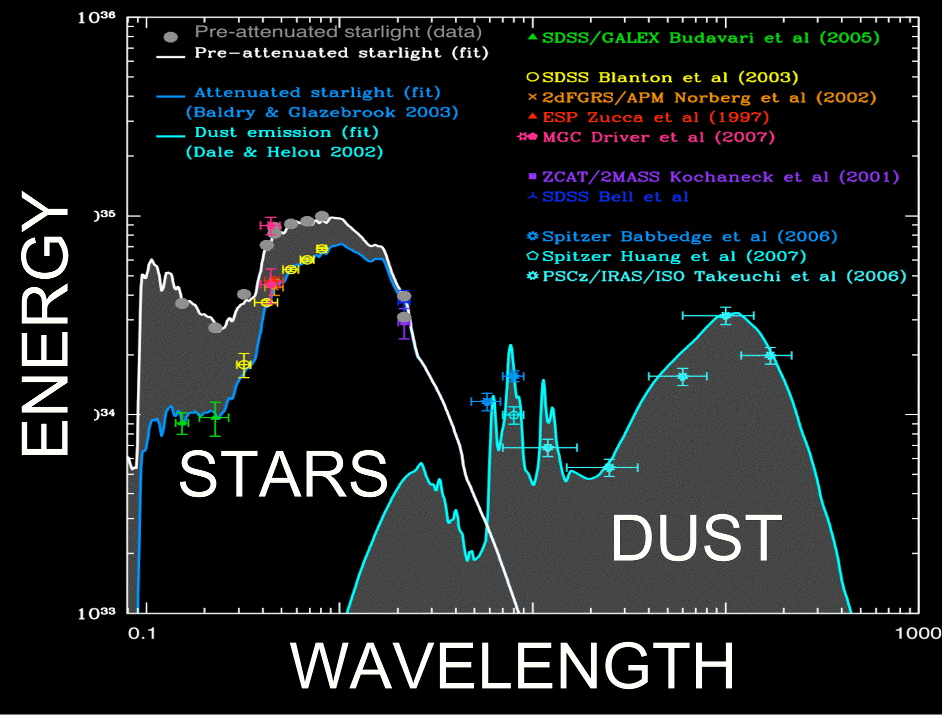
Luminous Matter and Luminous Energy

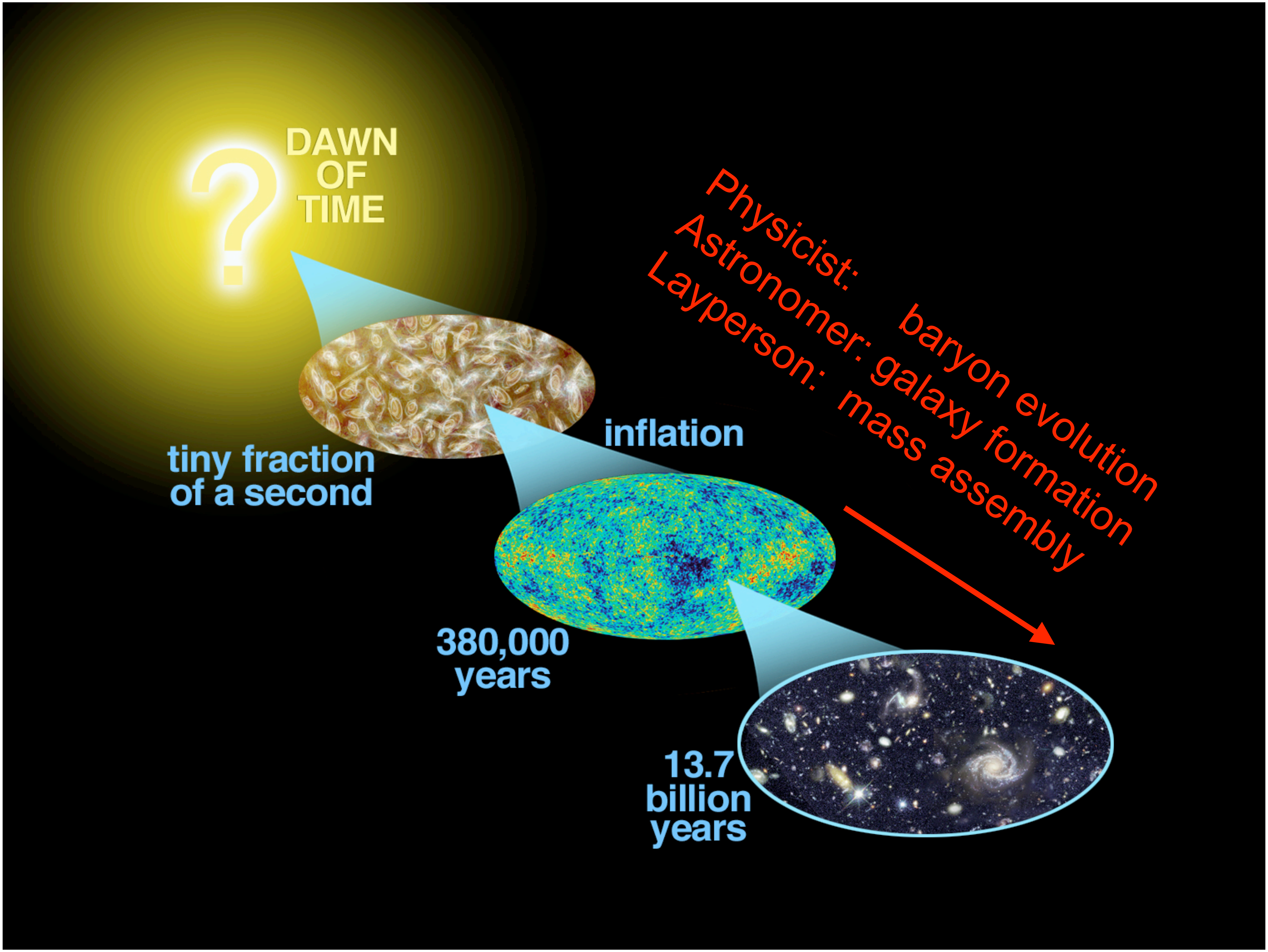
Simon Driver (+MGC+GAMA teams)

University of St Andrews

The baryon budget (z=0) & The Cosmic Energy Spectrum






DAWN
OF
TIME
tiny fraction
of a second
inflation
380,000
years
13.7
billion
years
Physicist: baryon evolution
Astronomer: galaxy formation
Layperson: mass assembly

Tracing the Luminous Matter and Luminous Energy

- Objectives:
  - –Build an empirical description of the *baryon concentrations* at all epochs
  - –Understand the *luminous energy* output within the Universe at all epochs

- Progress/Science:
  - –The Millennium Galaxy Catalogue (Medium Scale Galaxy Survey)
    - A local census of 10k galaxies over 37 sq deg of sky
  - –The significance of galaxy structure (the modes of evolution)
  - –The problem of dust attenuation
  - –The z=0 baryon breakdown and the energy budget (according to the MGC)
  - –A blueprint of galaxy formation ?

- Future directions:
  - –Galaxy And Mass Assembly (Legacy Scale Galaxy/Group Survey)
    - Going massively multi-wavelength
  - –Galaxy And Mass Assembly Deep (Legacy Galaxy/Group Survey)
    - Pushing back to very early epochs

Cosmological Context

$G_{\mu\nu} = -\kappa T_{\mu\nu}$

Geometry(Dynamics) = Contents(Mass-Energy)

Equation does not balance with normal luminous matter and energy.

Needs extra stuff (DM,DE) or extra effects (Modified Gravity).

Independent Observations (CMB, SnIa etc) ~ No of free parameters.

Solving galaxy formation via numerics requires "knowing" the above.

The empirical approach bypasses this issue and allows one to build a galaxy blueprint while the Dark debate goes on.

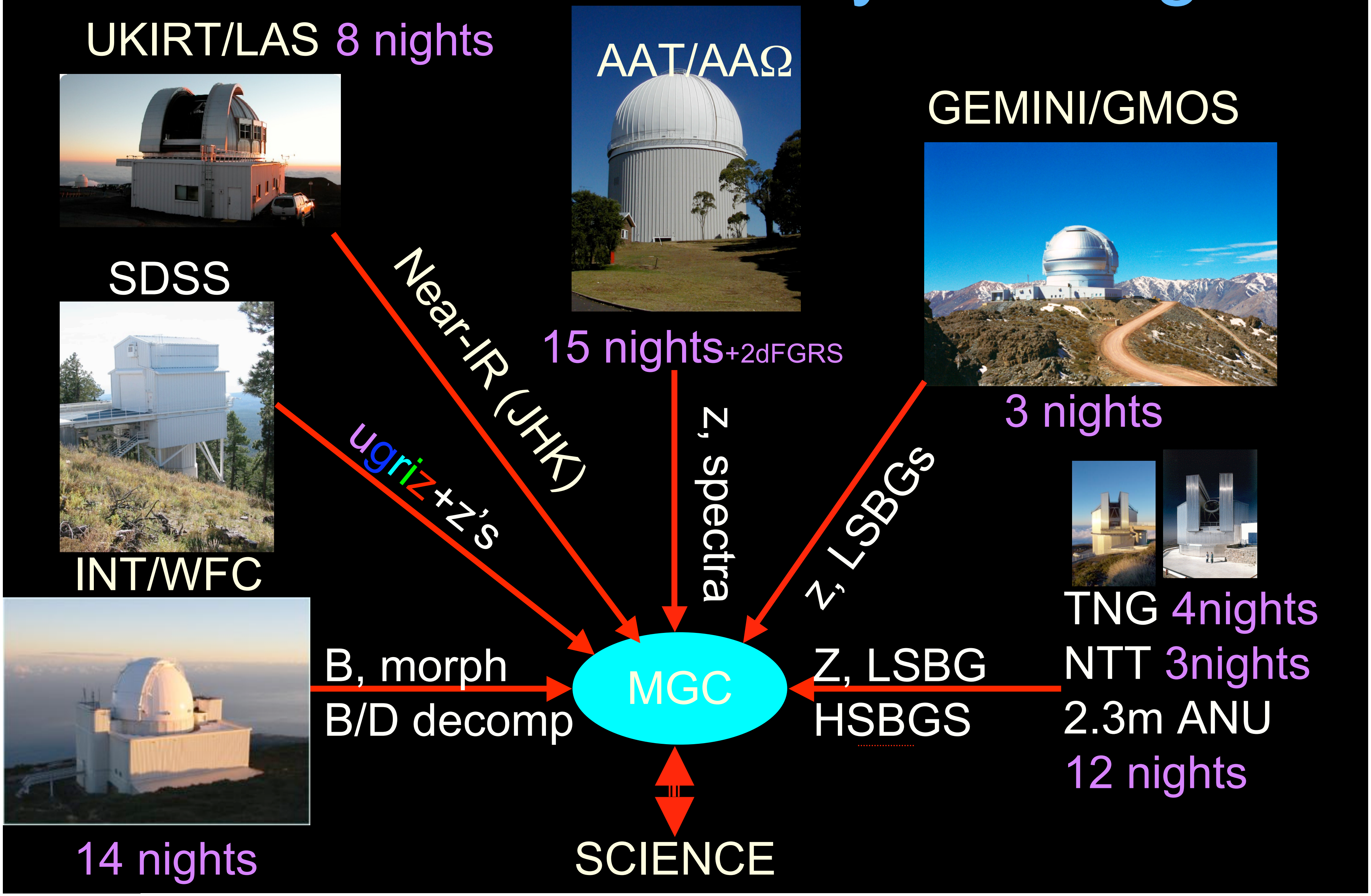
Almost all recent advances have come from empirical breakthroughs.

There is no robust (predictive) model of baryon evolution.

Technological (multi-wavelength) explosion underway = big opportunity

[(s)he who builds the best database will lead the gal. form debate]

The Millennium Galaxy Catalogue



The Millennium Galaxy Catalogue

The MGC Core Team

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Jochen Liske (ESO)
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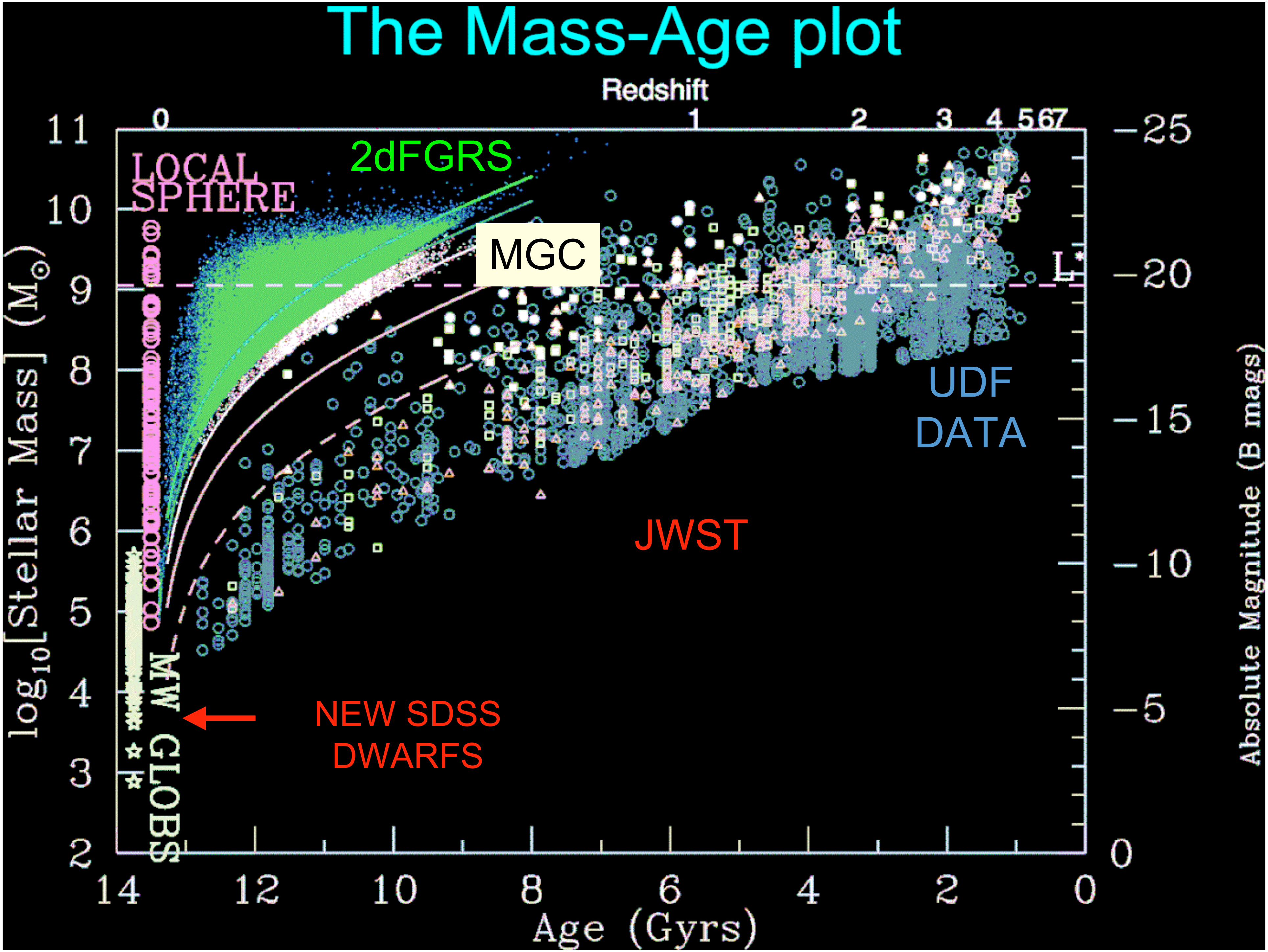
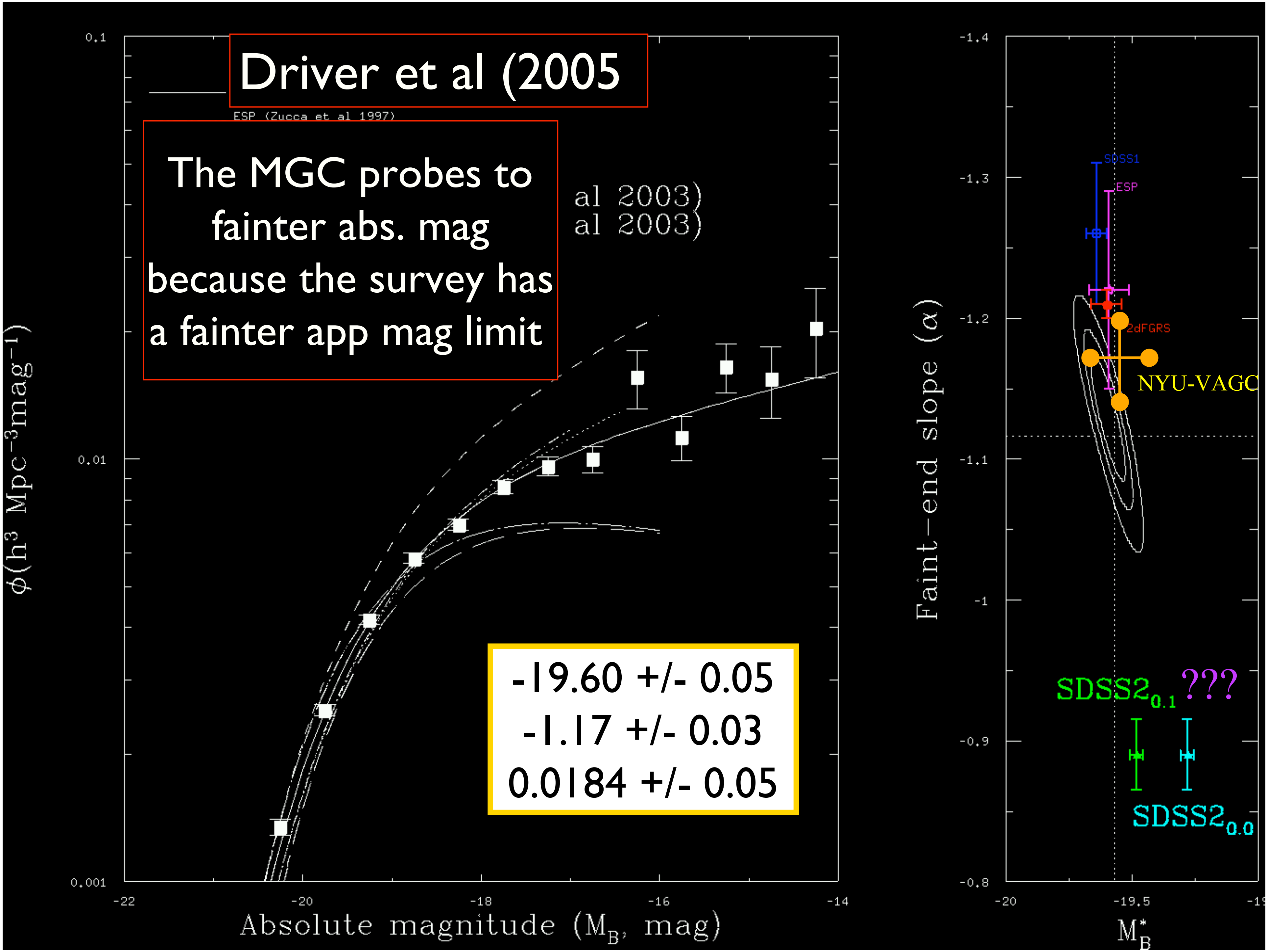
David Hill (St Andrews)

MGC Collaborators

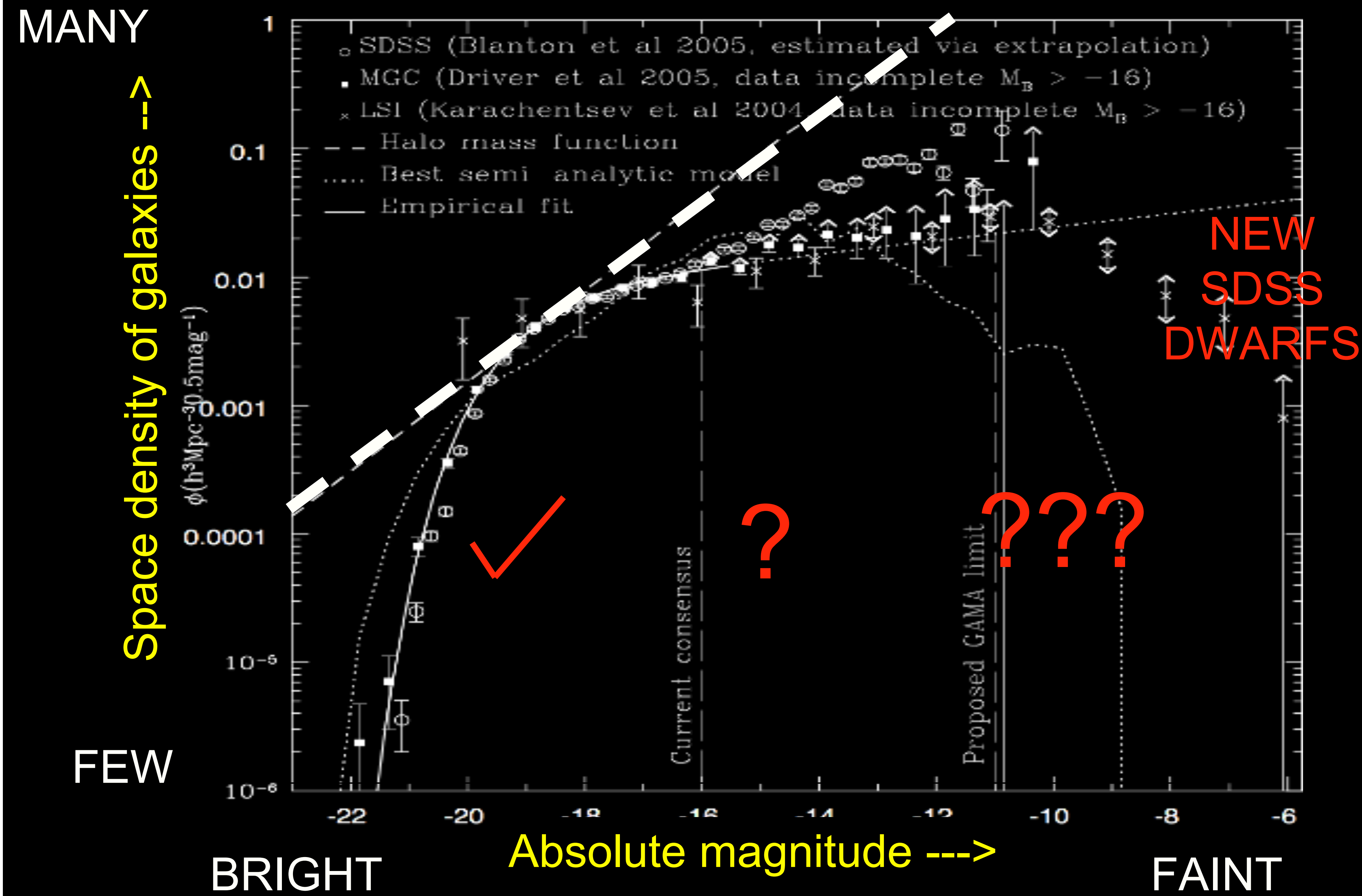
Chris Conselice (Nott.)
Nicholas Cross (ROE)
Roberto De Propris (CTIO)
Simon Ellis (AAO)
Richard Tuffs (MPIK)
Cristina Popescu (UCLAN)

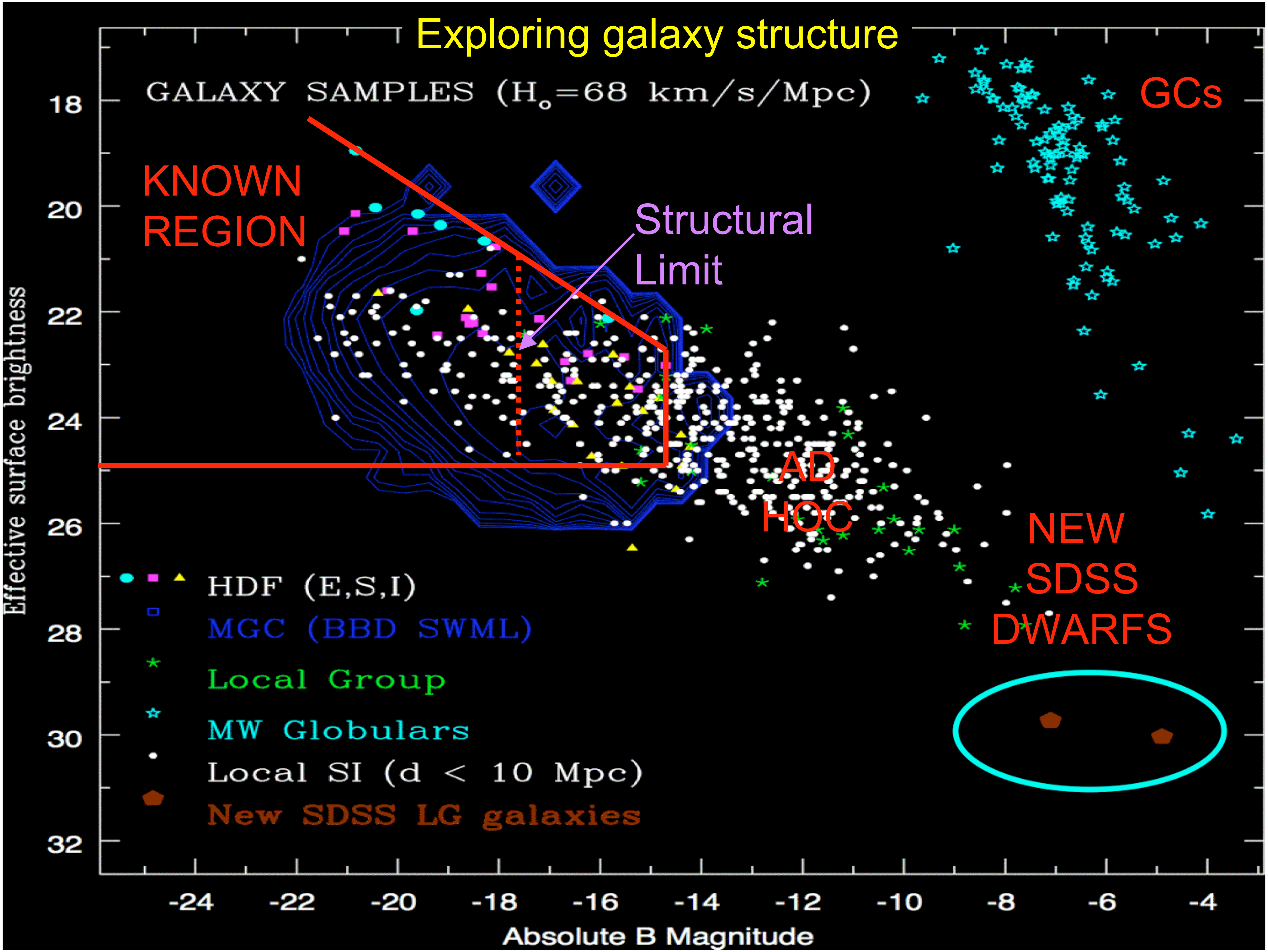


The Mass-Age plot
Redshift
0
1
2
3
4 5 6 7
11
10
9
8
7
6
5
4
3
2
log10[Stellar Mass] (M⊙)
LOCAL
SPHERE
2dFGRS
MGC
L*
UDF
DATA
JWST
MW GLOBS
NEW SDSS
DWARFS
−25
−20
−15
−10
−5
0
Absolute Magnitude (B mags)
14
12
10
8
6
4
2
0
Age (Gyrs)


Driver et al (2005
ESP (Zucca et al 1997)
The MGC probes to fainter abs. mag because the survey has a fainter app mag limit
al 2003)
al 2003)
-19.60 +/- 0.05
-1.17 +/- 0.03
0.0184 +/- 0.05
ϕ(h^3 Mpc^{-3}mag^{-1})
0.1
0.01
0.001
-22
-20
-18
-16
-14
Absolute magnitude (M$_B$, mag)
SDSS1
ESP
2dFGRS
NYU-VAGC
SDSS2$_{0.1}$???
SDSS2$_{0.0}$
Faint-end slope (α)
-1.4
-1.3
-1.2
-1.1
-1
-0.9
-0.8
-20
-19.5
M$^*_B$

BUT…still a long way to go at z=0




Exploring galaxy structure
GALAXY SAMPLES (H$_o$=68 km/s/Mpc)
KNOWN REGION
Structural Limit
GCs
AD HOC
NEW SDSS DWARFS
HDF (E,S,I)
MGC (BBD SWML)
Local Group
MW Globulars
Local SI (d < 10 Mpc)
New SDSS LG galaxies
Effective surface brightness
Absolute B Magnitude
18
20
22
24
26
28
30
32
-24
-22
-20
-18
-16
-14
-12
-10
-8
-6
-4

MGC bulge/disc decomposition

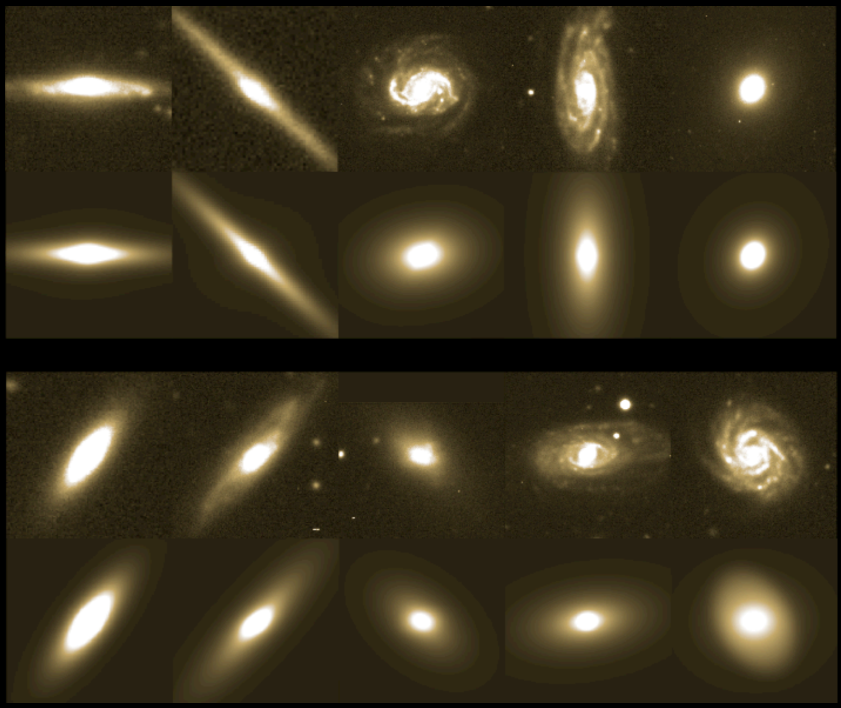
Simard et al (1998)

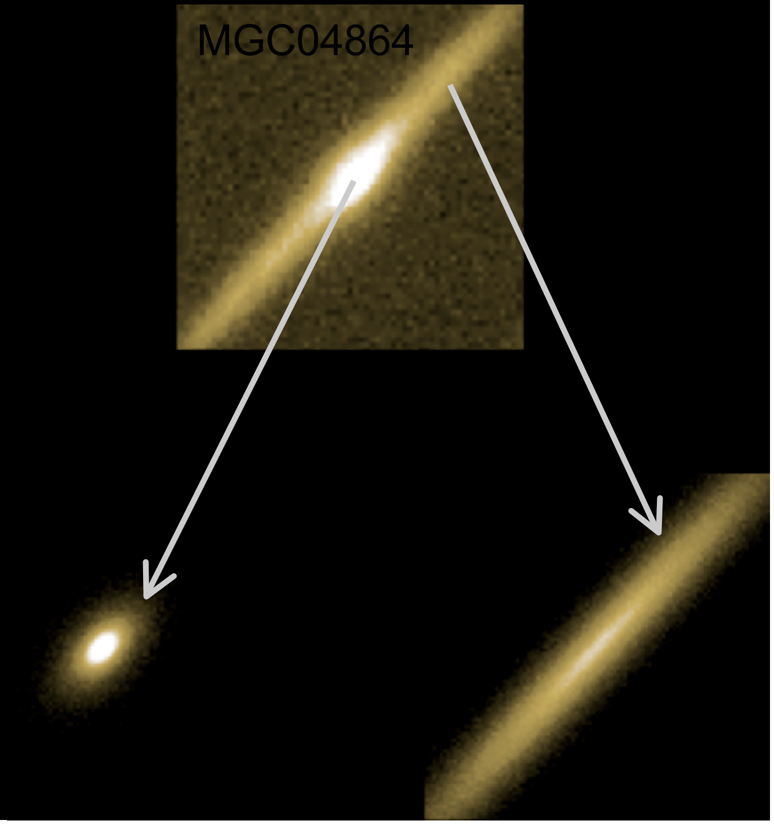
Allen et al (2006)

Driver et al (2005)

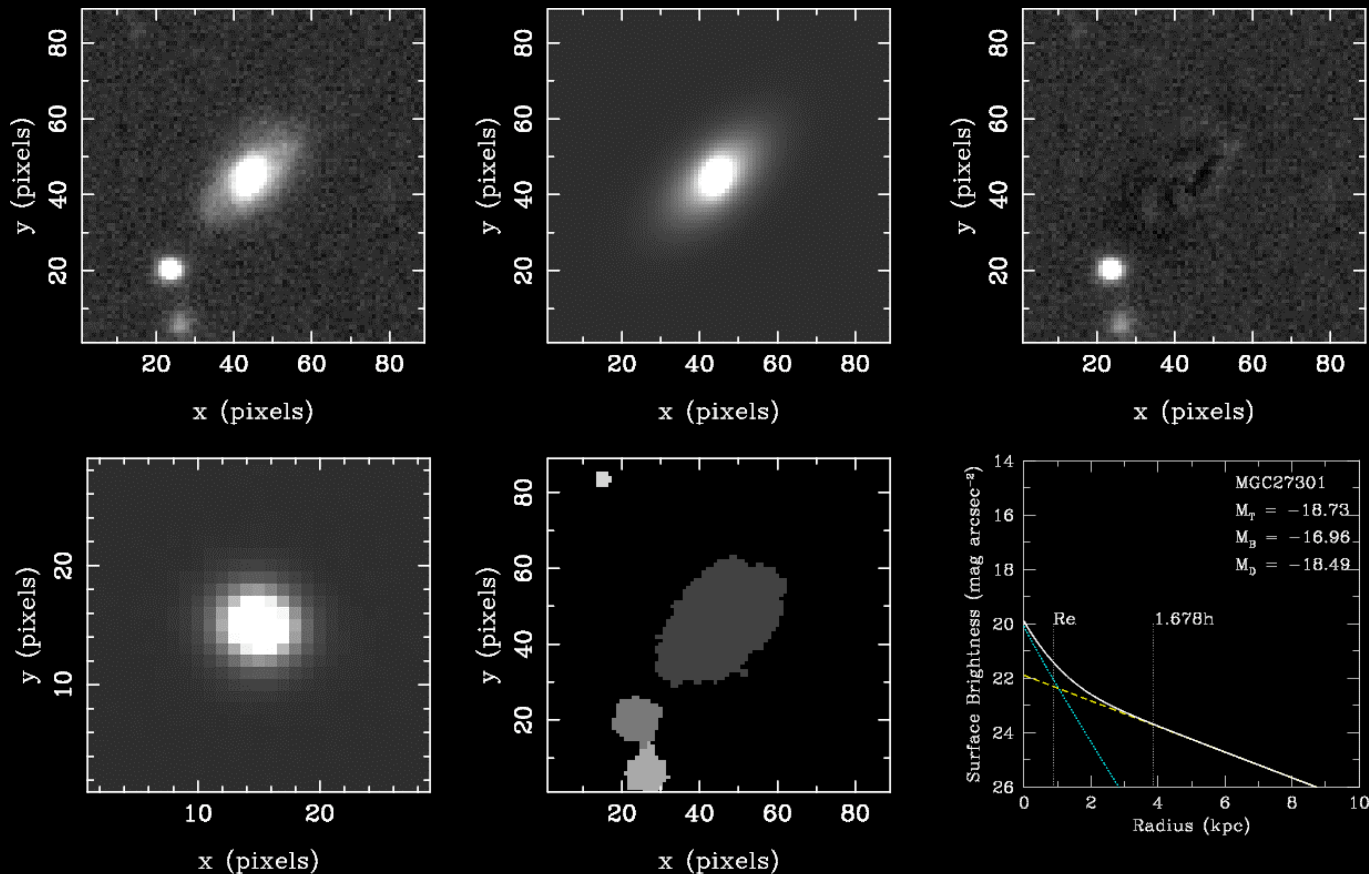
YJHK(UKIRT) imaging now 50% complete

All data available online: http://www.eso.org/~jliske/mgc/

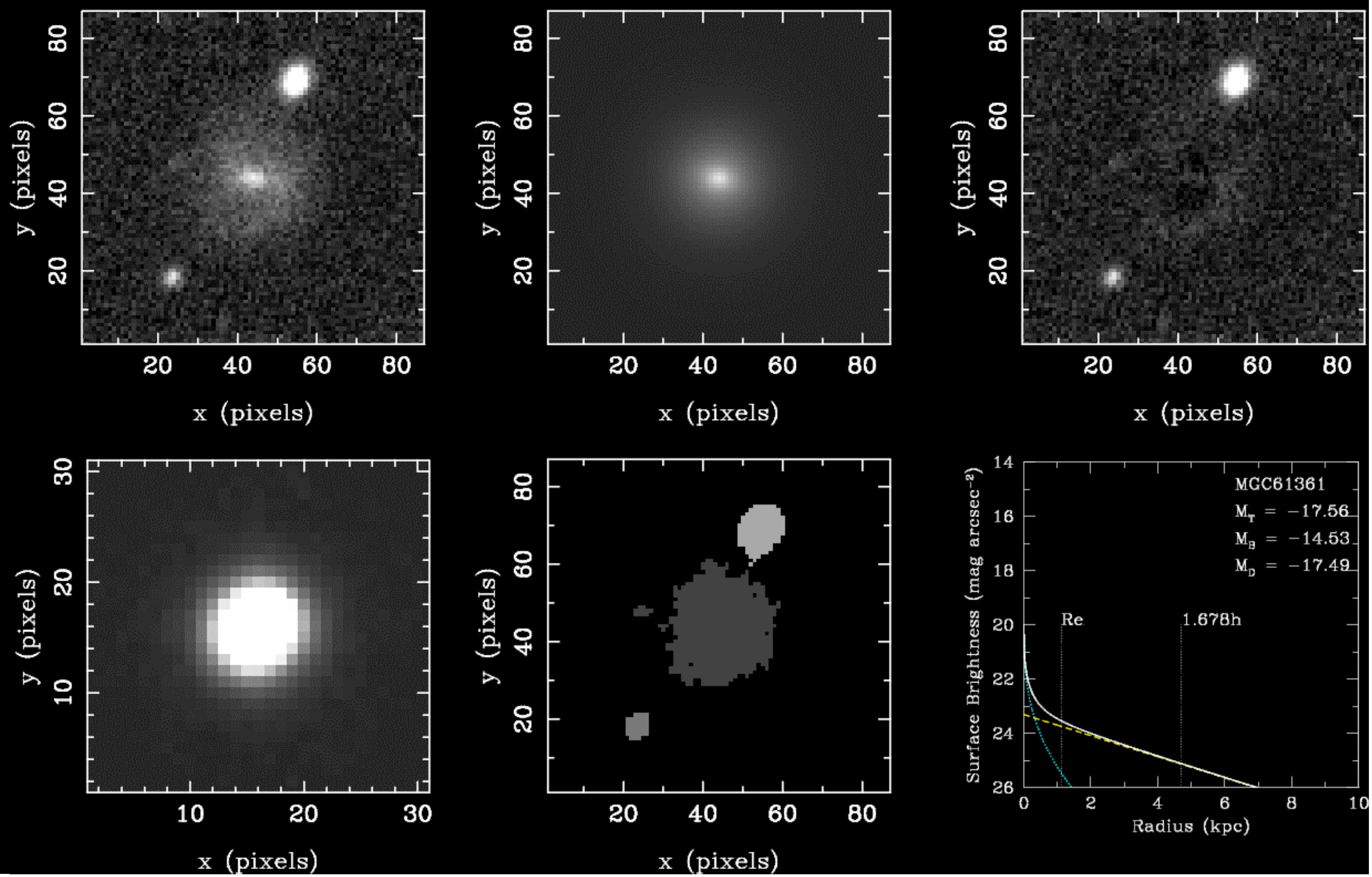




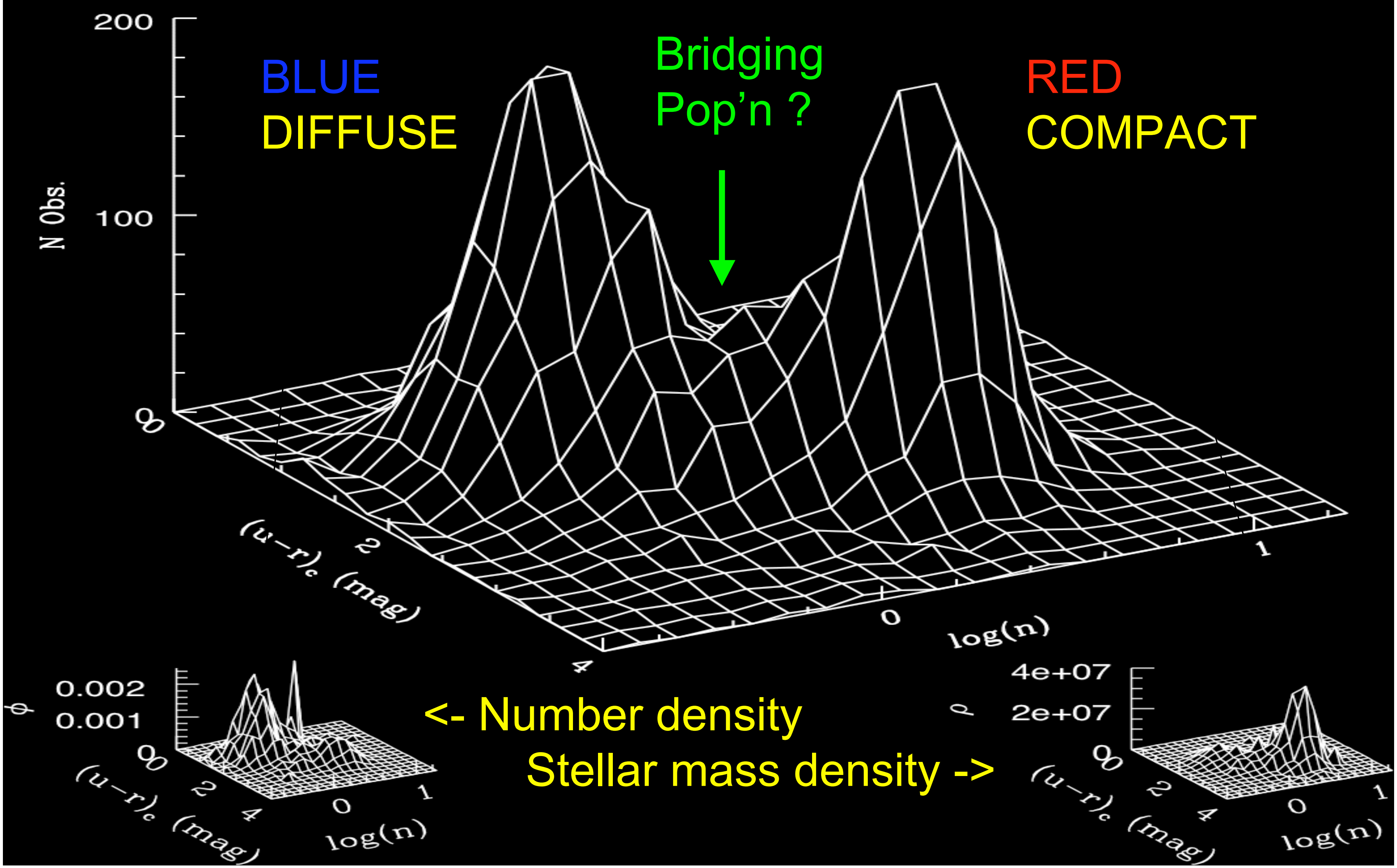
Example 1: MGC27301



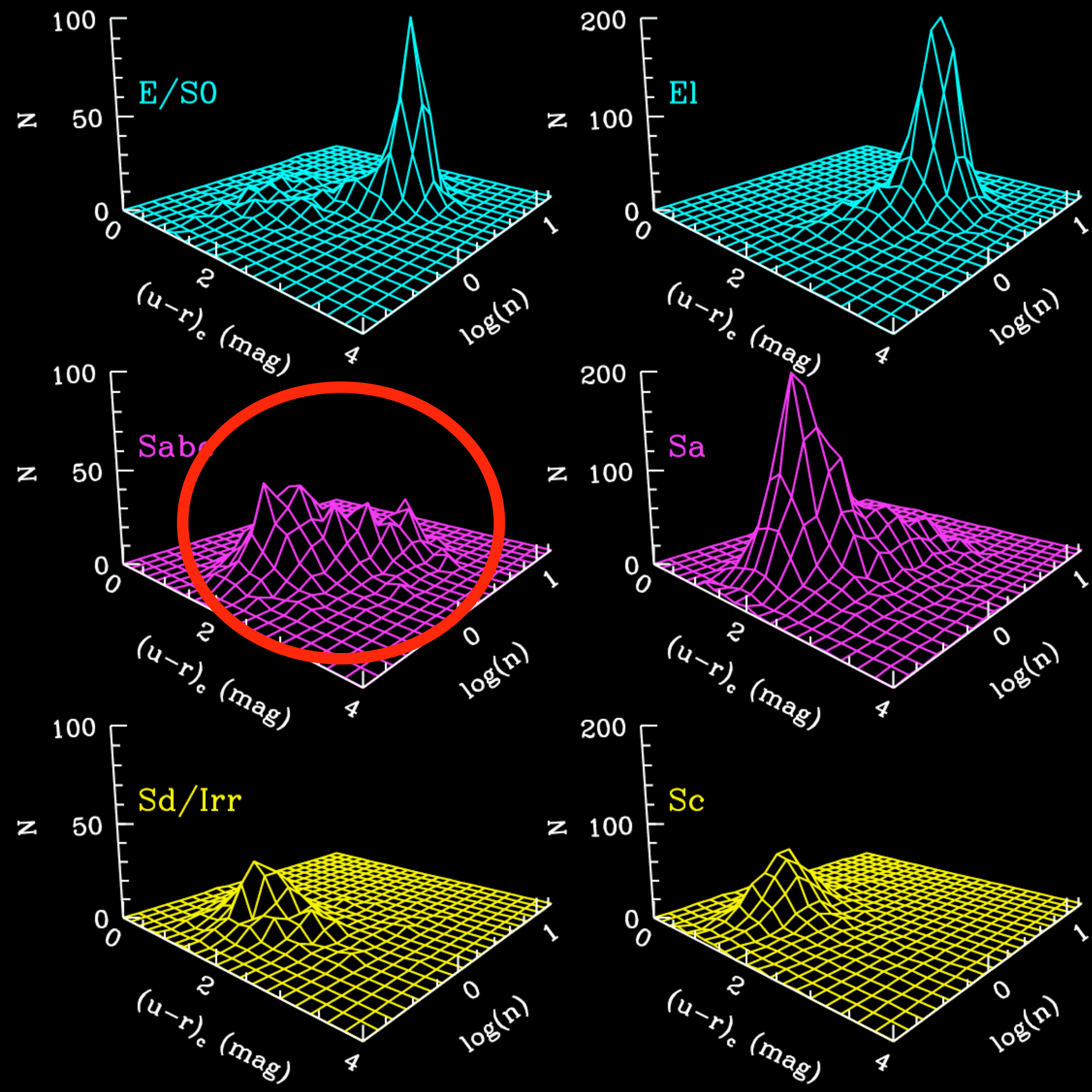
Example 2: MGC61361



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

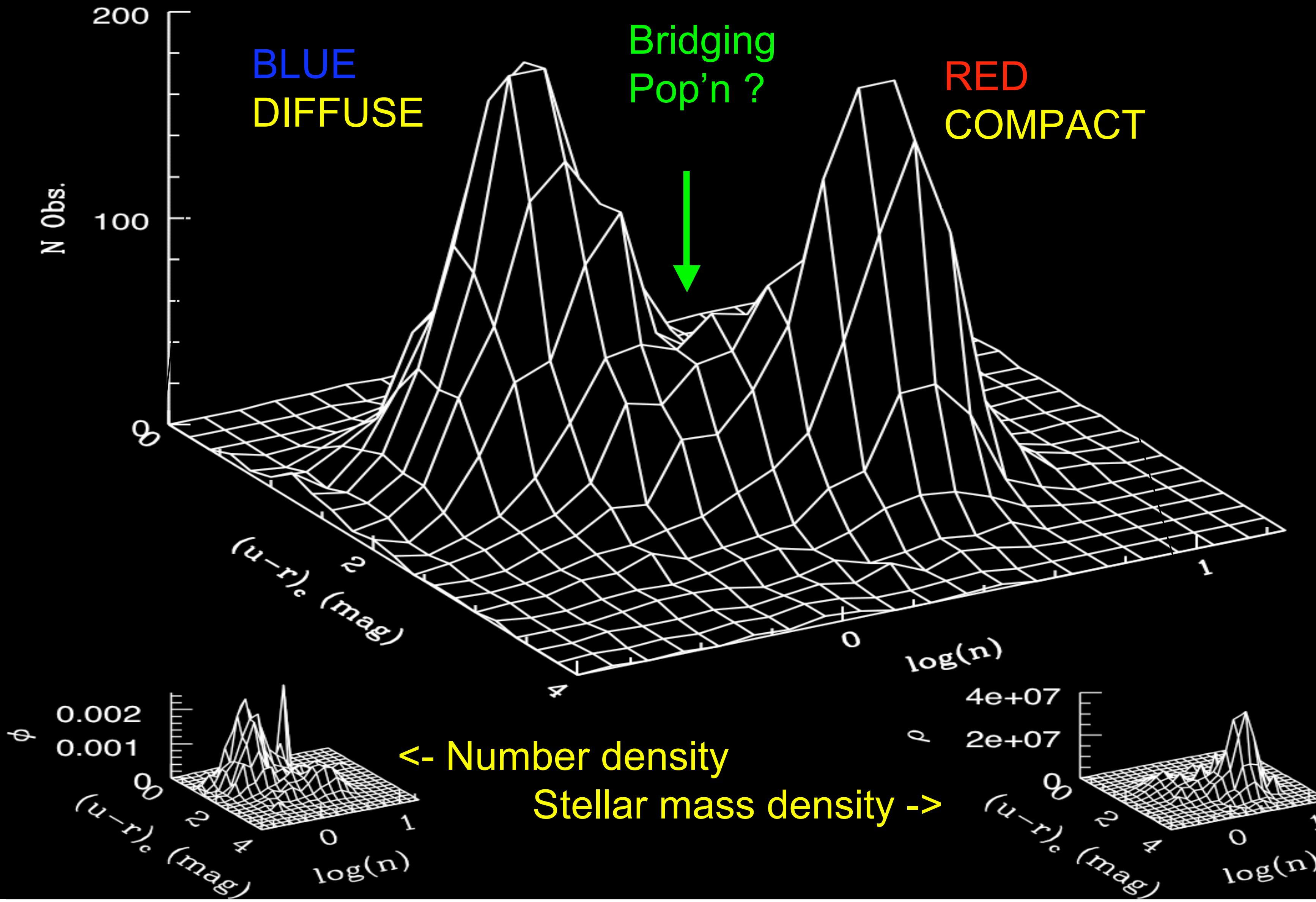


Two populations or two components ?



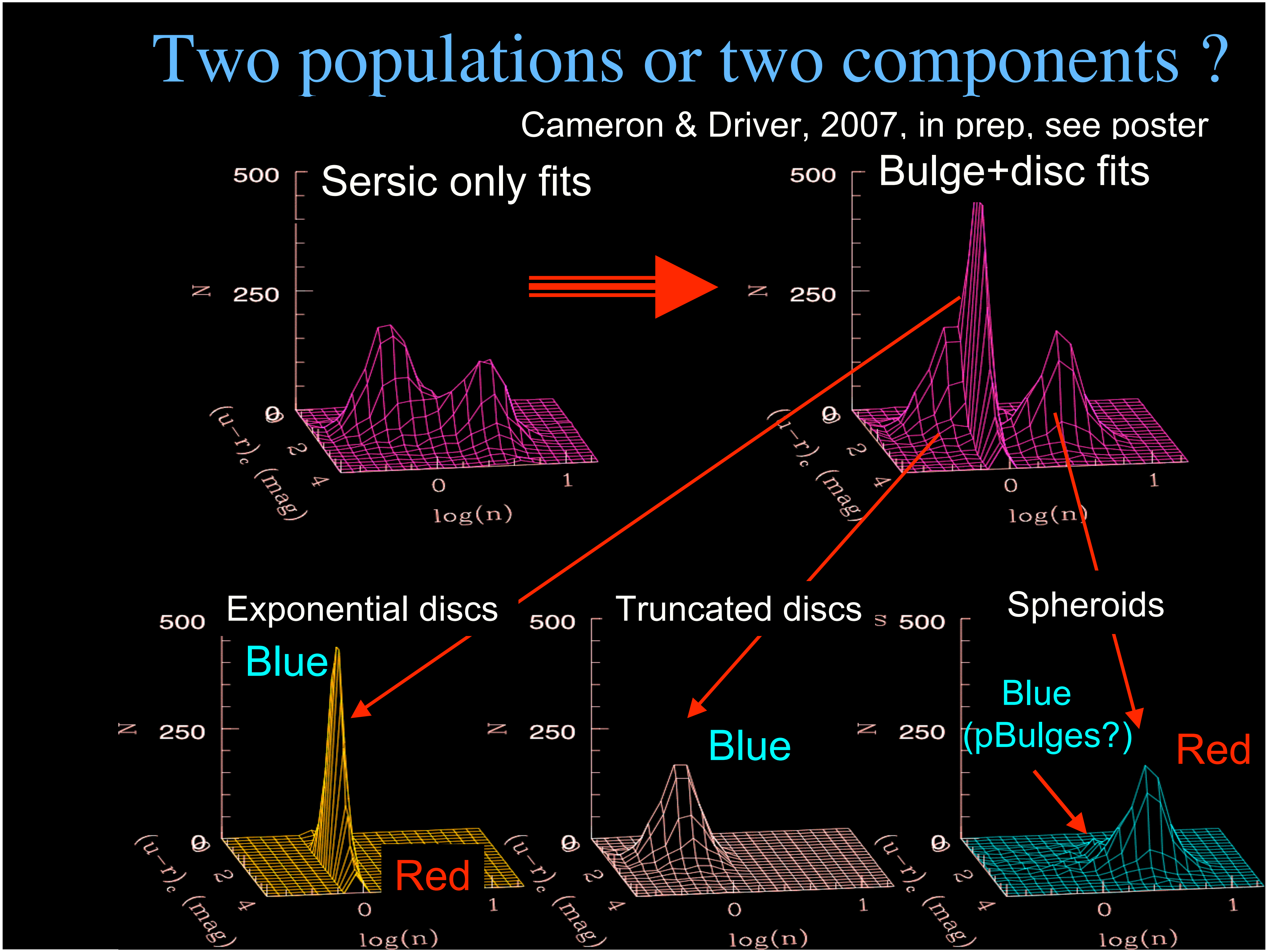
Galaxy bimodality in (u-r)-log(n)

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

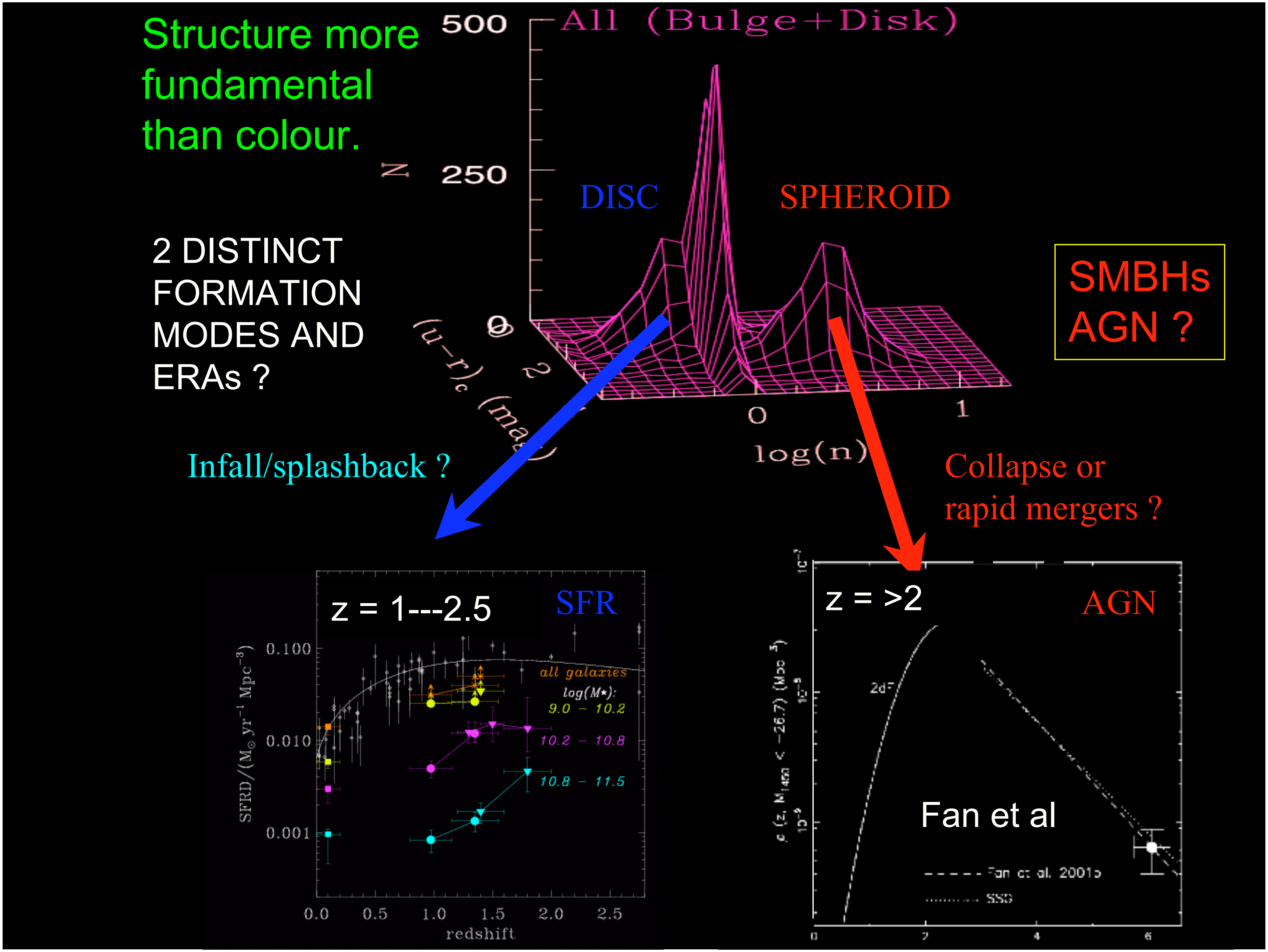


<- Number density

Stellar mass density ->

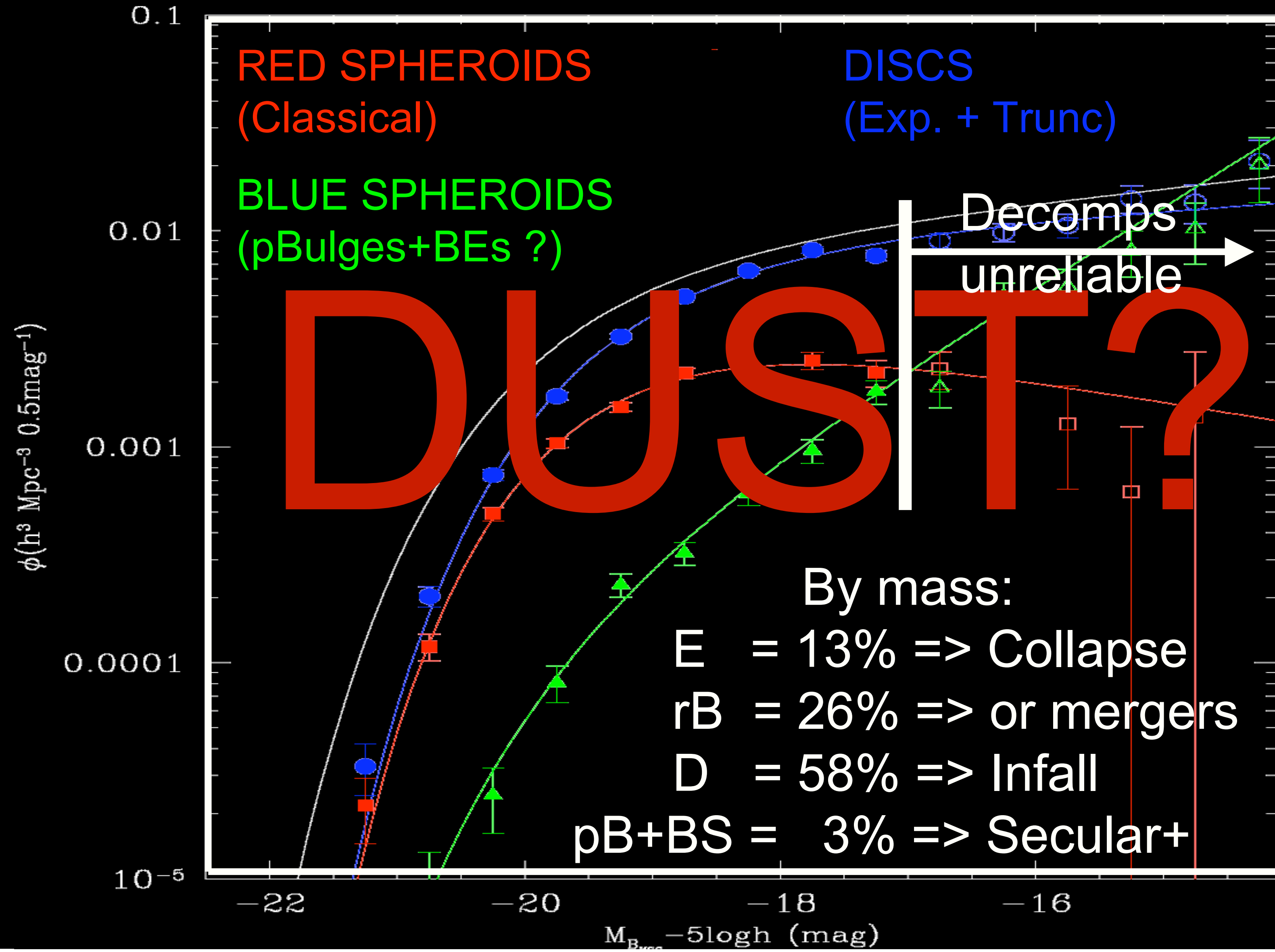


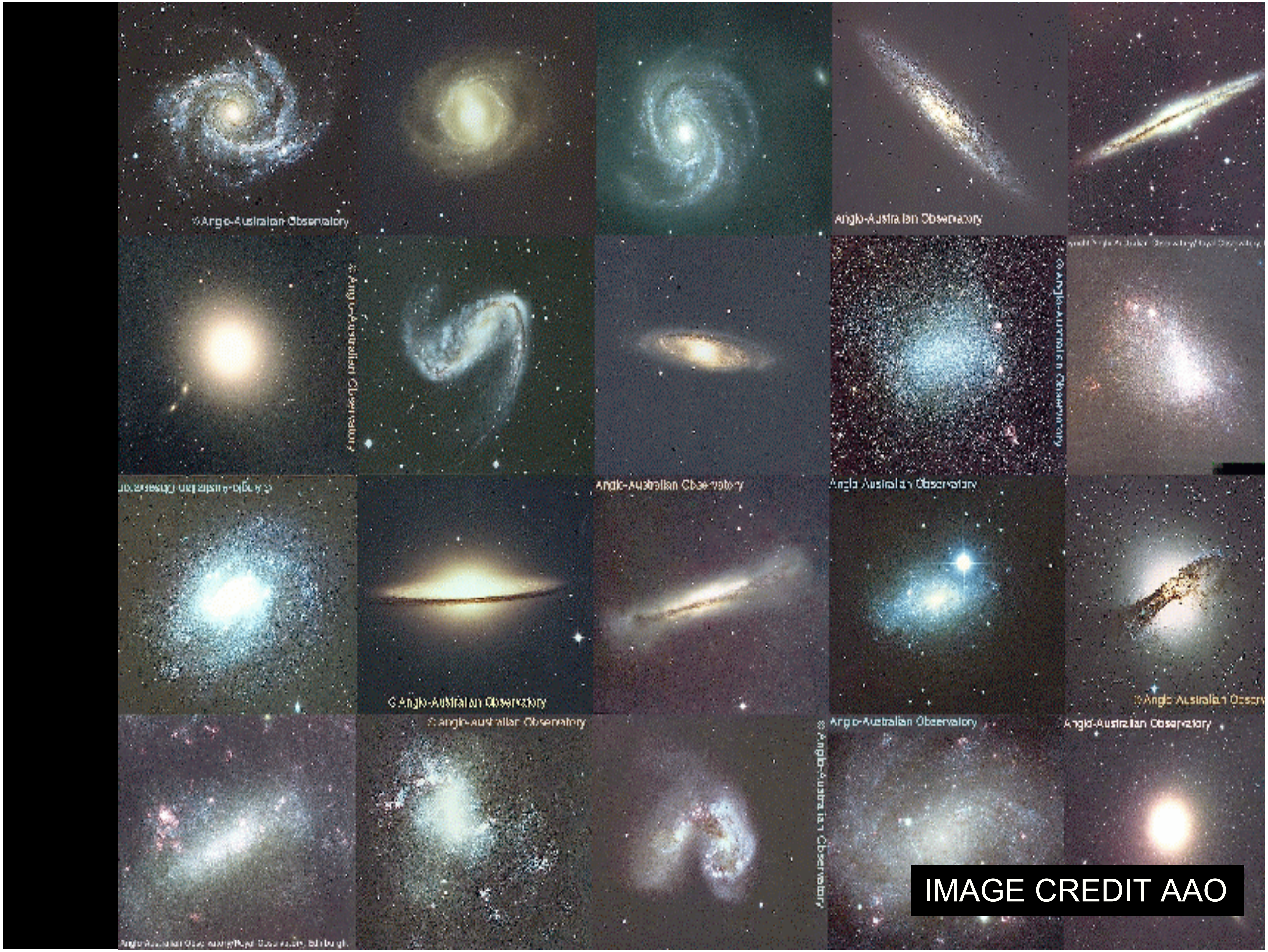
Two populations or two components ?
Cameron & Driver, 2007, in prep, see poster
Sersic only fits
Bulge+disc fits
500
250
0
N
(u−r)c (mag)
log(n)
Exponential discs
Truncated discs
Spheroids
Blue
Red
Blue
Blue
(pBulges?)
Red


Structure more fundamental than colour.
500
250
0
N
All (Bulge+Disk)
DISC
SPHEROID
SMBHs
AGN ?
2 DISTINCT FORMATION MODES AND ERAs ?
2
0
1
log(n)
Infall/splashback ?
Collapse or rapid mergers ?
z = 1---2.5
SFR
0.100
0.010
0.001
0.0
0.5
1.0
1.5
2.0
2.5
redshift
all galaxies
log(M*):
9.0 – 10.2
10.2 – 10.8
10.8 – 11.5
z = >2
AGN
Fan et al
SSG

The Component Luminosity Functions

Driver et al (2007), ApJL

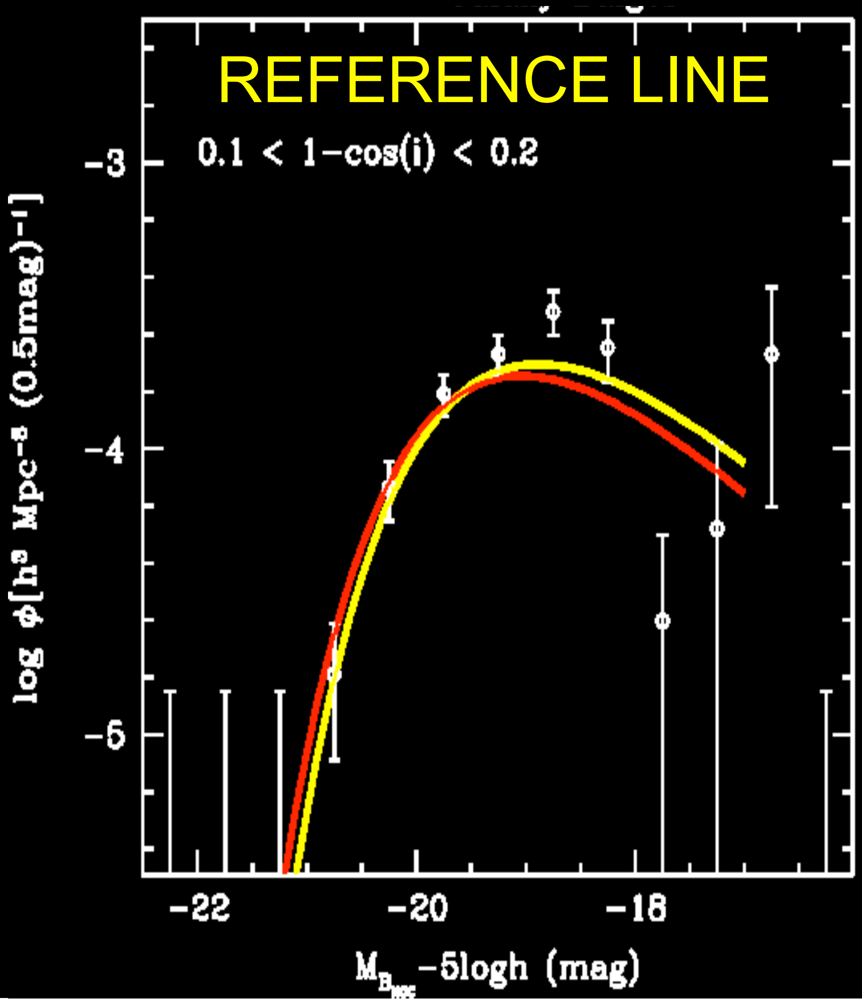


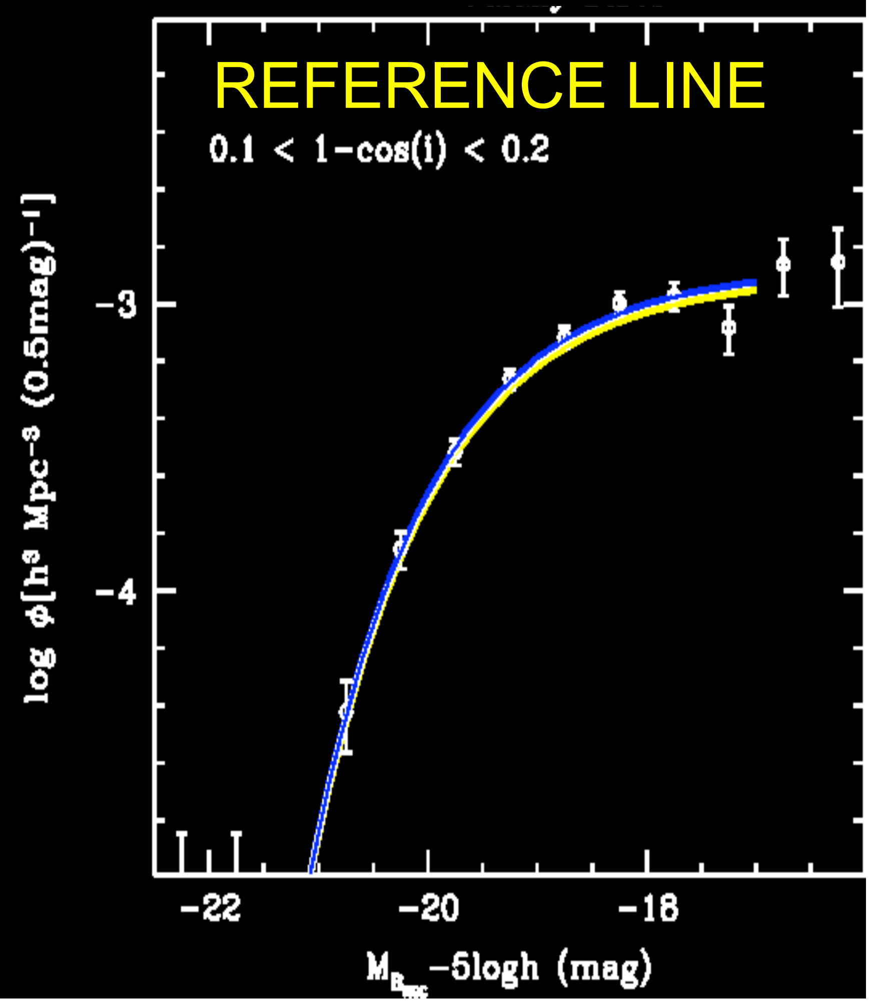

© Anglo-Australian Observatory
Anglo-Australian Observatory
IMAGE CREDIT AAO

Component LFs v cos(*i*)

Nearly face-on galaxies only

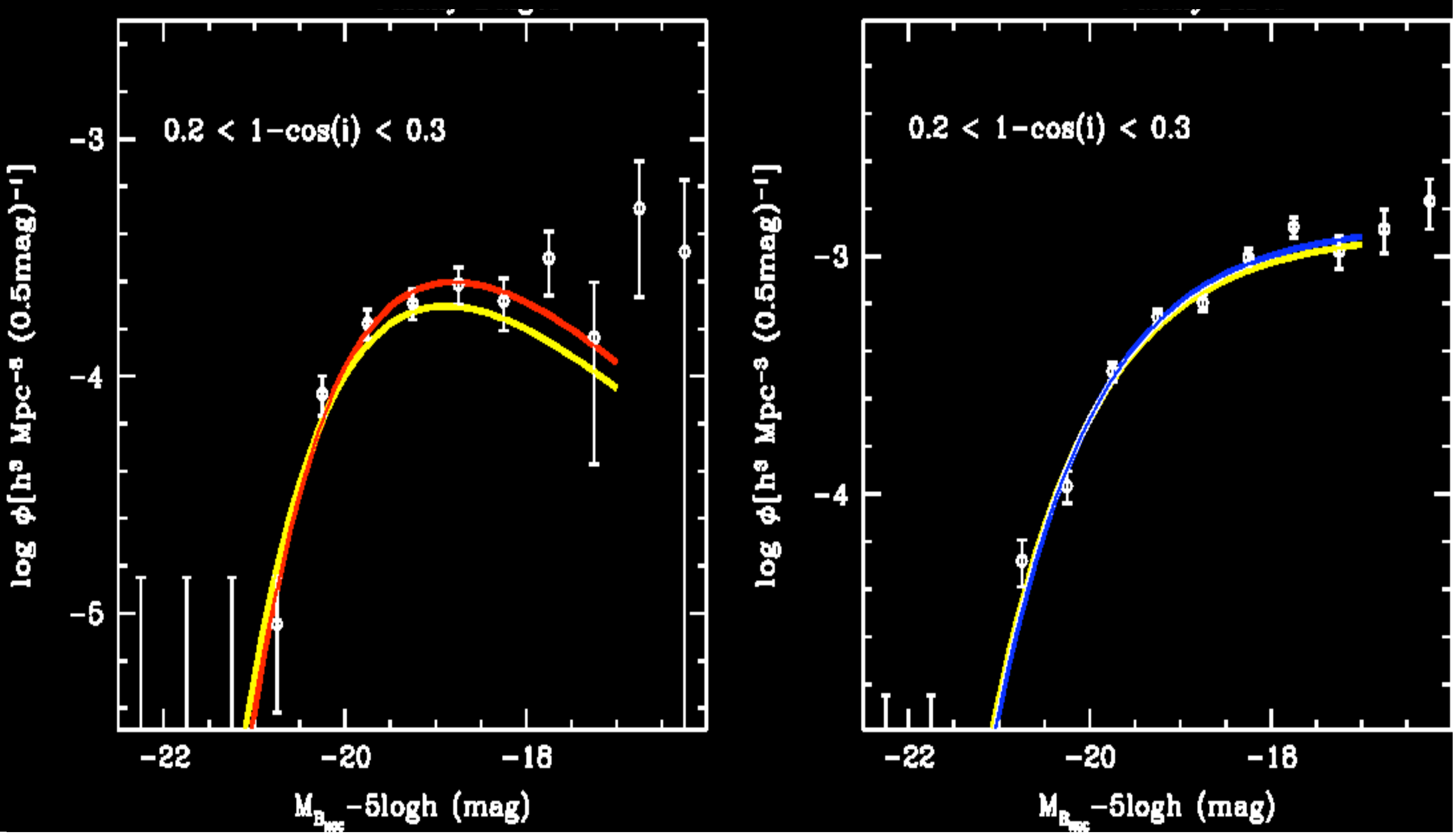
Bulges 0.1 < 1-cos(*i*) < 0.2 Discs





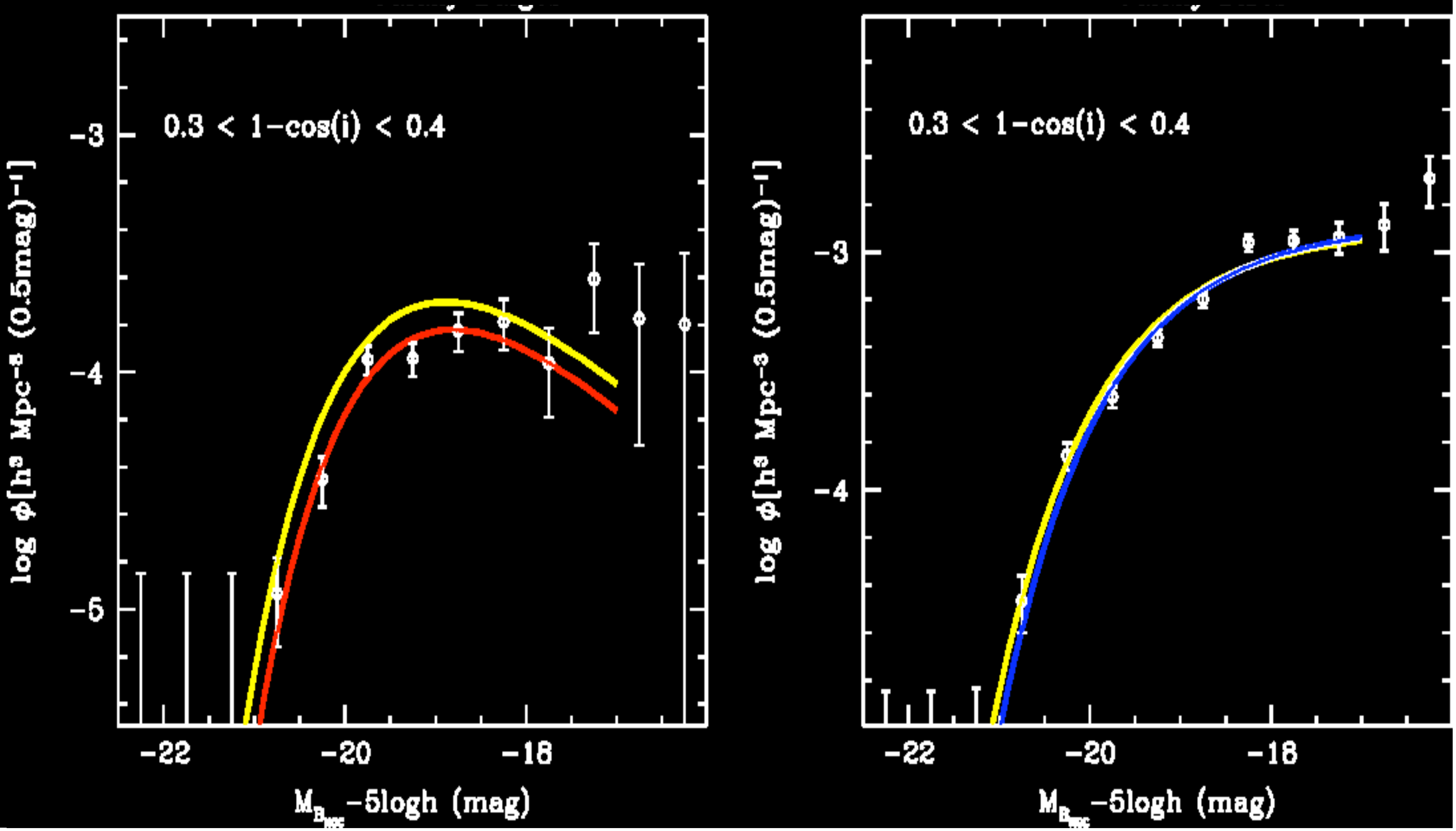
Component LFs v cos(*i*)

Bulges 0.2 < 1-cos(*i*) < 0.3 Discs



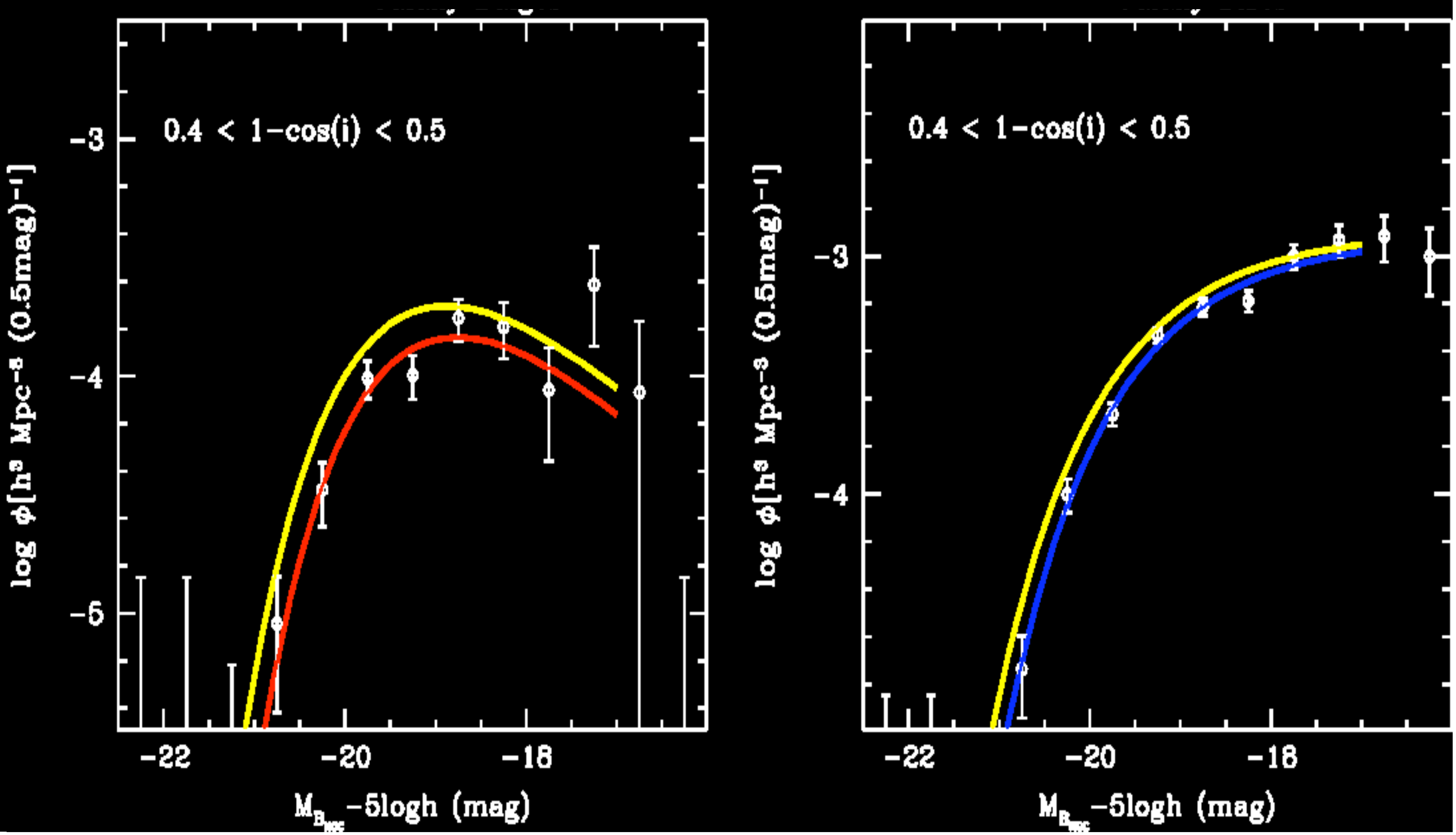
Component LFs v cos(i)

Bulges   0.3 < 1-cos(i) < 0.4   Discs



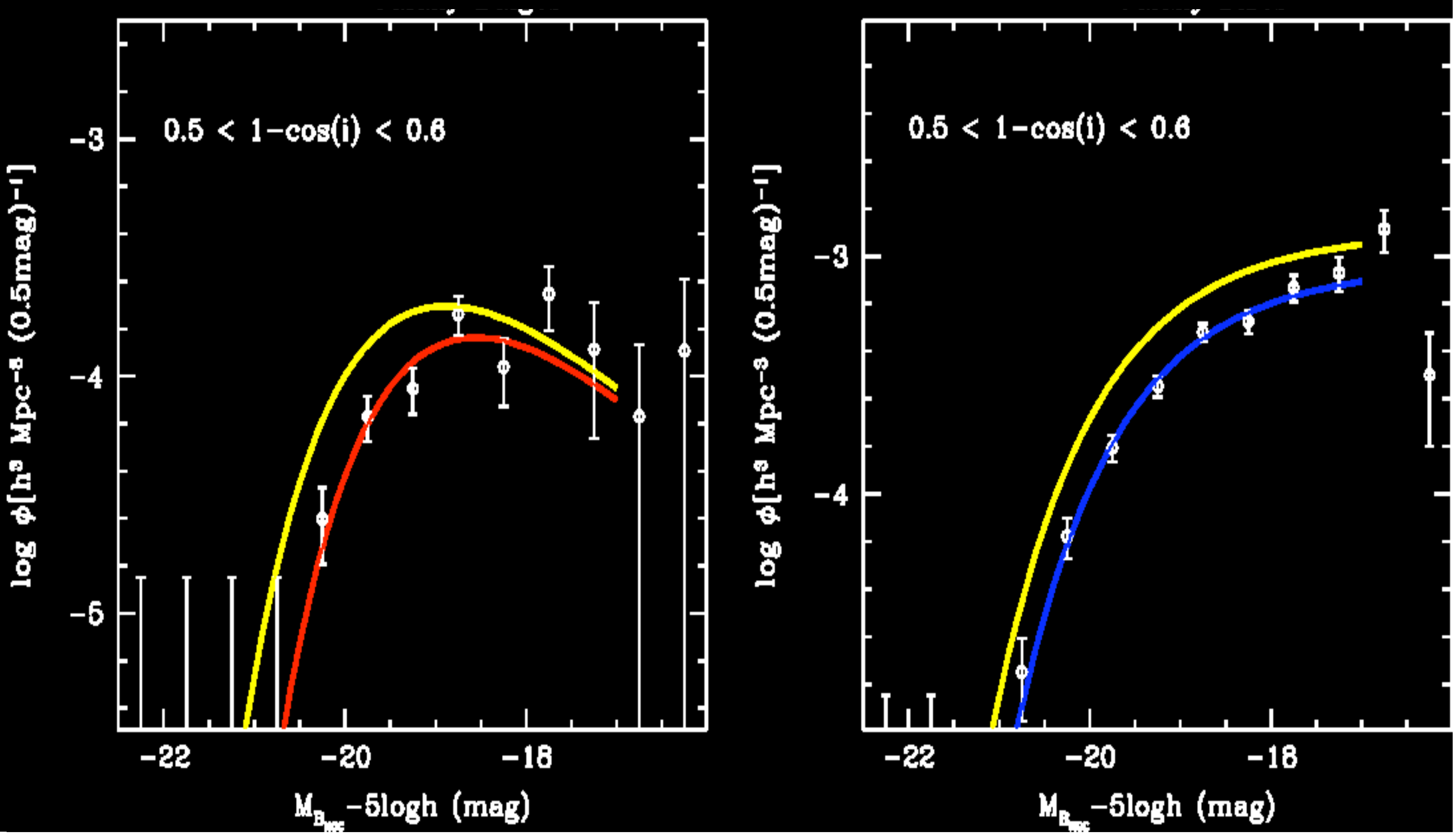
Component LFs v cos(*i*)

Bulges   0.4 < 1-cos(*i*) < 0.5   Discs



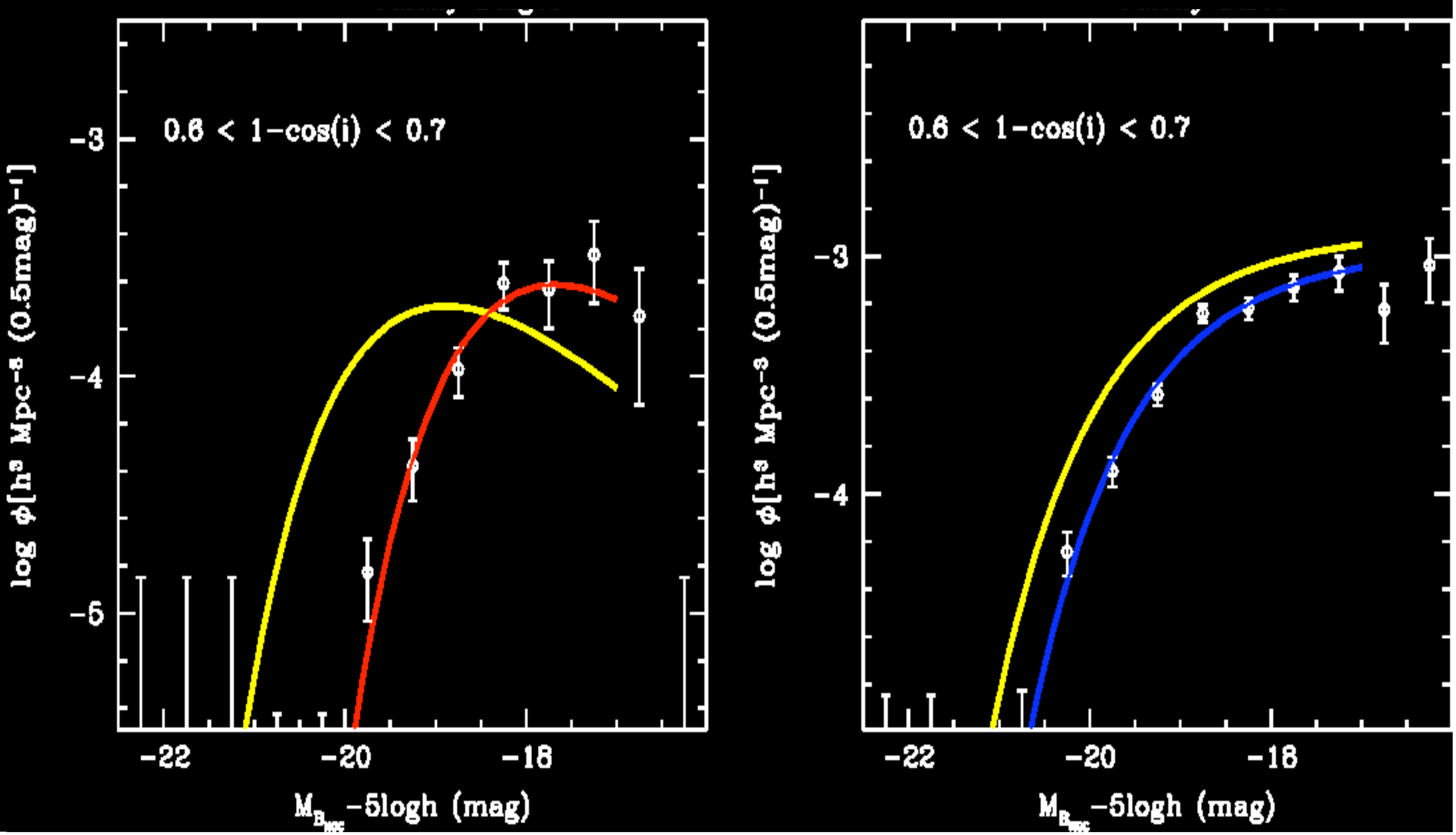
Component LFs v cos(*i*)

Bulges 0.5 < 1-cos(*i*) < 0.6 Discs



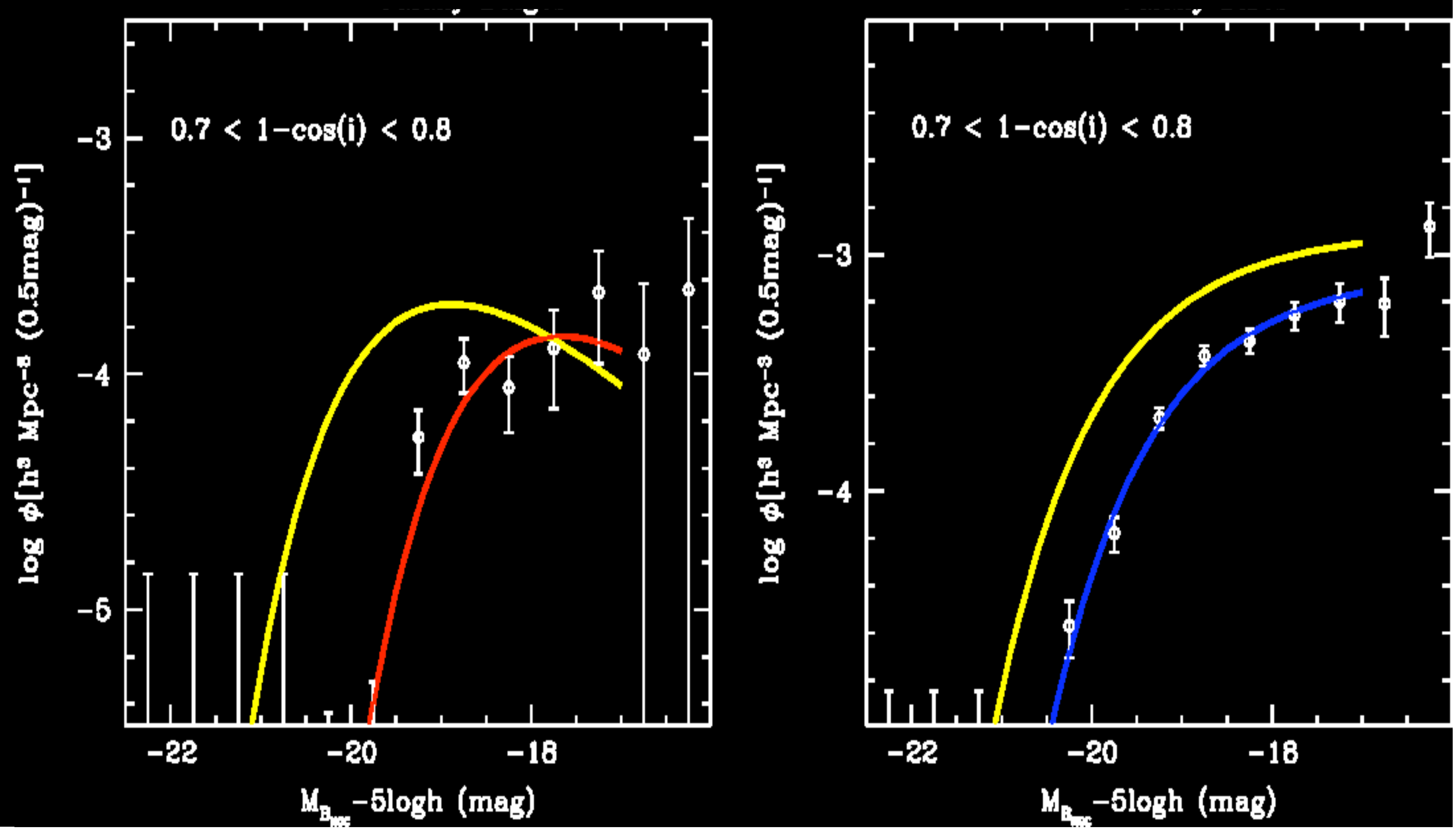
Component LFs v cos(*i*)

Bulges 0.6 < 1-cos(*i*) < 0.6 Discs



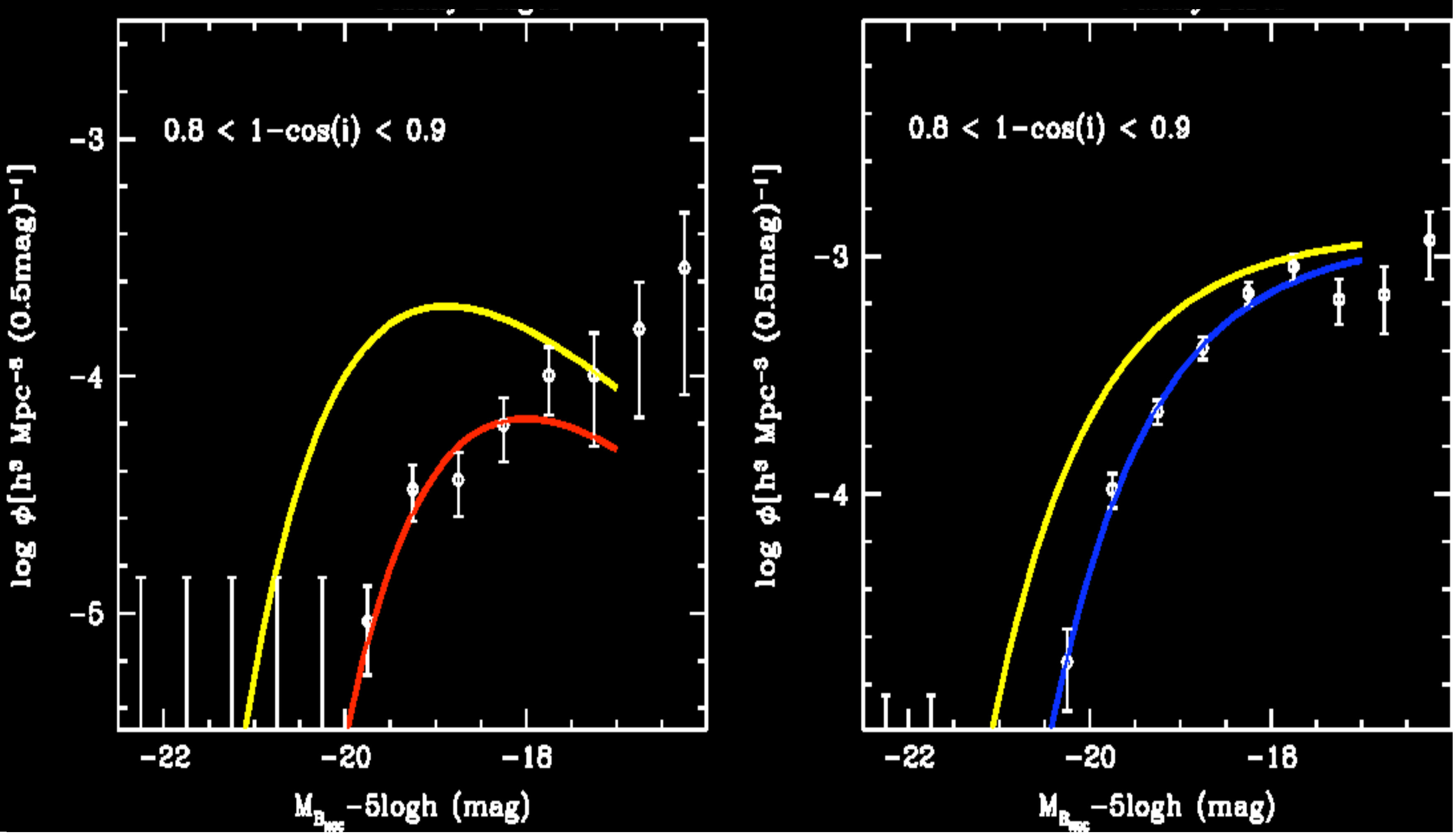
Component LFs v cos(*i*)

Bulges 0.7 < 1-cos(*i*) < 0.8 Discs



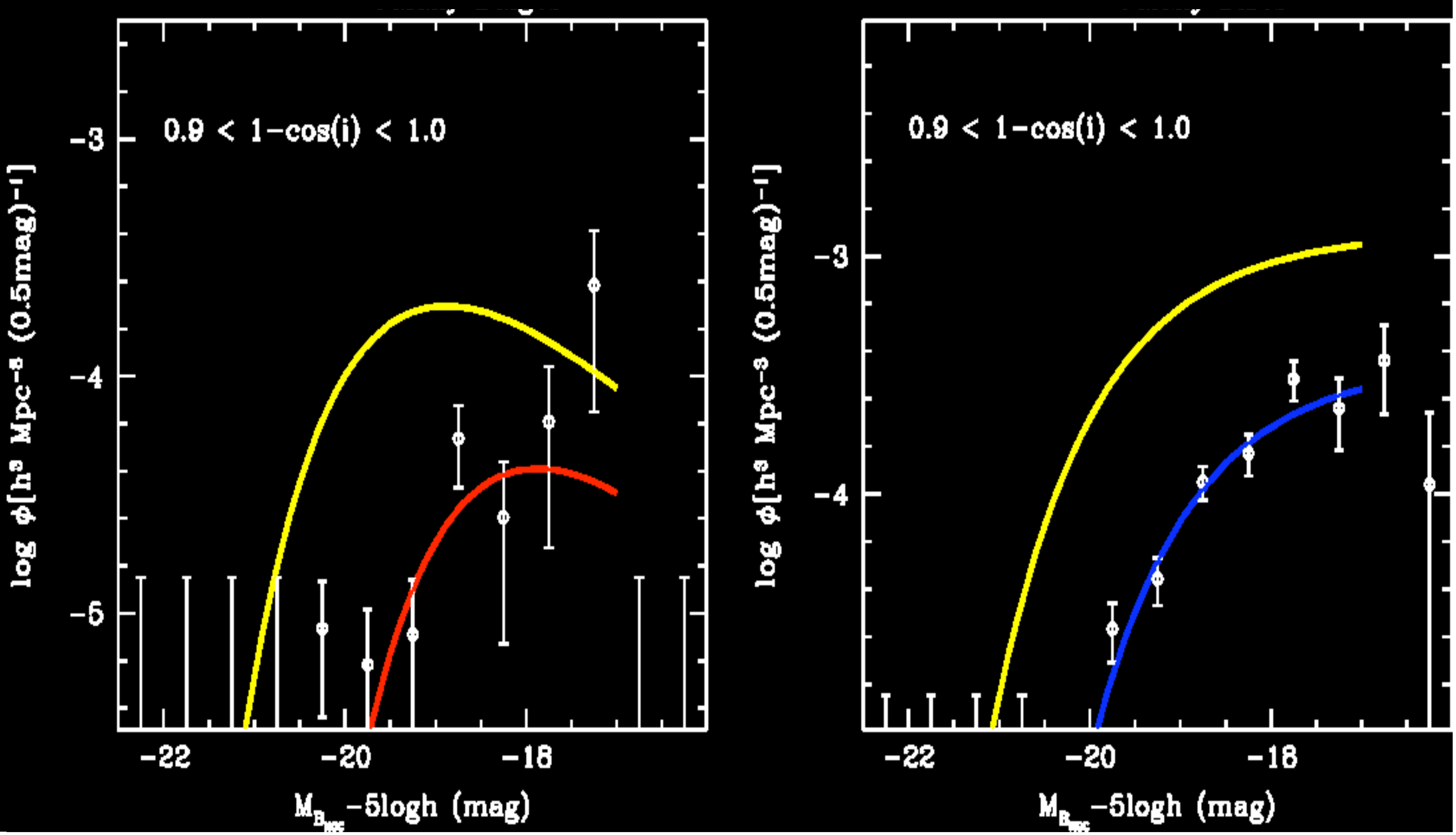
Component LFs v cos(*i*)

Bulges 0.8 < 1-cos(*i*) < 0.9 Discs



Component LFs v cos(*i*)

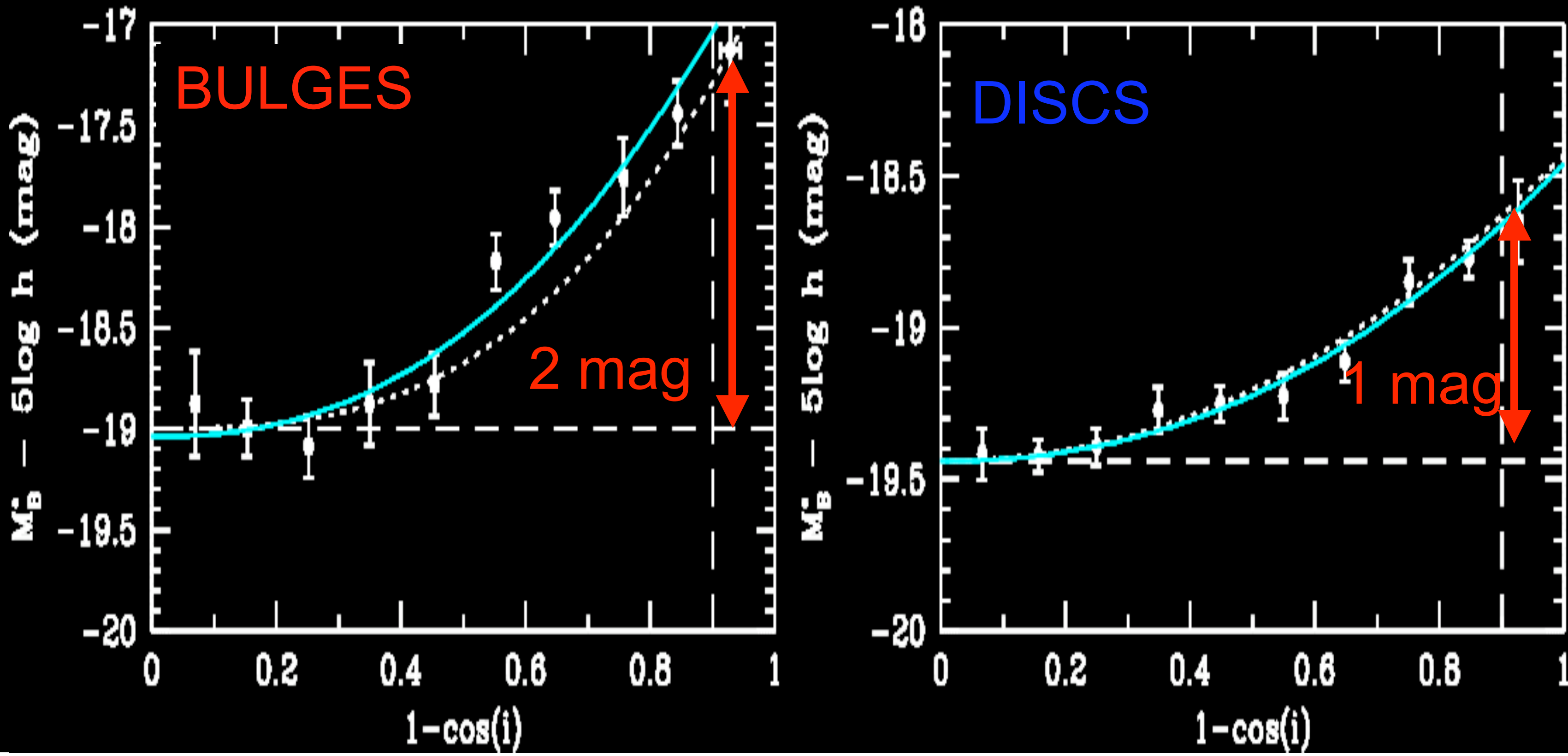
Bulges 0.9 < 1-cos(*i*) < 1.0 Discs



Purely empirical result

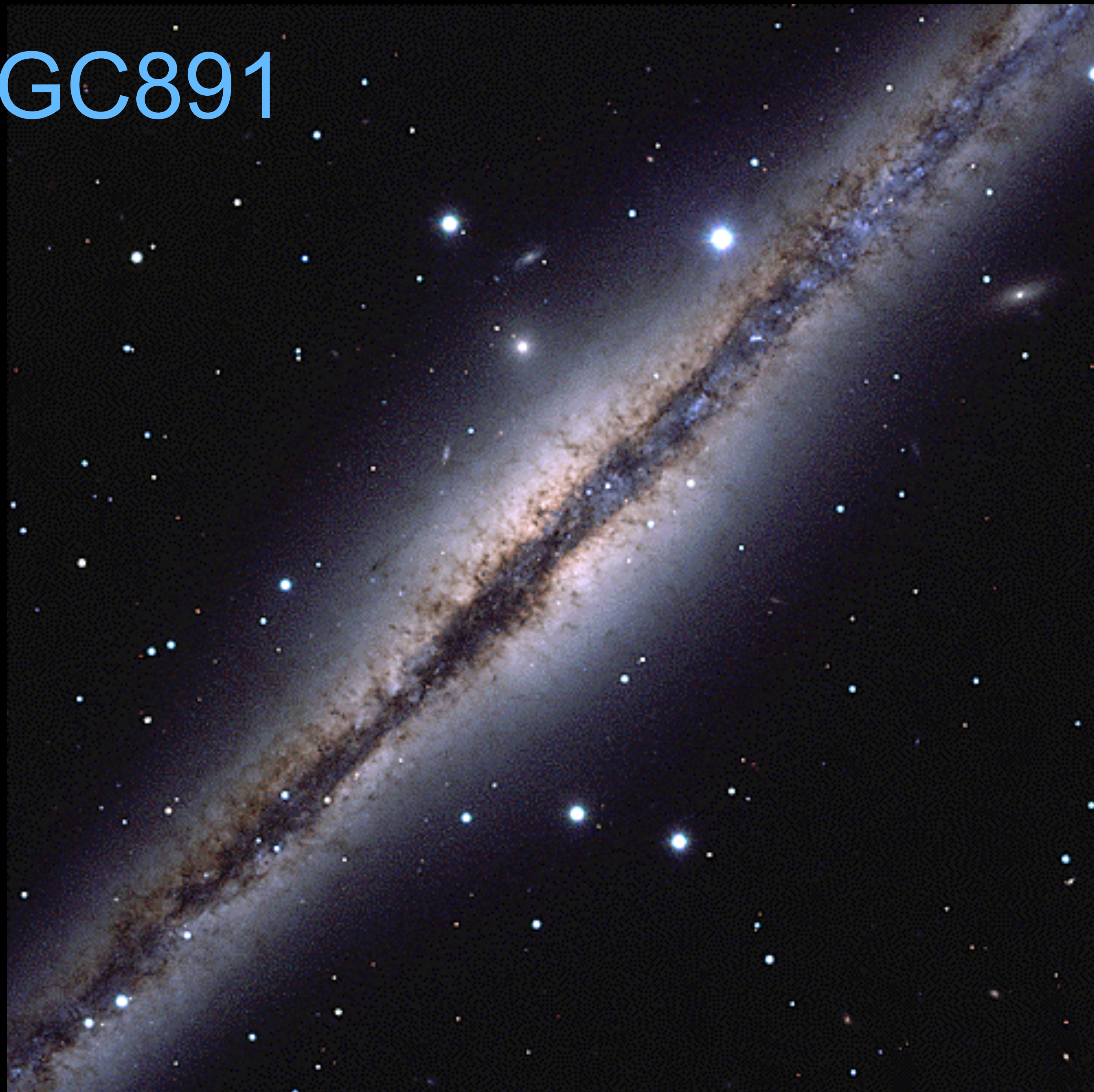
Bulges severely attenuated in inclined systems up to 2 mag ex. face-on correction !

Driver et al (2007), MNRAS,(astro-ph/0704.2140)

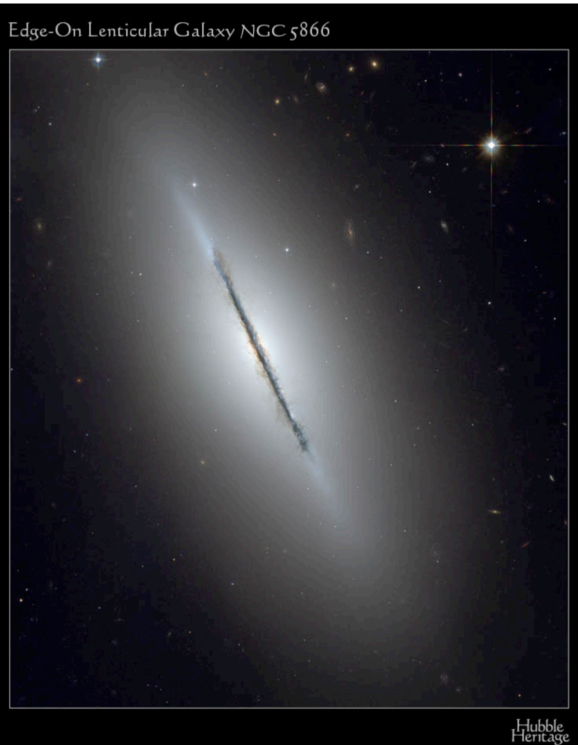


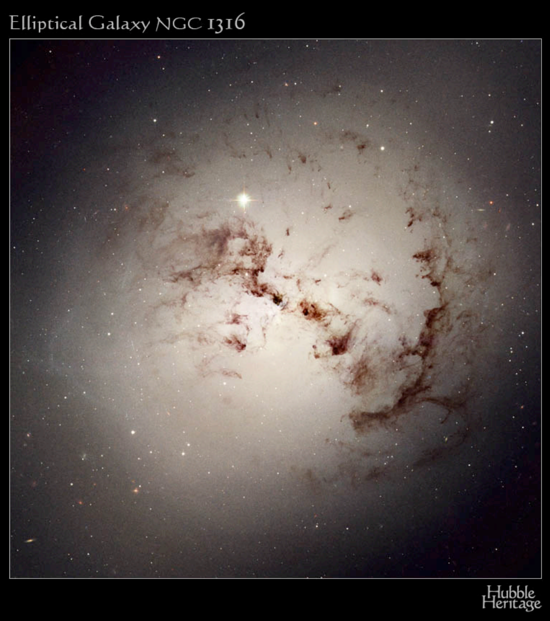
NGC4565

NGC891



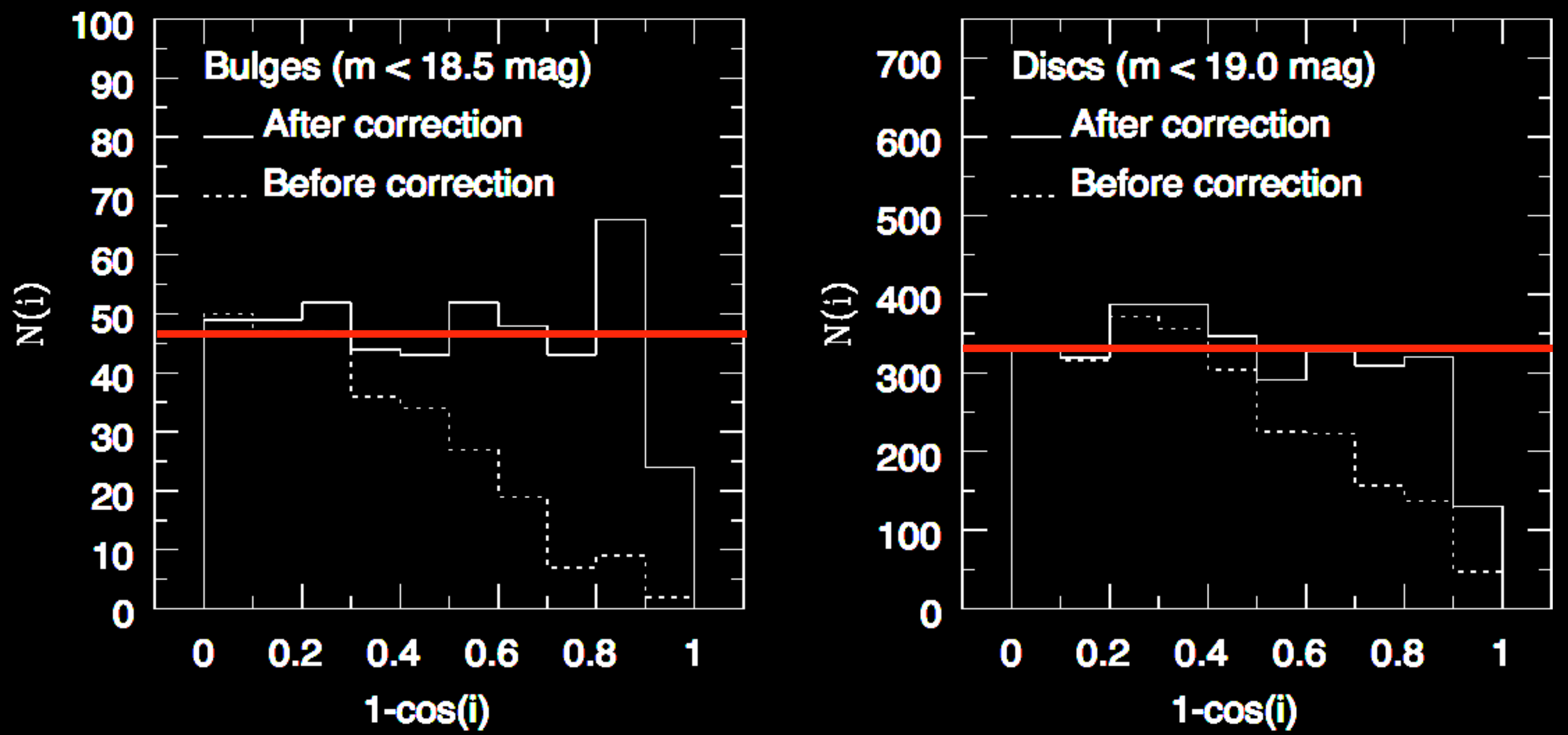
Dust in Lenticulars





Sanity check I: cos(i) distributions

- In the absence of dust the cos(i) density distribution should be flat. Initially they're not.
- After implementing the dust correction they are !

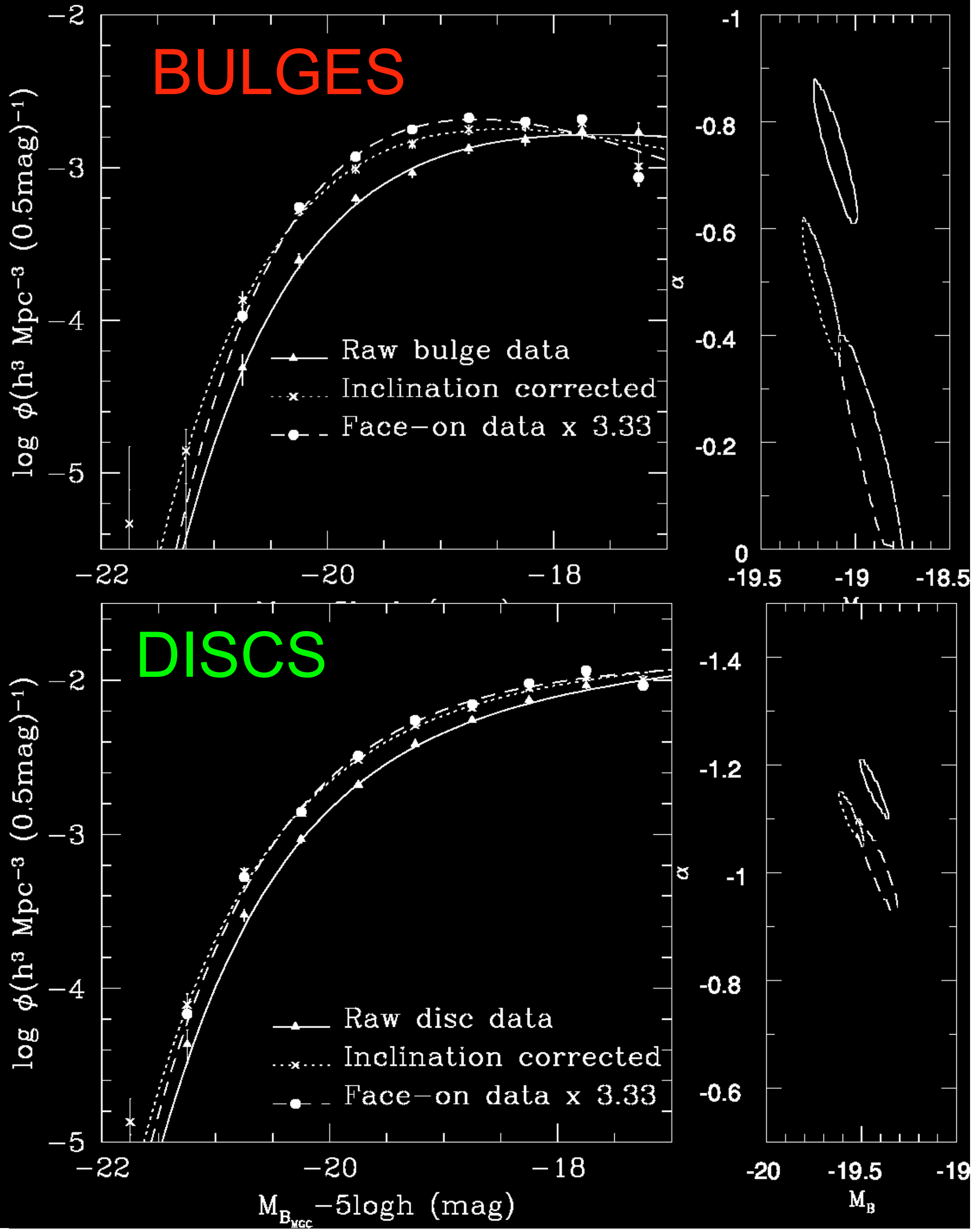


Sanity II: Face-on v corrected LFs

Can construct component LFs using just face-on data and compare to LFs from corrected data.

Results fully consistent

Still need face-on correction



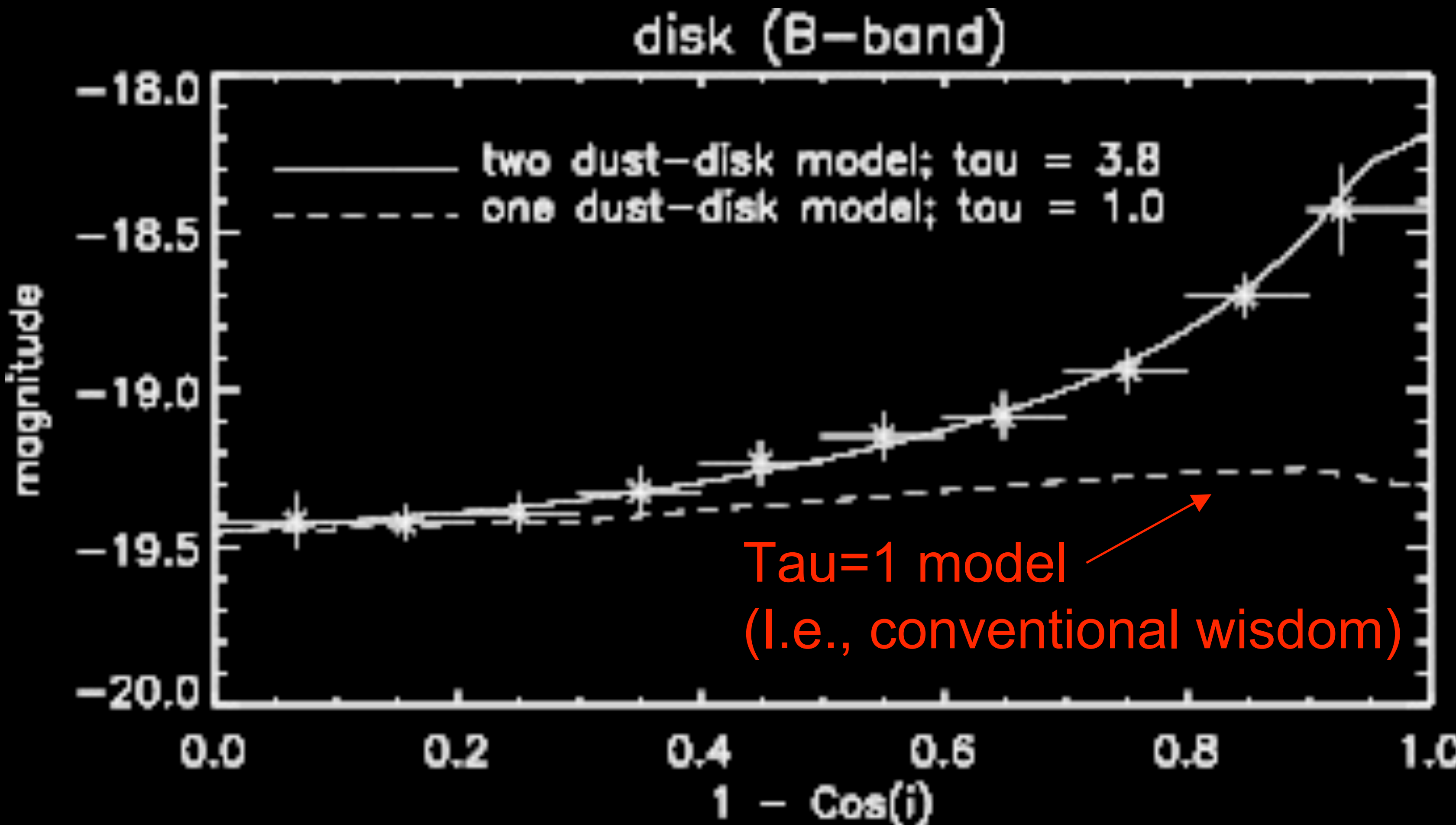
Sanity Check III

Similar results being reported from SDSS (although without bulge disc decomposition or a detailed dust model), e.g.,

- Shao et al (2007), astro-ph/0611714
- Choi et al (2007), astro-ph/0611607
- Unterborm & Ryden (2008), astro-ph/0801.2400
- Maller et al (2008), astro-ph/0801.3286
- Padilla & Strauss (2008), astro-ph/0802.0877

All reporting severe impact of dust !

Popular tau=1 dust models fail



Tuffs & Popescu Model

Old stellar bulge:

$$\eta(\lambda, R, z) = \eta^{\text{bulge}}(\lambda, 0, 0)\exp(-7.67\,B^{1/4})\,B^{-7/8},$$

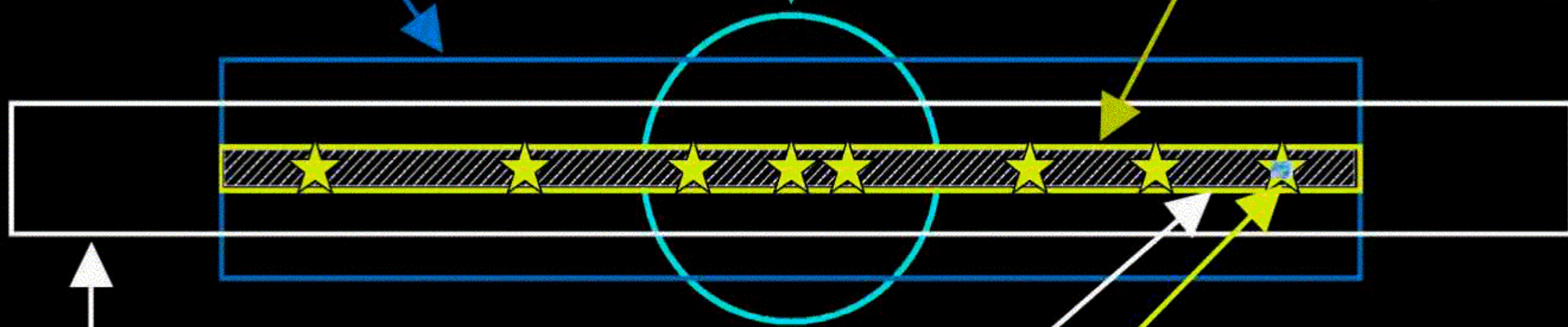
$$B = \frac{\sqrt{R^2 + z^2\,(a/b)^2}}{R_e}$$

Old stellar disk:

$$\eta(\lambda, R, z) = \eta^{\text{disk}}(\lambda, 0, 0)\exp\left(-\frac{R}{h_s^{\text{disk}}} - \frac{|z|}{z_s^{\text{disk}}}\right)$$

Young stellar disk:

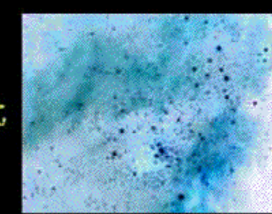
$$\eta^{\text{tdisk}}(\lambda, R, z) = \eta^{\text{tdisk}}(\lambda, 0, 0)\exp\left(-\frac{R}{h_s^{\text{tdisk}}} - \frac{|z|}{z_s^{\text{tdisk}}}\right)$$



Dust disk associated with the old stellar disk:

$$\kappa_{\text{ext}}^{\text{disk}}(\lambda, R, z) = \kappa_{ext}^{\text{disk}}(\lambda, 0, 0)\exp\left(-\frac{R}{h_d^{\text{disk}}} - \frac{|z|}{z_d^{\text{disk}}}\right)$$

Clumpy component

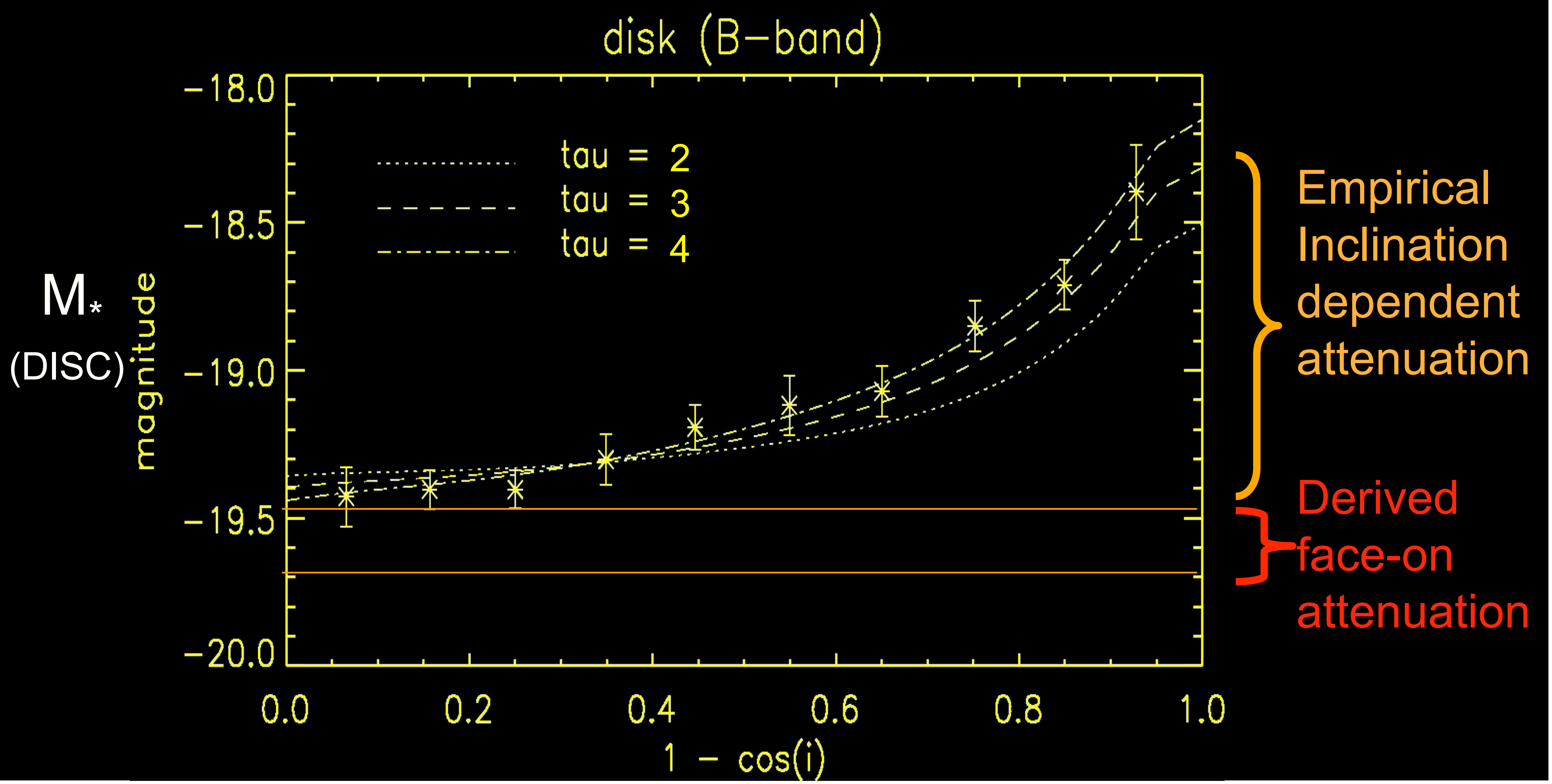


Dust disk associated with the young stellar disk:

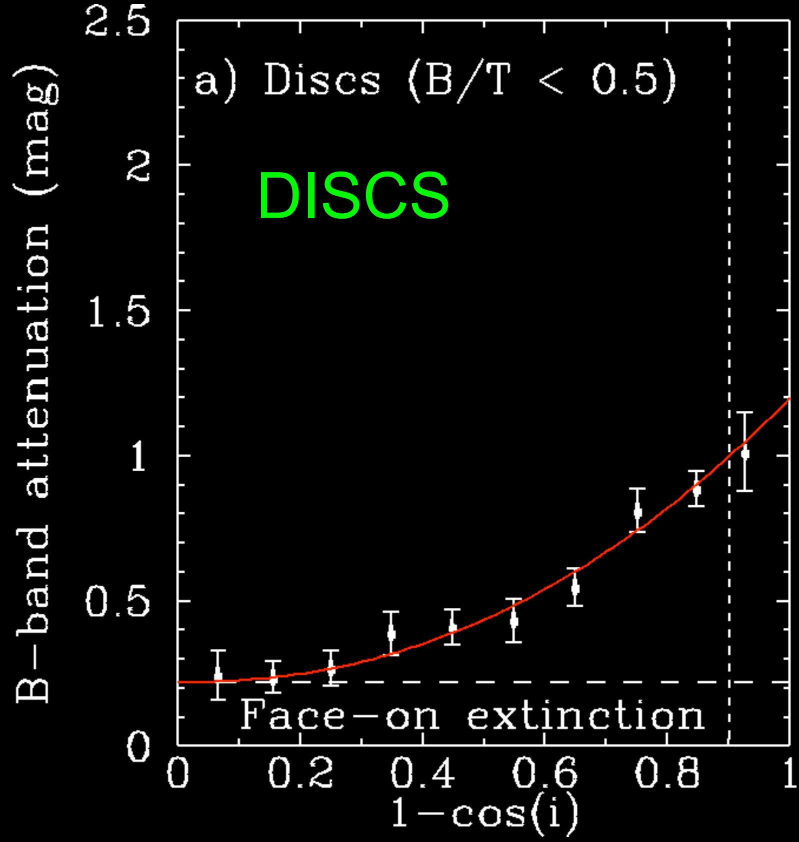
$$\kappa_{ext}^{\text{tdisk}}(\lambda, R, z) = \kappa_{ext}^{\text{tdisk}}(\lambda, 0, 0)\exp\left(-\frac{R}{h_d^{\text{tdisk}}} - \frac{|z|}{z_d^{\text{tdisk}}}\right)$$

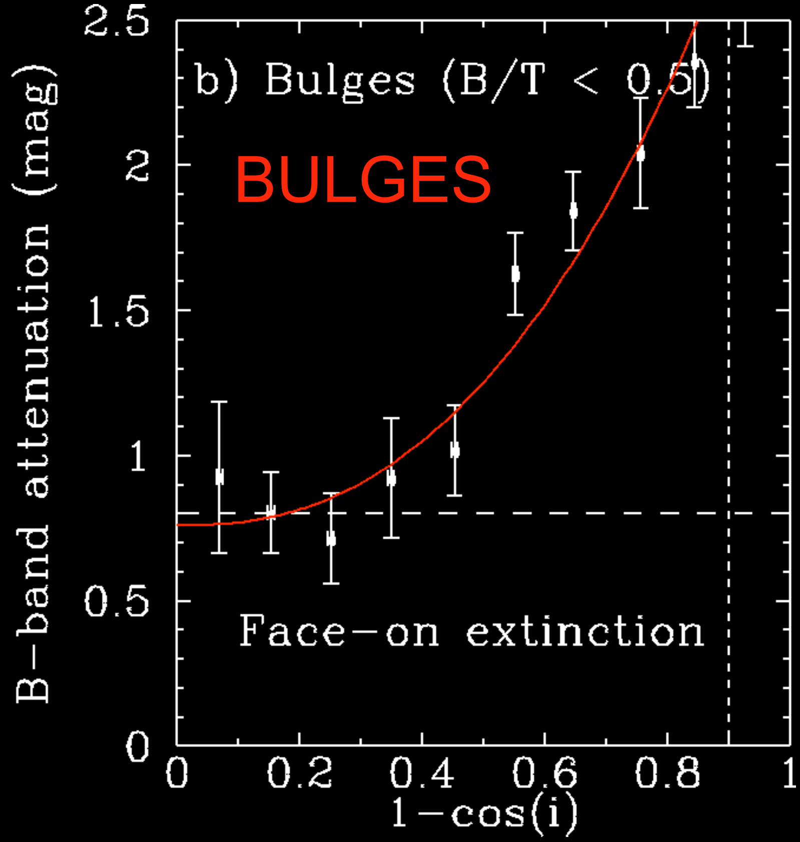
Face-on corr. via dust modeling

- We adopt the Tuffs and Popescu dust model and derive: **τ_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 = face-on central B band disc opacity



Dust Attenuation

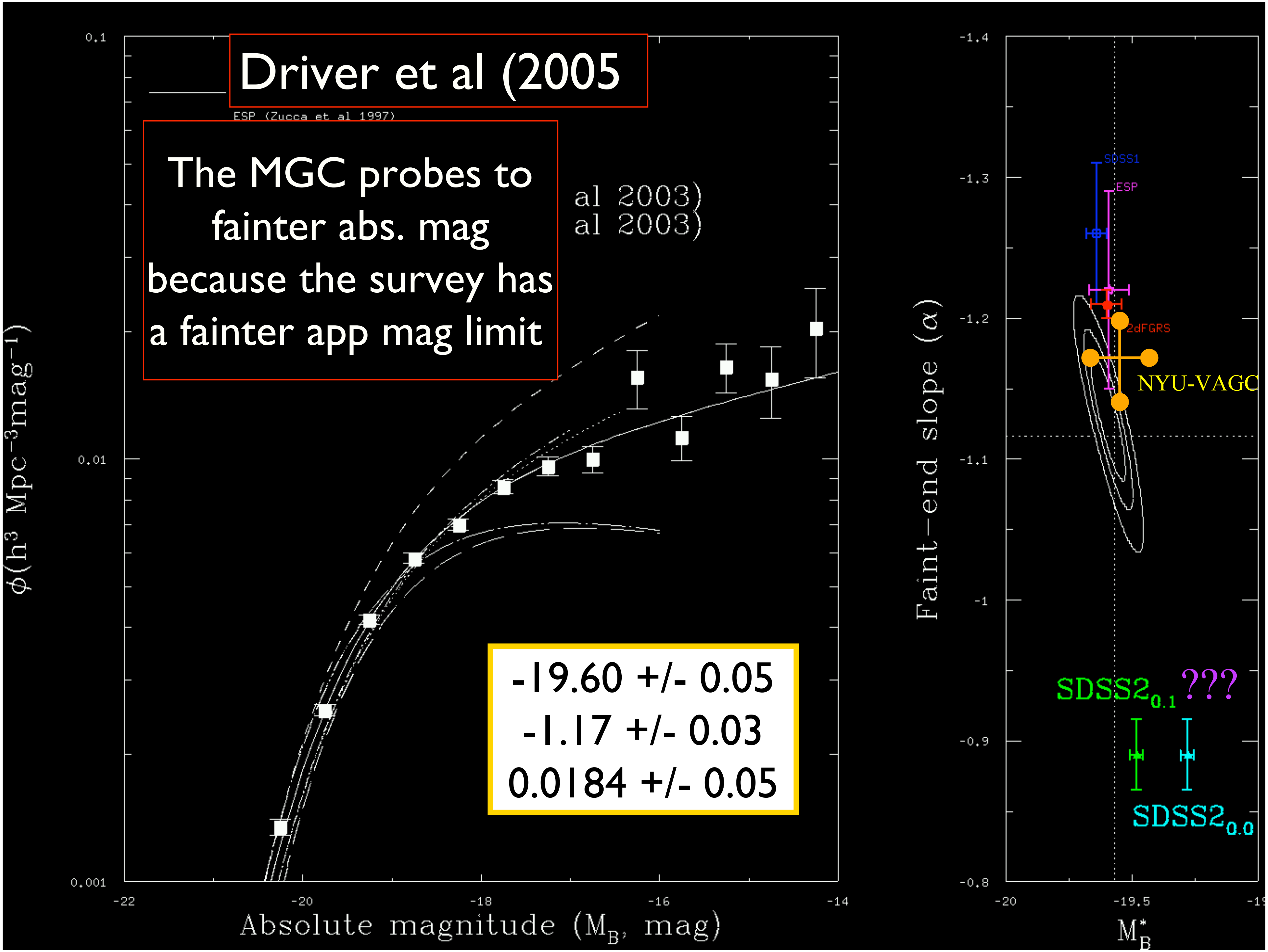




Models imply that discs are optically thick in the centre, Hence ~*half* of bulge flux is attenuated in face-on systems =0.75 mag, (as dust has thickness our value is 0.84).

Implications of the MGC dust results

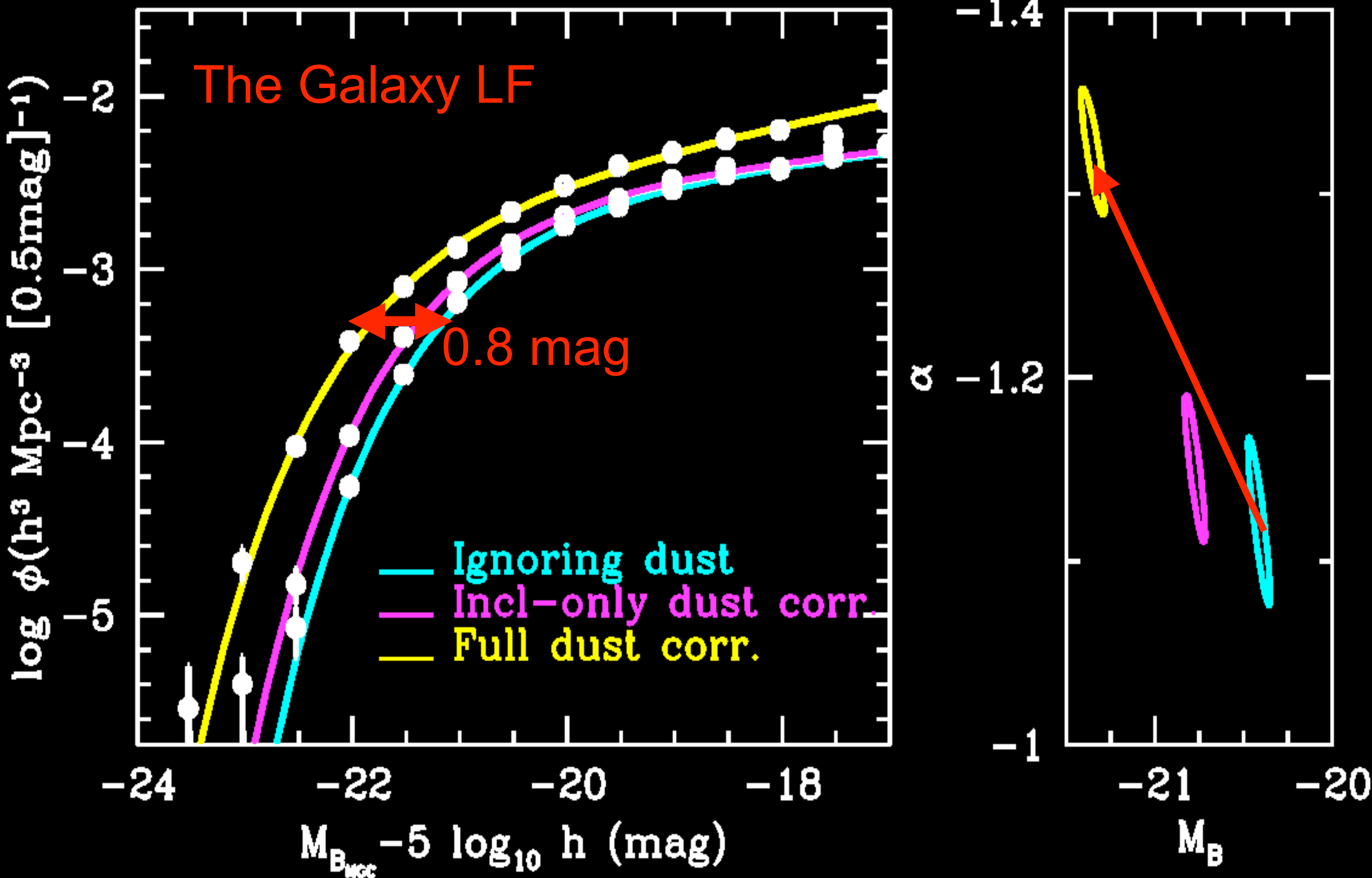
1. The galaxy luminosity function
2. The cosmic energy density estimates
3. Stellar mass function estimates
4. Morphological transformation via dust removal
5. All faint galaxy photometry and size measurements require revision!

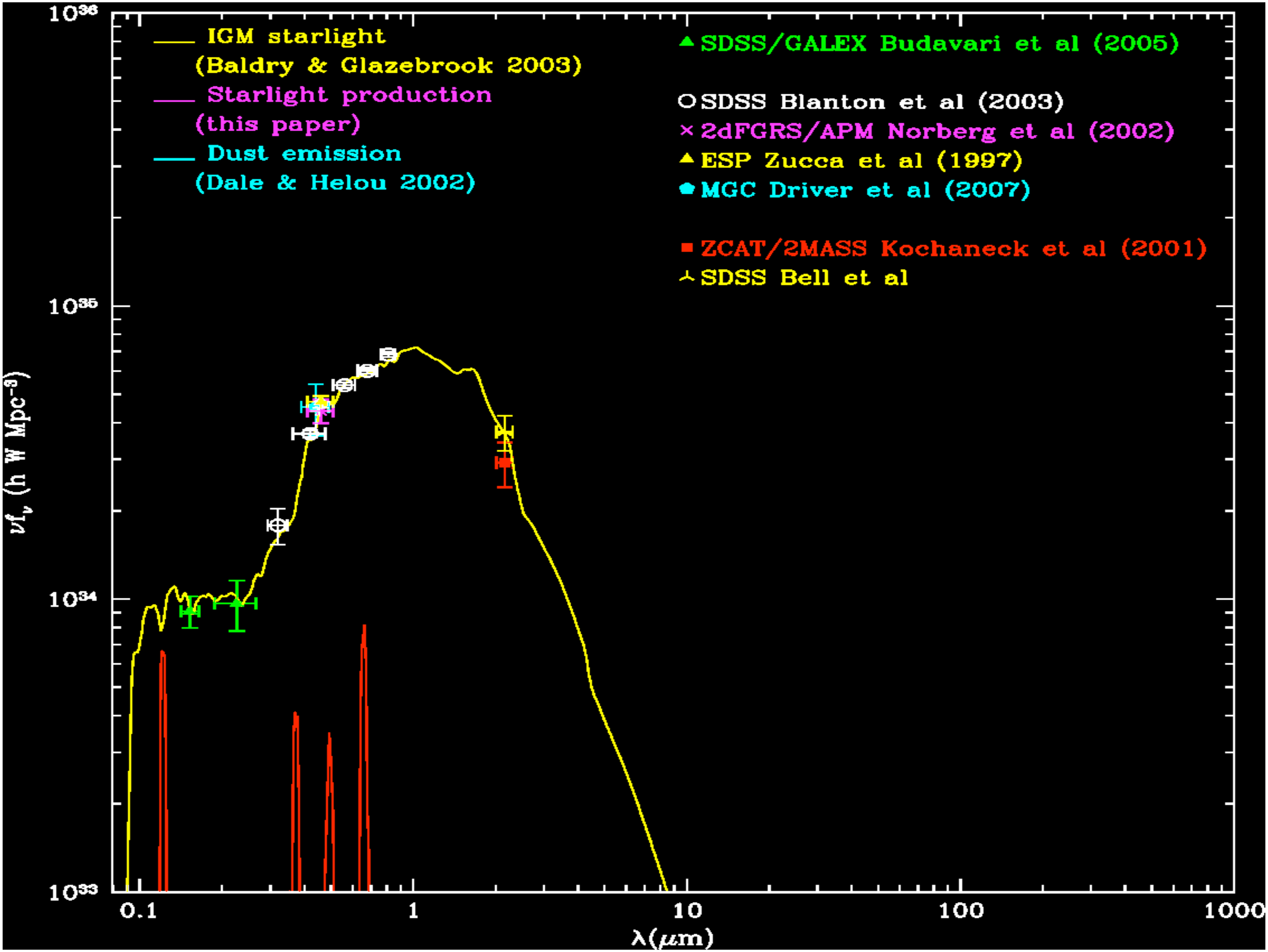


Driver et al (2005
ESP (Zucca et al 1997)
The MGC probes to fainter abs. mag because the survey has a fainter app mag limit
al 2003)
al 2003)
-19.60 +/- 0.05
-1.17 +/- 0.03
0.0184 +/- 0.05
0.1
0.01
0.001
-22
-20
-18
-16
-14
$\phi(h^3\ Mpc^{-3} mag^{-1})$
Absolute magnitude (M_B, mag)
SDSS1
ESP
2dFGRS
NYU-VAGC
$SDSS2_{0.1}$???
$SDSS2_{0.0}$
-1.4
-1.3
-1.2
-1.1
-1
-0.9
-0.8
-20
-19.5
Faint-end slope (α)
M^*_B

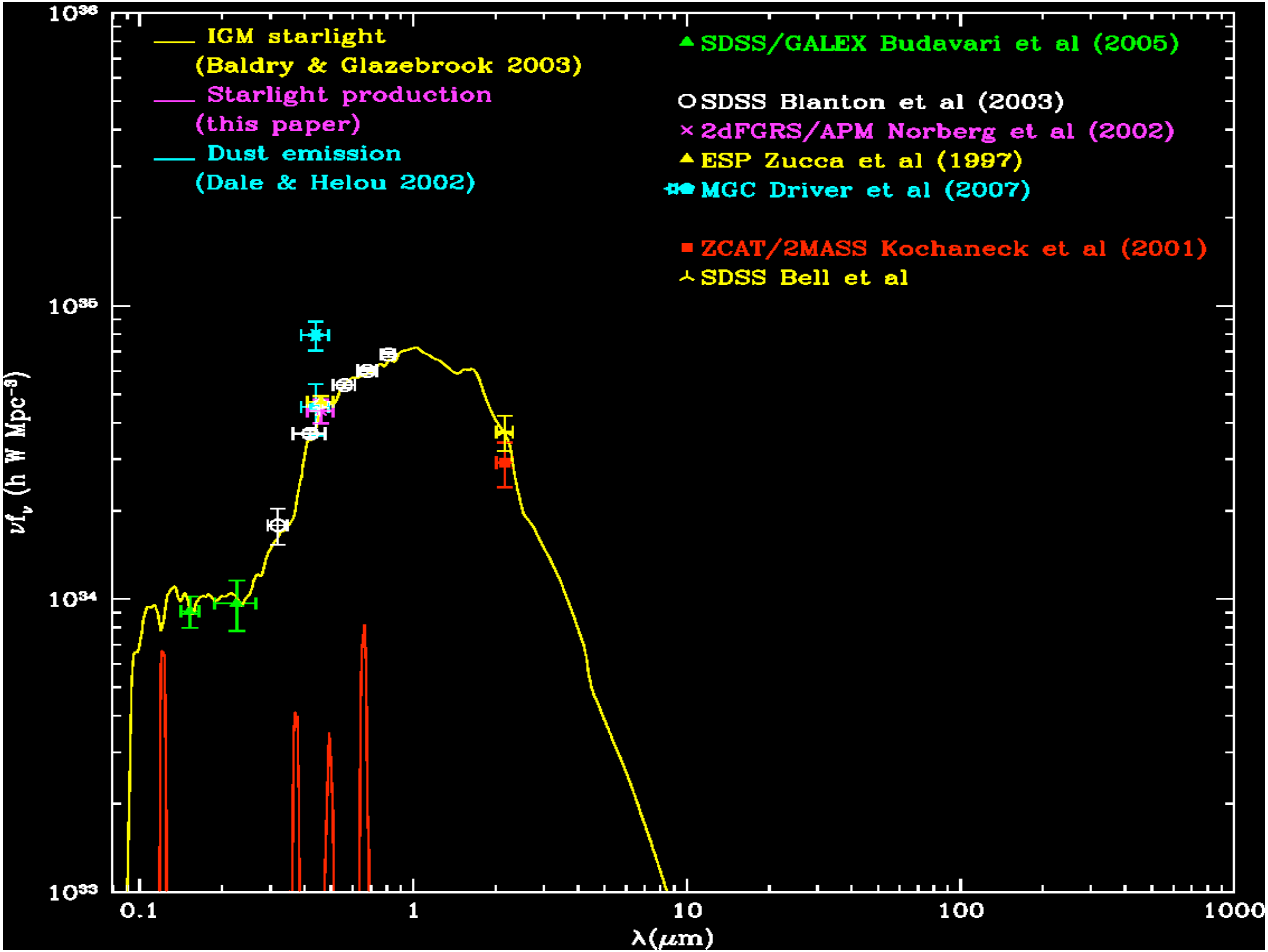
Impact on global B band LF

i.e., only 48% of B-band photons escape into the IGM





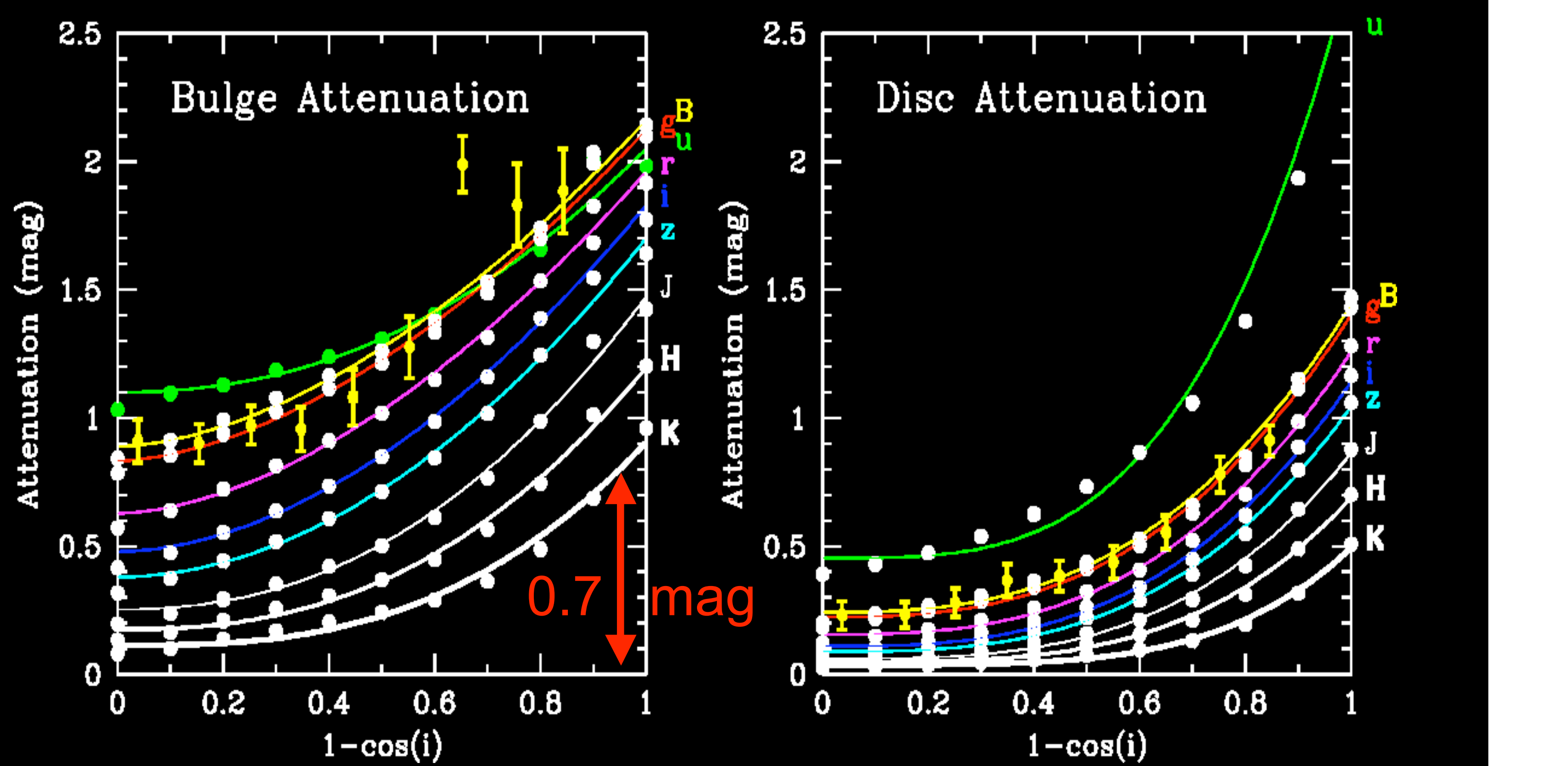
IGM starlight
(Baldry & Glazebrook 2003)
Starlight production
(this paper)
Dust emission
(Dale & Helou 2002)
SDSS/GALEX Budavari et al (2005)
SDSS Blanton et al (2003)
2dFGRS/APM Norberg et al (2002)
ESP Zucca et al (1997)
MGC Driver et al (2007)
ZCAT/2MASS Kochaneck et al (2001)
SDSS Bell et al
10^{36}
10^{35}
10^{34}
10^{33}
νf_ν (h W Mpc^{-3})
0.1
1
10
100
1000
$\lambda(\mu m)$



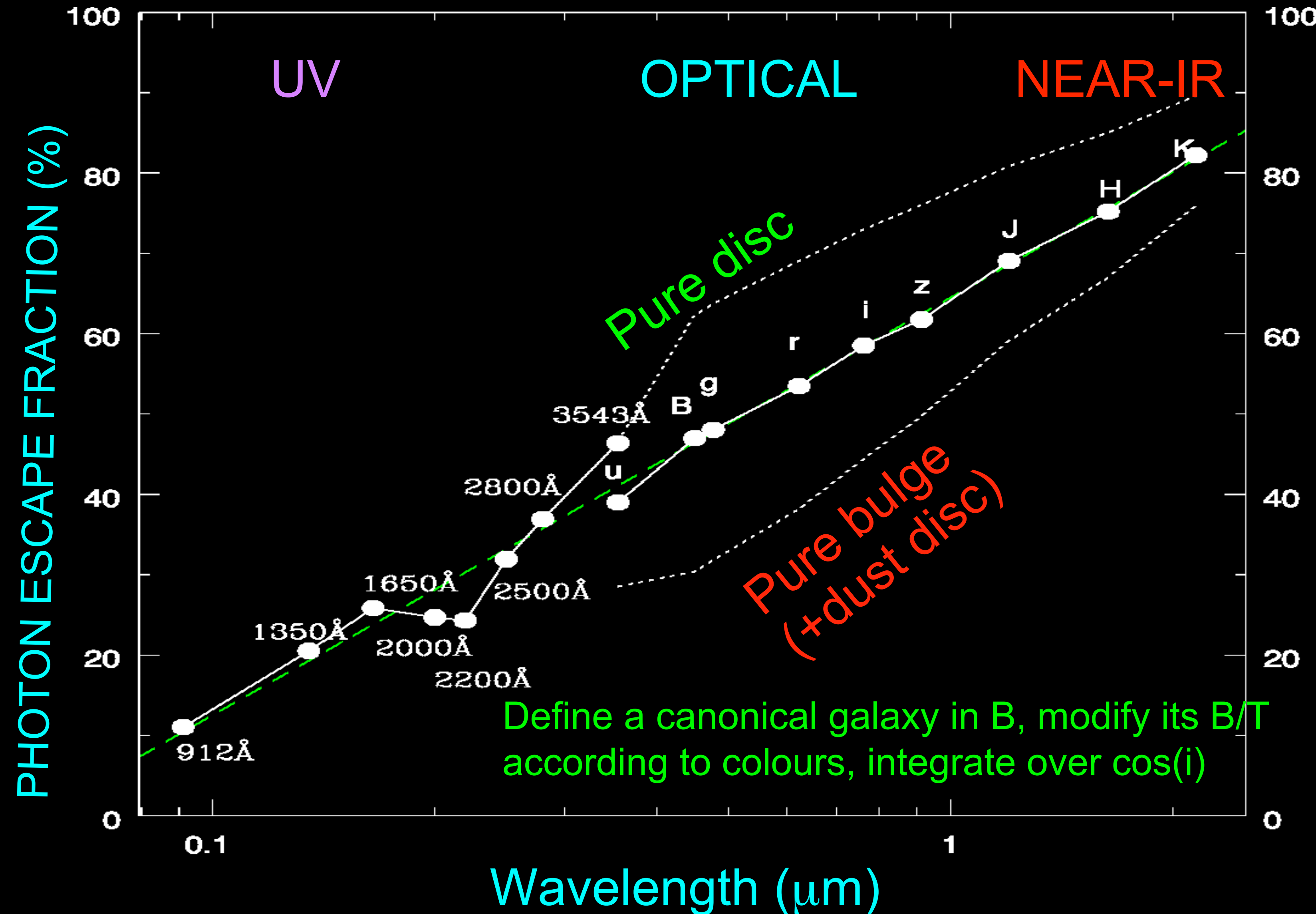
IGM starlight
(Baldry & Glazebrook 2003)
Starlight production
(this paper)
Dust emission
(Dale & Helou 2002)
SDSS/GALEX Budavari et al (2005)
SDSS Blanton et al (2003)
2dFGRS/APM Norberg et al (2002)
ESP Zucca et al (1997)
MGC Driver et al (2007)
ZCAT/2MASS Kochaneck et al (2001)
SDSS Bell et al
10^{36}
10^{35}
10^{34}
10^{33}
νf_ν (h W Mpc^{-3})
0.1
1
10
100
1000
$\lambda(\mu m)$

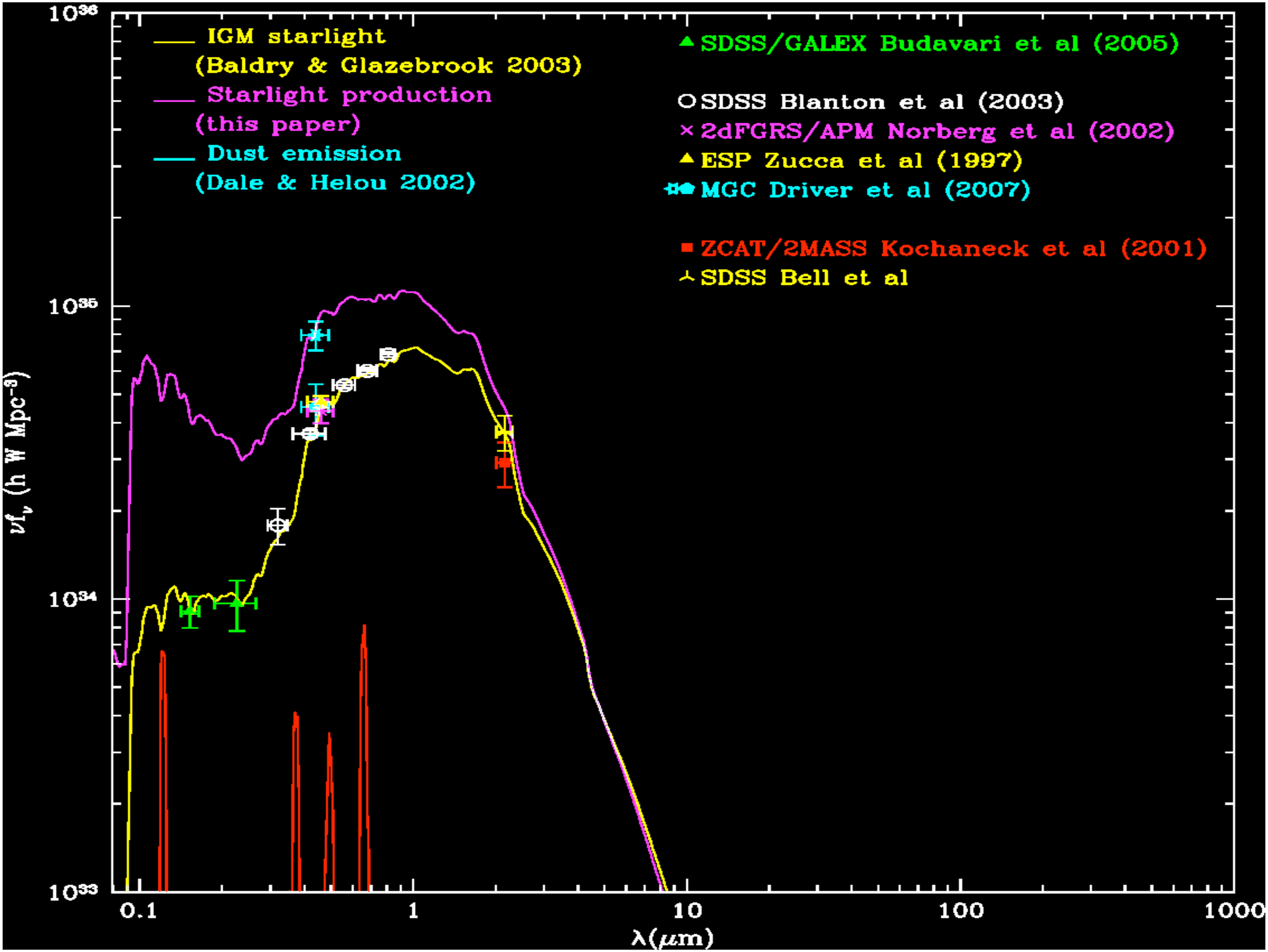
Dust attenuation versus λ

Using calibrated Tuffs & Popescu model can derive inclination-attenuation relation for any wavelength.
Attenuation still an issue in K for highly inclined systems



Photon escape fraction averaged over entire nearby galaxy population





IGM starlight
(Baldry & Glazebrook 2003)
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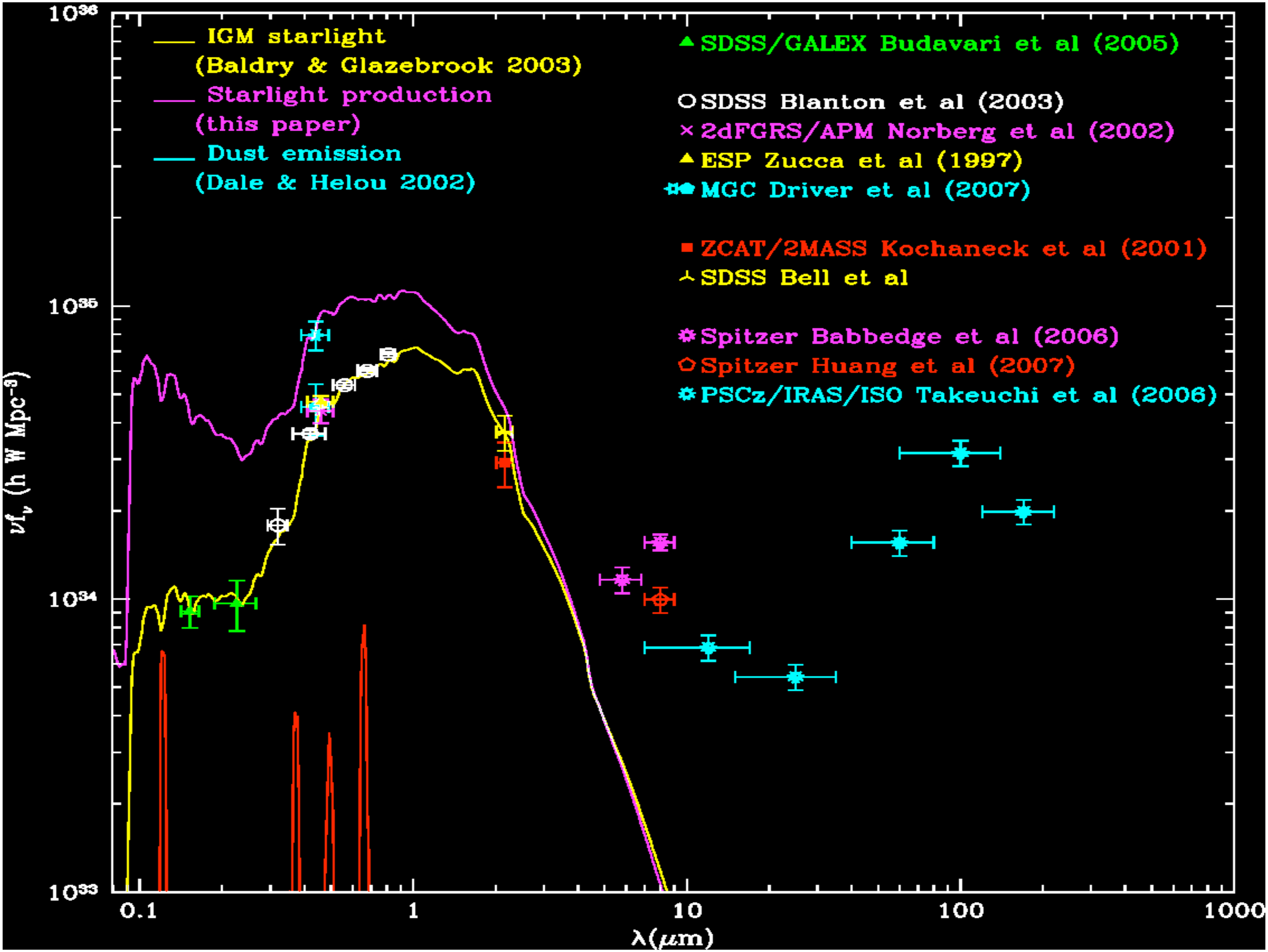
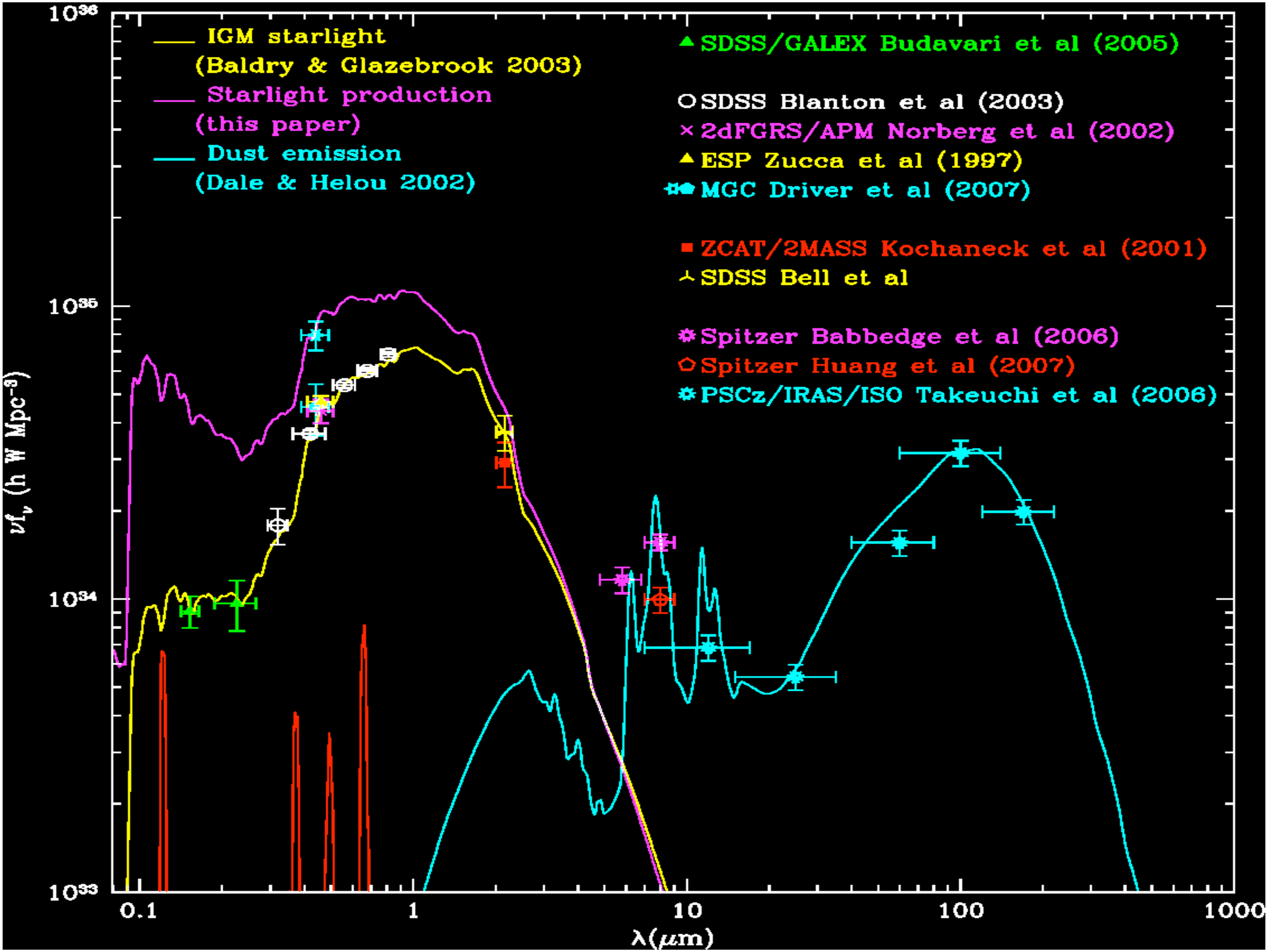
MGC Driver et al (2007)
ZCAT/2MASS Kochaneck et al (2001)
SDSS Bell et al
10^36
10^35
10^34
10^33
νf_ν (h W Mpc^-3)
0.1
1
10
100
1000
λ(μm)



IGM starlight
(Baldry & Glazebrook 2003)
Starlight production
(this paper)
Dust emission
(Dale & Helou 2002)
SDSS/GALEX Budavari et al (2005)
SDSS Blanton et al (2003)
2dFGRS/APM Norberg et al (2002)
ESP Zucca et al (1997)
MGC Driver et al (2007)
ZCAT/2MASS Kochaneck et al (2001)
SDSS Bell et al
Spitzer Babbedge et al (2006)
Spitzer Huang et al (2007)
PSCz/IRAS/ISO Takeuchi et al (2006)
νf_ν (h W Mpc^{-3})
10^{36}
10^{35}
10^{34}
10^{33}
0.1
1
10
100
1000
$\lambda(\mu m)$



IGM starlight
(Baldry & Glazebrook 2003)
Starlight production
(this paper)
Dust emission
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SDSS/GALEX Budavari et al (2005)
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2dFGRS/APM Norberg et al (2002)
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MGC Driver et al (2007)
ZCAT/2MASS Kochaneck et al (2001)
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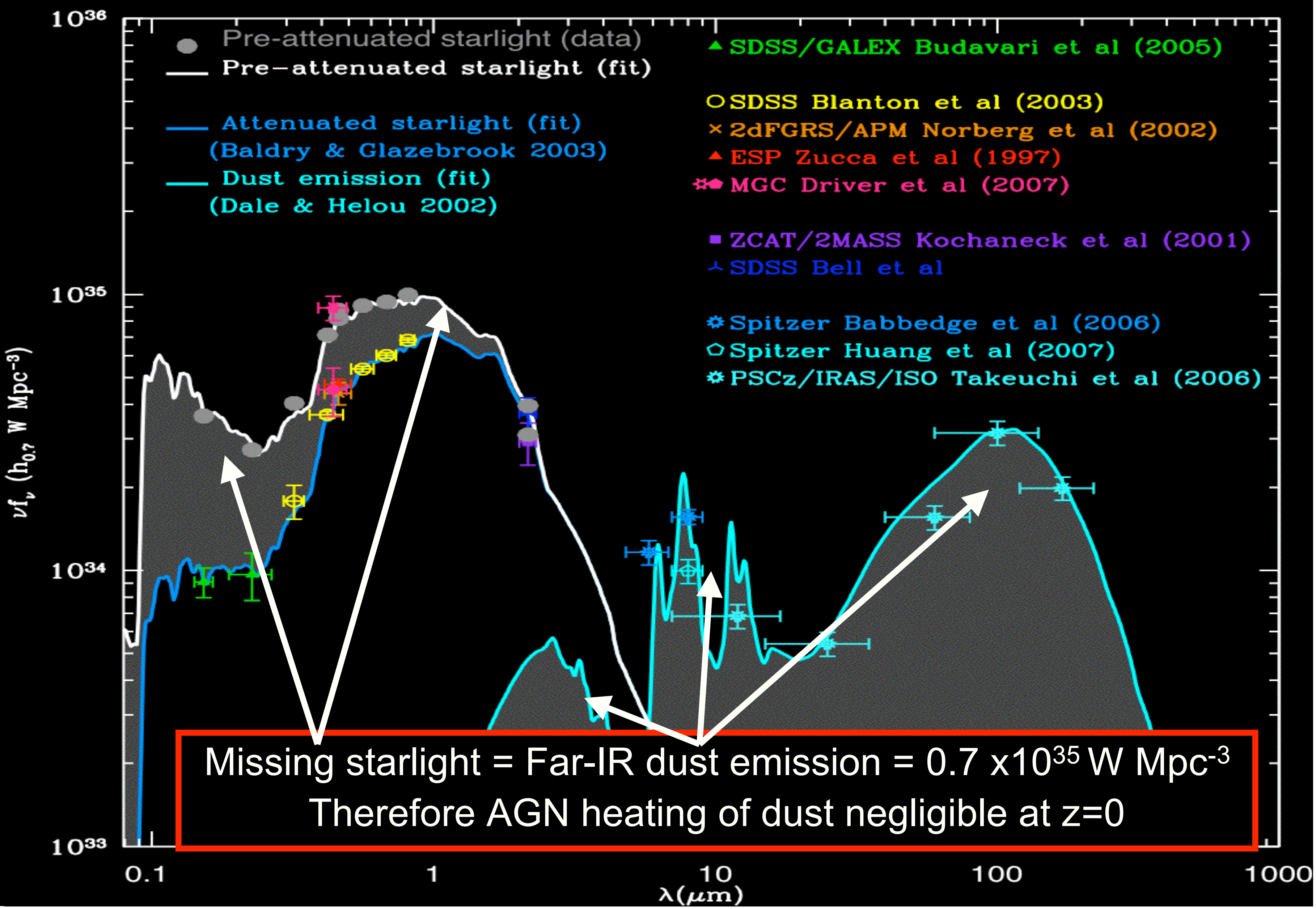
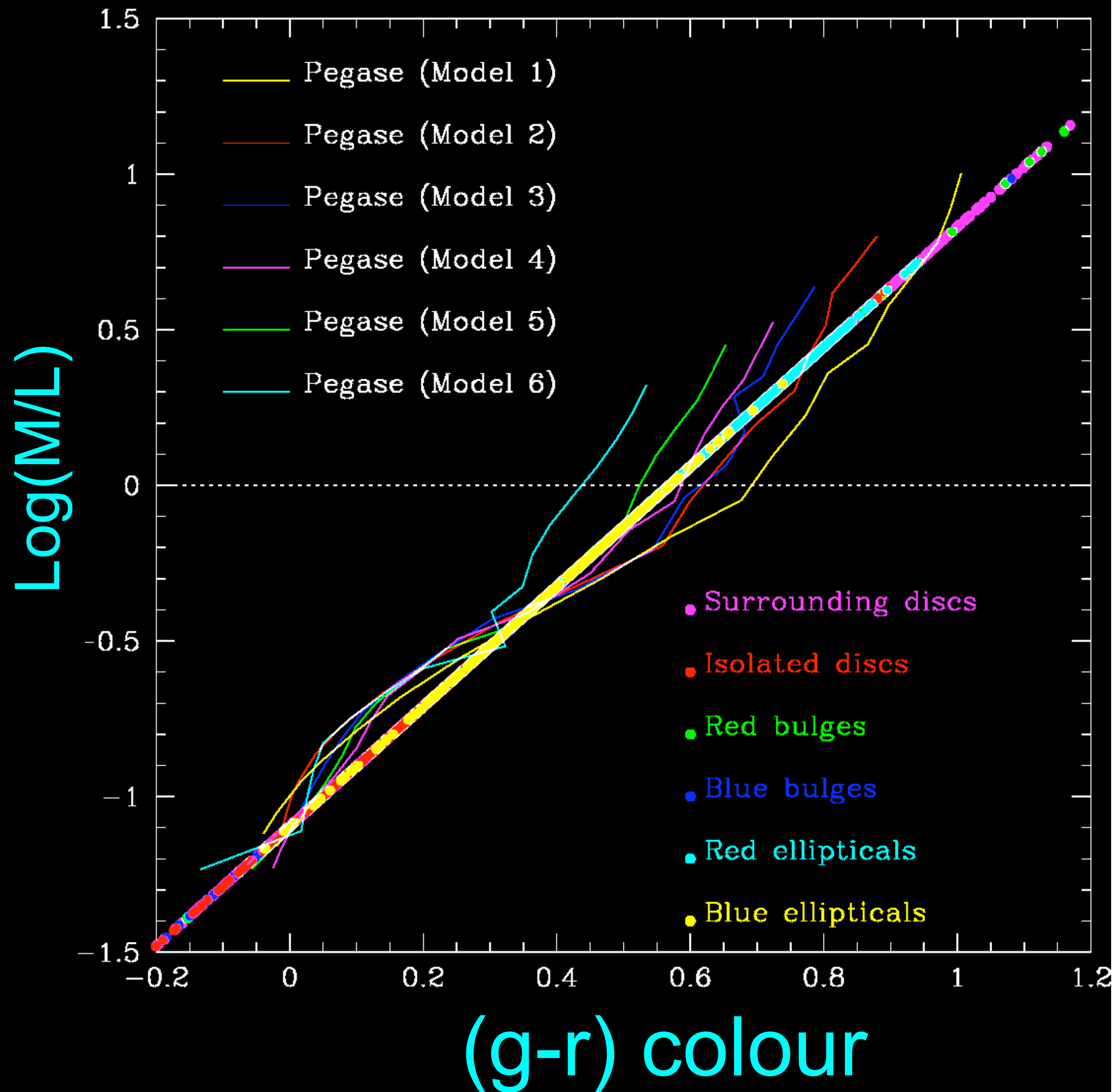
Spitzer Huang et al (2007)
PSCz/IRAS/ISO Takeuchi et al (2006)
10^{36}
10^{35}
10^{34}
10^{33}
νf_ν (h W Mpc^{-3})
0.1
1
10
100
1000
$\lambda(\mu m)$

The Cosmic Energy Budget

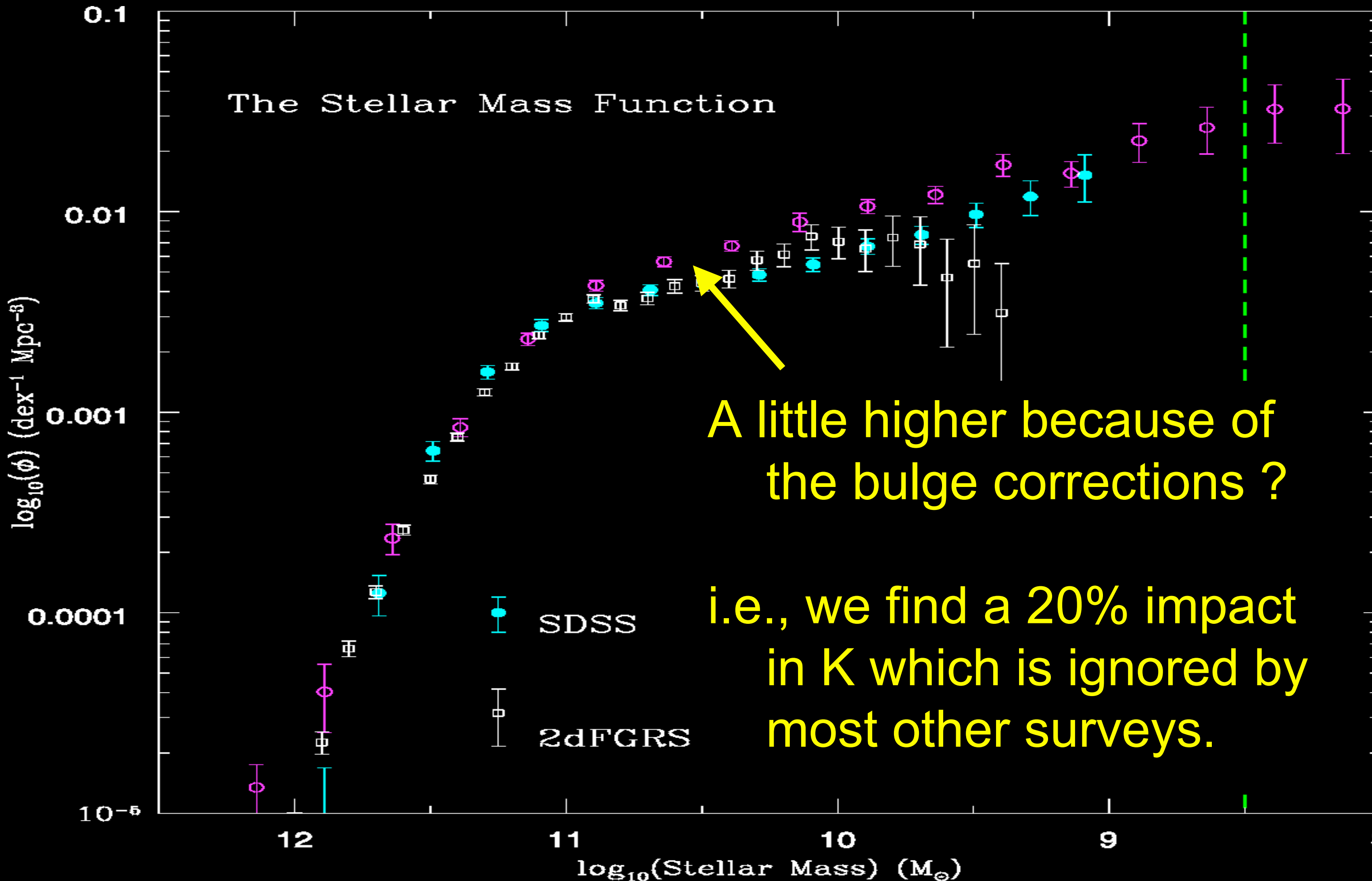


The stellar mass function

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

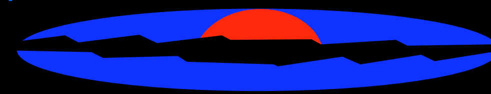


The MGC Stellar Mass Function

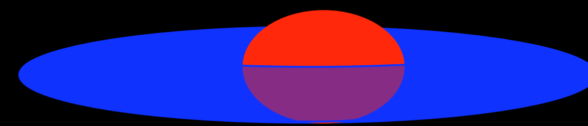


Hubble type transformation ?!

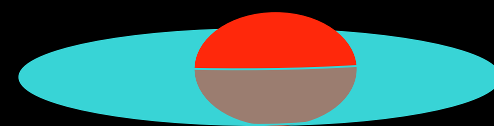
1. Mid-type spiral falling into cluster (cos*i*=0.5):
   B=0.2, D=0.8, B/T=0.2, L=1.0, Blue
   Sc (NB: cos(i)=0.0=Sa, cos(i)=1=Sd)



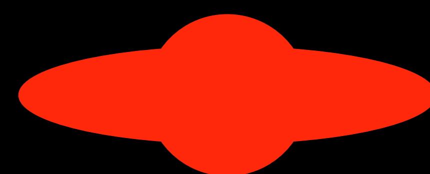
2. *destroy dust* (heating):
   B=0.6, D=1.2, B/T=0.3, L=1.8 Green
   Sab



3. Truncate star-formation in disc (stripping):
   B=0.6, D=0.8, B/T=0.4, L=1.4, Red
   Sa/S0

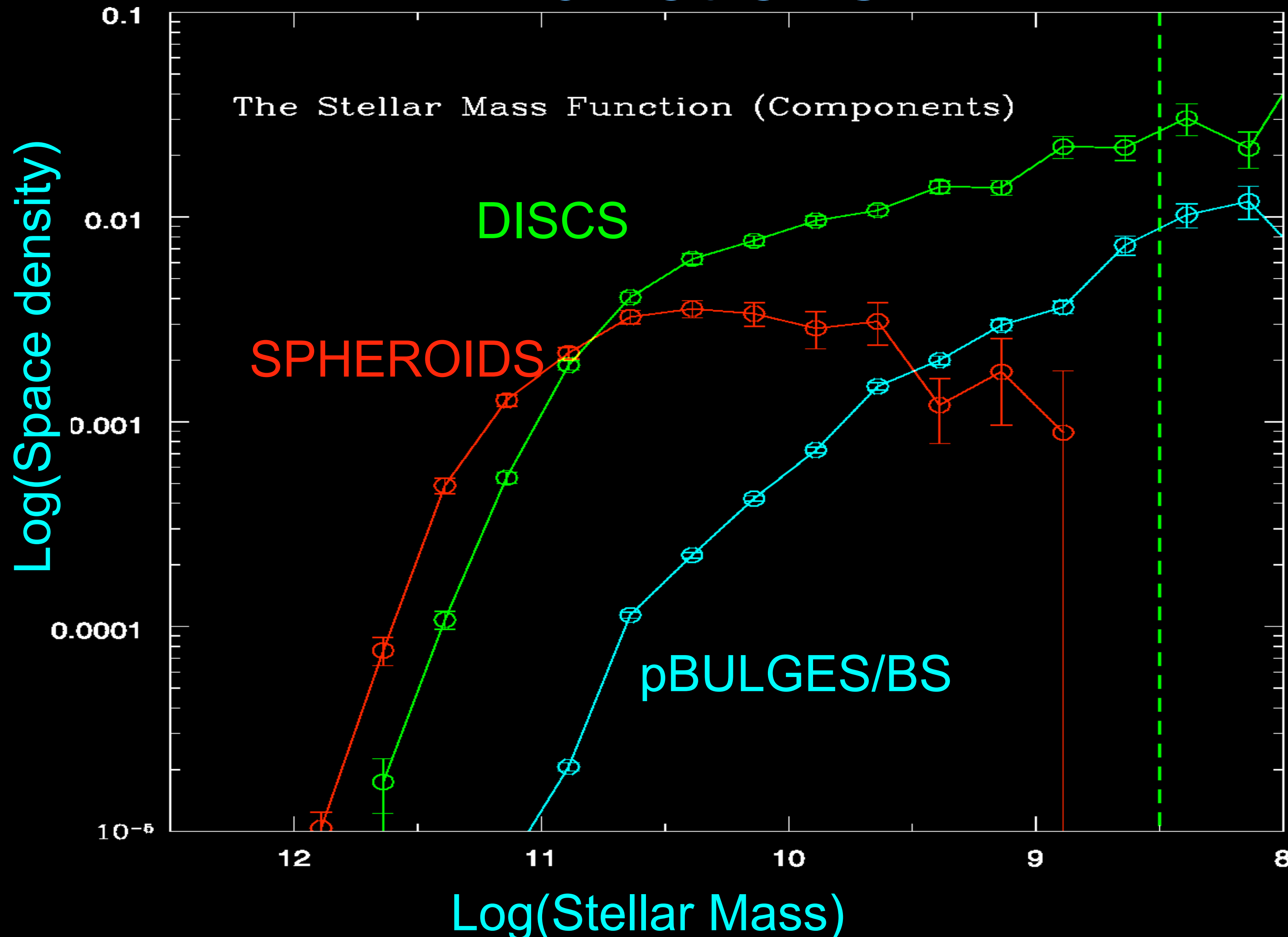


4. Further fading and harassment etc:
   B=0.6, D=0.6, B/T=0.5, L=1.2, Red
   S0a



5. Transformation from Sc-S0 purely by removing dust and switching off SF! it gets ***redder*** and ***brighter*** without dry mergers!

Component Stellar Mass Functions

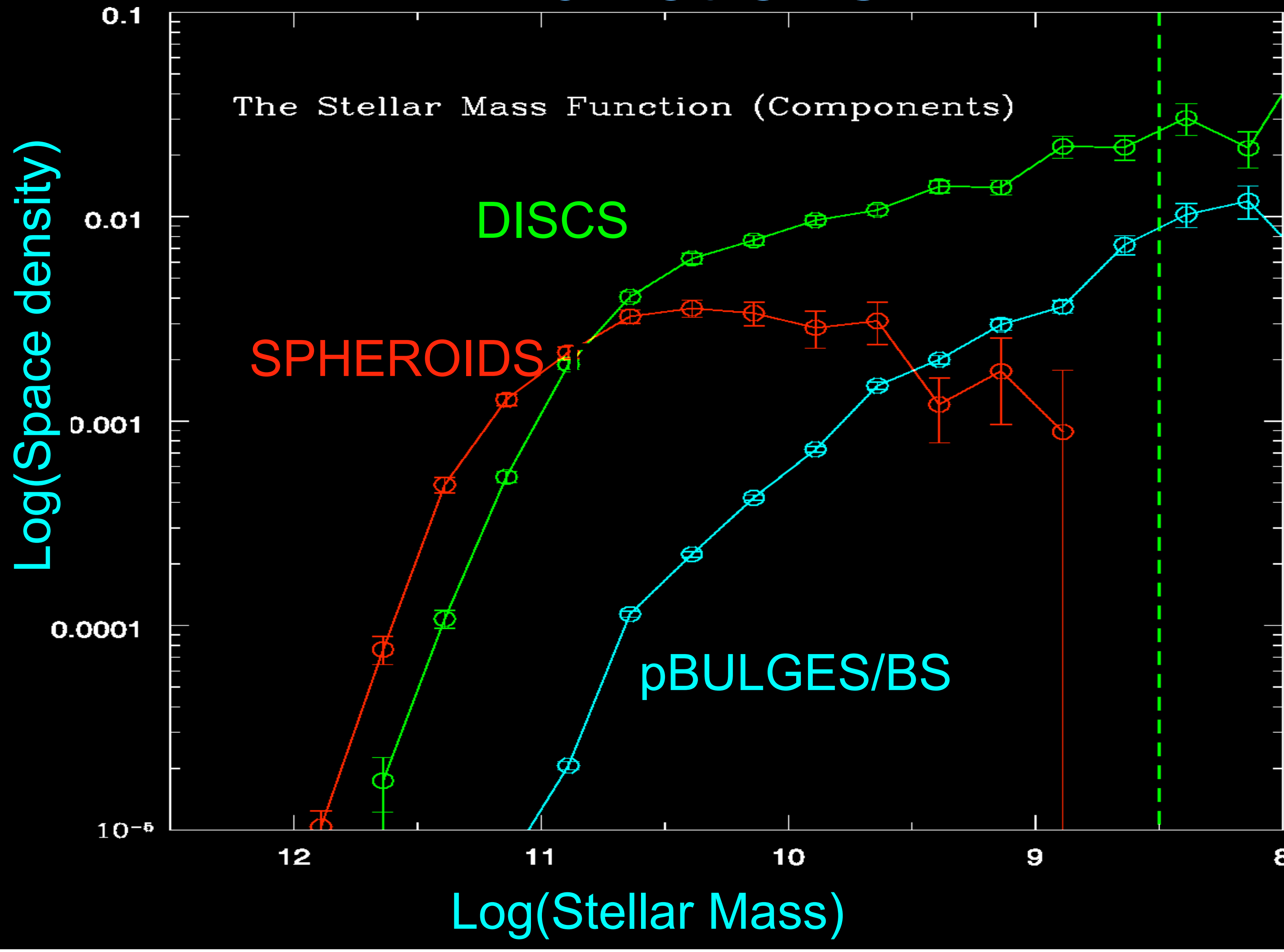


Spheroid formation

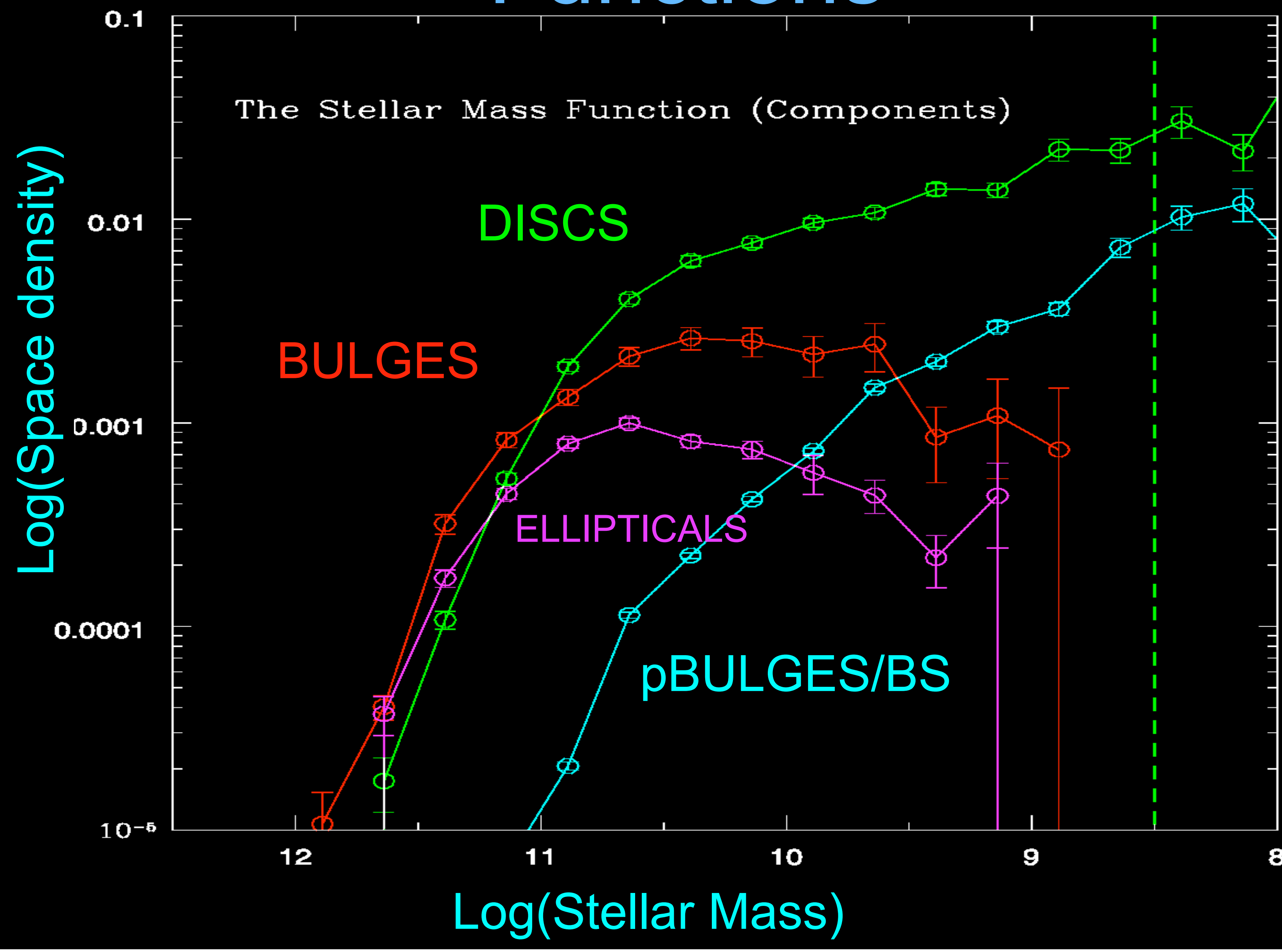
- Old population = early formation of stars
- [α/Fe]-enhanced = rapid formation (AGN feedback)
- SMBH-Bulge relation = formation coeval with peak of AGN activity, $z>2.5$
- No mini bulge-disc systems = mass regulation or downsizing with time

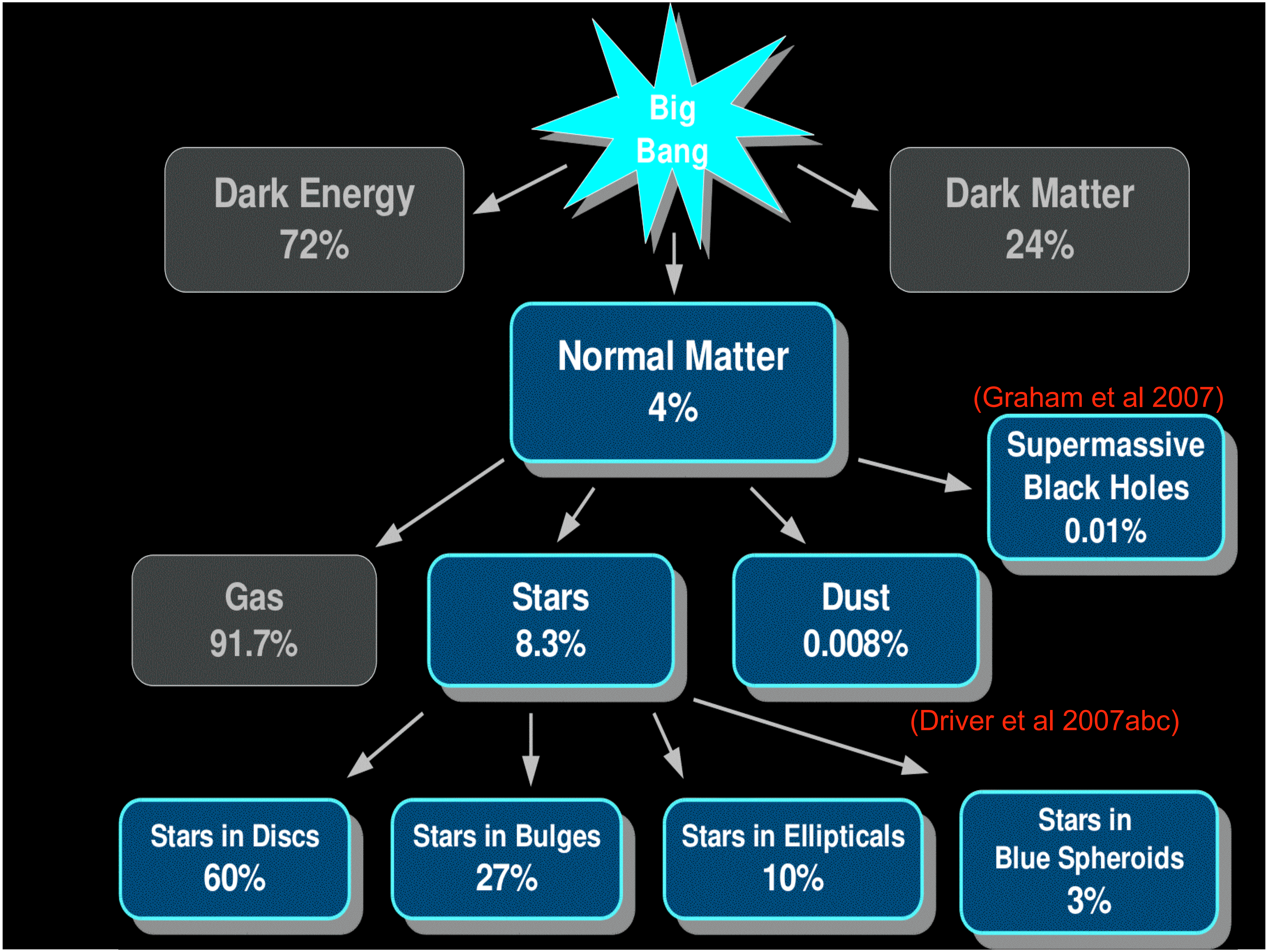
- Rapid merging or monolithic collapse ?
  - Merging: Elliptical SMF more massive than Bulge SMF
  - Collapse: Elliptical SMF = Bulge MF

Component Stellar Mass Functions

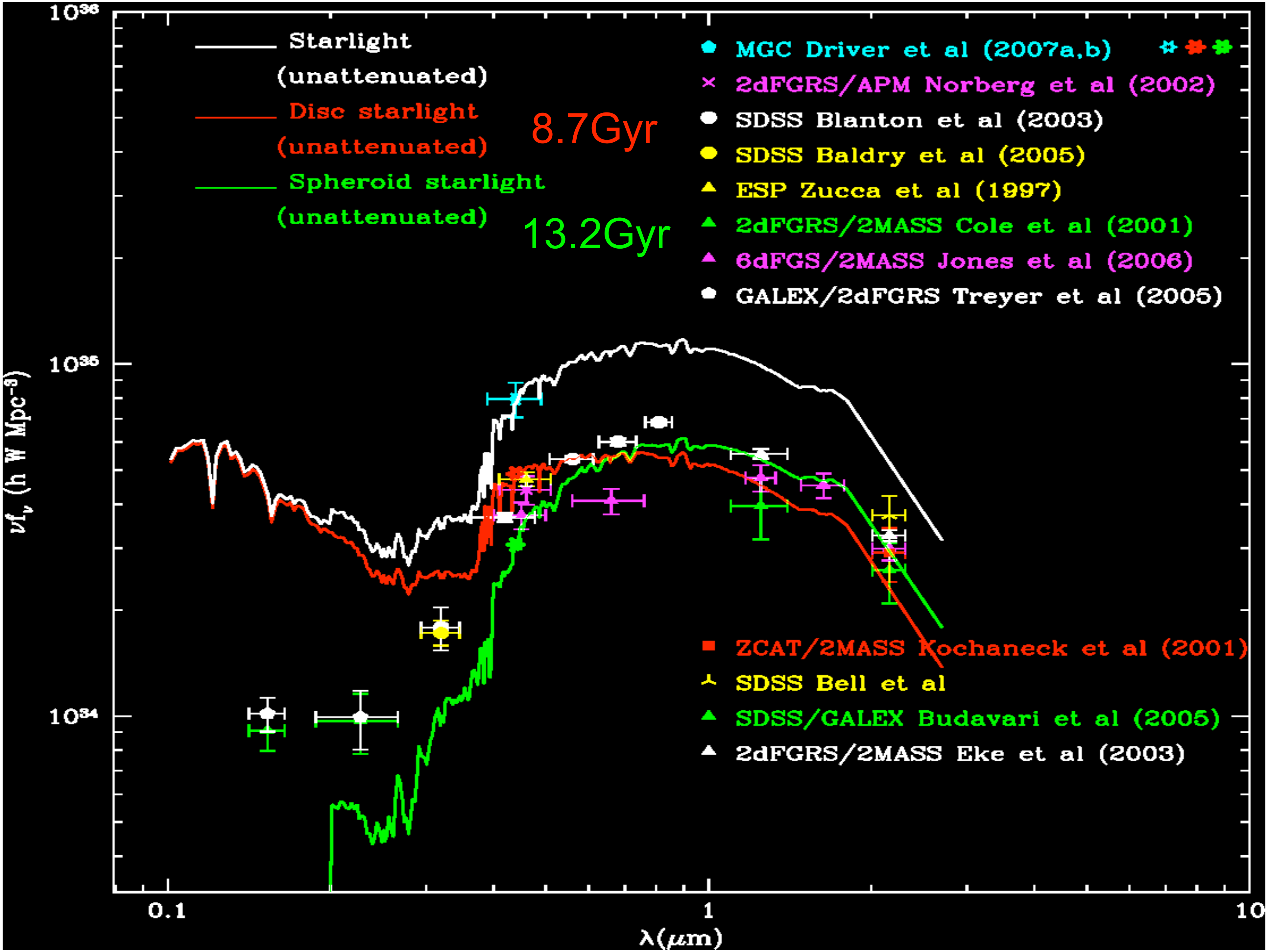


Component Stellar Mass Functions

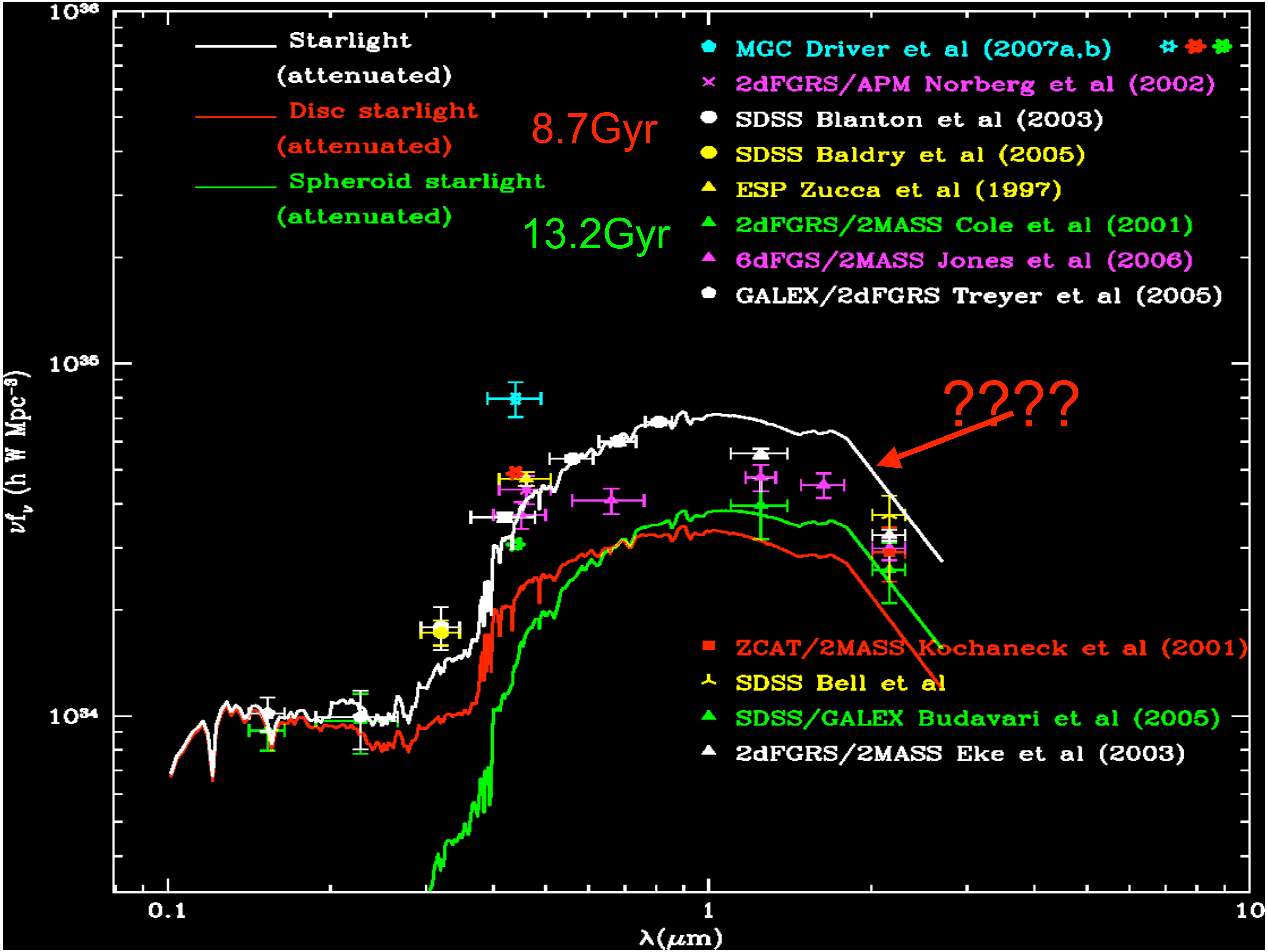




Big Bang
Dark Energy 72%
Dark Matter 24%
Normal Matter 4%
(Graham et al 2007)
Supermassive Black Holes 0.01%
Gas 91.7%
Stars 8.3%
Dust 0.008%
(Driver et al 2007abc)
Stars in Discs 60%
Stars in Bulges 27%
Stars in Ellipticals 10%
Stars in Blue Spheroids 3%



Starlight (unattenuated)
Disc starlight (unattenuated)
Spheroid starlight (unattenuated)
8.7Gyr
13.2Gyr
MGC Driver et al (2007a,b)
2dFGRS/APM Norberg et al (2002)
SDSS Blanton et al (2003)
SDSS Baldry et al (2005)
ESP Zucca et al (1997)
2dFGRS/2MASS Cole et al (2001)
6dFGS/2MASS Jones et al (2006)
GALEX/2dFGRS Treyer et al (2005)
ZCAT/2MASS Kochaneck et al (2001)
SDSS Bell et al
SDSS/GALEX Budavari et al (2005)
2dFGRS/2MASS Eke et al (2003)
10^{36}
10^{35}
10^{34}
νf_ν (h W Mpc^{-3})
0.1
1
10
$\lambda(\mu m)$



Starlight (attenuated)
Disc starlight (attenuated)
Spheroid starlight (attenuated)
8.7Gyr
13.2Gyr
MGC Driver et al (2007a,b)
2dFGRS/APM Norberg et al (2002)
SDSS Blanton et al (2003)
SDSS Baldry et al (2005)
ESP Zucca et al (1997)
2dFGRS/2MASS Cole et al (2001)
6dFGS/2MASS Jones et al (2006)
GALEX/2dFGRS Treyer et al (2005)
????
ZCAT/2MASS Kochaneck et al (2001)
SDSS Bell et al
SDSS/GALEX Budavari et al (2005)
2dFGRS/2MASS Eke et al (2003)
νf_ν (h W Mpc^{-3})
10^{36}
10^{35}
10^{34}
0.1
1
10
$\lambda(\mu m)$

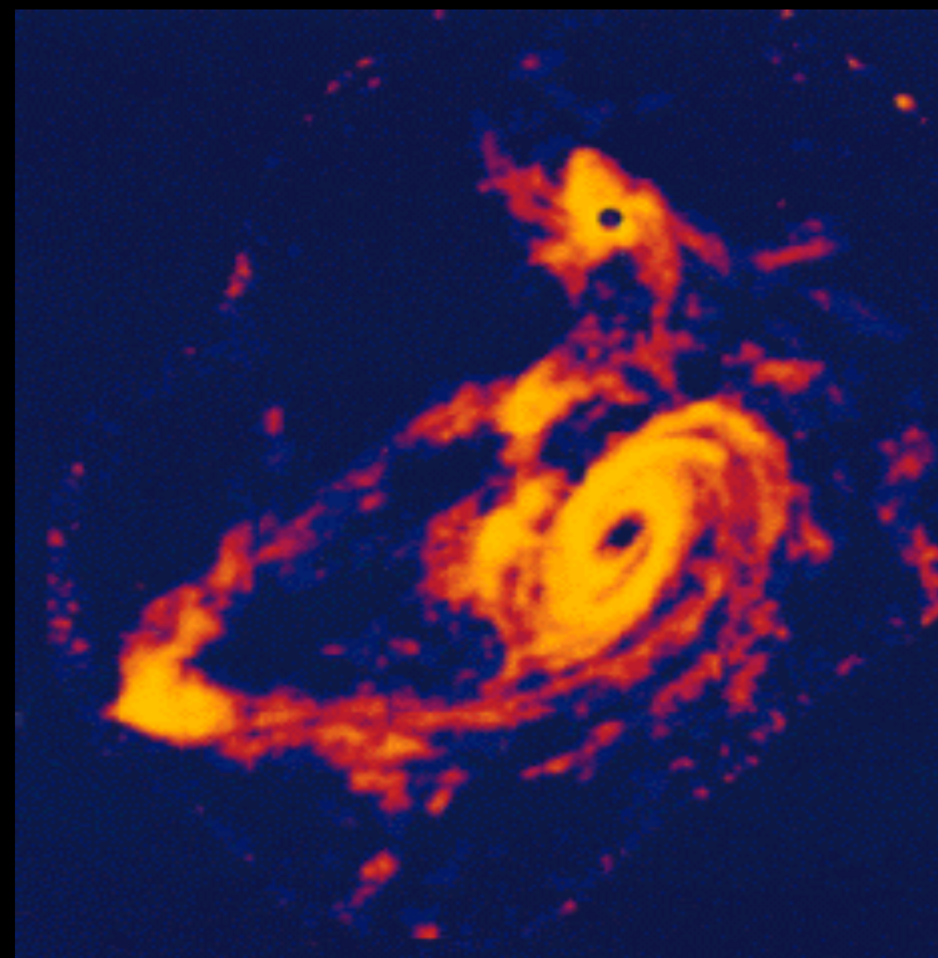
A blueprint for massive galaxy formation ?

8+ Gyrs	DM assembly via rapid merging
	- major mergers destroy discs so must end before 8Gyrs (coincident with second inflation?)
10-13 Gyrs	Spheroid formation via (predominantly) rapid collapse
	-37% of stellar mass (secondary mode)
	- Mean age of spheroids 10-13Gyrs = AGN peak
	- alpha-enhancement = short burst (AGN moderated)
	- collapse inhibited during DM assembly=>downsizing
5-8 Gyrs	Disc growth via infall/splashback
	- 60% of stellar mass (dominant mode)
	- coupled with falling SFR
	- mean age of discs 5-8Gyrs
0-5 Gyrs	Pseudo-bulge growth & morphological transformations
	- ages unchanged (material just shuffled)

But what is the variance, environmental & halo mass dependencies, and what about the neutral gas and plasma?

Optical image
(Stars)

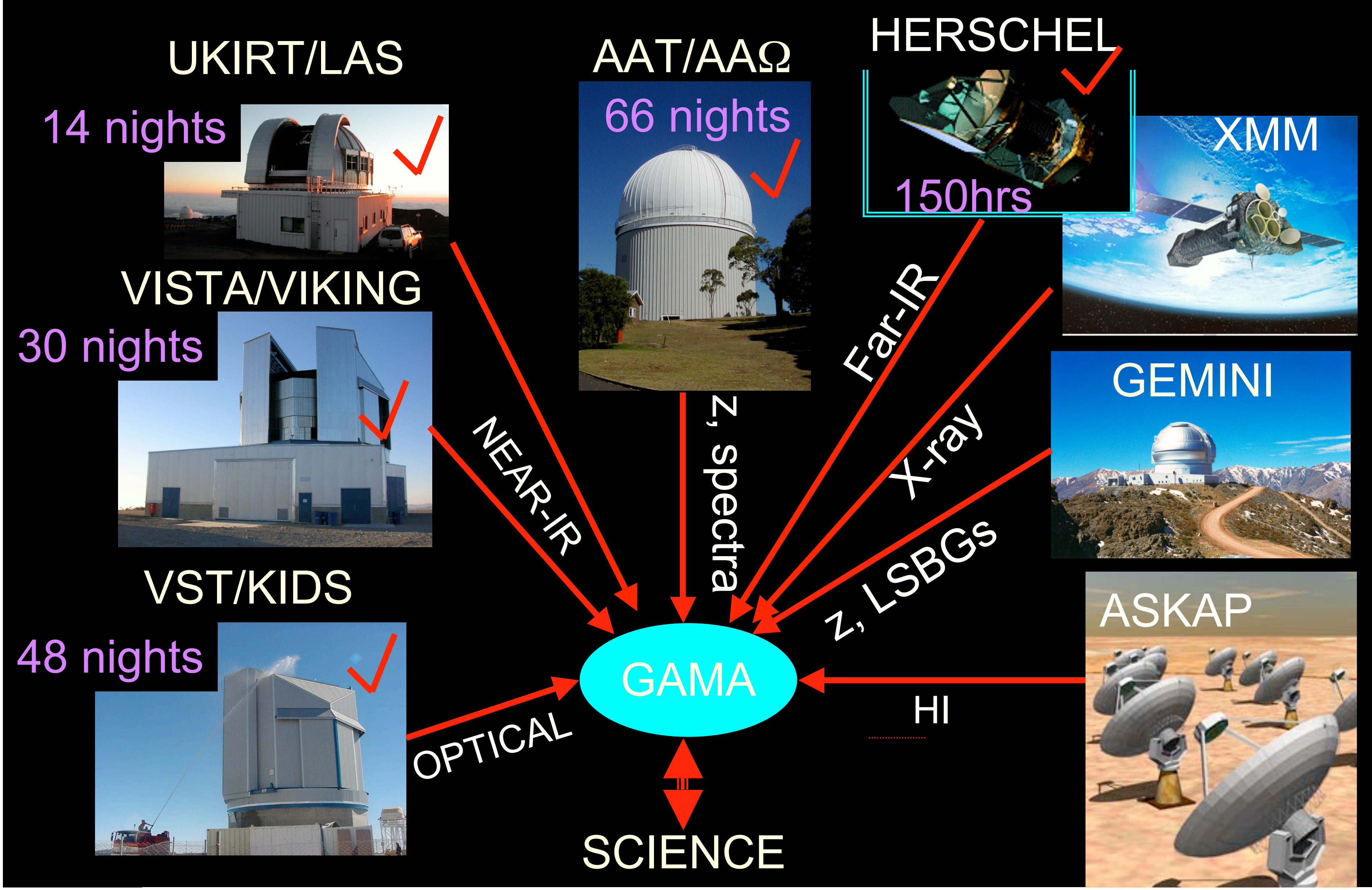
21cm image
(Gas)

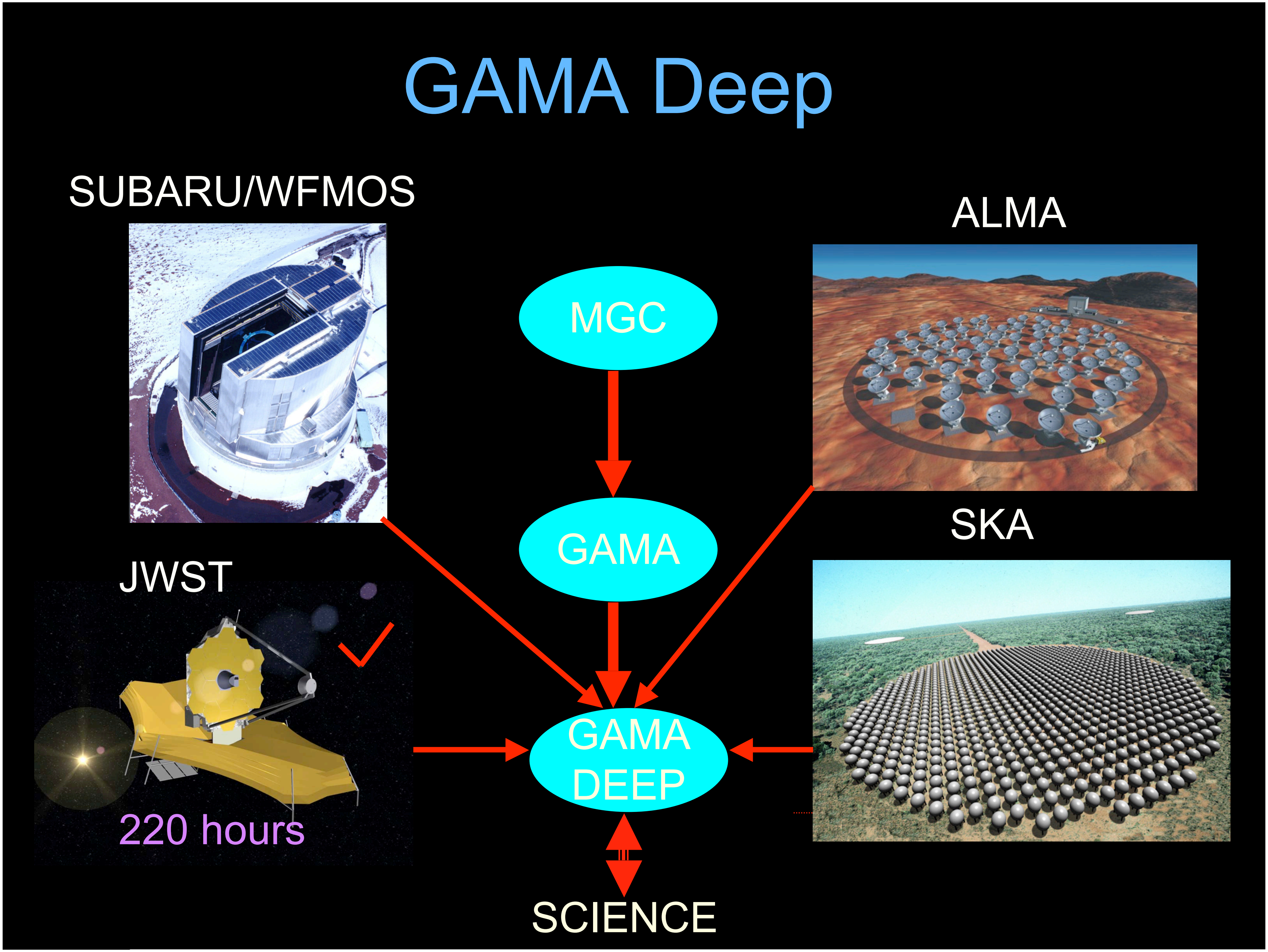


Galaxy And Matter Assembly

- Comprehensive
  - 250 sq degrees (5x50 sq deg. chunks), 250k galaxies (25x MGC)
- General science:
  - A study of structure on 1kpc-1Mpc scales, where baryon physics crucial
- Specific goals:
  - the CDM Halo mass function from group velocity dispersions
  - the stellar mass function into the intermediate mass regime
  - building total SEDs for galaxies and their components at $z < 0.5$
- Going massively multi-wavelength:
  - X-ray (XMM), UV (GALEX)
  - Optical: ugri (VST, SDSS), spectra (AAT)
  - Near-IR: ZYJHK (VISTA, UKIRT)
  - Far-IR (Herschel), sub-mm SCUBA-II
  - **Radio: 21cm (ASKAP or meerKAT)**
- Overcome secondary structural issues:
  - Nuclei-Bulge-Bar-Disc-Disc Truncation decompositions
- Disentangle environmental dependencies

GAMA: Contributing Facilities




GAMA Deep
SUBARU/WFMOS
ALMA
MGC
GAMA
SKA
JWST
GAMA DEEP
220 hours
SCIENCE

GAMA: Team Affiliations and Structure

PI: Driver (St Andrews)

WORKING GROUPS/HEADS

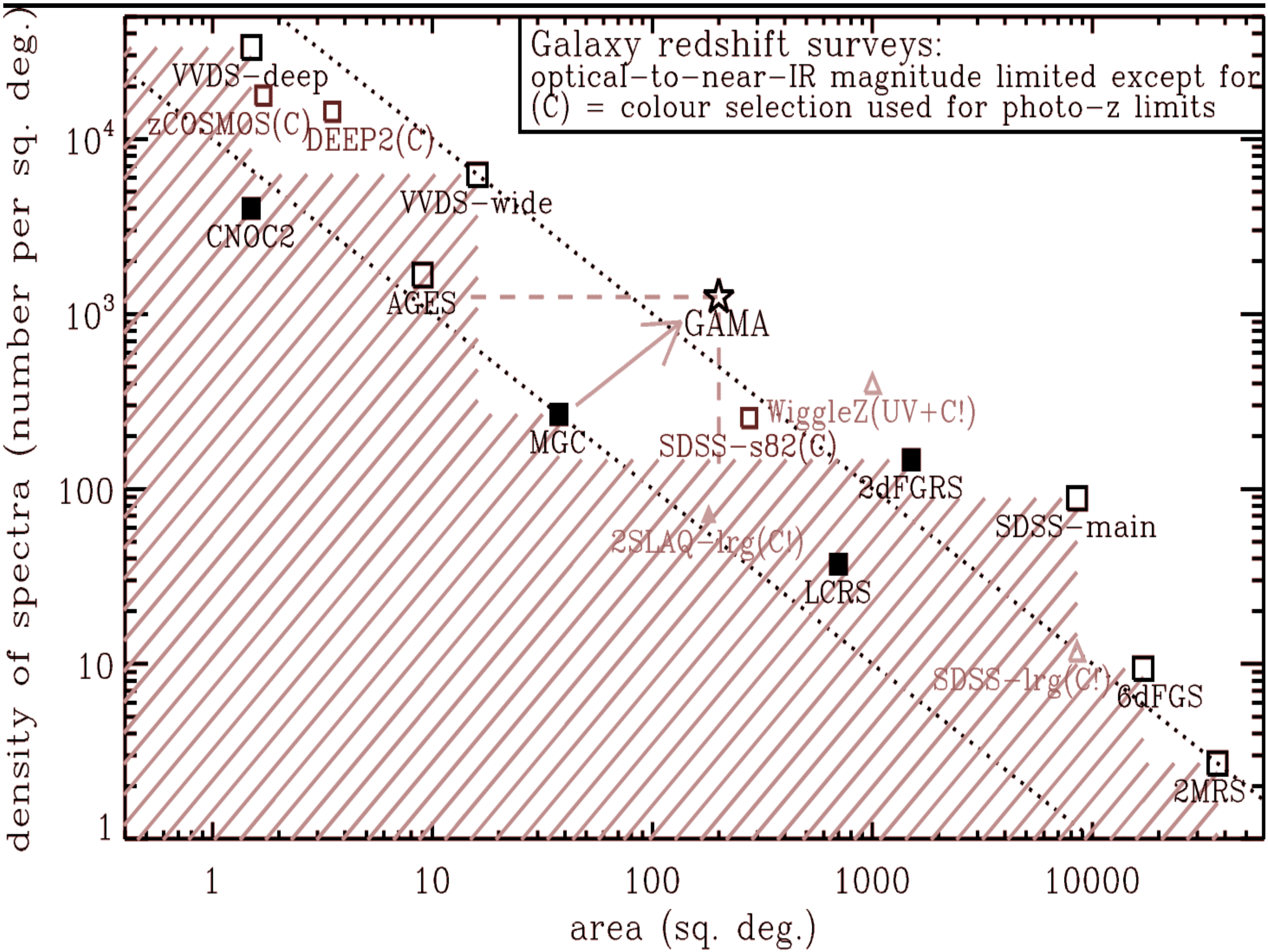
SCIENCE	CATS	DATABASE	OBS	MOCKS	RADIO	SPEC. PIPE.	IMAGE. PIPE.
Peacock (ROE)	Baldry (LJMU)	Liske (ESO)	Driver (St And)	Norberg (ROE)	Hopkins (USyd)	Loveday (Sussex)	Bamford (Ports.)

TEAM MEMBERS

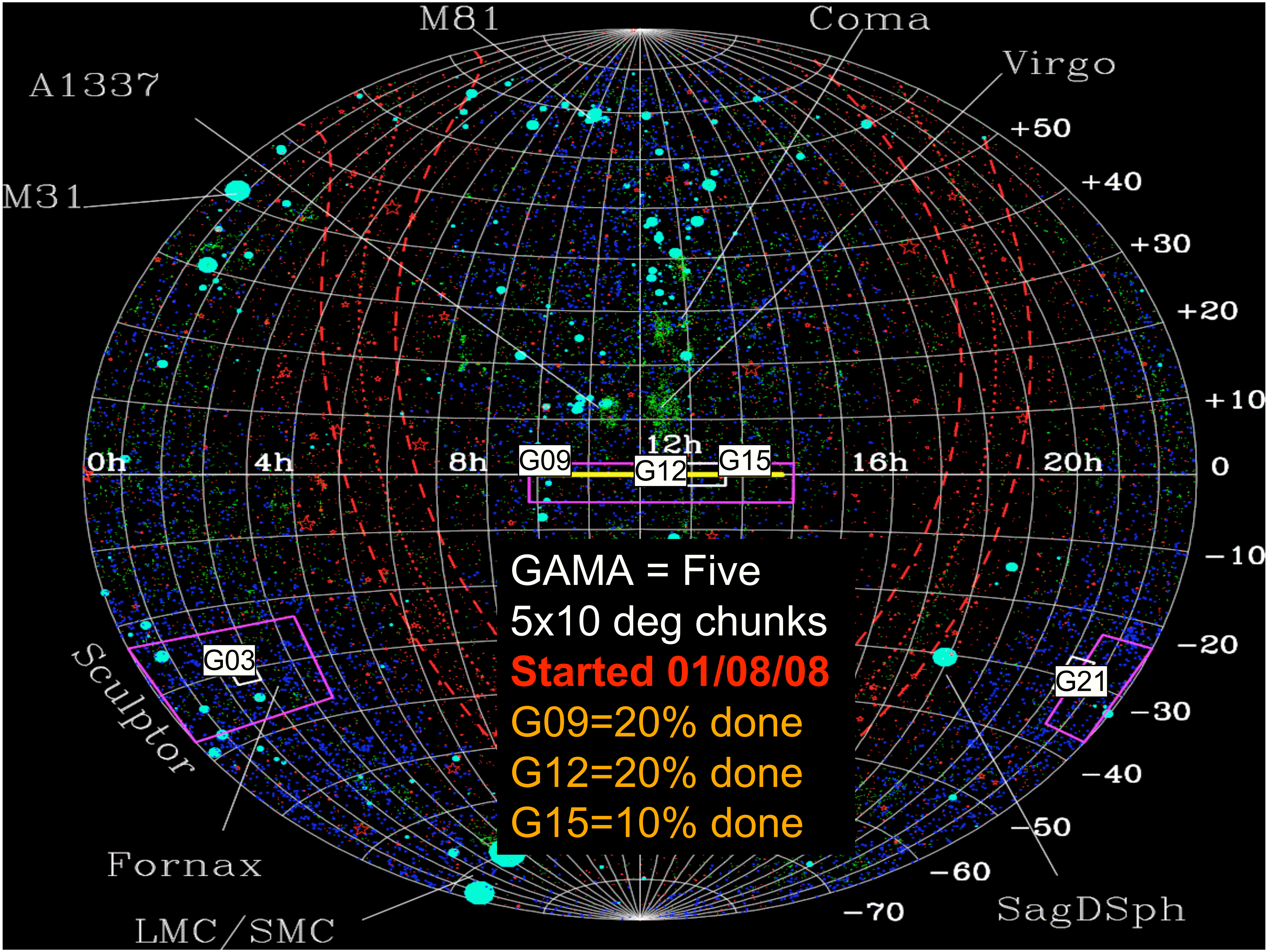
Bland-Haw'n (U.Syd)
Cameron (StA)
Couch (Swin.)
Croom (U.Syd)
Frenk (Durham)
Graham (Swin.)
Jones (AAO)
Kuijken (Leiden)
Lahav (UCL)
Oliver (Sussex)
Phillipps (Bristol)
Popescu (UCLan)
Proctor (Swin.)
Sharp (AAO)
Staveley-Smith (UWA)
Sutherland (Camb.)
Tuffs (MPIA)
van Kampen (Salzburg)
van Kampen
Warren (Imperial)
3 PDRAs pending
3 PhD Students

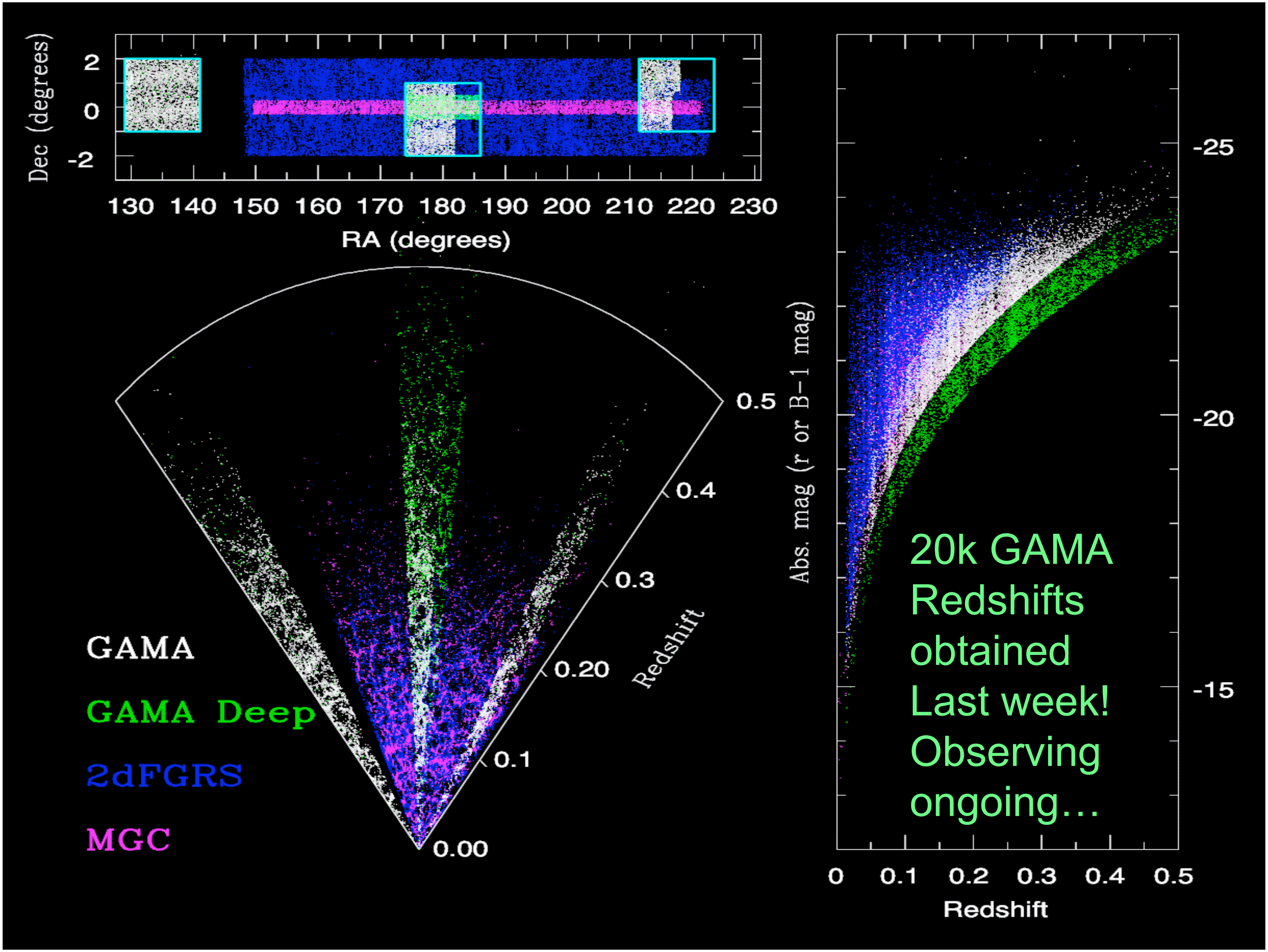
TEAM AFFILITATIONS:

UKIRT/LAS, VST/KIDS, VISTA/VIKING, HERSCHEL-ATLAS, DURHAM ICC

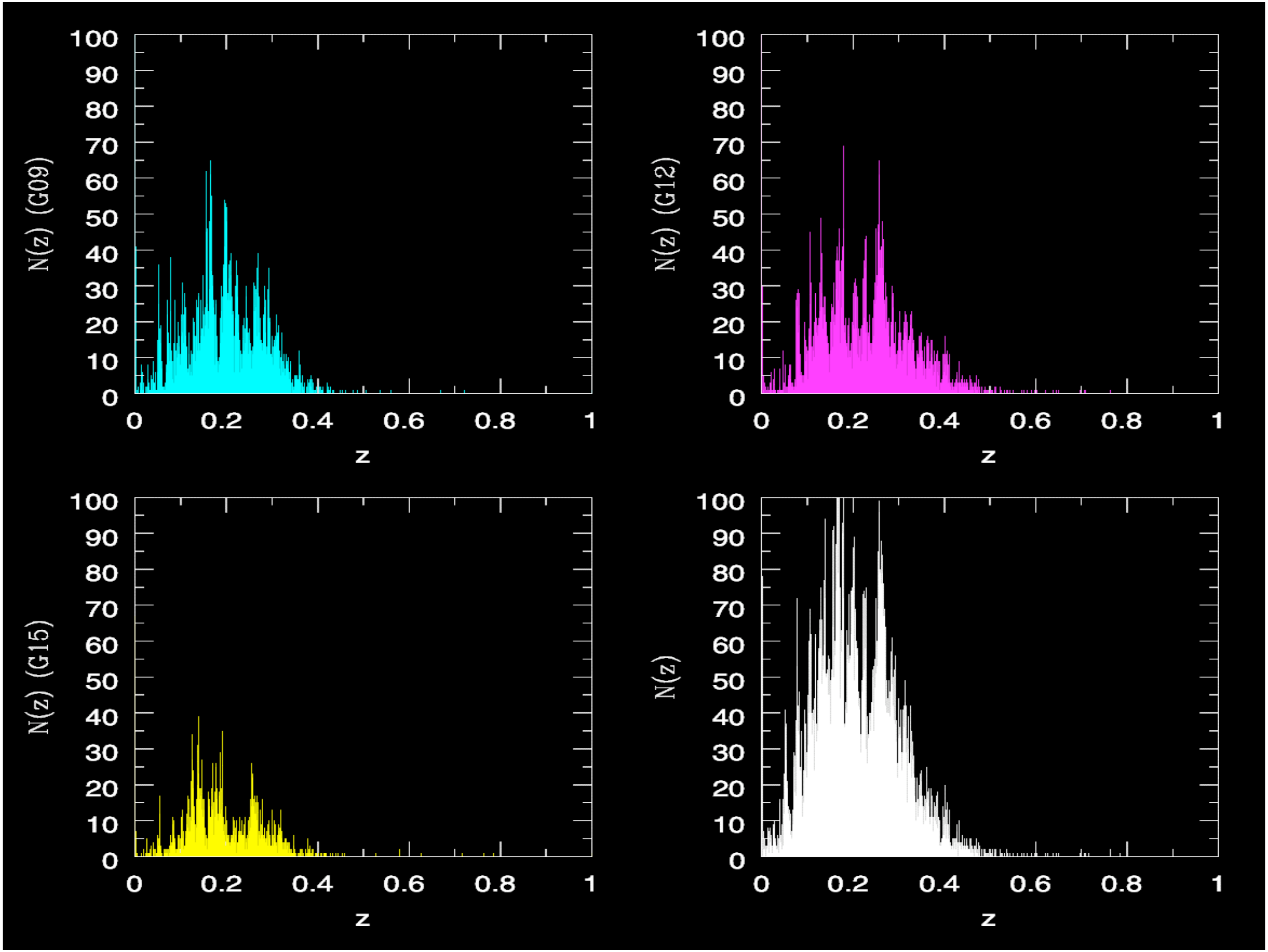


Galaxy redshift surveys:
optical-to-near-IR magnitude limited except for
(C) = colour selection used for photo-z limits
VVDS-deep
zCOSMOS(C)
DEEP2(C)
VVDS-wide
CNOC2
AGES
GAMA
MGC
WiggleZ(UV+C!)
SDSS-s82(C)
2dFGRS
SDSS-main
2SLAQ-lrg(C!)
LCRS
SDSS-lrg(C!)
6dFGS
2MRS
density of spectra (number per sq. deg.)
area (sq. deg.)
10^4
10^3
100
10
1
1
10
100
1000
10000


M81
Coma
Virgo
A1337
M31
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
0h
4h
8h
12h
16h
20h
G09
G12
G15
G03
G21
Sculptor
Fornax
LMC/SMC
SagDSph
GAMA = Five
5x10 deg chunks
Started 01/08/08
G09=20% done
G12=20% done
G15=10% done



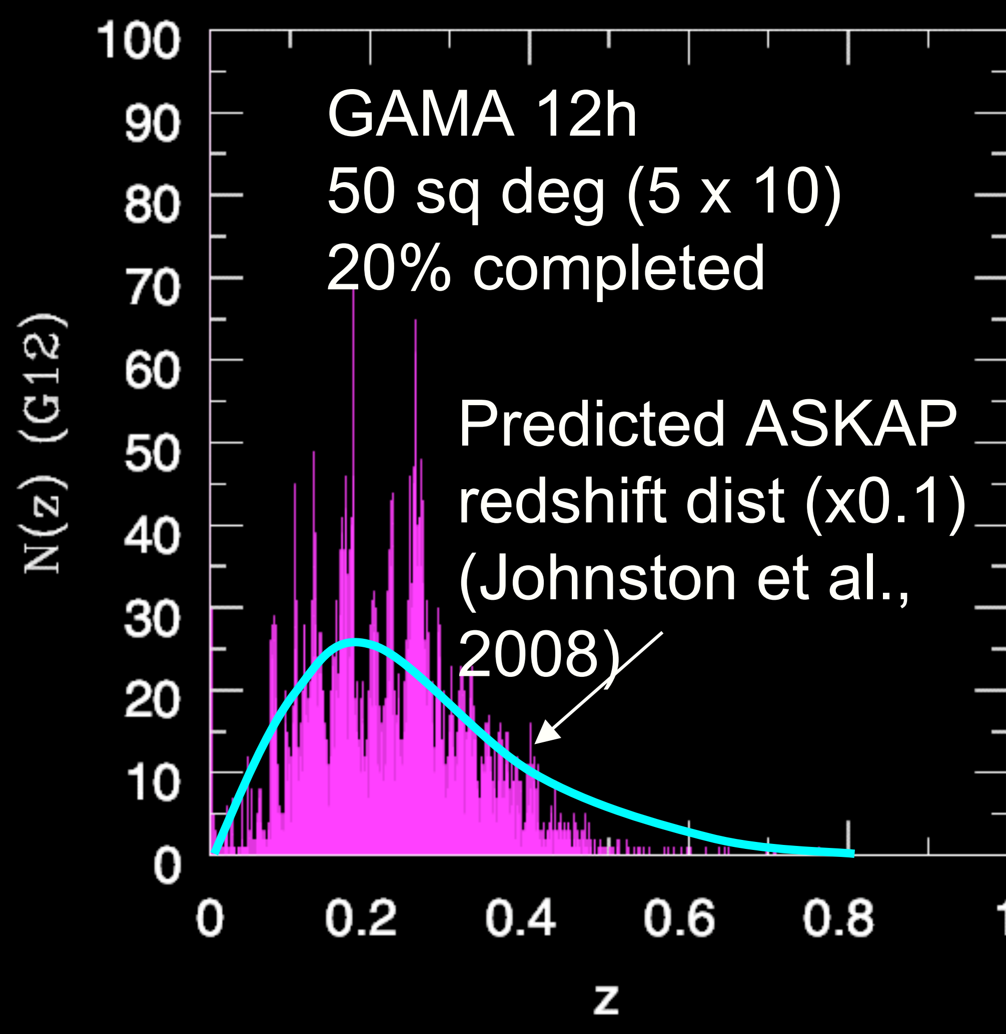
Dec (degrees)
2
0
-2
130 140 150 160 170 180 190 200 210 220 230
RA (degrees)
0.5
0.4
0.3
0.20
0.1
0.00
Redshift
GAMA
GAMA Deep
2dFGRS
MGC
Abs. mag (r or B−1 mag)
-25
-20
-15
0 0.1 0.2 0.3 0.4 0.5
Redshift
20k GAMA Redshifts obtained Last week! Observing ongoing…

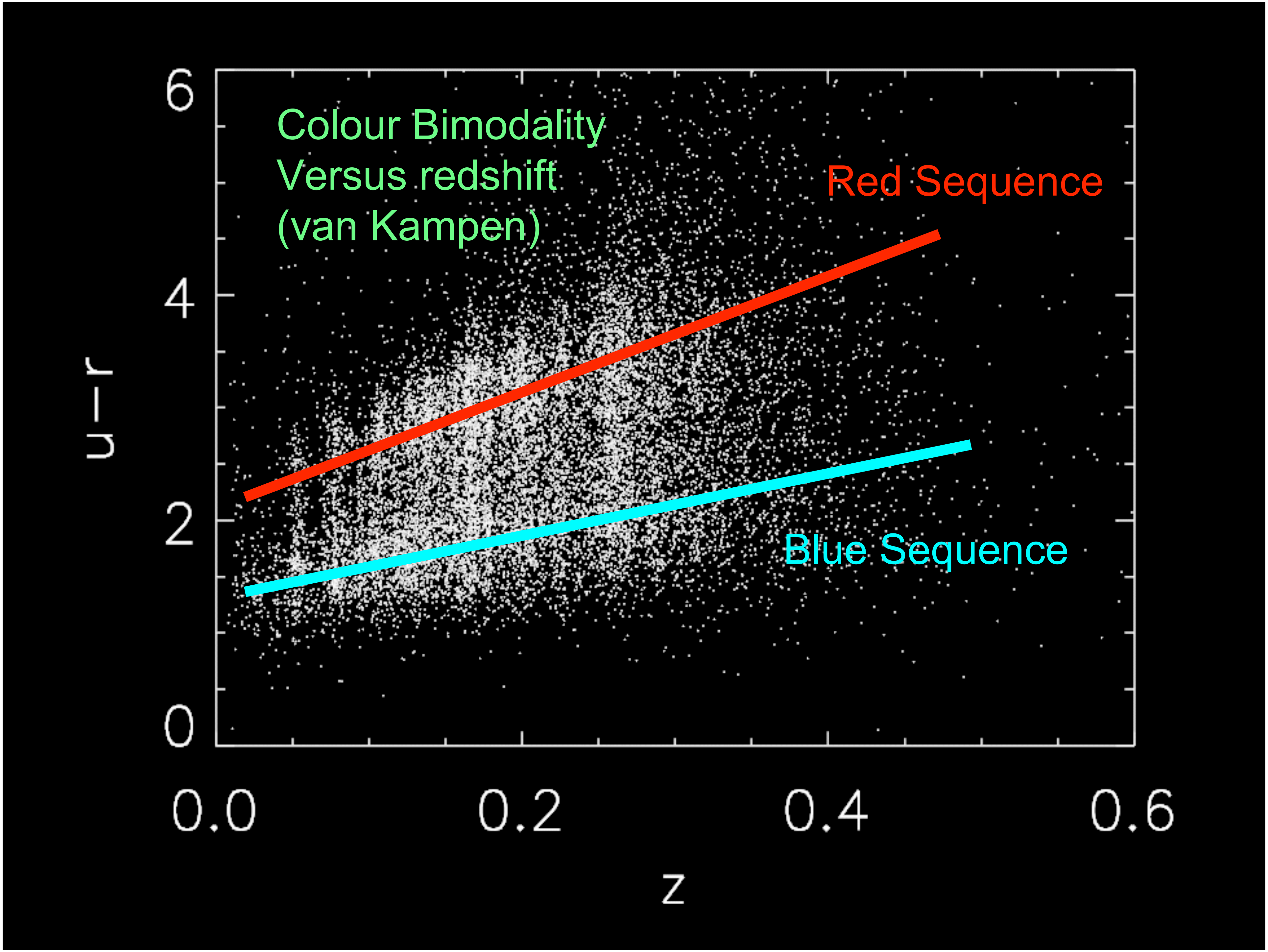


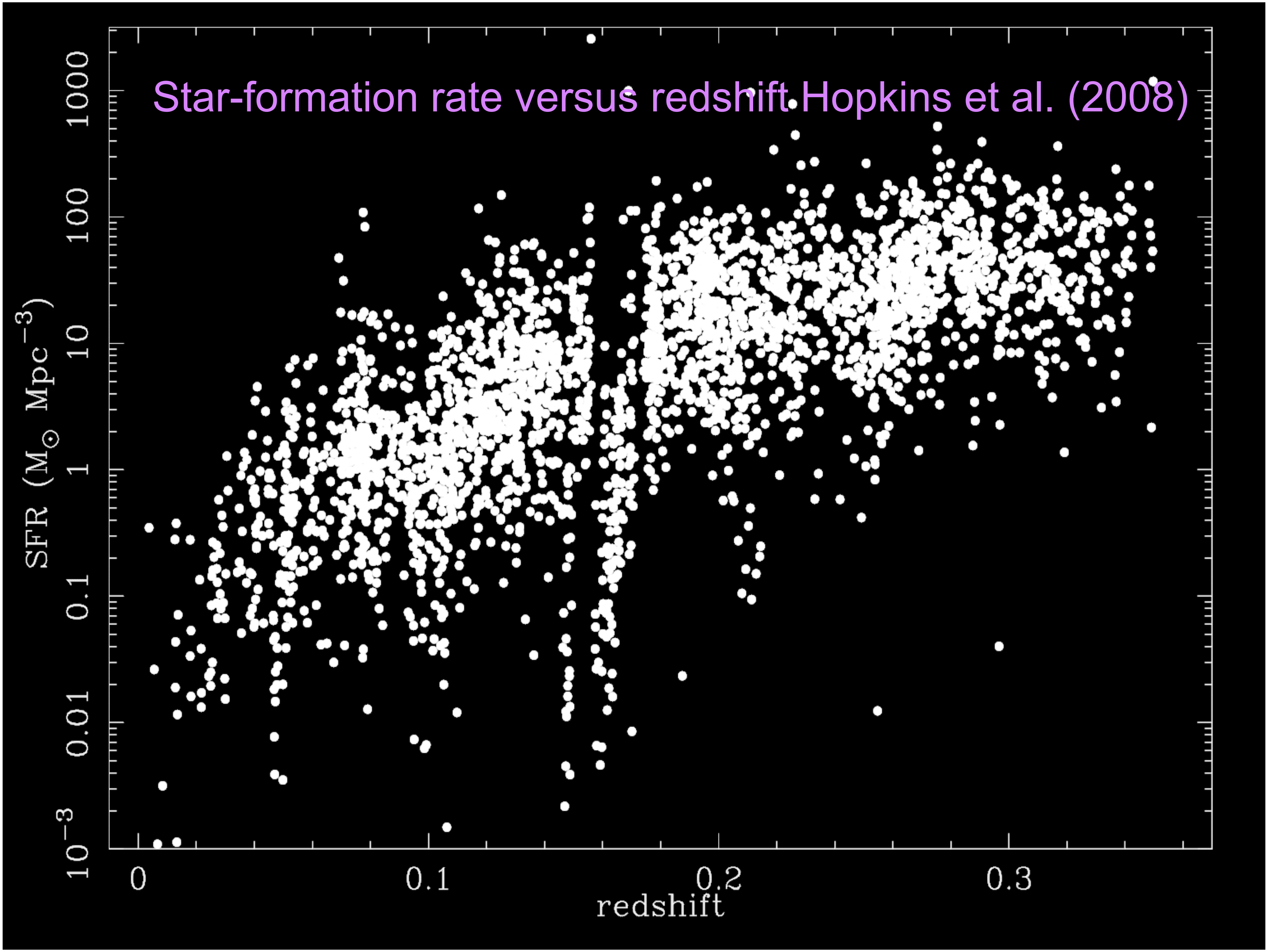
N(z) (G09)
N(z) (G12)
N(z) (G15)
N(z)
z
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80
90
100

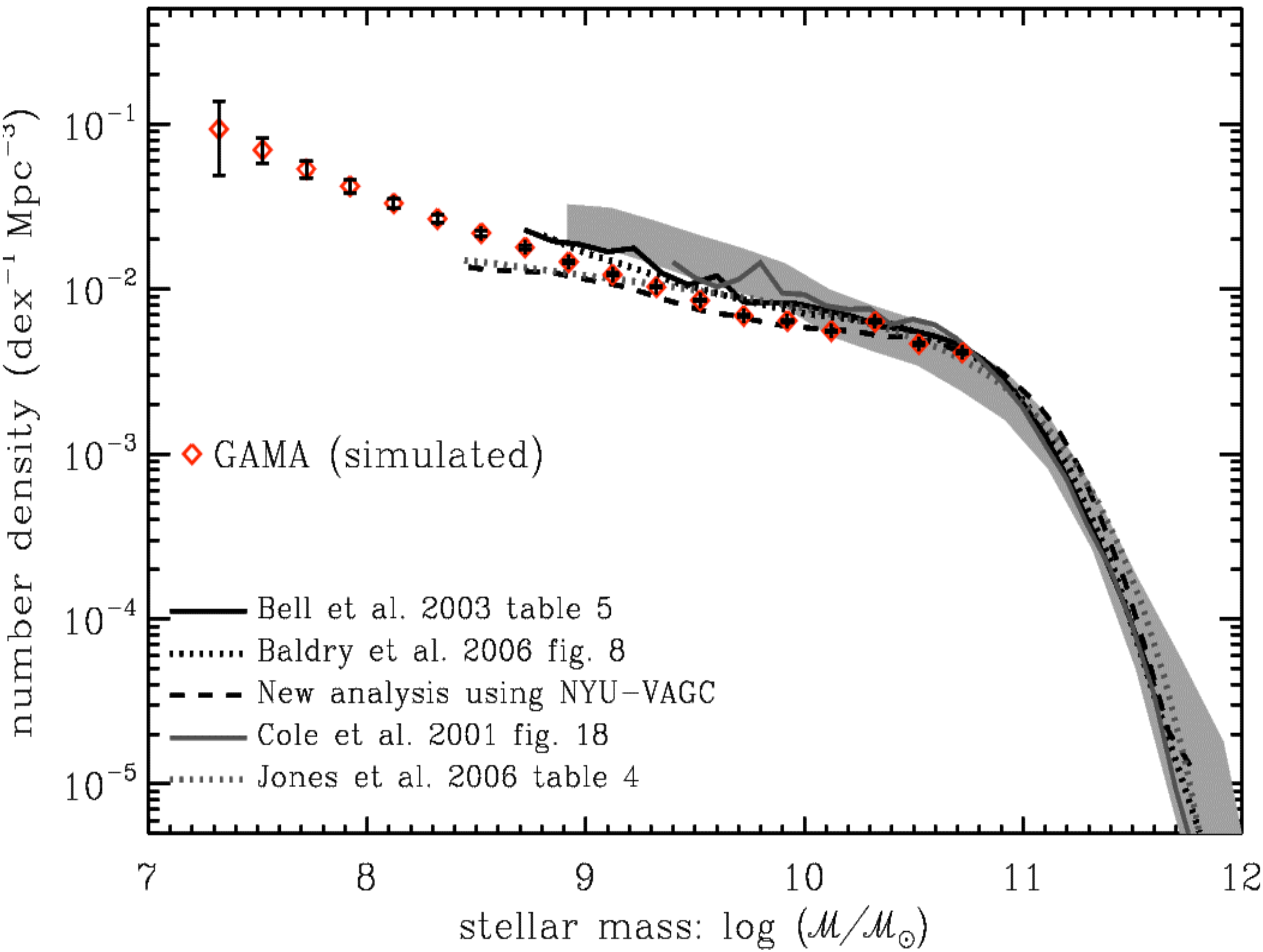
GAMA12h proposed for Deep ASKAP followup

- GAMA depth and area well matched to the proposed ASKAP deep stare.



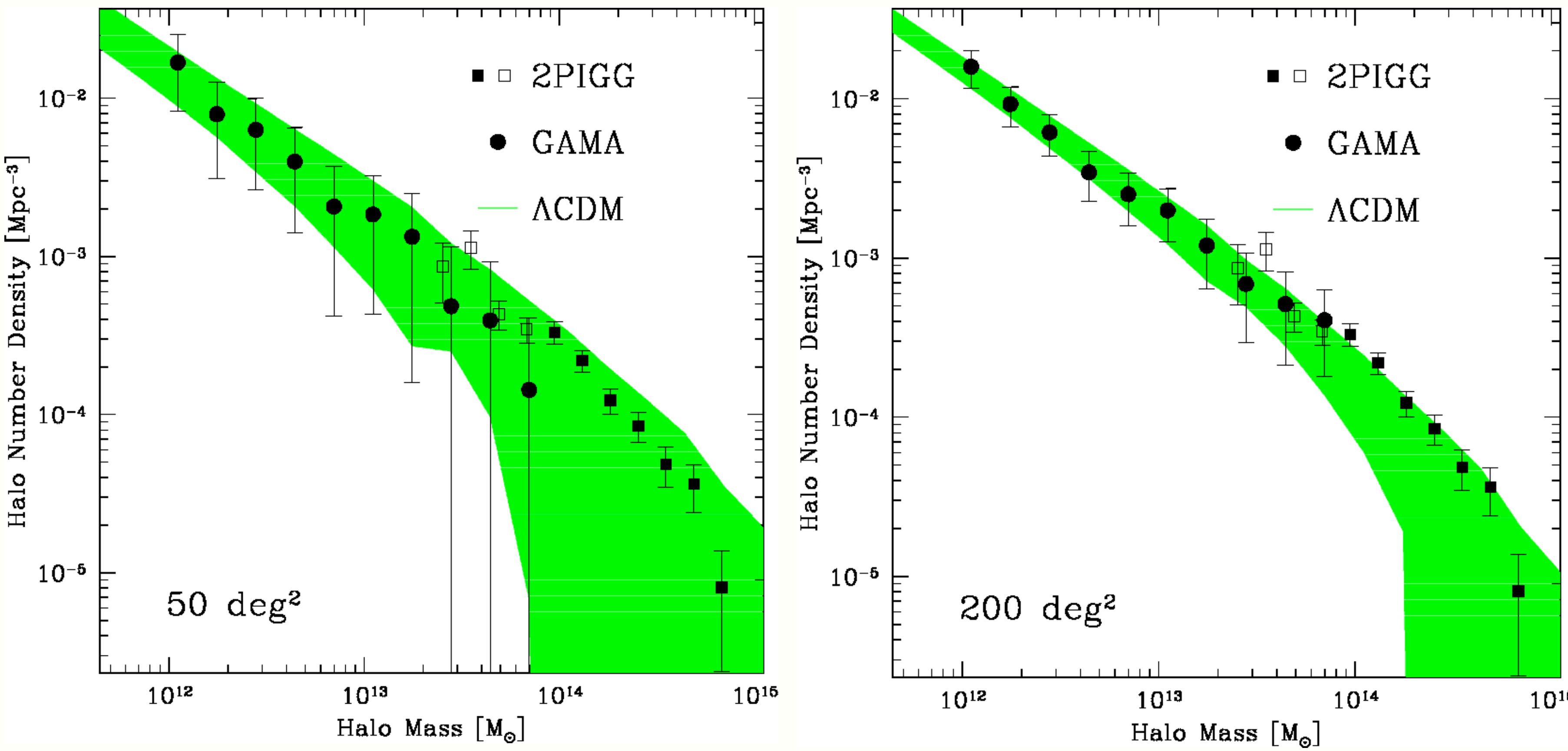

Colour Bimodality
Versus redshift
(van Kampen)
Red Sequence
Blue Sequence
6
4
2
0
u − r
0.0
0.2
0.4
0.6
z


Star-formation rate versus redshift Hopkins et al. (2008)
SFR ($M_\odot$ Mpc^{-3})
redshift
1000
100
10
1
0.1
0.01
10^{-3}
0
0.1
0.2
0.3



number density (dex^{-1} Mpc^{-3})
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
GAMA (simulated)
Bell et al. 2003 table 5
Baldry et al. 2006 fig. 8
New analysis using NYU−VAGC
Cole et al. 2001 fig. 18
Jones et al. 2006 table 4
7
8
9
10
11
12
stellar mass: log ($\mathcal{M}/\mathcal{M}_\odot$)

The CDM halo mass fn



SUMMARY

Bimodality due to two component nature of galaxies:

Structure more fundamental than colour: structure=1st order tracer of formation mechanism?

Fast/Hot mode (collapse/rapid merger) > Spheroids/AGN/SMBHs/high-[α/Fe], $z > 2$

Slow/Cold mode (accretion[lumpy]) > discs built slowly in field environment, $z < 2$-3

Stellar mass in each component: (D07 ApJL)

Discs = 60% Infall mode (half exponential, half truncated?, truncated are bluer)

Spheroids = 37% Collapse/Merger mode (ellipticals 10%, bulges 27%)

pBulges < 2% Secular mode (also see low luminosity blue spheroids at similar level)

Mean disc dust opacity high, bulges obscured by 0.8-2.5 mags ! (D07 MNRAS)

HTF an environmental effect of IGM & ICM ?

IGM allows disc construction via infall and dust production obscuring the bulges

ICM shuts down SF and destroys dust diminishing disc and unveiling bulge

Removing dust makes a galaxy redder and brighter (dry mergers may not be needed)

Cosmic energy budget balances: lost starlight=far-IR dust emission (D08 submitted)

Luminous Matter and Luminous Energy

Simon Driver (+MGC+GAMA teams)

University of St Andrews

The baryon budget (z=0) & The Cosmic Energy Spectrum