The Millennium Galaxy Catalogue: Galaxy Bulges (coarse properties)

Simon Driver

(University of St Andrews)

1. The Millennium Galaxy Catalogue (MGC)
2. Galaxy Bimodality = spheroid+disc dichotomy
3. The Luminosity functions of discs, spheroids & pBs
4. Bulge attenuation by dust (0.8 to 2.5 mag in B !)
5. The stellar mass function of ellipticals and bulges
6. The SMBH mass function of early and late-types
7. Galaxy And Matter Assembly (GAMA)

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

MGC Millennium Galaxy Catalogue

The Millennium Galaxy Catalogue

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

The MGC Core Team

Simon Driver (St Andrews)
Jochen Liske (ESO)
Paul Allen (St Andrews->HO)
Alister Graham (Swinburne)
Ewan Cameron (St Andrews)

MGC Collaborators

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The Millennium Galaxy Catalogue

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

INT WFC: 37 sq deg to *B*=26mag/s arcsec ~1 million gals < *B*=24 mag

SDSS DR5: *ugriz* to *B*~25mag/sq arcsec plus density parameters

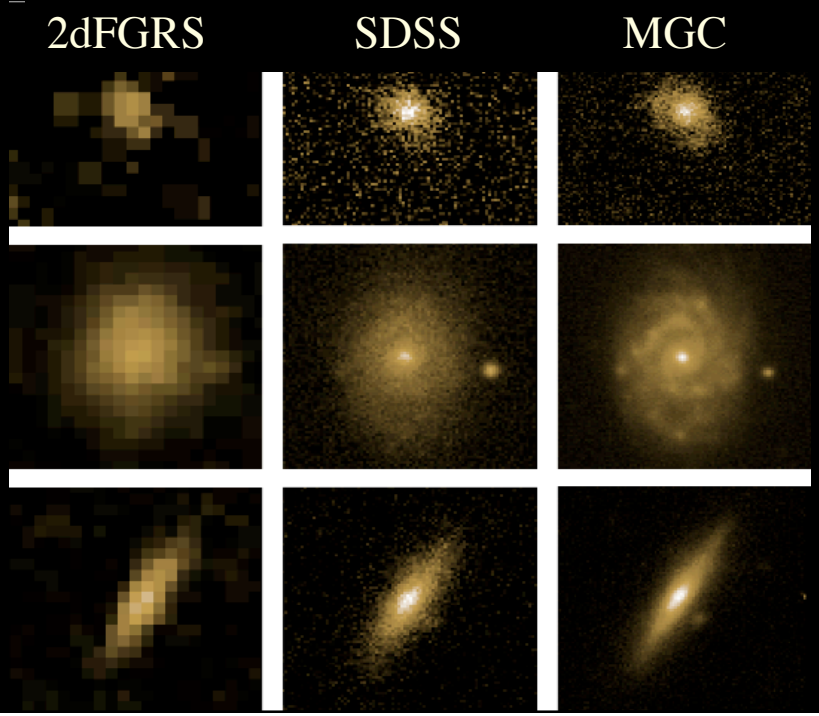
AAT 2dF+: ~10,000 redshifts to *B*=20 mag (96%)

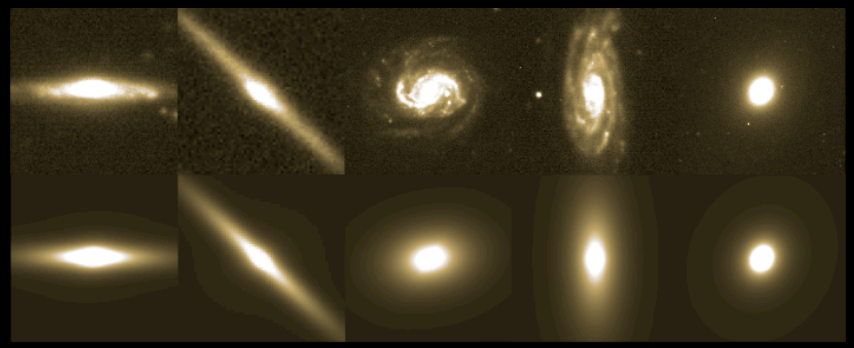
GIM2D: Sersic bulge+exp. disc decompositions of 10,096 gals

Liske et al (2003); Driver et al (2005); Allen et al (2006)

Science: 18 MGC papers in print/under review:

Galactic Halo - LFs - SMBHs - Merger rates - Dust etc.





A z=0 structural reference.

All data available online NOW.

Example 1: MGC27301

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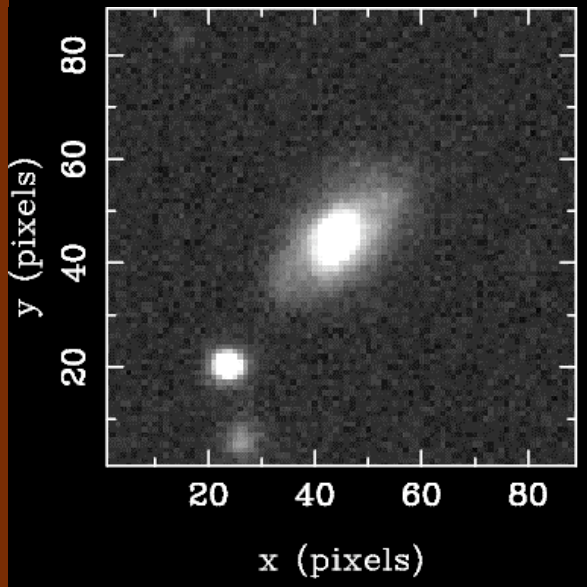

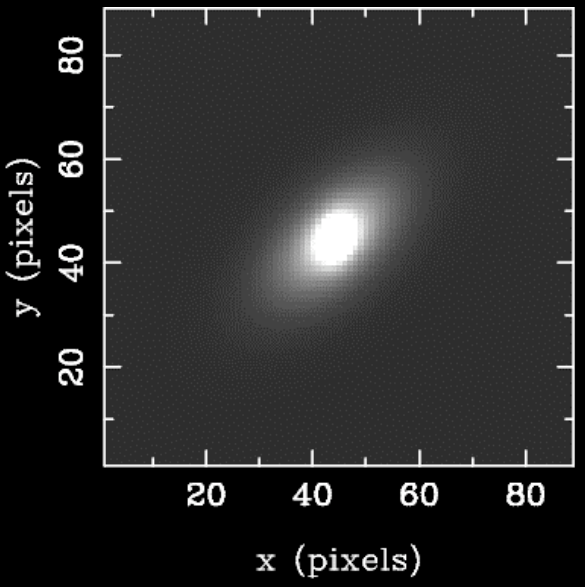

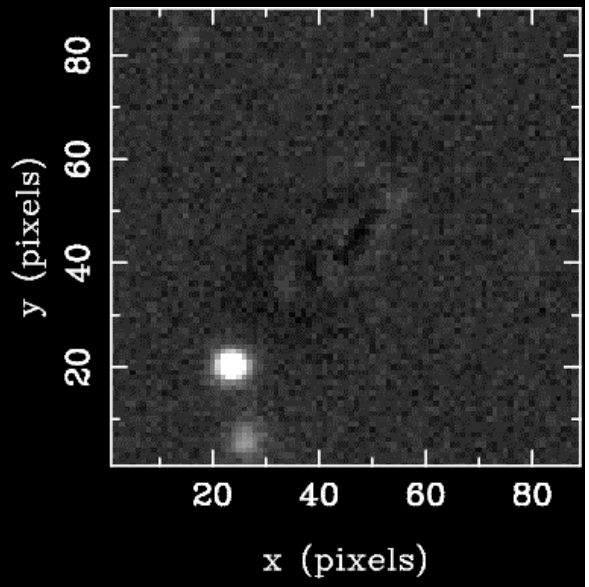

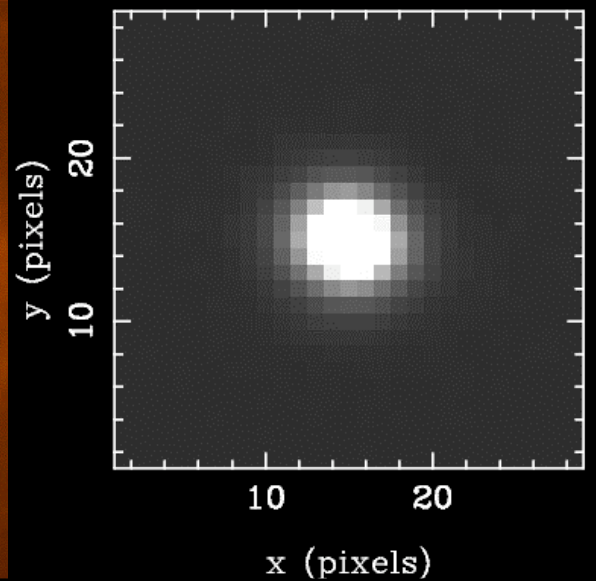

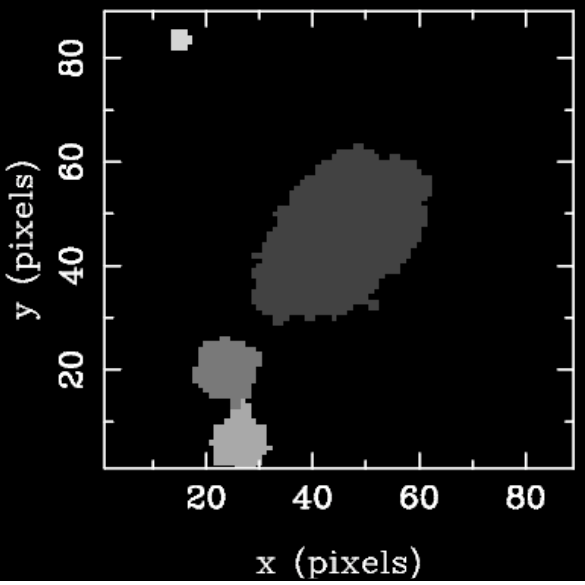

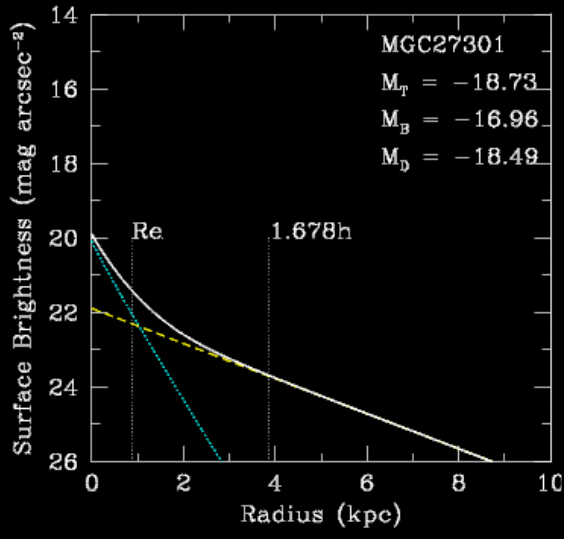

Example 2: MGC61361

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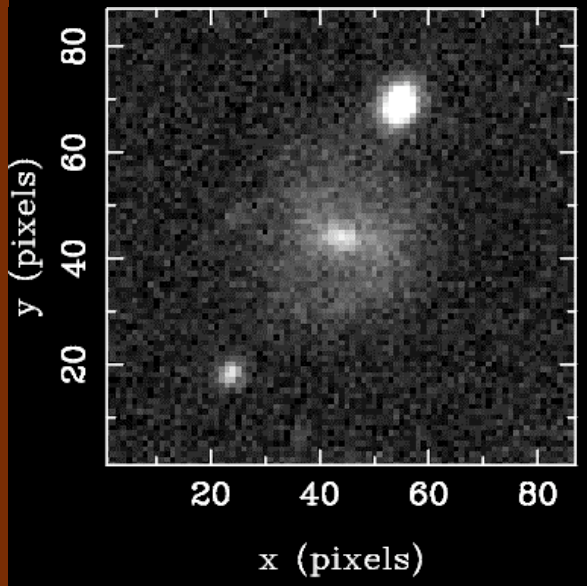

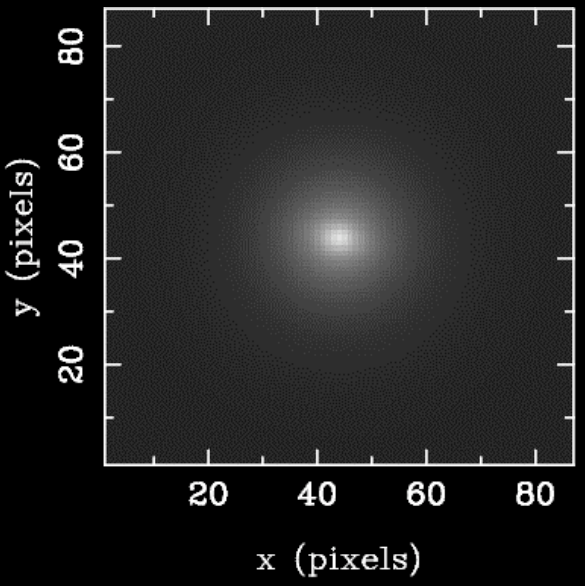

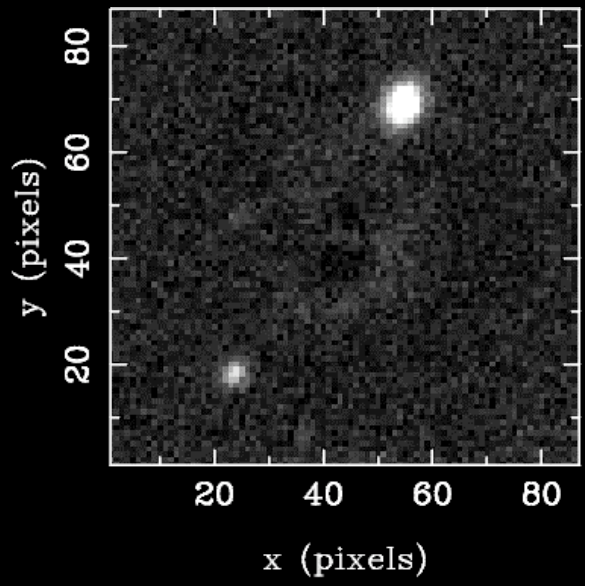

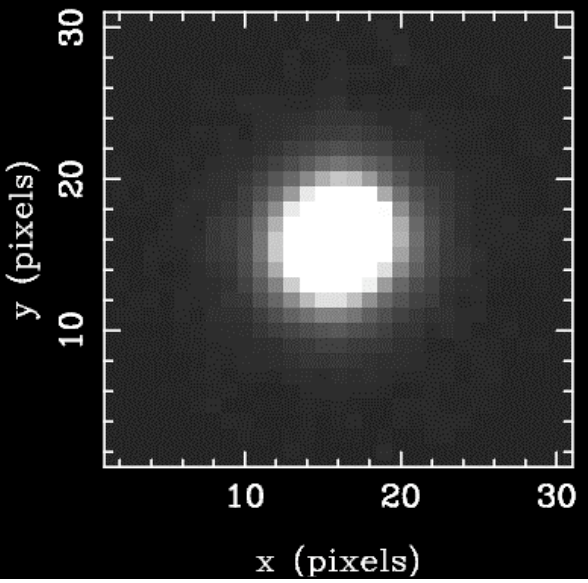

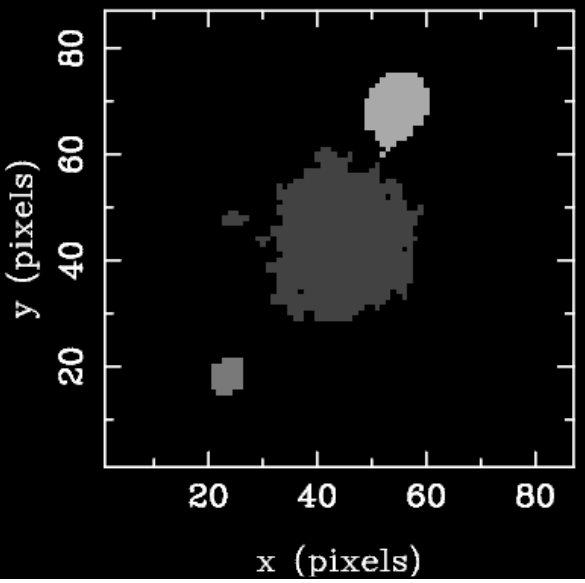

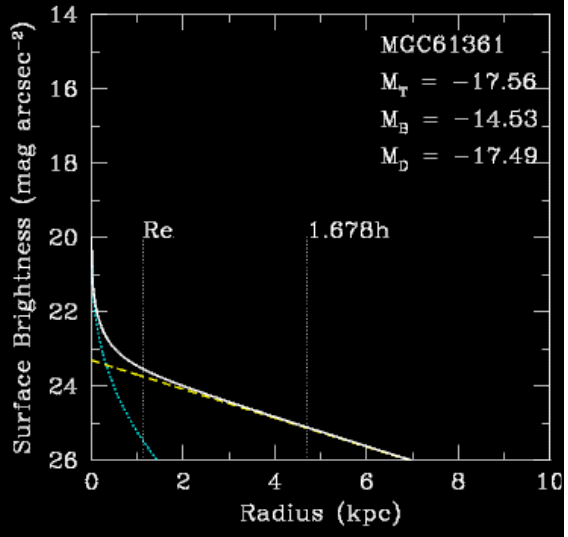

Example 3: MGC55593

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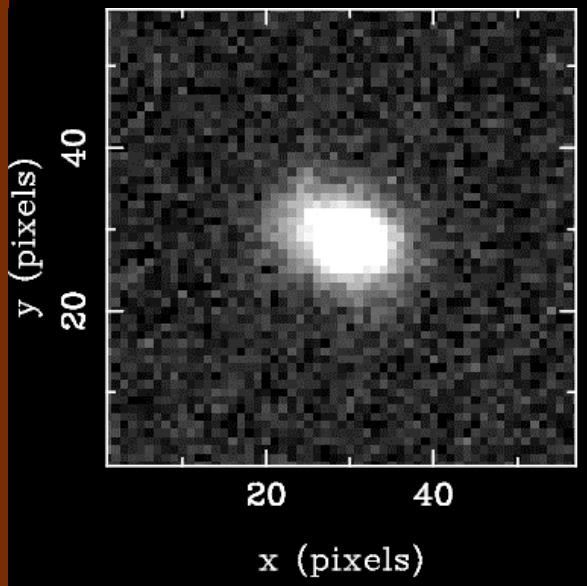
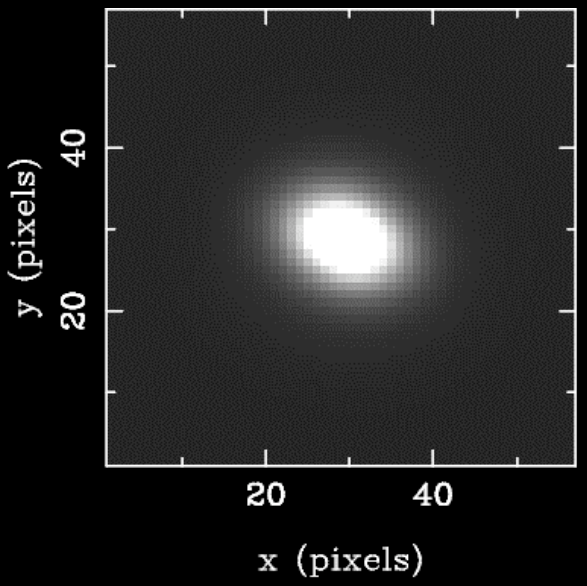
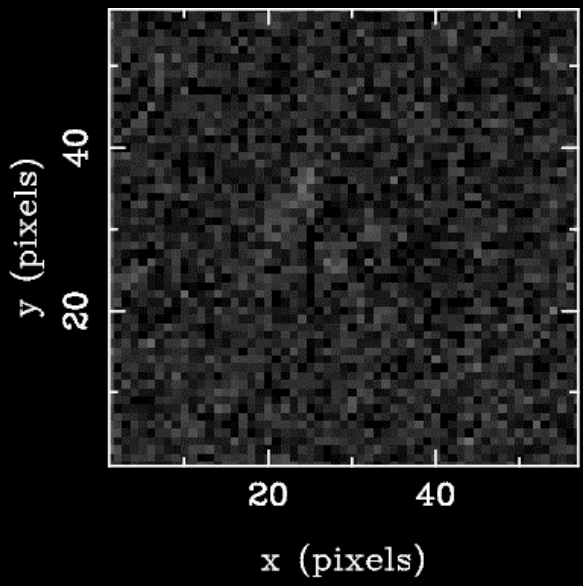
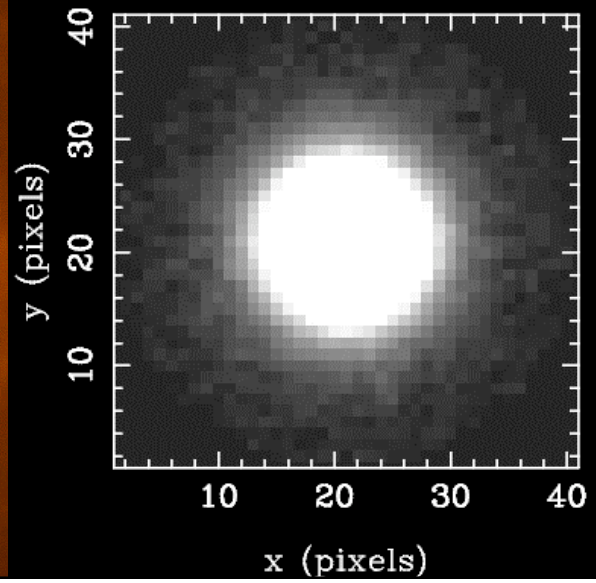
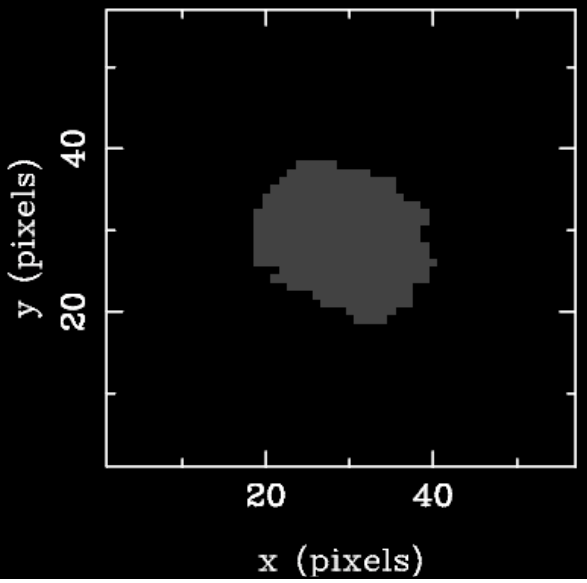
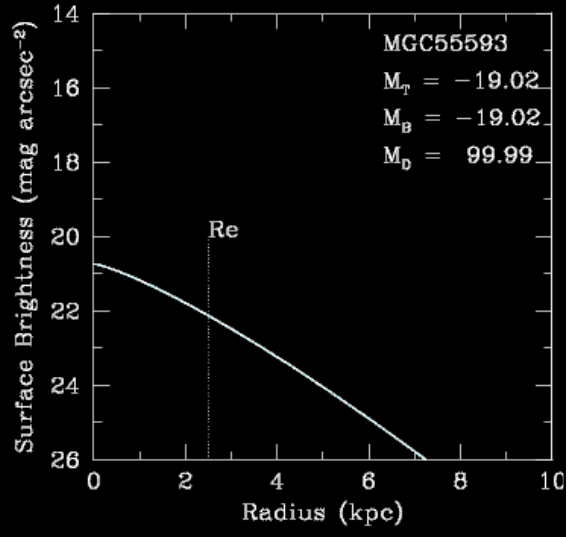












Repeatability of decompositions

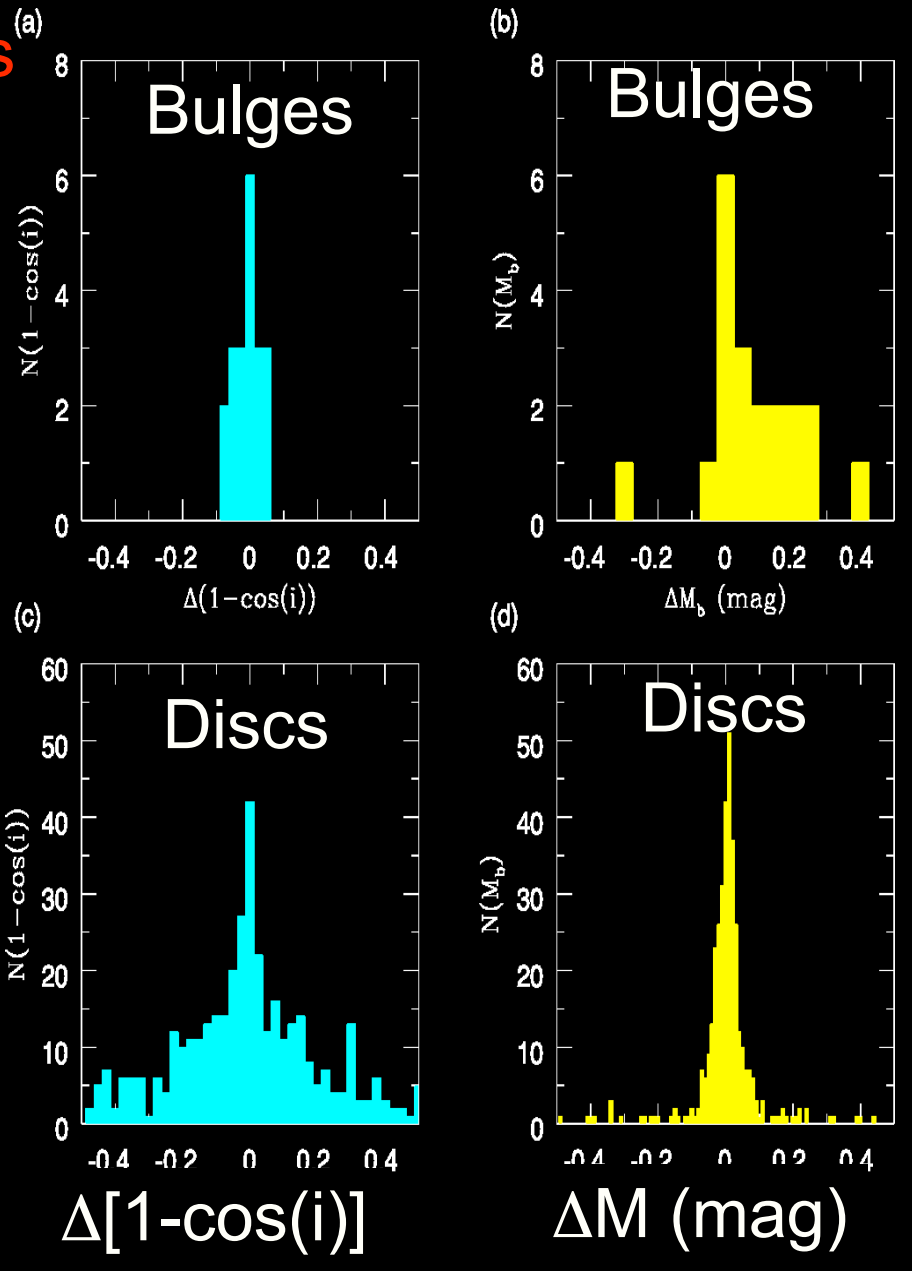
http://www.eso.org/~jliske/mgc/

From 780 repeat observations
different: CCD, date, time, PSF, calibration, analyst

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)

Blind test failure rate = 10%



1 download

2 awk cmds

1 plot =>

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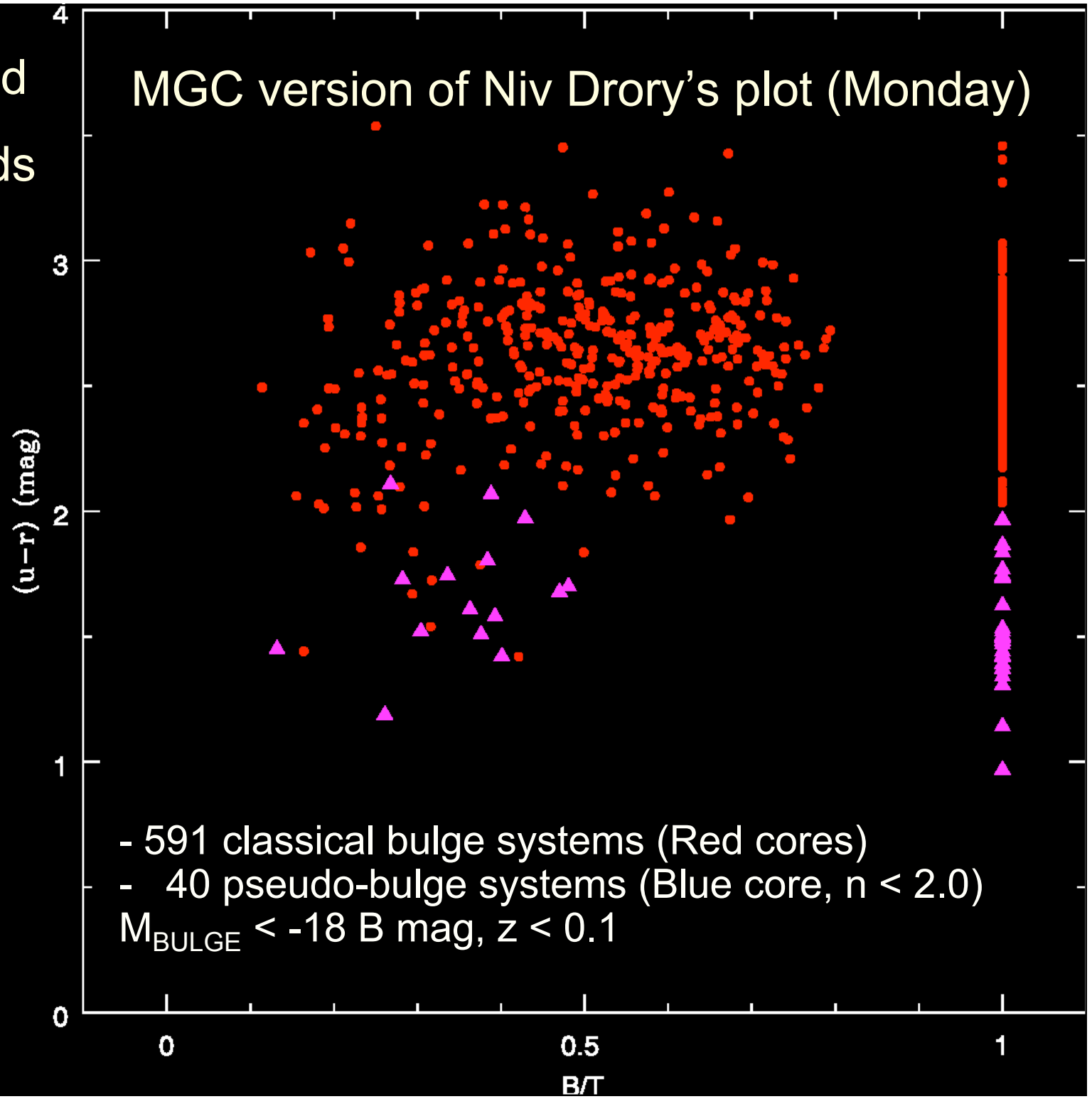

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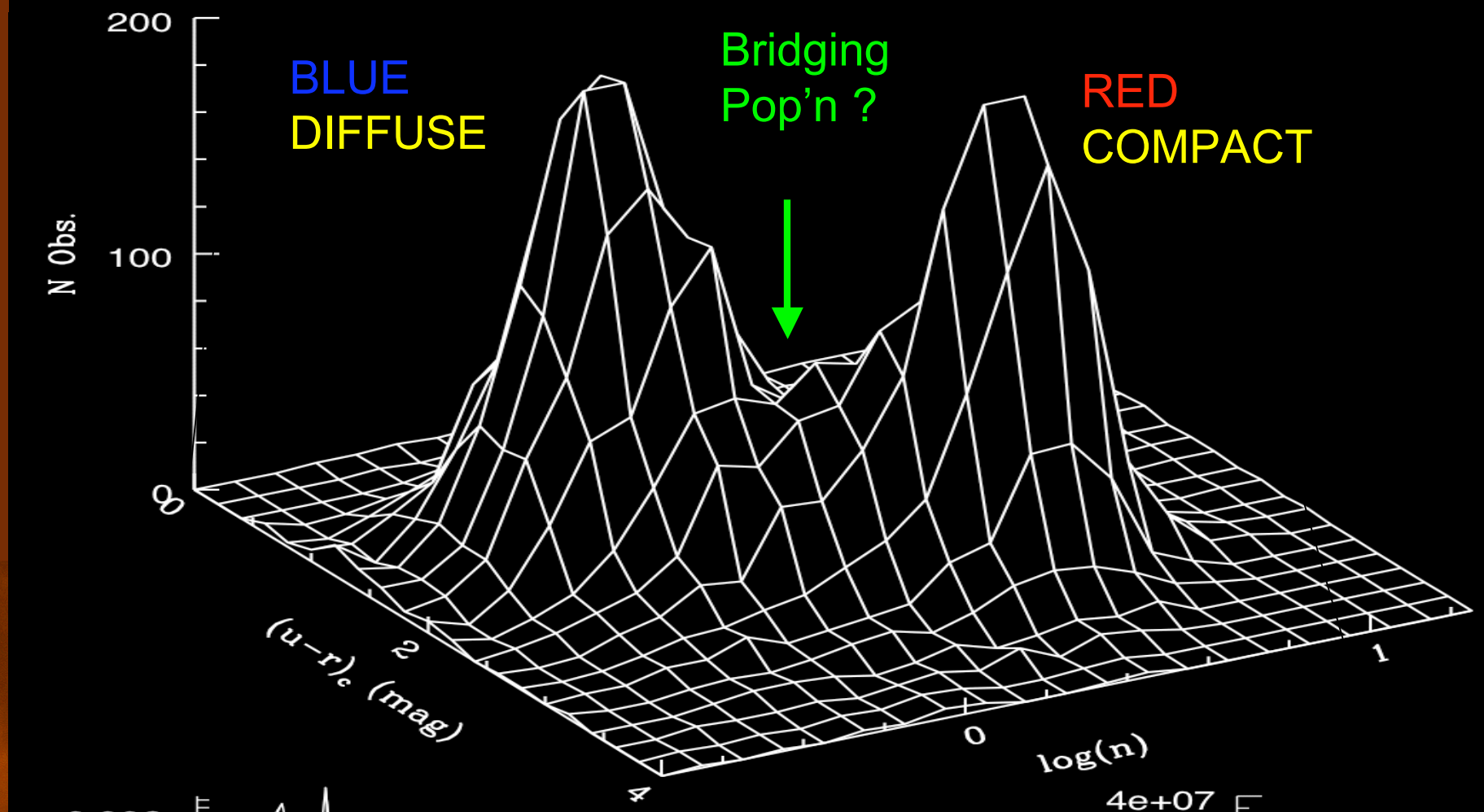
Galaxy bimodality in (u-r)-log(n)

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



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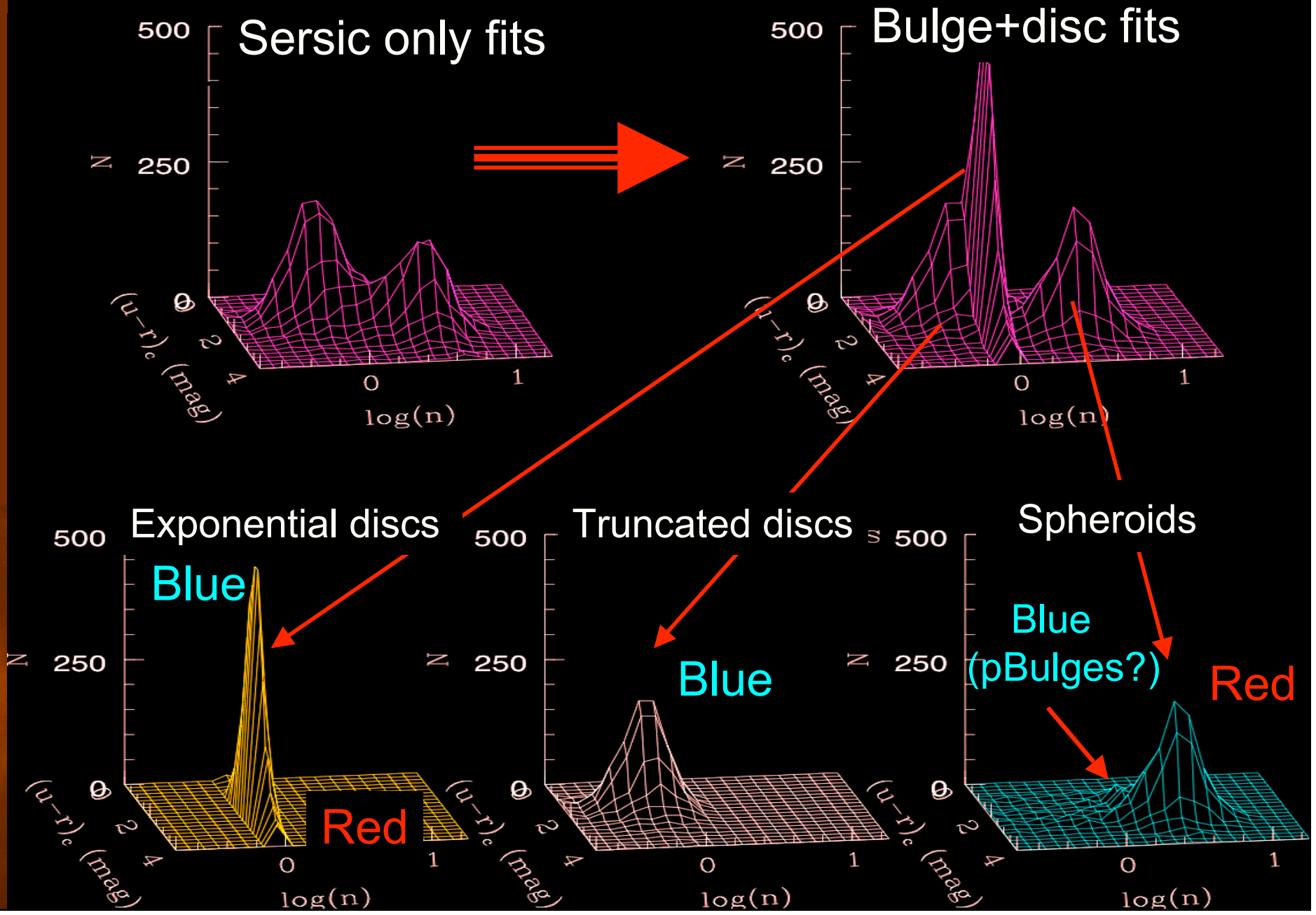
Two populations or two components ?

Cameron & Driver, 2007, in prep, see poster



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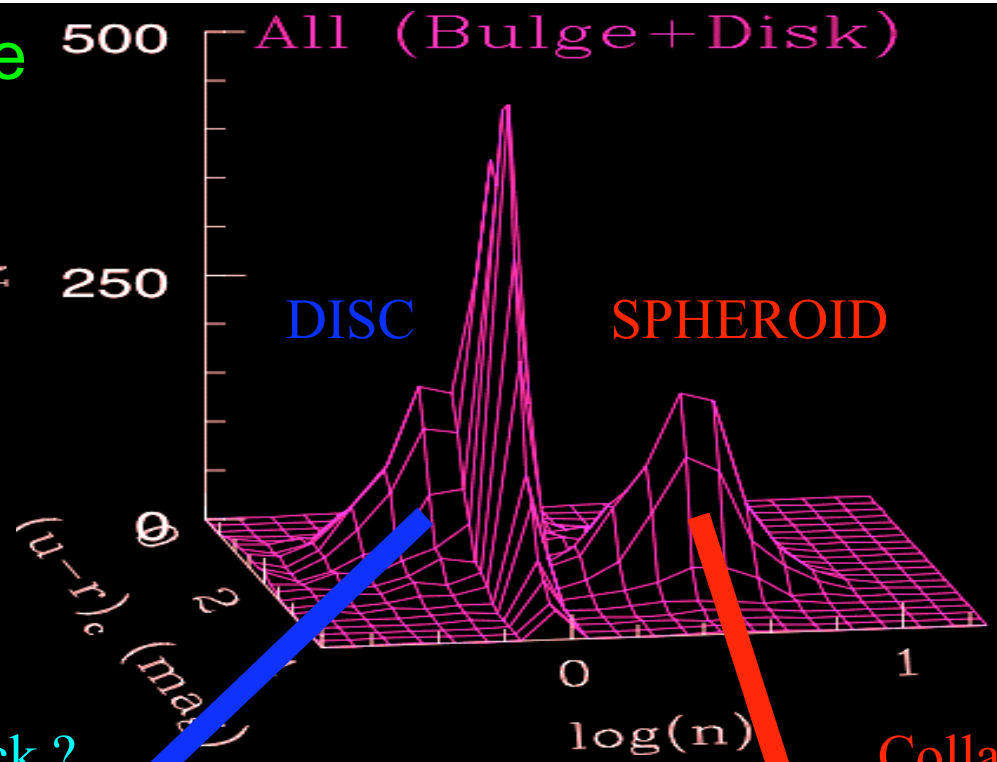
Structure more fundamental than colour.

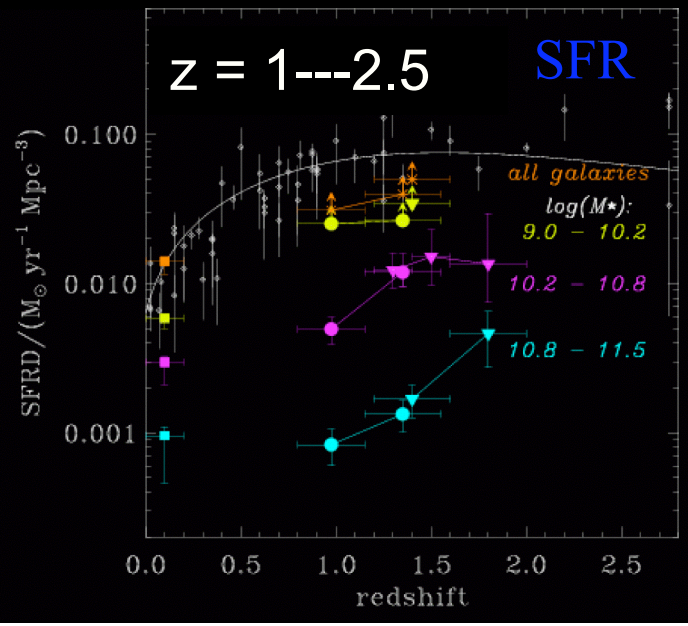
2 DISTINCT FORMATION MODES AND ERAs ?

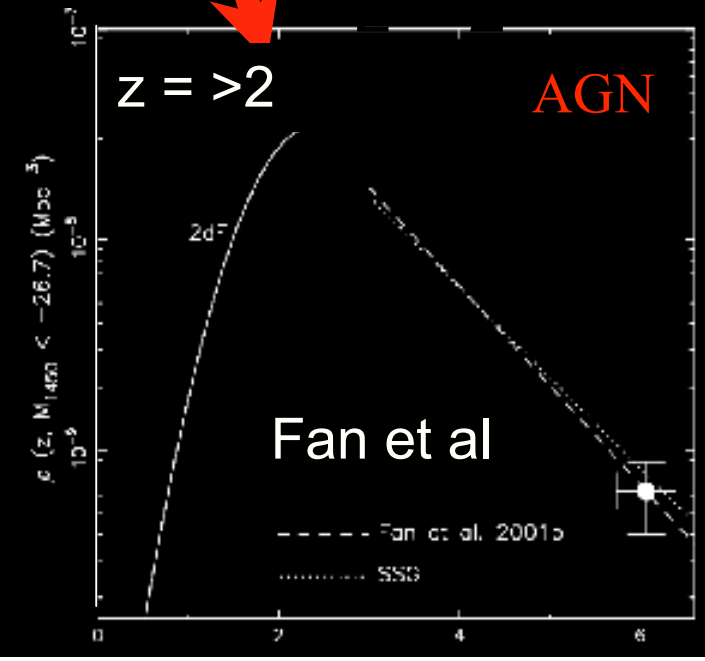


SMBHs AGN ?

Infall/splashback ?

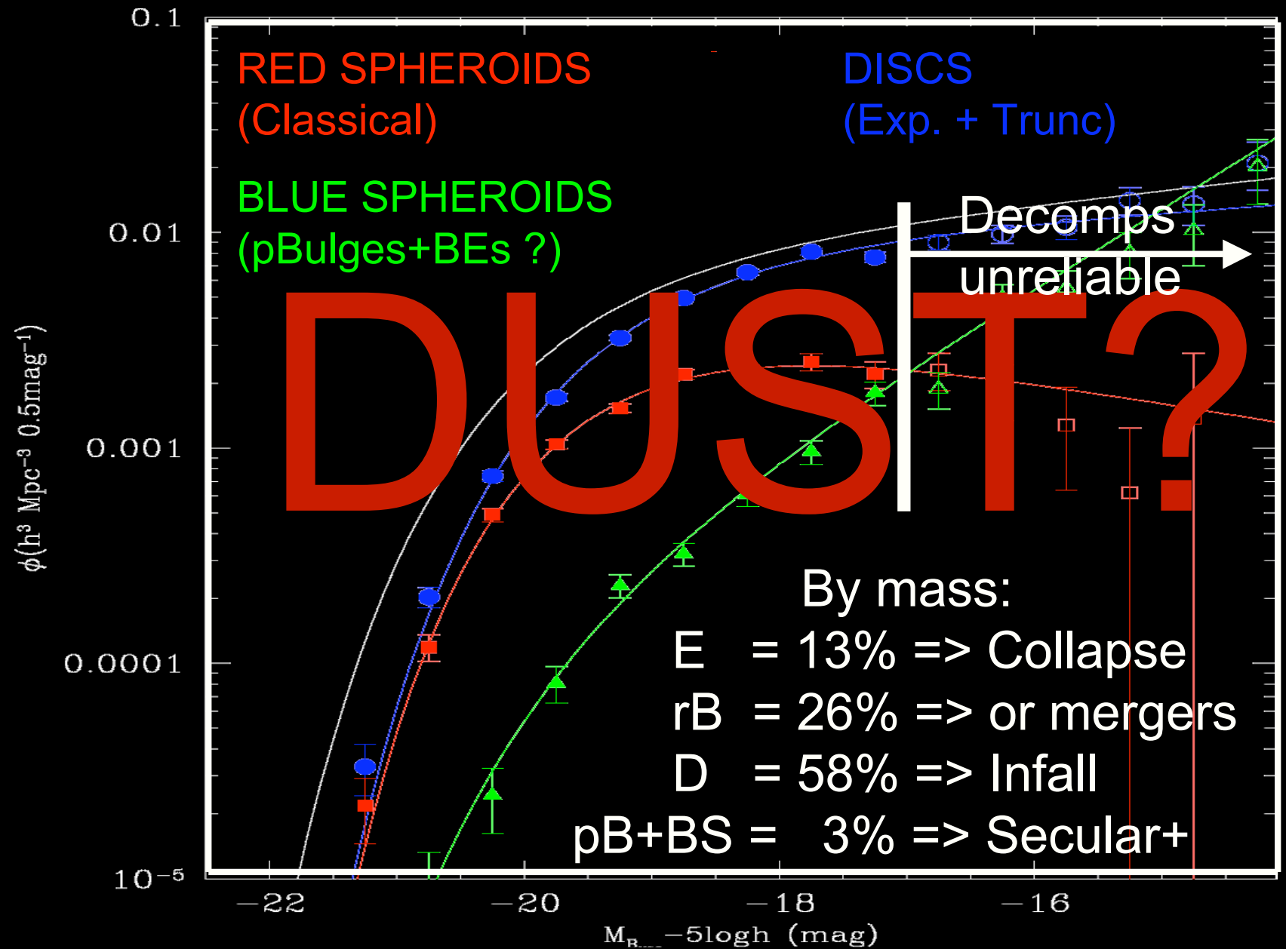
Collapse or rapid mergers ?





The Component Luminosity Functions

Driver et al (2007), ApJL



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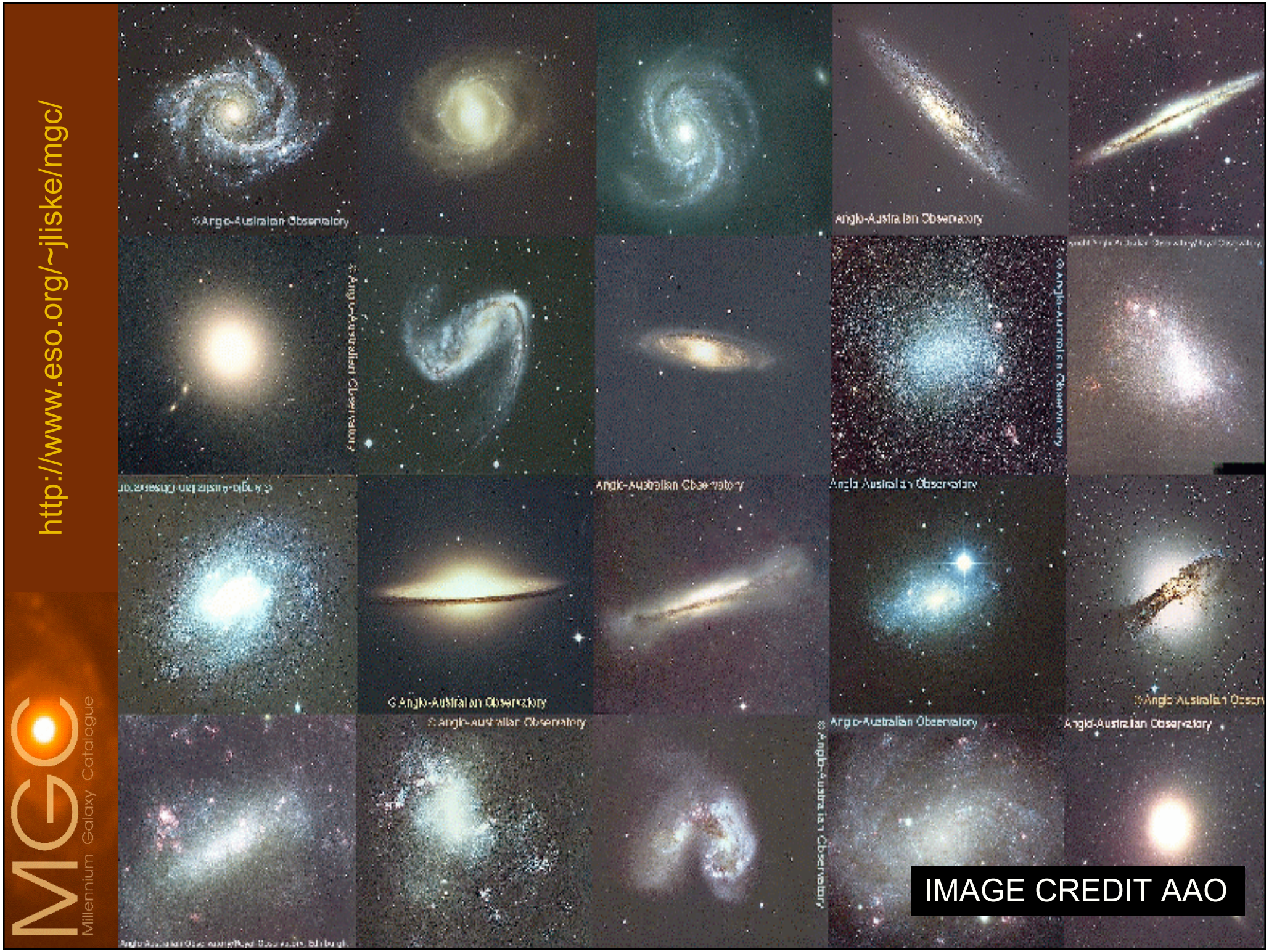
http://www.eso.org/~jliske/mgc/
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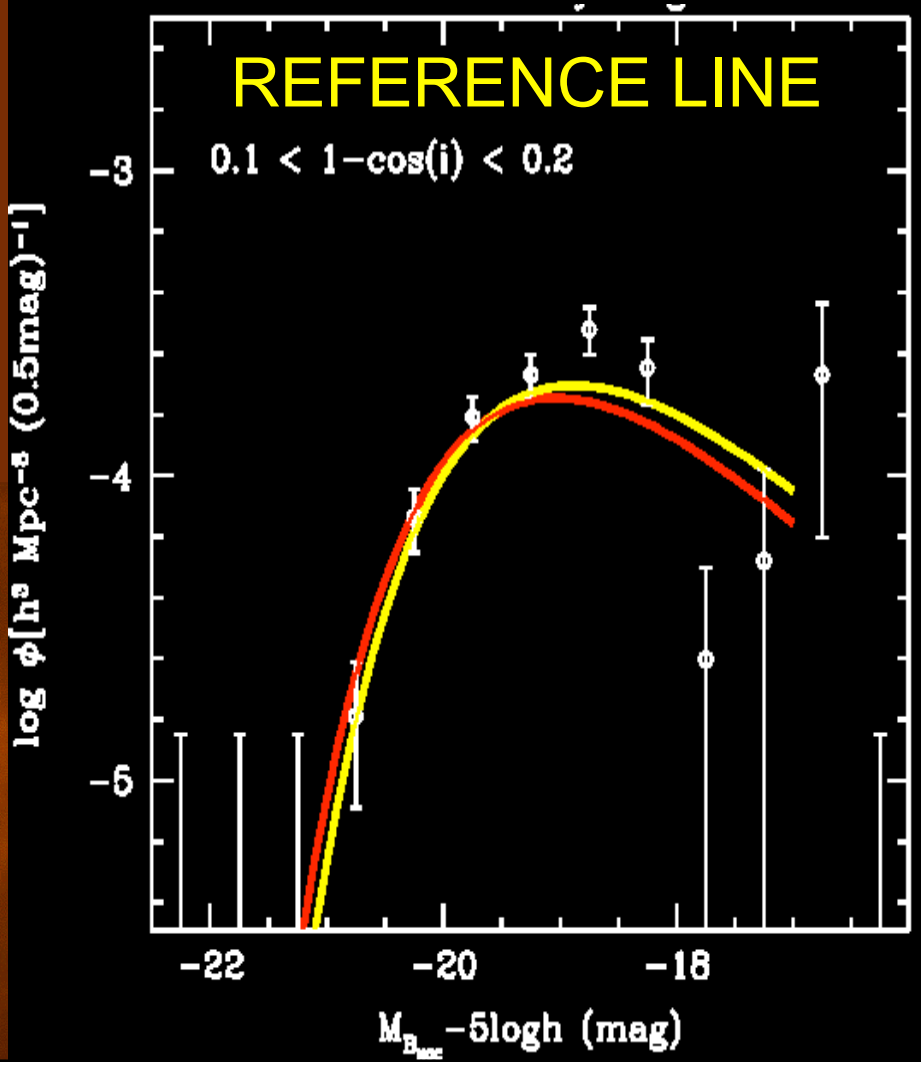
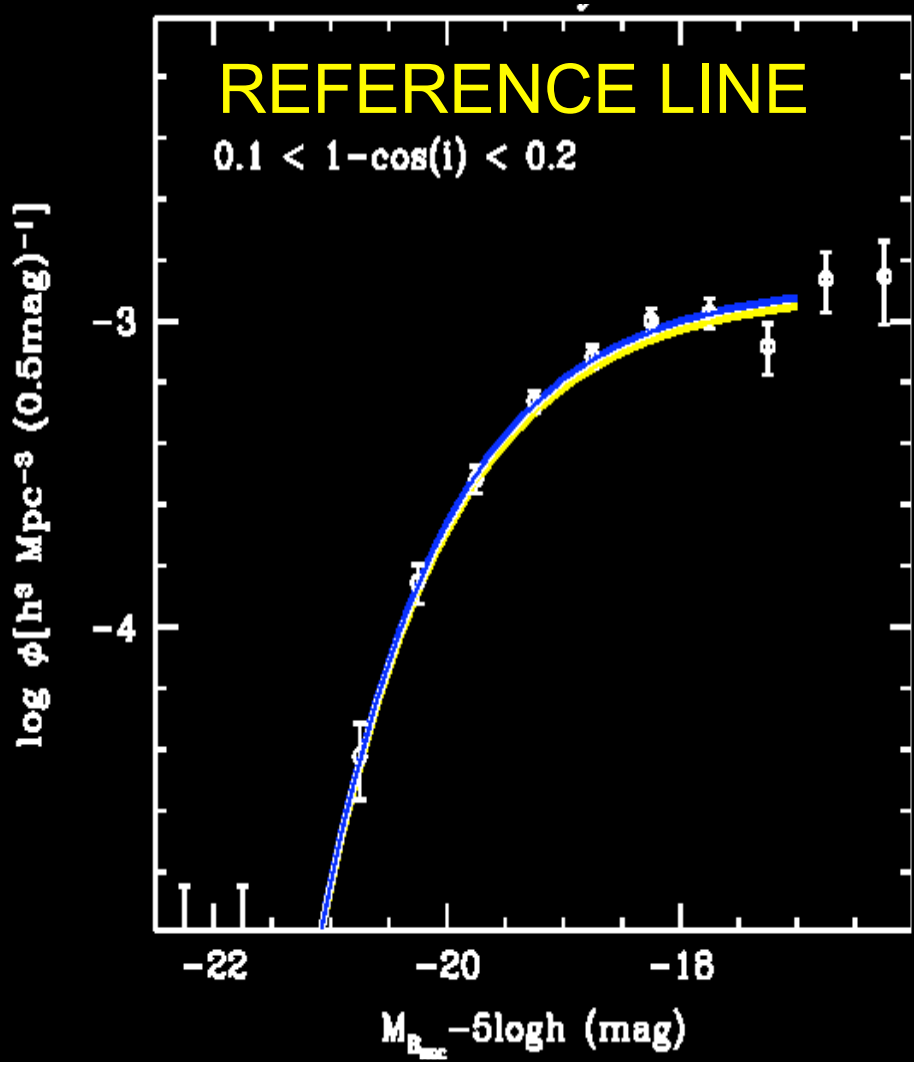
IMAGE CREDIT AAO

Component LFs v cos(*i*)

Nearly face-on galaxies only

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





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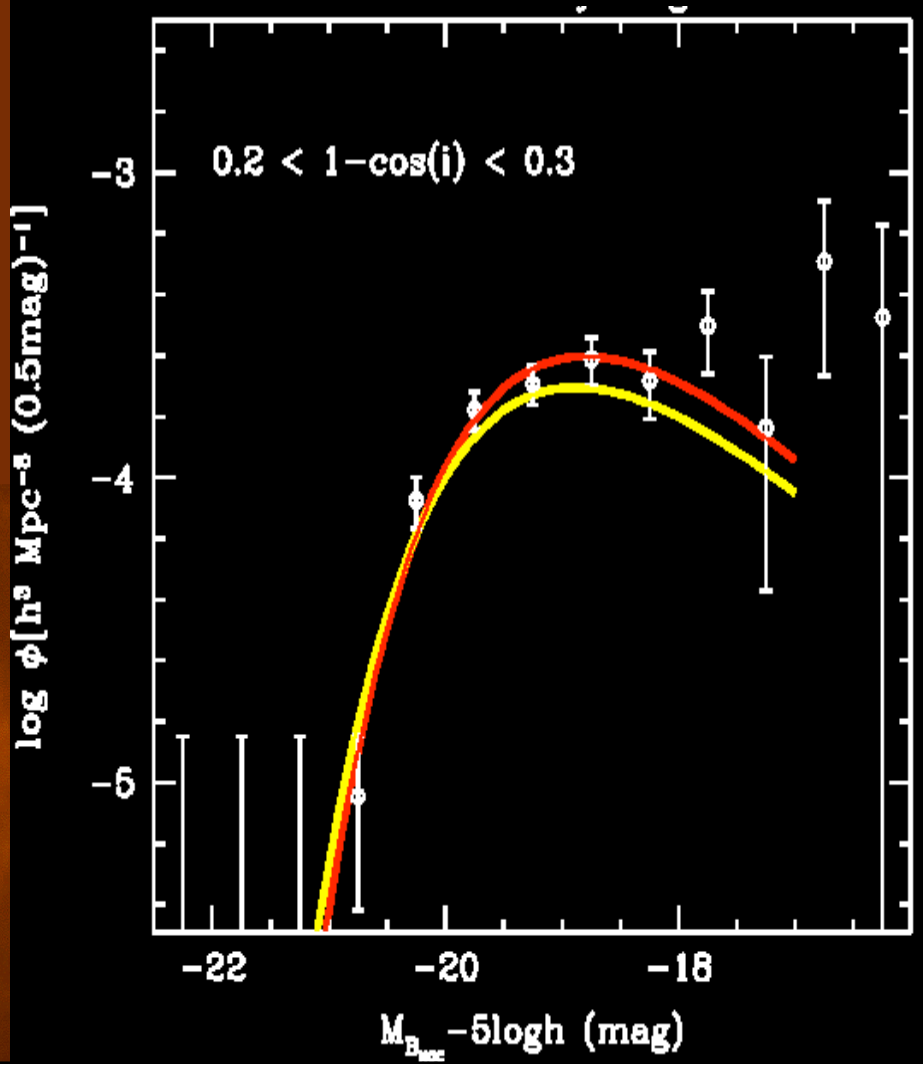
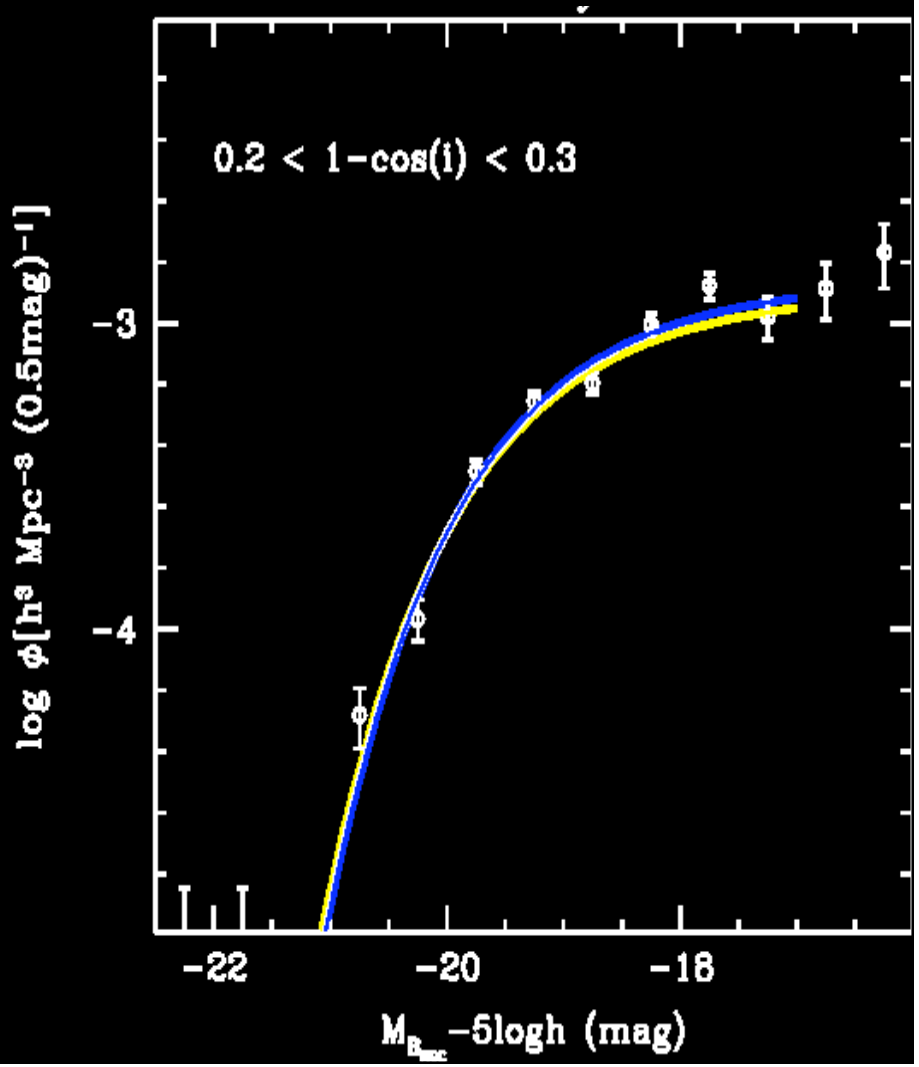
Component LFs v cos(*i*)

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





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

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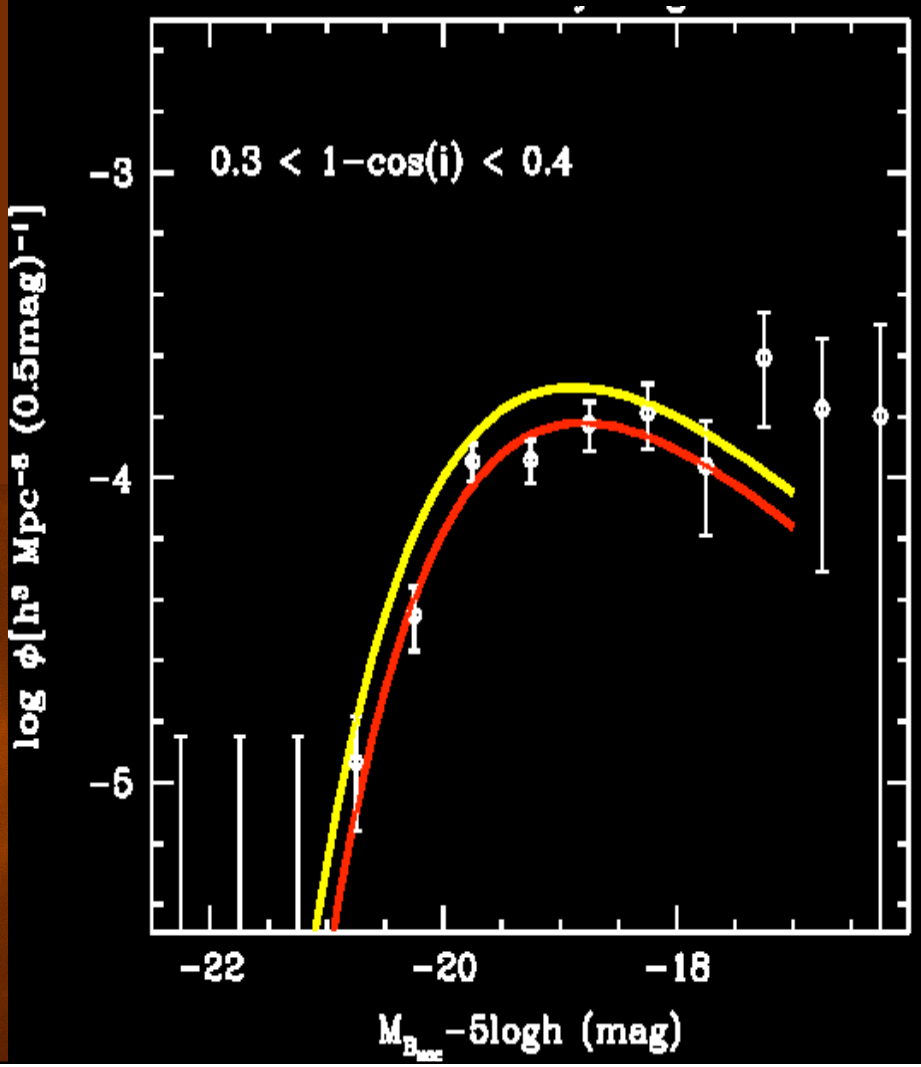
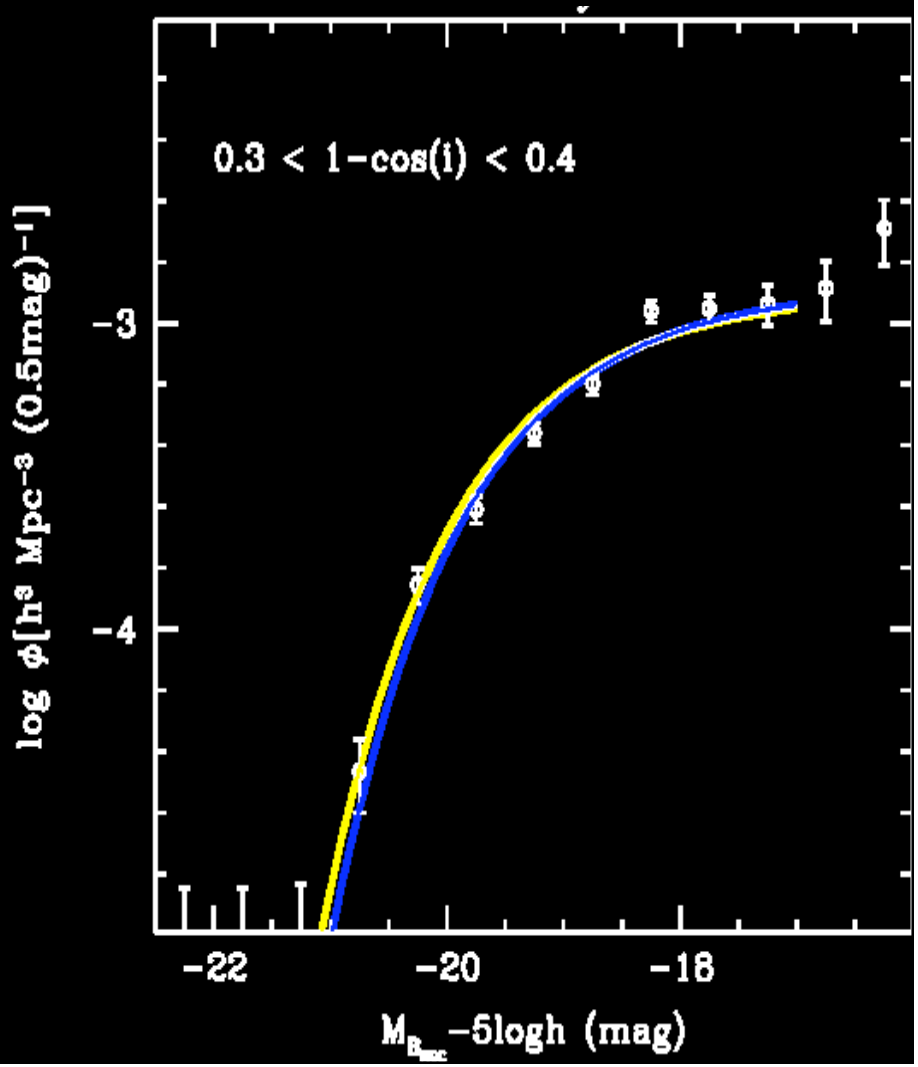
Component LFs v cos(*i*)

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





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

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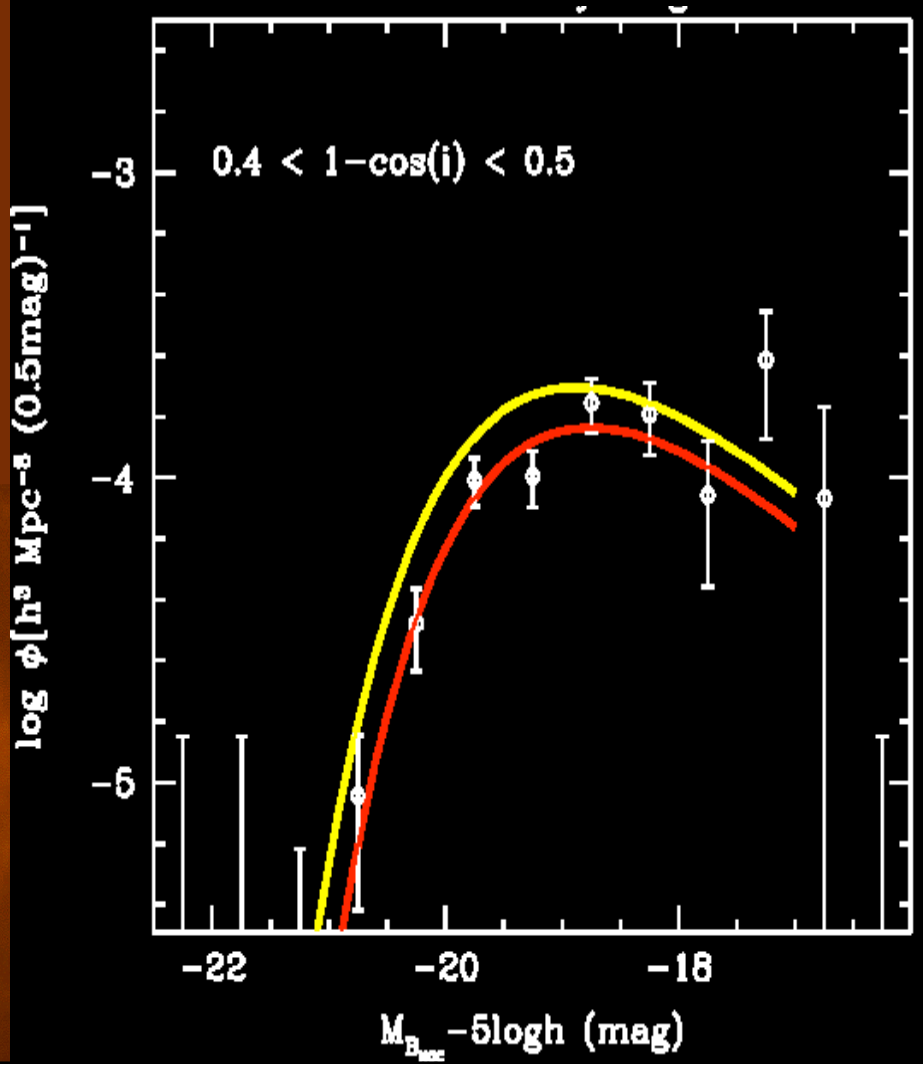
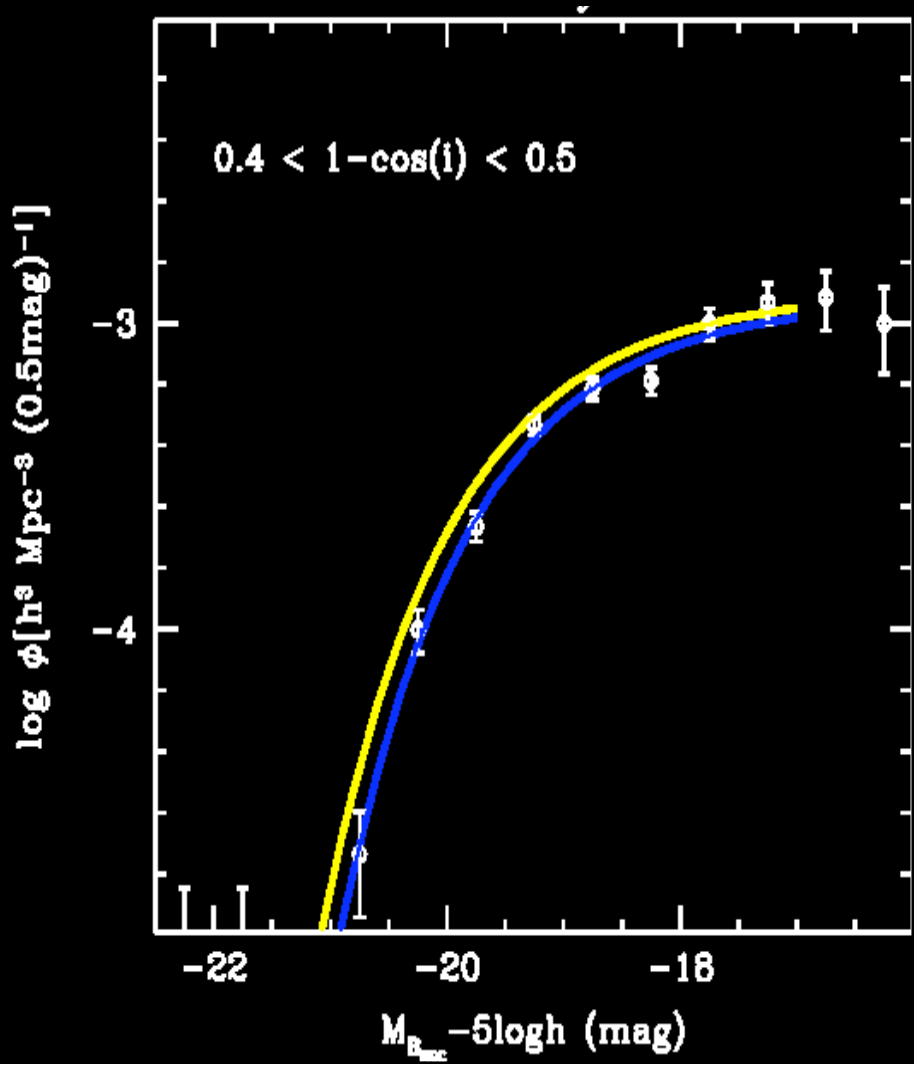
Component LFs v cos(*i*)

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





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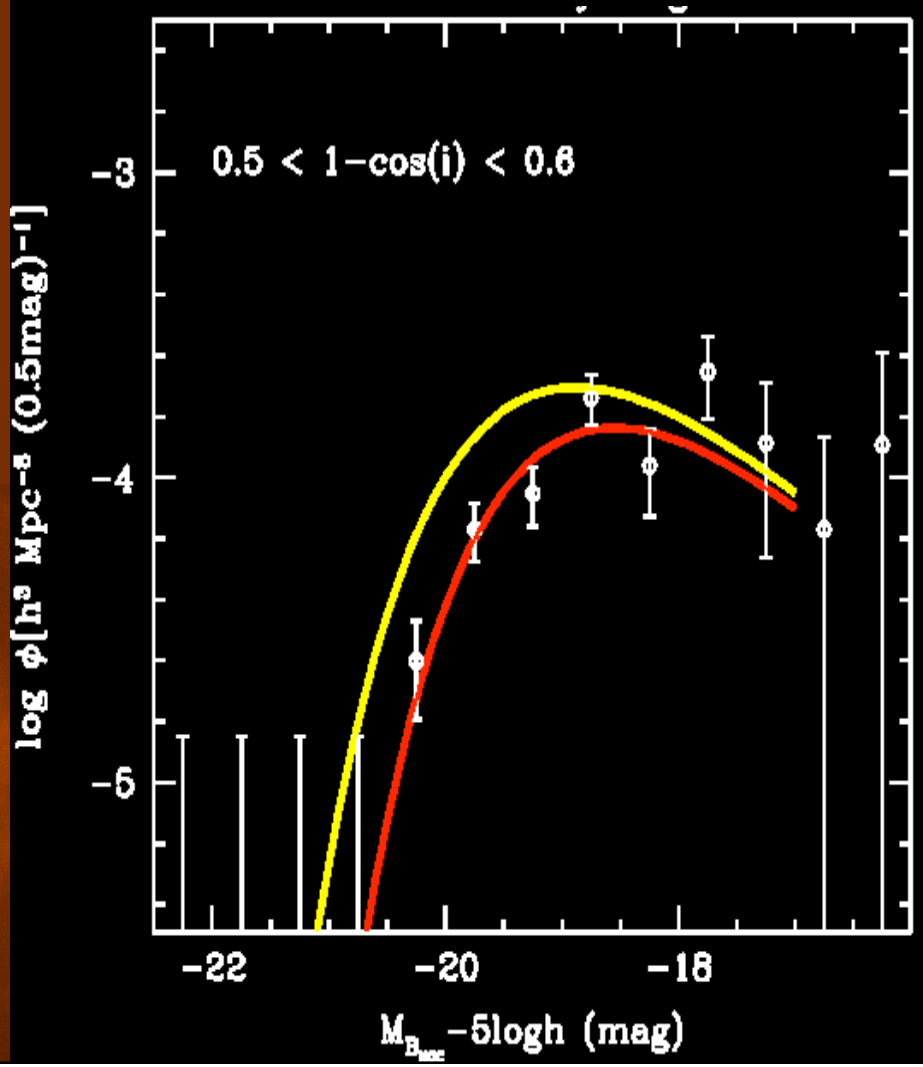
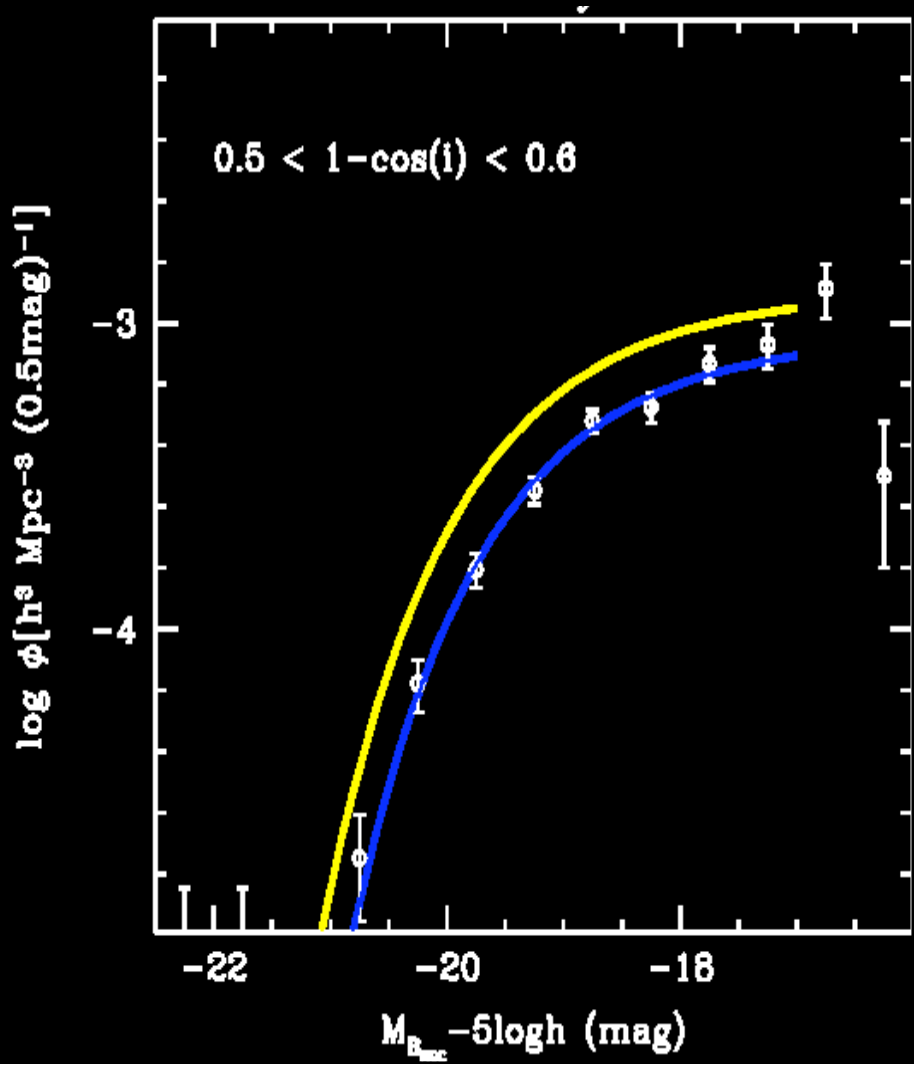
Component LFs v cos(*i*)

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





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Component LFs v cos(*i*)

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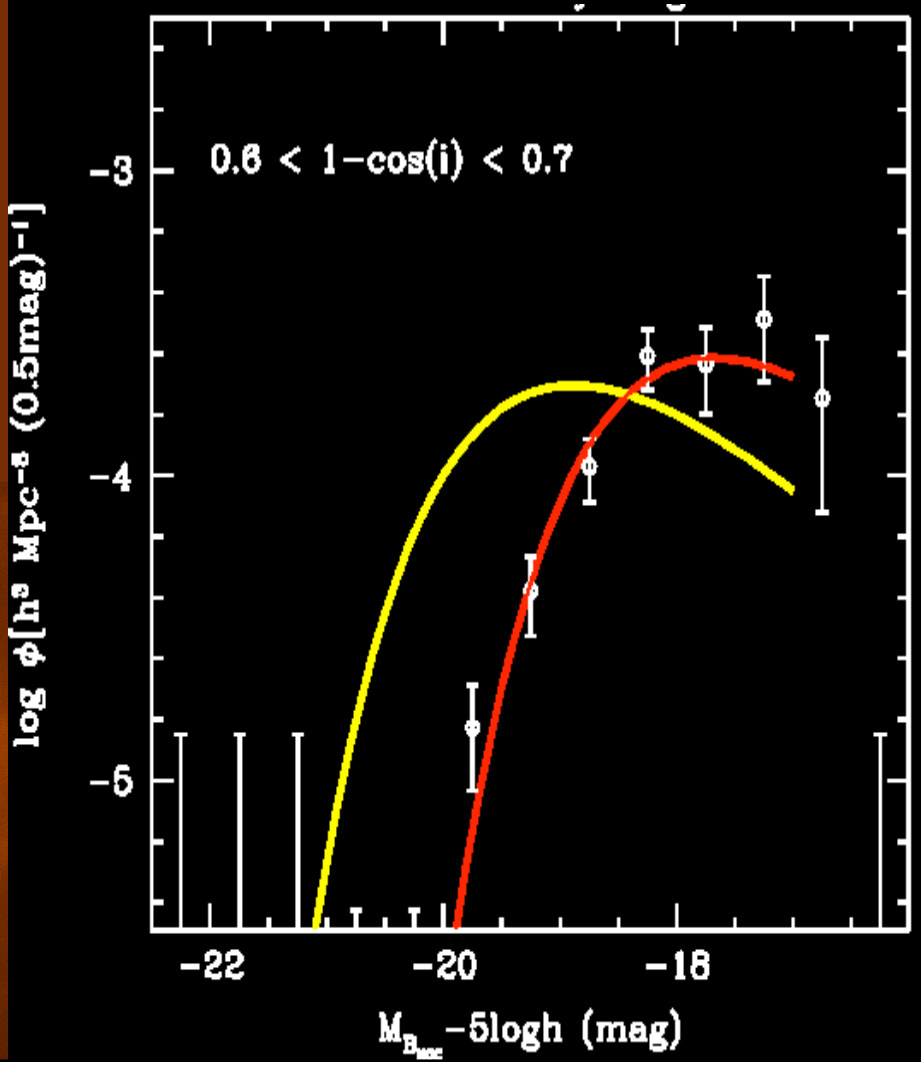
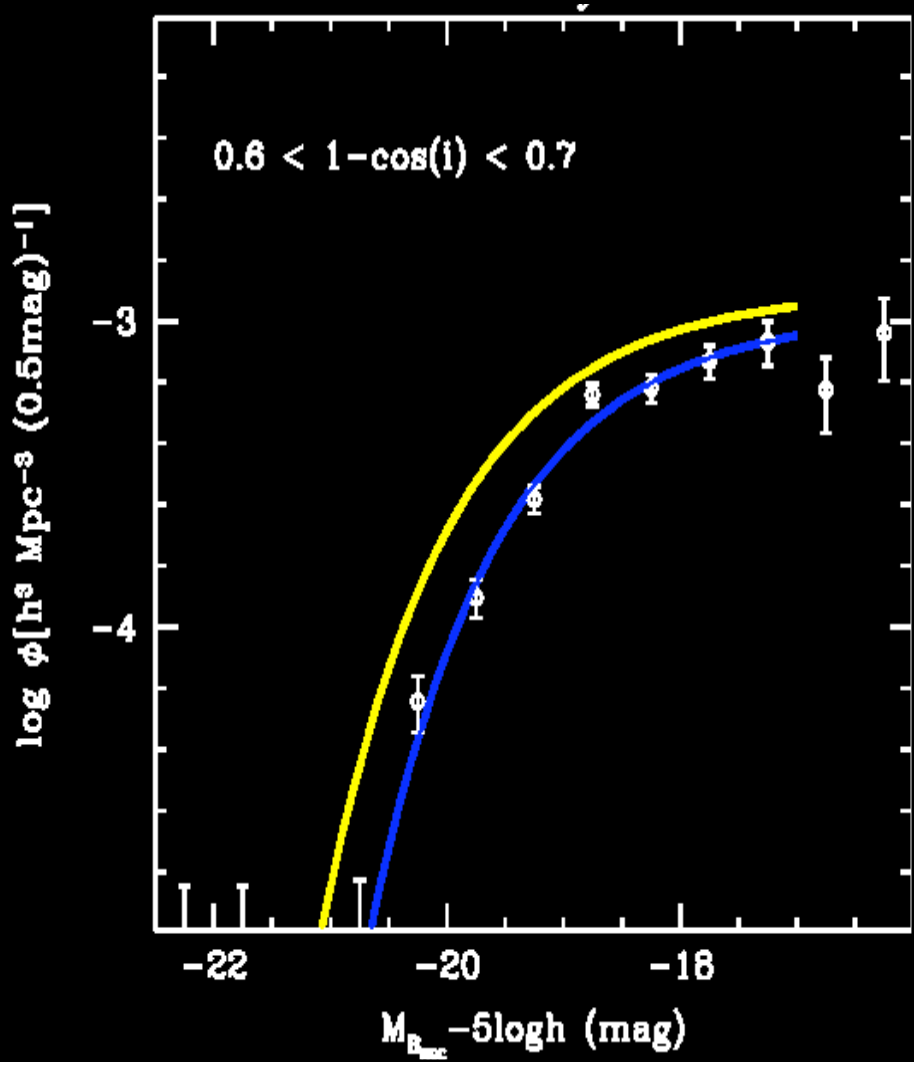
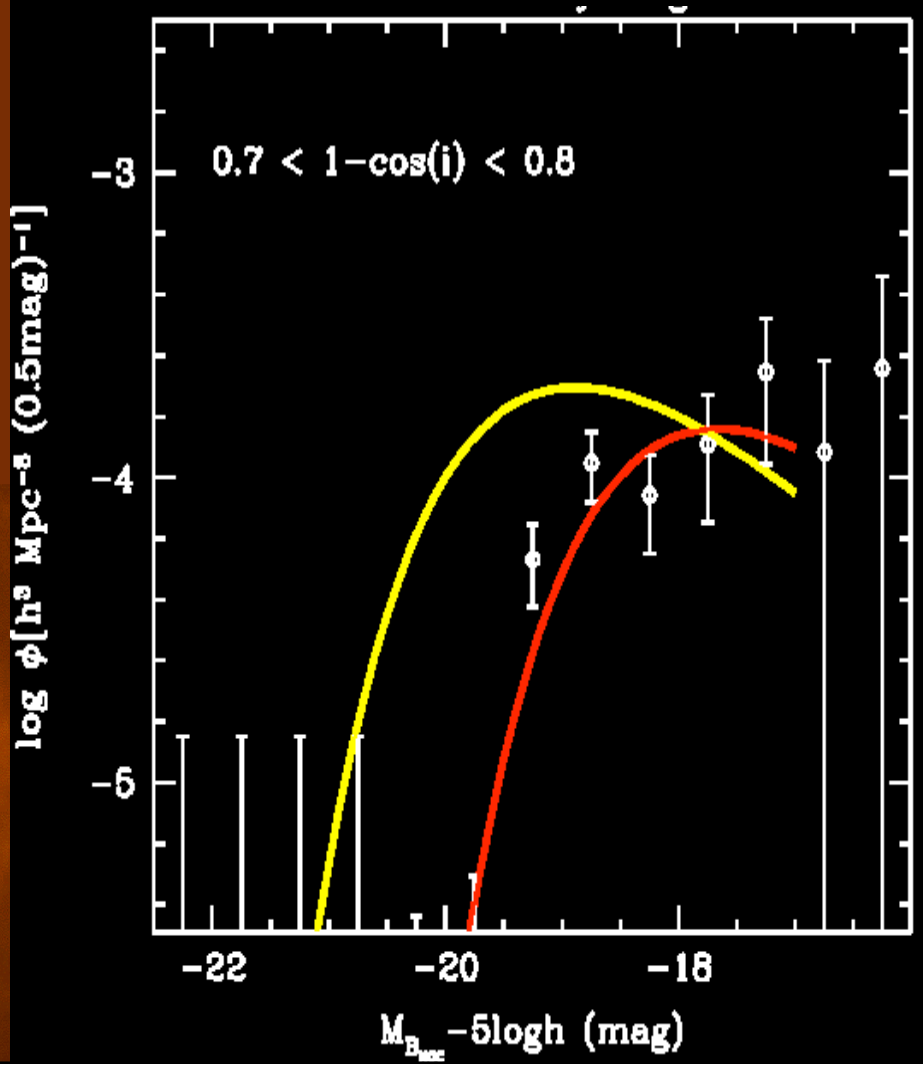
Bulges 0.6 < 1-cos(*i*) < 0.6 Discs

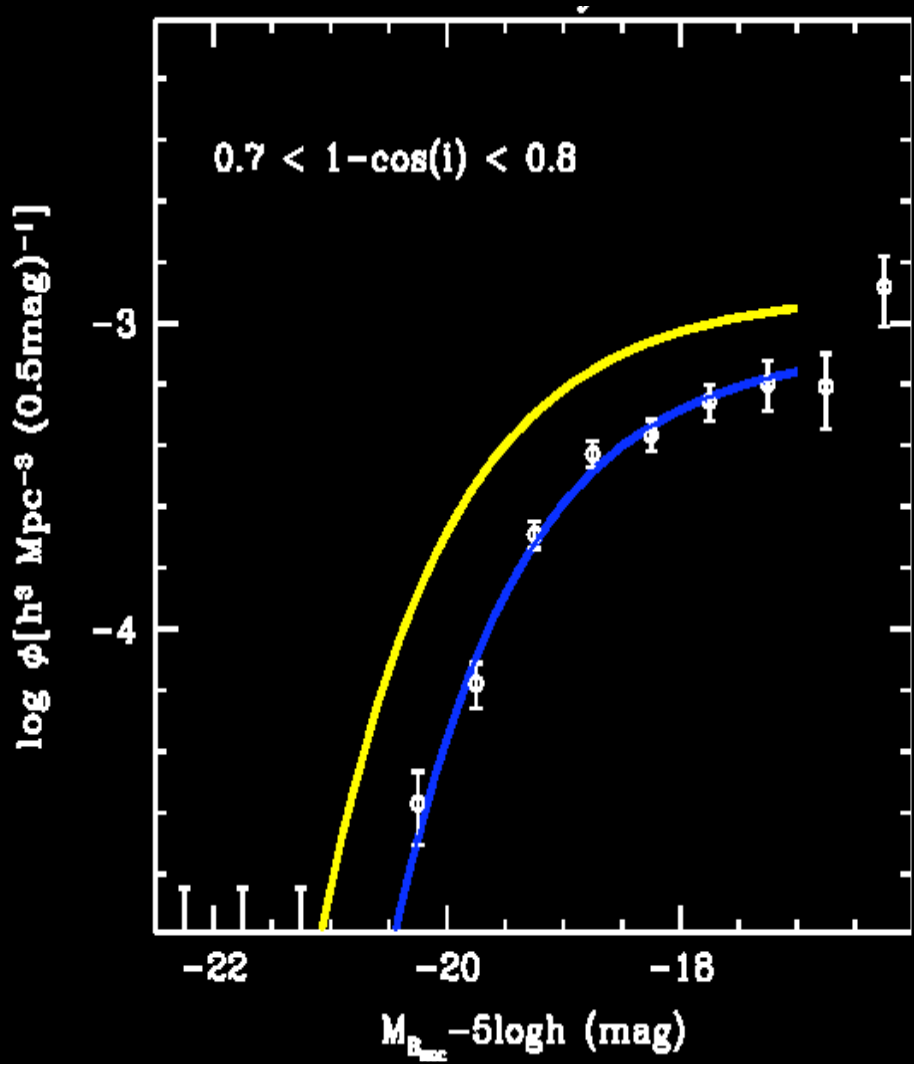




Component LFs v cos(*i*)

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





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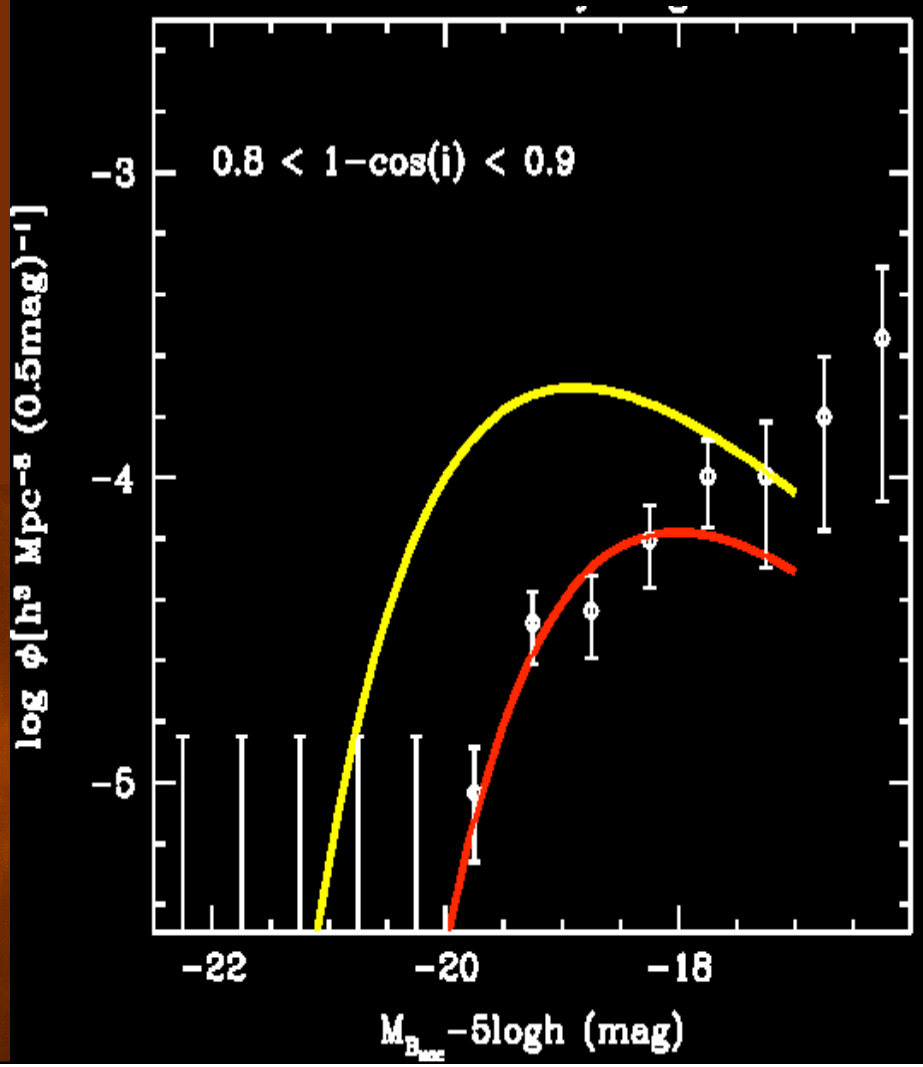
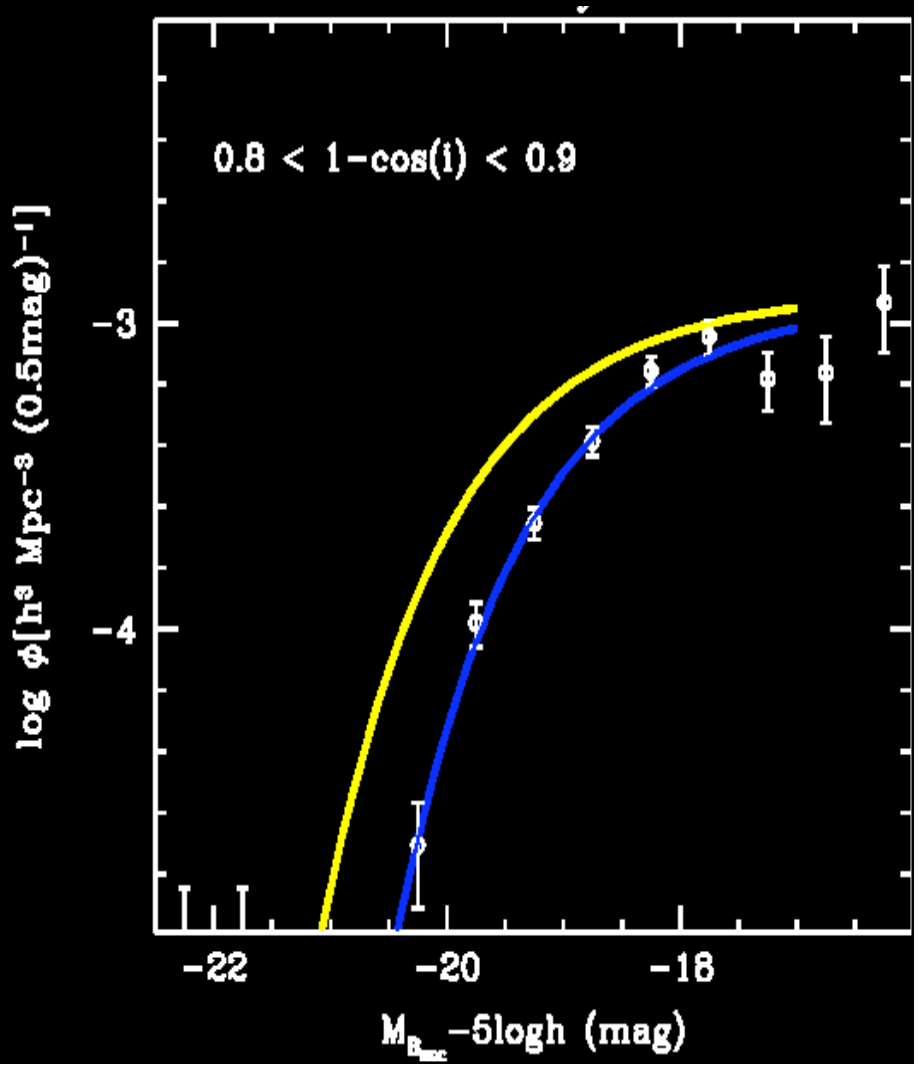
Component LFs v cos(*i*)

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





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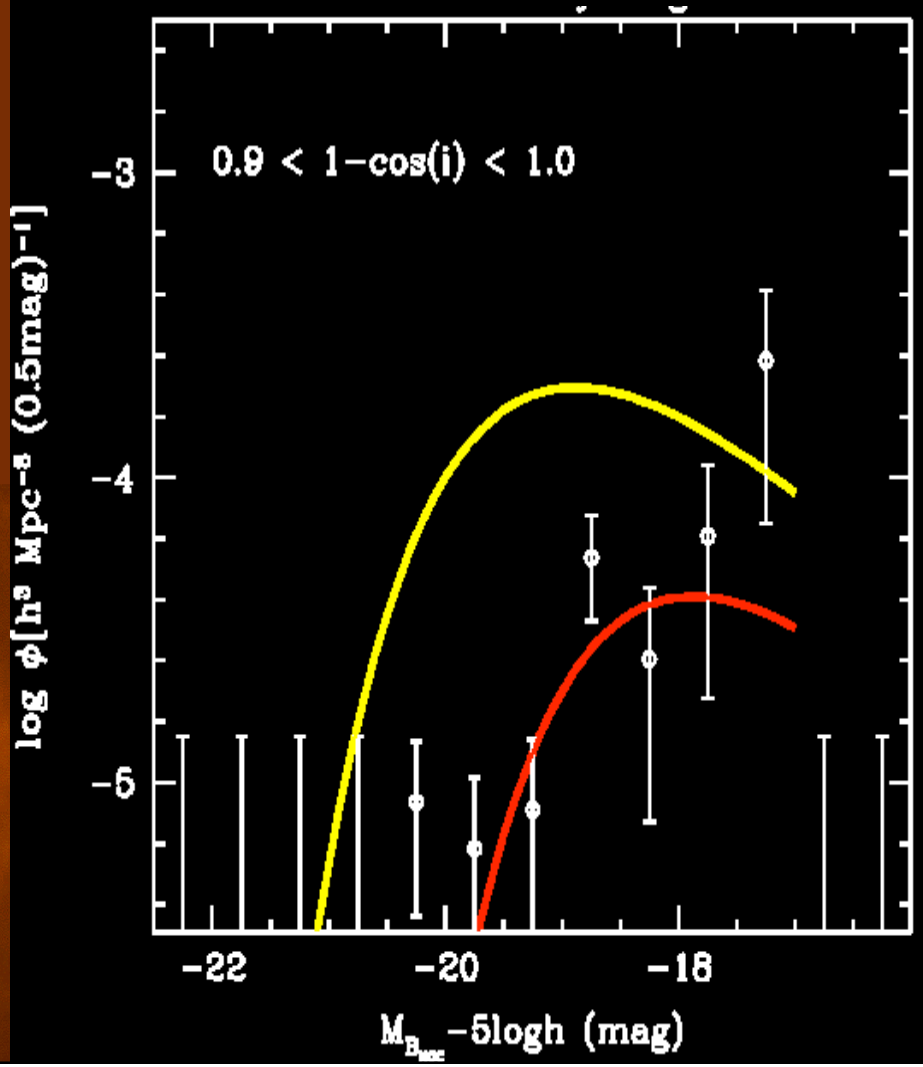
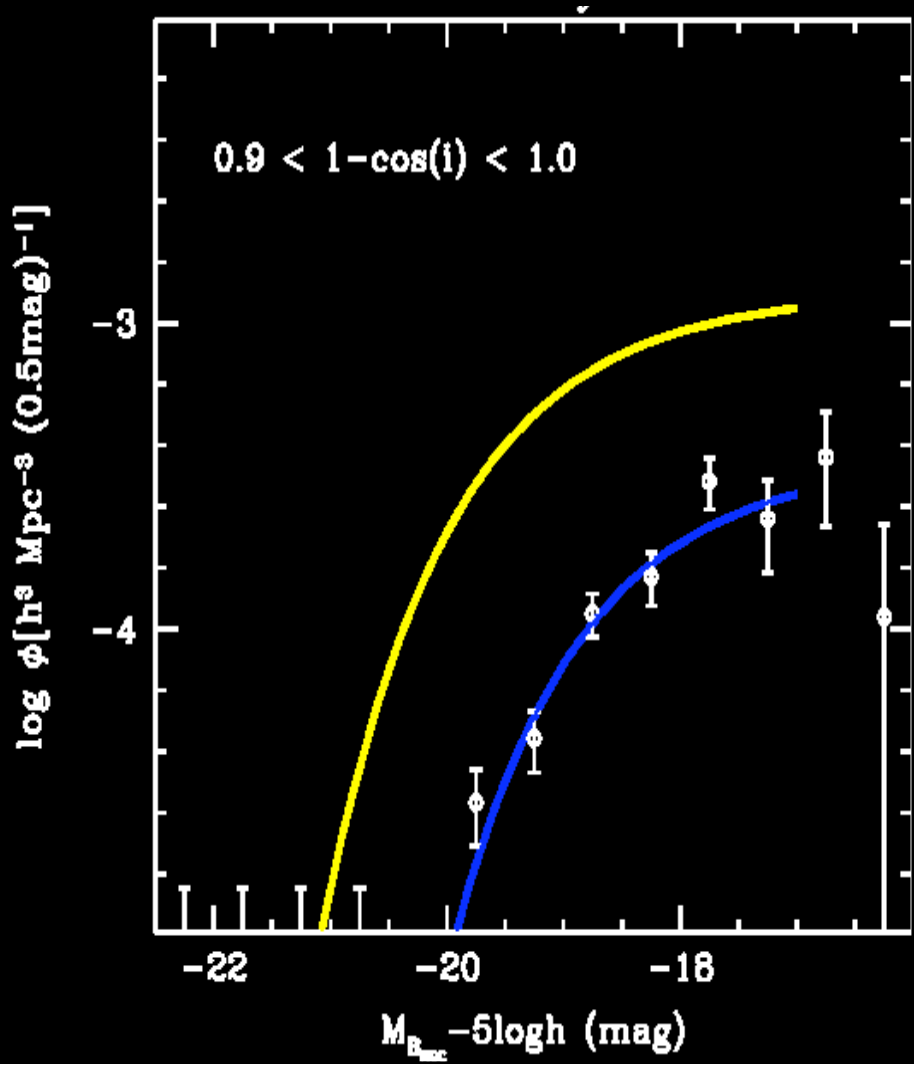
Component LFs v cos(*i*)

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





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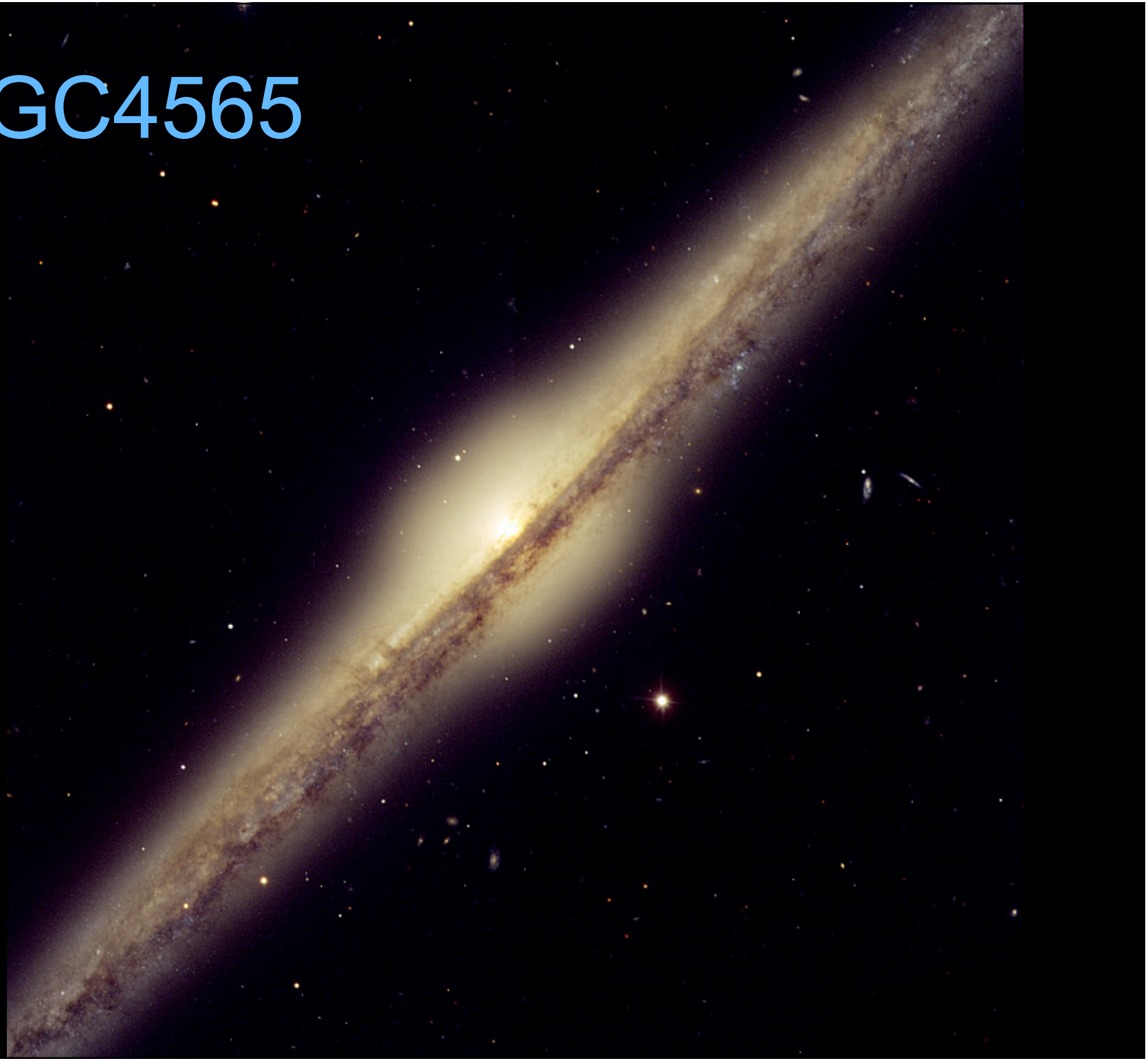
NGC4565



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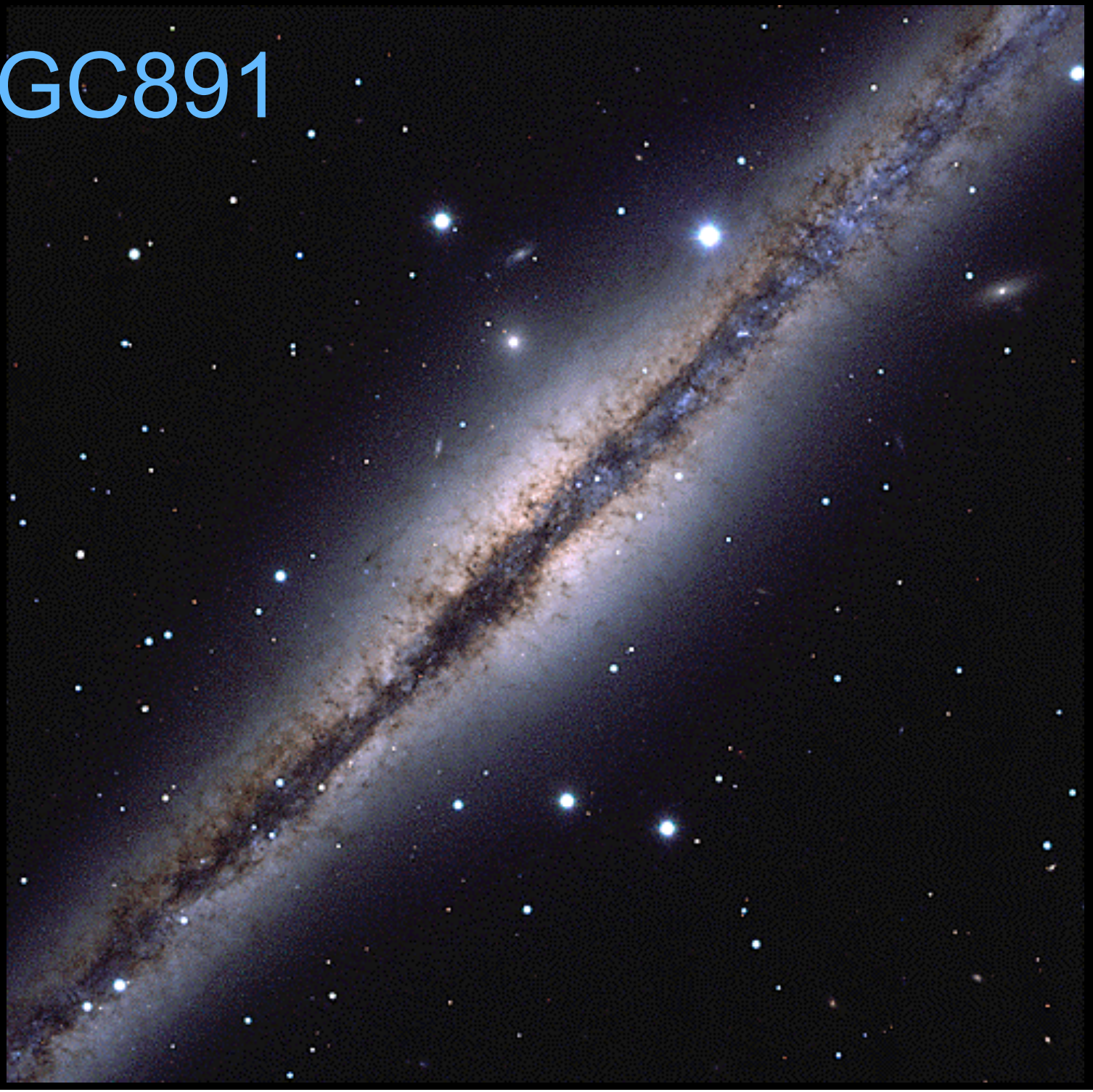
NGC891



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

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Millennium Galaxy Catalogue

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

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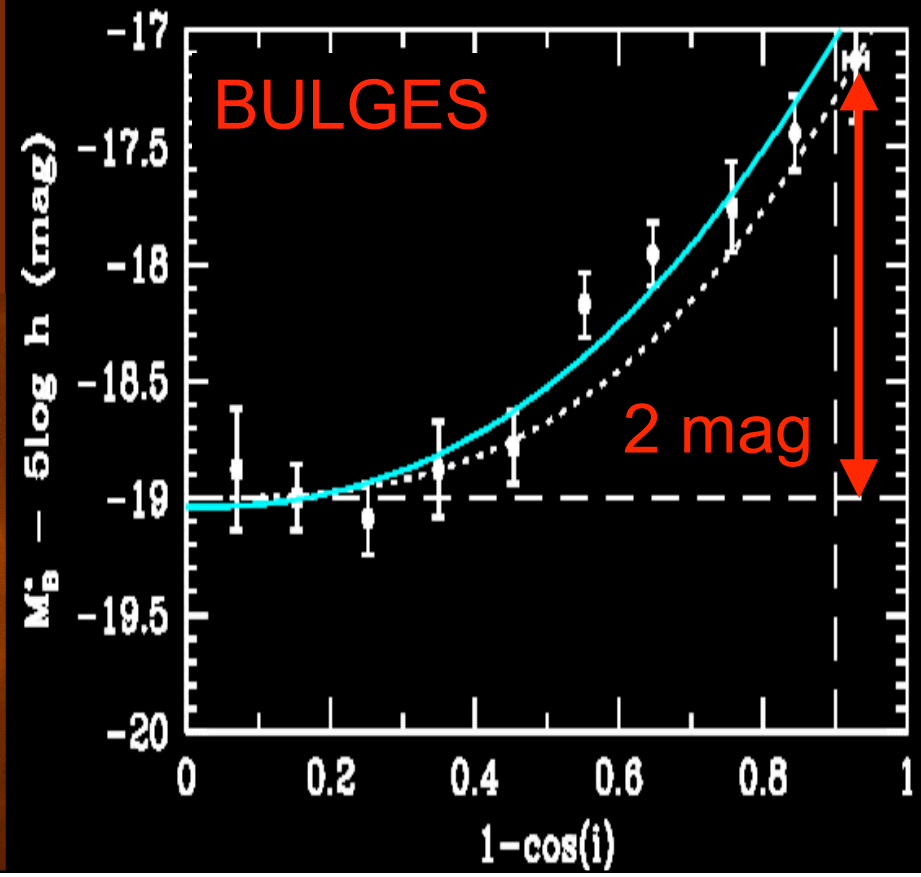
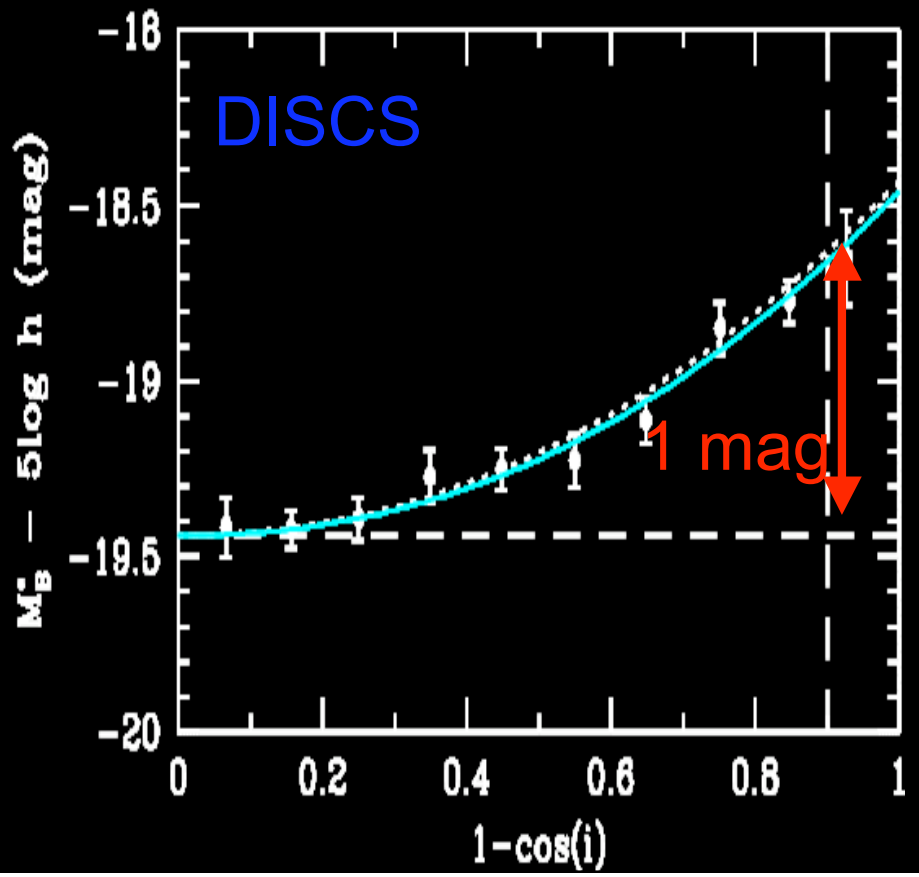
Purely empirical result

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

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





Opacity v B/T

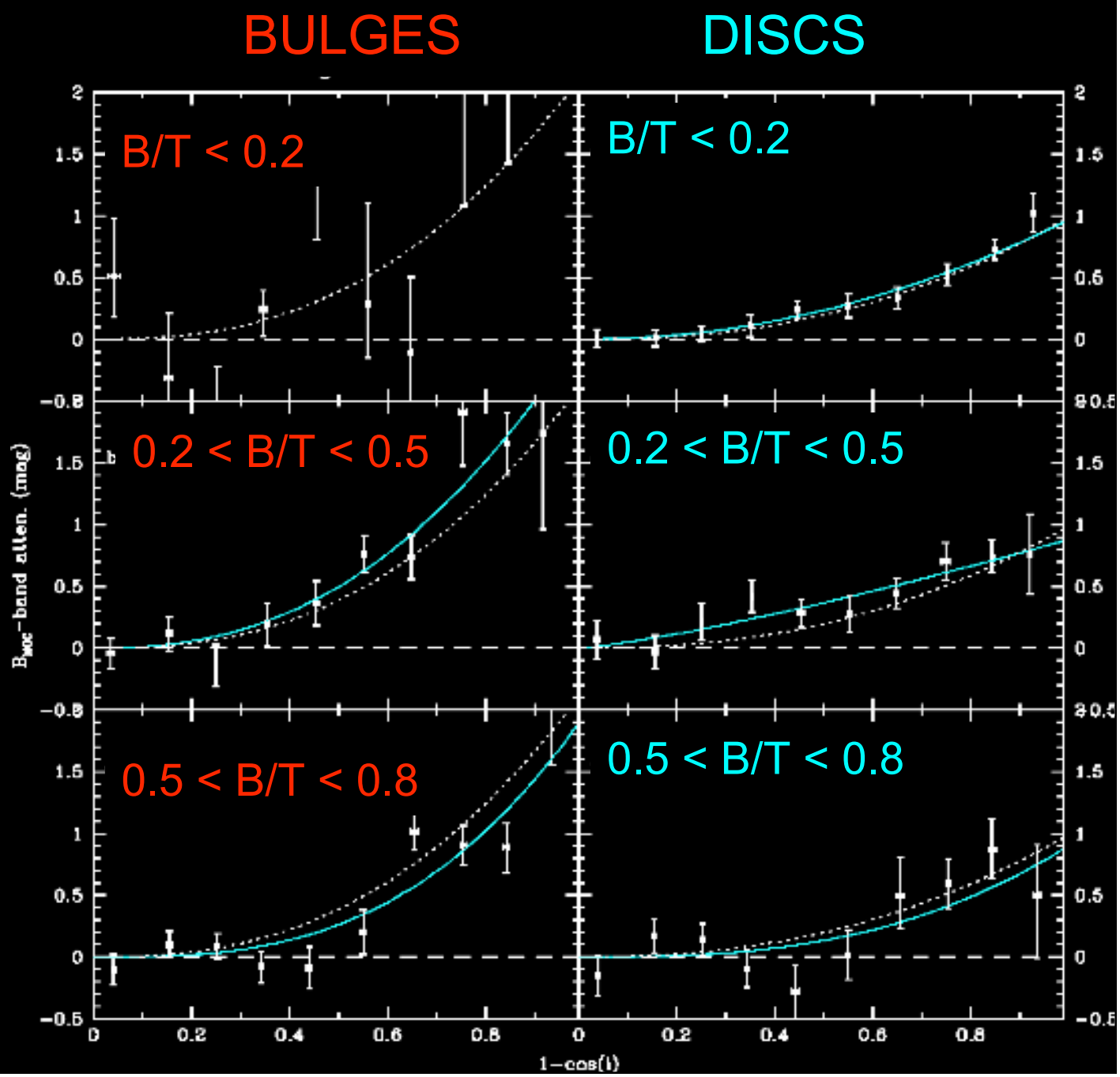
http://www.eso.org/~jliske/mgc/

Same trend seen in high-B/T systems, data getting ratty though.

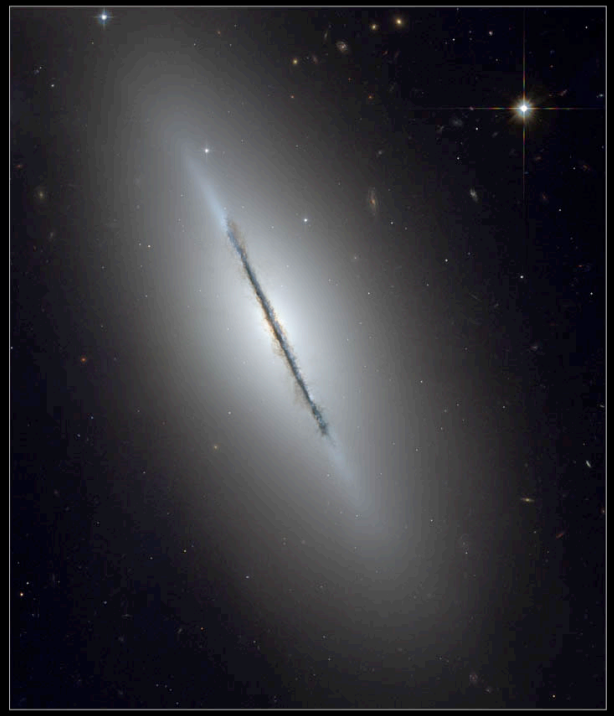
Our results only represent the mean opacity.

We have no constraints on the variance.

Need individual far-IR measurements HERSCHEL



Edge-On Lenticular Galaxy NGC 5866

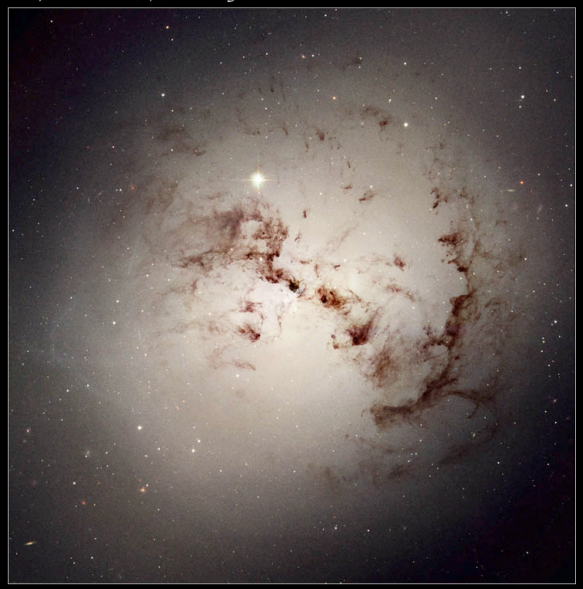


Hubble Heritage

Sombrero Galaxy • M104

Hubble Heritage

Elliptical Galaxy NGC 1316



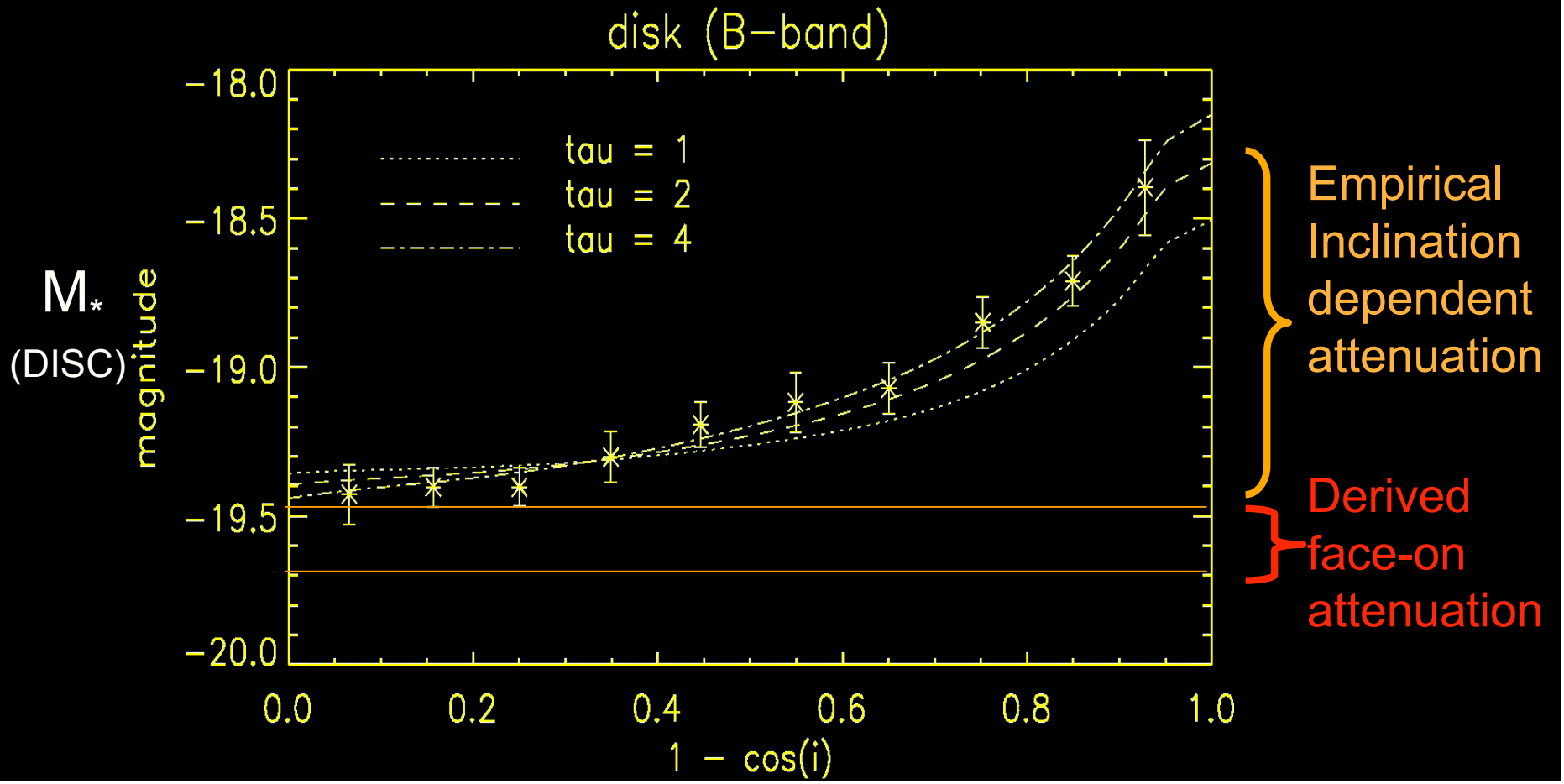
Hubble Heritage

NASA and The Hubble Heritage Team (AURA/STScI) • Hubble Space Telescope ACS • STScI-PRC03-28

Dust in Lenticulars

Face-on corr. via dust modeling

- We adopt 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 = face-on central B band disc opacity



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

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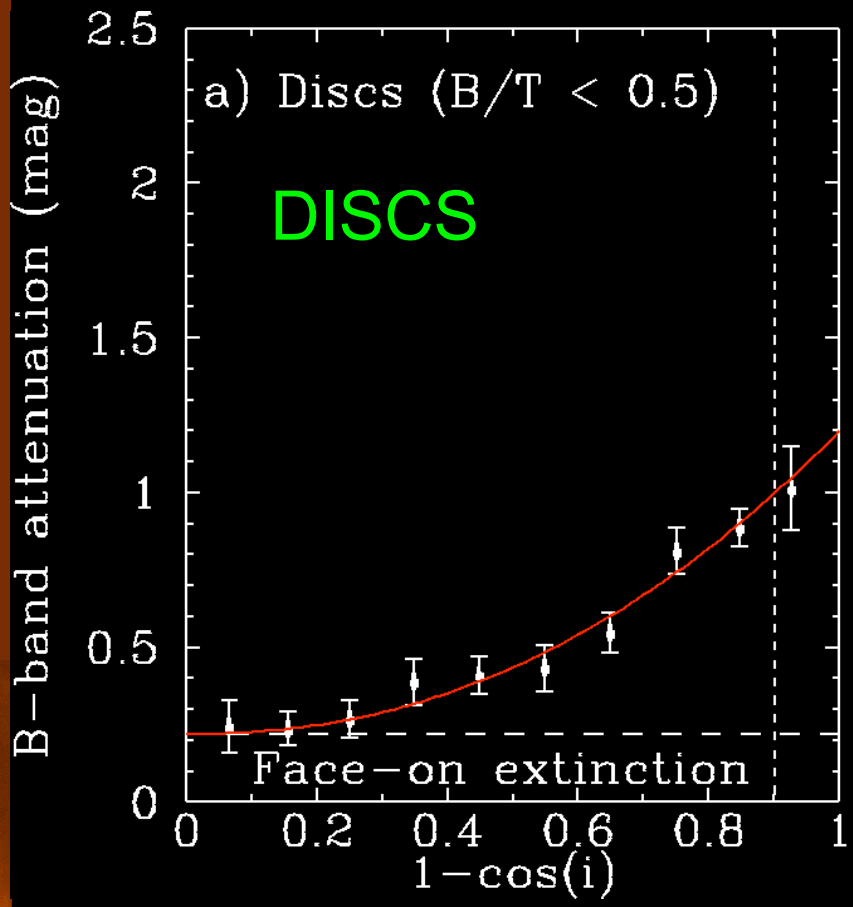
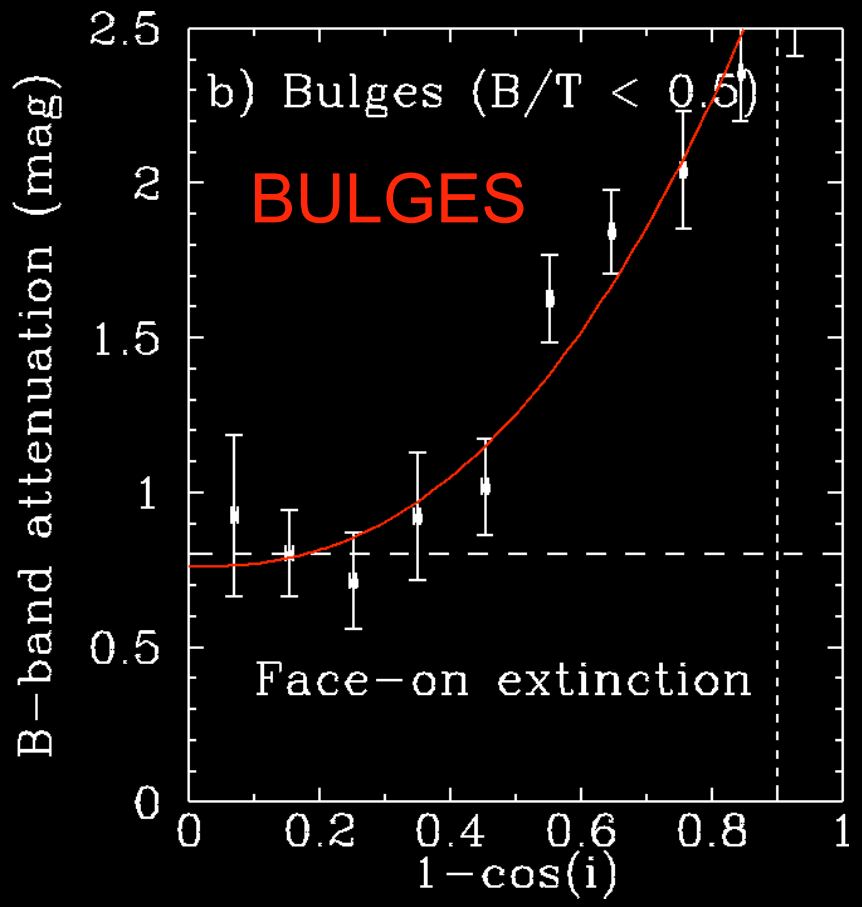
Dust Attenuation

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

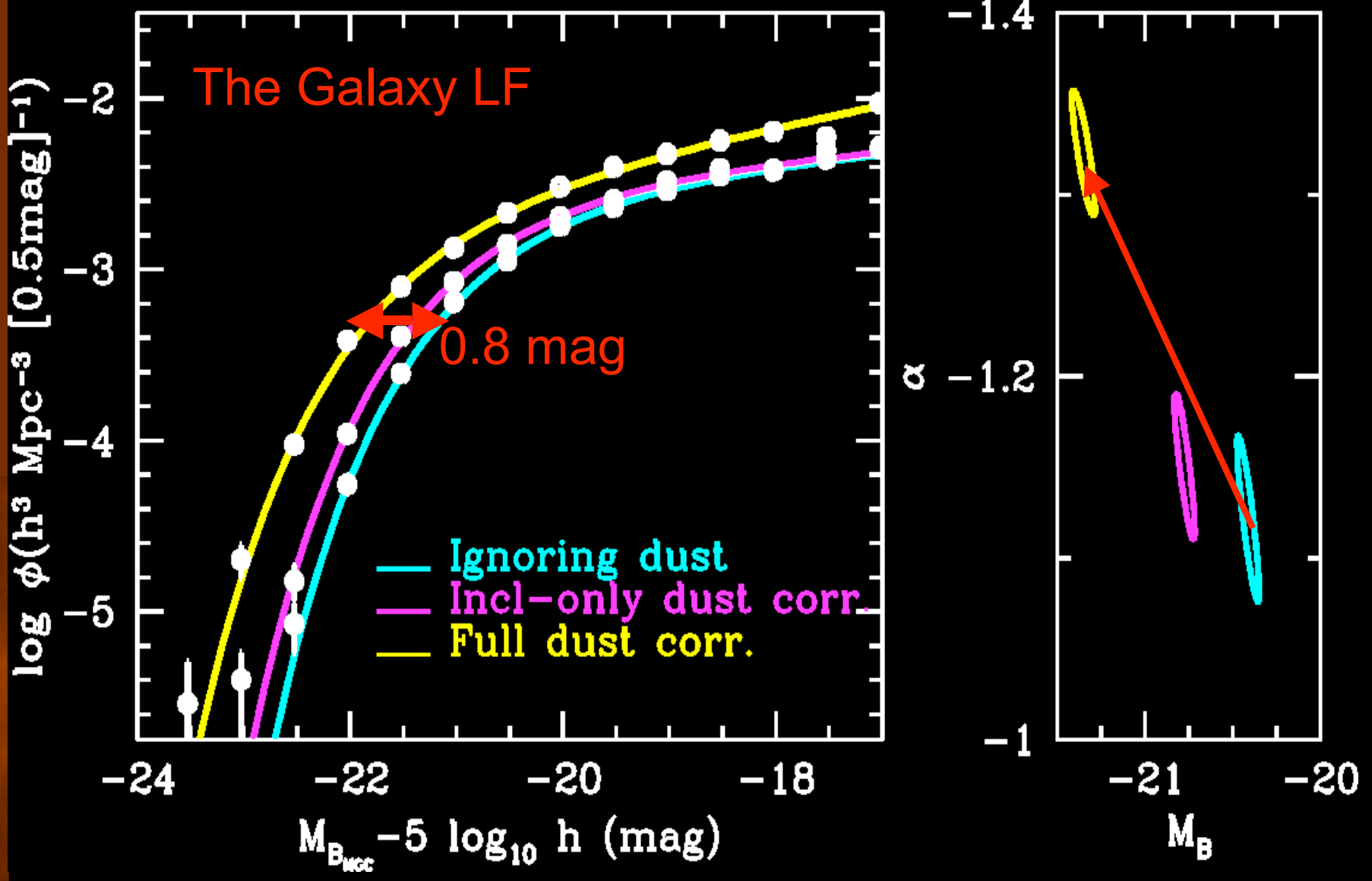




Models imply that discs are optically thick in the centre,
Hence ~*half* of bulge flux is attenuated in face-on systems
=0.75 mag, (as dust has thickness our value is 0.84).

Impact on global B band LF

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



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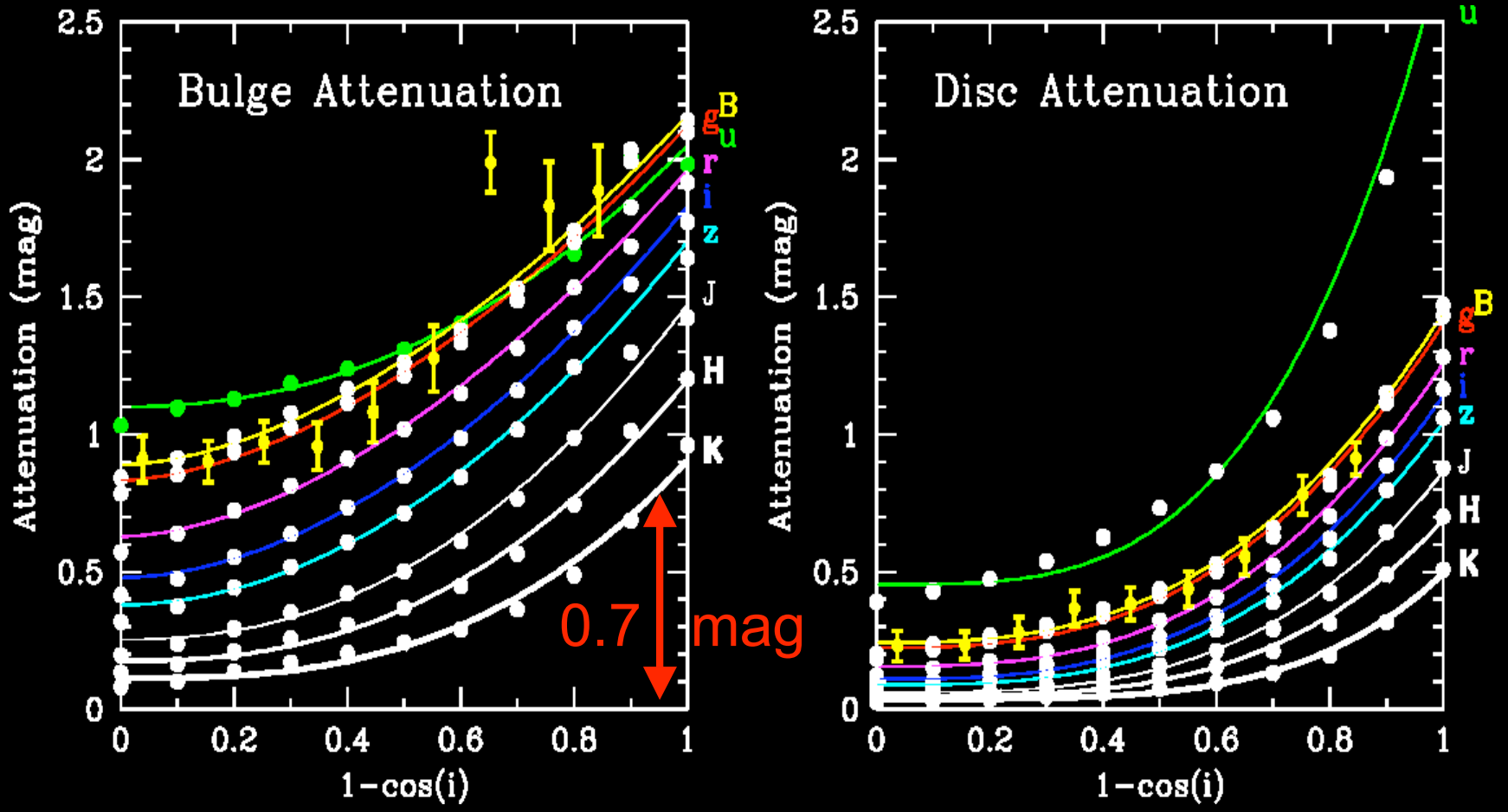
Dust attenuation versus λ

Using calibrated Tuffs & Popescu model can derive inclination-attenuation relation for any wavelength.

Attenuation still an issue in K for highly inclined systems



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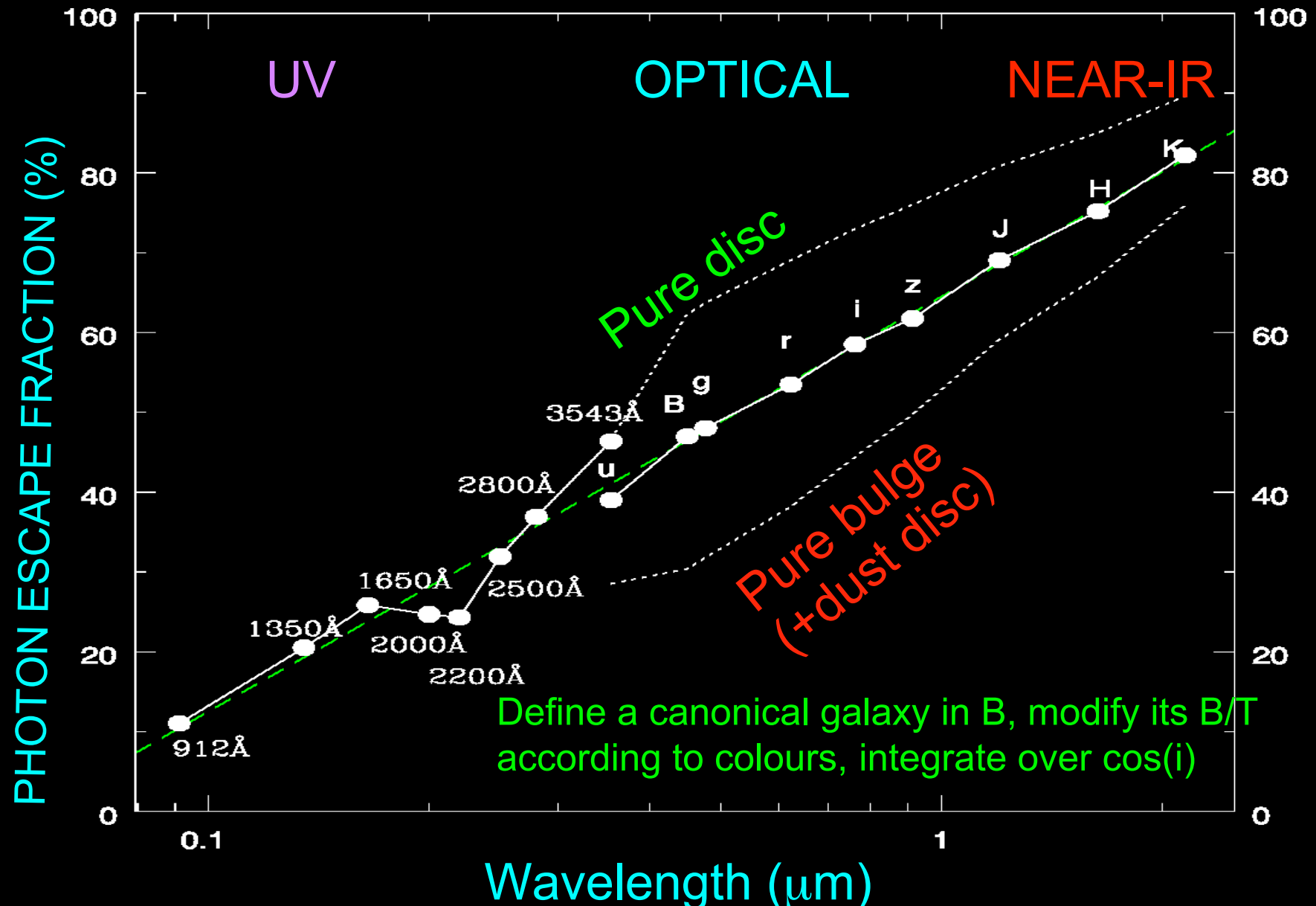
Photon escape fraction averaged over entire nearby galaxy population



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

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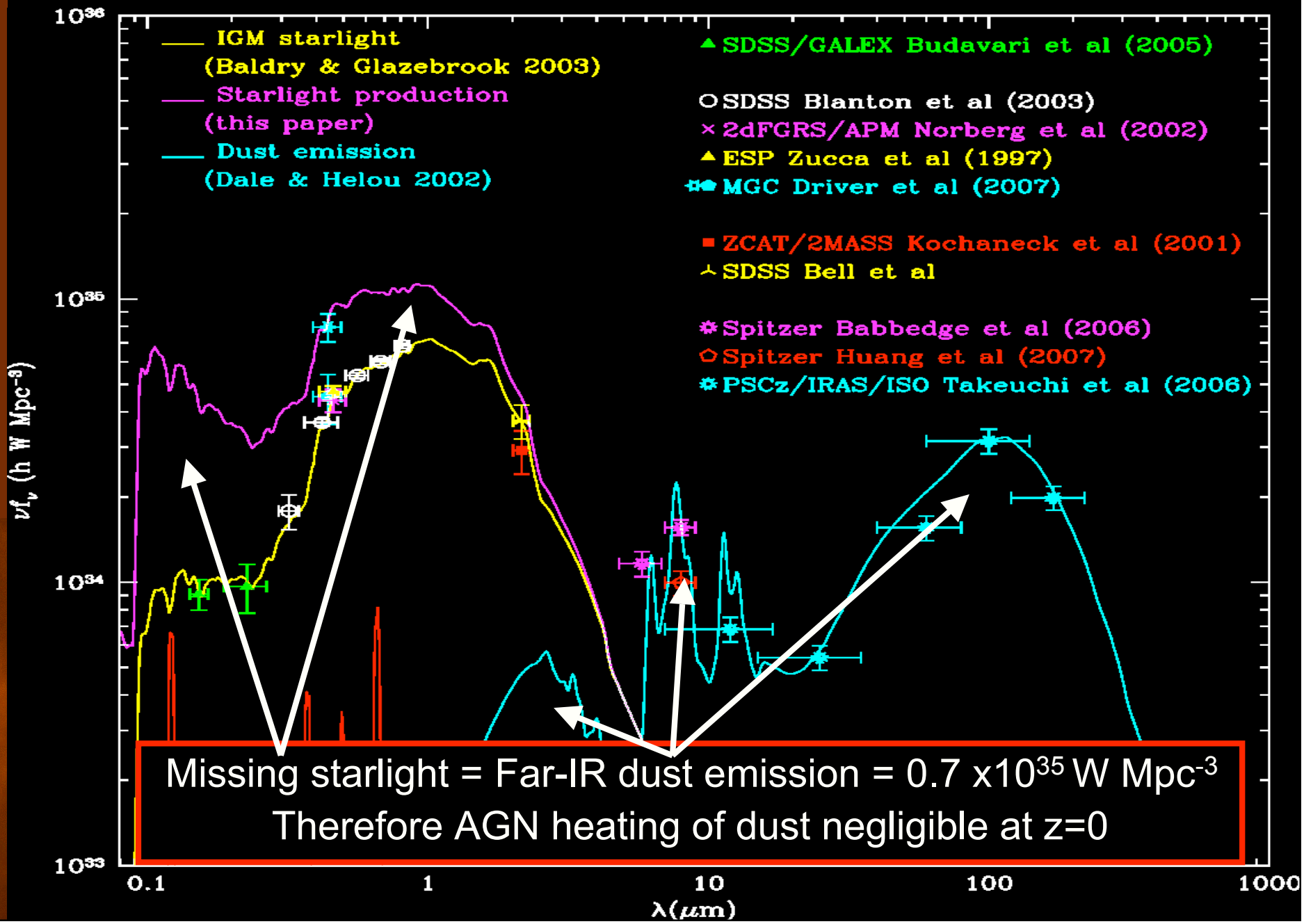
Cosmic Energy Budget



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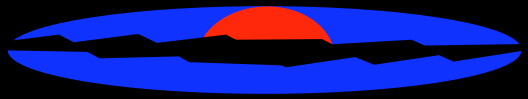
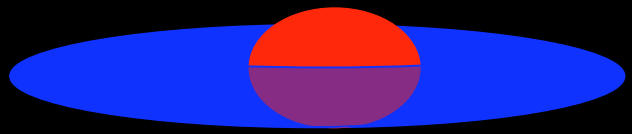
Hubble type transformation ?!

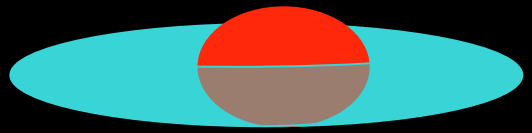
1. Mid-type spiral falling into cluster (cos*i*=0.5):
   B=0.2, D=0.8, B/T=0.2, L=1.0, Blue
   Sc (NB: cos(i)=0.0=Sa, cos(i)=1=Sd)



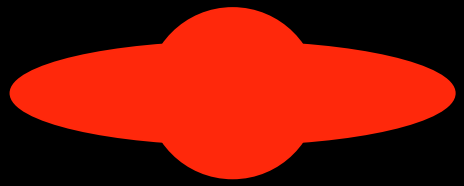
2. *destroy dust* (heating):
   B=0.6, D=1.2, B/T=0.3, L=1.8 Green
   Sab



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



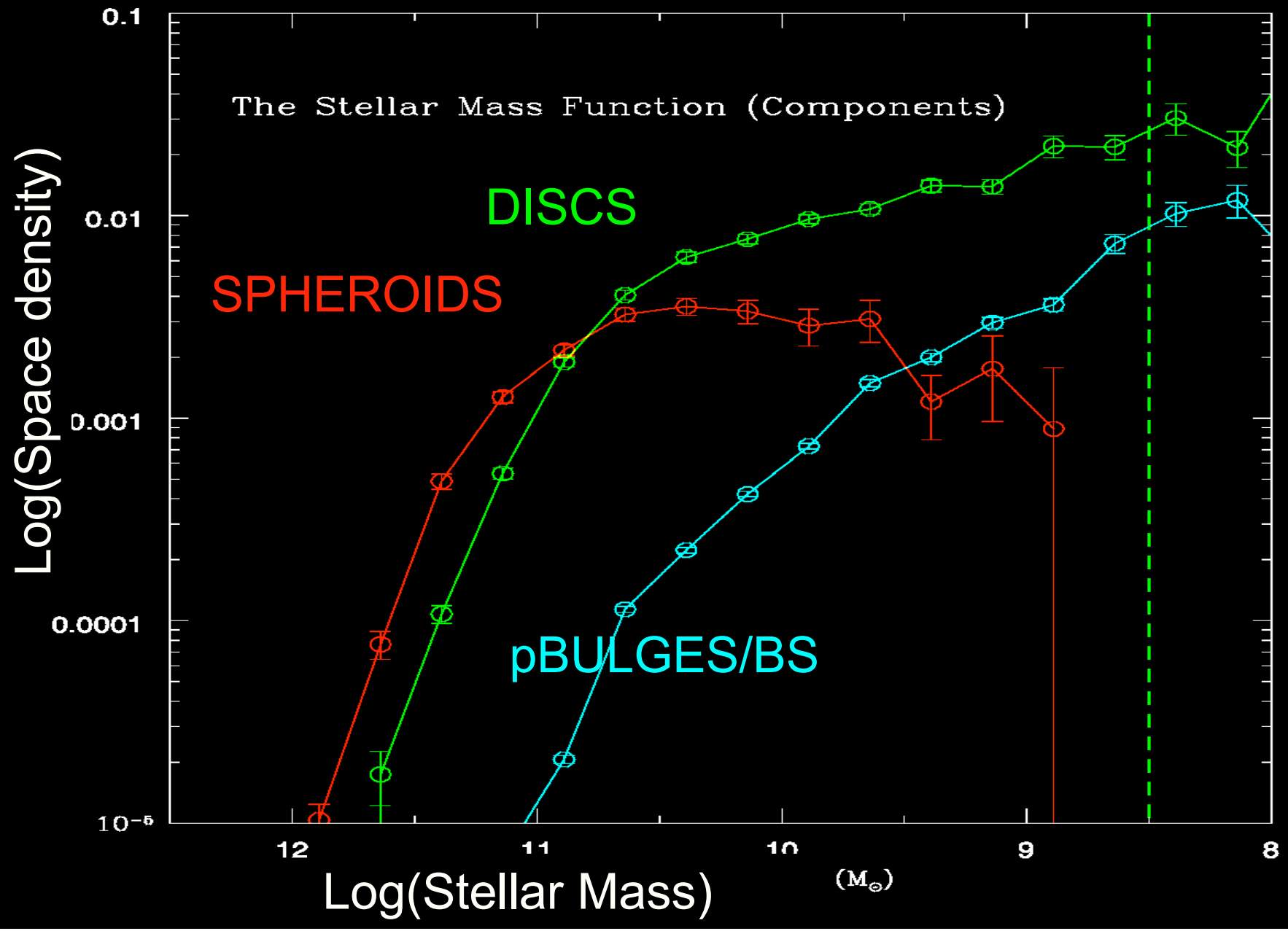
5. Transformation from Sc-S0 purely by removing dust and switching off SF! it gets ***redder*** and ***brighter*** without dry mergers!

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

MGC Millennium Galaxy Catalogue

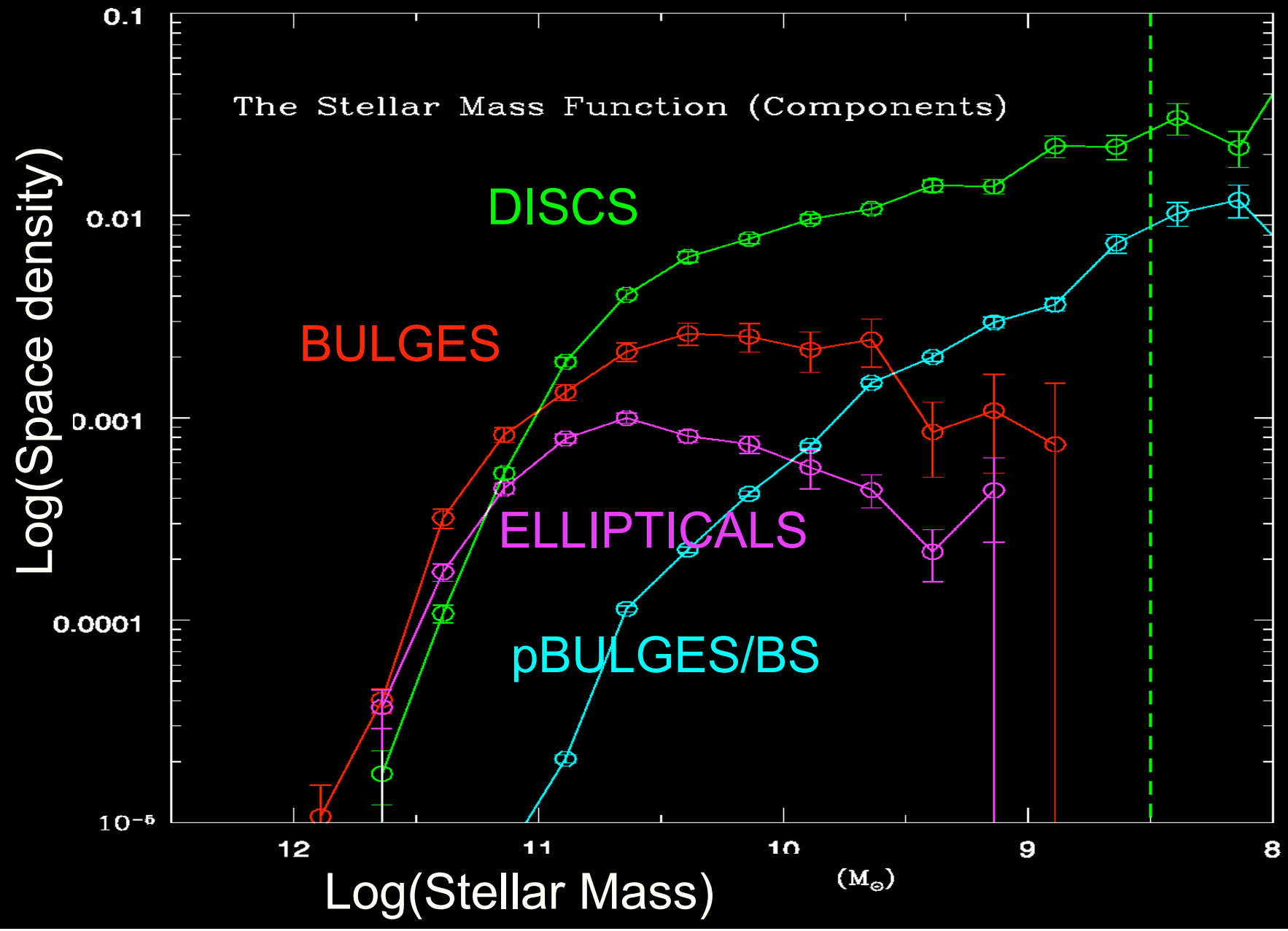
Component Stellar Mass Functions

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



MGC Millennium Galaxy Catalogue

Component Stellar Mass Functions

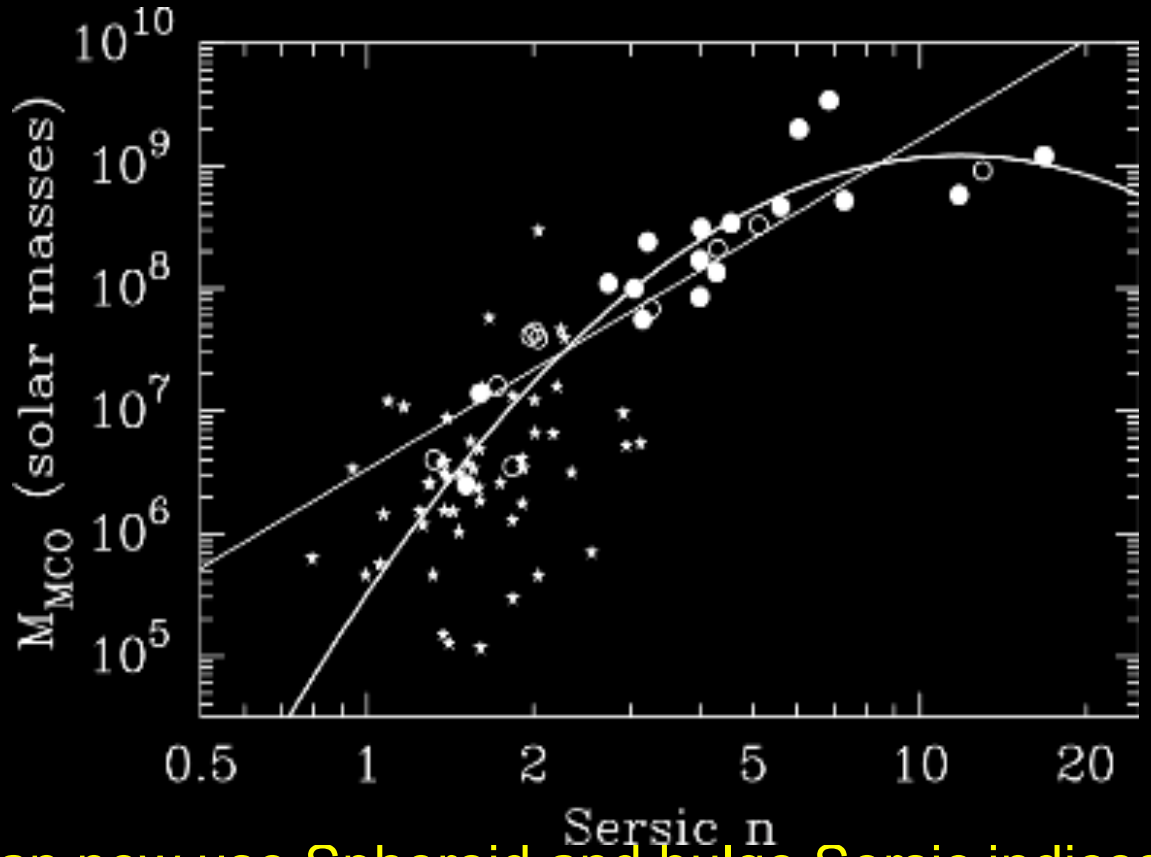


http://www.eso.org/~jliske/mgc/

MGC Millennium Galaxy Catalogue

Super Massive Black Holes

- BH mass Sersic index relation is as strongly correlated as BH-sigma relation (see Novak et al 2005) , comparable intrinsic scatter
- Recently recalibrated with a quadratic (Graham & Driver 2006)



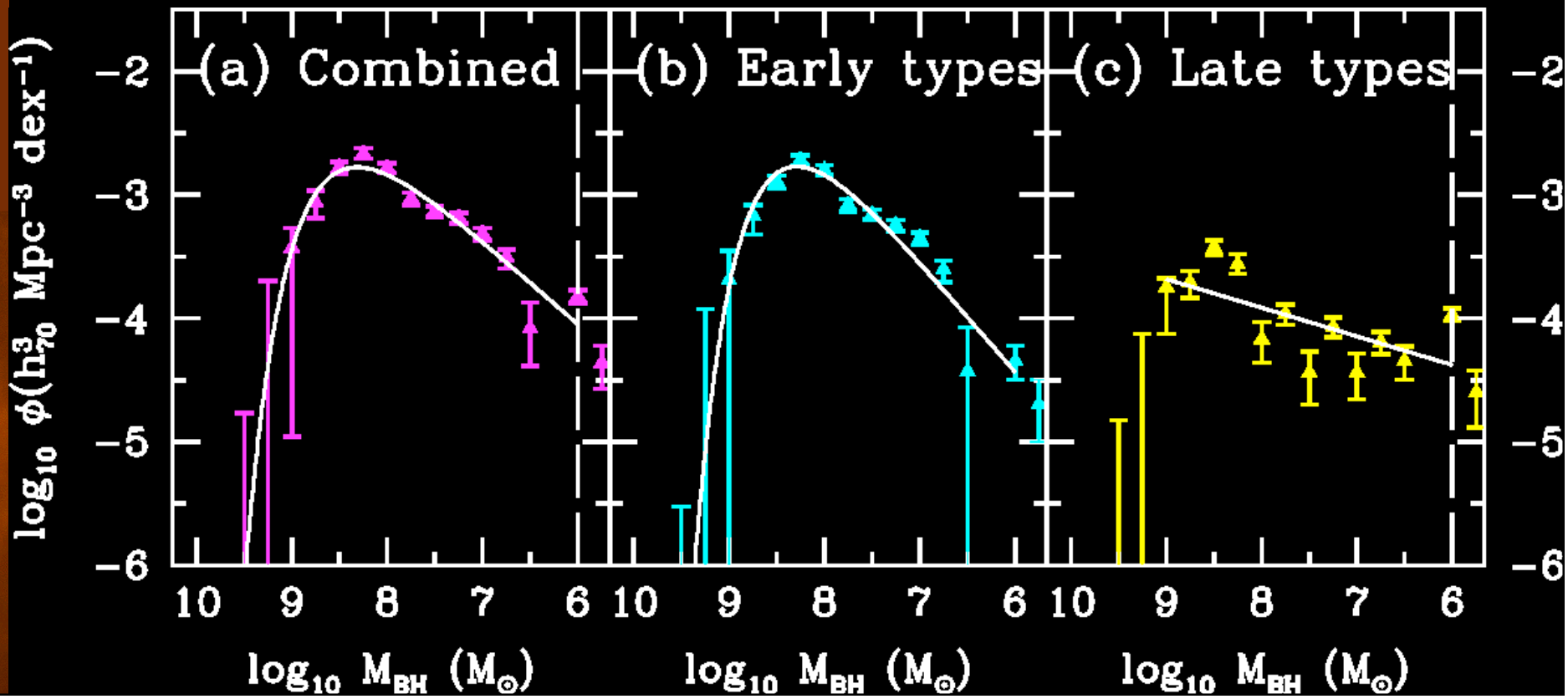
- Can now use Spheroid and bulge Sersic indices to predict BH masses and derive mass functions for early and late type bulges ==>

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

MGC Millennium Galaxy Catalogue

SMBH Mass Functions

- Using the M_{BH}-n relation (Graham & Driver 2006)
- We can derive SMBH masses for all MGC galaxies
- Error analysis includes MC errors in on n, main error derives from uncertainty in M_{BH}-n relation (TBD: recalibrate in K)
- See Graham et al (2007), in press



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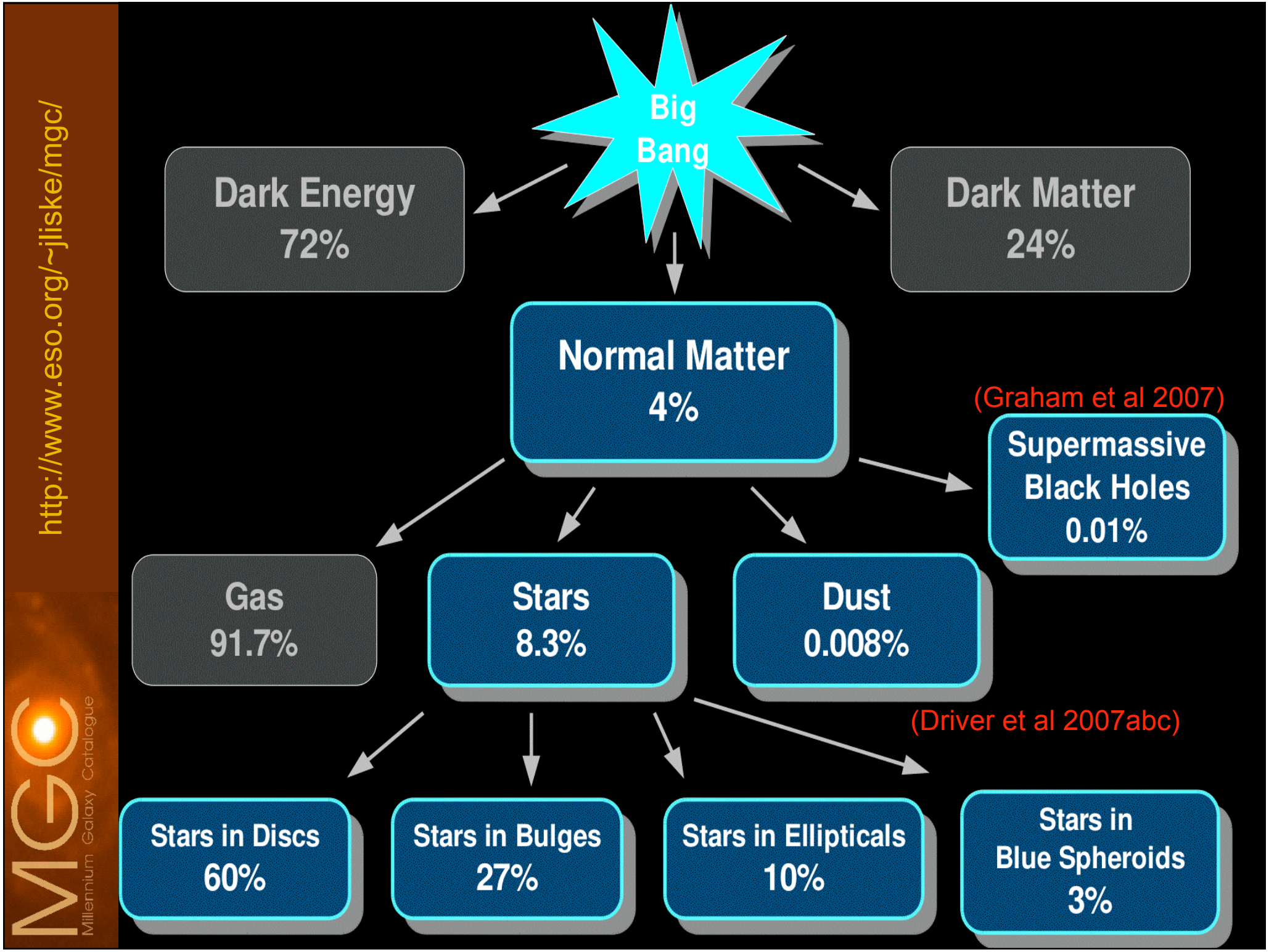
MGC Millennium Galaxy Catalogue


http://www.eso.org/~jliske/mgc/
MGC
Millennium Galaxy Catalogue
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%

Summary

Bimodality due to two component nature of galaxies: spheroids & discs (D06 MNRAS)

- 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 galaxy redder and brighter (dry mergers may not be needed)

Cosmic energy budget balances: lost starlight=far-IR dust emission (D07 submitted)

Bulge mass function = elliptical mass function ! (D08 in prep.)

- Bulges = Ellipticals: Favours collapse mode over merger mode for spheroid formation?!

Next steps:

- Bulge-disc decomposition essential to decipher galaxy evol.: need better codes (GIM2D++)
- Acquire *total energy* SEDs for large galaxy sample: GAMA (UKIRT+VST+VISTA+AAT+ HERSCHEL+SCUBAII+MIRANdA) ==>