“ Testing the predictive power of semi-analytic models using the Sloan Digital Sky Survey”

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Motivation

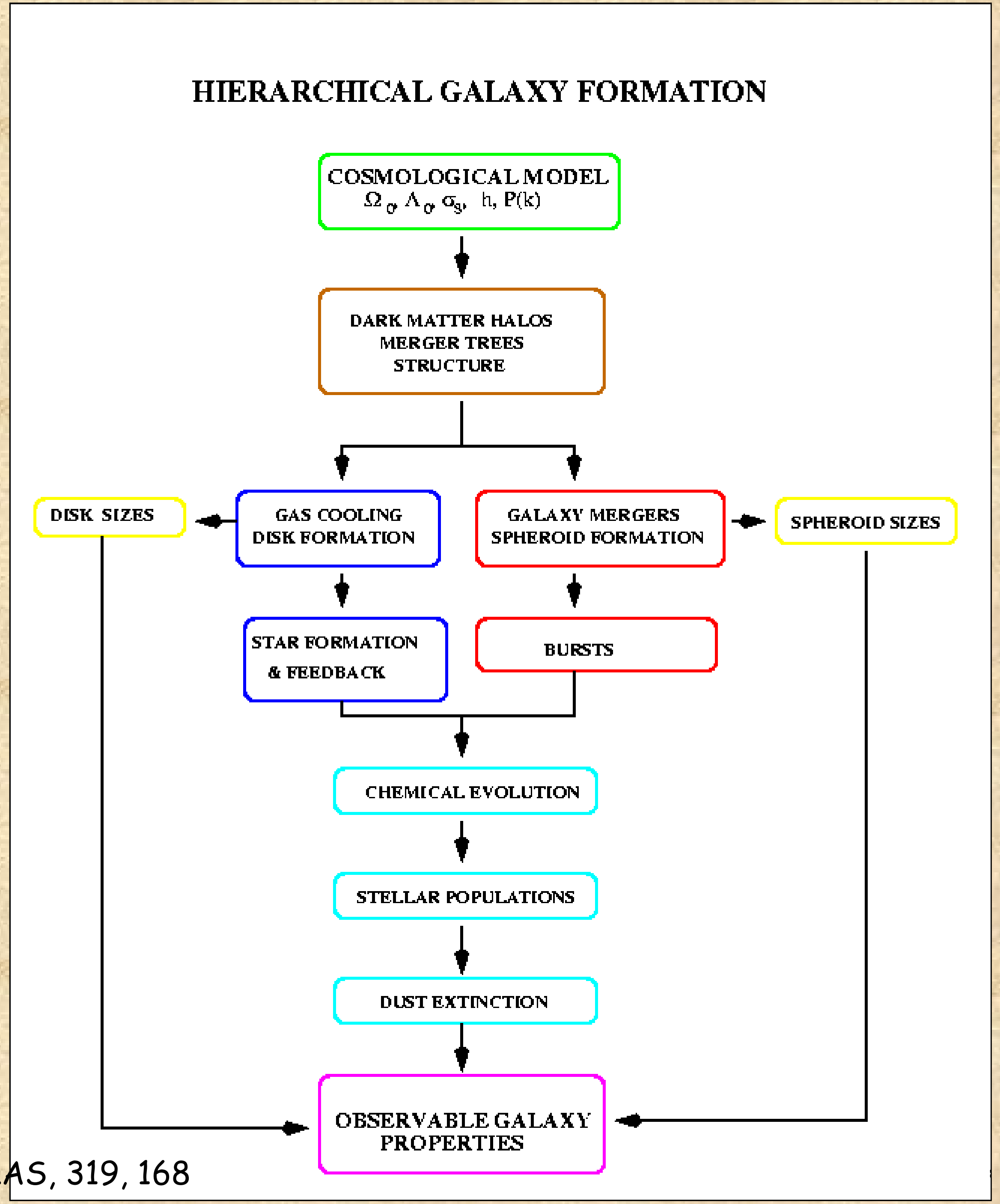
- Modelling the universe:
  - Understanding the physical processes responsible for galaxy formation and evolution,
- Semi-analytical models reproduce some range of properties.
- Test predictions with large observational datasets for an statistically meaningful comparison (SDSS, 2dF),
- Durham GALFORM semi-analytical galaxy formation model.
- Sloan Digital Sky Survey can help us to test the model in a snapshot of the universe at local redshift.

OUTLINE

- Galform:
  - Physical processes,
  - Baugh 2005 & Bower 2006 models,
- SDSS:
  - Spectroscopic sample, bands,
- Comparisons:
  - Luminosity function, colours, morphologies and sizes.

Galform:

- Processes included in the model:
  - gas cooling,
  - star formation, supernova feedback,
  - galaxy mergers,
  - chemical enrichment,
  - stellar population evolution,
  - dust extinction and emission.



Cole, Lacey, Baugh & Frenk, 2000, MNRAS, 319, 168

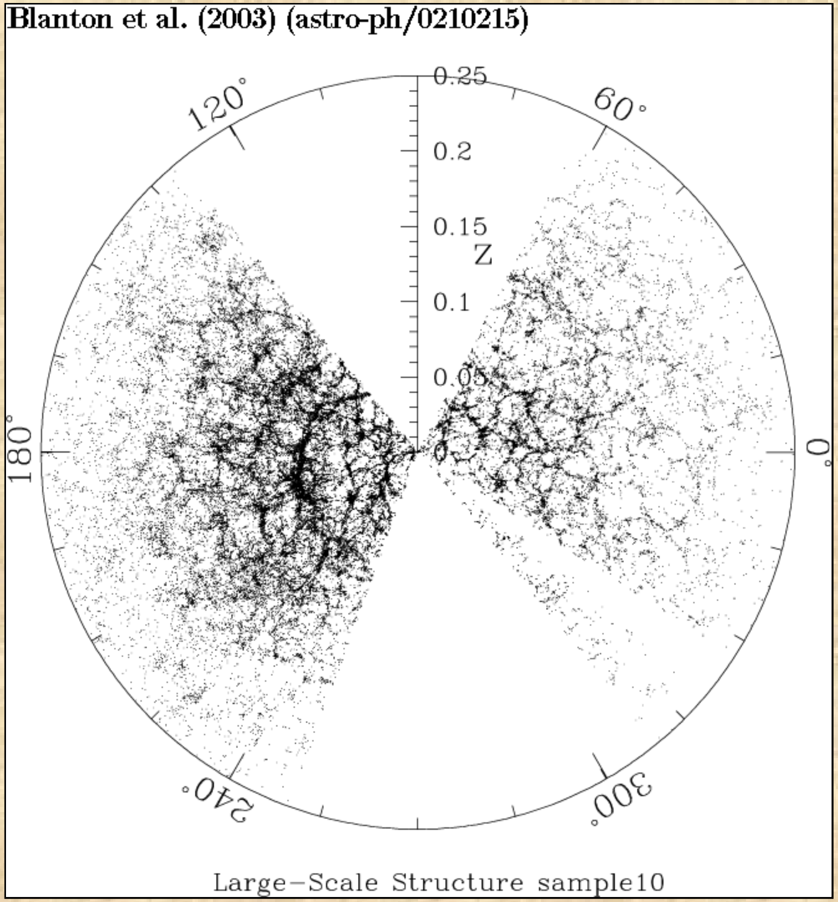
Baugh 2005 & Bower 2006

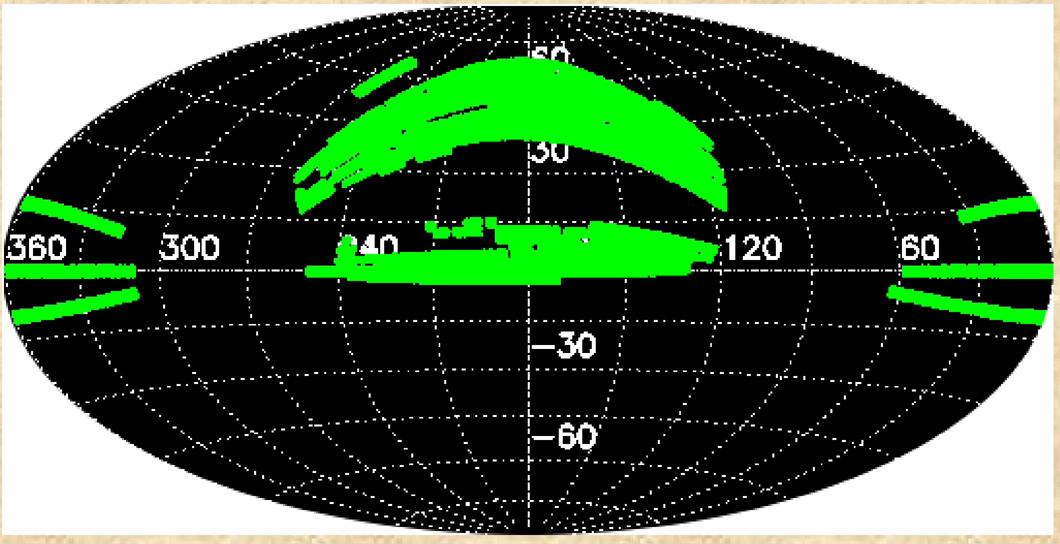
- Baugh et al 2005 version of GALFORM, which assumes a variable IMF, has been shown to successfully reproduce the local optical and IR luminosity functions, as well as the abundance of sub-mm and Lyman-break galaxies at high redshift.

- On the other hand, the Bower et al 2006 version of GALFORM, which incorporates AGN feedback, better reproduces the evolution of the K-band luminosity and stellar mass functions.

A Little About the Observational Data…

- SDSS, Survey to map a quarter of the sky in five bands (u,g,r,i,z) with a subsample of measured spectra for galaxies with $r_{Pet} < 17.77$.
- We use mainly a low redshift (z<0.05) catalogue from the DR4 (6670 square degrees, 806.400 spectra)





SDSS DR4

Petrosian Magnitude

The primary measure of flux used for galaxies is the SDSS Petrosian magnitude (in the absence of seeing it measures a constant fraction of a galaxy's light regardless of distance):

Ratio:

R=0.2

$$R \equiv \frac{\int_{0.8r_P}^{1.25r_P} dr' 2\pi r' I(r') / [\pi(1.25^2 - 0.8^2) r'^2]}{\int_0^{r_P} dr' 2\pi r' I(r') / (\pi r'^2)}$$

Petrosian Flux:

$$F_P \equiv \int_0^{2r_P} 2\pi r' dr' I(r')$$

~100% of the flux in pure exponential profiles.

~80% of the flux in pure de Vaucouleurs profiles.

Surface brightness profile for galaxies:

- In SDSS: concentic rings,

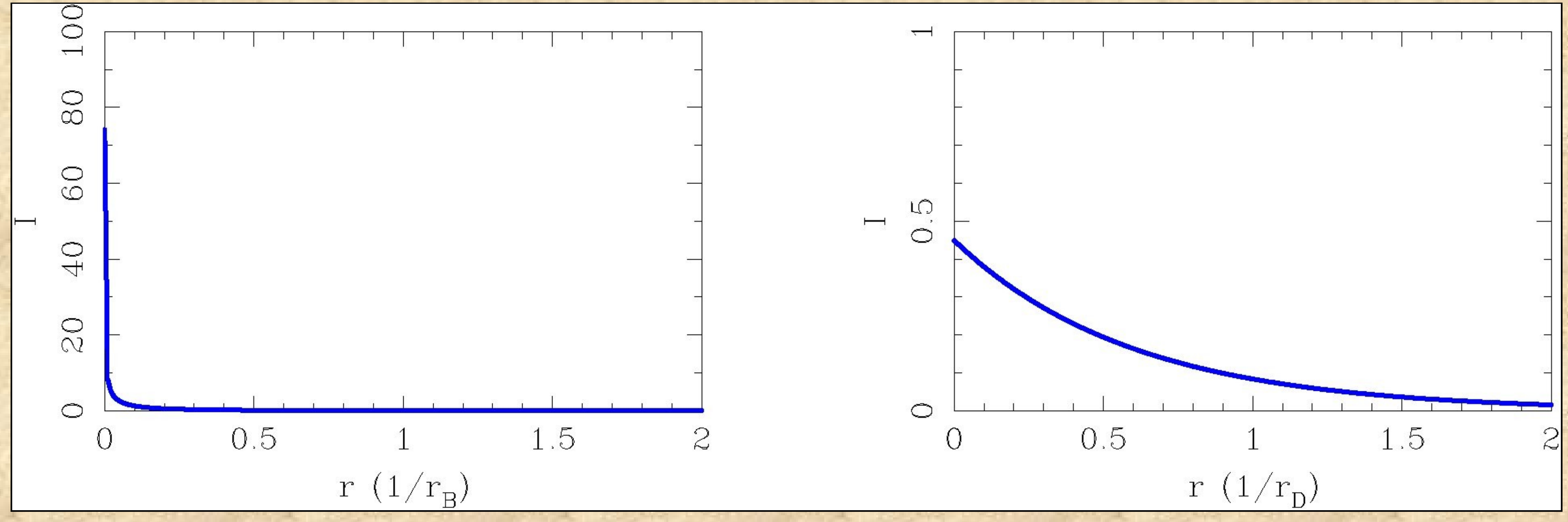
- In Galform:

for bulges, "de Vaucouleurs" profile:

$$I(r)\ \alpha\ \exp(-7.67(r/r_B)^{1/4})$$

for discs, exponential profile:

$$I(r)\ \alpha\ \exp(-1.68(r/r_D))$$



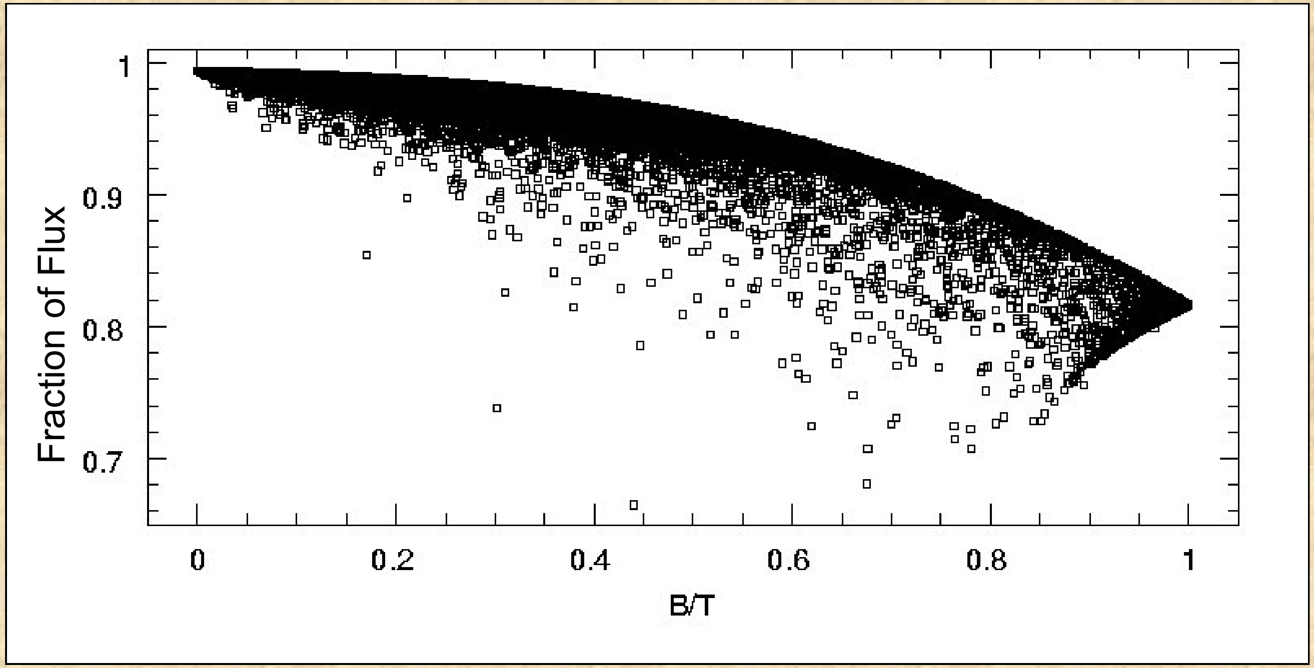
Early type galaxies

Late type galaxies

The total profile includes a disk and a bulge component.

Petrosian Flux

B/T: Bulge to Total Luminosity



B/T=1, pure bulge galaxy

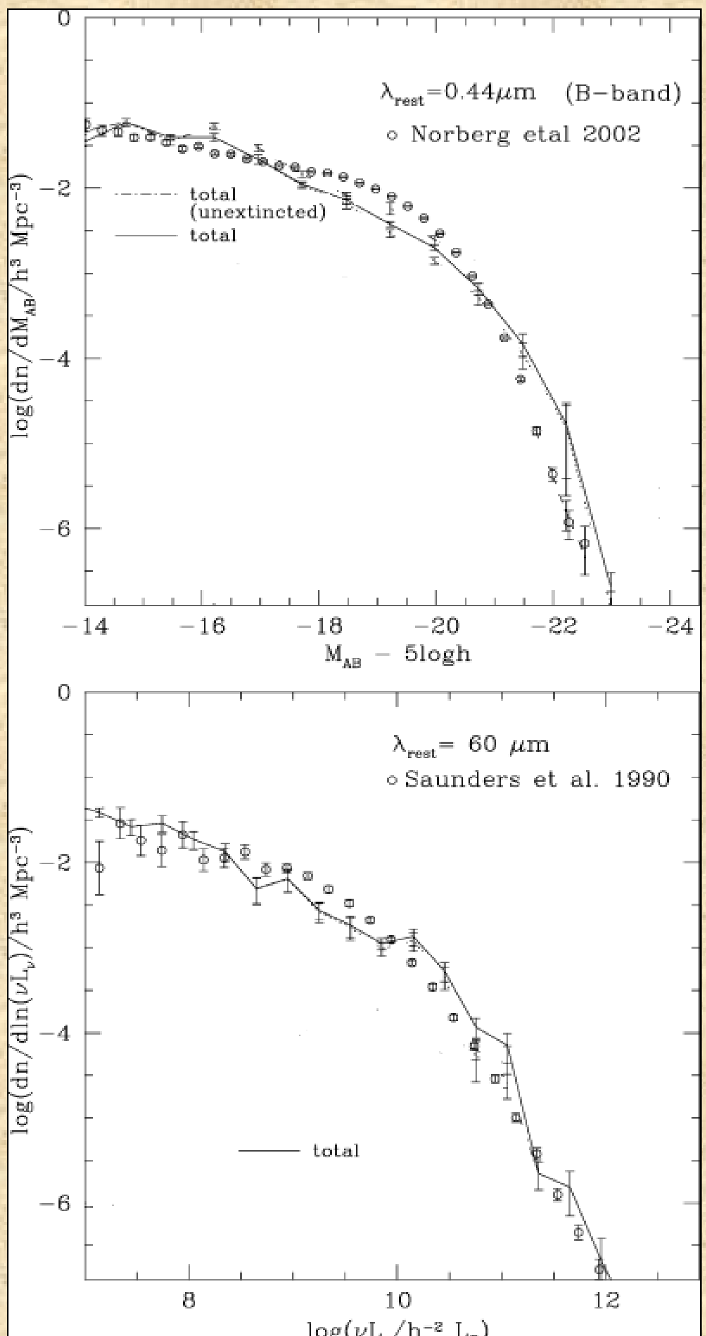
B/T=0, pure disk galaxy

~100% of the flux in pure exponential profiles (late type).

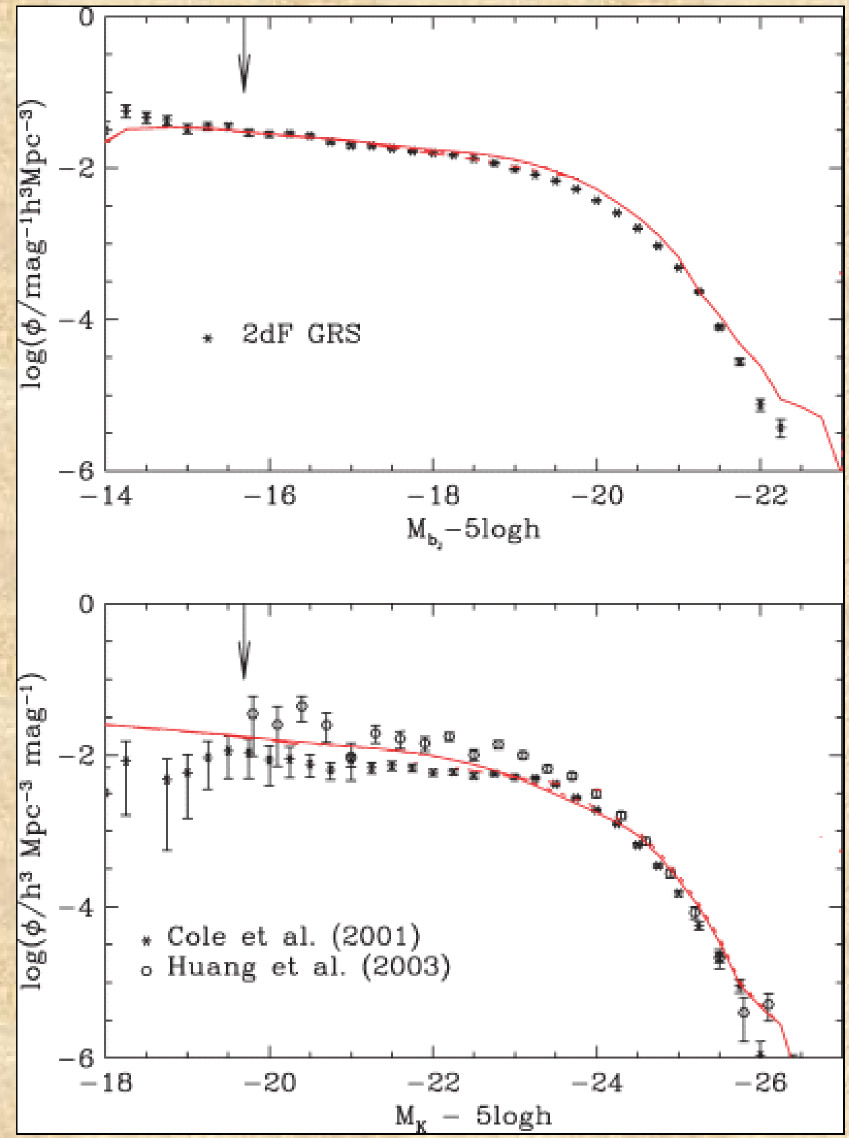
~80% of the flux in pure de Vaucouleurs profiles (early type).

Luminosity Function and Galaxy Colours

Luminosity Function



Baugh 2005

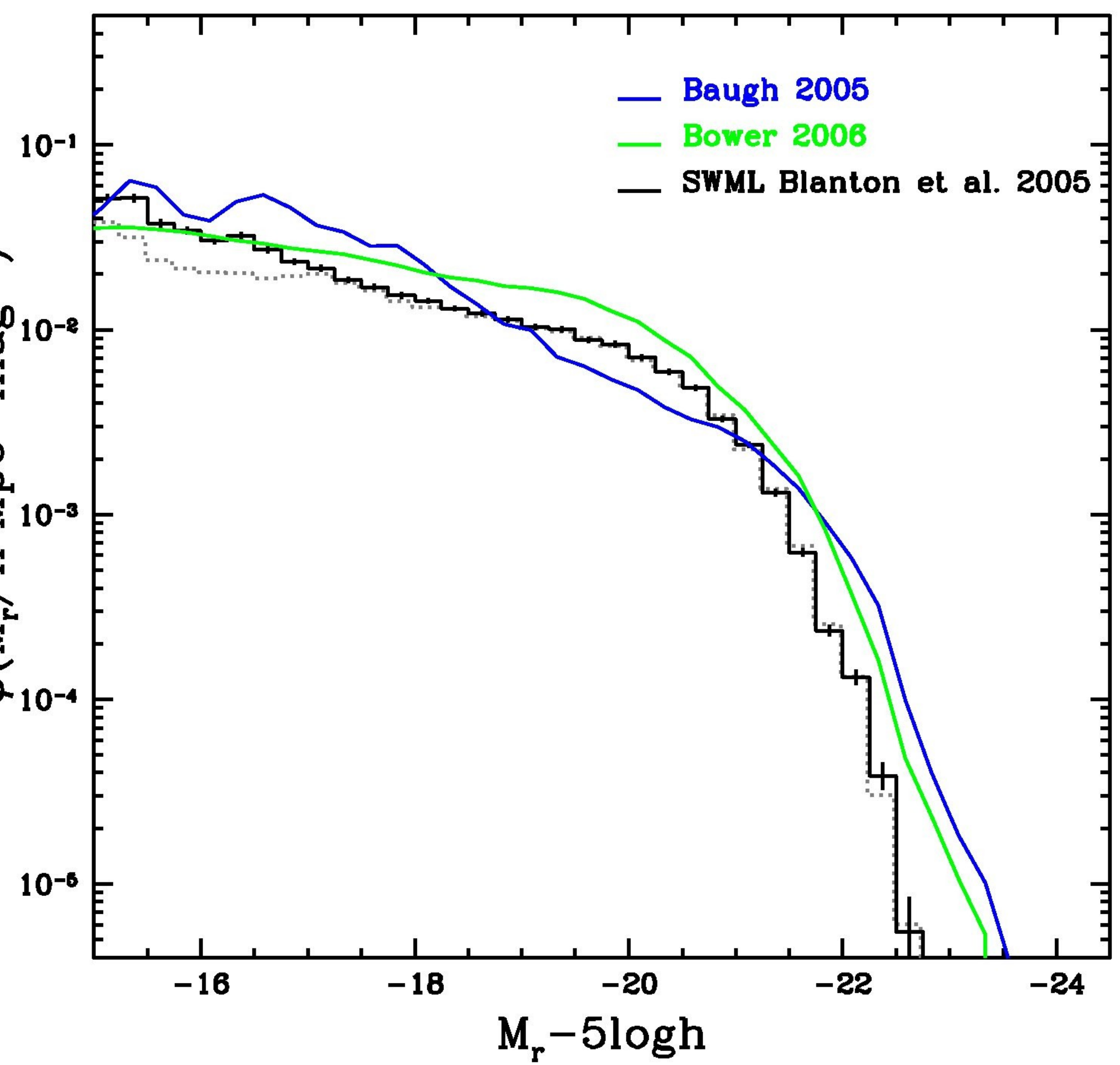


Bower 2006

Total Luminosity Function

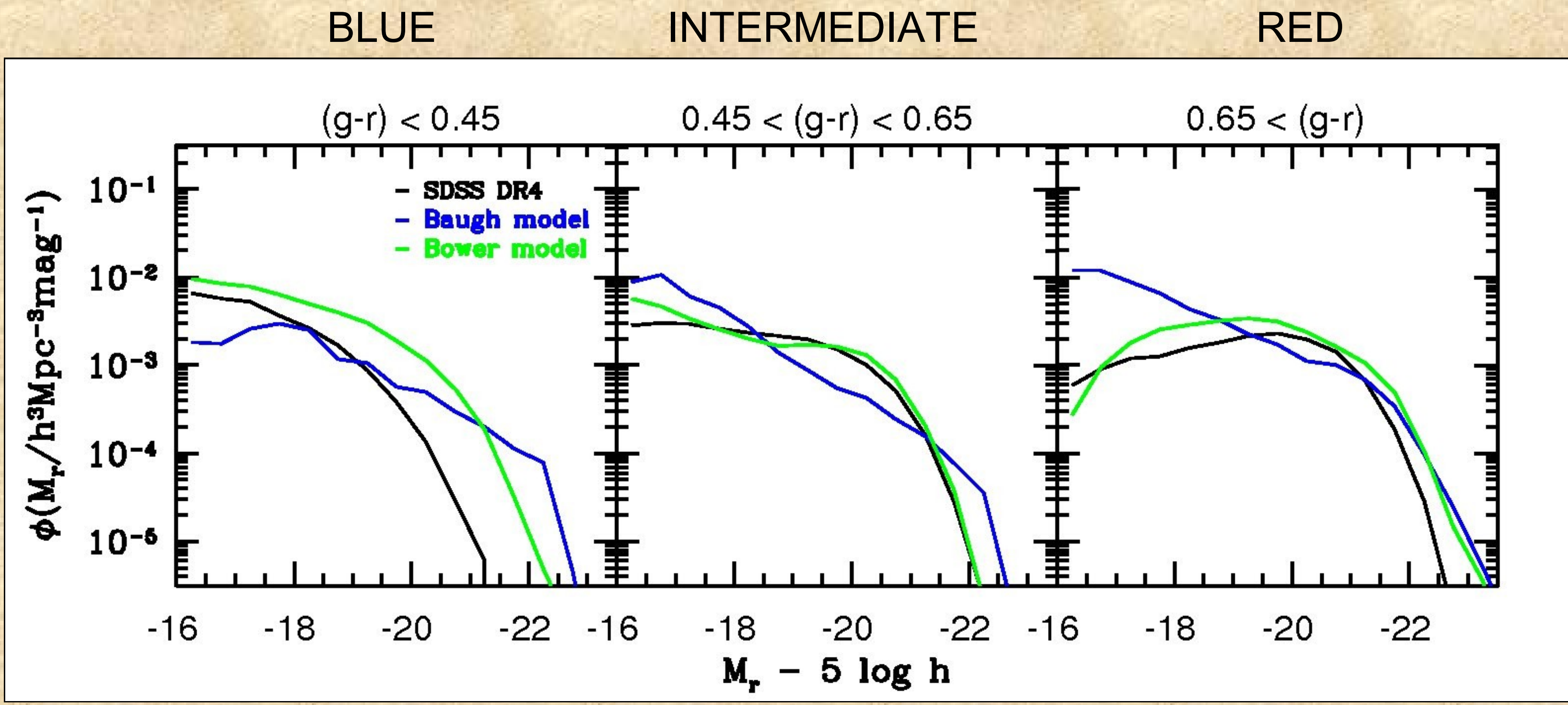
Feedback effects shape the luminosity function.

Models over-predict the number of high luminosity galaxies.



Median redshift = 0.035

Luminosity Function separated by colour g-r



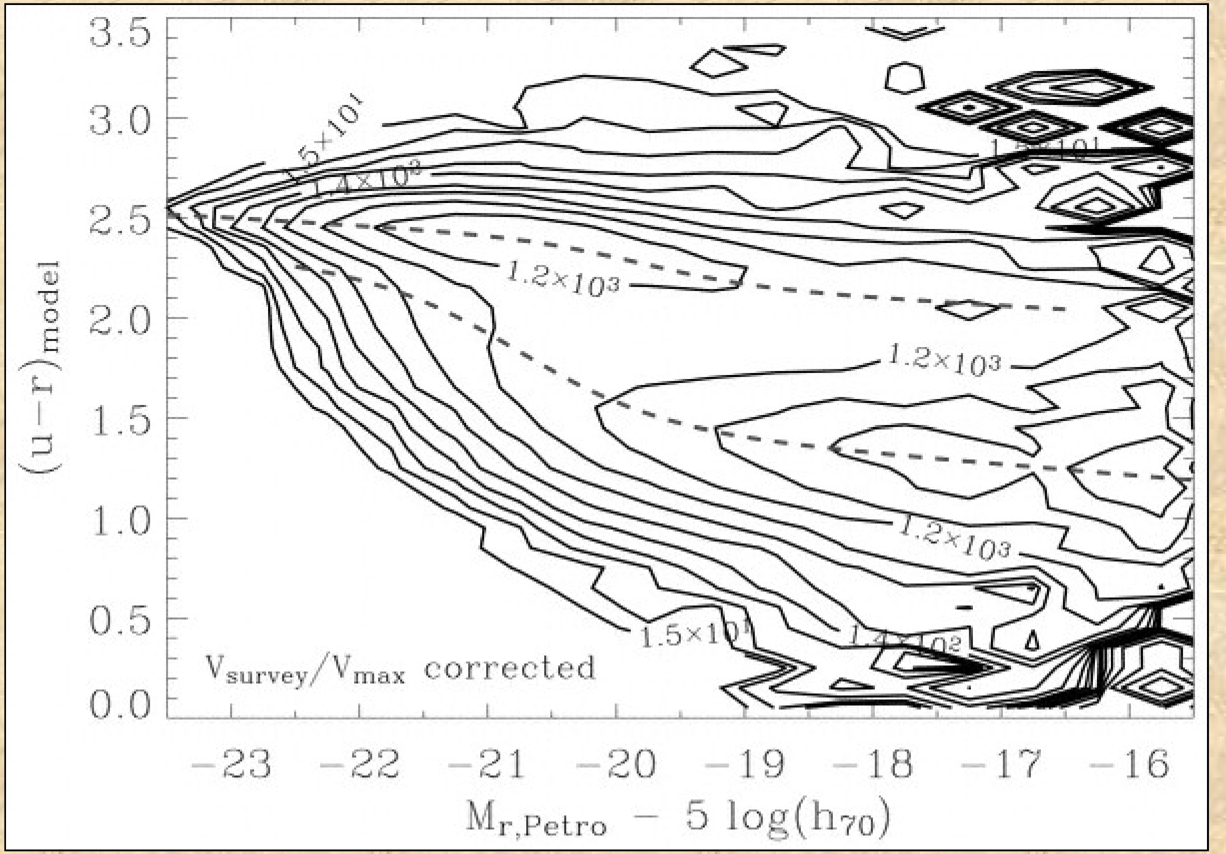
Median redshift = 0.035

Stronger SN feedback help to suppress the formation of red faint galaxies in Bower 2006.

Colour distributions of galaxies as function of luminosity

Baldry et al. 2004

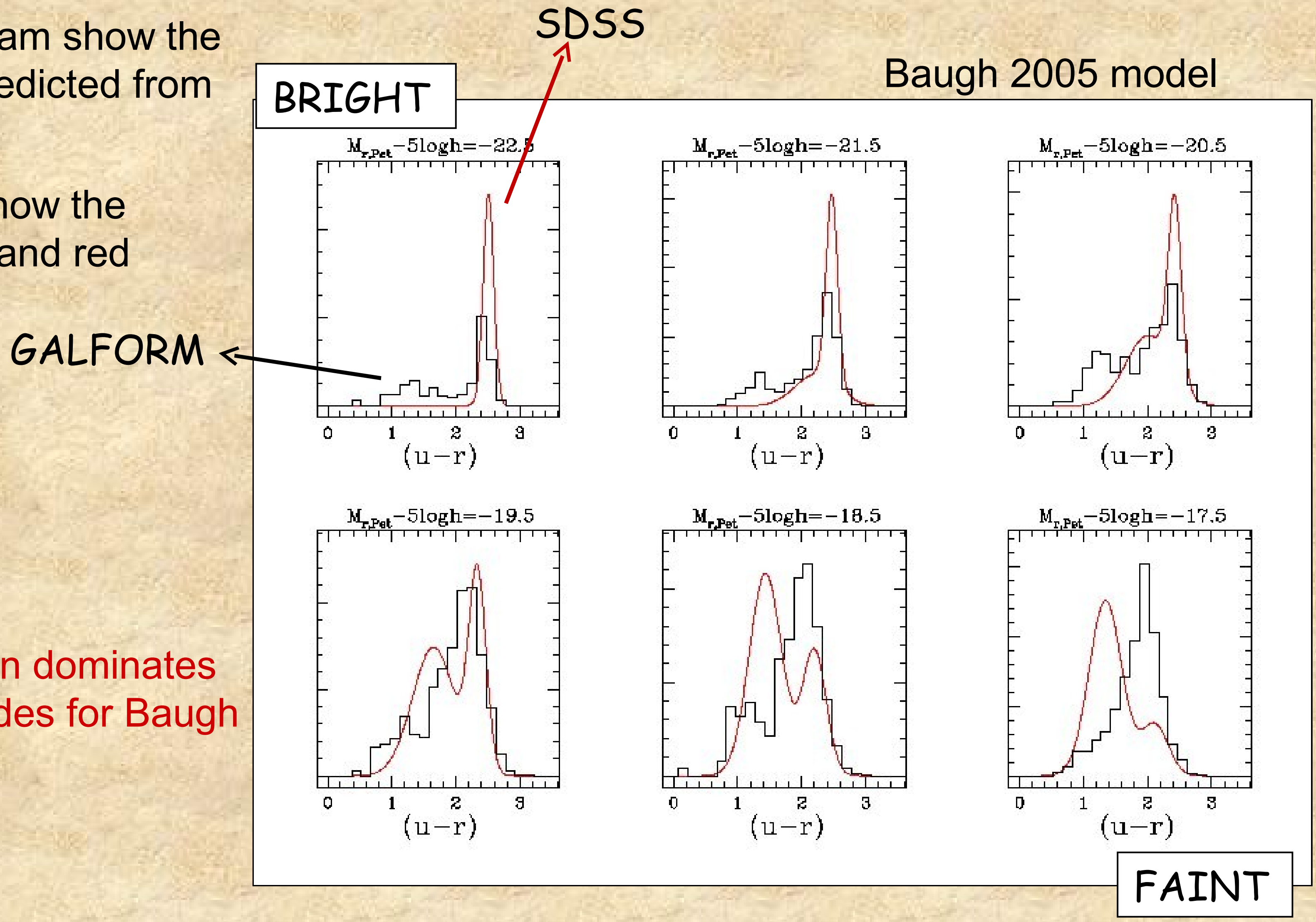
- A bimodality is seen in the distribution of galaxies from the SDSS.
- The upper and lower dashed lines represent a red and blue population.



Bimodal distribution of the sample in colour vs. absolute magnitude.

Colour distributions of galaxies as function of luminosity

- Black histogram show the distribution predicted from the model.
- Gaussians show the different blue and red population.

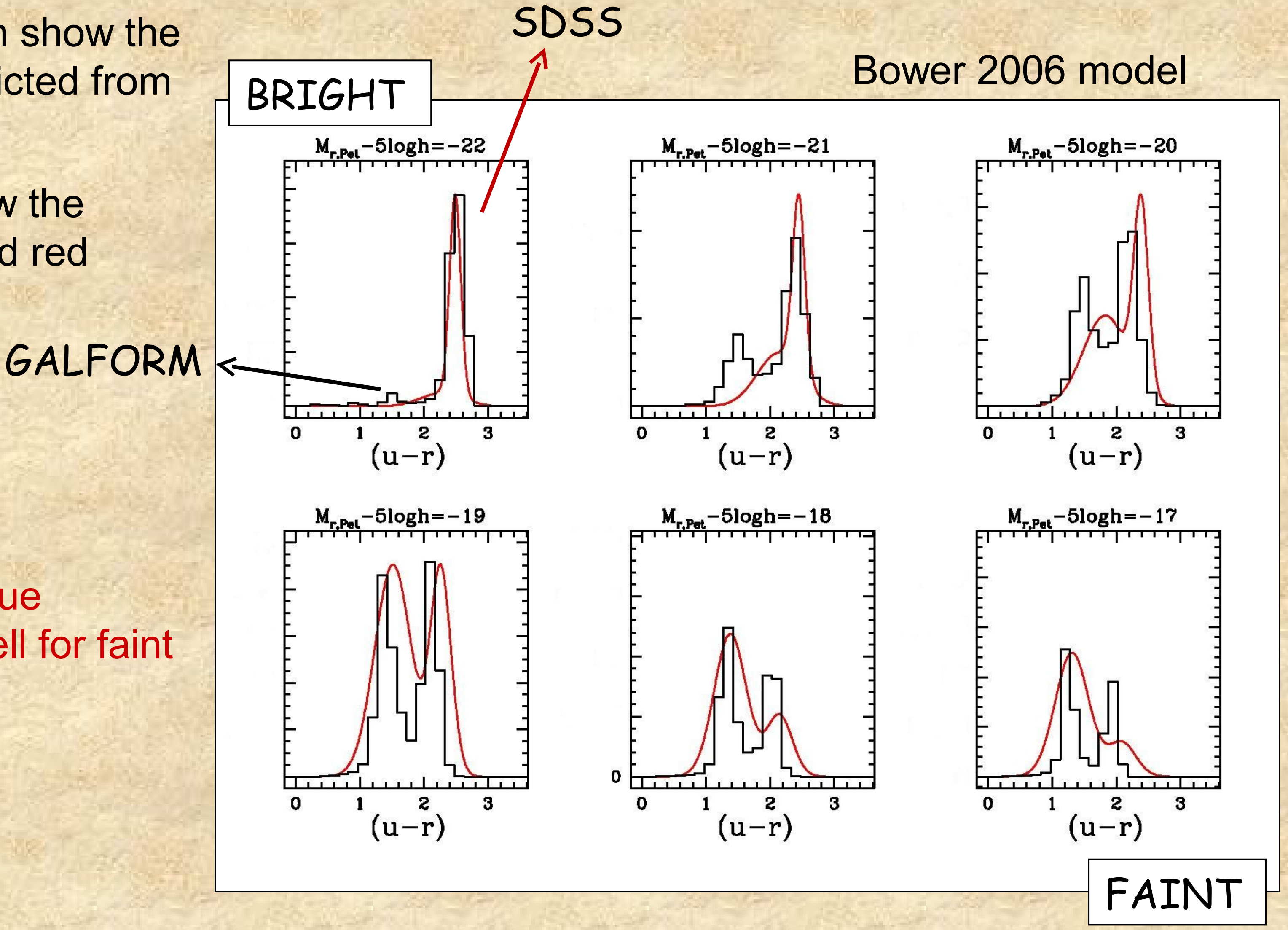


Red population dominates at all magnitudes for Baugh 2005 model

SDSS analysis: Baldry et al. 2004

Colour distributions of galaxies as function of luminosity

- Black histogram show the distribution predicted from the model.
- Gaussians show the different blue and red population.



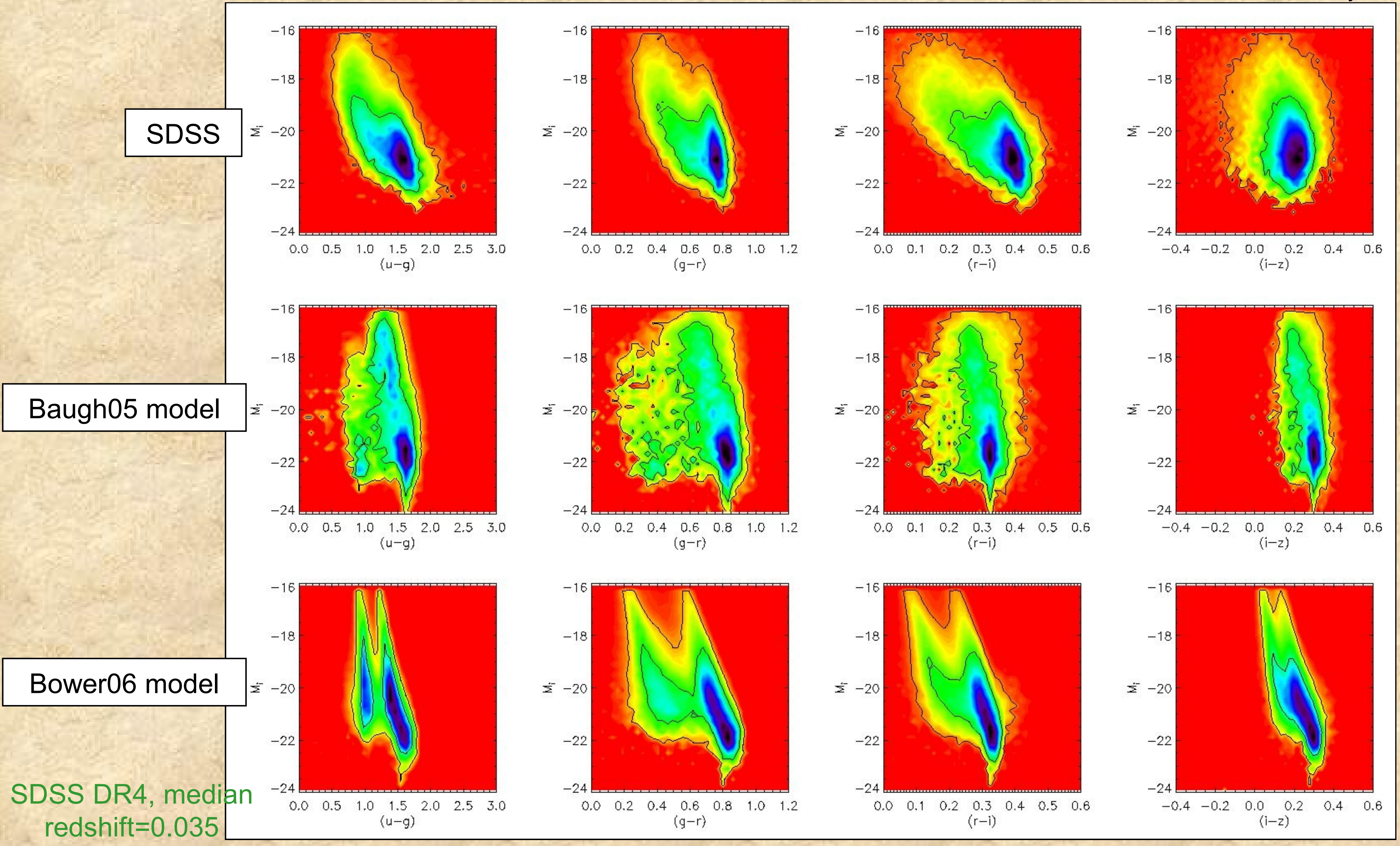
We can see a blue population as well for faint magnitudes.

SDSS analysis: Baldry et al. 2004

Comparing the distribution in colours vs. magnitude

The contribution of each galaxy to the density is weighted by its luminosity. A bimodality is observed.

Contours: regions containing 68% and 95% of the density.



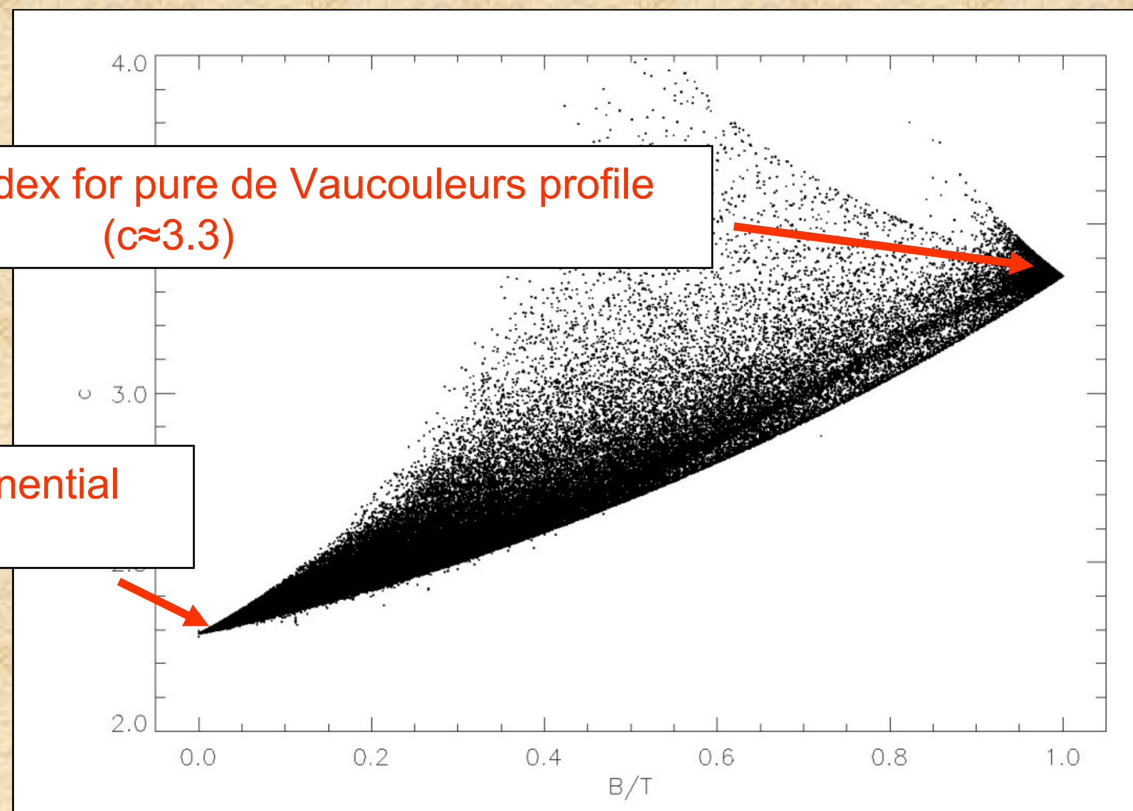
SDSS DR4, median redshift=0.035

Morphology Classifier 1: The concentration index

- The “concentration index” of galaxies, defined as c ≡ r90/r50 has been showed well correlated with visual morphological classifications for nearby and large galaxies.

B/T=1, pure bulge galaxy

B/T=0, pure disk galaxy



B/T: Bulge to Total Luminosity

Morphology Classifier 2: The Sérsic index

- It can be fitted a radial dependence for the surface brightness in the form:

$$I(r) = A \exp[-(r/r_0)^{1/n}]$$

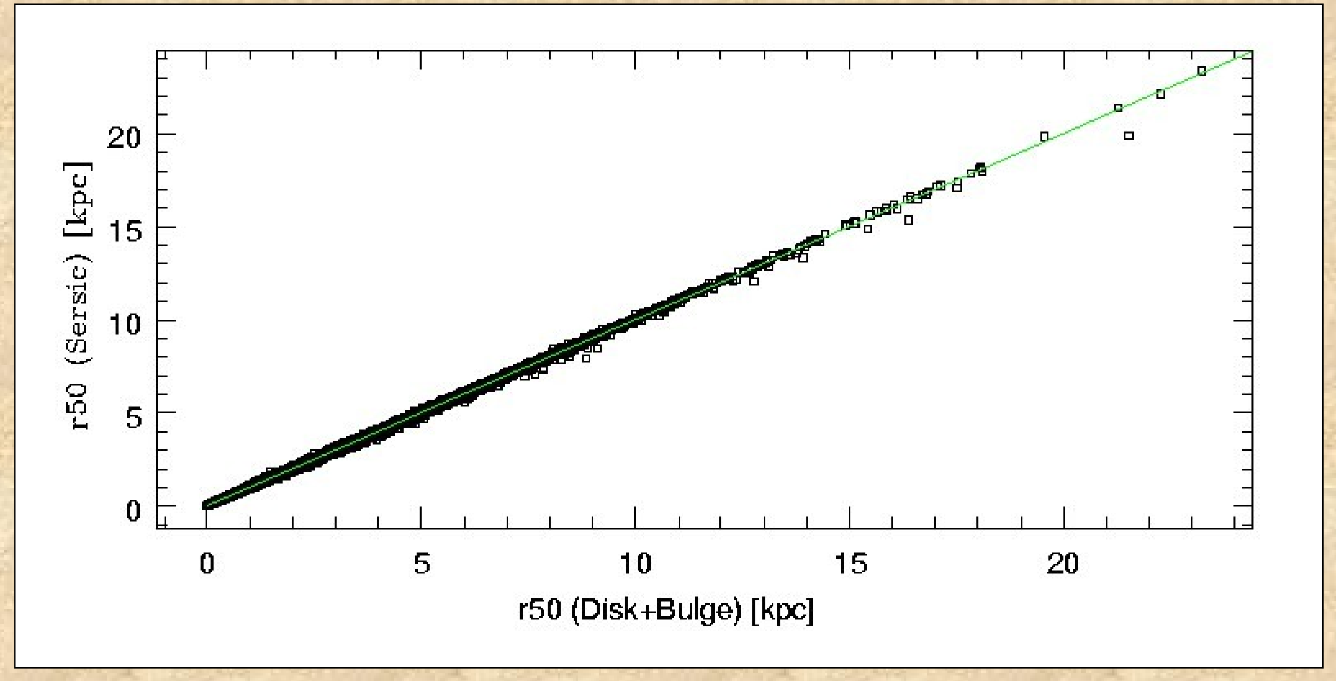
- Sérsic index n~1: exponential profile (pure disk galaxy)
- Sérsic index n~4: de Vaucouleur profile (pure bulge galaxy)

Sérsic Index: Fitting to model galaxies

- We find the parameters A, r_0 and n for the Sérsic profile by minimizing χ^2 with respect to the known Disk + Bulge profile.

$$\chi^2 = \sum_{1}^{N} [\log I_{Disk+Bulge}(r_i) - \log I_{Sérsic}(r_i, r_0, n)]^2 Wi$$

$$I(r) = A \exp[-(r/r_0)^{1/n}]$$



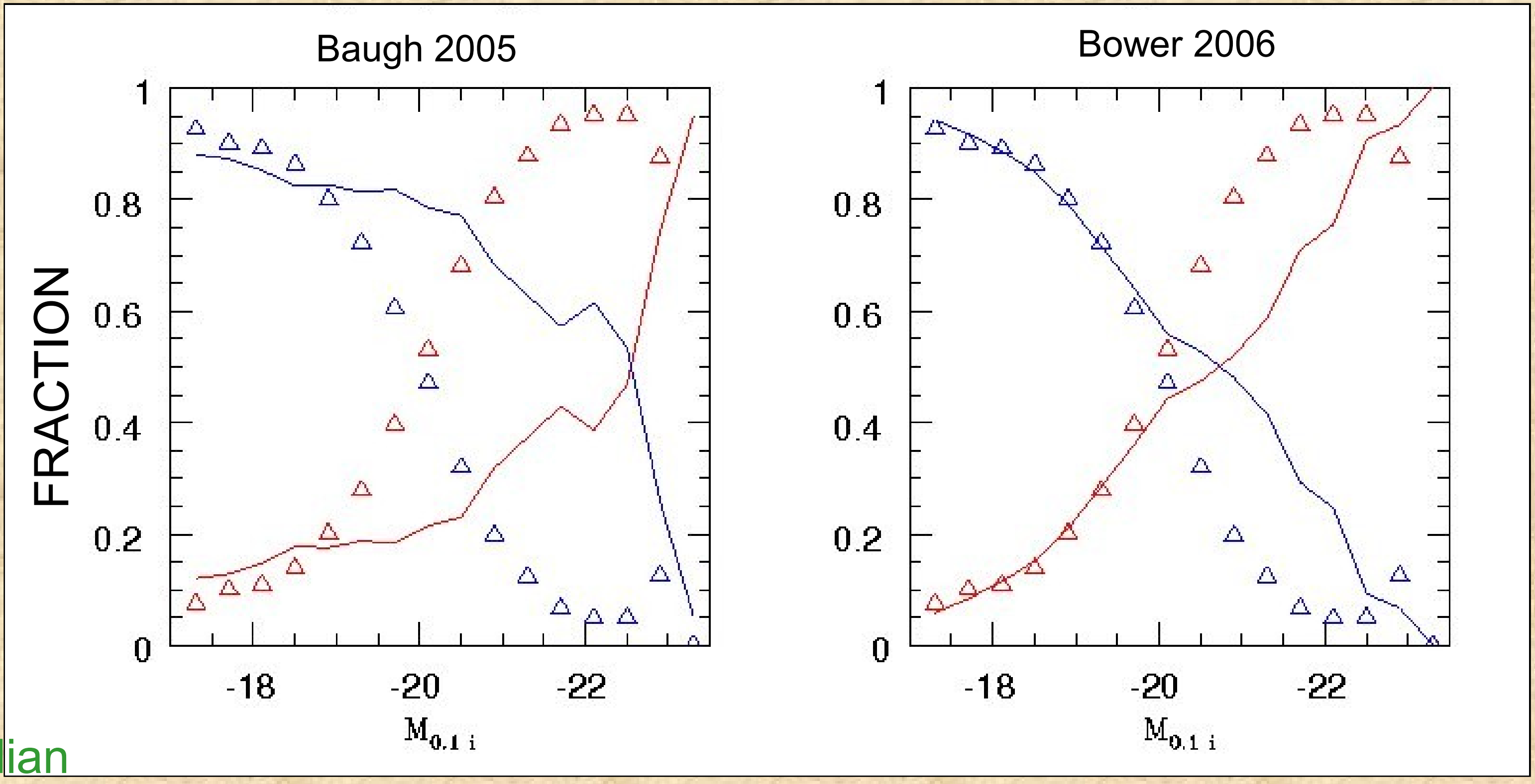
Morphology by Sérsic Index

- We can compare the fraction of different morphology galaxies given by the Sérsic index "n" in bins of Luminosity with the SDSS data.

disk dominated, n<2.5 —— GALFORM

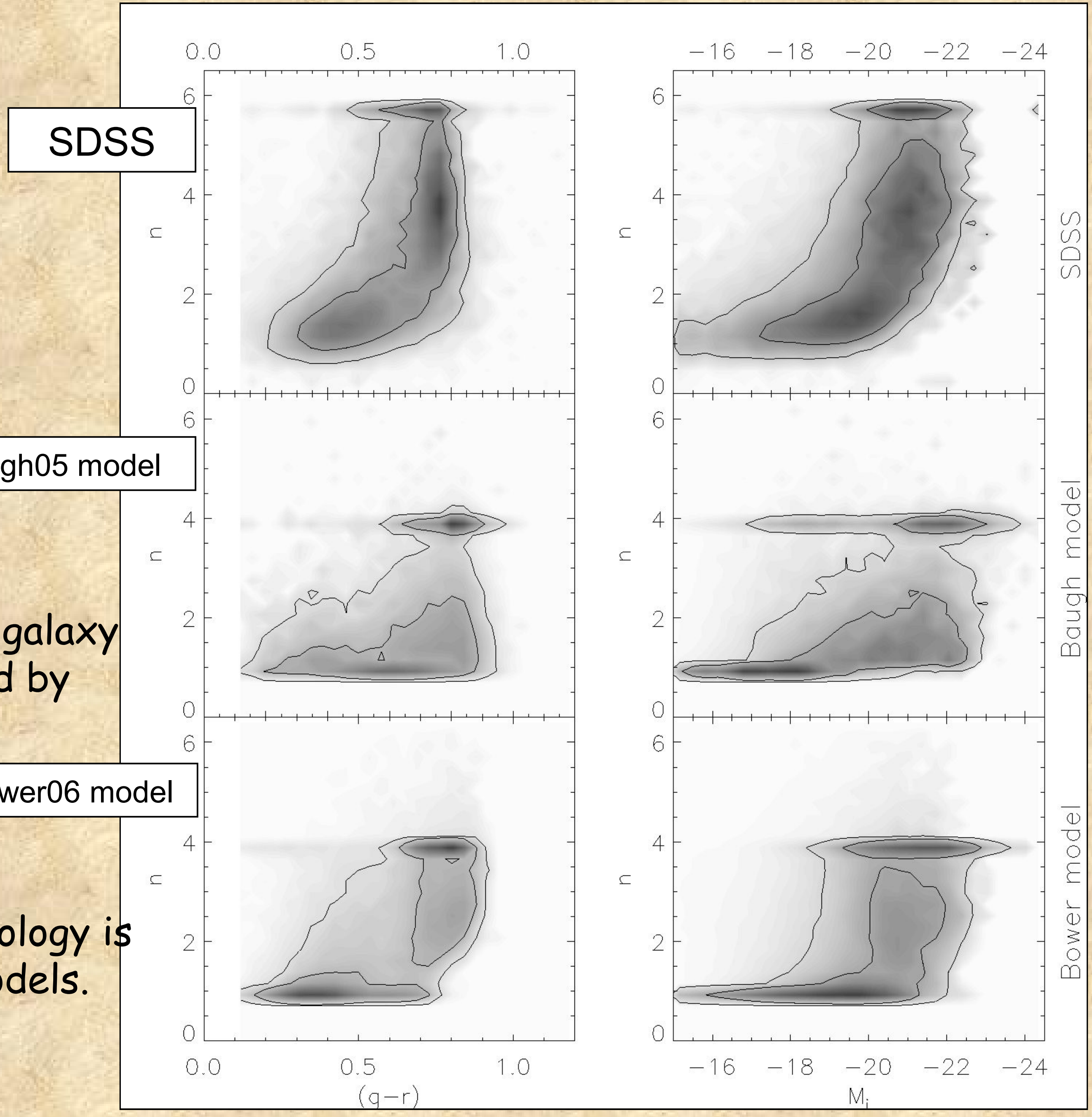
bulge dominated, n>2.5 Δ SDSS

Change in the dominating population at different magnitudes.



SDSS DR4, median redshift=0.035

Comparing the distribution in colour g-r, magnitude and Sérsic Index.



The contribution of each galaxy to the density is weighted by its luminosity.

Bimodality in colour, magnitude and morphology is seen as well in the models.

SDSS DR4, median redshift=0.035

Contours: regions containing 68% and 95% of the density.

Size distribution ($r_{50,Pet}$): DISK DOMINATED GALAXIES

Estimating the size of the discs

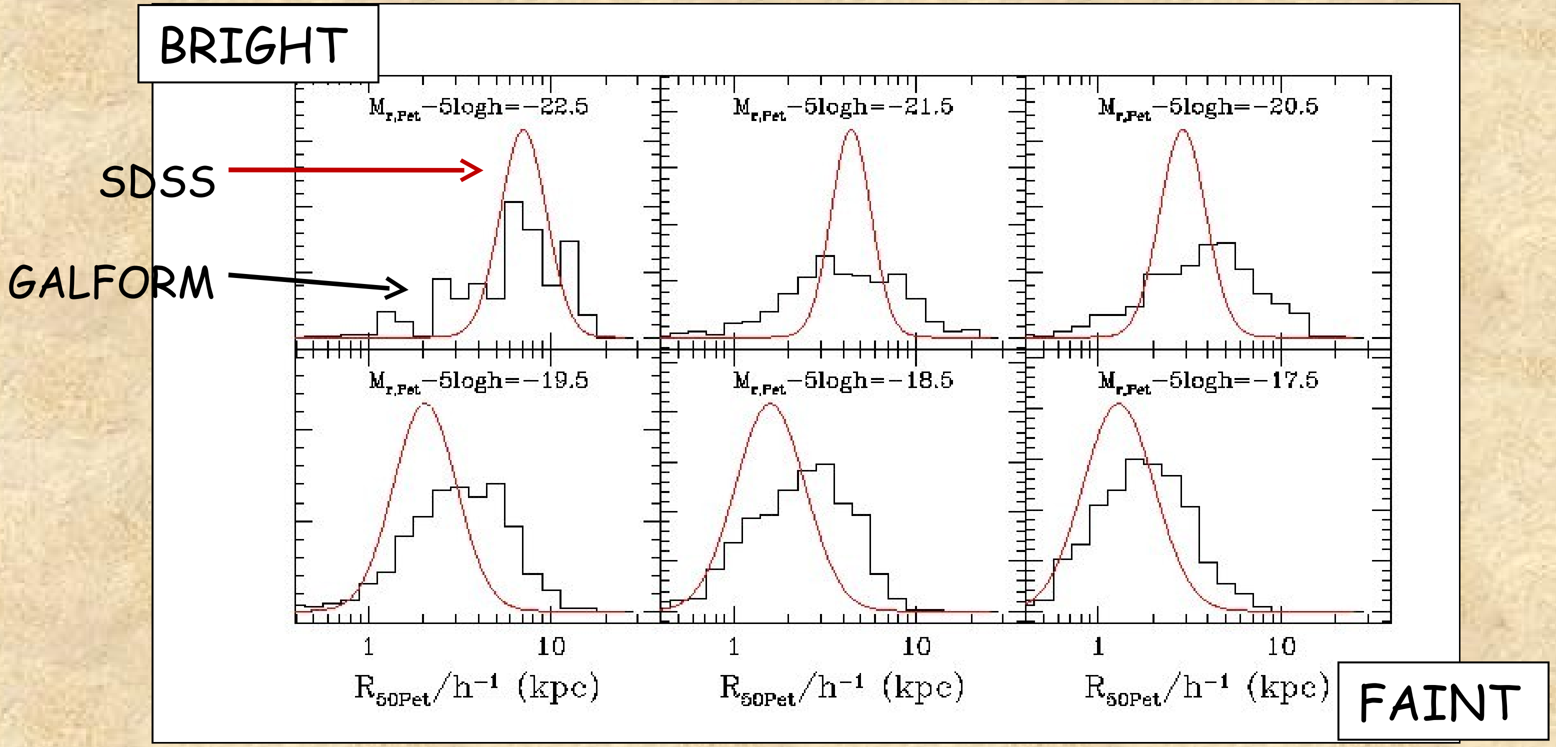
- Discs form by cooling of gas initially in the halo
- The size of the disc is determined by the angular momentum of the halo gas which cools.

Size distribution for disk dominated galaxies.

Baugh 2005 model

- Black histograms show the distribution of the Galform prediction.
- Red Gaussians represent the SDSS distribution.

Late Type (disk dominated): c<2.86



Median sizes are very similar compared to SDSS data.

SDSS analysis:
Shen et al. 2003

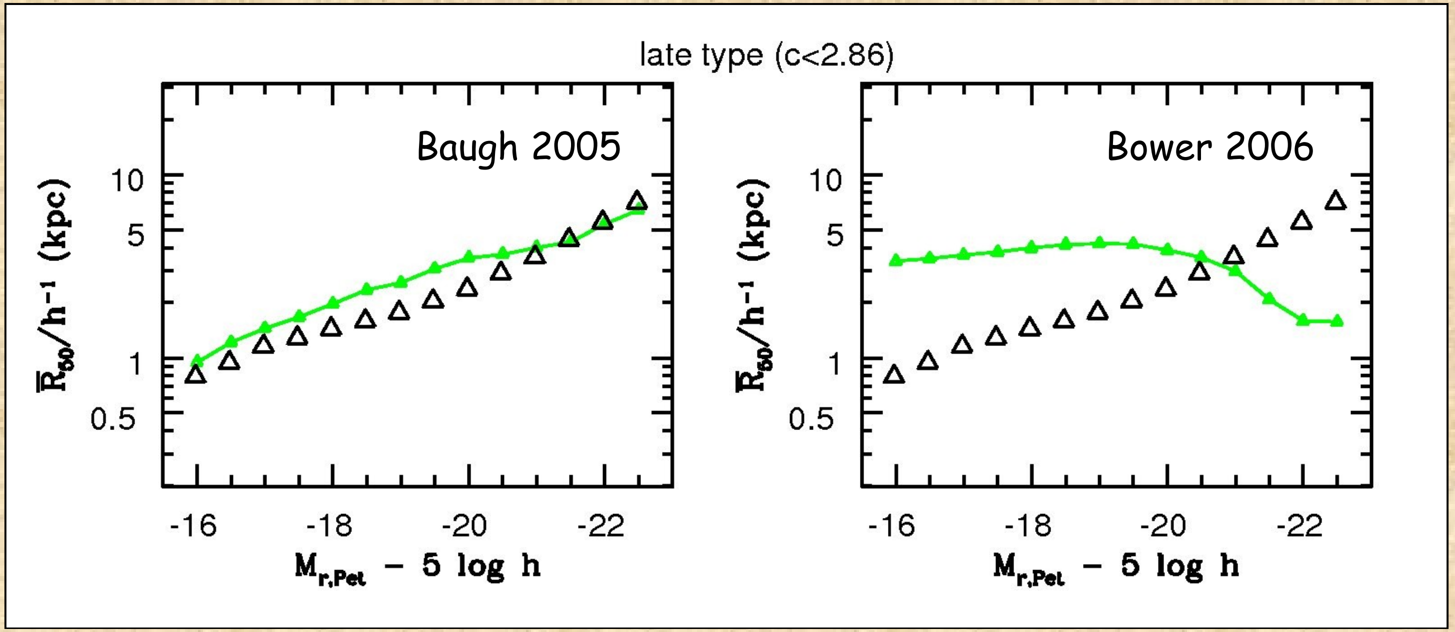
Sizes vs. Magnitude, late type galaxies

•Good agreement for late type galaxies for Baugh 2005. Bower 2006 model shows a different trend predicting low luminosity galaxies too big.

Big Triangles: SDSS

Separating by concentration index

late type (disk dominated)



- Disk sizes are very sensitive to feedback
- Gradually return of the gas in Bower 2006

Size distribution:
BULGE DOMINATED GALAXIES

Estimating the size of the bulges

The size of the spheroid formed in a merger is computed in the model using:

Binding energy,

$$E_{bind} = -\bar{c}\,\frac{GM^2}{r}$$

Orbital energy at the moment of merging,

$$E_{orbit} = -\frac{f_{orbit}}{2}\,\frac{GM_1M_2}{r_1 + r_2}$$

Virial theorem and Energy conservation,

$$\frac{E_{bind,new}}{2} = \frac{E_{bind,1}}{2} + \frac{E_{bind,2}}{2} + E_{orbit}$$

$$\frac{(M_1 + M_2)^2}{r_{new}} = \frac{M_1^2}{r_1} + \frac{M_2^2}{r_2} + \frac{f_{orbit}}{\bar{c}}\,\frac{M_1M_2}{r_1 + r_2}$$

M1, M2: Masses of the merging components.

r1,r2: half-mass radii of the merging components.

$\bar{c}$: form factor; $\bar{c}$=0.5

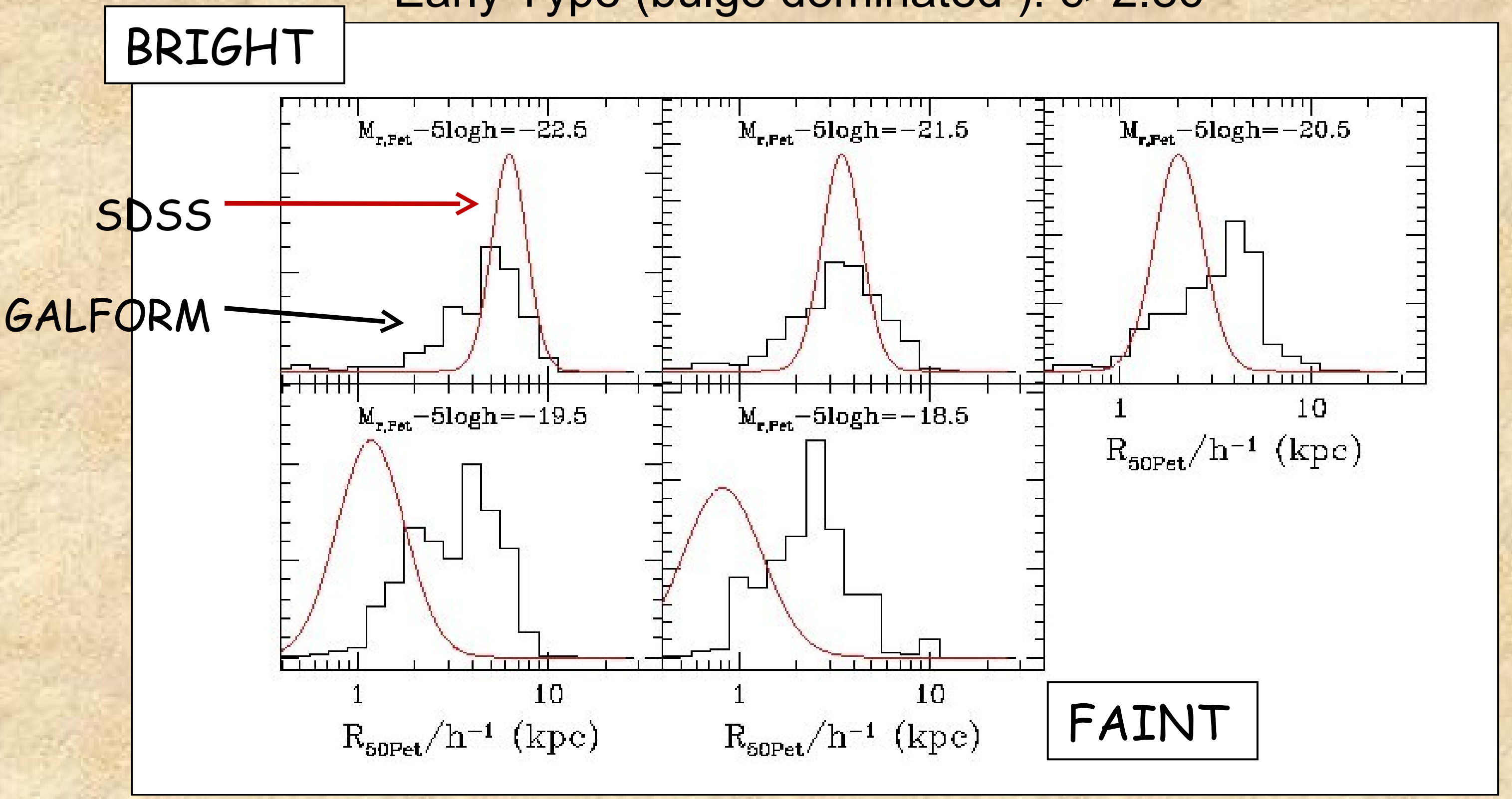
f_{orbit} is an uncertain parameter from theory (f_{orbit} *=1)*.

Size distribution for bulge dominated galaxies.

Baugh 2005 model

- The histograms show the distribution of the Galform predicted. The Gaussians represent the SDSS distribution.

Early Type (bulge dominated): c>2.86



For faint magnitudes the model predicts too big galaxies

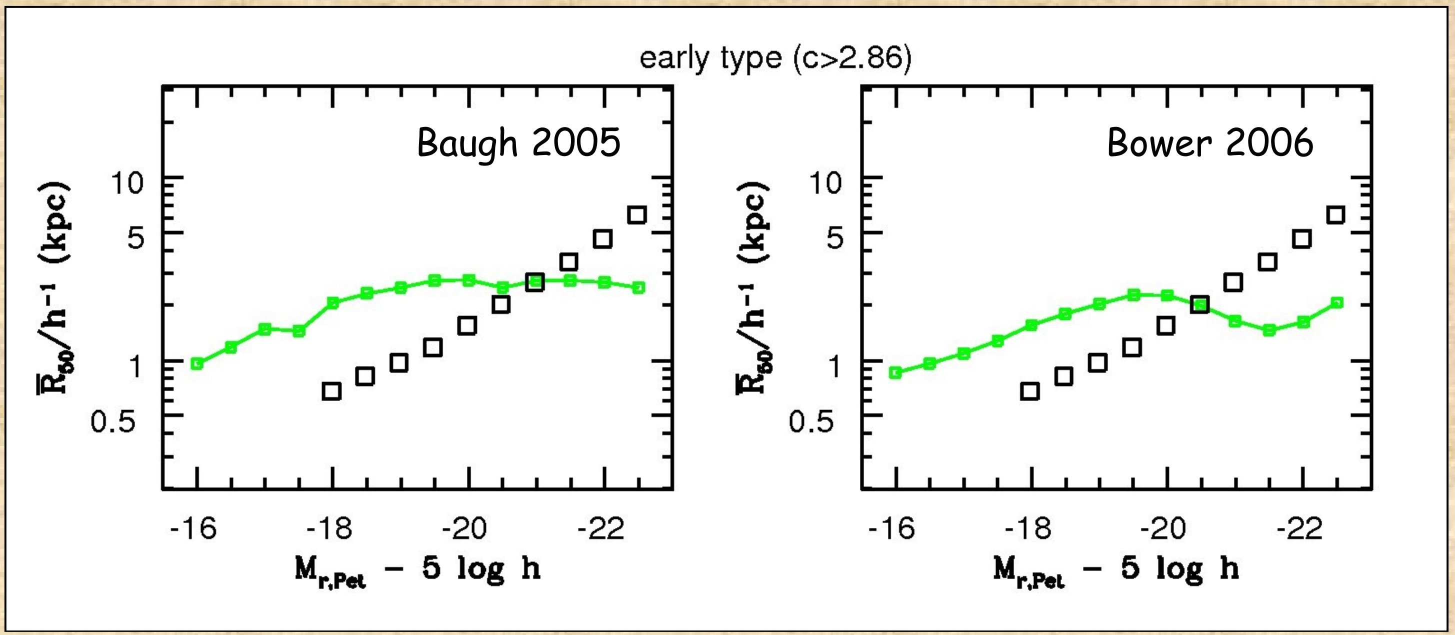
SDSS analysis:
Shen et al. 2003

•Both models predict bigger sizes for low luminosity galaxies.

Big squares: SDSS DR4

Separating by concentration index

early type (bulge dominated)



• Bulge sizes are less sensitive to feedback

Estimating the size of the bulges

The size of the spheroid formed in a merger is computed in the model using:

Binding energy,

$$E_{bind} = -\bar{c}\frac{GM^2}{r}$$

Orbital energy,

$$E_{orbit} = -\frac{f_{orbit}}{2}\frac{GM_1M_2}{r_1 + r_2}$$

Virial theorem and Energy conservation,

$$\frac{E_{bind,new}}{2} = \frac{E_{bind,1}}{2} + \frac{E_{bind,2}}{2} + E_{orbit}$$

$$\frac{(M_1 + M_2)^2}{r_{new}} = \frac{M_1^2}{r_1} + \frac{M_2^2}{r_2} + \frac{f_{orbit}}{\bar{c}}\frac{M_1M_2}{r_1 + r_2}$$

M1, M2: Masses of the merging components.

r1,r2: half-mass radii of the merging components.

$\bar{c}$: form factor; $\bar{c}$=0.5

f_{orbit} is an uncertain parameter from theory (*f_{orbit} =1)*.

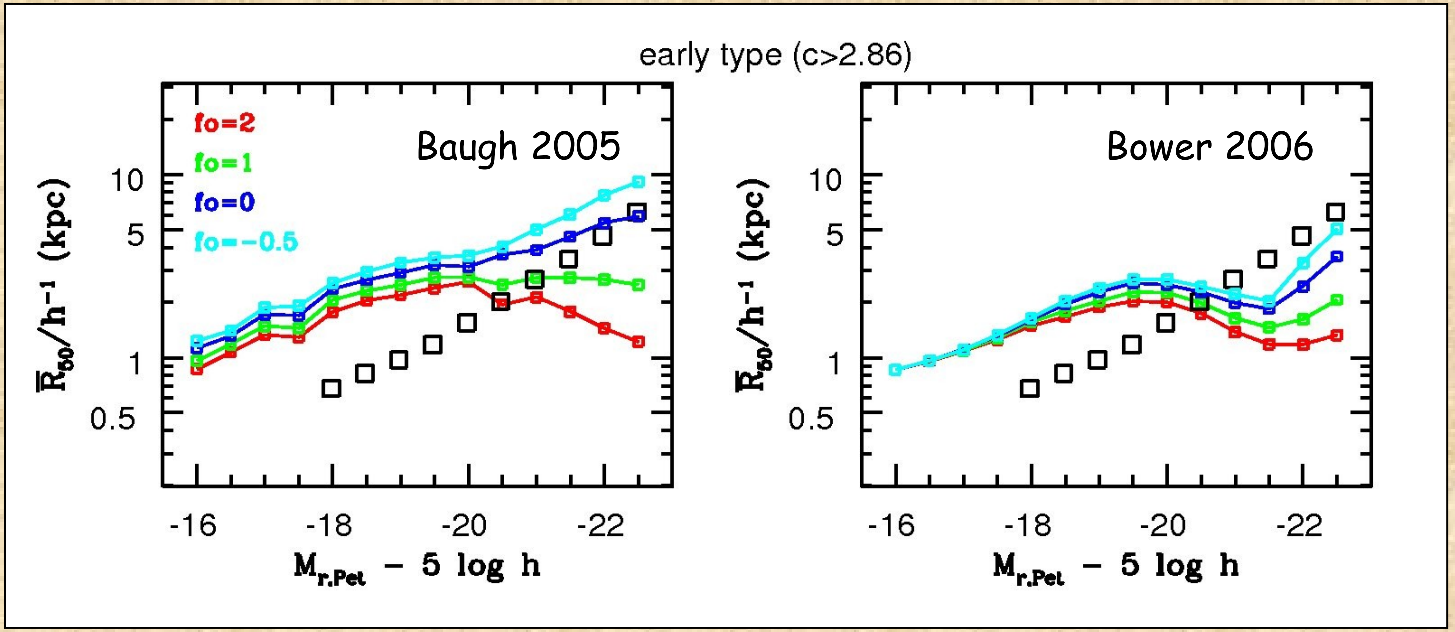
Testing different f_{orbit} for early type galaxies

•Both models predict galaxy sizes too big for low luminosity galaxies.

f_{orbit} = -0.5, 0, 1 and 2

Big squares: SDSS

Separating by concentration index



Best results with f_{orbit}=0 for Baugh 2005 model and with f_{orbit}=-0.5 for Bower 2006 model.

Conclusions

- AGN feedback better shapes the observed luminosity function,
- Models predict too many galaxies in the bright end in the r_{Pet} band,

- Fractions of morphology type by Sérsic index agree well with the observed data,

- Bimodality in colours, magnitudes and morphologies is seen as well in the models,

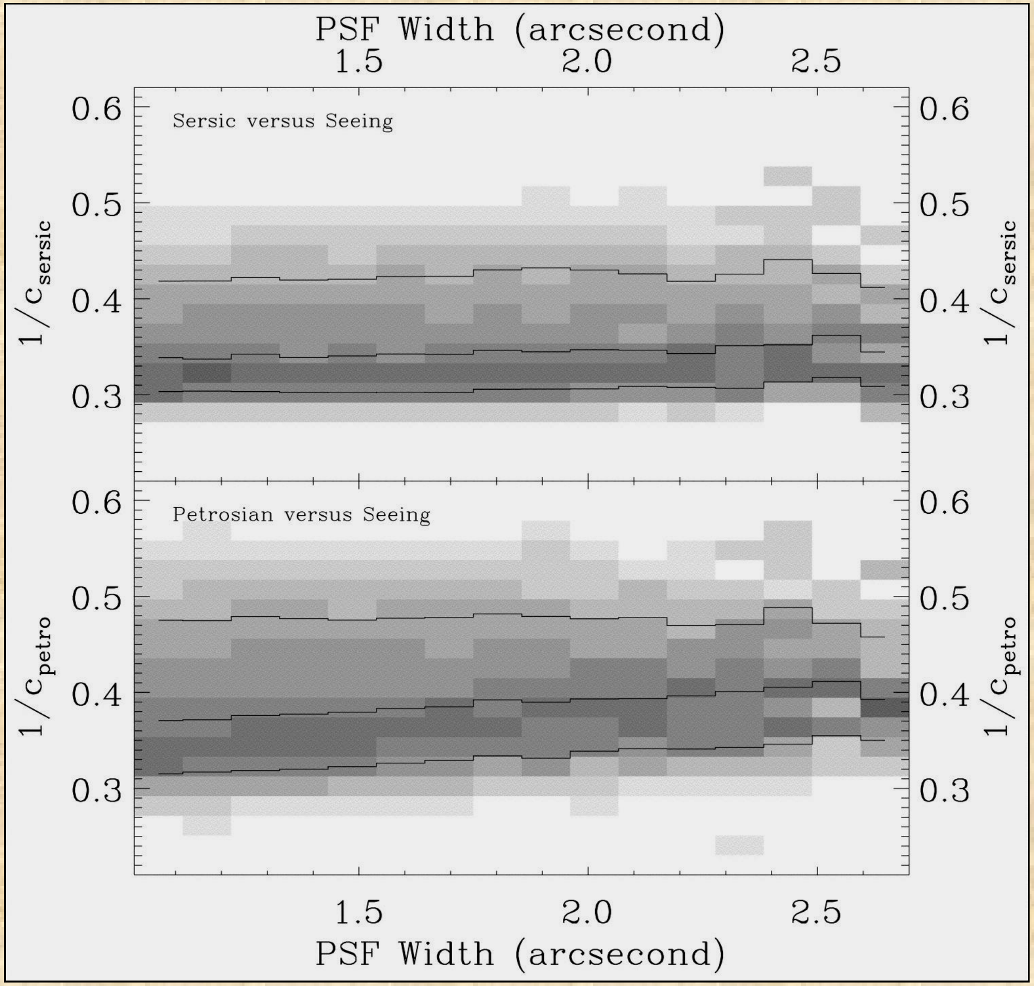
- Disk sizes very sensitive to feedback,
- Faint bulge dominated galaxies are predicted too big,
- These problems highlight the need to better understand both the effects of feedback processes and the assembly of galaxy bulges by mergers.

Sérsic Index

- Problems with the dependence in the "concentration index" with seeing. Median can changes from around 0.37 to 0.42. (Blanton et al. 2003)
- It can be fitted a radial dependence for the surface brightness in the form:

$$I(r) = A\exp[-(r/r_0)^{1/n}]$$

- Sérsic index n~1: late type
- Sérsic index n~4: early type

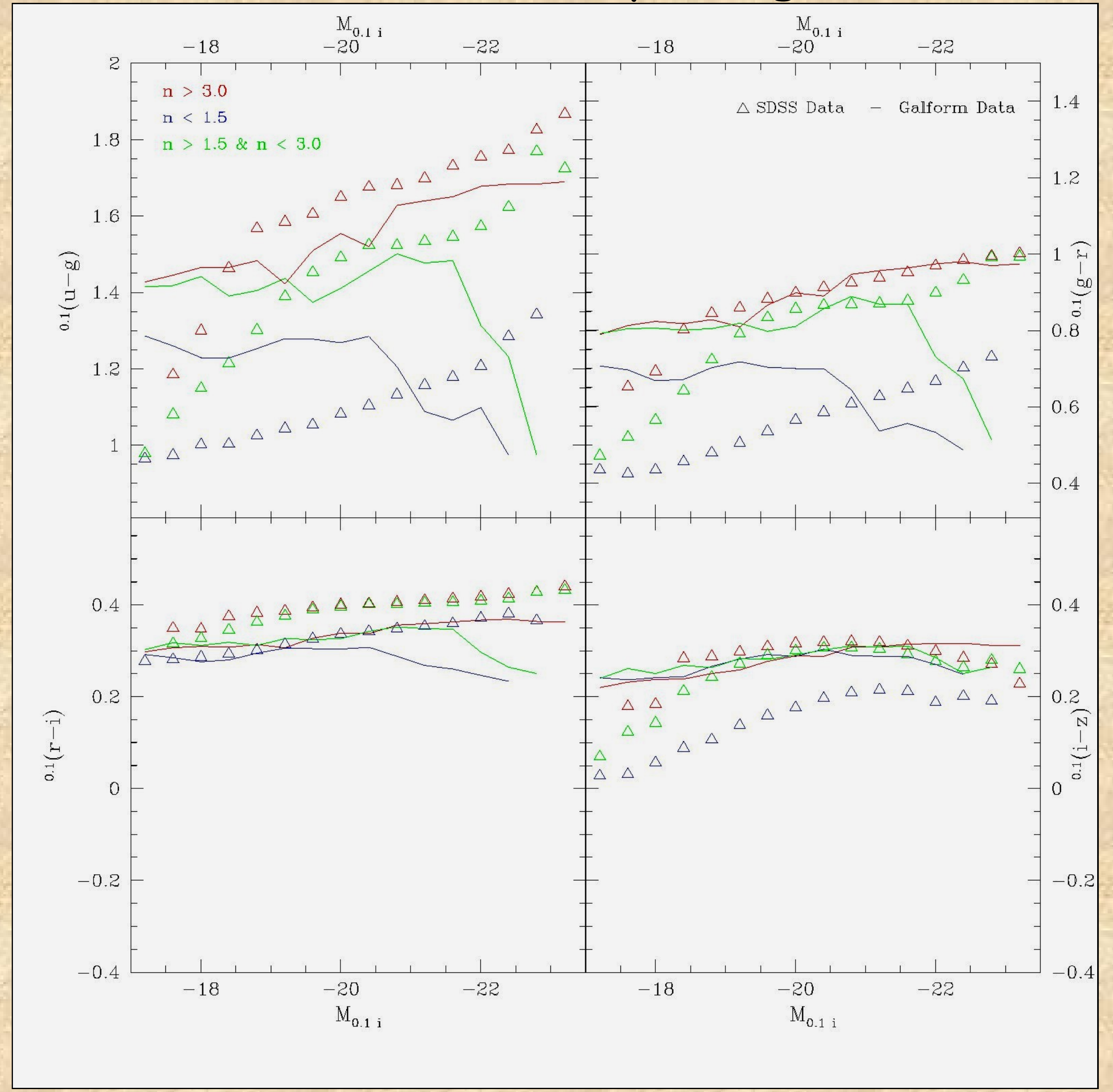


Dependence of the inverse concentration index on seeing.

Median colours as Function of Luminosity, Baugh model

•The colours of early type galaxies (de Vaucouleurs, n>3) agrees very well.

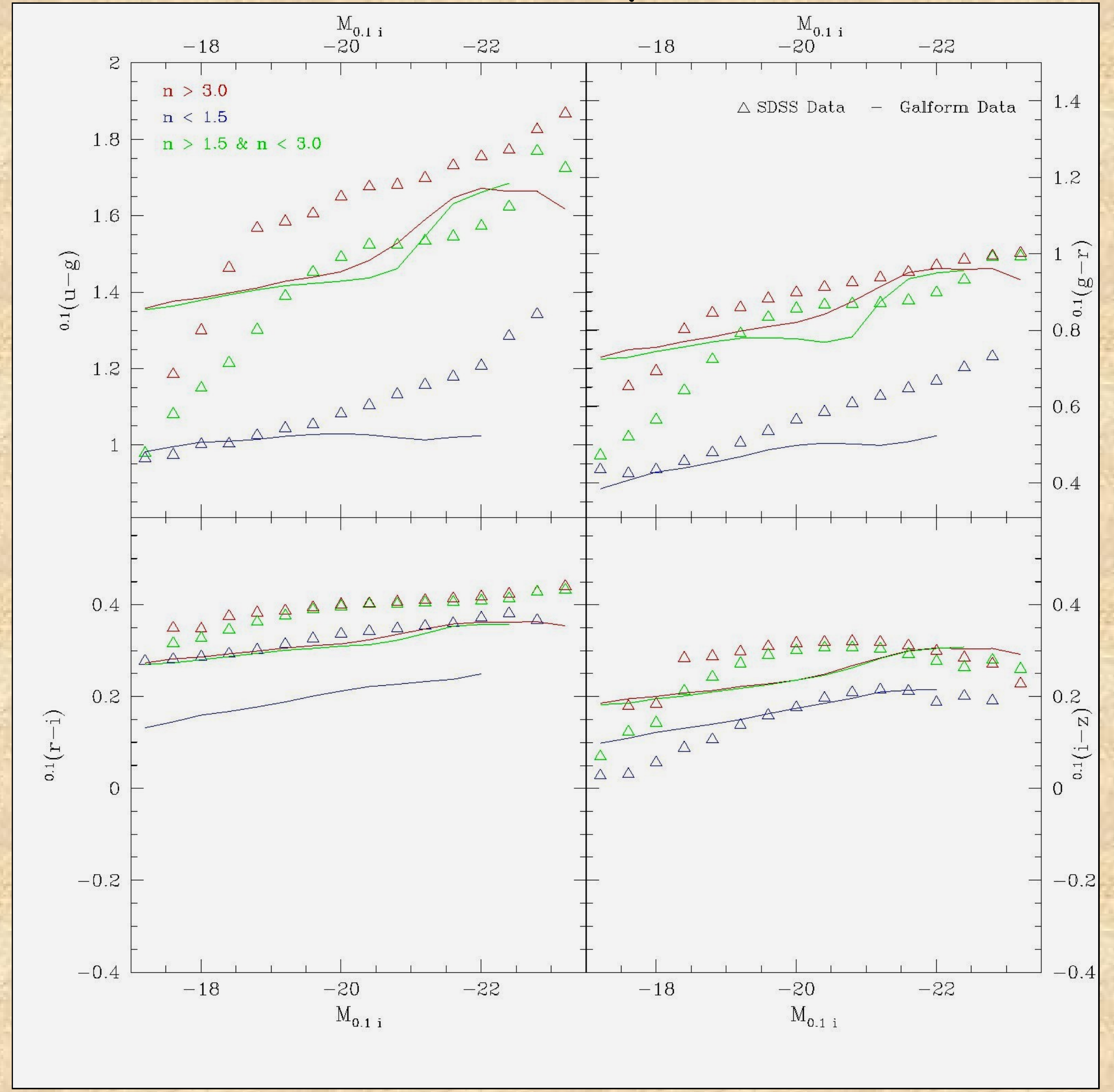
•The late type galaxies (exponential, n<1.5) seem to be too red for low luminosities.



SDSS DR4, median redshift=0.035

Median colours as Function of Luminosity, Bower model

- Colour bimodality is clearly seen in the Bower model.



SDSS DR4, median redshift=0.035