The galactic spin of disc galaxies through the SDSS

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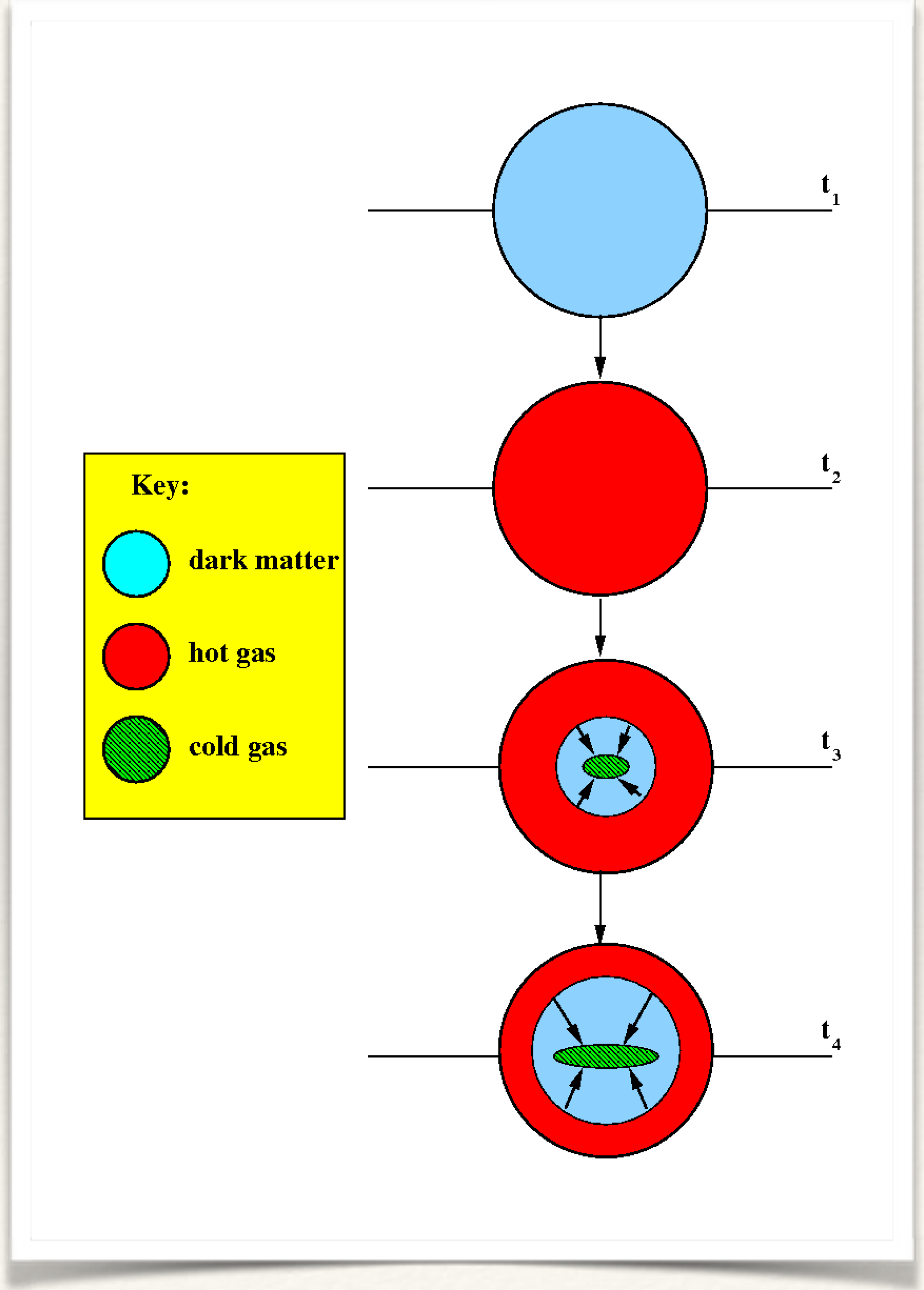
Outline

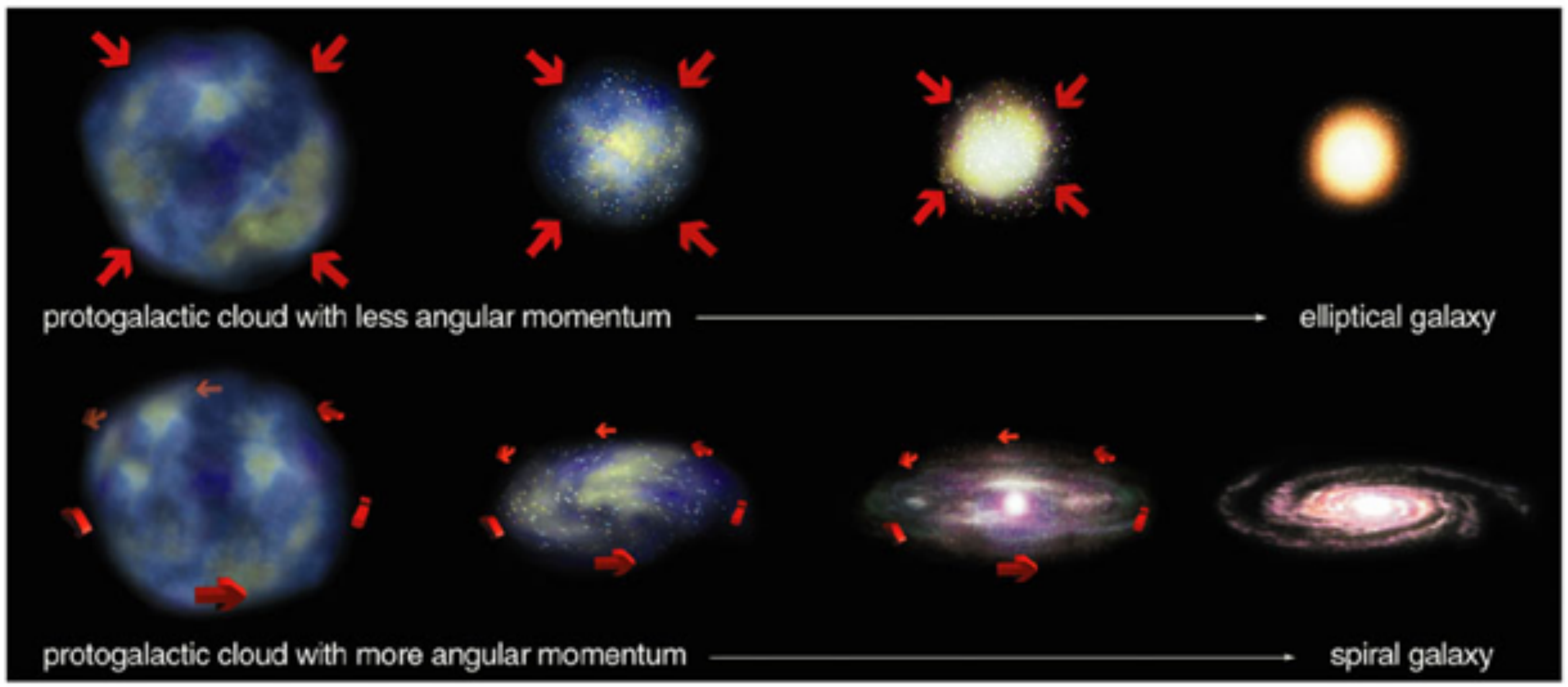
- Introduction:
    - what is the spin
    - its role on the structure of present day galaxies (theory / observations)
    - Distributions from N-body simulations
- Model for the estimation of the spin for SDSS galaxies
- General results (Emphasis on barred disc galaxies)
- Conclusions

Basic picture of galaxy formation (cartoon version)

- Halo collapses and drags baryons into the gravitational potential well
- Gas cools by radiating processes to settle down on a rotationally supported disc.



- According to the amount of angular momentum:

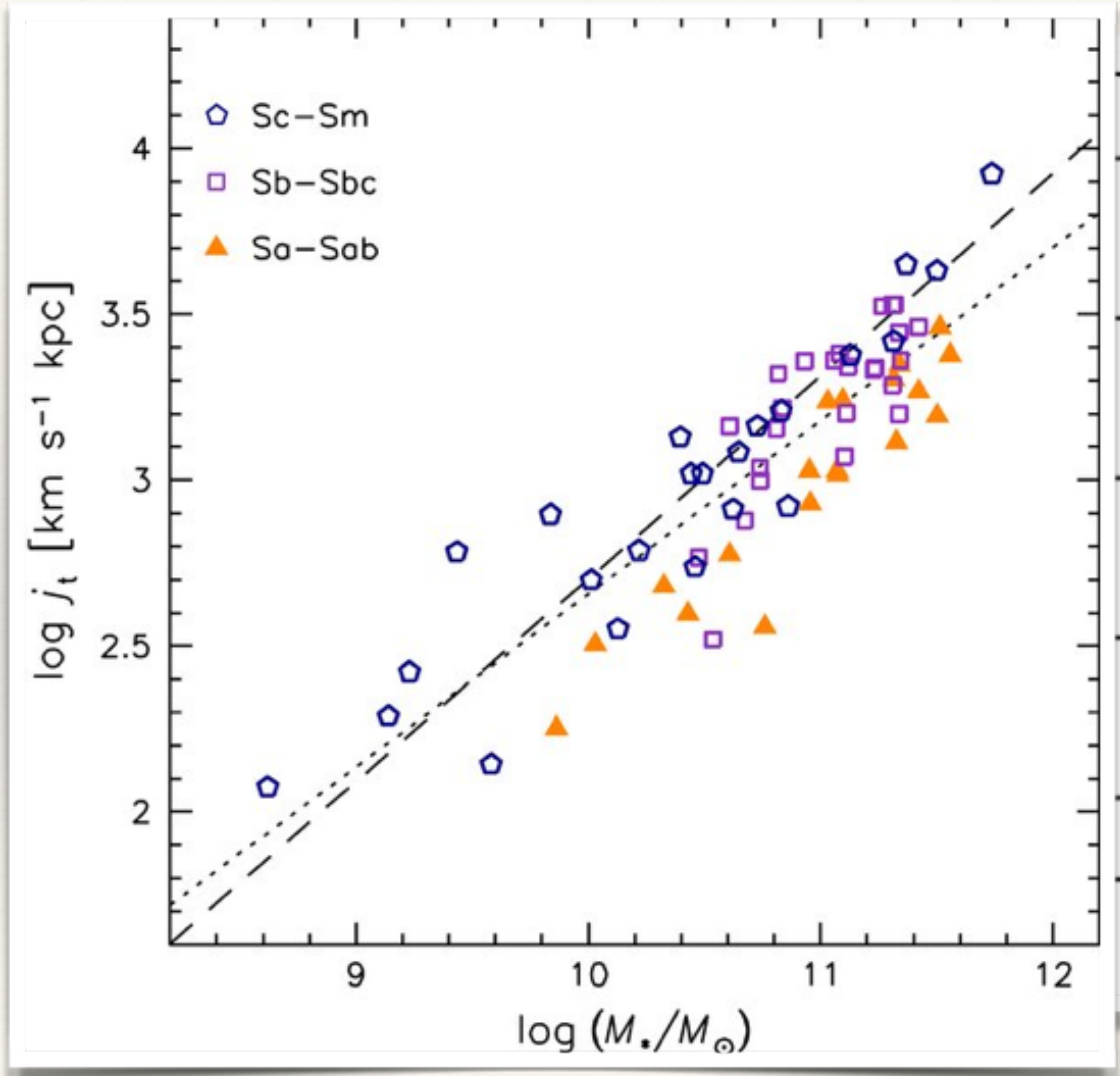


- This simple scenario leads to predictions of present day disc galaxies that show good resemblance with observations (Fall & Efstathiou 1980; Flores et al. (1993); Firmani, Hernandez & Gallagher (1996), Dalcanton, Spergel & Summers (1997); van den Bosch (1998); Avila-Reese et al. (1998), Zhang & Wyse (2000); Silk (2001); Kregel, van der Kruit & Freeman (2005); Klypin et al. (2002); …

Fall (1983) and Romanowsky & Fall (2013)

j = J / M ~ M**α** with **α** ≈ 0.6

Disc and elliptical galaxies show an offset of ~ 5 dex



The spin parameter λ

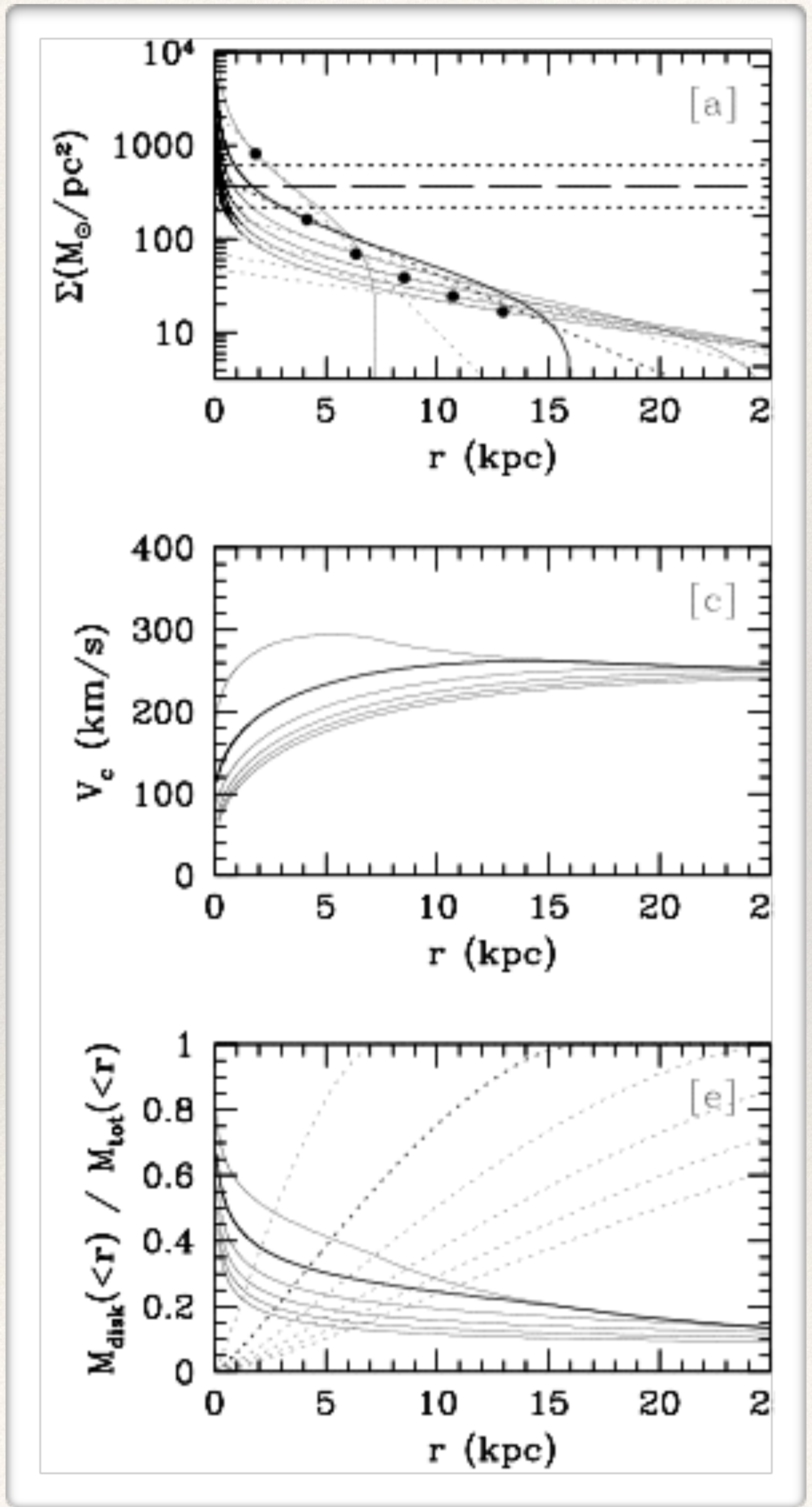
- Defined by Peebles (1969, 71):

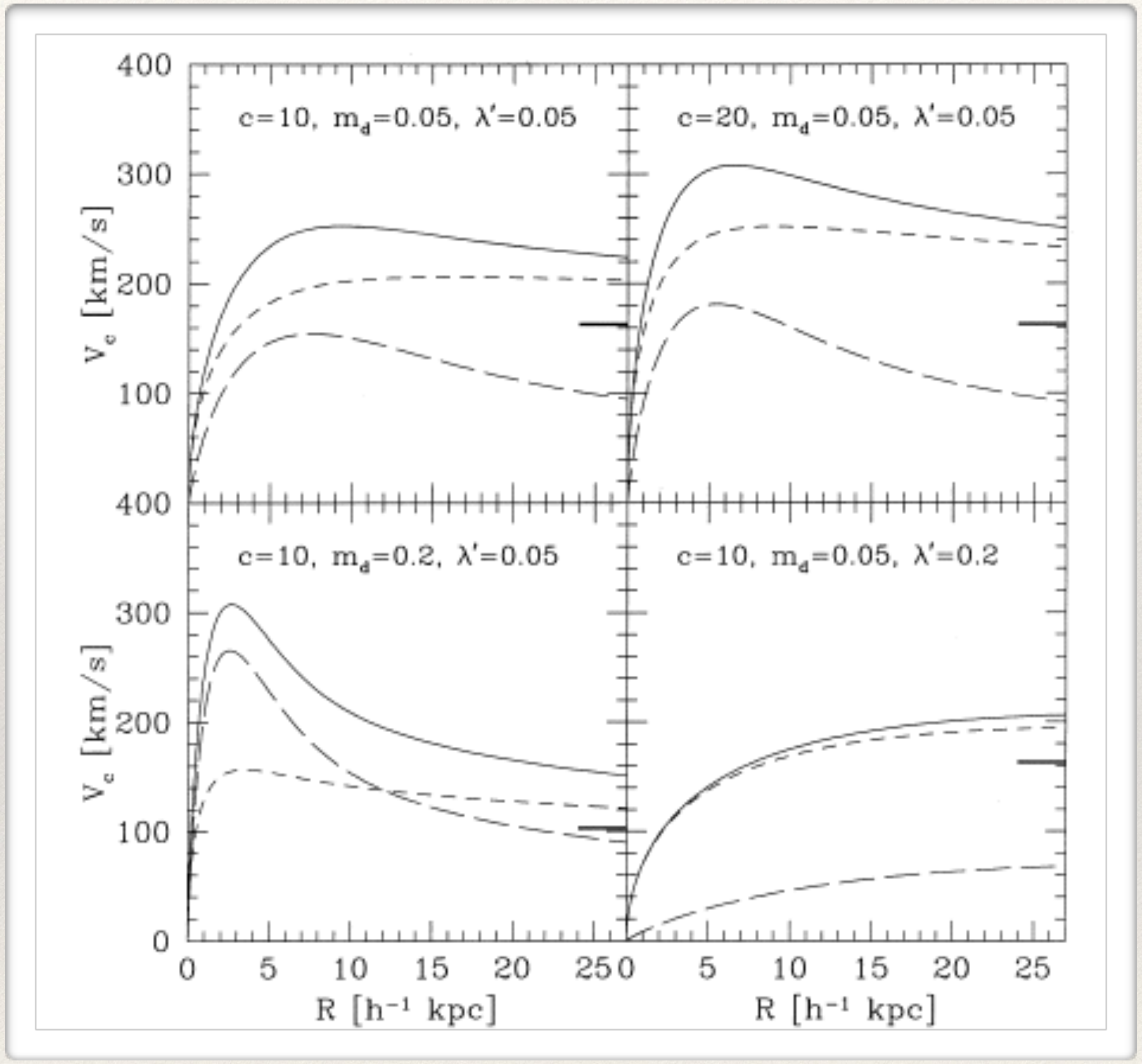
$$\boxed{\lambda = \frac{L|E|^{1/2}}{GM^{5/2}}}$$

- Measure of the degree of rotational support of the system

$$\frac{g_\phi}{g} \sim \frac{V_c^2}{r}\frac{r^2}{GM} = M^2 r^2 v_c^2 \frac{GM^2}{r}\frac{1}{G^2M^5} \sim \frac{L^2E}{G^2M^5}$$

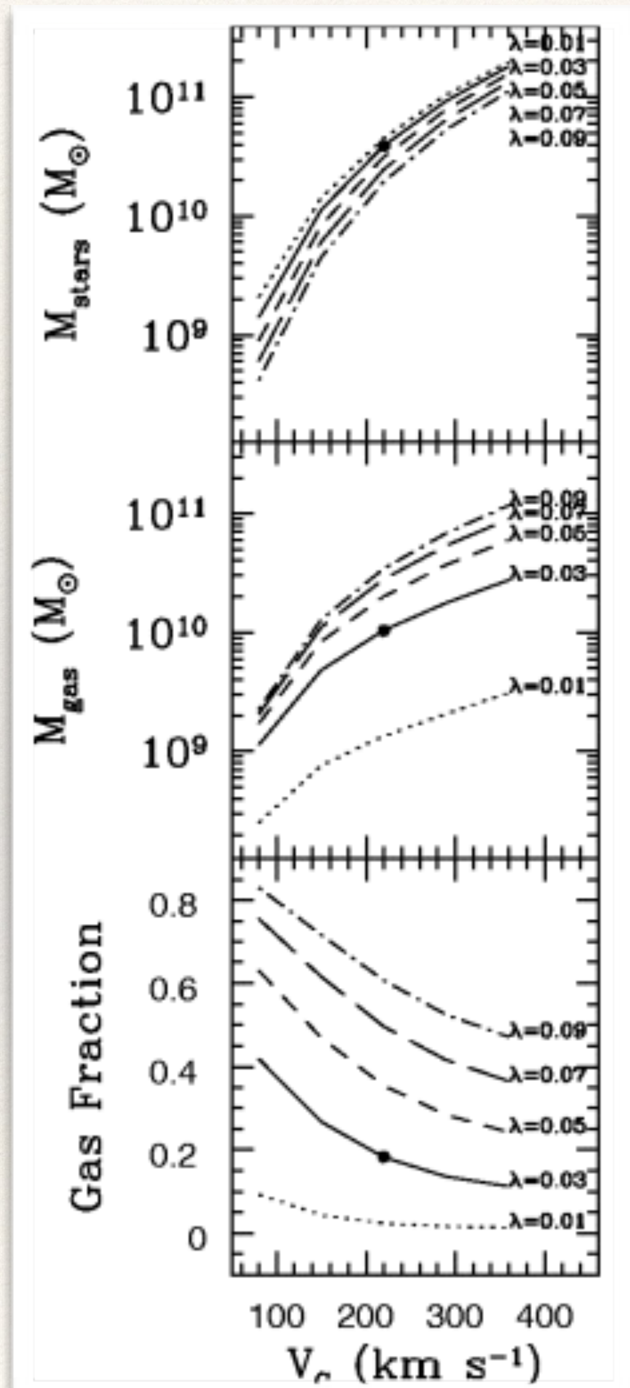
Influence of the spin on galaxy properties (semi-analytical models) I

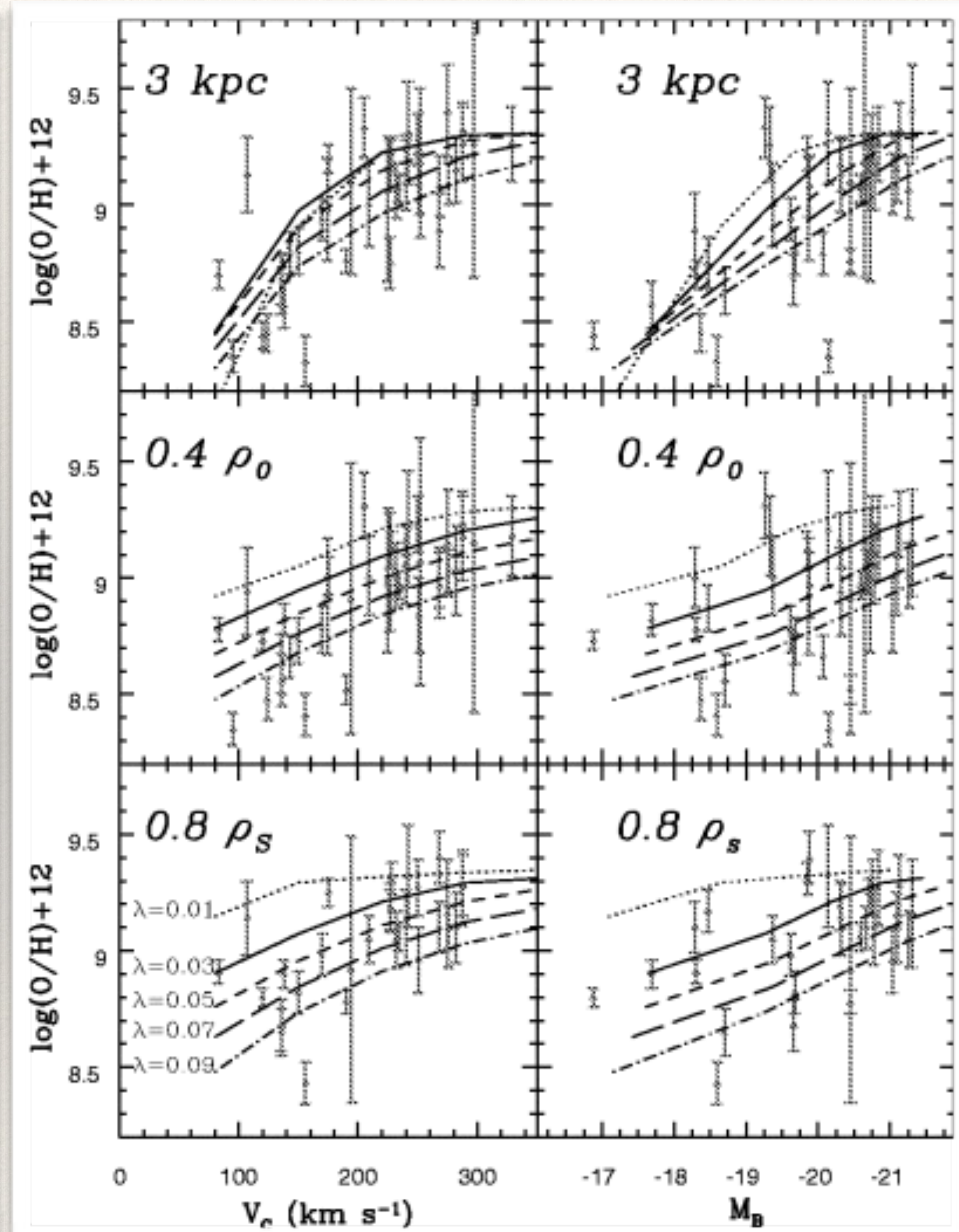




Dalcanton et al. 1997
Mo, Mao & White 1998

Influence of the spin on galaxy properties (semi-analytical models) II





Boissier & Prantzos (2000)

Efstathiou, Lake & Negroponte (1982)

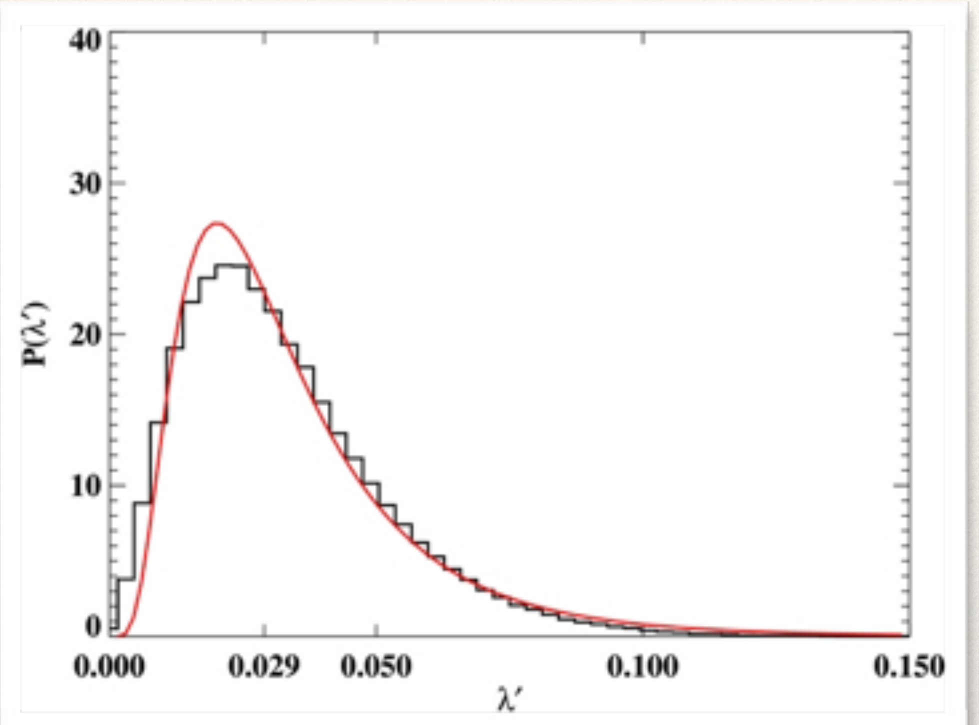
$$\epsilon_c = \frac{V_{max}}{GM_d/R_d} \leq 1.1$$

or int terms of the spin (Mo, Mao & White 1998):

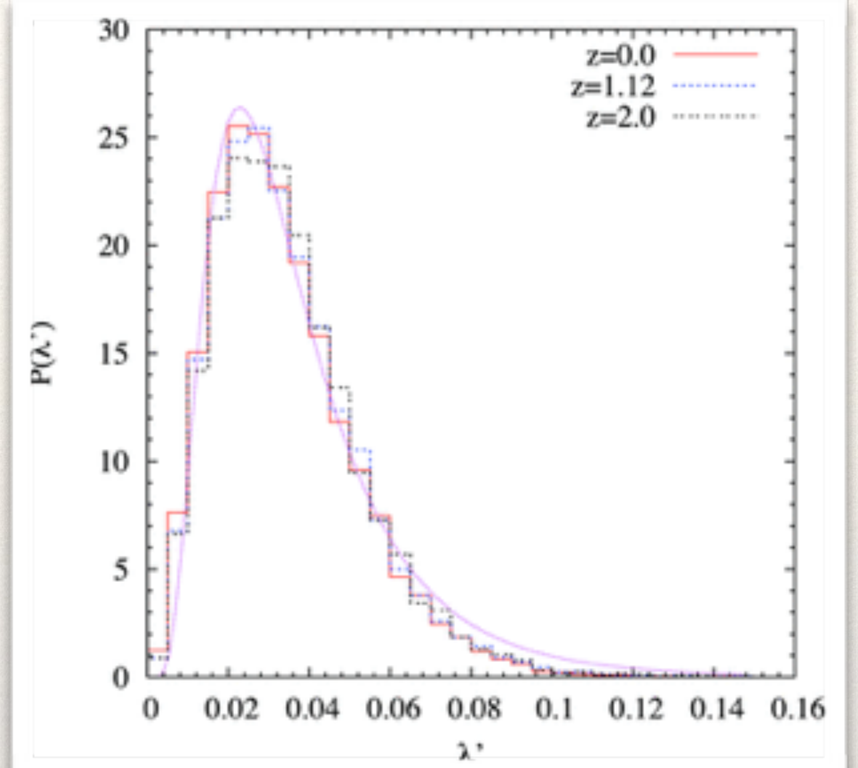
$$\epsilon_c = \frac{\lambda_d}{2^{1/2} f_d}$$

Galaxies with low spin, more compact and self gravitating, are expected to develop bar instabilities

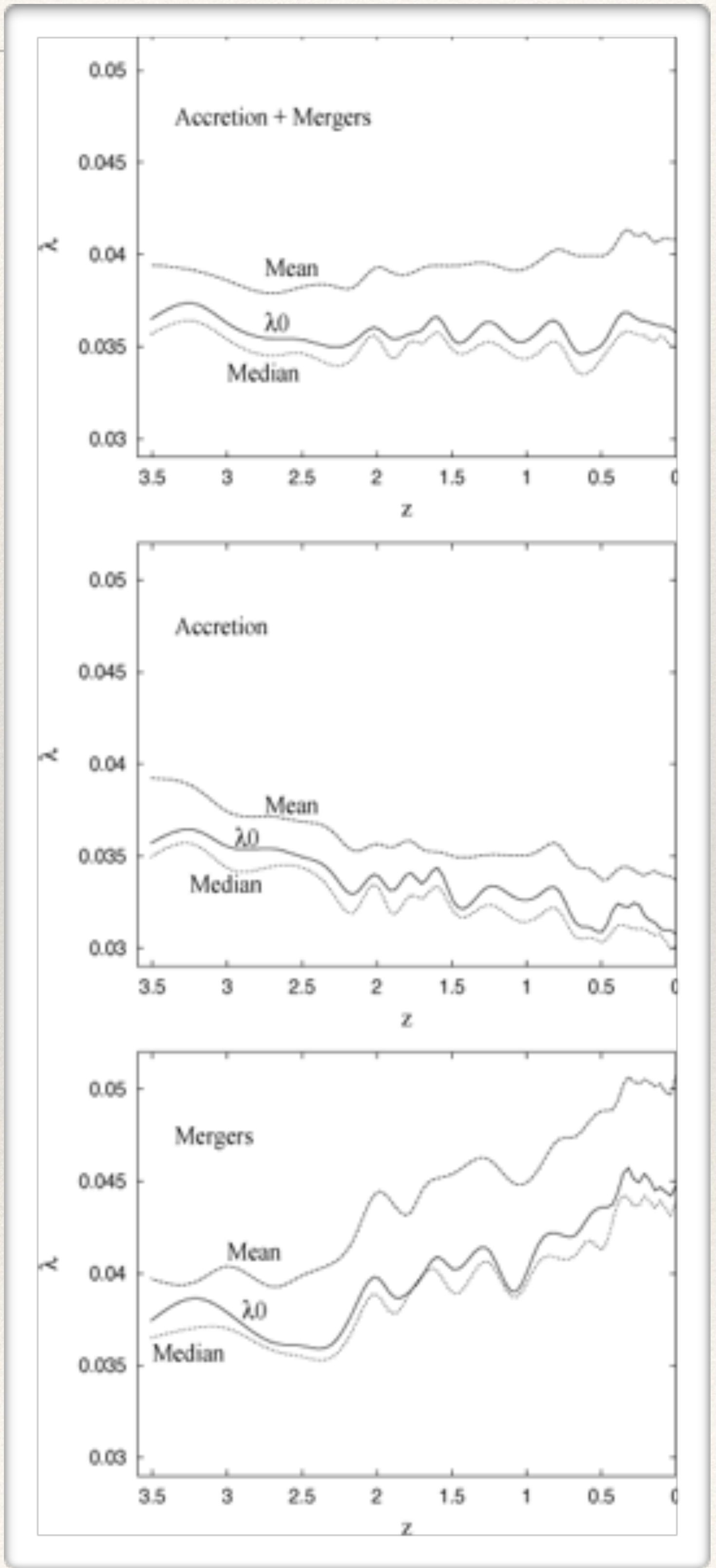
Spin distributions from N-body simulations



Trowland et al. 2013



Muñoz-Cuartas et al. 2010



Peirani et al. 2004

Spin determination I

(MMW 98, Boissier+00, Hernandez & Cervantes-Sodi 06, Tonini+06)

$$\lambda = \frac{L|E|^{1/2}}{GM^{5/2}}$$

- We consider a disc for the baryonic component of the galaxy with an exponential surface mass density profile:

$$\Sigma(r) = \Sigma_0 e^{-r/R_d}$$

- and a total disc mass:

$$M_d = 2\pi\Sigma_0 R_d^2$$

- and a dark matter halo with an isothermal density profile:

$$\rho(r) = \frac{1}{4\pi G}\left(\frac{V_d}{r}\right)^2$$

- and a finite radius given by:

$$R_H = \frac{M_H G}{V_d^2}$$

Spin determination II

- The energy is given by the halo:

$$E = \frac{-V_d^2 M_H}{2}$$

- For the angular momentum we consider that the specific angular momenta of disc and halo are equal (Fall & Efstathiou 1980):

$$L_d/M_d = l_d = 2V_d R_d$$

- Finally we adopt a specific prescription for the disc mass fraction:
  - f = cte.
  - f = f(Σ) following Gnedin et al. (2007)
  - f = f(M_*) following Guo et al. (2010)

Spin determination III

- Our final expression is:

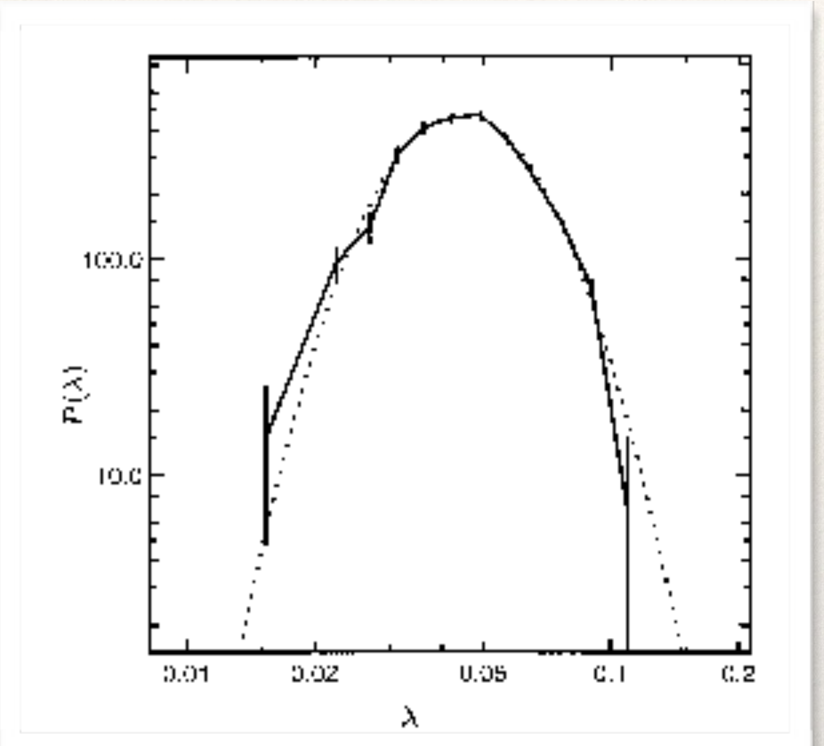
$$\lambda = \left(\frac{\sqrt{2}}{G}\right) F_d R_d V_c^2 M_d^{-1}$$

- In the most simplified version, considering a constant dark matter fraction, and introducing a baryonic Tully-Fisher relation:

$$\lambda = \frac{21.8 R_d/kpc}{(V_d/km * s^{-1})^{1.5}}$$

- Given that the SDSS does not provide measurements for the rotation curve, we introduce a traditional Tully-Fisher relation (Pizagno et al. 2007)

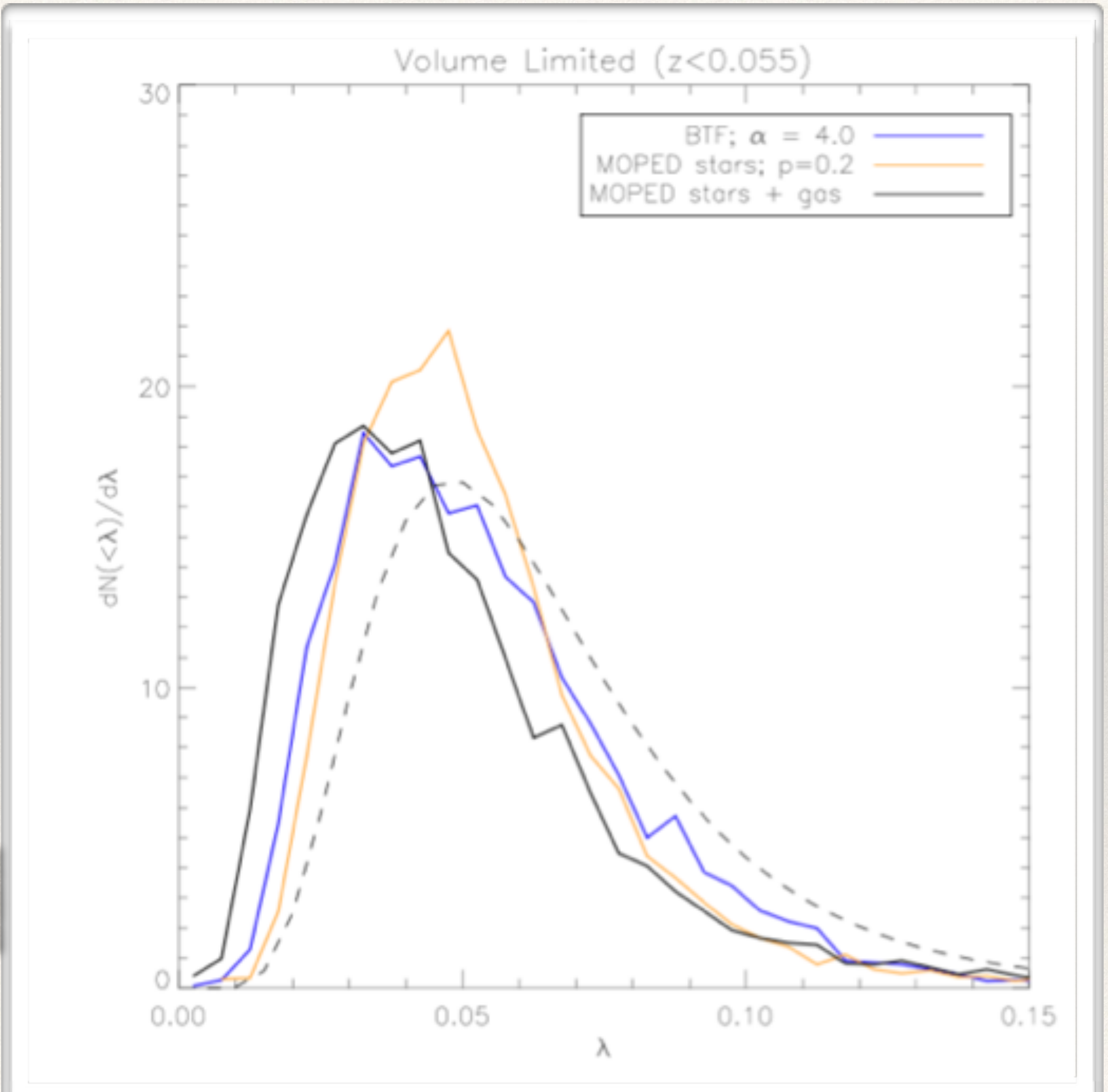
Empirical spin distributions



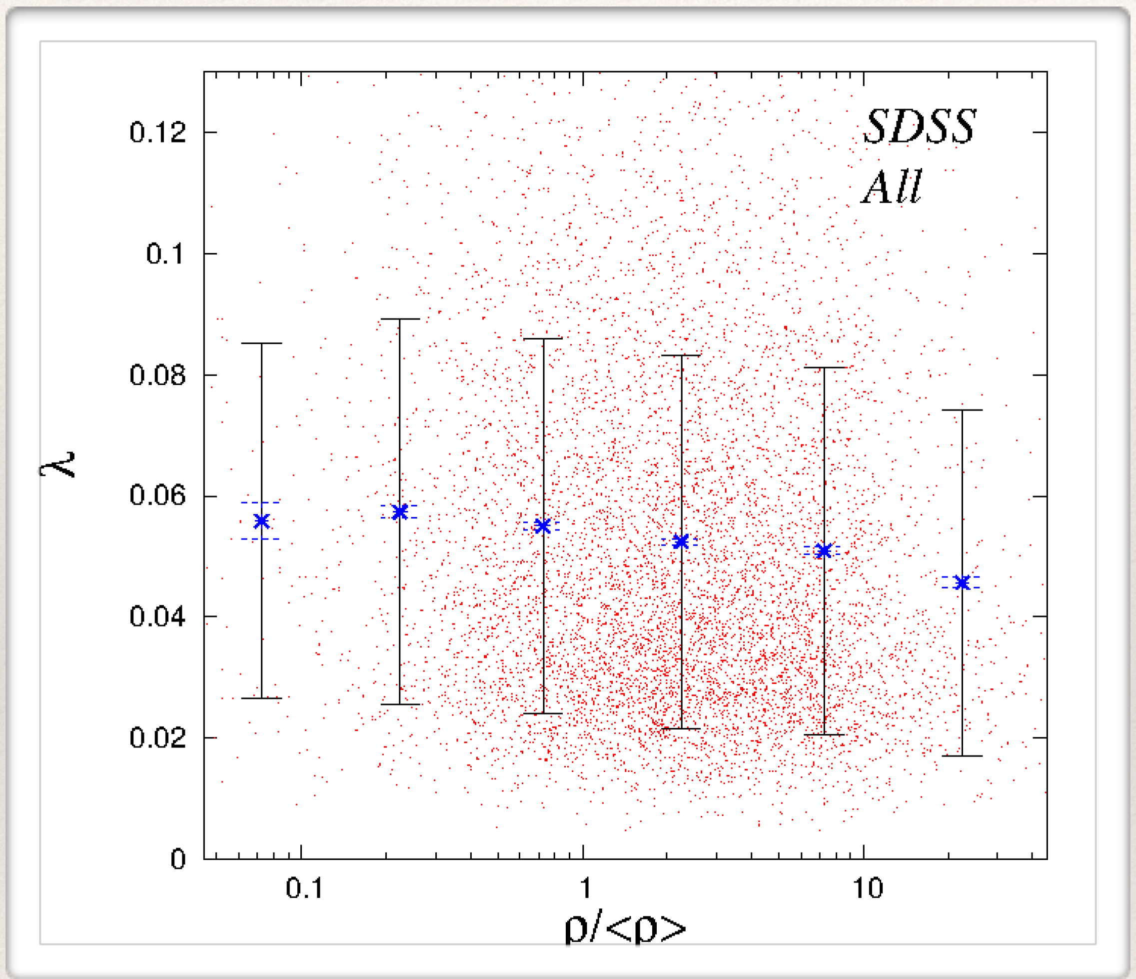
Syer, Mao & Mo (1999)

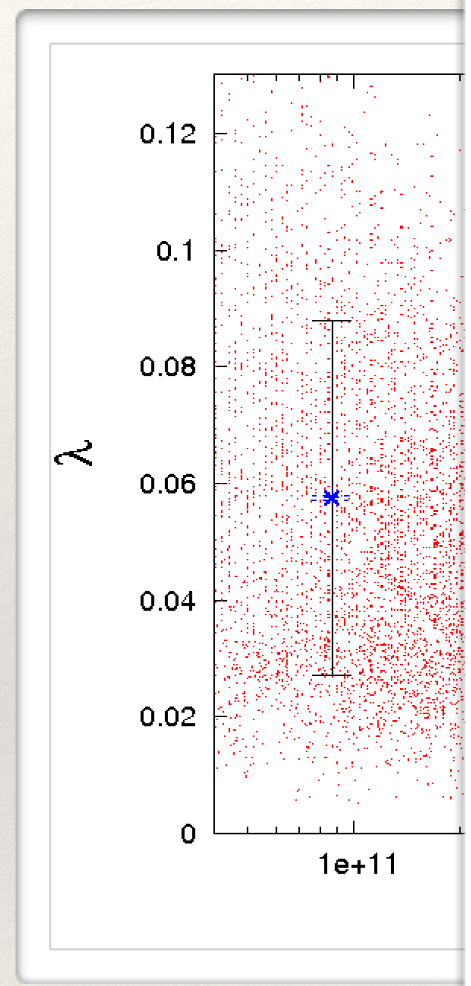
Hernandez et al. (2007)

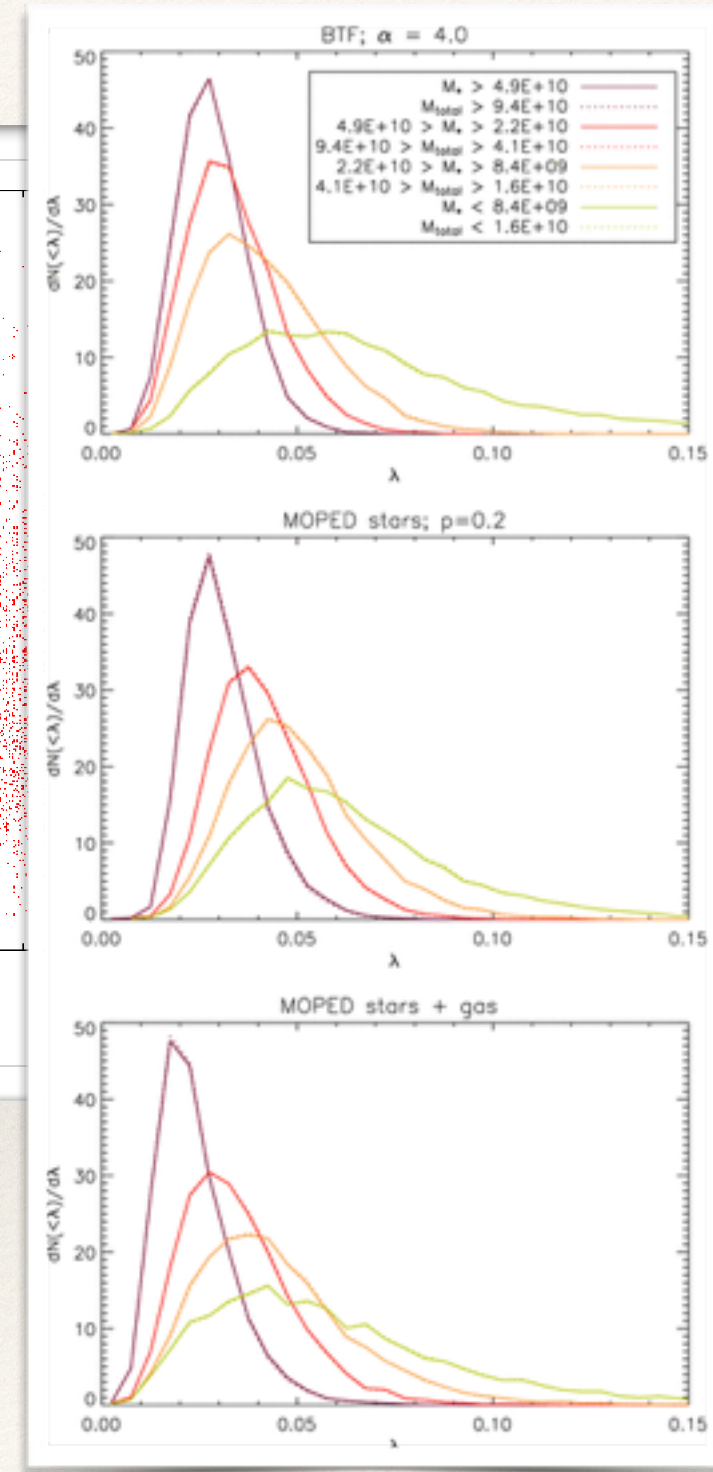
Berta et al. (2007)



Environmental and mass dependencies



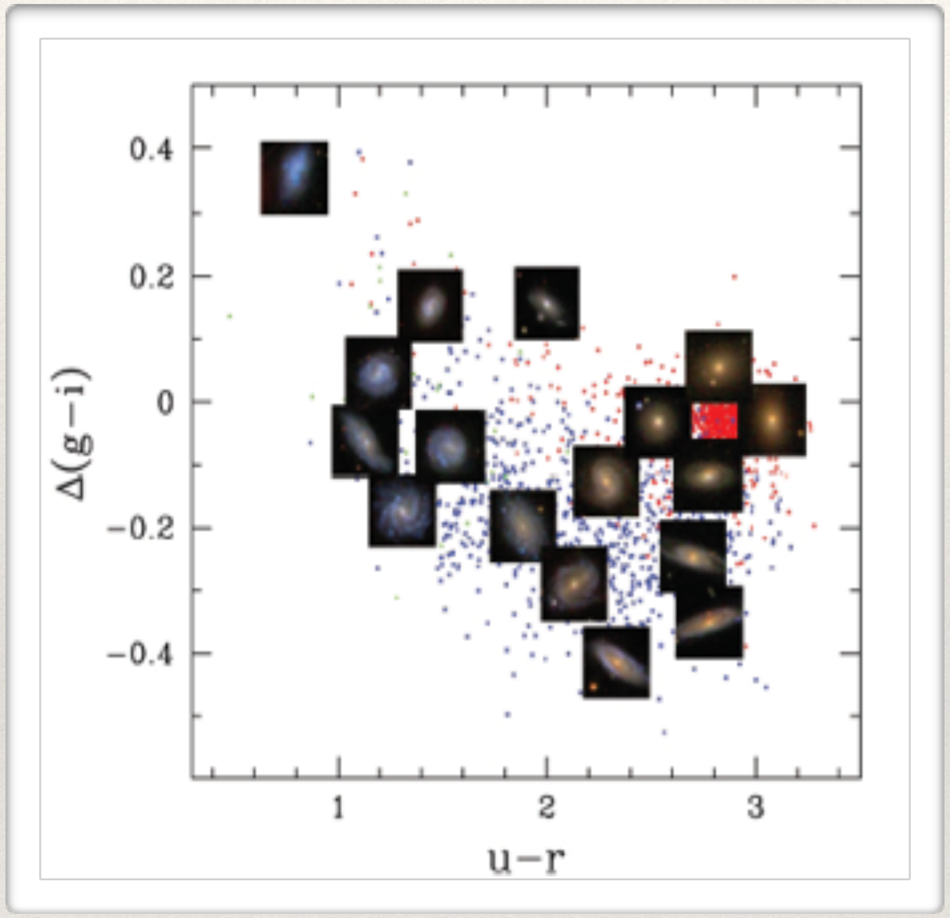




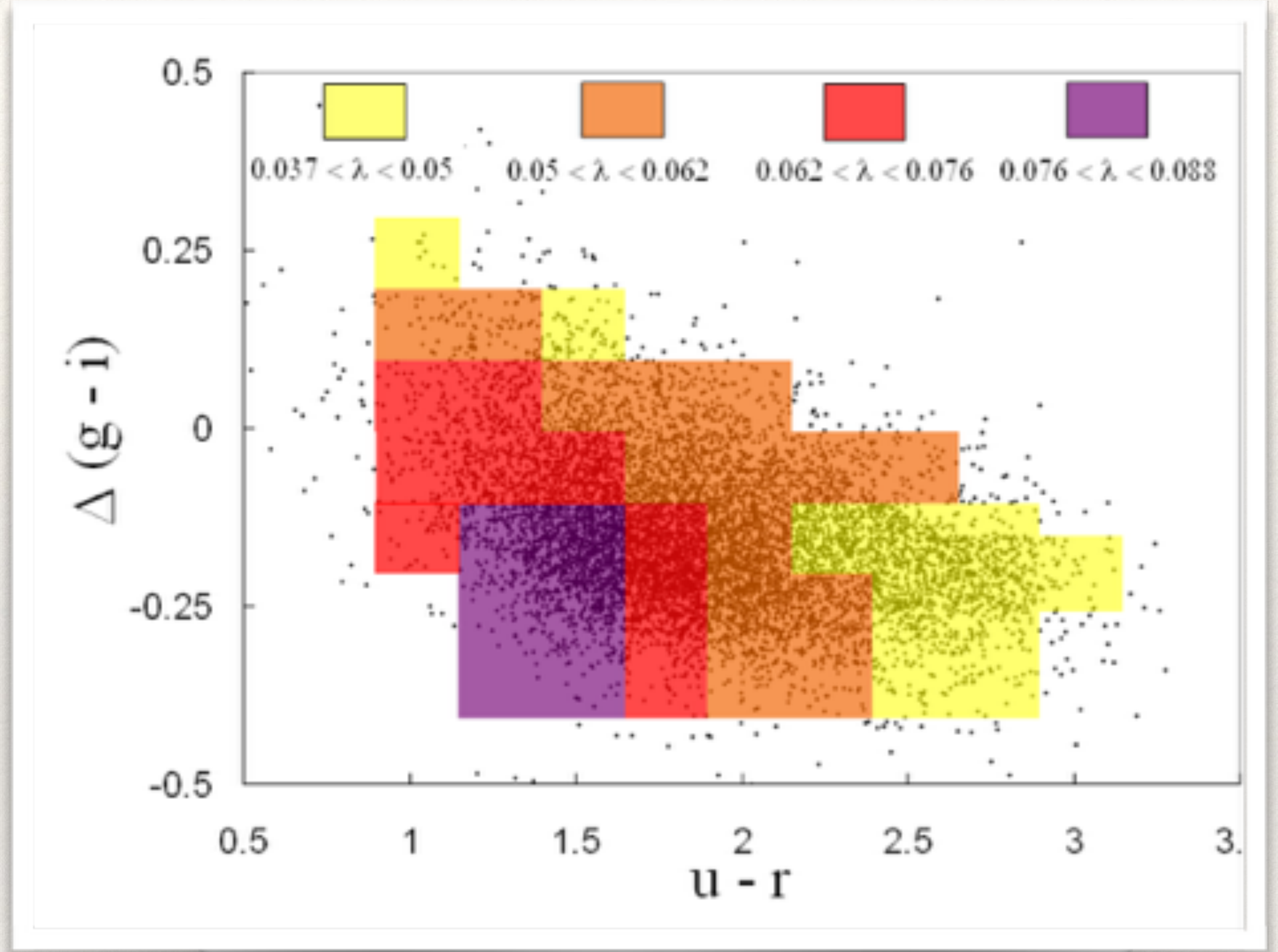
Cervantes-Sodi et al. (2008)

Berta et al. (2008)

Spin and galaxy morphology

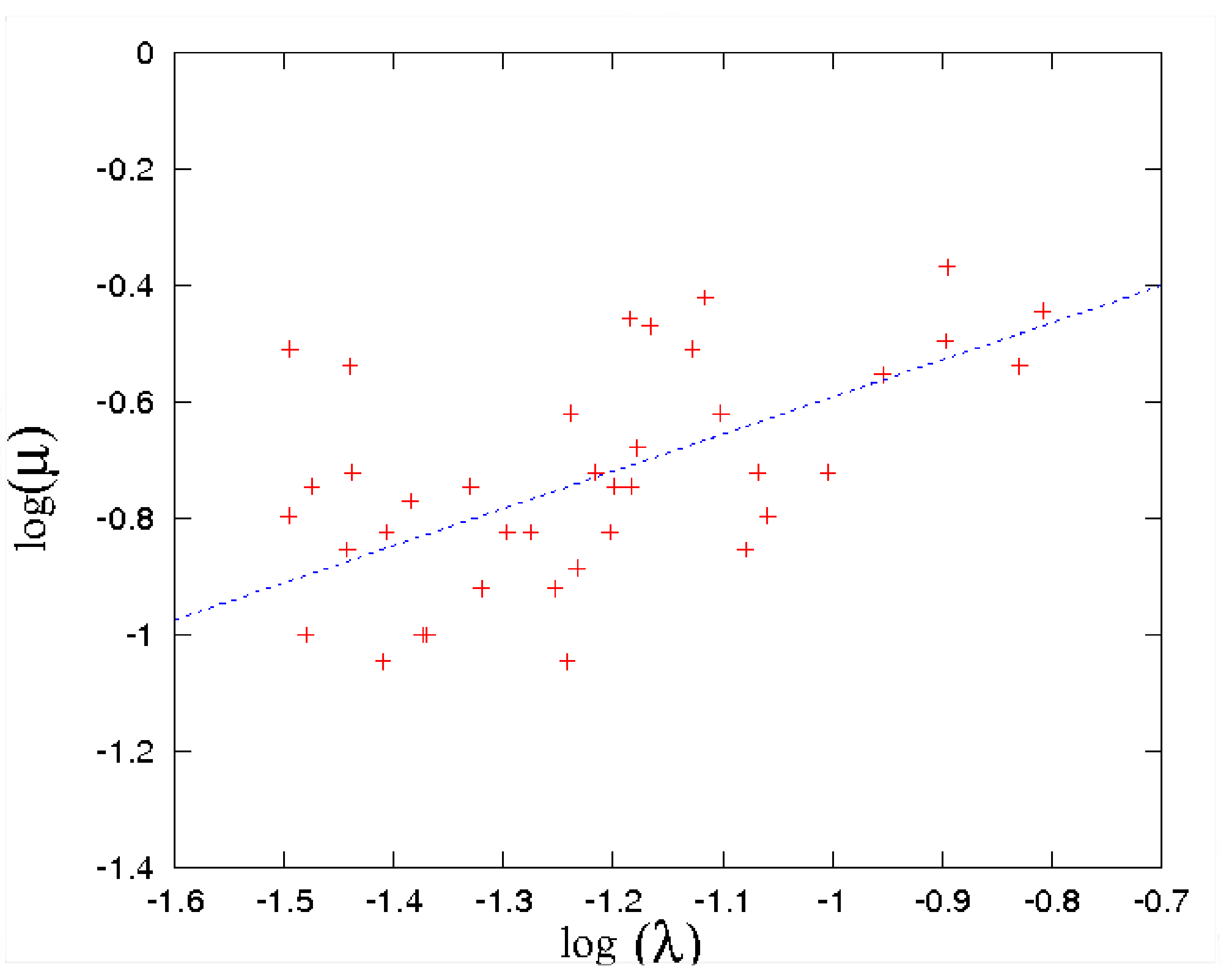


Park & Choi (2005)

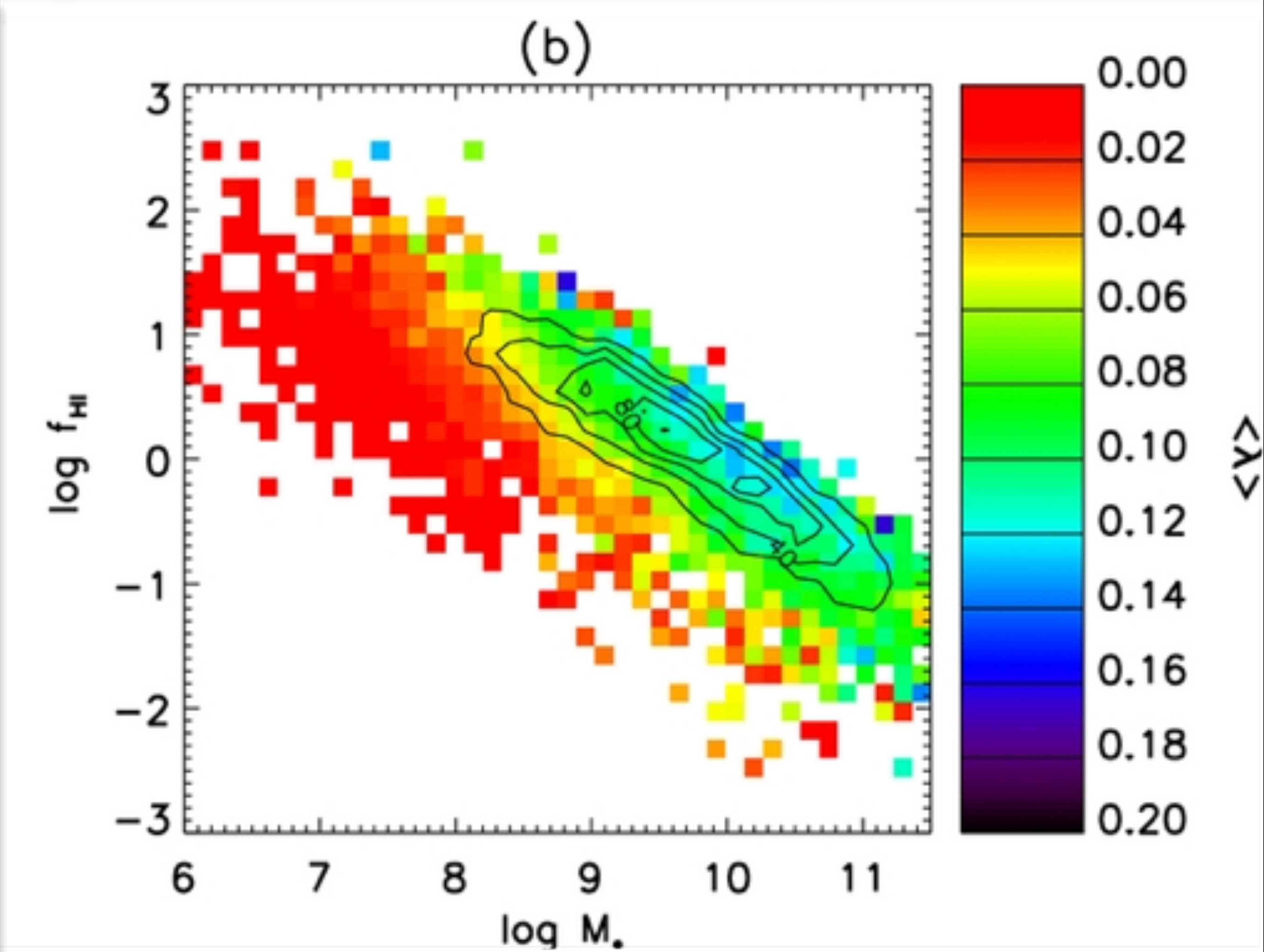


Cervantes-Sodi & Hernandez (2009)

Spin and gas mass fraction



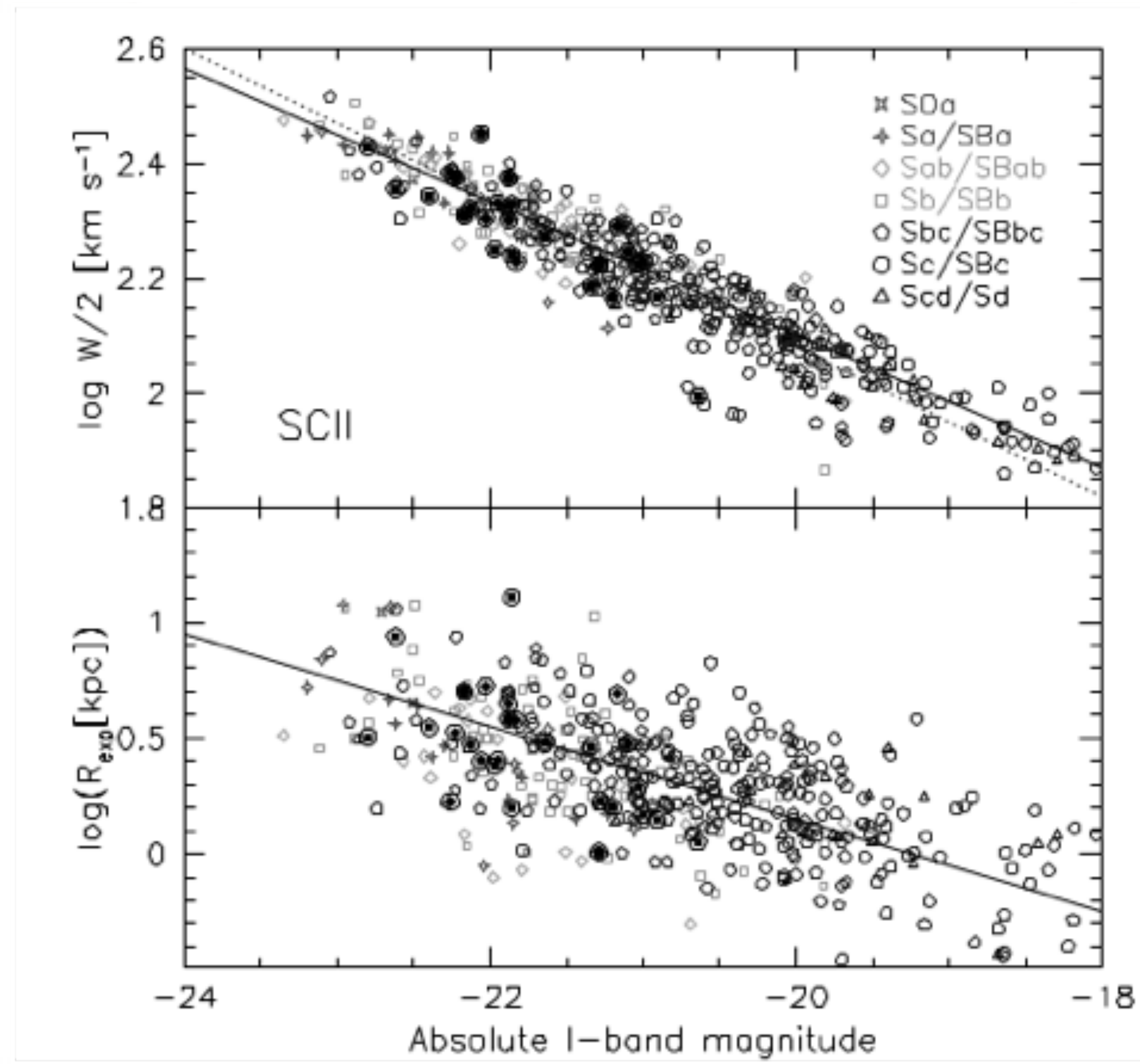
Cervantes-Sodi & Hernandez (2009)



Huang et al. (2013)

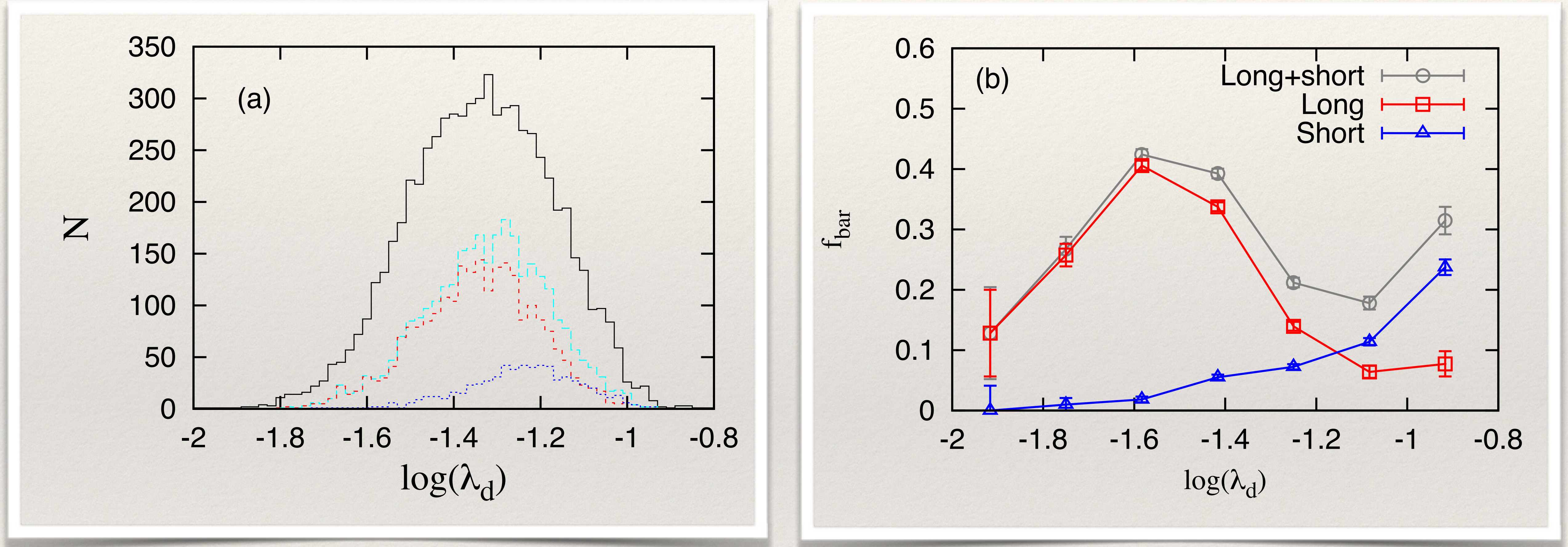
Spin and bar fraction

- Data drawn from Lee et al. (2012)
  - Sample of ~ 10,000 disc galaxies visually classified on:
  - Strong bars (the bar is larger than one quarter the size of the galaxy)
  - Weak bars
  - Unbarred galaxies



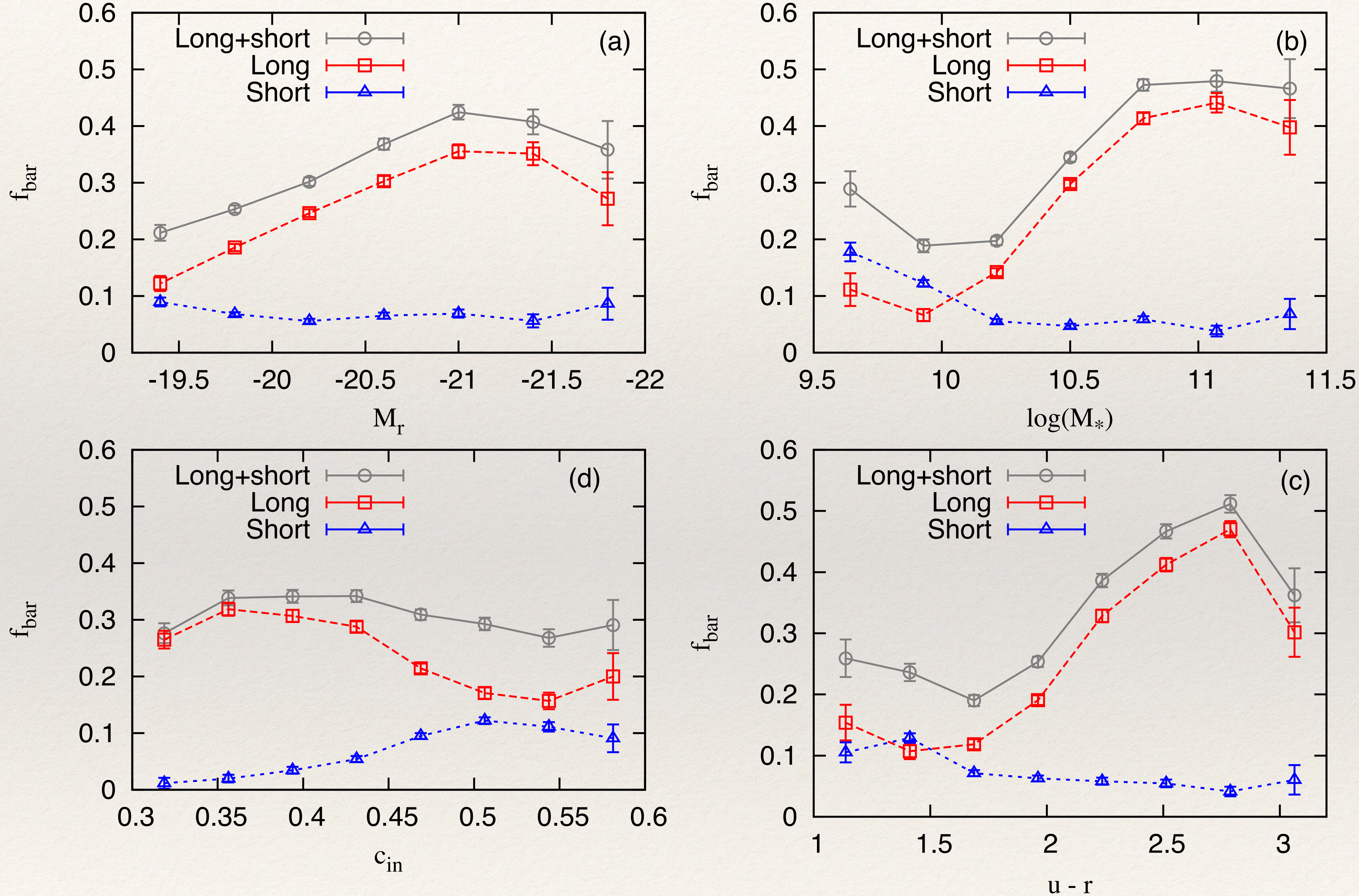
Courteau et al. (2003)

Spin and bar fraction



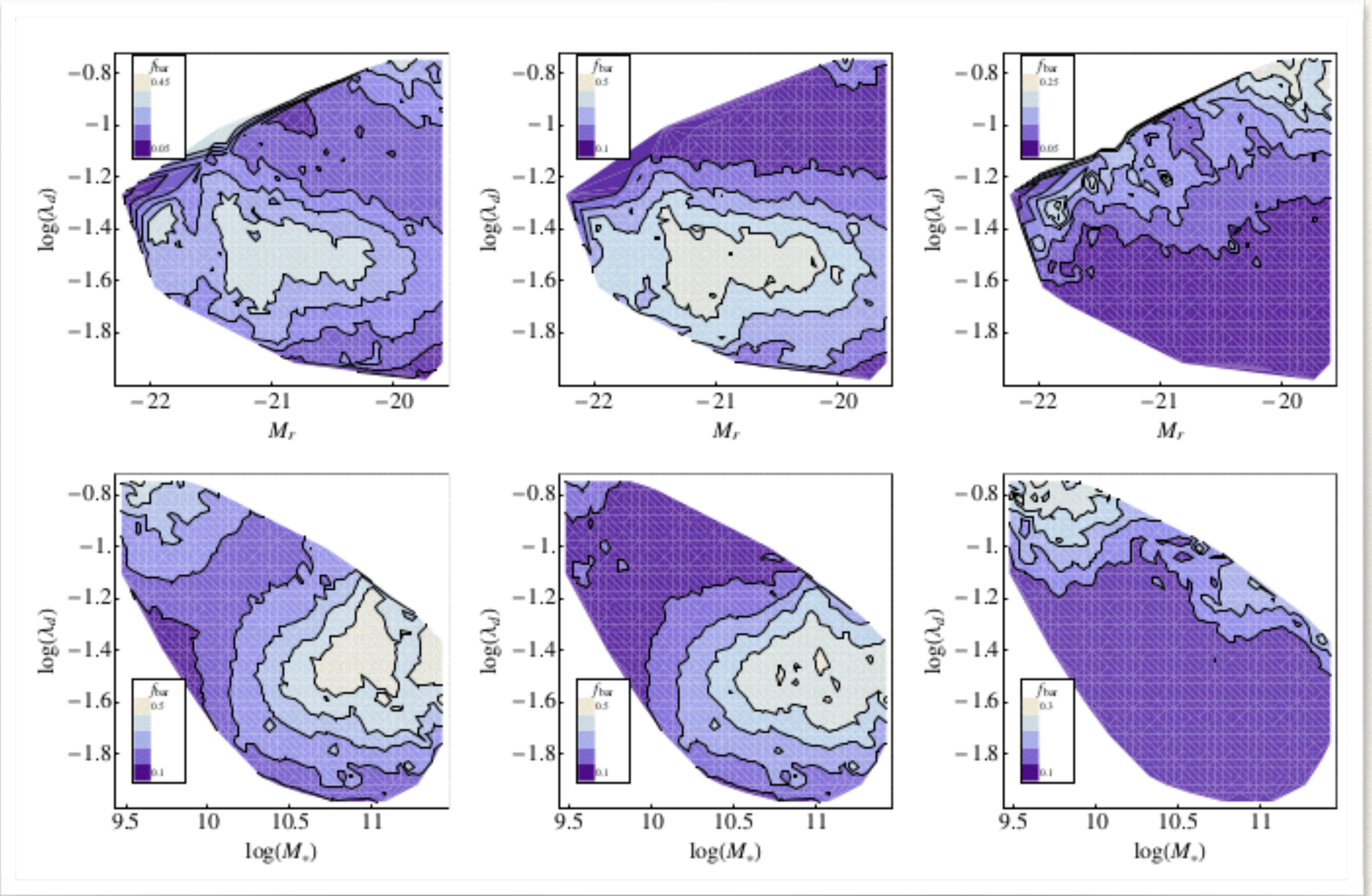
Cervantes-Sodi, Li, Park & Wang (2013)

Dependence on other galaxy properties



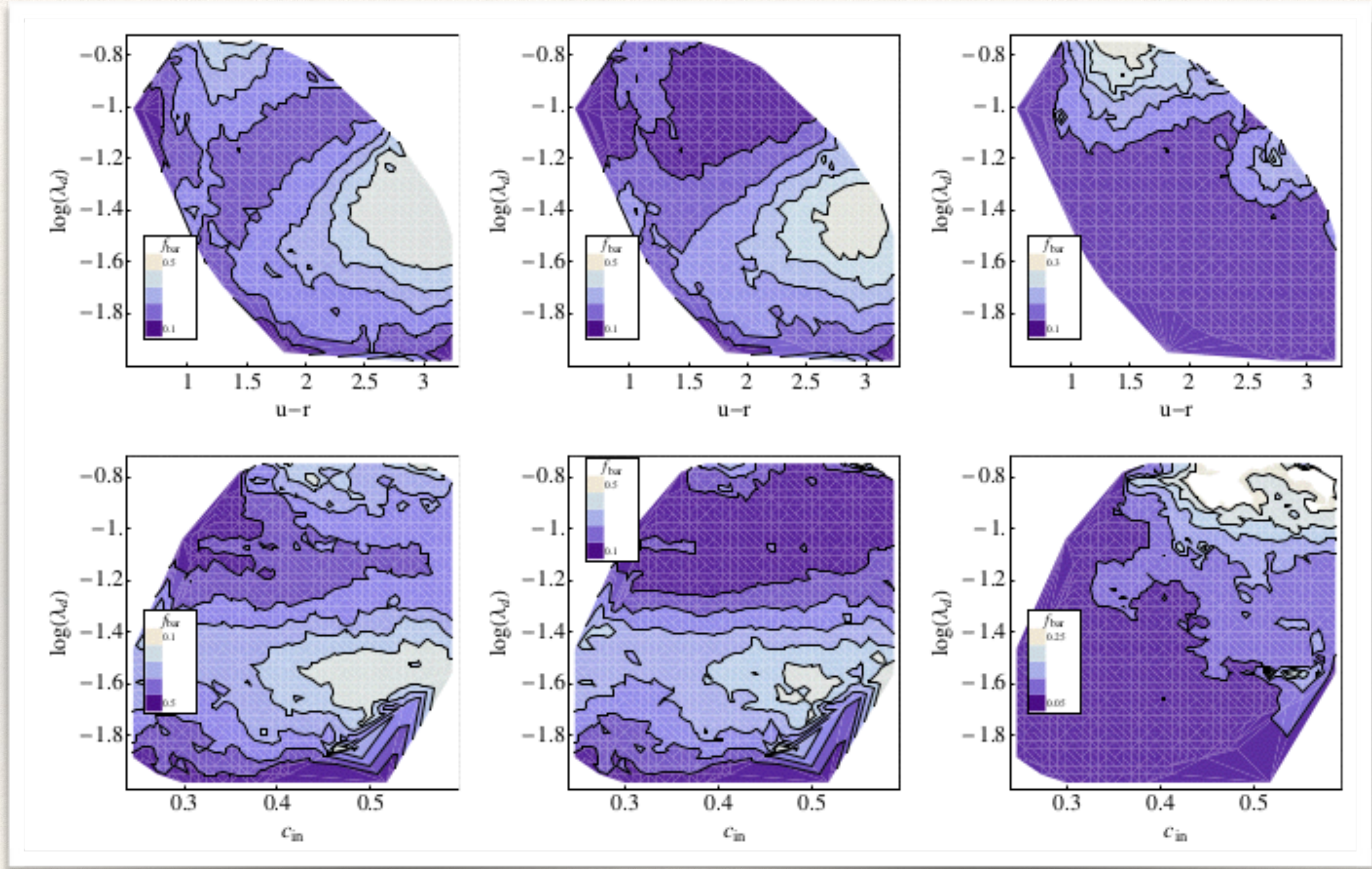
Cervantes-Sodi, Li, Park & Wang (2013)

Joint dependence I



Cervantes-Sodi, Li, Park & Wang (2013)

Joint dependence II



Cervantes-Sodi, Li, Park & Wang (2013)

Decreasing bar fraction for vanishing spin

Disc instabilities and semi-analytic modelling of galaxy formation

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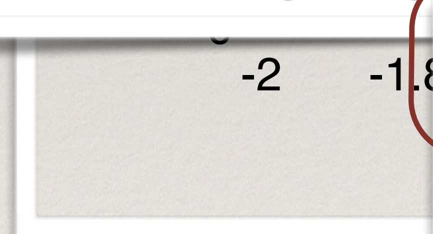
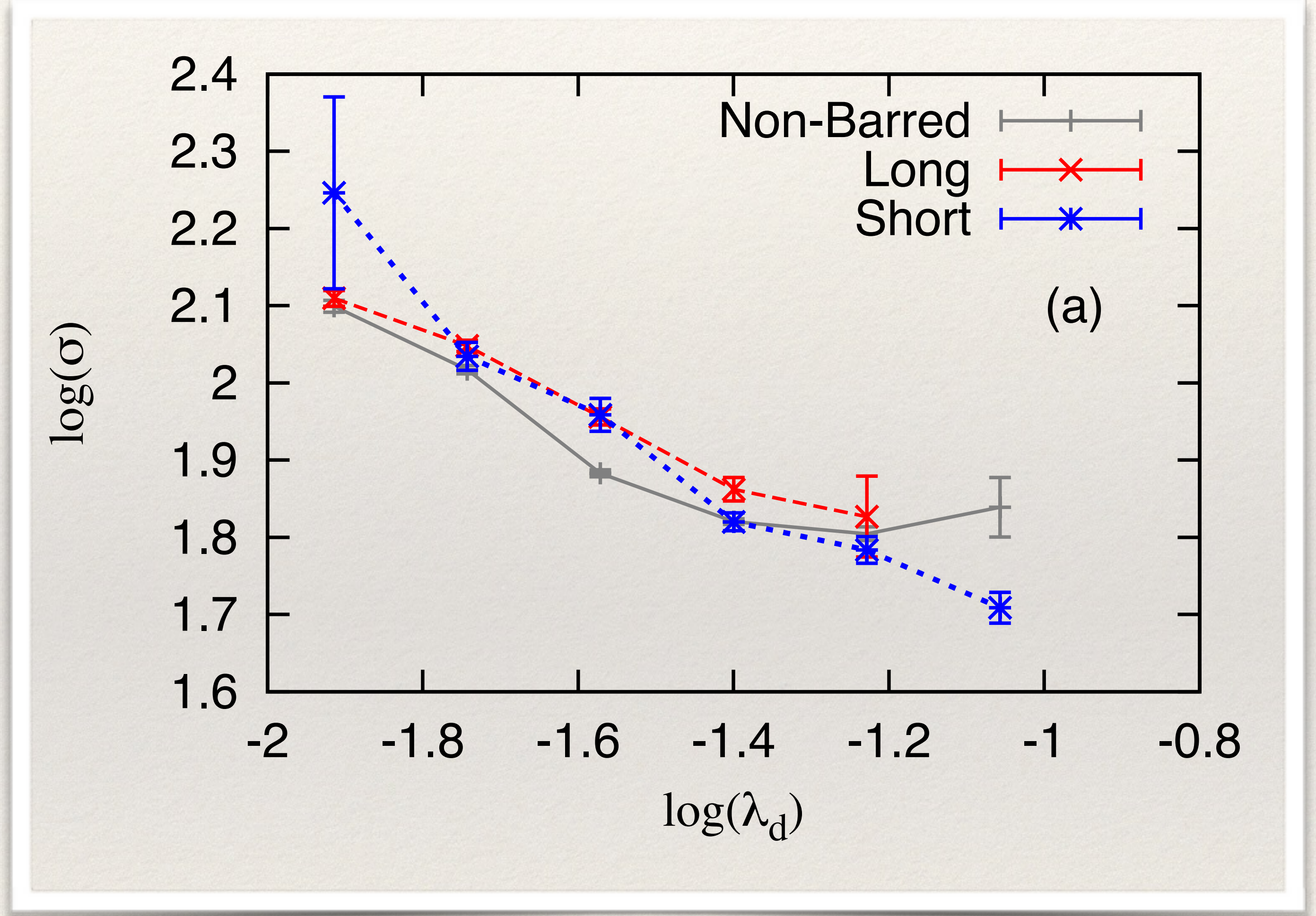
ABSTRACT

The Efstathiou, Lake and Negroponte (1982) criterion cannot distinguish bar stable from bar unstable discs and thus should not be used in semi-analytic galaxy formation simulations. I discuss the reasons for this, illustrate it with examples and point out shortcomings in the recipes used for spheroid formation. I propose an alternative, although much less straightforward, possibility.



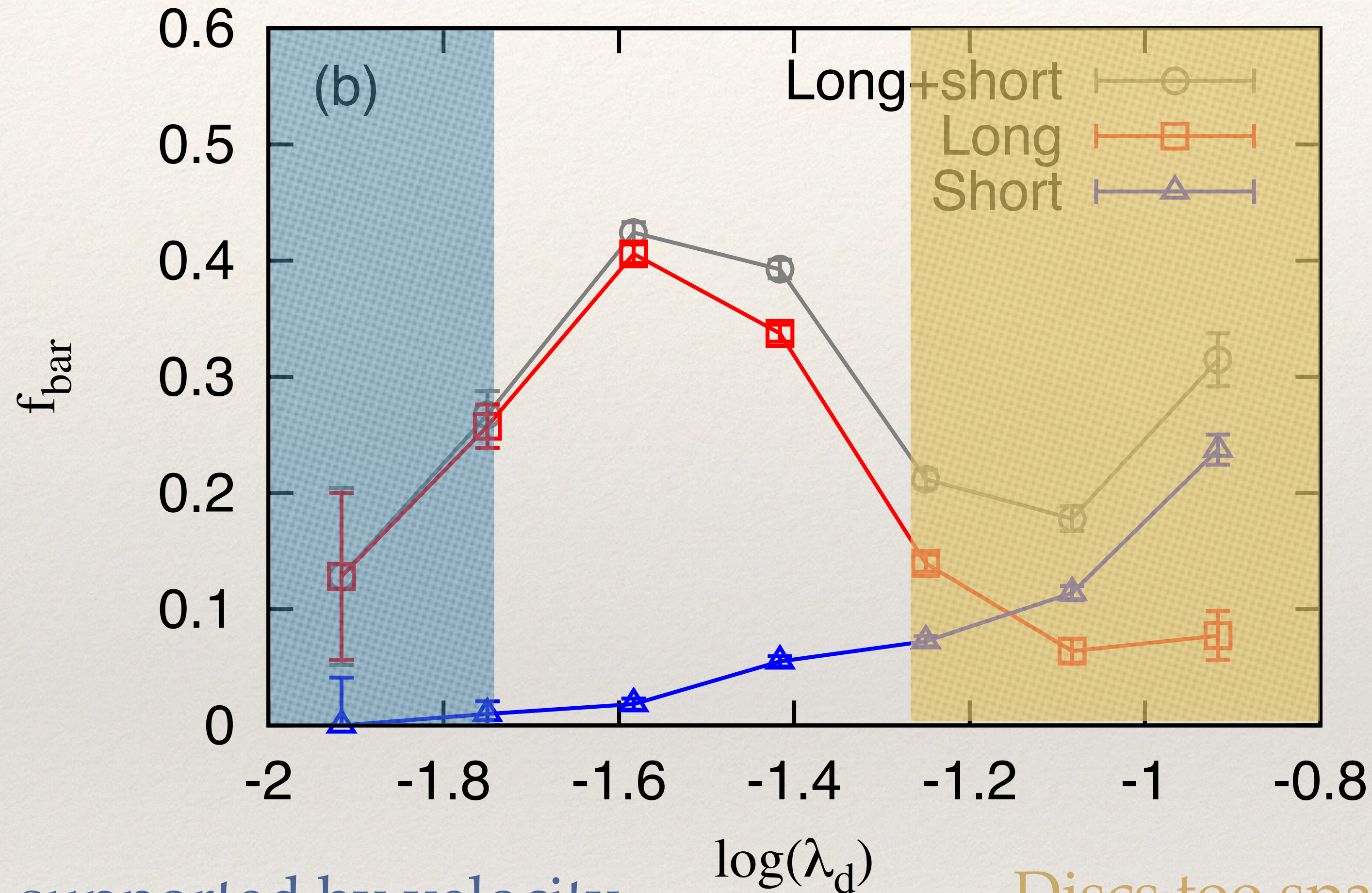
A more serious one is that the disc velocity dispersion is not taken into account. A few years after the ELN criterion was published, Athanassoula & Sellwood (1986) showed that velocity dispersion has an important influence on bar stability, which is, in fact, a function of both disc random motions and halo mass. They also presented a disc with no halo, which is stable because of its high-velocity dispersion. Although these results are based on

Ordered vs. random motion



Cervantes-Sodi, Li, Park & Wang (2013)

Three regimes



Systems supported by velocity dispersion, o ordered motion

Discs too sparse

What about weak bars?

ON THE FORMATION OF DISK GALAXIES AND MASSIVE CENTRAL OBJECTS

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maximum disks in all HSB galaxies presented in § 2. Moreover, while the normal bar instability provides a natural explanation for the existence of strong bars, we are not aware of a model for the origin of weak bars.

How large are the bars in barred galaxies?

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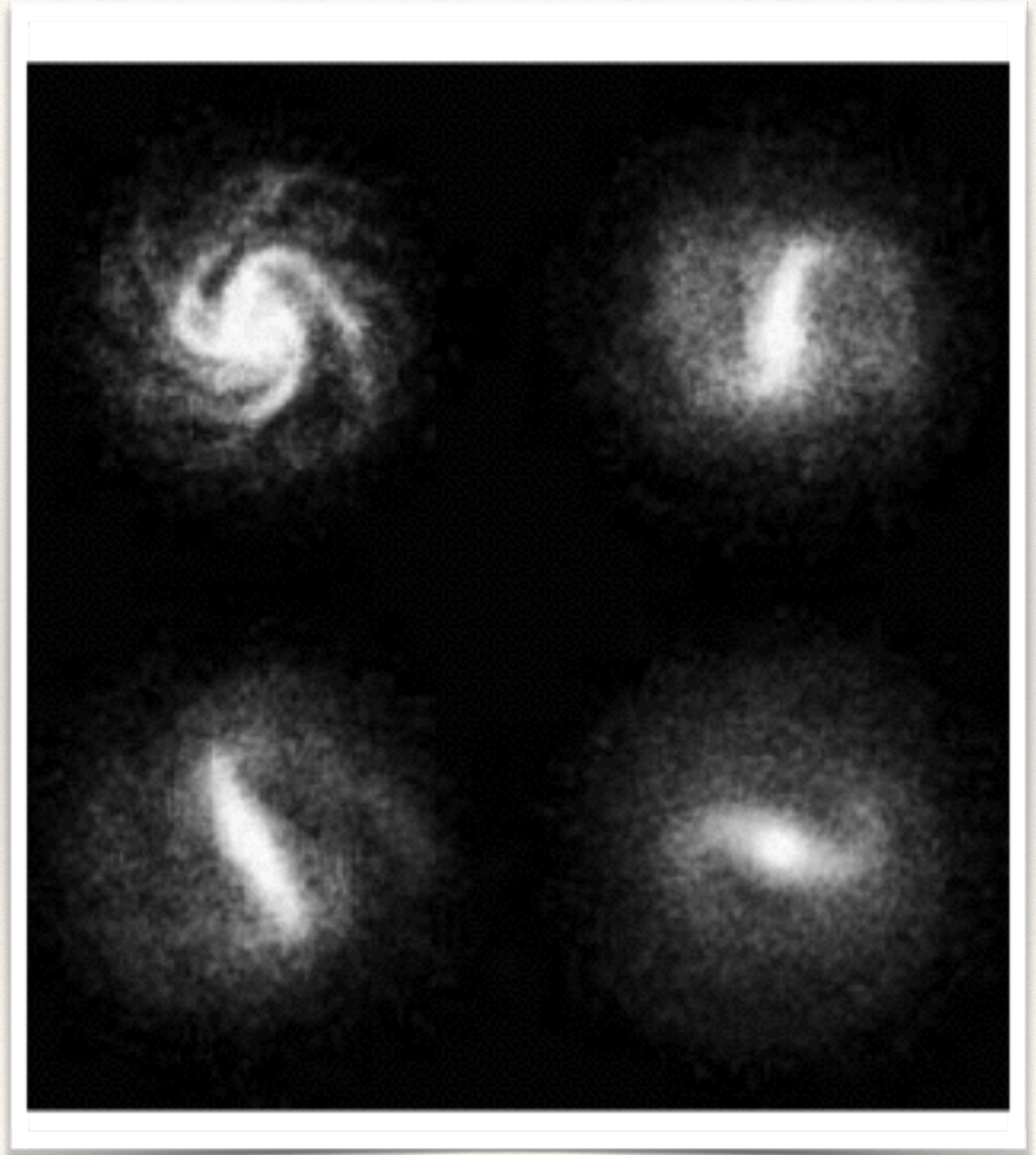
Table 8 summarizes results from eight different papers. In each case, I have included as many models from each study as possible, though in some cases additional models are left out because there were no bar or disc sizes for them. One thing is immediately apparent: *simulations tend to produce large bars*. Indeed, several simulations produce bars that are either at the upper end of the local distribution, or are larger than any seen in nearby galaxies. Except for two of the earlier simulations, no *N*-body bars are as small as typical Sc–Sd bars. (Ironically, one of these is the 'early-type' model CS2 of Combes & Elmegreen 1993, which produced a shorter bar than their 'late-type' model CSE.)

Study					R_{bar}/h	Notes
Pfenniger & Friedli (1991)					0.6	
Combes & Elmegreen (1993)					0.6	1
					1.8	2
Friedli & Benz (1993)					0.9	3
Berentzen et al. (1998)					3.6	4
					2.4	5
Athanassoula & Misiriotis (2002)					2.8–3.2	6
					1.5–2.3	6
Valenzuela & Klypin (2003)					1.4–1.5	7
	A_2	*N*-body	4.5–5.5	4.2	1.1–1.3	7
	B	*N*-body	4.2–5.0	5.0	0.8–1.0	7
Holley-Bockelmann et al. (2005)	F_5	*N*-body	0.026	0.01	2.6	8
Immeli et al. (2004)	F	*N*-body + gas + SF	3–4.5	1.9	1.6–2.1	9

Extreme case of high λ

- LSBs are extreme cases of high spinning disc galaxies (Jimenez et al. 1999; Kim & lee 2012)

- Simulations of LSBs tend to produce smaller, short lived bars when compared with the ones produced on massive discs (Mihos et al. 1997; Mayer & Wadsley 2004)



- Scannapieco & Athanassoula (2012) on fully cosmological hydrodynamical simulations of MW-mass galaxies :
  - Strongest bar is formed in a bulge-disk-halo system with the lowest spin
  - Weakest bar on a pure disk with the highest spin

(Erwin 2005)

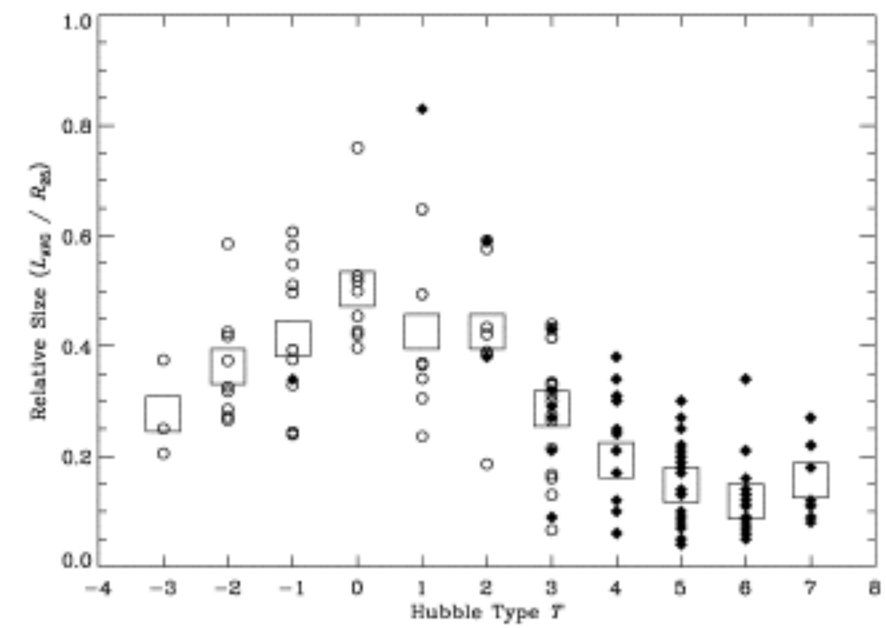
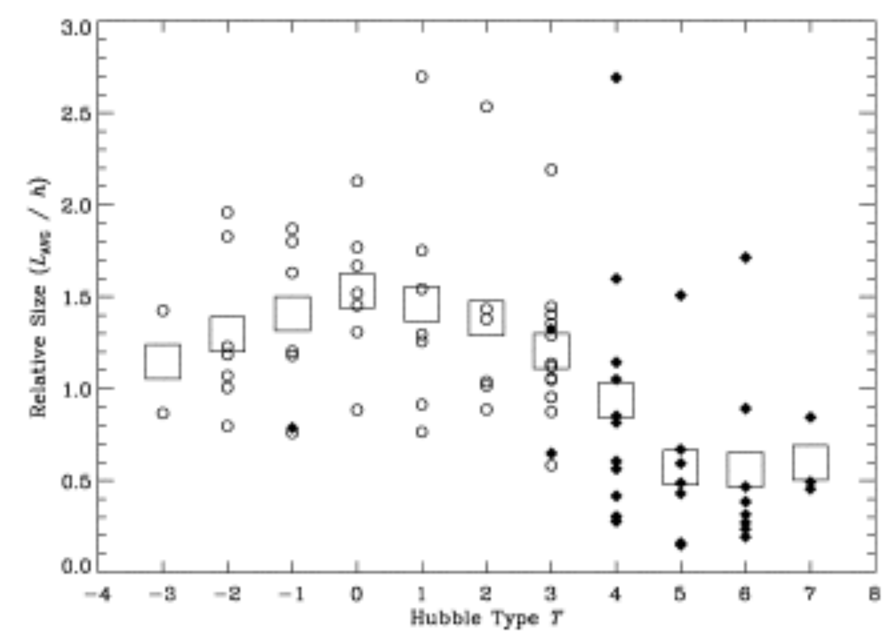


Figure 12. As for Fig. 11, but now showing size of bars relative to disc radius R_{25}.



General conclusions

- The spin parameter plays a crucial role shaping the structure and morphology of present day disc galaxies.
- Based on a simple model we can give an estimation of the λ spin parameter for any disc galaxy which can be used as an objective and quantitative parameter to describe the morphology of large samples of galaxies
- The well defined and objective nature of the dimensionless spin parameter makes it ideal for comparing the output of numerical galactic formation scenarios to real galactic samples

Regarding barred disc galaxies:

We found a strong dependence of the bar fraction on the galactic spin for the case of disc galaxies

Strong bars :

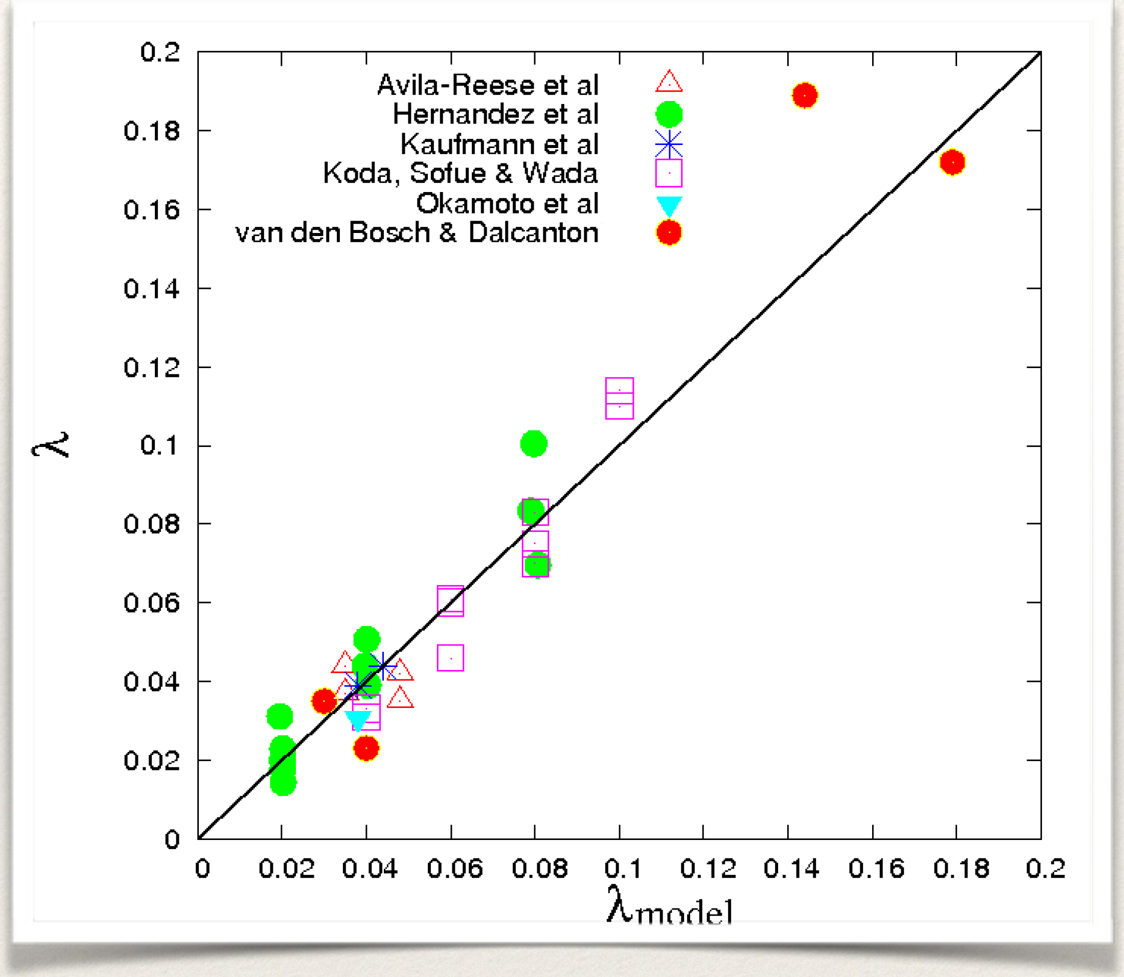
- Preferentially found at low-intermediate λ_d values due to their self-gravity
- At low λ_d the disc become dominated by random motions that prevents the formation/growth of bars

Weak bars :

- Hosted by galaxies with high λ_d values
- Their size might be restricted by the sparsity of the disc
- The large fraction of gas on these galaxies play an important role on restricting the growth of the bar.

Comparison with numerical simulations

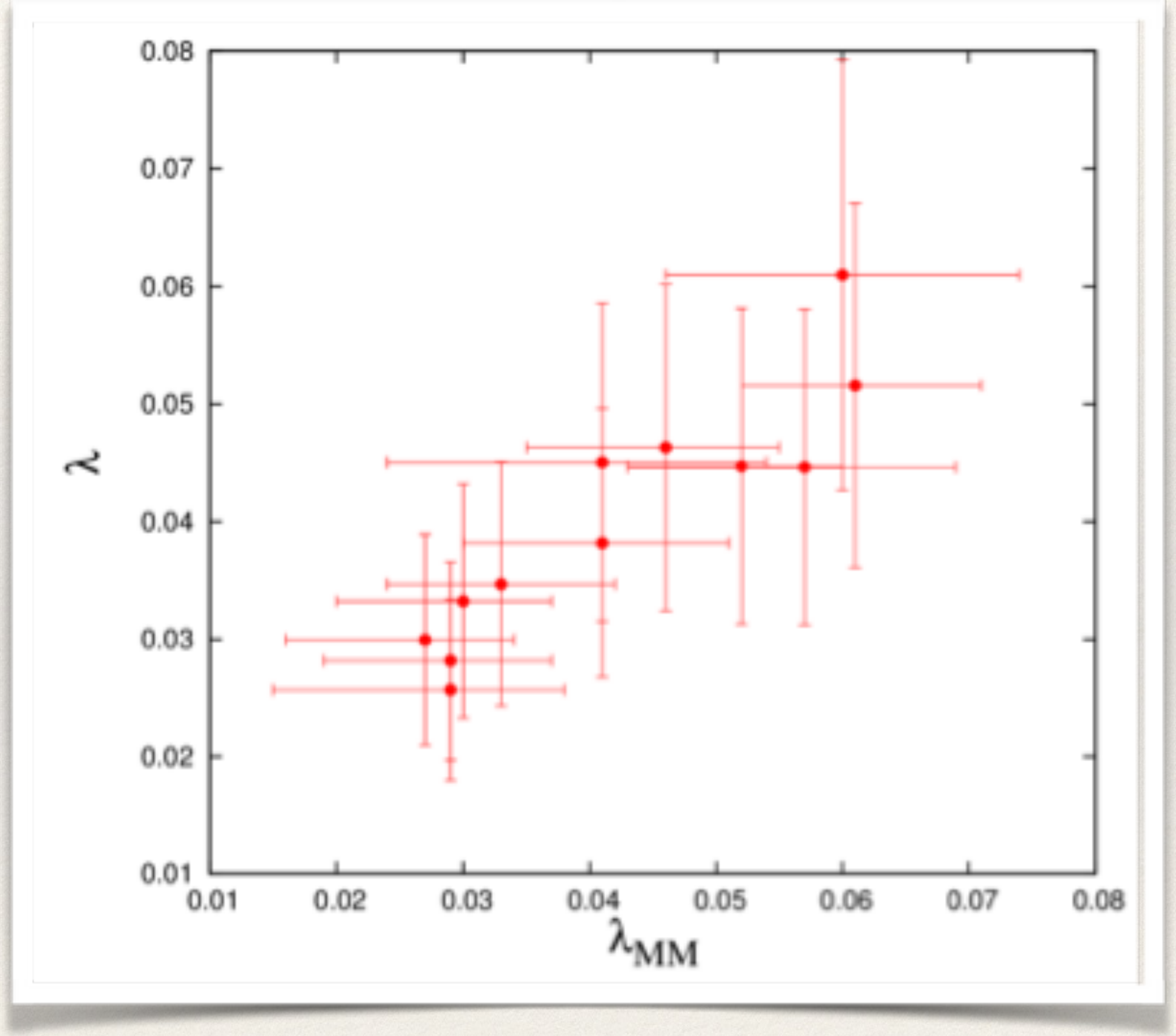
- For our galaxy, our estimation is $\lambda = 0.023$, in agreement with theoretical expectations ($\lambda = 0.02$: Natarajan 1998; Hernandez et al. 2001)



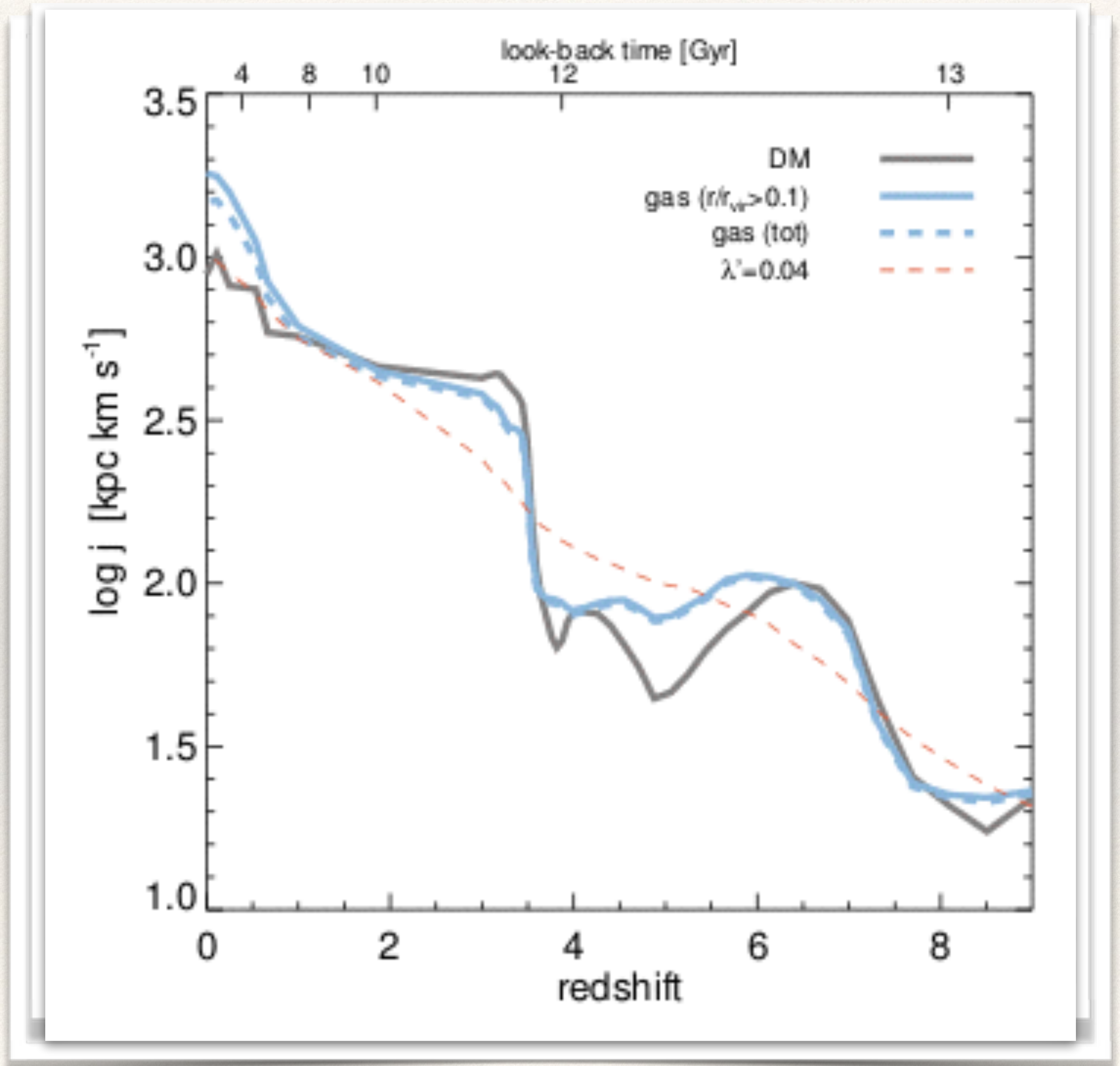
Cervantes-Sodi, et al. (2008)

Verification with highly accurate measurements of λ in observed galaxies

- Muñoz-Mateos et al. (2011)
- Models of observed disc galaxies, matching multi-wavelength luminosity profiles and rotation curves.



Specific angular momentum



Kimm, et al. (2011)

Sales, et al. (2009)

Zavala, et al. (2007)