The galactic spin through empirical distributions.

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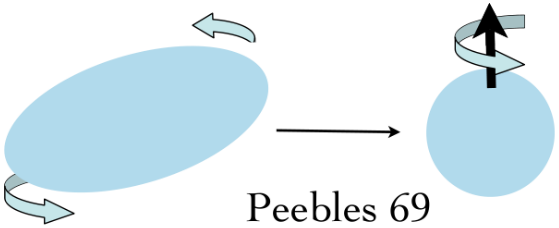
Outline

- Introduction
  - What is the spin
  - Its role on the structure of present day galaxies (theory)
- Model for the estimation of the spin for disc galaxies (observations)
- Results from SDSS samples
- Results using GOODS
- General conclusions

Basic picture of galaxy formation

- Proto-galaxies acquire angular momentum through tidal interactions



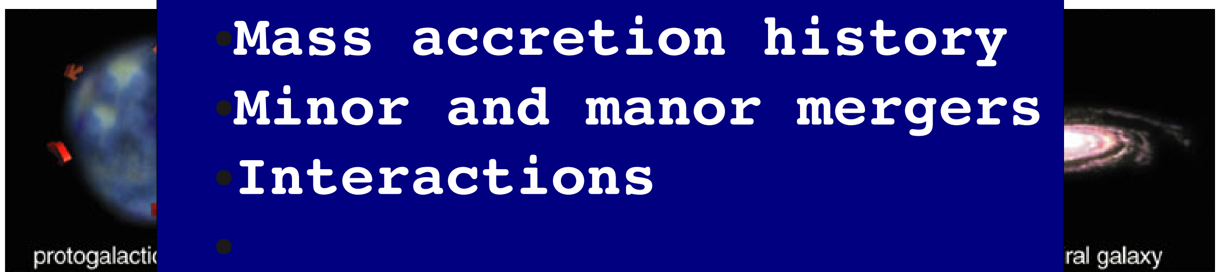
Hoyle 1949, Peebles 1969, White 1984.

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

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

Basic picture of galaxy formation

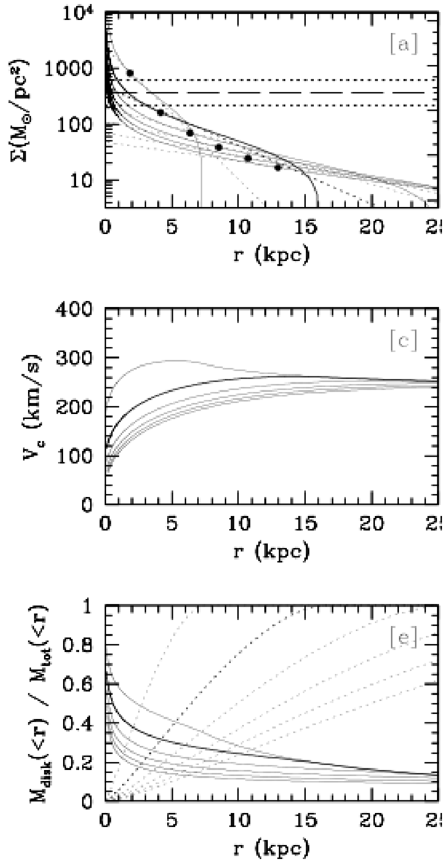
- By conservation of angular momentum, baryons settle down on a rotational supported disk (Fall & Efstathi



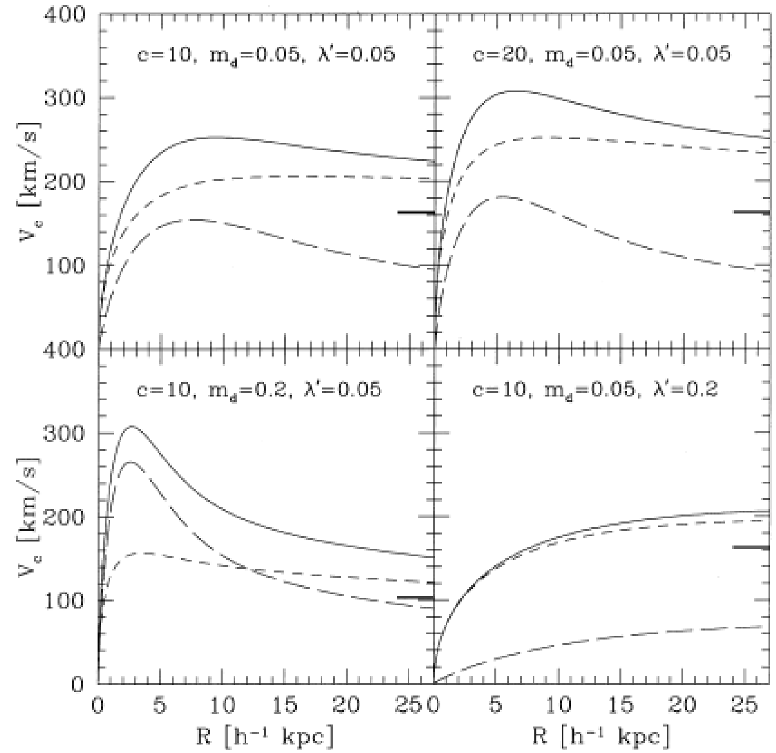
- Mass accretion history
- Minor and manor mergers
- Interactions

- 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); ...

Influence of the spin on galaxy properties

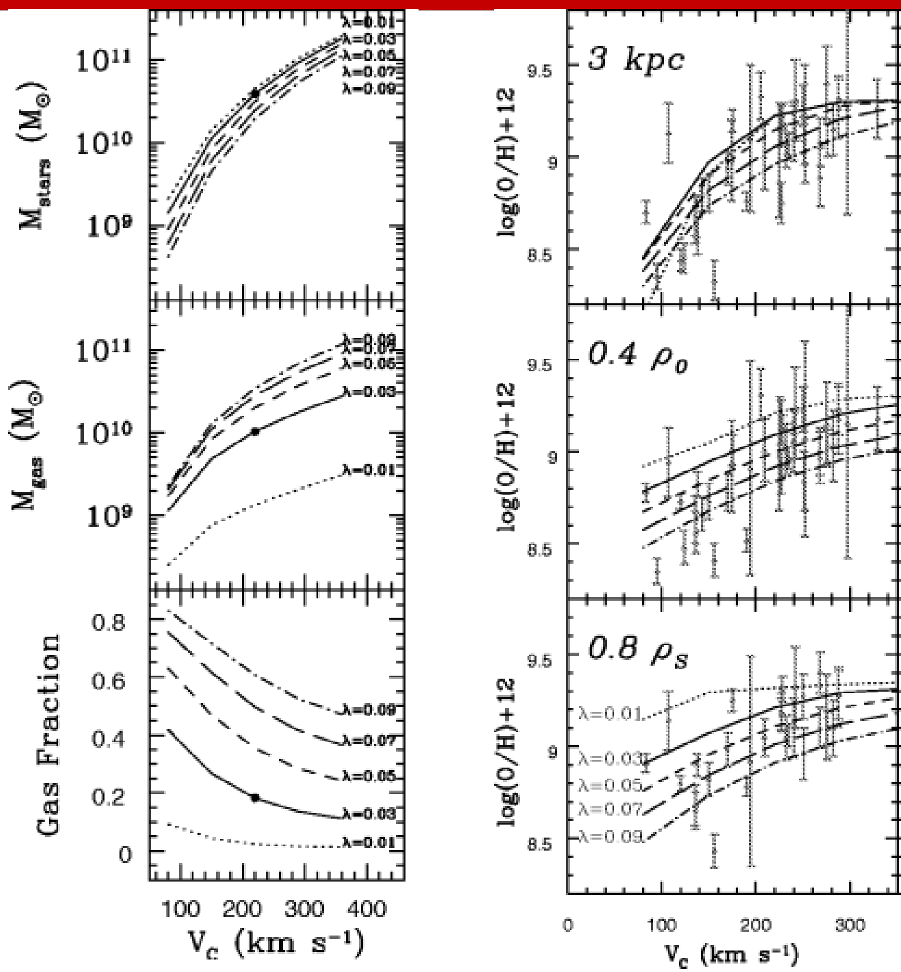


Dalcanton et al. 1997



Mo, Mao & White 1998

Influence of the spin on galaxy properties



Boissier & Prantzos (2000)

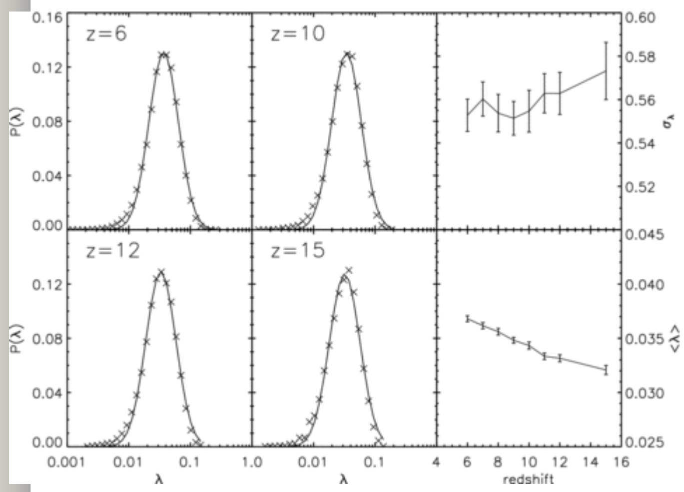
Efstathiou, Lake & Negroponte (1982)

$$\epsilon_c \equiv \frac{V_{max}}{(GM_d/R_d)^{1/2}} \leqslant 1.1$$

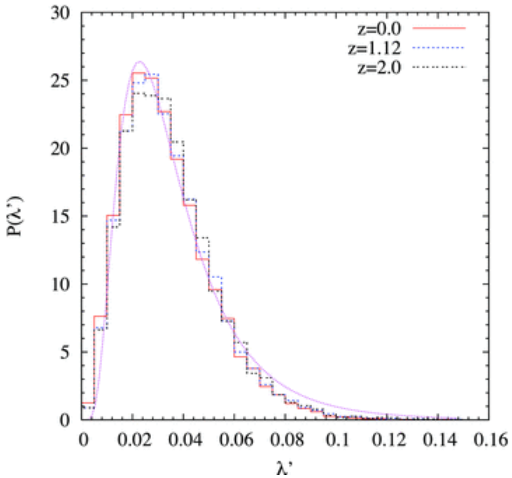
or in terms of the spin (Mo, Mao & White 1998): $\epsilon_c^2 = \frac{\lambda_d}{2^{1/2} f_d}$

Galaxies with low spin, more compact and self-gravitating, are expected to develope bar instabilities.

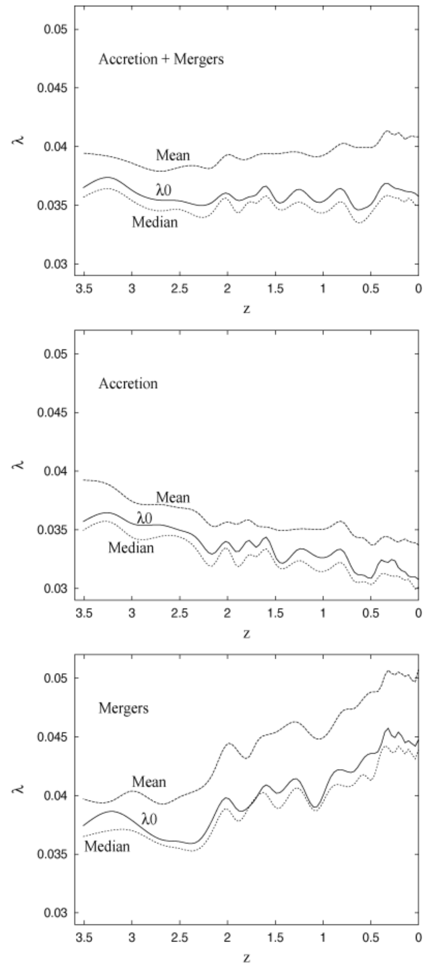
Predictions from N-body simulations



Davis & Natarajan 2009



Muñoz-Cuartas et al. 2010



Peirani et al. 2004

Spin determination

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

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

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

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

- and total disc mass:

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

- A dark matter halo with a isothermal density profile:

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

- with a finite radius given by

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

Spin determination

- The energy is given by the dark matter halo:

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

- For the angular momentum, we consider that the specific angular momenta of the disc and halo are equal, $l_d = l_H$ (Fall & Efstathiou 1980; Mo, Mao & White 1998), with :

$$l_d = 2 V_d R_d$$

- Finally we adopt a specific prescription for the disc mass fraction $F = M_d / M_H$:
  - f = cte
  - f = f(Σ) – Gnedin et al. (2007) :

$$F = F_0 \left(\frac{M_{stellar} R_d^{-2}}{10^{9.2} M_o \, kpc^{-2}} \right)$$

  - F=F(M_*), i. e. Guo et al. 2010.

$$\frac{M_{stellar}}{M_H} = 0.129 \times \left[\left(\frac{M_H}{10^{11.4} M_o} \right)^{-0.926} + \left(\frac{M_H}{10^{11.4} M_o} \right)^{0.261} \right]^{-2.440}$$

Spin determination

- Our final expression is :

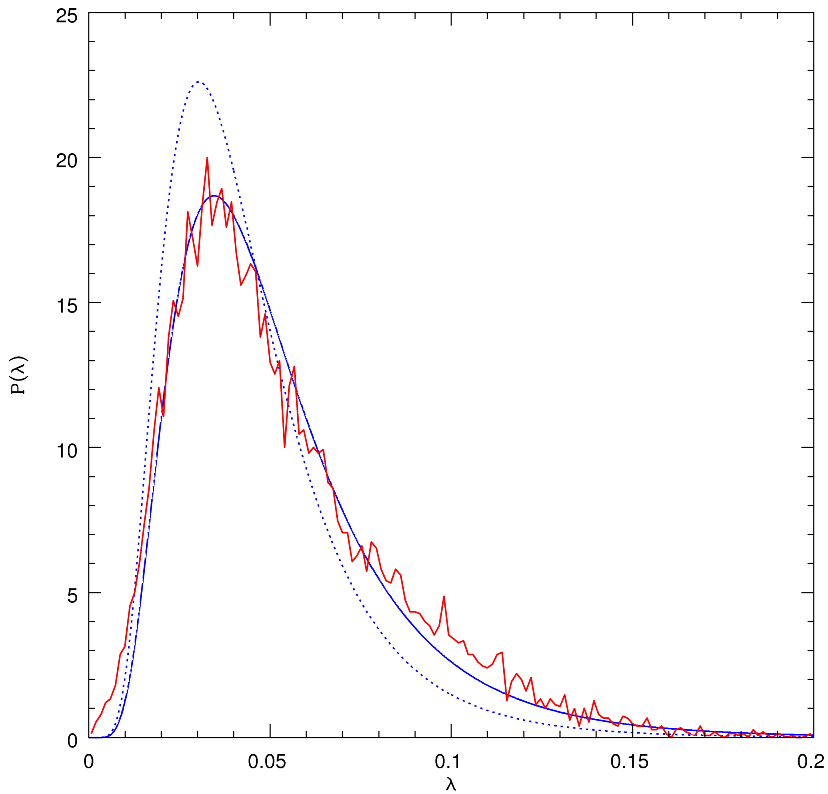
$$\lambda = \left(\frac{\sqrt{2}}{G} \right) F_d R_d V_c^2 M_d^{-1}$$

- In the most simplify form, with F_d cte, and assuming a baryonic Tully-Fisher relation of the form $M_d = A_{TF} V_d^{3.5}$

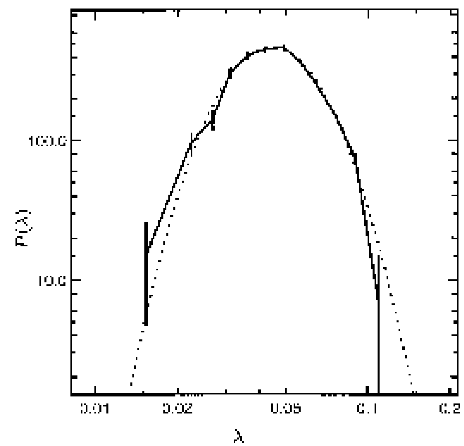
$$\lambda = \frac{21.8 \, R_d / kpc}{(V_d / km * s^{-1})^{1.5}}$$

- Or in the case of not counting with V_d, we can use :
  - Traditional Tully-Fisher relation to change the dependence on V_d for a dependence on Luminosity (SDSS)
  - A stellar mass Tully-Fisher relation to use stellar mass instead of V_d (GOODS)

Results with local samples from the SDSS

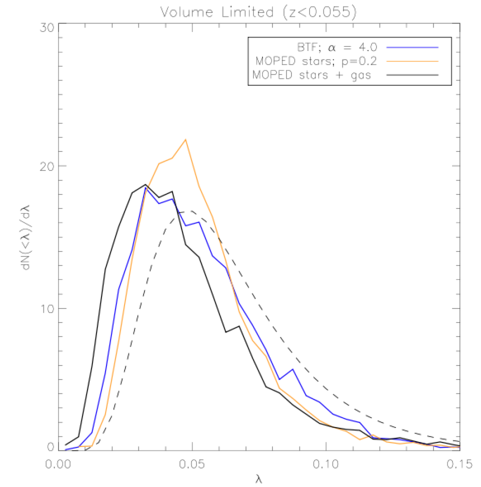


Hernandez et al. (2007)

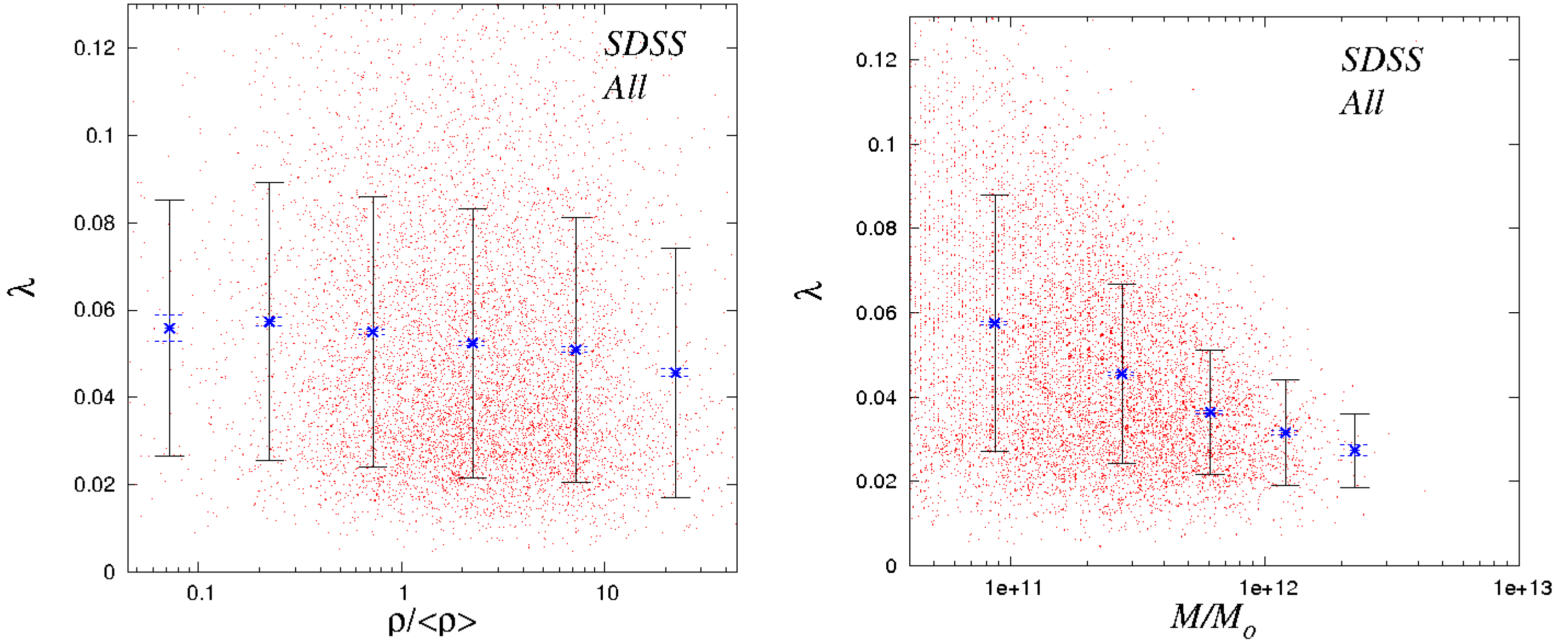


Syer, Mao & Mo (1999)

Berta et al. (2008)

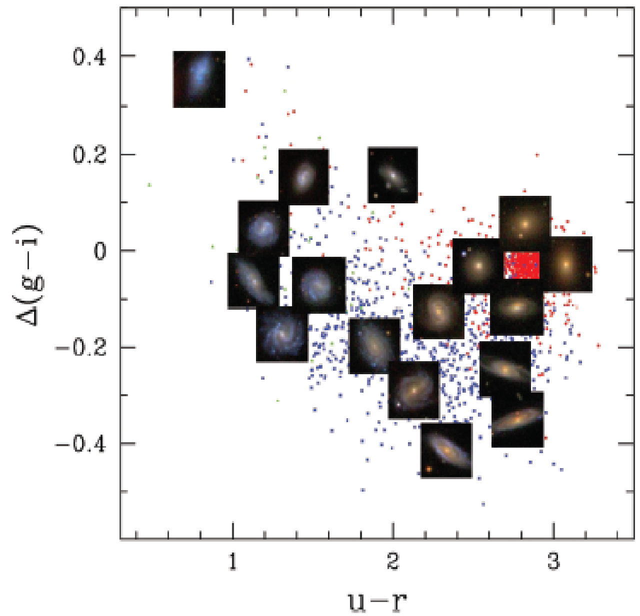


Results with local samples from the SDSS



Cervantes-Sodi et al. (2008)

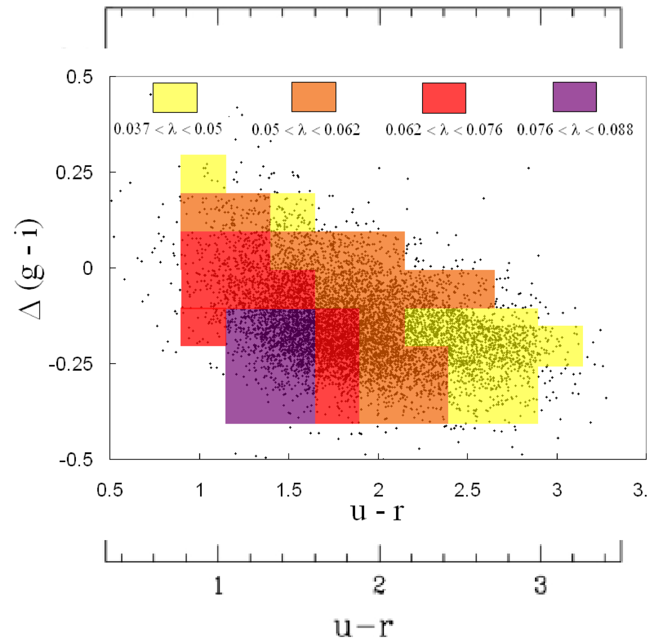
Spin and galaxy morphology



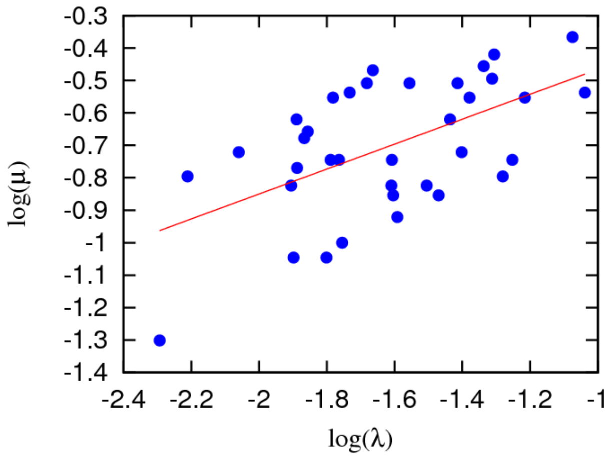
Park & Choi (2005)

Cervantes-Sodi & Hernandez (2009)

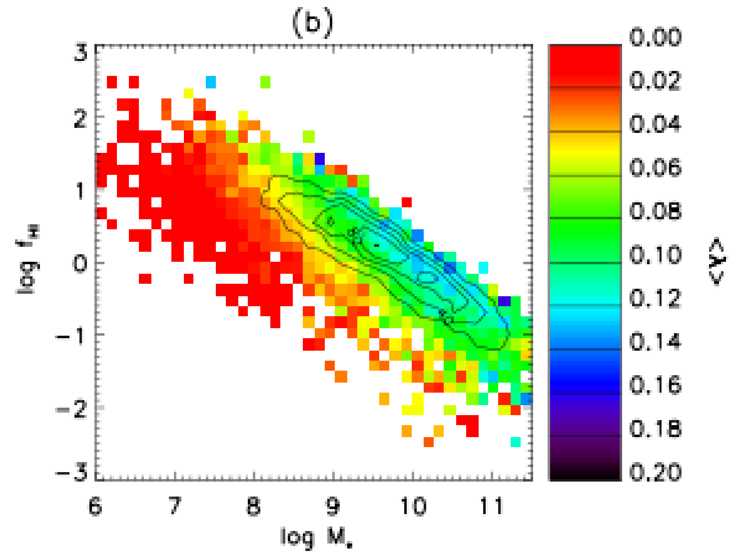
$|\lambda|_{Sa} = 0.0484$
$|\lambda|_{Sb} = 0.0608$
$|\lambda|_{Sc} = 0.0774$



Gas mass fraction



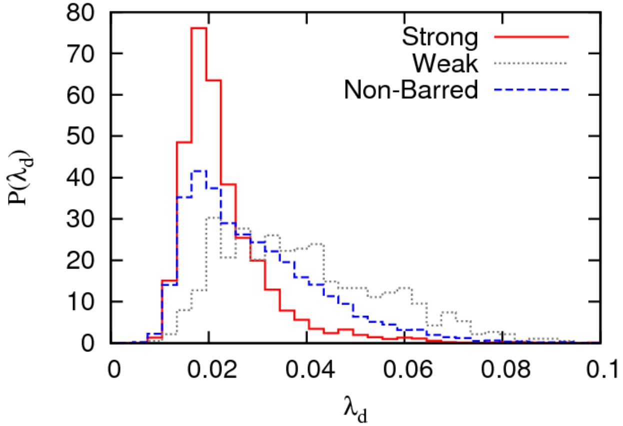
Cervantes-Sodi &
Hernandez 2009



Huang et al. 2012

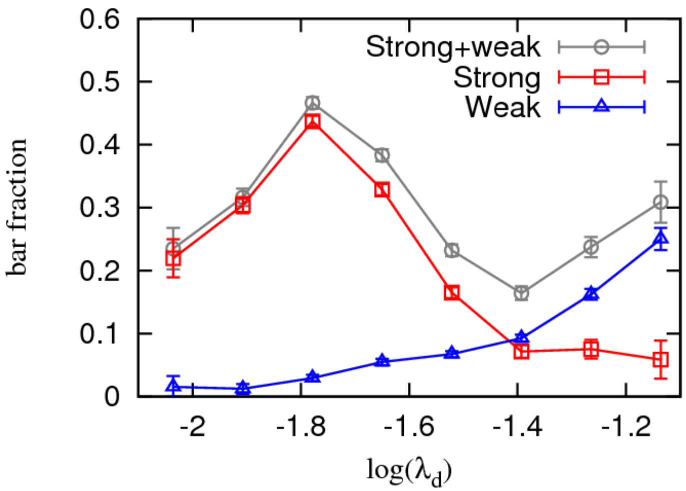
Spin and bar fraction

- Data drawn from Lee et al. (2012)
- Using a sample of ~ 10,000 visually classified galaxies on
    - Strong bars (the bar is larger than one quarter of the size of the galaxy)
    - Weak bars
    - Non-barred galaxies



Cervantes-Sodi et al. in preparation 2012

Spin and bar fraction



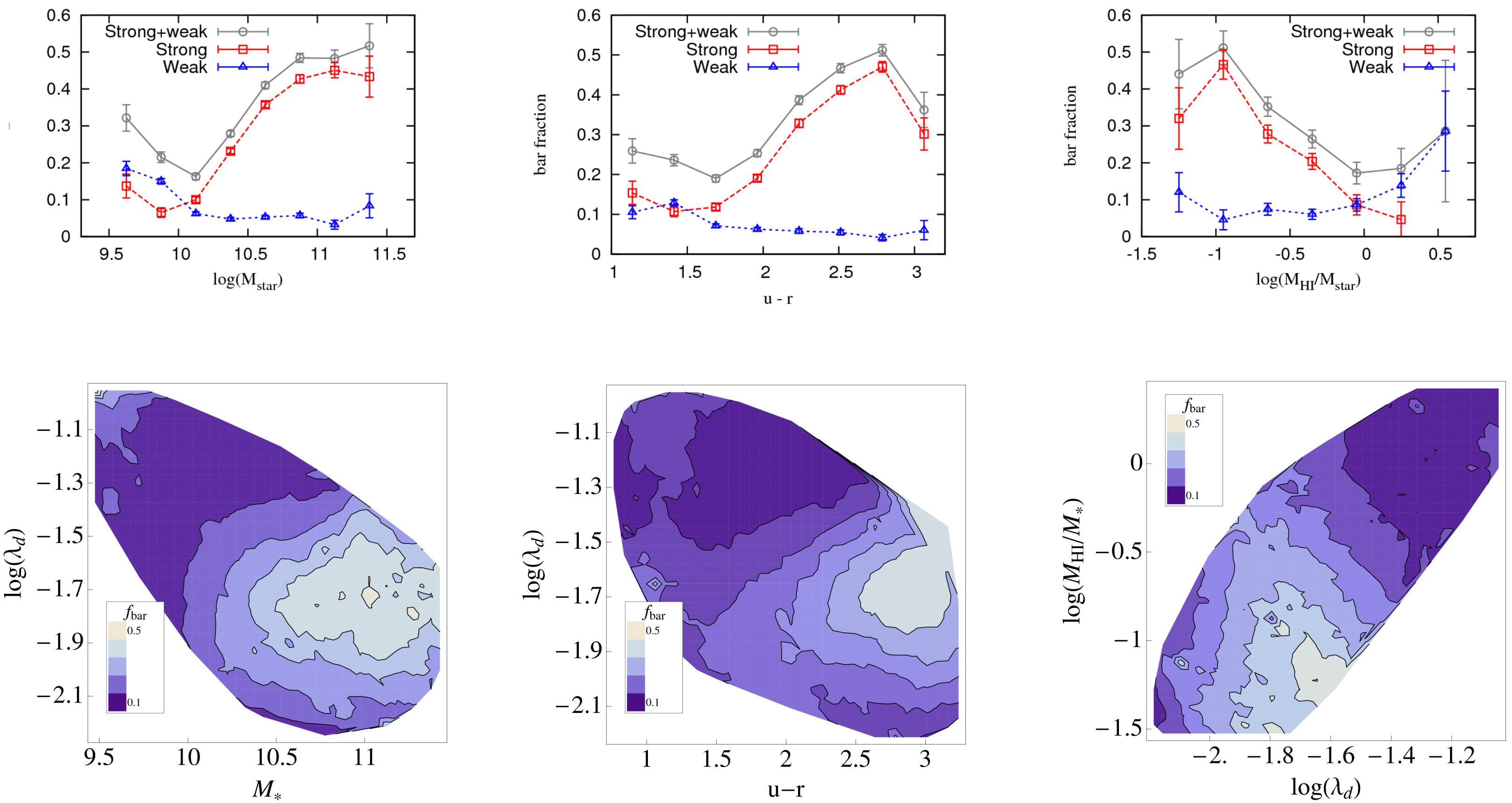
$$\epsilon_c \equiv \frac{V_{max}}{(GM_d/R_d)^{1/2}} \leqslant 1.1$$

with:

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

Cervantes-Sodi et al. in preparation 2012

Spin and bar fraction



Cervantes-Sodi et al. in preparation 2012

Spin evolution using GOODS

- Data drawn from Hwang & Park (2009) and Hwang et al. (2011)
- The final sample contains about ~1000 late-type galaxies on the redshift range $0.4 < z < 1.2$ with accurate total stellar masses and reliable spectroscopic redshifts
- To assign a DM fraction to the galaxies in our sample we employed 3 different prescriptions:

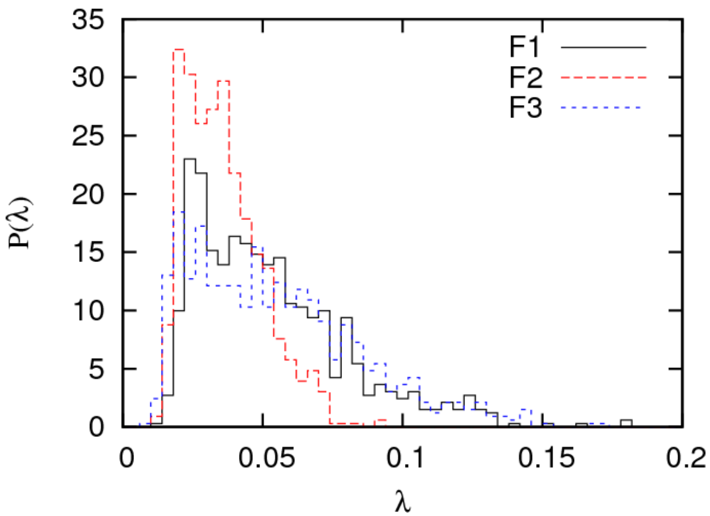
- f = cte
- f = f(Σ) – Gnedin et al. 2007 :

$$F = F_0 \left(\frac{M_{stellar} R_d^{-2}}{10^{9.2} M_o \, kpc^{-2}} \right)$$

- f = f(V,z) – Faucher-Giguere et al. 2011:

$$M_h = 10^{10} M_o \left(\frac{V_d}{50 \mathrm{km}\, s^{-1}} \right) \left(\frac{1+z}{4} \right)$$

Spin distribution at 0.4<z<1.2

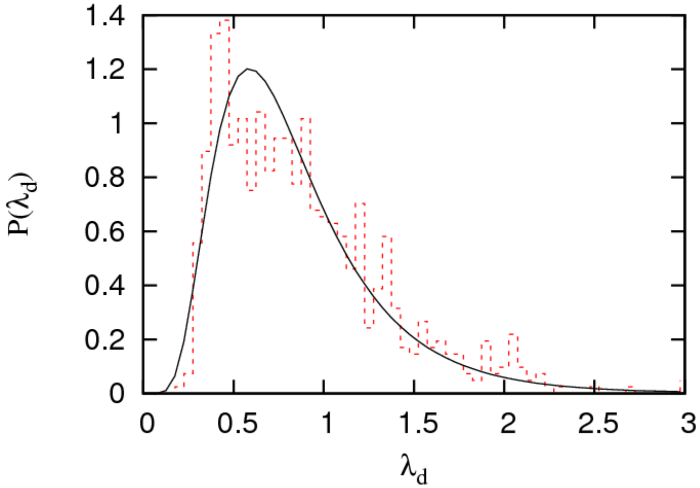


- The spin distribution depends strongly on the chosen DM fraction.
- The case of F1 and F2 are compatible with P(λ) at low redshift

- To avoid problems with the DM fraction, we define

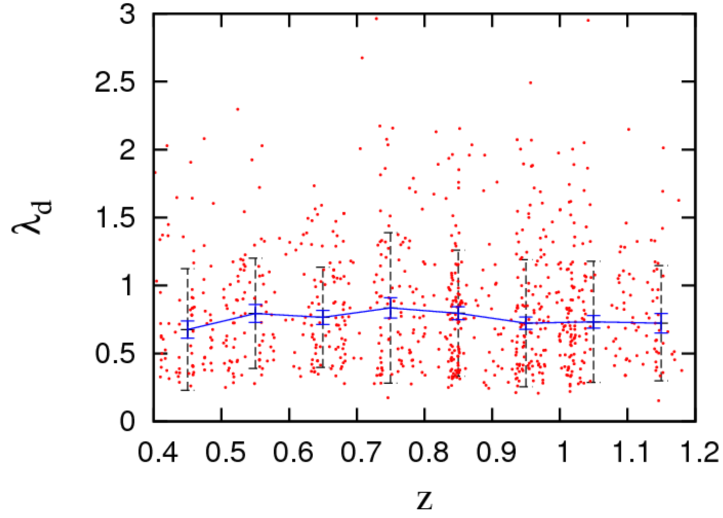
$$\lambda_d \equiv \lambda F_d$$

to accound only for the spin of the disc



Cervantes-Sodi et al. 2012

Spin evolution



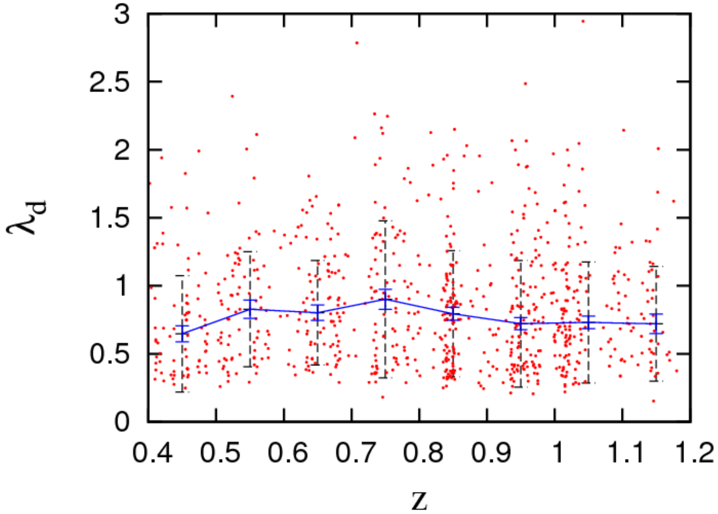
Based on a single stellar Tully-Fisher relation of the form:

$$\log(M_d) = [a + b \times \log(V_d)] \log(M_0)$$

valid in the redshift range 0.2<z<1.2 from Miller et al. (2011)

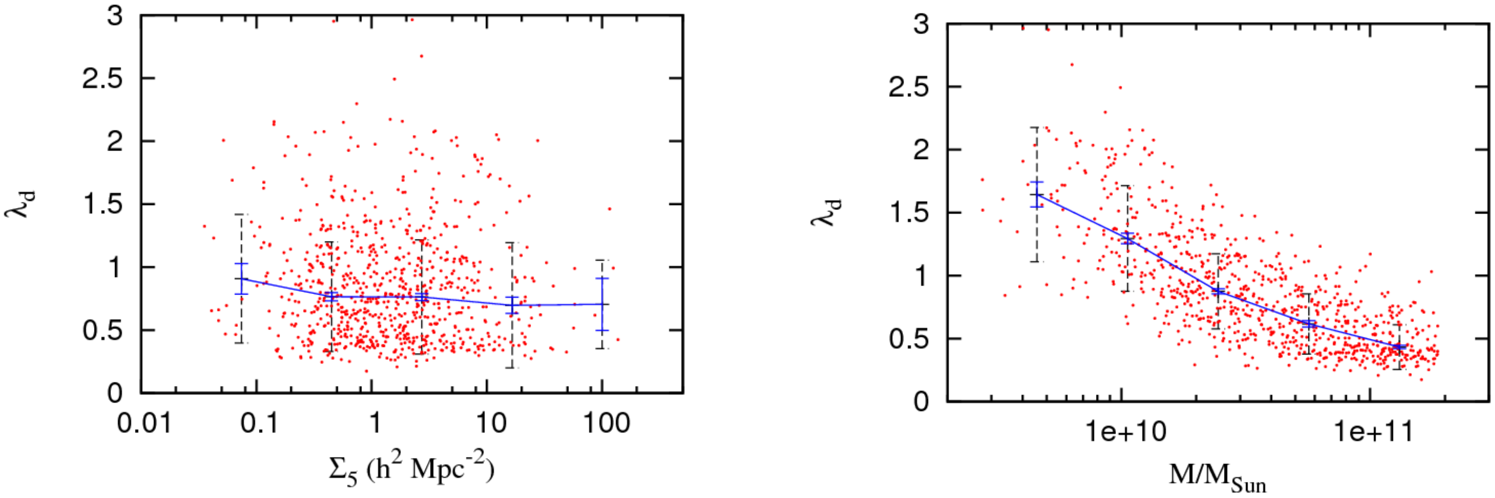
We also tried using three different TF relations for three different redshift ranges

Redshift range	a	b
$0.2 \le z \le 1.2$	1.718	3.869
$0.2 \le z \le 0.5$	1.755	Fixed
$0.5 \le z \le 0.8$	1.684	Fixed
$0.8 \le z \le 1.2$	1.720	Fixed



Cervantes-Sodi et al. 2012

Spin dependence on mass and environment at high redshift



- Where:

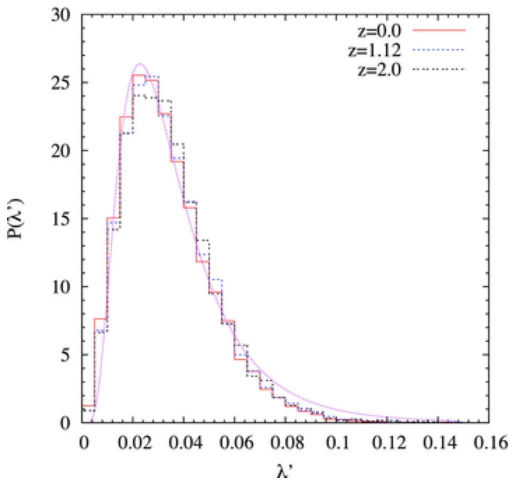
$$\Sigma_5 = 5\left(D_{p,5}^2\right)^{-1}$$

with $D_{p,5}$ the projected proper distance to the 5th-nearest neighbour

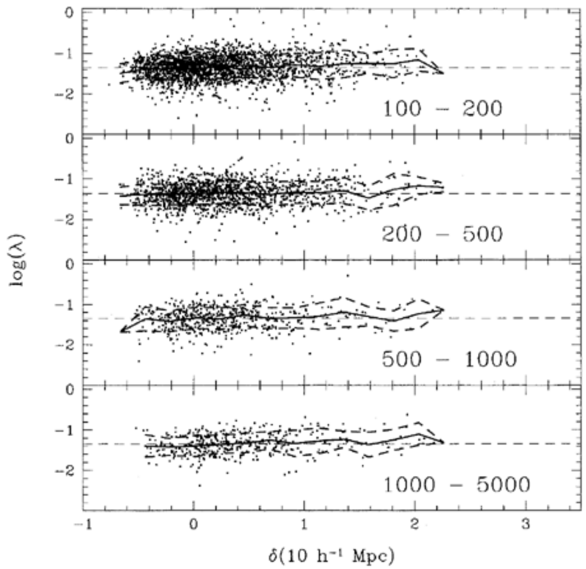
Cervantes-Sodi et al. 2012

Comparison with previous works

• From numerical simulations:

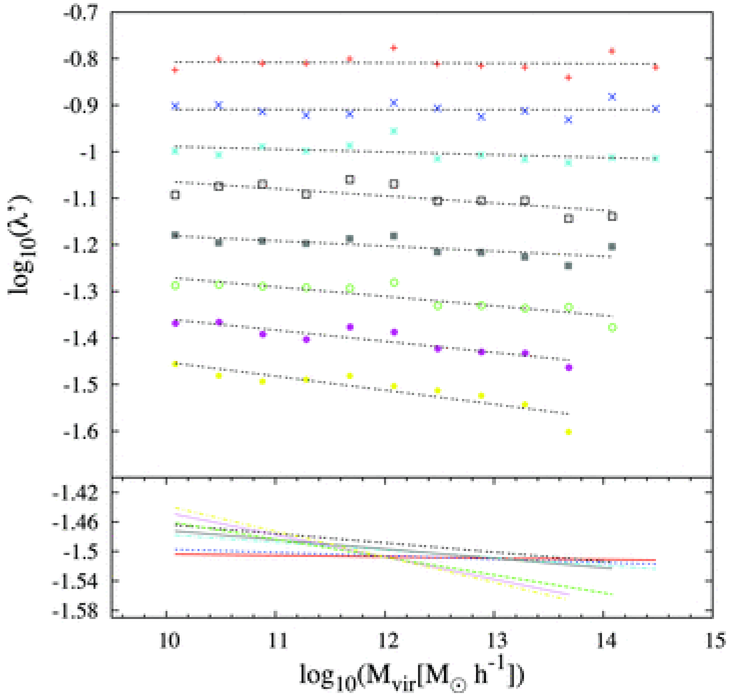


Muñoz-Cuartas et al. 2010



Lemson & Kauffmann 1999

Comparison with previous works



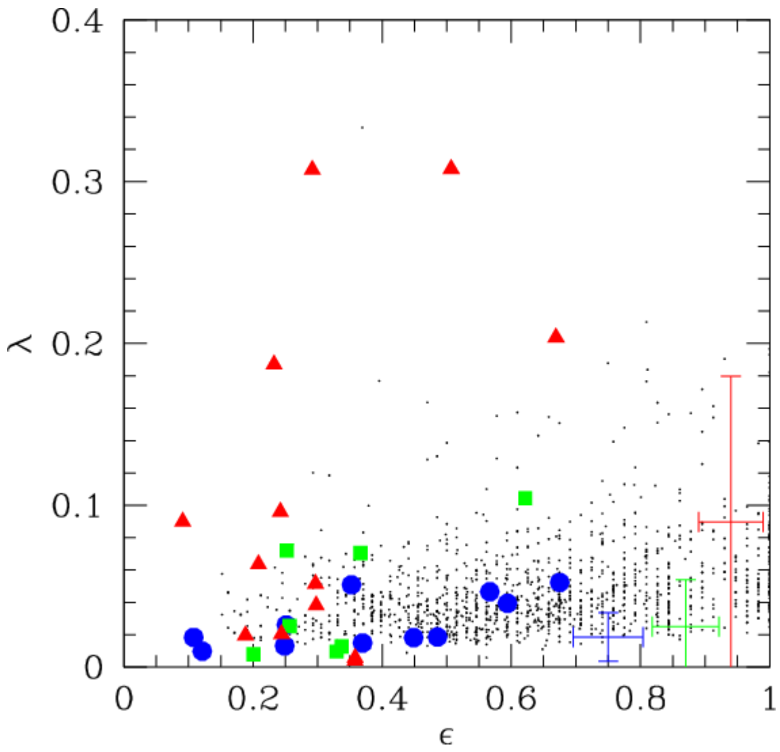
Muñoz-Cuartas, Macciò, Gottlöber & Dutton 2010.

See also de Souza, et. al. (2012)

$\log(M)$	$\bar{\lambda}$	$\sigma_{\log\lambda}$	z
10.00–10.75	0.041	0.327	1
10.75–11.50	0.037	0.318	1
11.50–12.25	0.027	0.329	1
10.00–10.75	0.039	0.354	0.5
10.75–11.50	0.034	0.349	0.5
11.50–12.25	0.028	0.367	0.5
10.00–10.75	0.037	0.387	0.1
10.75–11.50	0.033	0.377	0.1
11.50–12.25	0.030	0.375	0.1
12.25–13.00	0.021	0.369	0.1

Antonuccio-Delogu et al. 2010

Comparison with previous works



- Puech et al. (2007)
  - 35 galaxies
  - $0 < z < 0.6$
  - Blue: rotating discs
  - Green: perturbed rotators
  - Red: complex kinematics
  - Black: Courteau (1997)
  - "Only a mild increase of λ is found if any compared with the local sample"

Results at higher z

- Förster Schreiber et al. (2006) with a sample of 14 galaxies in the range z = 2.0–2.5:
  - They estimate the specific angular momentum of their galaxies: $j = \beta r_{1/2} v_c$
  - They find that for their sample $j \sim 1000$–2000 km s^{-1} kpc. Interestingly, these values are comparable to those of local late-type galaxies (Abadi et al. 2003)
  - And assuming that V_c traces the virial mass of the system, they get $\lambda \sim 0.05$, which is also the expected value for low redshift galaxies.

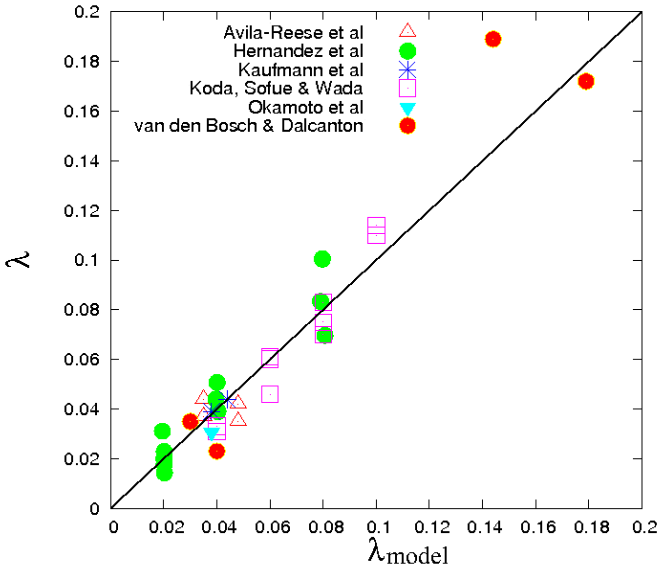
Conclusions

- 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
- Besides mass and gas content, the spin seems to play a major role determining the presence of bars on disc galaxies
- For our sample of high redshift galaxies, we do not notice any sign of evolution in the redshift range $0.4 < z < 1.2$

Comparisons with numerical simulations

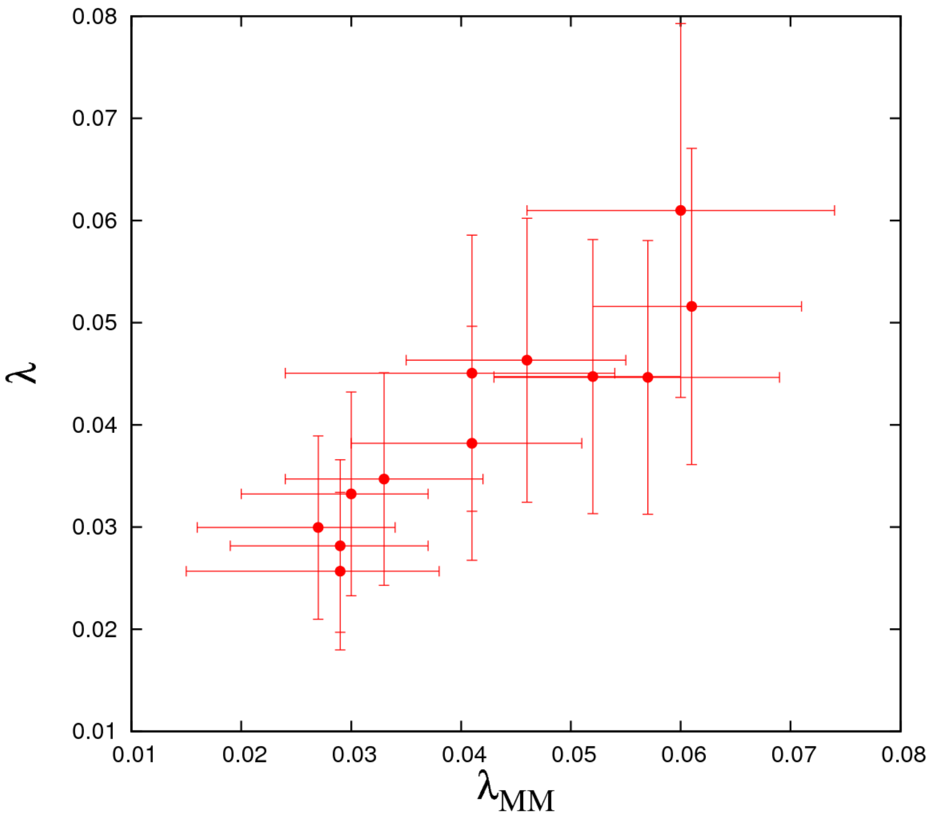
- For our galaxy, our estimation is λ = 0.023, in agreement with theoretical expectations (λ = 0.02: Natarajan 1998; Hernandez et al. 2001)

- Comparison between our λ estimate and results from numerical simulations



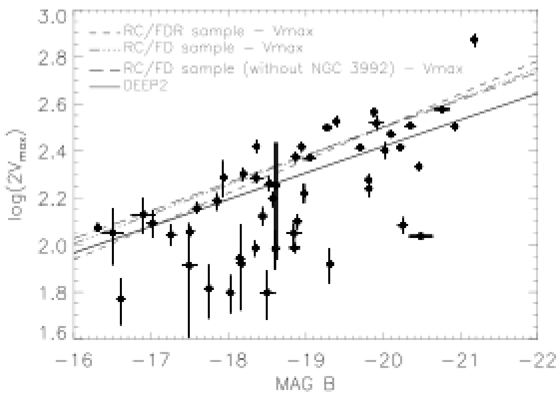
Verification with highly accurate measurements of λ in observed galaxies

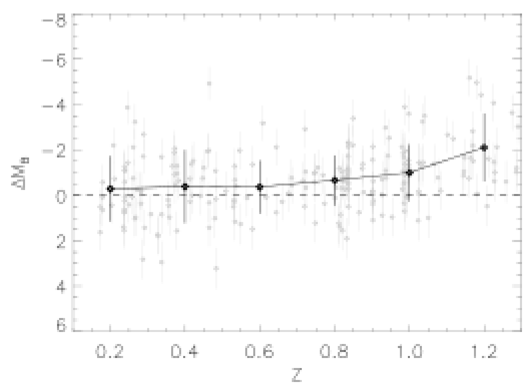
- Muñoz-Mateos et al. (2011)
- Models of observed disc galaxies, matching multi-wavelength luminosity profiles and rotation curves.



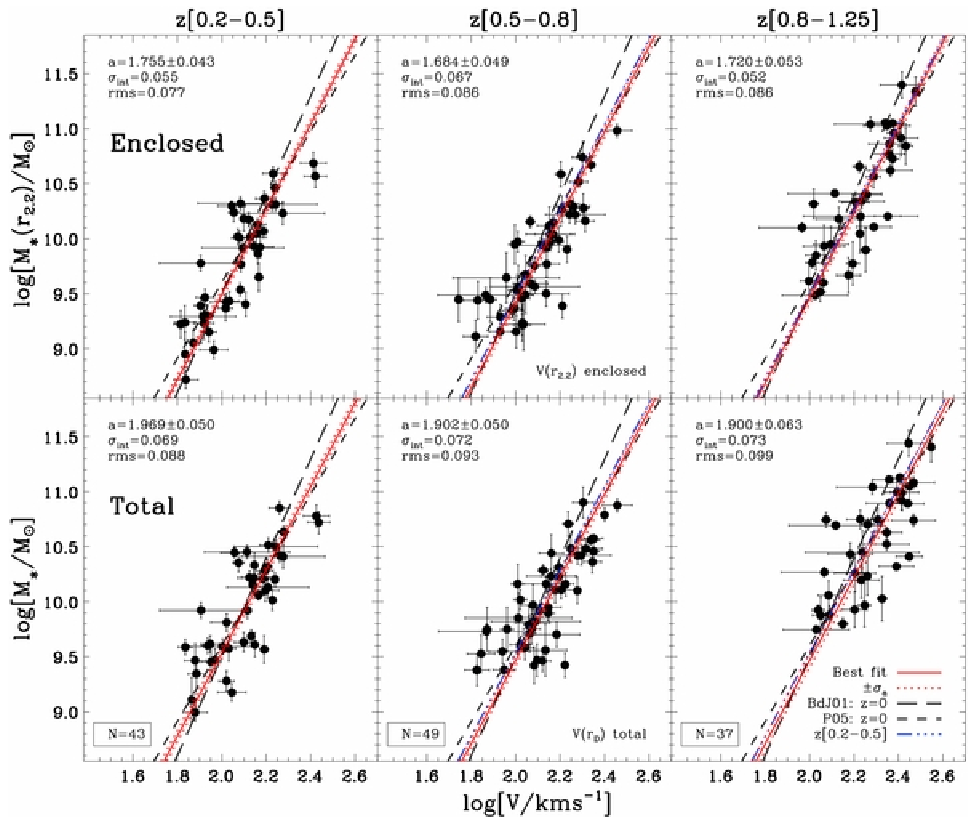
Tully-Fisher relations at high z

Miller et al. 2011 with DEIMOS up to z ~ 1.3





Fernandez-Lorenzo et al. 2009 (DEEP sample 0.2 < z < 1.3)



Specific angular momentum

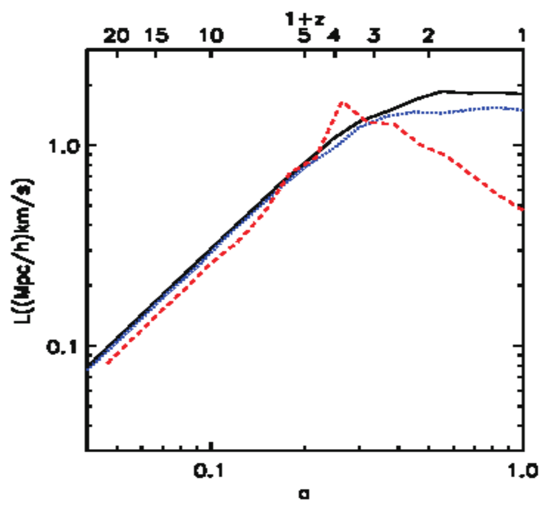
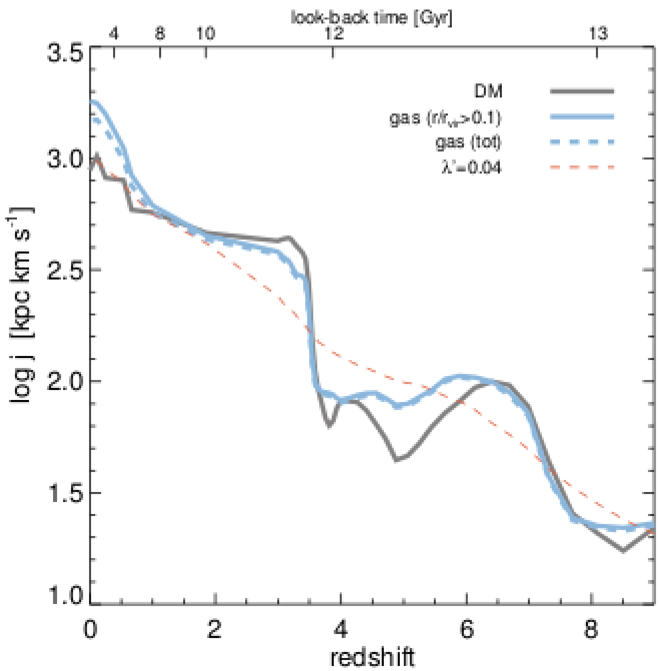


Figure 5. Specific angular momentum of the dark matter component (solid line) and of the baryonic component of the bluge-dominated galaxy (dashed line) and of the disk-dominated galaxy (dotted line).

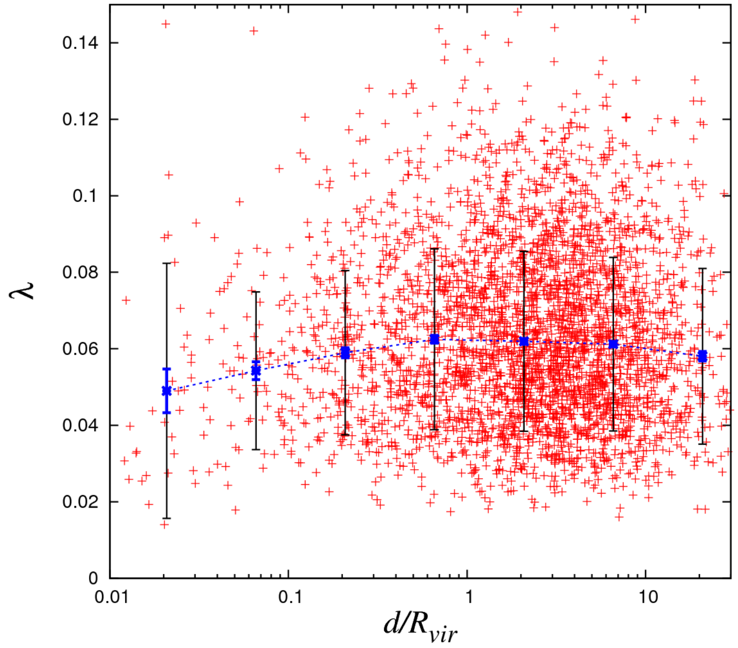
Zavala et al. 2007



Sales et al. 2009

Kimm et al. 2011

Interactions



Cluster environment