ICC, Durham, 19th July, 2012

The Tully-Fisher Relation in Hydrodynamical Simulations of Structure Formation

María Emilia De Rossi [1, 2, 3]

Patricia Beatriz Tissera [1, 2]

Susana Pedrosa [1, 2]

(1) Instituto de Astronomía y Física del Espacio, Argentina

(2) Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina

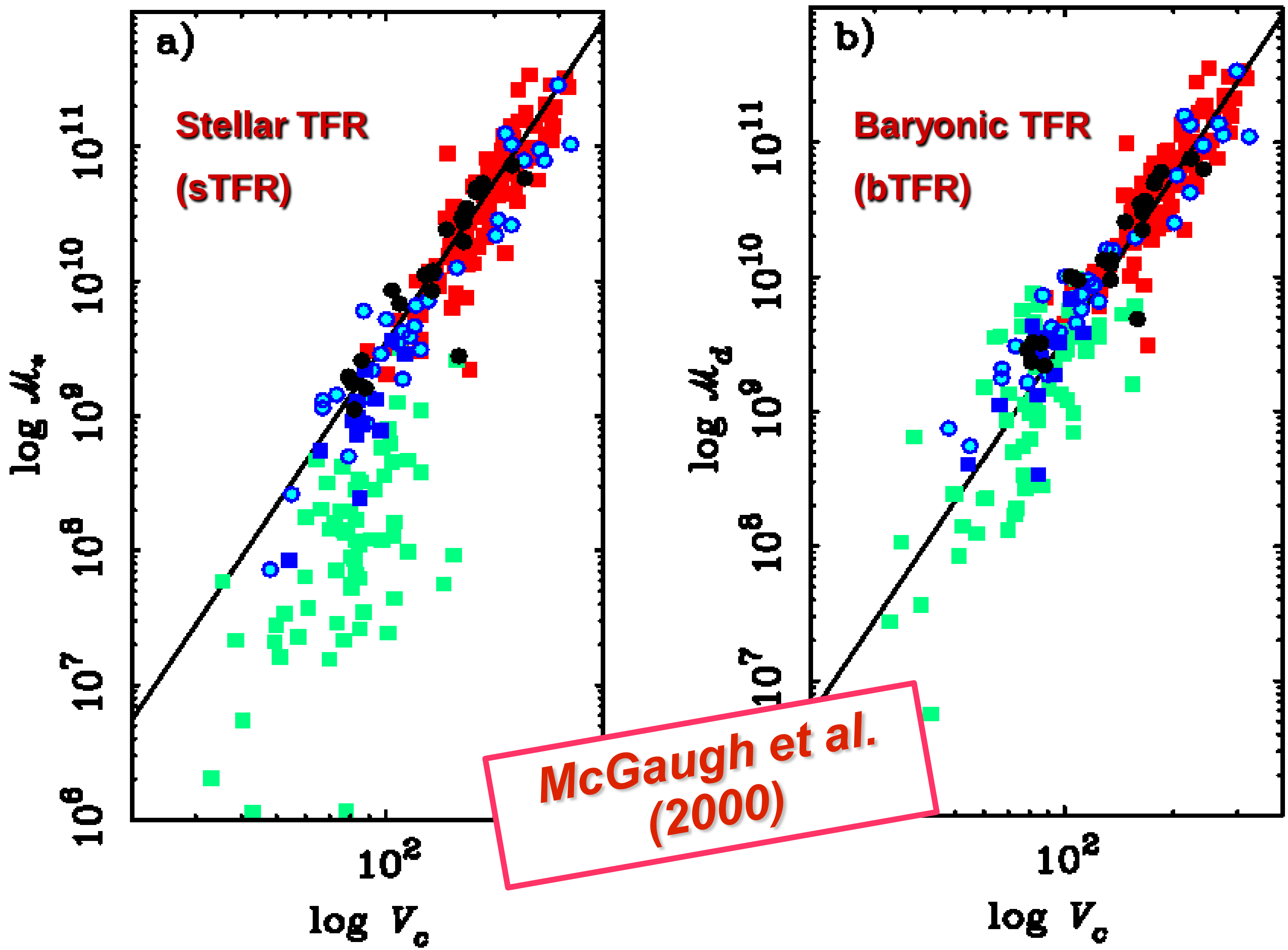
(3) Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Argentina

MAIN TOPICS

- The effect of Supernova feedback on the gas kinematics of galaxies and its relation to the observed bend of the Tully-Fisher Relation *(de Rossi et al. 2010).*

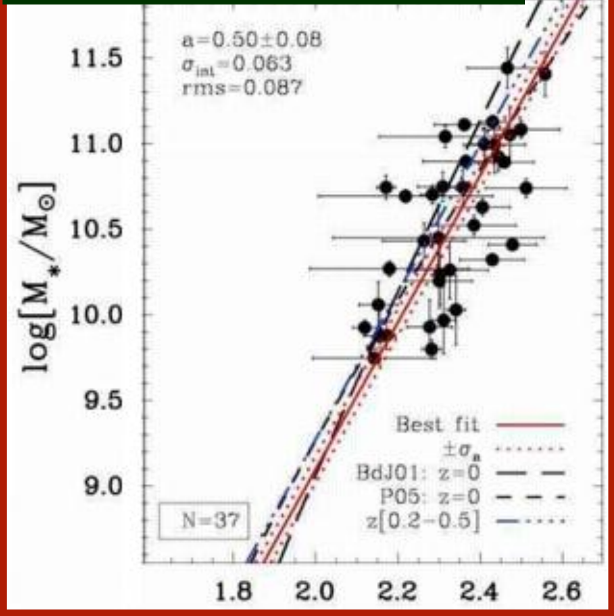
- The effect of the hierarchical aggregation of the structure on the gas kinematics of galaxies and its relation to the scatter of the Tully-Fisher Relation *(de Rossi et al. 2012).*

LOCAL STELLAR AND BARYONIC TFR



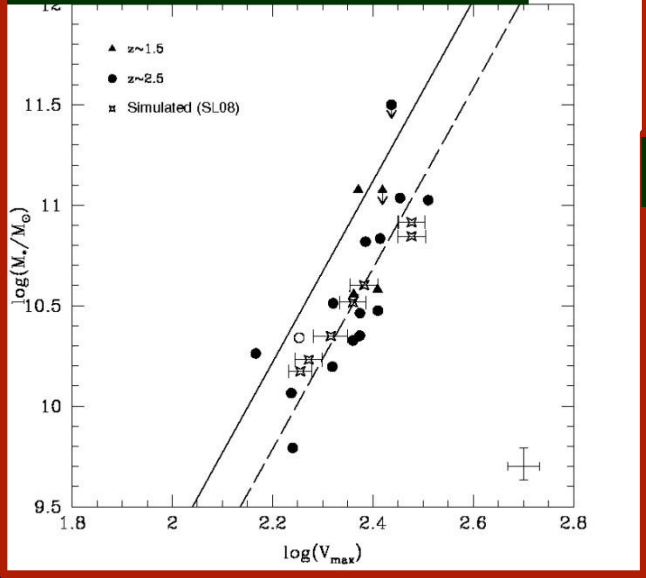
THE OBSERVED EVOLUTION

Miller et al. (2011)



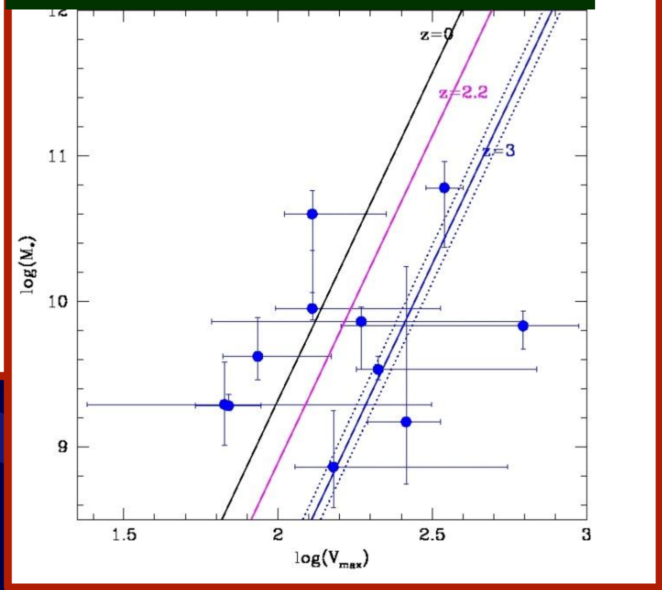
Evolution by
0.04 ± 0.07 dex in M* from z~1 to z~0.3

Cresci et al. (2009)



Evolution by
0.41 ± 0.11 dex in M* since z~2

Gnerrucci et al. (2011)



Large scatter (~1.5 dex) of the TFR at z~3 suggests that the relation is not yet in place at this redshift

Numerical Simulations

- Chemical code GADGET-3 (Scannapieco et al. 2008).
- Λ-CDM cosmology, with Ω_m=0.3, Ω_Λ=0.7, Ω_b=0.04 and H_0=100 h km s^{-1} Mpc^{-1} with h=0.7.
- Comoving cubic volumen of 10 Mpc h^{-1} side length.
- Mass resolution of 6 x 10^6 M_o h^{-1} and 9 x 10^5 M_o h^{-1} for dark matter and initial gas-phase particles, respectively.

Physical model

Scannapieco et al. (2005, 2006)

- ✓ *Metal-dependent radiative cooling*
- ✓ *Star formation*
- ✓ *Chemical enrichment*
- ✓ *Supernova feedback*

GALAXY CATALOGUES

IDENTIFICATION

FRIENDS-OF-FRIENDS

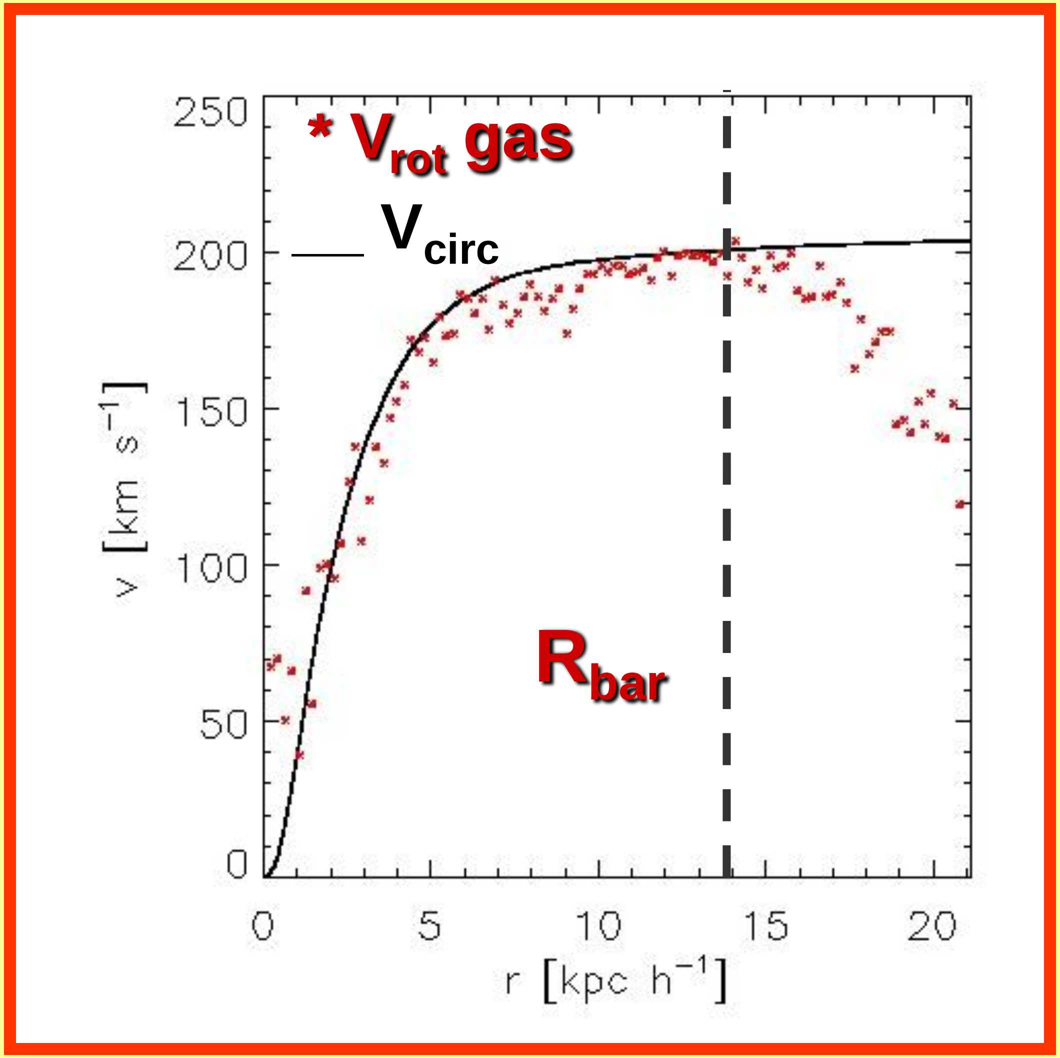
SUBFIND (Springel et al. 2001)

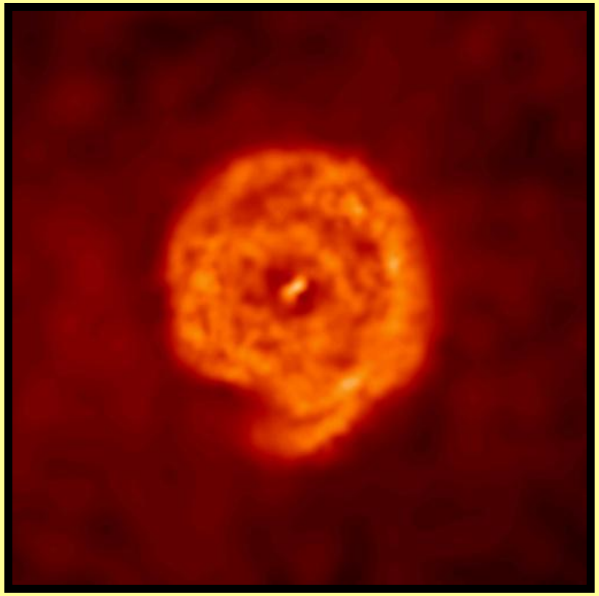
We estimate the mean properties of galactic systems within a BARYONIC RADIUS.

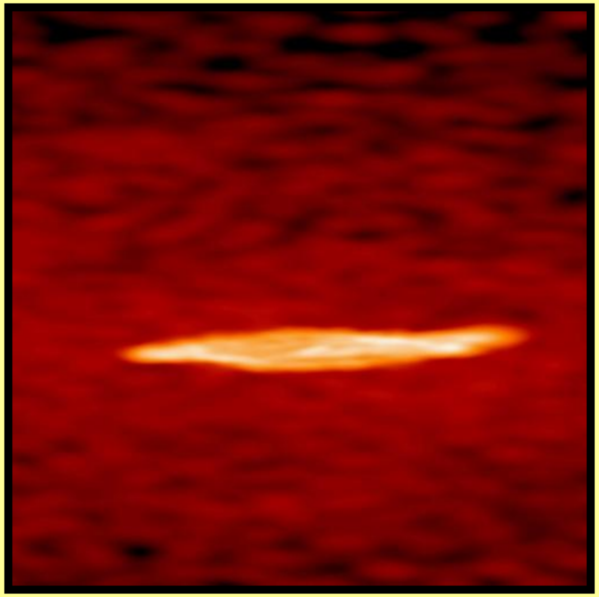
A BARYONIC RADIUS is defined as the one which encloses 83% of the baryonic mass of the system.

Rotation curves and selection of '*disk-like galaxies*'

D/T (gas) > 0.75

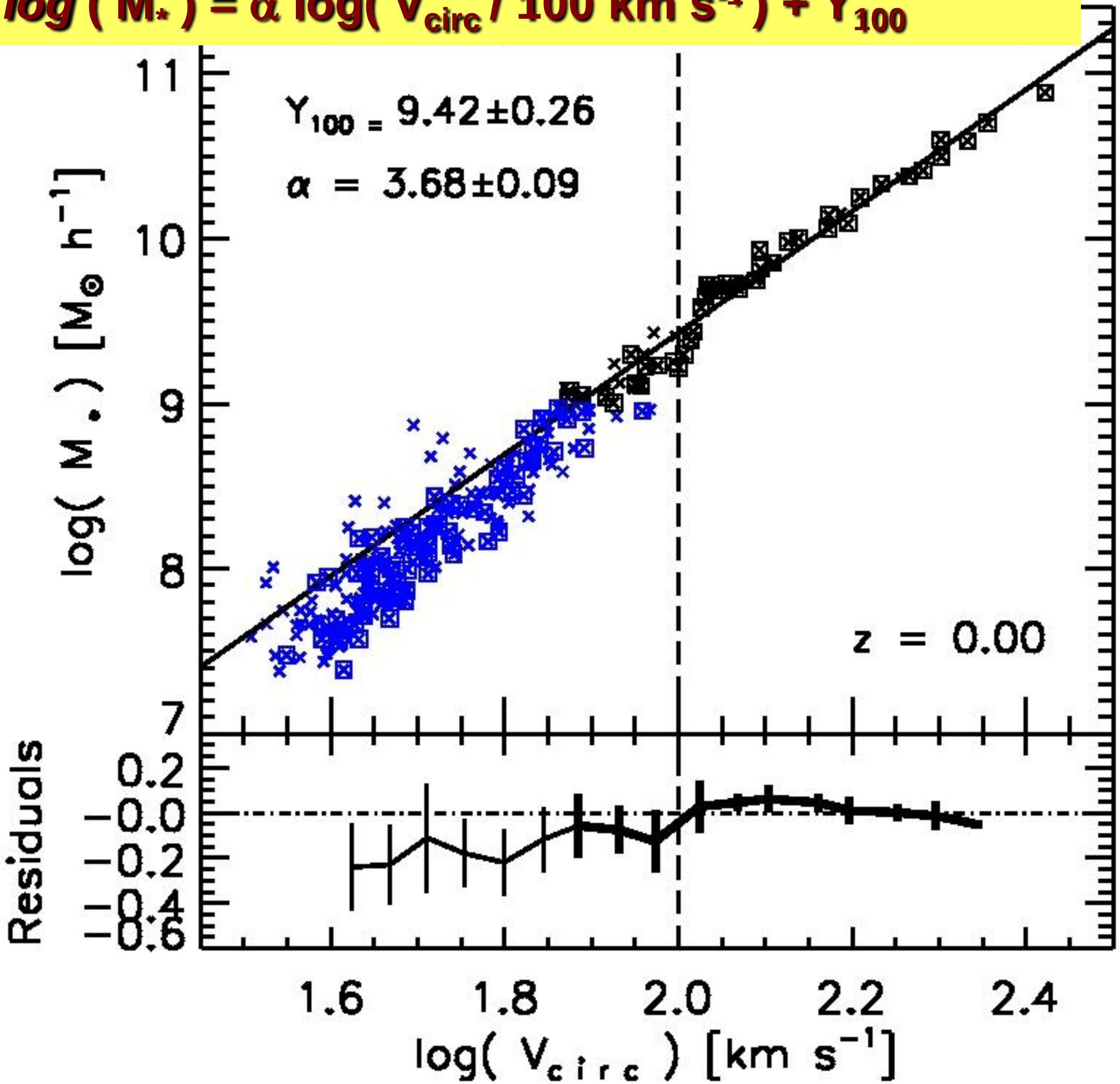






Local Simulated stellar TFR

log (M*) = α log(V_{circ} / 100 km s^{-1}) + Y_{100}



General agreement with observations (e.g. McGaugh et al. 2000; Reyes et al. 2011).

General agreement at intermediate masses with simulated results of McCarthy et al. (2012).

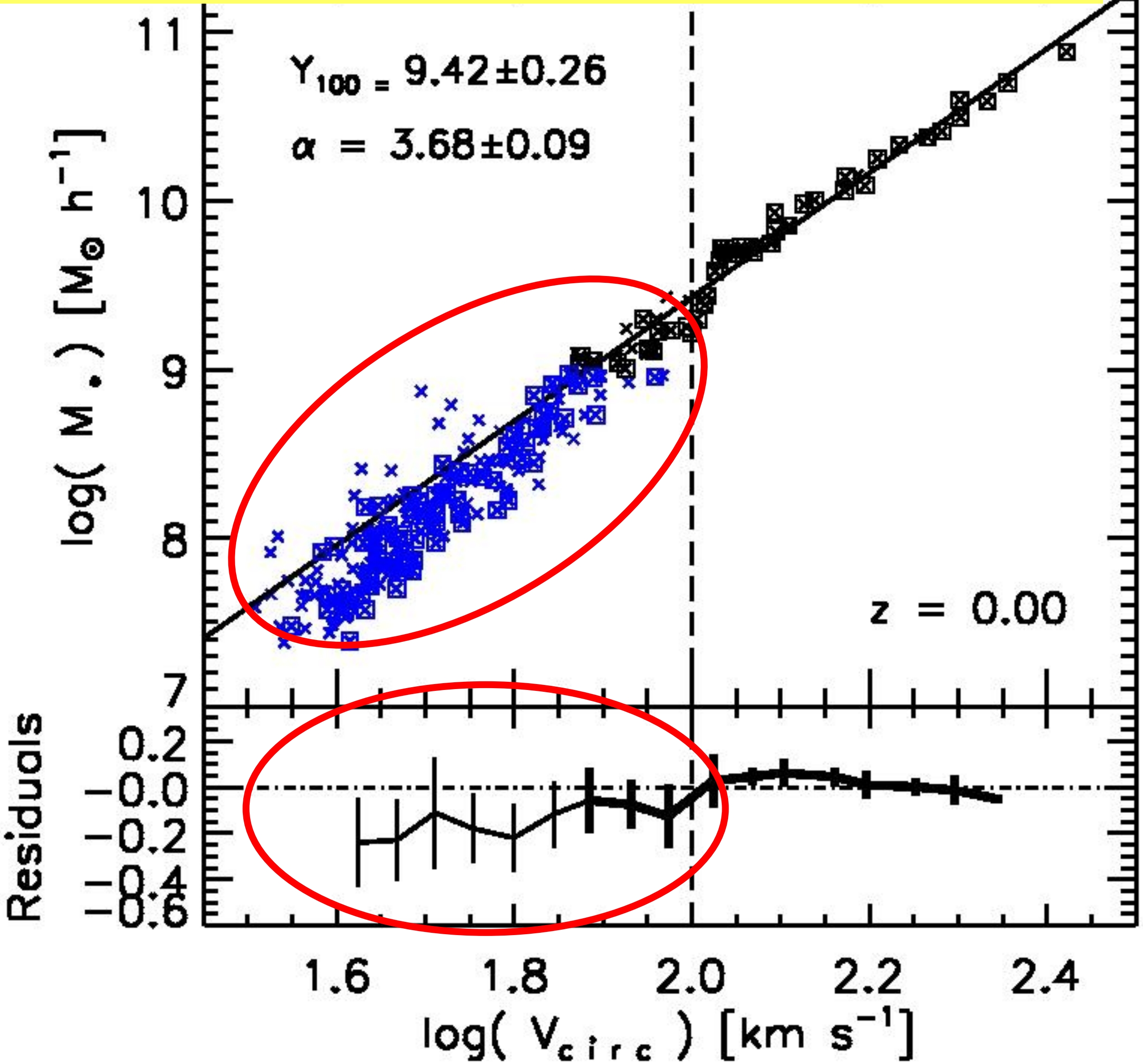
Residuals: systematic departure from zero below 100 km/s.

THERE IS A BEND: slow-rotators exhibit smaller stellar masses than those predicted by the fitting.

a SN feedback effect?

Local Simulated stellar TFR

$$\log(M_*) = \alpha \log(V_{circ} / 100\ \mathrm{km\ s^{-1}}) + Y_{100}$$



General agreement with observations (e.g. McGaugh et al. 2000; Reyes et al. 2011).

General agreement at intermediate masses with simulated results of McCarthy et al. (2012).

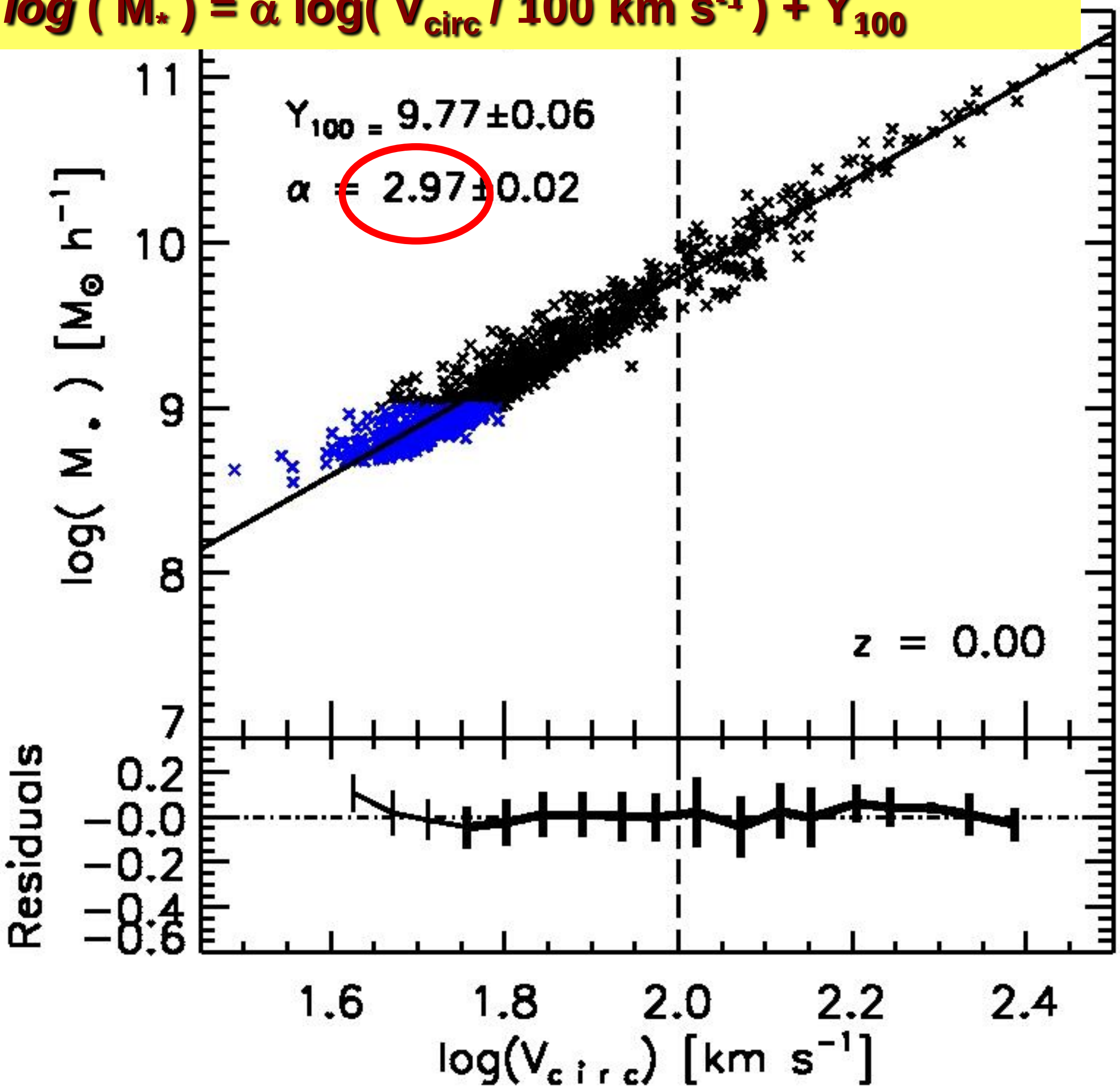
Residuals: systematic departure from zero below 100 km/s.

THERE IS A BEND: slow-rotators exhibit smaller stellar masses than those predicted by the fitting.

a SN feedback effect?

Stellar TFR in a wind-free model

$\log (M_*) = \alpha \log(V_{circ} / 100 \text{ km s}^{-1}) + Y_{100}$



Linear behaviour

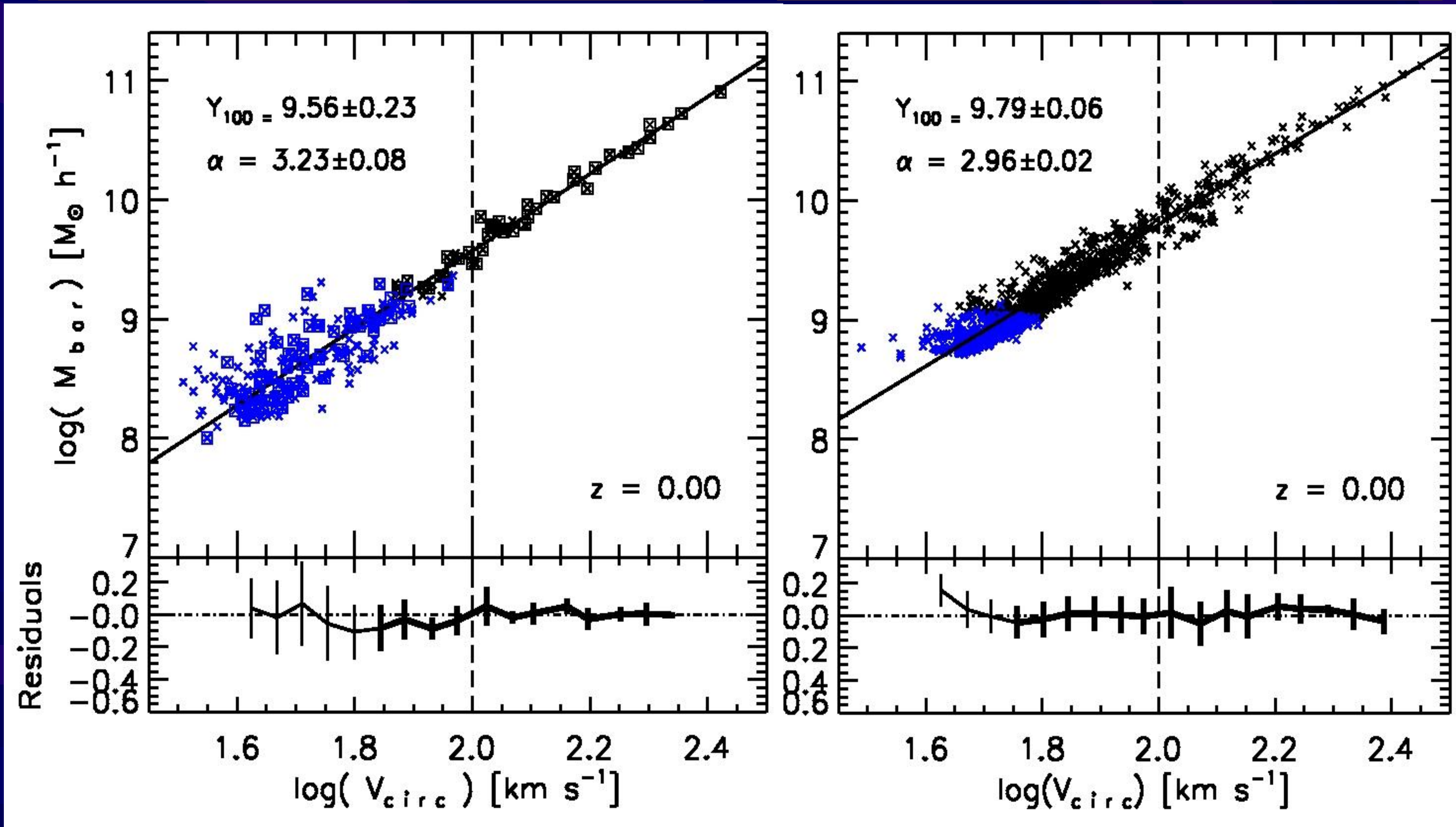
At similar velocities, larger stellar masses than in the SN-free model.

Flatter slope

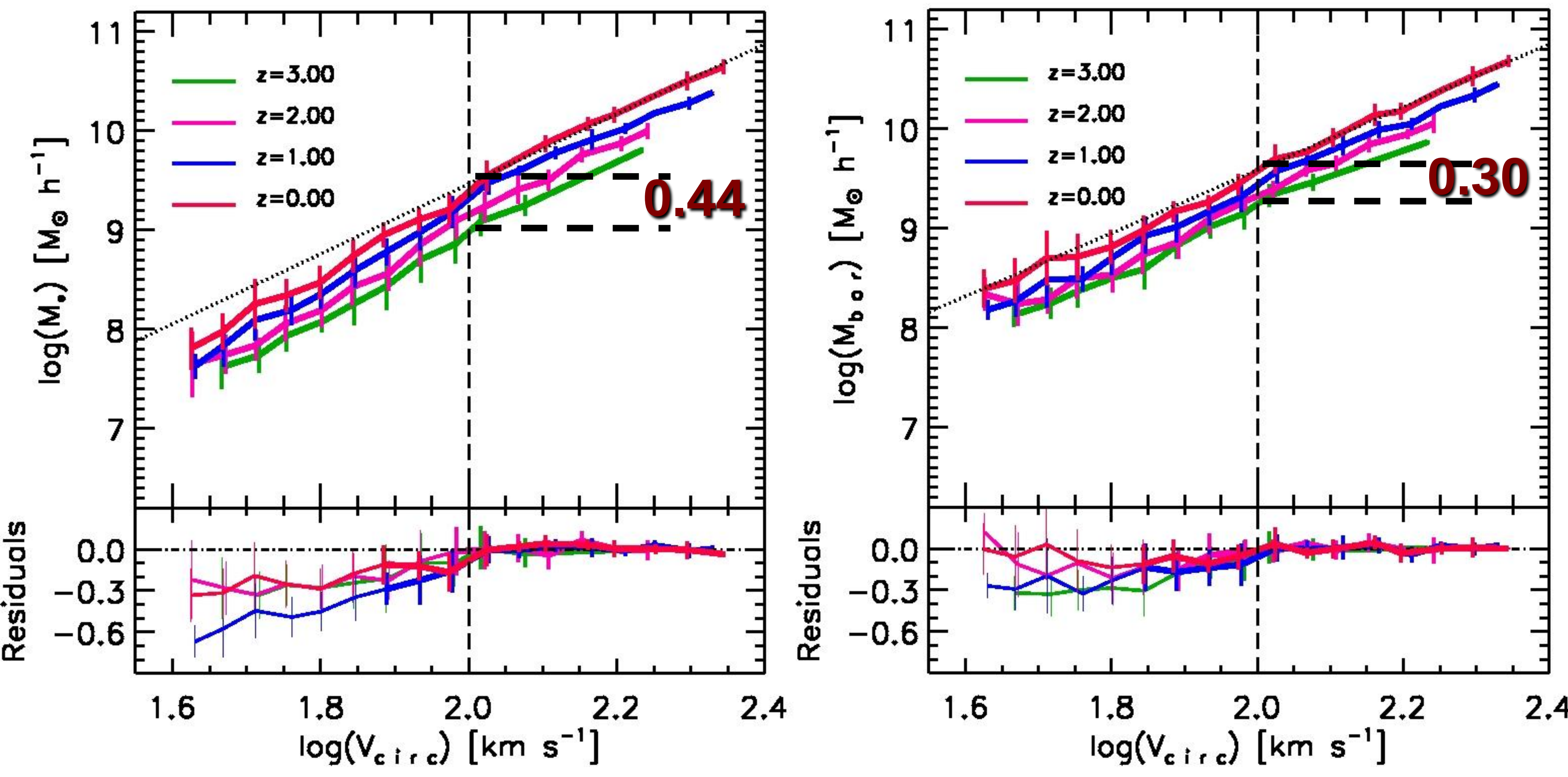
Galactic winds, crucial to reproduced the observed bend.

Local Baryonic TFR

SN feedback model | **Wind-free model**

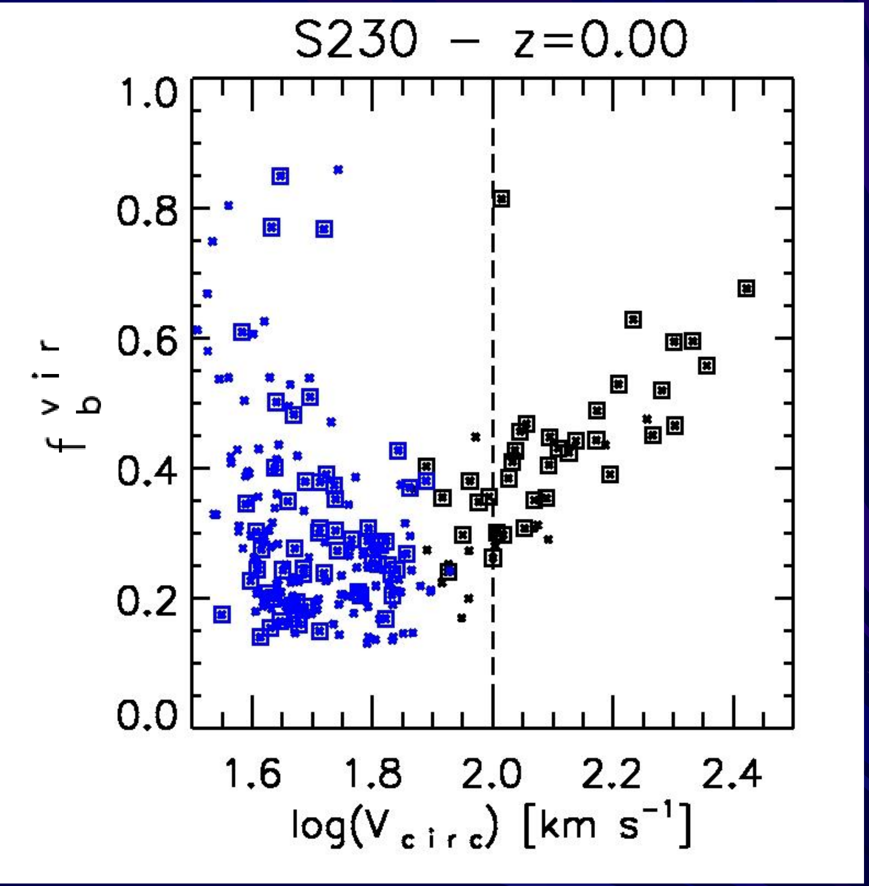


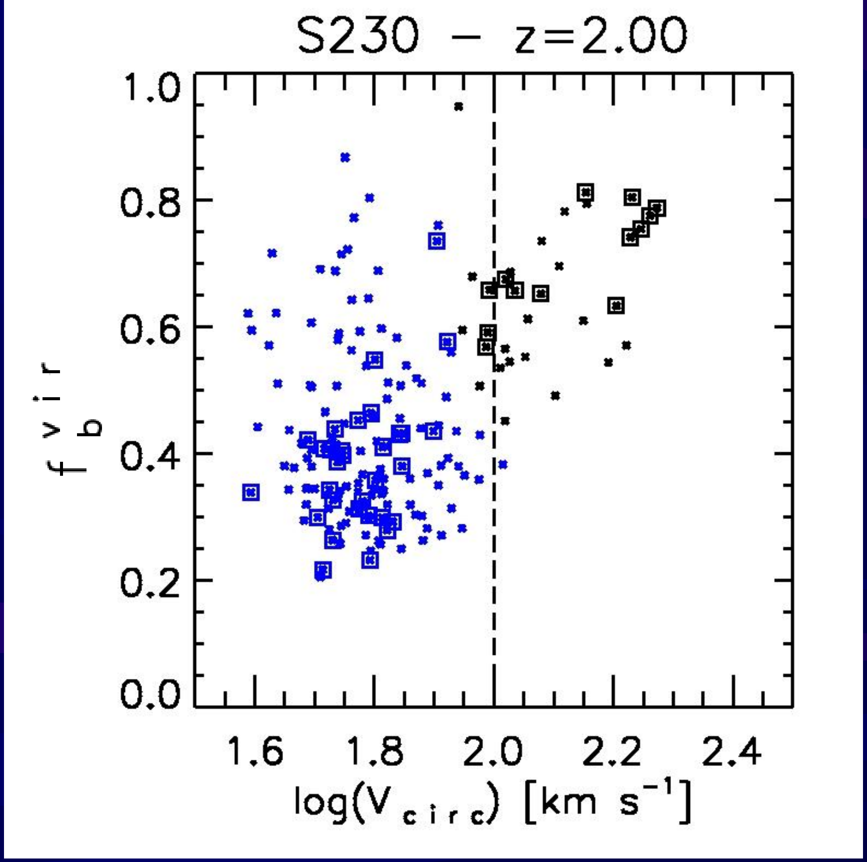
- These trends are also observed at higher redshifts (z>3).
- Our results seem to be robust against numerical resolution.



The impact of SN-driven outflows

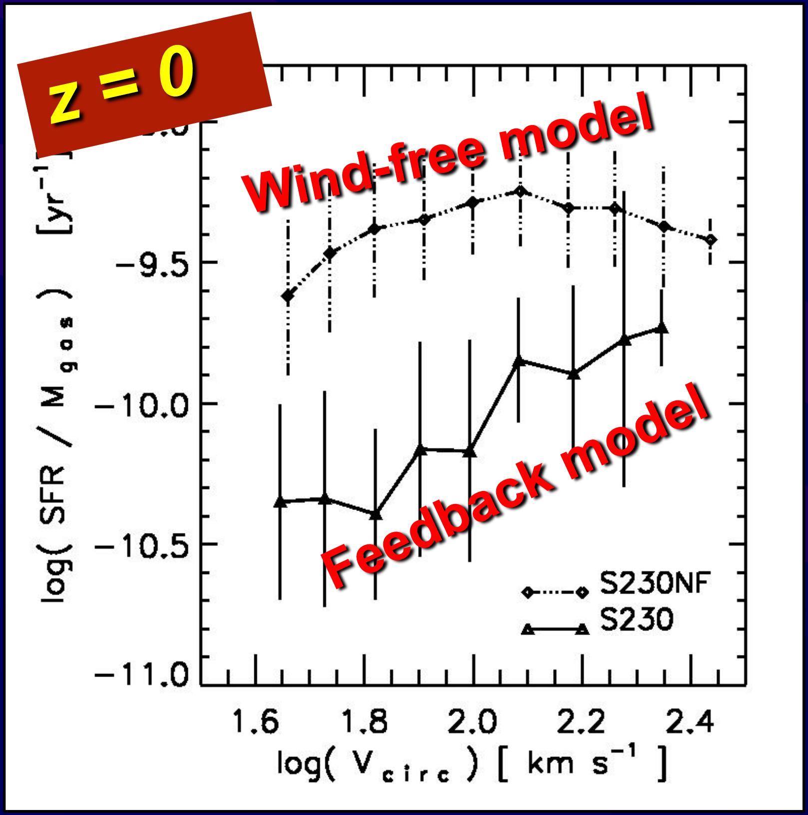
$$\frac{M_{bar}\ \text{inside}\ R_{vir}}{(\Omega_b/\Omega_m)\ M_{vir}}$$





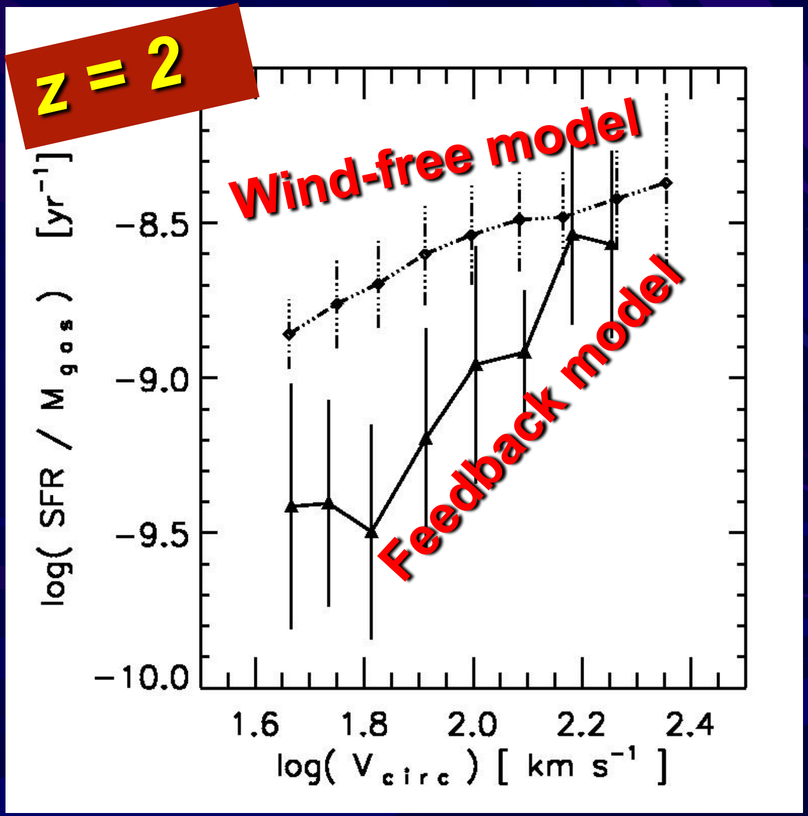
Smaller systems more affected by galactic outflows

The influence of SN feedback on the SFR



The wind-free model predicts larger eSFR at a given circular velocity.

Larger changes obtained at the low-mass end of the relation.



Consistent with the bend of the sTFR

Smaller vs massive galaxies

Slow rotators
(smaller virial temperatures)

Cold phase:
Star formation

Efficient radiative cooling

Efficient SN heating and outflows

Hot-phase

Fast rotators
(larger virial temperatures)

Cold phase:
Star formation

Inefficient radiative cooling

Inefficient SN heating and outflows

Hot-phase

SN feedback is not efficient at regulating star formation in larger galaxies.

Smaller vs massive galaxies

TRANSITION VELOCITY: 100 km/s

- Consistent with the bend of the TFR
- Agreement with previus observational (McGaugh et al. 2000; Amorín et al. 2009) and theoretical expectations (Larson 1974; Dekel & Silk 1986)

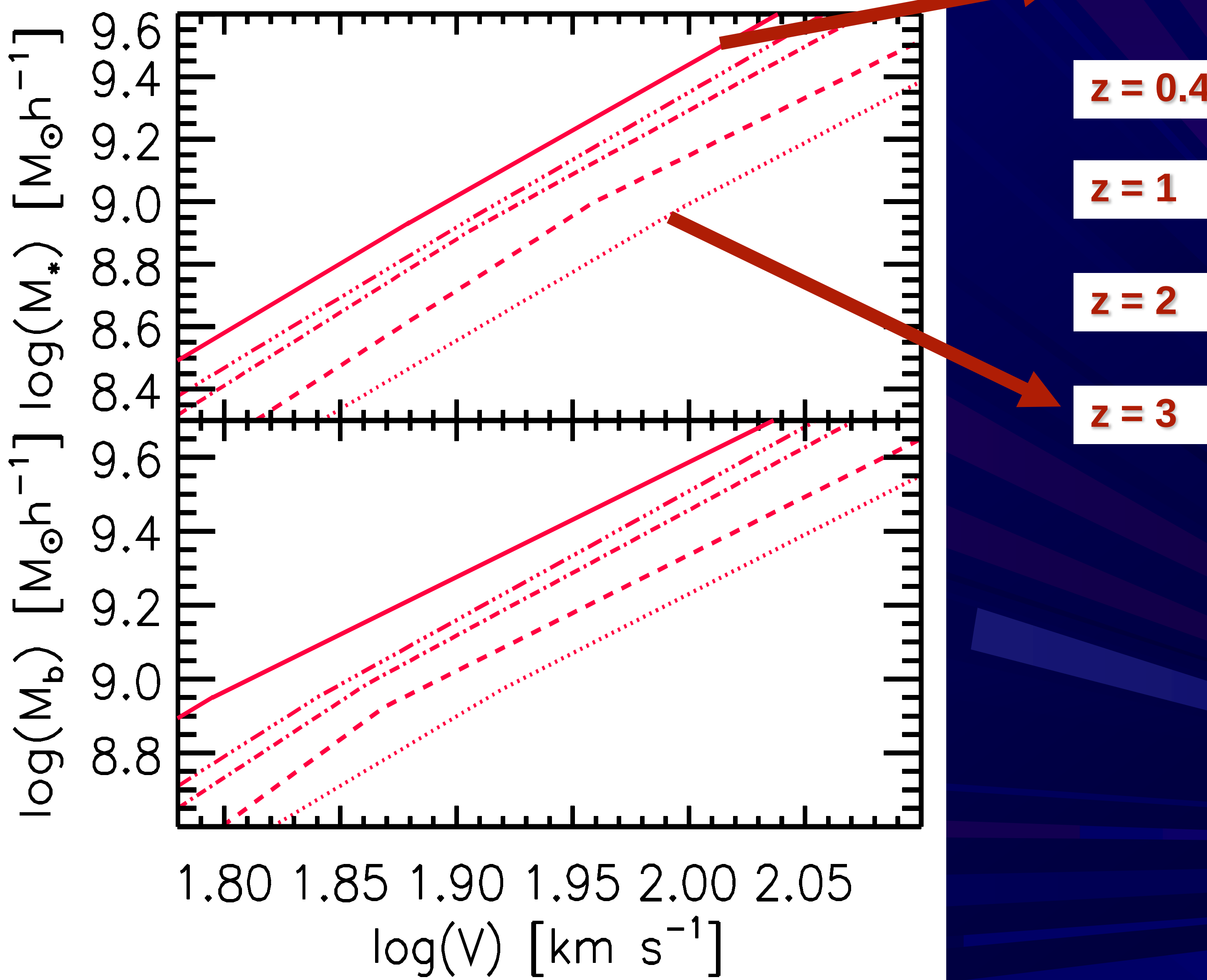
De Rossi, Tissera & Pedrosa (2010)

MAIN TOPICS

- The effect of Supernova feedback on the gas kinematics of galaxies and its relation to the observed bend of the Tully-Fisher Relation *(de Rossi et al. 2010)*. √

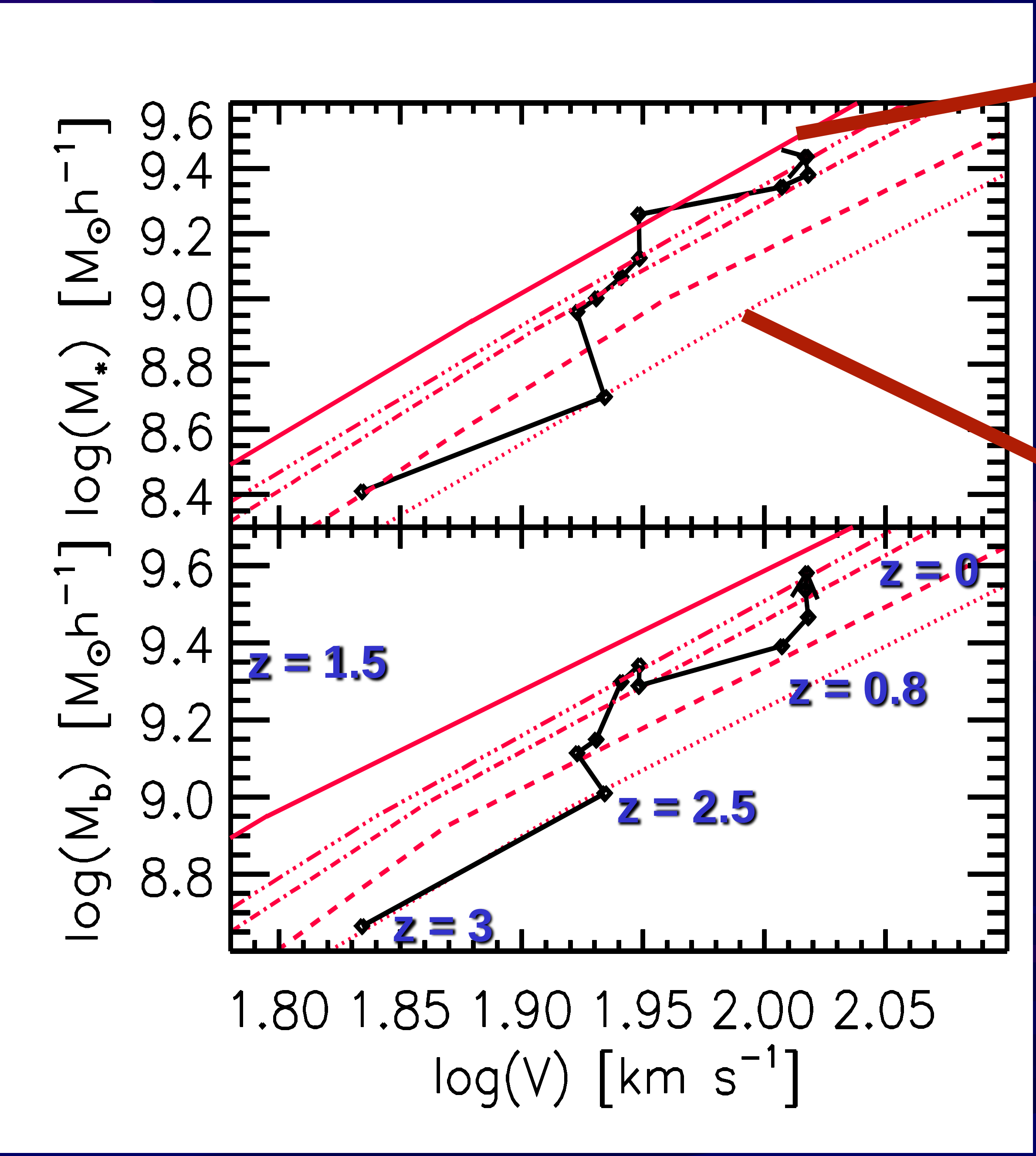
- The effect of the hierarchical aggregation of the structure on the gas kinematics of galaxies and its relation to the scatter of the Tully-Fisher Relation *(de Rossi et al. 2012)*.

Mean simulated TFR at different redshifts



Mean sTFR and bTFR by using V_{circ} as kinematic indicator.

Evolution of a typical galaxy in the TFR-plane



z = 0

z = 0.4

z = 1

z = 2

z = 3

Mean sTFR and bTFR by using V_{circ} as kinematic indicator.

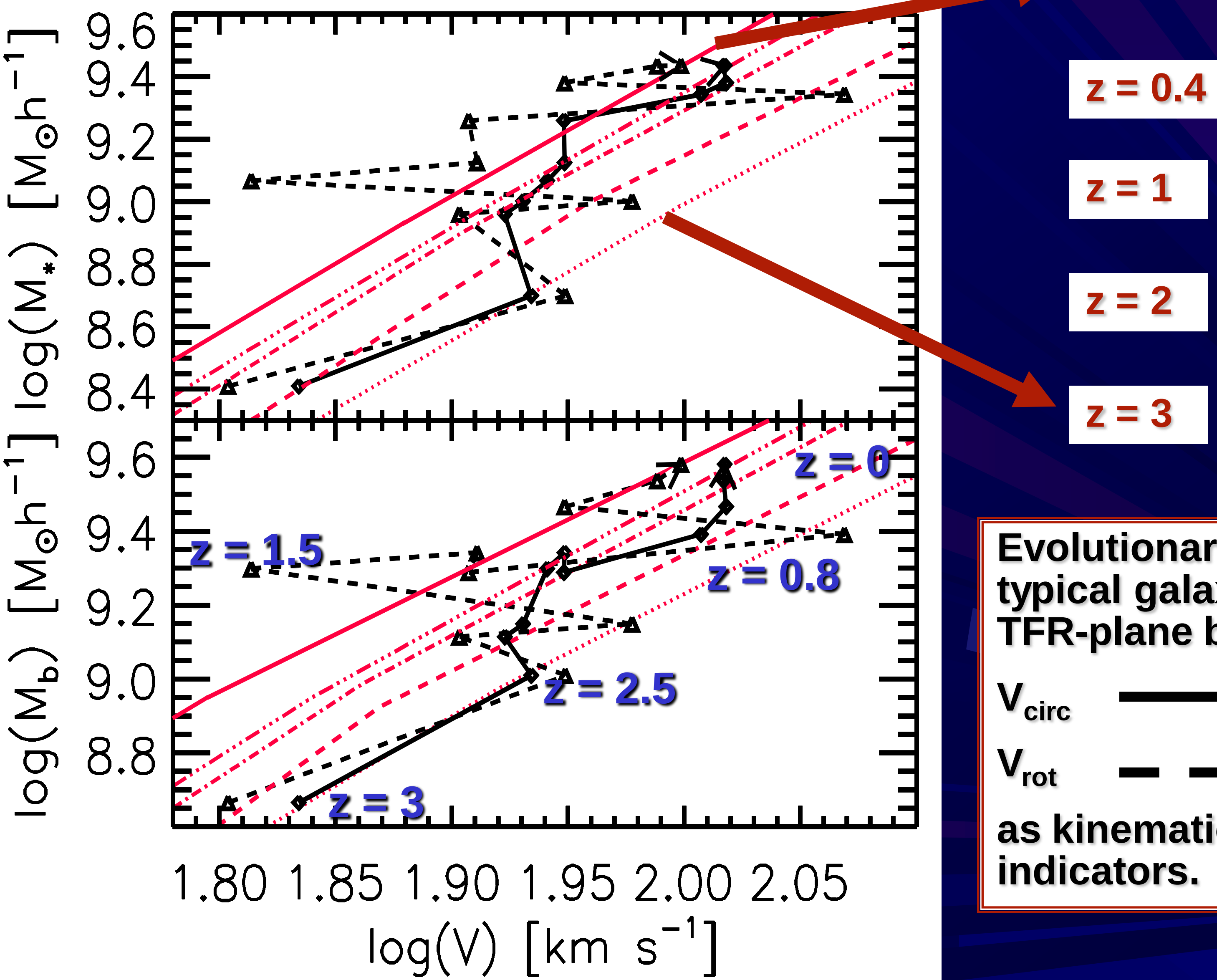
Evolutionary track of a typical galaxy on the TFR-plane by using:

V_{circ} ———

V_{rot} — — —

as kinematic indicators.

Evolution of a typical galaxy in the TFR-plane



Mean sTFR and bTFR by using V_{circ} as kinematic indicator.

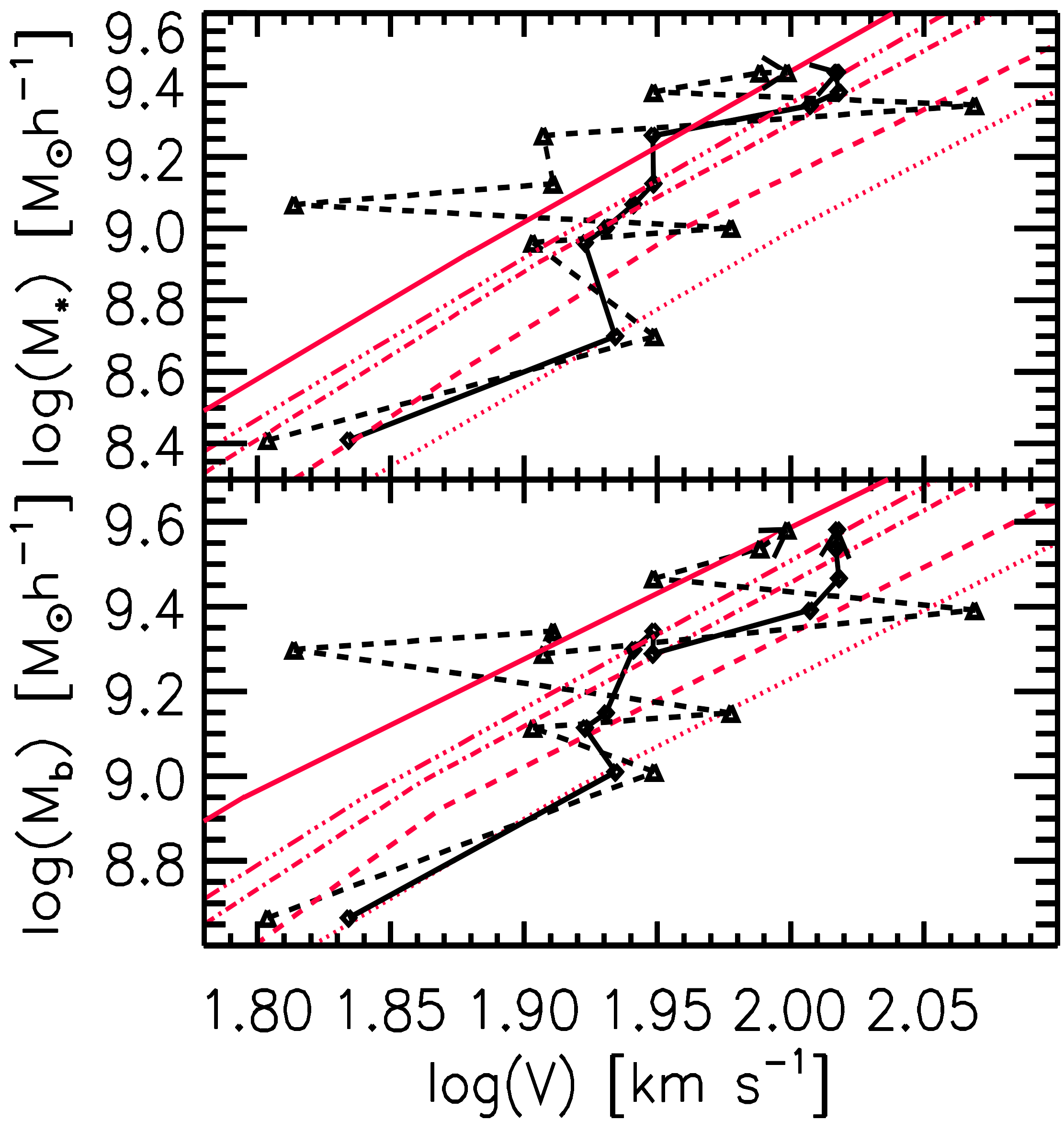
Evolutionary track of a typical galaxy on the TFR-plane by using:

V_{circ} ———

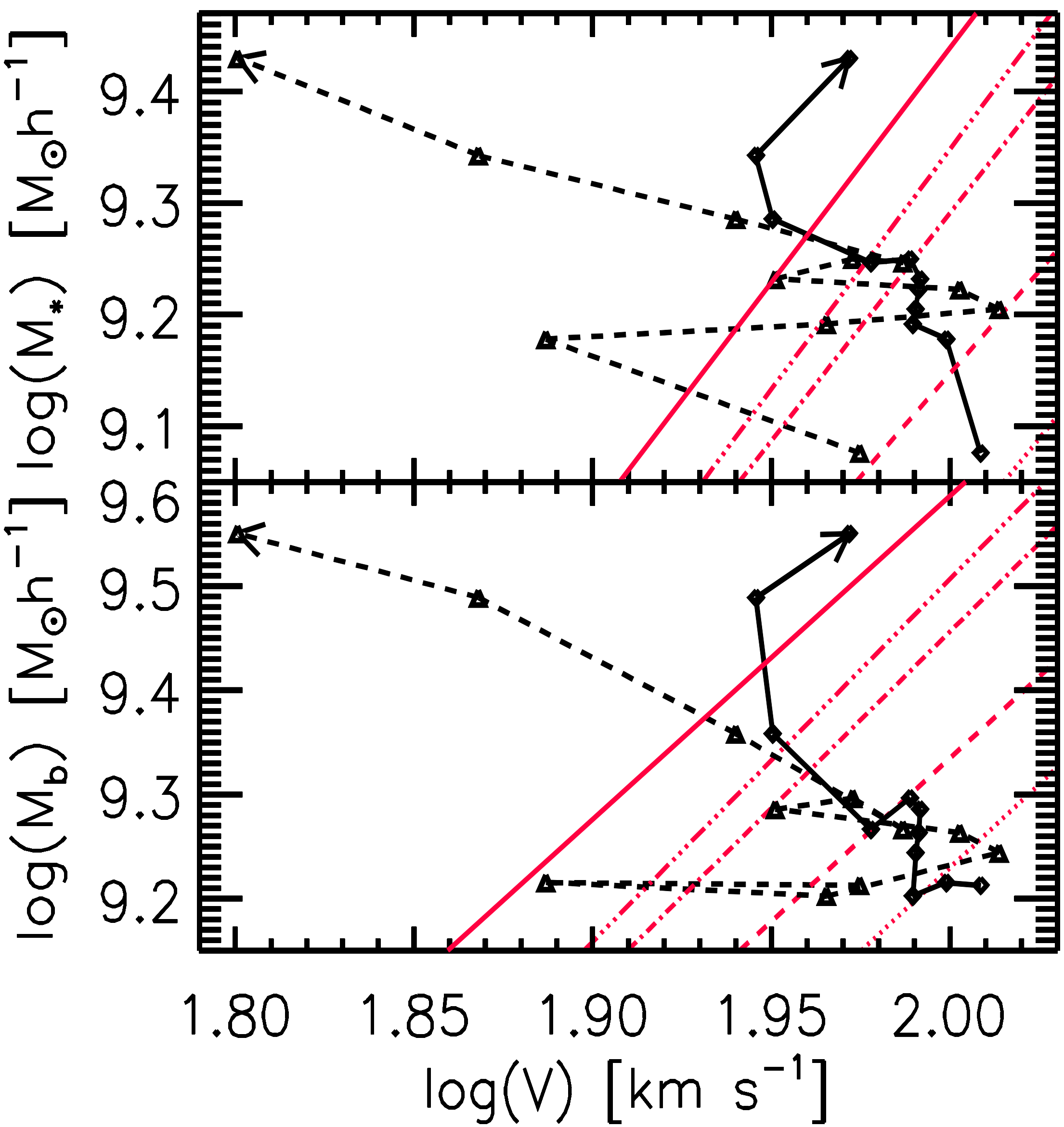
V_{rot} — — —

as kinematic indicators.

Scatter of the simulated TFR



Tracks given by V_{rot} noisier than those given by V_{circ}, with a **scatter** greater than the level of evolution of the mean TFR based in V_{circ}.



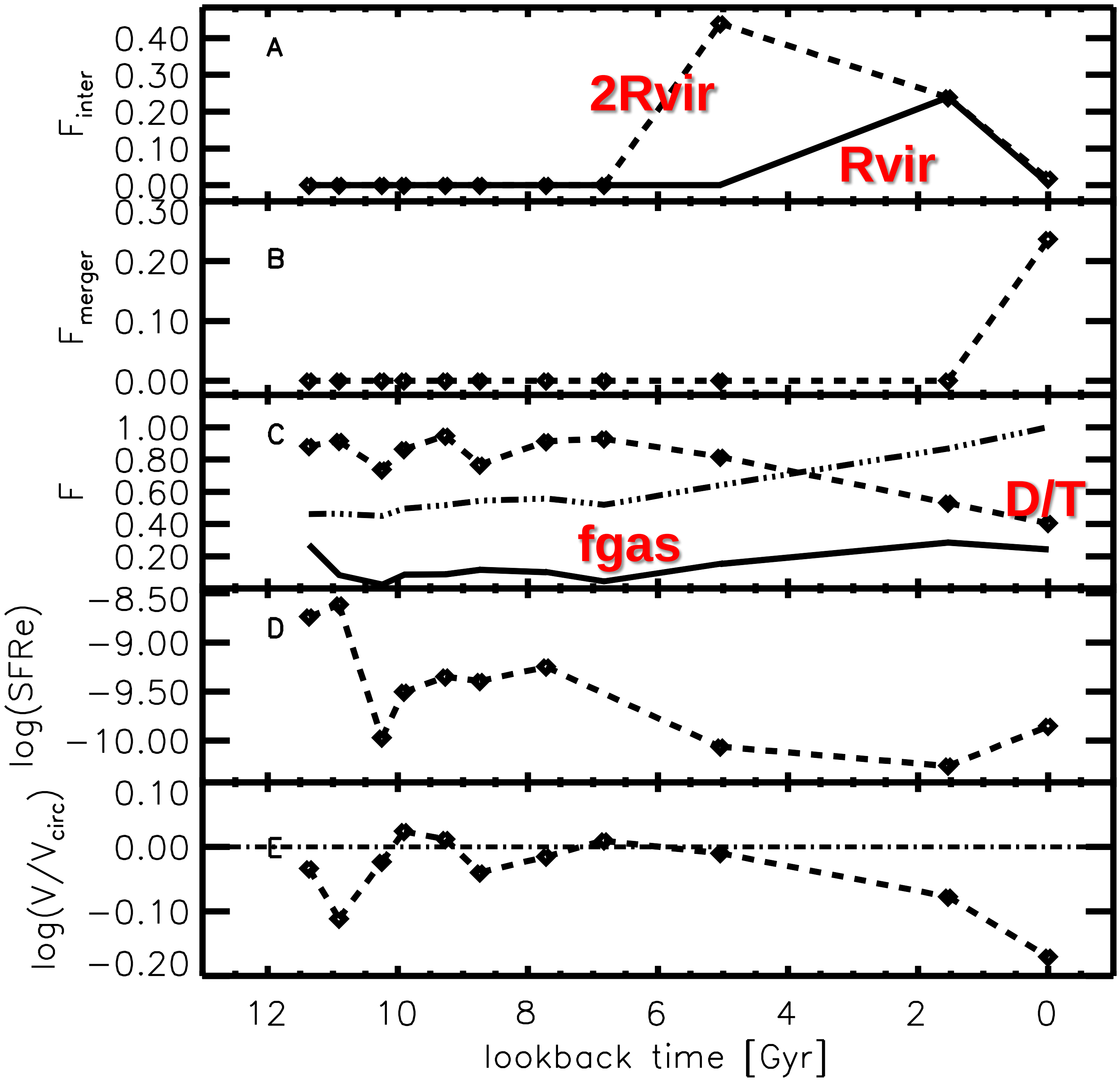
Tracks given by V_{rot} and V_{circ} may diverge.

Which events do disturb the rotation curves of galaxies leading to outliers in the TFR-plane in these simulations?

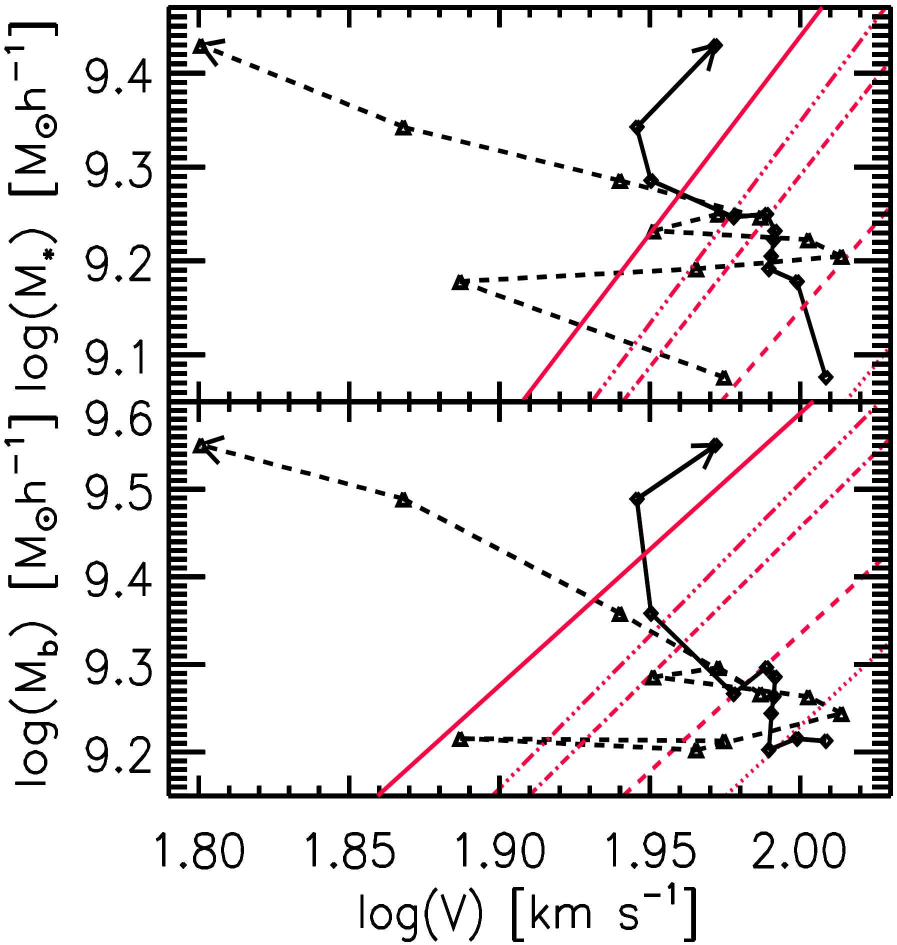
Formation Histories of Typical Galaxies

We follow the main properties of simulated galaxies as a function of time:

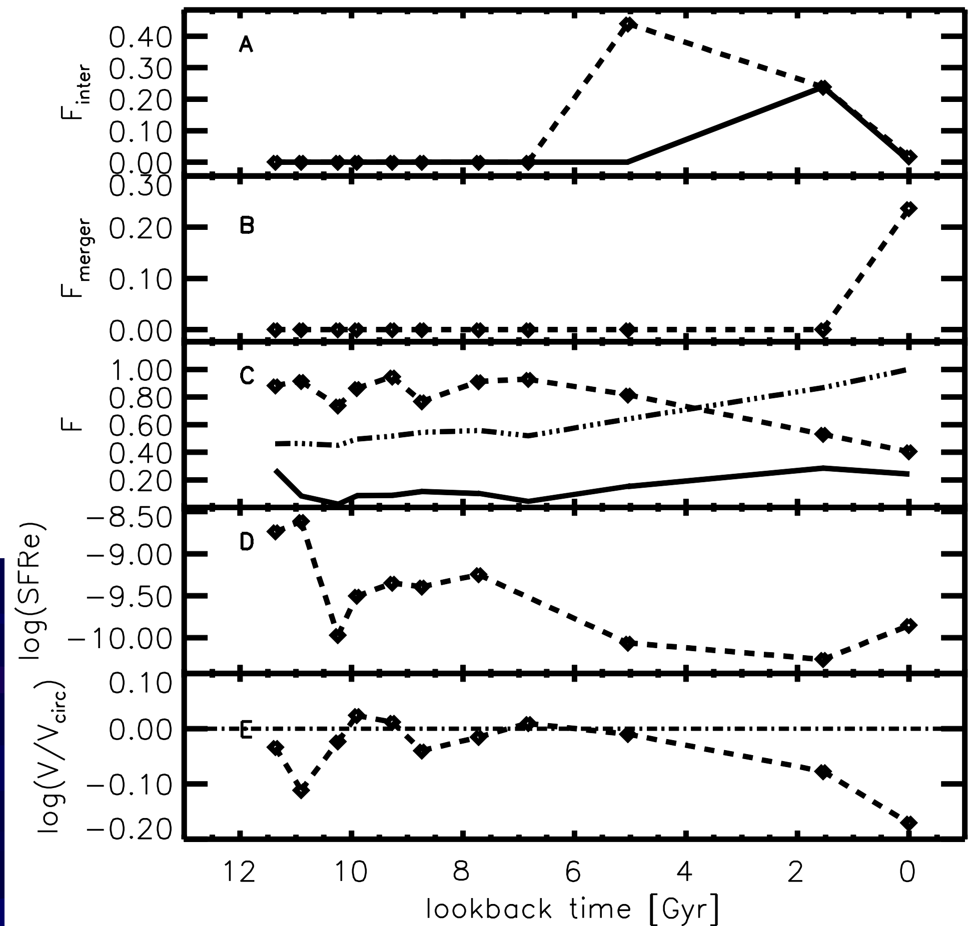
- Total mass within R_{bar}: $M_{dyn,main}$
- Mass of all its neighbours ($M_{dyn,neighb}$) located at a distance smaller than R_{vir} or $2R_{vir}$.
- Strength of the interactions: $F_{inter} = \sum M_{dyn,neighb} / M_{dyn,main}$
- Strenght of mergers: $F_{merger} = \sum M_{dyn,sat} / M_{dyn,main}$
- Gas fraction
- $M_{bar}/M_{bar}(z=0)$
- D/T (gas)
- Star Formation Rate Efficiency (SFRe)
- V_{rot}/V_{circ}



A
2Rvir
Rvir
F_{inter}
0.40
0.30
0.20
0.10
0.00
B
F_{merger}
0.30
0.20
0.10
0.00
C
F
1.00
0.80
0.60
0.40
0.20
D/T
fgas
D
log(SFRe)
−8.50
−9.00
−9.50
−10.00
E
$log(V/V_{circ})$
0.10
0.00
−0.10
−0.20
12
10
8
6
4
2
0
lookback time [Gyr]

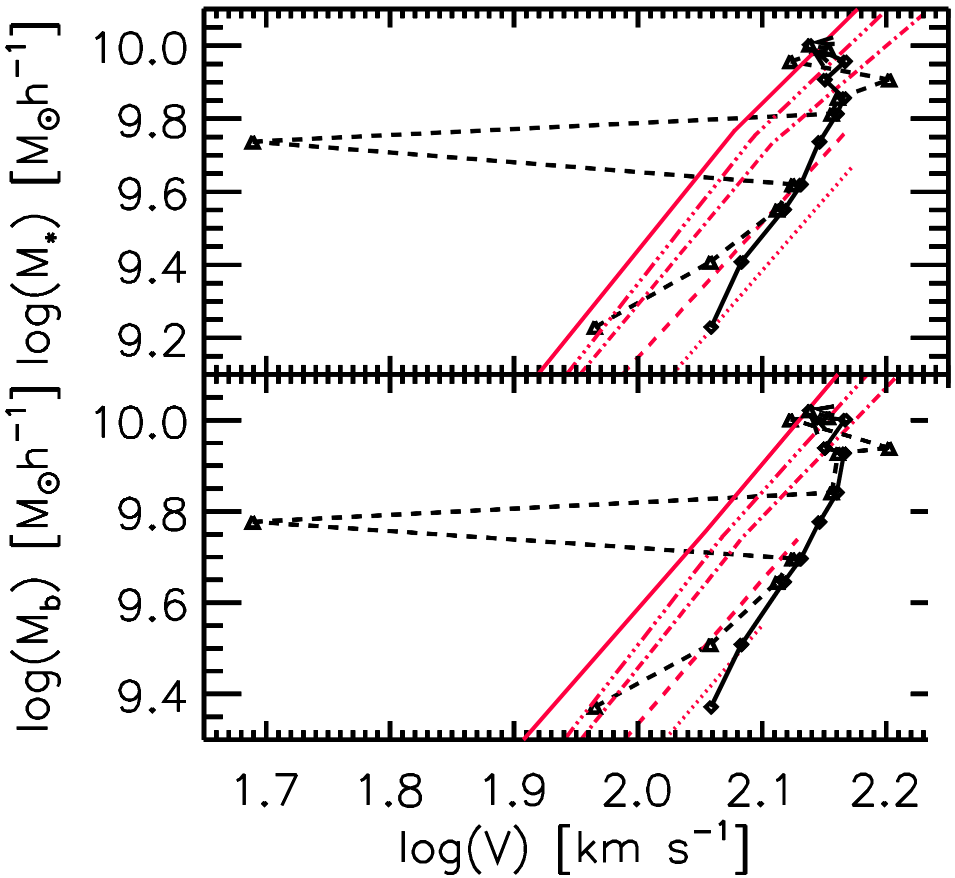


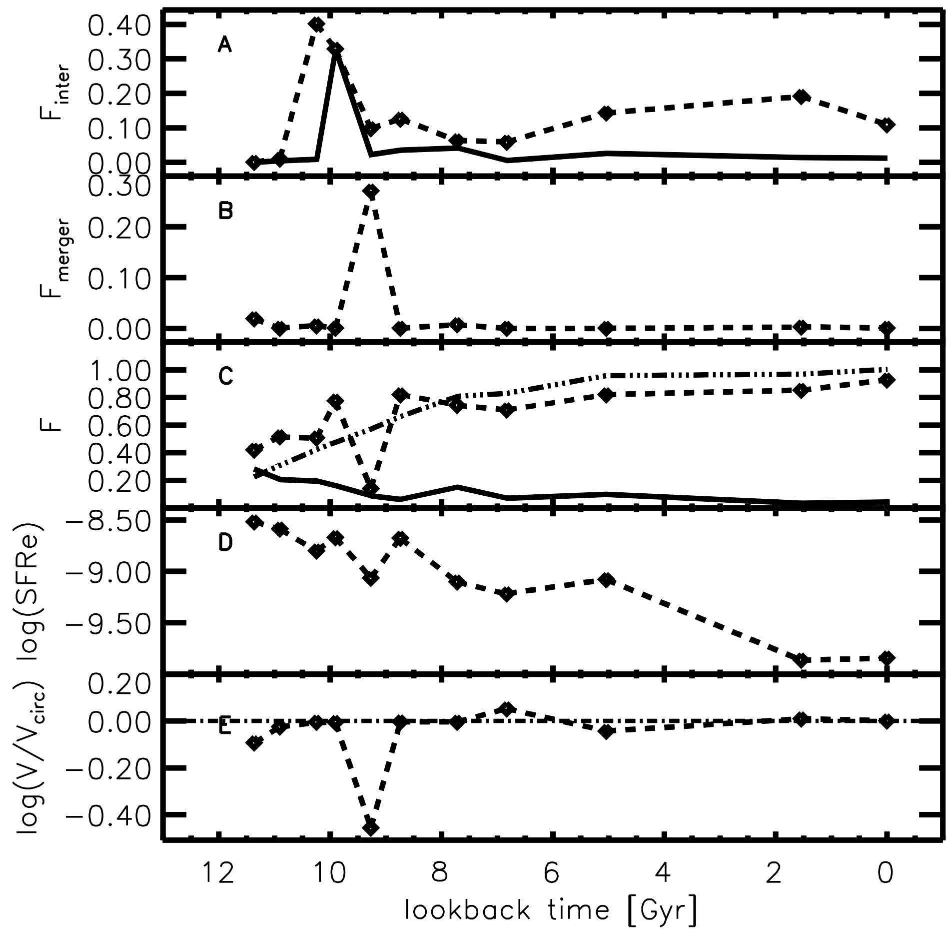
Simultaneously with interactions and mergers, the gas fraction increases and D/T decreases, indicating the presence of gas inflows which contribute more importantly to the formation of an spheroid component.



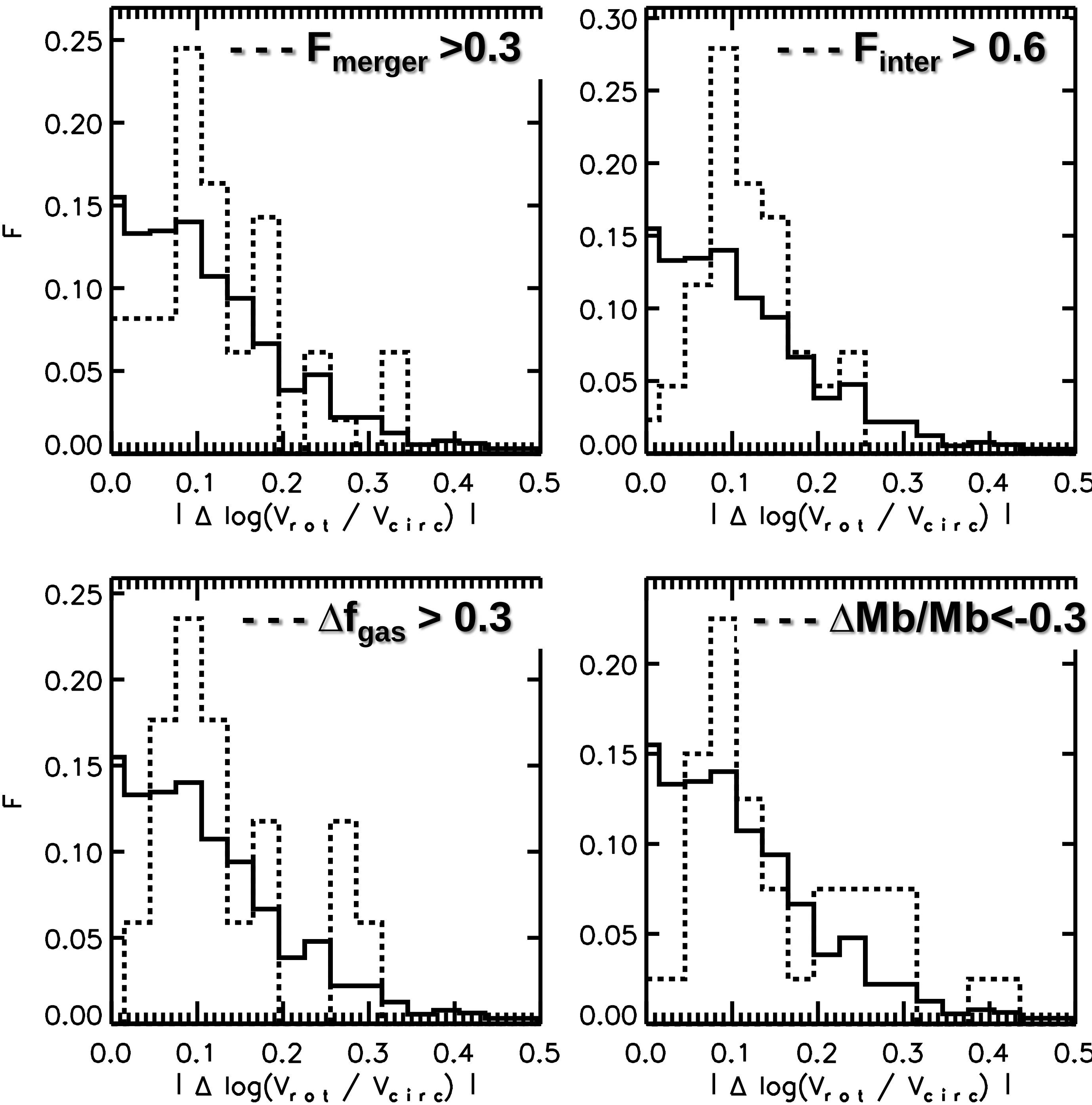
The galaxy reaches z=0 as an outlier of the TFR as a consequence of recent interactions and merger events.

~9Gyrs ago, the galaxy experienced important interactions and mergers which could be linked to a decreace in V_{rot}/V_{circ} by ~0.5 dex.
Note that D/T exhibit a minimum at that epoch.





As a consequence of the meger event, the galaxy became a TFR outlier ~9 Gyrs ago.



Galaxies subject to **extreme events** are biased to larger absolute values of ΔVrot/Vcirc, indicating that all these processes tend to generate **TFR outliers**.

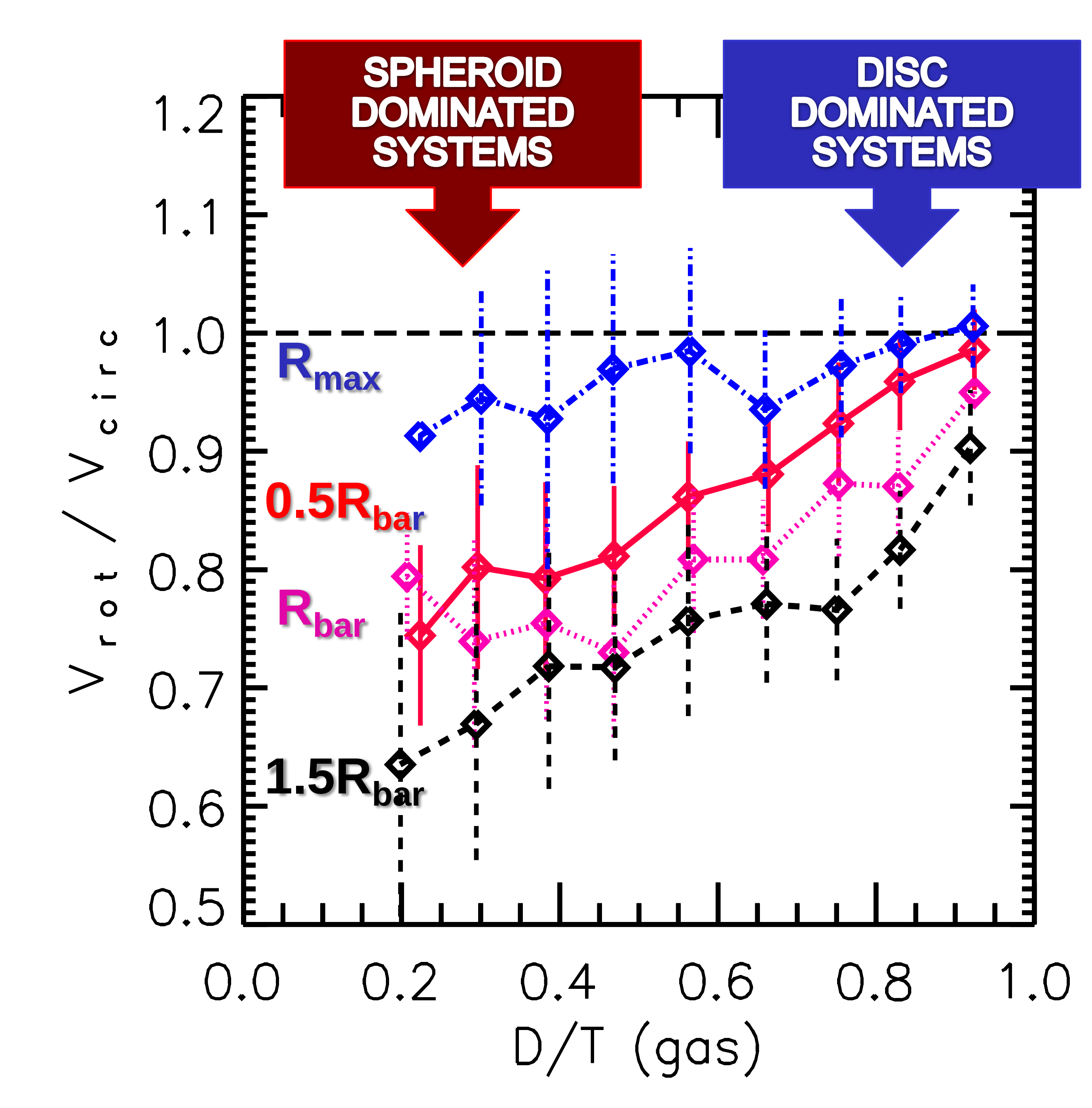
Weak trend for galaxies experiencing important **merger** or **outflows** to have negative variations (61% and 58%, respectively) while **strong interactions** and **gas inflows** can drive either positive or negative **outliers in the TFR-plane**.

Which is the best gas-phase kinematical tracer of V_{circ} in these simulations?

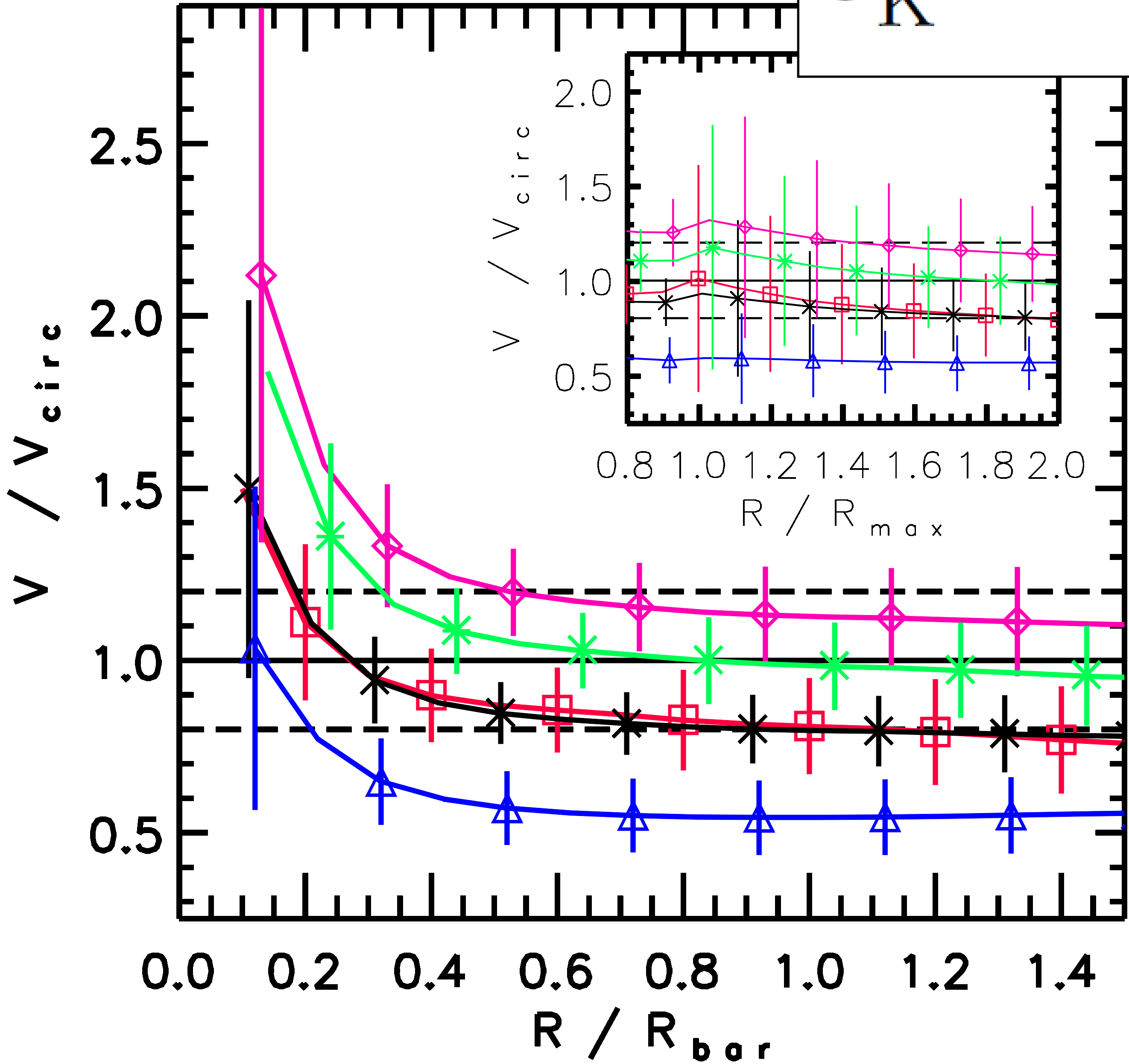
When the disc dominates the gas-phase, V_{rot} can approximate V_{circ} with good accuracy.

As D/T decreases, V_{rot}/V_{circ} becomes smaller, with the most important variations at larger radii.

V_{rot} at R_{max} can approximate V_{circ} with good accuracy for all simulated systems.



$$s_K^2 = KV_{rot}^2 + \sigma^2$$



(Weiner et al. 2006; Kassin et al. 2007; Covington et al. 2010)

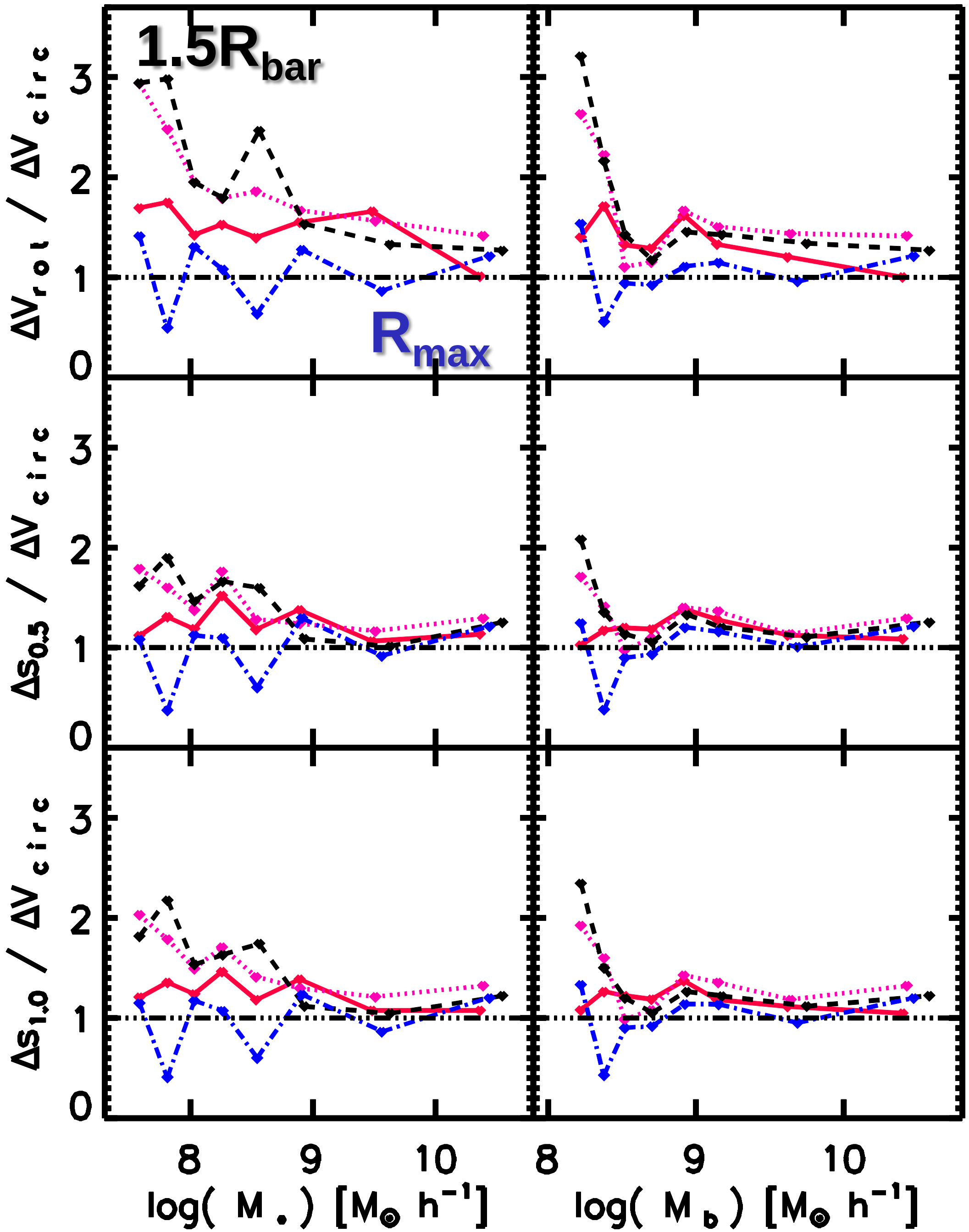
$2^{1/2}s_{0.5}$

$s_{1.0}$

V_{rot}

$s_{0.5}$

σ



By combining V_{rot} and σ in the definition of the kinematical indicator, the scatter in the sTFR and bTFR can be considerably reduced.

All kinematical indicators, including V_{rot}, lead to the tightest relation if evaluated at R_{max}. Note that we have already shown that V_{rot} at R_{max} is also a good proxy for V_{circ}.

$s_{1.0}$ and $s_{0.5}$ reduce the scatter of the sTFR and bTFR by similar amounts, but we consider that $s_{1.0}$ is a best kinematical indicator at larger radii in these simulations as it is also a good proxy for V_{circ}.

CONCLUSIONS I

- ✓ We studied the **TFR** by using **cosmological simulations**.
- ✓ **SN feedback** seems to be crucial to reproduced the observed **bend in the sTFR**.
- ✓ Our model is capable to described the observed behaviour as a consequence of the more efficient action of SN feedback in the **regulation of the SF in smaller galaxies**.
- ✓ Without introducing scale-dependent parameters, the model predicts a **transition velocity at around 100 km/s**, consistent with previous observational and theoretical works.

See De Rossi et al. (2010) for more details about this work.

Contact e-mail: derossi@iafe.uba.ar

Office: OC 322

CONCLUSIONS II

- In agreement with previous works, we found that the gas kinematics of simulated galaxies is significantly regulated by mergers and interactions, which play a key role in inducing gas accretion, outflows and starbursts.
- These events generate a scatter in the TFR larger than the simulated evolution since z=3.
- Kinematical indicators which combine V_{rot} and σ can reduce the scatter of the TFR. The lowest scatter is obtained if the velocity estimators are measured at R_{max}.
- $S_{1.0}=(V_{rot}^2+\sigma^2)^{1/2}$ seems to be the best tracer of V_{circ} at larger radii.
- V_{rot} at R_{max} was found to be the best proxy for the potential well regardless of morphology.

See De Rossi et al. (2012) for more details about this work.

Contact e-mail: derossi@iafe.uba.ar

Office: OC 322