Galaxies in dark matter halos: luminosity-velocity relation, abundance and baryon content

arXiv:1005.1289
arXiv:1002.3660

S. Trujillo-Gomez (NMSU)
in collaboration with:
A. Klypin (NMSU), J. Primack (UCSC)
& A.J. Romanowsky (UCO/Lick Observatory)

Santa Cruz Galaxy Workshop 2010 - August 16, 2010

outline

- introduction
- the luminosity-velocity relation
- the galaxies in our halos
  - the simulation
  - model LV relation
  - baryon content
  - galaxy circular velocity function
- conclusions
- preliminary results

introduction: galaxies in DM halos

introduction: galaxies in DM halos

- *simple questions:*

introduction: galaxies in DM halos

- *simple questions:*
  - what kind of galaxy will populate a given DM halo and which factors are determinant?

introduction: galaxies in DM halos

- *simple questions:*
  - what kind of galaxy will populate a given DM halo and which factors are determinant?
  - can we obtain the *right* galaxies using ΛCDM?

introduction: galaxies in DM halos

- *simple questions:*
  - what kind of galaxy will populate a given DM halo and which factors are determinant?
  - can we obtain the *right* galaxies using ΛCDM?
  - does ΛCDM predict the correct distributions?

introduction: galaxies in DM halos

- *simple questions:*
  - what kind of galaxy will populate a given DM halo and which factors are determinant?
  - can we obtain the *right* galaxies using ΛCDM?
  - does ΛCDM predict the correct distributions?
- *not so simple problems:* we understand physics of DM but baryons are complex to model

introduction: galaxies in DM halos

- *simple questions:*
  - what kind of galaxy will populate a given DM halo and which factors are determinant?
  - can we obtain the *right* galaxies using ΛCDM?
  - does ΛCDM predict the correct distributions?
- *not so simple problems:* we understand physics of DM but baryons are complex to model
  - gasphysics, star formation, feedback, radiation, stripping, interactions, hierarchical formation, etc.

introduction: galaxies in DM halos

- *simple questions:*
  - what kind of galaxy will populate a given DM halo and which factors are determinant?
  - can we obtain the *right* galaxies using ΛCDM?
  - does ΛCDM predict the correct distributions?
- *not so simple problems:* we understand physics of DM but baryons are complex to model
  - gasphysics, star formation, feedback, radiation, stripping, interactions, hierarchical formation, etc.
  - difficult for models to account for luminosity, mass, velocity distributions, clustering, etc.

introduction: galaxies in DM halos

- 3 main approaches:
  1. full N-body+hydro cosmological simulations
     - basic physics included
     - resolution good enough to produce *some* realistic galaxies (e.g. Governato et al. 2010, Agertz et al. 2010)
     - test scaling laws
     - feedback, subgrid processes not understood
     - still far from producing large samples to test distributions

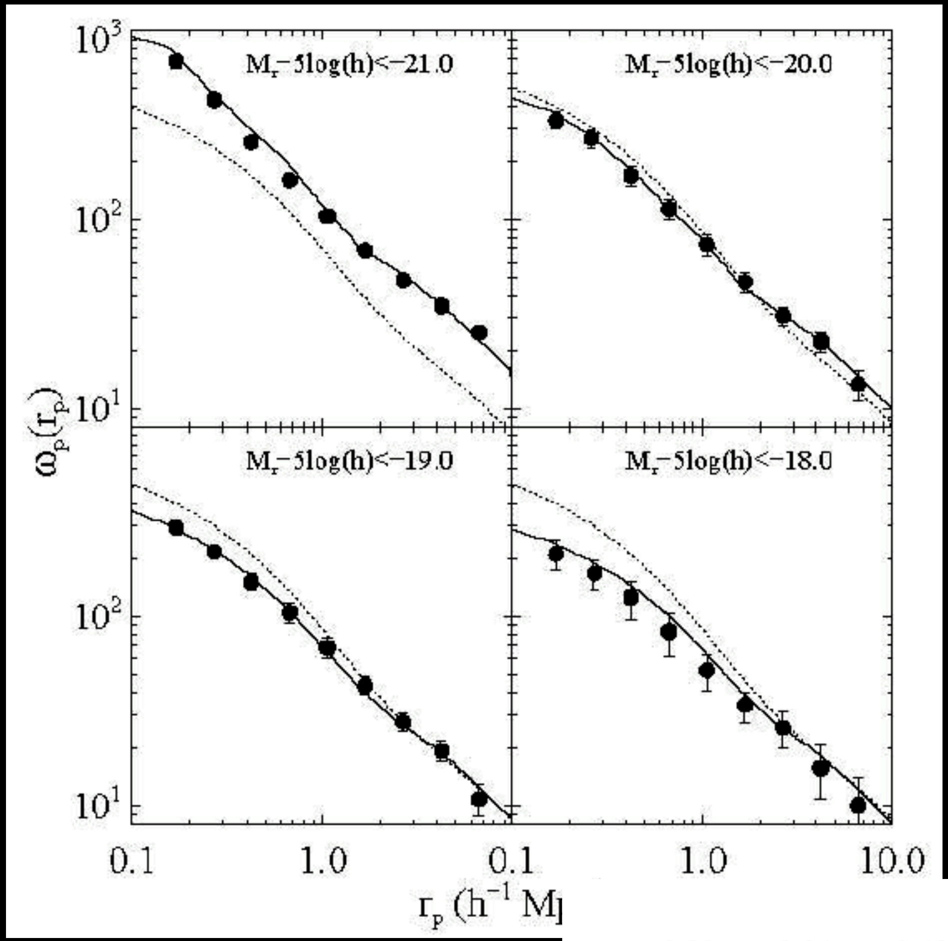
introduction: galaxies in DM halos

2. semi-analytics (SAMs)

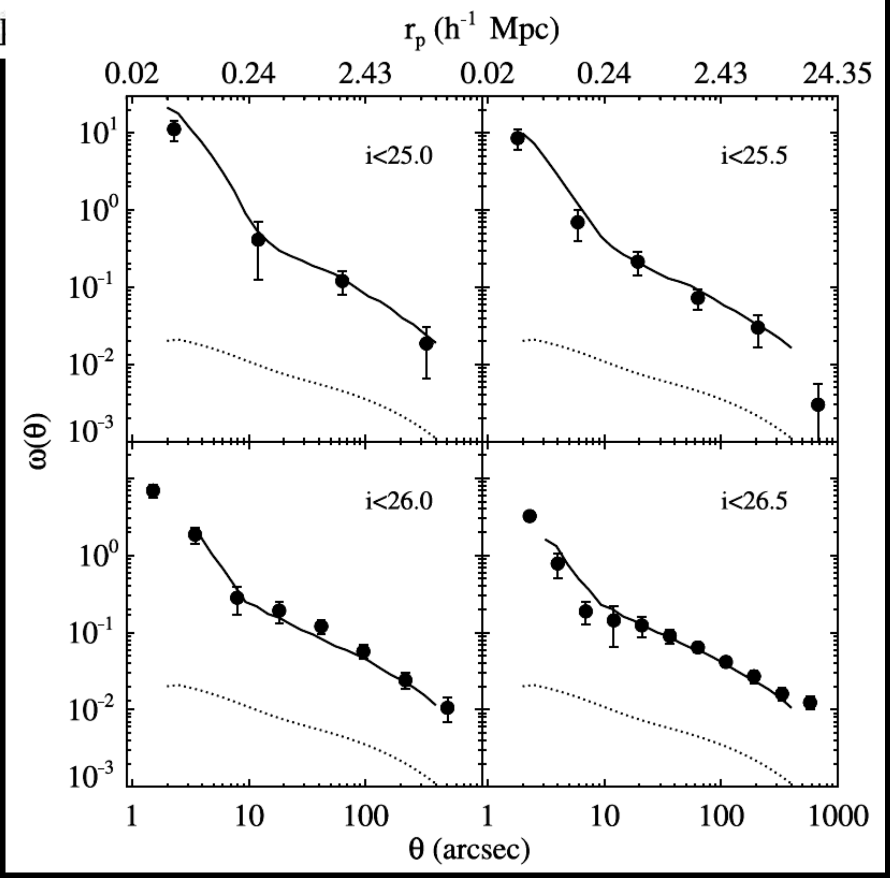
- halo model or cosmological DM-only simulations
- simplifying assumptions about key processes (cooling, SF, feedback, dynamical evolution, etc)
- computationally efficient
- *can* produce large statistical samples
- difficult to calibrate - many free parameters not well constrained by observations
- still difficult to reconcile with observations

introduction: galaxies in DM halos

3. abundance matching (Kravtsov et al. 2004, Conroy et al. 2006)
    - assume basic baryon distributions: LF, SMF
    - one-to-one monotonic relation between dynamical and baryon mass
    - recovers galaxy correlation function over luminosity and redshift !



Conroy et al. 2006



Conroy et al. 2006

introduction: galaxies in DM halos

- tests/diagnostics:
  - statistics: LF, stellar MF, galaxy velocity function
  - scaling relations: Tully-Fisher, Faber-Jackson, baryonic TF, radius-velocity relation, M_{halo}-M_{star} relation
  - clustering: correlation function, surface density profiles, morphologies, lensing statistics

the luminosity-velocity (LV) relation

- recompiled/reanalyzed the largest/highest quality data sets across galaxy types (~1000 spirals + 52 early types)
- 3 orders of magnitude in luminosity and mass
    - Tully-Fisher relation
    - mass modeling of ellipticals and S0s
- does not assume functional form
- dwarfs to giant ellipticals

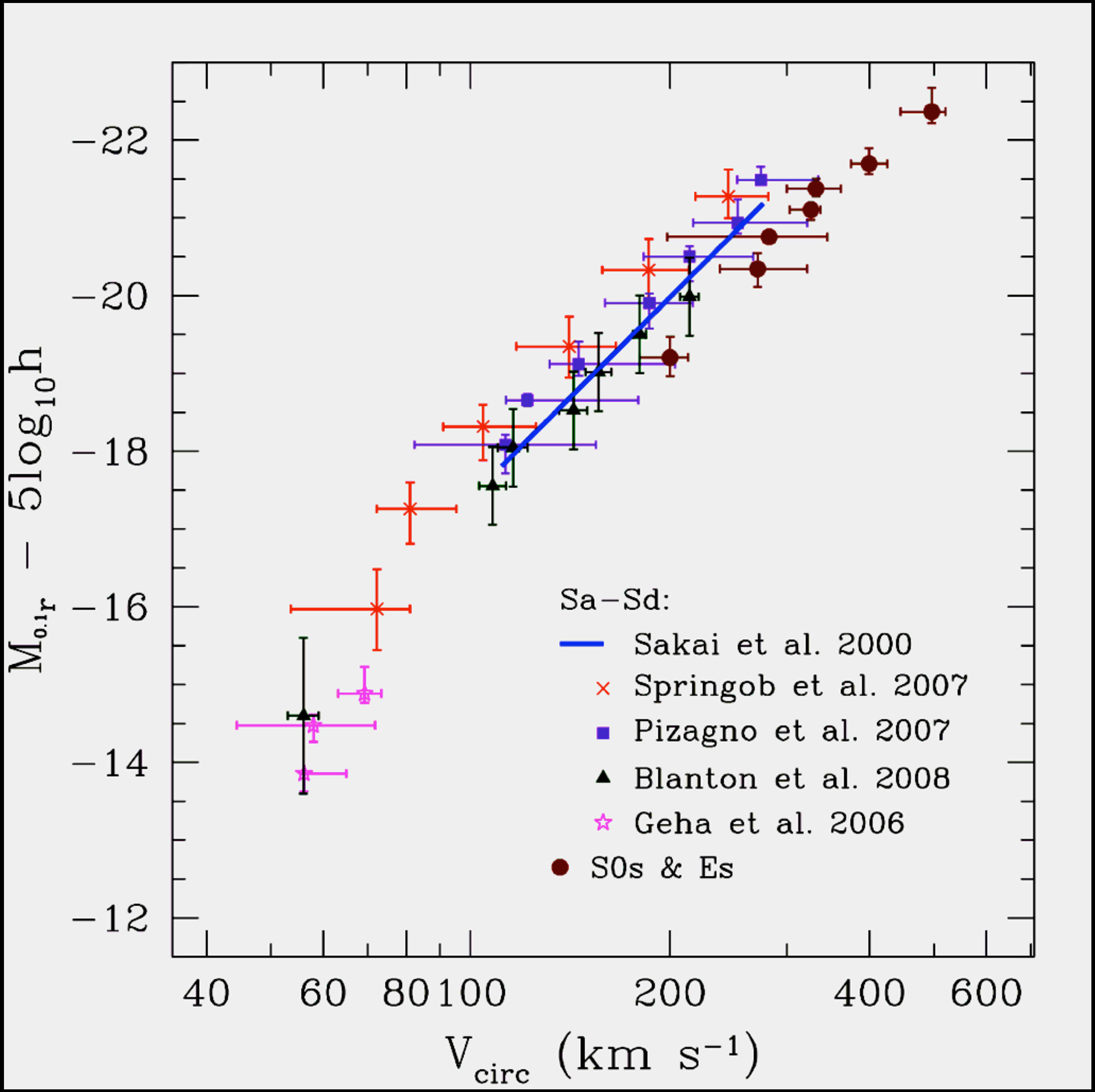
the luminosity-velocity (LV) relation

- recompiled/reanalyzed the largest/highest quality data sets across galaxy types (~1000 spirals + 52 early types)
- 3 orders of magnitude in luminosity and mass
    - Tully-Fisher relation
    - mass modeling of ellipticals and S0s
- does not assume functional form
- dwarfs to giant ellipticals

- r-band photometry avoids dust, recent SF
- uses a general metric: V_{10}
    - circular (not rotation) velocity at 10kpc
    - probe of dynamical mass
    - avoids complex baryon dynamics in central region (no $V_{2.2}$)
    - robust probe of flat regime of observed rotation curves

the luminosity-velocity (LV) relation

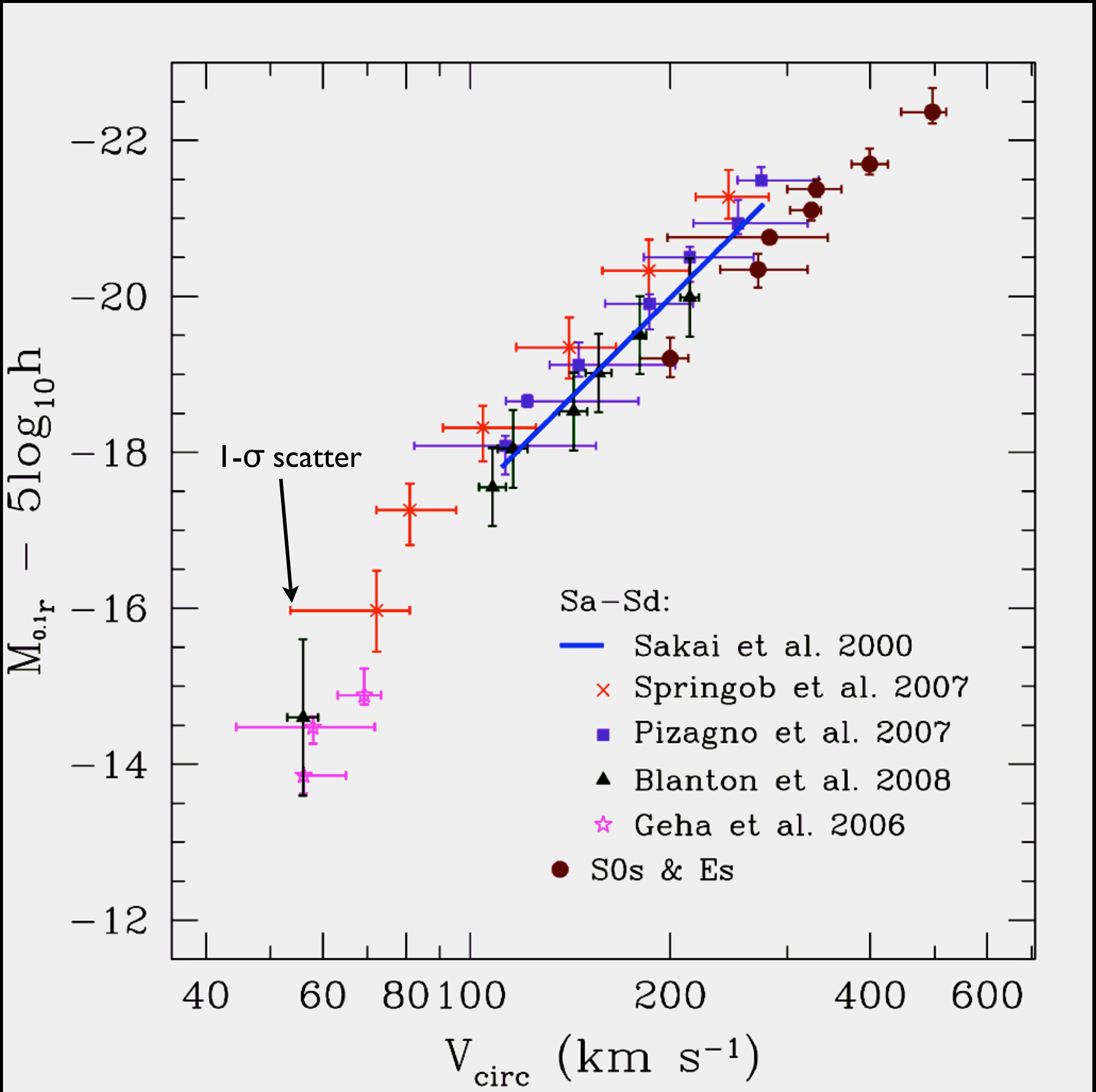
- not a power-law: dwarfs are underluminous
- shows morphological dependence
    - stellar evolution or baryon assembly?



Trujillo-Gomez et al. 2010

the luminosity-velocity (LV) relation

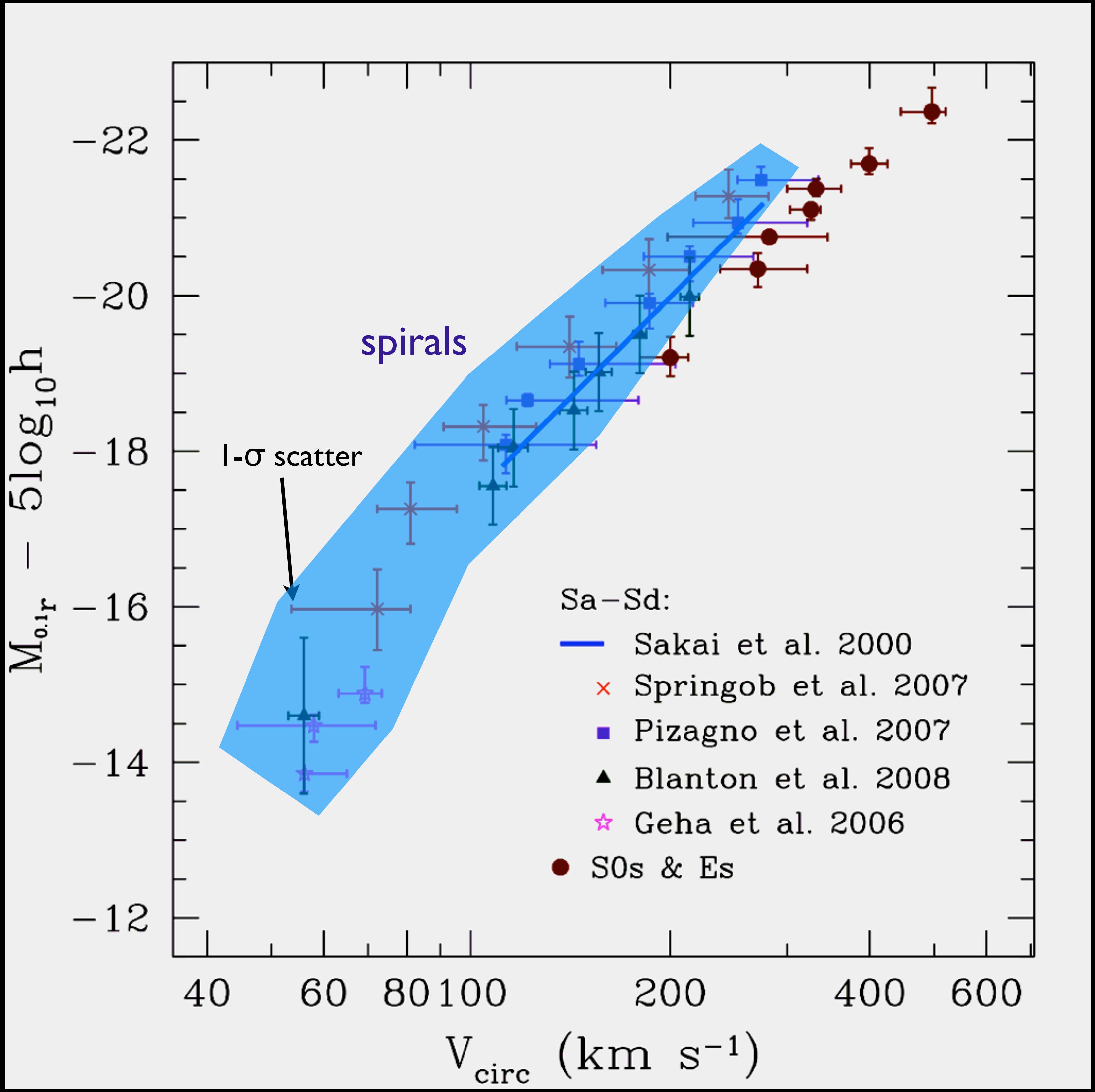
- not a power-law: dwarfs are underluminous
- shows morphological dependence
  - stellar evolution or baryon assembly?



Trujillo-Gomez et al. 2010

the luminosity-velocity (LV) relation

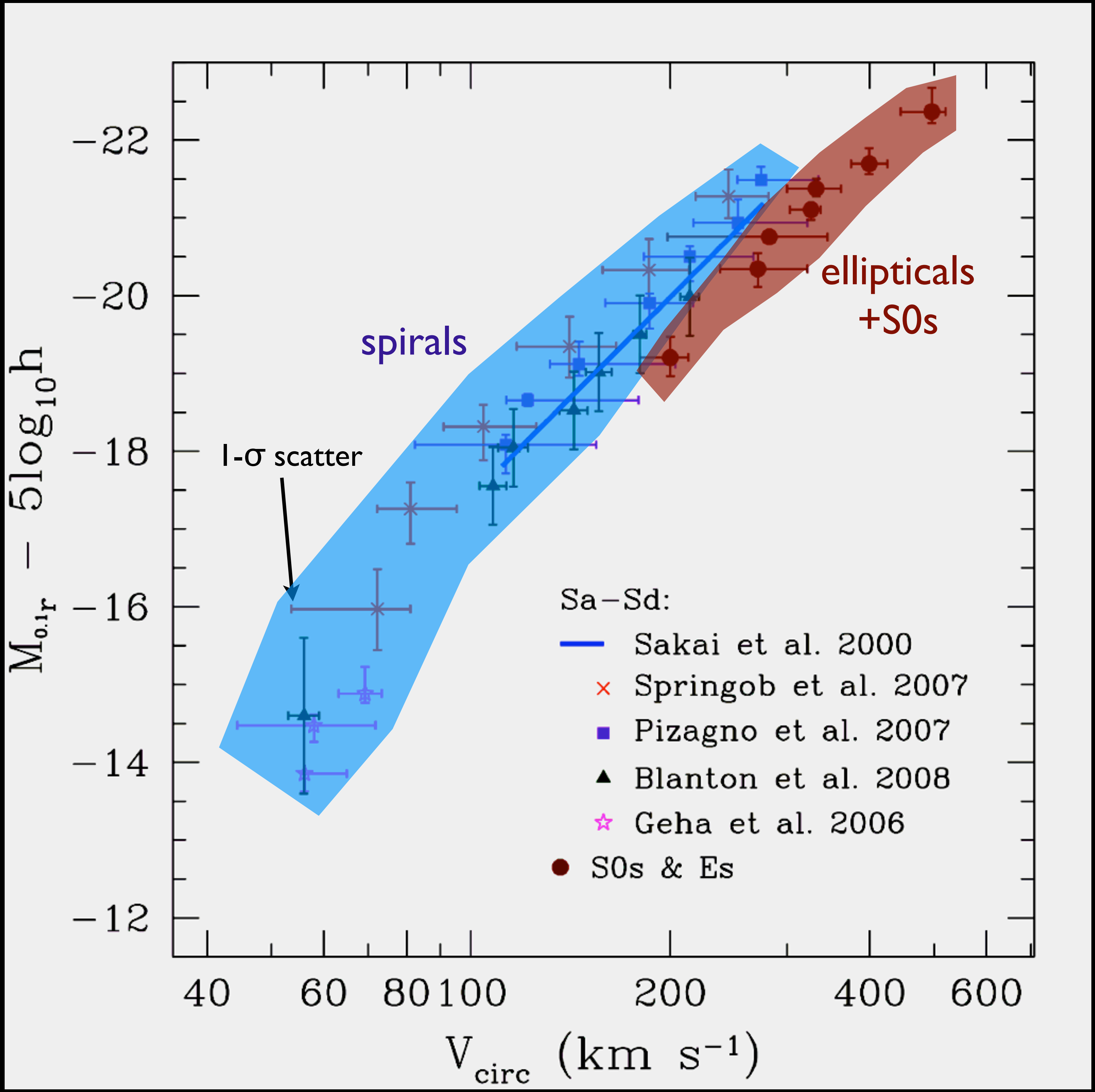
- not a power-law: dwarfs are underluminous
- shows morphological dependence
  - stellar evolution or baryon assembly?



Trujillo-Gomez et al. 2010

the luminosity-velocity (LV) relation

- not a power-law: dwarfs are underluminous
- shows morphological dependence
  - stellar evolution or baryon assembly?



Trujillo-Gomez et al. 2010

the galaxies in our halos - the simulation
(arXiv:1002.3660)

- *Adaptive Refinement Tree* code (Kravtsov 1997, 1999)
- $\Omega_m=(1-\Omega_\Lambda)=0.27$, h=0.7, $\sigma_8=0.82$, n=0.95
  - WMAP7, WMAP5+BAO+SNe, others
- 8B particles in $(250\ \mathrm{Mpc/h})^3$ ~ 1.8 times SDSS DR6
- AMR: min. mass=1.35e8 M_{sun}/h, force resolution=1kpc/h
- Bound-Density-Maxima: 9M halos, ~3M complete (>50km/s)
- V_{circ} main property of objects instead of mass
  - inner mass distribution
  - stripping-resistant
  - observable

$$V_{\rm circ} = \sqrt{\frac{GM(<r)}{r}}\Big|_{\rm max}$$

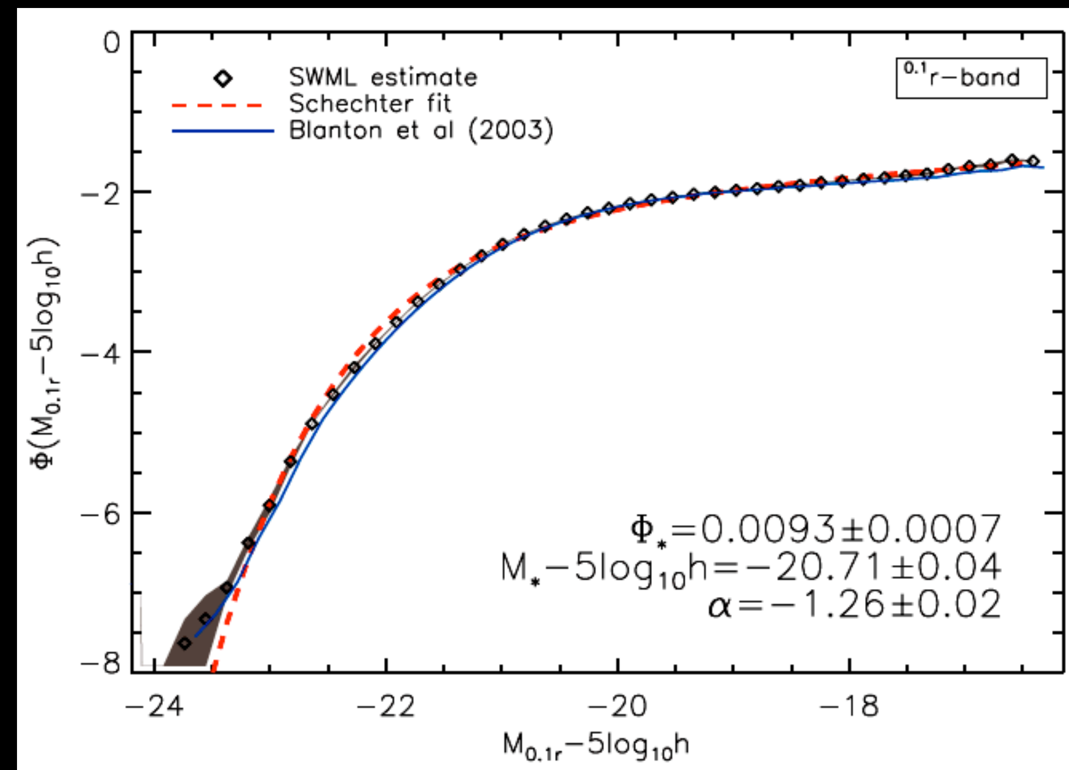
the galaxies in our halos - the model

1. obtain V_{acc} for each halo using merger trees - gives more direct correspondence to M_{star}

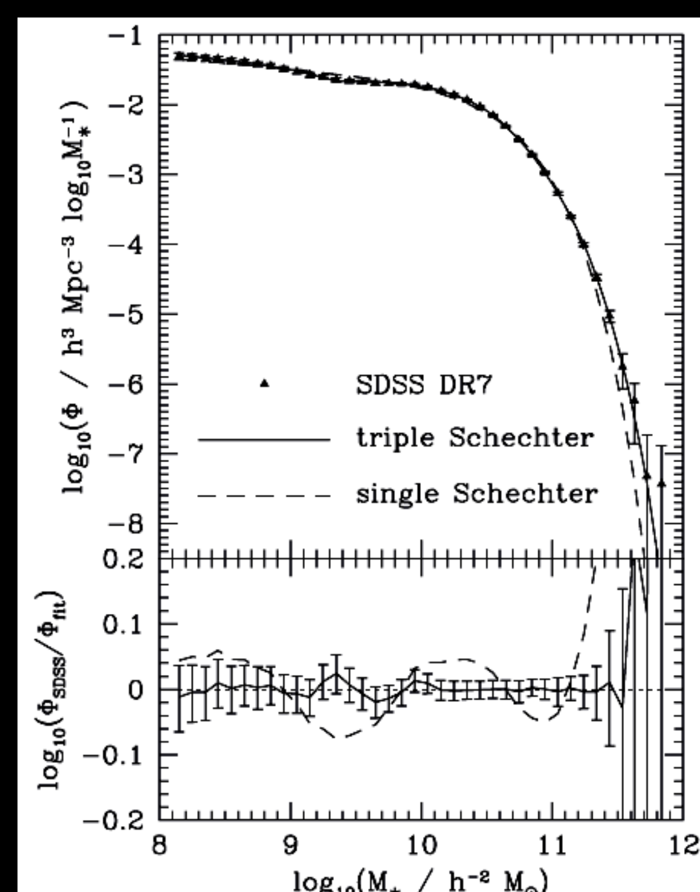
2. abundance matching: rank-order DM halos by V_{acc} and assign luminosities by matching abundance of SDSS DR6 LF: $n(>V_{acc}) = n(>L)$

3. perform AM to assign stellar masses using SDSS DR7 GSMF

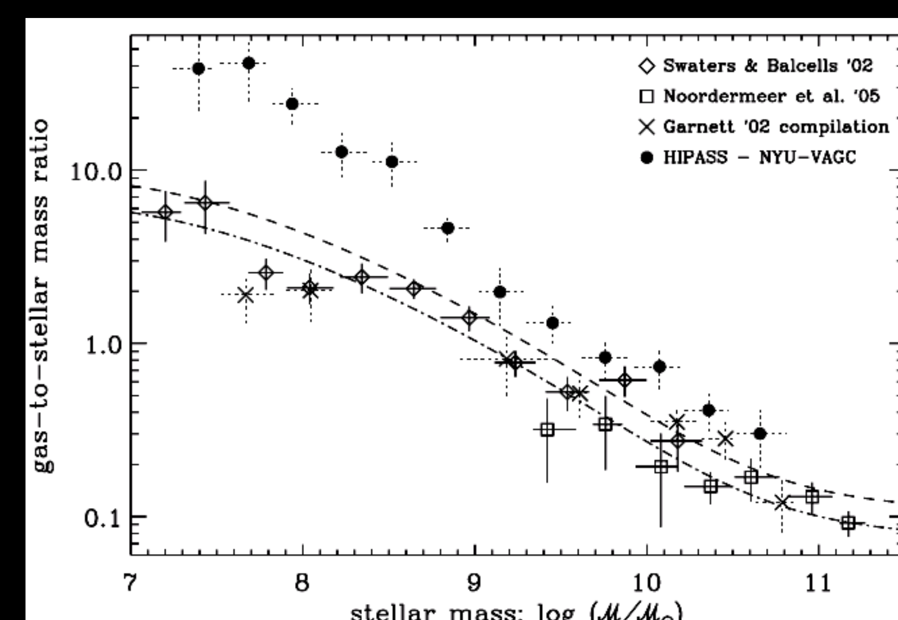
4. add average cold gas mass from observations (Baldry et al. 2008)



Montero-Dorta & Prada 2009

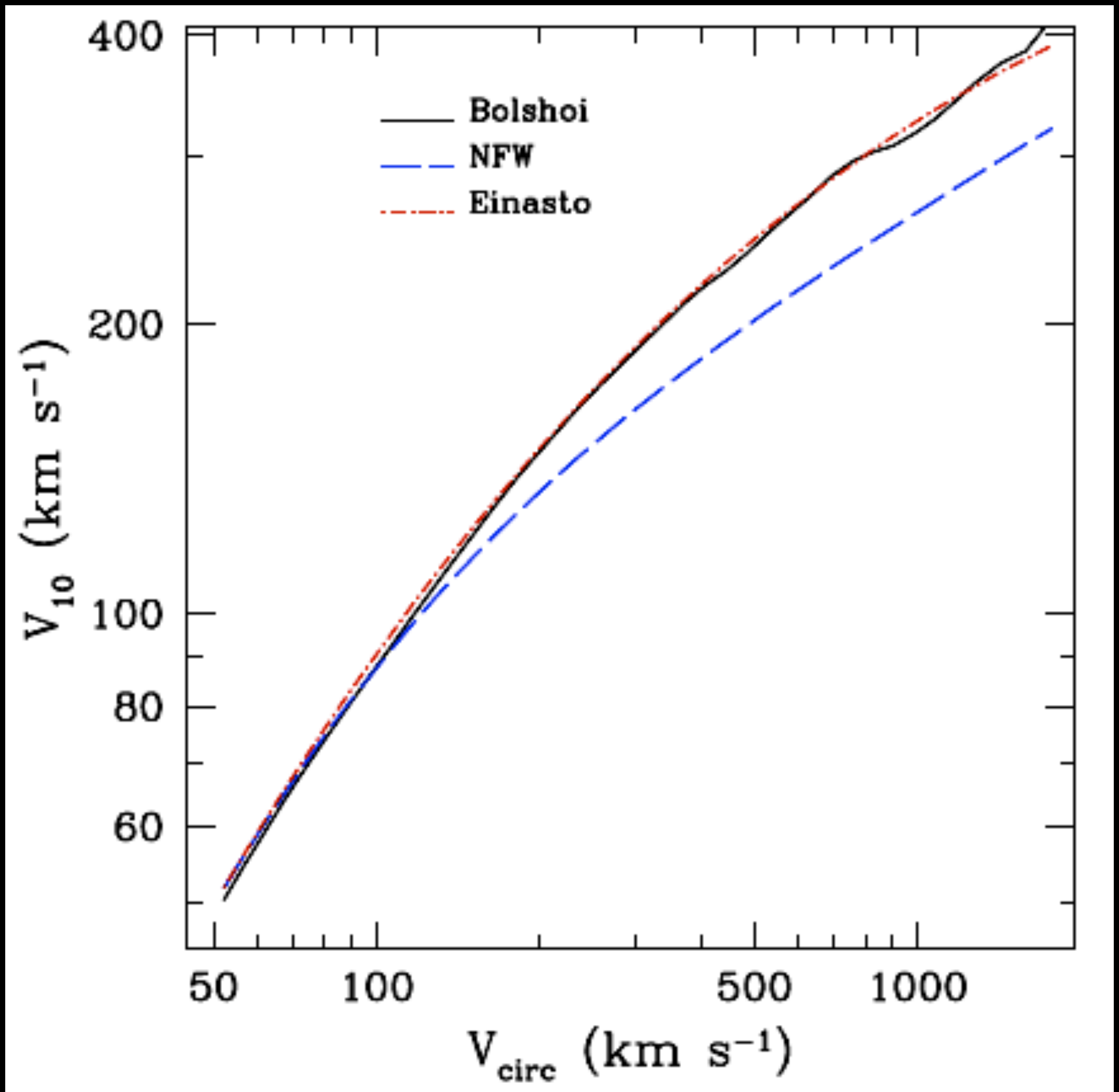


Li & White 2009



Baldry, Glazebrook & Driver 2008

the galaxies in our halos

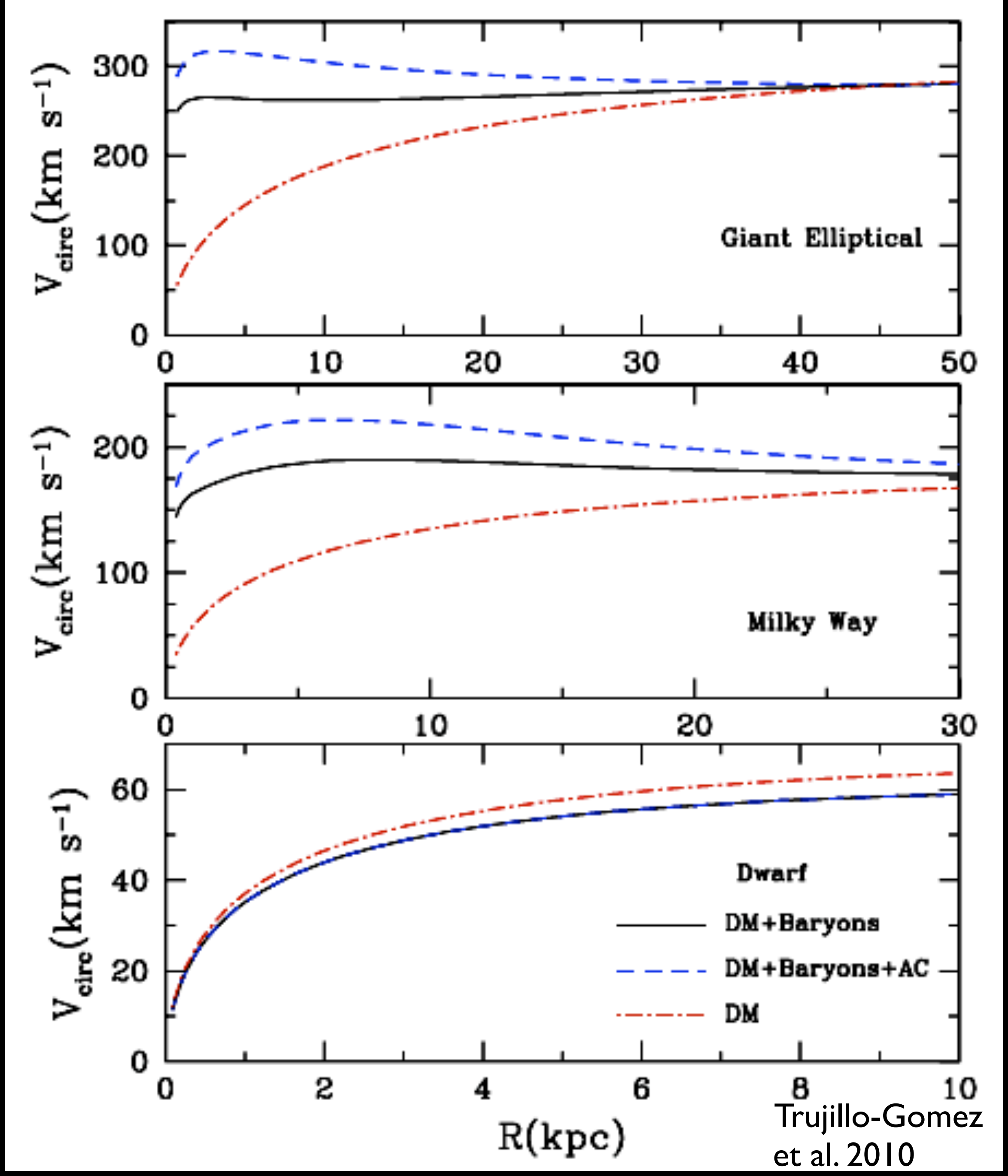


Trujillo-Gomez et al. 2010

5. using halo density profiles calculate V_{10} and add the baryon contribution enclosed within 10kpc

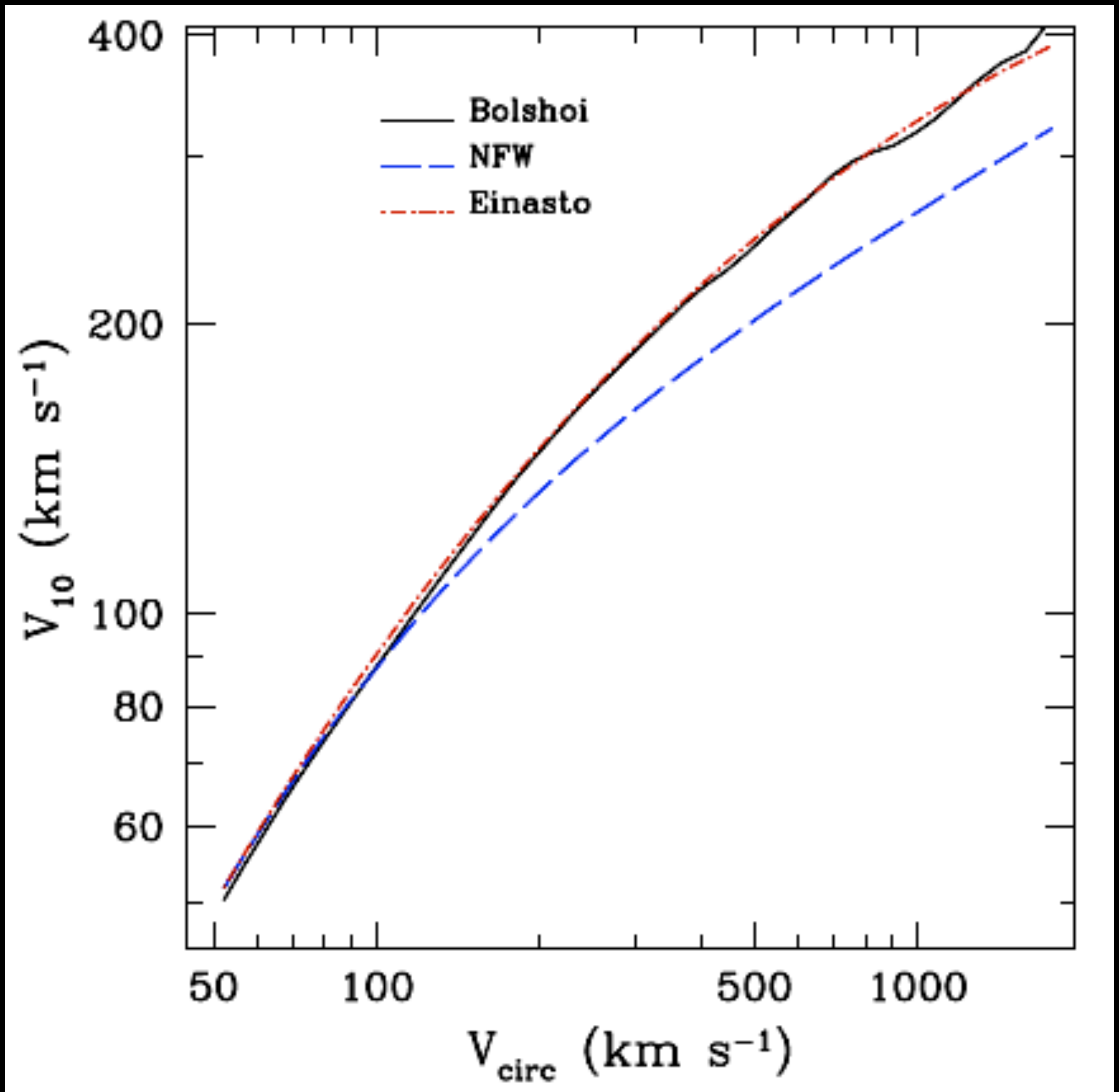
6. add the standard contribution to V_{10} due to adiabatic contraction:

$$M_{\rm tot}(r_{\rm i})r_{\rm i} = [M_{\rm DM}(r_{\rm i})(1 - f_{\rm bar}) + M_{\rm bar}(r_{\rm f})]r_{\rm f}$$



Trujillo-Gomez et al. 2010

the galaxies in our halos

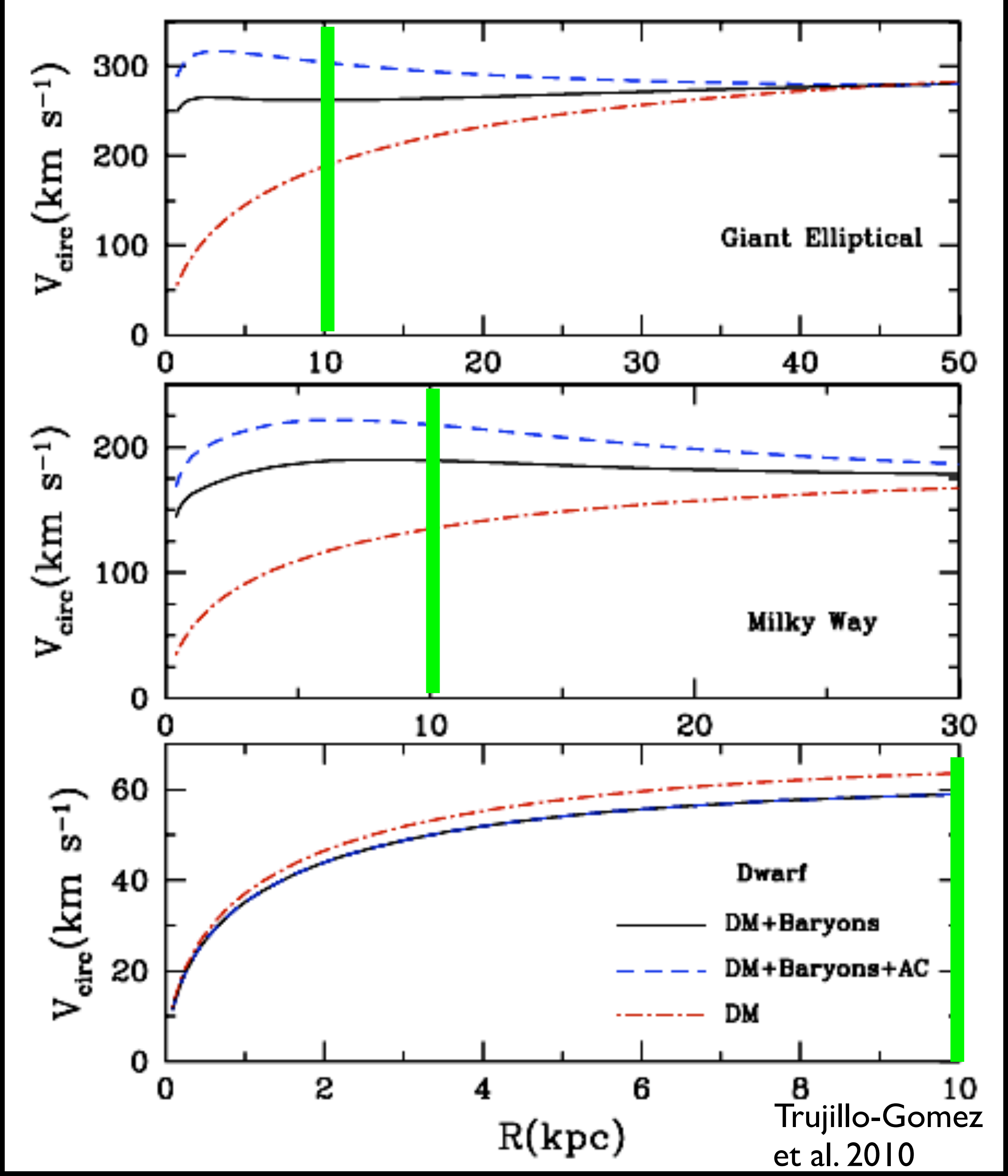


Trujillo-Gomez et al. 2010

5. using halo density profiles calculate V_{10} and add the baryon contribution enclosed within 10kpc

6. add the standard contribution to V_{10} due to adiabatic contraction:

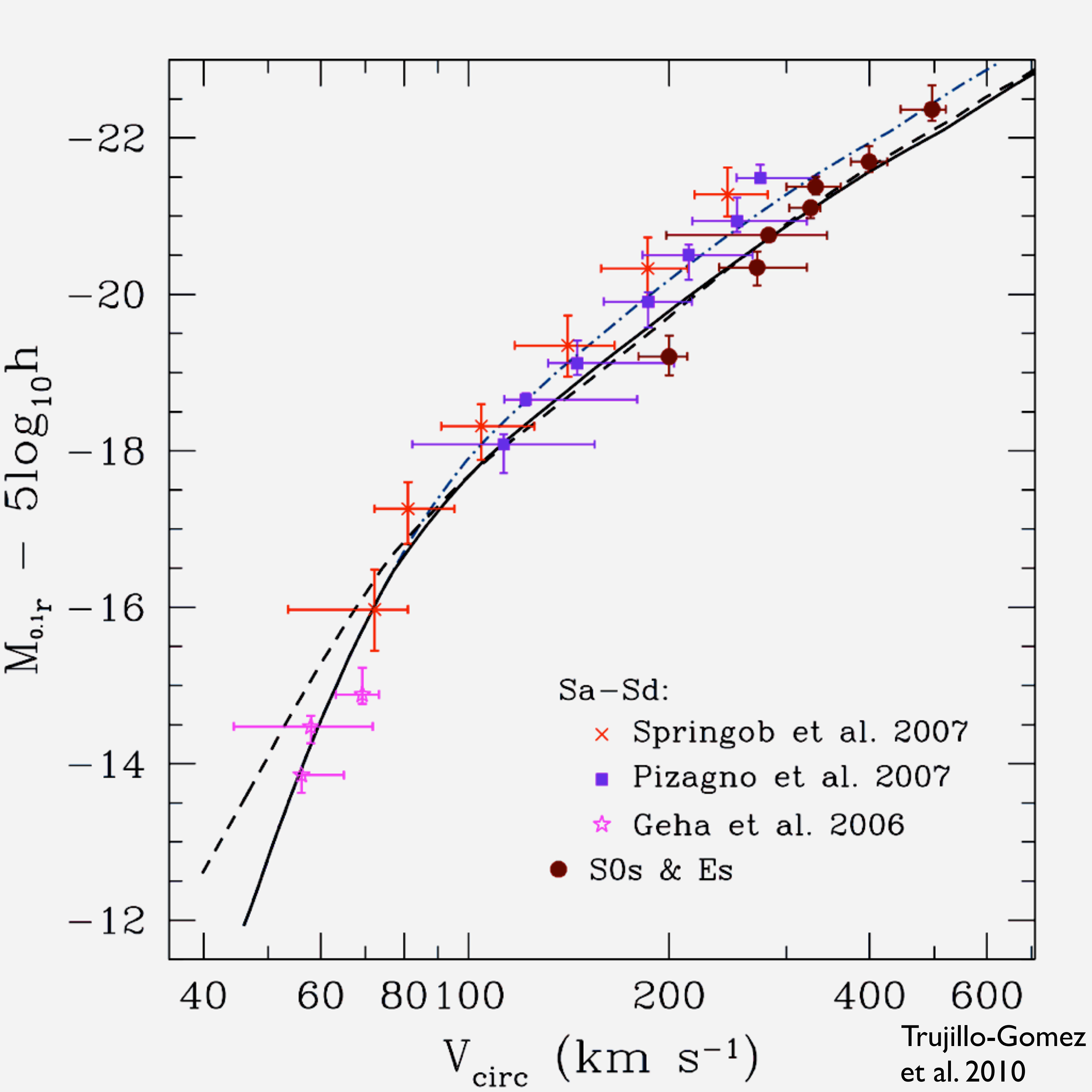
$$M_{\rm tot}(r_{\rm i})r_{\rm i} = [M_{\rm DM}(r_{\rm i})(1 - f_{\rm bar}) + M_{\rm bar}(r_{\rm f})]r_{\rm f}$$



Trujillo-Gomez et al. 2010

model LV relation

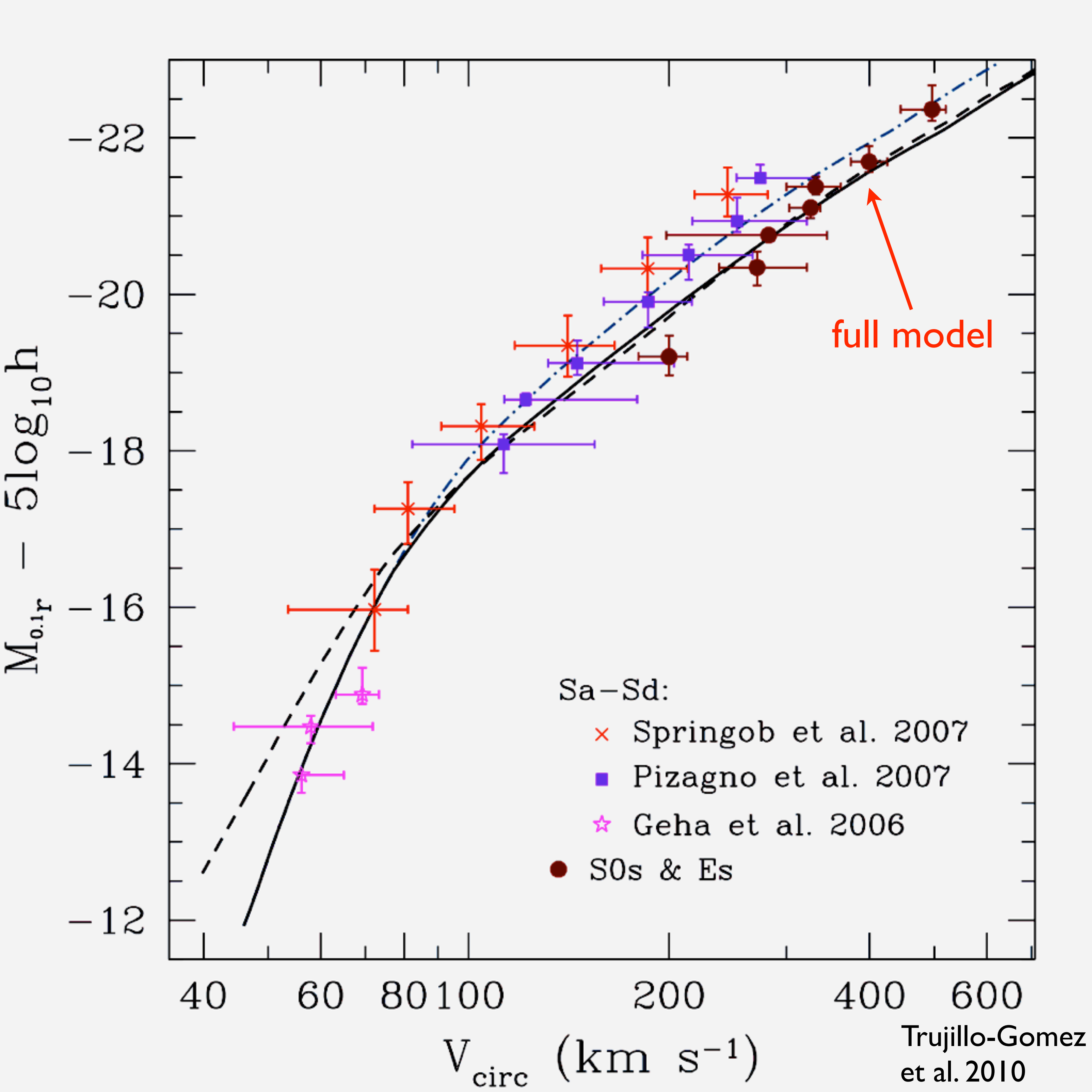
- model matches average populations - better model should include dichotomy
- uncertain faint end but possible to constrain
- max AC effect is small *and* consistent with data
- baryonless dwarfs constrained only by luminosity
- no scatter included - small effect except at bright end



Trujillo-Gomez et al. 2010

model LV relation

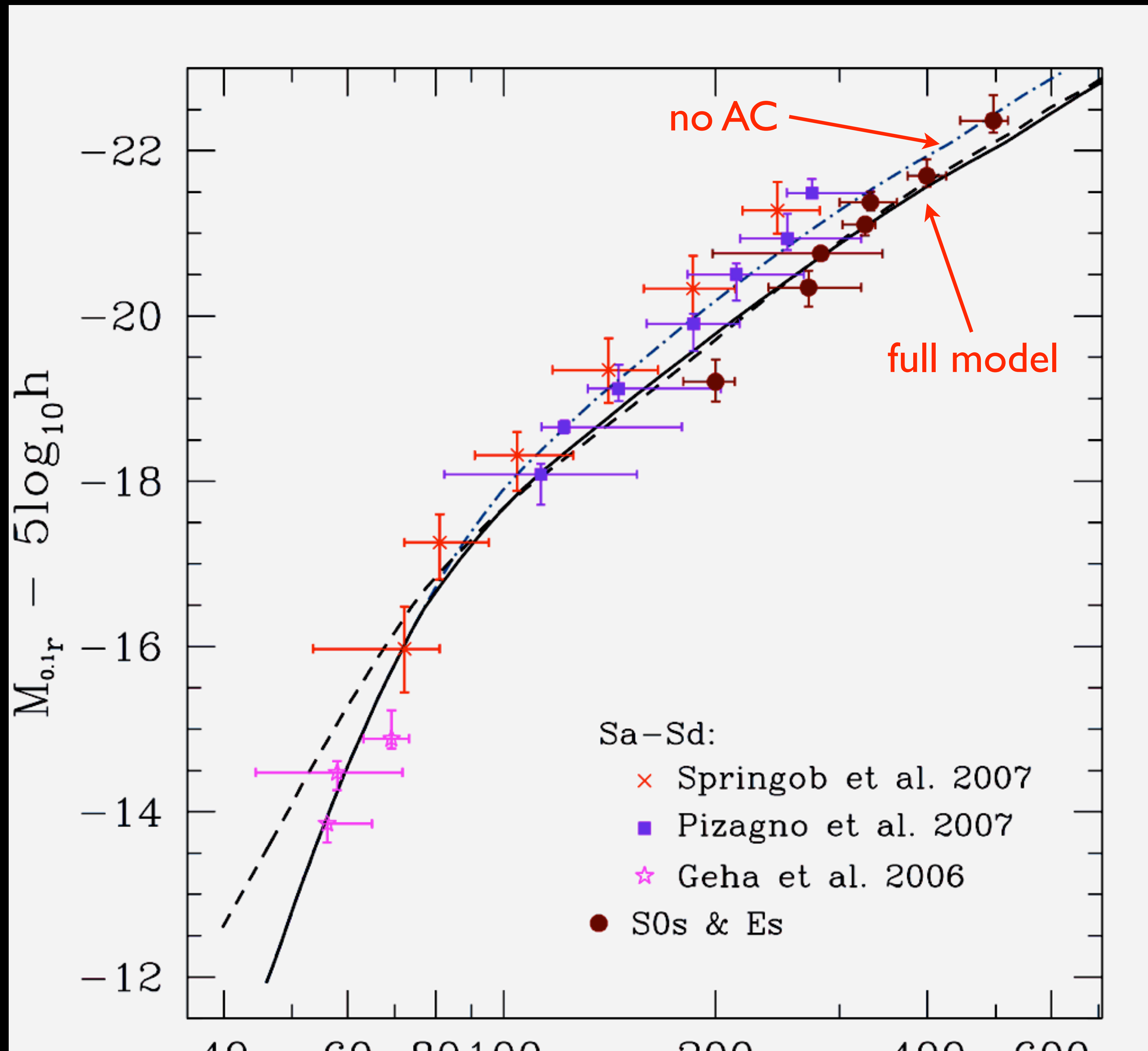
- model matches average populations - better model should include dichotomy
- uncertain faint end but possible to constrain
- max AC effect is small *and* consistent with data
- baryonless dwarfs constrained only by luminosity
- no scatter included - small effect except at bright end



Trujillo-Gomez et al. 2010

model LV relation

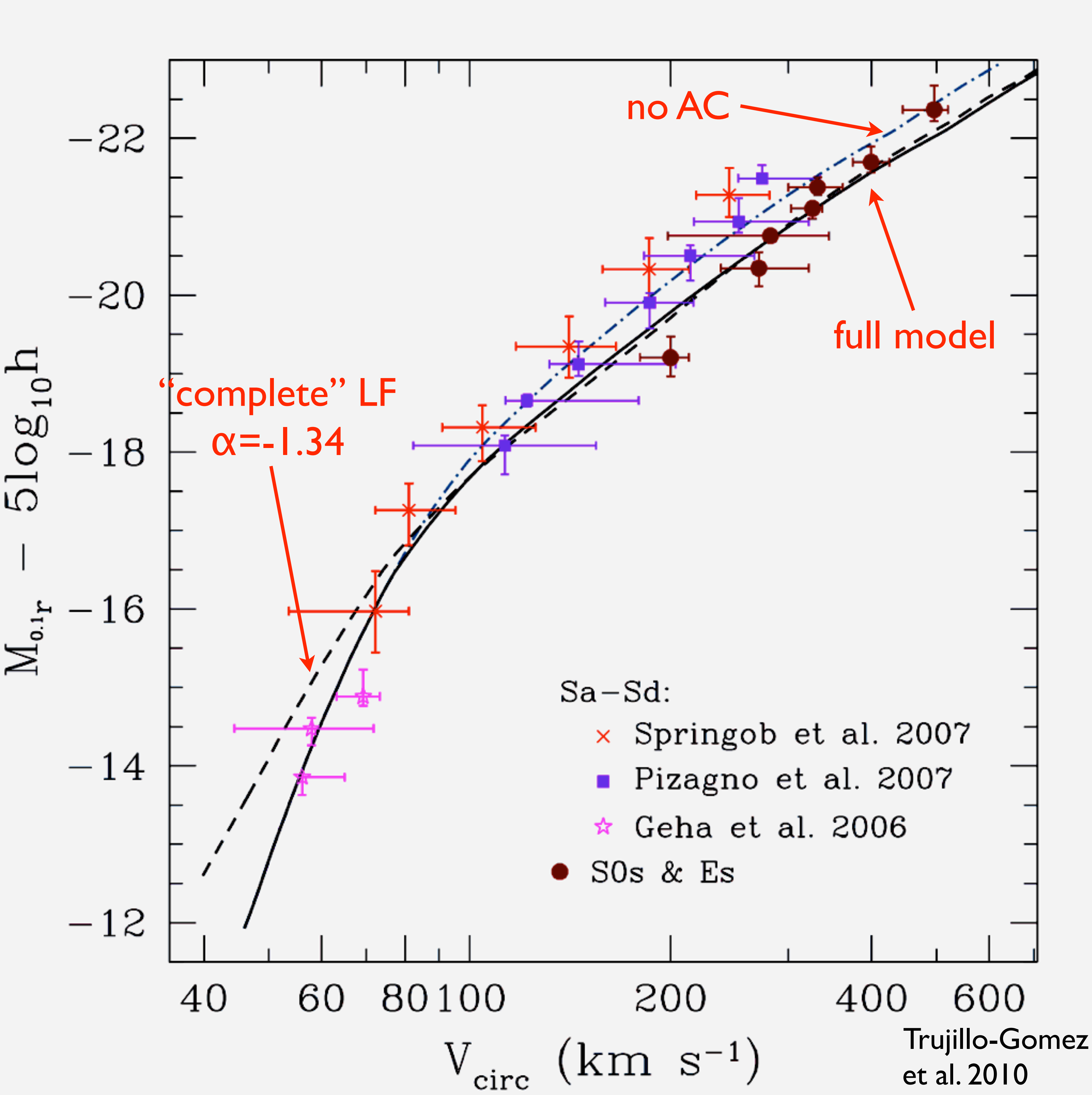
- model matches average populations - better model should include dichotomy
- uncertain faint end but possible to constrain
- max AC effect is small *and* consistent with data
- baryonless dwarfs constrained only by luminosity
- no scatter included - small effect except at bright end



Trujillo-Gomez et al. 2010

model LV relation

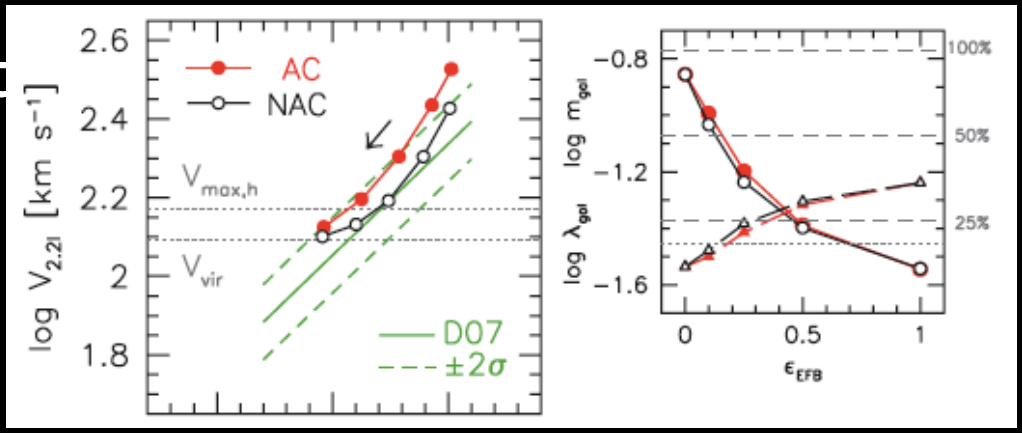
- model matches average populations - better model should include dichotomy
- uncertain faint end but possible to constrain
- max AC effect is small *and* consistent with data
- baryonless dwarfs constrained only by luminosity
- no scatter included - small effect except at bright end



Trujillo-Gomez et al. 2010

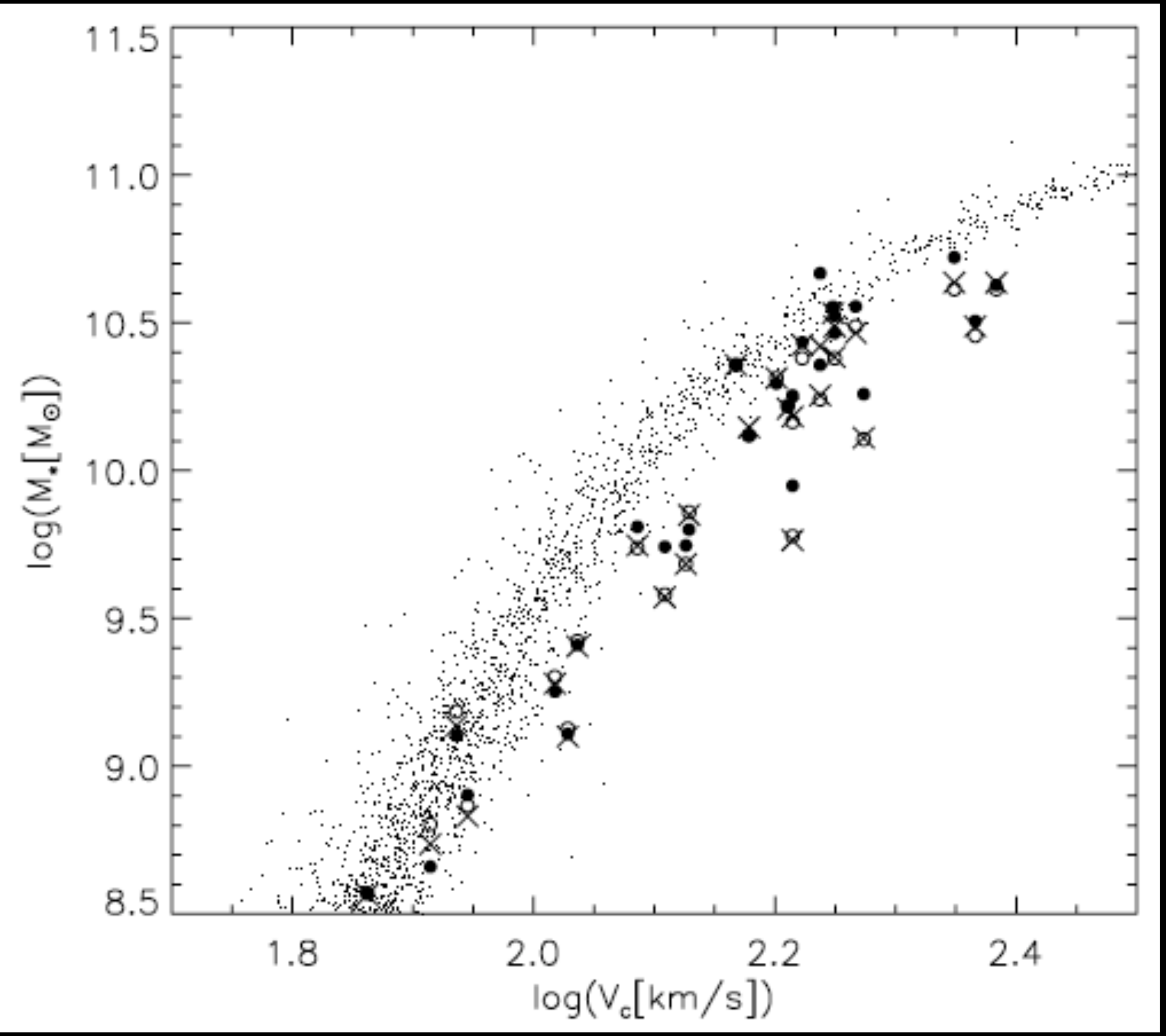
model LV relation - other results

- Dutton et al. 2010 - analytical model of disk formation:
  - no mergers: smooth DM accretion
  - angular momentum distribution of gas same as DM
  - momentum/energy driven feedback (mass eject
  - adiabatic contraction/expansion
  - results inconsistent with this work:
    - galaxy formation efficiency is too high ~35% (using low λ)
    - AC: 2σ offset in zero-point of TF regardless of feedback efficiency (vs. <10% effect in our analysis)
    - no AC: offset at high masses
  - difficult to constrain given assumptions (smooth accretion, no bulges, no gas flows)



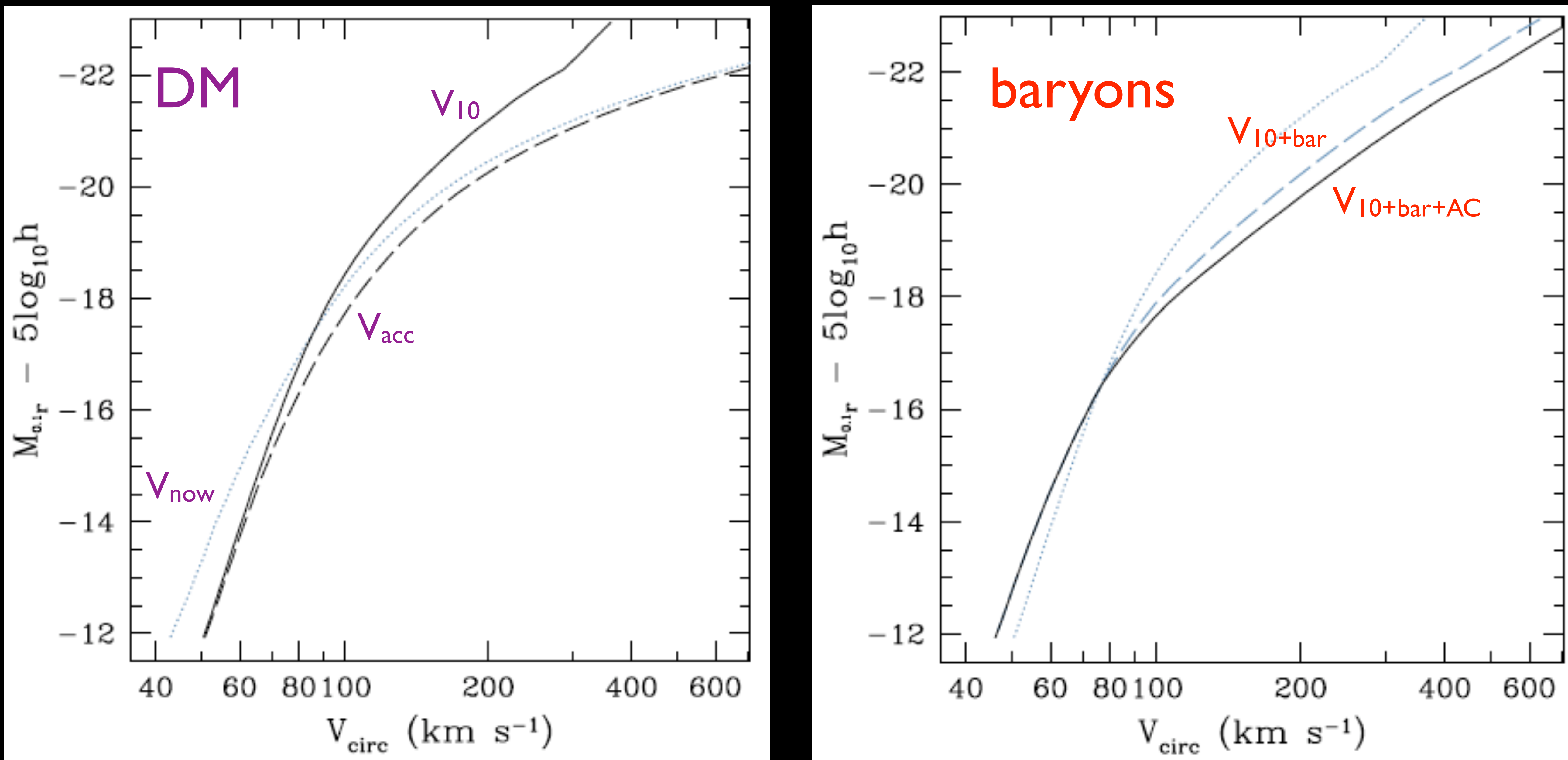
model LV relation - other results

- Guo et al. 2010 - Abundance Matching:
  - performed using halo MF from Millenium I & II (parameters several sigma away from current obs give >30% MW halos)
  - stellar mass TF relation: no corrections made for baryons
  - overall agreement but underpredict v_c by ~25% where spirals dominate

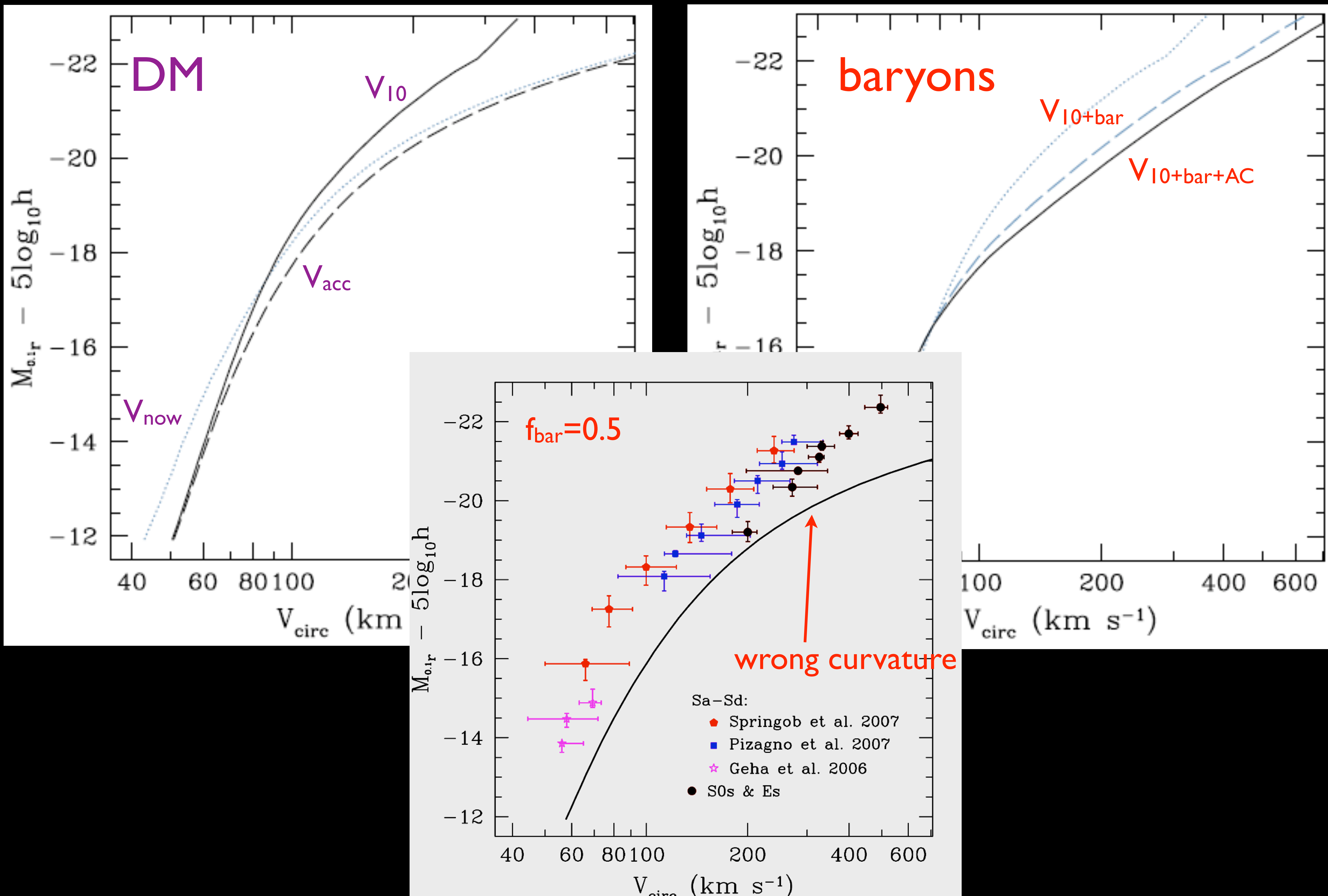


Guo et al. 2010

model LV relation

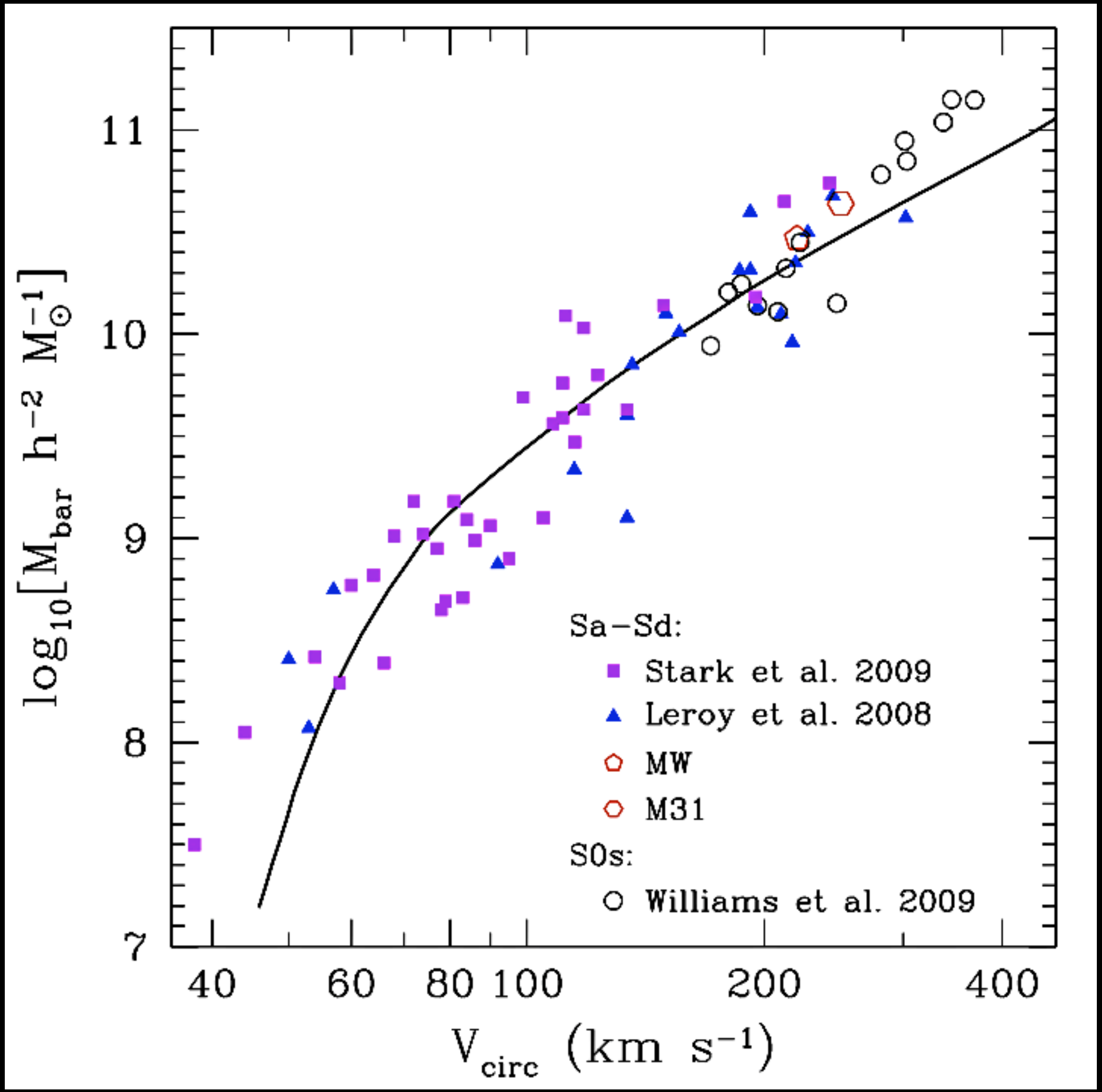


model LV relation



baryon content

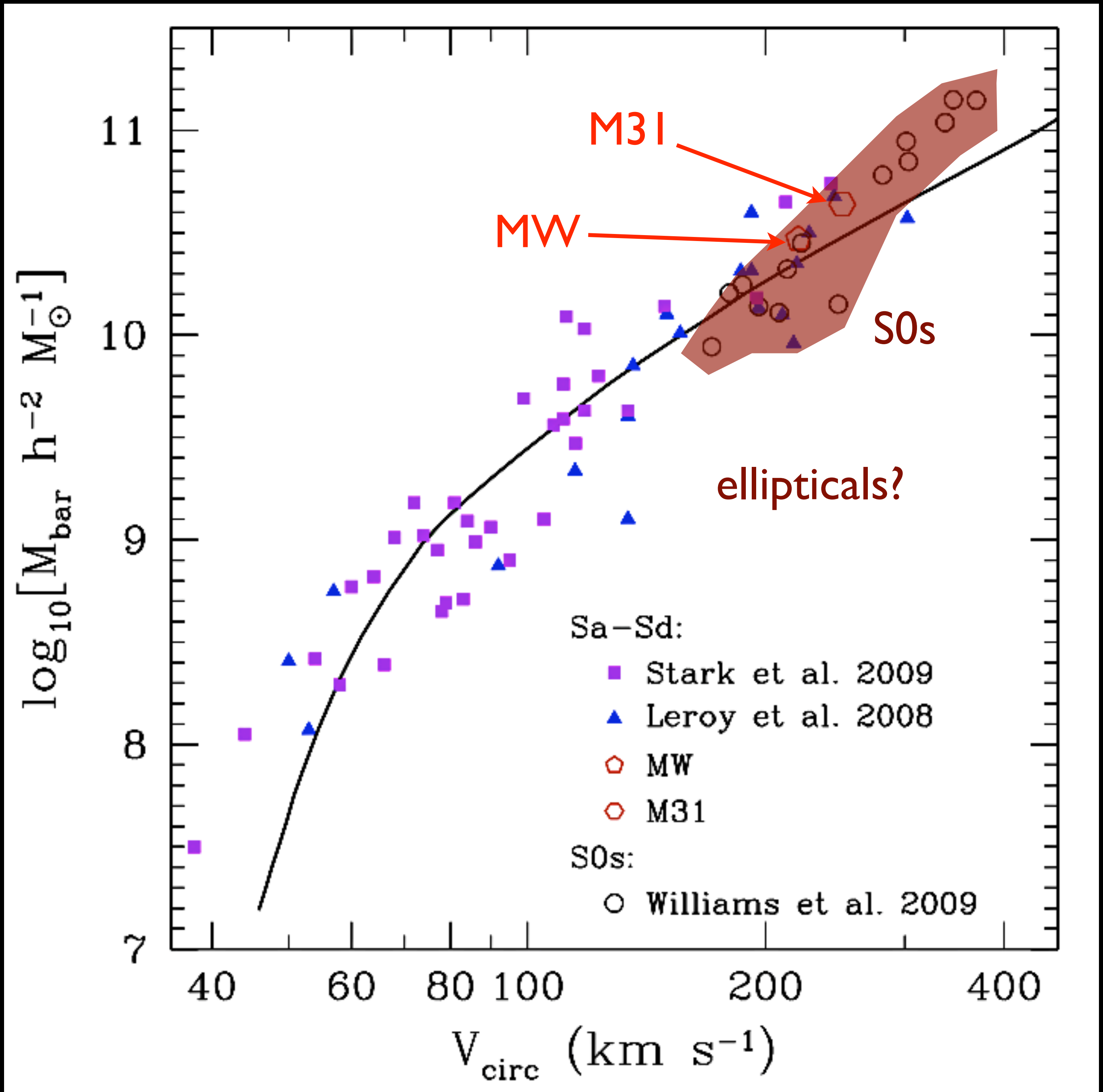
- BTF generalized to all types
- insensitive to SF and stellar pop. evolution
- may unite disks and ellipticals
- choice of IMF = factor of ~2 unless gas dominated



Trujillo-Gomez et al. 2010

baryon content

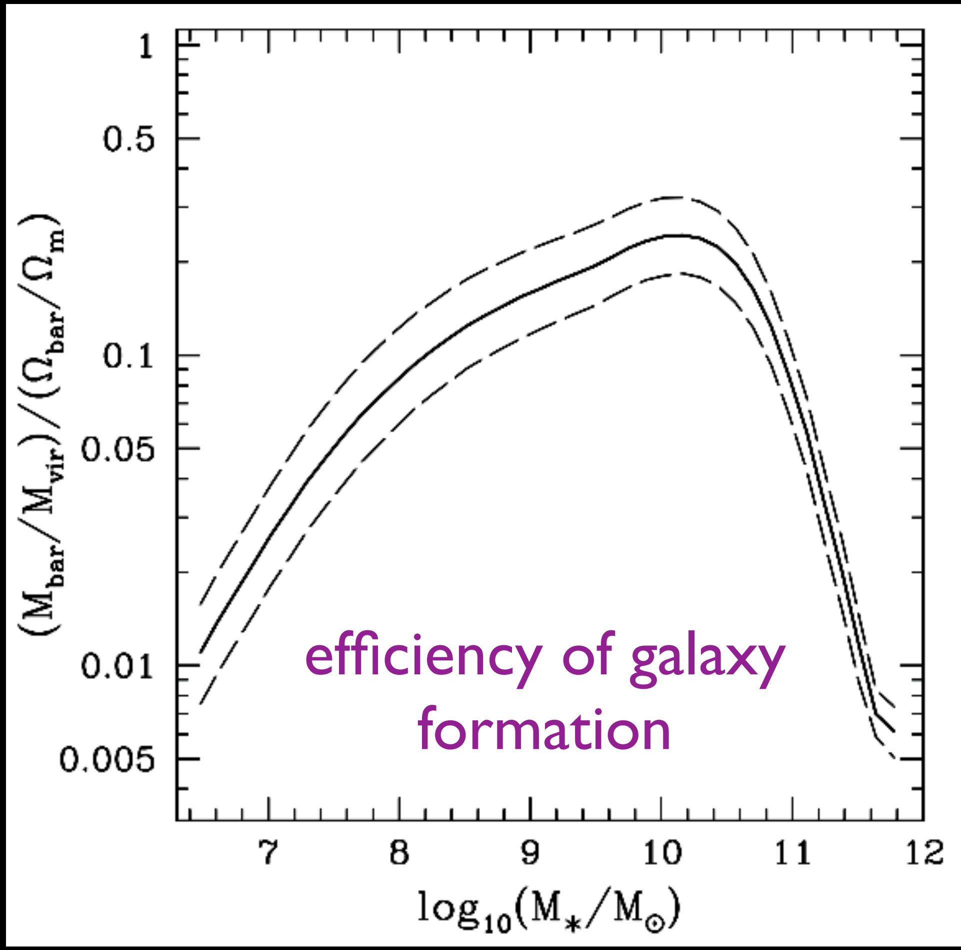
- BTF generalized to all types
- insensitive to SF and stellar pop. evolution
- may unite disks and ellipticals
- choice of IMF = factor of ~2 unless gas dominated

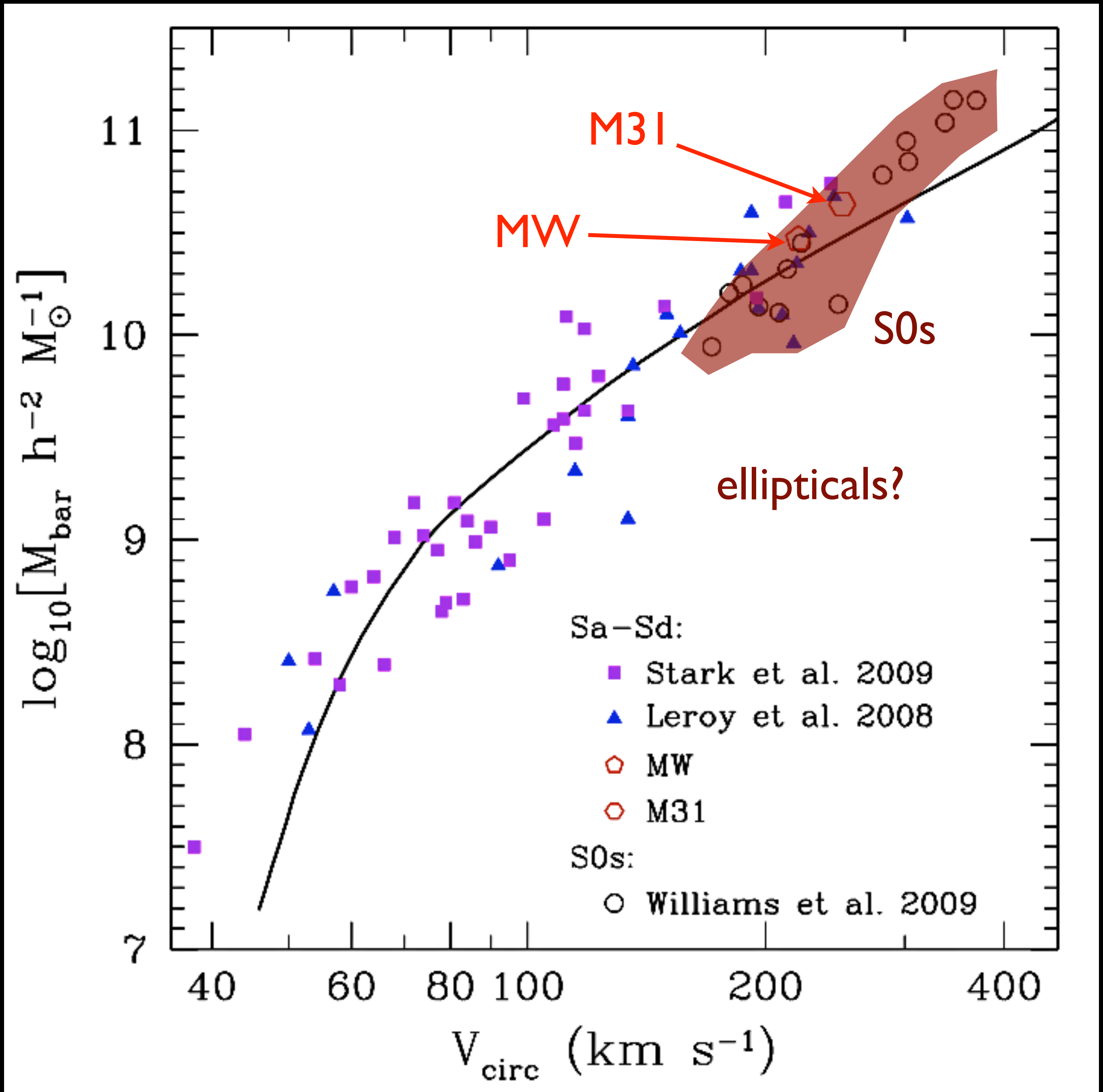


Trujillo-Gomez et al. 2010

baryon content

- BTF generalized to all types
- insensitive to SF and stellar pop. evolution
- may unite disks and ellipticals
- choice of IMF = factor of ~2 unless gas dominated



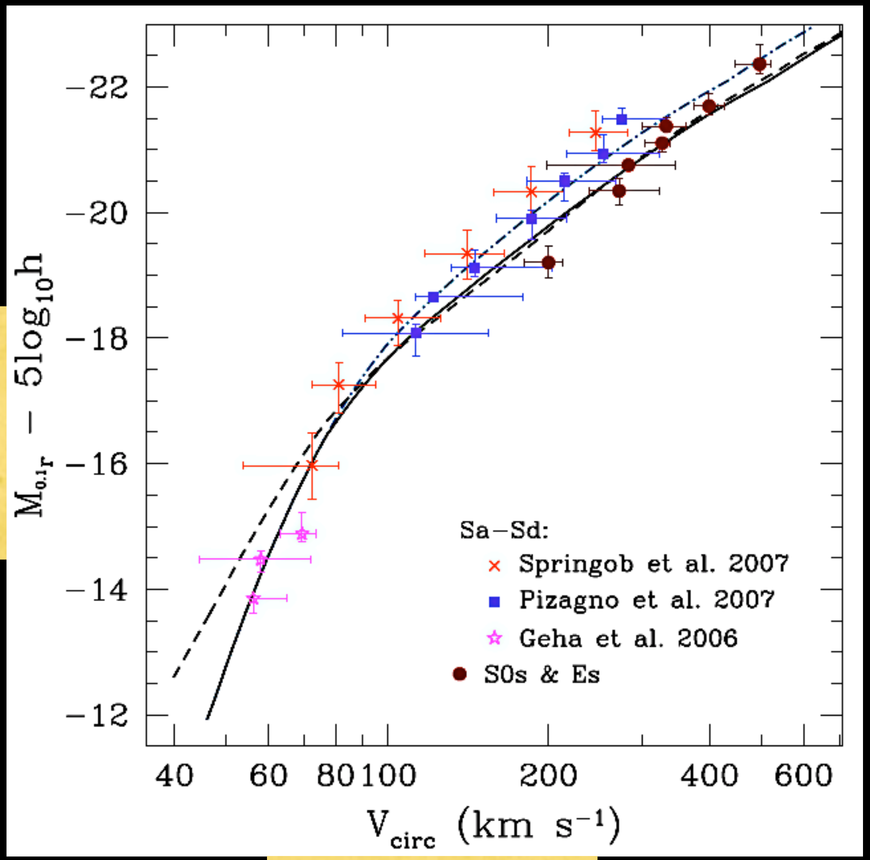


Trujillo-Gomez et al. 2010

galaxy circular velocity function

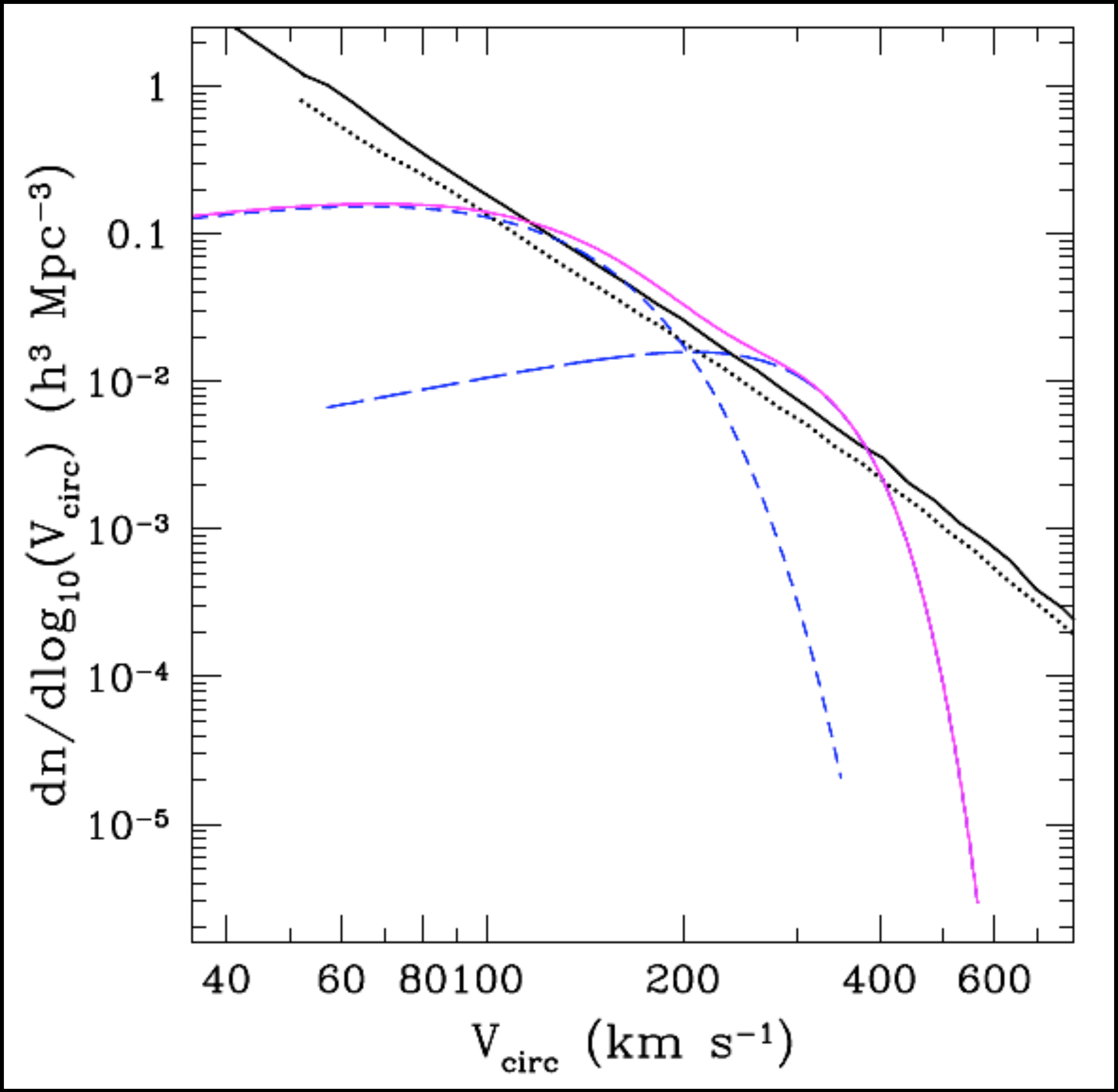
- measures abundance as function of “mass”
- sensitive to both DM and baryons
- further constrains LV relation
- difficult to measure directly
  - late types: HIPASS (Zwaan et al. 2010)
  - early types: SDSS + Faber-Jackson + σ_0-V_{circ} (Chae 2010)

LF

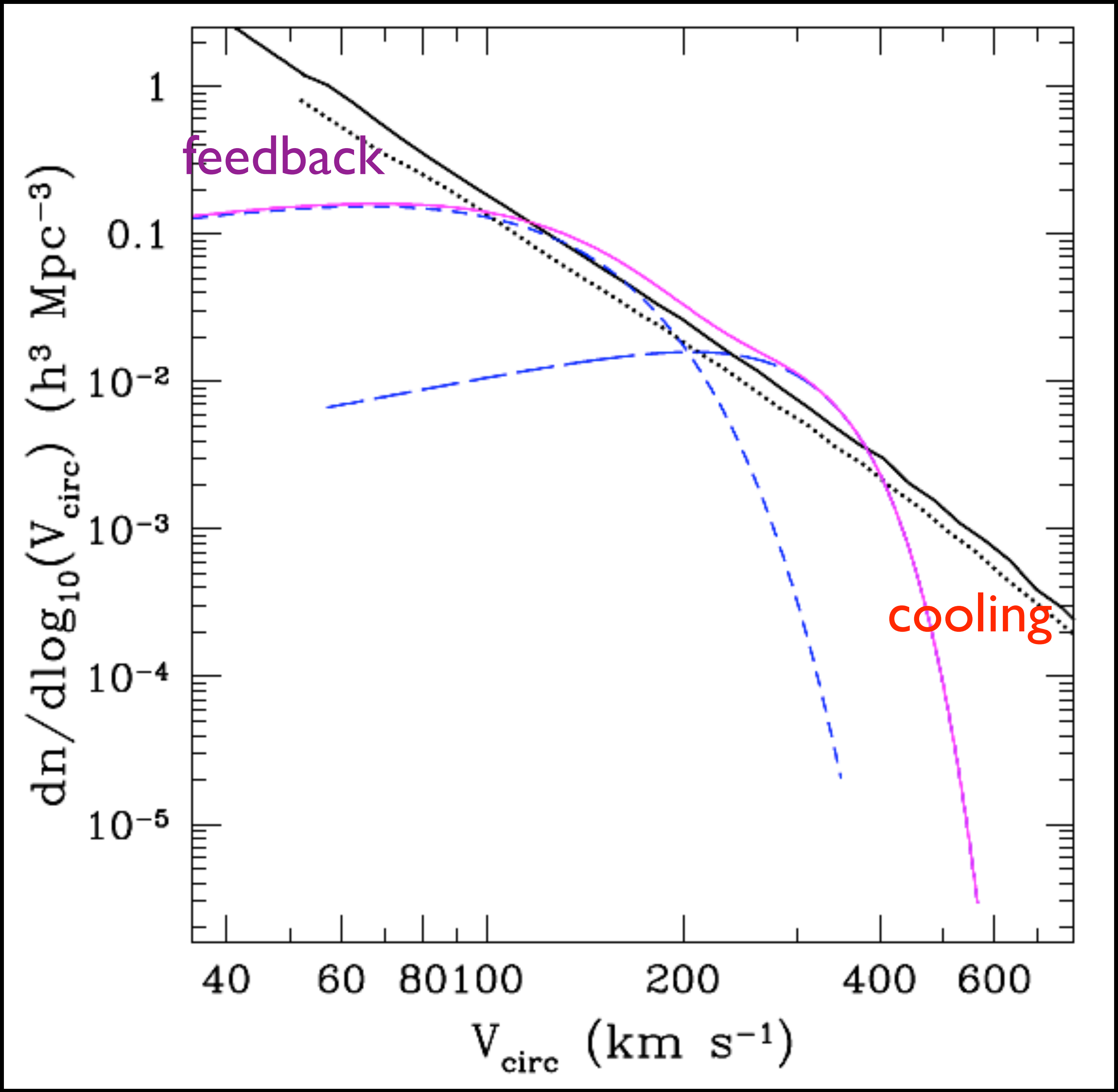


galaxy circular velocity function

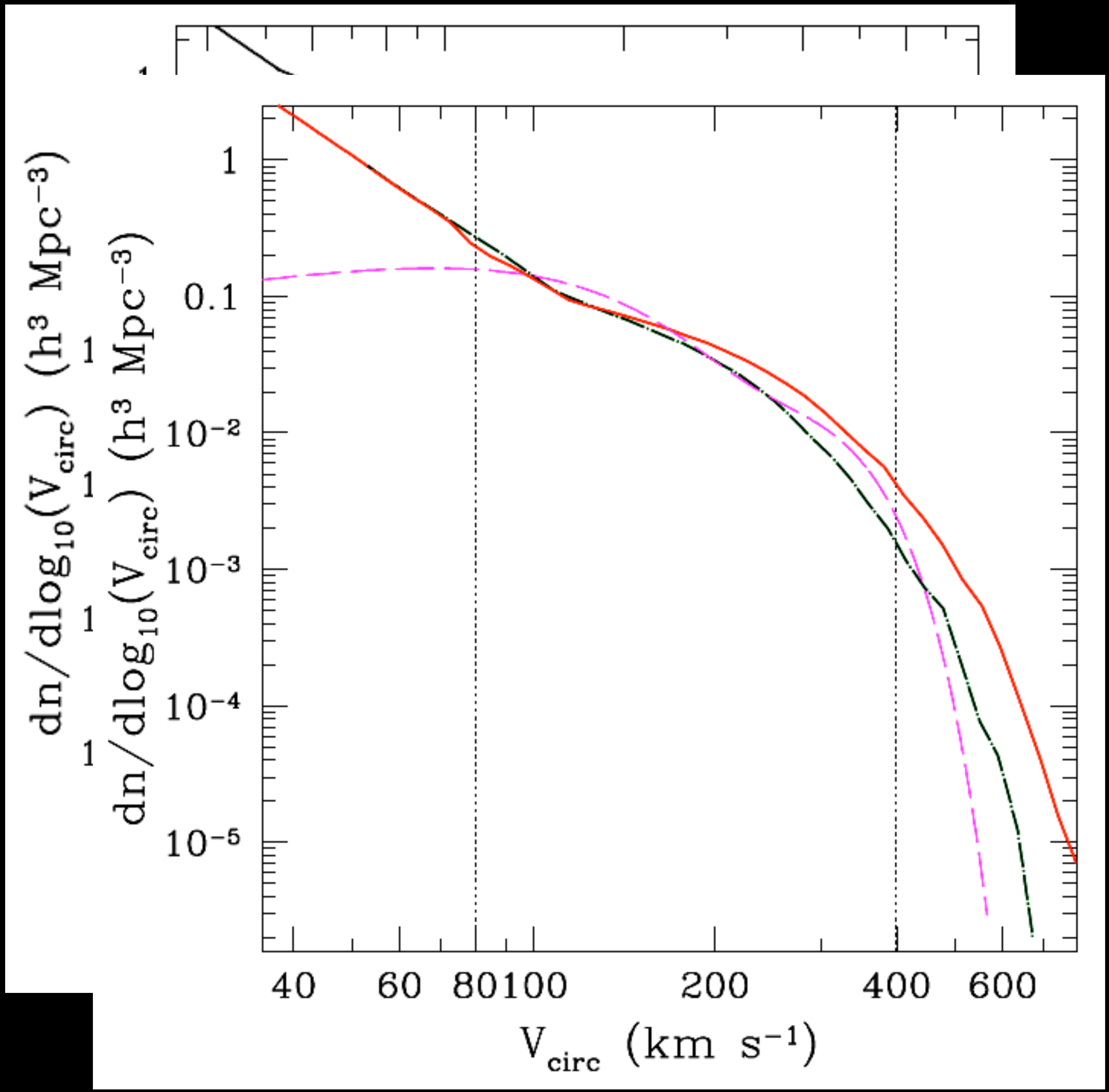
galaxy circular velocity function



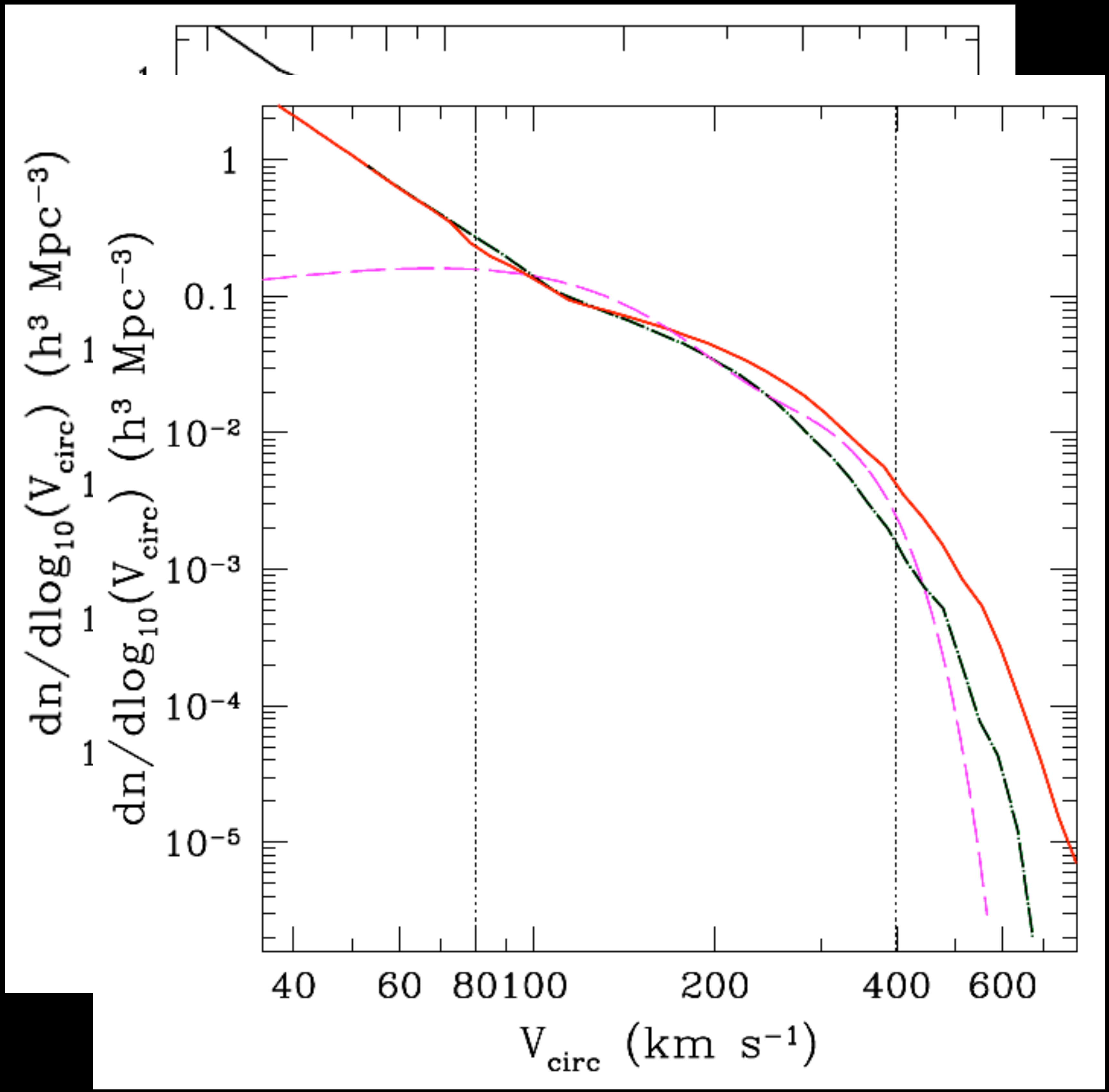
galaxy circular velocity function



galaxy circular velocity function



galaxy circular velocity function



- V_{acc} does ~50% better than V_{now} for MW
- overall agreement 80-400km/s
- number of MWs predicted to within 50% regardless of AC
- LV: need AC for ellipticals?
- >400km/s uncertain (BCGs?)
- <80km/s GCVF=halo VF - too many dwarfs (incomplete LF?)

conclusions

conclusions

- observed galaxies follow tight relation between dynamical mass and luminosity

conclusions

- observed galaxies follow tight relation between dynamical mass and luminosity
- AM+simple model accounts for LV relation in a statistical sense - galaxies assigned to correct potential wells

conclusions

- observed galaxies follow tight relation between dynamical mass and luminosity
- AM+simple model accounts for LV relation in a statistical sense - galaxies assigned to correct potential wells
    - v_{acc} good proxy for final stellar mass/luminosity

conclusions

- observed galaxies follow tight relation between dynamical mass and luminosity
- AM+simple model accounts for LV relation in a statistical sense - galaxies assigned to correct potential wells
  - v_{acc} good proxy for final stellar mass/luminosity
  - adiabatic contraction brackets observations within uncertainties

conclusions

- observed galaxies follow tight relation between dynamical mass and luminosity
- AM+simple model accounts for LV relation in a statistical sense - galaxies assigned to correct potential wells
  - v_{acc} good proxy for final stellar mass/luminosity
  - adiabatic contraction brackets observations within uncertainties
- baryon content: need more dwarfs and Es

conclusions

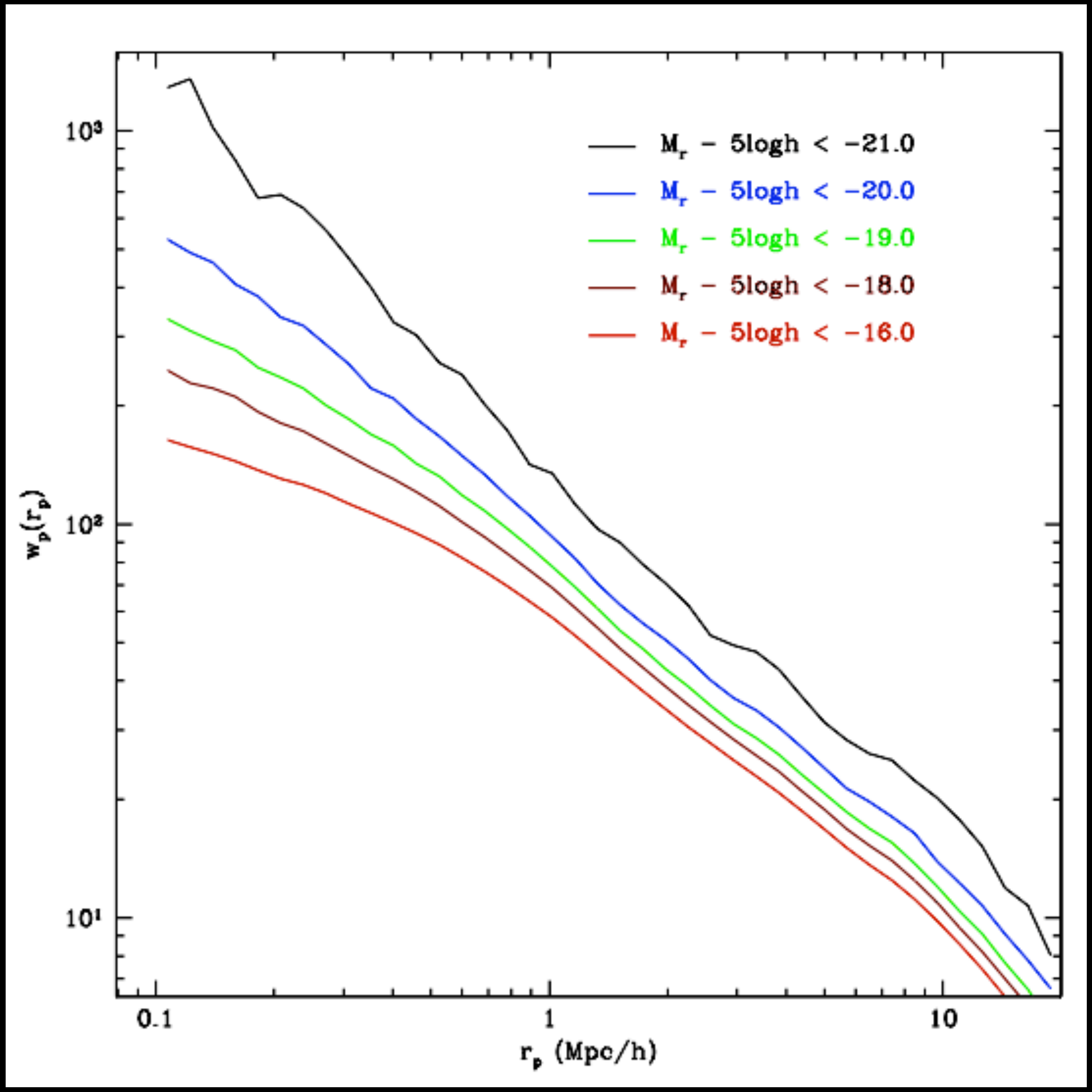
- observed galaxies follow tight relation between dynamical mass and luminosity
- AM+simple model accounts for LV relation in a statistical sense - galaxies assigned to correct potential wells
  - v_{acc} good proxy for final stellar mass/luminosity
  - adiabatic contraction brackets observations within uncertainties
- baryon content: need more dwarfs and Es
- morphologies: need to model different populations

conclusions

- observed galaxies follow tight relation between dynamical mass and luminosity
- AM+simple model accounts for LV relation in a statistical sense - galaxies assigned to correct potential wells
    - v_{acc} good proxy for final stellar mass/luminosity
    - adiabatic contraction brackets observations within uncertainties
- baryon content: need more dwarfs and Es
- morphologies: need to model different populations
- abundance constrain satisfied but dwarfs are still missing - SB completeness?

coming attractions

- 2-point galaxy correlation function



- effect of scatter in LF