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

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• the galaxies in our halos
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introduction: galaxies in DM halos
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• not so simple problems: we understand physics of DM but baryons are complex to model
  • gas physics, 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
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
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!
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, $M_{\text{halo}}-M_{\text{star}}$ 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
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- 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?
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![Graph showing the luminosity-velocity (LV) relation with data points and error bars.]
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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 $(250 \text{ Mpc}/h)^3 \sim 1.8$ times SDSS DR6
- AMR: min. mass = $1.35e8 \text{ M}_{\text{sun}}/h$, force resolution = 1kpc/h
- Bound-Density-Maxima: 9M halos, ~3M complete (>50km/s)
- $V_{\text{circ}}$ main property of objects instead of mass
  - inner mass distribution
  - stripping-resistant
  - observable

\[
V_{\text{circ}} = \left. \sqrt{\frac{GM(<r)}{r}} \right|_{\text{max}}
\]
the galaxies in our halos - the model

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

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

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

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

$$M_{\text{tot}}(r_i)r_i = [M_{\text{DM}}(r_i)(1 - f_{\text{bar}}) + M_{\text{bar}}(r_f)]r_f$$
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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
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![Graph showing the LV relation with data points and error bars, along with a model fit.](image)
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![Graph showing model LV relation](image)

- **no AC**
- **full model**

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Trujillo-Gomez et al. 2010
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\[ \alpha = -1.34 \]
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 ejection)
  - adiabatic contraction/expansion
  - results inconsistent with this work:
    - galaxy formation efficiency is too high \( \sim 35\% \) (using low \( \lambda \))
    - AC: 2\( \sigma \) 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 $\sim 25\%$ where spirals dominate
model LV relation

DM

\( V_{10} \)

\( V_{\text{acc}} \)

\( V_{\text{now}} \)

baryons

\( V_{10+\text{bar}} \)

\( V_{10+\text{bar+AC}} \)

\( M_{\odot} - 5 \log_{10} h \)

\( V_{\text{circ}} \) (km \( s^{-1} \))

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model LV relation

- DM
- Baryons
- $V_{10+\text{bar}}$
- $V_{10+\text{bar+AC}}$
- $f_{\text{bar}} = 0.5$
- Wrong curvature
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

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- 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 + $\sigma_0 - V_{\text{circ}}$ (Chae 2010)
galaxy circular velocity function
galaxy circular velocity function

dn/dlog_{10}(V_{circ}) (h^3 Mpc^{-3})

V_{circ} (km s^{-1})

feedback

cooling
galaxy circular velocity function
galaxy circular velocity function

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