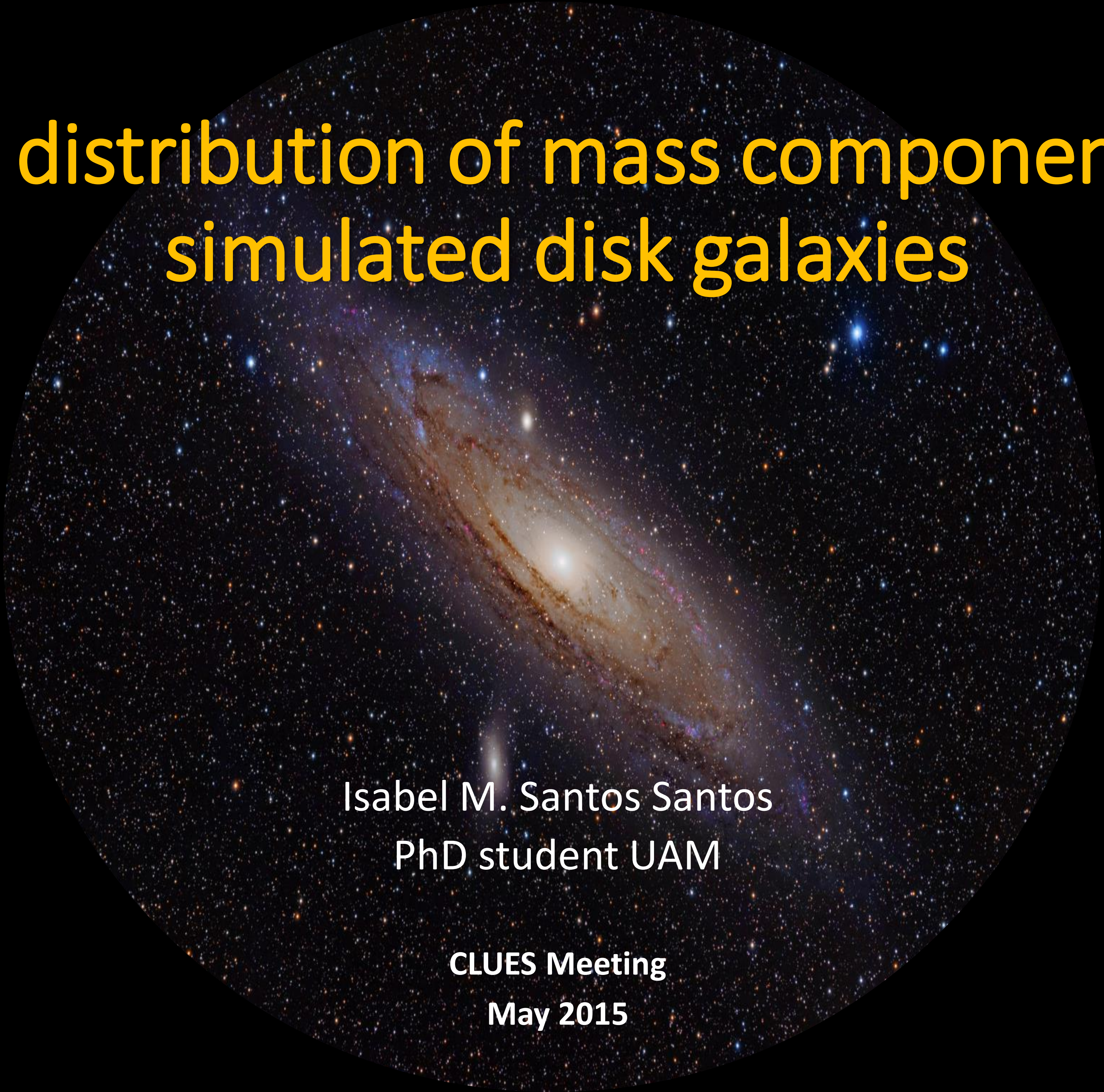
The distribution of mass components in simulated disk galaxies



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CLUES Meeting

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1. SIMULATIONS. SELECTED SUITE OF GALAXIES

5 MaGICC MW galaxies

$$m_{star} = 4.0 \times 10^4 M_\odot$$
$$m_{gas} = 5.7 \times 10^4 M_\odot$$
$$m_{dm} = 1.1 \times 10^6 M_\odot$$
$$\boldsymbol{\varepsilon} = 312\ pc$$

7 MaGICC Irr galaxies

$$m_{star} = 4.3 \times 10^3 M_\odot$$
$$m_{gas} = 7.1 \times 10^3 M_\odot$$
$$m_{dm} = 1.4 \times 10^5 M_\odot$$
$$\boldsymbol{\varepsilon} = 156\ pc$$

10 CLUES galaxies

- **Isolated**
- **Mvir> 4×10^{10} $M_\odot$**

$$2h^{-1} Mpc$$
$$4096^3\ particles$$
$$m_{star} = 1.3 \times 10^4 M_\odot$$
$$m_{gas} = 1.8 \times 10^4 M_\odot$$
$$m_{dm} = 2.9 \times 10^5 M_\odot$$
$$\boldsymbol{\varepsilon}_{bar} = 226\ pc$$
$$\boldsymbol{\varepsilon}_{dm} = 486\ pc$$

TOTAL=22 disk galaxies

WMAP 3 cosmology:

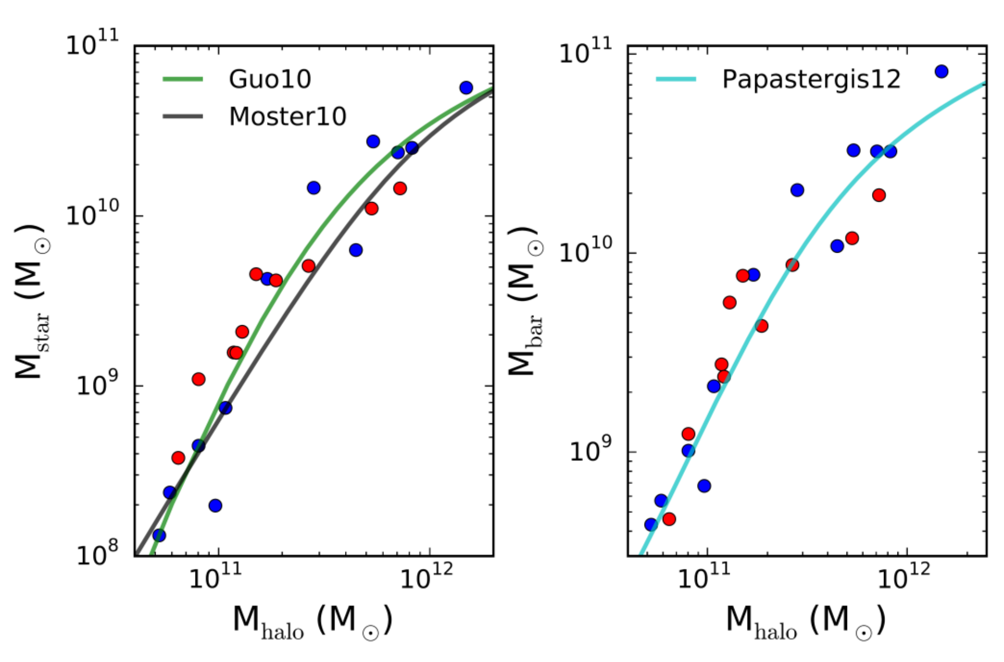
$$H_0 = 73\ km\ s^{-1} Mpc^{-1};\ \Omega_m = 0.24;$$
$$\Omega_\Lambda = 0.76;\ \Omega_{bar} = 0.04;\ \sigma_8 = 0.76$$

Name	M_{halo} ($M_\odot$)	M_* ($M_\odot$)	M_{HI} ($M_\odot$)	h (kpc)	μ_0 (mag as^{-1})	V_{max} (km s^{-1})	V_{flat} (km s^{-1})
g15784_MW	1.49×10^{12}	5.67×10^{10}	1.96×10^{10}	3.00	18.98	222.10	222.10
g21647_MW	8.24×10^{11}	2.51×10^{10}	5.62×10^{9}	1.34	17.50	189.79	163.84
g1536_MW	7.10×10^{11}	2.36×10^{10}	6.78×10^{9}	3.46	20.54	175.95	175.95
g5664_MW	5.39×10^{11}	2.74×10^{10}	4.19×10^{9}	2.17	19.32	196.66	151.40
g7124_MW	4.47×10^{11}	6.30×10^{9}	3.49×10^{9}	2.72	20.56	120.14	120.14
g15807_Irr	2.82×10^{11}	1.46×10^{10}	4.68×10^{9}	1.94	18.68	141.21	141.21
g15784_Irr	1.70×10^{11}	4.26×10^{9}	2.70×10^{9}	2.28	20.31	106.90	106.90
g22437_Irr	1.10×10^{11}	7.44×10^{8}	1.08×10^{9}	2.09	21.56	75.40	75.40
g21647_Irr	9.65×10^{10}	1.98×10^{8}	3.68×10^{8}	1.73	22.75	60.85	60.85
g1536_Irr	8.04×10^{10}	4.46×10^{8}	4.39×10^{8}	1.70	21.76	67.16	67.16
g5664_Irr	5.87×10^{10}	2.36×10^{8}	2.56×10^{8}	1.62	22.22	59.50	59.50
g7124_Irr	5.23×10^{10}	1.32×10^{8}	2.30×10^{8}	1.16	21.61	52.77	52.77
C1	7.23×10^{11}	1.45×10^{10}	3.86×10^{9}	1.56	19.56	168.83	127.10
C2	5.31×10^{11}	1.11×10^{10}	6.32×10^{8}	1.83	20.40	123.59	123.59
C3	2.67×10^{11}	5.08×10^{9}	2.79×10^{9}	2.25	21.22	119.75	119.75
C4	1.87×10^{11}	4.18×10^{9}	9.77×10^{7}	1.45	20.07	101.21	101.21
C5	1.51×10^{11}	4.54×10^{9}	2.42×10^{9}	1.35	20.30	116.63	116.63
C6	1.29×10^{11}	2.08×10^{9}	2.74×10^{9}	1.53	21.29	101.66	101.66
C7	1.18×10^{11}	1.57×10^{9}	9.10×10^{8}	1.48	20.44	88.89	72.92
C8	1.21×10^{11}	1.57×10^{9}	6.34×10^{8}	1.03	20.19	85.22	85.22
C9	8.04×10^{10}	1.10×10^{9}	1.05×10^{8}	1.55	22.64	70.85	70.85
C10	6.44×10^{10}	3.78×10^{8}	6.33×10^{7}	0.86	21.55	53.35	53.35

EVOLUTION CODE

- N-BODY SPH CODE GASOLINE:
  - Gas hydrodynamics and cooling
  - Star formation: Schmidt law with SFR $\propto \rho^{1.5}$
  - SN feedback: Blastwave formalism (Stinson06) $\epsilon_{SN} \times 10^{51} erg$ of thermal energy released
  - Deposition of metals → Chabrier IMF; Diffusion (Shen10)
  - Uniform background radiation field
  - Metal-line cooling (Shen10): MaGICC ✓, CLUES✗
  - Early stellar feedback (Stinson13): MaGICC ✓ CLUES✗

2. MATCHING SCALING RELATIONS: Stellar & Baryon to Halo mass relations

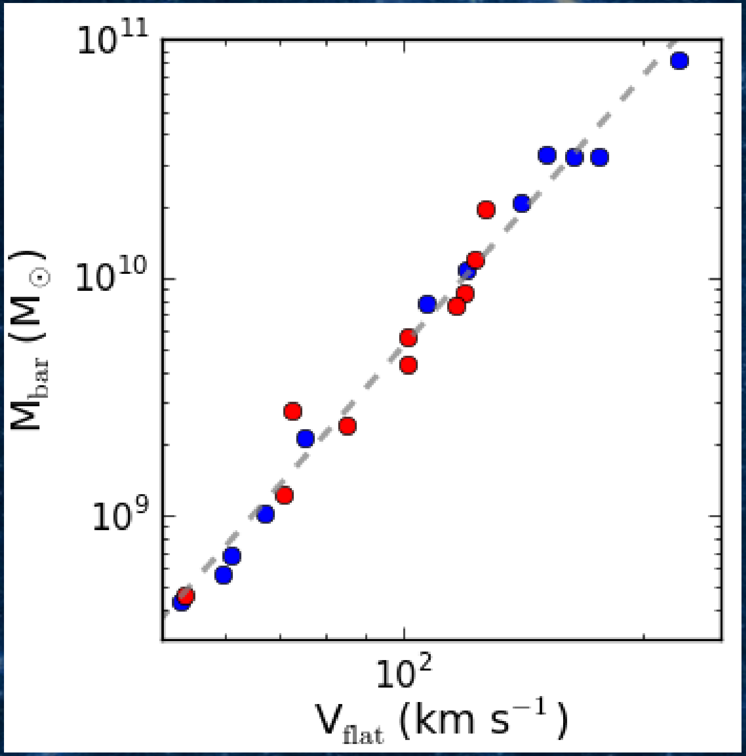


Simulations: CLUES, MaGICC

- M^*-M_{halo} relation matched over a wide mass range (Brook12b)
  - MaGICC sims tuned to match the M*-Mhalo relation at *ONE* galaxy mass. CLUES sims also calibrated from experience to match it.
- M_{bar} = stars + cold gas
- $M_{coldgas}$ =1.3xM_{HI} (McGaugh12)
- M_{bar}-Mhalo relation also matched→ not only correct total amount of stars, but also total cold gas (no parameter search)

Baryonic Tully-Fisher relation

Simulations: CLUES, MaGICC

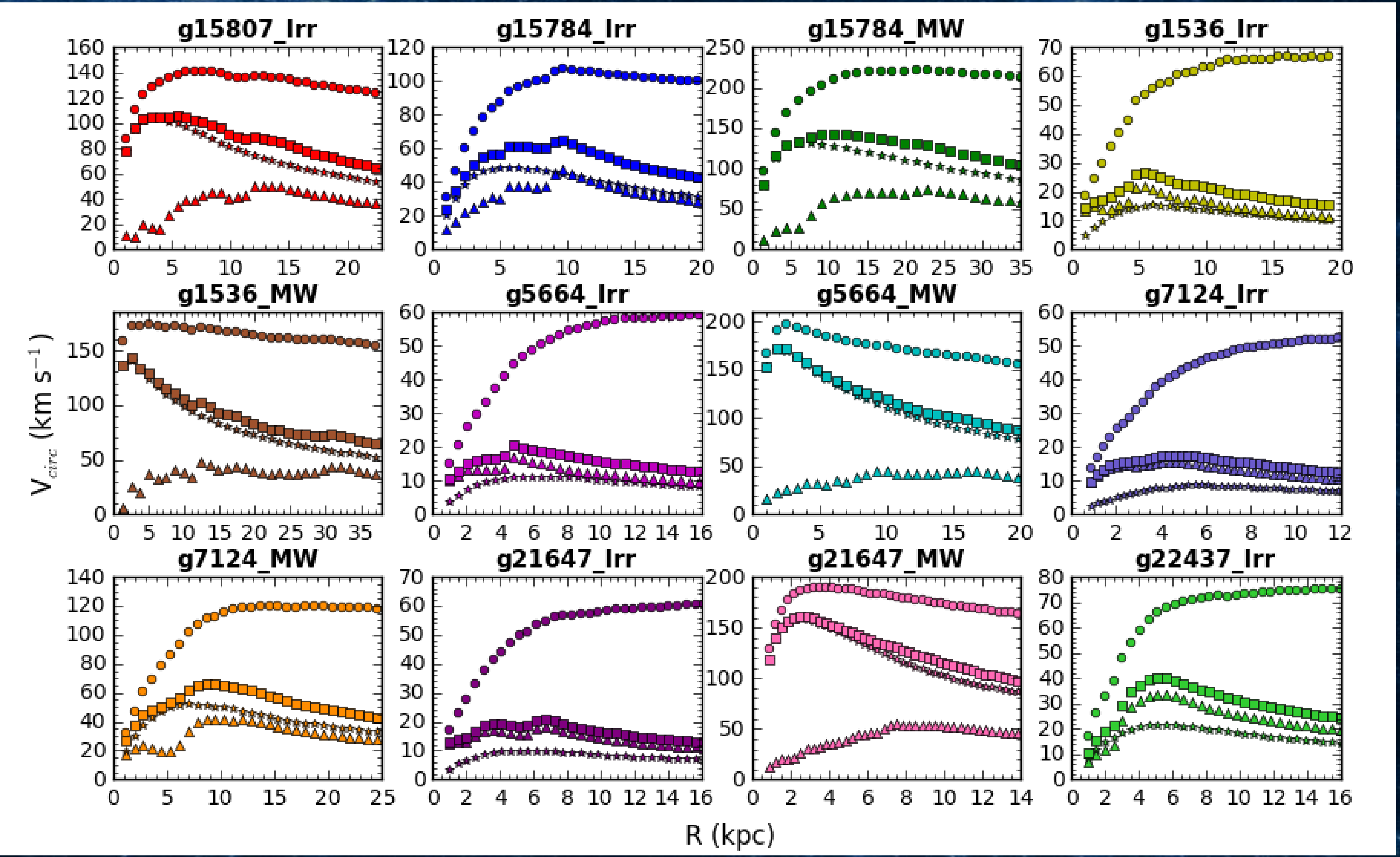


- Both sets of simulations follow a single linear relation that matches the slope (3-4) of the observed BTFR
- Simulating proper disk galaxies:
  - Simulations need of feedback processes to “feed” angular momentum so that it doesn’t die away due to mergers
  - Correct amount of angular momentum transferred to the gas→ gas settles into a disk with similar final flat velocities as observations

3. RESULTS:
Rotation curves

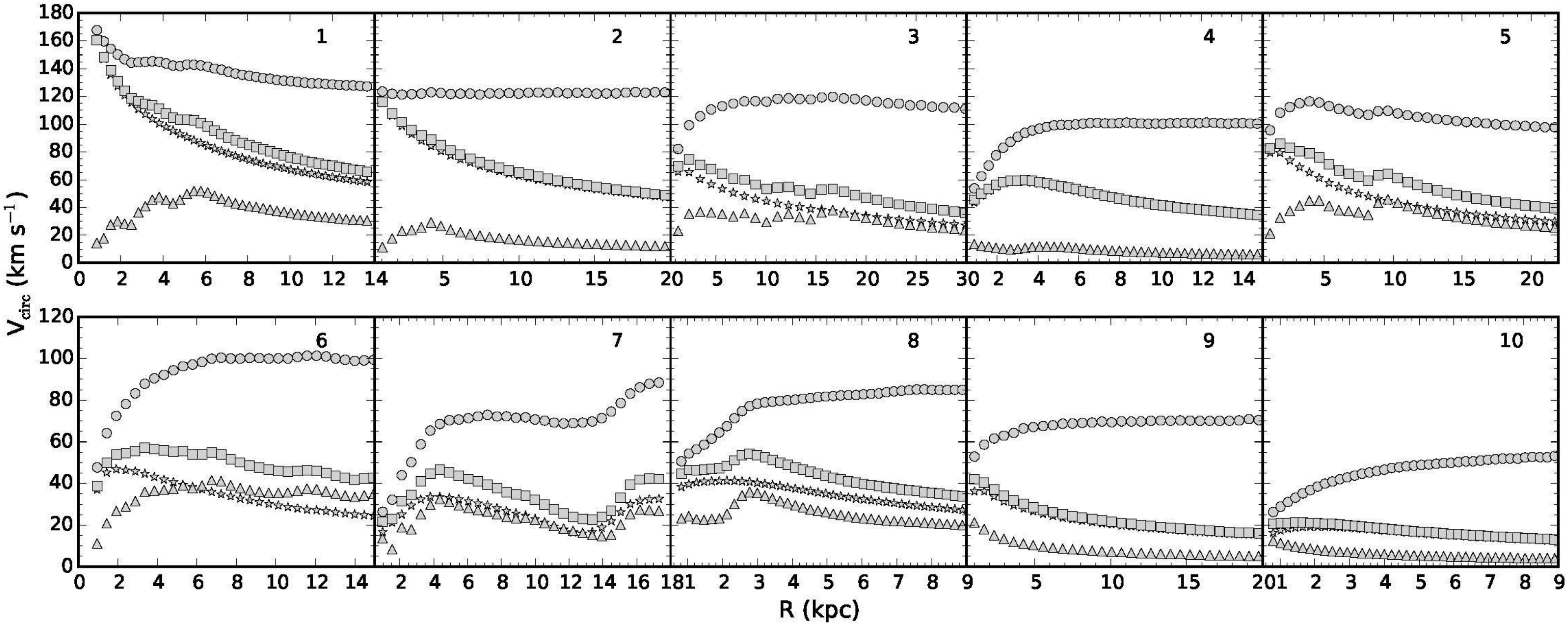
▲ Cold gas
☆ Stars
■ All baryons (stars +coldgas)
○ Total (all components)

MaGICC galaxies



Rotation curves

CLUES galaxies



- ▲ Cold gas
- ☆ Stars
- ■ All baryons (stars +coldgas)
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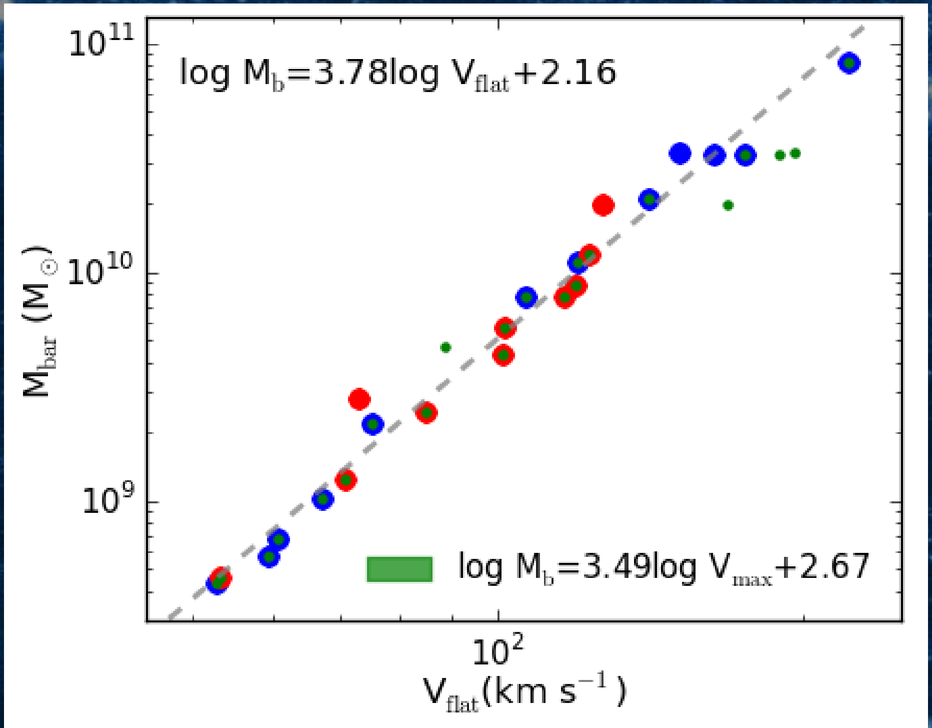
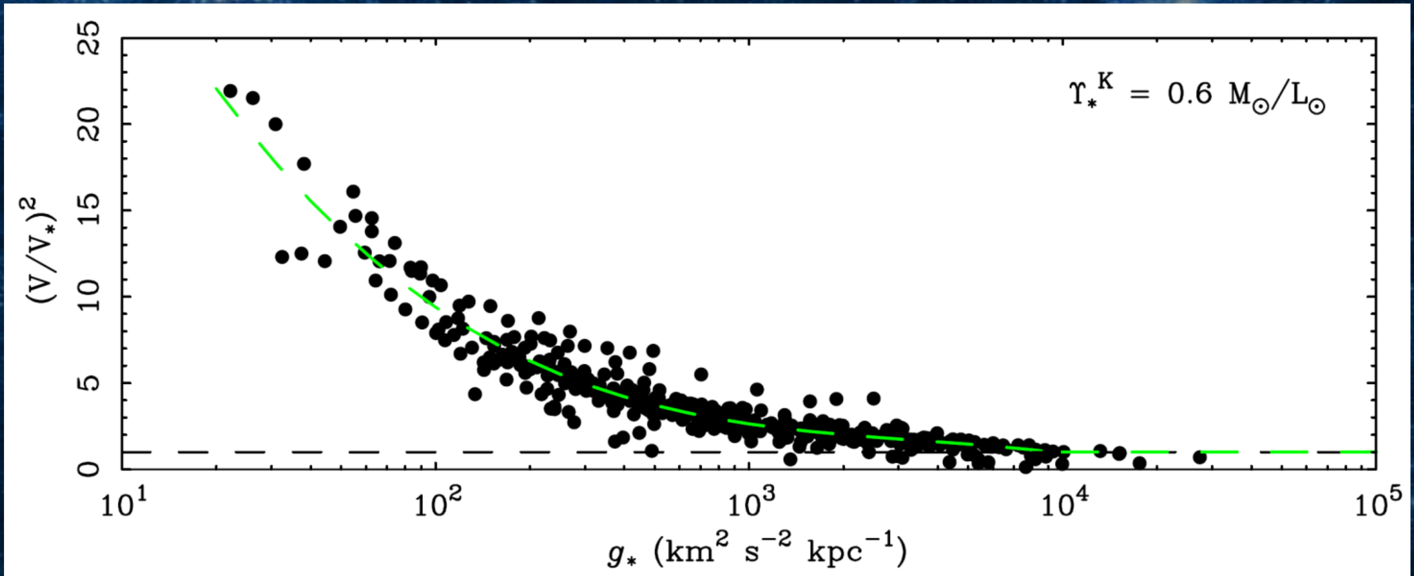
Baryonic Tully-Fisher relation

Simulations: CLUES, MaGICC



The Mass discrepancy – Acceleration relation

McGaugh, S. 2014



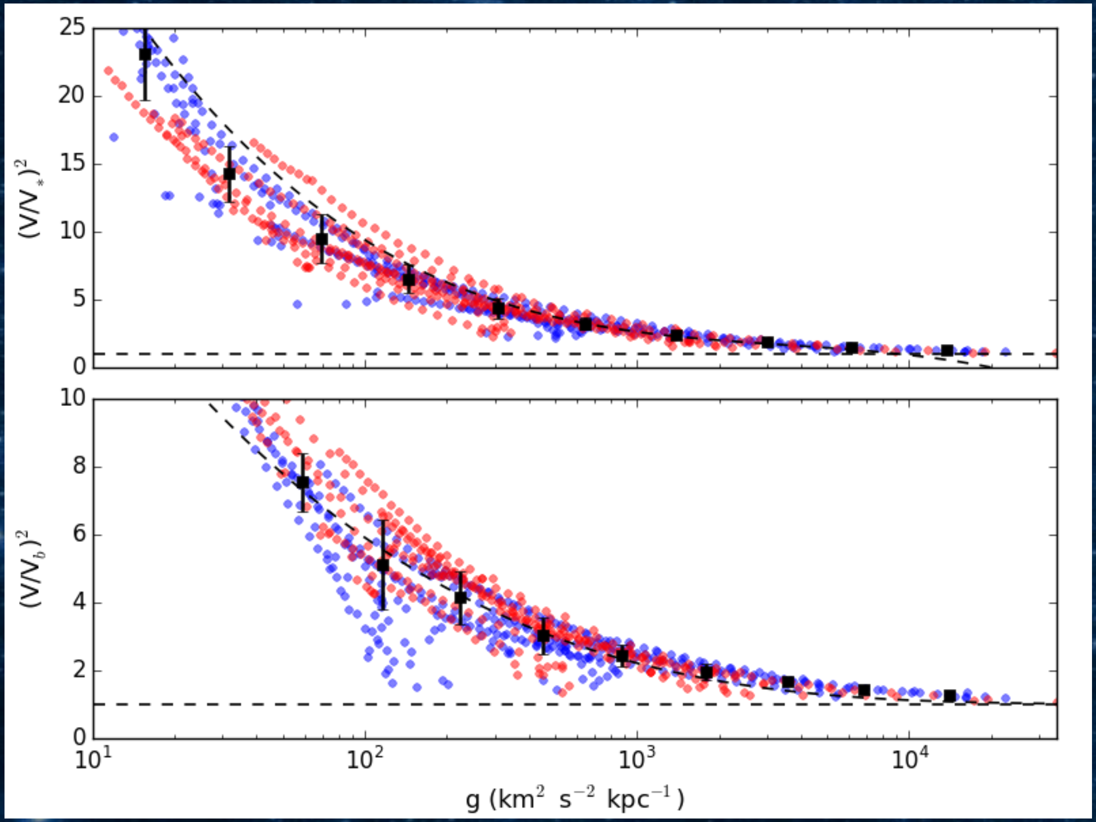
Mass Discrepancy = $$D_b = \left(\frac{V_r}{V_b}\right)^2 = \frac{M(r)}{M_b(r)}$$

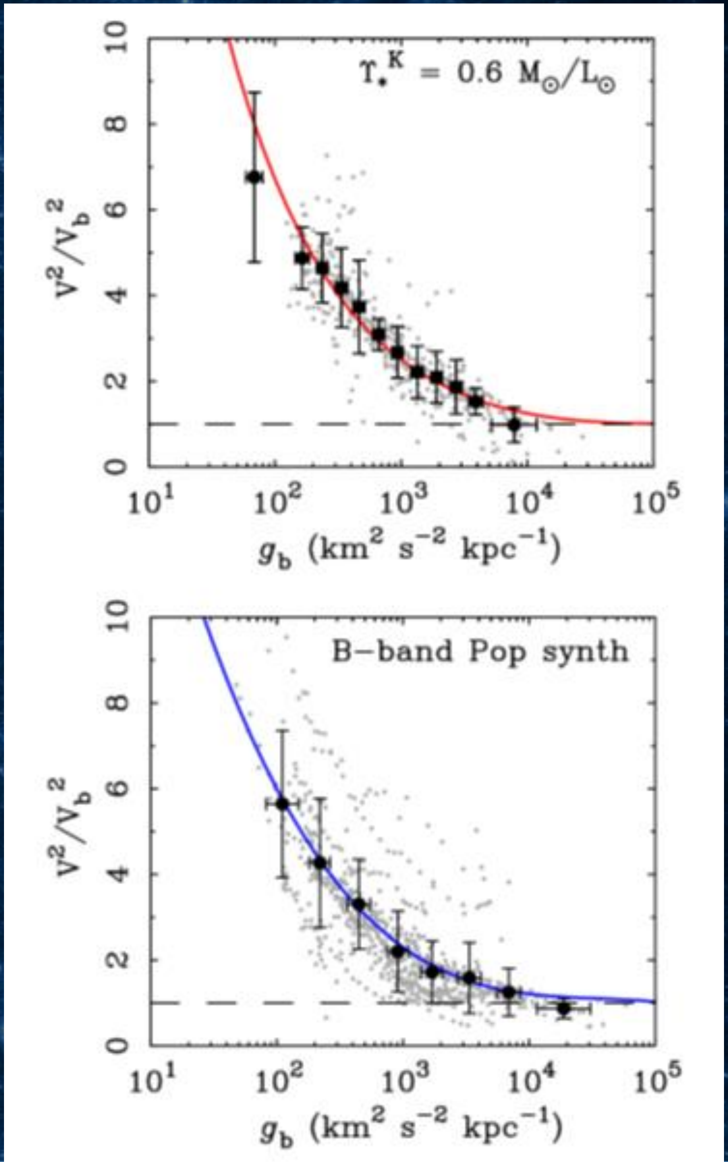
Acceleration = $$g_b = \left(\frac{V_b{}^2}{r}\right)$$

Mass discrepancy-Acceleration relation *D-g*

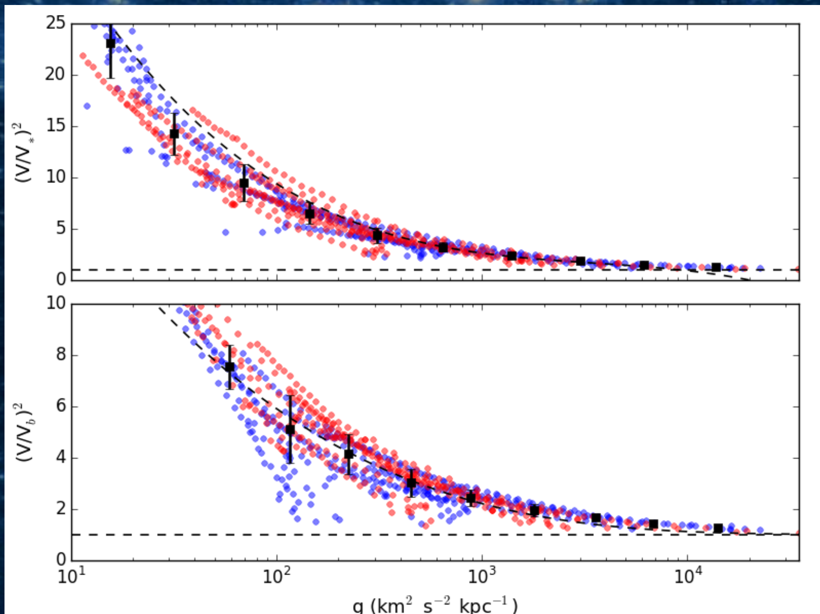
McGaugh, S. 2014

Top: stars, lower panel: all baryons
Simulations: CLUES, MaGICC

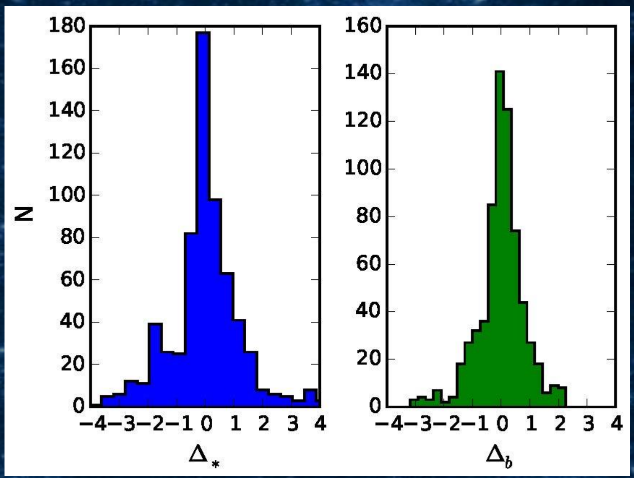




Residuals around the D-g fits

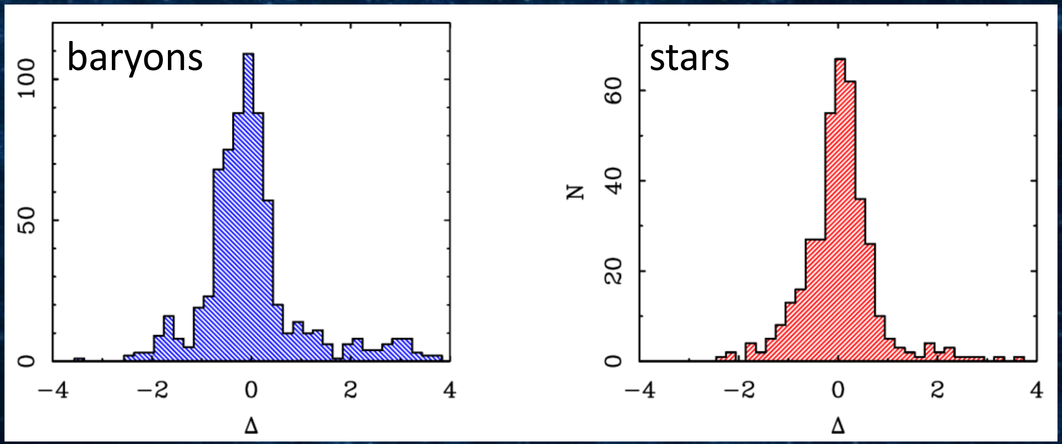


Simulations:



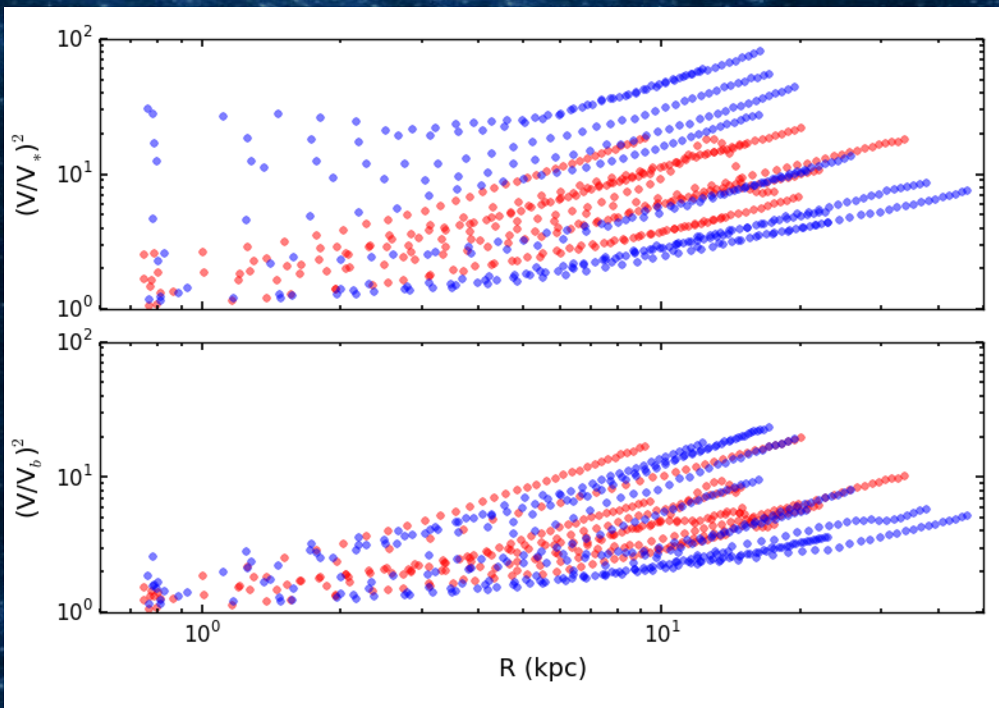
-*All* data divided in 10 bins
-A different 4 degree polynomial fit is found in each bin, giving higher weights to the points within it
-errorbars= stand. dev

Observations:McGaugh, S. 2014

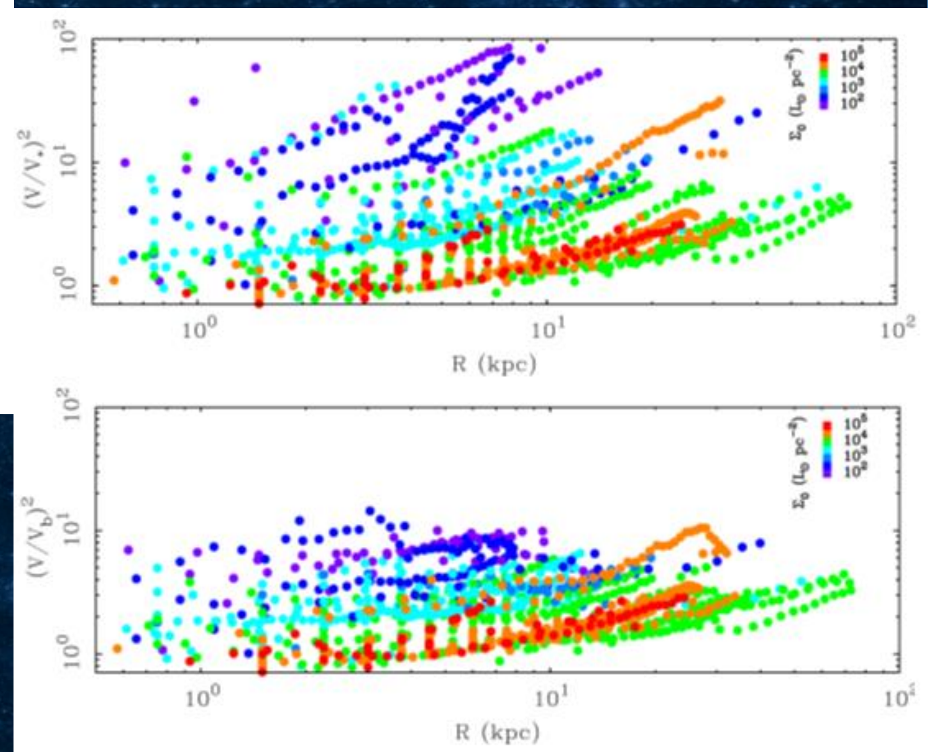


Mass discrepancy-Radius *D-r*

Simulations: CLUES, MaGICC



McGaugh, S. 2014



Observations: galaxies colored by their Surface brightness. LSB galaxies are more dominated by dark matter and thus have higher D at small radii.

4. SUMMARY

- We use extended rotation curve data (D-g relation)+TF to test the angular momentum content of simulated galaxies in LCDM
- The total suite of disk galaxies (spanning a wide range in masses and circular velocities) match:
  - M^* & M_{bar}-M_{halo} ✓→total amount of stars and cold gas is correct
  - BTFR✓→total amount of angular momentum is correct
  - D-g_{bar}✓→final internal distribution of gas, stars and DM at all radii through the disk is similar to that in real galaxies
- We show that the distribution of mass within disk galaxies with a wide range of masses and velocities, can also be well reproduced within a LCDM universe