The Baryonic Tully Fisher Relationship in Simulated Dwarf Galaxies

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Motivation

The Baryonic Tully Fisher Relationship (BTFR) is an empirical scaling between a galaxy's mass and rotation velocity. Baryonic mass is used to study this scaling relation for lower mass galaxies, since the contribution from cold gas ($T<10^4$ K) like HI is more significant.

The BTFR is expected to have a steeper slope at the low mass end as galaxy formation becomes less efficient (i.e., fewer baryons are retained). Constraining the BTFR at lower masses is difficult due to limited samples. Also, the rotation curves in dwarf galaxies are often still rising and don't trace V_{max}, unlike the flat rotation curves of more massive galaxies.

McQuinn+22 constrained the BTFR at $M_{bary}=10^7$-10^8 $M_\odot$. Since their rotation curves were still rising, they inferred the max velocity by assuming a density profile and corresponding rotation curve and fitting this to their data. Their cored Einasto analysis suggests a turndown in the BTFR below ~50 km/s.

Simulations & Methods

We use the **Marvel-lous suite** (Munshi+21) and the **Marvellous Merian suite**. Both simulations are zoom-ins made with ChaNGA (Menon+15), a smoothed particle hydrodynamic (SPH) + N-body code. Our sample requirements: HI masses > 10^6 $M_\odot$ and $M_{bary}=10^7$-10^{10} $M_\odot$.

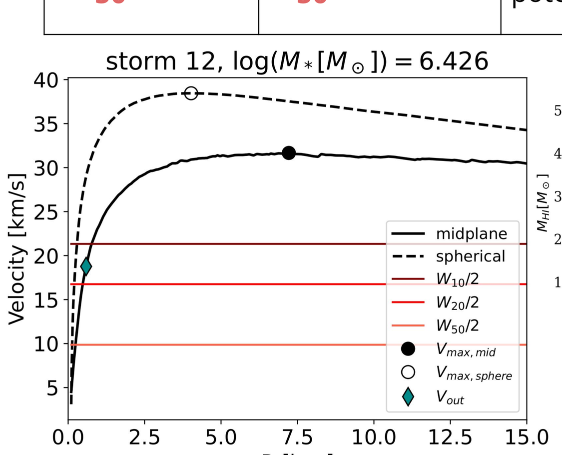
Analysis is done with pynbody (Pontzen+13), and mock HI data cubes are made with TIPSY (Katz & Quinn). Galaxies with stellar masses above 10^8 $M_\odot$ are likely more disky, so we orient them edge-on to get a max linewidth.

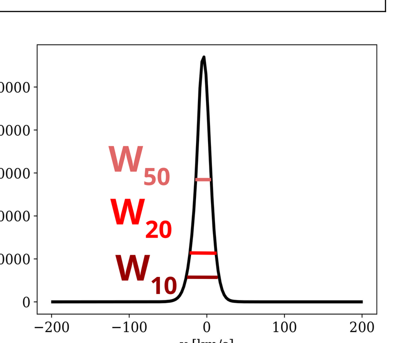
Resolutions for each simulation suite:

Simulation Suite	Cosmology	Dark matter mass [$M_\odot$]	Gas mass [$M_\odot$]	Initial star mass [$M_\odot$]	Force res. [pc]
Marvel (cptmarvel, storm, rogue, elektra)	WMAP3	6650	1410	420	60
Merian	Planck15	18000	3300	994	87

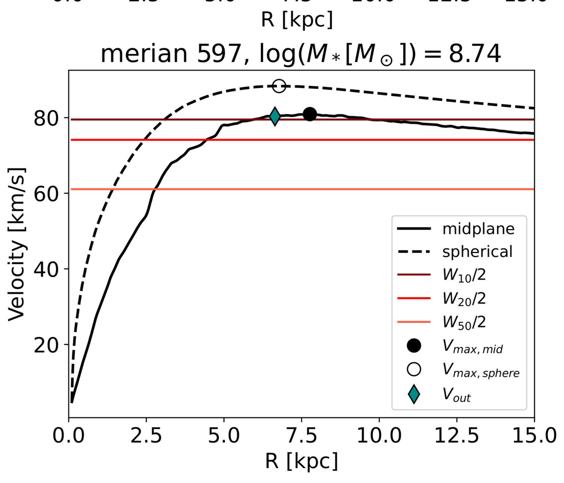
Definitions: $M_{bary} = 1.4M_{HI} + M_{star}$

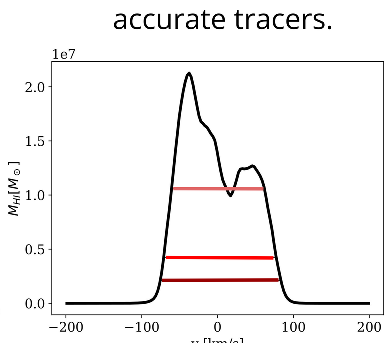
$V_{max,mid}$	$R_{max,mid}$	"truth", measured using the midplane potential
$V_{max,sphere}$	$R_{max,sphere}$	calculated based on enclosed mass
V_{out}	R_{out}	measured where HI surface density is 1 $M_\odot$/pc^2
W_{10}, W_{20}, W_{50}	R_{10}, R_{20}, R_{50}	W_x – HI linewidths at x% of the peak profile height. R_x – radii where these velocities intersect with the midplane potential rotation curve



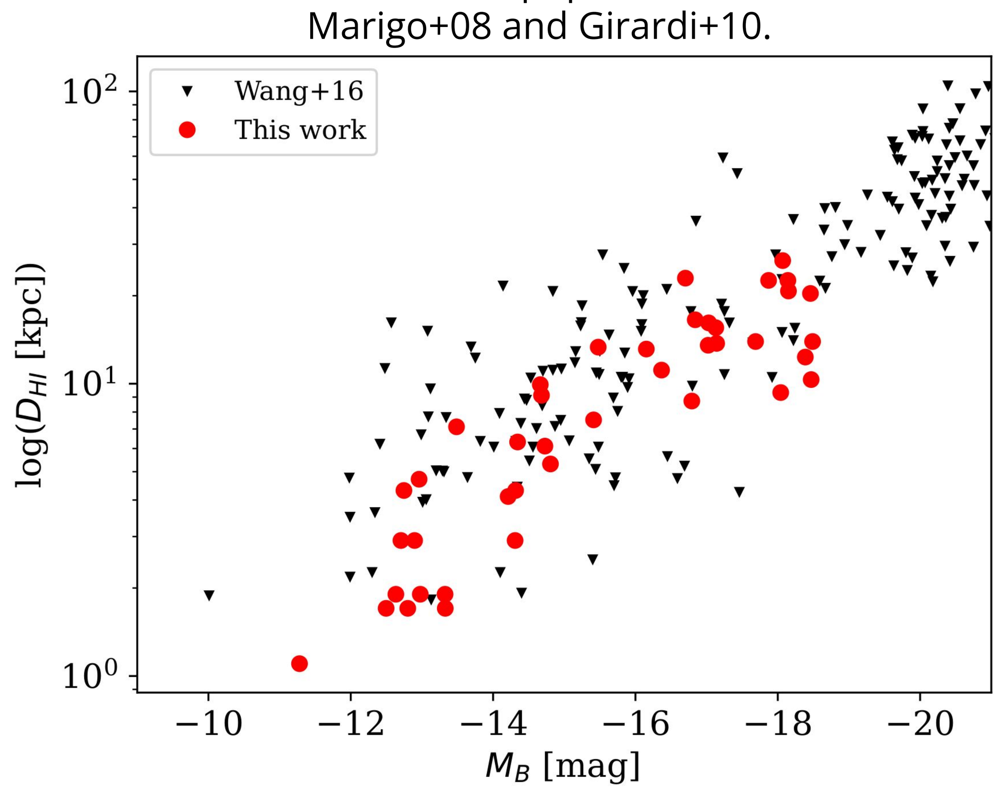


(top row) Storm 12 has a rising rotation curve and V_{out} underestimates V_{max}, whereas *(bottom row)* Merian 597 has more accurate tracers.

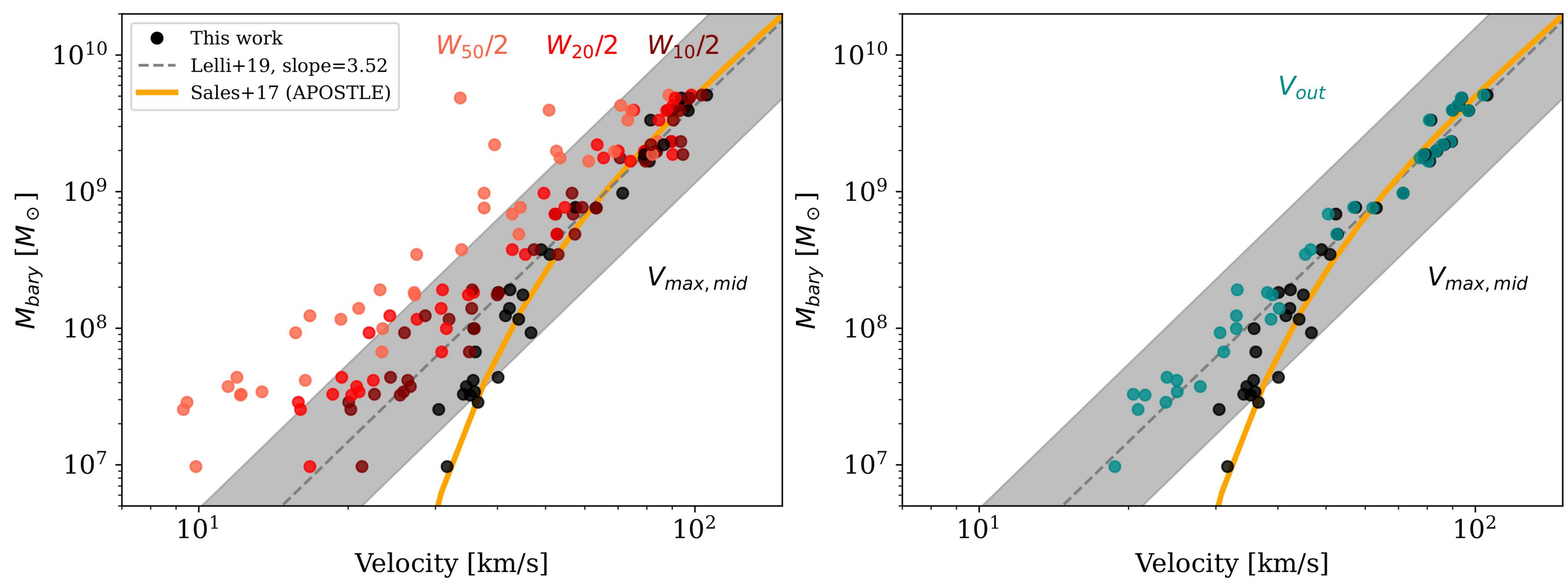




HI size and absolute B-band magnitude. Stellar magnitudes were determined from pynbody, which uses the stellar population models from Marigo+08 and Girardi+10.



BTFR slope and Tracing V_{max}



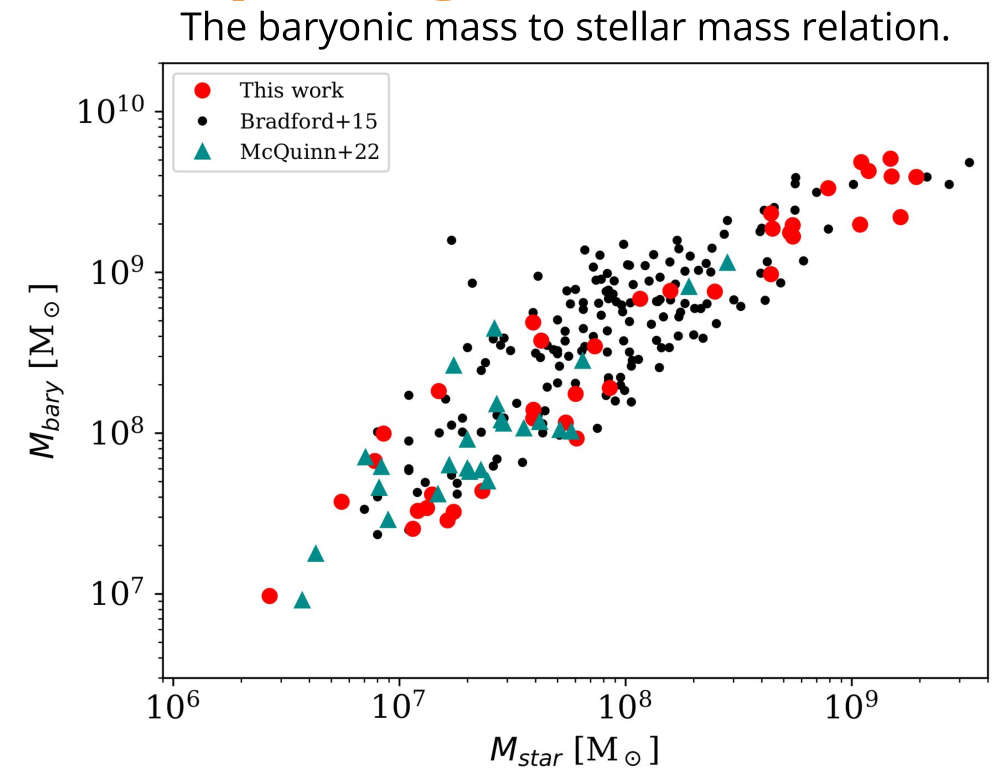
slope $W_{50}/2$ = 2.53 ± 0.26 | slope $W_{20}/2$ = 3.03 ± 0.15 | slope $W_{10}/2$ = 3.29 ± 0.15 | slope V_{out} = 3.39 ± 0.11

(Left): W_{10} provides the best measure of V_{max} in higher mass dwarfs, but underestimates V_{max} below ~50 km/s (see also Sardone+24). If V_{max} could be measured, we predict a turndown similar to other simulations (e.g., APOSTLE, Sales+17). We compare to the V_{max} trend in Lelli+19 (uses the max velocity on observed rotation curves, including rising rotation curves).

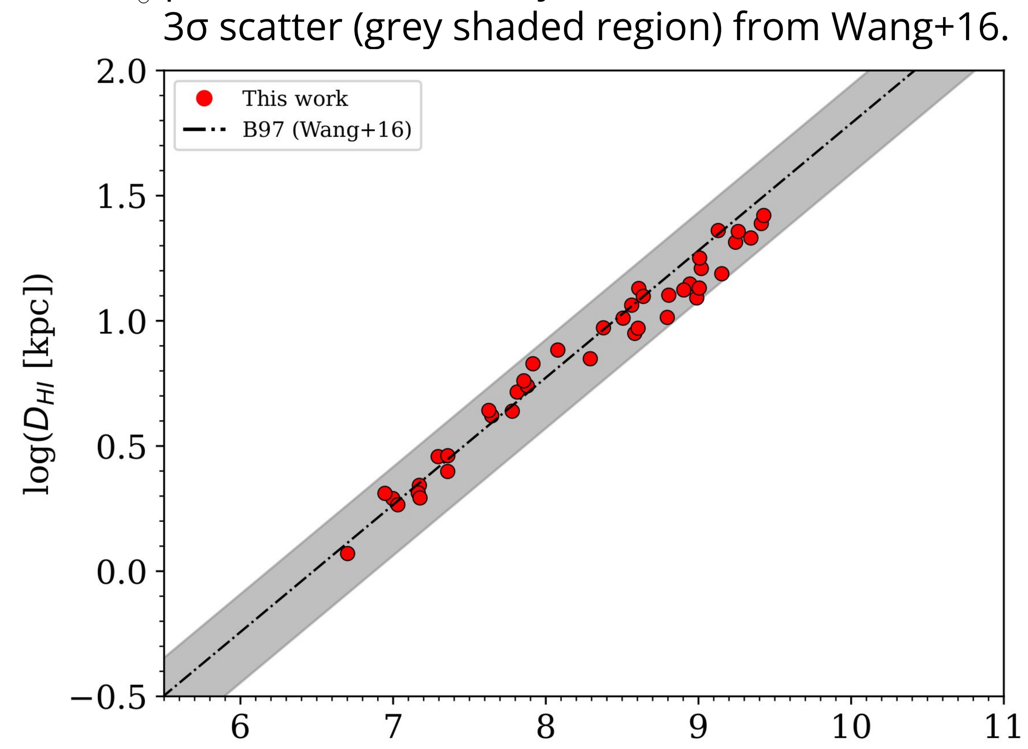
(Right): V_{out} traces V_{max} slightly better than W_{10}. The HI size shrinks such that the outermost rotation velocity appears to continue the trend from higher mass galaxies. However, the true V_{max} of the halo is higher, but not traceable by HI.

Comparing HI Observables

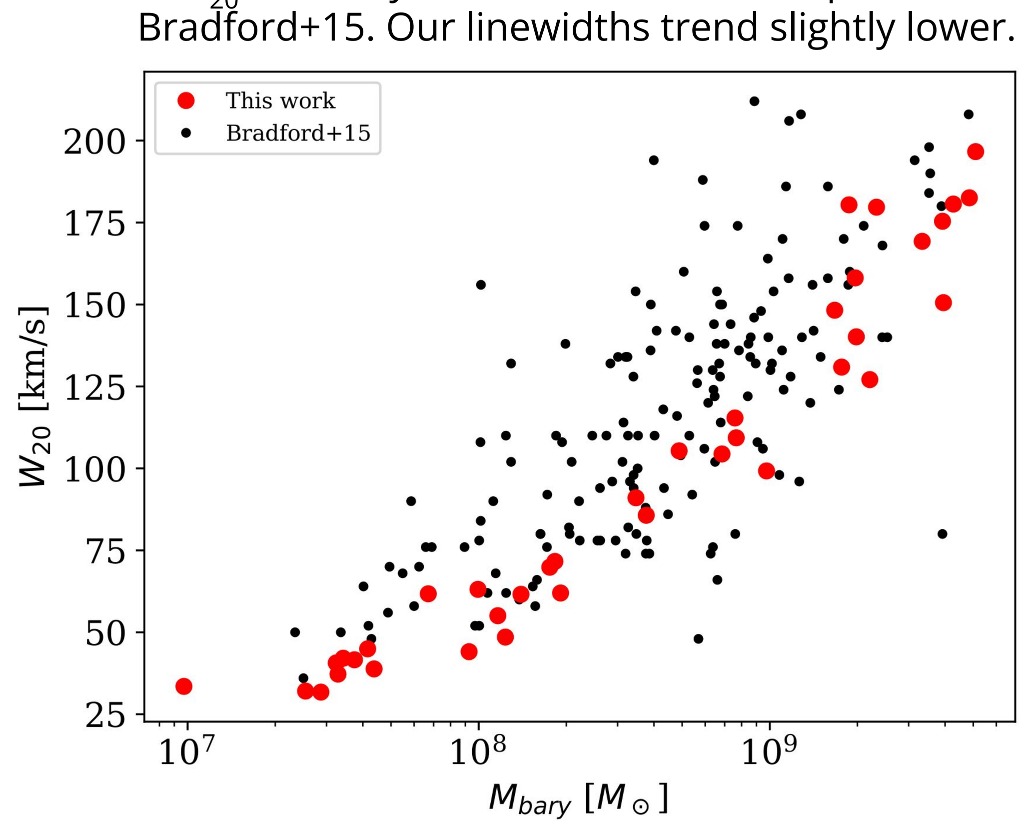
The baryonic mass to stellar mass relation.



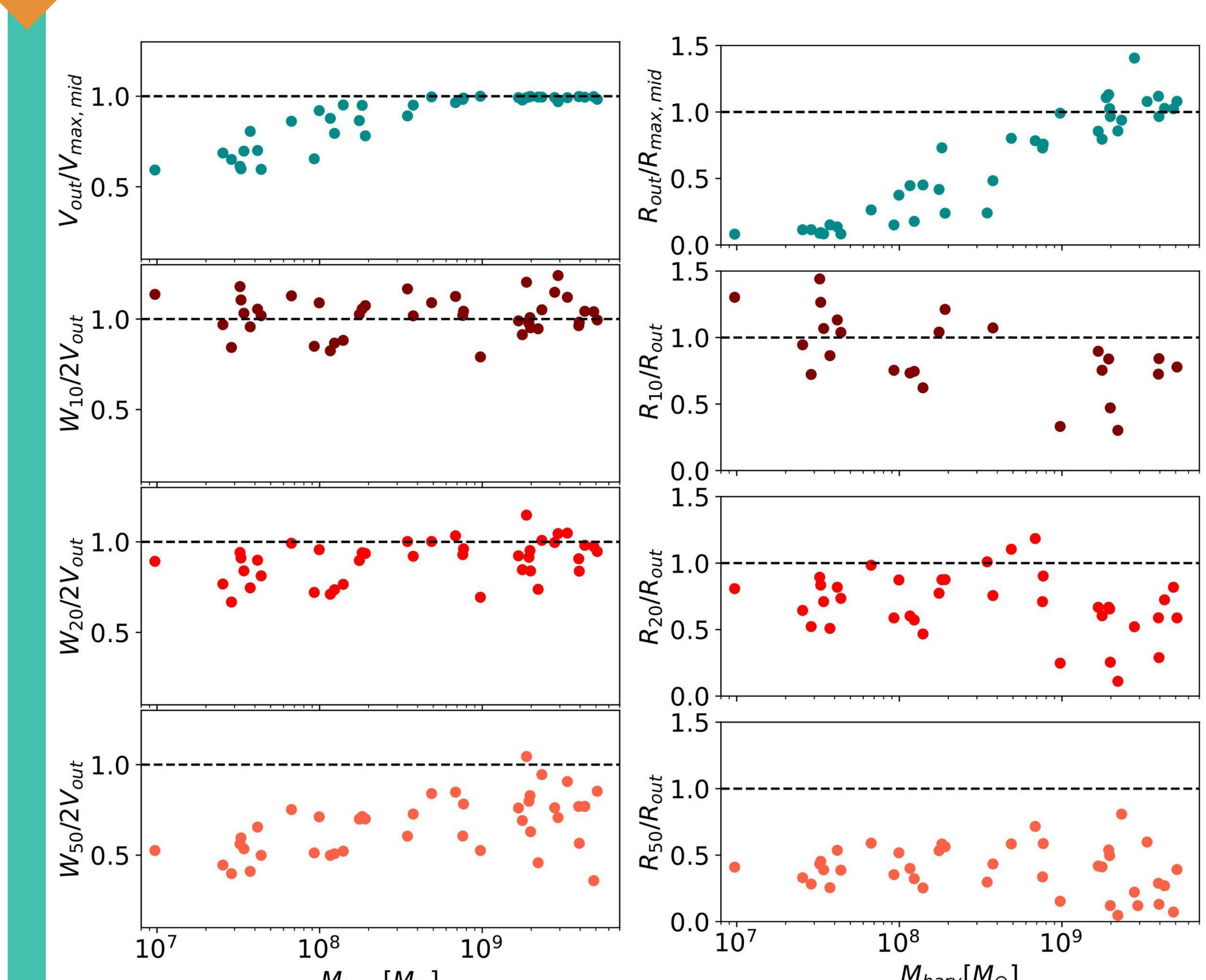
HI size vs. mass relation. The size is measured at 1 $M_\odot$/pc^2 HI surface density. Our simulations fit within the 3σ scatter (grey shaded region) from Wang+16.



W_{20} and baryonic mass relation compared to Bradford+15. Our linewidths trend slightly lower.



Radial Extent on Rotation Curves



(Left): Velocity comparison and *(Right):* Radius comparison, each as a function of baryonic mass. V_{out} and R_{out} are closer to the max midplane values at higher masses. Although $W_{10}/2$ matches V_{out} on all scales, R_{10} matches R_{out} best at lower masses.

Summary

With the newer Marvellous Merian suite, we extend the simulation work in Sardone+24 to $M_{bary}=10^7$-10^{10} $M_\odot$ and explore how different kinematic measurements trace V_{max}.

- Our simulations are consistent with observed HI quantities
- We find a turndown in the BTFR below a rotation velocity of 50 km/s when using the "true" V_{max} measured directly from the simulations.
- W_{10} is a decent tracer of V_{out} above 50 km/s, and both trace the midplane max rotation velocity. V_{out} is slightly more accurate.
- HI radius and mass scale such that the mock observed gas rotation velocity follows the BTFR set by higher mass galaxies, but the true V_{max} instead turns down.

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