DARK MATTER

ASTR 333/433 Fall 2013 M T 4:00-5:15pm Sears 552

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Empirical Laws of Galactic Rotation

Homework 2 due Oct 15

midterm Oct 29





Tully-Fisher relation



Luminosity and line-width are presumably proxies for stellar mass and rotation velocity.





double M*/L

...but stellar mass is completely dependent on choice of mass-tolight ratio (and degenerate with distance)



nominal M*/L

...but stellar mass is completely dependent on choice of mass-tolight ratio (and degenerate with distance)



half M*/L

...but stellar mass is completely dependent on choice of mass-tolight ratio (and degenerate with distance) Stark, McGaugh, & Swaters et al. (2009)

If you want to use Vflat, you have to observe far enough out to measure it.

$$\frac{\partial \log V}{\partial \log R} < 0.1$$

works well as a criterion.

Scatter in TF increases as threshold weakened.



Scatter in TF relation reduced with resolved rotation curves (Verheijen 2001)



Low mass galaxies tend to fall below extrapolation of linear fit to fast rotators (Matthews, van Driel, & Gallagher 1998; Freeman 1999)

$$M_* = \left(\frac{M_*}{L}\right)L$$



Gas mass by itself does NOT produce a good TF relation, at least for fast rotators.

 $M_g = 1.4 M_{HI}$





Adding gas to stellar mass restores a single continuous relation for all rotators.

$$M_b = M_* + M_g$$

Baryonic mass is the important physical quantity. It doesn't matter whether the mass is in stars or in gas.



Twice Nominal M*/L

Now instead of a translation, the slope pivots as we vary M^*/L .



Nominal M*/L

Now instead of a translation, the slope pivots as we vary M^*/L .



Half Nominal M*/L

Now instead of a translation, the slope pivots as we vary M^*/L .



Quarter Nominal M*/L

Now instead of a translation, the slope pivots as we vary M^*/L .



Zero M*/L

Now instead of a translation, the slope pivots as we vary M^*/L .



Low mass galaxies considerably expand range of the TF relation. Gas dominated galaxies can provide absolute calibration of mass scale.



Gotta believe the data.

Biggest challenge for low mass systems is the inclination

e.g., Begum et al. (2008) estimate inclinations from both optical and HI morphology. Only half agree to within 12% in sin(i).









Note that you can measure a line-width even if there is no evidence of rotation.





HI Tully-Fisher relation



Baryonic Tully-Fisher relation: slope & scatter depend on Velocity estimator



Gas dominated galaxies can provide absolute calibration of mass scale.



Systematic errors in M^*/L no longer dominate the error budget for galaxies with Mg > M^* .

Gas Rich Galaxy Baryonic Tully-Fisher relation (Stark et al 2009; Trachternach et al 2009; McGaugh 2011, 2012)



select $M_g > M_\star$

try fits with many different combinations of IMF and populations synthesis models

Table 4. BTF Fit to Gas Dominated Galaxies

 $M_b = A V_f^{\times}$

Subsample	Ν	$x_{v M}$	$A_{v M}$	$\chi^2_{ u,v M}$	$x_{M v}$	$A_{M v}$	$\chi^2_{ u,M v}$.	x_{bis}	A_{bis}
Portinari-Kroupa	23	3.77	2.08	1.28	4.11	1.43	1.18	3.93	1.78
Portinari-Salpeter	14	3.59	2.44	1.42	4.37	1.02	1.46	3.94	1.79
Portinari-Kennicutt	26	3.74	2.14	2.01	4.33	0.99	1.85	4.01	1.62
Bell-Scaled Salpeter	23	3.77	2.09	1.41	4.09	1.47	1.31	3.93	1.80
Bell-Kroupa	26	3.72	2.17	2.30	4.36	0.94	2.10	4.01	1.61
Bell-Bottema	36	3.55	2.45	2.02	3.96	1.63	2.06	3.74	2.06

slope $x = 3.94 \pm 0.07$ (random) ± 0.08 (systematic)

Stark, McGaugh, & Swaters (2009, AJ, 138, 392)

Fixing the slope to 4 gives $~A=47\pm 6~{
m M}_{\odot}\,{
m km}^{-4}\,{
m s}^4$



histogram: data line: distribution expected from observational uncertainties.

The data are consistent with zero intrinsic scatter.

Stellar mass-to-light ratios in good accord with population synthesis models









NGC 2403

UGC 128

Size/surface brightness variations from TF



Same (M,V) but very different size and surface density which is strange, since $V^2 = \frac{GM}{R}$

No residuals from TF with size or surface brightness

(Zwaan et al 1995; Sprayberry et al 1995; McGaugh & de Blok 1998)





Baryonic TF Relation

- Fundamentally a relation between the baryonic mass of a galaxy and its rotation velocity
 - $M_b = M_* + M_g = 47 V_f^4$ (McGaugh 2012)
 - doesn't matter if it is stars or gas
- Intrinsic scatter negligibly small
 - Can mostly be accounted for by the expected variation in stellar M*/L
- Physical basis of the relation remains unclear

Relation has real physical units if slope has integer value -Slope appears to be 4 *if* Vflat is used.