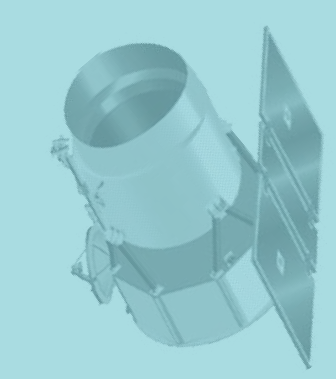
Calibrating the WISE W1 & W2 Tully-Fisher Relation

WISE
Nearby
Galaxy
Atlas

James Neill[1], Mark Seibert[2], Brent Tully[3], Helene Courtois[4], Jenny Sorce[4], T.H. Jarrett[5], Vicky Scowcroft[2], Frank Masci[6], Barry Madore[2],

[1]Caltech, [2]Carnegie Observatories, [3]University of Hawaii, [4]University of Lyon, [5]University of Capetown, [6]IPAC

Neill, J., Seibert, M., Tully, B. et al. 2014, ApJ, 792, 129

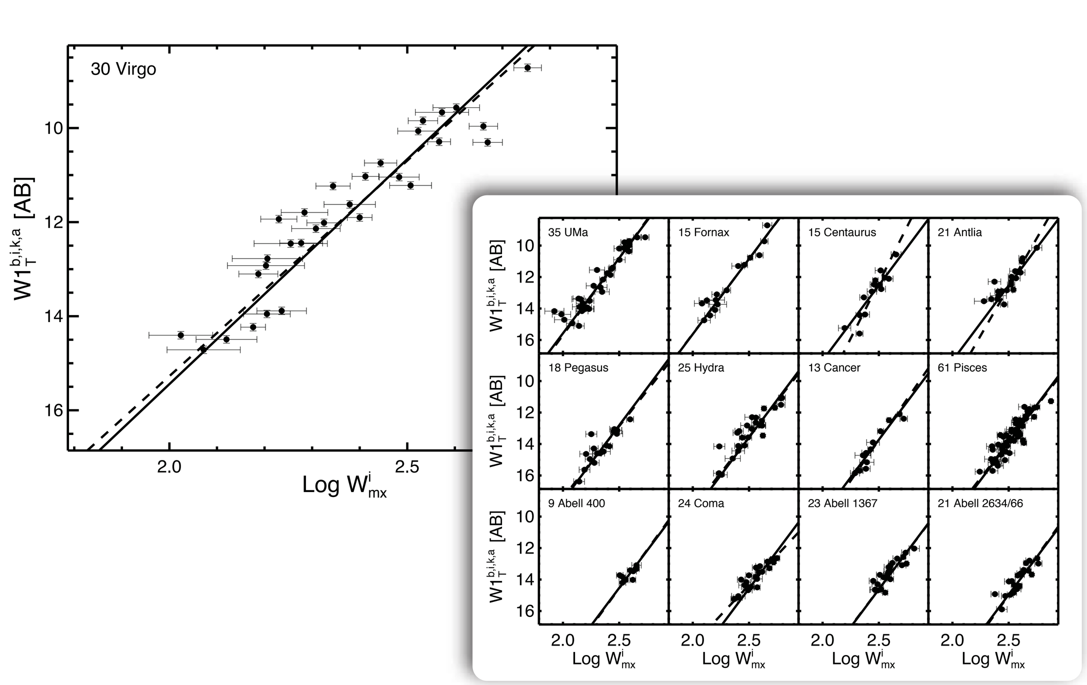


1. ABSTRACT

In order to explore local large-scale structures and velocity fields, accurate galaxy distance measures are needed. We extend the well-tested recipe for calibrating the correlation between galaxy rotation rates and luminosities – capable of providing such distance measures – to the all-sky, space-based imaging data from the Wide-field Infrared Survey Explorer (WISE) W1 (3.4μm) and W2 (4.6μm) filters. We present an HI linewidth to absolute magnitude correlation (known as the Tully-Fisher Relation, TFR) derived from from 310 galaxies in 13 clusters. We also update the I-band TFR using a sample 9% larger than in Tully & Courtois (2012). We find that the WISE TFRs show evidence of curvature and use quadratic fits to characterize this curved TFR for W1 and W2. These curved TFRs compared to the linear TFR reduce the scatter in the relations, but more importantly reduce a distance systematic when compared with the I-band TFR. Using our three independent TFRs (W1-curved, W2-curved and I-band), we calibrate the UNION2 supernova Type Ia sample distance scale and derive $H_0 = 74.4 \pm 1.4(\mathrm{stat}) \pm 2.4(\mathrm{sys})$ km s^{-1} Mpc^{-1} with 4% total error.

2. METHOD

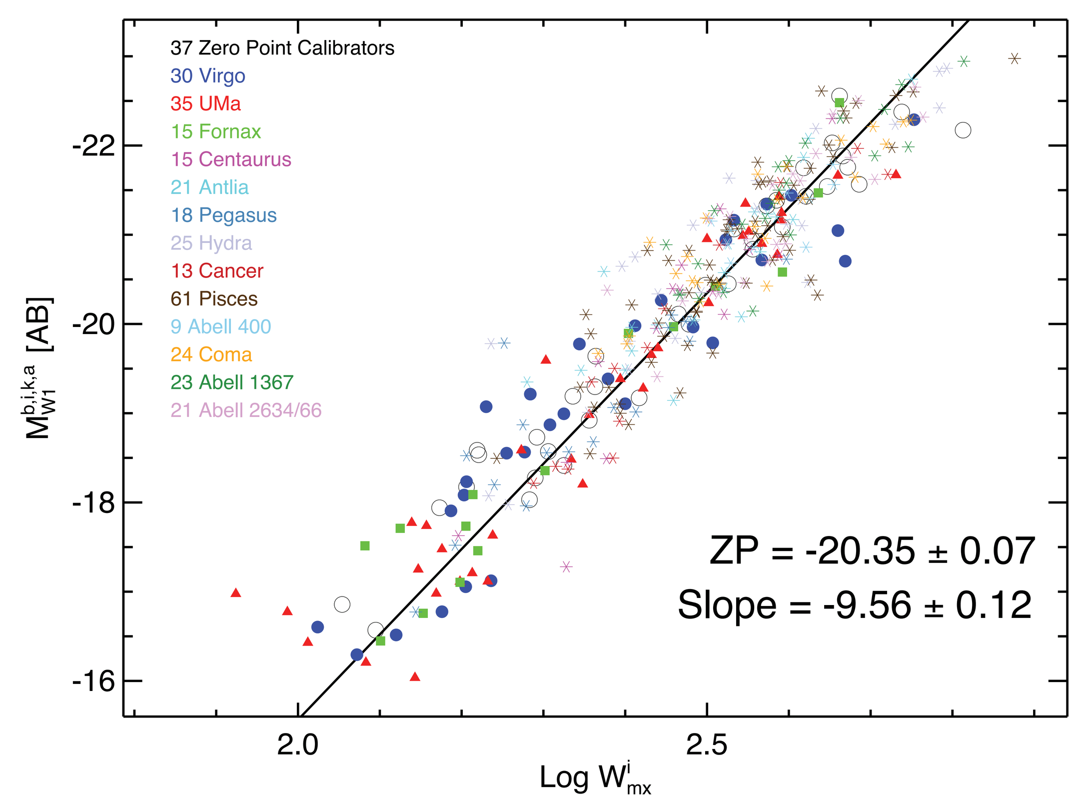
The TFR posits a universal slope in luminosity versus HI linewidth (W_{mx}). We adopt the galaxy cluster technique for deriving the calibration of this relation described by Tully & Courtois (2012). We take advantage of the fact that the galaxies within a given cluster are at the same distance and that the galaxy masses, and hence HI linewidths, span a range large enough to determine the slope of the correlation for each cluster. We then shift each cluster along the luminosity axis such that their data appear to be from a single cluster (plots below, dashed lines). We iteratively combine the galaxy data derived from a set of 13 nearby clusters to derive a universal slope (plots below, solid lines), and then set the zero-point of the relation using the universal slope applied to nearby galaxies with accurate distance measurements derived from independent techniques. To minimize the effect of the Malmquist bias, the slopes are derived from fitting the inverse Tully-Fisher relation (Willick, 1994). We use galaxy total WISE magnitudes from the WNGA (Seibert et al. 2015, see poster 32) and HI linewidths from the Cosmic Flows project (Tully et al. 2013). After applying various quality cuts, our total sample is 310 galaxies. Details can be found in Neill et al. (2014).



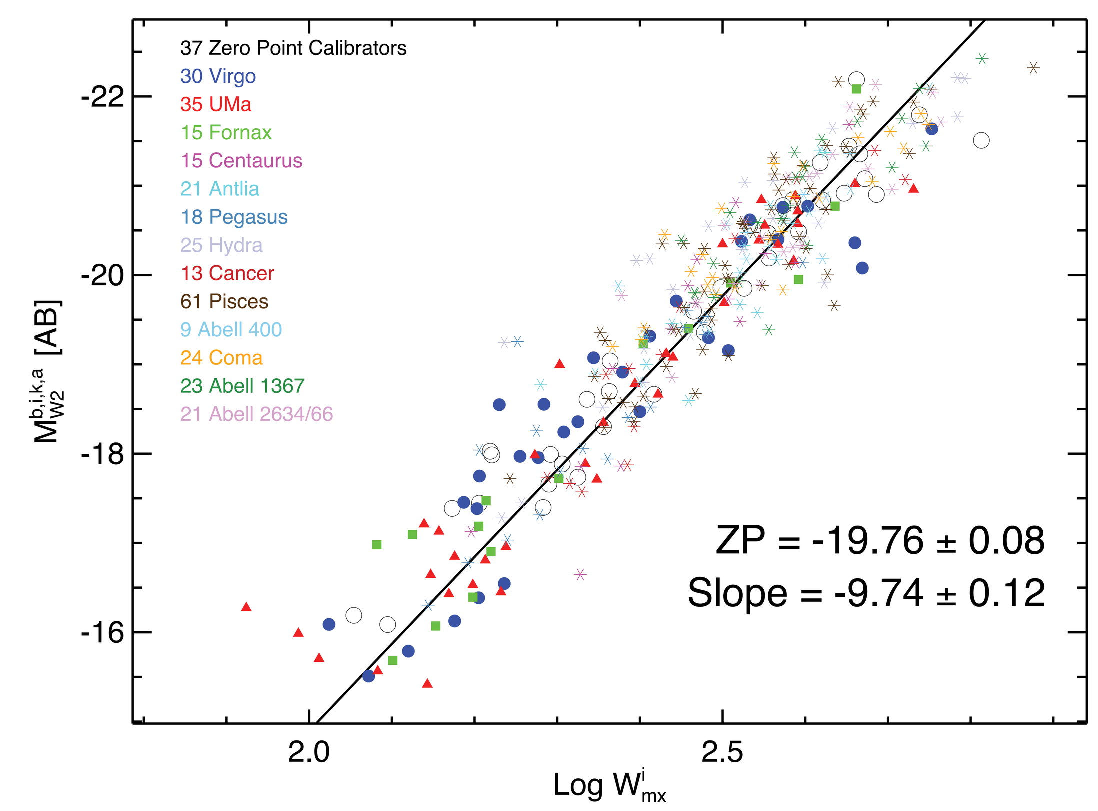
3. RESULTS

Our results are summarized in the four TFR plots and table below. The top two figures represent the linear fits for W1 and W2. The lower two figures represent a curved fits to the WISE TFRs.

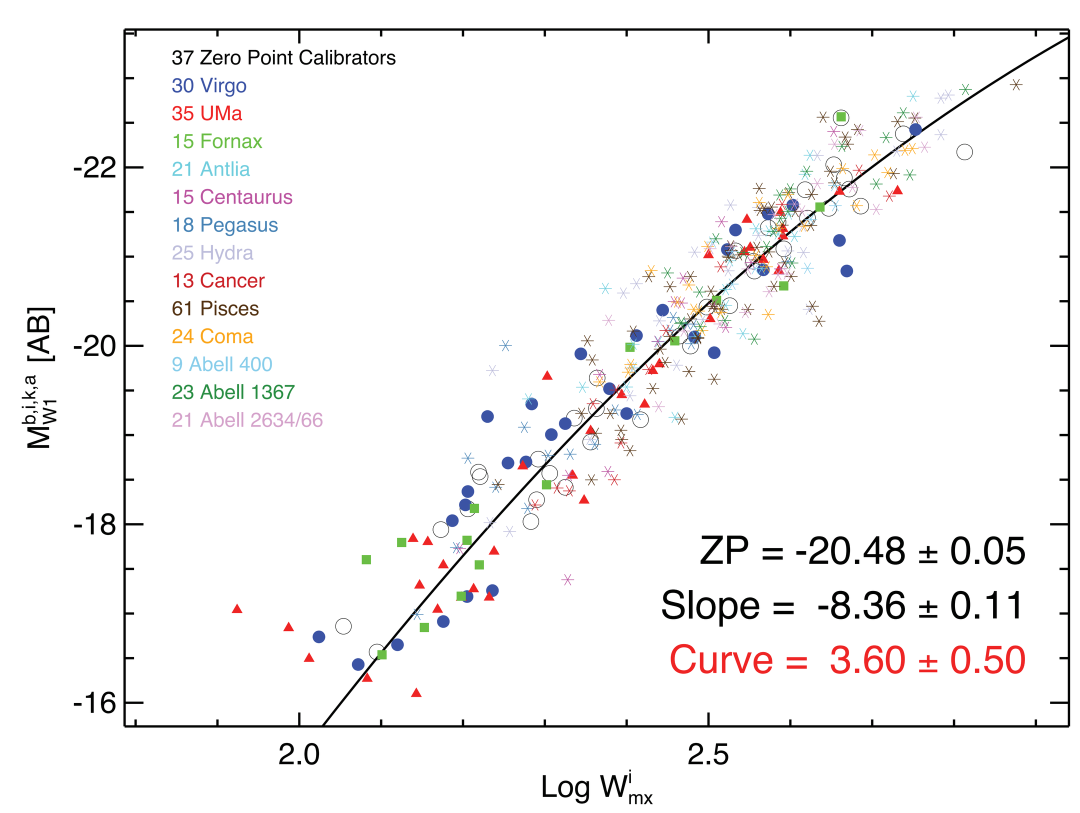
Curvature in the near-IR TFR has also been seen using H-band luminosities (Aaronson, 1986). Quadratic fits are also used in Sakai et al. 2000 (HST Key Project) for the BVRIH bands which show an increase in the curvature term with wavelength. The curved WISE TFRs offer an improvement over the linear WISE TFRs and provide the lowest scatter relying solely on WISE magnitudes (no color-correction using non-WISE photometry).



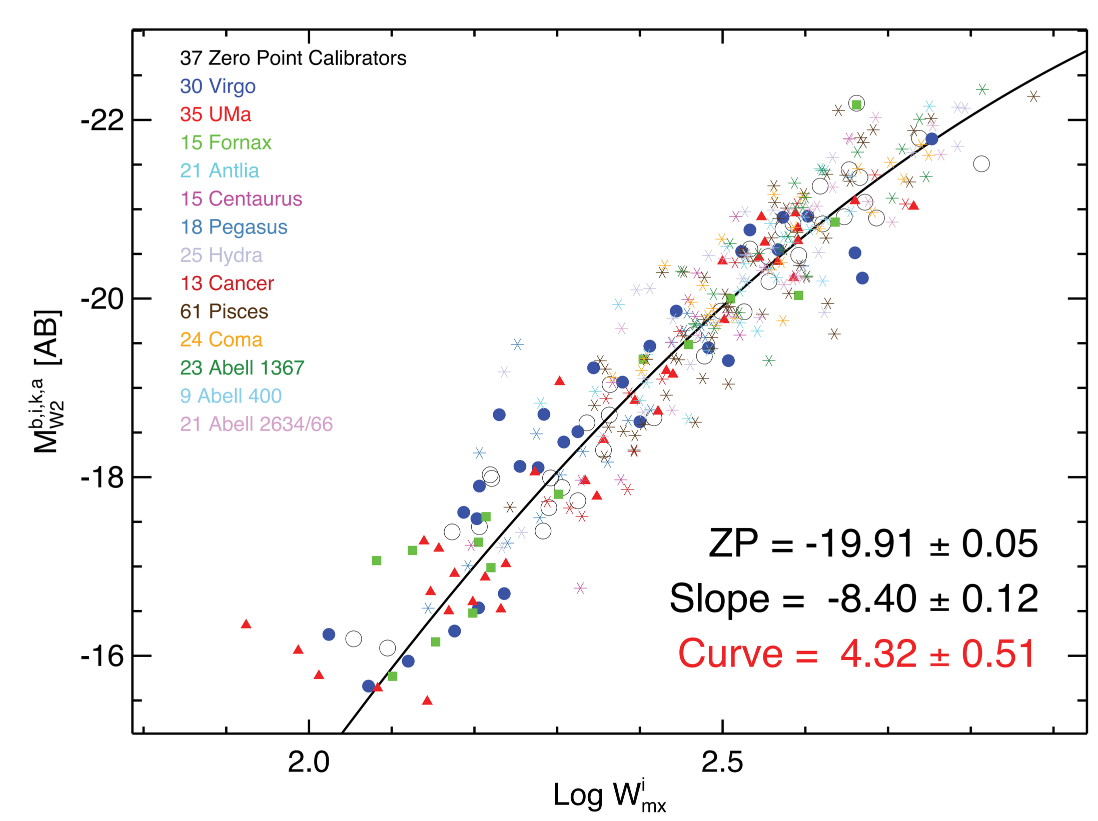
Linear TFR with slope fit to the galaxies in 13 clusters and the absolute magnitude scale set by 37 zero-point calibrators for W1.



Linear TFR with slope fit to the galaxies in 13 clusters and the absolute magnitude scale set by 37 zero-point calibrators for W2.



Curved TFR with slope fit to the galaxies in 13 clusters and the absolute magnitude scale set by 37 zero-point calibrators for W1.

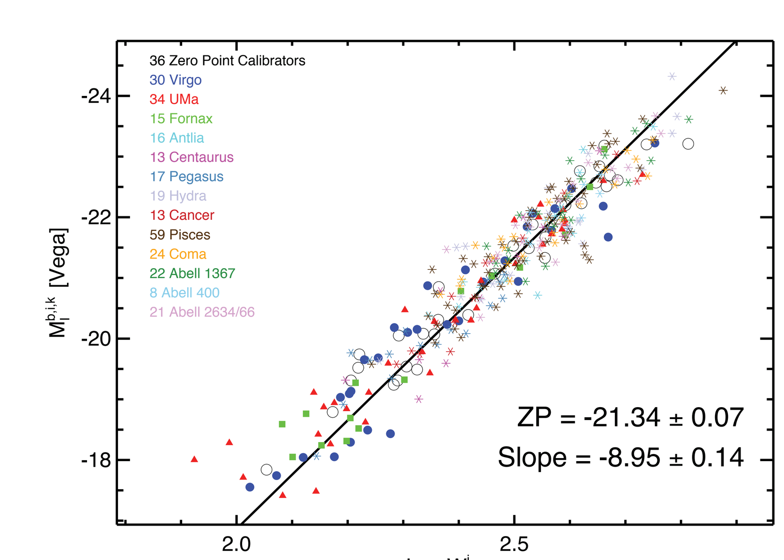


Curved TFR with slope fit to the galaxies in 13 clusters and the absolute magnitude scale set by 37 zero-point calibrators for W2.

TFR Parameter Comparison

Reference	Photometry	Universal Slope/Curve				Zero Point		
		N gal	Slope	Curve	rms	N gal	Mag	rms
Tully & Courtois (2012)	I-band (Vega)	267	−8.81 ± 0.16	...	0.41	36	−21.39 ± 0.07	0.36
This work	I-band (Vega)	291	−8.95 ± 0.14	...	0.46	36	−21.34 ± 0.07	0.40
Sorce et al. (2013)	IRAC [3.6] (AB)	213	−9.74 ± 0.22	...	0.49	26	−20.34 ± 0.10	0.44
This work	linear W1 (AB)	310	−9.56 ± 0.12	...	0.54	37	−20.35 ± 0.07	0.45
This work	curved W1 (AB)	310	−8.36 ± 0.11	3.60 ± 0.50	0.52	37	−20.48 ± 0.05	0.39
Lagattuta et al. (2013)	M_{corr} (AB)	568	−10.05	...	0.69	...	−19.54	...
This work	linear W2 (AB)	310	−9.74 ± 0.12	...	0.56	37	−19.76 ± 0.08	0.49
This work	curved W2 (AB)	310	−8.40 ± 0.12	4.32 ± 0.51	0.55	37	−19.91 ± 0.05	0.43

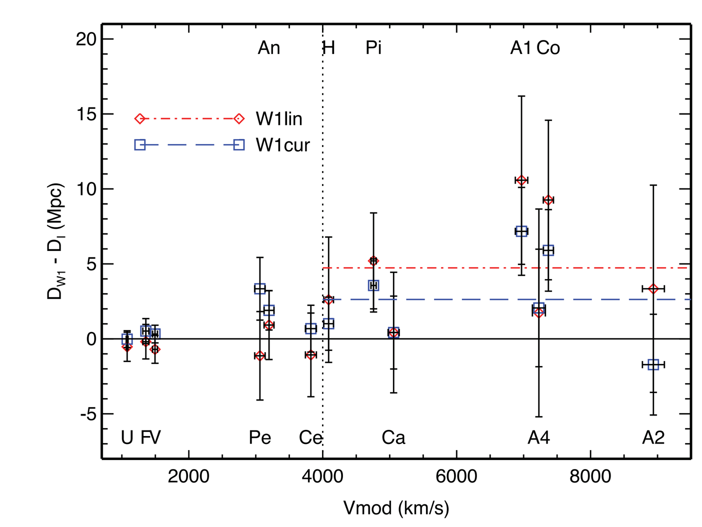
We also include the updated calibration for the I-band.



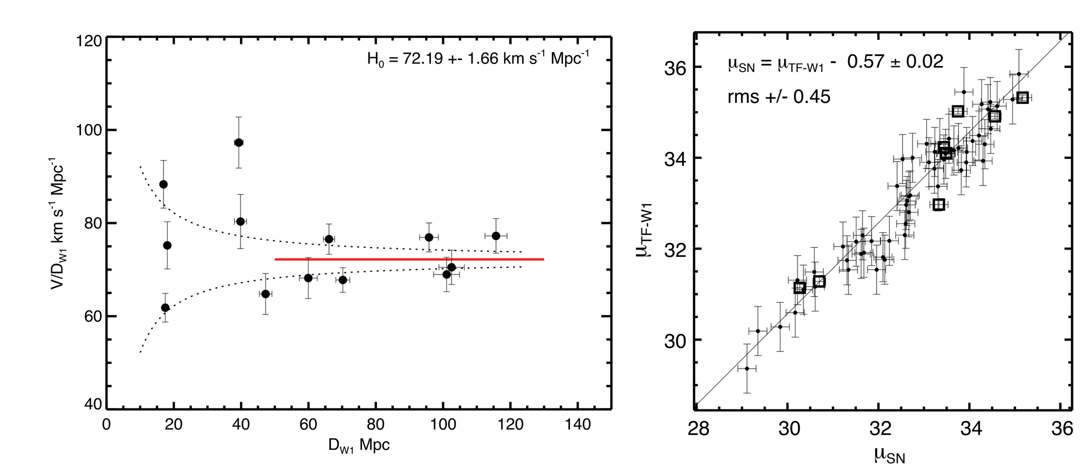
Linear TFR with slope fit to the galaxies in 13 clusters and the absolute magnitude scale set by 37 zero-point calibrators for the I-band.

4. APPLICATION

The final step before applying our calibration to distance measurement is to account for a residual bias due to the way photometry errors interact with the faint end of our sample. This allows us to use the distances derived from our TFR calibration for calculating the Hubble constant, H_0. The figure below illustrates our motivation for using a curved TFR: when compared with the I-band distances, the linear WISE TFR distances (red diamonds and lines) exhibit a systematic offset with distance that could bias our H_0 calculations. The curved WISE TFR distances (blue boxes and lines) are an improvement, although some bias could still exist.



The figure below left shows H_0 derived for each of the calibration clusters with the solid red line indicating the average value for clusters within the Hubble flow.



We perform a re-normalization of the UNION2 SN Ia sample (Amanullah et al. 2010, normalized to $H_0 = 100$) as illustrated in the above right figure, which shows the distance modulus offset when comparing TFR and UNION2 SN Ia distances. This offset allows us to calculate a more accurate H_0 from a sample that is well within the Hubble flow. The table below compares the various values of H_0 produced by our work and in the literature.

Hubble Constant Comparison

Reference	TFR band	Clusters [2,3]	SNe Ia[3,4]
Tully & Courtois (2012)	I-band	75.1 ± 1.0	...
Courtois & Tully (2012)	I-band	...	75.9 ± 3.8
This work	I-band	74.5 ± 1.6	75.9 ± 2.5
This work	W1 linear	71 ± 2	73.0 ± 2.7
This work	W2 linear	70 ± 2	72.7 ± 2.7
This work	W1curved	72 ± 2	73.7 ± 2.4
This work	W2curved	72 ± 2	73.7 ± 2.4
This work	<W1cur, W2cur, I>	73 ± 1	74.4 ± 2.8[5]

[2] seven clusters with $V_{mod} > 4000$ km s^{-1}
[3] km s^{-1} Mpc^{-1}
[4] offsets applied to UNION2 SNIa sample (Amanullah et al. 2010)
[5] includes statistical and systematic errors

5. REFERENCES

Aaronson, M., Bothun, G., Mould, J., et al. 1986, ApJ, 302, 536
Amanullah, R., Lidman, C., Rubin, D., et al. 2010, ApJ, 716, 712
Lagattuta, D. J., Mould, J. R., Staveley-Smith, L., et al. 2013, ApJ, 771, 88
Sakai, S., Mould, J. R., Hughes, S. M. G., et al. 2000, ApJ, 529, 698
Seibert, M., Neill, J., et al. 2015, in prep.
Sorce., J., Courtois, H., Tully, B., et al. 2013, ApJ, 765, 94
Tully, R. B., & Courtois, H. M. 2012, ApJ, 749, 78
Willick, J. A. 1994, ApJS, 92, 1