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Calibration of the Faber-Jackson relation for M31 globular clusters using Hipparcos data

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ABSTRACT

In this paper we present a data analysis regarding globular clusters as possible extragalactic distance indicators. For this purpose, we collected all velocity dispersion measurements published for galactic and M31 globular clusters. The slope and the zero-point of the Faber-Jackson relation were calibrated using Hipparcos distance measurements, and the relation was applied to extragalactic globular clusters in M31. A distance modulus of 24.12 ± 0.45 mag was found. This is coherent with what is found by fitting the red giant branches of globular clusters (24.47 ± 0.07, Holland 98), and is found from the peak of globular clusters luminosity function (24.03 ± 0.23, Ostriker and Gnedin 97), but shorter than the 24.7 ± 0.2 mag (Lanoix et al. 98) and 24.77 ± 0.11 mag (Feast and Catchpole 97), obtained by using Hipparcos data to calibrate the Cepheid period-luminosity. This calibrated Faber-Jackson relation can now be directly use for other Sc galaxies with resolved globular clusters, as soon as large amounts of spectra will become available, e.g., through the VLT.

Key words: globular cluster – extragalactic distance scale

1 INTRODUCTION

Since the 1970's much effort has been made to measure velocity dispersions of globular clusters (gc's) in the Galaxy and later in M31 (Peterson 88). Ten years after these pioneering measurements, new measurements have been published using essentially 3m (Dubath and Grillmair 97) to 10m (Djorgovski et al. 97) telescopes. Concordingly, the data of the Hipparcos satellite has been made available and the distance of galactic gc's can be derived from parallaxes independent of any standard candles. Detailed correlations of gc's properties analogous to elliptical galaxies properties, such as the Faber-Jackson (FJ) relation have been studied for the Galactic system (Meylan and Mayor 86, Paturel and Garnier 92, Fournier et al. 95, Djorgovski and Meylan 94, Djorgovski 95). A recent careful analysis of these properties for the extragalactic system of M31 can be found in Djorgovski et al. 97. In particular we consider that Djorgovski et al. 97 have demonstrated that M31 and the Galaxy gc's are similar systems in terms of metallicity. In agreement with all these studies, we show the validity of a FJ for gc's, and propose a calibration of the relation with the new Hipparcos data.

Section 2 describes the collection of data, section 3 includes the analysis and gives the calibration of the Faber-Jackson relation. In section 4, the calibrated relation is applied to M31 gc's and a distance modulus is derived in agreement with recent independent measurements, showing that this calibrated relation can now be applied to any unbiased set of extragalactic gc's of an Sc host galaxy.

2 THE DATA

2.1 The galactic globular clusters

2.1.1 Data up to 1997

In Table 1, we present all the published measurements of the velocity dispersion for 56 galactic gc's. In Table 1, one can find in columns : (1) NGC name, (2) the integrated apparent V magnitude, (3) the absolute V magnitude, (4) a raw average of all measurements of the velocity dispersion, from the compilation of 38 references in Pryor and Meylan 93 (PRY93), (5) the velocity dispersion from Dubath and Grillmair 97 (DUB97), Zaggia 91 (ZAG91), Illingworth 76 (ILL76), or an asterix if no measurement from an integrated light spectrum was available, (6) the distance modulus.

Data in columns (2), (3), (6), were taken from the electronic version dated 15th May 1997 of Harris 96 compilation.

2.1.2 Data from Hipparcos

For 11 galactic gc's we found new distance measurements from the Hipparcos observations. They are shown in Table 2. In Table 2, one can find in columns : (1) NGC name, (2) Hipparcos distance modulus measurements with reference number, (3) average of Hipparcos distance modulus measurements, (4) absolute V magnitude from Harris 97, (5) calculated absolute V magnitude using Hipparcos data, see section 3.2, (6) an asterix if the available velocity dispersion comes from individual star spectra.

2.2 Andromeda globular clusters

In Table 3 we present the data concerning 29 gc's of M31 with a published measurement of their velocity dispersion. Columns of Table 3 correspond to: (1) Name from Sargent et al. 77, (2) apparent V magnitude, (3) radial velocity, (4) all velocity dispersion measurements with reference, (5) mean velocity dispersion as used for the calculations in this paper. Velocity dispersion measurements are taken from Djorgovski et al. 97, Dubath and Grillmair 97, Dubath et al. 97, Peterson 88. All apparent magnitudes and mean radial velocities come from Huchra et al. 91.

3 THE ANALYSIS

3.1 The galactic globular clusters before Hipparcos

Using the 56 galactic gc's with a measured velocity dispersion, we performed a mean linear regression, assuming the errors are both on the absolute magnitudes and on the $log\sigma' s$. We obtain with one cluster (NGC 2419) rejected at 3σ :

$$M_V = (-4.00 \pm 0.33) log\sigma + (-4.71 \pm 0.27), \quad (1)$$

the direct linear regression (assuming larger errors on dispersions than on absolute magnitudes) gives:

$$M_V = (-3.29 \pm 0.33) log\sigma + (-5.24 \pm 0.27), \quad (2)$$

with r=0.81, r being the Pearson correlation factor, and a dispersion around the FJ relation of Disp=0.68.

Considering that a globular cluster is constituted by some hundreds of thousands of stars, we chose for a second analysis to eliminate the velocity dispersion data originating from the measurements of singular star radial velocities. As a matter of fact this kind of observations involve at the worst around 10 stars and at the best around 150 stars. The selection of the stars for observation strategy involves choosing bright stars or periferic ones. The selection criteria for the observation of those stars will obviously affect the measurement by adding biases such as the Malmquist one.
Eliminating gc's with a velocity dispersion measured from individual stars spectra and keeping only the measurements obtained from integrated light spectra, we obtained a subsample of 31 gc's. We performed a mean linear regression, and obtained with no cluster rejected at 3σ :

$$M_V = (-4.12 \pm 0.57) log\sigma + (-4.49 \pm 0.51), \quad (3)$$

the direct linear regression gives :

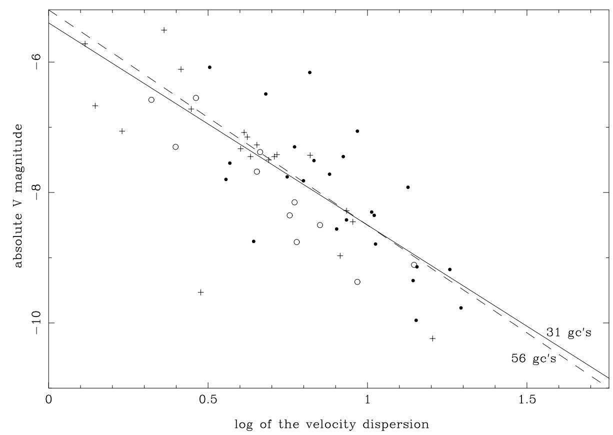

Figure 1. The Faber-Jackson relation for 56 galactic globular clusters, obtained with all the measurements (dashed line) and with only velocity dispersions (31 gc's) measured from an integrated light spectrum (solid line). The 11 gc's which will be calibrated by Hipparcos later in the paper are in open circles, the remaining 21 gc's with individual star measurement are plotted as crosses and the remaining 24 gc's with a velocity dispersion measured from an integrated light spectrum are plotted in filled circles.

$$M_V = (-3.08 \pm 0.57) log\sigma + (-5.39 \pm 0.51), \quad (4)$$

with r=0.71, r being the Pearson correlation factor, and a dispersion around the FJ relation of Disp=0.73.

One can see on Figure 1 the mean FJ relations for the 56 gc's obtained with all measurements (dashed line) and with only velocity dispersions (31 gc's) measured from an integrated light spectrum (solid line).

Excluding the 7 gc's calibrated by Hipparcos, the direct regression on the 24 remaining gc's gives, with no rejection :

$$M_V = (-3.33 \pm 0.71) log\sigma + (-5.03 \pm 0.66), \quad (5)$$

with r=0.71, and Disp=0.75.

3.2 The FJ calibration from globular clusters measured by Hipparcos

For 11 gc's with a new distance determination obtained by Hipparcos, we can re-calculate their absolute magnitude. In order to take into account the same extinction correction as in Harris 97 on the apparent magnitudes, we recalculated the absolute magnitude in V using:

$$M_V post = -dist.mod.Hip. + 5(logd) - 5 + M_V pre, \quad (6)$$

with d and $M_V pre$ from Harris 97 as in Table 1, and dist. mod. Hip. as in the third column of Table 2. The updated $M_V post$ magnitude is found in the fifth column of Table 2.

According to Hipparcos the clusters are systematically further away than thought from previous measurements. *In the mean we observe a shift of 0.34 mag between pre and post-Hipparcos measurements.* We performed a direct linear regression on the 11 gc's, assuming larger errors on the $log\sigma$'s than on the absolute magnitude, and obtain with no cluster rejected at 3σ :

$$M_V pre = (-3.59 \pm 0.50) log\sigma + (-5.44 \pm 0.38), \quad (7)$$

with r=0.92 and Disp=0.39.

$$M_V post = (-3.46 \pm 0.47) log\sigma + (-5.88 \pm 0.35), \quad (8)$$

with r=0.93 and Disp=0.37.

7 out of these 11 clusters have a velocity dispersion measured from an integrated light spectrum, we obtain for these 7 clusters, with zero rejection at 3σ , the direct regression :

$$M_V pre = (-3.58 \pm 0.66) log\sigma + (-5.48 \pm 0.52), \quad (9)$$

with r=0.92 and Disp=0.42.

$$M_V post = (-3.39 \pm 0.58) log\sigma + (-6.01 \pm 0.46), \quad (10)$$

with r=0.93 and Disp=0.37.

One can see in Figure 2 the direct pre-Hipparcos FJ relation obtained with only velocity dispersions measured from an integrated light spectrum (equation 9) in solid line and the direct post-Hipparcos (equation 10) in doted line. The dashed line reminds us of the direct FJ relation found for the subsample of 24 gc's studied previously (equation 5) excluding these former 7 gc's.

From Figure 2 a clear shift (about 1 mag) in the zero point between the 24 gc's sample and the post-Hipparcos one is noted, while the slope is not significantly modified. But only part of the offset arises from the Hipparcos result.

We have already seen in Figure 1 that the gc's measured by Hipparcos lie systematically below the fits of the FJ relations and in Figure 2, this is explicitely shown. We calculated an average difference of 0.55 mag between the FJ relation fitted on the 24 gc's and the pre-Hipparcos absolute magnitudes of the 7 gc's. Obviously the Hipparcos observations were dedicated to intrinsic bright gc's.

As we noted previously, the difference between the pre and post-Hipparcos absolute magnitudes is in the mean of 0.34 mag.

This means the real offset coming from the Hipparcos measurements is not of 1 mag but a shift of 0.34 mag on the 24 gc's. After shifting these gc's towards brighter absolute magnitudes, we obtain the calibrated direct FJ relation, (31 calibrated gc's):

$$M_V FJ = (-3.0 \pm 0.3) log\sigma + (-5.8 \pm 0.1) \quad (11)$$

3.3 Andromeda globular clusters

From Table 3 we eliminated 3 gc's : M31-279, M31-315, M31-090 for which no reliable measurement of the velocity dispersion is available.

Using the remaining 26 values of velocity dispersions, we looked for a correlation with the *apparent* V magnitude, taking into account that all these clusters are approximately at the same distance from the observer. If one finds a slope in apparent magnitude in agreement with the slope in absolute magnitude obtained for gc's in the Galaxy, one could suppose the sample isn't affected by a Malmquist bias regarding the selection of the extragalactic gc's. We obtained the best mean regression fit, after rejecting M31-144 and M31-219 at 3σ:

$$m_V = (-4.2 \pm 0.4) log\sigma + (20.0 \pm 0.5) \quad (12)$$

the direct linear regression gives :

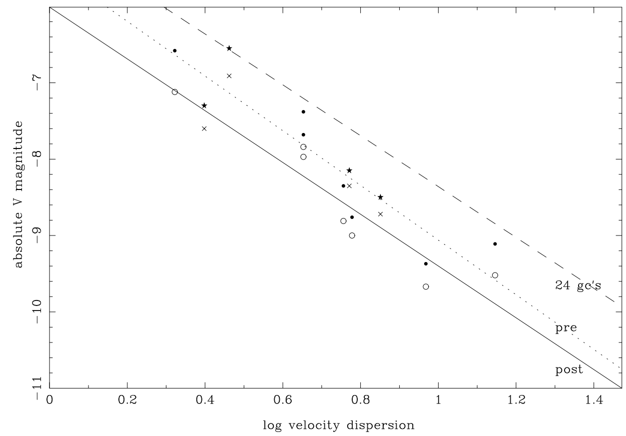

Figure 2. For the 7 gc's calibrated by Hipparcos and with a measurement of the velocity dispersion from an integrated light spectrum, one can see the pre-Hipparcos absolute magnitudes (filled circles) and the post-Hipparcos ones (open circles). For the 4 remaining gc's calibrated by Hipparcos and with a measurement of the velocity dispersion from singular star spectra one can see the pre-Hipparcos absolute magnitudes (filled stars) and the post-Hipparcos ones (crosses). The solid line represents the direct post-Hipparcos Faber-Jackson relation for 7 gc's both measured by Hipparcos and with velocity dispersions measured from an integrated light spectrum, the dotted line is the direct pre-Hipparcos relation. The dashed line reminds us of the direct FJ relation found for the subsample of 24 gc's studied previously. We observe a systematic shift towards brighter magnitudes on the zero points while the slopes are not significantly modified.

$$M_V = (-3.7 \pm 0.4) log\sigma + (19.4 \pm 0.5), \quad (13)$$

with r=0.87, Disp=0.34.

The slopes are quite coherent with the slopes obtained for the galactic globular clusters (equations 1-5) and the differences of slopes are included in the error bars. The direct FJ relation for M31 gc's is also coherent with the direct FJ relation calibrated from Hipparcos (equations 7-10). We conclude that this sample of extragalactic gc's can be considered as free from bias (although it is not complete of course). And thus we can apply our calibrated galactic direct Faber-Jackson relation to this sample.

We should also note that the velocity dispersions measured in M31 gc's are systematically larger than for the ones given in our galaxy. This is due to an observational selection effect, the intrinsic bright gc's which are easier to observe from a distance, have a larger velocity dispersion. From various comparative studies of the galactic and the M31 gc's systems, in particular on the metallicity, we can suppose the two systems are globally comparable. With the Very Large Telescope, one will be able to measure a larger sample of gc's in M31 and to compare the distribution in velocity dispersions.

We considered a foreground reddening of 0.1 mag (Frogel et al. 80). The absorption was taken to be 3.2 times the reddening (Da Costa and Armandroff 90).
Applying equation 11 to our sample we obtain the distance moduli shown in Figure 3. The resulting mean distance modulus for M31 is : 24.12. If we use the extremes given by the error bars on the slope and zero point of equation 11 we

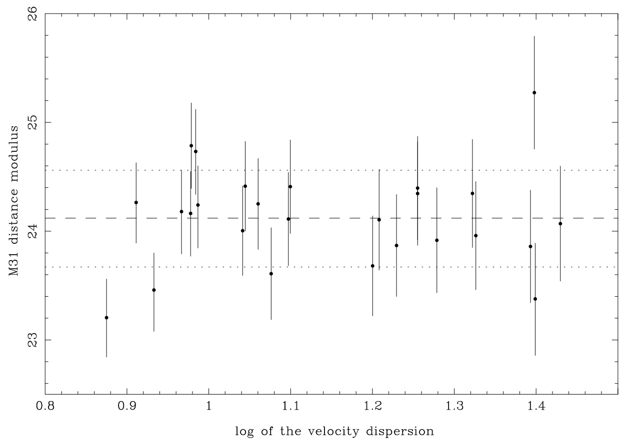

Figure 3. M31 distance modulus versus $log\sigma$, obtained from equation 11 and corrected for absorption, for 26 globular clusters.

obtain a mean error on the distance modulus of ± 0.45 mag In Figure 3 we draw the error bars for each gc given by the lowest slope and zero point and by the highest ones. The huge error bar on the determination of the distance modulus is directly due to the small numbers of objects involved in this analysis and large dispersions on the FJ relations.

One can see in Figure 3 that despite the poor common range of velocity dispersions between the galactic and M31 gc's available (0.85 to 1.15), there is no systematic effect seen towards larger dispersions on the calculated distance moduli. This implies that the slope of the FJ relation is similar to the one in our galaxy, as we suggested previously from the study of the apparent magnitudes versus the velocity dispersions.

4 CONCLUSION

In this paper, we present an analysis of globular cluster velocity dispersions as possible distance indicators. Using Hipparcos recent set of distance measurements published for 11 galactic gc's, we give a calibration of the Faber-Jackson relation for gc's. This calibration is used on 26 gc's in M31, to derive a mean distance modulus 24.12 ± 0.45 mag. The value we find is coherent with what is found by fitting the red giant branches of gc's (24.47 ± 0.07, Holland 98), and found from the peak of gc's luminosity function (24.03 ± 0.23, Ostriker and Gnedin 97), but shorter than the 24.7 ± 0.2 mag (Lanoix et al. 98) and 24.77 ± 0.11 mag (Feast and Catchpole 97), obtained by using Hipparcos data to calibrate the Cepheid period-luminosity. We also demonstrated that this calibration can be used for extragalactic gc's systems in an Sc host galaxy even though it's accuracy of 0.45 mag is not so good. The huge error bar on the determination of the distance modulus is directly due to the small numbers of objects involved in this analysis and large dispersions on the FJ relations. This shows a need to enlarge the set of galactic and M31 gc's measured in velocity dispersions.

Future measurements with the VLT for galaxies as far as Virgo will be ready for use with this calibration independent of any standard candles.

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Table 1. Galactic globular clusters

NGC (1)	m_{Vt} (2)	$M_V t$ (3)	σ km/s raw average from PRY93 (4)	σ km/s from integrated light spectra or * = from star spectra (5)	R_{sun} kpc (6)
104	3.95	-9.37	11.5	9.3 DUB97	4.3
288	8.09	-6.55	2.9	*	8.1
362	6.40	-8.35	6.4	5.7 DUB97	8.3
1851	7.14	-8.35	10.4	10.5 DUB97	12.2
1904	7.73	-7.80	5.2	3.6 DUB97	12.6
2419	10.39	-9.53	3.0	*	82.3
2808	6.20	-9.35	13.4	13.9 ZAG91	9.3
3201	6.75	-7.42	5.2	*	5.1
4147	10.32	-6.11	2.6	*	18.8
4590	7.84	-7.30	2.5	*	10.1
5053	9.47	-6.67	1.4	*	16.2
5139	3.68	-10.24	16.0	*	5.1
5272	6.30	-8.75	5.6	4.4 DUB97	10.0
5286	7.34	-8.56	8.0	8.0 DUB97	10.7
5466	9.04	-7.06	1.7	*	16.6
5694	10.17	-7.76	5.5	5.6 DUB97	33.9
5824	9.09	-8.79	11.6	10.6 DUB97	31.3
5904	5.65	-8.76	5.7	6.0 DUB97	7.3
5946	9.61	-7.55	3.7	3.7 DUB97	12.3
6093	7.33	-7.92	12.4	13.4 DUB97	8.7
6121	5.63	-7.15	4.2	*	2.2
6171	7.93	-7.08	4.1	*	6.3
6205	5.78	-8.50	7.1	*	7.0
6218	6.70	-7.27	4.5	*	4.7
6254	6.60	-7.43	6.6	*	4.3
6256	11.29	-6.16	6.5	6.6 DUB97	9.3
6266	6.45	-9.14	14.3	14.3 DUB97	6.7
6284	8.83	-7.82	6.2	6.3 DUB97	14.3
6293	8.22	-7.72	7.6	7.6 DUB97	8.8
6325	10.33	-7.30	5.8	5.9 DUB97	9.4
6341	6.44	-8.15	5.9	*	8.1
6342	9.66	-6.49	4.6	4.8 DUB97	9.1
6366	9.20	-5.72	1.3	*	3.6
6362	7.73	-6.72	2.8	*	7.5
6388	6.72	-9.77	18.9	18.9 ILL76	11.5
6397	5.73	-6.58	4.5	2.1 DUB97	2.2
6441	7.15	-9.18	18.0	18.1 DUB97	9.7
6522	8.27	-7.51	6.7	6.8 DUB97	7.0
6535	10.47	-4.68	2.4	*	6.8
6541	6.30	-8.42	8.2	8.6 ZAG91	7.4
6558	9.26	-6.08	2.9	3.2 DUB97	6.4
6624	7.87	-7.45	5.4	8.4 ZAG91	7.9
6626	6.79	-8.28	8.6	*	5.7
6656	5.10	-8.45	9.0	*	3.2
6681	7.87	-7.06	5.1	9.3 DUB97	8.7
6712	8.10	-7.45	4.3	*	6.7
6715	7.60	-9.96	14.2	14.2 ILL76	26.2
6752	5.40	-7.68	4.5	4.5 DUB97	3.9
6779	8.37	-7.33	4.0	*	9.9
6809	6.32	-7.50	4.9	*	5.3
6838	8.19	-5.51	2.3	*	3.8
6864	8.52	-8.30	10.3	10.3 ILL76	18.4
6934	8.83	-7.45	5.1	*	15.2
7078	6.20	-9.11	12.0	14.0 DUB97	10.2
7089	6.47	-8.97	8.2	*	11.4
7099	7.19	-7.38	5.6	4.6 DUB97	7.9

Table 2. New distance determinations from Hipparcos. References: (1) Gratton et al. 97a, (2) Bartkevicius et al. 97, (3) Reid in Heber et al. 97, (4) Gratton et al. in Heber et al. 97, (5) Pont et al. 97.

NGC (1)	Hipparcos distance moduli (2)	average (3)	pre-Hipparcos M_V (4)	post-Hipparcos M_V (5)	* = star spectra (6)
104	13.63 (1) 13.3 (2)	13.47	-9.37	-9.67	
288	14.95 (1) 15.00 (3) 14.76 (4)	14.90	-6.55	-6.91	*
362	15.06 (1)	15.06	-8.35	-8.81	
4590	15.32 (1)	15.32	-7.30	-7.60	*
5904	14.61 (1) 14.53 (3) 14.58 (4) 14.5 (2)	14.56	-8.76	-9.00	
6205	14.45 (1)	14.45	-8.50	-8.72	*
6341	14.61+-0.08 (5) 14.81 (1) 14.93 (3) 14.83 (4)	14.74	-8.15	-8.35	*
6397	12.25 (3)	12.25	-6.58	-7.12	
6752	13.32 (1) 13.17 (3) 13.20 (4)	13.25	-7.68	-7.97	
7078	15.45 (3)	15.45	-9.11	-9.52	
7099	14.95 (1)	14.95	-7.38	-7.84	

Table 3. Andromeda globular clusters

Sargent et al. 77 (1)	m_V (2)	mean Vr km/s (3)	various σ km/s (4)	mean σ km/s (5)
M31-001	13.70	-331.0	25.06 Dj	25.06
M31-002	15.80	-380.0	9.70 Dj	9.70
M31-058	15.80	-226.3	10.60 Du 11.56 Dj	11.08
M31-064	15.00	-373.0	16.15 Dj	16.15
M31-072	14.60	-210.5	19.00 Pe	19.00
M31-073	14.60	-350.8	18.00 Pe 14.27 Dj 15.3 Du	15.86
M31-078	14.20	-414.0	24.00 Pe 25.46 Dj	24.73
M31-090	16.70	-412.0	<10.00	10.00
M31-105	16.30	-400.8	9.08 Dj 10.20 Du	9.64
M31-108	15.80	-404.0	9.82 Dj 8.70 Du	9.26
M31-144	15.60	-344.0	25.00 Pe	25.00
M31-199	15.40	-88.0	11.00 Pe *6.00 Du	11.00
M31-213	14.50	-186.5	40.00 Pe 21.90 Du 20.50 Dj	21.20
M31-217	14.90	-161.0	21.00 Pe	21.00
M31-219	15.10	-292.0	7.10 Du 8.11 Dj	7.50
M31-222	15.10	-241.0	18.00 Pe	18.00
M31-233	15.15	-325.0	18.00 Pe	18.00
M31-244	15.34	-53.0	12.00 Pe 13.20 Dj	12.51
M31-272	14.70	-215.2	16.30 Du 17.62 Dj	16.96
M31-279	15.35	-131.0	<10.00 Pe	10.00
M31-280	14.30	-164.8	26.90 Du >40 Pe	26.90
M31-302	14.90	-8.0	11.92 Dj	11.92
M31-305	15.63	-205.0	12.58 Dj	12.58
M31-312	16.05	-352.0	8.15 Dj	8.15
M31-315	15.60	-95.0	<10.00 Pe	10.00
M31-319	15.75	-360.0	9.10 Du 10.10 Dj	9.50
M31-322	15.59	-349.0	11.49 Dj	11.49
M31-351	15.18	-208.0	8.57 Dj	8.57
M31-352	16.37	-326.0	9.52 Dj	9.52