A Survey of Eclipsing Binary Stars in the Eastern Spiral Arm of M31

Ian Todd¹*, Don Pollacco¹, Ian Skillen², D.M. Bramich³, Steve Bell⁴ and Thomas Augusteijn⁵

¹APS Division, Department of Physics and Astronomy, Queen’s University of Belfast, Belfast, BT7 1NN, UK
²Isaac Newton Group of Telescopes, Apartado 321, E-38700 Santa Cruz de La Palma, Tenerife, Spain
³Department of Physics and Astronomy, University of St Andrews, North Haugh, Fife, KY16 9SS, UK
⁴HM Nautical Almanac Office, CCLRC Rutherford Appleton Laboratory, Chilton, Didcot, Oxon., OX11 0QX, UK
⁵Nordic Optical Telescope, Apartado 474, E-38700 Santa Cruz de La Palma, Tenerife, Spain

Accepted ????. Received ????; in original form ????

ABSTRACT

Results of an archival survey are presented using B-band imaging of the eastern spiral arm of M31. Focusing on the eclipsing binary star population, a matched-filter technique has been used to identify 280 binary systems. Of these, 127 systems (98 of which are newly discovered) have sufficient phase coverage to allow accurate orbital periods to be determined. At least nine of these binaries are detached systems which could, in principle, be used for distance determination. The light curves of the detached and other selected systems are presented along with a discussion of some of the more interesting binaries. The impact of unresolved stellar blends on these light curves is considered.

Key words: binaries: eclipsing, galaxies: Local Group, galaxies: M31

1 INTRODUCTION

The determination of accurate distances to the galaxies of the Local Group is of fundamental importance in several areas of modern astronomy. These galaxies serve as a natural laboratory for studies of stellar formation and evolution over a wide range of physical environments. A knowledge of their distances permits the determination of the intrinsic physical properties of their resolved stellar content and provides an insight into population synthesis modelling of the formation and evolution of galaxies. Furthermore, the Local Group galaxies provide a critical step in determining the cosmological distance scale by calibrating standard candles such as Cepheids, extending the distance ladder to galaxies far beyond the Local Group. This leads to a determination of the Hubble Constant and the age of the universe. Recent results, primarily from the Distance Scale Key Project (Freedman et al. 2001; Mould et al. 2004), have led to considerable progress in this field and $H_0$ is now believed to be known to a precision of 10 per cent. At this level, the uncertainty is dominated by two systematic effects – the absolute distance to the LMC (the first step in the extragalactic distance scale) and the possible dependence of the Cepheid Period-Luminosity relationship on metallicity.

Detached eclipsing binary stars (EBs) offer the possibility of determining the absolute properties of a stellar system such as masses and radii. Kaluzny et al. (1998) have suggested that observations of detached EBs can be used to determine accurate absolute luminosities and hence their distance to better than 5 per cent and possibly even 1 per cent; see also Andersen (1991); Clausen (2004). As these distances are based mainly on geometrical arguments with only limited physical input they are often considered to be amongst the most reliable. Hence, distances derived from EBs can be used to calibrate the Cepheid period-luminosity relationship. More recently it has been proposed by Wilson (2004) that semi-detached systems could be used (possibly in preference to detached systems) to the same end. While light curves from these systems may appear more complicated, the physical processes underlying the variations (e.g. irradiation and tidal effects) are now well understood.

Gaposhkin (1968) first suggested that EBs could be used to determine distances to the Magellanic Clouds (MCs). In fact in recent years it has become clear that distances derived from EBs can give distances at least comparable to that obtained from the Cepheid period-luminosity relationship. For example, Harries et al. (2003) and Hilditch et al. (2005) have studied 50 SMC binaries and derived a distance of 60.6 kpc with an uncertainty of $\sim 5$ per cent. Including results from other, equally reliable, surveys

* E-mail: I.Todd@qub.ac.uk
of SMC binaries lead to an overall dispersion in results of ~10 per cent which is most likely due to depth effects in this galaxy.

Beyond the MCs, the Andromeda Galaxy, M31, is an important distance scale calibrator. It does not suffer from the extreme metallicities of the MCs and, being a spiral galaxy, its geometry is far better understood than that of the irregular MCs. This galaxy is also a fundamental calibrator of the zero-points of the planetary nebula and globular cluster luminosity functions, and is the first step of the Tully-Fisher relationship for spiral galaxies. Consequently, M31 is a more appropriate Local Group standard calibrator than the LMC (Clementini et al. 2001). However, recent distance estimates for M31 based on Cepheids and the brightness of the tip of the red giant branch (e.g., McConnachie et al. 2003; Freedman et al. 2001) show discrepancies at the ~10 per cent level.

There have been several surveys of M31 specifically to detect variable stars. For example, Baade & Swope (1963) used photographic plates to identify 684 variables in four fields, ~58 per cent of which were Cepheids and a further 9 per cent EBs. Currently, a total of around 300 binaries are known from various surveys (Guinan 2004).

The DIRECT Project (Kahnyay et al. 1998) has been attempting to derive distances to M31 and M33 from EBs with sufficient accuracy to calibrate the Cepheid distances. Using 1.0-m telescopes they have discovered a total of ~130 EBs in both galaxies.

In this paper, we present the results of an analysis of archival images obtained over a three year baseline and centred on the eastern arm of M31. We use these data to identify eclipsing systems, with an emphasis on those suited to detailed follow-up and distance determination.

2 OBSERVATIONS AND DATA REDUCTION

The data forming the basis of this study were obtained over the period 2000-2003 by scheduled observers on the 2.5-m Isaac Newton Telescope (INT) on the Island of La Palma in the Canary Islands. These data were retrieved from the Isaac Newton Group of Telescopes (ING) Archive located at CASU, University of Cambridge.1

The INT is equipped with a Wide Field Camera (WFC) comprising 4096×2048 EEV42 detectors. The f/3.3 prime focus of the INT has a plate scale of 0.33 arcsec pixel−1 on the CCD and the camera has a relatively unvignetted field of ~1,000 arcmin2 across the four chips. Data were obtained in weekly runs, scheduled in September or October of each year. BV exposures were made at approximately alternate intervals; around 200 images in B and 169 in V were taken, with exposure times of 900 s in each filter. The data used here were obtained in median seeing better than 1.3 arcsec, and a summary of the images used is given in Table 1. The observed fields approximately coincide with those of the DIRECT Project (fields A – D) and the fields of Magnier (1996) in the rich eastern spiral arm. The data are well sampled on short timescales, but are less well sampled for the intermediate periods of 4-10 d which are typical of massive, detached binaries.

2.1 Data reduction

Each of the four fields comprising the WFC was analysed individually. Reduction to science frames proceeded automatically using the IRAF2 data reduction package and a series of scripts. The master bias frame was created from all biases and subtracted from all flats and science frames, and a linearity correction was applied with cubic linearity correction. Coefficients obtained from the INT Wide Field Survey website3 are listed in Table 2. Master flats for each filter were created with appropriate bad pixel and cosmic ray rejections, and the raw object frames were reduced to science frames with CCDPROC.

2.2 Image Difference analysis

Lightcurves were derived from the science frame using difference image analysis (DIA). The software used in this study has been described in Bond et al. (2001) and Bramich et al. (2003), hereafter BBDIA. DIA attempts to match the point spread function (PSF) between the frames in a time sequence by generating a best seeing reference frame and then degrading that reference frame to the seeing of the individual frames of the observing run. The empirically-generated kernel solution models the changes to the PSF from one image to another; it is solved for each image – reference pair. Non-varying stars leave no residual on the difference image, and variables leave either positive or negative flux with respect to the reference frame. The flux is compared with the

---

1 ING archive at http://archive.ast.cam.ac.uk
2 IRAF is written and supported by the IRAF programming group at the National Optical Astronomy Observatories (NOAO) in Tucson, Arizona. NOAO is operated by the Association of Universities for Research in Astronomy (AURA), Inc. under cooperative agreement with the National Science Foundation
3 http://www.ast.cam.ac.uk/~wfcsur/technical/ccd/
reference frame and converted to magnitudes to generate light curves. DIA is essential in crowded fields such as M31, where the high stellar density makes aperture photometry inadequate, and varying backgrounds make PSF modelling alone difficult. An overview of the procedure is given here, however, a more detailed description can be found in BB-DIA.

2.2.1 Photometry

The reduced science frames were passed into the image subtraction pipeline for reference frame generation, subtraction and photometry.

Reference frame generation was performed by selecting several frames with optimal seeing and aligning and stacking them to increase signal to noise. Around 12 frames were chosen to create the reference frame, all with a FWHM of less than 1 arcsec. Each science frame was aligned to the reference frame and subtracted according to

\[ Diff(x, y) = I(x, y) - Ref(x, y) \odot Ker(u, v) - Bg(x, y) \]  

where \( Diff(x, y) \) is the difference image, \( I(x, y) \) is any image in the time series, \( Ker(u, v) \) is the kernel that matches the image and reference PSF, \( Ref(x, y) \) is the reference frame and \( Bg(x, y) \) is the spatially varying differential background. The remaining frame consists of Poisson noise and the residuals of varying objects. Photometry can then be performed on each residual flux to determine how it changes from frame-to-frame. An IDL\(^4\) script then converted this flux to magnitudes relative to the stacked reference frame according to equations 2 and 3 (from BB-DIA).

\[ f_{tot}(t) = f_{ref} + \frac{\Delta f_{diff}(t)}{p(t)} \]  

\[ m(t) = 25.0 - 2.5 \log(f_{tot}(t)) \]  

The total flux, \( f_{tot} \), from a star at time \( t \) represents the combination of reference flux \( f_{ref} \) and difference flux \( \Delta f_{diff} \). The photometric scale factor \( p(t) \) takes into account the change in extinction and exposure time from frame to frame. Uncertainties in all flux measurements are propagated accordingly. RMS diagrams for field A are shown in Figure 2 and demonstrate a photometric accuracy of better than 1 per cent for objects as faint as 21st magnitude.

The instrumental magnitudes were then mapped to the Magnier (1996) or Mochejska et al. (2001) dataset via a linear transformation using the stars found on the reference frame and solved for using a least squares process. Unresolved stellar blends can affect the absolute magnitude and amplitude calibrations. The impact of such blends on the light curves is discussed in more detail in Section 3.

2.2.2 Astrometry

The astrometric solution was calculated for the frame using tasks from the IRAF package IMCOORDS. Once again, the dataset used for reference frame was that of Magnier (1996). Ten widely-spaced stars on the frame were used as a starting point for the astrometric solution, followed by the use of automated scripts to correlate positions of bright stars.

\(^4\) IDL provided, under license, by Research Systems Inc.
An implementation of the Stetson Variability Index (SVI), have low intrinsic variability and high photometric error. Variability is important so as to remove light curves that
Since DIA only selects the stars that are variable, the de-
solution.

diii result is obtained for all the vari-
solution was then calculated for all the vari-
coordinates in the equatorial system based on the astrometric
ables, converting frame positions to J2000.0 celestial coo r-
in constructing the reference frame.
The plate solution was then calculated for all the vari-
2.2.3 Variability detection
Since DIA only selects the stars that are variable, the de-
tinction in the USNO-B1.0 catalogue. This procedure
quantifies the pin-cushion distortion present on the WFC; typi-
cal differences were approximately 0.4 arcsec RMS, due
to a combination of the CCD distortion and that introduced
in constructing the reference frame.
The plate solution was then calculated for all the vari-
able, converting frame positions to J2000.0 celestial coo r-
in constructing the reference frame.

with entries in the USNO-B1.0 catalogue. This procedure
quantifies the pin-cushion distortion present on the WFC; typi-
cal differences were approximately 0.4 arcsec RMS, due
to a combination of the CCD distortion and that introduced
in constructing the reference frame.

The plate solution was then calculated for all the vari-
able, converting frame positions to J2000.0 celestial coo r-
in constructing the reference frame.

2.2.3 Variability detection
Since DIA only selects the stars that are variable, the de-
tection of variability is not an issue. However, the level of
variability is important so as to remove light curves that
have low intrinsic variability and high photometric error. An implementation of the Stetson Variability Index (SVI),

based on that adopted by [Kaluzny et al. 1998], was em-
ployed to detect high amplitude stars with low errors. The index is given by

\[ J = \sum_{k=1}^{n} w_k \frac{s_{\text{gn}}(P_k) \sqrt{P_k}}{\sum_{k=1}^{n} w_k} \]  

(4)

where \( k \) pairs of observations are defined, each with weight \( w_k \). The value \( P_k \) is defined as the product of normaliz-
residuals of the paired observations \( i \) and \( j \):

\[ P_k = \begin{cases} \delta_{i(k)} \delta_{j(k)}, & \text{if } i(k) \neq j(k) \\ \delta_{i(k)} - 1, & \text{if } i(k) = j(k) \end{cases} \]

Finally \( \delta \) is the magnitude residual of a given obser-
vation from the mean, given over \( n \) observations in a passband by

\[ \delta = \sqrt{\frac{n}{n-1} \sum_{\nu} (\nu - \bar{\nu})^2} \]

(5)

where \( \nu \) is the magnitude. \( J \) should tend to zero for a
non-variable star and be positive for a variable. Observations
\( i \) and \( j \) will be in different pass bands at (approximately) the
same epoch. If only one observation is made at a particular
epoch, \( i(k) = j(k) \).

In determining the variability index, the maximum time
separation in the same filter for two measurements to be
considered a pair was around 90 minutes. If two points were
a pair then the weight given was 1.0, otherwise 0.25.

2.3 Matched Filters

Classification of the variable stars was performed automati-
cally by matching theoretical curves to the observed folded
light curve by least squares fit. Two simple classifying light
curves were chosen; EB and Cepheid. The classification
code sampled multiple parameter space in terms of period
and light curve shape, varying the amplitude and depth of
eclipses, and searched for periods the range 0.5 to 15 d. Sec-
ondary eclipse amplitudes adopted lay in the range 0.3 to
0.9 magnitudes and assumed to be at phase 0.5 (i.e. circular
orbits). Primary eclipse amplitudes were scaled to the ampli-
tude of the light curve. This allowed broad classification to
be made but in many cases light curves were mis-identified
due to sparse sampling. Some binaries were missed because
the light curves had higher than normal scatter or several
outlying observations distorted the \( \chi^2 \) fit.

To resolve this, a simple code was written that searched
each light curve in the time domain for linear trends, subject
to various gradients and fit coefficients. This is a similar ap-
proach to the 'box-fitting' technique used to search for the
short eclipses of extrasolar planets. This particular approach
could not be used here because the light curves are not con-
tinuously sampled over the eclipses. Instead, searches for
the 'characteristic fragments' of an EB were made – sharp,
almost linear, ascents and descents around eclipse. This re-
vealed at least twice as many EBs as the simple matched
filter algorithm, but also revealed many false positives, such
as Cepheids. All light curves classified as EBs were inspected
by eye to validate their classification, with rejection of those
that were not believed to be binaries.
2.4 Period Determination

Period finding in these sparse time series was difficult. Various methods such as PDM, Stellingworth (1978), ANOVA due to Schwarzenberg-Czerny (1981) and various string length techniques were tried; in general PDM gave more consistent results. A visual inspection code was also drawn up, whereupon a period was specified and the light curve folded appropriately. In cases where automated period-finding techniques failed to give reliable results, variable incremental shifts in period were applied and the folded light curve was inspected in real-time by eye. The major difficulty in the period determination is aliasing. Due to the sampling of the data induced by the observational constraints, some of the fainter and noisier light curves have several PDM peaks. In cases where the true peak could not be identified, it is impossible to say for certain whether the selected period is definitely the correct one without additional data, only that it is close; such cases have been noted in the tables. Ambiguity can also arise when limited phase coverage prevents both primary and secondary minima from being detected; a phase coverage simulation for this dataset is shown in Figure 3.

2.5 Results

The EBs identified in our analysis, with periods (where available) are listed in Tables 3, 4, 5 and 6. In these tables, objects with significant aliasing issues are annotated with their corresponding periods. Difference fluxes are an estimation of the depth of the primary and secondary eclipses in ADU/s, but in many cases the deepest part of the eclipses were not measurable. Quadrature magnitudes are listed, but in many cases the brightness measurements on the time axis to derive significance contours.

The DIRECT Project found 34 EBs coincident with the observed field, and the observations tabulated in this study have recovered all but 5 of these. The undetected objects are all long period systems, objects for which this study is not expected to be sensitive (see Fig. 3). Of particular interest are two objects, V6105B and V888B, classified as detached systems by DIRECT. Both of these objects have been recovered and their detached nature confirmed. In principle, these objects could be used for accurate distance determinations, and DIRECT considers them suitable systems for detailed follow-up both photometrically and spectroscopically (Macri, 2004).

Other noteworthy systems include: f1BEB1802. This is a short period system (P = 0.232 d), originally discovered by DIRECT (# V438). Its brightness and colour suggest it is a foreground object. The photometry presented here does not constrain the period well due to its high scatter when phased, indicating long-term intrinsic variability. f1BEB1205, f1BEB1448 (DIRECT #V10550), f3BEB456, and f1BEB1180 are all bright semi-detached systems. f3BEB760. This is a bright, long-period detached system, and is ideal for follow-up spectroscopy. f1BEB1763, f1BEB1181, f1BEB939 and f2BEB1850 are also detached systems. The photometry presented here is not of sufficient quality for accurate light curve analyses.

3.1 Blending

Unresolved background stars are believed to be a major cause of elevated background levels in the images studied here; the effect of this problem is demonstrated in Figure 2. It is reasonable to expect that crowding issues will affect the accuracy of the photometry presented here due to a significant proportion of unresolved blended images. This problem of blending is discussed in detail in Kiss & Bedding (2005). Blending will contribute errors in the absolute flux measurement on the reference image, and hence the quadratures magnitudes and eclipse depths of blended EBs will be incorrect. It is for this reason that results are presented here in terms of difference flux units, as periods and difference fluxes will be relatively unaffected by blending. The level of blending can be estimated with high resolution imaging by HST and such imaging of systems that are to be used in distance determination is essential.

The median FWHM of the images analysed here, ~1 arcsec, corresponds to a spatial resolution of 3.6 pc in M31. Mocheris et al. (2004) have investigated the third light contamination of ground-based photometry of 22 Cepheids in M31 using HST imaging. They find in the V-band that, on average, ~19 per cent of the stellar flux is caused by a resolvable companion. Given that the physical size of a WFPC2
Table 3. EBs in Field 1 of the Andromeda Galaxy. $D_p$ and $D_s$ are the depth of the primary and secondary eclipses in ADU/s respectively.

| ID   | RA (J2000)   | DEC (J2000) | P (d) | $B_{max}$ | $V_{max}$ | $D_p$ | $D_s$ | Notes          |
|------|--------------|-------------|-------|-----------|-----------|-------|-------|----------------|
| f1BEB1448 | 0:44:29.272 | 41:23:01.446 | 3.1690 | 19.20     | 19.28     | 50    | 42    | V10550 DIRECT |
| f1BEB1500 | 0:44:26.974 | 41:23:42.531 | 3.3641 | 21.11     | 20.97     | 7.2   | 4.1   | V9904 DIRECT  |
| f1BEB1141 | 0:44:40.021 | 41:26:49.084 | 1.2614 | 19.53     | 19.24     | 2.1   | 0.9   | V9607 DIRECT  |
| f1BEB1205 | 0:44:37.988 | 41:29:23.819 | 3.5497 | 19.17     | 19.22     | 56    | 42    | V12650 DIRECT |
| f1BEB1598 | 0:44:48.675 | 41:29:15.557 | 5.7526 | 19.25     | -         | 27    | 27    | DEB, V9037    |
| f1BEB2228 | 0:43:50.771 | 41:21:51.546 | 2.1767 | 20.36     | 20.34     | 12    | 8.5   |                |
| f1BEB2065 | 0:43:59.846 | 41:21:20.108 | 2.7559 | 21.37     | 21.30     | 6.2   | 3.2   | V12662 DIRECT |
| f1BEB2349 | 0:43:46.655 | 41:23:01.230 | 2.3705 | 20.47     | 20.55     | 13    | 12    | V12262 DIRECT |
| f1BEB294  | 0:45:00.513 | 41:31:39.543 | 5.2495 | 19.60     | 19.65     | 14    | 13    | V6105 DIRECT  |
| f1BEB575  | 0:44:53.782 | 41:31:11.045 | 7.00   | 21.55     | 21.52     | 7.5   | 4.9   | V4903 DIRECT  |
| f1BEB925  | 0:44:45.269 | 41:28:00.336 | 11.54  | 19.81     | 19.92     | 16    | 11    | V12594 DIRECT |
| f1BEB925  | 0:44:45.269 | 41:28:00.336 | 11.54  | 19.81     | 19.92     | 16    | 11    | V12594 DIRECT |
| f1BEB1205 | 0:44:37.988 | 41:29:23.819 | 3.5497 | 19.17     | 19.22     | 56    | 42    | V12650 DIRECT |
| f1BEB1598 | 0:44:48.675 | 41:29:15.557 | 5.7526 | 19.25     | -         | 27    | 27    | DEB, V9037    |
| f1BEB2228 | 0:43:50.771 | 41:21:51.546 | 2.1767 | 20.36     | 20.34     | 12    | 8.5   |                |
| f1BEB2065 | 0:43:59.846 | 41:21:20.108 | 2.7559 | 21.37     | 21.30     | 6.2   | 3.2   | V12662 DIRECT |
| f1BEB2349 | 0:43:46.655 | 41:23:01.230 | 2.3705 | 20.47     | 20.55     | 13    | 12    | V12262 DIRECT |

1 Multiple aliases within ±0.05 d of the quoted period.
2 Eclipse has no bottom, therefore flux depth unreliable.
3 The EBs with measured periods form a subset of those objects found. Where light curves were sufficient to indicate a probable EB, there were many cases where an estimate of the period was not possible. There are around 160 of these objects spread across the four fields. The level of completeness in detection of the EBs is presumed to be low—many will not have been detected due to inadequate sampling. Overall, 127 eclipsing binaries have been detected—98 of which are newly discovered. The matched filter analysis also detected many Cepheids and other long-period variables. A discussion of these results will follow in a subsequent paper.

Acknowledgements

The INT is operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias. The production of this work made use of the CONDOR distributed computing software, the Aladin and Vizier services and the NASA/ADS abstract service.
Figure 4. A selection of $B$-band light curves of interest from the dataset. The flux units are adu/sec in each case.

Figure 5. $B$-band light curves of detached EBs. The flux units are adu/sec in each case.
Table 4. EBs in Field 2 of the Andromeda Galaxy.

| ID     | RA (J2000)       | DEC (J2000)       | P (d) | $B_{\text{max}}$ | $V_{\text{max}}$ | $D_p$ | $D_s$ | Notes  |
|--------|------------------|------------------|-------|------------------|------------------|-------|-------|--------|
| f2BEB258 | 0:43:00.951     | 41:42:59.781     | 1.1793| 21.24            | 21.30            | 5.7   | 5.5   |        |
| f2BEB775 | 0:42:49.399     | 41:41:27.051     | 1.3603| 21.22            | 21.21            | 3.8   | 2.7   |        |
| f2BEB3137 | 0:42:47.357    | 41:42:55.285     | 0.80186| 21.48            | 21.67            | 3.2   | 3.1   |        |
| f2BEB450 | 0:42:29.063     | 41:42:31.489     | 1.9751| 20.90            | 20.45            | 6.25  | 6.1   | Nearby HII region$^1$ |
| f2BEB3693 | 0:43:13.561     | 41:30:00.140     | 1.7647| 21.75            | -               | 4.5   | 1.5   |        |
| f2BEB1197 | 0:42:55.767     | 41:40:12.860     | 0.83611| 20.83            | 20.88            | 5.8   | 5.6   |        |
| f2BEB330 | 0:42:25.435     | 41:42:50.649     | 1.3106| 21.31            | 21.52            | 3.5   | 3.5   |        |
| f2BEB3163 | 0:43:31.679     | 41:29:59.588     | 1.6121| 21.80            | 21.63            | 2.4   | 1.2   |        |
| f2BEB563 | 0:43:31.679     | 41:29:37.711     | 1.7114| 21.33            | 21.47            | 5.8   | 3.5   |        |
| f2BEB1649 | 0:43:31.561     | 41:30:00.140     | 1.7647| 21.75            | -               | 4.5   | 1.5   |        |
| f2BEB3785 | 0:43:07.370     | 41:38:39.269     | 1.8272| 22.18            | -               | 1.5   | 1.0   |        |
| f2BEB638 | 0:42:49.736     | 41:41:56.432     | 1.0639| 22.94            | -               | 1.1   | 1.1   |        |
| f2BEB5400 | 0:43:40.511    | 41:23:05.440     | 1.3987| 21.47            | -               | 2.5   | 1.5   |        |
| f2BEB162 | 0:43:31.679     | 41:29:37.711     | 1.7114| 21.33            | 21.47            | 5.8   | 3.5   |        |
| f2BEB330 | 0:42:47.357     | 41:42:50.649     | 1.3106| 21.31            | 21.52            | 3.5   | 3.5   |        |
| f2BEB3163 | 0:43:31.679     | 41:29:59.588     | 1.6121| 21.80            | 21.63            | 2.4   | 1.2   |        |
| f2BEB563 | 0:43:31.679     | 41:29:37.711     | 1.7114| 21.33            | 21.47            | 5.8   | 3.5   |        |
| f2BEB1649 | 0:43:31.561     | 41:38:39.269     | 1.8272| 22.18            | -               | 1.5   | 1.0   |        |
| f2BEB638 | 0:42:49.736     | 41:41:56.432     | 1.0639| 22.94            | -               | 1.1   | 1.1   |        |
| f2BEB5400 | 0:43:40.511    | 41:23:05.440     | 1.3987| 21.47            | -               | 2.5   | 1.5   |        |
| f2BEB162 | 0:43:31.679     | 41:29:37.711     | 1.7114| 21.33            | 21.47            | 5.8   | 3.5   |        |

$^1$from Walterbos & Braun (1992)

$^2$Eclipse has no bottom, therefore flux depth unreliable

REFERENCES

Andersen J., 1991, A&A Rev. 3, 91.
Baade W., Swope H.H., AJ, 1963, 68, 435.
Berkhuijsen E.M., Humphreys R.M., Ghigo F.D., Zumach W., 1988, A&AS 76, 65.
Bond I.A., Abe F., Dodd R.J., Hearnsaw J.B., Honda M., Jugaku J., Kilmartin P.M., Marles A. et al., 2001, MNRAS 327, 688.
Bramich D.M., Horne K., Bond I.A., Street R.A., Collier Cameron A., Hood B., Cooke J., James D., et al., 2005, MNRAS, 359, 1096.
Clausen J.V., 2003, A&A, 402, 509.
Clausen J.V., 2004, New Astron. Rev. 48, Issue 9, 679.
Clementini G., Federici L., Corsi C., Cacciari C., Bellazzini M., Smith H.A., 2001, ApJ, 559, L109.
Cole A.A., 1998, ApJ, 500, L137.
Fitzpatrick E.L., Ribas I., Guinan E.F., Maloney F.P., Claret A., 2003, ApJ 587, 685.
Freedman W.L., Madore B.F., Gibson B.K., Ferrarese L., Kelson D.D., Sakai S., Mould J.R., Kennicutt R.C., et al., 2001, ApJ, 553, 47.
Gaposhkin S., 1968, PASP, 80, 556.
Guinan E.F., Fitzpatrick E.L., Dewarf L.E., Maloney F.P., Maurore P.A., Ribas I., Fritchard J.D., Bradstreet D.H., 1998, ApJ, 509, L21.
Guinan E., 2004, New Astron. Rev. 48, Issue 9, 647.
Harries T.J., Hilditch R.W., Howarth I.D., 2003, MNRAS, 339, 157.
Hilditch R.W., Howarth I.D., Harries T.J., 2005, MNRAS, 357, 304.
Kaluzny J., Stanek K.Z., Krokenberger M., Sasselov D.D., Tonry J.L., Mateo M., 1998, AJ, 115, 1016.
# Table 5. EBs in Field 3 of the Andromeda Galaxy.

| ID     | RA (J2000)       | DEC (J2000)        | P (d)   | $B_{\text{max}}$ | $V_{\text{max}}$ | $D_p$ | $D_s$ | Notes             |
|--------|------------------|--------------------|---------|-------------------|-------------------|-------|-------|-------------------|
| f3BEB2506 | 0:43:58.089 | 41:50:28.572 | 2.7491  | 20.53            | 20.45             | 8.1   | 5.6   |                   |
| f3BEB670  | 0:45:19.706 | 41:45:05.364 | 7.061   | 20.38            | 19.41             | -     | -     | 2, V5407 DIRECT  |
| f3BEB1265 | 0:44:50.255 | 41:51:24.232 | 1.9428  | 20.65            | 20.55             | 8.4   | 6.0   |                   |
| f3BEB1285 | 0:44:49.119 | 41:52:52.890 | 2.6270  | 19.52            | 19.52             | 20    | 20    |                   |
| f3BEB2388 | 0:44:04.561 | 41:48:52.159 | 2.6475  | 20.60            | 20.17             | 11    | 10    |                   |
| f3BEB1784 | 0:44:30.461 | 41:52:04.393 | 6.2241  | 20.17            | 20.73             | 14    | 13    |                   |
| f3BEB750  | 0:45:20.086 | 41:45:04.227 | 1.6041  | 20.13            | 20.45             | 13    | 10    | V4741 DIRECT     |
| f3BEB456  | 0:45:32.433 | 41:47:42.806 | 2.7879  | 19.90            | 19.89             | 18    | 10    | V7393 DIRECT     |
| f3BEB1778 | 0:44:30.629 | 41:51:56.121 | 1.4067  | 20.46            | 20.32             | 3.8   | 3.8   |                   |
| f3BEB760  | 0:45:19.706 | 41:45:05.364 | 5.75    | 19.24            | 19.41             | 27    | 20    | DEB,V4636 DIRECT |
| f3BEB630  | 0:45:25.503 | 41:45:04.005 | 5.010   | 20.04            | 19.99             | 8.5   | 2     | V5912 DIRECT     |
| f3BEB1547 | 0:44:37.084 | 41:52:25.119 | 4.768   | 19.86            | 19.99             | -     | 9     | 2                 |
| f3BEB251  | 0:45:38.924 | 41:47:49.825 | 1.2772  | 20.46            | 20.86             | 5.5   | 5.5   |                   |
| f3BEB2260 | 0:44:09.540 | 41:47:04.875 | 2.7721  | 20.77            | 20.96             | 4.5   | -     | 2                 |
| f3BEB562  | 0:45:28.366 | 41:44:23.75 | 3.080   | 20.54            | 20.56             | 6.0   | 6.0   | V6450 DIRECT     |
| f3BEB580  | 0:45:28.150 | 41:49:32.961 | 4.37    | 20.80            | 20.76             | -     | -     | V6527 DIRECT     |
| f3BEB651  | 0:45:24.220 | 41:46:26.850 | 6.798   | 20.10            | 20.28             | 9     | 6.5   |                   |
| f3BEB505  | 0:45:31.116 | 41:46:49.598 | 4.504   | 21.31            | 21.47             | 1.8   | 1.8   |                   |
| f3BEB1276 | 0:44:49.372 | 41:52:17.821 | 4.771   | 20.47            | 20.39             | -     | -     | 2                 |

2Eclipse has no bottom, therefore flux depth unreliable

Kiss L.L., Bedding T.R., 2005, MNRAS, 358, 883.
Macri L., 2004, New Ast. Rev., 48, Issue 9, 675.
Magnier E.A., 1996, A& A Supp., 96, 379.
McConnachie A.W., Irwin M.J., Ferguson A.M.N., Ibata R.A., Lewis G.F., Tanvir N., 2005, MNRAS 356, 979.
Mochejska B.J., Kalluzny J., Stanek K.Z., Sasselov D.D., 2001, AJ 122, 1383.
Mochejska B.J., Macri L.M., Sasselov D.D., Stanek K.Z., Sasselov D.D., 2004, ASPC 310, 41.
Mould J., Saha A., Hughes S., 2004, ApJS, 154, 623.
Ribas I., Fitzpatrick E.L., Maloney F.P., Guinan E.F., Udalski A., 2002, ApJ, 574, 771.
Schwarzenberg-Czerny A., 1989, MNRAS, 241, 153.
Stellingworth R.F., 1978, ApJ, 224, 953.
Veltev T., Nedialkov P., Borisov G., 2004, A&A, 426, 495.
Walterbos R.A.M, Braun R., 1992, A&AS, 92, 625.
Wilson R.E., 2004, New Astron. Rev., 48, Issue 9, 695.

This paper has been typeset from a \TeX/ \LaTeX file prepared by the author.
Table 6. EBs in Field 4 of the Andromeda Galaxy.

| ID     | RA (J2000)  | DEC (J2000) | P (d)    | $B_{\text{max}}$ | $V_{\text{max}}$ | $D_p$ | $D_s$ | Notes       |
|--------|-------------|-------------|---------|------------------|------------------|-------|-------|-------------|
| f4BEB1695 | 0:44:27.199 | 41:36:08.223 | 4.5186  | 20.19            | 20.03            |       |       | V1266 DIRECT |
| f4BEB821  | 0:45:12.519 | 41:37:26.321 | 2.3584  | 19.33            | 19.29            |       |       | V7940 DIRECT |
| f4BEB1157 | 0:45:05.377 | 41:33:40.442 | 1.7699  | 20.12            | 20.22            | V6846 | V6840 | DIRECT      |
| f4BEB1180 | 0:45:04.843 | 41:37:29.350 | 3.0945  | 19.25            | 19.41            |       |       | DIRECT      |
| f4BEB1962 | 0:44:11.074 | 41:34:08.197 | 2.9202  | 19.84            | 19.84            |       |       |             |
| f4BEB2294 | 0:43:53.920 | 41:36:42.418 | 6.242   | 20.89            | 21.02            |       |       |             |
| f4BEB246  | 0:45:26.694 | 41:41:03.179 | 2.0833  | 20.71            | 20.95            |       | V6024 | DIRECT      |
| f4BEB1672 | 0:44:28.010 | 41:36:57.330 | 2.8949  | 21.62            | -                |       |       |             |
| f4BEB1763 | 0:44:24.763 | 41:39:02.422 | 4.763   | 19.98            | 20.04            | V888  | DIRECT |
| f4BEB1802 | 0:45:22.332 | 41:38:51.216 | 0.2326  | 18.68            | 17.80            | V438  | DIRECT |, Local WUMa |
| f4BEB74   | 0:45:37.723 | 41:43:07.777 | 1.902   | 20.94            | 20.81            | V8420 | DIRECT |
| f4BEB930  | 0:45:10.294 | 41:36:47.119 | 6.0972  | 18.78            | 18.85            | V7628 | DIRECT |
| f4BEB1621 | 0:44:31.171 | 41:36:15.288 | 1.553   | 20.52            | 19.61            |       | 1     |             |
| f4BEB1893 | 0:44:15.941 | 41:37:29.369 | 2.7262  | 21.84            | -                |       |       |             |
| f4BEB1168 | 0:45:05.200 | 41:38:46.464 | 0.91644 | 20.77            | 20.71            | V1555 | DIRECT |
| f4BEB2290 | 0:43:54.185 | 41:37:13.150 | 3.335   | 20.65            | 20.73            |       |       |             |
| f4BEB920  | 0:45:10.432 | 41:36:34.421 | 6.7657  | 20.40            | 20.33            | Unusual LC     |
| f4BEB990  | 0:45:09.190 | 41:38:41.867 | 4.4523  | 20.25            | 20.36            |       |       |             |
| f4BEB296  | 0:45:24.691 | 41:39:41.341 | 2.4223  | 21.61            | -                |       |       |             |
| f4BEB1617 | 0:44:31.538 | 41:37:22.253 | 4.6471  | 21.76            | -                |       |       |             |
| f4BEB1994 | 0:44:10.634 | 41:39:49.699 | 5.4995  | 21.72            | 1                |       |       |             |
| f4BEB527  | 0:45:18.676 | 41:40:47.040 | 2.0215  | 20.61            | 20.67            |       |       |             |
| f4BEB1465 | 0:44:49.047 | 41:32:59.691 | 0.95183 | 21.28            | 21.26            |       |       |             |
| f4BEB2006 | 0:44:10.277 | 41:39:49.409 | 2.8143  | 20.98            | 20.79            |       |       |             |
| f4BEB2050 | 0:44:08.816 | 41:39:48.889 | 1.7957  | 21.33            | -                |       |       |             |
| f4BEB953  | 0:45:09.761 | 41:34:17.287 | 1.7806  | 21.59            | 21.28            |       |       |             |
| f4BEB698  | 0:45:14.908 | 41:40:30.521 | 2.4350  | 20.49            | 20.47            |       |       |             |
| f4BEB428  | 0:45:20.771 | 41:38:27.814 | 1.9108  | 21.40            | -                |       |       |             |
| f4BEB453  | 0:45:20.351 | 41:41:44.412 | 1.0791  | 20.93            | 21.04            |       |       |             |
| f4BEB1915 | 0:44:13.536 | 41:39:19.126 | 1.9272  | 21.02            | 20.91            |       |       |             |

1 Multiple aliases within ±0.05 d of the quoted period.
2 Eclipse has no bottom, therefore flux depth unreliable