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The DIRECT Project

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Abstract. The DIRECT project aims to determine direct distances to two important galaxies in the cosmological distance ladder – M31 and M33 – using detached eclipsing binaries (DEBs) and Cepheids. I present an overview of the project and some results from follow-up observations.

1. Introduction

The DIRECT project (as in "direct distances") started in 1996 with the long-term goal of obtaining distances to two important galaxies in the cosmological distance ladder – M31 and M33 – using detached eclipsing binaries (DEBs) and Cepheids. These two nearby galaxies are the stepping stones in most of the current effort to understand the evolving universe at large scales. Not only are they essential to the calibration of the extragalactic distance scale, but they also constrain population synthesis models for early galaxy formation and evolution. However, accurate distances are essential to make these calibrations free from large systematic uncertainties.

Detached eclipsing binaries have the potential to establish distances to M31 and M33 with an unprecedented accuracy of better than 5% and possibly to better than 1%. Current uncertainties in the distances to these galaxies are in the order of 10 to 15%, as there are discrepancies of 0.2-0.3 mag between various distance indicators. Detached eclipsing binaries (Paczyński 1997) offer a single-step distance determination to nearby galaxies (Fitzpatrick et al. 2003) and may therefore provide an accurate zeropoint calibration for other distance indicators, including Cepheids.

2. DIRECT Observations and Results

The DIRECT project obtained time-series observations of M31 and M33 during 170 nights between 1996 September 6 and 2000 January 2 using the Fred L. Whipple Observatory 1.2-m telescope. Additional observations were carried out during 36 nights in 1996 and 1997 at the Michigan-Dartmouth-MIT Observatory 1.3-m telescope. In 1996 and 1997, images were obtained using a camera with $\sim 11' \times 11'$ field of view. In 1998 and 1999, data were collected using a camera with a $\sim 22' \times 22'$ field of view.Observations were obtained mainly in the V and I bands, with some additional data in the B band. The total area covered by the observations was $\sim 0.5\square^\circ$ in M31 and $\sim 0.3\square^\circ$ in M33 (see Figure 1).

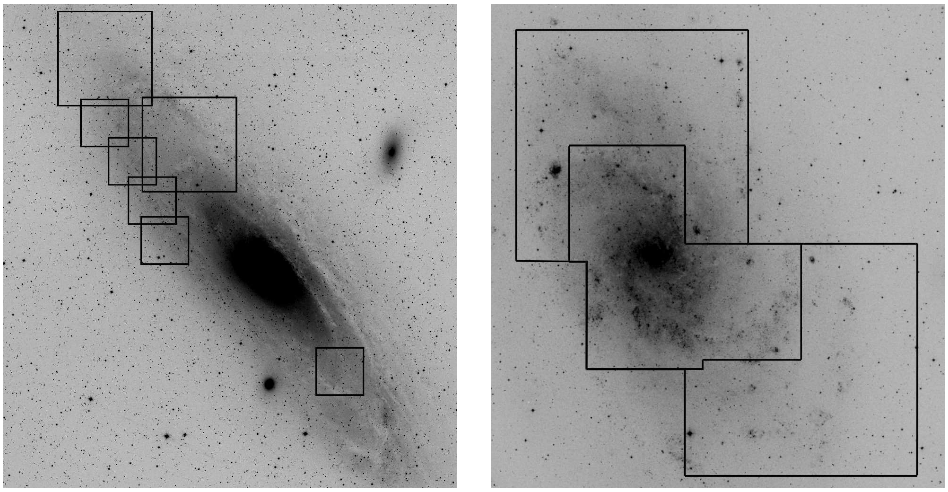

Figure 1. DIRECT fields in M31 and M33. The small and large fields are 11′ and 22′ on a side, respectively. M31 image: Schoening & Harvey/REU/NOAO/AURA/NSF. M33 image: DPOSS II © CalTech.

Most of the fields have been analyzed and published (Bonanos et al. 2003; Kaluzny et al. 1998; Kaluzny et al. 1999; Macri et al. 2001a; Mochejska et al. 1999; Stanek et al. 1998; Stanek et al. 1999). These publications contain a total of ∼ 130 eclipsing binaries, ∼ 600 Cepheid variables, and ∼ 500 miscellaneous variables. Representative light curves of Cepheid variables and eclipsing binaries discovered in M33 can be seen in Figures 2 and 3. Two additional publications will appear in the near future with the analysis of the remaining fields (Bonanos et al. 2004; Macri et al. 2004).

Additional publications related to the DIRECT project include: the discovery of cessation of pulsations in a long-period Cepheid in M33 (Macri, Sasselov, & Stanek 2001); the study of the influence of unresolved blends on the Cepheid Distance Scale (Mochejska et al. 2000; Mochejska et al. 2001a); a catalog of globular clusters in M31 and M33 (Mochejska et al. 1998); ancillary stellar catalogs and additional short-period variables (Macri et al. 2001b; Mochejska et al. 2001b; Mochejska et al. 2001c; Mochejska et al. 2001d).

3. Follow-up observations

3.1. Detached eclipsing binaries

Four promising detached eclipsing binary systems have been discovered in the DIRECT fields; two in M31 and two in M33. As a first step in their follow-up, higher quality light curves were obtained through observations conducted at the Kitt Peak National Observatory 2.1-m telescope in 1999 and 2001. ecently, a program was started to measure radial velocities of the DEBs using the Echelle Spectrograph and Imager (ESI) at Keck Observatory. Figure 4 shows the radial velocities measured for a system in M33 during the first two nights of that program, plotted against the radial velocity predicted by the photometric data.

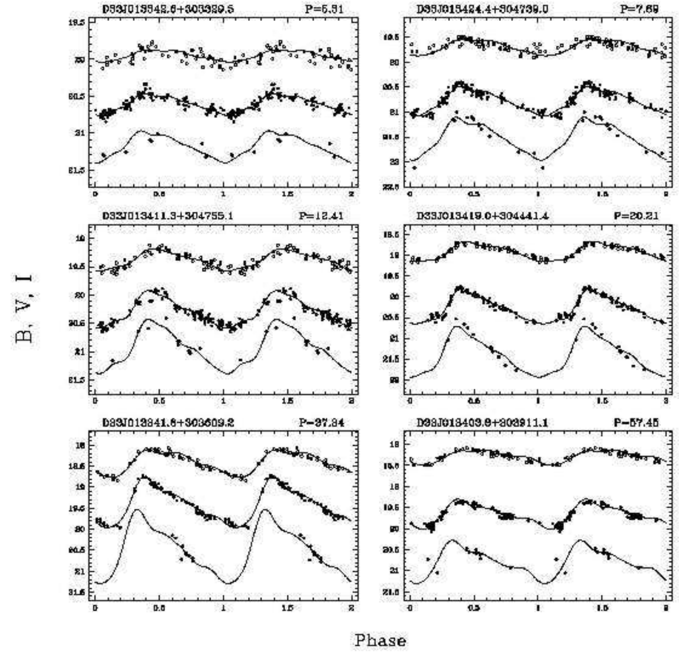

Figure 2. Representative light curves of Cepheid variables discovered by DIRECT in M33 (Macri et al. 2001a).

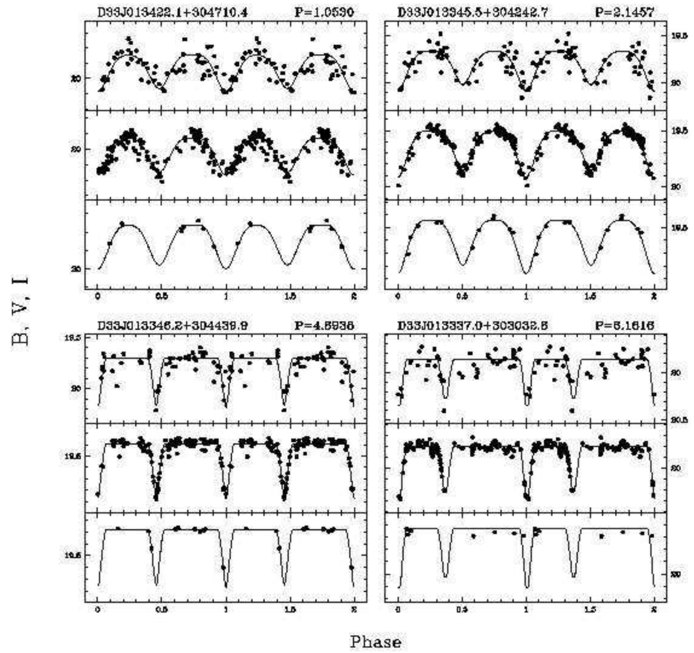

Figure 3. Representative light curves of eclipsing binaries discovered by DIRECT in M33 (Macri et al. 2001a).

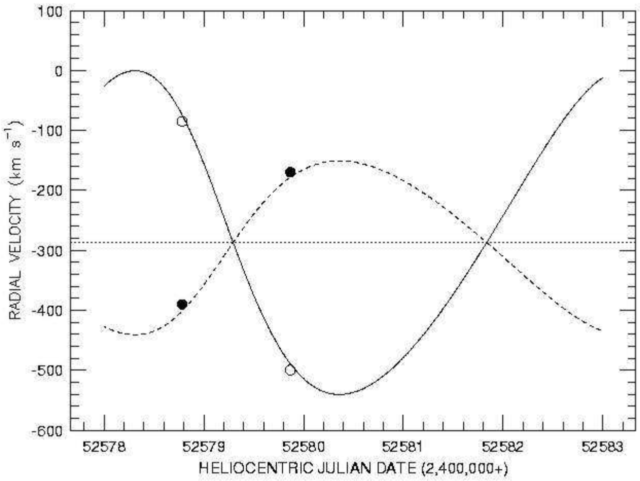

Figure 4. Radial velocities for one detached eclipsing binary system discovered by DIRECT, obtained during two nights of observation with ESI on Keck. The solid and dashed lines show the variation with phase predicted by the photometric data.

3.2. Cepheid variables

M33 has one of the largest abundance gradients among nearby spiral galaxies, ~ 0.2 dex/kpc (Henry & Howard 1995; Monteverde, Herrero, & Lennon 2000). The DIRECT Cepheid sample in this galaxy exceeds 700 variables and covers the majority of the disk, making it ideal for a study of the metallicity dependence of the Cepheid Period-Luminosity relation. A previous observational determination (Kennicutt et al. 1998) based on a similar differential test, but using Cepheids in M101, obtained a value for the dependence in the VI bands that is at odds with theoretical predictions (Bono et al. 1999). However, a recent analysis by Fiorentino et al. (2002) has postulated a possible solution for the disagreement.

Follow-up observations of M33 Cepheids were started in 2002 August using the MiniMosaic CCD imager at the WIYN 3.5-m telescope. Once these observations conclude in 2004 January, we expect to have obtained ~ 15 epochs in BVI with a greatly improved image quality relative to the original DIRECT survey ($0.7''$ vs. $1.5''$), which in turn will result in greatly improved photometric accuracy. We should be able to detect the metallicity effect predicted by Fiorentino et al. (2002) in the BVI bands at the 6σ level.

Additionally, we are carrying out near-infrared (JHK_s) observations, using the Near InfraRed Imager (NIRI) on the 8.1-m Fred Gillett Gemini North telescope, of a subsample of ~ 200 Cepheids well distributed across the disk of M33. Figure 5 shows preliminary H and K_s P-L relations for a subset of 95 variables located in the inner part of the galaxy. Once all data are collected, we should be able to detect the metallicity effect predicted by Fiorentino et al. (2002) in the K_s-band at the 4σ level.

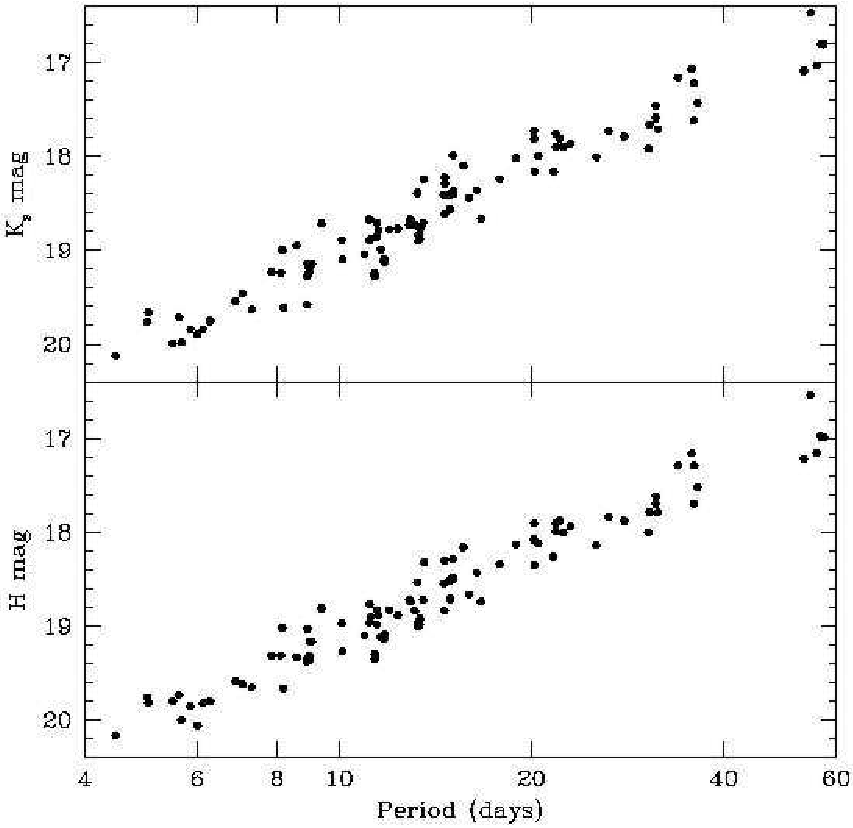

Figure 5. K_s and H-band Period-Luminosity relations for a subsample of 95 Cepheids located in the central part of M33. Based on observations obtained with NIRI on Gemini North.

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References

Bonanos, A.Z., Stanek, K.Z., Sasselov, D.D., Mochejska, B.J., Macri, L.M., & Kaluzny, J. 2003, AJ, 126, 175

Bonanos, A.Z., Stanek, K.Z., Sasselov, D.D., Mochejska, B.J., Macri, L.M., & Kaluzny, J. 2004, in preparation

Bono, G., Caputo, F., Castellani, V., & Marconi, M. 1999, ApJ, 512, 711

Fiorentino, G., Caputo, F., Marconi, M., Musella, I. 2002, ApJ, 576, 402

Fitzpatrick, E.L., Ribas, I., Guinan, E.F., Maloney, F.P., & Claret, A. 2003, ApJ, 587, 685

Henry, R.B.C. & Howard, J.W. 1995, ApJ, 438, 170

Kaluzny, J., Stanek, K.Z., Krockenberger, M., Sasselov, D.D., Tonry, J.L., & Mateo, M. 1998, AJ, 115, 1016

Kaluzny, J., Mochejska, B.J., Stanek, K.Z., Krockenberger, M., Sasselov, D.D., Tonry, J.L., & Mateo, M. 1999, AJ, 188, 346

Kennicutt, R.C., Stetson, P.B., Saha, A., Kelson, D., Rawson, D.M., Sakai, S., Madore, B.M., Mould J.R., Freedman, W.L., Bresolin, F., Ferrarese, L., Ford, H., Gibson, B.K., Graham, J.A., Han, M., Harding, P., Hoessel, J.G., Huchra, J.P., Hughes, S.M.G, Illingworth, G.D., Macri, L.M., Phelps, R.L., Silbermann, N.A., Turner, A.M., & Wood, P.R. 1998, ApJ, 498, 181

Macri, L.M., Stanek, K.Z., Sasselov, D.D., Krockenberger, M., & Kaluzny, J. 2001a, AJ, 120, 870

Macri, L.M., Stanek, K.Z., Sasselov, D.D., Krockenberger, M., & Kaluzny, J. 2001b, AJ, 120, 861

Macri, L.M, Sasselov, D.D. & Stanek, K.Z. 2001, ApJ, 550, L159

Macri, L.M., Stanek, K.Z., Sasselov, D.D., Mochejska, B.J., Bonanos, A.Z., & Kaluzny, J. 2004, in preparation

Mochejska, B.J., Kaluzny, J., Krockenberger, M., Sasselov, D.D., & Stanek, K.Z. 1998, Ac.A., 48, 445

Mochejska, B.J., Kaluzny, J., Stanek, K.Z., Krockenberger, M., & Sasselov, D.D. 1999, AJ, 118, 2211

Mochejska, B.J., Macri, L.M., Sasselov, D.D., & Stanek, K.Z. 2000, AJ, 120, 810

Mochejska, B.J., Macri, L.M., Sasselov, D.D., & Stanek, K.Z. 2001a, astro-ph/0103440

Mochejska, B.J., Kaluzny, J., Stanek, K.Z., & Sasselov, D.D. 2001b, AJ, 122, 1383

Mochejska, B.J., Kaluzny, J., Stanek, K.Z., Sasselov, D.D., & Szentgyorgyi, A.H. 2001c, AJ, 121, 2032

Mochejska, B.J., Kaluzny, J., Stanek, K.Z., Sasselov, D.D., & Szentgyorgyi, A.H. 2001d, AJ, 122, 2477

Monteverde, M.I., Herrero, A., & Lennon, D.J. 2000, ApJ, 545, 813

Paczyński, B. 1997, in The Extragalactic Distance Scale, ed. M. Livio, M. Donahue & N. Panagia (Cambridge: Cambridge Univ. Press), 273

Stanek, K.Z., Kaluzny, J., Krockenberger, M., Sasselov, D.D., Tonry, J.L., & Mateo, M. 1998, AJ, 115, 1894

Stanek, K.Z., Kaluzny, J., Krockenberger, M., Sasselov, D.D., Tonry, J.L., & Mateo, M. 1999, AJ, 117, 2810