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Summary

During September and October 1996 we obtained 32 nights on the FLWO 1.2-meter telescope to search for detached eclipsing binaries and Cepheids in the M33 galaxy. This is a first step in the ongoing program to improve the direct distance estimate to two important galaxies in the cosmological distance ladder – M31 and M33. Detached eclipsing binaries provide us with the potential to determine these distances with an accuracy better than 5% and eventually to better than 1%.

The massive photometry provides us with good light curves for known and new Cepheid variables. These are essential to the parallel project to derive direct Baade-Wesselink distances to Cepheids in M31 and M33. With both Cepheids and eclipsing binaries the distance estimates will be free of any intermediate steps. As a by-product, numerous variables of other types are detected. During January 1997 we are obtaining additional photometry for this project.

Classical Cepheid variables as primary distance indicators

The two nearby galaxies – M31 and M33, are stepping stones to most of our current effort to understand the evolving universe at large scales. They are essential to the calibration of the extragalactic distance scale and for constraining population synthesis models for early galaxy formation and evolution. There is one simple requirement for all this – accurate distances.

Of the primary distance indicators – proper motions, RR Lyr, Cepheids, and Supernovae type II (Huterer, Sasselov, & Schechter 1995), the Cepheids have a clear advantage over the old population radial pulsators, the RR Lyr stars. First, the former are significantly more luminous and can be seen much farther away, and second, in a given galaxy the Cepheids arise from a massive short-lived population with a much smaller spread of initial conditions (e.g. abundances). Also, the systematic uncertainties in Cepheid distances are smaller than those affecting RR Lyr distances. The method of expanding photospheres of SN type II has a virtue of offering a truly single-step distances into the Hubble flow (Eastman, Schmidt, & Kirshner 1996). However, the level of quantitative understanding of Cepheid atmospheres is vastly better than the level of understanding of the SN type II atmospheres.

The use of Cepheids as a standard candle requires one step – calibration, or anchoring the PL relation locally. This can be done in one of two ways: (1) by finding Cepheids in nearby stellar clusters with known distances, or (2) by deriving distances to Cepheids directly, using their radial pulsation. The first path is easy in principle, but impractical – it involves many uncertain intermediate steps and most importantly, has effectively exhausted its potential, because very few Cepheids are in clusters in our Galaxy. The second path is old (Baade 1926, Wesselink 1946) and has a strong physical foundation, but has been plagued by problems. It requires a level of theoretical understanding which has been possible to achieve only in the past 5 years.

The method is free of any intermediate steps and is based on complex, but well understood, physics. Overly simplifying the physics could account for most of the systematic errors in the past. The situation has been improving rapidly with the use of infrared bands (Welch 1994; Laney & Stobie 1995), and with treating line formation and surface brightness variations consistently (Krockenberger 1996). It seems now possible to determine directly, in a single step, the distance to the LMC accurate to 3% (with CTIO) and to M31 to 6% (with Keck), using a modern version of the Baade-Wesselink method (Krockenberger, Sasselov & Noyes 1997). These distances are now known to no better than 10%, as there are discrepancies of $0.2 - 0.3$ mag between RR Lyrae and Cepheids distance indicators (e.g. Huterer, Sasselov & Schechter 1995).

Fields selection, observing strategy

Fields were selected using the photometric survey of M33 by Ivanov, Freedman, & Madore (1994). Fig.1 shows the selection of the three fields in M33; they cover a major part of the galaxy. All three fields (A-C) were observed during September and October 1996 4-6 times per night in V and I bands, resulting in total of 90-110 exposures per field. Some exposures in B band were also taken.

Data reduction, first results

To reduce the data we use the DAOPHOT II stellar photometry reduction program (Stetson 1995). The PSF on the FLWO 1.2-meter telescope is stable over the CCD chip. There is about 10,000 stars with $V < 22\ mag$ in each field.

To date we have reduced the data for one of the fields, M33C. We have also reduced the data for one of the fields, M31B, observed in variability survey of M31 described in Poster 96.09 (Stanek et al. 1997). Some examples of new Cepheid variables found in both surveys can be seen in Figs.2-5. The quality of Cepheid light curves for periods in excess of 6 days is very good. With their good phase coverage, these light curves allow determination of their shape characteristics; hence discrimination of different pulsation modes and selection of best candidates for a precise Baade-Wesselink solution.

Future research

To supplement the data described in this poster, during January 1997 we are collecting additional observations. These additional epochs will be extremely useful from the point of view of improving our sample of Cepheid variables, by providing additional phase coverage. From the point of view of long period variables, these additional data will extend our coverage of M33 to $\sim$5 months.

As the next step of this project, during 1997 the ~ 10 most promising candidate objects will be selected from M31 and M33 variable star catalogs to do accurate ($\sim 1\%$) follow-up photometry in, for example, V and I bands. We would choose Cepheids with smooth light curves, preferably first overtone pulsators.

Another step of this project, obtaining very high S/N radial velocity curves to complete the BW-solutions and derive distances, will be realized using an echelle spectrograph on one of the new 6.5-10 meter class telescopes. An important requirement of the new version of the BW method is the use of spectral line profiles from the high-resolution spectra of the Cepheids.

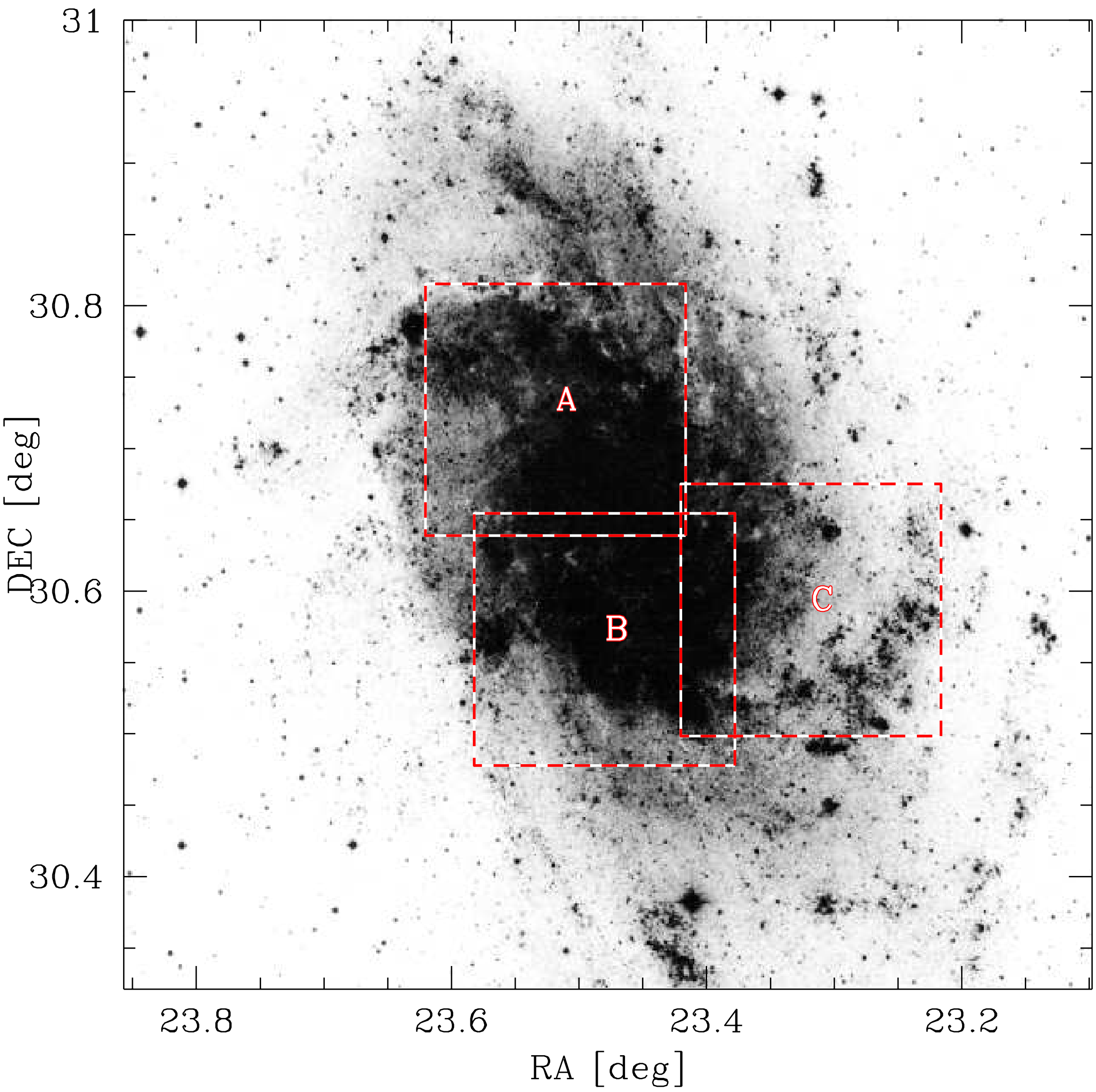

Fig. 1.— Fields observed in M33 during Fall 1996.

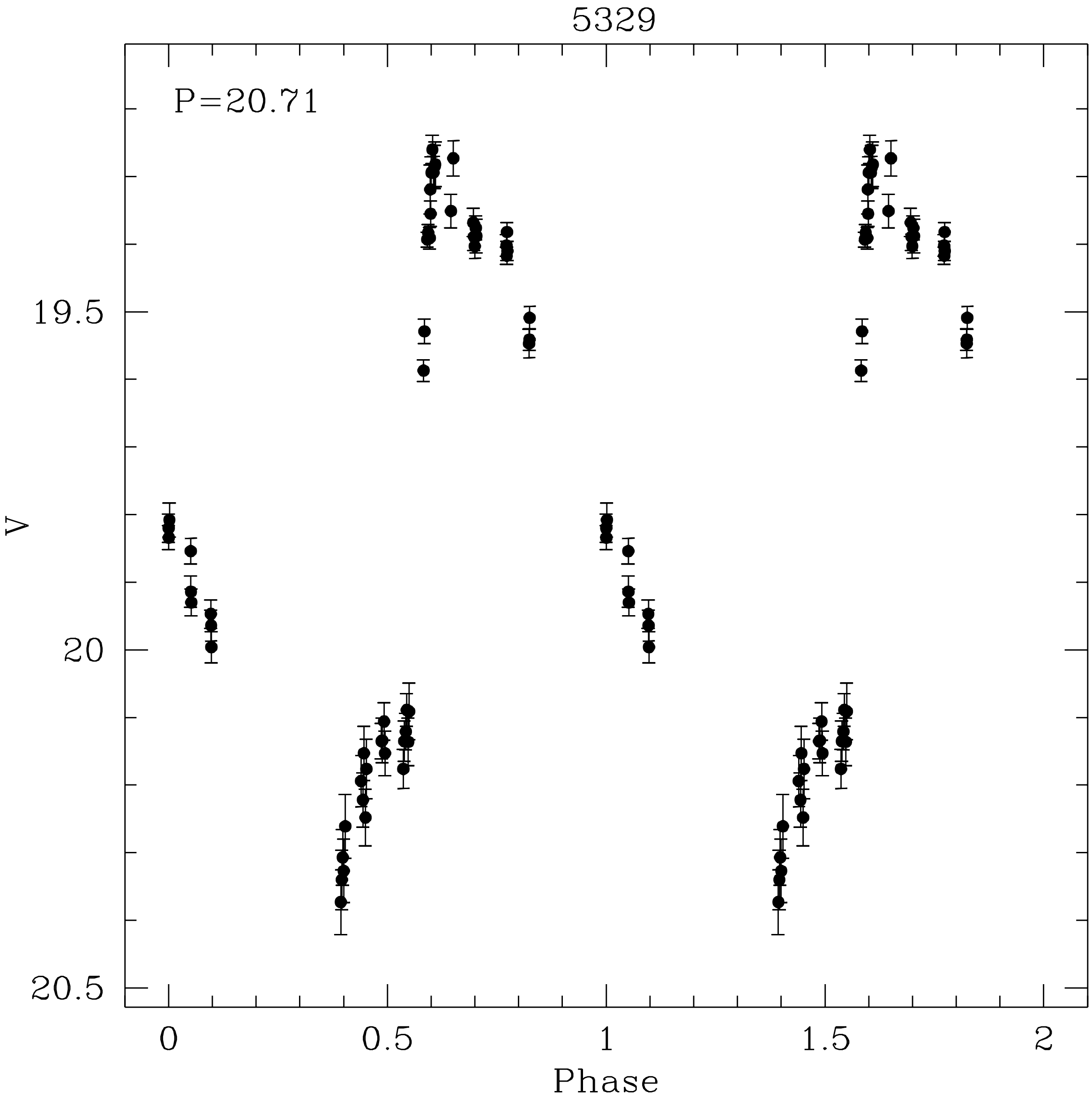

Fig. 2.— Light curve of a Cepheid variable detected in M33C.

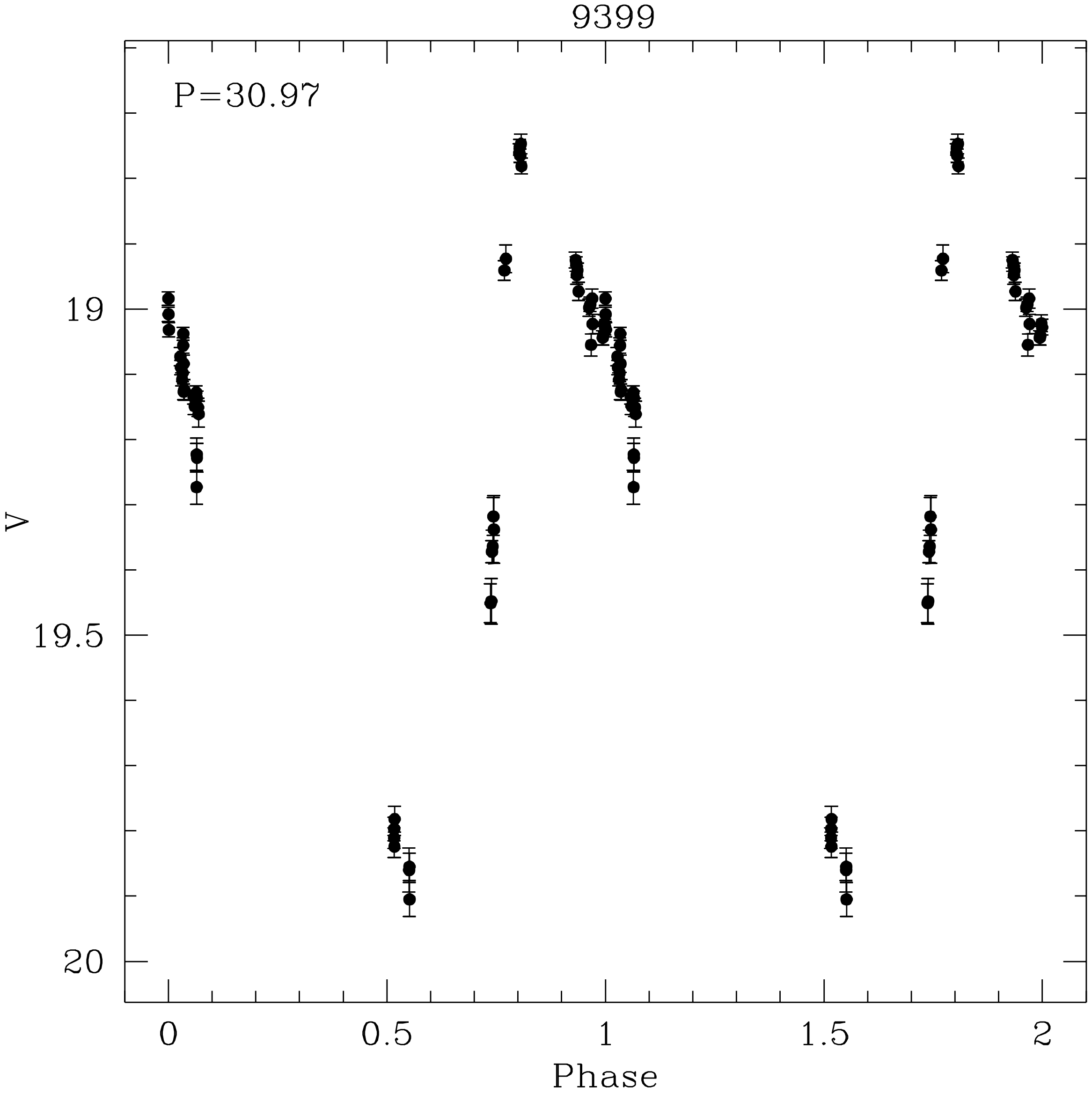

Fig. 3.— Light curve of a Cepheid variable detected in the field M33C.

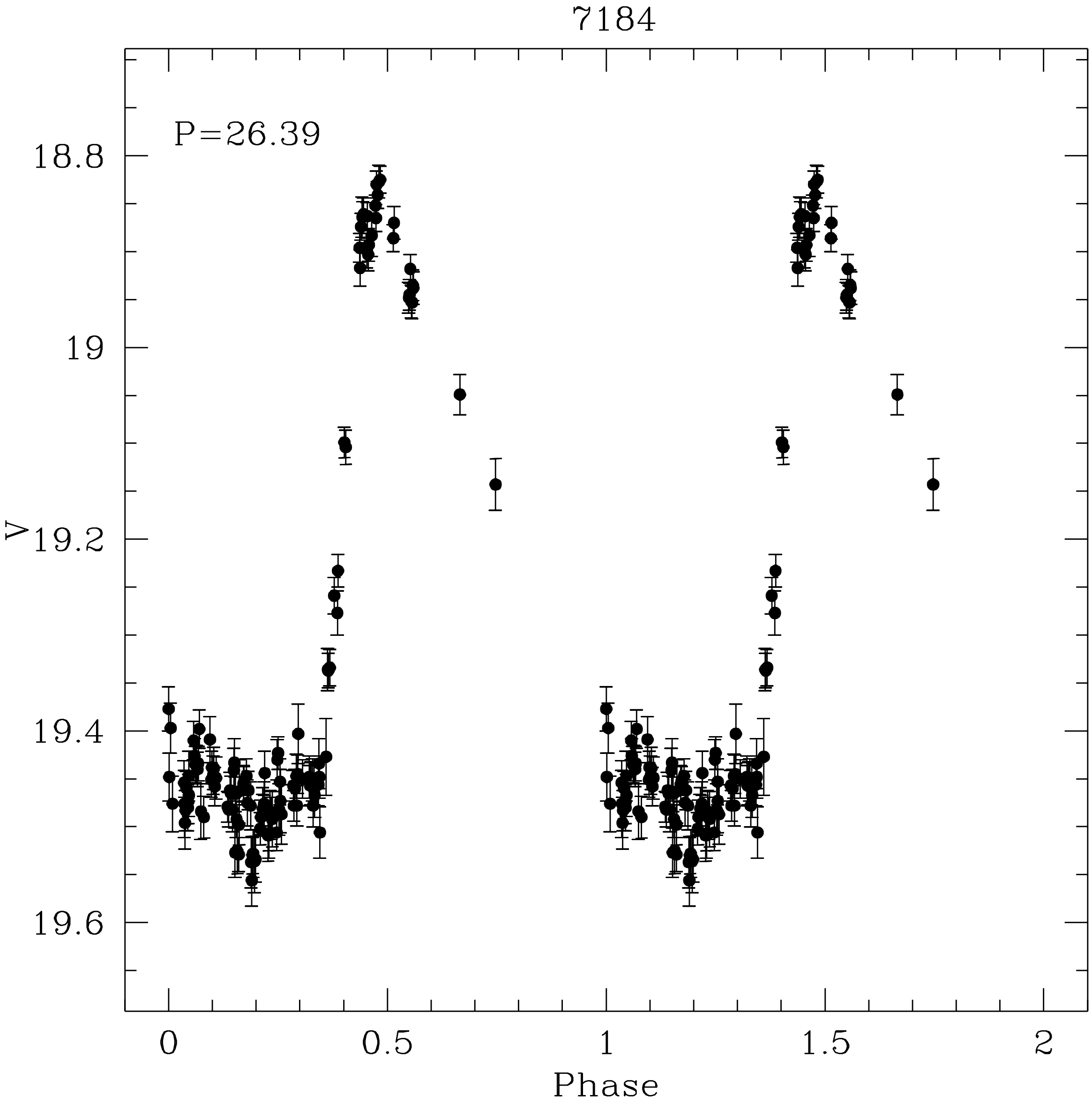

Fig. 4.— Light curve of a new Cepheid variable found in the field M31B.

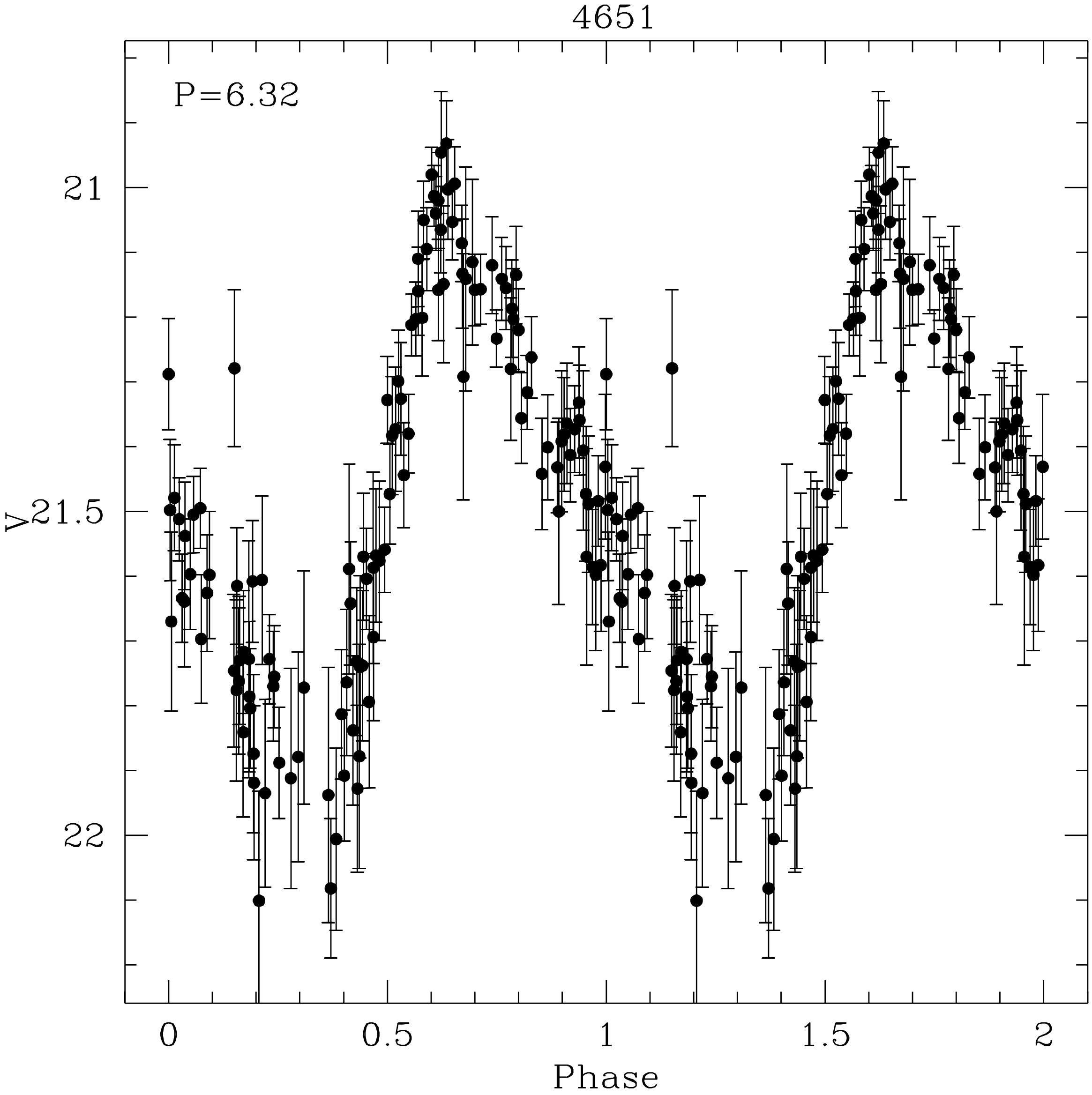

Fig. 5.— Light curve of a new Cepheid variable found in M31B.