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Summary

During September and October 1996 we have obtained 36 nights on the Michigan-Dartmouth-MIT (MDM) 1.3-meter telescope to search for detached eclipsing binaries and Cepheids in the M31 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 other variables are detected.

Detached eclipsing binaries 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.

Detached eclipsing binaries (DEBs) have the potential to establish distances to M31 and M33 with an unprecedented accuracy of better than 5% and eventually to better than 1%. These distances are now known to no better than 10-15%, as there are discrepancies of $0.2-0.3$ *mag* between RR Lyrae and Cepheids distance indicators (e.g. Huterer, Sasselov & Schechter 1995). Eclipsing binaries offer a single step distance determination to these galaxies and may therefore provide an accurate zero point calibration – a major step towards very accurate determination of the Hubble constant.

DEBs were not used so far as distance indicators to M31 and M33. Only now availability of modern CCD detectors and cheap CPUs makes it possible to organize a massive search for periodic variables, which will produce a handful of good DEB candidates. These can then be observed with the powerful new telescopes, like the new 6.5-meter MMT or the Keck 10-meter telescope.

Fields selection, observing strategy

Fields were selected using the MIT photometric survey of M31 by Magnier et al. (1992) and Haiman et al. (1994). Fig.1 shows stars from this survey with $B-V<0.4$, i.e. blue stars belonging to M31. We selected six $10' \times 10'$ fields, M31A-F, four of them (A-D) concentrated on the rich spiral arm, one (E) coinciding with the region of M31 searched for microlensing by Crotts & Tomaney(1996), and one (F) containing the giant star formation region known as NGC206 (observed by Baade & Swope 1963). Fields A-C were observed during September and October 1996 5-8 times per night in V band, resulting in total of 130-150 exposures per field. Fields D-F were observed once a night in V band. Some exposures in B and I bands were also taken. As an example, in Fig.2 we show the field M31E, dominated by the bulge of M31.

Data reduction, first results

To reduce the data we use the DAOPHOT II stellar photometry reduction program (Stetson 1995). The PSF on the MDM 1.3-meter telescope depends quite strongly on the position on the CCD chip, so in each fields we select > 100 PSF stars to allow for variable PSF. 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, M31B. Some examples of new variables found in our survey can be seen in Figs.3-6. Variable shown in Fig.6 comes from the variability survey of M33 described in Poster 96.10 (Sasselov et al. 1997). Also there we show few new Cepheid variables found in M33 and M31.

Future research

As the next step of this project, during 1997 the $\sim$ 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 DEBs with equal depth eclipses, preferably reaching $0.75\ mag$, i.e. systems consisting of identical components, in which there is no "third light" present. The accurate light curves obtained by the follow-up photometry program will then be used to determine the solutions of photometric orbits of eclipsing binaries, a well-understood problem in astronomy. The solutions would be simplified by the selection of the observed detached eclipsing binaries. By analyzing the light curves, the stellar radii (in the units of the orbital radius) and orbital inclination can be determined.

Another step of this project, obtaining very high S/N radial velocity curves to get the radii in physical units, will be realized using an echelle spectrograph on one of the new 6.5-10 meter class telescopes. For an idealized DEB system of two identical mass stars viewed exactly in the orbital plane, the expected semi-amplitude of the radial velocity curve is given by $K = 135\ \left(\frac{M_{star}}{M_{\odot}}\right)^{1/3} \left(\frac{P_{orbital}}{1\ day}\right)^{-1/3}\ km\ s^{-1}$. Determining the distance to an accuracy of 5% requires knowing the semi-amplitudes of the radial velocity curve to $\sim 5\ km\ s^{-1}$.

The last step will be the calculation of the distances: knowing the surface brightness and the stellar radii of the binary system we can obtain the absolute stellar luminosities in the observed band $F_{stellar\ surface}$, and from the apparent fluxes measured $F_{telescope}$ we can directly obtain the distance $d = \left(\frac{F_{stellar\ surface}}{F_{telescope}}\right)^{1/2} R_{star}$. This means that we need very accurate absolute photometry from the observed system in some selected band or, better, in several bands. This also means that we have to be able to estimate the surface brightness in some selected band of each star from the observed colors or spectra. Interstellar extinction is always a problem for any photometric distance determination. To correct for that, multi-band photometry outside the eclipse would be obtained. De-reddening for early type stars is a standard and simple problem.

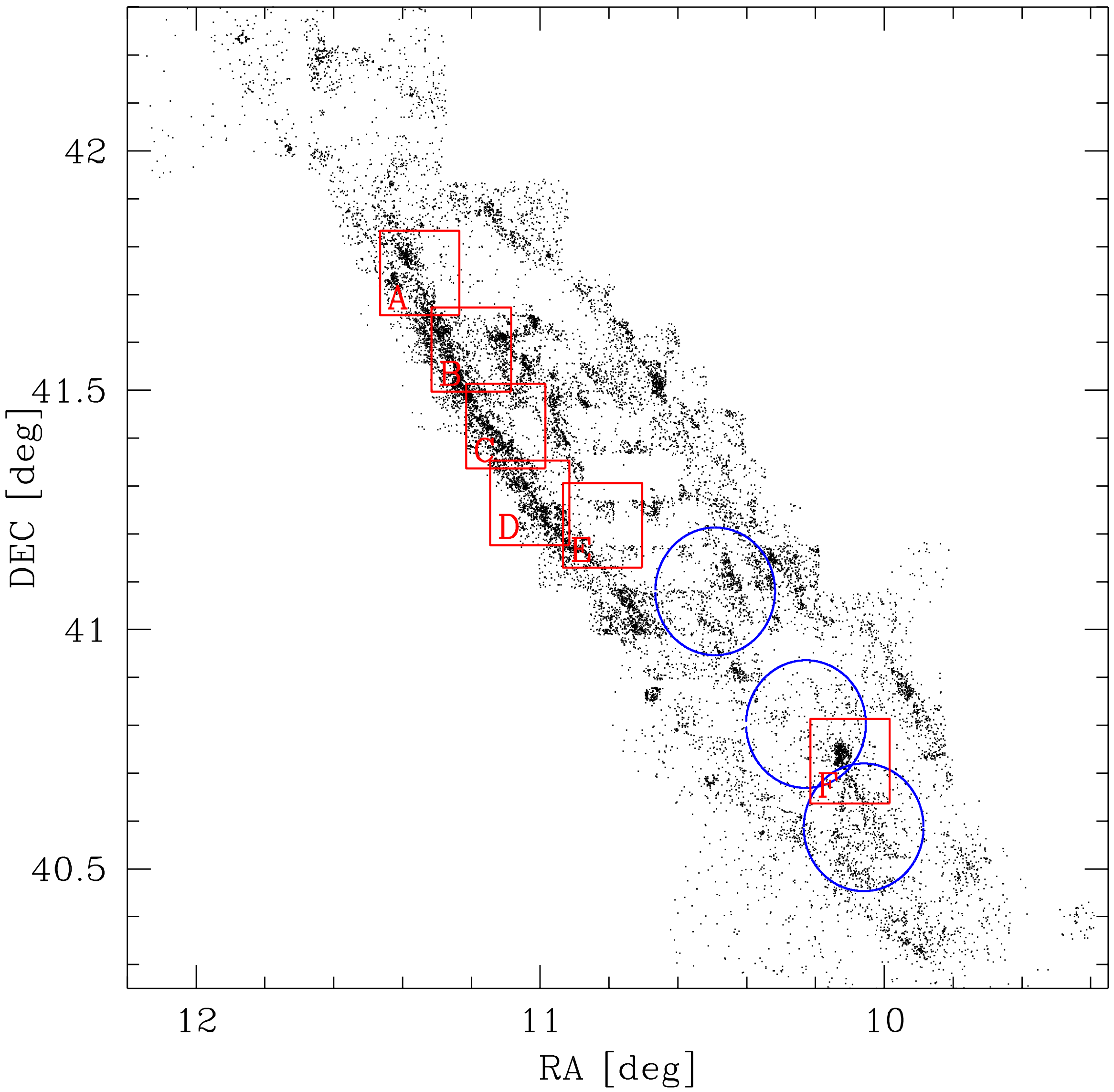

Fig. 1.— Fields observed in M31 during Fall 1996 (squares), based on the photometric survey of M31 by Magnier et al. (1992) and Haiman et al. (1994). Fields were selected as to maximize the number of blue stars in the field. Also shown (circles) are Baade's Fields I, II, III.

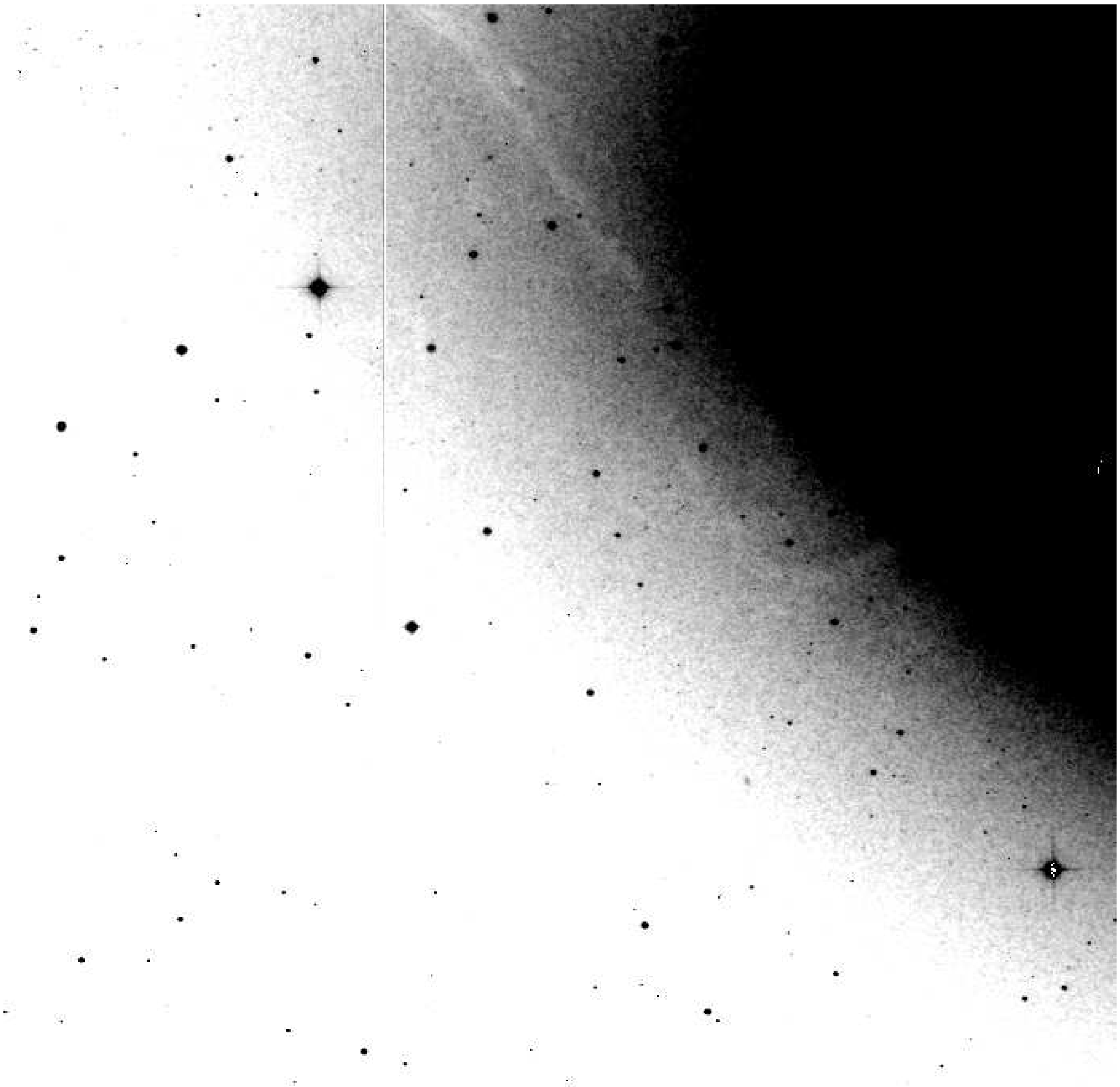

Fig. 2.— The M31E field (see Fig.1), dominated by the bulge of M31.

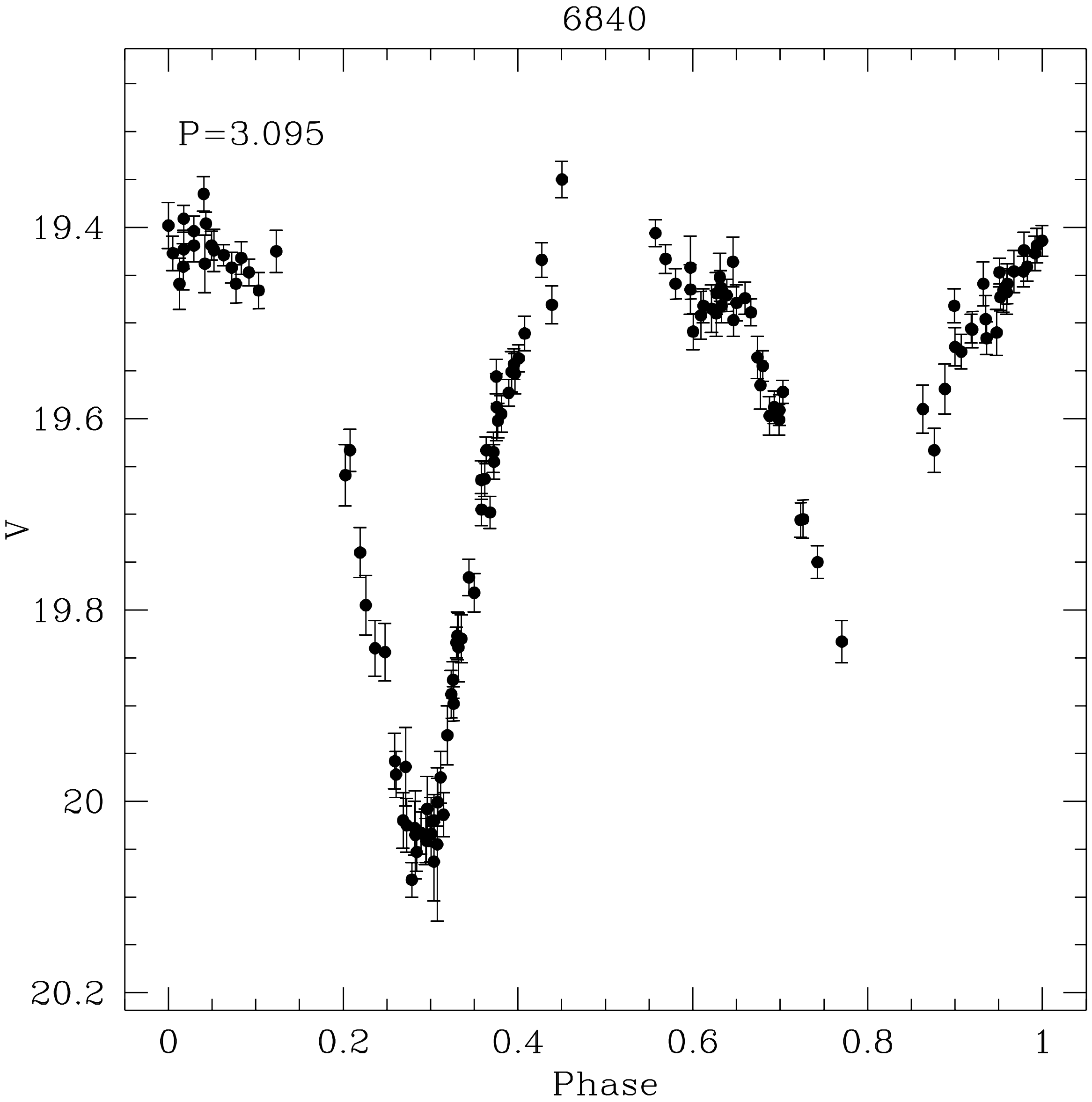

Fig. 3.— Light curve of an eclipsing variable found in the field M31B.

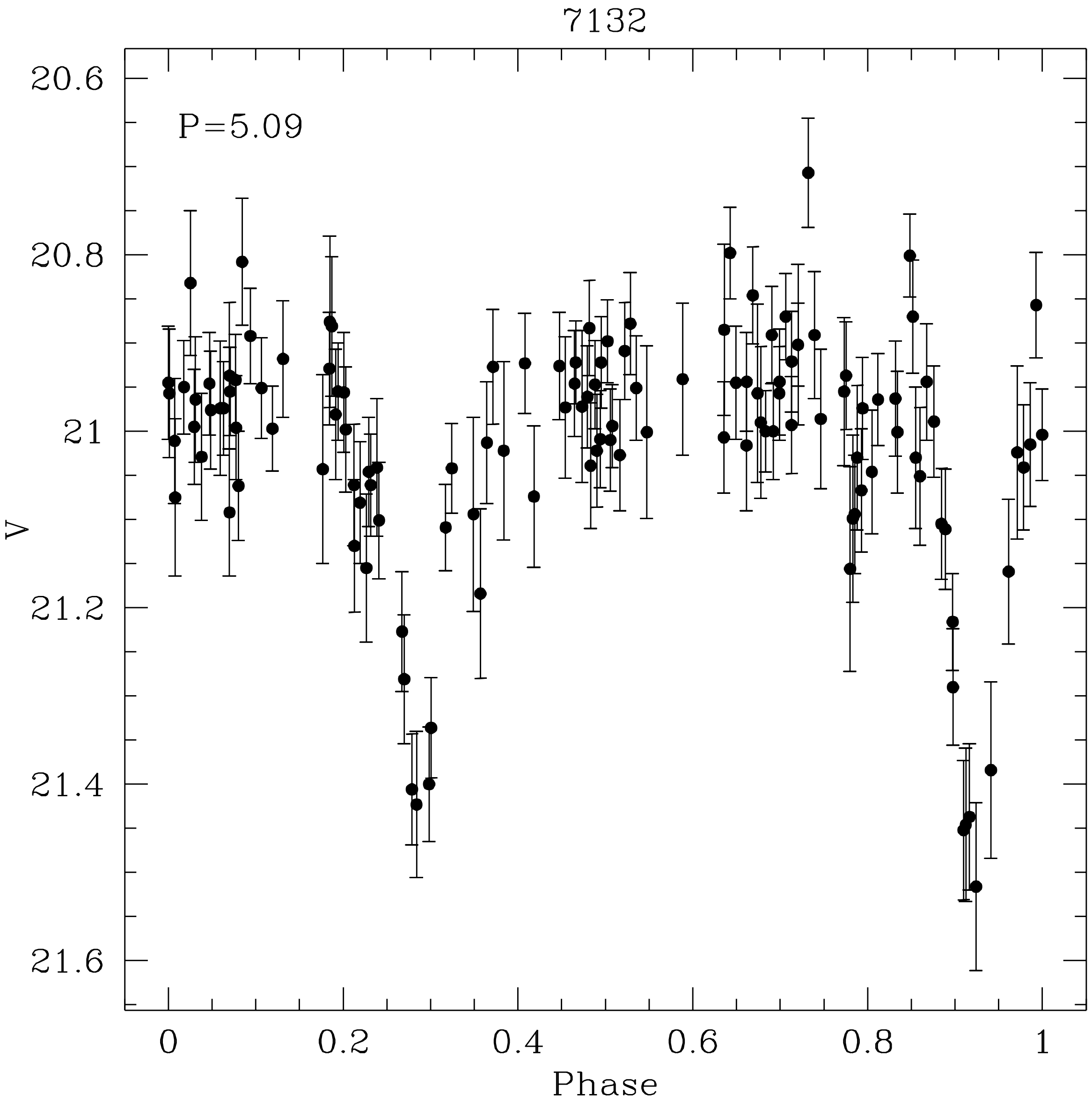

Fig. 4.— Light curve of a possible detached eclipsing binary found in the field M31B.

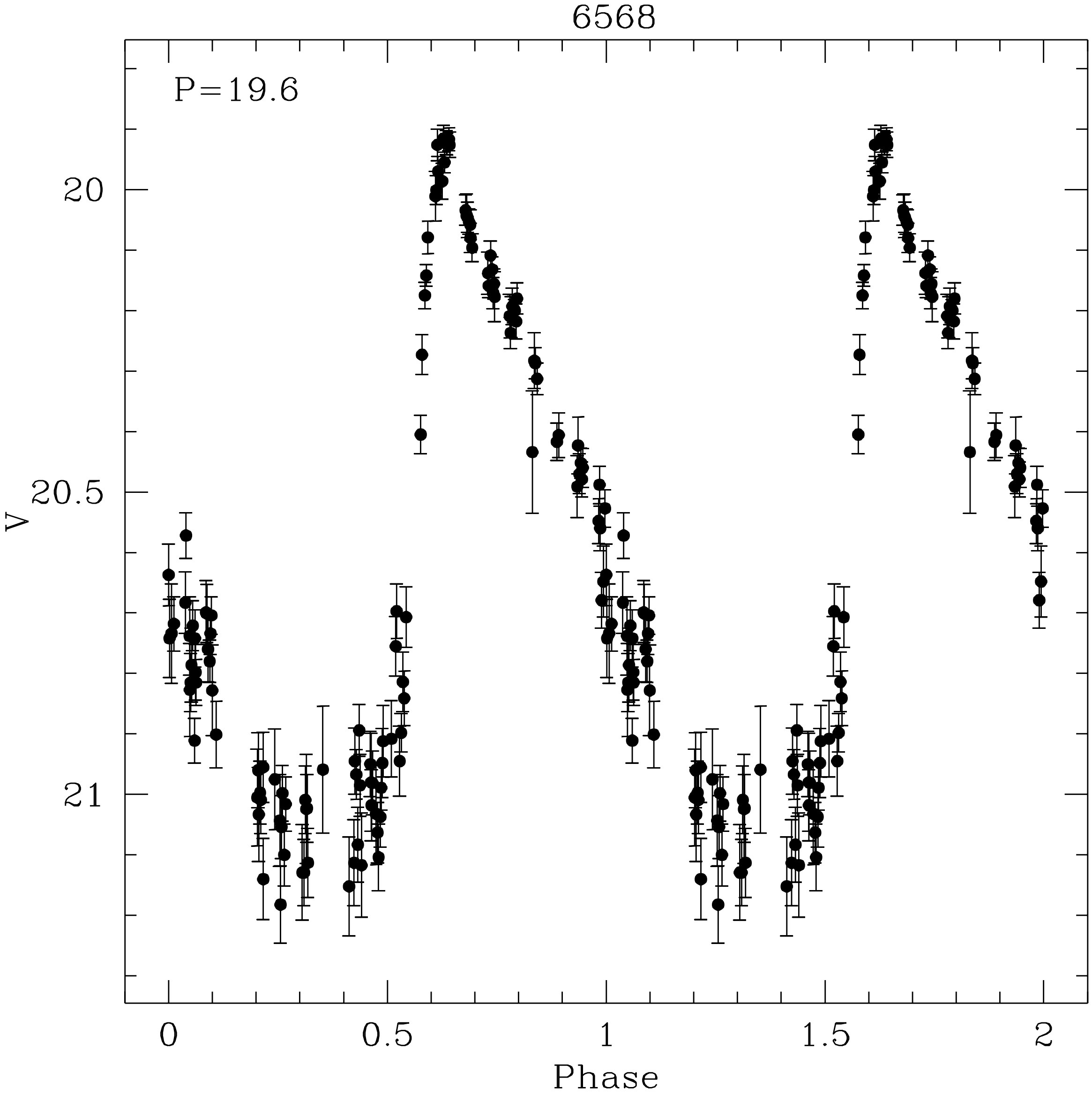

Fig. 5.— Light curve of a new Cepheid variable found in the field M31B.

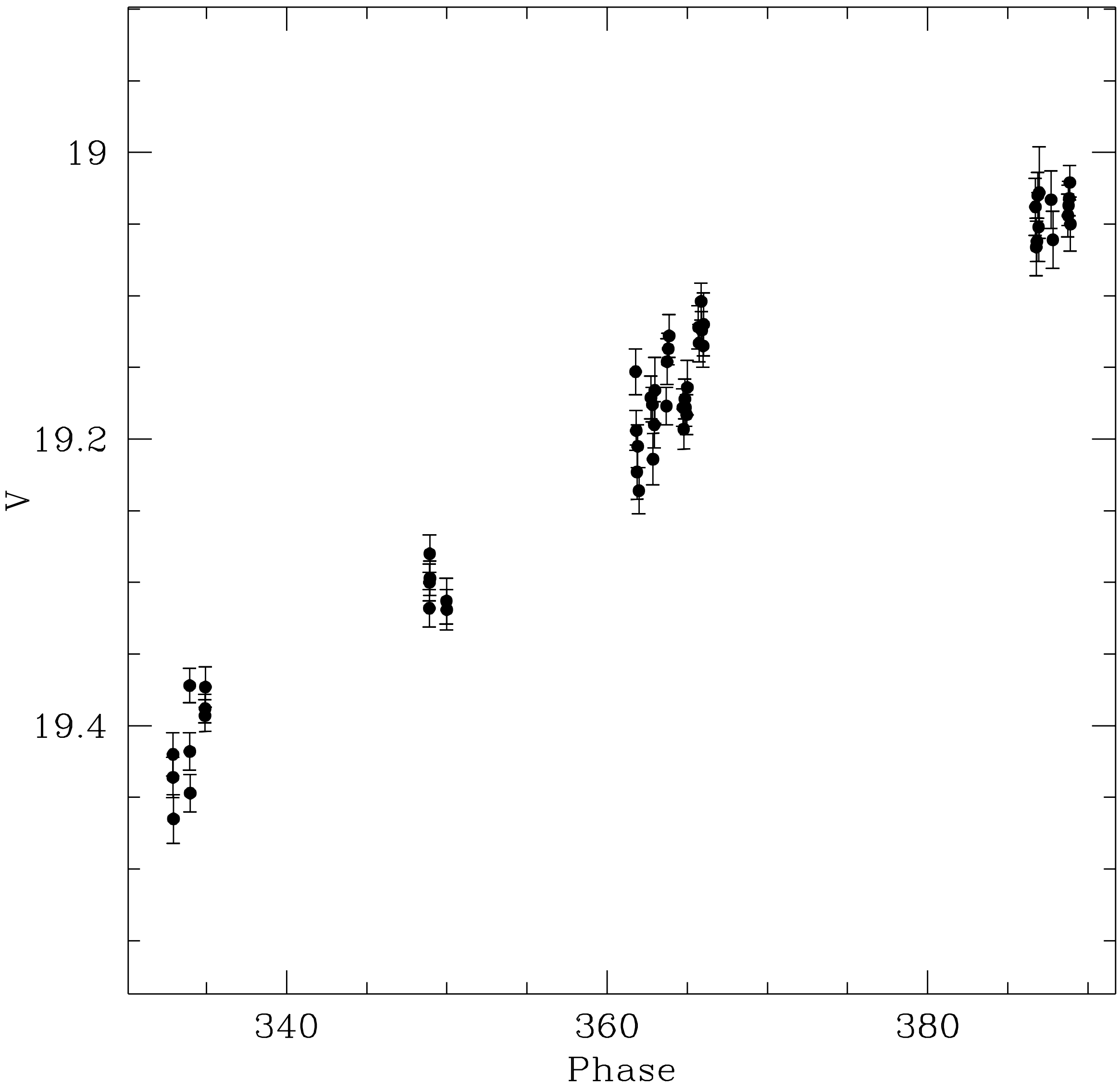

Fig. 6.— Light curve of a possible long-period variable found in the field M33C.