Advantages and drawbacks of the ISM method in globular cluster photometry

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The project

We have started a multicolour CCD survey of globular clusters at Konkoly Observatory in 1998. The main goal of our project is to obtain high quality time series for as many globular cluster variables as possible. The instrumentation enables us to simultaneously observe the clusters with two telescopes (1m RCC and 0.9/0.6m Schmidt), both equipped with professional CCD cameras. The fields of views (4'x 6' and 19' x 28', respectively) allow us to obtain images with sufficient resolution for accurate photometry of both the crowded central regions and the dispersed halos.

The present status of our project is shown in Table 1. In order to get the most and the best light curves from the observations the data were processed using different photometric methods (APPHOT, DAOPHOT, ISM).

Table 1: Status report on the globular cluster variable star survey at Konkoly Observatory. Participants: G.Á. Bakos, J.M. Benkő, J. Jurcsik and R. Szabó. The two numbers in the 4th column denote 90/60cm Schmidt and 1m RCC telescopes, respectively.

Cluster	Date	No. nights	No. frames	Colours
M 3	1998	14	509+304	BVI
	1999	5	0+313	BVI
M 15	1998	12	81+377	BVI
	1999	4	109+9	BVI
	2000	23	358+497	BVI
M 53	1999	6	0+284	BVI
	2000	13	0+333	VI
M 56	1999	2	0+30	BVI
	2000	4	0+110	VI
Pal 2	1999	1	0+16	VI
	2000	14	0+217	VI
NGC 2419	1999	3	0+83	VI

Application of the ISM method

Advantages

The Image Subtraction Method (ISM) developed recently by Alard & Lupton (1998), Alard (2000), proved to be the best algorithm to obtain high precision light curves even in the cores of the clusters.

The main steps of ISM is the following. We prepare a reference image from the best seeing frames and then we assume all the individual frames as a convolution of the reference image and a kernel function. The algorithm determines the kernel functions (which varies both in space and time) and subtracts each frame from the convolved reference image. The method conserves the flux of non-variable objects, and it handles the time and space variation of background as well.

A comparison of the method with DAOPHOT II (Stetson 1987, 1992) shows that, using ISM, much more variables become measurable in the most dense regions (see. Figure 1.), and the standard deviation of the light curves are also significantly better. That is, we came into the same conclusion as other authors (Olech et al. 1999, Kopacki 2000) who applied the ISM technique photometry to globular cluster variables and compared its efficiency to DoPhot (Schechter et al. 1993).

Transformation into the magnitude scale

All previously published data where ISM photometry was used were in relative units (e.g. e^-/ADU) and this is not an accident! The big strength of ISM – that it is a relative method – is at the same time its serious drawback as well. The method serves differential fluxes of the variables relative to their fluxes in the reference frame, that is:

$$\Delta I_i^{(j)} = I_0^{(j)} - I_i^{(j)}, \qquad i = 1, 2, ...,$$

where $I_0^{(j)}$ and $I_i^{(j)}$ are the fluxes of the jth variable in the reference image and in the ith frame, respectively.

To convert these to the usual instrumental magnitudes we need to measure the magnitudes ($m_0^{(j)}$) and fluxes ($I_0^{(j)}$) for each variables in the reference frames as accurately as possible.

- If we can directly determine these values, then we simply apply the formula

  $$m_i^{(j)} = 2.5 \log_{10} \frac{I_0^{(j)}}{I_0^{(j)} - \Delta I_i^{(j)}} + m_0^{(j)}.$$

  The above transformation give excellent result (see Figure 2) if the star is located in a relatively sparse region, where the traditional PSF methods provide reference values ($m_0^{(j)}$, $I_0^{(j)}$) accurate enough. In other cases the transformed light curves are strongly distorted.

- Since we know the magnitude values of two arbitrary points ($m_1^{(j)}$, $m_2^{(j)}$) of the light curve we can calculate the necessary reference values ($m_0^{(j)}$, $I_0^{(j)}$). Namely,

$$I_0 = \frac{\Delta I_1 10^{(m_1-m_2)/2.5} - \Delta I_2}{10^{(m_1-m_2)/2.5} - 1},$$

  and

$$m_0 = m_k - 2.5 \log_{10} \frac{I_0}{I_0 - \Delta I_k}, \text{ where k=1 or 2,}$$

  and index j was omitted.

- Sometimes, we know only the total amplitude ($\Delta m = m_1 - m_2$, where $m_1 = m_{\min}$, $m_2 = m_{\max}$), but it is sufficient to reconstruct the true shape of the light curve.

These transformations are, however, seriously affected by the errors of the reference magnitudes. The dependency of the light curve (amplitude and zero point) on the errors of the reference values (m_0 or Δm) is plotted in Figure 3. It can be seen that to obtain reliable result the reference magnitudes have to be known with some hundredth of magnitudes.

Miscellaneous problems

Beside the fundamental problem of magnitude transformation, we had some other difficulties as well. We used Alard's free code ISIS-2.1 as a realization of the ISM method. The registration and subtraction subprograms (apart from small bugs) worked well, but we found obscure behaviour of the PSF photometry part (see. Figs 4–5) resulting unreasonably large scatter in the descending branch of a few light curves. We have solved this problem by applying a plain aperture photometry to the subtracted images.

We notice, that the standard deviation of a light curve is getting worse if the variable is close to a saturated star or to an other variable, but these features are natural.

References

Alard C. 2000 *Astron. Astrophys. Suppl.* **144**, 363

Alard C. and Lupton R.H. 1998 *Astrophys. J.* **503**, 325

Kaluzny J., Hilditch R.W., Clement C., and Rucinski S.M. 1998 *MNRAS* **296**, 347

Kopacki G. 2000 *Astron. Astrophys.* **358**, 547

Olech A., Woźniak P.R, Alard C., Kaluzny J., Thompson I.B. 1999 *MNRAS* **310**, 759

Schechter P.L., Mateo M. and Saha A. 1993 *PASP* **105**, 1342

Stetson P.B. 1987 *PASP* **99**, 191

Stetson P.B. 1992 *ASP Conf. Ser.* **25**, 297

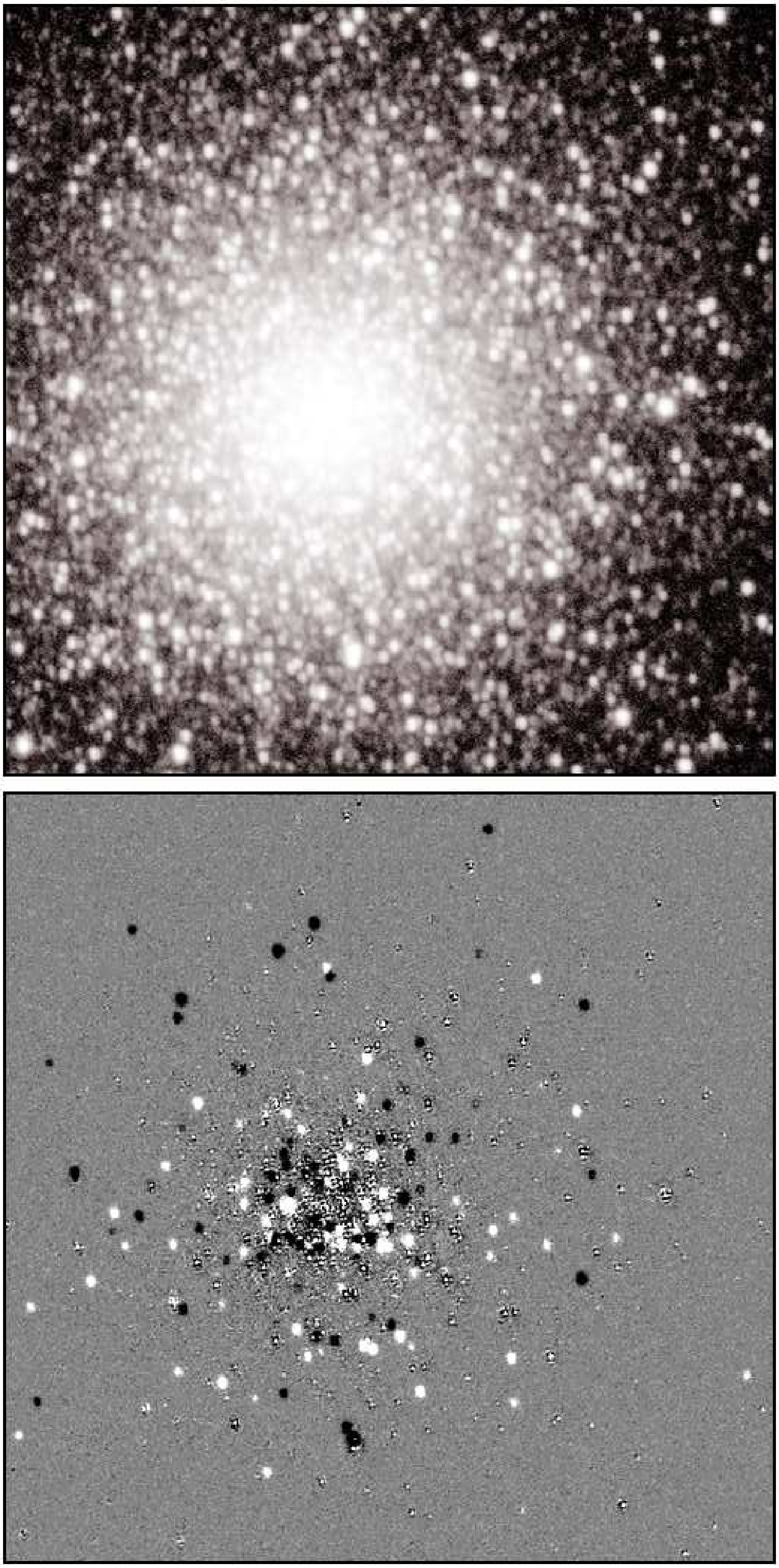

Figure 1: A typical result of the subtraction process applying the ISM method. The top panel shows the most crowded central part of the M3 (in V, 90/60cm Schmidt telescope, Konkoly Obs.) and the bottom panel shows the same area after subtraction. It is easy to identify the variables (white and black spots depending on whether they are brighter or fainter in the given frame than in the reference image), the other stars have been practically disappeared, except for few saturated ones.

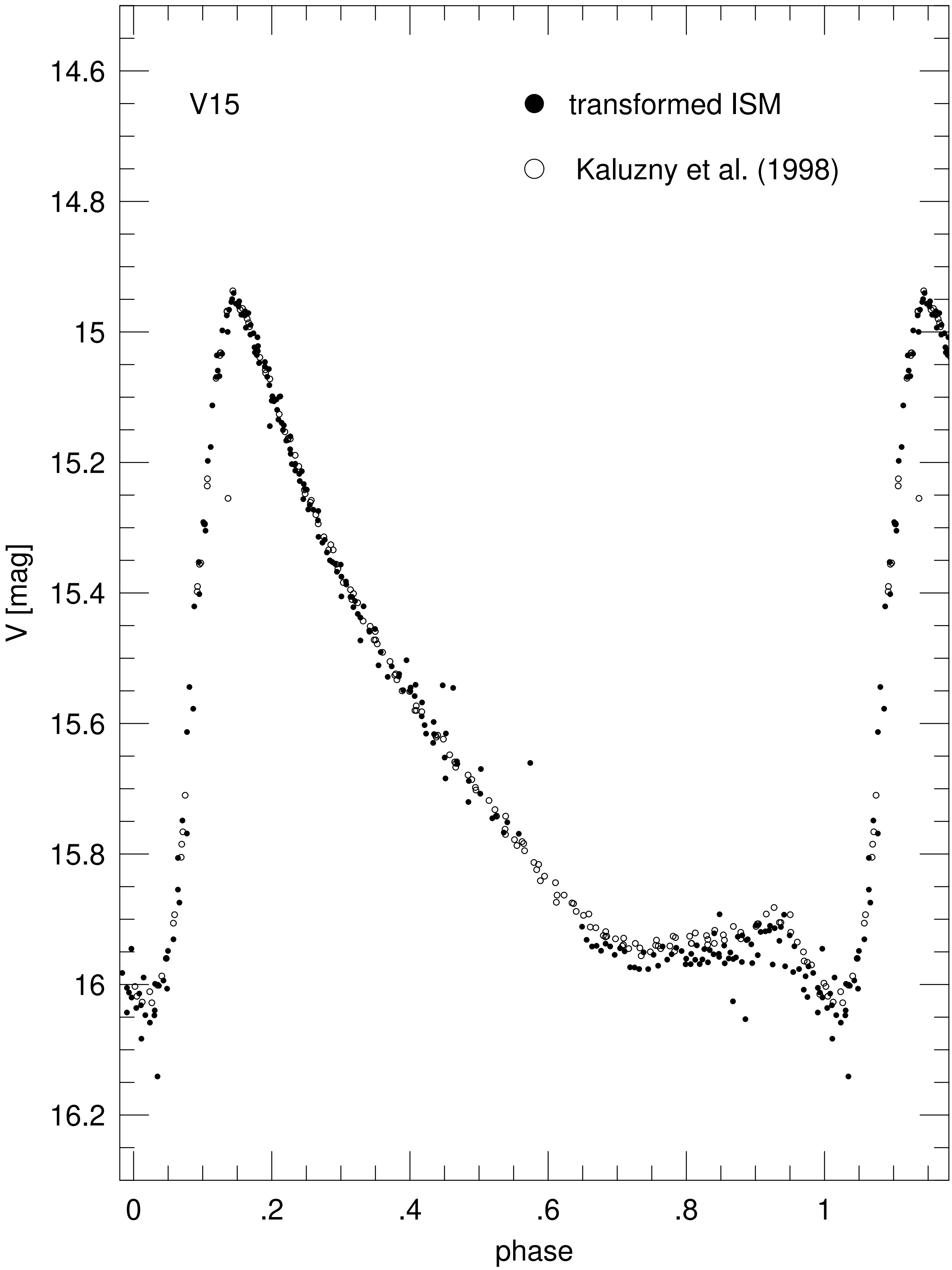

Figure 2: Transformed ISM flux into the magnitude scale in the case of V15 in M3. It is a good example of accurate magnitude transformation compared to previously published data (Kaluzny et al. 1998, DoPhot).

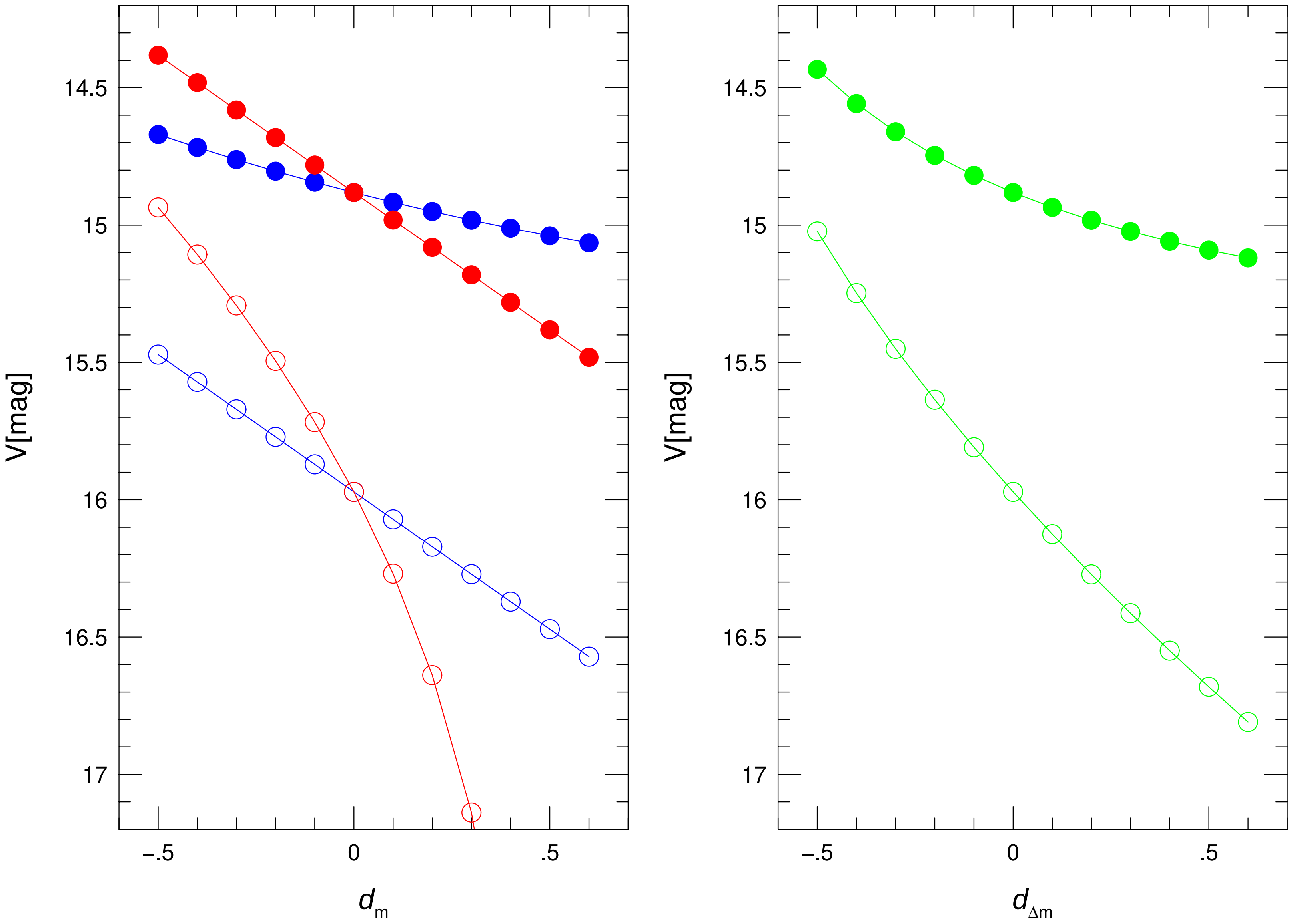

Figure 3: The effects of errors in magnitude zero points and amplitudes on the shape of the transformed light curve. We assume an RR Lyrae star at the distance of M3 with 1^{m} total amplitude. **a)** Supposing $m_0(= m_{\max})$ with an error of d_m, then the maximum (red filled circle) and minimum (red empty circle) of the transformed light curve change strongly. If the $m_0 = m_{\min}$ is known erroneously, the transformed light curve is located between the two blue lines. **b)** If we know the total amplitude ($\Delta m = m_{\min} - m_{\max}$) with the error $d_{\Delta m}$, the situation is similar.

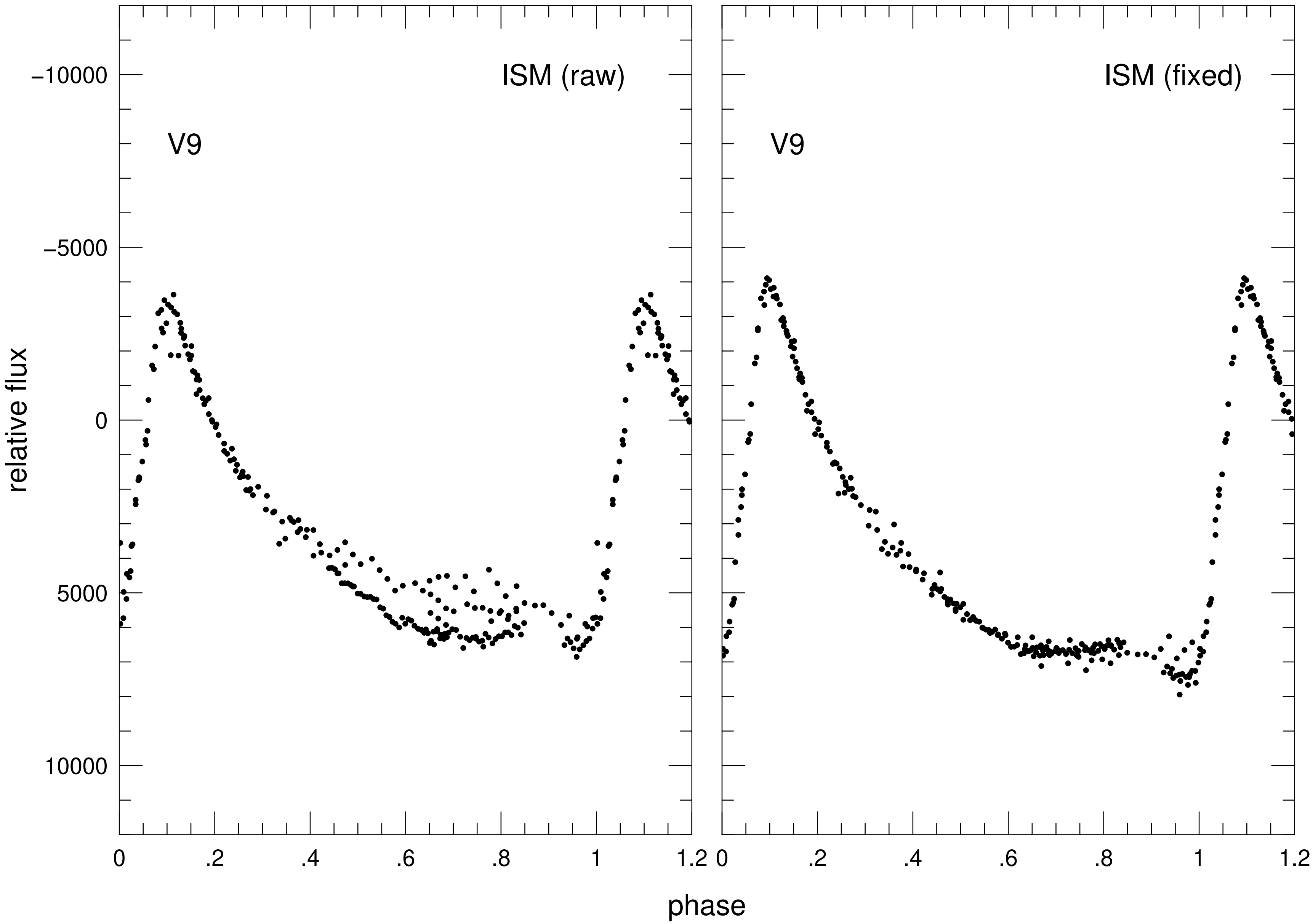

Figure 4: The figure demonstrates the obscure behaviour of the PSF algorithm of ISIS-2.1 on a typical example (V9 in M3). The fixed curve was obtained by applying an aperture photometry to the subtracted images.

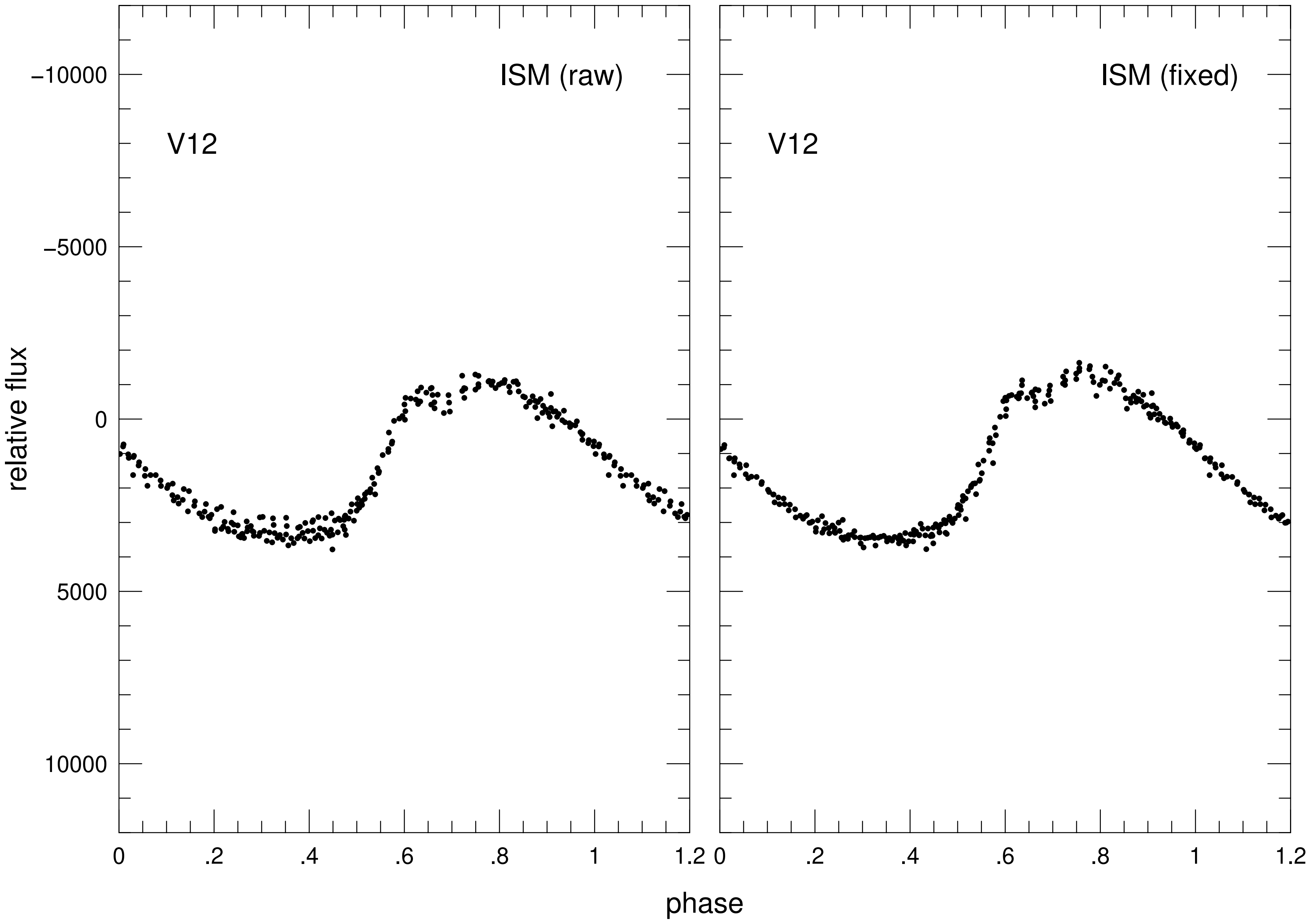

Figure 5: Same as in Fig. 4, but for a smaller amplitude RRc type star (V12 in M3).