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Variable stars in the old galactic cluster M67

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Abstract. Schmidt plates of the old open galactic cluster M67 were obtained on twelve nights to find the most probable variables in the cluster. The Sabattier technique was used to derive the magnitudes of the cluster members. The most probable variable stars in this cluster determined by this method are listed.

Key words : open clusters—variable stars

1. Introduction

A search for variables amongst late-type stars in galactic clusters is needed in order to study the relationship between variability and the ages of the stars. Especially useful would be studies that relate chromospheric activity of single and binary stars with age, and rotation, in the presence of magnetic fields. Any such project would need large amount of observation time on medium to large-sized telescopes. A short list of the most probable variables would be extremely useful to expedite the search. In this paper, we describe an attempt to get this information for the cluster M67 by photographic methods. In particular, the use of Sabattier technique to derive the magnitudes of stars (Bappu 1978) is discussed. This method is one of the possible ways of efficiently utilizing the photographic plates for getting quick results.

2. Observations

The Kavalur 45 cm Schmidt telescope has recently been put into regular use for a survey of solar system objects (Rajamohan *et al.* 1987). In order to reach the faintest possible limit, no filter is introduced in the light path for the survey project. All the photographs were obtained on the 103a–O plates.

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In all, twelve plates were obtained at an average interval of one day during the dark of the moon period from 1987 February 21 to March 9. The exposure time was sixty minutes. The details of the plates taken are given in table 1.

Table 1. Details of the plate material used in this study

Serial number	Plate number	Date of observations	Mid exposure (U.T.)
1	83	1987 Feb 21	$16^h\ 14^m$
2	90	23	16 50
3	94	25	14 52
4	98	26	14 25
5	100	27	14 32
6	104	28	18 20
7	105	Mar 2	14 42
8	111	3	15 35
9	115	4	16 54
10	119	5	18 00
11	122	6	18 52
12	125	7	19 57

3. The method adopted

The nonlinear response of the photographic emulsion is a distinct disadvantage but as a panoramic detector, its advantage is still unsurpassed. For survey type of work of the kind discussed here it is the most efficient detector provided we can also solve the problem of the nonlinear response. In order to get over this problem, if we can measure any quantity q which is representative of the incident intensity at the linear portion of the characteristic curve of the photographic plate, then we can expect the quantity q to be linearly related to the incident intensity of light. Such a linear relationship exists between image diameter from a Sabattiered plate and the apparent magnitude of stars (Bappu 1978). We decided to explore this possibility further and see if we can derive fairly accurate magnitudes for the members of the M67 cluster by photographic photometry.

All the plates listed in table 1 were Sabattiered and the diameters of the star images at a given density were measured with a Zeiss x–y measuring engine. The program was aimed initially at testing the adaptation of this method for the discovery of variable stars. Hence only those images which were free from overlaps and not likely to introduce large errors in measurements were chosen. The B magnitudes of the stars were related to their measured image diameters through a second order polynomial fit. The magnitudes of these stars were taken from Eggen & Sandage (1964).

The equidensity contours are obtained in this technique by taking a contact copy of the plate and exposing it for a short duration to uniform light during development. The exposure time during development can be varied to derive different equidensity contours. Initially, we derived different equidensity contours for a single plate to choose the one that would lead to the measurement of largest number of stars on a given plate. This choice was also dictated by the condition that the best fit between the magnitude and diameter should be very closely linear in order to minimize the errors of magnitude determination. An example of a least square fit between B magnitude and the measured diameter is shown in figure 1. The coefficients of the least-square fit for each plate together with their probable errors are given in table 2. The B magnitude and the diameters were related through an equation of the type

$$B = a + b.D + c.D^2,$$

where D is the measured diameter and B, the B magnitude of the star from Eggen & Sandage (1964). The smallness of the coefficient c indicates that the equidensity contours were obtained at a density which falls on the linear portion of the characteristic curve of the 103a-O plate.

The run of the residuals as a function of time were inspected from plots of $(O - C)$ versus the date of observation for each star. It was found that a fairly

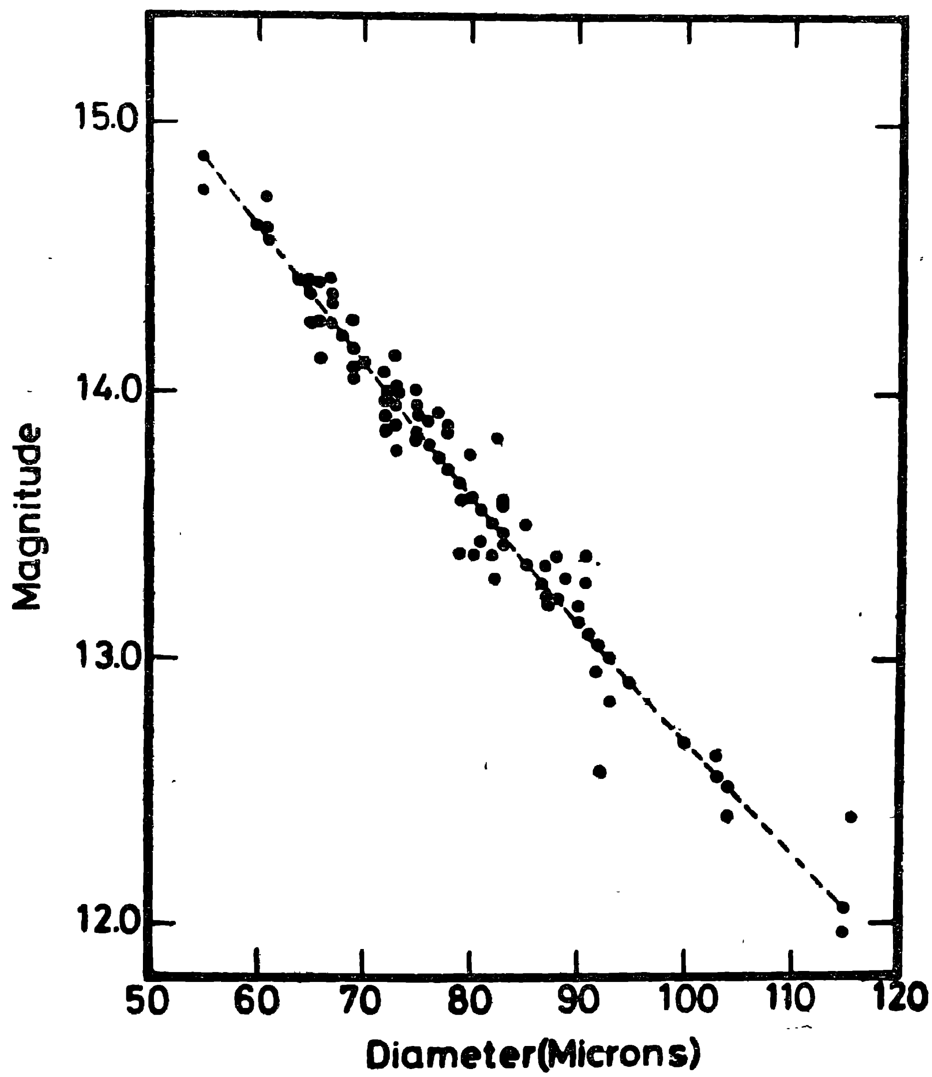


Figure 1. The relationship between the measured image diameters and the photoelectric B magnitudes of the M67 members. The dotted line is the second order least square fit to the data.

Table 2. The coefficients *a*, *b*, *c* and their probable errors derived for each plate

Serial number	Plate number	a	σ_a	b	σ_b	c	σ_c
1	83	17.35	0.12	−5.6 E-02	2.0 E-03	8.7 E-05	8.5 E-06
2	90	18.90	0.10	−5.6 E-02	1.6 E-03	6.3 E-05	5.5 E-06
3	94	18.74	0.11	−6.5 E-02	1.6 E-03	1.1 E-04	5.1 E-06
4	98	19.15	0.18	−7.1 E-02	3.4 E-03	1.4 E-04	1.6 E-05
5	100	17.60	0.14	−5.8 E-02	2.4 E-03	9.4 E-05	8.5 E-06
6	104	18.00	0.09	−6.1 E-02	1.7 E-03	9.3 E-05	6.8 E-06
7	105	18.20	0.11	−6.7 E-02	2.0 E-03	1.2 E-04	7.3 E-06
8	111	19.15	0.12	−7.1 E-02	1.9 E-03	1.2 E-04	6.4 E-06
9	115	19.02	0.09	−6.9 E-02	1.5 E-03	1.2 E-04	5.0 E-06
10	119	18.34	0.15	−5.8 E-02	3.2 E-03	6.0 E-05	1.7 E-05
11	122	18.57	0.13	−5.7 E-02	2.0 E-03	7.3 E-05	7.0 E-06
12	125	20.39	0.23	−6.7 E-02	3.7 E-03	9.3 E-05	1.5 E-05

good number were constant in brightness to within $\pm$ 0.06 magnitudes which was consistent with a measuring accuracy of 1 μm for the image diameters.

Accidental errors of the order of $\pm$ 3 μm seem to have affected some of the measured diameters. One possible source of error is the dark room procedure adopted. Any dust particle that gets imbedded between the original and the contact copy is likely to produce errors in the measured diameters of the equidensity contours. The fact that a fairly good number could be judged to be constant indicates that this source of error has not affected all the images. Also we have assumed that in order to call a star variable, the deviations should be systematic and, if random, should be much larger than the average observed deviations of the stars considered as non-variables. These judgements together with the criterion that the standard deviation should be greater than 0.14 mag (at the 2σ level) was finally adopted to call an object variable.

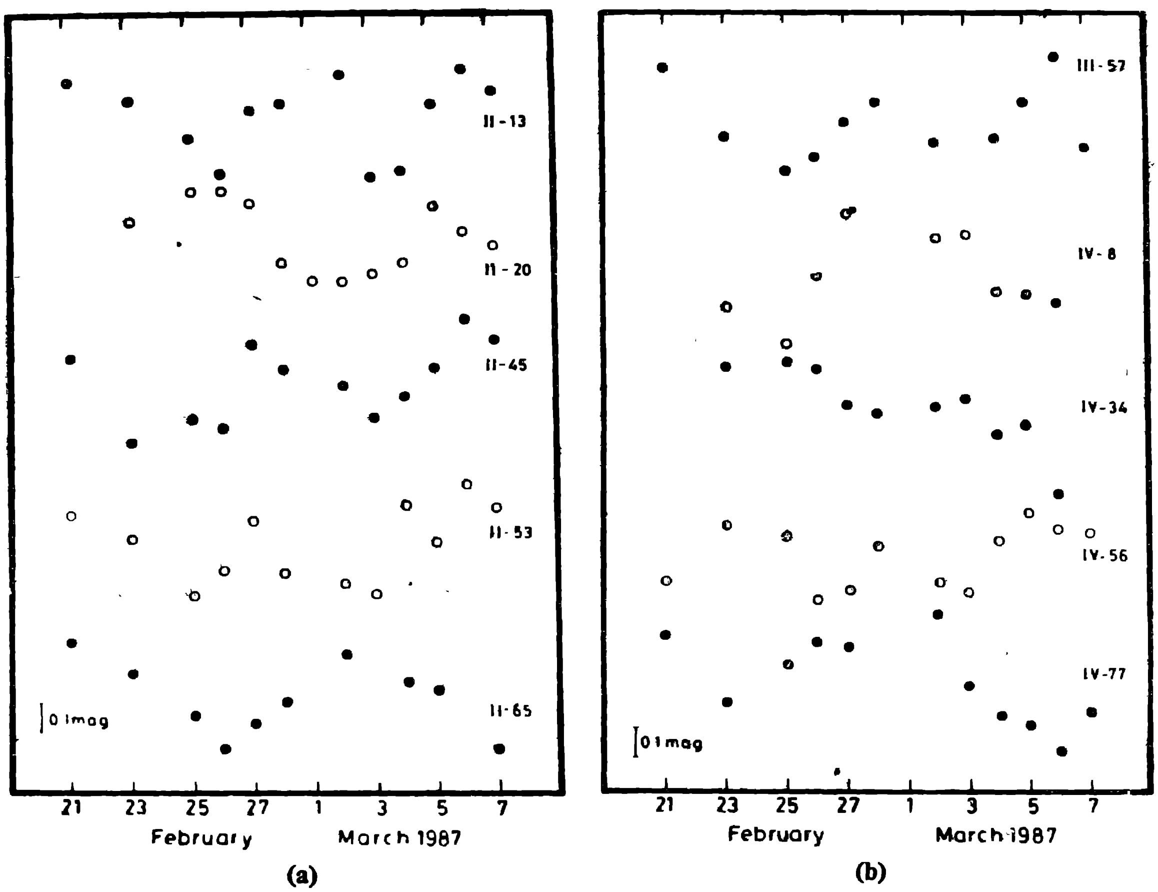
Table 3 lists the objects found likely to be variable from this study. Columns 2 and 3 gives the star number and *B* magnitude taken from Eggen & Sandage (1964), column 4 the average observed value of the residual and column 5 the standard deviation in the residuals measured.

For a random distribution of errors, only about 4 % of the nonvariable stars may be categorized as variables as a result of combined errors. That is, only three objects out of the 70 measured are expected to be wrongly classified as variable by this method. We find that the standard deviation in $(O - C)$ is greater than 0.14 mag for only four objects which indicates that probably none of the 70 objects observed is a variable. However, the run of the residuals in $(O - C)$ for many objects show systematic trends which seems to indicate that some of these objects are likely candidates for variability. In figures 2a, and 2b we show the run of the residuals for 10 out of the 14 objects listed in table 3. Even though the standard deviations in $(O - C)$ residuals is less than 0.14 mag for these objects, they are most probably variables.

Some comments on some of the variable candidates found in this study are as follows :

Table 3. List of probable variables in M67

Sl. number	Star number	Mag.	< (O–C) >	σ
1	I-24	14.05	−0.12	0.15
2	II-13	14.40	−0.04	0.13
3	II-20	13.22	−0.11	0.12
4	II-45	14.61	0.06	0.13
5	II-53	13.94	0.02	0.12
6	II-65	13.81	−0.08	0.12
7	III-57	13.95	−0.09	0.12
8	IV-8	14.79	0.08	0.13
9	IV-11	14.57	0.15	0.15
10	IV-25	14.72	0.07	0.14
11	IV-34	14.20	0.09	0.13
12	IV-56	——	0.11	0.13
13	IV-68	13.82	0.06	0.15
14	IV-77	13.81	−0.06	0.13



Figures 2a & 2b. The (O — C) residuals in magnitudes plotted against the date of observation for objects considered as likely to be variables.

I-24 : Nissen *et al.* (1987) find that the various photometric observations of this object indicate that it is probably a variable.

II-13 : Star numbers I-6, I-18, II-13 and IV-13 have V magnitudes different by about 0.1 mag between two independant determinations by Eggen & Sandage (1964) and Racine (1967).

II-20 : Double-lined spectroscopic binary according to Mathieu *et al.* (1986)
IV-25 : Suspected variable star (Racine 1967).

4. Conclusions

Even though these results are preliminary in nature and aimed at the application of Sabattier technique to photometry, we do find support for the expection that if M67 contains a large number of binaries (Racine 1967), then we must find that a good number of them are likely to be photometric variables due to enhanced chromospheric activity. The majority of the variables we have found are likely to be in binary systems with the period of variation being the orbital period. Also some of these could be single stars with high chromospheric activity. Even though M67 is one of the oldest galactic clusters, Barry *et al.* (1981) find that late-type dwarft in M67 fall into the chromospherically active groups. We hope to study some of these aspects in greater details.

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