Bull. Natn. Sci. Mus., Tokyo, Ser. E, **20**, pp. 9–22, December 22, 1997

# Recent Light Curves and Period Return Maps of RV Tauri Stars

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**Abstract** Visual light curves of 14 RV Tauri type variable stars, which are the object stars of polarimetric monitor observation carried out by us (Yoshioka, Saijo and Satoh 1997), in recent years are reported from the database of VSOLJ. From these light curves, variation of the period is investigated by using period return maps of these stars. Some discussions on differences of return maps among late-type long period pulsating variables and on chaotic variabilities are also given.

**Key words:** RV Tauri stars, Light curve, Period, Return map, Chaos

## 1. Introduction

RV Tauri stars are pulsating variables of spectral classes F to K supergiants, whose light curves are characterized by double maximum and/or alternative expression of deep minimum (primary) and shallow minimum (secondary). A period of RV Tauri type variables defined by the terms between two primary minimum is of 50–200 days. RV Tauri stars are classified in two subtypes, RVA and RVB. In RVB the typical changes in brightness are superimposed on a very long wave (about 1000 days or more) of greater amplitude. Around the phase of maximum, the spectra shows hydrogen emission lines and strong expansion shifts.

From the evolutionary point of view, RV Tauri stars are in the very late stage of steller evolution, post AGB (Asymptotic Giant Branch) stage. Therefore, study of RV Tauri stars is very important to clarify the last stage of steller evolution.

Polarimetric monitor observation of RV tauri stars has been carried out by us (Yoshioka, Saijo and Satoh, 1997) at Dodaira station of National Astronomical Observatory, Japan, for several years to examine circumstellar matters with phase around RV Tauri stars. Stars of this type show irregular variability as well as other types of late-type pulsating variables, such as, Mira, SR.

In this paper, I report visual light curves of fourteen RV Tauri stars in recent years, which are object stars of our polarimetric monitor observation program, from the database of VSOLJ (Variable Star Observers League in Japan, see Saijo and Kiyota 1991). From these and earlier obtained light curves, period variation of these stars are investigated by using first return map of period (Saijo and Watanabe 1987). Some discussions are also given.

## 2. Light Curve

Accomplishment of the database maneged by VSOLJ is reported by Saijo and Kiyota (1991). After the addition of observational date to the present time, this datebase collecting visual observations of variable stars in Japan from 1910's will be open very recently.

Light curves of 14 RV Tauri stars from the biginning of 1990 to the end of 1995 from the database of VSOLJ are shown in Figures 1 to 14. Characteristics

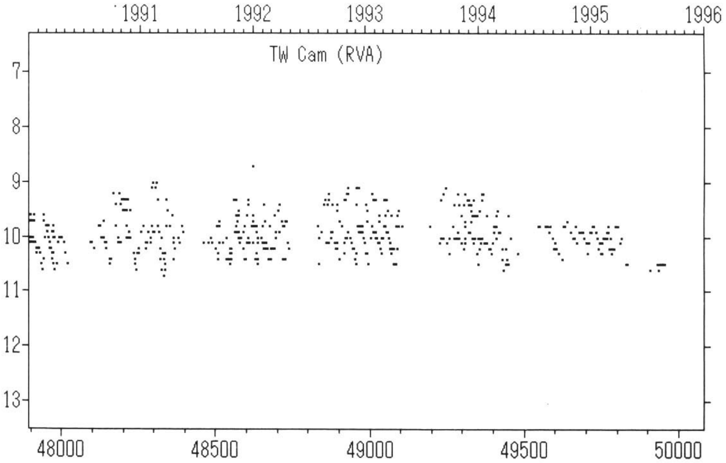

Fig. 1. Light curve of TW Cam. Ordinate shows visual magnitude, upper abscissa shows date and lower abscissa shows Julian-day minus 2400000, which are common in all the figures of light curve.

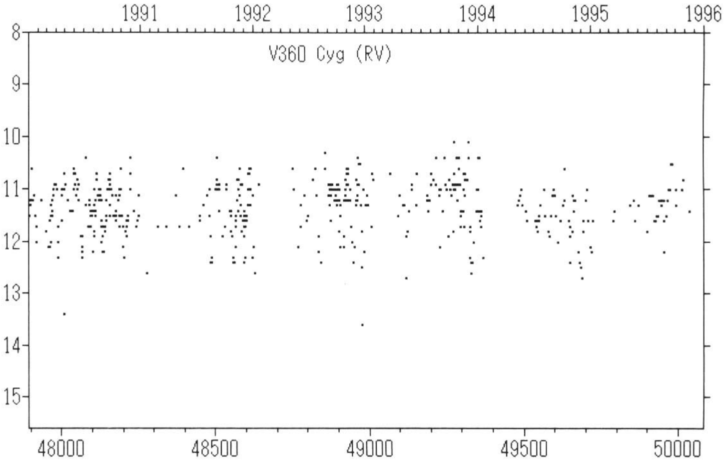

Fig. 2. Light curve of V360 Cyg.

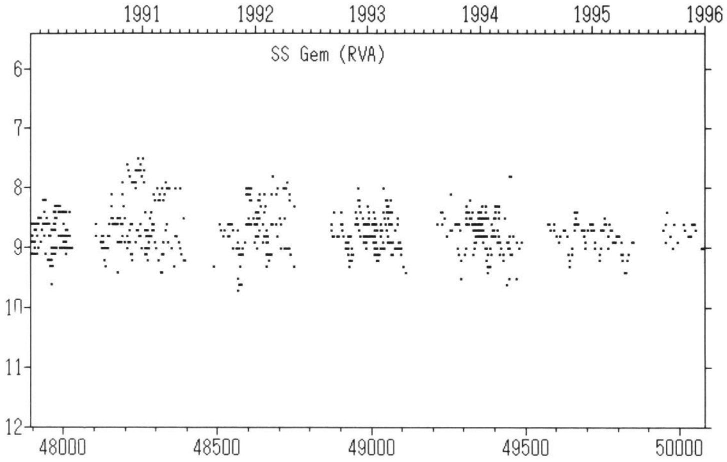

Fig. 3. Light curve of SS Gem.

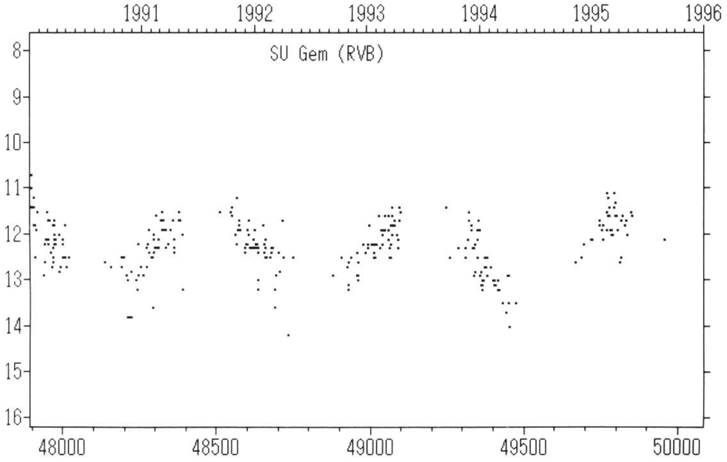

Fig. 4. Light curve of SU Gem.

of pulsating light variation of these stars are tabulated in Table 1 mainly from the fourth edition of GCVS (General Catalogue of Variable Stars 1985). Each column in Table 1 has usual meaning and the last column shows subtype of RV Tauri stars.

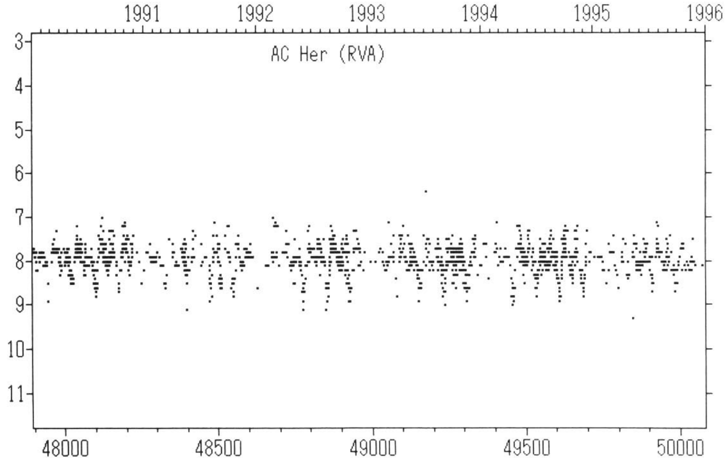

Fig. 5. Light curve of AC Her.

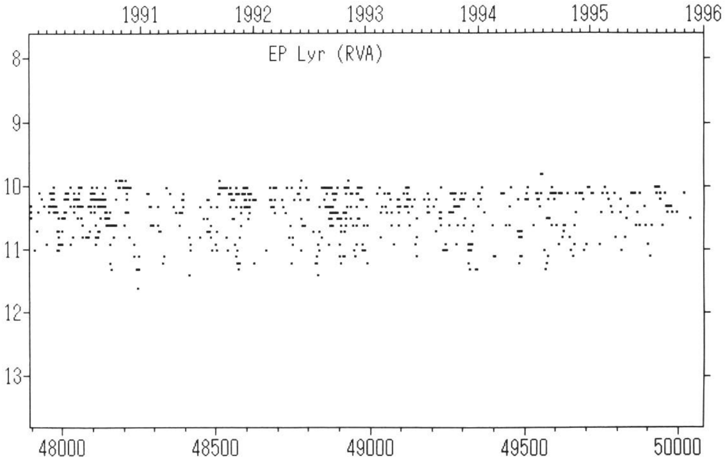

Fig. 6. Light curve of EP Lyr.

## 3. Period and Return-map

### 3.1. Period

To determine observed period by the date of light minimum is rather difficult because of some irregularity on the shape of the light variation and seasonal lack of the observation. In spite of these difficulties, after detailed investigation of

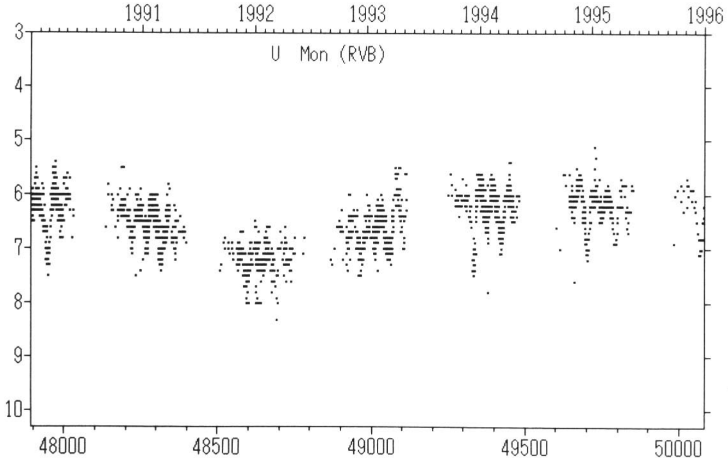

Fig. 7. Light curve of U Mon.

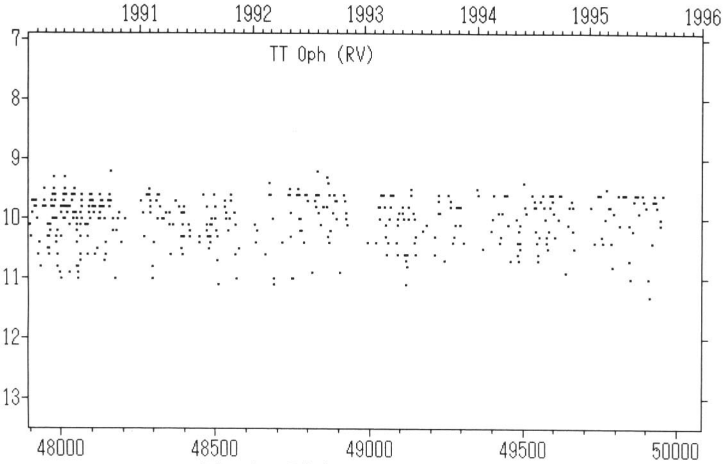

Fig. 8. Light curve of TT Oph.

light curves from Figures 1 to 14 and from data in the earlier term, observed mean period of each star is determined.

In the second column of Table 2, the mean period from observed light curve in each star in days is given. The values in parentheses in the same column are the number of obtained periods. However, the observed period of SU Gem

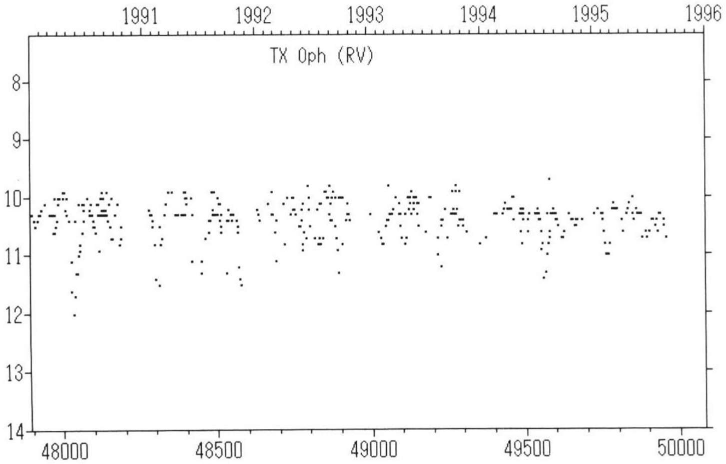

Fig. 9. Light curve of TX Oph.

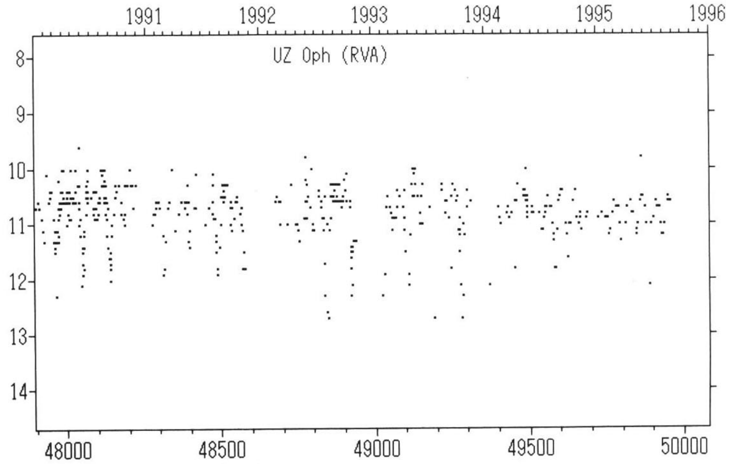

Fig. 10. Light curve of UZ Oph.

cannot be determined, since the affect of secondary wave and irregular variability on typical light variation are too large to have reliable light minima. The third column of Table 2 shows standard deviation of observed period in days. Although standard deviations are rather large, about 5 parcent or more, observed period is nearly equal to the published period to compare with Table 1.

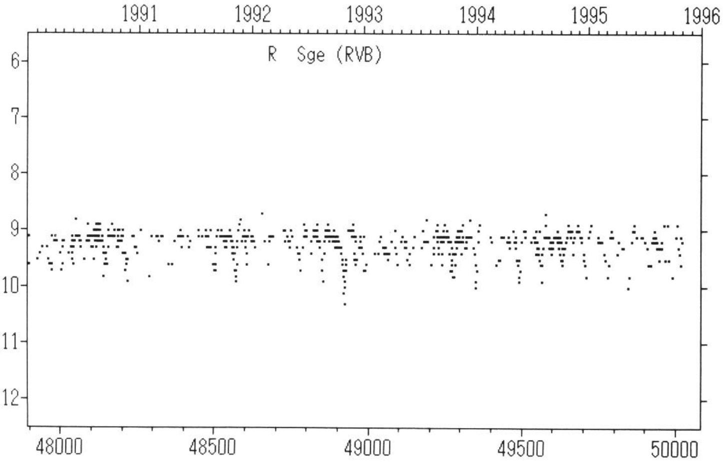

Fig. 11. Light curve of R Sge.

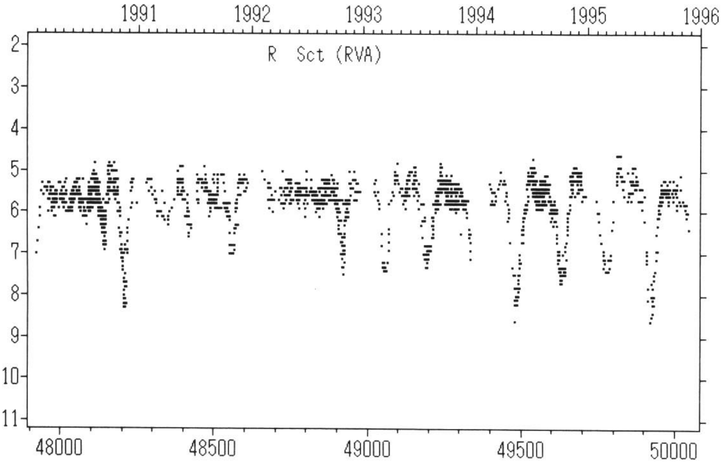

Fig. 12. Light curve of R Sct.

### *3.2. Period Return map*

Period return maps of 13 RV Tauri stars are obtained in Figures 15 to 27. Abscissa shows $P_i$, i-th period, and ordinate shows $P_{i+1}$,i+1-th period in each figure. The numerical results are tabulated in Table 2 after the fourth column. The fourth column of Table 2 shows the number of plot, which obtained from

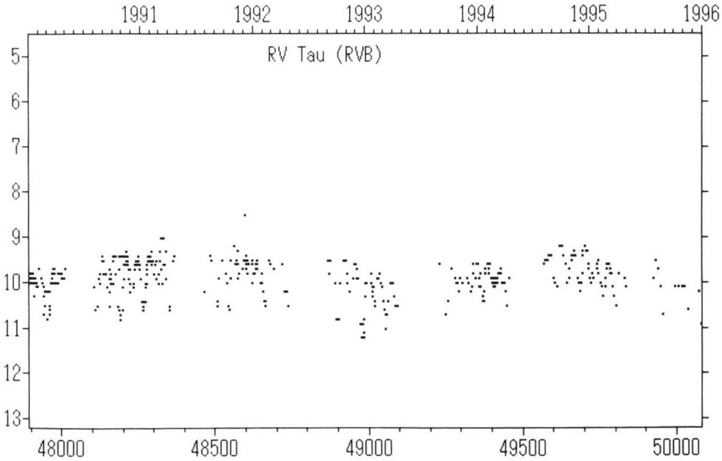

Fig. 13. Light curve of RV Tau.

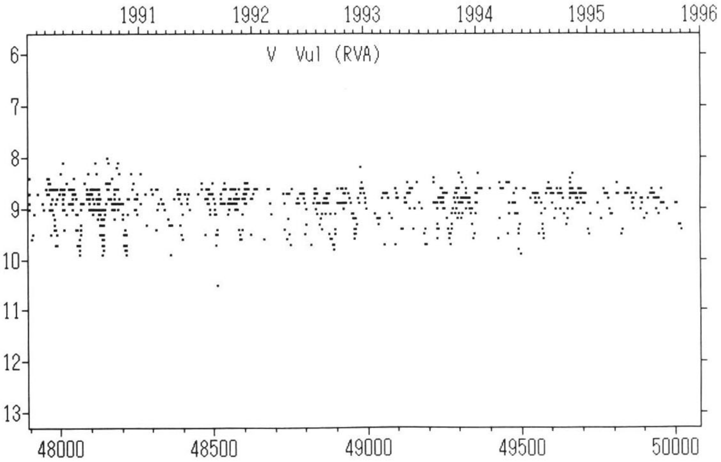

Fig. 14. Light curve of V Vul.

successive pair of $P_i$ and $P_{i+1}$, $(P_i, P_{i+1})$ on a $P_i$-$P_{i+1}$ plane. The fifth column shows correlation coefficients of each return map. The sixth column shows the type of return map defined in my previous works (Saijo and Watanabe 1987, Saijo 1988, Saijo 1989, Saijo 1991) after the values of correlation coefficient.

Although the number of plot is smaller than 20 in 7 stars, some character-

Table 1. Published Characteristics of RV Tauri Stars.

| Name | | Period | Max. | Min. | Sp. | Type |
|---|---|---|---|---|---|---|
| TW | Cam | 87.22 | 8.98 | 10.27 | F8Ib-G8Ib | RVB |
| V360 | Cyg | 70.39 | 10.36 | 12.23 | F5 -G0 | RVA |
| SS | Gem | 89.31 | 9.3 | 10.7 | F8Ib-G5Ib | RVA |
| SU | Gem | 50.00 | 9.8 | 14.1 | F5 -M3 | RVB |
| AC | Her | 75.01 | 6.85 | 9.0 | F2Ib-K4 | RVA |
| EP | Lyr | 83.34 | 9.96 | 10.90 | A4Ib-G5 | RVA |
| U | Mon | 91.32 | 6.1 | 8.8 | F8Ib-K0Ib | RVB |
| TT | Oph | 61.08 | 9.45 | 10.84 | G2 -K0 | RVA |
| TX | Oph | 135 | 9.7 | 11.4 | F5 -G6e | RVA |
| UZ | Oph | 87.44 | 9.93 | 11.50 | G2 -G8 | RVA |
| R | Sge | 70.8 | 8.0 | 10.4 | G0Ib-G8Ib | RVB |
| R | Sct | 146.5 | 4.2 | 8.6 | G0Ia-K2Ib | RVA |
| RV | Tau | 78.7 | 9.8 | 13.3 | G2Ia-M2Ia | RVB |
| V | Vul | 75.7 | 8.45 | 9.53 | G4 -K3 | RVA |

Table 2. Observed Period and Characteristics of Return-map.

| Name | | Period (n) | $\sigma$ | Number of Plot | Correlation Coefficient | Type of Return-map |
|---|---|---|---|---|---|---|
| TW | Cam | 85.00 (15) | 5.37 | 8 | −0.293 | 3 |
| V360 | Cyg | 69.94 (18) | 4.06 | 13 | −0.327 | 3 |
| SS | Gem | 90.14 (22) | 5.03 | 13 | 0.195 | 3 |
| SU | Gem | — | — | — | — | — |
| AC | Her | 75.43 (79) | 3.02 | 64 | −0.471 | 2 |
| EP | Lyr | 83.32 (28) | 6.49 | 25 | −0.817 | 2 |
| U | Mon | 91.33 (12) | 6.05 | 6 | −0.356 | 2 |
| TT | Oph | 61.24 (41) | 2.74 | 28 | −0.120 | 3 |
| TX | Oph | 132.46(13) | 10.88 | 10 | −0.332 | 3 |
| UZ | Oph | 87.10 (30) | 5.56 | 23 | −0.401 | 2 |
| R | Sge | 71.05 (43) | 3.53 | 37 | −0.286 | 3 |
| R | Sct | 141.69 (35) | 8.28 | 17 | 0.105 | 3 |
| RV | Tau | 78.94 (17) | 6.64 | 9 | −0.777 | 2 |
| V | Vul | 75.24 (34) | 4.67 | 31 | −0.552 | 2 |

istics are seen from figures and Table 2. Firstly, about half of the stars (6 of 13) belongs Type 2. Secondly, correlation coefficient of most stars are negative and in some absolute values are very large. Thirdly, in some return maps patterns of distribution of plots show very complicated figure alike bird wings.

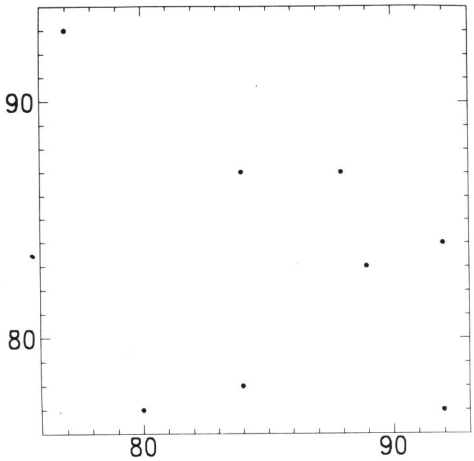

Fig. 15. Period return-map of TW Cam.

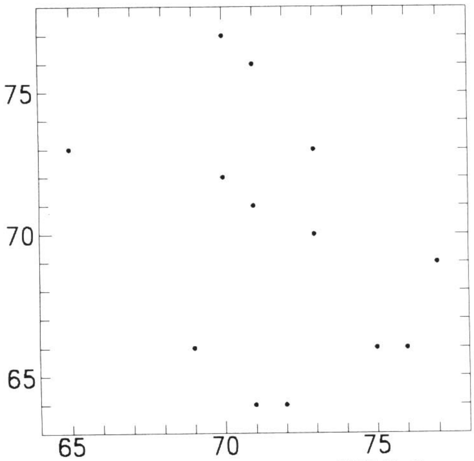

Fig. 16. Period return-map of V360 Cyg.

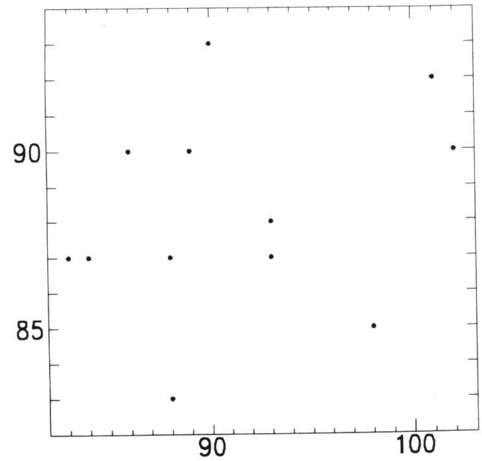

Fig. 17. Period return-map of SS Gem.

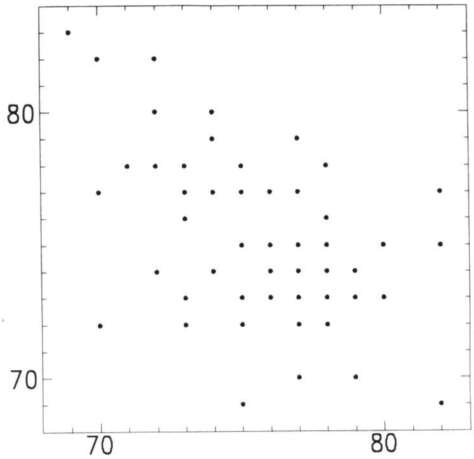

Fig. 18. Period return-map of AC Her.

## 4. Discussions

Return map of other late-type pulsating variables were studied in my previous works. Comparing the results in this paper with previous ones, the proportion of Type 2 pattern of period return map in RV Tauri stars is much larger than Mira and SR stars. In RV Tauri stars about 50 parcent stars belong

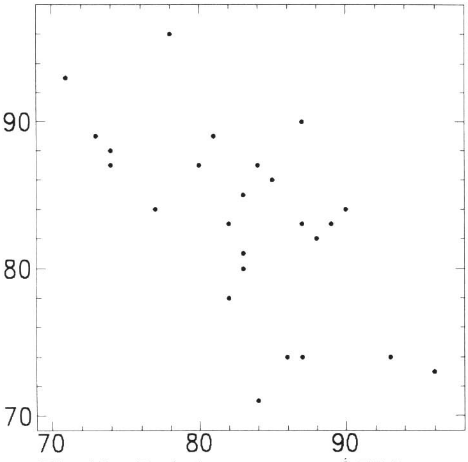

Fig. 19. Period return-map of EP Lyr.

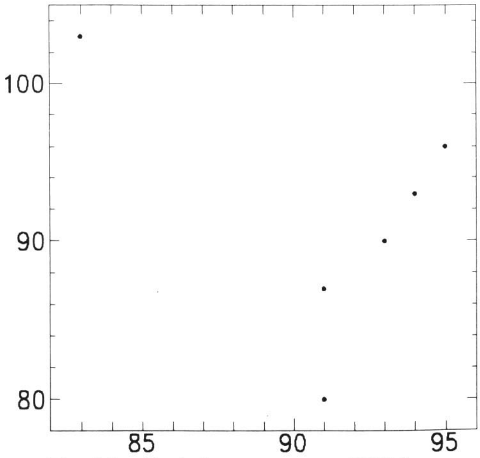

Fig. 20. Period return-map of U Mon.

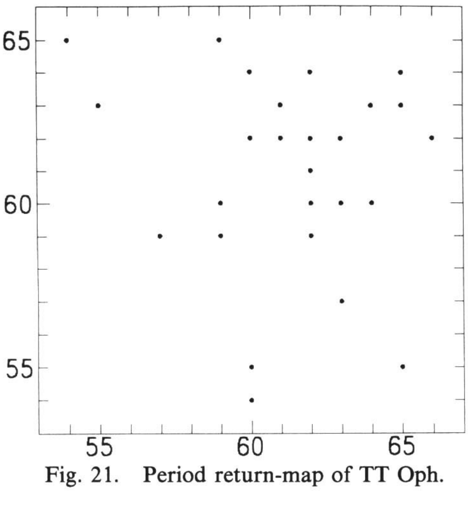

Fig. 21. Period return-map of TT Oph.

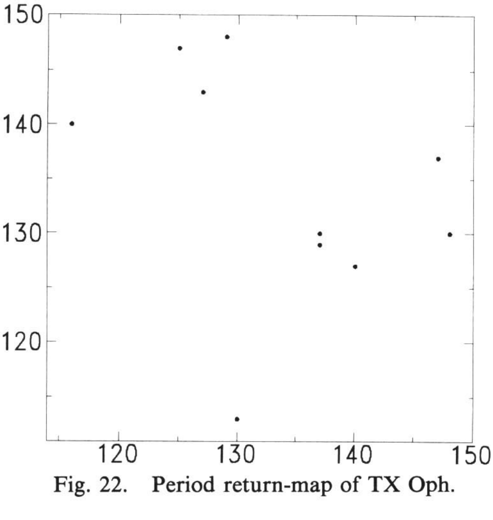

Fig. 22. Period return-map of TX Oph.

to Type 2. On the contrary, from Saijo (1991), 30 parcent are Type 2 in Mira and 5 parcent in SR. Majority of Mira and SR stars belong to Type 1. In addition, the more complicated distribution of plots are shown than in Mira and SR. These characteristics may come from the fact that RV Tauri is more evolved and more luminous than Mira and SR.

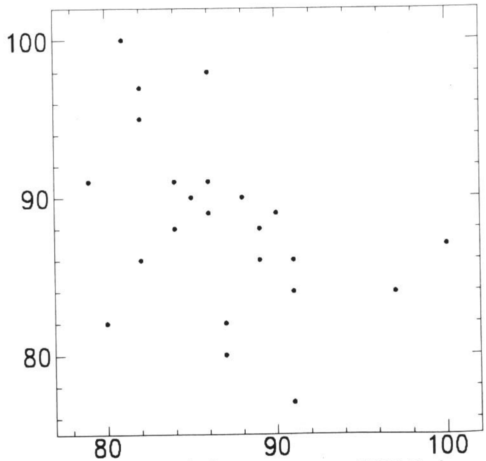

Fig. 23. Period return-map of UZ Oph.

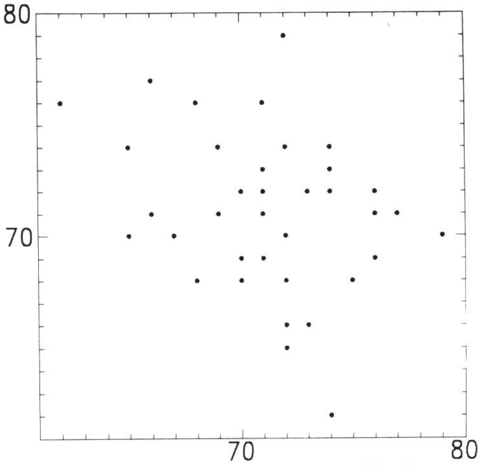

Fig. 24. Period return-map of R Sge.

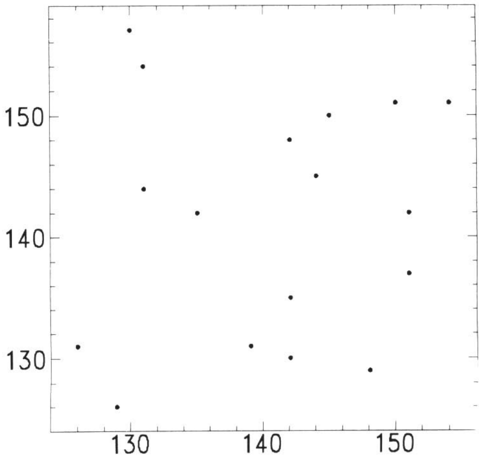

Fig. 25. Period return-map of R Sct.

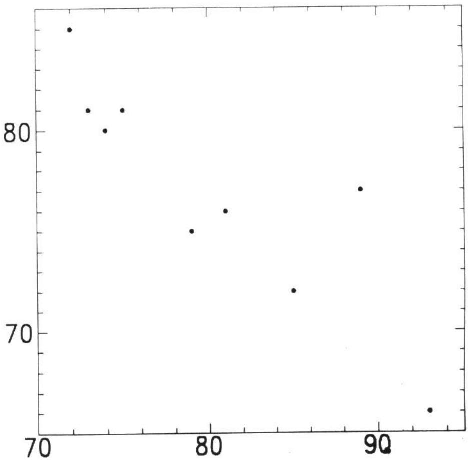

Fig. 26. Period return-map of RV Tau.

Irregularity in the light curves of pulsating variables require nonlinear theory and/or stochastic theory. In nonlinear dynamics, oscillating systems can show a sequence of 1 period oscillation to the chaotic ones in the course of period doubling bifurcation with the change of controll parameters. So the situation is similar in the case of late-type pulsating variables, such as RV Tauri. There are

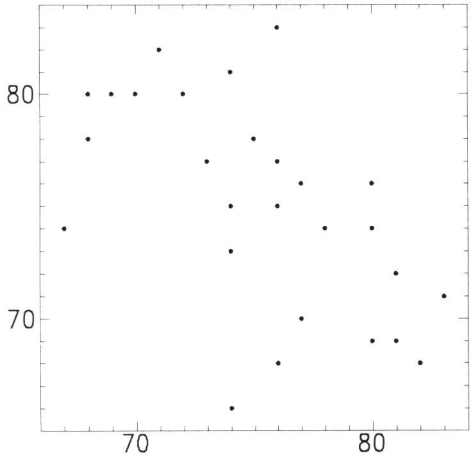

Fig. 27. Period return-map of V Vul.

some methods to search chaotic behavior. Return map is also a tool to find chaos in time series of data, because a return map is a Poincare section in a phase space.

By using correlation integral to the light curve of R Sct, one of RV Tauri type stars, Buchler *et al.* (1995) obtained embedding dimension of 3.1, which shows low dimensional chaotic behavior. Although their results are very important, corrlation integral method strongly depend on smoothing method of light curve. Therefore, their results are not confirmed yet. Similar studies of other authors are also not affirmative. For example, our study of Mira and SR (Yanagita, Satoh and Saijo, 1992) cannot find whether the variability of these stars are chaotic but showed that dimension of Mira is a little larger than 1 and that of SR is near 2.

By using return map, we cannot find chaos yet. But return map of RV Tauri stars in this paper implys more complicated behavior and larger dimension. The large negative values of correlation coefficients in RV Tauri stars may indicate chaotic variablility.

## Acknowledgement

The autor express his hearty thanks to the VSOLJ for kind permission to use their observational data in this paper.

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