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Detection of short-term variations in Mira-type variables from Hipparcos photometry*

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Abstract. The Hipparcos photometric observations carried out over 37 months have been investigated in detail for ∼250 Miras. This leads to an unexpected by-product of the mission that we already suspected from ESOC real-time reductions: the first detection from space of photometric short-term brightness variations in Mira-type variables. Altogether, 51 events in 39 M-type Miras are detected and no similar variations are found for S and C-type Miras. Their amplitude ranges from 0.23 mag up to 1.11 mag and their duration extends from 2 hours up to almost 6 days. These events seem to occur preferentially in late spectral types. We suggest that they might be related to molecular opacity effects.

Key words: stars: variables – stars: late-type – stars: AGB and post-AGB

1. Introduction

Long-Period Variables (LPV) are pulsating stars with quasi regular light curves and periods ranging from ∼50 to more than a few thousand days. They are located at the top of the Asymptotic Giant Branch and are characterized by large mass-loss rates. Miras variables have large amplitude light curves while the other LPV, with smaller amplitude and/or period, are classified as semi-regular (SR-type) or irregular (L-type). Up to now, most of the studies of the changes in the shape of the light curves of LPV are related to their long-term variability with timescales of months or years.

However short-term variations, over timescales of days or even less, and in any case much smaller than the period of these variables, have been suspected for several years in LPV. But rather few and scarce detections can be found in the literature. Smak & Wing (1979) observed rapid variations in the V, K and L bands for the oxygen-rich Mira R Aur (ΔV = 1 mag, ΔK = 0.57 mag and ΔL = 0.36 mag in 2 days). More recently, Maffei & Tosti (1995) observed several short-term variations in 18 LPV during the study of 182 Miras and SR in the field of M16-M17. Amplitudes from 0.5 mag to 1 mag in the I filter and duration ranging from one day to one month are reported for 28 events. Finally, short-term brightness drops with large amplitude in $UBVR_cI_c$ ($\Delta V > 1$ mag over timescales smaller than 10 days) for the Miras R Oct and RY Hyi have also been reported by de Laverny et al. (1997). Rapid changes in the spectra of Miras have also been found. Odell et al. (1970) observed unusual variations of the equivalent widths of Hδ, Hγ and TiO bands on timescales of 10 days for o Cet, the prototype of the Miras class. For the same star, Kovar et al (1972) observed modifications of the equivalent width of Pβ by a factor 2 on a timescale of about 2 days. Finally Schaefer (1991) collected 14 cases of suspected flares in Miras. These suspected variations were observed either photographically, photometrically, visually or at radio frequencies.

As for the other LPV, rapid spectrometric and photometric variations have been reported by Livi and Bergmann (1982) and Bouchet et al. (1983) (see also Querci, 1986 and Querci et al., 1982). Alksnis & Khozov (1975) detected several brightness fluctuations with a characteristic timescale of 1-30 days and amplitude of ∼1 mag in several bands of the visible for the SRa variable RW LMi. Gómez Balboa & Lépine (1986) also suspected variability on timescales of the order of one hour in the H_2O maser line of R Crt.

With the exception of the events shown by Maffei & Tosti (1995), no systemic study of short-term variations in LPV have been done so far, primarily because of the lack of adequate data. No large sets of accurate and frequent observations of these variable stars were available. The situation has dramatically changed with the Hipparcos mission, which collected on the average 110 individual photometric observations for each of the 118 218 program stars (including ∼1 200 LPV) during more than three years of its operation. Even if the coverage of the LPV light curve is rather irregular, since Hipparcos was not

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* Based on data from the Hipparcos astrometry ESA satellite

planned to monitor stars, short-term variations (if they do exist) should have been detected by the satellite. We therefore looked for such variations in the Hipparcos photometric data base and selected a large number of events (Sect. 2). Preliminary results have already been presented by Mennessier et al. (1995) and this paper provides an extension in term of coverage, data quality and statistical reliability. These rapid variations in brightness are examined in Sect. 3 against the relevant physical parameters of the star and a tentative explanation is set forth.

2. Hipparcos data and detection of rapid variations

One of the results of the Hipparcos mission is to provide accurate photometry of all the program stars at many different epochs. The Hipparcos magnitude, denoted Hp, with its error bar, the precise epoch of observation and a flag indicating the quality of the measurement are available as a standard Hipparcos product. The broad band Hipparcos filter extends from $\sim$380 nm to $\sim$800 nm and covers almost completely the Johnson B and V filters and partially the Cousins R_c filter. The photometric reduction was performed by two distinct consortia FAST and NDAC and the principles applied for this processing can be found respectively in Mignard et al., (1992) and Evans et al., (1992).

The time sampling of the Hipparcos observations is rather intricate: typically a star is observed over a grid-crossing, then again 20 minutes later. Usually this sequence is repeated several times, every two hours. Eventually the whole scheme returns after three to six weeks on a very different scanning direction. This allows the detection of rapid variations with timescales ranging from hours to few days.

2.1. Samples and search of events

For homogeneity reasons, we only considered 239 Miras variables observed by Hipparcos, 195 of them being known as M-type, 11 as S-type and 26 as C-rich. Their period ranges from 100 to 550 days. We analyzed 17 613 observations of oxygen-rich Miras, 2 890 of carbon-rich, 924 of S-type and 754 of Miras with unknown spectral type. These measurements range from $Hp \sim 3$ mag up to $Hp \sim 14$ mag with a pronounced concentration between 8 and 11 mag. The typical error, at 8 mag, is around 0.015 mag on the individual measurements and 0.08 mag for stars of magnitude 11.

We have studied sequences of at least three consecutive observations of a given star to determine the evolution of Hp with time. In this selection procedure, we defined the amplitude of a rapid variation as the largest difference between one observation and the mean of all the neighbouring ones.

To check the validity of our automatic procedure and avoid any instrumental effects, we applied the same principles to a set of observations of stars classified as *photometric standards* after the Hipparcos mission. This sample consists in 15 521 observations of 150 stars with perfect agreement between the FAST and NDAC solutions. The magnitude range was comparable to the mean magnitude of the Miras observed by Hipparcos.

Table 1. Numbers of short-term variations ($|\Delta Hp| > 0.2$) of Miras and standard stars. N_{Obs} is the total number of observations, N^+ and N^- are the number of variations found when the star becomes more luminous and less luminous respectively, and $N_{tot} = N^+ + N^-$.

FAST *and* NDAC data	N_{Obs}	N^+	N^-	N_{tot}
Standards	15 521	2	1	3
Miras	19 463	13	10	23

2.2. Results

We found only three standard stars for which one short-term variation with an amplitude larger than 0.2 mag was detected. That can be viewed as the residual "noise" in the observations. With the same selection criteria on the Miras data (19 423 observations), we detected 23 events with $|\Delta Hp| > 0.2$, i.e. 6 times as many detections. But, the selected standards have always a magnitude fainter than 10.5 and we have actually 5 292 observations of Miras with $Hp > 10.5$. Considering such a ratio, the number of detections is rather 20 times larger for Miras than for standard stars.

Setting the threshold to a smaller amplitude led to many more detections in the standard set, making difficult to distinguish between accidental and physical variations. We therefore decided to retain a variation for further analysis, provided, and only if, the change in magnitude, positive or negative, was larger than 0.2 mag. We, of course, left out several short-term variations with this rather severe criterion, but at least we are confident that the selected ones are real. We then considered all the available observations of Miras, including the ones appearing in the data of only one of the two consortia. Several new rapid variations were then found, but with less reliability.

The number of such detections for the samples of standard stars and Miras is summarised in Table 1. We indicate respectively by N^+ and N^- the number of cases when a variation ends up with a brighter or fainter star. The fact that the numbers are of the same order of magnitude for the Miras, indicates that only a very small number of detections could be due to an accidental pollution by a star of the conjugated field. This is confirmed by the events detected at several epochs for a given star as explained before. Furthermore, if one considers all the observations by FAST and/or NDAC, the total number of detections is nearly 5 times larger for Miras than for standard stars with a confidence level of about 6 σ.

By checking the light curve of the new events some of them (48) were removed because the variation occurred at a measurement not agreed between FAST and NDAC and the few preceding or following observations were suspect.

We eventually found 51 short-term variations on 39 Miras with an amplitude much larger than the error bar on individual measurements. They are listed in Table 2 and some of them are shown in Fig. 1. We give in Col. 7 the magnitude

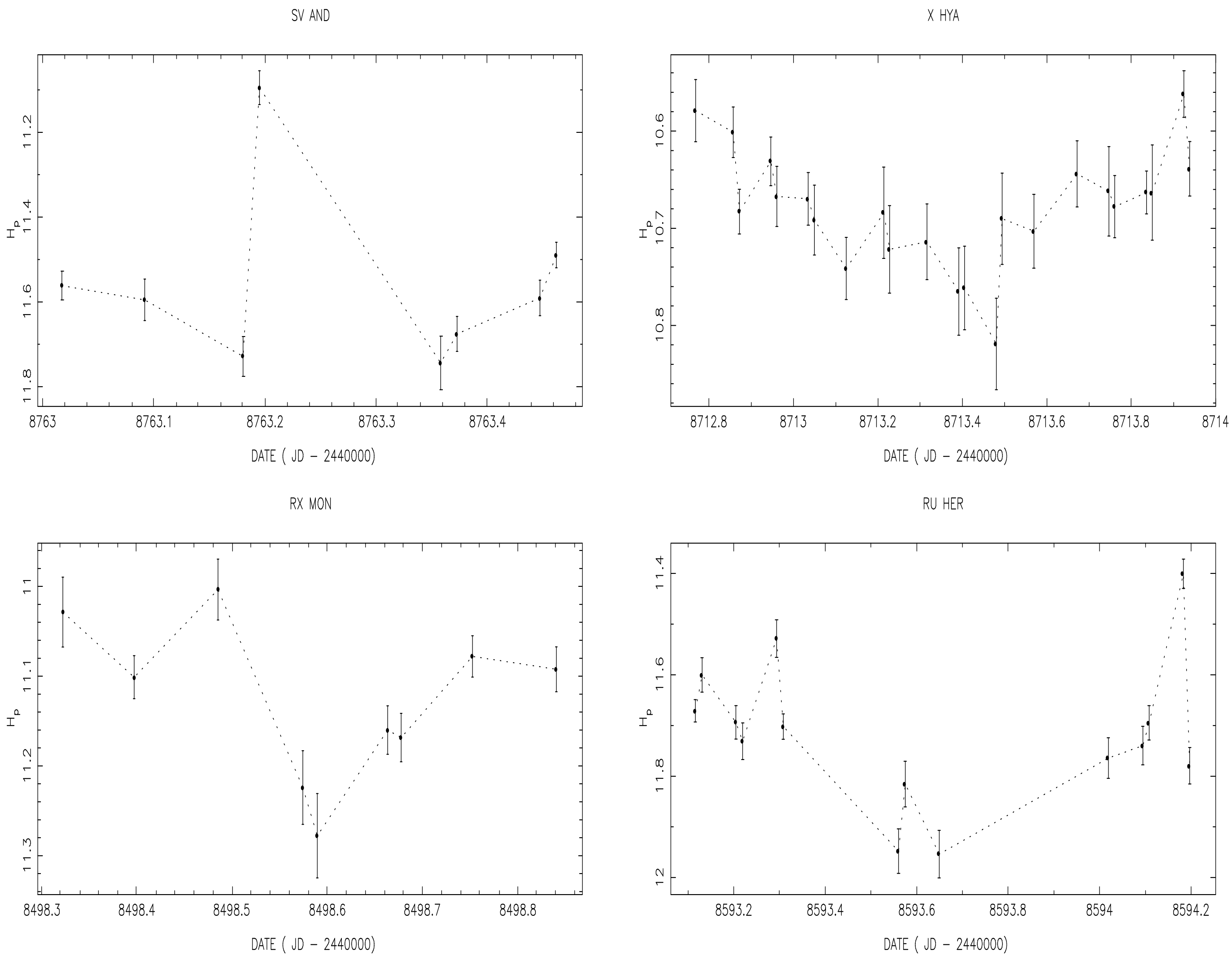

Fig. 1. Some examples of short-term variations detected by Hipparcos .

of the Miras when Hipparcos started to detect a rapid variation, in Col. 8 the amplitude $|\Delta Hp|$ representing the largest difference between all the observed points, and in Col. 9 the timescale (Δt) of these events or more exactly the timescale of the Hipparcos observations of a given event (the rapid variation can actually be longer). For 27 of them, the light curve of the star undergoes a sudden increase. The amplitude of these short-term variations ranges from 0.23 mag to 1.11 mag, and they last from 2.13 hours to 5.7 days. Most of them were detected when the star was fainter than Hp = 10 mag including one at Hp = 13 mag. We have also one event at Hp = 8.3 mag.

Finally let's note the significant fact that rapid variations have been detected twice for 8 Miras and three times for AM Cyg and X CrB.

The spectral type of 36 of these Miras is known: all of them being M-type. *No short-term variations are detected for Miras with spectral types S or C.* This is rather surprising since, if we assume the same detection probability for these spectral types as for M-type, we should have detected 8 events for C-rich Miras and at least two for the S-type. Although the total number of observations of these stars is perhaps too small, from these estimates it appears that short-term variations are much more frequent in M-type Miras than in Miras with other spectral types.

Nevertheless, to summarise this section, we can assert with confidence that the Hipparcos observations of oxygen-rich Miras show evidences of short-term brightness variations in the visible.

3. An attempt of explanation for oxygen-rich Miras

We did not find any peculiar characteristics (period, amplitude, spectral type extrema and/or ranges...) of the Miras with which short-term variations could be obviously linked. The only prevalent feature is that all these stars are oxygen-rich. Nonetheless, the number of events detected allows to do some statistics and to look for a possible relation between the brightness variations

Table 2. Rapid brightness variations of Miras detected by Hipparcos .

Name	Period (days)	Spectral Types Max - Min	J.D. 2440000+	Phase	Spectral Type	Hp	$\|\Delta Hp\|$	Δt (hours)
SV And	316.2	M5.0 - M7.0	8763.018	0.78	M6.6	11.56	0.65	10.66
X Ant	161.7	M2.0 - ?	8362.128	0.62		12.45	0.31	8.53
			8647.726	0.43		11.80	0.36	2.13
X Ara	175.8	M5.0 - M7.0	8004.774	0.63	M6.8	12.07	0.56	21.34
RR Boo	194.7	M2.0 - M6.0	8087.529	0.84	M4	11.54	0.25	4.27
RT Boo	273.9	M6.5 - M8.0	8201.877	0.38	M7.7[2]	11.48	0.34	10.67
			8728.438	0.33	M7.8[2]	11.41	0.36	8.53
R Cae	391.0	M6.0 - ?	8781.530	0.56		10.93	1.07	4.27
V Cap	275.7	M5.0 - M8.3	8712.639	0.26	M6	10.66	0.28	4.61
W Cen	201.6	M3.0 - M8.0	7967.272	0.63	M7.5	11.21	0.25	4.61
RX Cen	327.9	M5.0 - ?	8652.066	0.84		11.72	0.24	4.27
R Cet	166.2	M4.0 - M9.0	8824.122	0.75	M7	11.27	0.26	4.27
S Col	325.9	M6.0 - M8.0	8580.631	0.63	M7.8	11.92	0.38	6.40
X CrB	241.2	M5.0 - M7.0	8115.962	0.41	M6.9[2]	12.42	0.23	2.48
			8607.264	0.42	M6.6[2]	12.21	0.40	6.06
			8639.785	0.55	M7	13.05	0.58	2.13
AM Cyg	370.6	M6.0 - ?	8302.538	0.40		12.96	0.56	138.67
			8446.668	0.78		11.86	0.32	2.48
			9036.578	0.38		12.99	1.11	115.27
T Eri	252.3	M3.0 - M5.0	8594.414	0.56	M5	11.09	0.31	23.47
RU Her	484.8	M6.0 - M9.0	8593.116	0.57	M9	11.67	0.55	25.94
SS Her	107.4	M0.0 - M5.0	8179.928	0.62	M4	11.88	0.69	110.93
XZ Her	171.7	M0.0 - ?	8648.043	0.90		11.44	0.34	6.40
T Hor	217.6	M5.0 - ?	8776.198	0.46		11.37	0.27	4.27
T Hya	298.7	M3.0 - M9.0	8975.056	0.37	M8	10.86	0.34	11.01
X Hya	301.1	M7.0 - M8.5	8712.769	0.42	M8.3	10.58	0.26	28.08
			8718.279	0.43	M8.3	10.66	0.26	23.81
DH Lac	288.8	M5.0 - ?	8359.408	∼ min[1]		12.11	0.33	11.01
CE Lyr	318.0		8661.092	0.71		11.64	0.44	6.74
HO Lyr	100.4	M2.0 - ?	8442.309	∼ min[1]		12.52	0.27	2.48
V Mic	381.2	M3.0 - M6.0	8396.487	0.72	M5.2	12.80	0.40	4.61
V Mon	340.5	M5.0 - M8.0	8491.908	0.53	M8	11.26	0.32	4.61
RX Mon	345.7	M6.0 - M9.0	8312.466	0.69	M8.6[2]	12.20	0.42	15.28
			8498.322	0.24	M9[2]	11.03	0.27	12.46
R Oct	405.4	M5.3 - M8.4	8745.195	0.71	M8	10.49	0.29	6.06
Z Oct	335.0		8267.751	∼ min[1]		11.78	0.38	2.48
			8683.175	∼ min[1]		12.21	0.34	3.92
RT Oct	180.2	M2.3 - M6.8	8001.402	0.43	M6.6	12.89	0.29	2.13
RU Oct	373.0	M5.9 - M7.2	8525.166	0.88	M6.1	10.54	0.26	2.48
Z Pup	508.6	M4.0 - M9.0	8594.859	0.75	M9	12.10	0.24	4.27
S Ser	371.8	M5.0 - M6.0	8786.907	0.08	M5.1	8.35	0.32	93.86
AH Ser	283.5	M2.0 - ?	7991.777	0.95		10.96	0.34	96.00
V733 Sgr	101.0		8493.658	∼ min[1]		12.81	0.34	12.46
UU Tuc	335.0	M4.0 - ?	8479.154	0.25		11.31	0.44	96.00
W Vel	394.7	M5.0 - M8.0	8692.672	0.52	M7.8	11.36	0.27	6.74
			8712.669	0.57	M7.8	11.36	0.38	8.88
CI Vel	142.5	M0.0 - ?	8371.010	∼ max[1]		10.66	0.49	11.01
			8568.723	∼ min[1]		12.08	0.31	2.48
WX Vel	411.5	M5.0 - M7.0	7967.808	∼ min[1]	M7[1]	12.38	0.38	8.88
			8557.080	∼ max[1]	M5[1]	10.44	0.26	4.61
WW Vel	187.4	M5.0 - ?	8514.604	middle[1]		11.19	0.28	3.92

[1] Crude estimate from Hipparcos light curve of these Miras (see Sect. 3.1 and 3.2).
[2] For some Miras, later spectral types can be found at earlier phases because of the shape of their light curve. For instance, RX Mon exhibits two minima during its cycle.

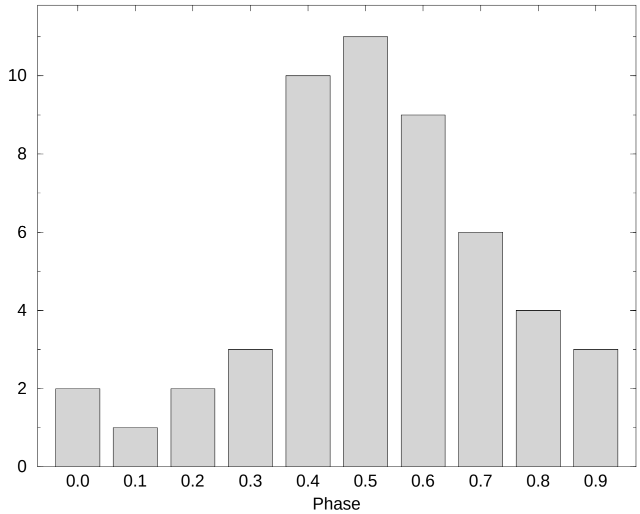

Fig. 2. Distribution of the phases in the Miras light curve, corresponding to the occurrence of a rapid brightness variation.

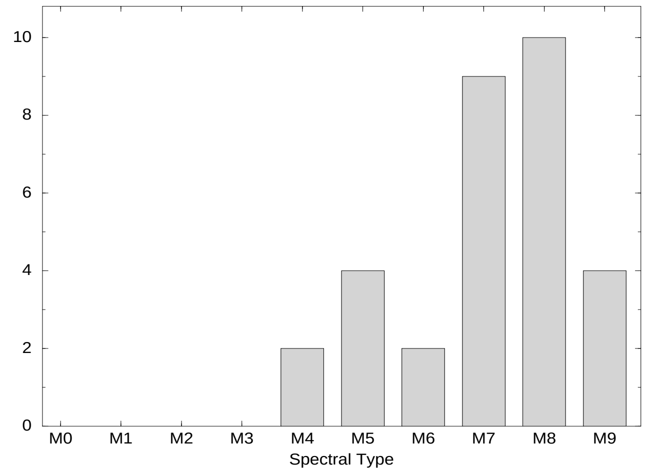

Fig. 3. Spectral types corresponding to a rapid change in brightness detected by Hipparcos .

and the phase at which they occur or relevant physical parameters of the star at these times.

3.1. Relation with the phase

From the AAVSO light curves of these 39 Miras, we have estimated their phase (ϕ) within the cycle at the time when the photometric variations occurred. We give in Col. 5 of Table 2 the phase of 41 short-term variations calculated with this rather accurate method. For the other 10 events, we crudely estimated from the extrema observed by Hipparcos if the star was close to its maximum ($\sim$ max) or minimum ($\sim$ min) of brightness or around ϕ = 0.25 or 0.75 (middle).

Looking at Fig. 2, it appears that most ($\sim$ 85%) of the short-term variations occured at phases ranging from 0.4 to 0.9, i.e. around the minimum of brightness and during the rise to the maximum. However, no correlation between these phases and the period of the Miras has been found.

We mentioned in Sect. 2 that Hipparcos observed 8 Miras for which rapid brightness variations have been detected twice in the Hipparcos data. In nearly half of these cases, the variations occur at virtually the same phase: RT Boo, X Hya, W Vel. In two instances (X Ant and RX Mon) the phases are almost symmetric with respect to the minimum of brightness. The two variations of Z Oct belongs to one of these two cases. Furthermore, two of the three variations of X CrB and AM Cyg have the same phase whereas the third one of X CrB is symmetric with respect to ϕ = 0.5. However, the number of stars with two detections is too small to draw firm conclusions about a link between rapid variations and phases. One can only say that, if such a link exists, the phase of occurence depends on the star.

3.2. Relation with the spectral type

The spectral types at (at least) one of the extrema of the light curve is known for 36 of these Miras from the General Catalog of Variable Stars (Kholopov et al. 1985) and de Laverny et al., 1997. The distribution of these spectral types at maximum brightness and their range of variations do not show any peculiar features.

From the phases previously determined and the shape of the AAVSO light curves (in order to take into account any possible asymmetry), we estimated the spectral types at the time of appearance of the variations for 29 events (see Col. 6 of Table 2). We also crudely estimated the two spectral types of WX Vel from its phases derived with Hipparcos data only (see preceding Subsection). For 16 short-term variations, only the spectral type at the maximum of brightness of the 12 corresponding Miras is known. The spectral types at the time of these detections are therefore later than these maxima. Finally, it was impossible to infer any reliable spectral type for CE Lyr, Z Oct (2 events) and V733 Sgr.

We show in Fig. 3 the distribution of the 31 spectral types corresponding to a short-term variation. It clearly appears that they are linked to the spectral type. The spectral types from M3.5 to M9.5 indeed account for all the events and 75% of them are found at spectral types later than M6.5 (80% are later than M5.5). We compared this distribution to the expected distribution of spectral types corresponding to observations of Miras performed at any time. It was computed from a sample of 146 oxygen-rich Miras with a known spectral type at maximum and minimum brightness, assuming for each star a uniform distribution of the spectral type in its observed range. The comparison of the two distributions confirms that brightness variations do occur preferentially at spectral types later than M6 and virtually never for spectral types earlier than M4. This link is also strengthened by the data of Table 2 suggesting that most of the 12 Miras, for which only the spectral type at maximum brightness is known, display a short-term variation at a spectral type later than $\sim$M6.

Furthermore, the 28 rapid variations observed by Maffei & Tosti (1995) also occured at spectral type later than M6. The other short-term variations of Miras found in the literature (see Sect. 1) all agree with this scheme since they are detected in Miras with late spectral types at the maximum of brightness. Finally, we observed in January 1992 at ESO the Mira S Pic during two successive nights and more than three times during each one. Variations in the $UBVR_cI_c$ filters with an average amplitude of about 1 mag (a little less in U and R_c) were detected. These variations over a timescale close to 12 hours cannot be ascribed to measurement errors since we did not detect any variations in the three measurements made each night, but only from one night to the following. We estimated a M7.5 spectral type for S Pic at that time.

It is clear that short-term variations are more frequently found in oxygen-rich Miras with a spectral type later than ∼M6, than at earlier spectral types. This fact also accounts for the distribution of the phases at which the events are detected. Indeed, the closer the event is to the minimum of the cycle, the more advanced the spectral type is.

3.3. Suggested explanation

For the latest spectral types, the TiO bands appear suddenly after M2, while the lines of VO appear after M6, increasing very slowly up to M8 to become suddenly very deep (Lockwood, 1972). It turns out that the rapid photometric variations detected by Hipparcos are predominantly associated with these peculiar ranges of late spectral type. Hence, it could be possible that the rapid brightness variations may be related to some effect linked to the VO molecule (changes in opacity due to molecular association - dissociation correlated with oscillatory relaxation of the temperature).

4. Conclusion

We have reported and discussed in this paper an unexpected Hipparcos result that we already observed when monitoring ESOC real-time reductions to predict the brightness of Miras: the first unambiguous detection from space of rapid brightness variations in oxygen-rich Miras variables. These rapid variations have a timescale ranging from few hours to few days and an amplitude larger than 0.2 mag. They occur at specific epochs in the duty cycle of the stars, more specifically when they have a very late spectral type.

Such variations might be related to molecular opacity changes and then to variations in the physical conditions of the stars, inducing instabilities. However, other mechanisms might be invoked like hydrodynamics effects. Indeed these short-term variations in the brightness of Miras remain largely unknown and need a firmer observational basis, simply to identify the key variables behind and start a classification. Are they regular or erratic ? What is their spectral signature ? etc. New detections and spectroscopic observations of such events are therefore required to achieve a better understanding.

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