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Microvariability among Selected Long Period Variables

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Abstract. DeLaverny et al. (1998) reported short-term brightness variations in 15 percent of the 250 Mira or Long Period Variable stars surveyed using the HIPPARCOS satellite, with the broadband 340 to 890 nm Hp filter. The abrupt variations ranged 0.2 to 1.1 magnitudes, on time-scales between 2 to 100 hours, with a preponderance found nearer Mira minimum light phases. However, the sampling frequency was extremely sparse and requires confirmation because of potentially important dust-formation physics that can be revealed. We report here ground-based photometric observations of several of these objects, that supports and tends to confirm, the deLaverny et al. findings. In our observations, four out of five Miras sampled (XZ Her, HO Lyr, AU Cyg and AM Cyg) were found to have significant fluctuations over these same short time-scales (at 95% confidence level and higher), based on analysis of photometric variance, and F-tests. Interpretation of this micro-variation is offered in terms of dust formation episodes in the upper atmosphere of the star, and tests using interferometric visibility curves are proposed.

1. Introduction

In 1989 the first satellite dedicated to automated astrometry was launched, the European Space Agency's High Precision Parallax Collecting Satellite, named HIPPARCOS (ESA, 1997). The main purpose of the mission was to measure stellar positions with unprecedented precision along with photometric measurements of all 118,218 stars within its grasp. HIPPARCOS completed these measurements in 1993, ultimately observing several thousand variable stars, including hundreds of Mira or Long Period Variable (LPV) stars. Even though the mission profile only allowed these measurements to be made infrequently, the information gathered has been indispensable in the research on these stars (cf. Perryman 1998; Bedding and Zijlstra 1998).

From this mission data, deLaverny et al. (1998) discovered a subset of variables (15 percent of the 250 Mira-type variables surveyed) that have exhibited abrupt short-term photometric fluctuations, within their long period cycle. All observations were made in a broadband mode, 340 to 890 nm, their so-called Hp magnitude. They reported variation in magnitude of 0.23 to 1.11 with durations of 2 hours up to almost 6 days, preferentially around minimum light phases. Instrumental causes could not be identified to produce this behavior. Most of

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these variations are below the level of precision possible with purely visual estimates of the sort collected by AAVSO, but may contribute to some of the scatter in visual light curves. 51 events in 39 M-type Miras were detected with HIPPARCOS, with no similar variations found for S and C-type Miras. These short-term variations were mostly detected when the star was fainter than Hp = 10 magnitude including one star at Hp = 13 magnitude and one at Hp = 8.3. For 27 of the original 39 observations, the star underwent a sudden increase in brightness.

From their study, deLaverny et al. found that 85% of these short-term variations were occurring around the minimum of brightness and during the rise to the maximum, at phases ranging from 0.4 to 0.9. No correlation was found between these phases and the period of the Miras, but that brightness variations do occur preferentially at spectral types later than M6 and almost never for spectral types earlier than M4. Similar results were reported by Maffei & Tosti (1995) in a photographic study of long period variables in M16 and M17, where 28 variations of 0.5 mag or more on timescales of days were found among spectral types later than M6. Schaeffer (1991) collected reports on fourteen cases of flares on Mira type stars, with an amplitude of over half a magnitude, a rise time of minutes, and a duration of tens of minutes. He concluded the phenomenon deserved more systematic study. Stencel and Ionson (1979) examined flare potential with magnetic heating in red giant atmospheres, suggestive of one mechanism for these reported brightenings. However, in analogy to the R CrB phenomenon, brightness variation could also be a consequence of dust formation (fading) and dissipation (brightening) in front of a star's visible hemisphere. Additional observations will be required to discriminate. The purpose of our report is to provide confirming observations of the deLaverny et al. results, and to suggest that the phenomenon can be placed in a larger context of episodic dust formation, with implications for detectability in ongoing mid-infrared studies of LPV stars, including spectra and interferometry.

2. Observations and Analysis

The stellar sample is drawn from the northern hemisphere accessible subset of the objects listed by deLaverny et al., as shown in Table 1, with the addition of IRAS name and LRS classification (Olnon and Raimond 1986). Observations of many of these stars have been made with a semi-automated 0.2 meter, f/10 Schmidt-Cassegrain telescope at the Student Observatory, adjacent to Denver University's Chamberlin Observatory. A small number of pre-2000 observations have come from the Mt. Evans Observatory, with a dual-aperture 0.7 meter, f/21 Ritchey-Chretien telescope, plus all of the year 2000 summer data. The images were obtained with an unfiltered SBIG ST-7 CCD camera, to approximate the broadband HIPPARCOS Hp magnitude. A total of 583 images were taken of deLaverny et al. variables during 33 observation sessions, over a period of approximately 15 months between 1998 and 2000, plus the additional flat field images, bias and dark frames were taken. At least two to five comparison stars were selected in each field, with HST Guide Star Catalog and/or SIMBAD entries for positions and magnitudes. Despite the modest instrumentation, care was taken to achieve instrumental stability, allowing photometric measurement repeatability to better than 0.05 magnitudes. Results of the observations and measurements are found in Table 1. We demonstrate statistical validity of the detected variations using the recommended CCD photometry methodology of Howell, Mitchell and Warnock (1988) and references therein. Limited space does not permit complete display of analysis methods. Larger F_T results (>1) indicate statistically significant fluctuations. Contact the authors for details. Observations are continuing.

3. TABLE 1 – SELECTED PHOTOMETRIC RESULTS

Star	MJD	Phase	V	n	σ_{V-C}	σ_{C-K}	F_T
XZ Her	1450.66	0.29	11.95	14	0.226	0.075	9.09
	1463.65	0.37	12.56	8	0.095	0.052	3.41
	1472.61	0.42	13.12	15	0.118	0.048	5.95
	1483.59	0.48	13.36	49	0.148	0.049	9.25
CE Lyr	1450.66	0.75	10.71	16	0.003	0.003	2.40
	1463.64	0.79	10.78	8	0.001	0.003	3.44
	1472.62	0.82	10.78	15	0.004	0.002	2.40
	1483.60	0.85	10.79	14	0.002	0.002	2.18
HO Lyr	1450.43	0.83	10.30	14	0.077	0.044	2.98
	1463.41	0.96	10.85	8	0.126	0.026	22.31
	1472.38	0.05	11.52	15	0.192	0.037	26.27
	1483.32	0.16	12.38	11	0.101	0.036	8.25
AU Cyg	1450.46	0.92	9.37	12	0.118	0.058	4.24
AM Cyg	1435.43	0.64	10.57	5	0.103	0.020	24.59
	1463.41	0.73	9.42	10	0.123	0.049	6.34
	1483.35	0.77	9.47	20	0.067	0.033	4.24

Columns:

1) Object name; 2) start date for observation series, JD - 2,450,000.; 3) variable star phase for start of observation series; 4) V magnitude at start of the time series; 5) Number of observations included in the time series; 6) Measured sigma (in magnitudes) for V-C; 7) Measured sigma (in magnitudes) for C-K; 8) Results of the F-ratio test (95% confidence level).

4. Discussion

In Table 1, we have provided supporting evidence for the deLaverny et al. (1998) claims that HIPPARCOS satellite observations detected short term, abrupt variations among a subset of Mira variable stars. It would seem appropriate to expend the effort for more careful monitoring of this class of variables in the future, with a wider variety of techniques and timescales, as suggested below.

If we adopt for the sake of argument, that these variations are real and significant, what might they tell us about the physical processes important in the atmospheres of such stars? The driving research question of the past decade concerns details of the mass loss process among evolved stars, especially when circumstellar dust plays a prominent role therein. A variety of lines of evidence point to the region between the stellar photosphere and the so-called inner dust radius (perhaps three to ten stellar photospheric radii) as the zone of activity that is crucial in this regard.

Optical spectroscopy shows that mass motions are detected in M-type giants with velocities in the range of 10 to 30 km sec^{-1} (Judge and Stencel 1991). The timescales for abrupt variations reported here and by deLaverny et al. include the range of 10^4 to 10^6 seconds. If the variation were associated with mass motion in the atmosphere, the transverse distance implied falls in the range 10^5 to 3 x 10^7 km, which is 0.03 to one full radius of a 50 solar radius giant star. Hence, mass motions cannot initially be dismissed in this context.

Studies of infrared spectra of related stars have begun to reveal variations in the shape of the silicate dust feature present at 10 microns in oxygen rich LPVs. Little-Marenin, Stencel and Staley (1996) used individual IRAS Low Resolution Spectrometer (LRS) data to reveal such changes in the spectrum of the Mira AU Cygni, discussed above. LRS scans made on subsequent days agree well, but differ from those separated by months. Onaka et al. (1999) report distinct variations in the silicate features of two M- type Miras variables, Z Cyg and T Cep, observed several times each during a light cycle with the ISO Short Wave Spectrometer (SWS). The stronger contrast silicate emission line object, Z Cyg, varies much like AU Cyg, but the weak silicate emission line star, T Cep, exhibits a more complicated variation according to those authors.

We note that a majority, but not all, of the HIPPARCOS-selected abrupt variables are of the weak silicate (or "featureless") LRS class (cf. Stencel et al. 1990). The few published spectra indicate that variations in the dust feature occur, but cannot alone fully establish timescales. With the newer mid-IR spectrometers now available and with impending launch of SIRTF, it is hoped that additional well-characterised mid-IR spectral monitoring will be forthcoming.

What testable hypothesis can be advanced, based on our observations and those of deLaverny et al.? Several lines of argument suggest that rather than mass motions, atmospheric phase changes between plasma and solid states, may be involved in the observed abrupt light variations. First, there is a demonstrated relationship between the subtype of the silicate feature and the maturity of the circumstellar dust envelope (Stencel et al. 1990): weak silicate emission line objects are bluer and show relatively little circumstellar maser activity, while strong silicate emission line sources are redder and have the most developed maser complexes, including SiO, H_2O and OH. Second, biweekly monitoring by Diamond and Kemball (1998) of the SiO masers in a similar star, TX Cam, over an entire light cycle, reveals complex structural changes that include both infalling and outflowing gas, and changing polarization structure of these close-in masers. Third, Mattei and Foster (1998) found that in the AAVSO database, 89% of 393 LPVs are exhibiting fainter minima over a timescale of decades, which could be associated with increasing the optical depth of the circumstellar dust envelope between putative helium-shell flashes every few thousand years (Steffen and Schoenberner, 2000).

Our hypothesis to explain low amplitude stochastic behavior involves the thermal instability between the warm plasma state (sustained by emerging pressure shocks), and the colder molecular state, given that the latter is capable of radiatively cooling via numerous ro-vibrational transitions (Cuntz and Muchmore 1994). Essentially, Mira outer atmospheres are poised between these thermal stability regimes, with the energetics of heating and cooling alternately prevailing to form or dissipate clouds, much as they do in our terrestrial atmosphere, but on a grander scale.

One line of argument in favor of this phase transition at quasi-stationary altitudes, considers the differences in terms of seconds per magnitude of light change, between the abrupt variations and the LPV pulsation. The Miras highlighted in this work have pulsational periods of 100 to 484 days (Table 1). Such pulsational variation changes brightness by more than 2.5 magnitudes over $\sim$1 to 5 x 10^7 seconds, or at a rate of more than 10^6 to nearly 2 x 10^7 seconds per magnitude. In contrast, the abrupt variations reported above involve fractions of a magnitude in times well under 10^6 seconds, or at rates well under 10^6 seconds per magnitude. The difference in rates argues for different mechanisms. Pulsation is a global phenomenon, while the abrupt changes spatially are more highly localized, perhaps reflective of higher order asteroseismic modes, as seen in multiple period Miras, semi-regular and irregular variables. The working hypothesis involves forming (and dissipating?) clouds of dust above the photosphere.

At this stage of discovery, it appears that the flickering is much less smooth than the Mira pulsation. What physics prevents the flickering from being larger amplitude and thus making the overall light curves appear stochastic? Many of these HIPPARCOS variables have an LRS class of 16, indicative of low dust optical depth. When the dust optical depth is low, the photosphere can be seen and the effects of low-order mode pulsation dominate. As the dust shell thickens, the photospheric contribution becomes less and less observable, to the point where the LPV characteristic is hidden. Again, the thin shell limit is marginally stable against vast amounts of dust production, due to dissociating radiation from the photosphere, unless opacity climbs locally. Verification of this hypothesis may be possible with interferometrically-derived visibility curves. Monnier et al. (2000) report that in a decade worth of mid-IR interferometry of related sources, changes are implied in the inner dust radius of circumstellar shells on timescales much longer than the pulsational one. Similarly, the Palomar Testbed Interferometer (PTI) group is beginning to report measured angular diameters with Mira phase (Thompson, Creech-Eakman and vanBelle 1999) and anticipates extending this work into the mid-IR with the Keck Interferometer. Future observations at Keck and VLTI may be capable of detecting the asymmetries implied by abrupt variations in dust opacity spanning portions of stellar hemispheres.

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