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A photometric study of the field RR Lyrae stars AW Dra, AQ Lyr and CN Lyr

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Abstract. We present CCD lightcurves for the three field RR Lyrae AQ Lyr, CN Lyr and AW Dra observed at the Teramo TNT telescope. Stellar temperatures have been derived from the observed mean colors, allowing a comparison with recent theoretical predictions on RR Lyrae lightcurves. As for the two metal rich pulsators in the sample we suggest that CN Lyr has been possibly misclassified; there is some indication that it could be conceivably a c-type pulsator. On the other hand, if CN Lyr belongs to the low amplitude, b-type fundamental pulsators, it shows a lightcurve with a slow risetime that the present theory fails to predict. AQ Lyrae appears to be a metal rich ab type pulsator, with the expected luminosity but with a lower amplitude than that predicted by theory. Finally, we find that AW Dra behaves as a metal poor fundamental (F) pulsator, crossing the instability strip well above the corresponding Zero Age Horizontal Branch (ZAHB) luminosity level.

Key words: stars: evolution – stars: fundamental parameters – stars: horizontal-branch – stars: variables: RR Lyrae

1. Introduction

RR Lyrae radial pulsators have been early recognized as interesting stellar objects, widely used as population tracers and distance indicators. In particular, the pulsational behavior of metal poor RR Lyrae in galactic globular clusters has stimulated a large amount of investigations both observational and theoretical. However, since the pioneering paper by Preston (1959), one knows that field RR Lyrae in the solar neighborhood have a metal rich component, not observed in galactic globular clusters, which appears characterized by objects with peculiarly short periods. The origin of such a behavior has been recently investigated by Bono et al. (1997a, BCCIM hereafter), who presented detailed theoretical predictions for the shape of lightcurves for different assumptions about star masses, chemical compositions, luminosities and temperatures. Accordingly, one can foresee the possibility of connecting several features of the lightcurves (such as the rising time and the occurrence of bumps or dips) to the structural parameters of the pulsating stars, testing the reliability of theoretical predictions and, possibly, deriving information on the evolutionary status of the observed objects.

However, one finds that several lightcurves available in the literature for metal rich field RR Lyrae rely on old photographic photometry, whose intrinsic inaccuracy does not allow a detailed analysis of the predicted features. Taking advantage of the CCD technology, one may now obtain rather accurate photometry even with small telescopes. In this paper we report the first results of such a program started at the Teramo Astronomical Observatory with the use of the 72 cm Teramo/Scuola Normale Telescope (TNT).

From the General Catalog of Variable Stars (4th Ed: Kholopov e al. 1988, GCVS4 hereafter) we selected the sample of RR Lyrae brighter than $B \simeq 14$ mag and with known periods which can be observed from Teramo and for which no accurate lightcurves are available in the literature. Among these objects, we chose as first targets the two metal rich ab-type RR Lyrae (RRab) AQ Lyr and CN Lyr. For AQ Lyr one has $\Delta S = 1.15$ i.e. [Fe/H]$= -0.59 \pm 0.08$ (Z=0.006) (Suntzeff et al. 1994), while for CN Lyr, Layden et al. (1996) give [Fe/H]$= -0.26 \pm 0.07$ (Z=0.01). To our knowledge, for AQ Lyr one finds in the literature only seven photographic BV measurements (Sturch 1966), whereas CN Lyr has photoelectric, but rather scattered, UBV lightcurves by Oosterhoff (1962). To these two target stars we added the RRab AW Dra for which neither a lightcurve nor a metallicity estimate were encountered in the literature.

2. Observations and data reductions

The TNT telescope is equipped with a Tektronics CCD 512x512 pixels, with a total field of view of 4 x 4$'$. Observational data were secured mainly during the 1995 campaigns: AQ Lyr from July 22 to 27; CN Lyr from July 25 to 27 (plus June 10, 1996); AW Dra from July 19 to 25. Single exposure times ranged from 30-90 sec in V to 120-300 in B filter, with a typical seeing of about 2.5 $''$. Several Bias and flat-field frames were taken at the beginning and at the end of each night; following the usual procedures, these frames were used to pre-reduce observational data.

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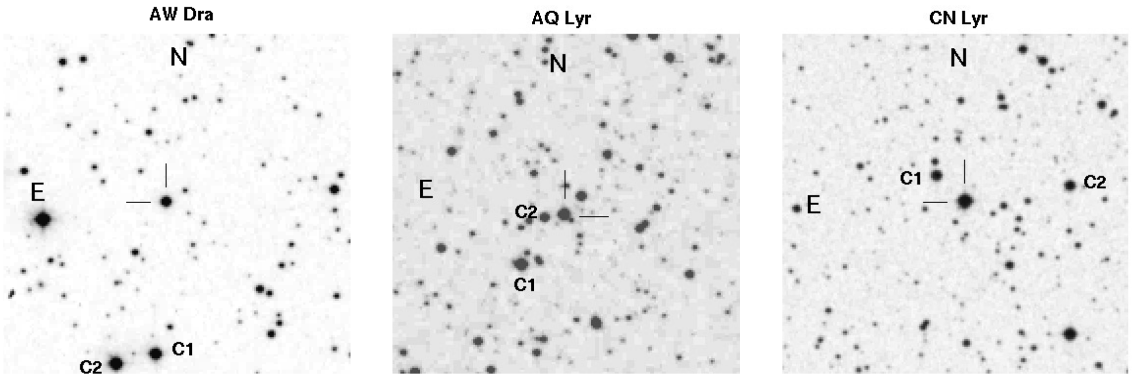

Fig. 1. Identification maps for AW Dra, AQ Lyr and CN Lyr; comparison stars are also indicated

Table 1. B and V magnitudes for comparison stars.

Var.	Comp.	V	$(B-V)$
AW Dra	C1	12.49± 0.02	1.05±0.02
AQ Lyr	C1	13.46± 0.02	1.11±0.02
AQ Lyr	C2	14.31± 0.04	0.77±0.02
CN Lyr	C1	13.37± 0.04	1.17±0.02
CN Lyr	C2	13.61± 0.02	1.18±0.02

In order to minimize the observation time and, consequently, to increase the sampling of the lightcurves, the magnitude of each variable has been obtained by evaluating the difference in magnitude between the target star and suitable comparison stars in the field of view of the telescope. Final data in standard B,V magnitudes have been obtained calibrating the comparison stars with several Landolt (1992) stars on three nights with good photometric conditions. Note that in this way one is also speeding up the reduction procedure, since no differential atmospheric extinction has to be taken into account in the magnitude differences between target and comparison stars.

The magnitudes of stars in each frame have been obtained through a suitable procedure for the ESO-MIDAS reduction package. Fig. 1 gives the identification maps for the three variables and for the chosen comparison stars. As shown in the figure, in all fields we chose two comparison stars. However, the comparison star C2 of AW Dra is suspected to be a variable star (see Fig. 2), whereas the non-variability of star C1 is ensured by the constancy of the AW Dra minima; so only the comparison star C1 was used.

In the other two cases, we derived a lightcurve with respect to each of the two comparison stars, thus averaging the two lightcurves to produce the final result. We found that differences between the two averaged curves are of the order of 0.01-0.02 magnitude. The magnitudes of the comparison stars in Fig. 1 are given in Table 1.

3. Lightcurves, amplitudes, mean magnitudes and colors

By using the periods given by GCVS4 one finally finds the lightcurves for AW Dra, AQ Lyr and CN Lyr reported in Fig. 3. Selected photometric data are reported in Table 2, 3, 4.

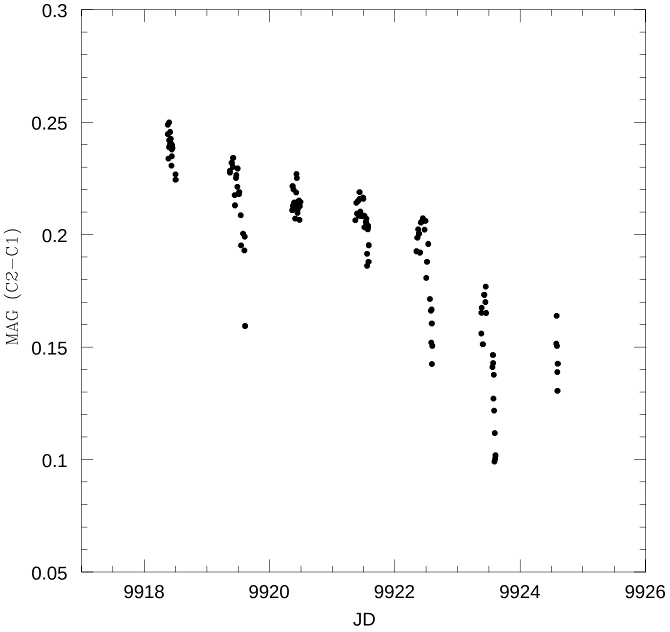

Fig. 2. Magnitude difference in the B band between comparison stars C2 and C1 of AW Dra; see the text for a short discussion.

For each variable, the lightcurves in B and V were fitted by means of smoothing splines, shown as a solid line in the quoted figures. From these fits we finally derived for the three RR Lyrae stars the amplitudes in V and B and the mean magnitudes and colors reported in Table 5. Fig. 4 (top) compares the present lightcurve for AQ Lyr with previous measurements given by Sturch (1966), while Fig. 4 (bottom) compares the lightcurve for CN Lyr with the photometry given by Oosterhoff (1962). One finds a reasonable agreement together with evidence for the great improvement achieved by the use of CCD even in rather small telescopes as the one used in this investigation.

As a final point, one may compare present results with the rich sample of lightcurves presented by Lub (1977) for field stars. For each of our 3 variables one finds in Lub's sample stars with similar periods and with quite similar lightcurves, supporting the reality of the various features and showing that in all cases we are dealing with "typical" field RR Lyrae pulsators.

Table 2. B and V magnitudes for AW Dra.

HJD	V	Phase	HJD	V	Phase	HJD	B	Phase	HJD	B	Phase
9918.3768	12.467	0.1201	9920.4803	12.596	0.1811	9918.4002	12.802	0.1541	9920.4930	12.969	0.1995
9918.3846	12.484	0.1314	9920.4842	12.605	0.1867	9918.4022	12.794	0.1570	9921.3719	13.425	0.4785
9918.3875	12.490	0.1356	9920.4911	12.622	0.1968	9918.4120	12.841	0.1713	9921.3856	13.459	0.4984
9918.3875	12.492	0.1356	9921.3709	12.983	0.4770	9918.4149	12.862	0.1755	9921.3993	13.482	0.5184
9918.3924	12.519	0.1428	9921.3846	13.006	0.4970	9918.4178	12.871	0.1797	9921.4120	13.506	0.5369
9918.3934	12.517	0.1442	9921.3983	13.017	0.5169	9918.4237	12.902	0.1883	9921.4256	13.507	0.5566
9918.3944	12.521	0.1457	9921.4120	13.030	0.5369	9918.4256	12.914	0.1911	9921.4383	13.513	0.5751
9918.3954	12.518	0.1471	9921.4256	13.037	0.5566	9918.4325	12.941	0.2011	9921.4413	13.508	0.5795
9918.4061	12.568	0.1627	9921.4373	13.043	0.5737	9918.4354	12.951	0.2053	9921.4520	13.501	0.5951
9918.4080	12.567	0.1655	9921.4520	13.047	0.5951	9918.4403	12.975	0.2125	9921.4940	13.532	0.6562
9918.4100	12.564	0.1684	9921.4911	13.052	0.6520	9918.4422	12.982	0.2152	9921.4969	13.531	0.6604
9918.4207	12.593	0.1839	9921.5116	13.085	0.6818	9918.4471	13.003	0.2224	9921.5125	13.538	0.6831
9918.4227	12.595	0.1868	9921.5389	13.121	0.7215	9918.4500	13.010	0.2266	9921.5155	13.549	0.6875
9918.4295	12.613	0.1967	9921.5438	13.130	0.7286	9918.4998	13.150	0.2990	9921.5399	13.589	0.7230
9918.4315	12.616	0.1997	9921.5457	13.137	0.7314	9918.5028	13.163	0.3034	9921.5477	13.613	0.7343
9918.4393	12.634	0.2110	9921.5536	13.151	0.7429	9918.5243	13.188	0.3347	9921.5506	13.624	0.7385
9918.4393	12.638	0.2110	9921.5555	13.154	0.7457	9918.5282	13.182	0.3404	9921.5565	13.629	0.7471
9918.4452	12.653	0.2196	9921.5623	13.162	0.7556	9919.3680	13.502	0.5624	9921.5594	13.632	0.7514
9918.4461	12.659	0.2209	9921.5633	13.167	0.7570	9919.3709	13.501	0.5667	9921.5643	13.623	0.7585
9918.4989	12.760	0.2977	9921.5711	13.184	0.7684	9919.3963	13.492	0.6036	9921.5731	13.665	0.7713
9918.5223	12.783	0.3318	9921.5721	13.188	0.7698	9919.3993	13.493	0.6080	9921.5760	13.677	0.7755
9918.5243	12.779	0.3347	9921.5789	13.198	0.7797	9919.4178	13.508	0.6349	9921.5819	13.682	0.7841
9919.3670	13.033	0.5610	9921.5799	13.202	0.7812	9919.4207	13.505	0.6391	9921.5848	13.681	0.7883
9919.3680	13.032	0.5624	9921.5868	13.214	0.7912	9919.4442	13.538	0.6733	9922.3465	13.366	0.8967
9919.4159	13.052	0.6321	9921.5877	13.219	0.7925	9919.4510	13.553	0.6832	9922.3622	13.006	0.9196
9919.4168	13.050	0.6335	9922.3612	12.728	0.9181	9919.4666	13.558	0.7059	9922.3748	12.783	0.9379
9919.4471	13.079	0.6775	9922.3739	12.541	0.9366	9919.4706	13.571	0.7117	9922.3875	12.632	0.9564
9919.4657	13.092	0.7046	9922.3866	12.425	0.9551	9919.4881	13.609	0.7372	9922.4032	12.399	0.9792
9919.4696	13.100	0.7103	9922.3983	12.276	0.9721	9919.4950	13.625	0.7473	9922.4188	12.348	0.0019
9919.4842	13.140	0.7315	9922.4178	12.188	0.0005	9919.5135	13.660	0.7742	9922.4344	12.430	0.0246
9919.4940	13.134	0.7458	9922.4334	12.256	0.0232	9919.5174	13.665	0.7798	9922.4491	12.481	0.0460
9919.5086	13.184	0.7670	9922.4481	12.281	0.0446	9919.5399	13.700	0.8126	9922.4745	12.599	0.0830
9919.5174	13.197	0.7798	9922.4881	12.430	0.1028	9919.5467	13.684	0.8225	9922.4891	12.672	0.1042
9919.5438	13.230	0.8183	9922.5008	12.468	0.1213	9919.5780	13.615	0.8680	9922.5018	12.736	0.1227
9919.5721	13.185	0.8594	9922.5145	12.519	0.1412	9919.6014	13.337	0.9021	9922.5155	12.797	0.1427
9919.5770	13.175	0.8666	9922.5282	12.567	0.1611	9919.6063	13.212	0.9092	9922.5350	12.879	0.1710
9919.5877	13.101	0.8821	9922.5819	12.700	0.2393	9919.6112	13.124	0.9163	9922.5604	12.980	0.2080
9919.6053	12.887	0.9078	9922.5868	12.727	0.2464	9920.3661	12.390	0.0149	9922.5770	13.061	0.2322
9919.6092	12.789	0.9134	9922.5907	12.733	0.2521	9920.3700	12.410	0.0205	9922.5829	13.080	0.2407
9920.3641	12.217	0.0120	9922.5956	12.748	0.2592	9920.3748	12.425	0.0275	9922.5877	13.102	0.2477
9920.3690	12.235	0.0191	9922.5995	12.756	0.2649	9920.3836	12.471	0.0403	9922.5916	13.127	0.2534
9920.3739	12.248	0.0262	9923.3797	12.887	0.4002	9920.3885	12.487	0.0475	9922.5956	13.136	0.2592
9920.3778	12.262	0.0319	9923.3836	12.891	0.4059	9920.3934	12.510	0.0546	9922.6004	13.148	0.2662
9920.3875	12.290	0.0460	9923.3875	12.901	0.4116	9920.3983	12.532	0.0617	9923.3807	13.326	0.4017
9920.3924	12.305	0.0531	9923.4071	12.938	0.4401	9920.4129	12.596	0.0830	9923.3846	13.333	0.4074
9920.3973	12.320	0.0603	9923.4237	12.958	0.4643	9920.4286	12.717	0.1058	9923.3885	13.336	0.4130
9920.4110	12.369	0.0802	9923.4452	13.010	0.4956	9920.4315	12.737	0.1100	9923.4071	13.376	0.4401
9920.4266	12.455	0.1029	9923.4559	13.022	0.5111	9920.4373	12.726	0.1185	9923.4286	13.421	0.4714
9920.4315	12.472	0.1100	9923.5594	13.071	0.6617	9920.4432	12.744	0.1271	9923.4481	13.491	0.4998
9920.4364	12.468	0.1172	9924.5780	12.528	0.1440	9920.4471	12.765	0.1327	9923.4530	13.495	0.5069
9920.4403	12.474	0.1228	9924.5819	12.536	0.1497	9920.4510	12.786	0.1384	9923.4569	13.508	0.5126
9920.4461	12.487	0.1313	9924.5868	12.547	0.1568	9920.4549	12.804	0.1441	9924.5789	12.831	0.1453
9920.4500	12.504	0.1370	9924.5926	12.587	0.1652	9920.4598	12.829	0.1512	9924.5829	12.865	0.1511
9920.4539	12.522	0.1426	9924.5975	12.581	0.1724	9920.4725	12.877	0.1697	9924.5887	12.888	0.1596
9920.4598	12.536	0.1512	9924.6024	12.597	0.1795	9920.4774	12.901	0.1768	9924.5936	12.909	0.1667
9920.4754	12.584	0.1739	9924.6073	12.611	0.1866	9920.4803	12.916	0.1811	9924.5985	12.938	0.1738
						9920.4852	12.937	0.1882	9924.6034	12.965	0.1810

Table 3. B and V magnitudes for AQ Lyr.

HJD	V	Phase	HJD	V	Phase	HJD	B	Phase	HJD	B	Phase
9921.3630	13.431	0.8095	9924.4177	13.145	0.3627	9921.3649	13.981	0.8148	9923.4147	13.805	0.5542
9921.3786	13.374	0.8532	9924.4343	13.173	0.4091	9921.3796	13.898	0.8560	9923.4196	13.827	0.5680
9921.3913	13.208	0.8887	9924.4450	13.205	0.4391	9921.3932	13.611	0.8940	9923.4362	13.871	0.6144
9921.4050	12.869	0.9271	9924.4587	13.233	0.4775	9921.4059	13.118	0.9296	9923.4411	13.880	0.6282
9921.4186	12.453	0.9652	9924.4704	13.239	0.5102	9921.4206	12.610	0.9708	9924.3942	13.496	0.2969
9921.4470	12.456	0.0447	9924.4860	13.272	0.5539	9921.4323	12.559	0.0035	9924.4079	13.598	0.3352
9921.4587	12.546	0.0774	9924.5016	13.315	0.5976	9921.4489	12.691	0.0500	9924.4196	13.655	0.3680
9921.4802	12.702	0.1376	9924.5329	13.367	0.6852	9921.4597	12.811	0.0802	9924.4245	13.666	0.3817
9921.5036	12.850	0.2032	9924.5583	13.392	0.7563	9921.4831	13.047	0.1458	9924.4352	13.706	0.4117
9921.5280	13.001	0.2715	9925.3600	12.423	0.0011	9921.4870	13.081	0.1567	9924.4470	13.709	0.4447
9922.3327	13.267	0.5246	9925.3796	12.510	0.0560	9921.5046	13.255	0.2060	9924.4597	13.742	0.4803
9922.3542	13.295	0.5848	9925.3913	12.586	0.0887	9921.5085	13.276	0.2169	9924.4724	13.765	0.5158
9922.3815	13.343	0.6613	9925.4157	12.743	0.1571	9922.3347	13.784	0.5302	9924.4880	13.811	0.5595
9922.3932	13.369	0.6940	9925.4313	12.838	0.2007	9922.3561	13.825	0.5902	9924.5036	13.857	0.6032
9922.4089	13.397	0.7380	9925.4440	12.918	0.2363	9922.3688	13.849	0.6257	9924.5348	13.926	0.6905
9922.4255	13.415	0.7845	9925.4655	13.041	0.2965	9922.3825	13.896	0.6641	9924.5602	13.969	0.7617
9922.4401	13.408	0.8254	9925.4850	13.121	0.3511	9922.4098	13.950	0.7405	9925.3806	12.773	0.0588
9922.4518	13.316	0.8581	9925.5329	13.225	0.4852	9922.4147	13.961	0.7542	9925.3923	12.870	0.0915
9922.4557	13.301	0.8690	9926.3443	13.402	0.7574	9922.4265	13.959	0.7873	9925.4040	13.019	0.1243
9922.4821	12.743	0.9430	9926.3609	13.393	0.8039	9922.4304	13.958	0.7982	9925.4167	13.101	0.1599
9922.4948	12.441	0.9785	9926.3834	13.311	0.8669	9922.4421	13.936	0.8310	9925.4333	13.219	0.2063
9922.5075	12.405	0.0141	9926.3961	13.157	0.9025	9922.4450	13.923	0.8391	9925.4450	13.342	0.2391
9922.5222	12.490	0.0552	9926.4088	12.844	0.9380	9922.4567	13.781	0.8718	9925.4860	13.607	0.3539
9922.5417	12.630	0.1098	9926.4361	12.429	0.0145	9922.4597	13.738	0.8802	9925.5065	13.735	0.4113
9922.5681	12.802	0.1838	9926.4488	12.486	0.0500	9922.4831	12.985	0.9458	9925.5407	13.756	0.5071
9923.4138	13.271	0.5517	9926.4615	12.561	0.0856	9922.4860	12.876	0.9539	9926.3463	13.920	0.7630
9923.4352	13.318	0.6116	9926.4732	12.650	0.1183	9922.4958	12.621	0.9813	9926.3619	13.916	0.8067
9924.3923	13.033	0.2915	9926.4869	12.732	0.1567	9922.4987	12.610	0.9894	9926.3844	13.776	0.8697
9924.4069	13.104	0.3324	9926.5025	12.821	0.2004	9922.5085	12.607	0.0169	9926.3980	13.575	0.9078
						9922.5124	12.623	0.0278	9926.4107	13.149	0.9433
						9922.5231	12.725	0.0578	9926.4498	12.729	0.0528
						9922.5261	12.747	0.0662	9926.4625	12.844	0.0884
						9922.5515	13.018	0.1373	9926.4752	12.944	0.1239
						9922.5534	13.048	0.1426	9926.4879	13.051	0.1595
						9922.5690	13.191	0.1863			

4. Comparison with the theory of pulsation

In recent times the use of non-linear, non-local, time-dependent convective models by Bono and coworkers has produced a large amount of theoretical predictions concerning RR Lyrae pulsations. (See the most recent papers by Bono et al. 1997a (BCCIM), 1997b (BCCM) and reference therein). Taking advantage of this theoretical framework, in this section we will discuss the pulsational properties of the three studied variables.

As a first step, Fig. 5 shows the location in the Bailey (period-amplitude) diagram for our three variables, as compared with selected samples of field RRab and with theoretical results from BCCIM; the field stars were selected to lie within the limits of metallicity given in the figure. Periods and amplitudes of field RR Lyrae are from Blanco (1992), while metallicities are from Layden (1994, 1995) and Layden et al. (1996). In all three panels our variables are reported with four-pointed stars: going toward lower periods one finds AW Dra, CN Lyr and AQ Lyr. One finds that AW Dra lies in a region where only low metallicity pulsators occur. Accordingly one can predict for this variable a metallicity as low as [Fe/H]$\leq$ -1.4. On the contrary, both AQ Lyr and CN Lyr clearly are members of the high metallicity group, as expected in particular for CN Lyr ([Fe/H]$\sim$ -0.26). One may notice that both stars lie on the lower envelope of the observed distributions, well below theoretical expectations even for “young” massive pulsators (see Fig. 16b in BCCIM and the discussion in that paper). We conclude that, if these stars are “bona fide” ab-type pulsators, theory has to be improved to account for such kind of unpredicted variables.

To allow a closer comparison with predicted lightcurves one can estimate temperatures from the observed colors, provided that the reddenings are known. For AQ Lyr Burstein & Heiles (1978) provided $E(B-V)$ = 0.127 mag. Since AQ Lyr has ΔS values by Suntzeff et al. (1994), one may use the method by Sturch (1966), as improved by Blanco (1992), to test this reddening with an independent estimate. As a result we find for AQ Lyr $E(B-V)$ = 0.13 mag, in excellent agreement with

Table 4. B and V magnitudes for CN Lyr.

HJD	V	Phase	HJD	V	Phase	HJD	B	Phase	HJD	B	Phase
9924.3717	11.228	.9288	9926.4429	11.140	.9636	9924.3717	11.718	.9288	9926.4692	11.526	.0275
9924.3756	11.208	.9383	9926.4555	11.079	.9942	9924.3765	11.698	.9405	9926.4829	11.579	.0608
9924.3990	11.086	.9952	9926.4682	11.084	.0251	9924.4010	11.540	.0000	9926.4946	11.615	.0892
9924.4137	11.095	.0309	9926.4819	11.115	.0584	9924.4137	11.548	.0309	9926.4975	11.644	.0963
9924.4293	11.128	.0688	9926.4936	11.138	.0868	9924.4303	11.598	.0713	9926.5161	11.714	.1415
9924.4400	11.156	.0948	9926.5161	11.207	.1415	9924.4410	11.648	.0973	10245.4027	11.996	.3002
9924.4517	11.187	.1233	10245.4008	11.364	.2956	9924.4527	11.705	.1257	10245.4047	11.989	.3051
9924.4517	11.190	.1233	10245.4017	11.366	.2978	9924.4674	11.767	.1615	10245.4086	11.992	.3146
9924.4664	11.228	.1590	10245.4076	11.375	.3121	9924.4791	11.824	.1899	10245.4115	12.004	.3216
9924.4781	11.264	.1875	10245.4076	11.375	.3121	9924.4820	11.842	.1969	10245.4203	12.029	.3430
9924.4928	11.299	.2232	10245.4183	11.395	.3381	9924.4928	11.871	.2232	10245.4232	12.027	.3501
9924.5484	11.414	.3583	10245.4203	11.400	.3430	9924.4967	11.894	.2327	10245.4271	12.044	.3595
9924.5689	11.461	.4082	10245.4252	11.404	.3549	9924.5484	12.055	.3583	10245.4291	12.056	.3644
9925.3746	11.427	.3667	10245.4262	11.410	.3574	9924.5699	12.112	.4106	10245.4340	12.067	.3763
9925.3863	11.438	.3951	10245.4320	11.420	.3715	9925.3756	12.041	.3691	10245.4359	12.068	.3809
9925.3971	11.459	.4214	10245.4330	11.422	.3739	9925.3873	12.051	.3976	10245.4398	12.091	.3904
9925.4097	11.477	.4520	10245.4388	11.432	.3880	9925.3980	12.088	.4236	10245.4418	12.078	.3953
9925.4390	11.507	.5232	10245.4388	11.431	.3880	9925.4107	12.121	.4545	10245.4457	12.066	.4048
9925.4556	11.524	.5636	10245.4457	11.442	.4048	9925.4264	12.157	.4926	10245.4486	12.075	.4118
9925.4762	11.543	.6137	10245.4486	11.447	.4118	9925.4390	12.157	.5232	10245.4545	12.125	.4261
9925.4918	11.561	.6516	10245.4535	11.455	.4237	9925.4566	12.191	.5660	10245.4574	12.128	.4332
9925.5230	11.601	.7274	10245.4564	11.467	.4308	9925.4605	12.189	.5755	10245.4603	12.119	.4402
9926.3696	11.594	.7854	10245.4594	11.466	.4381	9925.4771	12.211	.6159	10245.4633	12.133	.4475
9926.3911	11.543	.8376	10245.4623	11.470	.4451	9925.4801	12.190	.6232	10245.4662	12.122	.4546
9926.4038	11.449	.8685	10245.4652	11.471	.4522	9925.4928	12.199	.6540	10245.4691	12.128	.4616
9926.4175	11.306	.9018	10245.4681	11.473	.4592	9925.5230	12.258	.7274	10245.4721	12.121	.4689
9926.4302	11.214	.9327	10245.4711	11.476	.4665	9926.3559	12.252	.7521	10245.4750	12.121	.4760
						9926.3706	12.222	.7878	10245.4789	12.137	.4855
						9926.3911	12.146	.8376	10245.4828	12.132	.4949
						9926.4048	11.996	.8709	10245.4887	12.144	.5093
						9926.4184	11.775	.9040	10245.4945	12.151	.5234
						9926.4311	11.689	.9349	10245.5004	12.147	.5377
						9926.4429	11.583	.9636	10245.5062	12.155	.5518
						9926.4565	11.518	.9966			

Table 5. Observational results for AW Dra, AQ Lyr and CN Lyr.

Var.	Period	Epoch	$< V >$	$(B-V)$	$< B-V >$	$< B > - < V >$	$(B-V)_{cm}$	$A(V)$	$A(B)$
AW Dra	0.6871941	9918.2925	12.777	0.380	0.375	0.346	0.368	1.041	1.338
AQ Lyr	0.3571424	9921.0703	13.004	0.441	0.434	0.396	0.424	1.000	1.381
CN Lyr	0.41138232	9923.9861	11.374	0.586	0.582	0.573	0.575	0.527	0.728

the previous value. For CN Lyr and AW Dra the literature gives no indications. To get the missing values, we again used the reddening maps by Burstein & Heiles (1982), obtaining for AW Dra $E(B-V)$ = 0.06 mag and for CN Lyr $E(B-V)$ = 0.21 mag. According to the quoted authors, the error on these estimates is of the order of 0.03 mag.

An alternative way to derive information about reddenings is that of using statistical relations such as those provided by Caputo & De Santis (1992). These authors used the Lub (1977) sample of field ab type variables to derive relations between periods, B amplitudes, metallicities and mean de-reddened colors. Using their Eq. (10) we obtain for CN Lyr $(B-V)_0$ = 0.38 mag and thus $E(B-V)$ = 0.20 mag, in good agreement with the value given by Burstein & Heiles (1982). The same procedure for AQ Lyr provides $(B-V)_0$=0.33 mag, this means $E(B-V)$ = 0.10 mag, slightly lower (about 0.03) than the value previously determined from Blanco's reddening law and from Burstein & Heiles (1978) maps but within the errors. Hence we adopt those estimates in order to compute the temperature of the variable in Table 6. For AW Dra there is no available metallicity evaluation in the literature, but we can estimate lower and upper limits for it from our Fig. 5. We get, for [Fe/H]= -1.4, $(B-V)_0$=0.33

Table 6. Selected fundamental quantities for AW Dra, AQ Lyr and CN Lyr.

Var.	$\log P$	$A(B)$	Z	$E(B-V)$	$<V>_0$	$(B-V)_{0cm}$	$\log T_e$	T_e	m_{bol}
AW Dra	-0.16292	1.338	~ 0.0005	0.06	12.584	0.308	3.826	6700	12.428
AQ Lyr	-0.44716	1.381	0.005	0.13	12.586	0.294	3.838	6890	12.468
CN Lyr	-0.38575	0.728	0.01	0.21	10.700	0.365	3.829	6750	10.600

Table 7. Luminosities coming from period-temperature-mass-luminosity relations (see text) by BCCM, for the three RR Lyrae investigated in this study; F and FO mean fundamental and first overtone pulsation mode respectively.

AW Dra

F				FO			
$\mathrm{M=0.65M_\odot}$		$\mathrm{M=0.75M_\odot}$		$\mathrm{M=0.65M_\odot}$		$\mathrm{M=0.75M_\odot}$	
$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$	$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$	$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$	$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$
3.820	1.81	3.820	1.84	3.820	1.97	3.820	2.02
3.826	1.84	3.826	1.88	3.826	2.00	3.826	2.04
3.833	1.87	3.833	1.91	3.833	2.02	3.833	2.07

AQ Lyr

F				FO			
$\mathrm{M=0.53M_\odot}$		$\mathrm{M=0.58M_\odot}$		$\mathrm{M=0.53M_\odot}$		$\mathrm{M=0.58M_\odot}$	
$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$	$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$	$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$	$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$
3.831	1.43	3.831	1.46	3.831	1.60	3.831	1.62
3.838	1.46	3.838	1.49	3.838	1.62	3.838	1.65
3.844	1.48	3.844	1.51	3.844	1.65	3.844	1.68

CN Lyr

F				FO			
$\mathrm{M=0.53M_\odot}$		$\mathrm{M=0.58M_\odot}$		$\mathrm{M=0.53M_\odot}$		$\mathrm{M=0.58M_\odot}$	
$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$	$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$	$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$	$\log \mathrm{T_e}$	$\log \mathrm{L/L_\odot}$
3.823	1.47	3.823	1.50	3.823	1.64	3.823	1.67
3.829	1.50	3.829	1.52	3.829	1.66	3.829	1.69
3.836	1.52	3.836	1.55	3.836	1.69	3.836	1.72

mag and, for [Fe/H]= -1.9, $(B-V)_0$=0.32 mag, which in terms of reddening means $0.04 < E(B-V) < 0.05$ mag, well within the error of the reddening as derived from Burstein & Heiles (1982) maps.

After correction for reddening, mean colors have been evaluated in three ways: as intensity-weighted ($<B-V>$ or $<B>-<V>$) and as magnitude-weighted $(B-V)$; all these values are reported in Table 5. However Bono et al. (1995, BCS hereafter) have once again shown that the color of the static model does not match exactly any observed mean color. To all these mean colors we thus applied the corresponding correction as tabulated by BCS for Z=0.001; we estimated that errors due to the different metallicity should not exceed few thousandths of magnitude, thus preserving the general trend $[(B-V)] > [<B-V>] > [(B-V)_{static}] > [<B>-<V>]$. After applying the BCS correction the three substantially different mean colors for each star become very similar, so we proceeded to average them and we took this mean value as our best estimate of the RR Lyrae mean colors, as given by $(B-V)_{mc}$ in Table 5. Finally, RR Lyrae mean colors have been translated into temperatures by estimating gravities from the period - gravity relation obtained from the period - temperature - luminosity - mass relation by BCCM and using Kurucz (1992) models. One finds $\log g = 3.0$ for both AQ Lyr and CN Lyr, whereas for AW Dra one has $\log g = 2.75$. The estimated error on the temperature is about $\pm 100K$, largely dominated by the error in the reddening. Temperatures for the three RR Lyrae studied in this paper are reported in Table 6 together with further pertinent quantities.

Given period and temperature, one can obtain an estimate of the star luminosity from the period - temperature - luminosity - mass relation, provided that suitable assumptions of the pulsator masses are made. Evolutionary constraints indicate that one can

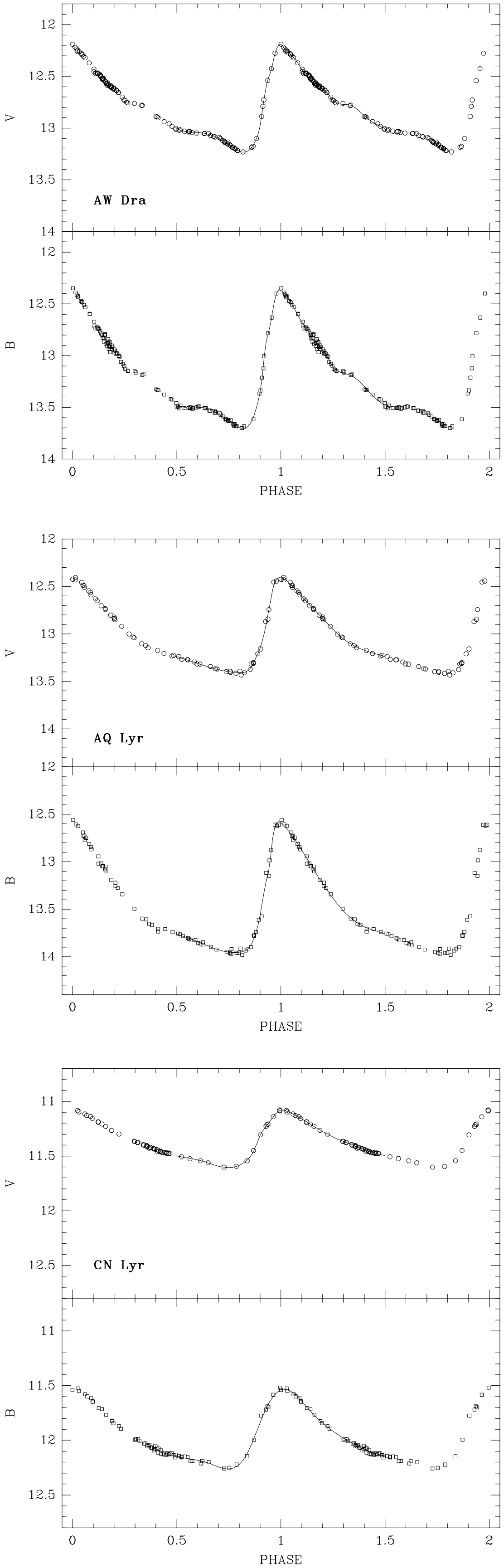

Fig. 3. B and V lightcurves for AW Dra, AQ Lyr, CN Lyr

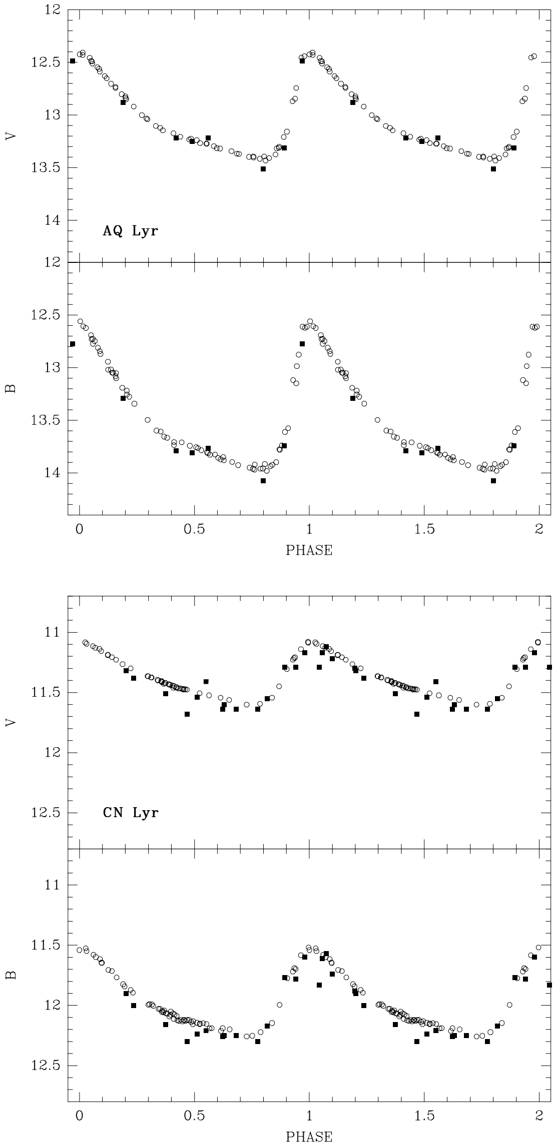

Fig. 4. Comparison with previous photometry (full squares) for AQ Lyr (top) and CN Lyr (bottom). For both variables new data are reported as open circles.

safely assume M= 0.53-0.58 $M_\odot$ for the two metal rich RR Lyrae, and M=0.65-0.75 $M_\odot$ for AW Dra. Making use of the relations given by BCCM (corrected by $\Delta \log P \sim +0.02$ for fundamental metal rich pulsators, as stated by BCCIM) one finally derives the range of luminosity given in Table 7 under the two alternative assumptions about the mode of pulsation. We are now able to compare observed lightcurves with the atlas presented by BCCIM and BCCM. For the various stars one finds:

CN Lyr: If this is an F-pulsator, it would be out of the range explored by theory when Z=0.01. However, comparison with results for Z=0.02 suggests that the theoretical rising time of an F-pulsator should be much shorter than observed. Comparison with theoretical predictions for Z=0.01 and Z=0.02 could suggest that this star should be a FO pulsator crossing the strip at

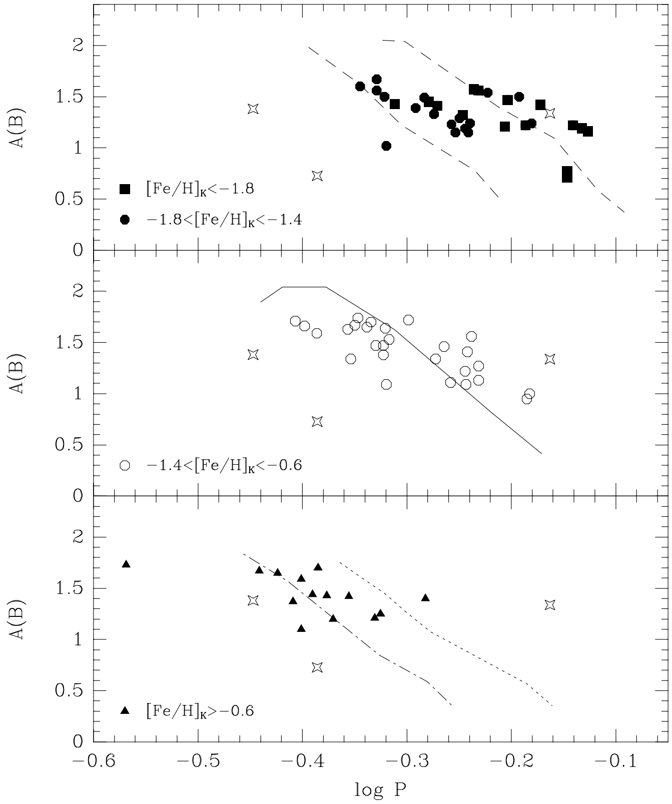

Fig. 5. The Bailey diagram for the three RR Lyrae of this study, in comparison with selected theoretical and observational results. For details see the text and Figs. 16a and 16b in BCCIM

large luminosity well above the ZAHB. Even though the star is beyond the limit of the atlas, one finds, e.g., that Z=0.02 FO pulsators with similar temperatures and large luminosities ($\log \mathrm{L}/\mathrm{L}_{\odot}$= 1.61 and 1.81) show the asymmetric lightcurve disclosed by our observations. Note that in this case one cannot derive the intrinsic color from the quoted Caputo & De Santis (1992) relation, and the reasonable prediction about the CN Lyr reddening should be regarded as obtained by chance. However, as suggested by our referee, on observational grounds CN Lyr (like, e.g., FW Lup in the Lub (1977) sample) has to be regarded as a typical low-amplitude, type b fundamental pulsator, as found towards the red edge of the instability strip. Appropriate theoretical investigation is needed before possible mismatches with the theory can be discussed.

AQ Lyr: There is, apparently, no way to fit the observed lightcurve to theoretical predictions for FO pulsators. The shape of the curve is in good agreement with predictions for F pulsators in the quoted range of luminosities and temperature. Note that the luminosity is the one predicted by BCCIM for metal rich HB stars. However, bearing in mind that the bolometric amplitude is roughly comparable with the amplitude in the V band (Marconi, private communication) theory predicts a larger amplitude. A similar instance has been already discussed in BCCM (see Fig. 18 in that paper).

AW Dra: This star appears to be a classical ab type pulsator. As a matter of fact, in BCCM one finds that a metal poor FO pulsator at the required large luminosity should have a symmetric lightcurve, contrary to observation. Both amplitude and shape of the lightcurve appear in reasonable agreement with predictions for F pulsators, even if the atlas lacks models in the range $\mathrm{T_e} = 6500 - 6800$K. Thus one finds that AW Dra is a fundamental pulsator crossing the strip at $\log \mathrm{L}/\mathrm{L}_{\odot} \sim 1.8 - 1.9$, i.e. above the ZAHB luminosity level.

5. Conclusions

In this paper we presented lightcurves for the three field RR Lyrae AQ Lyr, CN Lyr and AW Dra. As for the two metal rich pulsators in the sample we suggest that CN Lyr has been possibly misclassified, being possibly an asymmetric c-type pulsator. However, CN Lyr could also be a b-type fundamental pulsator with lightcurve not well predicted by the available theory. AQ Lyrae appears to be a metal rich ab type pulsator, with the expected luminosity but with an amplitude lower than that predicted by theory. Finally, we find that AW Dra behaves as a metal poor fundamental pulsator, crossing the instability strip well above the corresponding ZAHB luminosity level.

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References

Blanco, V.M., 1992, AJ 104, 734
Bono G., Caputo F., Stellingwerf R.F., 1995, ApJS 99, 263 (BCS)
Bono G., Caputo F., Cassisi S., Incerpi R., Marconi M., 1997a ApJ, 483, 811 (BCCIM)
Bono G., Caputo F., Castellani V., Marconi M., 1997b, A&AS 121, 327 (BCCM)
Burstein D., Heiles C., 1978, ApJ 225, 40
Burstein D., Heiles C., 1982, ApJ 87, 1165
Caputo F., De Santis R. 1992, AJ 104, 253
Kholopov P.N., Samus N.N., Frolov M.S. et al. 1988, General Catalogue of Variable Stars, 4th Ed. (GCVS4), Moscow: "Nauka" Publishing House
Kurucz R. 1992, CD ROM 13
Landolt A. 1992, AJ 104, 340
Layden A.C. 1994, AJ 108, 1016
Layden A.C. 1995, AJ 110, 2312
Layden, A.C., Hanson, R.B., Hawley, S.L., Klemola, A.R., Hanley, C.J., 1996, AJ 112, 2210
Lub J. 1977, A&AS 29, 345
Oosterhoff P.T., 1962, BAN 15, 1990
Preston G.W., 1959, ApJ 130, 507
Suntzeff N.B., Kraft R.P., Kinman T.D., 1994, ApJS 93, 271
Sturch C., 1966, ApJ 143, 774