

BULGARIAN VIRTUAL OBSERVATORY. MULTICOLOR OBSERVATIONS OF OPEN CLUSTERS IN OUR GALAXY

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Abstract. Ca. 900 CCD frames in U,B,V,R,I on the 2-m RCC telescope and in B,V,R,I on the 60-cm telescope have been taken for 30 open clusters, including 7 bright clusters, 16 (8 x 2) probably double open clusters and 7 clusters in the anticenter of the Galaxy.

For photometric reduction Stetson's DAOPHOT and ALLSTAR program packages, implemented in MIDAS were used. Standards in several star clusters were used - the clusters M92 (mainly), NGC 7790, NGC 4147 and M67 and the improved standard sequences from the latest years have been taken.

1. INTRODUCTION

Open clusters are physically related groups of stars held together by gravitational attraction. Originating from large cosmic gas and dust clouds, all member stars are of similar age and as all the stars in a cluster formed from the same diffuse nebula, they are all of similar initial chemical composition. Over 1600 open clusters are known in our Milky Way Galaxy (Dias 2002), and this is probably only a small percentage of the total population which is probably some factor higher. Nearly half of them have been observed so far in at least one photometric system and ca. 420 are comparatively well studied. The number of stars per cluster goes from several tens for the poorest objects, to several thousands for the most prominent clusters. According to *WEBDA* (*see below*), open clusters are of great interest for astrophysicists because of these properties:

The stars are at the same distance

This is true for most objects, because the effect of the cluster volume is smaller than the usual errors on magnitude determination and negligible in comparison with other effects like binarity and rotation. There is one cluster, namely the Hyades, for which a precise determination of the distances of the individual stars has been possible, thanks to the Hipparcos satellite.

The stars have the same age

This assumption is true for intermediate-age and old clusters, but is questionable for very young and extremely young open clusters. The problem arises from our lack of knowledge on how a molecular cloud contracts and which is the sequence of stellar formation. Which one of the low mass stars or the massive stars do form first? Obviously, in young clusters, the massive stars are already on the main sequence or even started their evolution away from the main sequence, while the low mass stars are still in a phase of contraction. This is a domain in which the contribution of star clusters to the understanding of the laws of star formation has been and will be fundamental.

The stars have the same chemical composition

So far, it has not been possible to prove the opposite and this is a good assumption. It implies that the material from which the stars formed was rather homogeneous. But the precise determination of the chemical composition is a difficult task and the uncertainties on the results are still rather large.

The stars differ in their mass

Open clusters usually contain stars over a large range of mass from more than 80 solar masses in the extremely young clusters, to stars less massive than 0.08 solar masses, i.e. the limit for brown dwarfs.

Therefore, comparing the "standard" Hertzsprung-Russel Diagram (HRD), derived from nearby stars with sufficiently well-known distances, or the theory of stellar evolution, with the measured CMD of star clusters, provides a considerably good method to determine the distance of star clusters. Comparing their HRD with stellar theory provides a reasonable way to estimate the age of star clusters. The theoretical study of stellar evolution has provided convincing evidence that the stars of a cluster are all roughly of the same age, and thus have formed within a short period of time on the cosmic time scale, i.e. their HRDs represent isochrones, or pictures of stars of all the same age. The result that all the cluster HRDs can be explained by the theory of stellar evolution gives convincing evidence for this theory.

WEBDA is a site devoted to observational data on stars in galactic open clusters. It is intended to provide a reliable image of the available data and knowledge on these objects and to offer a wide access to the existing observations. This database has been conceived to bring at one place most data that could be useful to decide upon the membership of the stars and their physical characteristics, and store them with a coherent numbering scheme. In spite of the limitations due to the lower precision of some older data, the database is the best starting point for many astrophysical studies involving open clusters. Nowhere else are complete data collections to be found and one merit of the database is to give a clear report of the present observation status. The present database offers *astrometric data* in the

form of coordinates, rectangular positions, and some proper motions, *photometric data* in the major system in which star clusters have been observed (UBV, uvby, Geneva, Vilnius, DDO and others), *spectroscopic data*, like spectral classification, radial velocities, rotational velocities. It contains also miscellaneous *types of data* like membership probabilities, orbital elements of spectroscopic binaries, periods of variability for different kinds of variable stars. List of interesting and peculiar stars have also been compiled. Finally a whole set of *bibliographic references* allows every one to locate the interesting publications on his or her favorite open clusters easily.

2. DESCRIPTION OF THE PROJECT

Several years ago a joint project "*Structure of the GALAXY*" started, included astronomers from University of Bonn and Hoer List Observatory and Institute of Astronomy of the Bulgarian Academy of Sciences. The project itself includes three directions of investigations – selected open clusters in the direction of anticenter, bright open clusters and probably binary open clusters.

- Studied of selected open clusters in the direction of anticenter was devoted to add the available data for the spiral structure of our Galaxy. Here we studied seven such cluster.
- Some bright open clusters were chosen to complete "color – magnitude" diagrams and to determine their ages – this is the important parameter we are interested in (for example see Bica et al., 1993). For the larger clusters – i.e. such with large angular diameter mosaic from several frames in each color was used to cover all the field of the cluster. For all of them the central part with the brightest stars was investigated.

A *binary open star cluster* could be defined as an object consisting of two open clusters. They can be basically described as: (i) binary physical systems with common origin formed together from one and the same Giant Molecular Cloud (GMC), having comparable age and chemical composition - this is a true binary cluster; (ii) binary physical systems arising from clusters formed in different part of the Galaxy and forming a pair with mutual gravitational capture - these clusters are expected to have different ages and chemical composition.

3. REALIZATION OF THE PROJECT

For the period of 3 years - namely: end of 1996, 1997, 1998, 1999 in the project "Structure of the GALAXY..." the next basic steps have been finished:

- 1) Installed and tested CCD-camera ST-8 (Alexander von Humboldt support) on the 2-m RCC telescope, latterly becomes as basic camera at 60-cm telescope at the Belogradchick observatory

- 2) Preliminary testing of the simple focal reducer on the 60-cm telescope
- 3) Ca. 900 CCD frames in U,B,V,R,I on the 2-m RCC telescope and in B,V,R,I on the 60-cm telescope have been taken for 30 open clusters from the program list, including 7 bright clusters, 16 (8 x 2) probably double open clusters and 7 clusters in anticenter.

For the reduction of the data some additional steps have been done:

4) Simple MIDAS procedures was created for determining of the SKY of the CCD frames - "@@ sky", full width of half maximum of star images - "@@ fwhm" etc.

5) Full complete of procedures for photometric calibration written in PASCAL.

Due to the bad self guiding of the telescopes, normally several 60-, 120-sec exposures have to be averaged for better S/N ratio:

6) All the frames have been SHIFTED to one position - usually the middle of the exposure times and AVERAGED. For the final image only the free regions have been subtracted

7) For all averaged images the AIRMASSES for the observations have been calculated

8) FWHM have been determined for all images of the clusters

9) All the frames have been REDUCED with DAOPHOT and ALLSTAR.

For photometric calibration the standards in several star clusters were used. The clusters M92 (mainly), NGC 7790, NGC 4147 an M67 were used and the improved standard sequences from the latest years have been taken:

a) Cristian et.al. (1985) - Standard sequences in M92, N4147, N7790, N7006, N2264, N2419 in B,V,R,I.

b) Odewahn et.al. (1992) - Improved standard sequences in N7790, N4147 and N7006 in B,V,R.

c) Majewski et al. (1994) - Standard sequences in M92, SA 57 and Hercules in U,B,V,R,I. As for the clusters itself, Stetson's DAOPHOT and ALLSTAR program packages in their MIDAS variants were used to analyze the standards and to construct the photometric calibration procedure.

d) Petrov et al. (2001) - CCD standards for U and I in the open cluster NGC 7790.

Some important data for telescopes and CCD cameras equipment:

- 1) 2-m RCC + CE200: Unbinned --> scale 0.31"/px; Binned x2 --> scale 0.31"/px
- 2) 2-m RCC + ST-8: Unbinned --> scale 0.12"/px; Binned x2 --> scale 0.24"/px;
Binned x3 --> scale 0.36 "/px
- 3) 60-cm + ST-8: Unbinned --> scale 0.21"/px; Binned x2 --> scale 0.42"/px;
Binned x3 --> scale 0.63"/px

The next steps to be done:

- a) Implementation of the photometric calibration procedures in MIDAS
- b) Repeated frames of the clusters of interest

- c) Additional data for the clusters, observed in one date only
- d) Making stable construction of the focal reducer for the 60-cm telescope

4. PRELIMINARY RESULTS

The existence of star cluster pairs in our neighboring galaxies - Magellanic Clouds is established from several authors: Bhatia and Hatzidimitriou (1988); Vallenari et al. (1998); Dieball and Grebel (2000); de Oliveira et al. (2000). Dieball (2002) proposed a catalog of binary and multiple cluster candidates in the Large Magellanic Cloud with 473 members. Amongst the more than 1600 open clusters in our Galaxy only one is well established double or binary cluster - h & χ Persei (NGC 869 and NGC 884), **Fig. 1**. Our Galaxy seems to show a lack of binary or multiple clusters when compared with the Magellanic Clouds. Whether this apparent lack of binary clusters in the Galaxy is real or not is a subject to discussion and several lists of binary open clusters candidates are proposed and studied by various authors: Lynga and Wramdemark (1984); Pavlovskaya and Filippova (1989); Tiganelli et al. (1990); Subramaniam et al. (1995); Loktin (1997); Muminov et al. (2000). One of the most complete and well studied list is the one of Subramaniam et al. (1995) with 18 candidates pairs, including the clusters NGC 1907 and NGC 1912 – see **Fig. 2** (Kopchev and Petrov, 2006).



Figure 1: On left - h Persei, on right - χ Persei.
North is UP, East – to the left.

To answer of the two principal questions -

- Is the difference between our Galaxy and Magellanic Clouds co. binary open clusters is real?
- Are there another typical binary open clusters as “h and χ Persei” in our Galaxy?

we shall use the methods of extragalactic and stellar astronomy. One step is to define correctly “what binary open clusters are?”. As working definition we accept “two clusters at distances ≤ 20 pc and with differences in the ages ≤ 10 Myr”. Next steps are analyzing of “color-magnitude” diagrams and determining of the ages of the clusters.

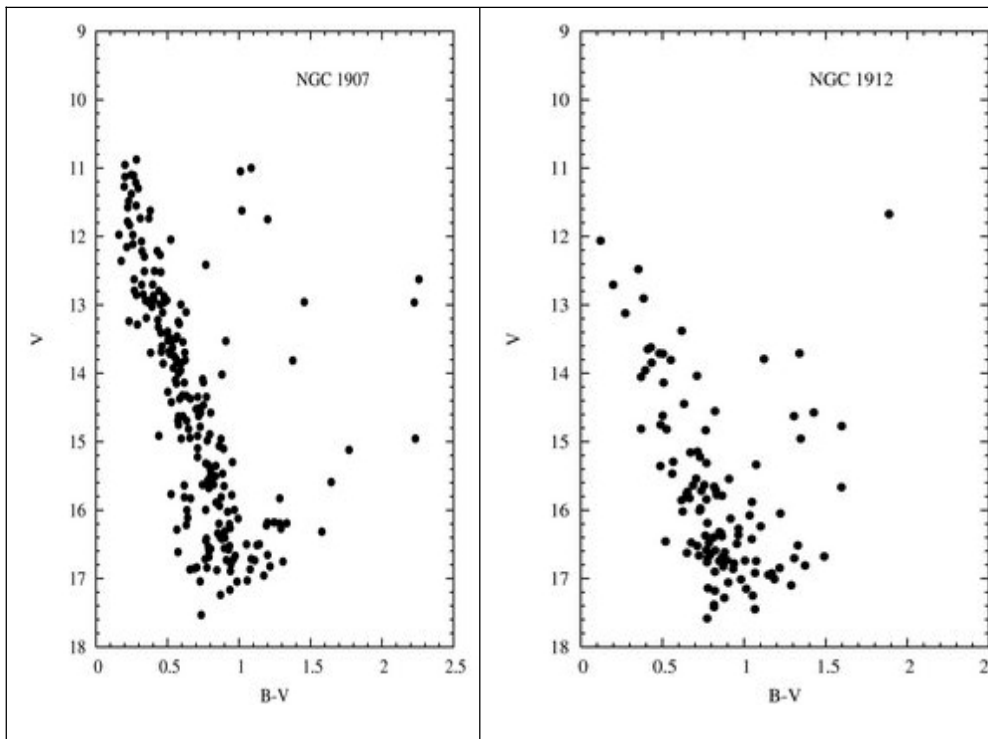


Figure 2: “Color – magnitude” diagrams for NGC1907-NGC1912 according to our observations.

The summary of our preliminary results are presented in **Table 1**, where in the column are cluster’s name, date of observation, Exposure times and numbers of frames, Airmass during the observations, Number of measured stars and FWHM of the frame.

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Table1: A list of all observations of OPEN CLUSTERS, sorted by objects:

Object	Date	Texp	Airmass	Stars	Object	Date	Texp	Airmass	Stars
bas10b	98-09-28	120x3	1.04108	149	n2251b	98-02-28	60x2	1.21870	240
bas10i	98-09-29	120x3	1.03860	158	n2251i	99-01-22	60x2	1.2256	179
bas10r	98-09-29	120x3	1.03897	158	n2251i	98-02-28	30x2	1.21284	394
bas10v	98-09-28	120x3	1.04108	357	n2251r	99-01-22	60x2	1.2228	244
					n2251r	98-02-28	30x2	1.21368	399
bas8b	98-02-28	60x2	1.20956	247	n2251u	98-02-28	120x2	1.22278	123
bas8i	99-01-22	120x2	1.2304	200	n2251v	99-01-22	60x2	1.2203	147
bas8i	98-02-28	30x2	1.20548	291	n2251v	98-02-28	30x2	1.21543	350
bas8r	99-01-22	120x2	1.2173	207					
bas8r	98-02-28	30x2	1.20644	331	n6755b	98-07-18	10x5	1.26107	863
bas8u	98-02-28	120x2	1.21223	88	n6755b	07-04-12	3x3x60	Mosaic	
bas8v	99-01-22	120x2	1.2143	257	n6755i	98-05-28	120x2	1.27693	2165
bas8v	98-02-28	30x2	1.20750	260	n6755i	98-07-19	120x2	1.27505	3446
					n6755i	98-07-18	10x5	1.26107	6560
ber1b	98-08-24	120x2	1.1078	48	n6755r	97-08-04	120	2.11573	116
ber1b	99-09-06	90x4	1.11194	168	n6755r	98-05-28	120x2	1.29049	1571
ber1i	98-08-24	60x2	1.1117	650	n6755r	98-07-19	120x2	1.27606	3006
ber1i	99-09-06	60x5	1.11746	757	n6755r	98-07-18	10x5	1.25983	4199
ber1r	98-08-24	60x2	1.1095	845	n6755r	07-04-12	3x3x20	Mosaic	
ber1r	99-09-06	60x5	1.12008	506	n6755u	98-07-18	40x5	1.25912	383
ber1u	98-08-24	180	1.1068	86	n6755v	98-05-28	120x2	1.28556	1290
ber1u	99-09-06	90x5	1.11490	20	n6755v	98-07-19	120x2	1.27796	2171
ber1v	98-08-24	60x2	1.1087	569	n6755v	98-07-18	10x5	1.25902	3280
ber1v	99-09-06	60x5	1.12281	348	n6755v	07-04-12	3x3x40	Mosaic	
col428b	98-07-21	45x6	1.20102	605	n6756b	97-08-10	120x3	2.02622	152
col428i	98-07-18	20	1.01792	xx	n6756b	98-07-18	15x5	1.25319	1155
col428i	98-07-18	120x2	1.01497	676	n6756b	07-03-15	300+240		
col428i	98-06-01	120x2	.00363	818	n6756i	98-05-28	120x2	1.26883	1867
col428i	98-07-21	60x4	1.01122	1398	n6756i	98-07-19	120x2	1.27787	2694
col428r	98-07-18	20	1.01860		n6756i	97-08-10	120x3	2.24511	458
col428r	98-07-18	120x2	1.01167	691	n6756i	98-07-18	10x5	1.25480	4639
col428r	98-06-01	120x2	1.00557	714	n6756r	97-08-10	120x2	2.11939	242
col428r	98-07-21	30x6	1.01505	1368	n6756r	98-05-28	120x2	1.26761	1452
col428u	98-07-21	60x6	1.02588	139	n6756r	98-07-19	120x2	1.27375	1707
col428v	98-07-18	20	1.01938	xx	n6756r	98-07-18	10x5	1.25512	4313
col428v	98-07-18	120x2	1.00869	502	n6756r	07-03-15	60+10		
col428v	98-06-01	120x2	1.00716	622	n6756u	98-07-18	60x5	1.25465	342
col428v	98-07-21	30x6	1.02077	1013	n6756v	98-05-28	120x2	1.26722	1104
					n6756v	98-07-19	120x2	1.27070	1676
king14i	99-01-19	120x2	1.40938	236	n6756v	98-07-18	10x5	1.25308	2775
king14i	99-02-16	120x2	1.57241	271	n6756v	07-03-15	300+120		
king14r	99-02-16	120x2	1.55370	272					
king14r	99-01-19	120x2	1.39471	325	n6811b	96-07-12	120	1.02756	950
king14v	99-02-16	120x2	1.53560	231	n6811b	98-09-28	120x3	2.23456	140
king14v	99-01-19	120x2	1.38464	636	n6811i	96-07-12	120	1.03535	592
king14i	98-07-21	120x2	1.14293	2077	n6811i	98-09-28	120x3	1.11427	249
king14r	98-07-21	120x2	1.14893	2334	n6811r	96-07-12	120	1.02276	752
king14v	98-07-21	120x2	1.15522	1845	n6811r	98-09-28	120x3	1.15683	247
king14i	99-01-22	120x2	1.1688	356	n6811v	96-07-12	120	1.03109	764
king14r	97-08-06	120	1.11893	405	n6811v	98-09-28	120x3	1.14288	247
king14r	99-01-22	120x2	1.1611	384					
					n6819b	96-07-13	120	1.04333	426
mrk50i	98-07-20	120x2	1.09116	976	n6819b	98-09-28	150x4	1.00091	570
mrk50r	98-07-19	120x2	1.10283	831	n6819i	96-07-13	120	1.05639	645
mrk50v	98-07-19	120x2	1.10866	667	n6819i	98-09-28	150x4	1.00871	1055

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					n6819r	96-07-13	120	1.05187	868
n146b	97-08-06	120	1.10707	204	n6819r	98-09-28	150x4	1.00548	1016
n146i	97-08-06	120	1.10496	440	n6819v	96-07-13	120	1.04755	896
n146i	99-01-22	120x2	1.2113	268	n6819v	98-09-28	150x5	1.00164	798
n146i	99-02-16	120x2	1.65777	273					
n146i	98-07-21	120x2	1.14494	1819	n6939b	96-07-13	120x2	1.05840	145
n146r	97-08-06	120	1.11252	433	n6939b	98-07-20	120x2	1.06836	1044
n146r	99-01-22	120x2	1.2034	252	n6939b	99-09-06	45x5	1.10612	113
n146r	99-02-16	120x2	1.63860	270	n6939i	96-07-13	120	1.06329	157
n146r	98-07-21	120x2	1.13057	1520	n6939i	98-07-20	120x2	1.06002	1203
n146v	99-01-19	120	1.19164	161	n6939i	99-09-06	45x5	1.12214	288
n146v	97-08-06	120	1.10927	457	n6939r	96-07-13	120	1.06508	191
n146v	99-01-22	120x2	1.1957	215	n6939r	98-07-20	120x2	1.06259	1395
n146v	99-02-16	120x2	1.61861	225	n6939r	99-09-06	45x5	1.11672	235
n146v	98-07-21	120x2	1.12620	1665	n6939u	99-09-06	60x3	1.10053	38
					n6939v	96-07-13	120	1.0688	185
n433i	98-09-25	120x3	1.05324	437	n6939v	98-07-20	120x2	1.06542	1269
n433r	98-09-25	120x3	1.05095	355	n6939v	99-09-06	45x5	1.11136	183
n433v	98-09-25	120x3	1.04942	223					
					n6996b	98-07-20	45x6	1.00412	263
n609i	98-09-26	120x2	1.08258	782	n6996i	98-07-18	20	1.02076	xx
n609r	98-09-26	120x2	1.08397	328	n6996i	98-07-18	120x2	1.02389	1142
n609v	98-09-26	120x2	1.08555	169	n6996i	98-06-01	120x2	2.65078	1869
					n6996i	98-07-20	30x7	1.00161	1004
n1193i	98-09-26	120x2	1.00353	140	n6996r	98-07-18	20	1.02000	xx
n1193r	98-09-26	120x2	1.00241	635	n6996r	97-08-04	120x2	1.10429	769
n1193v	98-09-26	120x3	1.00136	401	n6996r	98-07-18	120x2	1.02812	1091
					n6996r	98-06-01	120x2	2.75430	2172
n1348i	98-09-27	120x3	1.01405	345	n6996r	98-07-20	30x5	1.00212	758
n1348r	98-09-27	120x3	1.01575	456	n6996u	98-07-20	60x5	1.00587	76
n1348v	98-09-27	120x3	1.01800	234	n6996v	98-07-18	20	1.01933	xx
					n6996v	98-07-18	120x2	1.03395	1137
n1513i	99-01-22	120x2	1.0075	246	n6996v	98-06-01	120x2	2.84409	1718
n1513r	99-01-22	120x2	1.0073	244	n6996v	98-07-20	30x6	1.00296	542
n1513v	99-01-22	120x2	1.0073	238					
					n7031i	98-07-18	120	1.01963	805
n1545i	99-01-22	120x2	1.0130	163	n7031r	98-07-18	120x2	1.01786	503
n1545r	99-01-22	120x2	1.0117	186	n7031v	98-07-18	120	1.01559	260
n1545v	99-01-22	120x2	1.0106	127	n7031b	06-05-30	20x1		
					n7031v	06-05-30	10x1		
n1883b	99-02-16	120	1.30261	48					
n1883i	99-02-16	120x2	1.34898	227	n7086i	98-07-18	120	1.01232	771
n1883r	99-02-16	120x2	1.33115	187	n7086r	98-07-18	120	1.01513	578
n1883v	99-02-16	120x2	1.31419	170	n7086v	98-07-18	120x2	1.02212	571
					n7086b	06-05-30	25x1		
n1907b	98-02-28	60x2	1.03179	494	n7086v	06-05-30	15x1		
n1907i	99-01-22	60x2	1.1122	254					
n1907i	99-03-14	120x2	1.10823	265	n7209b	96-07-13	120	1.26969	xx
n1907i	98-02-28	30x2	1.02688	731	n7209i	96-07-13	120	1.24502	xx
n1907r	99-01-22	60x2	1.1071	262	n7209r	96-07-13	120	1.23291	xx
n1907r	99-03-14	120x2	1.07811	262	n7209v	96-07-13	120	1.25705	xx
n1907r	98-02-28	30x2	1.02833	673					
n1907u	98-02-28	120x2	1.03595	131	n7243b	96-07-13	120	1.24811	xx
n1907v	99-03-14	120	1.07300	234	n7243i	96-07-13	120	1.28330	xx
n1907v	99-01-22	60x2	1.1019	257	n7243r	96-07-13	120	1.27129	xx
n1907v	98-02-28	30x2	1.02984	667	n7243v	96-07-13	120	1.26010	xx
n1912b	98-02-28	60x2	1.04335	217	n7245b	96-07-15	120	1.03667	xx
n1912i	99-03-14	60	1.17850	182	n7245i	96-07-15	120	1.04056	xx
n1912i	99-03-14	60	1.23169	180	n7245r	96-07-14	120	1.04235	xx
n1912i	99-03-14	60	1.26382	191	n7245v	96-07-15	120	1.03856	xx

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n1912i	99-01-22	60x2	1.1429	201					
n1912i	98-02-28	30x2	1.03725	431	n7261b	96-07-15	120	1.05290	xx
n1912i	99-03-14	60x2	1.13180	207	n7261i	96-07-15	120	1.04855	xx
n1912r	99-03-14	60	1.22250	206	n7261r	96-07-15	120	1.04983	xx
n1912r	99-03-14	60	1.25428	170	n7261v	96-07-15	120	1.05923	xx
n1912r	99-01-22	60x2	1.1361	282					
n1912r	98-02-28	30x2	1.03907	562	n7429i	98-07-19	120x2	1.10129	655
n1912r	99-03-14	60x2	1.13258	218	n7429r	98-07-19	120x2	1.10773	590
n1912r	99-03-14	60x2	1.16972	187	n7429v	98-07-19	120x2	1.11485	403
n1912u	98-02-28	120x2	1.04844	81					
n1912v	99-01-22	60x2	1.1289	197					
n1912v	98-02-28	30x2	1.04094	375					
n1912v	99-03-14	60x2	1.12642	162					
n1912v	99-03-14	60x2	1.15565	177					
n1912v	99-03-14	60x2	1.21471	265					
n1912v	99-03-14	60x2	1.24500	260					

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