Faint and peculiar objects in GAIA: results from GSC-II

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Abstract.

The one billion objects in the GSC-II make up a formidable data set for the hunt of peculiar and rare targets such as late type stars, white dwarfs, carbon dwarfs, asteroids, variable stars, etc. Here we present a survey to search for ancient cool white dwarfs, which led to the discovery of several stars with peculiar spectral distributions and extreme physical properties. Finally, we discuss the impact of the GAIA mission with respect to these peculiar and faint white dwarfs.

1. The Second Guide Star Catalogue

The Second Guide Star Catalogue (GSC-II) project (Lasker et al. 1995, McLean et al. 2000) is a collaborative effort between the Space Telescope Science Institute (STScI) and the Osservatorio Astronomico di Torino (OATo) with the support of the European Space Agency (ESA) - Astrophysics Division, the European Southern Observatory (ESO) and GEMINI. The aim of this project is the construction of an all-sky catalogue containing classifications, colors, magnitudes, positions and proper motions of ~1 billion objects down to the magnitude limit of the plates ($B_J \sim 22.5$). At the moment, GSC-II is one of the largest stellar catalogue with the only comparable one being USNO-B (Monet et al. 2002).

GSC-II is based on about 7000 photographic Schmidt plates (POSS and AAO) with a large field of view ($6.4^\circ \times 6.4^\circ$). All plates were digitized at STScI utilizing modified PDS-type scanning machines with 25 $\mu$m square pixels (1.7 $\prime\prime$/pixel) for the first epoch plates, and 15 $\mu$m pixels (1 $\prime\prime$/pixel) for the second epoch plates. Each digital copy of the plate was analyzed by means of a standard software pipeline which performs object detection and computes parameters, features and classification for each identified object. Position and magnitude for each object was found from astrometric and photometric calibrations which utilized the Tycho2 (Høg et al. 2000) and the GSPC-2 (Bucciarelli et al. 2001)
The first public release of GSC-II (GSC2.2) was delivered in June 2001 and contains 445,851,237 objects down to $B_J < 19.5$ and $R_F < 18.5$ providing positions with an average accuracy of 0.2 arcsec, photographic photometry $B_J$ and $R_F$ with 0.15-0.2 mag accuracy and classification (stellar/extended objects) accurate to 90%.

2. Search for nearby Halo White Dwarfs

Cool white dwarf (WD) stars are the remnants of stars which were born when the Milky Way was very young. A WD cools and fades in a well defined manner, thus the WD luminosity function is imprinted with the star formation history of the Galaxy back to its very beginning. In particular, detecting the end of the WD sequence will provide a direct measure of the age of the Galaxy and its fundamental components, i.e. the disk, thick disk and the halo (Fontaine, Brassard & Bergeron 2001). The usefulness of WDs as stellar chronometers has been stimulated by the recent progress in the cooling models based on non-grey atmospheres and refinements of the internal physics (e.g. Hansen 1999, Chabrier et al. 2000) for both DA and non-DA WDs with $T_{\text{eff}} < 4000$ K, which are the temperatures expected for ancient halo WDs. In this range, cooling WDs with hydrogen atmosphere start to become fainter but bluer because of the strong H$_2$ opacity due to the collision induced absorption (CIA) towards longer wavelengths, whereas helium atmosphere WDs continue to redden.

In addition, it has been suggested that Pop.II WDs could contribute significantly to the baryonic fraction of the dark Halo. In fact they are obvious candidates for the MACHOs revealed by the LMC microlensing surveys (Alcock 2000) which seem to indicate that $\sim 20\%$ of the dark matter is tied up in objects with $\sim 0.5$ M$_\odot$. The most extensive survey to date (Oppenheimer et al. 2001) provides a lower limit on the space density of $\rho \sim 10^{-4}$ pc$^{-3}$, that is, 5 times larger than expected from the canonical stellar halo, and $\sim 1\%$ of the expected local dark halo density. These results are still a matter of debate. In fact Reid, Sahu and Hawley (2001) claimed that the kinematics of the Oppenheimer sample is consistent with the high-velocity tail of the thick disk. Moreover these stars have a spread in age that is more consistent with a thick disk population (Hansen 2001).

The aim of our survey is to search for halo WDs using plate material from the GSC-II in the Northern hemisphere and improve the measurements of halo WDs space density. Also, we will confront the WD models with our sample of cool ancient objects in order to improve the cooling tracks of WDs with $T_{\text{eff}} < 4000$ K. Although WDs should be a typical component of the Halo, such objects are very difficult to observe because they are extremely faint. In fact, theoretical cooling tracks by Chabrier et al. (2000) predict an absolute magnitude of $M_V = 16.2$ and 17.3 for a 0.6 M$_\odot$ WD of 10 and 13 Gyr respectively (excluding the nuclear burning phases). Objects with these magnitudes are observable only within a few tens of parsecs with the GSC-II material which contains objects down to the plate limits of 22.5, 20.8 and 19.5 mag for the blue $B_J$, red $R_F$ and infrared $I_N$ plates respectively.
2.1. Plate material, processing and selection criteria

Our survey covers an area of $\sim 1300$ square degrees which corresponds to 40 regions in the sky, mostly located toward the North Galactic Pole (NGP). In order to detect high proper motion objects, we processed POSS-II plates (blue, red, infrared) with epoch difference $\Delta t \sim 2$-10 yr by means of the standard GSC-II pipeline. Also, we performed object matching and derived proper motions using the procedure described in Spagna et al. (1996), then faint ($R_F > 16$ mag) and fast moving ($0.3 < \mu < 2.5\,\text{yr}^{-1}$) stars were identified. Each target was checked by a visual inspection of POSS-I and POSS-II plates in order to reject the false detections (e.g. mismatches and binaries) and to confirm its proper motion. Another very useful parameter for the selection of the targets is the reduced proper motion (RPM), $H = m + 5 \log \mu - 5$. The RPM diagram, $H_R$ vs. $(B_J - R_F)$, was adopted to identify faint objects with high proper motion and to separate disk ad halo WDs from late type dwarfs and subdwarfs. Figure 1 (left panel) shows the RPM diagram for a set of regions. Here, the thick solid and dotted lines show the locus of the disk dwarfs and the halo subdwarfs based on the 10 Gyr isochrones down to 0.08 $M_\odot$ from Baraffe et al. (1997, 1998) with
Figure 2. A sample of peculiar objects. Top left: the peculiar DQ WD with strong \textit{C}$_2$ Deslandres-d’Anzubuja and Swan bands. Top right: a very hot magnetic WD candidate. Bottom left: a magnetic DQ WD. Bottom right: a binary system (WD+dM) [Fe/H]=0 and -1.5, respectively. Dashed and dot-dashed lines show the cooling tracks of 0.6 M$_\odot$ WDs with hydrogen atmosphere from Chabrier et al (2000). We adopted mean tangential velocities (towards the NGP) of $V_T = 38$ km/s (disk) and 270 km/s (halo). Thin lines indicates the 2σ kinematics thresholds. Finally, spectral analysis is required for a confirmation of the nature of the selected candidates.

2.2. Spectroscopic follow-up and preliminary results

Low resolution spectroscopy is suitable to recognize the spectral type and the main chemical composition of the stars. Spectroscopic observations were carried out with the 3.5 m TNG (La Palma), the 4.2 m WHT (La Palma), and the 3.5 m at Apache Point Observatory (USA). Most of the targets were observed in the first semester 2002 at TNG using the low resolution spectrograph DOLORES (Device Optimized for Low Resolution) with the LR-B Grism1 which gave a nominal dispersion of 2.8 Å/px and useful wavelength coverage from 3000 to 8800 Å. We performed spectroscopic follow-up for candidates from 800 square degrees (1/50 of the sky) which corresponds to ~ 60% of our total area. The number of halo WD candidates after the selection criteria was 47 and we obtained 32 spectra plus JHK infrared photometry for 12 stars during 3 nights. The results are remarkable: of the 32 observed targets, 23 are WDs and 12 have no H\textalpha line. We also found 4 M dwarfs, 2 subdwarfs, a binary system (dM+WD) and 3 interesting peculiar objects. The left panel of Figure 1 shows the RPM
diagram for these 800 square degrees. The observed objects and those classified as white dwarfs are marked with different symbols. The right panel of Figure 1 shows a few confirmed cool WDs in our sample, including a "coolish" DA (top spectrum) with a weak Hα line and two cool WDs, while Figure 2 shows the peculiar objects.

3. Peculiar objects and classification problems

An unexpected result of this survey is the discovery of a significant fraction of objects with a very complex nature. Some examples are presented in Figure 2, where the top left panel shows a peculiar DQ WD, with extremely strong $C_2$ absorption bands, while the bottom left shows a magnetic carbon rich WD. On the top right is a probable very hot magnetic WD and the bottom right an unresolved binary system WD+dM. We point out that all these cases could not be classified properly till their spectra became available. Even when spectra are available, the classification can be tricky for objects with extreme physical properties and no previous observations or good theoretical models. This was the case of the peculiar carbon rich WD named GSC2U J131147.2+292348 (Fig. 1, top left). The object is fast moving ($\mu \simeq 0.48$ arcsec yr$^{-1}$), and faint ($V \simeq 18.7$). A check on the SIMBAD database revealed that the star was not in the NLTT catalogue (Luyten 1979) but, quite surprisingly, was listed as a quasar candidate (object OMHR 58793) by Moreau & Reboul (1995), who measured an UV excess but did not detect any proper motion, perhaps because of a cross-matching error. The real nature of this object was realized after a thorough analysis of its spectrum with the support of infrared photometry (Carollo et al. 2002), even though the lack of adequate models in the literature was a serious problem.

4. The impact of the GAIA mission

The main impact of GAIA with respect to the faint and nearby objects, such as the large variety of WD types, will be the determination of accurate distances by means of the trigonometric parallaxes for all the objects detectable in the solar neighborhood down to $V \approx 20$ mag. Distances will directly provide the absolute magnitudes which will permit a robust, even if preliminary, identification of these objects as WDs. Thus, the fact that the information from the GAIA spectrograph and the medium band photometric system will not be available for the faintest objects is not as dramatic a problem as in the case of current ground based surveys.

We expect that GAIA will carry out a complete census of WDs, including the faintest ancient and cool WDs previously discussed. To this regard, GAIA will provide a complete and unbiased sample (i.e. not kinematically selected). Moreover, accurate tangential velocities will be derived from proper motions also in the cases where radial velocities are not available, and will help to separate the halo and disk WDs. Of course, a large fraction of non-DA WDs including a certain percentage of peculiar objects will also be detected by GAIA. Broad band photometry should help to identify these cases by means of their anomalous colors also for the dimmest objects without any further spectro-photometric data. Clearly, this is a challenging and non trivial issue for the classification
task of the GAIA data reduction. Moreover, among the many science cases that GAIA data will address, these objects point out the logical necessity to complement the astrometric and spectro-photometric observations of peculiar or unclassified objects with a spectroscopic follow-up with large ground based telescopes. Fortunately, it will probably not be difficult to obtain observing time with 4-8 meters telescopes at the epoch when the first GAIA results will be delivered (~2015?).

Finally, we mention the fact that objects with such a peculiar spectral distribution as those shown in Figure 2 could be affected by residual systematic errors due to a chromaticity effect (Gai et al. 1998, Lindegren 1998) not properly corrected by the standard astrometric calibrations. However, this does not seem a critical problem for nearby objects (i.e. having large values of parallax and proper motion). Also, the possibility that the multiple observations of these high proper motion objects are not correctly matched in crowded regions can probably be avoided by means of a robust matching algorithm.

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