UV-excess sources with a red/IR-counterpart: low-mass companions, debris disks and QSO selection

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ABSTRACT

We present the result of the cross-matching between UV-excess sources selected from the UV-excess survey of the Northern Galactic Plane (UVEX) and several infrared surveys (2MASS, UKIDSS and WISE). From the position in the (J − H) vs. (H − K) colour-colour diagram we select UV-excess candidate white dwarfs with an M-dwarf type companion, candidates that might have a lower mass, brown-dwarf type companion, and candidates showing an infrared-excess only in the K-band, which might be due to a debris disk. Grids of reddened DA+dM and sdO+MS/sdB+MS model spectra are fitted to the U, g, r, i, z, J, H, K photometry in order to determine spectral types and estimate temperatures and reddening. From a sample of 964 hot candidate white dwarfs with (g − r) < 0.2, the spectral energy distribution fitting shows that ~2-4% of the white dwarfs have an M-dwarf companion, ~2% have a lower-mass companion, and no clear candidates for having a debris disk are found. Additionally, from WISE 6 UV-excess sources are selected as candidate Quasi-Stellar Objects (QSOs). Two UV-excess sources have a WISE IR-excess showing up only in the mid-IR W3 band of WISE, making them candidate Luminous InfraRed Galaxies (LIRGs) or Sbc star-burst galaxies.

Key words: surveys – stars: white dwarfs – stars: binaries – ISM:general – Galaxy: stellar content – infrared: stars

1 INTRODUCTION

One of the main goals of the European Galactic Plane Surveys (EGAPS) is to obtain a homogeneous sample of evolved objects in our Milky Way with well known selection limits. The EGAPS data also contains more esoteric objects (e.g. Nova V458 Vul, Wesson et al., 2008; Necklace Nebula, Corradi et al., 2011; photo-evaporating proplyd-like objects, Wright et al., 2012). Over the last years the data of large sky surveys yielded several known white dwarfs with gas or dust disks (Gänsecke et al., 2007; Gänsecke et al., 2011; Gänsecke et al., 2008; Zuckermand and Becklin, 1987; Brinkworth et al., 2009; Brinkworth et al., 2012; Kilic et al., 2012; Debets et al., 2011). When optical surveys are cross-matched with the data of infrared (IR) surveys (e.g. SDSS-UKIDSS: Silvestri et al., 2006; Heller et al.,...
A catalogue of 2170 UV-excess sources was selected in V12a. These UV-excess candidates were selected from the \( (U−g) \) versus \( (g−r) \) colour-colour diagram and \( g \) versus \( (U−g) \) and \( g \) versus \( (g−r) \) colour-magnitude diagrams by an automated field-to-field selection algorithm. Less than \(~1%\) of these selected UVEX sources are known in the literature. Spectroscopic follow-up of 132 UV-excess candidates selected from UVEX, presented in Verbeek et al. (2012b; hereafter V12b), shows that most UV-excess candidates are indeed genuine UV-excess sources such as white dwarfs, subdwarfs and interacting white dwarf binaries.

In this work we present the IR photometry of the UV-excess sources in the UVEX catalogues of V12a. Our goals are i) to see what fraction of the hot white dwarfs have a companion (late MS or BD), ii) to see if we can use IR photometry to select non-white dwarfs from our UV-excess catalogue, and iii) to see if we can find any debris disks. In Sect. 2 the cross-matching of the full UV-excess catalogue with IR/red surveys is presented. In Sect. 3 hot UV-excess candidate white dwarfs with \( (g−r)<0.2 \) with an IR-excess are selected and classified by fitting grids of reddened DA+dM and sdO/sdB models to the optical and infrared photometry. The spectral types of companions later than M6 are determined from the IR-excess. From these results the fraction of hot white dwarfs with a low mass companion is derived. In Sect. 4 the matches of the UV-excess sources in the WISE data are presented, and additionally a list of candidate QSOs with \(|b|<5^\circ\) is selected. Finally in Sect. 5 we summarise and discuss the conclusions.

2 CROSS-MATCHING WITH IR SURVEYS: UKIDSS, 2MASS AND WISE

The UV-excess catalogue of V12a (2170 sources) is cross-matched with different surveys that image (parts of) the Galactic Plane at red/infrared (IR) wavelengths. An overview of the cross-matching is given in Table 1. Note that the coverage of the Galactic Plane and the overlap with the UVEX fields of V12a is not complete for all surveys (see Sect. 3). The results of the cross-matching are shown in the colour-colour diagrams of Figs. 1 to 5, where the spectroscopically classified sources of V12b are labelled. The UKIDSS and 2MASS colour-magnitude diagrams are shown in the Appendix. As expected, in particular the redder and brighter UVEX UV-excess sources have a larger fraction of IR matches, as can be seen in the UVEX colour-colour and colour-magnitude diagrams of Figs. 1 to 2. The different IR surveys and the number of matches with the full UV-excess catalogue of V12a are described below:

- The UKIRT InfraRed Deep Sky Survey (UKIDSS, Lawrence et al., 2007) is a near-infrared survey imaging the northern sky in the \( J, H \) and \( K \) (1.2, 1.6 and 2.2 micron) filters using the Wide Field Camera (WFCAM) mounted on the 3.8m United Kingdom Infra-red Telescope (UKIRT) on Hawaii. The UKIDSS Galactic Plane Survey (UKIDSS GPS, Lucas et al., 2008, Lawrence et al., 2012) images the northern Galactic Plane in the same Galactic
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Figure 1. Colour-colour diagram with the UV-excess matches in UKIDSS, 2MASS and WISE. UV-excess sources spectroscopically classified in V12b are overplotted with different symbols. The lines are the simulated colours of unreddened main-sequence stars (solid black) and the O5V-reddening line (dashed black) of V12a. The cyan and green dashed lines are respectively the simulated colours of unreddened Koester DA and DB white dwarfs. The grey dots are the sources from the complete UV-excess catalogue of V12a.

Table 1. Summary of the cross-matching: No of matches with the full UV-excess catalogue and No of matches in the Deacon PM/Witham Hα catalogues (Deacon et al., 2009, Witham et al., 2008).

<table>
<thead>
<tr>
<th>Catalogue</th>
<th>Full UV-excess</th>
<th>PM/Hα</th>
</tr>
</thead>
<tbody>
<tr>
<td>UKIDSS-GPS</td>
<td>227</td>
<td>4/6</td>
</tr>
<tr>
<td>2MASS</td>
<td>60</td>
<td>2/5</td>
</tr>
<tr>
<td>WISE</td>
<td>19</td>
<td>1/2</td>
</tr>
<tr>
<td>IPHAS-IDR</td>
<td>1 203</td>
<td>26/15</td>
</tr>
<tr>
<td>SDSS DR8</td>
<td>378</td>
<td>0/3</td>
</tr>
</tbody>
</table>

The Two-Micron All-Sky Survey (2MASS, Skrutskie et al., 2006, Cutri et al., 2003) imaged the entire sky in the three near-infrared filter bands J, H and K (1.2, 1.7 and 2.2 micron) with a limiting magnitude of J=17.1, H=16.4 and K=15.3, using 2 automated 1.3m telescopes, one at Mt. Hopkins, Arizona, and one at CTIO, Chile. The overlap of the 2MASS All-Sky Catalog of Point Sources (Cutri et al., 2003) data and the UVEX fields of V12a is 100%. In 2MASS there is a match for 60 sources of the complete UV-excess catalogue in all three 2MASS filter bands within a radius of 1 arcsec (3%). Eighteen of these matches were spectroscopically classified in V12b, 2 matches are the IPHAS-POSSI catalogue (1 classified as DA+dM) and 5 matches are in the Hα emitter catalogue (3 classified as T Tauri, Be star and Cataclysmic Variable). The UV-excess matches in 2MASS are plotted in the colour-colour diagram of Fig. 4.

The Wide-field Infrared Survey Explorer (WISE, Wright et al., 2010) mapped the sky at four mid-infrared bands at 3.4, 4.6, 12, and 22 micron (W1, W2, W3 and W4). The overlap of the WISE All-Sky Data Release (Cutri et al., 2012) and the UVEX fields of V12a is 100%. The WISE data are used to select and classify UV-excess sources with a mid-IR excess, and a list of UV-excess candidate QSOs is selected in Sect. 4. There is a match for...
20 UV-excess sources in WISE within a radius of 1 arcsec in at least the first three filters (W1, W2, W3). Thirteen of them have a match in all four WISE filters. The 3-filter matches are shown in the colour-colour diagram of Fig. 5.

- The INT/WFC Photometric Hα Survey of the Northern Galactic Plane (IPHAS, Drew et al., 2005) has imaged the same survey area as UVEX with the same telescope and camera set-up using the r, i and Hα filters. There is a match for 1203 of our 2170 UV-excess sources in the IPHAS initial data release (IDR, González-Solares et al., 2008) within a radius of 1.0 arcsec (55%). Note that the overlap of the IPHAS IDR with the UVEX fields of V12a is not complete, but ~90%. The result of the cross-match between the UV-excess catalogue and IPHAS IDR was already shown in Figs. 10 and 11 of V12a and Fig. 3 of V12b. If available, the IPHAS data is used to distinguish UV-excess white dwarfs from UV-excess sources showing Hα emission, and the i-band photometry is used in the spectral fitting in Sect. 3.2. In the colour-colour diagrams of Figs. 3 to 5 the sources that are in the IPHAS Hα emitter catalogue (Witham et al., 2008) or IPHAS-POSS proper motion (PM) catalogue (Deacon et al., 2009) are circled red and blue respectively. The Witham Hα emitter catalogue covers the magnitude range 13<r<19.5 and the Deacon IPHAS-POSS PM catalogue covers the magnitude range 13.5<r<19. Matches in the Hα emission line star catalogue are expected to be Galactic sources, except for QSOs with redshift 0.5 or 1.3, which have emission lines exactly in the bandpass of the IPHAS Hα filter (Scaringi et al., 2013).

- Additionally, the Sloan Digital Sky Survey (SDSS, York et al., 2000) Photometric Catalog DR 8 (Adelman-McCarthy et al., 2011) overlaps with some UVEX Galactic

Figure 2. Colour-magnitude diagrams with the UV-excess matches in UKIDSS, 2MASS and WISE. Spectroscopically identified UV-excess sources of V12b are overplotted with different symbols. The grey dots are the sources from the complete UV-excess catalogue of V12a.
Plane fields. SDSS images the sky in the filters u, g, r, i, z down to ~ 22^m magnitude, using the 2.5m wide-angle optical telescope at Apache Point Observatory, New Mexico, US. For the full UV-excess catalogue 378 sources have a match in SDSS within a radius of 1 arcsec. Note that the overlap between SDSS and the UVEX fields of V12a is not complete. There are 6 SDSS UV-excess matches in the IPHAS-POSS PM catalogue and 3 SDSS UV-excess matches are in the IPHAS Hα emitter catalogue. For the UV-excess sources that have an SDSS match, the additional i-band and z-band photometry is used for the spectral fitting (Fig. 1, Rebassa-Mansergas et al., 2012) in Sect. 3.2 on hot white dwarfs with an IR-match. For that reason a sub-sample of 964 UV-excess candidate white dwarfs with (g − r) < 0.2 is selected, which corresponds with the simulated unreddened colours of DA white dwarfs hotter than T_{eff} > 9000K. This sub-sample does not contain DA white dwarfs cooler than T_{eff} < 9000K or strongly reddened white dwarfs. From spectroscopic follow-up (Fig. 1, V12b) it is known that 97% of the DA white dwarfs identified in UVEX are in this colour range, but there will be ~25% white dwarfs of other types and sdO/sdB stars which also may have infrared counterparts. Only the IR-matches of the sources from this UV-excess candidate white dwarf sub-sample are plotted with error bars in the colour-colour diagrams of Figs. 3 to 5.

3 CANDIDATE WHITE DWARFS WITH AN INFRARED COUNTERPART

The UV-excess catalogue consists of a mix of different populations. From the spectroscopic follow-up of V12b, 52% of the UV-excess sources are single DA white dwarfs, 14% are white dwarfs of other types (DAB/DB/DC/DZ/DAe), 4% are DA+dM white dwarfs, 11% are sdB/sdO stars, 9% are Hα emission line objects, 8% are BHB/MS stars and 2% are QSO. In Sects. 3.1 and 3.2 we focus in particular on hot white dwarfs with an IR-match. For that reason a sub-sample of 964 UV-excess candidate white dwarfs with (g − r) < 0.2 is selected, which corresponds with the simulated unreddened colours of DA white dwarfs hotter than T_{eff} > 9000K. This sub-sample does not contain DA white dwarfs cooler than T_{eff} < 9000K or strongly reddened white dwarfs. From spectroscopic follow-up (Fig. 1, V12b) it is known that 97% of the DA white dwarfs identified in UVEX are in this colour range, but there will be ~25% white dwarfs of other types and sdO/sdB stars which also may have infrared counterparts. Only the IR-matches of the sources from this UV-excess candidate white dwarf sub-sample are plotted with error bars in the colour-colour diagrams of Figs. 3 to 5.

3.1 Classification of white dwarfs in UKIDSS and 2MASS

In the hot sub-sample there are 46 UV-excess candidate white dwarfs with a UKIDSS match, and 3 with a 2MASS match. These matches are plotted with error bars in the colour-colour diagrams of Figs. 3 and 4. To separate single white dwarfs from white dwarfs with a companion or white dwarfs with a debris disk the (J − H) vs. (H − K)
3.2 Determination of Spectral Types

For the UV-excess candidate white dwarfs with an IR-excess match in UKIDSS and/or 2MASS the Spectral Energy Distributions (SEDs) are fitted in order to determine the spectral types. Grids of DA+dM model spectra, in the range 0<\(E(B-V)<1.0\) at \(E(B-V)=0.1\) intervals, using the reddening laws of Cardelli, Clayton & Mathis (1989), are fitted to the optical and infrared photometry in order to determine white dwarf temperatures. For the fitting the white dwarf atmosphere models and M-dwarf models are both placed at the same distance. The spectral fluxes of Beuermann, 2006 are used to calibrate the absolute fluxes of the M-dwarfs. The grid of DA+dM model spectra is constructed from white dwarf atmosphere model spectra of Koester (2001) with \(log g=8.0\) in the range 6\(000<T_{\text{eff}}<80000\)K, and template spectra of main-sequence stars from the library of Pickles (1998) using the reddening laws of Cardelli, Clayton & Mathis (1989). For the DA+dM SED fitting the photometry of Pickles (1998), UKIDSS and/or SDSS photometry is used for 40 candidate white dwarfs. The WISE photometry is not used since the wavelength range of the DA+dM models only covers \(3000-25000\) Å, but consistency with the WISE photometry...
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Figure 5. WISE matches within 1 arcsec plotted in the WISE colour-colour diagram. Sources which are classified from their spectra in V12b are overplotted with different symbols, all UV-excess matches are plotted with error bars. The 2 sources at \((W2 - W3)=0\) and \((W2 - W3)=5.8\) are UV-excess candidate white dwarfs with \((g - r) < 0.2\), 1 classified as DA white dwarf in V12b and 1 unclassified source with a strong \(W3\) excess and \((W3 - W4)=2.1\).

was checked, see e.g. Fig. [4].

The DA+dM models do not give a good fitting result for all candidate white dwarfs with an IR-excess match. Some UV-excess sources with an IR-excess match can be fully explained by a reddened sdB or sdO spectrum without any companion, or the IR-excess can be explained by an sdB/sdO stars with an F-, G- or K-type main-sequence companion. SdB/sdO stars with later companions can not be identified with the current photometry because the SdB/sdO dominates the SED out to the \(K\)-band. Grids of TheoSSA (Ringat, 2012) sdB/sdO models with \(log g=5.5\) in the range \(20000<T_{\text{eff}}<50000\)K and \(0<E(B - V)<5.0\) at \(T_{\text{eff}}=1000\)K and \(E(B - V)=0.1\) intervals are fitted to the optical and infrared photometry to determine \(T_{\text{eff}}\) and the reddening of the sdB/sdO stars. For the sdO/sdB stars with a possible main-sequence companion, a grid is constructed from the reddened sdB/sdO models and the template spectra of main-sequence stars from the library of Pickles (1998) with spectral types A5V to M5V. Also here the WISE photometry is not used, but consistency was checked, since the sdO/sdB+MS models cover the wavelength range \(3000-25000\) Å.

Candidate white dwarfs in region 3 of the IR colour-colour diagrams have companions with spectral types later than M6. The spectral types of these companions are determined using the \((J - K)\) colours resulting after subtracting the white dwarf flux as explained in Reid et al., 2001 and Leggett et al., 2002. The UKIDSS colours are converted to AB colours taking into account the correction \((J - K)=0.962\) of Hewett et al. (2006).

In the original UV-excess catalogue there might be a possible systematic shift in the UVEX \(U\)-band data, which would influence the result of Spectral Energy Distributions fitting in this paper. For that reason recalibrated UVEX data, as explained in Greiss et al. (2012), is used. The shift in the original UVEX data does not influence the content of the UV-excess catalogue because the selection in V12a was done relative to the reddened main-sequence population. The magnitudes and colours of the UV-excess sources might still show a small scatter, similar to the early IPHAS data (Drew et al., 2005), since a global photometric calibration is not applied to the UVEX data.

To convert the magnitudes into fluxes \((F)\) we use: 
\[
F = 10^{-0.4 \times (mag_{AB} + 48.6)}
\]
for EGAPS and SDSS. For EGAPS photometry the AB offsets \(U=0.927\), \(g=-0.103\), \(r=0.164\) and \(i=0.413\) need to be added to convert to AB magnitudes (González-Solares et al., 2008; Blanton & Roweis, 2007 and Hewett et al., 2006). To convert
UKIDSS photometry to AB magnitudes the correction
\(J=0.938, H=1.379\) and \(K=1.900\) need to be taken into
account (Hewett et al. 2006). For 2MASS the flux is
derived using
\[ F = F_0 - 0 \text{mag} \times 10^{-0.4 \times (\text{mag}(V_{\text{phot}}))}, \]
where \(F_0 - 0 \text{mag}\) is 1574, 1074 and 1567 (Jy) for \(J, H\) and \(K\)
respectively (Cutri et al., 2003). The WISE photometry is
converted into fluxes using
\[ F = F_0 \times 10^{-0.4 \times \text{mag}(V_{\text{phot}})}, \]
where \(F_0\) is the “Zero Magnitude Flux Density” for the
WISE filter bands: \(W_1=309.54, W_2=171.487, W_3=12.82, W_4=9.26\) (Jy) (Wright et al. 2010).

### 3.3 Fitting results
To test our photometric fitting routine first the method is
applied to the UV-excess candidate white dwarfs that were
spectroscopically classified in V12b. Note that the aim of
the fitting is not to derive accurate temperatures, spectral
types and reddening, but to classify the sources, and to
confirm (or to rule out) the presence of a companion or disk.
Fitting results for 7 UV-excess sources, spectroscopically
classified in V12b, with an IR-excess or just an IR match,
are shown in Figs. 5 to 12. For some of these sources there
is also a match in WISE (see Sect. 3.4).

- The object UVEXJ1909+0213, classified as DA+dM
objects in V12b, is shown in Fig. 5. This source has \((g - r)=0.87\), so it is not in the UV-excess candidate white dwarf
sub-sample. The best-fit model consists of a white dwarf with\(T_{\text{eff}}=14\)kK with an M4V companion. This source is
in region 2 of the 2MASS colour-colour diagram of Fig. 3
and in region 2 of the UKIDSS colour-colour diagram of Fig. 5.
Note that only the photometry was used for the fitting.

- The object UVEXJ2122+5526, also classified as
DA+dM objects in V12b, is shown in Fig. 7. This source has \((g - r)=0.47\), so it is also not in the UV-excess candidate white dwarf
sub-sample. The model that fits best consists of a white dwarf with \(T_{\text{eff}}=20\)kK with an M3V companion,
which is consistent up to the \(W_3\) WISE photometry.
This source is in region 2 of the 2MASS colour-colour diagram of
Fig. 3 and is plotted in the WISE colour-colour diagram of
Fig. 5.

- The SED of UVEXJ2239+5857, classified as He-sdO in V12b, shows a decreasing flux in the IR which can be
explained with a reddened sdB/sdO spectrum with \(T_{\text{eff}}=50\)K, \(log g=5.5\) and \(E(B-V)=0.8\), which is the model that fits
best for this object, see Fig. 6.

- The SED of UVEXJ0421+4651, classified as sdB+F in V12b, can be explained by a single reddened sdB/sdO spectrum,
but the combination of a sdB and a K5V spectrum
gives a slightly better fit with \(T_{\text{eff}}=50\)K, \(E(B-V)=1.0\),
see Fig. 9. This source was classified as sdB+F in V12b due
to the CaII lines present in the optical spectrum.

- The photometry of UVEXJ0328+5035, classified as a
sdB star in V12b, can be fully explained by a reddened sdB spectrum with \(T_{\text{eff}}=30\)K, \(log g=5.5\) and \(E(B-V)=0.4\),
see Fig. 10. However, this object is known to be a sdB+M binary from its radial velocity (Kupfer et al., in prep.). No
sign of the companion is seen in the SED.

- The SED fitting method finds a DA+dM as best solution for source UVEXJ2034+4110 (Fig. 11), classified as a
DA white dwarf in V12b. The best-fit DA+dM model is a
\(T_{\text{eff}}=13\)kK DA white dwarf plus an M6V companion.
The strong infrared-excess is due to a low-mass companion with
spectral type L8 as determined from the \((J - K)\) colour.
However, the contribution of an low-mass companion with
spectral type L8 would be less luminous than in Fig. 11, so
the white dwarf is probably at a larger distance compared
to the brown dwarf. Additionally, the blue/optical images have a match within 0.1 arcsec, while there is an offset for the
infrared images of 0.6 arcsec. The white dwarf and L8 brown dwarf are expected to be at different distances and
not physically associated.

- The source UVEXJ2102+4750 in Fig. 12 classified as
a DA white dwarf with \(T_{\text{eff}}=13.3\)K and \(log(g)=8.1\) in V12b,
shows an IR-excess. None of the DA+dM models fit the pho-
tometry well, making it candidate for having a companion
with spectral type L5 as determined from the \((J - K)\) colour.
This source was classified as a DA white dwarf in V12b since
there is no sign of the companion in the optical spectrum,
which is consistent with the IR-excess which increases for
wavelengths larger than \(\lambda > 8000\) Å.

The results of the fitting for all UV-excess candidate
white dwarfs with an IR-excess match in UKIDSS and/or
2MASS are shown Table A1 of the Appendix B. Note
that \(T_{\text{eff}}\) of the white dwarf and the spectral types of the
companions are rough estimates, since only photometry is
used for the fitting. From the positions in the \((J - H)\) vs.
\((H - K)\) colour-colour diagram, and from the SED fitting,
24 UV-excess candidate white dwarfs are classified as white
dwarf with an M-dwarf companion, 7 sources are candidate
white dwarfs probably with a brown dwarf type companion
(later than M-type), 19 UV-excess candidate white dwarfs
are single white dwarfs or single sdO/sdB stars without a
companion, and no UV-excess white dwarfs are clear debris
disk candidates.
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3.4 UV-excess sources in the Wide-field Infrared Survey data

The release of the all-sky WISE catalog (Cutri et al., 2012) contains all sky data in four mid-infrared bands centered at 3.4, 4.6, 12 and 22 micron. There are 9 classified UV-excess sources with a WISE match, 1 classified as DA white dwarf, 1 classified as Cataclysmic Variable, 1 classified as DA+dM, 1 classified as T Tauri star, 3 classified as sdB stars, and 2 classified as QSOs in V12b. The QSOs and 4 new QSO candidates are discussed in Sect. 4. The SEDs of objects of other types, classified in V12b, with a match in WISE are shown in Fig. 13. The two unclassified UV-excess sources (UVEXJ2039+3647 and UVEXJ0009+6514) at (W2 − W3) ∼ 5.5 show a strong excess in the W3-band (UVEXJ0009+6514 has ccd-flag “H” in W2). From their SEDs and position in the WISE colour-colour diagram, these two sources are candidate Luminous InfraRed Galaxies (LIRGs)/star-burst Sbc (Fig. 12 of Wright et al., 2010). The four remaining sources are DA+dM or sdB/sdO+MS candidates.
Figure 11. The SED of UVEXJ203411.72+411020.3, classified as single DA white dwarf in V12b, can not be explained by one of our DA white dwarf plus a late type companion models. The best-fit DA+dM model is a $T_{\text{eff}}=13$kK white dwarf plus M6V companion (blue). The strong infrared-excess in 2MASS, UKI DSS and WISE can be explained by a later companion with spectral type L8. However, the contribution of this L8 dwarf is significantly more luminous than expected, so the WD and BD are expected to be at different distances and not physically associated. Plotted here are the UVEX, IPHAS, SDSS, 2MASS, UKIDSS and WISE photometry with error bars and the Hectospec spectrum of V12b (red).

Figure 12. The SED of UVEXJ210248.44+475058.9, classified as DA white dwarf with $T_{\text{eff}}=13.3$kK and $\log(g)=8.1$ in V12b, shows a clear excess in the infrared which can be explained by a companion. The best-fit DA+dM model is a $T_{\text{eff}}=80$kK white dwarf plus M1V companion (magenta), which is clearly too hot for the white dwarf. From the $(J-K)$ colour the spectral type of the companion is L5. Plotted here are the UVEX and UKIDSS photometry with error bars, the WHT spectrum of V12b (red) and a Koester DA white dwarf atmosphere model with $T_{\text{eff}}=13$kK and $\log(g)=8.0$ (blue).

Figure 13. The SEDs of the UV-excess sources classified in V12b with a match in WISE and the 2 unclassified sources at $(W2-W3) < 5.5$ which are candidate star-burst Sbc/LIRGs (dashed lines).

4 CANDIDATE QSOS SELECTED FROM UVEX AND WISE

Since the release of the all-sky WISE catalog, the data have been used to select Quasi-Stellar Objects (QSOs, Bond et al., 2012, Stern et al., 2012, Xue-Bing Wu et al., 2012, Scaringi et al., 2012). The IR-excess of the QSOs in WISE is probably due to optically thick material surrounding most QSOs (Roseboom et al., 2012). In Fig. 5 there are 6 UV-excess sources at the QSO location in the WISE colour-colour diagram ($2.5<(W2-W3)<4.5$ and $0.6<(W1-W2)<1.7$, see Fig. 12 of Wright et al., 2010). Two of these sources (UVEXJ0008+5758 and UVEXJ0110+5829) were already spectroscopically classified as QSOs in V12b. For UVEXJ0110+5829 $W4$ is an upper limit, the other candidate QSOs have “good” photometry in all WISE bands. All 6 candidate QSOs have similar UVEX colours $(g-r)\sim0.8$ and $(U-g)\sim-0.2$. In V12a these 6 sources were selected in $g$ vs. $(U-g)$ and not in $g$ vs. $(g-r)$ (selection flags “515” and “514”) and they are all at Galactic latitude $-5^\circ<\delta<-4^\circ$ and Galactic longitude $117^\circ<l<157^\circ$. This might be due to the warp and flare of the Milky Way at this latitude and longitude (Cabrera-Lavers et al., 2007). The effects of the shape are different at different lines of sight, the height of the disk is smaller at some directions and therefore QSOs may be picked-up by UV-excess surveys. The two brightest candidate QSOs have a match in 2MASS, and 3 of the candidate QSOs have a match in UKIDSS. The SEDs of the 2 QSOs and new candidate QSOs are shown in Fig. 14. The characteristics of the 6 UV-excess candidate QSOs are summarized in Table 2.

5 DISCUSSION AND CONCLUSIONS

There are 46 white dwarfs with an infrared match in UKIDSS and 3 with a match in 2MASS. Seventeen sources in the $(g-r)<0.2$ sample turn out to be single white dwarfs. These white dwarfs have bright UVEX $g$-band
UV-excess sources with a red/IR-counterpart: low-mass companions, debris disks and QSO selection.

Table 2. UV-excess candidate QSOs from WISE

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Figure 14. The SEDs of the 2 classified QSOs of V12b (dashed lines) and the 4 new candidate QSOs from WISE (solid lines).

...magnitudes, have in general a higher $T_{\text{eff}}$, and are more reddened compared to the candidate DA+dM sources in the UV-excess candidate white dwarf sample.

In the $(g-r)<0.2$ sample there are 24 DA+dM candidates, which is a fraction of 2% of the complete UV-excess candidate white dwarf sample. This fraction given here is a lower limit, since the fraction of white dwarfs with a companion is higher for the brighter UV-excess sources (see Figs. 1 to 2). If only UV-excess candidate white dwarfs brighter than $g<20$ are considered, the fraction of white dwarfs with a companion is 4%. If we compare this result to other studies, the DA+dM fraction is in the range 6-22% (Farihi, Becklin & Zuckerman, 2005; Debes, 2011). The presence of an M-dwarf has a strong influence on the optical colours for the cooler white dwarfs. Due to the contribution of the M-dwarf the colours of the most DA+dM sources are redder than $(g-r)>0.2$. An unreddened DA+M4V has $(g-r)=0.2$ for a $T_{\text{eff}}\sim28\text{K}$ white dwarf (Fig. 1 of Rebassa-Mansergas et al., 2012; Fig. 2 of Augusteijn et al., 2008), while a single DA white dwarf with $T_{\text{eff}}=28\text{K}$ is $(g-r)=-0.185$. The effects on the UV and optical spectrum due to the presence of a debris disks around white dwarfs is negligible (Zabot et al., 2009).

There are 7 candidates for white dwarfs with a companion later than type M6V in the UV-excess candidate white dwarf sample. These sources are all brighter than $g<20$ and the white dwarfs all have an effective temperature lower than $T_{\text{eff}}<20\text{K}$. This number is in agreement with the WD+BD fractions of other studies (Farihi, Becklin & Zuckerman, 2005; Debes, 2011).

No convincing debris disk candidates were found. If the expected rate of white dwarfs with a dust/debris disk would be $\sim1\%$ (Girven et al., 2011), there would be $\sim4$ of them brighter than $g<20$ in the UV-excess catalogue. Additionally, the IR-excess of one source (UVEXJ0328+5035) can be fully explained by a reddened sdB spectrum without the need for a low-mass companion.

There are 2 known QSOs and 4 UV-excess candidate QSOs in WISE. Since the number of QSOs from the WISE cross-matching (6 of 2170) is much smaller than the fraction of QSOs found in the spectroscopic follow-up of UV-excess sources in V12b (2 of 132), there might be some more QSOs in the UV-excess catalogue. However, the QSOs at $|b|<5$ are expected to be clustered at specific lines of sight where absorption is not so strong. The fact that all known UVEX QSOs have a WISE match shows that adding WISE data is a good additional selection criteria. A list of UV-excess candidate QSOs is given in Table 2. The UVEX colours of these candidate QSOs are at $0.65<(g-r)<1.10$ and $-0.21<(U-g)<-0.03$ (Figs. 1 and 2), which are the colour ranges of known QSOs.

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part of the activities of the German Astrophysical Virtual Observatory. This research has made use of the Simbad database and the VizieR catalogue access tool, operated at CDS, Strasbourg, France. The original description of the VizieR service was published in A&AS 143, 23. This publication makes use of data products from the Wide-field Infrared Survey Explorer (WISE), which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration. This publication makes use of data products from the Two Micron All Sky Survey (2MASS), which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. This work is based in part on data obtained as part of the UKIRT Infrared Deep Sky Survey (UKIDSS). We want to credit the efforts of the teams which built WFCAM, processed the data, and implemented the UKIDSS surveys. The UKIDSS project is defined in Lawrence et al. (2007). UKIDSS uses the UKIRT Wide Field Camera (WFCAM; Casali et al., 2007). The photometric system is described in Hewett et al. (2006), and the calibration is described in Hodgkin et al. (2009). The pipeline processing and science archive are described in Irwin et al. (in prep) and Hambly et al. (2008). This paper uses data obtained by the Sloan Digital Sky Survey (SDSS) DR8 (Aihara et al. 2011a). The Sloan Digital Sky Survey III (Eisenstein et al. 2011) is an extension of the SDSS-I and II projects (York et al. 2000). It uses the dedicated 2.5-meter wide-field Sloan Foundation Telescope (Gunn et al. 2006) at Apache Point Observatory (APO). Funding for the Sloan Digital Sky Survey has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the U.S. Department of Energy, the Japanese Mombukagakusho, and the Max Planck Society. The SDSS Web site is http://www.sdss.org/. The SDSS is managed by the Astrophysical Research Consortium (ARC) for the Participating Institutions. KV is supported by a NWO-EW grant 614.000.601 to PJG and by NOVA.

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Ringat E., 2012, ASPC 452, 99R


APPENDIX A: UV-EXCESS SOURCES WITH AN IR-EXCESS
Figure A1. The $K$ vs. $(J-K)$ colour-magnitude diagram with the UKIDSS-GPS matches. UV-excess sources spectroscopically classified in V12b are overplotted with different symbols, UV-excess candidate white dwarfs with $(g-r)<0.2$ are plotted with error bars, other UV-excess sources are plotted with dots.

Figure A2. $K$ vs. $(J-K)$ colour-magnitude diagram with the UV-excess matches in 2MASS. Classified sources are labelled with different symbols, UV-excess candidate white dwarfs are plotted with error bars, other UV-excess sources are plotted with dots. There is one more match at $(J-K)=3.7$, $K=10.8$, classified as DA white dwarf in V12b, not visible in this figure.
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UV-excess sources with a red-JP counterpart: low-mass companions, debris disks and QSO selection.