LETTER TO THE EDITOR

Solid confirmation of the broad DIB around 864.8 nm using stacked Gaia–RVS spectra

H. Zhao (赵赫)1,2, M. Schultheis3, T. Zwitter4, C. A. L. Bailier-Jones4, P. Panuzzo5, P. Sartoretti5, G. M. Seabroke6, A. Recio-Blanco1, P. de Laverny6, G. Kordopatis1, O. L. Creevey1, T. E. Dharmawardena4, Y. Frémat7, R. Sordo7, R. Drimmel8, D. J. Marshall10, P. A. Palicio1, G. Contursi1, M. A. Álvarez11, S. Baker6, K. Benson6, M. Cropper6, C. Dolding6, H. E. Huckle6, M. Smith6, O. Marchal12, C. Ordenovic1, F. Pailler1, and I. Slezak1

1 University Côte d’Azur, Observatory of the Côte d’Azur, CNRS, Lagrange Laboratory, Observatory Bd, CS 34229, 06304 Nice Cedex 4, France
2 e-mail: he.zhao@oca.eu; mathias.schultheis@oca.eu
3 Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210023, PR China
4 Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia
5 Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany
6 GEPI, Observatoire de Paris, Université PSL, CNRS, 5 Place Jules Janssen, 92190 Meudon, France
7 Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, Surrey RH5 6NT, UK
8 Royal Observatory of Belgium, 3 Avenue Circulaire, 1180 Brussels, Belgium
9 INAF – Osservatorio Astronomico di Padova, Vicolo Osservatorio 5, 35122 Padova, Italy
10 INAF – Osservatorio Astrofisico di Torino, Via Osservatorio 20, 10025 Pino Torinese, Italy
11 IRAP, Université de Toulouse, CNRS, UPS, CNES, 9 Av. Colonel Roche, BP 44346, 31028 Toulouse Cedex 4, France
12 CIGUS CITIC – Department of Computer Science and Information Technologies, University of A Coruña, Campus de Elviña s/n, A Coruña 15071, Spain
13 CNES Centre Spatial de Toulouse, 18 Avenue Edouard Belin, 31401 Toulouse Cedex 9, France

Received 24 June 2022 / Accepted 30 September 2022

Context. Studies of the correlation between different diffuse interstellar bands (DIBs) are important for exploring their origins. However, the Gaia–RVS spectral window between 846 and 870 nm contains few DIBs, the strong DIB at 862 nm being the only convincingly confirmed one.

Aims. Here we attempt to confirm the existence of a broad DIB around 864.8 nm and estimate its characteristics using the stacked Gaia–RVS spectra of a large number of stars. We study the correlations between the two DIBs at 862 nm (λ862) and 864.8 nm (λ864.8), as well as the interstellar extinction.

Methods. We obtained spectra of the interstellar medium (ISM) absorption by subtracting the stellar components using templates constructed from real spectra at high Galactic latitudes with low extinctions. We then stacked the ISM spectra in Galactic coordinates (ℓ, b) – pixelized by the HEALPix scheme – to measure the DIBs. The stacked spectrum is modeled by the profiles of the two DIBs, Gaussian for λ862 and Lorentzian for λ864.8, as well as the interstellar extinction.

Results. We obtained 8458 stacked spectra in total, of which 1103 (13%) have reliable fitting results after applying numerous conservative filters. This work is the first of its kind to fit and measure λ862 and estimation of its FWHM. The DIB λ864.8 is very broad and shallow. That at λ862 correlates better with E(BP − RP) than λ864.8.

Conclusions. We find solid confirmation of the existence of the DIB around 864.8 nm based on an exploration of its correlation with λ862 and estimation of its FWHM. The DIB λ864.8 is very broad and shallow. That at λ862 correlates better with E(BP − RP) than λ864.8.

Key words. ISM: lines and bands

* The fitting results for all stacked spectra are only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsarc.u-strasbg.fr/viz-bin/cat/J/A+A/666/L12
1. Introduction

Diffuse interstellar bands (DIBs) are a set of absorption features with profiles that are much broader than those of the interstellar atomic lines (e.g., Na I lines). To date, over 600 DIBs have been identified at optical and near-infrared wavelengths (0.4–2.4 μm; Galazutdinov et al. 2017; Fan et al. 2019). However, our knowledge about their origins is still very limited. So far, only C_2 has been confirmed as the carrier for five DIBs between 950 and 965 nm (see Linnartz et al. 2020 for a review). Gas-phase carbon-bearing molecules are thought to be the most probable DIB carriers (e.g., Snow et al. 2014).

Despite the unknown nature of DIBs, absorption intensity maps have been built for several such features detected in large spectroscopic surveys (e.g., Kos et al. 2014; Zasowski et al. 2015; Baron et al. 2015b; Lan et al. 2015; Puspitarini et al. 2015) in order to explore the interstellar medium (ISM) and Galactic structure. Among them, the latest map was built for the DIB at 862 nm (DIB862) using data from the Gaia Radial Velocity Spectrometer (RVS; Seabroke et al., in prep.) in Data Release 3, which has the largest sky coverage to date (see Gaia Collaboration 2022d for more details). Their wavelengths and line widths are expressed in nanometers following the unit used in the Gaia analysis, while their strength is still expressed in Ångströms due to their small line depth (see Linnartz et al. 2020 for a review). Gas-phase carbon-bearing molecules are thought to be the most probable DIB carriers (e.g., Snow et al. 2014).

The stellar parameters and chemical abundances (of up to 13 chemical species, are derived by the General Stellar Parameterizer from spectroscopy (GSP-Spec) module of the Astrophysical parameters inference system (Apsis, Gaia Collaboration 2022b,c). We refer to Gaia Collaboration (2022c) for detailed descriptions of the parametrization and a validation of the measurement of λ862 in individual RVS spectra.

About one million Gaia–RVS spectra have been published in Gaia DR3. We use a sample of 648 944 spectra that meet the following criteria (given as an ADQL query example in Appendix A):

1. Stellar parameters (T_{eff}, log g, [M/H]) and radial velocity (V_{rad}) are not NaN values.
2. 3500 K ≤ T_{eff} ≤ 7500 K and log g < 6 dex.
3. Stellar distances derived from parallax measurements (1/σ) are within 6 kpc.
4. The signal-to-noise ratios (S/N) of the observed spectra are greater than 20.
5. The uncertainty of V_{rad} is smaller than 5 km s^{-1}.

This work processes stars with T_{eff} ≤ 7500 K, defined as “cool stars”. The whole set of the averaged GSP-Spec (λ862 and λ864.8 simultaneously in cool-star spectra. To do so, first we derive the ISM spectrum for each target by subtracting their stellar components using the reference spectra. We then stack the ISM spectra of the targets according to their Galactic coordinates (l, b), per HEALPix. Finally we fit and measure the two DIBs, λ862 and λ864.8, in the stacked spectra.

The first step follows the main principles of Kos et al. (2013). For a given target, we find a set of reference spectra with similar parameters to the GSP-spec values of the target that have T_{eff} ± 20%, log g ± 0.6 dex, and [M/H] ± 0.4 dex. These ranges are arbitrary, but chosen to be larger than the parameter uncertainties (Kos et al. 2013). The constraints on the stellar parameters are not necessary but they can speed up the procedure. The similarity between the target spectrum and each reference spectrum is then calculated by the average absolute difference of their flux at all pixels, except a masked region of 860–868 nm where the two DIBs are located. When measuring the difference, the central regions of the Ca II triplet are down-weighted to 30% because Ca II lines dominate the whole Gaia–RVS spectra of cool stars whereas the similarity between Fe I lines (close to DIBs) is more important than between the Ca II lines for constructing the templates (see examples in Contursi et al. 2021). In practice, the two Ca II regions of concern are defined as 849.43–851.03 nm and 853.73–855.73 nm and are down-weighted. The Ca II line near 866.5 nm is within the masked DIB region. Reference spectra with average differences of greater than the inverse of the square of the target S/N are discarded. For the rest, up to 500 (and at least 10) best-matching reference spectra are aver-
The FWHM of \( \lambda_{862} \) and \( \lambda_{864.8} \) are greater than 0.2 nm and 0.5 nm, respectively. In each of these pixels, we stack all of the ISM spectra (54 on average with a maximum of 362) to generate one stacked spectrum. We stack the ISM spectra in each pixel by taking the mean of the individual flux uncertainties divided by their \( S/N \) for a reliable measurement of \( \lambda_{864.8} \). The pixelation of the sky is done by the HEALPix\(^1\) (Górski et al. 2005) scheme. We choose level 5 (\( N_{side} = 32 \)) corresponding to 12,288 pixels and a spatial resolution about 1.8°. We note that 8458 HEALPix pixels (69% of the total) contain at least ten targets that have ISM spectra (\( N_{src} > 10 \)). In each of these pixels, we stack all of the ISM spectra (54 on average with a maximum of 362) to generate one stacked spectrum. We stack the ISM spectra in each pixel by taking the mean of the individual flux uncertainties divided by \( \sqrt{N_{src}} \), which is the standard error in the mean. The \( S/N \) of the stacked spectra is calculated between 860.2 and 861.2 nm as \( \text{mean} / \text{std} \). We have 8458 stacked spectra in total, one for each HEALPix pixel.

In the third and final step, a Markov chain Monte Carlo (MCMC) procedure (Foreman-Mackey et al. 2013) is used to fit each stacked spectrum between 860 and 868 nm (the DIB region) with a Gaussian function for the profile of \( \lambda_{862} \), a Lorentzian function (better than Gaussian when considering the goodness of fit to the line wings) for the profile of \( \lambda_{864.8} \), and a linear function for the continuum placement, masking 866–866.5 nm for the \( \text{Ca}^{II} \) line residuals. The best estimates and statistical uncertainties are taken in terms of the 50th, 16th, and 84th percentiles of the posterior distribution. We note that the \( \text{Ca}^{II} \) region slightly changes after the shifting to the heliocentric frame, considering that the radial velocities of most stars lie mainly within \( \pm 50 \) km s\(^{-1} \), corresponding to \( |\Delta \lambda| \approx 0.14 \) nm at 866.5 nm. Furthermore, the wings of the \( \text{Ca}^{II} \) lines are better modeled than their central parts (Gaia Collaboration 2022b,c).

Fig. 2 shows the distributions of the FWHM of \( \lambda_{862} \) (red histogram) and \( \lambda_{864.8} \) (blue histogram), as well as their joint distribution (middle colored map), measured in 1962 stacked spectra after applying the general filtering. The colors represent the densities of the joint FWHM distribution, estimated by a Gaussian KDE. The white star indicates the peak density. The red line in the central panel indicates a contour with a probability density of 1.2, about one-third of the peak density. The orange lines indicate the median FWHM of \( \lambda_{862} \) and \( \lambda_{864.8} \), respectively.

4. Results

The aforementioned fit of the DIB was done for each of the 8458 stacked spectra (one per HEALPix pixel). To get reliable results, we only retain the stacked spectra that meet the following criteria, which leaves us with 1962 spectra:

- \( S/N \) of the stacked ISM spectrum is greater than 100.
- \( \text{CD}_{862} > 3 \text{RC} \) and \( \text{CD}_{864.8} > 3 \text{RC} \).
- The FWHM of \( \lambda_{862} \) and \( \lambda_{864.8} \) are greater than 0.2 nm and 0.5 nm, respectively.

\( \text{CD}_{862} \) and \( \text{CD}_{864.8} \) are as their joint distribution, for the 1962 stacked spectra. The FWHM of \( \lambda_{864.8} \) has a much wider distribution than that of \( \lambda_{862} \), and both slightly deviate from a Gaussian. We apply a Gaussian kernel density estimation (KDE) to their

\(^{1}\) https://healpix.sourceforge.io
Fig. 3. Galactic distributions of the 1103 reliable measurements of the strength of \(\lambda 862\) (top), \(\lambda 864.8\) (middle), and \(E(BP-\cdot RP)\) (bottom), in Mollweide projection, with the Galactic center in the middle and Galactic longitude increasing to the left.

joint distribution with a bandwidth of 0.2826 nm (automatically determined by the Python package \texttt{scipy}). The median FWHM is to the upper left of the peak density estimated by the KDE (white star in Fig. 2), which is caused by the fits to some very shallow profiles that result in broader \(\lambda 862\) and narrower \(\lambda 864.8\). The outliers in low-density regions are due to the noise in stacked spectra.

Therefore, we discard the points that lie in the region with a density less than 1.2 (red line in Fig. 2), which is about one-third of the peak density. After this final filtering, our sample comprises 1103 reliable measurements of the two DIBs, about 13% of the total stacked spectra.

The two-dimensional intensity map of \(\lambda 862\) and \(\lambda 864.8\) as well as \(E(BP-\cdot RP)\) are shown in Galactic coordinates in Fig. 3. Limited by our sample, the spatial distributions of EW\(_{862}\) and EW\(_{864.8}\) cannot be well described. However, it is clear that large EWs for both \(\lambda 862\) and \(\lambda 864.8\) concentrate in the Galactic plane. Furthermore, decreasing EW\(_{862}\) and EW\(_{864.8}\) with latitude (up to \(b = \pm 30^\circ\)) can be found near Galactic center (GC, \(|\ell| < 30^\circ\)), which are similar to each other and that of \(E(BP-\cdot RP)\).

Intensity correlations between \(\lambda 862\), \(\lambda 864.8\), and \(E(BP-\cdot RP)\) are shown in Fig. 4. For \(E(BP-\cdot RP)\), we use std(\(E(BP-\cdot RP)\))/\(\sqrt{N}\) to represent its uncertainty in each HEALPix pixel. EW\(_{862}\) and EW\(_{864.8}\) are well correlated with each other with a Pearson coefficient of \(r_p = 0.78\). A systematic deviation can be seen when EW\(_{862}\) \(\geq 0.2\) Å. The cause of this is unclear: either it has a physical origin or is due to the FWHM dispersion seen in Fig. 2. To avoid this effect, we apply simple linear fits with 2\(\sigma\) clipping and zero intercept for EWs and dust reddening, resulting in the following relations:

\[
\begin{align*}
\text{EW}_{864.8} & = 1.651(\pm 0.011) \times \text{EW}_{862} \\
E(BP-\cdot RP) & = 3.627(\pm 0.021) \times \text{EW}_{862} \\
E(BP-\cdot RP) & = 1.953(\pm 0.017) \times \text{EW}_{864.8}
\end{align*}
\]

We also apply the linear fits without any clipping. For the two DIBs, the coefficient from the no-clipping fit becomes 6% lower (1.548 \(\pm\) 0.015) for their EWs and 5% lower (0.350 \(\pm\) 0.006) for their CDs, compared to the 2\(\sigma\)-clipped results. The relative strength between DIB and dust is 13% above for \(\lambda 862\) \((E(BP-\cdot RP)/\text{EW}_{862} = 4.096\pm0.038)\) and 21% above for \(\lambda 864.8\) \((E(BP-\cdot RP)/\text{EW}_{864.8} = 2.367\pm0.034)\), respectively, when not clipping. This is not surprising, as significant scatter about the fit can be found around \(E(BP-\cdot RP)\) \(\sim 1\) mag and \(\text{EW}_{862} \sim 0.1\) Å. Similar scatter exists for \(\lambda 864.8\) as well, but this latter is more significant. This scattering could be a result of the overestimation of \(E(BP-\cdot RP)\) as seen in Fig. 7 in Gaia Collaboration (2022d). We prefer the 2\(\sigma\)-clipped results because the scattering is not only caused by the measurement uncertainties but may indicate a spatial disconnection between their carriers and dust grains. Thus, the fitted coefficients with a strong filtering would represent their mean relative strength in the regions where these ISM materials are well mixed.

Compared to EWs, the CDs of the two DIBs are better correlated with each other with \(r_p = 0.87\) and no systematic deviations. The depth of \(\lambda 864.8\) is about 37% of that of \(\lambda 862\), while its EW is over 1.6 times \(\text{EW}_{862}\). We note that \(\text{EW}_{862}\) shows good correlation with \(E(BP-\cdot RP)\) with \(r_p = 0.85\) as expected, but their relative strength is about 20% below that derived from the DIB sample in Gaia-DR3 (4.507 \(\pm\) 0.137, Gaia Collaboration 2022d). The reason could be that different templates – from GSP–Spec and from reference spectra – would introduce differences in EW measurements (see e.g., Elyajouri & Lallement 2019). It should also be noted that \(E(BP-\cdot RP)/\text{EW}_{862}\) fitted in this work with no clipping is closer to the result in Gaia Collaboration (2022d, 9% difference) where the authors did not make any filtering either. Also, \(\lambda 864.8\) does not correlate as well as \(\lambda 862\) \((E(BP-\cdot RP))\), showing a much smaller \(r_p = 0.64\) and a larger dispersion.

In a similar manner to Munari et al. (2008) and Zhao et al. (2021), in order to estimate the rest-frame wavelength (\(\lambda_0\)) of \(\lambda 864.8\), we assume that the median radial velocity in the Local Standard of Rest of the DIB carrier is zero toward the GC. There are 43 cases with \(|\ell| \leq 10^\circ\), \(|b| \leq 10^\circ\), and small uncertainties in \(\lambda_C\) (<0.1 nm for \(\lambda 862\) and <0.15 nm for \(\lambda 864.8\)). For \(\lambda 862\), we derive a \(\lambda_0\) of 862.319 \(\pm\) 0.018 nm, which is highly consistent with the result of 862.323 \(\pm\) 0.0019 nm in Gaia Collaboration (2022d). For \(\lambda 864.8\), we derive \(\lambda_0 = 864.53 \pm 0.14\) nm in the vacuum, corresponding to 864.29 nm for air wavelength. This result is smaller than the commonly suggested air wavelength measured in the spectra of early-type stars, such as 865.0 nm (Sanner & Snell 1978), 864.9 nm (Herbig & Leka 1991), and 864.83 nm (Jenniskens & Desert 1994).

5. Discussion

Until now, the FWHM of the \(\lambda 864.8\) feature has not been well determined. Sanner & Snell (1978) noted that this DIB profile extends from 863 to 866 nm and its strength did not correlate with spectral type, but they did not measure its FWHM. We found two measurements of FWHM\(_{864.8}\) in the literature that are dramatically different from each other: 1.4 nm

---

L12, page 4 of 7
by Herbig & Leka (1991) and 0.42 nm by Jenniskens & Desert (1994). The difficulty is that this band is shallow and superposed across several blended stellar lines, such as the He\(^i\) line at 864.83 nm in early B-type supergiants (Herbig & Leka 1991). This may be the reason why a stellar origin has been claimed at 864.83 nm in early B-type supergiants (Herbig & Leka 1991).

This work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC). https://www.cosmos.esa.int/web/gaia/dpac/consortium. Funding for the DPAC has been provided by national institutions, in particular the Gaia Collaboration (2022d).

6. Conclusions

Based on the measurements in 1103 stacked Gaia–RVS spectra, we provide solid confirmation of the DIB around 864.8 nm through its correlation with λ862 and its clear and broad profile in the stacked spectra. λ864.8 is a very broad and shallow DIB. The FWHM of λ864.8 is estimated to be 1.62 ± 0.33 nm. Using 43 high-quality measurements toward GC ([l] < 10\(^\circ\), [b] < 10\(^\circ\)), the rest-frame wavelength of λ864.8 is determined as \(\lambda_0 = 864.53 \pm 0.14\) nm in the vacuum, which is smaller than previous reported measurements. \(\text{EW}_{862}\) correlates better with \(E(BP - RP)\) than \(\text{EW}_{864.8}\).

Our work shows the power of using a large set of cool-star spectra to study the DIBs in the ISM. The extremely small depth of these lines (CD\(_{864.8} < 3\%\)) and the ability to assess their properties is a clear demonstration of the quality of Gaia–RVS spectra as published in Gaia DR3.

Acknowledgements. This work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the
institutions participating in the Gaia Multilateral Agreement. This work was supported in part by: the German Aerospace Agency (DLR) grant 50 QG 2102; SFB 881 “The Milky Way System” of the German Research Foundation (DFG).

References

Baron, D., Poznanski, D., Watson, D., et al. 2015a, MNRAS, 451, 332
Baron, D., Poznanski, D., Watson, D., Yao, Y., & Prochaska, J. X. 2015b, MNRAS, 447, 545
Contursi, G., de Laverny, P., Recio-Blanco, A., & Palicio, P. A. 2021, A&A, 654, A130
Cropper, M., Katz, D., Sartoretti, P., et al. 2018, A&A, 616, A5
Elyajouri, M., & Lallement, R. 2019, A&A, 628, A67
Elyajouri, M., Lallemand, R., Monreal-Ibero, A., Capitanio, L., & Cox, N. L. J. 2017, A&A, 600, A129
Fan, H., Hobbs, L. M., Dahlstrom, J. A., et al. 2019, ApJ, 878, 151
Foreman-Mackey, D., Hogg, D. W., Lang, D., & Goodman, J. 2013, PASP, 125, 306
Friedman, S. D., York, D. G., McCall, B. J., et al. 2011, ApJ, 727, 33
Gaia Collaboration (Prusti, T., et al.) 2016, ApJ, 813, 15
Gaia Collaboration (Andrae, R., et al.) 2022a, A&A, in press https://doi.org/10.1051/0004-6361/202243462
Gaia Collaboration (Creevey, O. L., et al.) 2022b, A&A, in press https://doi.org/10.1051/0004-6361/202243688
Gaia Collaboration (Recio-Blanco, A., et al.) 2022c, A&A, in press https://doi.org/10.1051/0004-6361/202243750
Gaia Collaboration (Schultheis, M., et al.) 2022d, A&A, in press https://doi.org/10.1051/0004-6361/202243283
Gaia Collaboration (Vallenari, A., et al.) 2022e, A&A, in press https://doi.org/10.1051/0004-6361/202243949
Galazutdinov, G., Lee, J.-J., Han, L., et al. 2017, MNRAS, 467, 3099
Galazutdinov, G., Bondar, A., Lee, B.-C., et al. 2020, AJ, 159, 113
Górski, K. M., Hivon, E., Banday, A. J., et al. 2005, ApJ, 622, 759
Herbig, G. H., & Leka, K. D. 1991, ApJ, 382, 193
Jenniskens, P., & Desert, F. X. 1994, A&AS, 106, 39
Kos, J., Zwitter, T., Grebel, E. K., et al. 2013, ApJ, 778, 86
Kos, J., Zwitter, T., Wyse, R., et al. 2014, Science, 345, 791
Krebowsk, J., Galazutdinov, G., Godunova, V., & Bondar, A. 2019, Acta Astron., 69, 159
Lan, T.-W., Ménard, B., & Zhu, G. 2015, MNRAS, 452, 3629
Linnartz, H., Cami, J., Cordiner, M., et al. 2020, J. Mol. Spectrosc., 367, 11243
Maíz Apellániz, J. 2015, Mem Soc. Astron. It., 86, 553
Munari, U., & Zwitter, T. 1997, A&A, 318, 269
Munari, U., Tomasella, L., Fiorucci, M., et al. 2008, A&A, 488, 969
Puspitarini, L., Lallement, R., Babusiaux, C., et al. 2015, A&A, 573, A35
Sanner, F., Snell, R., & vanden Bout, P., 1978, ApJ, 226, 460
Snow, T. P. 2014, in The Diffuse Interstellar Bands, eds. J. Cami, & N. L. J. Cox, 297, 3
Vollmann, K., & Eversberg, T. 2006, Astron. Nachr., 327, 862
Vos, D. A. I., Cox, N. L. J., Kaper, L., Spaans, M., & Ehrenfreund, P. 2011, A&A, 533, A129
Wallenstein, G., Sandström, K., & Gredeh, R. 2007, PASP, 119, 1268
Zasowski, G., Ménard, B., Bizyaev, D., et al. 2015, ApJ, 798, 35
Zhao, H., Schultheis, M., Rojas-Arriagada, A., et al. 2021, A&A, 654, A116
Appendix A: ADQL queries

SELECT *
FROM gaiadr3.astrophysical_parameters AS gaia
INNER JOIN gaiadr3.gaia_source AS xmatch
ON gaia.source_id = xmatch.source_id
WHERE (xmatch.has_rvs='T' AND gaia.teff_gspspec > 3500 AND gaia.teff_gspspec < 7500
AND gaia.logg_gspspec < 6 AND xmatch.parallax > 0.0 AND 1/xmatch.parallax < 6 AND
xmatch.radial_velocity_error < 5.0 AND xmatch.rv_expected_sig_to_noise > 20.0 AND
gaia.mh_gspspec is NOT NULL)