ON THE GAIA DR3 REFLECTANCE SPECTRA

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For the community of observers in the Minor Planets Section and beyond, we present a study on the reflectance spectra contained in the ESA Gaia DR3 database. This data set has great potential for the amateur astronomer community, especially for the classification of asteroids that do not have any previous classifications. A taxonomic classification has been carried out for 14954 asteroids. Of these, there are 1214 asteroids in common with the SMASSII catalogue, of which for 914 the taxonomic classification agrees (78%). The quality of the Gaia spectra sometimes is not very high, so it is advisable to proceed with caution, using a visual inspection in the most ambiguous cases.

The ESA Gaia database Data Release 3 (June 13, 2022) includes 60518 asteroid reflectance spectra, primarily from the main belt. The spectra cover the visible spectrum band and a part of the near infrared band, between the wavelengths of 374 and 1034 nm. The procedures and methods used for the reduction are reported by Galluccio et al. (2023), to which one can refer for further information and references.

The ESA Gaia DR3 reflectance spectra represent, due to their extensiveness, one of the main sources of information for the taxonomic classification of asteroids.

This study is inspired by that of Galluccio et al. (2023), with some simplifications. The main goal is to encourage the use of ESA Gaia DR3 spectro-photometric data by the amateur astronomer community, whose contribution is often limited to photometric lightcurves only. For this work we used *Scilab 6.11* (2021) for scripting language environment and *Orange 3.34* (Demsar et al., 2013) for data analysis.

The reflectance spectra were downloaded from the Gaia ESA Archive (2025) with an ADQL query (Astronomical Data Query Language; See Appendix). A total of 60518 reflectance spectra were extracted, relating to as many asteroids. Each reflectance spectrum is sampled in 16 wavelength band (between 374 and 1034 nm) and is normalized to the 550 nm wavelength. For each record a 'reflectance_spectrum_flag' is provided for indicates the quality of the single reflectance value (0=good, 1=poor, 2=compromised).

Most of the Gaia spectra have reflectance values with reflectance_spectrum_flag=2. It was therefore decided to limit this study only to the spectra with the quality flag set to 0 and 1. A total of 14966 spectra were selected (25% of the total), discarding 45552 (75% of the total).

For comparison and reference, the mean spectra of the Bus-DeMeo taxonomy (DeMeo et al., 2009) were used, downloadable from the Planetary Data System, Small Bodies Node (2020), cut at 1050 nm (13 wavelength samples for each reflectance spectrum), for homogeneity with the spectral extension, in wavelength, of the ESA Gaia sample.

Following the approach of DeMeo and Carry (2013) and Galluccio et al. (2023), for all the spectra (Gaia DR3 and the mean reflectance values from Bus-DeMeo taxonomy), we evaluated the spectral slope and *z-i* color, because these explain many of the distinctive taxonomic features of the asteroids. In the reflectance spectrum, the slope characterizes the UV wavelength region, while the *z-i* color takes into account the presence and the depth of the 1-μm absorption band.

First of all, the Gaia reflectance spectrum is sampled on slightly different wavelengths than the Bus-DeMeo taxonomy reference spectra. For homogeneity, we chose to resample the Gaia spectrum on the same wavelength intervals as the Bus-DeMeo reference spectra through a cubic spline interpolation. Specifically, we used the *Scilab* functions *splin*() and *interp*(), setting the wavelength range from 0.45 to 1.05 μm with 0.05 μm steps.

In detail, the slope parameter was determined from the regression line between the points of the reflectance spectrum between 0.45 and 0.75 μm. While the *z-i* color parameter was obtained calculating the follow expression from Galluccio et al. (2023): *z-i* = -2.5*log10(Rz/Ri), where Rz and Ri are respectively the reflectance value at wavelength of 0.75 and 0.90 μm. These last are a very close approximation to those used by Galluccio et al. (2023) at 748 and 893 nm.

The plot of the slope vs *z-i* parameters for the Gaia DR3 reflectance spectra sample shows a discrepancy on the overlap areas with respect to the reference parameters of the Bus-DeMeo taxonomy, differently from what one might have expected (Figure 1). In detail the *z-i* values appear all systematically higher respect to the values of the Bus-DeMeo reference taxonomy. Note, for example, that the S sub-classes, despite being one of the most populous classes, all appear off-center and fall within a low-density area occupied by the Gaia data.

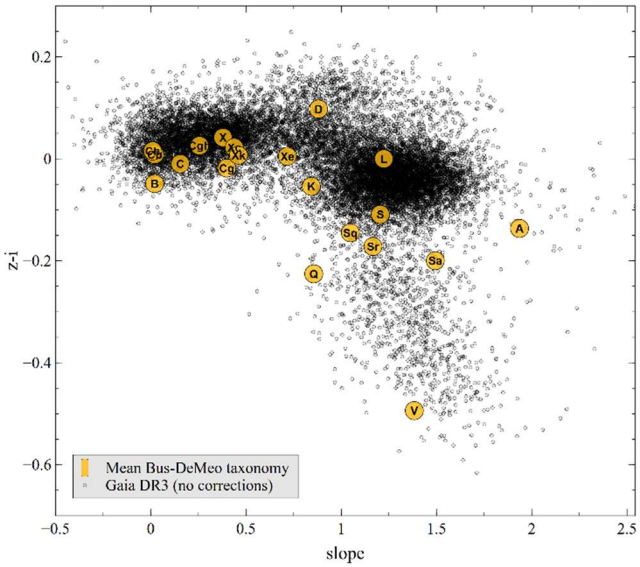

Figure 1: The Gaia DR3 sample distribution for the slope and *z-i* parameters. A discrepancy is noted on the overlap areas compared to the reference parameters represented by the Bus-DeMeo taxonomy. Note that the S sub-classes fall within a low-density area occupied by the Gaia data.

To investigate this discrepancy, we plotted the relation Gaia vs Bus-DeMeo for slope and *z-i* color, using as reference the sample of asteroids in common from the Gaia DR3 and the SMASSII (Bus and Binzel, 2002), grouped for each spectral class and averaging the

slope and the *z-i* color parameters (Figure 2). We confirm the *z-i* color difference for Gaia, compared to that of SMASSII (Bus and Binzel, 2002), with an average value of -0.06, close to that found by Galluccio et al. (2023; -0.08).

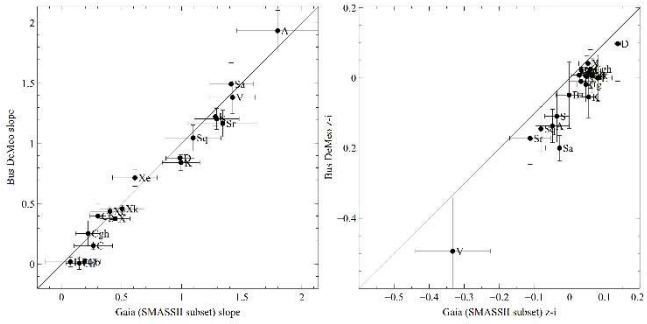

Figure 2: The relation for slope and *z-i* color for Gaia DR3 sample and Bus-DeMeo reference taxonomy, on the basis of the of the SMASSII sub-set. The *z-i* color color for Gaia DR3 is systematically below to Bus-DeMeo reference.

In order to correct this discrepancy we calculated the differences for slope and *z-i* from the Bus-DeMeo and the Gaia DR3 (SMASSII common sub-set). Plotting that differences respect to the Gaia slope and *z-i* color (Figure 3), we obtained the following regression line expressions:

(BusDeMeo_slope - Gaia_slope) = 0.02712 * Gaia_slope - 0.06128

(BusDemeo_zi - Gaia_zi) = -0.05559 * Gaia_slope - 0.02046

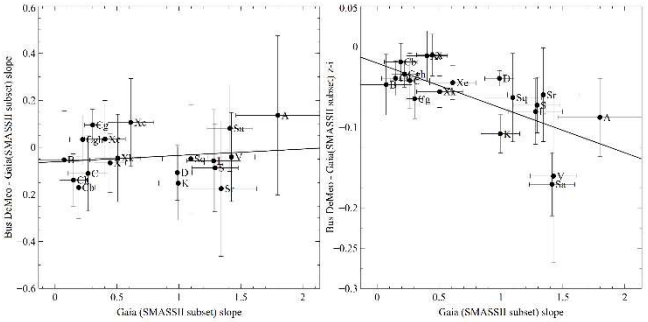

Figure 3: Differences for slope and *z-i* from the Bus-DeMeo and the Gaia DR3 (SMASSII common sub-set).

By applying these corrections to the slope and *z-i* color parameters we obtained a better distribution of the overlap areas with the Bus-DeMeo taxonomy and with the common SMASSII sub-set (Figure 4).

Once the distribution of the slope and *z-i* color parameters on the Gaia DR3 data had been corrected, it was possible to proceed with their taxonomic classification, following the approach proposed by DeMeo and Carry (2013) for the SDSS data.

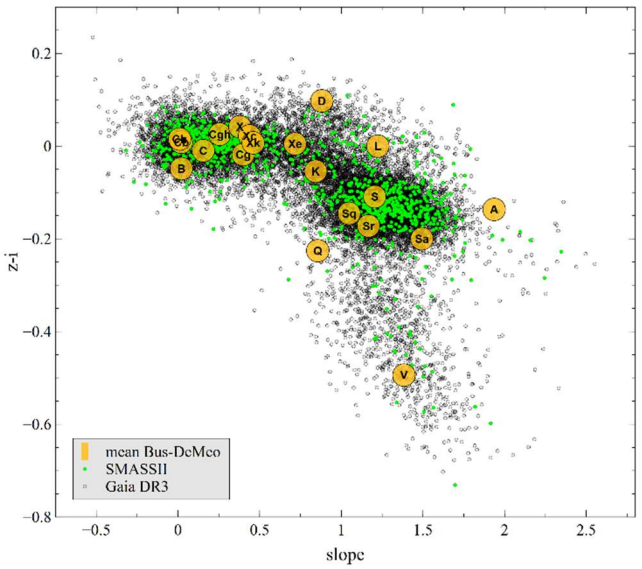

Figure 4: Slope vs *z-i* color parameters, once the linear correction has been applied. Gaia DR3 (gray), SMASSII (green), and the mean Bus-DeMeo taxonomy (orange) for each spectral class.

In detail, the sub-classes S, C, X have been merged into their broader complex, reducing the distinct taxonomic classes to the following A, B, C, D, K, L, Q, S, V, X. For each taxonomic class a specific area of the cartesian plane (slope vs *z-i*) was assigned, on the basis of the Table 3 of DeMeo and Carry (2013) and following a decision tree approach. The resulting taxonomic distribution of the Gaia DR3 sample is reported on Figure 5 with a total of 14954 assigned spectral classes and 12 undefined assignments. The catalogue of the assigned spectral classes is available in a .csv file format, with the following data fields: Num, Denomination, slope, *z-i*, and SpType (Balzaretto Observatory, 2025).

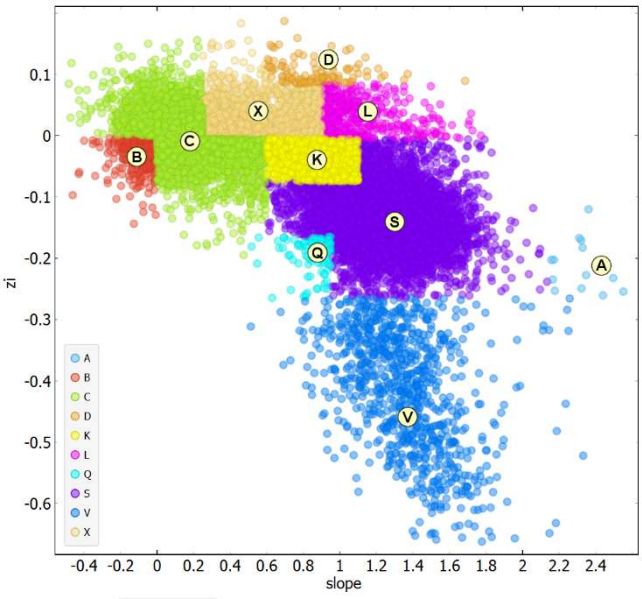

Figure 5: Taxonomic distribution for the Gaia DR3 sample, on the basis of the criteria defined by DeMeo and Carry (2013) for the areas of the plane (slope, *z-i* color).

The sample in common between Gaia DR3 and SMASSII (Bus and Binzel, 2002) is composed by 1214 asteroids, and for 914 of that sample (78%) was assigned the same taxonomic class, while for the

remain 270 asteroids (22%) the taxonomic class assigned was result different.

The Figure 6 compare the distribution of the taxonomic classes for the common SMASSII sub-set (1214) and for whole sample of the Gaia DR3 (14954). The distribution of spectral classes between SMASSII and Gaia DR3 is quite similar in percentage terms, although with some differences for the spectral classes V and K, where the percentage is clearly higher for Gaia DR3 data.

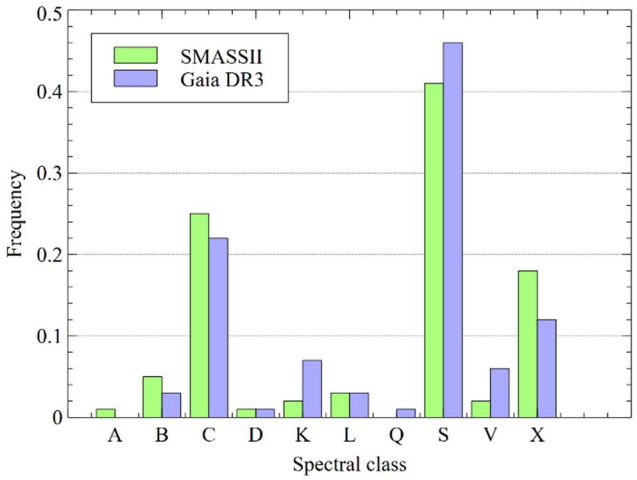

Figure 6: Histogram of the frequency for the spectral classes of the Gaia DR3 sample (sky blue) compared with the common SMASSII sub-set (light green).

In Figure 7 we plot a sample of the Gaia DR3 reflectance spectra. The first row reports the spectra for which the classification of this work, based on slope and *z-i*, coincides with that of SMASSII (Bus and Binzel, 2002). The second row instead reports the spectra for which the classification of this work differs from the SMASSII one. The third row report the classification of three asteroids for which there is no reference classification. Of these, for Nerina the classification based on slope and *z-i* assign a C-type, while the best fit suggests a X-type.

To conclude, this work confirms the potential of the Gaia DR3 reflectance spectra for the spectral classification of asteroids, in the absence of more detailed, and better quality, spectra. The automatic classification, based on slope and *z-i* color parameters, although very effective in most cases, still shows the need to resolve the most ambiguous cases with a direct inspection of the data. For the amateur astronomer community, ESA Gaia reflectance spectra can represent a useful resource for the taxonomic classification of asteroids, better if supported also by multi-band photometric observations.

References

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Appendix

Keywords for Astronomical Data Query Language

SELECT number_mp, denomination, wavelength, reflectance_spectrum, reflectance_spectrum_err, reflectance_spectrum_flag

FROM gaiadr3.sso_reflectance_spectrum

ORDER by number_mp, wavelength

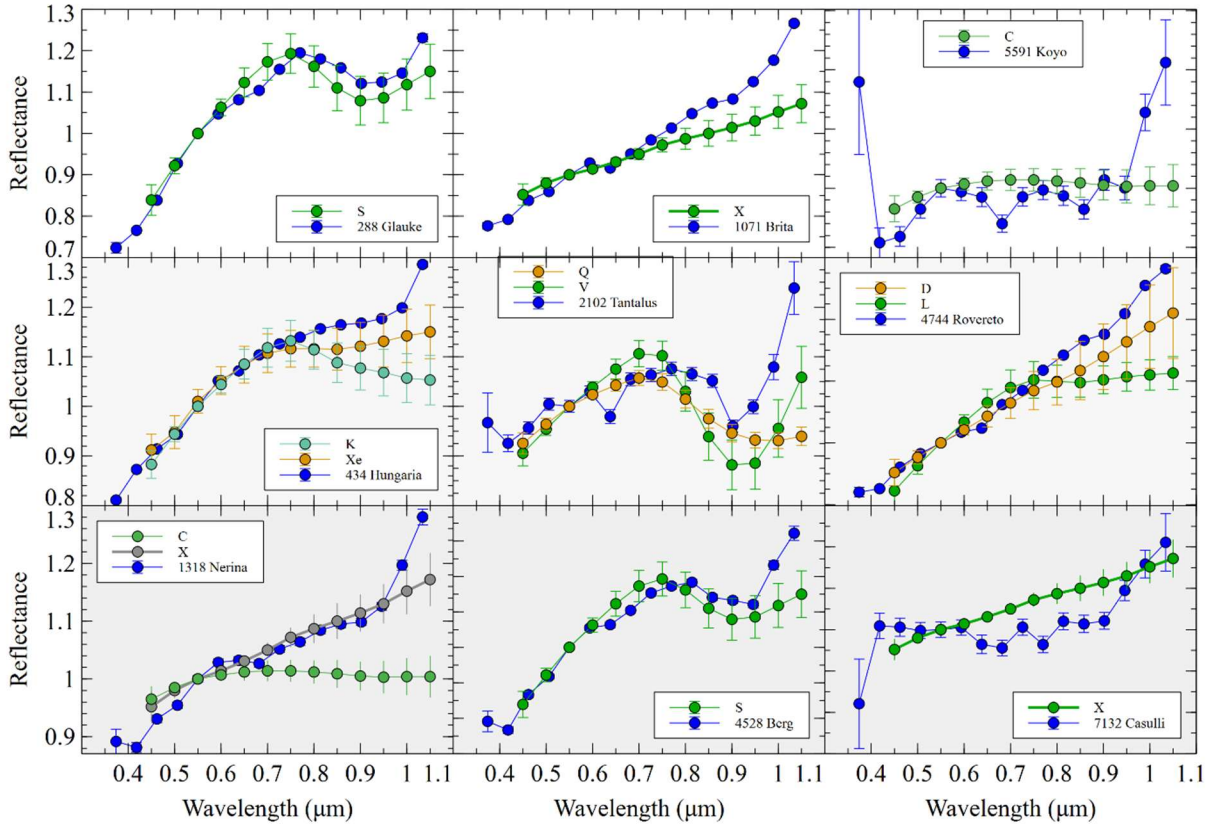

Figure 7: Sample of the Gaia DR3 reflectance spectra (blue color) compared with those from the mean Bus-DeMeo reference spectra. The first row reports the spectra of the asteroids 288 Glauke, 1071 Brita, and 5591 Koyo, for which the taxonomic classification of this work coincides with that of SMASSII (green color). The second row report the spectra of 434 Hungaria, 2102 Tantalus, and 4744 Rovereto, for which the classification of this work (green color) differs from the SMASSII one (orange color). The third row report the spectra of the asteroids 1318 Nerina, 4528 Berg, and 7132 Casulli, for which the classification of this work (green color) assign respectively the classes C, S and X. To note that for 1318 Nerina the most appropriate classification is X-type, on the best fit basis.