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Minor Planet Science with the VISTA Hemisphere Survey

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We have carried out a serendipitous search for Solar System objects imaged by the VISTA Hemisphere Survey (VHS) and have identified 230 375 valid detections for 39 947 objects. This information is available in three catalogues, entitled MOVIS. The distributions of the data in colour-colour plots show clusters identified with the different taxonomic asteroid types. Diagrams that use (*Y–J*) colour separate the spectral classes more effectively than any other method based on colours. In particular, the end-class members A-, D-, R-, and V-types occupy well-defined regions and can be easily identified. About 10 000 asteroids were classified taxonomically using a probabilistic approach. The distribution of basaltic asteroids across the Main Belt was characterised using the MOVIS colours: 477 V-type candidates were found, of which 244 are outside the Vesta dynamical family.

Context

The total number of minor planets (small Solar System bodies orbiting the Sun) known today exceeds 700 000. The vast majority of them are concentrated between the orbits of Mars and Jupiter, in the asteroid Main Belt. These objects are the remnants of planetesimals from which the planets formed, and understanding their properties in detail allows the formation and evolution of the Solar System to be constrained. Other arguments for studying minor planets are related to more practical reasons: their use as resources for space exploration; and in order to mitigate the risk of impacts by near-Earth objects.

The physical properties of minor planets are known for just a small fraction of these objects: spectroscopic studies and light curves exist only for several thousand. The results show an unexpected diversity in the composition, density and shape of these bodies. The Sloan Digital Sky Survey (SDSS) and Wide-field Infrared Survey Explorer (WISE) provide information for about 100 000 minor planets. The resulting visible colours and albedos show a greater mixing of the bodies as a function of their orbital parameters, which can be explained by the turbulent history of the Solar System (DeMeo et al., 2015 and references therein). However, some of the most important spectral features used to reveal the compositions of minor planets are in the near-infrared region. A large survey with observations sampling this spectral region allows us to refine and complement the global picture of these bodies provided by SDSS and WISE data.

The survey conducted with the Visible and Infrared Survey Telescope for Astronomy (VISTA), the VISTA Hemisphere Survey (VHS[1]), provides such a survey for minor planets. VHS is the largest survey being conducted by the VISTA telescope. VHS images the entire southern hemisphere using four filters in the near-infrared region, namely *Y*, *J*, *H* and *Ks* (McMahon et al., 2013; Cross et al., 2012). The band centres of these filters are located at 1.02, 1.25, 1.65 and 2.15 μm respectively. Figure 1 shows the transmission curves of the VISTA filters compared to the spectra of two of the most typical asteroid classes, the primitive C-type and the rocky S-type. Notice that these four filters allow sampling of some of the main spectral features we expect for asteroids: the spectral slope and the two wide absorption bands at 1 and 2 μm, produced by minerals like olivine and pyroxene.

Detection of minor planets in VHS

With the aim of characterising the minor planet population in the VHS, we performed a serendipitous search within the observational products of the survey. In order to detect the minor planets, we used the fact that Solar System objects

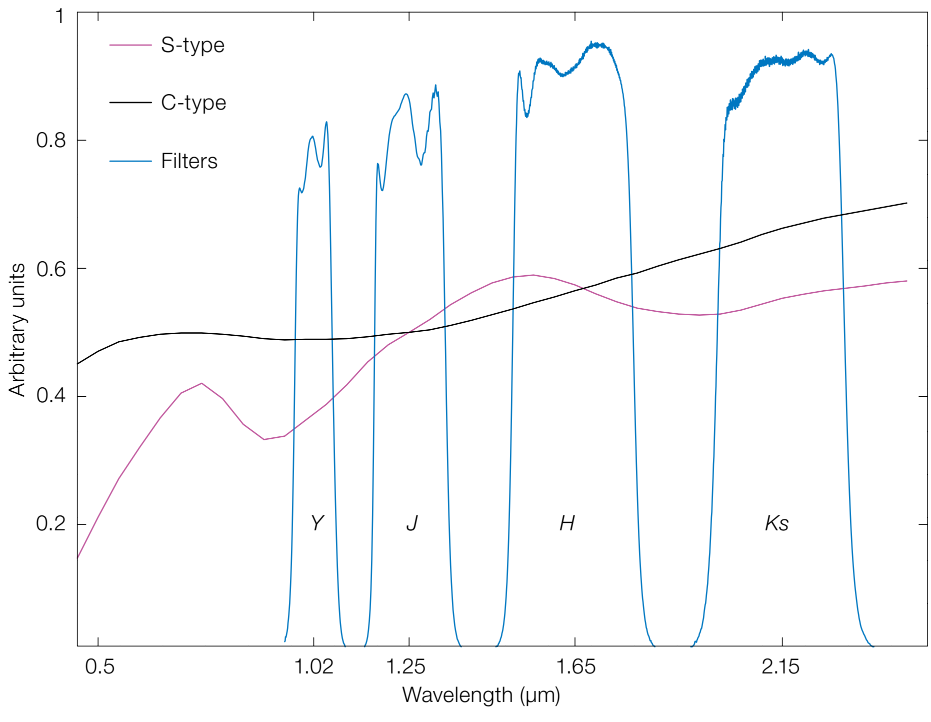

Figure 1. The normalised throughput profiles of the VISTA filter compared with two asteroid spectral types.

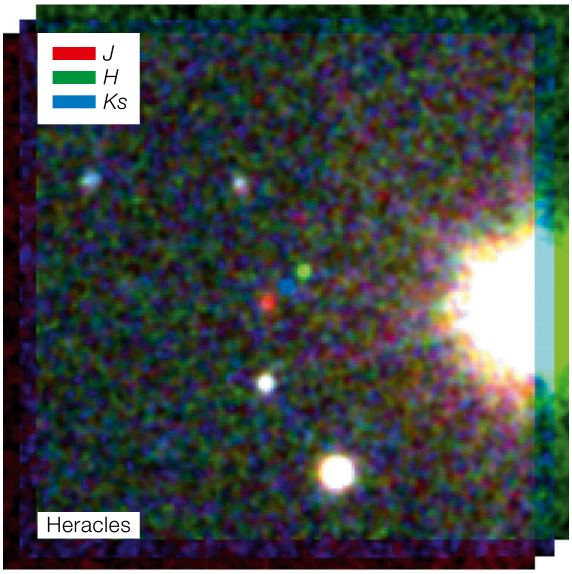

Figure 2. (Left) False-colour image obtained by combining the stack of frames observed with *J*, *H* and *Ks* filters on 5 November 2010. Owing to the differential motion of 0.24 arcseconds per minute, the asteroid (5143) Heracles appears as a different source in each filter.

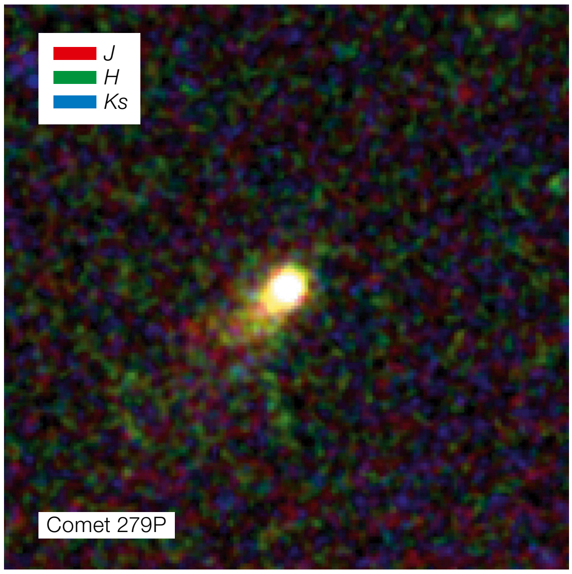

Figure 3. (Right) False-colour image obtained by combining the stack of frames observed with *J*, *H* and *Ks* filters for the comet 279P.

appear as moving sources compared with the background stars. This is exemplified in Figure 2, using a false-colour image obtained by combining the stack of frames observed with *J*-, *Ks*- and *H*-band filters on 5 November 2011 at 02:32, 02:42 and 02:52 UT, respectively. In this case, the near-Earth asteroid (5143) Heracles moved about 2.5 arcseconds between the three consecutive observations and hence appears as three separate images compared with the background stars.

Identifying the Solar System objects observed in a given field requires cross-matching of the detected coordinates with those computed at the moment of observation. A dedicated pipeline — called MOVIS (Moving Objects VISTA Survey) was designed for this task. The first step consists of predicting the position of Solar System objects potentially imaged in each field and retrieving the corresponding detections from the survey products. Secondly, MOVIS removes the mis-identifications based on an algorithm that takes into account the difference between the observed and the computed (O–C) positions and also by comparing with the PPXML star catalogue (of positions, proper motions, Two Micron All Sky Survey [2MASS] near-infrared and optical photometry). Finally, the information is provided in three catalogues for the purpose of organising the data for different types of analysis: MOVIS-D contains the parameters corresponding to all detections; MOVIS-M contains the magnitudes obtained with different filters for each object and selected by taking into account the timing constraints; and MOVIS-C lists the colours which are useful to infer the mineralogy.

The MOVIS catalogues are available online via the Centre de Données astronomiques de Strasbourg (CDS[2]) portal. The information provided includes observational details, and photometric and astrometric measurements. The astrometric positions, corresponding to 230 375 valid detections, were submitted to the International Astronomical Union Minor Planet Center[3], and all of them were validated. The observatory site received the code W91-VHS-VISTA.

The first published catalogues (Popescu et al., 2016a) used the VHS-DR3 data release, which contains the observations performed between 4 November 2009 and 20 October 2013. A total of 39 947 objects were detected, including 52 Near Earth Asteroids (NEAs), 325 Mars Crossers, 515 Hungaria asteroids, 38 428 Main Belt asteroids, 146 Cybele asteroids, 147 Hilda asteroids, 270 Trojans, 13 comets (see example in Figure 3), 12 Kuiper Belt objects and Neptune with its four satellites. About 10 000 objects have accurate spectro-photometric data (i.e., magnitude errors less than 0.1) allowing compositional information to be inferred (Popescu et al., 2016a).

The VHS-DR3 release covers ~ 40 % of the planned survey sky area; thus by the end of the survey the total number of Solar System objects observed will be at least double these numbers.

Near-infrared colours of minor planets

In order to derive compositional information for minor planets, it is necessary to correlate the spectral behaviour with the colours. This can be accomplished using the taxonomic classes of asteroid spectral data (since the large majority of the objects are asteroids). The main goal of taxonomies is to identify groups of asteroids that have similar surface compositions. The fact that spectra similar to the templates proposed by the taxonomic systems were systematically recovered by independent authors using diverse data sets and different methodologies provides confidence in these systems.

The first approach consisted of analysing the observed MOVIS-C colours for the objects already classified taxonomically. There are about 185 objects with spectra obtained by the Small Main-belt Asteroid Spectroscopic Survey (SMASS) and the S3OS2 visible spectroscopic survey of 820 asteroids. Within an error of ~ 5 %, the main compositional groups are completely

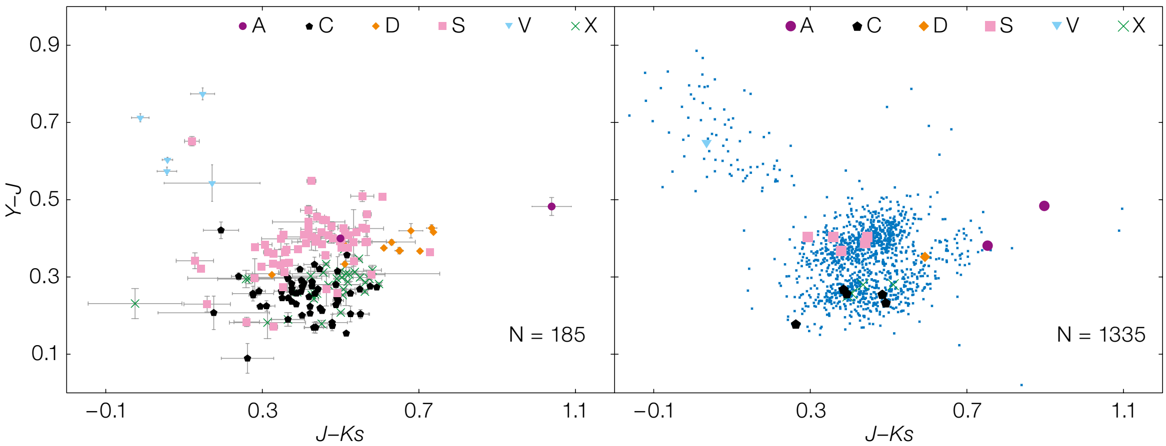

Figure 4. Left panel: the colours of asteroids with visible spectra, having an assigned taxonomic type. Right panel: the colours computed for the template spectra of the taxonomic classes from DeMeo et al. (2009) compared with the MOVIS-C data with colour errors less than 0.033 mag. From Popescu et al. (2016a).

separated (Figure 4) using the (*Y–J*) versus (*J–Ks*) colour-colour plot (Popescu et al., 2016a). This is the case for S-, C-, A-, D-, V- and C-type asteroids. S-type are objects with spectra similar to ordinary chondrite meteorites; C-type spectra are similar to carbonaceous chondrites; A-type are olivine-rich asteroids; D-type are objects with low albedo and a featureless red spectrum; V-type are asteroids with a basaltic composition, the most representative one being the asteroid (4) Vesta. The X-types present featureless spectra with a moderate slope and are representative of objects of different compositions: primitive, like carbonaceous chondrites; or metallic, like enstatite chondrites. Knowledge of the albedo is necessary to derive compositional information of an X-type asteroid.

The second approach is to compare the distribution of MOVIS-C data in colour-colour space with the position of colours computed for the template spectra of the different taxonomic classes spanning the visible to the near-infrared region (DeMeo et al., 2009).

In Popescu et al. (2016a) we show that the (*Y–J*) colour is a key parameter for a taxonomic classification: those with the 1 μm band have a large value of (*Y–J*) colour. The colour-colour plots which use the *Y* filter allow separation of the taxonomic classes much better than has previously been possible using other colours. Even for large photometric errors (up to 0.15 mag), the diagrams (*Y–J*) *vs* (*Y–Ks*) and (*Y–J*) vs (*J–Ks*) clearly separate the asteroids belonging to the main spectroscopic S- and C-complex, as well as the end taxonomic type members A-, D-, R-, and V-types (Popescu et al., 2016a). This survey thus provides an important tool for investigating the faint asteroids which are hard to observe spectroscopically.

Based on the available data we were able to classify about 10 000 objects using a probabilistic approach which takes into account the errors in the object photometry and the position of the class in colour space (Popescu et al., 2017). A further step is to integrate into this schema the photometric data obtained by SDSS and WISE.

A particular case: the basaltic asteroids

Basaltic asteroids are considered to be fragments of large bodies whose interiors reached the melting temperature of silicate rocks and subsequently differentiated (a core of heavy minerals is formed with a mantle of lighter minerals, such as olivine and pyroxene). These asteroids are classified as V-types and are identified by their spectrum in the 0.5–2.5 μm region which shows two deep and sharp absorption bands at 0.9 and 2 μm. Most of the objects with these characteristics orbit in the inner part of the Main Belt and are members of the Vesta collisional family, or are likely scattered members of this family. These objects are chunks of the crust of the asteroid (4) Vesta, ejected from it due to a collision. The presence of basaltic asteroids, unlikely to be scattered members of the Vesta family, clearly shows that there were other big differentiated basaltic asteroids in the Main Belt in the early age of the Solar System. This hypothesis challenges the models of the radial extent and the variability of the early Solar System temperature distribution, which generally do not predict melting temperatures in this region. V-type asteroids with orbits in the middle and outer part of the Main Belt are unlikely to be scattered Vesta family objects.

Near-infrared colours allow the easy identification of the V-type candidates: asteroids with (*Y–J*) > 0.5 and (*J–Ks*) > 0.3 mag are likely to be members of this class. Using the more accurate MOVIS-C data (with uncertainties < 0.1 mag), and the colour criteria described above, we have identified 477 objects, of which 244 of the V-type candidates are outside the Vesta dynamical family (Figure 5). This sample almost doubles the number of known V-types that are not members of the Vesta family (Licandro et al., 2016). In particular we identified 19 V-type asteroids beyond the 3:1 mean motion resonance, 13 of them in the middle part of the Main Belt and six in the outer part.

Acknowledgements

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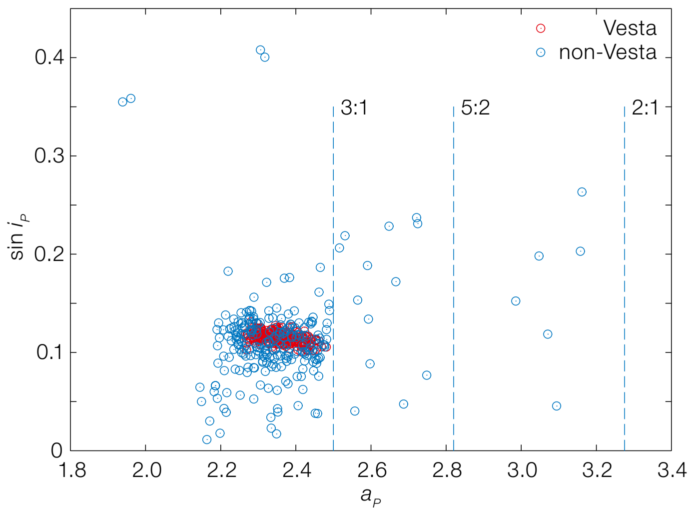

Figure 5. Distribution in proper orbital elements of the V-type candidates from the VHS survey. The figure shows the proper semi-major axis (a_p) *vs* the sine of the proper inclination (i_p). Red circles are Vesta family members, while blue circles indicate objects out of the Vesta family. The vertical dashed lines correspond to the most relevant mean motion resonances (Licandro et al., 2016).

References

Cross, N. J. G. et al. 2012, A&A, 548, A119
DeMeo, F. E. et al. 2009, Icarus, 202, 160
DeMeo, F. E. et al. 2015, Asteroids IV, University of Arizona Press, 13
Licandro, J. et al. 2016, A&A, submitted
McMahon, R. G. et al. 2013, The Messenger, 154, 35
Popescu, M. et al. 2016a, A&A, 591, A115
Popescu, M. et al. 2017, in preparation

Links

[1] VHS: http://www.vista-vhs.org/
[2] CDS catalogues: http://cdsarc.u-strasbg.fr/viz-bin/Cat
[3] IAU Minor Planet Center: http://www.minorplanetcenter.net/iau/mpc.html
[4] http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=J/A%2BA/591/A115

R. Wesson/ESO

Composite image of sunset and star trails over the La Silla Observatory photographed from the 3.6-metre telescope with a series of long exposures. See Picture of the Week potw1647 for information.