Asteroid Colours in the PS1 Photometric System

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1. Introduction

MOPS and OSS-pipeline detections of moving objects primarily come from the SS field survey in the PS1 w-filter, and via the 3-pi survey in the PS1 grizy system. The (somewhat discrepant) findings of previous investigations into the colours of solar system objects have been summarized by Rob Jedicke and Richard Wainscoat and are given on the PS1wiki at: http://ps1sc.ifa.hawaii.edu/PS1wiki/index.php/KP1-PS1-Filter-Transformations-Summary-2011-Mar-18

For detections in the surveys, observations of single objects with small cadence between tracklets in pairs of filters may give colour and therefore taxonomic information. For the 3pi survey as a whole, the hundreds of thousands of detections should allow statistical derivation of mean colours of groups of main belt asteroids by averaging out the variations due to lightcurve modulation (up to ~1 magnitude). Investigations of dynamical families and collisional families will also be possible.

In the w-filter it may be important to know whether the composition gradient in the asteroid belt leads to a measurable effect in completeness in absolute magnitude H, beyond the first-order effect of increasing distance. These studies require knowledge of the predicted colours of asteroids of various taxonomic classes in the PS1 system.

2. Initial PS1 Solar Colours

Magnitudes and colours can be calculated in the AB system according to the definitions given by Fukugita et al. (1996) along with the initial atmospheric, telescope, instrument and filter data compiled by John Tonry (2010). For the majority of asteroids the above-atmosphere spectrum can be considered as a perturbation of the solar spectrum, apart from some extreme objects such as (3200) Phaethon. Therefore solar colours in the PS1 system were calculated using two sources for the solar spectrum, that contained in the CALSPEC package which was obtained from Colina, Bohlin, & Castelli (1996), and the ASTM standard extraterrestrial spectrum reference E-490 (2006). These were then compared with colours calculated by Tonry (2010), and also by calculating colours using the polynomial relationships relating UBVRcIc - SDSS colours and similar equations for PS1-SDSS conversion by Tonry (2010).

PS1 Solar Colour (old system throughputs)	(g-r)	(r-i)	(i-z)	(z-y)	(w-g)	(w-r)
ASTM E-490	0.39	0.12	-0.02	0.01	-0.33	0.06
CALSPEC	0.40	0.11	0.02	0.00	-0.33	0.06
Tonry (2010)	0.40	0.11	0.02	0.00	-0.33	0.07
Polynomial transformations	0.35	0.11	0.02			0.06

In general the agreement is excellent, the ~0.04 mag disagreement in the polynomial transformation of (g-r) is may be due to the relatively poor fit between the PS1 and SDSS magnitudes in the g-band transformation equation. It is interesting that the two solar reference spectra used differ by 0.04 magnitudes or 4% in (i-z). In order to maintain as close a correspondence between the expected and calculated colours, the CALSPEC solar spectrum was used in all further calculations.

3. PS1 asteroid and solar grizyw asteroid colours

Following the previous calculations, revised system throughputs were provided by John Tonry, showing subtle changes caused primarily by the inclusion of more accurate atmospheric absorption and scattering functions. These revised throughputs are used in the paper defining the PS1 photometric system (Tonry et al. 2011, in preparation); comparison with the old throughputs showed differences in calculated colours of ≤ 0.01 magnitudes.

Calculation of asteroid colours should be simply a matter of taking the solar spectrum, multiplying it by a high quality reflectance spectrum such as those obtained in the SMASSII database (REF), and calculating the colours as above. The problem here is the wide wavelength span encompassed by the PS1 filter set, from <400nm for the g and w-filters, to >1050nm for the z-filter. There are no modern spectroscopic surveys of asteroids that encompass this entire wavelength range, so the asteroid reflectance spectra have been constructed by using the mean taxonomic class reflectances given by deMeo et al. (2009) at >=450nm together with reflectances of bright asteroids in those classes from the ECAS survey by Tholen et al. (1989).

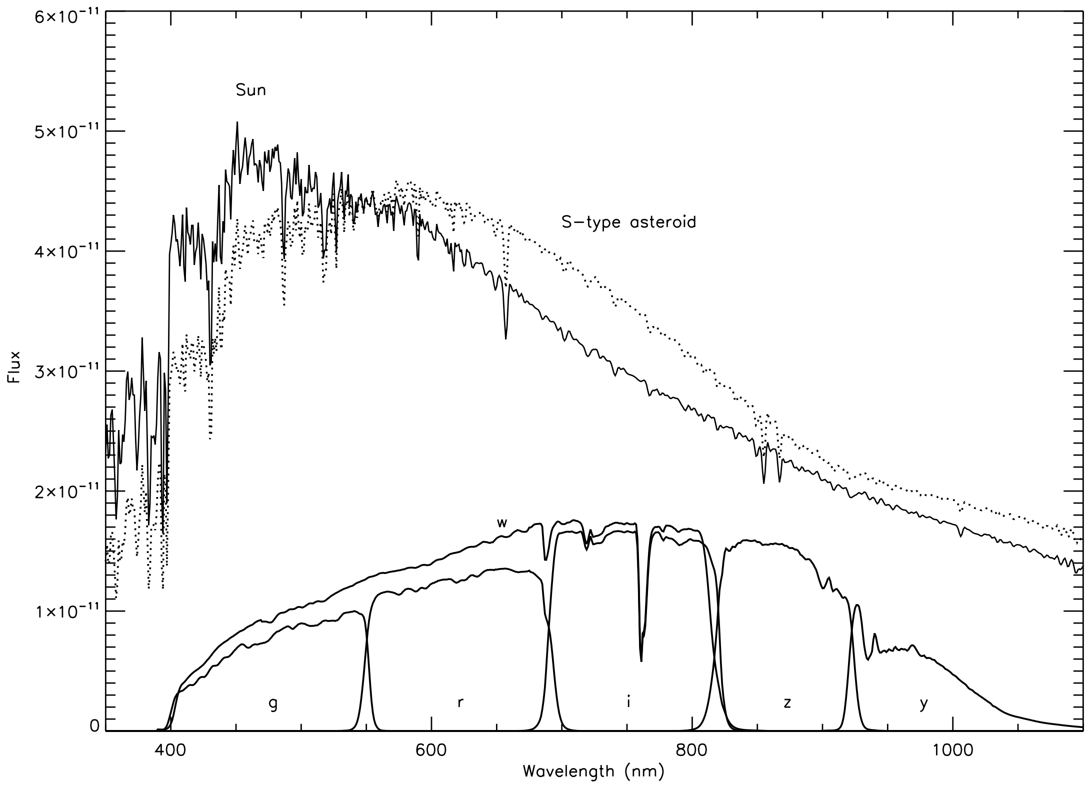

Figure 1: Comparison of the spectra of the Sun and a S-type asteroid, together with the relative system throughputs in the PS1 grizyw filter bandpasses.

Taxonomic Class	(g-r)	(r-i)	(i-z)	(z-y)	(w-g)	(w-r)
Solar	0.400	0.109	0.018	0.000	-0.331	0.069
S	0.600	0.196	-0.054	-0.006	-0.524	0.076
Q	0.563	0.128	-0.141	-0.080	-0.468	0.095
C	0.432	0.114	0.012	-0.005	-0.358	0.074
B	0.416	0.087	-0.017	-0.026	-0.336	0.080
X	0.454	0.160	0.052	0.030	-0.392	0.061
D	0.527	0.214	0.092	0.075	-0.472	0.056
Total Range	**0.17**	**0.10**	**0.23**	**0.16**	**0.17**	**0.04**
Mean colour (S+C)	**0.52**	**0.16**	**-0.02**	**-0.01**	**0.44**	**0.08**

Although colours are given to three decimal places, it should be remembered that uncertainties and variations in the instrumental optical and filter throughputs, plus the natural variation between asteroids of similar mineralogies, will likely cause a scatter of >0.02 magnitudes. The largest intrinsic difference between spectral classes occurs in the (i-z) colour, as this spans the onset of the strong pyroxine absorption band longwards of 800nm.

It can be seen that the colour differences between classes are only ~0.1-0.2 magnitudes. Hence individual colours of most asteroids will be highly suspect due to lightcurve effects. However, with $>10^5$ asteroids already observed, mean colours should allow accurate statistical conclusions to be made.

4. Johnson-PS1 colours

To calculate V-band magnitudes, the V-band response function from Bessell (1990) and the CALSPEC spectra of Vega and the Sun were used. A V-band magnitude for Vega of 0.035 was assumed to give the absolute calibration on the Johnson system.

Taxonomic Class	(V-g)	(V-r)	(V-i)	(V-z)	(V-y)	(V-w)
Sun	-0.217	0.183	0.292	0.311	0.311	0.114
S	-0.325	0.275	0.470	0.416	0.411	0.199
Q	-0.312	0.252	0.379	0.238	0.158	0.156
C	-0.238	0.194	0.308	0.320	0.316	0.120
B	-0.229	0.187	0.274	0.257	0.231	0.107
X	-0.247	0.207	0.367	0.419	0.450	0.146
D	-0.281	0.246	0.460	0.551	0.627	0.191
Total range of asteroid colours	**0.09**	**0.08**	**0.16**	**0.31**	**0.47**	**0.09**
Mean colour (S+C)	**-0.28**	**0.23**	**0.39**	**0.37**	**0.36**	**0.16**

5. <u>Colour variations within taxonomic classes.</u>

Being able to differentiate between different taxonomic types depends on (a) the amount of lightcurve variation present between filter measurements, normally taken within ~20 minutes for a trackelty in the 3Pi survey, and (b) the inherent spread of colours within taxonomic classes. To test this a set of asteroid spectra were obtained from the PDS asteroid node. Optical spectra came from the extensive SMASSII database, with the provisio that many do not extent down to the blue wing of the g-filter and hence g magnitudes cannot be calculated.

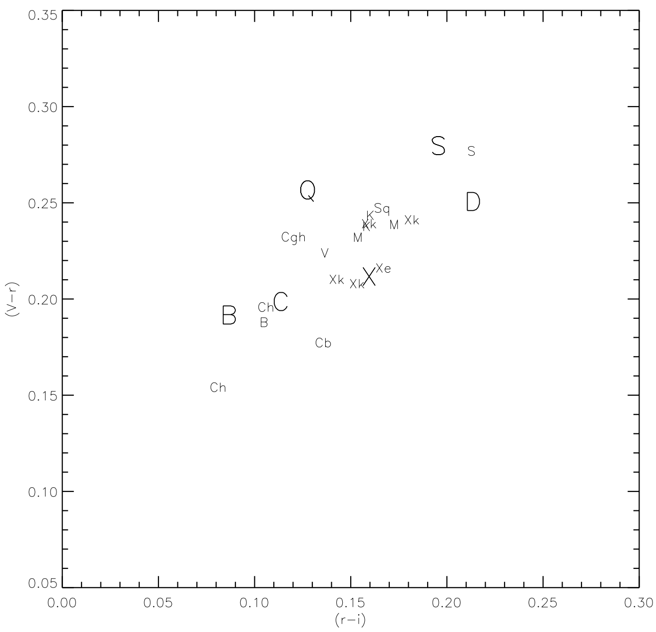

Figure 2(a): (V-r) versus (r-i) calculated for individual asteroids (small characters) and DeMeo taxonomic classes (large characters).

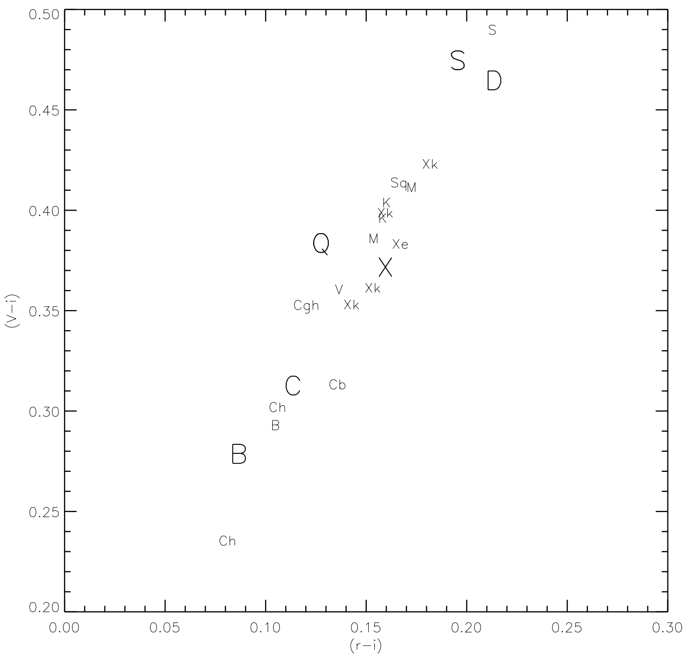

Figure 2(b): (V-i) versus (r-i) calculated for individual asteroids (small characters) and DeMeo taxonomic classes (large characters).

These figures indicate that natural variations within the general taxonomic classes can result in a colour spread ~0.1 magnitudes.

6. Conclusions

Two conclusions are drawn from this study.

First, the current transformations used by the MPC need a small adjustment (albeit at a level < 0.1 magnitudes), as they broadly reflect the colours expected of only S-type asteroids in the PS1 photometric system. Given that PS1 is detecting objects throughout the main-belt, and due to the likely dominance of S and C-class asteroids, it is suggested that the mean of the S+C colours given in the bottom of the table row are used. In due course a transformation based on orbital semi-major axis could also be considered at the MPC for objects with known orbital elements.

Second, considering survey completeness as a function of absolute magnitude H_V through the asteroid belt, the composition gradient means that systematic offsets of ~0.1 magnitudes can arise between the S-class and C-class dominated regions either side of the 3:1 mean motion resonance at 2.5AU.