Asteroid color photometry with Gaia and synergies with other space missions

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&

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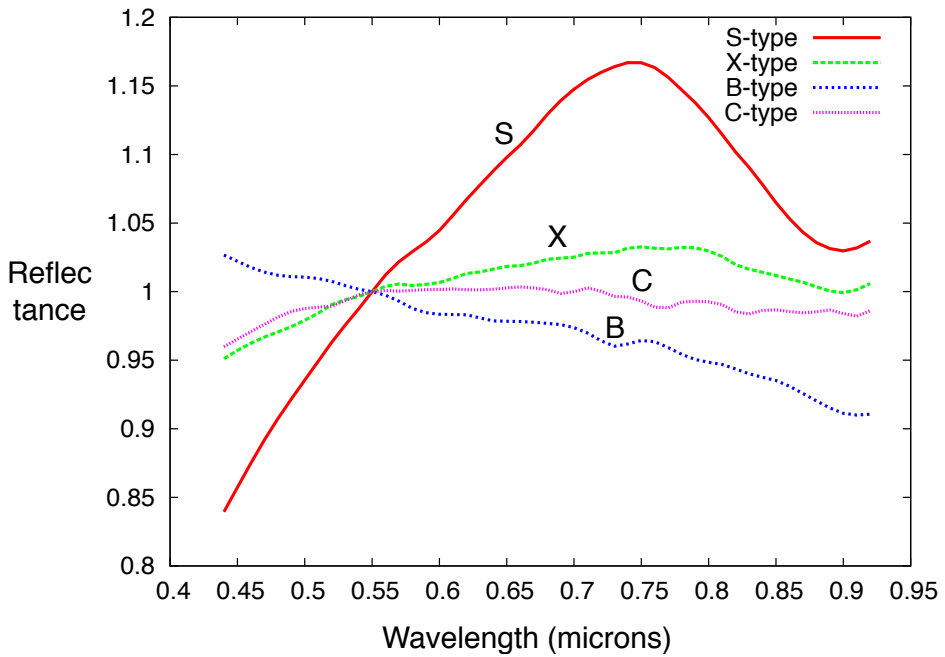
Outline of the presentation

Asteroid spectral types

Asteroids are assigned a type based on spectral shape. These types are thought to correspond to an asteroid's surface composition.

Bus and Binzel spectral types:

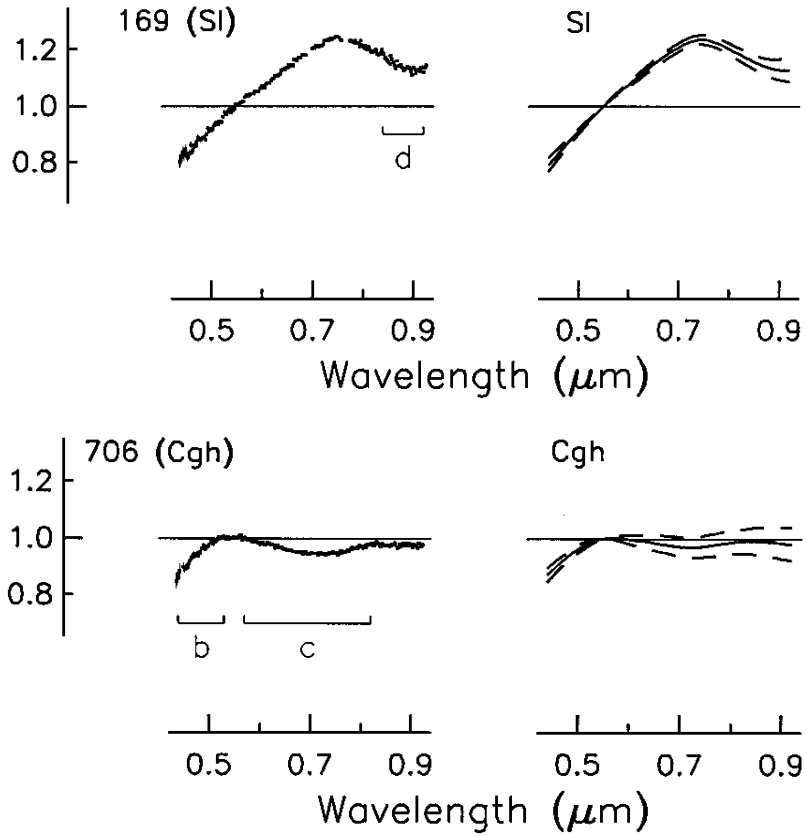
- C-group (carbonaceus) with a featureless spectrum
  - B-type (featureless and blue)
- S-group (stony) with silicate absorption bands
- X-group of mostly metallic objects including enstatite-chondrite like spectra



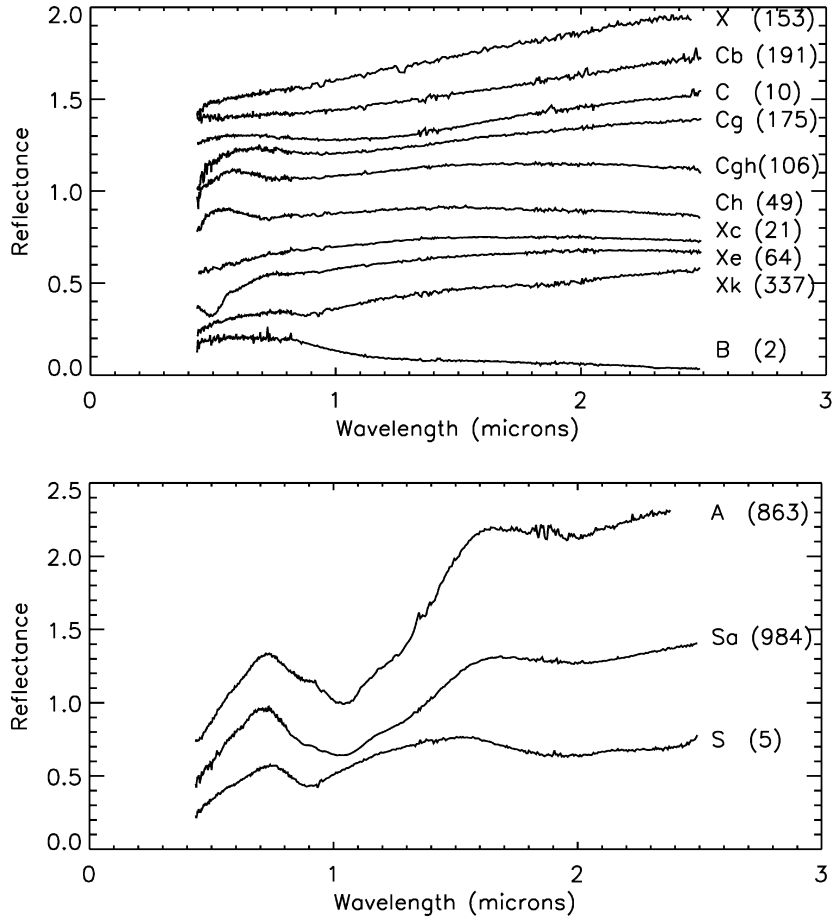
from the SMASS web site, by R. Binzel and collaborators

Modern CCD based asteroid spectroscopy

Bus and Binzel 2002



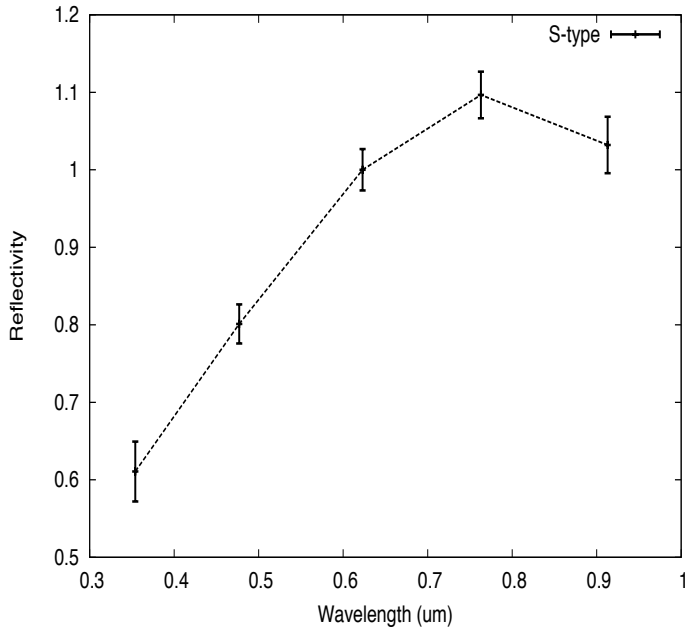
DeMeo et al., 2009

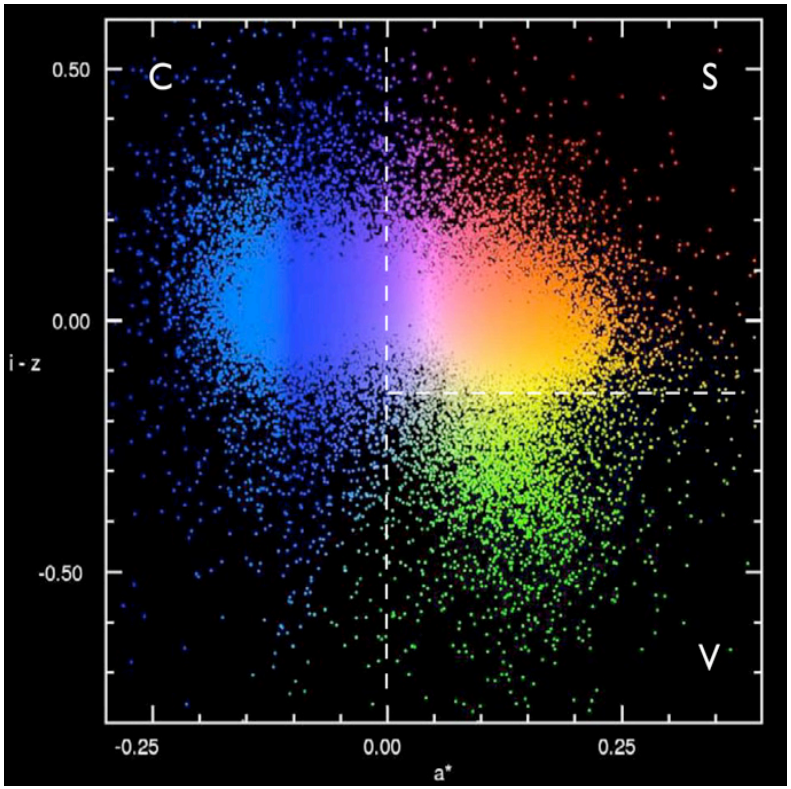


- However, all spectra do not go shortwards 450nm.
- Most available data in the blue region (340-550nm) are very poor in quality.

Sloan Digital Sky Survey (SDSS); Parker et al. (08) colors

SDSS: color photometry of more than 100,000 asteroids.
Example from the SDSS Moving Object Catalog 4 (MOC4).

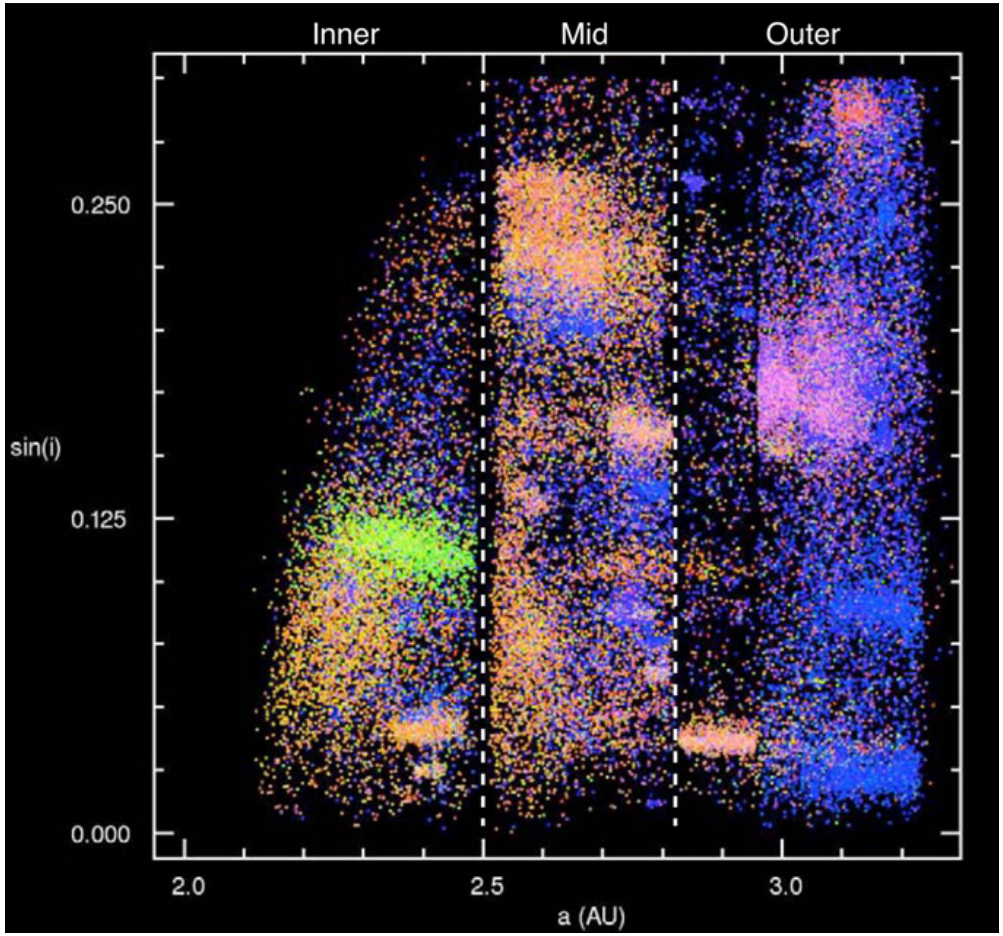




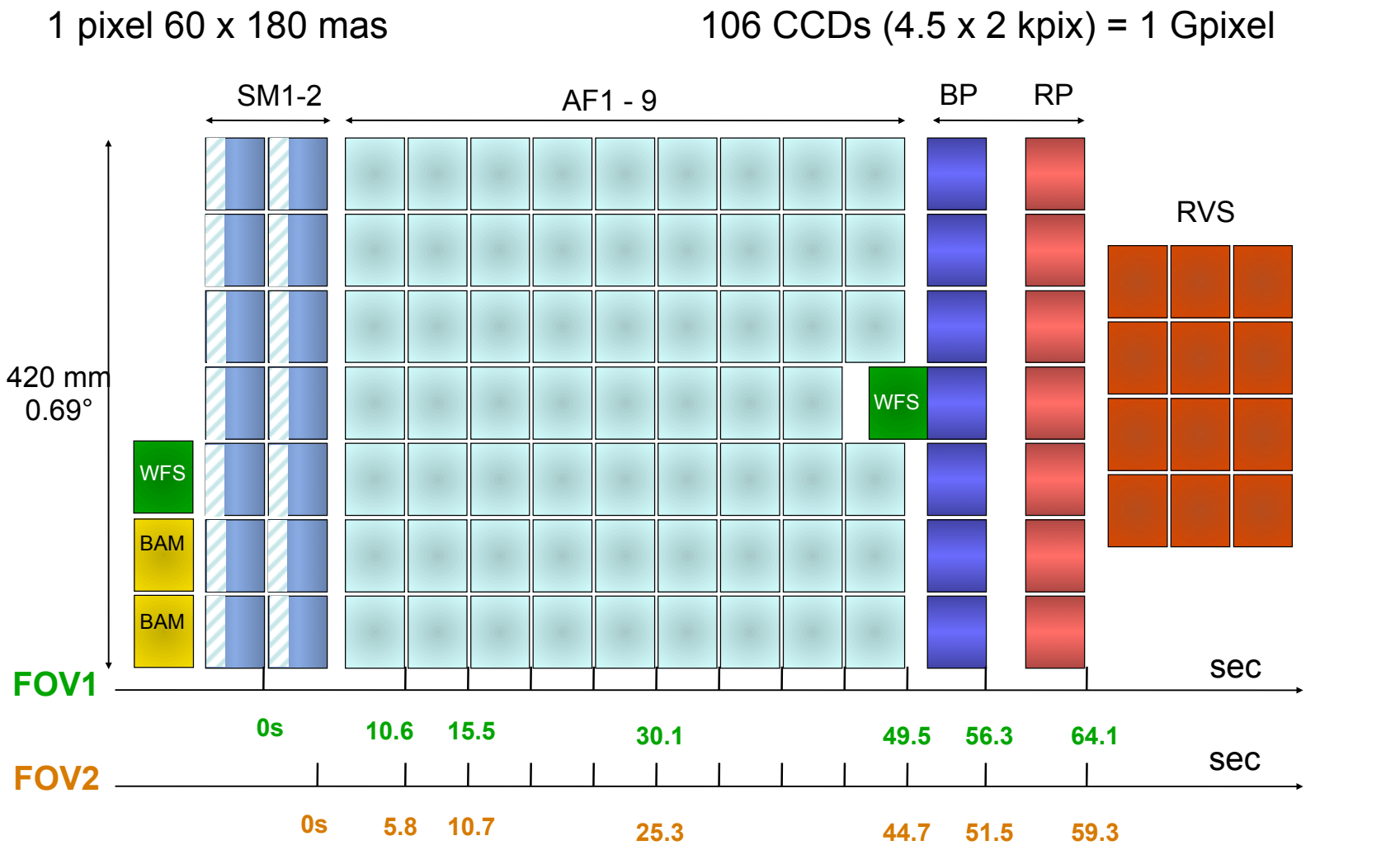
bands: u':354, g':477, r':623, i':763, z':913 (mn)
with $a^* = 0.89(g' - r') + 0.45(r' - i') - 0.57$.

Asteroid spectral classes and mineralogy of the main belt

- Investigation of the mineralogy of families.
- Comparison of spectra of NEAs with those of families near the NEA source regions...
  with the help of dynamical models; see e.g. De Leon et al. 2010; Campins et al. 2010; Jenniskens et al. 2010; Walsh et al. 2011; Gayon-Markt et al. 2011; etc..)

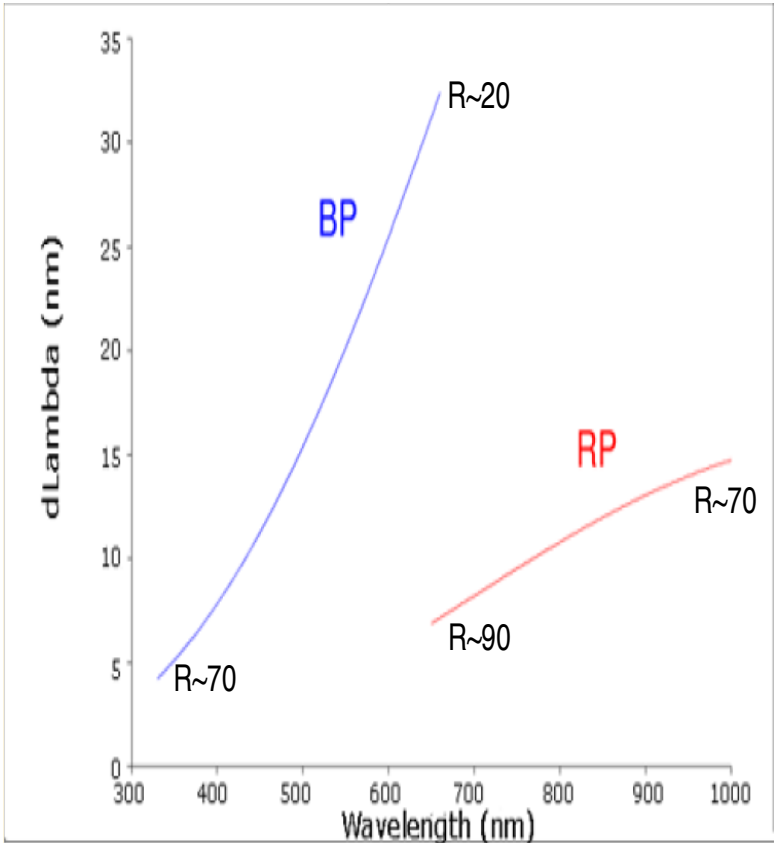


The photometers on the focal plane of Gaia



disclaimer: in the Gaia community, BP-RP data is called color phometry; it is low resolution ($R \sim 20 - 90$) slit-less spectroscopy, though.

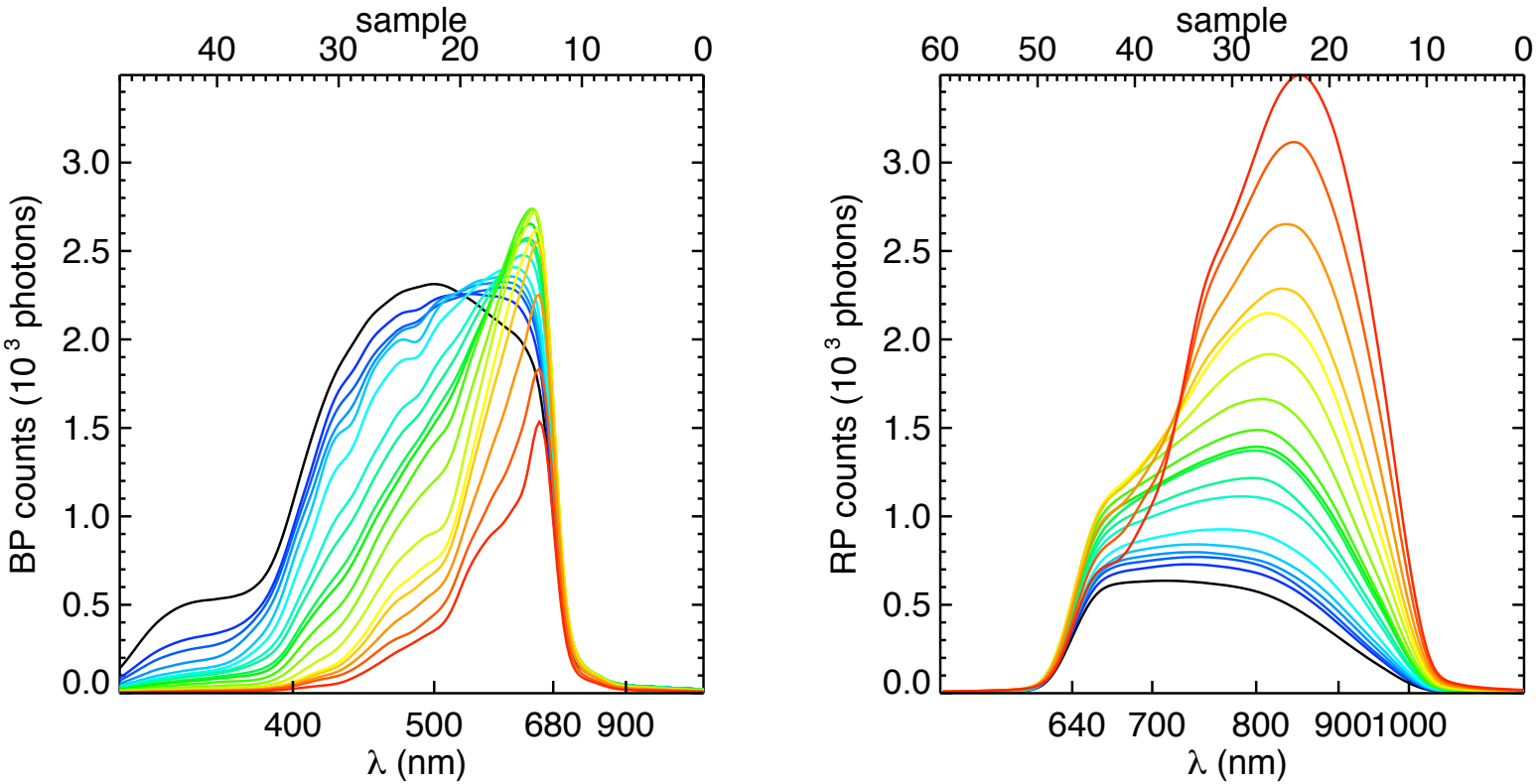
The photometers: resolving power ($R = \frac{\lambda}{\Delta\lambda}$)



- Sampling is such to have about 18 independent bands in the BP-RP domain (A. Brown, spring 2011)
- Sampling is 60 pixel per photometer, signal is in general contained in 40 pixel per photometer.
- Telescope PSF FWHM is about 2 pixels AL (40/2∼20 independent bands) and 1 pixel AC.
- 80% of asteroid observations have velocities $\leq$15 mas/s.
  Beacuse a CCD transit lasts 4 s $\rightarrow$ $\leq$1 pixel widening of the PSF: this is not too bad.

BP-RP response for point like sources

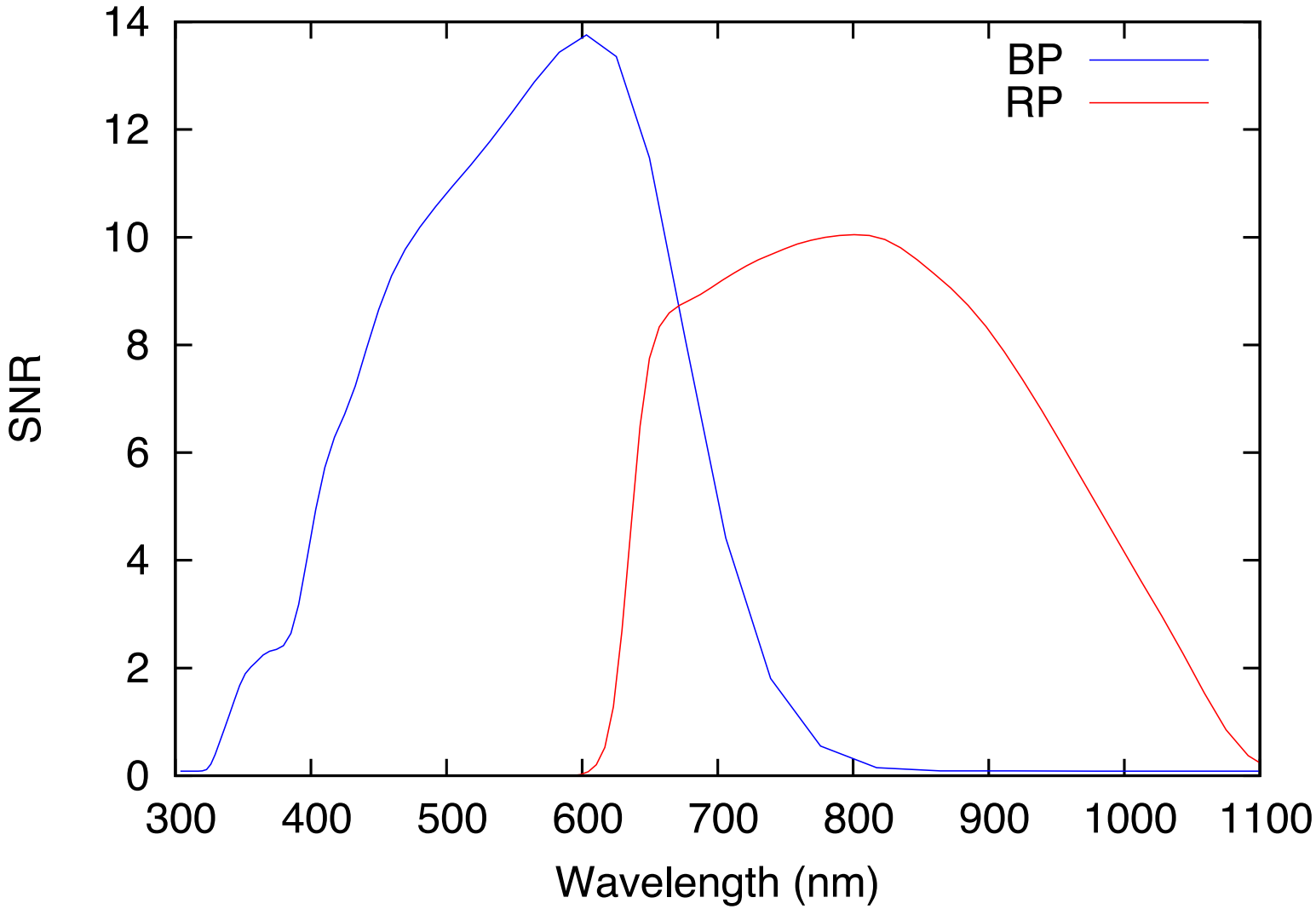
G=15 point source with different colors.



G2V star is the middle green curve.

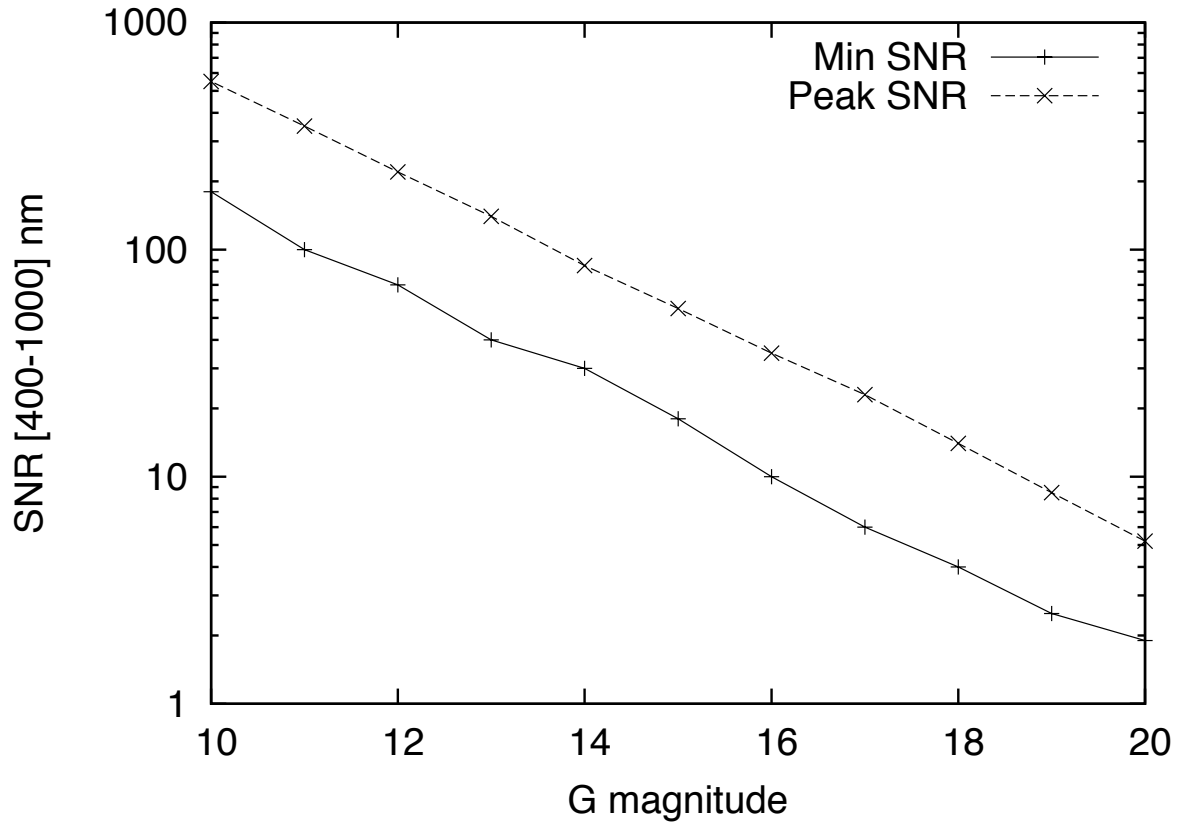
Credits: Busso, G. & Brown, A. 2009

BP-RP SNR for an asteroid with G=17



Photon Noise limited in general. So SNR=$\sqrt{N_{photons}}$

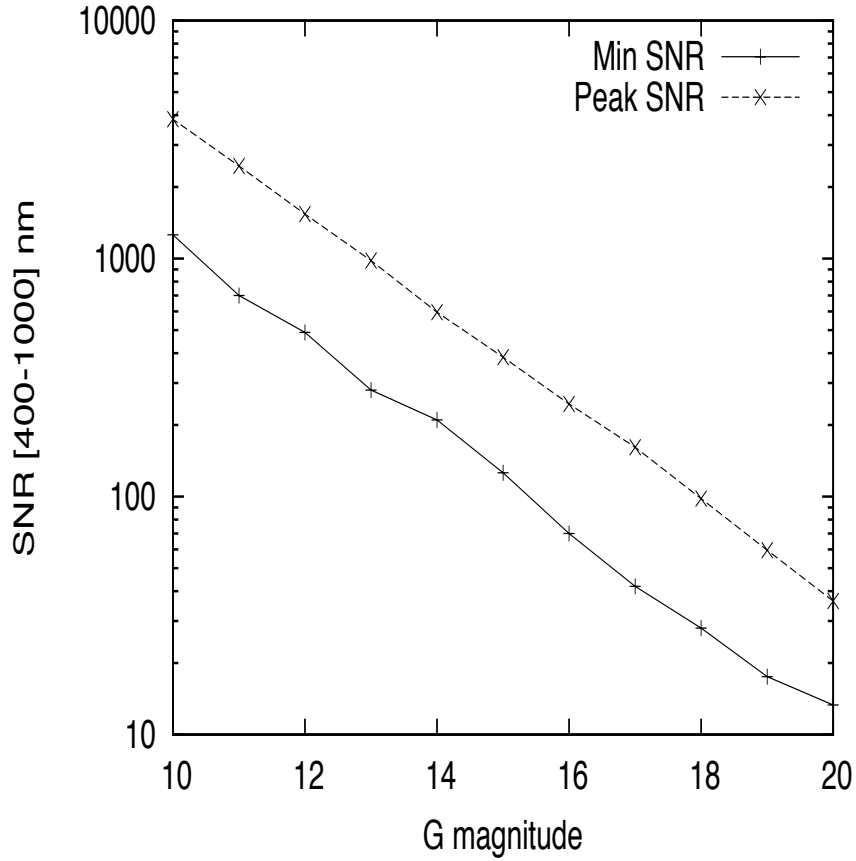
BP-RP SNR as function of magnitude (1 transit)



- Minimum and Peak SNR in the range 400-1000 nm per transit.
- Best fit to min SNR: SNR$=17631 \times 10^{-0.201317 * G}$

Average SNR for BP-RP at the end of mission

- The large majority of asteroids (main belt) are observed at least 60 times [Mignard, F. 2001 (SAGFM09)]
- The SNR of the accumulated (avarage spectrum) is 8 times larger

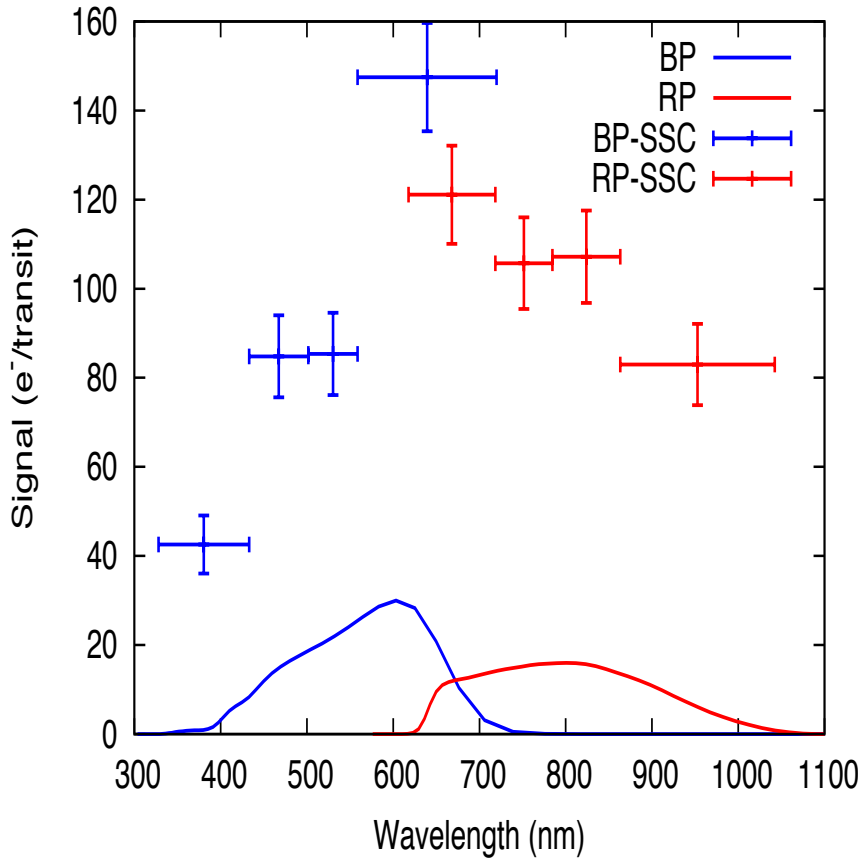


Minimum SNR at the end of the mission assuming 50 transit/asteroid

For asteroids with G=19-20 spectral classification will be difficult.
Solution:?!: Spectral binning.

Spectral Shape Coefficients: 8-colors asteroid survey

- Spectral Shape Coefficients (SSCs; 4 for BP and 4 for RP; 8 colors for each source) are calculated by IDT (Initial Data Treatment).
- SSCs calculated also by PhotPipe and refined at every cycle.
- Potentially very interesting for performing an 8-colors asteroid survey.



Example of SSC values calculated for a BP-RP signal of a G=20 asteroid (solar-like spectrum).

Data products for asteroid color photometry

- The spectral energy distribution (SED) is obtained from accumulated BP-RP data.
  - Average SEDs is produced (1 per asteroid).
  - Epoch SEDs is also produced where possible (for SNR$\geq$20 per transit $\sim$G$\leq$15).
  - Smearing due to proper motion is taken into account.
- Asteroid reflectivity is calculated from the SED.
  - BP and RP SEDs are combined into one SED.
  - The SED is divided by the solar spectrum and the results normalized at 0.55 microns.
- The asteroid reflectivity is used to determine the asteroid spectral class.
  - Unsupervised clustering algorithm.
  - Comparison with other classifications (e.g. Bus & Binzel).

Clustering method based on Minimal Spanning Tree (MST)

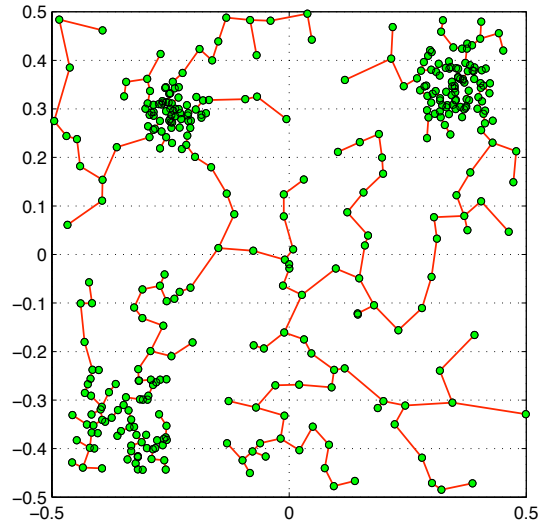
Galluccio et al. (2008)
Method for partitioning a set V of N data points ($V \in \mathbb{R}^L$) into K non-overlapping clusters with:

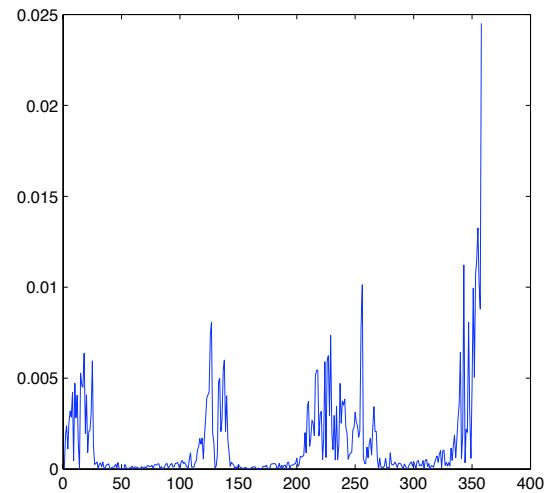
- the inter-cluster variance is maximized;
- the intra-cluster variance is minimized.

Identification of the number of clusters:

- The lenght of the edge at each addition of a vertex of the MST is recorded.
- Then by identifying valleys in this curve, we can estimate the number and positions of high density regions of points $\rightarrow$ i.e. the clusters.

Example of MST in $\mathbb{R}^2$





Test of the classification algorithm

- Spectra of asteroids belonging to all spectral classes were obtained at the Telescopio Nazionale Galileo (TNG) under Gaia-like observing geometry.
  PI Paolo Tanga; Data analysis in progress.

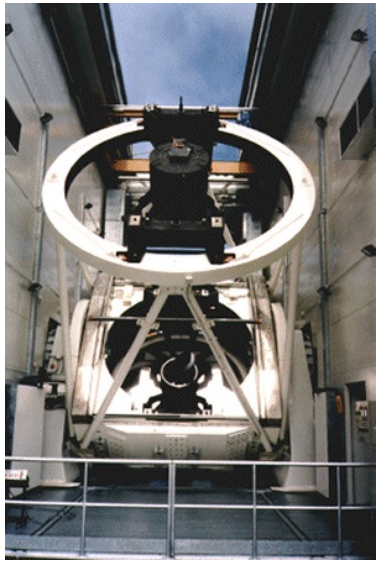
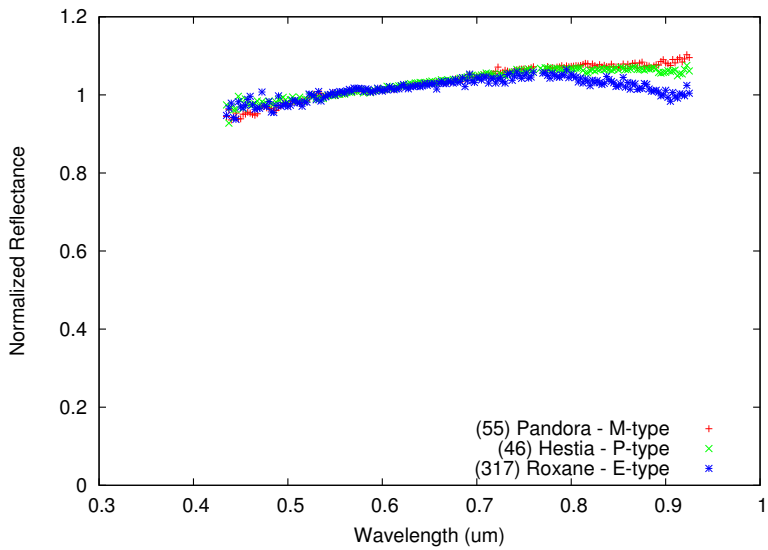


photo credits: P. Tanga

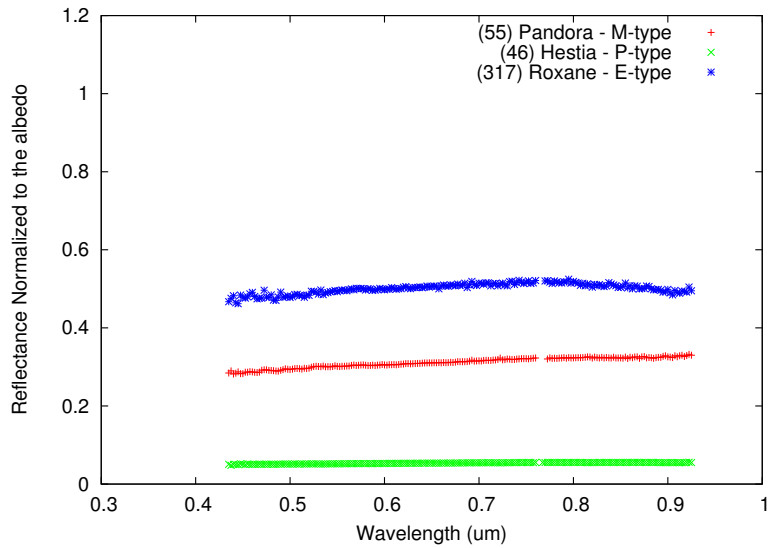
- See next talk by Julie Gayon-Markt.

Removal of spectral classification degeneracies

There are some well known degeneracies in the mineralogical interpretation of asteroid spectral classes.
For instance, asteroids (46) Hestia, (55) Pandora, and (317) Roxane have very similar spectra.



But asteroids (46) Hestia, (55) Pandora, and (317) Roxane have different albedos.

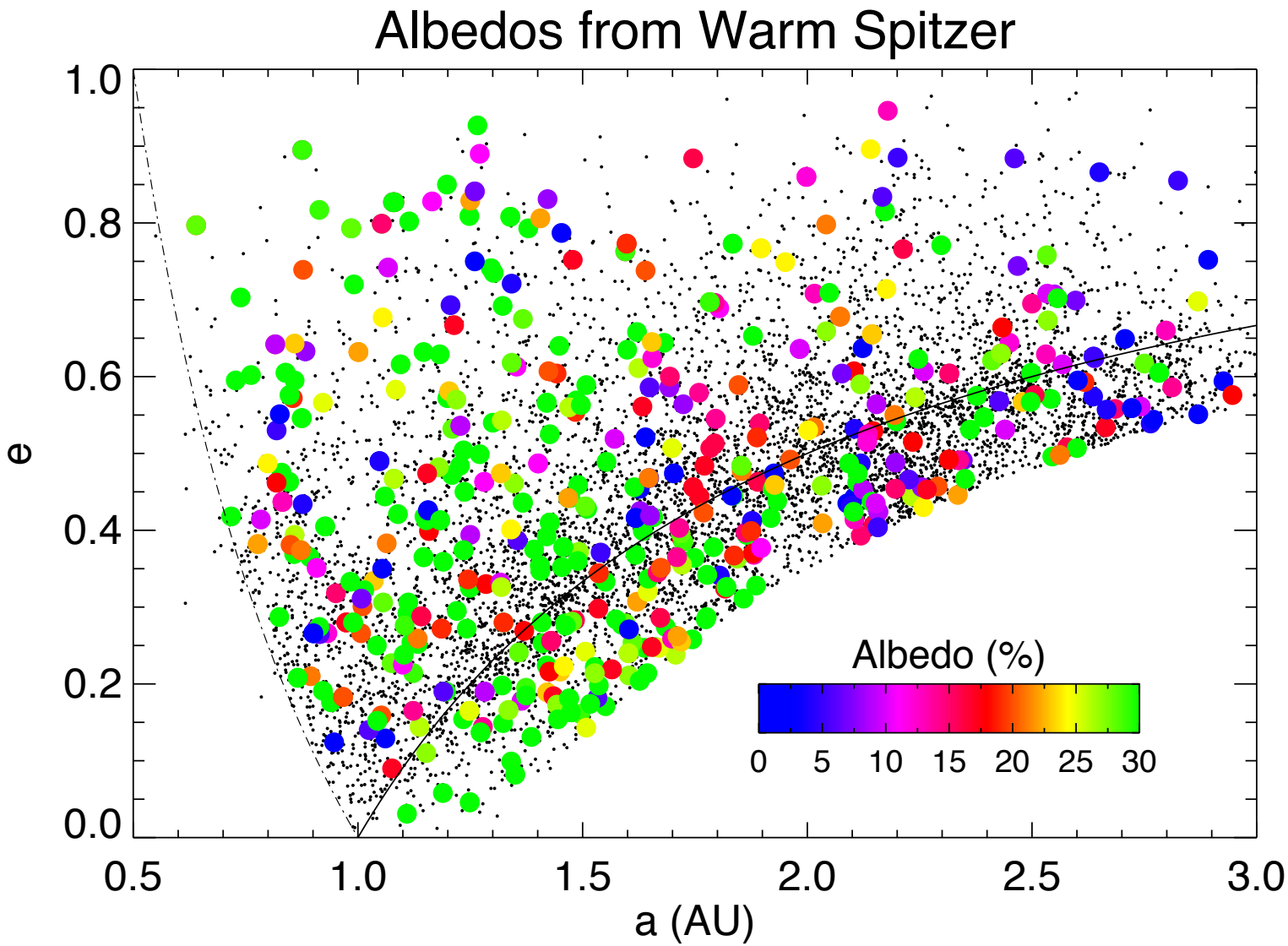


Albedo + spectra $\rightarrow$ removal of spectral class degeneracies.

Asteroid spectral classification (Gaia + WISE data)

- NASA WISE has observed 100,000 asteroids in the thermal IR.
- Albedos will be obtained from WISE data.
- First data (IR images) already released.
- Albedo + spectra $\rightarrow$ removal of spectral class degeneracies.
- Albedo and spectra can be classified using our non supervised classification algorithm.

ExploreNEOs with Warm Spitzer: PI D. Trilling (NAU)



Conclusions

DPAC products (from Gaia observations only):

- Gaia will obtain $R \sim 20 - 90$ visible spectra of asteroids.
- Average spectra (reflectancies) will be published.
- Epoch spectra for the brighter asteroids.
- Spectral classes of asteroids will be also published.

Gaia + Auxiliary data (e.g. WISE albedos):

- Albedo from WISE or Spitzer will allow spectral classes degeneracies to be removed
  $\rightarrow$ mineralogical map of the main belt.