EXCELENCIA SEVERO OCHOA

Near-infrared color of small bodies from VISTA-VHS survey

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OUR TEAM

RESEARCHERS AT IAC:

- Javier Licandro (PI – Investigador Titular)
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- Julia de León (post-doc)
- Miquel Serra Ricart (staff)
- David Morate (PhD student)
- Vania Lorenzi (PhD student, TNG support astronomer)
- Mário da Pra ("Ciencia sem fronteras" PhD student)

MORE ACTIVE COOPERATIONS:

Humberto Campins (UCF – OSIRIS-Rex)

Marco Delbo & Víctor Alí Lagoa (Nice)

Fernando Moreno (IAA)

Marcel Popesku (Rumania)

Gonzalo Tancredi and Julio Fernández (UdelaR, Uruguay)

Jorge Marcio Carvano et al. (ON)

OUR SCIENCE

PRIMITIVE ASTEROIDS:

- OSIRIS-Rex Science Team
- Physical characterization of NEAs that can be space mission targets
- Inner MB primitive families (Polanas, Erigones, Sulamitis, Massalia)
- The B-type asteroids
- Outer main belt primitive asteroids

TRANSITIONAL OBJECTS (ACOs and activated asteroids)

The VHS-VISTA small bodies infrared catalogue
J-PLUS & J-PASS (via "Ciencia sem Fronteiras" cooperation)

EURONEAR

- follow-up and photometry
- Precovery
- Spectroscopy
- lowDeltaV & NASA program (follow-up spectroscopy)

TNOs and CENTAURS

MID-IR camera/spectrograph for space missions

OUR TOOLS

OBSERVATIONS:

- Spectroscopy, from 0.35 to 25 microns
- Imaging, from 0.35 to 25 microns

USE OF CATALOGUES AND DATABASES:

- WISE/NEOWISE
- SDSS
- VHS-VISTA
- Preparing for J-PLUS, J-PASS and GAIA
- NEA Precovery

MODELLING:

- Light-Scattering models
- MGM and Gaffey analysys of asteroid bands
- MC Dust-tail models
- Thermal and thermophysical models

TECHNOLOGY:

- Mid-infrarred detectors for space mission

Baseline Detector for THERMAP: the uncooled 640x480 ULIS microbolometer array

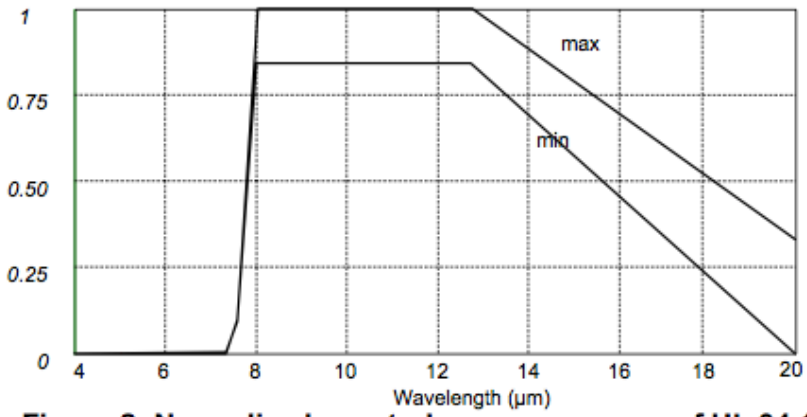
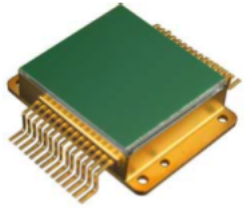
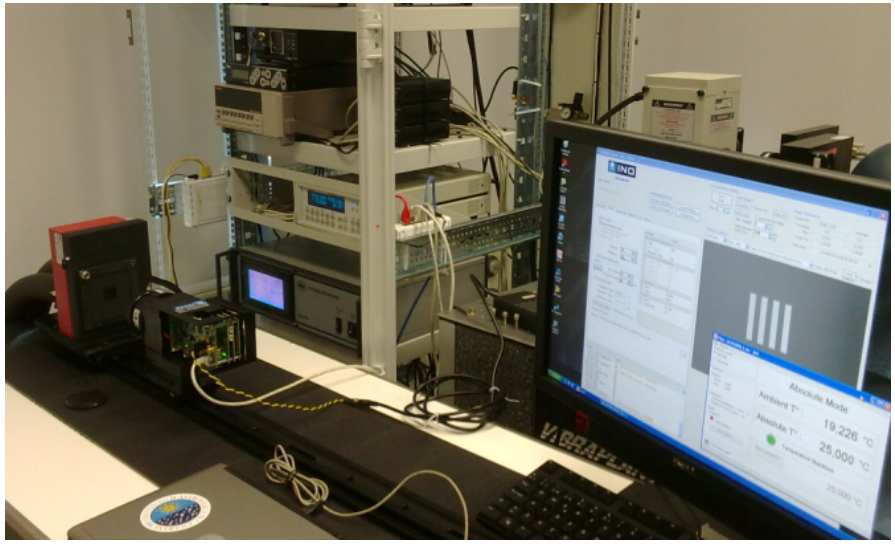
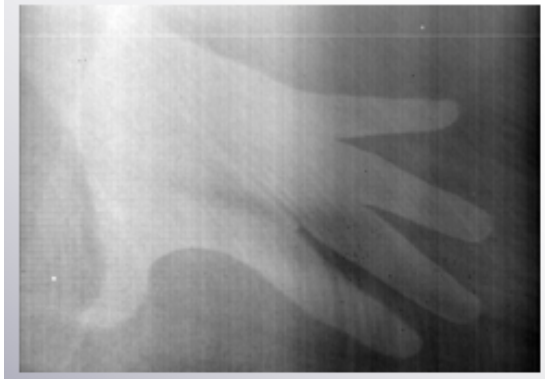


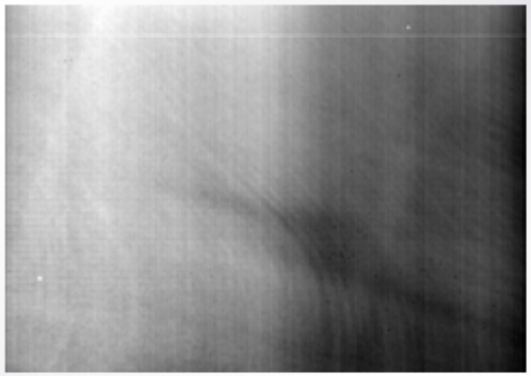
Figure 2: Normalized spectral response gauge of UL 04 17 1



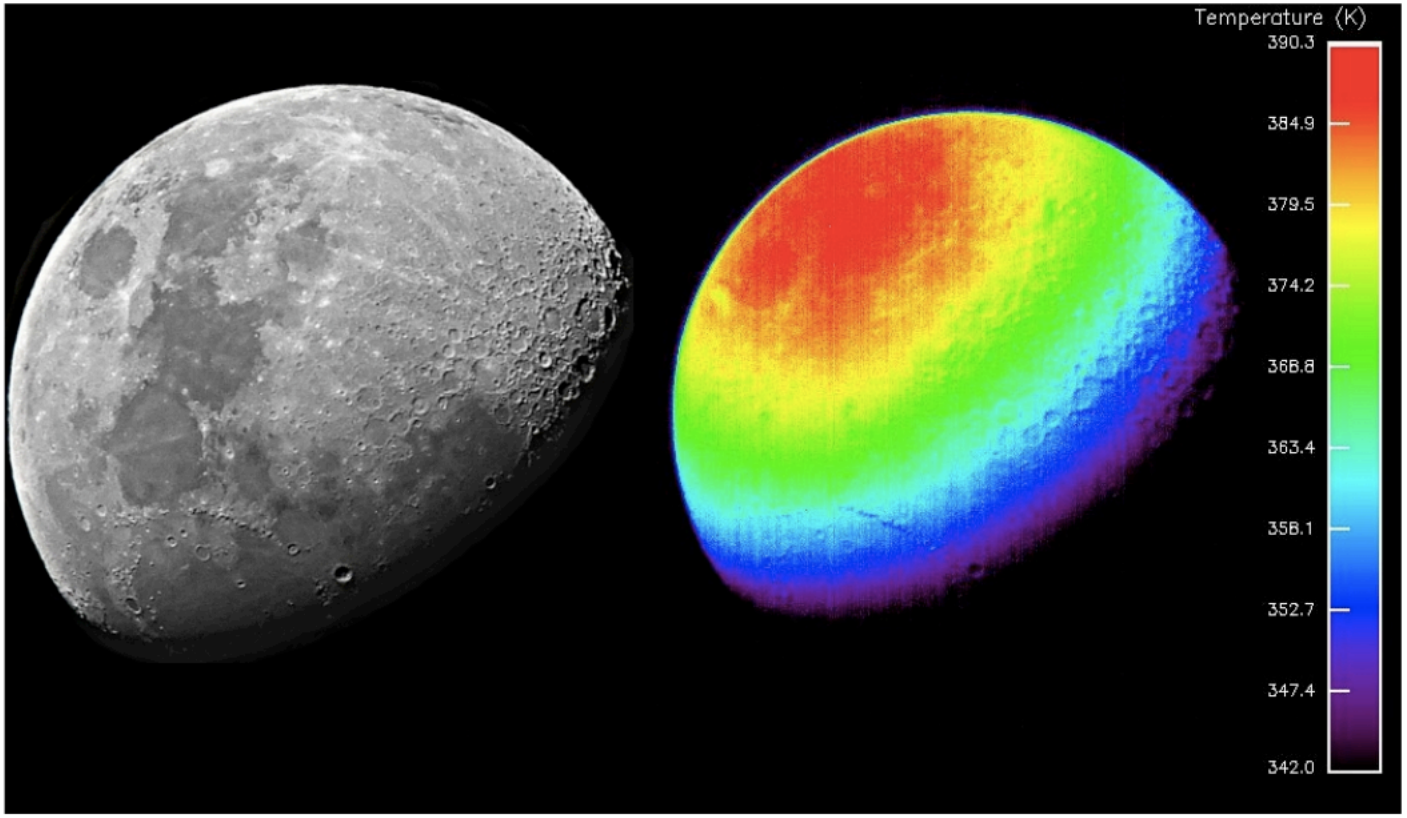
- Good sensitivity, low noise level in the 8-15 microns region
- Uncooled microbolometer array NO NEED FOR COOLING
- Low mass, low consumption
- Vacuum & radiation tests to TRL 5
- FPA & FEE develop at IAC at PDR level







Raw image – Offset image = Corrected image



The VHS-VISTA small bodies catalogue

- **Aims**

  ✓ Investigate the colors and the astrometric positions of the *known* Solar System objects present in the VISTA data;

Popescu et al. (2015) In prep.

- **Objectives**

  ✓ Find all known Solar system objects with apparent V magnitudes brighter than 21 present in the images of the VISTA survey;

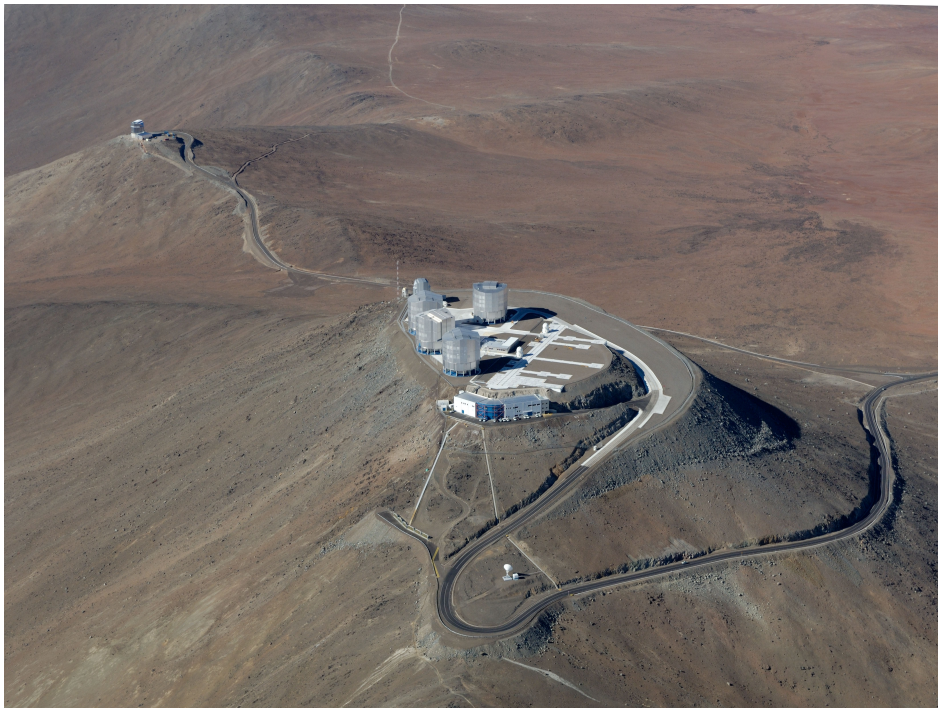
  ✓ Retrieve their flux/magnitudes for each of the available filter. Compute the infrared colors;

  ✓ Combine the obtained data with complementary measurements, or with spectral data in order to significantly improve the image of physical properties of solar system objects;

  ✓ Retrieve their accurate astrometric position in order to improve the uncertainty of the orbit.

Images from VISTA VHS survey for 279P/La Sagra (15 Dec 2009)

The VHS-VISTA small bodies catalogue

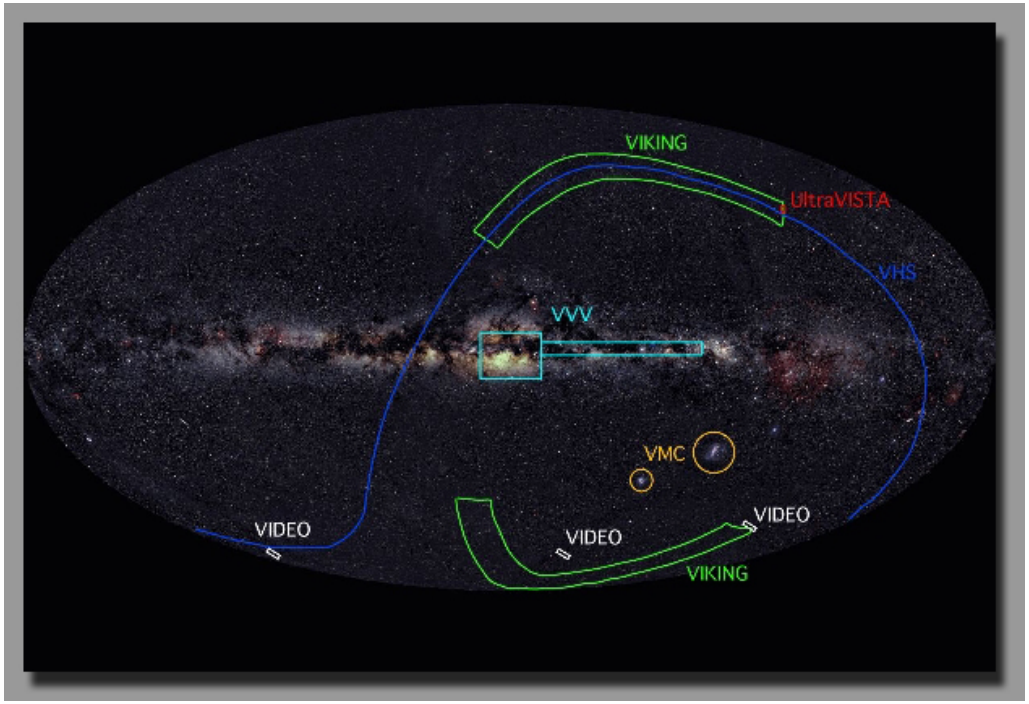


VISTA telescope on ESO Paranal. Source: http://www.eso.org/sci/facilities/paranal/instruments/vircam.html, http://www.vista.ac.uk/Images/site/hires/VISTAandParanal.jpg

- VISTA (Visible and Infrared Survey Telescope for Astronomy) is a 4-m class
- Dedicated to wide field survey telescope for the southern hemisphere ➔Near infrared camera VIRCAM (VISTA InfraRed CAMera)
- VHS: VISTA Hemisphere Survey : The VHS will image almost the entire southern hemisphere

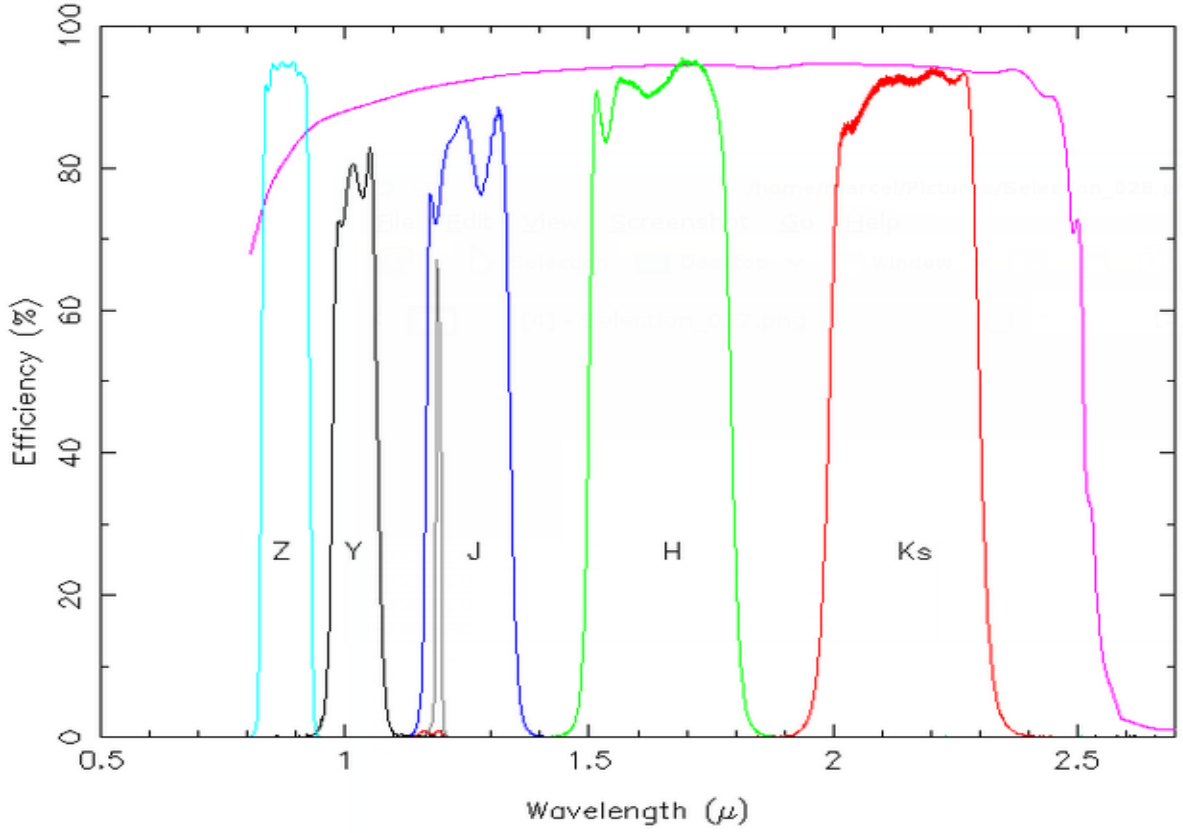
The VHS-VISTA small bodies catalogue

Sky coverage of VISTA surveys, overlaid on a 2MASS image of the whole sky.



- VHS is a panoramic wide field Infra-Red sky survey, which when combined with other VISTA Public Surveys will result in coverage of the whole southern celestial hemisphere (~19,000 deg2)
- a depth 30 times fainter than the 2MASS/DENIS in at least two wavebands (J and K).
- In the South Galactic Cap, ~4500 deg2 will be imaged deeper, including H band, and will have supplemental deep multiband grizY imaging data provided by the Dark Energy Survey (DES).
- The remainder of the high galactic latitude sky will be imaged in YJHK to be combined with the VST ATLAS survey.

Near-infrared filters used in VISTA



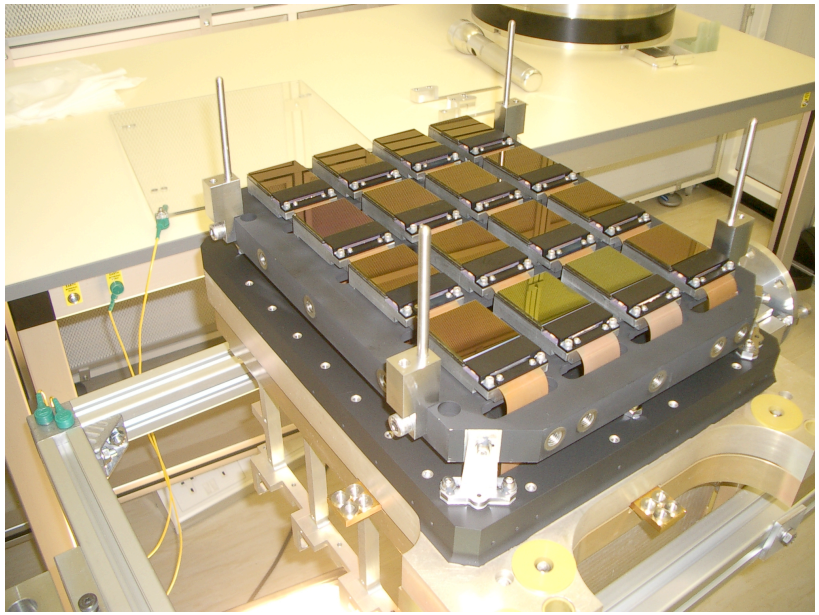
	Z	Y	J	H	K_s	1.18μm
Central Wavelength (μm)	0.877	1.020	1.252	1.645	2.147	1.191
Width (μm)	0.097	0.093	0.172	0.291	0.309	0.011
Effective Wavelength (μm)	0.878	1.021	1.254	1.646	2.149	1.191
Vega to AB	0.521	0.618	0.937	1.384	1.839	0.853

Transmission characteristics of filters used by VISTA. Source:
http://casu.ast.cam.ac.uk/surveys-projects/vista/technical/filter-set

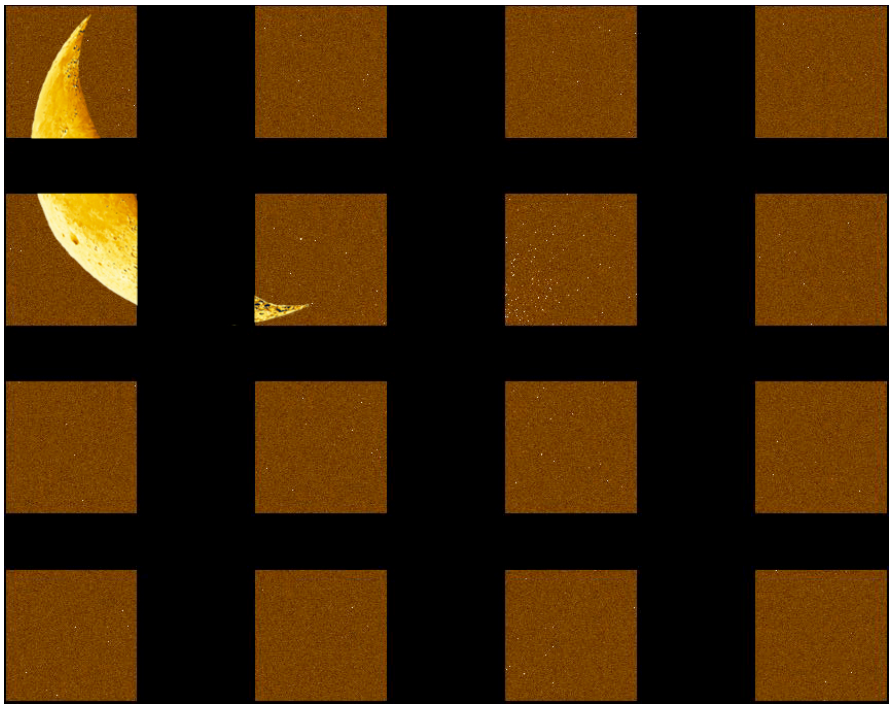
VISTA VHS survey areas

- VHS - ATLAS (5000 deg2): divided ~evenly between N & S Galactic caps, 60 sec. exposures in Y, J, H, and Ks
- VHS - Dark Energy Survey (4500 deg2): SGC, 120 sec. exposures in J, H, and Ks
- VHS - GPS (8200 deg2): Galactic Plane Survey (excl. VVV), 60 sec. exposures in J, and Ks

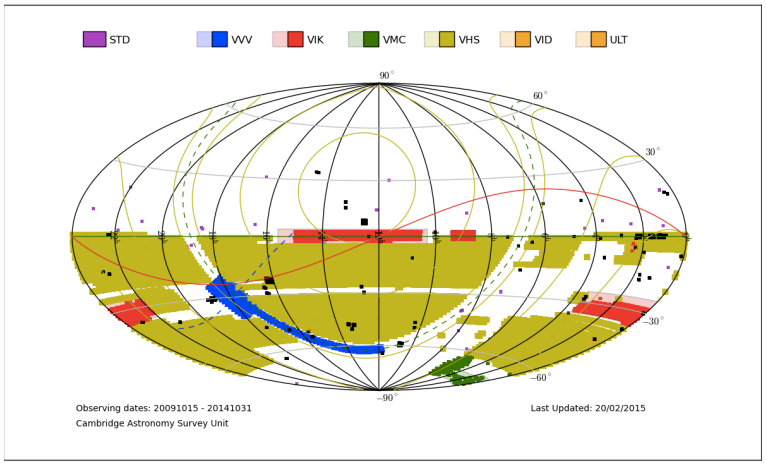
Each VISTA tile requires 6 sparse filled pawprints. Thus the total on-sky time for the 3 components above are 360, 720 and 1080 seconds respectively.

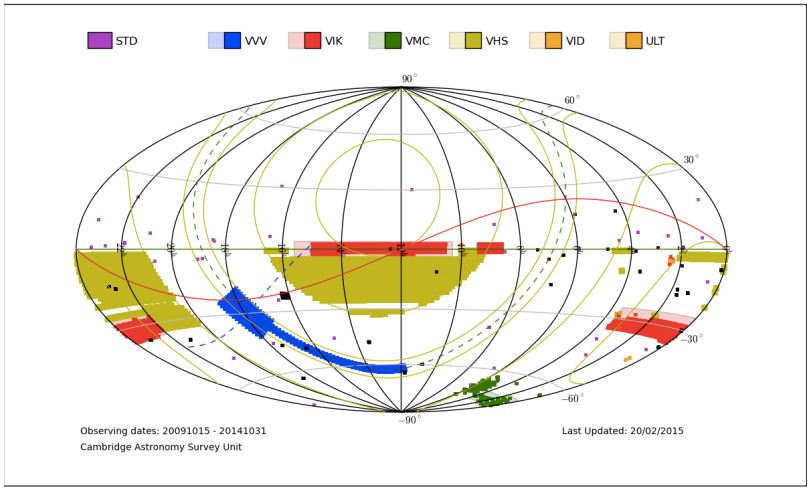


16 Raytheon VIRGO detectors
(2048x2048 pixels) 0.34 arcsec/pix
1.5°×1° filed of view



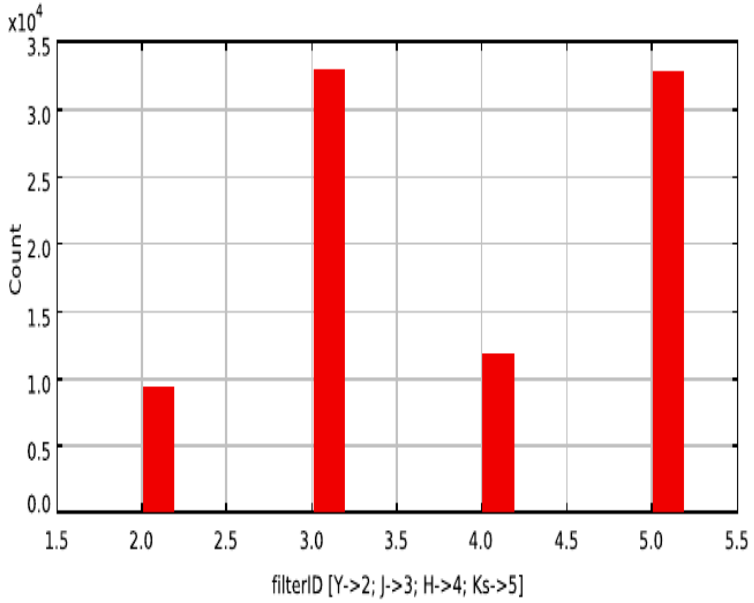
Present sky covered by VISTA





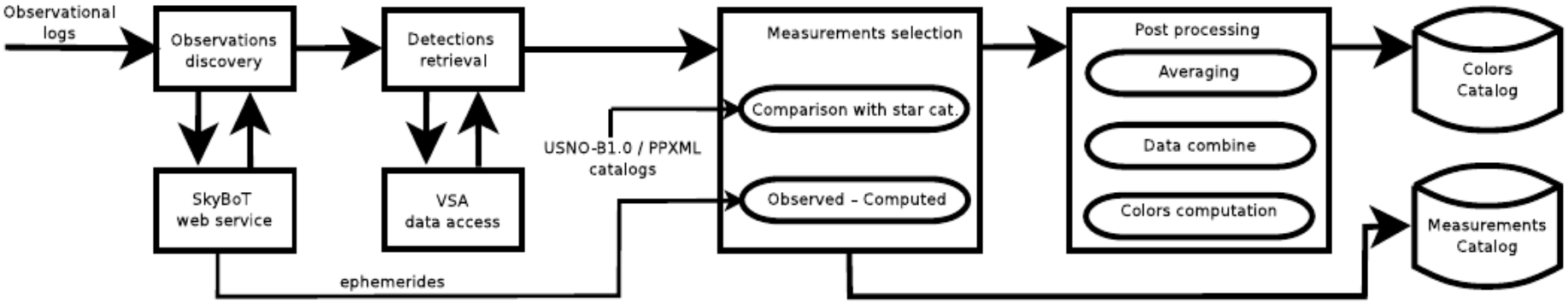
At least one filter

Y,J,H,K



Statistics of images taken in each filter.

Flowchart



Flowchart of NICMPV pipeline

- ✓ Find the known Solar System objects that were imaged by the survey
- ✓ Retrieve the corresponding astrometric and photometric measurements
- ✓ Validate the detections

  Post-processing of measurements for obtaining colors and
- ✓ accurate spectrophotometry

Present statistics

We worked on **86.562 images** from VISTA VHS survey, covering observations **from 2009-11-04 to 2013-10-01.**

8239 square deg (any band) (~ 20% of the sky area)

- 9.276 (11%) measurements were done using Y filter,
- 32.796 (38%) measurements were done using J filter,
- 11.760 (14%) measurements were done using H filter,
- 32.730 (38 %) measurements were done using Ks filter.

Detected objects:

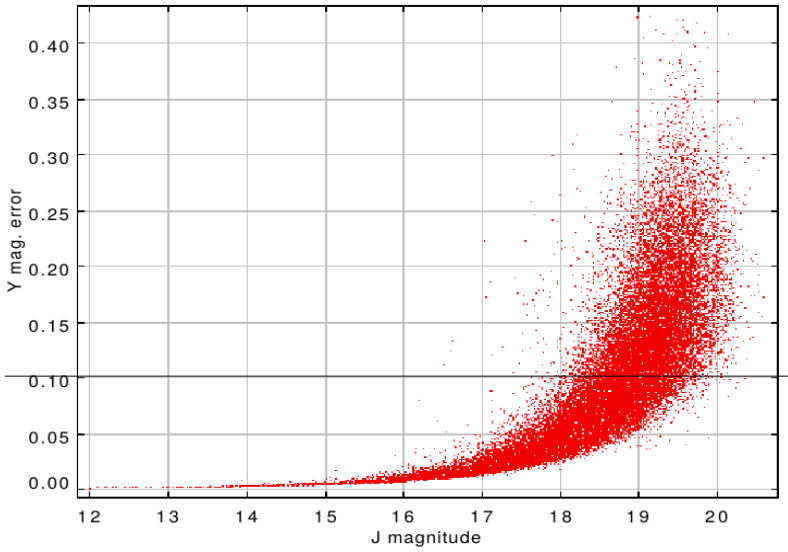
- 29.675 unique objects with detection in more than 1 filter.
- 1500 asteroids with uncertainties between 10 and 1500 arcsec could be found

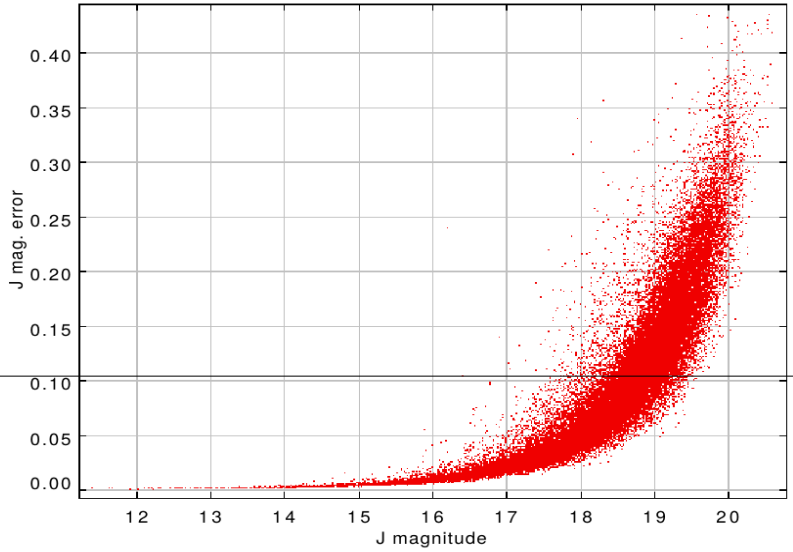
- 22678 objects with observations in a single night;
- 4469 objects with observations in two nights;
- 816 objects with observations in three nights;
- 180 objects with observations in more than 3 nights

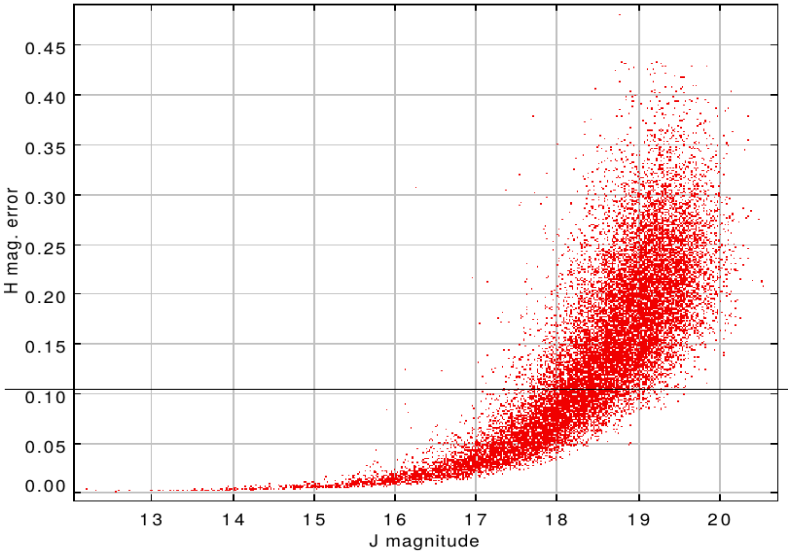
2006 objects with uncertainties below 0.1 and Y, J, H, K filters (3813 Y,J,H)
425 objects with uncertainties below 0.03 and Y, J, H, K fulter (903 Y,J,H)

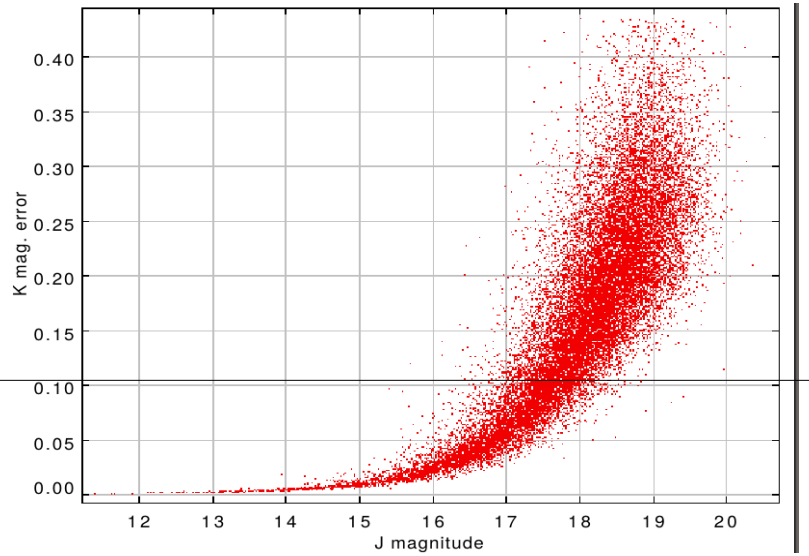
One order of magnitude more than 2MASS with 60% of the survey complete

Measurement errors









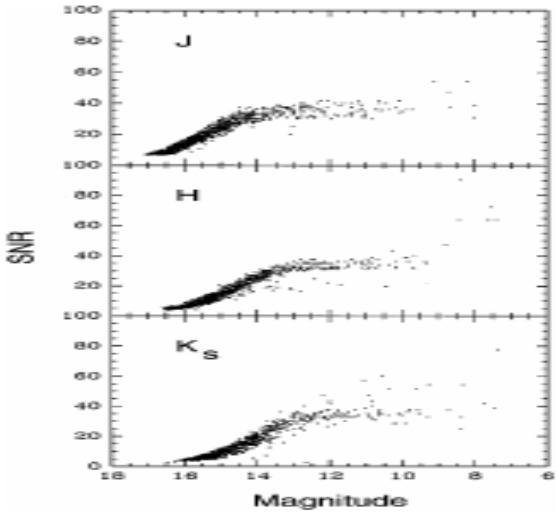
Aperture photometry: 1 arcsec aperture radius

Comparison w/previous surveys

- ***Asteroid detections in 2MASS survey(Sykes et al. (2000))***

TABLE IV
Asteroid Detections

	All	SNR > 10	SNR > 20
J only	62	7	0
H only	0	0	0
K only	0	0	0
J & H only	1736	0	0
J & K only	20	0	0
H & K only	2	1	0
J, H, and K	885	473	212



- ***Asteroid detections in DENIS survey (A. Baudrand et al. A&A 2001, 2004)***

Table 1. Number of asteroids detected one or two times and number of associations validated.

	one time	two times	associations
I only	257	29	315
I and J only	542	75	692
I, *J*, and *K*	282	48	378
Total	1233	152	1385

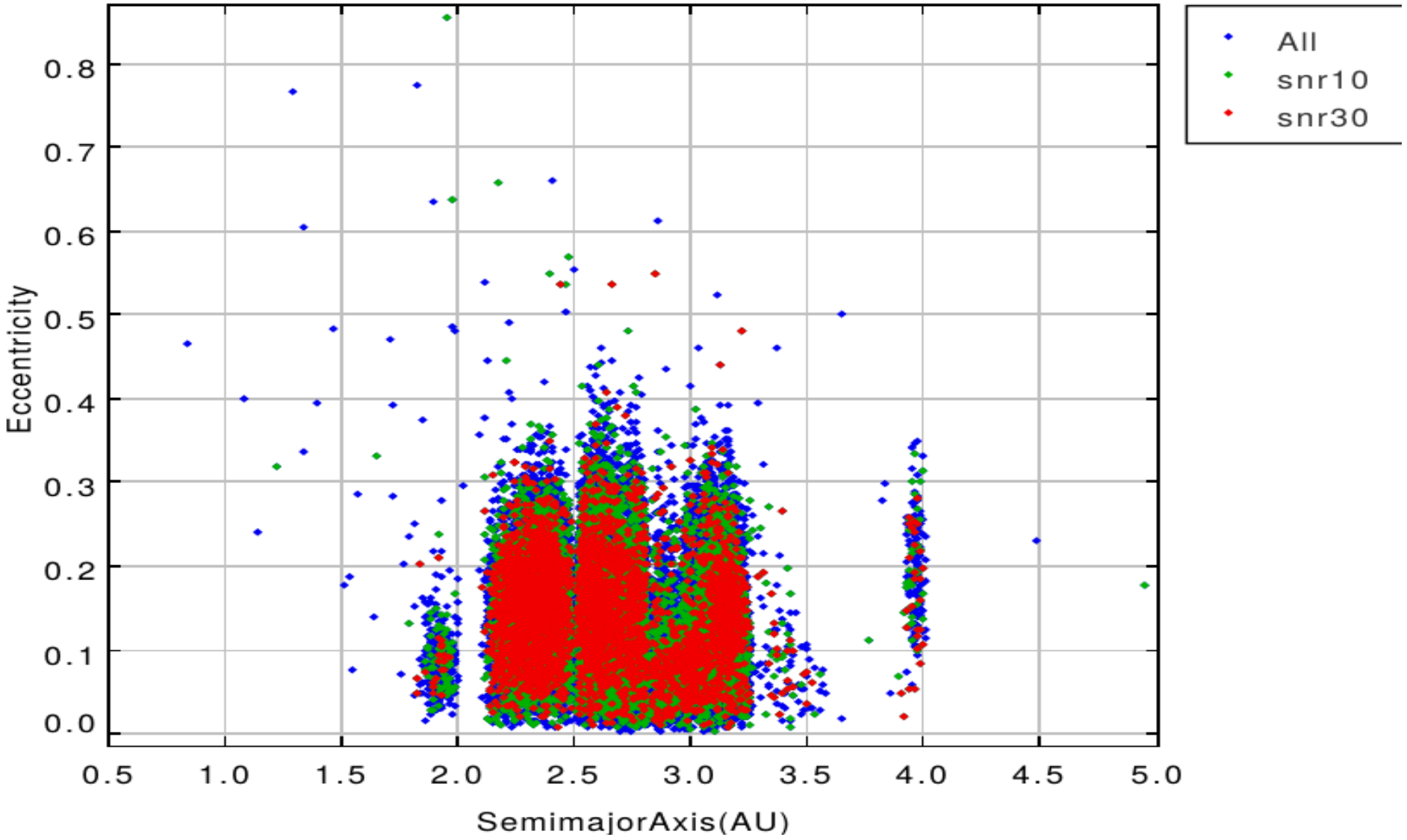
First release

Table 1. Number of asteroids detected one or two times and number of validated associations.

	One time	Two times	Associations
I only	183	8	191
I and *J* only	379	16	395
I, *J*, and *K*	205	14	219
Total	767	38	805

Second release

Distribution of observed objects



Final products

The final product of our pipeline are three catalogs:

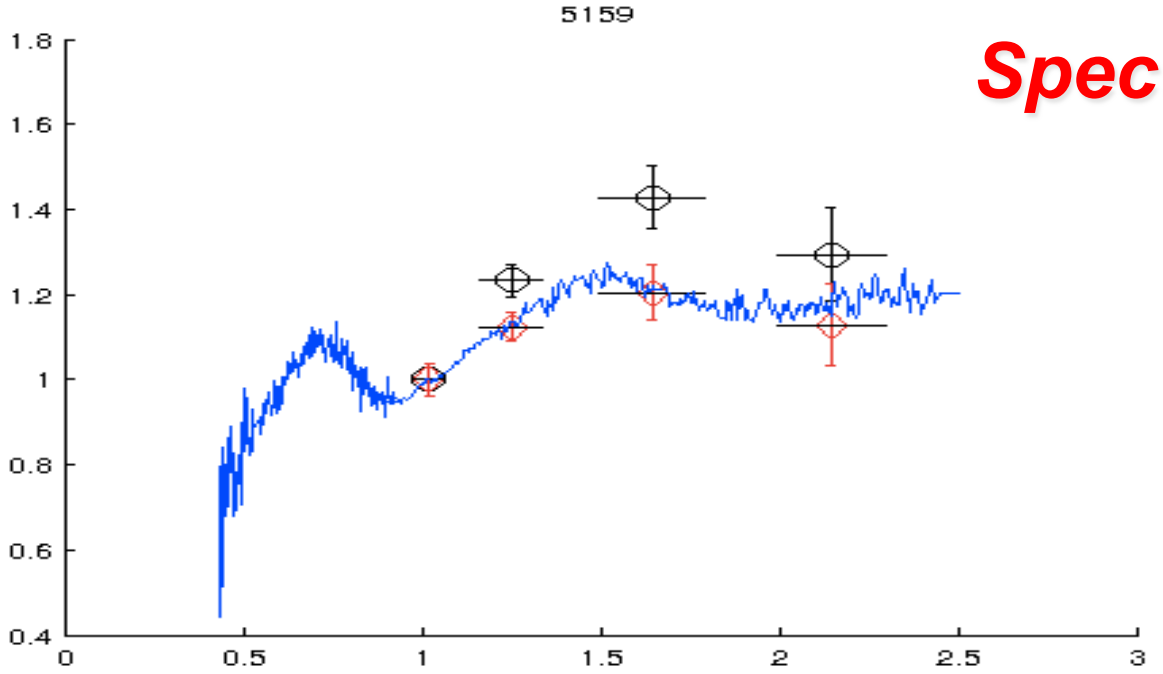
✔ the measurements catalog (NICMPV-M)

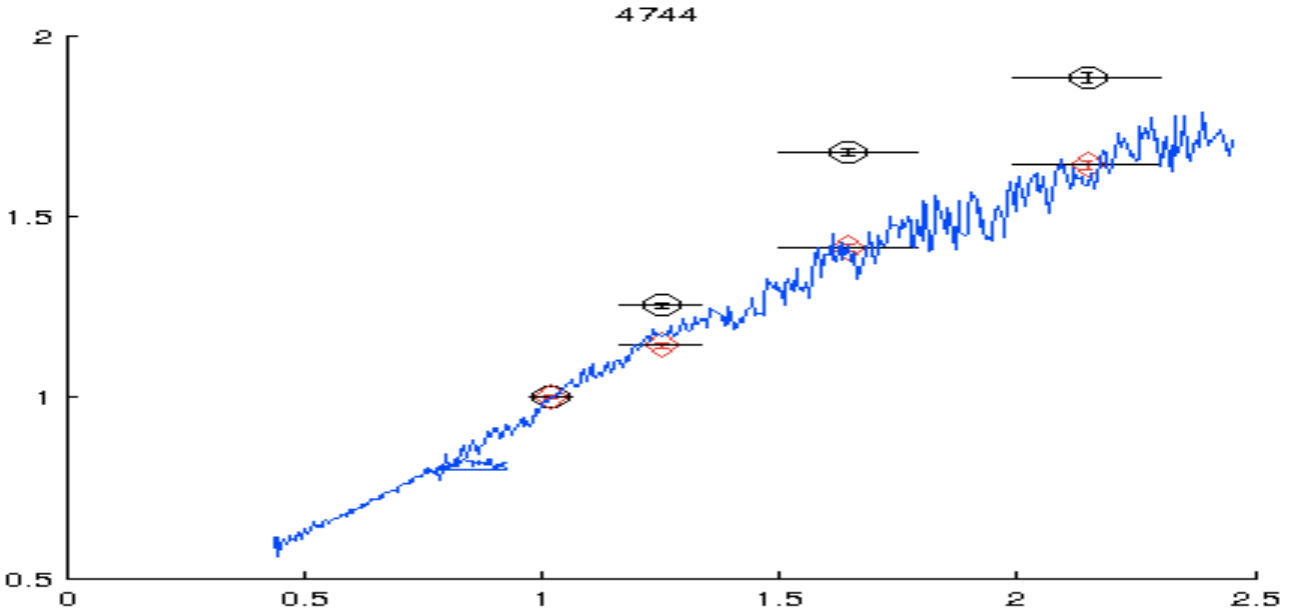
✔ the magnitudes catalog (NICMPV-F)

✔ the colors catalog (NICMPV-C)

We plan to upload the catalogs to CDS-Strasbourg & other public services (e.g. MP3C), thus they will be accessible via VO services

Spectrophotometry

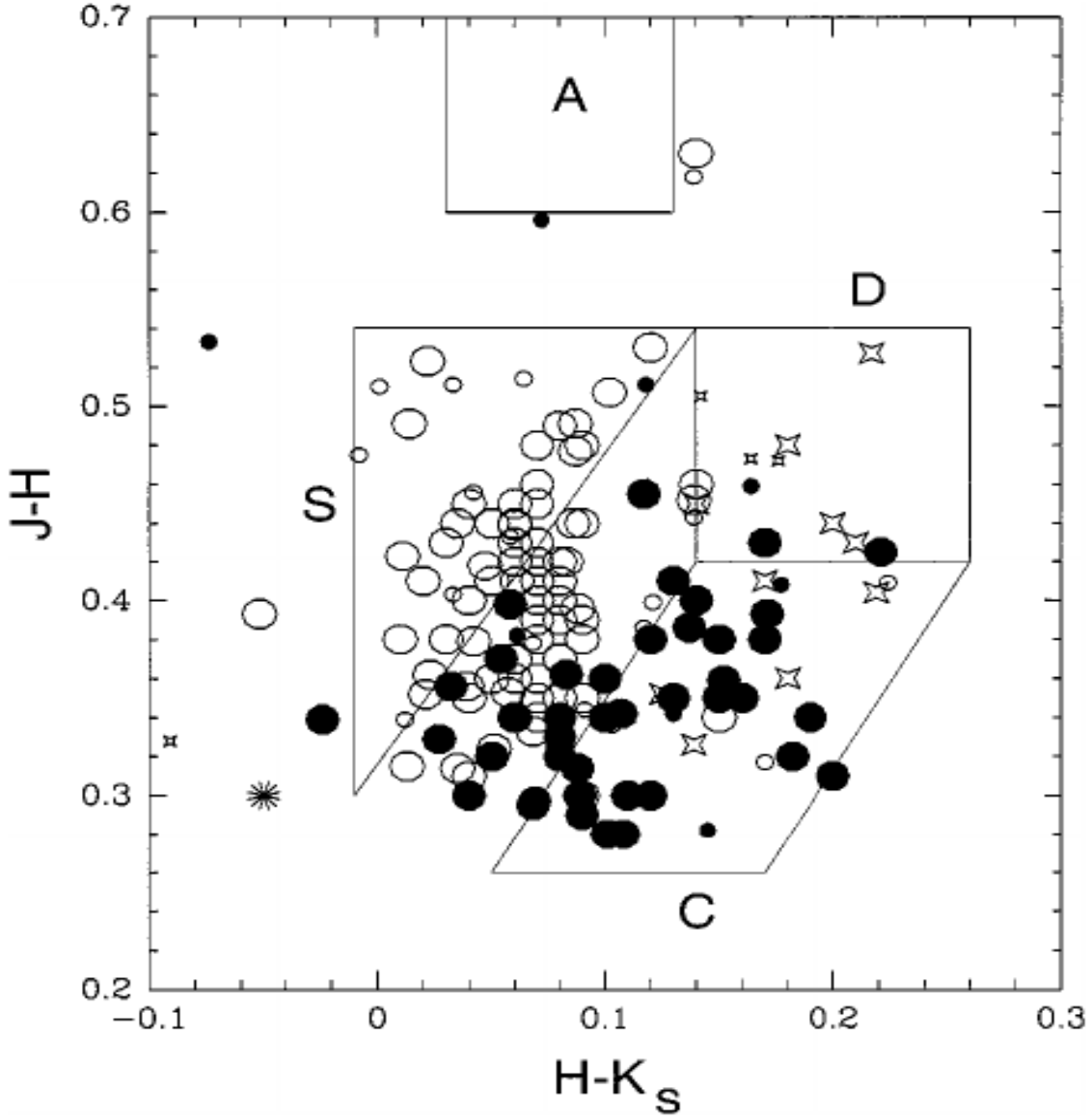




Red dots: reflectance w/solar colors computed using solar spectrum & VISTA filter tranmission.

Black dots: reflectance w/computed Solar colors transformed from SMASS

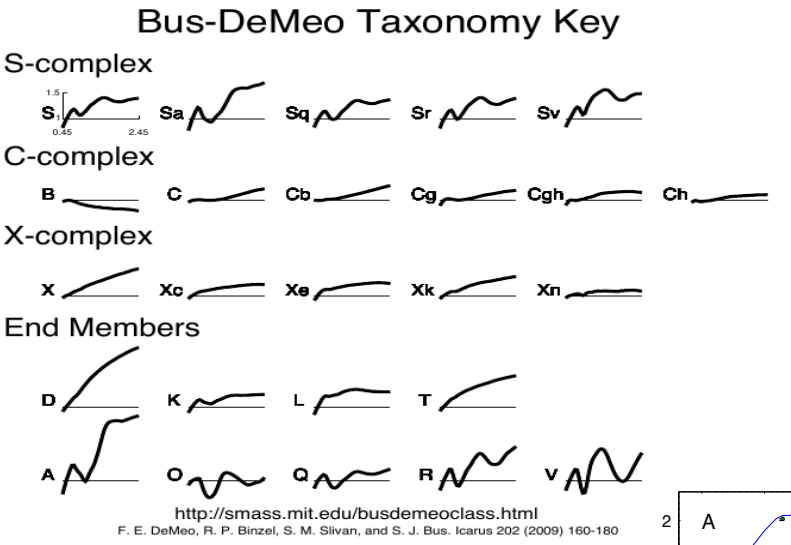
Color-color plots & spectral classes



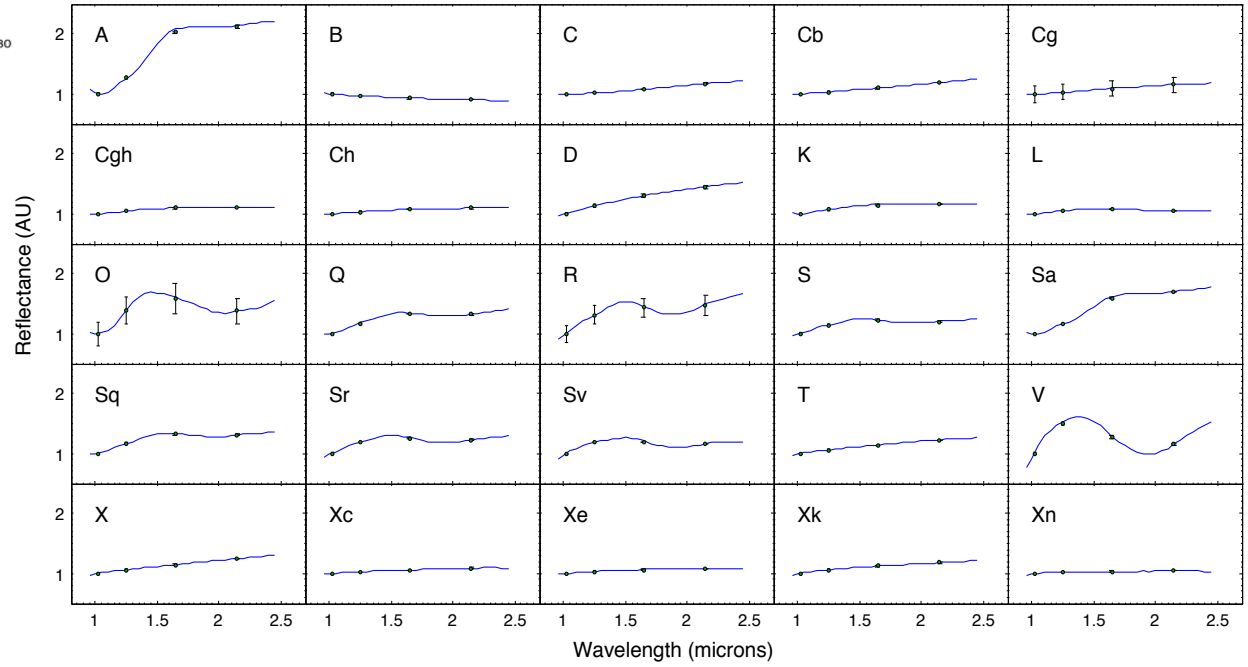
2MASS - Sykes et al. (2000)

1054 asteroids J,H,K
473 w/ SNR > 10

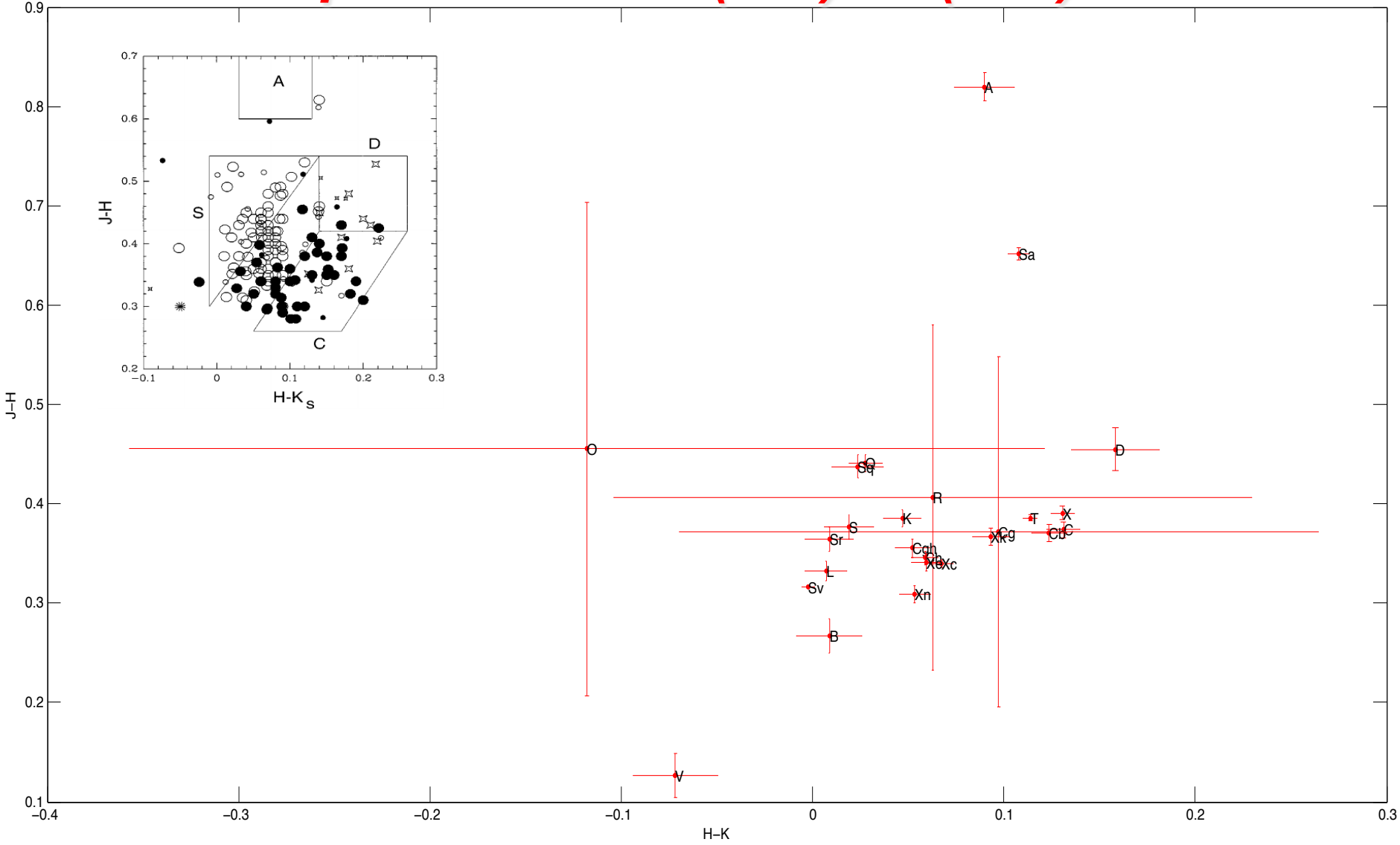
Bus-DeMeo spectral classes



Credit: F. DeMeo, Icarus 2009

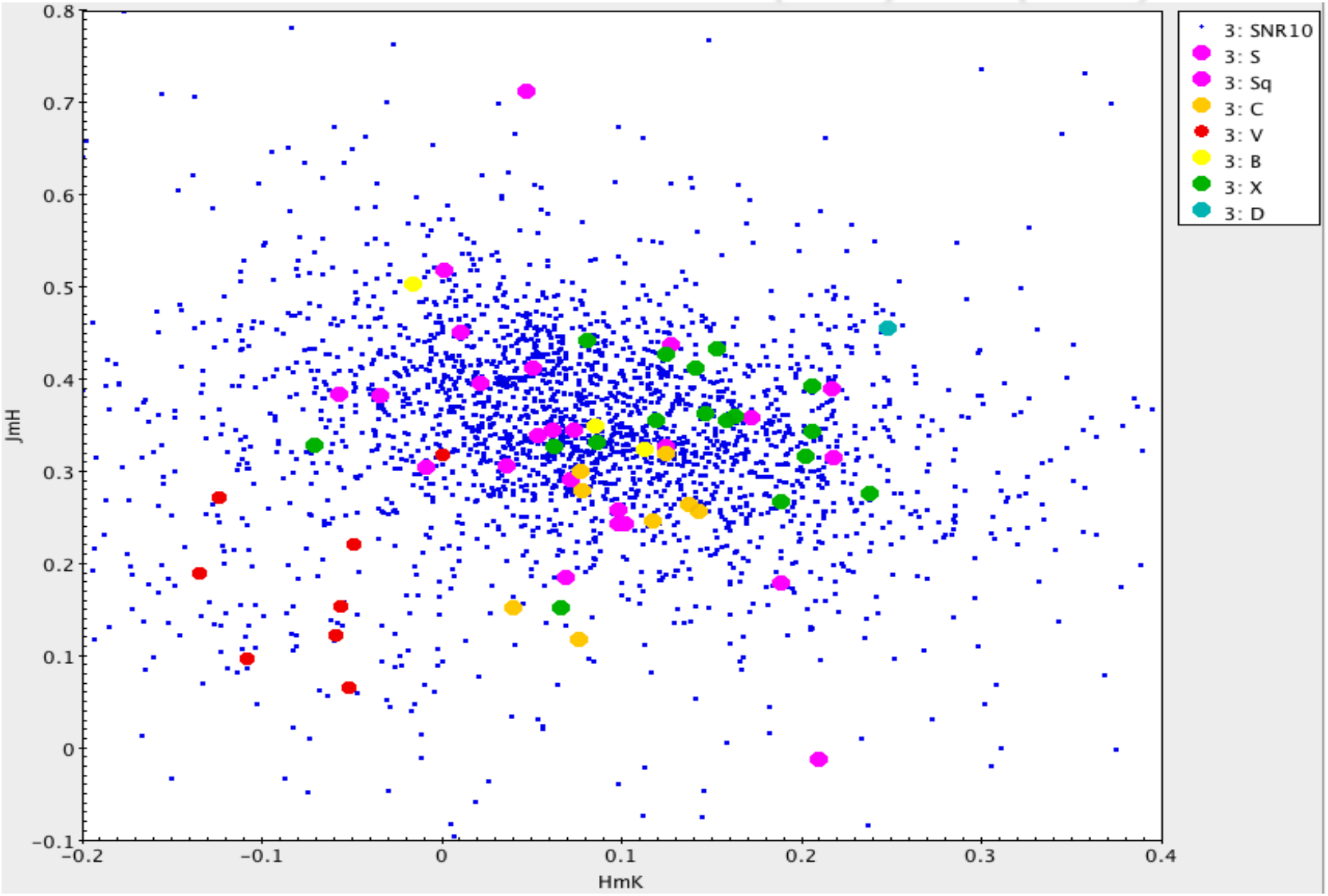


Color-color plots of spectral classes: Expected colors (J-H) vs (H-K)



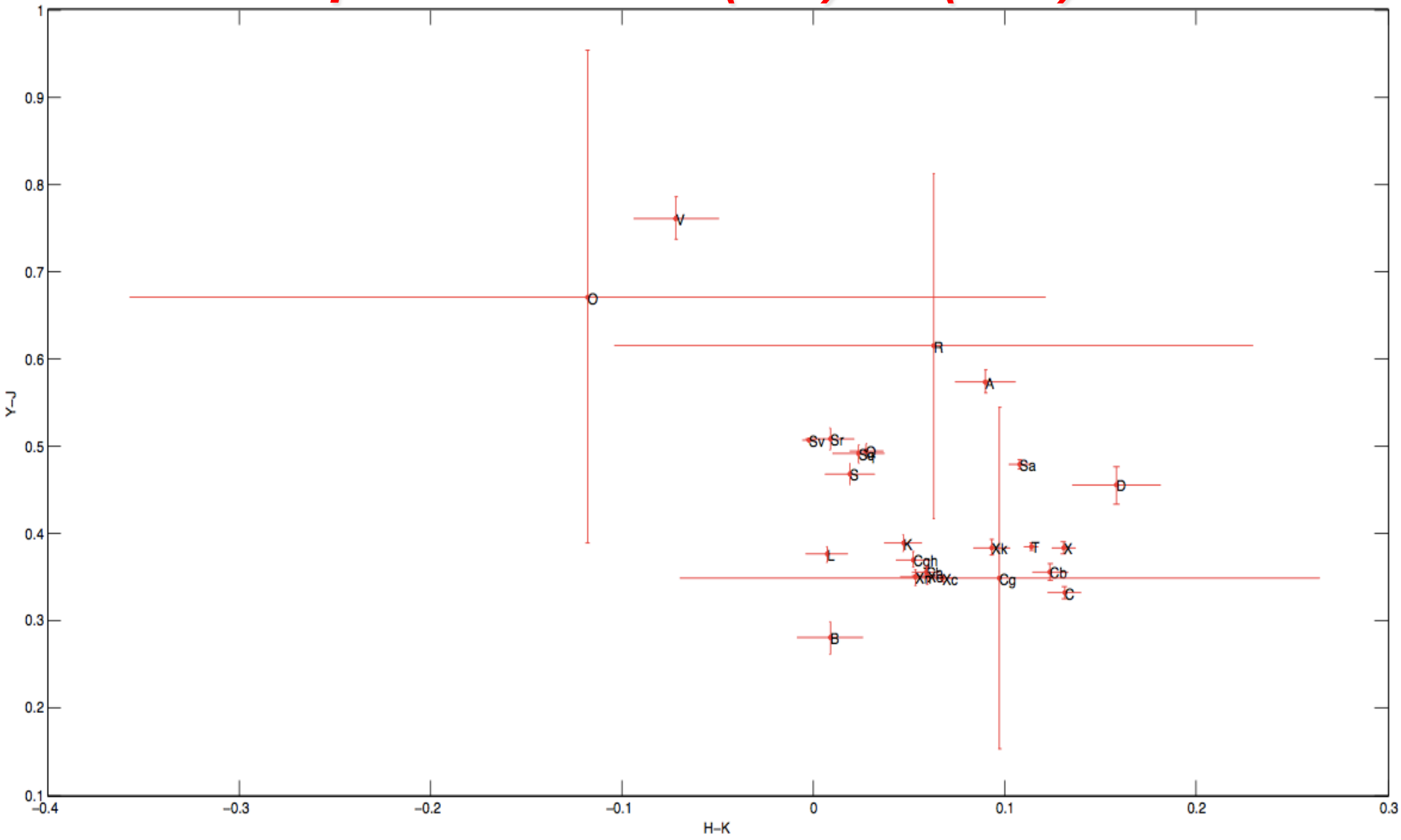
Bus – DeMeo classes

Color-color plots of spectral classes: observed colors (J-H) vs (H-K)

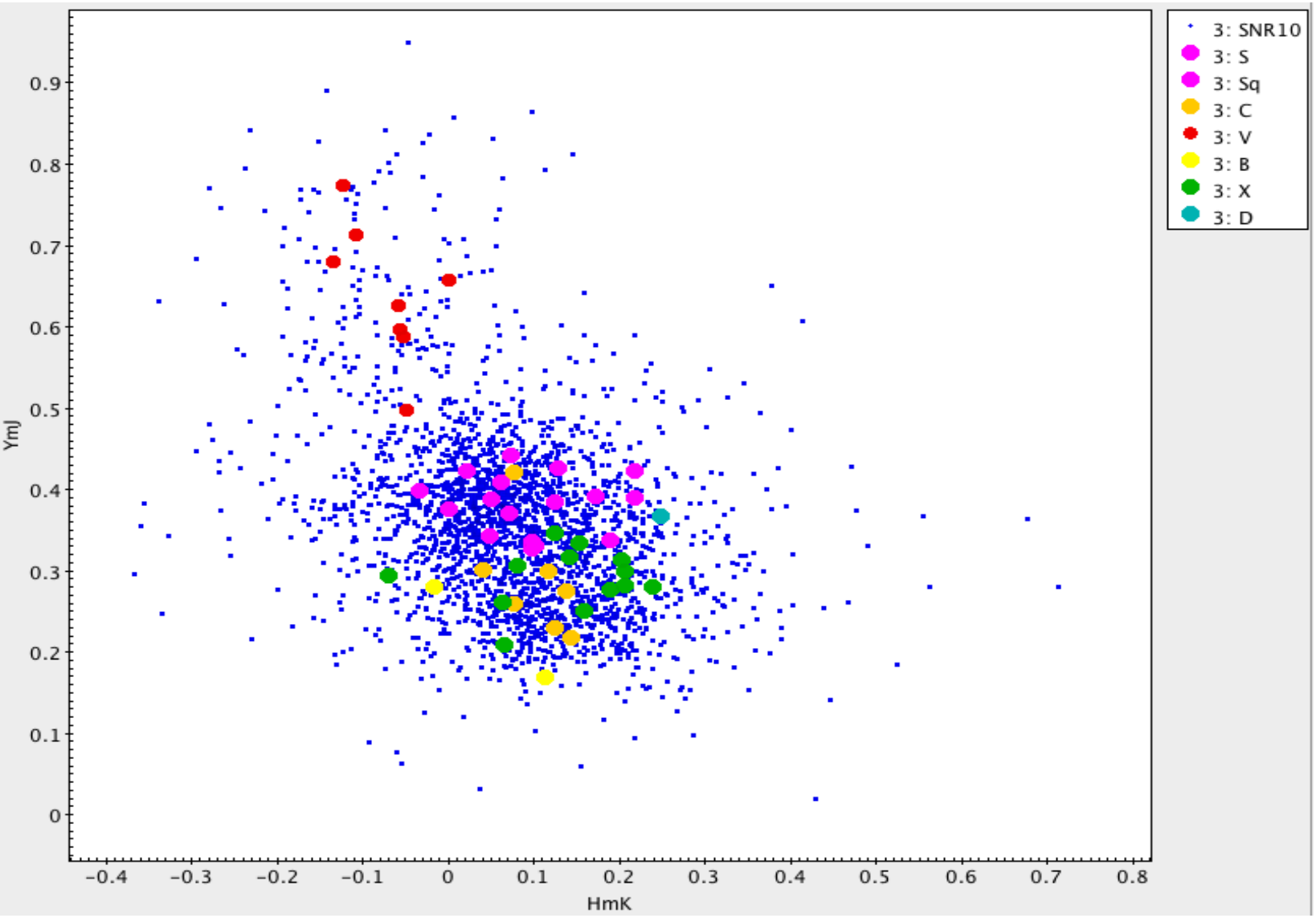


SNR > 10

Color-color plots of spectral classes: Expected colors (Y-J) vs (H-K)

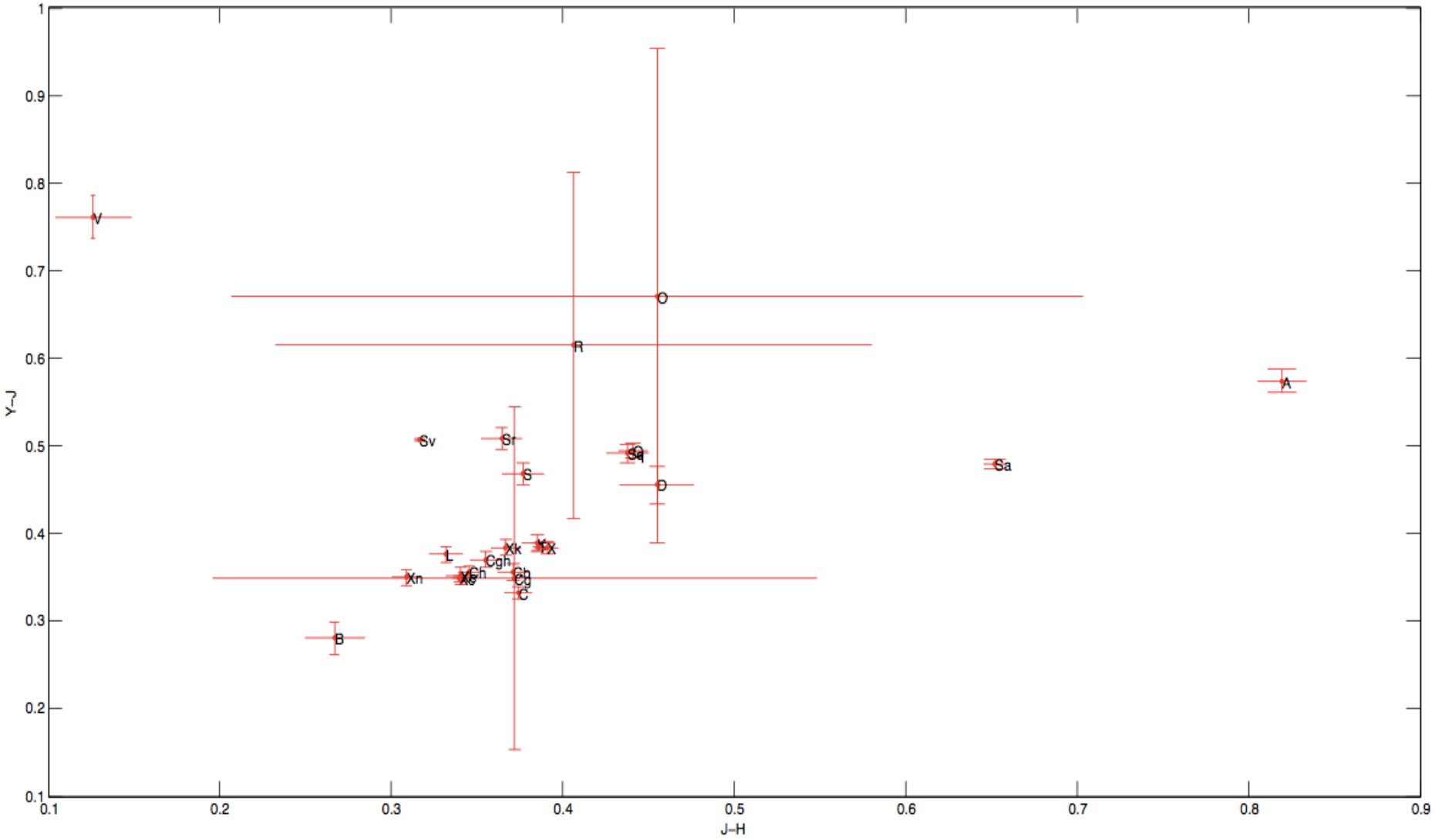


Color-color plots of spectral classes: observed colors (Y-K) vs (H-K)

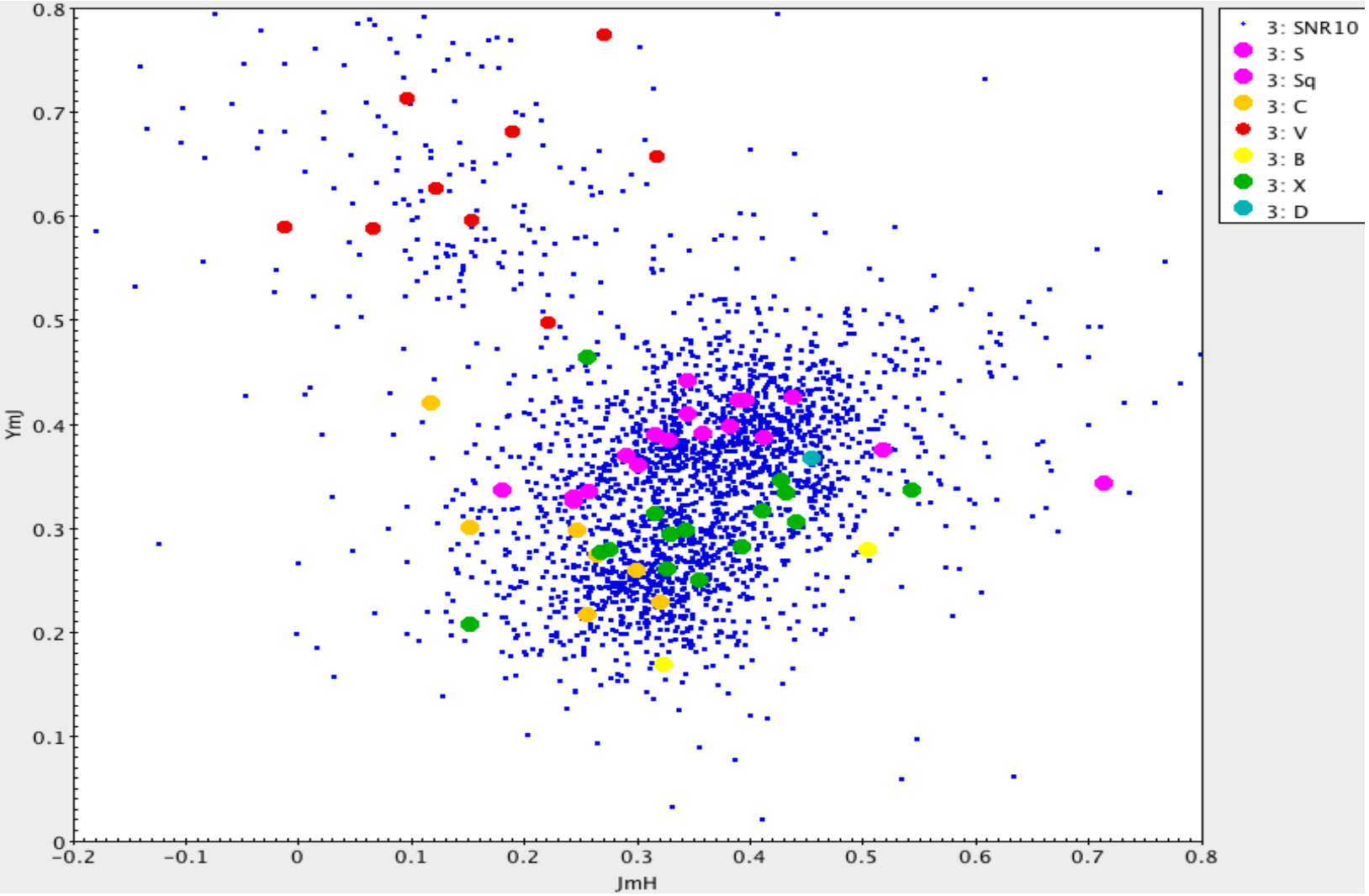


SNR > 10

Color-color plots of spectral classes: Expected colors (Y-J) vs (J-H)

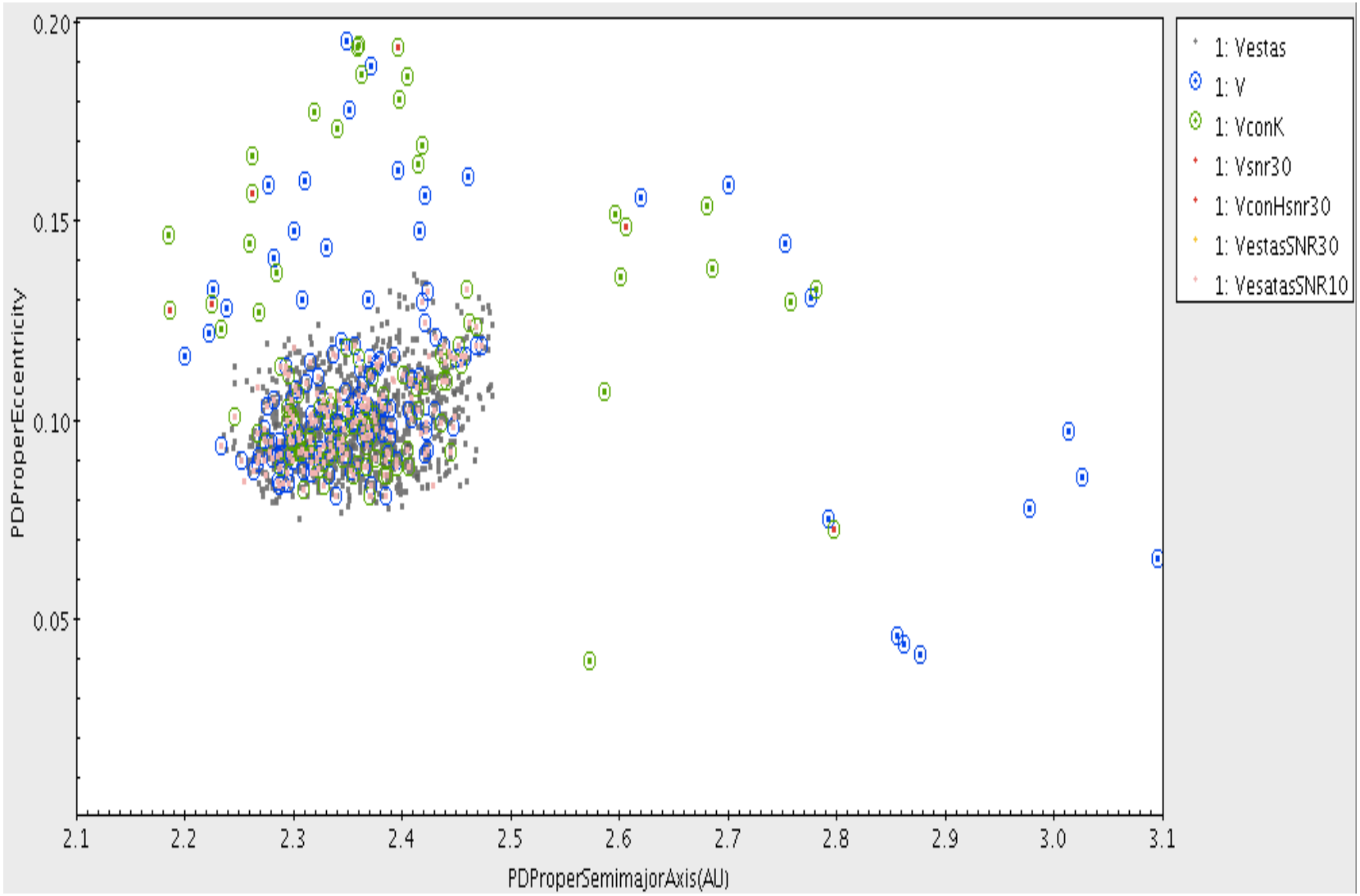


Color-color plots of spectral classes: observed colors (Y-K) vs (J-H)

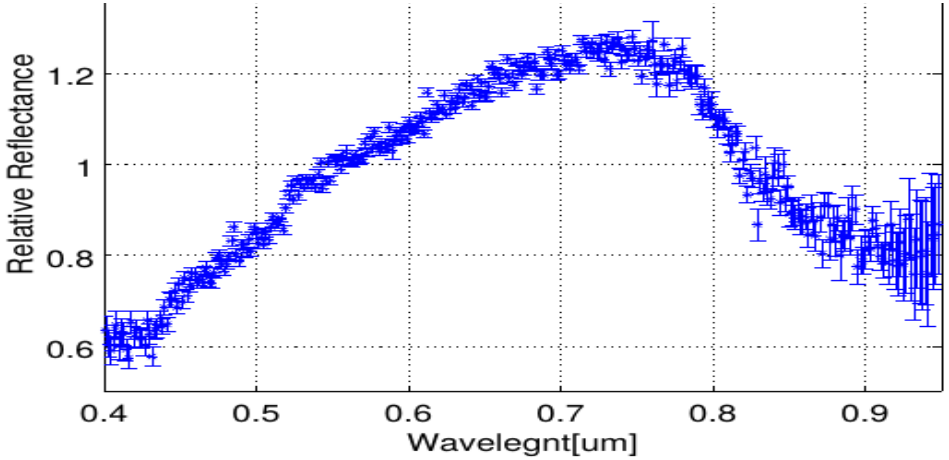


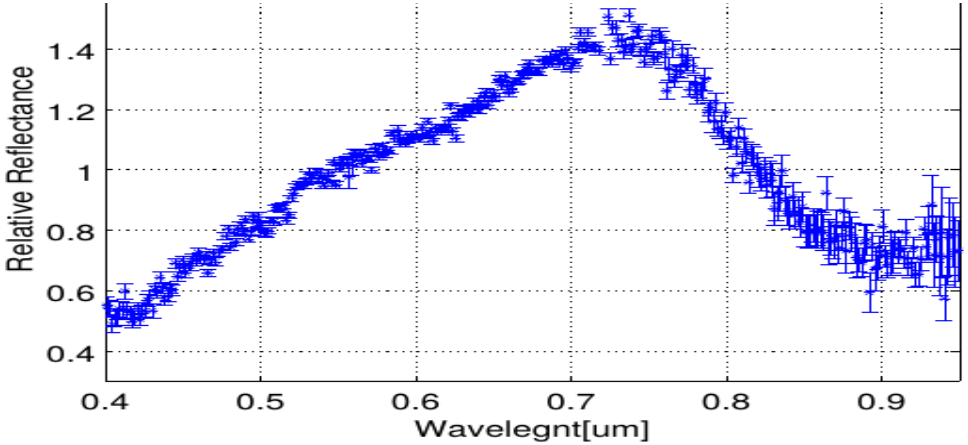
SNR > 10

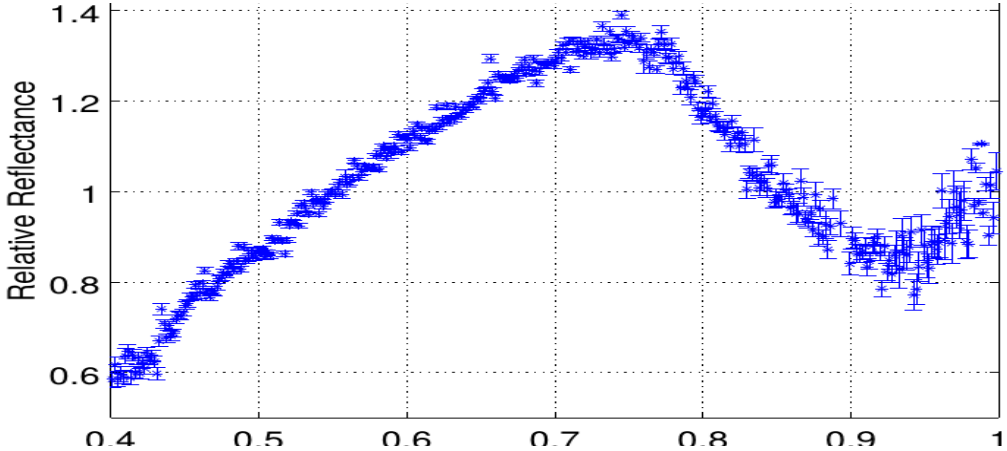
The V-types



SNR > 10





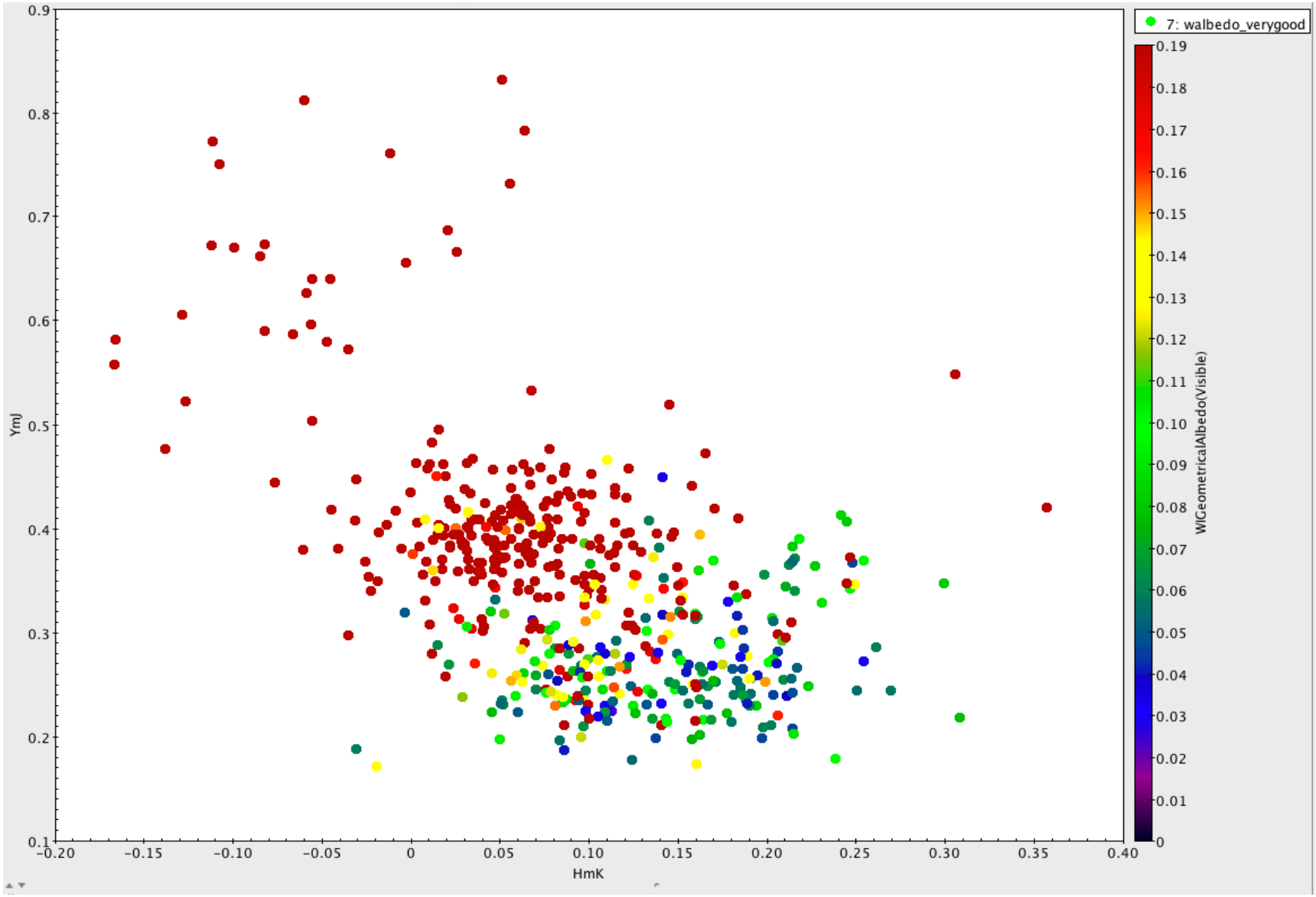


The V-types

INT visible spectroscopy of 3 V-type candidates

TNG near-ir Amici spectra of 2 of them (in reduction process,), both out of the Vesta family

Color-color plots and WISE albedo



SNR > 30

Conclusions & further work

- We obtained the astrometric and NIR spectrophotometry of ~30.000 known small bodies imaged by VISTA-VHS survey
- Continue running the pipeline as the survey progress
- Compare the taxonomic classes with the obtained colors
- Obtained reflectances, combine with SDSS visible reflectances
- New taxonomy? (***no please no more!***)
- Derive statistical properties of different groups and families of small bodies

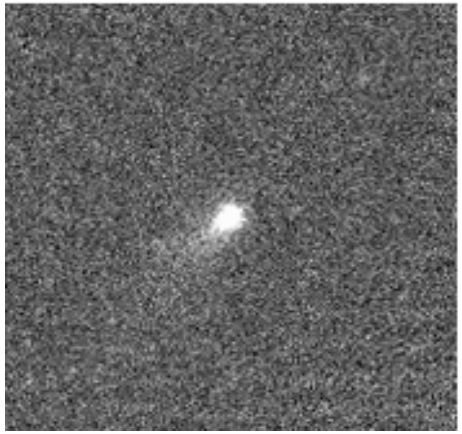
EXTRA SLIDES

Discovering observations of SSo

- Based on RA, DEC, MJD we used Simple Cone Search (SCS) web-service provided by SkyBoT (Berthier, 2006). The SkyBoT cone-search method allows to retrieve all the known solar system objects located in a field of view.

```
// Query to SKYBOT server
$param = array('epoch'    => $jd, // Epoch(Julian Day)
               'alpha'    => ($ra*15), // Right ascension of the FOV center in degrees
               'delta'    => $dec, // Declination of the FOV center
               'radius'   => '3000', //Radius of the FOV OR Size of the FOV as RAxDEC
               'mime'     => "text",
               'output'   => "obs",
               'observer' => "309", //309 289.595690.909943-0.414336Cerro Paranal
               http://www.eso.org/sci/facilities/paranal/instruments/vircam/overview.html
               'filter'   => "0",
               'objFilter'=> "111");
$from = 'MarcelPopescu';
```

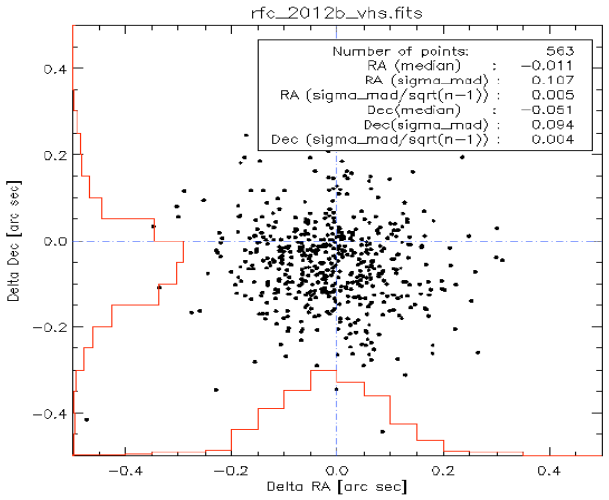
- 300 queries/hour & monitoring routine for reliability
- V = 21, limiting magniude
- 68 237 objects found, 62 340 objects with uncertainty lower than 10 arcsec

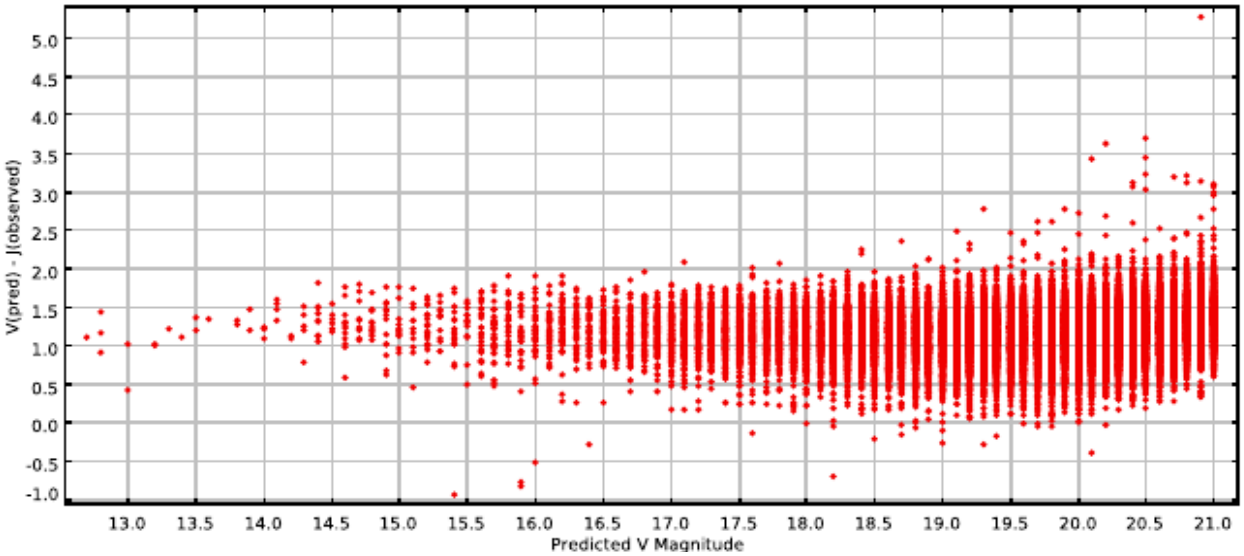


Images from VISTA VHS survey for 279P/La Sagra (15 Dec 2009)

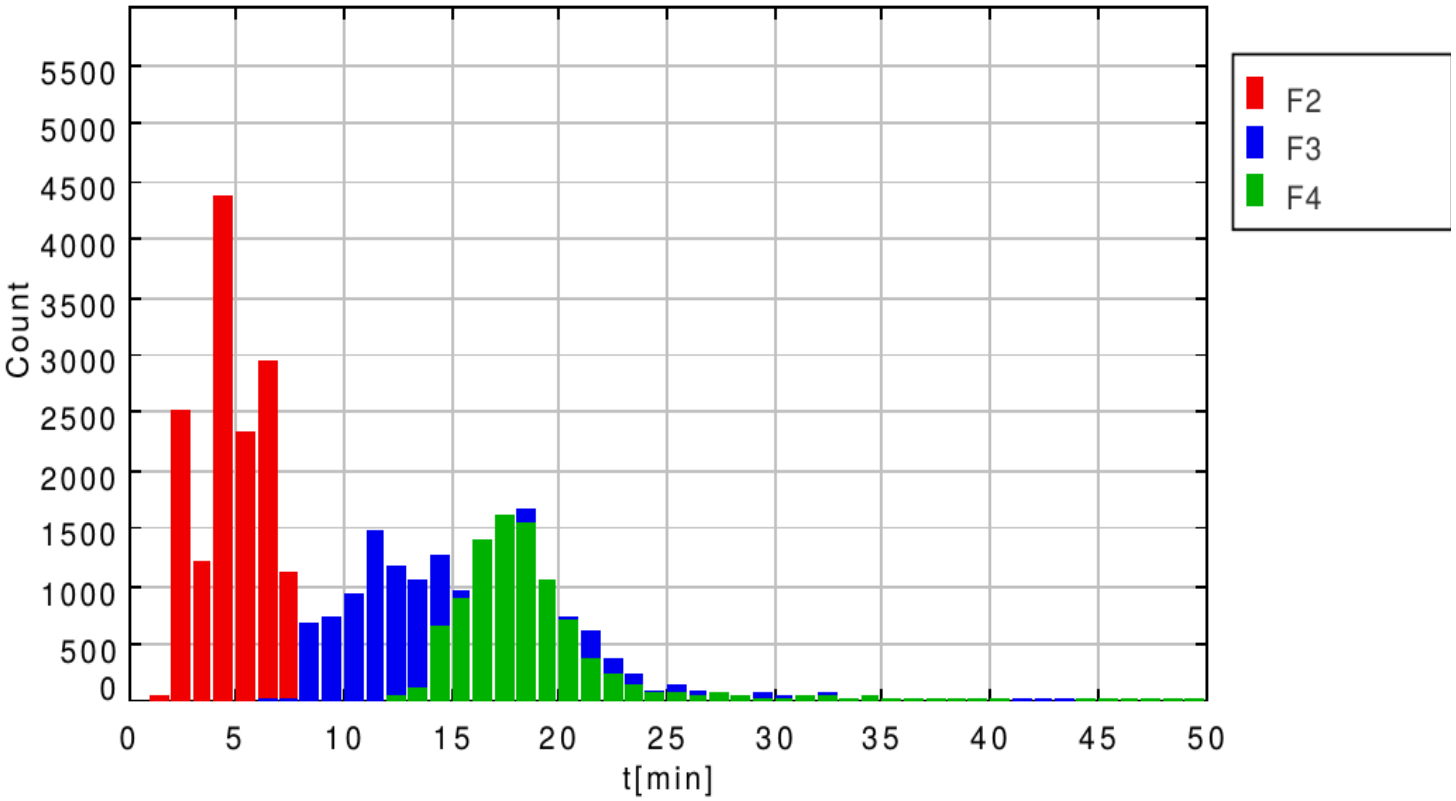
Validation

- ✔ Remove measurements marked as deprecated, saturated, or with quality issues
- ✔ Remove measurements for which the position overlay with a background star (comparison with USNO B1.0 catalog) (within 1 arcsec)
- ✔ Algorithm to remove detections based on O-C on position and magnitudes
- ✔ Comparison of V(predicted)-J(observed)





Comparison between VHS positions and the VLBI radio reference frame [Source: R. McMahon - VISTA HEMISPHERE SURVEY DATA RELEASE 2]

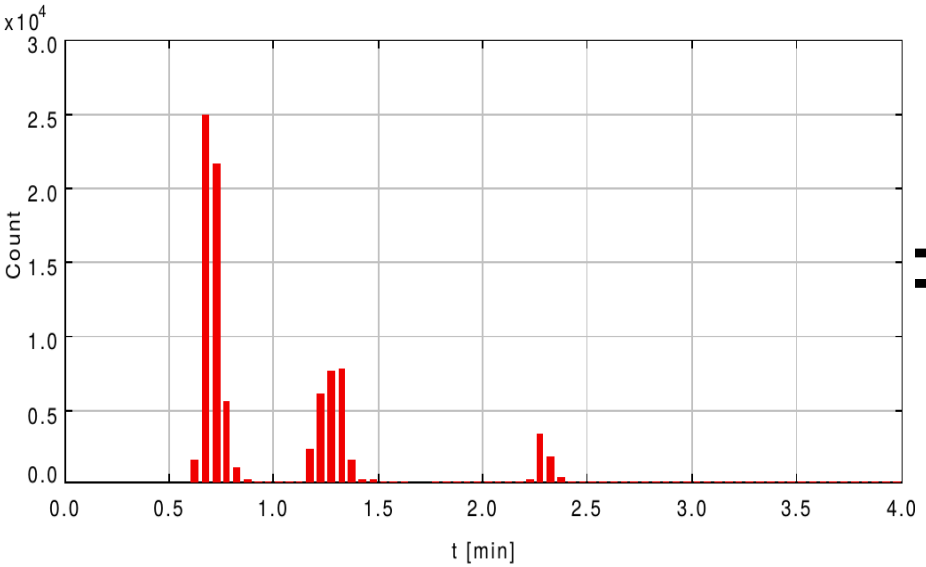


Time spanning required to obtain the mganitudes in all filters.

Post-processing of the data

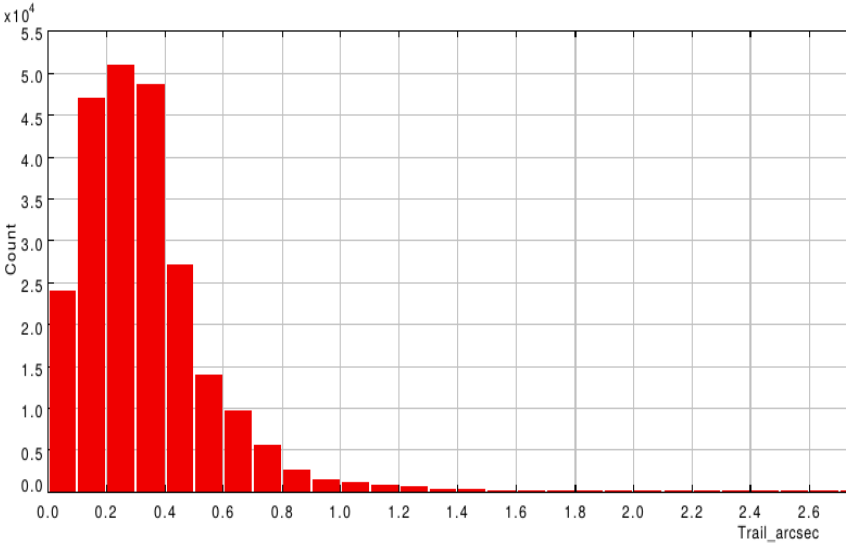
- Comparing minor planets magnitudes observed at different epochs is difficult since it needs to take into account: 1) the brightness is variable due to lightcurve variation and 2) apparent magnitude varies with heliocentric distance
- Assumptions:
  - Apparent magnitude variations can be neglected for a single night
  - Lightcurve variations can be ignored for intervals less than 15 minutes (0.01 day)
  - Asteroids surface is compositionally homogeneous, thus we can compare colors obtained at different epochs
- Post-processing:
  - a) Average measurements obtained with the same filter in an interval less than 15 minutes
  - b) Select magnitudes obtained with different filters such that the interval between observations to be minimum
  - c) Obtain colors by combining the closest in time observations from two different filters
  - d) Combine colors obtained at different epochs

Imaging strategy



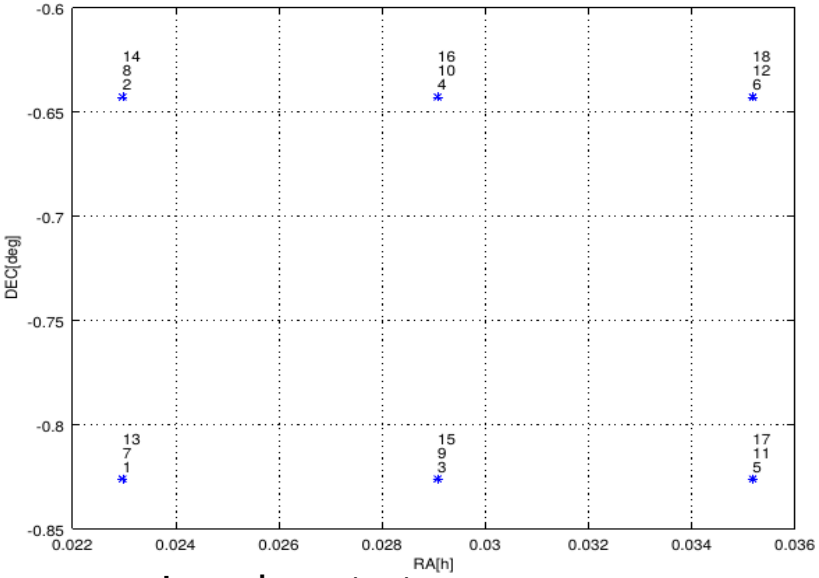
Statistics of durations for obtaining stackframes

=>



Trail length of the observed asteroids.

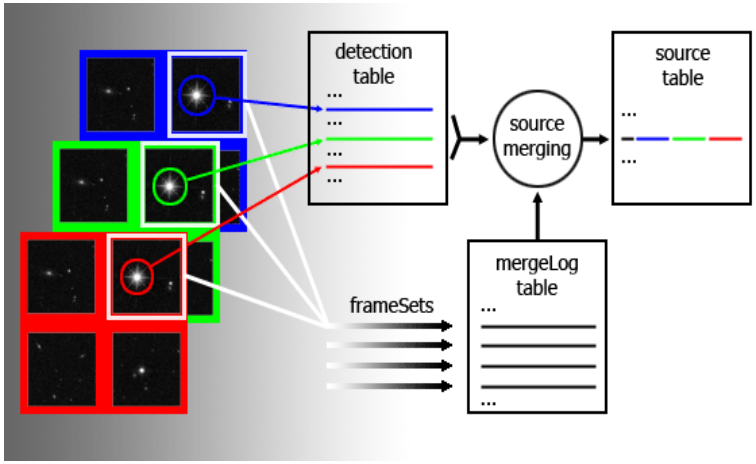
- Accurate timing is crucial for Solar System objects (SSo)
- The movment rate of SSos ranges from tens of miliarcsec/minute (for trans-neputian objects) to several arcsec per minute for near-Earth asteroids (NEAs), beeing typical 0.3 arcsec/min for Main Belt Asteroids (MBA)
- Apparent magnitude vary with time



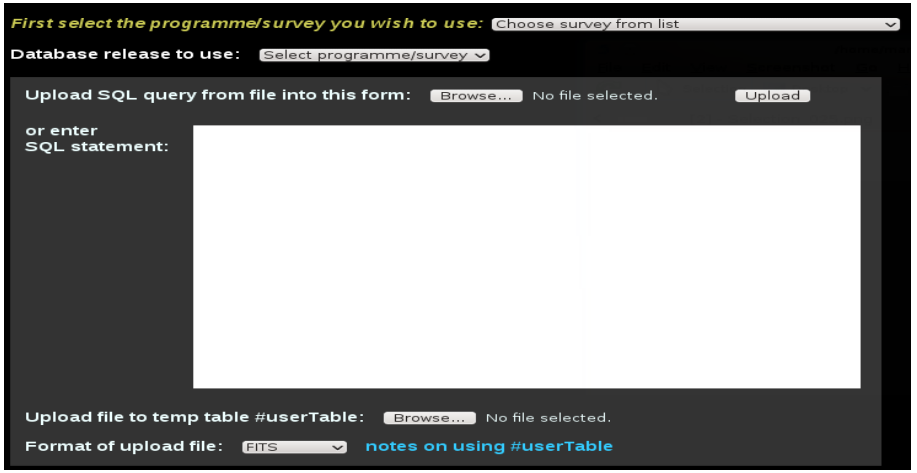
Imaging strategy

Detections retrieval

- The VISTA Data Flow System - VDFS (Emerson et al. 2004) is the pipeline that accomplish the end-to-end requirements of the VISTA survey
- All the detections (a detection is referring to a single object extracted from a single image in a single filter) found in VISTA survey images are stored in the vhsDetection table
- The cross-matching imply a square box search centered at the predicted position in vhsDetection table. The side of the box is 6σ, but no less than 2 arcsec
- 332 111 detections corresponding to 47 666 objects



[Data tables of VISTA. Source: http://horus.roe.ac.uk/vsa/dboverview.html]



Freeform SQL used to access the data.


ANY QUESTIONS?