VVV-SkZ_pipeline: an automatic photometric pipeline for Vista

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August 2010: *the birth of VVV-SkZ_pipeline, an adaption to VVV data of my fully-automatic PSF-photometry pipeline*

2 main cornerstones:

1. Specifically designed for the VVV images
2. Being totally automatic with the least needed intervention by the user, but being also highly configurable.

Main files that you need to prepare

- **VVV-SkZ_pipeline.opt** : overall option file of the pipeline
- **VVV-input** : input file where you said for each pawprint how to name the extracted images and which chips you want it to extract
- **login.cl** : the initialization file of IRAF
- **Pawprints** in not compressed format (.fits)
- Catalog of standard stars

Main structure of the pipeline

- **VVV-GetImgInfoHdr.pl** : it extracts images from the pawprints and the needed info from the headers;
- **VVV-DpAls4psf.pl** : it calculates the PSF in 5 iteration (VAR from -1 to 2) and produces a preliminary psf-photometry with allstar;
- **VVV-AllframeMntg.pl** : it stacks the images;
- **VVV-DpAlsMnt.pl** : it creates the master list of the stars using the stacked image in 4 iterations;
- **VVV-AllframeLast.pl** : it runs allframe with list of “all” the stars;
- **VVV-MetrCalibMatch.pl** : it uses the WCS to astrometrize and the 2MASS catalog to calibrate each image and then matches all the bands in a single catalog.
- Sigma-clipping cleaning procedure to remove spurious detection

Calibration

The calibration is done using the normal 2MASS, but only the stars with magnitude inside a given interval and with contamination smaller than 0.03 mag from stars nearer than 2.2" (2.5" is the smallest FWHM of 2MASS) .

The least square-fit program assigns a “fudging factor” to the data to weight less the furthest points, instead of a sigma clipping.

Calibration

The calibration is operated twice.

The first time it is applied to output of allframe and is the classical correction for zero point and color term

$$M_{2\mathrm{MASS}} - m_{VSp} = a_1 (J - Ks)_{2\mathrm{MASS}} + a_0$$

The second time it is applied to output of daomaster, after the match of photometries of the same band, and it's just a correction for zero point.

This correction is operated to avoid the propagation of small errors in the zero-point in a file to the final catalog.

A practical example: M22

3 different offset for a field of 4100x2100pxl

VVV-input:

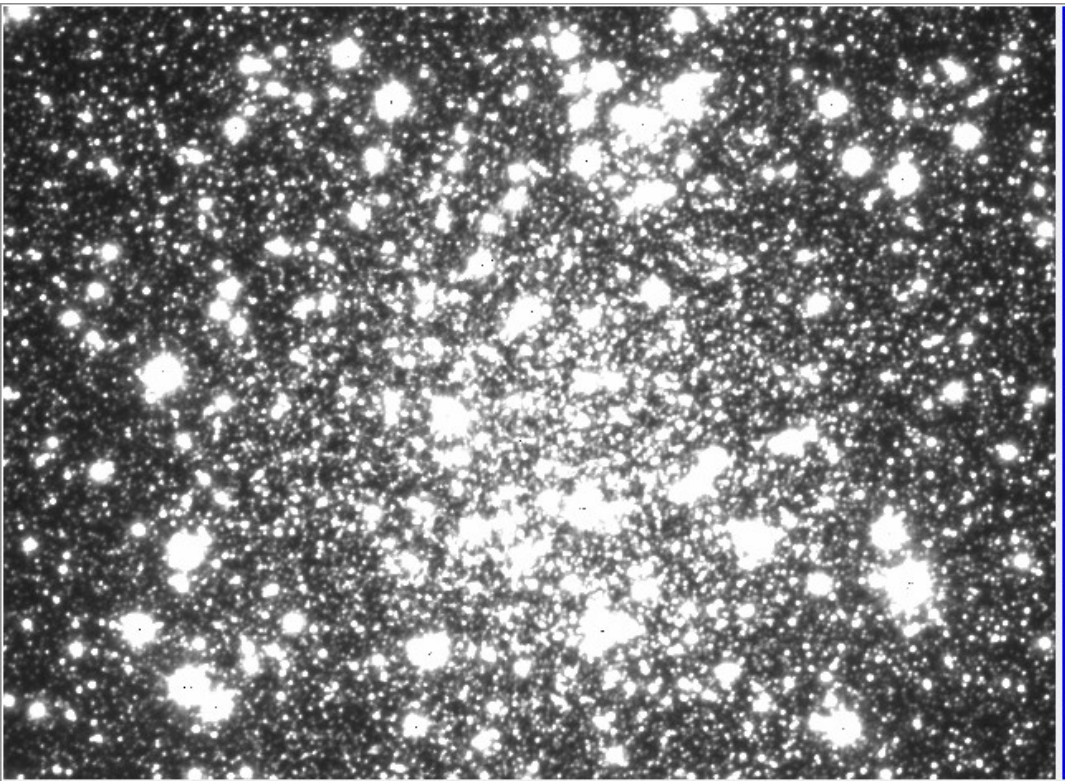
```
v20100407_00619_st.fits  M22-01  10
v20100407_00621_st.fits  M22-02  11
v20100407_00623_st.fits  M22-03  11
v20100407_00631_st.fits  M22-04  10
v20100407_00633_st.fits  M22-05  11
v20100407_00635_st.fits  M22-06  11
v20100407_00643_st.fits  M22-07  10
v20100407_00645_st.fits  M22-08  11
v20100407_00647_st.fits  M22-09  11
v20100825_00508_st.fits  M22-10  10
v20100825_00510_st.fits  M22-11  11
v20100825_00512_st.fits  M22-12  11
v20100826_00420_st.fits  M22-13  10
v20100826_00422_st.fits  M22-14  11
v20100826_00424_st.fits  M22-15  11
```

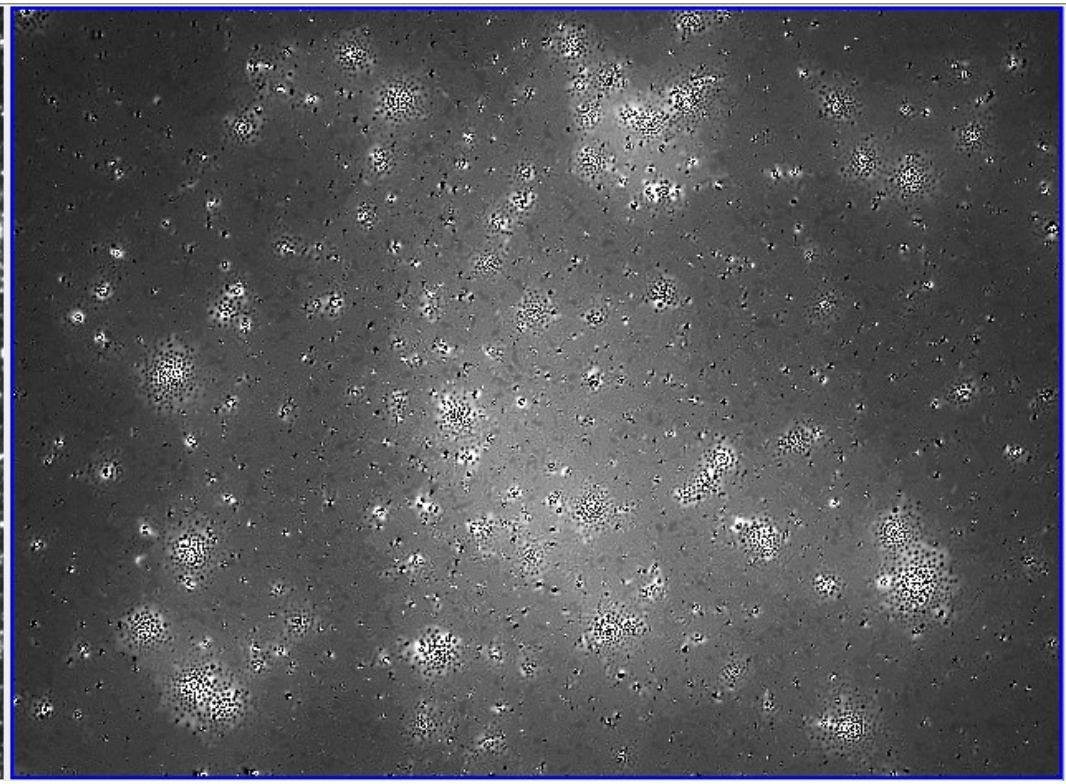
Chi2 of the PSF according to DAOPhot

After 4h

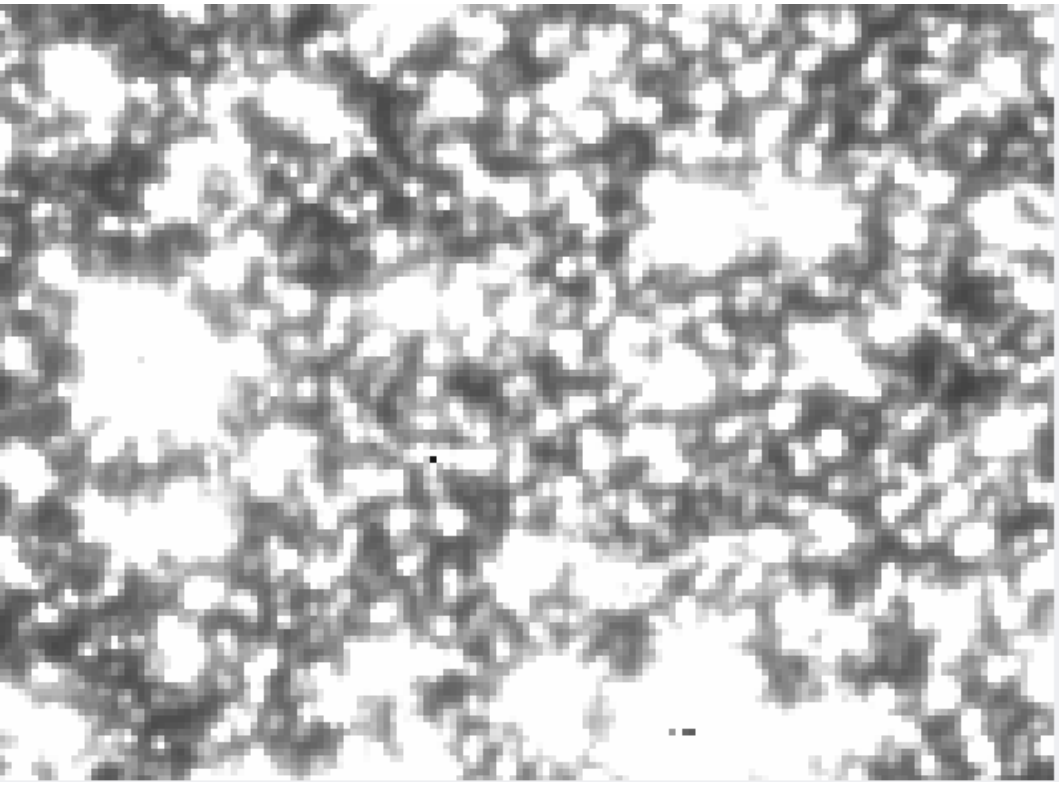
M22-01 => 0.0198
M22-02 => 0.0174
M22-03 => 0.0196
M22-04 => 0.0239
M22-05 => 0.0258
M22-06 => 0.0245
M22-07 => 0.0139
M22-08 => 0.0139
M22-09 => 0.0179
M22-10 => 0.0173
M22-11 => 0.0168
M22-12 => 0.0153
M22-13 => 0.0153
M22-14 => 0.0189
M22-15 => 0.0166

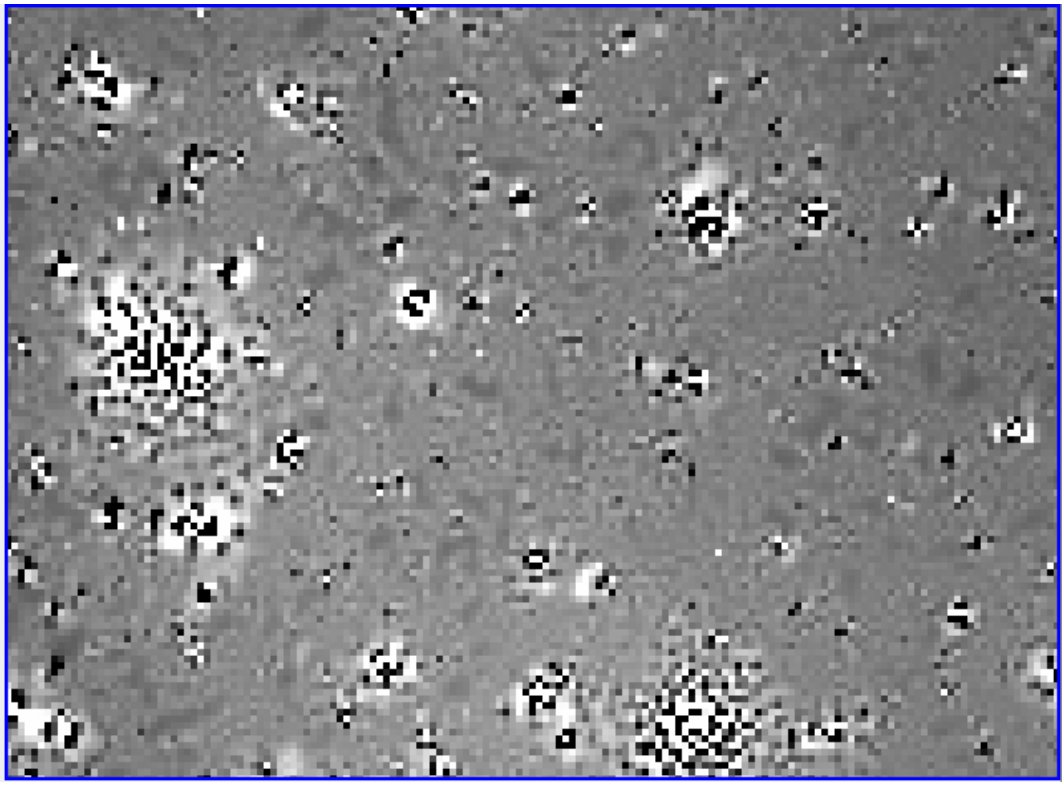
Example of montaged image of the cluster



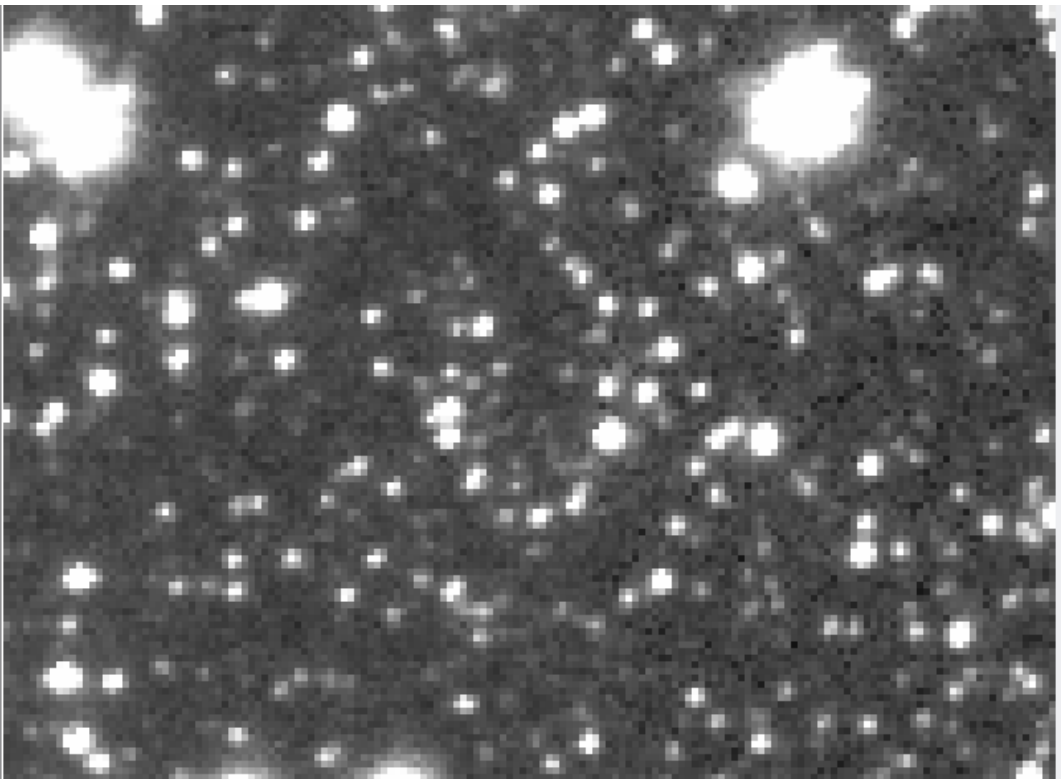


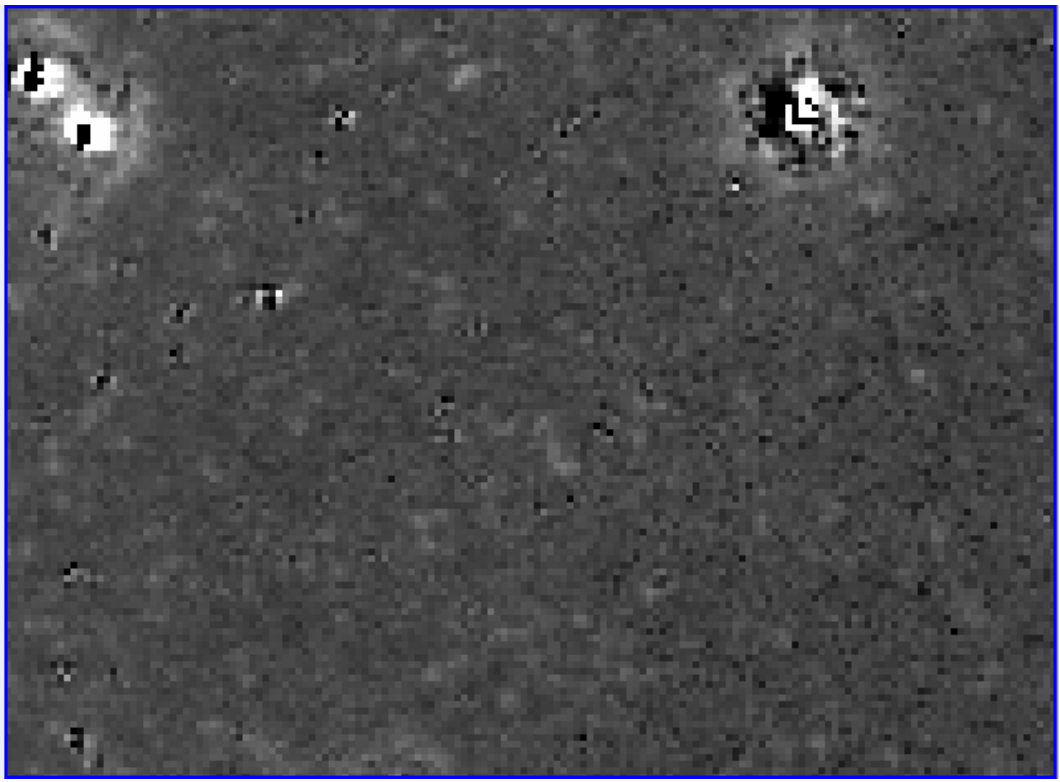
Montaged image of the inner part of the cluster



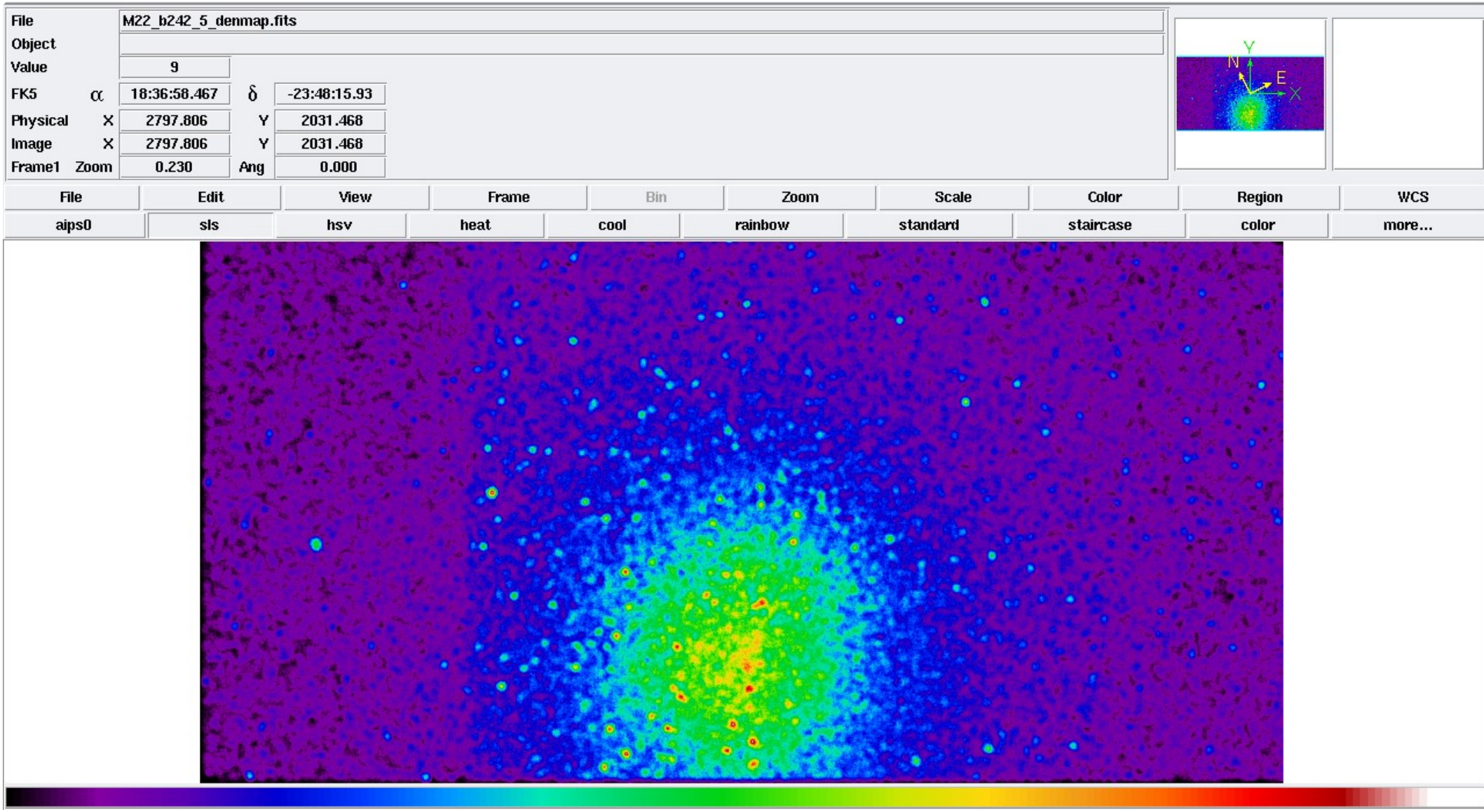


Montaged image of the field

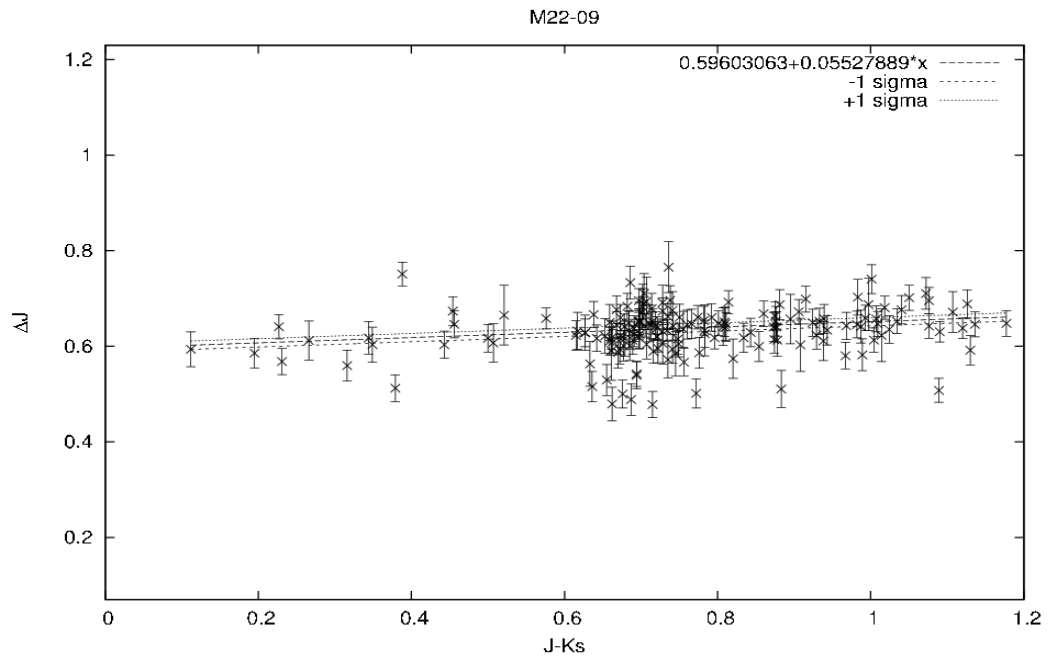


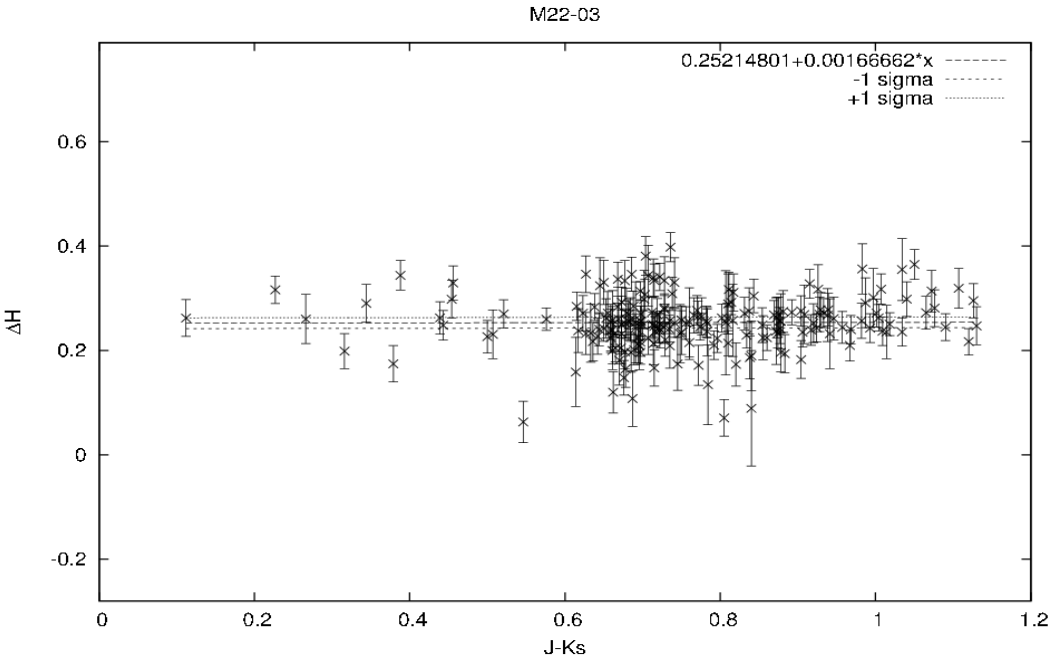


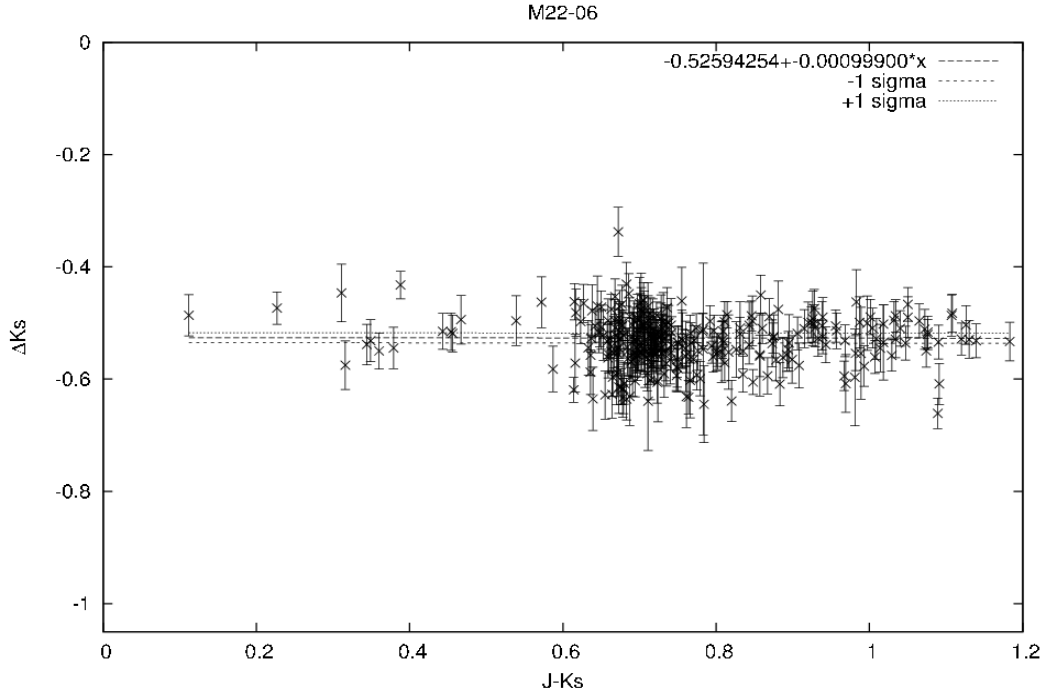
Density map in fits format

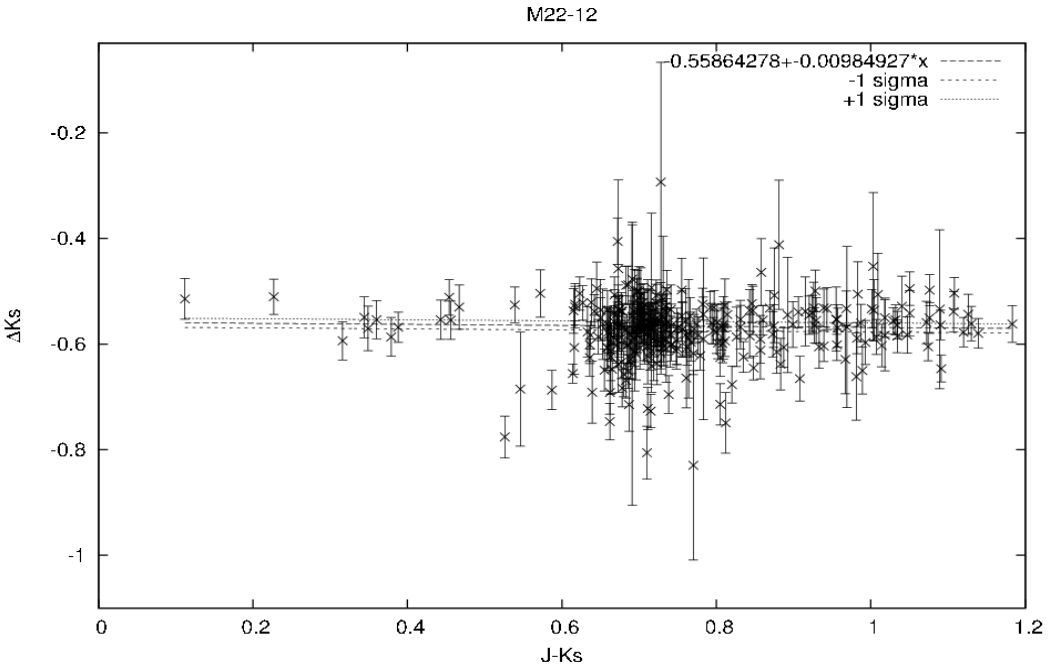


Examples of calibration

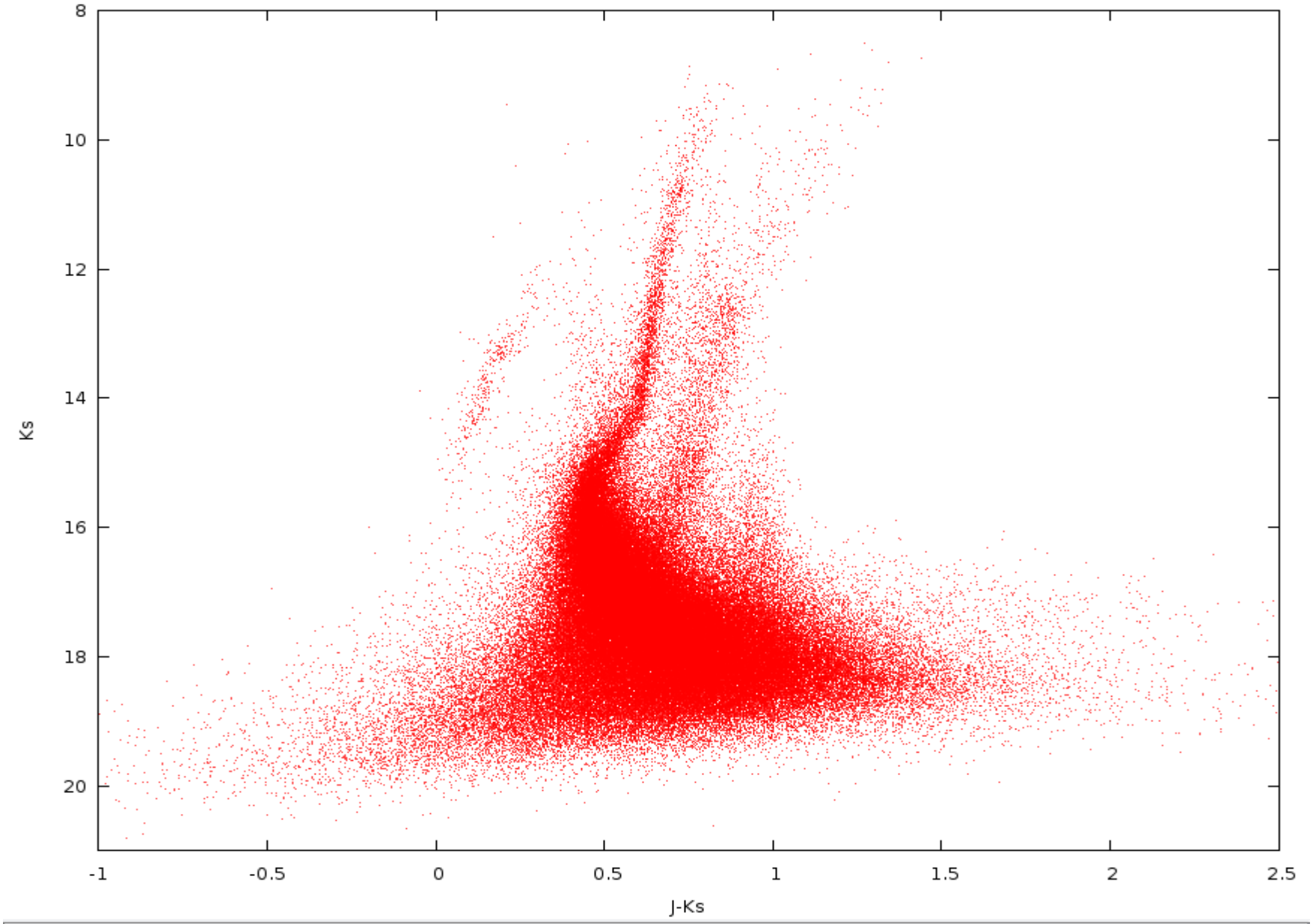




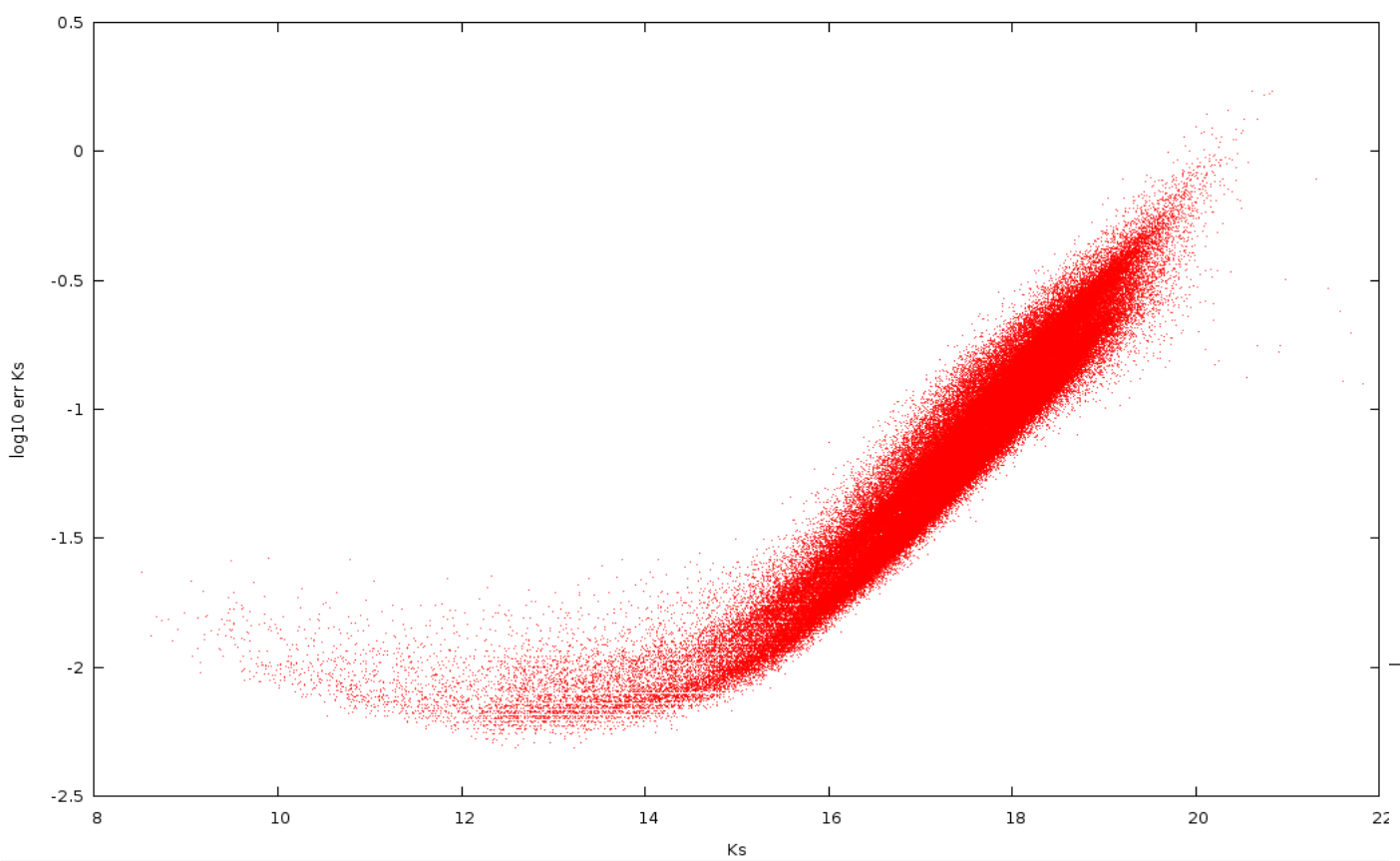


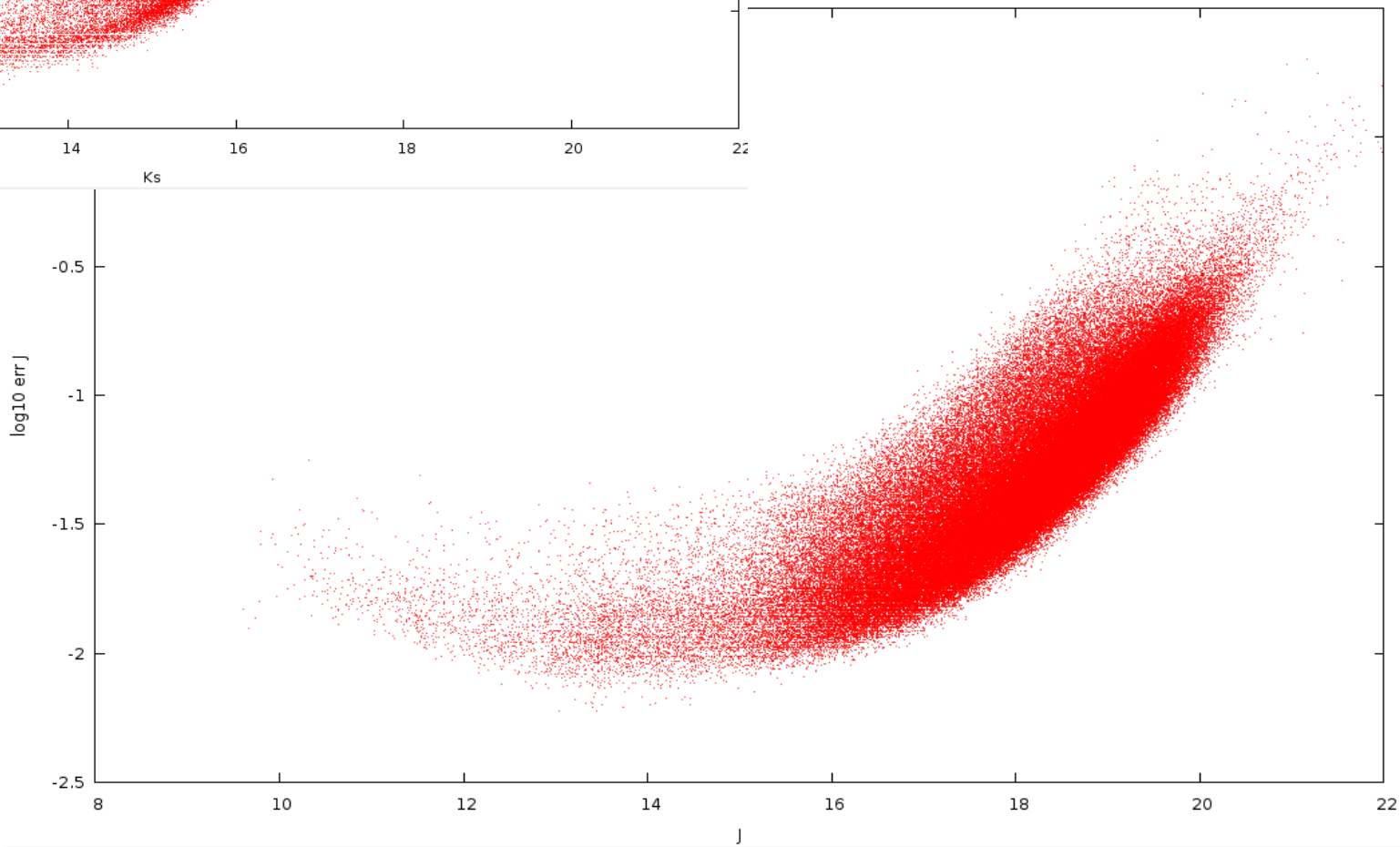


After ~12h, the final cleaned catalog of 218658 stars



Errors in Ks and J

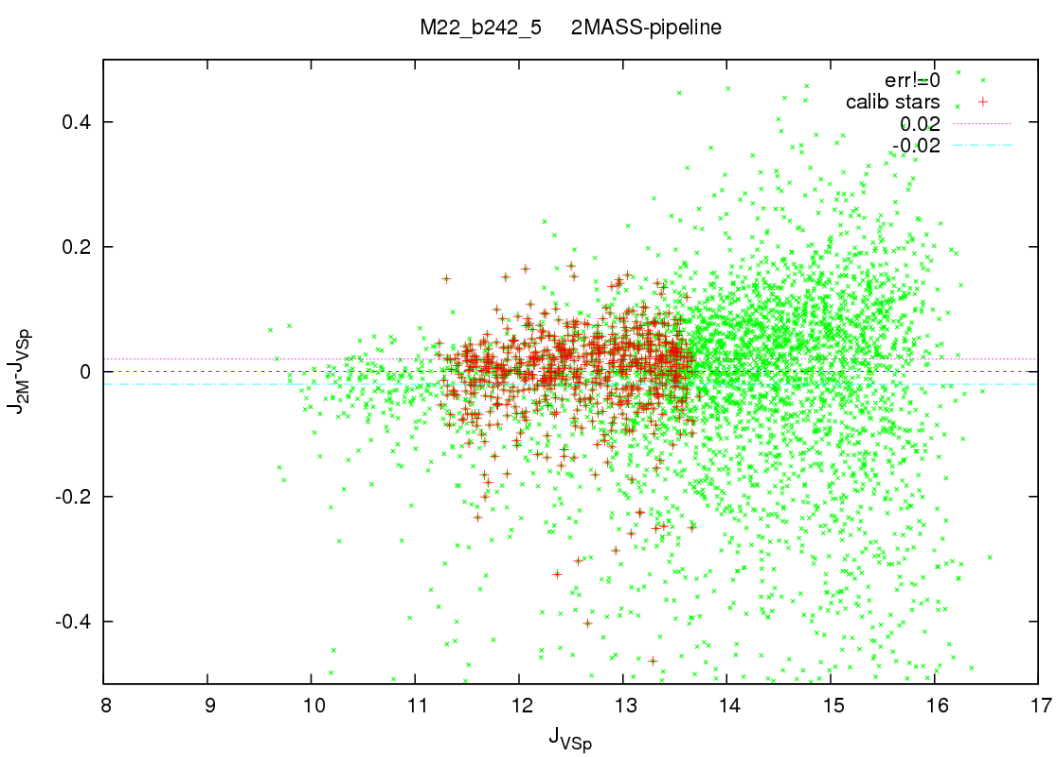




Testing the catalog:
1- Comparison with 2MASS

Being the 2MASS catalog the reference point for both photometry and astrometric system, the first comparison was done with it.

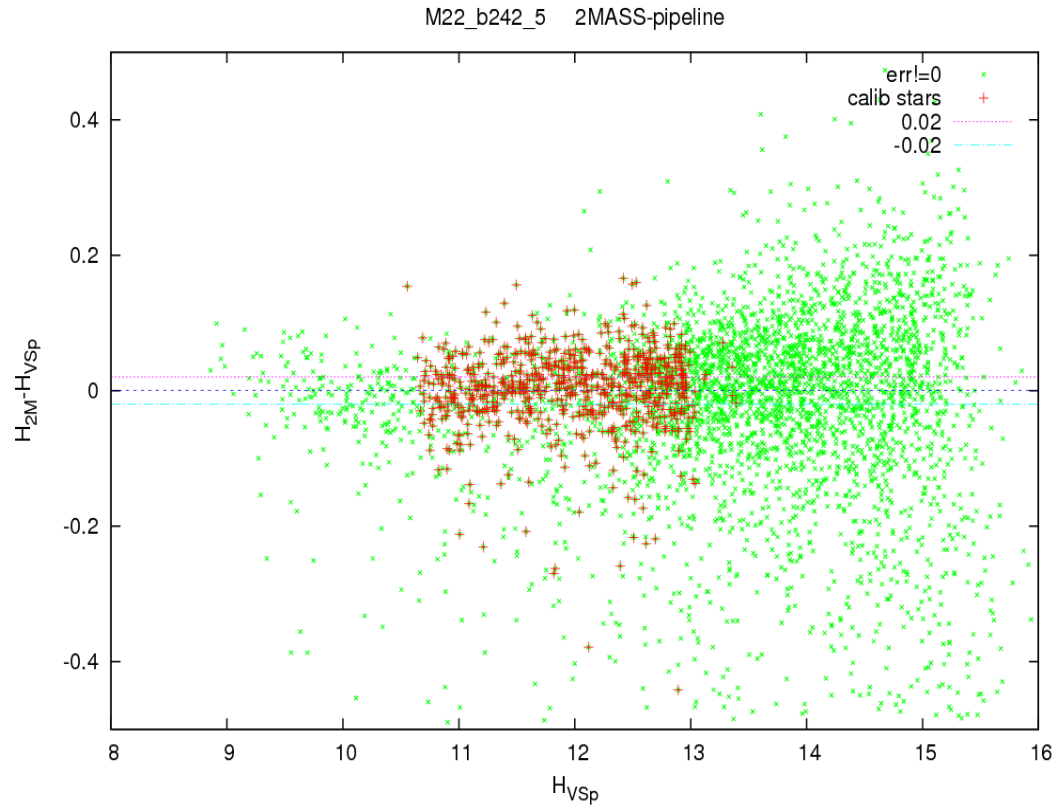
This comparison is also one of the outputs of the VVV-SkZ_pipeline.

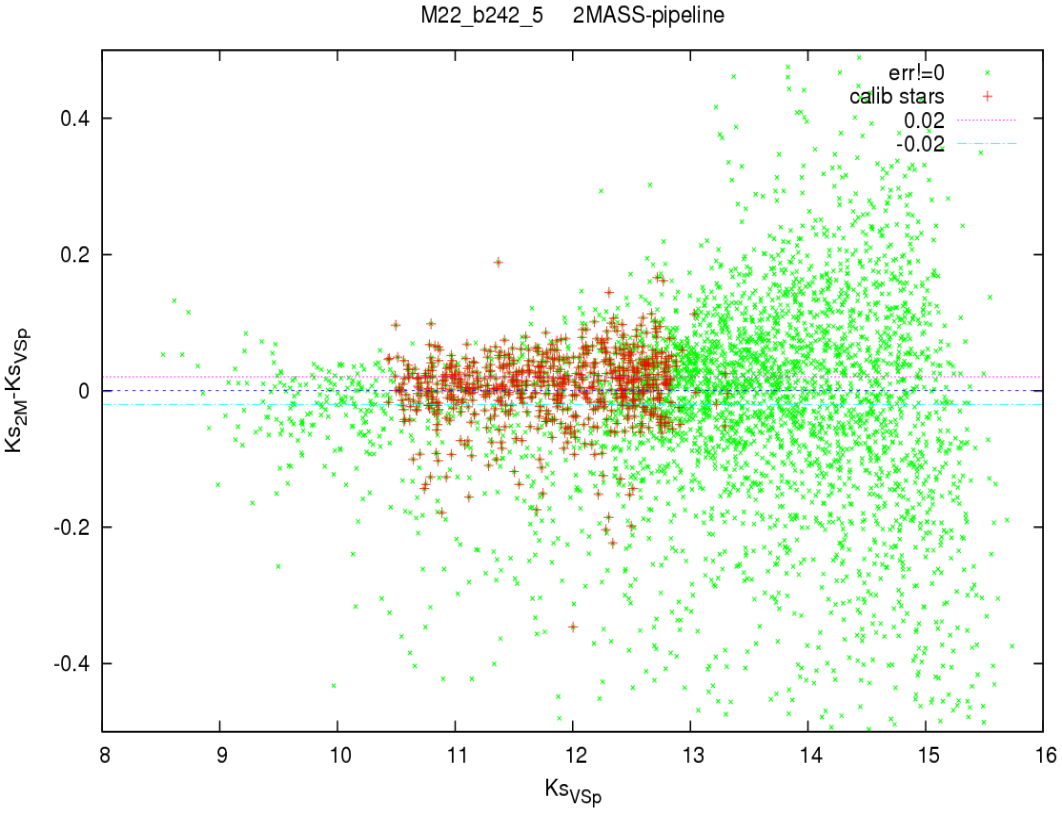


Comparison with 2MASS: bands

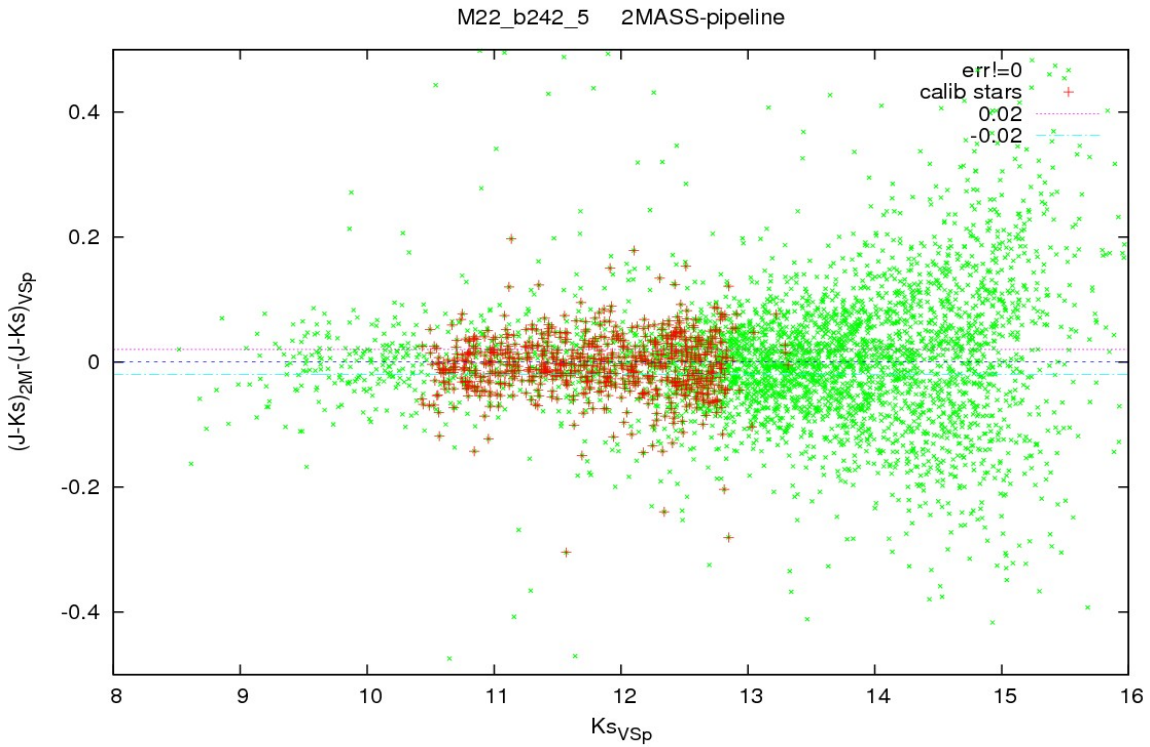
Good agreement down to 13-14, where the known deviation starts

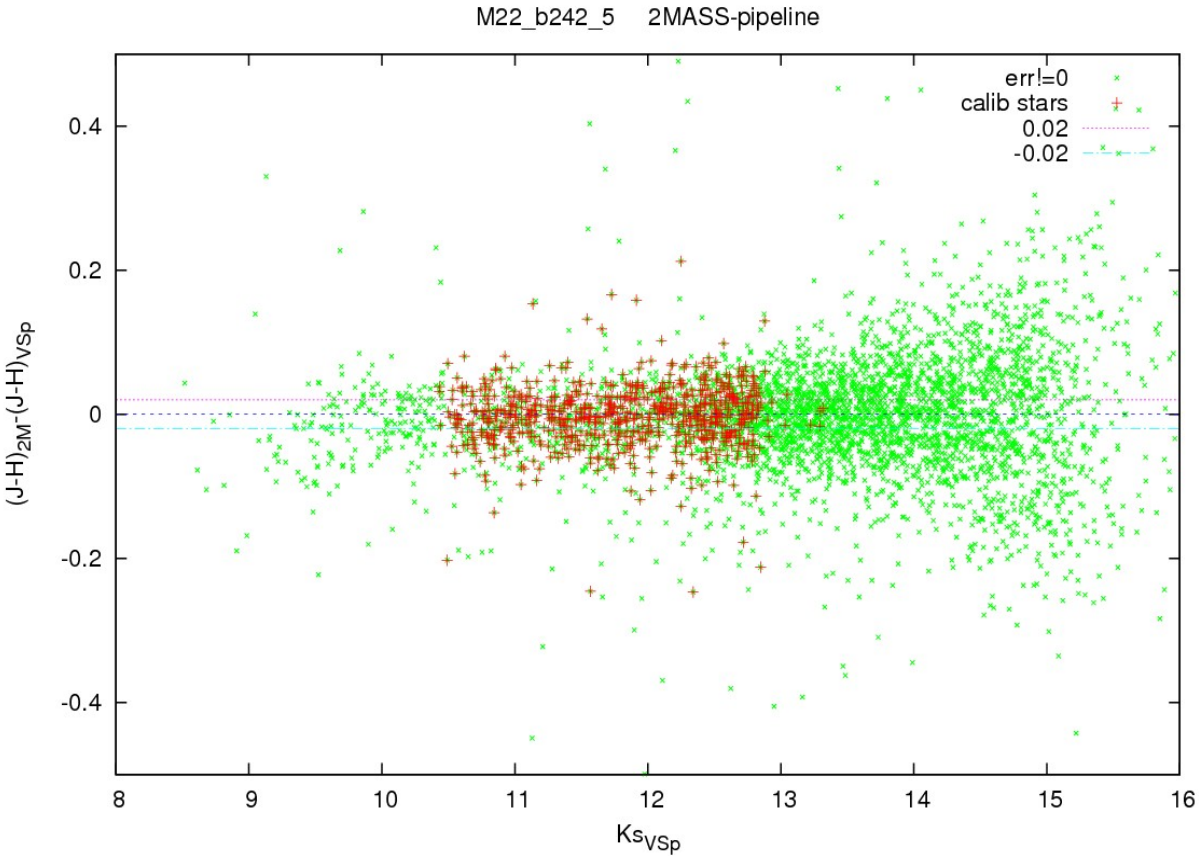
J reliable up to 10.0-10.5
H reliable up to 9.5-10.0
Ks reliable up to 9.5-10.0



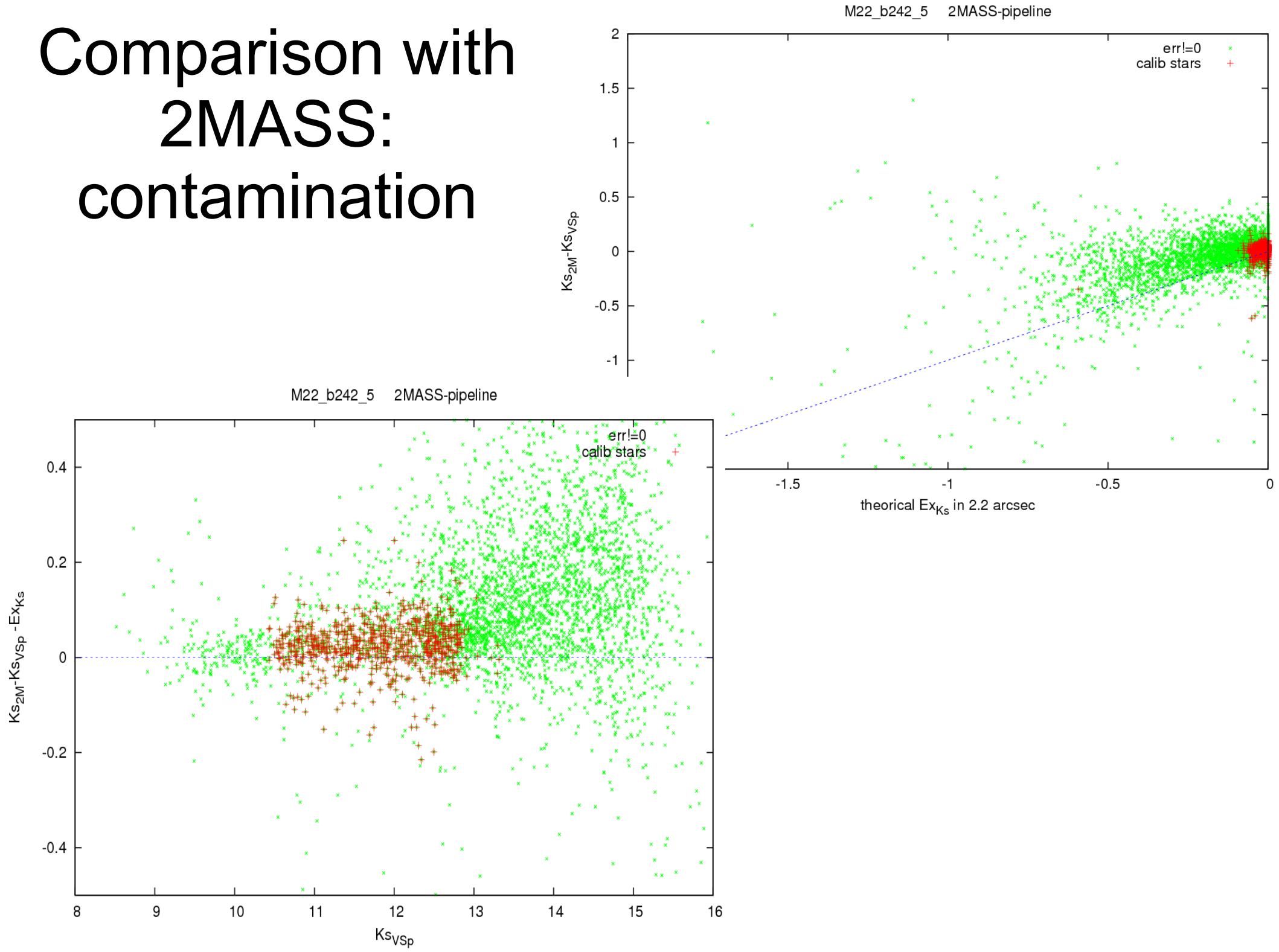


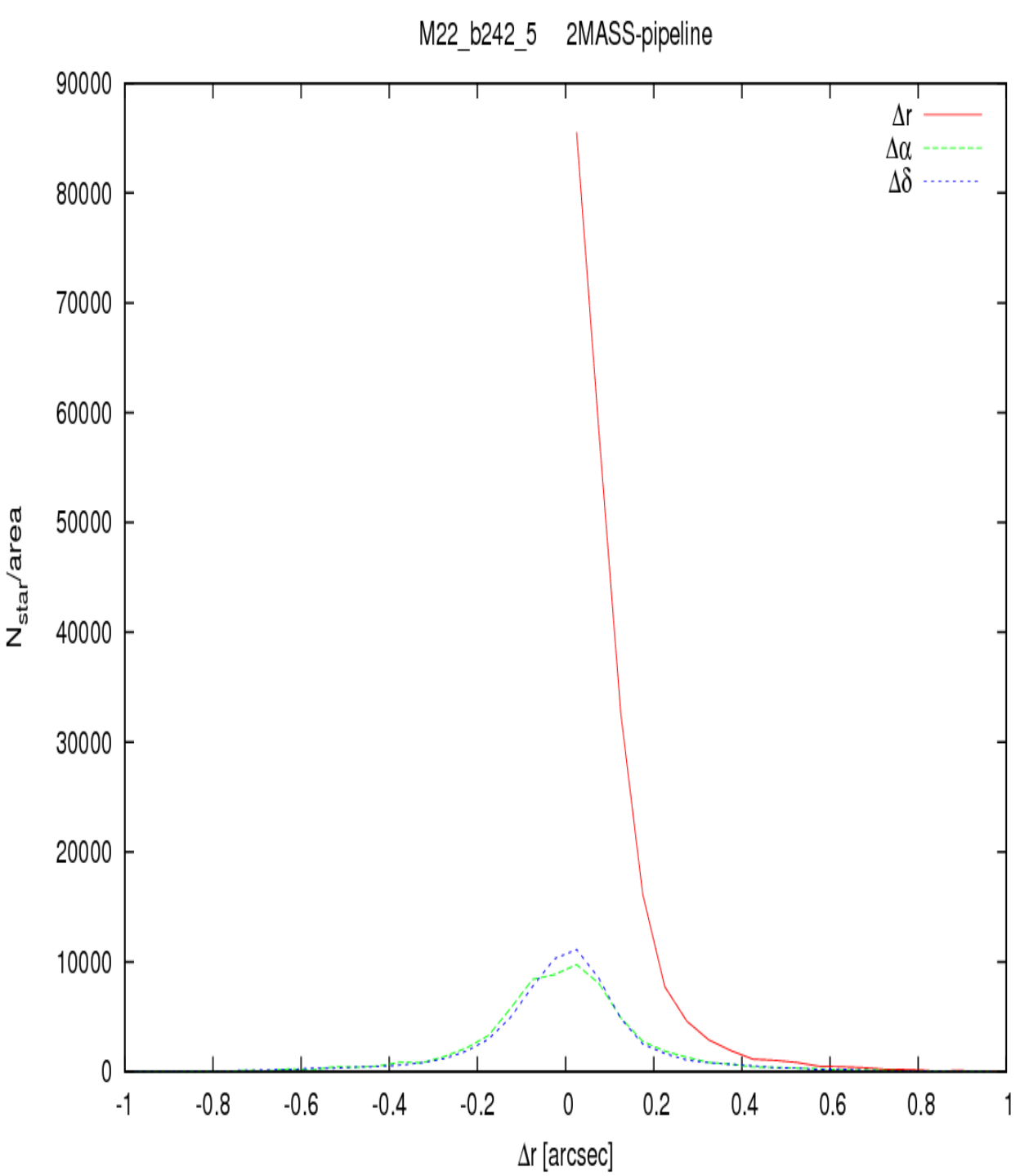
Comparison with 2MASS: colors





Comparison with 2MASS: contamination



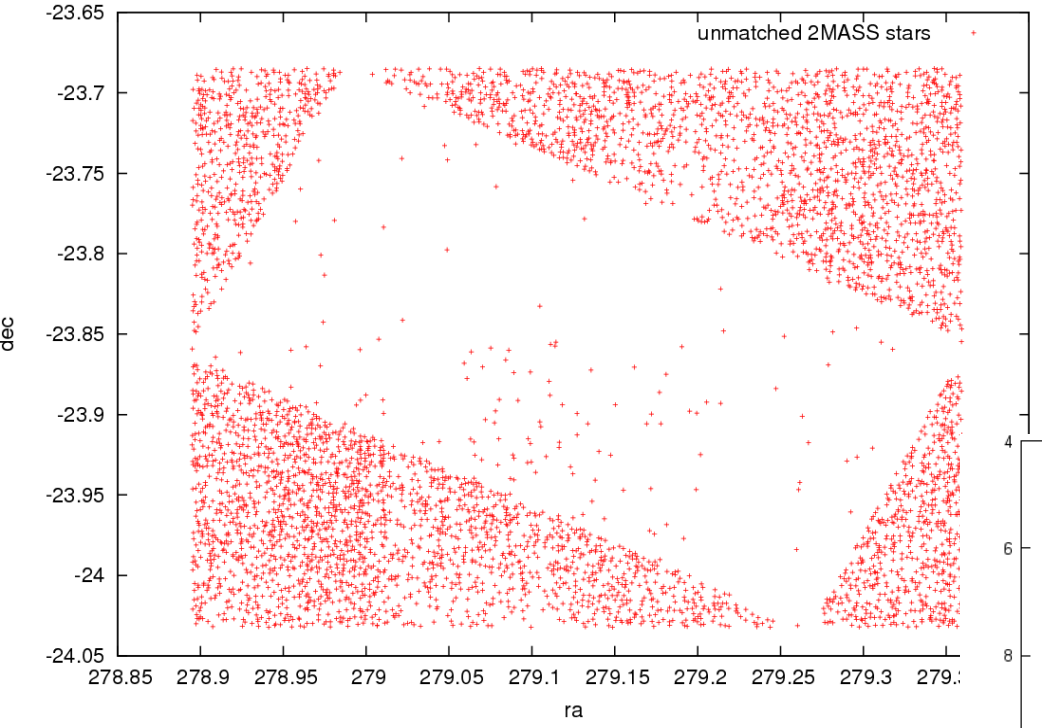


Comparison with 2MASS: positions

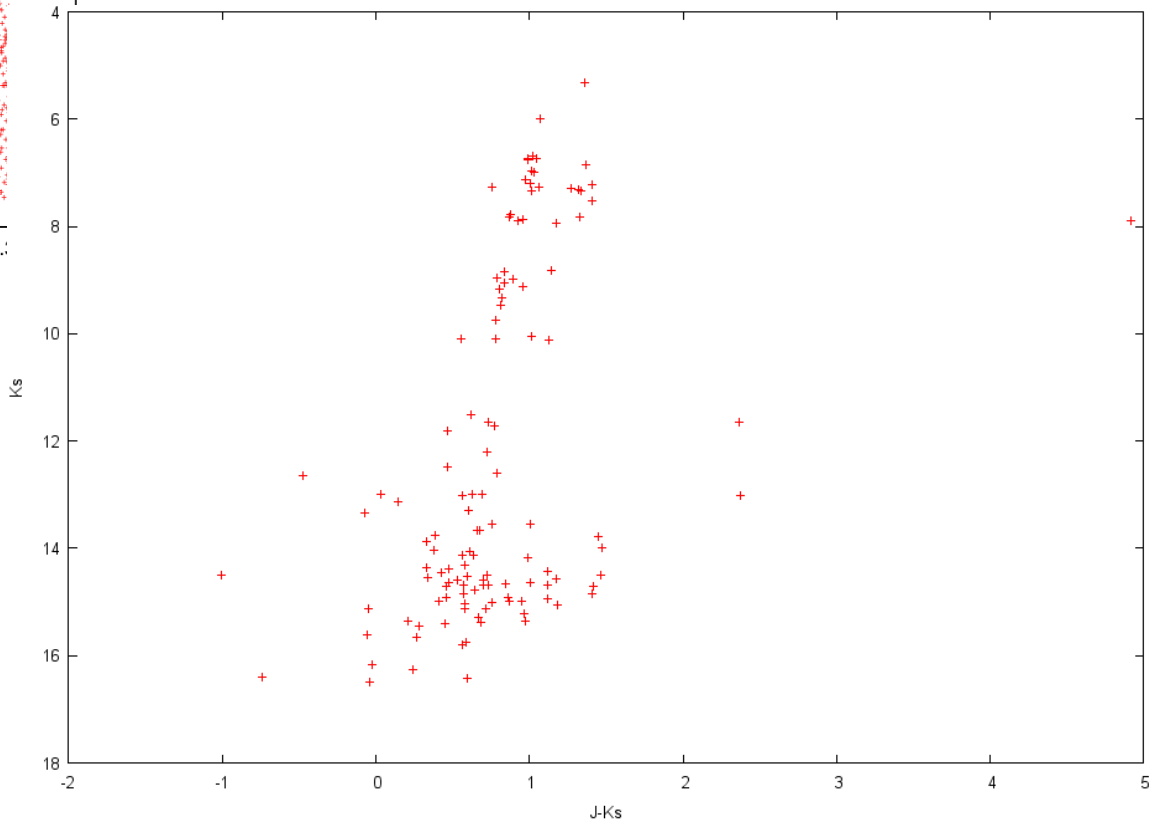
Mean delta ra: -0.004"
sSD: 0.193"

Mean delta dec: -0.003"
sSD: 0.190"

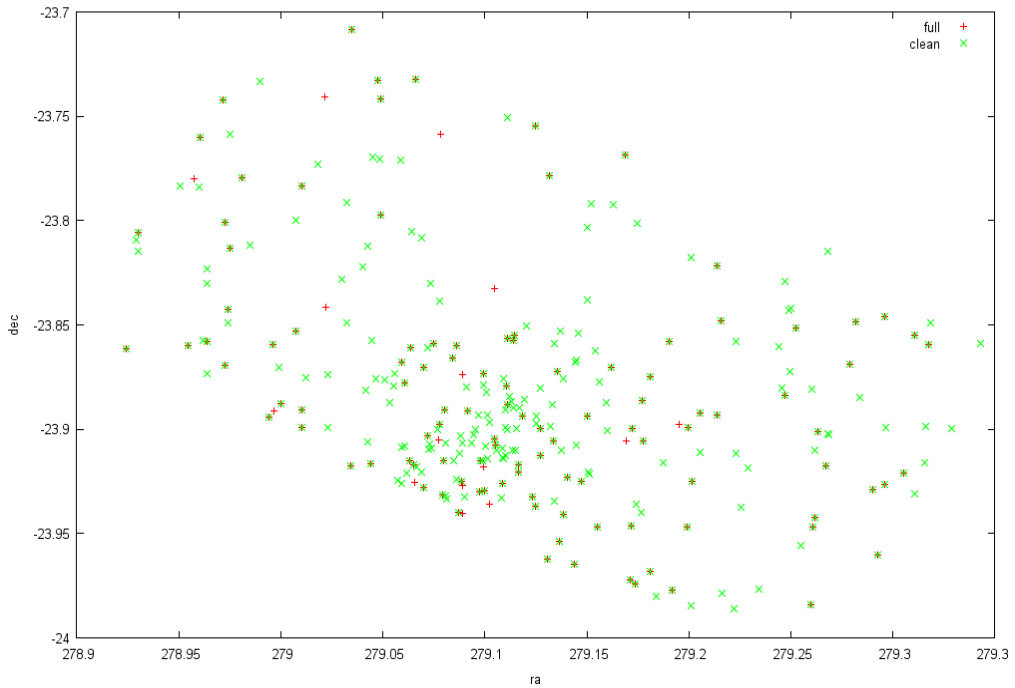
Comparison with 2MASS: unmatched stars



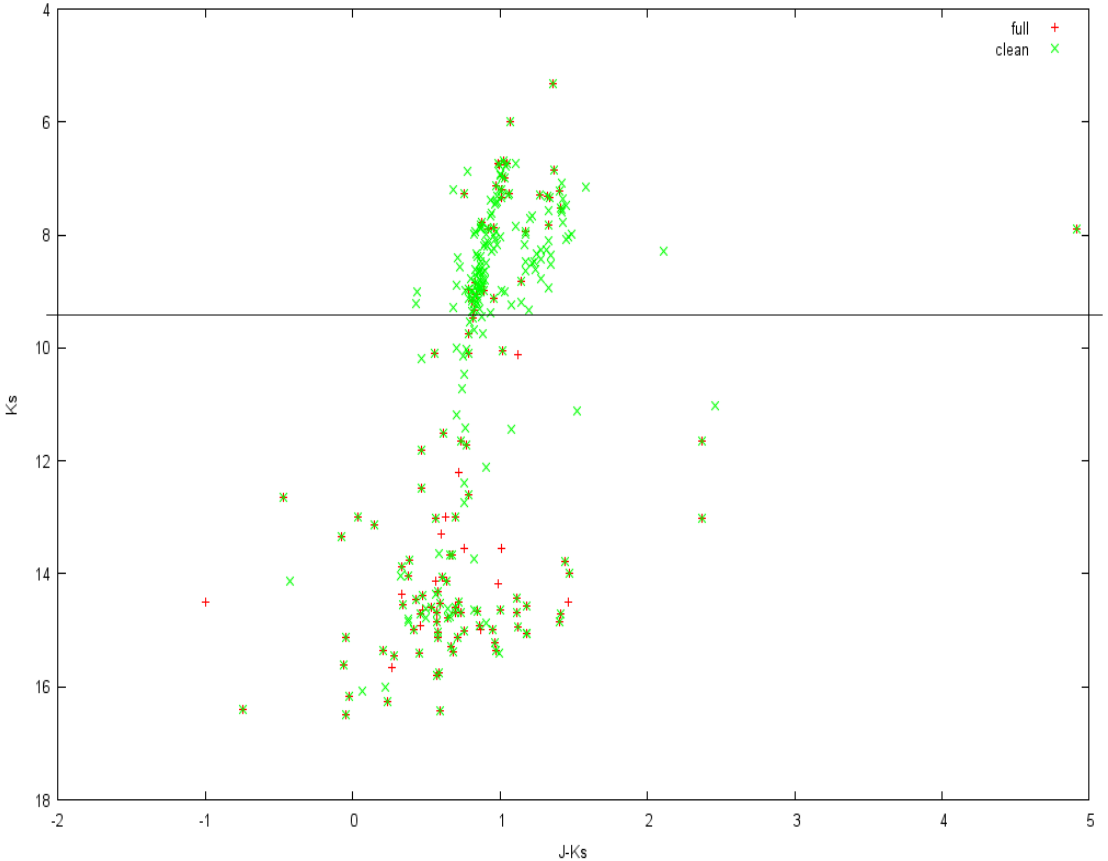
124 stars
26 with Ks<8
14 with 8<Ks<11
25 with 11<Ks<14
59 with 14<ks<16.5



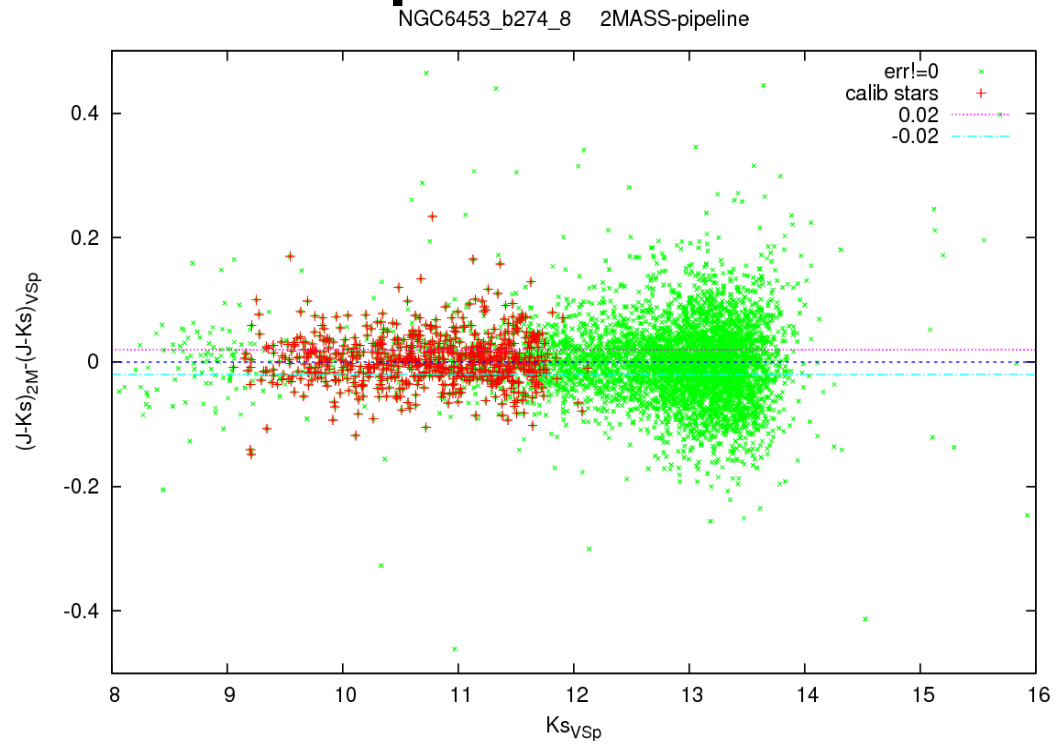
Comparison with 2MASS: unmatched stars with un/cleaned catalogs

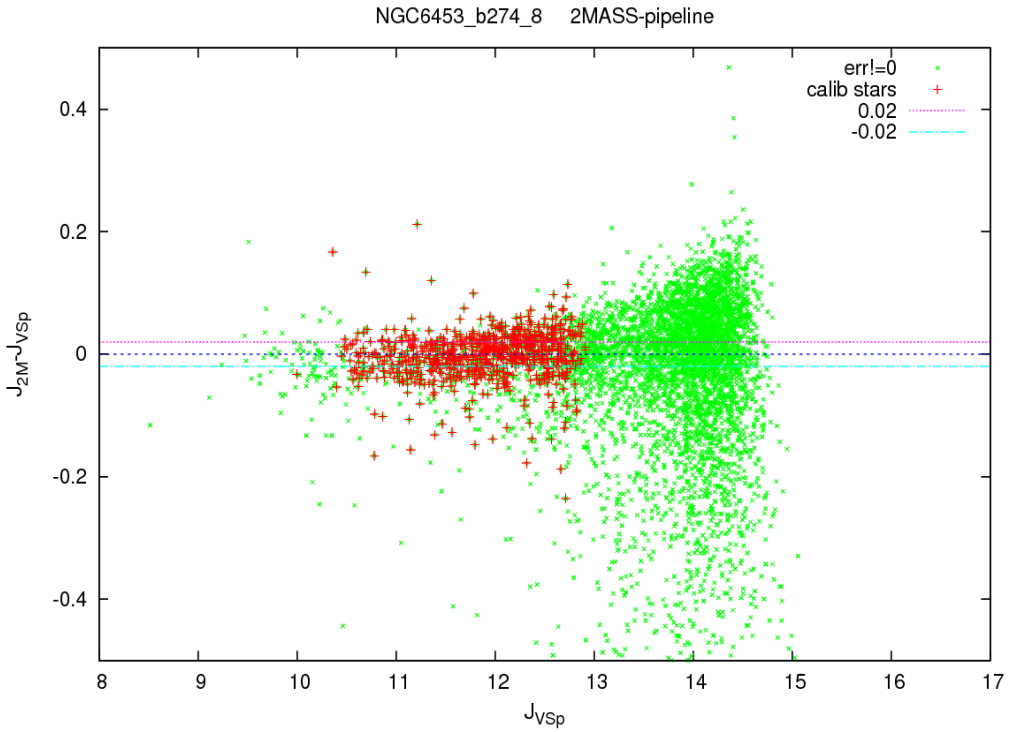


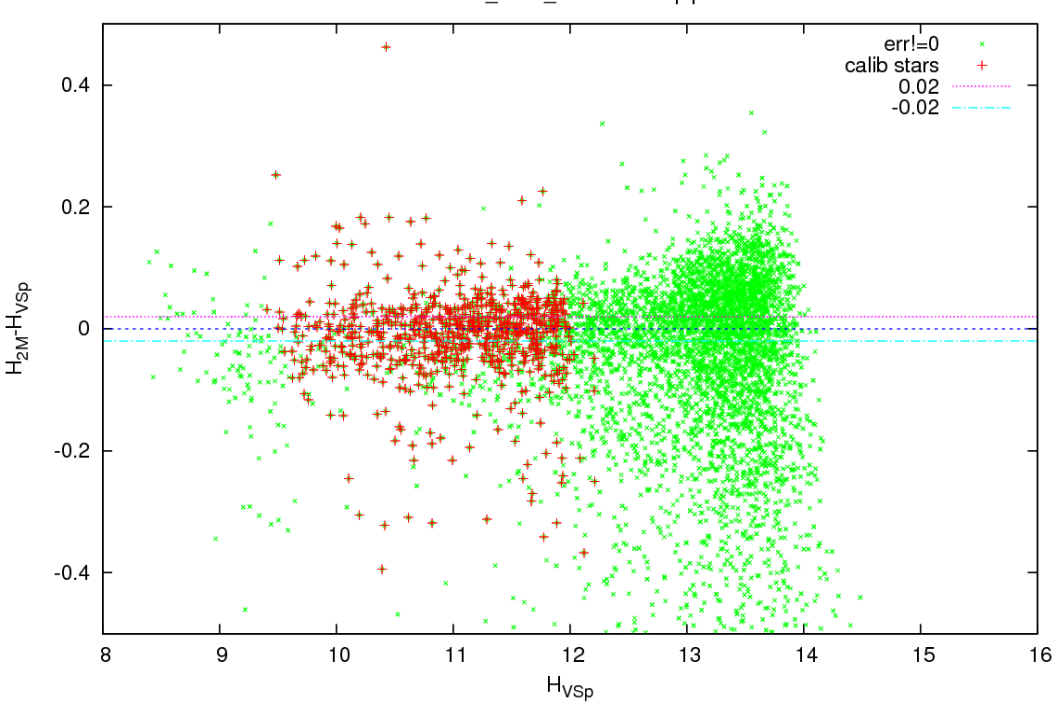
uncleaned;cleaned
124;259
26;61 with Ks<8
14;103 with 8<Ks<11
25;31 with 11<Ks<16
59;64 with 14<ks<16.5

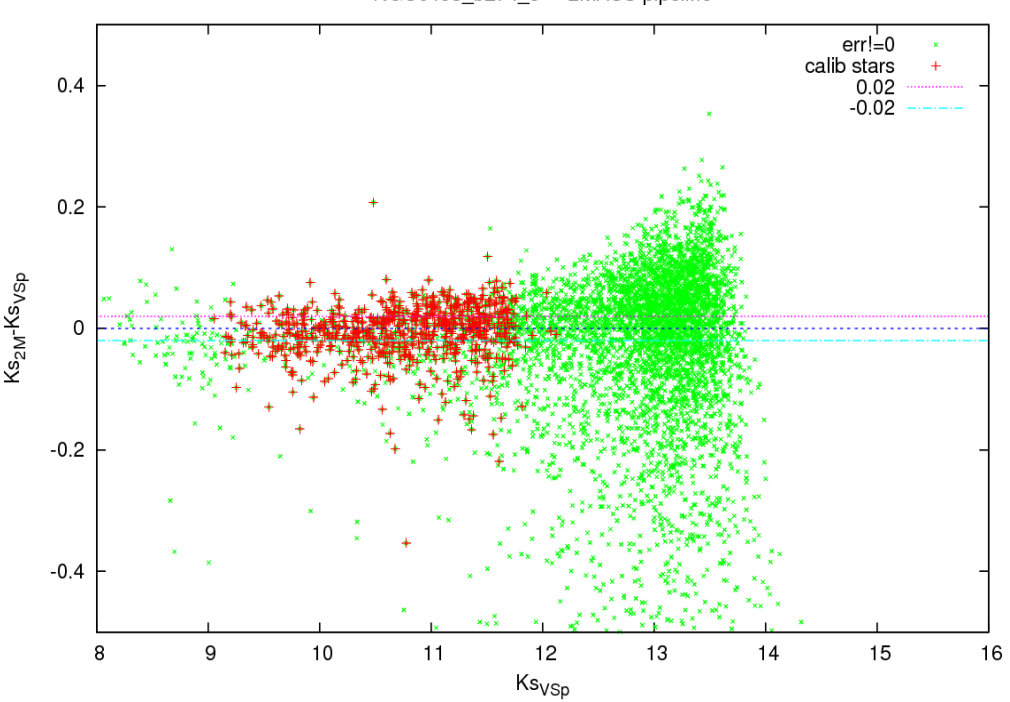


Comparison with 2MASS: NGC 6453

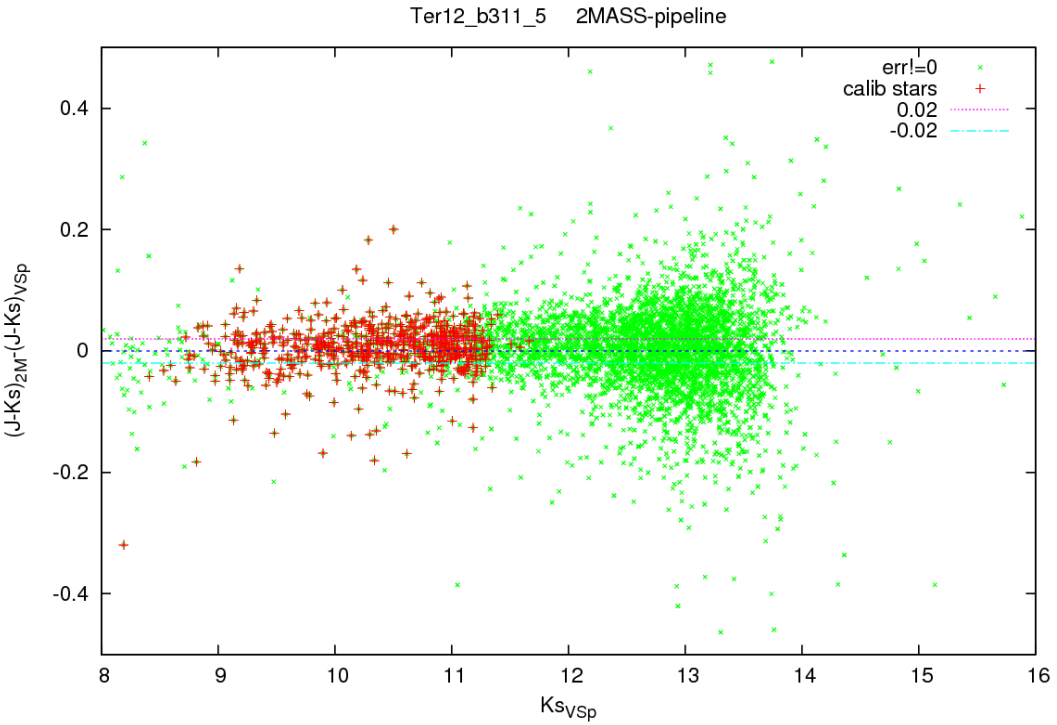


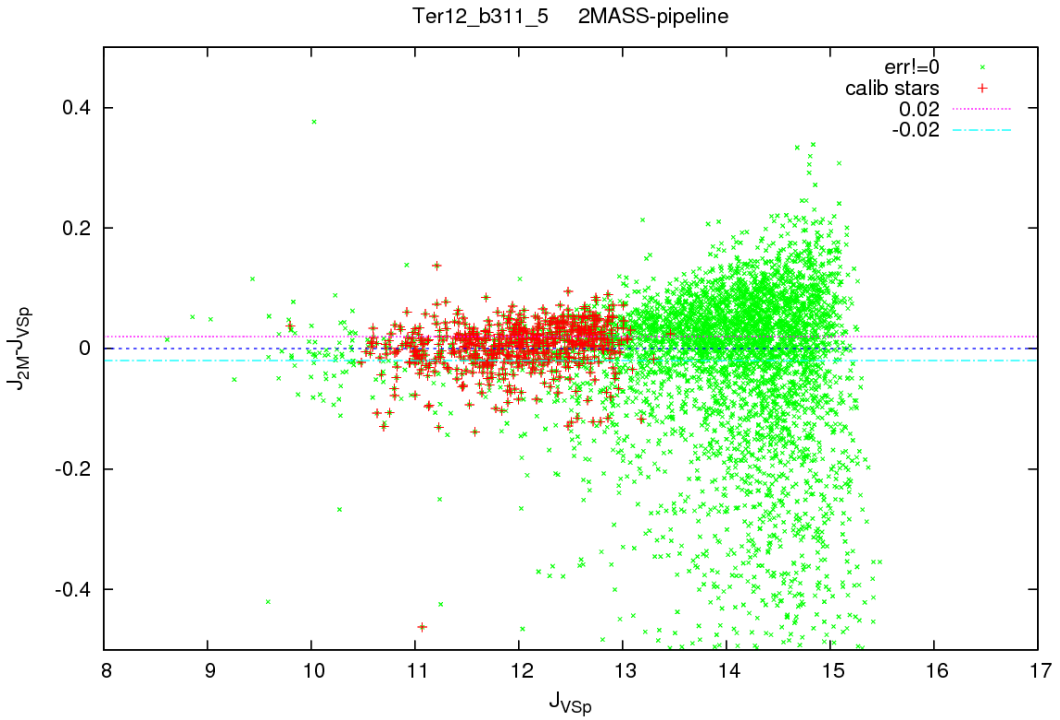


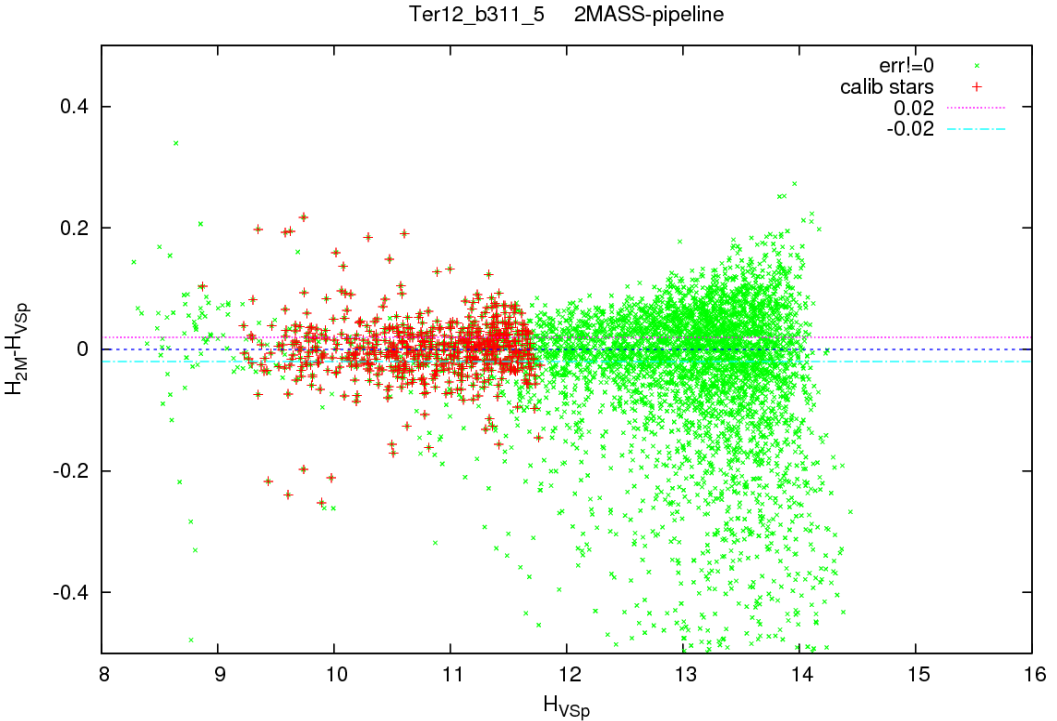


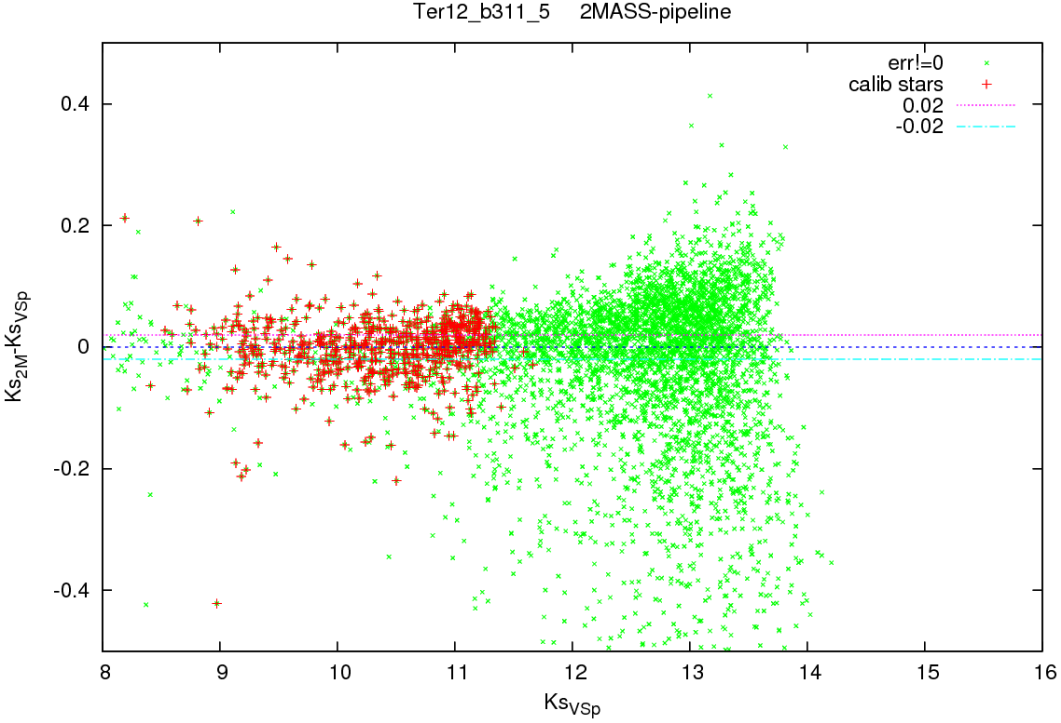


Comparison with 2MASS: Terzan 12









Testing the catalog:
2- Comparison with CASU catalog

Since the CASU catalog is the official output of the survey, the second comparison was done with it

./fitsio_cat_list v20100407_00643_st_tl_cat.fits => J.cat

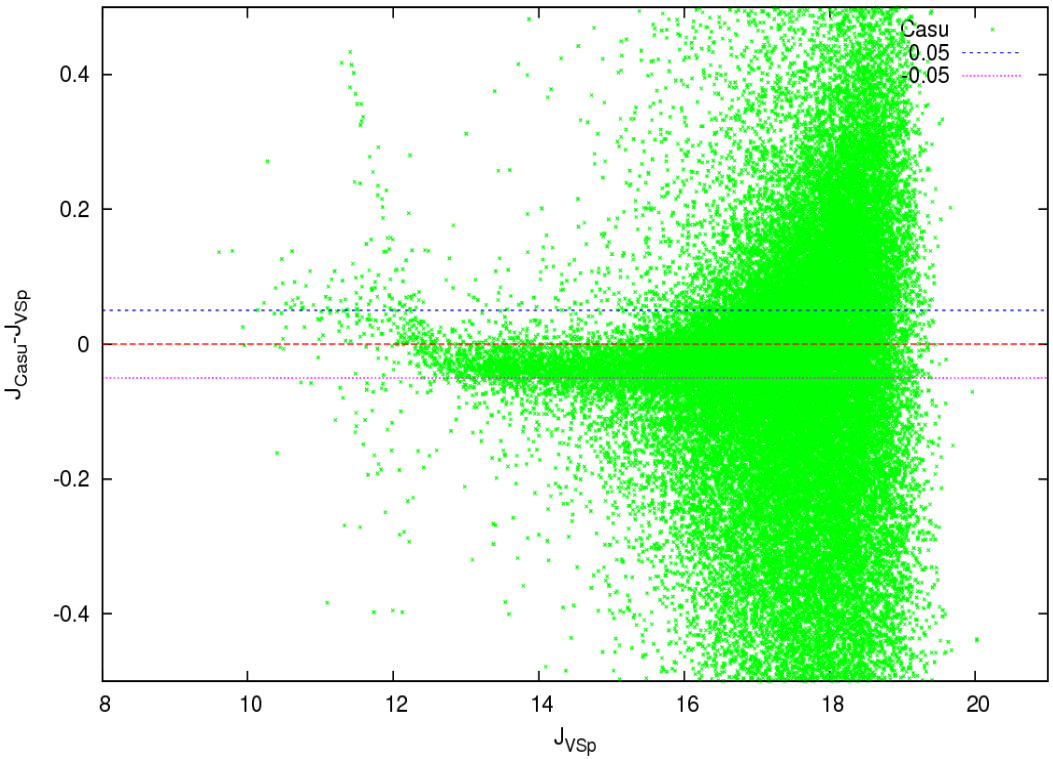
./fitsio_cat_list v20100407_00619_st_tl_cat.fits => H.cat

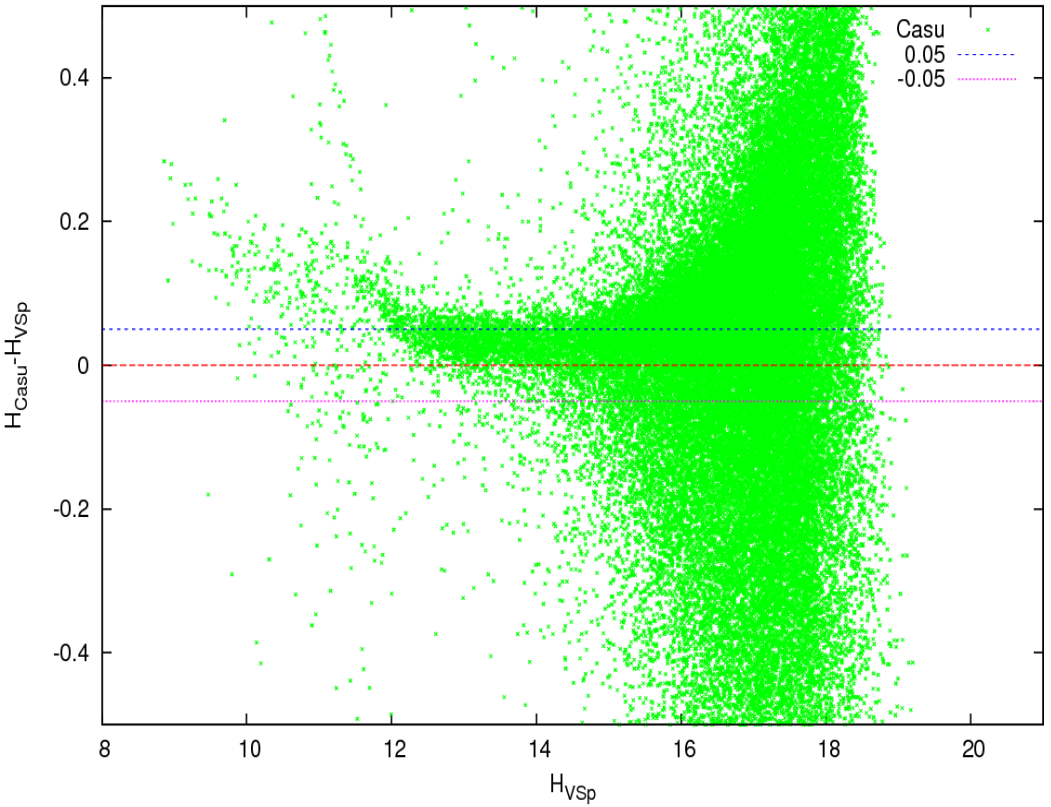
./fitsio_cat_list v20100407_00631_st_tl_cat.fits => Ks.cat

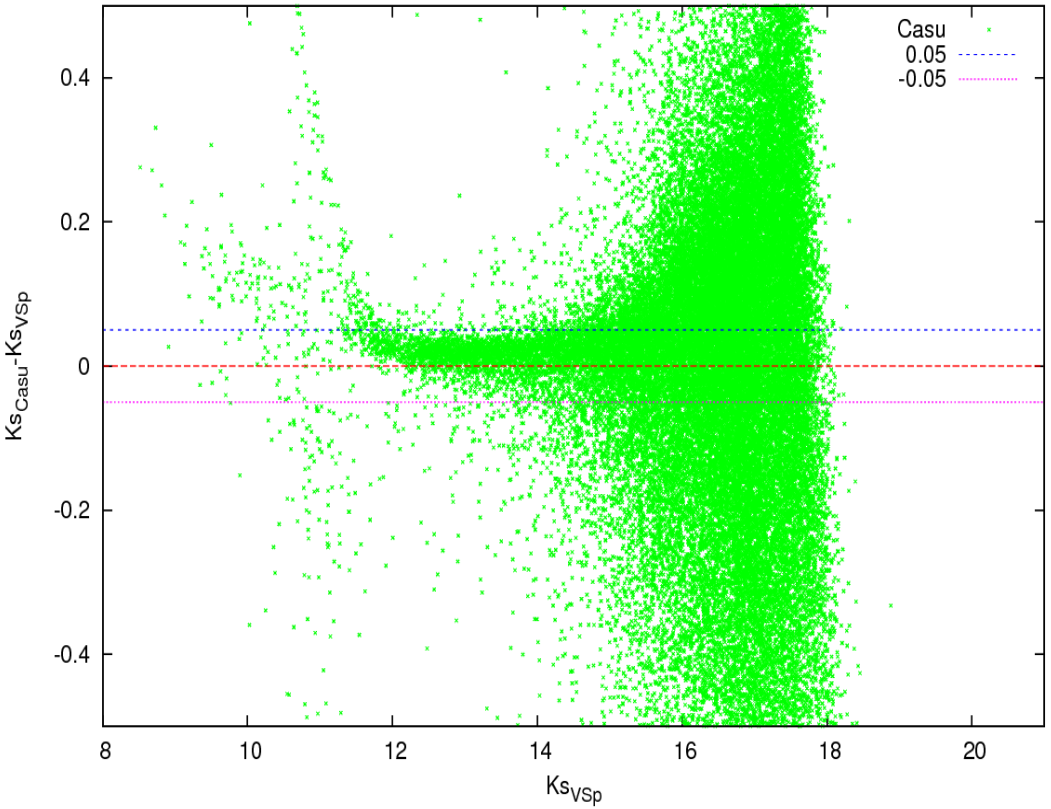
then the stars were selected based on position and matched using daomatch/daomaster.

Comparison with CASU catalog: bands

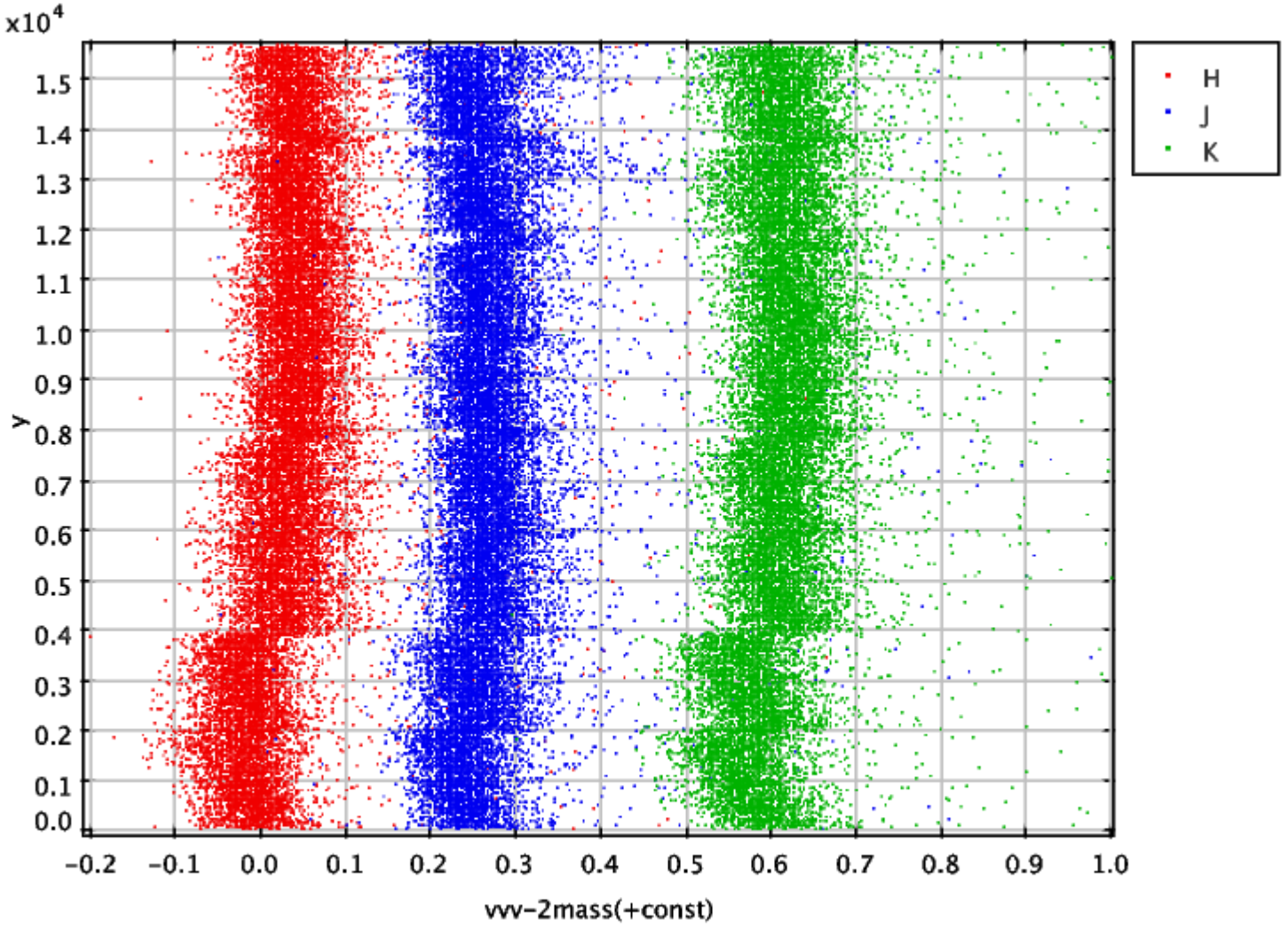
Considering the good agreement 2MASS-VSp down to 13-14,
the CASU catalog loses reliability for
J<12.9-13.2
H<12.5-12.9
Ks<12.2



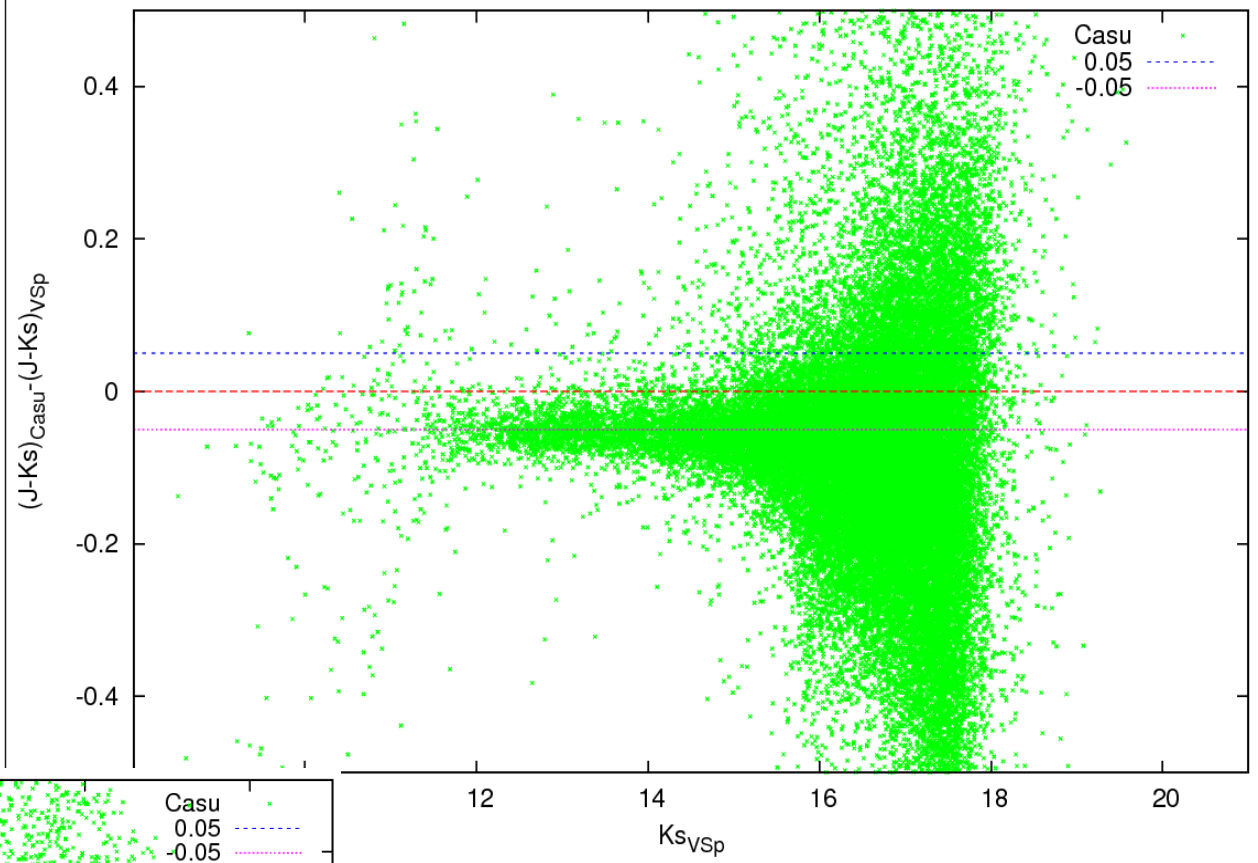


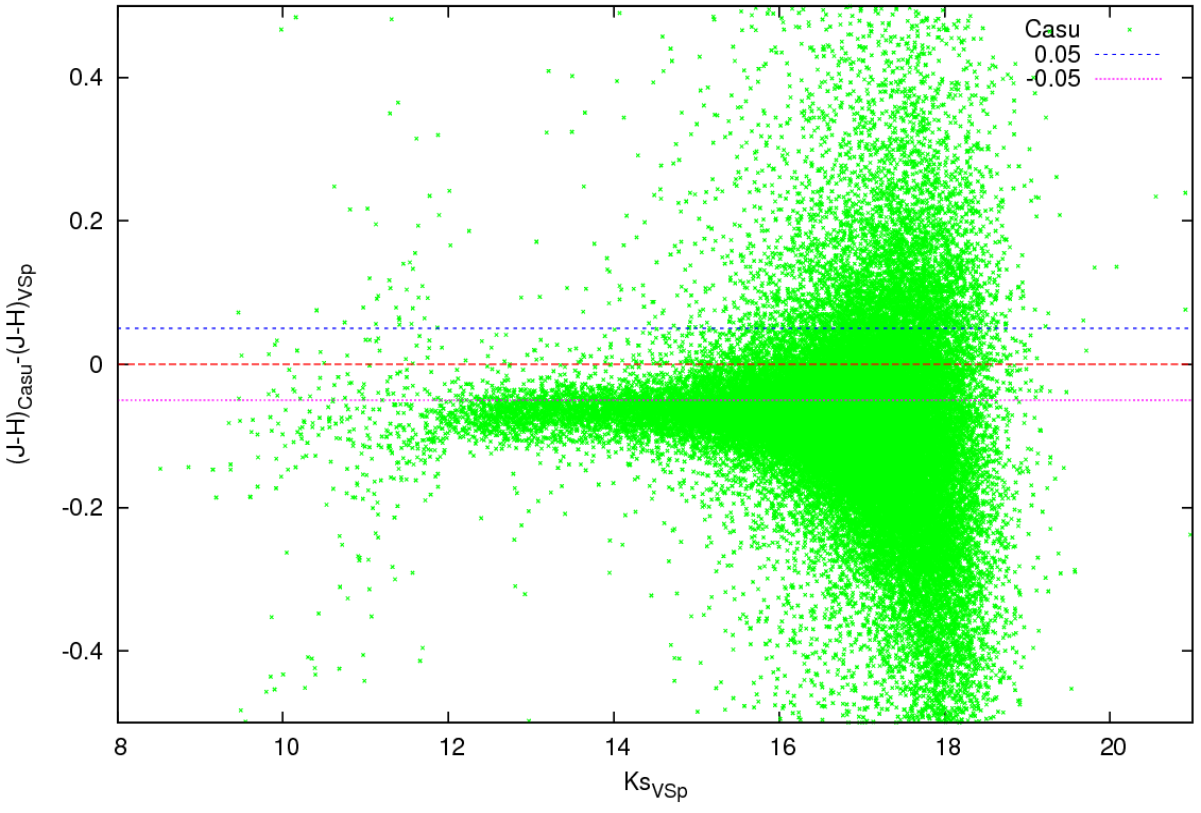


Comparison CASU-2MASS differences in tile b250



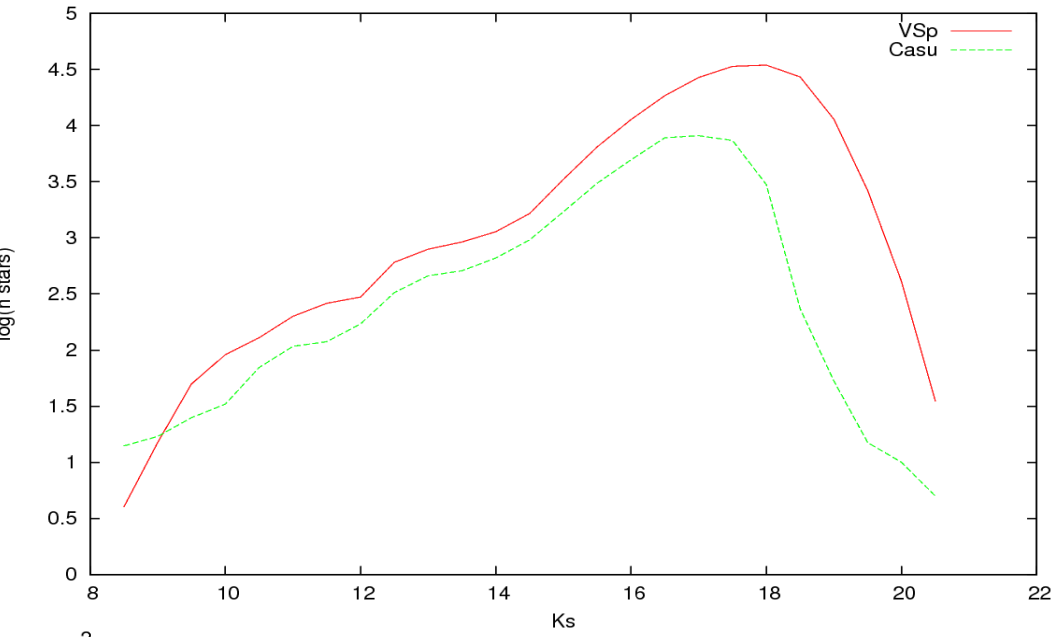
Comparison with CASU catalog: colors



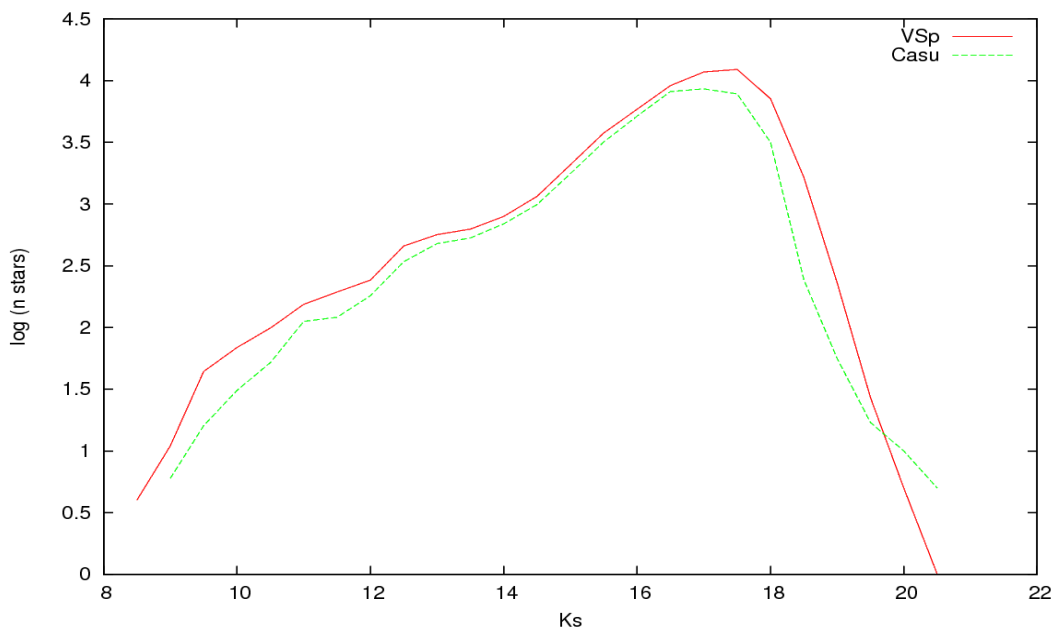


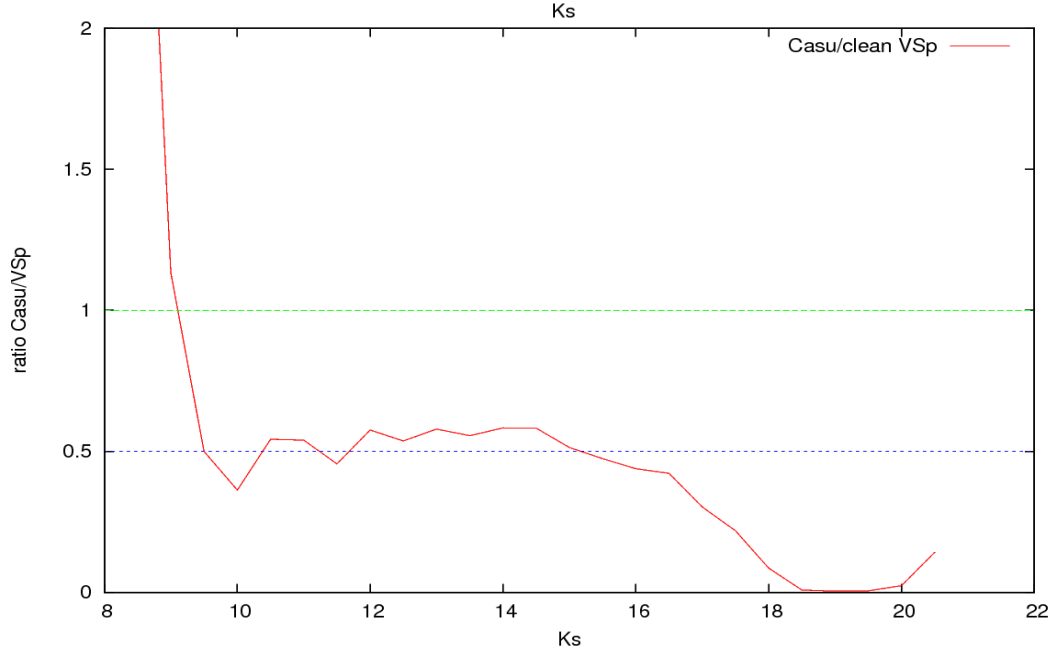
Comparison with CASU catalog: luminosity distribution

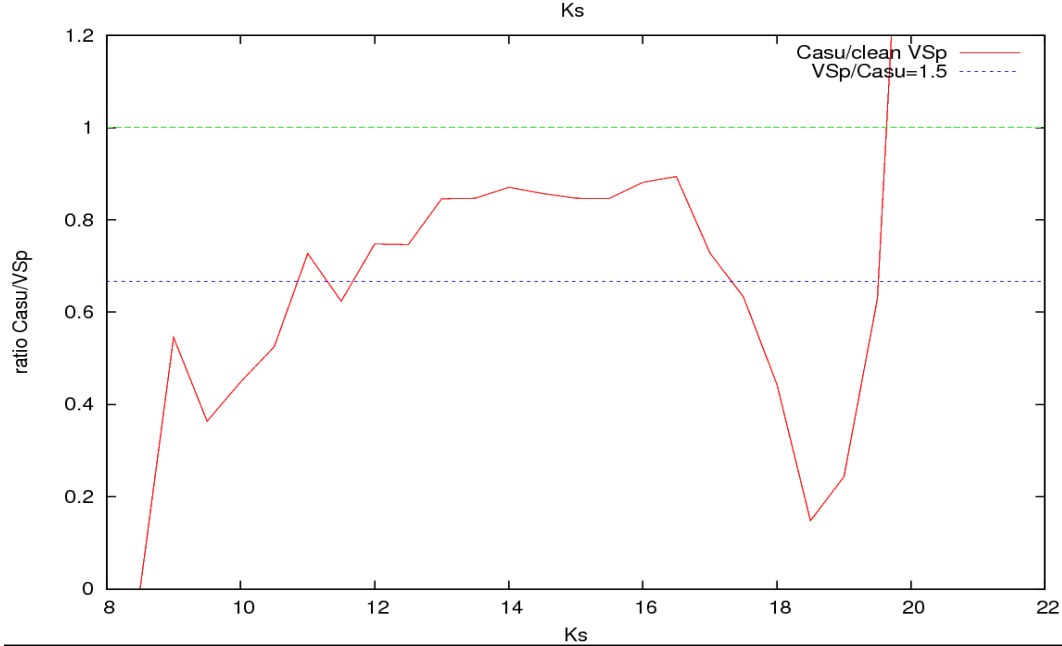
Un-matched



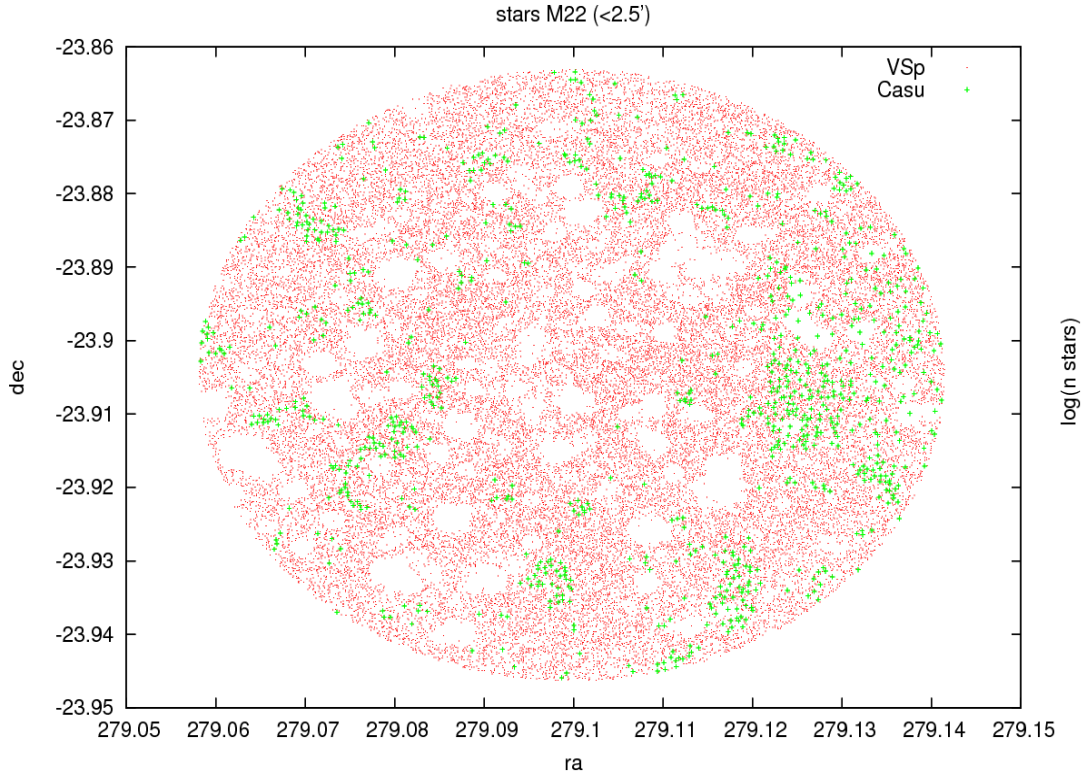
Matched

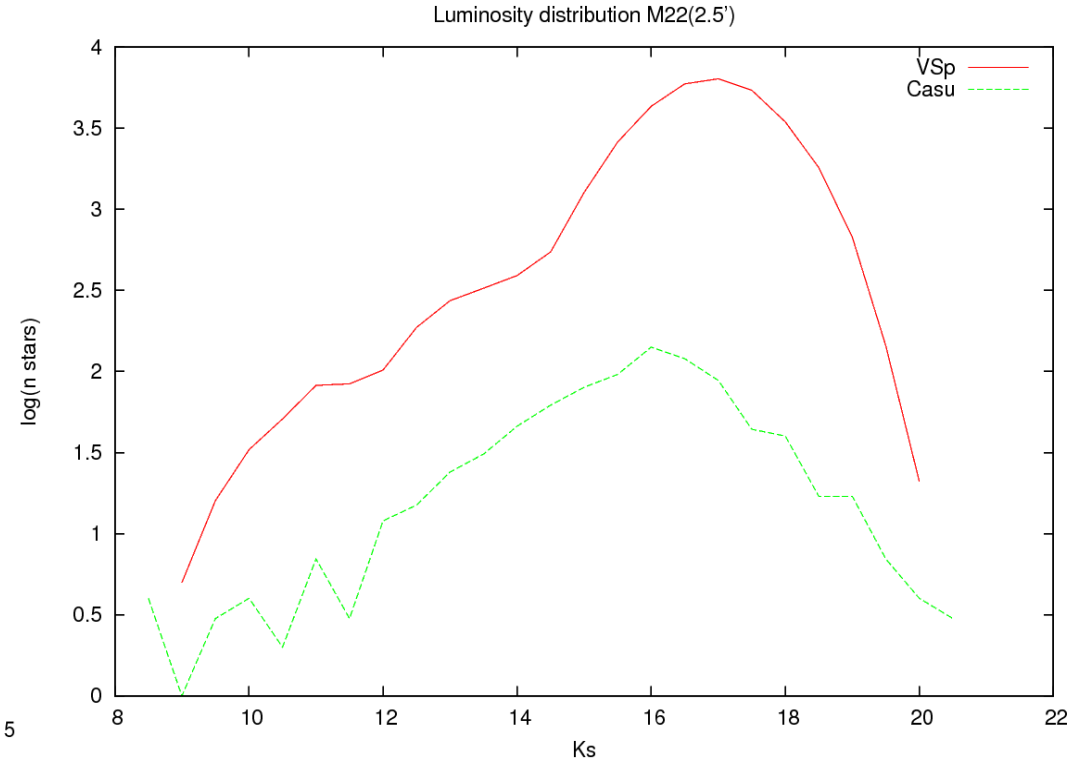




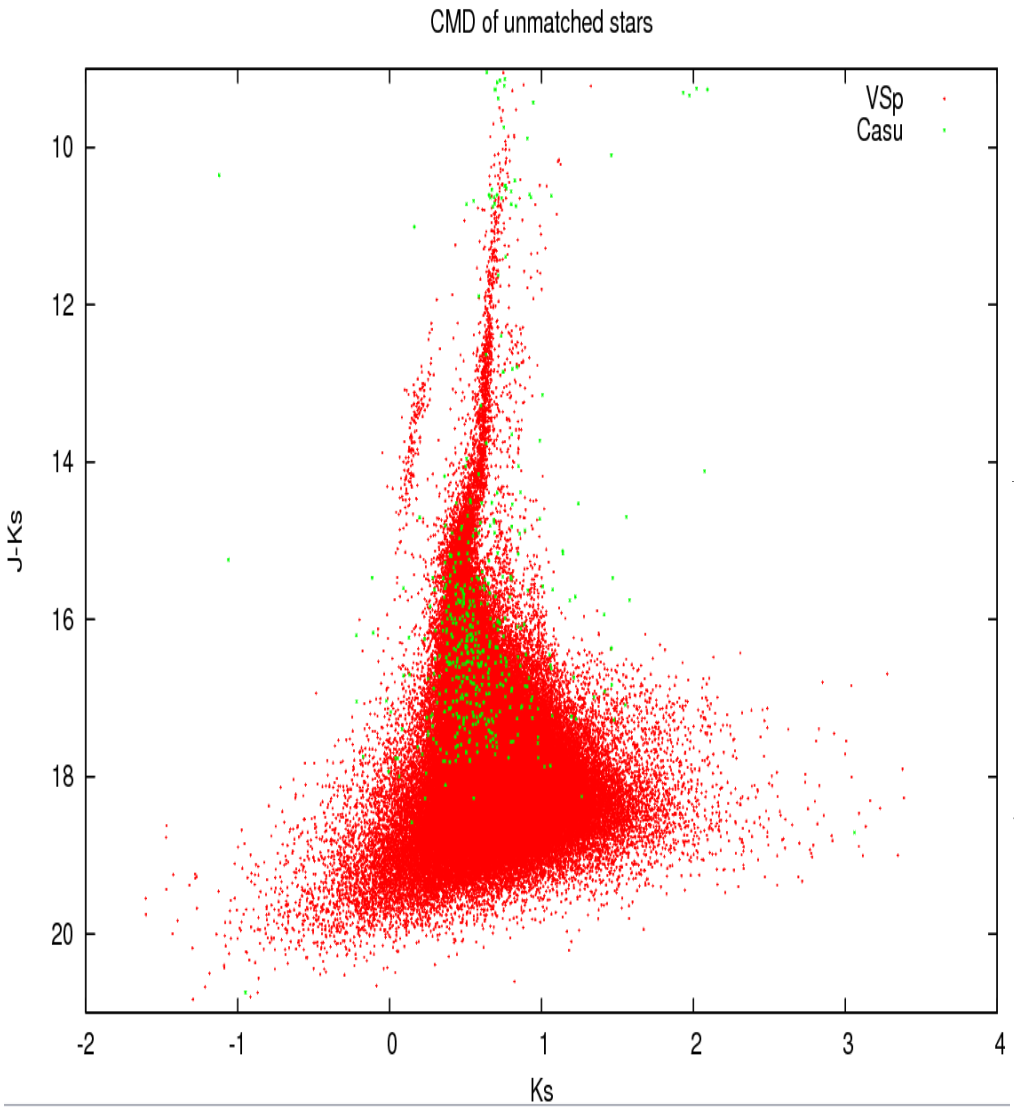


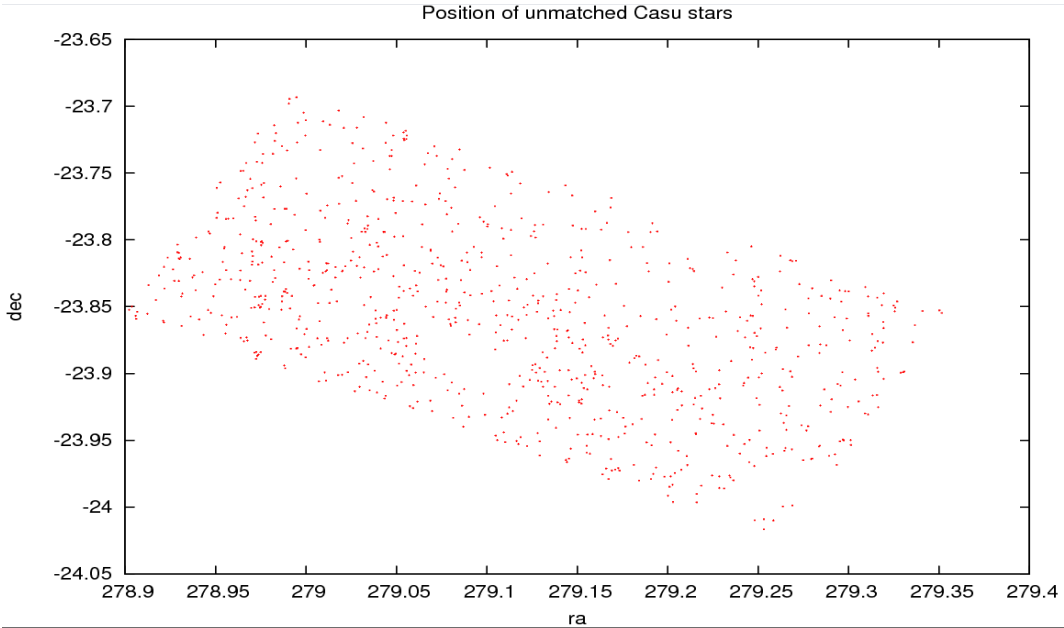
Comparison with CASU catalog: 2.5' inner area of M22

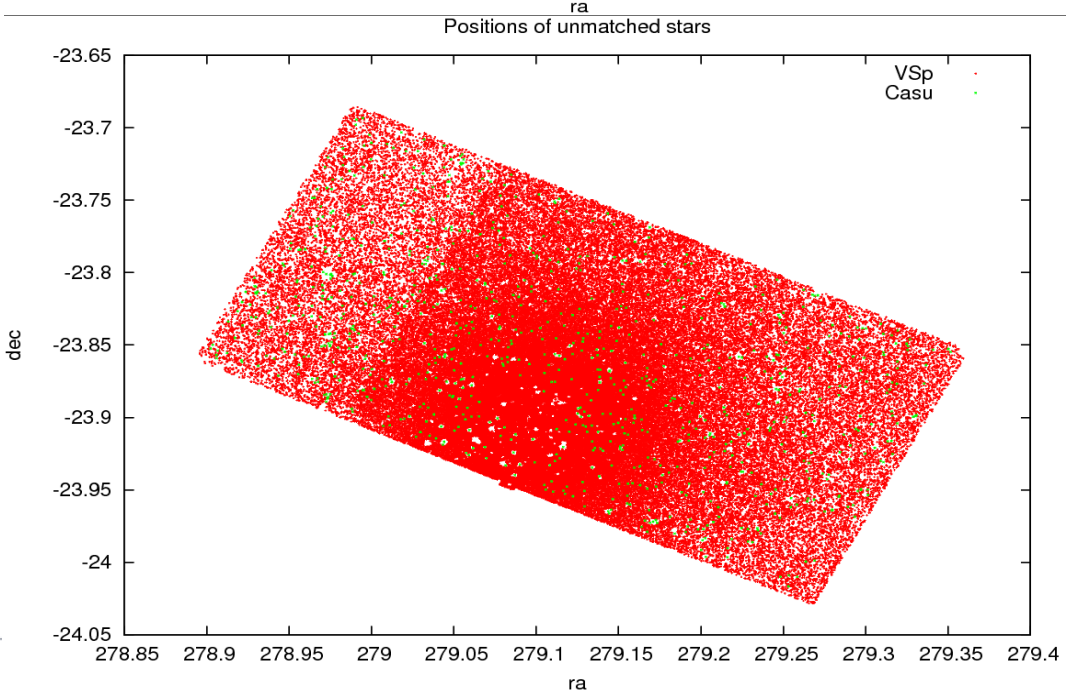




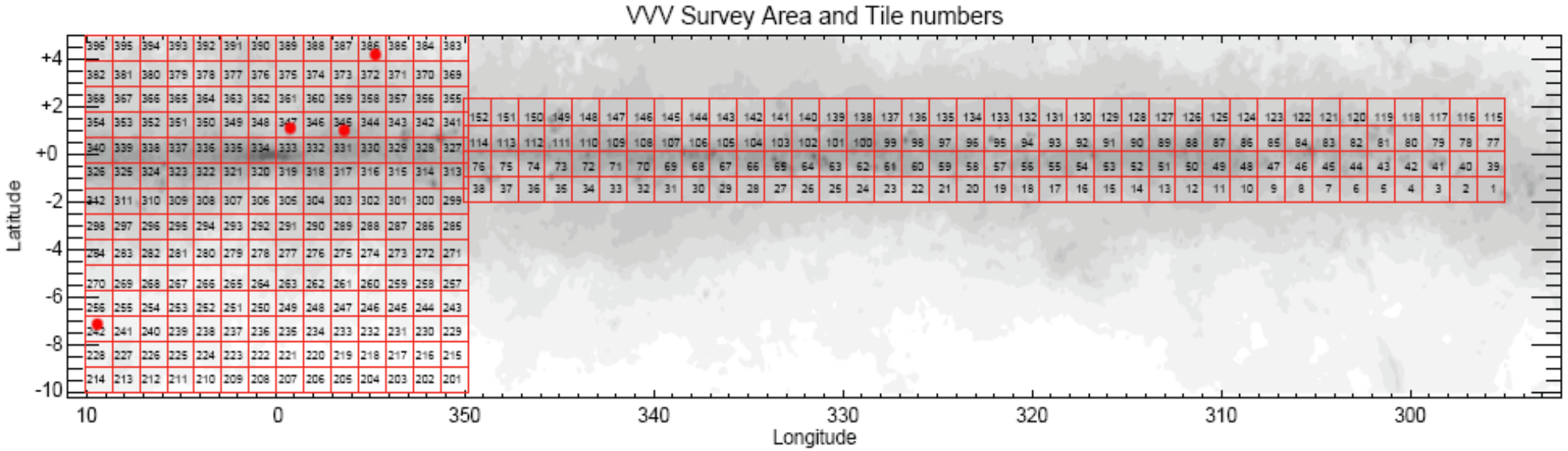
Comparison with CASU catalog: unmatched stars



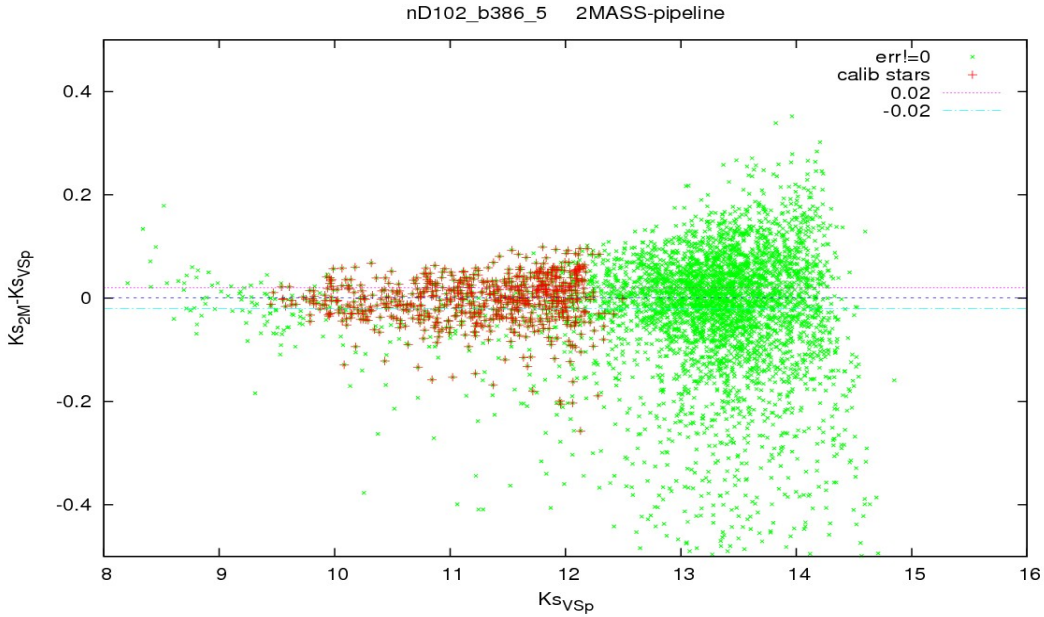


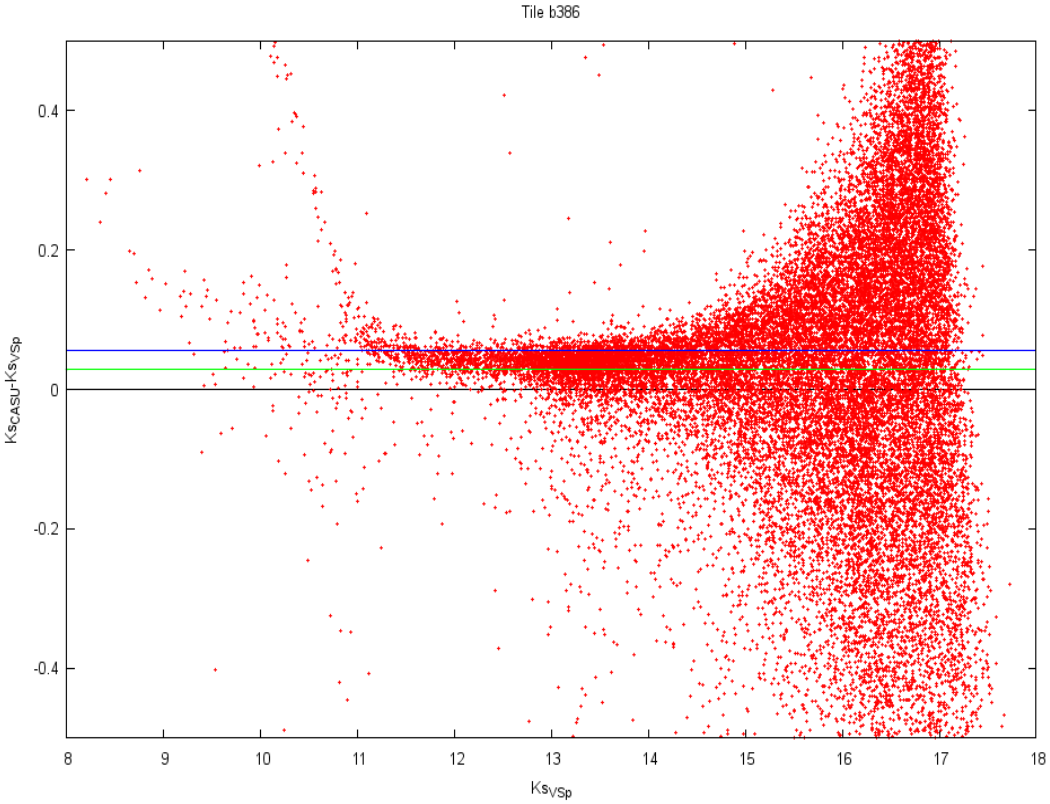


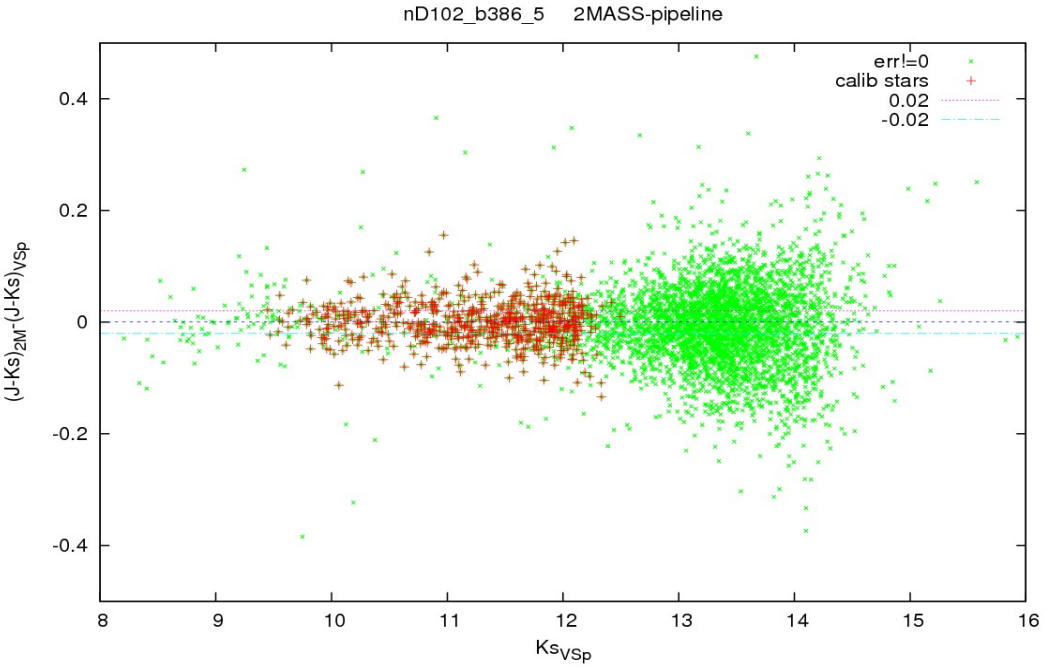
Comparison with CASU catalog



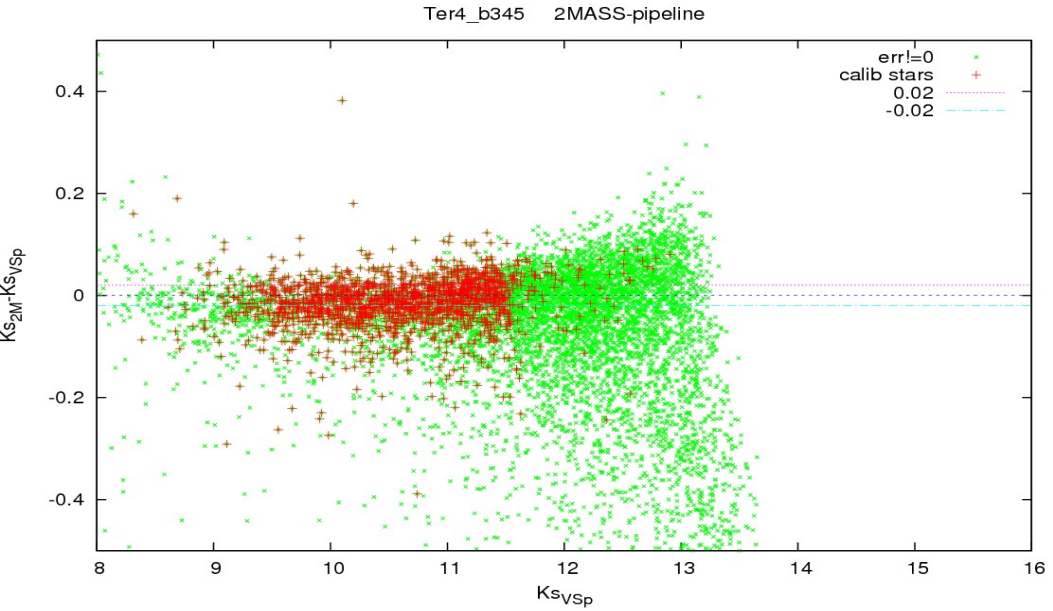
Comparison with CASU catalog: tile b386

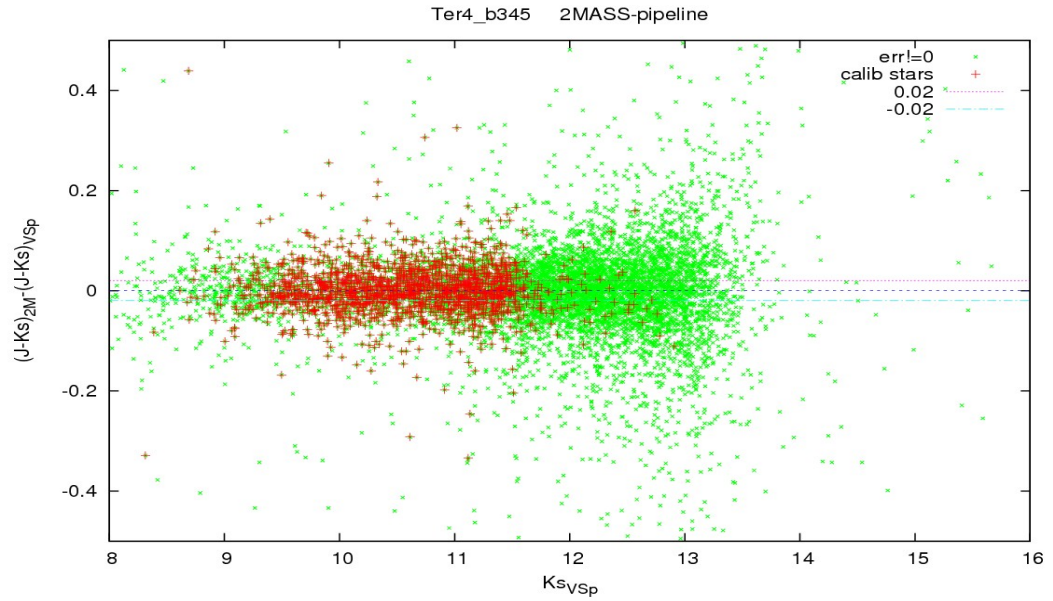


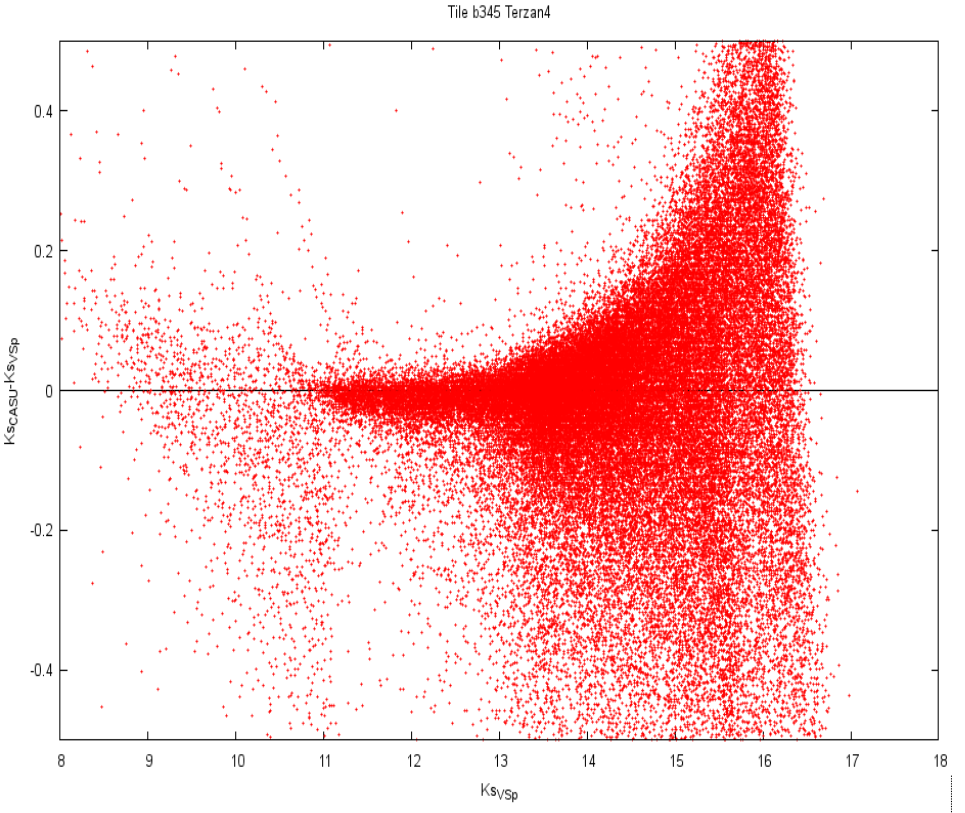




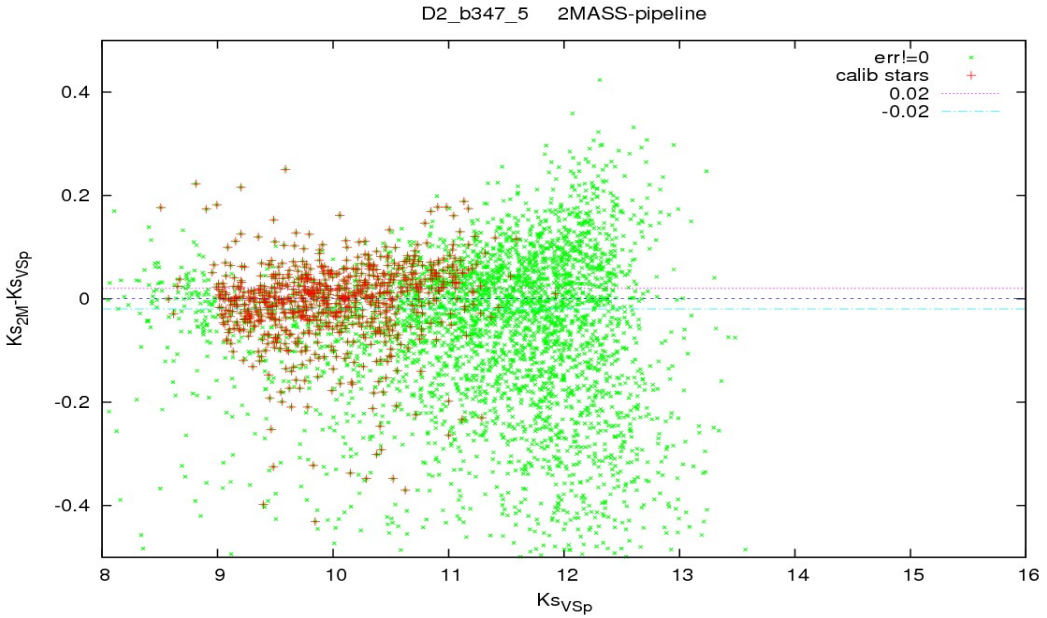
Comparison with CASU catalog: tile b345

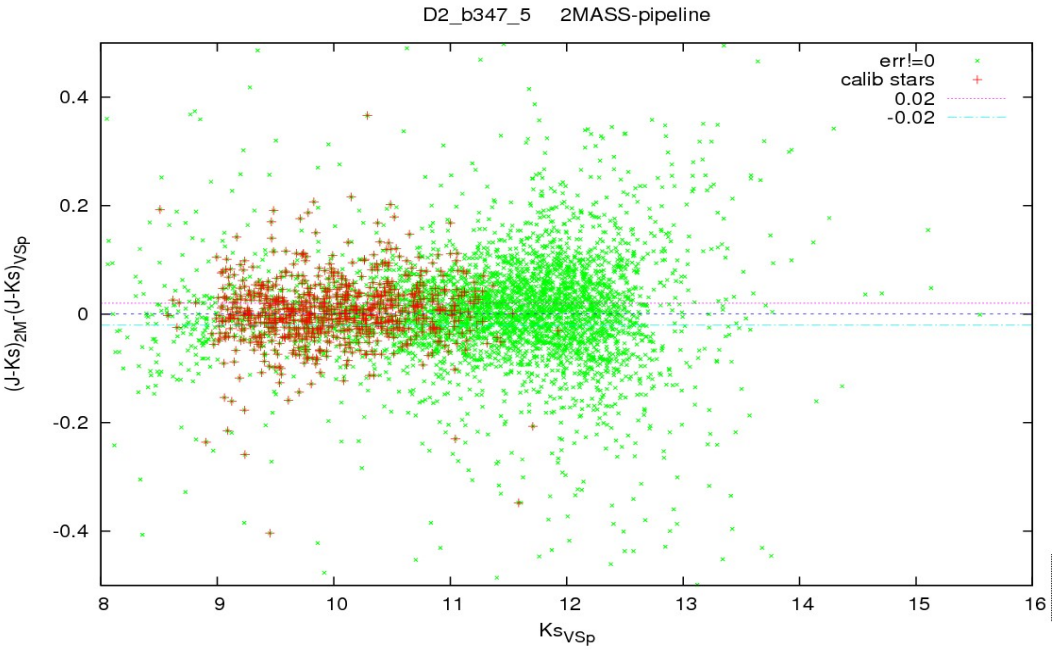


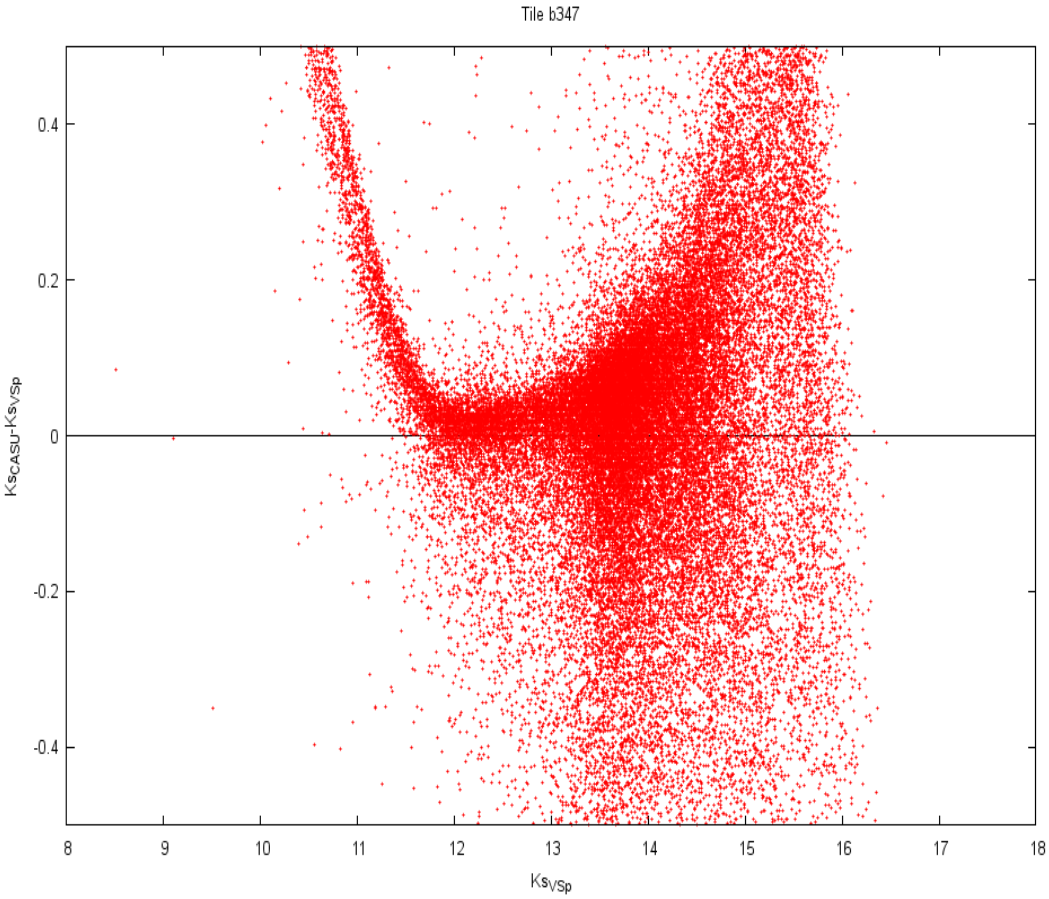




Comparison with CASU catalog: tile b347





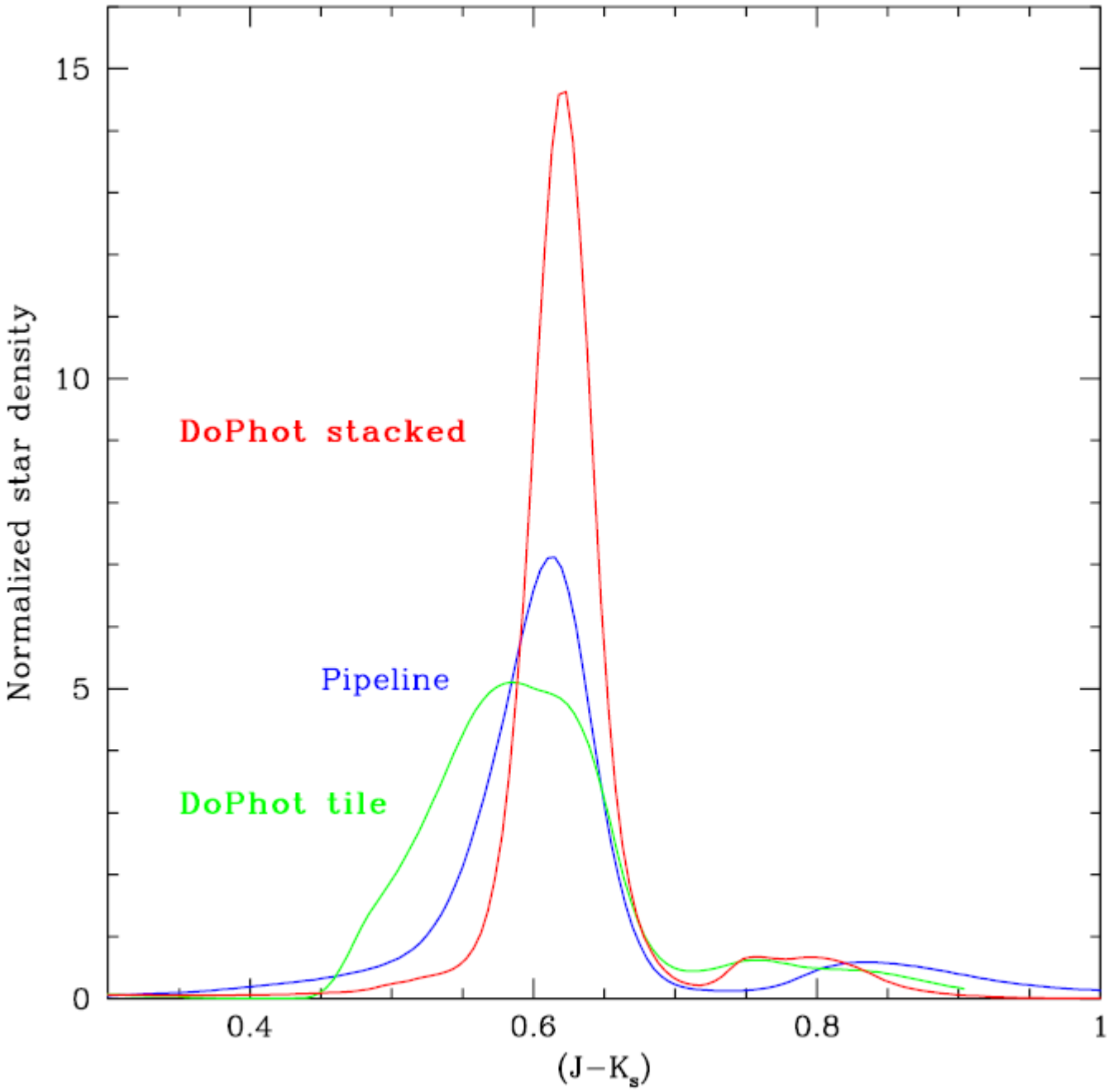


Comparison with other psf-photometry: DoPhot catalog

Why DoPhot and not other programs?

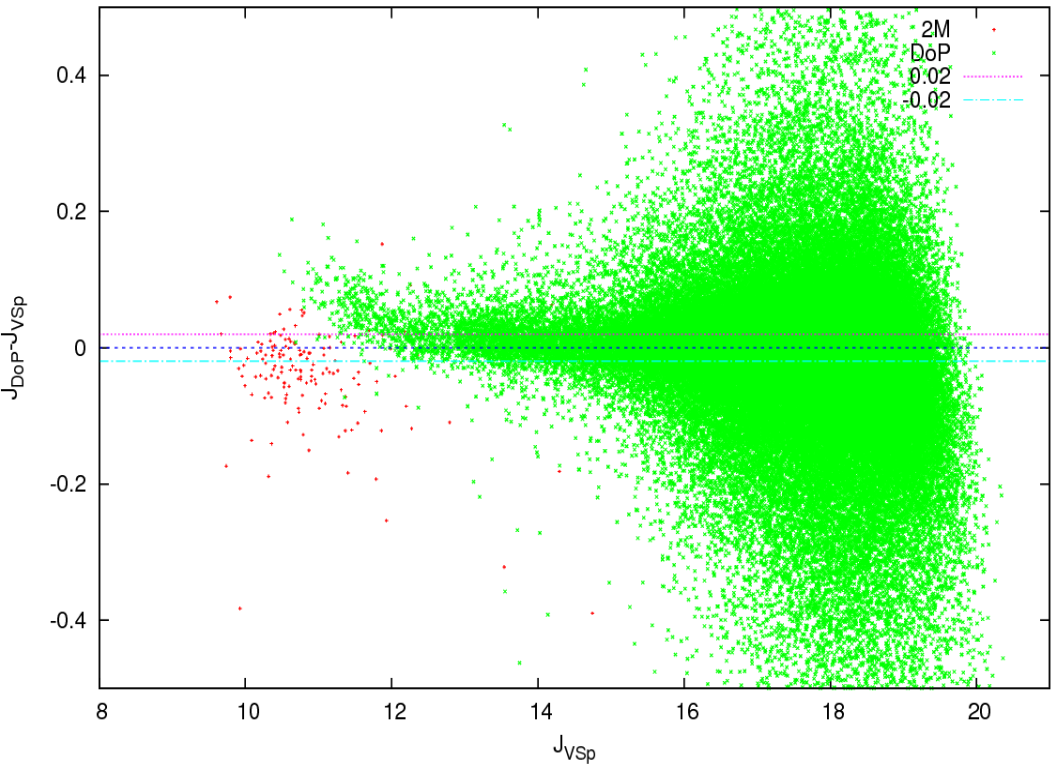
Availability, collaboration and better results for a reliable comparison.

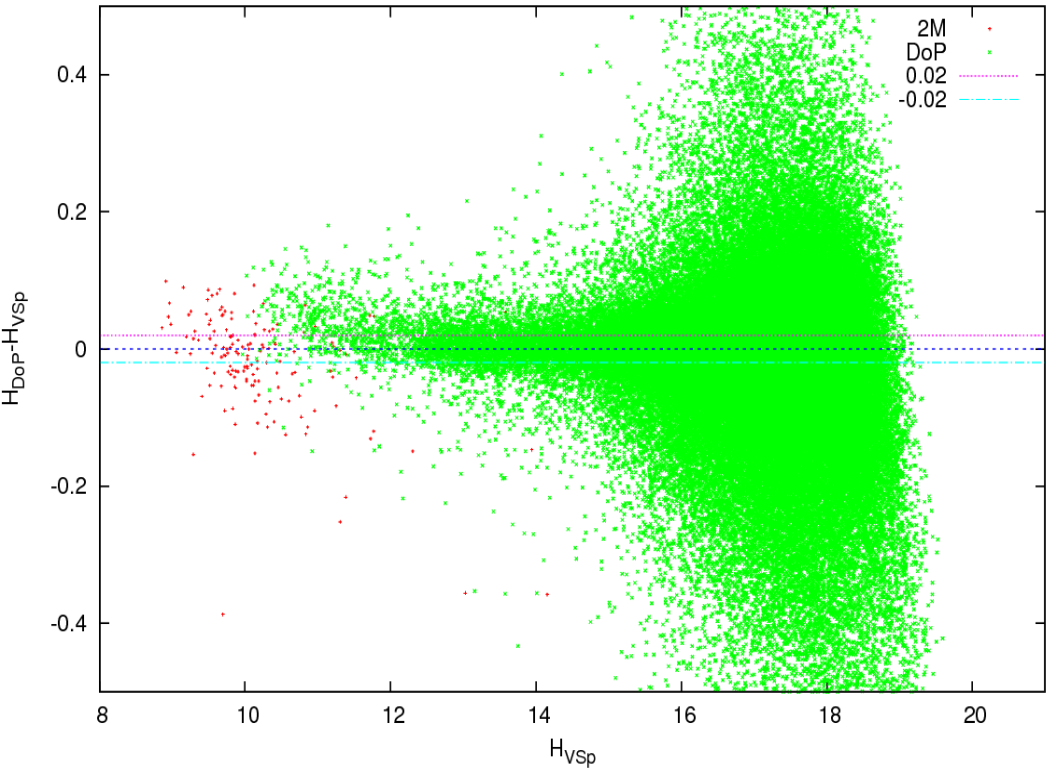
Starting from December 2010 three comparison were done between VVV-SkZ_pipeline and DoPhot to check and improve the procedures.

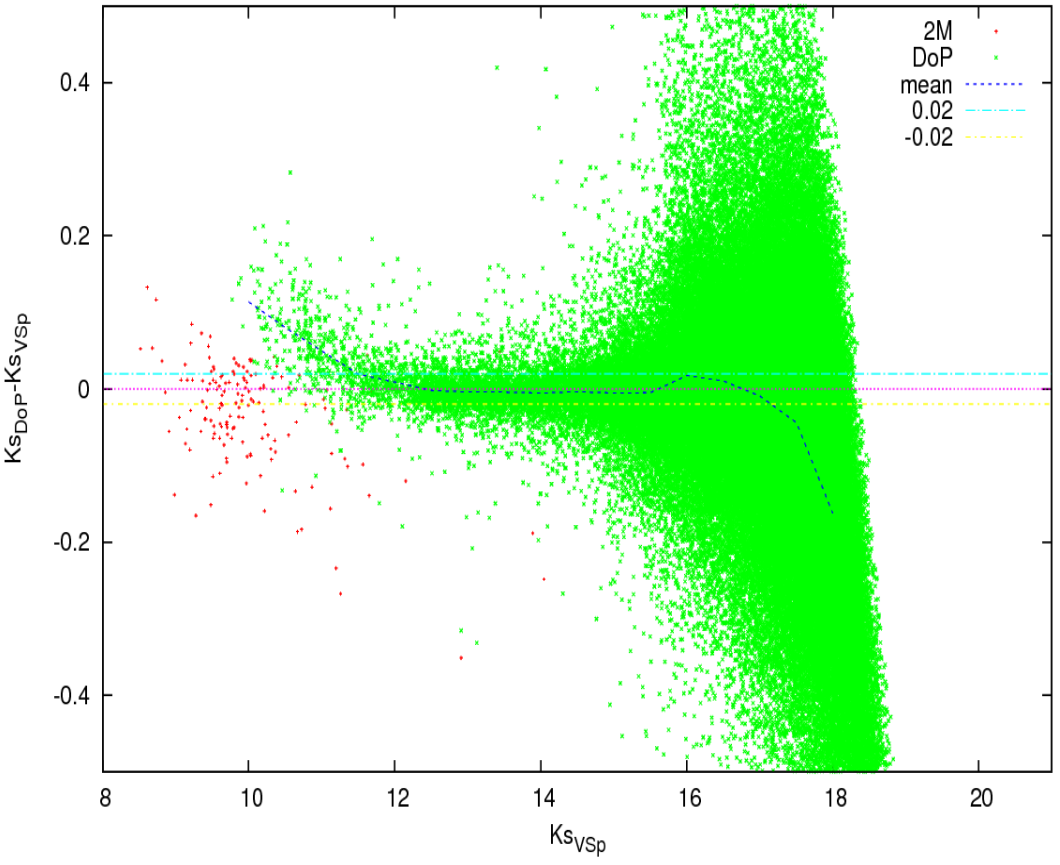

Normalized star density
15
10
5
0
0.4
0.6
0.8
1
(J−K$_s$)
DoPhot stacked
Pipeline
DoPhot tile

Alonso J.

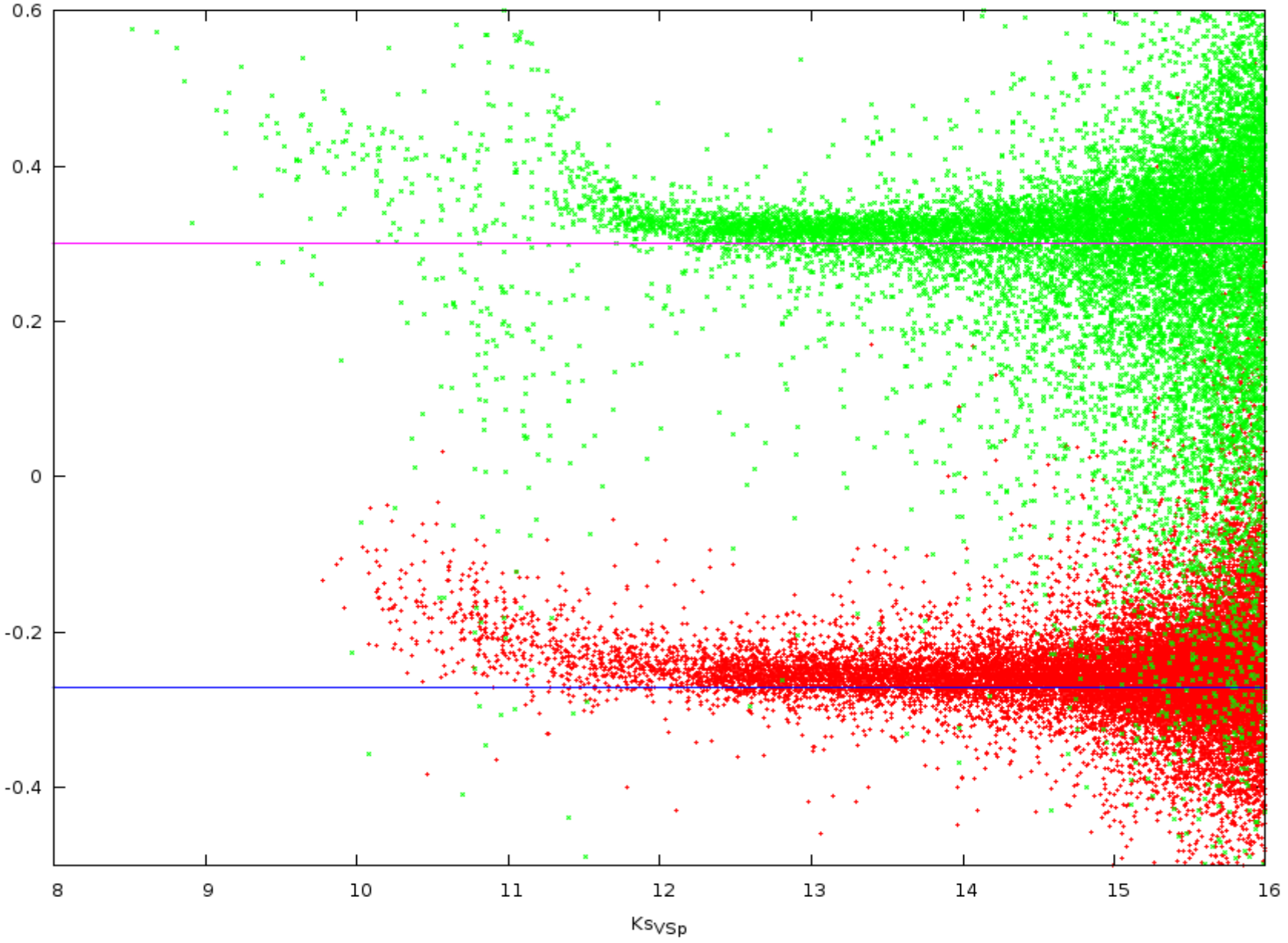
Comparison with DoPhot catalog: bands



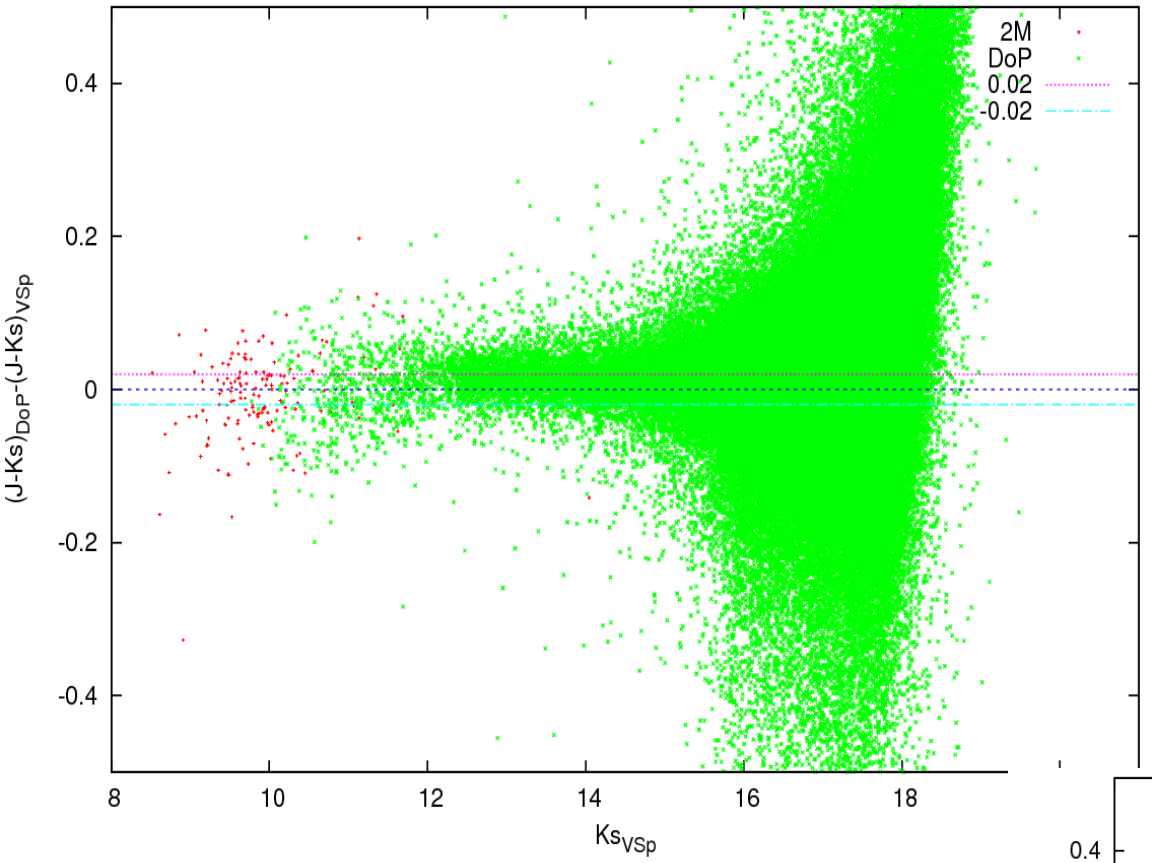


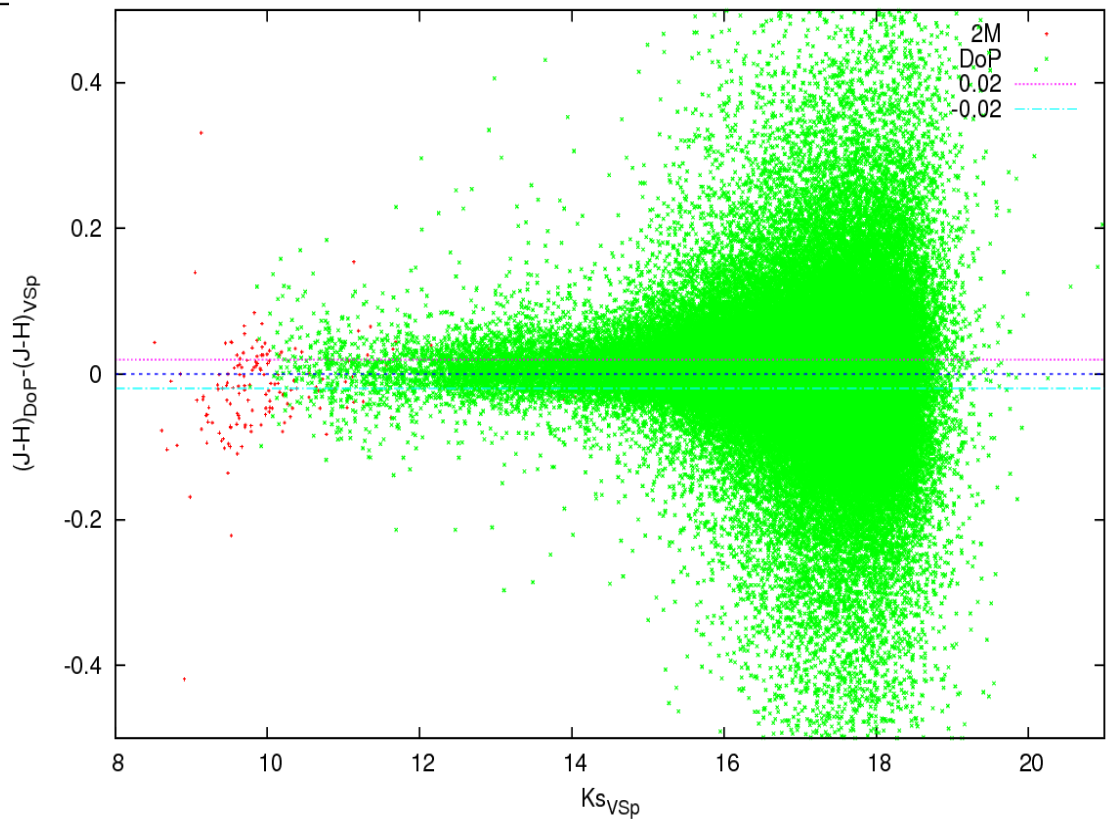


Comparison with DoPhot catalog: saturation limit

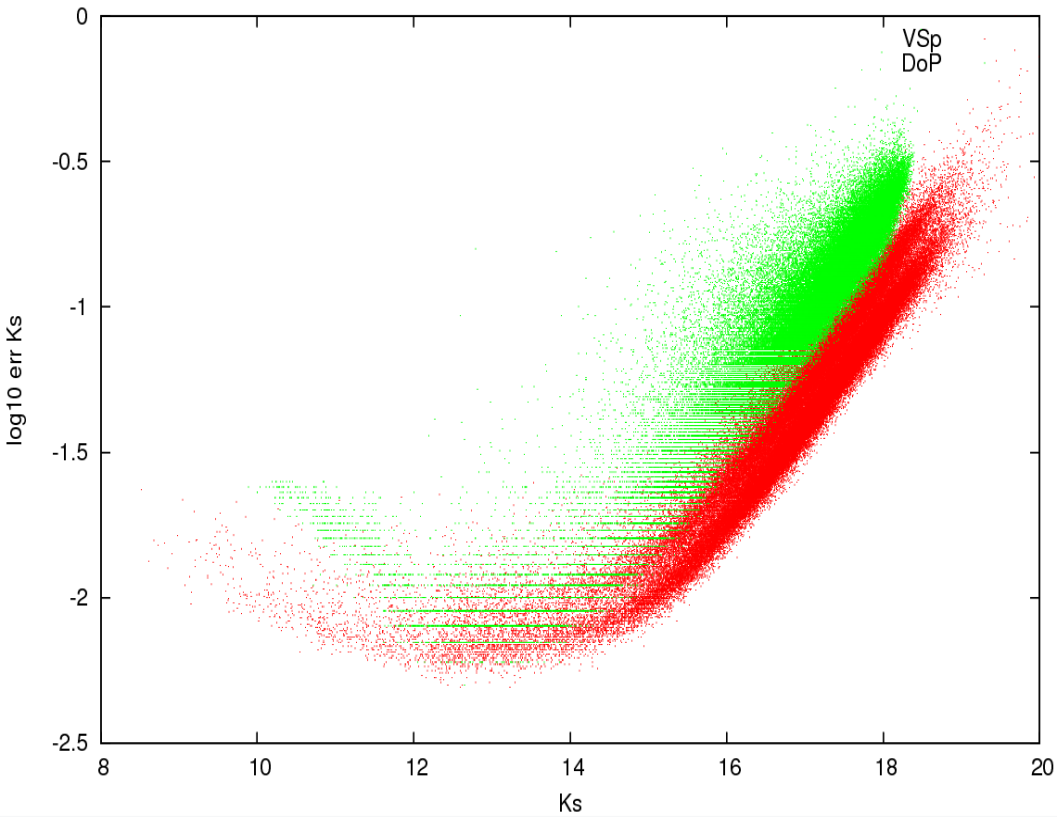


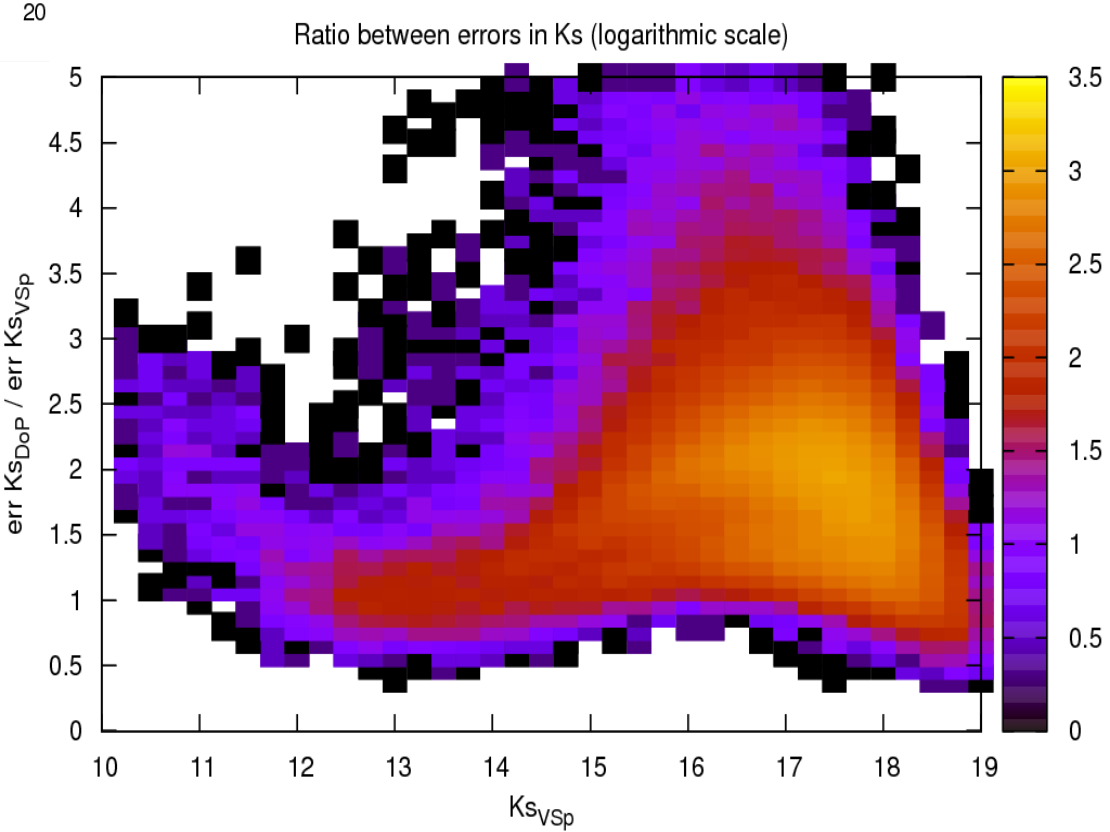
Comparison with DoPhot catalog: colors





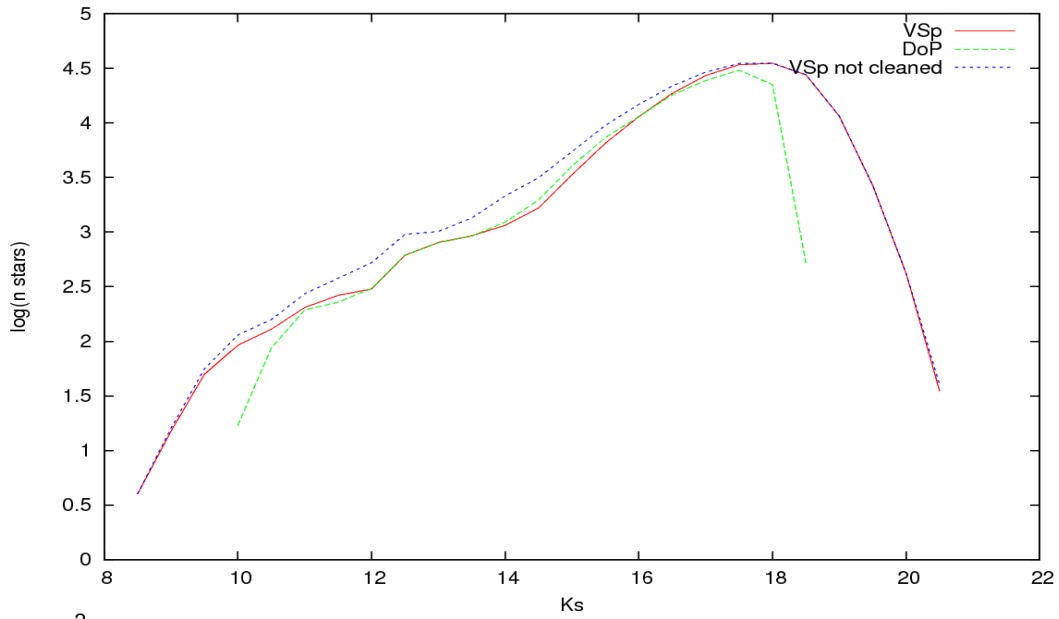
Comparison with DoPhot catalog: errors



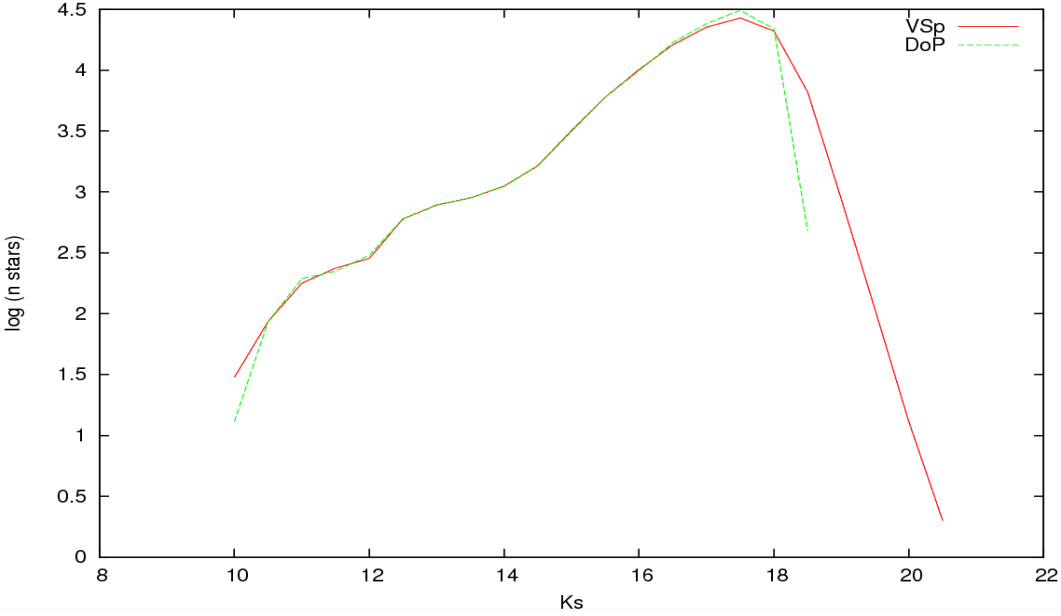


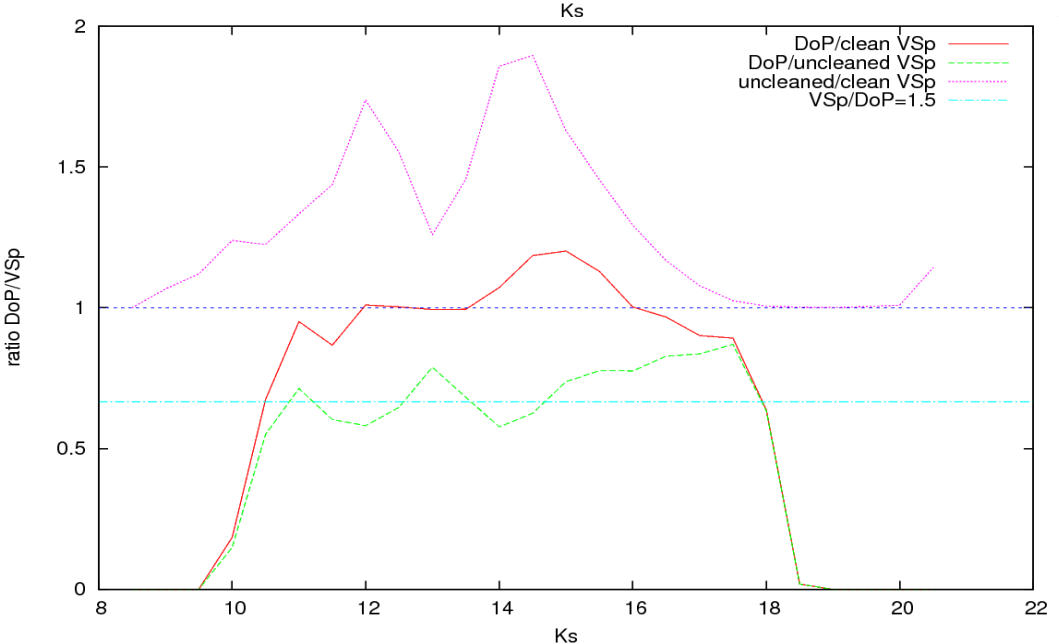
Comparison with DoPhot catalog: Luminosity distribution

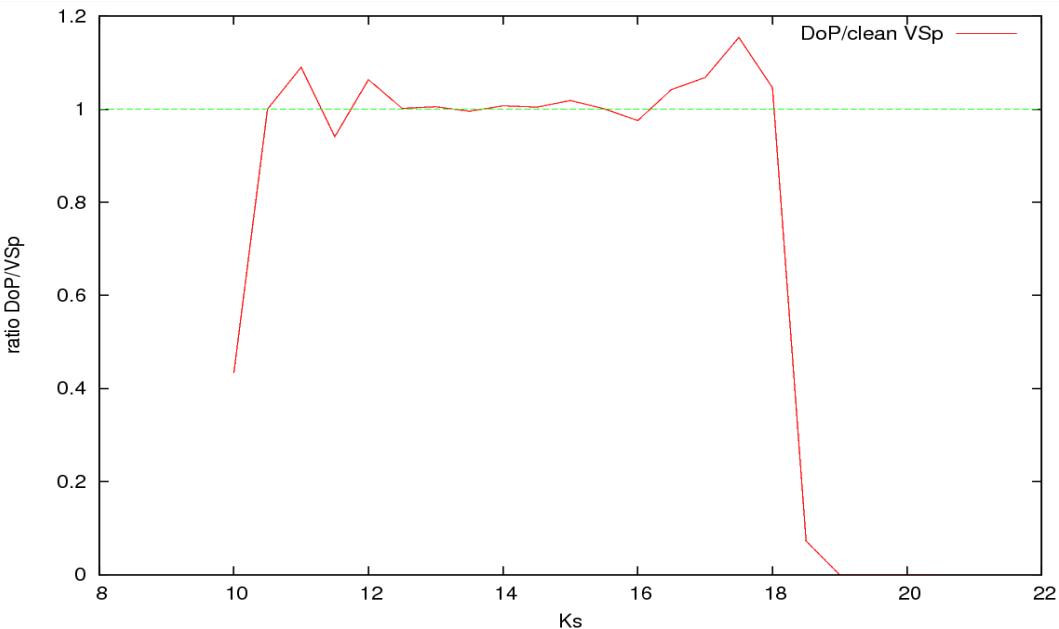
Un-matched



Matched with 5s-clipping

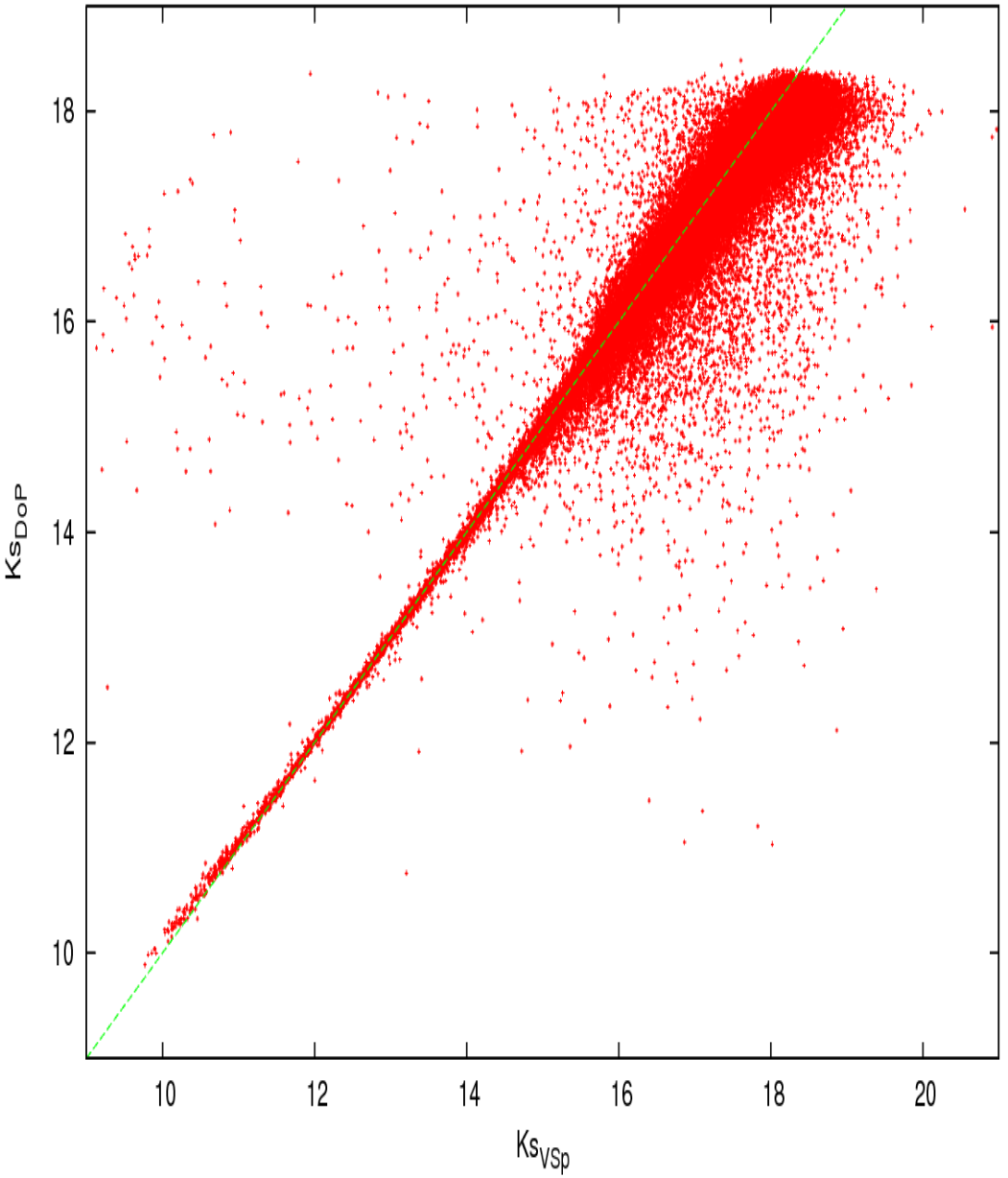




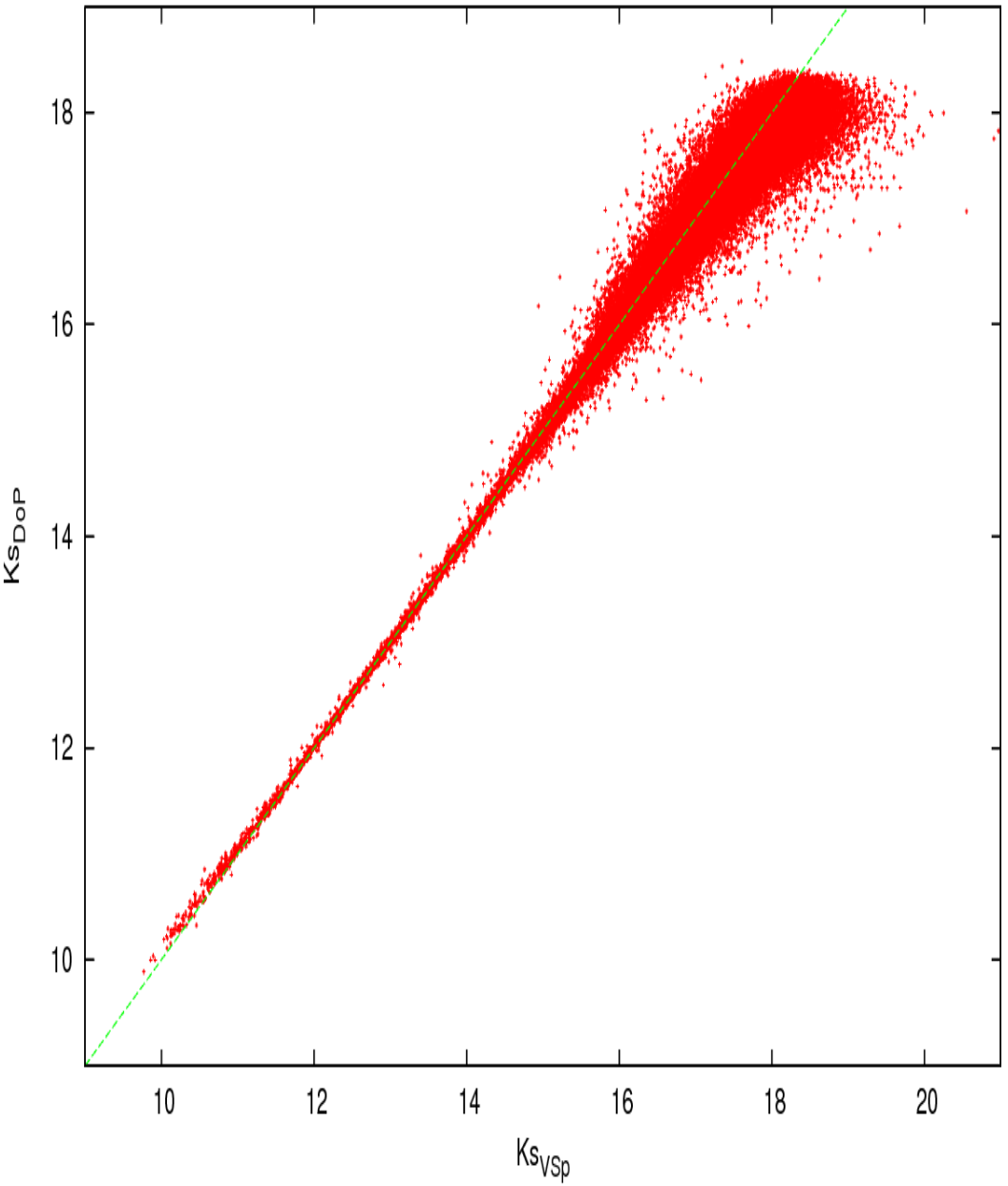


Comparison with DoPhot catalog: Luminosity distribution

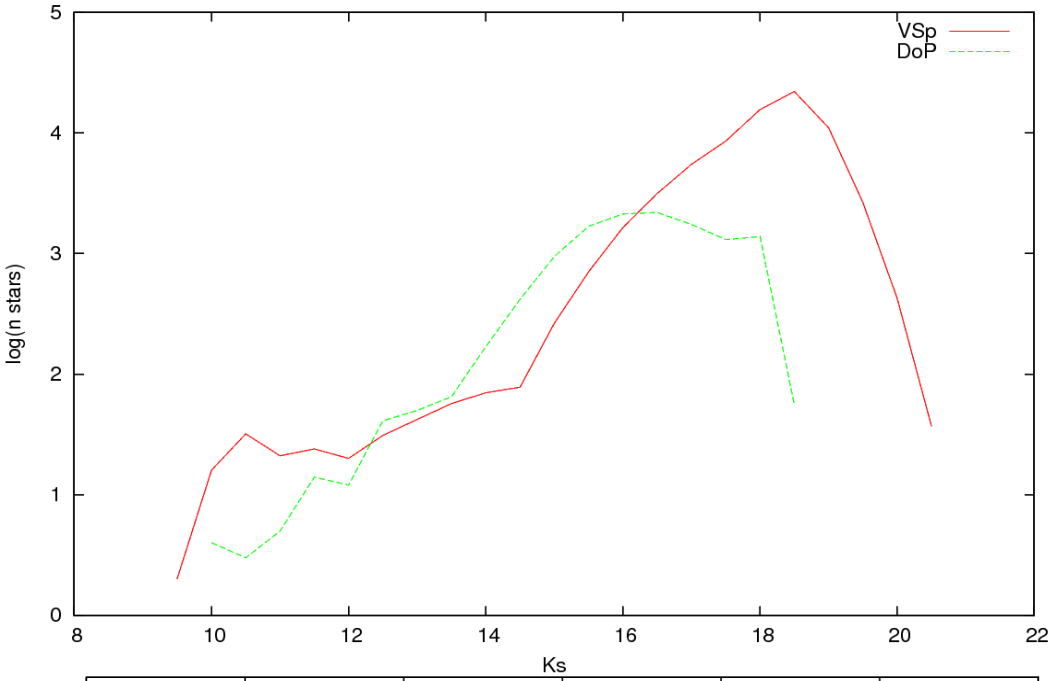
Matched with no clipping

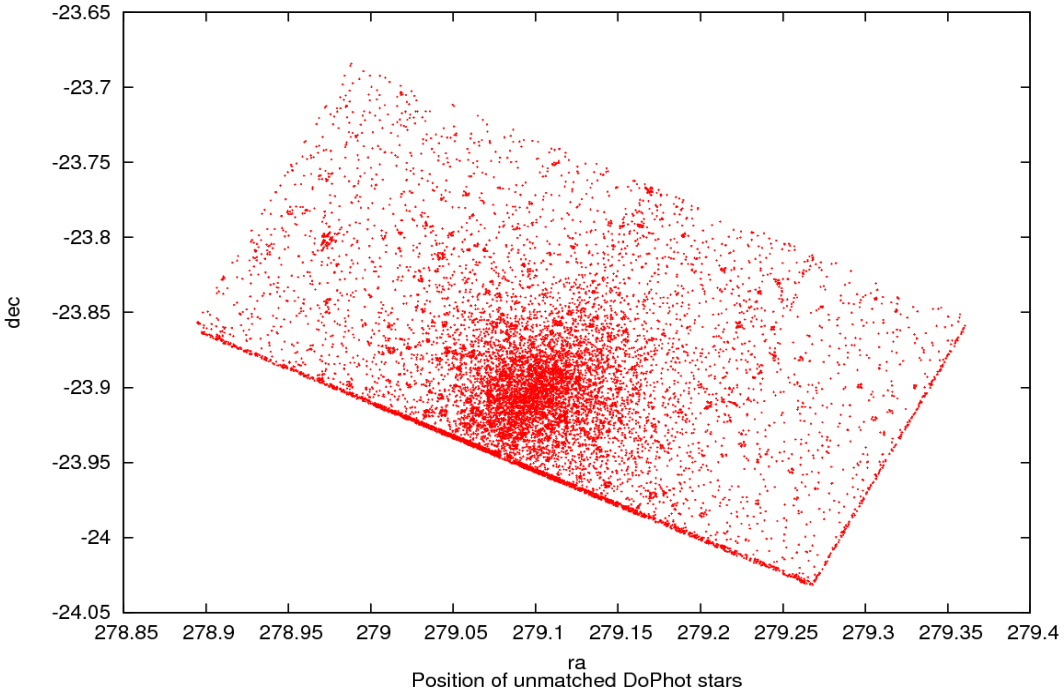


Matched with 5s-clipping

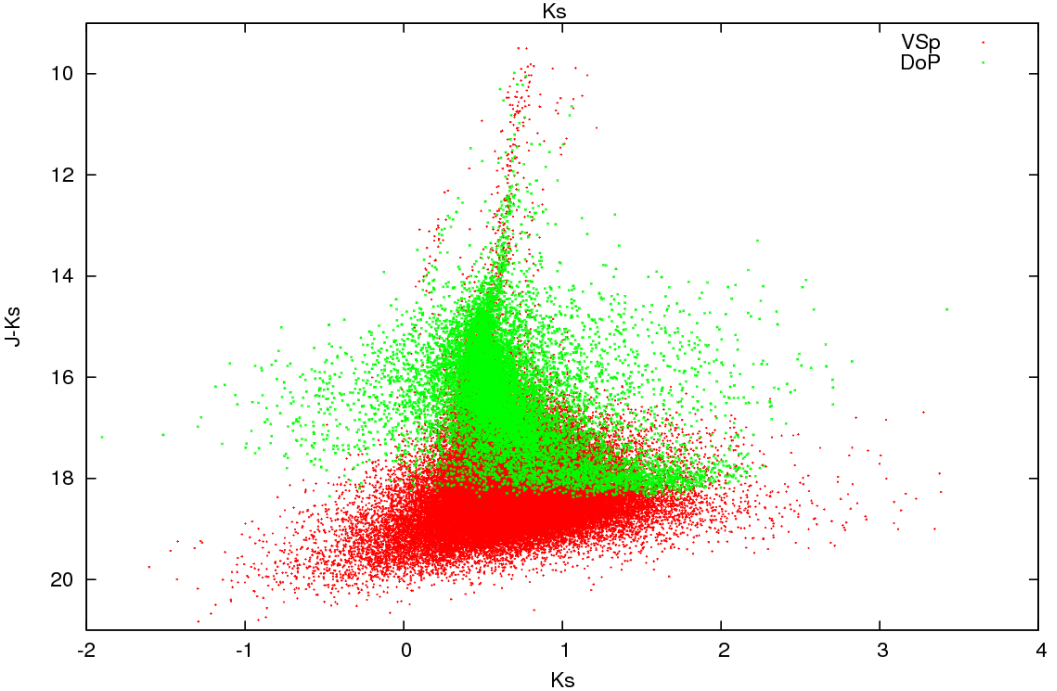


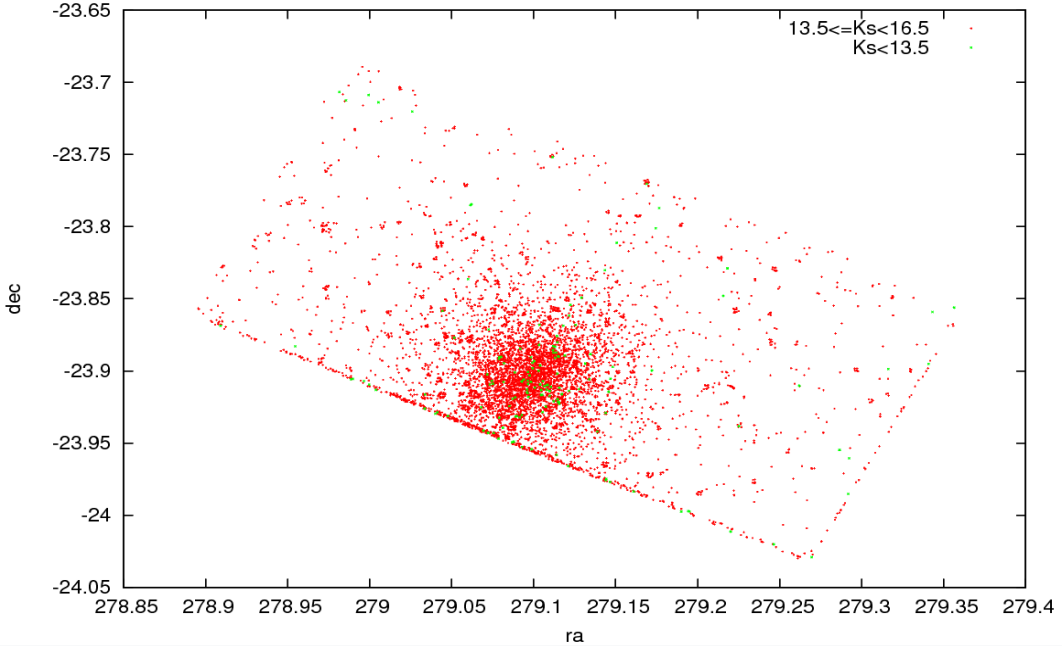
Comparison with DoPhot catalog: un-matched stars



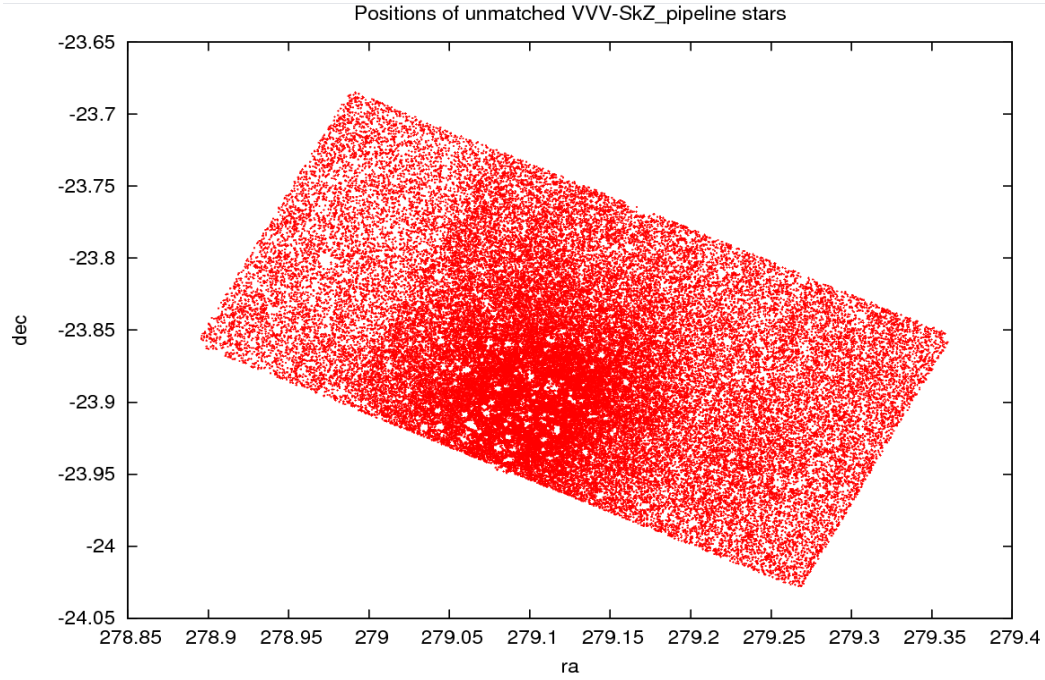


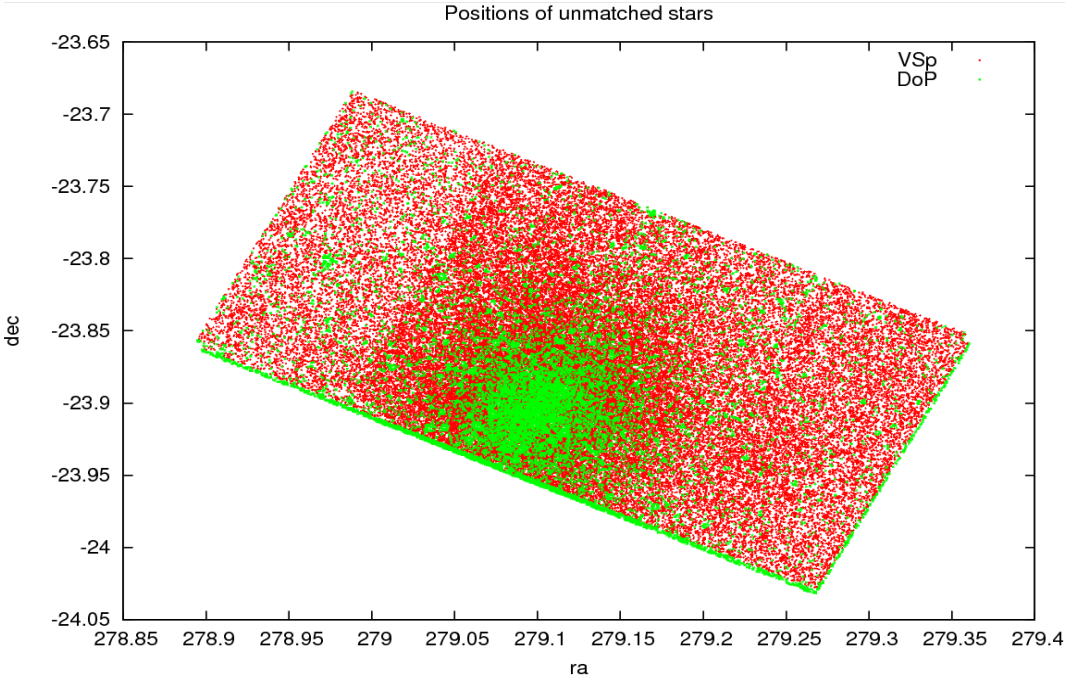
Position of unmatched DoPhot stars

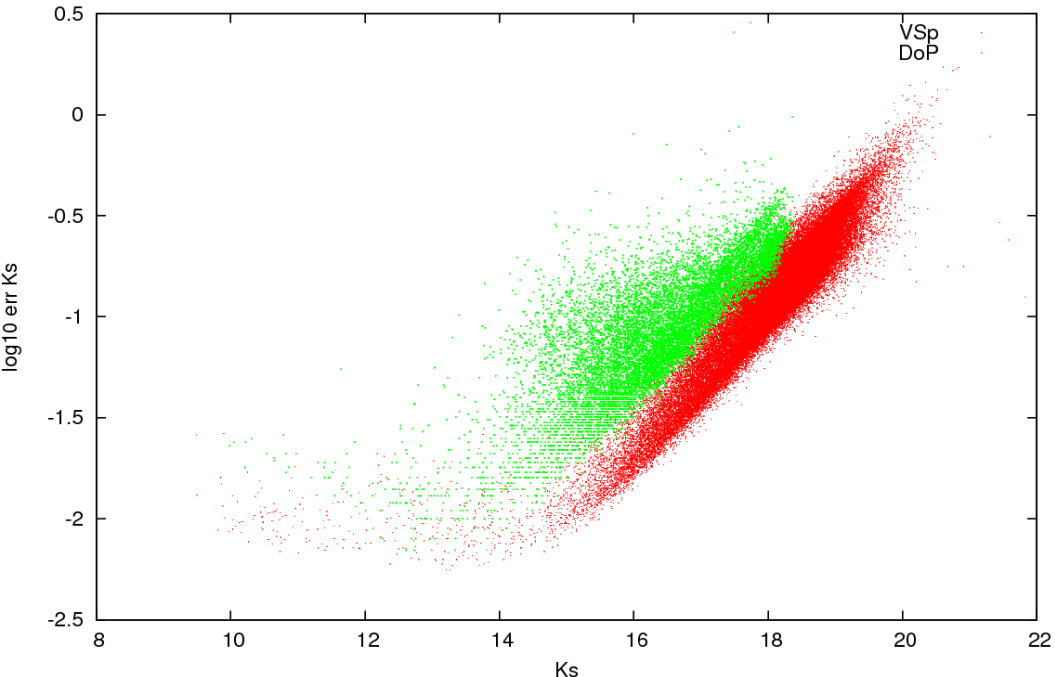




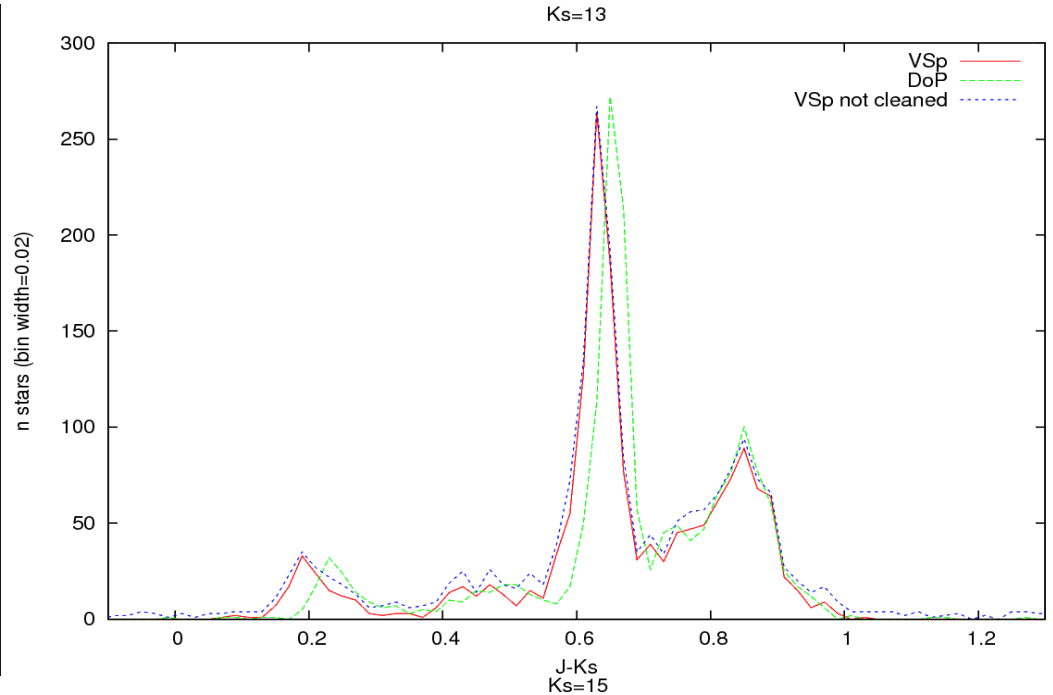
Comparison with DoPhot catalog: un-matched stars

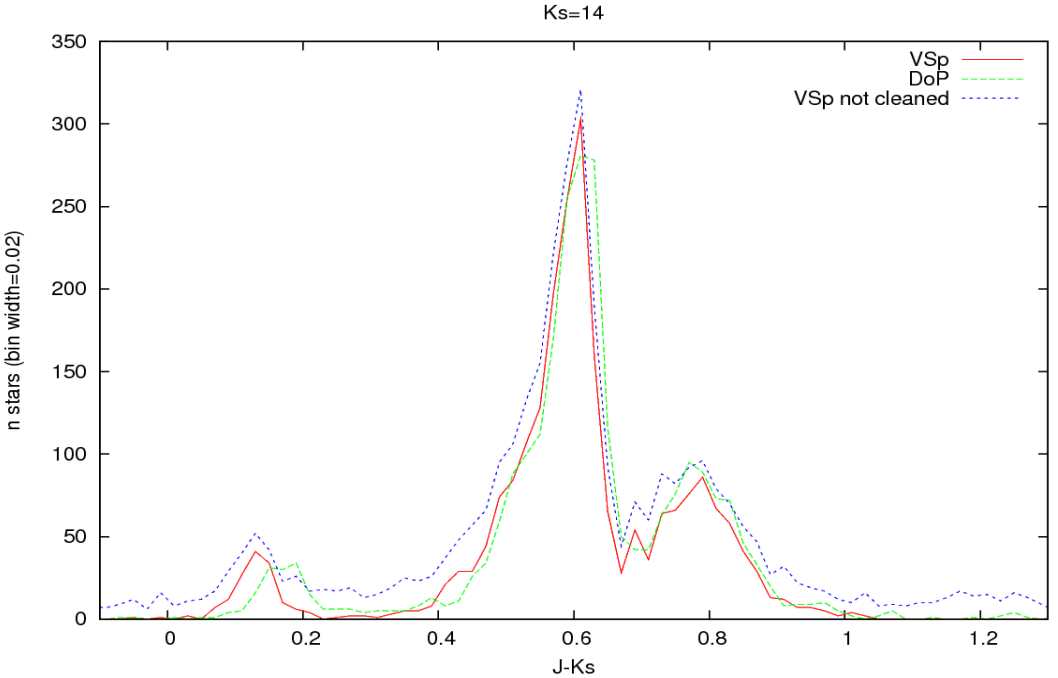


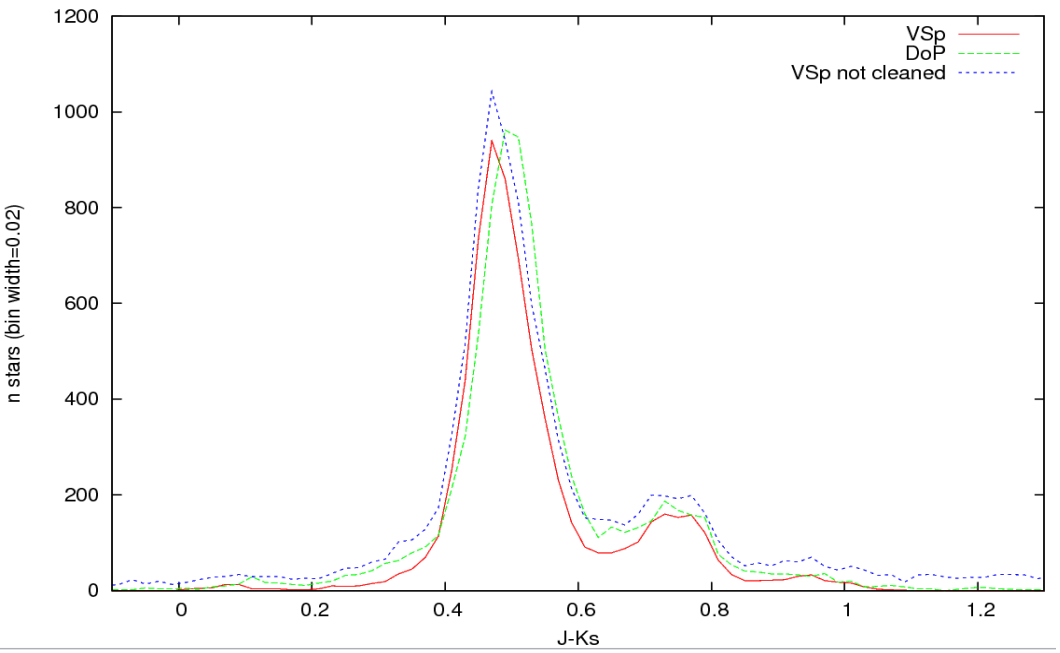


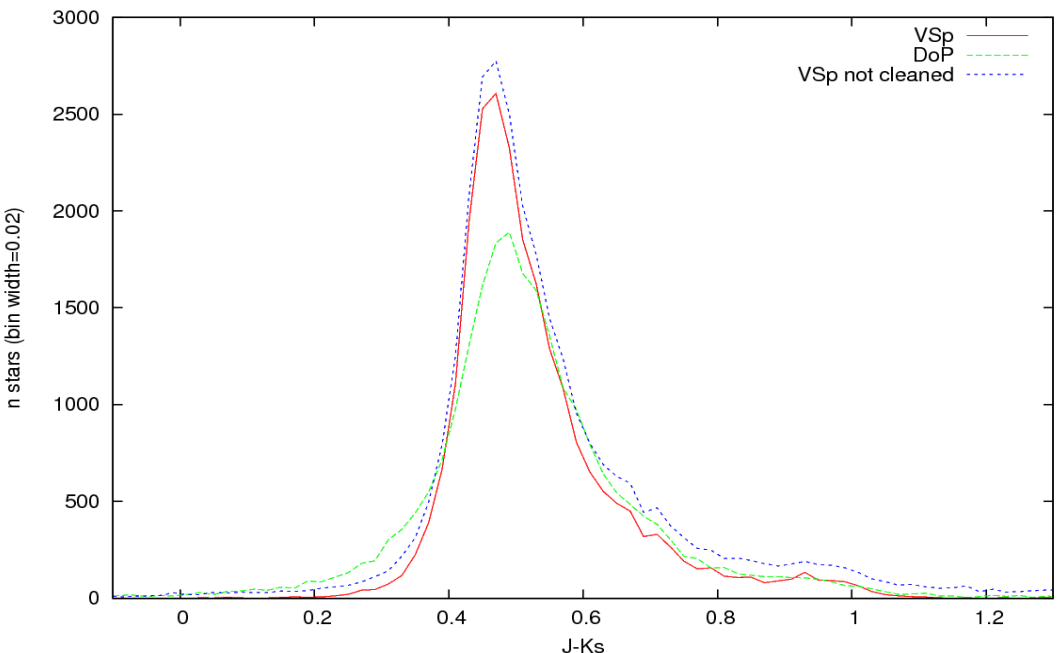


Comparison with DoPhot catalog: distribution in color

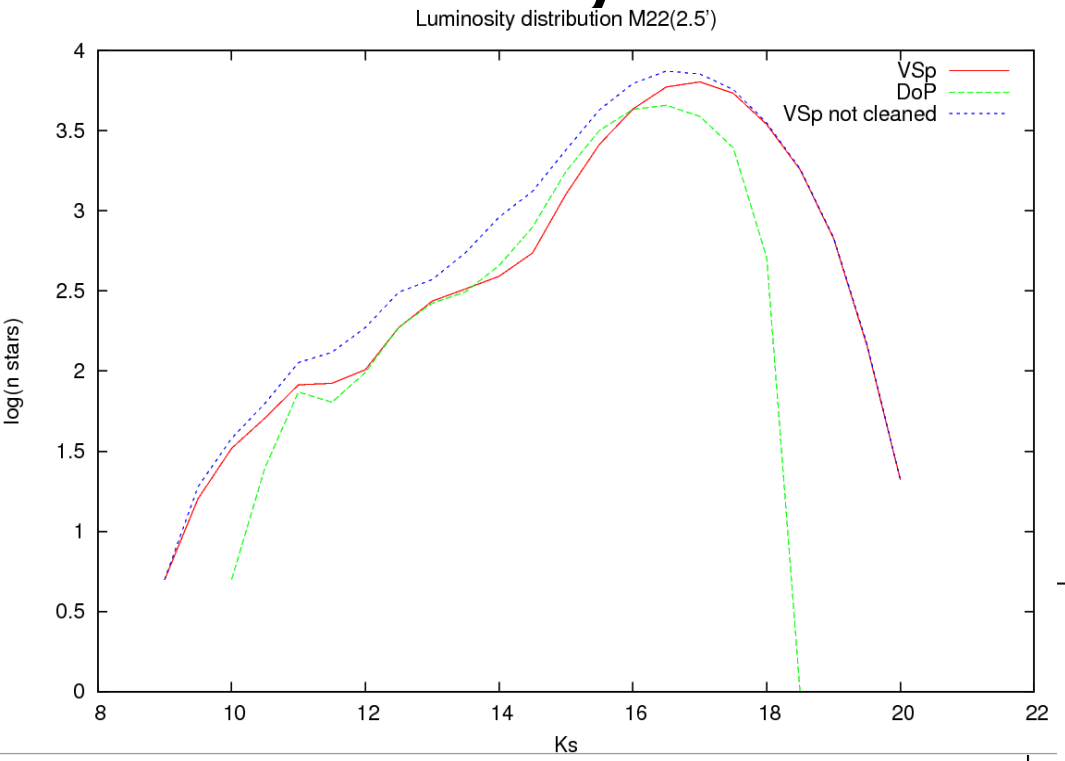


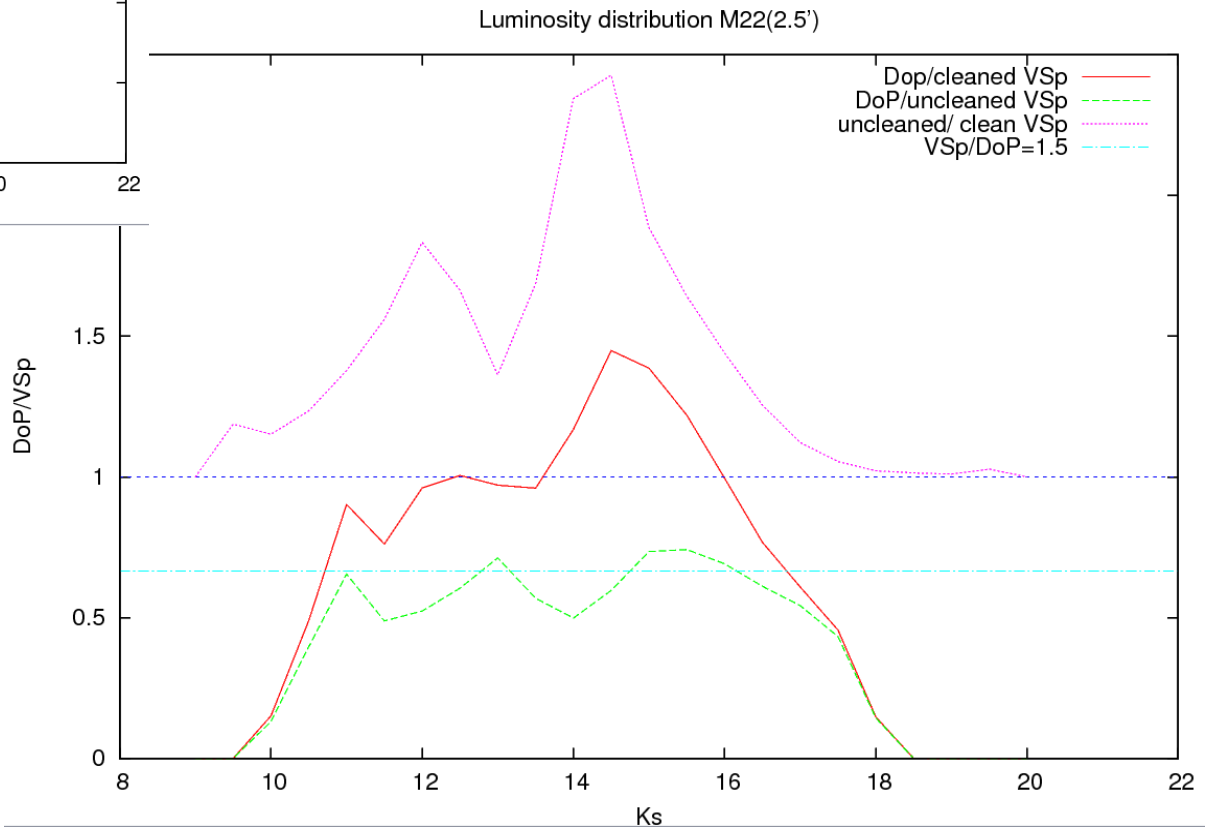




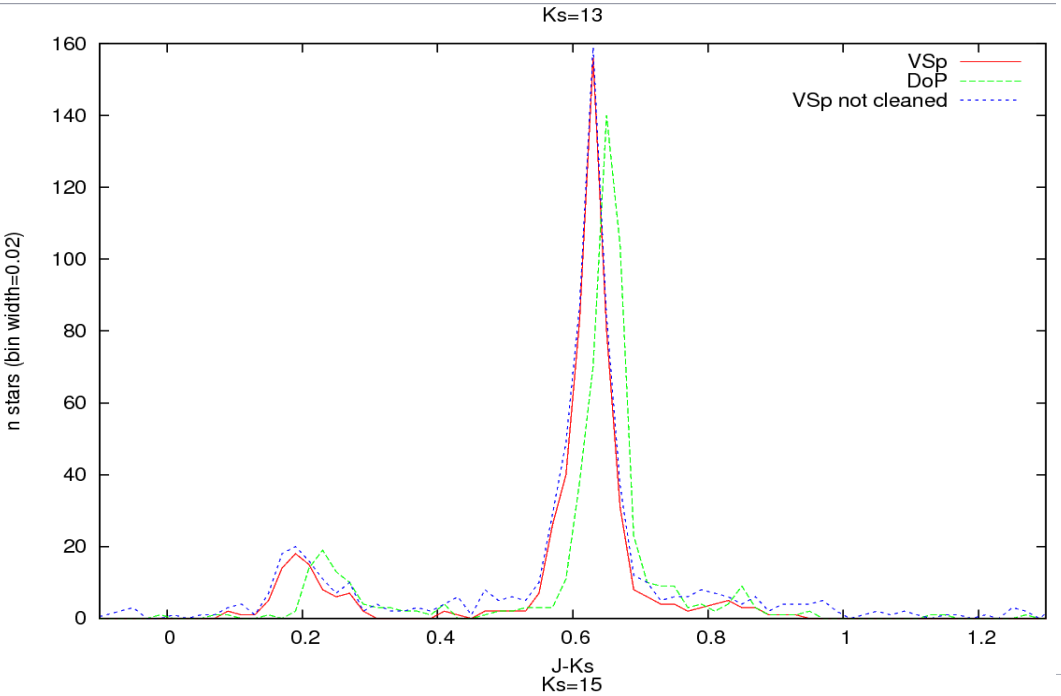


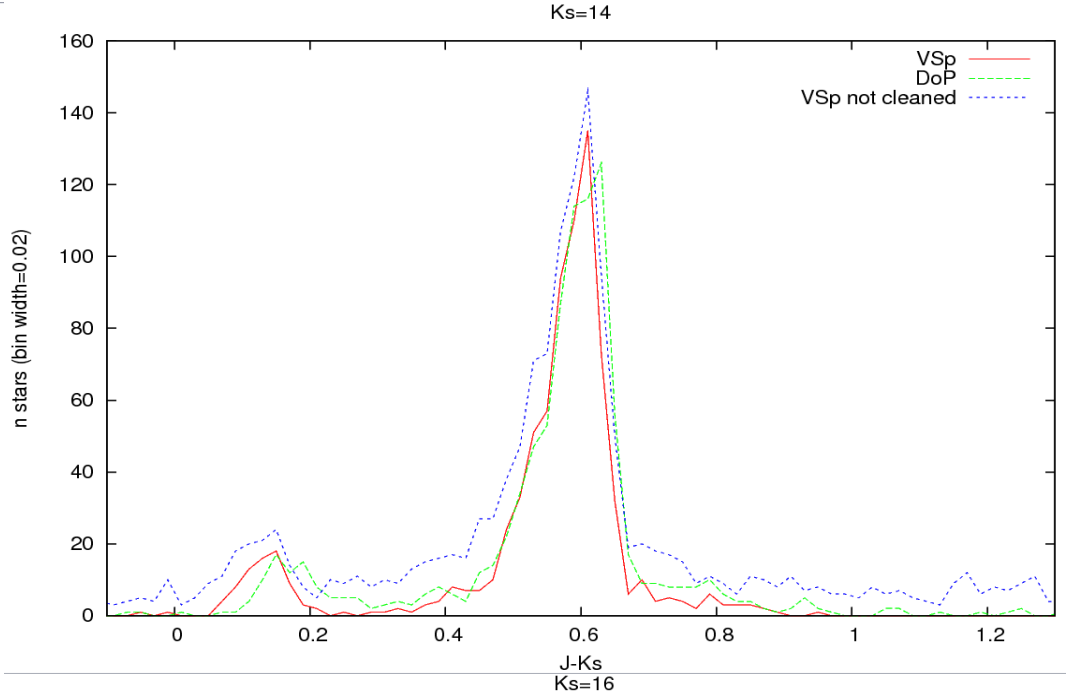
Comparison with DoPhot catalog: Luminosity distribution in 2.5' inner area

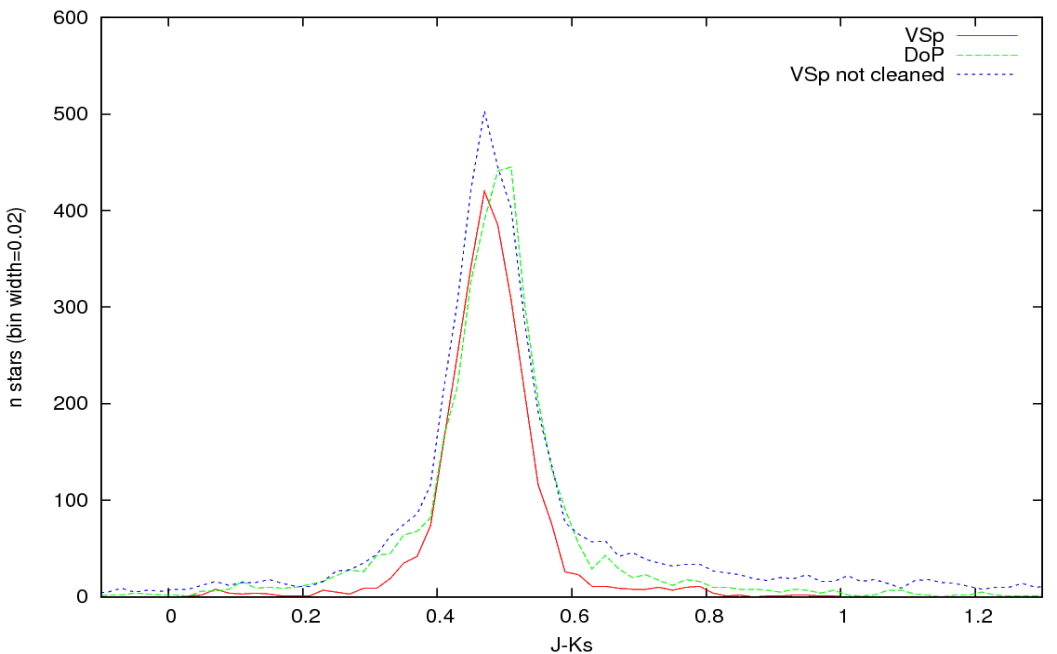


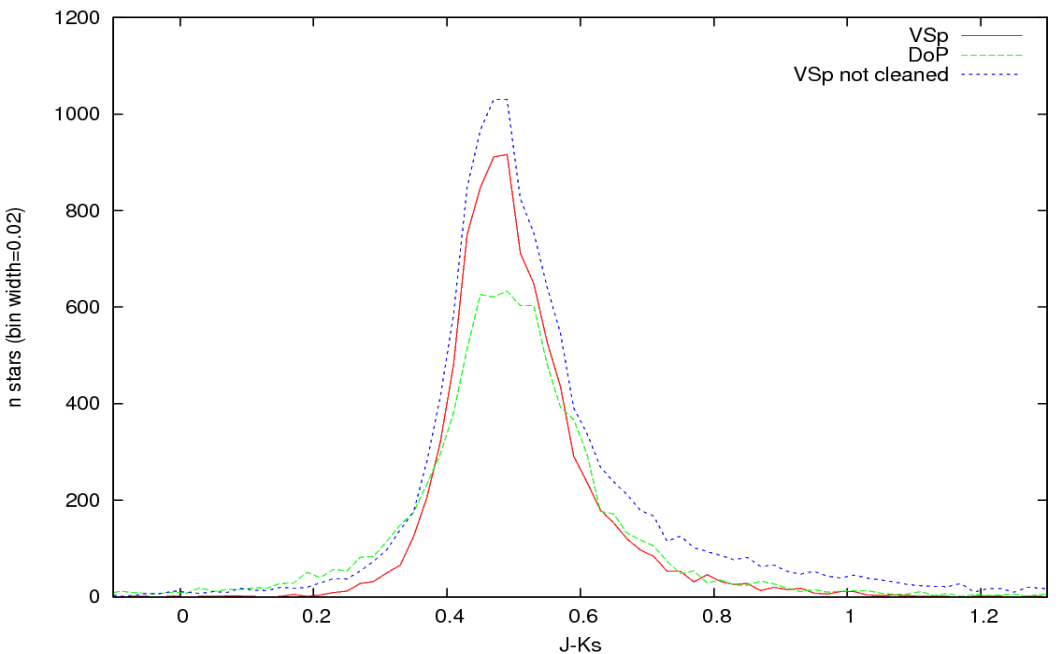


Comparison with DoPhot catalog: distribution in color in 2.5' inner area

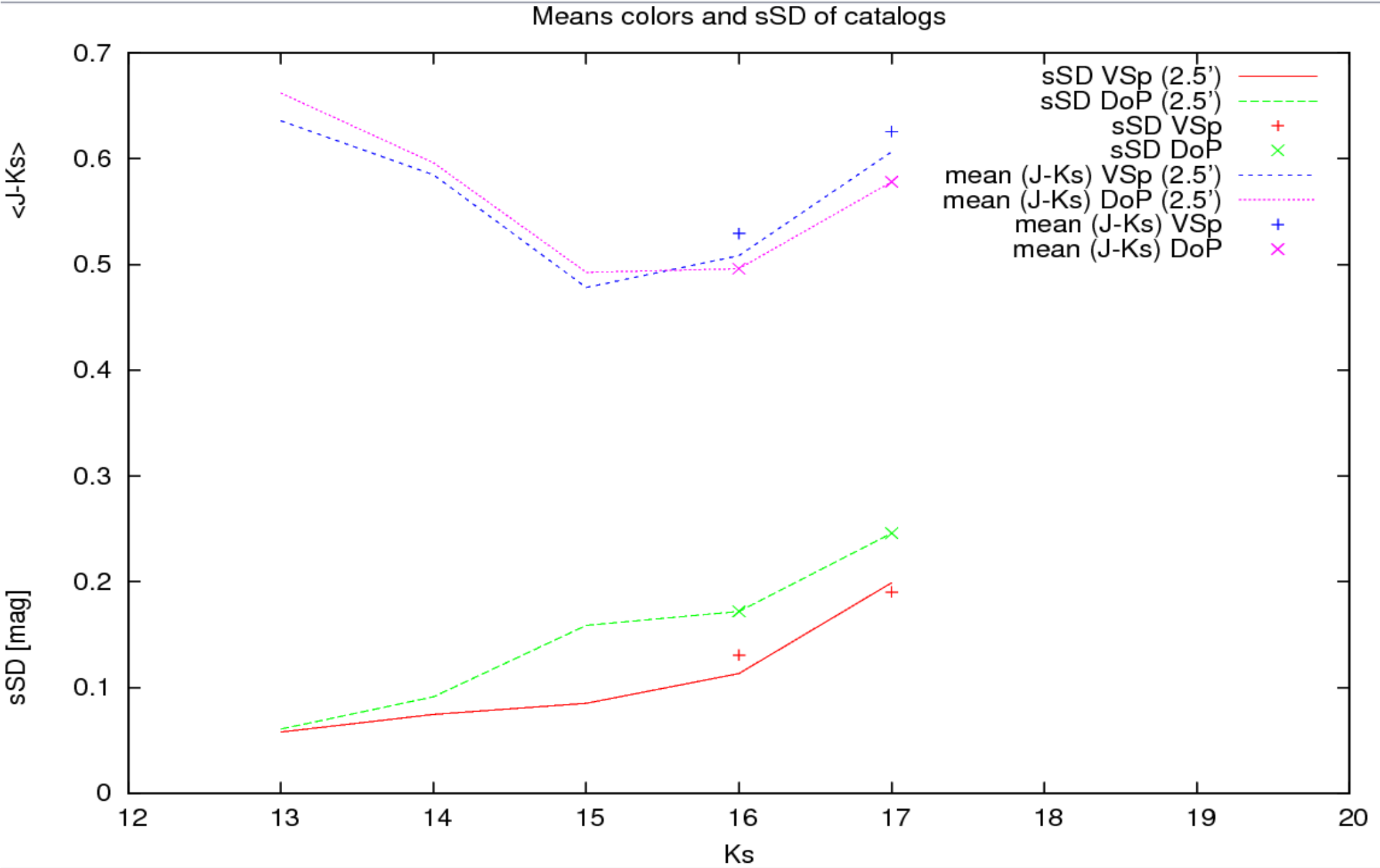




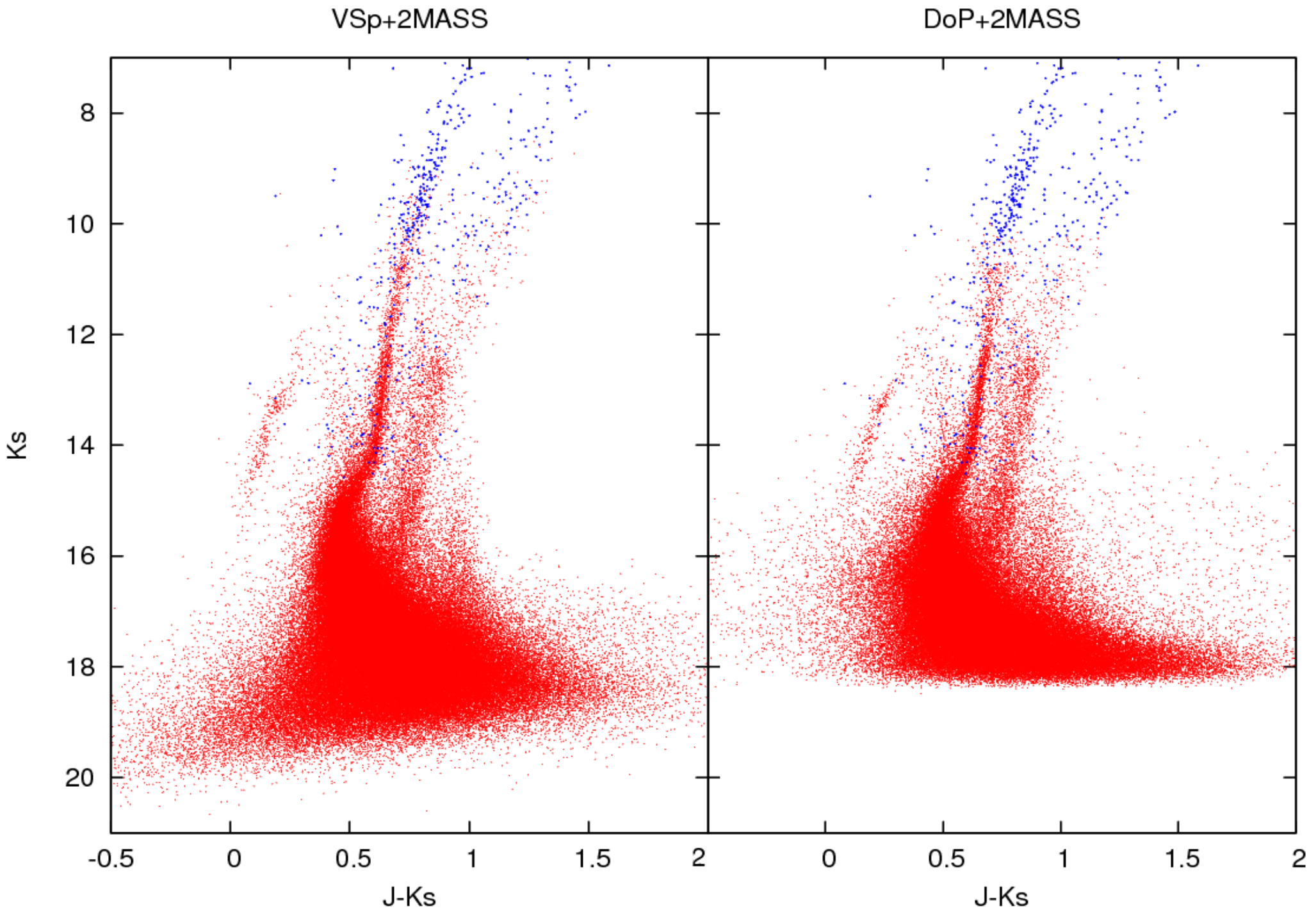




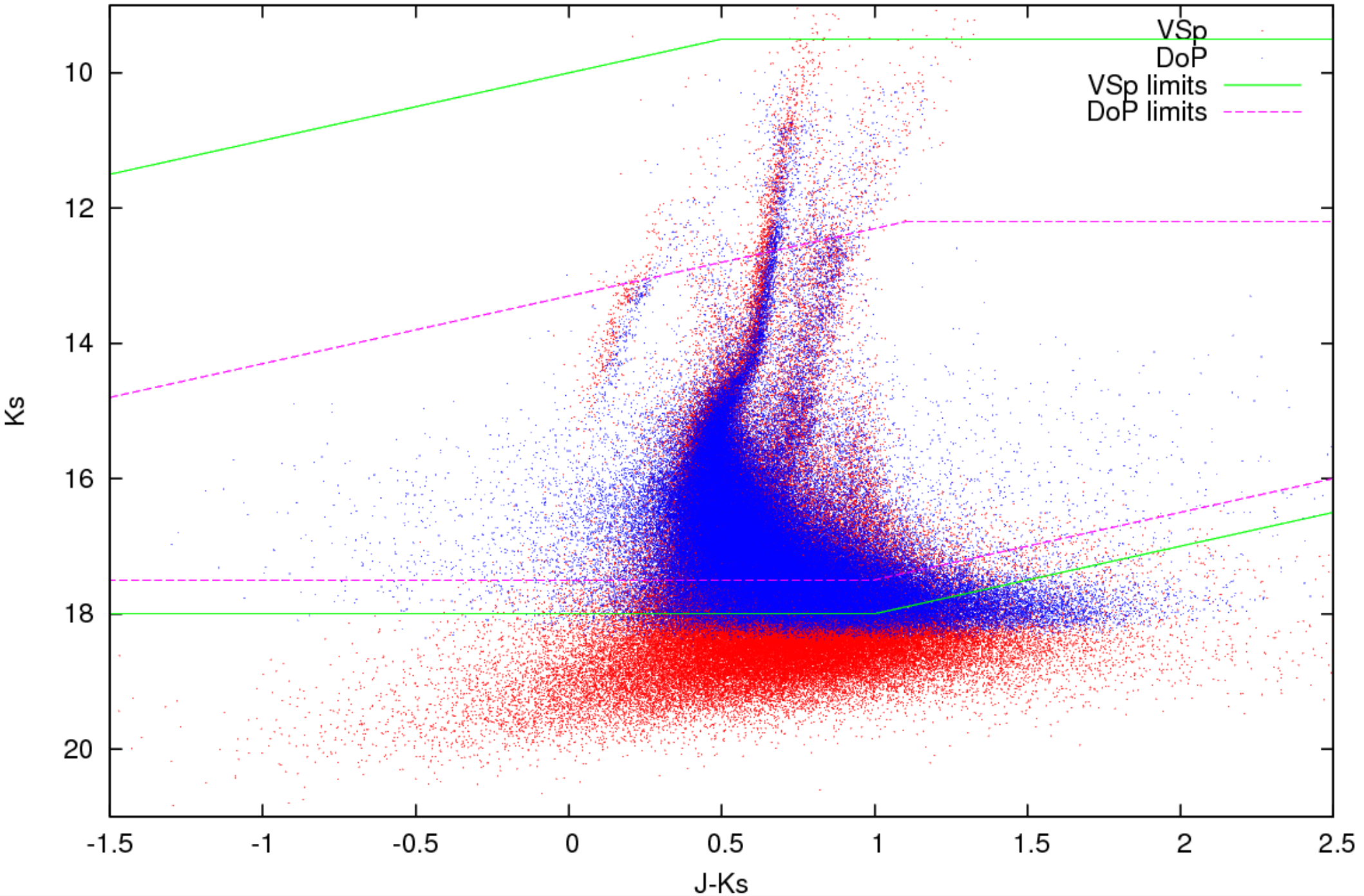
Comparison with DoPhot catalog: distribution in color



Comparison with DoPhot catalog

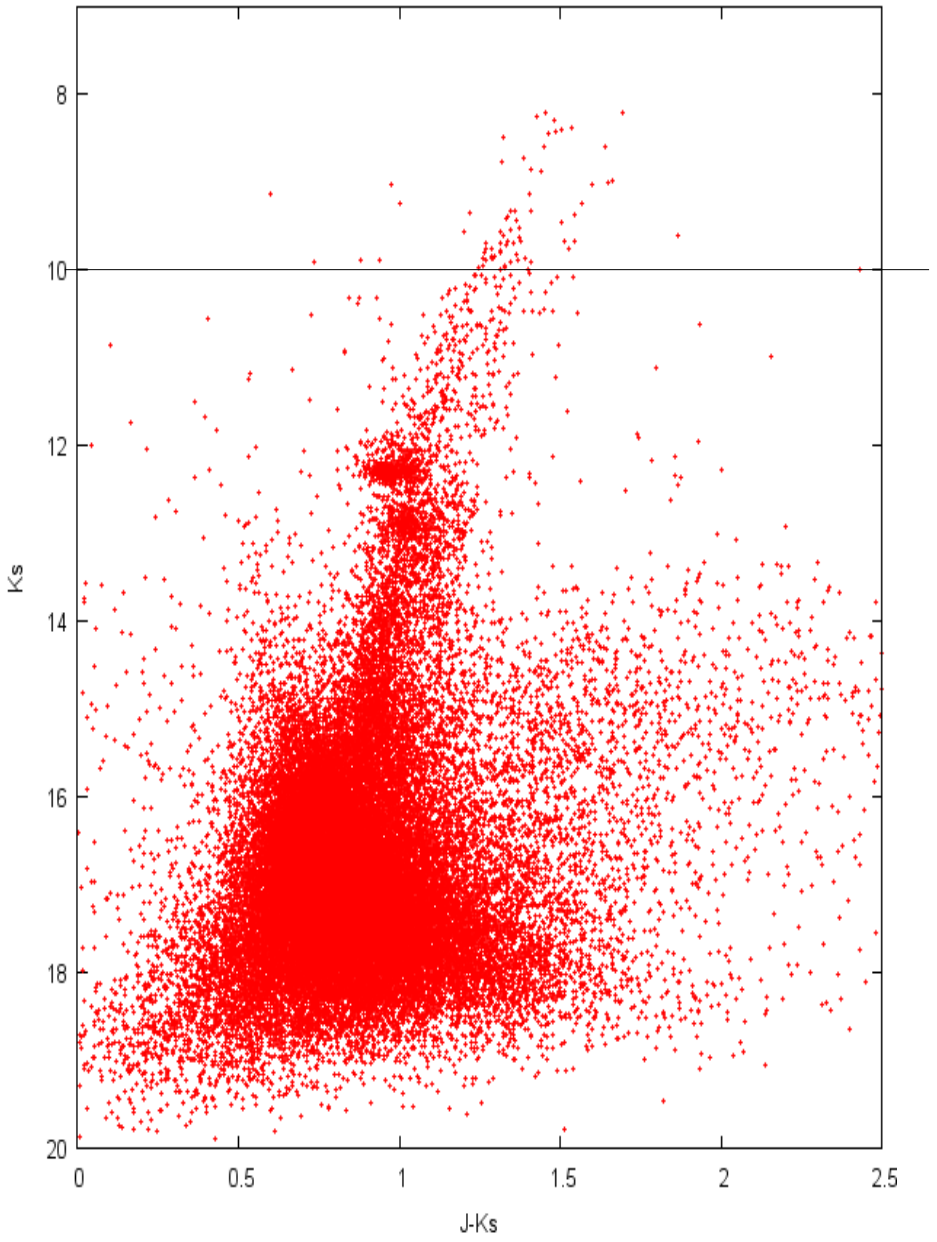


Reliable parts of the CMD

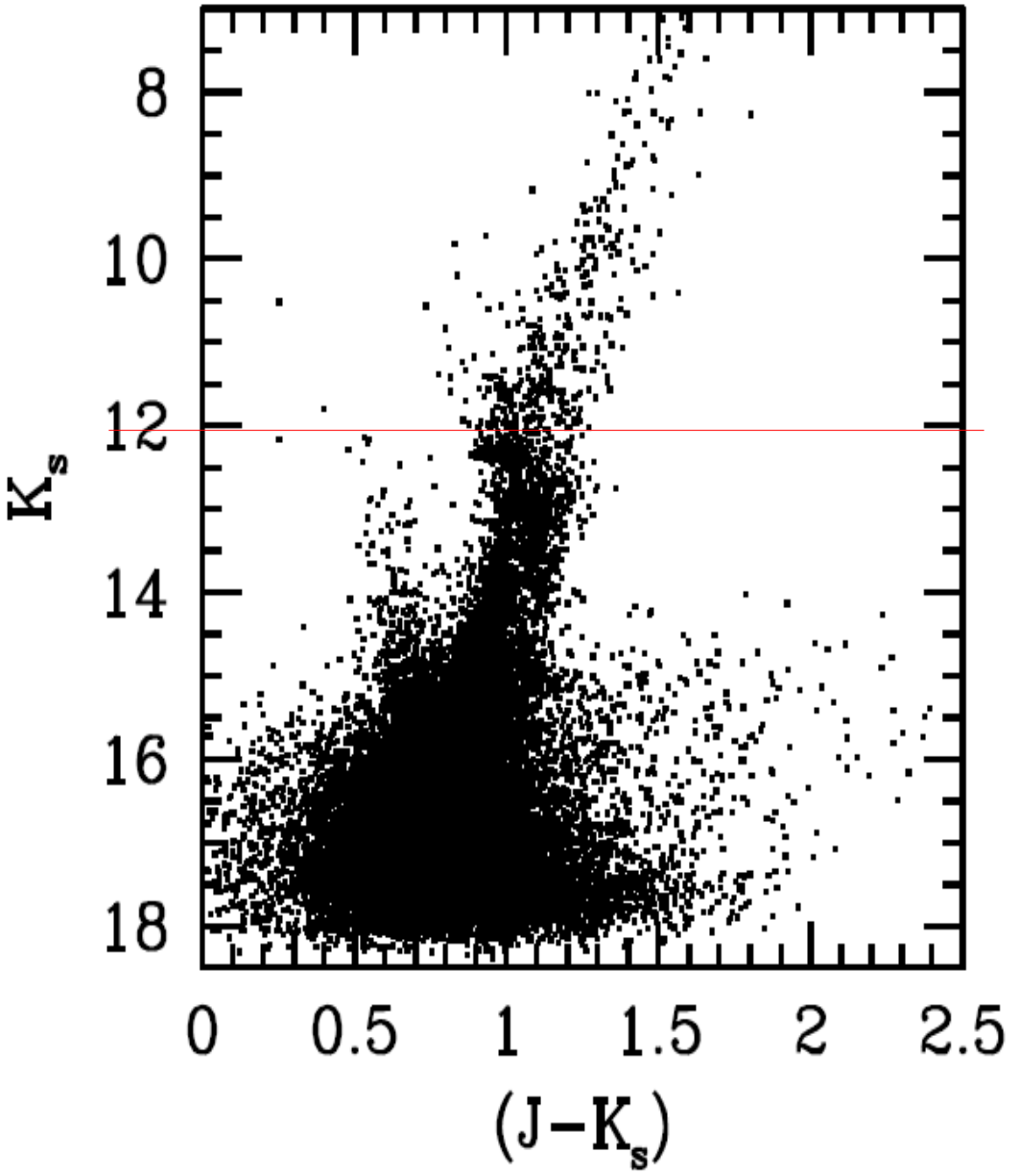


Reliable parts of CMD: NGC 6553 (b295)

Uncleaned Vsp catalog



Dophot catalog plus 2MASS for saturated stars (i.e. Ks<11)



Saturation limit

POPULATION	$A_V = 0$ $A_J = 0$ $A_K = 0$ E(B-V)=0	$A_V = 1.5$ $A_J = 0.4$ $A_K = 0.2$ E(B-V)=0.5	$A_V = 5.0$ $A_J = 1.4$ $A_K = 0.6$ E(B-V)=1.5	$A_V = 10.0$ $A_J = 2.8$ $A_K = 1.1$ E(B-V)=3.2	$A_V = 15.0$ $A_J = 4.2$ $A_K = 1.7$ E(B-V)=4.8
Bulge RGB tip	K=8.0*	K=8.2*	K=8.6*	K=9.0*	K=9.7
Sgr RGB tip	K=10.5	K=10.7	K=11.1	K=11.6	K=12.2
Bulge RGB Clump	K=12.9	K=13.1	K=13.5	K=14.0	K=14.6
Bulge RR Lyrae	K=14.3	K=14.5	K=14.9	K=15.4	K=16.0
Sgr RGB Clump	K=15.4	K=15.6	K=16.0	K=16.5	K=17.1
Sgr RR Lyrae	K=16.8	K=17.0	K=17.4	K=17.9	K=18.5*
Bulge MS TO	K=17.0	K=17.2	K=17.6	K=18.1	K=18.7*
* = beyond detection					

Next improvements for the pipeline

- Artificial stars
- Handling variable stars
- Better cleaning procedure
- Improving algorithms
- Improving WCS