



Improving photometry  
of the Pi of the Sky

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*for the Pi of the Sky Collaboration*

Wilga, May 27, 2010

# Data processing

- On-line analysis not covered in this talk

Fast algorithms optimised for transient search - real time analysis frame by frame:

- dark frame subtraction
- fast photometry including „Laplace filter”
- comparison with reference image  
(based on series of previous images)
- multilevel selection system to reject backgrounds  
(fluctuations, hot pixels, cosmic ray hits, satellites)  
start with simple cuts, more time for deeper analysis ( similar to particle physics pipelines )
- coincidence between cameras crucial

# Data processing

- Off-line analysis

Algorithms optimised for data reduction:

- adding 20 subsequent frames (equiv. 200 s exposure)
- dark frame subtraction, flat correction
- multiple aperture photometry (ASAS)
- astrometry, reference star selection
- normalization to V magnitudes from TYCHO catalog
- cataloging of lightcurves to the PostgreSQL database
- flagging new objects added to the catalog

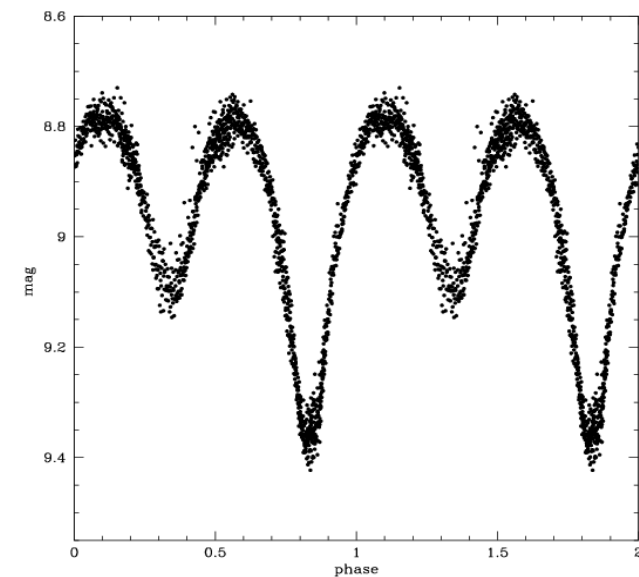
# Database

- Open access to data May 2006 - Apr 2009 (16.7 million of objects, 2.16 billion measurements)

<http://grb.fuw.edu.pl/pi/databases>

The screenshot shows the Pi Stars Browser interface. At the top, it says "Database: Pelna baza 2006-2007 (# of objects = 9.7 mln)". Below that, there's a "Searching:" section with various search criteria. The criteria include: Ra (min: 15:32:10, max: 20:32:49), Dec (min: -31:33:00, max: -18:14:24), Search around (Ra: 12:00:00, Dec: 00:00:00, radius [arcsec]: 1), Magnitude (min: 2.063, max: 9.844), Error [mag] (min: 0.0184, max: 0.4111), No. observations (min: 1000, max: 1000000), Amplitude [mag] (min: 0, max: 100), and Period [days] (min: 0, max: 100). There are also checkboxes for "Advanced" and "Show star: stand". At the bottom, there are two plots: "Sky Map" and "Variability Diagram".

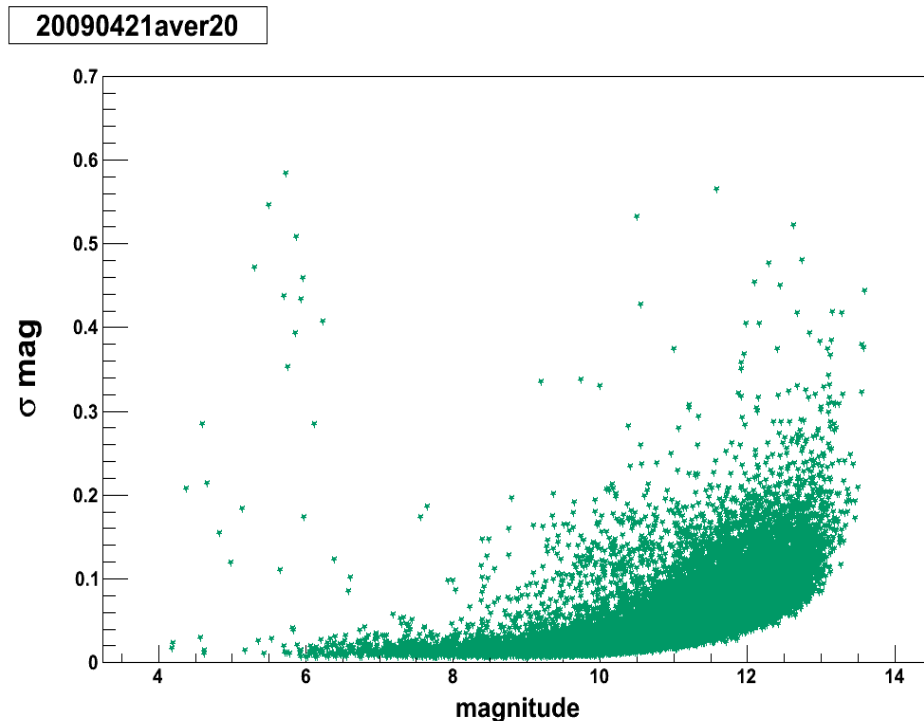
Example of phased lightcurve



# Database

- Unfiltered measurements

measured brightness dispersion vs magnitude (example)



Few variable stars,  
but large dispersion  
mainly due to bad  
measurements

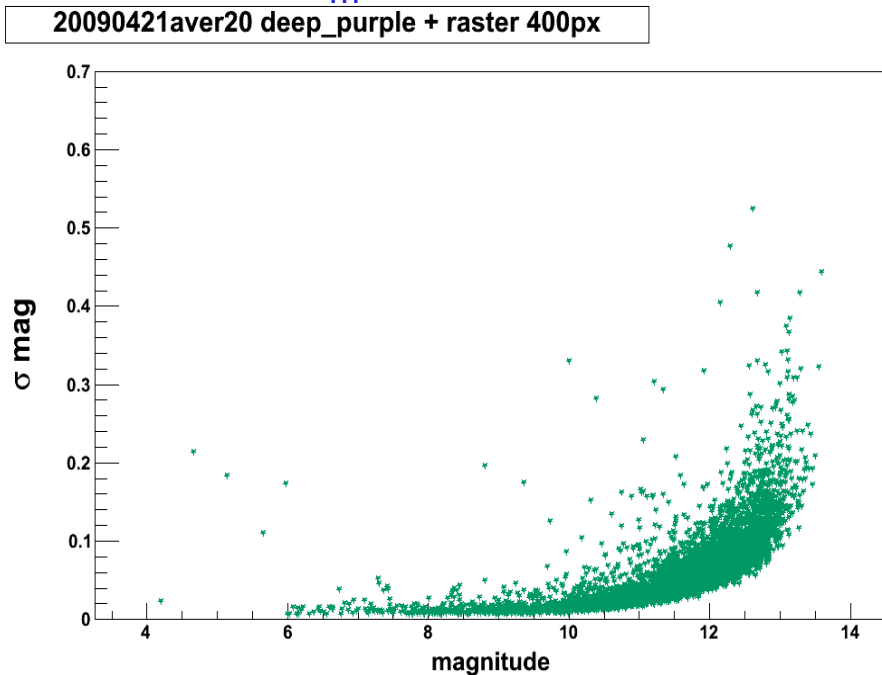
# Data analysis

- Dedicated filters developed to remove bad measurements or frames
  - hot pixels
  - measurements near CCD edge  
(require at least 100 pixel from edge)
  - planet or planetoid passage
  - columns around bright stars  
(in opened shutter mode)
  - frames with too few matched stars
  - frames with very high background level
  - frames with large astrometric error

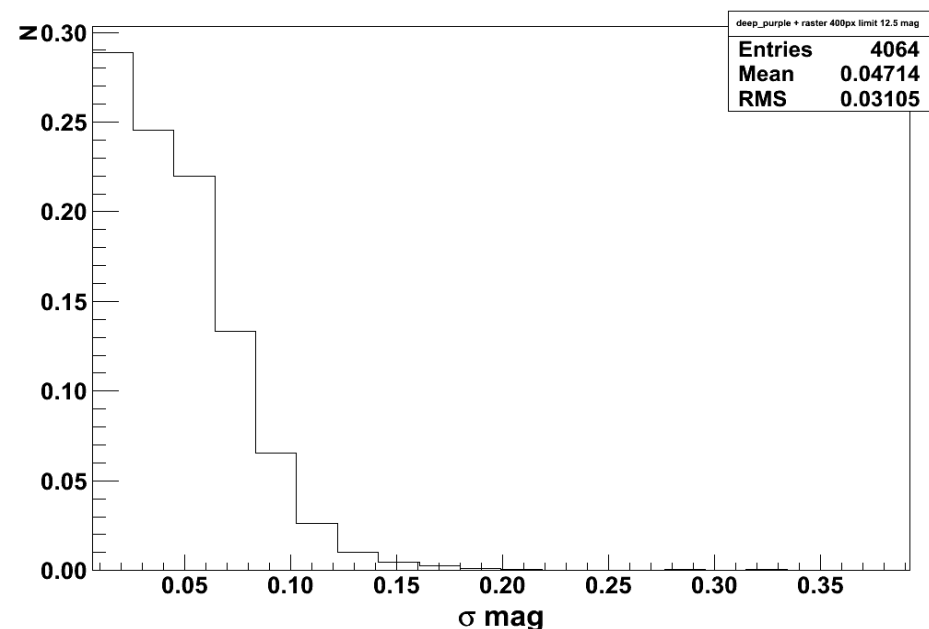
# Data analysis

- Photometry accuracy significantly improves after removing bad quality data
  - For stars  $7^m - 10^m$   $\langle \sigma_m \rangle \approx 0.015$  achieved

$\sigma_m$  vs mag

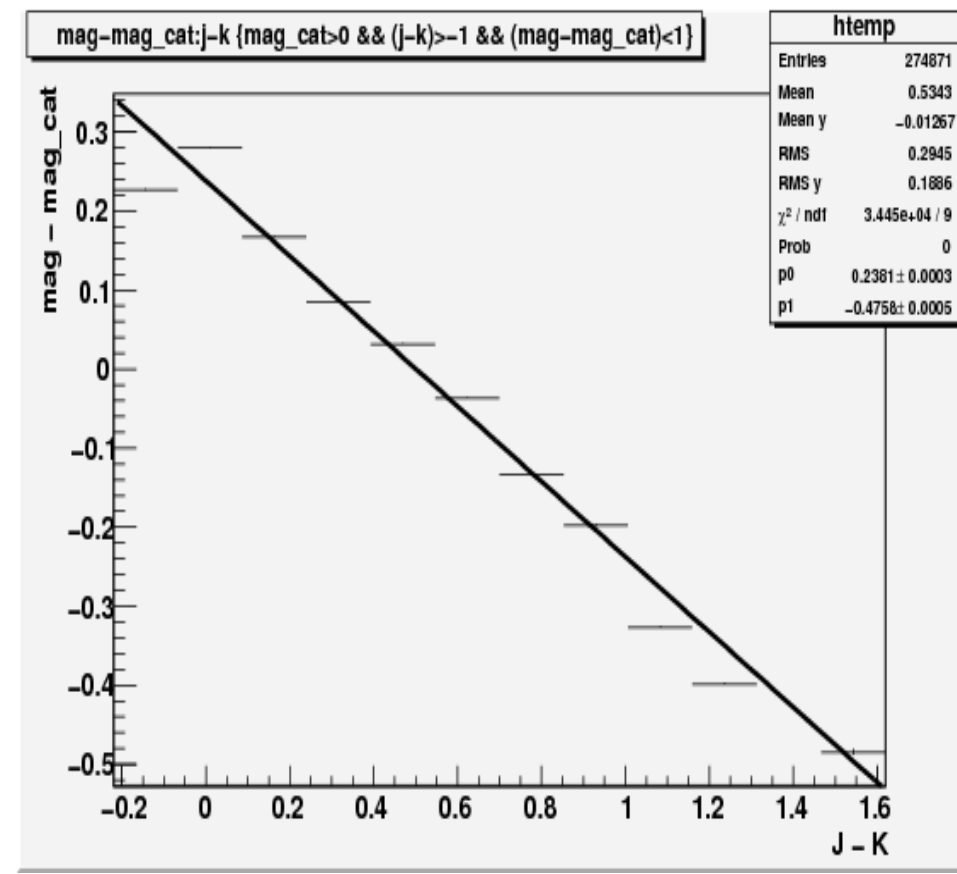
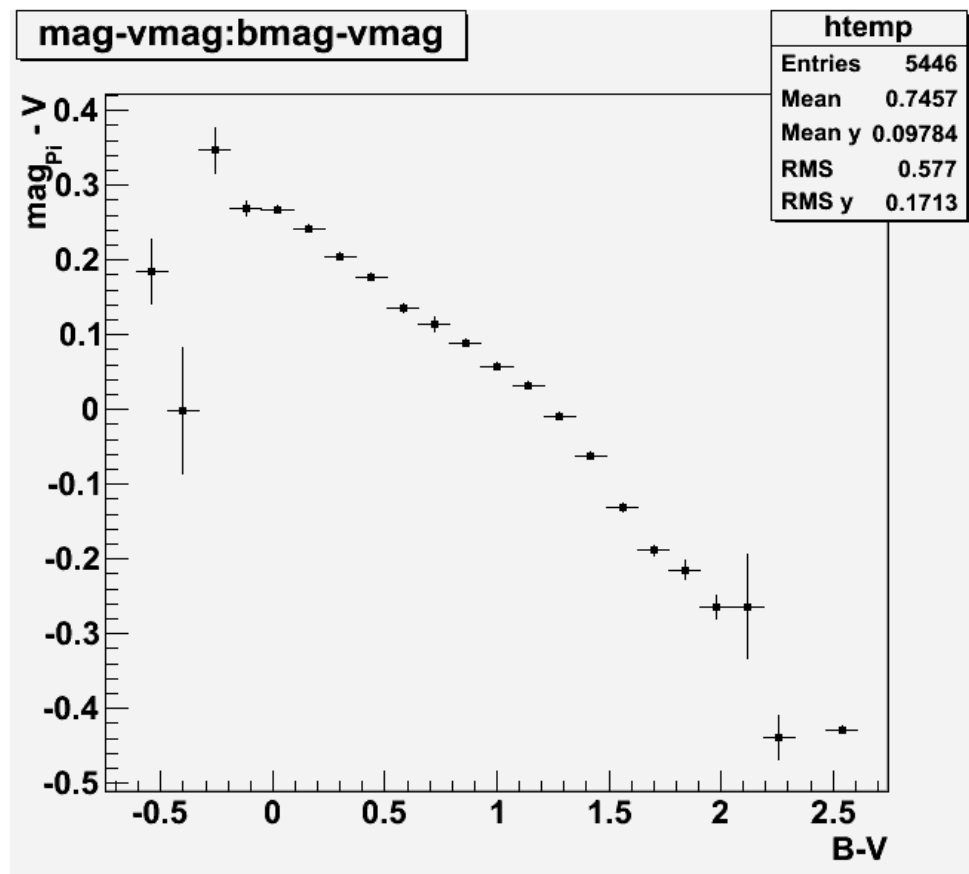


$\sigma_m$  for mag < 12.5



# New approach

- It turned out that detector response is correlated with the star spectral type (B-V or J-K)





# New approach

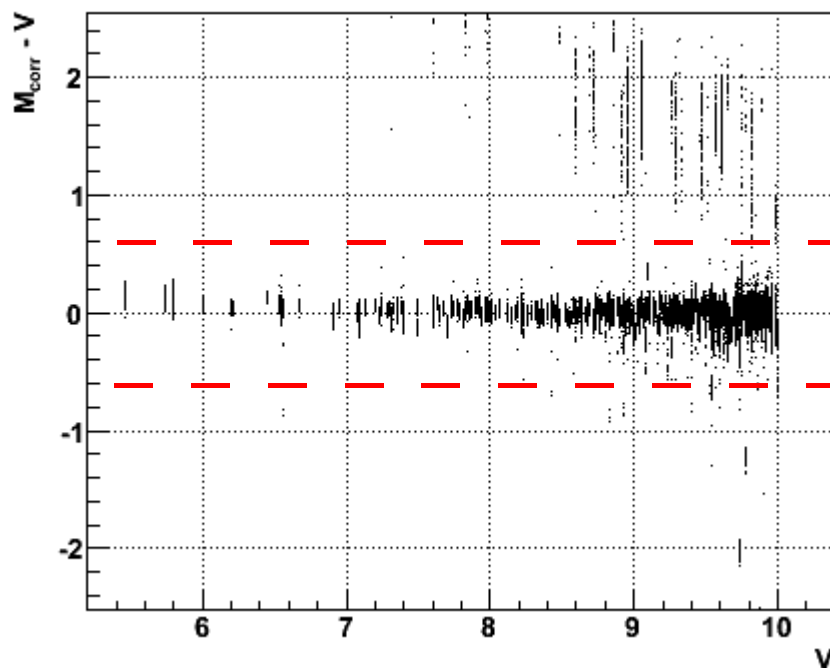
- Reference stars measurements are corrected for spectral type:

$$M_{\text{corr}} = M - 0.2725 + 0.5258*(J - K)$$

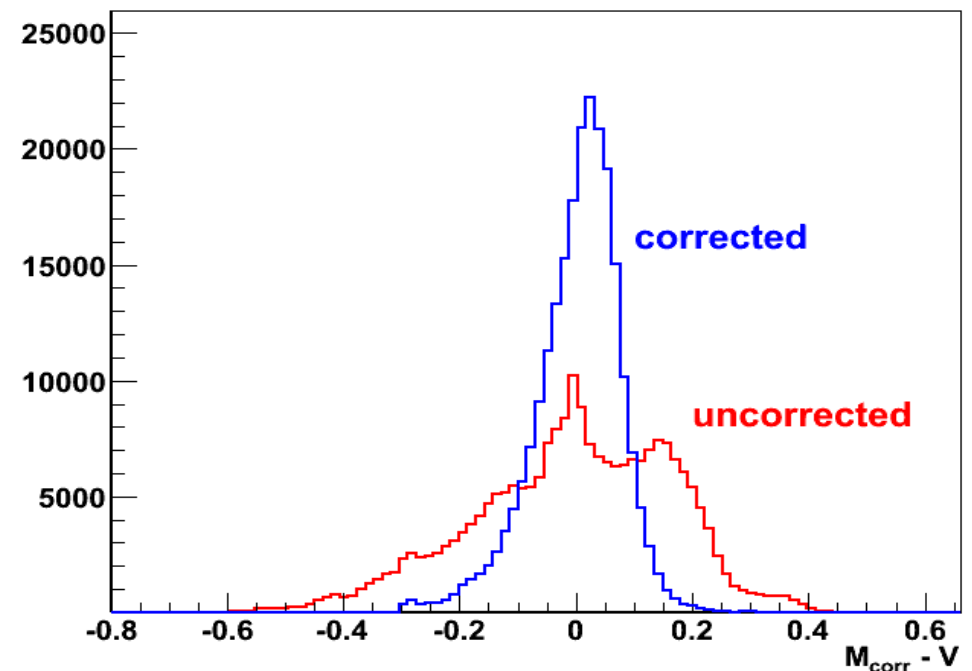
stars with large  $\Delta M$  rejected

corrections more precise and stable

Corrected magnitude shift for reference stars



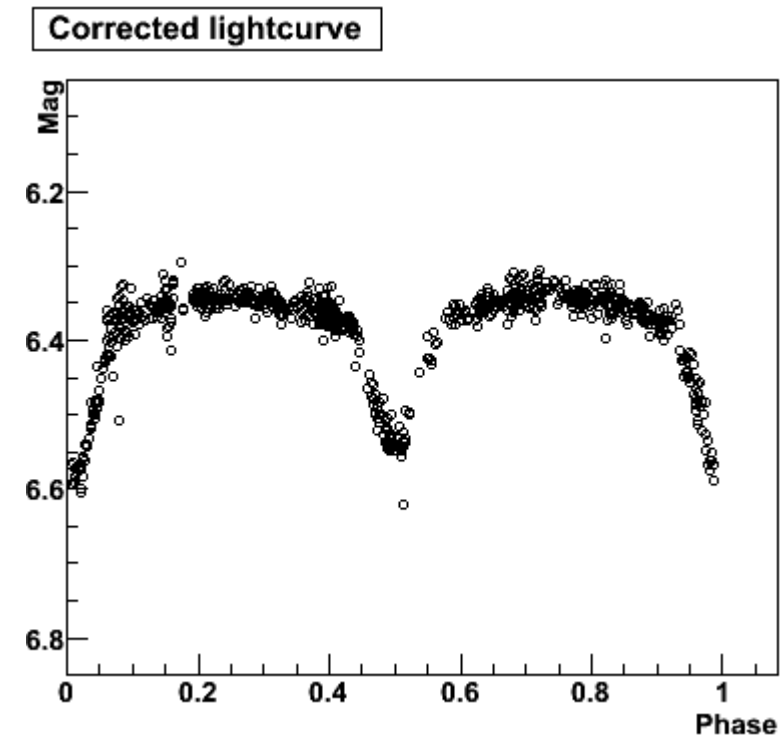
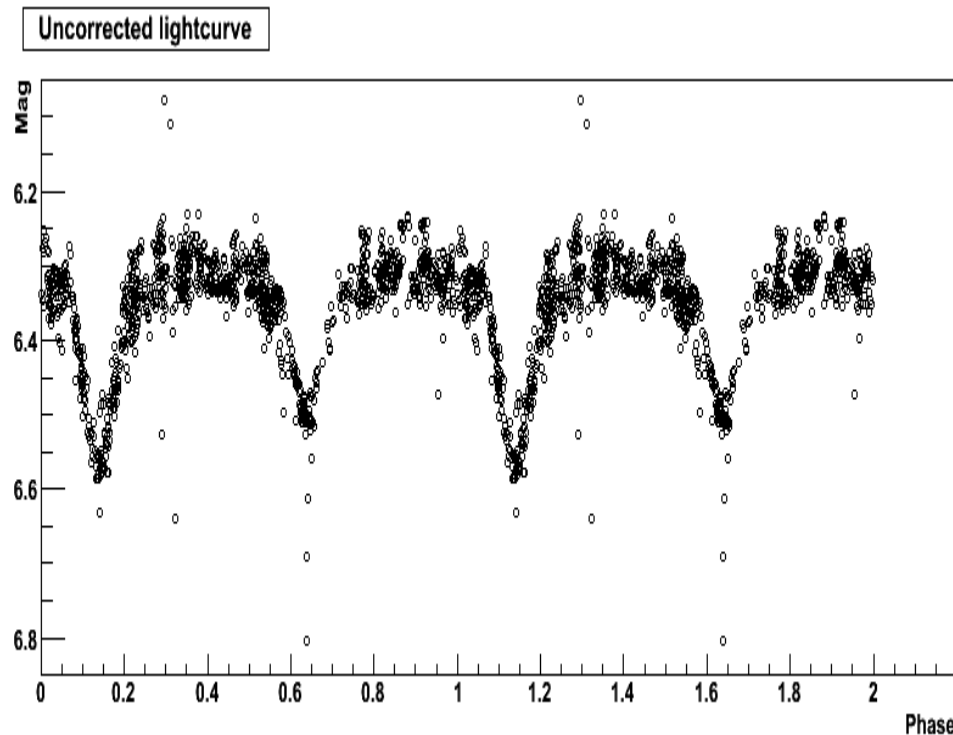
Reference stars magnitude shift



# New approach

- Normalization method
  - quadratic corrections fitted to reference stars
  - weights depending on distance and brightness

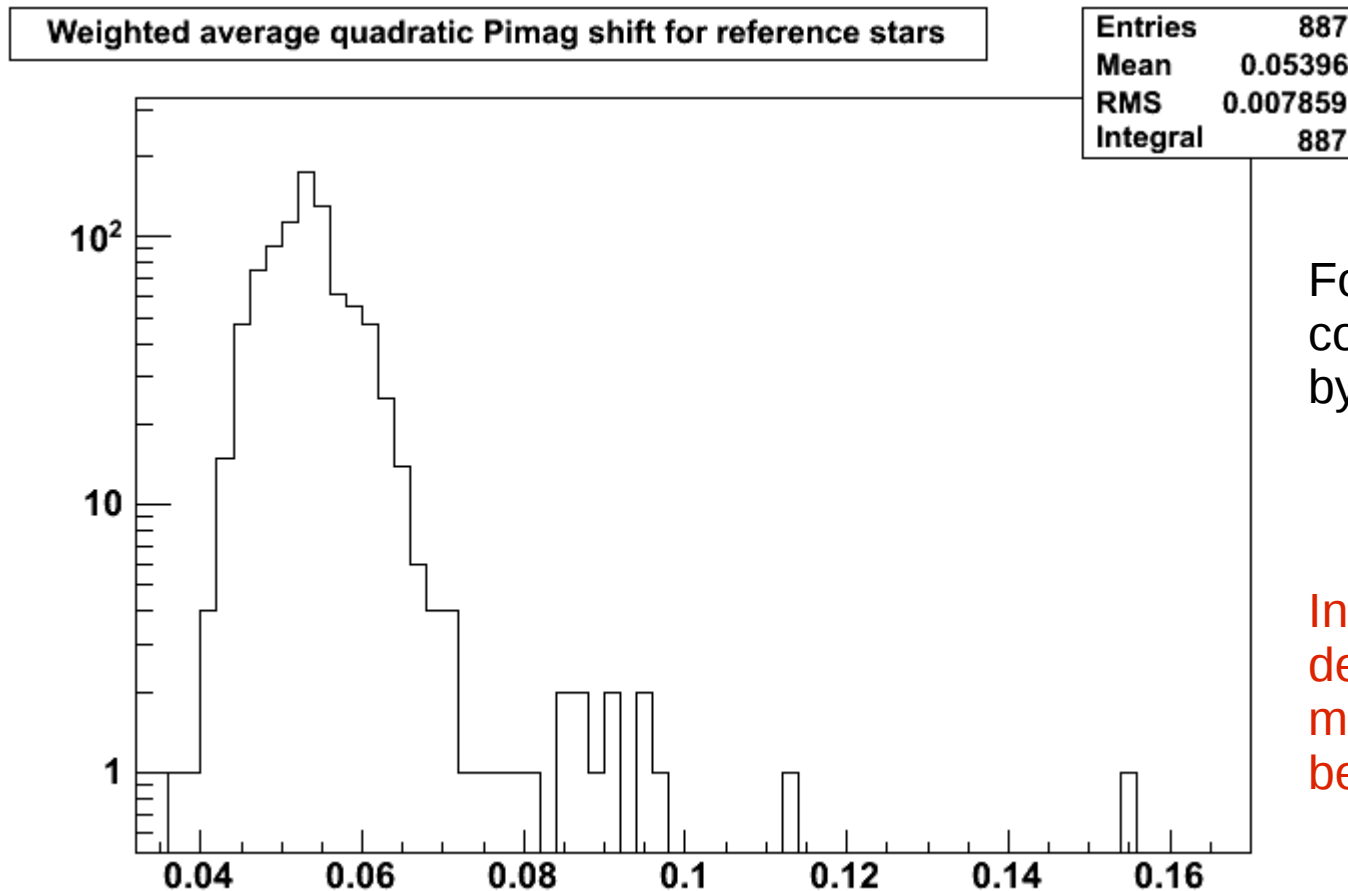
Comparison of uncorrected and corrected lightcurves for BGInd variable



# New approach

- Correction fit quality check

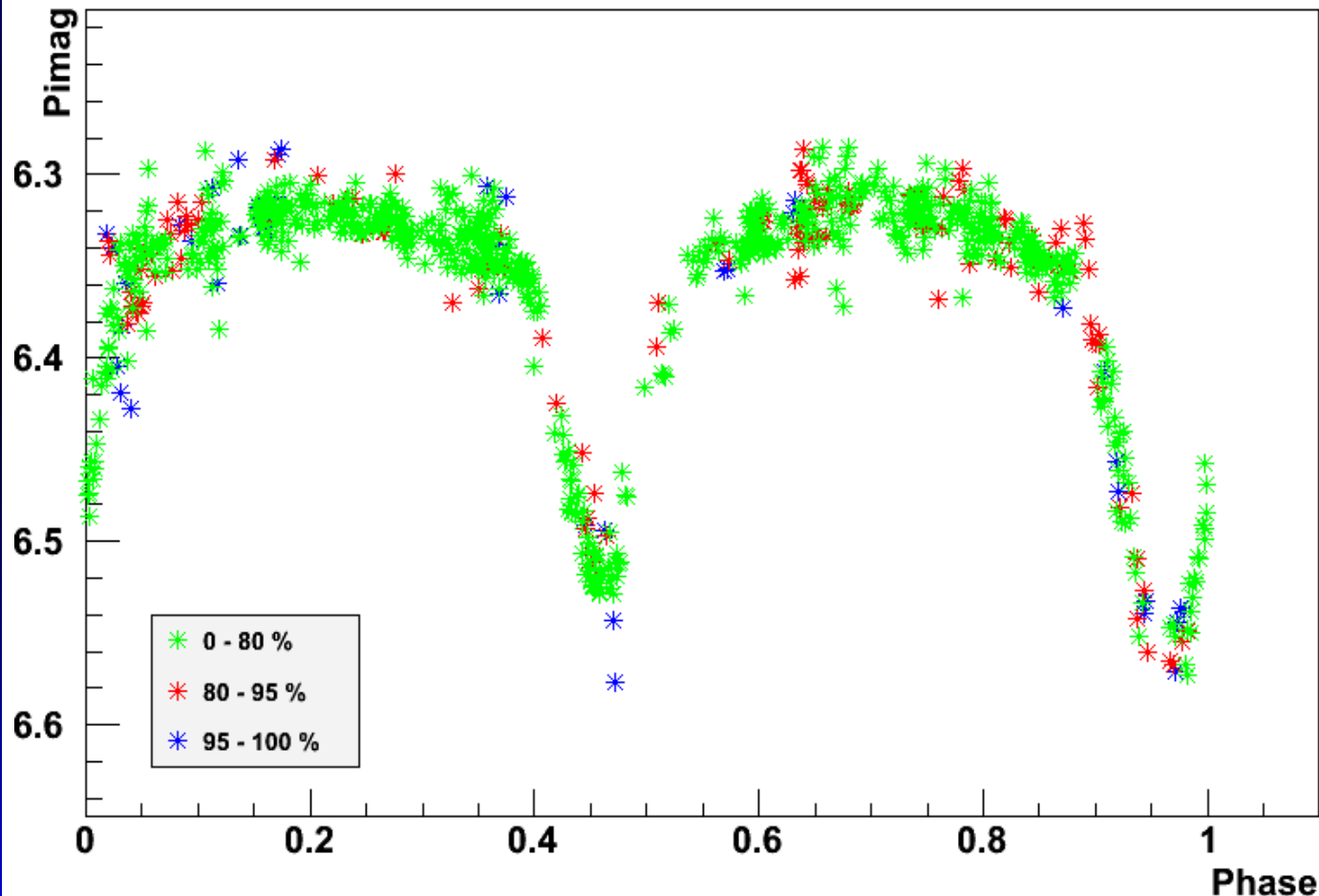
Average square distance of the reference stars from the fitted correction surface



# New approach

- BGInd light curve with correction quality cut

BGInd corrected lightcurve in fit quality bins



Brightness fluctuations much larger for 5% of measurements with largest correction spread (blue stars)

Light curve quality improves when these measurements are removed.

# Possible improvements

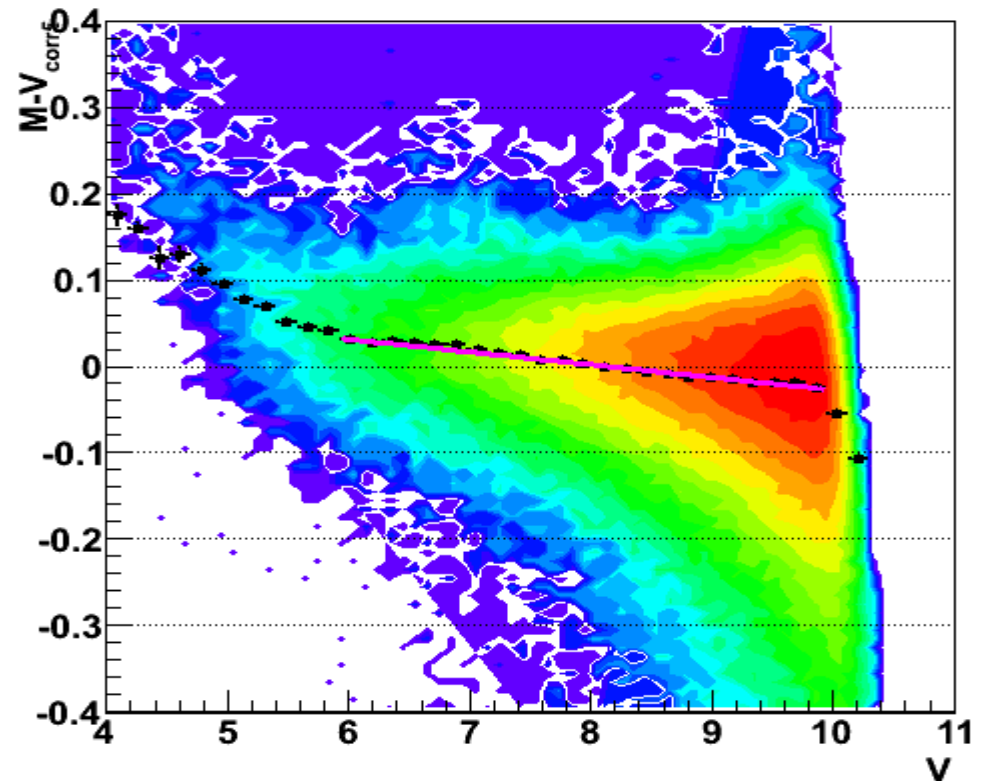
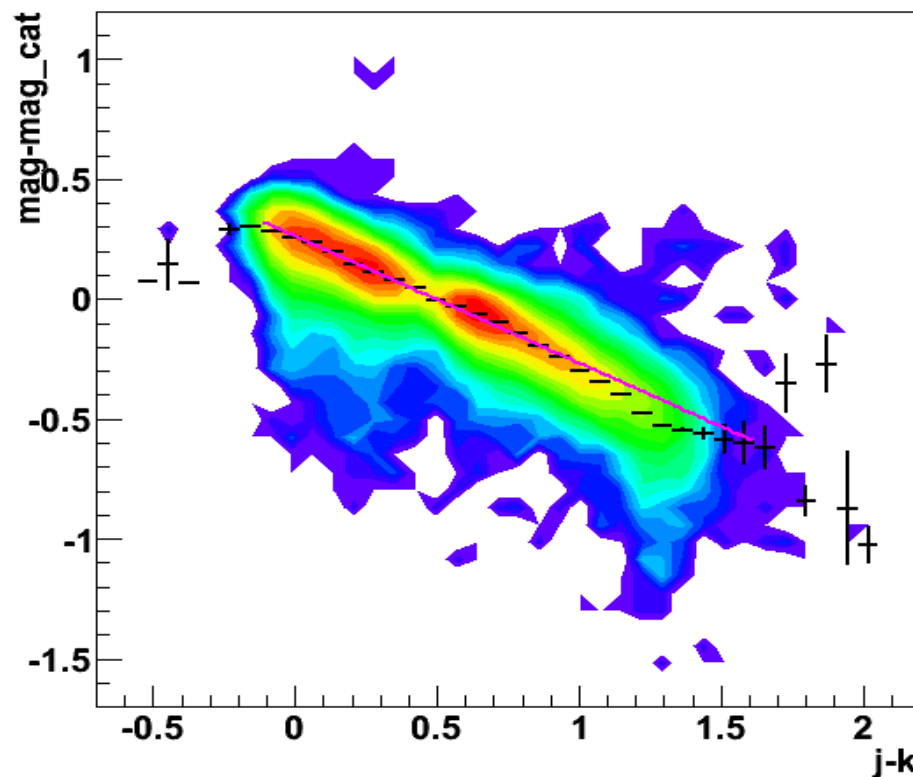
- Better spectral type and magnitude corrections

Spectral type dependence  
Correction non linear!

Brightness shift vs Magnitudo  
Additional correction needed!

`mag-mag_cat:j-k {mag_cat>6&&mag_cat<9&&jmk<2&&jmk>-0.5&&abs(mmv-0.2374+0.5683*jmk)<1}`

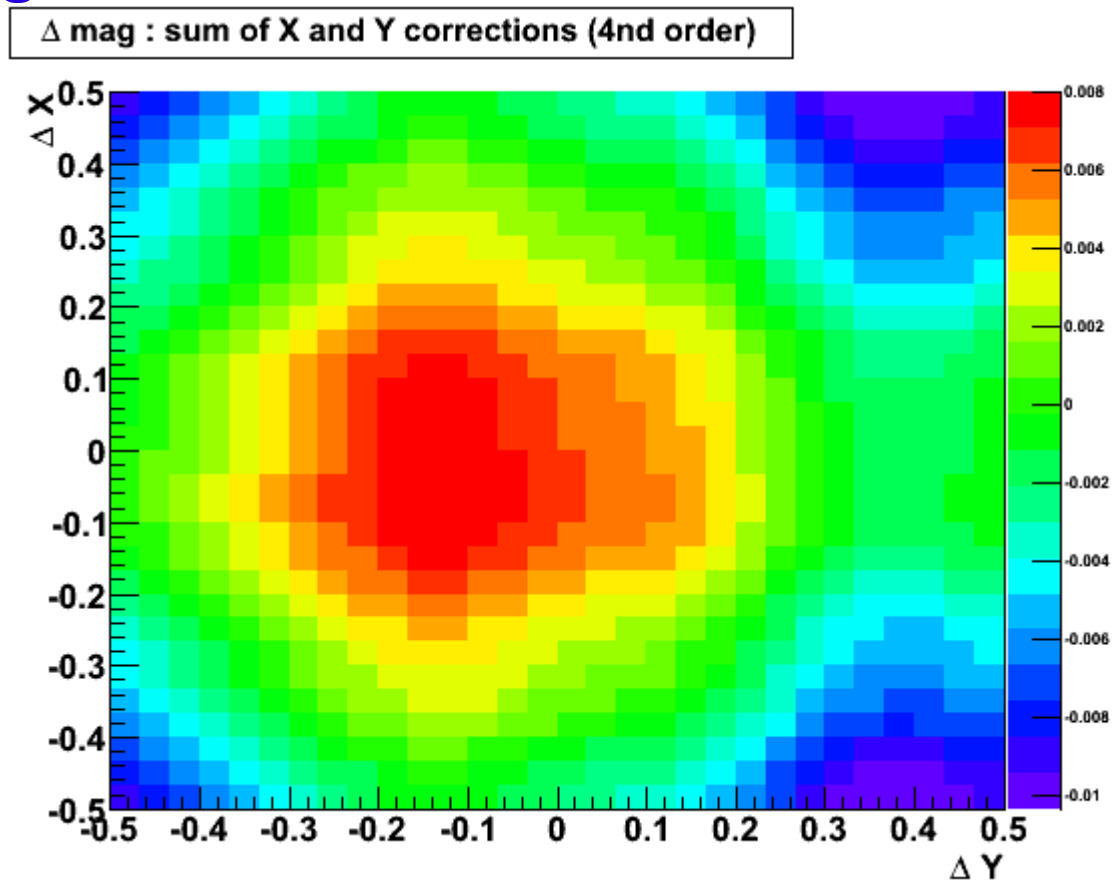
Magnitude shift for stars with  $M+V < 20$



# Possible improvements

- Correction taking into account CCD structure

magnitudo shift  
vs star position  
w.r.t. pixel edge



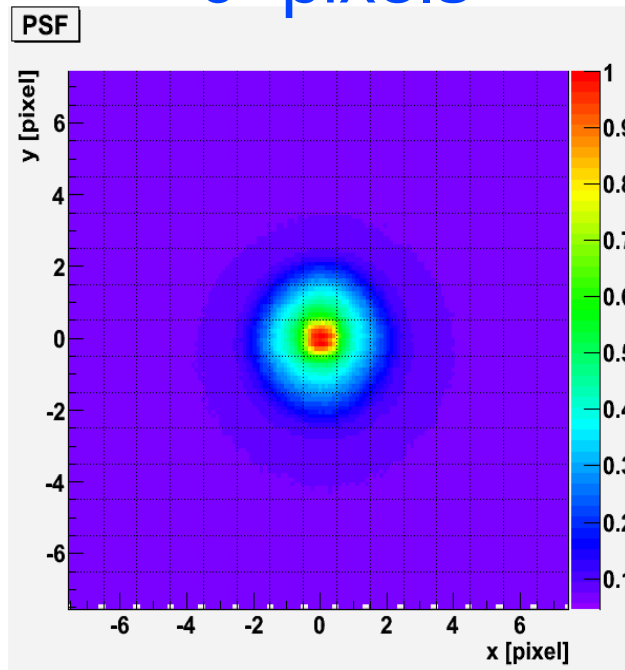
can depend on position and spectral type – more studies needed...

# Possible improvements

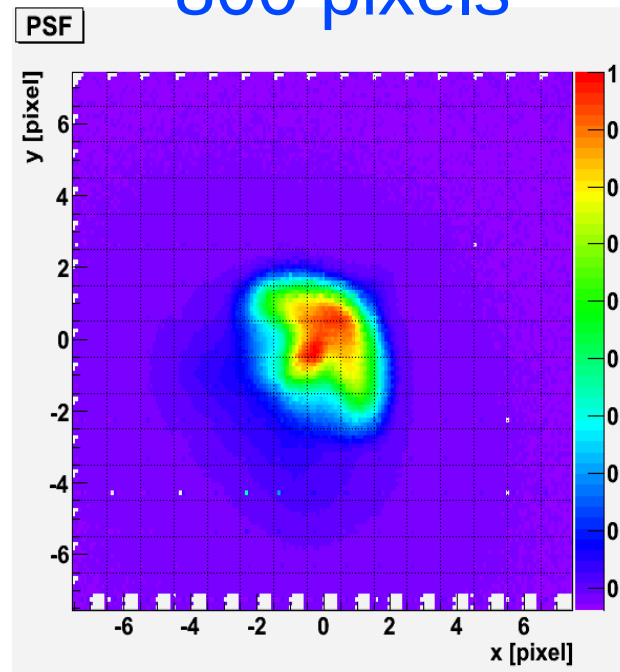
- Photometry based on detailed PSF model

Laboratory PSF measurements (distance from CCD center):

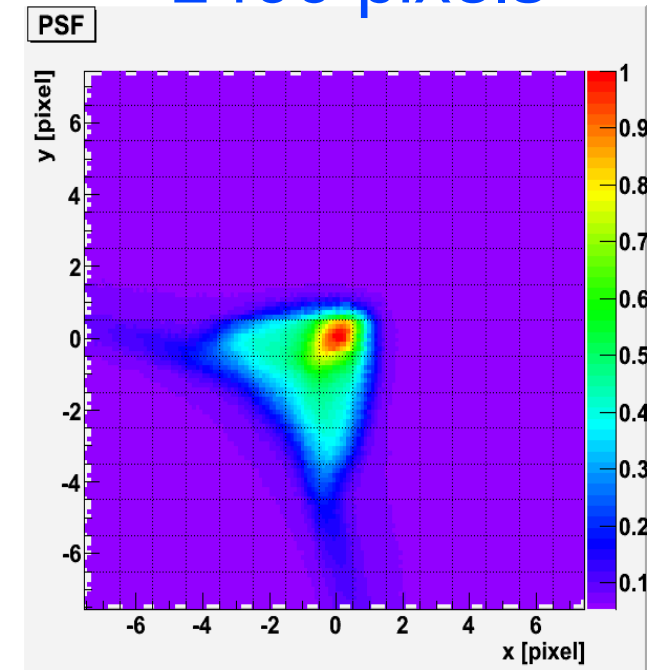
0 pixels



800 pixels



1400 pixels



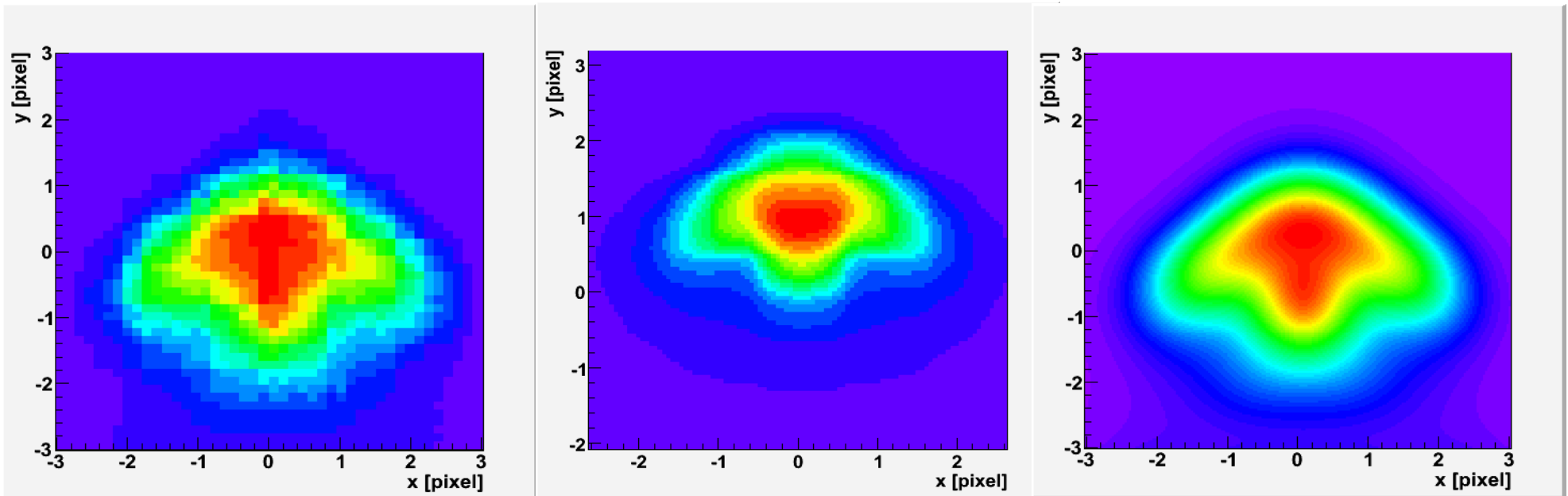
# Possible improvements

- Different approaches possible for PSF modelling
  - numerical wavefront integration
  - parametrization with Zernike polynomials

Data

wavefront integral

Zernike polynomials



Position, focus and color dependence – very difficult to parametrize all, still not successful..



# Conclusions

- Pi of the Sky prototype working 2006-2009 delivered large amount of photometric data:  
<http://grb.fuw.edu.pl/pi/databases>
- With improved understanding of the detector and new filtering algorithms data quality can be significantly improved
- Further improvements seem feasible, including pixel structure and spectral type corrections  
we aim at  $\sigma_m \approx 0.01$  for stars up to  $10^m$