Improving photometry of the Pi of the Sky

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for the Pi of the Sky Collaboration

IBWS2010, April 15, 2010

Pi of the Sky Collaboration

- Leading Polish academic and research units:
  - The Andrzej Soltan Institute for Nuclear Studies
  - Center for Theoretical Physics, Polish Academy of Science
  - Institute of Experimental Physics, University of Warsaw
  - Warsaw University of Technology
  - Space Research Center
  - Faculty of Mathematics, Informatics and Mechanics, University of Warsaw
  - Cardinal Wyszynski University
  - Pedagogical University of Cracow

Cooperation with: G.Pojmański (Univ. of Warsaw; ASAS), Creotech

Scientific goals

Study objects varying on scales from seconds to months

- Search for optical counterparts of GRBs
  - wide field sky monitoring
  - high temporal resolution
  - automatic detection (independent on GCN alerts)
- Search for other flash like phenomena
  (supernovae, novae, flare stars explosions)
- Continuous monitoring of interesting objects
  (blasars, AGNs)
- Variable stars
  (identification and cataloging)

Prototype

- Las Campanas Observatory in Chile

Prototype

Installed in June 2004
new lenses from June 2006

- 2 CCD cameras 2000×2000
- Canon f=85mm, d=f /1.2 lenses
- Common FoV 20°×20°
- 10 s exposures, ~11^m range
  13^m for 20 coadded frames
- Fully autonomous running
  including diagnostics and recovery from known problems
- Human supervision via internet

Final system

- two sets of 12 CCD cameras (same optics as prototype)

  following SWIFT FoV ⇒ every SWIFT alert should be in our FoV

  extension to 16 cameras possible in the future

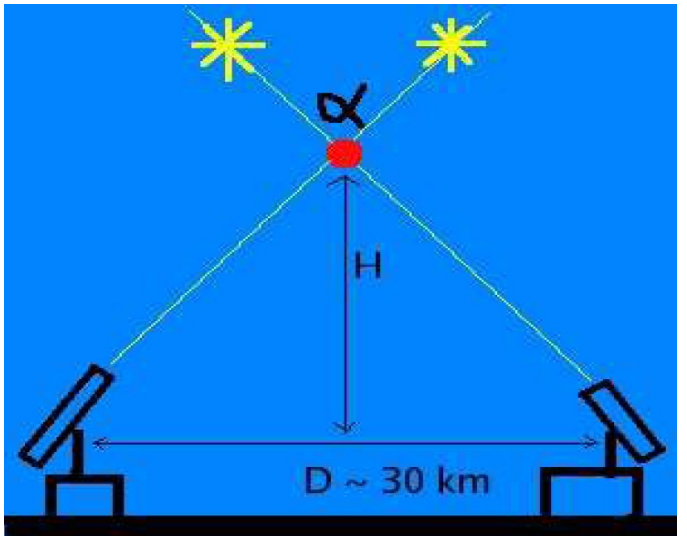
- upgraded cameras with ethernet interface

  fast data transfer, CCD binning possible

  software CCD voltage tuning for noise reduction

  shutter designed for 10^7 cycles

- satellite and other near-Earth objects rejection by paralax

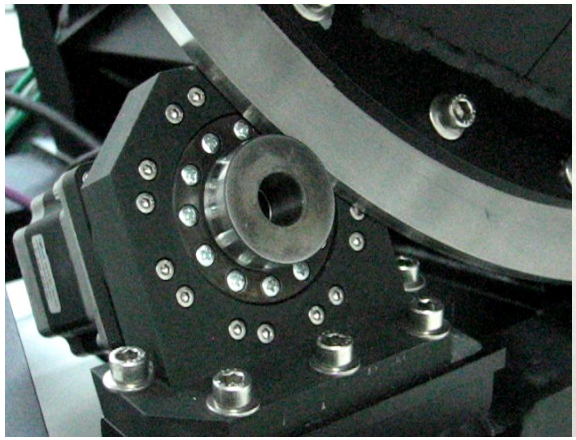


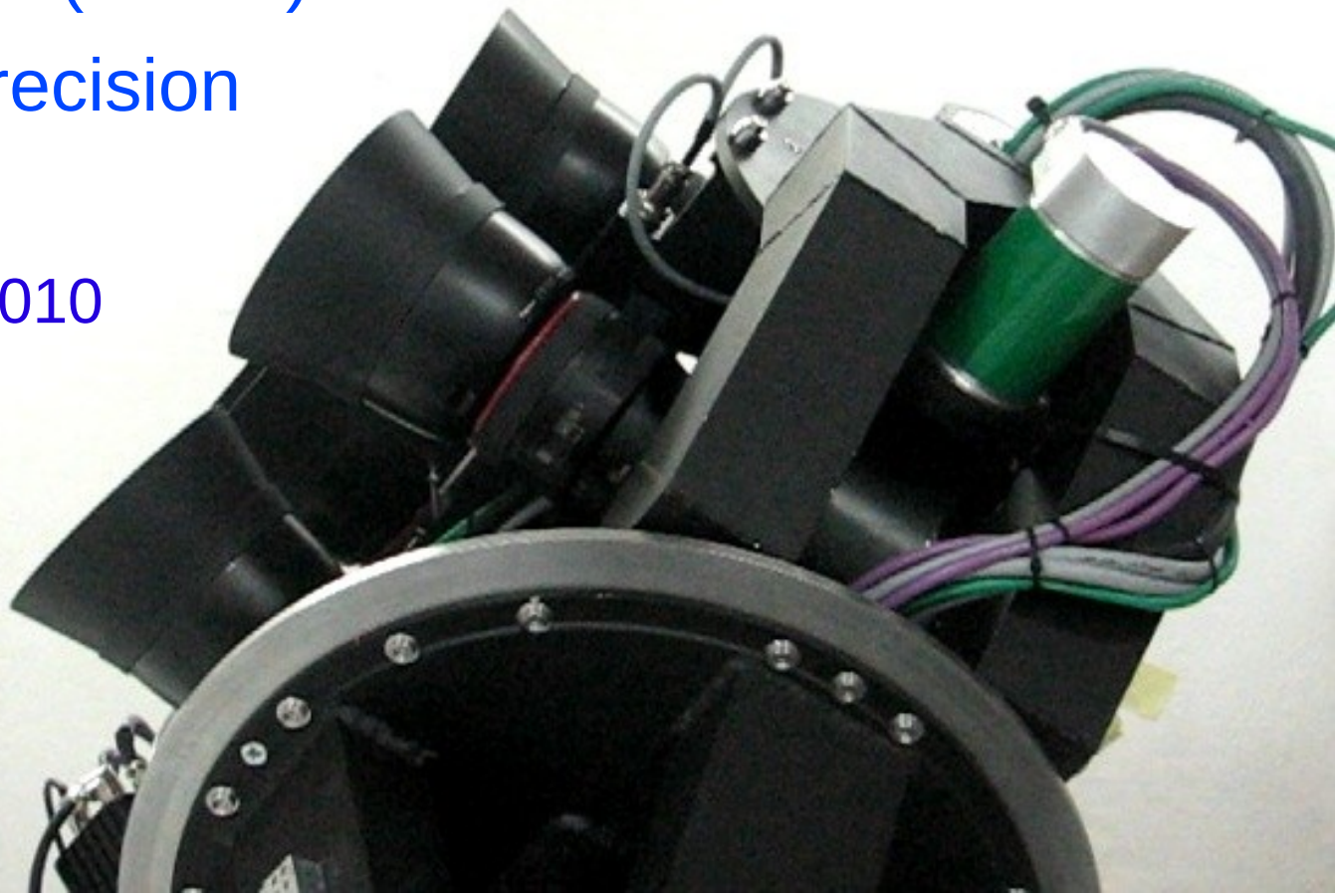
Final system

- new paralactic mount (Space Research Center PAS)
  - two observation modes: side-byside (WIDE) or common-target (DEEP)
  - high tracking precision

To be completed in 2010

Harmonic gear





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

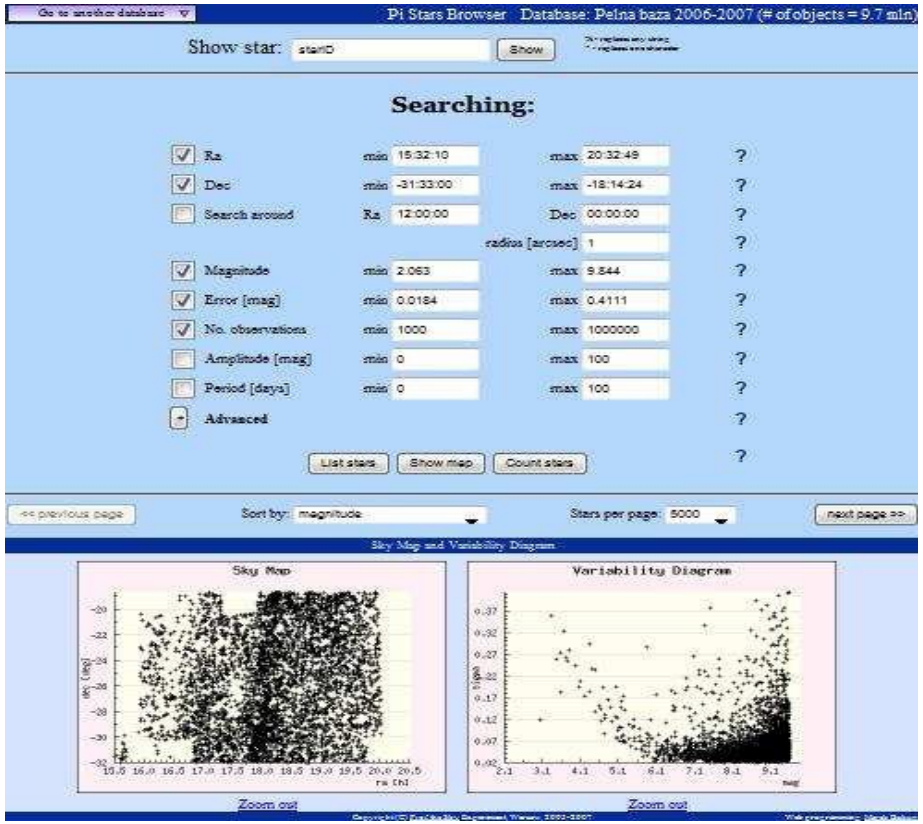
Algorithms optimised for data reduction:

- 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

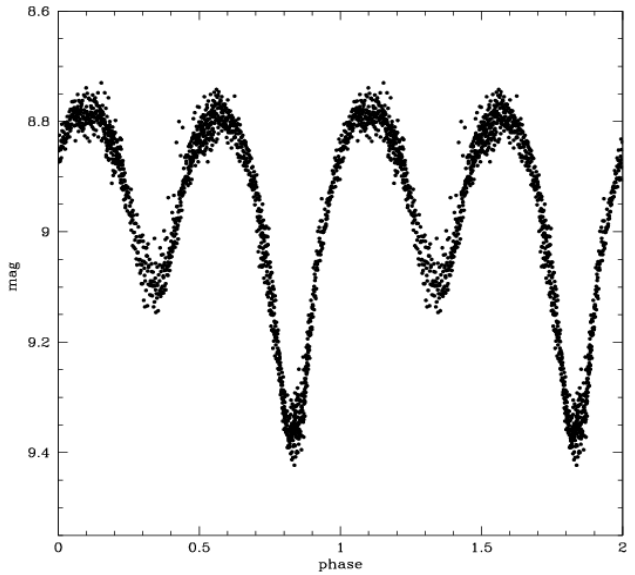
Database

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

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



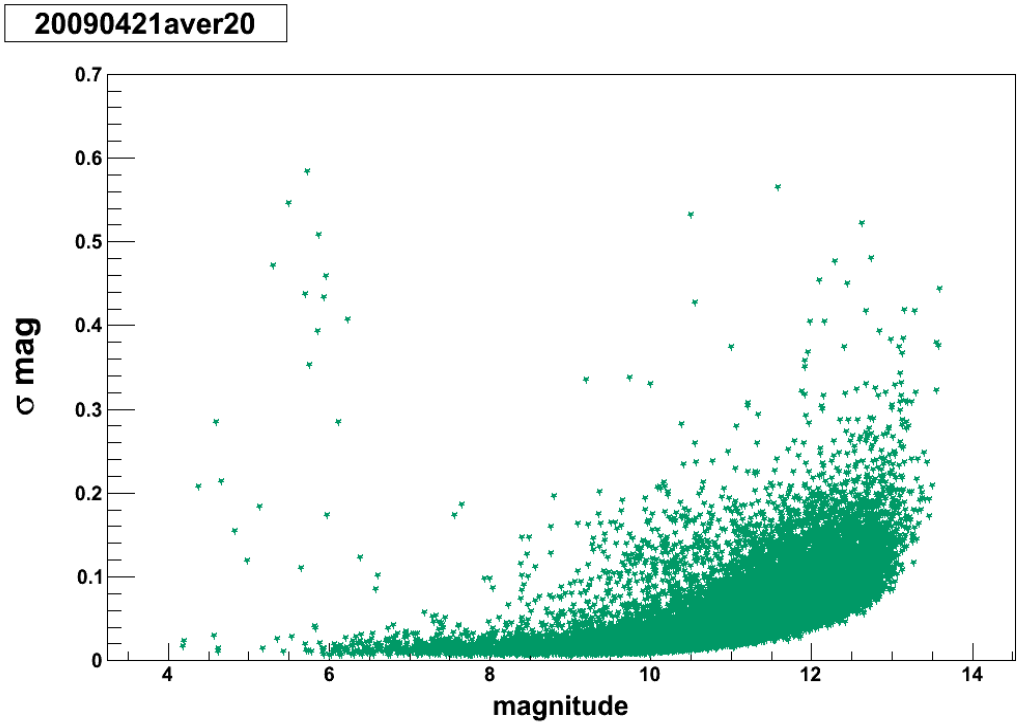
Example of phased lightcurve



Database

- Unfiltered measurements

  measured brightness dispersion vs magnitudo (example)



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

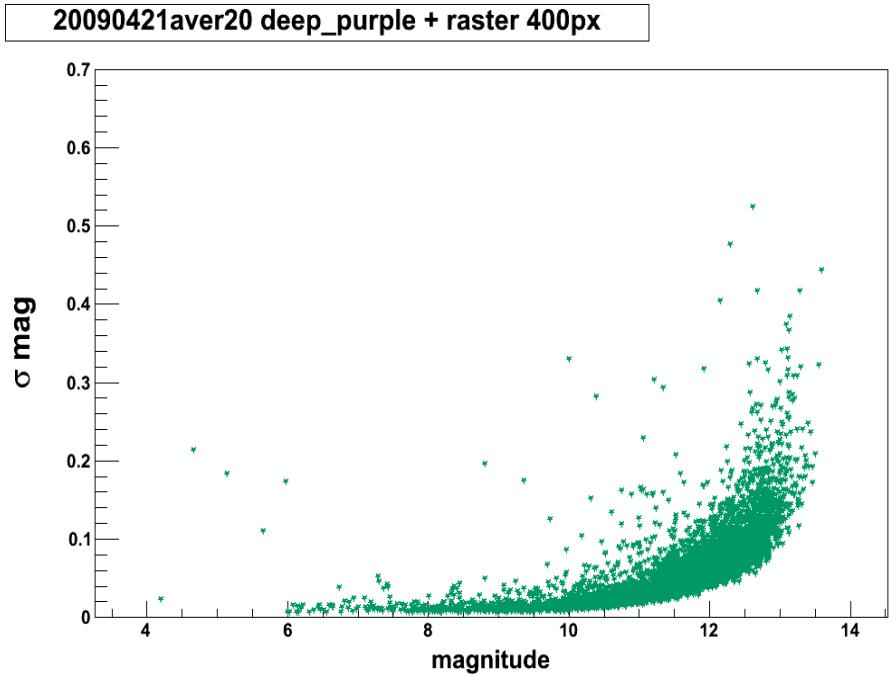
Data analysis

- Dedicated filters developed to remove bad measurements or frames
  - hot pixels
  - measurements near CCD edge
    (require at lease 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

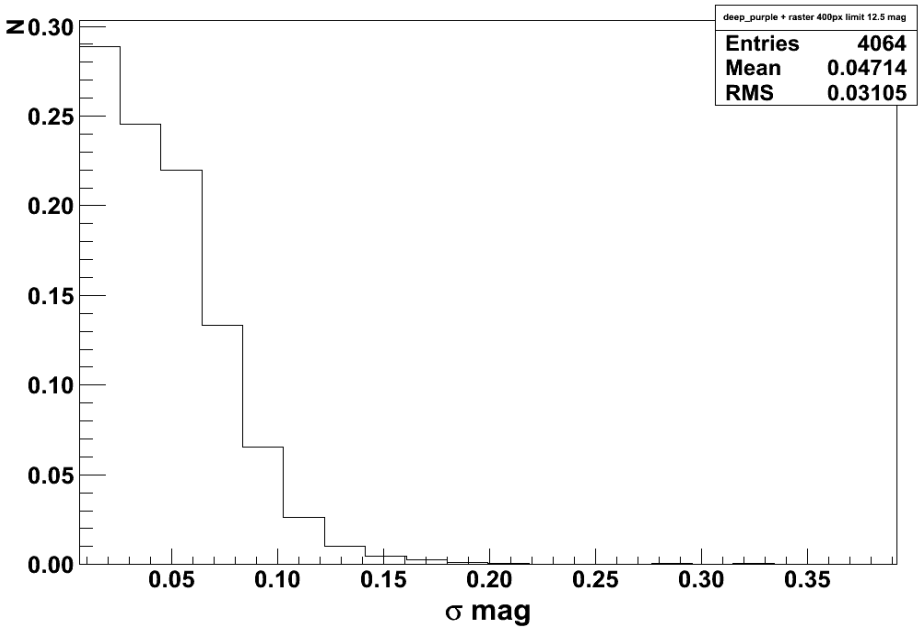
Data analysis

- Photometry accuracy significantly improves after removing bad quality data
  - For stars 7^m – 10^m $<\sigma_m> \approx 0.015$ achived

σ_m vs mag

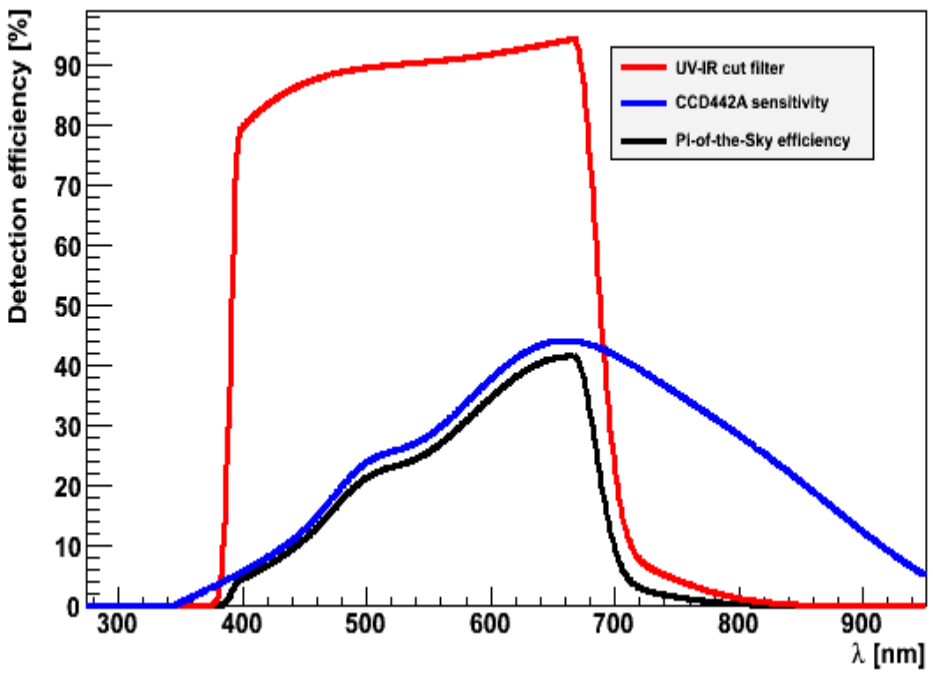


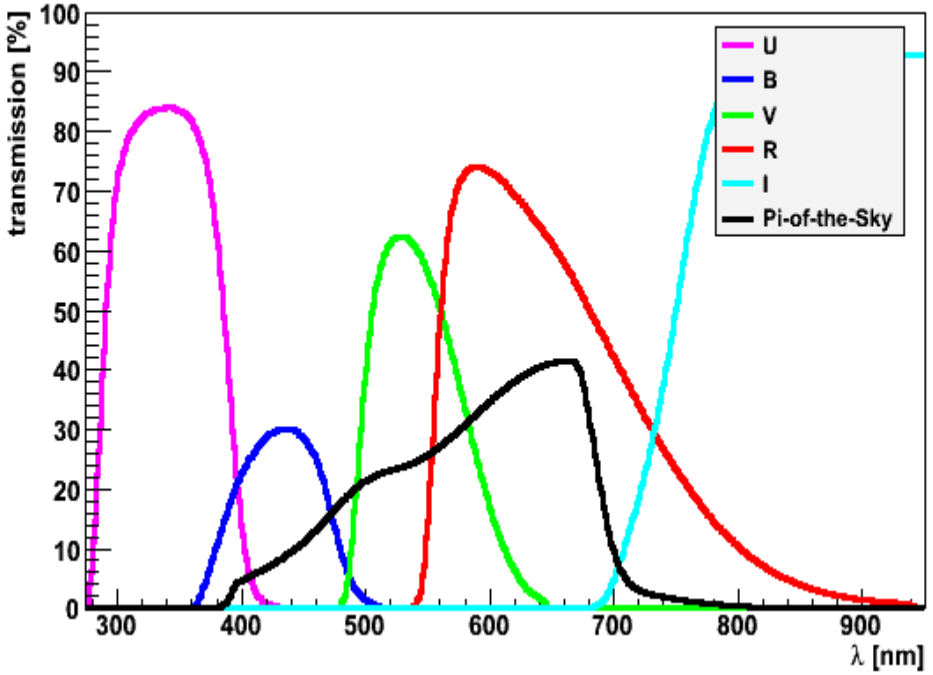
σ_m for mag < 12.5



New approach

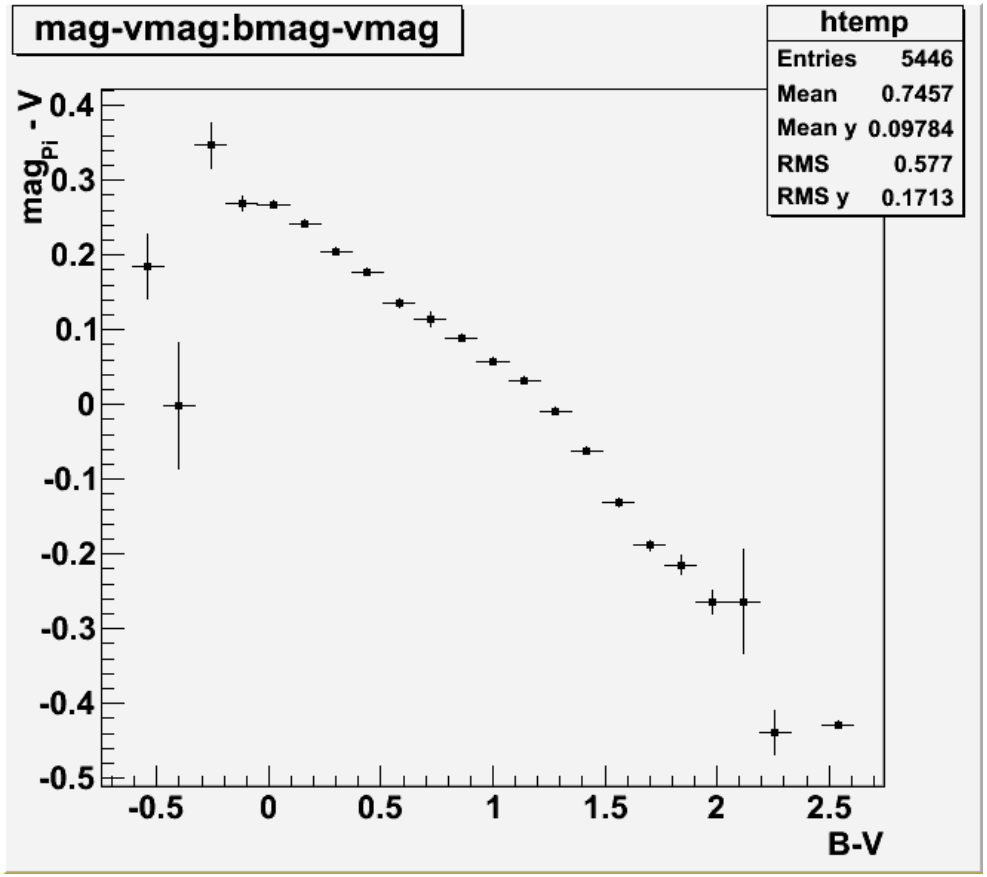
- Spectral sensitivity of Pi of the Sky
  - CCD sensitivity ⊗ UV-IR filter, relatively wide
  - average $\lambda \approx 585$ nm (closest to V filter)

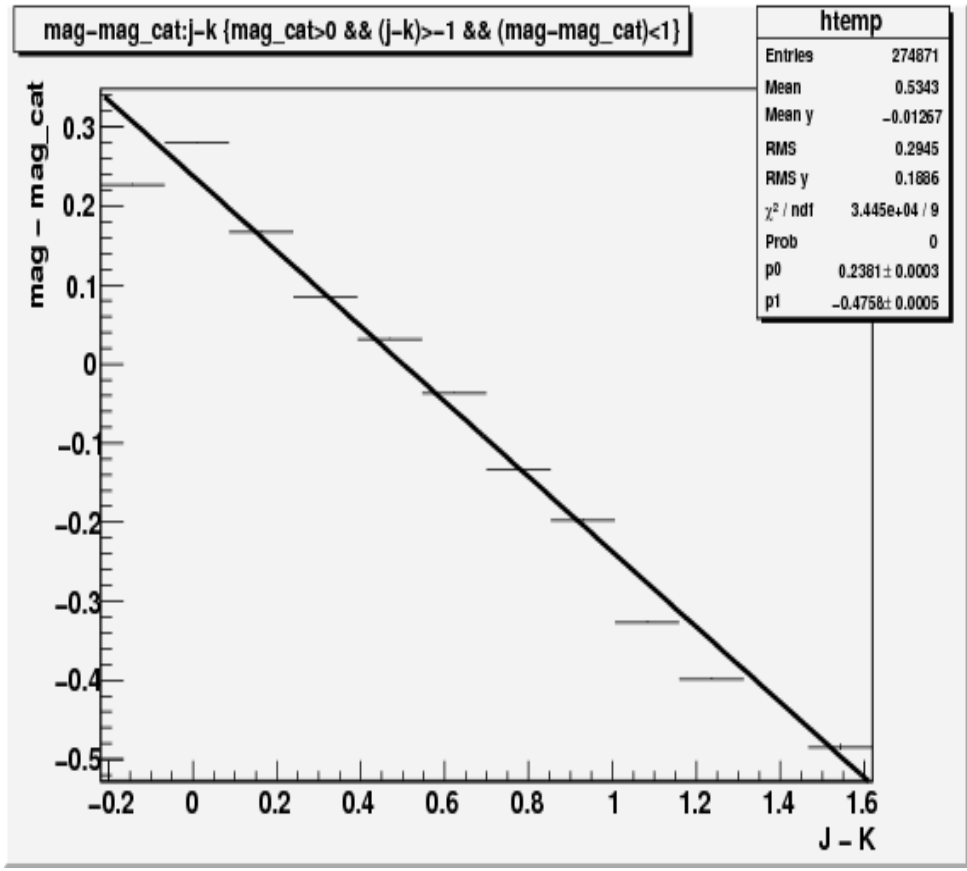




New approach

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



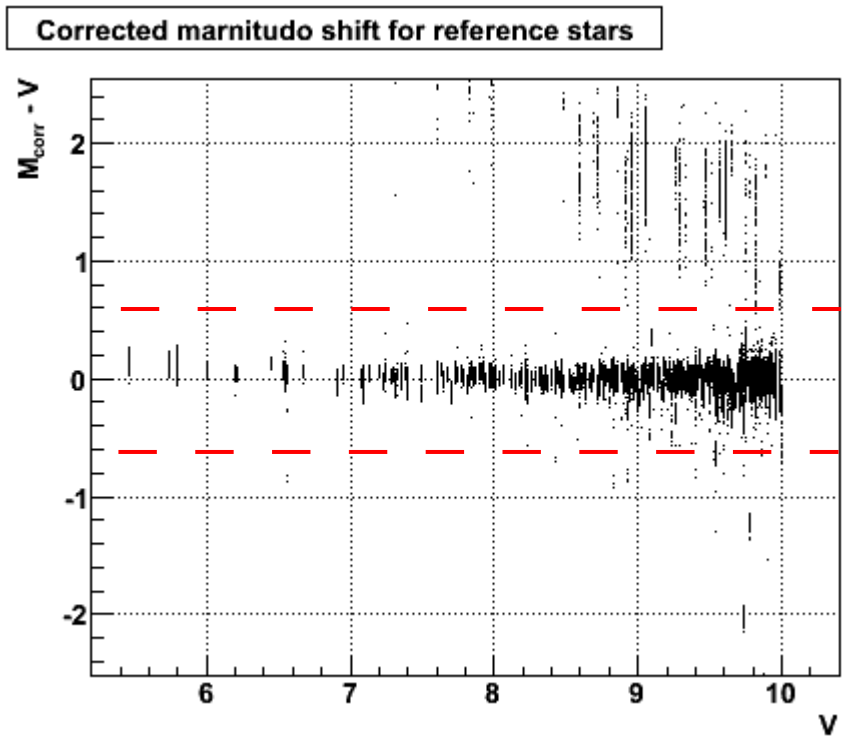


New approach

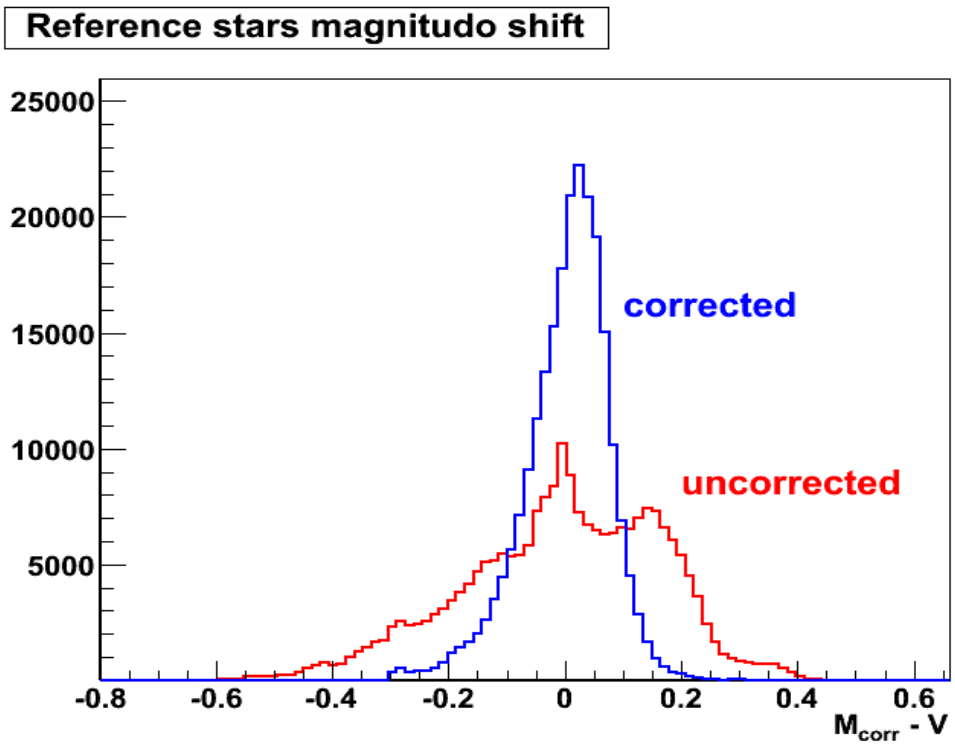
- Reference stars measurements are corrected for spectral type:

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

stars with large ΔM rejected



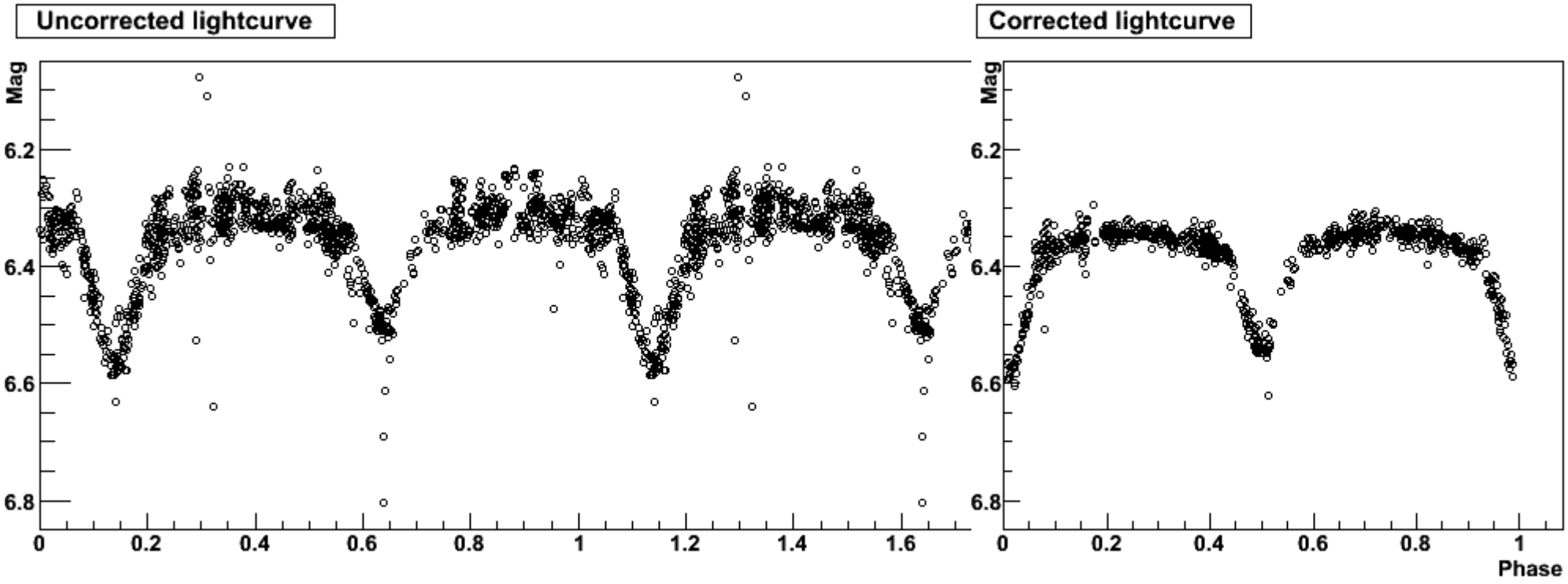
corrections more precise and stable



New approach

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

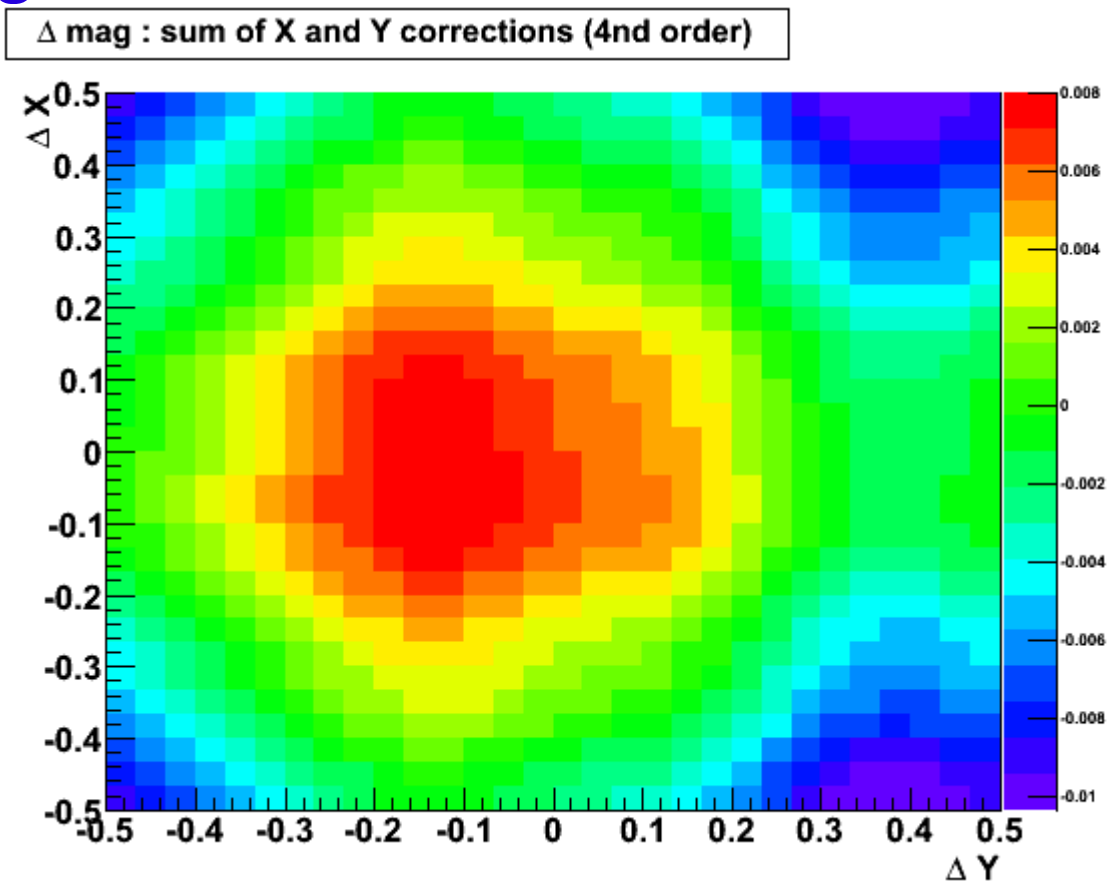
Comparison of uncorrected and corrected lightcurves for BGInd variable



Possible improvements

- Correction taking into account CCD structure

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



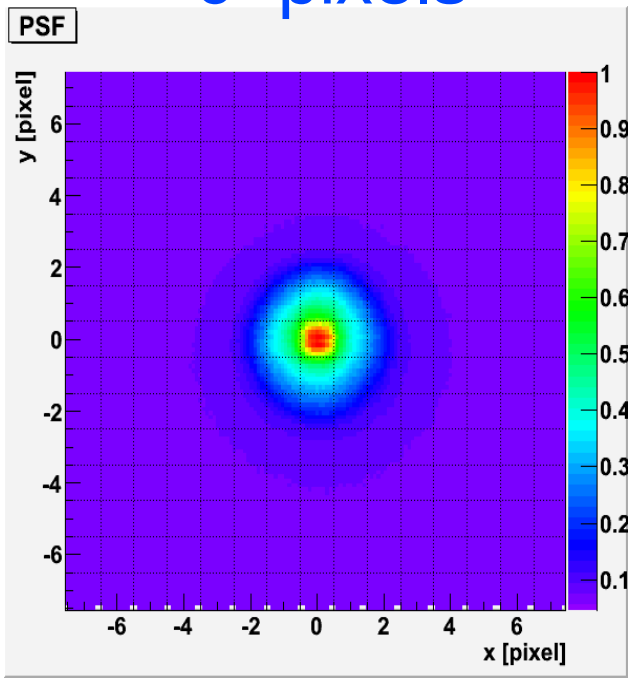
can depend on position and spectral type – more studies needed...

Possible improvements

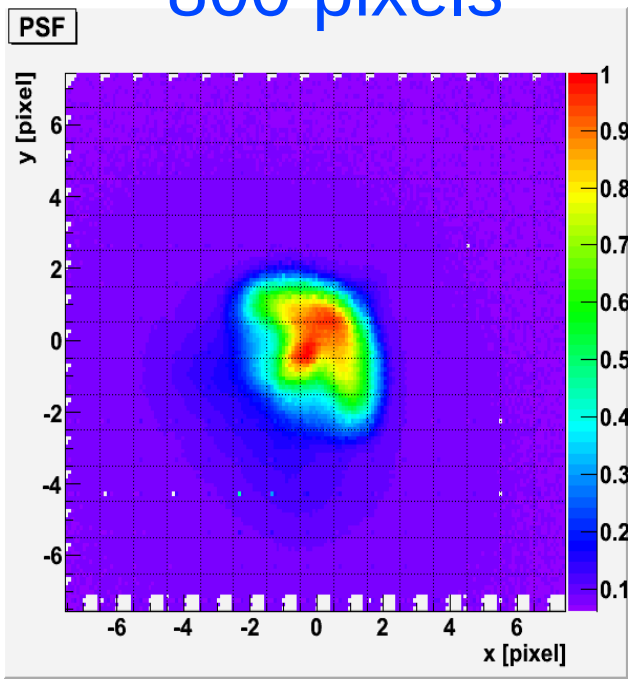
- Photometry based on detailed PSF model

Laboratory PSF measurements (distance from CCD center):

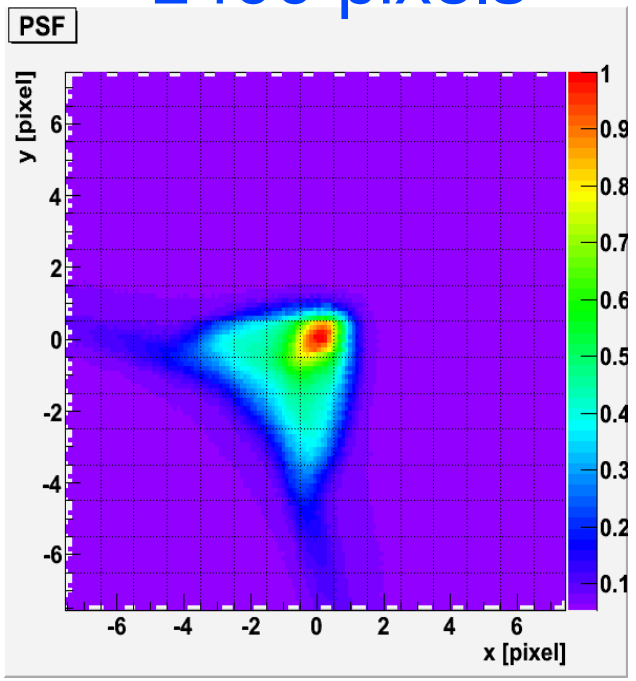
0 pixels



800 pixels



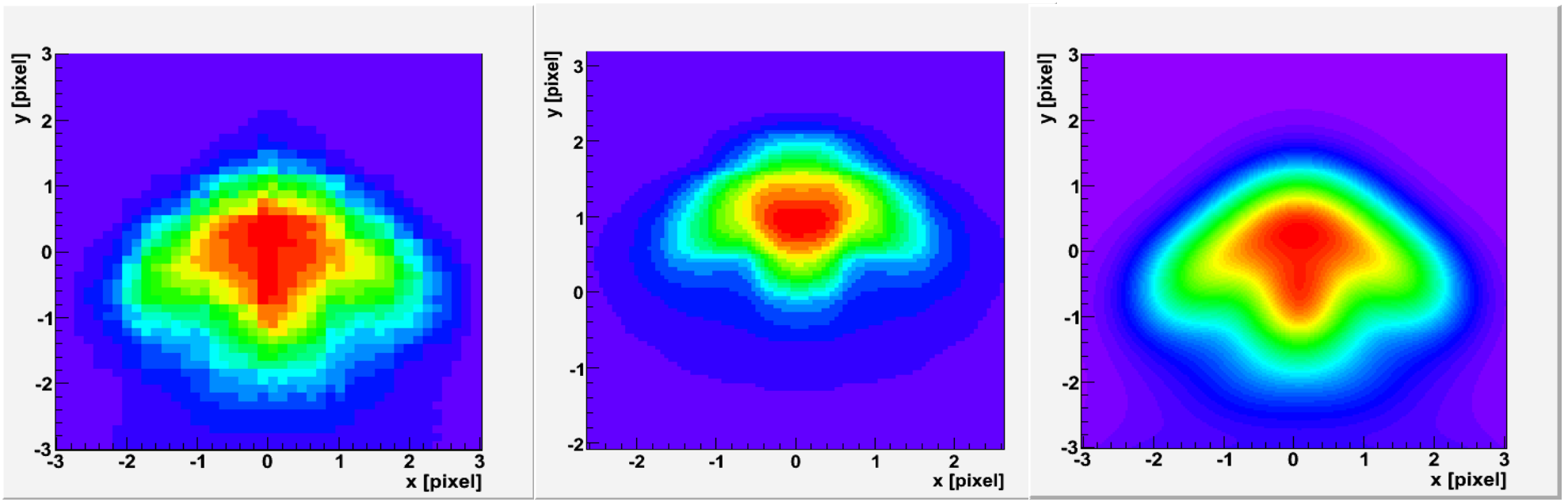
1400 pixels



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:

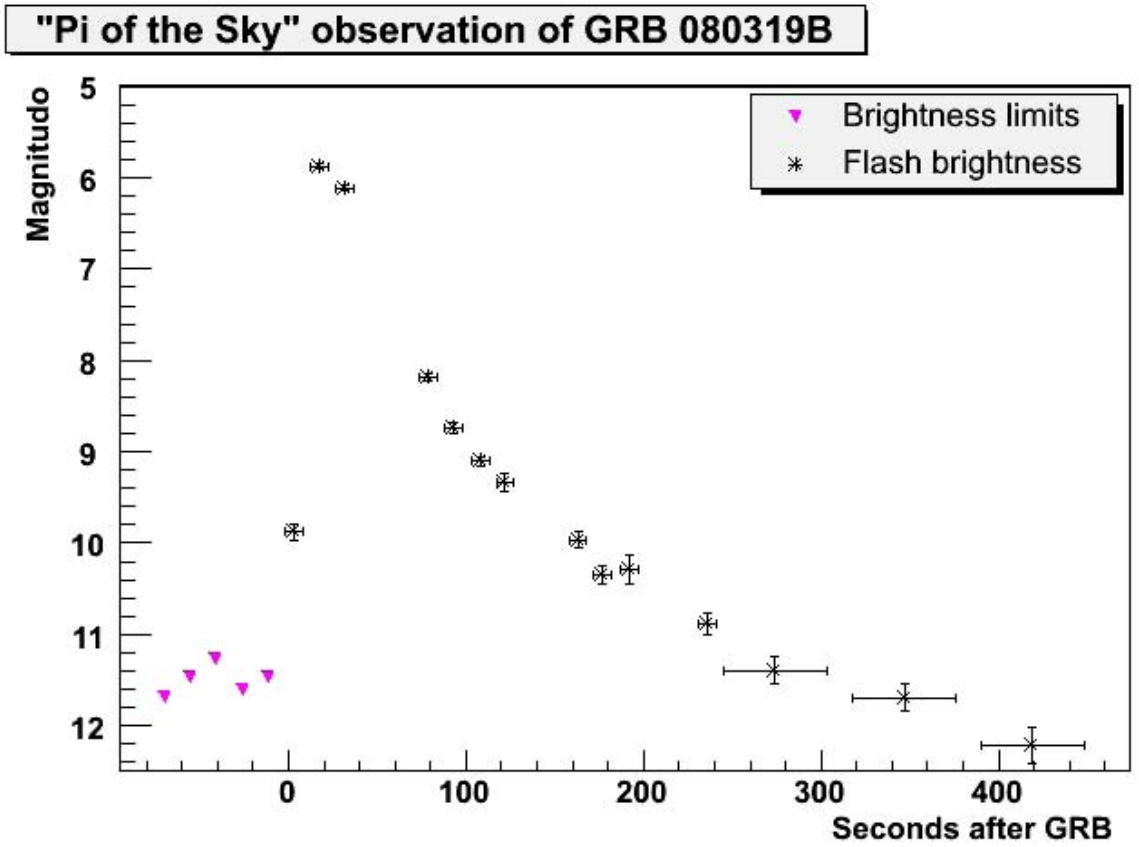
  http://grb.fuw.edu.pl/pi/databases

- 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

Backup slides

GRB080319B

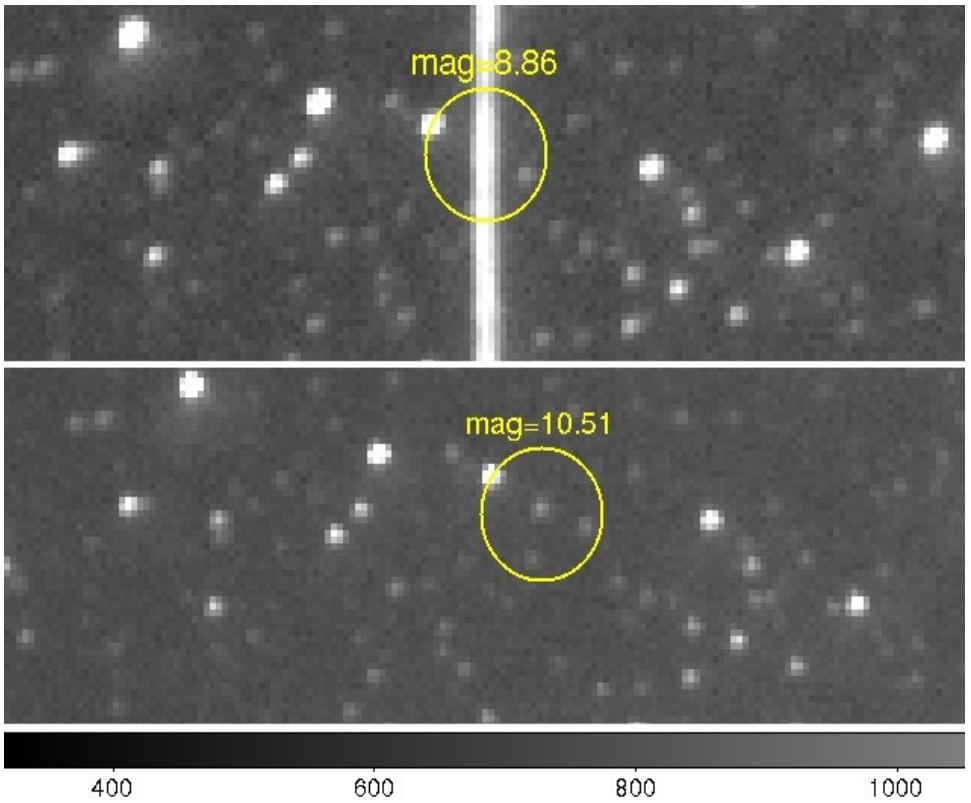
- Main success and proof of principle
  - recognized by on-line algorithm



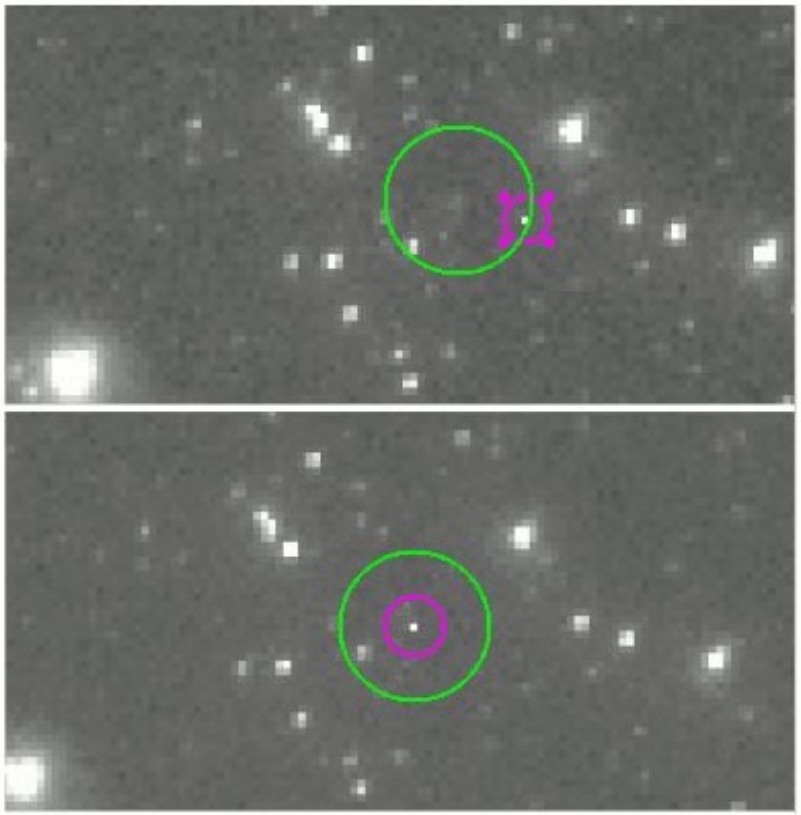
Data analysis

Examples of removed measurements

Tail of bright star (opened shutter mode)



Hotpixel



PSF measurements

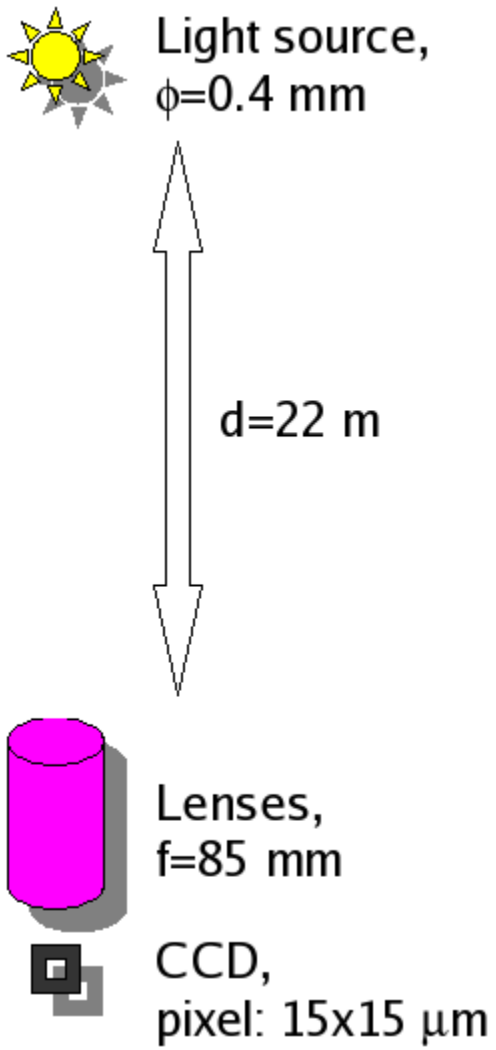
- Laboratory “beam tests” to measure PSF with sub-pixel resolution

“artificial star”

(LED diod with 0.1-0.4 mm apertur)

mounted on a movable table,

observed from 22 m



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