Photometric analysis of Pi of the Sky data

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Presentation outline

- Introduction.
- Reduction and analysis of collected data.
- Color correction.
- Statistical data quality estimate.
- Examples.
- Summary.
Detector in SPDA.

Moving prototype to San Pedro de Atacama Observatory, Chile, March, 2011

The SPdA panorama

The open dome and cameras at sunrise
Detector in INTA.

INTA El Arenosillo, Huelva, October 2010.
Observed frames.

Choose a camera: 

Submit

colors legend:  
dark or flat  scan  GRB  target of opportunity  dome closed or clouds  system error  other

previous night  10 nights earlier  last night

next night  10 nights later

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<th>Field Name</th>
<th>α [h]</th>
<th>δ [°]</th>
<th>Azimuth [°]</th>
<th>Altitude [°]</th>
<th>Date UT [y-m-d]</th>
<th>Time UT [h:m:s]</th>
<th>Distance to the Moon [']</th>
<th>Frame number frames</th>
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Frame count = 1317

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Reduction and analysis.

- on-line reduction.
  - flash recognition in real time analysis frame by frame.
  - dark frame subtraction.
  - fast photometry including numerical filter.
  - comparison with reference image (series of previous images).

- off-line reduction.
  - algorithms optimized for data reduction.
  - adding 20 subsequent frames.
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  - multiple aperture photometry (ASAS)
  - astrometry
  - normalization to V magnitudes from TYCHO catalog.
  - cataloging of raw data to the database.

- additional analysis.
  - multilevel selection system to reject strong backgrounds caused by such effects as fluctuations, hot pixels, cosmic ray hits, satellites etc.
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* additional analysis.
  - multilevel selection system to reject strong backgrounds caused by such effects as (fluctuations, hotpixels, cosmic ray hits, satellites etc.).
Photometry accuracy significantly improves after removing bad quality data.

For stars $7^m - 10^m$

$< \sigma_m > \approx 0.018 - 0.024$ achieved.
Example of HD 208338 star.
Example of HD 208338 star.
Color correction.

We also introduce additional correction taking into account facts that:

- we have not any filters.
- detector response is correlated with the star spectral type (B-V or J-K).
- catalog stars measurements are corrected for spectral type:

\[ M_{\text{corr}} - M = -0.2725 + 0.5258 \times (J - K) \] (1)
Catalog stars cuts.

- Reference stars $6^m - 10^m$ with angular distance smaller than 5 degrees
- Accepting reference stars with $M_{\text{coor}} - V < 0.2$
- Accepting reference stars with $\text{RMS}_{M_{\text{coor}}} < 0.07$
- Accepting reference stars with number of measurements $> 100$
Color calibration algorithm.

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

Correction fit quality check
Average square distance of the reference stars from the fitted correction surface:
- $\chi^2$ of about 0.05-0.06
- For about 20% of frames, calculated $\chi^2$ is greater than 0.058
- This information can be used to select measurements with most precise photometry
Results.

Uncorrected light curve for BG Ind variable

- Quality improves significantly
- Uncertainty $< \sigma_m$ of the order of $0.013^m$ can be obtained


Różyczka, M., Kalużyń, J., Pych, W., Konacki, M., Malek, K., L. Mankiewicz, M. Sokolowski, A.F. Żarnecki,
Example HD 208338 star.

**Light Curve 3389549**

- Time [HJD]
- Magnitude

**Histogram for 3389549**

- Constant: $93.73 \pm 0.00$
- Mean: $8.568 \pm 0.000$
- Sigma: $0.01113 \pm 0.00025$
In this case, in order to check if the measurement is good or not, we are taking into account statistical properties of the group of frames. Every frame which contain analysed star measurement is analysed in the same way:

- based on measurements taken from the same field we calculate median (Med) for each catalog star visible on given frame.
- later for each catalog star visible on given frame we calculate $M_{corr} - Med$ values where $M_{corr}$ is corrected catalog star magnitude given by the (1) equation.
- we calculate all analysed frames quality depending on the percentage of the catalog stars which have $M_{corr} - Med$ grather than $2\sigma$. 

![% of Bad Stars Histogram](chart.png)
Statistical methods.

After using this correction photometry accuracy significantly improves. After removing bad data $\sigma$ from 0.01 to 0.03 for stars $6^m - 10^m$ is achieved.
Statistical methods.
Example HD 208338 star.
Comparison of used methods.

We are trying to find the best combination of used methods which can give us the best quality and not remove a lot of data.
Example HD 208338 star.

At the beginning $\sigma = 0.02018$, after all cuts $\sigma = 0.009106$ is achieved.
Summary

- A lot of informations about Pi of the Sky project you can find on the project webpage http://grb.fuw.edu.pl.

- We created a system of dedicated filters to mark bad measurements or frames which is applied with cataloging procedure for new data.

- To improve the quality of the data we created approximate color calibration algorithm based on the spectral type of catalog stars.

- We also developed another statistical method, taking into account all stars on the frame, allowing to reject bad quality exposures.

- After the new frame selection is applied, photometry accuracy of 0.01-0.03 can be obtained. Further improvement is possible in dedicated analysis of selected objects.

- The quality of the data is good enough to be used by another scientists in their research.