"Pi of the Sky": modelling of the detector response for more effective search for optical GRB counterparts

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Kraków, 16.VII.2009

GRBs

Gamma Ray Bursts

One of the most powerful explosions in the Universe known to man, probably created by a Hypernovae collapse (long bursts) or two neutron stars merge (short bursts), leading to a black hole creation.

(very short) Characteristics:

- Distance: cosmological (most distant: z=6.7)
- Radiation: mainly γ-rays, additionally X-ray, optical and radio
- Estimated energy (radiation in jets): $\sim 10^{51}$ erg

Observational facts:

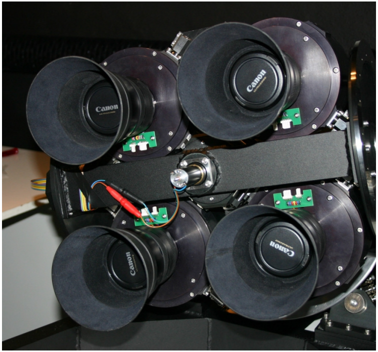
- γ-rays: constant sky monitoring by satellites
- X, optical, radio: follow-up observations (delayed)
  Challenge: observation from the very beginning.

Simltanous observations are crucial for GRBs' understanding.

Optical sky monitoring - Pi of the Sky

Full system (under construction): 2 arrays of cameras, 16 cameras each, placed far apart ($\sim$ 100 km), observing same part of the sky

- Field of view: 2 sr (comparable to main GRB satellite experiments)
- Good time resolution: $\sim$10 s
- $\sim$3000 frames/night/camera
- Large data stream: $\sim$1 TB/night
- Multilevel trigger for real-time flash recognition
- Arrays' coincidence - required for satellite flash rejection (significant background source)
- Autonomous operation
- Expected range: $12^m - 14^m$



Pi of the sky - cameras

The cameras - unique concept and design:

- CCD sensors: 2000×2000 pixels, 16-bits, low noise
- Fast programmable electronics
- Shutter sustains: 10^7 cycles
- Canon lenses: f=85mm, f/d=1.2
- $20^\circ \times 20^\circ$ field of view
- Pixel size: 36"
- Full control over ethernet

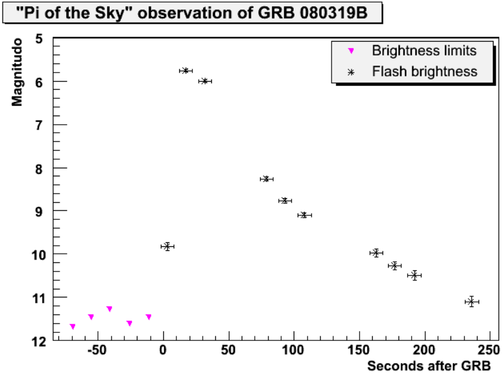
Working prototype:

- Two cameras working in coincidence
- Collecting data since June 2004 in Las Campanas Observatory, Chile.

"Pi of the Sky" prototype - two cameras on paralactic mount

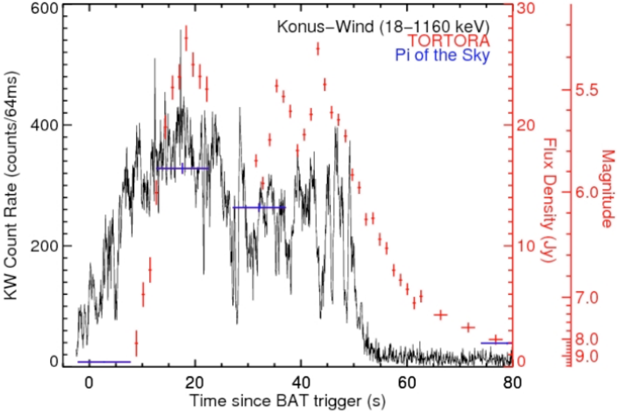
GRB080319B

- The brightest (in optical and X) GRB ever observed
- Peak brightness ~ 18 s after the trigger: 5.7^m
- Distance: $z = 0.97$
- Observed by "Pi of the Sky" from the very beginning
  First optical observations starting 2.25 s before the γ-ray trigger



The main success - GRB080319B

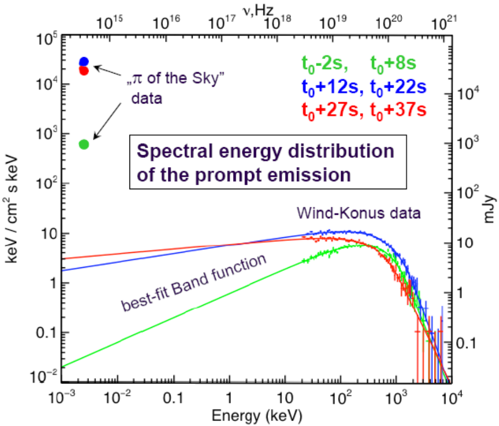
- Clear correlation of peaks in γ-ray and optical emission



J. L. Racusin et al., *Broadband observations of the naked-eye big γ-ray burst GRB 080319B*, Nature 455, 183-188 (2008)

The main success - GRB080319B

- Clear correlation of peaks in γ-ray and optical emission
- Optical flux much above expectations $\rightarrow$ different production mechanism
- Challenge for GRB models



J. L. Racusin et al., *Broadband observations of the naked-eye big γ-ray burst GRB 080319B*, Nature 455, 183-188 (2008)

Pi of the Sky PSF

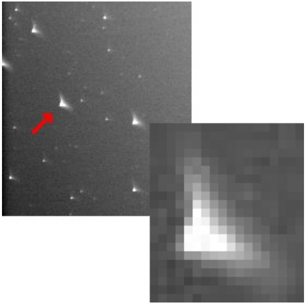
Large field of view → problems with deformed shape - Point Spread Function (PSF)

The closer the image to the centre of the frame

- the more gaussian profile
- the better standard photometry and astrometry

The closer to the edge of the frame

- the more distorted PSF
- the larger brightness and position uncertainties



GRB 080319B, 12 s after the trigger

Solutions

- reject the most distorted star images: only for analysis with large statistics (eg. variable stars)
- find parametrisation of distorted profiles

Idea of PSF measurements

Parametrization requires precise shape measurements - very hard to obtain from real star images → laboratory measurements required.

Star

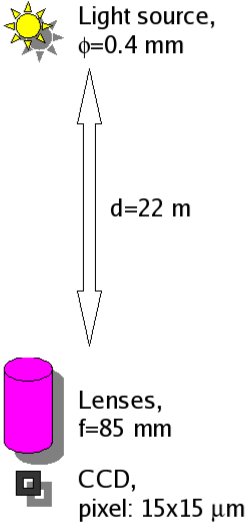
a point-like source

Point-like source

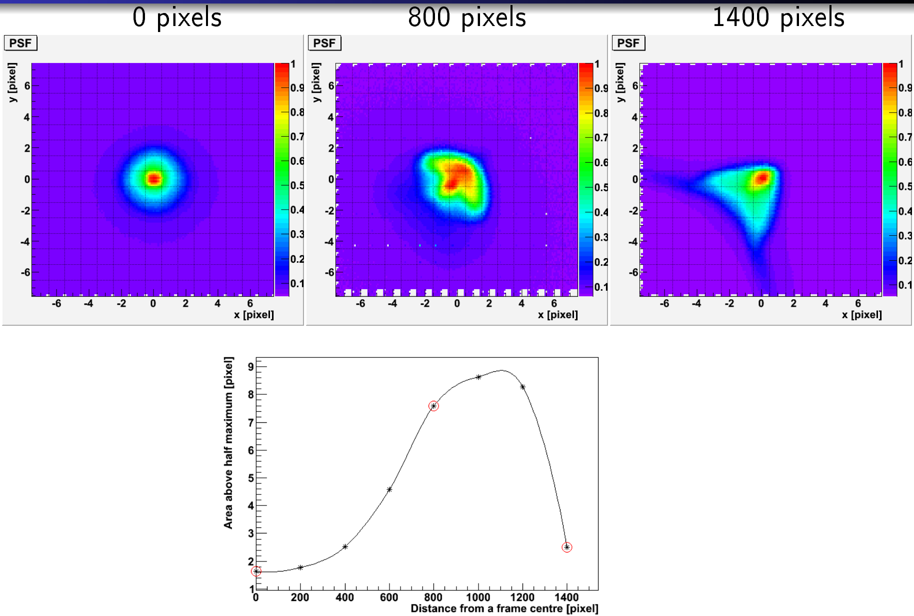
source image size much smaller than angular resolution corresponding to a pixel size

- light source: LED diode (colour or white)
  - covered by 0.1-0.4 mm aperture
  - powered from a pulse generator
  - mounted on a movable stand
- placed 22 m from the camera

→ geometrical spot size $<$ 0.1 pixel size



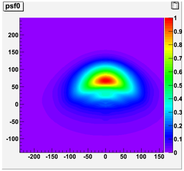
PSF of Pi of the Sky cameras

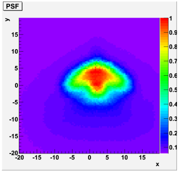


PSF parametrisation

PSF deformation

due to optics errors - superposition of optical aberrations like coma, astigmatism, spherical aberration, defocus, etc.





In general:

$$PSF(x_i, y_i) \sim \left| \iint_{aperture} \frac{\cos\theta}{r} T(x,y)\; e^{-ik(W(x,y,\theta)+L(x,y))} \right|^2$$

where x, y - aperture (lens) coordinates, x_i, y_i - image coordinates, $T(x, y)$ - lens transmission, k - wavevector, $W(x, y, \theta)$ - wavefront.
$L(x, y)$ - lenses focusing function, can be approximated by a sum of Zernike polynomials (in thin lenses approximation).

Problems:

- paraxial approximation not possible
- significant transmission changes with observation angle

Parametrisation challenges:

- Non-paraxial approach
- Measured PSF is an integral of real PSF over CCD pixels - deconvolution may be needed
- Parametrisation implementation into a photometric algorithm

However, if those challenges are overcame, we gain:

- more precise photometry and astrometry
  - better measurement of objects variability
  - higher sensitivity to optical flashes
- new possibilities:
  - simulation of Pi of the Sky star images and frames
  - transformation of a real frame to a frame without deformations

Other results from "Pi of the Sky":
A. Majczyna, "Search for optical flashes of astronomical origin with "Pi of the Sky" prototype" at the poster session

More information:
http://grb.fuw.edu.pl

The "Pi of the Sky" is a collaboration of:

- Soltan's Insitute for Nuclear Studies
- Center for Theoretical Physics of the Polish Academy of Science
- Faculty of Physics, University of Warsaw
- Institute of Electronic Systems, Warsaw Univ. of Technology
- Space Research Centre of the Polish Academy of Science
- Faculty of Physics, Warsaw Univ. of Technology