The Source is Swift

- BAT sees 1.4 ster
- Automated slew to GRB position
- X-ray telescope and UV/Optical telescope pinpoint the afterglow
- Positions available to ground observers within minutes
GRB 050509B: Swift Detection

- BAT: very faint GRB
- XRT: T+62 s detects 11 photons(!)
- No optical, no radio. very faint limits
  - Low energy event and/or low density medium?
- Giant elliptical galaxy in cluster @ z=0.22 Host?

\[ T_{90}=40 \text{ ms} \]

\[ \text{Rate (c/s/cm}^2\text{)} \]

\[ 15-25 \text{ keV} \]
\[ 25-50 \text{ keV} \]
\[ 50-100 \text{ keV} \]
\[ 100-350 \text{ keV} \]
GRB 050509B
GRB 050709
GRB 050709

We have performed PSF-matched image subtraction on the images acquired by Jensen et al. (GCN #3589). The images were obtained from the Danish 1.54m DROSC at La Silla on 2005 July 11.9 and 12.3 UT.

PSF-matched image subtraction using the Pan-STARRS Optimal Image Subtraction (POI Sub) code reveals a residual, in the sense that the source fades between the first and the second epochs. The position of the variable source corresponds to the source identified by Jensen et al. (GCN #3589) on the edge of a nearby galaxy (z=0.16; Price, Roth & Fox, GCN #3605) as consistent with the Chandra source (Fox et al., GCN #3585). This detection of optical variability increases the likelihood that this source is the afterglow of the short/hard GRB 050709.

A figure showing the subtraction is available at http://www.ifa.hawaii.edu/~price/grb050709candidate.jpg

This message may be cited.
GRB 050709

$z = 0.16$

$E_{\text{iso}} = 6 \times 10^{49} \text{ erg}$

Gemini North + GMOS
GRB 050724 Host Galaxy
Keck/LGSAO/Narrow Camera
K'-Band

Kulkarni & Cameron, 2005
GRB 050724

$E_{\text{iso}} = 10^{50} \text{ erg}$

$z = 0.257$

GN + GMOS

Keck + LRIS
Some short conclusions

- Short/hard GRBs are of cosmological origin
  - Relatively low redshift compared to long/soft GRBs
- Typical energy release of several $10^{49}$ erg
  - Jets?
- Afterglows typically fainter than for long/soft
  - Brightness correlated with position on host galaxy?
- Observed in both star forming galaxies and ellipticals
  - Points to compact merger
Long/soft GRBs at $t_{GRB} + \frac{1}{2}$ hour

- $0.5 < z < 1.5$
- $2.5 < z < 3.5$
- $4.5 < z < 5.5$
- $7 < z < 8$
- $9 < z < 11$
- $14 < z < 16$
To the Edge of the Universe...

Swift: x-ray position to a few arcsec

MAGNUM: Precise position, colour

Gemini North: Spectroscopy
Gemini ToOs

- Gemini observes (mostly) in queue mode, so minimal interruption to observers
- Telescope and instrument status available on www
- Pre-defined observation templates: easy
- Jukebox instruments: can observe in both optical and NIR
- Trigger via Observing Tool or www: no phone calls!

- 4' position from Swift
- Optical observations at 3h didn't see anything
- Bright NIR afterglow

\[ z > 6.08 \]

\[ z = 6.29 \text{ (Subaru)} \]
GRB 050904 for Cosmology
Processing Petabytes for Pan-STARRS

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Pan-STARRS

- Panoramic Survey Telescope And Rapid Response System
- A fore-runner to the LSST, funded by AFRL
- A dedicated optical survey instrument, $54 \text{ m}^2\text{deg}^2$
  - 4 individual 1.8m telescopes, each with a gigapixel camera
  - Orthogonal transfer CCDs
- Mission:
  - Secure future employment for Bruce Willis
  - To boldly see what no-one has seen before
  - Things that go bump in the night
The Data Reduction Challenge

- PS1: 1.4 Gpix / 35 sec --> 2.8 TB raw data per night
- PS4: 5.6 Gpix / 35 sec --> 11.5 TB raw data per night
- Must process data in near-real time to avoid drowning in data, and in order to identify TGBN
- Finite $$$, personnel, time
- Can't afford ($ or time) to reprocess the data many times
- Identification of TGBN must be of high quality: can't afford an army of grad students
- For testing purposes, want a flexible system that can be used to reduce other mosaic data (e.g., MegaCam, SuprimeCam, YourCameraHere)
- Keep all the collaborators happy (all things to all researchers?)
Required Operations

- Detrend: Bias, dark, flat-field, fringe
- Photometry and astrometry of objects
- Warp images to sky
- Subtract template sky; identify and characterise transients
- Combine multiple exposures; more photometry
- Generate master detrend images / validate new detrend images
Hardware

~ 80 nodes
~ 2.4 PB
~ ¼ Google

Acquiring: 16 nodes, 160 TB
Software Hierarchy

PanTasks

ippdb, ippTools, ippScripts

ppMerge

ppStats

ppImage, pswarp, poiSub, stac

psModules

psLib

cfitsio, gsl, fftw

psphot, psastro

psStatLib

Ohana

glibc
psLib

- System utilities: Memory allocation, tracing, logging, errors
- Data collections: linked lists, hashes, arrays, metadata
- Arithmetic: Vectors/matrix operations, statistics, polynomial fitting, spherical geometry
- Simple image handling: rotations, extractions, FITS
- Time handling: UTC, LST, JD, leap seconds...
- Database interaction: mysql
Pipeline
Pipeline Phases

- Register – Ingest images + metadata into database
- Guide – Determine rough astrometry and QA from guide stars
- Chip – Apply detrend images, performs basic object detection, determines improved astrometry and photometry
- Camera – Tweak astrometry, photometry
- Warp – Warp images to the sky
- Diff – Difference sky image against a template, photometry and astrometry of variable objects
- Stack – Combine multiple sky images, photometry and astrometry on combined image
- Detrend – Process, combine, normalise, and reject detrend images
Final Data Products

- Subtracted images
- List of variables identified in subtracted images
- Static sky images
- Source catalogues from calibrated and sky images
- Client Science Programs will plug in to have access to the streams (e.g. planet transits)
- Other access via Pan-STARRS Published Science database
IPP passed CDR January 2006
psLib mostly complete
psModules quite mature
psphot being validated against SDSS
Pipeline running register, chip, camera, detrend phases on prototype cluster
Demonstrated image subtraction and stacking using pipeline
MegaCam, ISP, CTIO-MOSAIC2