CMOS for GRB prompt optical observations

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• Science Aims : (1) GRB
  (2) Short transient
• WIDGET (Current Robotic Instruments)
• Planned upgrade of WIDGET & Testing CMOS
• Summary
(2) Science 1: Gamma Ray Burst (GRB)

- Most energetic explosion in the Universe (after Big Bang)
- Most luminous event → Optical flash ~5.5 mag@GRB080319B
- Progenitor is massive star → The First star?
- No a-priori information on WHEN and WHERE (wide field sky monitoring essential) → Observational difficulties (1~2 GRBs/day)
- Multi-wavelength approach essential (γ-ray, X-ray, Opt, IR, …)

![Image of GRB distribution and afterglow phases]

- **Uniform GRBs Distribution on sky**
- **Energy or Wavelength**
  - γ-ray 0.1~100s
  - X-ray
  - Optical
  - IR

**Time since GRB explosion**
- t=0~100s Prompt
- t<Shours Afterglow
- t>Shours~10days
- t~1 month

**Host Galaxy**
- 99.9% of GRB
- 99.9% of GRB
- ~40% of GRB
- 30-40% of GRB
- 90% of GRB with OIR afterglow
- 90% of GRB with OIR afterglow

**Fade out quickly**

Huang, Urata et al. 2007

Optical

X-ray
Science (1) GRB Optical flash

Puzzle of emissions
- optical brightness is 4 order brighter than expected from gamma-ray and X-ray emission.
- Cannot explain standard model

What is emission mechanism?
- Synchrotron & Compton ??
- Optical spectrum (or color) is essential

GRB080319B V=5.7
GRB990123 V=8.9
Difficulties of optical prompt observations

(1) Transient phenomena
Don’t repeat & short duration (several ten second)

(2) Uniform distribution

(3) High time variability

Monitor large part of sky

High time resolution with multi-color

Wide Field Monitoring with high time resolution
Science 2 : Unexpected Transient

Search for **totally new transient**

- High variation in brightness (e.g. ≥1 mag)
- Short time interval (e.g. 10s)
- Now, we know various transients..
- Some of them cannot be expected........
Unexpected Important Discoveries

• Radio Pulsar (unexpected; during QSO obs.)
• Starting of X-ray Astronomy (unexpected)
• Discovery of GRB (unexpected....)
  US’s Defense Support Program Satellite
  Watching Nuclear bomb testing by the Soviet Union
• Neutrino Astronomy (SN1987A)
  Kamiokande : Proton decay experiment

Unexpected events are important...
Transient in Phase Space

Current surveys (e.g. PanSTARRS, PTF, LSST, SUBARU/HSC)

Short (min~hr scale) Bright

GRB Optical flash

Transient in Phase Space

M_R (mag.)

sec~hrs

Rau et al. 2009

Decay Time (days)

Classical Novae

Luminous Red Novae

Luminous Supernovae

CCSNe

SNe Ia

Tidal Disruption Flares

LBVs

Macro Novae

Long GRB Orphan Afterglows

Short GRB Orphan Afterglows

Fallback Supernovae
2 High Variation of Unexpected Transient

MONS OT J004240.69+405142.0

\[ \Delta t = 6 \text{ min} \]

\[ m = 9.69 \]

Marcos et al., 2009

Actually, we have something interesting objects??!

Should not be cosmic rays...

Star-like
How to make realize?

(1) Wide Field
   All sky is best....
(2) Higher Sensitivities
   Deep as much as possible
(3) Higher time resolution (sec order)
(4) Smaller & lighter instruments
(5) Lower cost (as much as possible..)

Balance of these five issues....
Wide Field → lower sensitivities,
High time resolution→ Lower sensitivities
etc ....
WIDGET (as the 1\textsuperscript{st} step)

- Wide Field \(62^\circ \times 62^\circ\) (with 4 CCD)
- Higher Sensitivities \(r' = 11\sim 12\) mag
- Higher time resolution \(5s + 5s = 10s\)
- Smaller & lighter instruments: 1camera = 3 kg
  Enclosure 2m x 2m x 3m
- Lower cost \$120k (70\% for CCD)

\textbf{Comparison with other similar instruments}

<table>
<thead>
<tr>
<th>Name</th>
<th>Site</th>
<th>FOV</th>
<th>Limit</th>
<th>System</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIDGET</td>
<td>Kiso, Japan</td>
<td>((32^\circ \times 32^\circ) \times 4)</td>
<td>12</td>
<td>CCD</td>
<td>This work</td>
</tr>
<tr>
<td>Pi of the sky</td>
<td>Las Capanas</td>
<td>((20^\circ \times 20^\circ) \times 2)</td>
<td>~ 12.5</td>
<td>CCD</td>
<td>Sokolowski et al. (2009)</td>
</tr>
<tr>
<td>TORTORA</td>
<td>La Silla</td>
<td>30$^\circ \times 24^\circ$</td>
<td>10\sim 11</td>
<td>TV-CCD</td>
<td>Greco et al. (2009)</td>
</tr>
<tr>
<td>RAPTOR-Q</td>
<td>Fenton Hill, USA</td>
<td>All sky</td>
<td>9.5</td>
<td>CCD</td>
<td>Wozniak et al. (2009)</td>
</tr>
<tr>
<td>RAPTOR-P</td>
<td>Fenton Hill, USA</td>
<td>((8^\circ \times 8^\circ) \times 4)</td>
<td>15</td>
<td>CCD</td>
<td>Wozniak et al. (2009)</td>
</tr>
</tbody>
</table>
WIDGET (WIDe-field telescope for GRB Early Timing)

- Fully Robotic Telescope at Kiso Observatory, Japan
- 4 CCD + camera lens (2kx2k 28.7x28.7mm, pixel size 14μm)
- Total field of view: 62° x 62°, pixel scale 55"
- Takahashi’s polar mount (optics up to 40kg)
- Unfiltered observations
Handmade.... (cheaper...)

Relay board for remote controls
roof
power (CCD, mount, PC etc)
rain sensor, etc...
Site: Kiso, Japan
4 CCD cameras and 1 mount
32 x 32 degree
Fully automatic operation
Provide several GB/night

Normal CCD
Apgee U10
2kx2k pixel
(1 pixel = 14um)
Readout time 5s

Canon
EF50mm F1.2L USM
(Normal lens)
Consept of WIDGET Observation

Continuously monitors the field of view of GRB observatories

Stored the images every 10 seconds (5s exposure+5s readout)

We can retrieve the data of whenever we want, at the moment of burst or even before the burst
Actual observations

- 11 GRB observations
- All are upper limit

Some of upper limits constrain the radiation mechanism of GRB prompt emission

Need detections!
Demands

- Improve sensitivities

(1) Sky background  -> narrower FOV or Smaller Pixel size

(2) Read out

(3) Dark current (short exposure 5s)

Wide field imager case, the system tend to be under sampling system. Smaller pixel size is essential to reduce sky background for each pixel.

- Time line (before 2014)

New GRB satellite (SVOM) will be ready in 2014 or late

SVOM will observe anti-Sun direction
WIDGET upgrades

- **Sensitivities**: replace optical lenses currently commercial CANON’s camera lens → custom designed lens
  - distortion less
  - larger aperture

- **Multi-color**: replace detectors currently conventional CCDs (single color)
  → Three layer CMOS sensors
  - Multi color observation
  - faster readout (for dense monitor)
  - Reduce sky background (14um → 5~8um)
Multi-color obs.

The 2 most used technologies
(1) Filter wheel + single CCD/CMOS
   No simultaneous observations....
(2) DICROIC focal plane splitter + several CCD
   Instrument become large & heavy
   Need several CCD, cost will be huge....

→ Three layer CMOS?
Testing 3layer CMOS

• Foveon Chip on SD14/15
  pixel 2652 x 1768 x 3 layer 1pixel = 7.8um
  size 20.7 x 13.8 mm
  f=50mm (lens) → FOV 23.4° x 15.7° (1pixel = 32”)
  2010/11/30@Mt. Maunakea, Hawaii (USA)
  by Peikang Tsai (IANCU)

• Planned testing 2011/01/07-09 @BOAO, Korea
  same sensor with f=85mm (lens)
  FOV 13.9° x 9.3° (1 pixel = 19”)

• Panned testing of new sensor
  Sigma’s new 3layer CMOS
  pixel 4800 x 3200 x 3 layer 1pixel=5um
  size 24.0 x 16.0 mm
Preliminary result 1: Image
Preliminary result 1: Image

Part of Big Dipper  FOV 23°x16° (1pixel = 7.8um ~ 23")
Preliminary result 2: Photometry

FOVEON bands...
Different with the photometric Standard systems (e.g. SDSS filters..)

Comparison with SDSS stars
CMOS/Blue vs SDSS-g’
CMOS/Green vs SDSS-r’
CMOS/red vs SDSS-i’

Acceptable Acceptable
~0.2 mag ~0.2 mag
Summary

• For short-duration transients, wide field imaging monitoring are needed.

• CMOS has higher potential to be used these instrument

• Testing 3 layer CMOS (multi-color obs)