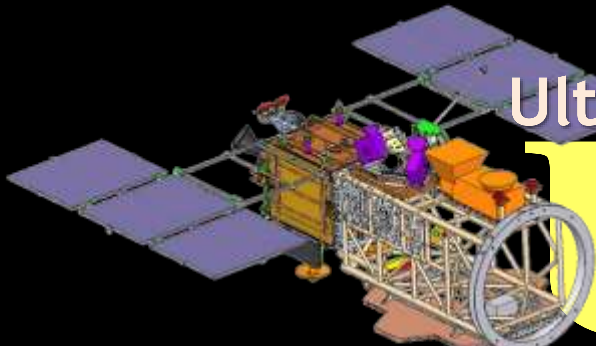
Ultra Fast Flash Observatory



UFFO

For observation of early photons from Gamma Ray Bursts

Gamma Ray Bursts with UFFO/*Lomonosov*

Il H. Park (SKKU: Sungkyunkwan U., Korea)
on behalf of the UFFO collaboration

Gamma-Ray Bursts: New Missions to New Science, the ExUL GRB Workshop,
Moscow State University, Russia, Oct. 7-11, 2013

Outline

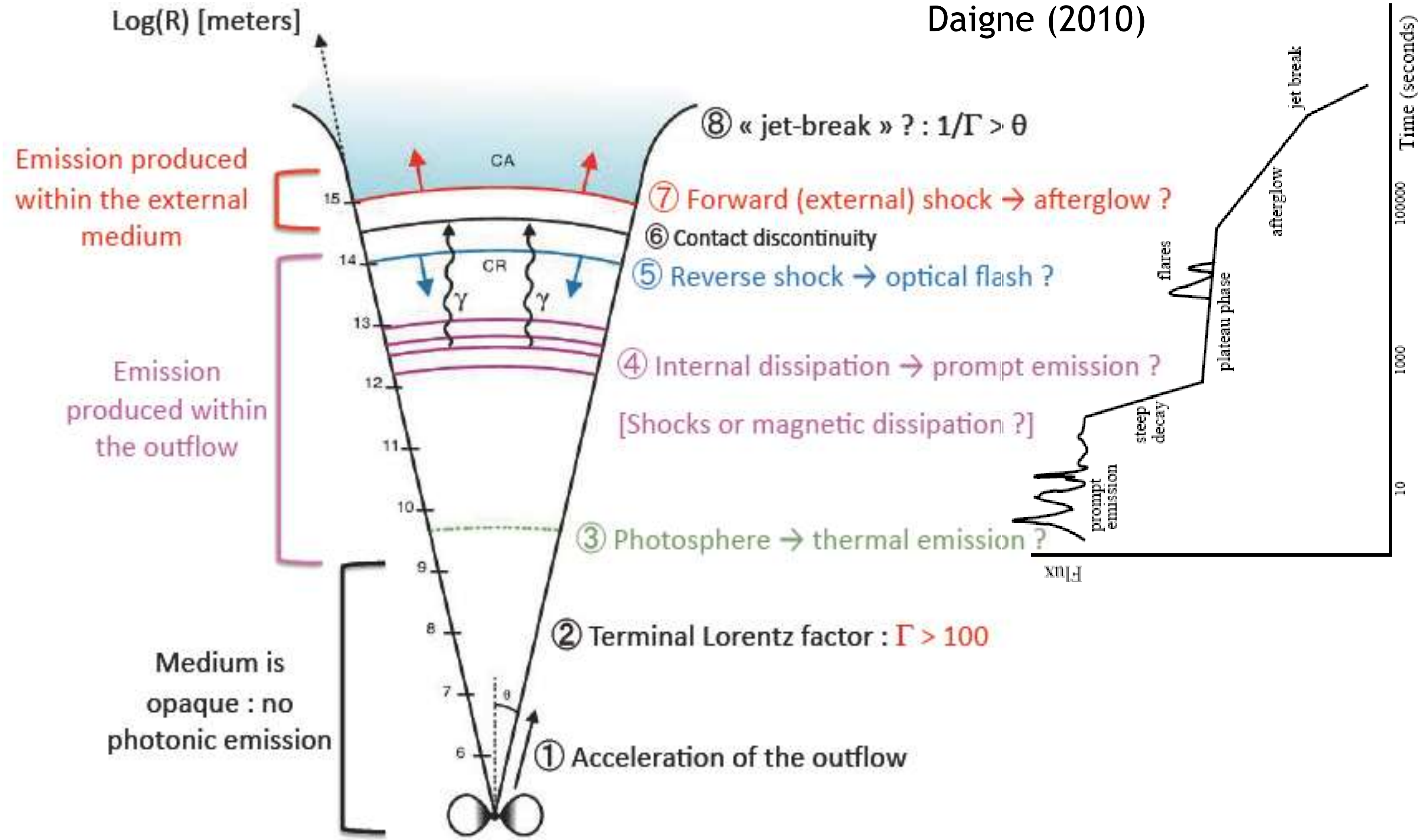
- Prospects of Future GRB Missions
- Present Limits in Optical Observations
- UFFO-pathfinder aboard *Lomonosov* Spacecraft
  - Slewing Mirror Telescope (SMT), key of UFFO to explore "new time domain"
  - UFFO BAT (UBAT), localization of GRBs including faint/soft nearby GRBs and "high redshift GRBs"
- Summary

Prospects of GRB Physics

- Origin of GRBs (Progenitors), Central Engine, Jet dynamics, Progenitor environment, etc.
- Short GRB, Dark GRB, Fast transient cosmic flashes like Primordial Black Holes, DM accretion
- Potential candidate of candle → see if can be calibrated, i.e., rise time correlation with luminosity, E-peak, t_lag, etc.
- Early Universe: Reionization history, First stars, Star formation history
- Extreme Universe: Black hole, Event horizon, Gravity, Shock breakout, Tidal disruption, etc.
- Fundamental Physics: Lorentz invariance & CPT violation
- Synoptic astronomy & Multi-messenger astrophysics: Neutrino & Gravitational wave counterparts
- Dark Universe: Dark energy, Dark matter

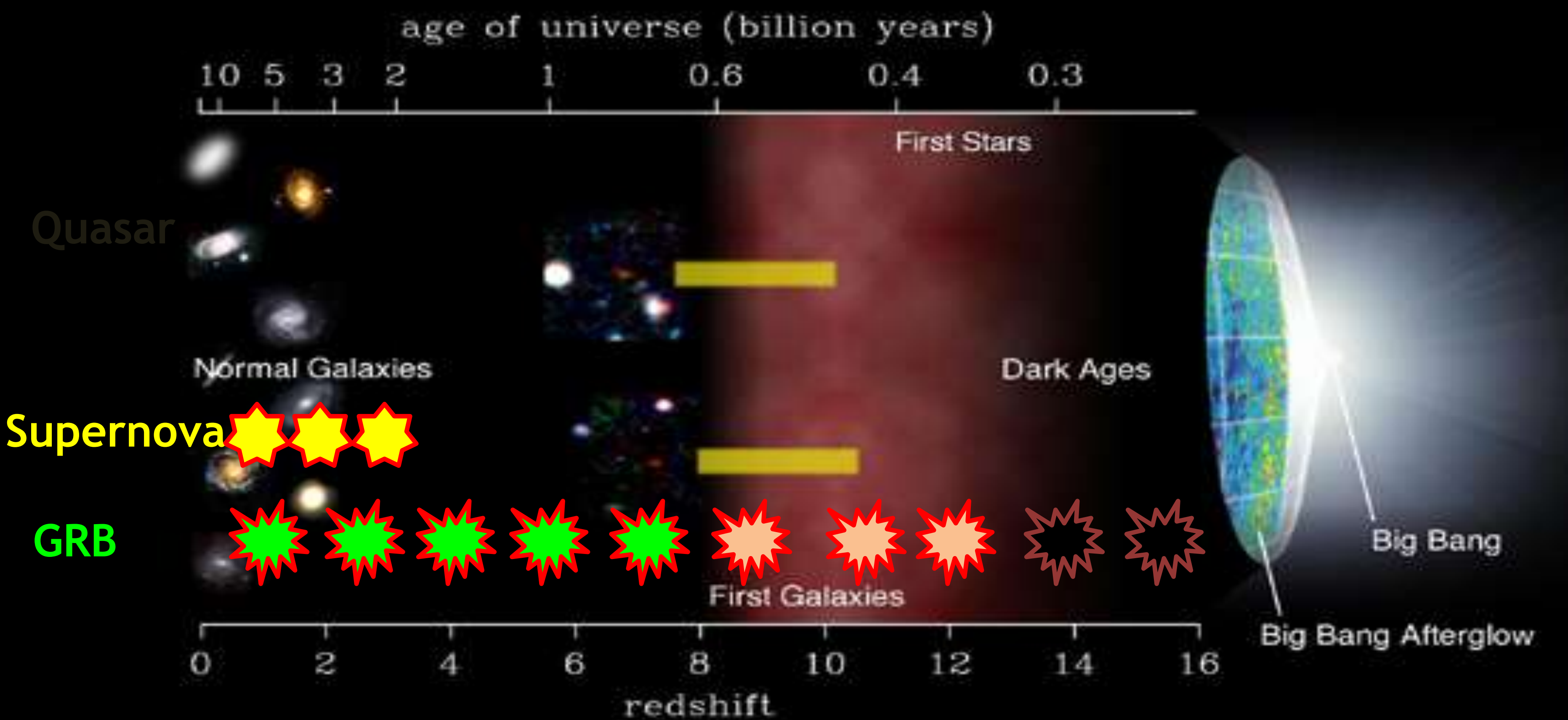
The afterglow

Daigne (2010)



GRBs, Early Universe Proves?

- GRBs are the most energetic explosions in the universe
  - Potential candidate of standard candles? Early universe probes!

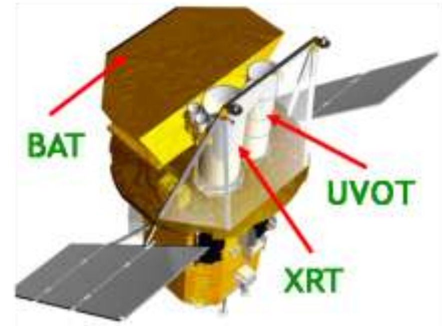


- GRBs have great leverage in time
  - ✓ GRBs could probe the epoch of first star formation, at z~10-15
  - ✓ GRBs could probe the epoch of reionization at z~7

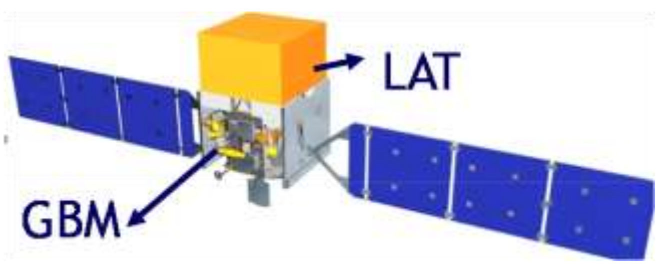
Renaissance of GRB

BATSE (1991)
(Burst and Transient Source Experiment)

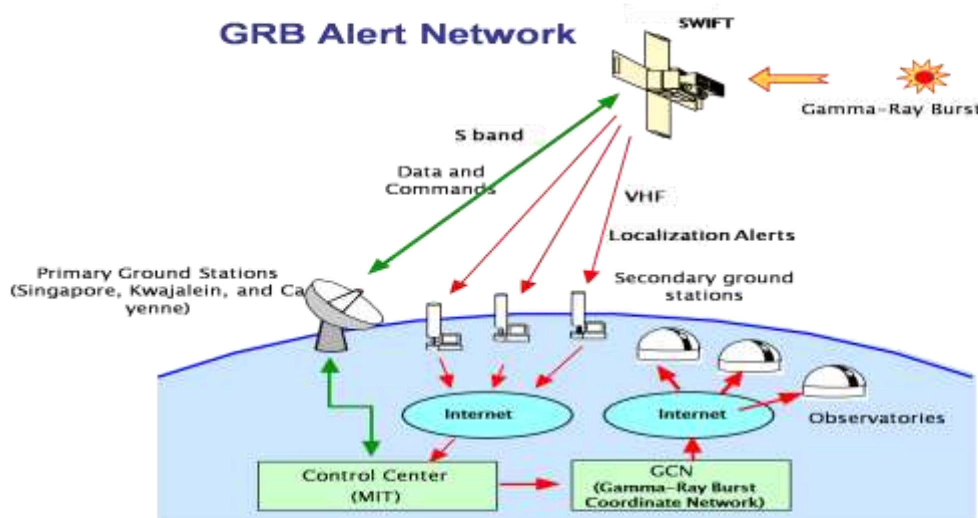
HETE-2 (2000)
(High Energy Transient Explorer-2)



SWIFT (2004)
NASA's MEDEX
GRB dedicated mission



Fermi Gamma-ray Space Telescope (2008)



X-ray missions (BeppoSAX, Integral, MAXI, …), ground telescopes, as well, UFFO-pathfinder, SVOM, SRG, YANUS, POLAR, UFF-100, … in near future

Instrumental Progress in FUTURE MISSIONS?

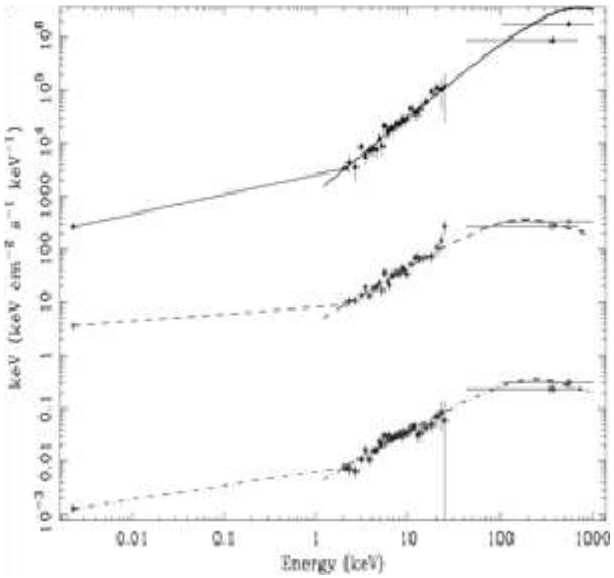
- Swift won't run forever, will end its mission in near future
- Improvement in terms of sensitivity, bandwidth, precision, in the domain of "flux, color, and time"
  - Higher sensitivity in photometry, wider energy band with lower E, rapider time response → larger, finer, faster detectors & telescopes
- High-z GRBs observation, for early universe probe
  - First star/galaxy, reionization, dark age, cosmology to z=16

  → IR observation, higher sensitivity in X-ray (E<10 keV)
- Early (or prompt) photons, as early as X-ray
  - Progenitor/powering/shock/radiation/classification, shock breakout, short GRBs, dark GRBs, DM accretion, Primordial BH

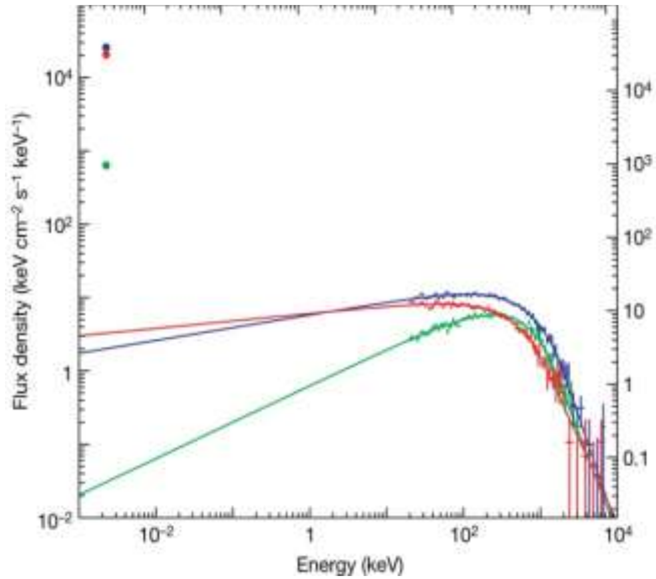
  → Rapid response slewing technology
- Polarization measurement, for γ/X-ray/UV/optical/IR
  - Early/extreme universe probes
- Synoptic (multi-band observation) and Multi-messenger astronomy with dedicated mission(s) for "Alert" to ground telescopes
  - World wide collaboration and endless contribution

Energy Spectrum of Prompt Emission

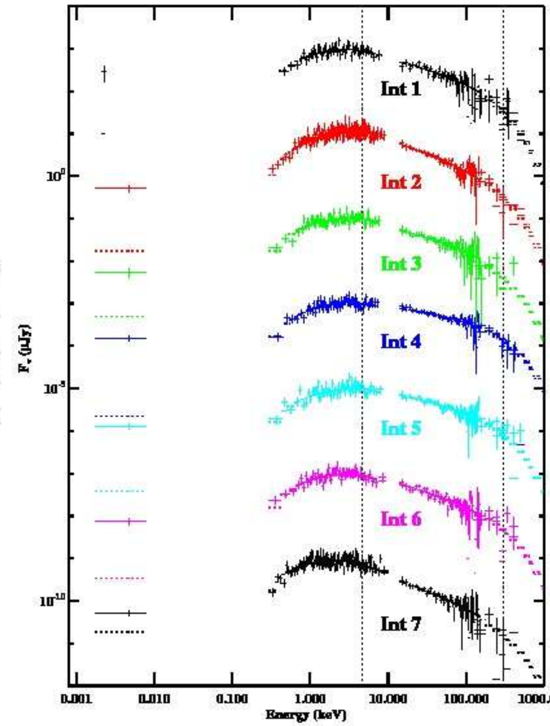
Corsi et al. 2005, GRB 990123



Racusin et al. 2008, GRB 080319B



Zhang et al. 2012, GRB 110205A

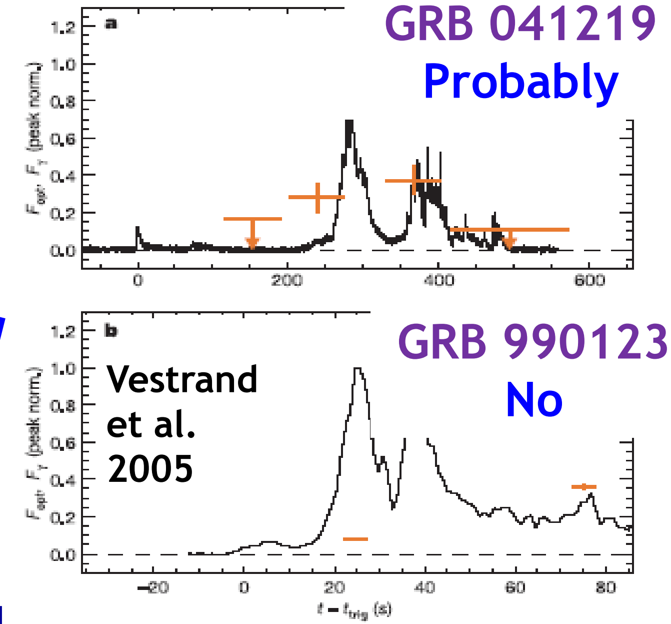


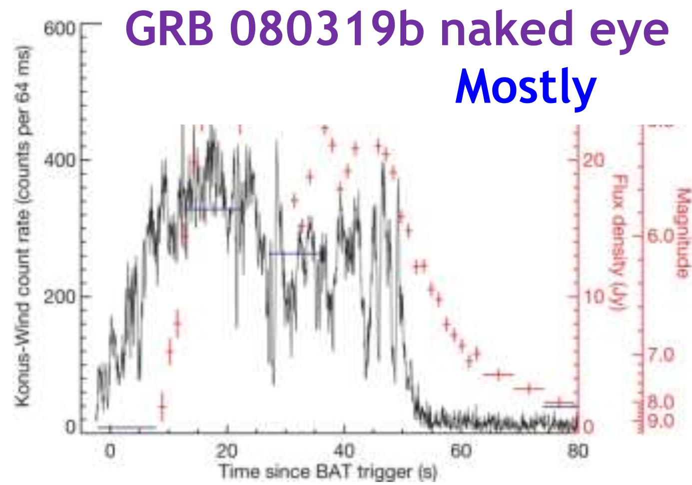
- γ-ray / optical emissions may have different physical mechanisms
  → multi-band optical data & low energy X-ray → high precision data needed
- GRB 990123: Mostly emitted by γ-rays, > 2 orders of mag larger than optical → a break between high and low energies, different physical origin
- GRB 080319B: Optical by synchrotron / γ-rays by SSC / second order IC → GeV emission detected by LAT

→ multi-band observation in optical needed

Correlation between X-ray and Optical

- **Origin of GRBs**
  - Correlation or delay of light curves from different bands → physical linkage bet. emission processes in two wave bands
  - Correlation of early optical & gamma
    - ✓ Accidental (or rare) measurements of only handful events since 1999
    - ✓ Data marginal except for 080319b
  - Is this clue to additional processes(internal shock, reverse shock, central engine afterglow, late time activity), or different origin of GRBs like SNIa and SNIb?
  - What about these correlations of early emission of SGRBs?
  - Need faster response & resolution (can't wait until luck happens again)

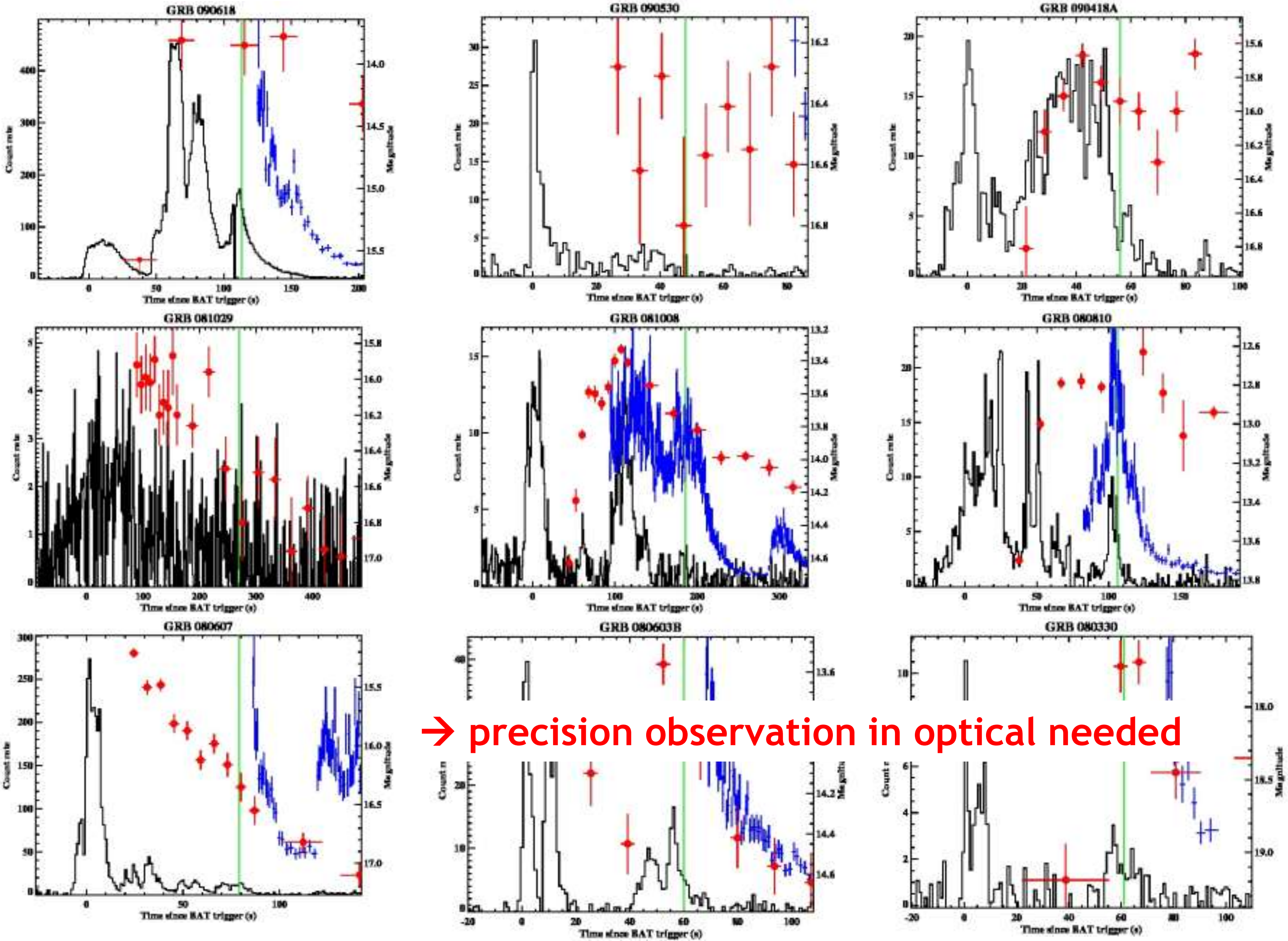




Racusin et al. 2008

(Pandey, GRB2012, Marbella)

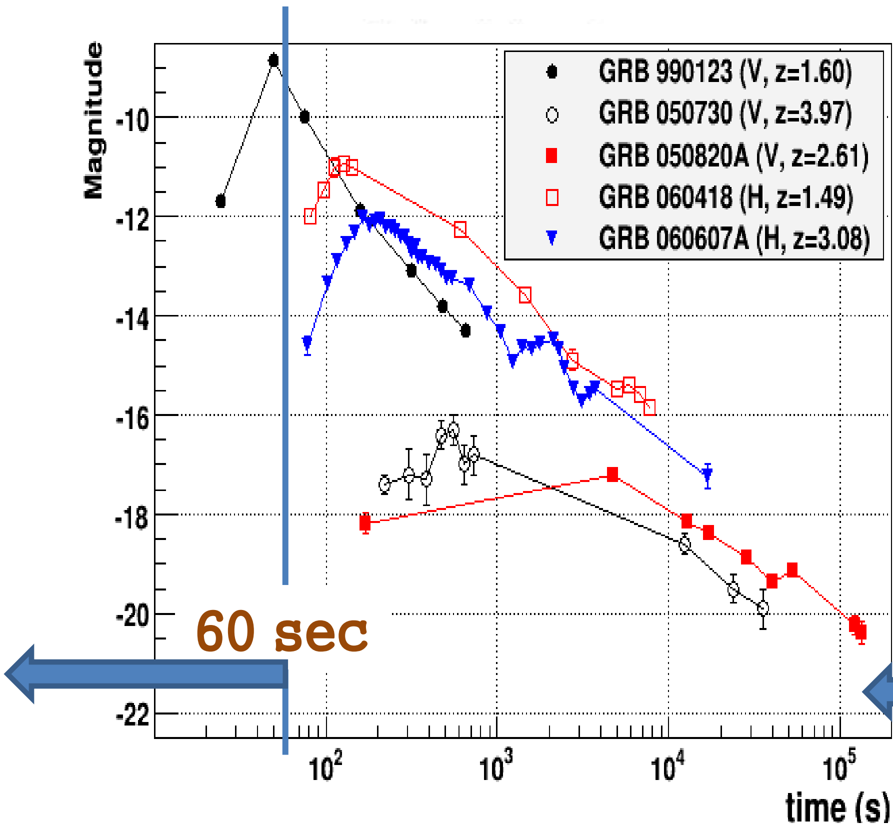
Correlation: Data from ROTSE

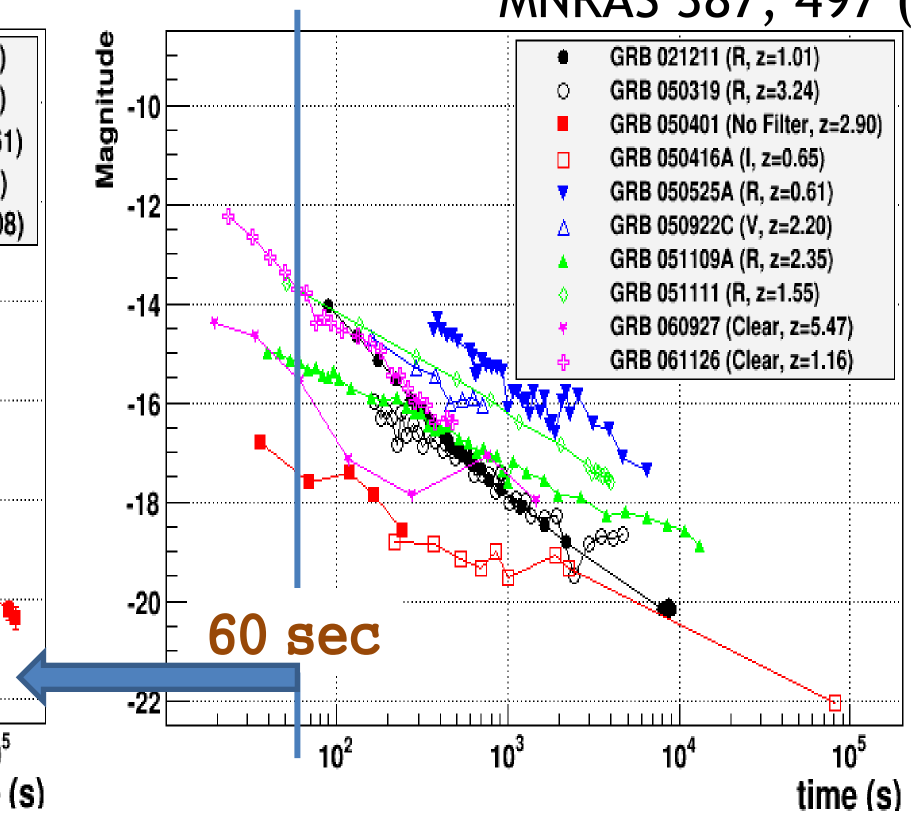


→ precision observation in optical needed

Early Time Measurements of Optical

Panaitescu, A. & Vestrand, W., MNRAS 387, 497 (2008)





Huge variation in light curves !

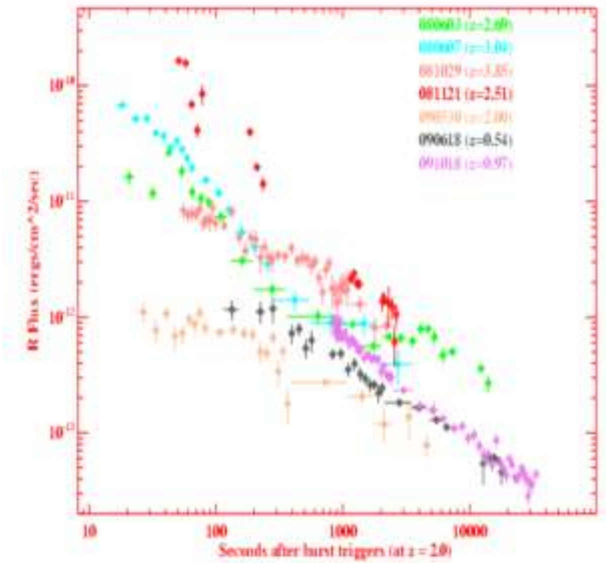
Prompt optical emission, the rise phase of the light curve ?

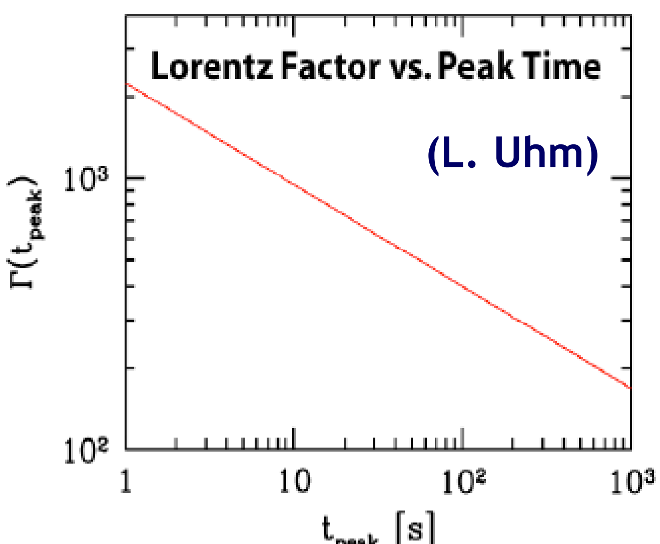
Event statistics is poor, data with only one or few points

Rising Time of Optical

Forward Shock (Afterglow) Emission

(Pandey et al. 2011)

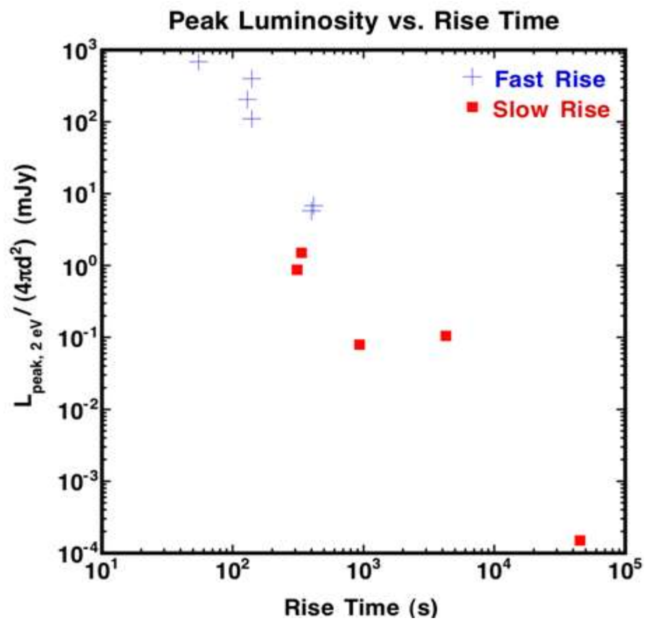


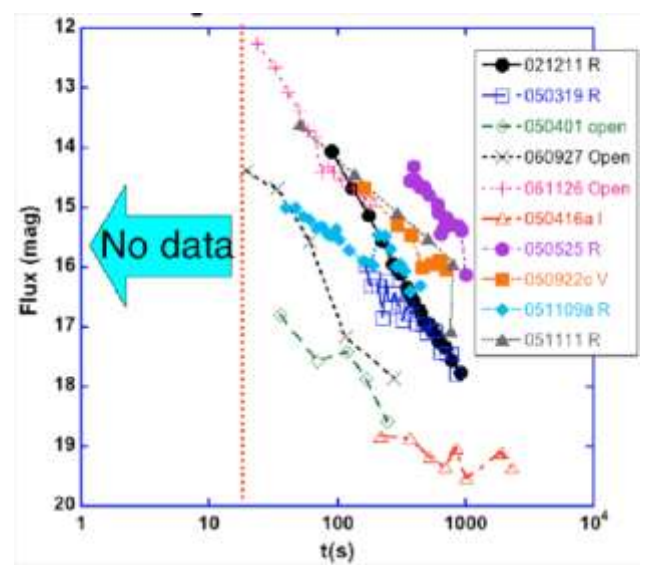


- Peak time of the rising optical light curves → initial Lorenz factor Γ_0 (Sari & Piran 1999, Molinari et al. 2007).
    - For BLF=1000, need to respond faster than 10 sec!
- The rising light curves are also important to understand the onset of the afterglow (Sari et al. 1999):
    - $F(t) = At^{\alpha}$
    - α~2 ($\nu_c < \nu_{optical}$) or α~3 ($\nu_c > \nu_{optical}$) in the case of ISM or α~0.5 for a WIND density profile.
- And to constrain off-axis (Zhang & Meszaros 2002; Kumar & Granot 2003 Van Eerten & MacFadyen 2011, 2012; Granot 2012), and structured jet models (Painatescu et al. 1998, Granot, Ramirez-Ruiz & Perna 2005).

Rising time of Optical for Cosmology

- Luminosity (might) correlate with rise time (Panaitescu & Vestrand 2008)
  - Majority of sample data not used due to the lack of early data
    - 2/30 total in PV08 have <60 sec peak, but majority (18/30) have no clear peak
  - MOST t_{rise} unknown
  - Need data at earlier time!
- Γ ←→ Eiso_52 (Liang et al. 2010, Lu et al. 2012)
- Γ ←→ E_{peak} (Kann et al. 2010, Ghirlanda et al. 2011, GCNs)
- etc.
- **Clear Demanding of Faster Response**



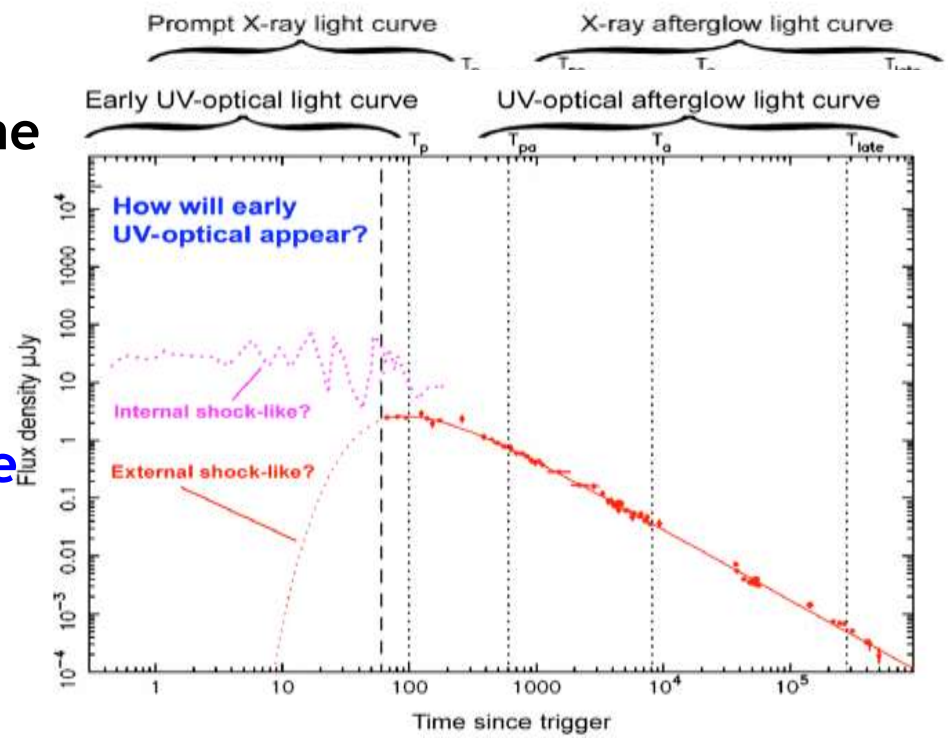


Early Afterglow

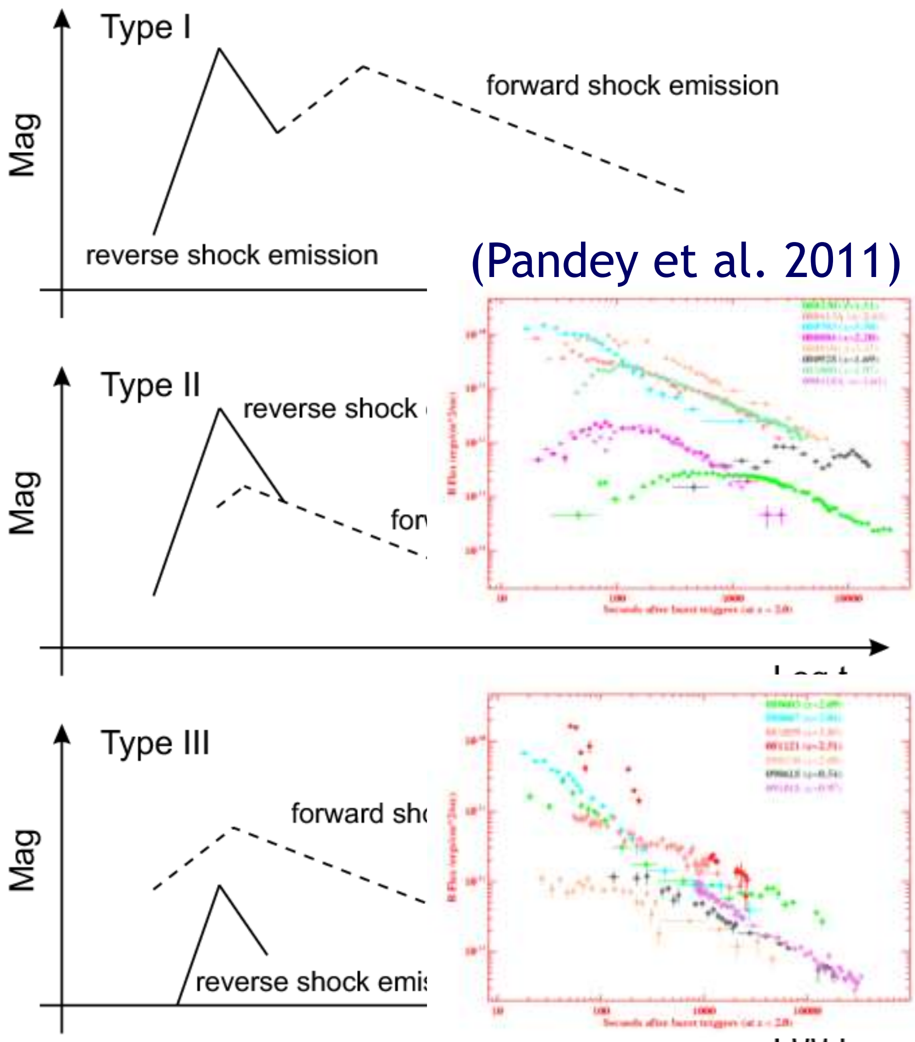
- Early observations of afterglows are important constrains to progenitor models and underlying physical mechanisms, and geometry of the outflow (Gehrels, Ramirez-Ruiz & Fox 2009)
- The so called "afterglow" is likely a superposition of the traditional external shock afterglow and internal dissipation of a long-lasting wind launched by a gradually dying central engine. (Bing Chang, GRB2012, Mabella)

- UV/optical emission at early time is believed to be from external forward shocks

  → But, they also could be from reverse shock, internal shocks, central engine afterglow, or late time activity
- Faster response than current, high time resolution, required

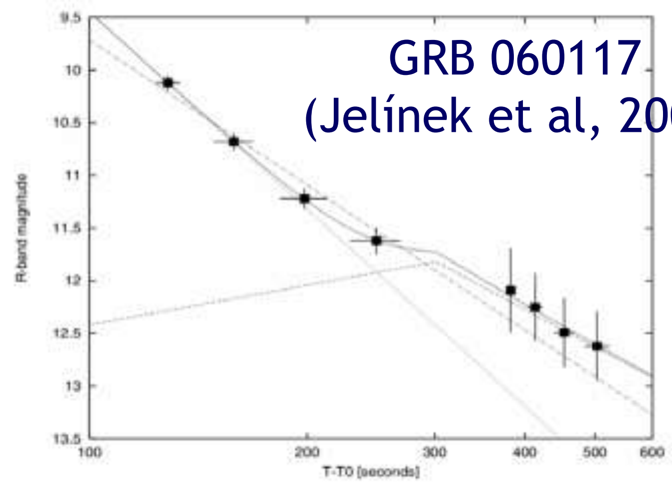


Forward Shock versus Reverse Shock



(Pandey et al. 2011)

- Strength of RS depends on magnetization content of the ejecta
- **In general reverse shock feature is not clearly visible at optical frequencies**
- **Why ? Faint, merged, other lower frequencies Baryonic / magnetized outflow? Time scale?**

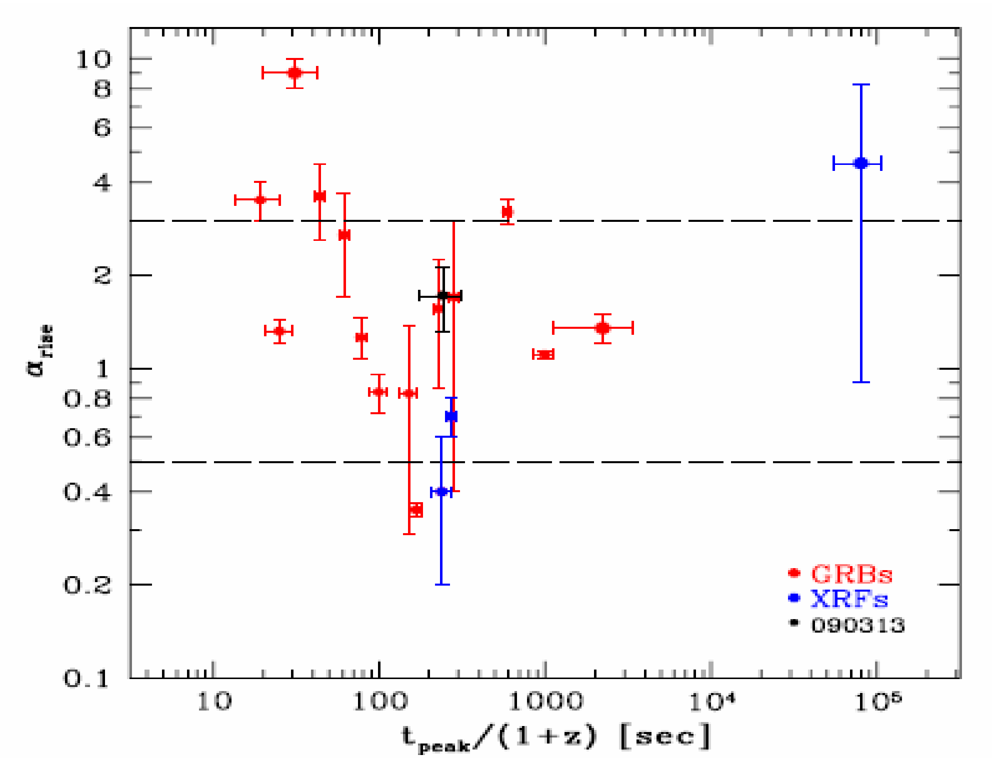


GRB 060117
(Jelínek et al, 2006)

Sari & Piran 1999;
Zhang, Kobayashi, Meszaros (2003);
Gomboc et al. (2009)

Dark bursts

- Expectation 20-30 long GRBs/yr, but ~30% will be dark events (Melandri et al. 2012)
- No optical emission observed → Dark bursts
  - ✓ Believed to be circumstellar extinction or Lya absorption
  - ✓ Host Obscured, High-redshift, or Intrinsically dim
  - ✓ Maybe due to faded out too fast



Melandri et al. (2010)

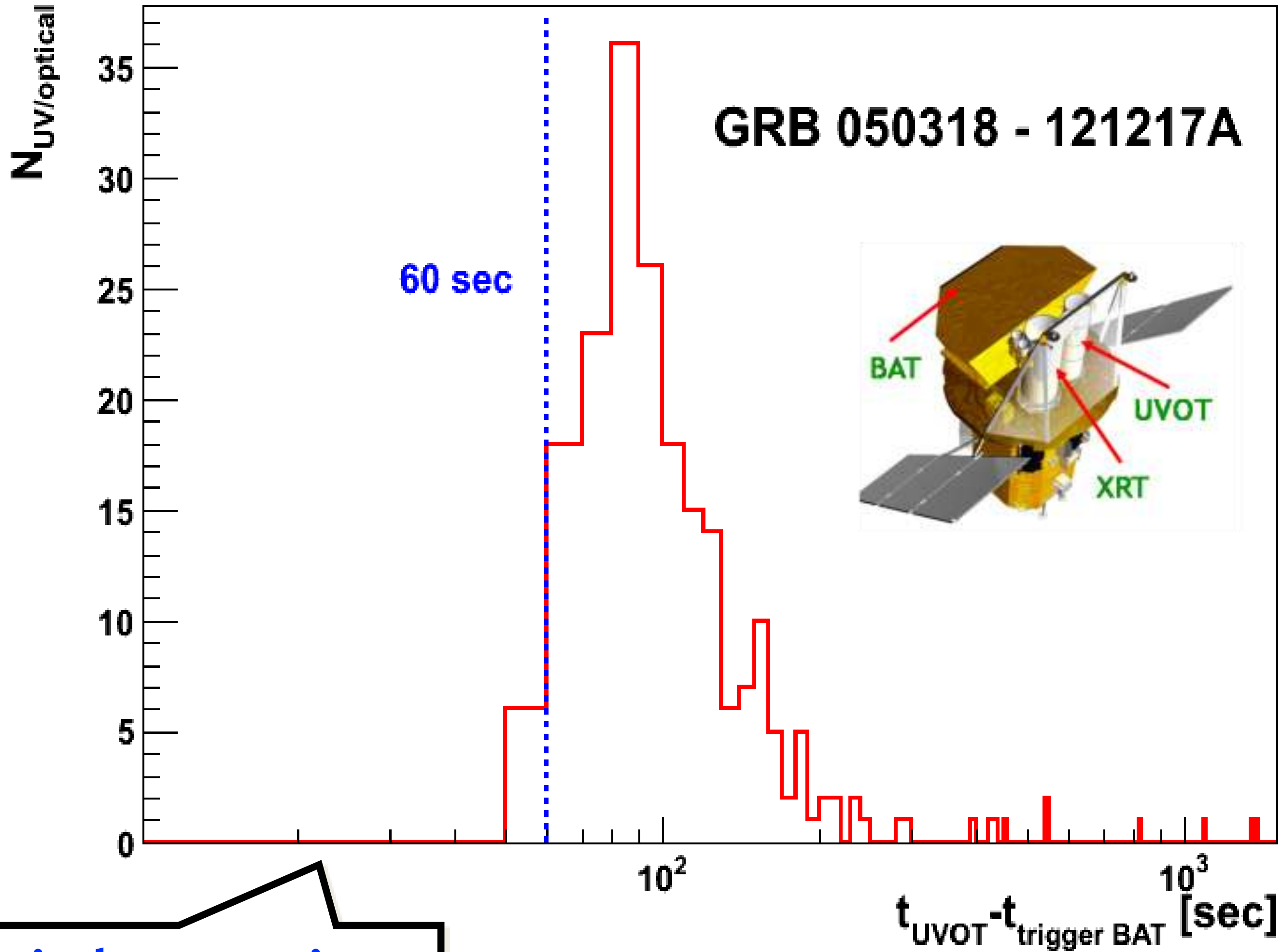
Short Hard GRB

- **Short GRBs**
  - Physical time scales: light curve peak time at any epoch gives a hint of the most important physical processes in that epoch
  - Light crossing time of outer accretion disk bounds, dynamic time scales of large accretion disk systems, and other time scales → sub-minute regime → require rapid response
  - Also the time scales of jet formation or deceleration in this small system
- **Very Short GRBs**
  - May originate from the evaporation of Primordial Black Holes and its time scale <100 msec (Cline, Otwinowski, Czerny, Janiuk 2011)
  - DM accretion to NS (Perez-Garcia's talk)

Multi-messenger

- **Multi-messenger Astrophysics**
  - Physics in correlation and delay for
    - Lorentz violation from the time delay between different energy photons, and photons and non-EM emission
    - Short GRB: gravitational waves vs. optical-gamma light
      - Cosmology with space GW also needs z. Perhaps get many from prompt observations of SHGRB
    - Neutrinos vs. optical-to-gamma prompt light
    - HE vs. Low E delay – GR alternative models (high-z vs. low-z)
    - These time scales potentially very short, need faster response, which may revolutionize astronomy and great understanding of black holes, neutron stars, cosmology, strong filed gravity

Limit in *Swift* Response Speed

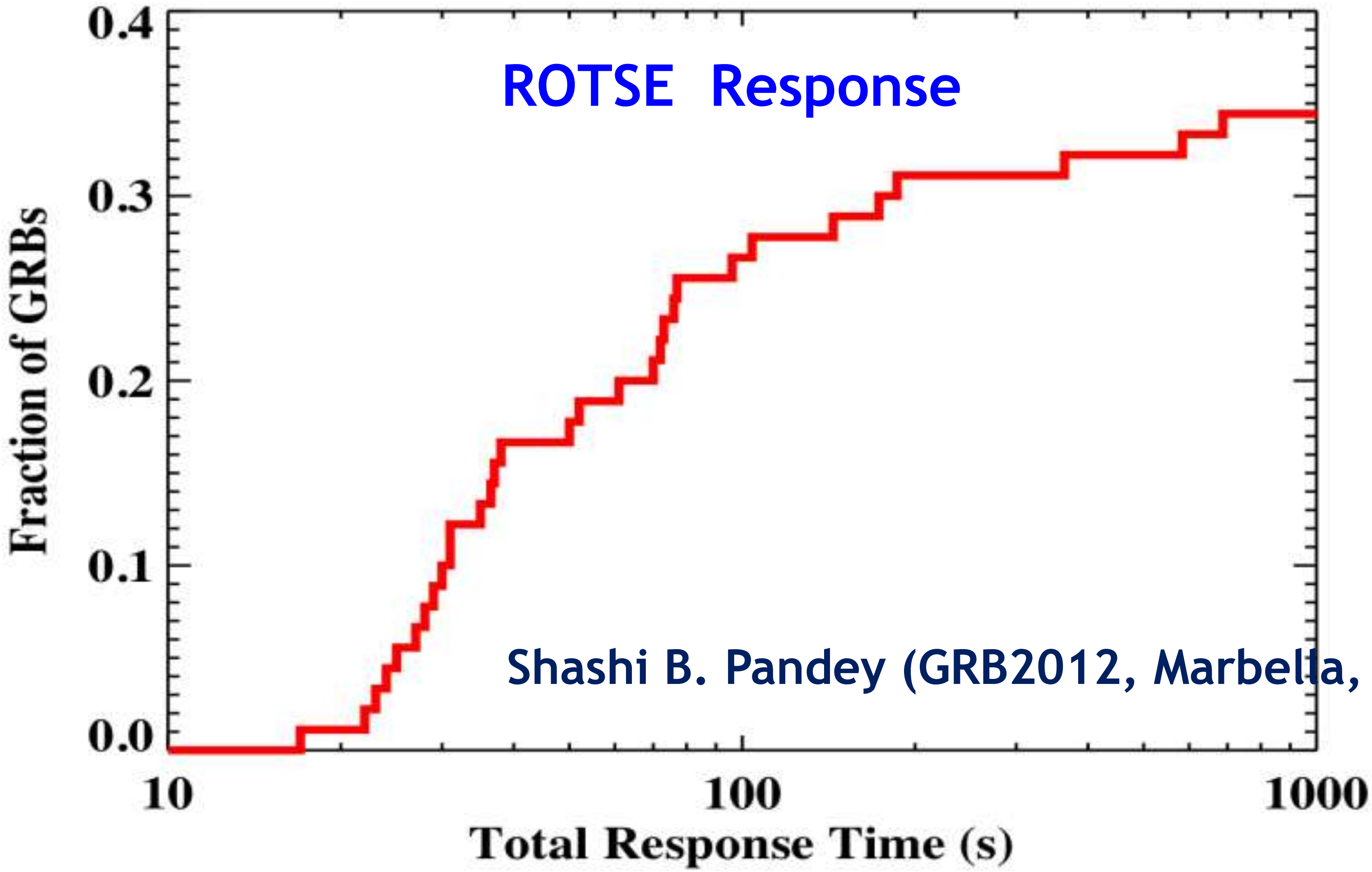


What is happening (optically) at shorter time scales?

Park et al. 2013, New Journal of Physics 15, 023031

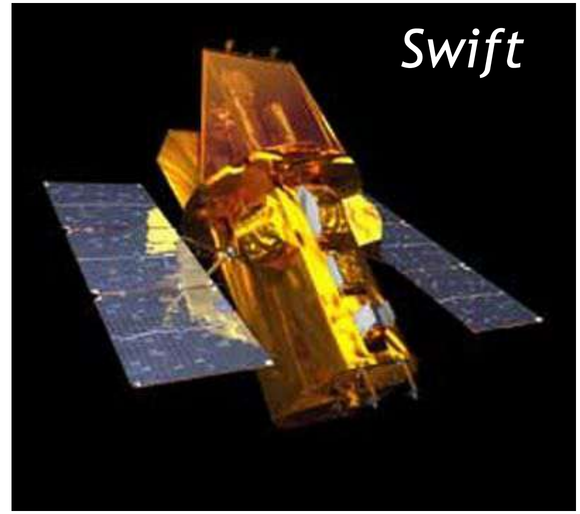
Early time optical follow-up observations of GRBs

- Robotic telescope: BOOTES 1-5, BOOTES-IR, Pi of the sky, PROMT, ROTSE-III, Super-LOTIS, TORTORA
- Large telescope: Keck, GROND, Faulkes, P60, Gemini



Shashi B. Pandey (GRB2012, Marbella, Spain)

Swift is swift



"First" GCN space telescope

"First" pointing telescope

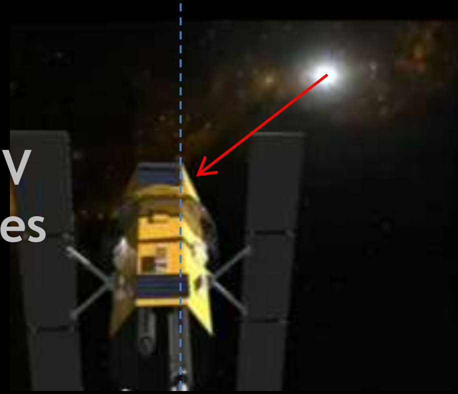
- GRB afterglows can be followed up by satellite itself besides sending the position to the Earth (*BeppoSAX* in 6-8 hr, *Swift* in ~1 min)
- Early follow-up (within ~1 hr) only available to *Swift* so far (even very early sometimes with response of ~1 min) due to the slewing time of the spacecraft

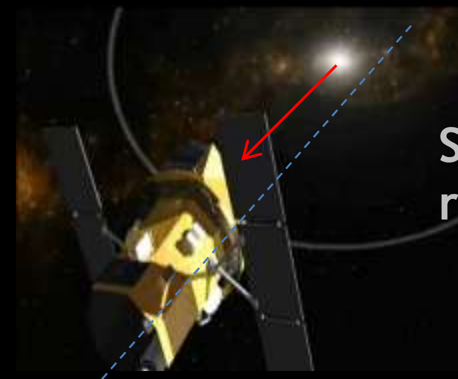
Is it possible to beat this 1 min barrier FROM SPACE?

First sub-second response telescope?

Swifter than *Swift*?

Step 1: wide FOV X/γ camera locates GRB

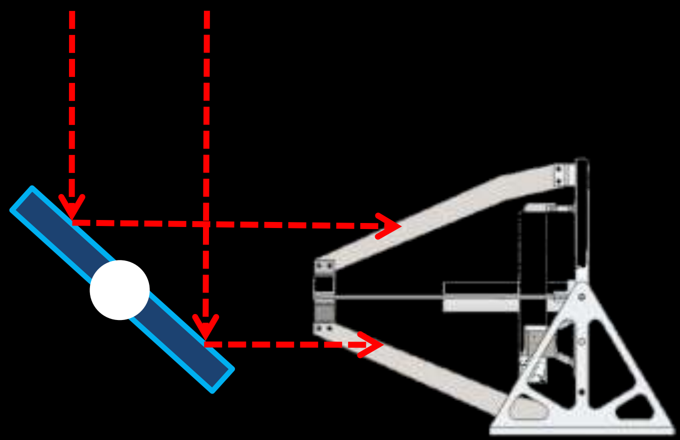


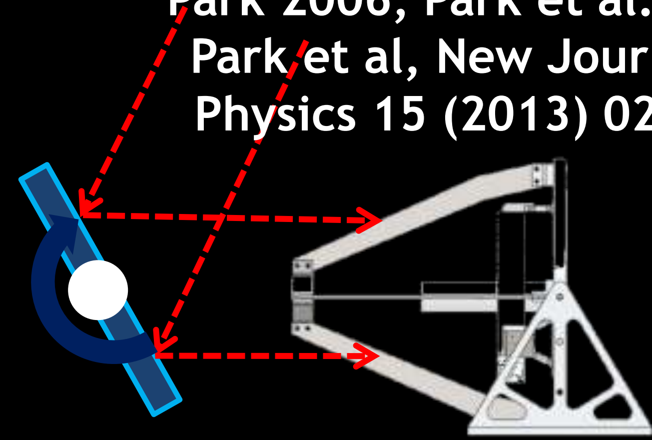


Step 2: Spacecraft rotates to point at GRB

SWIFT rotates entire spacecraft to point telescopes

Park 2006; Park et al. 2009; Park et al, New Journal of Physics 15 (2013) 023031





UFFO Concept: Move the optical path, not the spacecraft with fast slewing mirror system → much faster

(Slewing system can be built either with flat mirror or with MEMS Mirror Array + Gimbal Platform)

Comparison of Space Instruments

Space mission	BATSE/*CGRO*	*BeppoSAX*	HETE-2	*Swift*	GBM/*Fermi*	UFFO/ *Lomonosov*	UFFO-100
Gamma/X-ray energy range	20 keV ~ 8 MeV	2~30 keV	2~25 keV	15~150 keV	8 keV ~ 40 MeV	5~150 keV	3~300 keV
X-ray instrument: • **detector type** • **detection area** • **FOV(half coded)** • **localization acc.**	• NaI(TI) • 8×126 cm^2 • 4p sr • ~2 arcdeg in 68%	• coded mask+ prop.counter • 140 cm^2 • 40×40 deg^2 • <5 arcmin (~1.5 in 99%)	• coded mask+ prop.counter • 350 cm^2 • 80×80 deg^2 • 10 arcmin in 90%	• coded mask + CZT • 5240 cm^2 • 100×60 deg^2 • 1~4 arcmin (4 in 8σ)	• NaI+BGO • 14×126 cm^2 • 2.5 sr • 1~5 arcdeg	• coded mask + YSO • 191 cm^2 • 90.2×90.2 deg^2 • 10 arcmin in 7σ	• coded mask + Si & YSO • 1024 cm^2 • 90×90 deg^2 • 7 arcmin in 7σ
UV/optical/NIR	None	None	None	UV/optical	None	UV/optical	UV/optical/ NIR
UV/optical/IR response time after trigger(typical)	Not applicable	Not applicable	Not applicable	60 sec	Not applicable	1 sec	0.01~1 sec
GRB events/year	~300	~10	~12	~100	~260	20~30	>70
Launch ~ termination year	1991~2000	1996~2002	2000~2006	2004~	2008~	2014~	2018~

Park et al, New Journal of Physics 15 (2013) 023031

Explored or Accessible Domain for GRBs

Park et al. 2013, New Journal of Physics 15, 023031

γ-ray

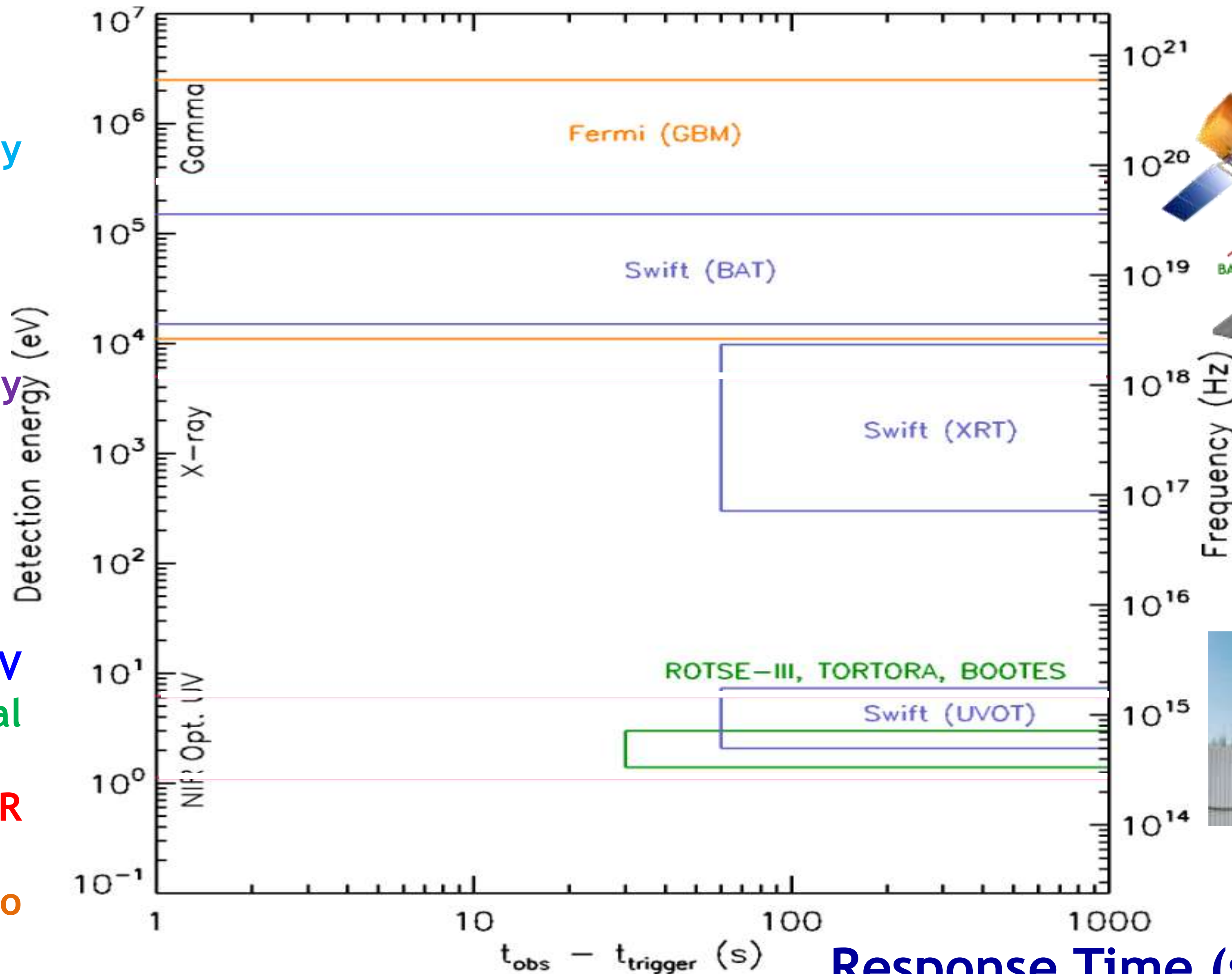
X-ray

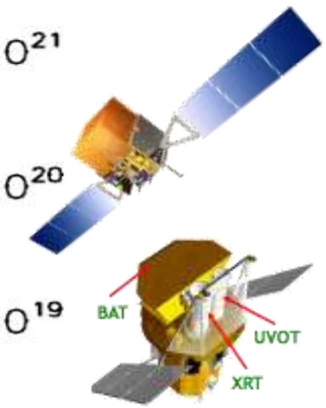
UV

Optical

IR

Radio

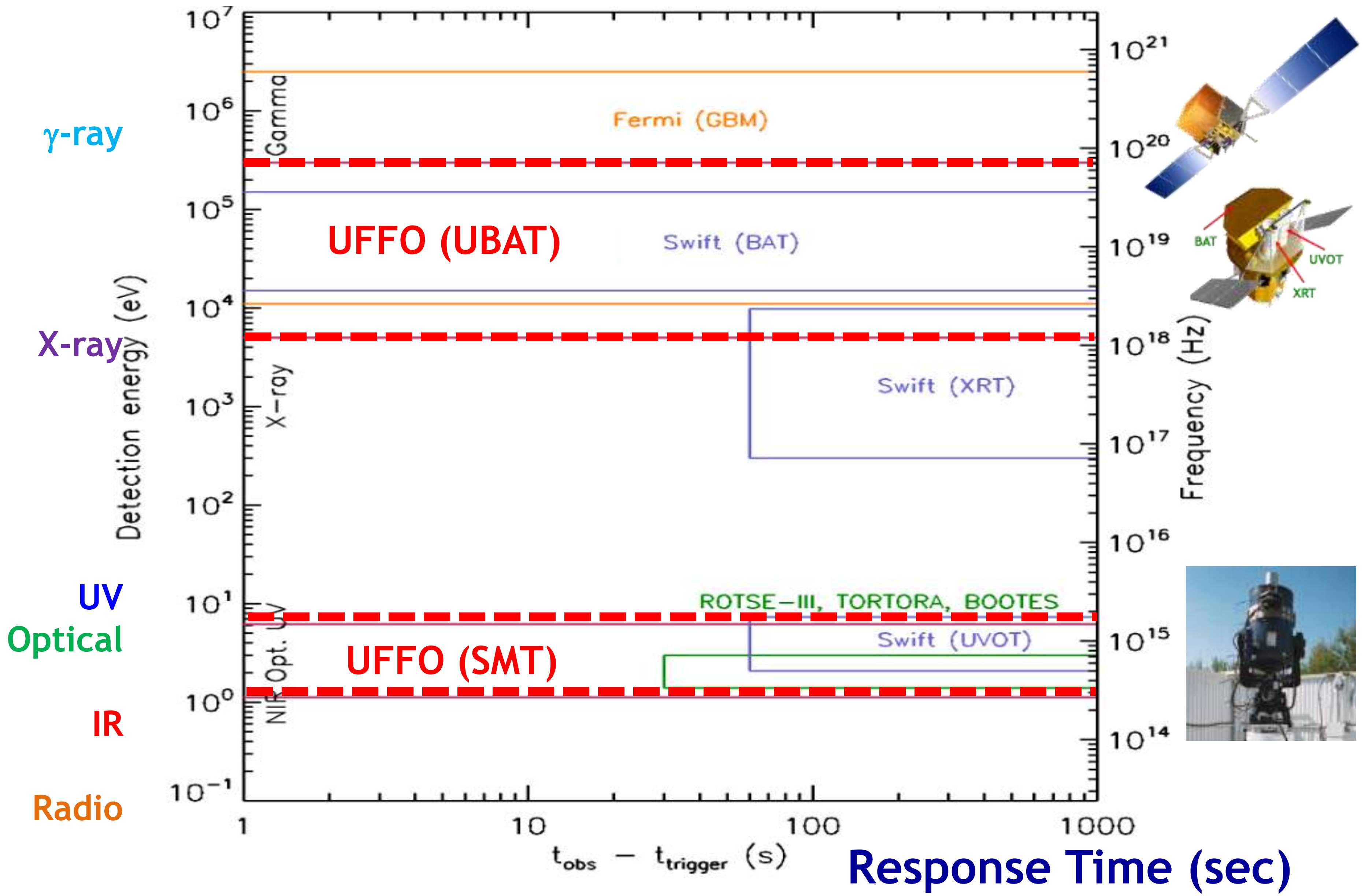




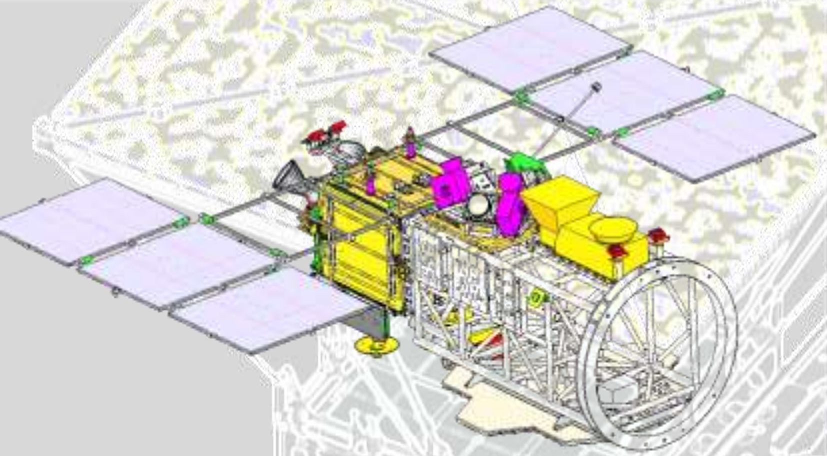
Response Time (sec)

Explored or Accessible Domain for GRBs

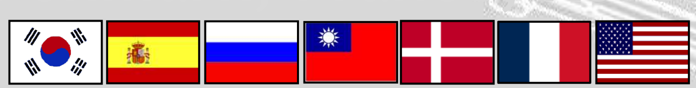
Park et al. 2013, New Journal of Physics 15, 023031



UFFO/*Lomonosov*

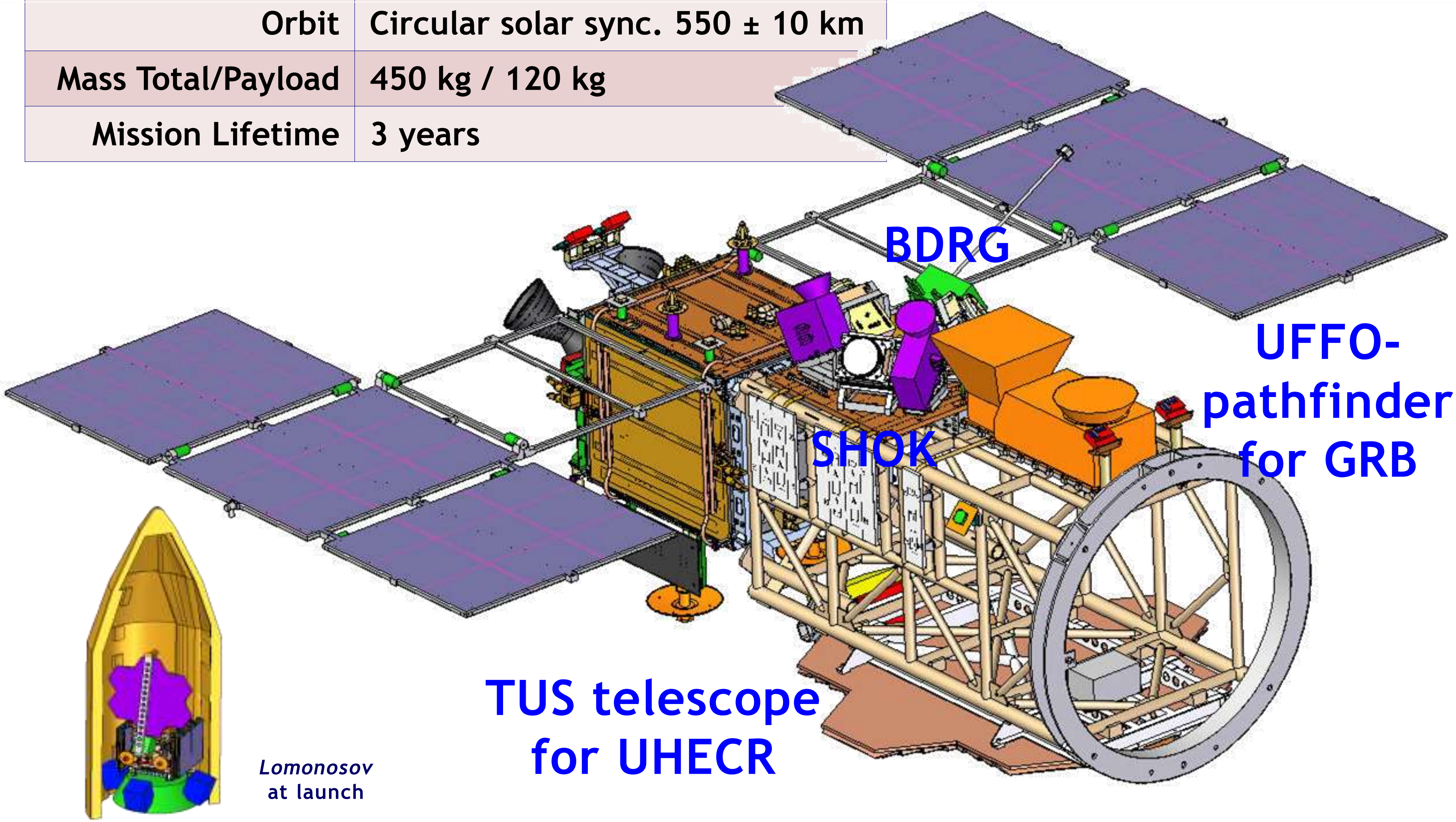


- Pioneering mission to prove the concept of Slewing Mirror Telescope by measuring early photons (1 sec after X-ray trigger)
- 10 cm aperture Slewing Mirror Telescope with small X-ray coded mask onboard *Lomonosov* spacecraft



Lomonosov Spacecraft & Payloads

Spacecraft	*Lomonosov* & FGUM-VNIIEM
Launch Date	2014
Orbit	Circular solar sync. 550 ± 10 km
Mass Total/Payload	450 kg / 120 kg
Mission Lifetime	3 years

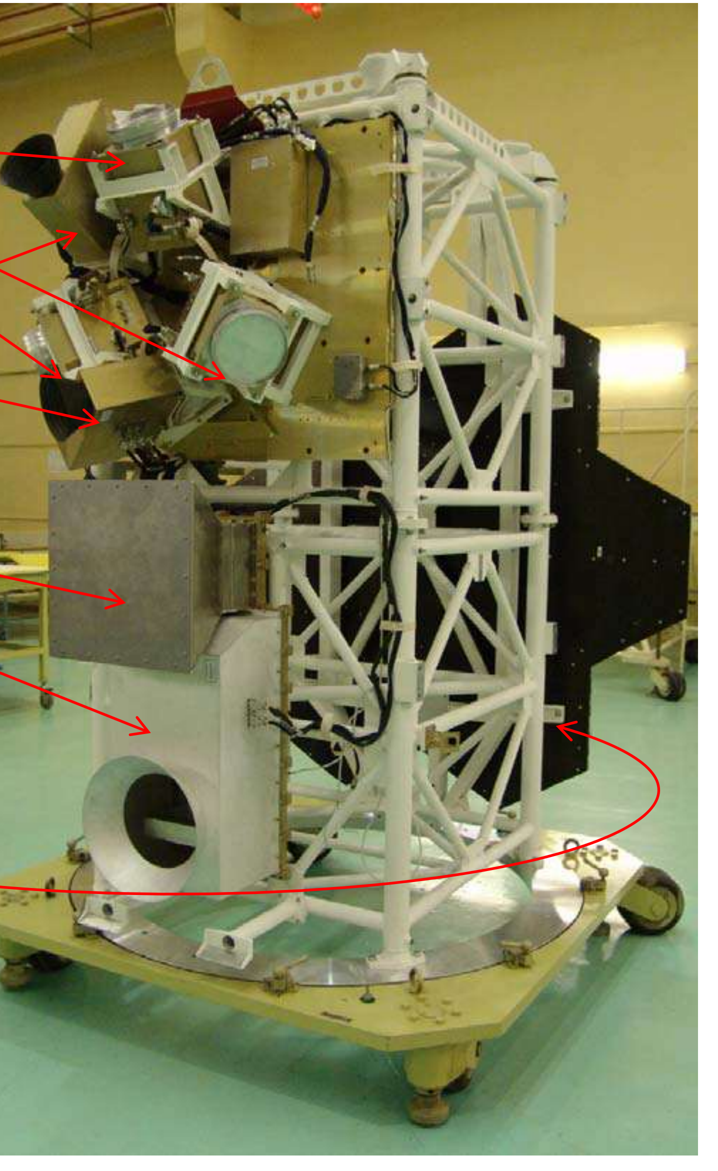


Lomonosov at launch

Payloads onboard *Lomonosov (2012)*

Lomonosov Capabilities for GRB research

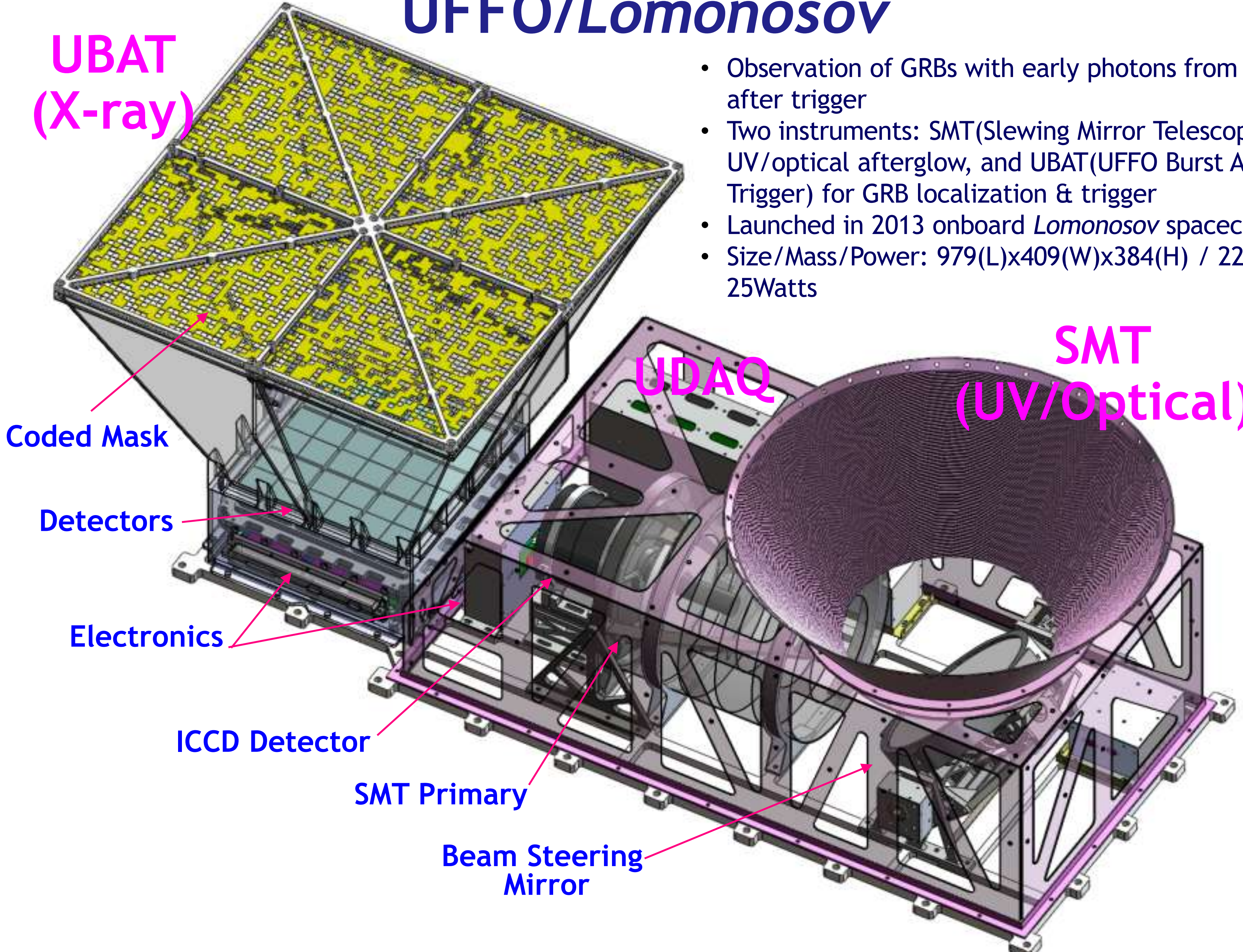
- BDRG (GBM/*Fermi* type)
  - γ-ray, 0.01-30 MeV
  - CsI crystals
- SHOCK
  - optical observations, fast
  - wide FOV, R_{lim} = 13 mag
- UFFO-pathfinder (*Swift* type)
  - X-ray, 5-150 keV, t_{samp}=20ms
  - UV/opt, B_{lim} ~19.5 (5σ in 100s) with t_{samp} =20ms
- TUS (pathfinder of JEM-EUSO)
  - UHECR, 10^{20}-10^{21} eV
  - 1.5m Fresnel mirror optics



bonus: simultaneous UHECs with GRBs? but not yet seen by Auger in 2004-2009 for 115 GRBs in the Auger FOV (Thomas et al. 2009)

UFFO/*Lomonosov*

- Observation of GRBs with early photons from 1 sec after trigger
- Two instruments: SMT(Slewing Mirror Telescope) for UV/optical afterglow, and UBAT(UFFO Burst Alert Trigger) for GRB localization & trigger
- Launched in 2013 onboard *Lomonosov* spacecraft
- Size/Mass/Power: 979(L)x409(W)x384(H) / 22kg / 25Watts



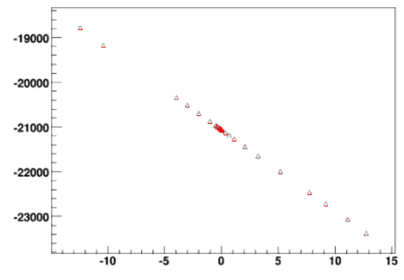
UV/Optical Instrument

Slewing Mirror Telescope

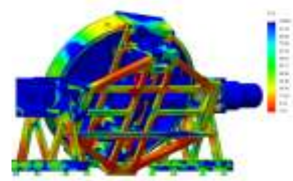
Jeong et al. 2013, Optics Express

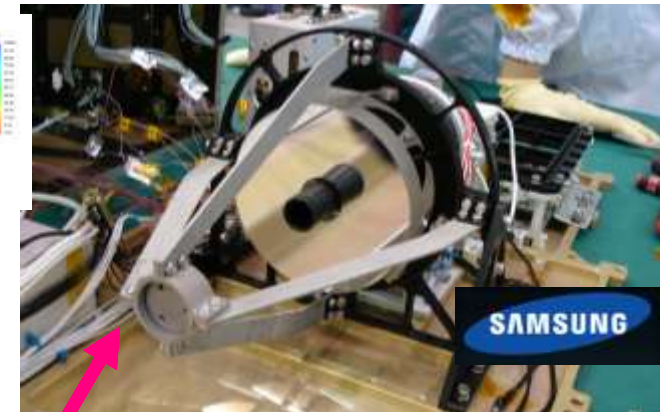
SMT (Slewing Mirror Telescope, UV/optical)

- Aperture: 10 cm diameter
- F-number: 11.4
- FOV: 17 x 17 $arcmin^2$
- Coverage FOV: 70° x 70°
- Detector: Intensified CCD
- Pixel scale: 4 arcsec
- Location accuracy: 0.5 arcsec
- Wavelength: 200~650nm



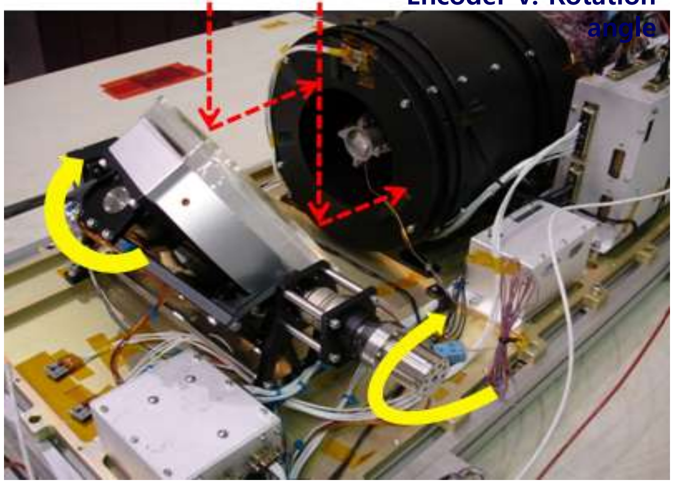
Encoder v. Rotation angle

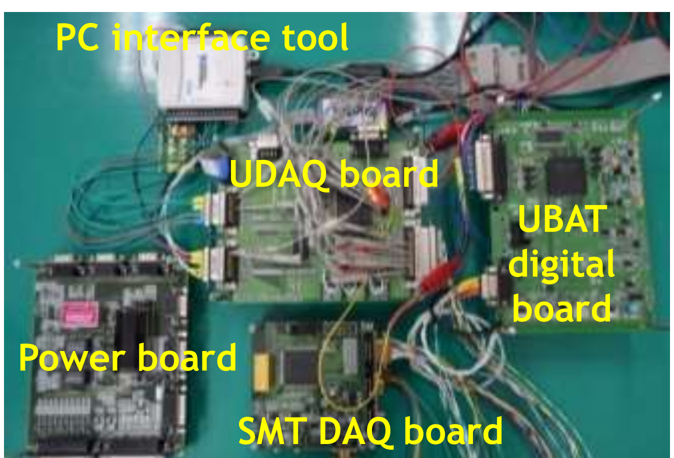


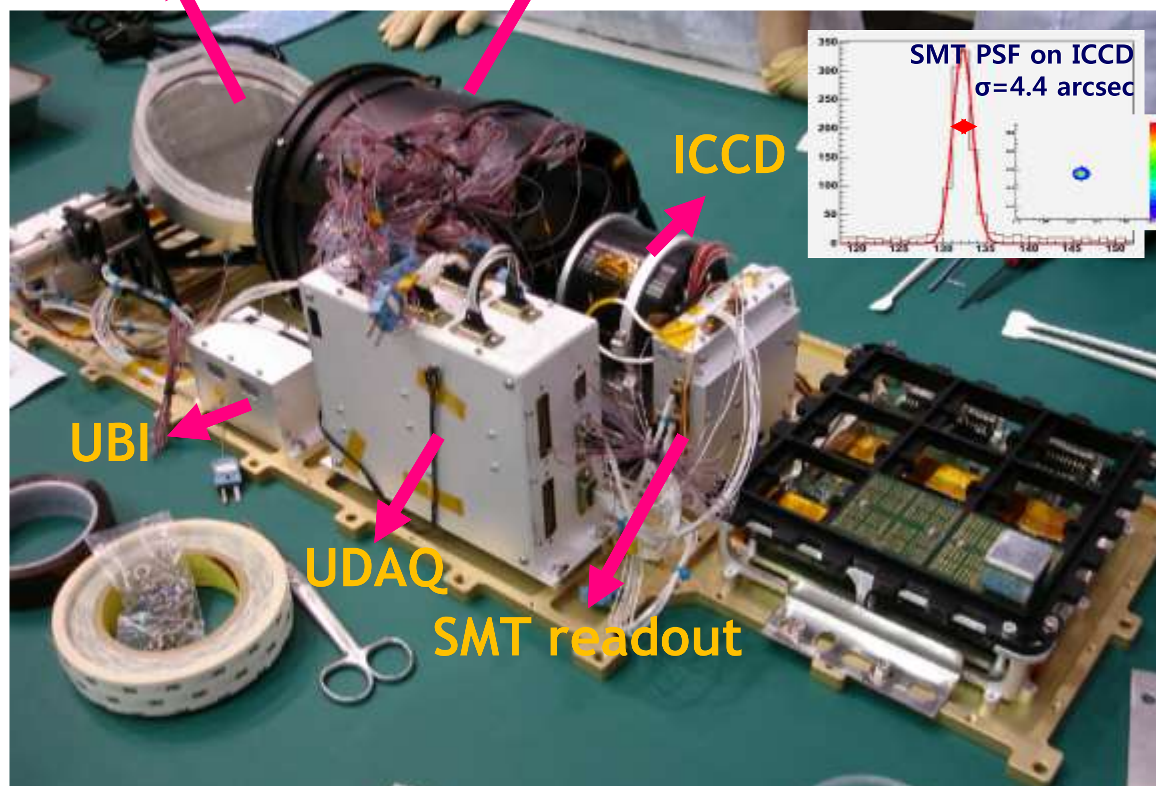


Slewing mirror & stage

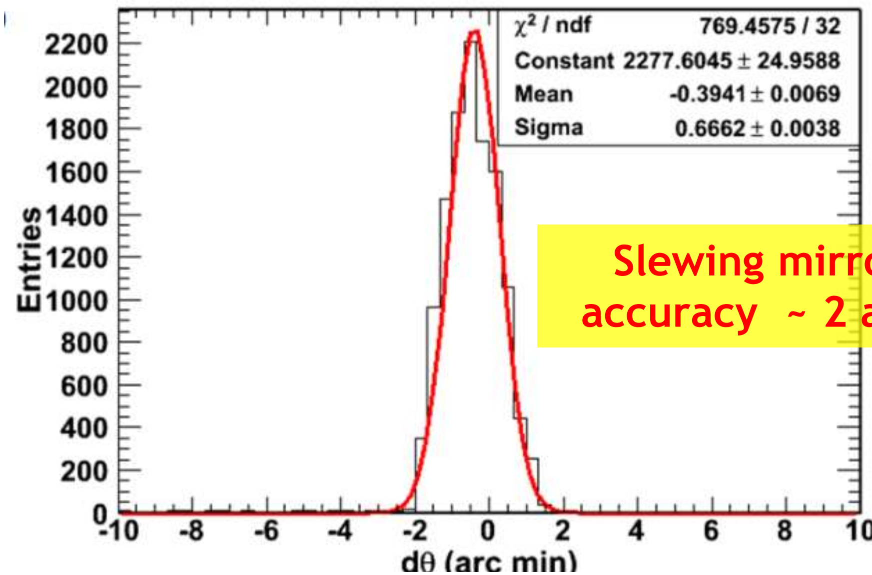
Ritchey-Chrétien telescope



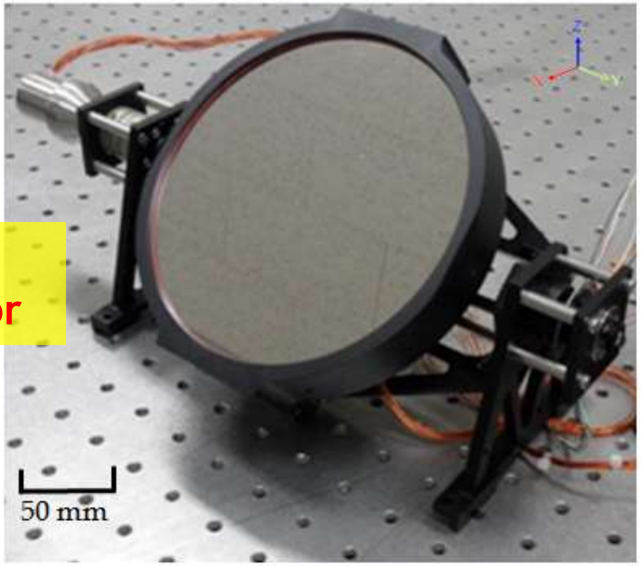


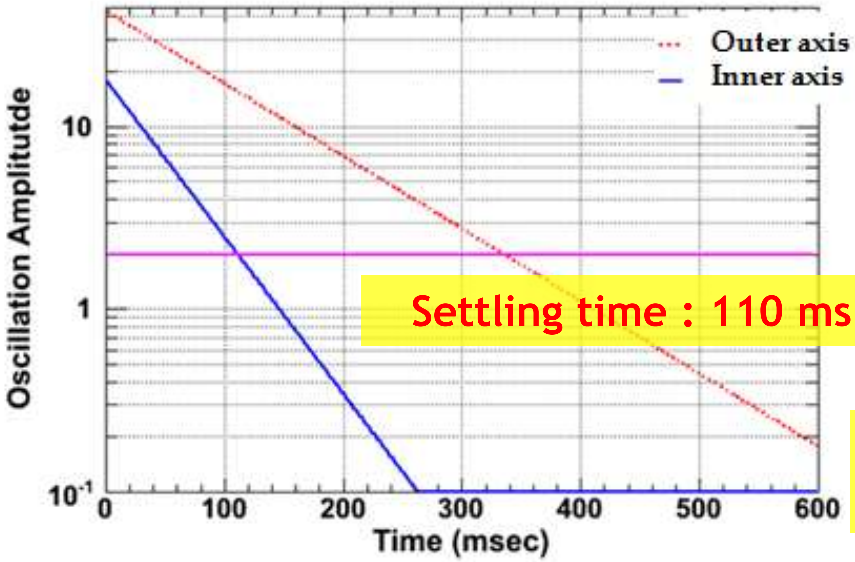


Slewing Mirror



Slewing mirror pointing accuracy ~ 2 arcmin error





Settling time : 110 ms and 330 ms

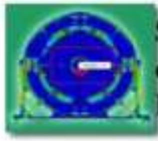
Jeong et al. 2013, Optics Express

"***Spotlight on Optics***" by Optics Society of America, March 2013

Current Slewing speed: ~1.5 sec over whole FOV → to be optimized logic update → 1 sec

Spotlight on Optics
HIGHLIGHTED ARTICLES FROM OSA JOURNALS

"*Spotlight on Optics*"
by the Optical Society,
March 2013



Slewing Mirror Telescope optics for the early observation of UV/optical photons from Gamma-Ray Bursts

Published in Optics Express, Vol. 21 Issue 2, pp.2263-2278 (2013)
by S. Jeong, J. W. Nam, K. B. Ahn, I. H. Park, S. W. Kim, J. Lee, H. Lim, S. Brandt, C. Budtz-Jorgensen, A. J. Castro-Tirado, P. Chen, M. H. Cho, J. N. Choi, B. Grossan, M. A. Huang, A. Jung, J. E. Kim, M. B. Kim, Y. W. Kim, E. V. Linder, K. W. Min, G. W. Na, M. I. Panasyuk, J. Ripa, V. Reglero, G. F. Smoot, J. E. Suh, S. Svertilov, N. Vedenkin, and I. Yashin

Spotlight summary (from Optics Society of America)

For nearly 30 years following the discovery of Gamma Ray Bursts (GRBs) the origin of these brief flashes of high-energy radiation has been a complete mystery. The key to unraveling the physics of these enigmatic objects and the main challenge lies in the ability to accurately localize events in time to obtain detailed follow-up observations with X-ray, optical, and radio telescopes.

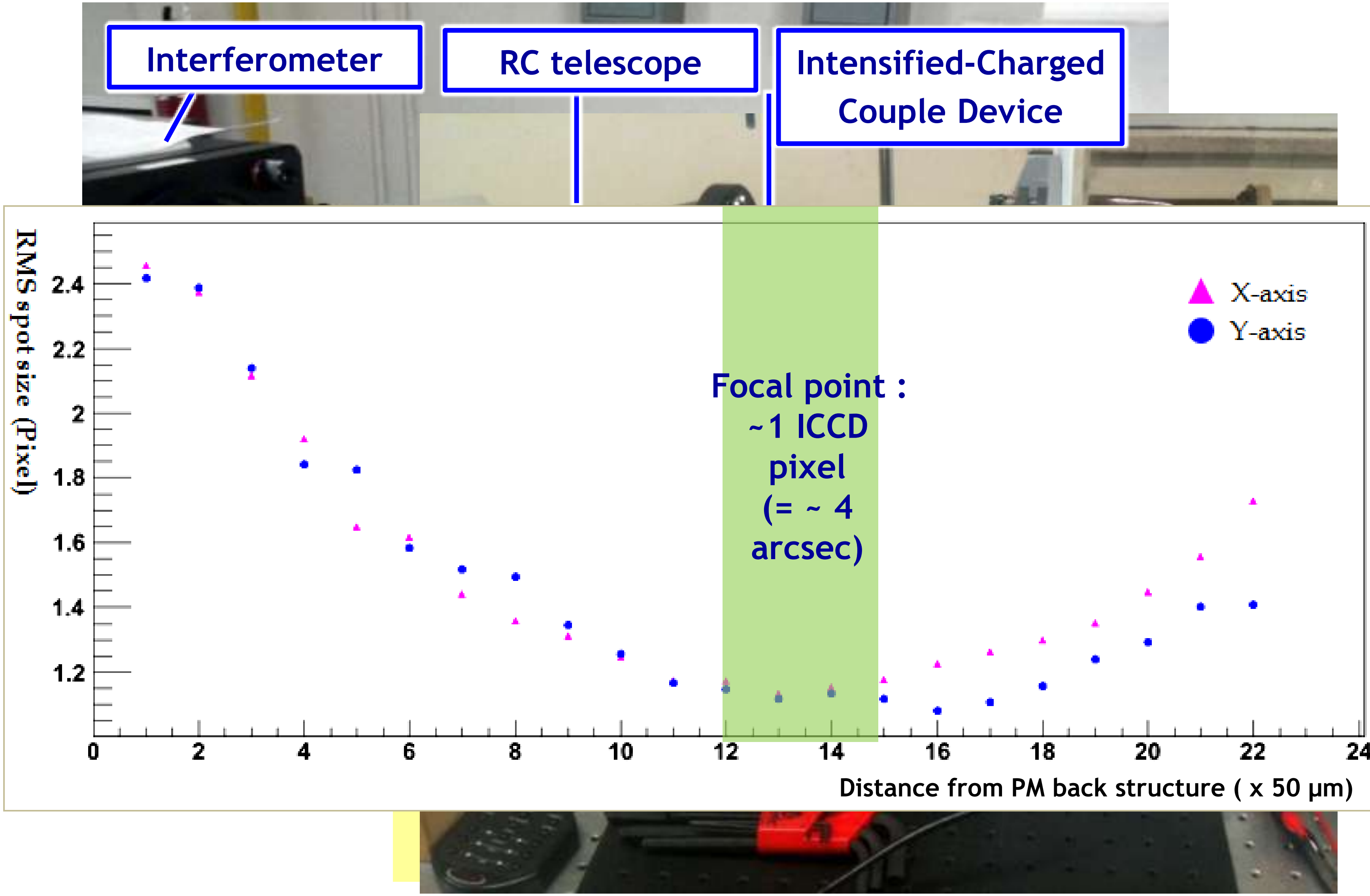
A major breakthrough in this area was the launch of the Swift satellite featuring rapid slewing technology and sophisticated onboard computing that together deliver accurate localizations in less than a minute after the burst is detected. This new way of detecting bursts from space coupled with the development of robotic optical telescopes on the ground capable of autonomous response within seconds of receiving the localization enabled, for the first time, high-fidelity studies of GRBs. In the Swift era multi-wavelength observations within the first few minutes of the explosion became routine and produced an impressive stream of discoveries widely recognized among the top scientific breakthroughs of the last decade. Examples include: 1) firm association of GRBs with the gravitational collapse of massive stars in young stellar populations, 2) discovery of flaring activity in early X-ray and optical light curves of GRBs, and 3) discovery of the prompt optical emission associated with internal shocks in the ultra-relativistic outflows powering GRBs. The game in this field is now shifting to even earlier times requiring even faster response that will allow detailed multi-wavelength studies of the explosion mechanism. The Slewing Mirror Telescope (SMT) onboard the Ultra-Fast Flash Observatory-pathfinder (UFFO-p) is a great step forward in this direction. The paper by Jeong et al. discusses the design, construction, and testing of SMT.

The UFFO-p concept, like Swift, couples the high-energy localization capability of the UFFO Burst Alert Telescope (UBAT) with an immediate optical/UV follow-up using a 10-cm telescope. A major advance of the design by Jeong et al.is the application of the 15-cm flat slewing mirror that effectively allows pointing the optical telescope at any target within the ±35 deg UBAT field of view without slewing the entire spacecraft. This in turn cuts the response time down to approximately 1 second (30-100 times faster than Swift). The telescope is a Ritchey-Chretien design with effective focal length of 1.14 m. The pointing accuracy, determined by the finite spacing between the teeth in the drive gear, is 2.56 arcmin, fully sufficient given the 17-arcmin field of view. The primary mirror, made of Zerodur, weighs only 482 g (57% reduction compared to typical mass) to facilitate fast slewing without excessive torque and recoil. Assuming a further reduction in weight (about 70% total), this design can be scaled to 40-cm aperture weighing approximately 7.5 kg that can still be accommodated on small spacecraft.

The authors devote special attention to testing in preparation to the launch of the instrument onboard the Lomonosov satellite on a 96-minute orbit. This includes thermal analysis, static load tests, slewing mirror performance (speed, pointing accuracy, settling time), optics performance, and an overall system validation test of the flight model. Space environment testing includes measurements of response to thermal shock and vibration. All results were well within the design specifications, indicating that the instrument will survive the launch and deployment for a successful mission. The UFFO SMT promises to be the first space instrument to use fast slewing mirror technology in GRB observation and will deliver critically important multi-wavelength data within the critical first seconds of the explosion.

- Przemyslav Wozniak

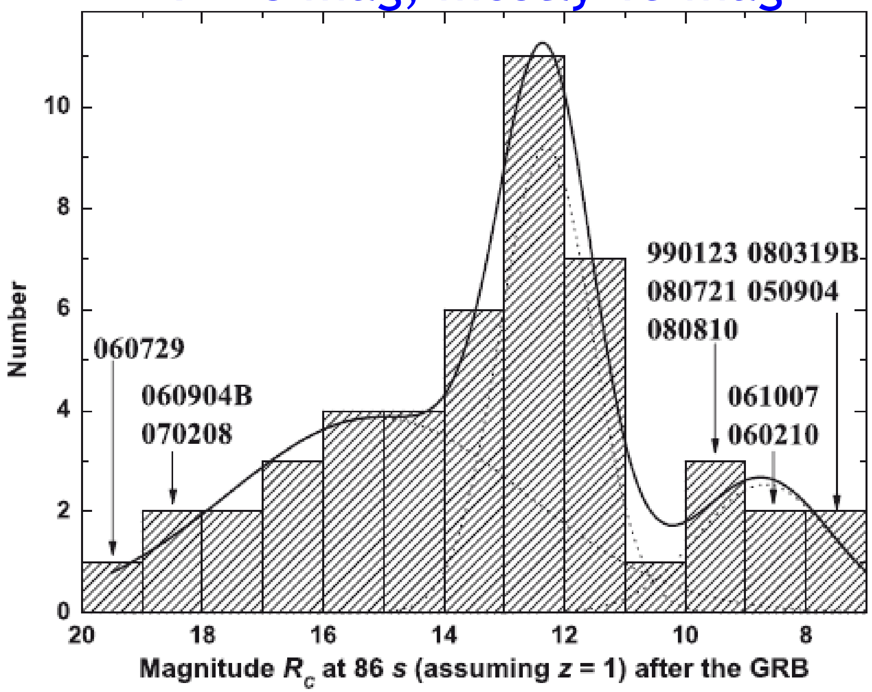
Point Spread Function of ICCD

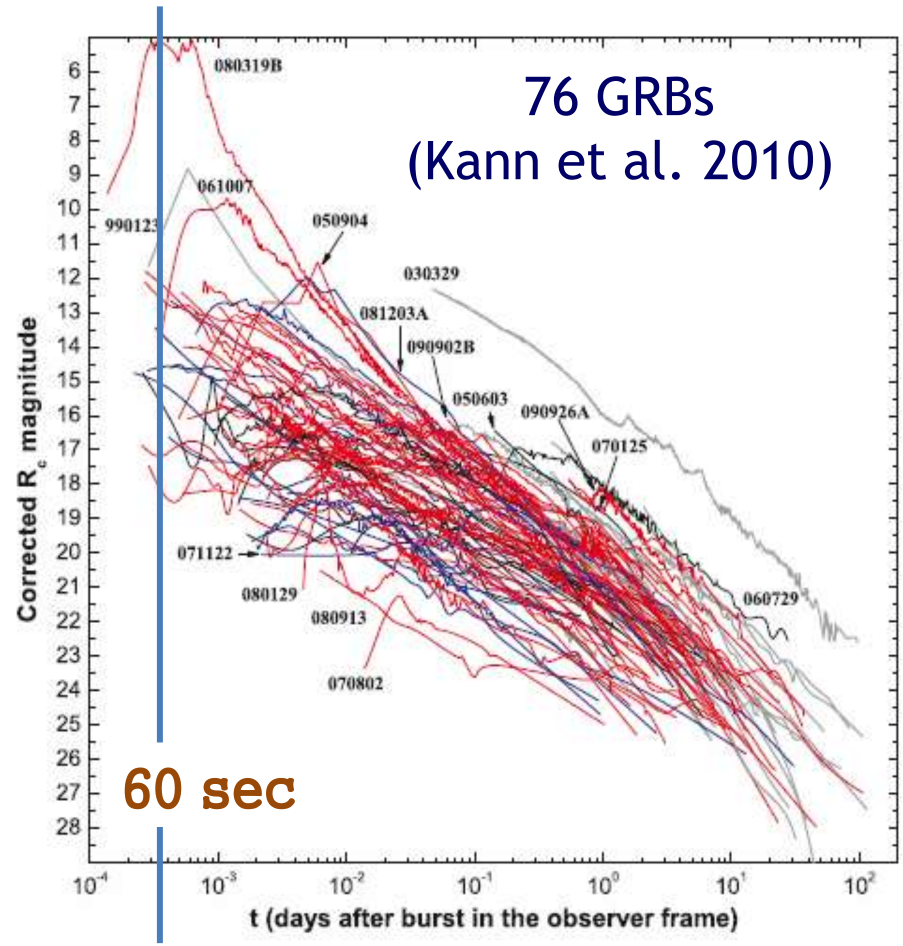


UV/Optical Sensitivity

- Sensitivity of SMT is 19.5 mag for 100 sec
- Should detect long duration GRBs unless they are extinguished by dust in their host galaxies *or* at high *z* (> 6). X-ray and optical measurements

Magnitude at 86 sec after trigger:
7 ~ 8 mag, mostly 13 mag

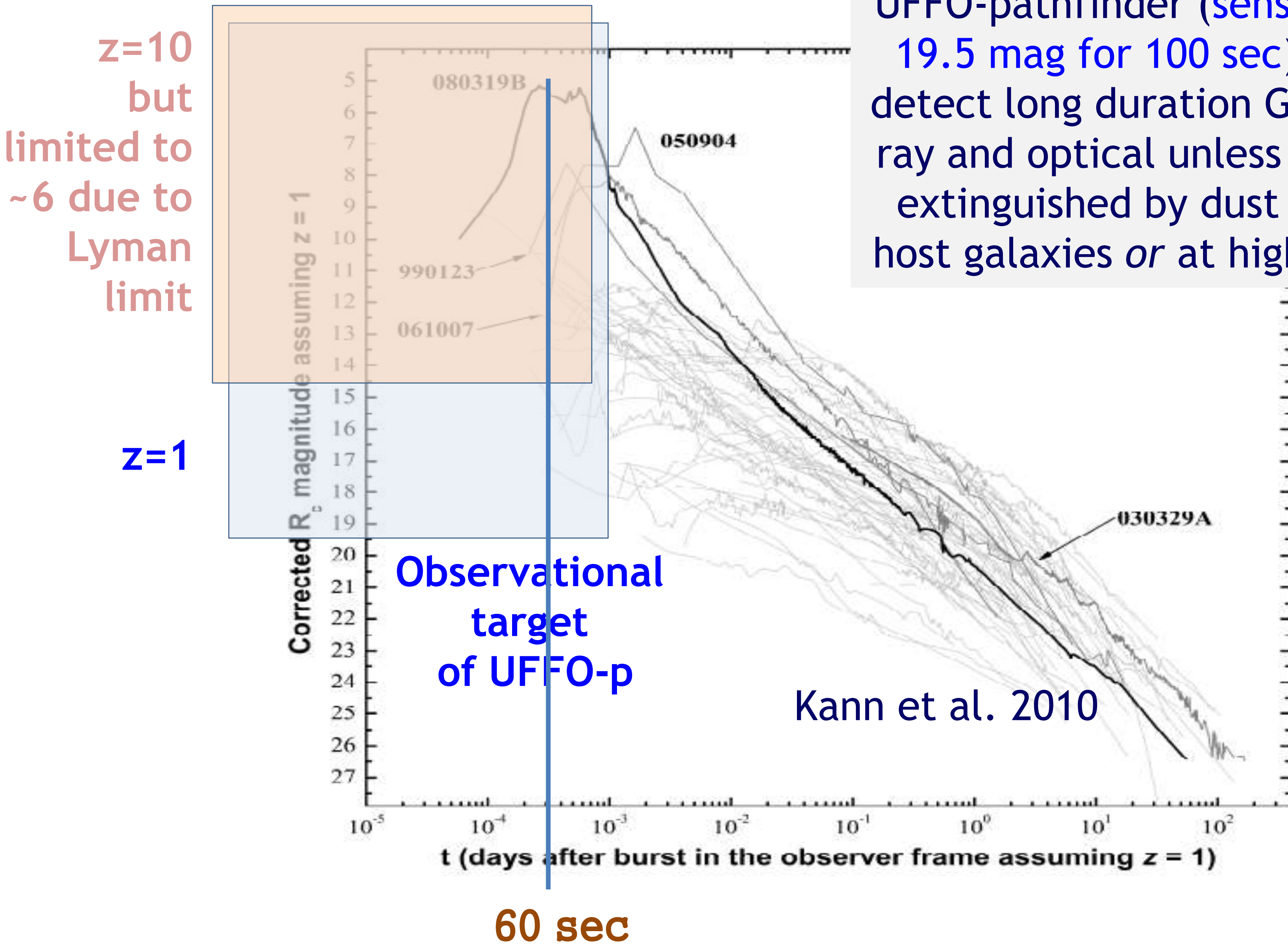




See Fall 2012 GRB (Marbela) EDP Proceedings

Optical Sensitivity at Early Time with Redshift

UFFO-pathfinder (sensitivity of 19.5 mag for 100 sec) should detect long duration GRBs in X-ray and optical unless they are extinguished by dust in their host galaxies *or* at high *z* (> 6).



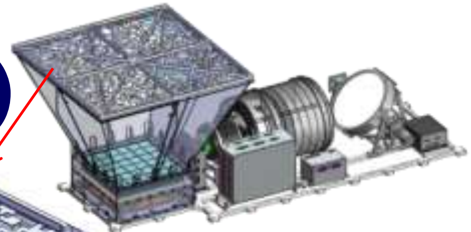
Specification of SMT

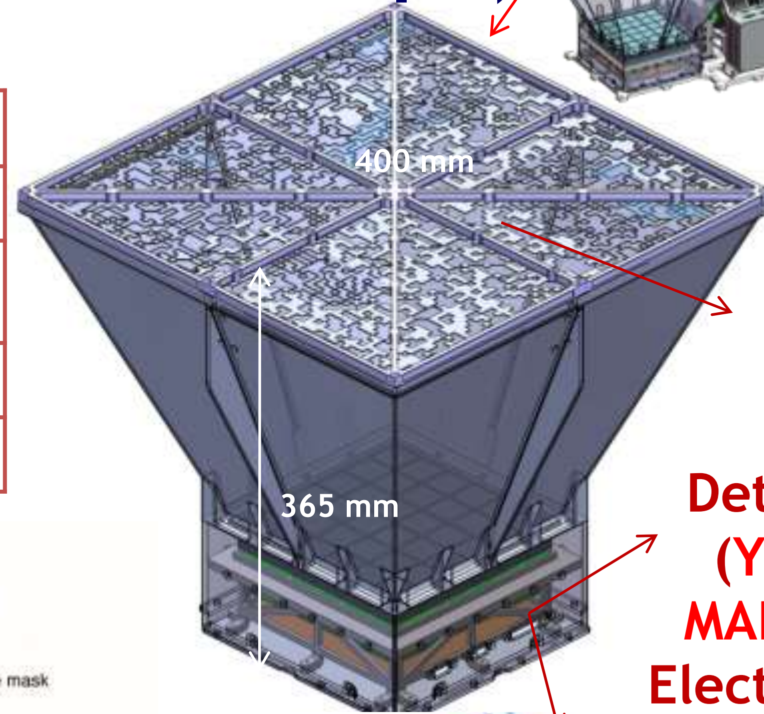
Parameter	UFFO-pathfinder	UFFO-100	*Swift*
Telescope type	Ritchey-Chrétien + Slewing mirror	Modified Ritchey-Chrétien + Slewing mirror	Modified Ritchey-Chrétien
Aperture	10 cm	40 cm	30 cm
Field of View	17 × 17 $arcmin^2$ over 70 × 70 deg^2	17 × 17 $arcmin^2$ over 90 × 90 deg^2	17 × 17 $arcmin^2$
Wavelength range	200~650 nm	200~1100 nm	170~650 nm
Number of pixels	256 × 256	256 × 256	256 × 256
Physical pixel scale	4 arcsec	4 arcsec	4 arcsec
Telescope PSF(centroiding)	0.5 arcsec	0.5 arcsec	0.5 arcsec
UV/optical/NIR Sensitivity	B = 19.5 mag in 100 sec with 5σ	UV/optical = 21.5 NIR = 23.5 mag in 100 sec (5σ)	B = 24 (22.3) mag in 1000 sec with 5σ
Data taking start time after trigger	1 sec	0.01~1 sec	40~200 sec, typically 80 sec
Number of UV/optical observation / year	10~20 (estimated from the extrapolation of early light curves)	30~40	~40

X-ray Instrument

UBAT (UFFO Burst Alert Telescope)

UBAT (UFFO Burst Alert Telescope)



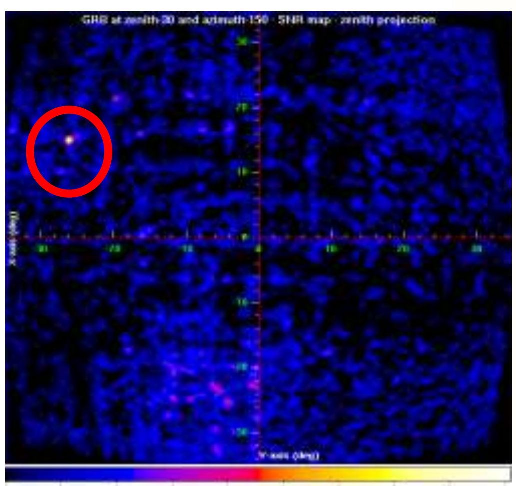


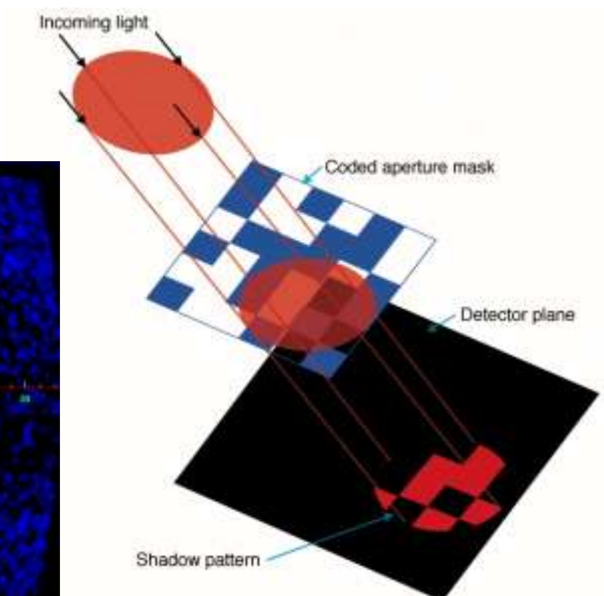
"Design" values of parameters

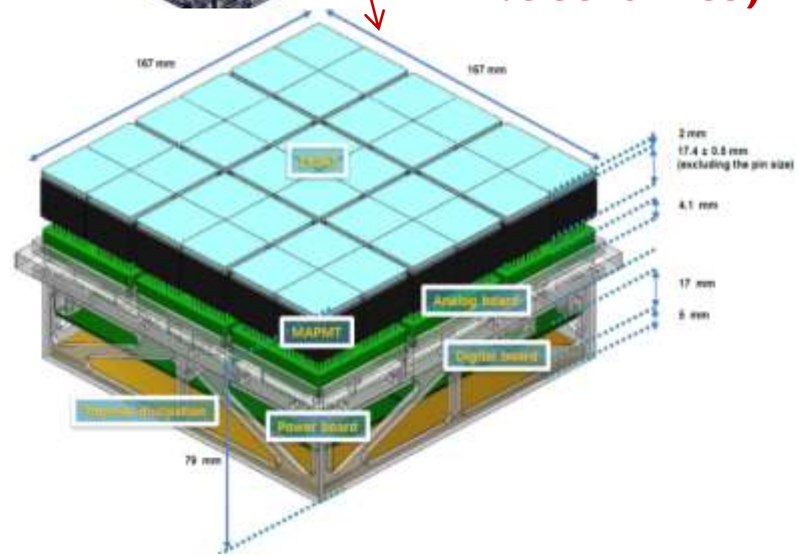
Telescope	Coded mask aperture
Field of view	90.2° x 90.2°
Source position accuracy	≤ 10 arcmin for > 7σ
Energy range	15 - 150 keV
Processing time	a few seconds

Coded Mask

Detector (YSO + MAPMT + Electronics)

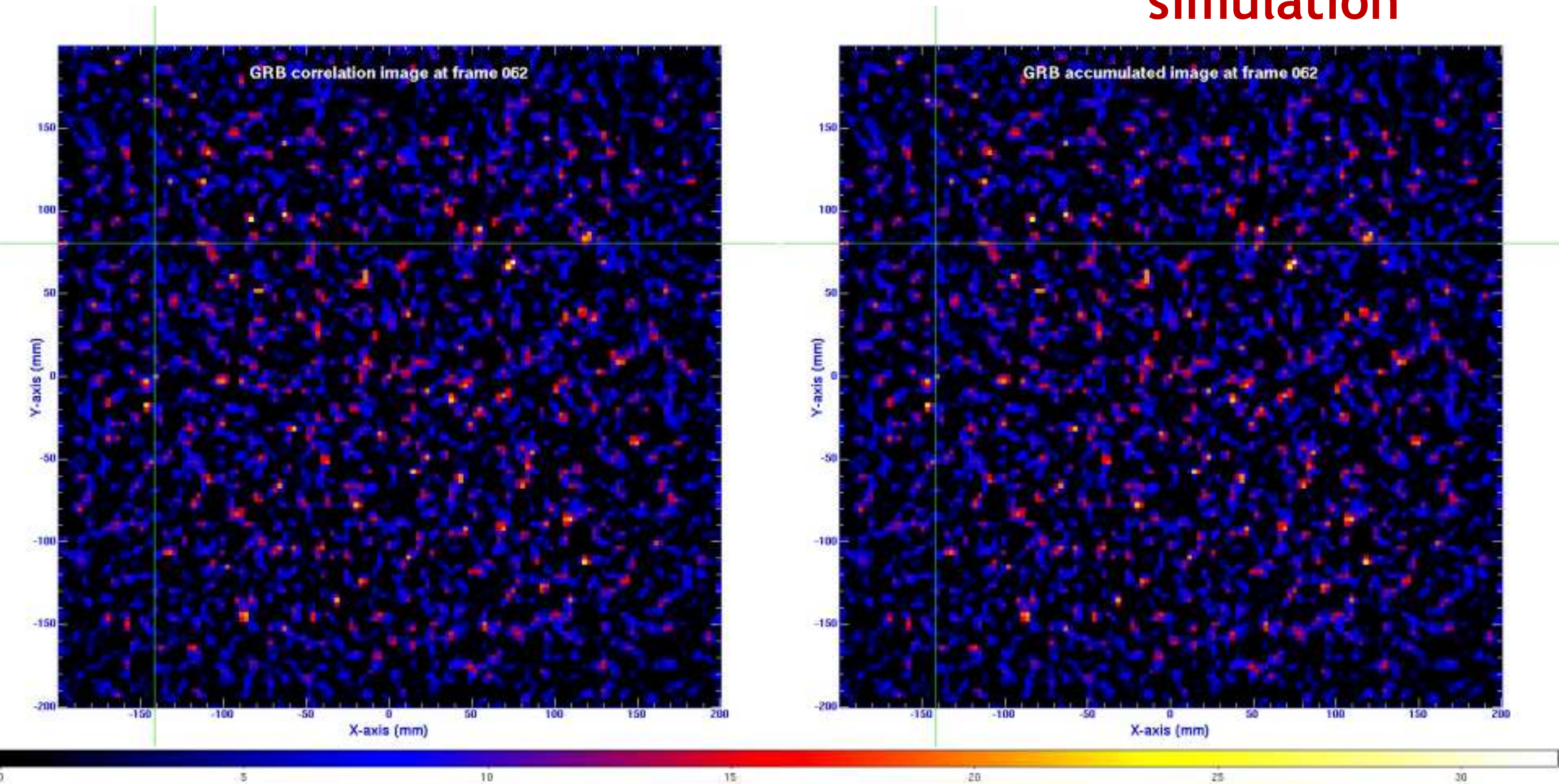


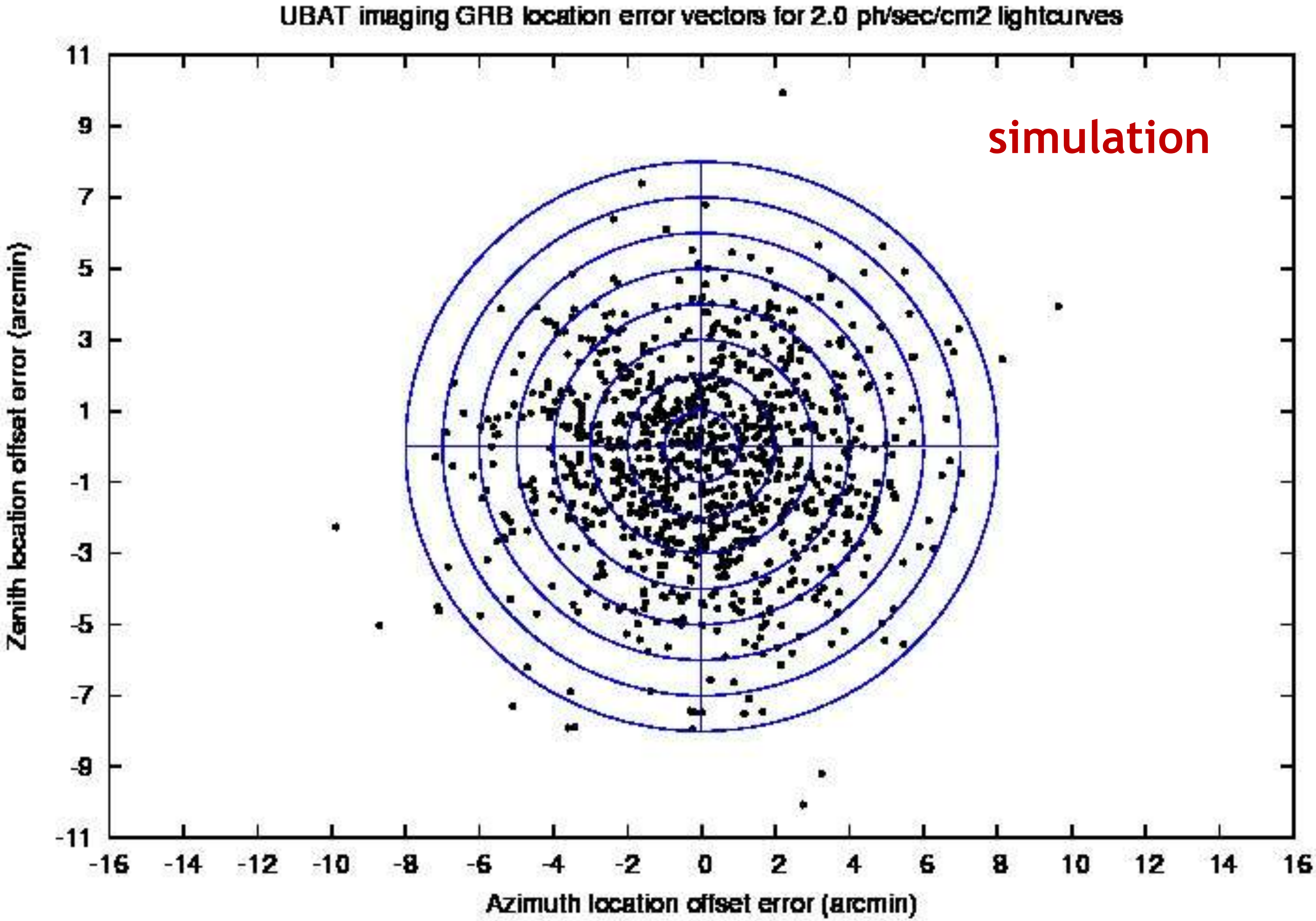




Video of correlation imaging time evolution for an off-axis source

simulation

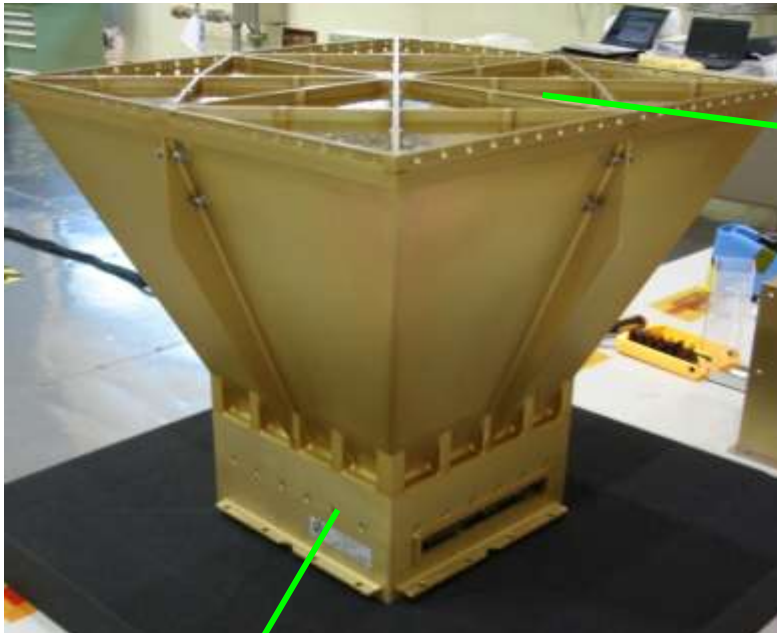


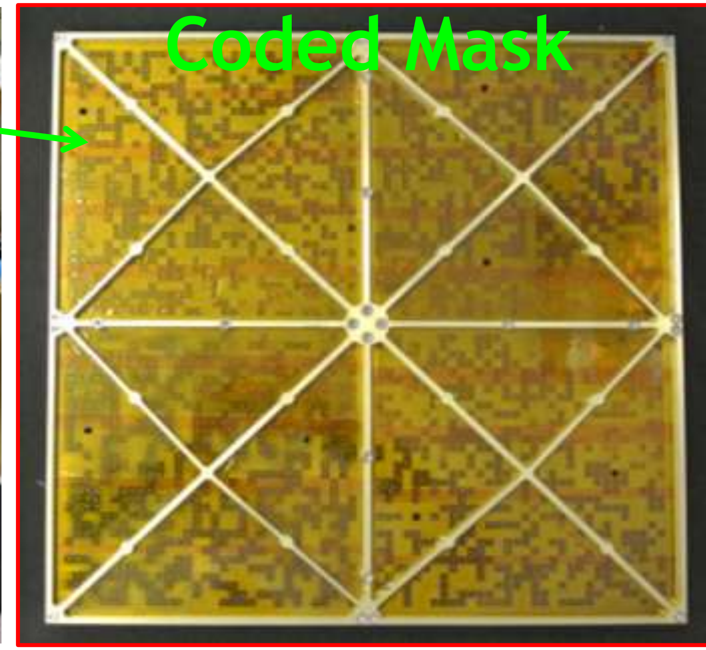


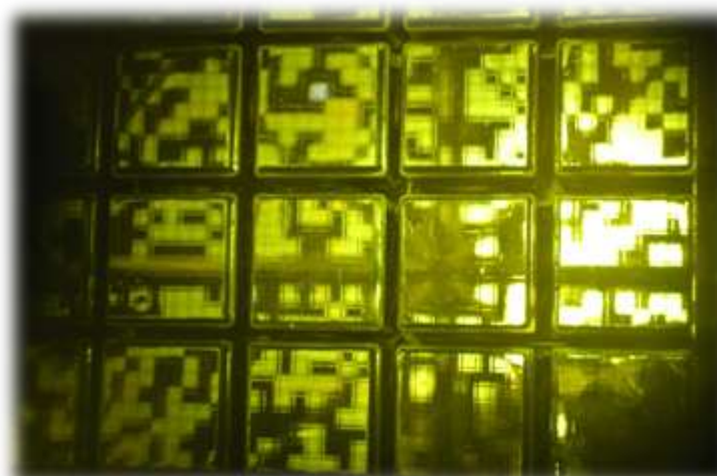
UBAT GRB location estimate error-vector scatter diagram

UBAT (UFFO Burst Alert Telescope, X-ray)

- Coded mask aperture camera
- FOV: 90.2° x 90.2°
- Fully coded FOV: 45.1° x 45.1°
- Source position accuracy: ≤ 10 arcmin for > 7σ
- Energy range: <5~200 keV
- Mask size: 400x400 mm2
- Detector pixel size: 2.5x2.5 mm2
- Total 48x48 pixels

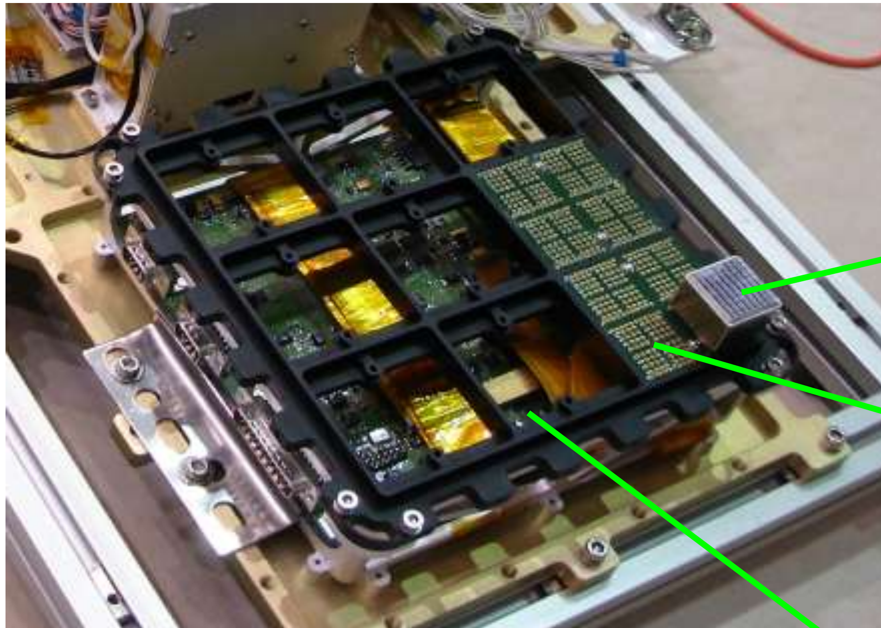






UBAT Detector

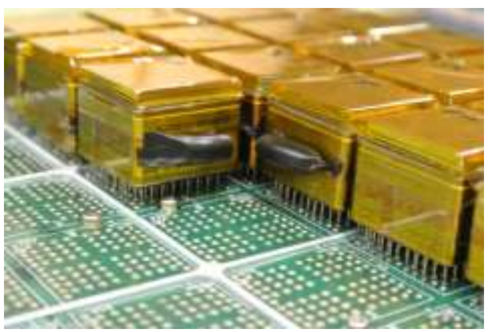
- 191 cm2 active area
- YSO crystal + MAPMTs
- Total 48 x 48 pixels
- Detector pixel size: 2.5x2.5 mm2
- Energy range: <5~200 keV



Analog Boards

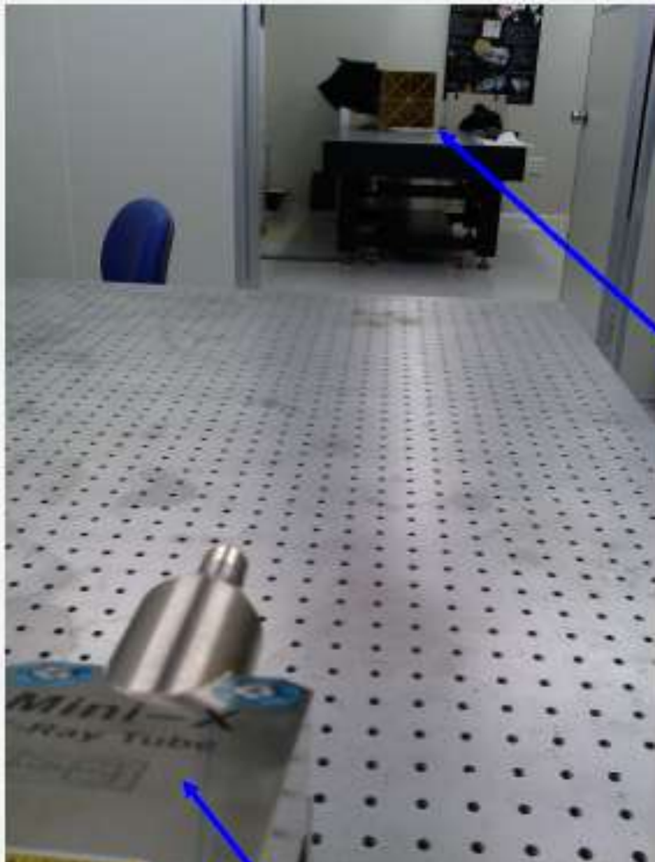
Digital board

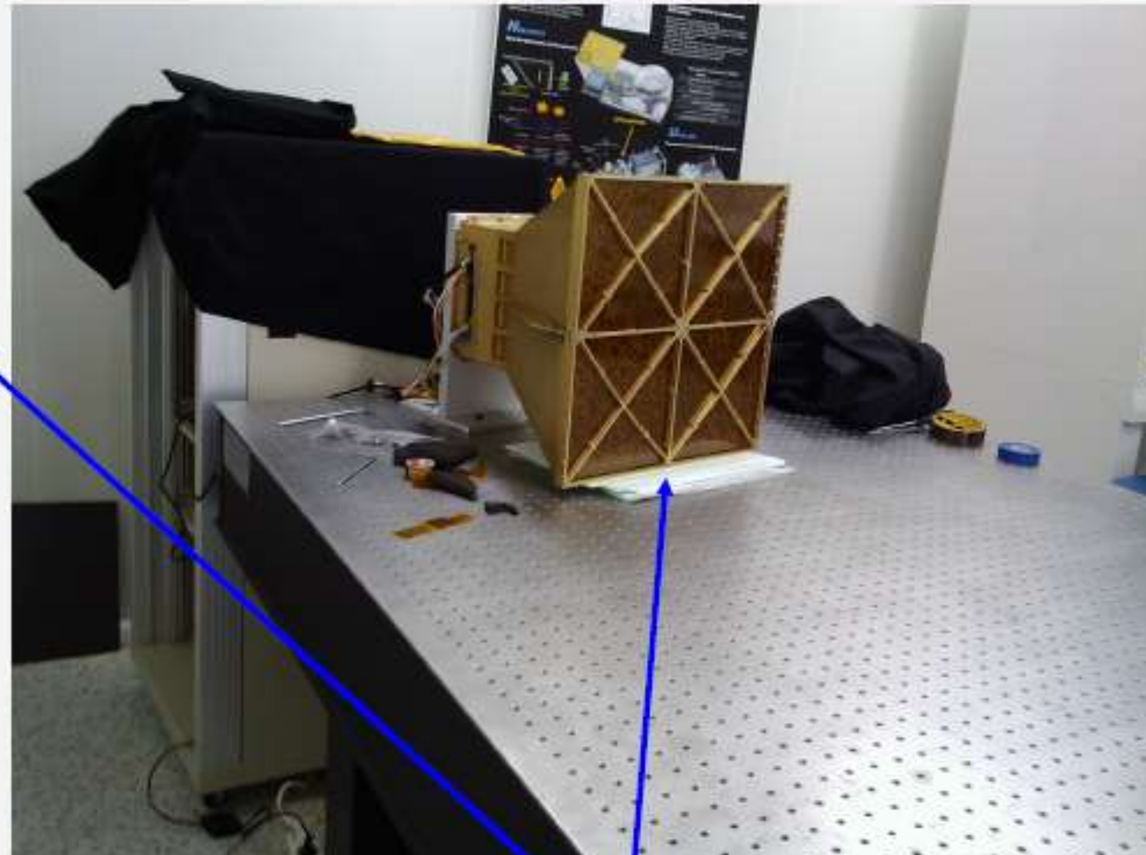
HV board



X-ray Source Test (April 2013)

We used Amptek Mini-X ray tube placed at distance 6.98 m from top of YSO crystals on UBAT's axis. The source was set to produce X-rays up to 50 keV. The source flux at 6.98 m was 25x of background level.



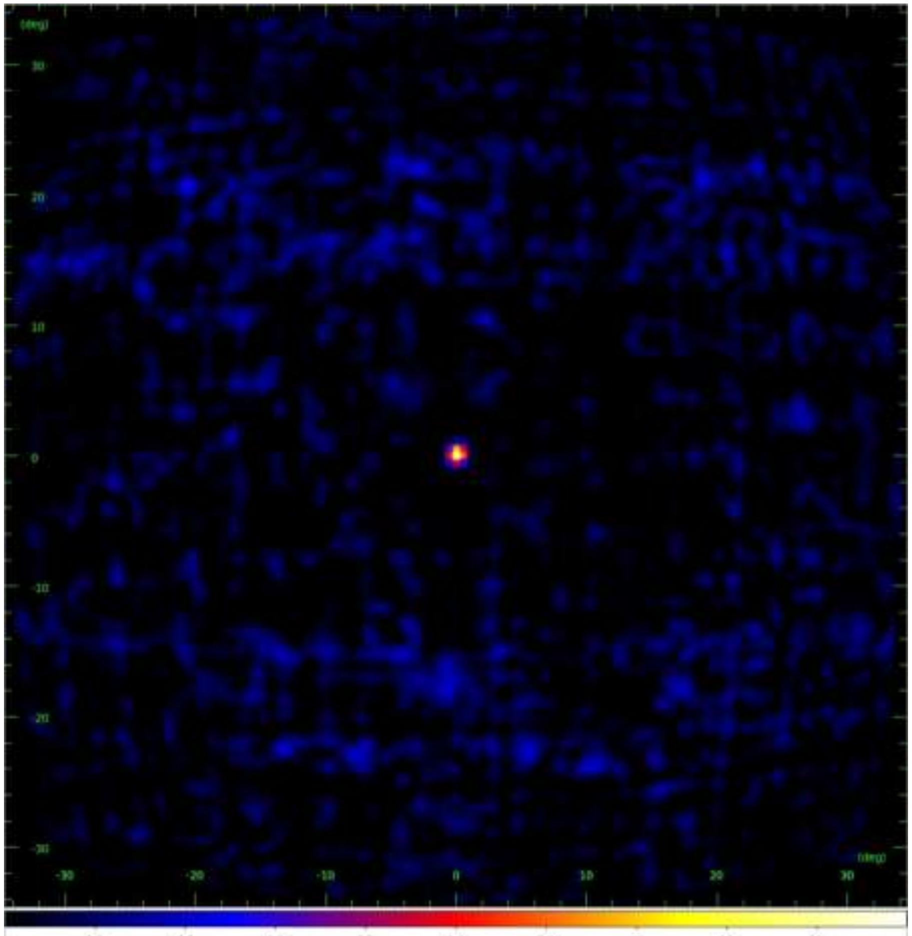


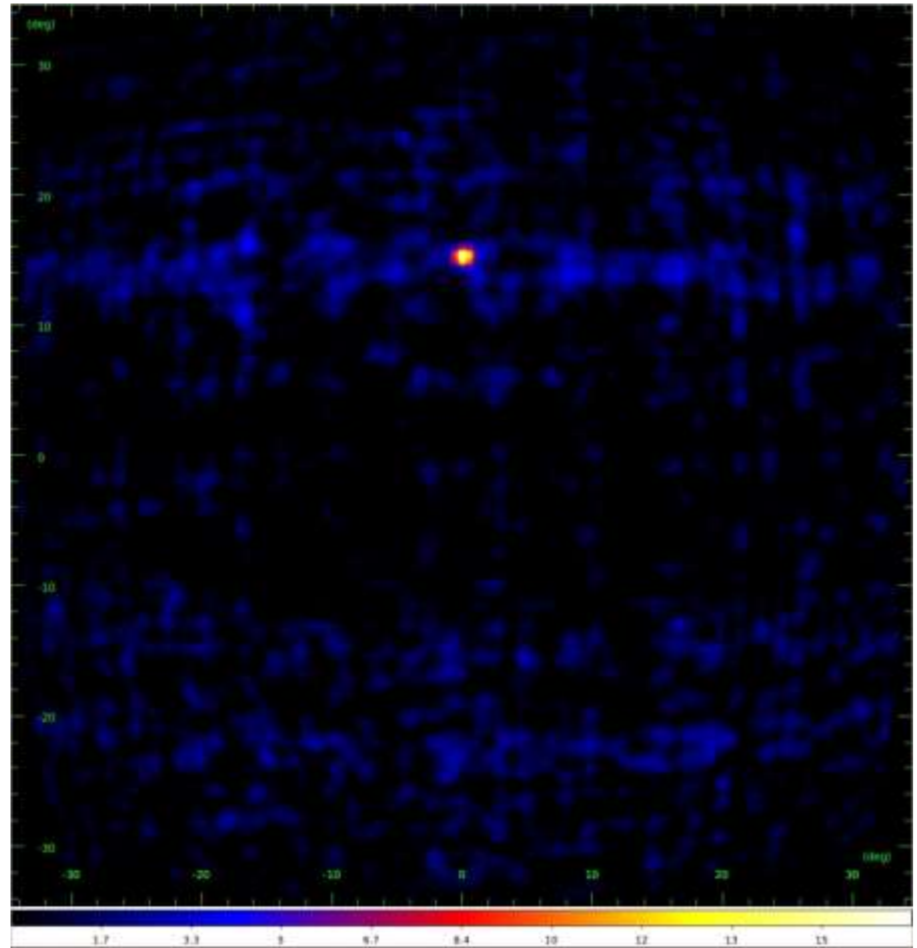
X-ray tube

UBAT

Reconstructed X-ray image ! (April 2013)

- Image as an SNR map for 1 s of exposure time.
- Maximum SNR in the image: 16.4 (left) and 16.7 (right)
- Position: (X,Y)=(0.046,0.110) deg (left) and (0.098,15.256) deg (right)



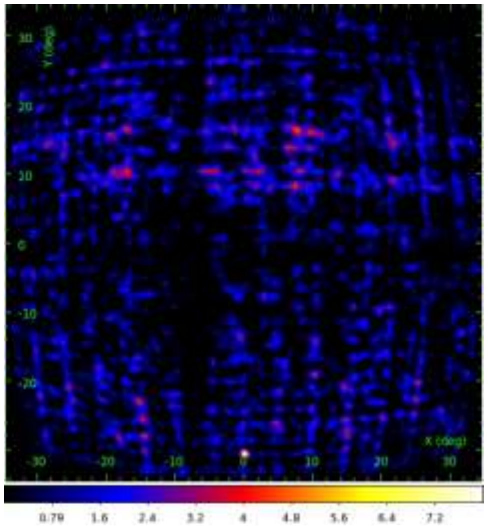


- X-ray source with energy up to 50 keV, placed at 7 m away from the detector
- Source flux is ~25x higher than background level (from dosimeter)
- 6 MAPMTs out of 36 were not included in imaging (4 missing and 2 problematic, to be replaced)

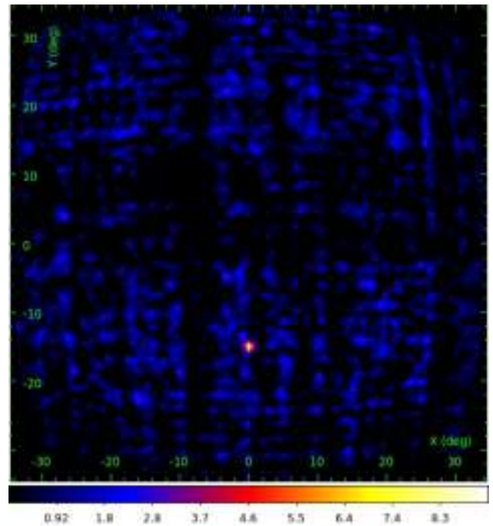
Reconstructed X-ray image ! (April 2013)

- X-ray source with energy up to 50 keV, placed at 7 m away from the detector, exposed for 3 sec
- Source flux is ~1.8 cnts/sec/cm2, background is 1.1 cnts/sec/cm2
- 6 MAPMTs out of 36 were not included in imaging (4 missing and 2 problematic, to be replaced)

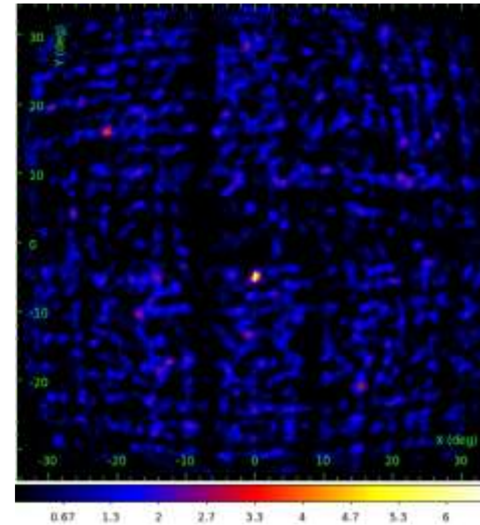
X≈0.0° ; Y≈-30.0°(partially coded)



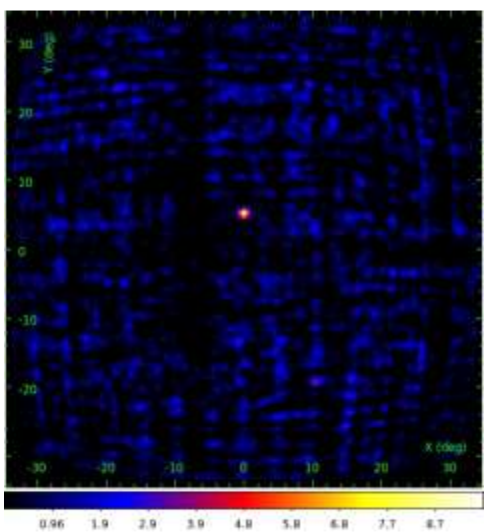
X≈0.0° ; Y≈-15.0°(fully coded)



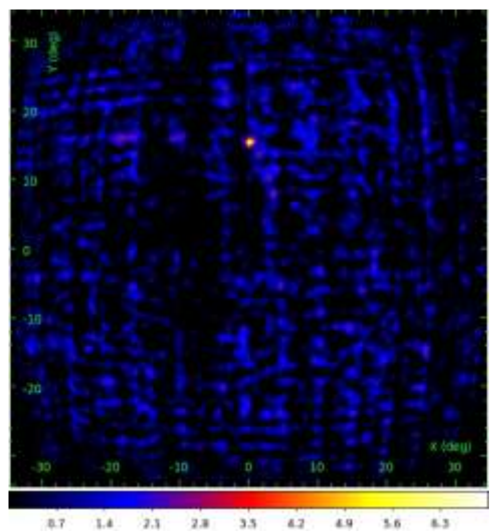
X≈0.0° ; Y≈-5.0°(fully coded)



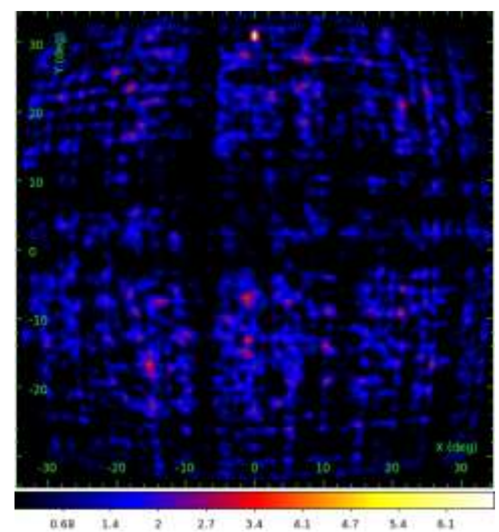
X≈0.0° ; Y≈+5.0°(fully coded)



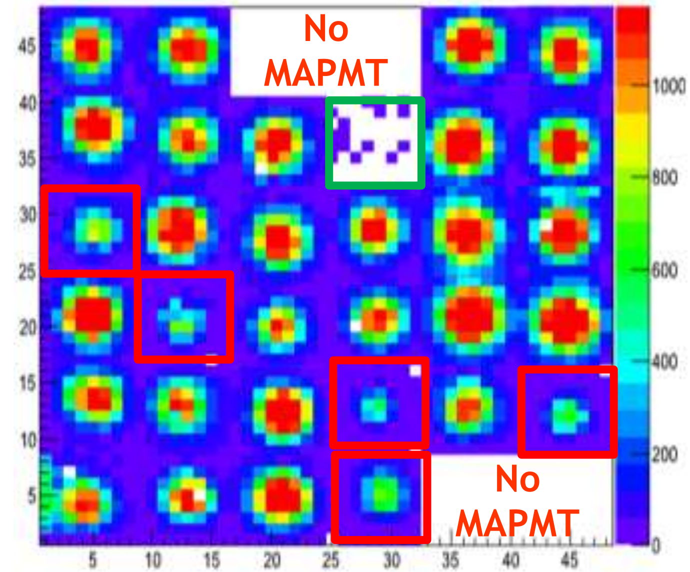
X≈0.0° ; Y≈+15.0°(fully coded)

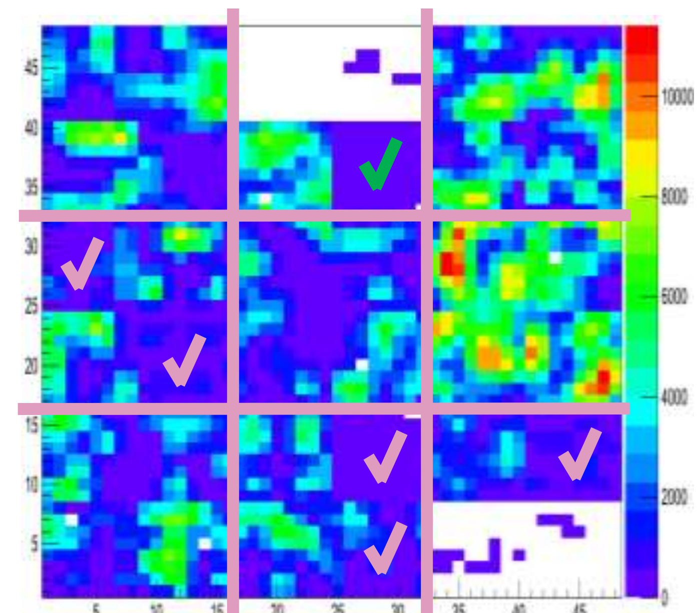


X≈0.0° ; Y≈+30.0°(partially coded)



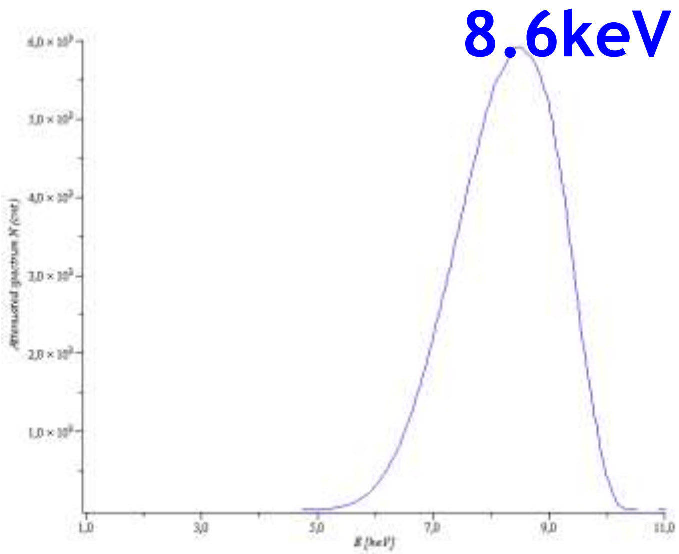
2nd set of UBAT detector (April 2013)

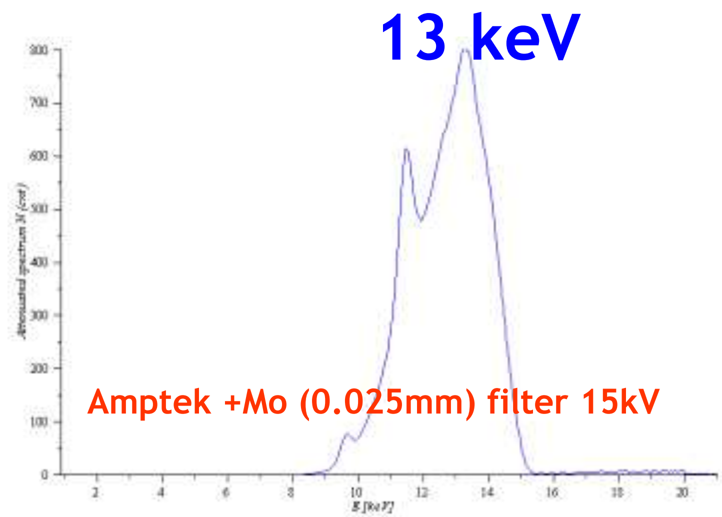


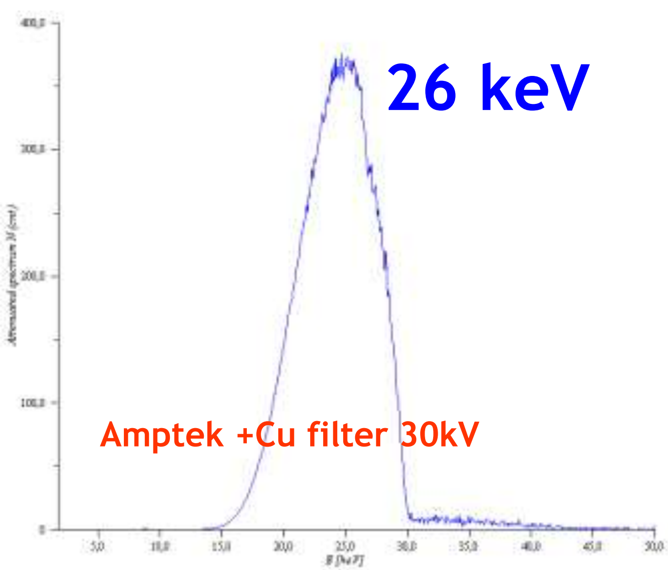


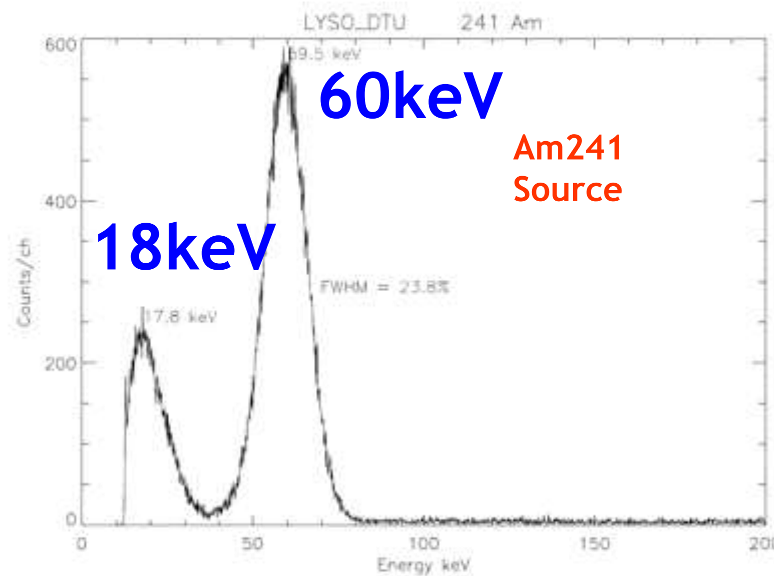
Illuminated by Am241 (upper right) and Amptek x-ray tube (bottom right)

Input X-rays to measure UBAT sensitivity

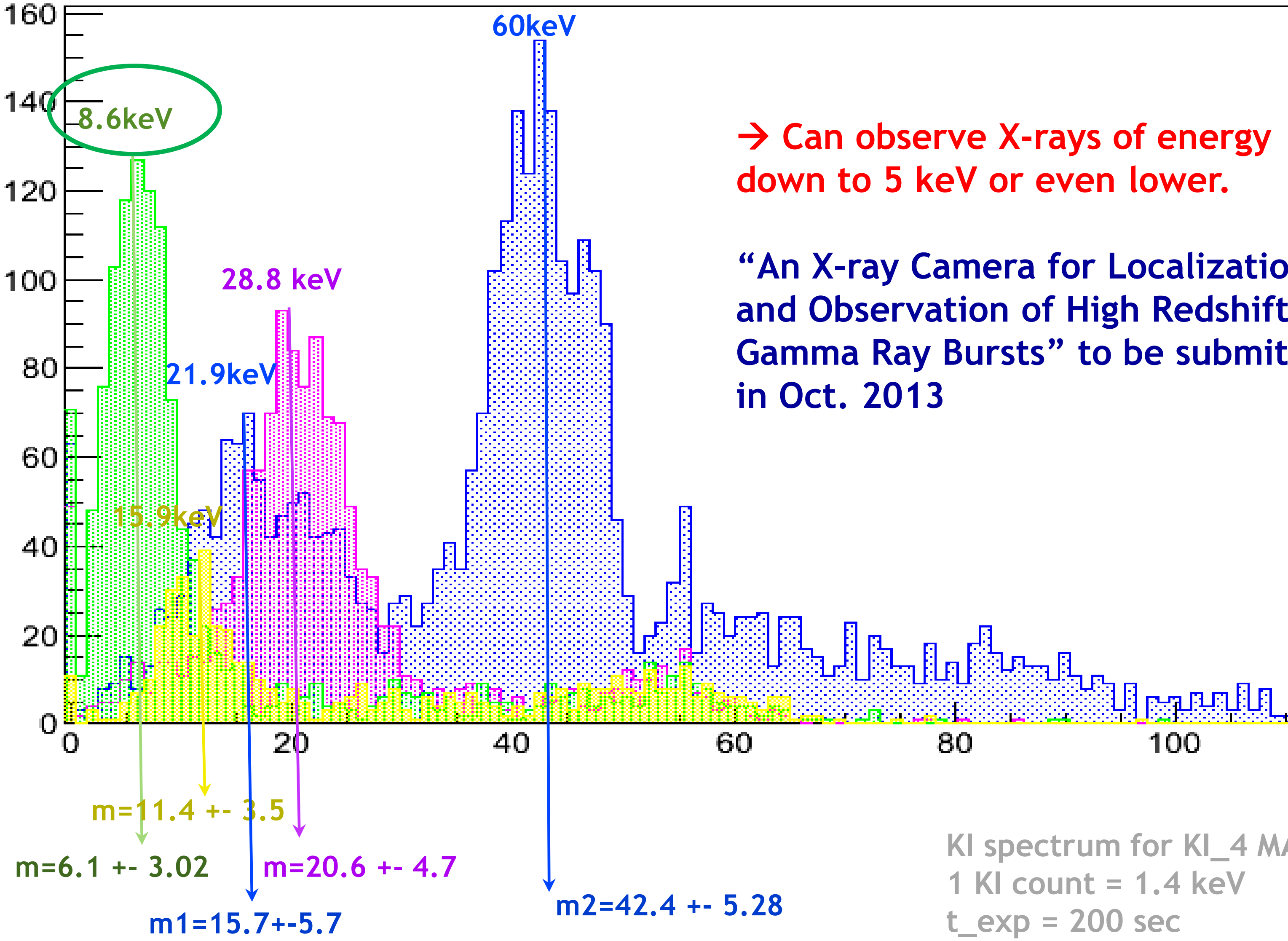








UBAT Sensitivity Measured (April 2013)



→ Can observe X-rays of energy down to 5 keV or even lower.

"An X-ray Camera for Localization and Observation of High Redshift Gamma Ray Bursts" to be submitted in Oct. 2013

KI spectrum for KI_4 MAPMT# 11
1 KI count = 1.4 keV
t_exp = 200 sec

Fast Response of UBAT: Small Size but Fast Trigger

- All readout/trigger/control/housekeeping/bus-interface implemented into several FPGAs, no CPUs
- Trigger latency in electronics: ~0.1 second → fast response

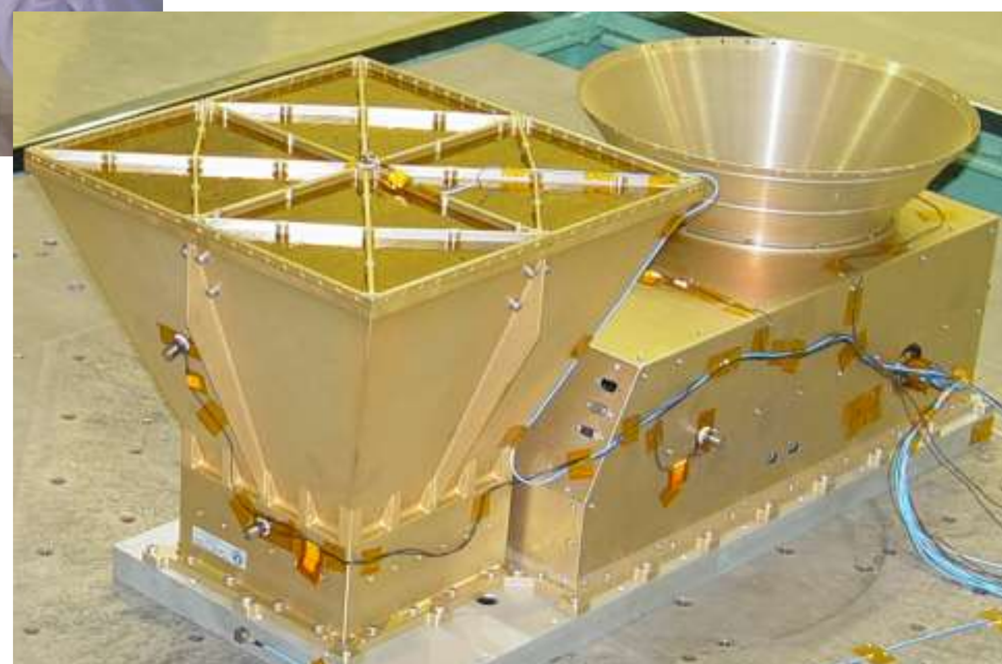
	X-ray collection for trigger	Trigger calculation	Slewing	Optical observation
UFFO-p	1 sec for bright GRB	0.1 sec	1 sec	
Swift	40 msec for bright GRB	5~7 sec	100 sec	

~100 X-rays/sec hit the UBAT detector, assuming that GRB signal rate is 1/cm2/sec and background 2/cm2/sec, while ~100 X-rays/40msec hit the Swift BAT

Parameters & expected performance of UBAT

Parameter or performance	UFFO-p/Lomonosov	UFFO-100	Swift
Detector	YSO crystal + MAPMT	Silicon strip and [YSO + SiPM)]	CdZnTe
UBAT Field of View (half coded)	90.2×90.2 deg^2 (1.8 sr)	90.2×90.2 deg^2 (1.8 sr)	100×60 deg^2 (1.4 sr)
Detection area	191 cm^2	1024 cm^2	5240 cm^2
Detection element	48 × 48 pixels	64 × 64 pixels	256 × 128 pixels
Pixel size	2.8 × 2.8 mm^2	2 × 2 mm^2	4 × 4 mm^2
Sensitivity	5~150 keV	3~300 keV	15~150 keV
GRB localization error	10 arcmin	4 arcmin	1~4 arcmin
X-ray collection time / GRB position calculation time	1~64 / 0.1 sec	0.1~64 / 0.01 sec	0.025~64 / 5~7 sec
Number of GRB localization per year	20~30 (duty cycle and fluence taken into account)	~70	~ 100

Thermal/Vacuum/Shock/Vibration Test of UFFO/*Lomonosov* at NSPO, Taiwan (July 2011)



FM of UFFO/*Lomonosov* Delivered to NIIEM

SMT final validation in NIIEM, Moscow (April 2012)

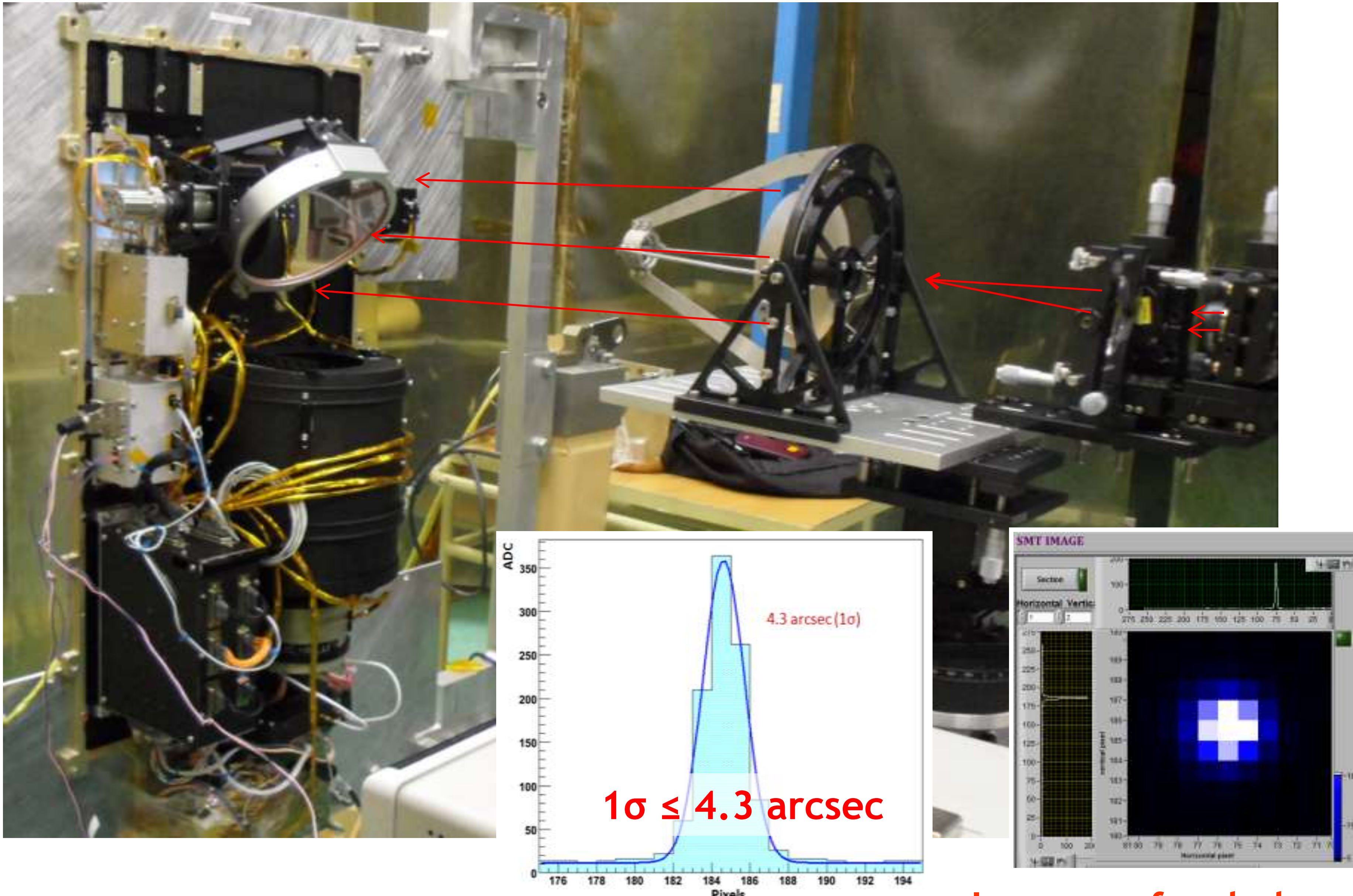
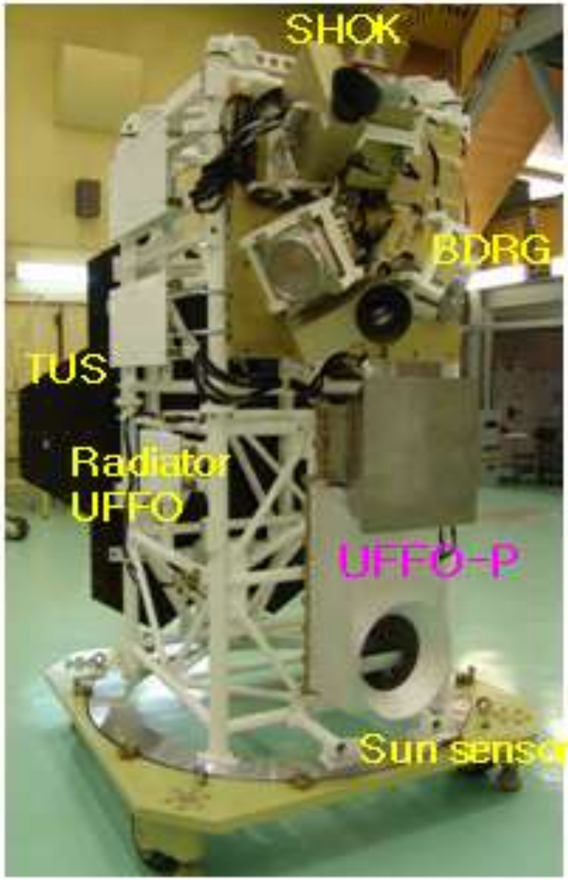


Image on focal plane

Integration to Platform Structure at NIIEM, Moscow (Oct. 2011 ~ Jun. 2012)



Institutional Partners of UFFO

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- Yonsei U.
- KAIST
- U. de Valencia
- CSIC-IAA
- INTA
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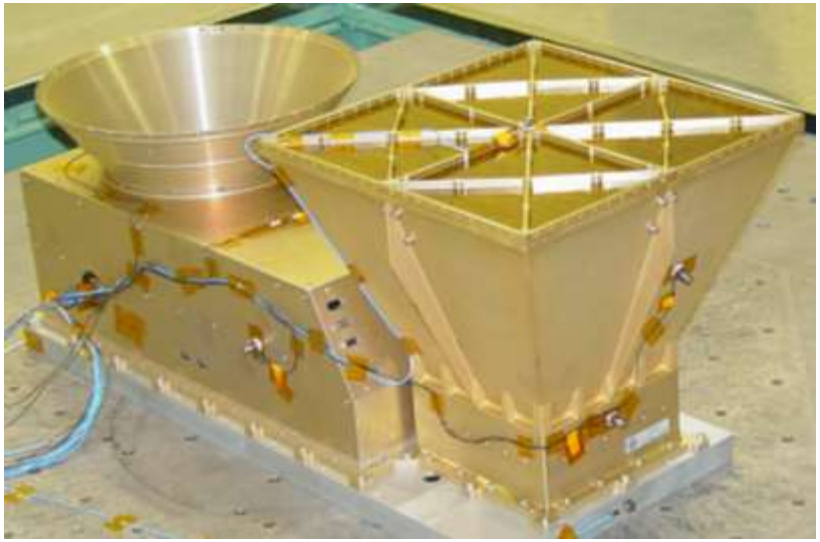

Summary

- GRBs are unique probes for physics including studies of early/extreme/dark universe, fundamental physics
- In spite of great success of Swift, it leaves many unknowns and many exciting features that should be explored by future missions by exploring a new domain of time and color, as well as increasing sensitivity (photometry, spectroscopy, polarimetry), to gain insight into the progenitors, environments, abundances, metallicities, host galaxies... Multi-messenger information also highly valuable.
- UFFO will open a new time domain of GRB optical emission in the first few seconds, and foresees triggers of high redshift GRBs with fast alerts to ground robotic telescope (e.g. BOOTES network)
- UFFO/*Lomonosov* is to be launched in 2014 !

Thanks SINP, NIIEM, VNIIEM, NSPO and institutional partners of UFFO