GWPAW June 4–7, 2012

Optical, X, gamma, neutrino follow-ups of KAGRA candidate GW sources

- Short GRB: properties and GW counterpart detection strategy
- Follow-up resources: MAXI, ground telescopes
- Supernova: new development of neutrino detector

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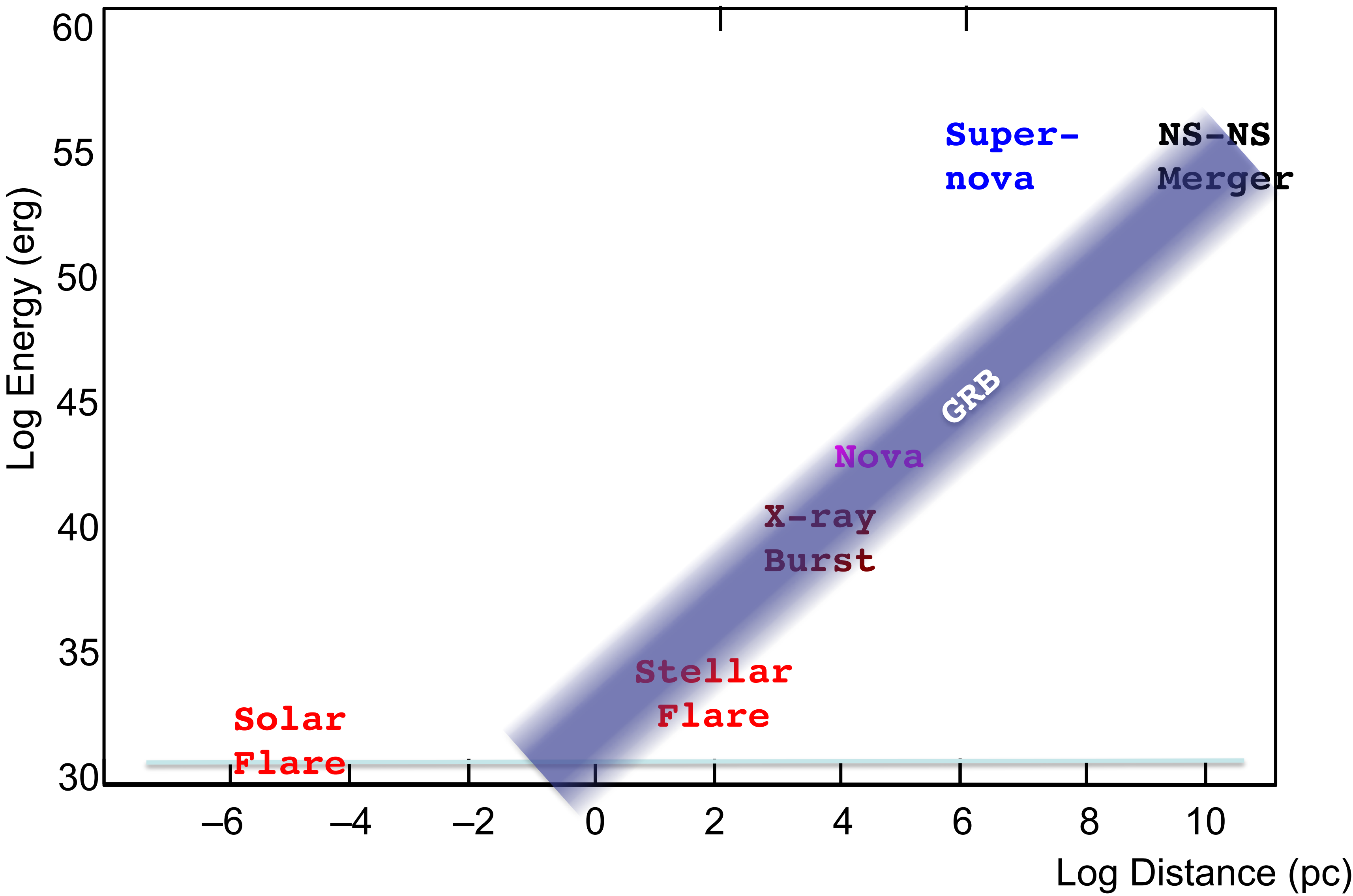
Short GRBs

- "Short GRB" is the prime candidate for EM counterpart of promised GW source (NS merger)

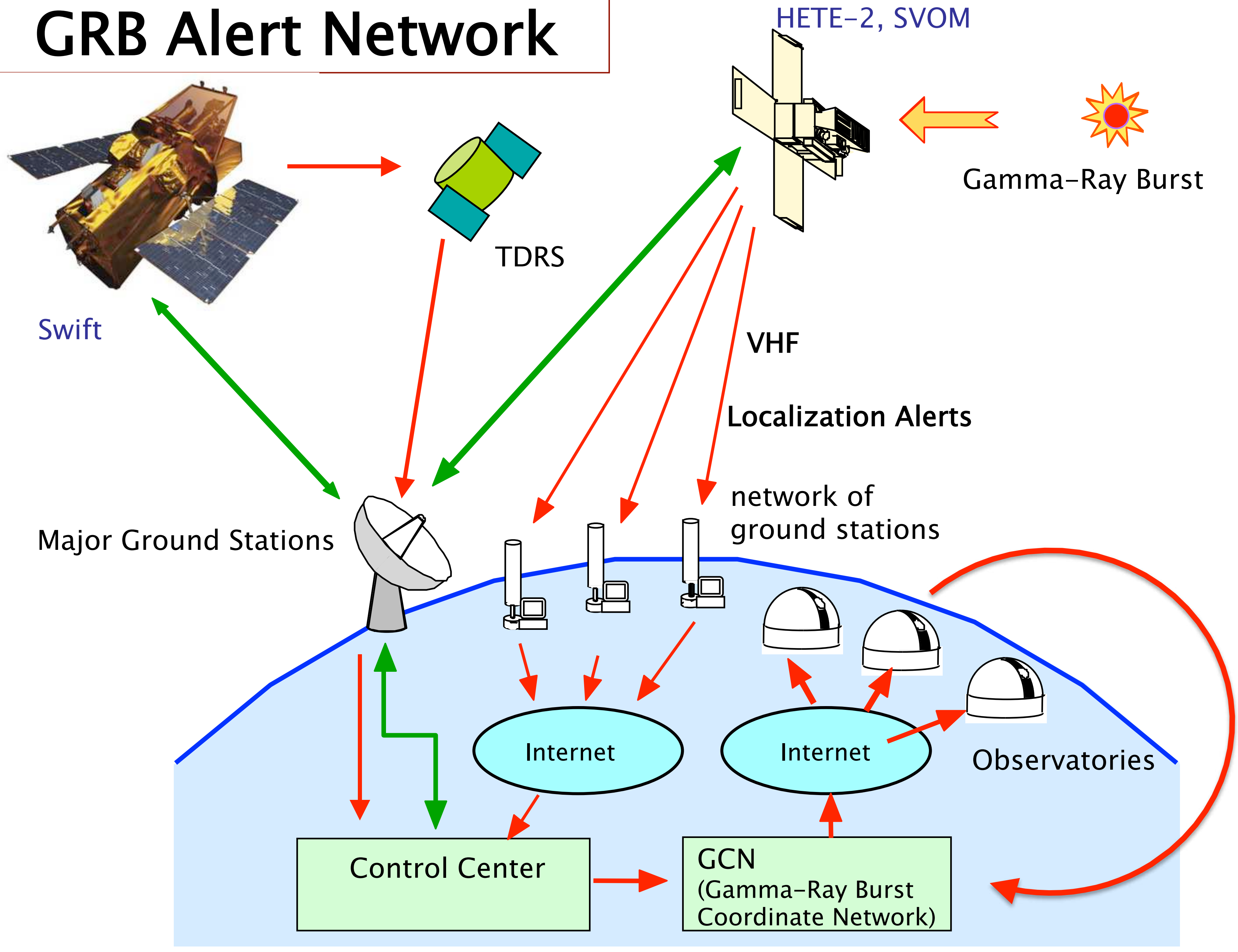
- Lessons from the history of GRB research
  - Cosmic source with poor localization
    - First detection (~1967, published in 1973)
    - First identification of counterpart (1997)

Energy vs distance

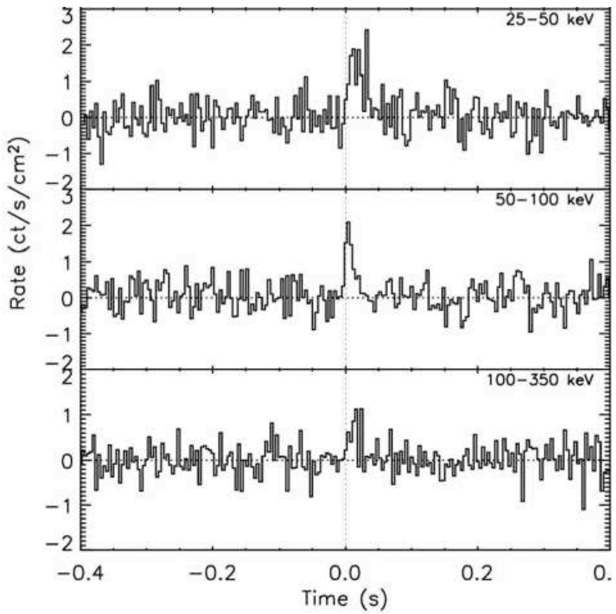
(at reasonable occurrence rates)

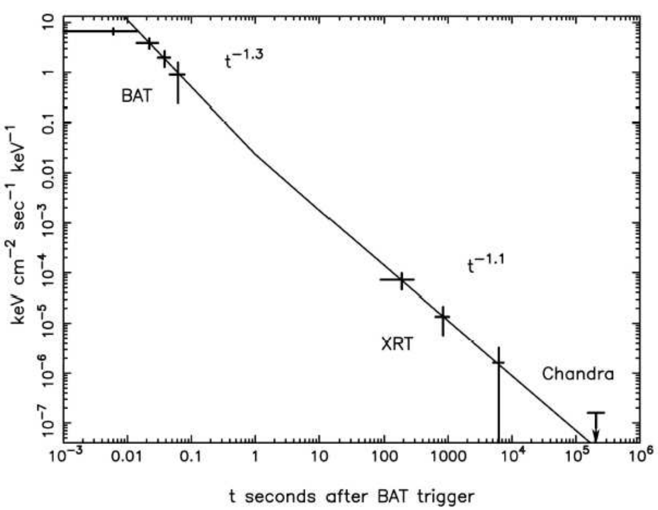


GRB Alert Network



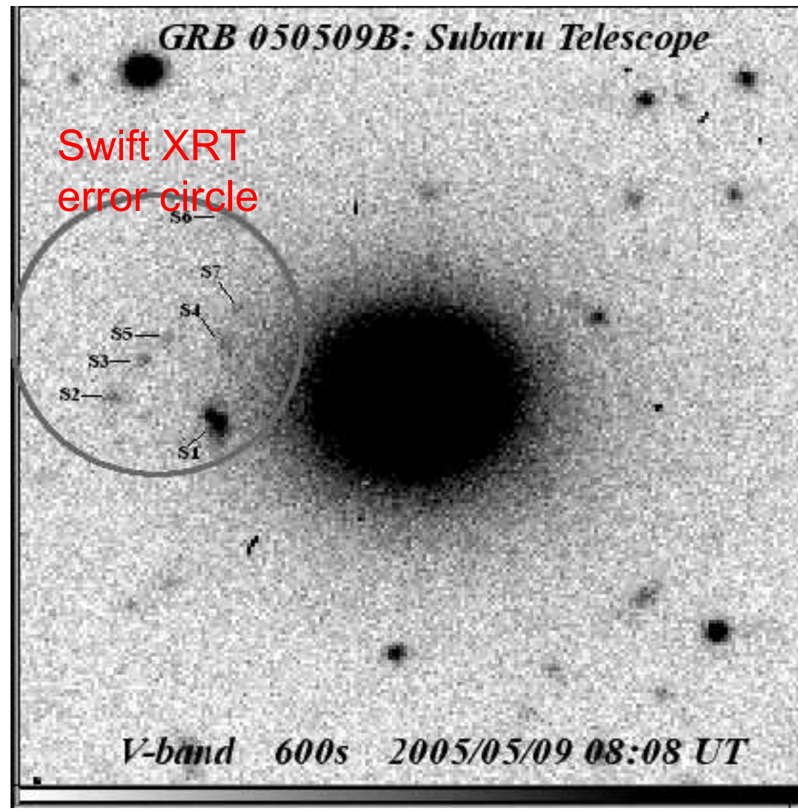
GRB 050509B – first short GRB with arcmin localization





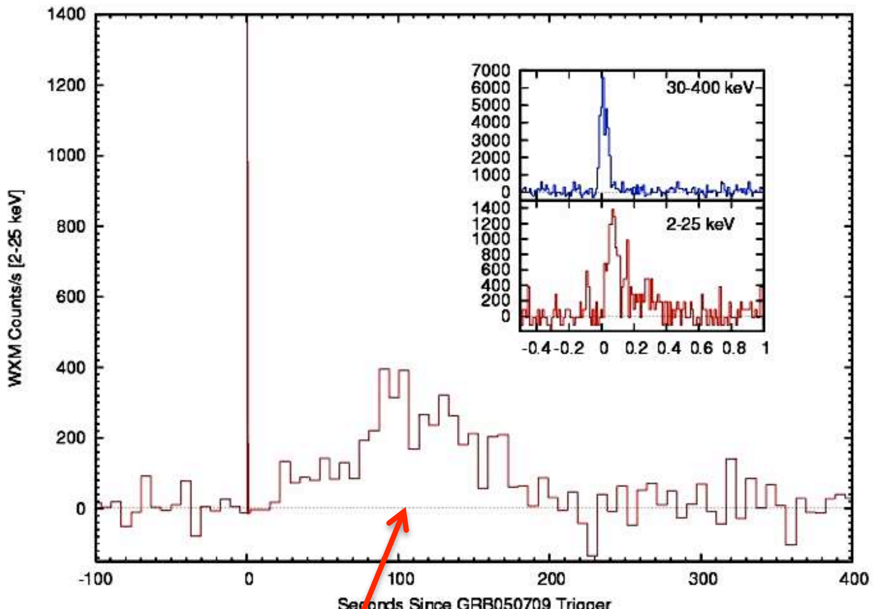
Gehrels et al. 2005

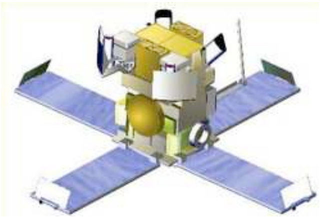
- Swift BAT →X-ray afterglow by Swift XRT
- Association with an elliptical galaxy at z=0.225: likely, but not conclusive

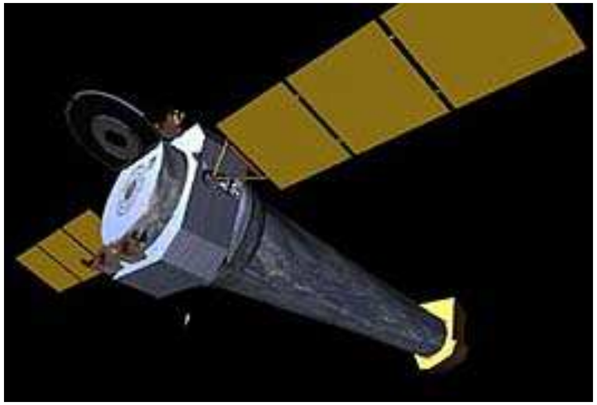


Subaru (Kosugi, et al. 2005

GRB050709
short GRB localized by HETE-2

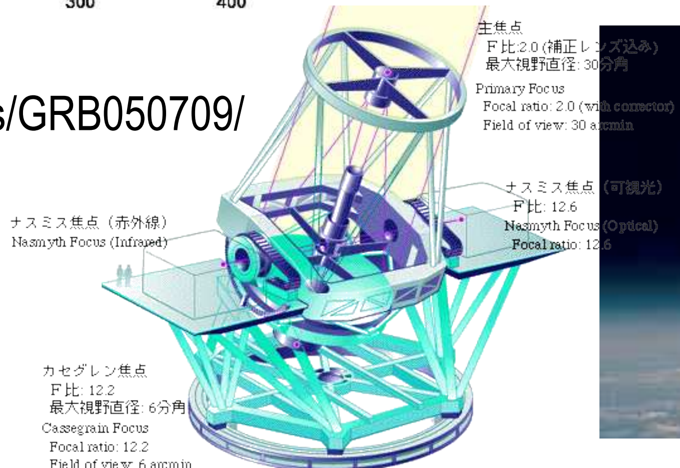




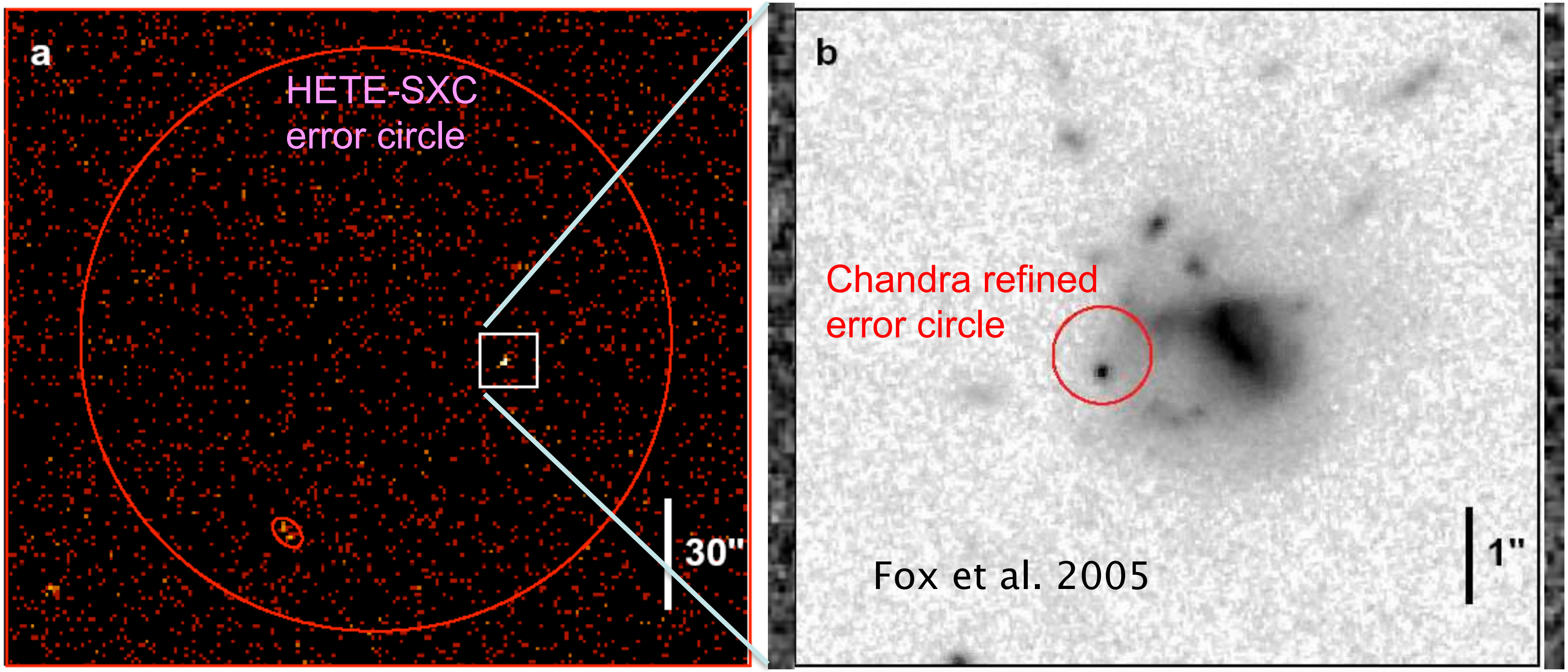


http://space.mit.edu/HETE/Bursts/GRB050709/

Soft extended emission



GRB 050709:
localization of X-ray and optical afterglow



Chandra X-ray Observatory

Hubble Space Telescope

- HETE WXM+SXC ~1 arcmin
- Chandra ~0.5 arcsec
- Hubble localized it to a dwarf starforming galaxy

z=0.160
Dwarf irregular galaxy
SFR = 0.2 M_{sun}/yr

Lessons from GRB low-freq counterpart search

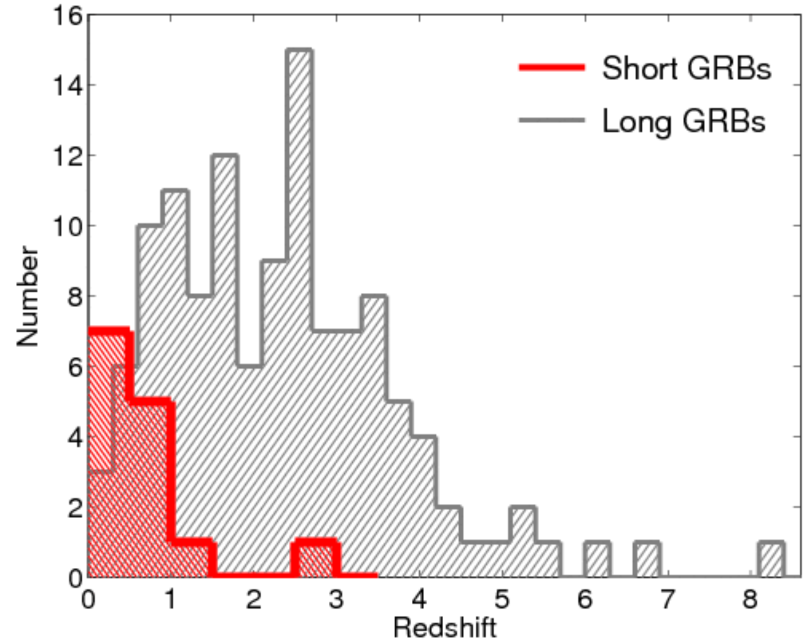
- Quick location is the key
  - arcmin position can be useless if too late
  - prompt degrees position is useful with more constraining information
- Optical astronomers do not look at error circles larger than their field of view
- Swift XRT: even arcmin position does not give conclusive identification
- Optical/Near infrared imaging/spectroscopy required for unambiguous identification

Host galaxy and redshift of short GRBs

Berger et al. 2007; Berger 2009

- Elliptical:Star-forming = 2:11
  - Can happen from old stars

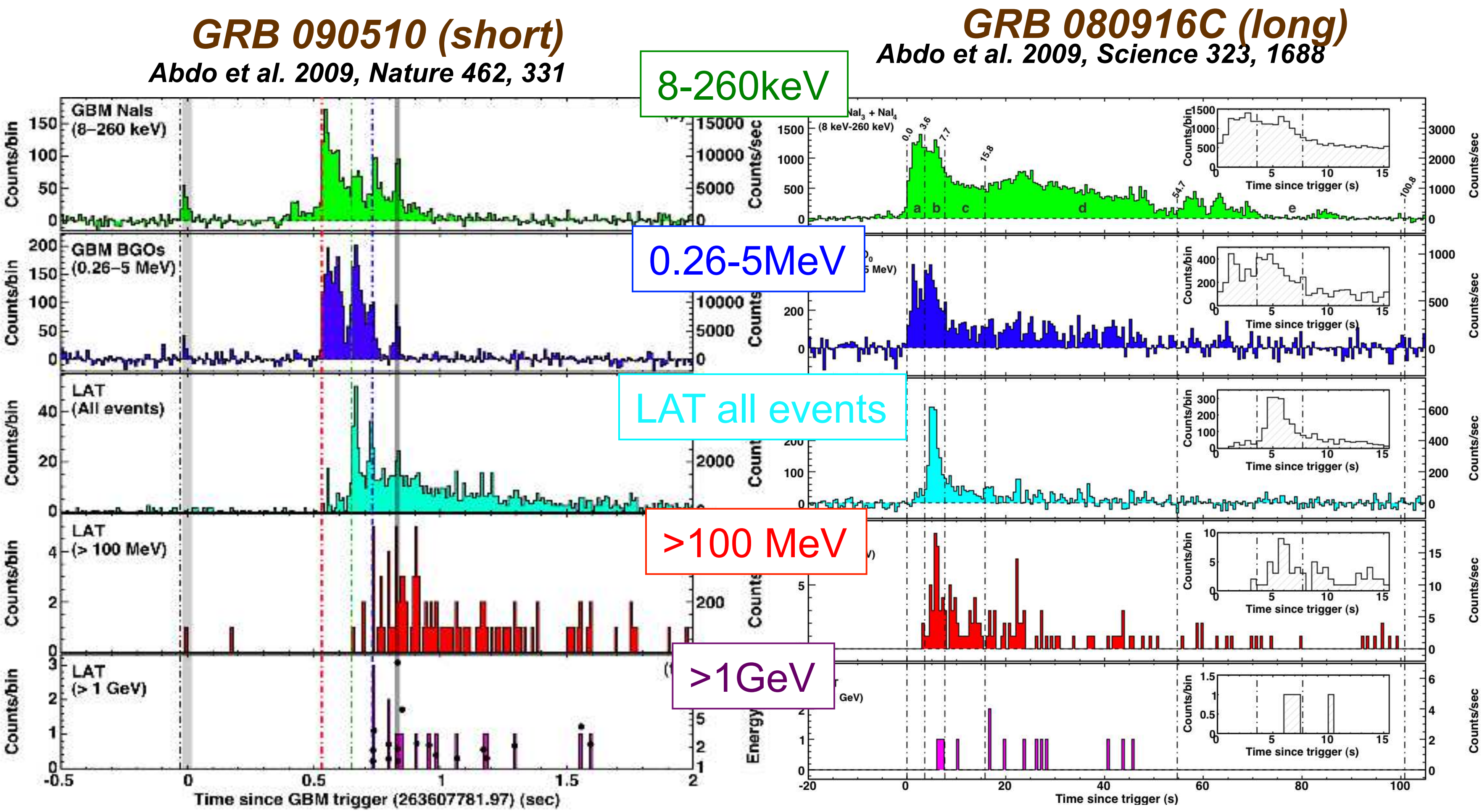
- No preference on metallicity or star formation rate
  - unlike long GRB hosts



Half of short GRB at $z > 0.7$

$\Rightarrow \langle \text{age} \rangle \leq 7$ Gyr

Prompt emission of long and short GRBs



Delay in HE onset: 0.1-0.2 s

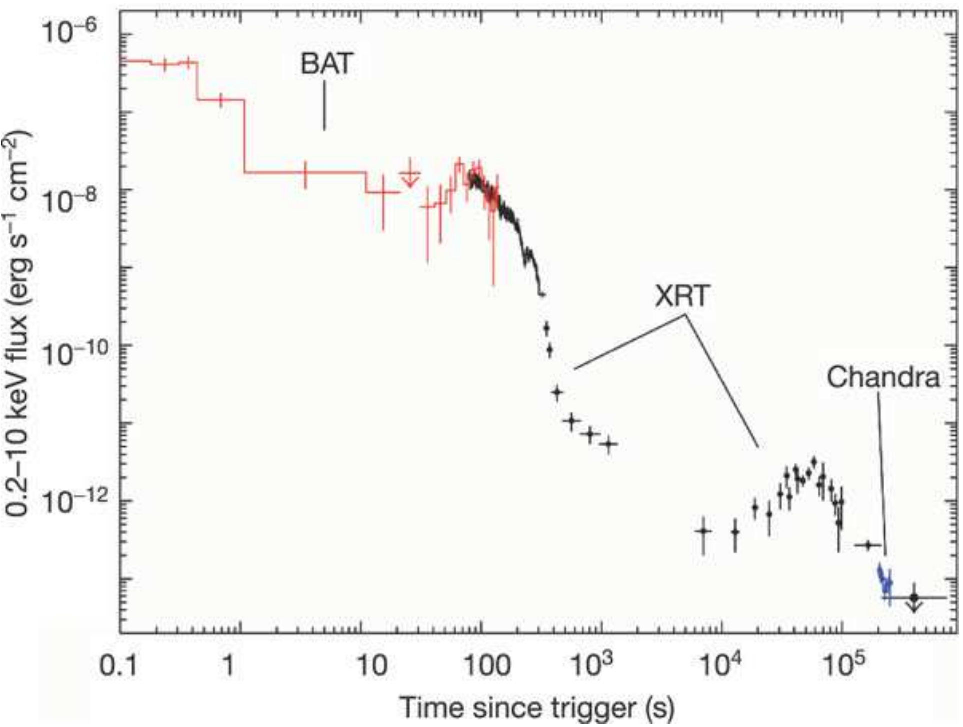
Delay in HE onset: ~4-5 s

<u>HE delayed onset can be seen from almost all LAT GRBs</u>

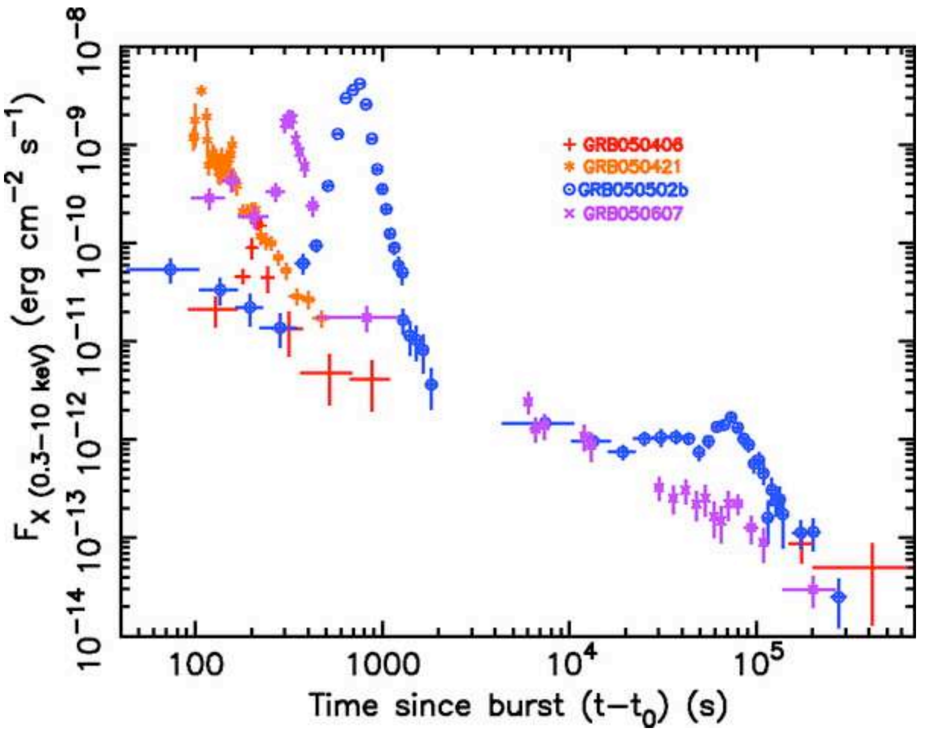
Afterglow of short and long GRBs

Short GRB050724

Long GRBs



Barthelmy et al. 2005



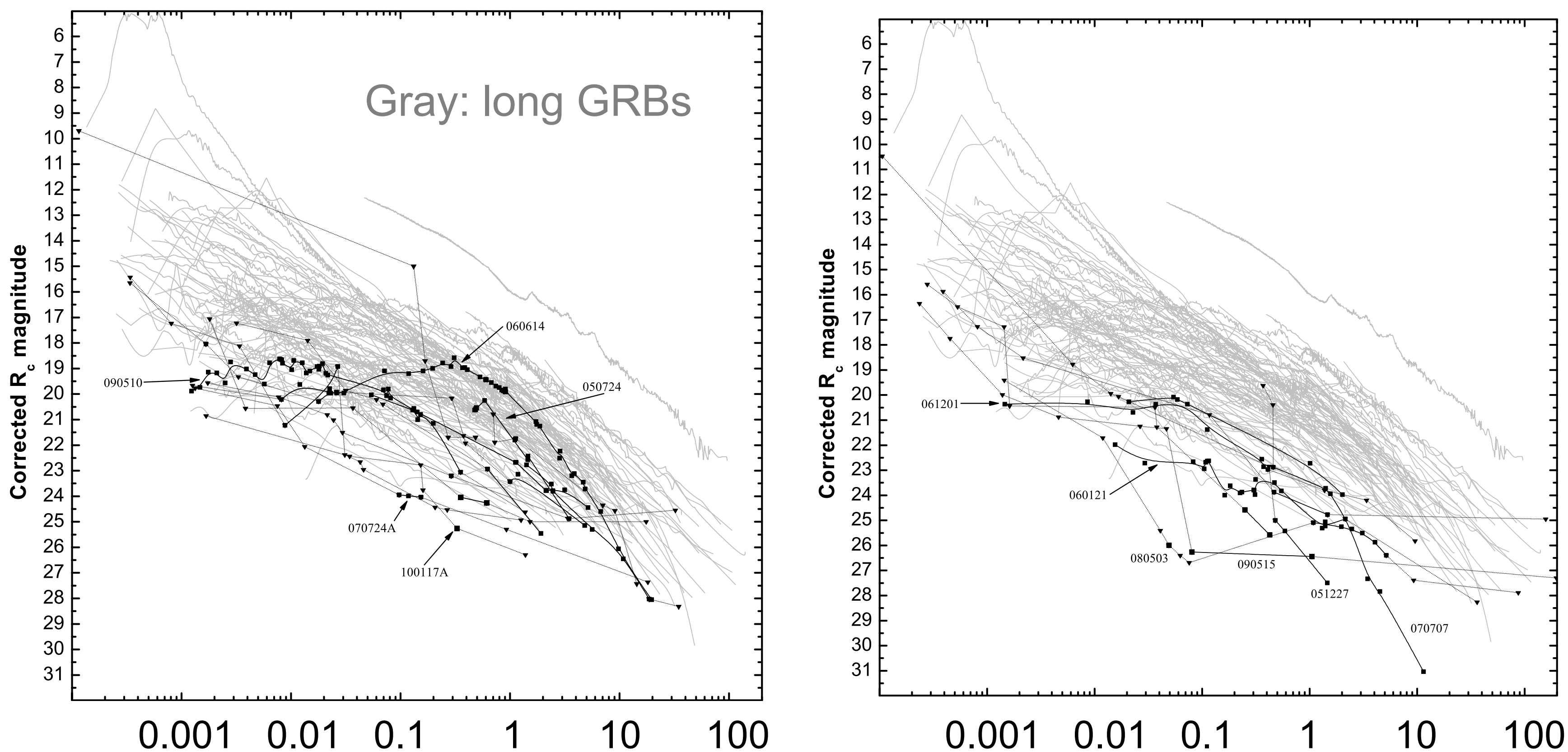
Nousek et al. 2006

X-ray afterglows are similar to those of long GRBs

Optical afterglow of GRBs

Short GRBs with measured redshifts   Short GRBs without measured redshifts

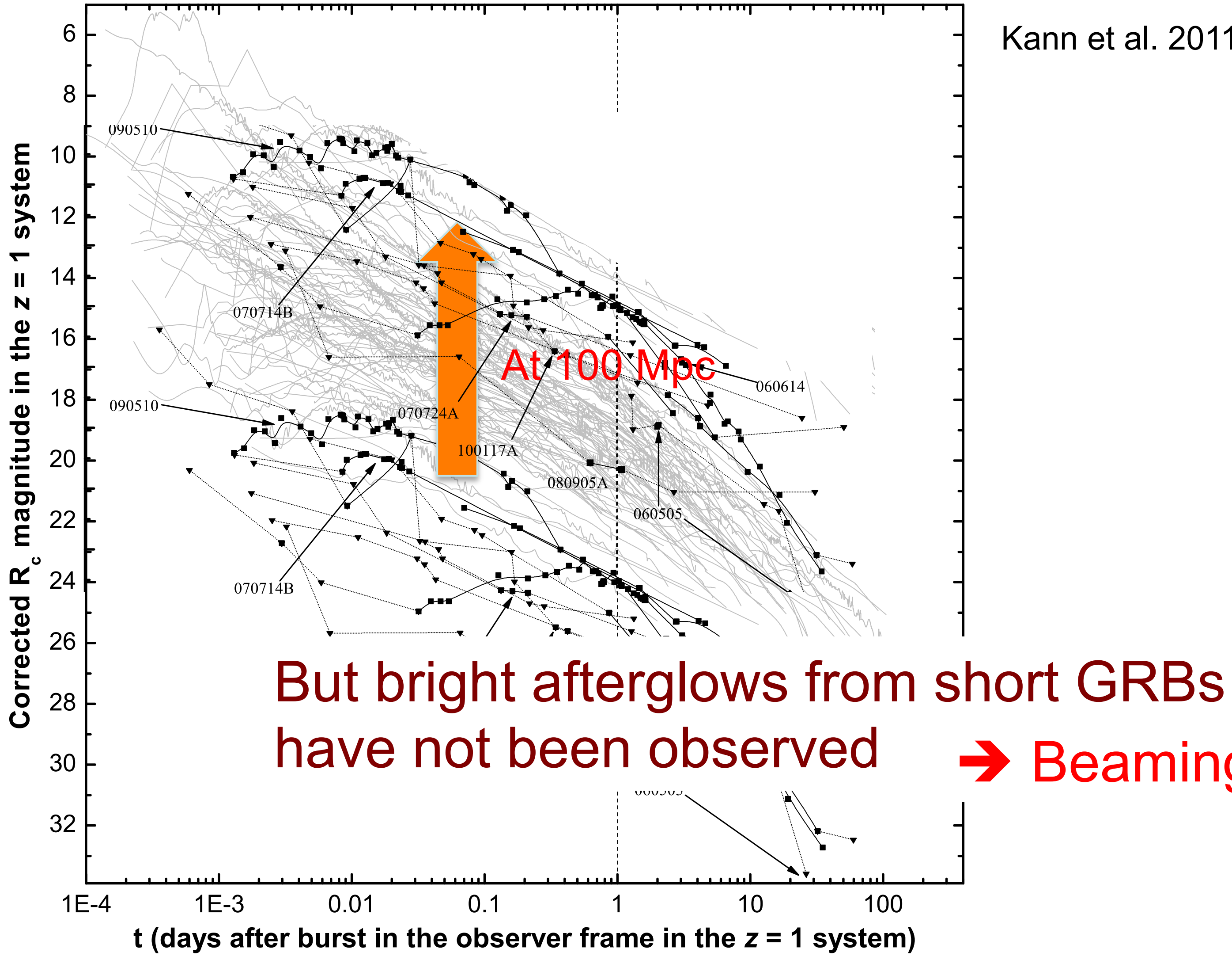
R band magnitude at observer frame



Days after burst in the observer frame

Kann et al. 2011

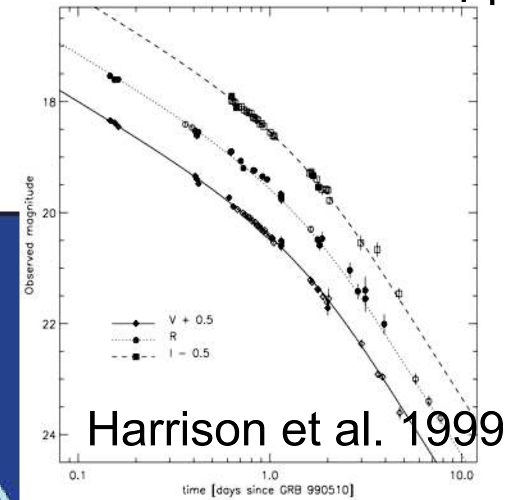
Optical afterglow of SGRB at z=1 and at 100 Mpc

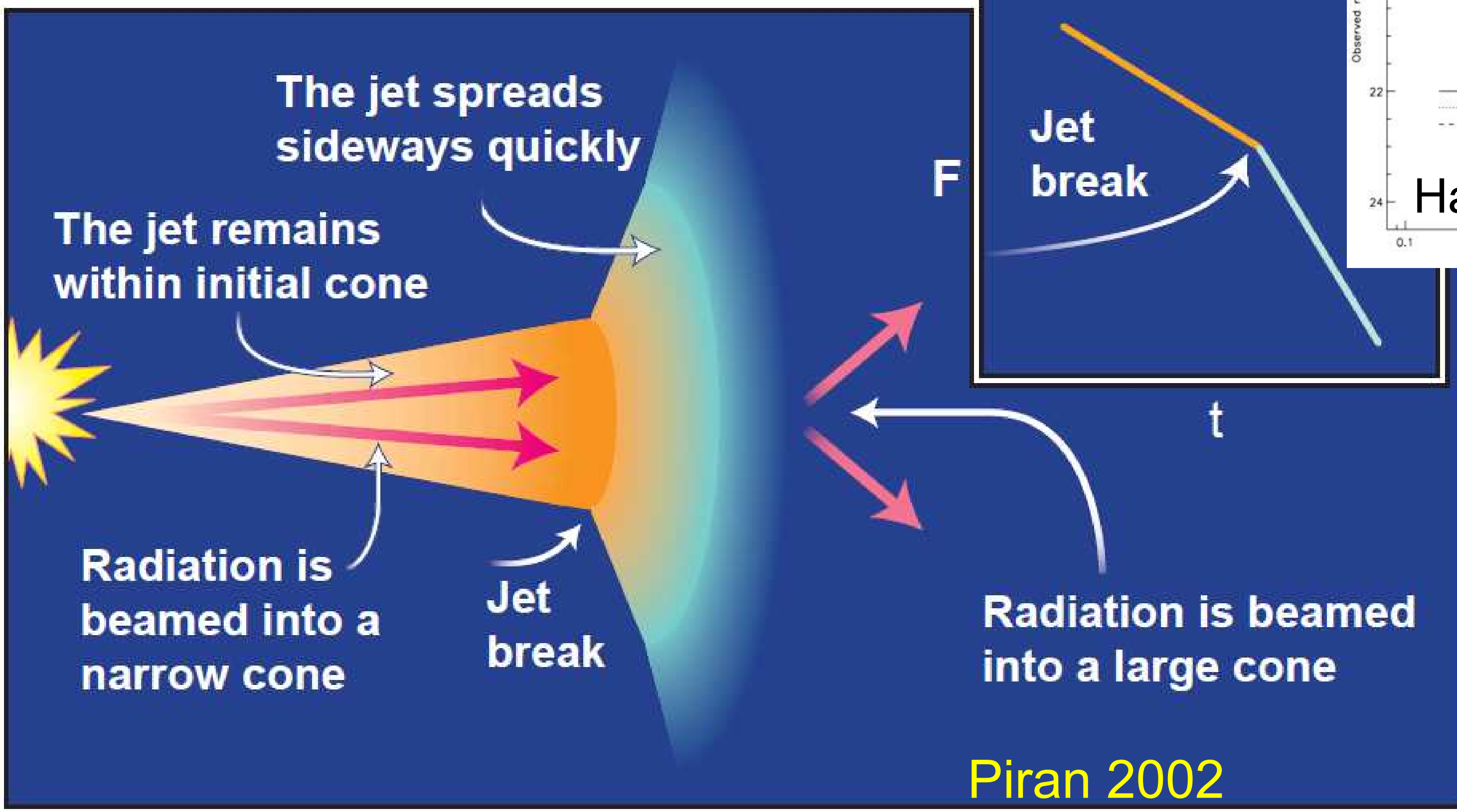


But bright afterglows from short GRBs have not been observed

➔ Beaming!

“jet break”

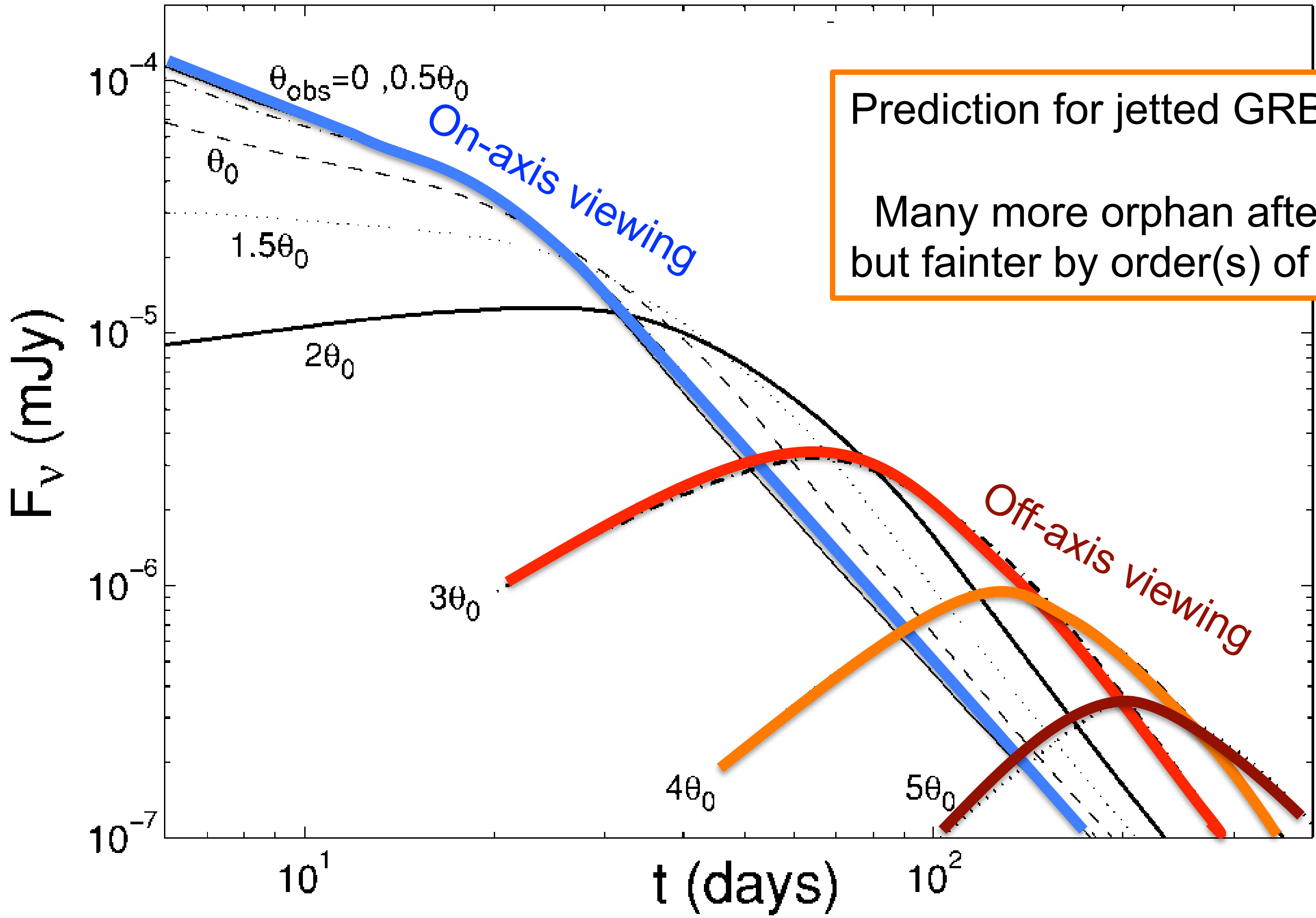




Beamed emission. A relativistic jet with a Lorentz factor γ and an opening angle θ moves forward until its Lorentz factor $\gamma = \theta^{-1}$. Then it expand sideways rapidly, resulting in a “jet break” in the light curve. A schematic light curve is depicted at the top right.

Orphan afterglow for off-axis GRBs

Granot et al. 2002



Prediction for jetted GRBs

Many more orphan afterglows, but fainter by order(s) of magnitude

Is neutron star merger detactable as a short GRB?

- GW telescope localization ≈ degrees
  - Extremely difficult to find optical counterpart
    - Error circle too large for "normal" telescopes
    - however、$z<0.015$ → much closer than usual GRBs

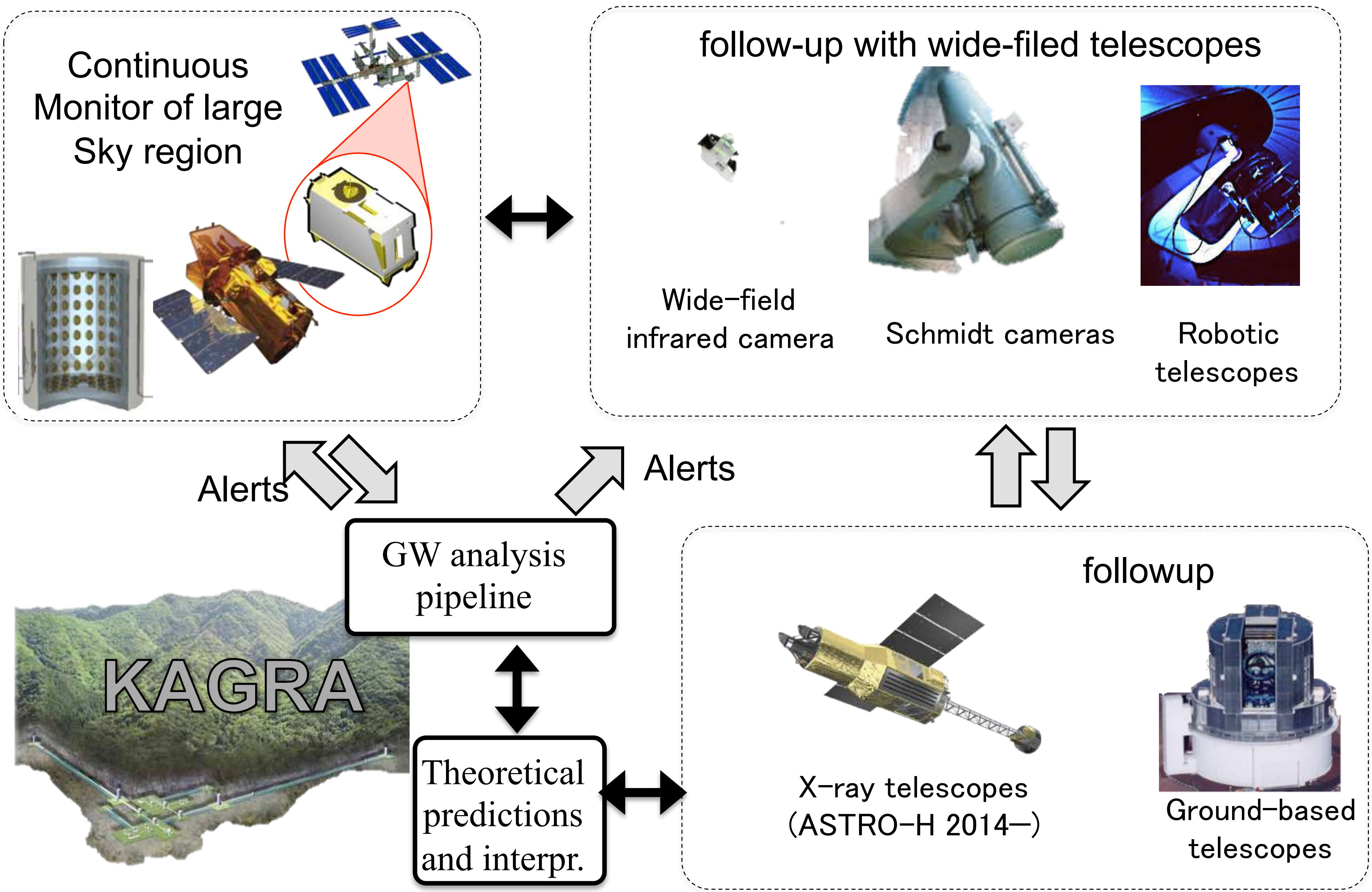
    ➔need different strategy for counterpart search

(1) Cover the large error circle (≥10 deg)

(2) Continuous monitor of large sky

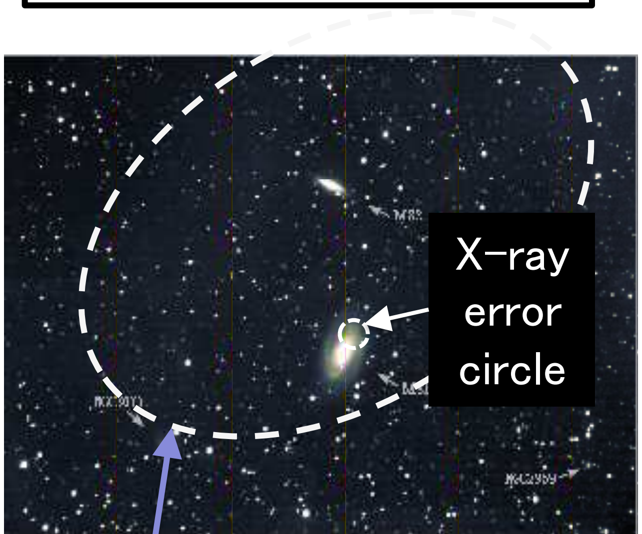
- Find temporary coincidence with GW event
- Search for orphan afterglow

Counterpart search strategy



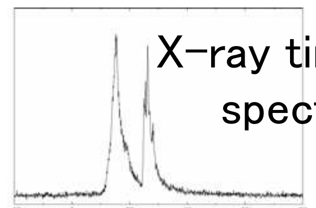
Steps of localization and identification of GW events

Smaller error circle by EM

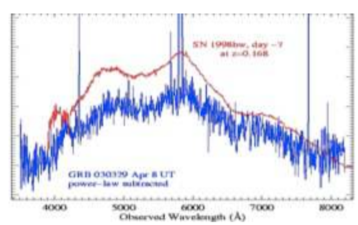


Error region for GW event

Detailed observation

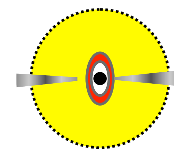


X-ray timing and spectroscopy

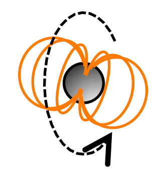


Optical llight curve and spectroscopy

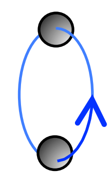
Identification to astrophysical event



Star collapse

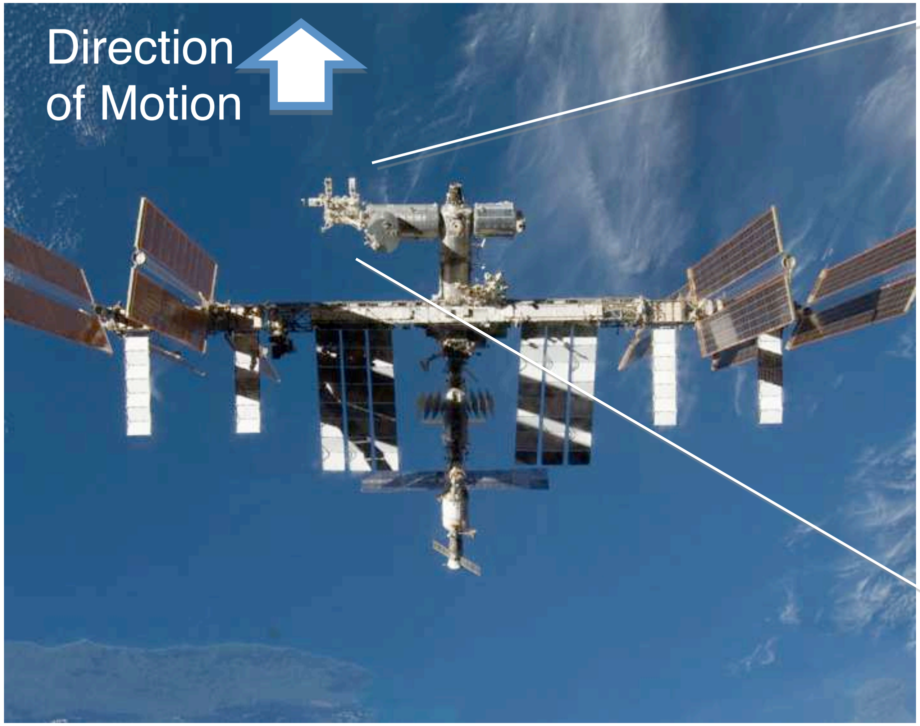


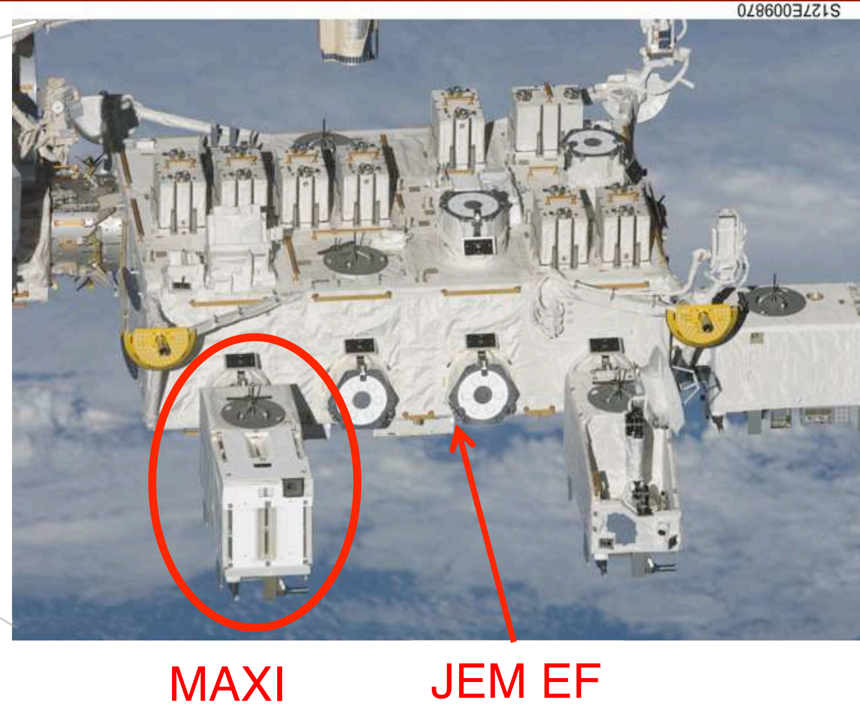
Pulsar glitch



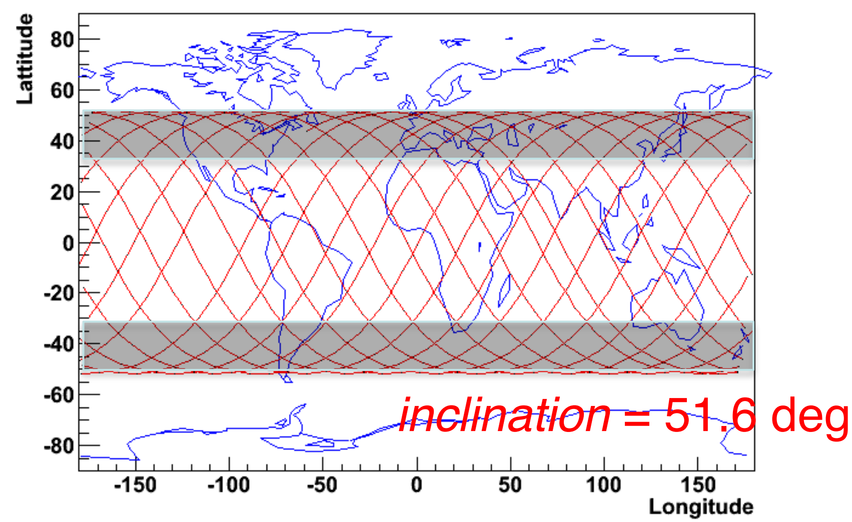
NS merger

MAXI (Monitor of All-sky X-ray Image) on ISS



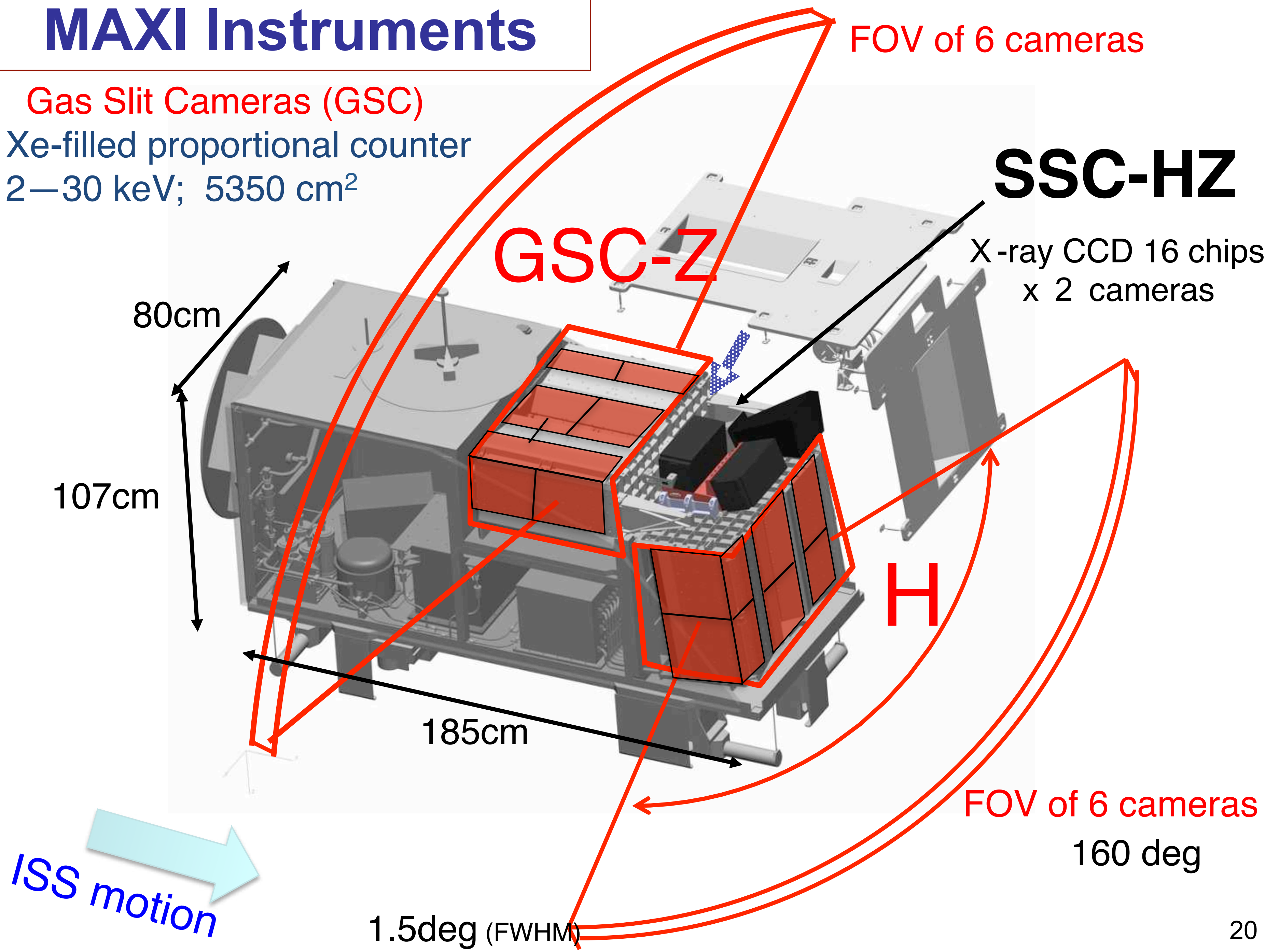


- The first astronomical mission on ISS
- Transported by Space Shuttle (Endeavour) on July16, 2009
- Installed on JEM (Japanese Experimental Module, KIBO) EF (Exposed Facility) on July 23.
- First Light on August 15, 2009.



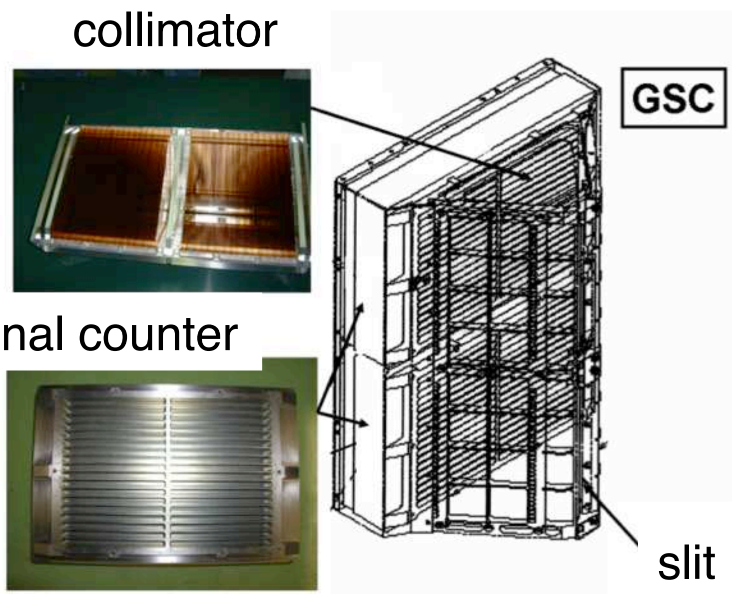
MAXI Instruments

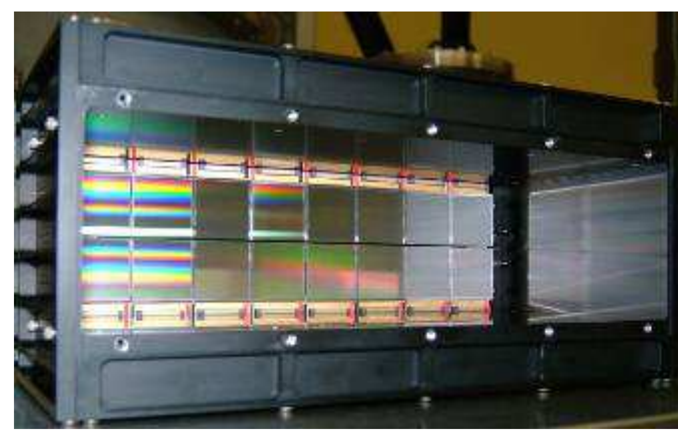
Gas Slit Cameras (GSC)
Xe-filled proportional counter
2—30 keV; 5350 cm^2



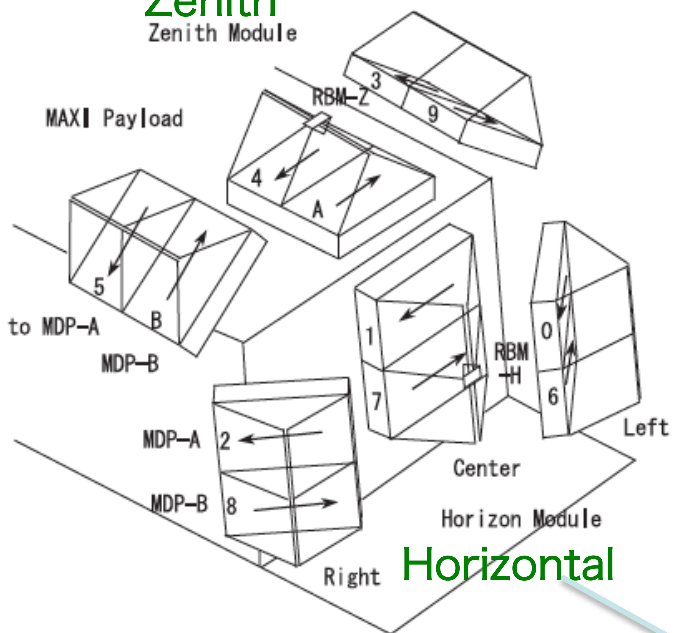
Detectors

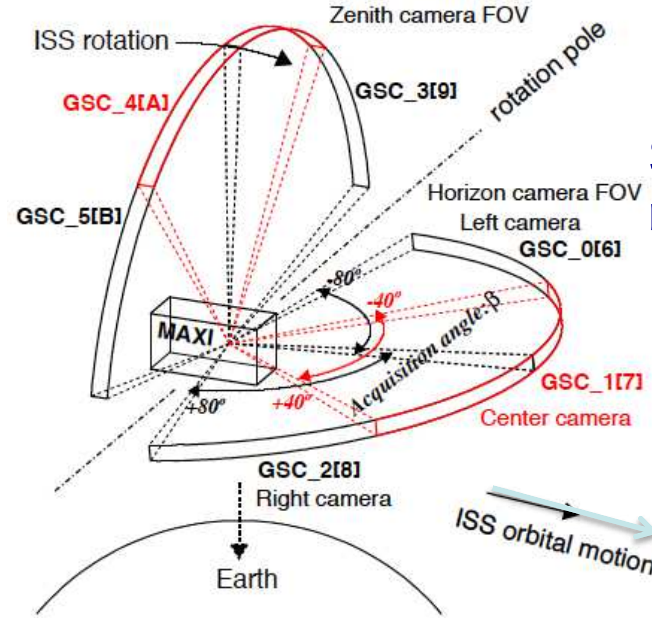
	GSC (X-ray Gas Camera)	SSC (X-ray CCD Camera)
Detector	Gas(Xe) prop. counter x12	CCD 16 chips x 2 camera
Energy range (Q.E.>10%)	2−30 keV	0.5−12 keV
Energy resolution (FWHM)	15.7%(at 8.0keV)	< 2.5%(150eV) (at 5.9keV)
Time resolution & accuracy	＜200μsec	～6 sec
Instantaneous sky coverage	2.4 % of the whole sky (160 deg x 3 deg x 2 sets)	1.4% of whole sky (90 deg x 3 deg x 2 sets)
Point Spread Function	1.5 degree	1.5 degree
sensitivity	2 mCrab (week)	5 mCrab (week)





Field of Views

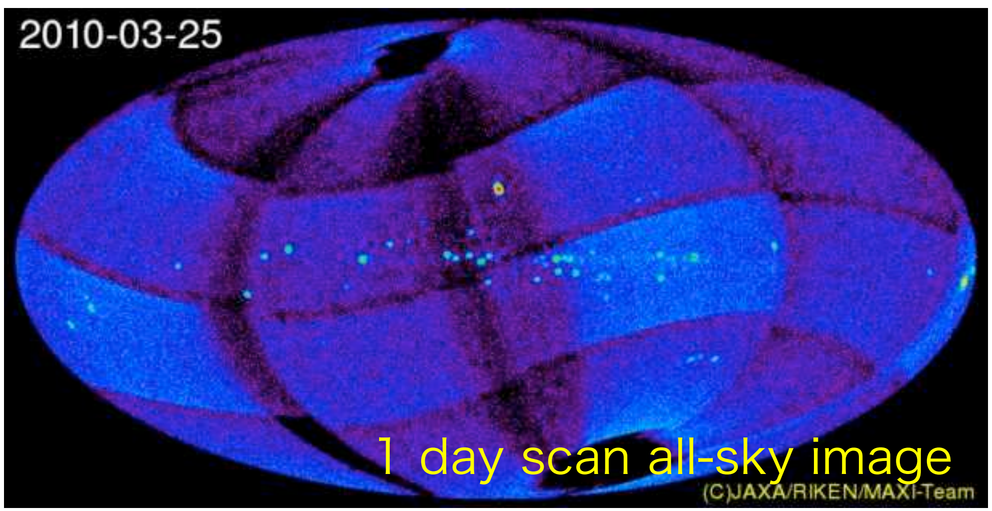




ISS ram direction

Scan with narrow FoVs (160° x 3°)

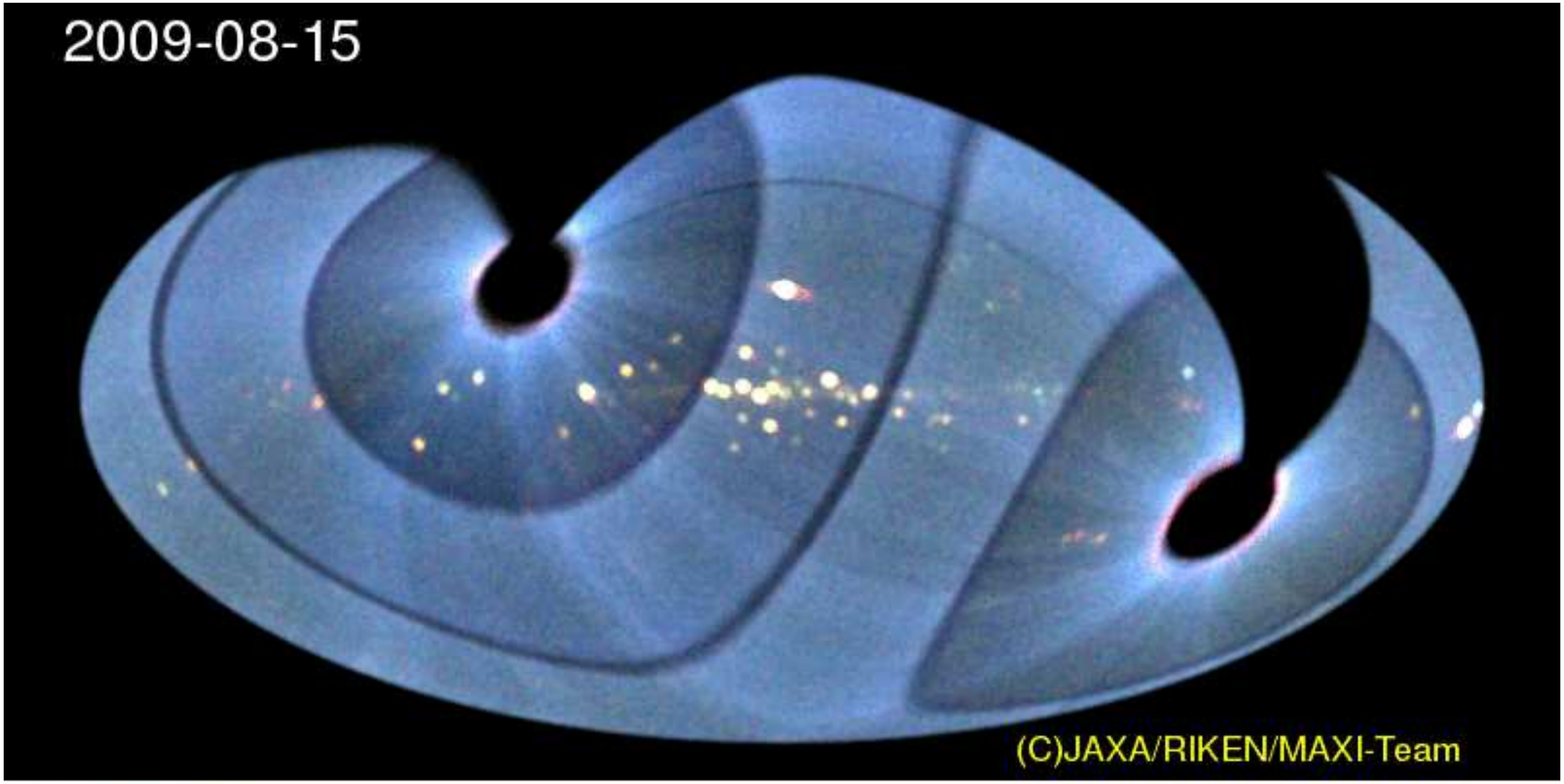
(SSC 80°x3°)



Sky coverage 80% in an orbit

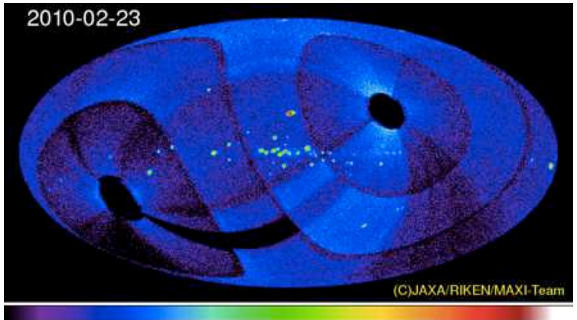
Unbiased survey for transients

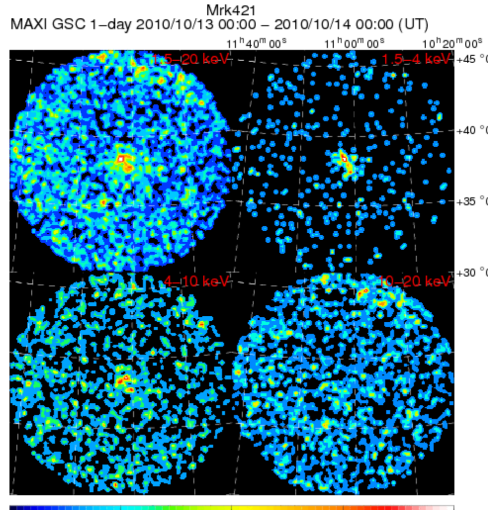
GSC All-Sky Scan Movie

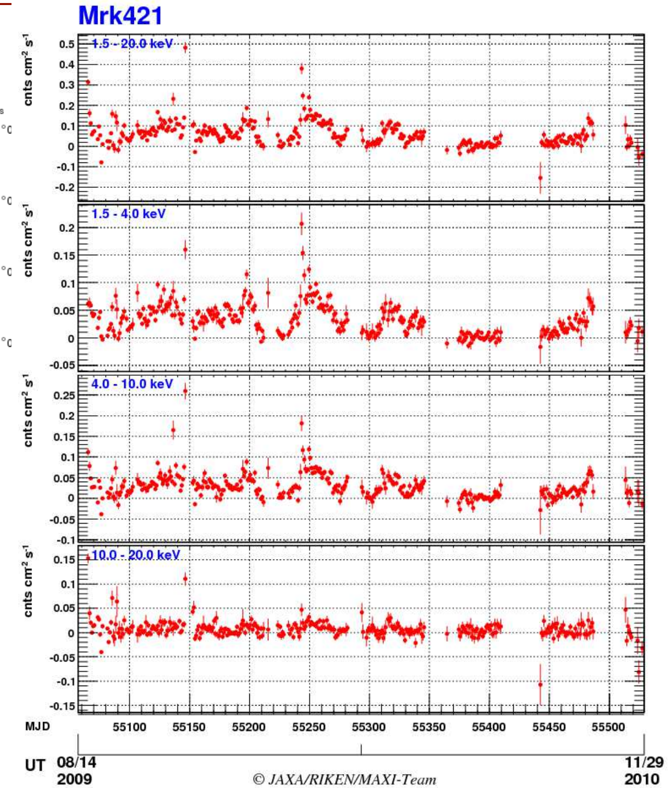


- Red: 2-4 keV, Green: 4-10keV, Blue: 10-20 keV.
- Raw data. Exposure not corrected.
- Not cleaned for background variation, sun-light leak, and solar-paddle reflection.

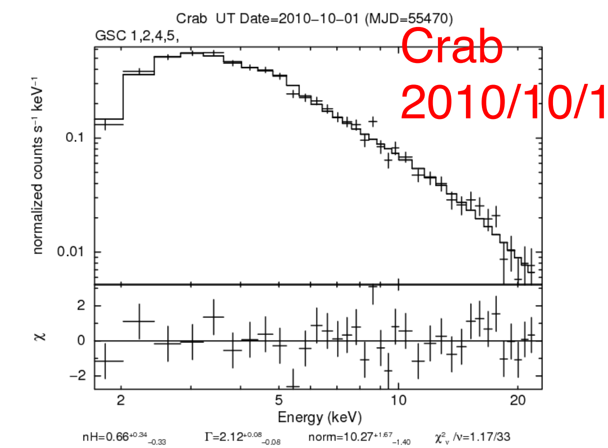
MAXI Public Data (http://maxi.riken.jp)







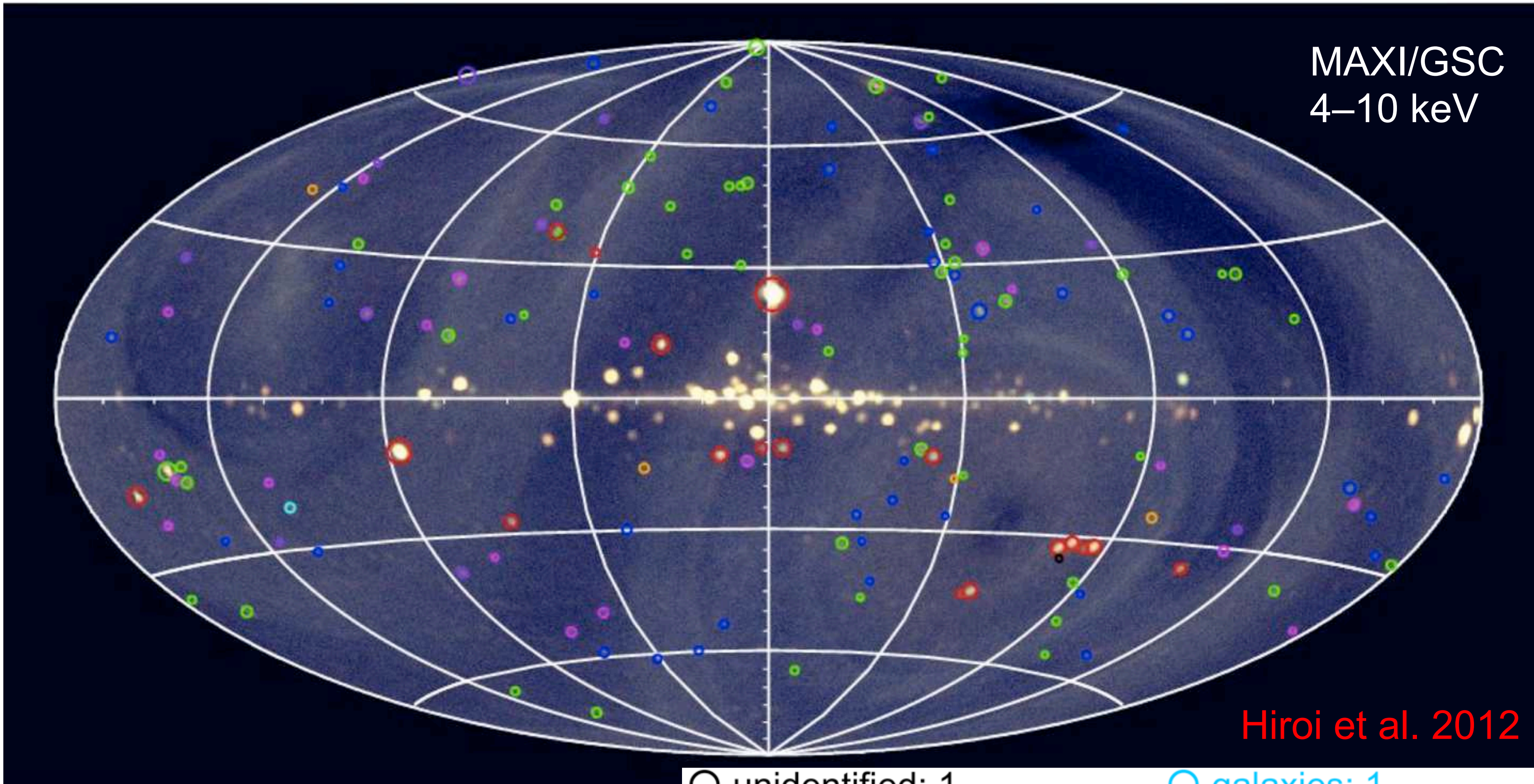
- Daily all-sky image
- For 259 listed Sources
  - Field image
  - Light curve in three energy bands
  - (updated daily)
- For selected sources (currently ~50 sources)
  - Daily energy spectrum with RMF
  - Sources
    - Crab, Sco X-1, Cen X-3, Her X-1, GX 9+9, GX 9+1, GX 13+1, GX 17+2, GRS 1915+105, Cyg X-2, …



MAXI alerts

- Transient alert e-mails
  - Sent after human inspection
    - (except for bright new transients)
  - five categories
    - New Transient (incl. GRBs)
      - Automatic alerts for transients with >150 mCrab
      - Rate: ~1 event/month
      - Automatic alerts followed by manual ones
    - X-ray star
    - Nova-CV
    - AGN
    - Supernova
  - Subscribe at maxi.riken.jp
- GCN notices (to be automated soon)
- ATels

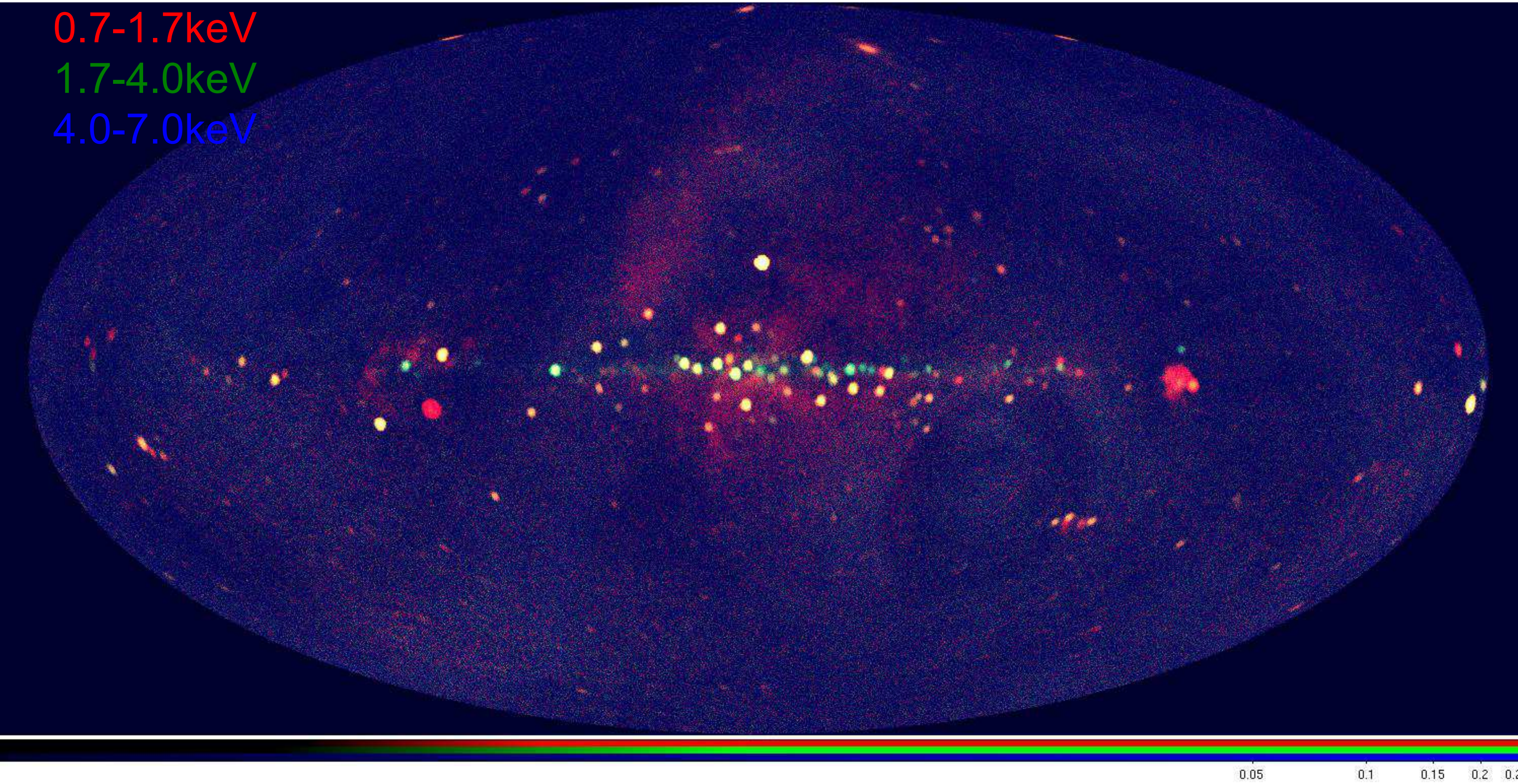
MAXI 7-month catalog



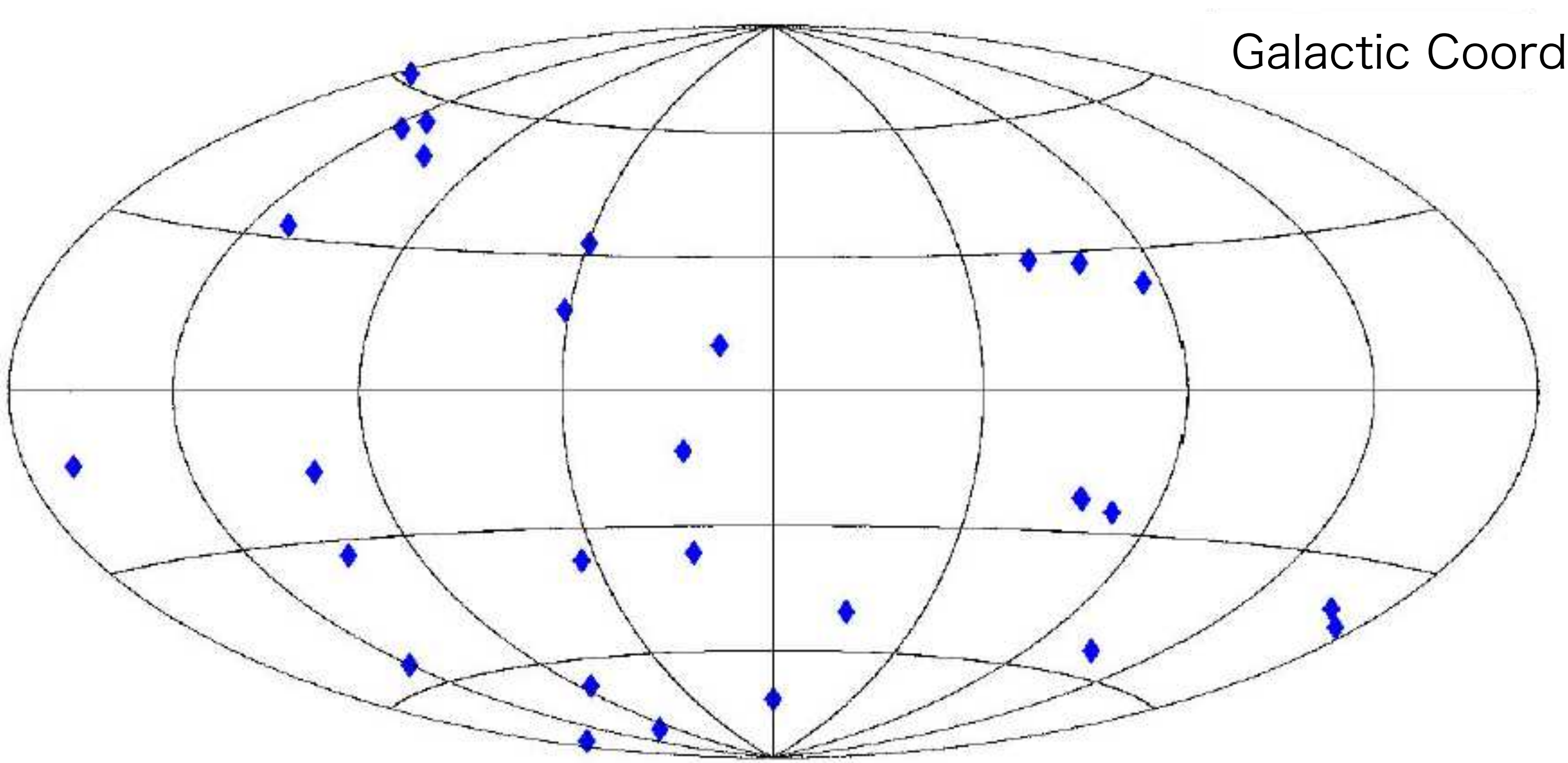
- 143 sources (>7 σ, |b|>10°)
- limiting sensitivity:
  ~1.5x10^{-11} ergs cm^{-2} s^{-1} (4-10 keV)
- Consistent with, but deeper than HEAO

O unidentified: 1
O galaxy clusters: 48
O blazars: 12
O X-ray binaries: 18
O galaxies: 1
O Seyfert galaxies: 39
O CVs/stars: 20
O confused: 4

SSC all-sky map (23 month)



Short X-ray Transients (4-10 keV)

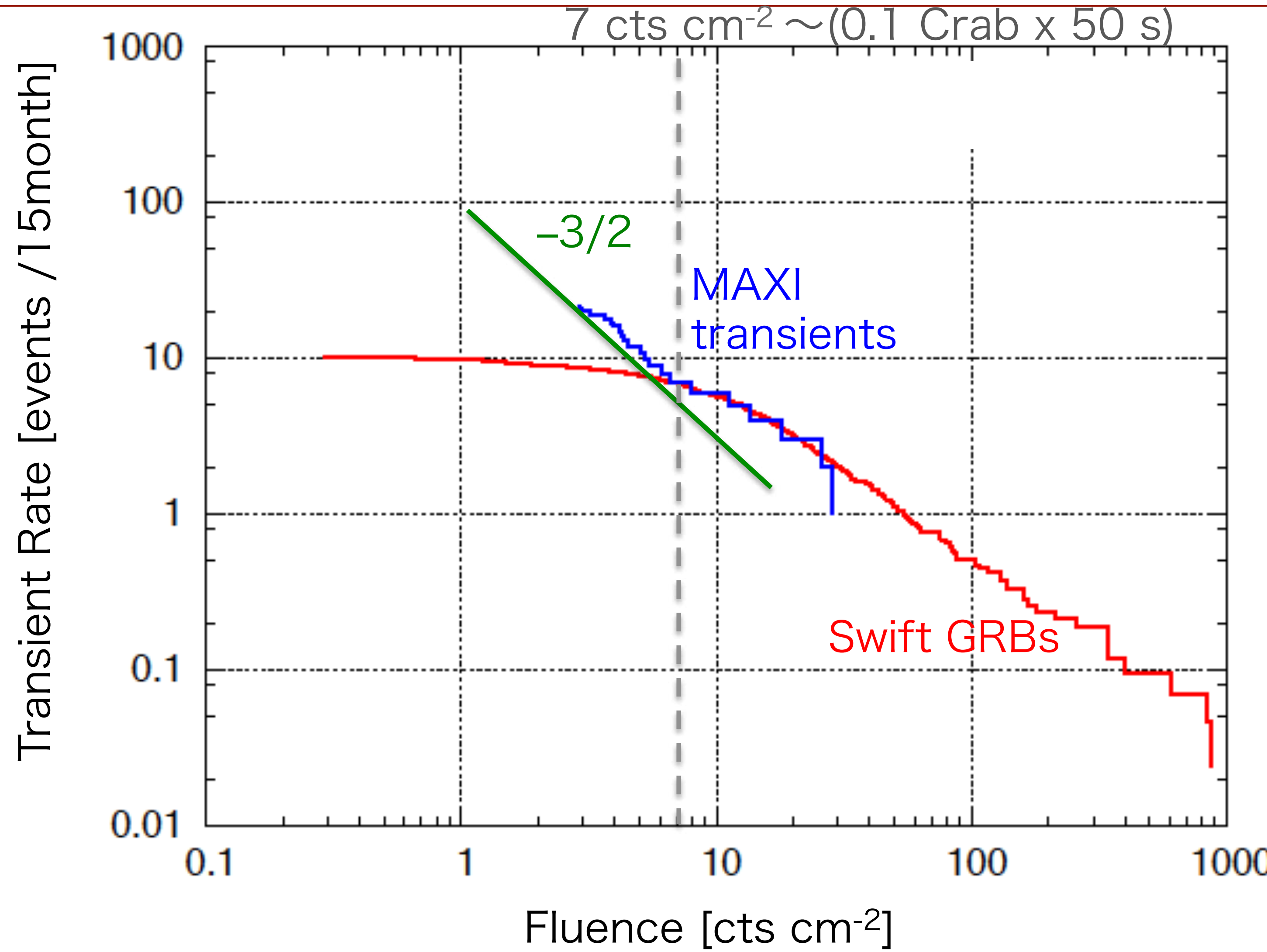


29 transients with >9 σ significance in 15 months
(8 GRBs, 3 stellar flares, 2 possible ID, 15 unID)

<cos θ> = 0.04 +- 0.17
<V/V_{max}> = = 0.52 +- 0.05

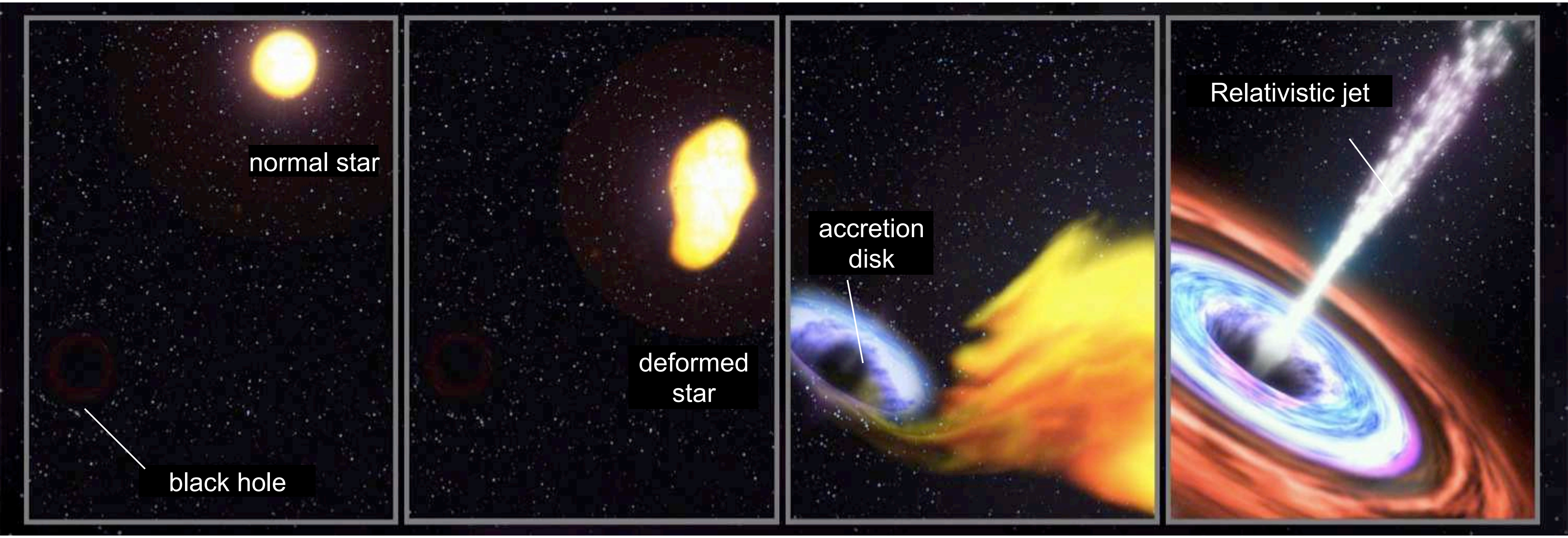
Consistent with isotropy and uniform Eucledean

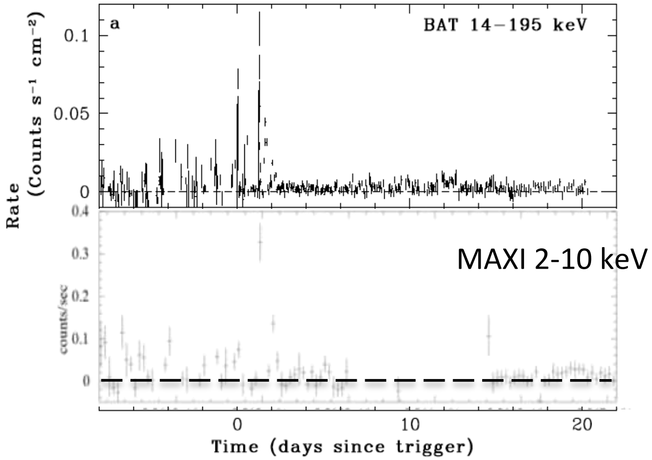
Log N-Log S MAXI short transients



Swift J1644+57:

Tidal disruption of a star producing a reltivistic jet





- MAXI pre-outburst upper limit $< 1.1 \times 10^{-11}$ erg s^{-1} cm^{-2}

Images prepared by NASA

MAXI GSC and SSC detection of a soft X-ray transient near SMC: XRF 111111A / MAXI J0158-744

ATel #3756; *M. Kimura (Osaka U.), H. Tomida (JAXA), T. Sootome, M. Serino, T. Mihara, (RIKEN), M. Morii (Tokyo Tech), M. Matsuoka, M. Sugizaki, S. Nakahira, T. Yamamoto (RIKEN), S. Ueno, M. Kohama, M. Ishikawa (JAXA), N. Kawai, K. Sugimori, R. Usui, T. Toizumi, Y. Aoki, S. Song (Tokyo Tech), A. Yoshida, K. Yamaoka (AGU), H. Tsunemi, H. Kitayama (Osaka U.), H. Negoro, M. Nakajima, F. Suwa (Nihon U.), Y. Ueda, K. Hiroi, M. Shidatsu (Kyoto U.), Y. Tsuboi, T. Matsumura, K. Yamazaki (Chuo U.) report on behalf of the MAXI team*
on ***11 Nov 2011; 08:20 UT***
Credential Certification: Motoko Suzuki (motoko@crab.riken.jp)

Subjects: X-ray, Nova, Transient

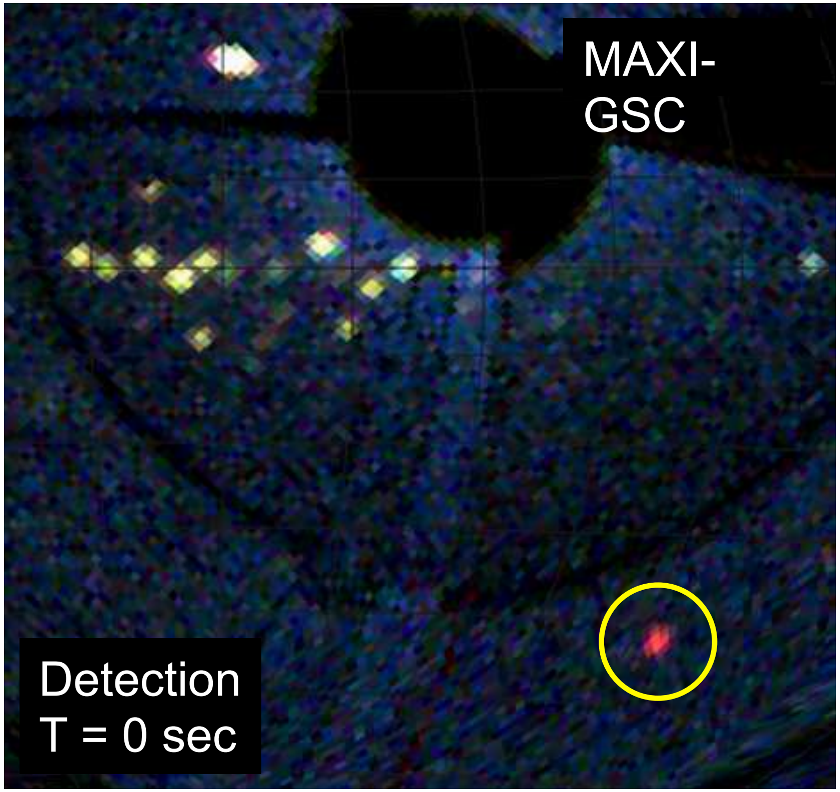
Referred to by ATel #: 3758, 3759, 3765

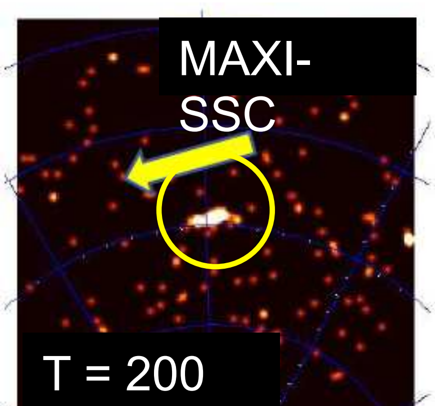
MAXI/GSC triggered a bright uncatalogued X-ray transient source at UT 2011-11-11T05:05:59. The source is extremely soft and most of the flux is emitted below 4keV. Assuming that the source flux was constant over the transit, we obtain the source position at
(R.A., Dec) = (+29.5 deg, -74.4 deg) = (01 58 03, -74 24 01)(J2000)
with a 90% C.L. statistical error of 0.42 deg. There is additional systematic uncertainty of 0.1 deg (90% containment radius). This position is in the outskirts of SMC.
The preliminary flux of the transient source was 400 mCrab (2-4 keV), and that corresponds to the luminosity of 6.4×10^{38} erg s^{-1} (distance of SMC 61.3kpc is assumed). The hardness ratio gives the blackbody temperature of about 0.4 keV. This source is also detected by SSC with the flux of 1 Crab (0.7-7 keV).
There was no significant detection at the transit location in the previous and the next orbit (92 min before and after the detection) with an upper limit of 20 mCrab. There is no known bright X-ray source at the detected position. There are at least four super soft sources known in SMC, and any of them does not match this transient.
Follow-up observations are encouraged.

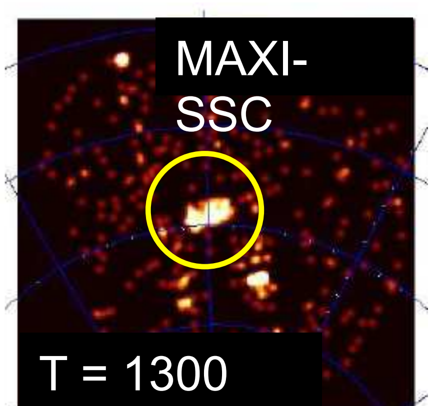
Related
3765 Swift XRT/UVOT observations of the supersoft X-ray source candidate MAXI J0158-744
3759 Swift observations of the supersoft X-ray transient XRF 111111A / MAXI J0158-744
3758 MAXI J0158-744/XRF 111111A: Swift X-ray and U band detection
3756 MAXI GSC and SSC detection of a soft X-ray transient near SMC: XRF 111111A / MAXI J0158-744

Soft X-ray transient detected by MAXI GSC and SSC

MAXI J0158–744

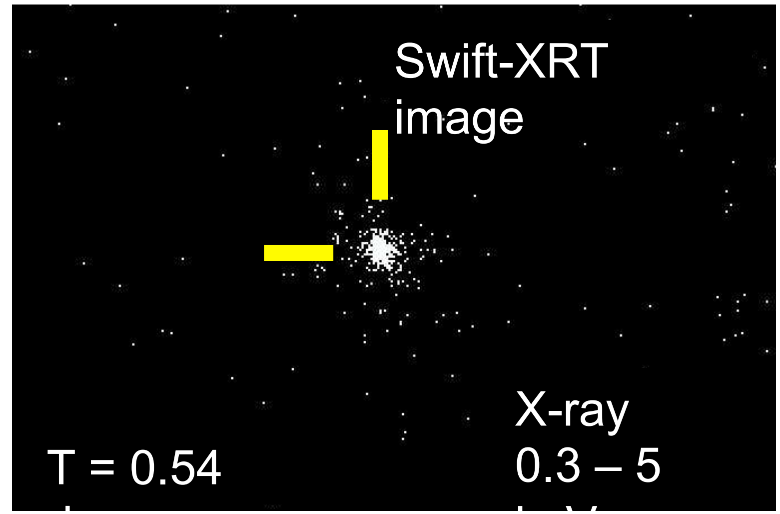


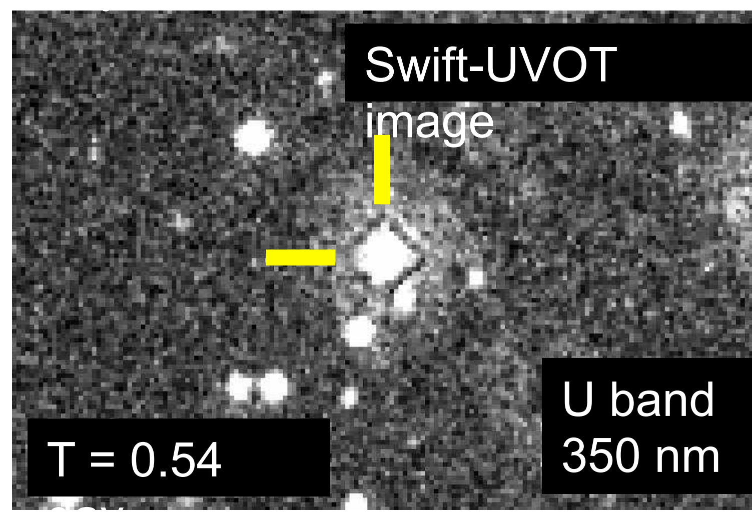




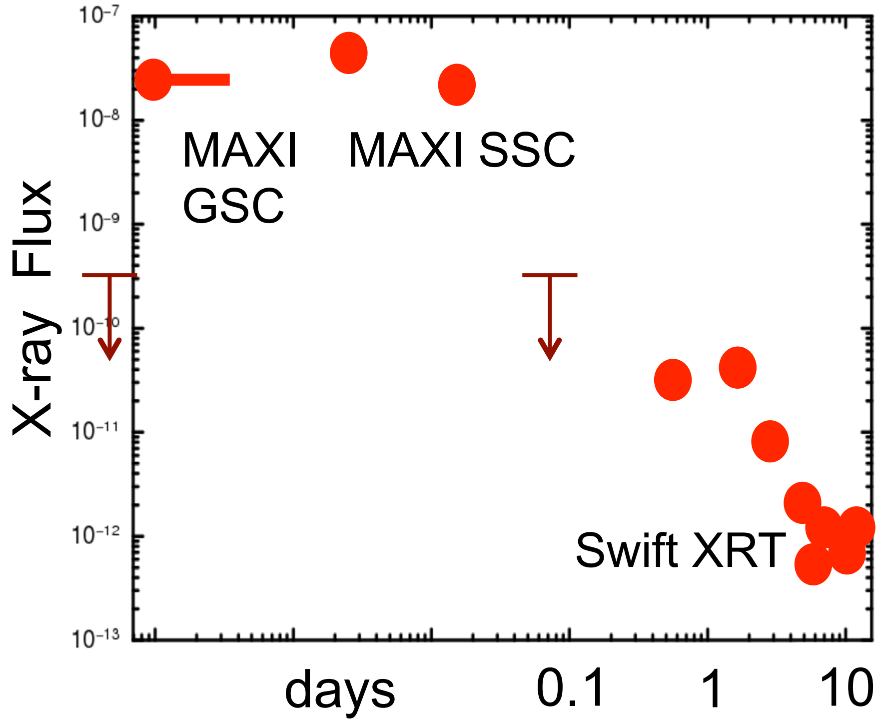
Morii et al. in prepration

Swift follow-up observation

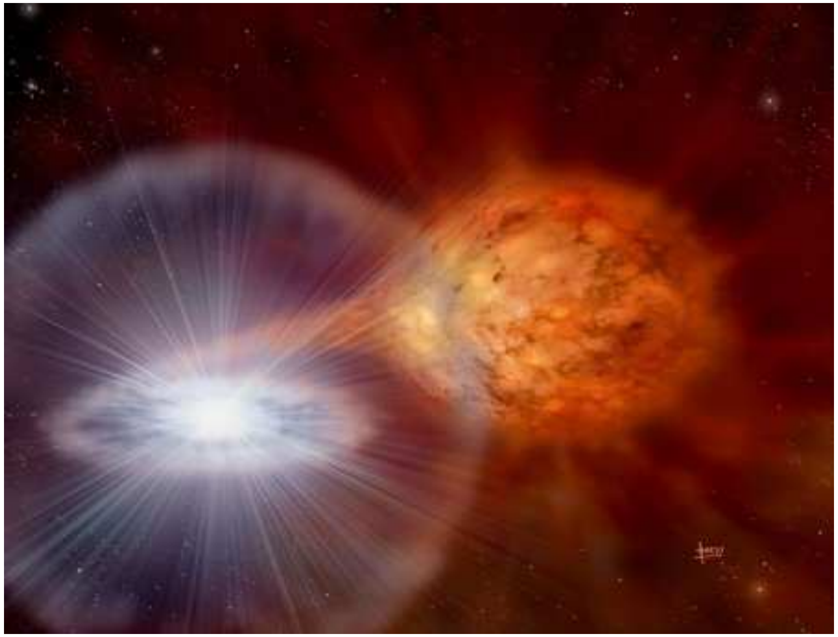




MAXI J 0158-744
Soft X-ray transient near SMC

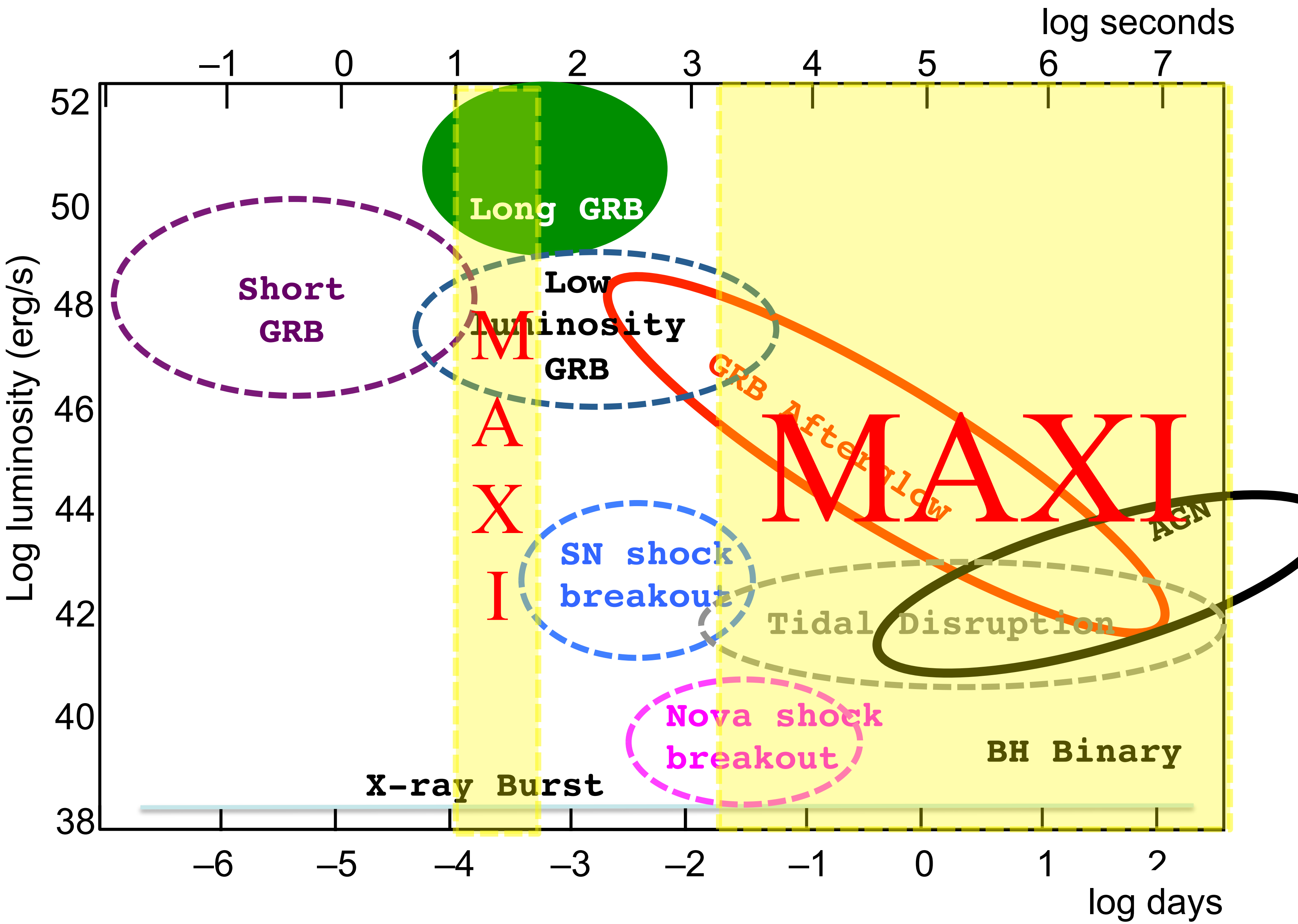


X-ray light curve

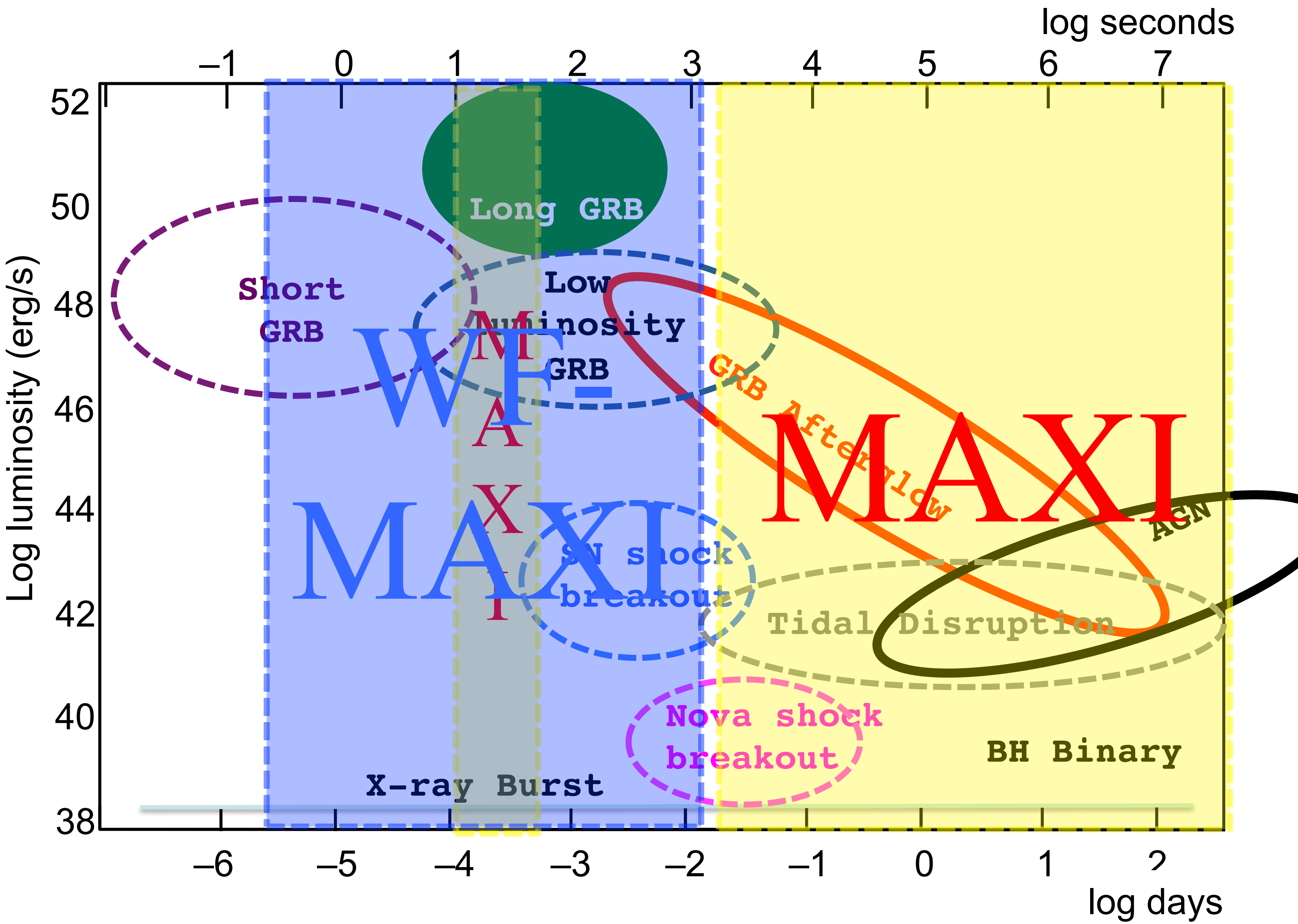


Morii et al. in prepration

X-ray transients: L-Δt



X-ray transients: L-Δt



WF-MAXI

Platform: ISS JEM ("Kibo") exposed facility

goals: Survey, localization, and notificatin of short (<1s ～1 hour) X-ray transients

Field of view: ≈ 1–1.5 str

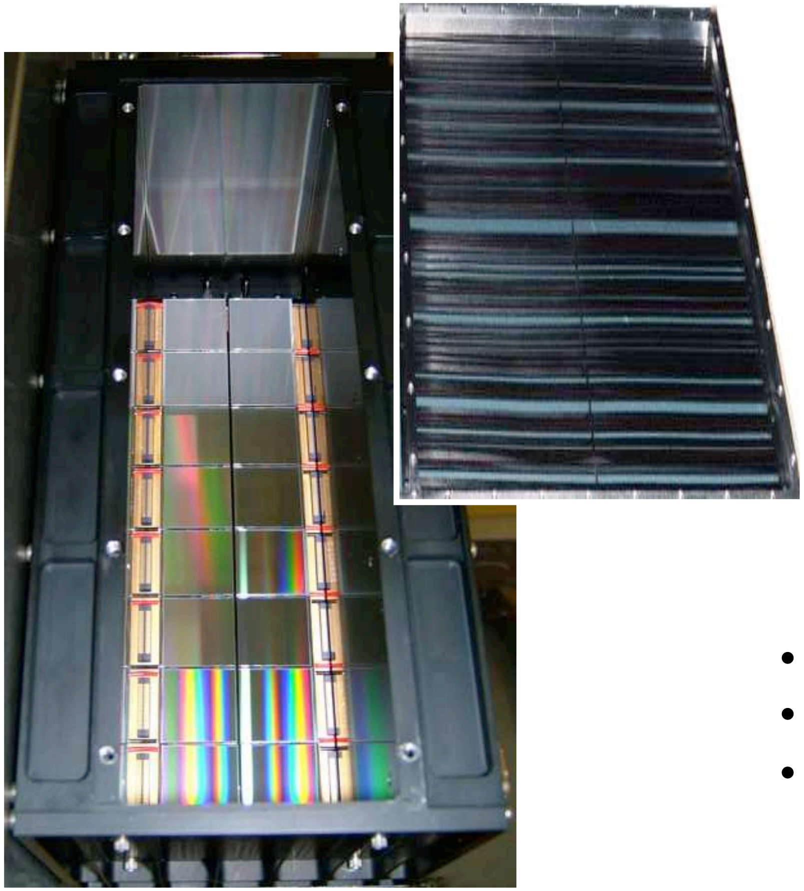
Instruments: Soft X-ray L.S. Camera (SLC: 0.7–10 keV)

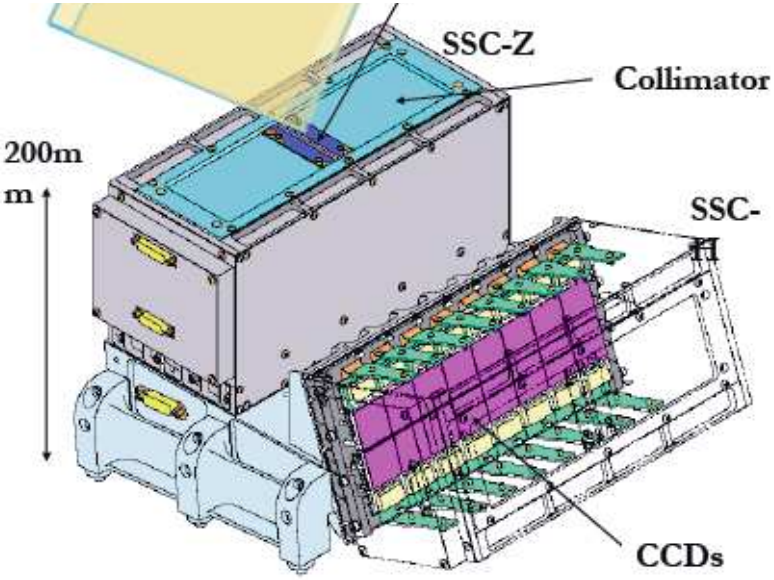
Hard X-ray monitor (HXM: 30-200 keV)

sensitivity: 50mCrab/30 s (SLC)

Positional accuracy: 0.1°

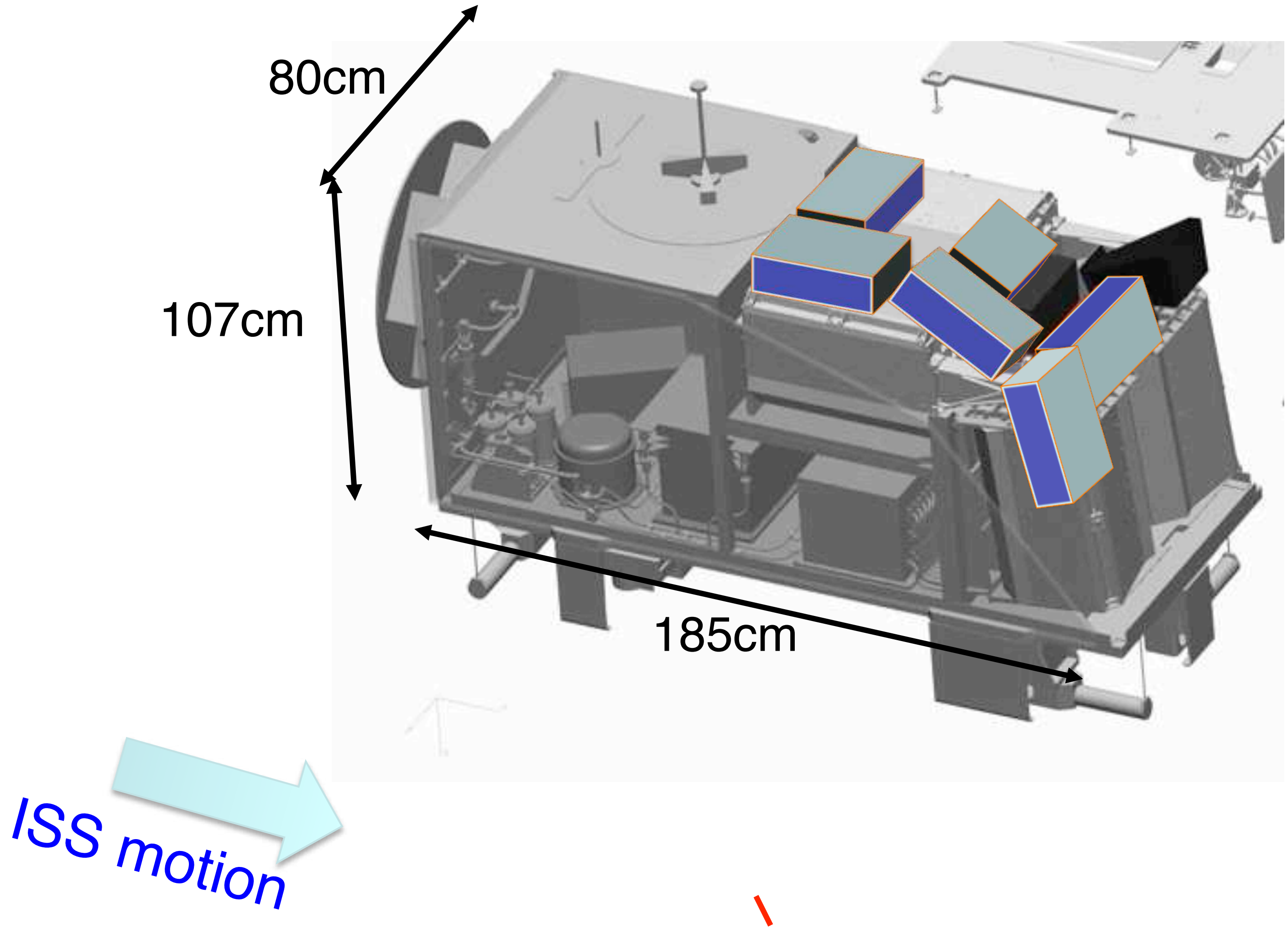
SLC
Soft X-ray Large solid angle Camera





- CCD: MAXI/ASTRO-H/Subaru heritage
- Electronics, cryogenics: ASTRO-H heritage
- Coded mask: HETE

Possible Camera Layout

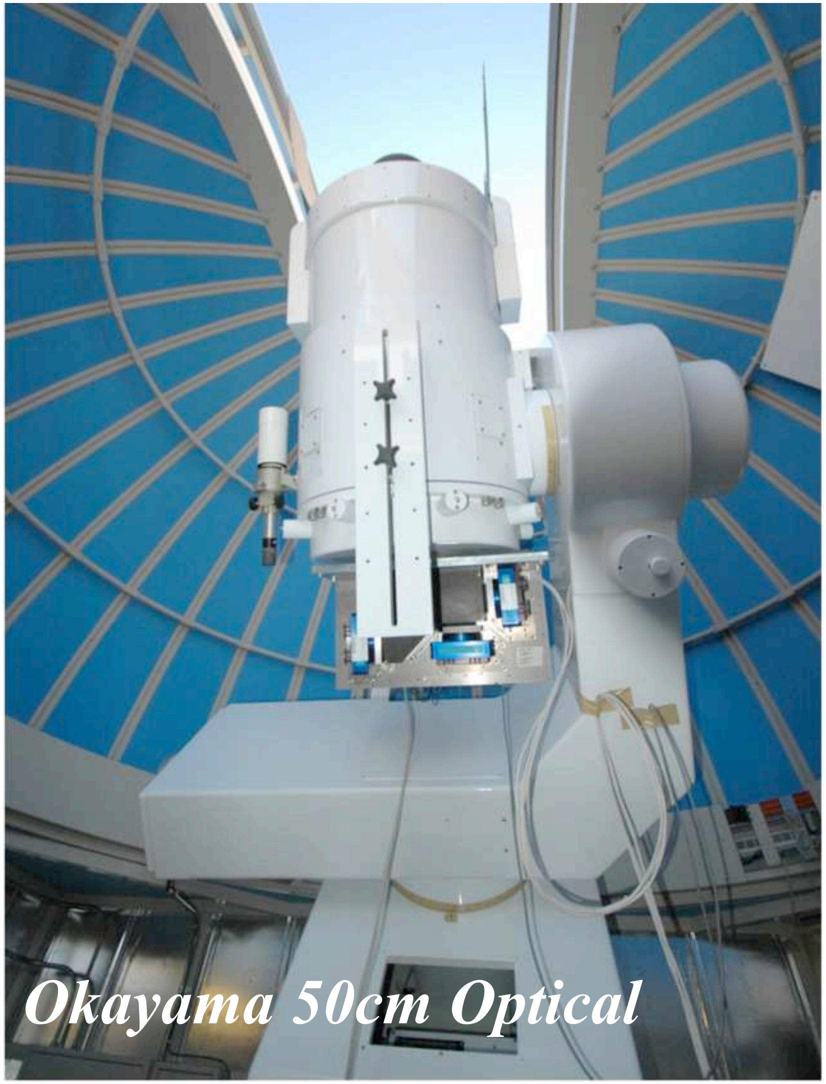


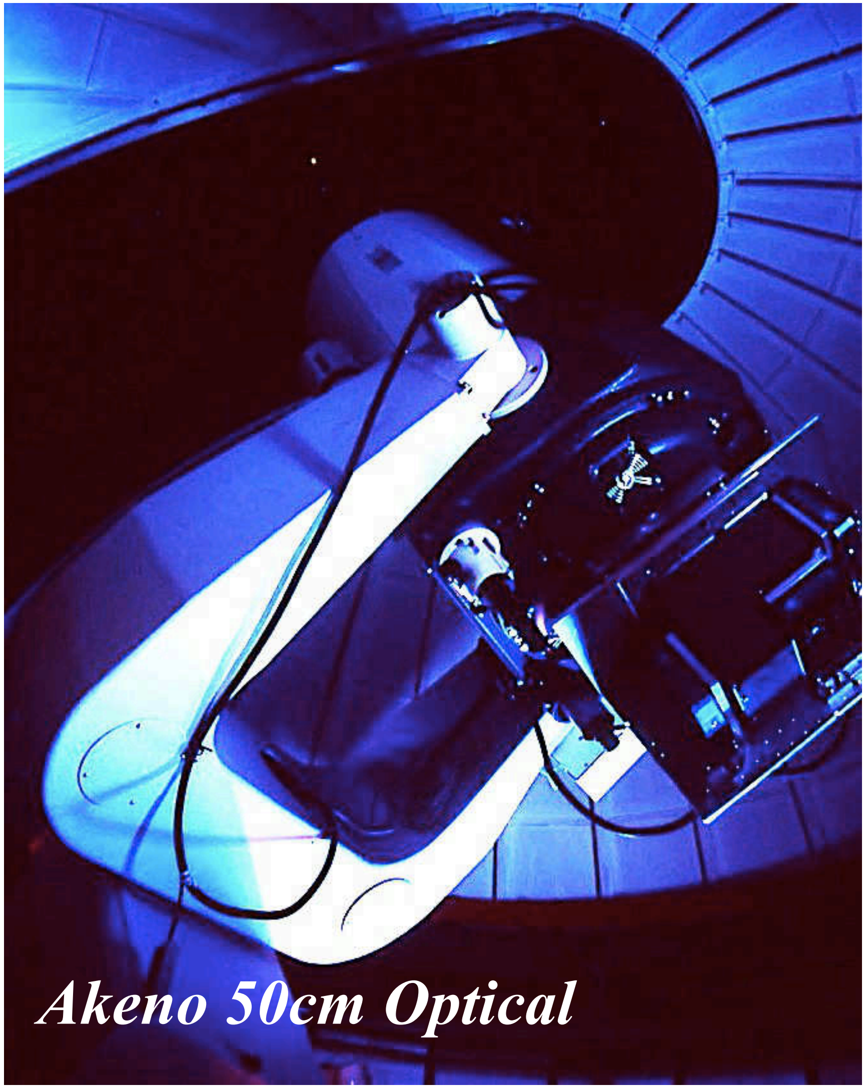
Optical and Infrared Synergetic Telescopes for Education and Research

Multimode, multiwavelength

- Optical wide-field telescope
  - University of Tokyo, Kiso Schmidt Telescope 105 cm
    - large format CMOS sensor development in progress
- Optical polarimetry
  - University of Hiroshima, Kanata 1.5 m robotic telescope
- nIR wide-field camera
  - Okayama Astronomical Observatory 90 cm
    - FoV 60 arcmin, 4 bands (y, J, H, K)
- Simultaneous multicolor imaging
  - Tokyo Tech Mitsume, 0.5m robotic telescopes (g’, Rc, Ic)
  - Nagoya University IRSF/SIRIUS (J, K, H) in South Africa
  - University of Tokyo MiniTAO (optical/IR) in Chile
- Big telescope by ToO (target of opportunity)
  - Subaru 8.2 m telescope

MITSuME Telescopes

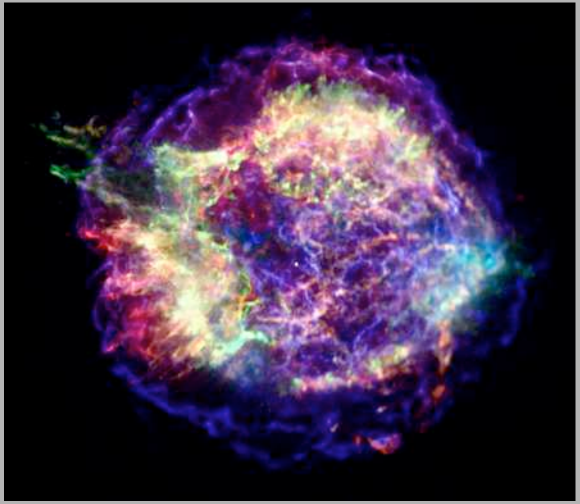




Galactic Supernovae have been missed

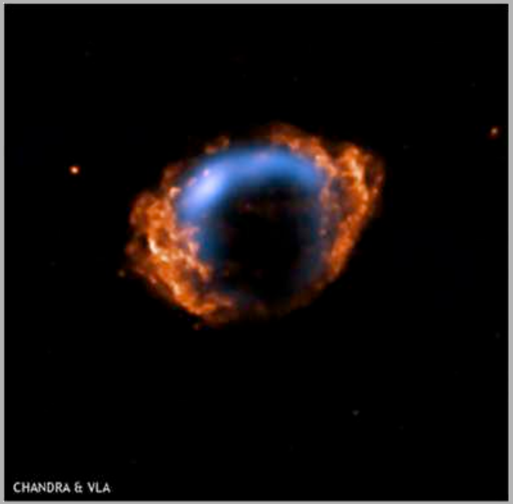
Kepler's SN 1607

Last Galactic SN seen



Cas A – SN 1667

Not seen



G1.9+0.3– SN 1870

Not seen

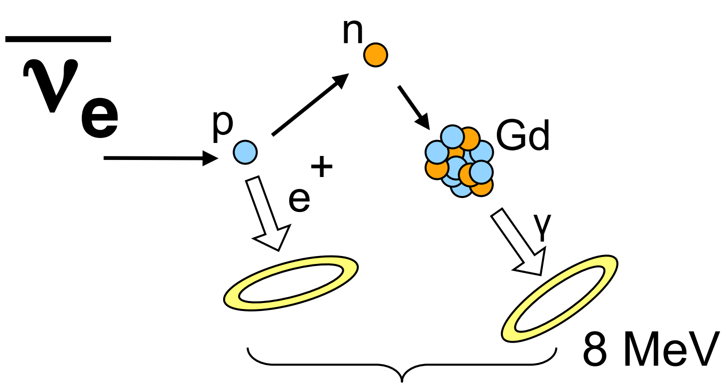
No supernova has been seen in the last 400 years, while 4–10 expected.

OAO 91 cm telescope with NIR Wide-Field Camera

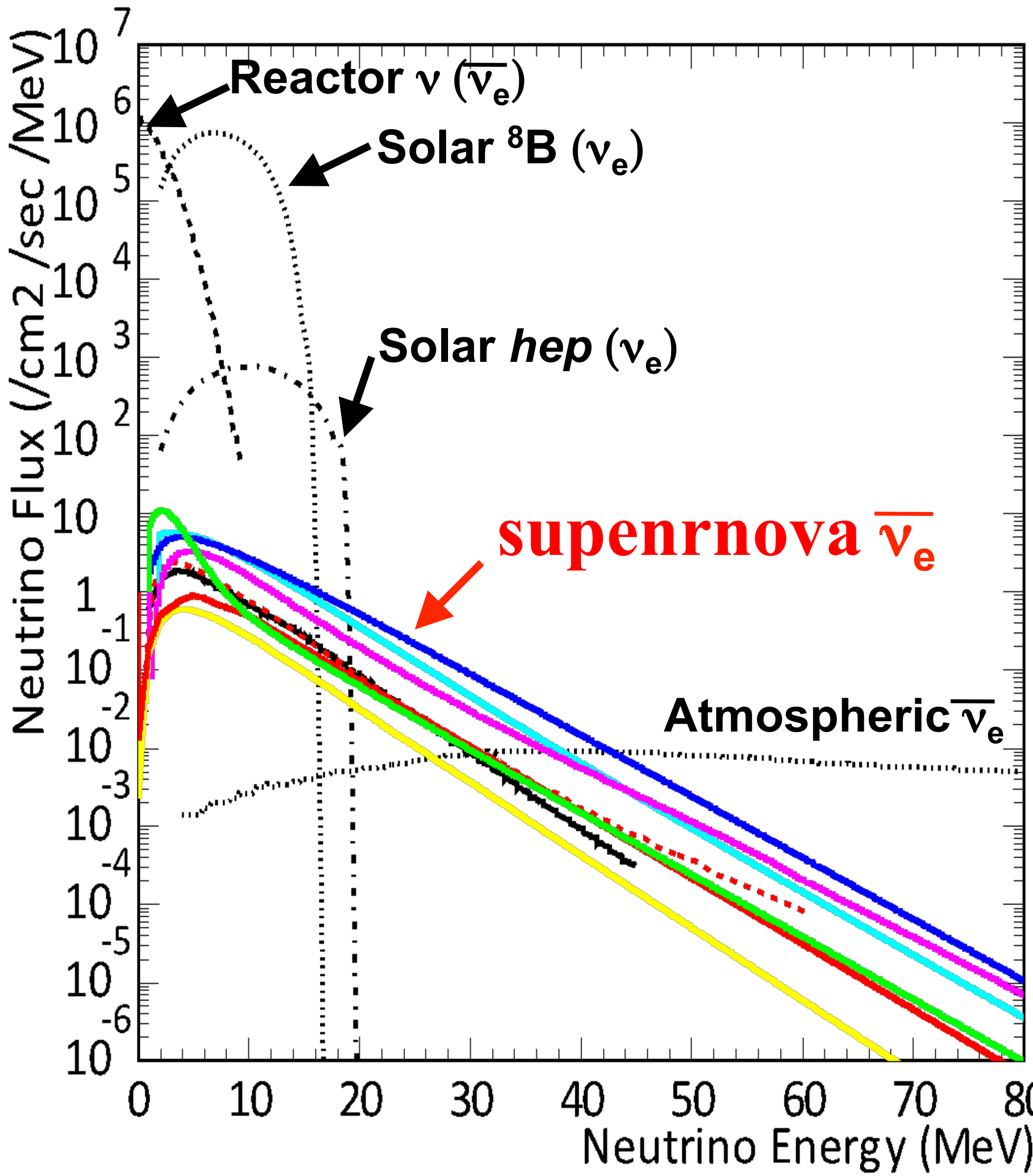
Supernova Neutrino

- Common advantage of neutrino and GW
  - Direct measurements of core collapse starting from t=0
  - No attenuation during travel:
    - can observe Galactic Center, and out to the edge of MW
- New development optimized for supernova neutrino
  - Super Kamiokande (50000 t) too sensitive for Galactic SN – current electronics cannot handle the event rate
  - ν_e detection by n-tagging enabled by doped Gd
    - study neutrino and anti-neutrino separately
    - reduce background (mu and solar nu)
  - Test system converted to a SN neutrino detector
    - 3000 neutrinos from a SN at 10 kpc

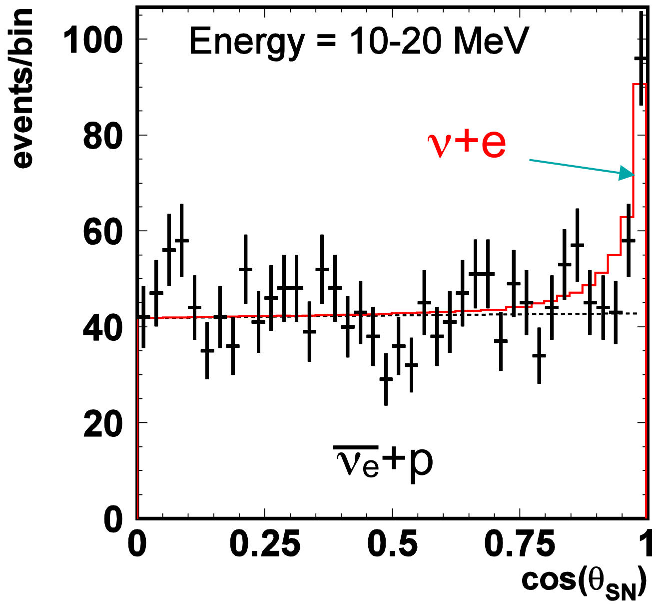
Neutron tagging with Gadolinium

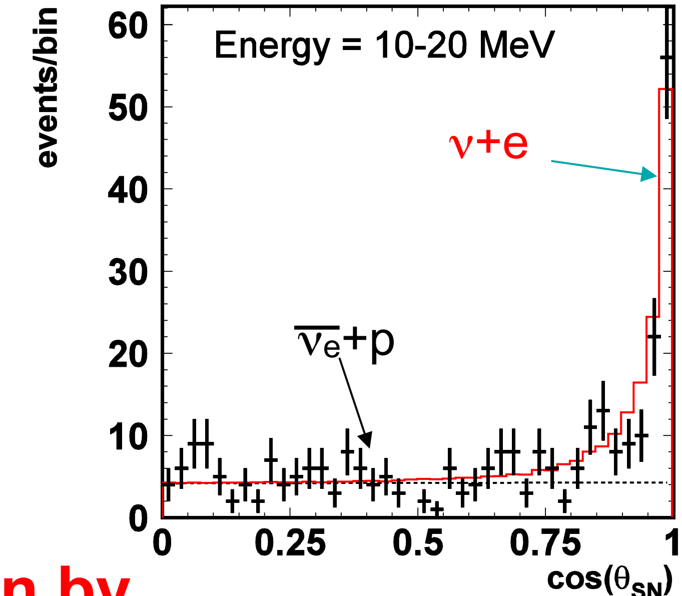


ΔT~20μs
Vertices within 50cm



Neutron tagging with Gadolinium



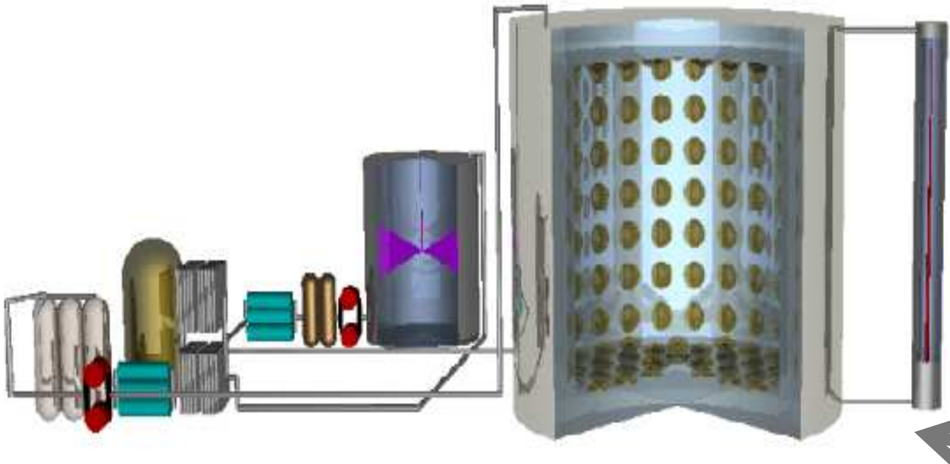


With $\overline{\nu}_e p$ identification by neutron tagging

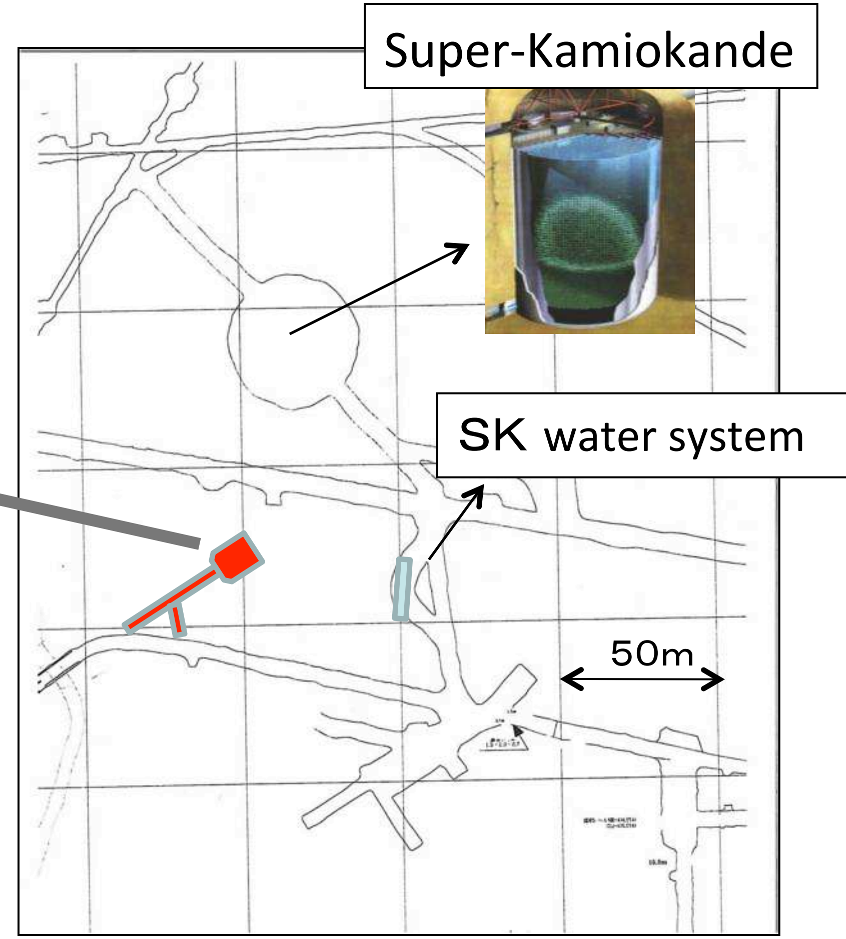
Direction accuracy (measured with scattered ν_e) improved to 3 deg

SN at 10kpc

EGADS (gadolinium test setup)

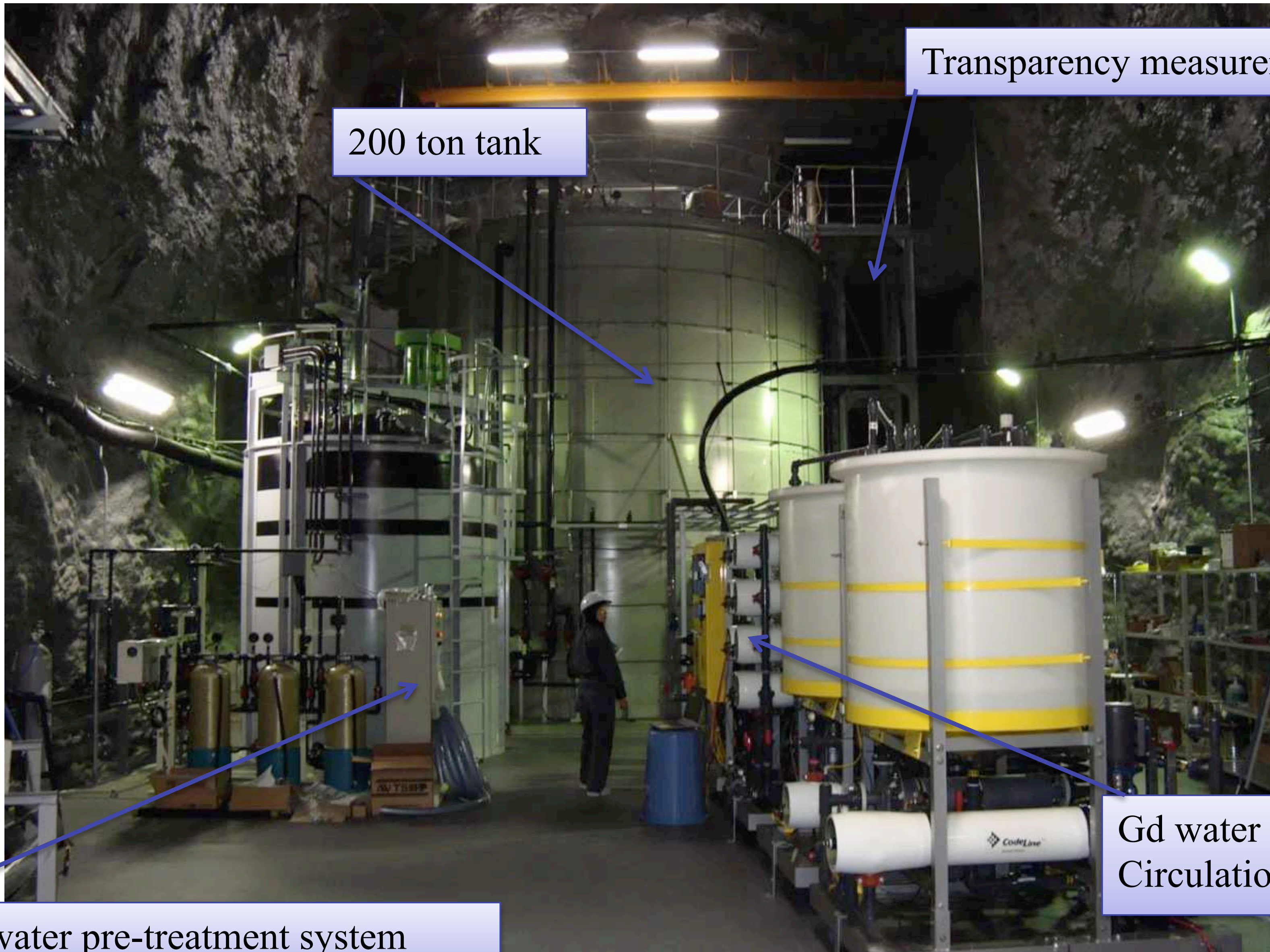


- New cavity was excavated (Sep.-Dec., 2009)
- 200ton tank constructed (Apr.-Jun., 2010)
- Gd water purification system installed (Jan.-Mar., 2011)



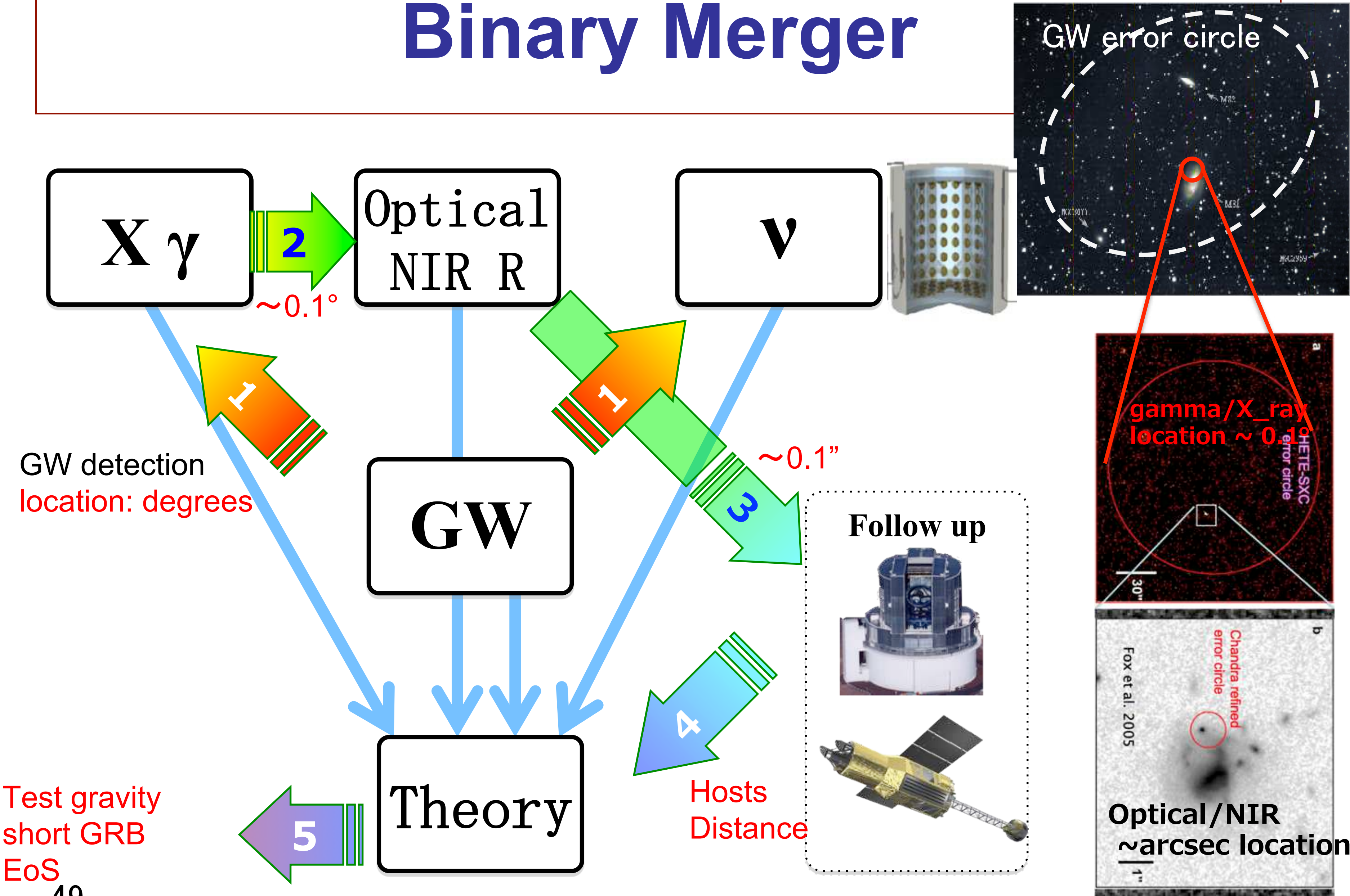
Underground map

EGADS (gadolinium test setup)

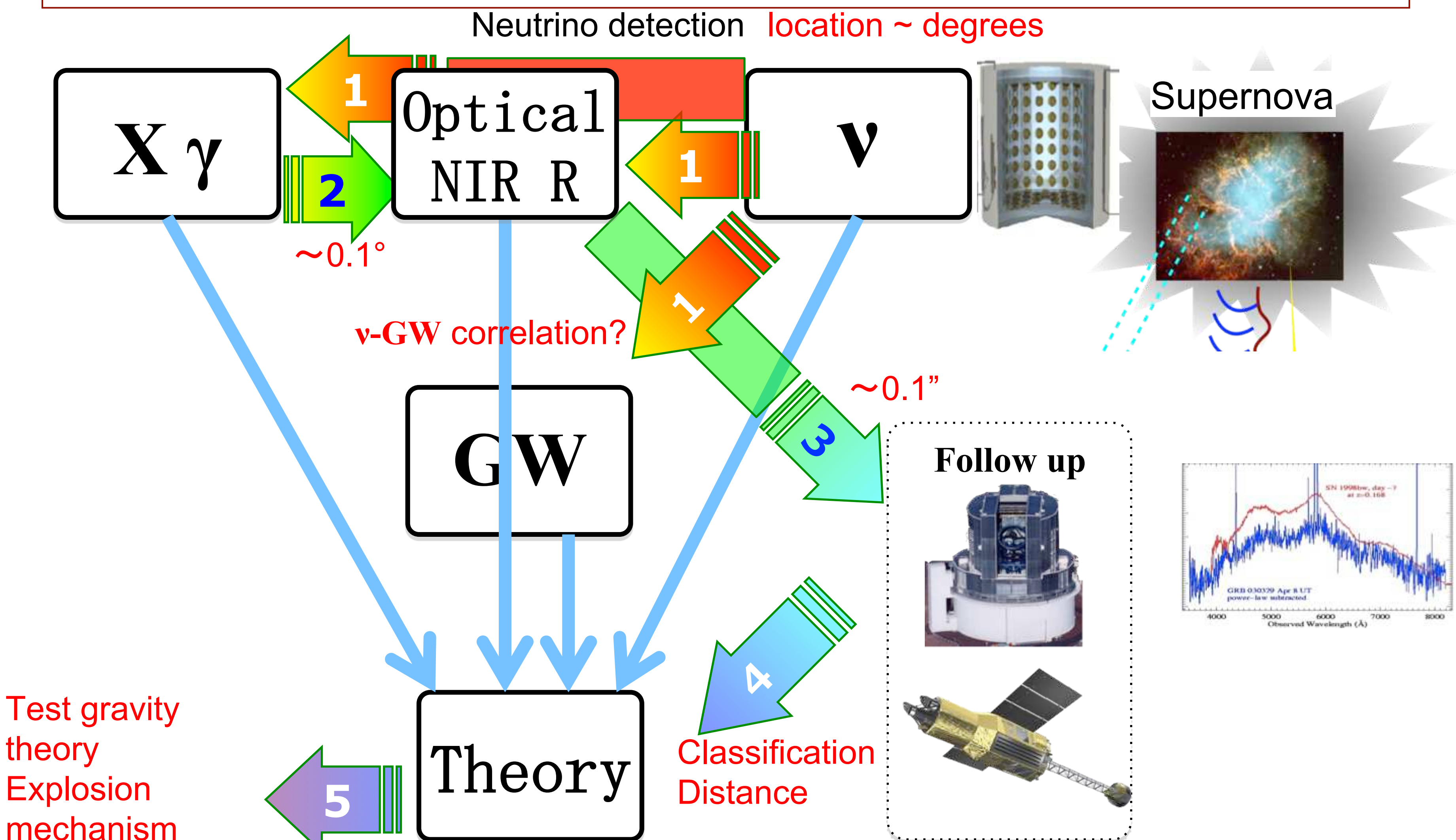


Feb.16, 2011

Binary Merger



Galactic Supernova



Conclusion (or concerns)

- Multi-messenger follow-up team for GW events are being assembled.
- Resources on the ground seem OK
- Largest concern is X-ray/Gamma-ray monitor
  - Swift is aging, SVOM delayed,
    - GRB missions not selected at NASA and ESA
  - need strong support for GRB mission
- Public and prompt distribution of GW event is important
  - Collaborate rather than compete. You (not the follow-op astronomers) will get the NP anyway.