Adventures in Time Domain Astronomy

Neil Gehrels

NASA-GSFC

UMd Space & Cosmic Ray Physics Seminar

April 1, 2013

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University of Maryland

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Outline

→ Early discoveries of γ-ray transients

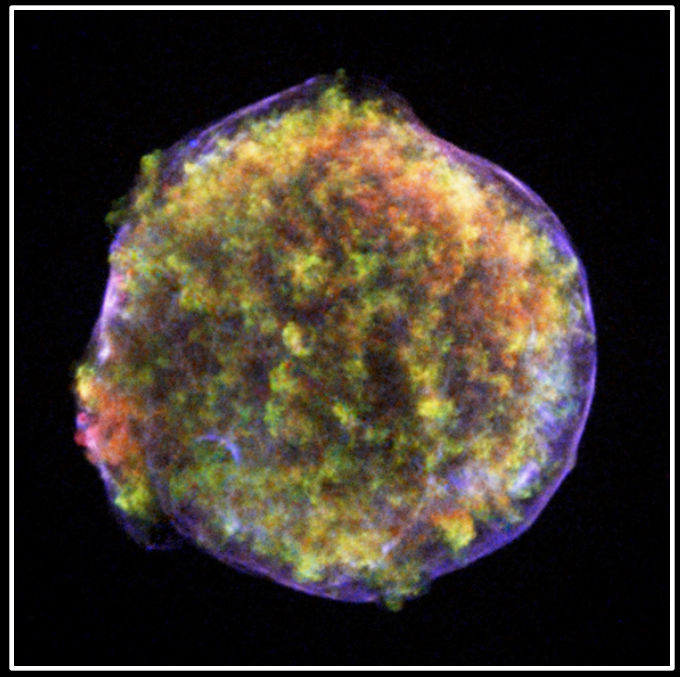
→ *Fermi* transients

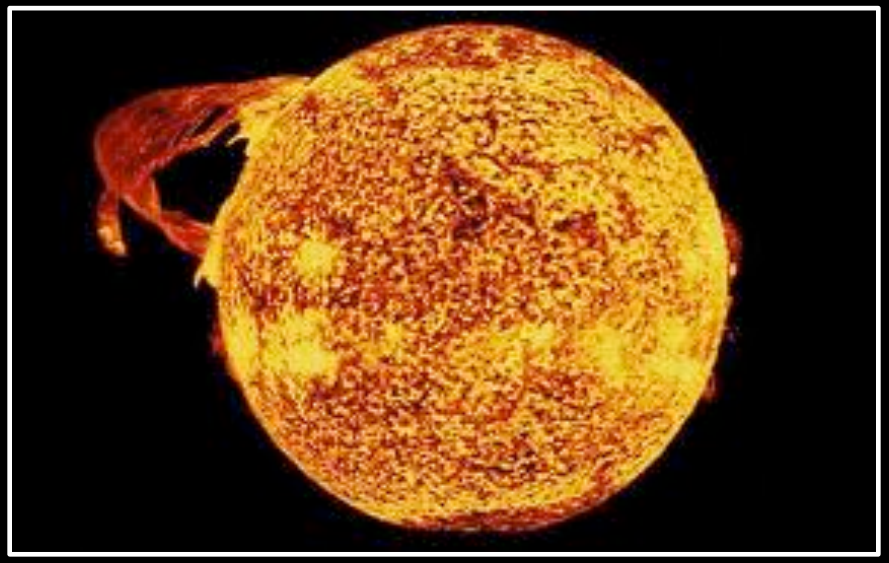
→ *Swift* transients

→ Oddball transients

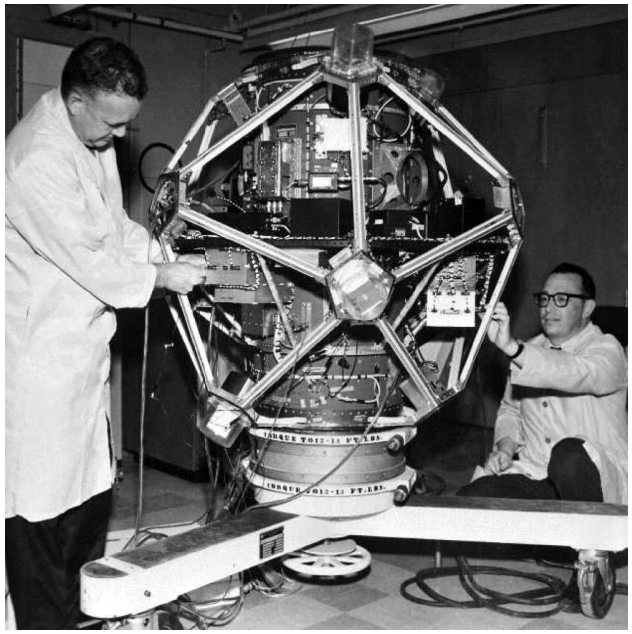
→ The future

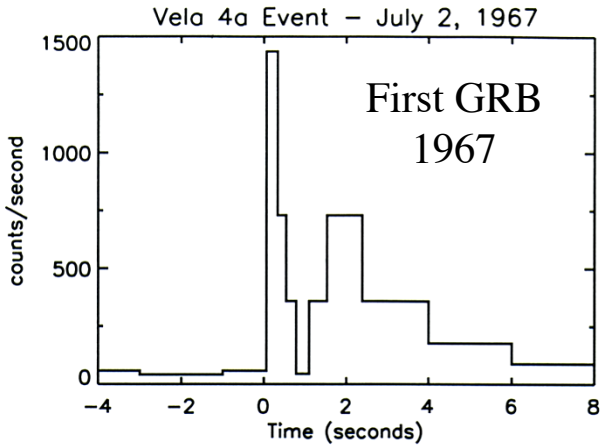

LANL 1957
Plumbob Fizeau
AtomCentral.c





First GRB Detection



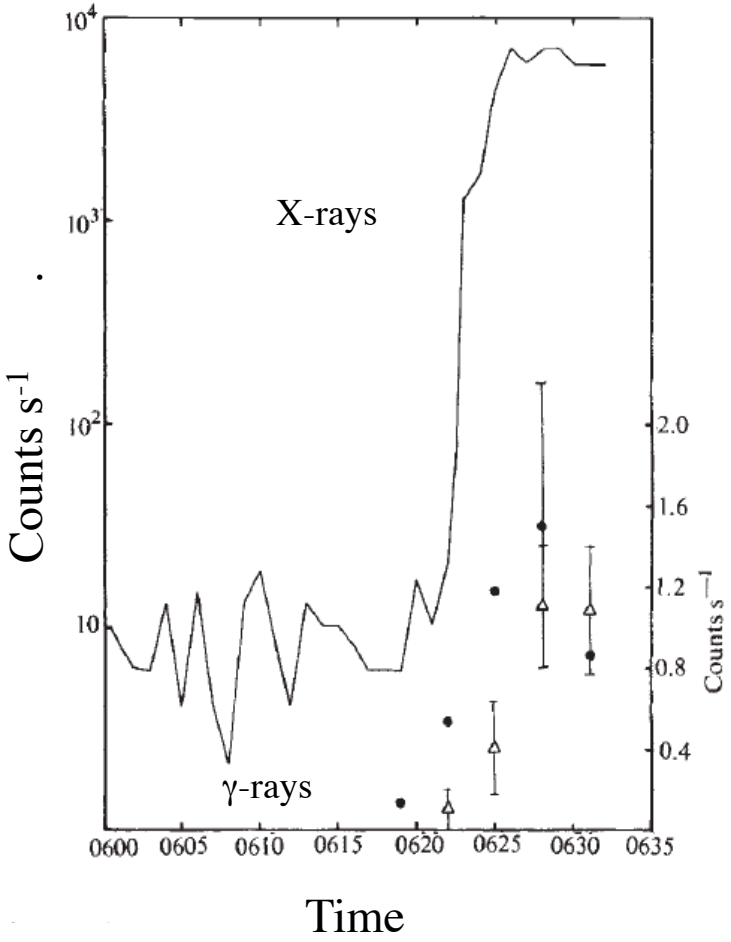


(Klebesadel, Strong & Olson 1973)

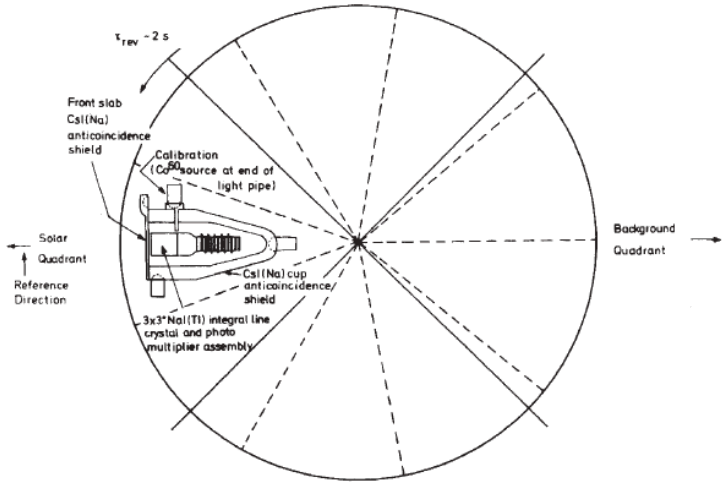
Vela Satellites - Los Alamos

First Solar Flare γ-Ray Detection

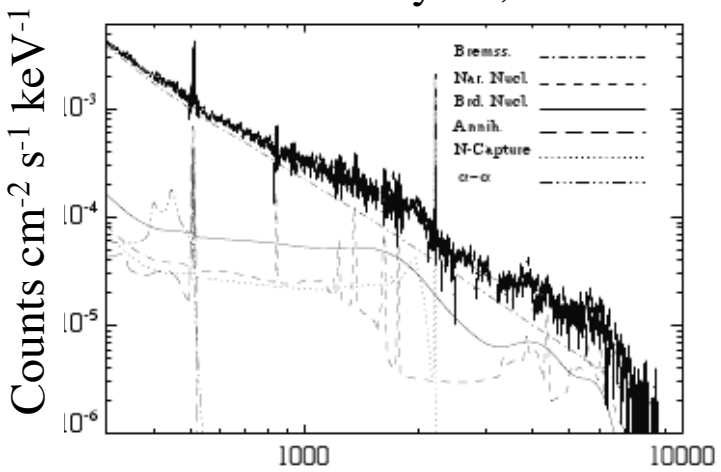
OSO-7 Dec 20, 1972



OSO-7 Detector

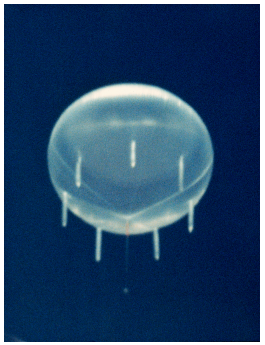


RHESSI July 23, 2002

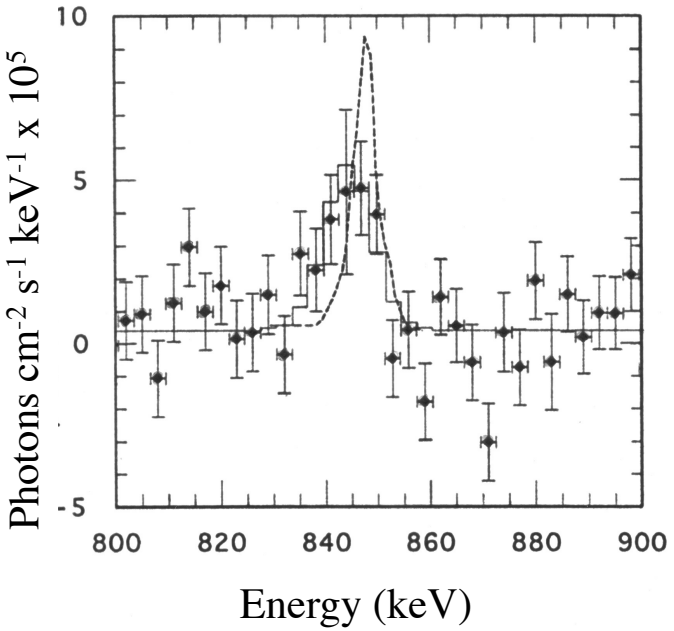


Early Supernova γ-Ray Detection

GRIS Team – Alice Springs 1987



SN87A
847 keV Line

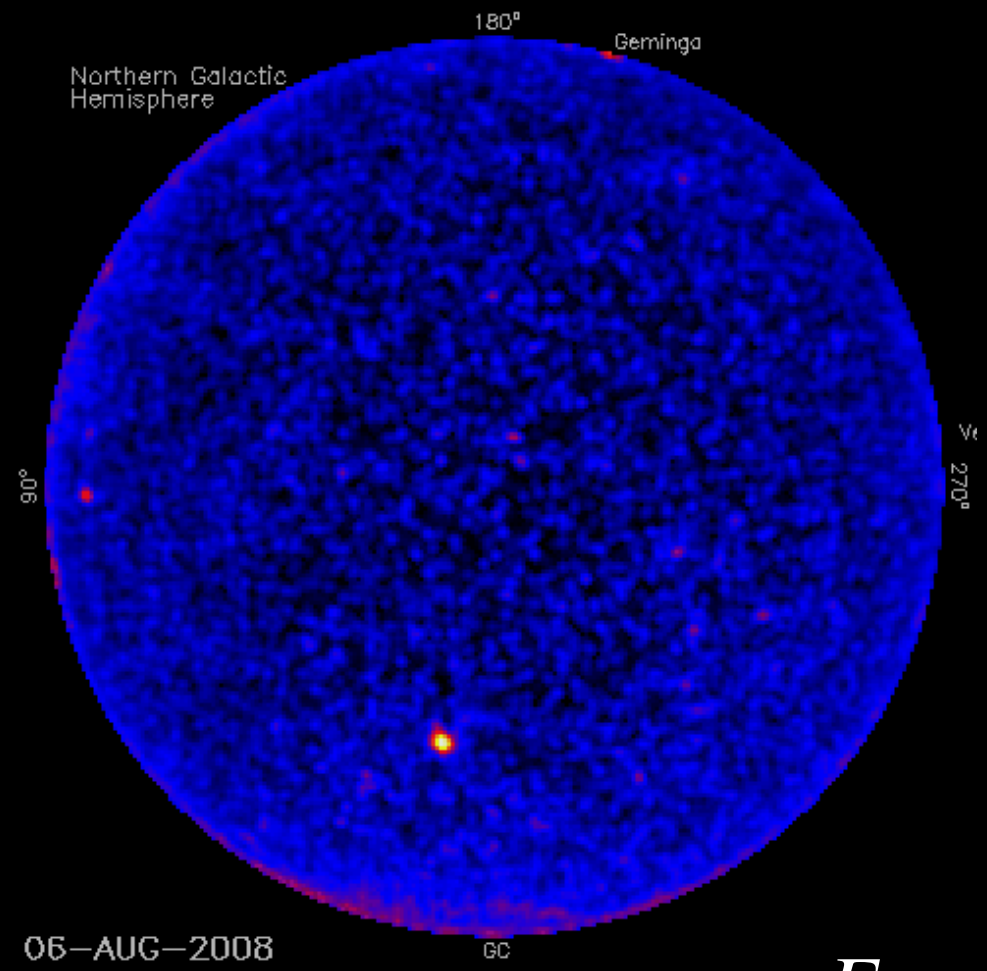


- Teegarden, Tueller et al. 1988


GRIS

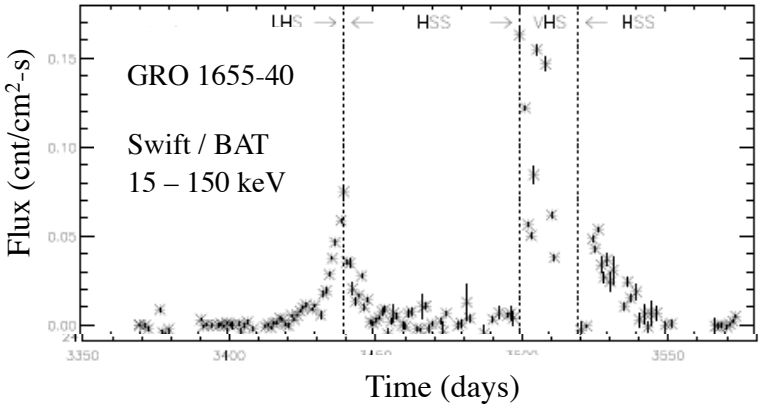
Fermi

The Variable Gamma-ray Sky
100 MeV – 100 GeV

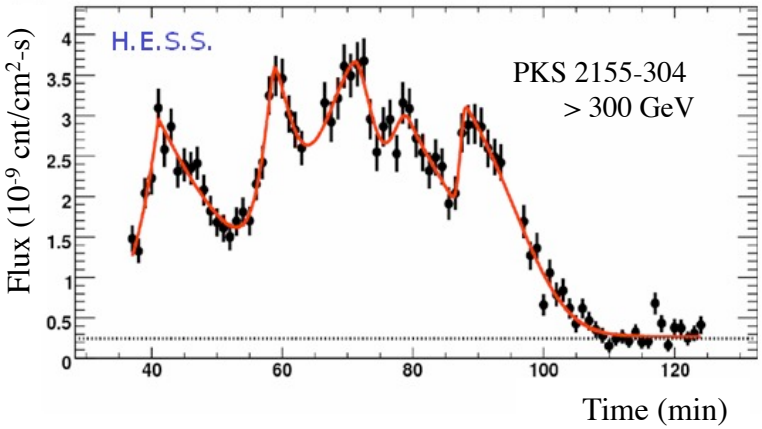


Fermi LAT

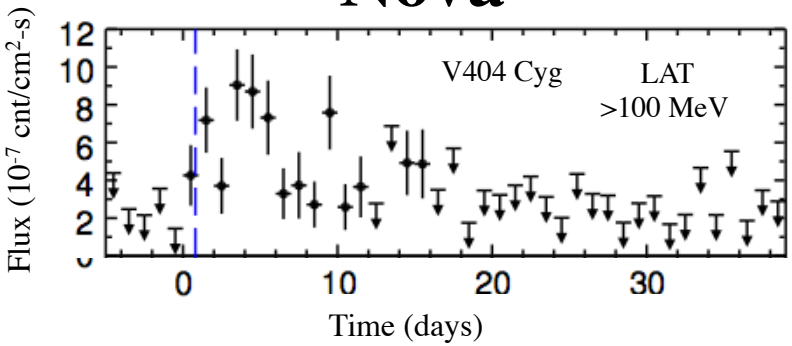
Galactic BH Transient



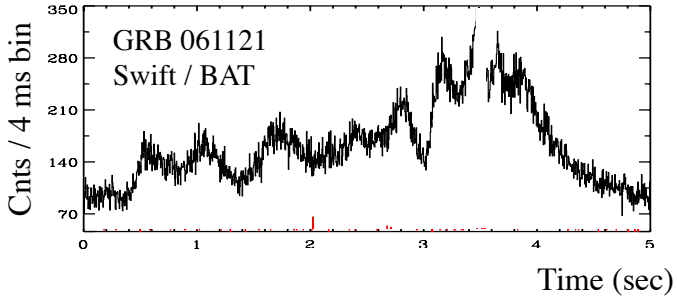
Blazar



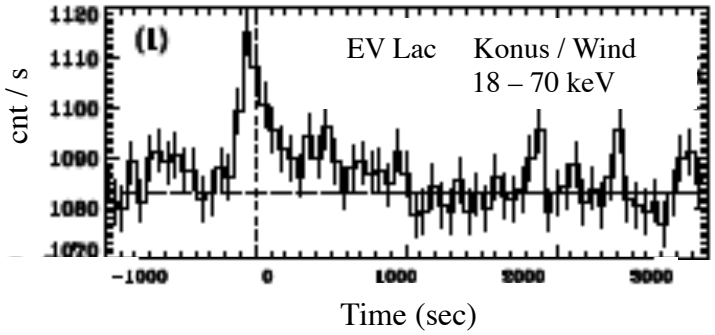
Nova



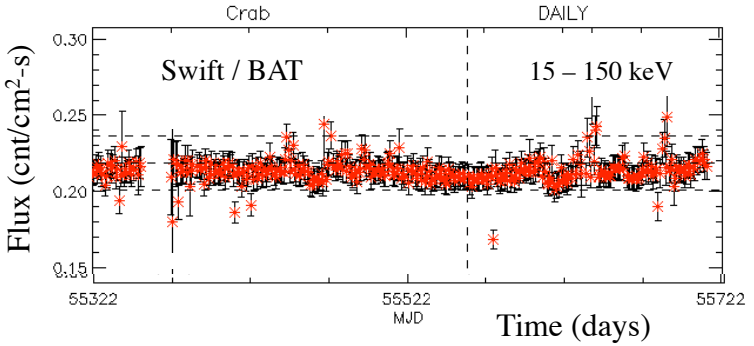
Gamma Ray Burst



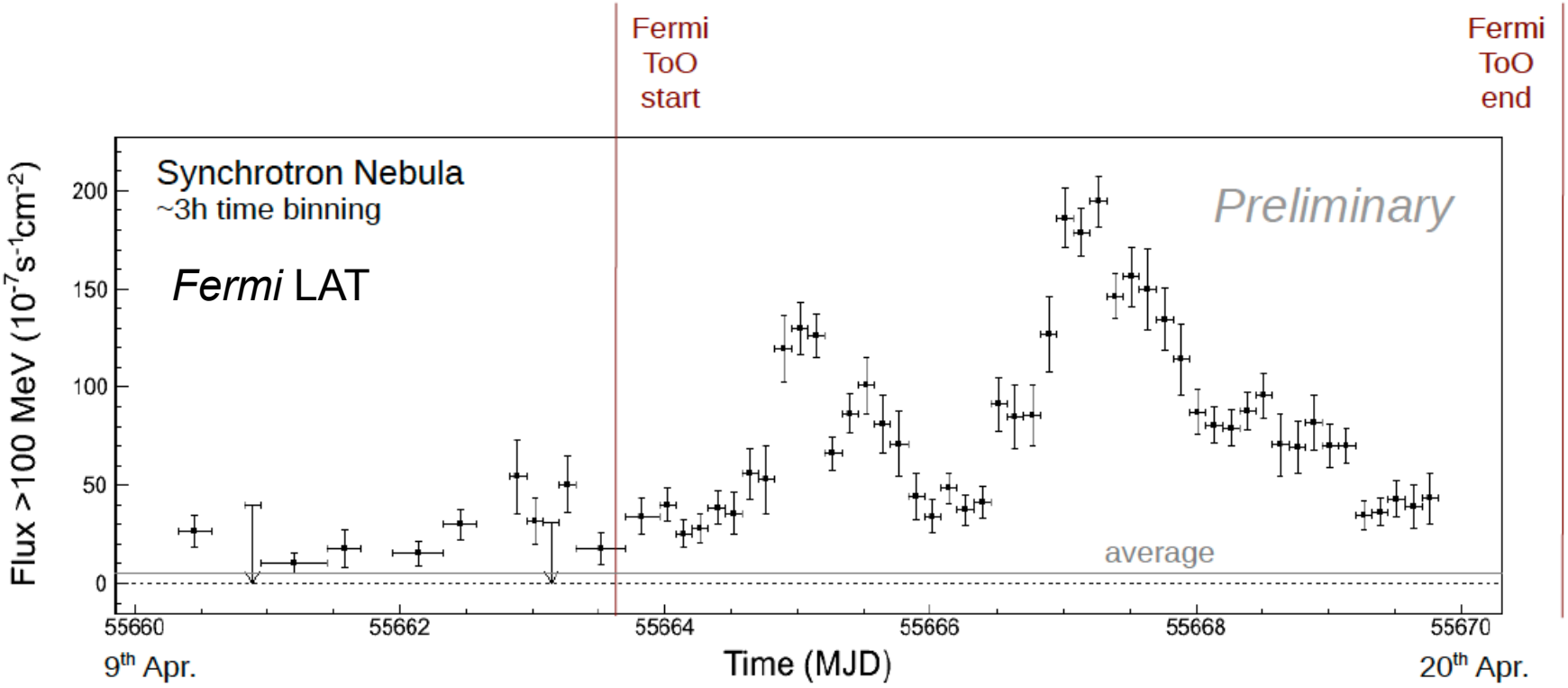
Flare Star



Crab Nebula



Crab GeV Flare



Synchrotron nebula increased by factor ~30 during very good Fermi and Chandra coverage

also AGILE

Credit: Rolf Buehler and Fermi LAT

Crab GeV Flare – Interpretation
SN 1054 Messier M1

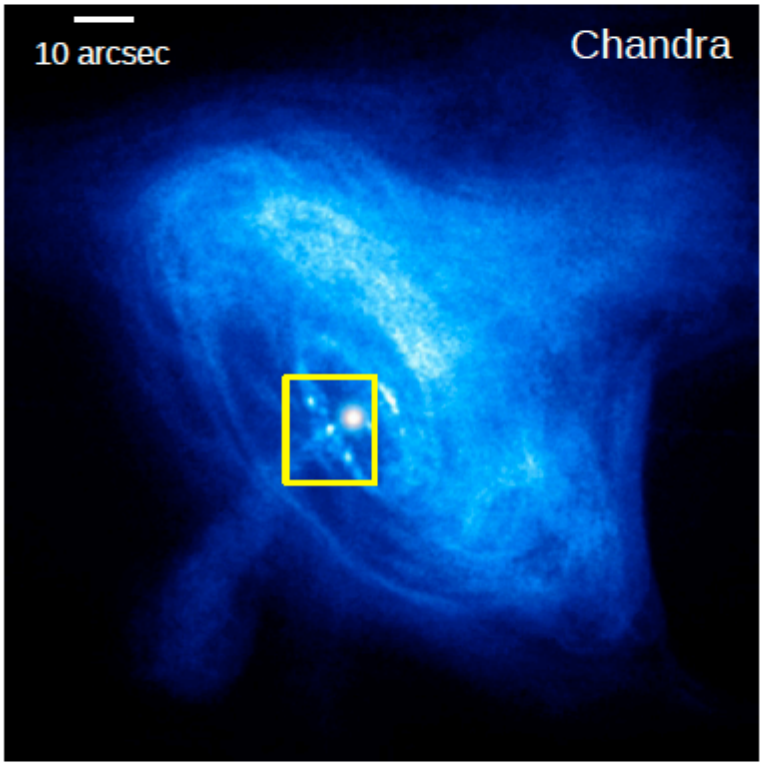
- Chandra, *Swift*, RXTE & MAXI observations during flares

- No variability seen at other wavelengths !!

- 1 hour timescales implies few AU source size ~ 4 milli-arcsec at Crab

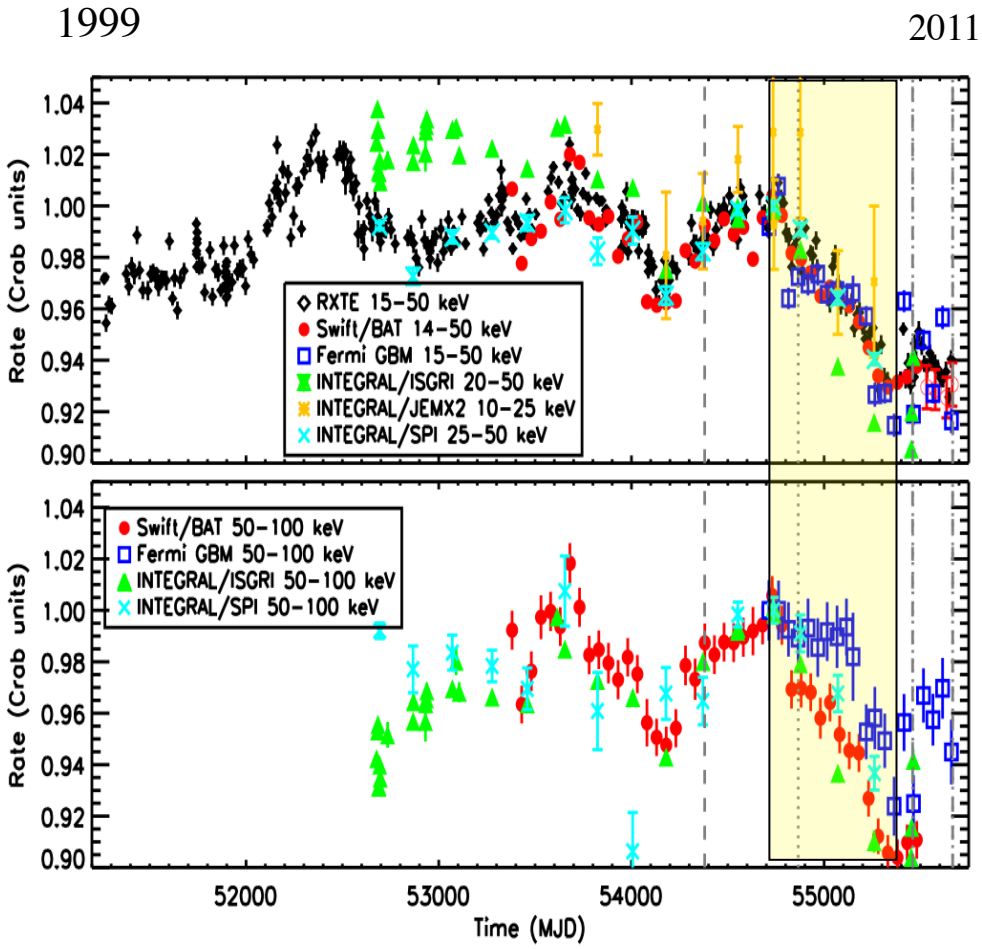
- ~10^{39} erg s^{-1} during brightest flare

- Magnetic reconnection in tiny knot ??



Crab Hard X-ray Variability

Colleen Wilson-Hodge



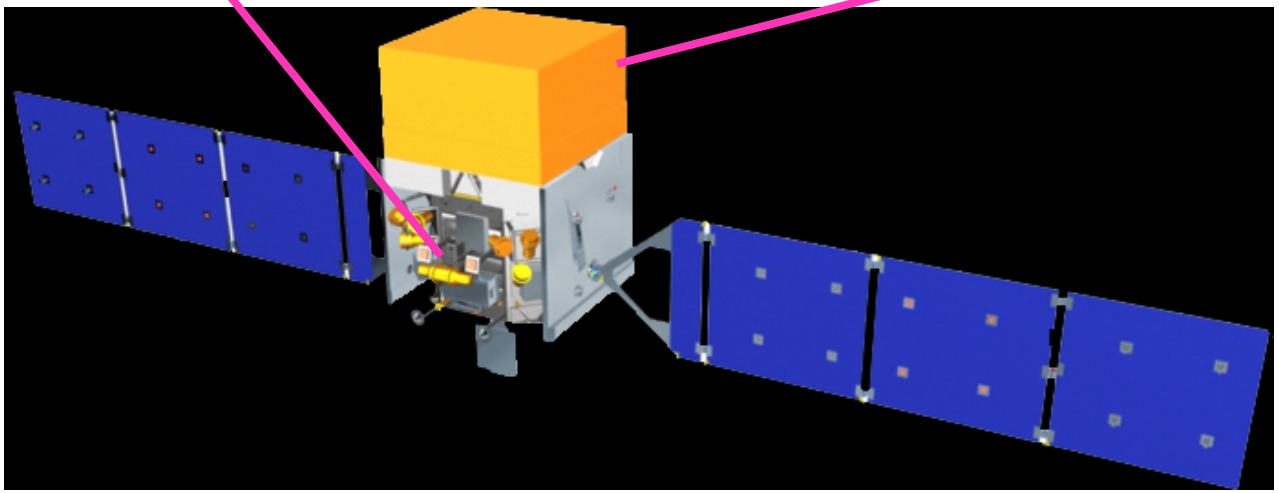
- Hard X-ray variability found first in GBM data
- Now confirmed by 5 other instruments
- ~7% decrease seen from 2008 to 2011

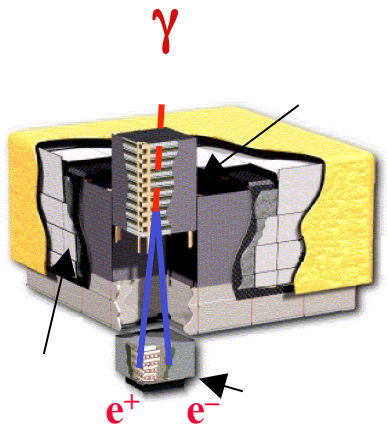
Wilson-Hodge+ 11

Fermi Gamma Ray Mission

Gamma-ray Burst Monitor (GBM)

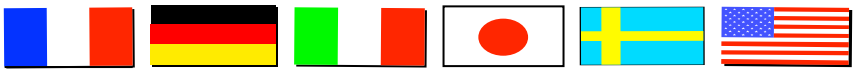
Large Area Telescope (LAT)





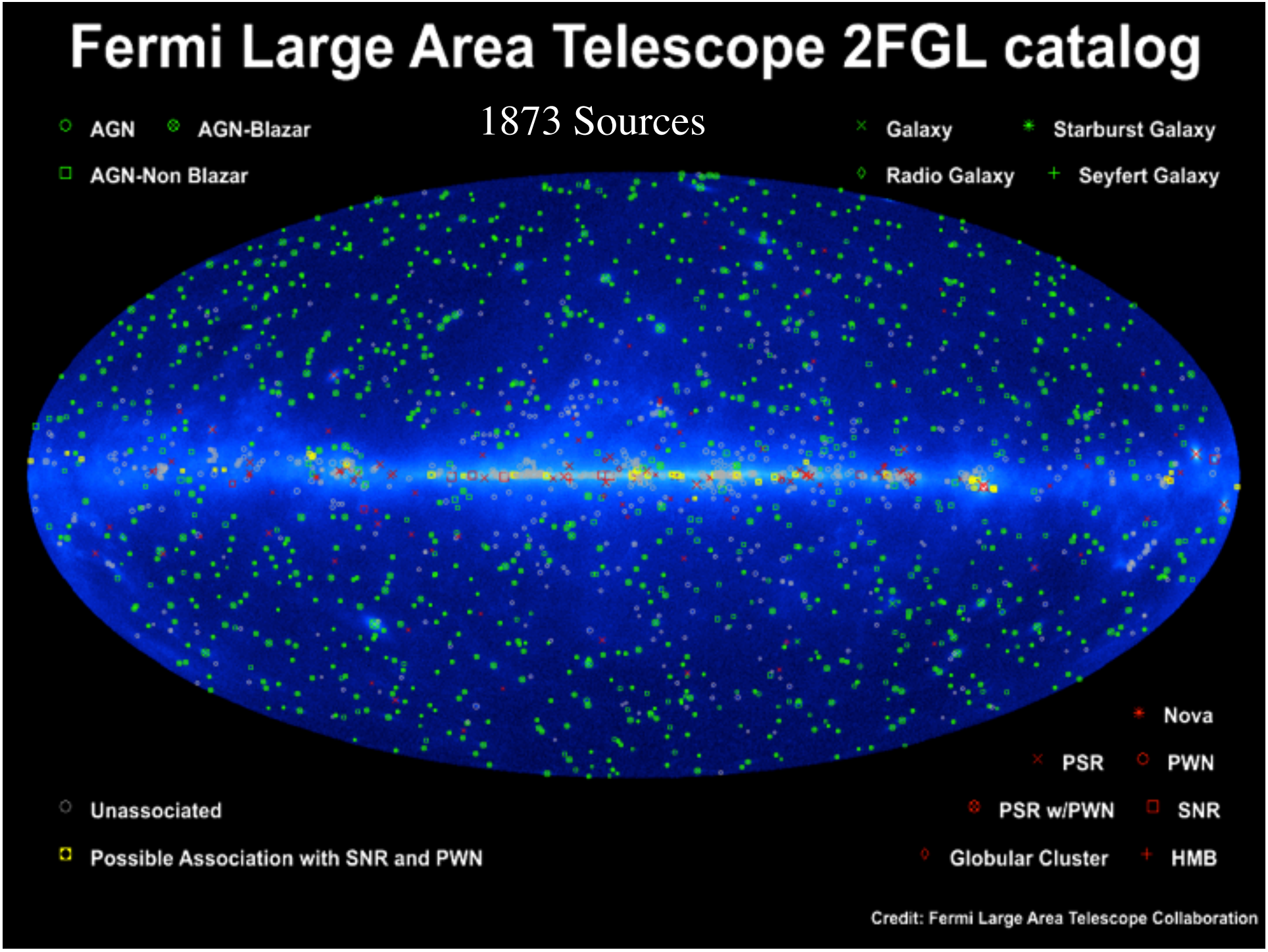
LAT - 20 MeV - >300 GeV
GBM - 8 keV - 40 MeV

3000 kg instrument
77 m^2 Si detectors



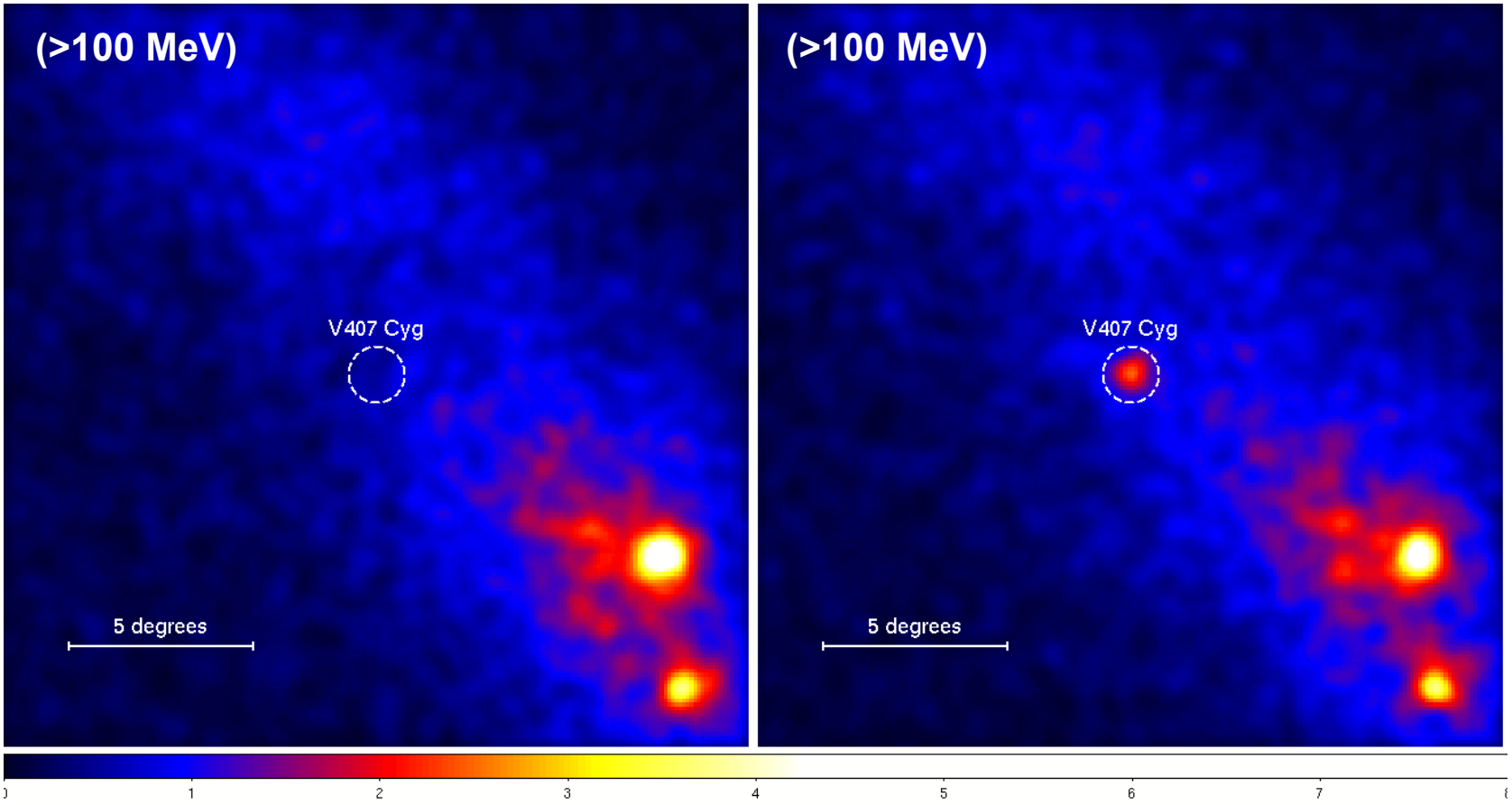
Scans full sky every 3 hours
All data public immediately

Fermi Launch


Fermi Large Area Telescope 2FGL catalog
1873 Sources
AGN
AGN-Blazar
AGN-Non Blazar
Galaxy
Starburst Galaxy
Radio Galaxy
Seyfert Galaxy
Nova
PSR
PWN
PSR w/PWN
SNR
Unassociated
Possible Association with SNR and PWN
Globular Cluster
HMB
Credit: Fermi Large Area Telescope Collaboration

Galactic transient – V407 Cyg

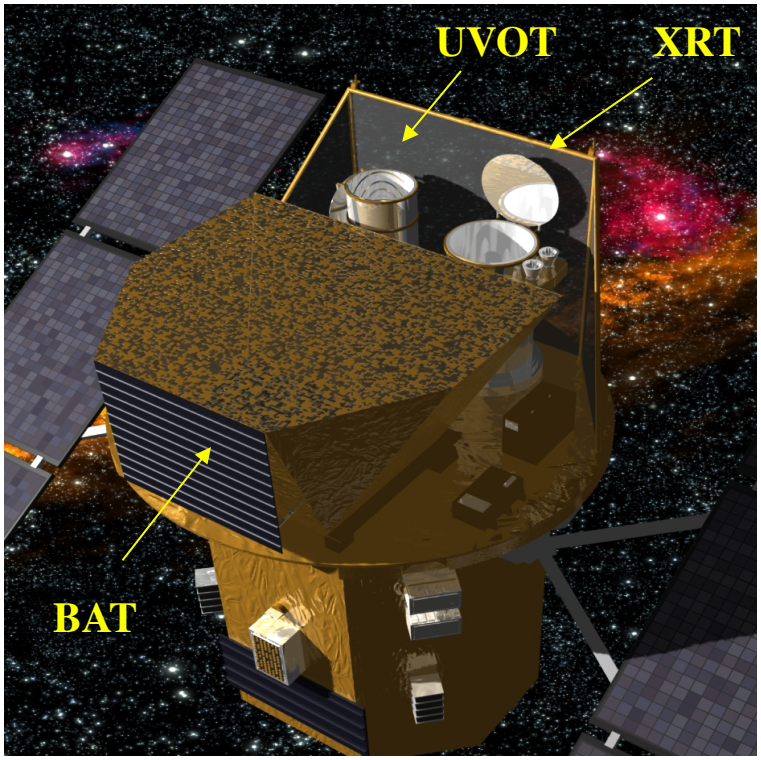
March 2010



Nova: white dwarf + giant star symbiotic binary


Swift

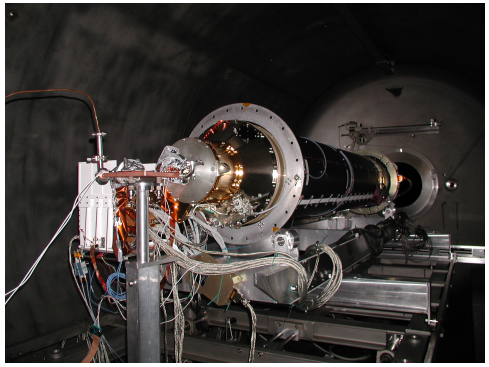
Launch November 20, 2004



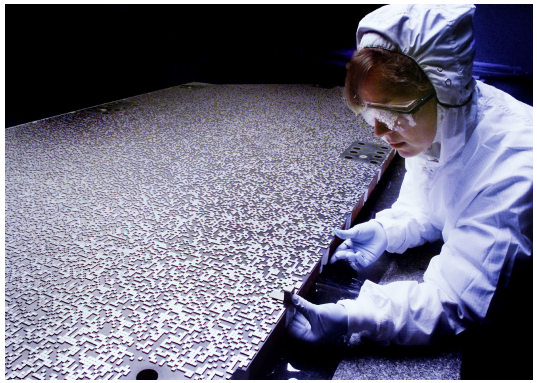
Swift Mission

- 3 instruments
- Rapid slewing spacecraft
- BAT instrument
  32,000 CdZnTe detectors
- Follow-up with sensitive
  XRT and UVOT
- >700 GRBs (long & short)
  localized to arcsec accuracy

XRT

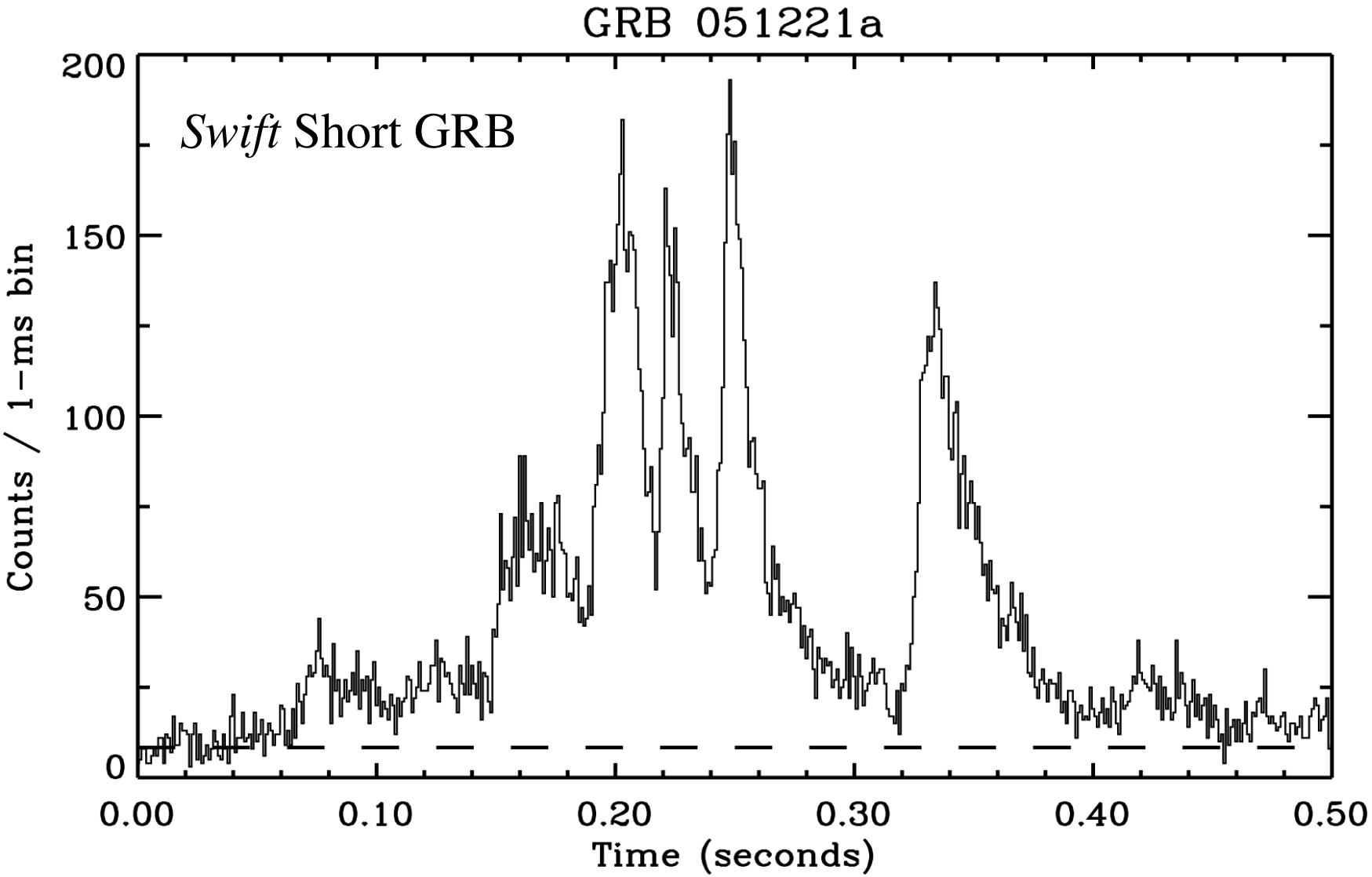


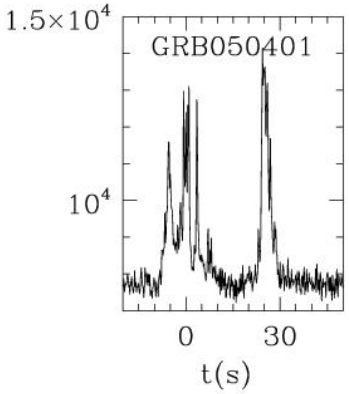
BAT Mask



UVOT

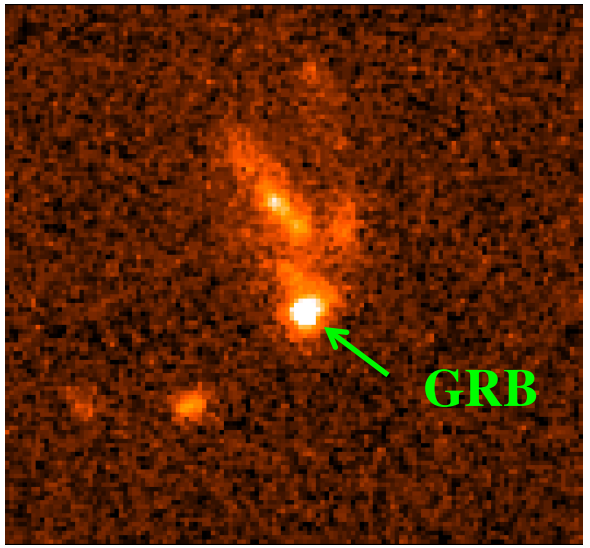
GRB Variability



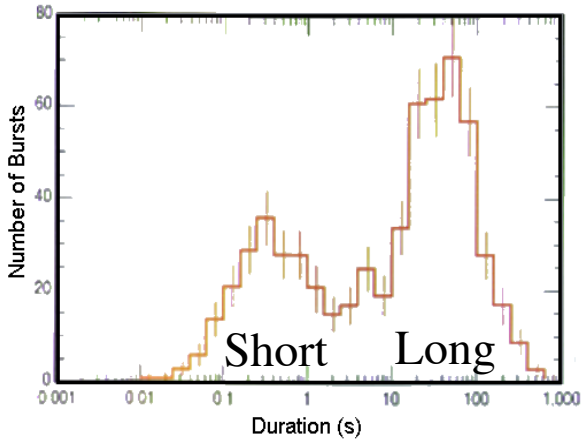


The GRB Phenomenon

GRB 990123 - HST



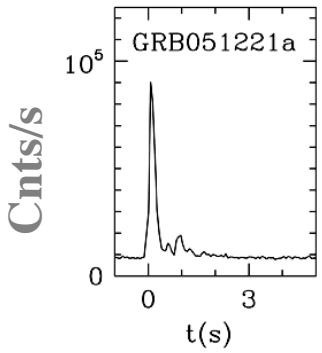
- ⇒ GRBs in distant galaxies
- ⇒ Distance z ~ 2
- ⇒ Energy ~ 10^{51} ergs in γ-ray flash
- ⇒ Gamma rays in ~5° beams
- ⇒ Millisecond time structure



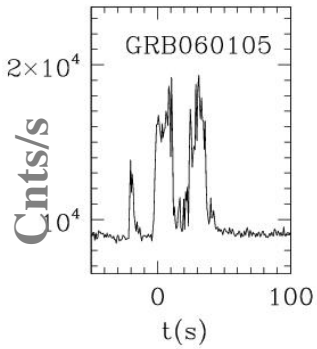
Kouveliotou et al. 1993

Short vs Long GRBs

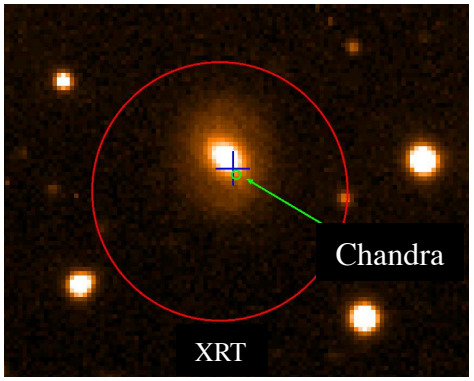
Short GRB



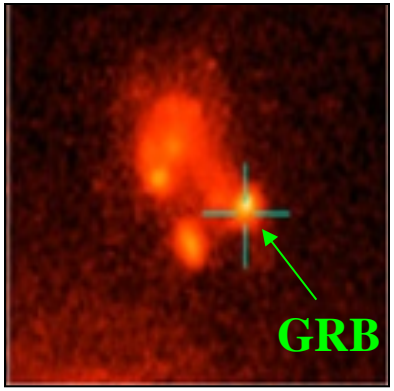
Long GRB



GRB 050724 - *Swift*
elliptical host



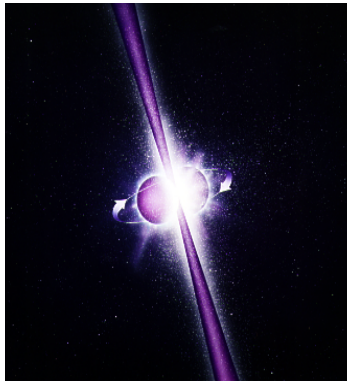
GRB 020903 - *SAX*
SF dwarf host

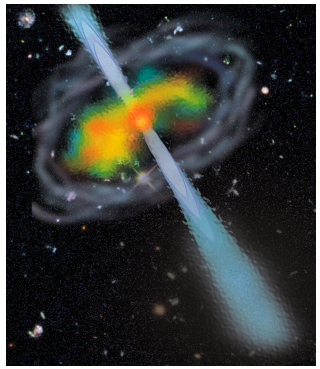


In non-SF
and SF galaxies

No SNe detected

Possible **merger**
model





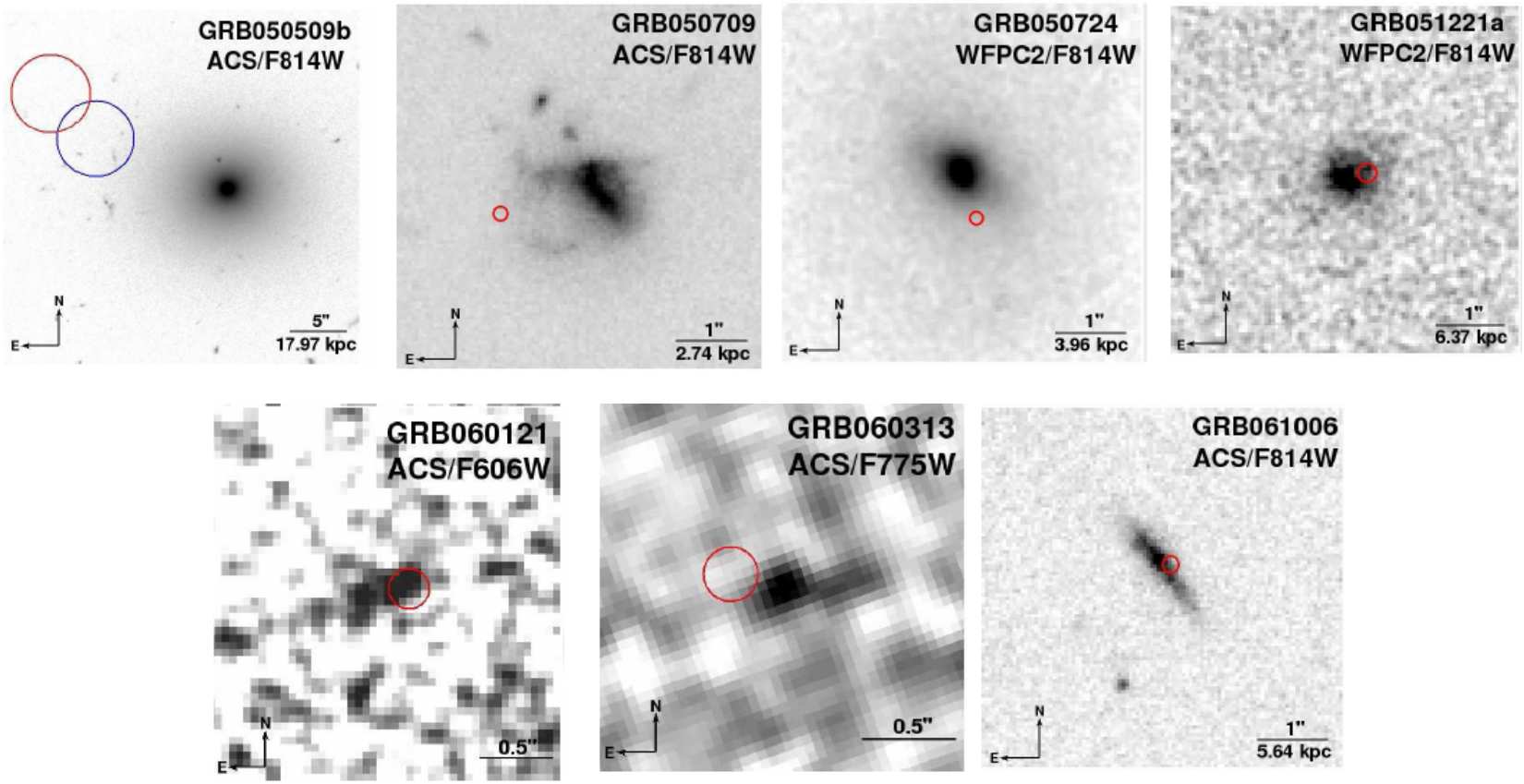
BH

In SF
galaxies

Accompanied by SNe

Collapsar model
well supported

Short Burst HST Images



Fong, Berger & Fox 2010

Delayed GeV Emission – *Fermi* LAT

Short GRB 090510

z = 0.903 (7.5 billion light yr)

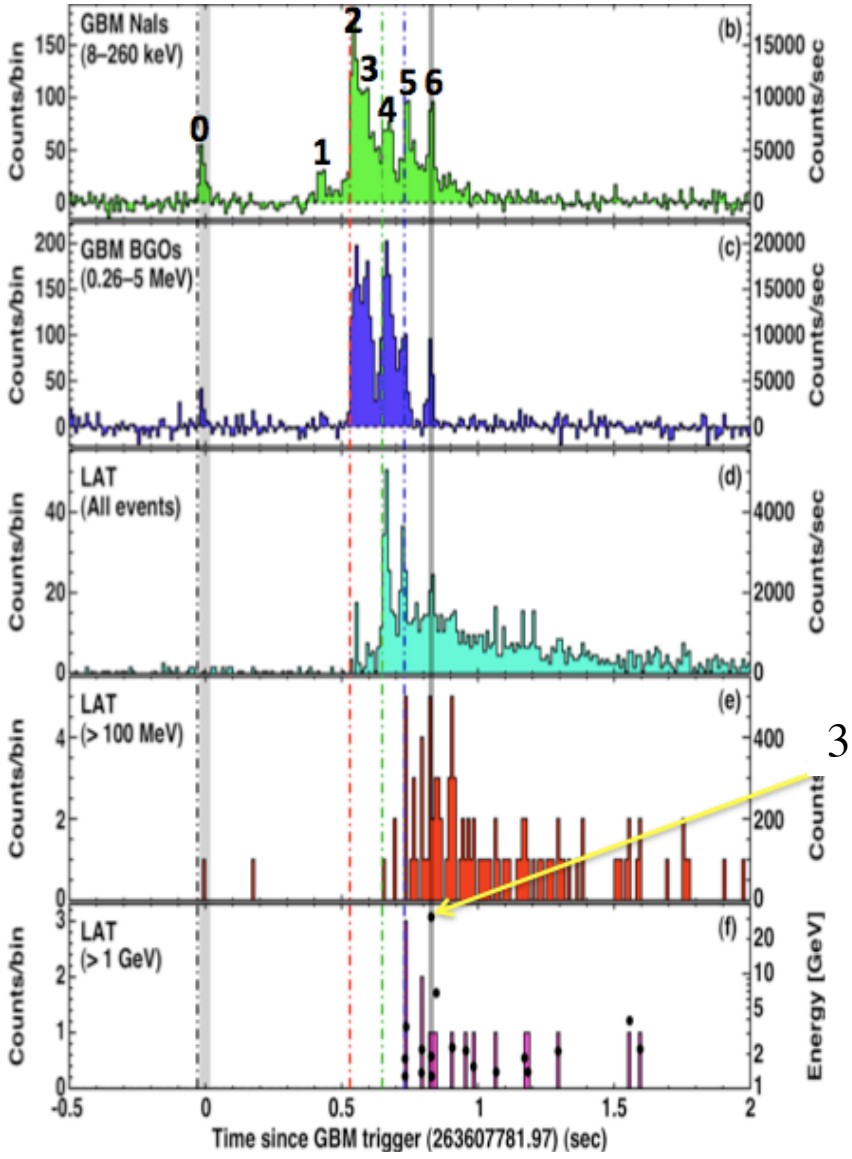
Extended emission

Lag in MeV/GeV onset

Extended emission

Lorentz invariance limits
- no observed dispersion

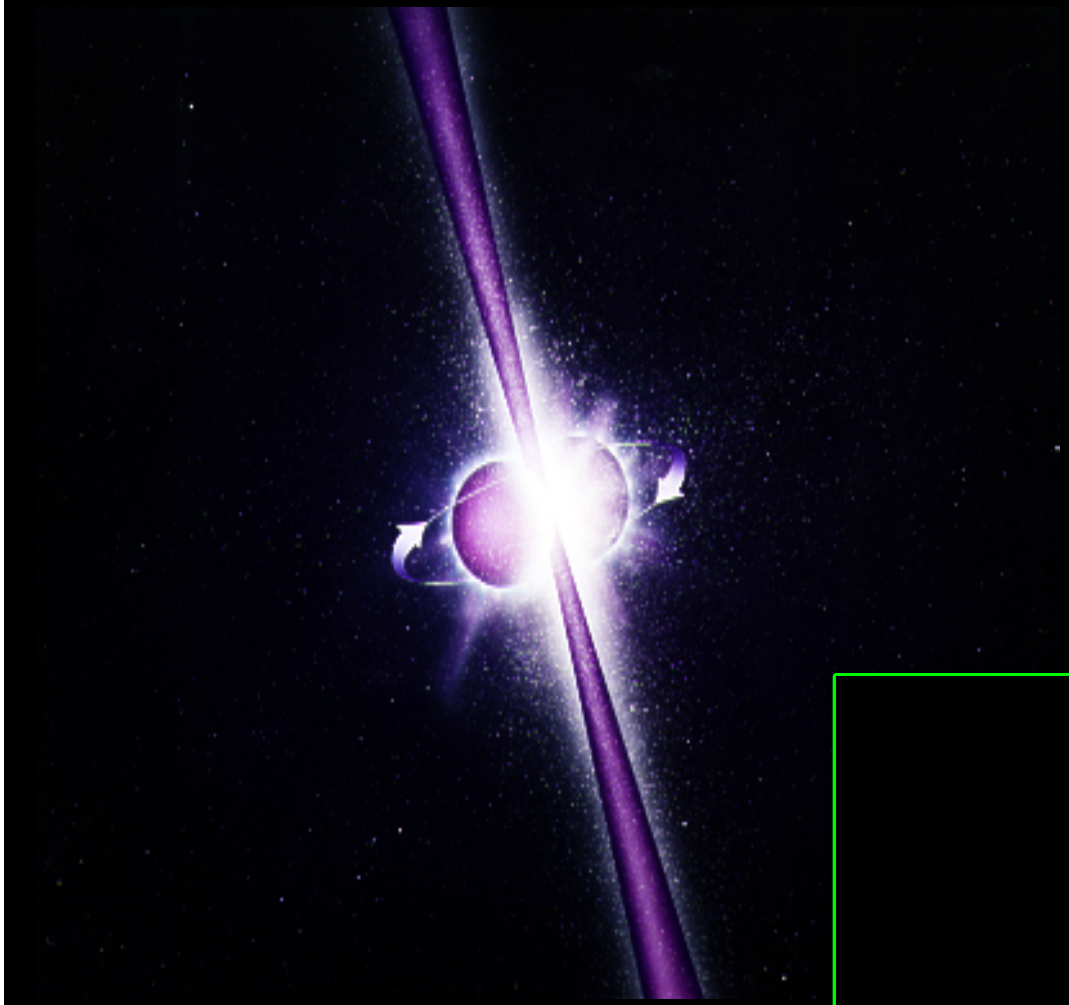
Speed of light constant to part in 10^{16}

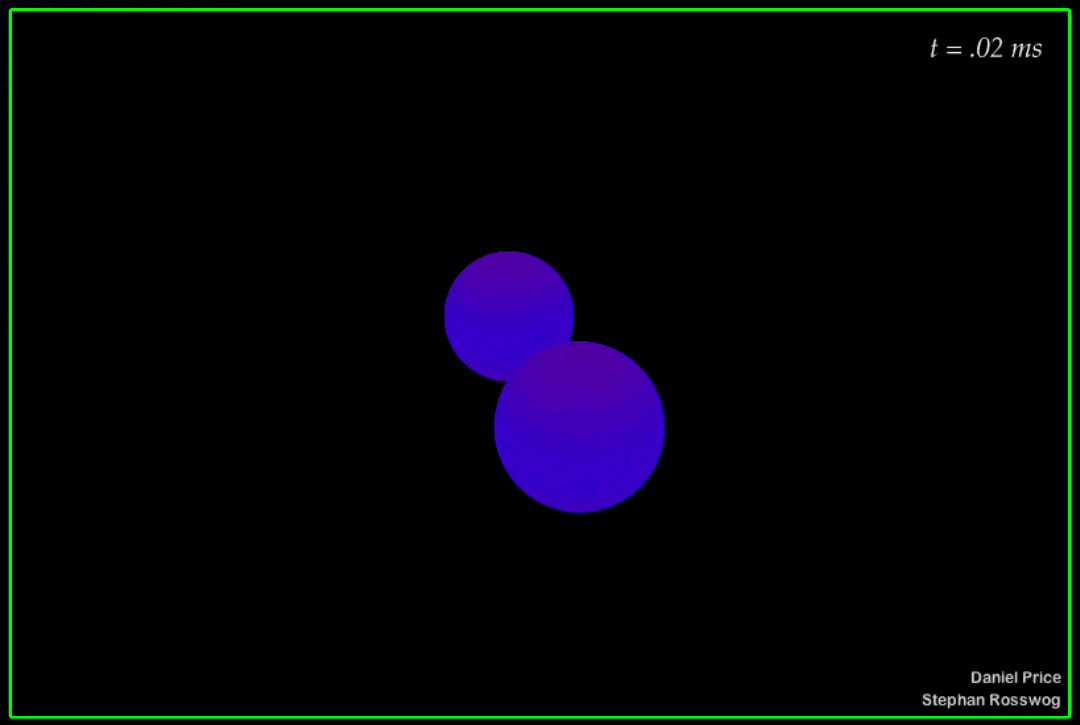


31 GeV

Abdo+ 09 Nature

Short GRBs
Merger Model

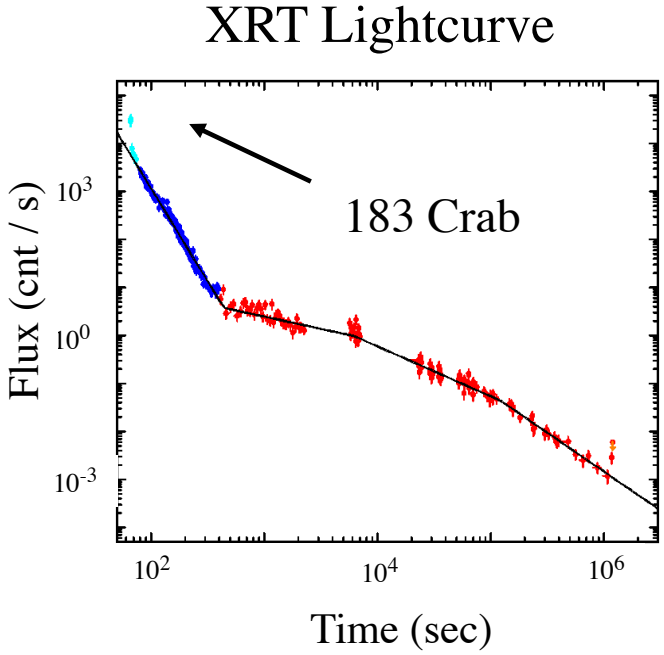


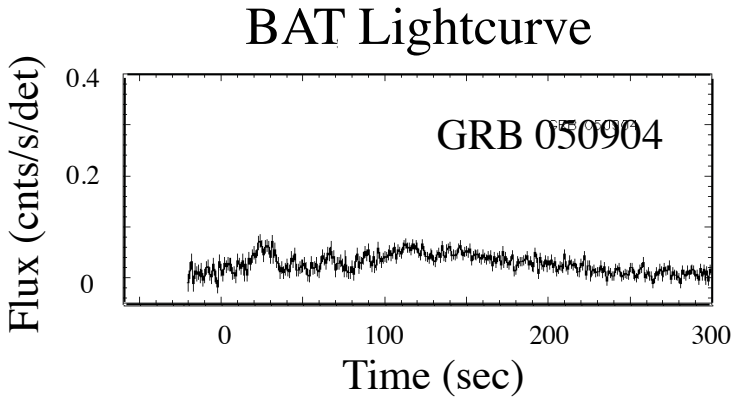


Credit: Daniel Price and Stephan Rosswog

High Redshift GRBs

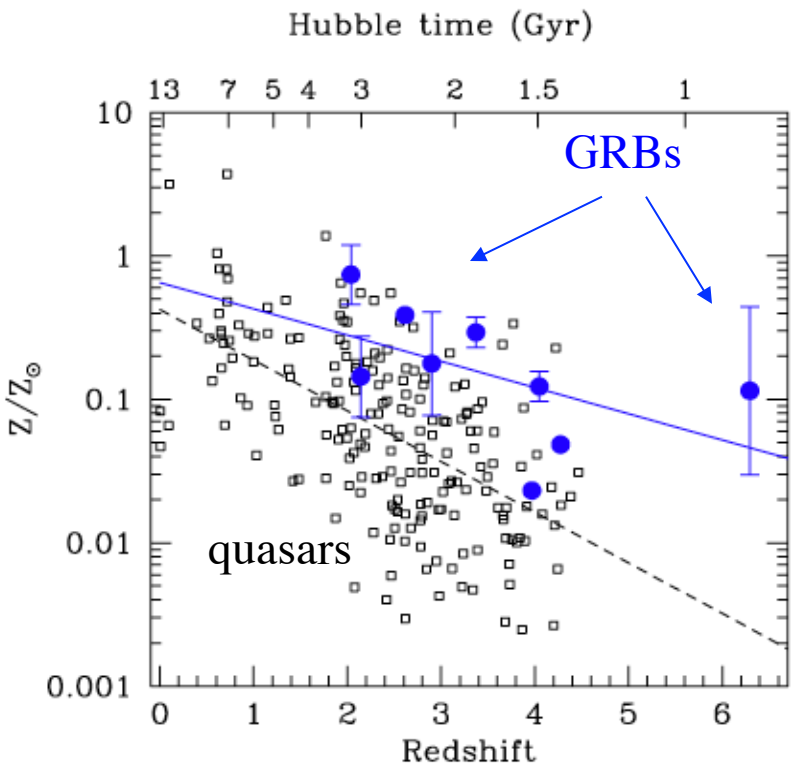
z	Look-Back Time (Gyr)	GRB	Optical Brightness
9.4	13.1	090429B	K = 19
8.2	13.0	090423	K = 20
~8	13.0	120923A	
7.5	13.0	100905A	H ~ 19
6.7	12.8	080813	K = 19
6.3	12.8	050904	J = 18
6.2	12.8	120521C	
5.6	12.6	060927	I = 16
5.3	12.6	050814	K = 18
5.11	12.5	060522	R = 21





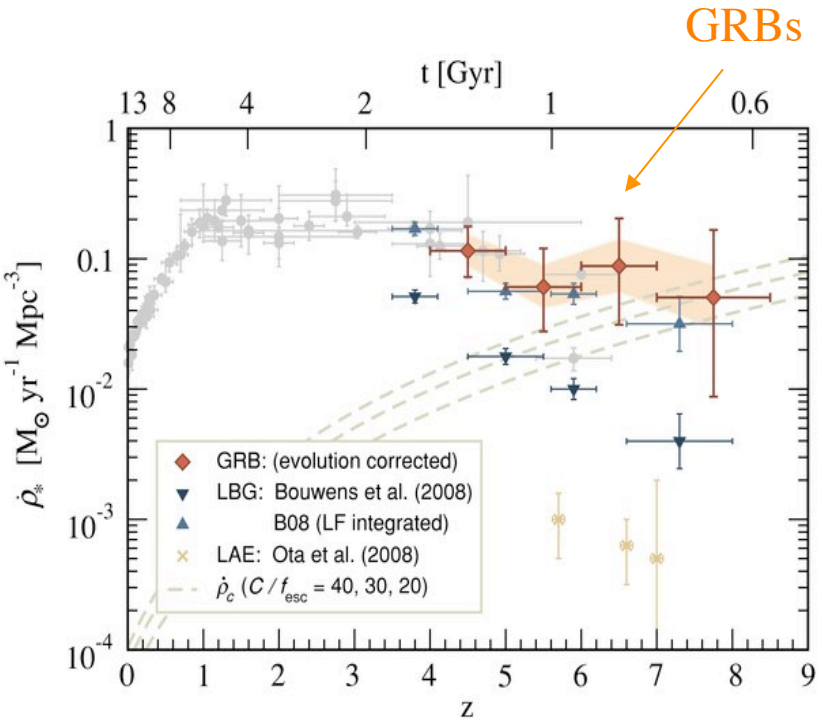
Tools to Study the High-z Universe

Metallicity



Savaglio 06

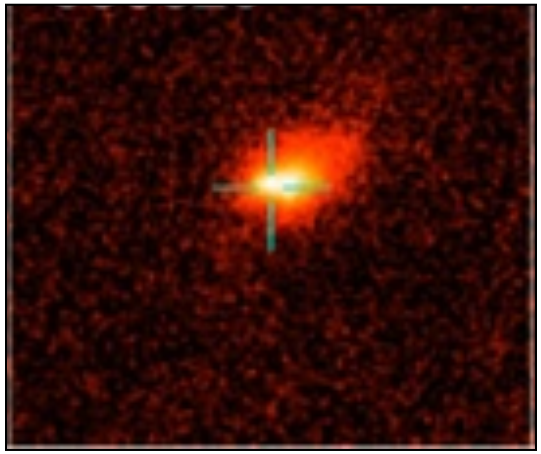
Star Formation Rate



Kistler + 09;
Robertson & Ellis 11

Long GRB Understanding

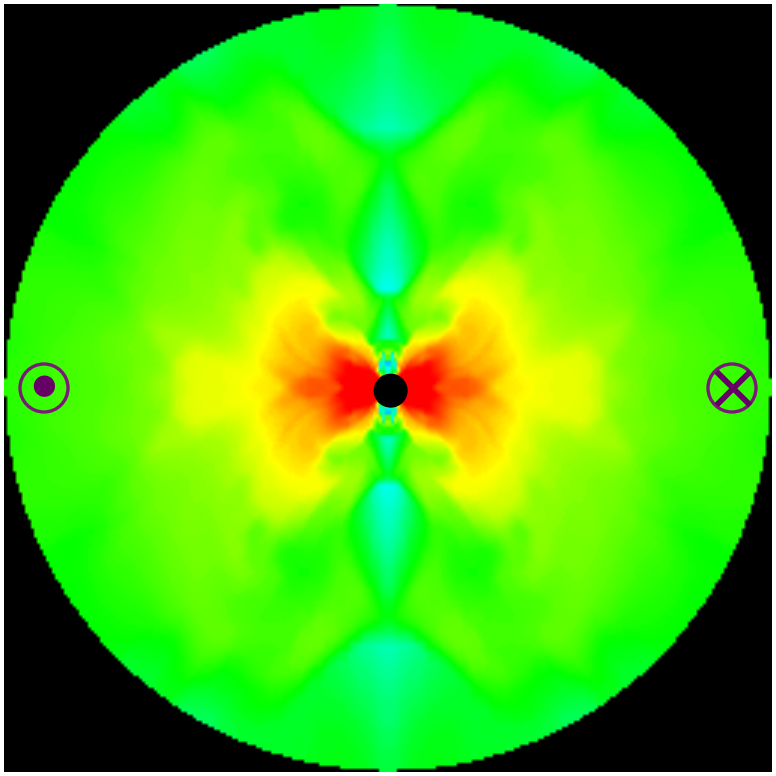
HST image



Occur in bright star-forming regions of galaxies

Accompanied by SN Ib/c

Caused by core collapse of rotating massive star

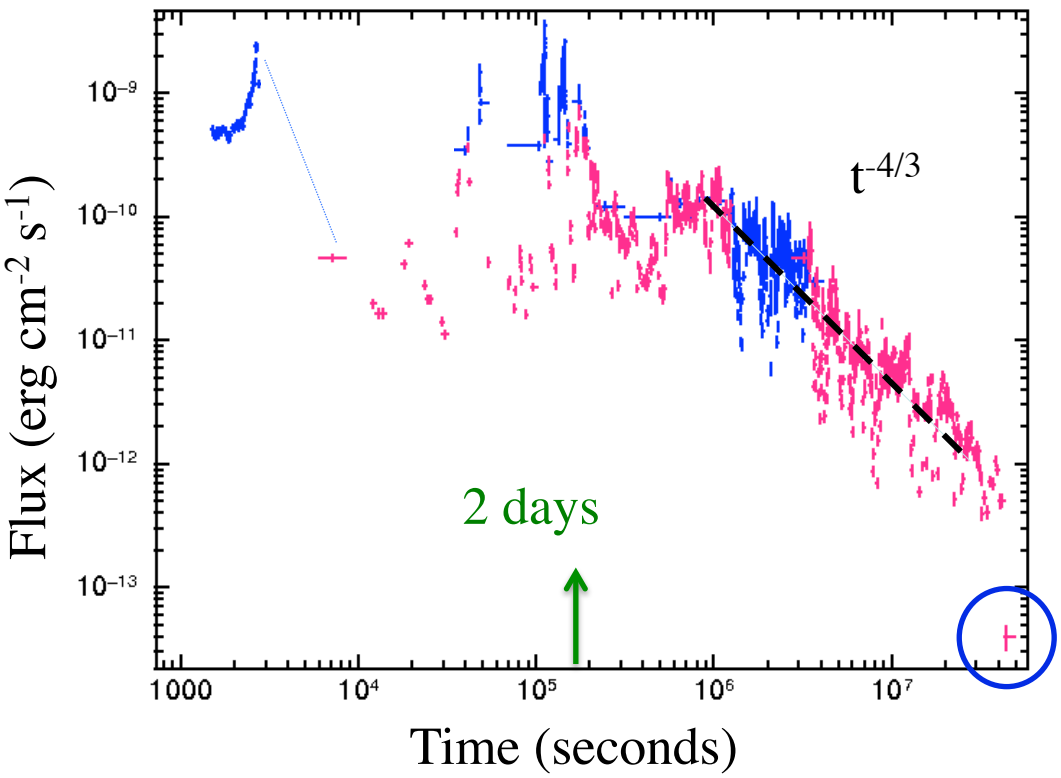


MacFadyen & Woosley

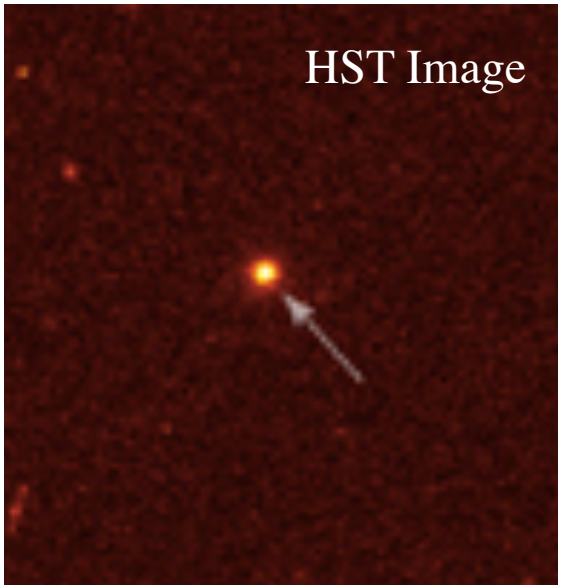
Unexpected & Oddball Transients

Swift Transient - Sw J1644+57

Swift Light Curve



28 March 2011



Transient at center of dwarf non-AGN galaxy at z=0.35

$L_x \sim 10^{48}$ erg s^{-1}

$E \sim 10^{51}$ ergs

$M_{BH} \sim 10^6 - 10^7\ M_\odot$

Tidal Disruption Events

- Star disrupted when it comes within BH tidal radius

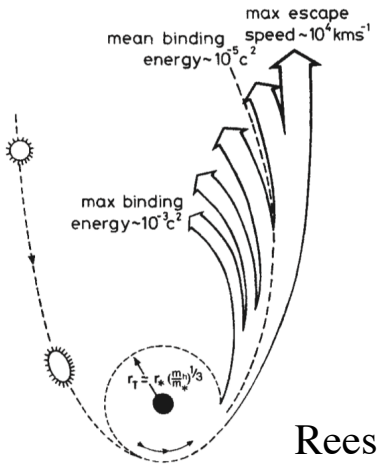
- Handful of early ROSAT, XMM and GALEX events

- Recent Pan-STARRS detection of He-rich stellar core disruption

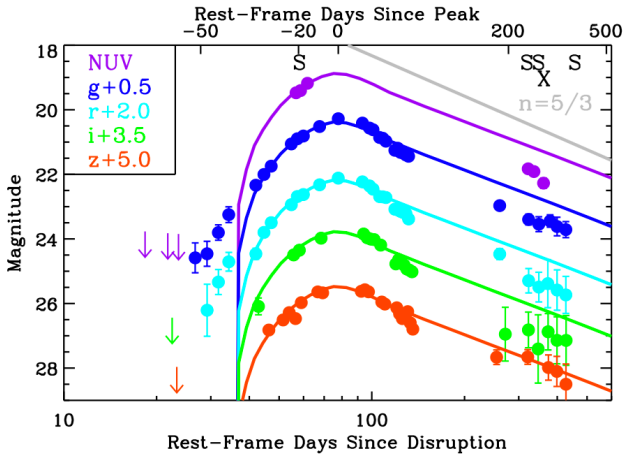
- Relativistic beamed events Sw J1644+57 & Sw J2058+05 (Cenko+ 12)

- Galactic center ~ 3 $M_\oplus$ cloud being disrupted

- Many candidates Sw J1741.5-6548, LSQ12heq, XMMSL1_J061926, PTFS1222ar, Sw J1112.2-8238



Rees 1988



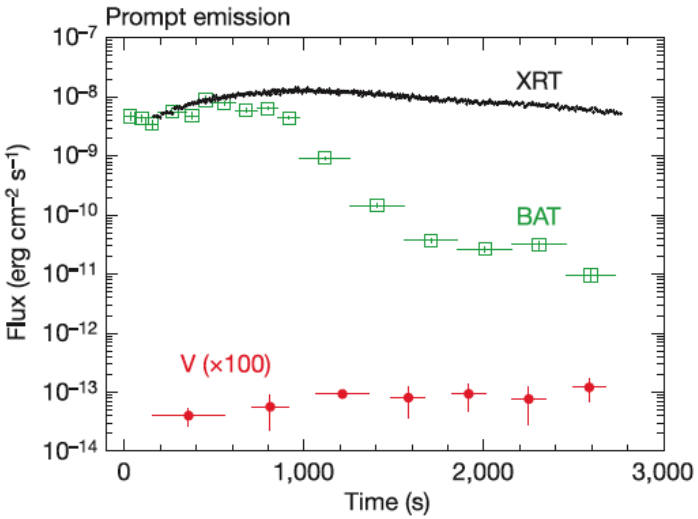
Gezari+ Nature 2012

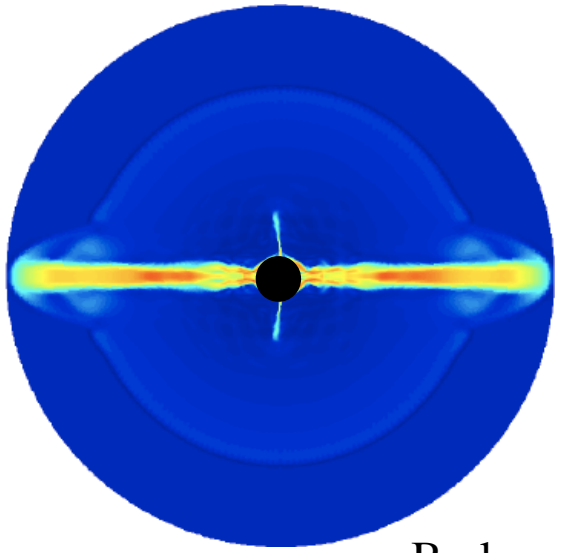
Swift Oddball Events (1)

- **Short "GRB" 050925**: near galactic plane with soft spectrum and T_{90}=0.07s. Galactic source or SGR? (Markwardt+ 05)

- **RS Oph 2006**: bright 60-day XRT outburst with super-soft state from recurrent nova. Such SSS CVs are thought to be precursors of SNe Ia. (Osborne+ 11)

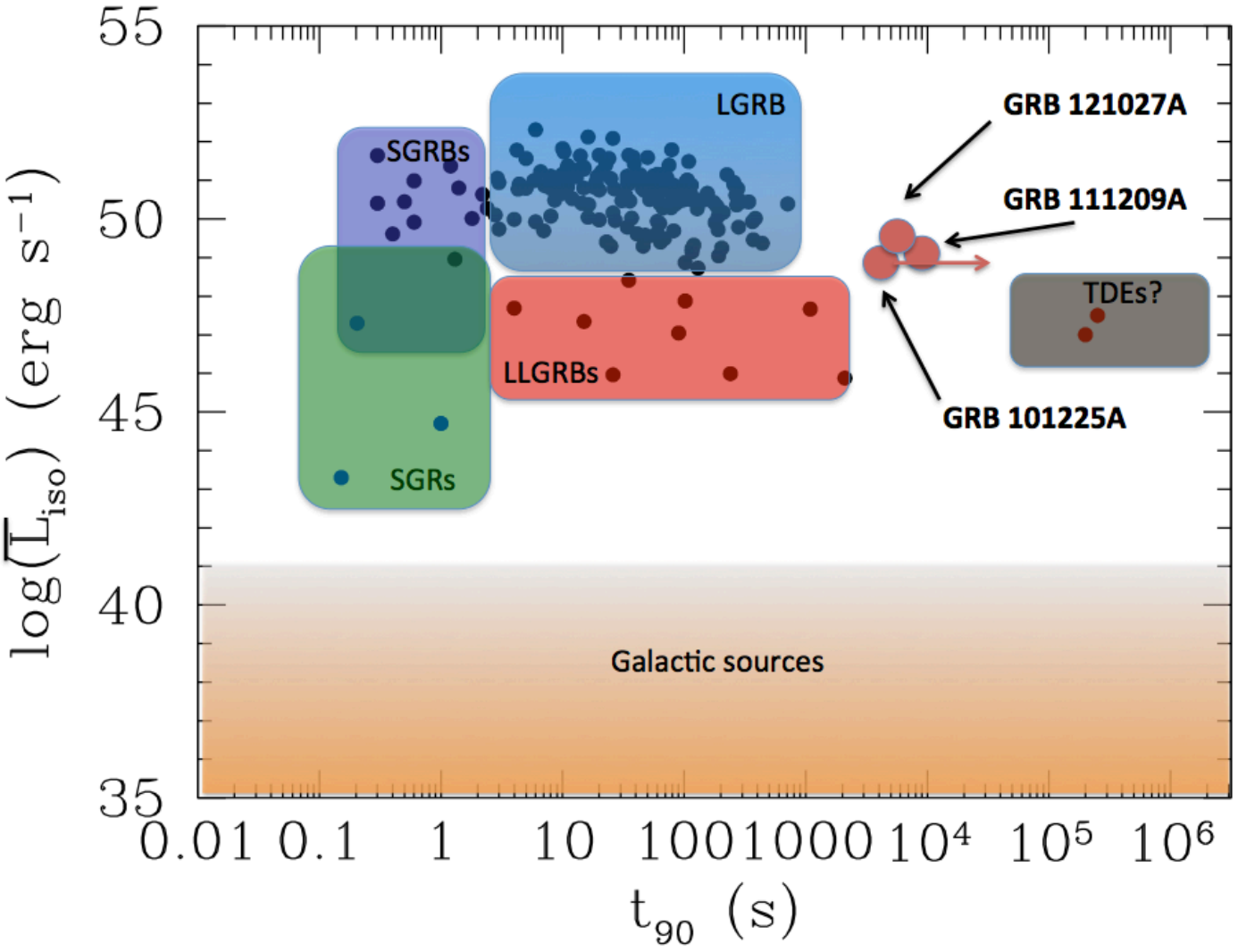
- **SN GRBs 060218**: nearby ($z \sim 0.033$), underluminous ($E_{iso} \sim$ few 10^9), very long (T_{90} = 35 minutes) GRB with SN 2006aj





Barkov & Komissarov

Ultra-long GRBs – Separate Class ?

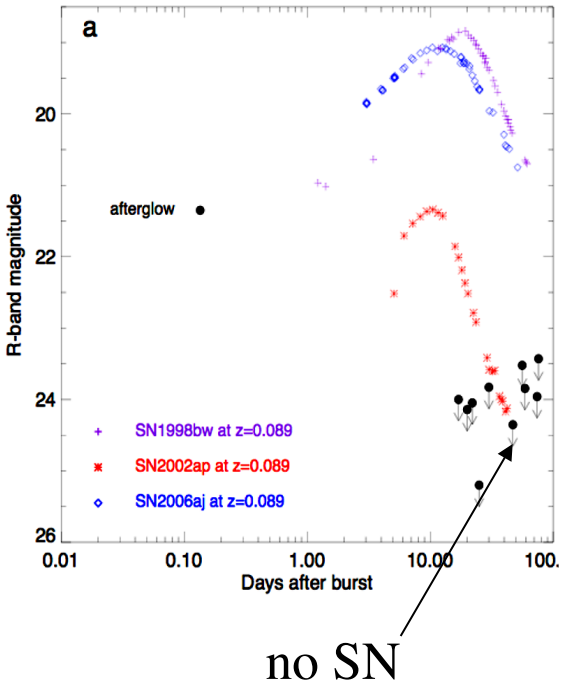


Levan+ 13
see also Gendre+ 12

Swift Oddball Events (2)

- **GRBs 060505 & 060614**: nearby (z ~ 0.1) GRBs with T_{90}>>2s and no supernovae detected to deep limits. (~10 papers)

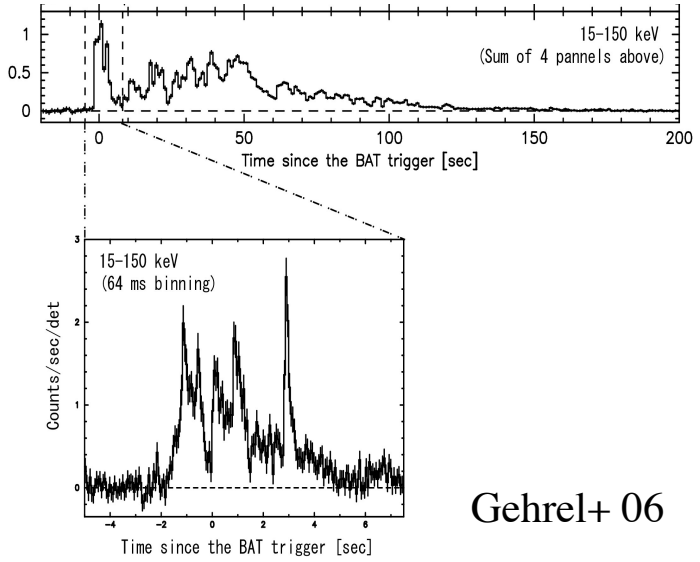
GRB 060505 z=0.089



no SN

Fynbo+ 06

GRB 060614 - Short burst episode followed by bright soft tail



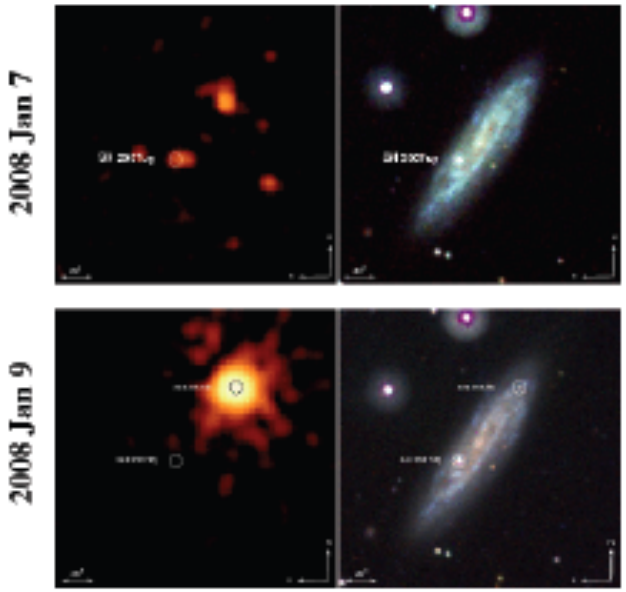
Gehrel+ 06

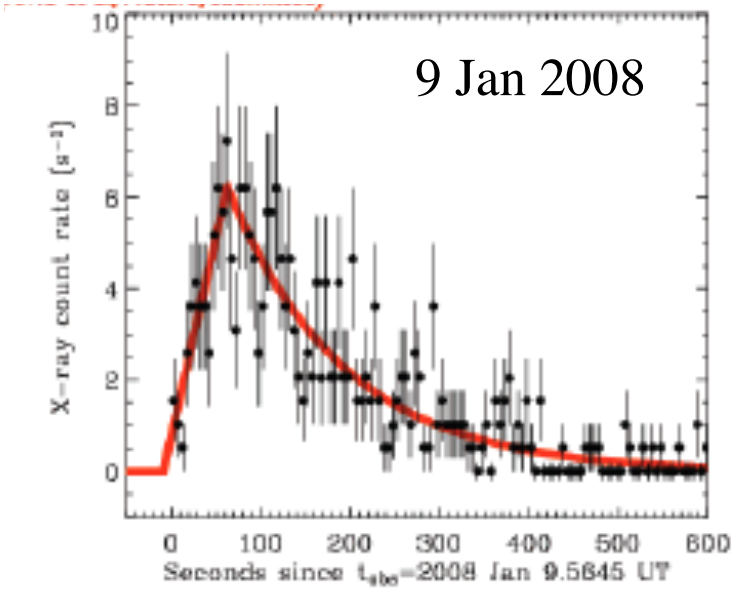
- **Hostless GRB 070125**: z<1.5 with no spectral absorption features and no host detected. Compact-star-forming cluster far from a galaxy??

Swift Oddball Events (3)

- **Galactic "GRB" 070610**: Galactic transient. Possibly a new class of BH binary fast X-ray nova. (Kasliwal+ 08)

- **XRF 080109 – SN 2008D**: shock break-out X-ray outburst from a supernova (Soderberg+ 08)



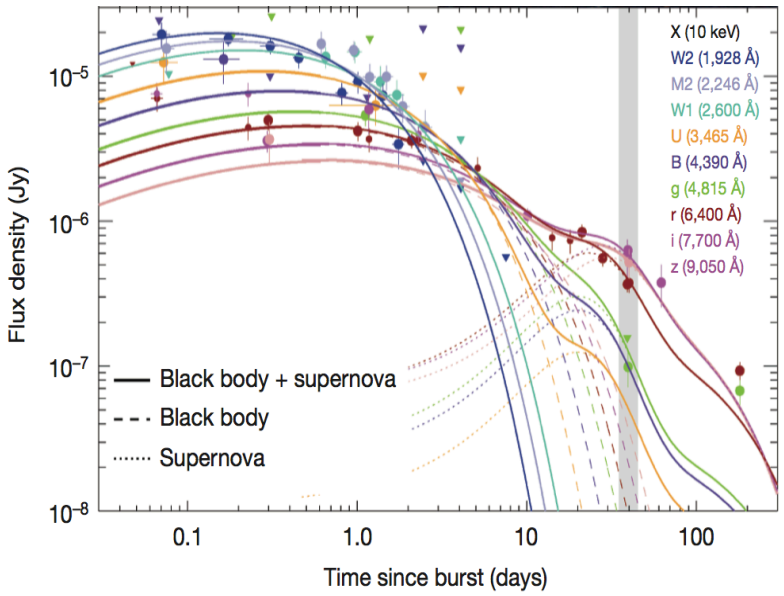


Swift Oddball Events (4)

- **EV Lac superflare**: 25 Apr 2008 hard X-ray superflare from dMe star triggers BAT (Osten+ 05)

- **Pulsing GRB 090709**: 8 s pulsations in prompt emission (Markwardt et al. 2009). Host galaxy indicating extragalactic origin (Perley+ 10)

- **GRB 101225 "Christmas burst"**: bizarre transient, either He star - NS merger GRB or galactic NS capturing an asteroid (Thöne+ 11; Campana+ 11)



The Future

Bright Future for TD Astronomy

PTF, PanSTARRS, LSST .....
optical wide-field

LOFAR, SKA
radio

ICECUBE
neutrinos

LIGO/Virgo
gravitational wave

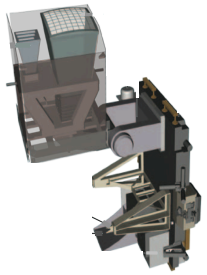
Swift, Lobster concept
GRBs

Fermi, HAWC
high energy γ-rays

LIGO

HAWC

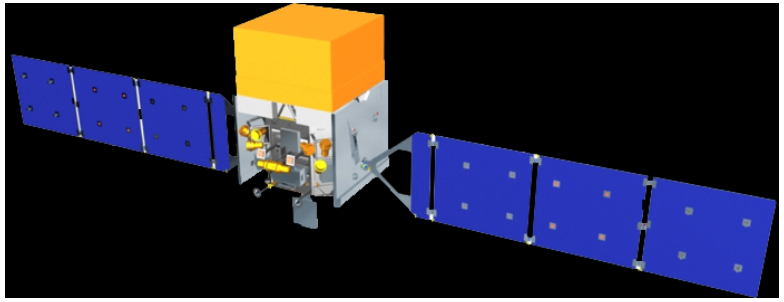
Lobster



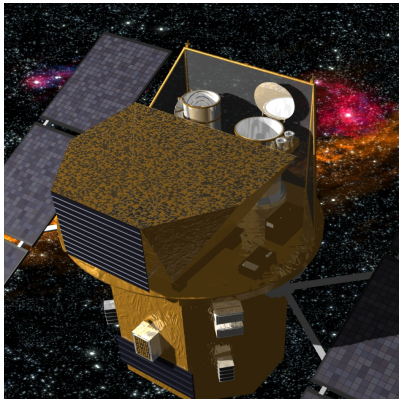
Gravitational Wave Trigger & Follow-up

Counterpart identification between GW and EM can go both ways:

1) Multi-wavelength (gamma-ray) trigger for deep GW searches

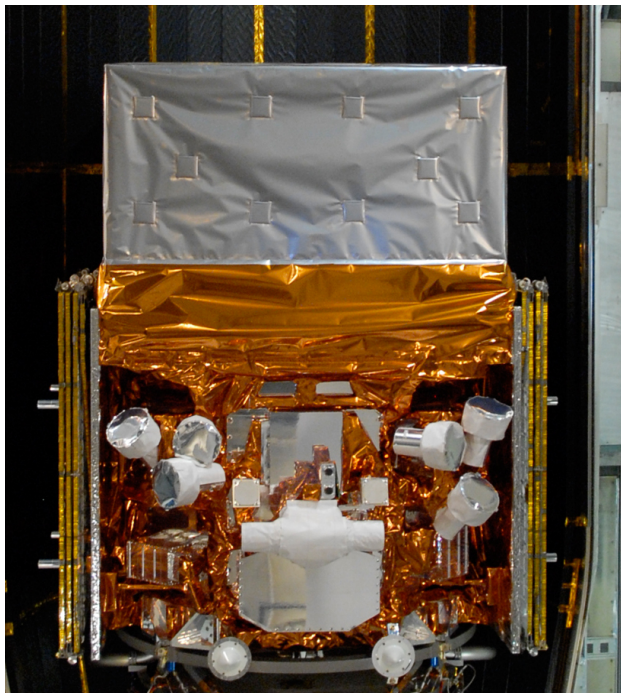


2) Multi-wavelength observations of GW events (deep GW searches)



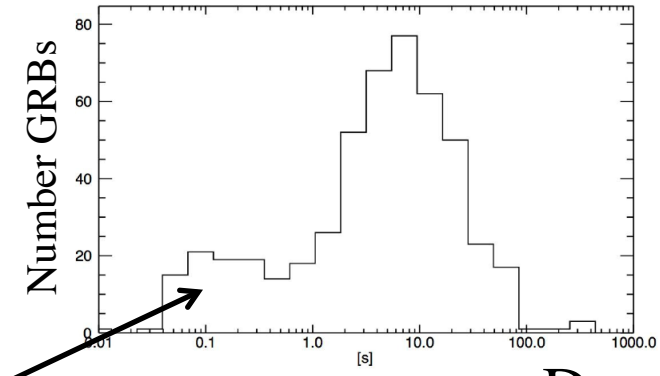
GRB Trigger – GW Follow-up

Best Instrument is *Fermi* GBM



Meegan+ 09

- Views entire unocculted sky
- High GRB rate
- High fraction of short GRBs
- Accurate time stamp



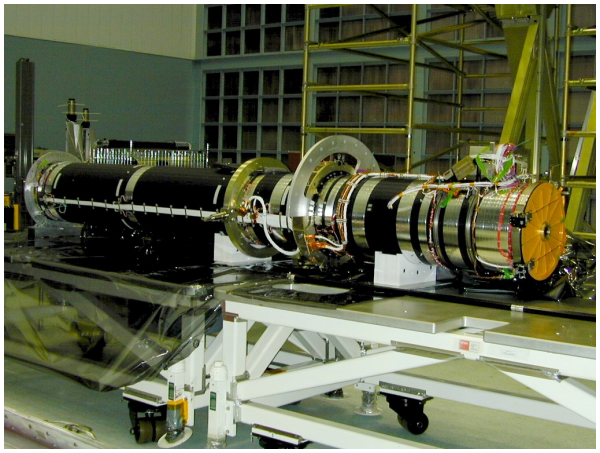
~25% short GRBs

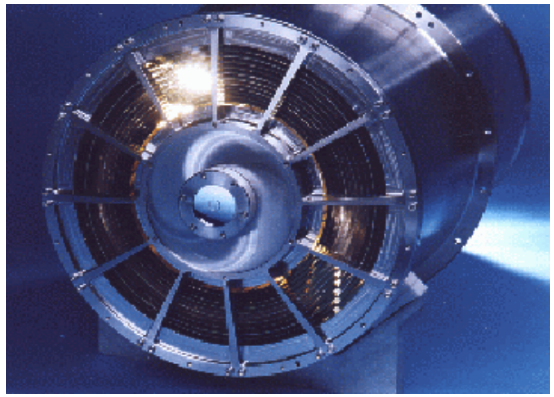
Duration (s)

GW Trigger – EM Follow-up

Best Current Instrument is *Swift* XRT

- X-rays are most promising wavelength band for afterglow
- Flexible Swift scheduling gives <1 hour turn around
- Strategy is to observe nearby galaxies in error box
- Follow-up performed of 2 ELIGO S6 triggers (Evans+ 12)

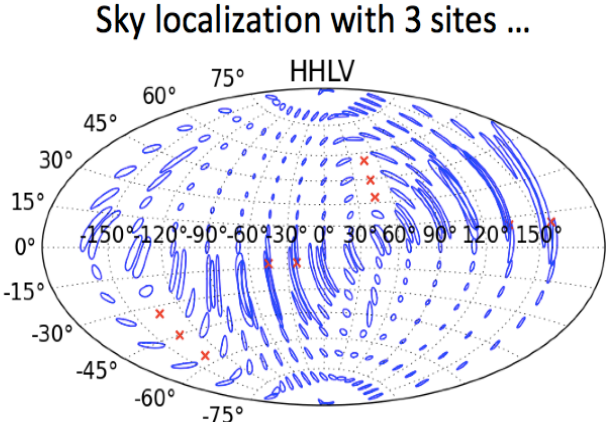


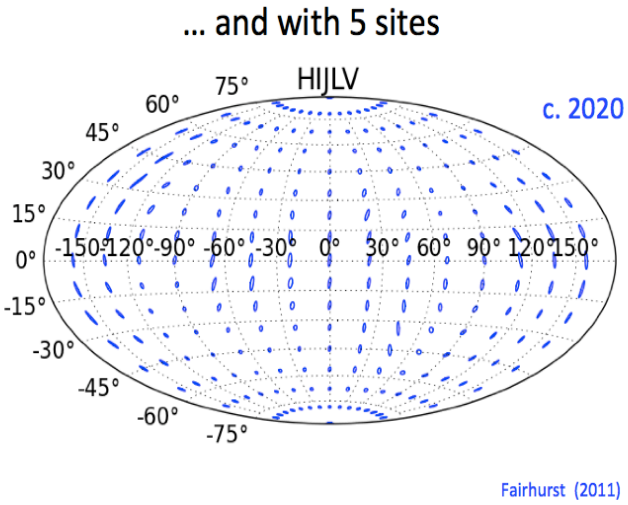


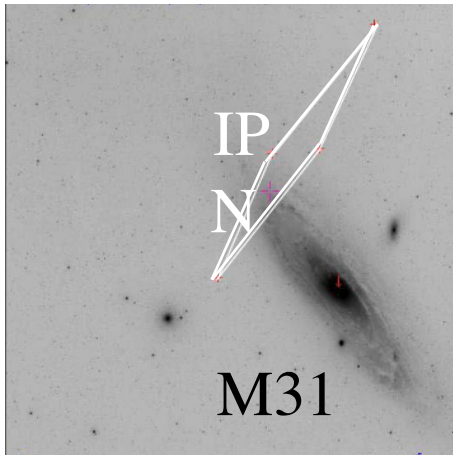
Burrows+ 05

Covering Large Error Boxes

- Large error boxes from IPN, GBM, & GWs
- Tiling & coordination with wide-field telescopes
- *Swift* tiling of IPN already successful twice
- In preparation of ALIGO/Virgo, goal is to detect a GBM afterglow with PTF + *Swift*





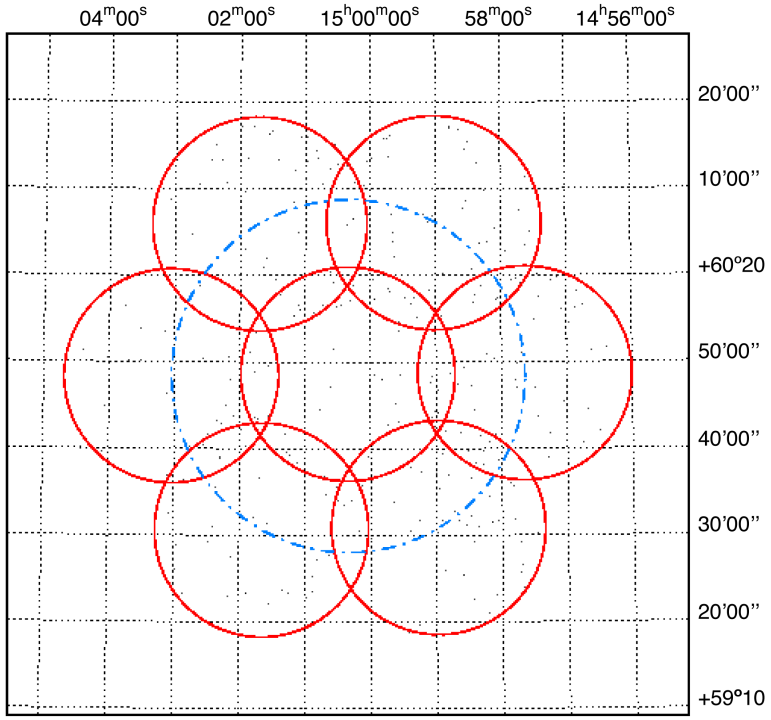


Auto Sky Tiling

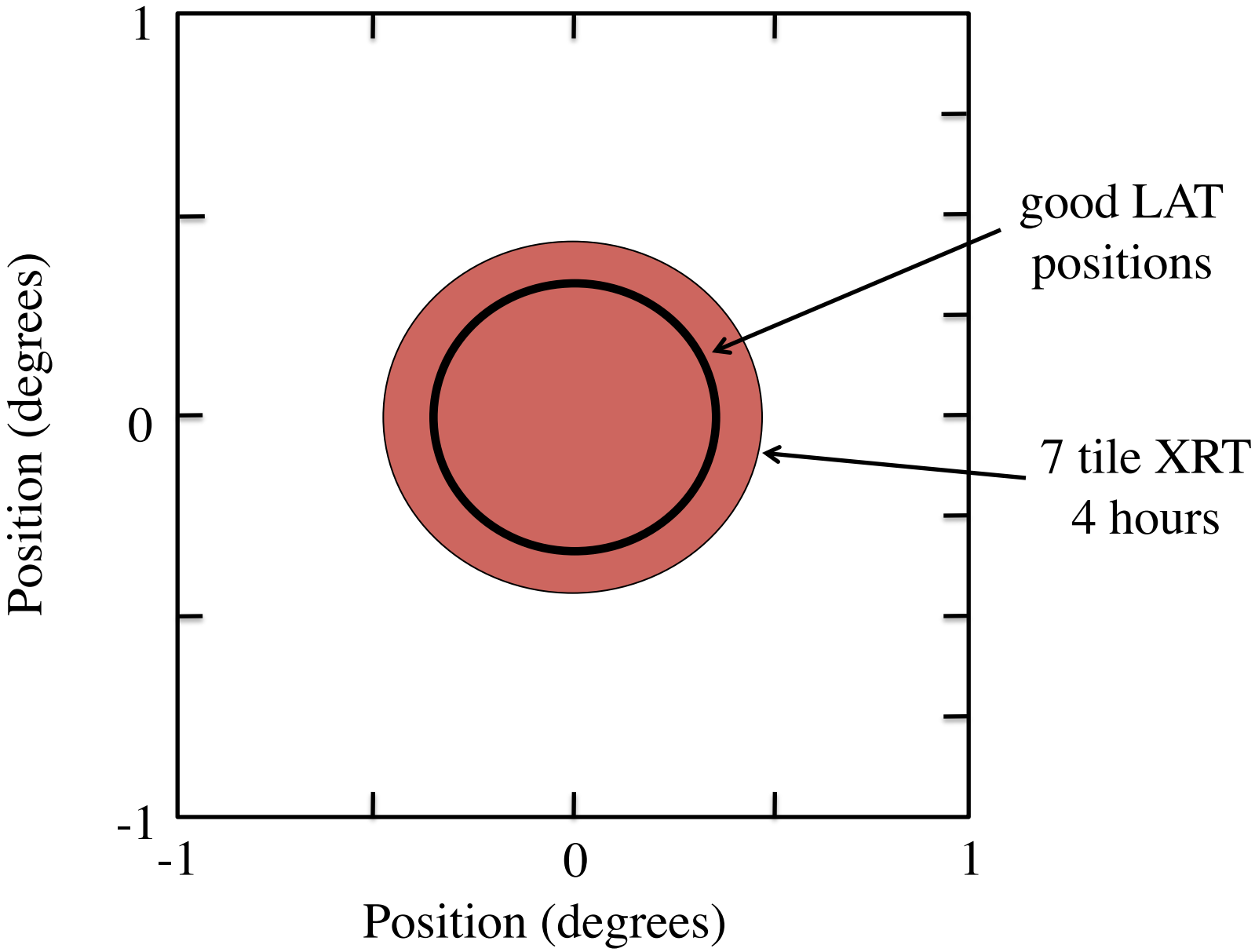
LAT GRB position accuracy <1 deg

GRB GRB position accuracy ~5 deg

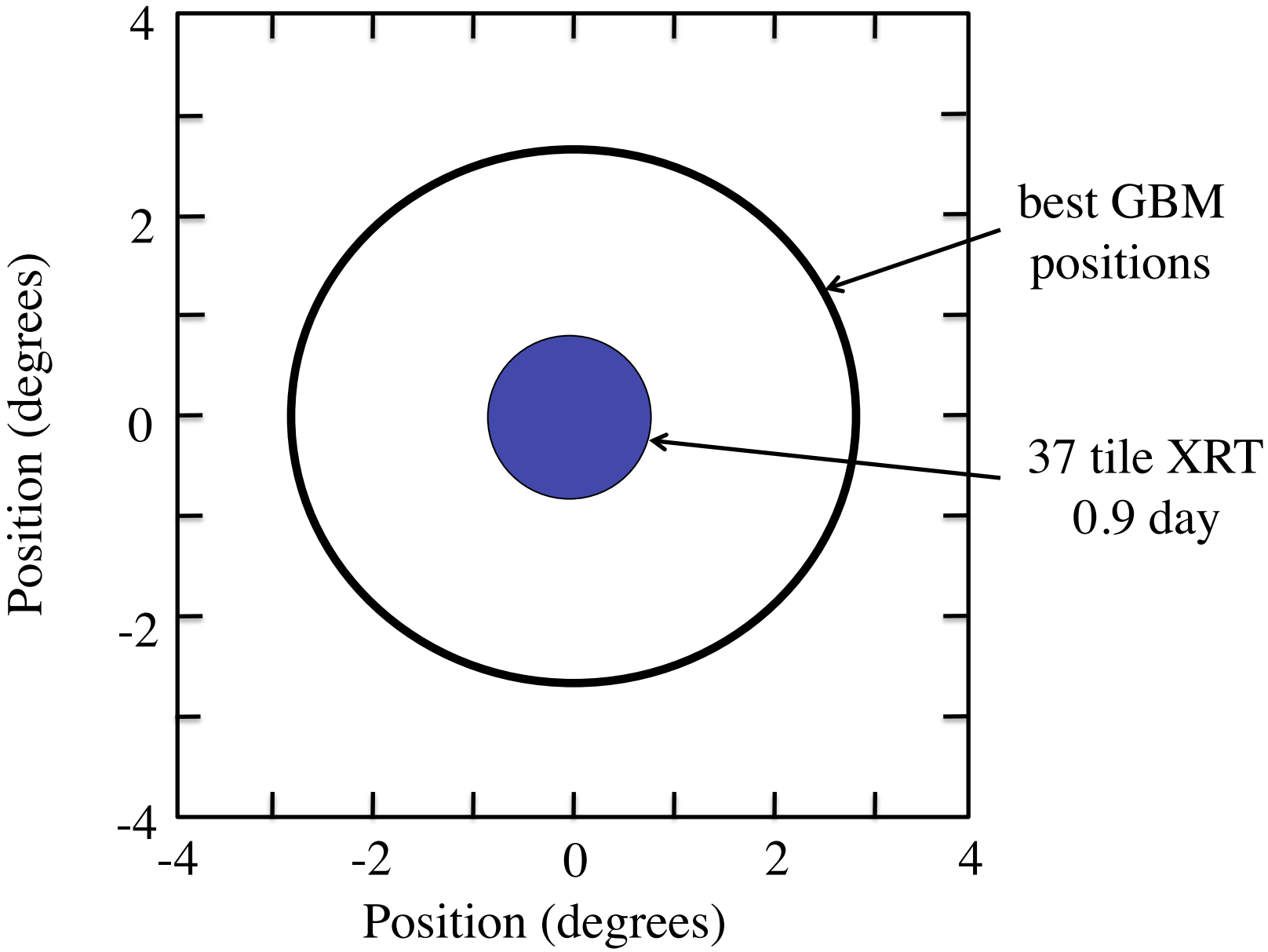
XRT 7 Tile Pattern



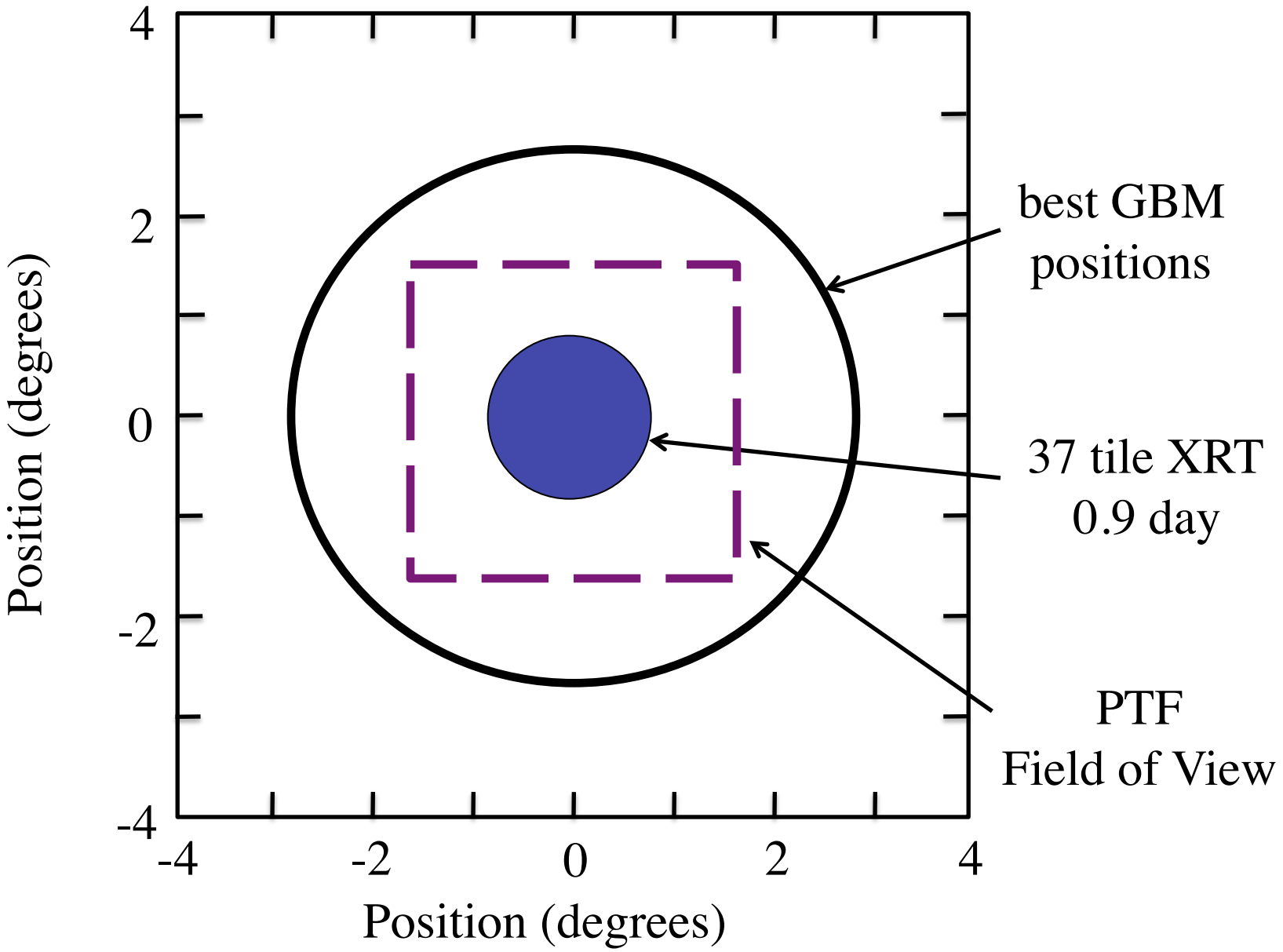
Swift XRT Tiling LAT Error Box



Swift XRT Tiling GBM Error Box

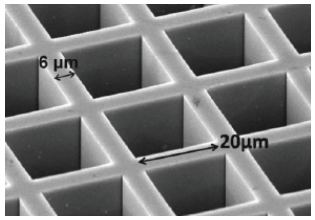


Swift XRT Tiling GBM Error Box



Future - Lobster X-ray Imager

lobster optic

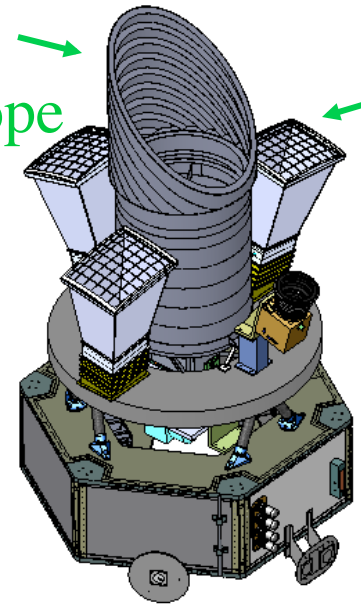


- Two Explorer proposals enabled by new, very sensitive wide-field X-ray optics
- Light-weight and inexpensive
- Future way to do X-ray transient astronomy

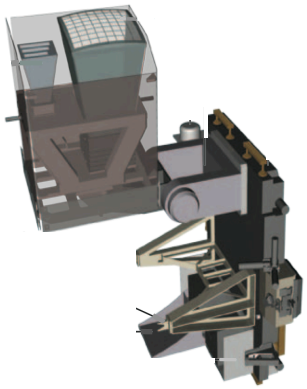
EX Proposal

IR Telescope

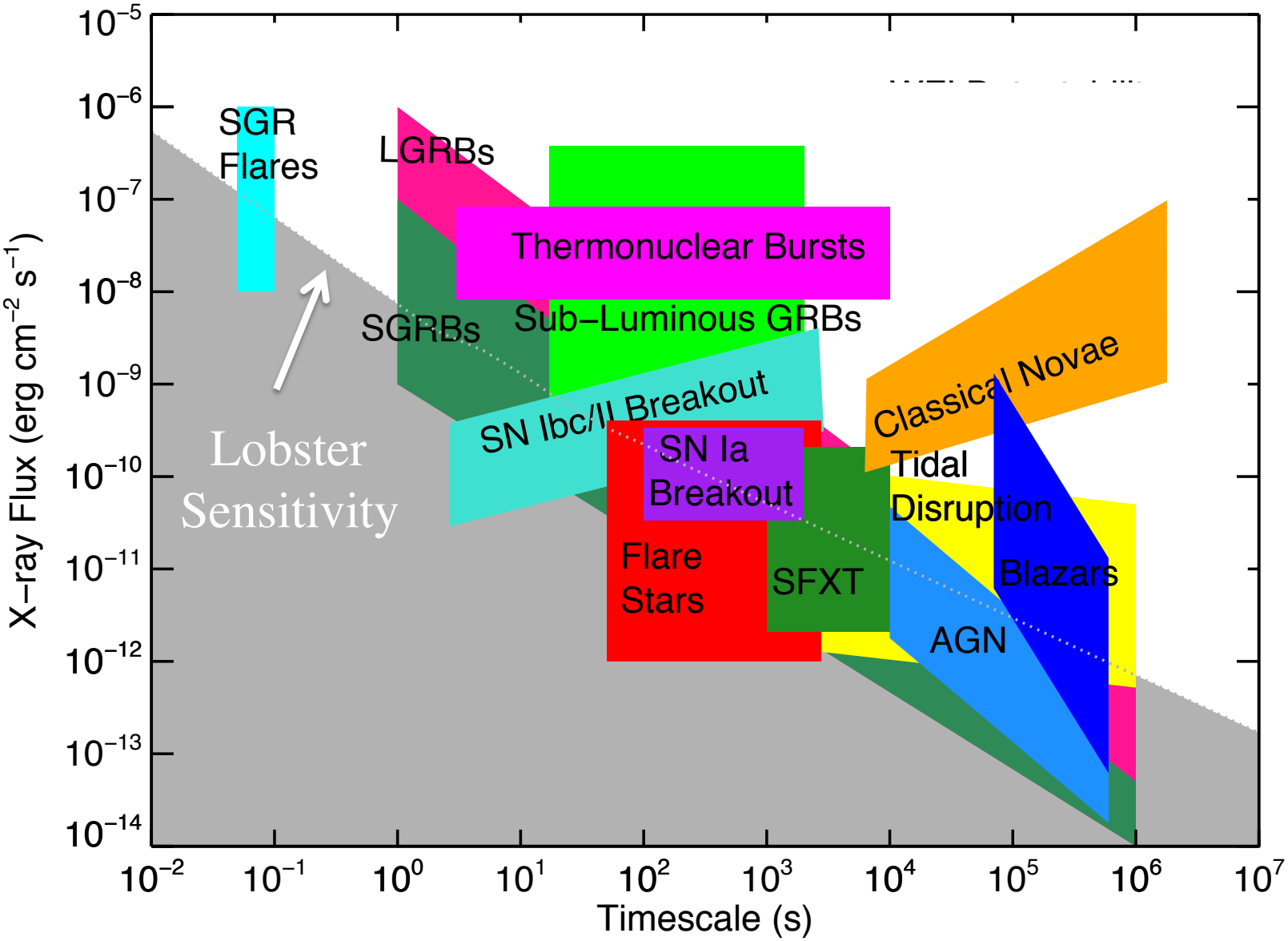
Lobster X-ray Imagers



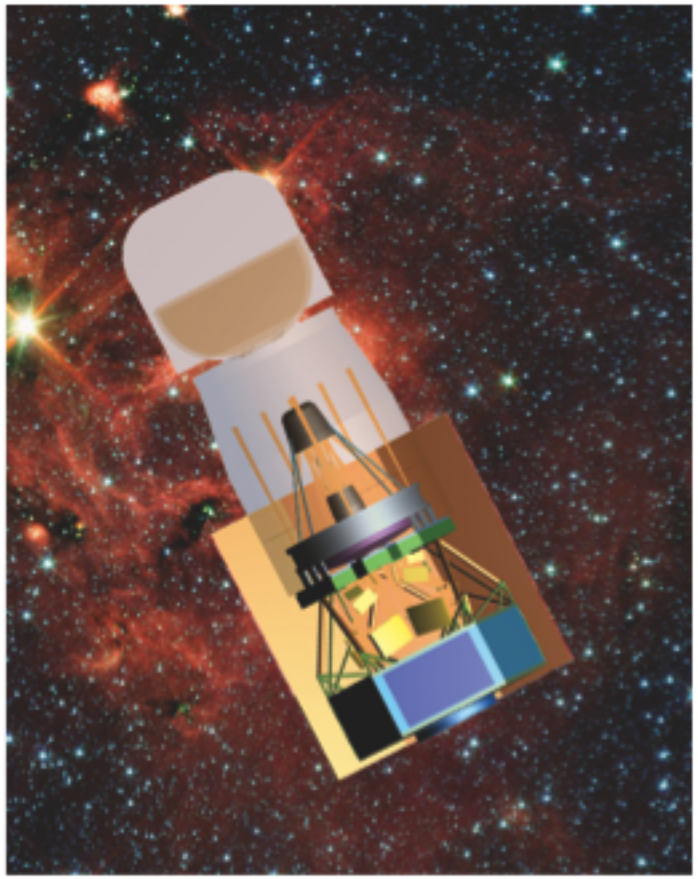
ISS MOO Proposal



Lobster Transient Science



WFIRST-2.4m

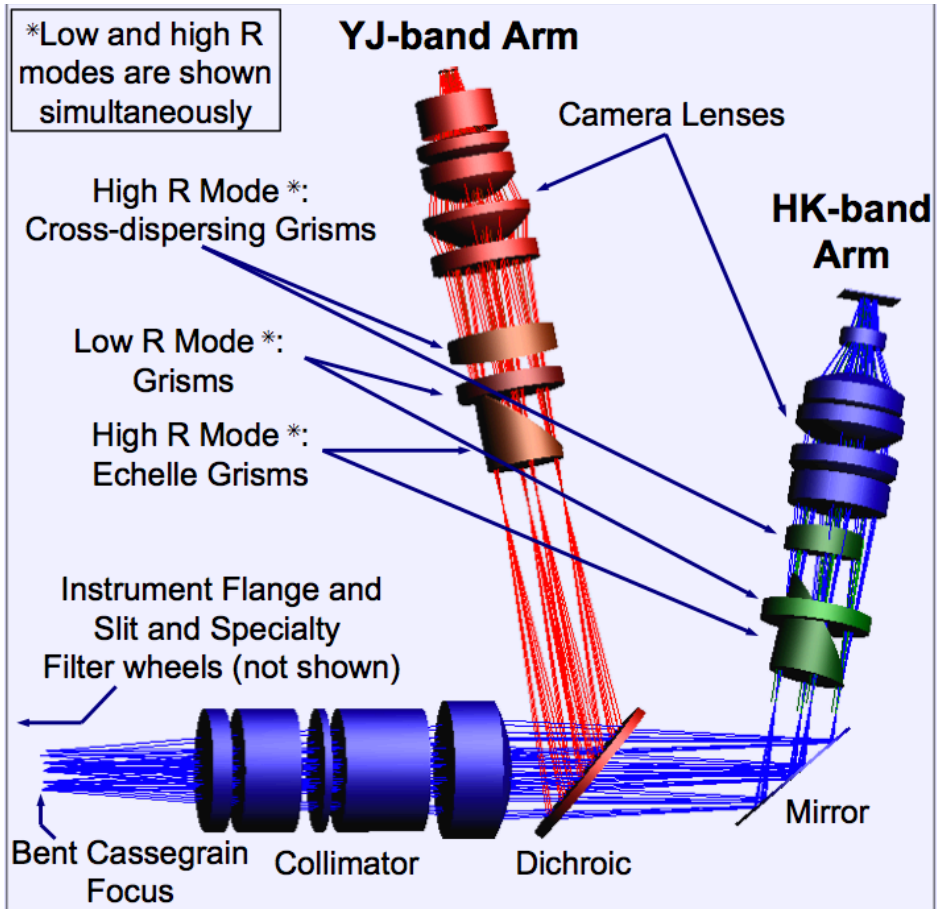


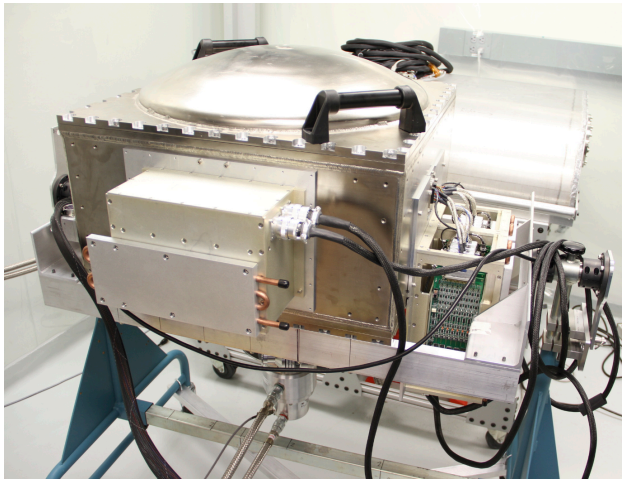
- WFIRST-2.4m (with NRO telescope) will be a powerful time domain observatory
- Baseline GEO orbit gives ~1 hour TOO response
- Field of Regard = 60% of sky
- Combination of fast response, sensitivity & wide field ideal for TDA

RIMAS Instrument

on DCT (Lowell)

UMd, GSFC, Lowell





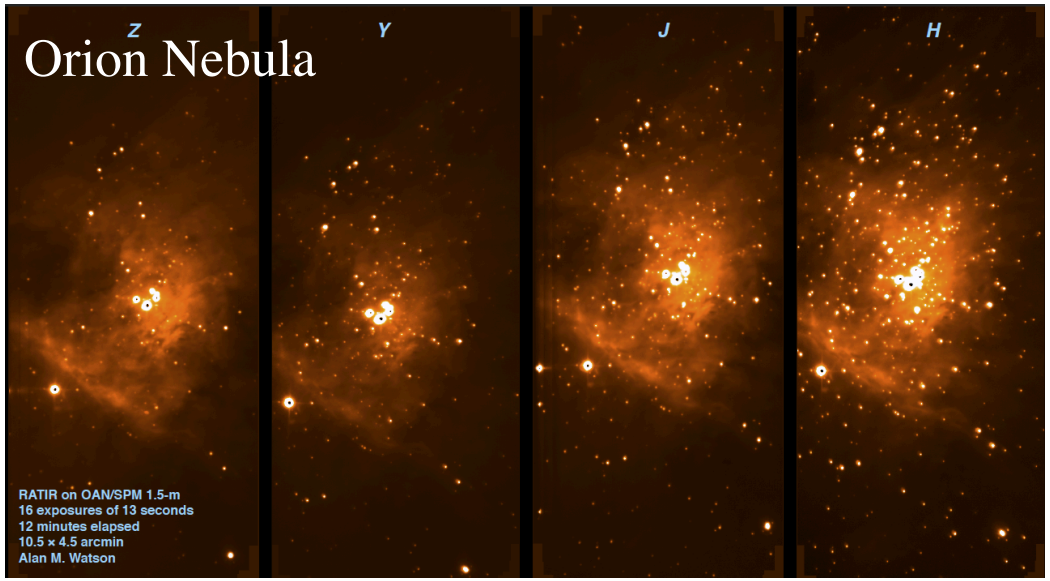
RATIR Instrument

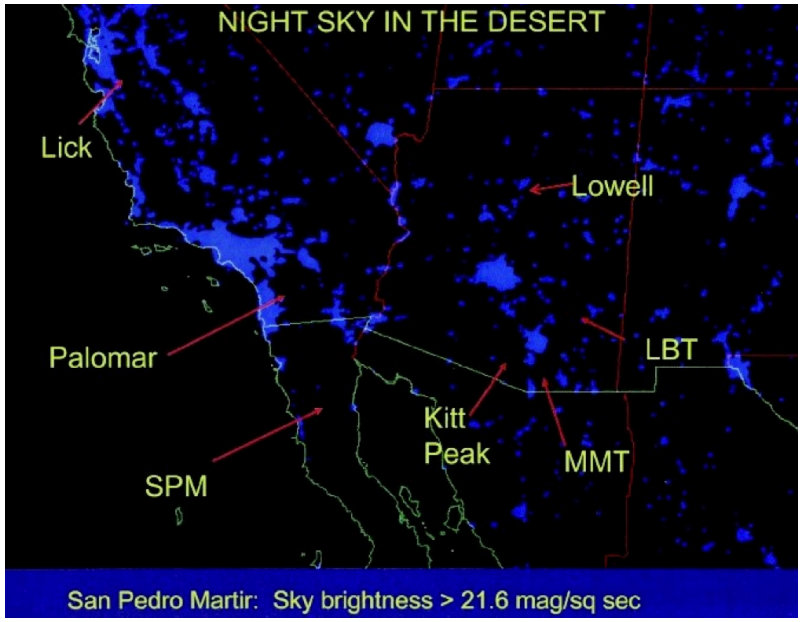
on Harold Johnson Telescope (Baja)

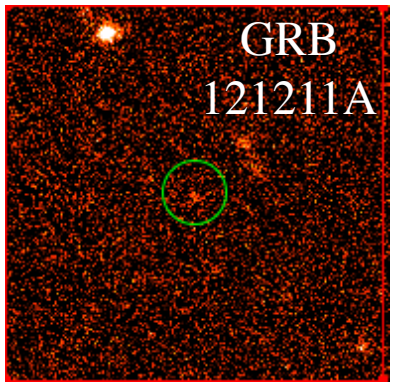
UCB, GSFC, UNAM

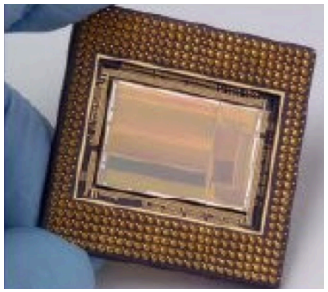
NIR imager

Photo spectroscopy z, Y, J, H









H2RG

Summary

- The gamma-ray sky is dominated by transient sources
- Even the Crab nebula has unexpected large flares
- *Fermi* and *Swift* are sensitively & continuously monitoring sky
- Long & short GRBs have different origins
- A new type of tidal disruption transient has been discovered
- Many new Time Domain instruments coming on line ... *soon*