

Swift Science and Future



Neil Gehrels
NASA-GSFC



SAPIENZA
UNIVERSITÀ DI ROMA



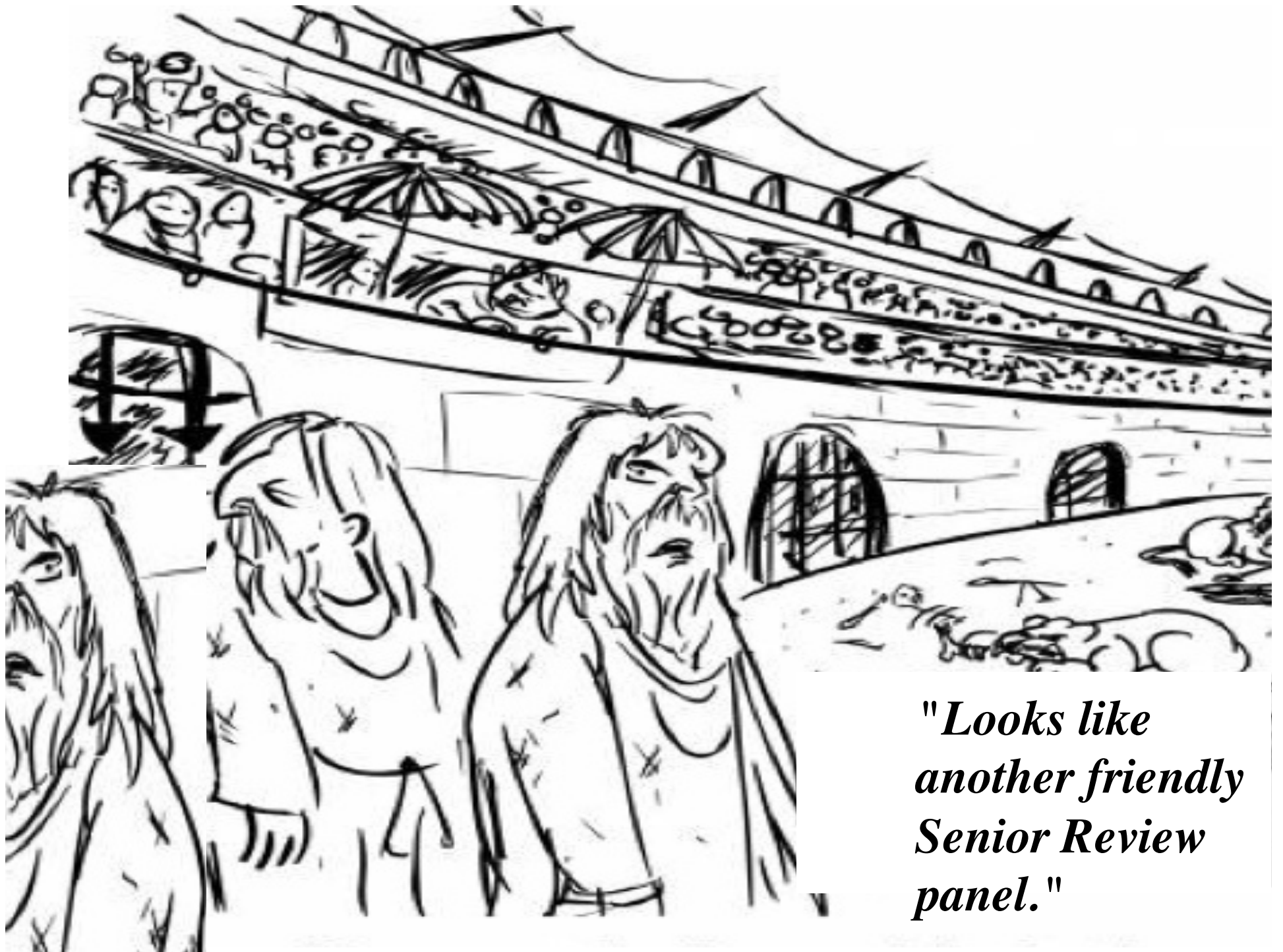
Associazione Romana per le Astro-Particelle

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C.F. 97457450589

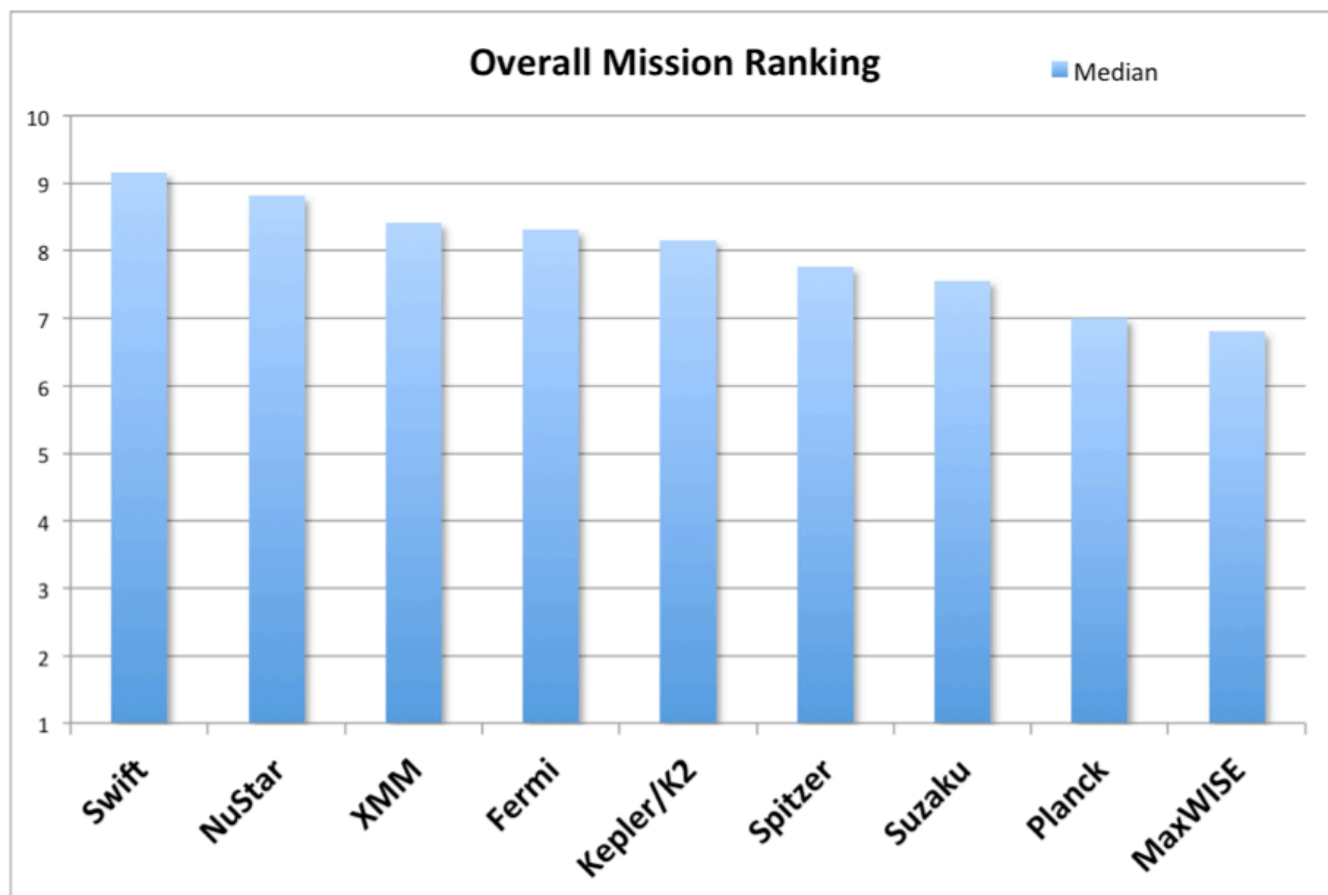


Swift 10 Year Rome Conference

December 2, 2014



"Looks like another friendly Senior Review panel."



*like
friendly*

*Senior Review
panel."*

Swift Game-Changing Discoveries

2005: **Short burst mystery** solution. NS-NS mergers

2005: **Flares & bright afterglows** in GRBs

2008: Supernova **shock breakout** from Type Ib SN

2008: Naked-eye GRB from reverse shock in jet

2009: **Discovery of GRBs at $z>8$**

2010: Galaxy mergers in hosts of absorbed AGN

2011: **Tidal disruption flare** of star eaten by BH

2012: SFR and metallicity evolution to $z>5$

2012: Discovery of very young (2500 year old) SNR

2012; Discovery of **ultra-long class** of GRB

2013: Nearest luminous Swift + Fermi **GRB 130427**

2013: Anti-glitch in magnetar 1E 2259+586

2013: Evidence for **kilonova/macronova** emission in a short GRB

The New York Times

October 29, 2009

"Extraordinarily violent explosion that ended the life of a distant star."

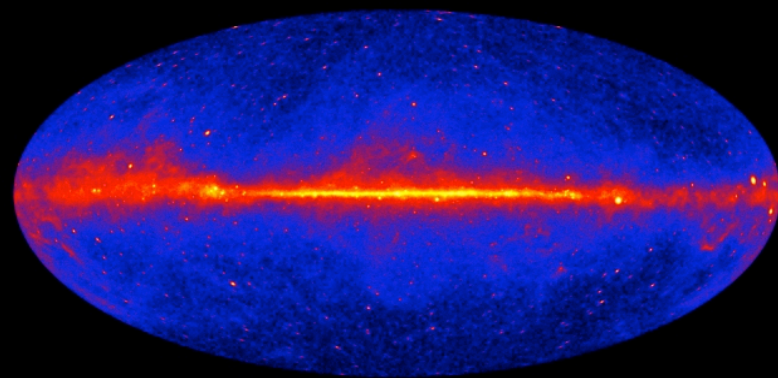
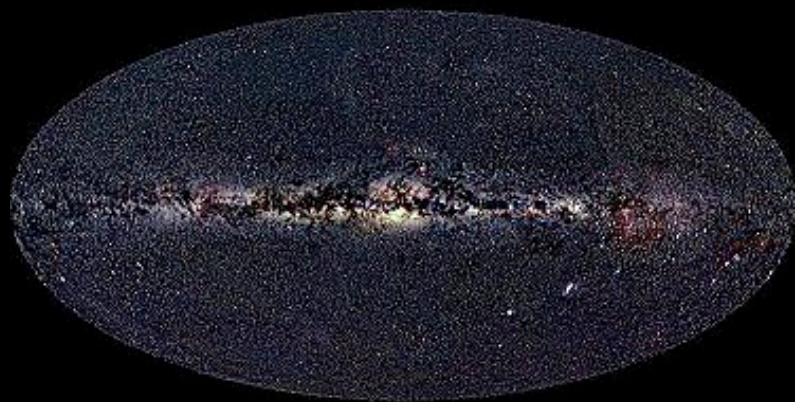
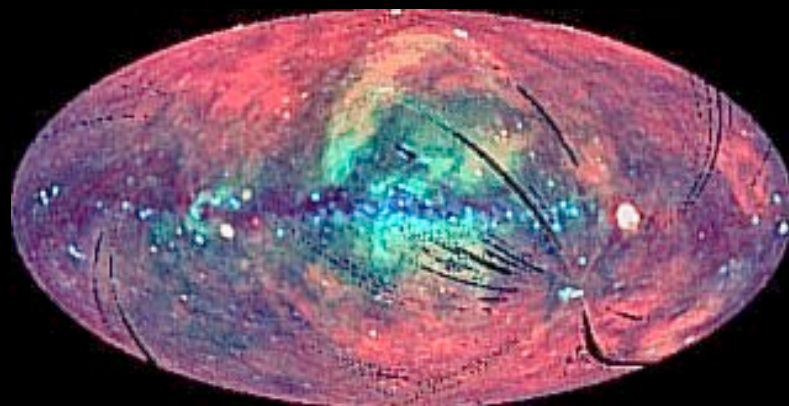
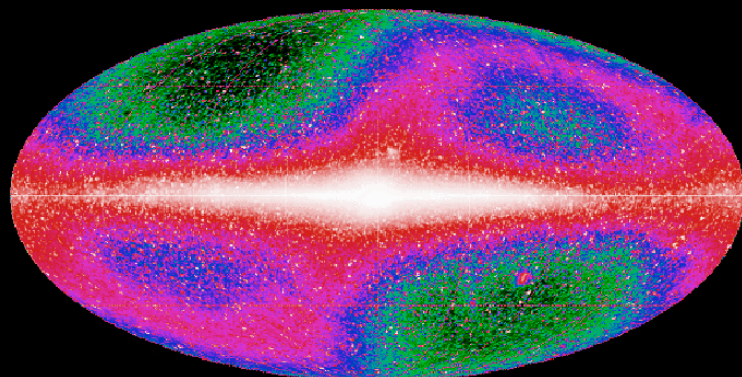
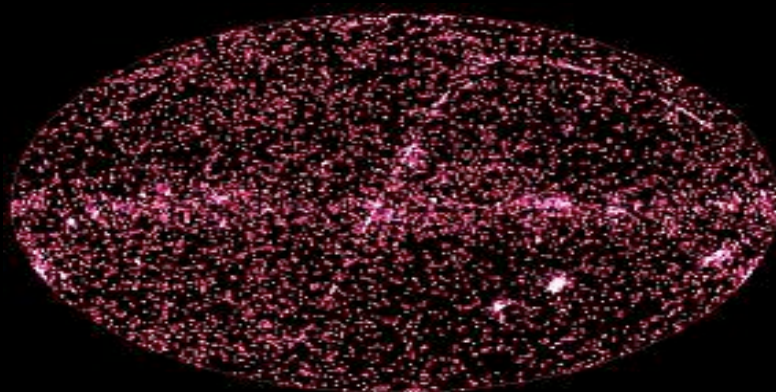
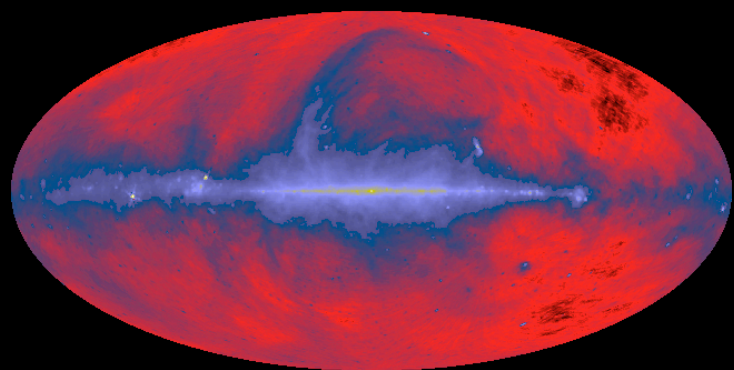
April 16, 2011

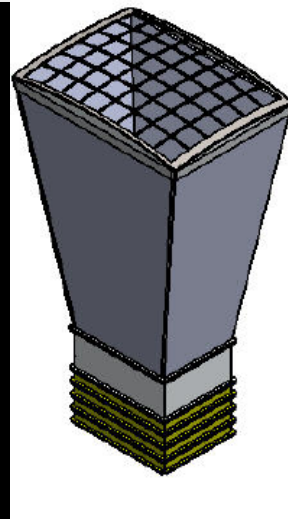
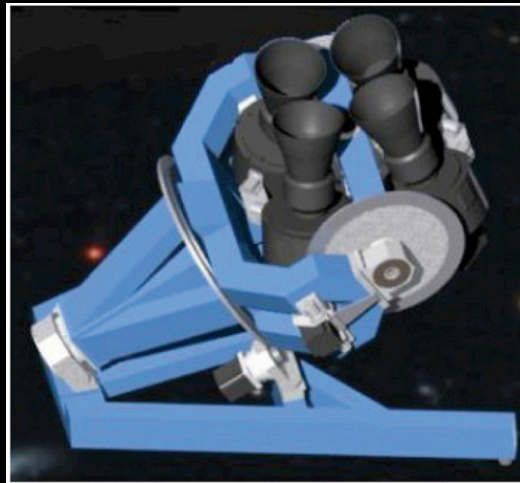
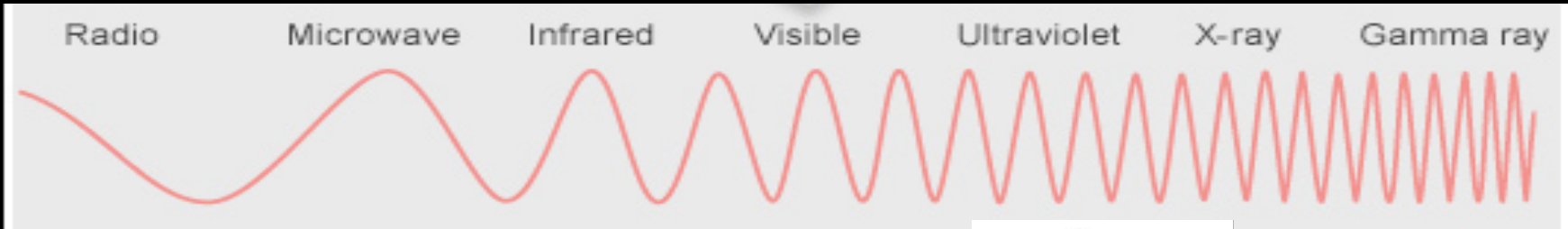
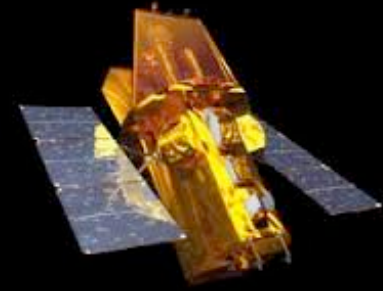
"Unusual celestial event was black hole swallowing a star."

July 19, 2013

"Origin of gold found in rare neutron-star collisions."

Yearly breakthroughs with *Swift*



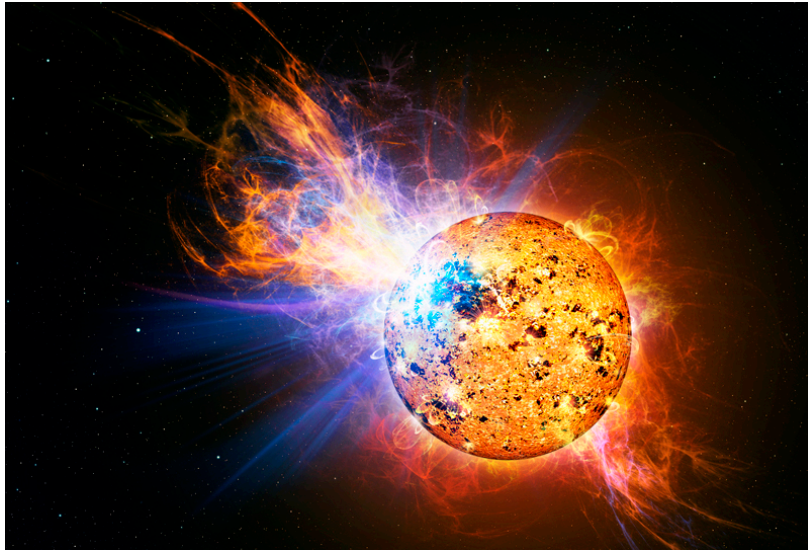


BAT Trigger
XRT "Trigger"
TOOs

Swift & Transients

Gamma Ray Burst
LMXB Superburst
X-Ray Burst
Soft Gamma Repeater
LMXB & HMXB Flare
Sgr A* flare
Tidal Disruption Event
Nova
Supernova Shock Breakout
BH Transient & X-ray Nova
Stellar Superflare
Super Fast X-ray Transient
Microquasar Flare
Supernova
ULX Transient

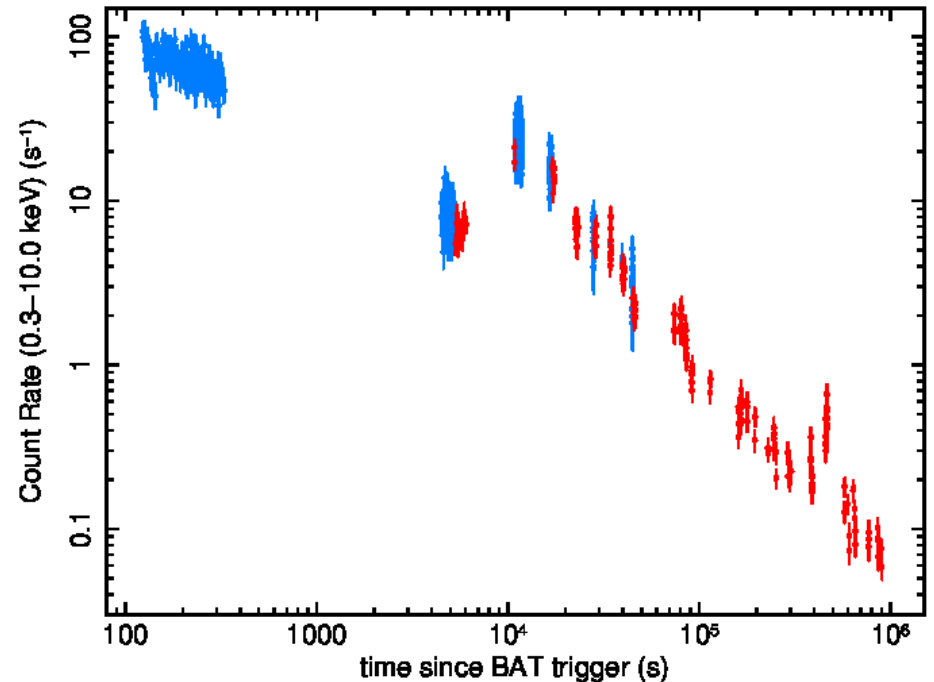
DG CVn Large Stellar Flare



Large X-ray "super-flare"
Brighter than star luminosity
100x largest solar flare
Young star at 18 pc

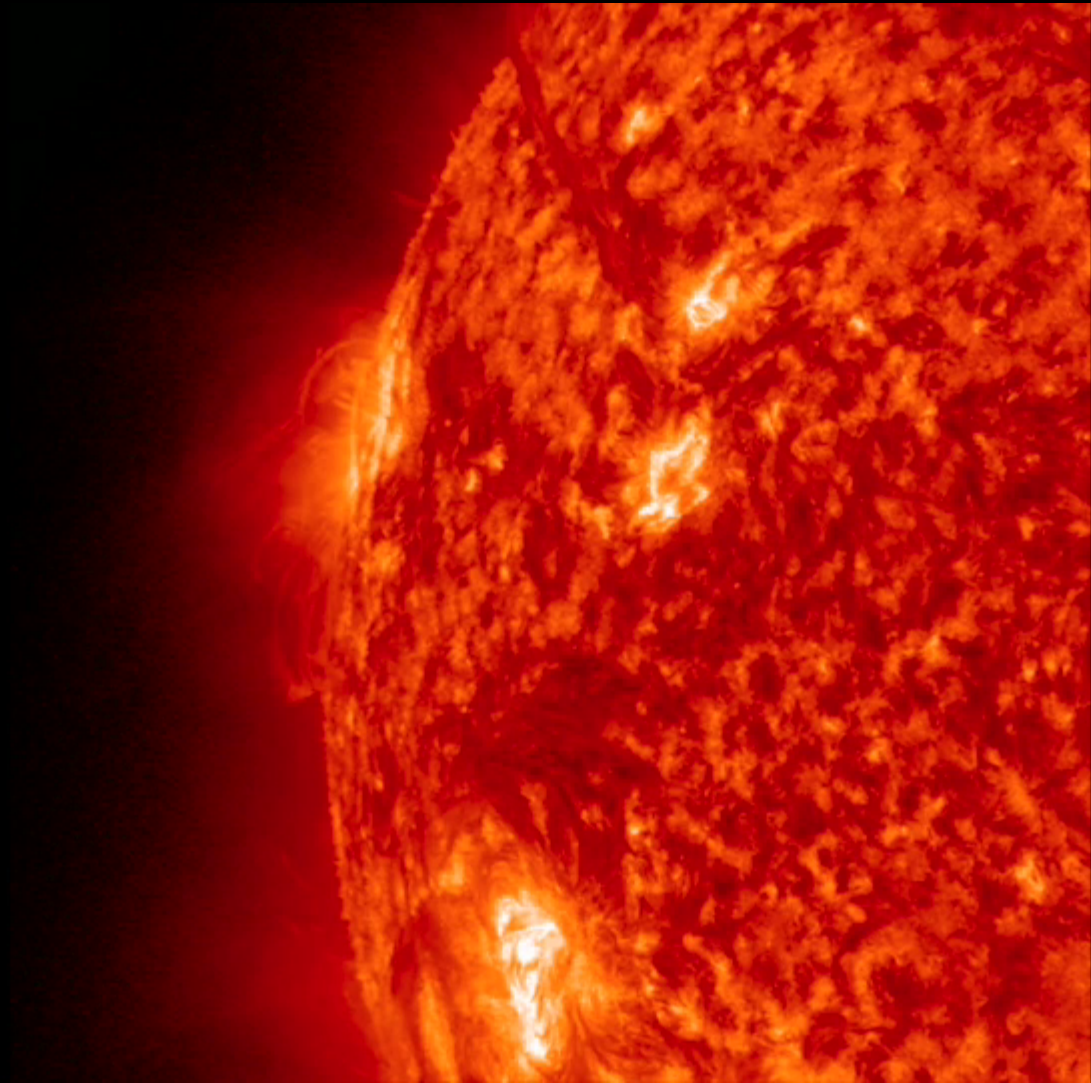
Power source:
B field reconnection

DG CVn - April 23, 2014



previous events: EV Lac, II Peg

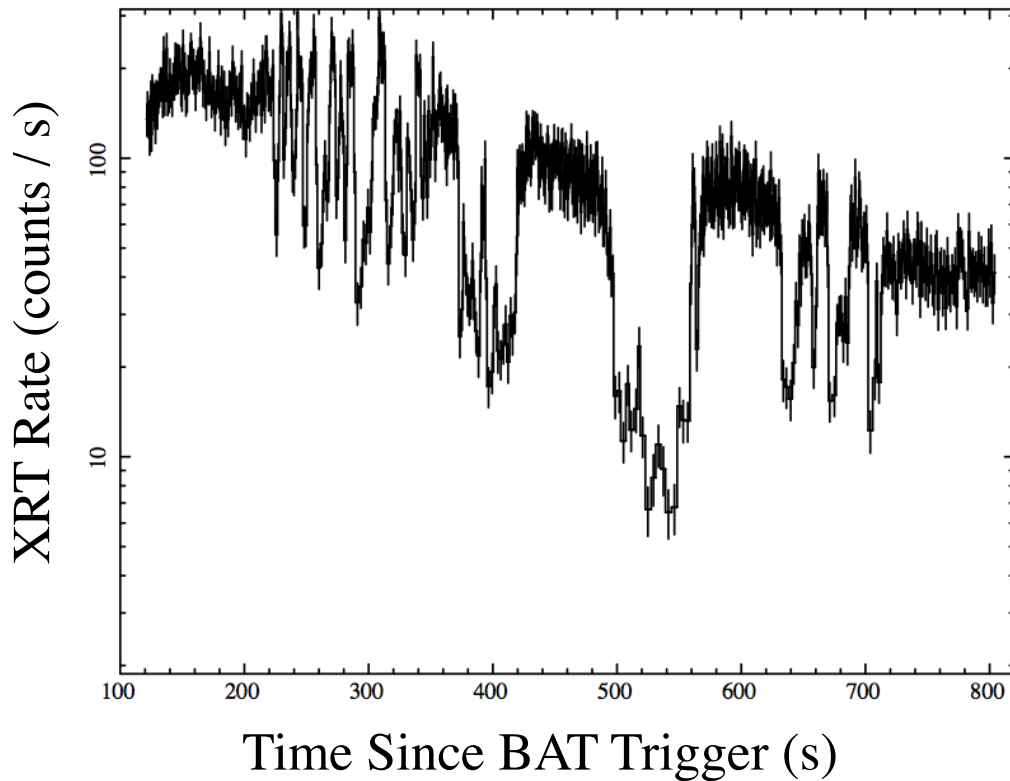
Drake, Osten, Page, Oats +



LMXB Superburst

SAX J1712.6-3739 27-Sept-2011
4U 1850-08 10-Mar-2014

SAX J1712.6-3739



Large thermonuclear burn
Carbon burning of XRB ashes
Factor 1000 longer and less
frequent than XRBs
Discovered by RXTE
BAT fluence trigger

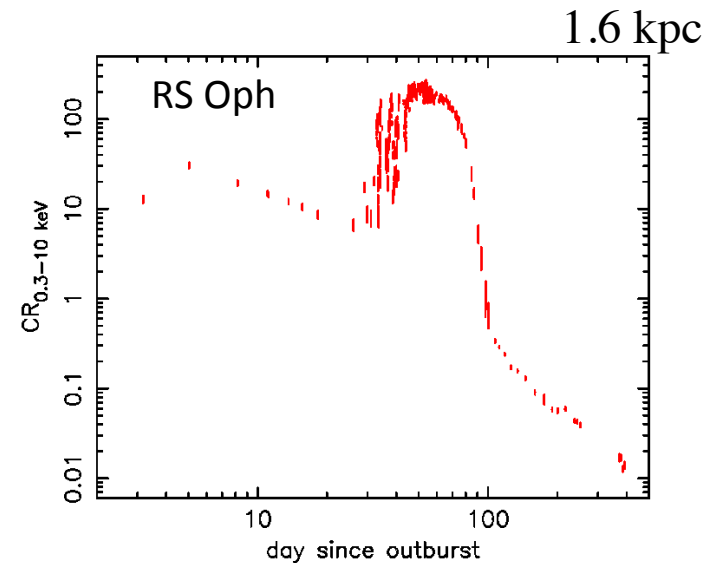
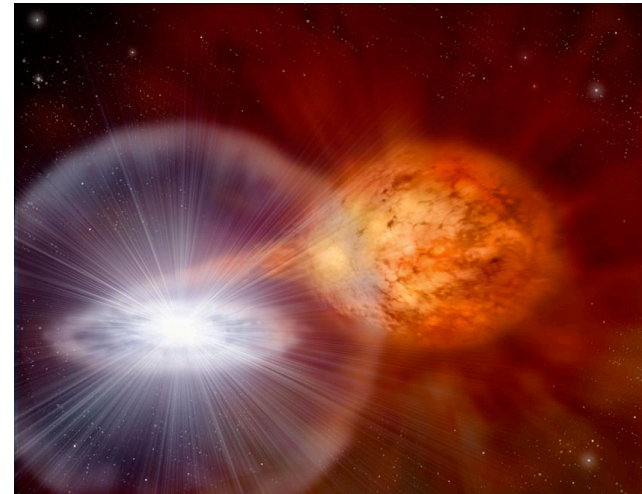
Power source:
Nuclear burning

in't Zand, Strohmayer,

Nova Outbursts

Thermonuclear detonation of accumulated accretion on white dwarf

- 28 novae observed
- keV emission from shocked ejecta
- Super-Soft emission from WD surface
- Extensive observations of RS Oph 2006 (~400 ksec)
- Earth mass ejected at ~ 4000 km/s into wind of companion Red Giant



Power source:
Nuclear burning



Sgr A* Flares

Daily XRT monitoring of GC

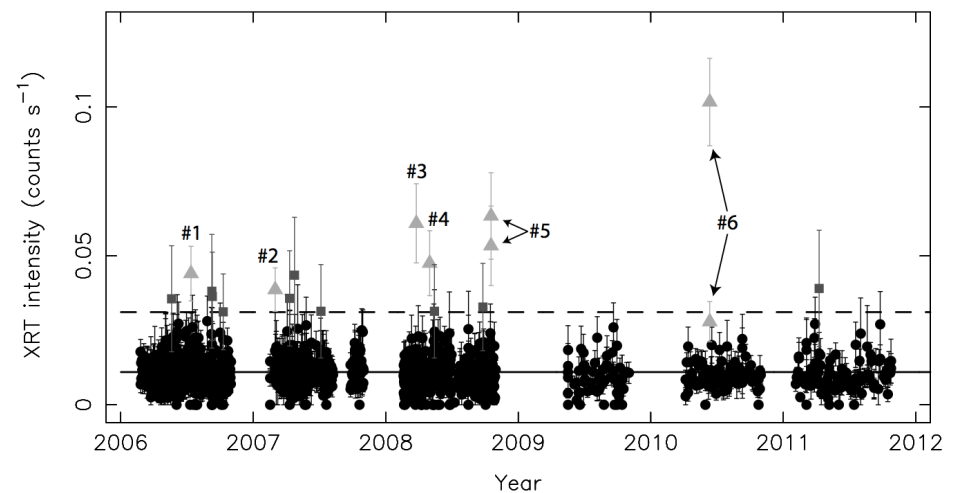
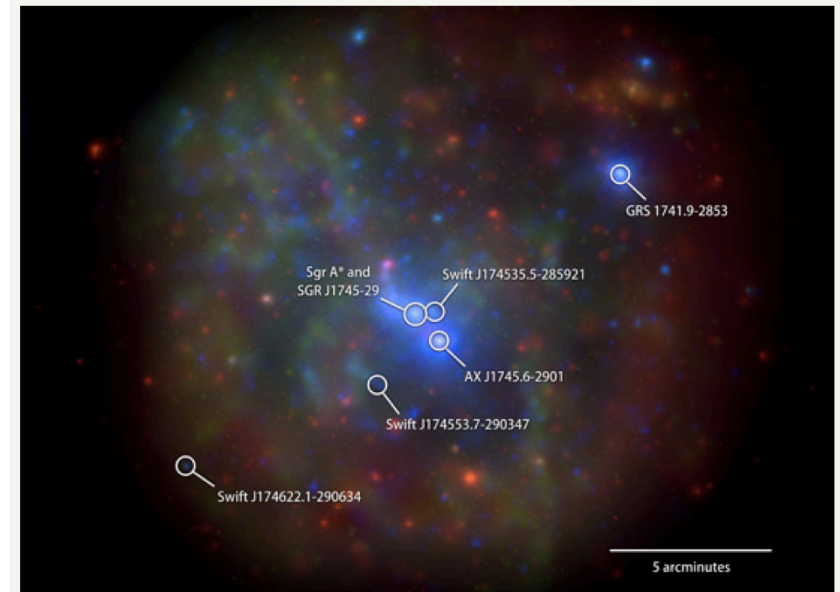
6 flares seen from Sgr A*
+ 10 weak candidate flares

Sgr A* is not dormant

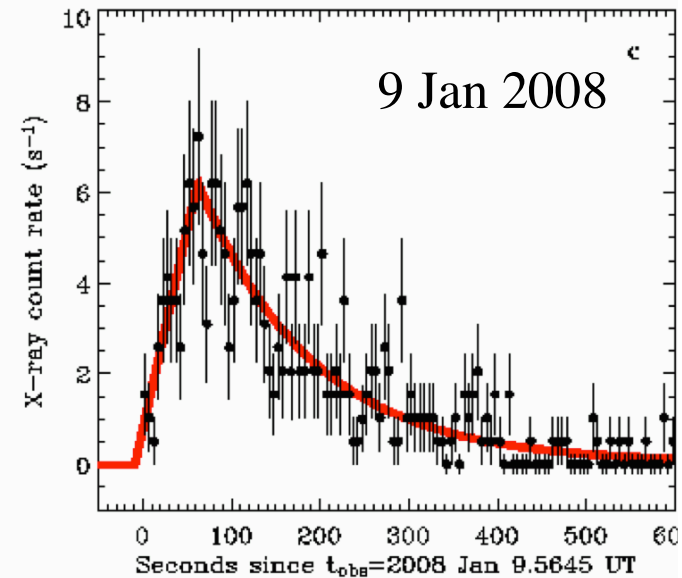
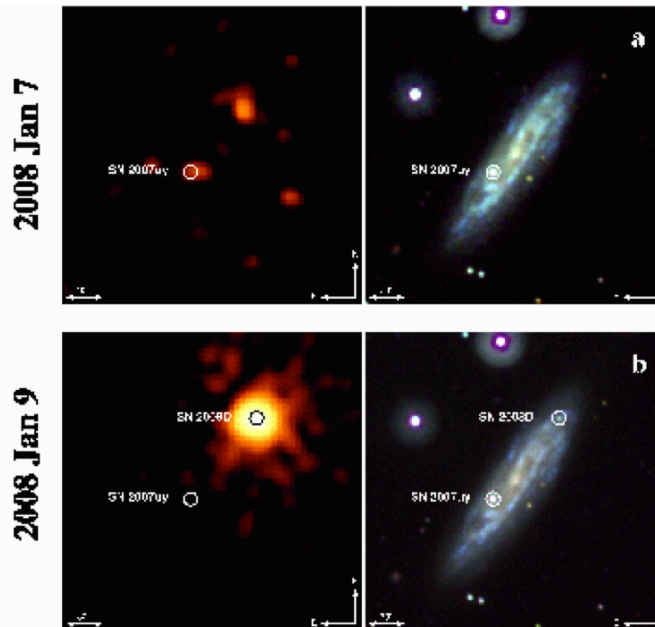
$L_X \sim \text{few} \times 10^{35} \text{ erg/s}$
 $\sim 1 \text{ billionth Eddington}$

Degenaar+ 13

Power source:
Gravity



SN 2008D Shock Breakout



Soderberg+ 08

XRT narrow-field monitoring of SN 2007y

Luminous X-ray outburst from SN 2008D

Shock breakout. May occur for all SNe

Power source:
Gravity + E&M

Swift Transient - Sw J1644+57

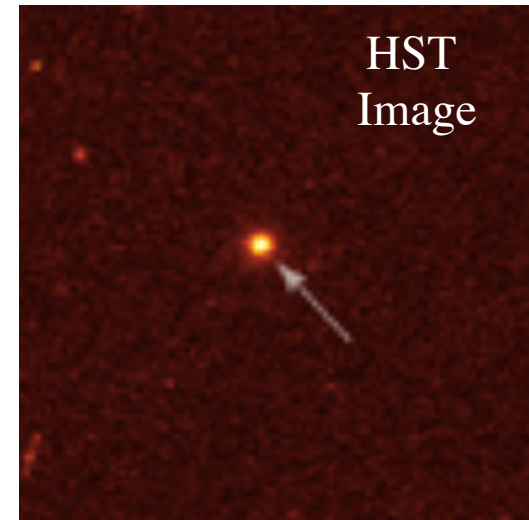
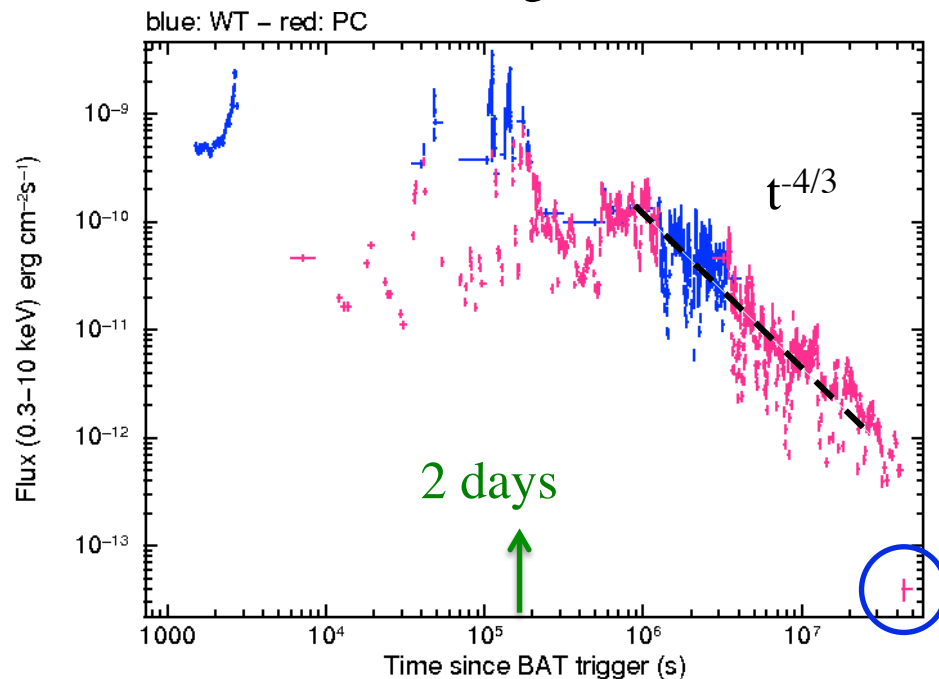
Highly erratic γ -ray and X-ray light curve, March 28, 2011

Like a GRB, but lasting 2 days instead of 20 second

Tidal disruption event beamed at us

$$E \sim 10^{51} \text{ ergs} \quad M_{\text{BH}} = 10^6 - 10^7 M_{\text{solar}}$$

Swift Light Curve



Center of galaxy at $z=0.35$

Bloom+, Burrows+, Levan+ ... 11



What's in a name?

THE ASTROPHYSICAL JOURNAL, 678:1127–1135, 2008 May 10

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GRB 070610: A CURIOUS GALACTIC TRANSIENT

M. M. KASLIWAL,¹ S. B. CENKO,² S. R. KULKARNI,¹ P. B. CAMERON,¹ E. NAKAR,¹ E. O. OFEK,¹ A. RAU,¹
A. M. SODERBERG,¹ S. CAMPANA,³ J. S. BLOOM,⁴ D. A. PERLEY,⁴ L. K. POLLACK,⁵ S. BARTHELMY,⁶
J. CUMMINGS,⁶ N. GEHRELS,⁶ H. A. KRIMM,^{7,8} C. B. MARKWARDT,^{7,9} G. SATO,⁶ P. CHANDRA,¹⁰
D. FRAIL,¹¹ D. B. FOX,¹² P. A. PRICE,¹³ E. BERGER,^{14,15} S. A. GREBENEV,¹⁶
R. A. KRIVONOS,^{16,17} AND R. A. SUNYAEV^{15,16}

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ABSTRACT

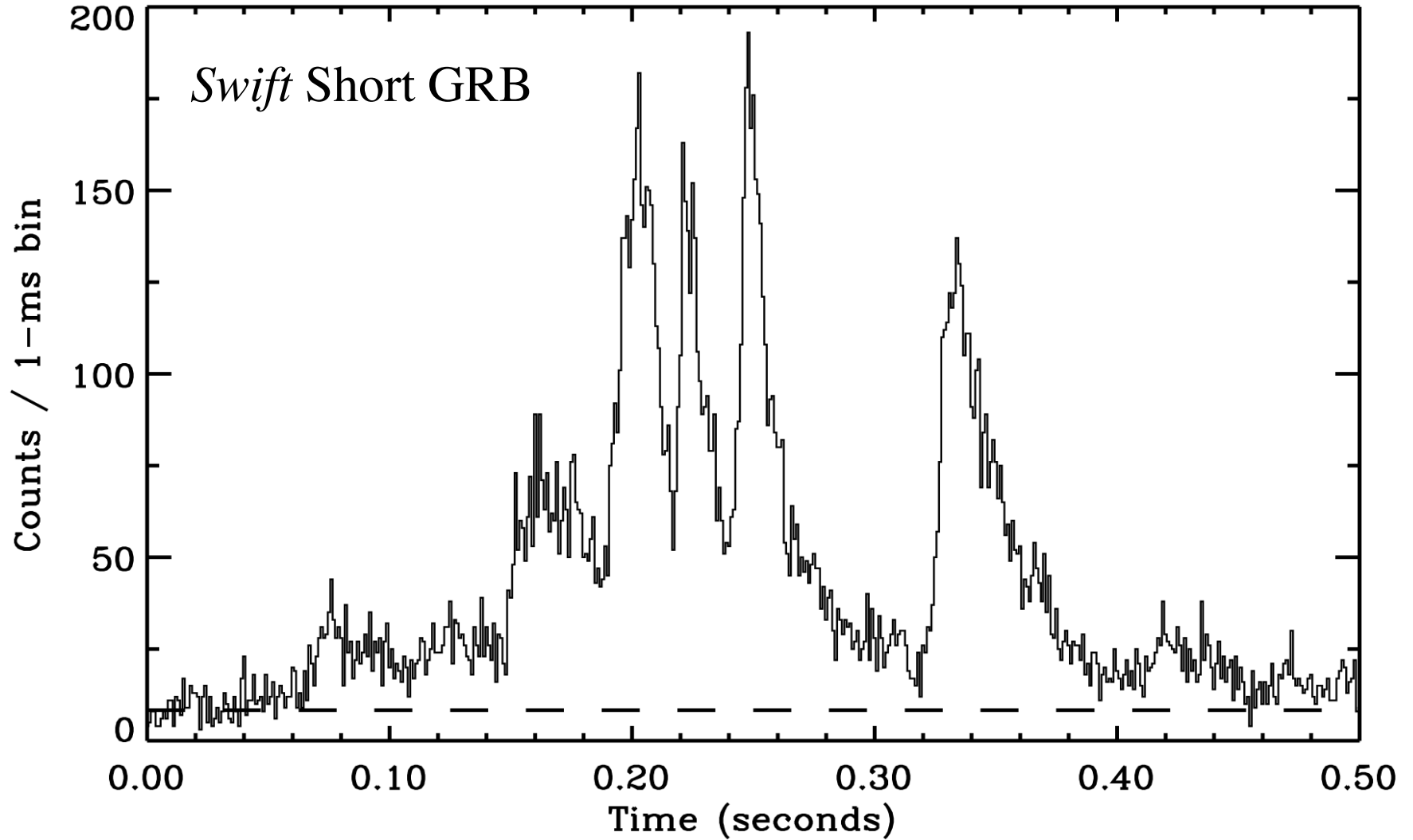
GRB 070610 is a typical high-energy event with a duration of 5 s. Yet within the burst localization we detect a highly unusual X-ray and optical transient, Swift J195509.6+261406. We see high-amplitude X-ray and optical variability on very short timescales even at late times. Using near-infrared imaging assisted by a laser guide star and adaptive optics, we identified the counterpart of Swift J195509.6+261406. Late-time optical and near-infrared imaging constrain the spectral type of the counterpart to be fainter than a K-dwarf, assuming it is of Galactic origin. It is possible that GRB 070610 and Swift J195509.6+261406 are unrelated sources. However, the absence of a typical X-ray afterglow from GRB 070610 in conjunction with the spatial and temporal coincidence of the two motivate us to suggest that the sources are related. The closest (imperfect) analog to Swift J195509.6+261406 is V4641 Sgr, an unusual black hole binary. We suggest that Swift J195509.6+261406 along with V4641 Sgr define a subclass of stellar black hole binaries—the fast X-ray novae. We further suggest that fast X-ray novae are associated with bursts of gamma rays. If so, GRB 070610 defines a new class of celestial gamma-ray bursts and these bursts dominate the long-duration GRB demographics.

Subject headings: gamma rays: bursts — stars: flare — X-rays: binaries — X-rays: bursts —
X-rays: individual (Swift J195509.6+261406)

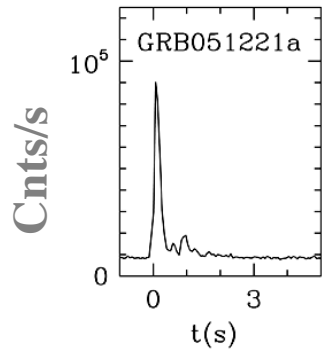
Online material: machine-readable table

GRB Variability

GRB 051221a

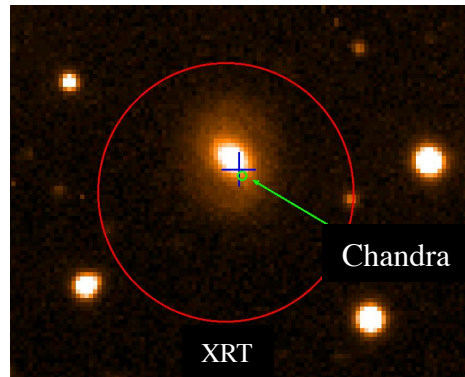


Short GRB

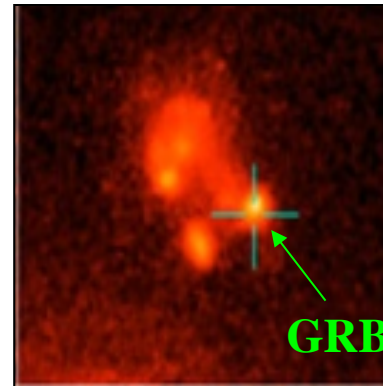


Short vs Long GRBs

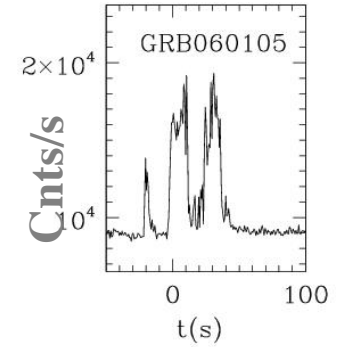
GRB 050724 - *Swift*
elliptical host



GRB 020903 - *SAX*
SF dwarf host



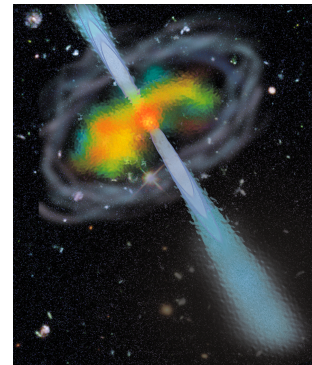
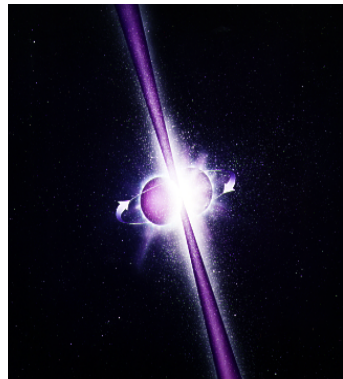
Long GRB



In non-SF
and SF galaxies

No SNe detected

Possible **merger**
model



BH

In SF
galaxies

**Accompanied by
SNe**

Collapsar model
well supported

Short GRBs - Page #3

Name	Redshift	Afterglow	Host	Fluence (γ -ray) (10^{-8} erg/cm 2)	E_{iso} (10^{49} erg)	Duration (s)	Spectral+ Lag (ms)	Extended Emission	Origin /Comment
100206A	0.4068	X	luminous IR	14 \pm 2	-	0.12	-	-	Perley 2011
100213A	-	X	-	17 \pm 3	-	2.4	15 \pm 15	-	Y?
100224A	-	-	-	3.2 \pm 2	-	\sim 0.5	-	-	untriggerred
100625A	0.452	X	host	23.	-	3.3	-	-	N soft, weak tail Fong+
100628A	0.102?	X	galaxy @ z=0.1	2.5	-	0.035	-	-	N weak pulse
100702A	-	X	-	1.2	-	0.16	-6 \pm 7	-	N
100724A	1.288	X, O	-	12.	-	1.4	300 \pm 82	-	N probably LGRB
100816A	0.8035	X, O (UVOT)	galaxy	200.	-	2.9	20 \pm 20	-	Y short ?
101129A	-	-	-	9.	-	0.35	-	-	N untriggerred
101219A	0.718	X	host	46.	-	0.6	-	-	N Fong+ '13
101224A	-	X	-	5.0	-	0.2	2 \pm 100	-	N
110112A	-	X, O	-	5.8	-	0.5	60 \pm 160	-	N Fong+ '13
110402A	-	X, O	-	340.	-	6 (60)	3.7 \pm 3	-	Y
111117A	-	X	galaxy	14.0	-	0.47	0.6 \pm 2.4	-	N Chandra X
111211A	-	X	-	110.	-	1.5 (119)	10 \pm 2.6	-	Y
120219A	-	sun cnstrn	possible galaxy	41.	-	0.22	3.6 \pm 5	-	N
120305A	-	X	-	20.	-	0.1	-2.6 \pm 0.6	-	N brightest BAT GRB
120521A	-	X	-	7.8	-	0.45	-18 \pm 18	-	N
120630A	-	X	-	6.1	-	0.6	-	-	-
120804A	-	X	-	88.	-	0.81	16 \pm 12	-	N
121226A	-	X	-	14.	-	1.0	50 \pm 100	-	N
130313A	-	X	-	3.9	-	0.26	9 \pm 9	-	- short spike
130515A	-	X	possible galaxy	15.	-	0.29	4 \pm 5	-	N short spike
130603B	0..356	X, O	galaxy	63.	21 \pm 2.	0.18	-2.5 \pm 0.7	-	N spike, kilonova
130626A	-	X?	-	5.2	-	0.16	-	-	N short spike
130716A	-	-	-	-	-	0.8	2 \pm 50	-	- no TdRSS
130822A	-	X	-	-	-	0.04	2.5 \pm 3.0	-	N short spike
130912A	-	X, O	-	17.	-	0.28	-1.9 \pm 5.0	-	N
140320A	-	X	-	4.9	-	0.45	-	-	-
140402A	-	LAT, BAT	-	3.8	-	0.032	-	-	- untriggerred
140414A	-	-	-	12.	-	0.7	-	-	- untriggerred
140516A	-	X	-	2.3	-	0.19	-	-	-
140606A	-	-	-	5.1	-	0.34	0.7 \pm 13.0	-	late slew
140622A	0.959	X, O	-	2.7	-	0.13	-	-	soft thermal BAT
140705A	-	X	-	3.8	-	0.08	.1 \pm 2	-	possible SGR
140903A	0.35	X, O	-	14.	-	0.30	16 \pm 7	-	lag inconclusive

Short GRB Info

Short Compared to Long GRBs

Lower Redshifts

$\langle z \rangle = 0.4$ short

$\langle z \rangle = 2.3$ long

Weaker Afterglows

$\langle F_X \rangle = 7 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$ short

$\langle F_X \rangle = 3 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$ long

Lower Energy release

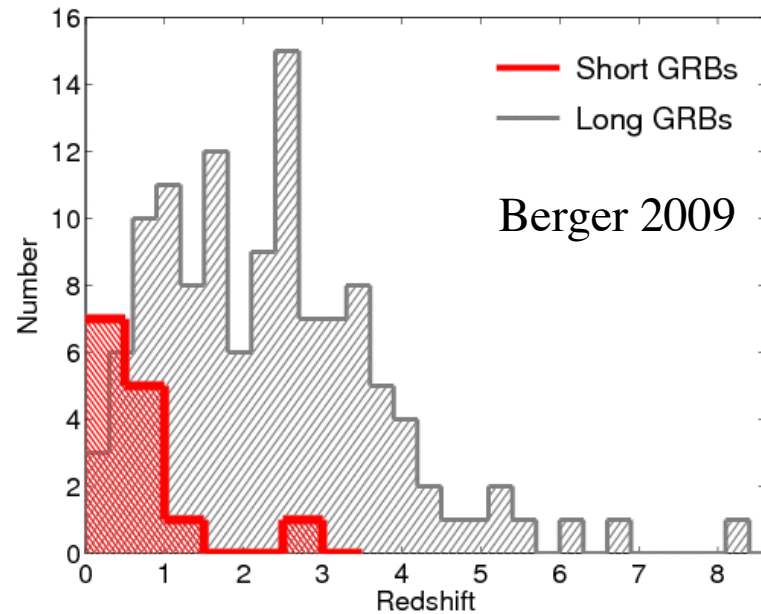
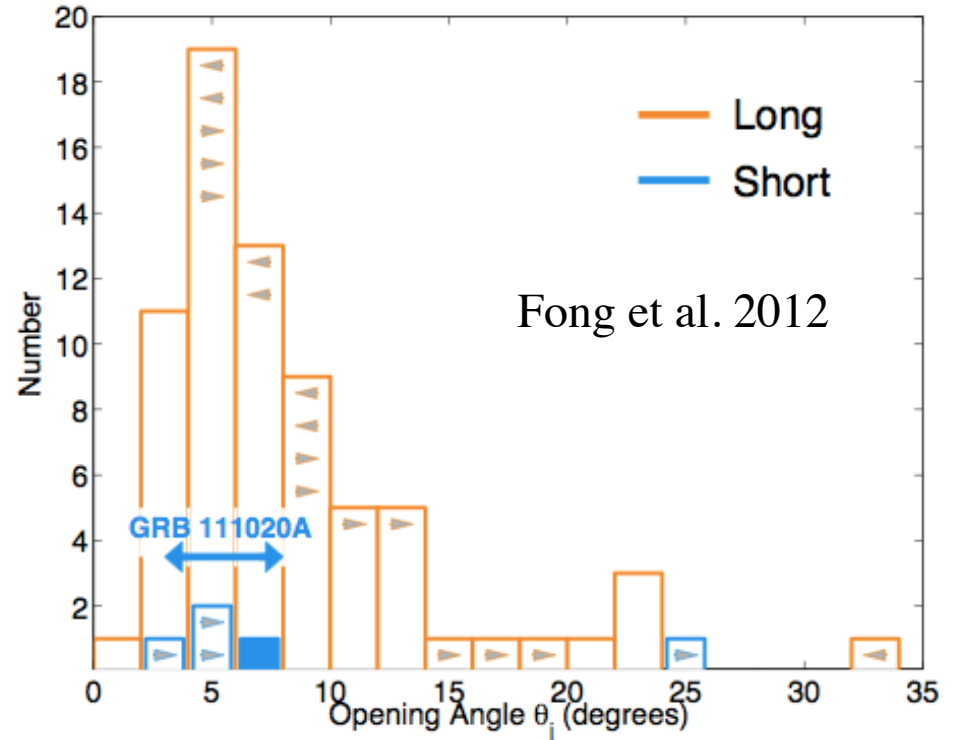
$E_{\text{iso}} \sim 10^{50}$ $E_{\gamma} \sim 10^{49}$ short

$E_{\text{iso}} \sim 10^{53}$ $E_{\gamma} \sim 10^{51}$ long

Similar Jet Opening Angle

$h \sim 5^\circ - 10^\circ$ short

$h \sim 5^\circ$ long



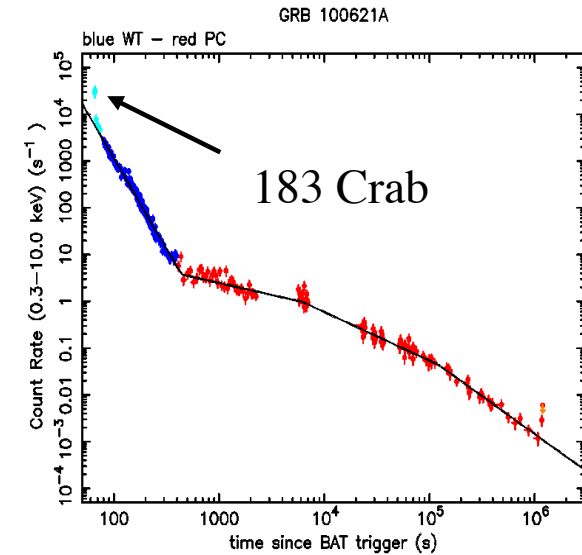
Short Burst Merger Model



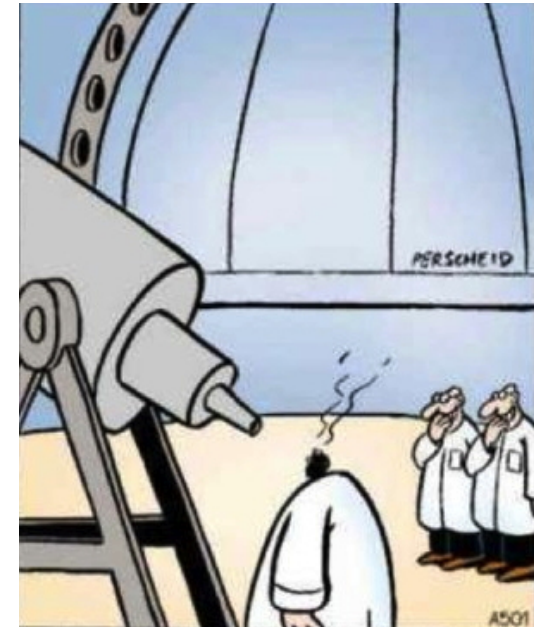
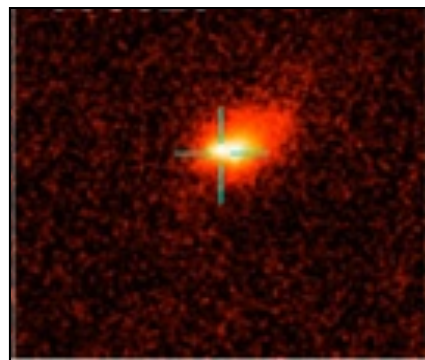
High Redshift GRBs

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

XRT Lightcurve

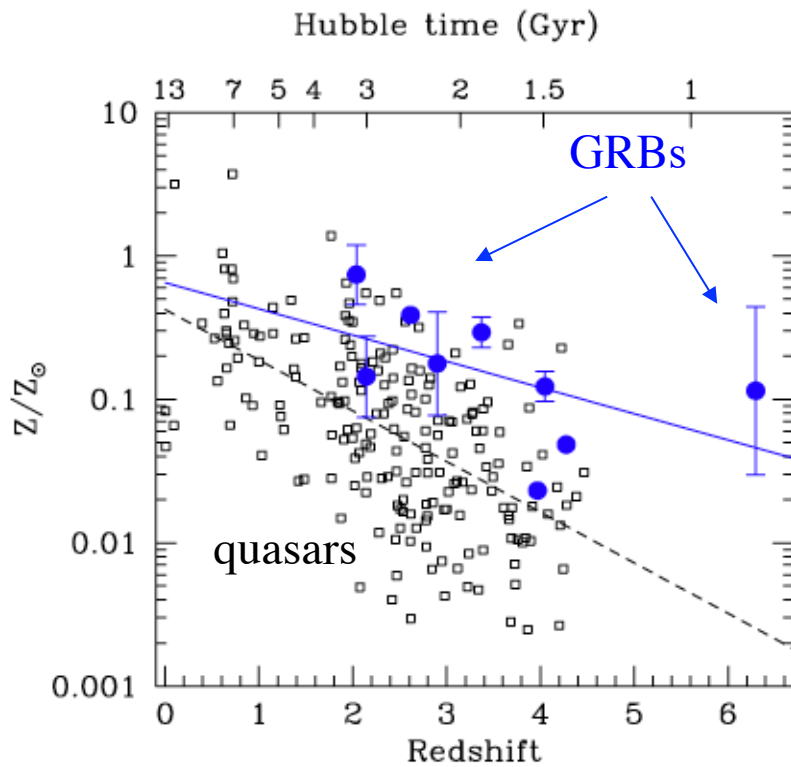


HST image



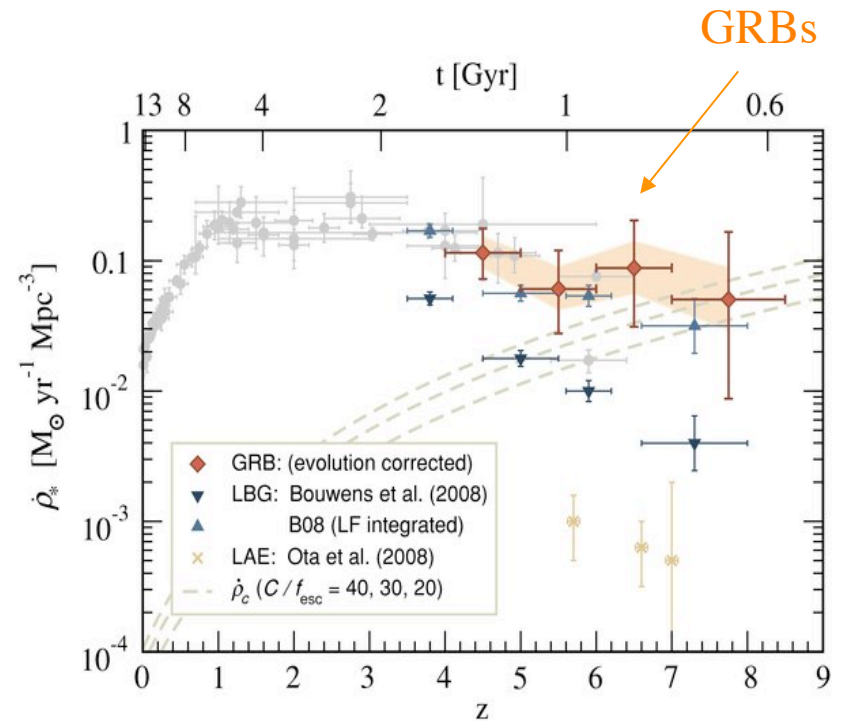
Tools to Study the High-z Universe

Metallicity

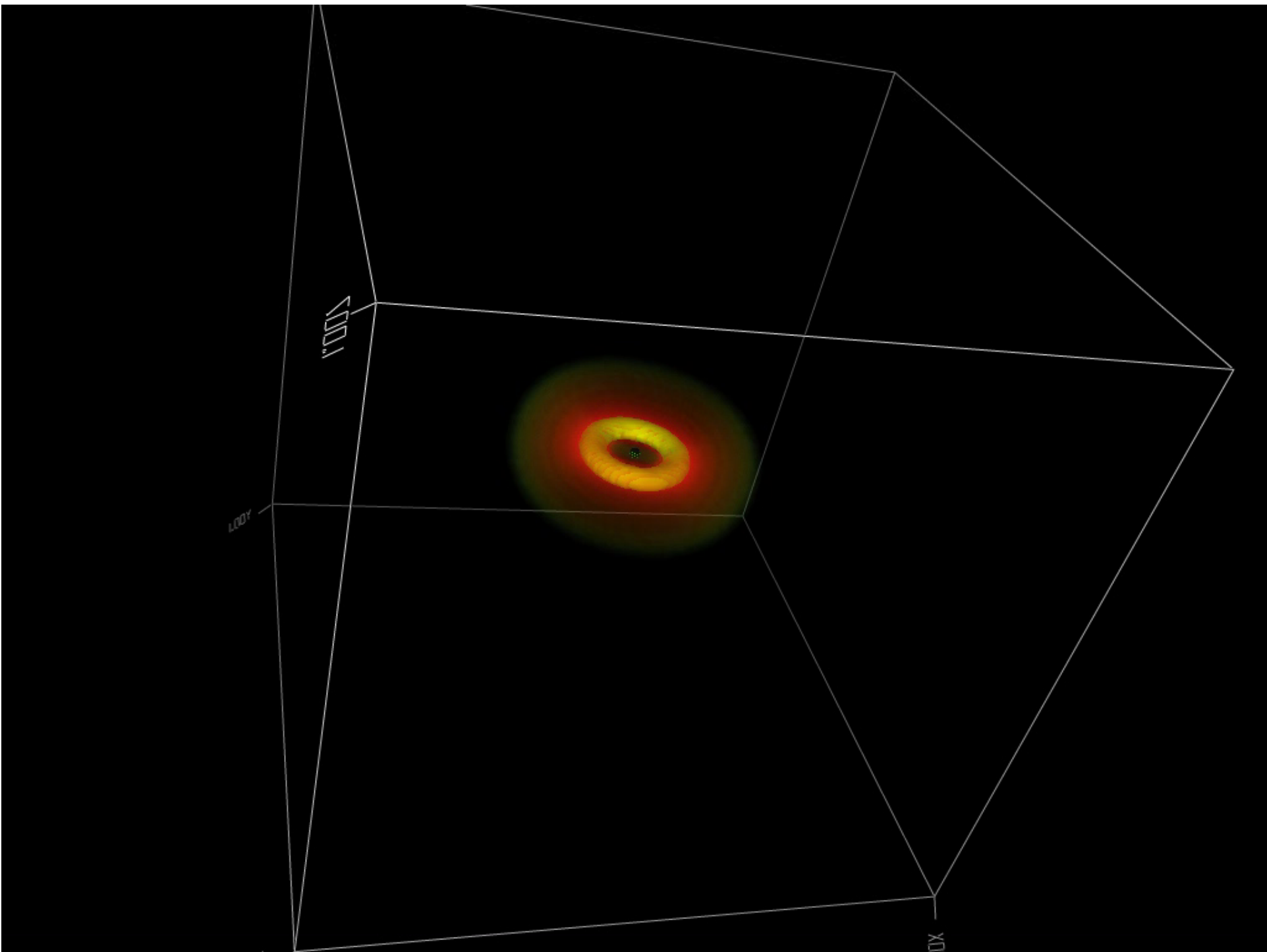


Savaglio 06

Star Formation Rate



Kistler + 13;
Robertson & Ellis 11



Swift Science

Supernova TOO program

Magnetars

BAT survey

AGN monitoring – NGC 5548

Blazar campaigns

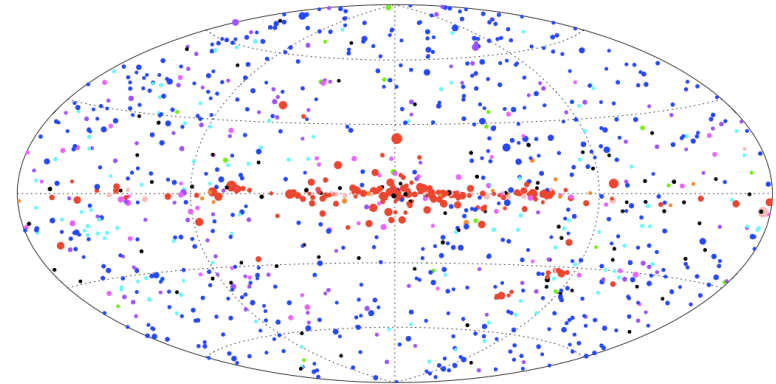
Comets / asteroids

ULX

UVOT galaxy surveys

BH / NS outbursts

Joint observations (NuSTAR, Fermi, MAXI, INTEGRAL, PTF,
Kepler, ACTs, ν experiments, LIGO/Virgo)



The Future

New Science Themes

- **Towards a “Smoking Gun” Short Burst Progenitor:**
 - Coordinate observations with aLIGO/Virgo
 - Confirm r-process “kilonovae”
- **Probing the Epoch of Reionization:**
 - Use new NIR spectrometers to study $z > 7$ GRBs
- **Supernovae and Cosmology:**
 - Construct the first large sample of UV light curves for SNe Ia
 - Use Swift data to improve SNe Ia standardization
- **Serendipitous Time-Domain Discoveries:**
 - Increase the likelihood of unanticipated discoveries through new mission initiatives and partnerships with wide-field optical and radio transient surveys



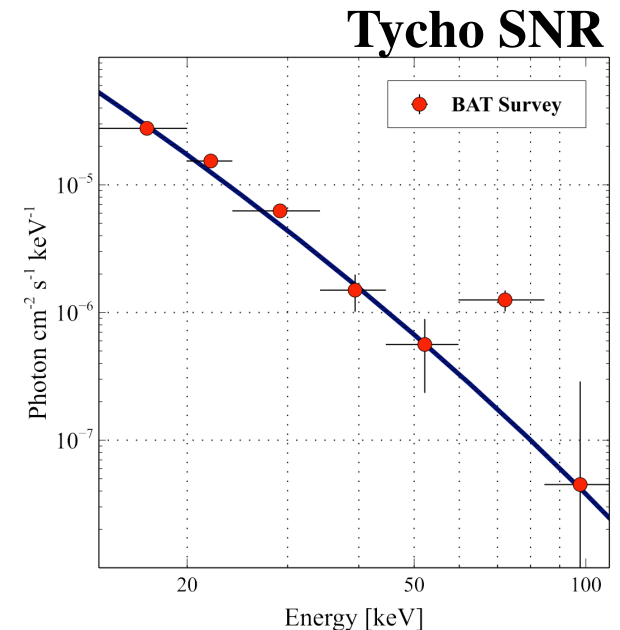
New NIR Spectrometers

Table 2: – New GRB NIR Follow-up Spectroscopic Capabilities

Facility	Location	Aperture (m)	Date	Wavelength (nm)	Resolution
VLT/X-Shooter	Chile	8.2	2009	320–2500	4000-6000
Magellan/FIRE	Chile	6.5	2010	800–2500	6000–8000
Gemini-N/GNIRS	Hawai'i	8.1	2011	900–2500	1700, 5000, 18000
Keck/MOSFIRE	Hawai'i	10.0	2012	900–2400	2300–4700
VLT/KMOS	Chile	8.2	2013	800-2500	1800–4200
Gemini-S/Flamingos-2	Chile	8.1	2013	900–2400	1200–3000
Keck/NIRES	Hawai'i	10.0	2014	1100–2400	2500
LBT/LUCI2	Arizona	2 × 8.4	2014	850–2400	2000–8000
DCT/RIMAS	Arizona	4.2	2014	900–2400	25, 5000

New Initiatives

- 1: Automation for rapid response and risk reduction (improved ToO capabilities, aLIGO/Virgo counterpart searches)
- 2: Automated ID of new XRT transients (discovery and dissemination)
- 3: UV/X-ray survey of 400 nearby galaxies (treasury survey)
- 4: Real-time downlink of BAT subthreshold triggers (multi-messenger)
- 5: Enhanced Guest Investigator program with a large key project element
- 6: Augmented BAT hard X-ray survey spectra (spectral curvature for AGN, ^{44}Ti for SNRs)





Conclusions



- The sky is rich in transients of many types.
- Swift is exploring the transient sky with unprecedented sensitivity and coverage
- Every year brings new discovery in time domain science
- Explosion mechanisms range from gravitational collapse to nuclear burning to B field reconnection.
- Swift will hopefully last another 10 years and has exciting science to perform partnering with new ground observatories and increasing capabilities.

