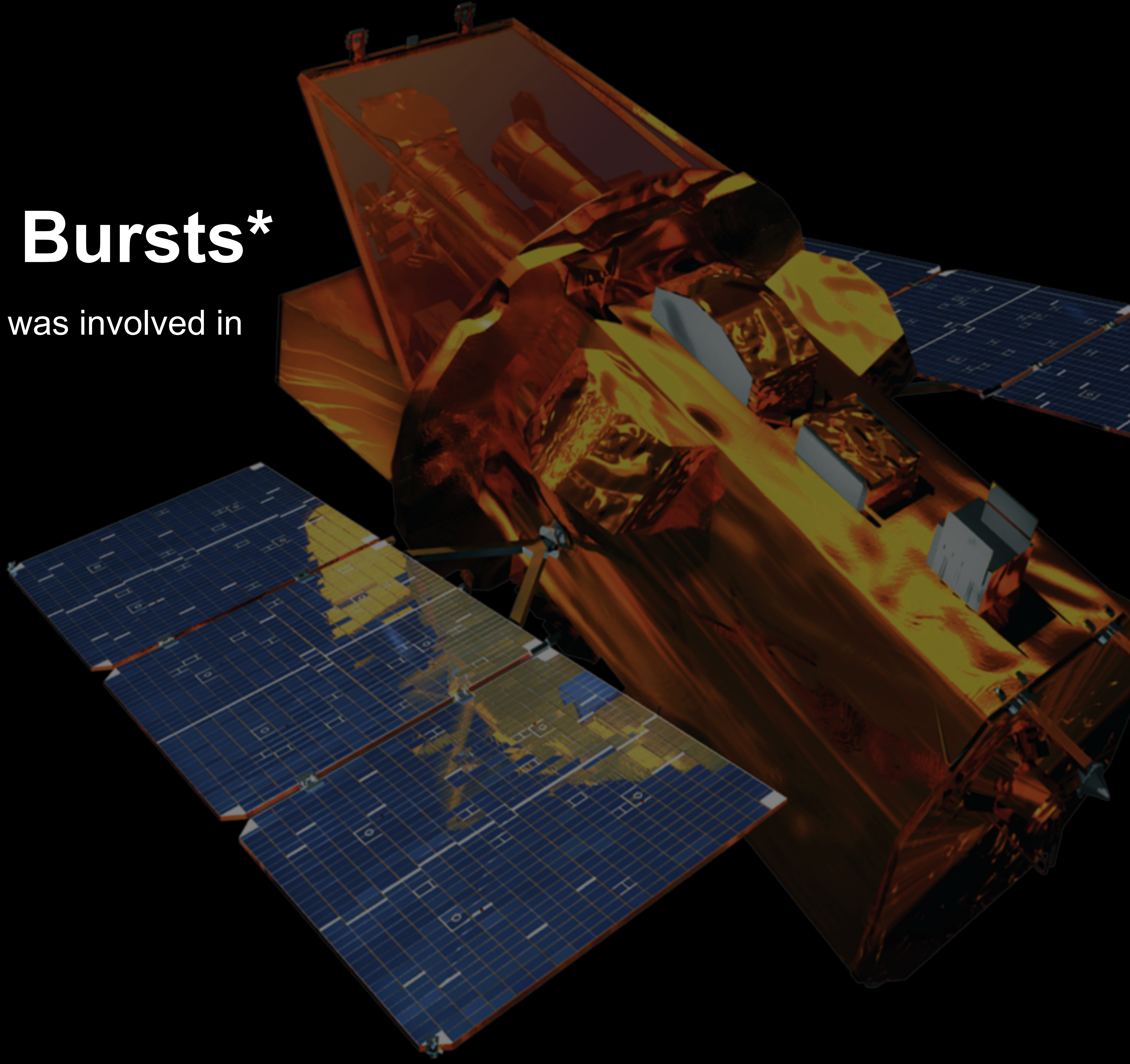
# 50 Years of Gamma-Ray Bursts*

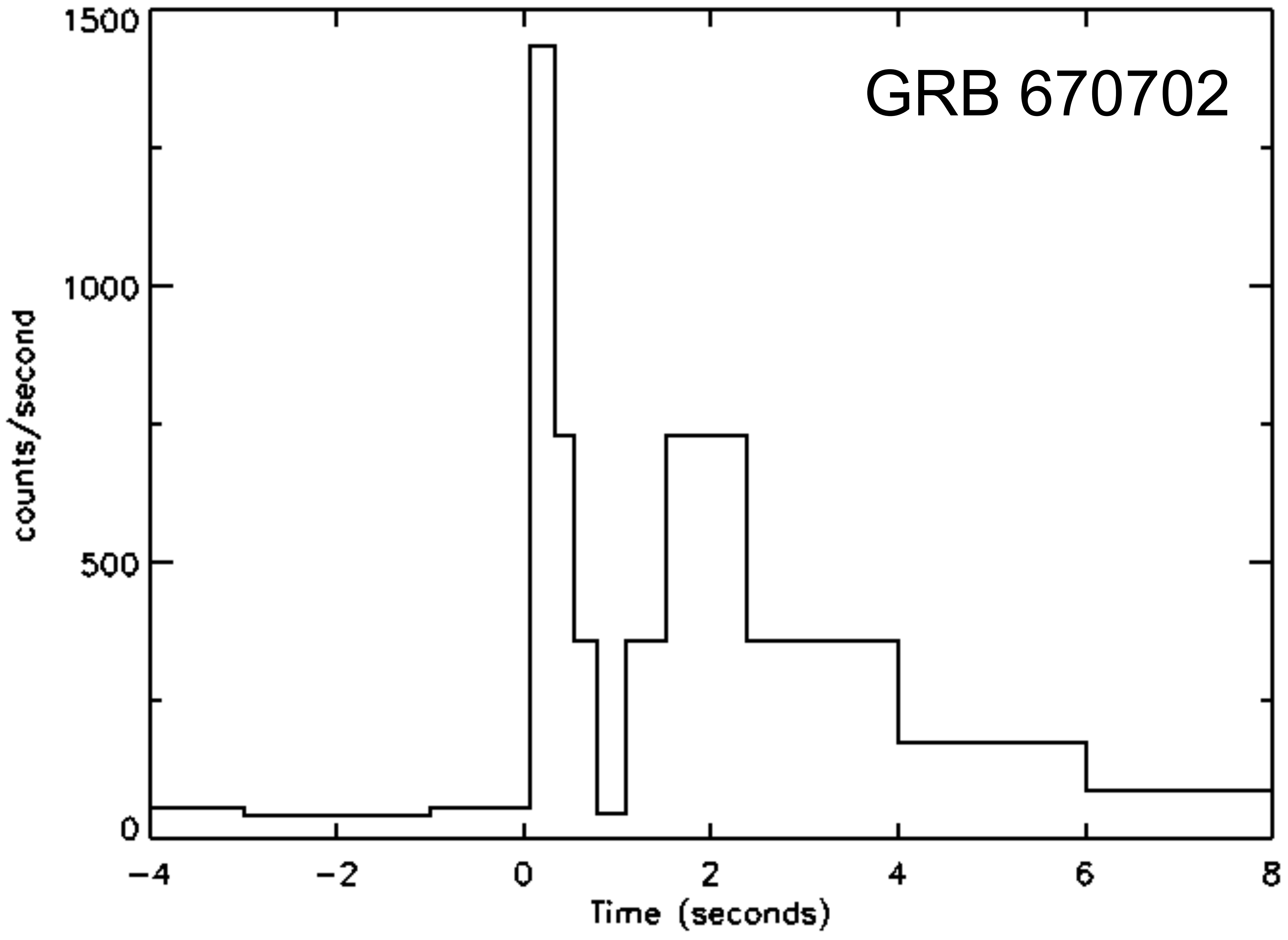
* With a biased overemphasis on Neil & stuff I was involved in



Josh Bloom
UC Berkeley
@profjsb

IPN
Vela Series
CGRO (BATSE)
Swift
HETE-2
Fermi
BeppoSAX
INTEGRAL
High-Energy Era
Afterglow Era
Multimessenger Era
Events
GRB 670702
March 5 Event (SGR 0525-66)
GRB 980425/SN 1998bw
GRB 130603B
GRB 090423
GRB 030329/SN 2003dh
GRB 970508
GRB 080319b
GRB 130427A
Sw J1644+57
GRB 970228
GRB 050509b
GW/GRB 170817
1970
1980
1990
2000
2010
2020
Theory & Aggregate Insights
Colgate May 68
Klebesadal, Olson & Strong 73
Paczyński 86
Eichler+89
Great Debate
Frail+01
Burrows+05
Berger 14
Sari, Piran, Narayan 98
Mészáros & Rees 97
Gehrels, Ramirez-Ruiz, & Fox 09
Band+93/Kouvelitou+93
Lamb & Reichart 00
Paczyński & Rhoads 93
Li & Paczyński 98
Meegan+92
MacFadyen & Woosley 99
50 Years of GRBs Gehrels Memorial
Josh Bloom

# Discovery & Demographics
# High-energy Era




Theory: Colgate 68

THE ASTROPHYSICAL JOURNAL, **182**:L85–L88, 1973 June 1


## OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
*Received 1973 March 16; revised 1973 April 2*

### ABSTRACT

Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from $\sim 10^{-5}$ ergs cm$^{-2}$ to $\sim 2 \times 10^{-4}$ ergs cm$^{-2}$ in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.

*Subject headings:* gamma rays — X-rays — variable stars

### I. INTRODUCTION

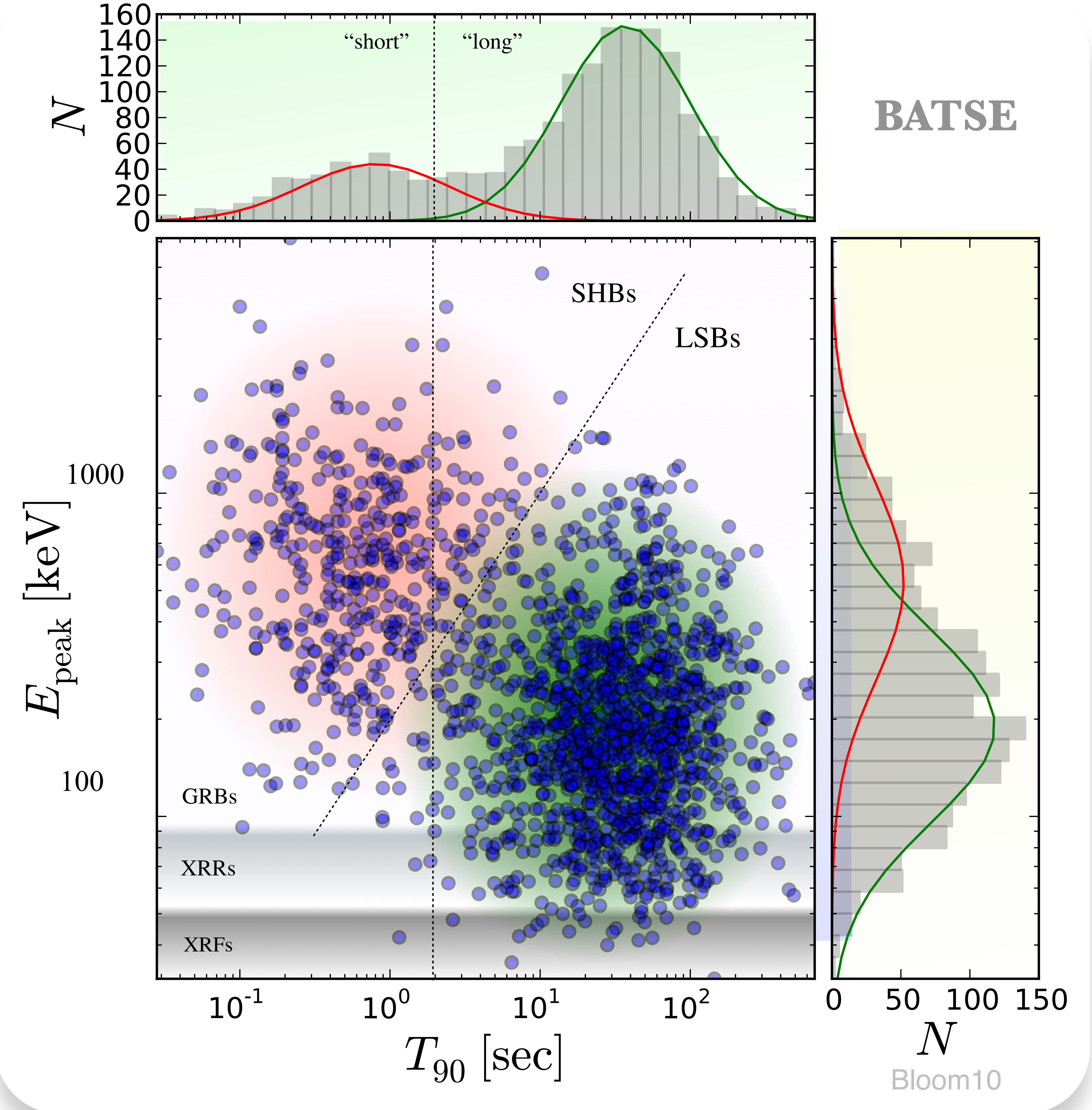
On several occasions in the past we have searched the records of data from early *Vela* spacecraft for indications of gamma-ray fluxes near the times of appearance of supernovae. These searches proved uniformly fruitless. Specific predictions of gamma-ray emission during the initial stages of the development of supernovae have since been made by Colgate (1968). Also, more recent Vela spacecraft are equipped with much improved instrumentation. This encouraged a more general search, not restricted to specific time periods. The search covered data acquired with almost continuous coverage between 1969 July and 1972 July, yielding records of 16 gamma-ray bursts distributed throughout that period. Search criteria and some characteristics of the bursts are given below.

### II. INSTRUMENTATION

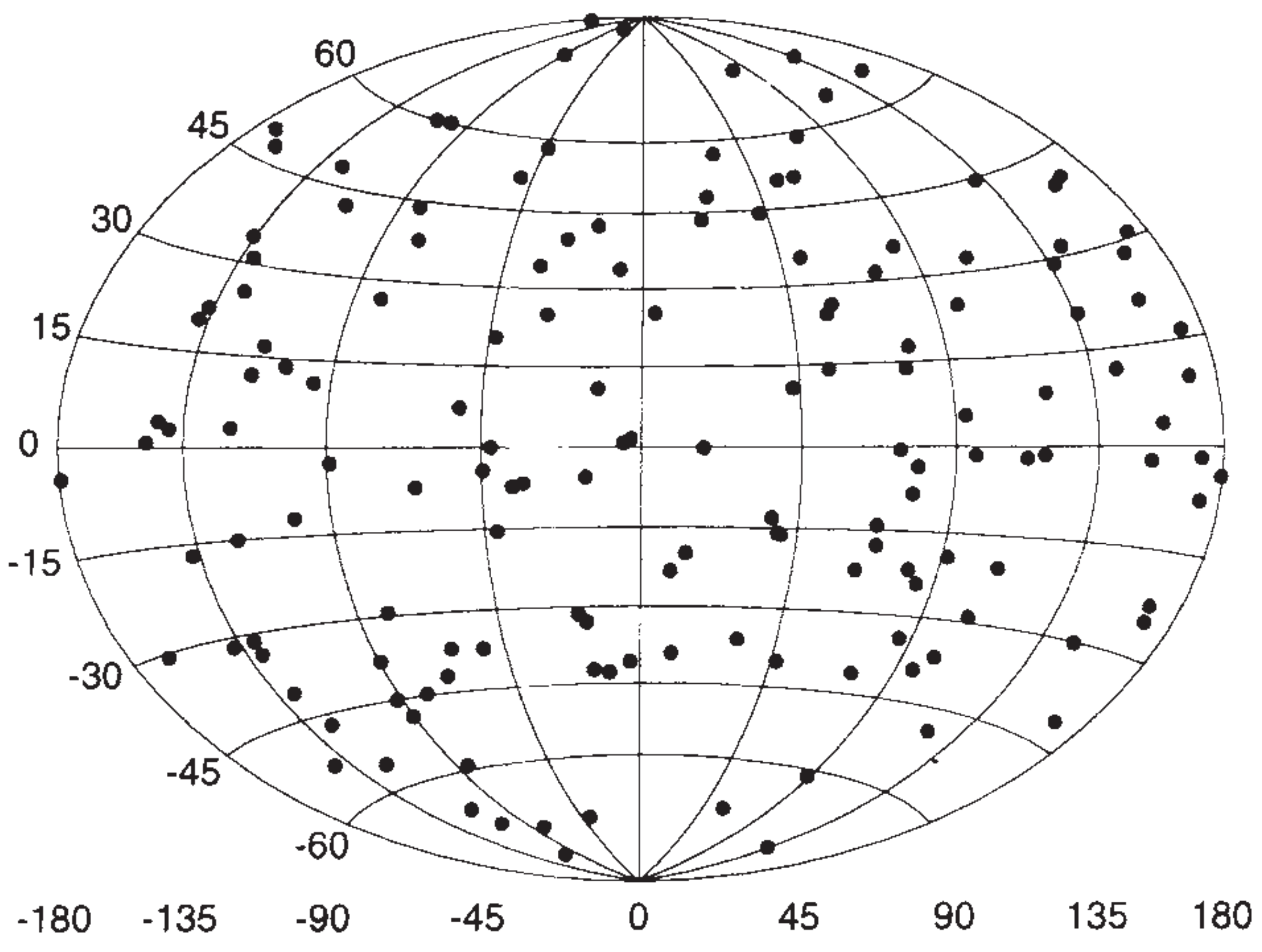
The observations were made by detectors on the four *Vela* spacecraft, *Vela 5A*, *5B*, *6A*, and *6B*, which are arranged almost equally spaced in a circular orbit with a geocentric radius of $\sim 1.2 \times 10^5$ km.

On each spacecraft six 10 cm$^3$ CsI scintillation counters are so distributed as to achieve a nearly isotropic sensitivity. Individual detectors respond to energy depositions of 0.2–1.0 MeV for *Vela 5* spacecraft and 0.3–1.5 MeV for *Vela 6* spacecraft, with a detection efficiency ranging between 17 and 50 percent. The scintillators are shielded against direct penetration by electrons below ~0.75 MeV and protons below ~20 MeV. A high-*Z* shield attenuates photons with energy below that of the counting threshold. No active anticoincidence shielding is provided.

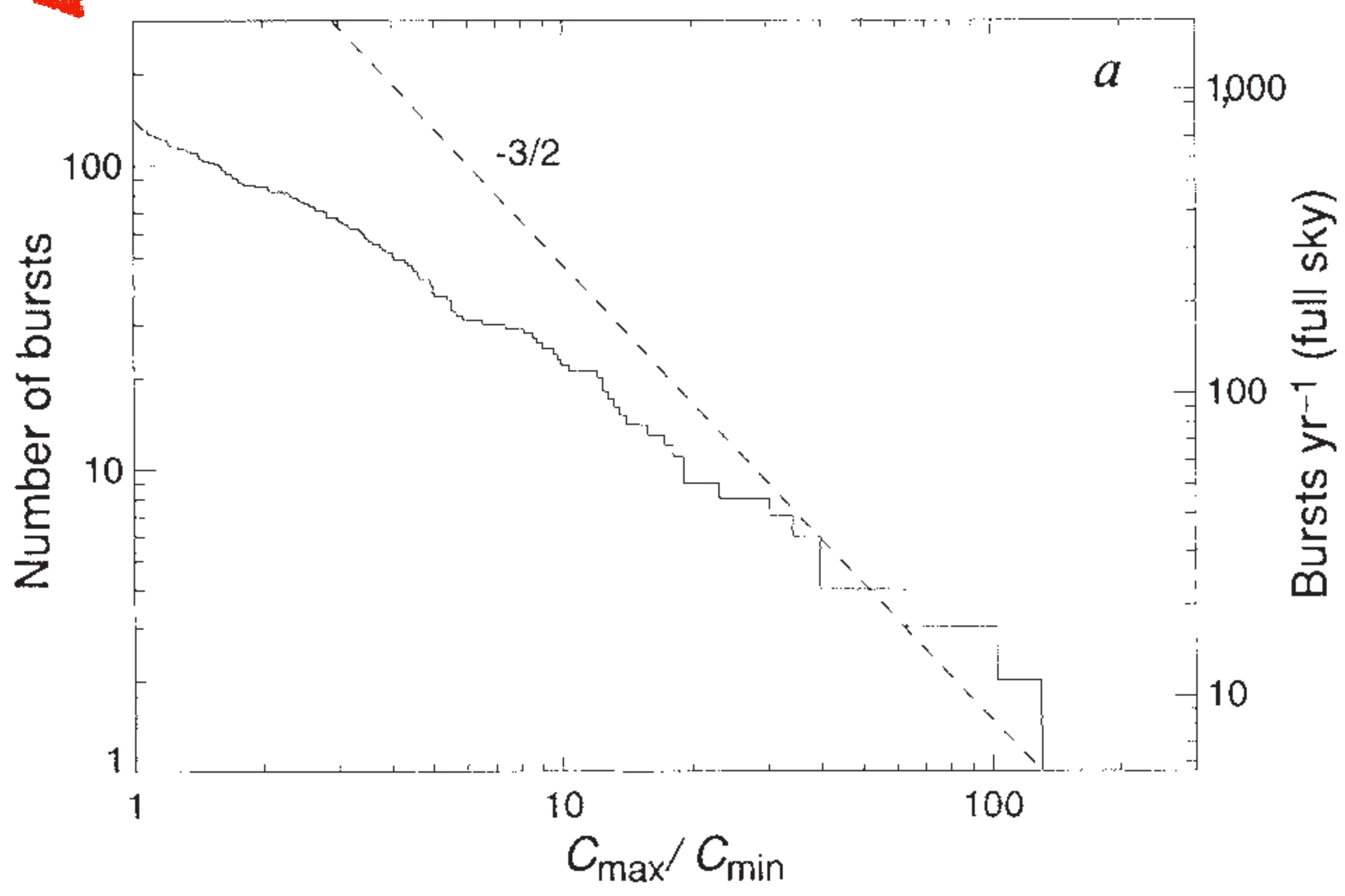
# Discovery & Demographics
# High-energy Era




- Isotropic
- Non-Euclidean/ Inhomogeneous
- Two Populations




Meegan+92




Kouvelitou+93, Mazets+81
Norris+84

# Discovery & Demographics
# High-energy Era

“No Host Problem” (cf. Larson 97)

“Great Debate” here in DC (Apr 95):
*Galactic* *or* *Cosmological?*

**Rees, Paczyński, Lamb**

https://apod.nasa.gov/debate/debate95.html

## Discovery & Demographics
## High-energy Era

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3rd Huntsville Conference (Oct 95)

# THE CORRECTED LOG N-LOG FLUENCE DISTRIBUTION OF COSMOLOGICAL $\gamma$-RAY BURSTS

Joshua S. Bloom[1,2], Edward E. Fenimore[2], Jean in 't Zand[2,3]

[1] *Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138*
[2] *Los Alamos National Laboratory, Los Alamos, NM 87544*
[3] *Goddard Space Flight Center, Greenbelt, MD 20771*

Recent analysis of relativistically expanding shells of cosmological $\gamma$-ray bursts has shown that if the bursts are cosmological, then most likely total energy ($E_0$) is standard and not peak luminosity ($L_0$). Assuming a flat Friedmann cosmology ($q_o = 1/2$, $\Lambda = 0$) and constant rate density ($\rho_0$) of bursting sources, we fit a standard candle energy to a uniformly selected log $N$-log $S$ in the BATSE 3B catalog correcting for fluence efficiency and averaging over 48 observed spectral shapes. We find the data consistent with $E_0 = 7.3^{+0.7}_{-1.0} \times 10^{51}$ ergs and discuss implications of this energy for cosmological models of $\gamma$-ray bursts.

## INTRODUCTION

On the basis of strong threshold effects of detectors, Klebesadel, Fenimore, and Laros (7) concluded that GRB fluence tests were largely inconclusive. As a result, nearly all subsequent number-brightness tests have used peak flux ($P$) rather than fluence ($S$). However, the standard candle peak luminosity assumption that is required by log $N$-log $P$ studies is unphysical. If, for instance, bursts originate at cosmological distances and are produced by colliding neutron stars then one might expect that total energy would be standard and not peak luminosity. Moreover, recent analysis of relativistically expanding shell models has cast doubt on the standard $L_0$ assumption (9).

In this paper, we seek to eliminate the large threshold effects present in

# Discovery & Demographics
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THE CORRECTED LOG N-LOG FLUENCE DISTRIBUTION OF COSMOLOGICAL $\gamma$-RAY BURSTS

Joshua S. Bloom[1,2], Edward E. Fenimore[2], Jean in 't Zand[2,3]

**CONCLUSIONS**

Our fit of $E_0 = 7.0^{+0.7}_{-1.0} \times 10^{51}$ [30–2000 keV] ergs seems a plausible number on the basis that GRBs last on the average 10 sec and $L_0 = 4.6 \times 10^{50}$ erg $s^{-1}$ from log $N$-log $P$ studies (2). However, this $E_0$ implies a rather large efficiency of energy conversion to $\gamma$-rays ($\sim$ 10%) if the bursting mechanism is colliding neutron stars ($M_{\rm total} \simeq 2.8 M_\odot$). Nevertheless, this result would seem to help resolve the "no-host" problem (cf. ref (3)). Interestingly, that the dimmest bursts ($S \simeq 5 \times 10^{-8}$ erg cm$^{-2}$) are required to be at a redshift of $1 + z \simeq 6.4$ given this $E_0$, would seem to rule out several cosmological models that require GRB progenitors to be within galaxies (although see reference (8)). This surprisingly high redshift is due to the correct blueshifting of the baseline spectra back to the source in eq. (1). If we neglect this factor, we obtain a smaller, more tenable redshift of the dimmest bursts ($1 + z = 5.2$).

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https://apod.nasa.gov/debate/debate95.html

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# High-energy Era

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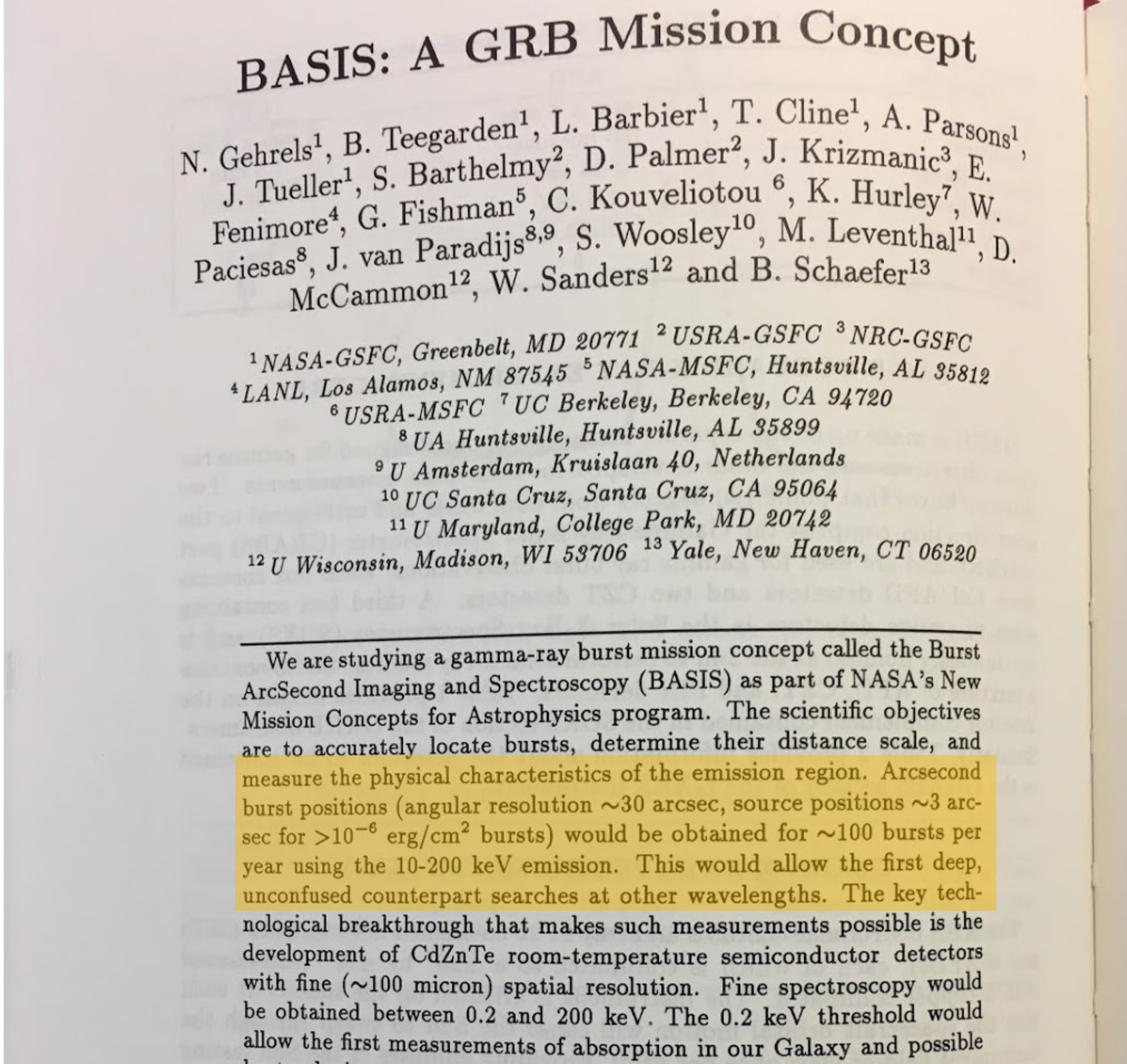


# BASIS: A GRB Mission Concept

N. Gehrels[1], B. Teegarden[1], L. Barbier[1], T. Cline[1], A. Parsons[1], J. Tueller[1], S. Barthelmy[2], D. Palmer[2], J. Krizmanic[3], E. Fenimore[4], G. Fishman[5], C. Kouveliotou [6], K. Hurley[7], W. Paciesas[8], J. van Paradijs[8,9], S. Woosley[10], M. Leventhal[11], D. McCammon[12], W. Sanders[12] and B. Schaefer[13]

*[1] NASA-GSFC, Greenbelt, MD 20771 [2] USRA-GSFC [3] NRC-GSFC*
*[4] LANL, Los Alamos, NM 87545 [5] NASA-MSFC, Huntsville, AL 35812*
*[6] USRA-MSFC [7] UC Berkeley, Berkeley, CA 94720*
*[8] UA Huntsville, Huntsville, AL 35899*
*[9] U Amsterdam, Kruislaan 40, Netherlands*
*[10] UC Santa Cruz, Santa Cruz, CA 95064*
*[11] U Maryland, College Park, MD 20742*
*[12] U Wisconsin, Madison, WI 53706 [13] Yale, New Haven, CT 06520*

We are studying a gamma-ray burst mission concept called the Burst ArcSecond Imaging and Spectroscopy (BASIS) as part of NASA's New Mission Concepts for Astrophysics program. The scientific objectives are to accurately locate bursts, determine their distance scale, and measure the physical characteristics of the emission region. Arcsecond burst positions (angular resolution ~30 arcsec, source positions ~3 arcsec for $>10^{-6}$ erg/cm$^2$ bursts) would be obtained for ~100 bursts per year using the 10-200 keV emission. This would allow the first deep, unconfused counterpart searches at other wavelengths. The key technological breakthrough that makes such measurements possible is the development of CdZnTe room-temperature semiconductor detectors with fine (~100 micron) spatial resolution. Fine spectroscopy would be obtained between 0.2 and 200 keV. The 0.2 keV threshold would allow the first measurements of absorption in our Galaxy and possible

Afterglow predictions:
Paczyński & Rhoads 93, Katz 94,
Mészáros & Rees 97

# Afterglows

**GRB 970228**

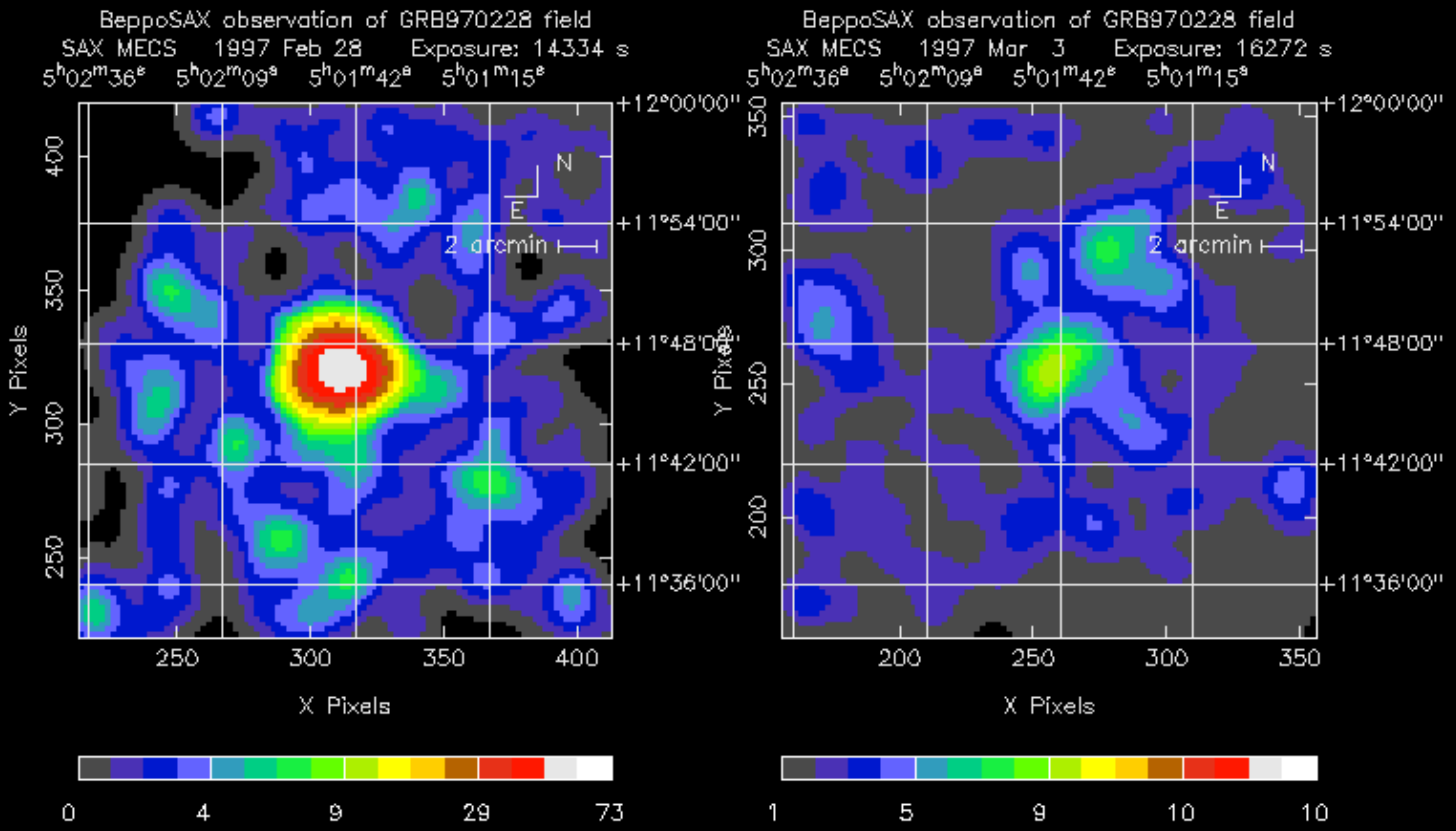
X-ray afterglow discovery
Optical afterglow discovery

Costa+97, van Paradijs+97

**GRB 970508**

Radio afterglow discovery
Absorption redshift
Host galaxy

Frail+97, Metzger+97, Taylor+97…

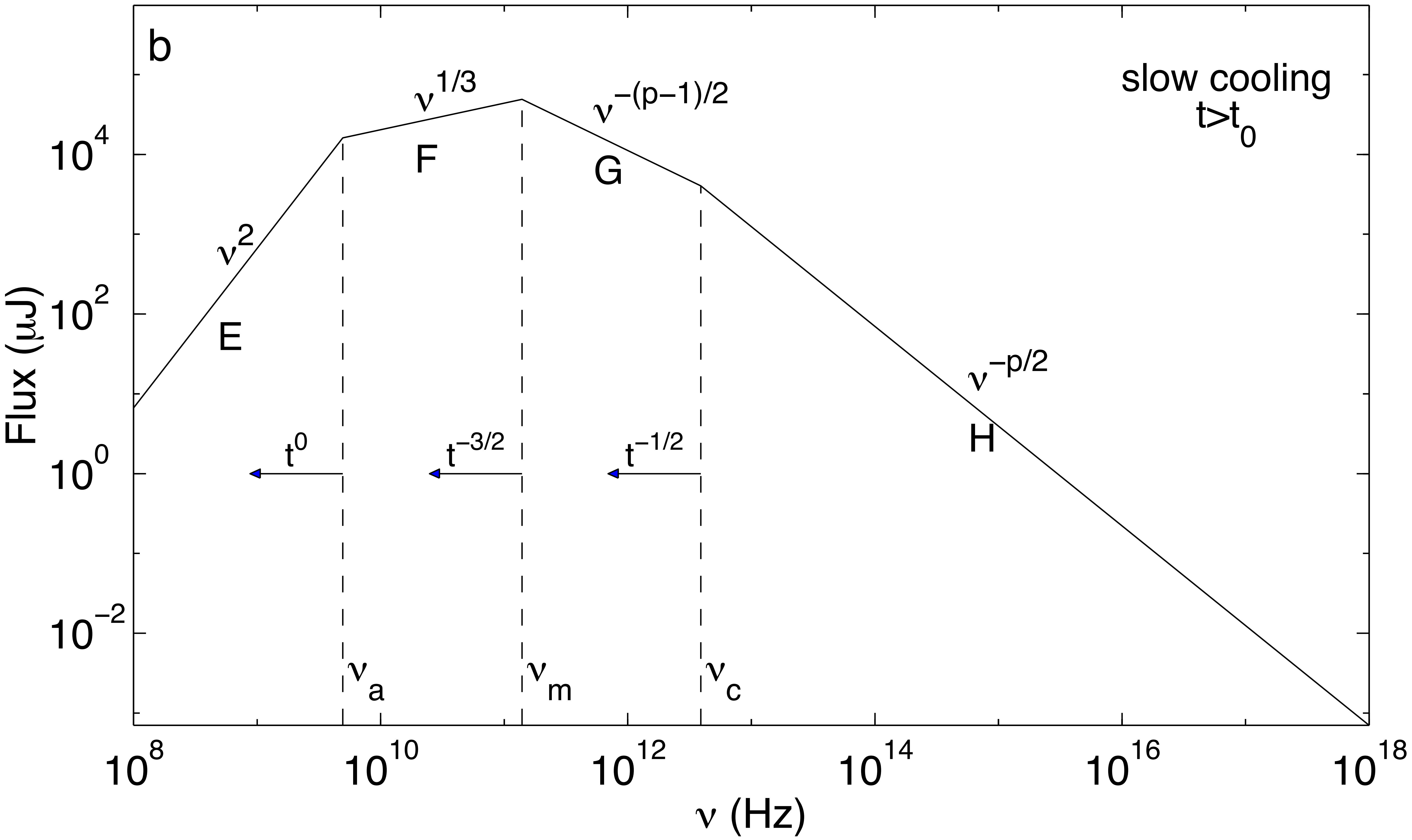



Burrrows: this afternoon

# Afterglows

**Paradigmatic Model Emerges**

Relativistic external shock model for Afterglows




Sari, Piran, Narayan 98

# Afterglows

**Paradigmatic Model Emerges**

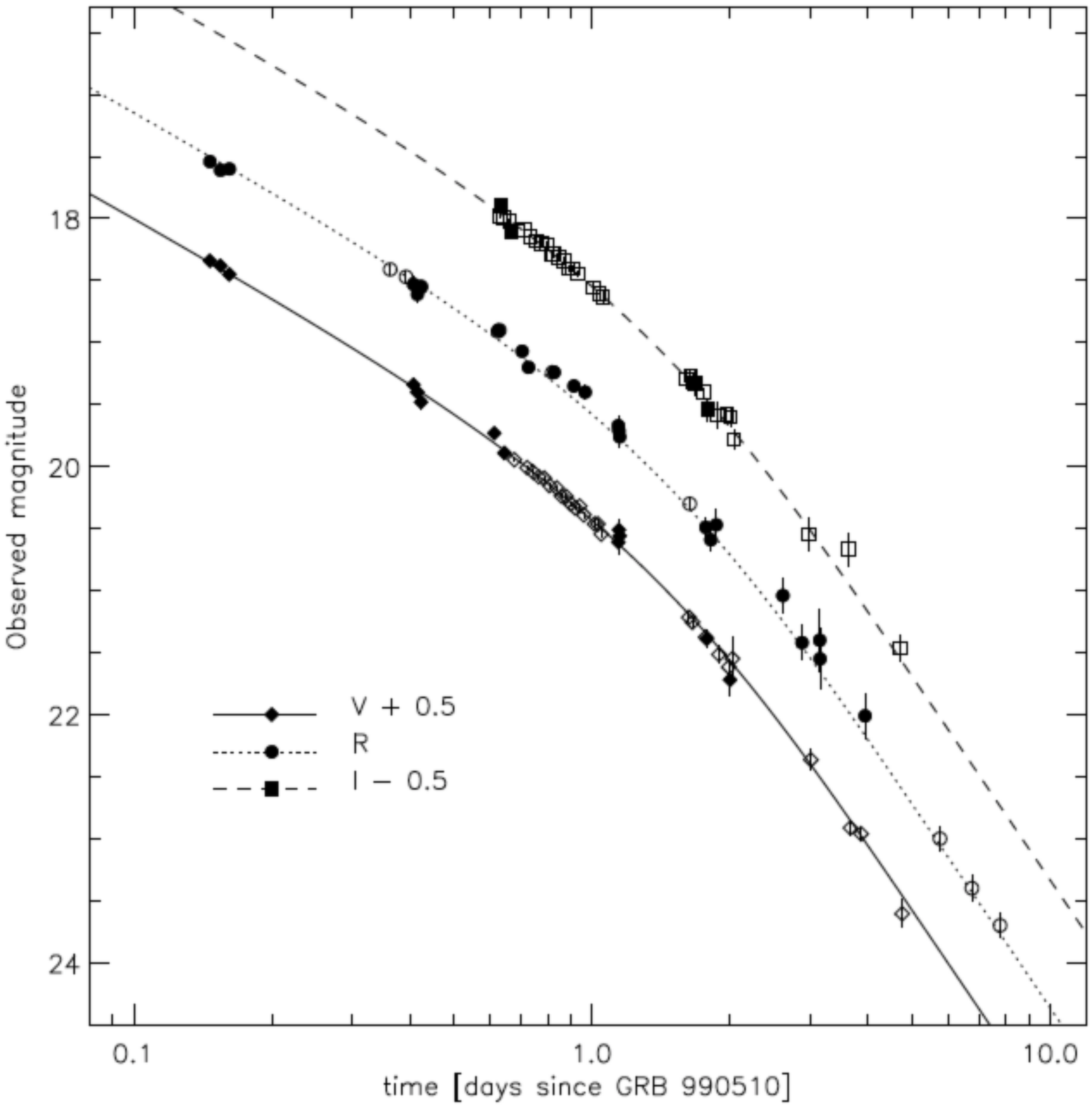
<u>Collimation</u>

Theory: Rhoads 97

Early Events:

- GRB 971214 Kulkarni+98
- GRB 990510
  Harrison+99, Stanek+99

Summary: Frail+01

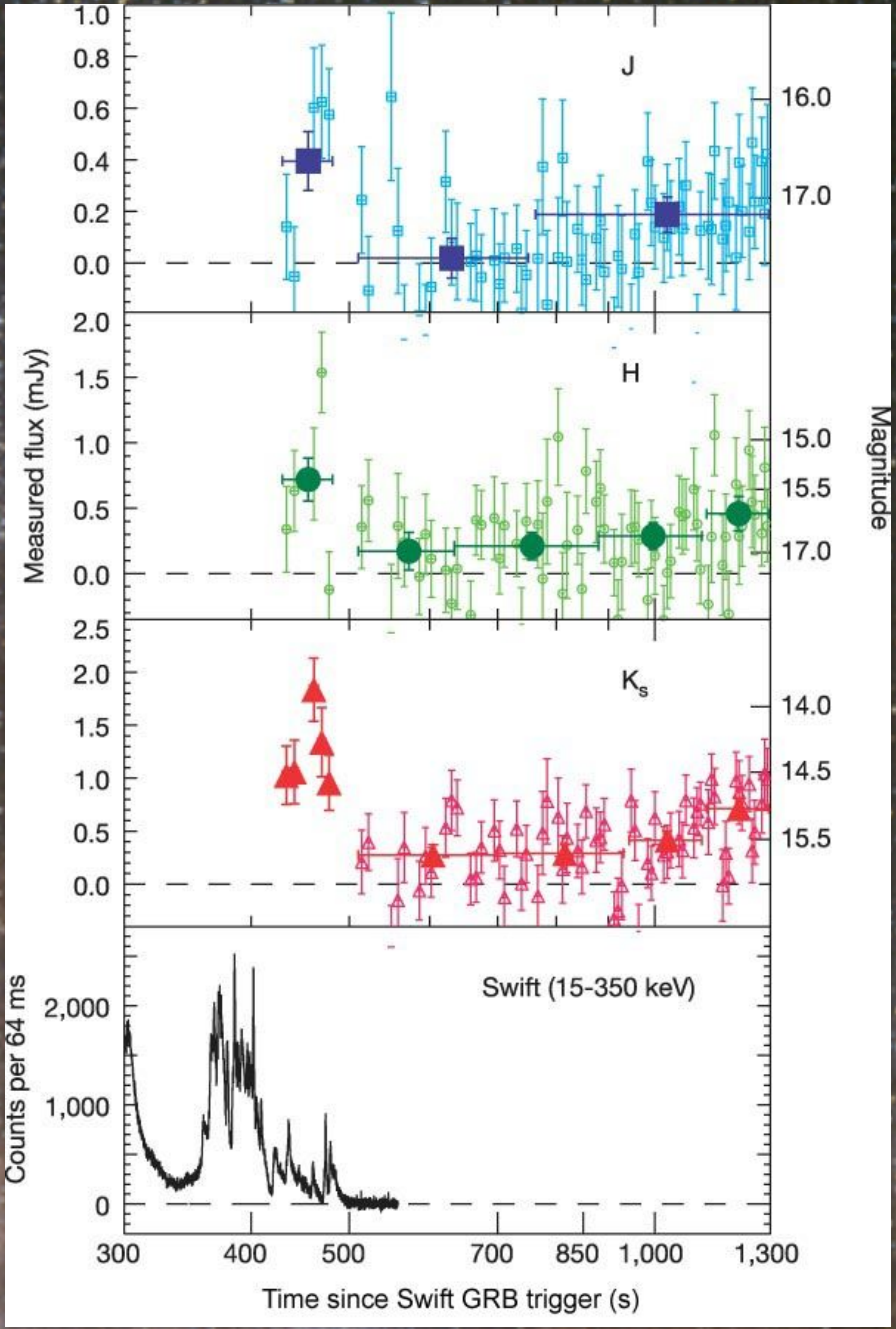


# An infrared flash contemporaneous with the γ-rays of GRB 041219a

C. H. Blake[1], J. S. Bloom[1,2], D. L. Starr[13], E. E. Falco[3], M. Skrutskie[9], E. E. Fenimore[7], G. Duchêne[12], A. Szentgyorgyi[3], S. Hornstein[10], J. X. Prochaska[4], C. McCabe[11], A. Ghez[10], Q. Konopacky[10], K. Stapelfeldt[11], K. Hurley[5], R. Campbell[6], M. Kassis[6], F. Chaffee[6], N. Gehrels[8], S. Barthelmy[8], J. R. Cummings[8], D. Hullinger[8,14], H. A. Krimm[8,15], C. B. Markwardt[8,14], D. Palmer[7], A. Parsons[8], K. McLean[7] & J. Tueller[8]

[1]*Harvard College Observatory, Cambridge, Massachusetts 02138, USA*
[2]*Astronomy Department, University of California at Berkeley, Berkeley, California 94720, USA*

NATURE | VOL 435 | 12 MAY 2005 |




- 3rd Swift localized event
- 1st long-wavelength afterglow detected for Swift

- “Forward shock” flashes (eg., GRB990123 Akerlof+00 )

http://w.astro.berkeley.edu/~jbloom/Autotel/Workshop_Talks/Bloom_grb.pdf

Re: IR instrumentation project

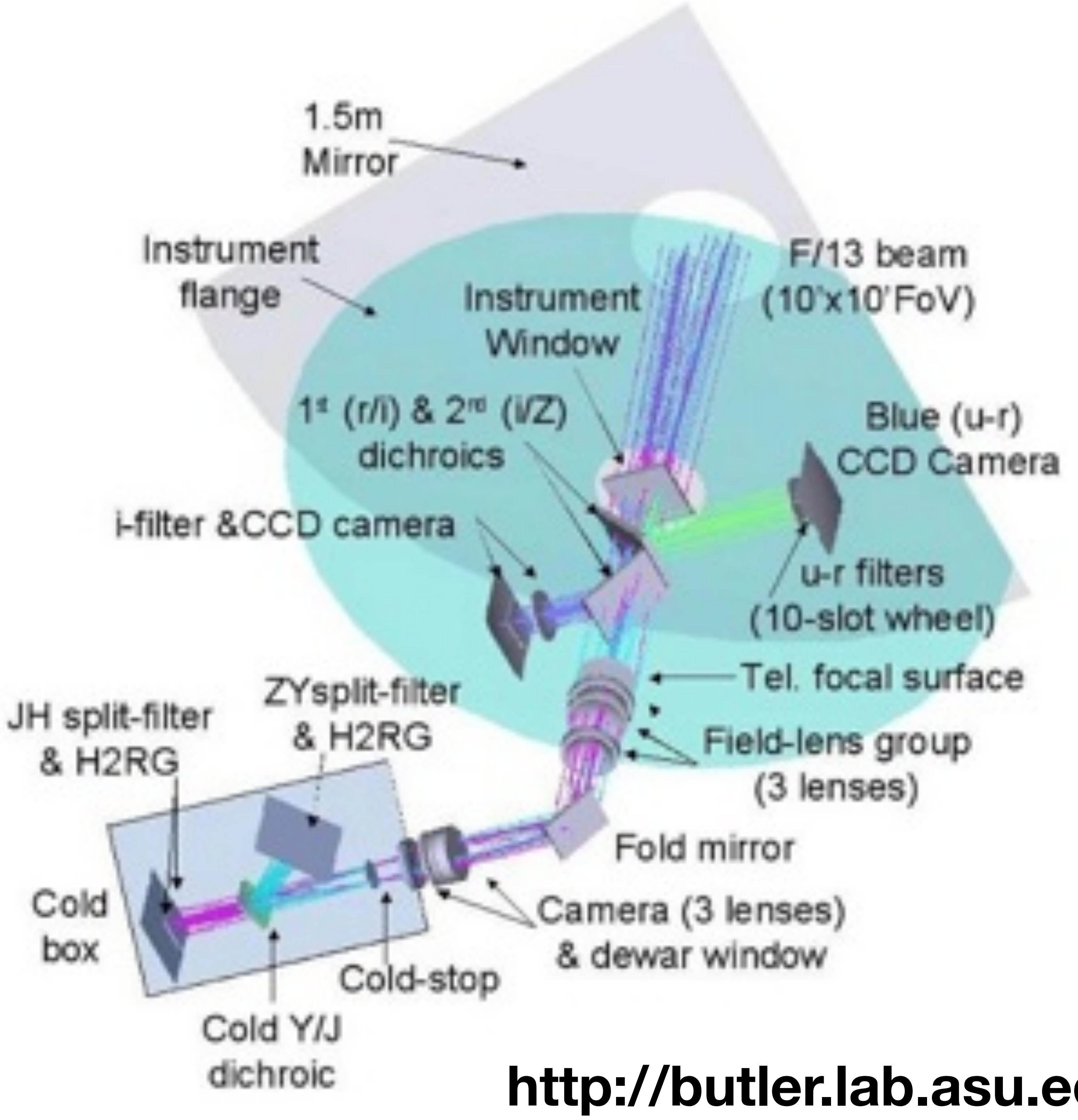
**Neil Gehrels** to Joshua, Nat 10/12/08

Hi Josh,

This looks excellent and exactly what is need for GRB progress. You can say that you have identified $50k to begin support without being specific. I may use some non-Swift hardware development funds for that support. I don't want to advertise such support too broadly because, then, everyone will be knocking at the door. On the other hand, it is not a secret and we should give straight answers when anyone asks directly.

THE REIONIZATION AND TRANSIENTS INFRARED/OPTICAL PROJECT

# RATIR



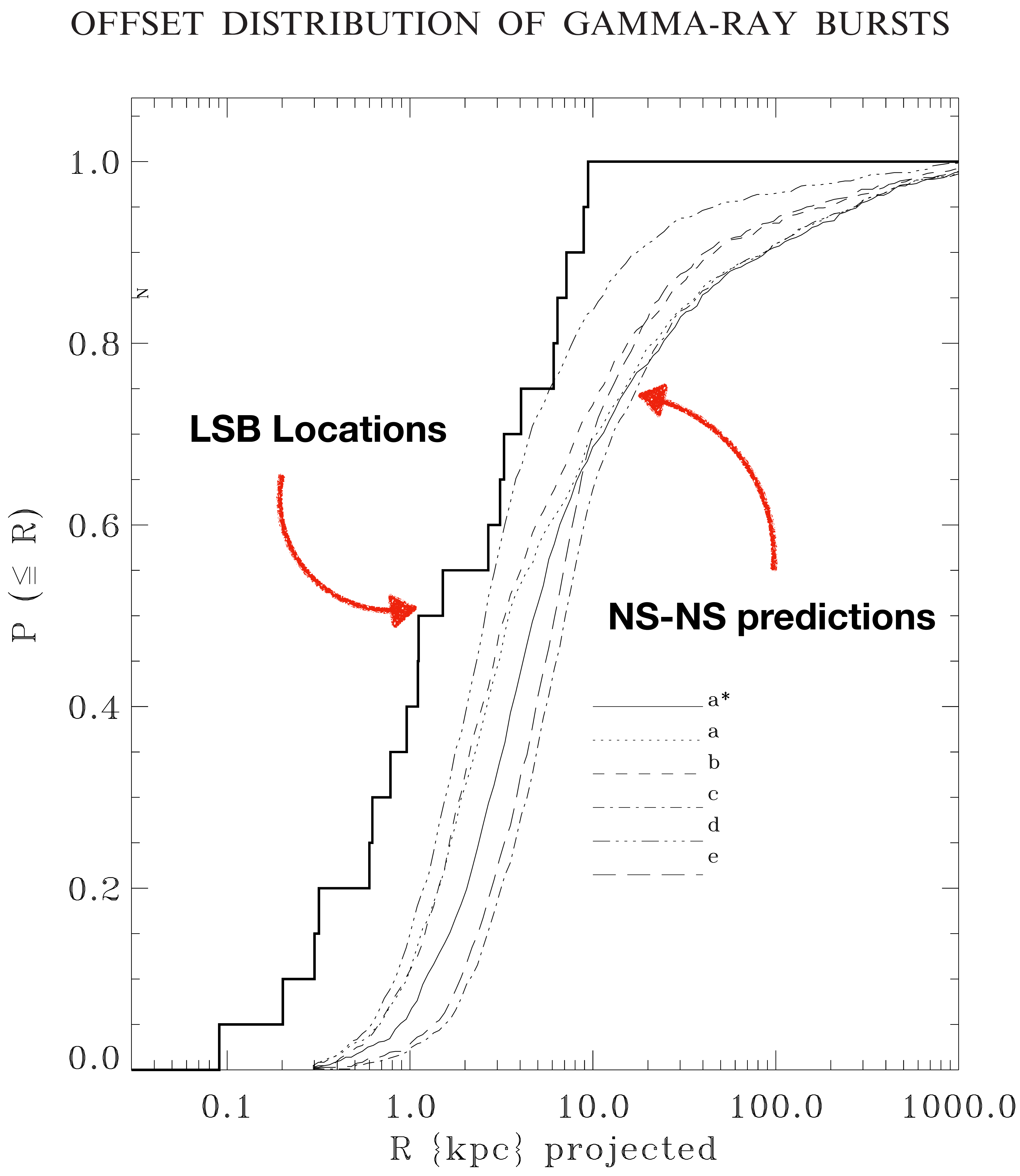

Collaboration: Butler, N., Watson, A. M., Kutyrev, A., Lee, W. H., Richer, M. G., Fox, O., Prochaska, J. X., Bloom, J., Cucchiara, A., Troja, E., Littlejohns, O., Ramirez-Ruiz, E., de Diego, J. A., Georgiev, L., Gonzalez, J., Roman-Zuniga, C., Gehrels, N., Moseley, H., Capone, J., Golkhou, V. Z., Klein, C., Toy, V.

http://butler.lab.asu.edu/RATIR/

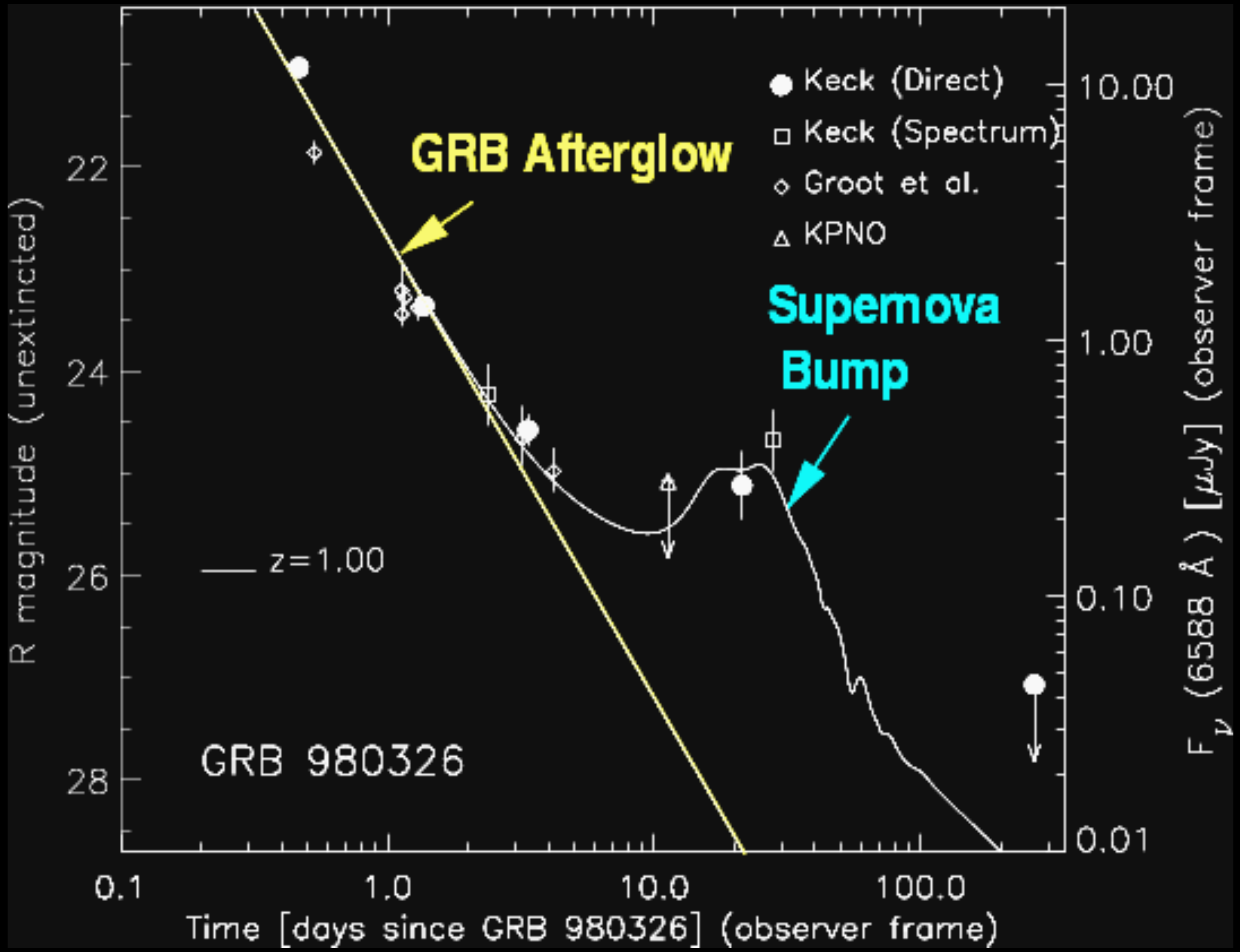
# Progenitors

- Long-soft GRBs (LSB) from massive stars ("collapsars")
  Model: MacFayden & Woosley 99

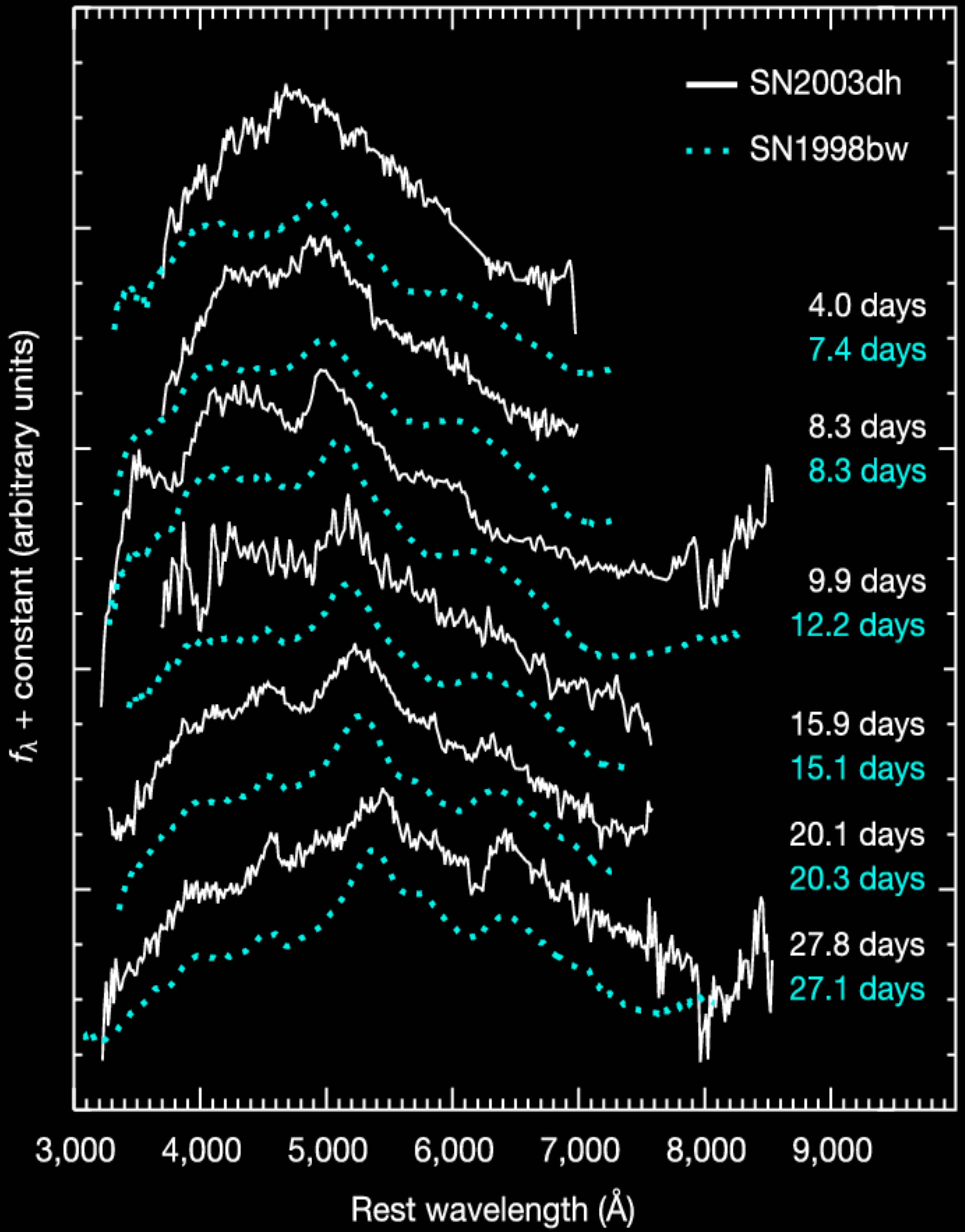
- LSB locations correlated with the light of star forming galaxies
  Bloom, Kulkarni, Djorgovski 02, Fruchter+06



# Progenitors




- Early Photometric evidence for a supernova connection
  GRB980326 Bloom+98
  GRB970228 Reichart+98

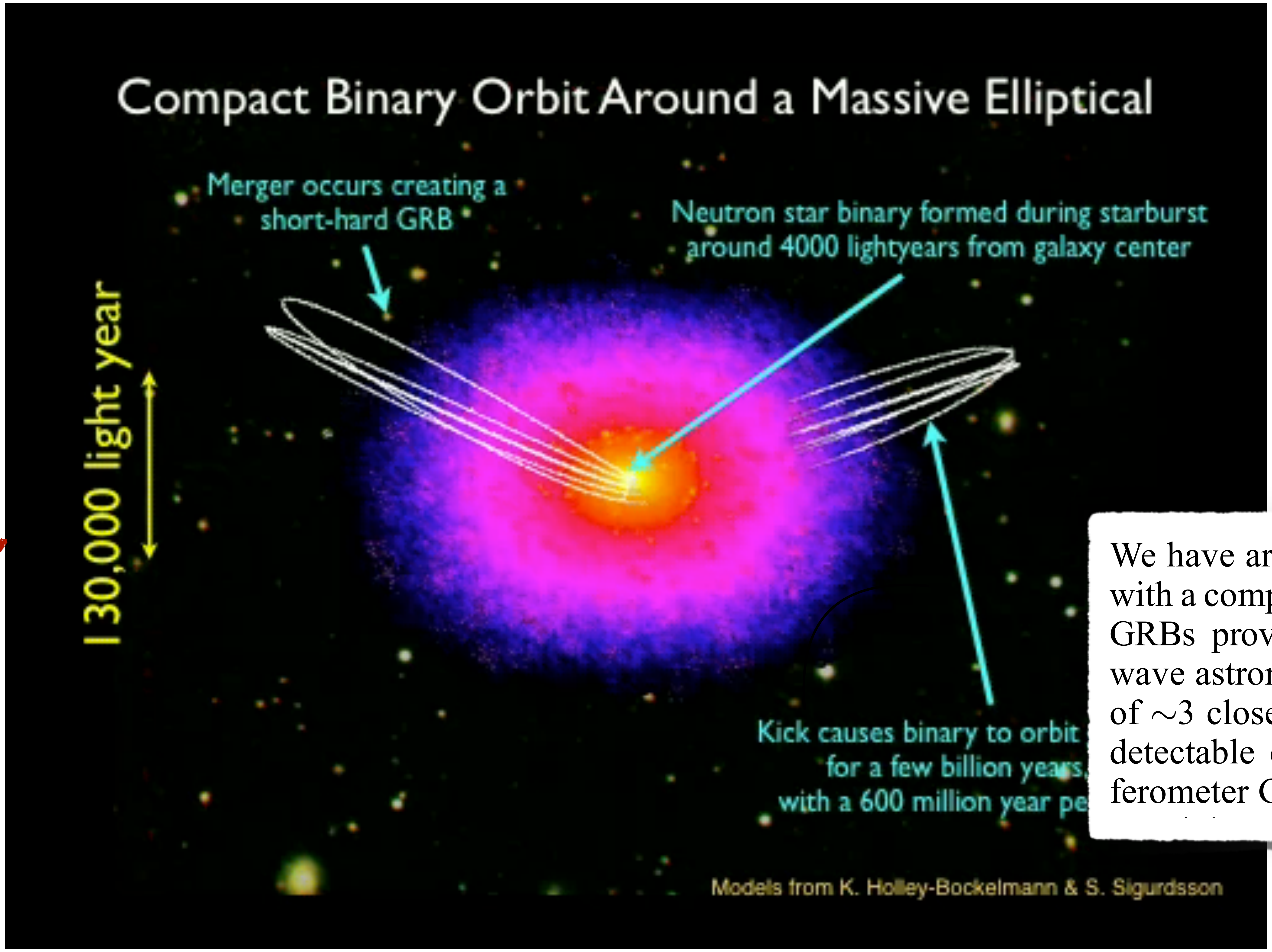



- Spectroscopic Confirmation: GRB030329
  Stanek+03

cf., Woosley & Bloom 06; Hjorth & Bloom 12 for review

# GRB 050509b First Well-Localized Short-Hard GRB by Swift (BAT/XRT)

*Video from AAS press release (May 31, 2005)*




We have argued that the observations find natural explanation with a compact merger system progenitor. If so, then short-hard GRBs provide a bridge from electromagnetic to gravitational wave astronomy: indeed, had GRB 050509b occurred a factor of ∼3 closer in luminosity distance, it might have produced a detectable chirp signal with the next-generation Laser Interferometer Gravitational-Wave Observatory (LIGO II).[26]

CLOSING IN ON A SHORT-HARD BURST PROGENITOR: CONSTRAINTS FROM EARLY-TIME OPTICAL IMAGING AND SPECTROSCOPY OF A POSSIBLE HOST GALAXY OF GRB 050509b


J. S. Bloom,[1] J. X. Prochaska,[2] D. Pooley,[1,3] C. H. Blake,[4] R. J. Foley,[1] S. Jha,[1] E. Ramirez-Ruiz,[2,3,5] J. Granot,[5,6] A. V. Filippenko,[1] S. Sigurdsson,[7] A. J. Barth,[8] H.-W. Chen,[9] M. C. Cooper,[1] E. E. Falco,[4] R. R. Gal,[10] B. F. Gerke,[11] M. D. Gladders,[12] J. E. Greene,[4] J. Hennanwi,[1,13] L. C. Ho,[12] K. Hurley,[14] B. P. Koester,[15] W. Li,[1] L. Lubin,[10] J. Newman,[13,16] D. A. Perley,[1] G. K. Squires,[17] and W. M. Wood-Vasey[4]



*Received 2005 May 24; accepted 2005 September 3*

arXiv [v1] Tue, 24 May 2005 18:27:28 GMT

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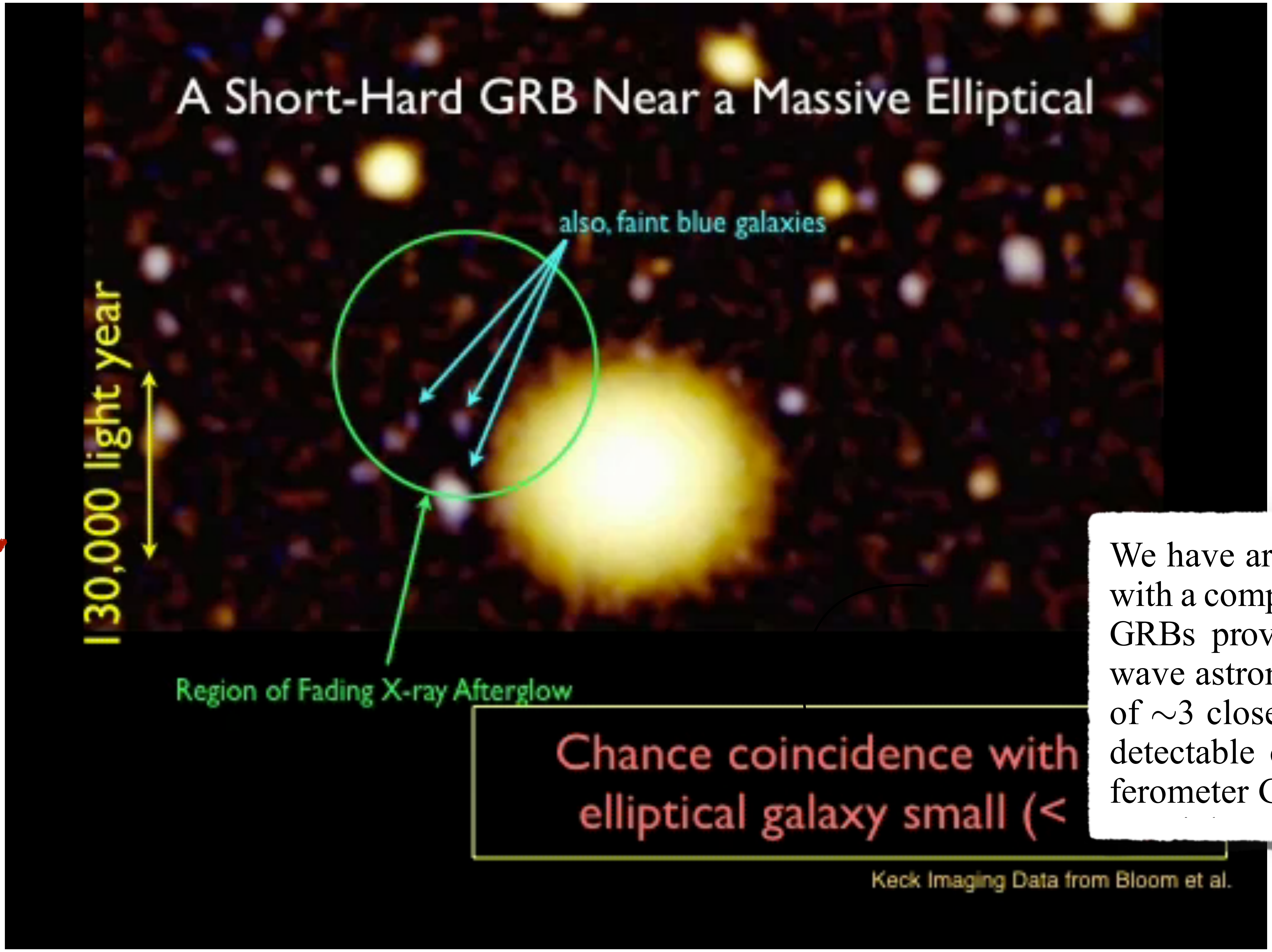


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# First Well-Localized Short-Hard GRB by Swift (BAT/XRT)

*Video from AAS press release (May 31, 2005)*

**Origin of the Species**
*Leading Theories for GRBs*

Short-Hard

| | | Age | Location | Timescale |
|---|---|---|---|---|
| Collapsar | massive star explodes to make GRB + supernova e.g., GRB 030329 | from young stars (< few million years old) ✗ | near star formation ✗ | ~10 seconds ✗ |
| Magnetar | star quake from highly-magnetized neutron star e.g., SGR 1806-20/ GRB 041227 | from young stars (< tens of millions years old) ✗ | near star formation ✗ | < 1 second ✓ |
| Mergers | old compact objects (black holes and neutron stars) coalesce after binary orbit decays | from old stars (> tens of millions years; ~Gyr ) ✓ | not closely associated with star formation ✓ | < 1 second ✓ |

We have argued that the observations find natural explanation with a compact merger system progenitor. If so, then short-hard GRBs provide a bridge from electromagnetic to gravitational wave astronomy: indeed, had GRB 050509b occurred a factor of ~3 closer in luminosity distance, it might have produced a detectable chirp signal with the next-generation Laser Interferometer Gravitational-Wave Observatory (LIGO II).[26]

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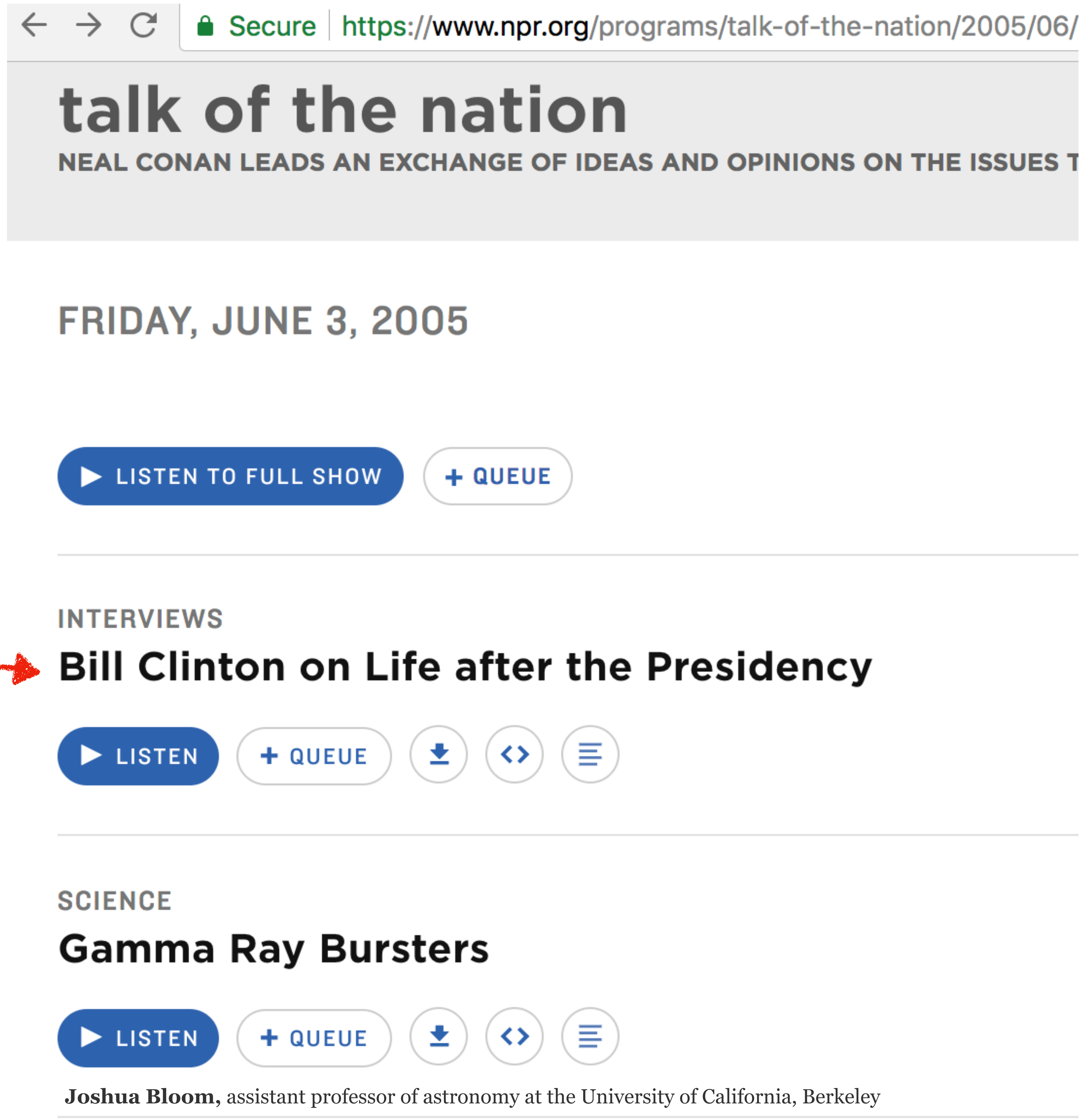
A tough act to follow


Secure https://www.npr.org/programs/talk-of-the-nation/2005/06/

talk of the nation

NEAL CONAN LEADS AN EXCHANGE OF IDEAS AND OPINIONS ON THE ISSUES T

FRIDAY, JUNE 3, 2005

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INTERVIEWS

Bill Clinton on Life after the Presidency

LISTEN + QUEUE

SCIENCE

Gamma Ray Bursters

LISTEN + QUEUE

**Joshua Bloom,** assistant professor of astronomy at the University of California, Berkeley

Vol 437|6 October 2005|**doi:10.1038/nature04142** nature

LETTERS

# A short γ-ray burst apparently associated with an elliptical galaxy at redshift $z = 0.225$

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**Gamma-ray bursts (GRBs) come in two classes[1]: long (>2 s), soft-spectrum bursts and short, hard events. Most progress has been made on understanding the long GRBs, which are typically observed at high redshift ($z \approx 1$) and found in subluminous star-forming host galaxies. They are likely to be produced in core-collapse explosions of massive stars[2]. In contrast, no short GRB had been accurately (<10″) and rapidly (minutes) located. Here we report the detection of the X-ray afterglow from—and the localization of—the short burst GRB 050509B. Its position on the sky is near a luminous, non-star-forming elliptical galaxy at a redshift of 0.225, which is the location one would expect[3,4] if the origin of this GRB is through the merger of neutron-star or black-hole binaries. The X-ray afterglow was weak and faded below the detection limit within a few hours; no optical afterglow was detected to stringent limits, explaining the past difficulty in localizing short GRBs.**

The new observations are from the Swift[5] satellite, which features

GRB survey made with the Burst and Transient Source Experiment (BATSE). The 15–150 keV fluence is $(9.5 \pm 2.5) \times 10^{-9}$ erg cm$^{-2}$, which is the lowest imaged by BAT so far and is just below the short GRB fluence range detected by BATSE (adjusted for the different energy ranges of the two instruments).

Swift slewed promptly and XRT started acquiring data 62 s after the burst ($T$+62 s, where $T$ is the BAT trigger time). Ground-processed data revealed an uncatalogued X-ray source near the centre of the BAT error circle containing 11 photons (5.7$\sigma$ significance due to near-zero background in image) in the first 1,640 s of integration time. The XRT position is shown with respect to the Digitized Sky Survey (DSS) field in Fig. 1. A *Chandra* target-of-opportunity observation of the XRT error circle was performed on 11 May at 4:00 UT for 50 ks, with no sources detected in the XRT error circle. The light curve combining BAT, XRT and *Chandra* data are shown in Fig. 3. The UVOT observed the field starting at $T$+60 s. No new optical/ultraviolet sources were found in the XRT error circle to

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Secure https://www.npr.org/programs/talk-of-the-nation/2005/06/

# talk of the nation

NEAL CONAN LEADS AN EXCHANGE OF IDEAS AND OPINIONS ON THE ISSUES T

## FRIDAY, JUNE 3, 2005

LISTEN TO FULL SHOW + QUEUE

INTERVIEWS

### Bill Clinton on Life after the Presidency

LISTEN + QUEUE

SCIENCE

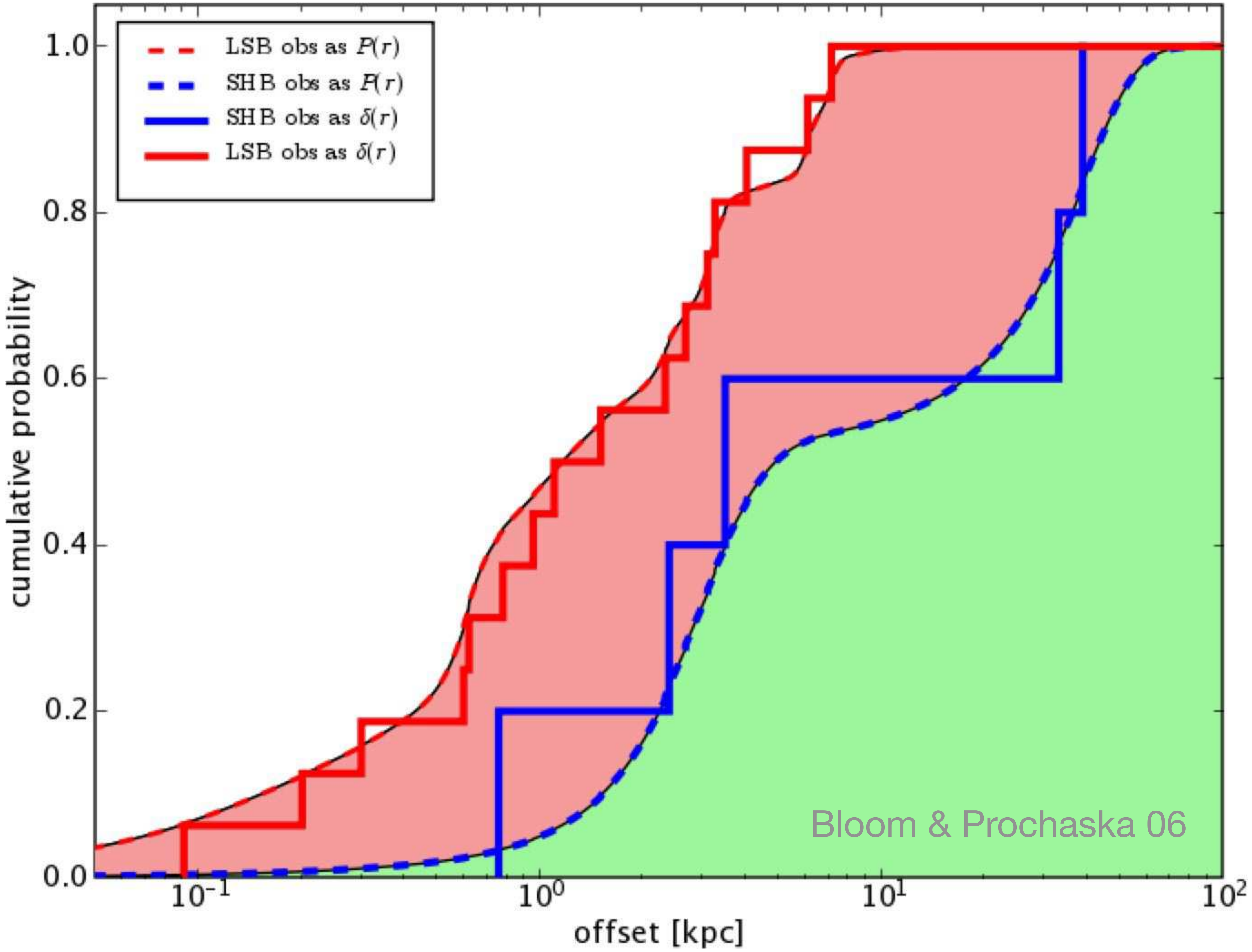
### Gamma Ray Bursters

LISTEN + QUEUE

**Joshua Bloom,** assistant professor of astronomy at the University of California, Berkeley

## Progenitors

Early indications that SHBs were from a different population




<u>Short-Hard GRBs (SHBs):</u>

- More diffusely positioned around galaxies
- More massive, earlier-type putative hosts
- Consistent with NS-NS/NS-BH merger simulations

Bloom & Prochaska 06, Troja+07; Fong+09; Gehrels, Ramirez-Ruiz & Fox 09; Berger 14

- Coincident GW would be the only smoking gun

P. O'Brien, P. Mészáros: this afternoon; W-f Fong tomorrow

# Progenitors

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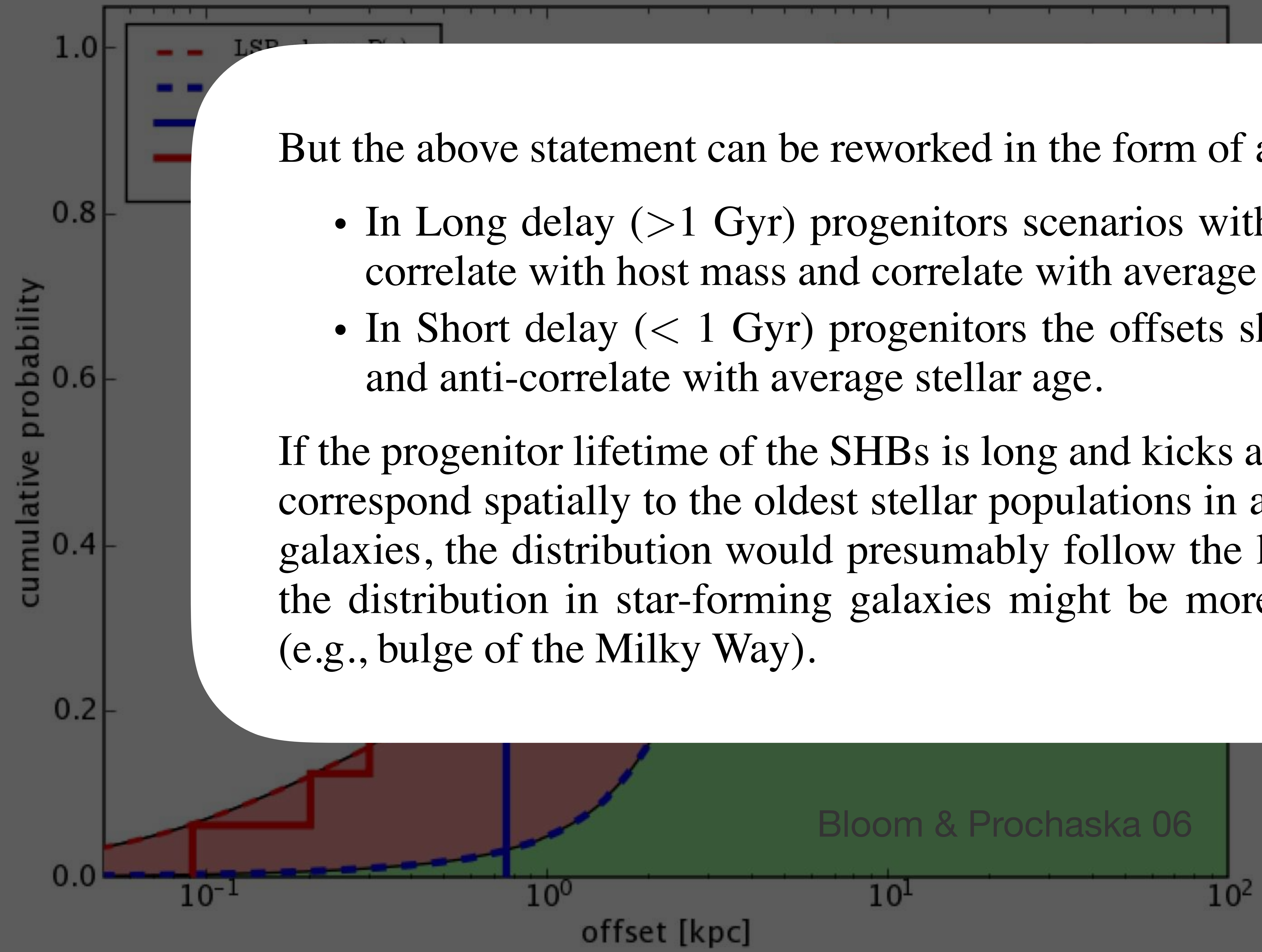


But the above statement can be reworked in the form of a generic set of predictions:

- In Long delay (>1 Gyr) progenitors scenarios with kicks the offsets should anti-correlate with host mass and correlate with average stellar age
- In Short delay (< 1 Gyr) progenitors the offsets should correlate with host mass and anti-correlate with average stellar age.

If the progenitor lifetime of the SHBs is long and kicks are small, then the bursts should correspond spatially to the oldest stellar populations in a given galaxies. For early-type galaxies, the distribution would presumably follow the light of the galaxy. In contrast, the distribution in star-forming galaxies might be more concentrated in the spheroid (e.g., bulge of the Milky Way).

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putative

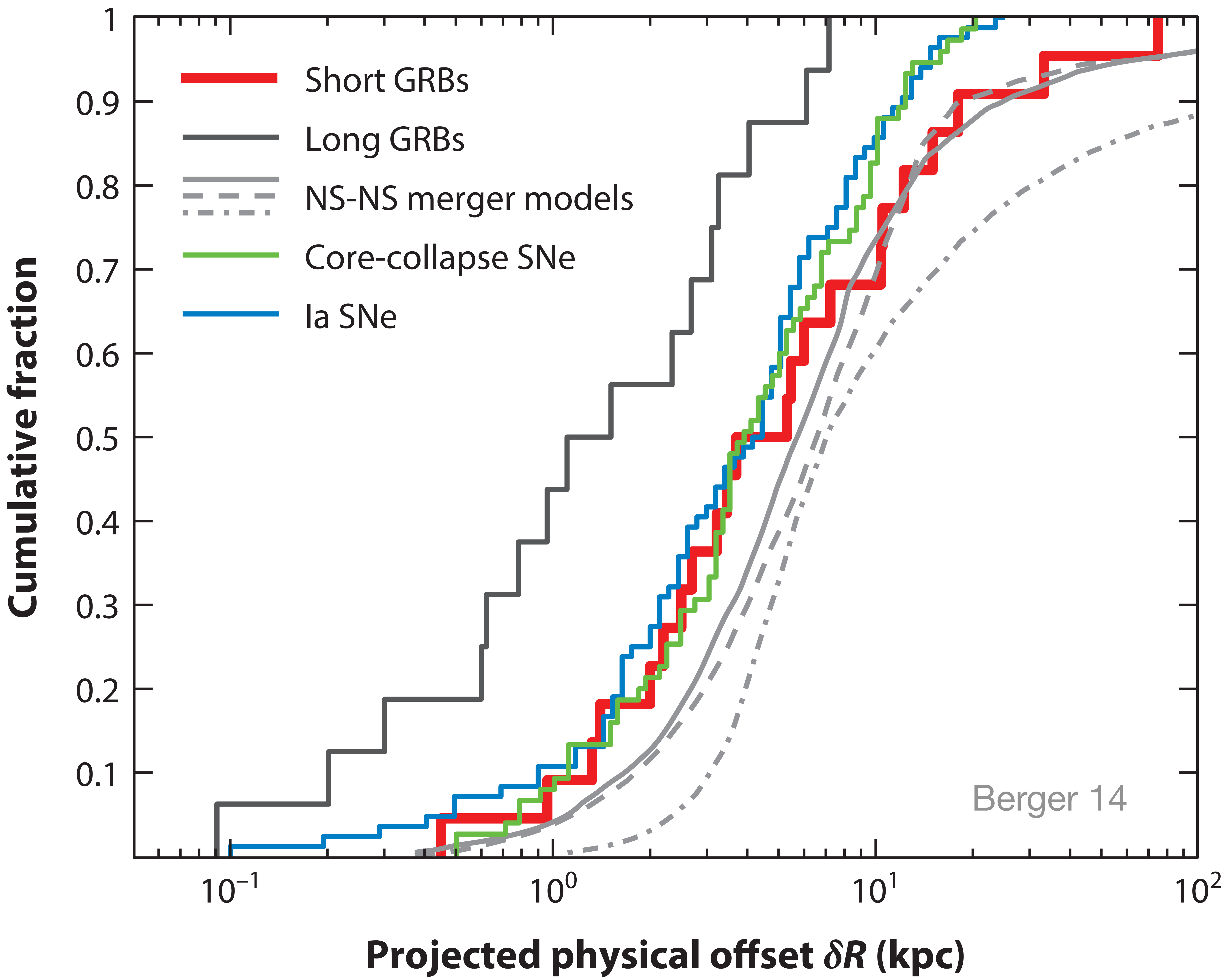
BH

ong+09;
erger 14

e only

P. O'Brien, P. Mészáros: this afternoon; W-f Fong tomorrow

# Progenitors

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**Oddballs,**
**or Nature is good at Making Bursts of Gamma rays**

X-ray Flashes (XRFs)
Lower-energy events

Relativistically Beamed Tidal Disruption Events - Sw 1644+57

Soft-gamma Ray Repeaters (SGRs) - March 5 Events
~15 known

Long GRBs without Supernovae

## GRBs as Probes

- ISM/IGM/Host via Absorption Spectroscopy

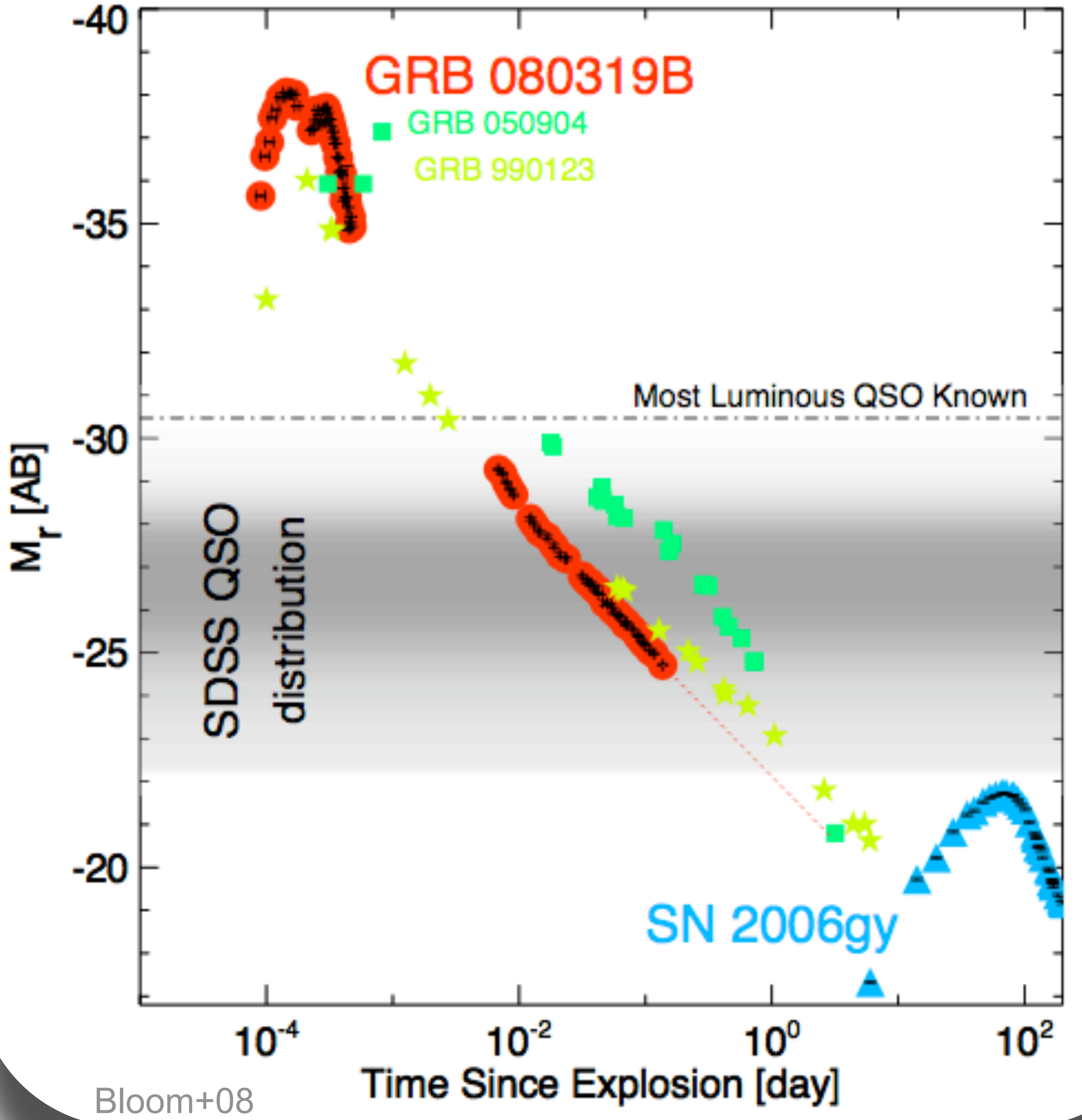
  Chen+05, Savaglio+07, Prochaska+07

- Reionization (Neutral Fraction vs Redshift)

  Miralda-Escudé 98, Bromm & Loeb 02, Kawai+05, Totani+06

- Signposts to Pop III stars in the early universe

  Bromm+00




Bloom+08

# GRBs as Probes

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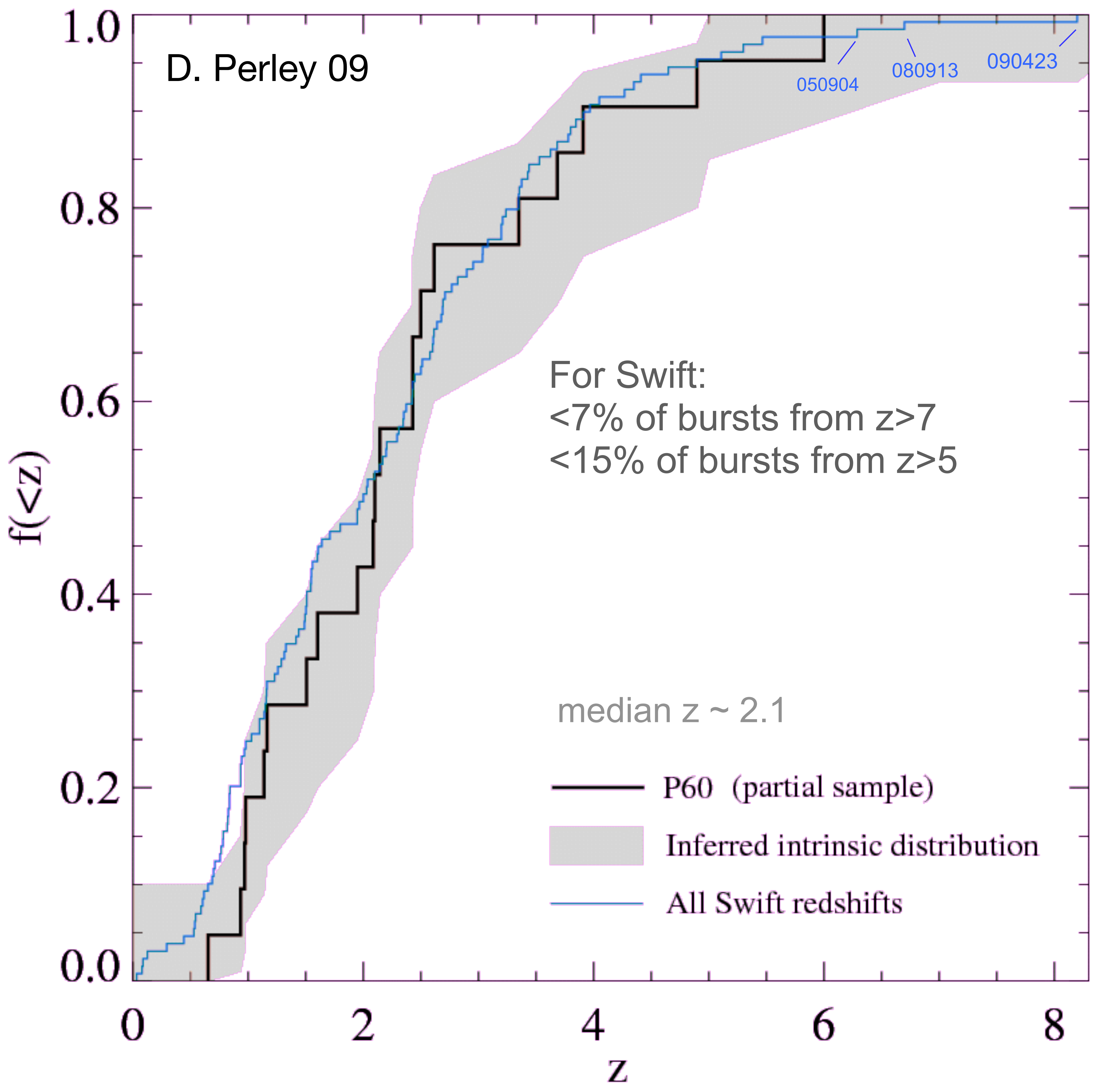


# GRBs as Probes


Screenshot From My Talk at "Swift 5th Birthday" Meeting (18 Nov 2009)

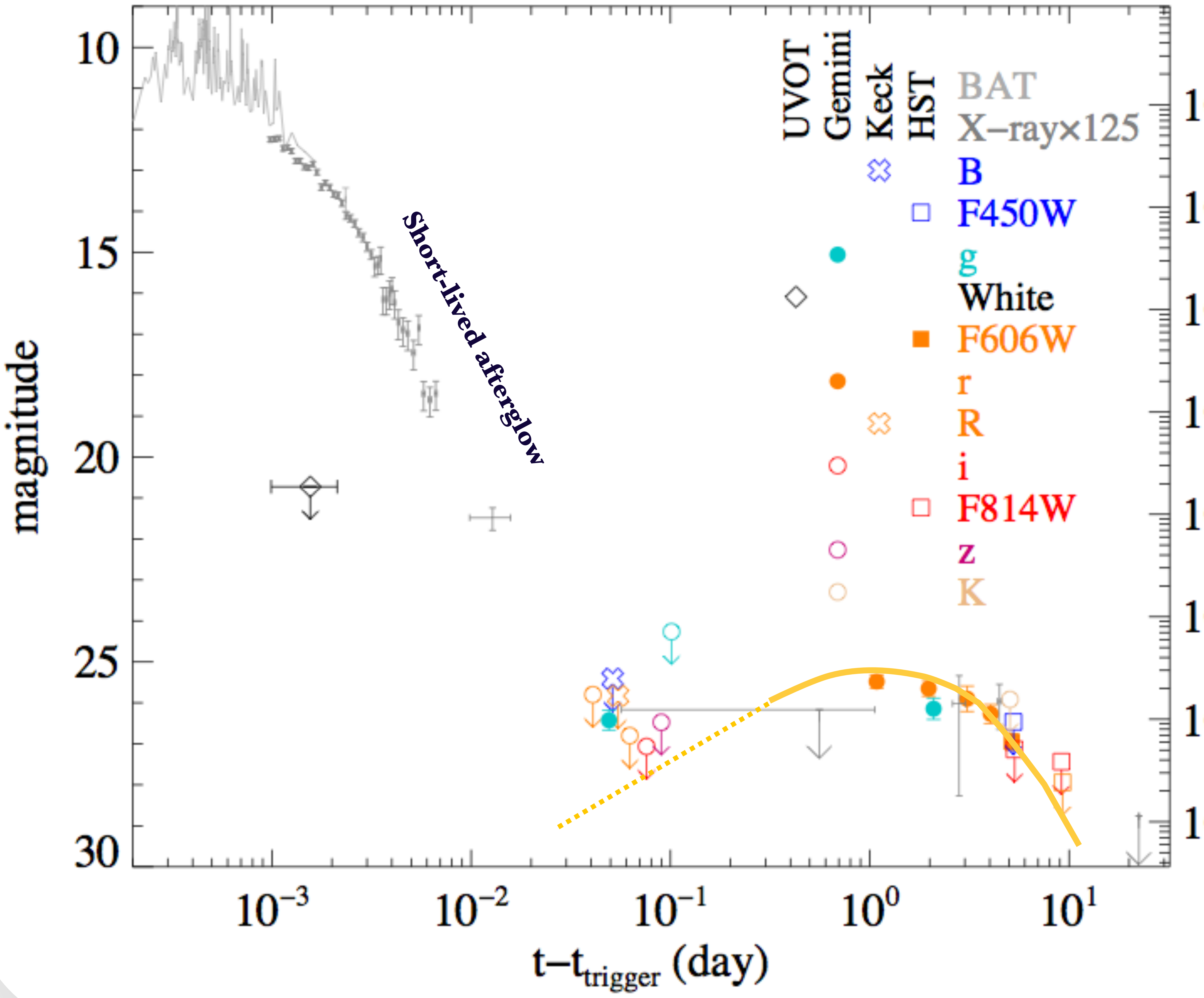
# Multimessenger

short GRB 080503

**Neil Gehrels** to Fynbo, Berger, Tanvir, Kawai, Fox, Bloom, … 5/3/08

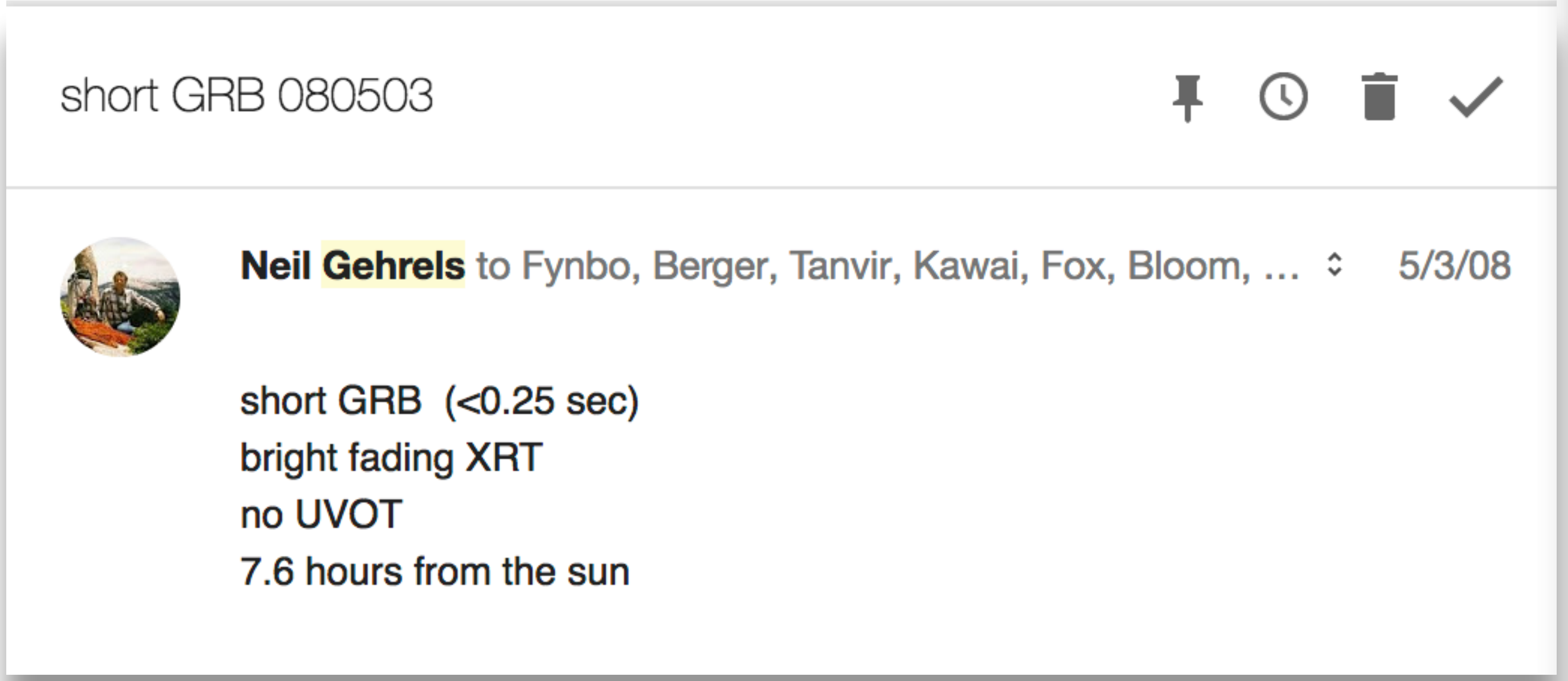
short GRB (<0.25 sec)
bright fading XRT
no UVOT
7.6 hours from the sun

## GRB 080503




Perley, Metzger+08; Also, GRB 130603B, Tanvir+03

## Multimessenger




## GRB 080503

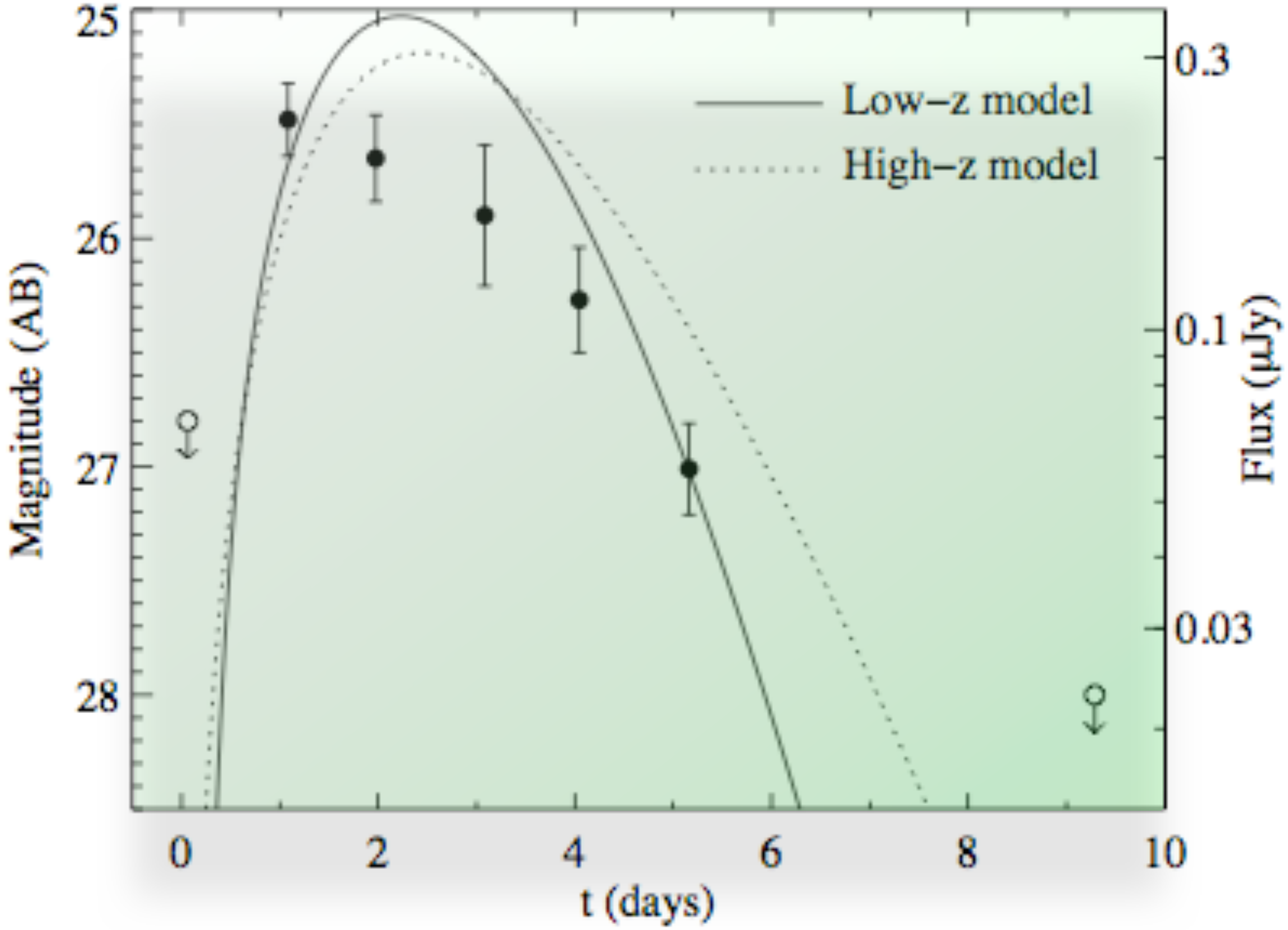
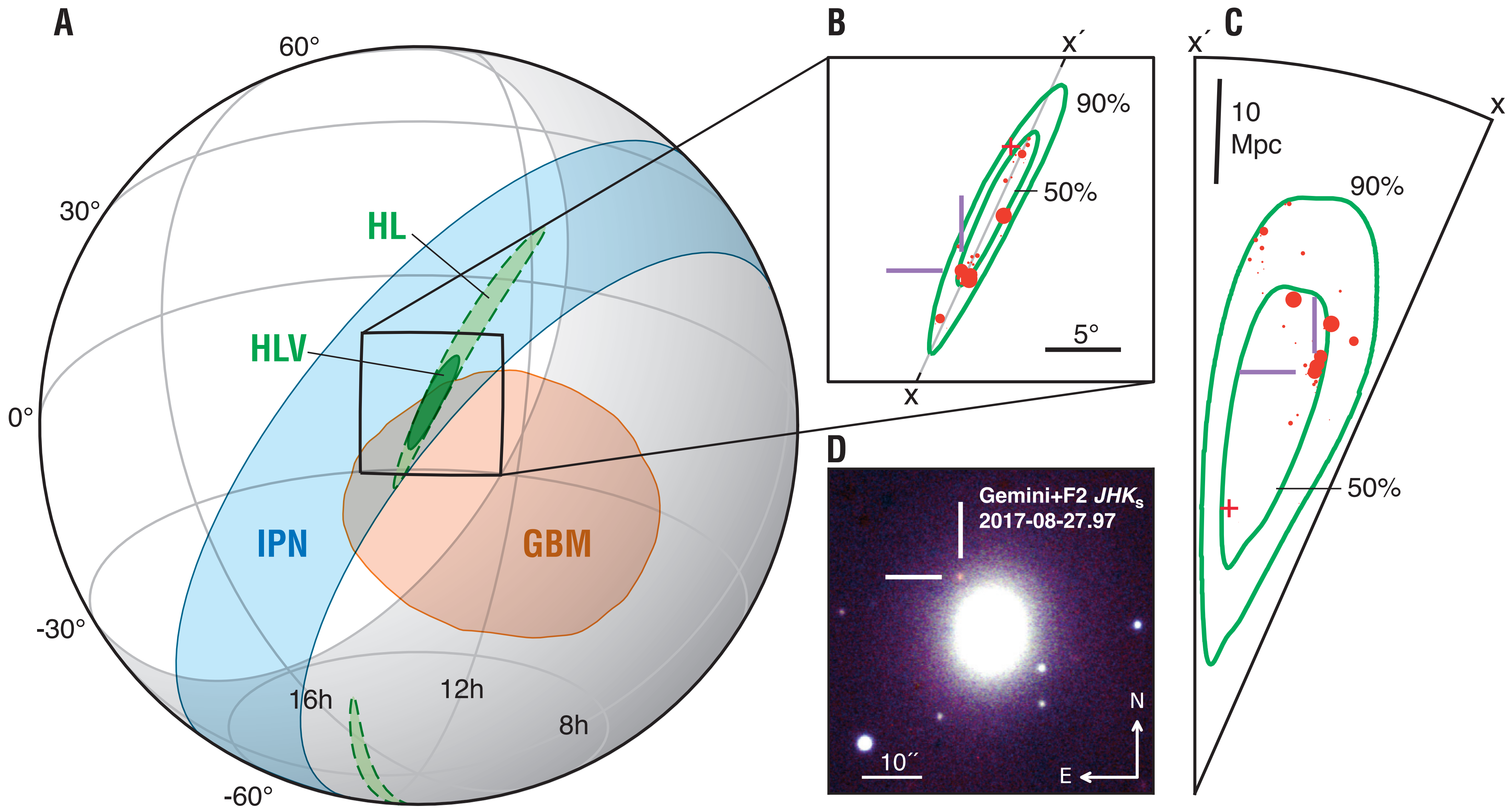



FIG. 11.— Two AB magnitude (Oke 1974) light-curve models for a Ni-powered "mini-SN" from GRB 080503, based on the model of Li & Paczyński (1998), Kulkarni (2005), and Metzger et al. (2008b). The solid line indicates a model at $z = 0.03$ with a $^{56}$Ni mass $\approx 2 \times 10^{-3}$ $M_\odot$, total ejecta mass $\approx 0.4$ $M_\odot$, and outflow velocity $\approx 0.1c$. The dotted line is for a pure Ni explosion at $z = 0.5$ with mass $\approx 0.3$ $M_\odot$ and velocity $\approx 0.2c$. Also shown are our $r$-band and F606W detections and upper limits from Gemini and *HST*.

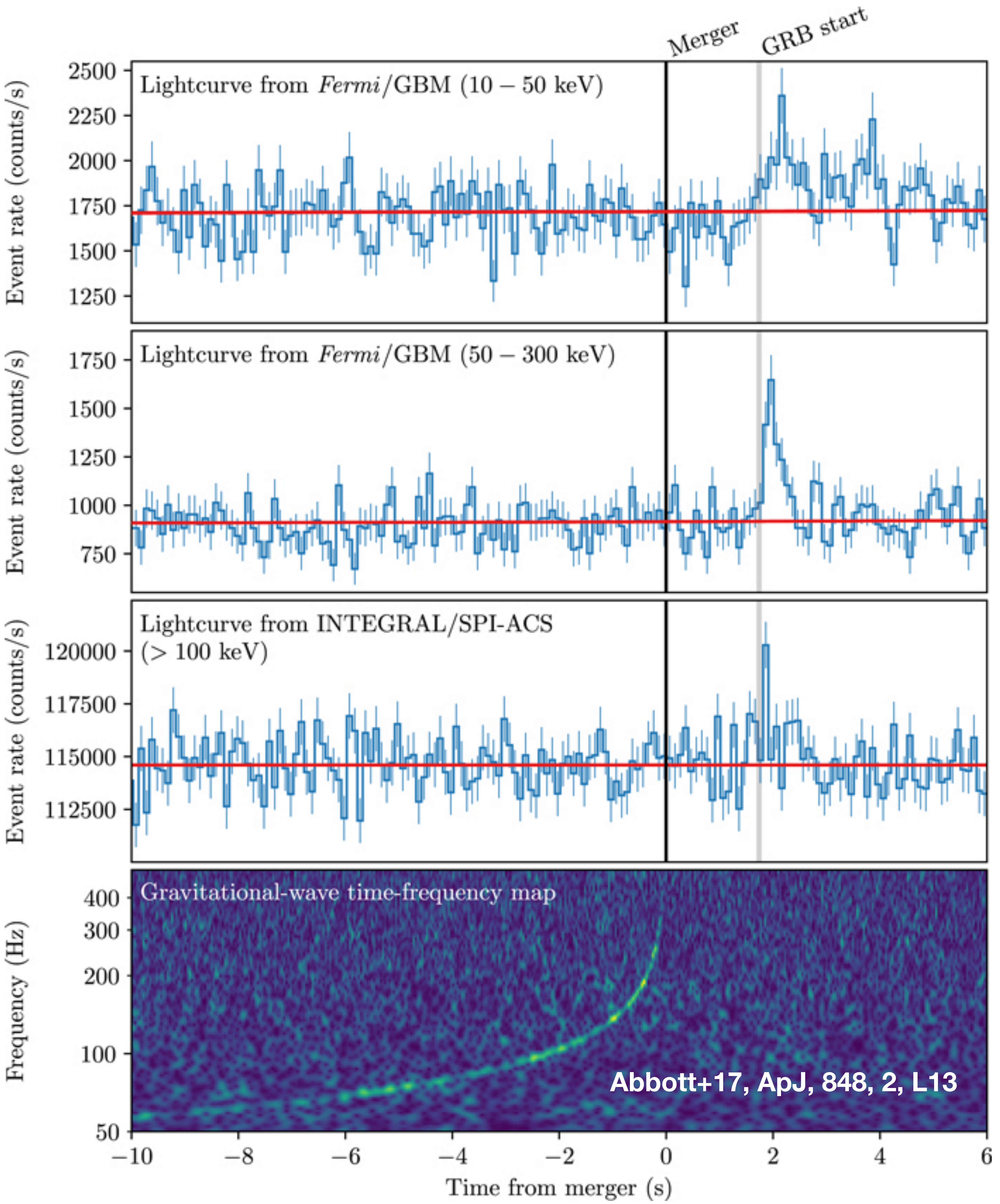
Perley, Metzger+08; Also, GRB 130603B, Tanvir+03

# Multimessenger

**GRB/GW 170817 - NS-NS merger produced a GRB & kilonova**

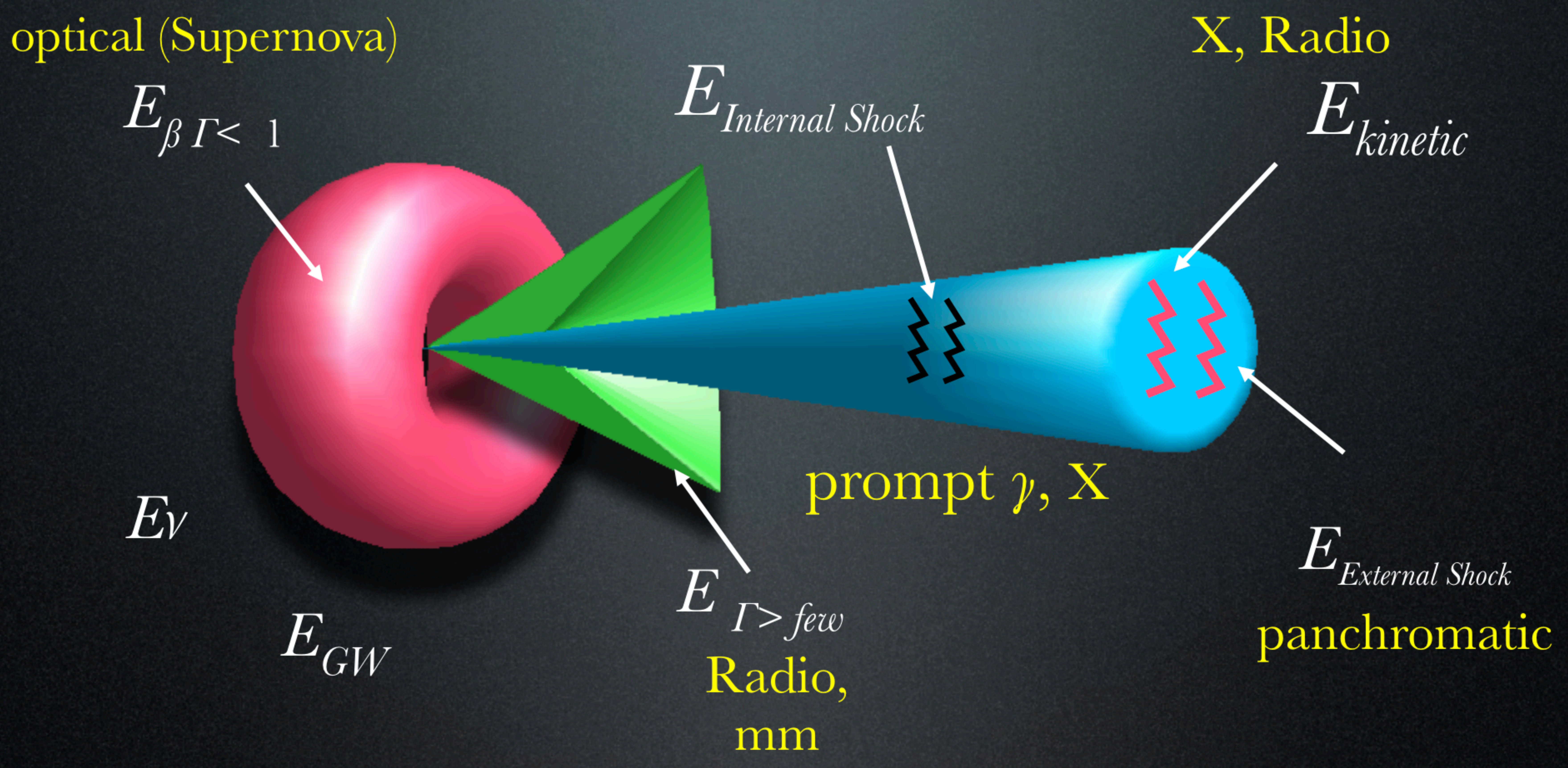



Kasliwal+17, Science




E. Troja, V. Kalogera: this afternoon; L. Singer, T. Piran: tomorrow

# Energetics // A Schematic




$$E_{\nu,\,\mathrm{GW}} > E_{SN}(\Gamma<2) \gtrsim E_{rel}(\Gamma > 2) \gtrsim E_{\gamma}$$

(?)

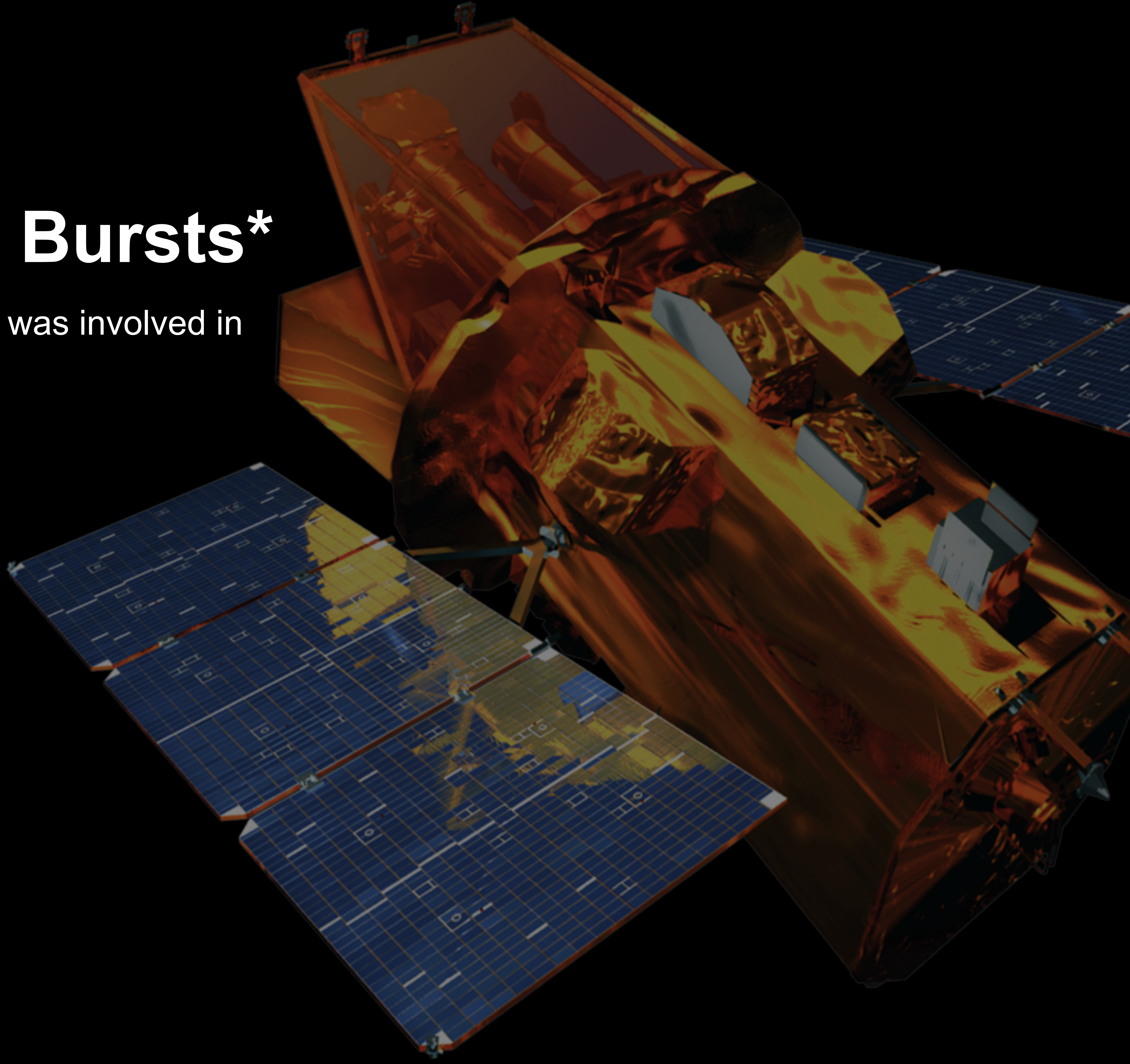
Woosley & Bloom (ARAA) 06

From a talk by me in Cefalu, 2008


IPN
Vela Series
CGRO (BATSE)
Swift
HETE-2
Fermi
BeppoSAX
INTEGRAL
High-Energy Era
Afterglow Era
Multimessenger Era
Events
GRB 670702
March 5 Event (SGR 0525-66)
GRB 980425/SN 1998bw
GRB 130603B
GRB 090423
GRB 030329/SN 2003dh
GRB 970508
GRB 080319b
GRB 130427A
Sw J1644+57
GRB 970228
GRB 050509b
GW/GRB 170817
1970
1980
1990
2000
2010
2020
Theory & Aggregate Insights
Colgate May 68
Klebesadal, Olson & Strong 73
Paczyński 86
Eichler+89
Great Debate
Frail+01
Burrows+05
Berger 14
Sari, Piran, Narayan 98
Mészáros & Rees 97
Gehrels, Ramirez-Ruiz, & Fox 09
Band+93/Kouvelitou+93
Lamb & Reichart 00
Paczyński & Rhoads 93
Meegan+92
Li & Paczyński 98
MacFadyen & Woosley 99
50 Years of GRBs Gehrels Memorial
Josh Bloom

# 50 Years of Gamma-Ray Bursts*

* With a biased overemphasis on Neil & stuff I was involved in



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