News from the Niels Bohr International Academy

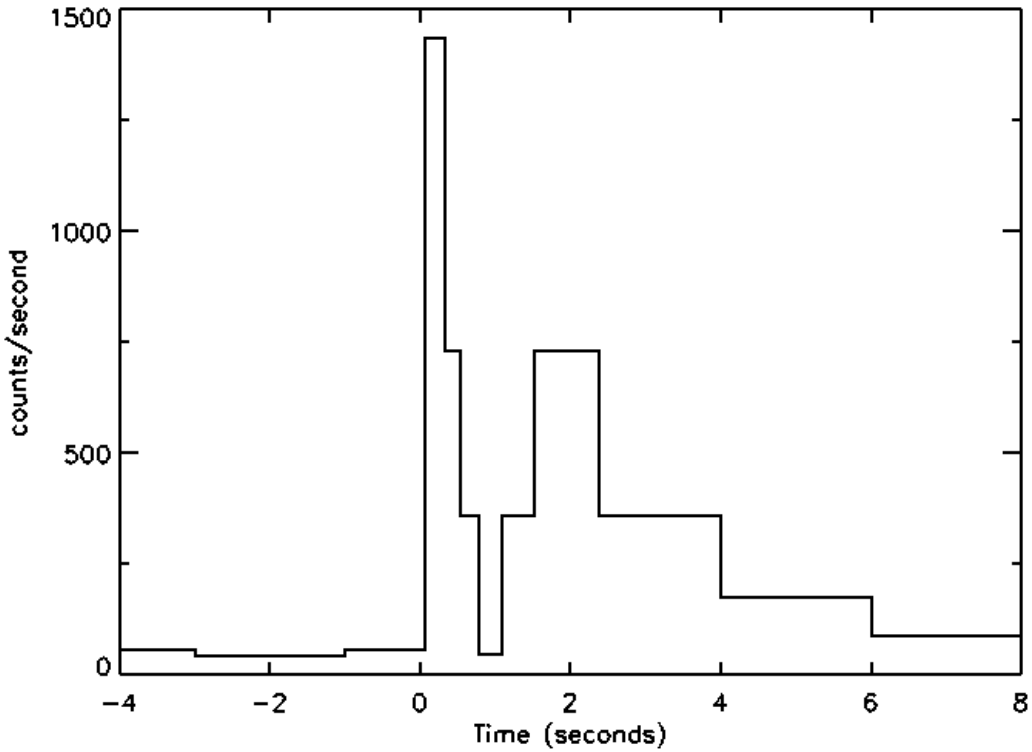
- What is a gamma-ray burst?
- The development of our understanding of the phenomenon illustrated by important events (including very recent results on gravitational waves).

Johan Fynbo, Niels Bohr Institute

pMC/ percent

GRB670702: The first known burst

gamma-ray burst = burst of γ-rays



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

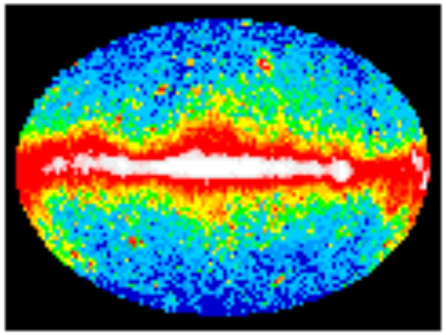
ABSTRACT

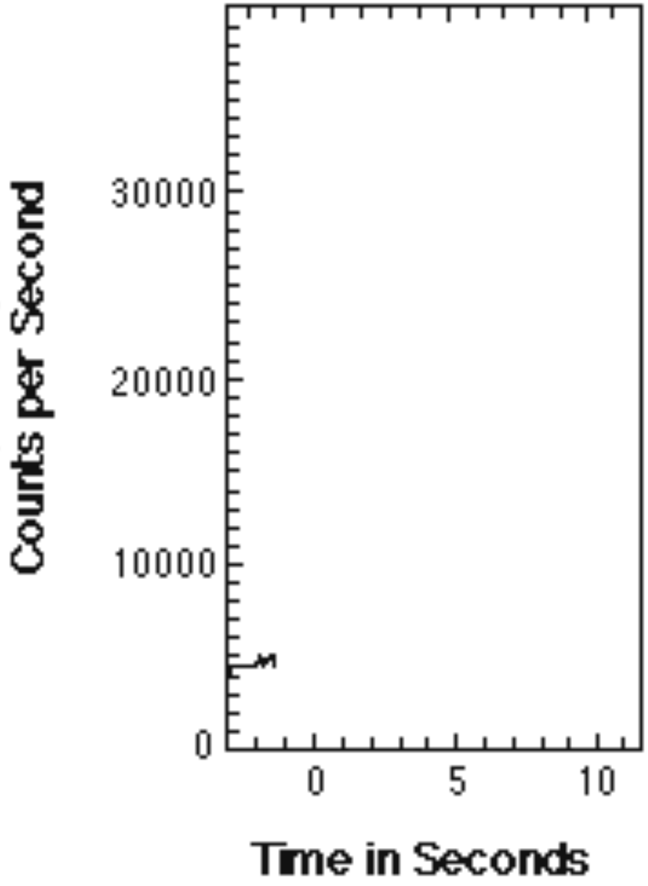
Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to $\sim$30 s, and time-integrated flux densities from $\sim 10^{-5}$ ergs cm^{-2} to $\sim 2 \times 10^{-4}$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

Conclusions

- Gamma-ray bursts are short intense bursts of γ-rays. They do not originate from the earth or the sun.





Counts per Second
30000
20000
10000
0
0
5
10
Time in Seconds

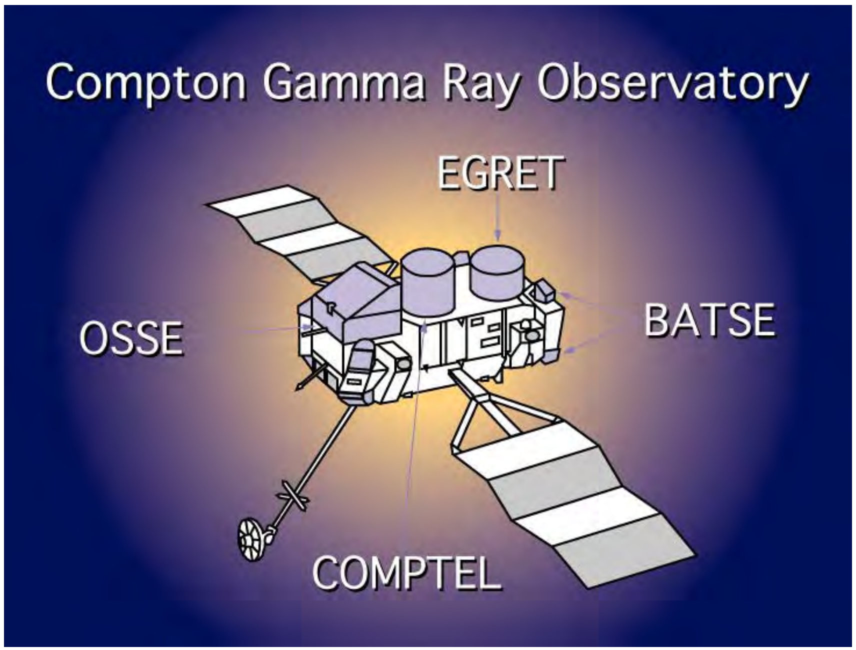
#	Author	Year Pub	Reference	Main Body	2nd Body	Place	Description
1.	Colgate	1968	CJPhys, 46, S476	ST		COS	SN shocks stellar surface in distant galaxy
2.	Colgate	1974	ApJ, 187, 333	ST		COS	Type II SN shock brem, inv Comp scat at stellar surface
3.	Stecker et al.	1973	Nature, 245, PS70	ST		DISK	Stellar superflare from nearby star
4.	Stecker et al.	1973	Nature, 245, PS70	WD		DISK	Superflare from nearby WD
5.	Harwit et al.	1973	ApJ, 186, L37	NS	COM	DISK	Relic comet perturbed to collide with old galactic NS
6.	Lamb et al.	1973	Nature, 246, PS52	WD	ST	DISK	Accretion onto WD from flare in companion
7.	Lamb et al.	1973	Nature, 246, PS52	NS	ST	DISK	Accretion onto NS from flare in companion
8.	Lamb et al.	1973	Nature, 246, PS52	BH	ST	DISK	Accretion onto BH from flare in companion
9.	Zwicky	1974	Ap & SS, 28, 111	NS		HALO	NS chunk contained by external pressure escapes, explodes
10.	Grindlay et al.	1974	ApJ, 187, L93	DG		SOL	Relativistic iron dust grain up-scatters solar radiation
11.	Brecher et al.	1974	ApJ, 187, L97	ST		DISK	Directed stellar flare on nearby star
12.	Schlovskii	1974	SovAstron, 18, 390	WD	COM	DISK	Comet from system's cloud strikes WD
13.	Schlovskii	1974	SovAstron, 18, 390	NS	COM	DISK	Comet from system's cloud strikes NS
14.	Bisnovatyi- et al.	1975	Ap & SS, 35, 23	ST		COS	Absorption of neutrino emission from SN in stellar envelope
15.	Bisnovatyi- et al.	1975	Ap & SS, 35, 23	ST	SN	COS	Thermal emission when small star heated by SN shock wave
16.	Bisnovatyi- et al.	1975	Ap & SS, 35, 23	NS		COS	Ejected matter from NS explodes
17.	Pacini et al.	1974	Nature, 251, 399	NS		DISK	NS crustal starquake glitch; should time coincide with GRB
18.	Narlikar et al.	1974	Nature, 251, 590	WH		COS	White hole emits spectrum that softens with time
19.	Tsygan	1975	A&A, 44, 21	NS		HALO	NS corequake excites vibrations, changing E & B fields
20.	Chanmugam	1974	ApJ, 193, L75	WD		DISK	Convection inside WD with high B field produces flare
21.	Prilutski et al.	1975	Ap & SS, 34, 395	AGN	ST	COS	Collapse of supermassive body in nucleus of active galaxy
22.	Narlikar et al.	1975	Ap & SS, 35, 321	WH		COS	WH excites synchrotron emission, inverse Compton scattering
23.	Piran et al.	1975	Nature, 256, 112	BH		DISK	Inv Comp scat deep in ergosphere of fast rotating, accreting BH
24.	Fabian et al.	1976	Ap & SS, 42, 77	NS		DISK	NS crustquake shocks NS surface
25.	Chanmugam	1976	Ap & SS, 42, 83	WD		DISK	Magnetic WD suffers MHD instabilities, flares
26.	Mullan	1976	ApJ, 208, 199	WD		DISK	Thermal radiation from flare near magnetic WD
27.	Woosley et al.	1976	Nature, 263, 101	NS		DISK	Carbon detonation from accreted matter onto NS
28.	Lamb et al.	1977	ApJ, 217, 197	NS		DISK	Mag grating of accret disk around NS causes sudden accretion
29.	Piran et al.	1977	ApJ, 214, 268	BH		DISK	Instability in accretion onto rapidly rotating BH
30.	Dasgupta	1979	Ap & SS, 63, 517	DG		SOL	Charged intergal rel dust grain enters sol sys, breaks up
31.	Tsygan	1980	A&A, 87, 224	WD		DISK	WD surface nuclear burst causes chromospheric flares
32.	Tsygan	1980	A&A, 87, 224	NS		DISK	NS surface nuclear burst causes chromospheric flares
......							
99.	Pineault	1990	Nature, 345, 233	NS	COM	DISK	Young NS drifts through its own Oort cloud
100.	Trofimenko et al.	1991	Ap & SS, 178, 217	WH		HALO	White hole supernova gave simultaneous burst of g-waves from 1987A
101.	Melia et al.	1991	ApJ, 373, 198	NS		DISK	NS B-field undergoes resistive tearing, accelerates plasma
102.	Holcomb et al.	1991	ApJ, 378, 682	NS		DISK	Alfen waves in non-uniform NS atmosphere accelerate particles
103.	Haensel et al.	1991	ApJ, 375, 209	SS	SS	COS	Strange stars emit binding energy in grav rad and collide
104.	Blaes et al.	1991	ApJ, 381, 210	NS	ISM	DISK	Slow interstellar accretion onto NS, e- capture starquakes result
105.	Frank et al.	1992	ApJ, 385, L45	NS		DISK	Low mass X-ray binary evolve into GRB sites
106.	Woosley et al.	1992	ApJ, 391, 228	NS		HALO	Accreting WD collapsed to NS
107.	Dar et al.	1992	ApJ, 388, 164	WD		COS	WD accretes to form naked NS, GRB, cosmic rays
108.	Hanami	1992	ApJ, 389, L71	NS	PLAN	COS	NS - planet magnetospheric interaction unstable
109.	Meszaros et al.	1992	ApJ, 397, 570	NS	NS	COS	NS - NS collision produces anisotropic fireball
110.	Carter	1992	ApJ, 391, L67	BH	ST	COS	Normal stars tidally disrupted by galactic nucleus BH
111.	Usov	1992	Nature, 357, 472	NS		COS	WD collapses to form NS, B-field brakes NS rotation instantly
112.	Narayan et al.	1992	ApJ, 395, L83	NS	NS	COS	NS - NS merger gives optically thick fireball
113.	Narayan et al.	1992	ApJ, 395, L83	BH	NS	COS	BH - NS merger gives optically thick fireball
114.	Brainerd	1992	ApJ, 394, L33	AGN	JET	COS	Synchrotron emission from AGN jets
115.	Meszaros et al.	1992	MNRAS, 257, 29P	BH	NS	COS	BH-NS have neutrinos collide to gammas in clean fireball
116.	Meszaros et al.	1992	MNRAS, 257, 29P	NS	NS	COS	NS-NS have neutrinos collide to gammas in clean fireball
117.	Cline et al.	1992	ApJ, 401, L57	BH		DISK	Primordial BHs evaporating could account for short hard GRBs
118.	Rees et al.	1992	MNRAS, 258, 41P	NS	ISM	COS	Relativistic fireball reconverted to radiation when hits ISM

What causes GRBs

?

How find the answer?

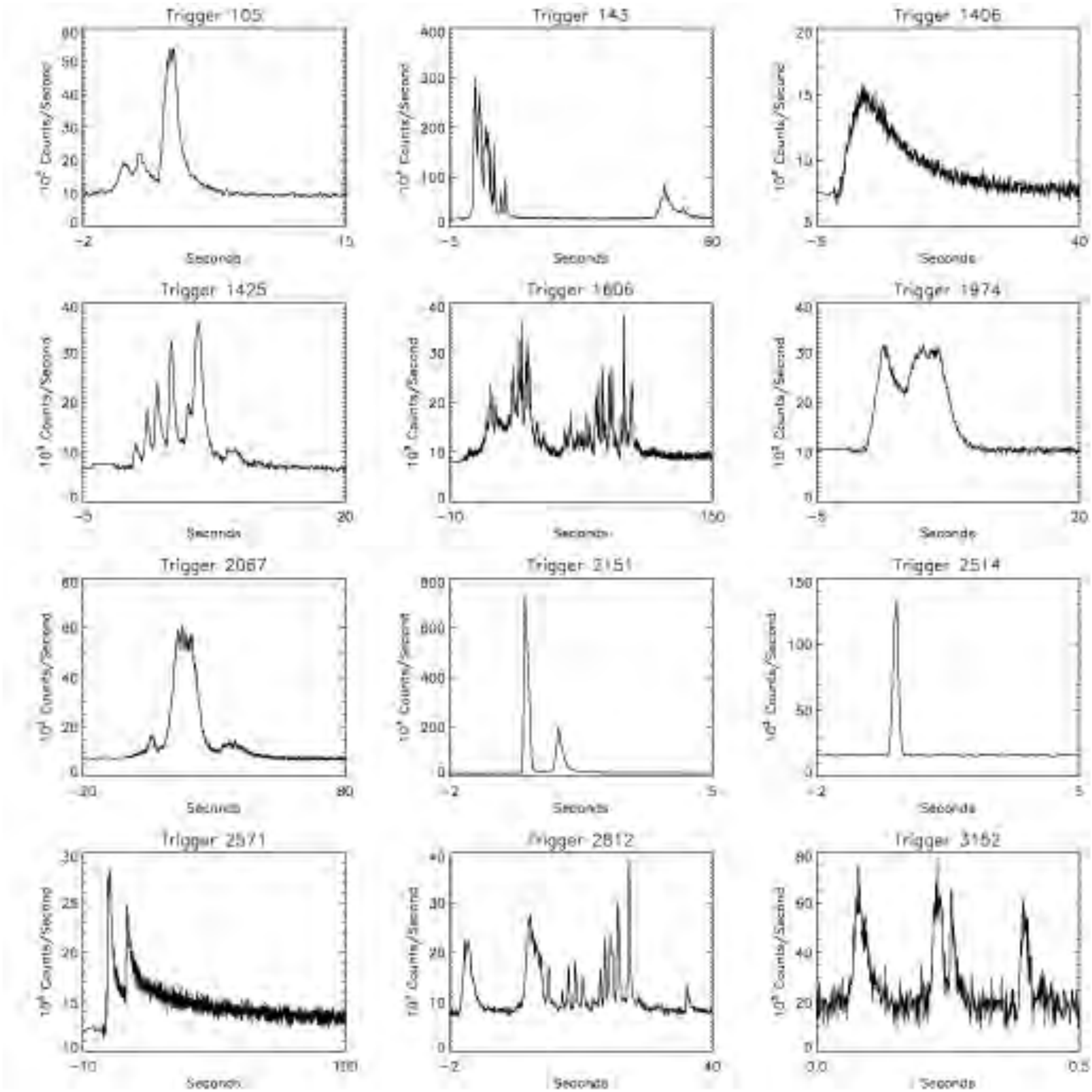
How find the answer: launch a new satellite!



- CGRO (Compton Gamma Ray Observatory)
- The satellite was launched in 1991 and deorbited into the Atlantic in June 2000.
- The main purpose of BATSE (Burst and Transient Source Experiment was to study GRBs.
- BATSE triggered on 2704 GRBs during its nine years of operation (ca. 1 per day).

CGRO

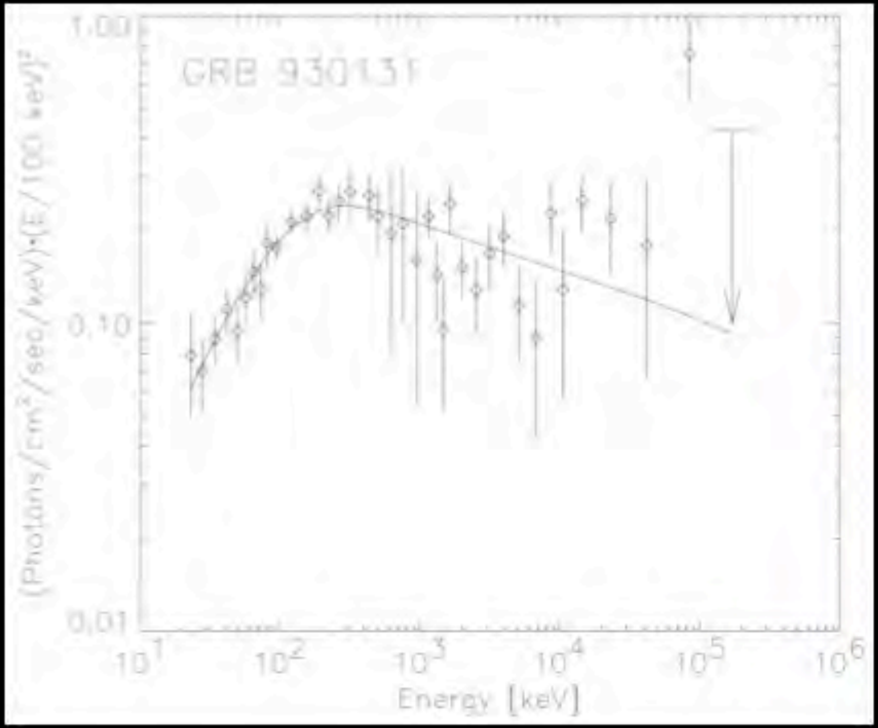
BATSE: Examples of GRBS



Spectral properties: Non-thermal

High energy spectra:
(Band function)

$$N(E) = \begin{cases} A E^{\alpha} \exp(-\frac{E}{E_0}) & E < (\alpha - \beta) E_0 \\ B E^{\beta} & E > (\alpha - \beta) E_0 \end{cases}$$

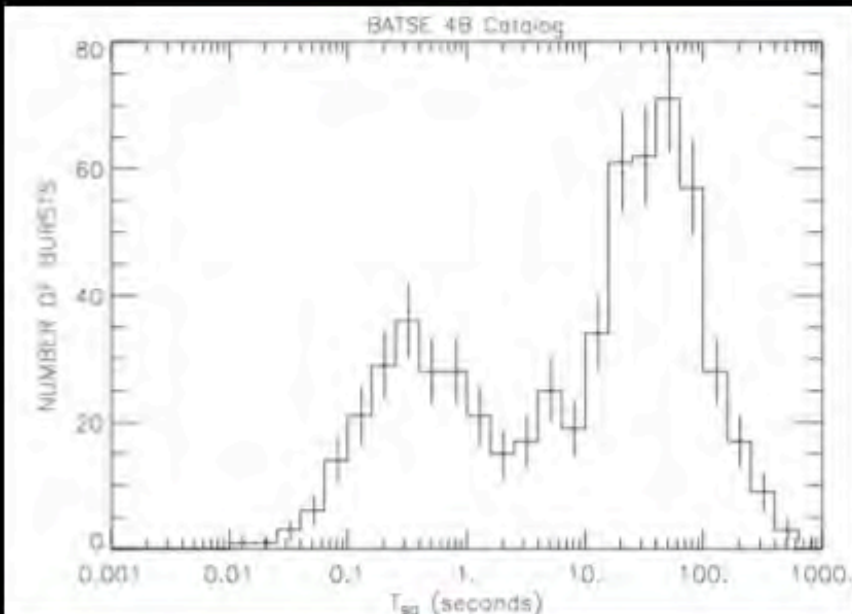


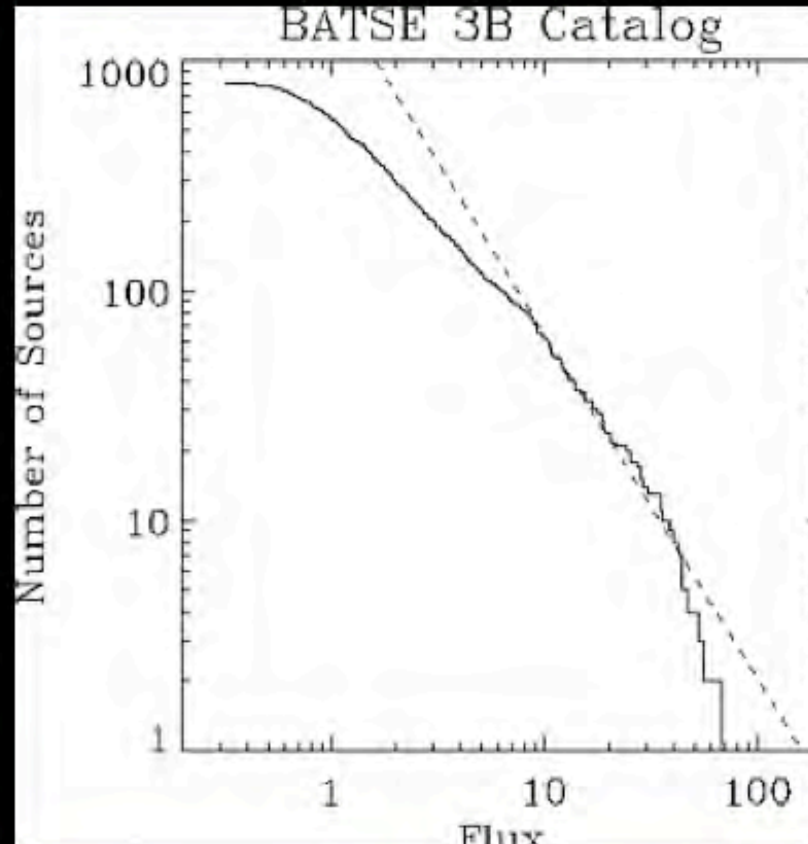
$$E_{peak} = E_0 \times (2 + \alpha)$$

E_{peak} ~250 keV (within factor 2-3)

$\alpha \in [-2,0]$ $\beta \in [-4,-2]$

Other key BATSE results

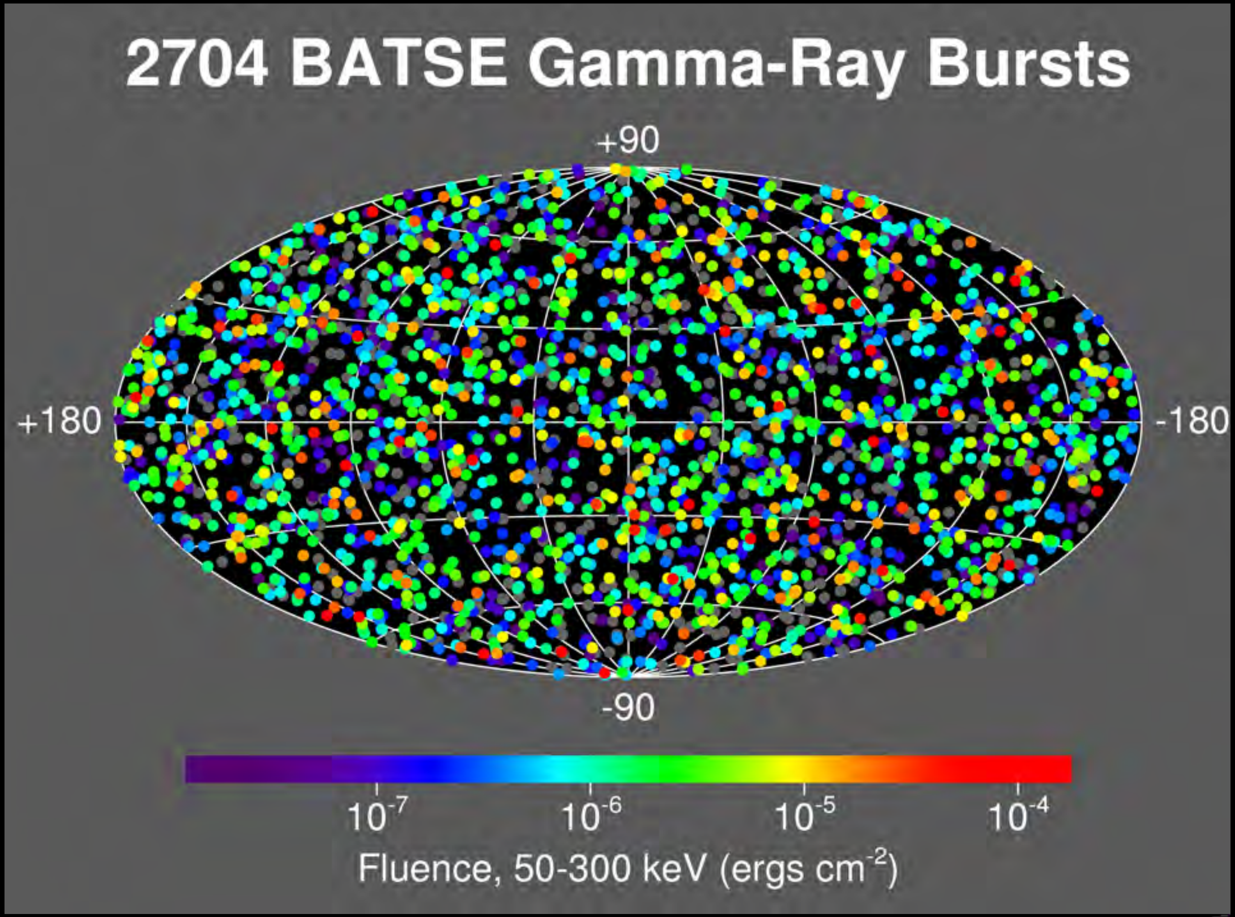




Two classes of GRBs: short and long duration GRBs. Short GRBs have harder spectra than long GRBs.

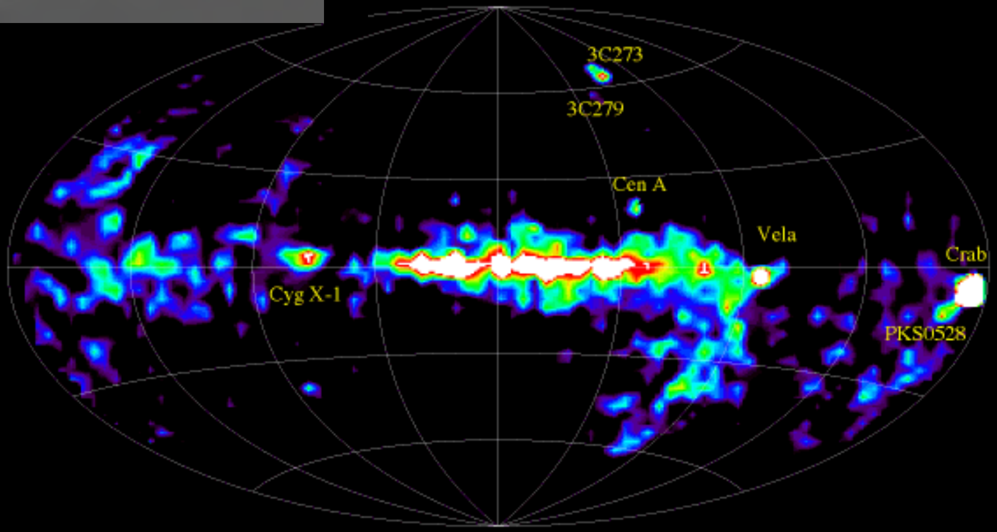
A deficit of faint sources is a strong hint that the soucers have a cosmological distribution (or that we see the end of the distribution).

$$F \propto \text{distance}^{-2}, N \propto \text{distance}^{3}$$
$$\rightarrow N \propto F^{-3/2}$$



← distribution of GRBs on the sky: Isotropic

Distribution on the sky of persistent γ-ray sources → Mainly in the Milky Way disk (or AGN)



The Compactness Problem

Many photons with energy above 500keV. Hence, pair creation is possible:

$$\gamma + \gamma \rightarrow e^{+} + e^{-}$$

Variability on 10 ms timescale. Hence, very compact source:

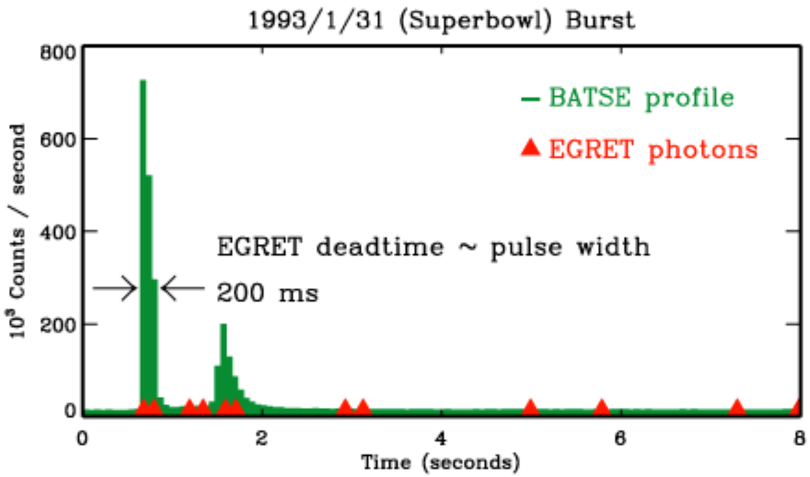
$$R \leqslant c\,\delta t \approx 3 \times 10^{6}\,\mathrm{m}$$

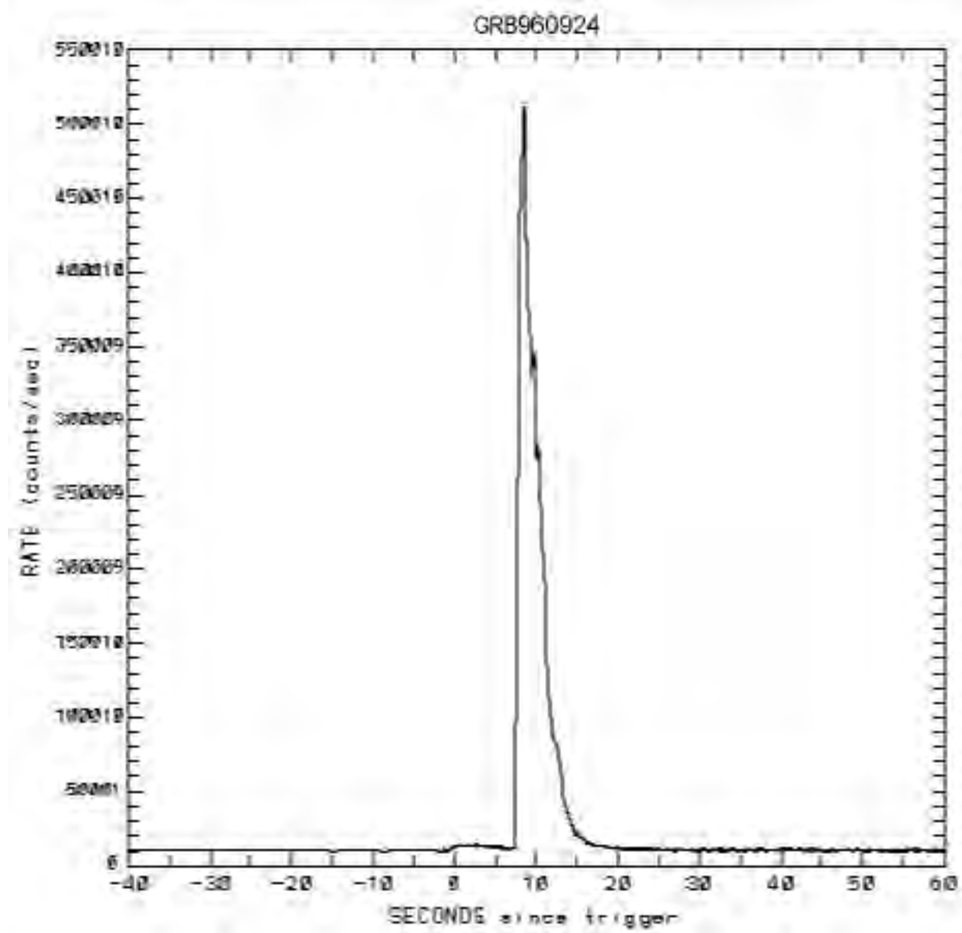
Cosmological distance scale implies extremely high photon densities: → Optically thick.

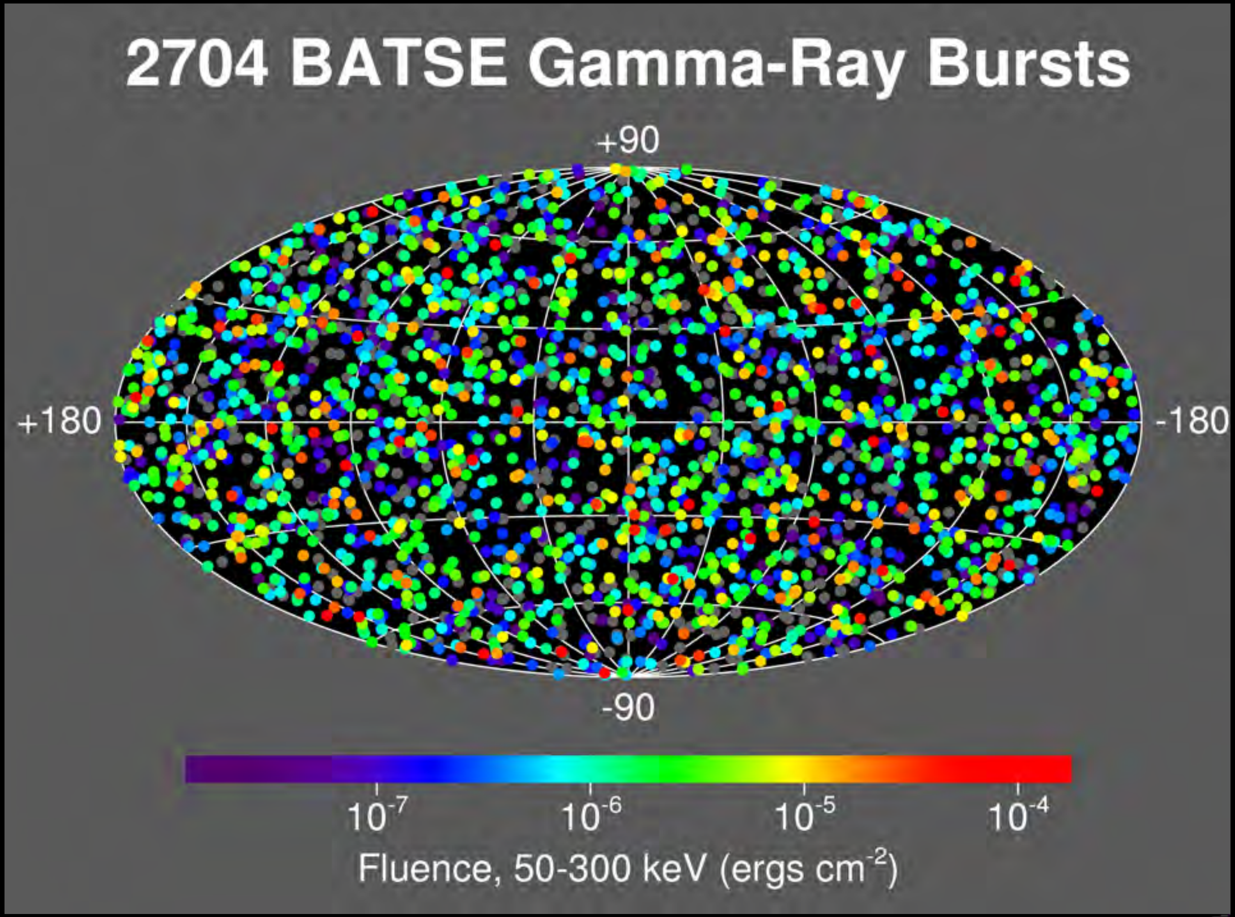
$$\tau_{\gamma\gamma} \approx 10^{13} f_p \left(\frac{F}{10^{-7}\,\mathrm{erg/cm^2}}\right)\left(\frac{D}{3000\,\mathrm{Mpc}}\right)^{2}\left(\frac{\delta T}{10\,\mathrm{ms}}\right)^{-2}$$

Spectrum non-thermal: Optically thin	⇔	Size & Energy: Optically thick

BATSE: Extreme GRBs

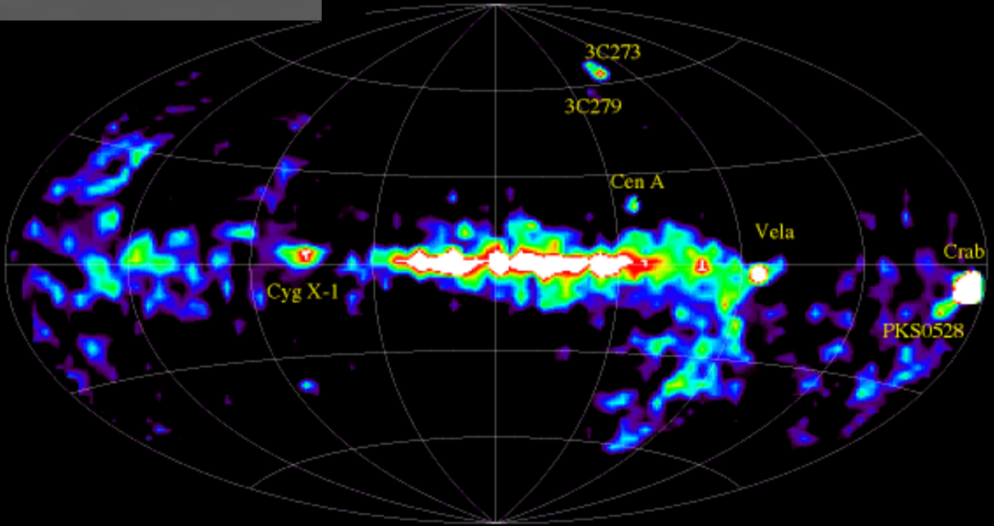






← distribution of GRBs on the sky: Isotropic

Distribution on the sky of persistent γ-ray sources
Mainly in the Milky Way disk (or AGN) →

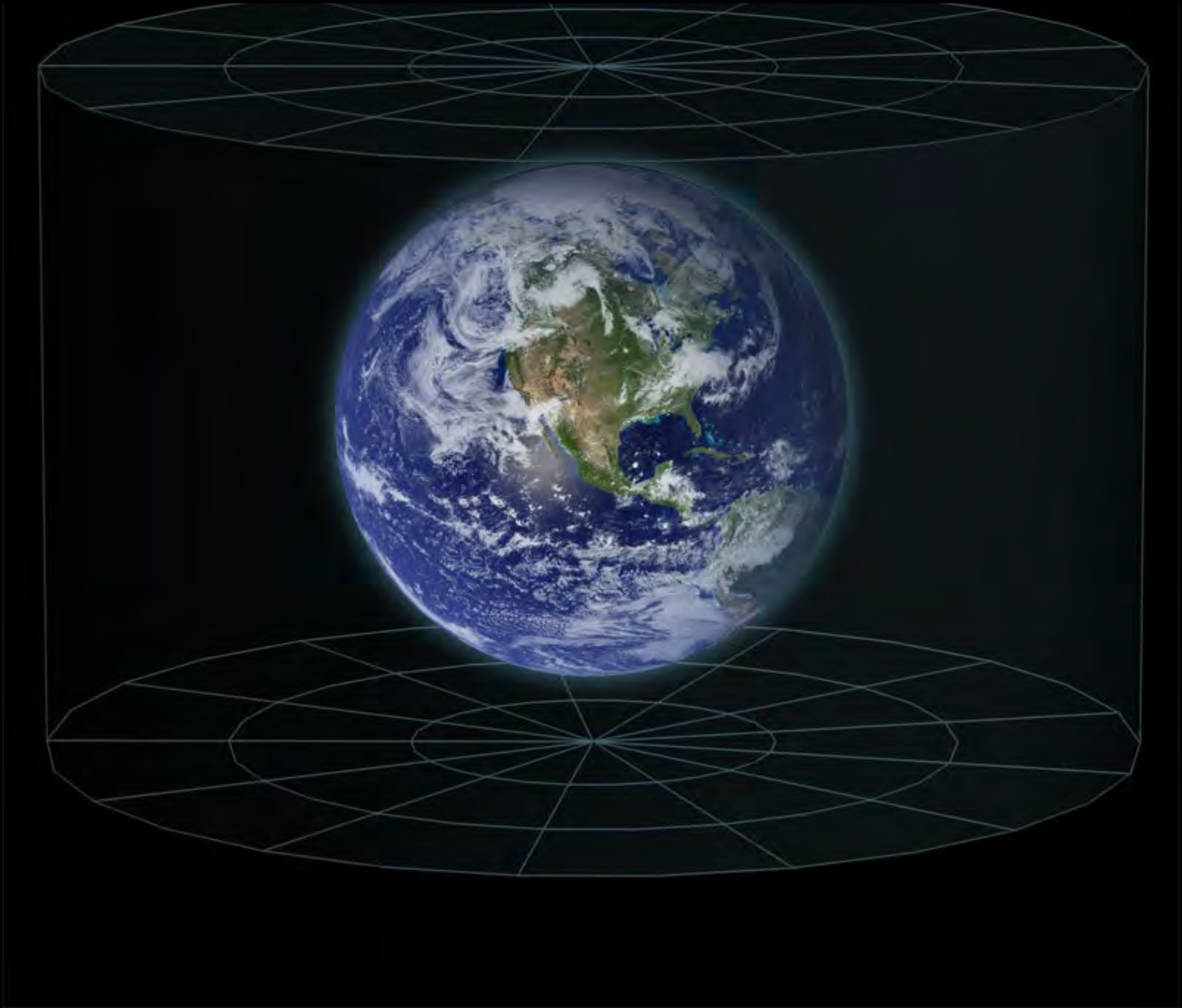


Conclusions

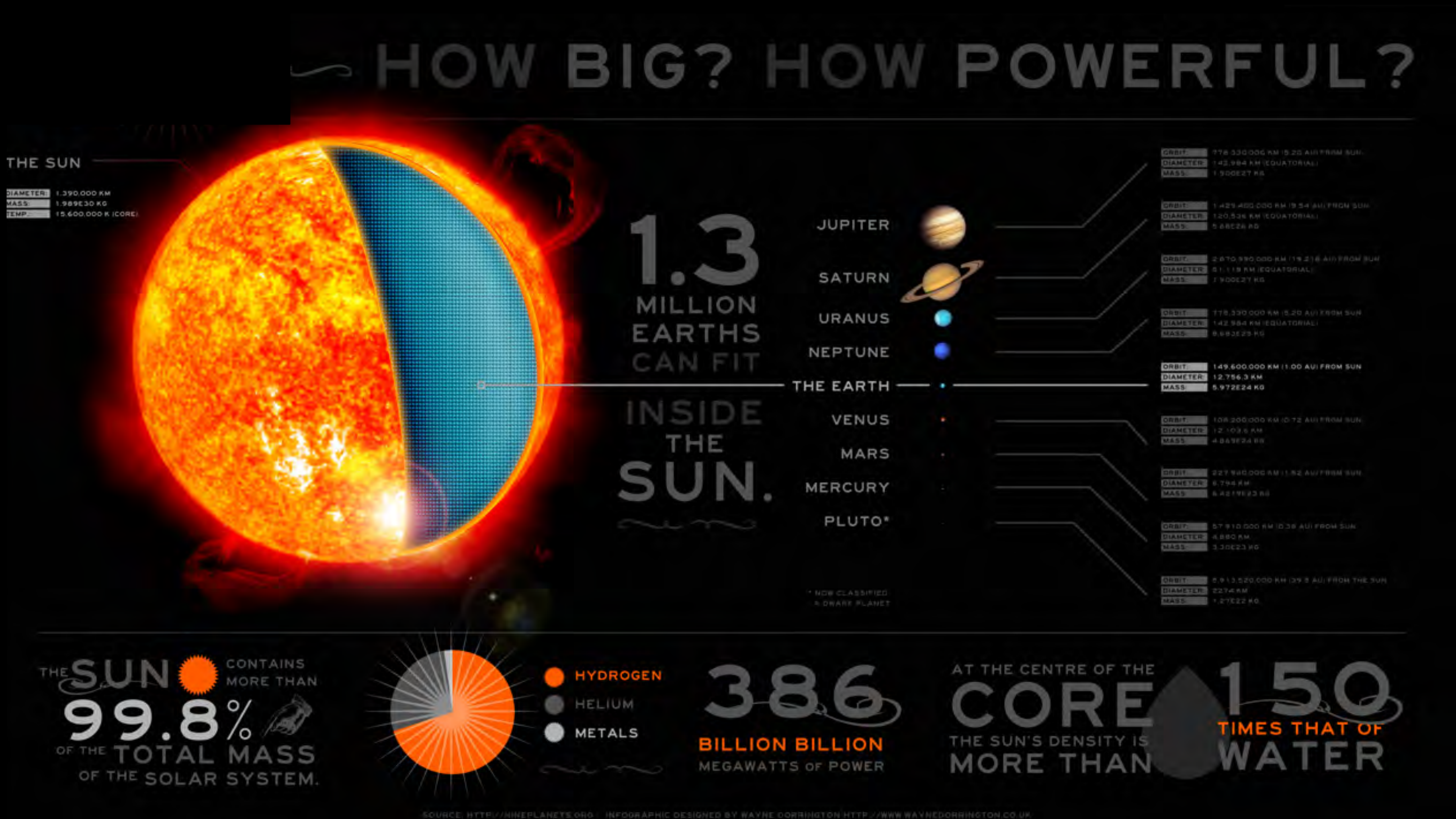
- Gamma-ray bursts are short intense bursts of γ-rays. They do not originate from the earth or the sun.
- GRBs are isotropically distributed on the sky.

What can be inferred from the celestial distribution of GRBs?

Earth

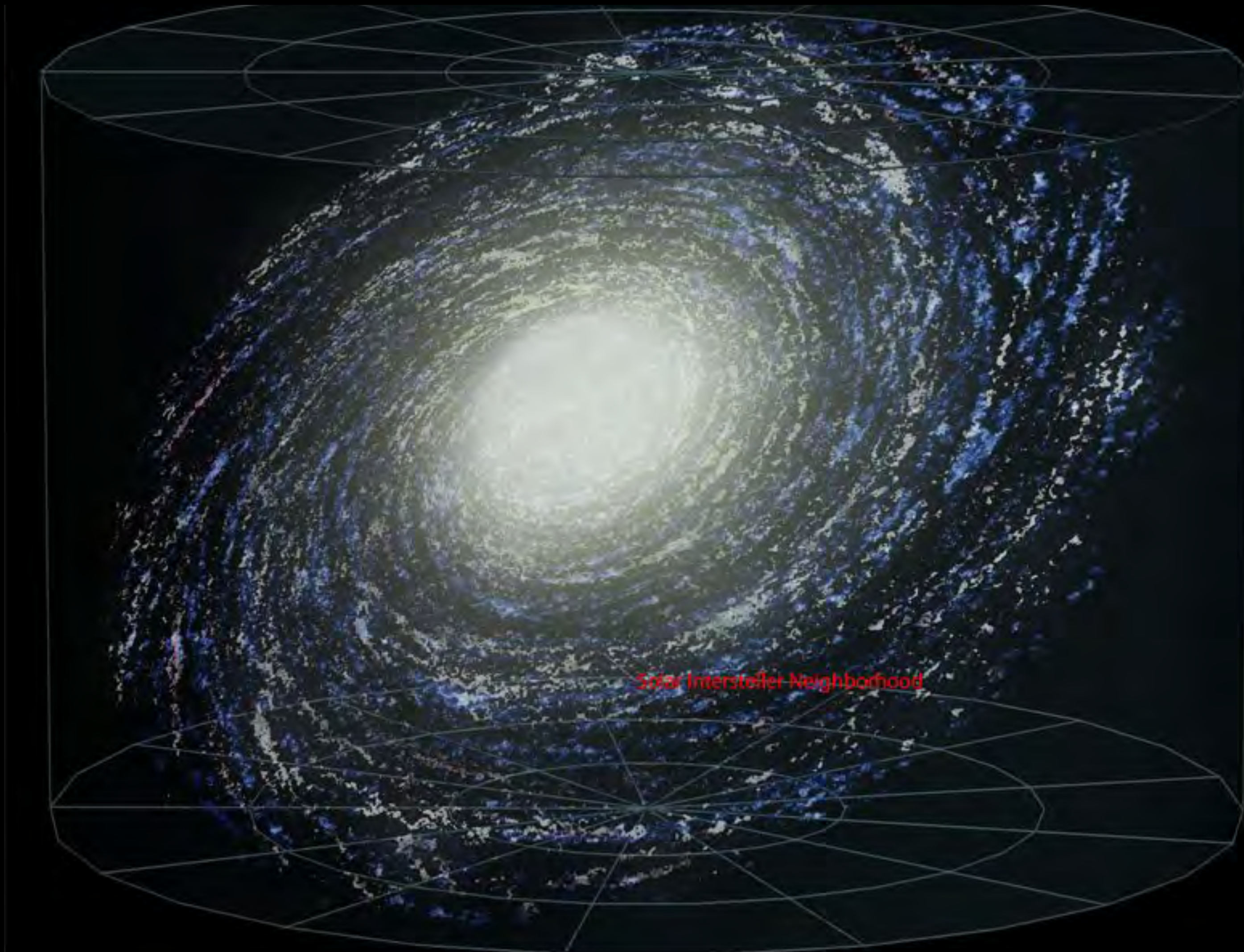


Sun

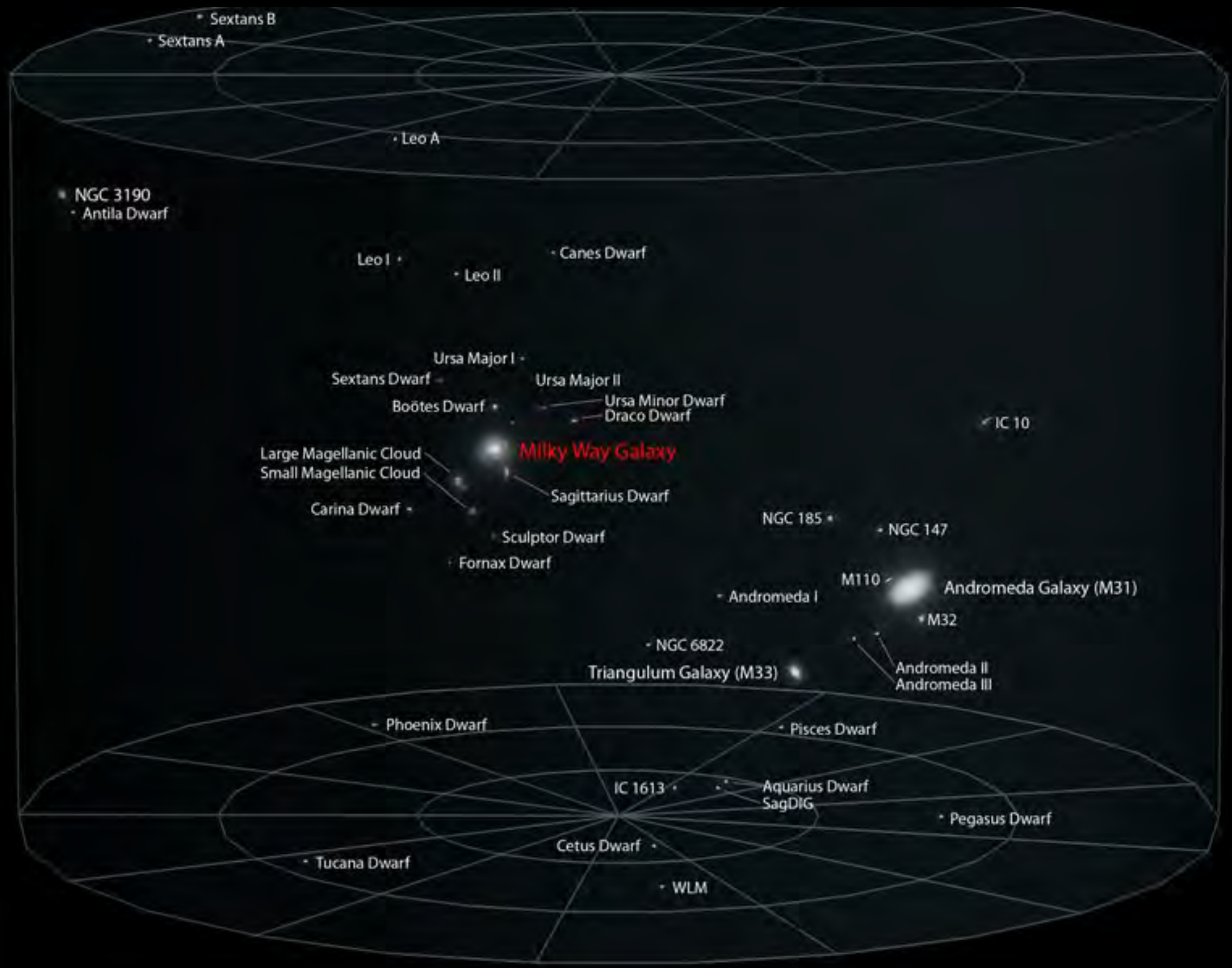

HOW BIG? HOW POWERFUL?
THE SUN
DIAMETER: 1,390,000 KM
MASS: 1,989E30 KG
TEMP.: 15,600,000 K (CORE)
1.3 MILLION EARTHS CAN FIT INSIDE THE SUN.
JUPITER
SATURN
URANUS
NEPTUNE
THE EARTH
VENUS
MARS
MERCURY
PLUTO*
ORBIT: 149,600,000 KM (1.00 AU) FROM SUN
DIAMETER: 12,756.3 KM
MASS: 5.972E24 KG
THE SUN CONTAINS MORE THAN 99.8% OF THE TOTAL MASS OF THE SOLAR SYSTEM.
HYDROGEN
HELIUM
METALS
386 BILLION BILLION MEGAWATTS OF POWER
AT THE CENTRE OF THE CORE THE SUN'S DENSITY IS MORE THAN 150 TIMES THAT OF WATER

Solar neighborhood

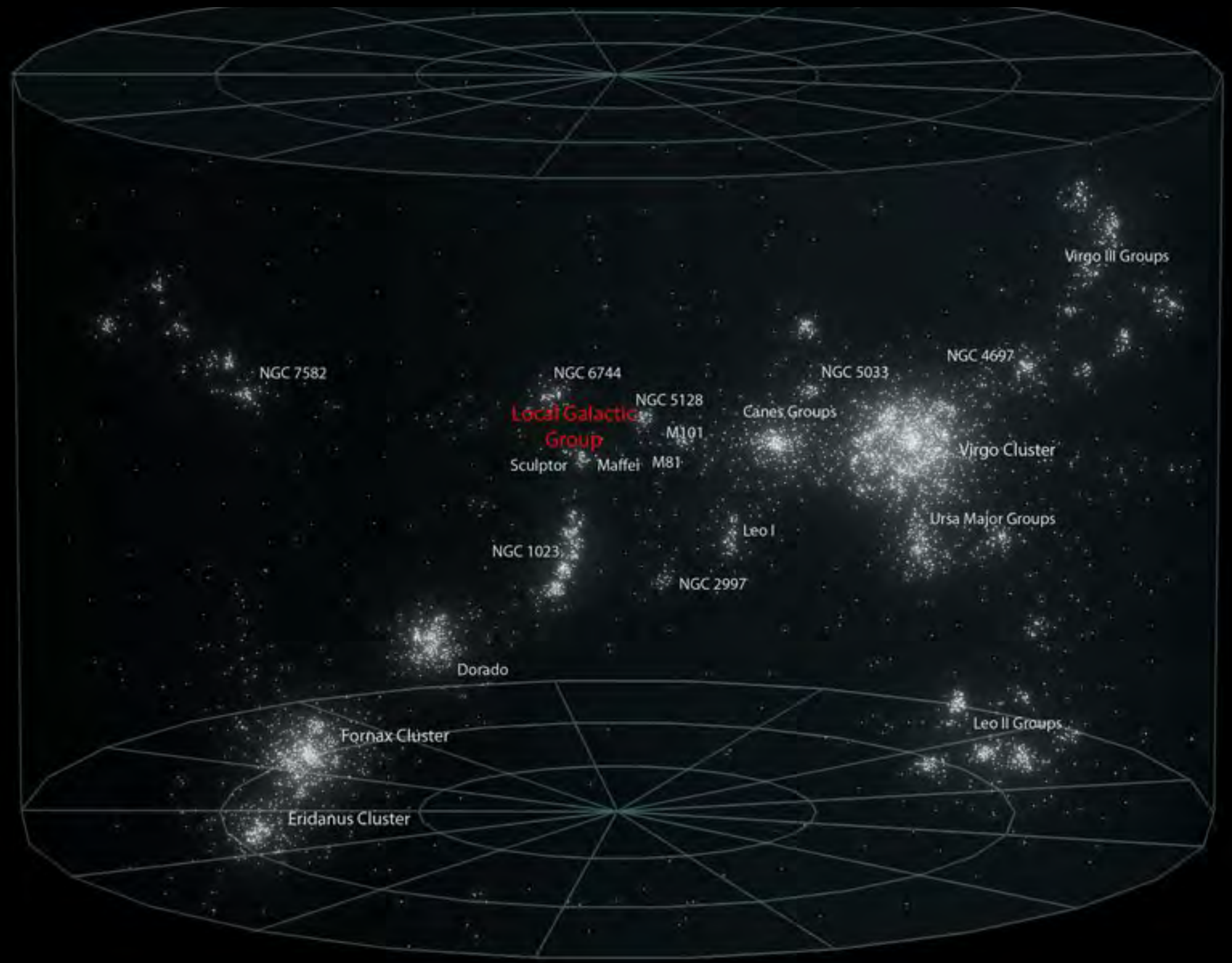
Milky Way



The local group



Virgo Supercluster



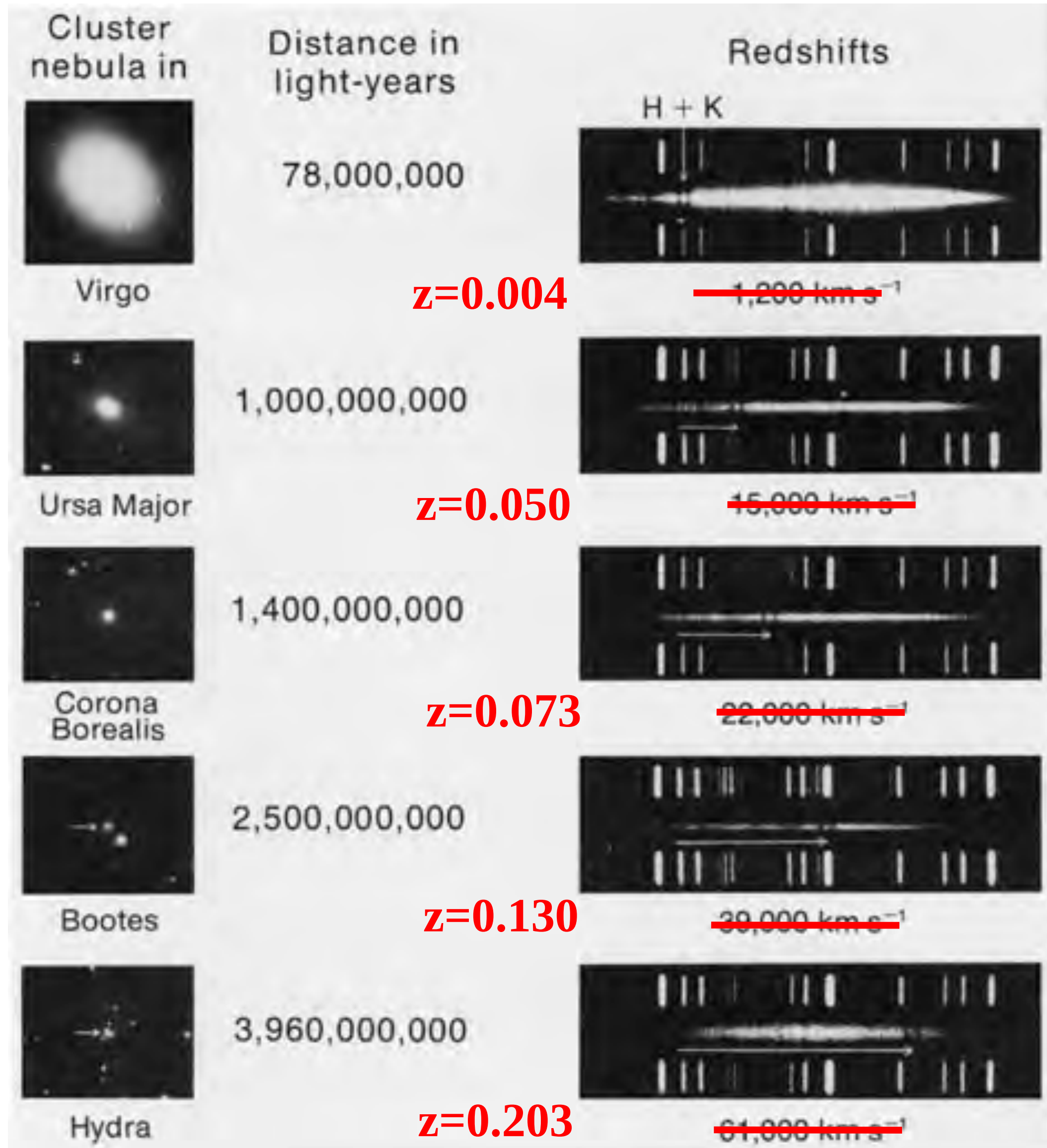
The observable Universe


the BIG
BANG
THEORY

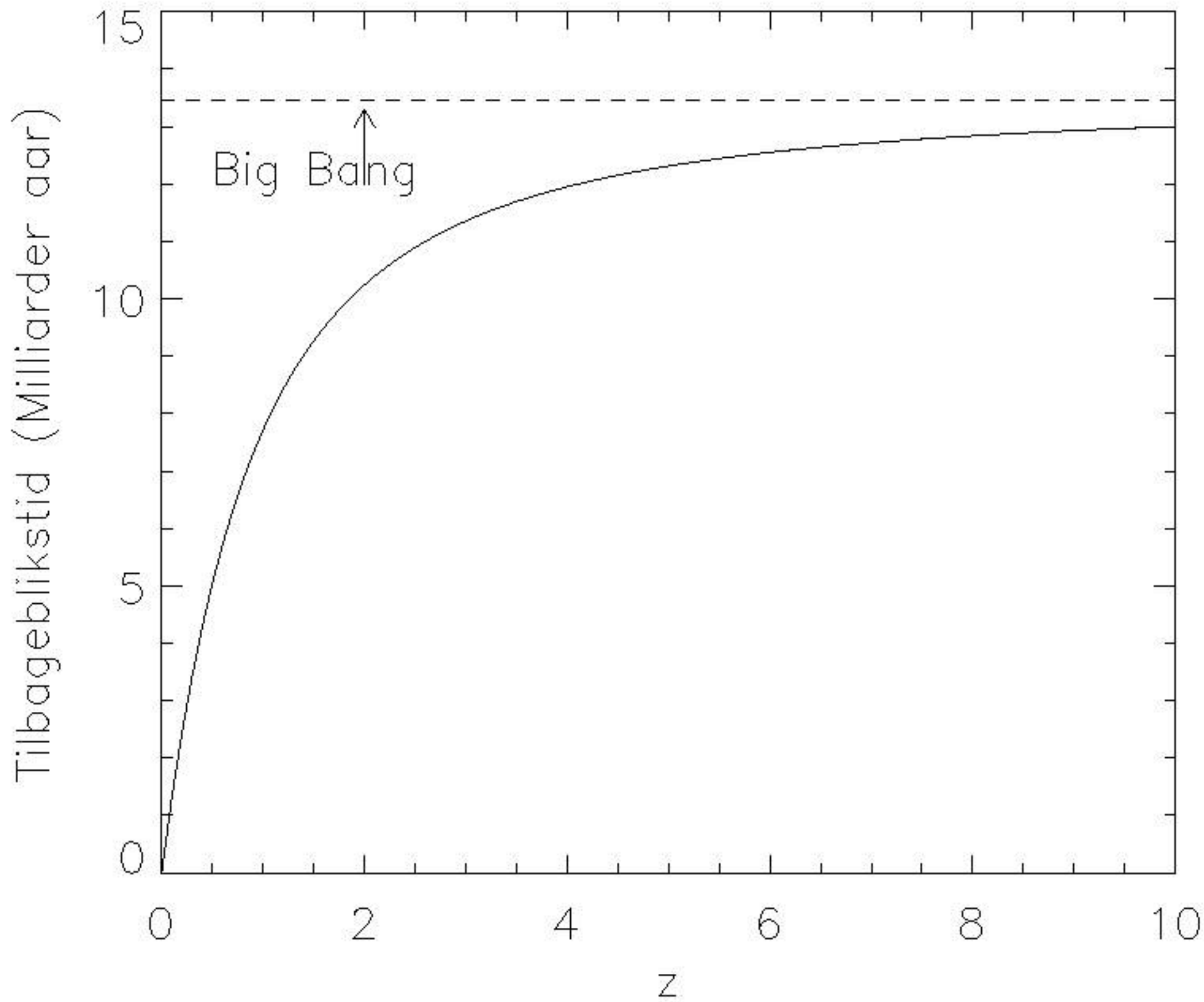
The cosmological redshift

$$1 + z = \frac{\lambda_{obs}}{\lambda_{lab}}$$

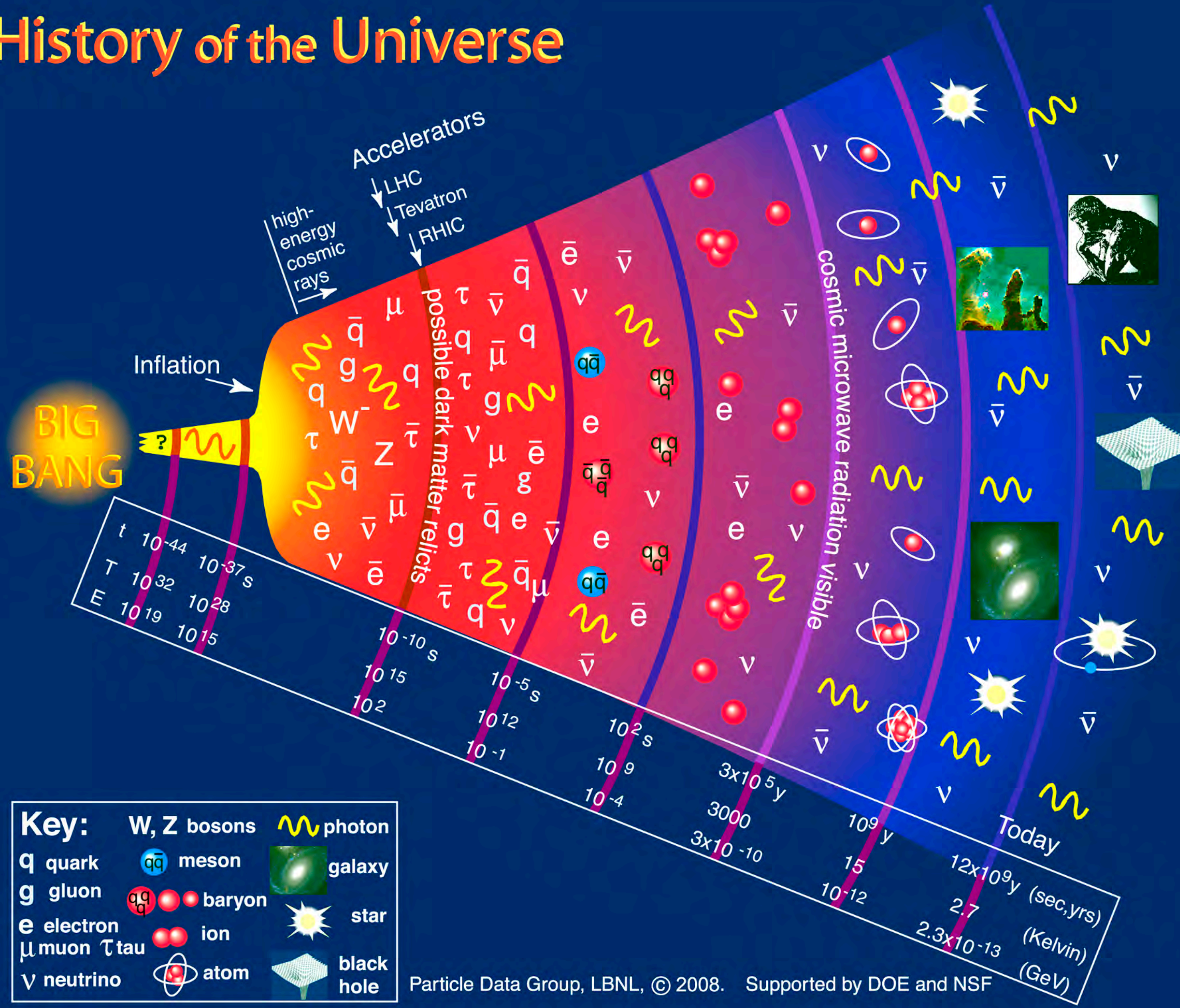
The redshift is a measure of how much the Universe has expanded between emission and observation of the light : (1+z) per dimension.



Redshift and time



History of the Universe



The Great Debate 1995

http://antwrp.gsfc.nasa.gov/diamond_jubilee/debate95.html

- Bohdan Paczyński
- Extragalactic

Explosions in remote galaxies.

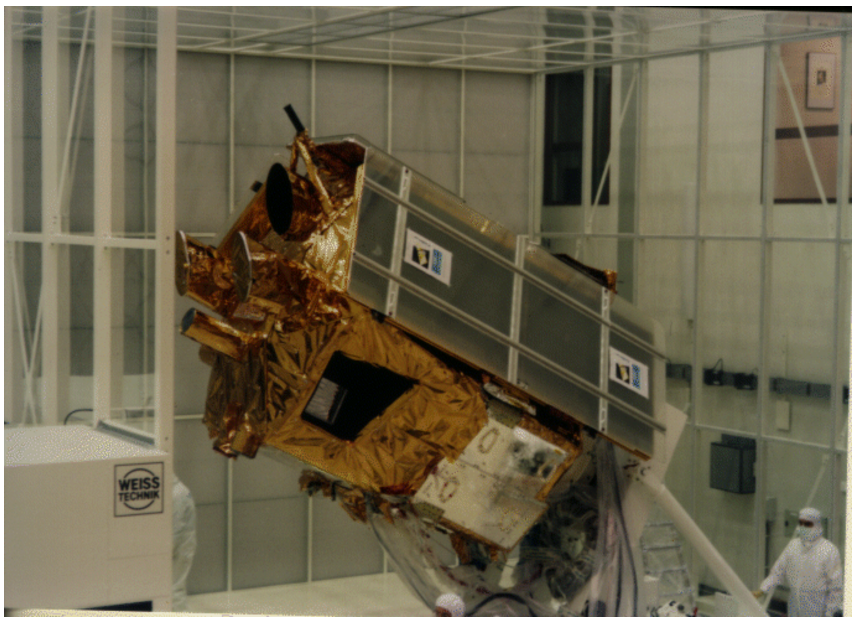
- Donald Q. Lamb
- Galactic (Milky Way)

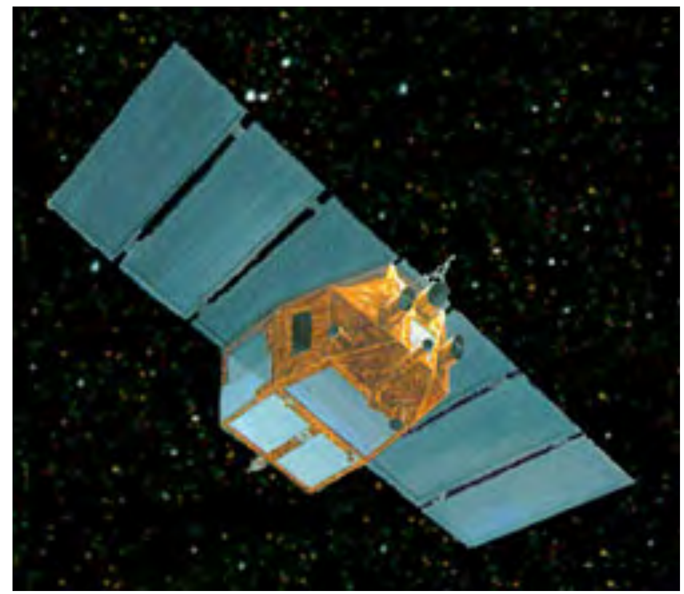
Neutron stars ejected from the disk with large velocities and hence distributed in an extended halo.

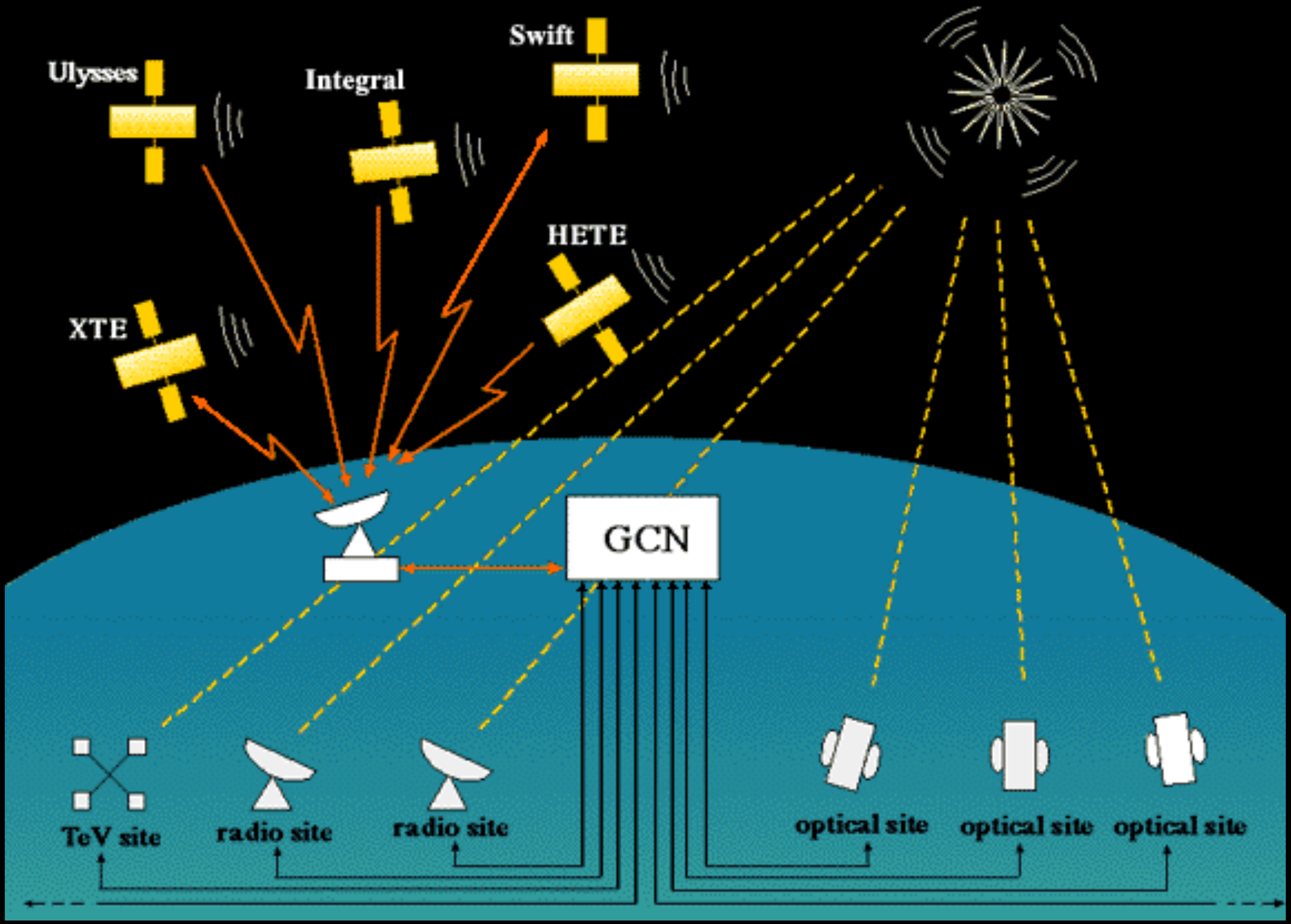
Tests: precise positions

Andromeda galaxy

How to find the answer:
Launch a new satellite!
BeppoSax (1996-2002)

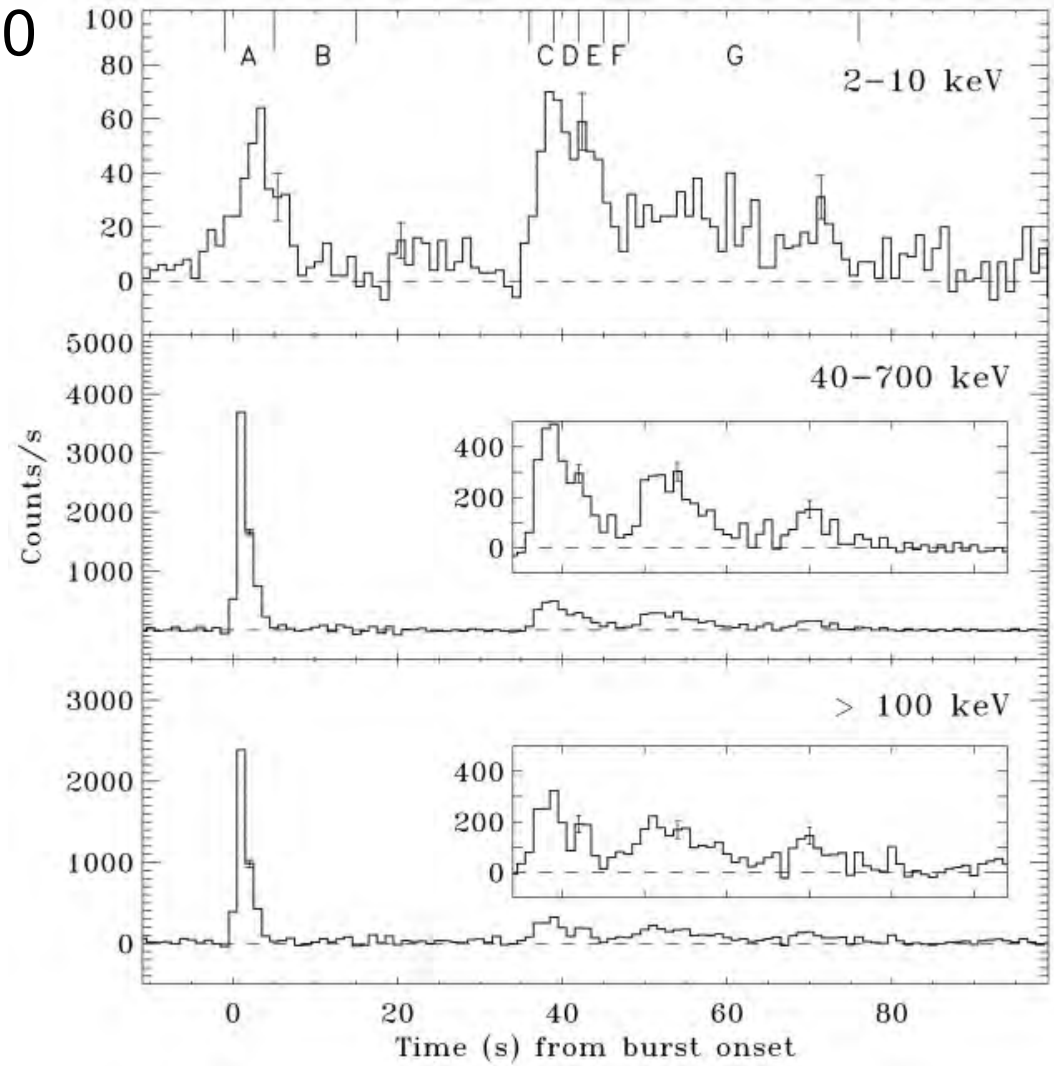




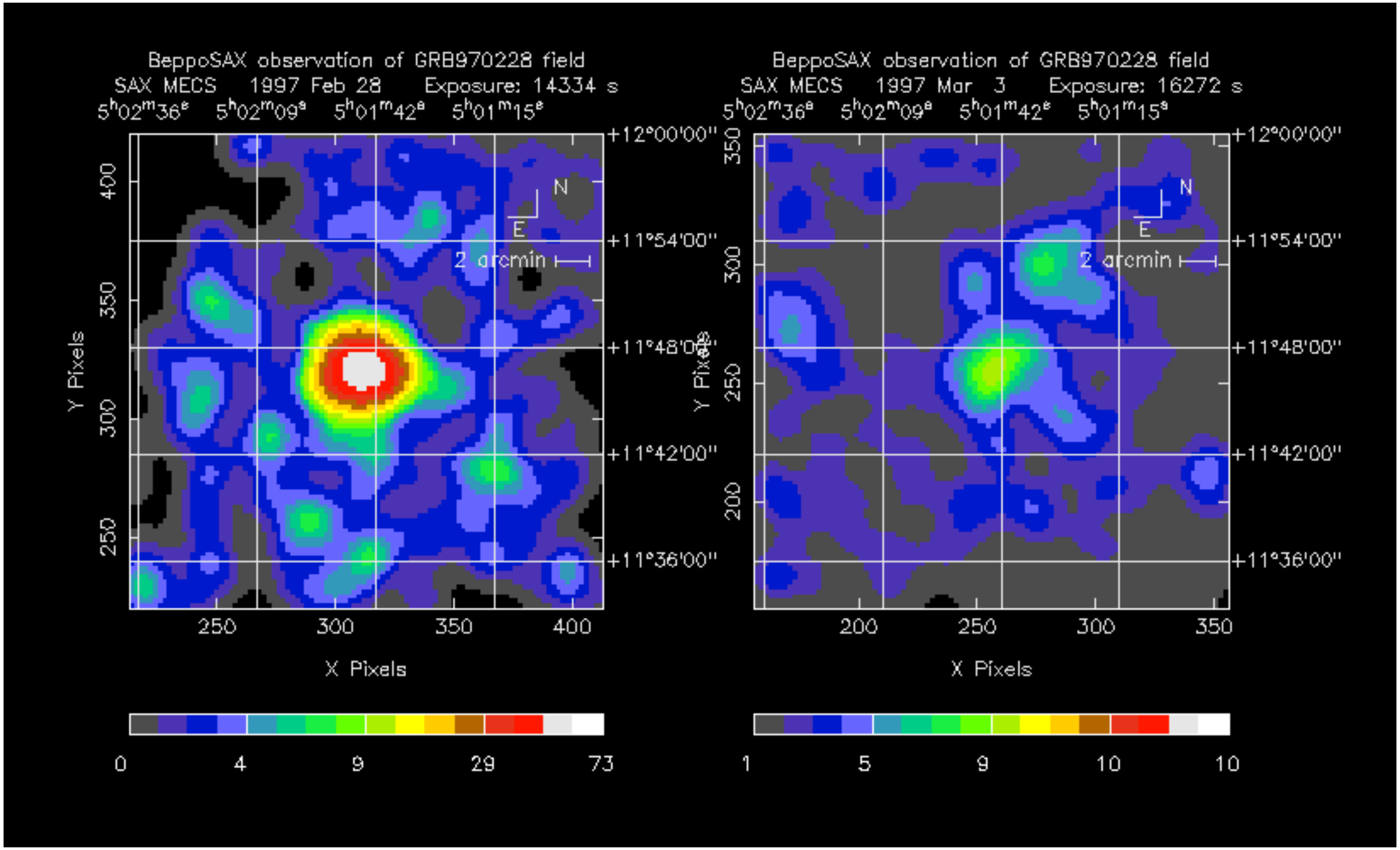

Ulysses
Integral
Swift
HETE
XTE
GCN
TeV site
radio site
radio site
optical site
optical site
optical site

GRB970228: breakthrough

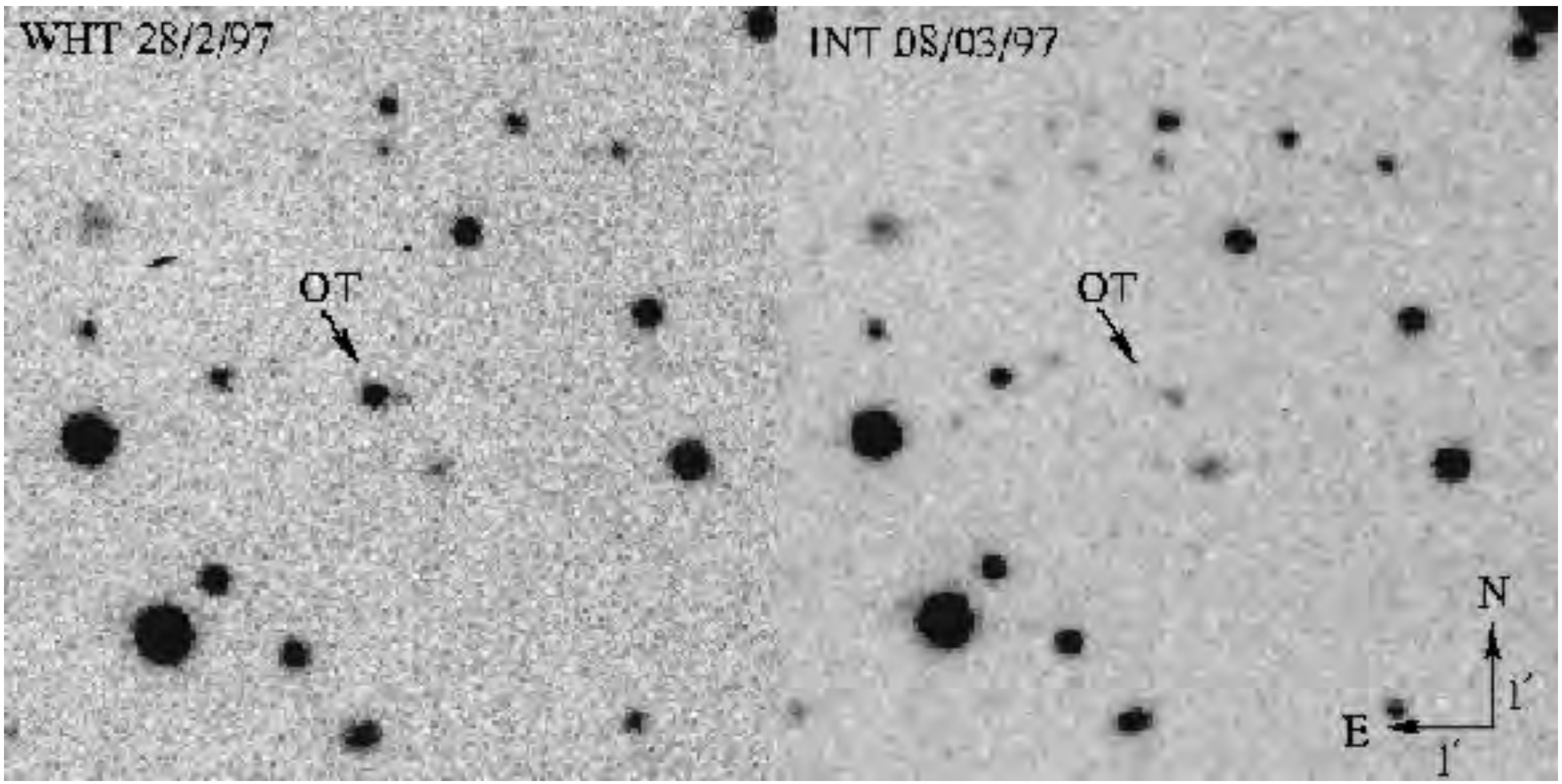
February 28.123620



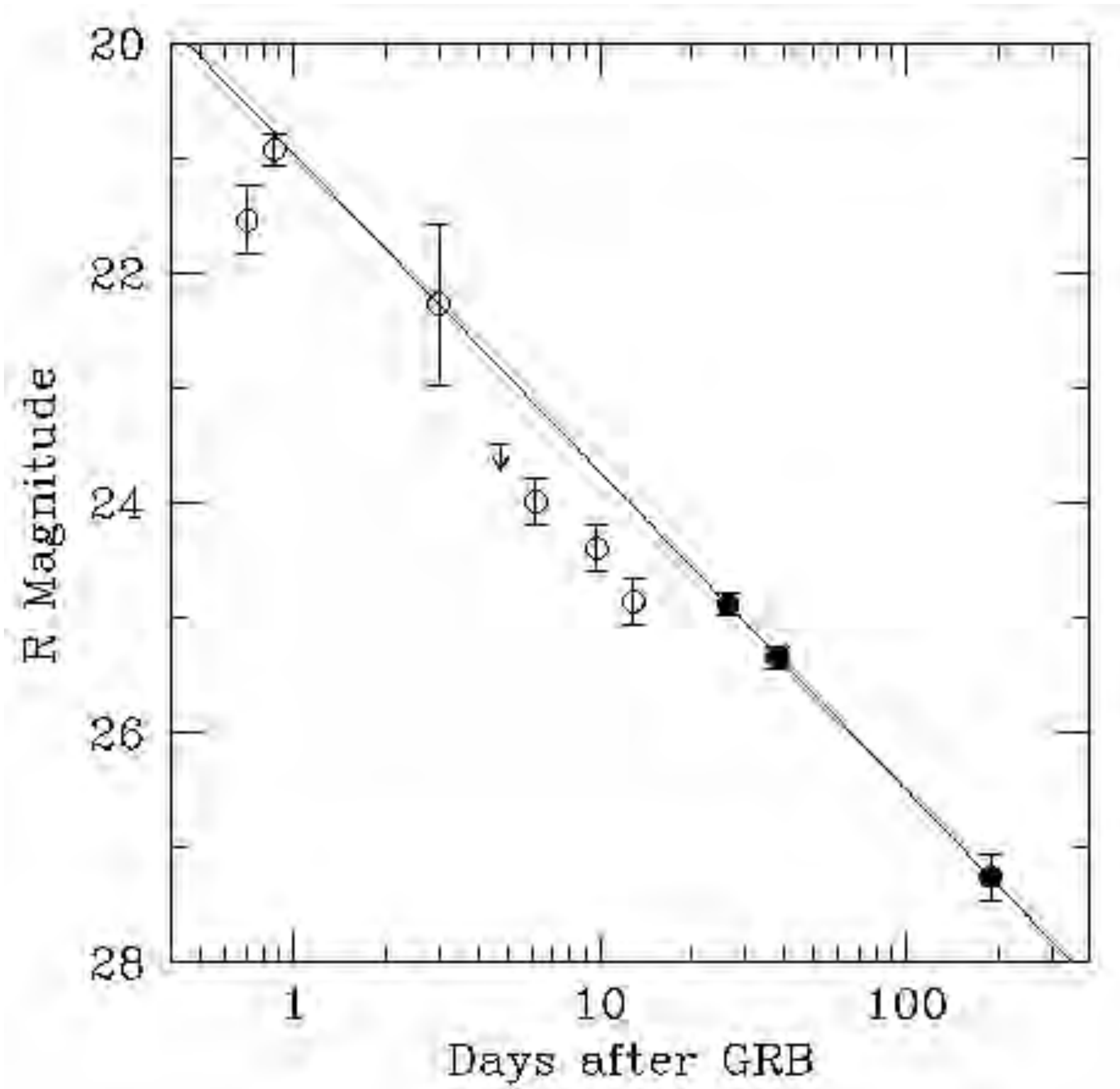
GRB970228: X-ray afterglow



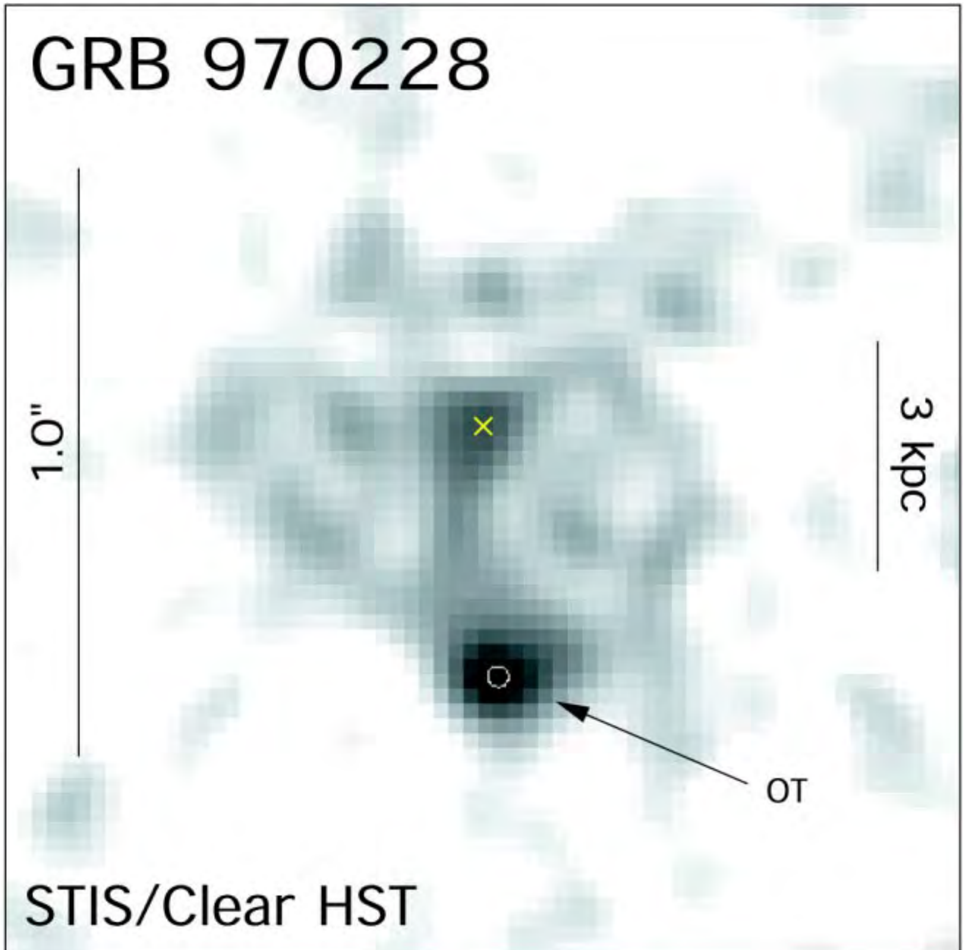
GRB970228: optical afterglow



Lightcurve for the optical afterglow of GRB970228: powerlaw



Host galaxy (z=0.695, d=4.2 Gpc)



↓

COSMOLOGICAL!

Conclusions

- Gamma-ray bursts are short intense bursts of γ-rays. They do not originate from the earth or the sun.
- GRBs are isotropically distributed on the sky.
- GRBs originate from galaxies at "cosmological" distances. Very energetic explosions. Synchrotron radiation from highly relativistic electrons?

Solution: highly relativistic motion

t_1 → t_2

$v\Delta t$

$$\Delta t = t_2 - t_1$$

$$\Delta t_{obs} = \Delta t - \frac{v\Delta t}{c} = \Delta t(1-\beta)$$

$$\gamma^2 = \frac{1}{1-\beta^2} = \frac{1}{(1+\beta)(1-\beta)} \rightarrow 1-\beta = \frac{1}{\gamma^2(1+\beta)} \approx \frac{1}{2\gamma^2}$$

$$\rightarrow \Delta t_{obs} = \frac{\Delta t}{2\gamma^2}$$

Rees (1966)

Solution: highly relativistic motion

Photons in the source frame have much smaller energi:

$$E_{source} = E_{obs}/\gamma$$

The true timescale is much larger so the size limit is much less severe.

$$\Delta t_{obs} = \frac{\Delta t}{2\gamma^2}$$

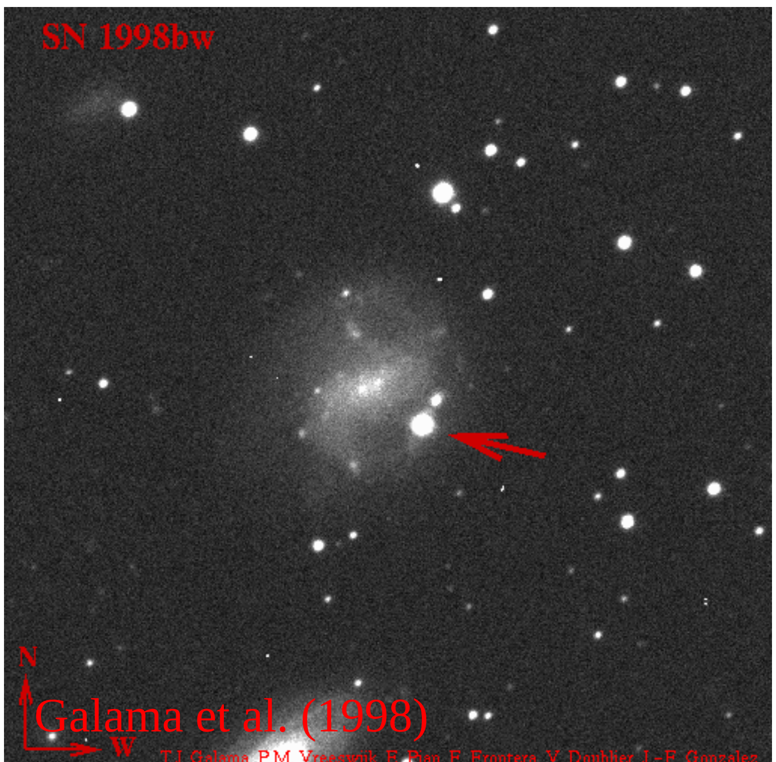
Optical depth strongly reduced:

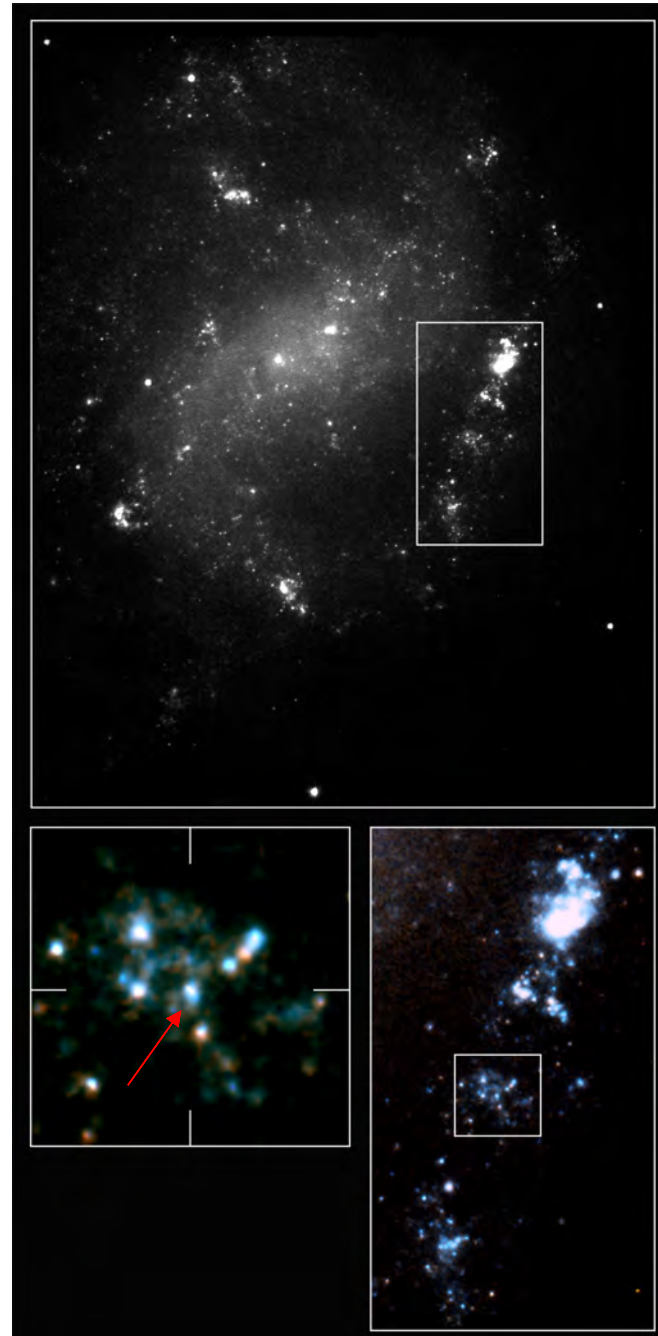
$$\tau_{\gamma\gamma} \approx \frac{10^{13}}{\gamma^{4+2\alpha}} f_p \left(\frac{F}{10^{-7}\,\mathrm{erg/cm^2}}\right)\left(\frac{D}{3000\,\mathrm{Mpc}}\right)^2\left(\frac{\delta T}{10\,\mathrm{ms}}\right)^{-2}$$

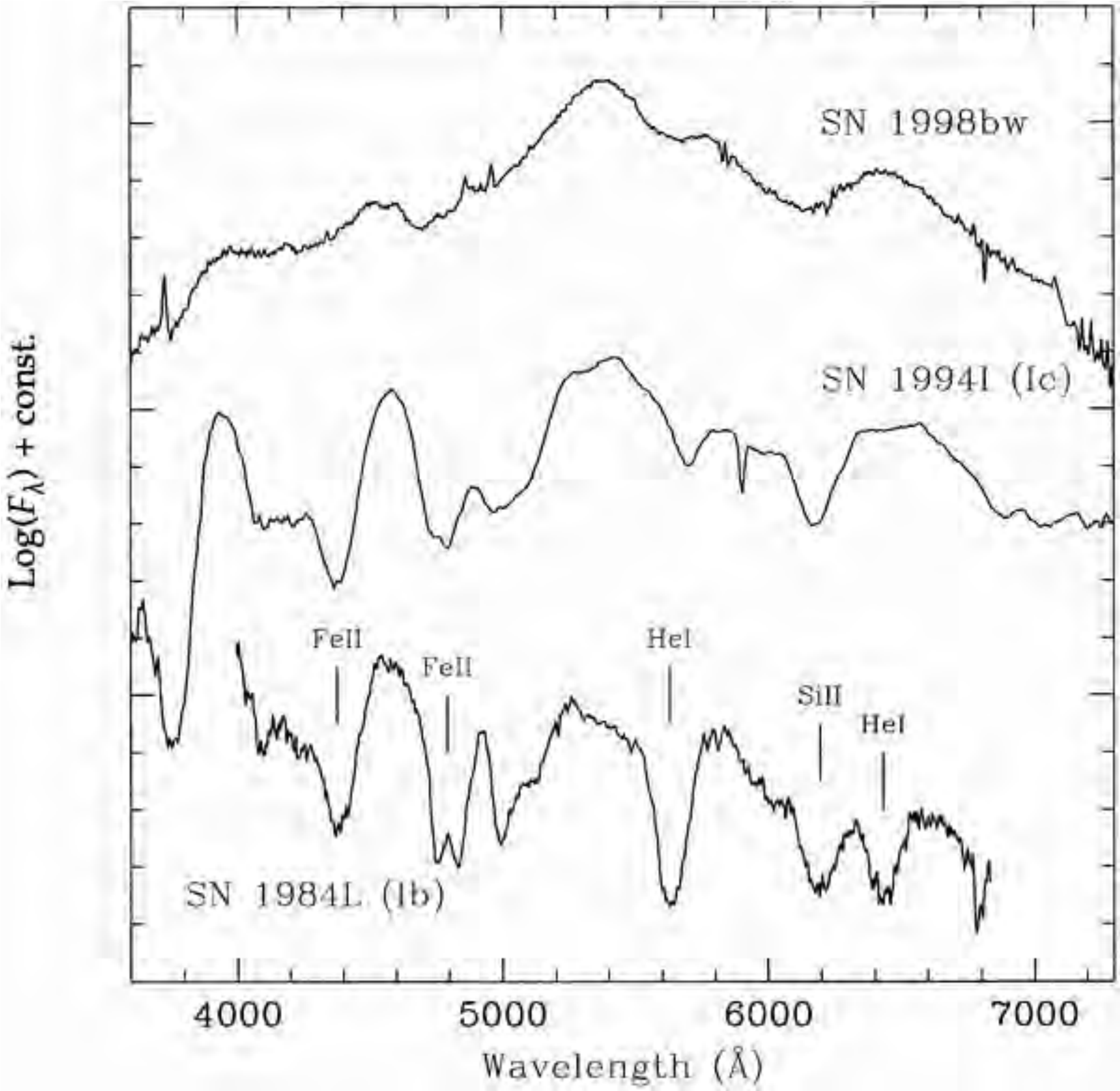
$$\tau_{\gamma\gamma} < 1 \rightarrow \gamma \geqslant 100$$

GRB980425: supernova

z=0.0085 (nearby!). No optical afterglow!, but a bright SN Ib/c SN1998bw – SN of the century!






SN 1998bw
SN 1994I (Ic)
SN 1984L (Ib)
FeII
FeII
HeI
SiII
HeI
Log(F_λ) + const.
4000
5000
6000
7000
Wavelength (Å)

Conclusions

- Gamma-ray bursts are short intense bursts of γ-rays. They do not originate from the earth or the sun.
- GRBs are isotropically distributed on the sky.
- GRBs originate from galaxies at “cosmological” distances. Very energetic explosions. Synchrotron radiation from relativistic electrons?
- Connection to supernovae?

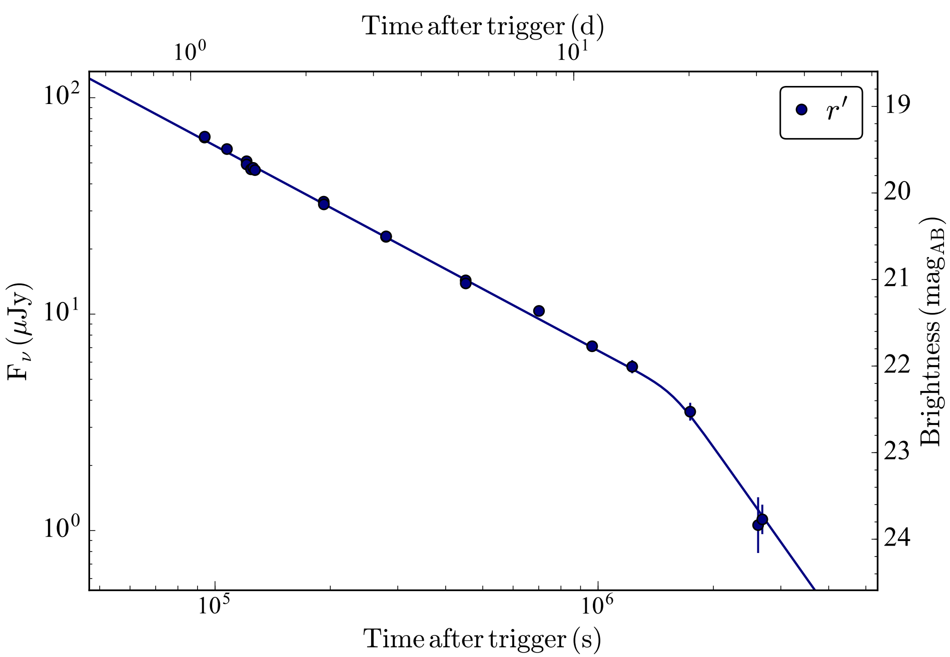
GRB160625B

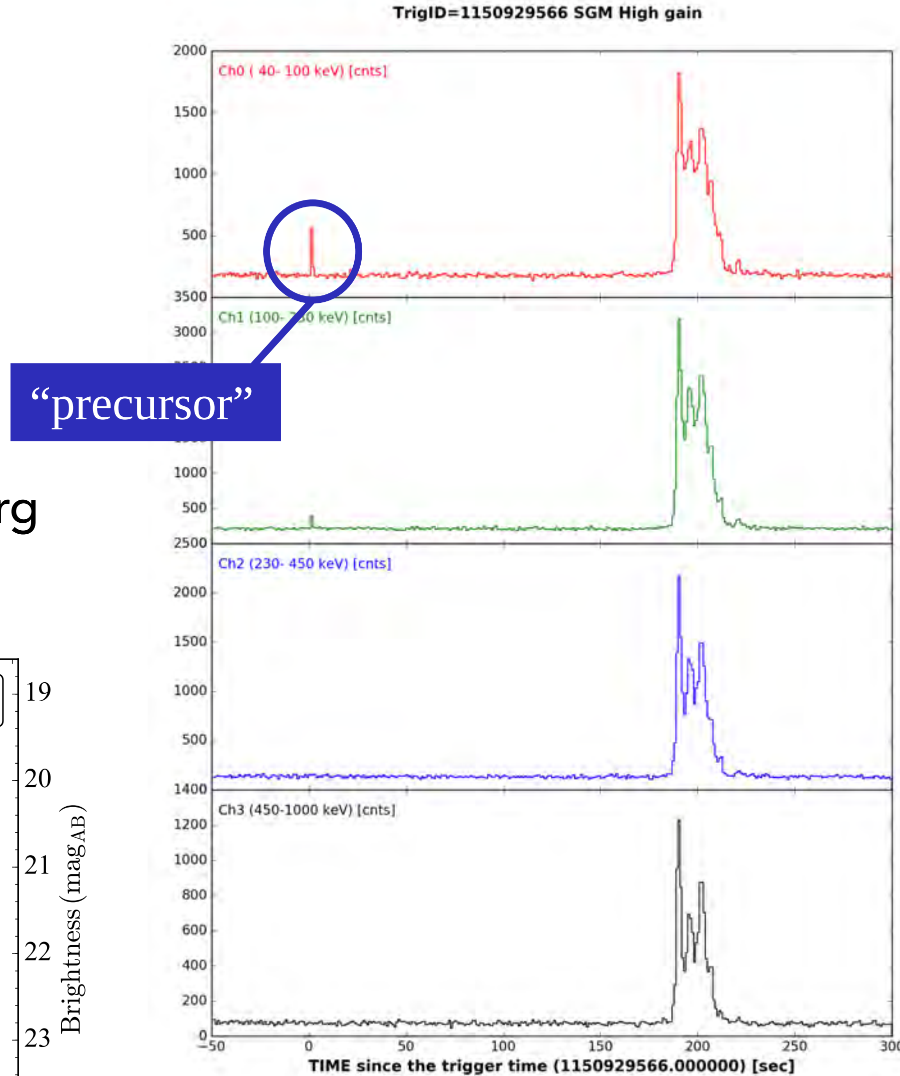
CALET, *Fermi*/GBM, *INTEGRAL* og Konus/*WIND*

Duration 460 s

z = 1.406

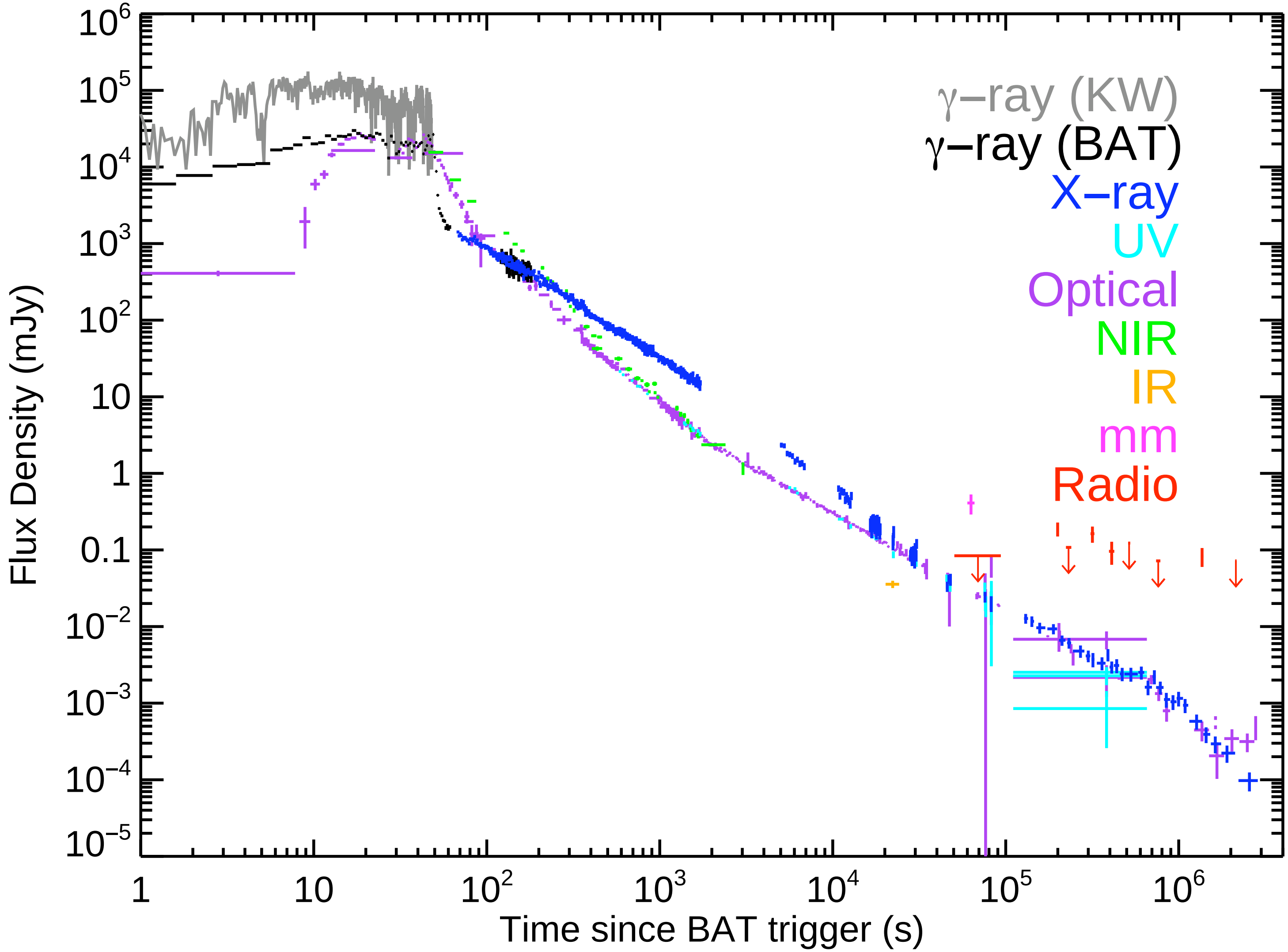
Isotropisk energy release: 4×10^{54} erg



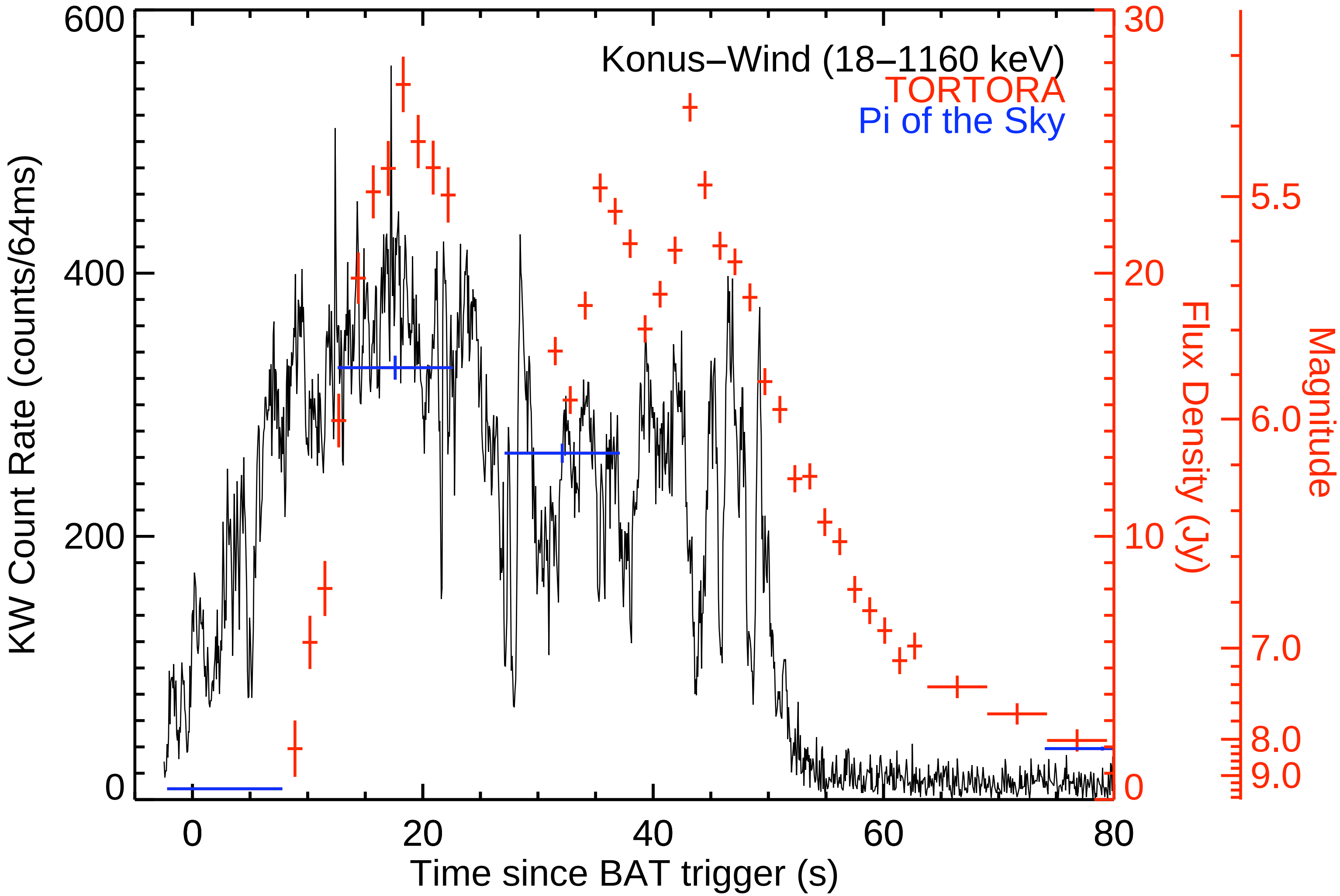


CALET SGM High gain light curve

Broadband Observations



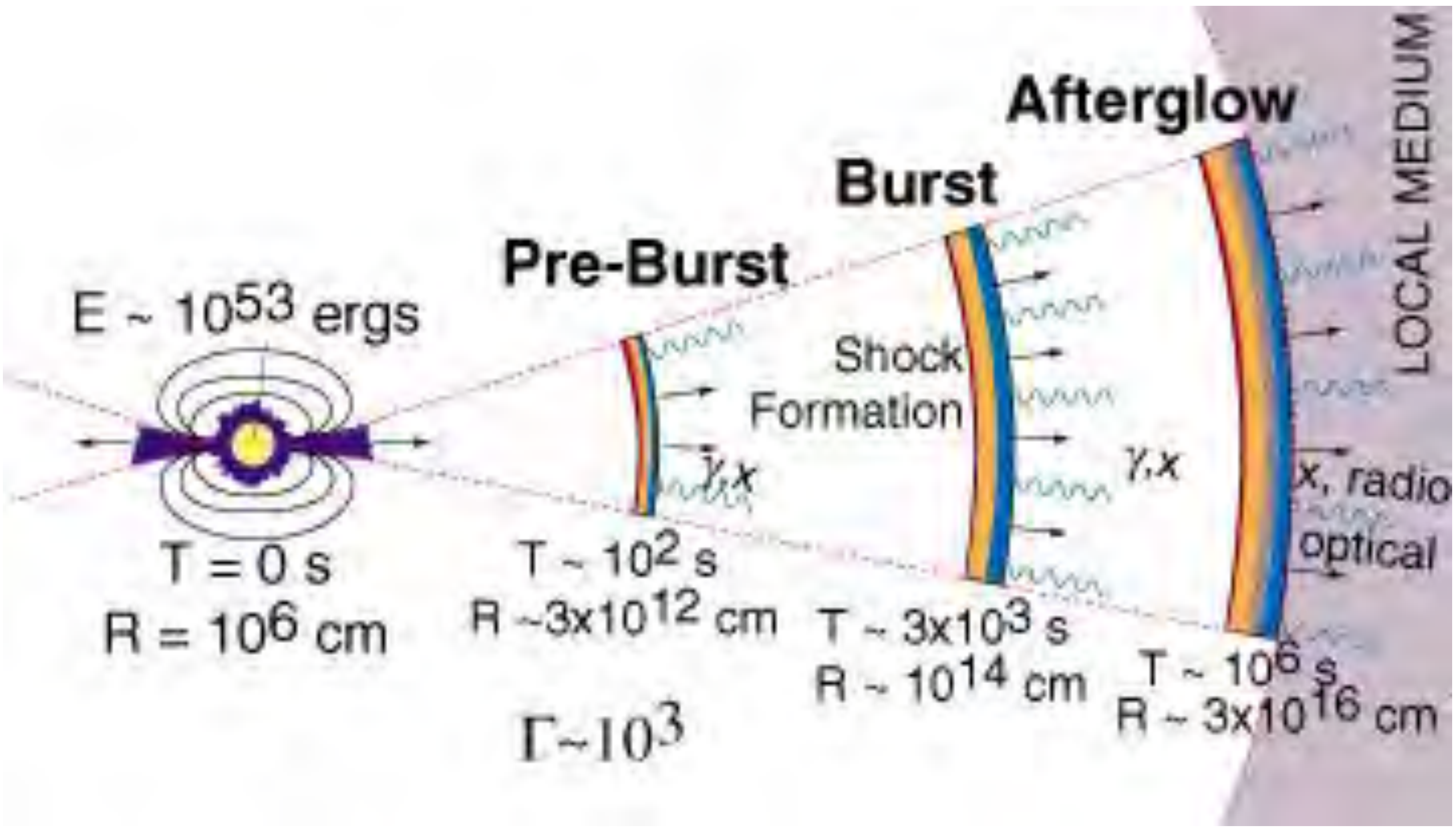
“Naked Eye Burst” (GRB080319B)



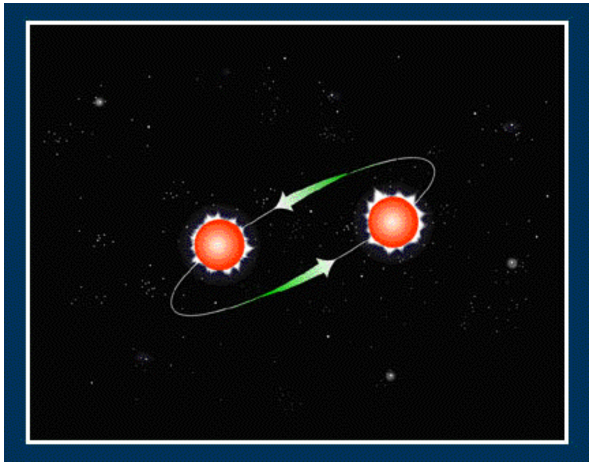
Conclusions

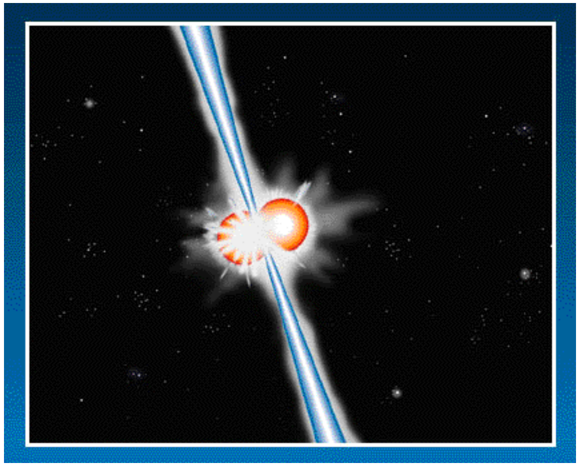
- Gamma-ray bursts are short intense bursts of γ-rays. They do not originate from the earth or the sun.
- GRBs are isotropically distributed on the sky.
- GRBs originate from galaxies at "cosmological" distances. Very energetic explosions. Synchrotron radiation from relativistic electrons?
- Connection to supernovae?
- Beaming: opening angles few degrees. There are many more GRBs than those we see.

Sketch model for GRBs

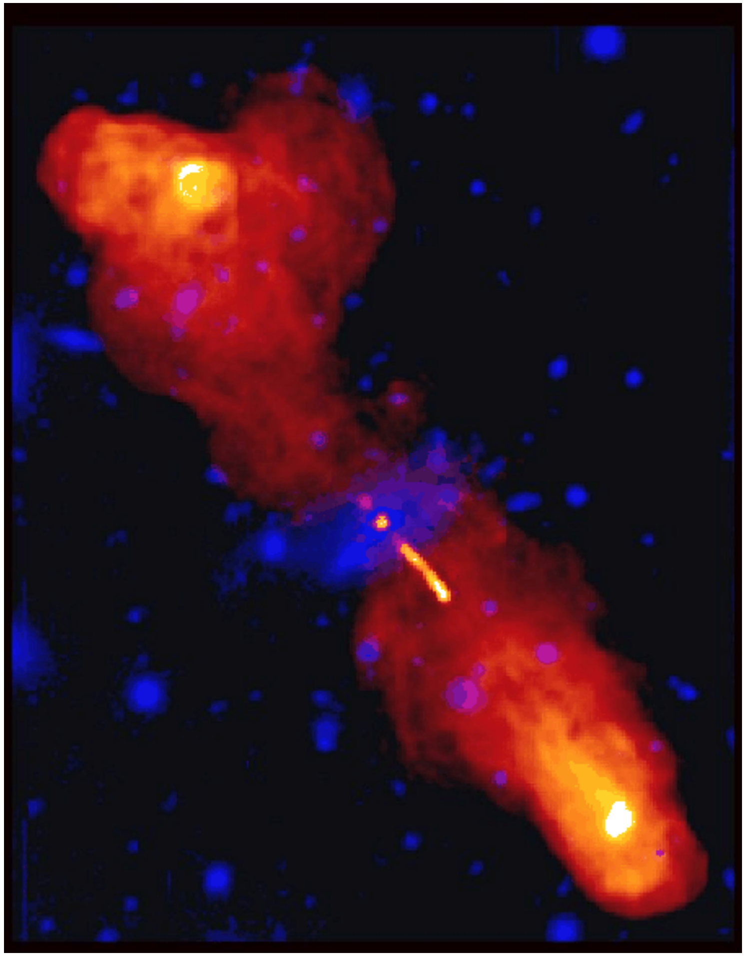


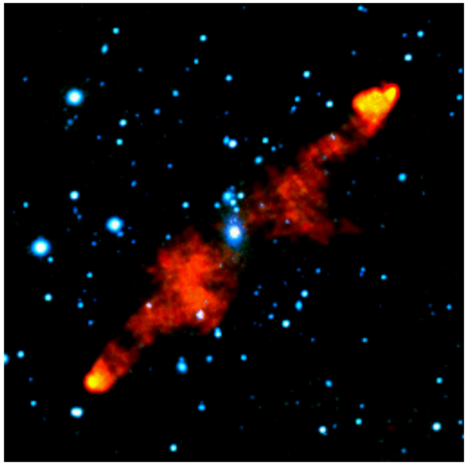
Likely "inner engines"

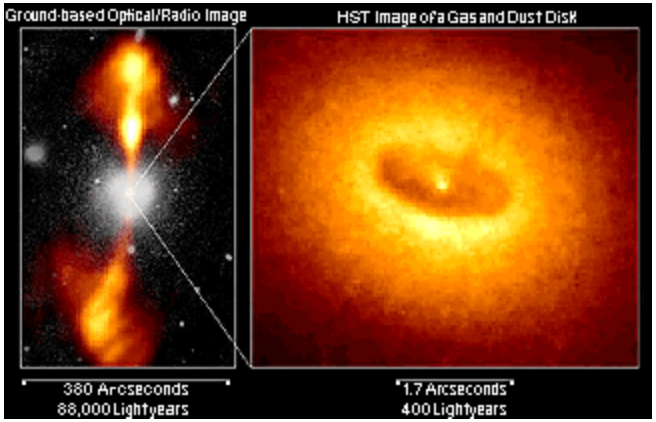


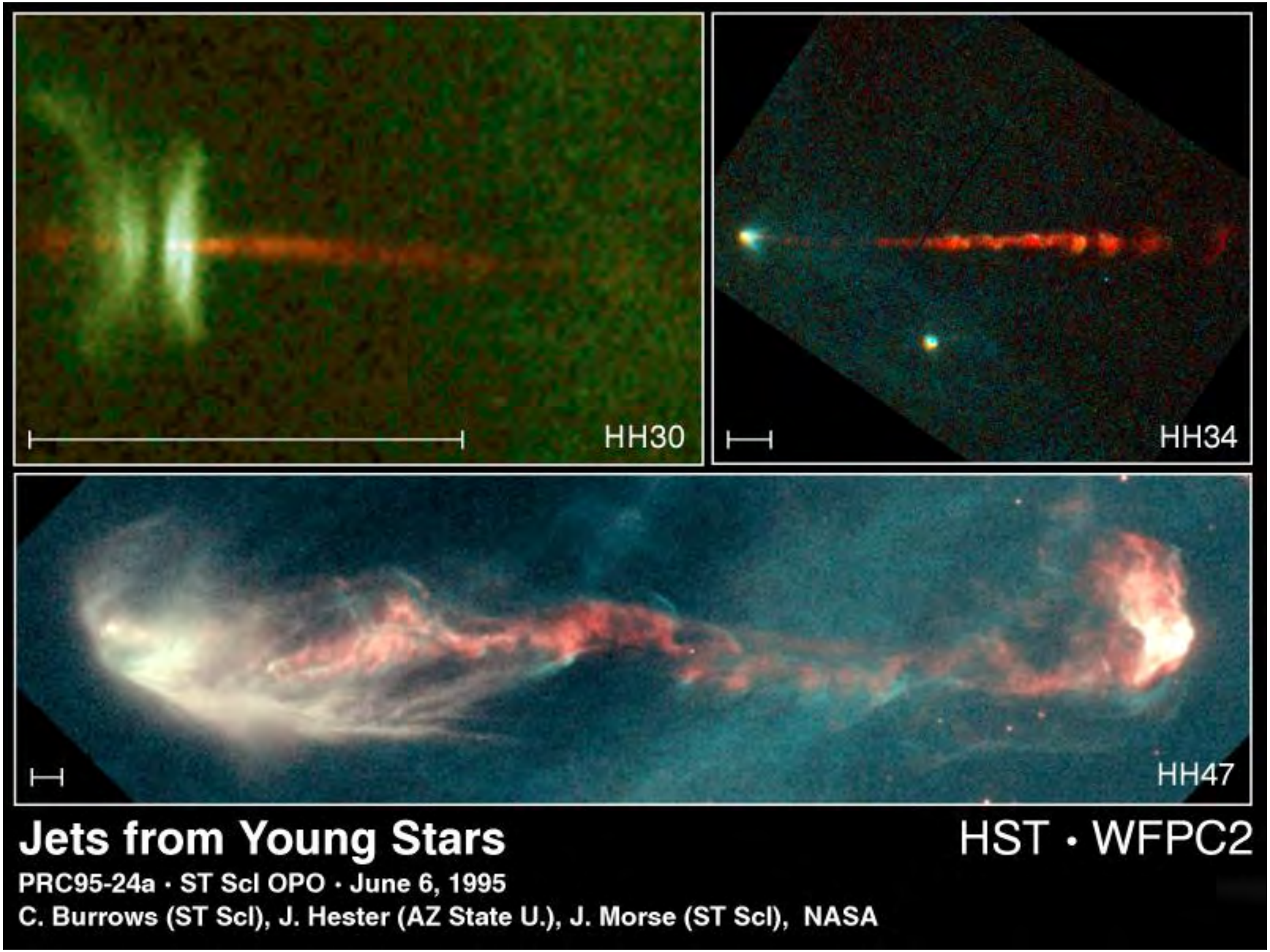


Other objects making jets



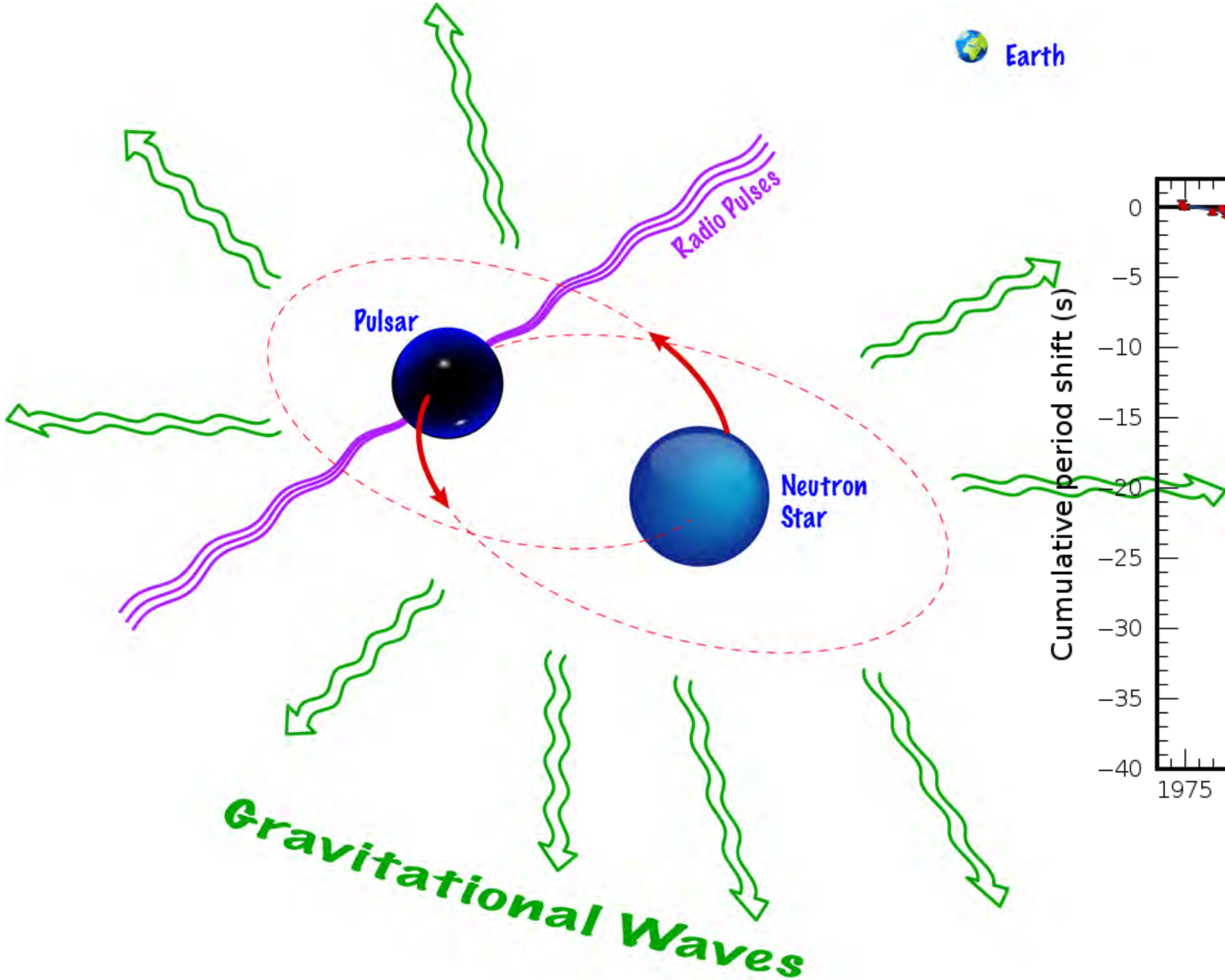


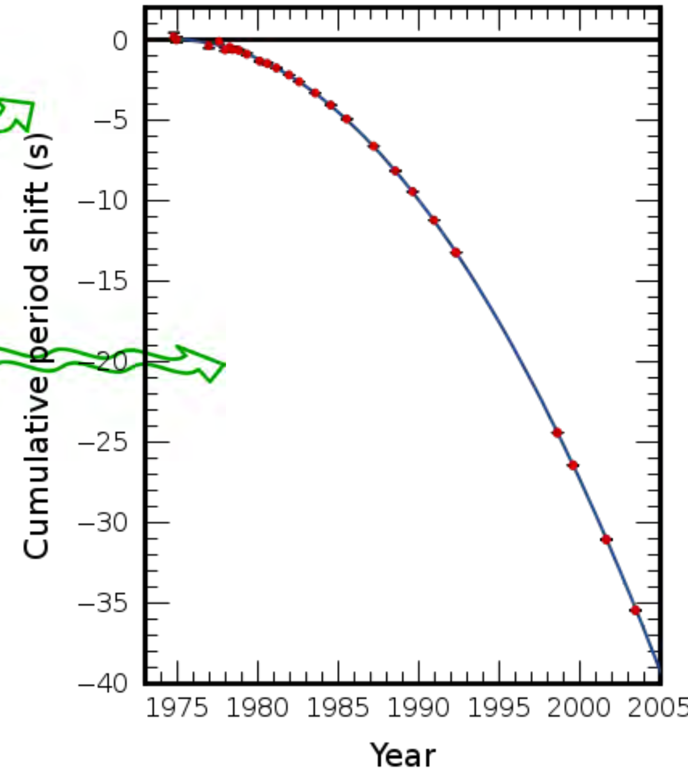



HH30
HH34
HH47
Jets from Young Stars
HST • WFPC2
PRC95-24a • ST ScI OPO • June 6, 1995
C. Burrows (ST ScI), J. Hester (AZ State U.), J. Morse (ST ScI), NASA

Independent evidence for colliding compact objects

Hulse-Taylor system





Selected for a Viewpoint in *Physics*

PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

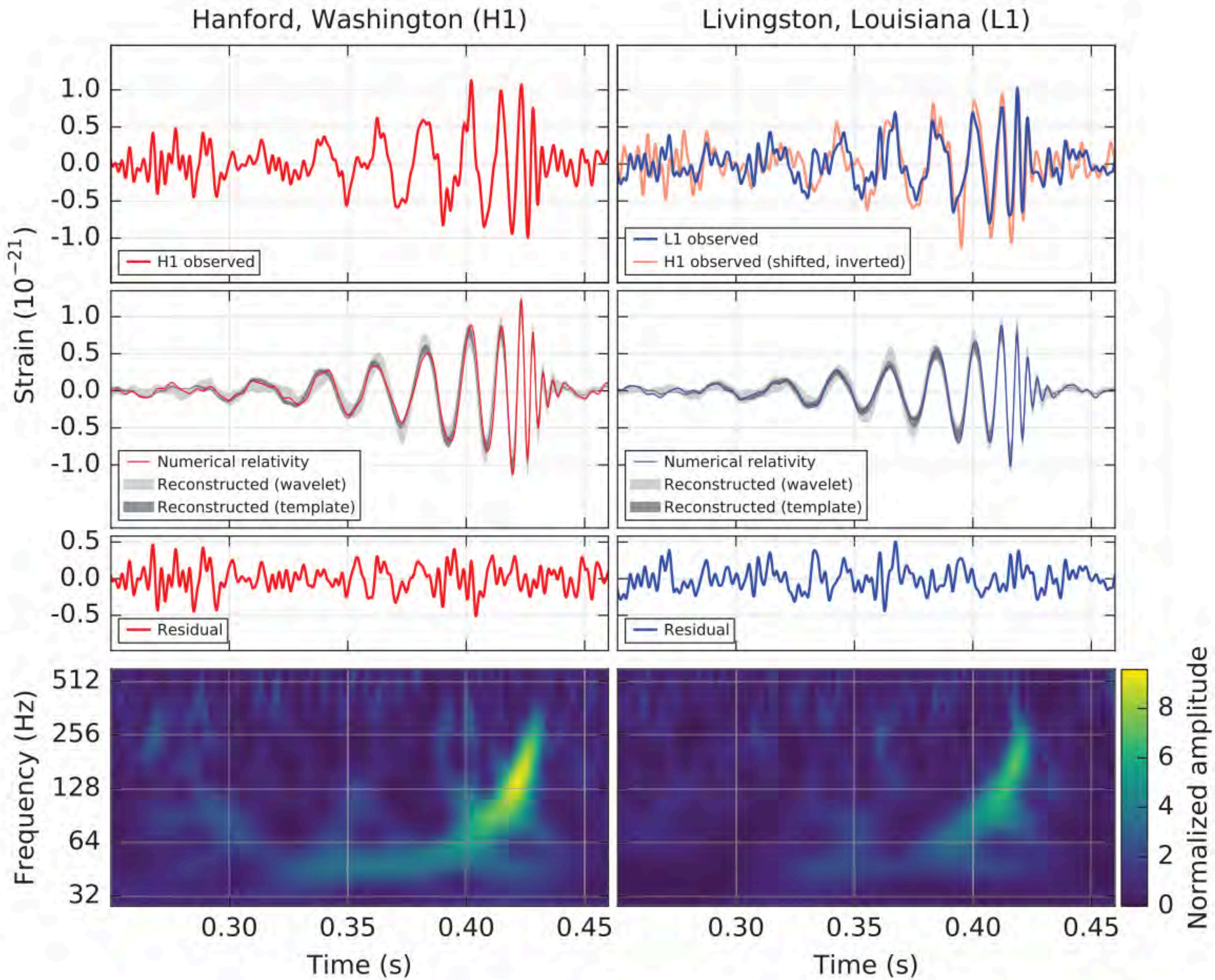
B. P. Abbott *et al.**

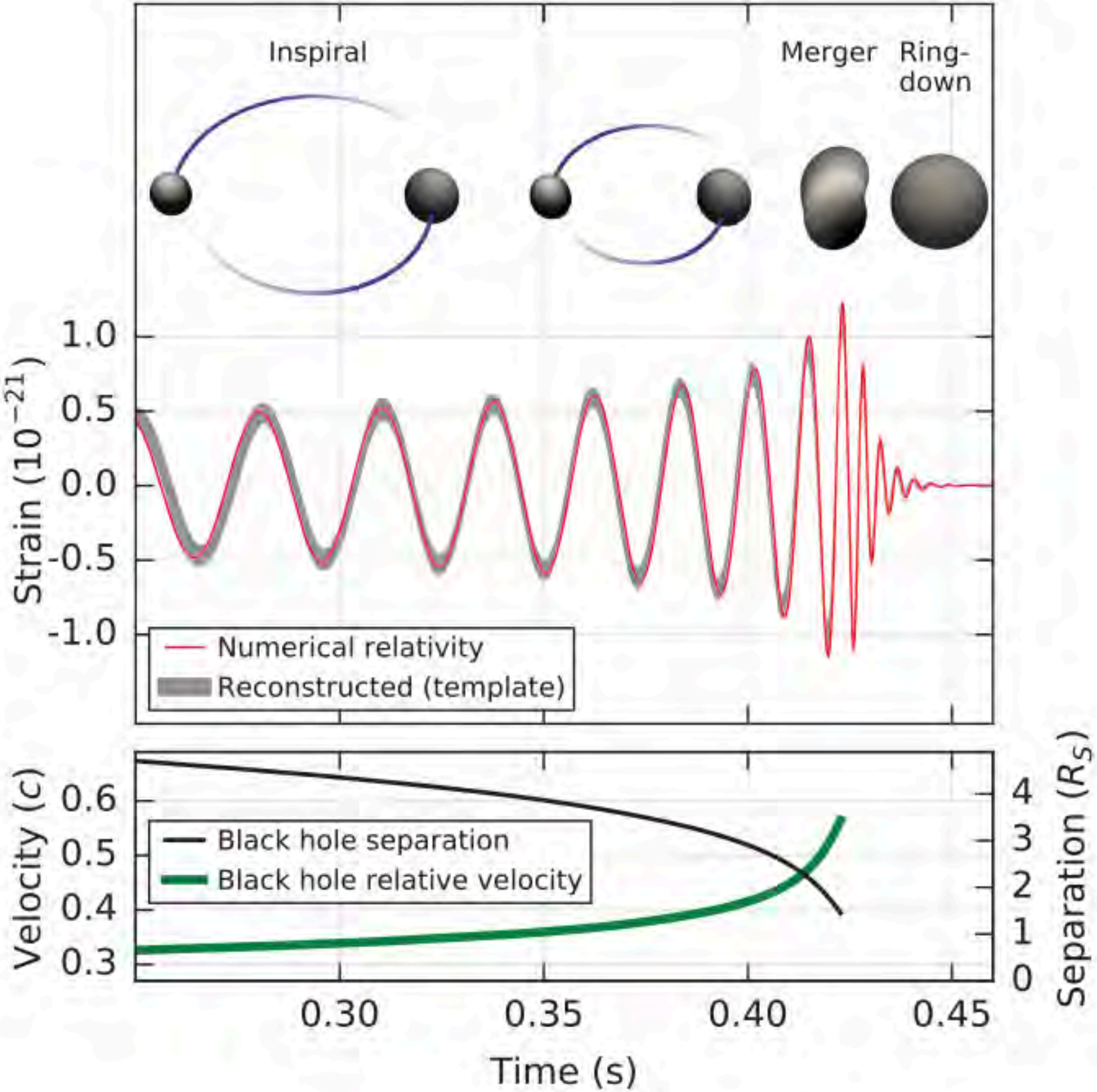
(LIGO Scientific Collaboration and Virgo Collaboration)

(Received 21 January 2016; published 11 February 2016)

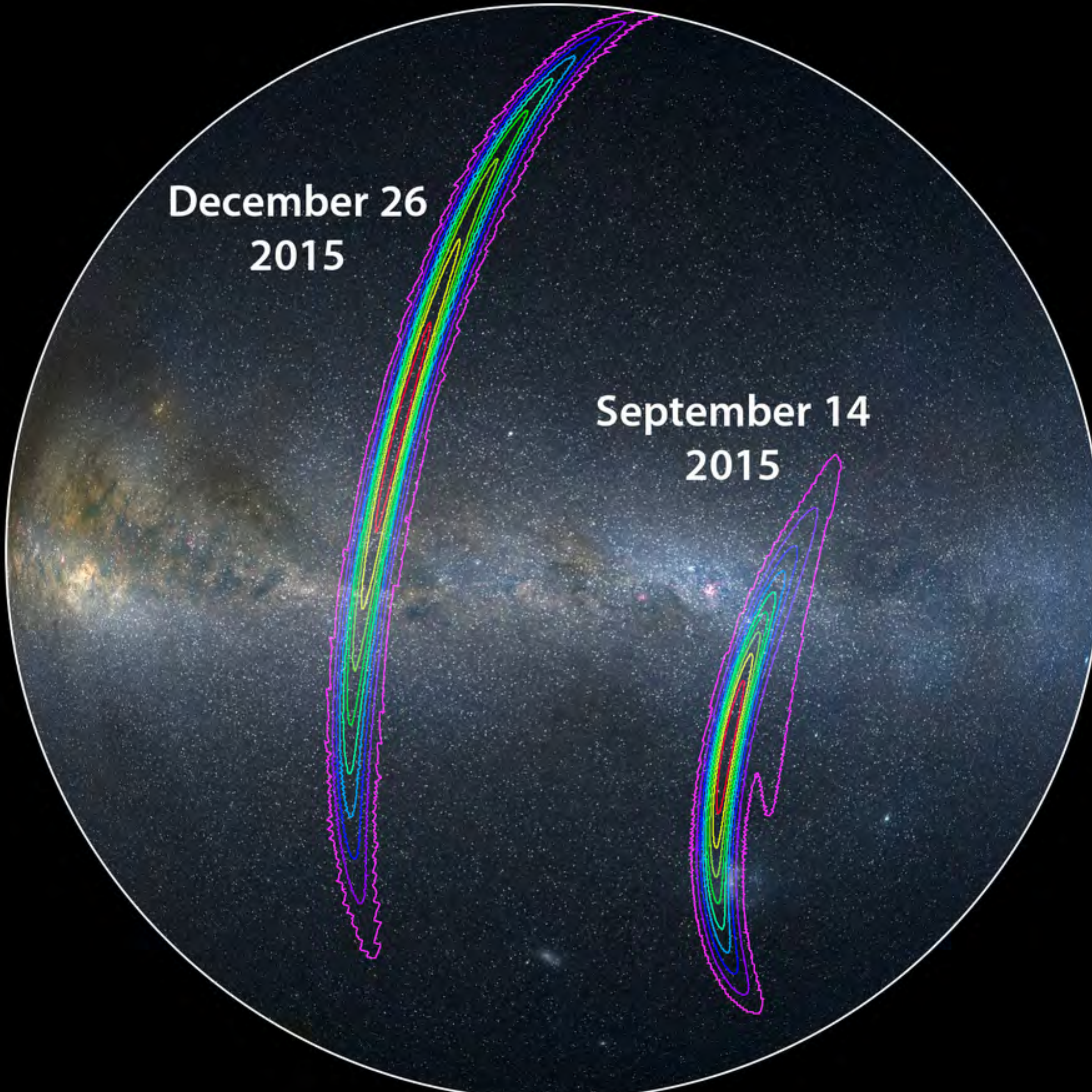
On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_\odot$ and $29^{+4}_{-4} M_\odot$, and the final black hole mass is $62^{+4}_{-4} M_\odot$, with $3.0^{+0.5}_{-0.5} M_\odot c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

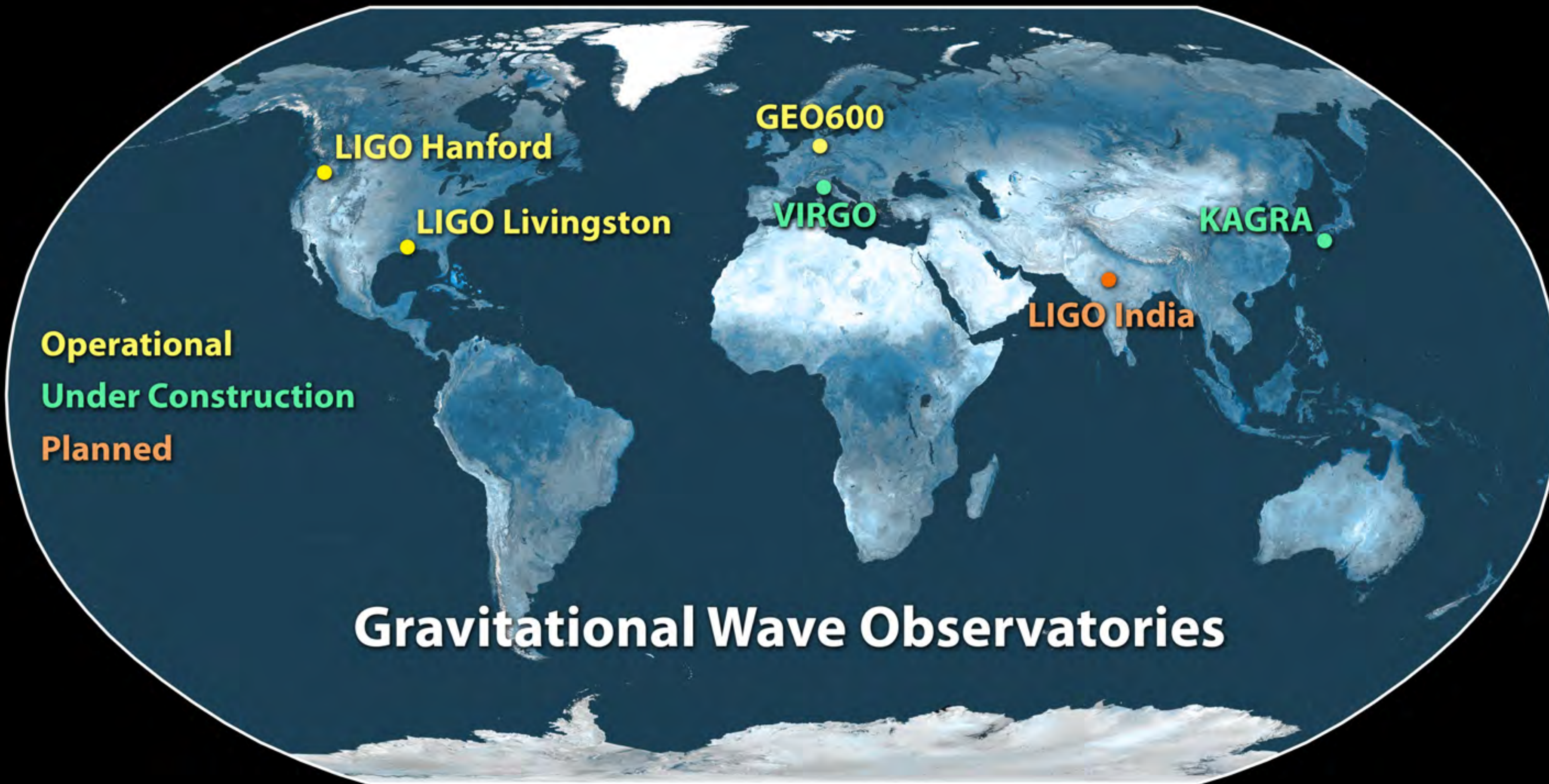
DOI: 10.1103/PhysRevLett.116.061102


Hanford, Washington (H1)
Livingston, Louisiana (L1)
Strain (10^{-21})
H1 observed
L1 observed
H1 observed (shifted, inverted)
Numerical relativity
Reconstructed (wavelet)
Reconstructed (template)
Residual
Frequency (Hz)
512
256
128
64
32
Normalized amplitude
Time (s)
0.30
0.35
0.40
0.45


Inspiral
Merger
Ring-down
Strain (10^{-21})
1.0
0.5
0.0
-0.5
-1.0
Numerical relativity
Reconstructed (template)
Velocity (c)
0.6
0.5
0.4
0.3
Black hole separation
Black hole relative velocity
Separation (R_S)
4
3
2
1
0
0.30
0.35
0.40
0.45
Time (s)

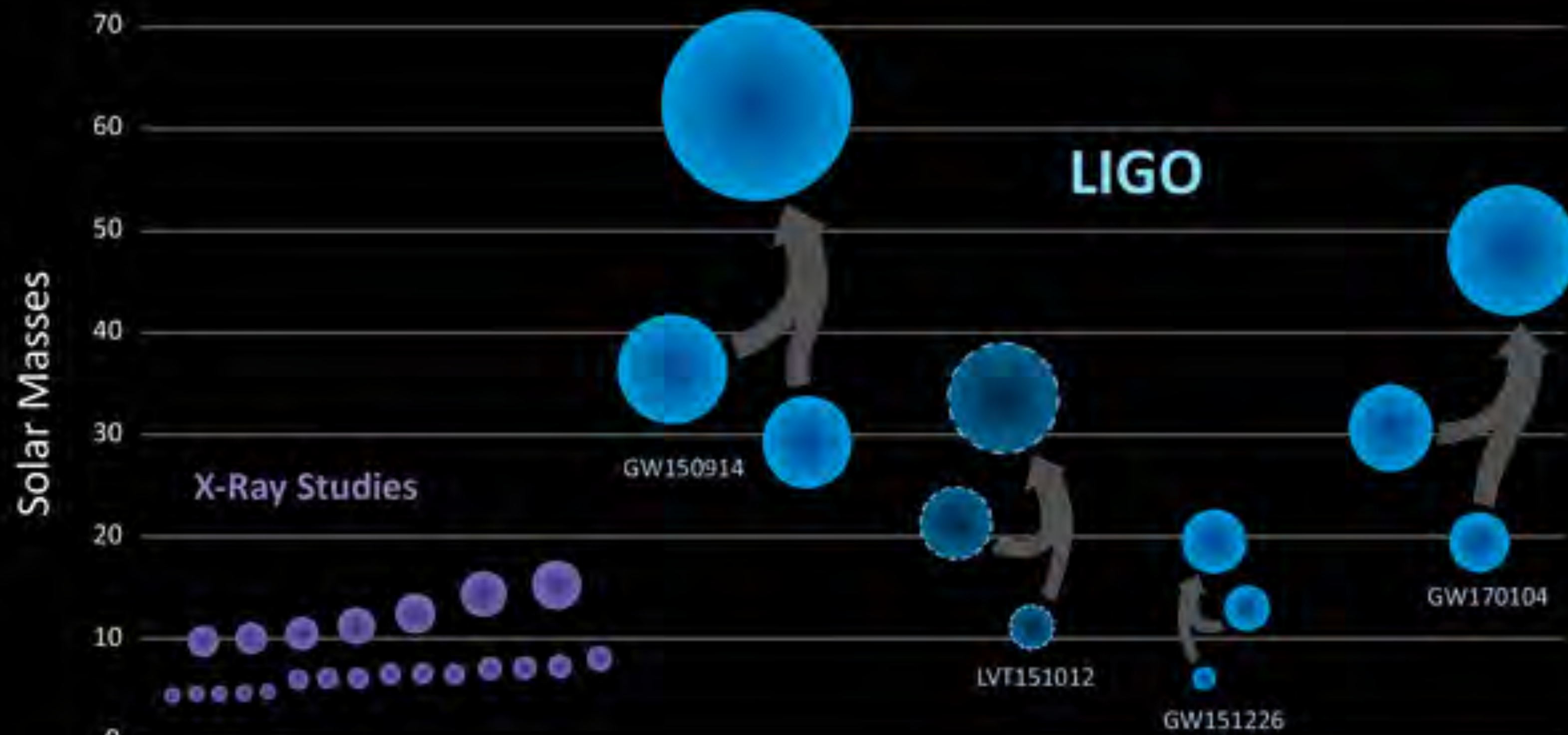
LIGO The LIGO Laboratory Sites


December 26
2015
September 14
2015



GEO600
LIGO Hanford
LIGO Livingston
VIRGO
KAGRA
LIGO India
Operational
Under Construction
Planned
Gravitational Wave Observatories

Black Holes of Known Mass

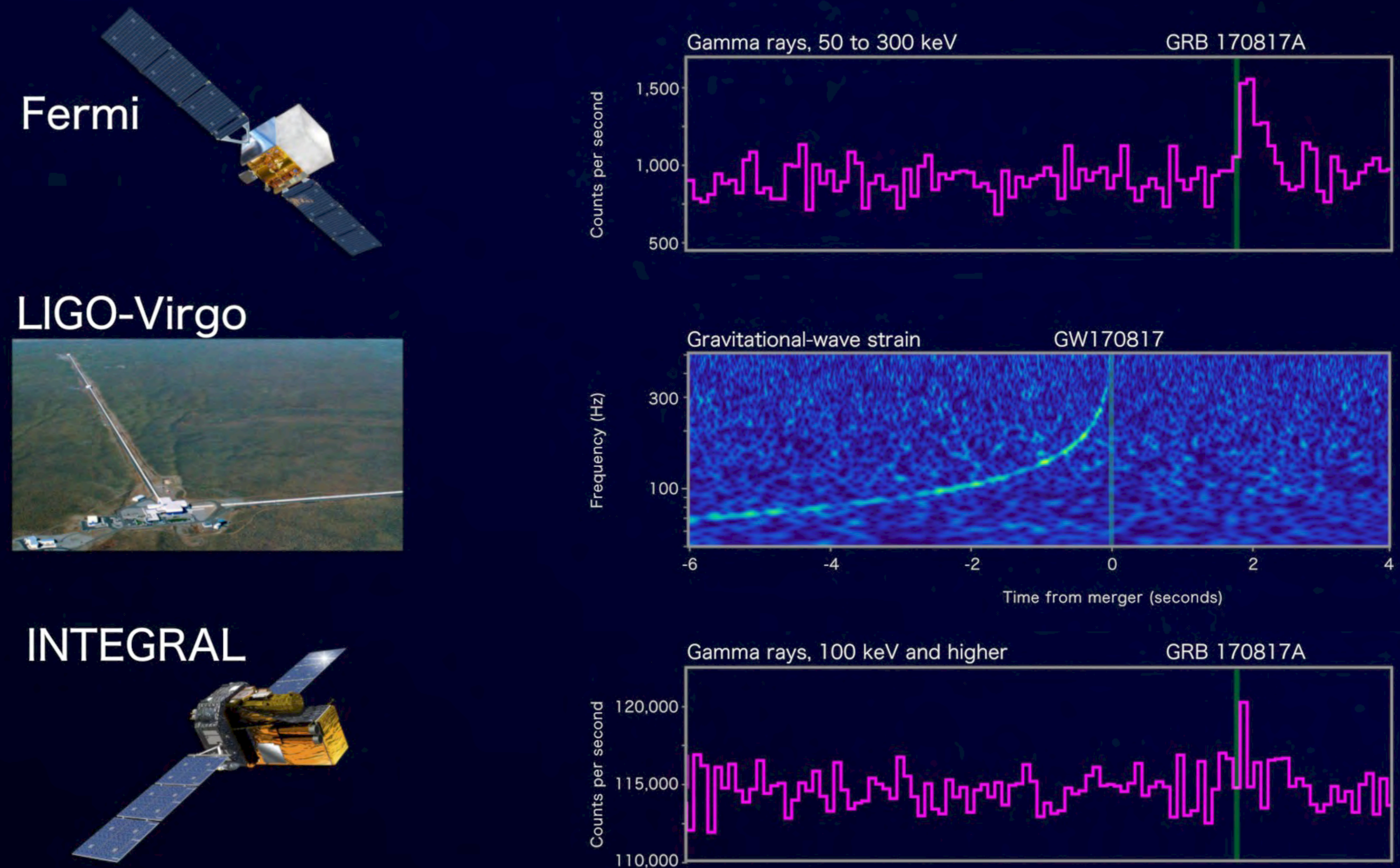


GW170817

- NS-NS merger in NGC4993 17. august

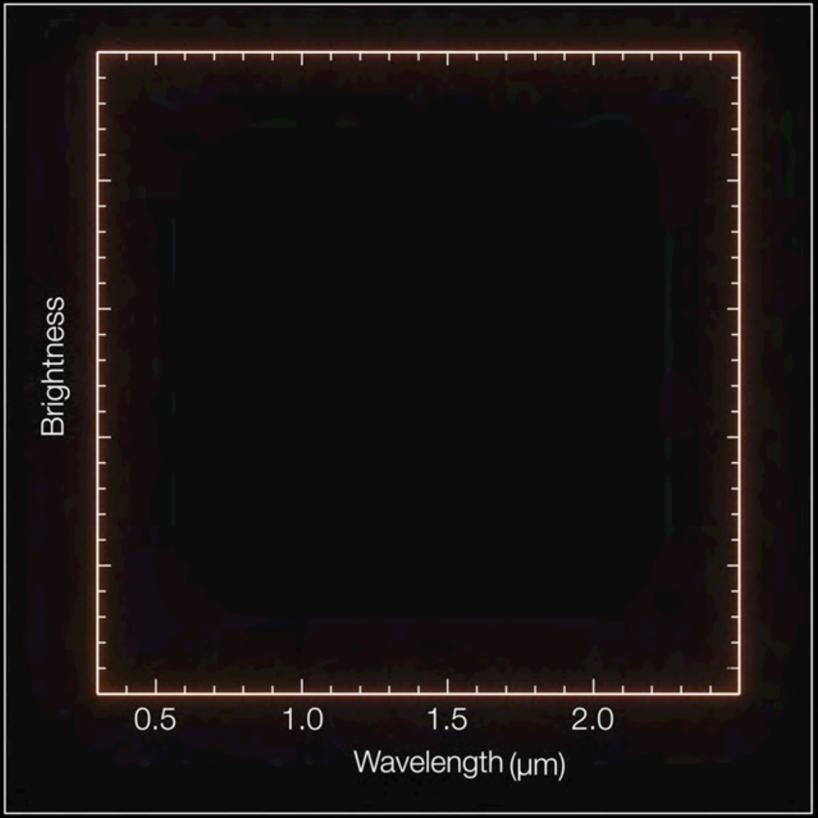
- https://telescoper.wordpress.com/2017/08/23/ligo-leaks-and-ngc-4993/

GW170817



Fermi
LIGO-Virgo
INTEGRAL
Gamma rays, 50 to 300 keV
GRB 170817A
Counts per second
1,500
1,000
500
Gravitational-wave strain
GW170817
Frequency (Hz)
300
100
-6
-4
-2
0
2
4
Time from merger (seconds)
Gamma rays, 100 keV and higher
GRB 170817A
Counts per second
120,000
115,000
110,000

GW170817



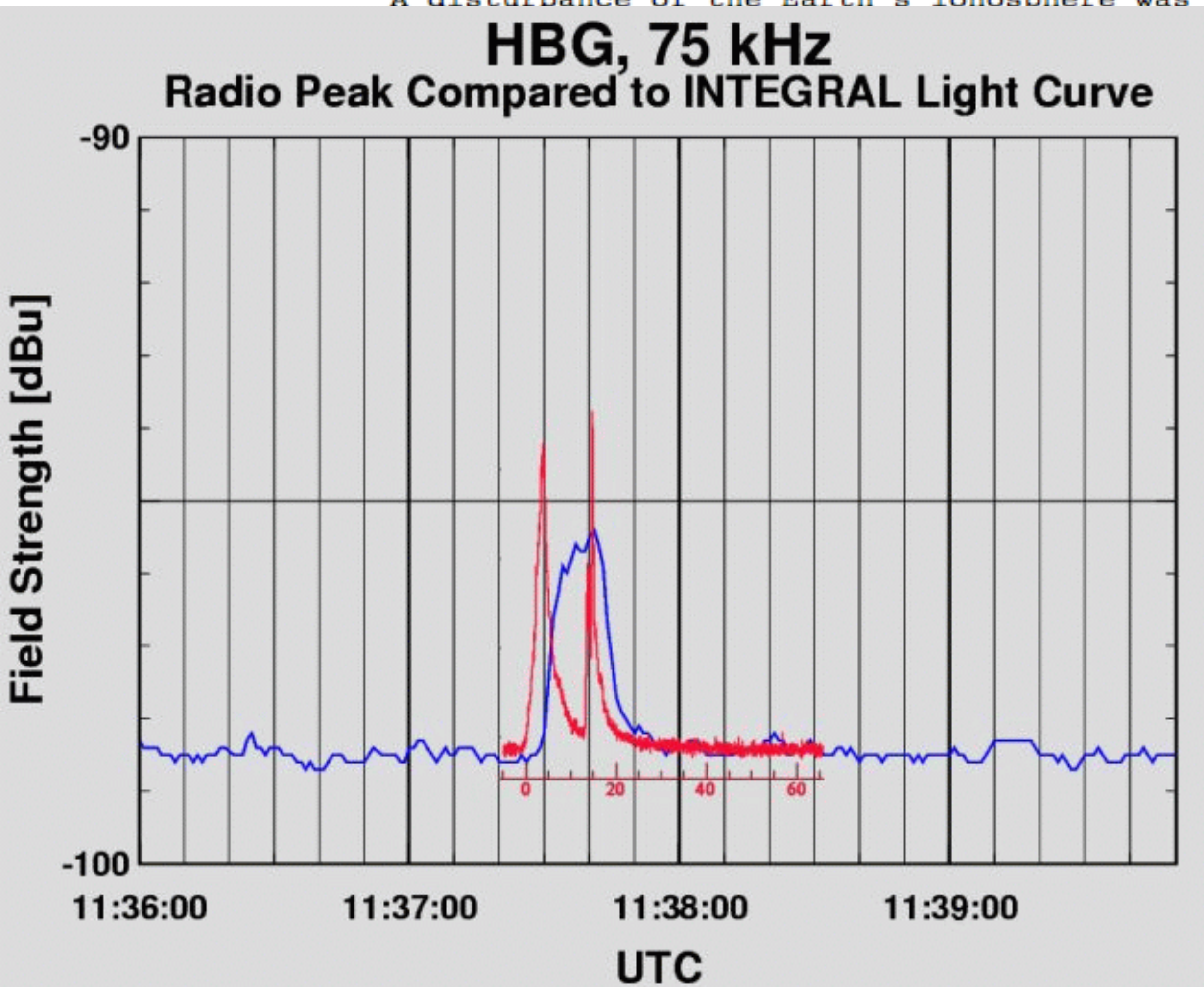
Time: -1225 days

Conclusions

- Gamma-ray bursts are short intense bursts of γ-rays. They do not originate from the earth or the sun.
- GRBs are isotropically distributed on the sky.
- GRBs originate from galaxies at “cosmological” distances. Very energetic explosions. Synchrotron radiation from relativistic electrons?
- Connection to supernovae?
- Beaming: opening angles few degrees. There are many more GRBs than those we see.
- (Some) short GRBs are caused by merging neutron stars

P.W. Schnoor, D.L. Welch, G.J. Fishman and A. Price report, on behalf of the AAVSO GRB-SID Network, on the detection of GRB030329 as a sudden ionospheric disturbance (SID), observed by Peter Schnoor of Kiel, Germany.

A disturbance of the Earth's ionosphere was observed coincident with the



en as an increase in the signal
con received in Kiel, transmitted
ear Geneva, 920 km from the
on of GRB030329; this
and/or gamma-rays from GRB030329
the radio propagation properties
urst longitude and latitude and
ons and monitoring stations, this
) where GRB030329 illuminated the

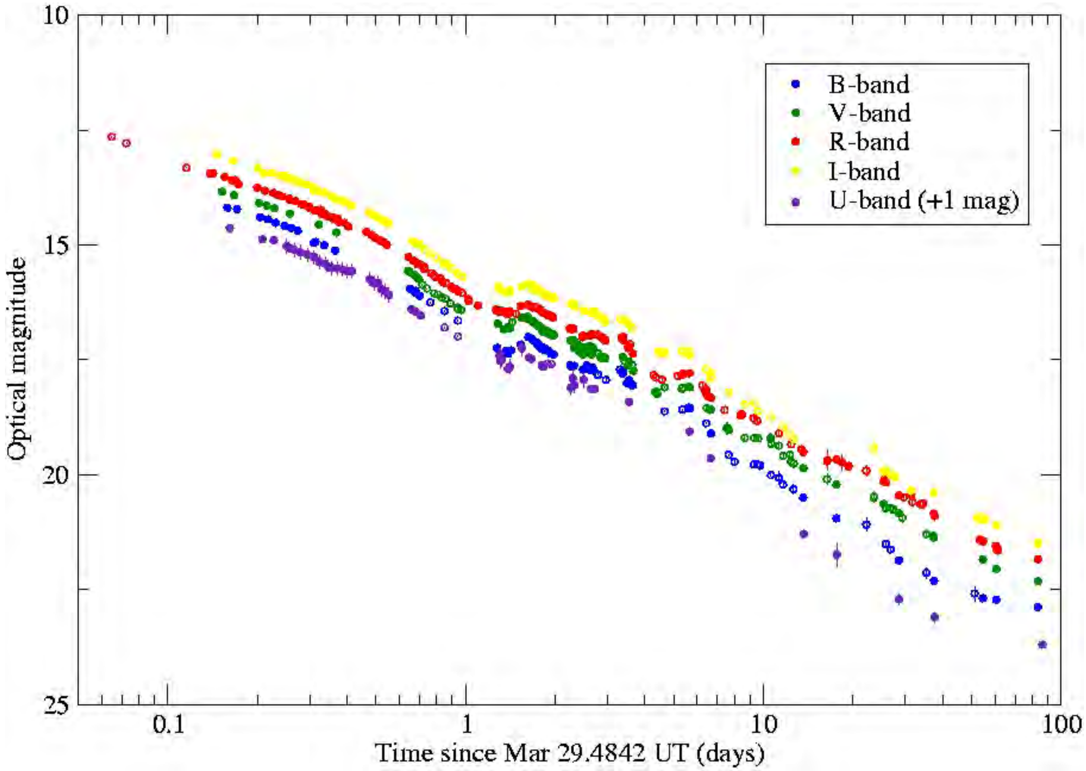
g one with an overlay of
he URL
sid/index.html
so available at this site.

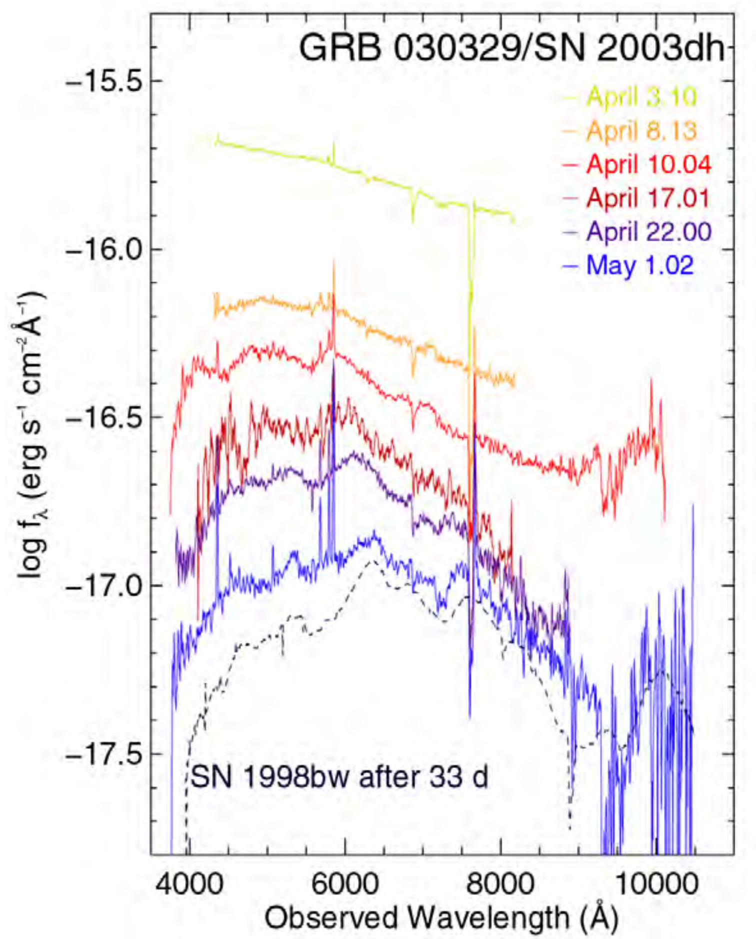
antitative, future observations
urement to be made of the prompt,
incident at the Earth over an
nt is not now attainable with any
launch of the NASA GLAST mission

high-energy sources have
, as measured with VLF
re v.331, p.418, 1988); XRF
er-flare from SGR 1900+14 (Inan,
999).

The AAVSO SID-GRB network is a worldwide network of observers monitoring VLF and LF beacons for SIDs of non-solar origin. The AAVSO Solar Committee has been monitoring and reporting solar-induced SIDs since the 1950's. This group intends to continue and expand this monitoring network.

GRB 030329 optical afterglow and SN

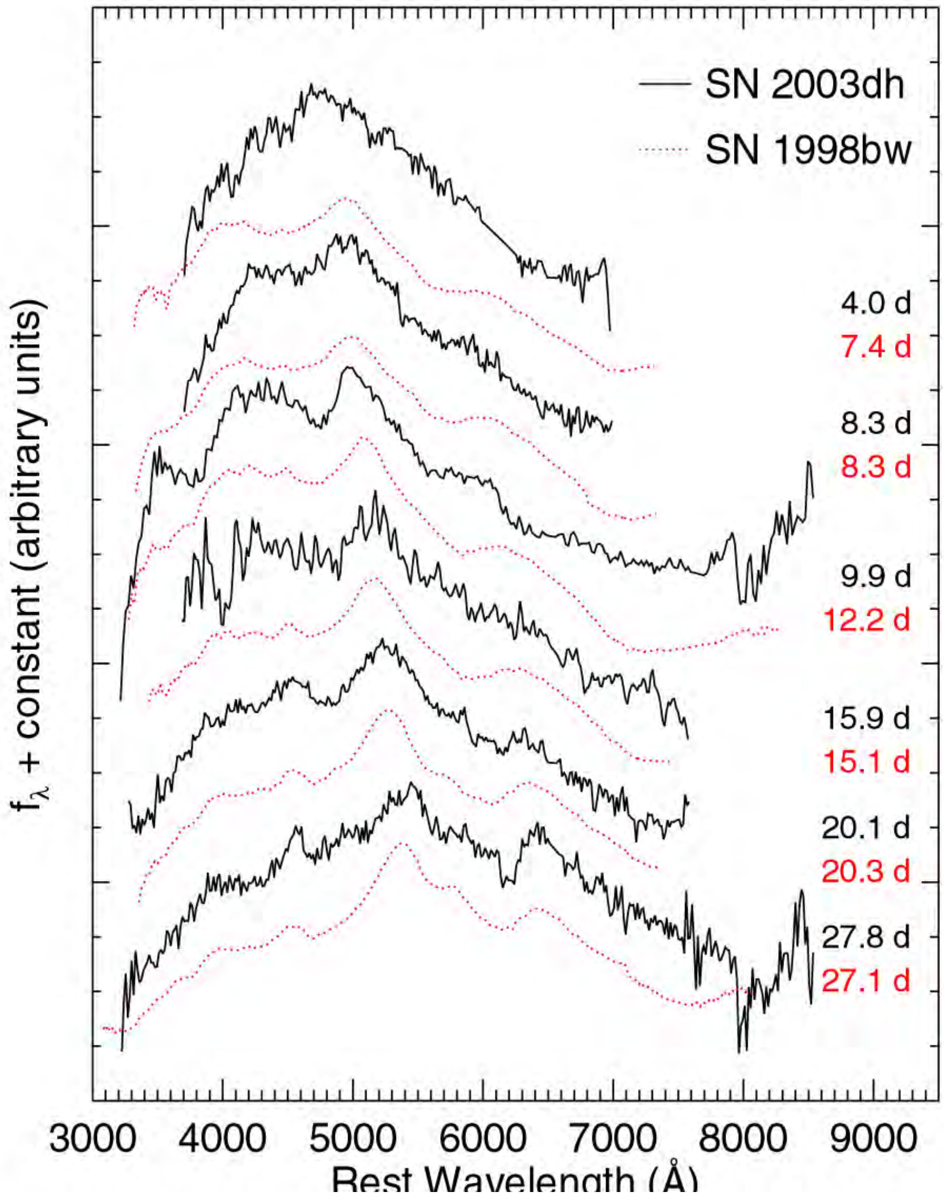




Redshift: z=0.1685 (0.810 Gpc).

Afterglow: very bright X-ray/optical/radio

SN 2003dh/GRB030329



Very similar to SN1998bw:

-broad lines ® large Expansion velocity

- type Ic (no H or He abs.)
- very bright
- "Hypernova"

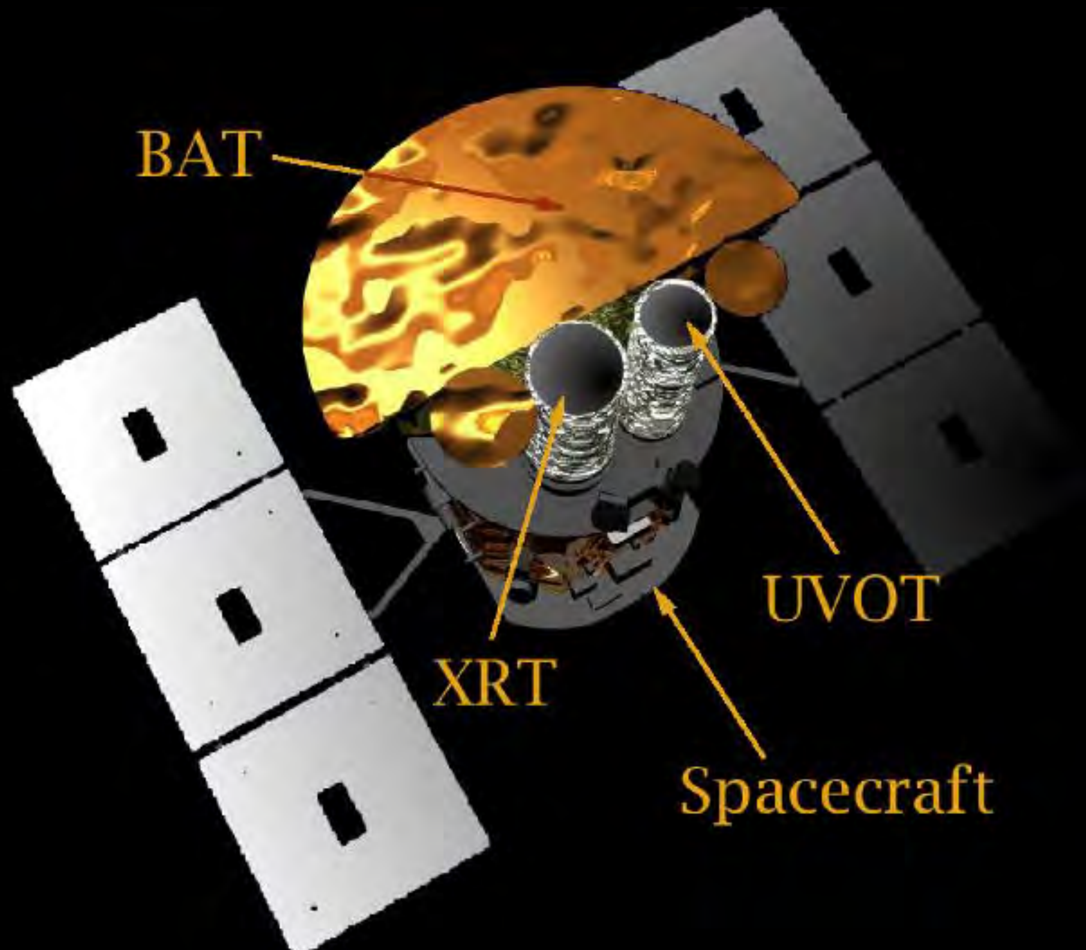
® Progenitor Wolf Rayet star ("envelope stripped").

Conclusions

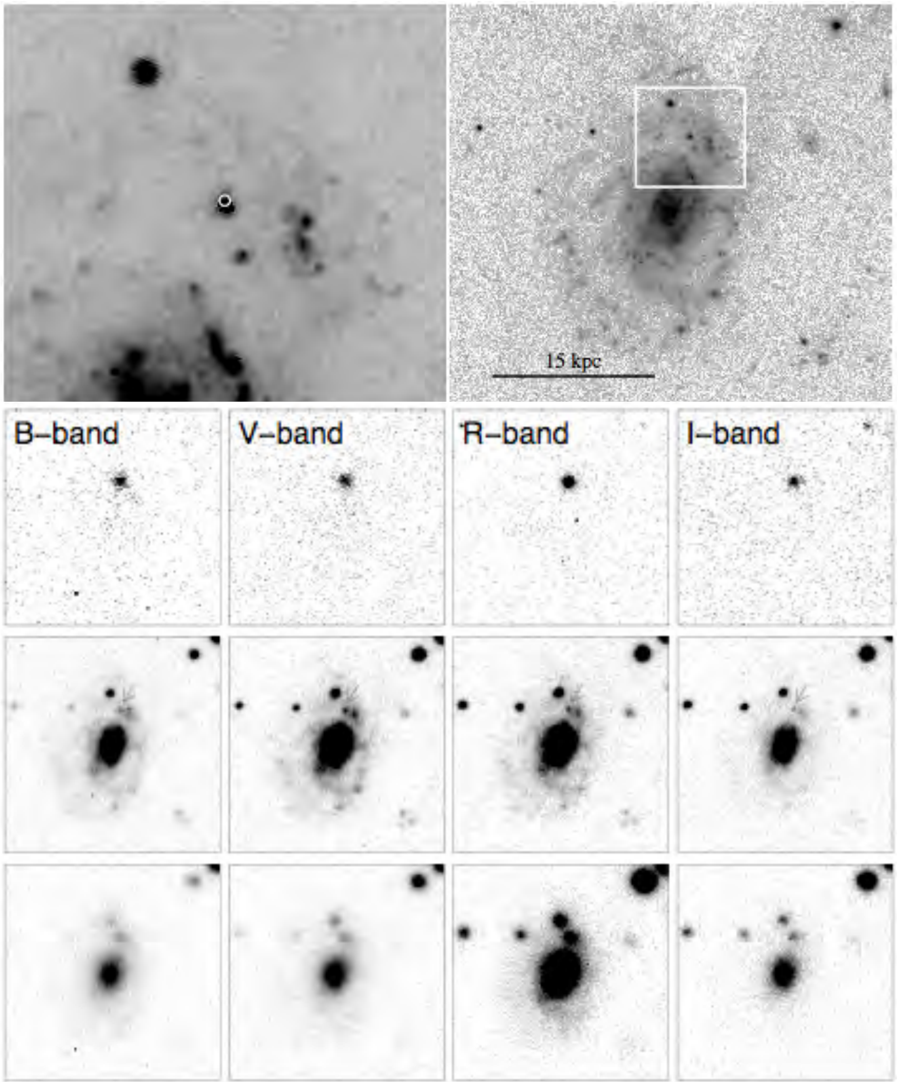
- Gamma-ray bursts are short intense bursts of γ-rays. They do not originate from the earth or the sun.
- GRBs are isotropically distributed on the sky.
- GRBs originate from galaxies at "cosmological" distances. Very energetic explosions. Synchrotron radiation from relativistic electrons?
- Connection to supernovae?
- Beaming: opening angles few degrees. There are many more GRBs than those we see.
- (Some) short GRBs are caused by merging neutron stars.
- GRBs and supernovae type Ic firmly connected.

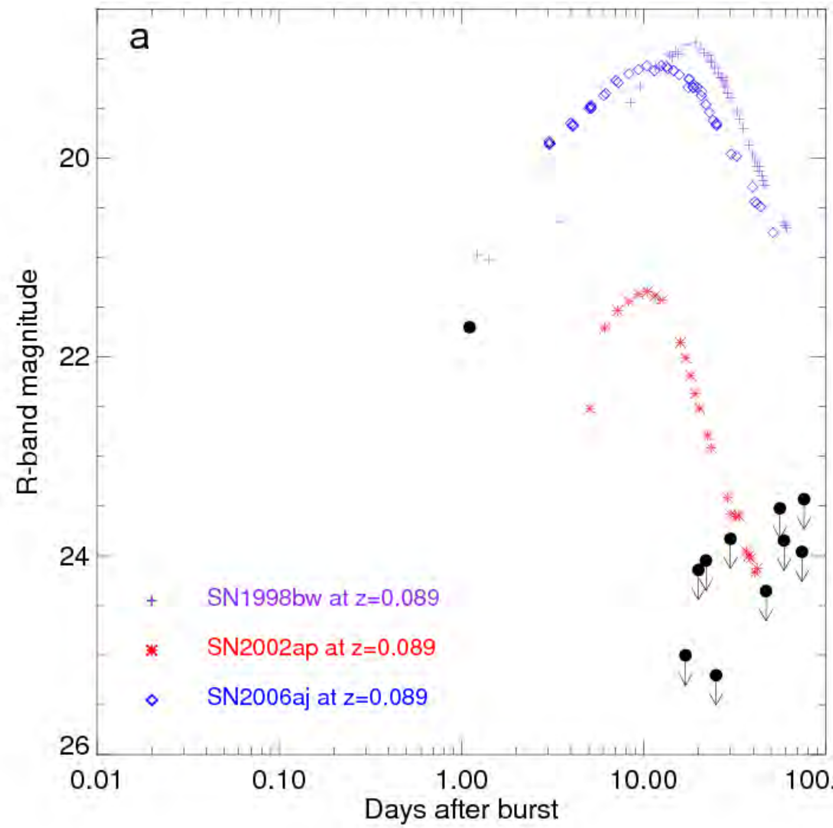
Latest GRB satellite: Swift (2. november 2004)

-More detections (1 per weak)
-More precise positions
 BAT: 1-3 arcmin / 100%
 XRT: 2-6 arcsec / >90%
 UVOT: <1 arcsec / 30%
-More rapid (few sec after the bursts)



GRB060505: Can massive stars die without supernova-explosions?



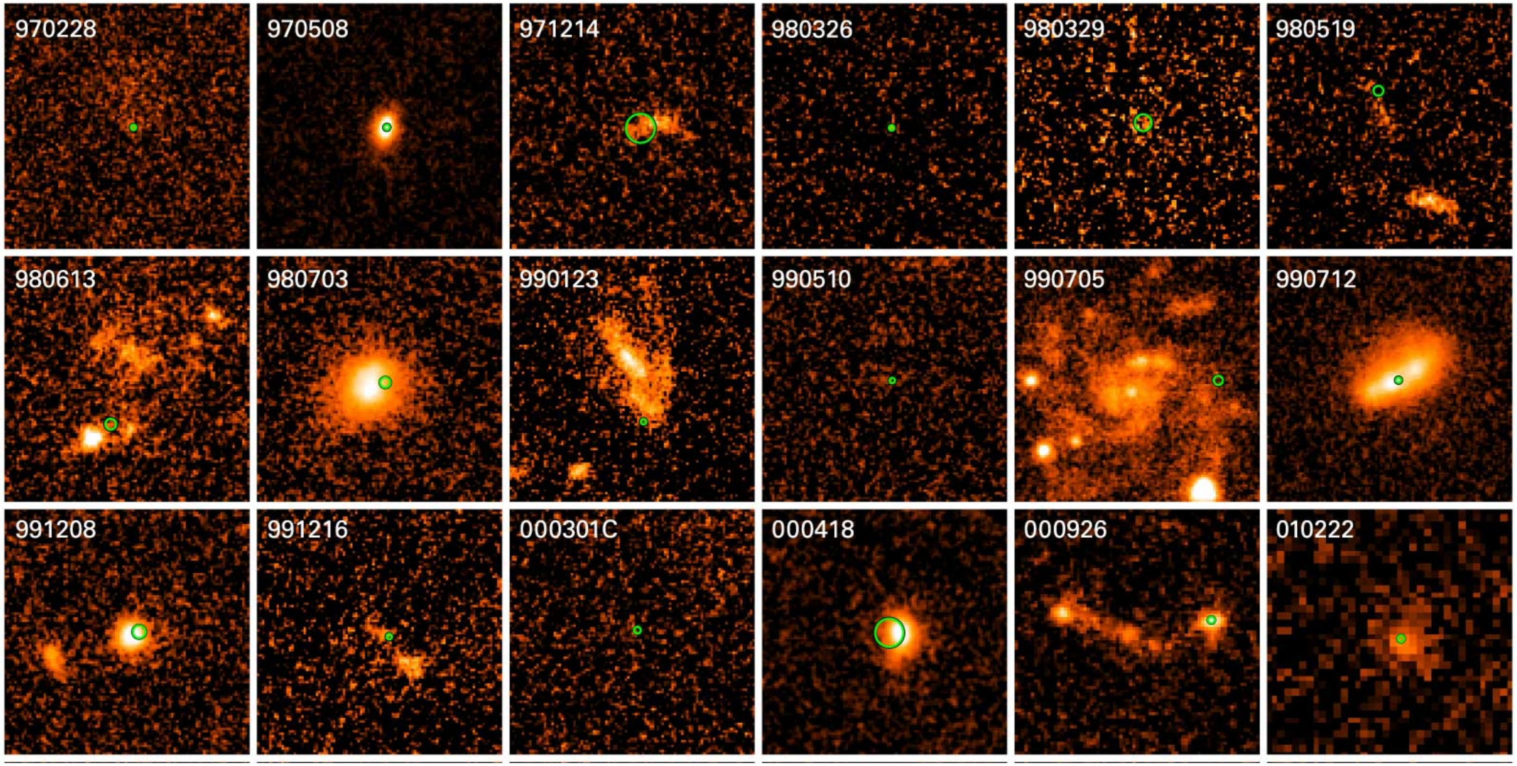


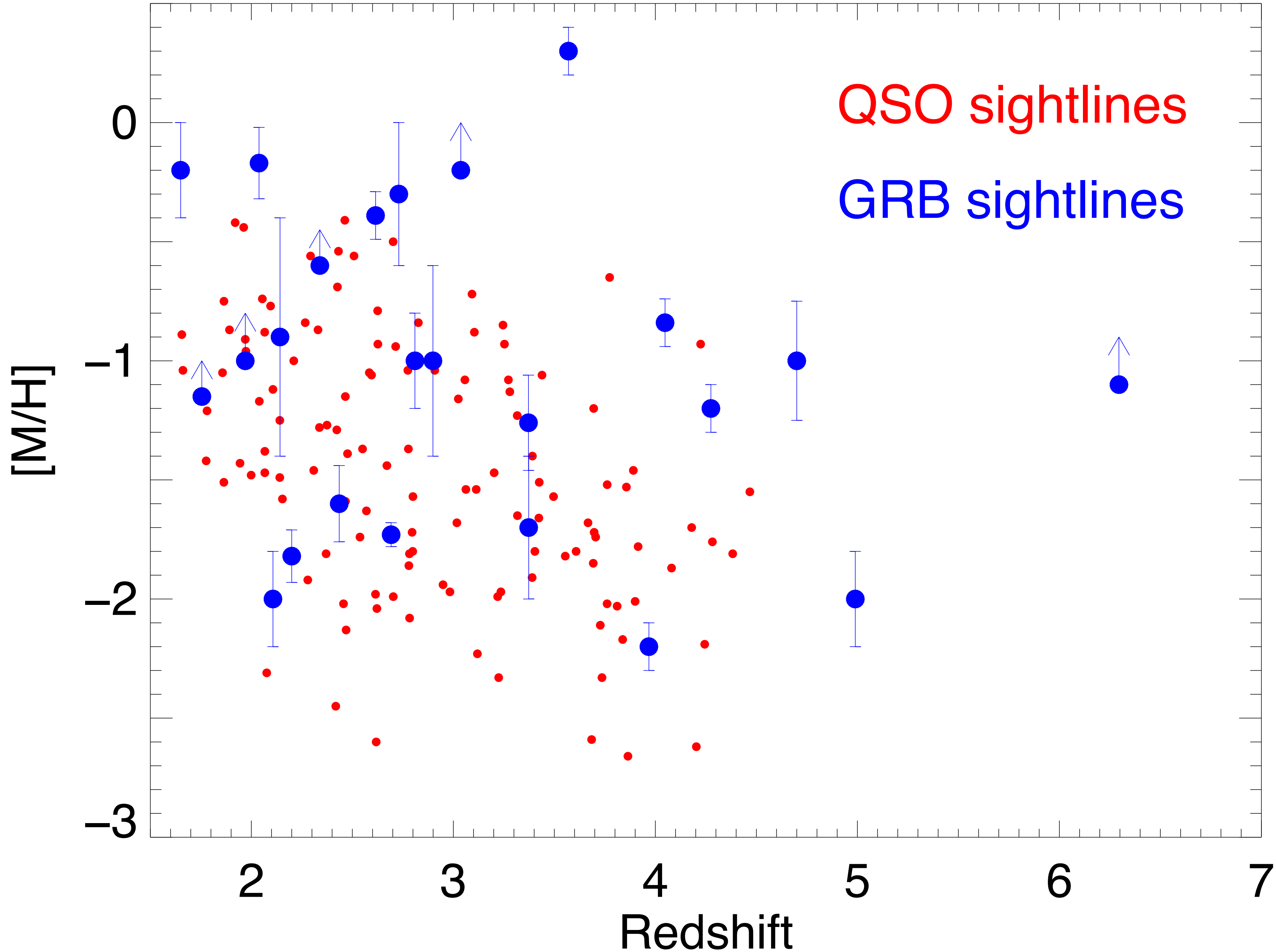
Conclusions

- Gamma-ray bursts are short intense bursts of γ-rays. They do not originate from the earth or the sun.
- GRBs are isotropically distributed on the sky.
- GRBs originate from galaxies at "cosmological" distances. Very energetic explosions. Synchrotron radiation from relativistic electrons?
- Connection to supernovae?
- Beaming: opening angles few degrees. There are many more GRBs than those we see.
- (Some) short GRBs are caused by merging neutron stars.
- GRBs and supernovae type Ic firmly connected.
- **Not all long GRBs associated with SNe!?**

What are we we doing now?

- We try to buld a statistical sample of GRBs to probe star formation and galaxies through out osmic history. Hard work, but very interesting...





D’Elia et al. (2010), Thöne et al. (2012); Sparre et al. in prep.; D’Elia et al., in prep; Savaglio et al (2012)

Thanks for your attention…

Astronomisk.dk