From Gamma-Ray Bursts (GRBs) to Fast Radio Bursts (FRBs): Unveiling the Mystery of Cosmic Bursting Sources

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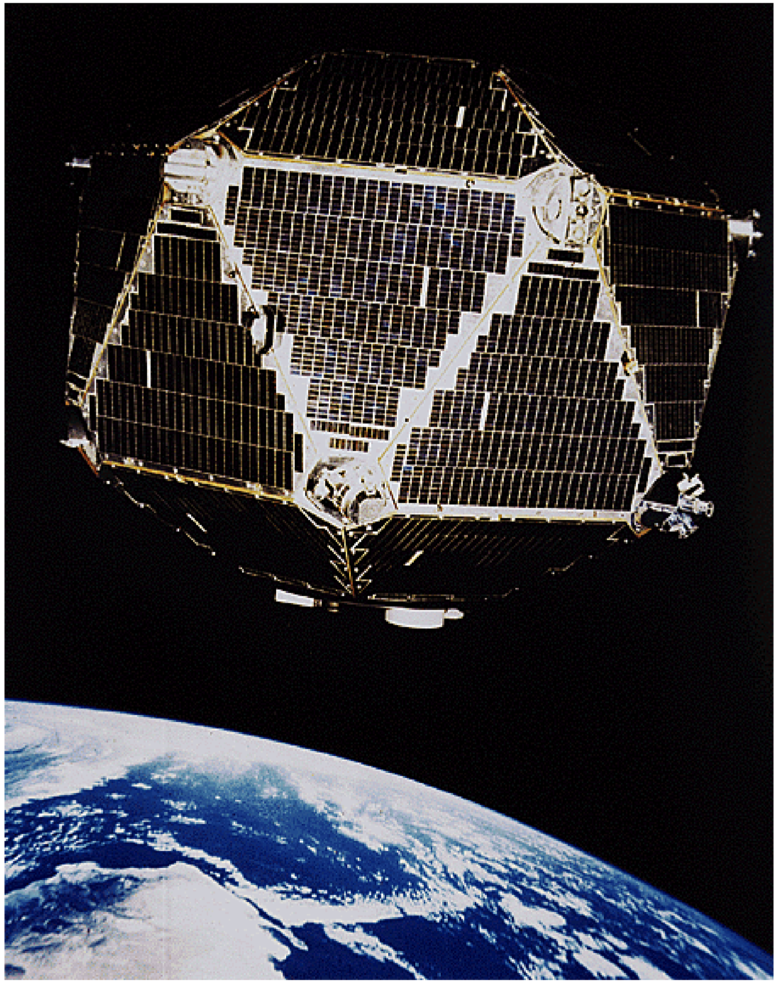
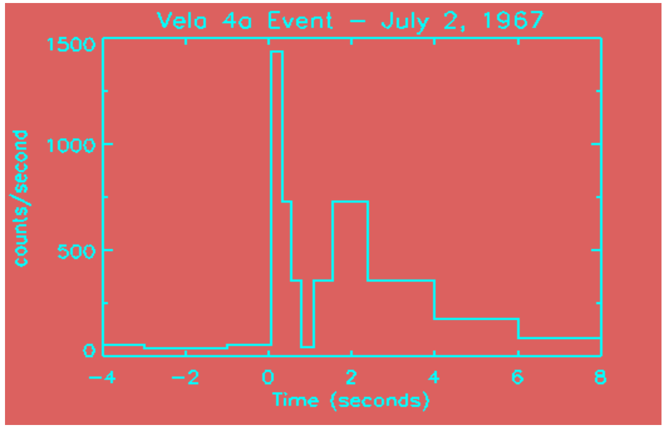
A tale of two bursts: part one

Gamma-Ray Bursts

1967-1973: Are they astrophysical?



The Vela ("Watch") Satellites (1959-1985)
Monitor compliance with the 1963 Partial Test Ban Treaty



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

GRB 670702

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

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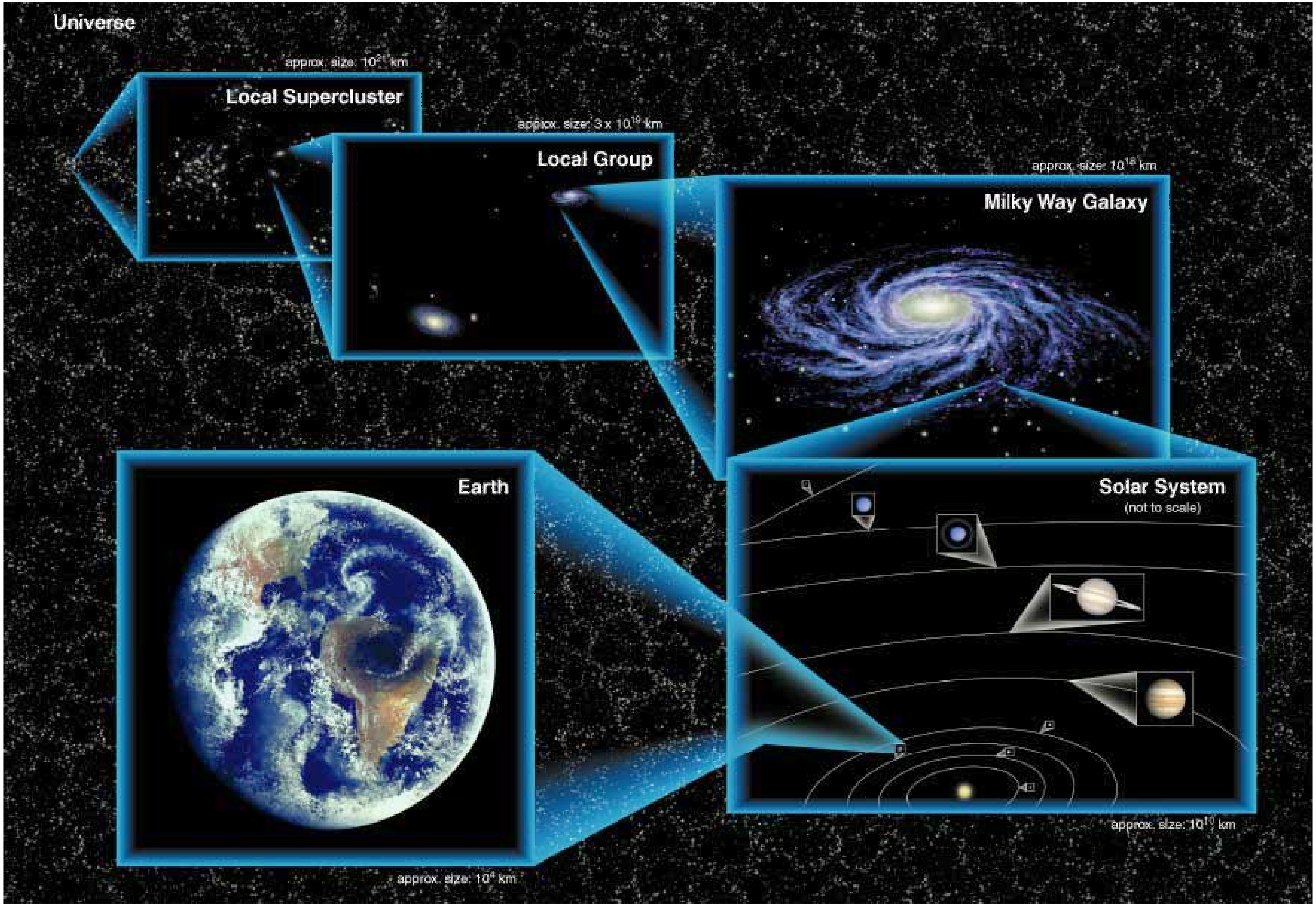
Received 1973 March 16; revised 1973 April 2

ABSTRACT

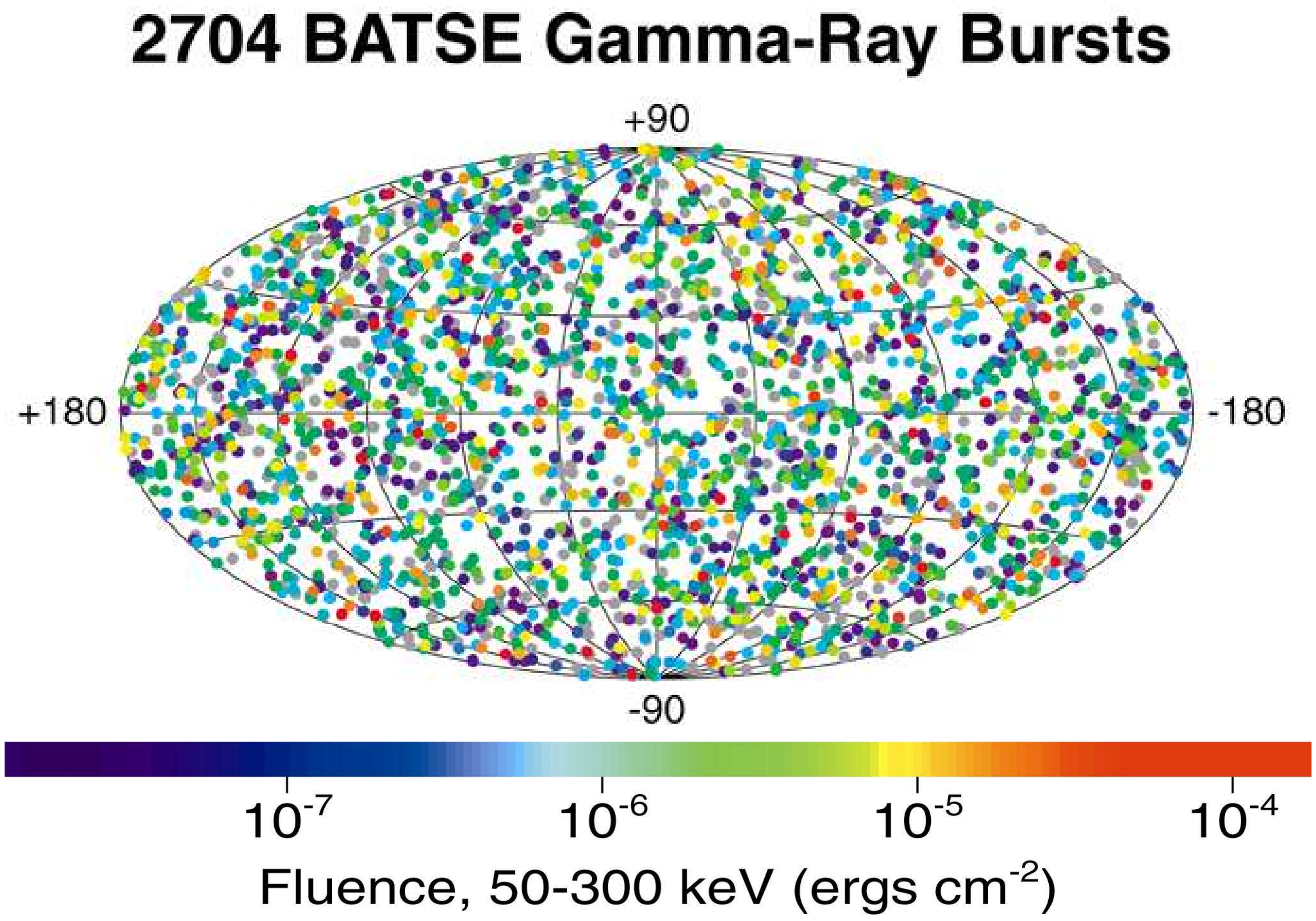
Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from ~10^{-5} ergs cm^{-2} to ~2×10^{-4} ergs cm^{-2} in the energy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

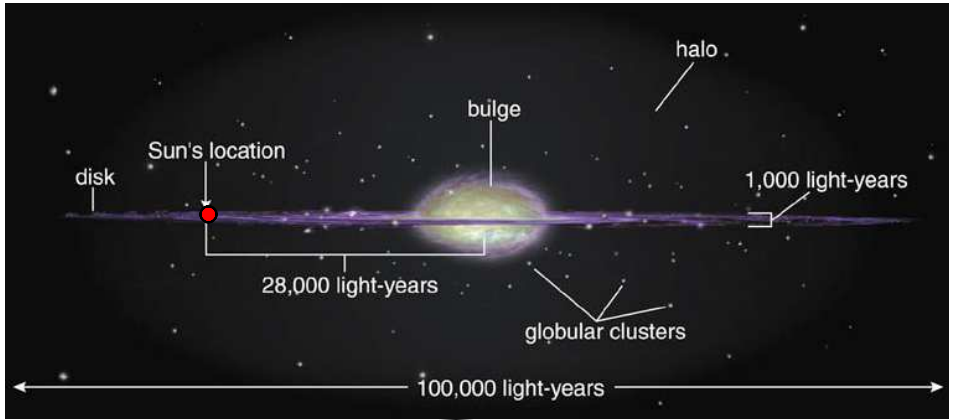
Where are they?

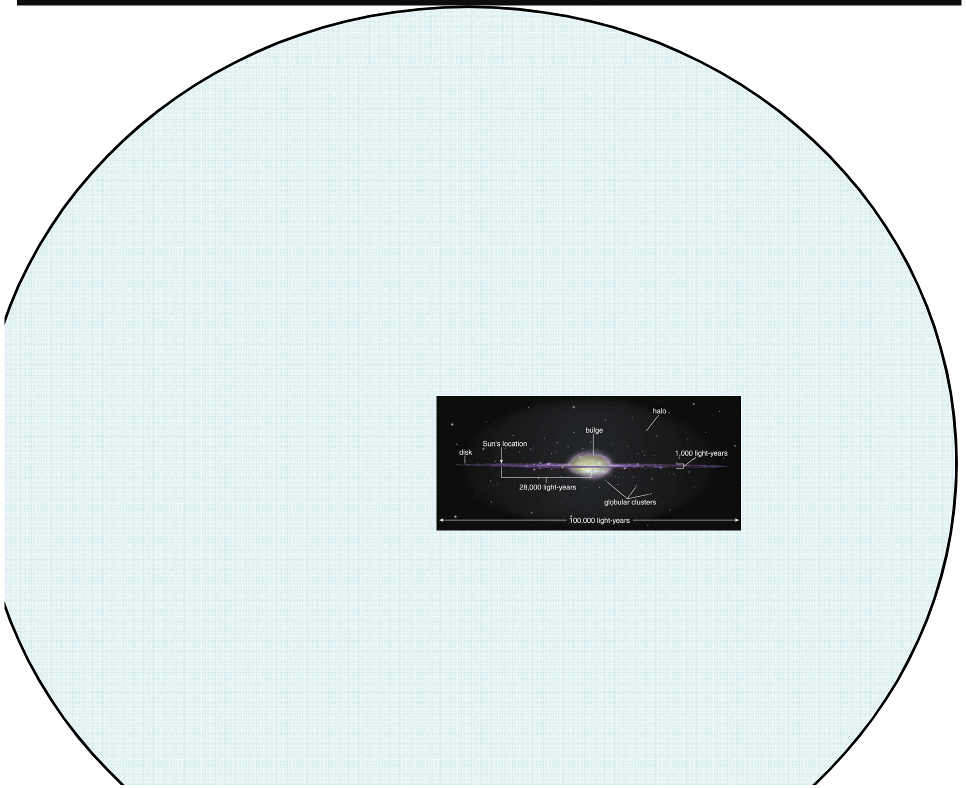


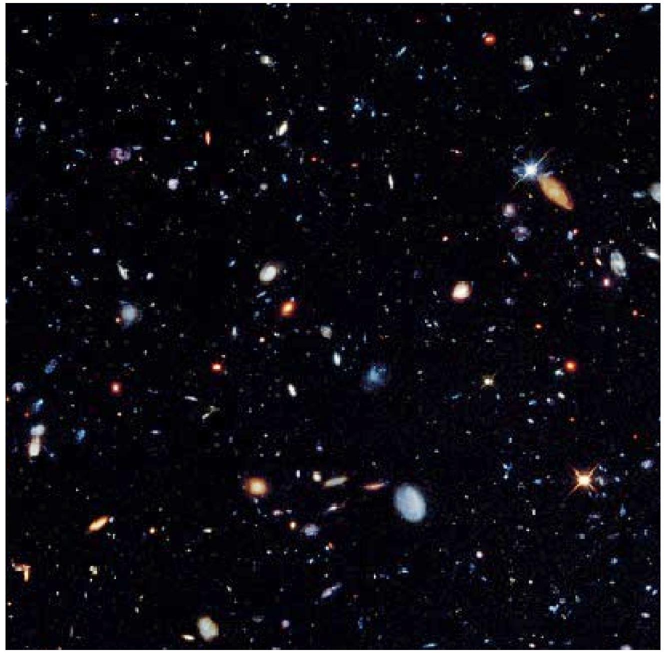
Isotropic Distribution



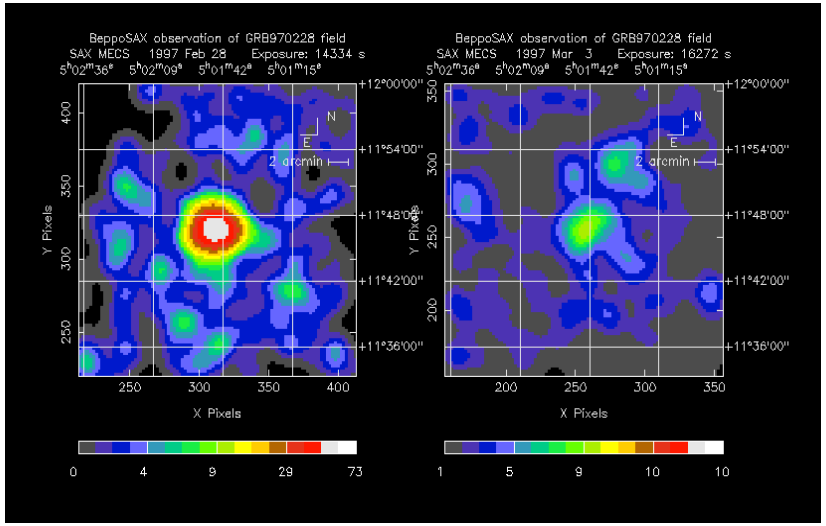
Distance Debate



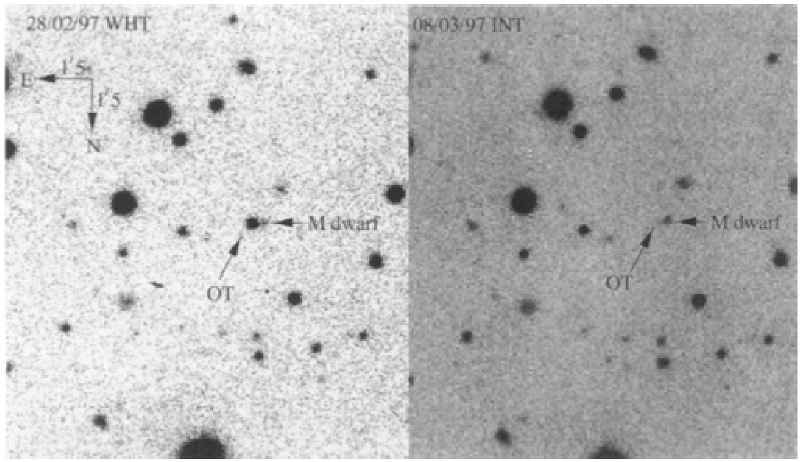




1997: Discovery of afterglow & redshift

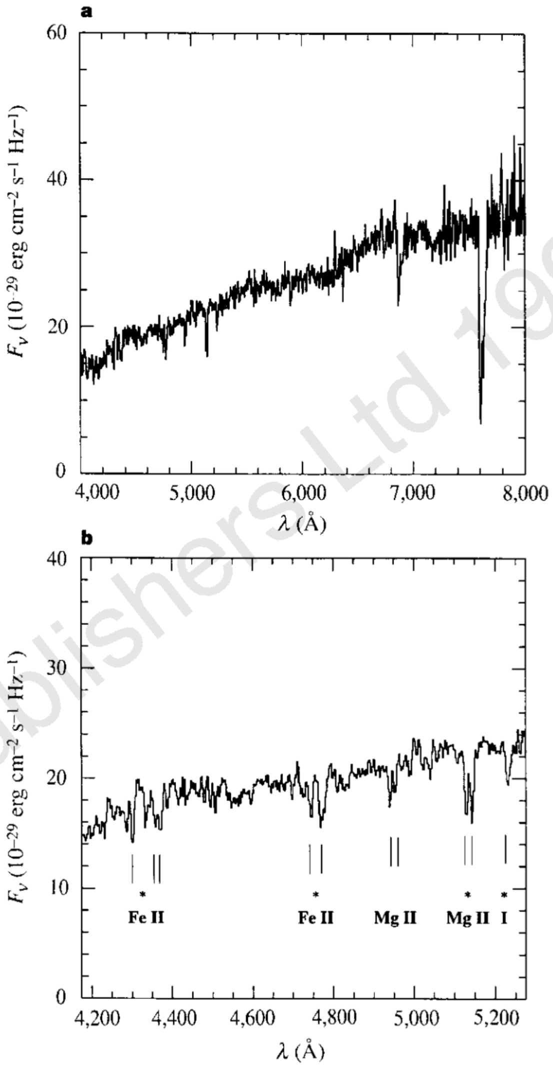


X-ray afterglow: Costa et al. 1997
GRB 970228



NATURE | VOL 386 | 17 APRIL 1997

Optical afterglow: van Paradijs et al. 1997



GRB970508
z=0.,767

Metzger et al. 1997

GRBs are at cosmological distances, and GRBs are the most luminous explosions in the universe.

What make them?

Table 1

#	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
33.	Ramaty et al.	1981	Ap & SS, 75, 193	NS		DISK	NS vibrations heat atm to pair produce, annihilate, synch cool
34.	Newman et al.	1980	ApJ, 242, 319	NS	AST	DISK	Asteroid from interstellar medium hits NS
35.	Ramaty et al.	1980	Nature, 287, 122	NS		HALO	NS core quake caused by phase transition, vibrations
36.	Howard et al.	1981	ApJ, 249, 302	NS	AST	DISK	Asteroid hits NS, B-field confines mass, creates high temp
37.	Mitrofanov et al.	1981	Ap & SS, 77, 469	NS		DISK	Helium flash cooled by MHD waves in NS outer layers
38.	Colgate et al.	1981	ApJ, 248, 771	NS	AST	DISK	Asteroid hits NS, tidally disrupts, heated, expelled along B lines
39.	van Buren	1981	ApJ, 249, 297	NS	AST	DISK	Asteroid enters NS B field, dragged to surface collision
40.	Kuznetsov	1982	CosRes, 20, 72	MG		SOL	Magnetic reconnection at heliopause
41.	Katz	1982	ApJ, 260, 371	NS		DISK	NS flares from pair plasma confined in NS magnetosphere
42.	Woosley et al.	1982	ApJ, 258, 716	NS		DISK	Magnetic reconnection after NS surface He flash
43.	Fryxell et al.	1982	ApJ, 258, 733	NS		DISK	He fusion runaway on NS B-pole helium lake
44.	Hameury et al.	1982	A&A, 111, 242	NS		DISK	e- capture triggers H flash triggers He flash on NS surface
45.	Mitrofanov et al	1982	MNRAS, 200, 1033	NS		DISK	B induced cyclo res in rad absorp giving rel e-a, inv C scat
46.	Fenimore et al.	1982	Nature, 297, 665	NS		DISK	BB X-rays inv Comp scat by hotter overlying plasma
47.	Lipunov et al.	1982	Ap & SS, 85, 459	NS	ISM	DISK	ISM matter accum at NS magnetopause then suddenly accretes
48.	Baan	1982	ApJ, 261, L71	WD		HALO	Nonexplosive collapse of WD into rotating, cooling NS
49.	Ventura et al.	1983	Nature, 301, 491	NS	ST	DISK	NS accretion from low mass binary companion
50.	Bisnovatyi- et al.	1983	Ap & SS, 89, 447	NS		DISK	Neutron rich elements to NS surface with quake, undergo fission
51.	Bisnovatyi- et al.	1984	SovAstron, 28, 62	NS		DISK	Thermonuclear explosion beneath NS surface
52.	Ellison et al.	1983	A&A, 128, 102	NS		HALO	NS corequake + uneven heating yield SGR pulsations
53.	Hameury et al.	1983	A&A, 128, 369	NS		DISK	B field contains matter on NS cap allowing fusion
54.	Bonazzola et al.	1984	A&A, 136, 89	NS		DISK	NS surface nuc explosion causes small scale B reconnection

By mid 90's:
128 different
theoretical models !

"The only feature that all but one (and perhaps all) of the very many proposed models have in common is that they will not be the explanation of gamma-ray bursts."
--- Malvin Ruderman (1975)

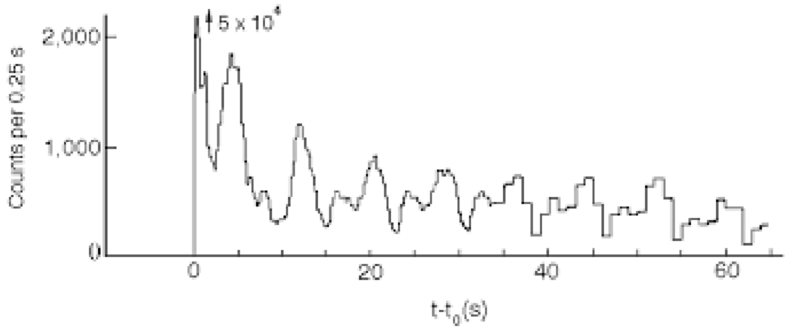
A theorist's
heaven or hell?

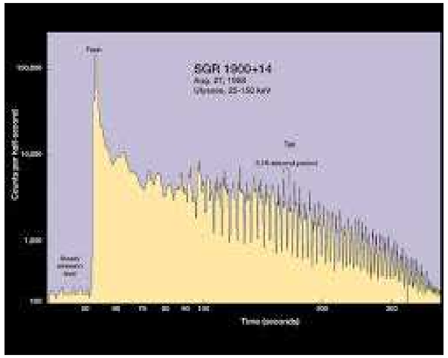
Destructive (non-repeating) or non-destructive (repeating)?

- GRB 790305

= SGR 0525-66

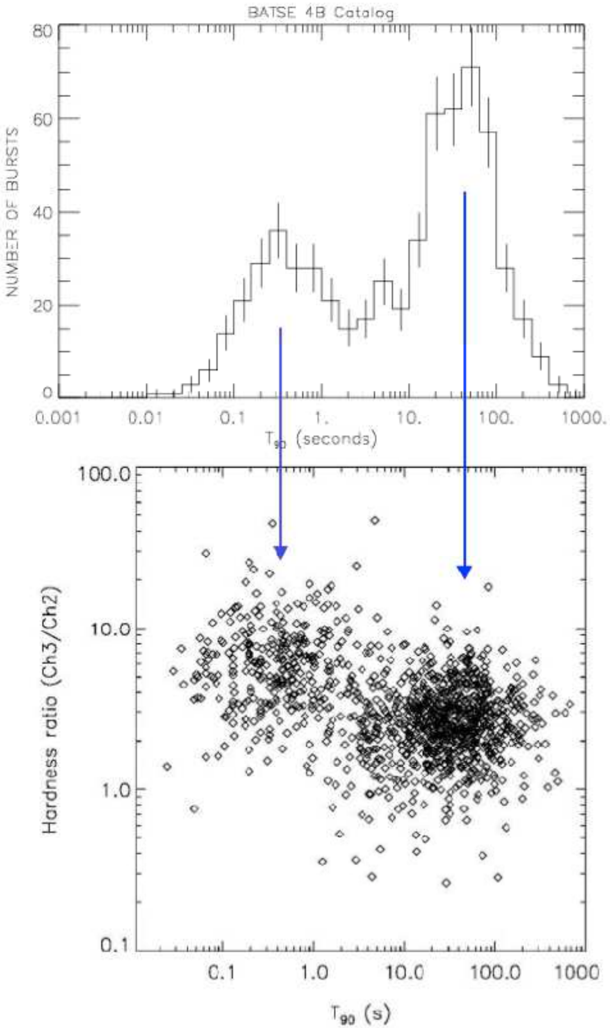
- Soft Gamma-Ray Repeaters (SGRs)
- Magnetars: slowly-rotating, highly-magnetized neutron stars

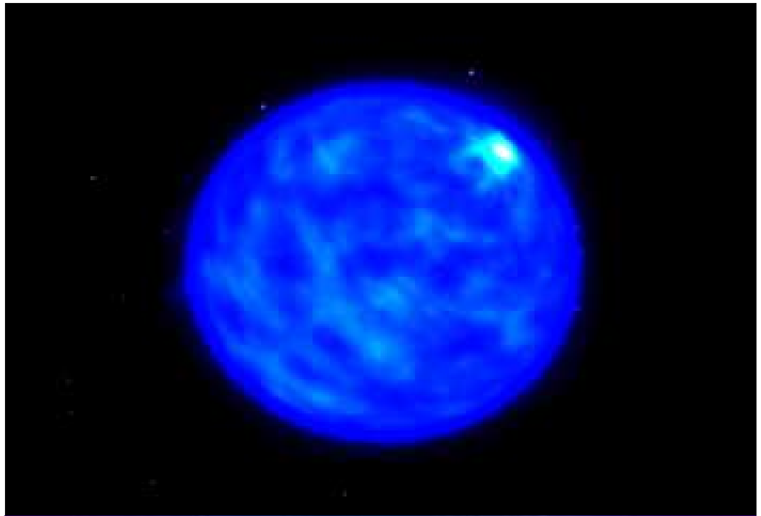




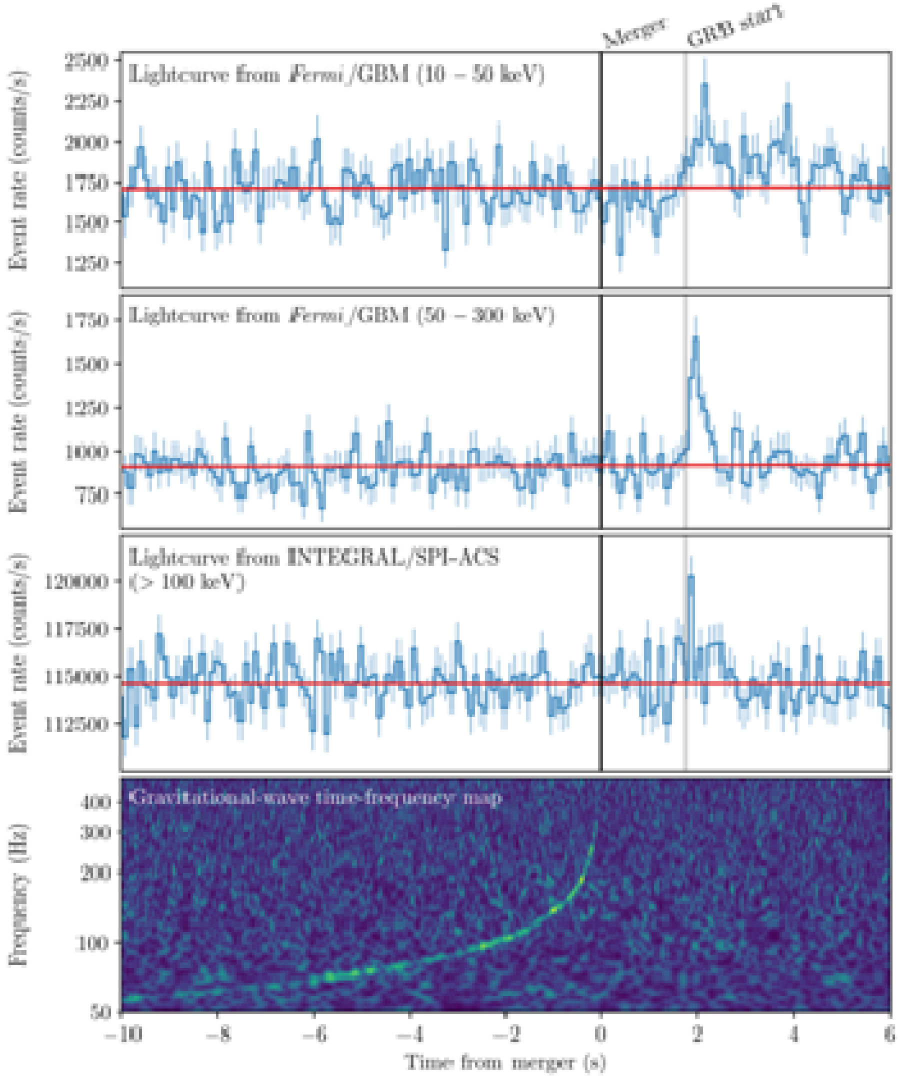
SGR 1900+14 (Hurley+ 99)

Destructive ones: Short/Hard vs. Long/Soft



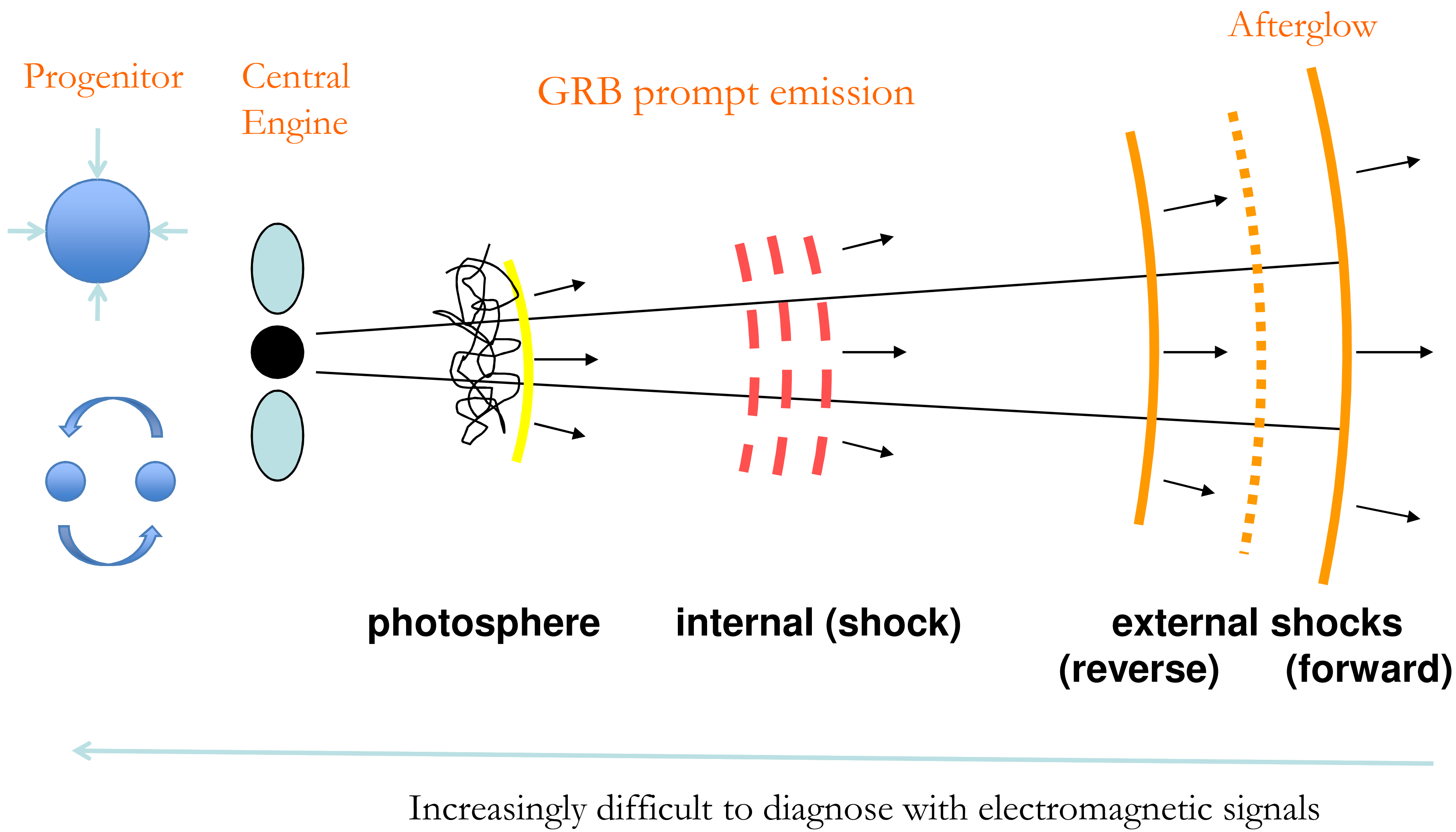


2017: GW170817/GRB 170817A



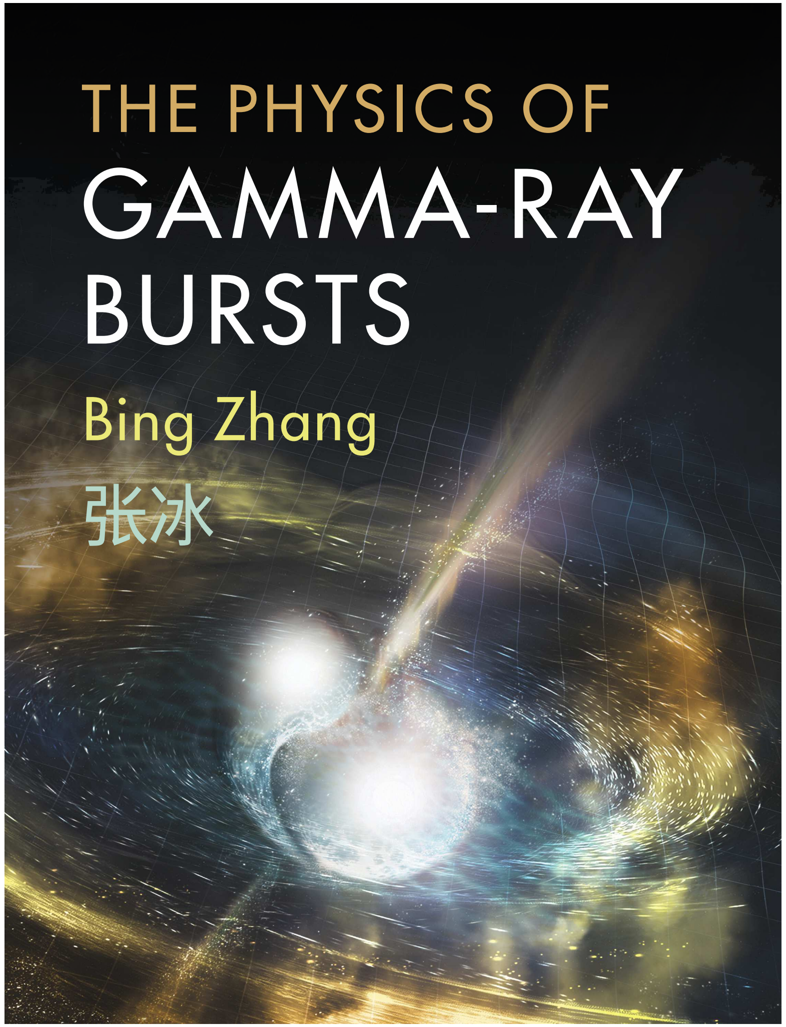
Most beautiful plot in astrophysics

Theoretical framework of GRBs



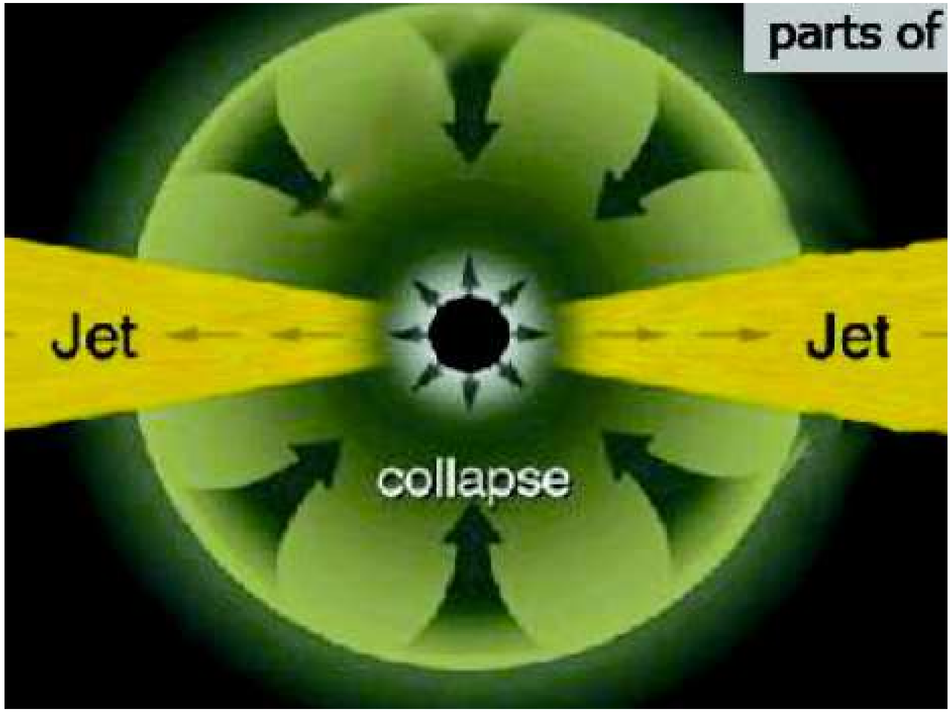
Open Questions in GRB Physics

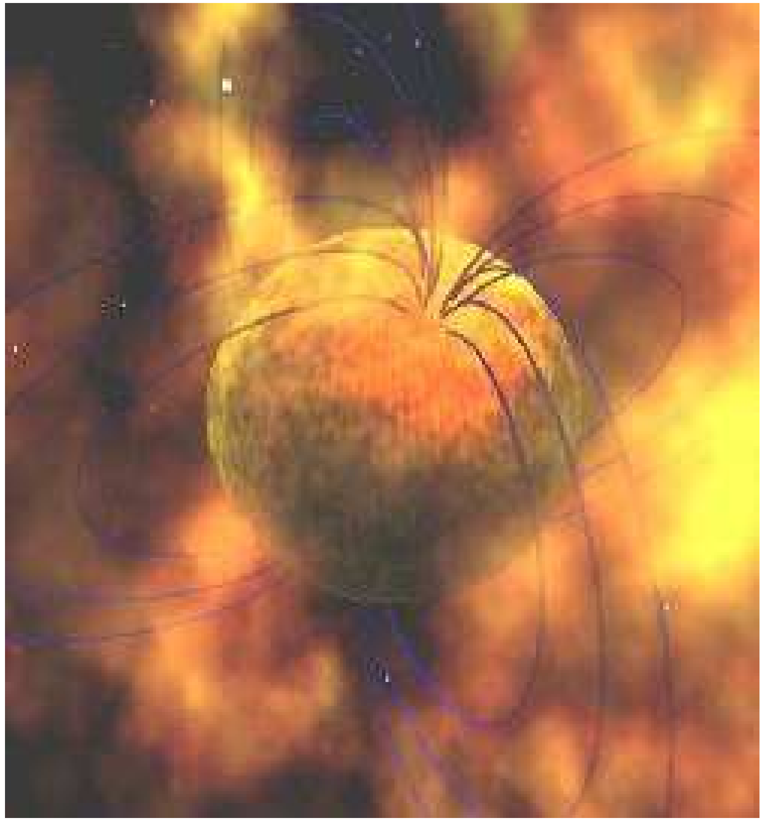
- Progenitors & classification (massive star core collapse vs. compact star mergers; others progenitor systems?)
- Central engine (black hole vs. millisecond magnetar)
- Ejecta composition (fireball vs. Poynting-flux-dominated outflow)
- Energy dissipation mechanism (shock vs. magnetic reconnection)
- Particle acceleration & radiation mechanisms (synchrotron, inverse Compton, vs. quasi-thermal)
- Afterglow physics (medium interaction vs. long-term engine activity)



Cambridge University Press

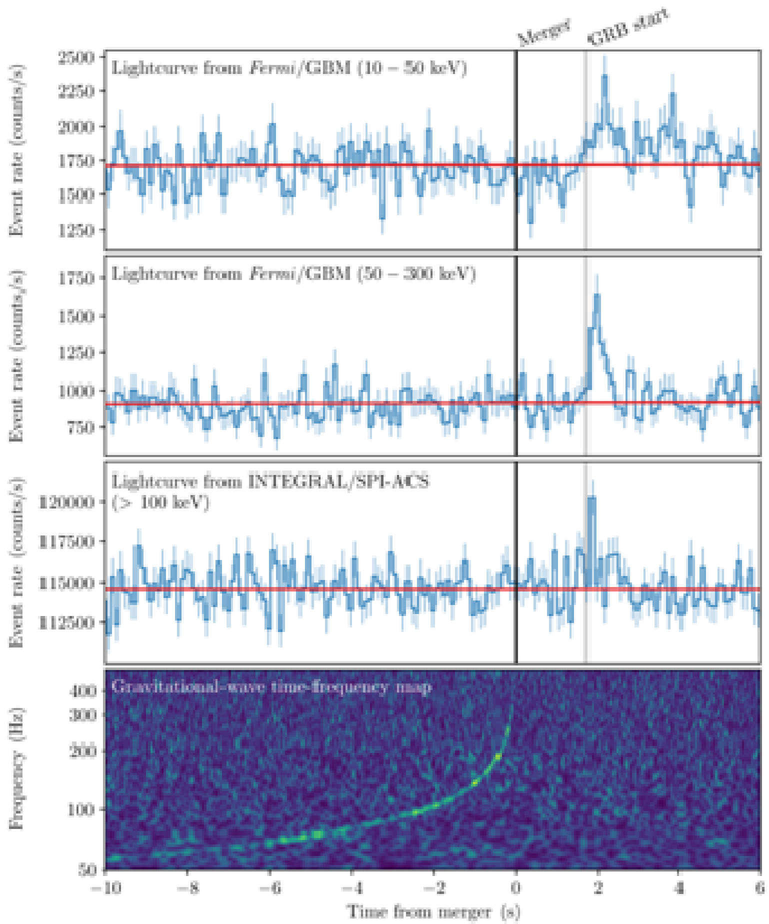
Central Engine:
Black hole vs. millisecond magnetar?





Both engines seem to work in both long and short GRBs

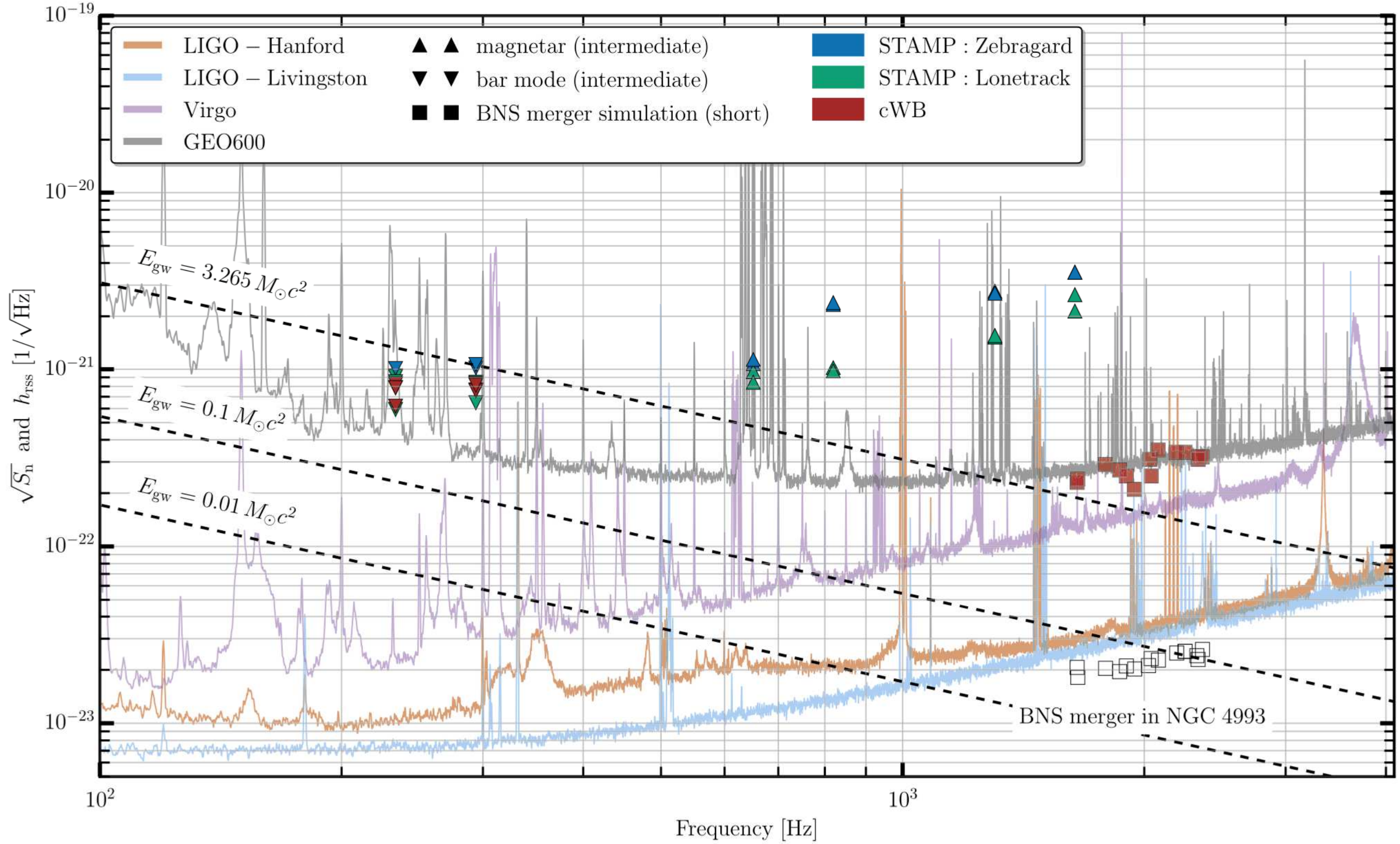
Origin of the 1.7 s delay?



GW170817/GRB 1708917A

- Delayed launch of the jet?
  - What did the system do in 1.7 s (very long time)?
- Delayed formation of a BH?
  - BH not needed to produce short GRBs!
- Delayed dissipation (magnetic field amplification)?
  - Allowed but not needed
- Negligible central engine delay at all (propagation)!
  - Duration ~ 2 s, Delay ~ 1.7 s, both time scales ~ R/Γ^2c)
  - Traditional GRB mechanism (large emission radius, Poynting-flux dissipation)
  - Negligible engine delay, no significant cocoon emission
  - No BH formation needed

GW170817:
Is a long-lived NS allowed?

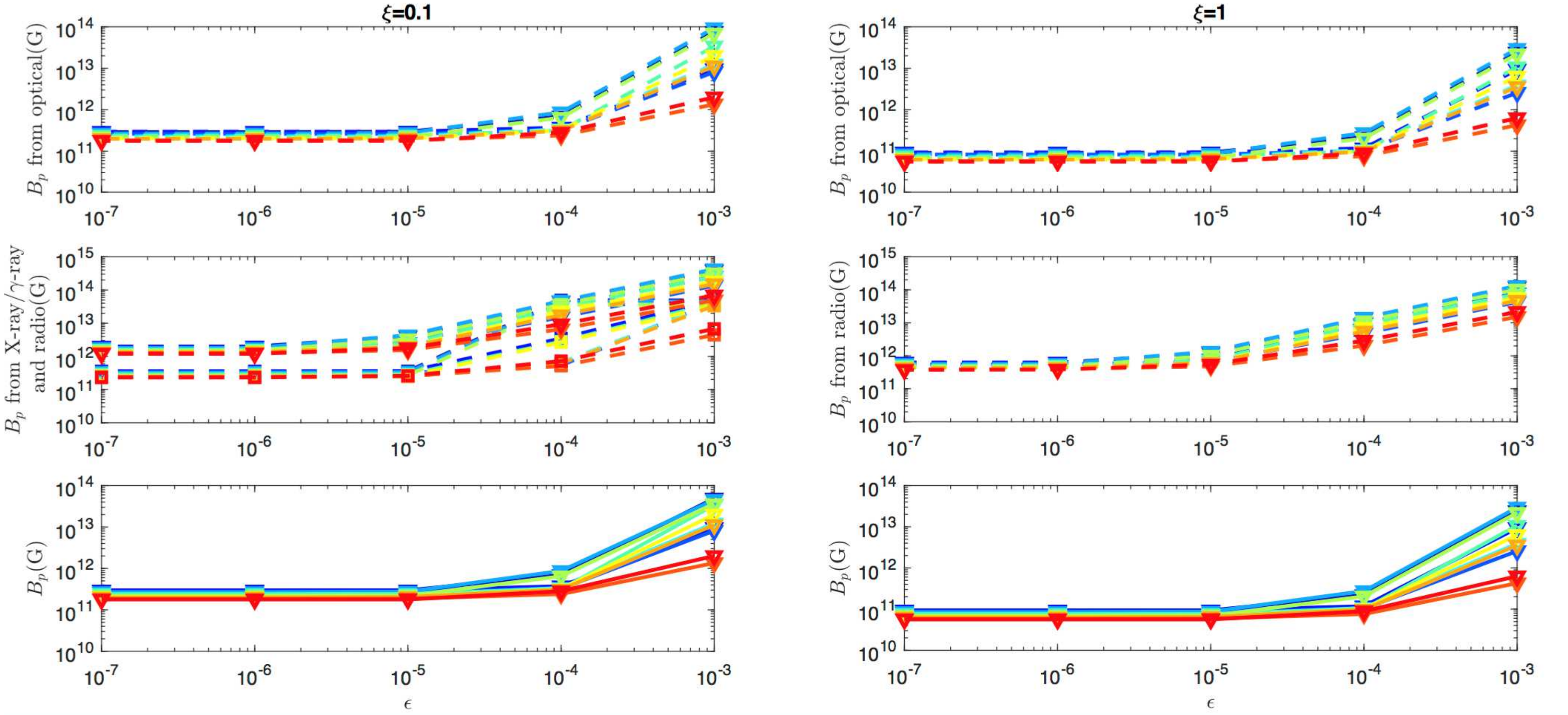


GW constraints: upper limit at least one order above prediction

Abbott et al. 2017, ApJL, 851, L16 Chassande-Mottin's talk

GW170817:

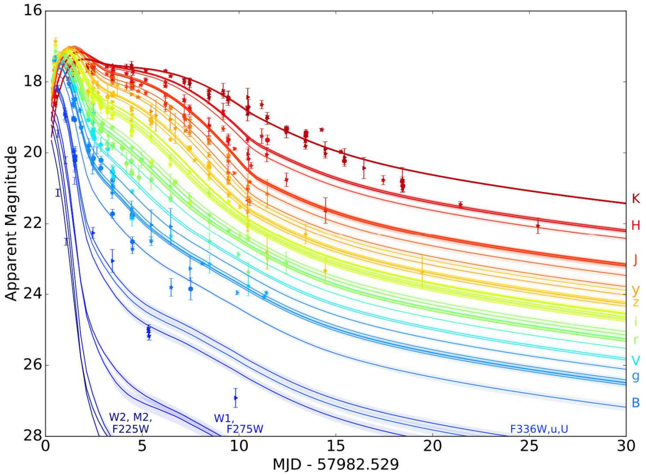
Is a long-lived NS allowed?



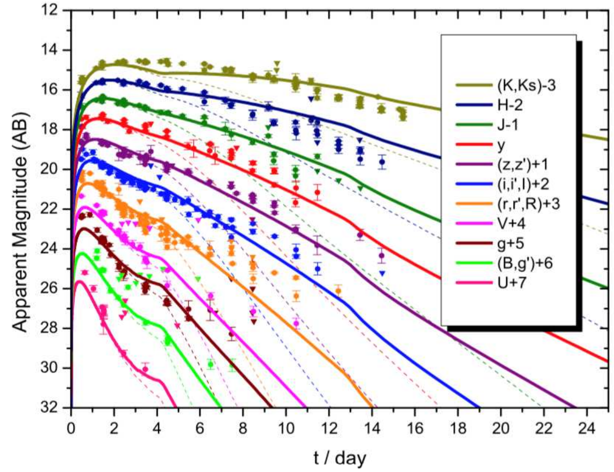
EM constraints: As long as Bp is low – constraints from UV/optical/IR (upper), gamma/X/radio (middle) and multi-band (lower)

Ai et al. 2018, ApJ, 860, 57

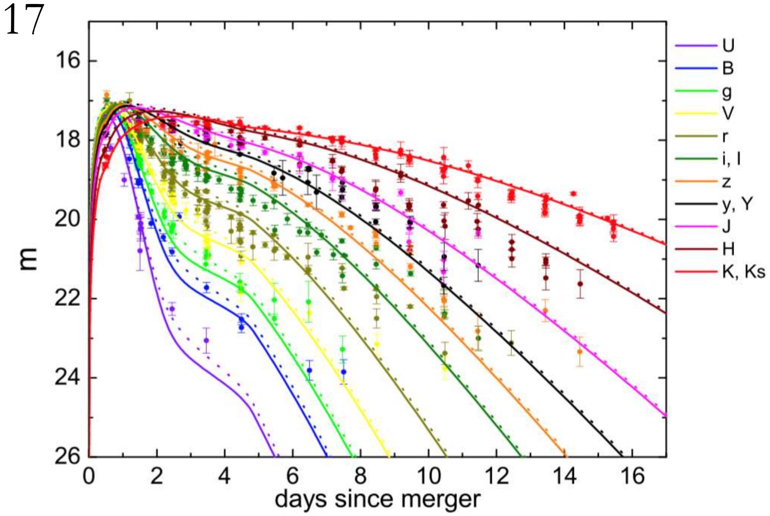
AT2017gfo: long-lived-NS-driven?



Villar et al. 2017



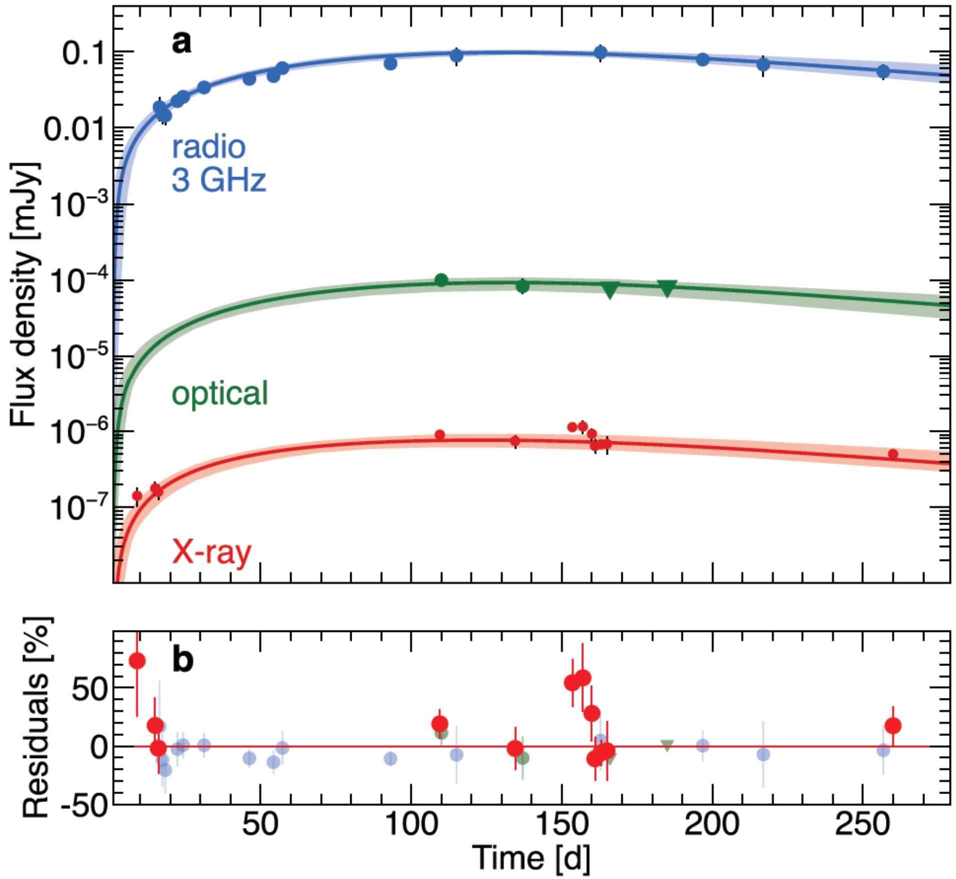
Yu et al., ApJ, arXiv:1711.01898

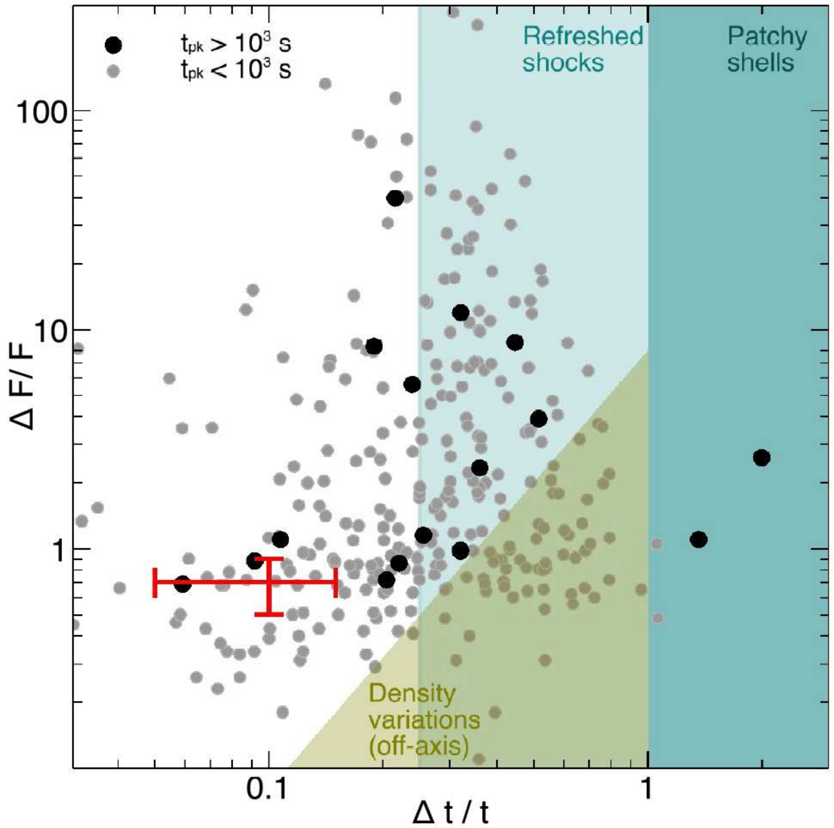


Li et al. ApJL, arXiv:1804.06597

	$M_{\mathrm{fb,i}}/M_{\odot}\mathrm{s}^{-1}$	$L_{\mathrm{md,i}}/\mathrm{erg\,s}^{-1}$	$t_{\mathrm{sd,gw}}/\mathrm{s}$	B/G	ϵ	ejecta	$M_{\mathrm{ej}}/M_{\odot}$	$\kappa/\mathrm{cm}^2\mathrm{g}^{-1}$	$v_{\mathrm{ej,i}}/c$	Ω	δ	ζ	A
NS	-	3.4×10^{44}	500	3.4×10^{12}	0.0035	polar	1×10^{-3}	1	0.35	2π	-1	10	6
						equatorial	5×10^{-3}	5	0.2	2π	-1	10	6

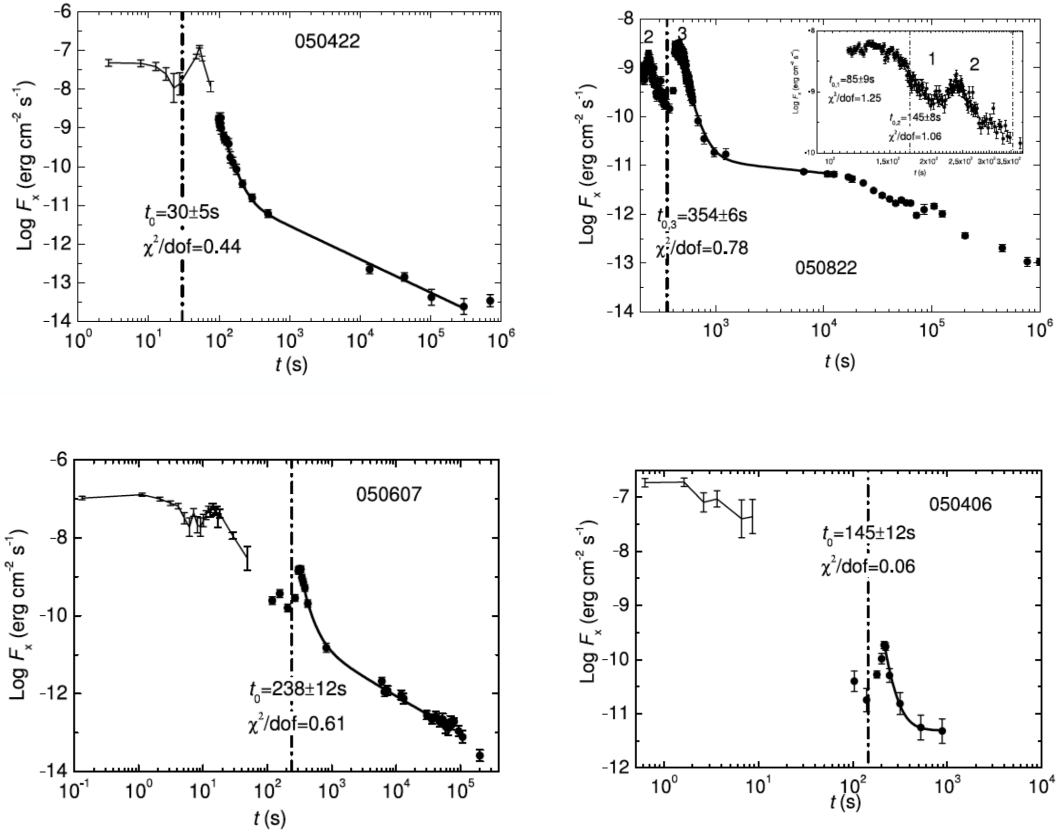
A late time X-ray “flare”?

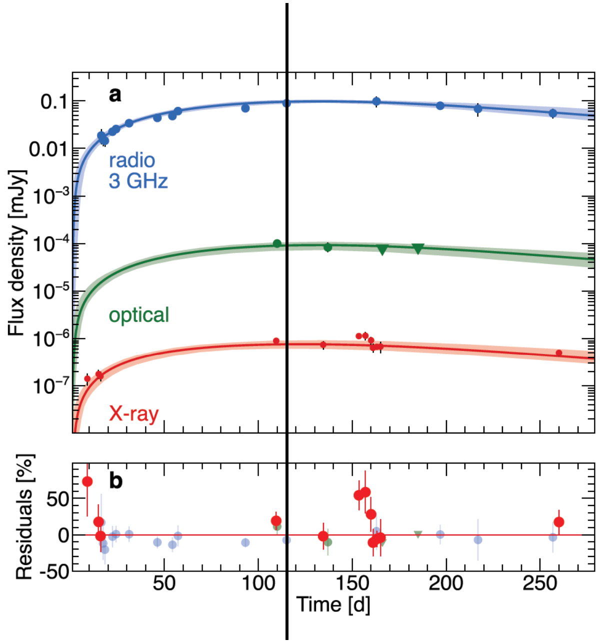




Piro, Troja, Zhang et al., 2018, submitted

Swift X-ray flares and restarting central engine





Piro, et al., 2018, submitted

$$F_\nu \propto t^{-\alpha} \nu^{-\beta} \quad \alpha = 2 + \beta$$

There is a long-lived NS/QS!

Liang et al. 2006, ApJ, 646, 351

Implications

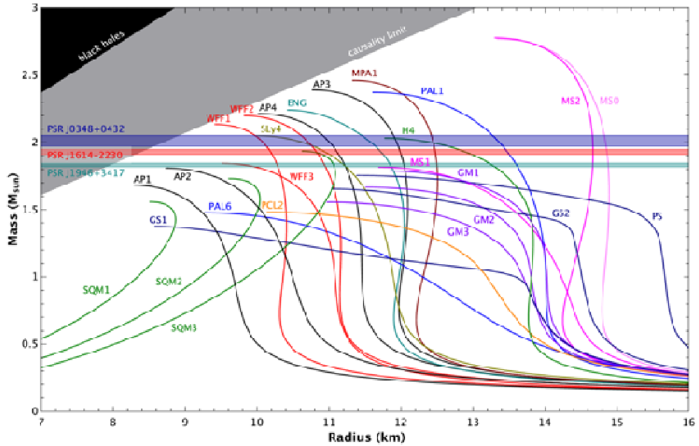
- M_{TOV} is large! Rule out many soft EoSs

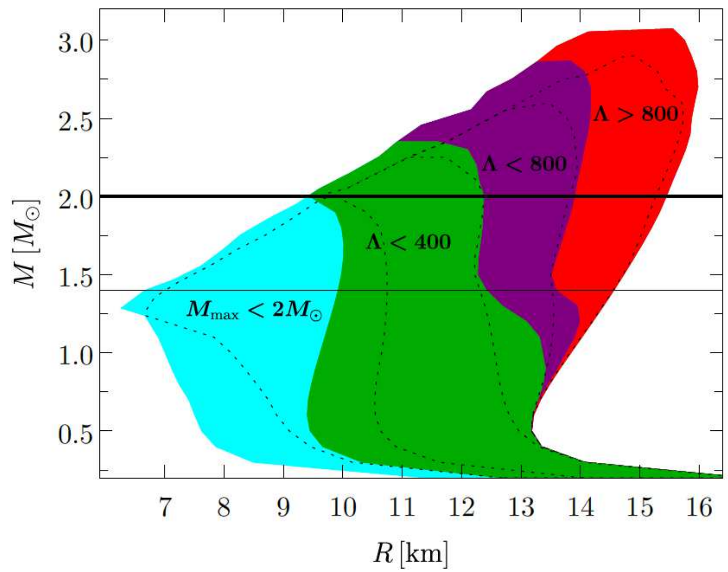
  M_{TOV} at least **2.16 - 2.28 $M_{\odot}$**

- Small tidal deformability rules out many stiff EoSs
- “Goldilocks” EoSs

  M_{TOV} >~ (2.35-2.4) $M_{\odot}$

- Consistent with conclusions drawn from short GRB observations and modeling



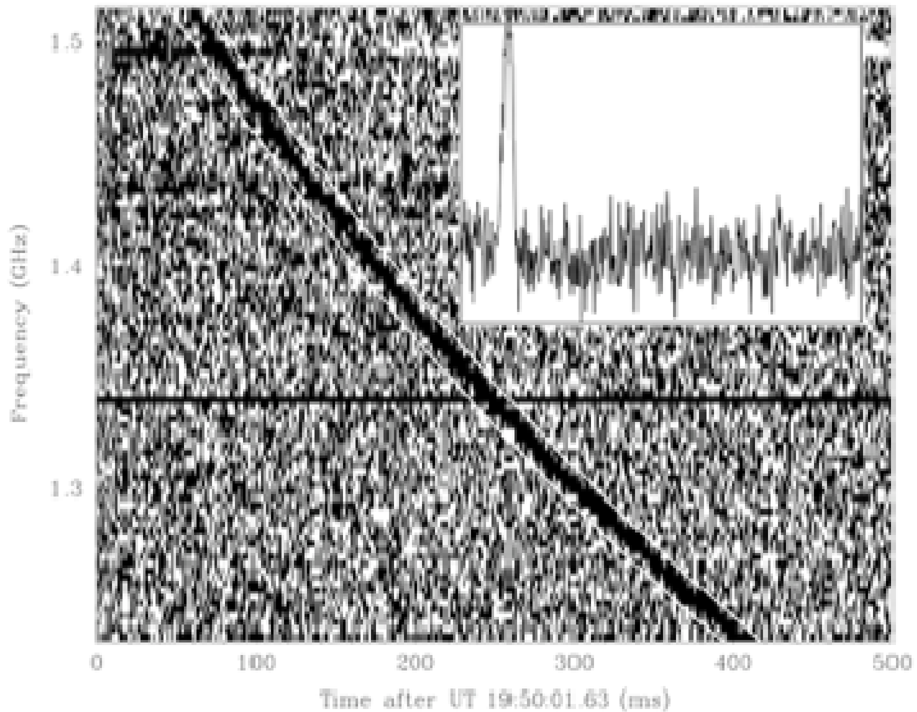


A tale of two bursts: part two

Fast Radio Bursts

The history is astonishingly
repeating itself ……..

2007: Report of the first FRB: Lorimer Burst



Lorimer et al. (2007)
First event: FRB 010125

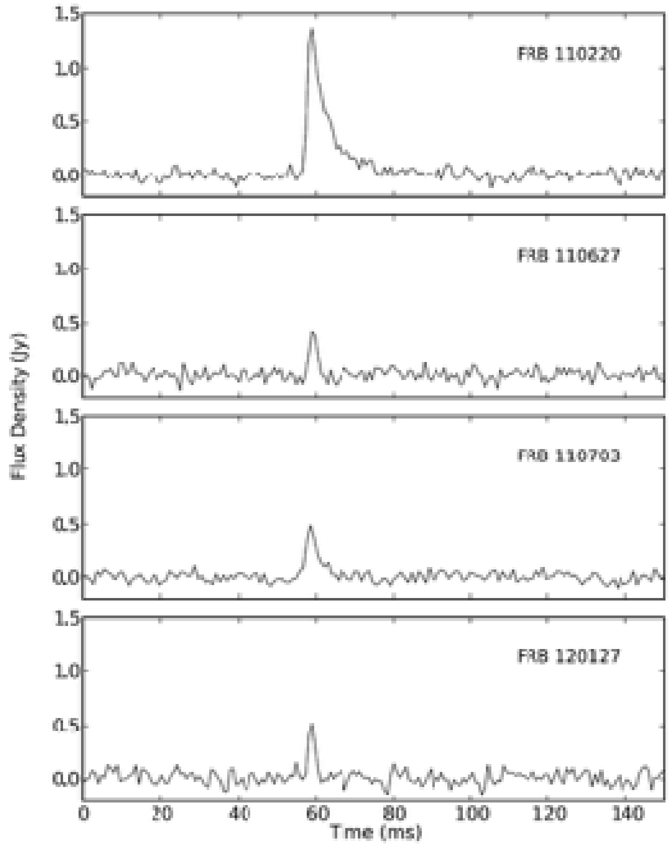


Fig. 1. The frequency-integrated flux densities for the four FRBs. The time resolutions match the level of dispersive smearing in the central frequency channel (0.8, 0.6, 0.9, and 0.5 milliseconds, respectively).

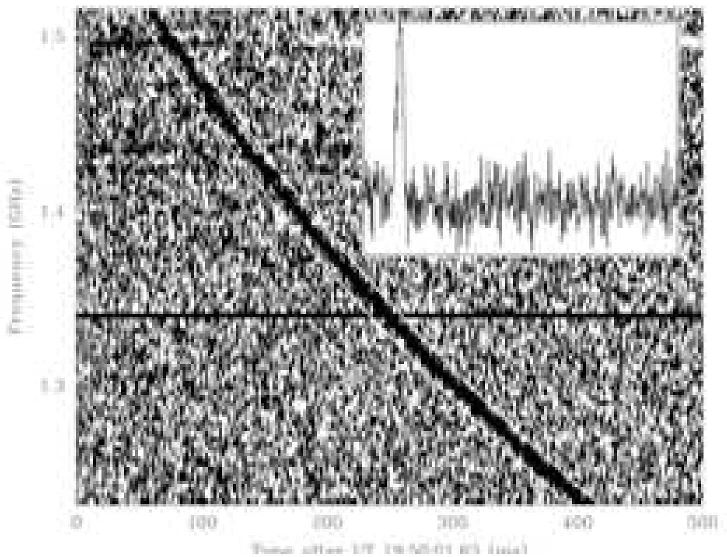
Took 8 years to confirm their astrophysical origin

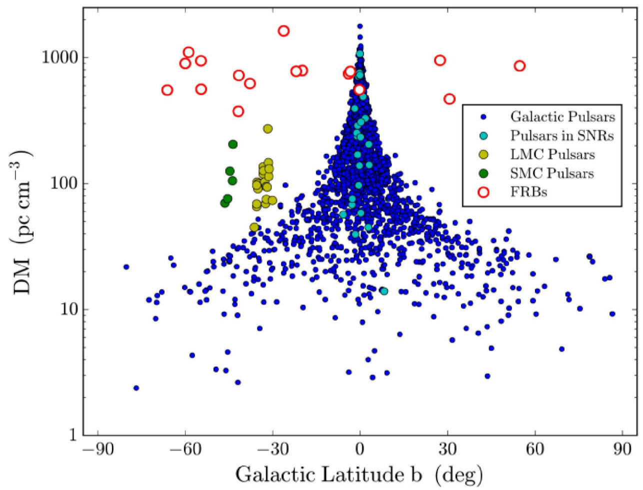
Thornton, et al., 2013, Science

FRBs: Observational Clues

- Milliseconds duration: compact objects
- High Galactic latitudes, high dispersion measure (DM): cosmological distances
  - Extreme luminosity (10^{43} erg/s)
  - Extreme brightness temperature

  ($T_b \sim 10^{34}$ -10^{37} K)
- High rate: ~1000 per day all sky: common phenomenon
- At least one FRB repeating: non-destructive





Cordes +, 2016, ApJ

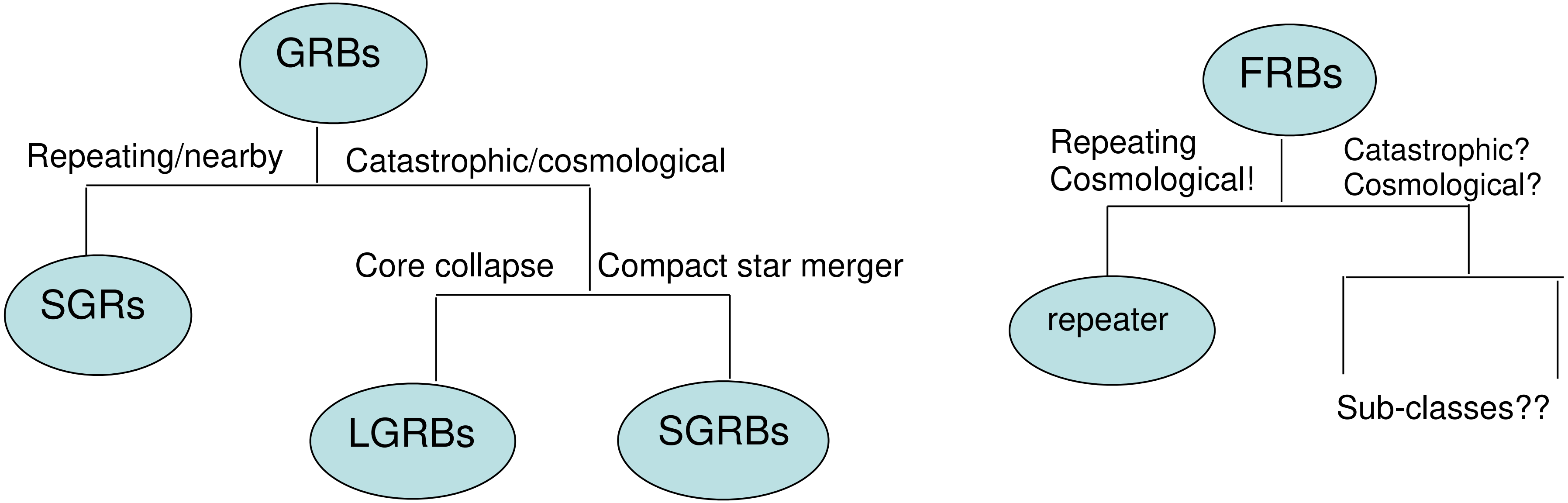
Kaspi's talk

FRBs vs. GRBs

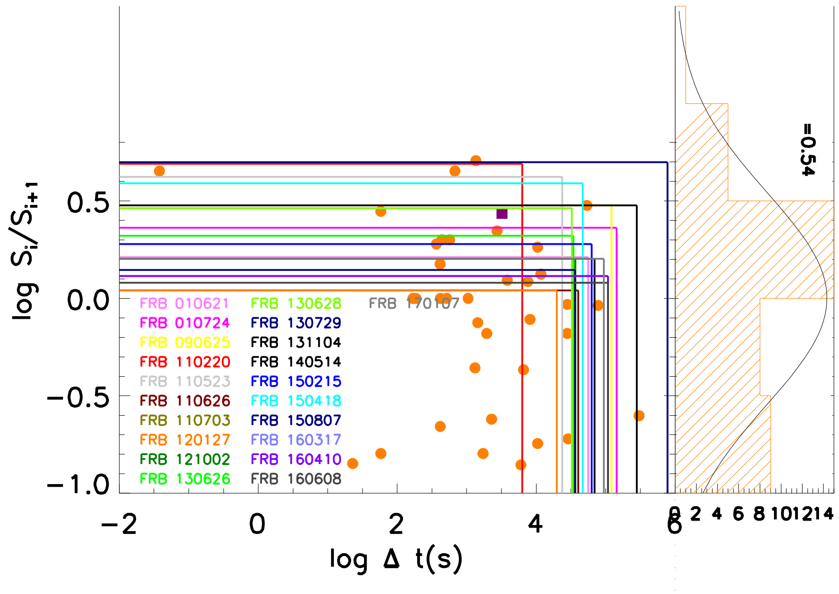
	GRBs	FRBs
Step one: Are they astrophysical?	1967 – 1973	2007 – 2015
Step two: Where are they (distance)?	1973 – 1997 – 2004 (Afterglow counterpart, host galaxy)	2016 (Persistent radio source, host galaxy)
Step three: What make them?	1998 – 2017 (SN Ic, GW)	??? (pulsars? massive black holes? GRBs? GWs?)

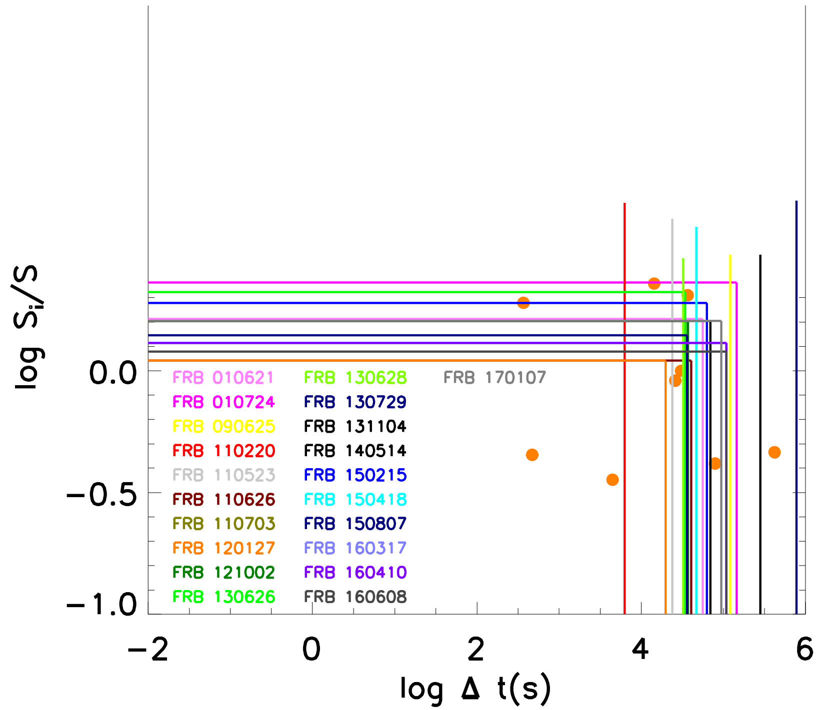
Observationally driven
Healthy dialog between observers and theorists

Multiple progenitor systems?



Known observationally-defined transients have multiple progenitors (SNe & GRBs)





If other FRBs are similar to FRB 121102, the chance that none of them is detected to repeat yet is $\sim (10^{-4} - 10^{-3})$

- Instability within pulsar magnetosphere (Philippov, Katz)

Catastrophic:

- Collapses of supra-massive neutron stars to black holes (thousands to million years later after birth, or in a small fraction hundreds/thousands of seconds after birth), ejecting "magnetic hair" (Falcke & Rezzolla 2013; Zhang 2014)
- Magnetospheric activity after NS-NS mergers (Totani 2013)
- Unipolar inductor in NS-NS mergers (Piro 2012; Wang et al. 2016)
- Mergers of binary white dwarfs (Kashiyama et al. 2013)
- BH-BH mergers (charged) (Zhang 2016; Liebling & Palenzuela 2016)
- Kerr-Newman BH instability (Liu et al. 2016)
- Cosmic sparks from superconducting strings (Vachaspati 2008; Yu et al. 2014)
- Evaporation of primordial black holes (Rees 1977; Keane et al. 2012)
- White holes (Barrau et al. 2014; Haggard)
- Axion miniclusters, axion stars (Tkachev 2015; Iwazaki 2015)
- Quark Nova (Shand et al. 2015)
- Dark matter-induced collapse of NSs (Fuller & Ott 2015)
- Higgs portals to pulsar collapse (Bramante & Elahi 2015)

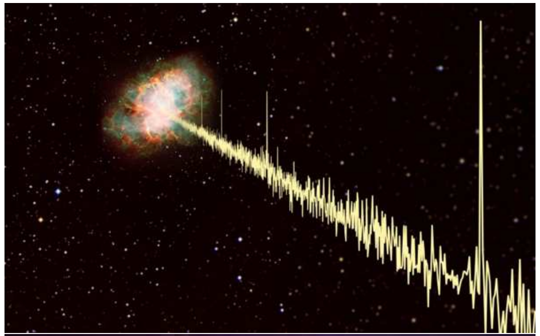
……

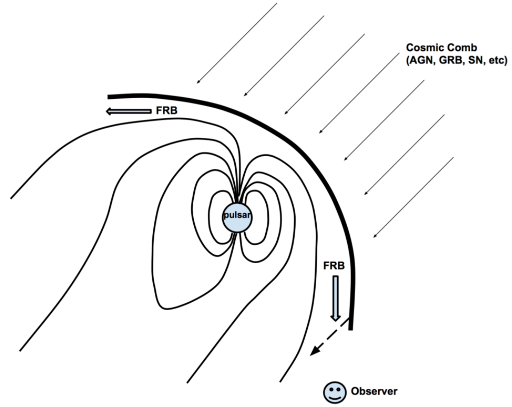
Most will not be the correct interpretation

Models for repeating FRBs

- Extremely bright giant pulses from young pulsars? (Connor et al.; Cordes)
- Associated with magnetar giant flares? (Popov et al; Kulkarni et al.; Katz)
- Synchrotron maser from young magnetars? (Metzger et al; Ghisellini; Waxman; Beloborodov)
- Comets – neutron star collisions (Dai et al)

- Kinetically powered magnetospheric reconfiguration (cosmic combs)?

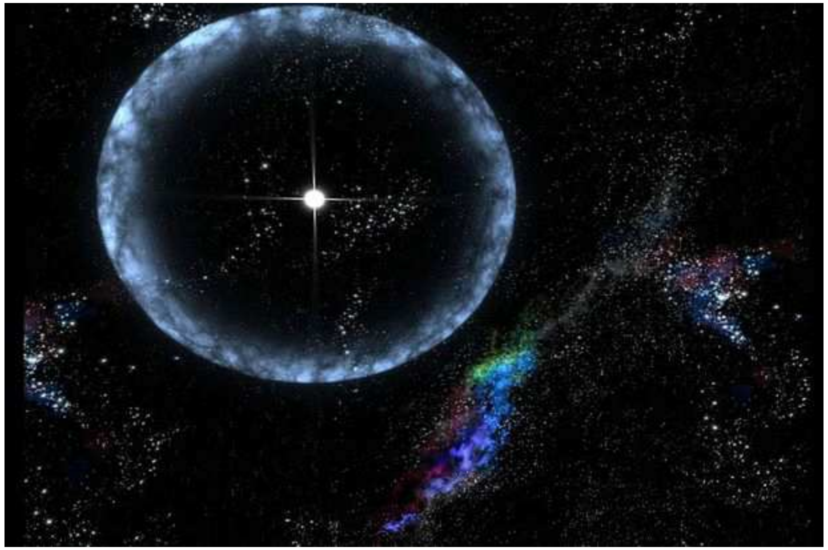


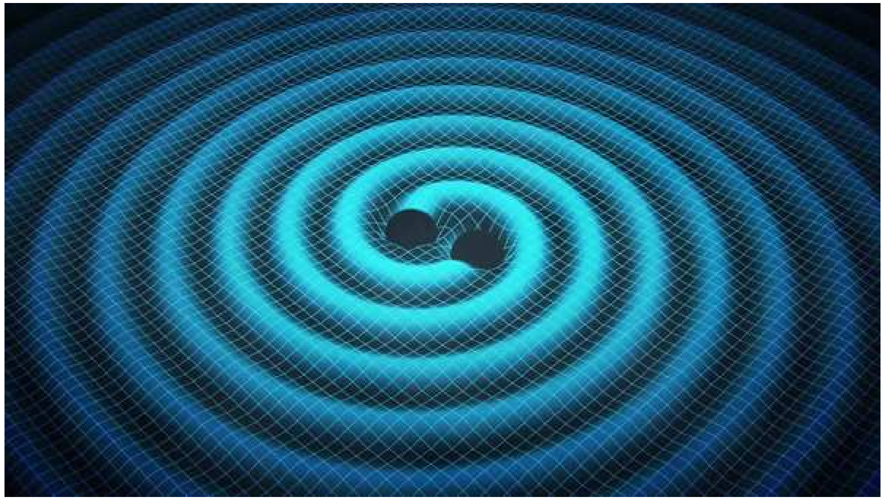


Zhang (2017; 2018)

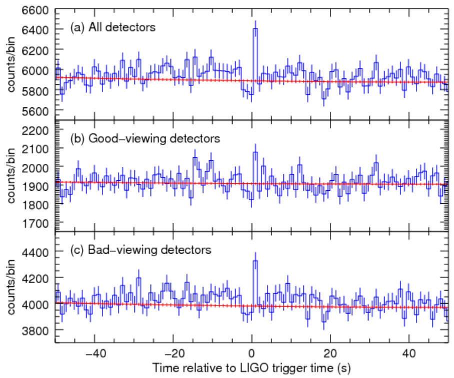
Models for catastrophic FRBs

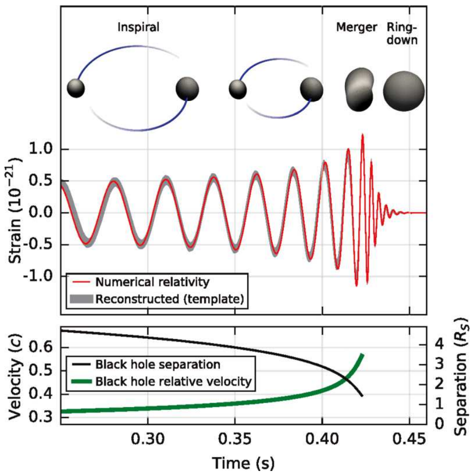
- "blitzars": collapse of supra-massive neutron stars? (Falcke & Rezzolla 2014; Zhang 2014)
- NS-NS mergers (Totani 2013; Wang et al. 2016)
- Mergers of charged compact objects (BH-BH. BH-NS, NS-NS) (Zhang, 2016)

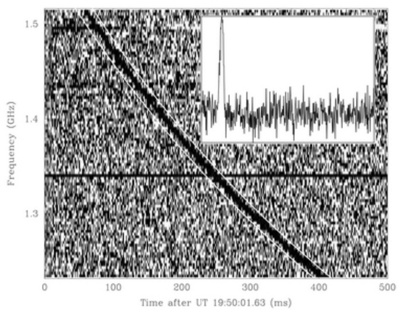


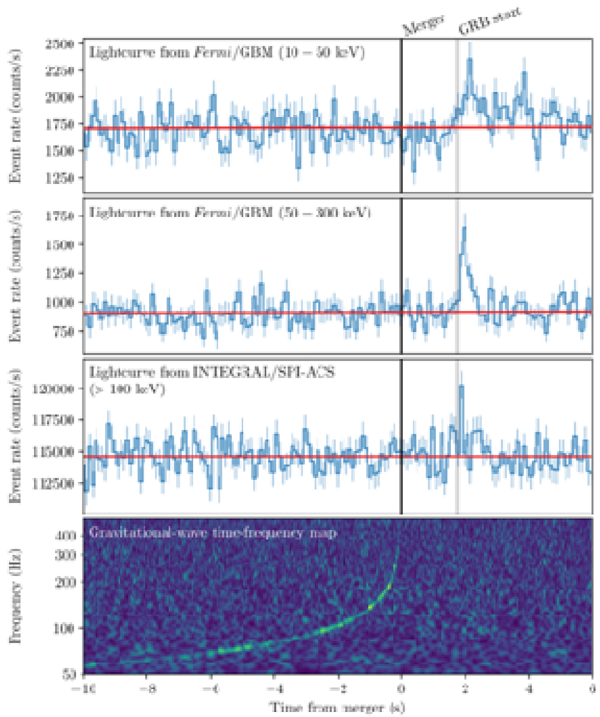


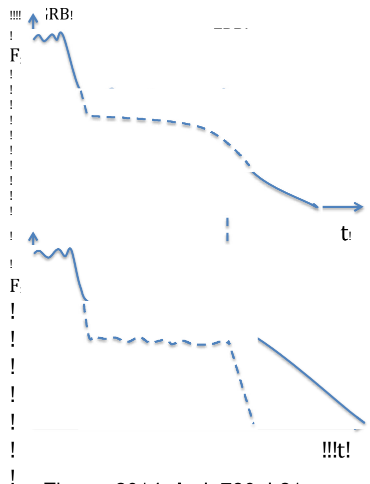
An even more beautiful plot in astrophysics?











Zhang, 2014, ApJ, 780, L21

Concluding remarks

Gamma-Ray Bursts

•It has been a lot of fun studying GRBs;

•Still a lot of fun coming in the era of multi-messenger (EM, GW, neutrinos …) astronomy

Fast Radio Bursts:

•The fun has just started in the field of FRBs

•Instead of reading history, one can actually make history (both observationally & theoretically)