LCGT: listening to core-collapse supernovae and GRBs

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Application for LCGT membership by KIAS
in view of the approved Korea-Joint Research Project (T.H. Yoon/MHPM van Putten - S. Kawamura)

LCGT f2f meeting, University of Tokyo, August 3 2011
(Yukawa Institute of Theoretical Physics, Kyoto, July 28 2011)

KIAS Astrophysics and Cosmology:

~ 7 people, group of Prof. Changbom Park

Present collaborators:

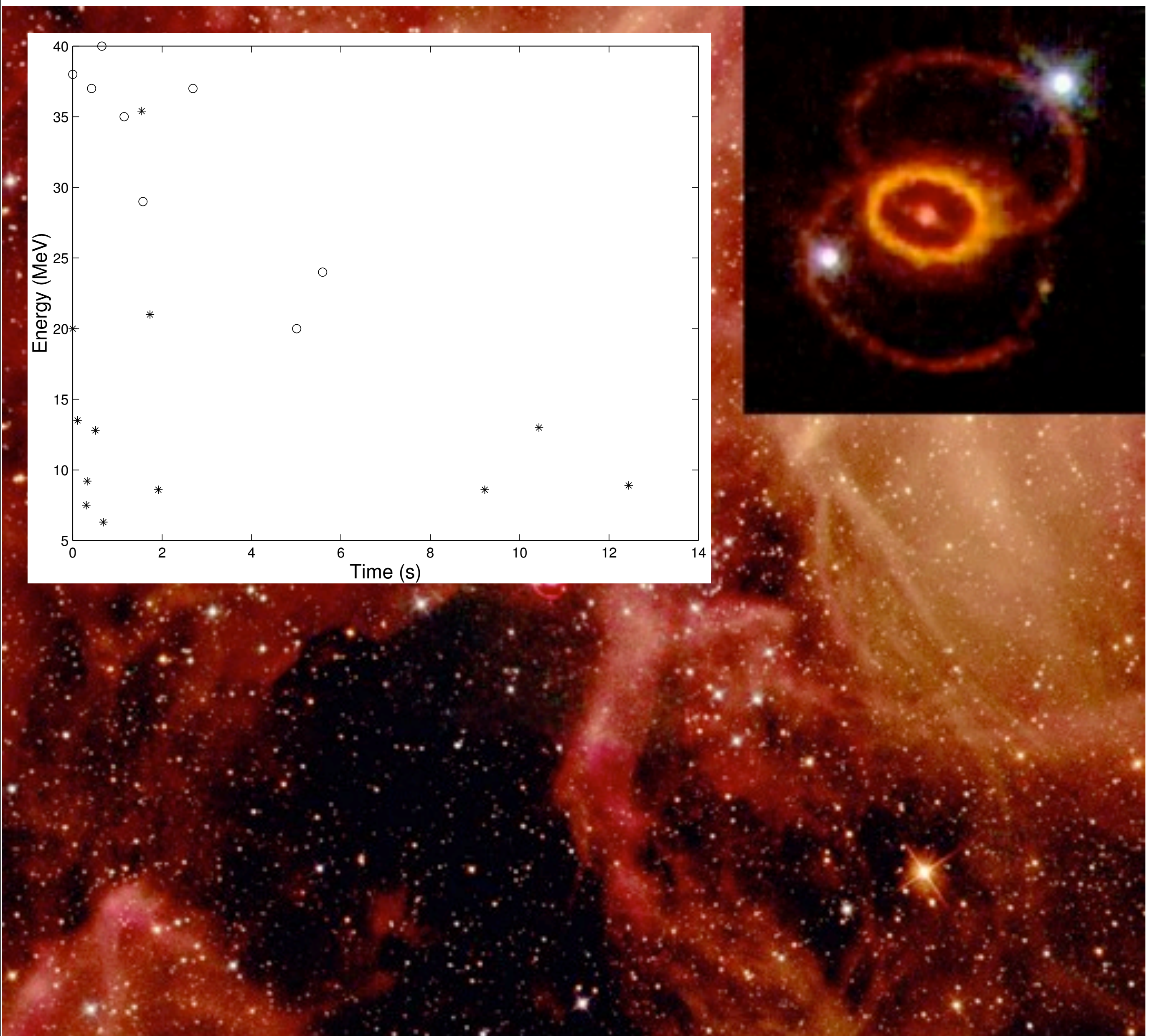
Prof. T.H. Yoon (Korea University)
Prof. Nobuyuki Kanda (Osaka, TAMA 300/LCGT)
Prof. Hideyuki Tagoshi (Osaka, TAMA 300/LCGT)
Prof. Daisuke Tatsumi (JNAO, TAMA 300/LCGT)
Prof. Fujimoto Masa-Katsu (NAOJ, TAMA 300/LCGT)
Prof. Shigehiro Nagataki (numerical simulations, Yukawa Institute, Kyoto)
Prof. Massimo Della Valle (Director Observatory di Capodimonte, Italy)
- supernovae, GRBs

Prof. Amir Levinson, Tel Aviv University, Israel
- high-energy radiation processes

Dr. Alok Gupta, ARIES, India
- QPOs observations in AGN

SN1987A

SN1998bw



Radio-loud (Turtle et al. 1987) and aspherical, > 10 s > 10 MeV neutrino burst, EK~1e51erg with relativistic jets (Nisenson & Papaliolios 1999) (with BH remnant?)

Radio-loud and aspherical with EK~2e51 erg $(M_{ej} / 2M_{\odot})$ (Hoeflich at al. 1999) with relativistic ejecta $v_{ej} / c \sim 20\%$ (Wieringa et al. 1999)

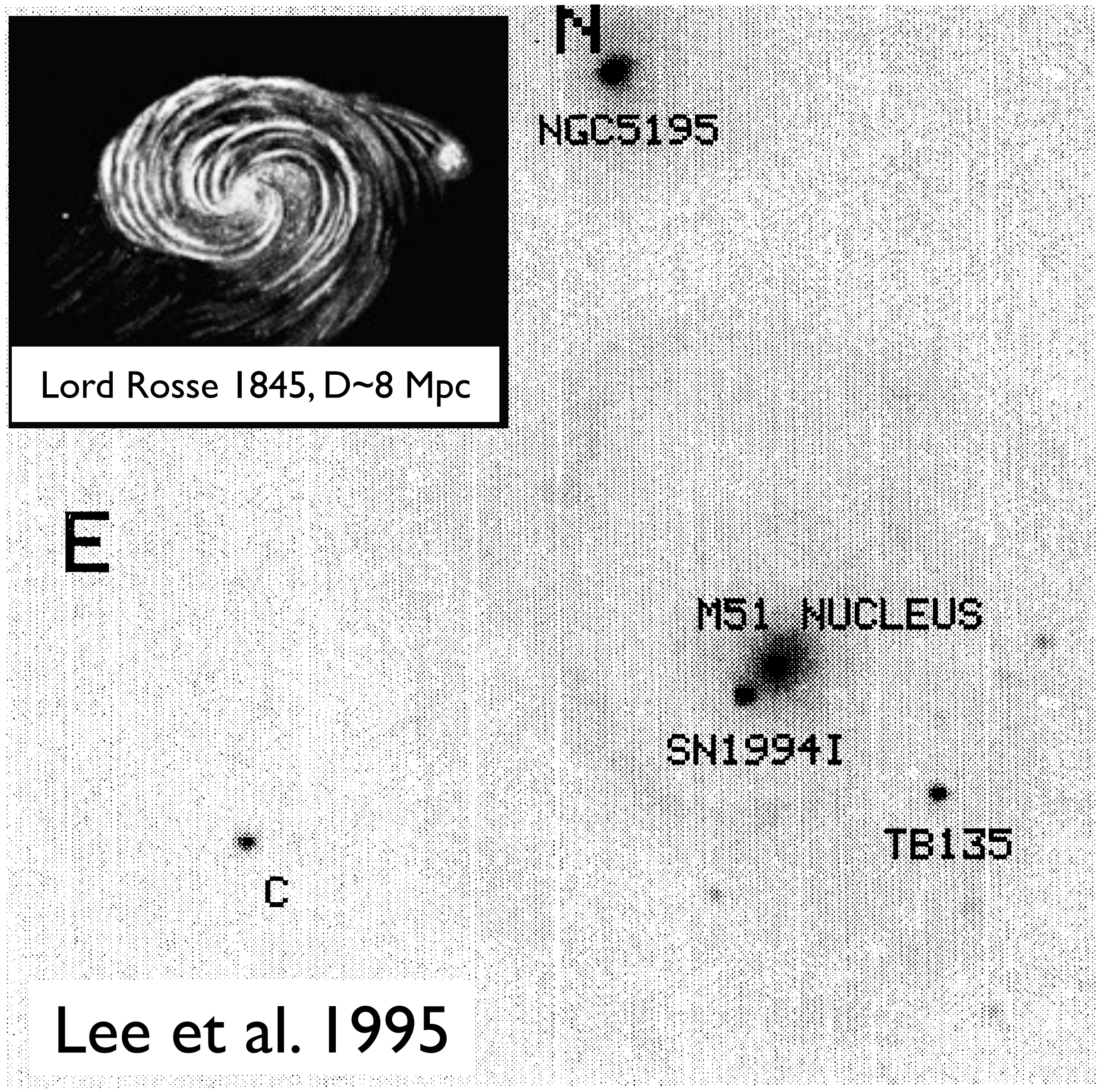
hyper-energetic GRBs

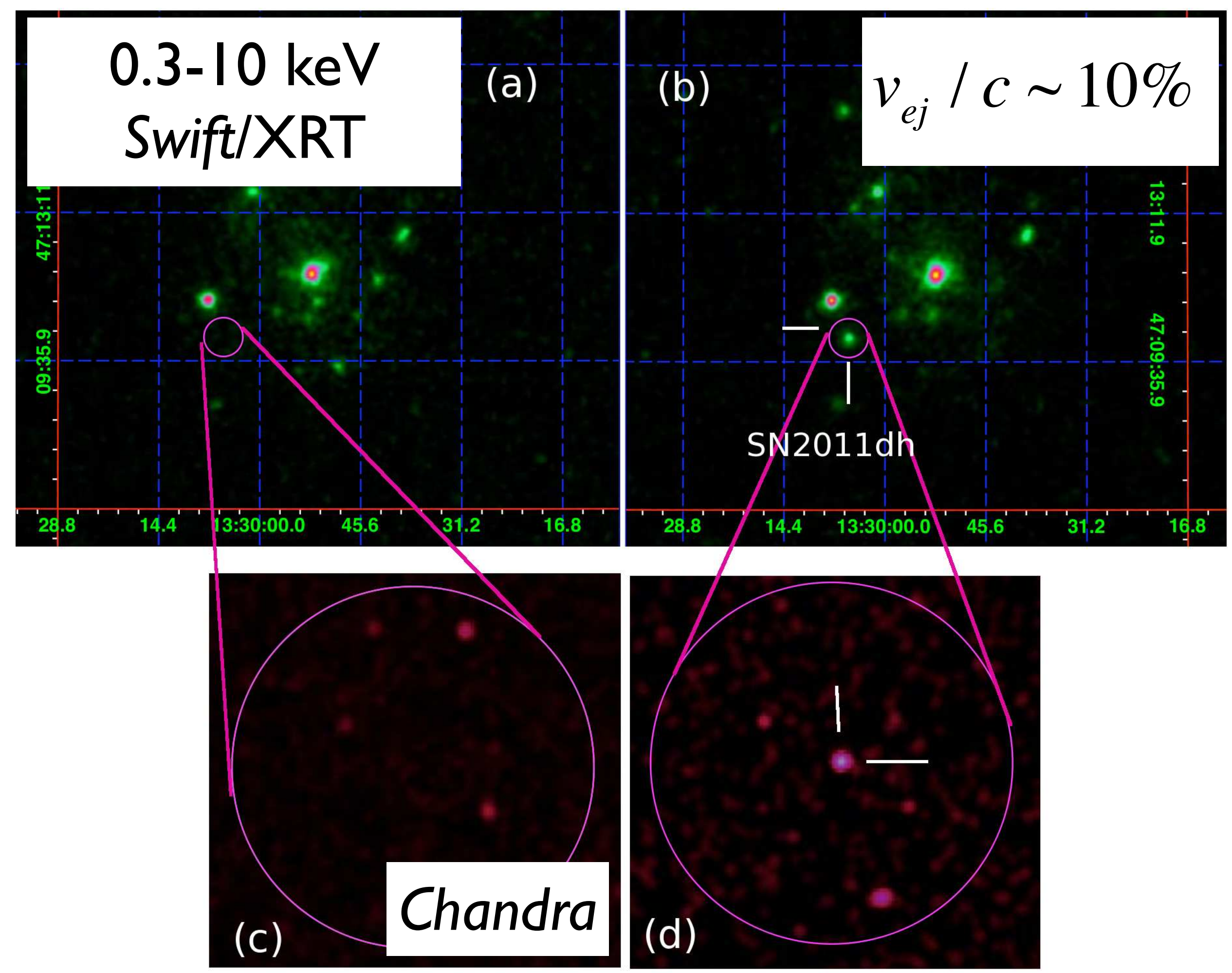
Burst	Redshift	T90[s]/1+z	E_{iso} [erg]	$E_\gamma + E_k$ [erg]
GRB 990123	1.61	9.6	1.2e54	1.2e52(*)
GRB 050820A	1.71	97	1.2e54	4.2e52(c)
GRB 050904	6.3	31	0.66-3.2e54	2.1e52(c)
GRB 070125	1.55	78	1.1e54	3e52(c)
GRB 080319B	0.937	31	1.3e54	1.3e52(c)
GRB 080916C	4.25	11.4	8.8e54	8e52(*)
GRB 090926A	2.1062	6.3	1.9e54	1.4e52(c)

c) Swift sample of Cenko et al. 2010ab

*) estimated using $\eta_\gamma = \frac{E_\gamma}{E_\gamma + E_k} \approx 0.35$ (Frail et al. 2003)
and a conservative average 300 of estimated beaming factors: 500 (Frail et al. 2003), 450 (van Putten & Regimbau 2003), 75 (Guetta, Piran & Waxman 2004)

"The total energy release we measure for the hyper-energetic (>1e52 erg) events in our sample is large enough to start challenging models with a magnetar as the compact central remnant" (Cenko et al. 2010)





Soderberg, et al., 2011, arXiv:1107.1876

SN1994i: Type Ic, M~12-30 solar

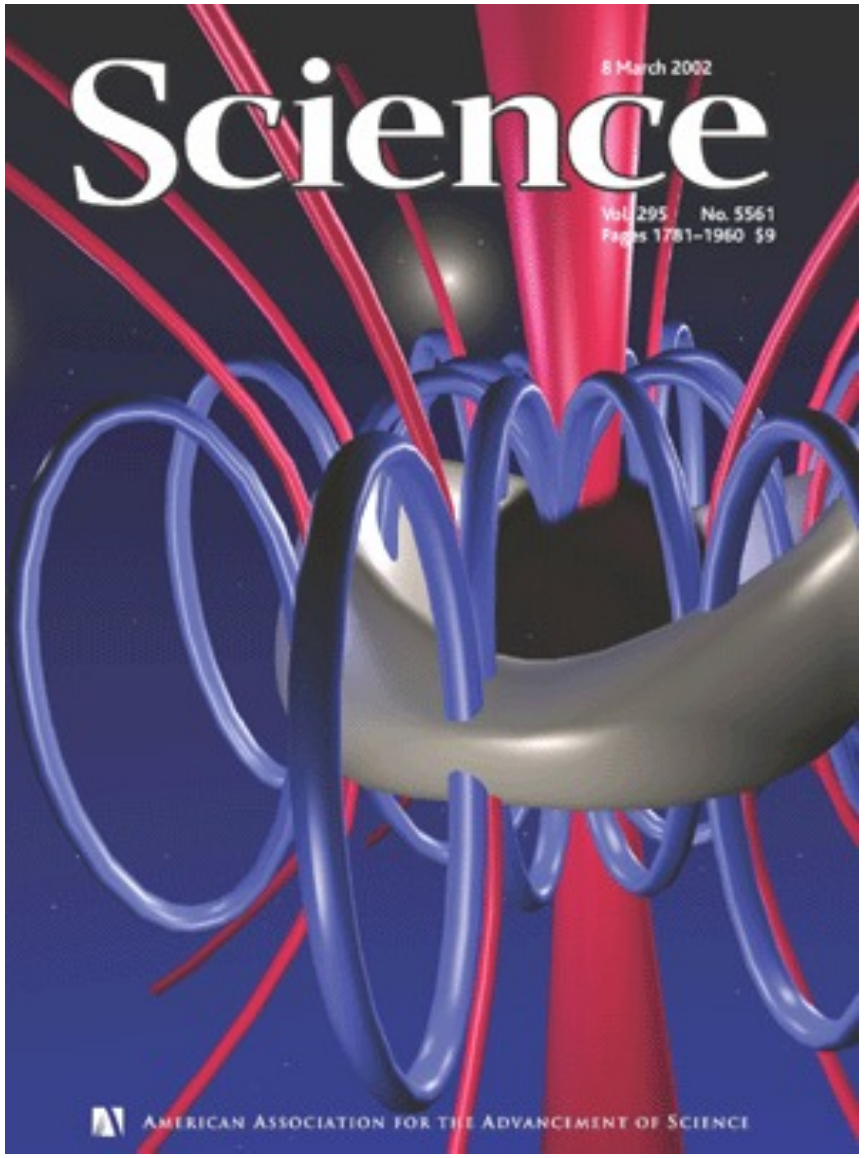
SN2005cs: Type II, M~18.1 solar

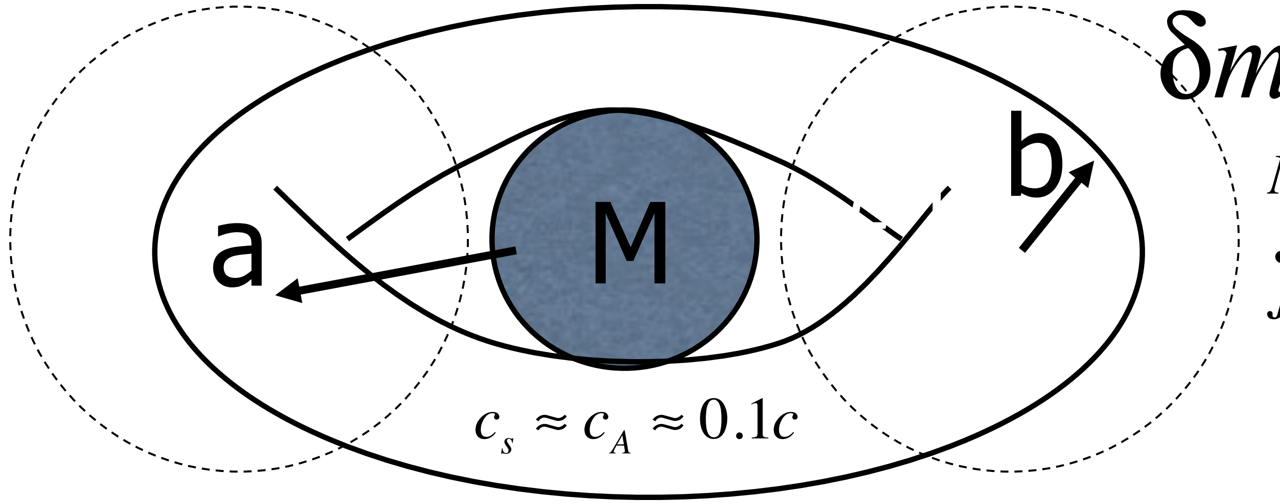
SN2011dh: Type II-P, M~13 solar

once every ~8.5 years?!

Multimessenger emissions

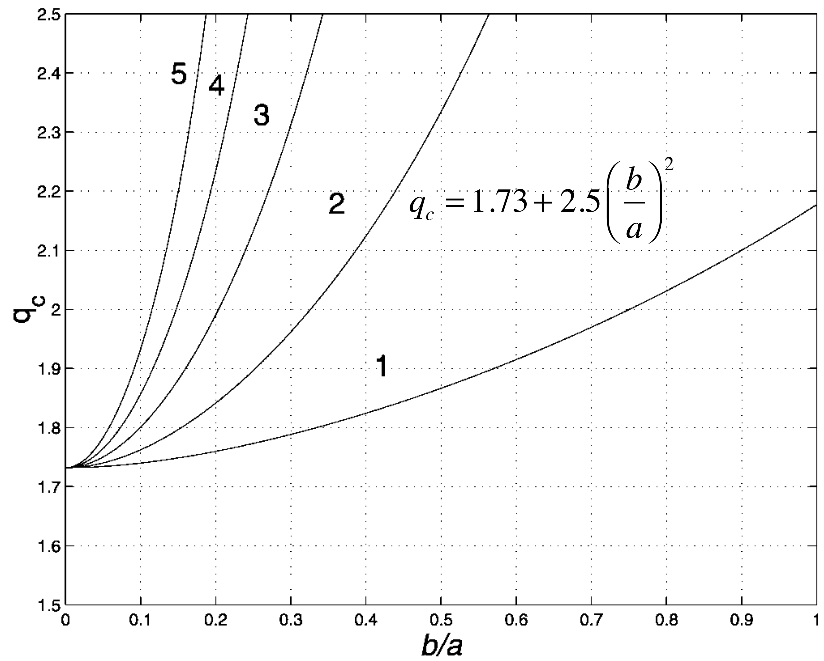
(GWs, MeV neutrinos and magnetic winds)





$$\dot{M} = -\kappa(\Omega_H - \Omega_T)\Omega_T$$

$$\dot{J} = -\kappa(\Omega_H - \Omega_T)$$

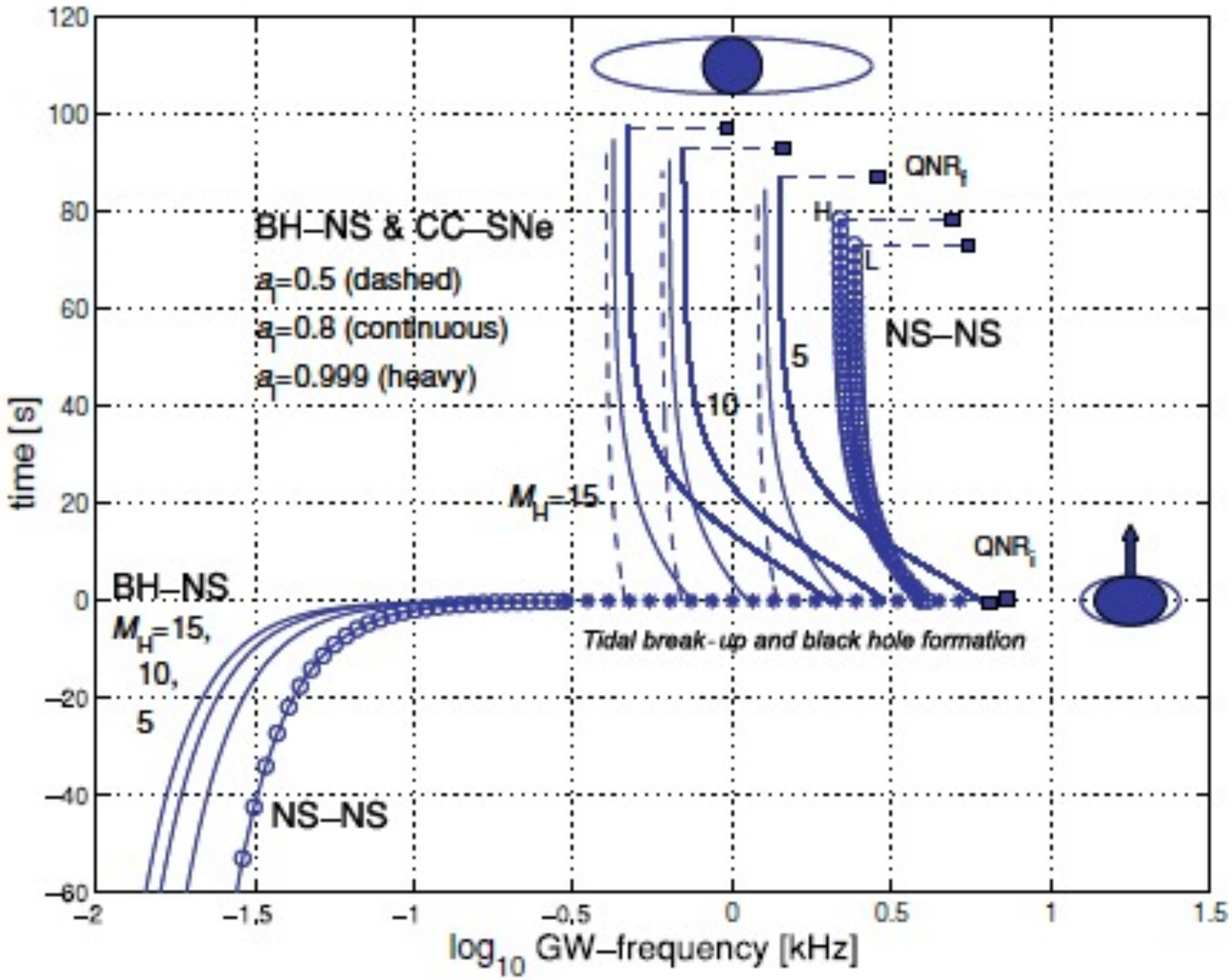


Thermal and magnetic pressure-driven Papaloizou-Pringle instability

van Putten 2002, van Putten & Levinson 2003

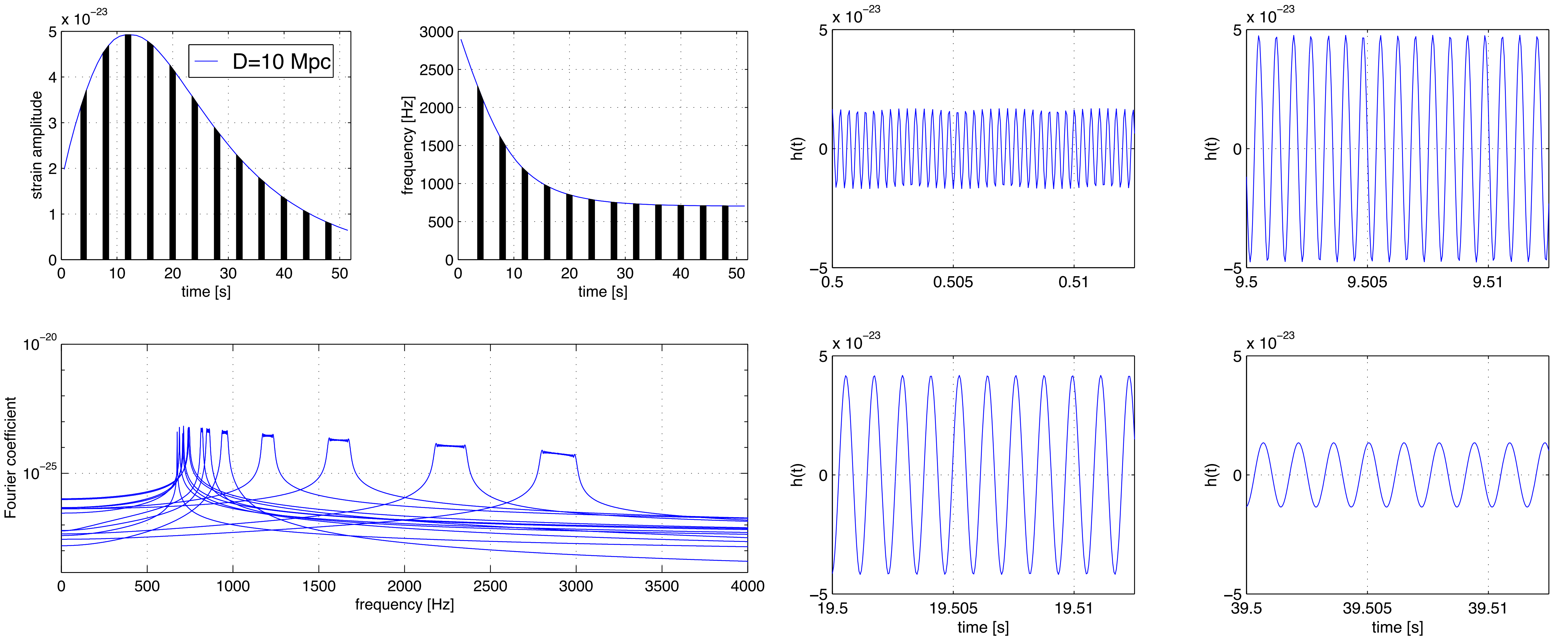
BH spin energy - non-axisymmetric torus - low m most/first unstable - most GW output in LIGO, Virgo, LCGT bandwidth!

Time frequency diagram for GWs from GRBs



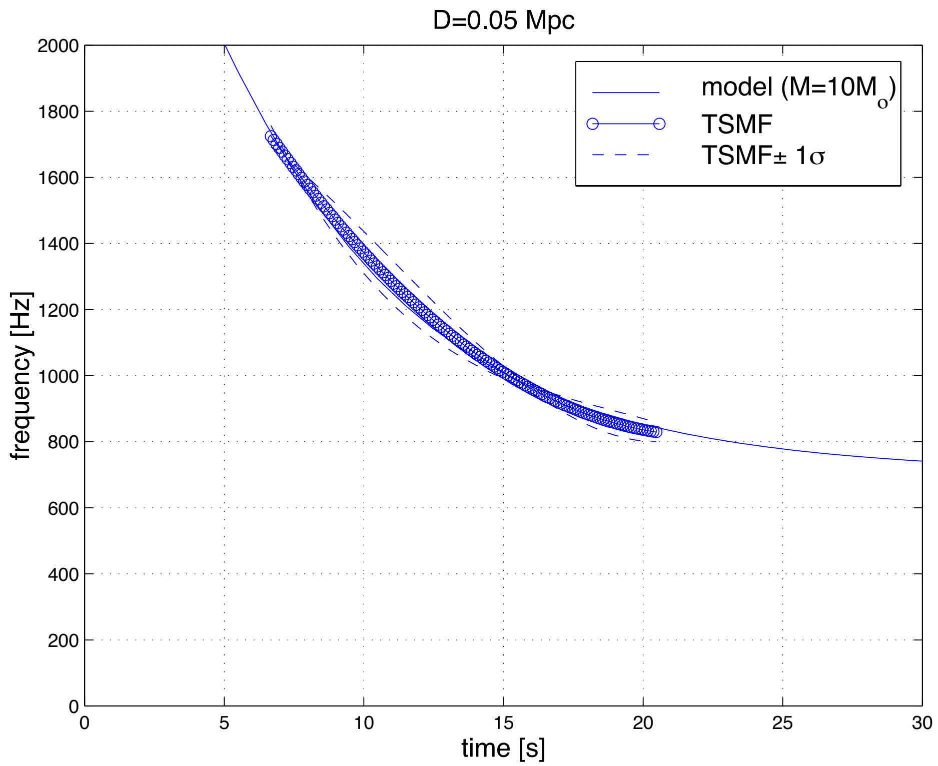
van Putten, 2009, MNRAS, 396, L81

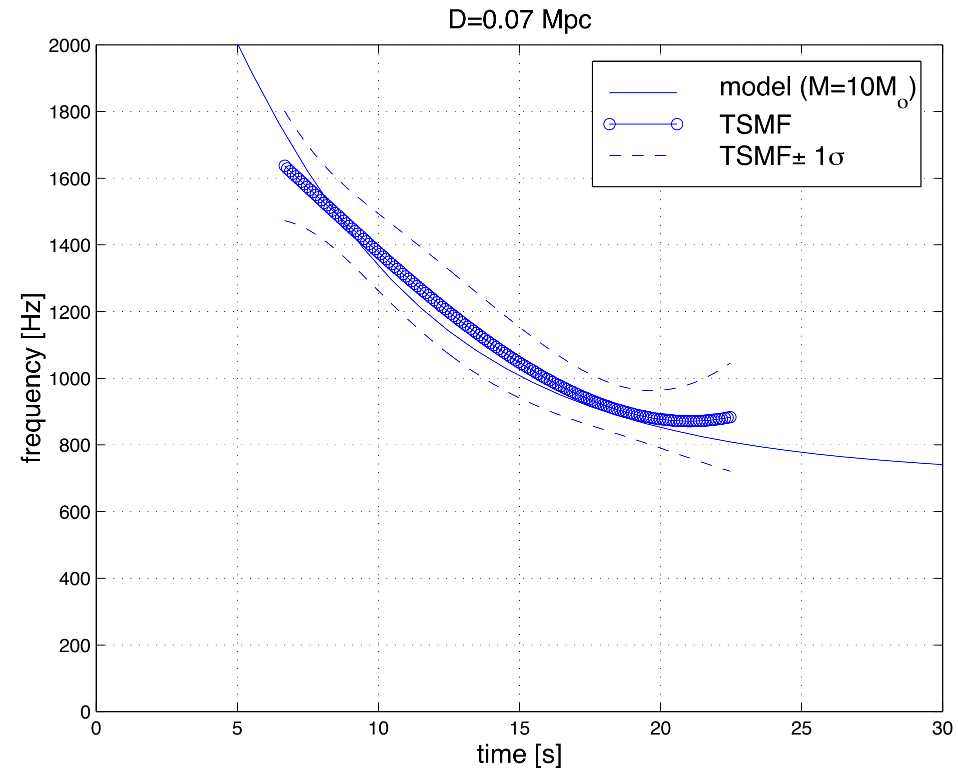
Gravitational-wave form templates



$$f_{GW} = 595 - 704\,\mathrm{Hz}\left(\frac{10M_{\odot}}{M}\right)$$

Sensitivity distances for chirp extraction





Advanced detectors (LIGO-Virgo, LCGT): h~2e-24@1000Hz

$$D \approx 35 \text{ Mpc}$$

van Putten, Kanda, Tagoshi, Tatsumi, Masa-Katsu & Della Valle, 2011, PRD, 83, 044046

Type II SN 2011dh in M51 at *D*=8 Mpc on May 31 2011

(*v*/*c*~10% in X-ray/radio analysis and radio-loud (Soderberg et al. ,2011))

TABLE II. Estimated $1-\sigma$ uncertainty in the extracted time-frequency trajectories by TSMF as a function of distance applied to long bursts in GWs produced by black hole spin down against high-density matter, expected to form in some of the CC-SNe and mergers of neutron stars with a rapidly rotating companion black hole. We do not include results on neutron-star–neutron-star mergers, in view of their relatively high frequencies of 1.5–2 kHz away from the region of maximal sensitivity of the existing gravitational-wave detectors.

Mass ($M_\odot$)	D[TAMA][a] (Mpc)	D[Adv][b] (Mpc)	R_D[c]	σ	max(SNR_i)[d]	sum(SNR_i)[e]
8	0.05	25	0.1	6%	6.4	74
8	0.07	35	0.3	22%	5.0	54
8	0.10	50	1.2	27%	4.5	46
10	0.05	25	0.1	4%	8.2	96
10	0.07	35	0.3	11%	6.2	68
10	0.10	50	1.2	22%	4.9	43
12	0.05	25	0.1	<1%	10.5	130
12	0.07	35	0.3	4%	7.8	87
12	0.10	50	1.2	9%	6.0	61

[a]With $h_n \simeq 10^{-21}$ Hz$^{-1/2}$ at 1 kHz during DT8 (2/2003–4/2003).
[b]With $h_n = 2 \times 10^{-24}$ Hz$^{-1/2}$ at 1 kHz.
[c]Estimated event rate within distance D[Adv], assuming 10 times more relativistic CC-SNe than successful GRB-SNe with otherwise similar inner engines and the observed event rate of 1 long GRB per year within $D = 100$ Mpc.
[d]Based on $\rho_i(\delta)$, $0 < \delta < 23$ s, $\tau = 1$ s, and averages over 10 frames.
[e]Based on $SNR_i > 4$ and averages over 10 frames.

LIGO off,

Virgo (3000m) sensitivity = 10x TAMA (300m): < 1 Mp

LCGT Collaborative Projects

1. Expect LGWB (tens of seconds) from LGRBs and some CC-SNe

2. Harvest CC-SNe from nearby farms: create a catalogue of interacting galaxies ~ M51 in collaboration with astronomy community

3. Develop a fast and efficient TSMF LCGT pipeline(s) for long bursts (presently 1000 hr/1hr TAMA data)

4. Develop opportunities to reach out to the scientific community at large (joint projects, data sharing for R&D)

van Putten & Levinson, Cambridge University Press, 2012 (to appear)

$L_{Edd} \sim 10^{10}$

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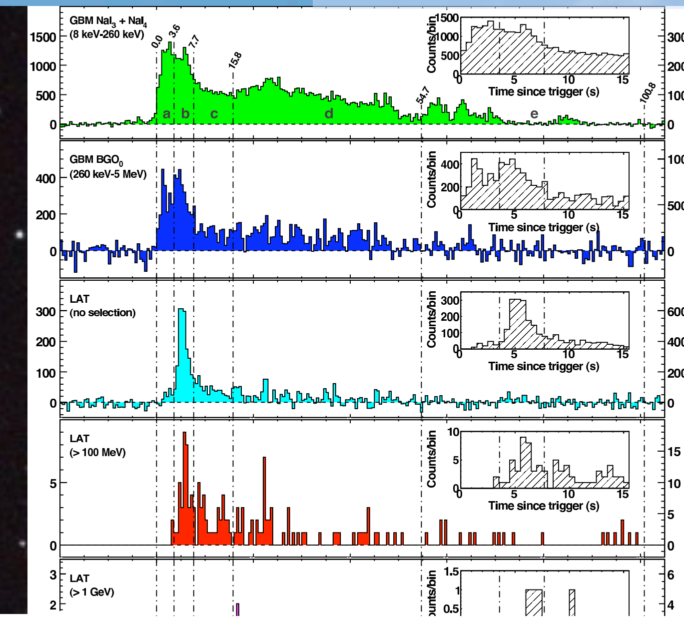

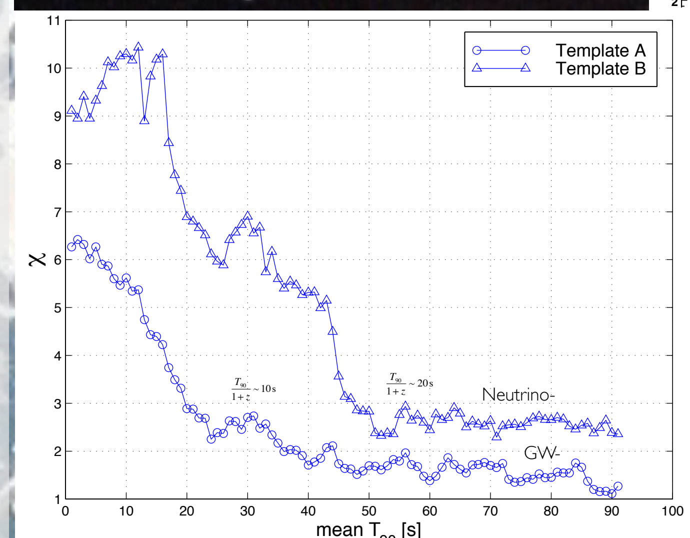

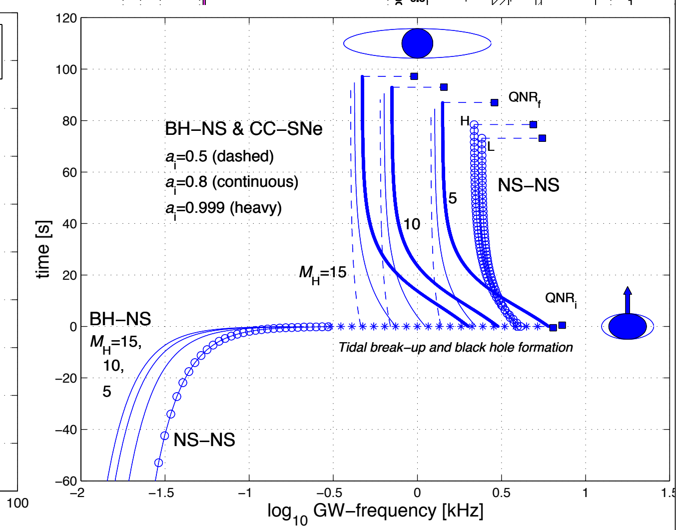

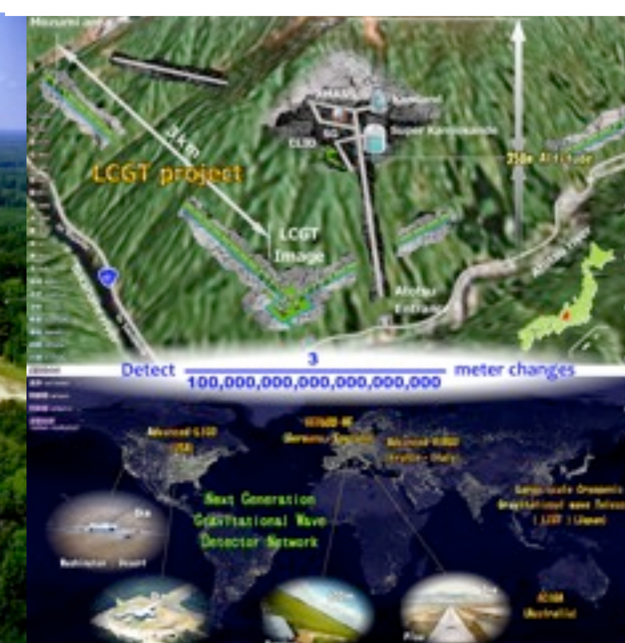

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Relativistic SNe rotationally powered?

Bisnovatyi-Kogan 1970
LeBlanc & Wilson 1970
Ostriker & Gunn 1971
Paczynski 1991

(proto-)magnetar	**Kerr black hole**
$E_{sp} \approx 3 \times 10^{52}$ erg Tanaka 1991 ... Metzger et al. 2011	$E_{sp} \approx 6 \times 10^{54} \left(\frac{M}{10 M_{\odot}} \right)$ erg van Putten 2003 van Putten & Levinson 2003
Efficiency? **(expelling the envelope)**	**Efficiency ~** $(v_{ej}/c) E_w$, $E_w \approx E_H - E_{gw} - E_{\upsilon,MeV}$, $E_H \approx f(a/M) E_{sp} \sim 0.5 E_{sp}$
Formation probability? **(max'l spin, B~1e15-16G)**	**Inevitable outcome of massive progenitors in intra-day binaries**