Searches for gravitational waves from supernovae and long GRBs

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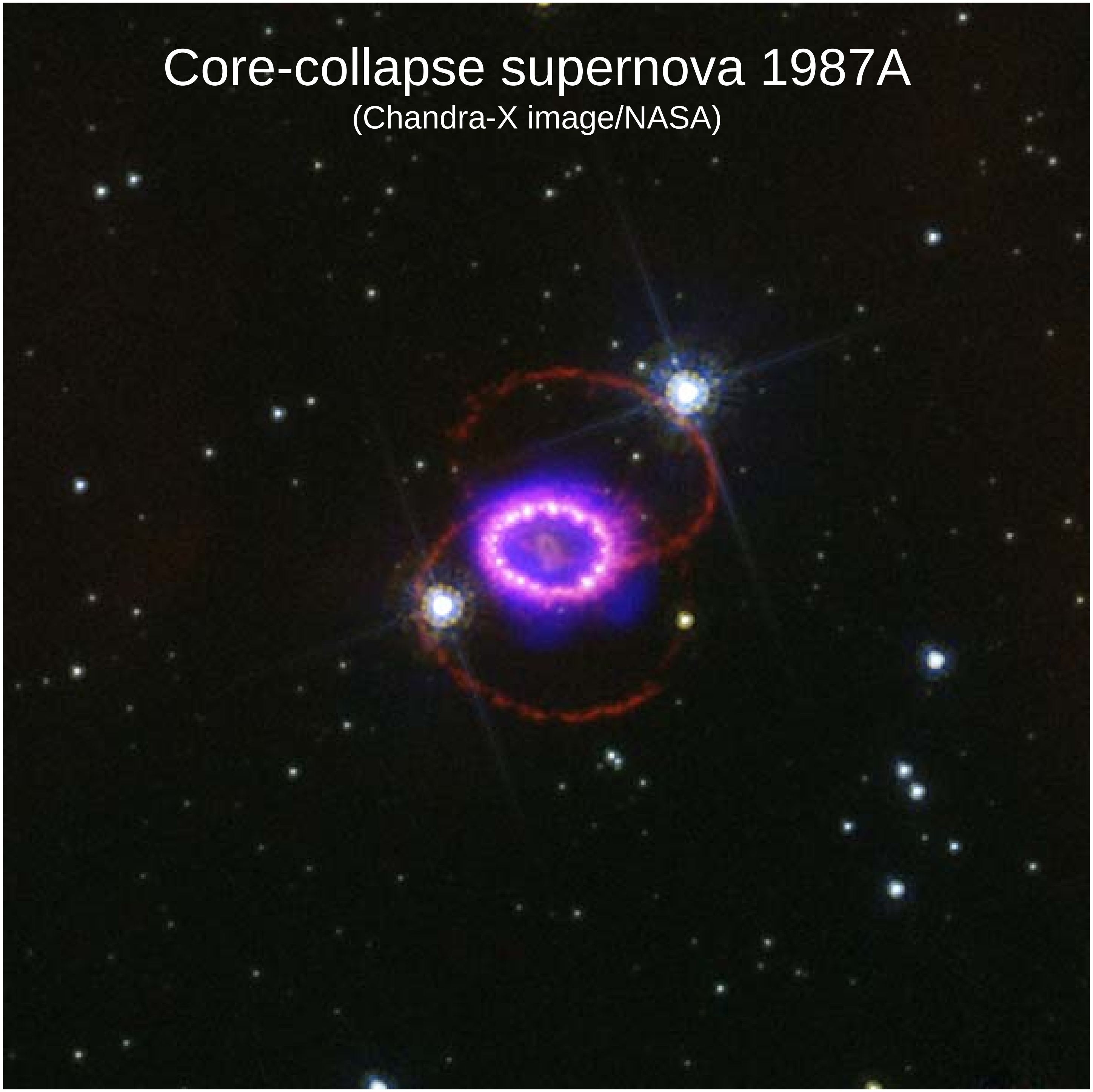
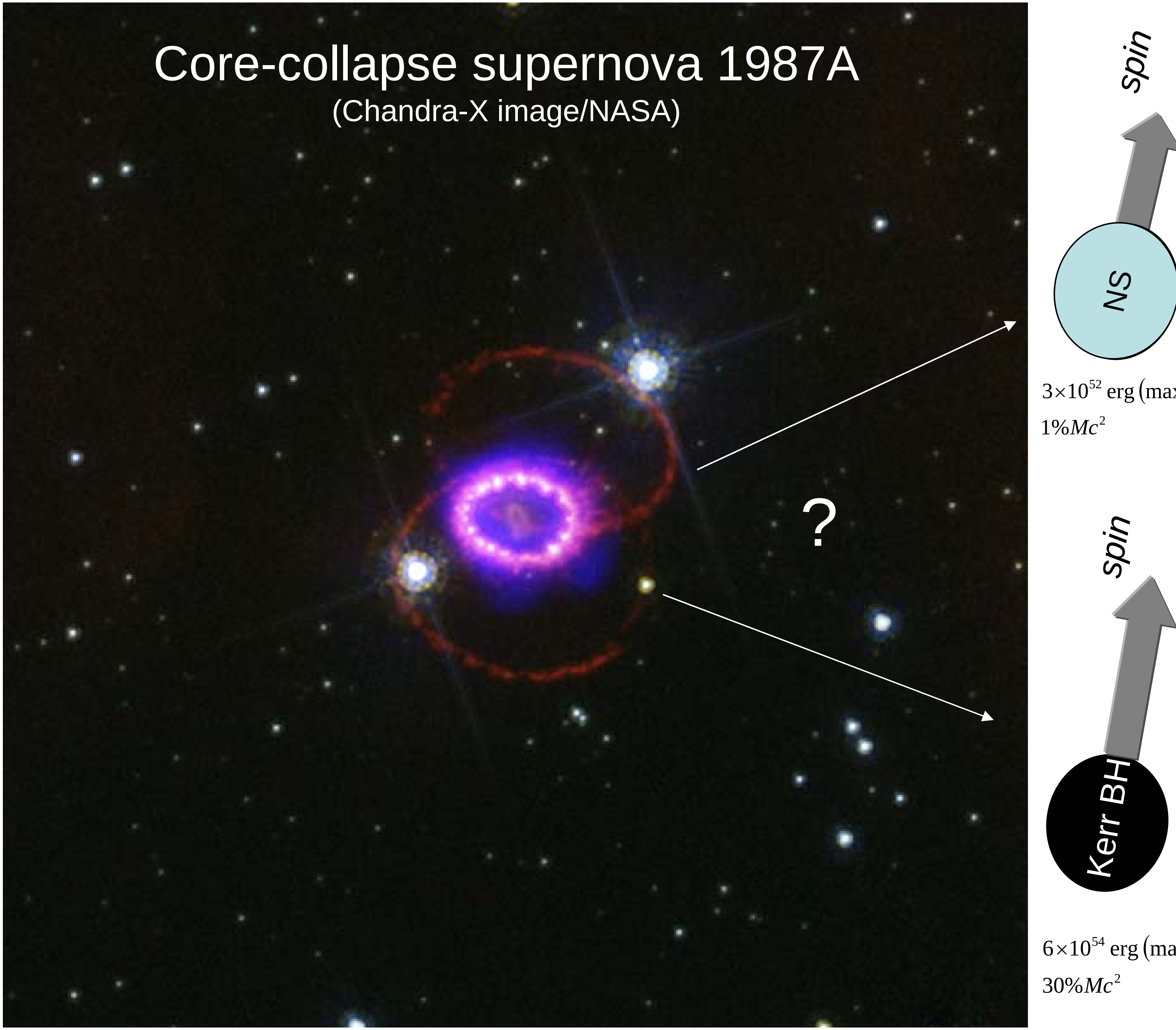
Vulcano Workshop 2012, Vulcano


Core-collapse supernova 1987A
(Chandra-X image/NASA)



3×10^{52} erg $\left(\text{maximal spin}, 1.5M_{Sun}\right)$

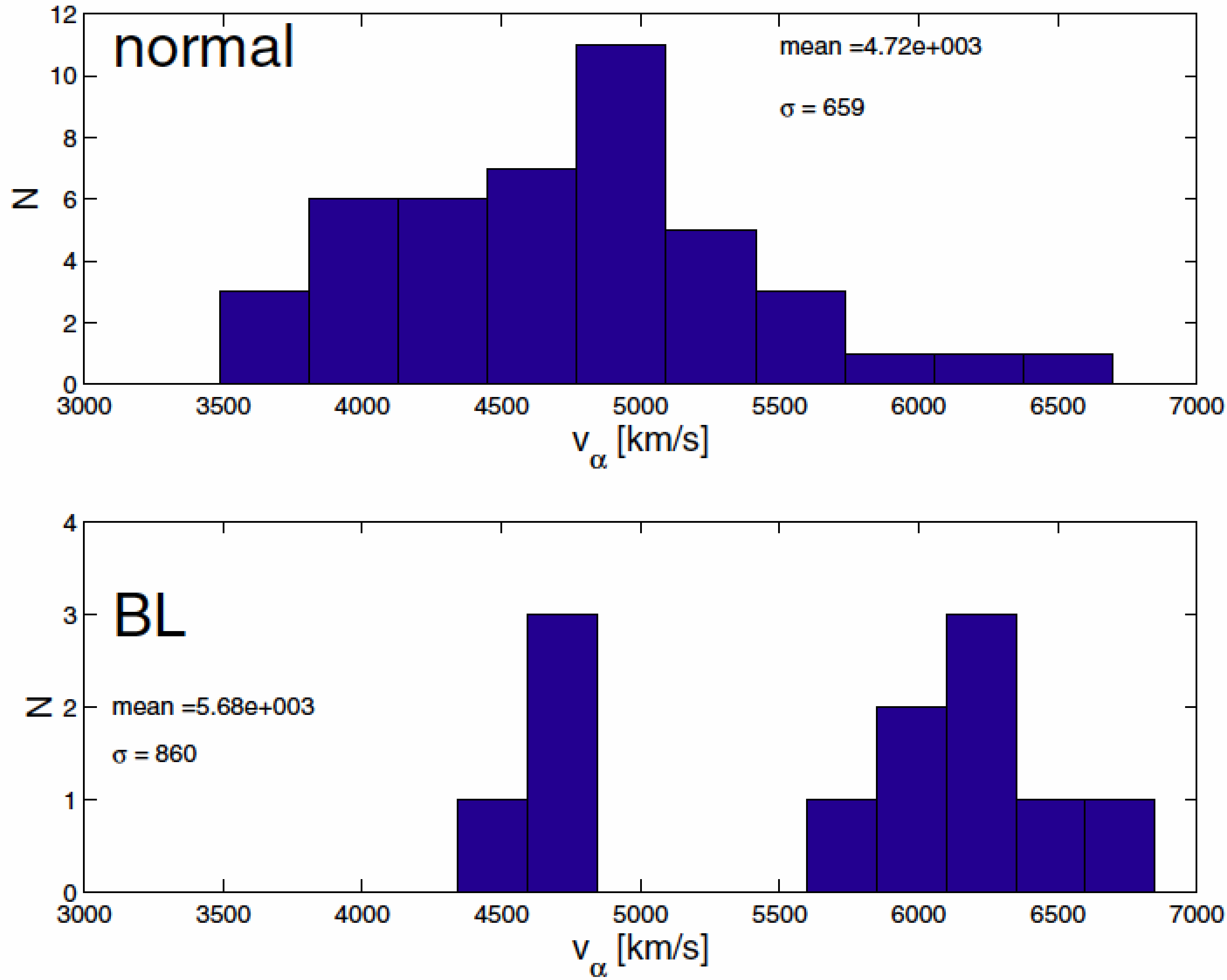
$1\% Mc^2$

6×10^{54} erg $\left(\text{maximal spin}, 10M_{Sun}\right)$

$30\% Mc^2$

Van Putten, Della Valle & Levinson, 2011, A&A, 536, L6
Maurer et al. 2010, MNRAS, 402, 161

CC-SNe are not all the same



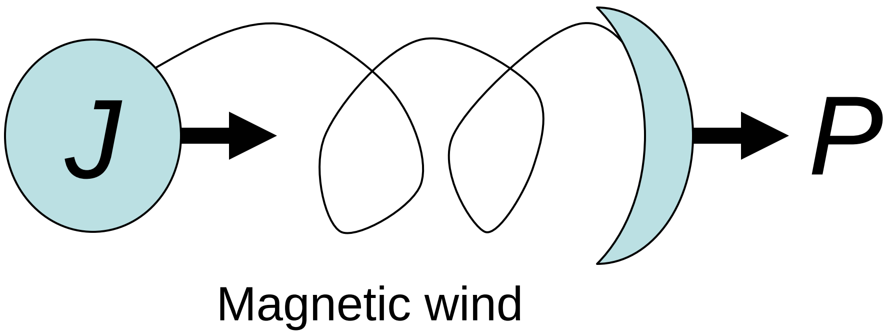
Bisnovatyi-Kogan, 1970, Astron. Zh., 47, 813
Van Putten, Della Valle & Levinson, 2011, A&A, 536, L6

Efficiency of explosion process

$$E_{SN} = \frac{1}{2} M_{ej} c^2 \beta_{ej}^2$$

Conversion of spin energy into radial momentum

$$\frac{1}{2} \beta_{ej} < \eta < 1$$



$$\eta = \frac{E_{SN}}{E_w}$$

Efficiency is high/low when baryon-rich/poor

Van Putten, Della Valle & Levinson, 2011, A&A, 536, L6

Energizing GRB-supernovae

NS produce winds of **one** type

GRB association indicative of a baryon-poor outflow

Whence low efficiency for accompanying supernova

$$E_{rot,\max} = E_c, \quad E_c = 3\times 10^{52}\ \mathrm{erg} = 1\% Mc^2$$

Van Putten, Della Valle & Levinson, 2011, A&A, 536, L6

Hyper-energetic events

GRB	SN	z	E_{tot} $[10^{51}\text{erg}]$	E_{SN} $[10^{51}\text{erg}]$	η	E_{rot} $[E_c]$	
GRB 031203	SN2003lw	0.1055		60	0.25	**10**	(!)
GRB 030329	SN2003dh	0.1685		40	0.25	**5.3**	(!)
GRB 100316D	SN2006aj	0.0591		10	0.25	**1.3**	
GRB 050820A		1.71	42		<1	**>1.4**	
GRB 080319B		0.937	30		<1	**>1.0**	

$$\left(E_c = 3\times10^{52}\ \text{erg}\right)$$

NS spindown is not a universal inner engine to all long GRBs

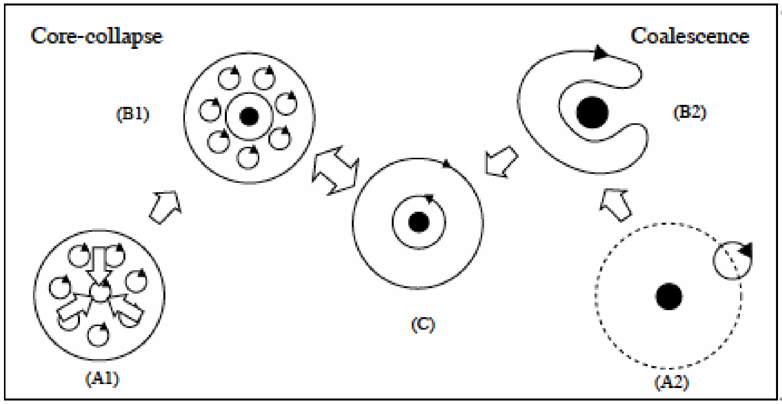
Some CC-SNe stand out

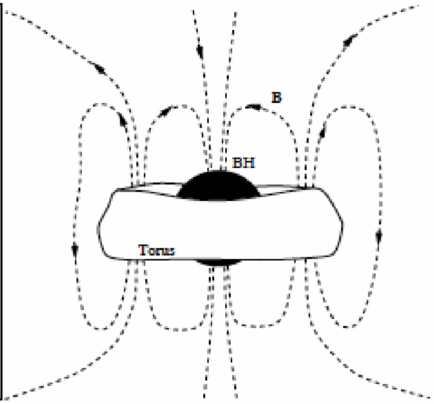
“Type IX”

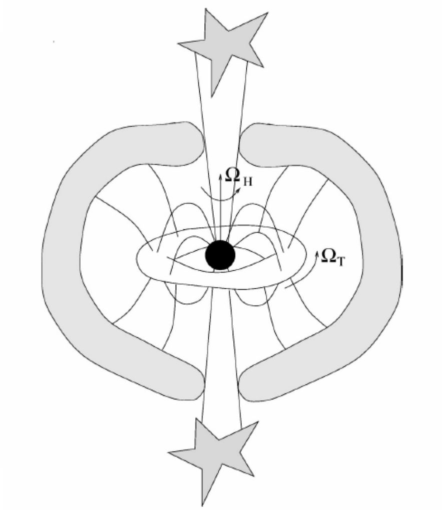
X=hyper-energetic, mysterious, extra large...
from a central engine with a black hole

Van Putten, 1999, Science, 294, 115
Van Putten & Levinson, 2003, ApJ, 587, 937
Van Putten, Levinson, Lee, Regimbau, Punturo & Harry, 2004, Phys. Rev. D, 69, 044007

High-density disks formed in catastrophic events







CC-event BH-NS merger BH-torus

GRB-SNe

Van Putten, Levinson, Lee, Regimbau, Punturo & Harry, 2004, Phys. Rev. D, 69, 044007
Van Putten, Della Valle & Levinson, 2011, A&A, 536, L6

Energizing GRB-supernovae

BH-disk systems can simultaneously produce winds of **two** types:

Baryon-poor jets produced by BH producing a GRB

Baryon-rich disk wind can produce accompanying supernova

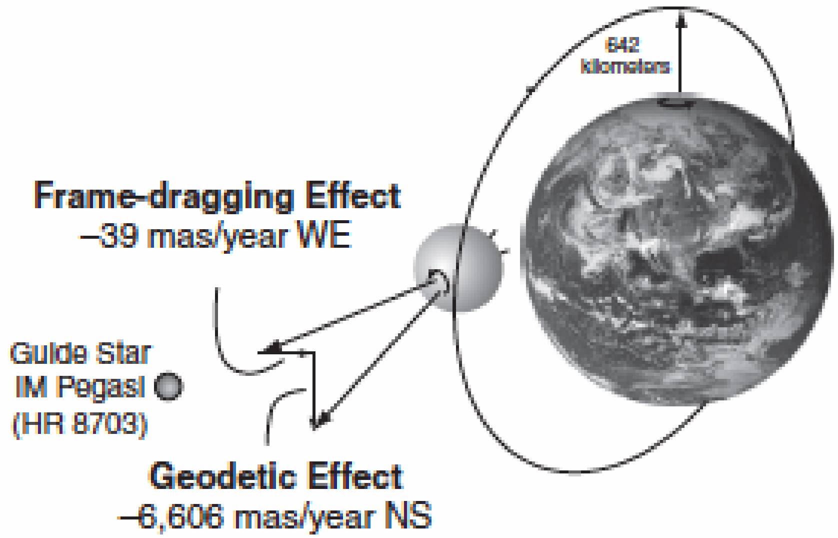
$$E_{rot,\max} = 6 \times 10^{54} \text{ erg} = 30\% Mc^2$$

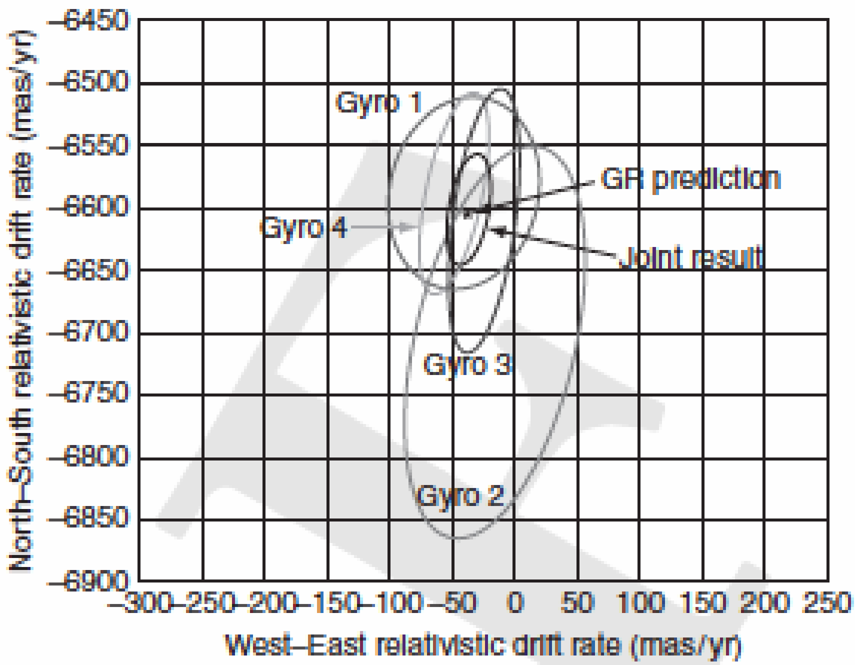
Frame-dragging

Now a real experimental science!

Everitt, F., et al., 2011, PRL, 106, 221101
Ciufollii, I. & Pavils, E.C., 2004, Nature, 431, 958

Satellite measurements – around the Earth





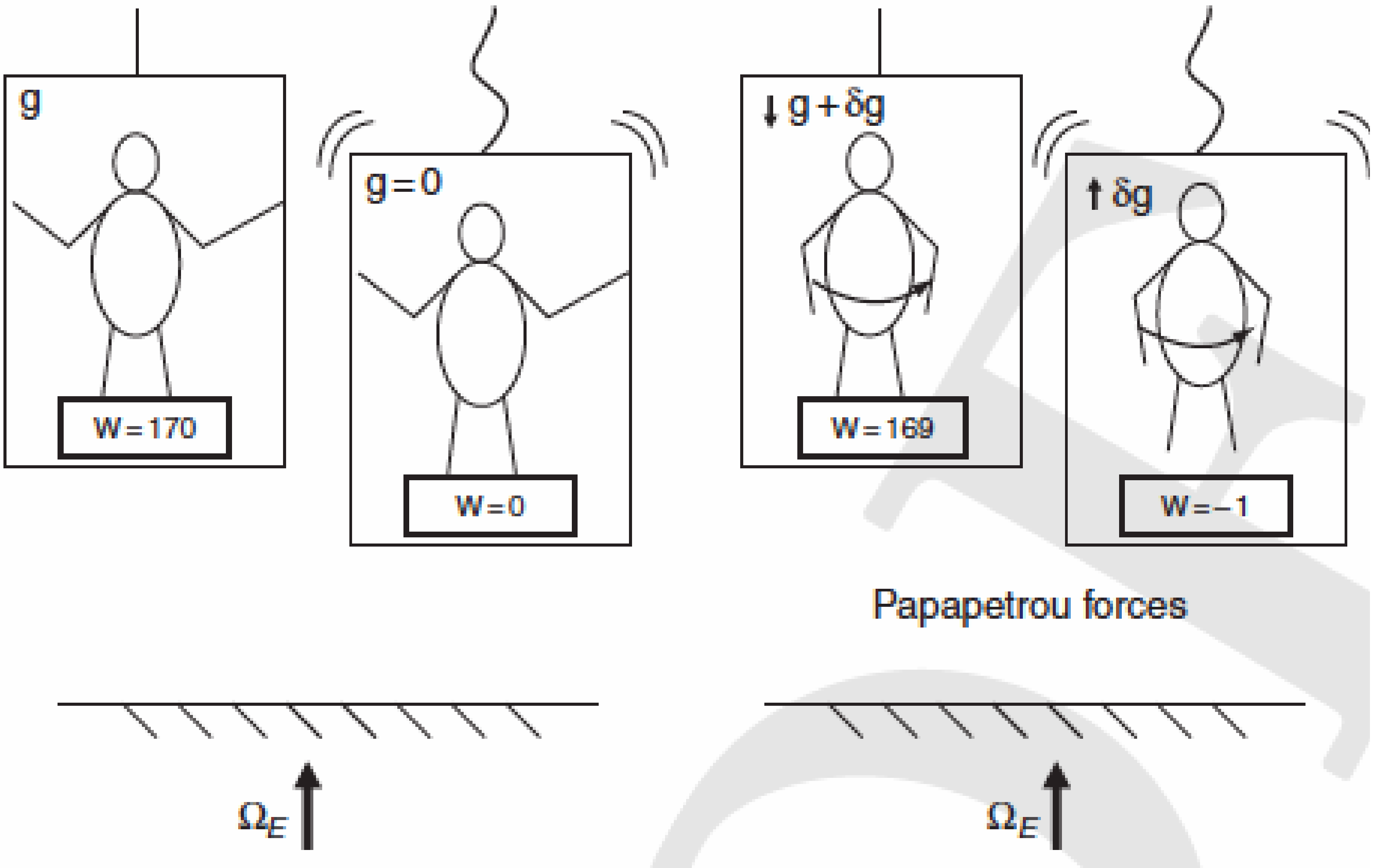
Two complementary experiments:

GPB (after 47 years!): Riemann tensor "tangible" in local measurement

LAGEOS satellites: Riemann tensor measured by orbital averaging

Van Putten & Levinson, 2012, Cambridge University Press, to appear

Frame-dragging induced forces

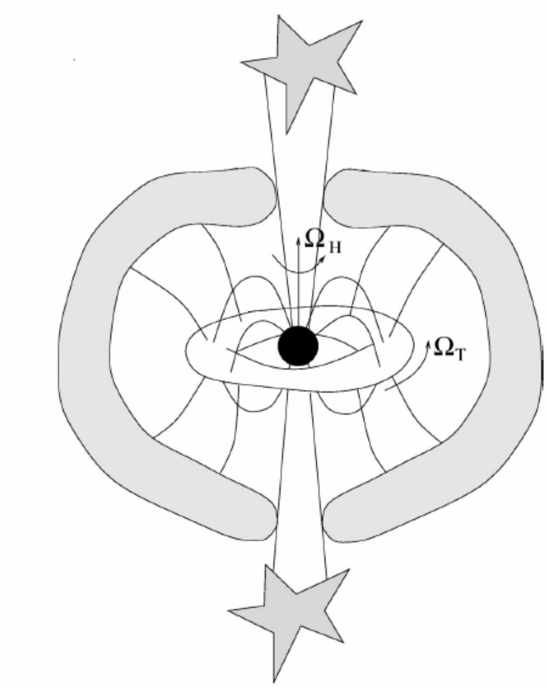


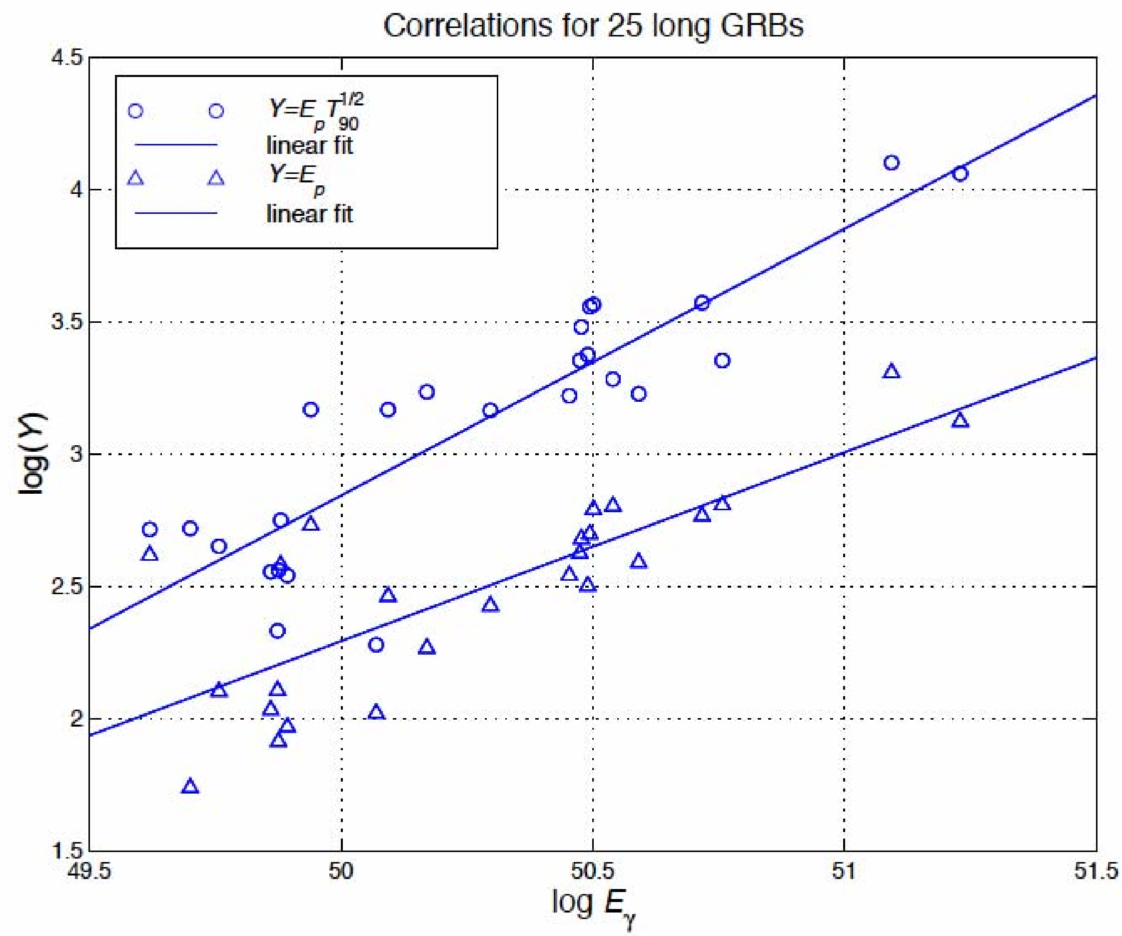
Van Putten, 2008, ApJ, 6845 L63

Induced spectral-energy correlation in GRBs

$$E = \omega J_p \left(J_p = eA \right)$$

$$E_p T_{90}^{1/2} \propto E_\gamma$$

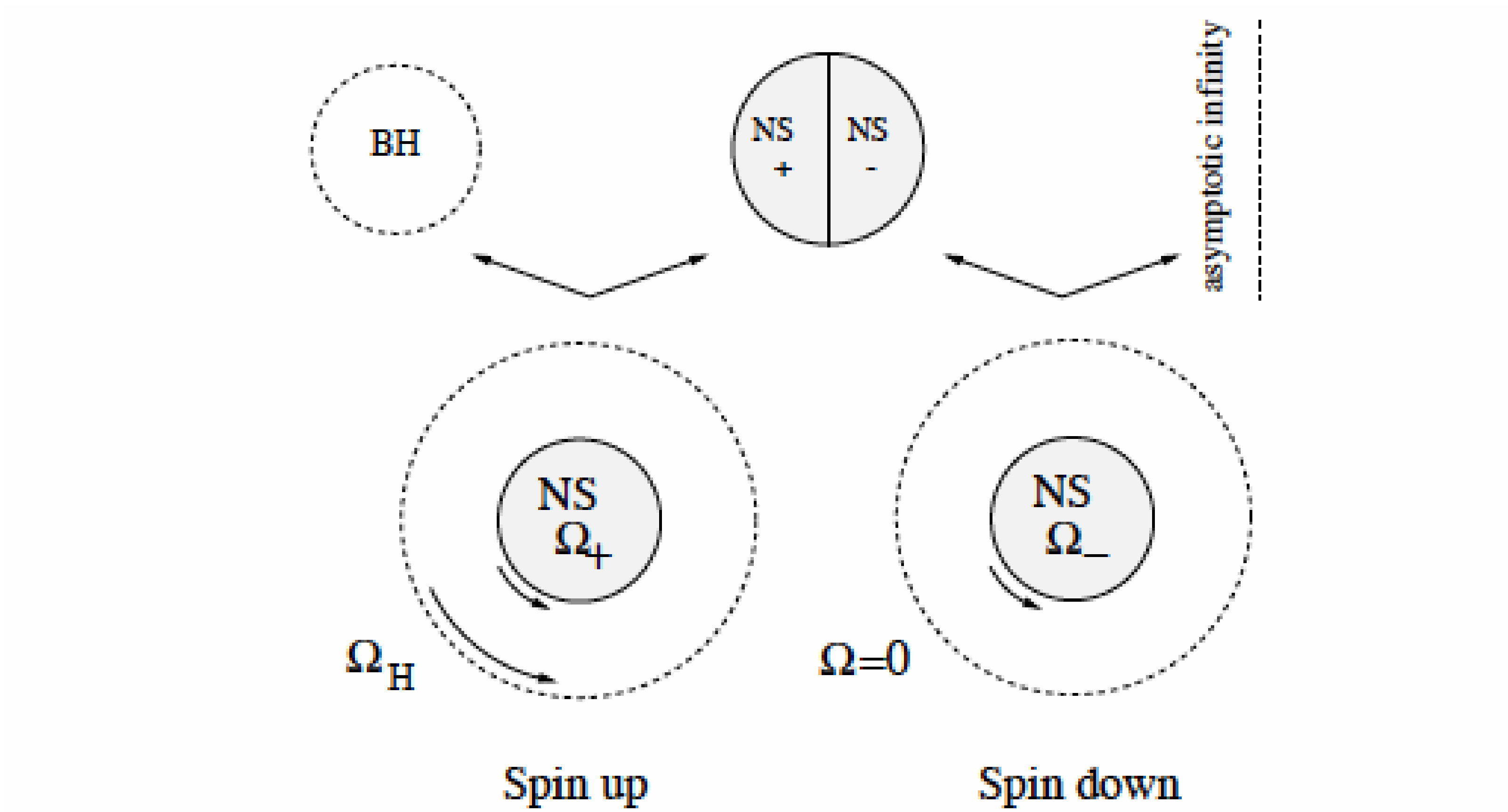




Van Putten, 1999, Science, 284, 115
Van Putten, Della Valle & Levinson, 2011, A&A, 536, L6
Van Putten, 2012, Prog. Theor. Phys., 127, 331

Spin-up of an inner disk or torus

Equivalence in poloidal topology to neutron star magnetospheres



Transfer of E and J from BH to the inner disk, leaving a lifetime of BH spin ~ 1 minute

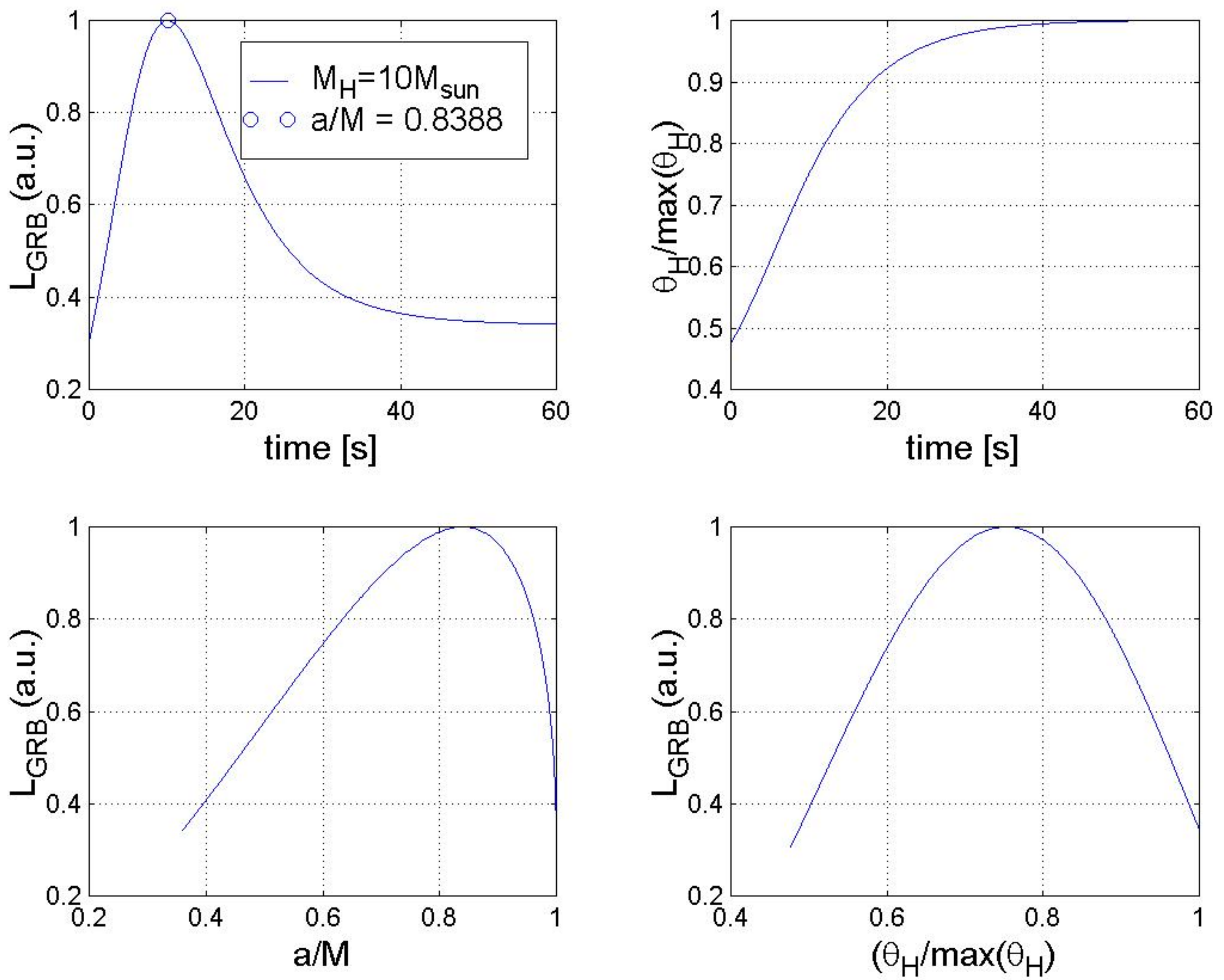
Van Putten, 1999, Science, 294, 115

Model light curves in BH spindown

$$T = -\dot{J}, \; L_H = -\dot{M}$$

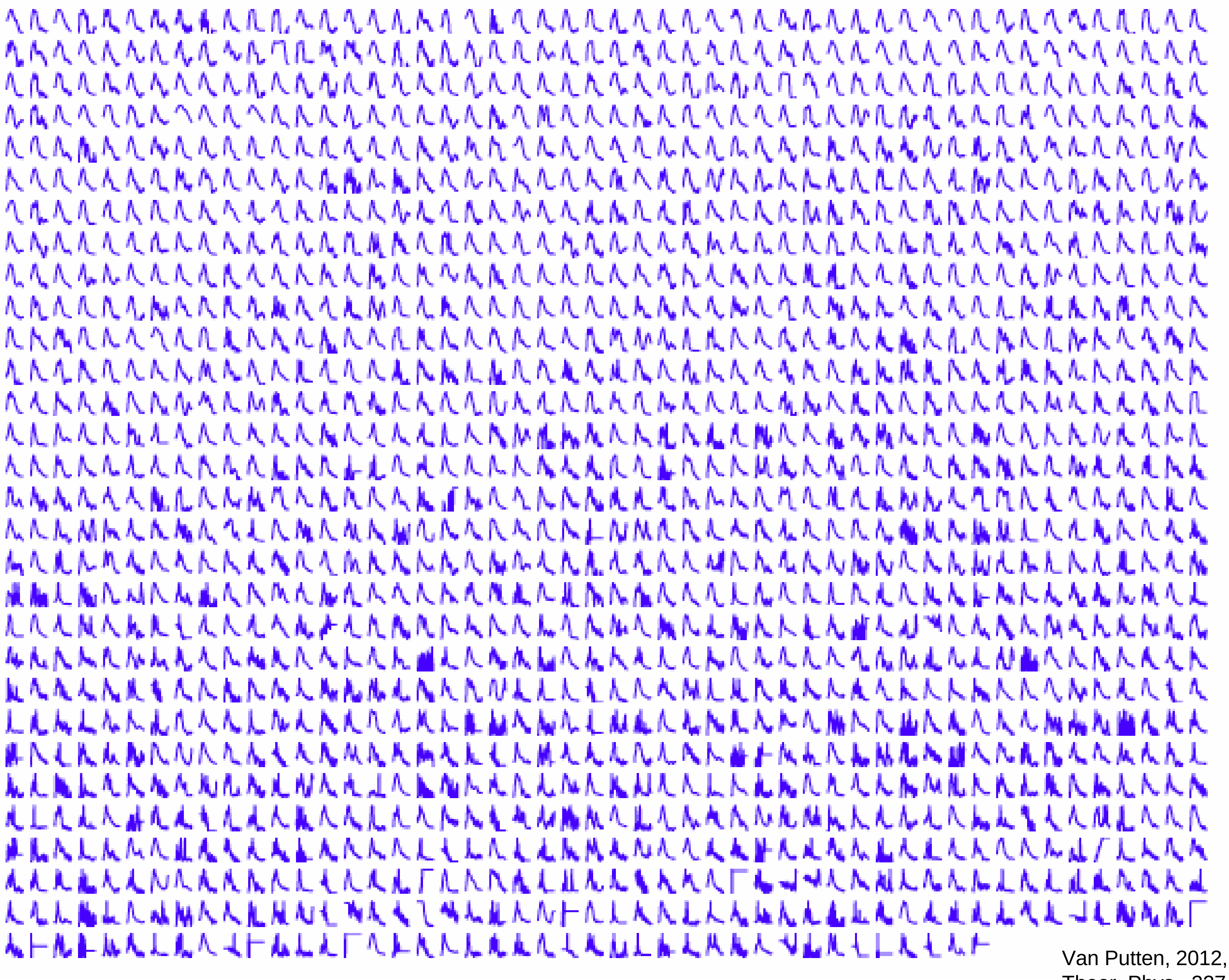
Van Putten, 2008, ApJ, 684, L91

Model light curve in BH spindown against matter at ISCO

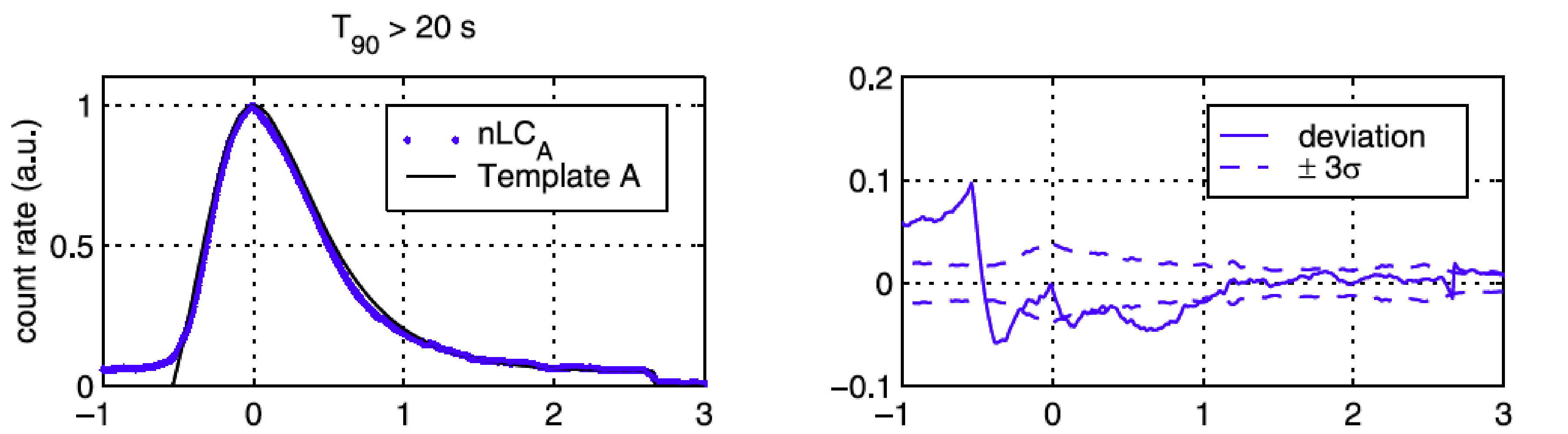


The BATSE Catalogue of 1491 light curves of long GRBs

(smoothed, scaled and ordered by T90)

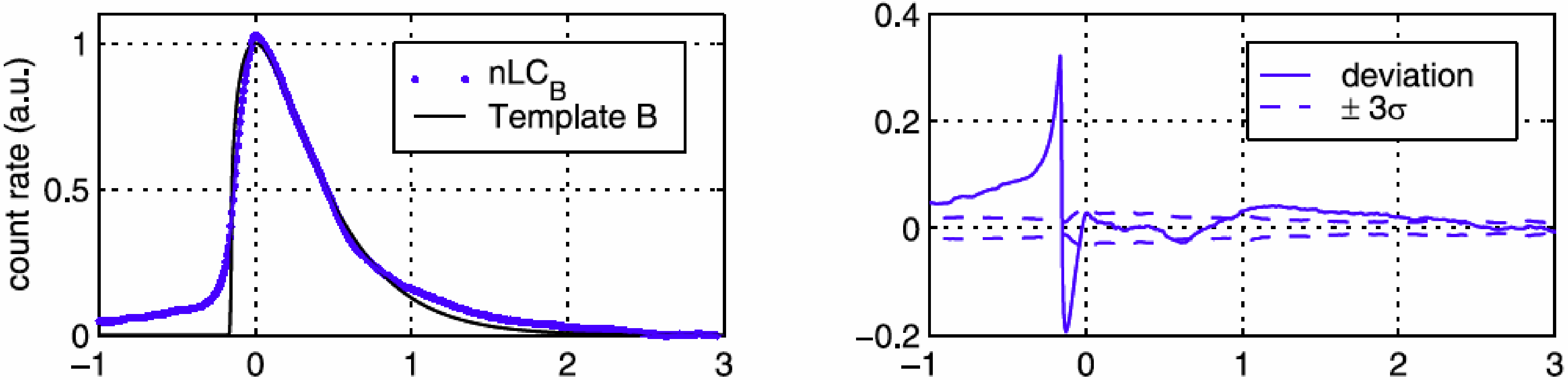


Van Putten, 2012, Prog. Theor. Phys., 227, 331



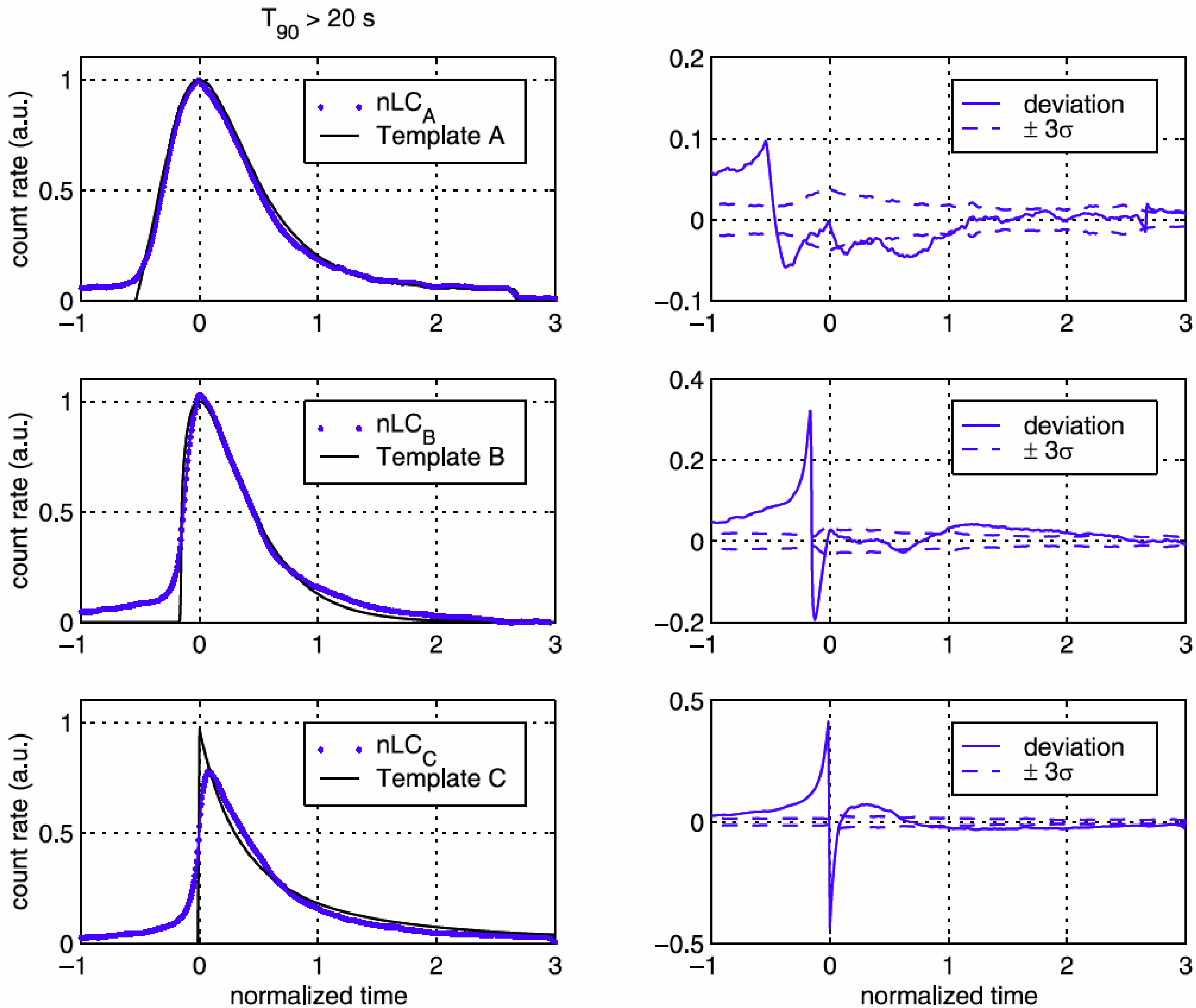
T90 > 20 s
count rate (a.u.)
nLCA
Template A
deviation
± 3σ

$$\text{Model B}: \quad \Omega_T = \frac{1}{2}\Omega_H$$



count rate (a.u.)
1
0.5
0
−1
0
1
2
3
nLC$_B$
Template B
0.4
0.2
0
−0.2
−1
0
1
2
3
deviation
± 3σ

Model C : light curve from NS spindown



T_{90} > 20 s
count rate (a.u.)
nLC$_A$
Template A
nLC$_B$
Template B
nLC$_C$
Template C
deviation
± 3σ
normalized time
normalized time

Van Putten, 2012, Prog. Theor. Phys., 127, 331

Theory confronts observation on BH spindown in nLC of GRBs

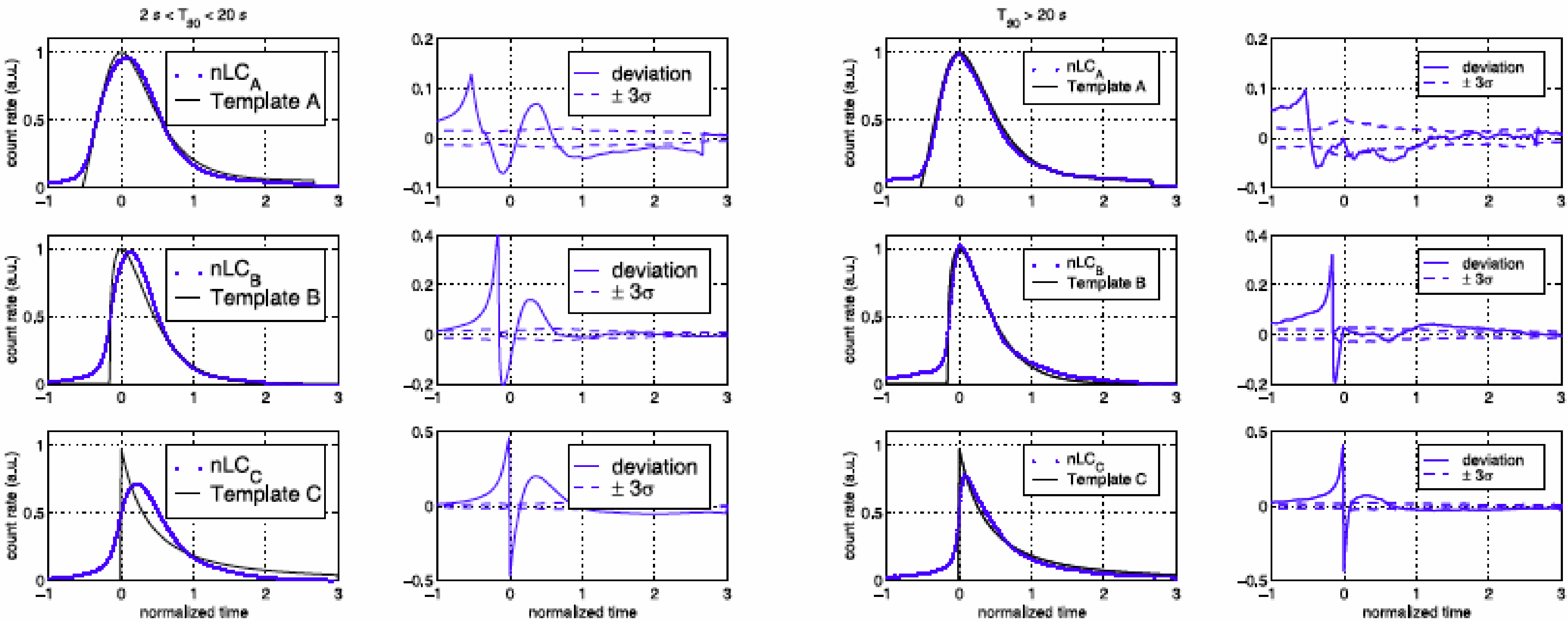
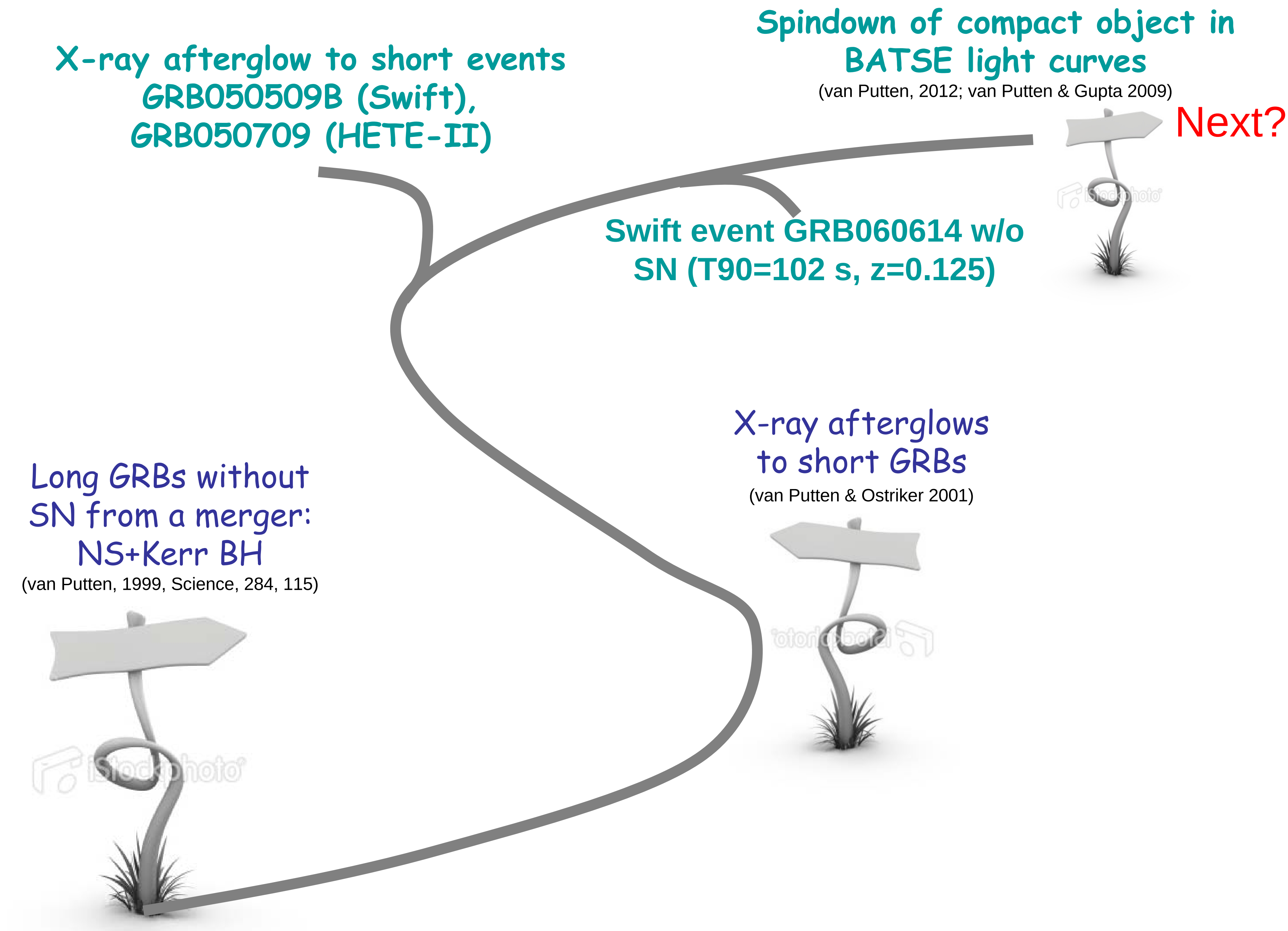
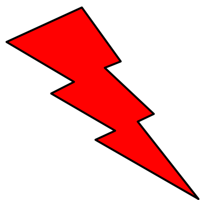


Fig. 6. Shown are the nLC (*circles*) generated by model templates A–C (*lines*) for the ensemble of 531 long duration bursts with 2 s $< T_{90} <$ 20 s (*left*) and the ensemble of 960 long bursts with $T_{90} >$20 s (*right*) and the associated deviations for Templates A–C. Here, the standard deviation σ is calculated from the square root of the variance of the photon count rates in the ensemble of individually normalized light curves as a function of normalized time.

Are we on the right track?


X-ray afterglow to short events
GRB050509B (Swift),
GRB050709 (HETE-II)
Spindown of compact object in
BATSE light curves
(van Putten, 2012; van Putten & Gupta 2009)
Next?
Swift event GRB060614 w/o
SN (T90=102 s, z=0.125)
X-ray afterglows
to short GRBs
(van Putten & Ostriker 2001)
Long GRBs without
SN from a merger:
NS+Kerr BH
(van Putten, 1999, Science, 284, 115)

Non-thermal multimessenger emissions by from inner disk or torus



Van Putten, 1999, Science, 294, 115
Van Putten, 2001, Phys. Rev. Lett., 87, 091101
Van Putten, 2002, ApJ, 575, L71
Bromberg, Levinson & van Putten, 2006, NewA 11, 619

Model light curves in BH spindown

$$T = -\dot{J}, \quad L_H = -\dot{M}$$

Powerful input establishes a turbulent disk subject to non-axisymmetric instabilities

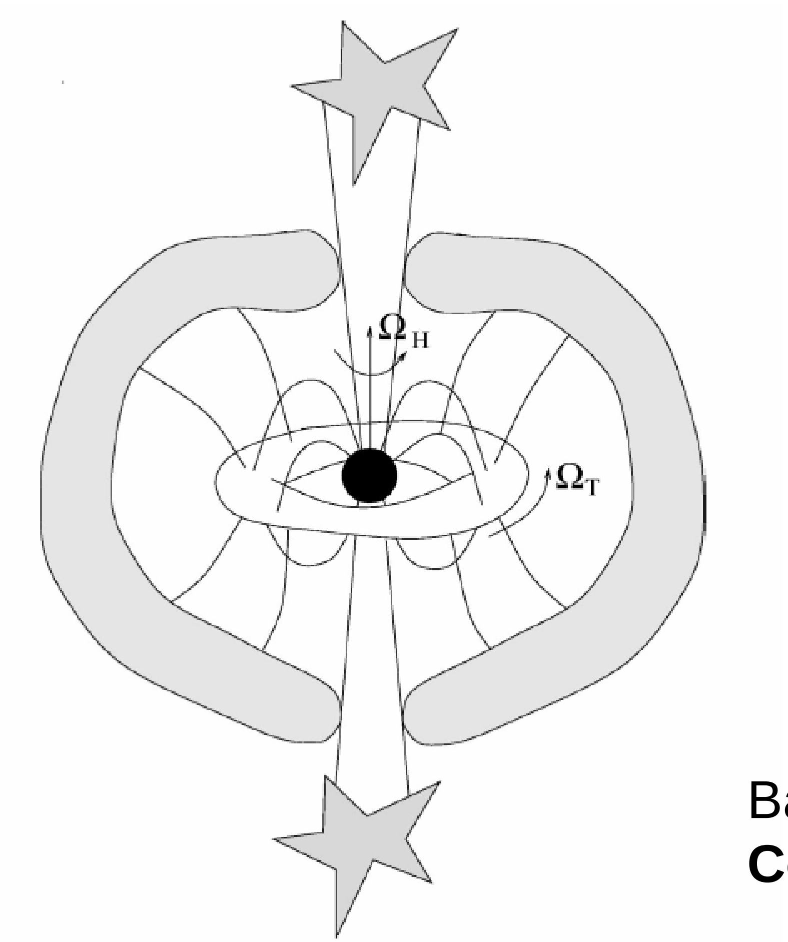
Thermal pressure induced, e.g., Papaloizou-Pringle

Magnetic pressure induced, from numerical simulations in a torus toy model

Van Putten, 1999, Science, 294, 115

Van Putten, Levinson, Lee, Regimbau, Punturo & Harry, 2004, Phys. Rev. D, 69, 044007

GRB-SNe from rotating BHs



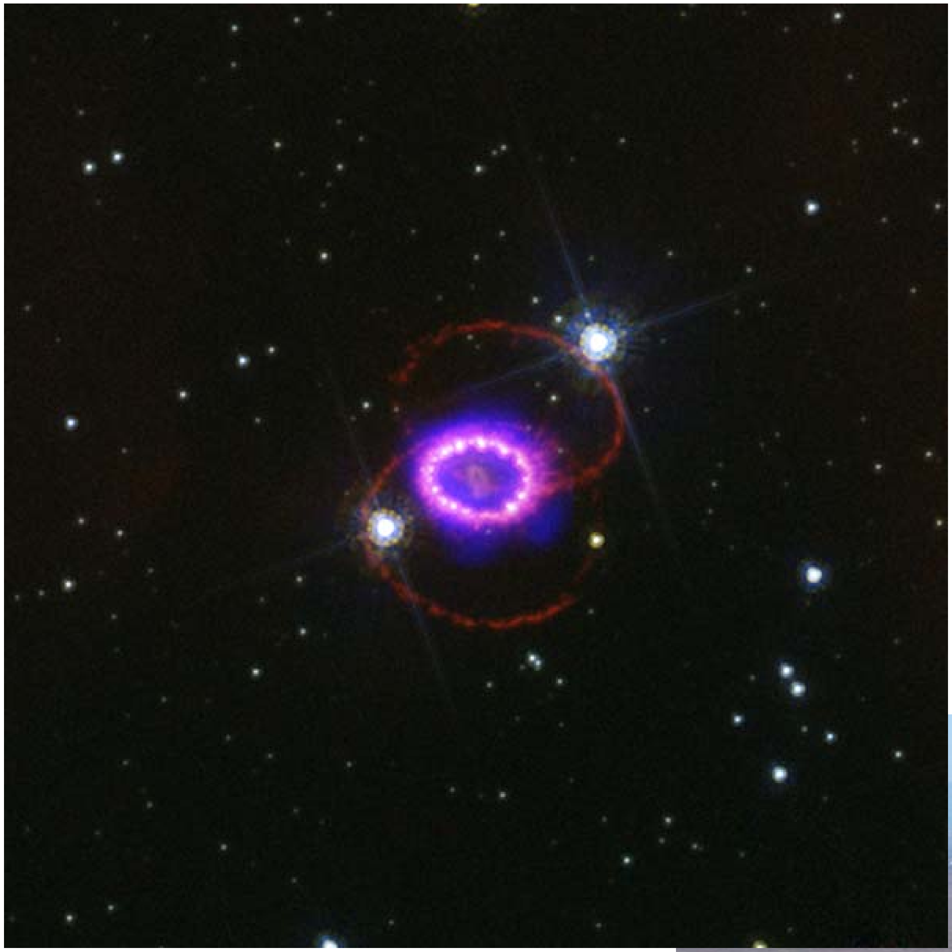
High-energy output

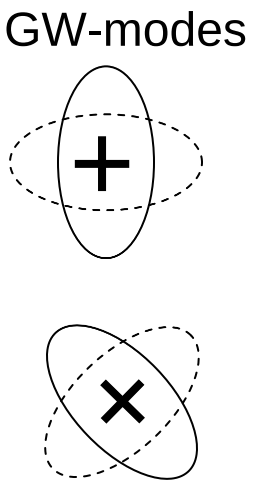
GRB-afterglow from baryon-poor jet

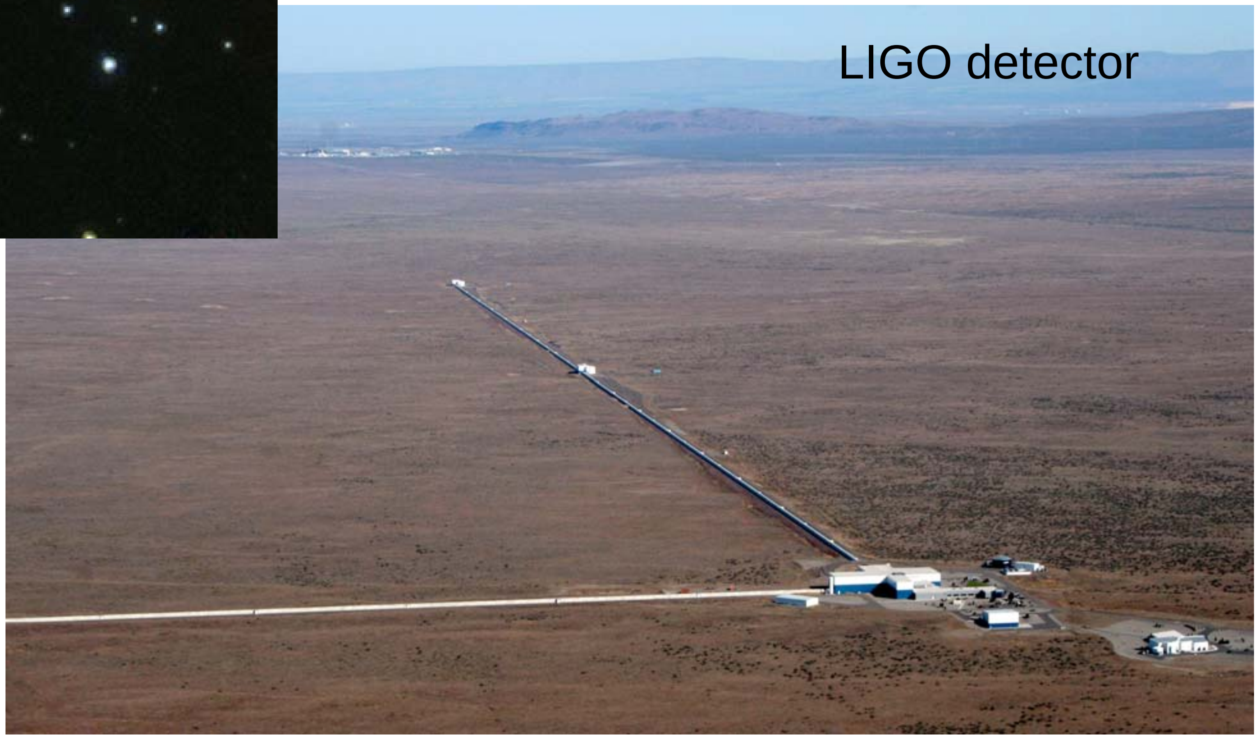
Low-energy output

Baryon-rich disk winds powering CC-SNe

Cooling by MeV neutrinos and GWs

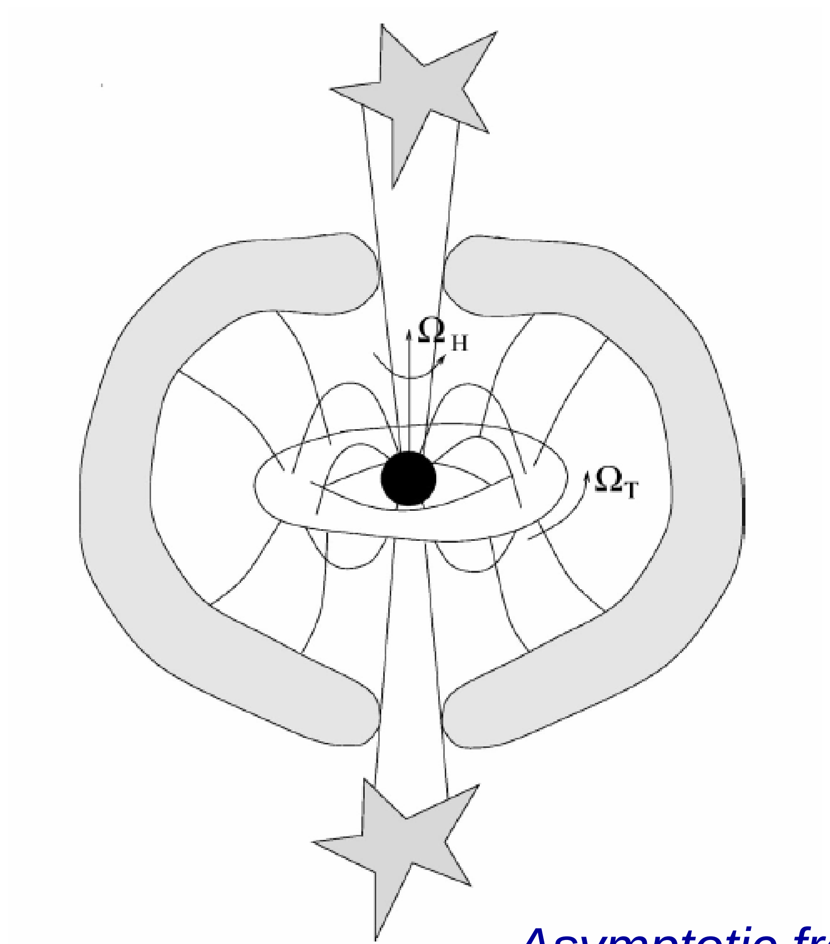


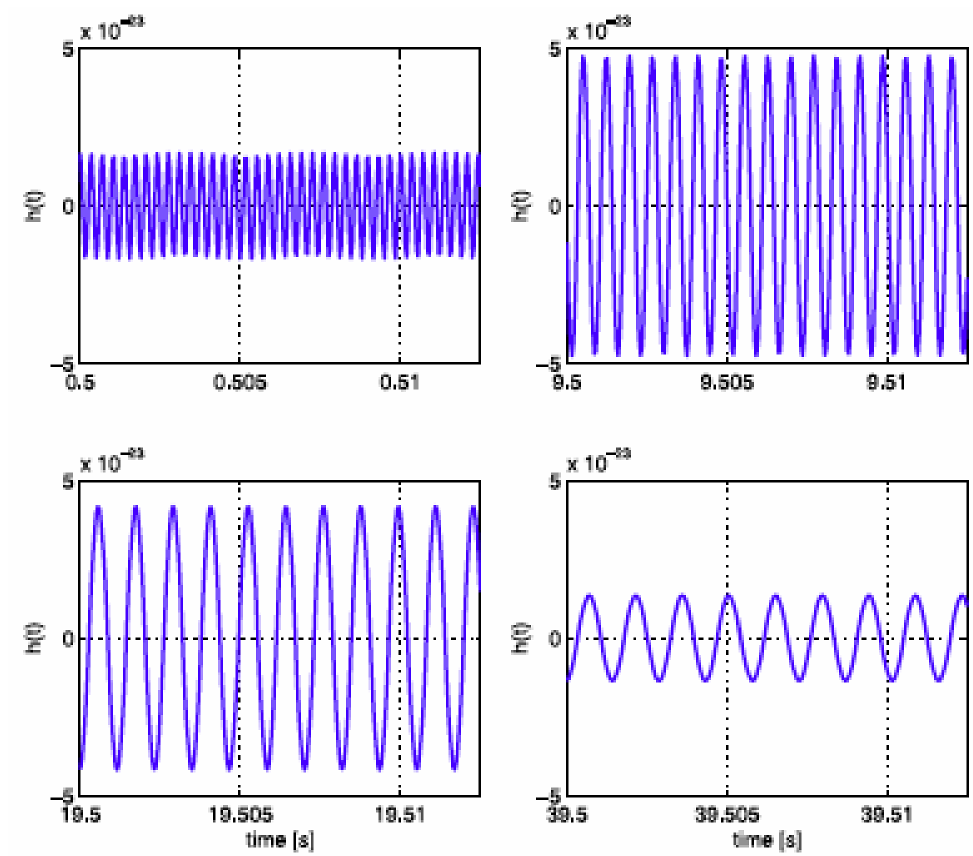

GW-modes
+
×


LIGO detector

Van Putten, 2002, ApJ, 575, L71
Van Putten, 2008, ApJ, 684, L91

Gravitational wave forms BH spindown





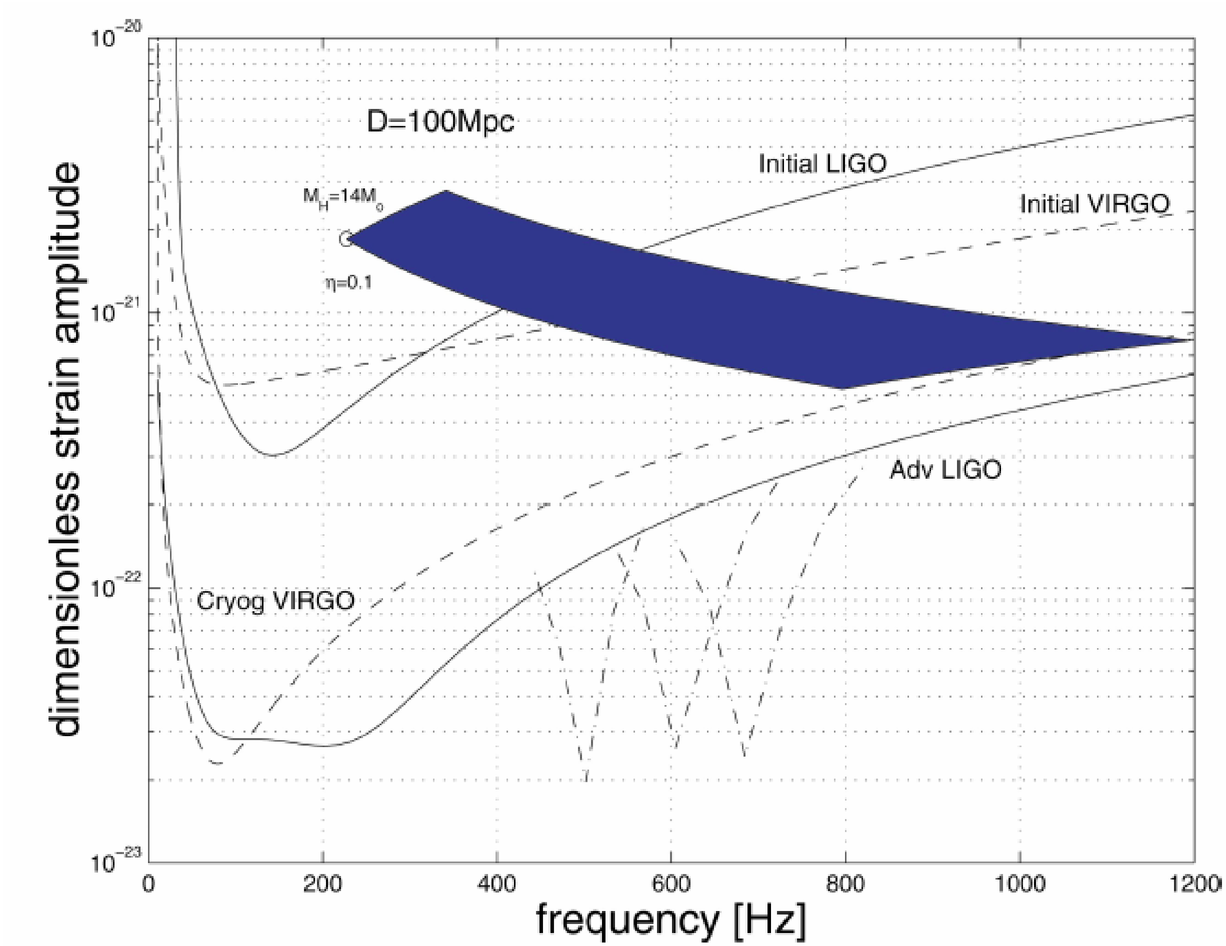
Asymptotic frequency at late times

$$f_{GW} = 595 - 704 \text{ Hz} \left(\frac{M}{10 M_\odot} \right)^{-1}$$

Van Putten, Levinson, Lee, Regimbau, Punturo & Harry, 2004, Phys. Rev. D, 69, 044007

Van Putten, Kanda,Tagoshi,Tatsumi,Masa-Katsu & Della Valle, 2011, Phys. Rev. D, 83, 044046

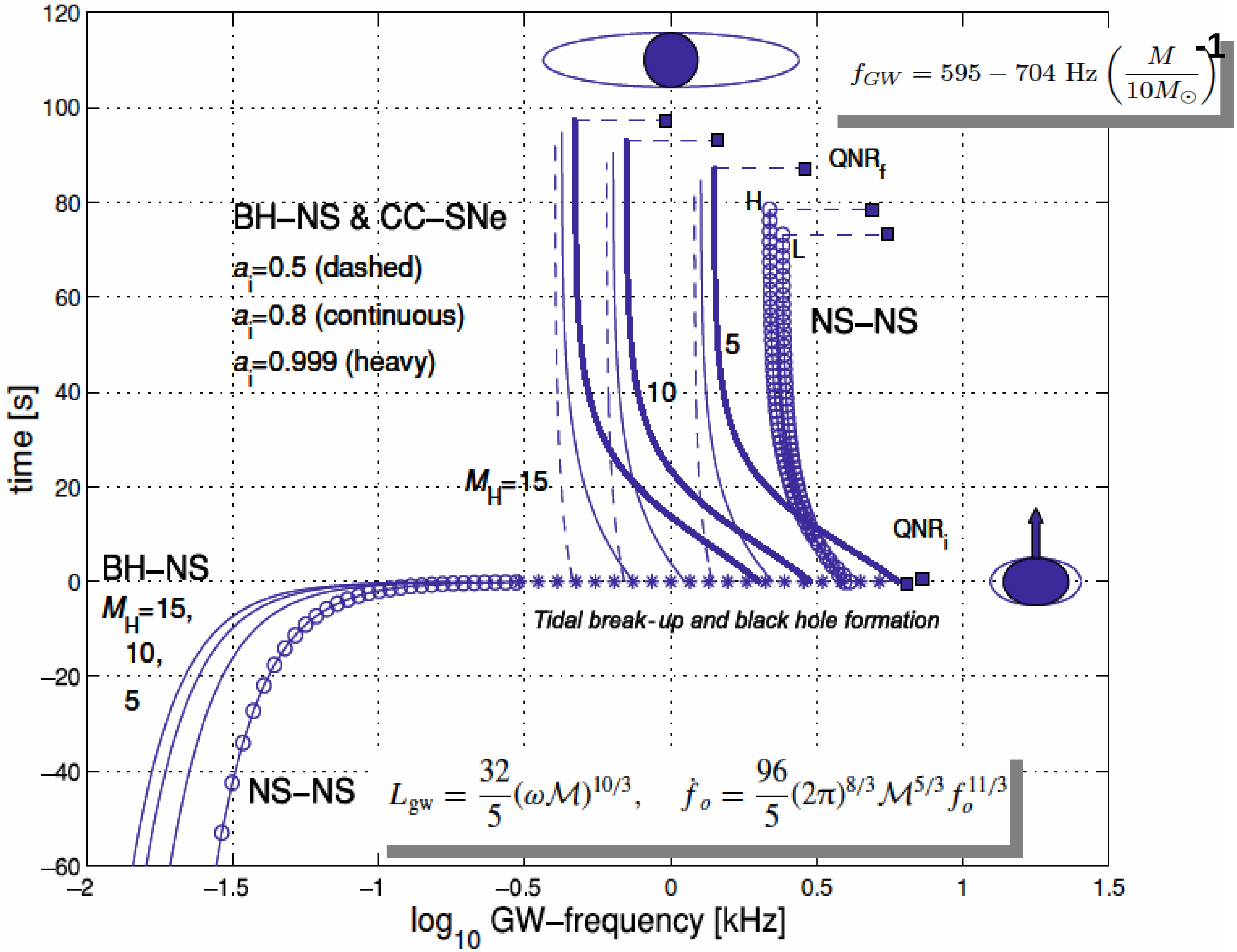
Sensitivity distance for Adv Detectors



D for a full chirp detection ~ 35 Mpc

Van Putten, 2009, MNRAS, 396, L81

Positive (precursor) and negative GW chirps associated with long GRBs



Summary

Neutron stars are NOT universal inner engines to all long GRBs
The energy reservoir in the “Type IX” event GRB 031203/SN2003lw exceeds the rotational energy of a neutron star by an order of magnitude

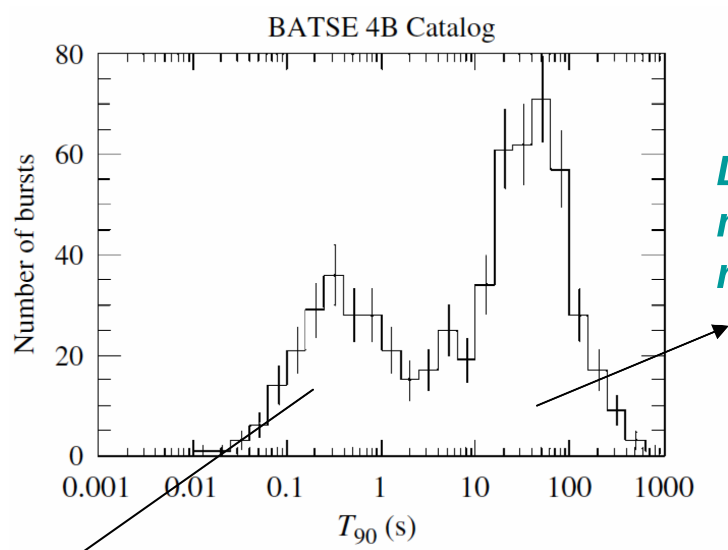
Frame-dragging now a real measurement science (courtesy LAGEOS and GPB)
Opens multimessenger radiation channels along black hole spin axis and via inner disk or torus

Rotating black holes are a universal inner engine for GRBs with and without SNe
Rapidly/slowly spinning black holes can power long/short GRBs
Produce GRB-SNe from CC-events, “naked” GRBs from mergers (GRB060614)
Energy reservoir sufficient for GRB 031203/SN2003lw

Spindown of rotating black holes against a high-density inner disk at ISCO
Observed in the nLC extracted from 1491 light curves of long GRBs in BATSE
Matter at ISCO predominantly emits GWs

Outlook for LIGO-Virgo and KAGRA

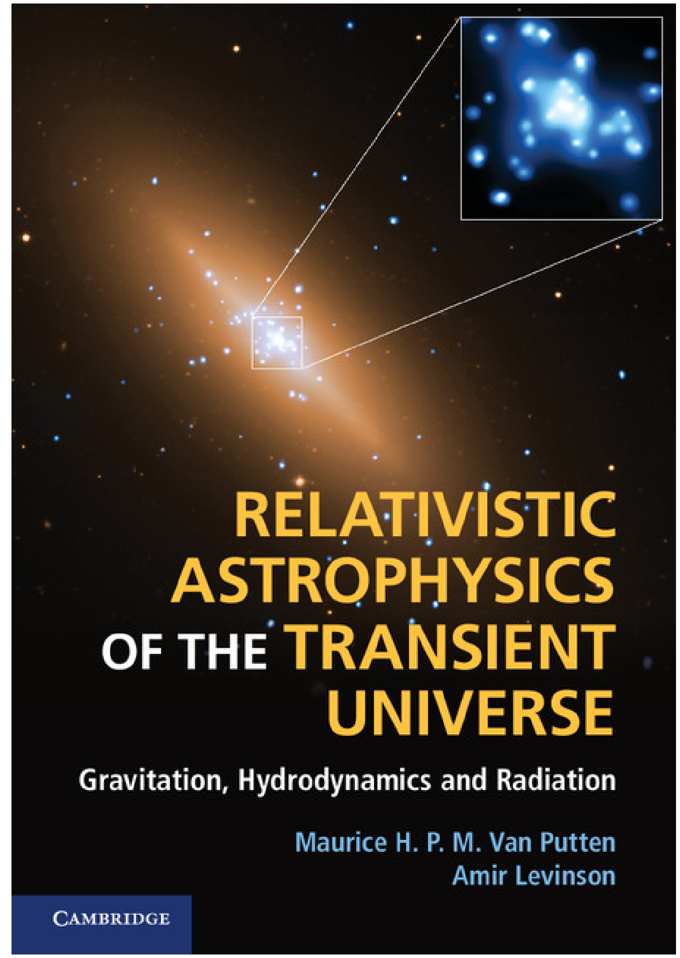
Search for “mirror imagage” in GWs of the bi-modal duration of GRBs



Long GWBs from CC-SNe and mergers involving rapidly rotating BHs

Short GWBs (following a long precursor chirp from a merger) from mergers involving slowly rotating BHs; also from some CC-SNe?

Conclusions



- Bright outlook for long bursts in GWs

- Realization by "smart" harvesting of the most

  -nearby SNe

  -extreme CC-SNe (radio-loud, aspherical, "Type IX")

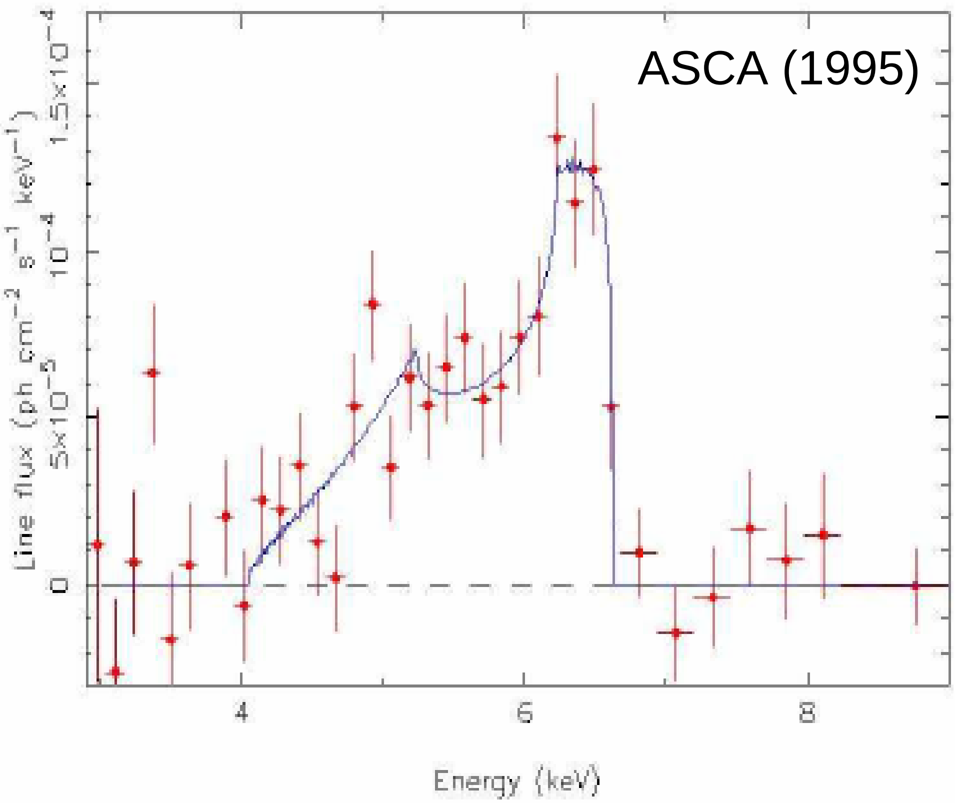
  -SN-farms nearby: M51, M82, … (R ~ 1/10 per year)

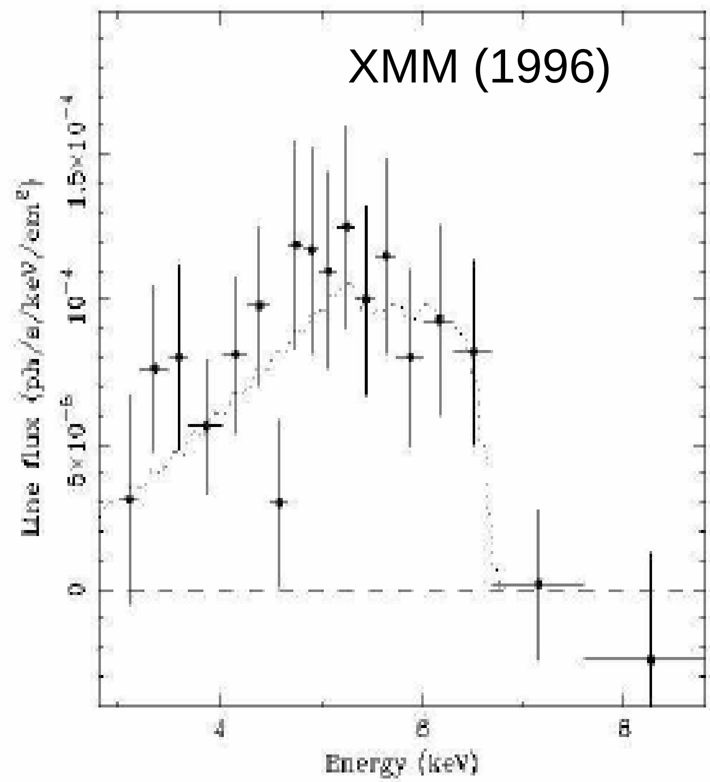
- New **multiwindow collaborations** between radio-optical surveys identifying TOOs for GW detectors and high-energy surveys (Swift,Fermi)

(extra slides)

Tanaka, Y., et al., 1995, Nature, 375, 659
Iwasawa, K., et al., 1996, MNRAS, 282, 1038

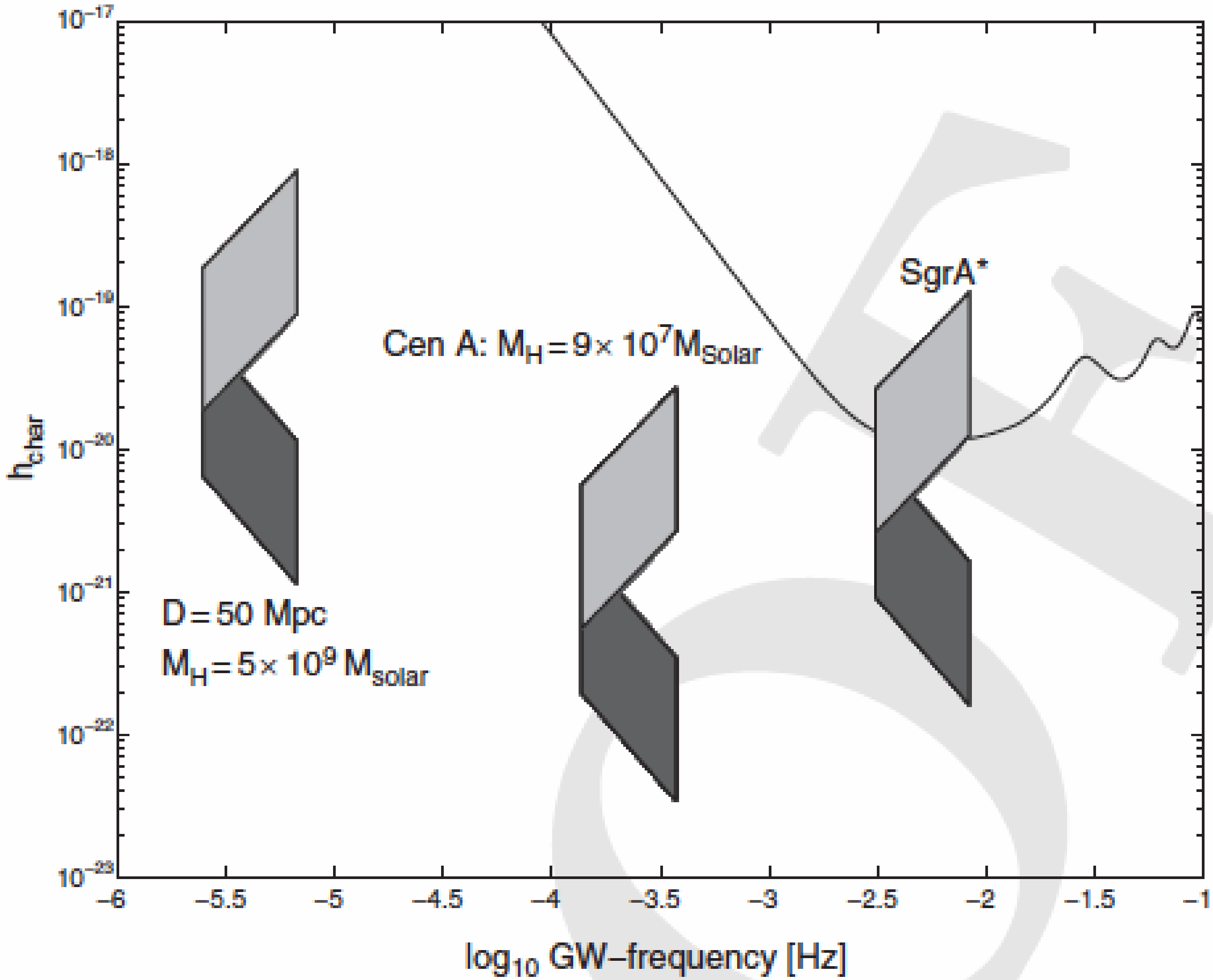
X-ray spectroscopy around BHs





Kα emission spectrum from variable inner disk around MCG 6-30-15

Outlook for (the original) LISA



*Energized by spin-energy of the SMBH in SgrA**