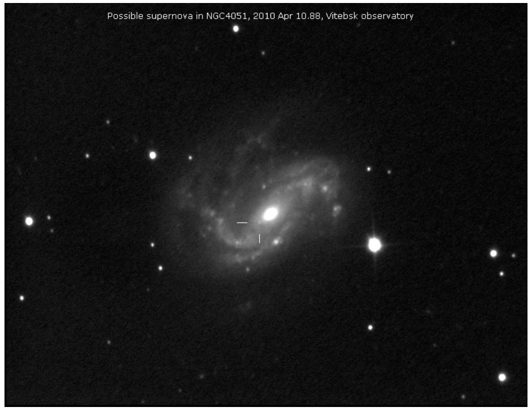
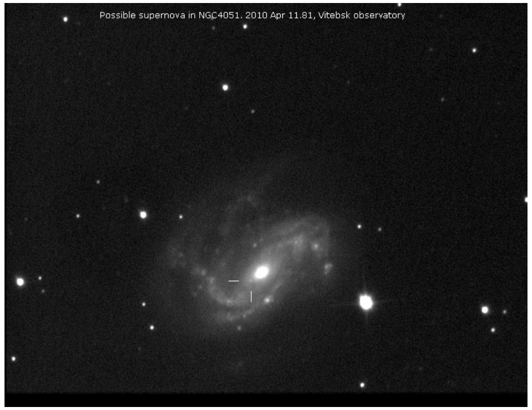




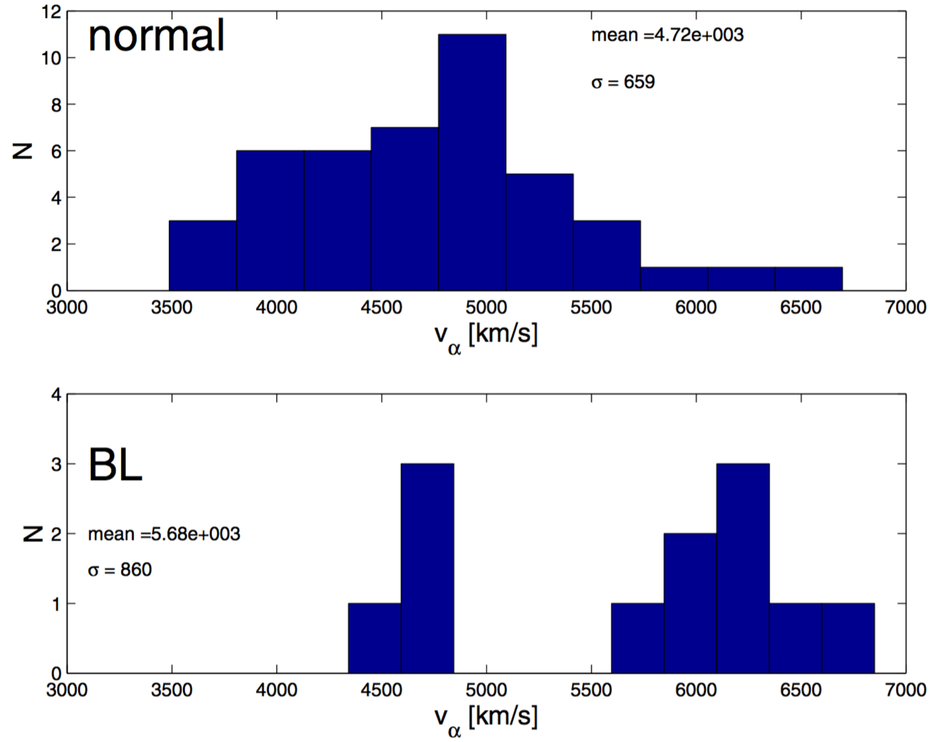
Directed searches for broadband extended gravitational-wave emission in nearby energetic core-collapse supernovae

Maurice H.P.M. van Putten

KAGRA Meeting, ICRR
February 23 2016

Core-collapse supernovae

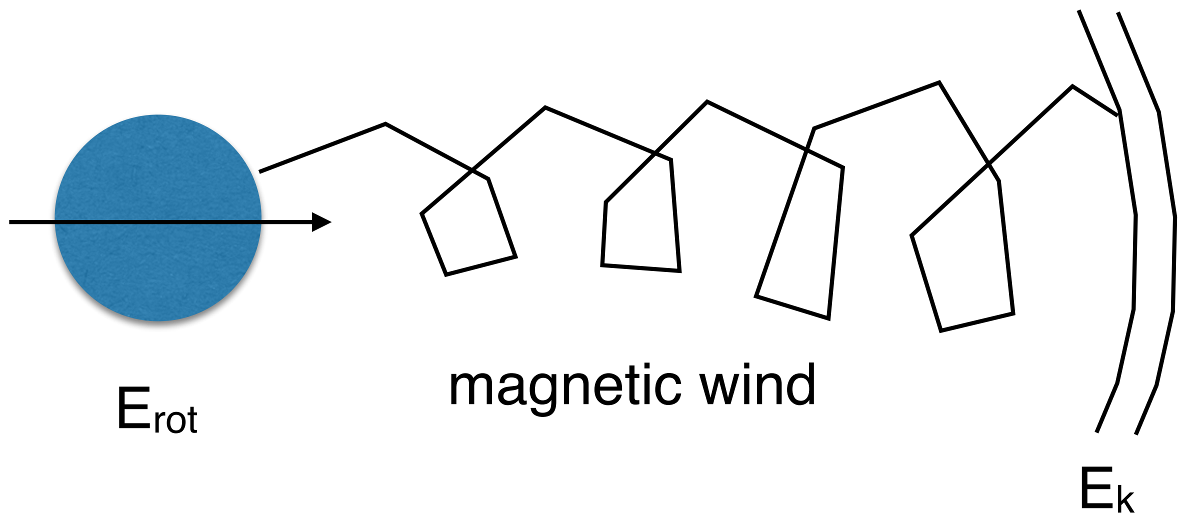
Diverse:



ejection velocities

Produced in the formation of a new neutron star or black hole

Stellar explosion from rotational energy

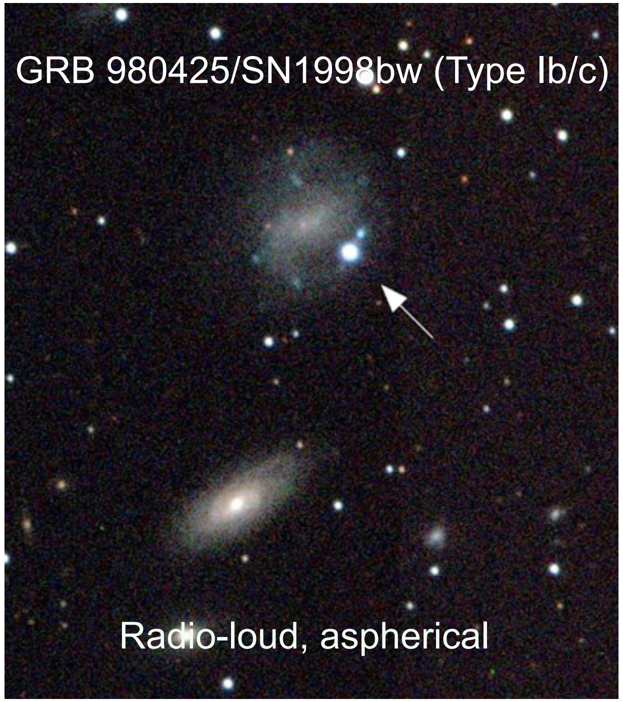


Bisnotavyi-Kogan, G., ,1970, Astron. Zh., 47, 813

$E_k \sim 0.5$ baryon-loading fraction x $E_{rot} < E_{rot}$

van Putten, Levinson, Della Valle, 2011, A&A, 535, L6

Hints for BH powered engines



GRB-supernovae: tail of SN Type Ib/c

NS: $E_{rot} < E_c$=3e52 erg

BH: $E_{rot} <$ 6e54 erg (M/10MSolar)

in units of 10^{51} erg.

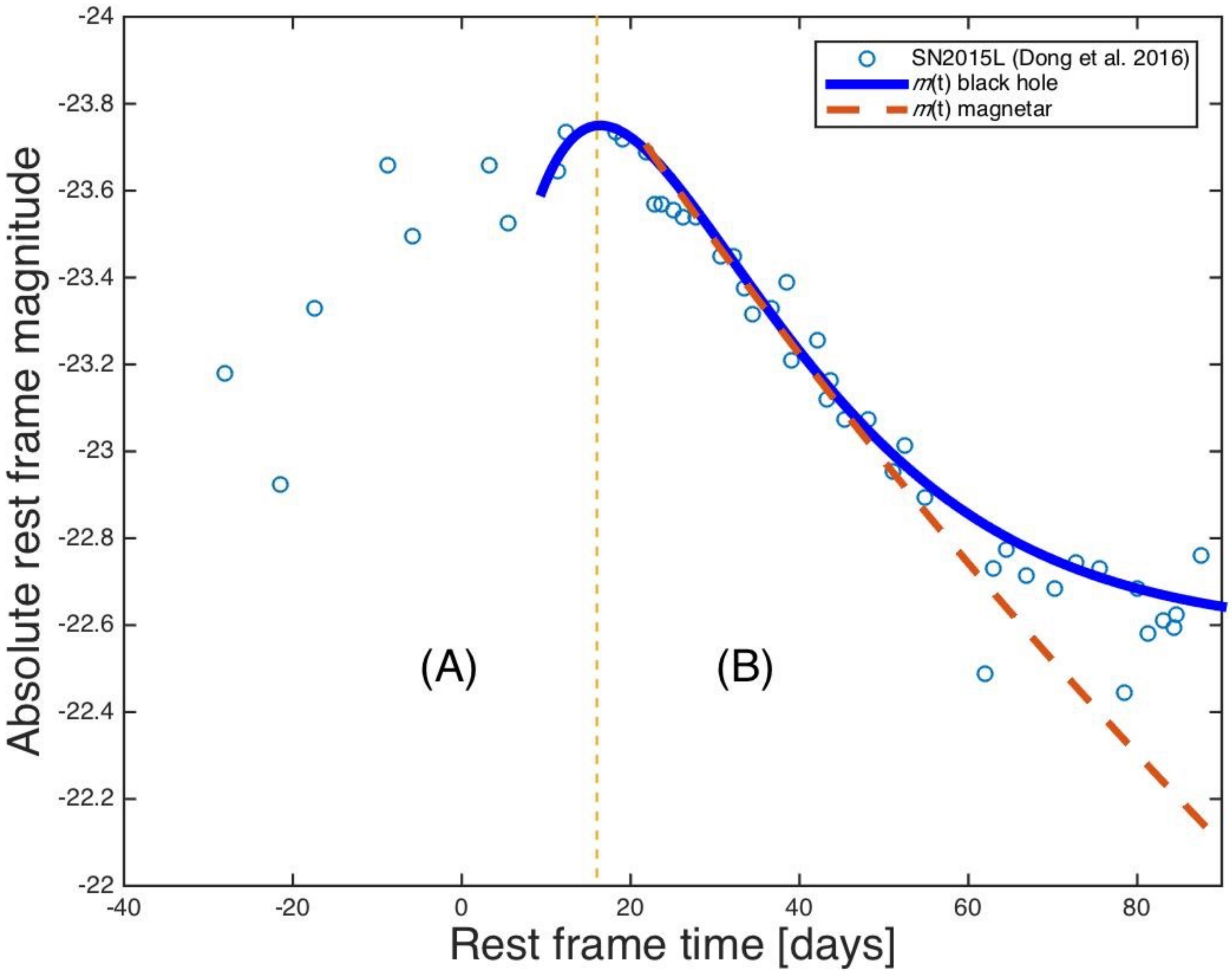
GRB	Supernova	z	E_γ	E_k	η_1	E_{rot} / E_c	Ref.
980425	Sn1998bw	0.008	< 0.001	50	1	1.7	
031203	SN2003lw	0.1055	< 0.17	60	0.25	10	★
060218	SN2006aj	0.033	< 0.04	2	0.25	0.25	
100316D	SN2006aj	0.0591	0.037-0.06	10	0.25	1.3	
030329	SN2003dh	0.1685	0.07-0.46	40	0.25	5.3	★

van Putten, Della Valle & Levinson, 2011, A&A, 535, L6

Super luminous SN2015L: a rotating BH losing its charm?

★ E_{rad} = 1.1e52 erg

Dong, S., et al., 2016, Science, 351, 257



Change in magnitude post-peak to plateau:

BH wind: 1.154
Observed: 1.2

van Putten & Della Valle, 2016, under review

General picture:

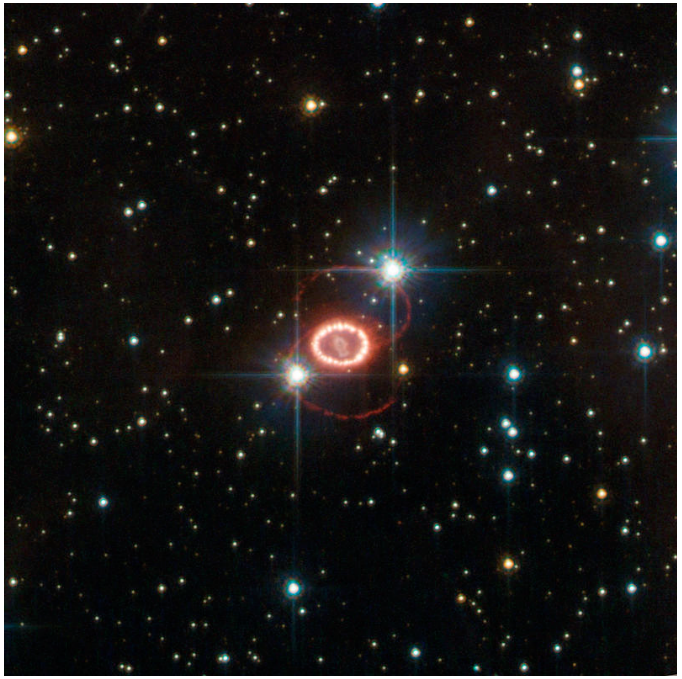
Explosions powered by winds or jets from an angular momentum-rich compact central engine - a magnetar or black hole

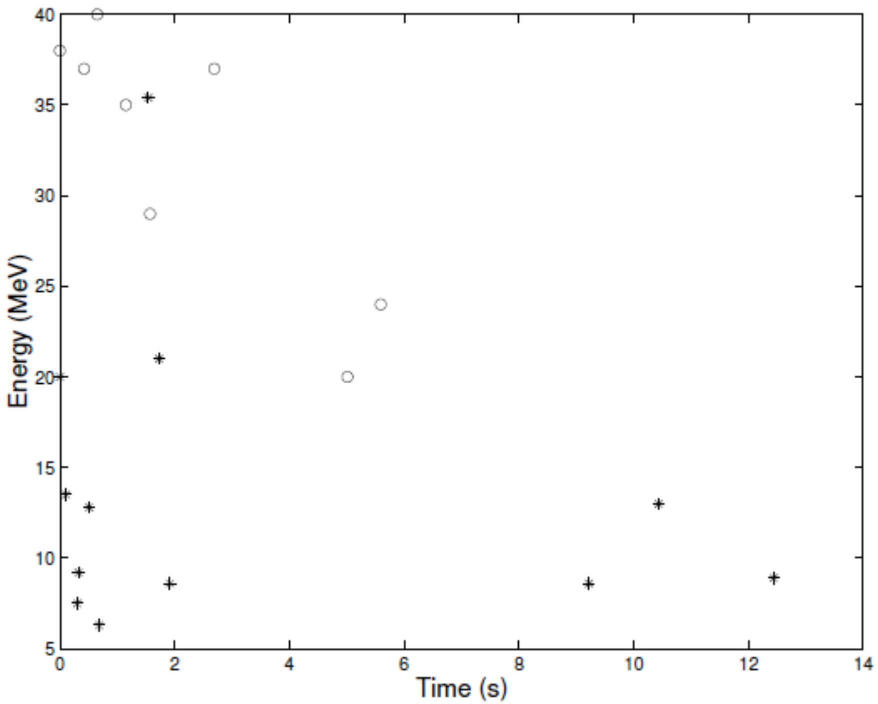
Most extreme probably powered by newly formed stellar mass black holes

High density matter in SN1987A

$E_k \cong 1 \times 10^{51}$ erg

$E_\nu \cong 10^{53}$ erg





Gravitational waves from energetic CC-SNe?

angular momentum-rich BH-disk or torus formation?

10% non-axisymmetric matter:

$$L_{GW} = 2 \times 10^{51} \left(\frac{\xi}{0.1}\right)^2 \left(\frac{\sigma}{0.01}\right)^2 \left(\frac{4M}{a}\right)^5 \text{ erg s}^{-1}$$

$$h = 3.4 \times 10^{-23} M_1 \frac{\xi}{0.1} \frac{\sigma}{0.01} \left(\frac{D}{20\,\text{Mpc}}\right)^{-1} \left(\frac{f}{600\,\text{Hz}}\right)^{\frac{2}{3}}$$

$E_{GW} = 0.1\text{-}1 M_{Solar}$ from E_{rot} of a $10 M_{Solar}$ extreme Kerr BH

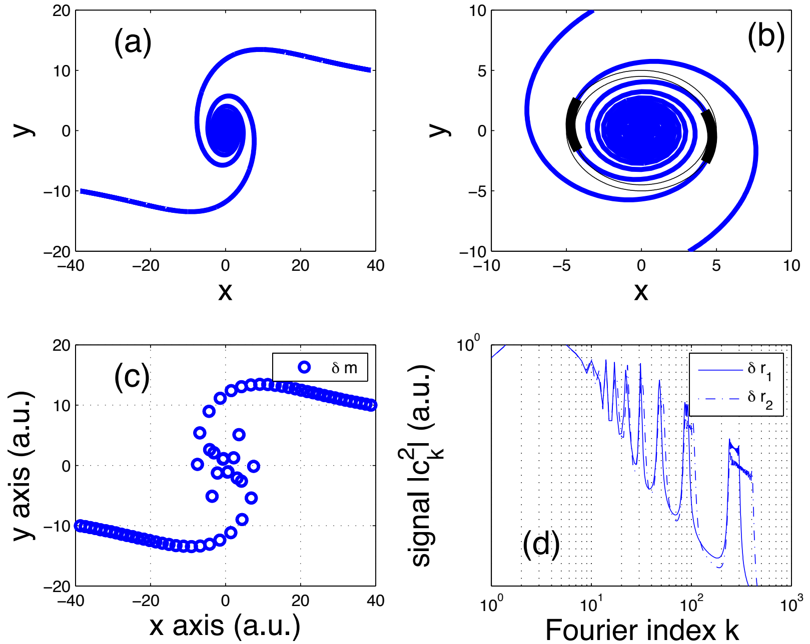
Levinson, van Putten & Pick, 2015, ApJ, 812:124;
van Putten, 2015, ApJ, 810:7;
van Putten, 2008, ApJ,684:L91

Dark calorimetry:

Measure E_{GW} nearby energetic CC-SNe

Ascending and descending chirps

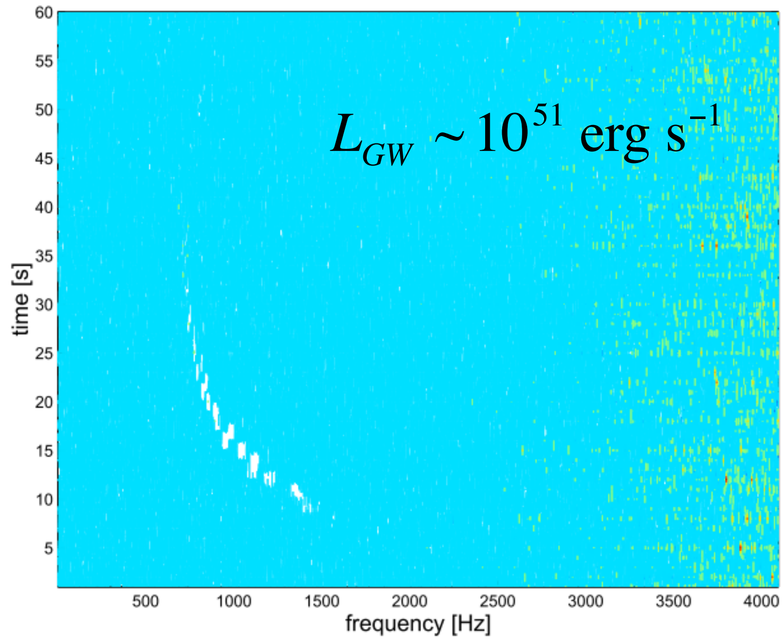
Ascending: patterns in accretion



(Levinson, van Putten & Pick, 2015)

GWs from orbital motion

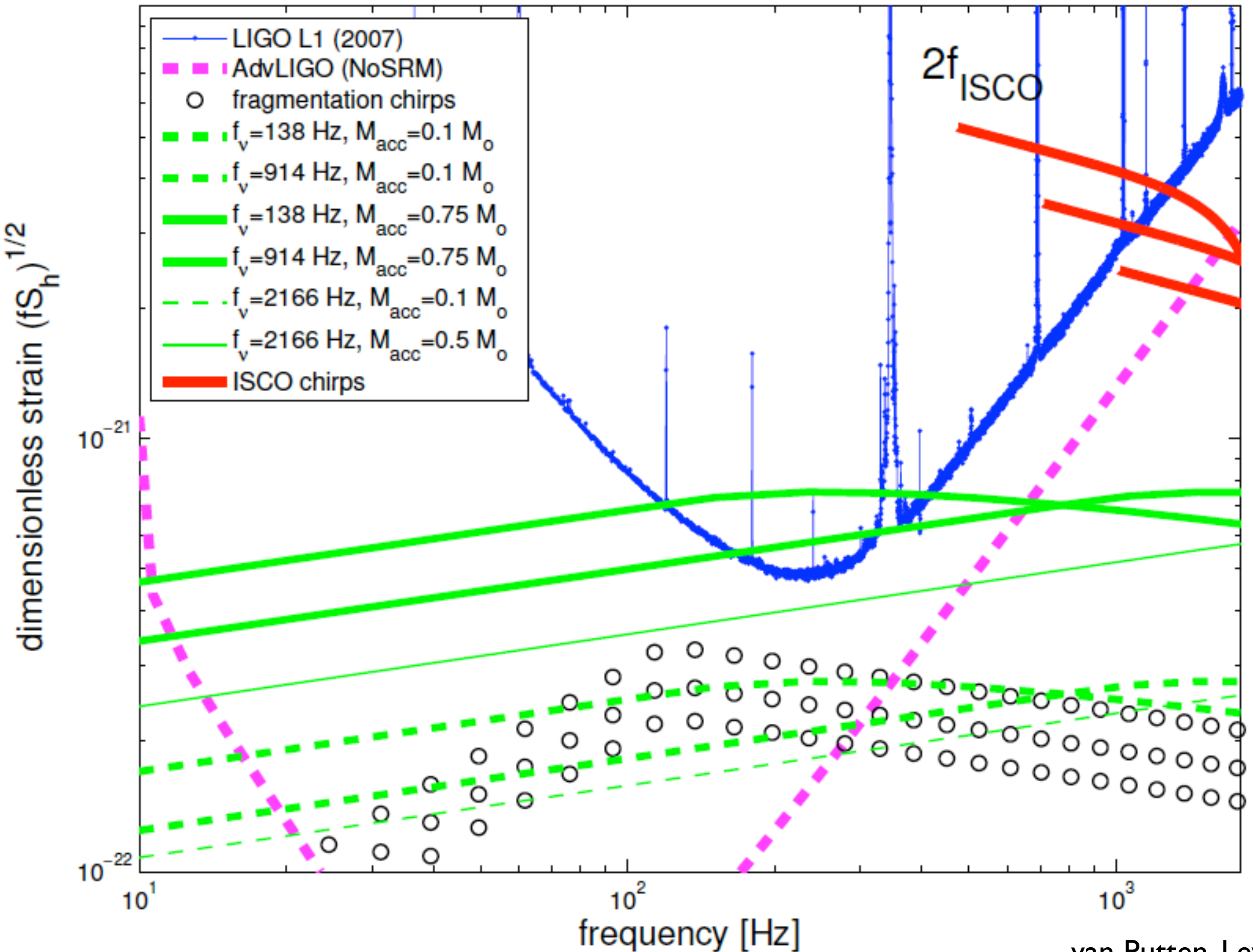
Descending: ISCO waves



(van Putten, 2008)

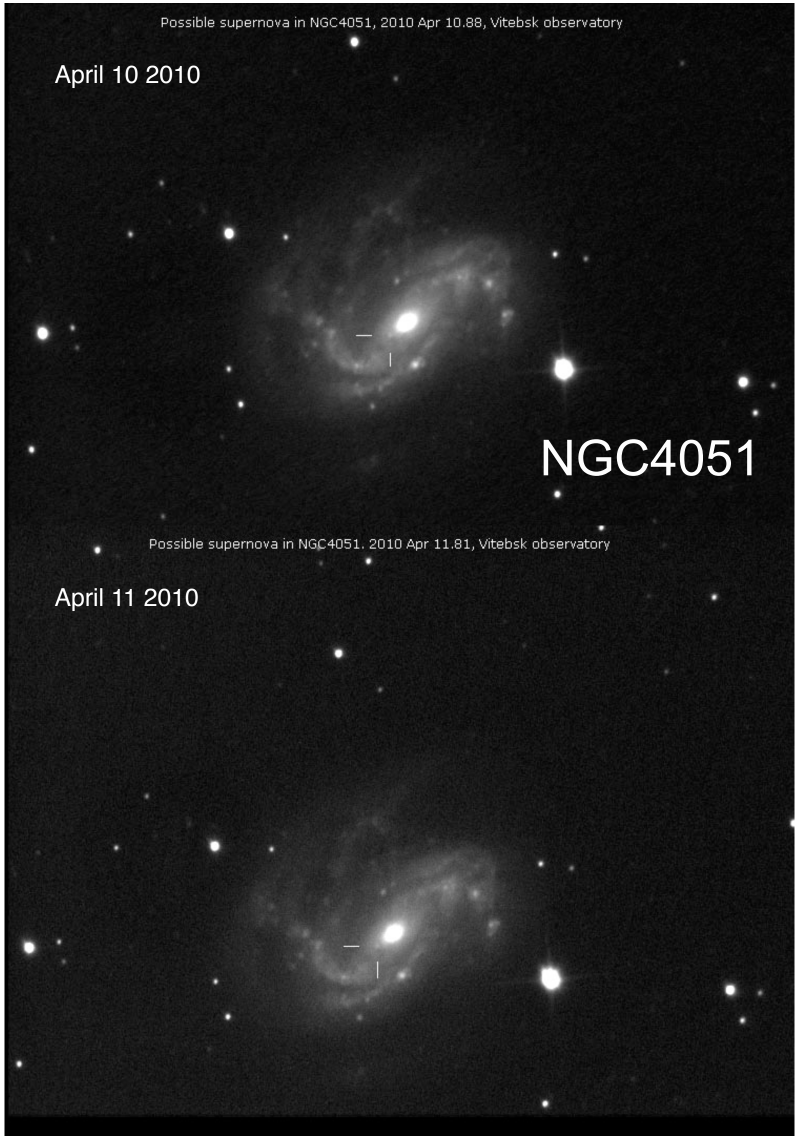
GWs from spin

Broadband GW emission from CC-SNe



van Putten, Levinson, Frontera, Guidorzi, Amati & Della Valle, 2015, under review

SN 2010br: Type Ibc (z=0.0023)



Discovery:

April 10 2010 during LIGO sixth science run (Vitali Nevski, CBET#2245)

Extremely close:

D=12 Mpc (1/decade for SN Ib/c's)

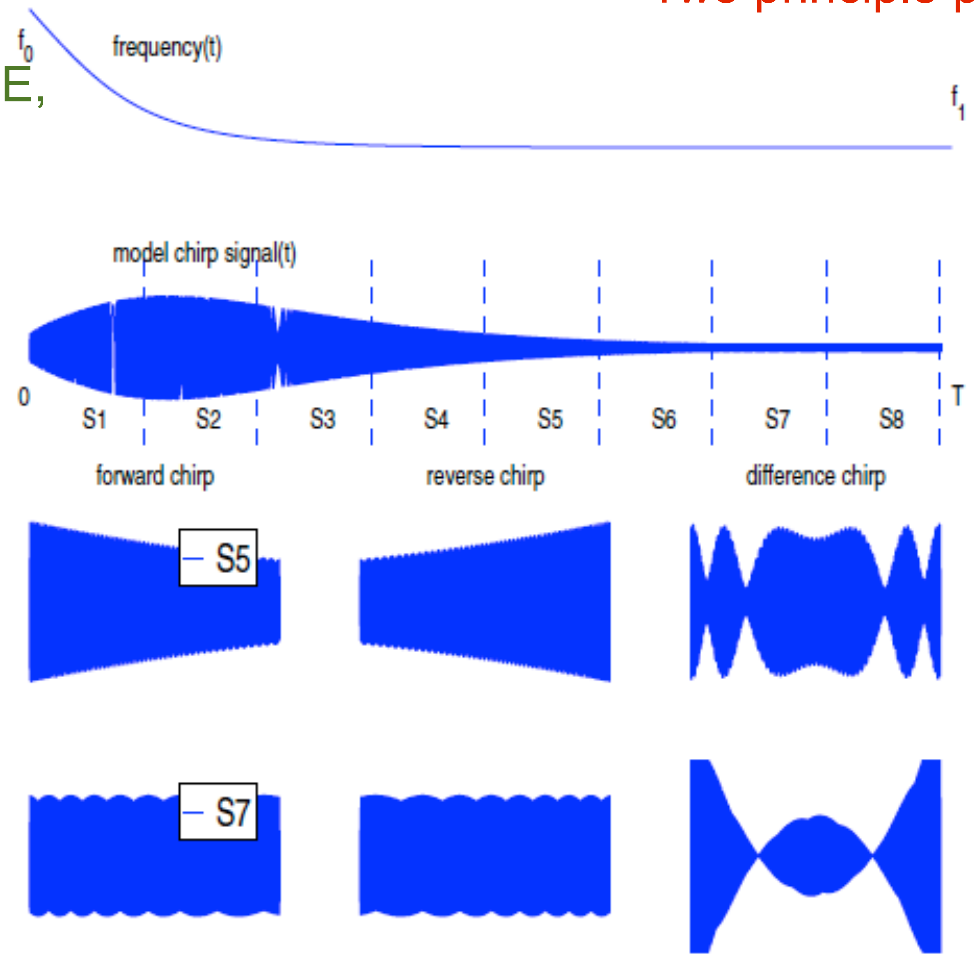
Challenging:

poorly resolved optical light curve, anomalously weak or late-time tail, time-of-onset uncertain

Mixed ascending-descending chirp templates

Two principle parameters: T and f_0

Numerical solution to ODE, BH spin-down against ISCO

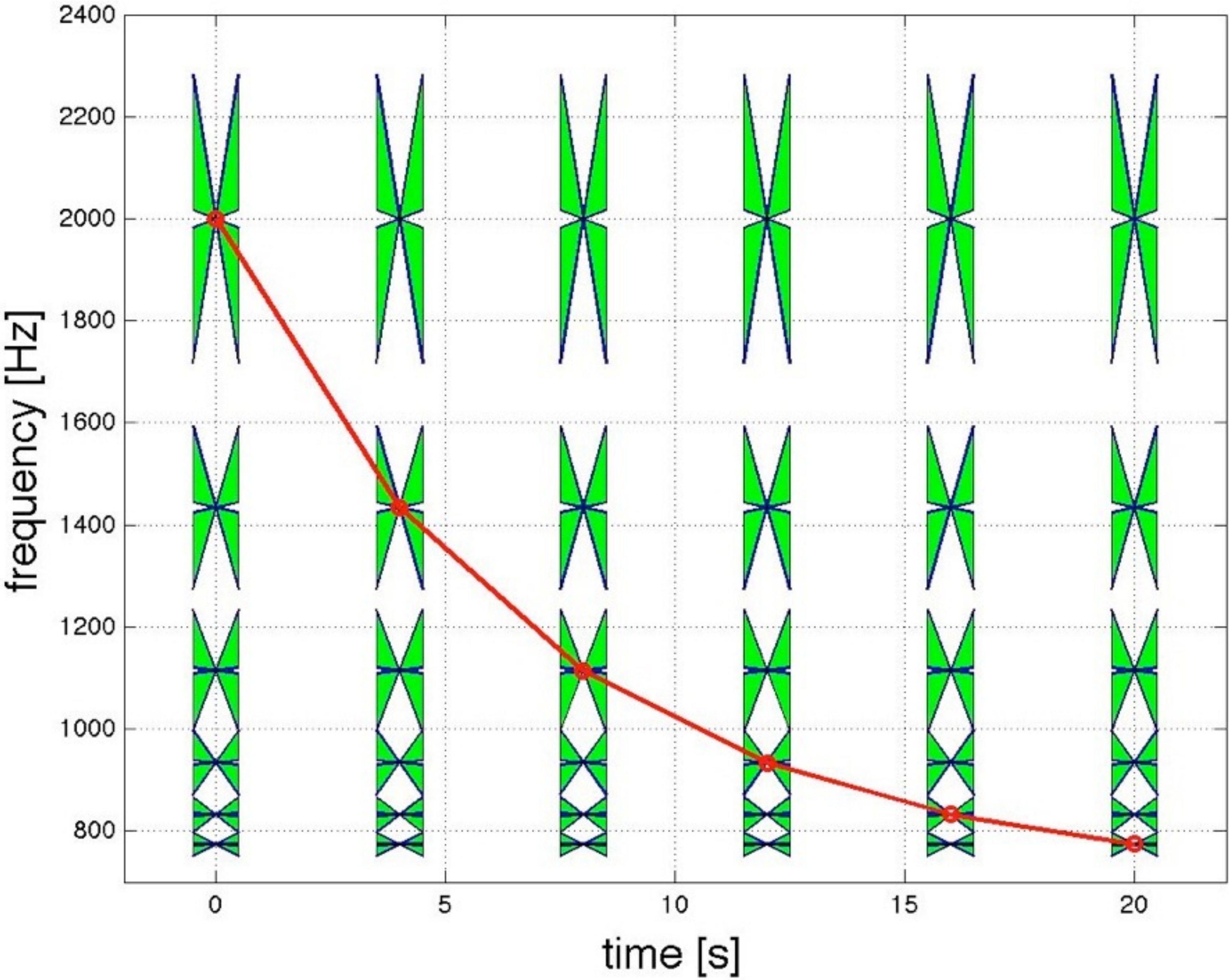


van Putten, Guidorzi & Frontera, 2014, ApJ, 786, 146

van Putten, M.H.P.M., 2016, Zenodo, doi:10.5281/zenodo.45298

Universal: applies to broadband frequency analysis of light curves of gamma-rays and gravitational waves

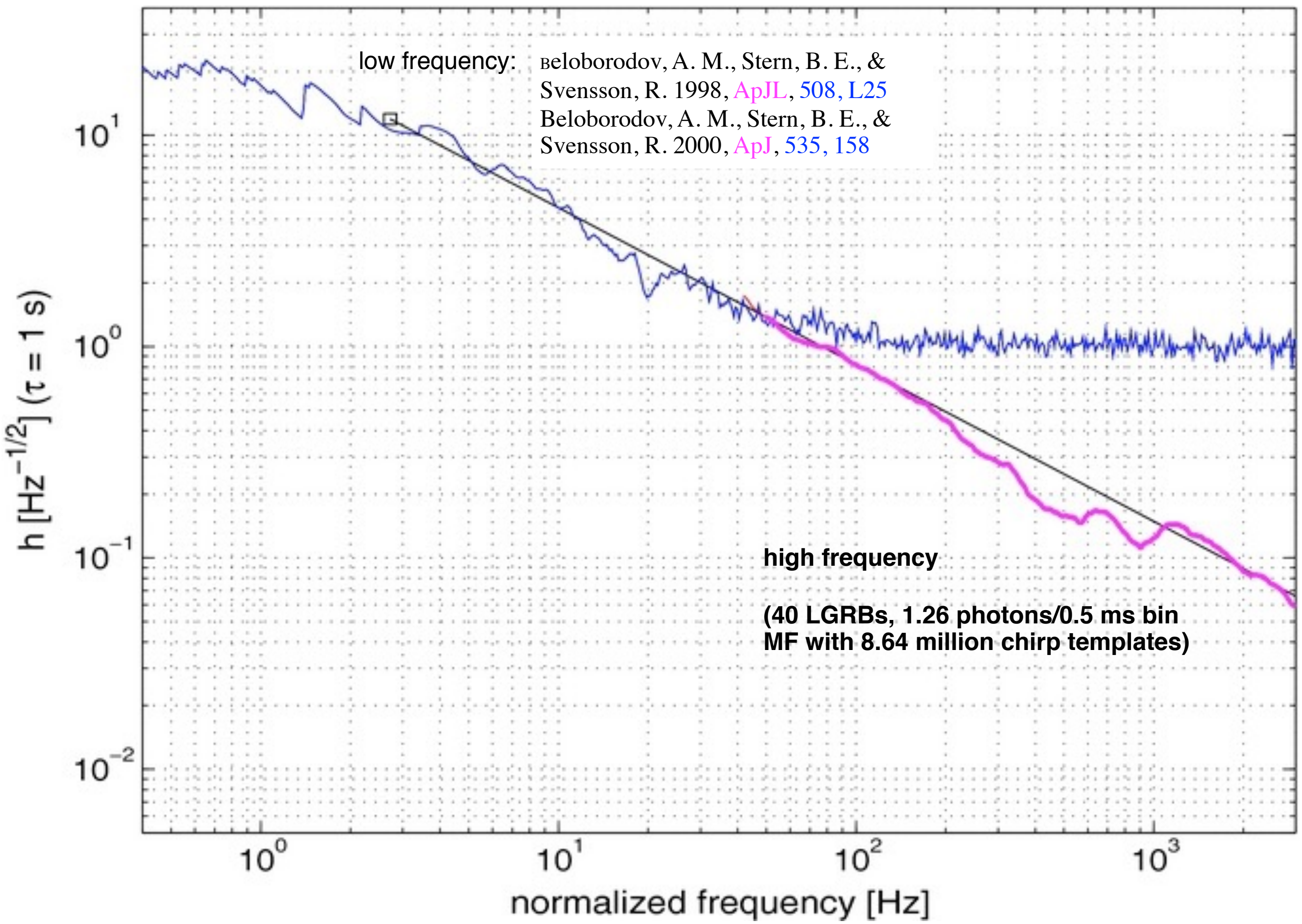
Butterfly filter on df/dt



van Putten, 2016, ApJ, to appear (axrXiv:1602.03634)

BeppoSAX broadband Kolmogorov spectrum

Matched filtering analysis of 2 kHz light curves (1.26 photons/0.5ms bin)



Smooth extension of Kolmogorov spectrum

van Putten, Guidorzi & Frontera, 2014, ApJ, 786, 146

no evidence for proto-PSR

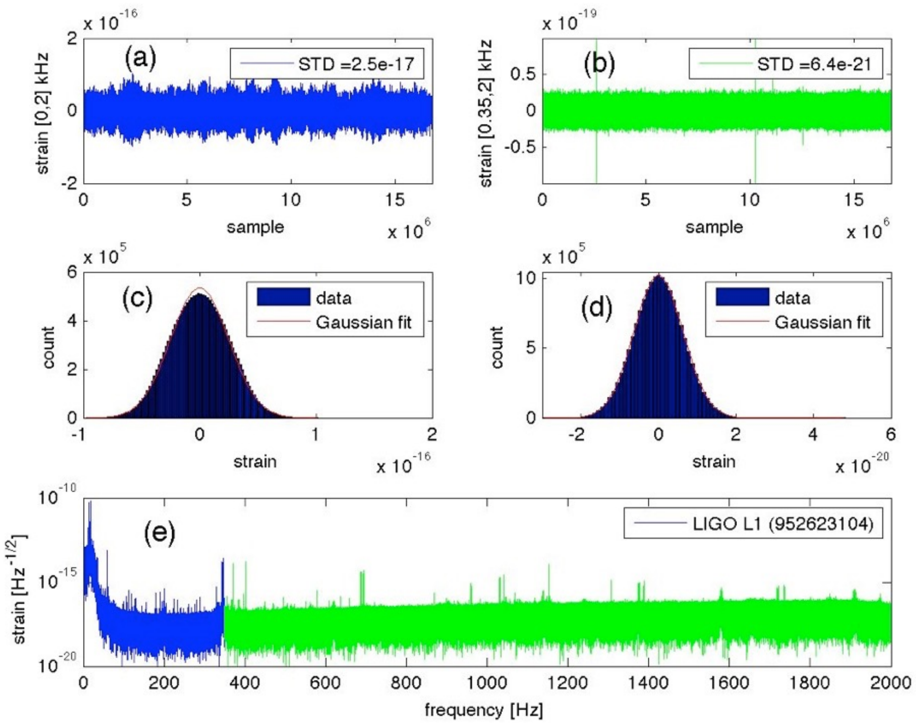
Completely general bandpass filter in df/dt

Near-optimal MF sensitivity for LGWBs (tens of seconds)

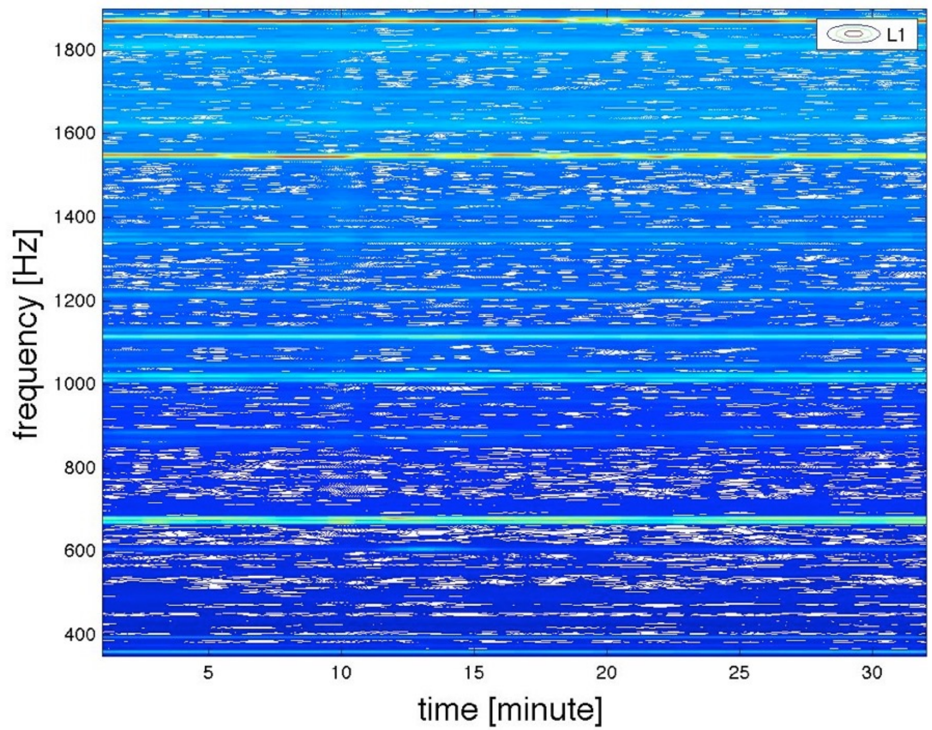
Applicable to completely “un-modelled sources” (even Kolmogorov!)

van Putten, 2016, ApJ, to appear (axrXiv:1602.03634)

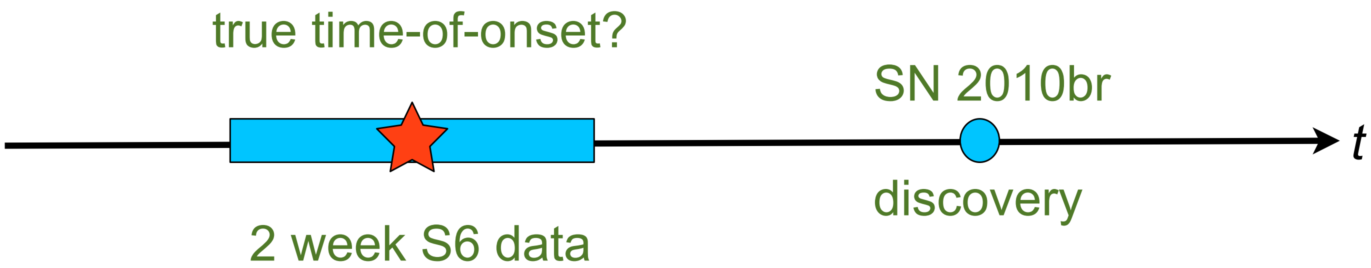
LIGO S6 data



(a)
STD =2.5e-17
strain [0,2] kHz
sample
(b)
STD =6.4e-21
strain [0.35,2] kHz
sample
(c)
data
Gaussian fit
count
strain
(d)
data
Gaussian fit
count
strain
(e)
LIGO L1 (952623104)
strain [Hz^-1/2]
frequency [Hz]

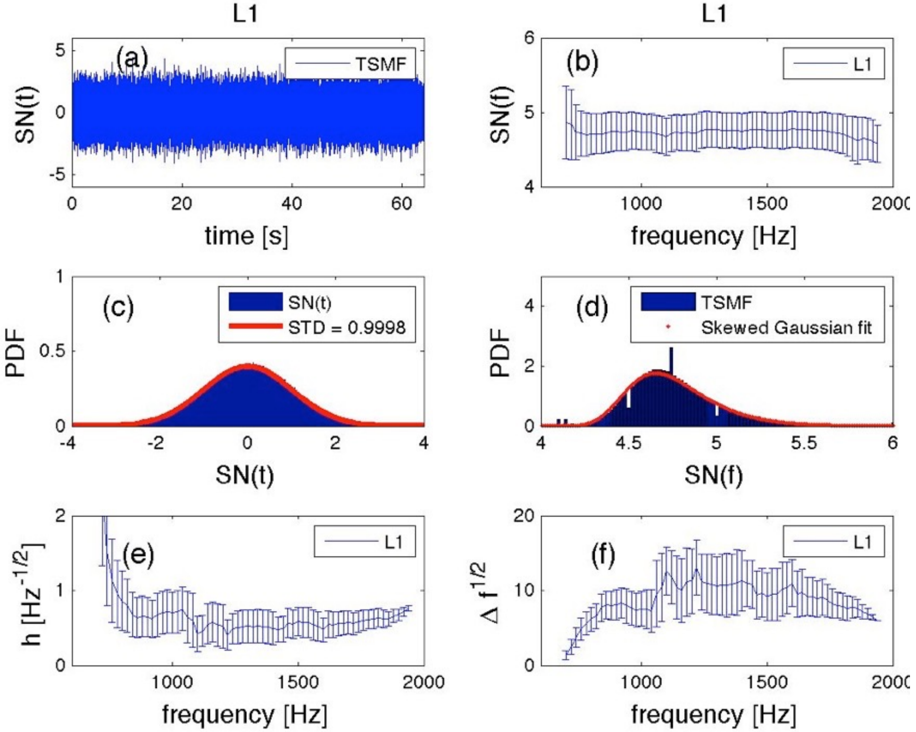


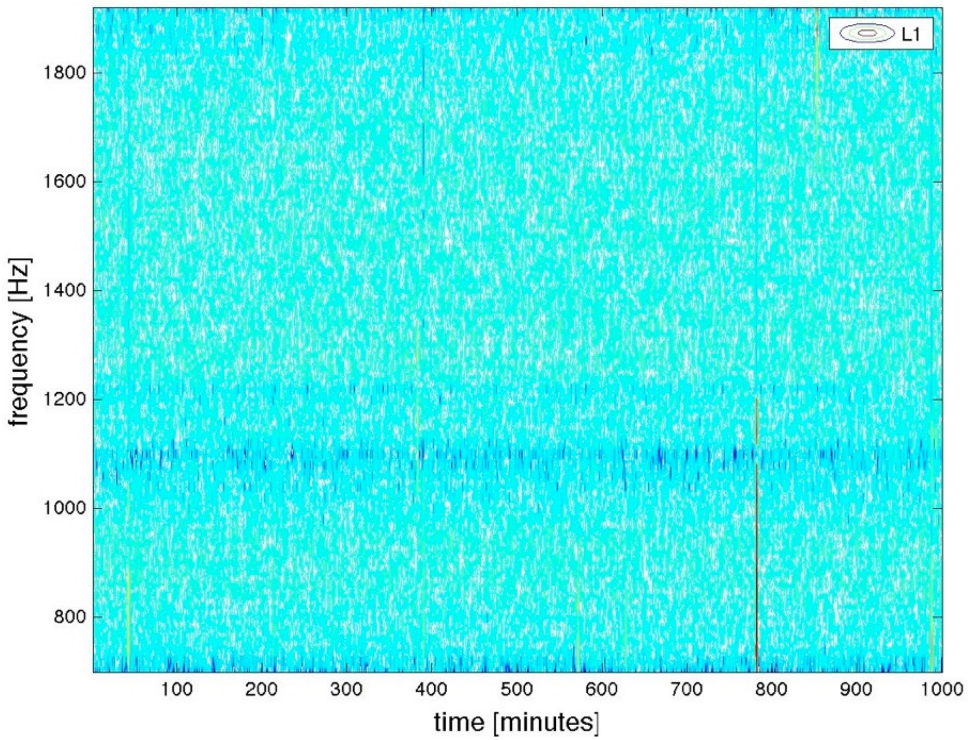
L1
frequency [Hz]
time [minute]



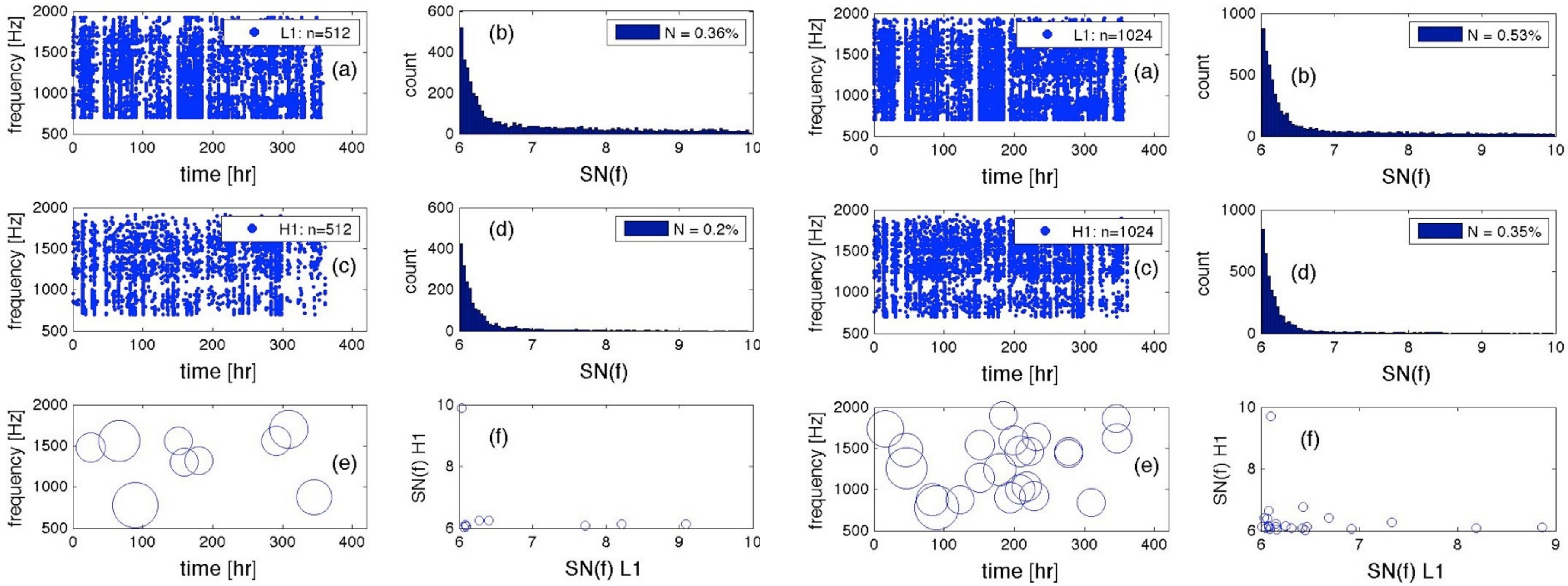
true time-of-onset?
SN 2010br
t
discovery
2 week S6 data

Butterfly filtered LIGO S6 data





Application of L1-H1 coincidence criteria



van Putten, 2016, to appear

Outlook for nearby CC-SNe

LGWB: > 1% ascending/descending chirps from accretion flows onto ISCO

Science: determine inner engines and calorimetric identification Kerr BH

Strategy:

- Search nearby Type Ib/c SNe (numerous) and SLSNe (few)
- Probe events at 10Mpc/100Mpc at initial/advanced sensitivity
- GW-EM detection with single detector? (Relevant to limited duty cycles)

HPC Challenge:

``Butterfly" chirp search with large number of templates