2010 International School on Numerical Relativity and Gravitational Waves

7/26~30 @ 浦項、韓国

帰朝報告

八木絢外 (京大天体核)

研究会概要

http://apctp.org/conferences/2010/NRG2010/index.html

・数値相対論、データ解析、実験、理論の研究会。

来年からsessionを2つに分けるそうです。

・School形式。Mini-workshopで自分の講演もできる。

・毎年夏に韓国のソウルか浦項(またはそれ以外？)で開かれる。

去年は豚インフルエンザの影響で冬でした。

・参加人数：70人 (大半は韓国人。日本人は9人。)

・普段聴けない話を聴ける良い機会。

・招待講師や韓国人若手研究者と仲良くなれる。

・毎晩おいしいマッコリが飲める。

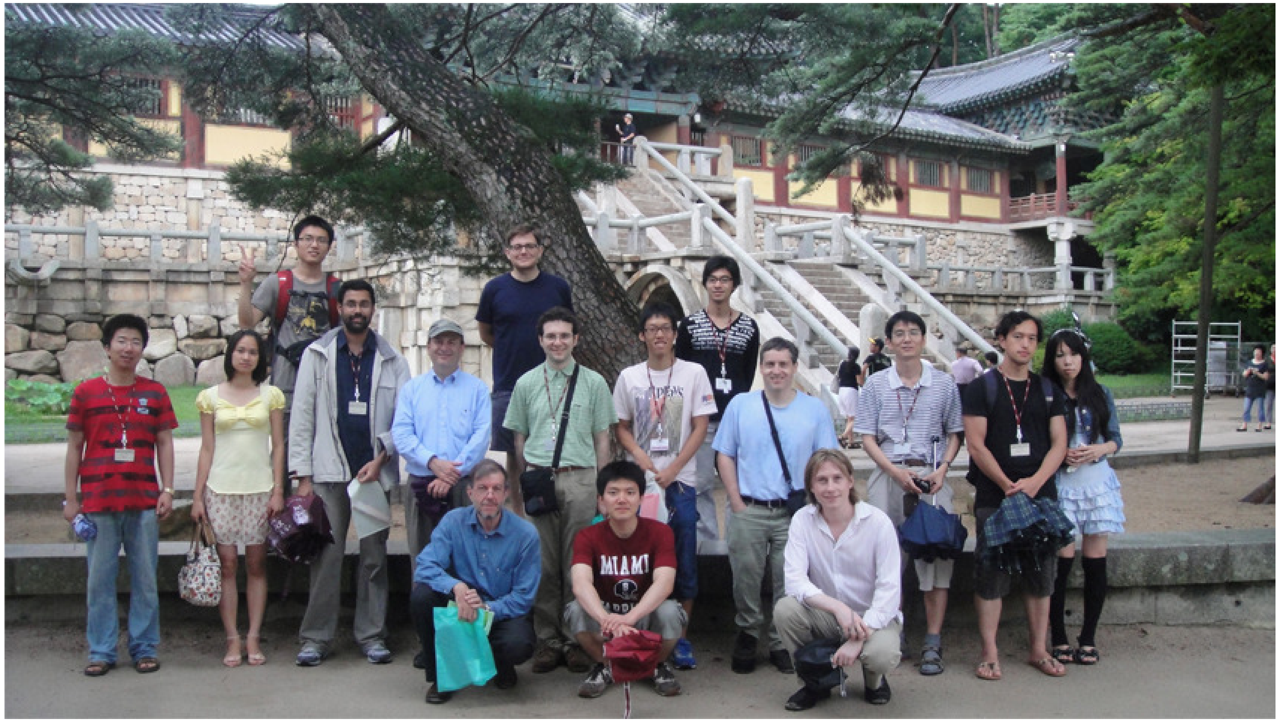
韓国人は強い・・・

・個人的には、非常に有意義で楽しめた。


by airplane
by land
by seaway
ソウル
Gangwondo
Incheon international airport
Incheon
Seoul
Gimpo airport
Chungcheong -bukdo
Chungcheong -namdo
Daejeon
Gyeongsang -bukdo
Daegu
Gyeongju
浦項
ulleungdo
Ulsan
Gimhae international airport
Gyeongsang -namdo
釜山
Jeollabukdo
Gwangju
Jeollanamdo
Jeju international airport
Jeju island


Outline of this lecture


2010 Int'l School on Numerical Relativity and Gravitational Waves
Date: July 26 ~ 30, 2010


MIAMI

Invited Lecturers

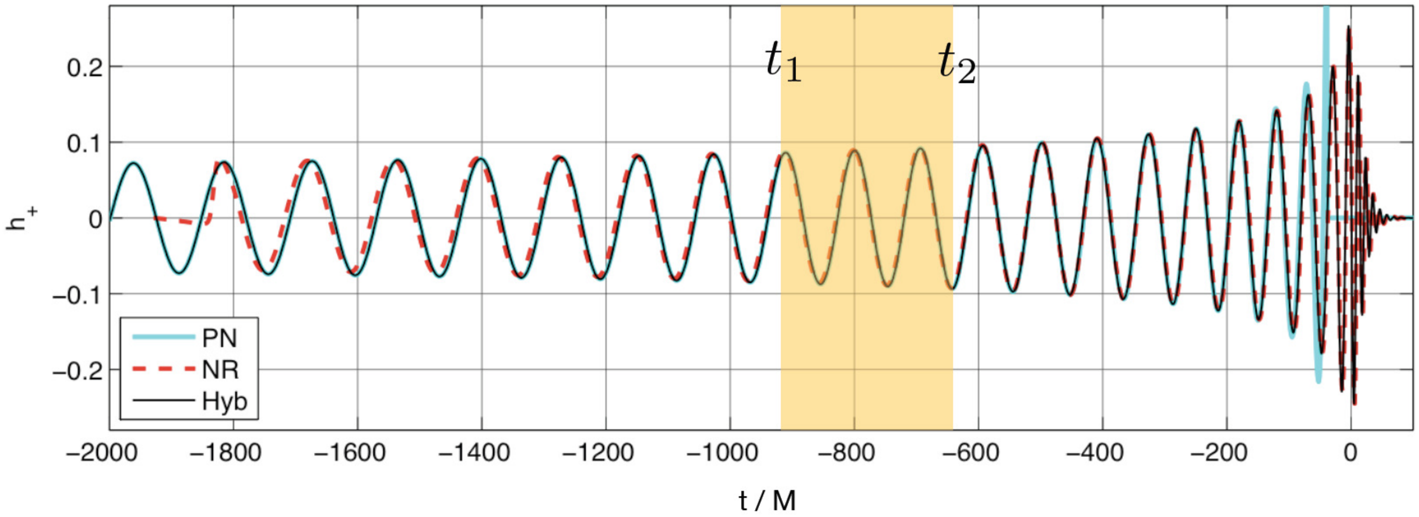
- Ajith, Parameswaran (Caltech):
  "Interface between numerical relativity and gravitational wave astronomy"
- Diener, Peter (Center for Computation & Technology, Louisiana State University):
  "BH-BH merger simulations and Cactus"
- Gouaty, Romain (Universite' de Savoie, CNRS/IN2P3):
  "The Search for Gravitational Waves in Real Life"
- Kotake, Kei (National Astronomical Observatory of Japan):
  "Supernovae and Gravitational Waves"
- Liu, Yuk Tung (University of Illinois at Urbana-Champaign):
  "NS-NS and BH-NS merger simulations"
- Price, Larry (U. of Wisconsin-Milwaukee):
  "Introduction to Gravitational Wave Data Analysis"
- Sasaki, Misao (Yukawa Institute for Theoretical Physics):
  "Black hole perturbations"
- Saulson, Peter R. (Syracuse University):
  "Introduction to Gravitational Wave Detection and the LIGO Detector"
- Vaulin, Ruslan (U. of Wisconsin-Milwaukee):
  "Interpreting the results of gravitational-wave search: from detection to astrophysics"
- Whiting, Bernard (U. of Florida):
  "Introduction to stochastic gravitational wave searches"

Time	Mon Jul 26	Tue Jul 27	Wed Jul 28	Thu Jul 29	Fri Jul 30
9:00	Opening address **Saulson I** 9:10-10:00	**Saulson II** 9:00-10:00	**Saulson III** 9:00-10:00	Mini-Workshop (II) 9:00-12:20 **J. Cao, D. Kim,** **K. Yagi,** **S. Oh, K. Kim,** **K. Kyutoku,** **K. Kiuchi,** **C. Lin**	**Whiting I** 9:00-10:00
10:00	*Coffee break*	*Coffee break*	*Coffee break*		*Coffee break*
11:00	**Liu I** 10:20-11:20	**Liu II** 10:20-11:20	**Kotake I** 10:20-11:20		**Price III** 10:20-11:20
12:00	**Price I** 11:20-12:20	**Price II** 11:20-12:20	**Liu III** 11:20-12:20		**Vaulin II** 11:20-12:20
1:00	*Lunch* *12:20-2:00*	*Lunch* *12:20-2:00*	**Committee Meeting** *Lunch* *12:20-1:20*	*Lunch* *12:20-1:40*	*Lunch* *12:20-2:00*
			Mini-Workshop (I) *1:20-3:00* **D. Yeom, Y. Lee,** **C. Yoo, M. Park,** **H.Kim, S.Woelfel**	**Gouaty III** 1:40-2:40	
2:00	**Gouaty I** 2:00-3:00	**Gouaty II** 2:00-3:00		*Coffee break*	**Kotake II** 2:00-3:00
3:00	*Coffee break*	*Photo session* */Coffee break*	*Free time:* *Excursion,* *Free* *discussion,* *etc.*	**Ajith I** 3:10-4:10	*Coffee break*
4:00	**Sasaki I** 3:30-4:30	**Sasaki II** 3:30-4:30		**Vaulin I** 4:10-5:10	**Ajith II** 3:30-4:30
5:00	**Diener I** 4:30-5:30	**Diener II** 4:30-5:30			**Diener III** 4:30-5:30
				Saulson: Public Lecture 5:30-6:40	Closing remarks 5:30-5:40
6:00	*Welcoming* *Dinner* *6:30-8:30*	**Gouaty:** Tutorials on Follow-up 6:30-9:00		*Banquet* *7:00-9:00*	

Ajith, Parameswaran (Caltech):
"Interface between numerical relativity and gravitational wave astronomy"

- **Lecture 1**
  - Inspiral-merger-ringdown templates for binary black hole signals and their implication in GW astronomy.
- **Lecture 2**
  - Characterizing the efficiency of detection & parameter-estimation pipelines - NINJA.
  - Tuning/improving the burst searches.

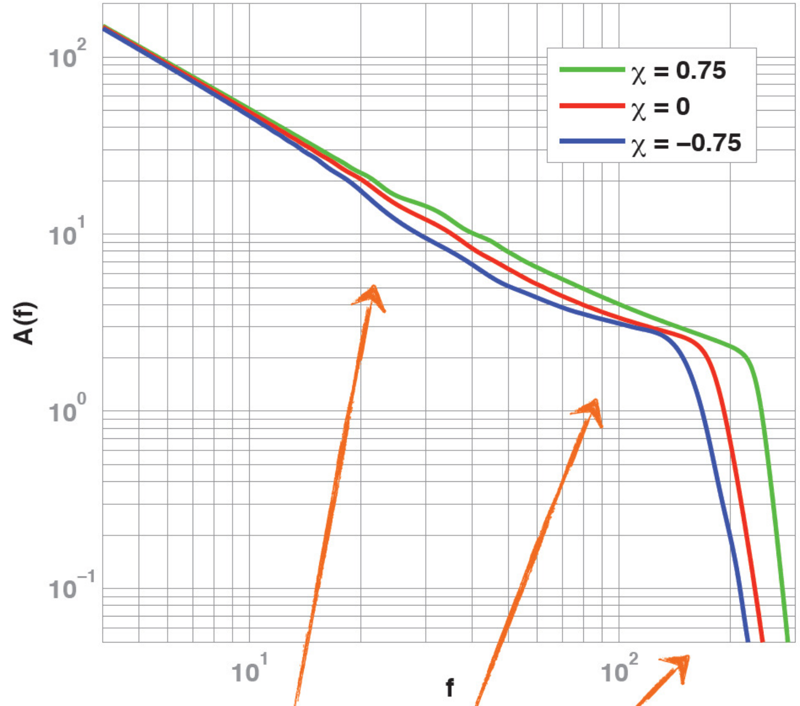
Constructing NR-PN hybrid waveforms



PN波形とNR波形をmatching ⇒ hybrid波形

Parametrizing the hybrid waveforms

- Modelling the amplitude:



PN corrections to the inspiral amplitude

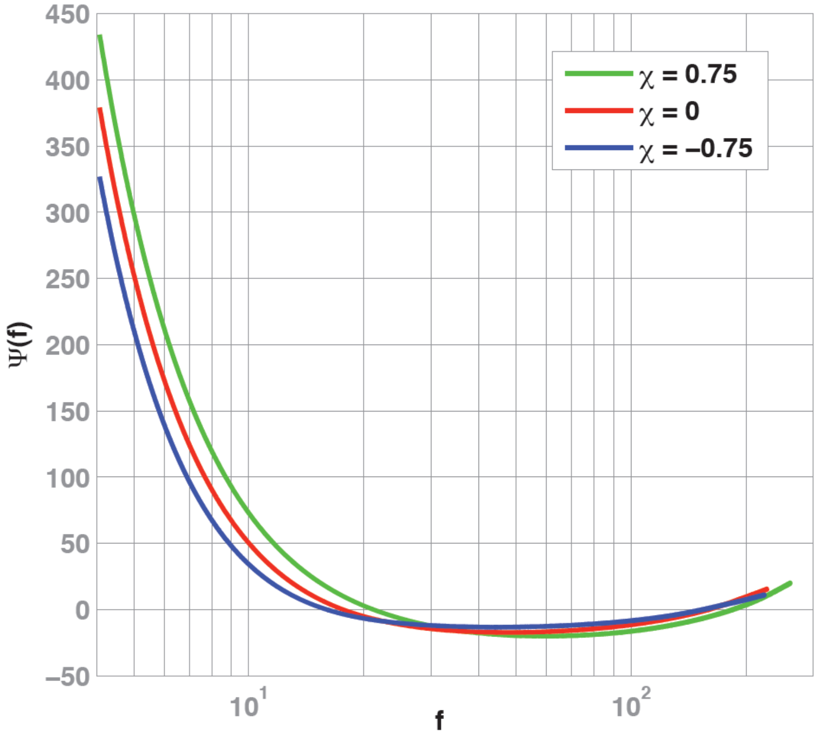
$$A(f) \equiv C f_1^{-7/6} \begin{cases} f'^{-7/6}\left(1+\sum_{i=2}^{3}\alpha_i v^i\right) & \text{if } f < f_1 \\ w_m f'^{-2/3}\left(1+\sum_{i=1}^{2}\varepsilon_i v^i\right) & \text{if } f_1 \le f < f_2 \\ w_r \mathscr{L}(f, f_2, \sigma) & \text{if } f_2 \le f < f_3, \end{cases}$$

Lorentzian (amplitude of the dominant QNM)

calibrated from the NR waveforms

Parametrizing the hybrid waveforms

- Modelling the phase:



Newtonian phasing term

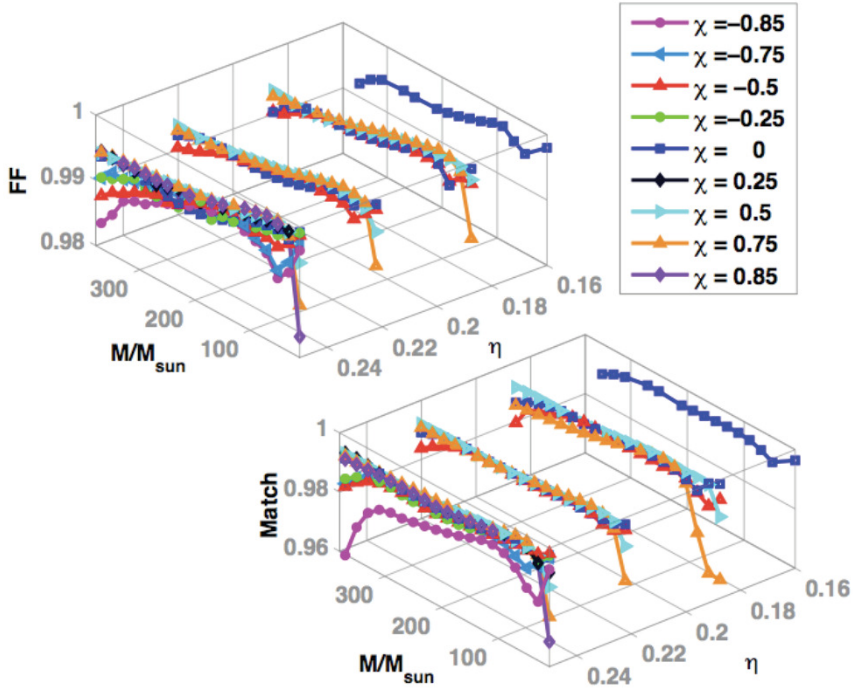
$$\Psi(f) \equiv 2\pi f t_0 + \varphi_0 + \frac{3}{128\eta v^5}\left(1 + \sum_{k=2}^{7} v^k \psi_k\right)$$

PN-like series. Coefficients determined from the hybrid waveforms

$$\psi_k = \sum_{i=1}^{3}\sum_{j=0}^{N} x_k^{(ij)}\, \eta^i \chi^j + \psi_k^0 ,$$

Testing the analytical waveforms & Improved Distance Reach

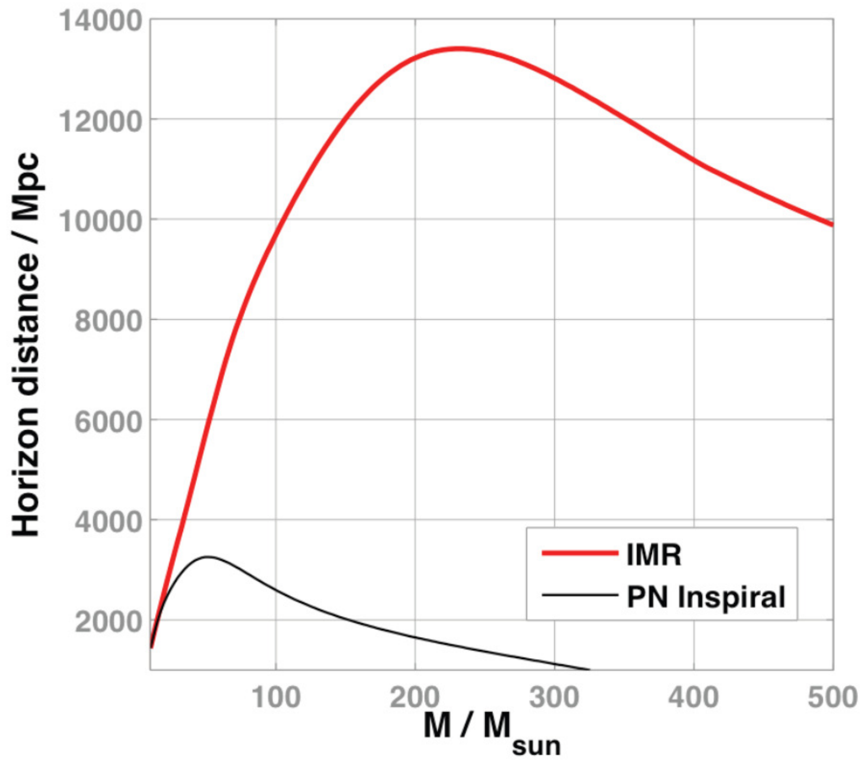
Using BAM Simulations



Equal-spin hybrids (used to construct the template family)

[P. Ajith et al (2009)]

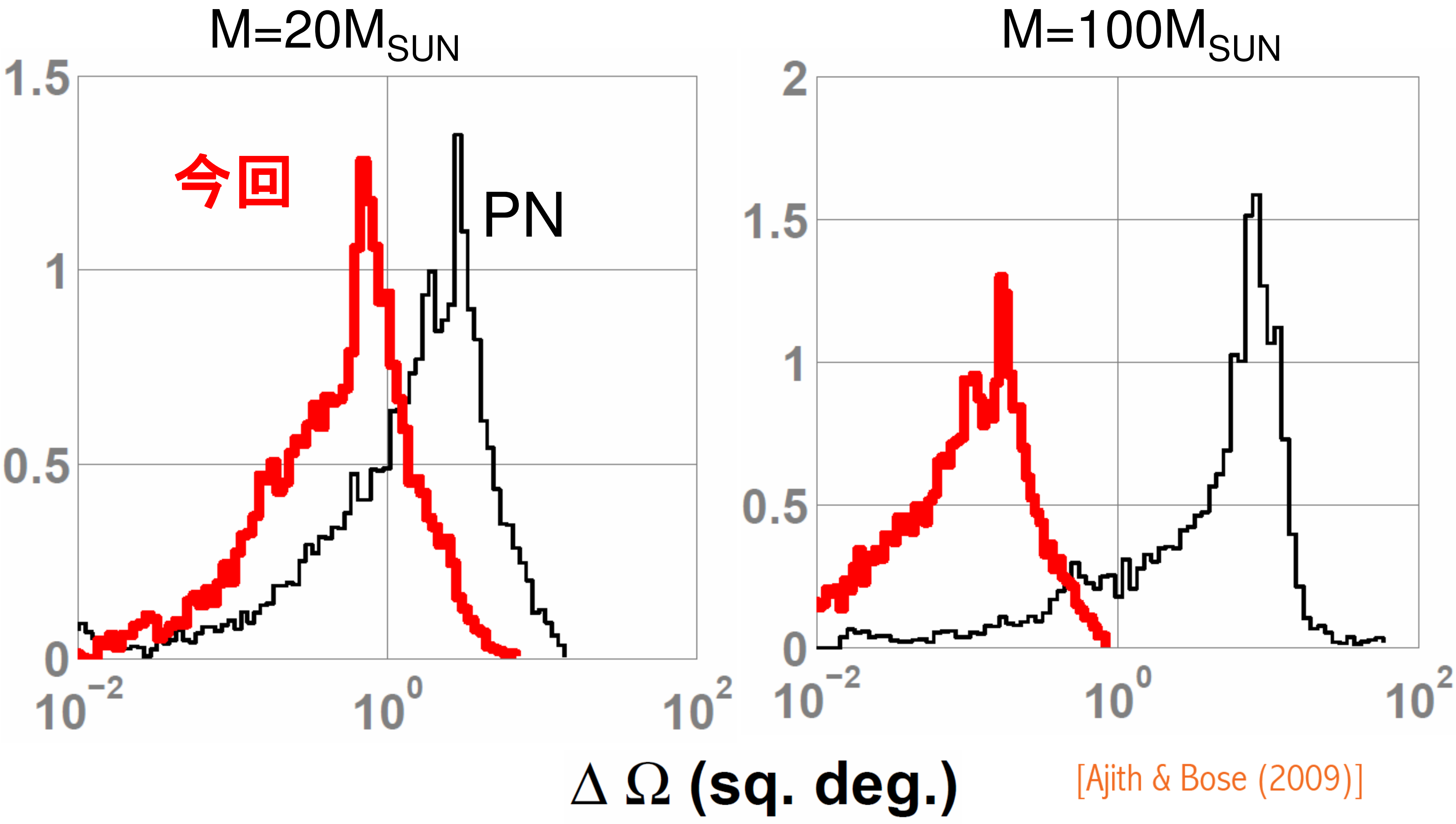
SNR = 8 in Adv LIGO



FF > 0.98 for $q \leq 4$, $|\chi| \leq 0.85$ in Initial/Enhanced LIGO

IMPLICATIONS Improved parameter estimation

- η=0.25(equal mass), d_L=1Gpcでの角度誤差の確率分布



[Ajith & Bose (2009)]

Test of General Relativity

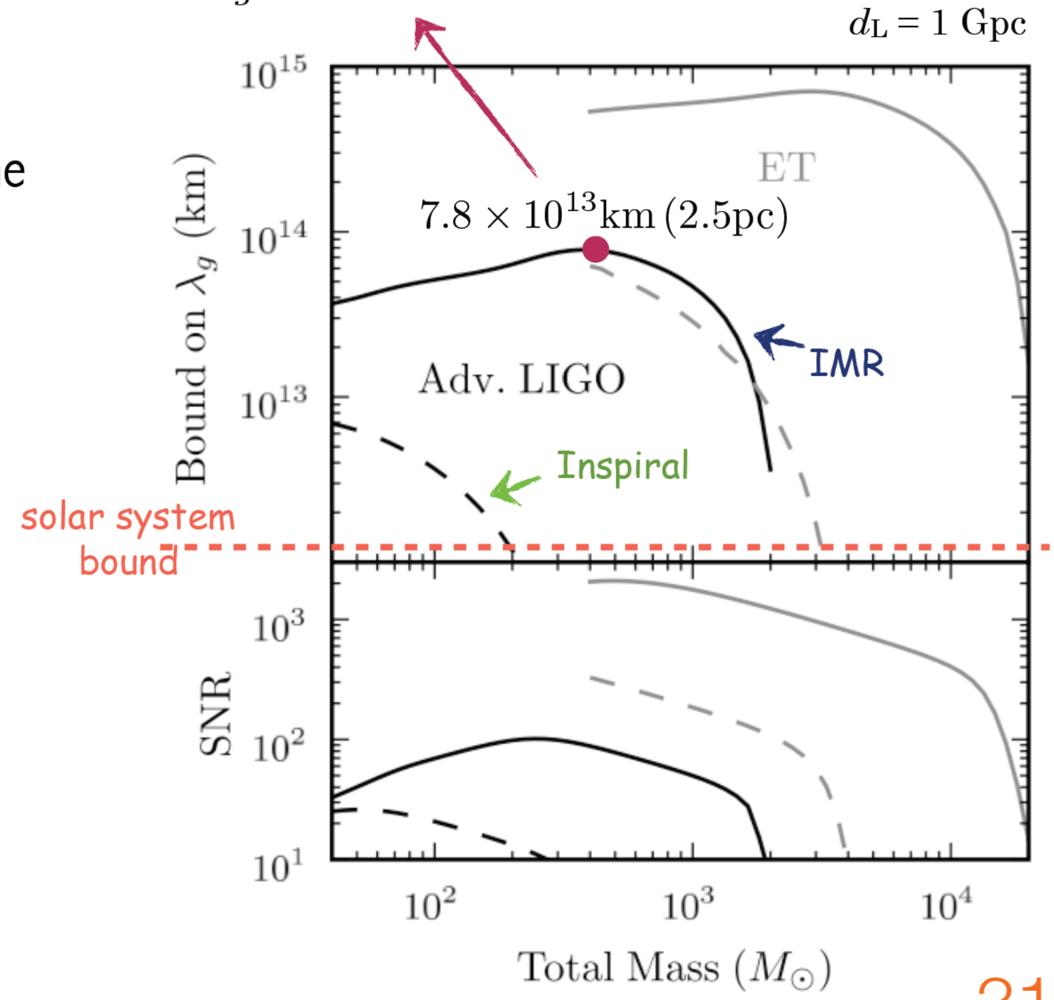
- **Constraining the mass of graviton**
  Massive graviton will propagate with (frequency-dependent) speed < c, producing an observable signature in the GW signal.

$$h(f) = A(f)\, e^{i\left[\Psi_{\rm GR}(f) - \beta f^{-1}\right]}$$

$$\frac{\pi D}{\lambda_g^2 (1+Z)}$$

Compton wavelength of graviton

$m_g < 1.6 \times 10^{-23}$ eV



[Keppel & Ajith (2010)]

忍者

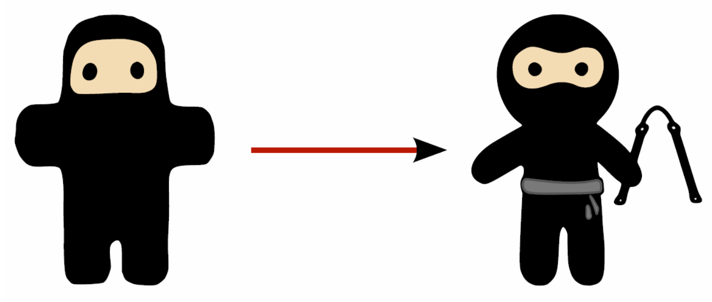
Numerical-Relativity Injection Analysis (NINJA)

The first NINJA project *2008-2009*

- Study the response of GW search pipelines to NR binary-black-hole waveforms in simulated noise.

What Needed Improvement

NINJA-1 was, by construction, unable to address several crucial questions related to GW searches. The emphasis was on creating a common platform and "language".



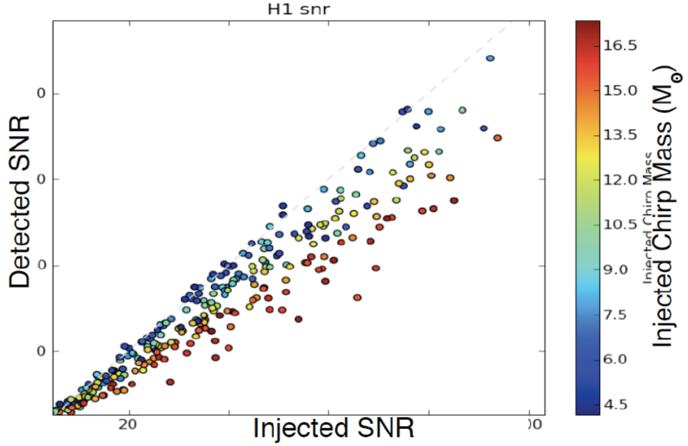
- Gaussian noise prevented realistic false alarm calculation ⟶ NEED REAL DETECTOR DATA.
- No requirements on NR waveform accuracy ⟶ TIGHTER REQUIREMENTS.
- Short NR waveforms. Unable to do low-mass injections ⟶ MATCH NR WAVEFORMS WITH POST-NEWTONIAN. INJECT THESE "HYBRID" WAVEFORMS.
- Only qualitative comparison between the analysis approaches ⟶ FALSE ALARM CALCULATION WILL PERMIT MORE RIGOROUS COMPARISONS.

Some results from training data set (Gaussian)

DETECTION PIPELINES

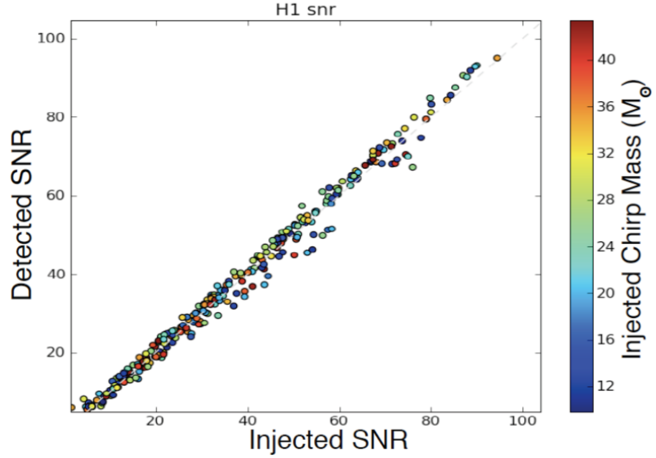
[S. Mohapatra, L. Pekowsky, A. Weinstein]

Low-mass data set (10 - 40 M_{sun})



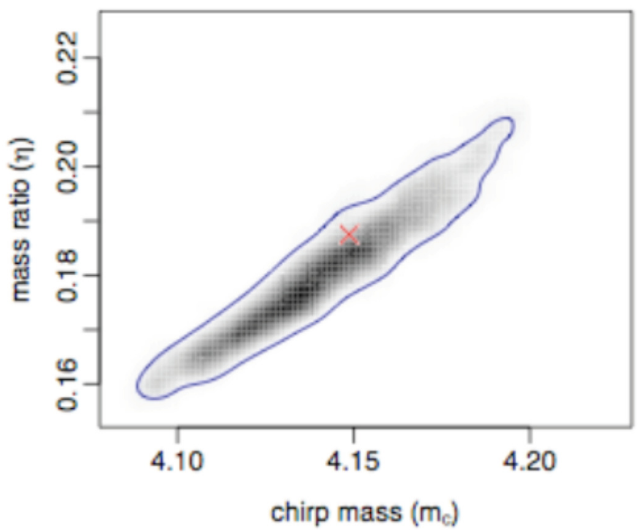
"low-mass" CBC pipeline

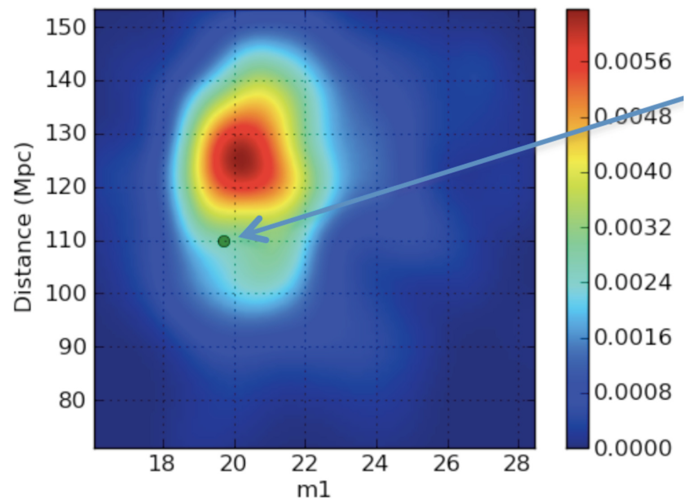
High-mass data set (25 - 100 M_{sun})



"high-mass" CBC pipeline

[C. Roever]





[B. Aylott, R. Smith, A. Vecchio, J. Veitch]

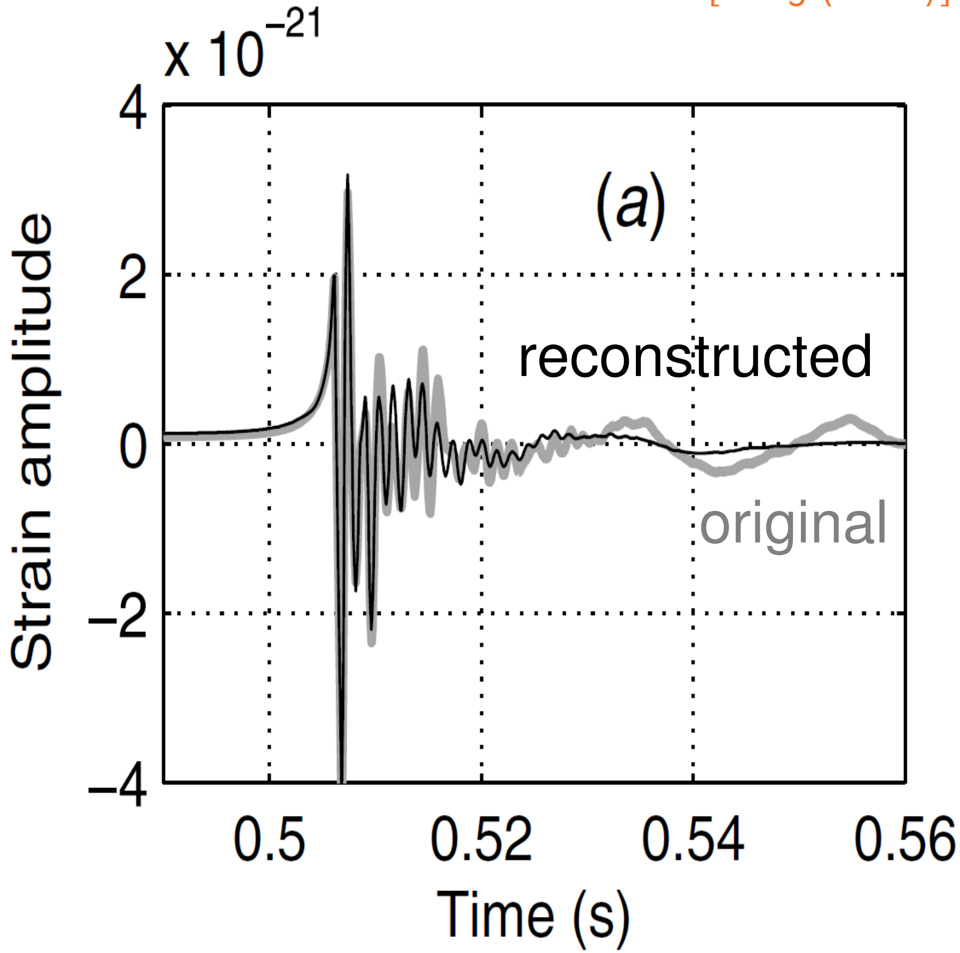
The dirty Ninja!

The next stage of the Ninja project (including matter physics) is in progress

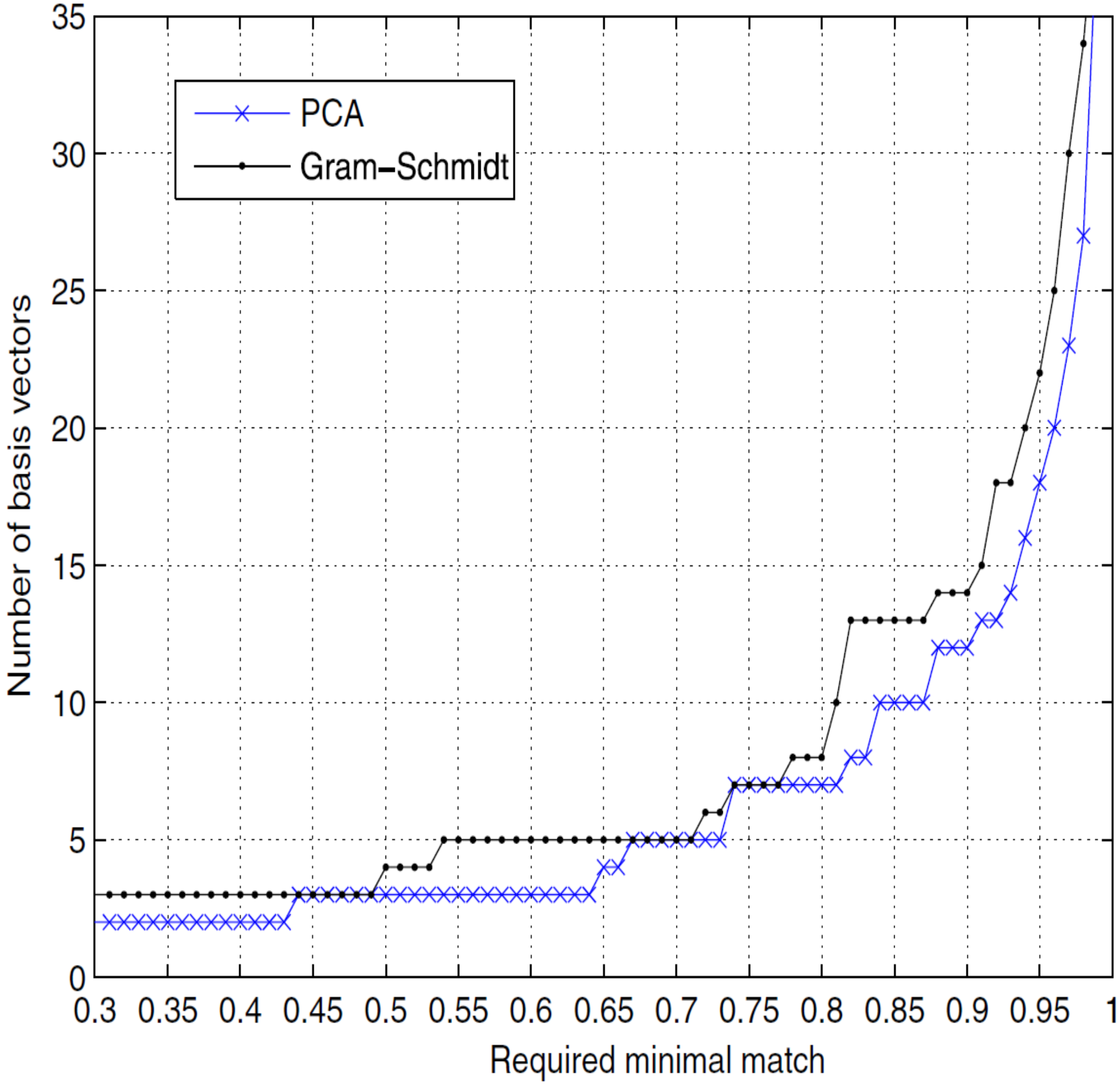
Waveform templates for burst sources?

- Identify an orthonormal basis to decompose an entire catalogue of supernova waveforms.
- An entire catalogue can be represented using ~10 basis vectors. カタログ数:54
- Can identify dominant features in the waveform. Useful for parameter estimation. Potential for matched filter search.

[Heng (2008)]



正規直交波形の数



Matching factor

Diener, Peter (Center for Computation & Technology, Louisiana State University): "BH-BH merger simulations and Cactus"

- Binary Black Hole Initial Data.
- Black Hole Horizons.
- Binary Black Hole Inspiral Process.
- Calculating Kicks.
- Kick Results.
- Kick Fitting Formula.
- Ongoing and Future Work.

<u>Gouaty, Romain</u>
(Universite' de Savoie, CNRS/IN2P3):
"The Search for Gravitational Waves in Real Life"

- **CH1: Introduction to the Search for Gravitational Waves emitted during Compact Binary Coalescences ("CBC searches")**
  → ***the detectors, the sources, the waveforms, the analysis technique***

- CH2: CBC pipeline – From calibrated data to the production of single interferometer triggers
  → *parameter space and template banks, matched filtering*

- CH3: CBC pipeline – Coincident analysis and Vetoes
  → *techniques to separate signals from background*

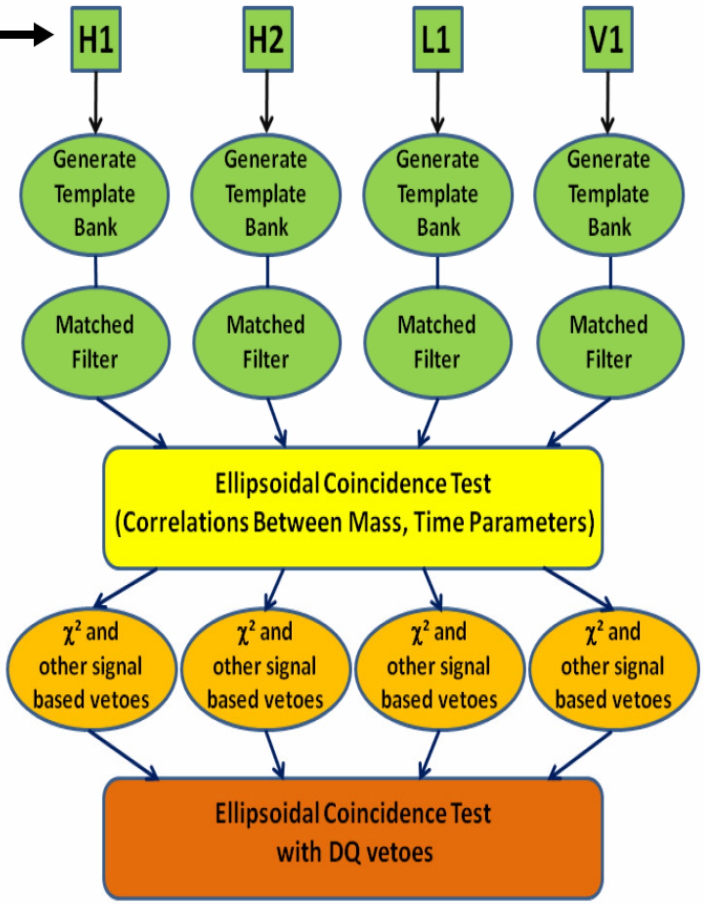
- CH4: CBC pipeline – Dealing with the surviving coincident triggers
  → *ranking the triggers obtained at the output of the pipeline*
  → *review of interesting "candidate-events"*

- Computing scale of the CBC pipeline and introduction to LDG

- A brief discussion about techniques used in other analyses

CBC search pipeline (1/7) [REF 5]

One data set per interferometer

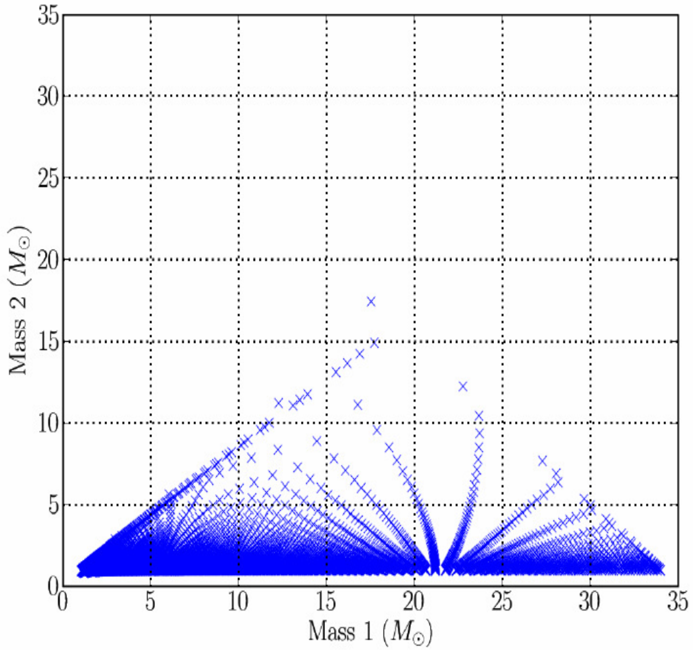


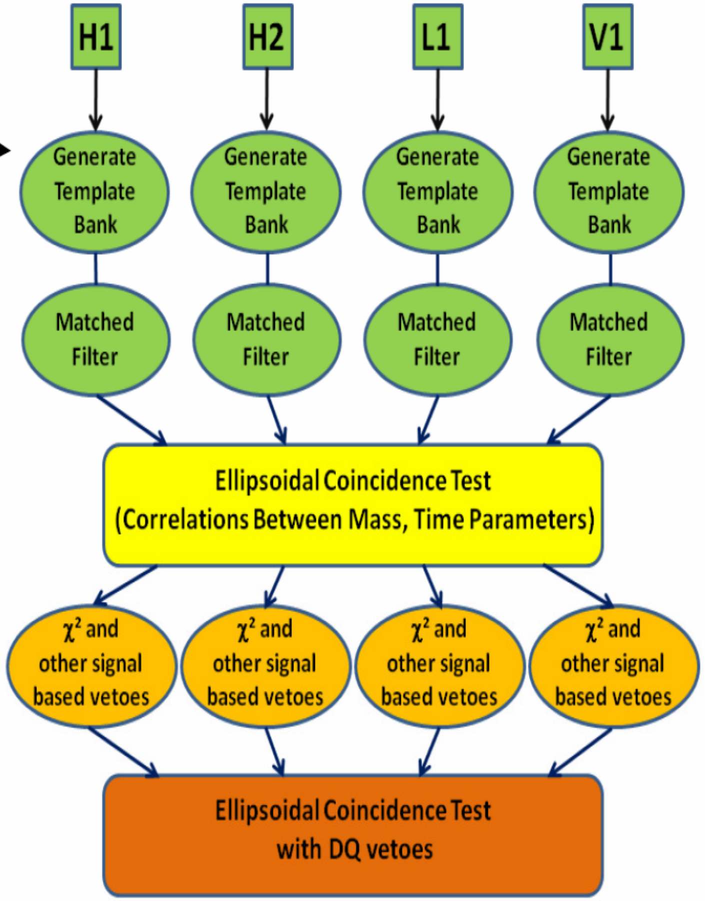
CBC search pipeline (2/7) [REF 5]

The waveform depends on the system parameters

⇒ **Scan the mass space with template banks**

Example for « Low Mass » search (2-35 Msun)

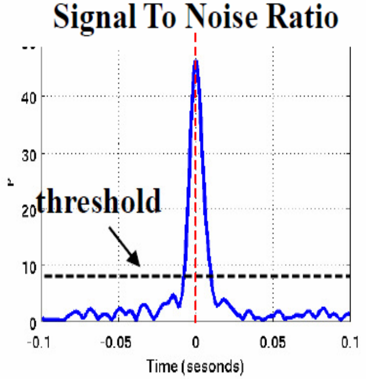


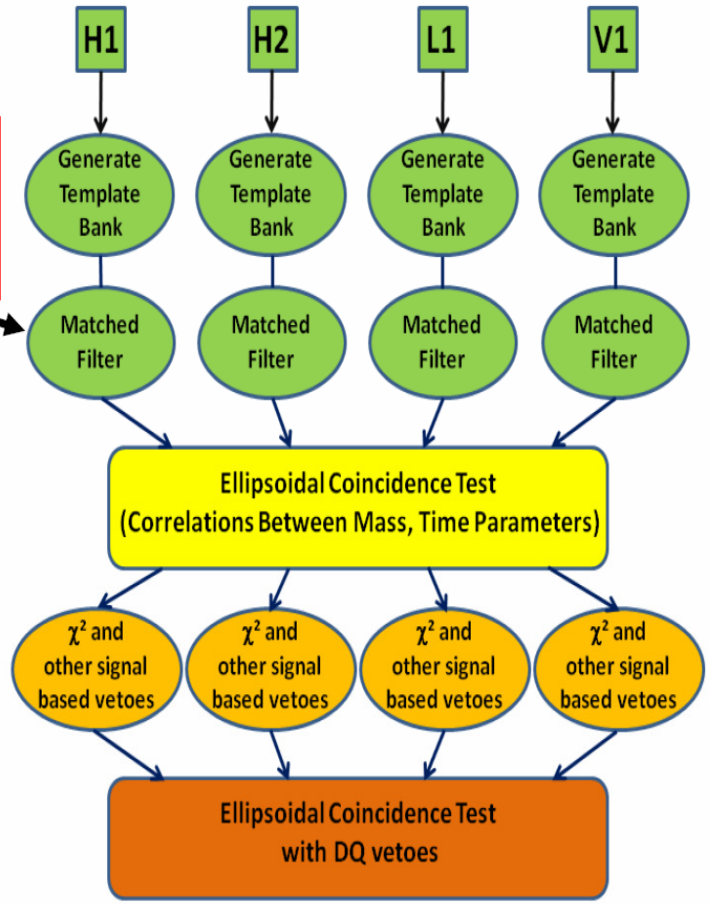


CBC search pipeline (3/7) [REF 5]

Match filter:

⇒ keep triggers above some SNR threshold

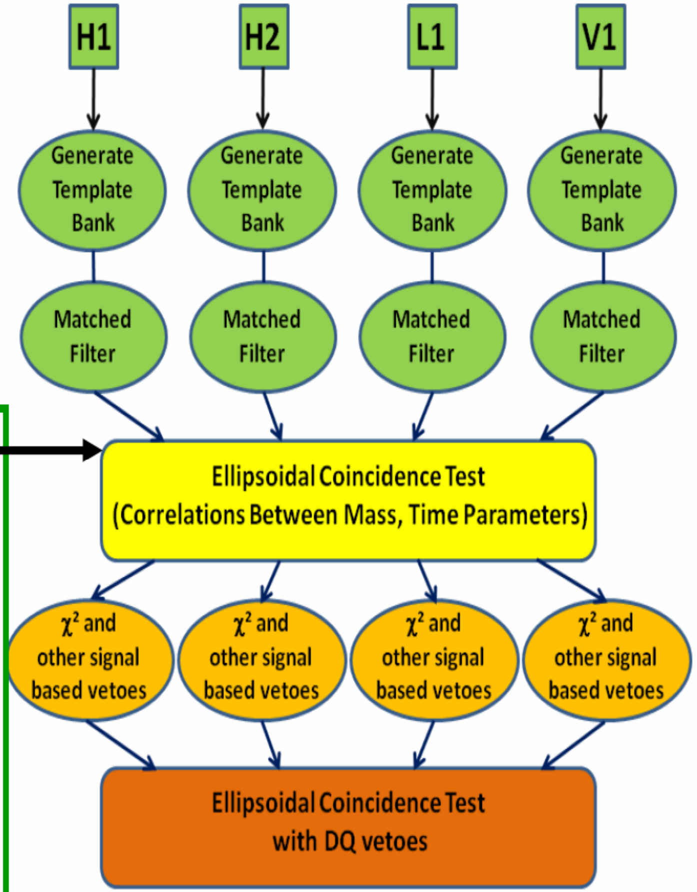




CBC search pipeline (4/7) [REF 5]

Require coincidence between two or more detectors

- Time and mass parameters
- Allows reducing the false alarm rate
- Allows estimating the background by applying time offsets to the data



CBC search pipeline (5/7) [REF 5]

Identify rare and weak events in detector noise that is non-Gaussian and not stationary:

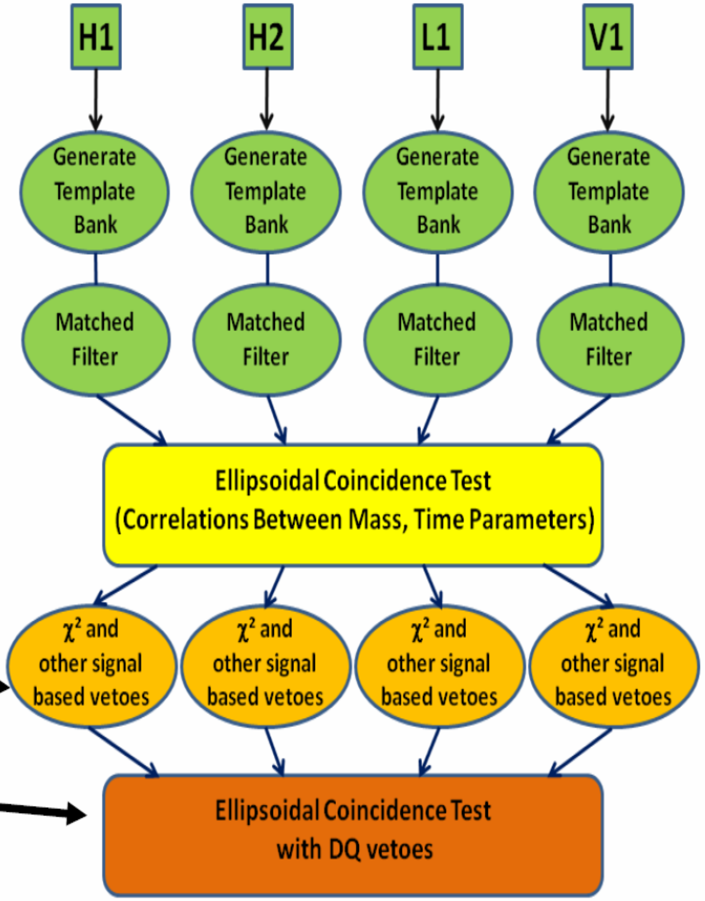
⇒Need to apply vetoes

- **Signal based vetoes**

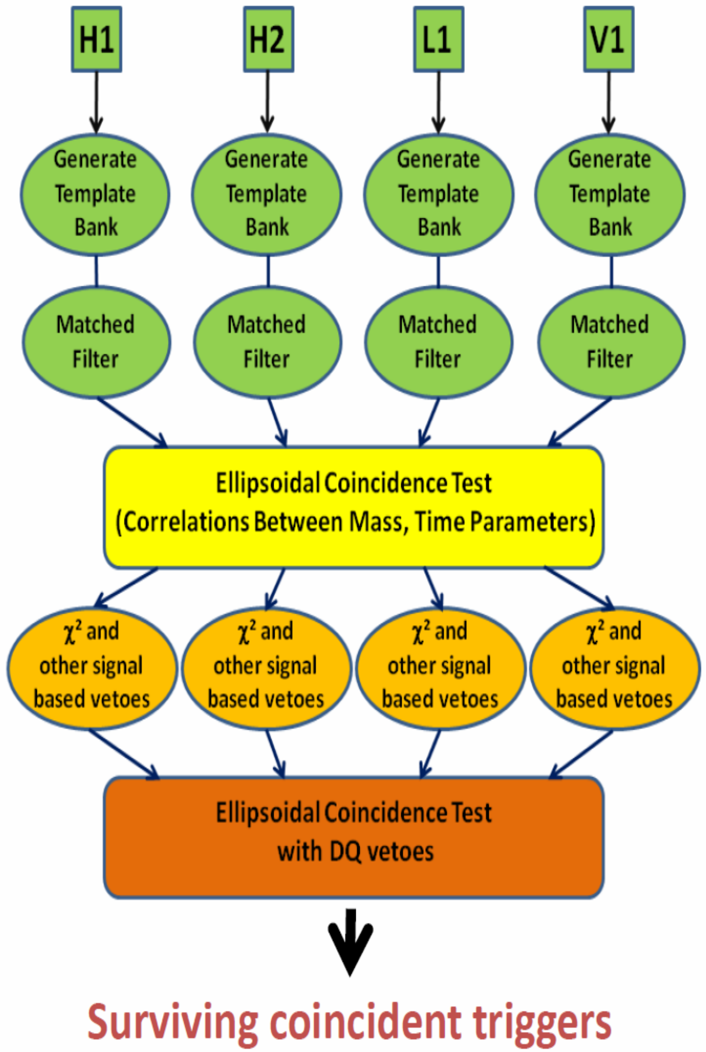
Check consistency between measured and expected signals (e.g. χ^2 test)

- **Instrumental vetoes**

Eliminate poor data quality times due to artifacts in detector or environment



CBC search pipeline (6/7) [REF 5]



- Surviving coincident triggers are ranked according the a **detection statistics**
- Triggers that stand above the background are submitted to a **detection checklist**

Instrumental vetoes
Categories (5/5)

Vetoes are categorized according to severity, statistical correlation and dead time:

- **Category 1:**
  - Data not suitable for being analyzed
  - Ex: Detector not at operating point, missing data, ...

This data is not analyzed

- **Category 2:**
  - Coupling noise source/GW channel is well established
  - Strong statistical correlation (high ratio "efficiency over dead
  - Ex: overflow in ADC digitizing photodiode signals, **well understood** glitches

Check for possible detections

- **Category 3:**
  - Suspected instrumental problems
  - Positive statistical correlation, but not well understood
  - Dead time can be large
  - Includes add-hoc vetoes based on auxiliary channels
  - Ex: high seismic activity, strong wind

Check for possible detections And calculate upper limits on event rates

- **Category 4:**
  - Poorly understood, weak but positive correlation
  - May veto whole noisy epochs

Only used for follow-ups

Signal based vetoes: χ^2 test (1/3)

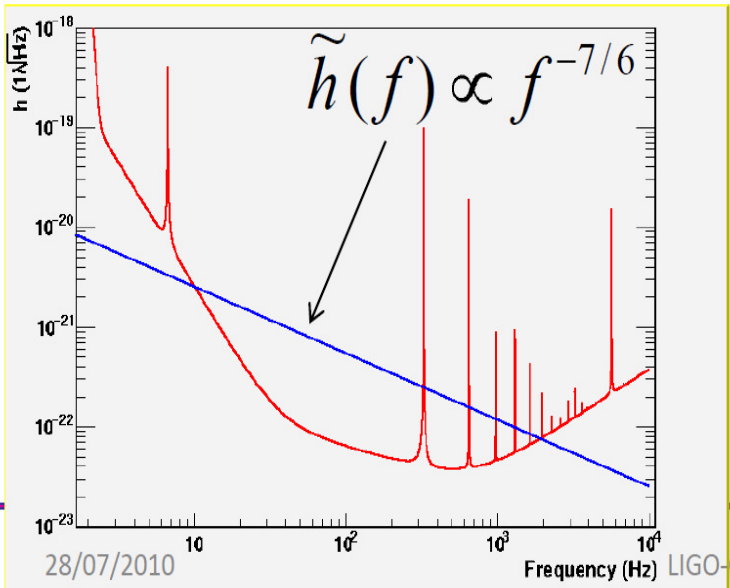
- **Matched filter is optimal to distinguish GW signal from stationary Gaussian noise**
- **But loud instrumental transients ("glitches") can generate loud SNR triggers**

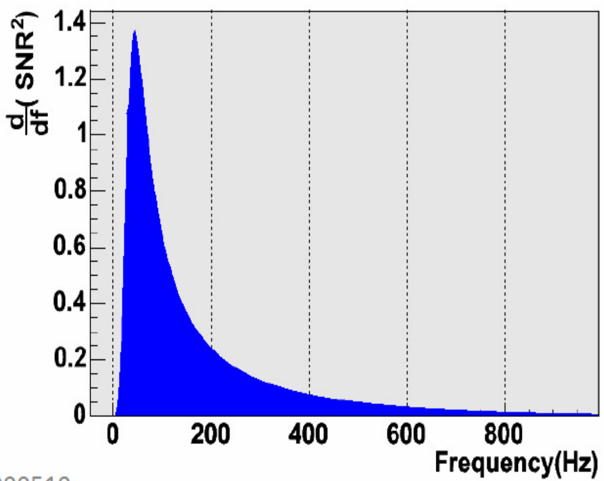
Basic idea:

Look at how the SNR is distributed across the detector bandwidth and check whether this is consistent with what is expected from a true signal

SNR for a GW signal matching the template T(f)

$$SNR^2 = 4A \int_{f_{low}}^{f_{final}} \frac{T(f)\ \tilde{T}^*(f)}{S_n(f)} df \propto A \int_{f_{low}}^{f_{final}} \frac{f^{-7/3}}{S_n(f)} df$$





Signal based vetoes: χ^2 test (3/3)

χ^2 distribution for true signals in practice:

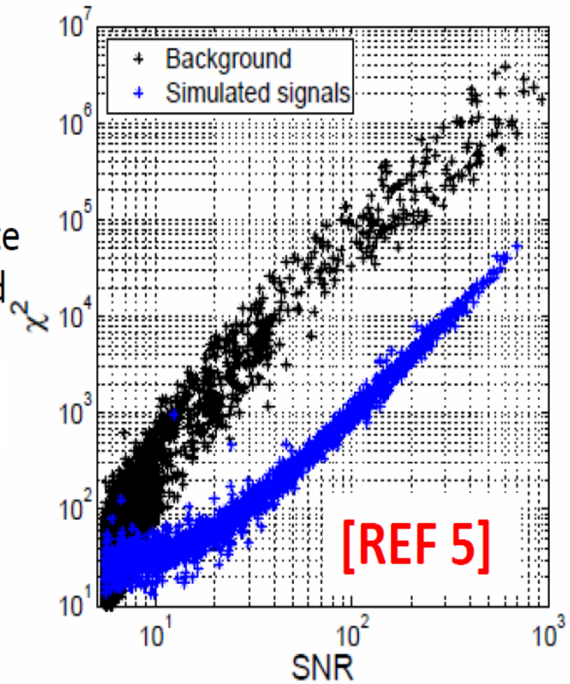
Large SNR events tend to show larger χ^2 values than expected from the naive distribution

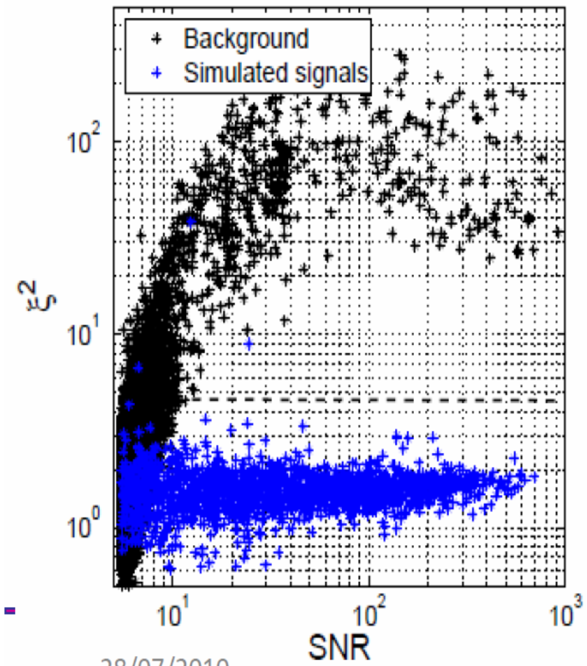
⇒ An effect of using discrete template banks

The slight mismatch between the signal and the template is enough to evidence differences between the expected SNR frequency distribution and the measured one

⇒ high χ^2

$$\chi^2 = p\sum_{j=1}^{p}(\Delta\rho_j)^2 \quad with \quad \Delta\rho_j = \rho_j - \frac{\rho}{p}$$





The cut used to eliminate background must take into account the SNR dependency of the χ^2

⇒Apply threshold on variable $$\xi^2 = \frac{\chi^2}{p(1+\delta^2\rho^2)}$$

⇒ Parameters p, δ and threshold are tuned to not reject simulated signals

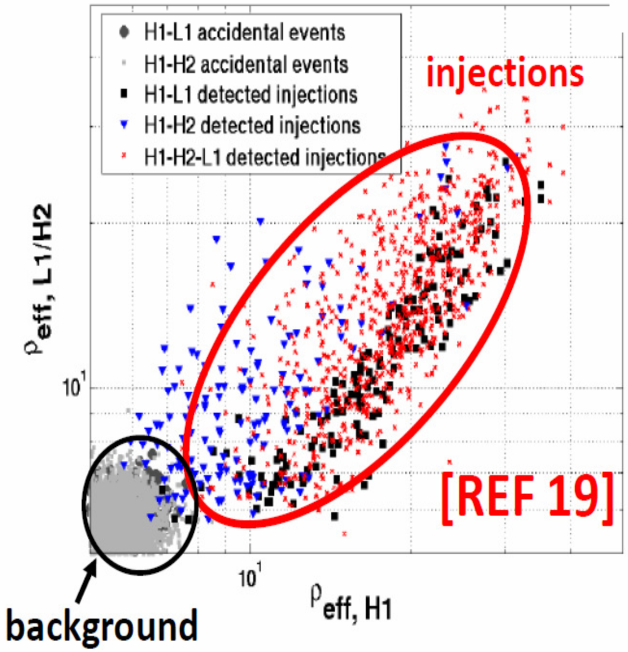
Ranking Statistic: Effective SNR

Combine SNR with $\chi 2$ parameter to better separate background triggers from simulated signals

$\Rightarrow$ Give less value to triggers with high χ^2

$\Rightarrow$ Define an effective SNR:

$$\rho_{\text{eff}} = \frac{\rho}{\left[\left(\frac{\chi^2}{2p-2}\right)\left(1+\frac{\rho^2}{\rho_c}\right)\right]^{1/4}}$$ **[REF 5]**



Definition of a combined effective SNR for coincident triggers:

Incoherent sum over effective SNR of each detector

$$\rho_{Comb} = \sqrt{\sum_{ifo} \rho_{eff,ifo}^{\ 2}}$$

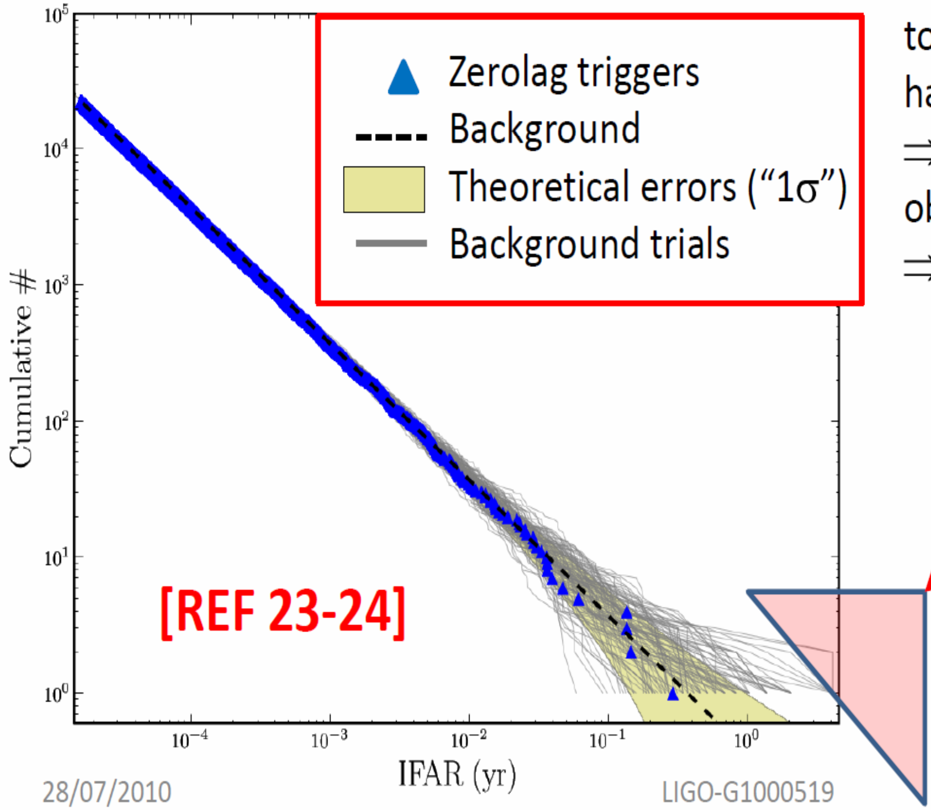
Ranking Statistic: Inverse false alarm rate (2/2)

Combined FAR is in units of year^{-1}

Inverse Combined FAR (IFAR) is used as the detection ranking statistics

⇒ Guarantee that all categories bring the same background

Example: Result of the S5 1yr Low Mass Search for analyzed triple time



Warning:

All categories are not equally sensitive to true signals (for ex. if detectors have different sensitivities)

⇒ weight IFAR with probability to observe louder signal

⇒ this is called **"likelihood statistic"**

[REF 25]

After CBC pipeline and follow-ups ?

- **If no detection:**
  - $\Rightarrow$ put upper limits on coalescence rate

- **If there are candidates that pass the checklist:**
  - ➢ Need to be discussed within the CBC group and the Collaboration
  - ➢ Decision on detection/no detection based on False Alarm Rate

Kotake, Kei
(National Astronomical Observatory of Japan):
"Supernovae and Gravitational Waves"

✓ 1st part (on Wednesday)

§ 1-1 **General introduction:** GWs from supernovae

§ 1-2 **Supernova theory:** how to blow up massive stars?

§ 1-3 **Candidate mechanisms:**

based on the state-of-the-art numerical simulations

✓ 2nd part (on Friday)

- **Gravitational-wave signatures from recent supernova simulations :**

can we learn the explosion mechanism from GW observations?

Expected GW amplitudes from Stellar Collapse

GW amplitude from the quadrupole formula

$$h_{ij} = \frac{2G}{c^4 R} \frac{\partial^2}{\partial t^2} Q_{ij} \sim \frac{R_s}{R} \left(\frac{v}{c}\right)^2$$

Quadrupole moment

Typical values at the formation of NS

$$R_s = 3 \text{ km} \left(\frac{M}{M_\odot}\right) \quad v/c = 0.1 \quad R = 10 \text{ kpc}$$

$$h \sim 10^{-20}$$

- SN in our galaxy is the target of GWs

More correctly,

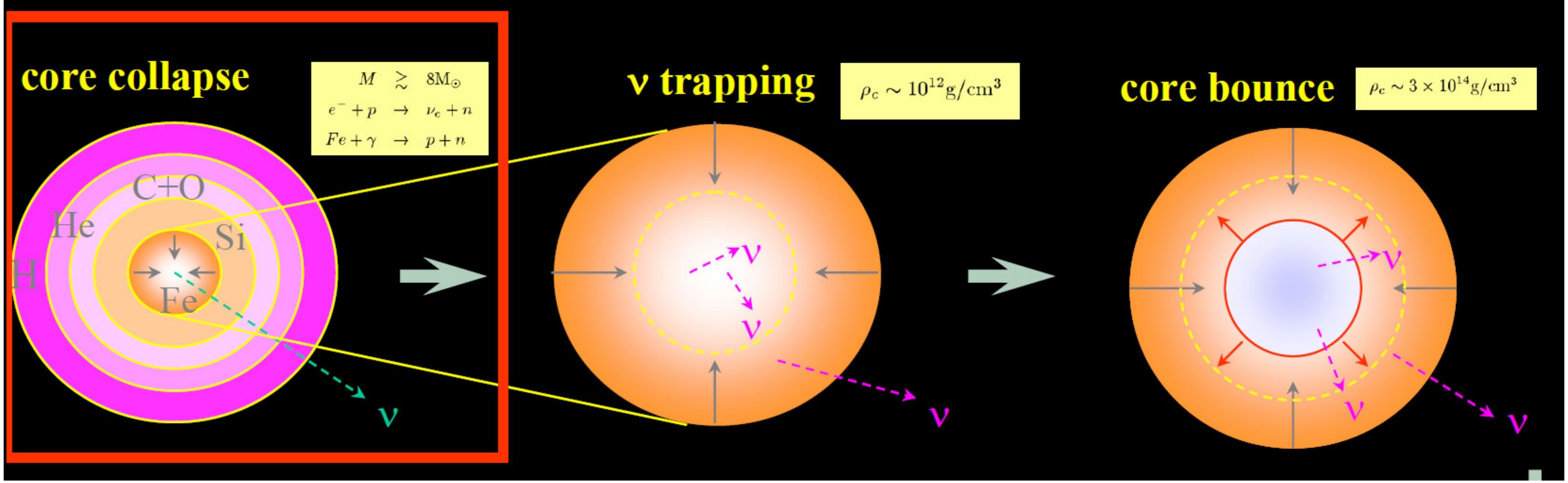
$$h_{ij} = \epsilon \frac{R_s}{R} \left(\frac{v}{c}\right)^2$$

ϵ represents the degree of anisotropy.

If collapse proceeds spherically, $\epsilon = 0$ no GWs can be emitted.

What makes the SN-dynamics deviate from spherical symmetry ?

Standard scenario of core-collapse SNe



・bounce時にshockが発生。

⇒外層を吹き飛ばす⇒SN!!

・しかし、shockは途中で止まってしまう。

Shock を温めるmechanismが必要。

A garden variety of multi-D candidate SN models

Energy-drivers for explosions:

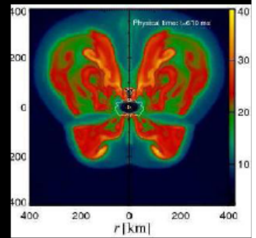
☆Neutrino

✓ Neutrino-heating mechanism + convection/SASI

SASI: Low modes oscillatory instability of standing accretion shock

: Explosion of 2D, low-stars (11.2 Ms), **(Buras+. 2006)**

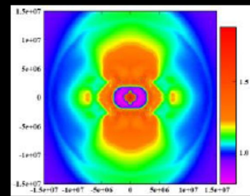
: Onset of SASI-aided neutrino driven explosion of 15 Ms star **(Marek & Janka 09)**



(Marek & Janka 07)

✓ Rotation & anisotropic neutrino radiation:

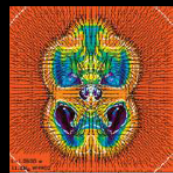
(KK+03,06, Walder+05,Ott+08)



(KK+06)

☆Acoustic-power

Acoustic mechanism: **(Burrows+. 2005,6, Ott+07)**

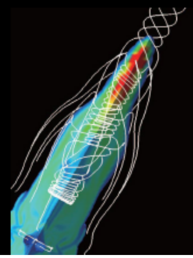


(Burrows+06)

☆ Extraction of rotational energy via B-fields

MHD mechanism:

(LeBlanc & Wilson (70), Symbalisty (85), KK+04, Shibata+06, Obergaulinger+06, Sawai et al. (05), Cerda Duran+07, Burrows+07, Suwa+07, Takiwaki+08, Ono+09 ….)



(Takiwaki+08)

When/How GWs are emitted from Core-Collapse SNe?

Origins	when	Why ? (Cause of asphericity)
Bounce	At bounce (duration、～100 msec)	Aspherical(:non-spherical) motions of rapidly rotating inner core
Convection /SASI, or PNS oscillations	After bounce (duration、～ 1 sec)	Aspherical motions of matter outside/inside the PNS
Anisotropic neutrino radiation	After bounce (duration、～ 1 sec)	Aspherical radiation of neutrinos

Typical frequencies and amplitudes of bounce signals

✓Order-of-magnitude estimation

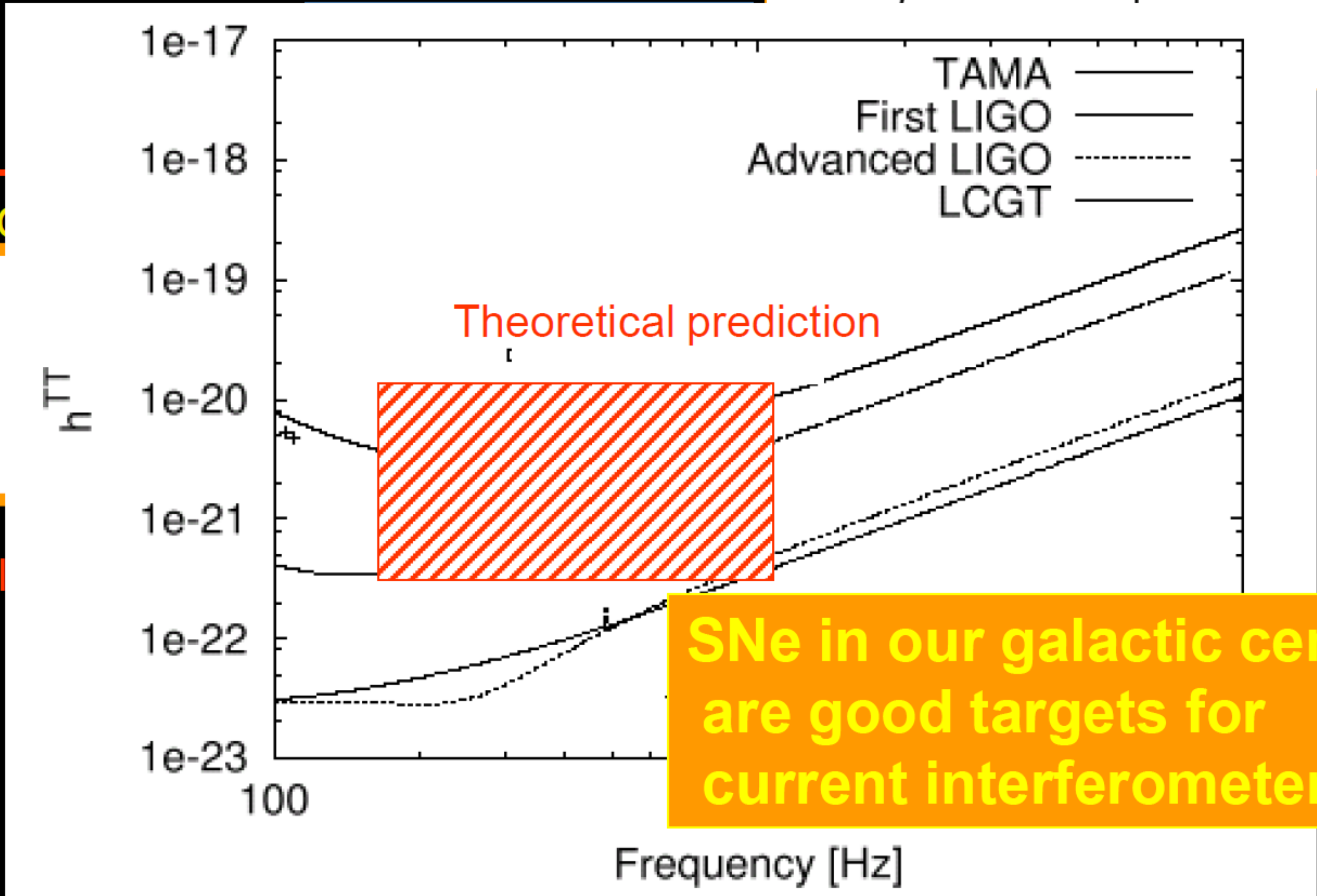
Quadrupole formula：

$$h_{i,j}^{TT}(R) = \frac{2G}{c^4}\frac{1}{R}\frac{d^2}{dt^2}I_{i,j}^{TT}(t-\frac{R}{c})$$

(ref. Gravitation & Cosmology, Weinberg
Landau Lifshitz、Classical Field theory)

✓Typical

✓ Typical

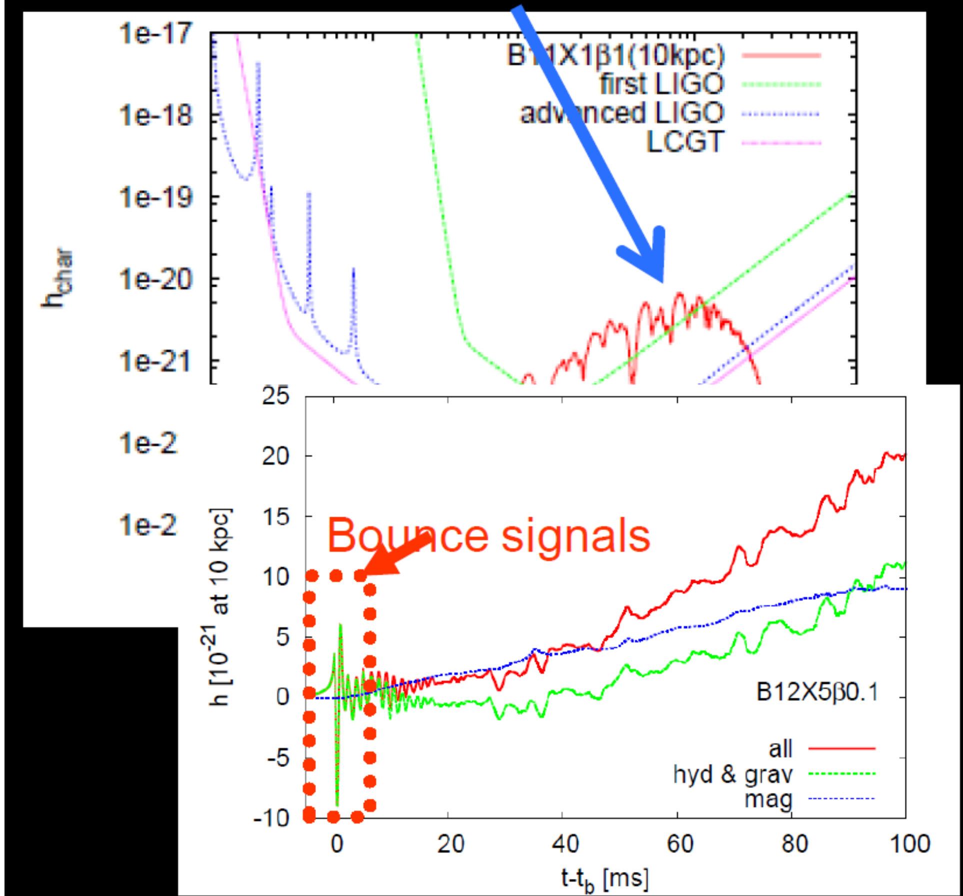


SNe in our galactic center are good targets for current interferometers！

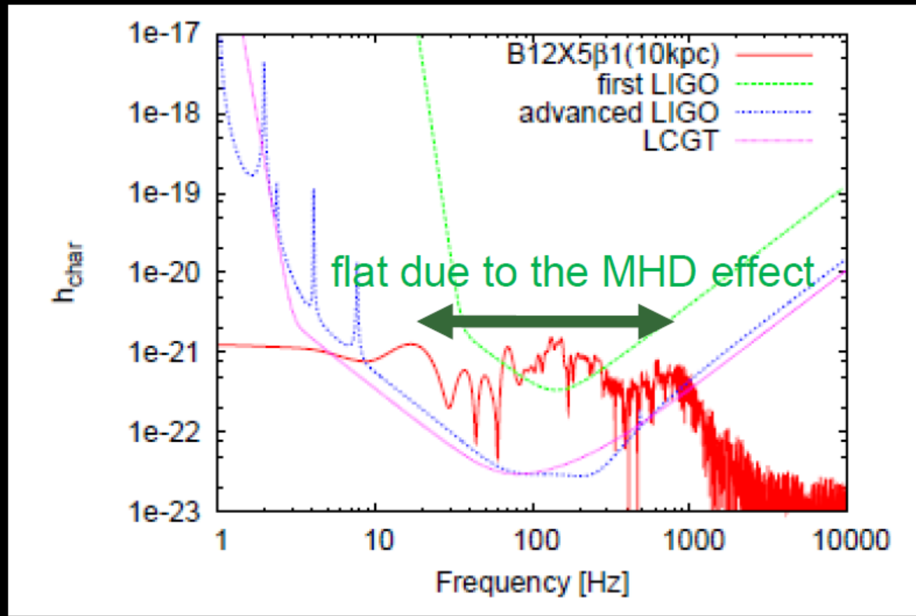
Unique GW feature in magneto-driven explosions

Takiwaki & Kotake (submitted)

The bounce signal without B-fields



The bounce signal with B-fields



✓ Type IV waveform : an indicator of the MHD explosion !

GWs from anisotropic neutrino radiation

$$h^{\mu\nu}(t, \boldsymbol{x}) = 4 \int \frac{T^{\mu\nu}(t - |\boldsymbol{x} - \boldsymbol{x}'|, \boldsymbol{x}')}{|\boldsymbol{x} - \boldsymbol{x}'|} d^3x'$$

$$T^{\mu\nu} = T^{\mu\nu}_{\mathrm{matter}} + T^{\mu\nu}_{\mathrm{neutrino}}$$

Epstein(78),Mueller & Janka (97)

$$h_\nu(t) = \frac{2G}{c^4 R} \int_0^t dt L_\nu(t') \alpha(t')$$

Neutrino anisotropy: degree of anisotropic neutrino radiation (zero if spherical)

Typical amplitude :

$$|h_\nu| \sim 10^{-21} \left(\frac{\alpha}{0.01}\right) \left(\frac{L_\nu}{10^{52} \mathrm{erg/s}}\right) \left(\frac{\delta t}{1\ \mathrm{sec}}\right) \left(\frac{R}{10\ \mathrm{kpc}}\right)^{-1}$$

$$|h_\nu| \sim h_{\mathrm{bounce}} \sim 10^{-21} \quad (10\mathrm{kpc})$$

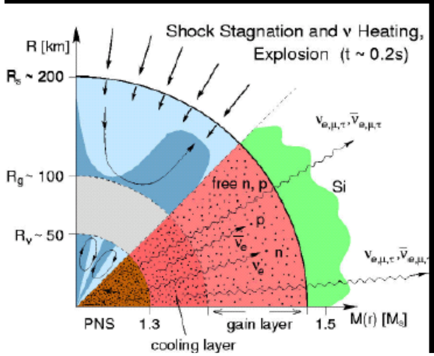
~ as large as the one at bounce

Typical frequency :

$$t_\nu \sim \frac{1}{\sqrt{G\rho}} \geq 10\ \mathrm{msec} \left(\frac{\rho_{\mathrm{trap}}}{10^{11}\ \mathrm{gcm}^{-3}}\right)^{-1/2}$$

$$\nu_\nu \sim \frac{1}{t_\nu} \leq 100\ \mathrm{Hz}$$

, longer than the bounce signal because the dynamical time scale is determined at the position of neutrino sphere, where forms further out from the center.

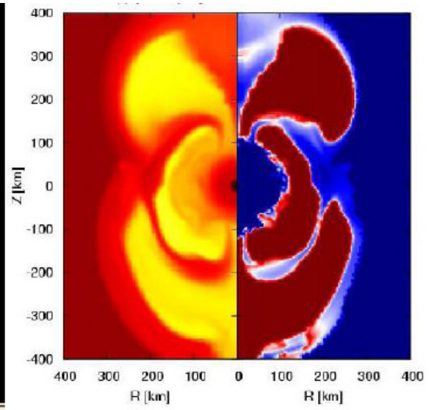


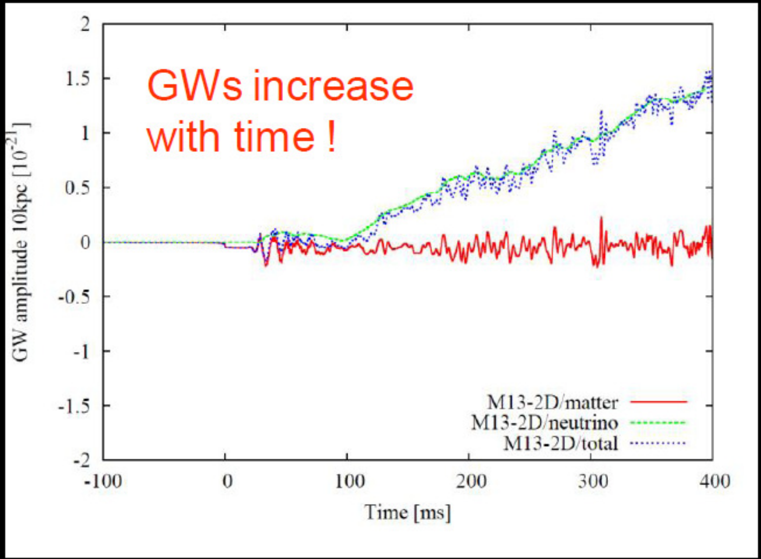
Frequencies of GWs from neutrinos are to be lower than for the bounce signals (~ 1kHz).

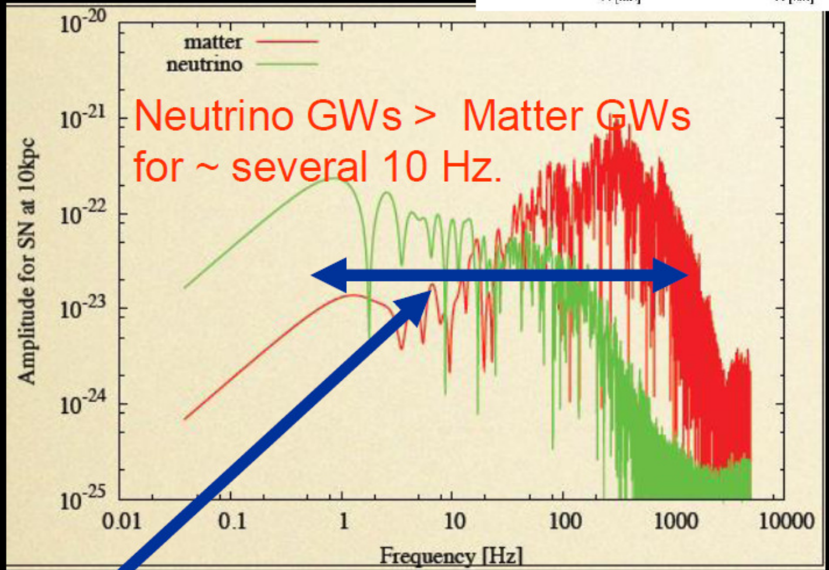
Tokyo-Basel simulations

✓ GW from no-rotating 13 Msun star → explosion

Suwa et al. in prep







✓ GW from convection and SASI is broadband, f ~ 1 – 1000 Hz.

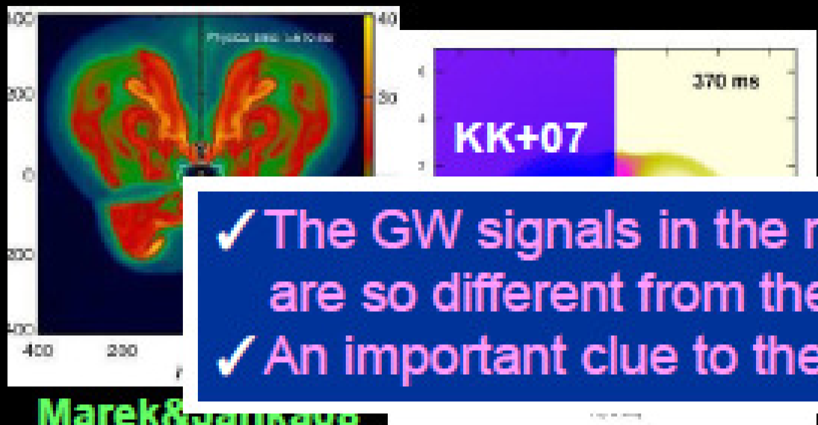
✓ Waveforms are divergent among models to models.

→ GW from convection/SASI has a stochastic nature
(governed by turbulent and chaotic fluid motion,non-linear hydrodynamics)

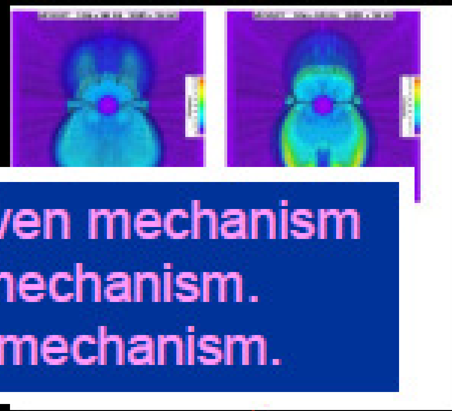
✓ For detection, the next generation detectors are required.

GWs from the two scenarios

Neutrino heating with SASI



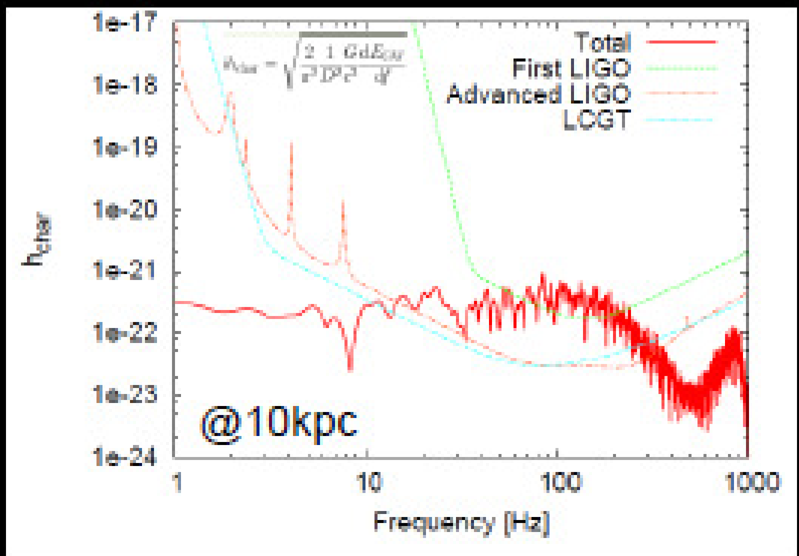
Acoustic-wave mechanism



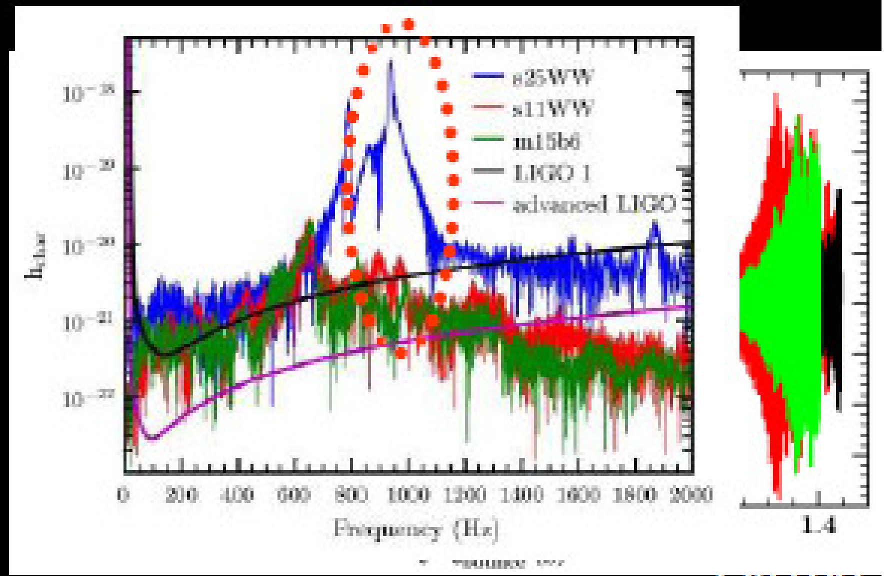
Burrows+06

- ✓ The GW signals in the neutrino-driven mechanism are so different from the acoustic mechanism.
- ✓ An important clue to the explosion mechanism.

GW spectrum



KK+09.



Liu, Yuk Tung (University of Illinois at Urbana-Champaign):
"NS-NS and BH-NS merger simulations"

- Lecture 1: Formalism and Numerical Method
- Lecture 2: NS-NS Simulations
- Lecture 3: BH-NS Simulations

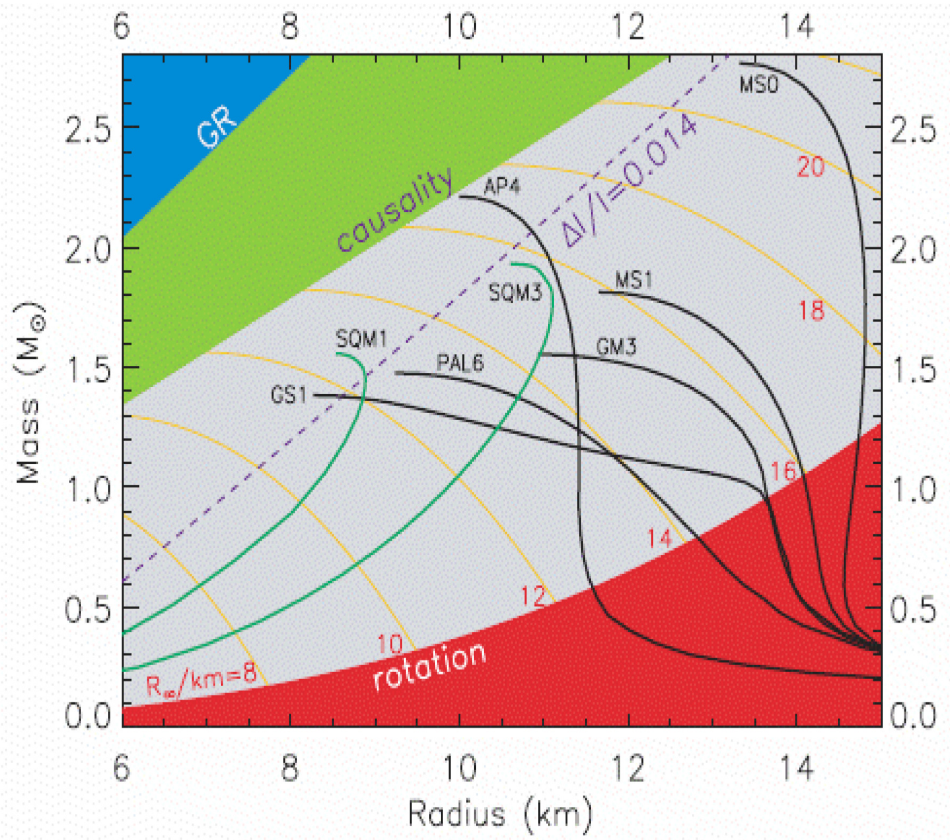
・高密度状態方程式 (EoS) ⇒ NSの質量と半径が独立に決まればわかる。

・NS/NS連星やNS/BH連星

Inspiral時：質点近似⇒EoSによらない。

Merger時：潮汐破壊⇒EoSによる。

⇒merger時のGW波形からEoSの情報が引き出せる!



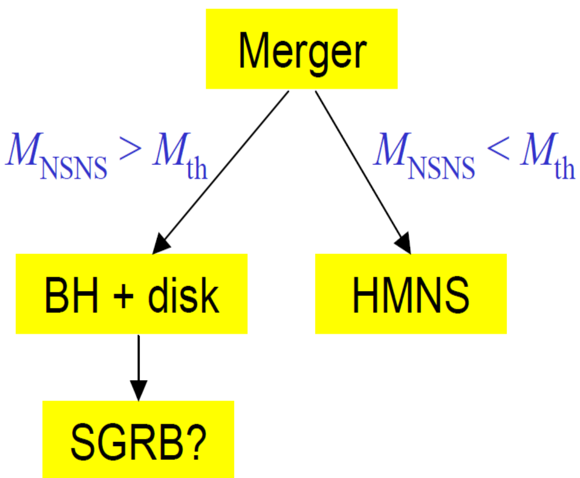
Lattimer & Prakash, Science **304** (2004) 536

Fates of NSNS Merger

- Two NSs of masses $1.4M_\odot + 1.4M_\odot$ produce a $\approx 2.8M_\odot$ object after merger
- What happens after merger?

- Maximum mass of a nonrotating NS: $M_{\mathrm{TOV}} \approx 1.5$—$2.5M_\odot$ (depending on EOS)
- Supramassive NS: A rigidly rotating NS with $M > M_{\mathrm{TOV}}$
- Maximum mass of supramassive NS: $M_{\mathrm{sup}} \approx 1.2\ M_{\mathrm{TOV}}$
- Hypermassive NS (HMNS): A differentially rotating NS with $M > M_{\mathrm{sup}}$

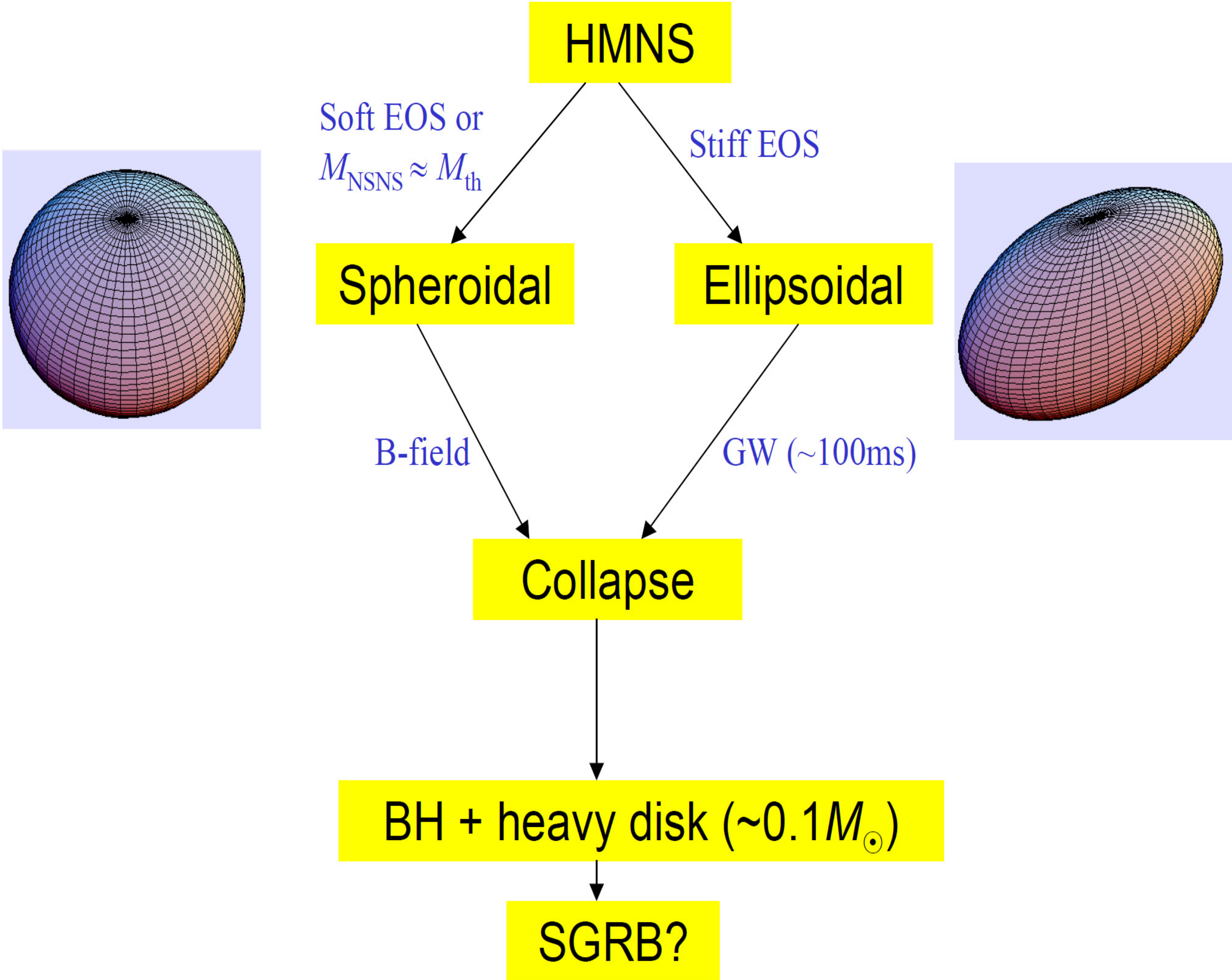
GR simulations:



$M_{\mathrm{th}} \approx 1.7\ M_{\mathrm{TOV}}$ for $\Gamma=2$ EOS
(Shibata & Taniguchi, PRD **68** (2003) 084020)

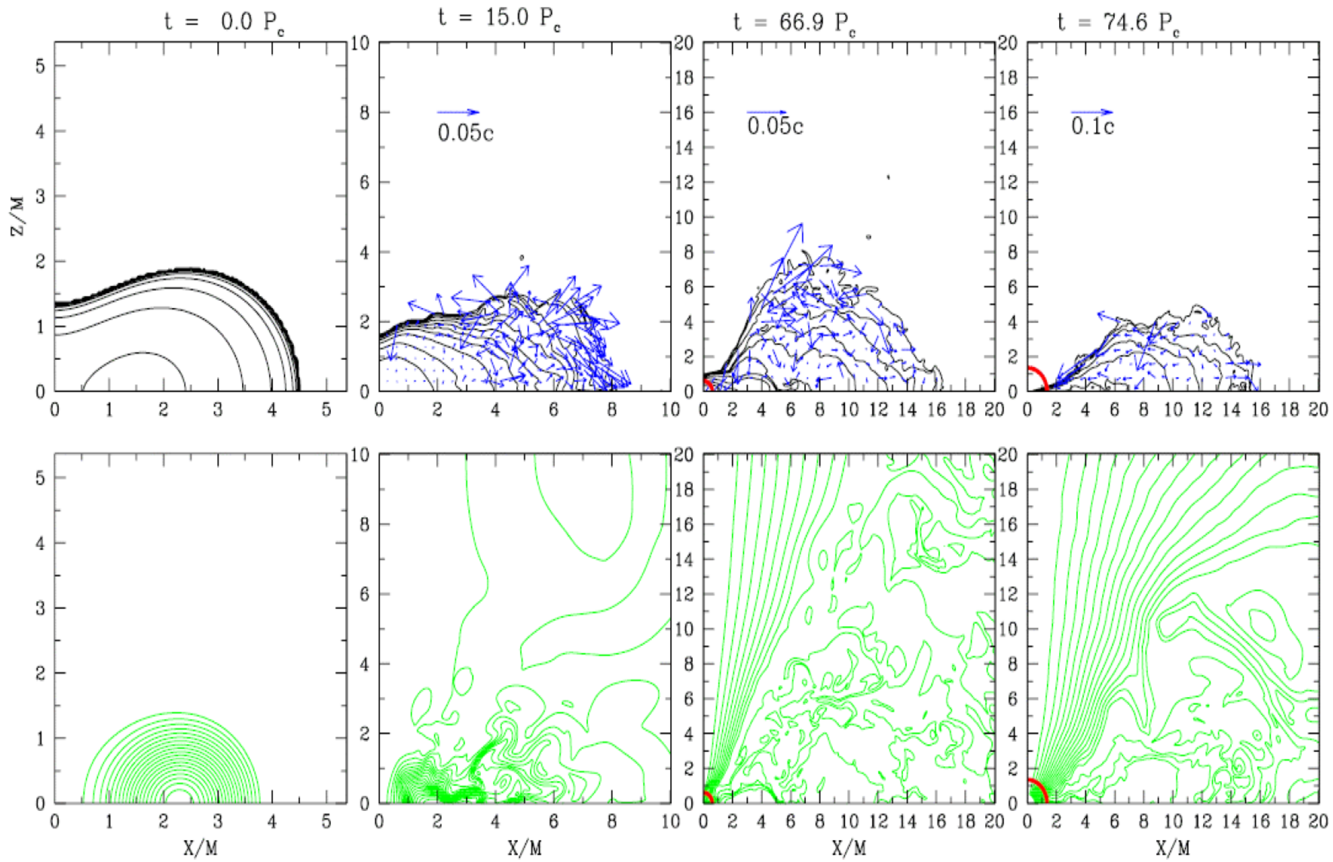
$M_{\mathrm{th}} \approx 1.3$—$1.35\ M_{\mathrm{TOV}}$ for stiff EOSs such as FPS, SLY, and APR EOSs
(Shibata & Taniguchi, PRD **73** (2006) 064027; Kiuchi, Sekiguchi, Shibata & Taniguchi, PRD **80** (2009) 064037)

Hypermassive Remnants



Evolution of Magnetized Hypermassive NS

Duez, Liu, Shapiro, Shibata, Stephens, PRD **73** (2006) 104015



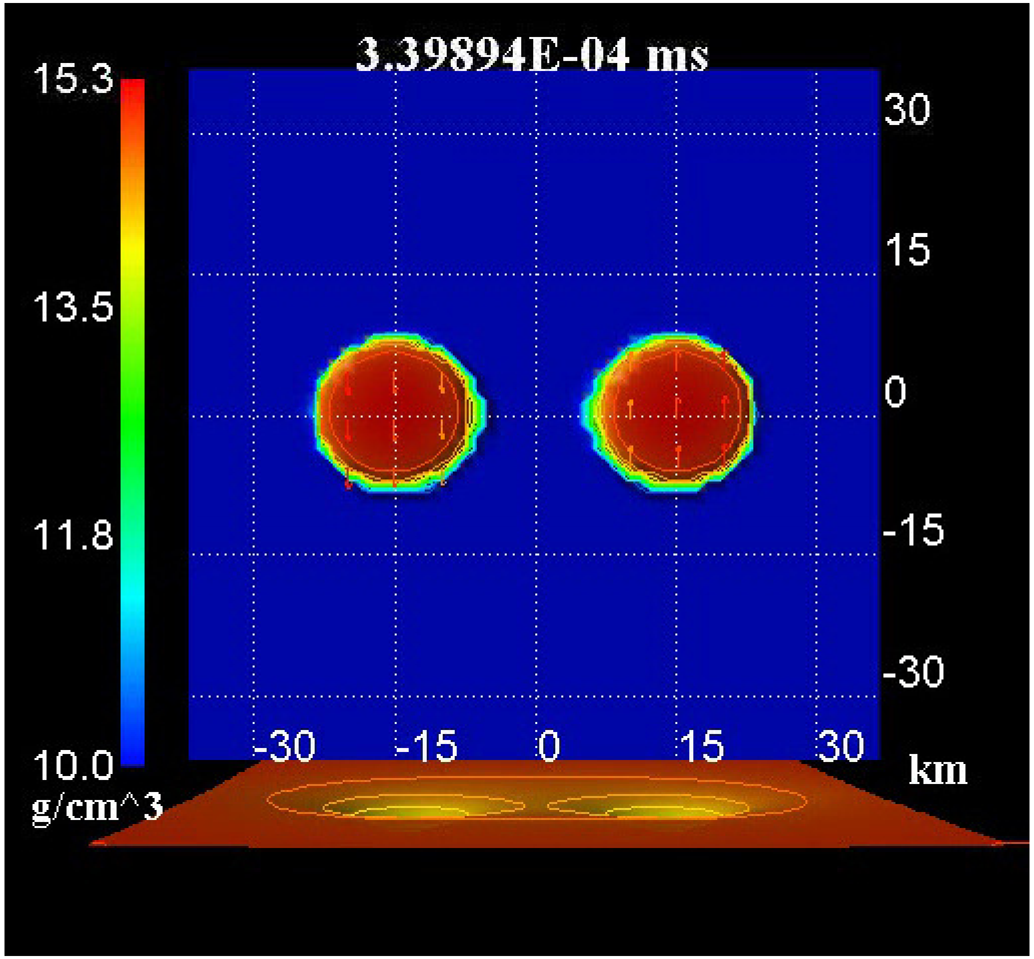
ρ contours & velocity field

B-field lines

Red lines: BH's apparent horizon

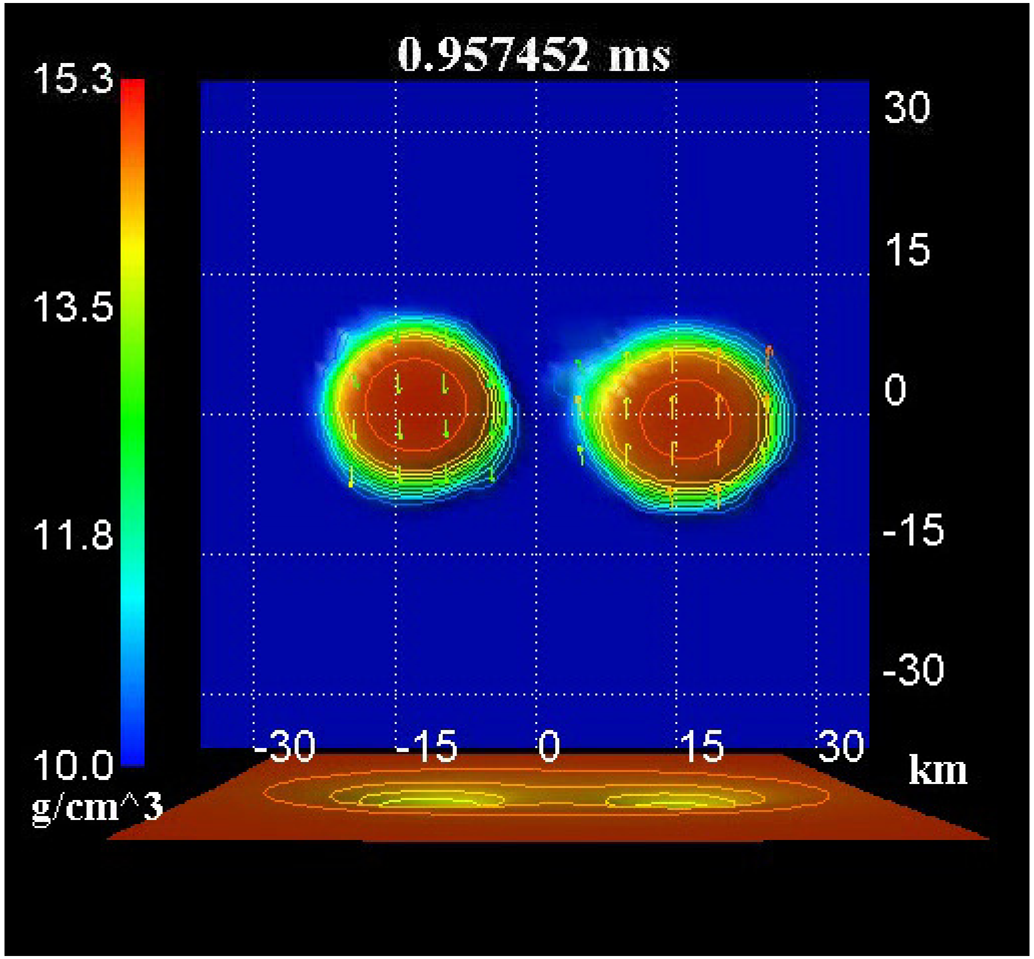
Hot disk + rot BH + collimated B-field ⇒ SGRB engine?

(1.4+1.4) M⊙

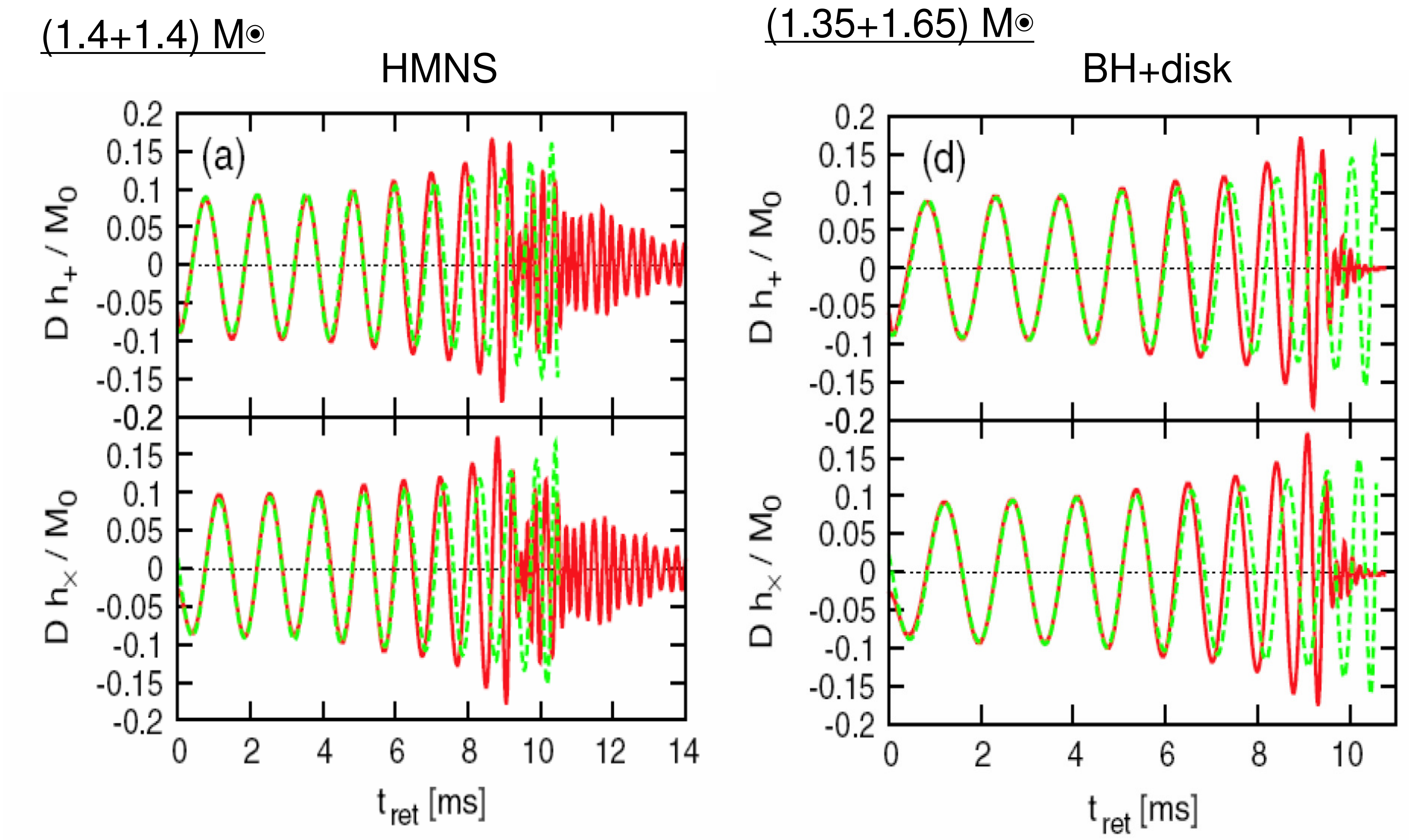


柴田さんのHPより

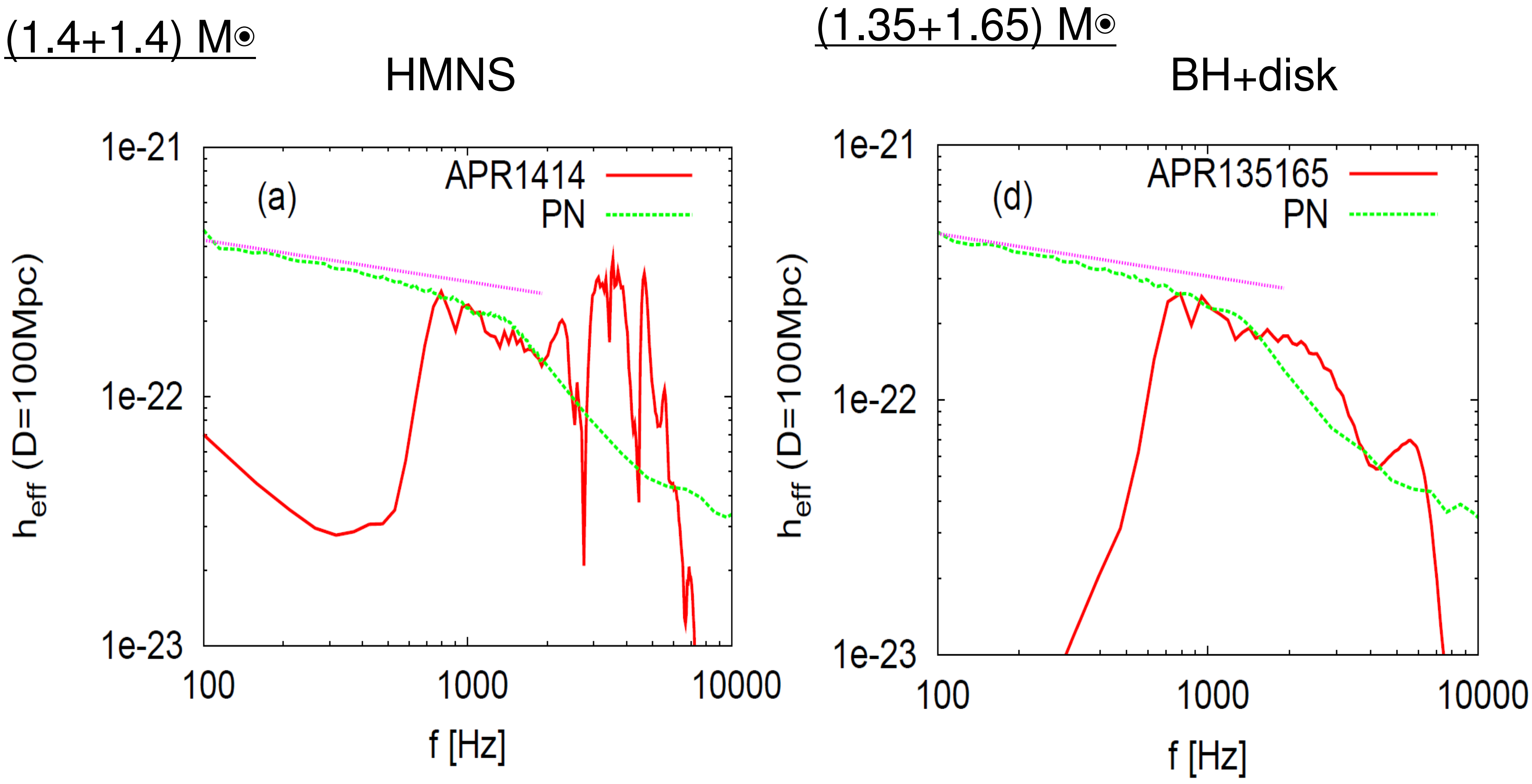
(1.35+1.65) M⊙



柴田さんのHPより

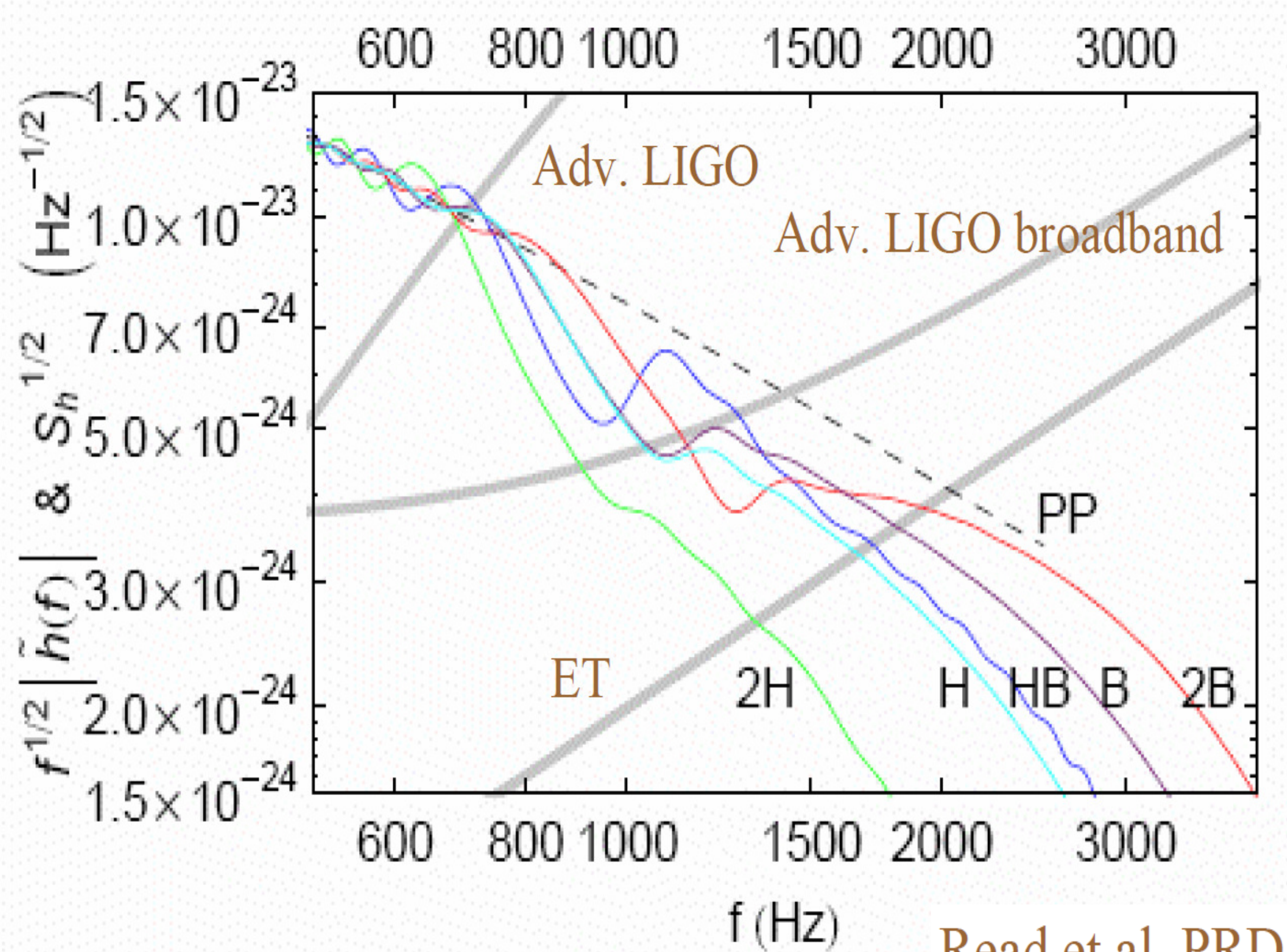


Kiuchi, Sekiguchi, Shibata & Taniguchi, PRD **80** (2009) 064037



Kiuchi, Sekiguchi, Shibata & Taniguchi, PRD **80** (2009) 064037

観測可能性



$D = 100\mathrm{Mpc}$

Read et al, PRD **79** (2009) 124033

Correlation between GW signals and Disk Mass

Kiuchi, Sekiguchi, Shibata & Taniguchi, PRL **104** (2010) 141101

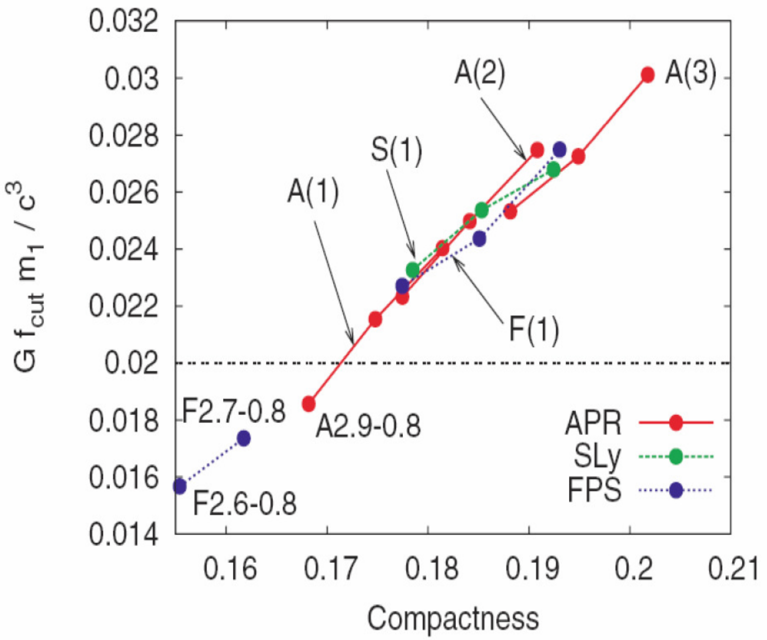
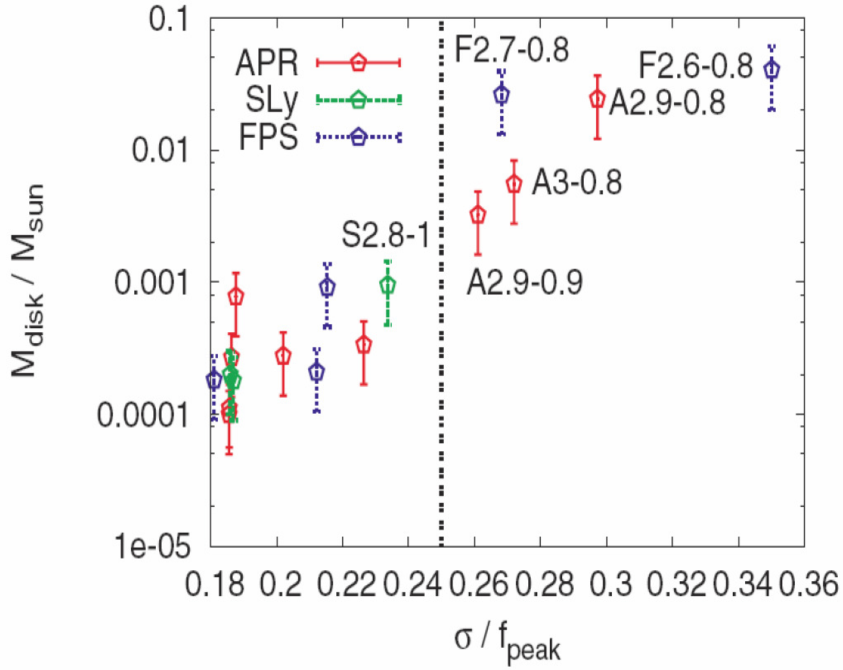
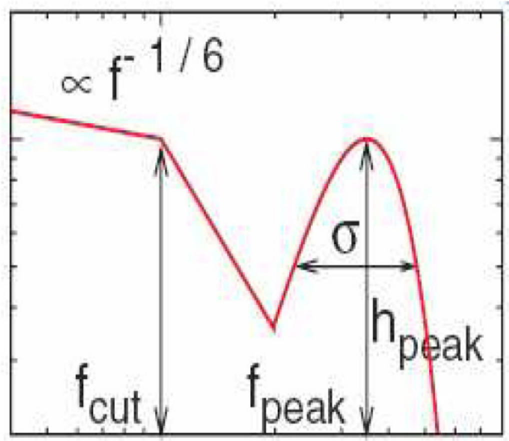


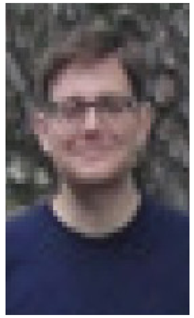
FIG. 3 (color online). $Gf_{\rm cut}m_1/c^3$ as a function of compactness of a less massive binary component for all the models. Sequence A(1) represents the models A2.9-0.8, A3-0.8, and A3.1-0.8 from left to right. In a similar way, A(2) is a sequence of A2.9-0.9, A3-0.9, and A3.1-0.9, A(3) is A2.9-1, A3-1, and A3.1-1, S(1) is S2.8-1, S2.9-1, and S3-1, and F(1) is F2.6-1, F2.7-1, and F2.8-1. The models below the horizontal line of $Gf_{\rm cut}m_1/c^3 = 0.02$ can produce disks of mass $\geq 0.01 M_\odot$.

$$\text{Compaction} = \frac{Gm_1}{R_1 c^2}$$





Price, Larry (U. of Wisconsin-Milwaukee): "Introduction to Gravitational Wave Data Analysis"



- Lecture 1: Brief introduction to the instrument and what it measures. Introduction to time series analysis.
- Lecture 2: Frequentist vs. Bayesian. Bayes's Theorem. Decision Rules. The likelihood function.
- Lecture 3: Optimal statistics for detecting signals in noise.

Sasaki, Misao
(Yukawa Institute for Theoretical Physics):
"Black hole perturbations"

1. Introduction

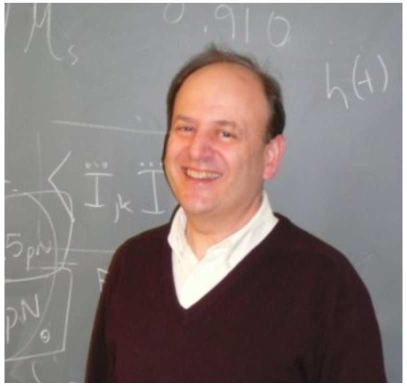
2. Perturbation of Schwarzschild Black Hole

3. Perturbation of Kerr Black Hole

4. MiSaTaQuWa self-force

5. Adiabatic approximation to radiation reaction

<u>Saulson, Peter R.</u> (Syracuse University): “Introduction to Gravitational Wave Detection and the LIGO Detector”



- What is a gravitational wave?
  How do gravitational waves interact with test masses?
- How can we make a gravitational wave visible with an interferometer?
- How to calculate interferometer response to a gravitational wave

1. Multi-pass arms: Fabry-Perot cavities
2. Other enhancements to interferometer optics
   - Power recycling
3. A look at LIGO, Virgo, and GEO
4. A look ahead to advanced interferometers
   - aLIGO
   - Advanced Virgo
   - Congratulations to LCGT!

- Measurement noise vs. displacement noise
- Shot noise
- Radiation pressure noise and the quantum limit
- Thermal noise
- Seismic noise

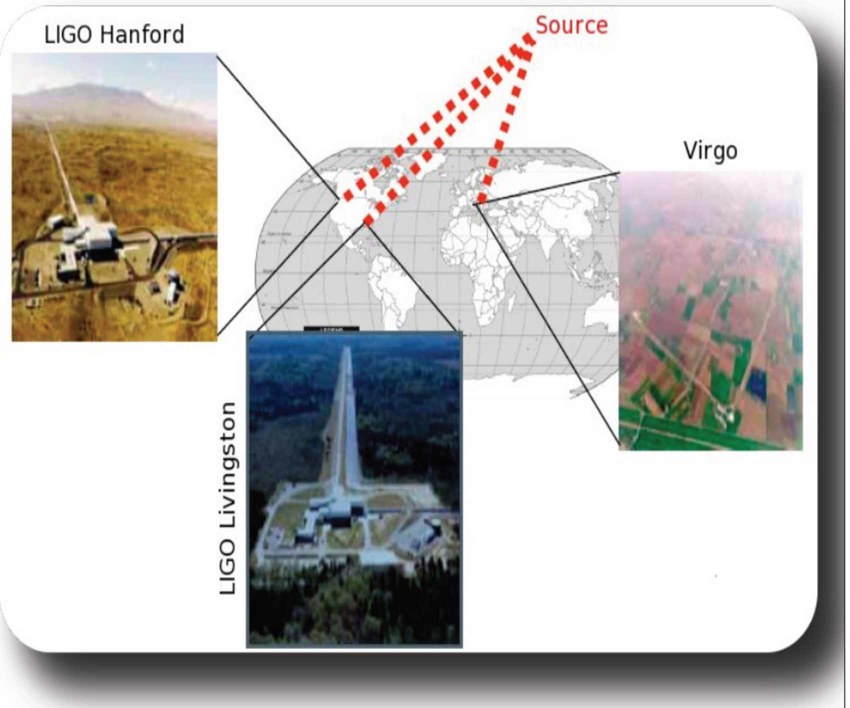
Vaulin, Ruslan
(U. of Wisconsin-Milwaukee):
"Interpreting the results of gravitational-wave search: from detection to astrophysics"

- Sources of transient gravitational-wave signals.
- Generic search.
- Working example: search for CBC in S5/VSR1 data paper.
  - Introduction and Data Quality
  - Pipeline: tuning and detection statistic
  - Results: detection candidates
  - Interpretation: upper limits on rates of CBC
  - Appendix: blind injection challenge
- Summary

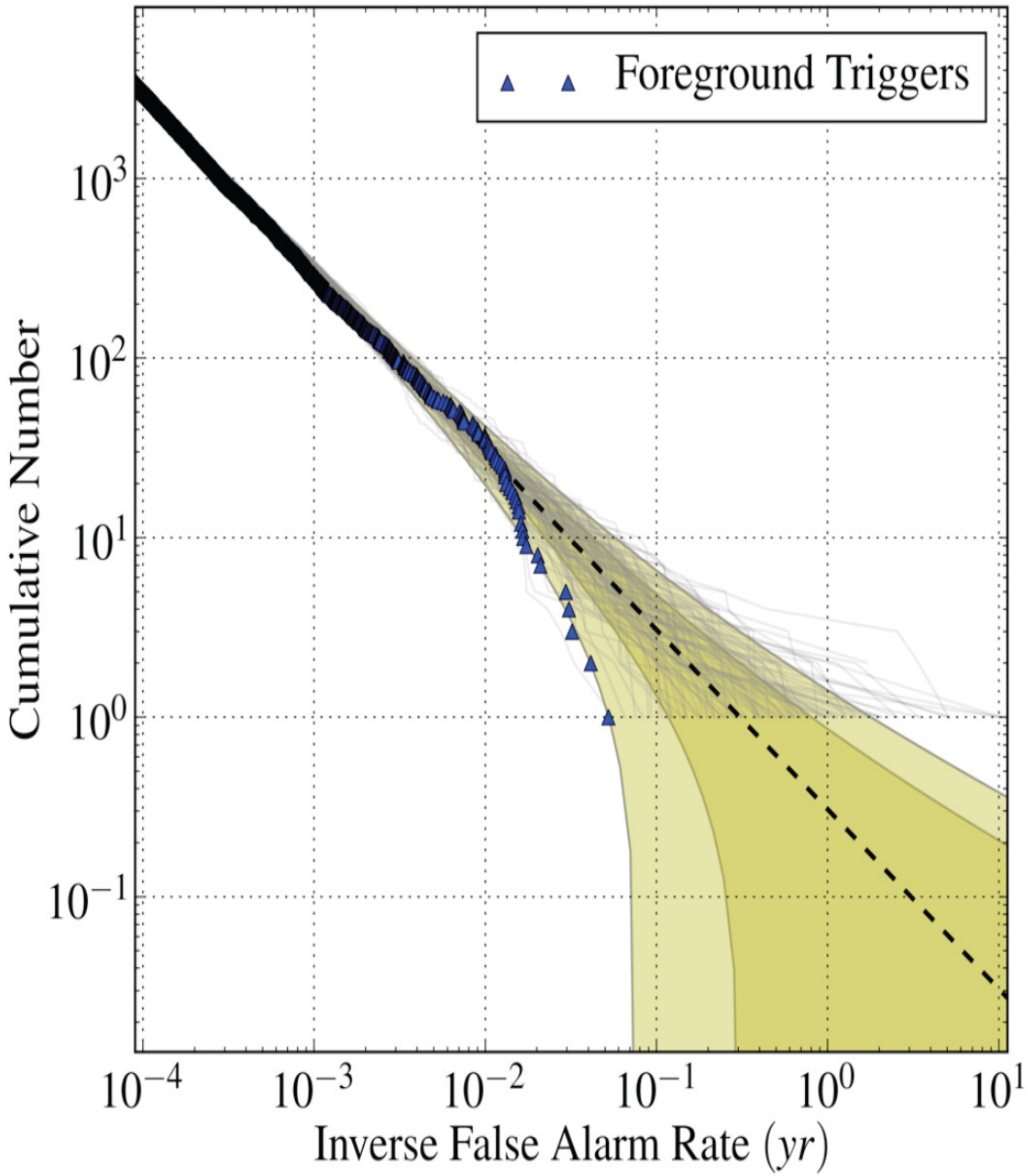
S5/VSR1 low mass CBC search

arXiv:1005.4655

- Network: H1, H2, L1, V1
  - Hanford, Washington, USA: H1, H2
  - Livingston, Louisiana, USA: L1
  - Cascina, Italy: V1
- S5: November 2005 – October 2007
- VSR1: May 2007 - October 2007
- Searched last 5 months
- low mass, up 35 M_{sun} CBC



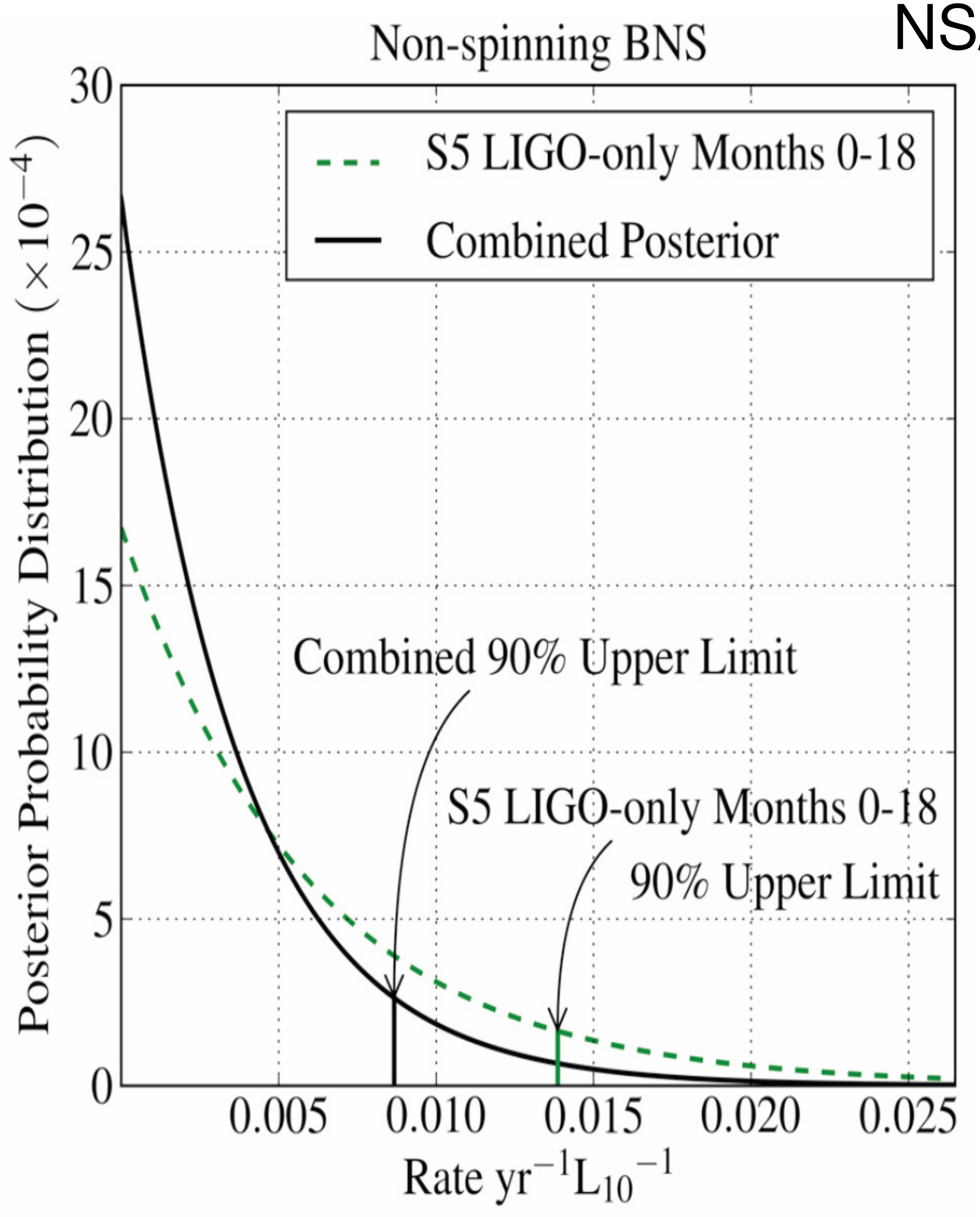
結果



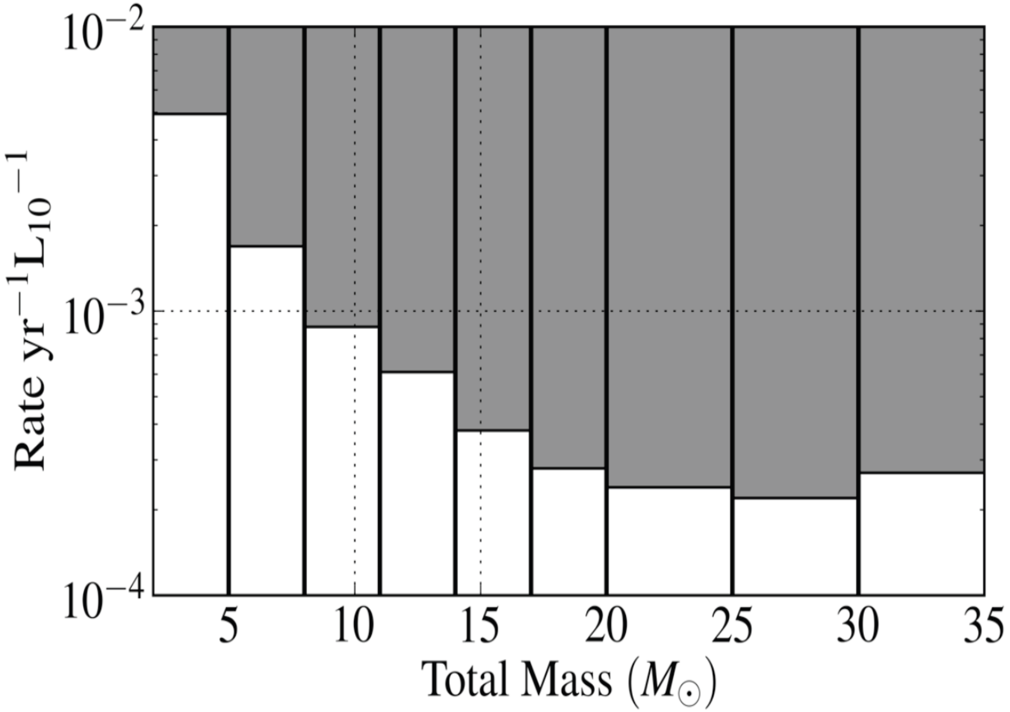
No
detection

Upper limit on the event rate

NS/NS

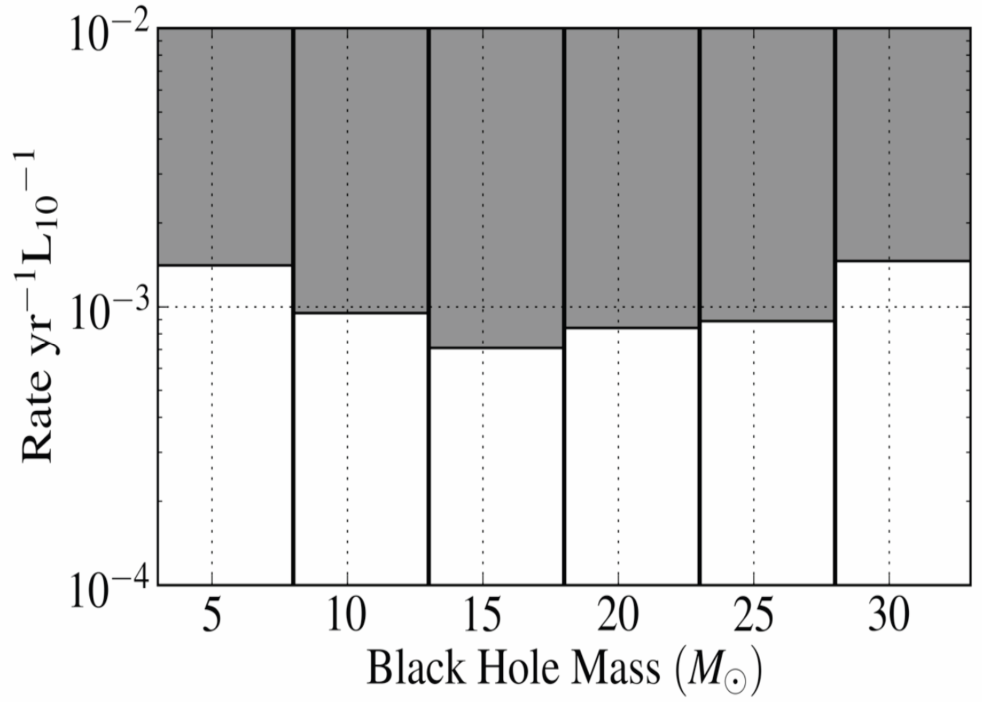


BH/BH



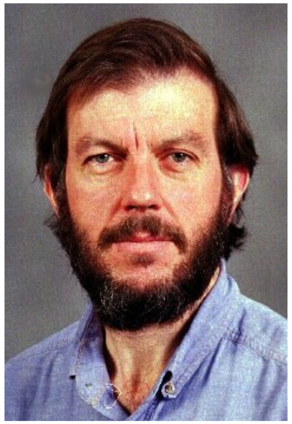
10^{-2}
10^{-3}
10^{-4}
Rate yr^{-1}L$_{10}$$^{-1}$
5
10
15
20
25
30
35
Total Mass ($M_{\odot}$)

BH/NS

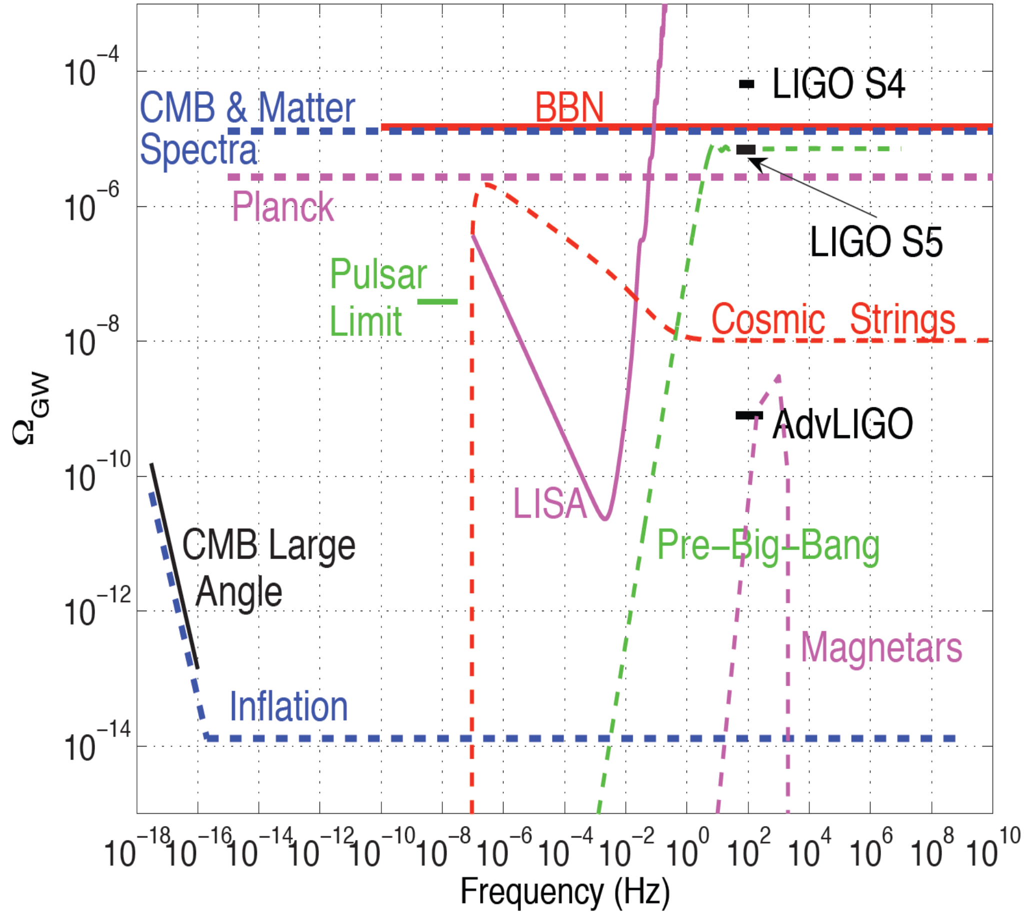


10^{-2}
10^{-3}
10^{-4}
Rate yr^{-1}L$_{10}$$^{-1}$
5
10
15
20
25
30
Black Hole Mass ($M_{\odot}$)

Whiting, Bernard (U. of Florida): "Introduction to stochastic gravitational wave searches"

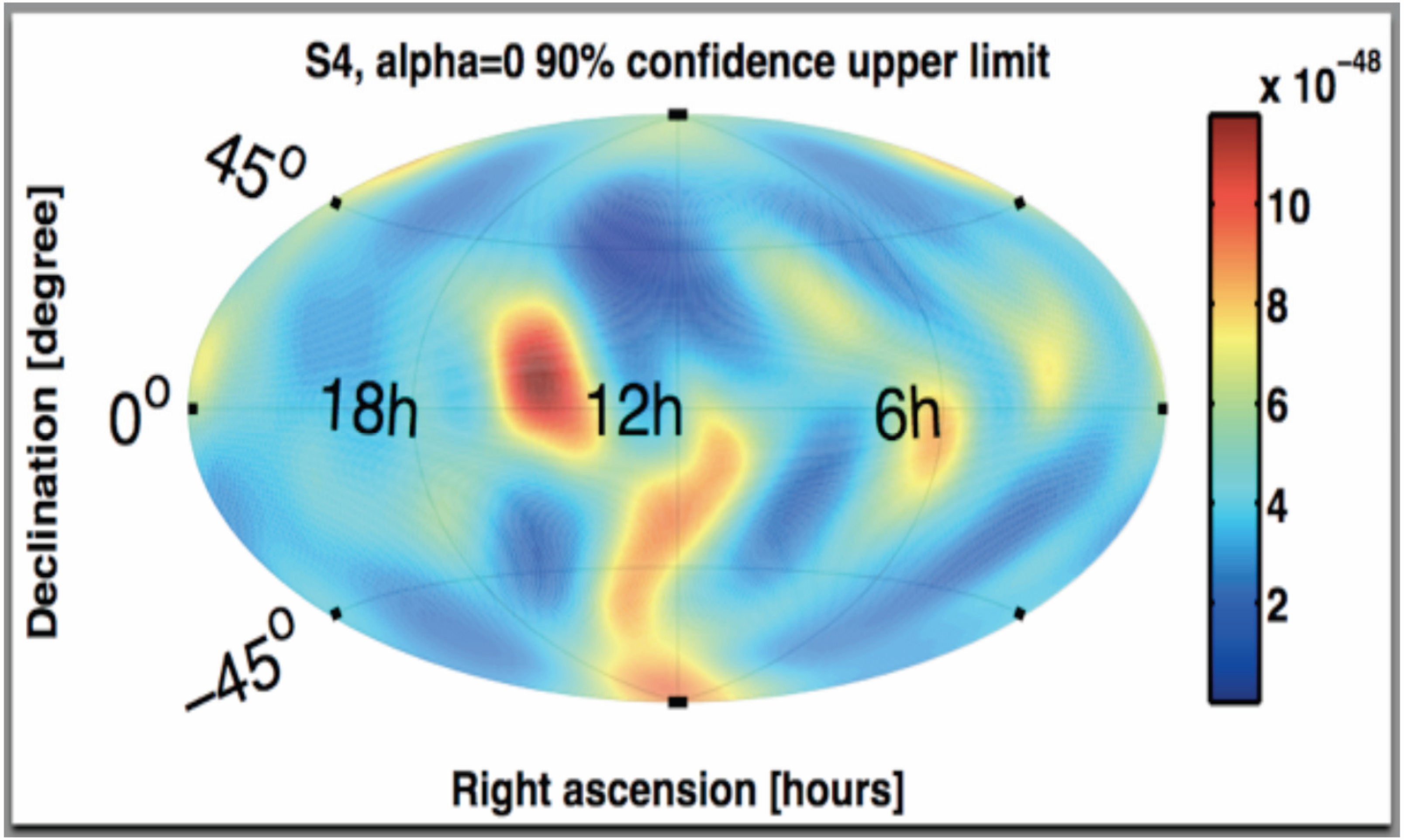


- Isotropic search
- Implications
- BBN bounds
- Probing cosmic strings
- Cosmic string models
- Probing early universe
- Pre-Big Band models
- Conclusion



Nature 460, 990 (2009)

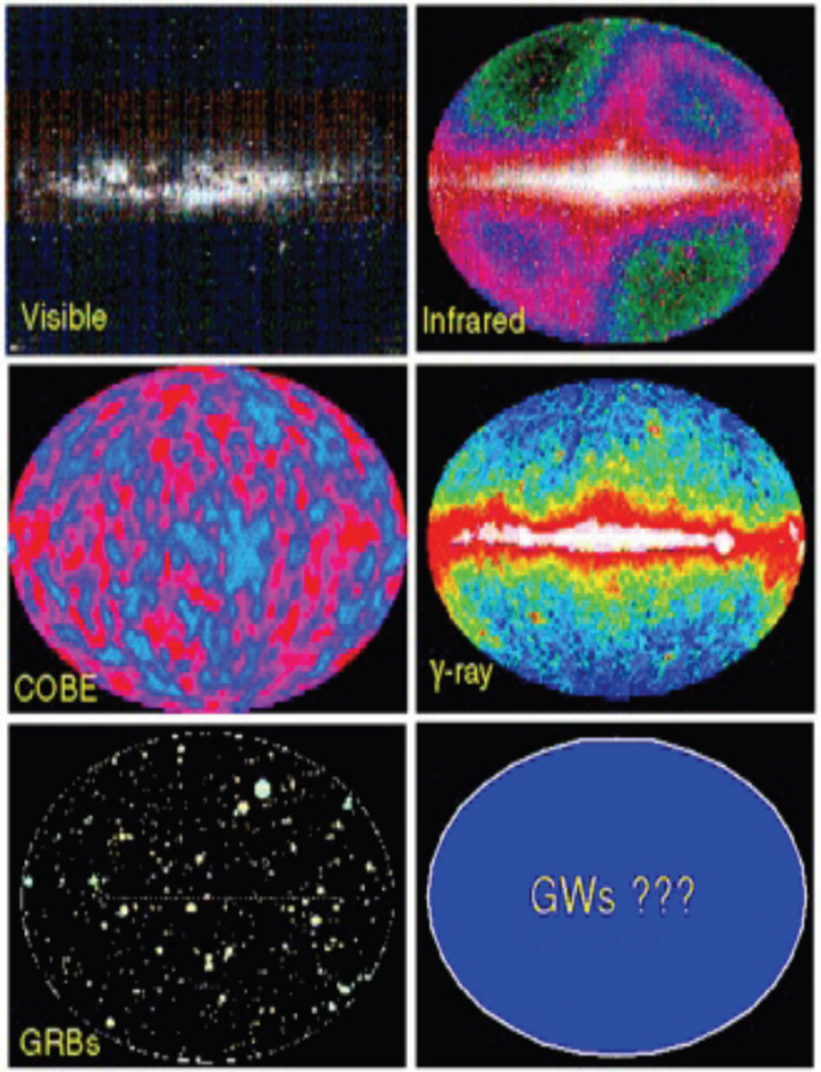
Sky maps (PRD76, 082003,2007)



- First upper limit map on point sources with flat, broadband strain power spectrum

Spherical Harmonics

- Versatile & more efficient than multi-cell analysis
- Can tune analysis depth to quality of data (SNR)
- Up to L=30 appears possible from test data
- Seek plots comparable to those of CMB data, with spatial structure evident



今日はお話する機会を与えていただき、
どうもありがとうございました。

興味がある方は、
来年からぜひ参加してみて下さい。