Multi-Messenger Observation using LCGT

(Case study: LCGT--Super K connection)

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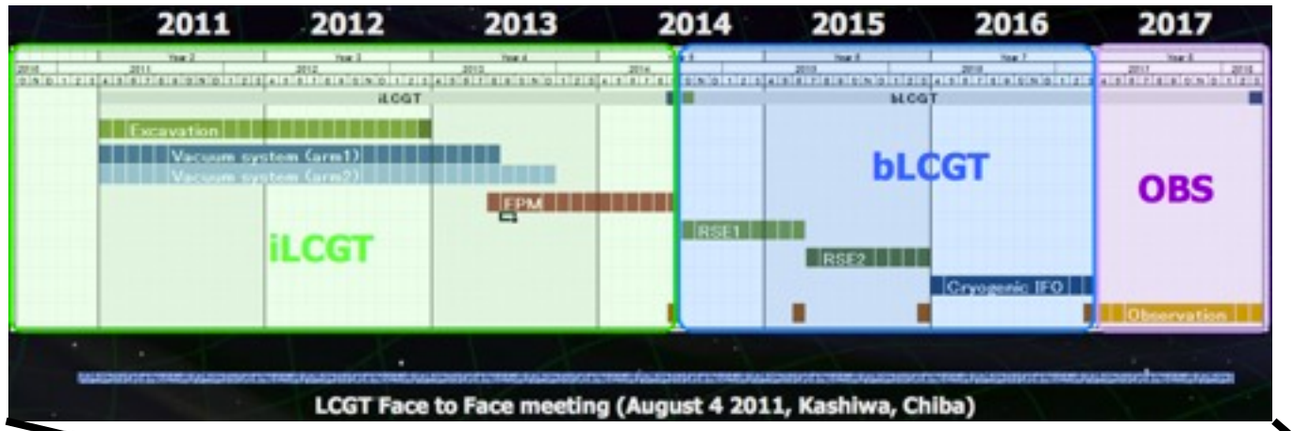
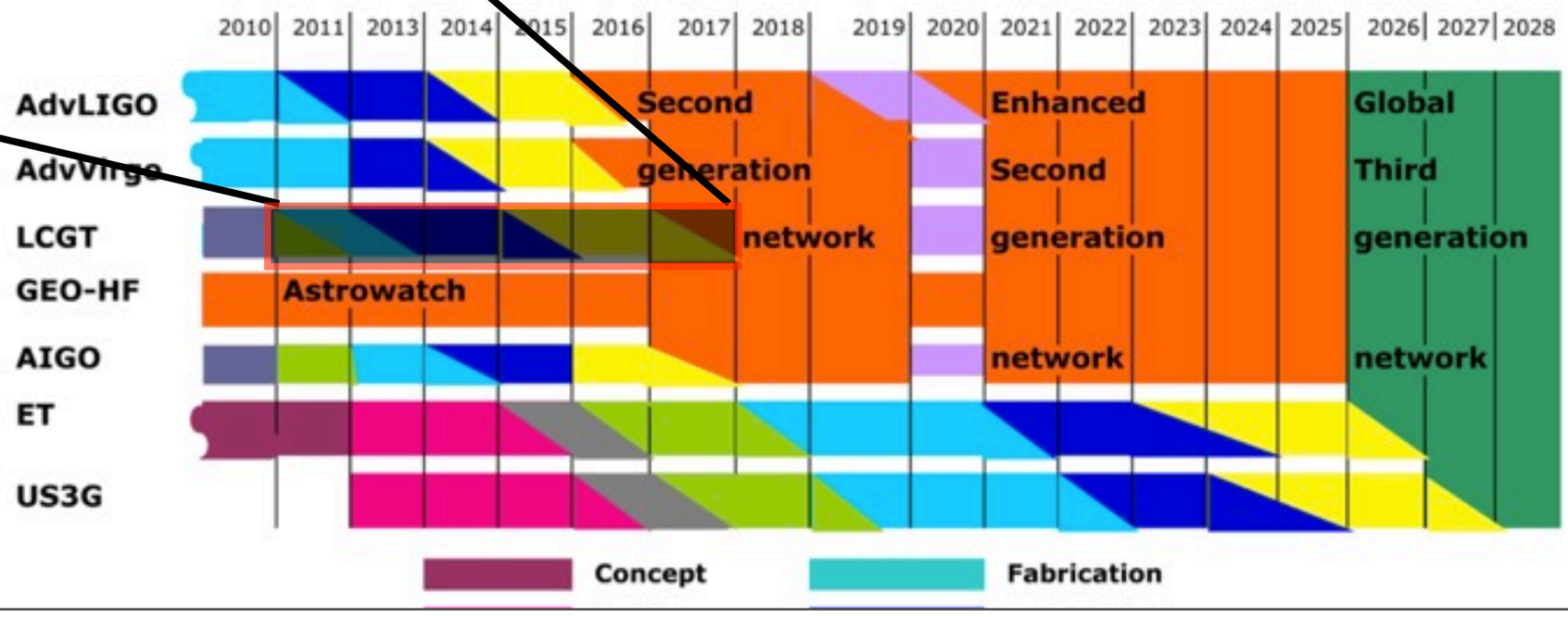
GW Observation using LCGT

- iLCGT : 1 month observation is planned in 2014.
- bLCGT : long duration observation is planned in 2017~
- Both LCGTs will try to make 1st detection of gravitational waves.
- ... Even only LCGT is in operation.



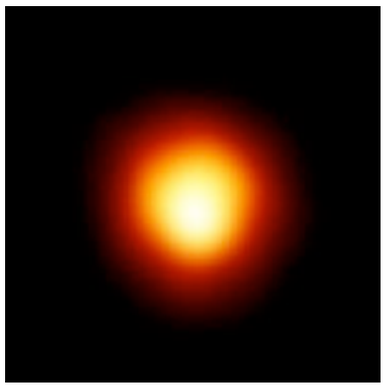
from LCGT Road map

from GWIC Road map

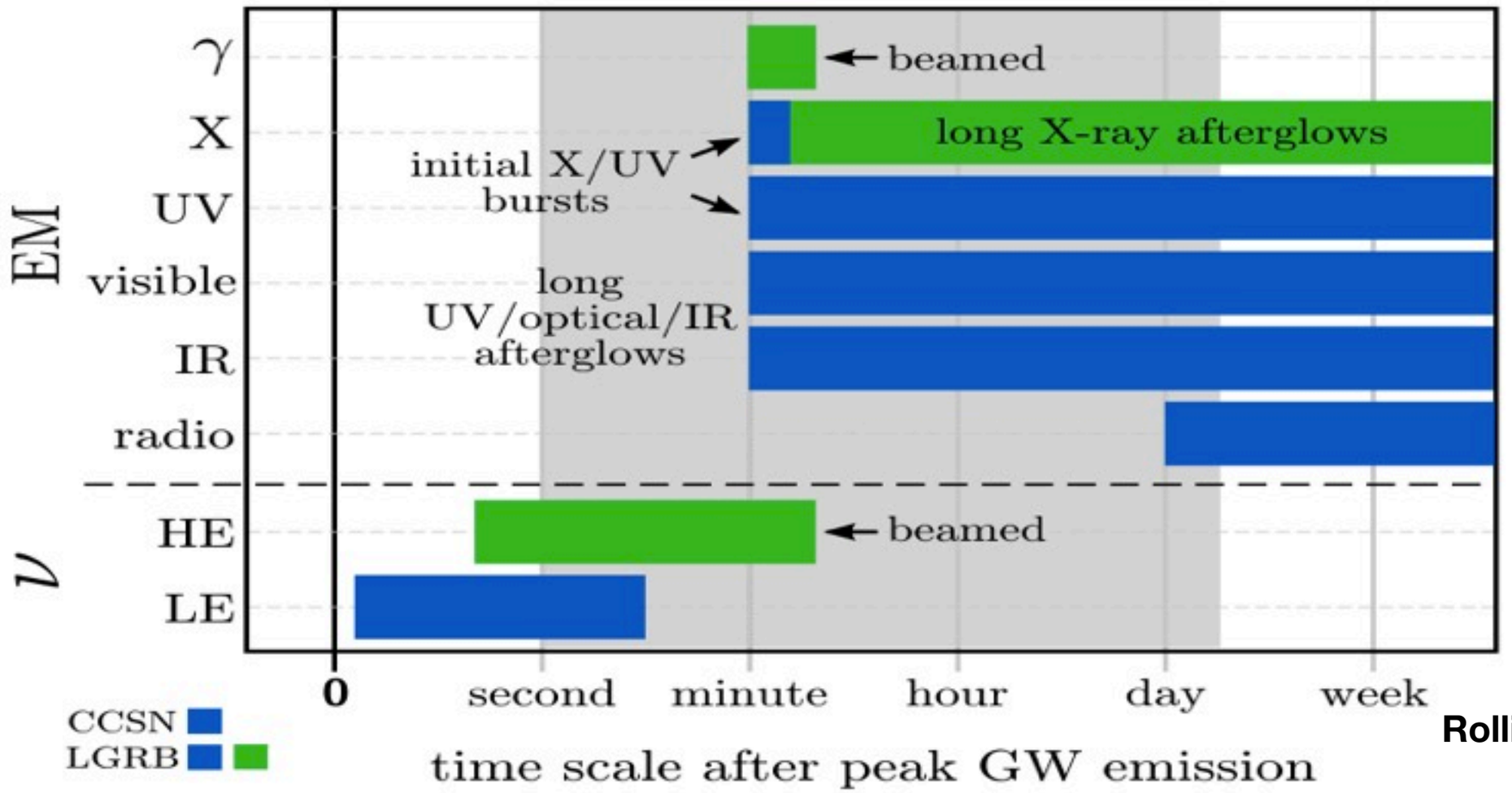


GW Sources : Supernovae

- Core-Collapse SuperNova is one of promising sources.
  - Betelgeuse -- Red supergiant star
    - Distance : 196 pc
    - Mass : 20 $M_\odot$
- Besides GW, neutrino and EM wave will be radiated.
- Both GW and neutrino emission will occur within 20[s] after the core bounce. ~hours later EM emission will occur.



Betelgeuse

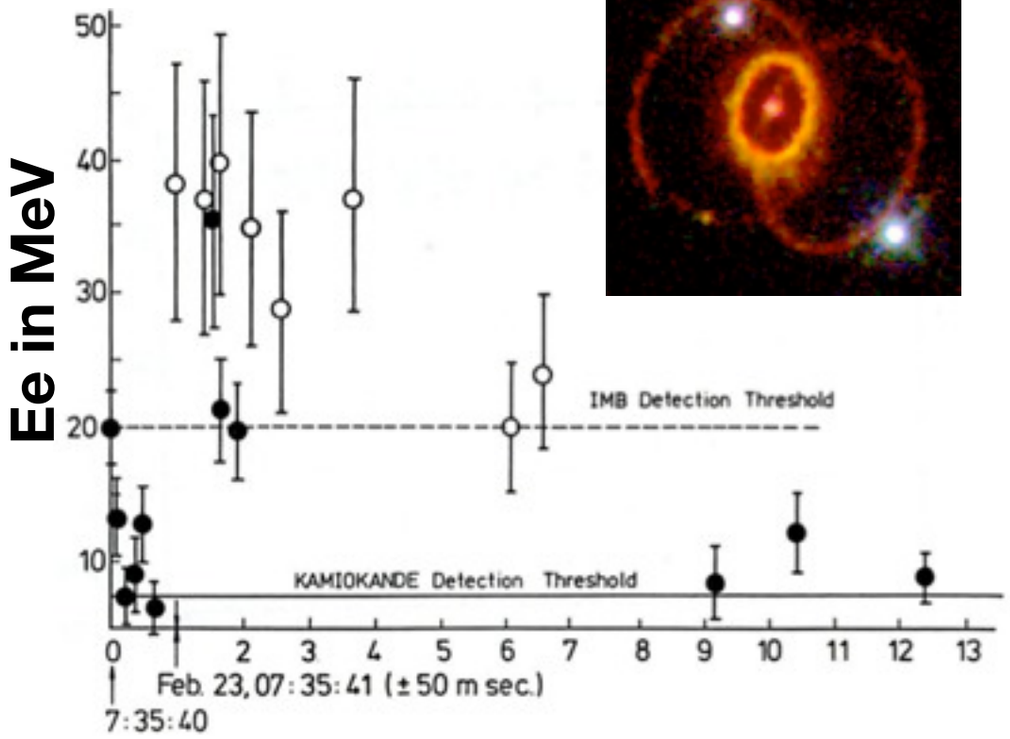


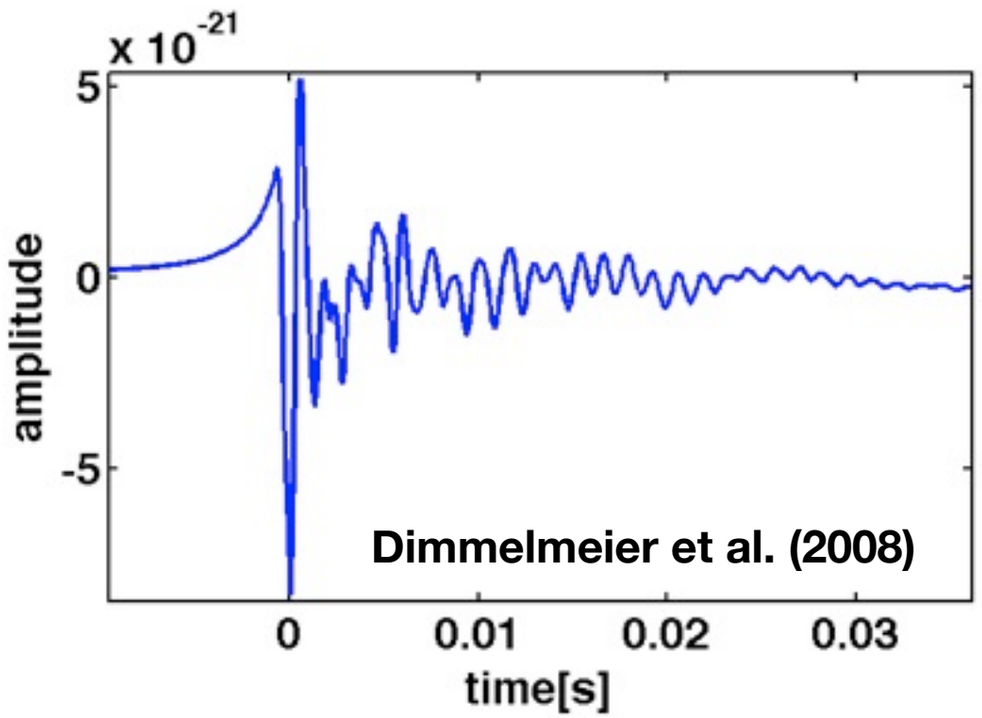
Rollins.J Thesis(2011)

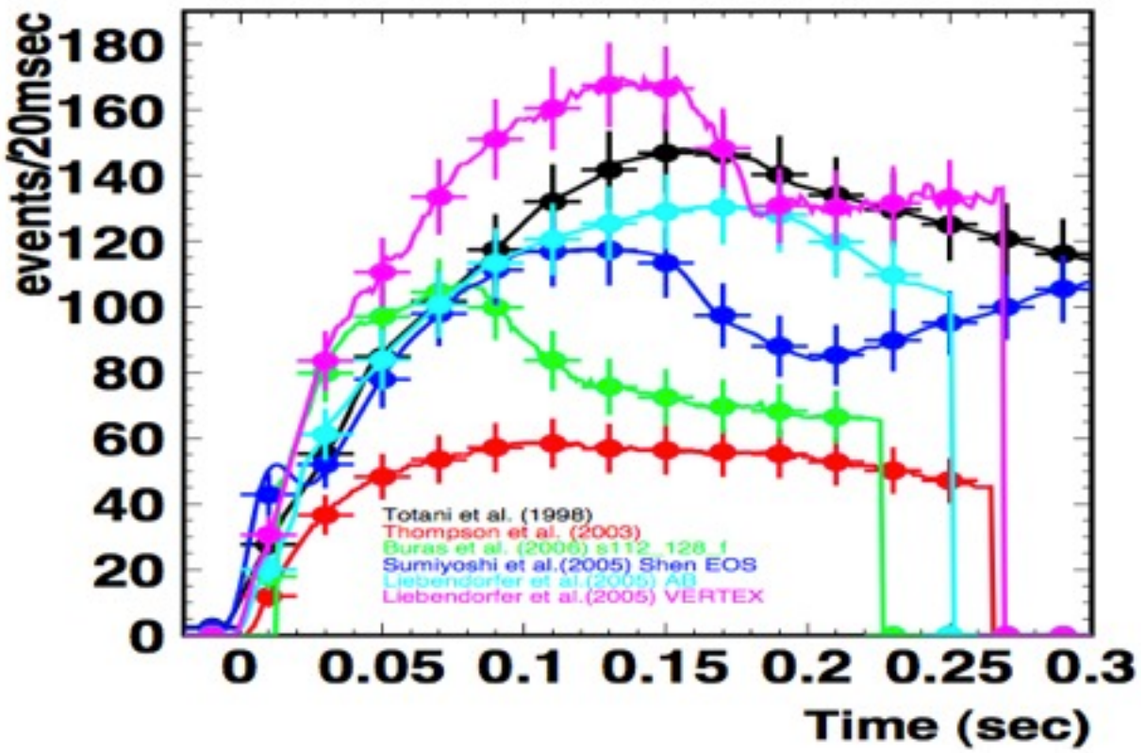
Figure 4-5: Relative arrival time of various emissions from core-collapse supernovae, as a function of time relative to peak gravitational emissions.

GW+Neutrino from Supernova

- In case of SN1987A, ~10-50 MeV neutrinos were detected in < 20[s] time window
- Simulation shows GW is produced at the core bounce and last a few [ms] to 100 [ms].
- Coordinated neutrino and GW search will improve detection.
  - tight time window, reduced FAR







Nakahata (2008)

Coordinated Neutrino + GW Observation

- **SNEWS (SuperNova Early Warning System)**
  - **Send alert within ~minutes**
  - **False alert rate is < 1 per century**
  - **Detection threshold is high**

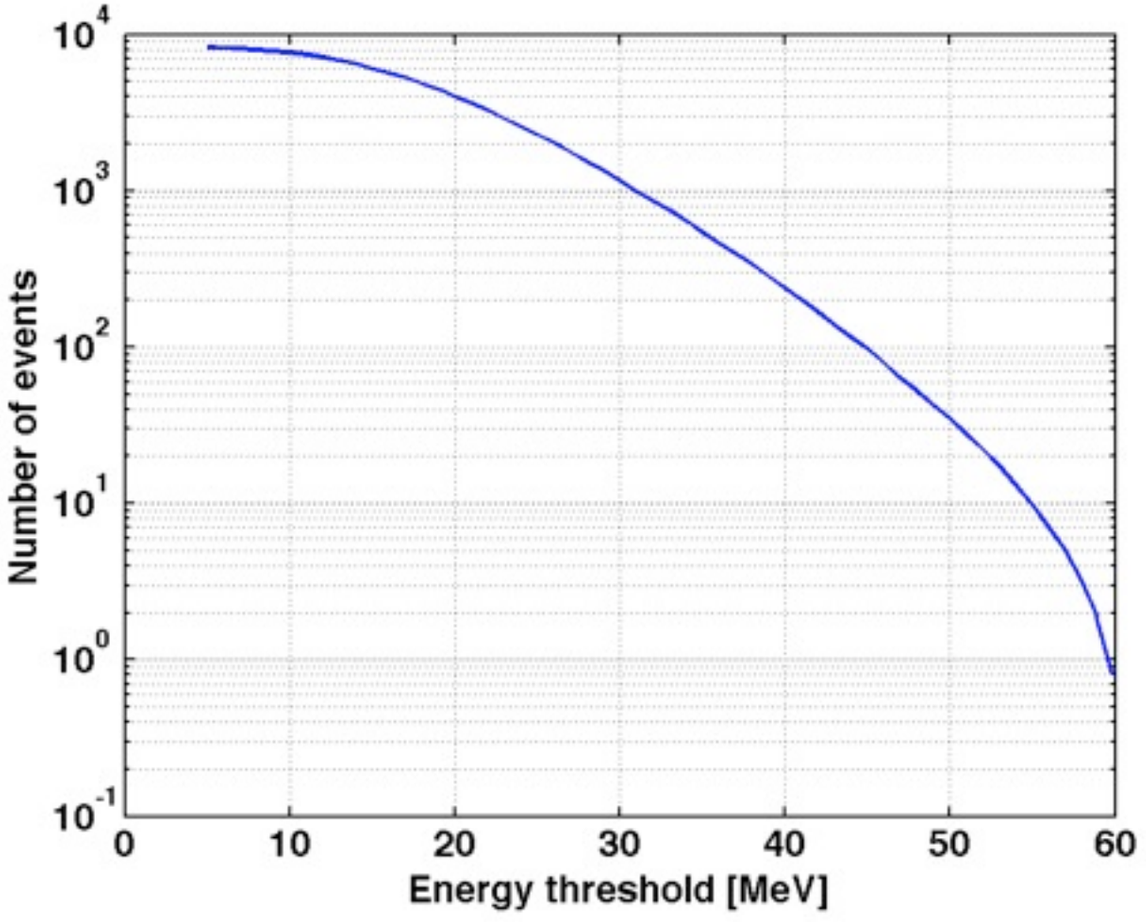
- **Another way is to perform GW-neutrino coincidence analysis. Since coincidence analysis reduces false alarm rate, we can set low threshold for both GW and neutrino search.**

- **From the observation of neutrinos from SN1987A and various simulations, the time window of the coincidence will be at most 20 seconds, which is shorter than GRB triggered search (180[s])**

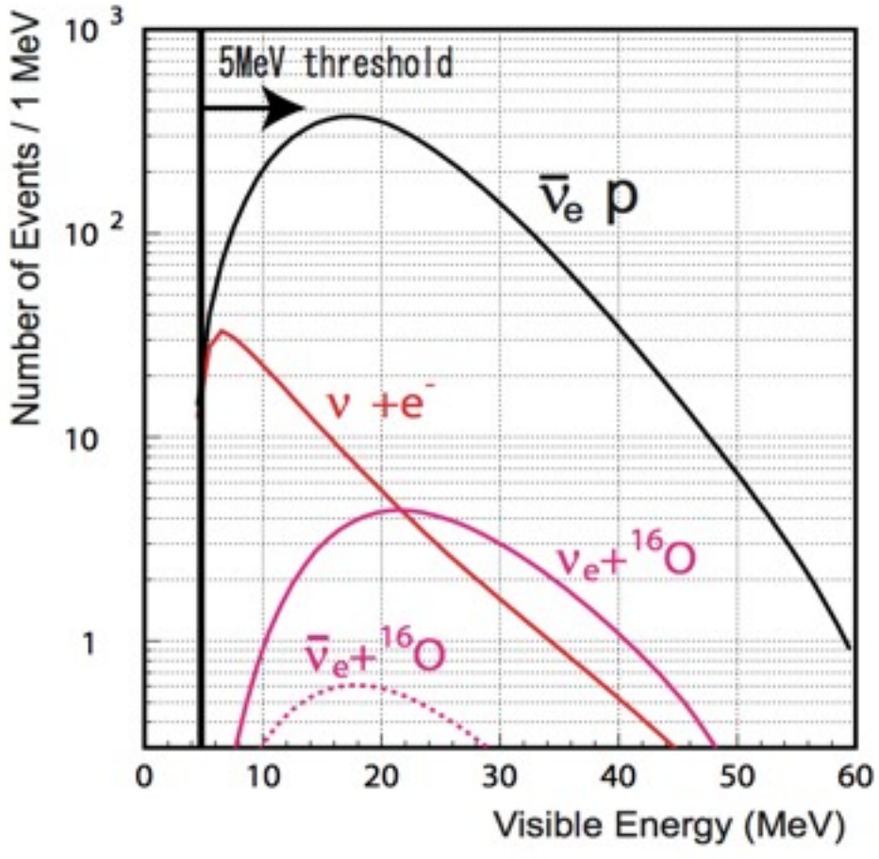
Neutrinos Super-K detecting at 10kpc

- **Taking into account of all neutrino flavor, Super K will detect ~10000 events in 20 [s] when a supernova occurs at 10kpc.**

Number of events from SN at 10kpc above the threshold



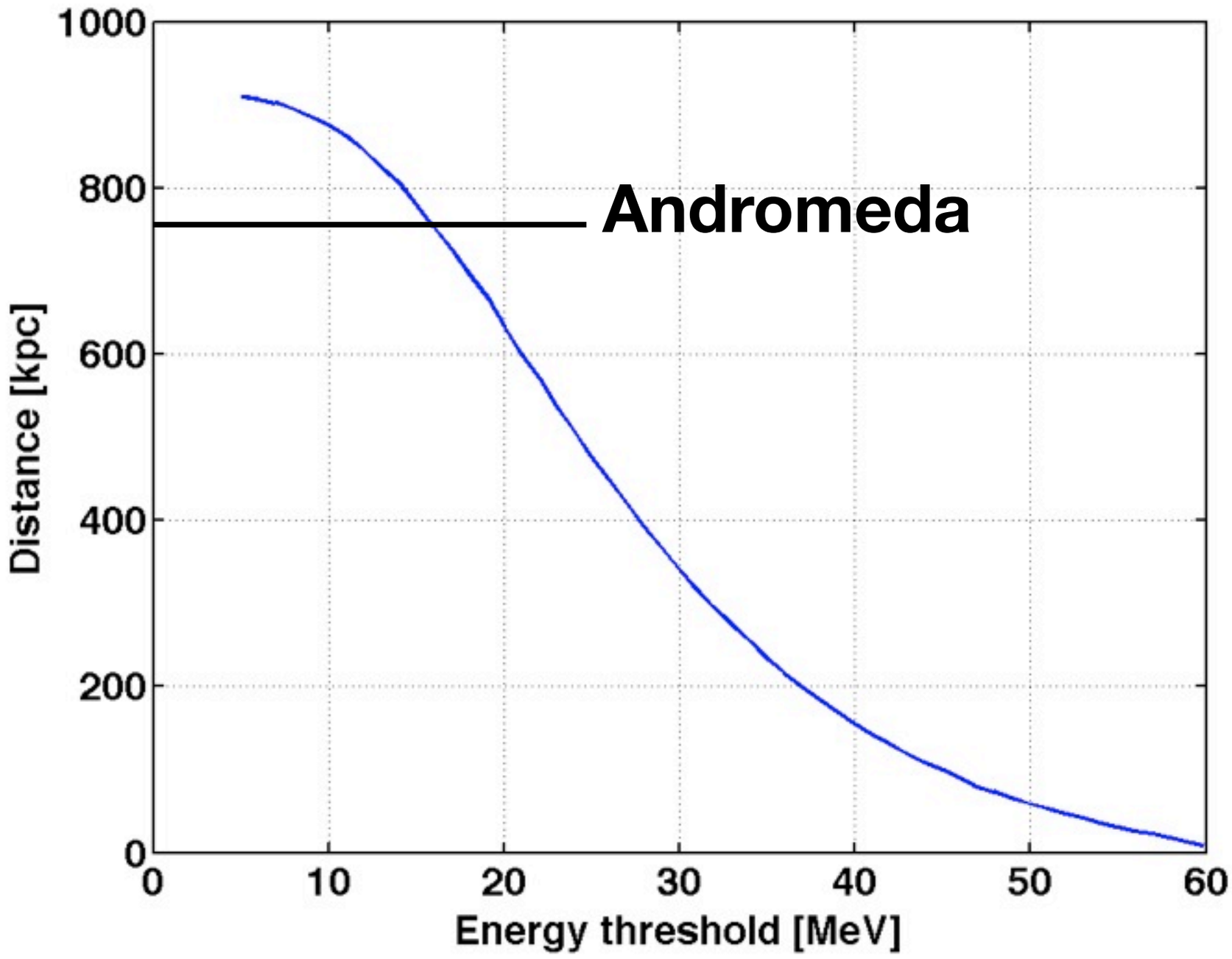
Number of events from SN at 10kpc as energy



Ikeda et al. 2007

Energy threshold vs Distance

- **Distance@neutrino event count=1**

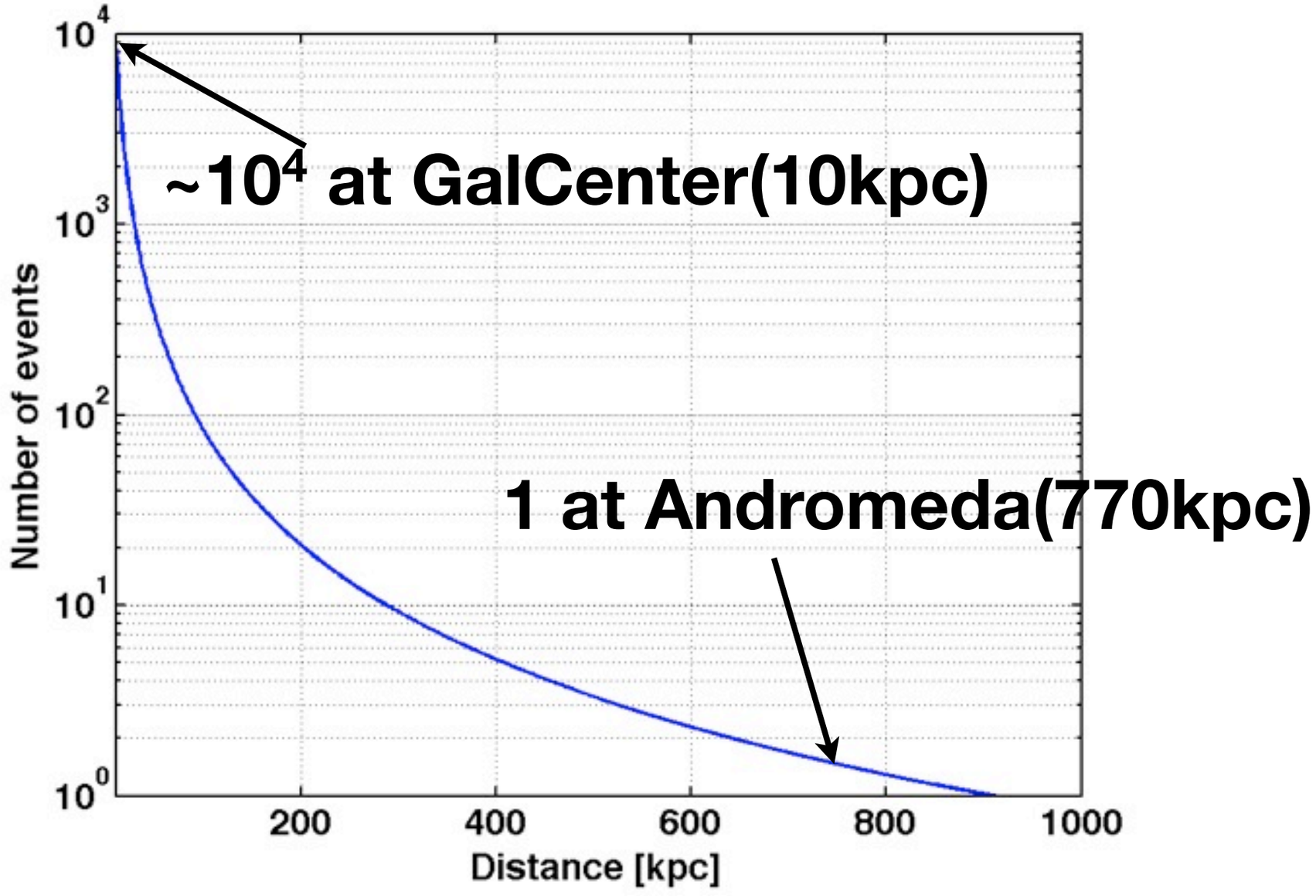


Simulation : SN neutrino search by Super-K

- We estimate the number of neutrino events Super-K will detect by fitting the right plot in the previous page.
- We don't apply any cut (Spallation cut etc.)
- Multiplicity of neutrinos in a given time window is subject to Poisson probability distribution.

Event number Super-K will detect

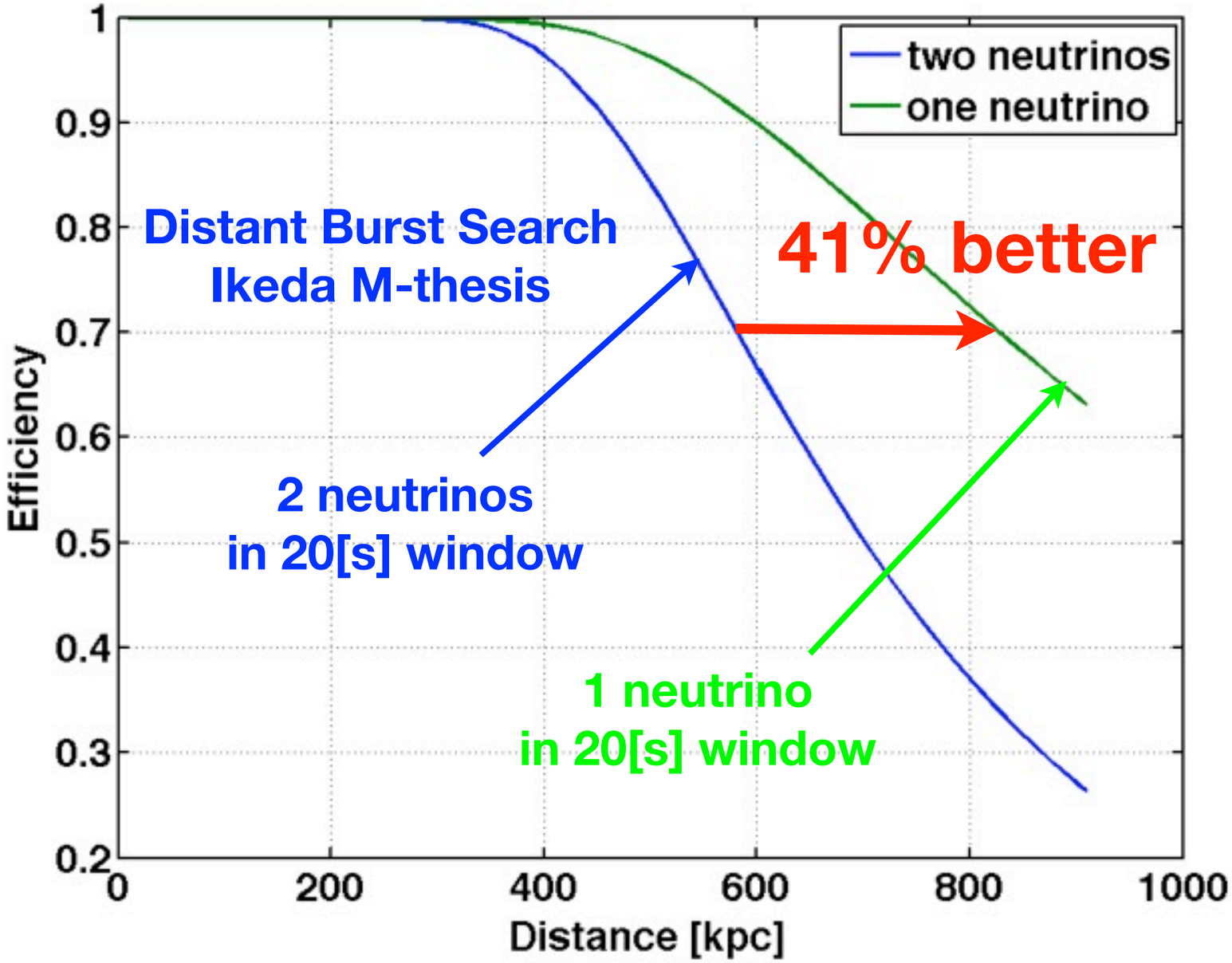
- Number of events as a function of the distance of a supernova.
- Can detect 1 event from a supernova at Andromeda.



Distant Supernova Search using Super-K

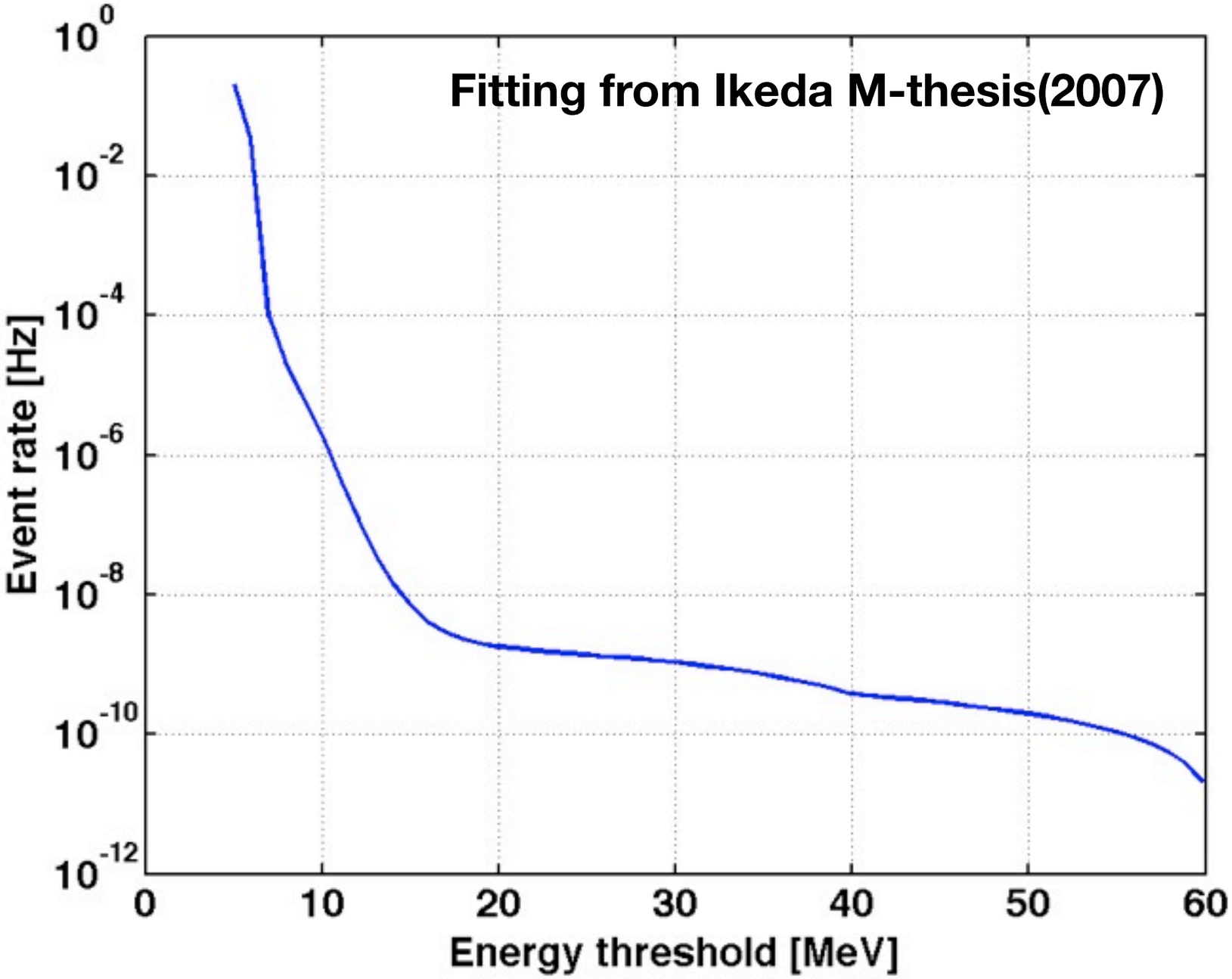
- **Lower threshold extends the detectable distance to supernova.**

$$Eff_2 = 1 - \exp(-N) - N\exp(-N) \qquad Eff_1 = 1 - \exp(-N)$$



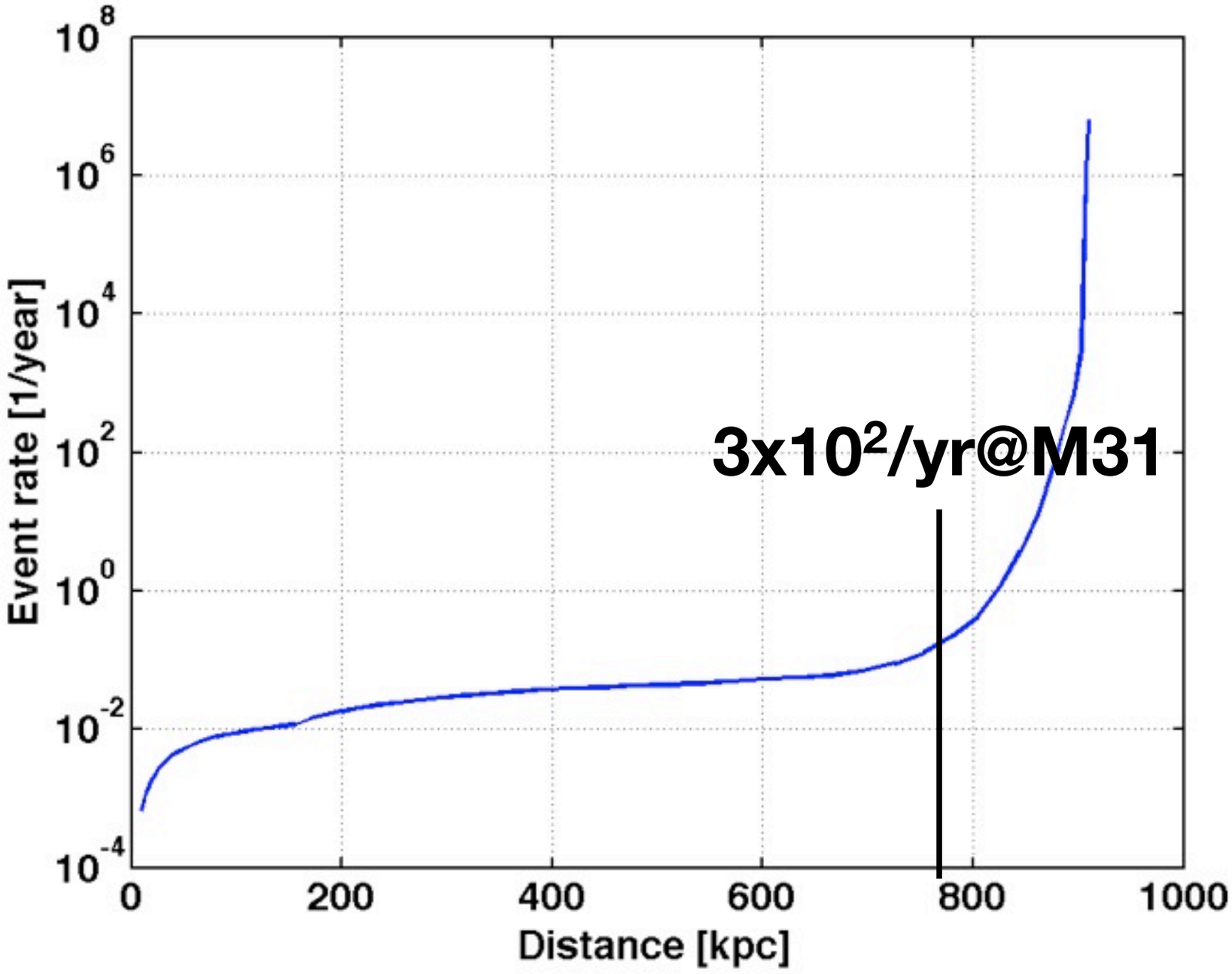
Background Event Rate

- SK background rate depends on a energy threshold.



Background event rate vs Distance

- **Energy threshold-Distance plot & Energy threshold-Event rate plot**



Chance Coincidence Probability

- We consider GW search triggered by neutrino.
- Chance coincidence probability is

$$P \approx N p_v$$

$$p_v = 1 - [1 + (R_v \times t)] \exp(-R_v \times t)$$

$$N = R_{GW} \times T$$

R_v : Event rate of neutrinos per seconds

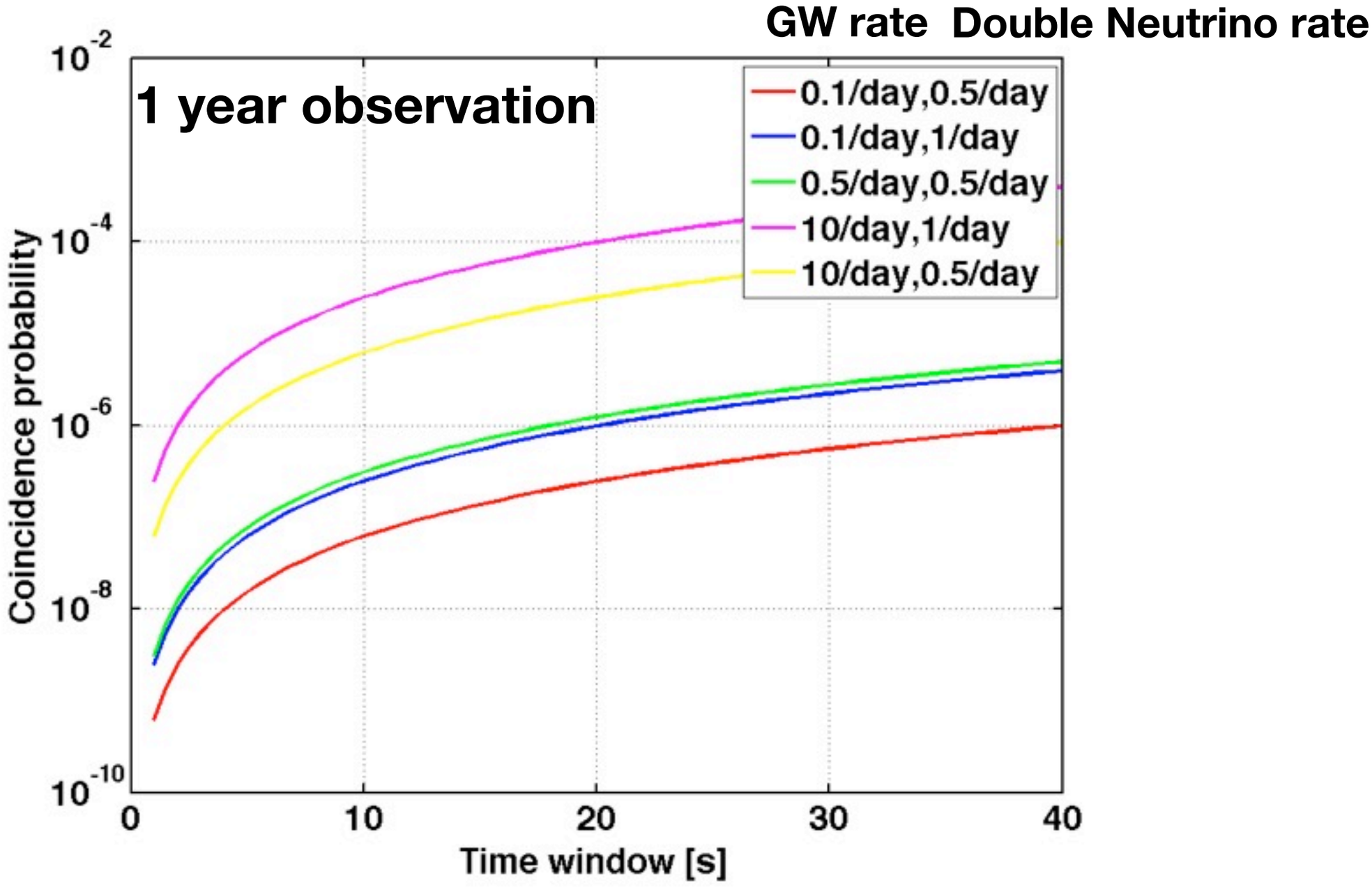
R_{GW} : Event rate of GWs per seconds

T : Total live time

t : coincidence time window

Accidental Coincidence Probability

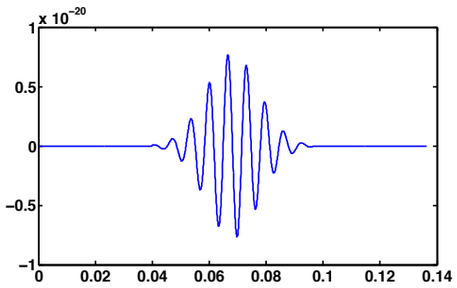
- Taking 20[s] for time window, (GW rate, Neutrino rate) =(0.1,0.5), (0.1,1),(0.5,0.5) per day can reach 10^{-6} .

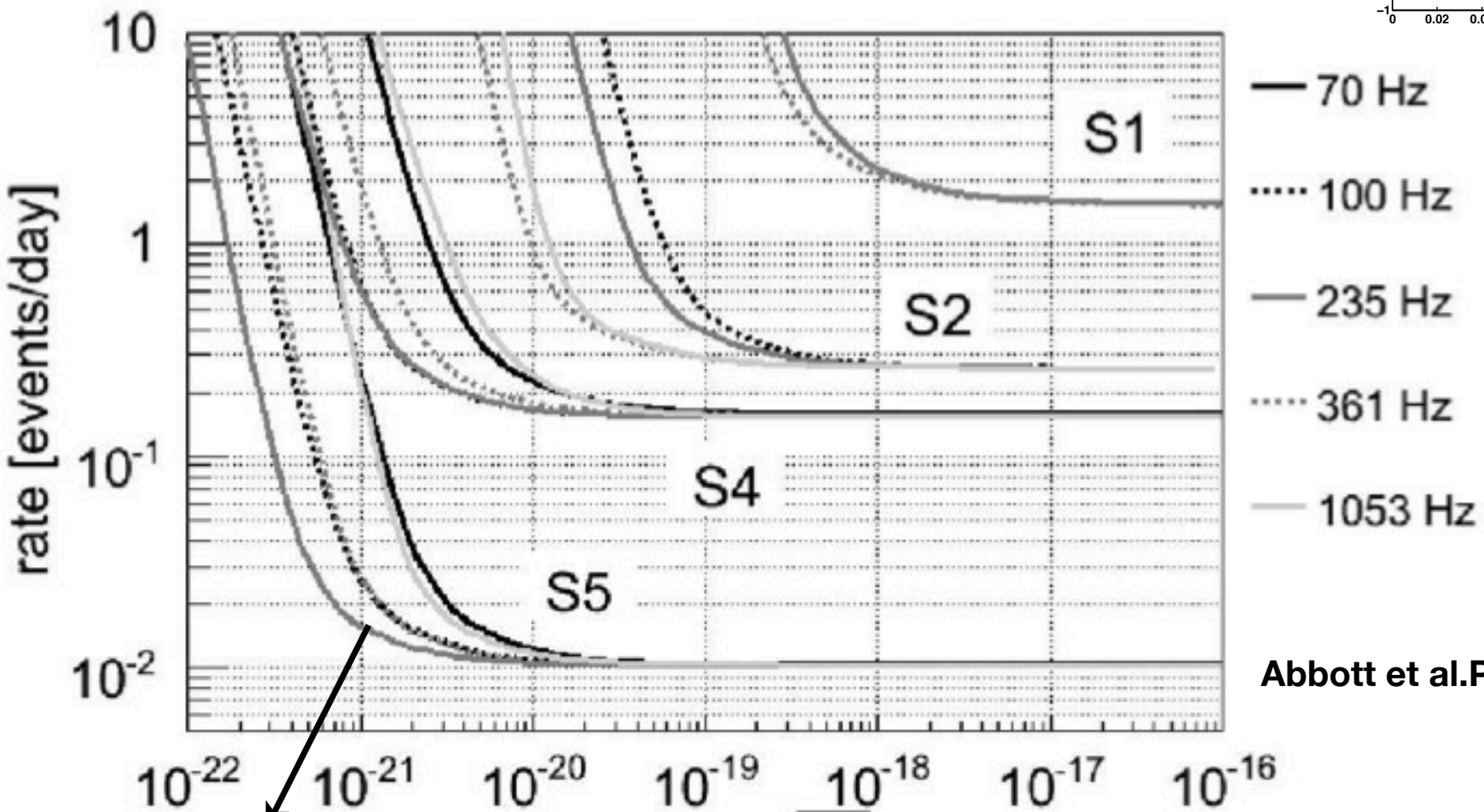


LIGO burst upper limit

- Upper limit of LIGO burst search with injection of Sine Gaussian signals.
- For SG235Q9, $h_{rss}=2\times10^{-22}$ corresponding to 1 event/day, $h_{rss}=4\times10^{-22}$a corresponding to 0.1 event/day
- For aLIGO, very roughly $h_{rss}=10^{-22}$ corresponding to 0.1 event/day

Sine Gaussian





Abbott et al.PRD80(2009)

aLIGO: ~x6

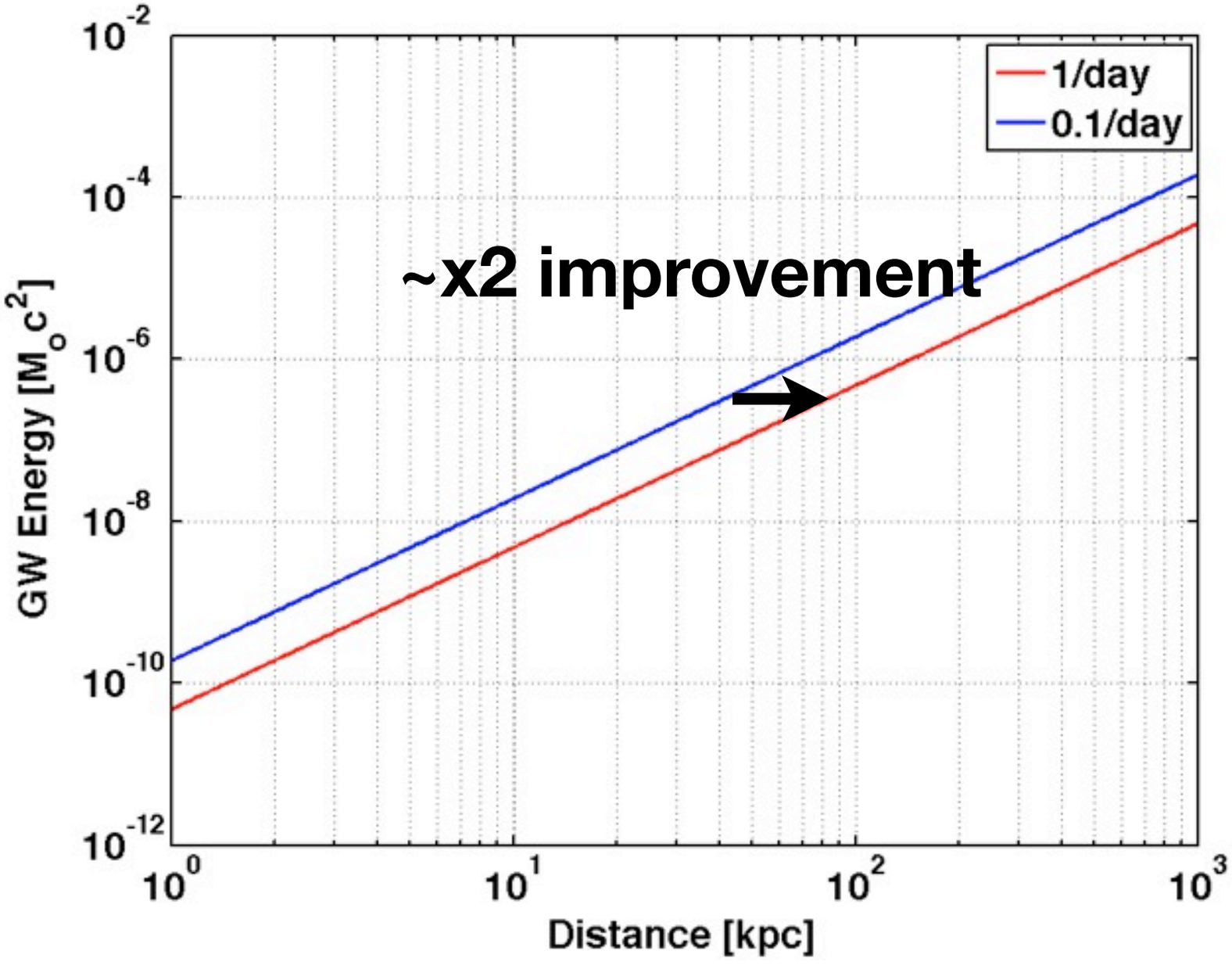
$$h_{rss}=\sqrt{\int(h_+^2+h_\times^2)dt}$$

GW energy vs Distance

- **Assuming isotropic GW radiation:**

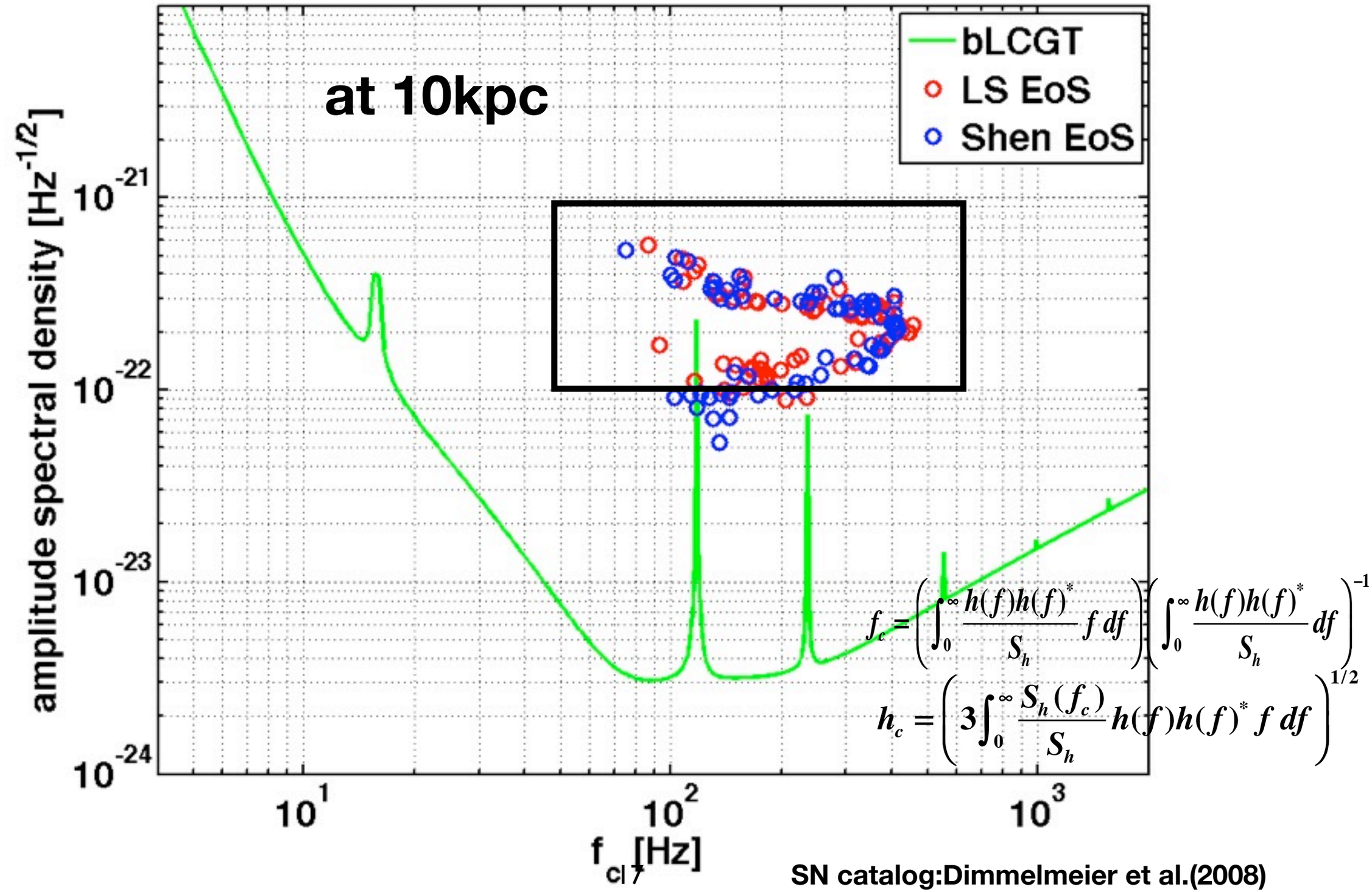
$$E_{GW} \approx \frac{\pi^2 c^3}{G} D^2 f^2 h_{rss}^2$$

GW rate



h_{rss} vs f_c on bLCGT

- If bLCGT reaches $h_{rss}=10^{-22}$ at 0.1 event/day and SK 1 event/day, CCP satisfy 10^{-6}.



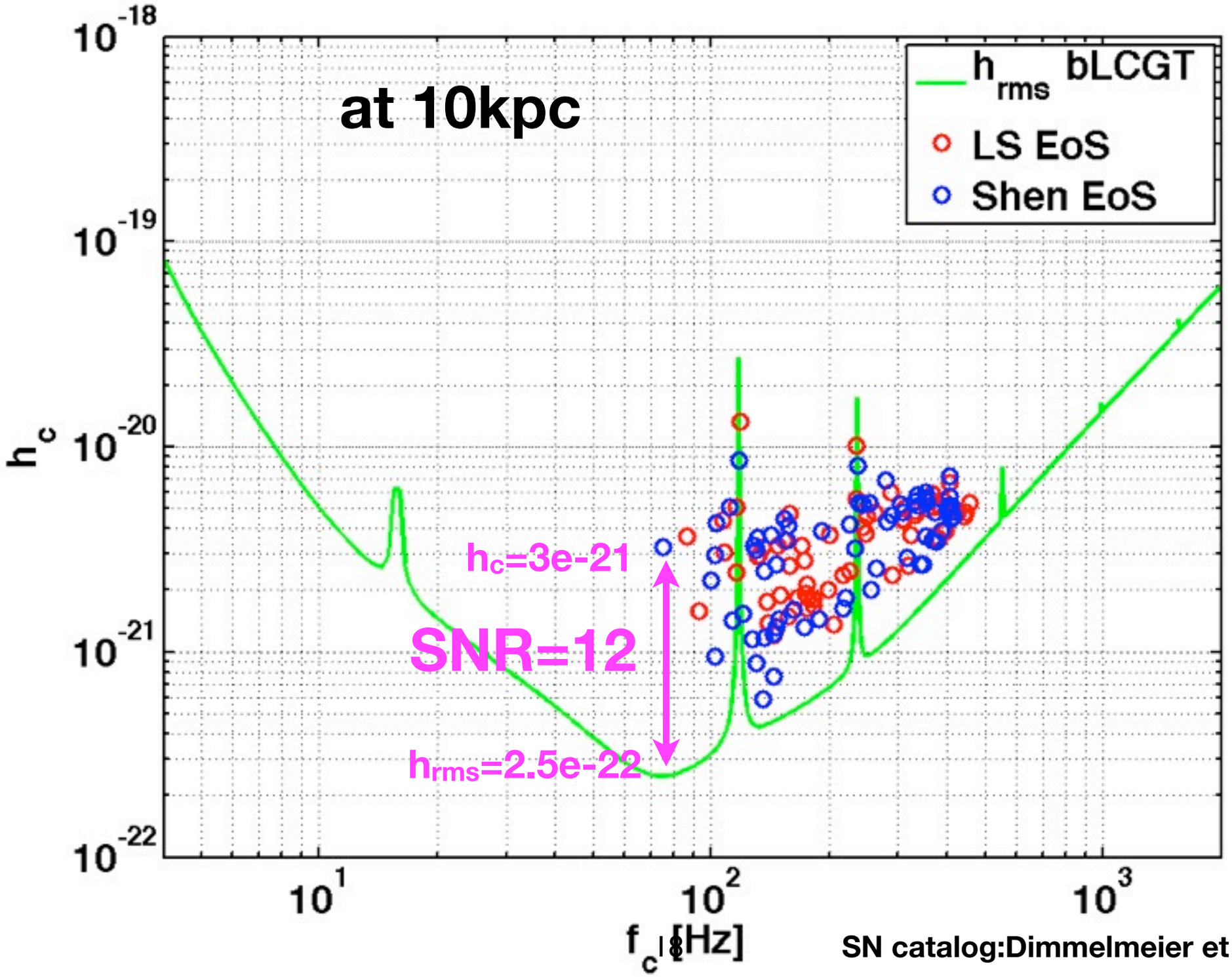
$$f_c = \left(\int_0^\infty \frac{h(f)h(f)^*}{S_h} f\, df \right) \left(\int_0^\infty \frac{h(f)h(f)^*}{S_h} df \right)^{-1}$$

$$h_c = \left(3 \int_0^\infty \frac{S_h(f_c)}{S_h} h(f)h(f)^*\, f\, df \right)^{1/2}$$

SN catalog:Dimmelmeier et al.(2008)

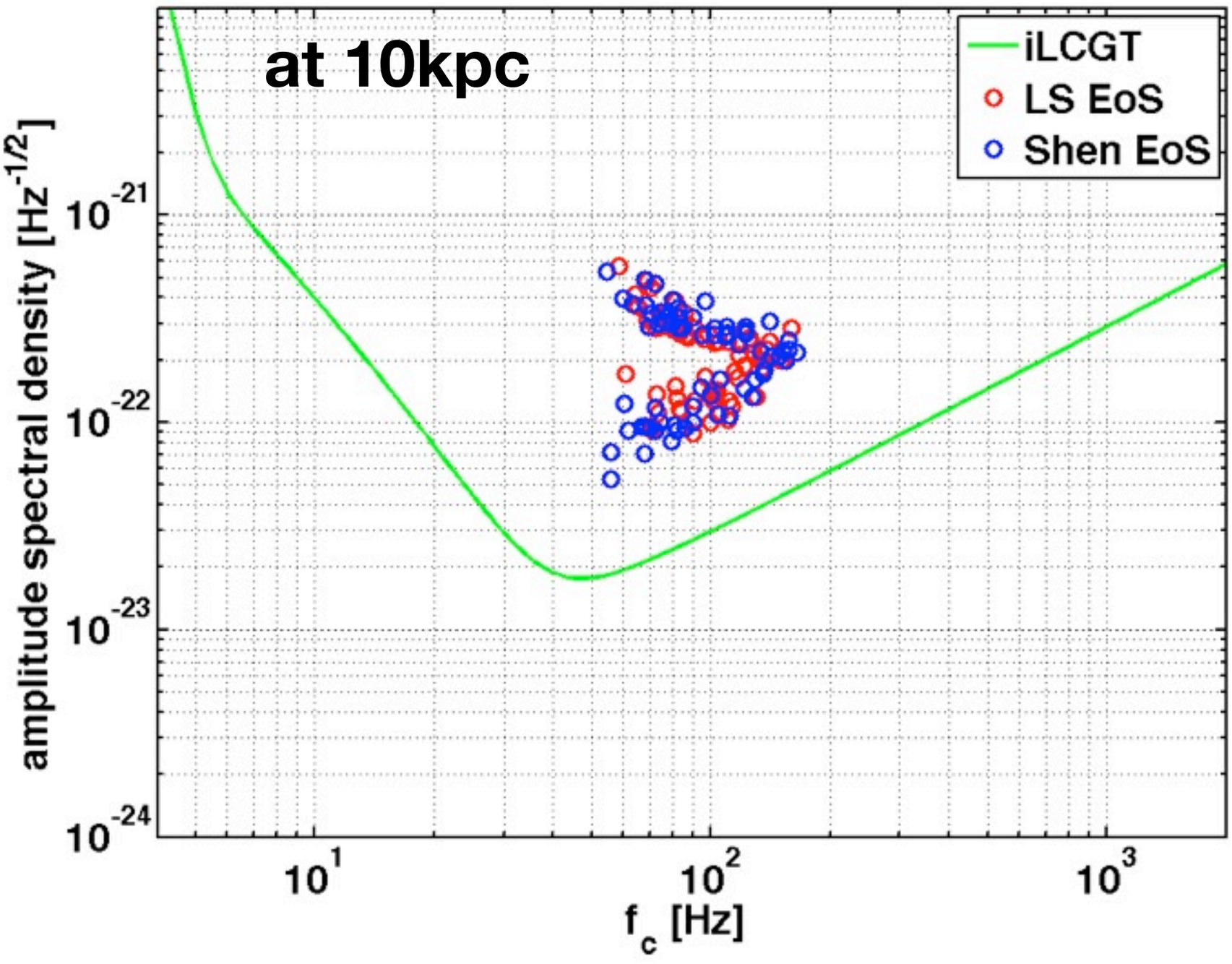
h_c vs f_c on bLCGT

- h_c/h_{rms} is Signal-to-Noise Ratio.



SN catalog:Dimmelmeier et al.(2008)

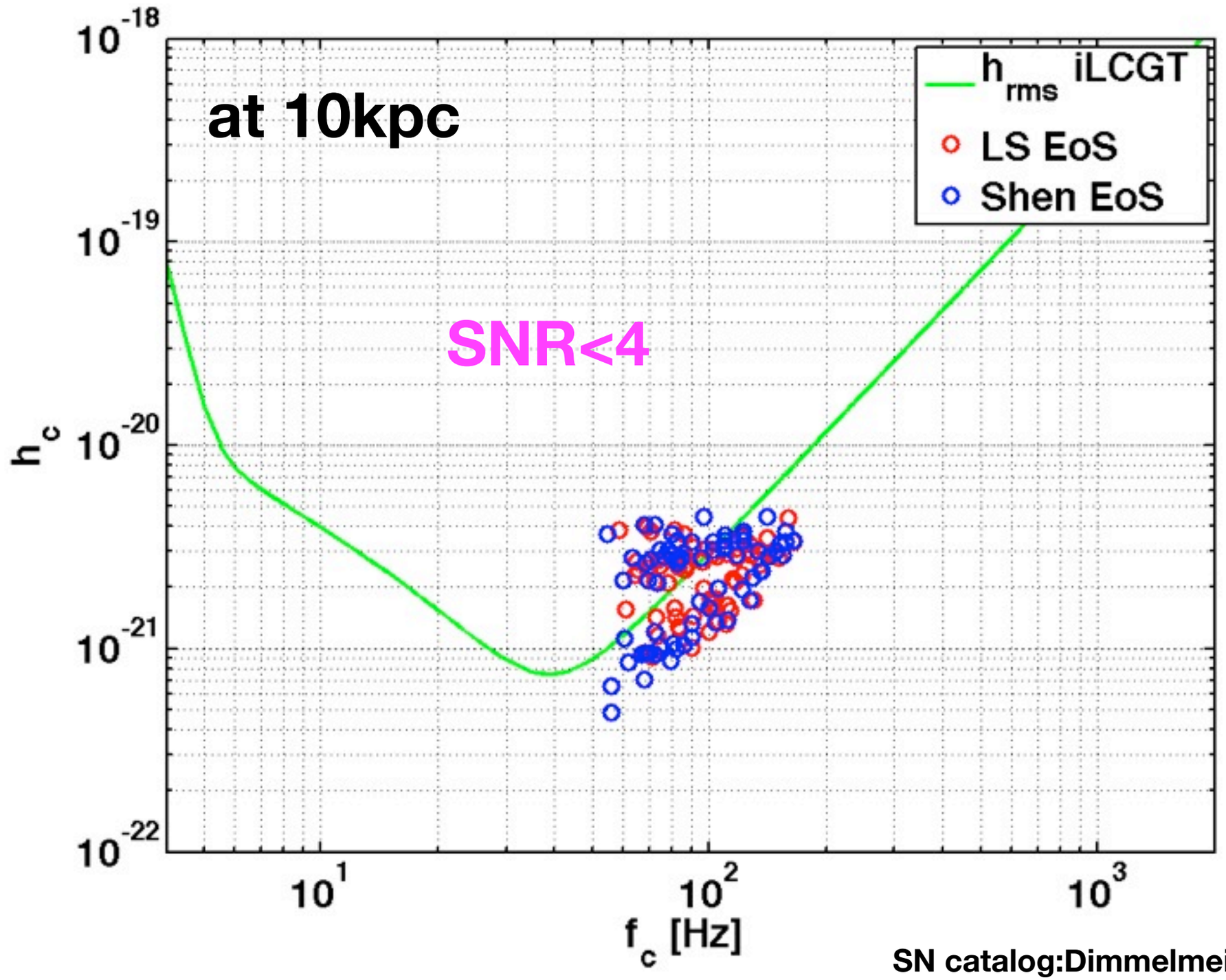
h_{rss} vs f_c on iLCGT



SN catalog:Dimmelmeier et al.(2008)

h_c vs f_c on iLCGT

- At most SNR < 4, so lower threshold search is required.

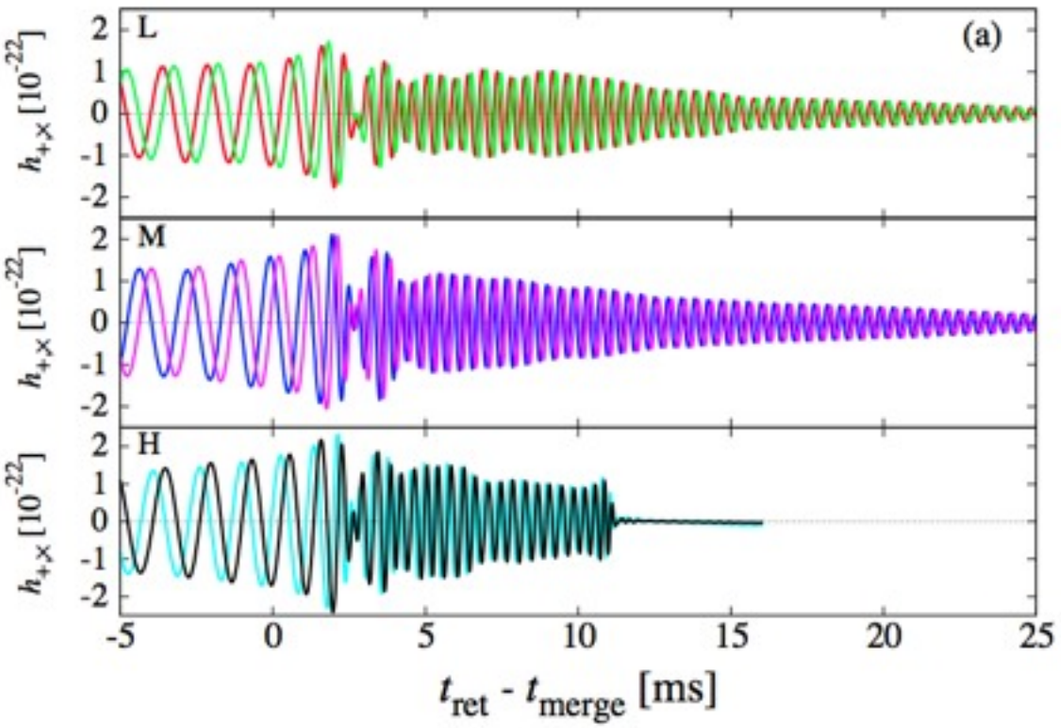


SN catalog:Dimmelmeier et al.(2008)

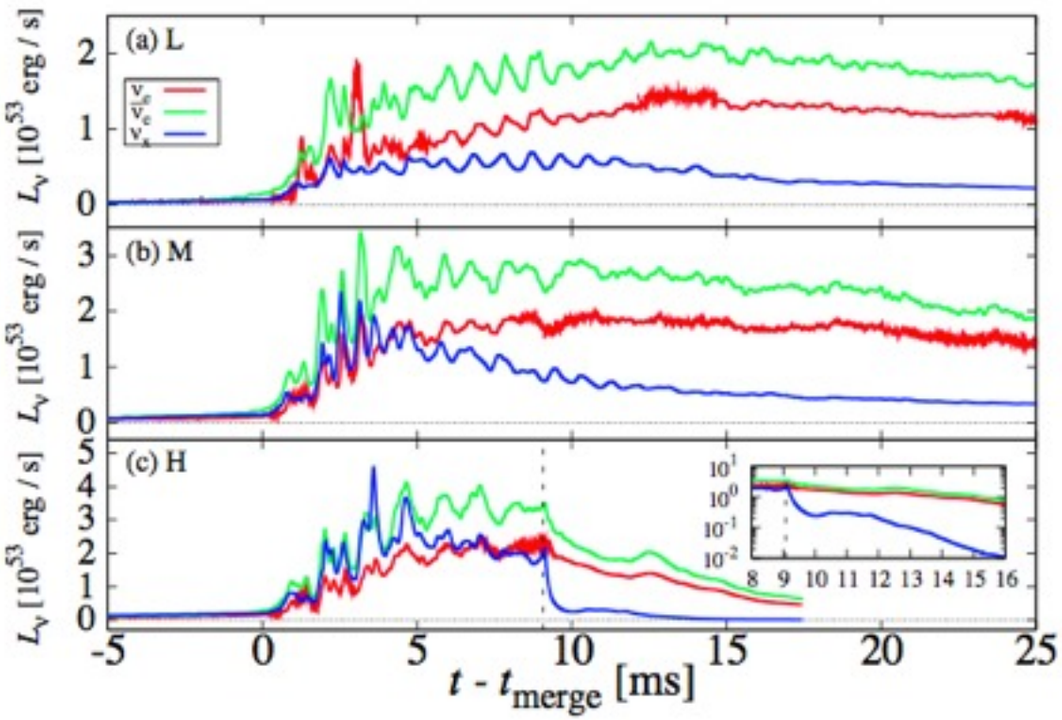
GW+Neutrino from CBC

- **In case of compact binary coalescence : in progress.**

Compact Binary Coalescence



Neutrino Flux



Sekiguchi et al. (2011)

Summary

- The coincidence between GW and Neutrino relaxes detection threshold
  - GW: by relaxing the rate threshold from 0.1/day to1/day, the sensitivity gains ~2 times better.
  - Neutrino: by relaxing number threshold from 2 events in a time window to 1 event, the detectable distance gains ~41% better.
- More sophisticated estimation, like applying various cut to SK data, should give more accurate information.

- This is just a kick-off study. I'd propose to have a special working group for studying coordinated LCGT-SK search.