

# **Multi-Messenger Observation using LCGT**

**(Case study: LCGT--Super K connection )**

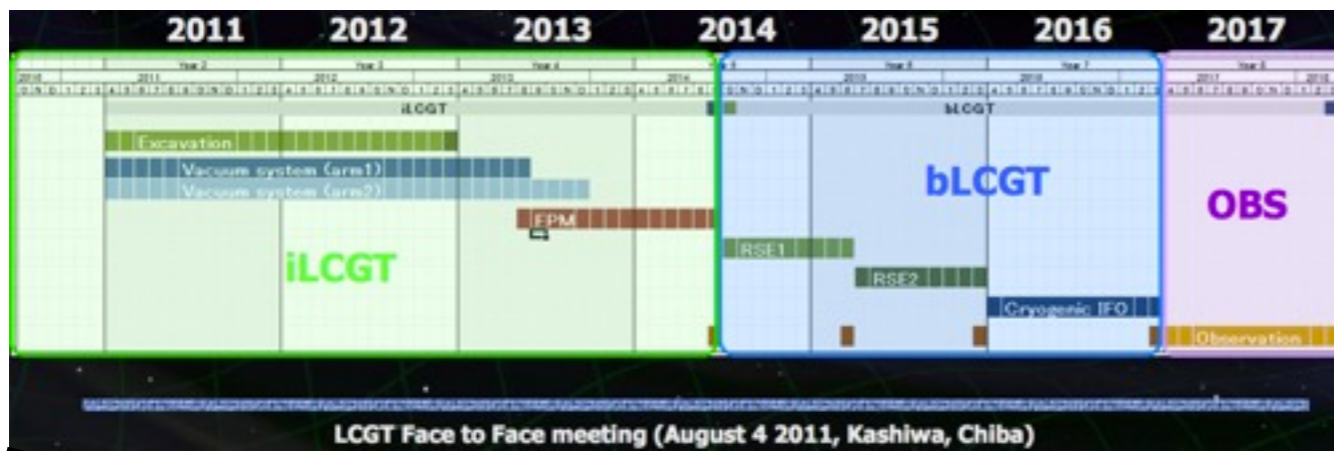


**Kazuhiro Hayama**

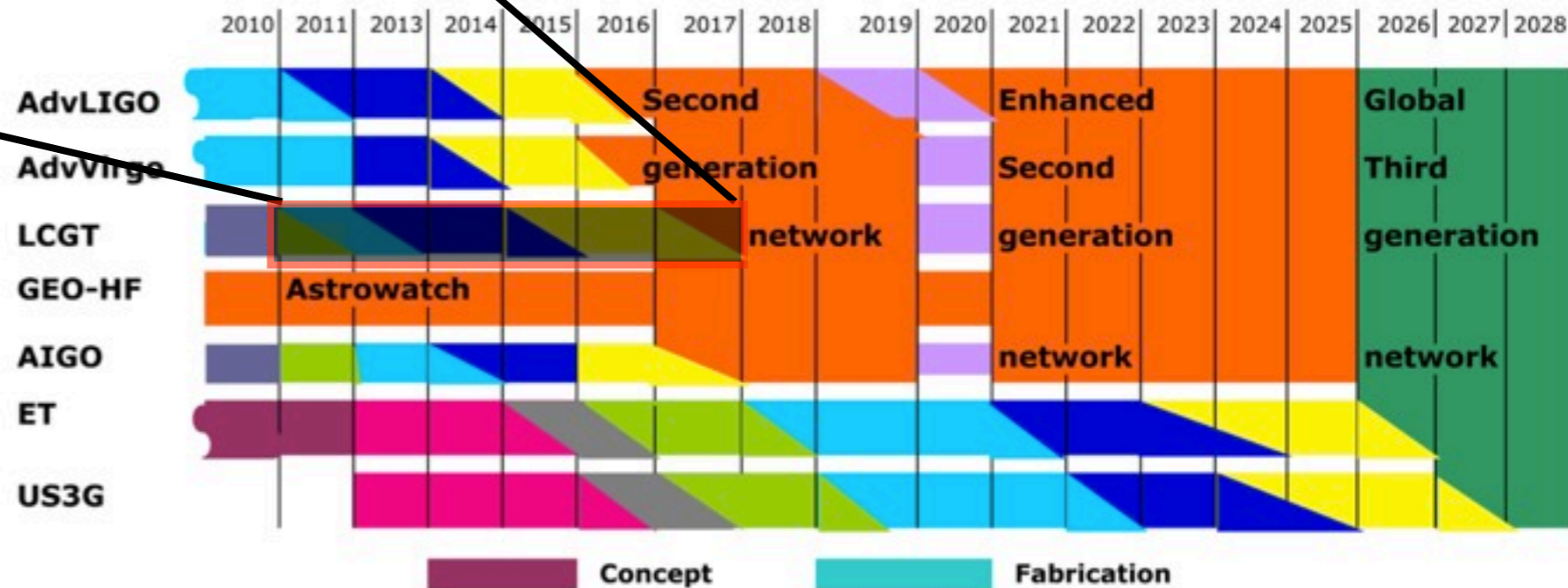
National Astronomical Observatory of Japan



- 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 GWIC Road map



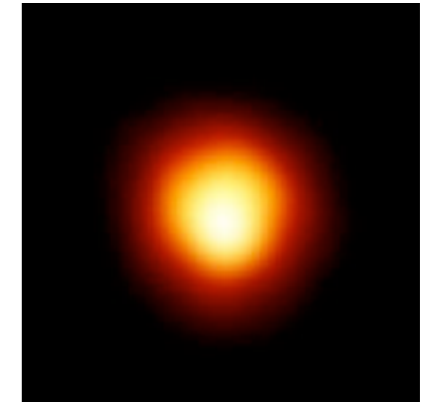
from LCGT Road map

● Core-Collapse SuperNova is one of promising sources.

● Betelgeuse -- Red supergiant star

● Distance : 196 pc

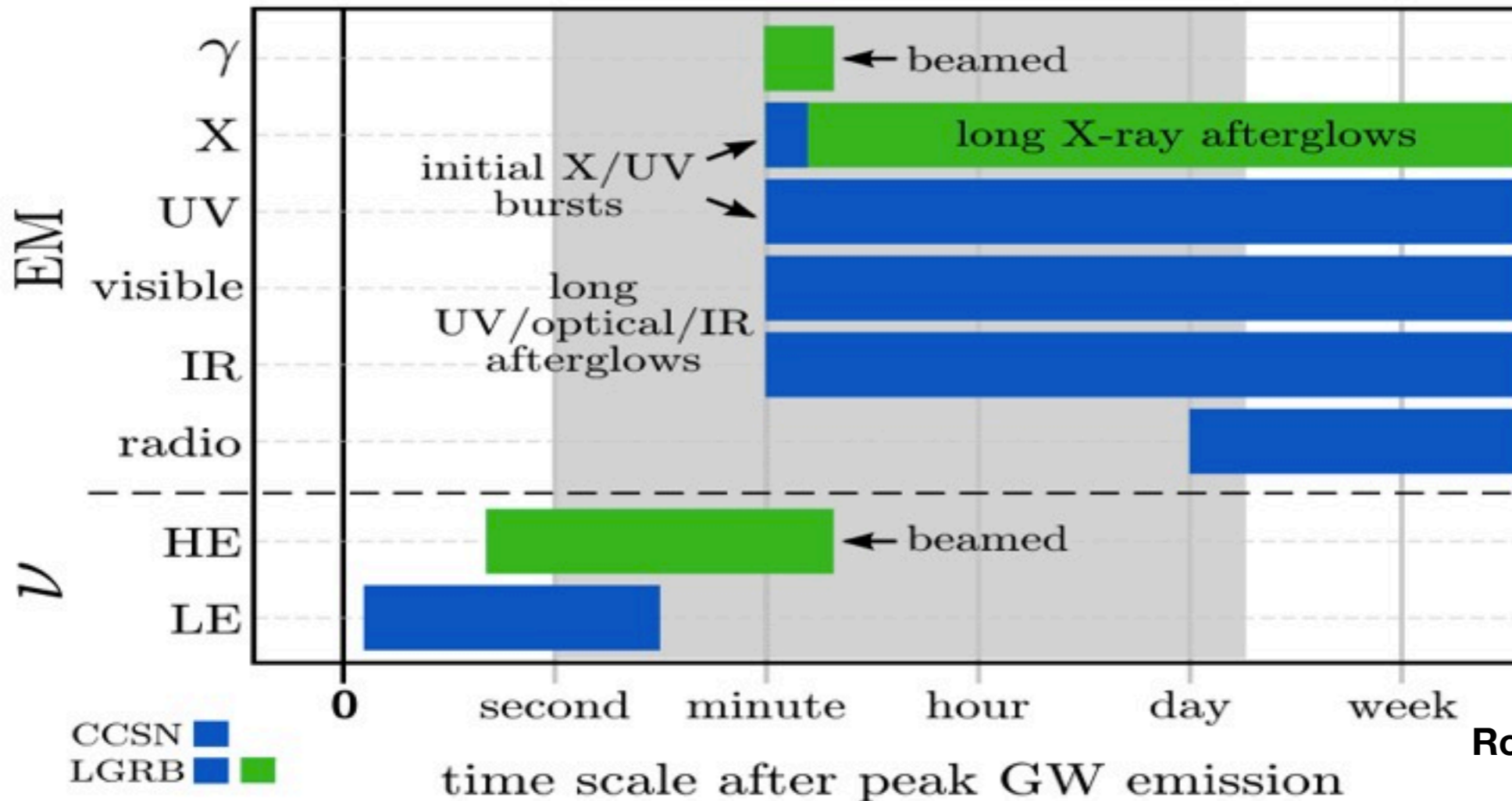
● Mass : 20  $M_{\odot}$



Betelgeuse

● 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.



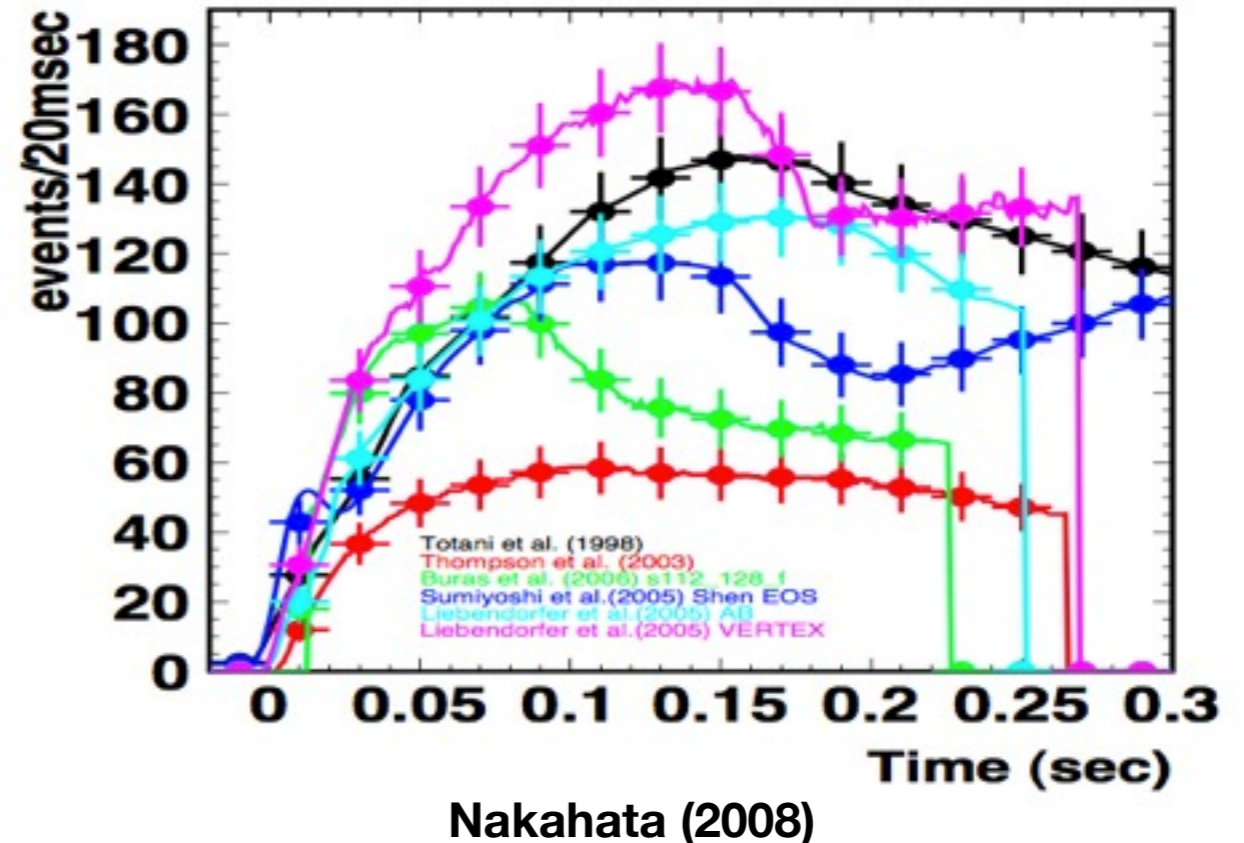
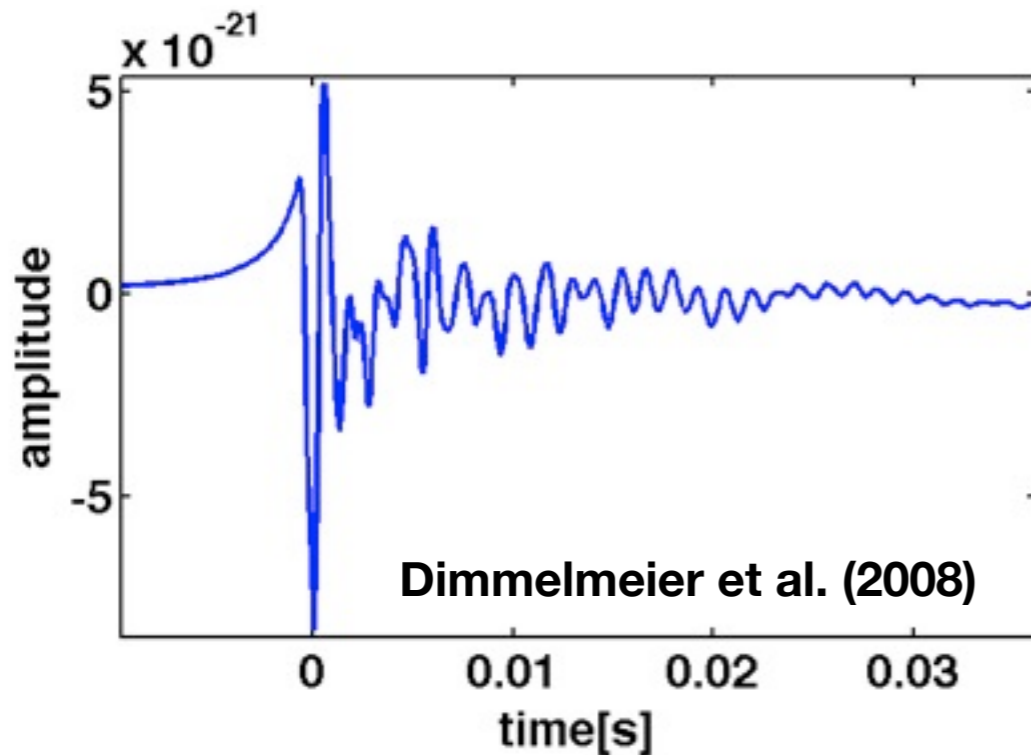
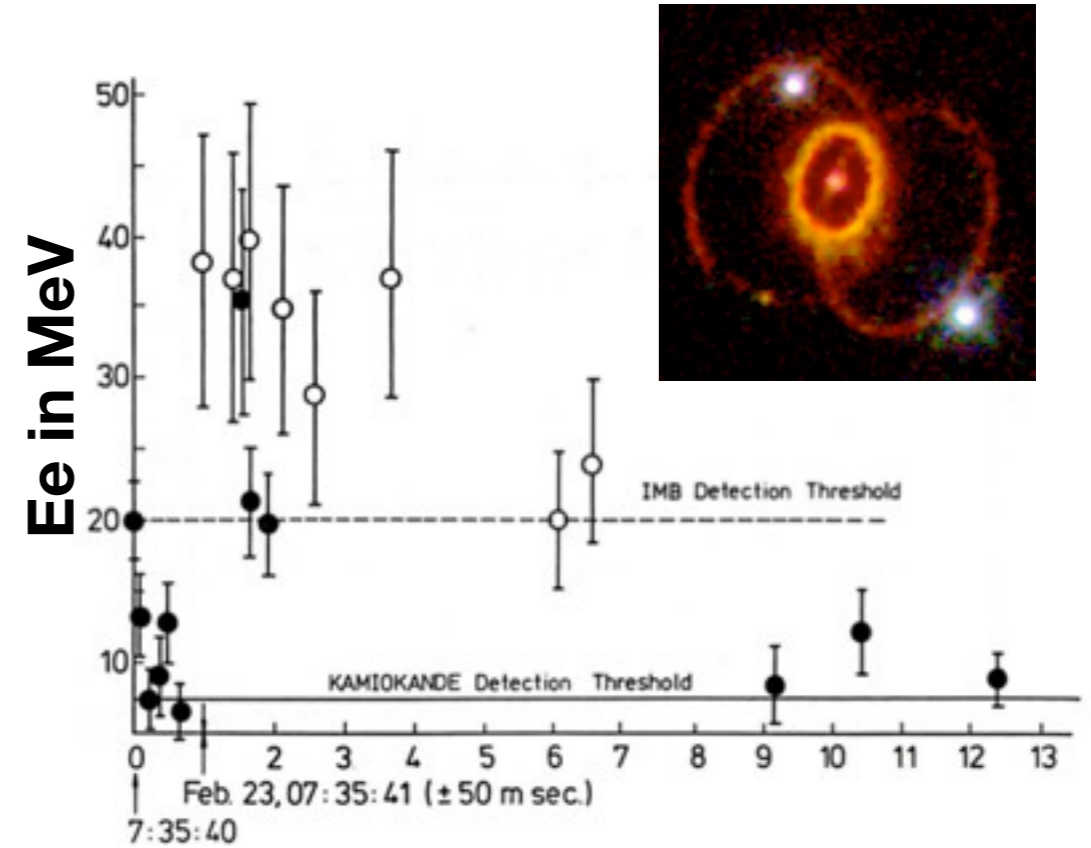
Rollins.J Thesis(2011)

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





- 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





- SNEWS (SuperNova Early Warning System)

- Send alert within ~minutes
- False alert rate is  $< 1$  per century
- Detection threshold is high

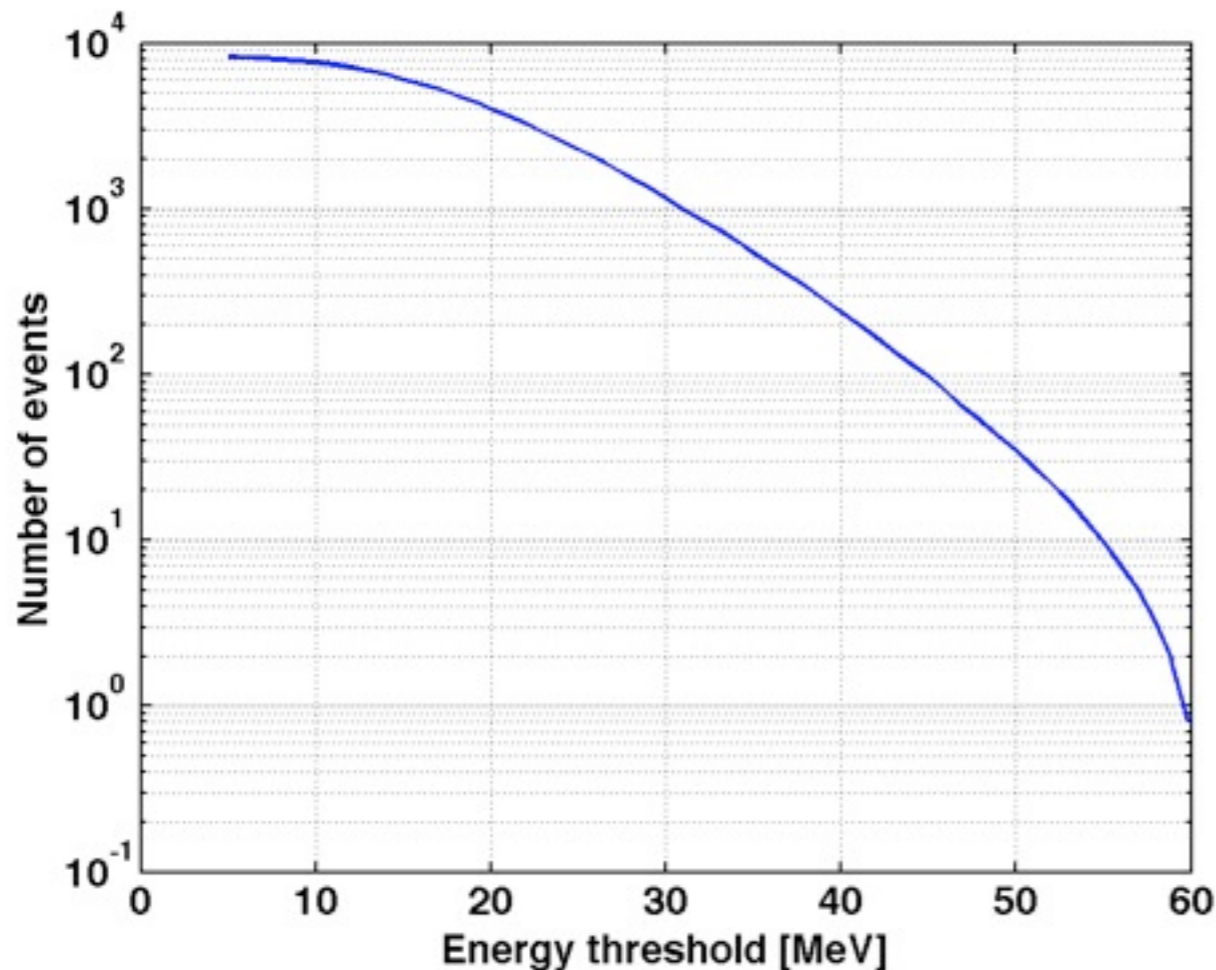


- Another way is to perform GW-neutrino coincidence analysis. Since coincidence analysis reduces false alarm rate, **we can set low threshold for both GW and neutrino search.**
- From the observation of neutrinos from SN1987A and various simulations, **the time window of the coincidence will be at most 20 seconds**, which is shorter than GRB triggered search (180[s])

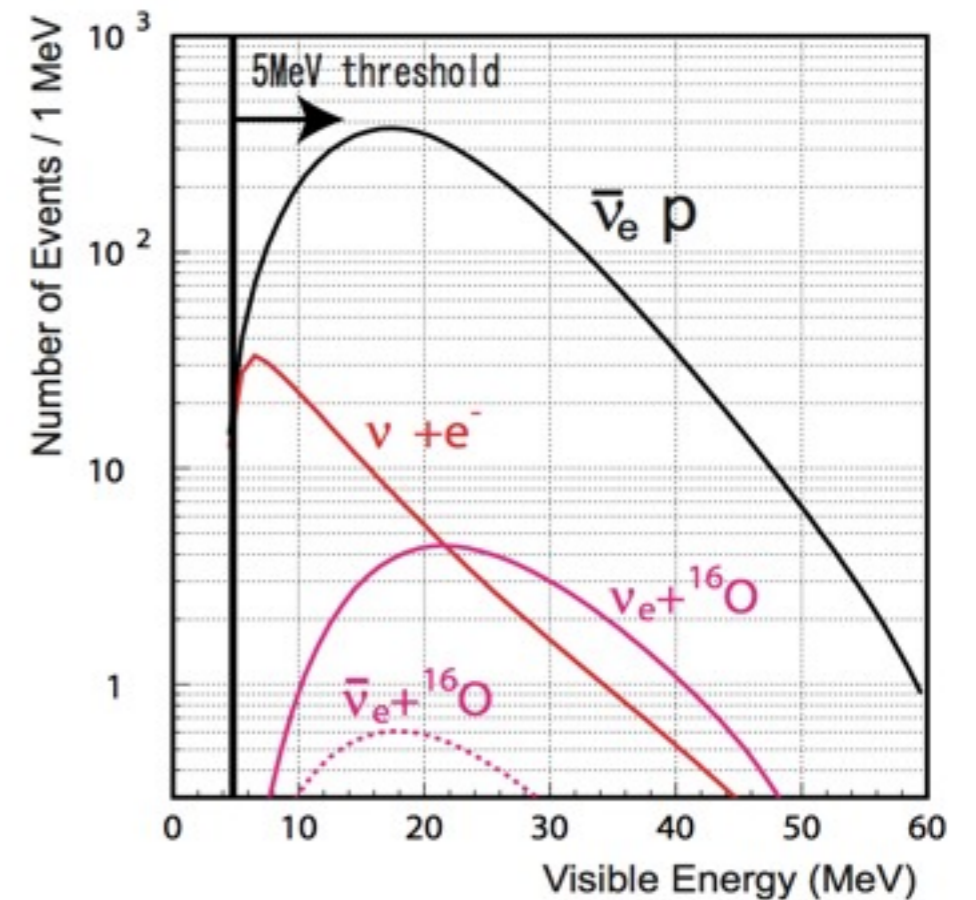


- Taking into account of all neutrino flavor, Super K will detect ~10000 events in 20 [s] when a supernova occurs at 10kpc.
- We did not apply any cut in the entire analysis.

Number of events from SN at 10kpc above the threshold



Number of events from SN at 10kpc as energy

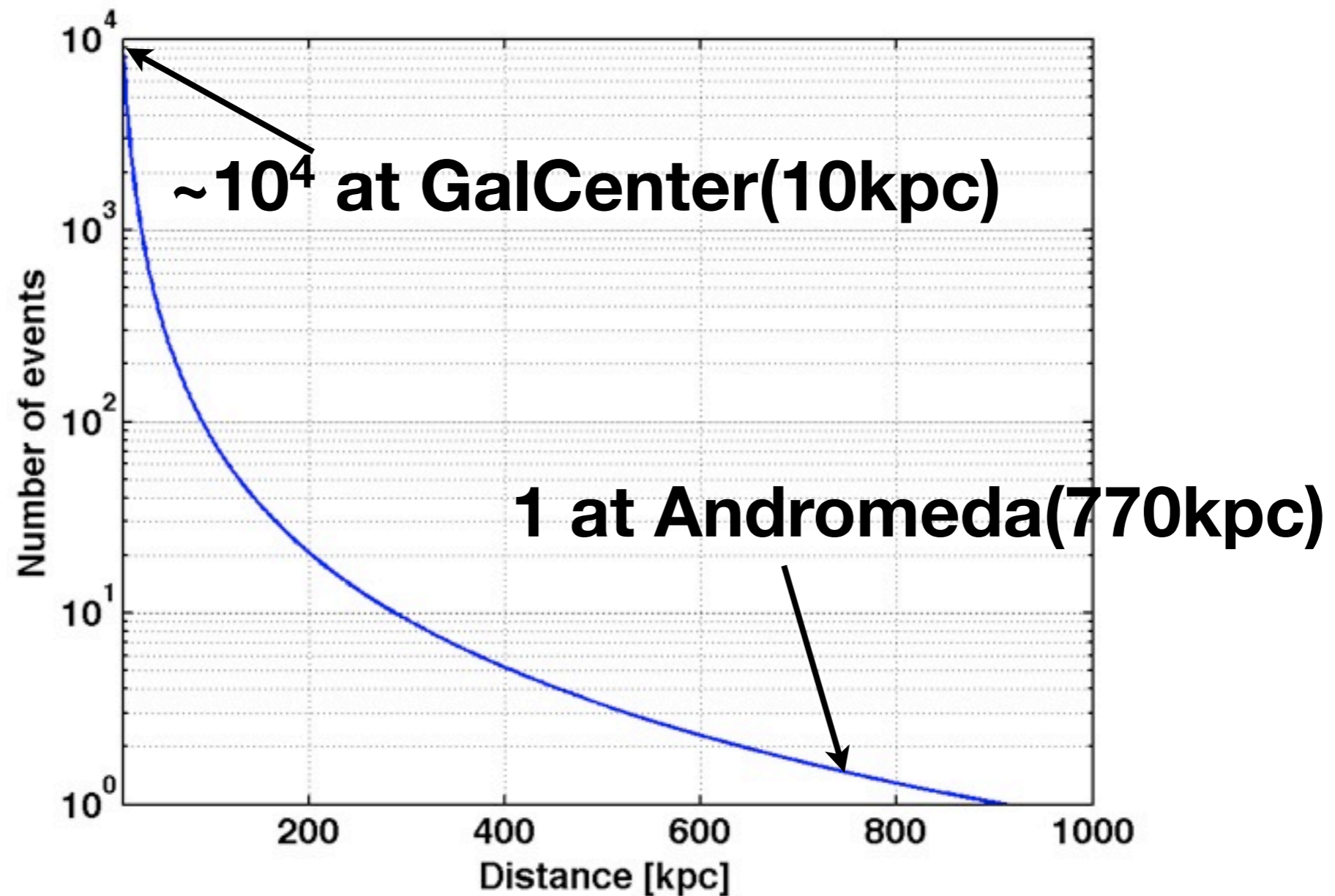


Ikeda et al. 2007





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

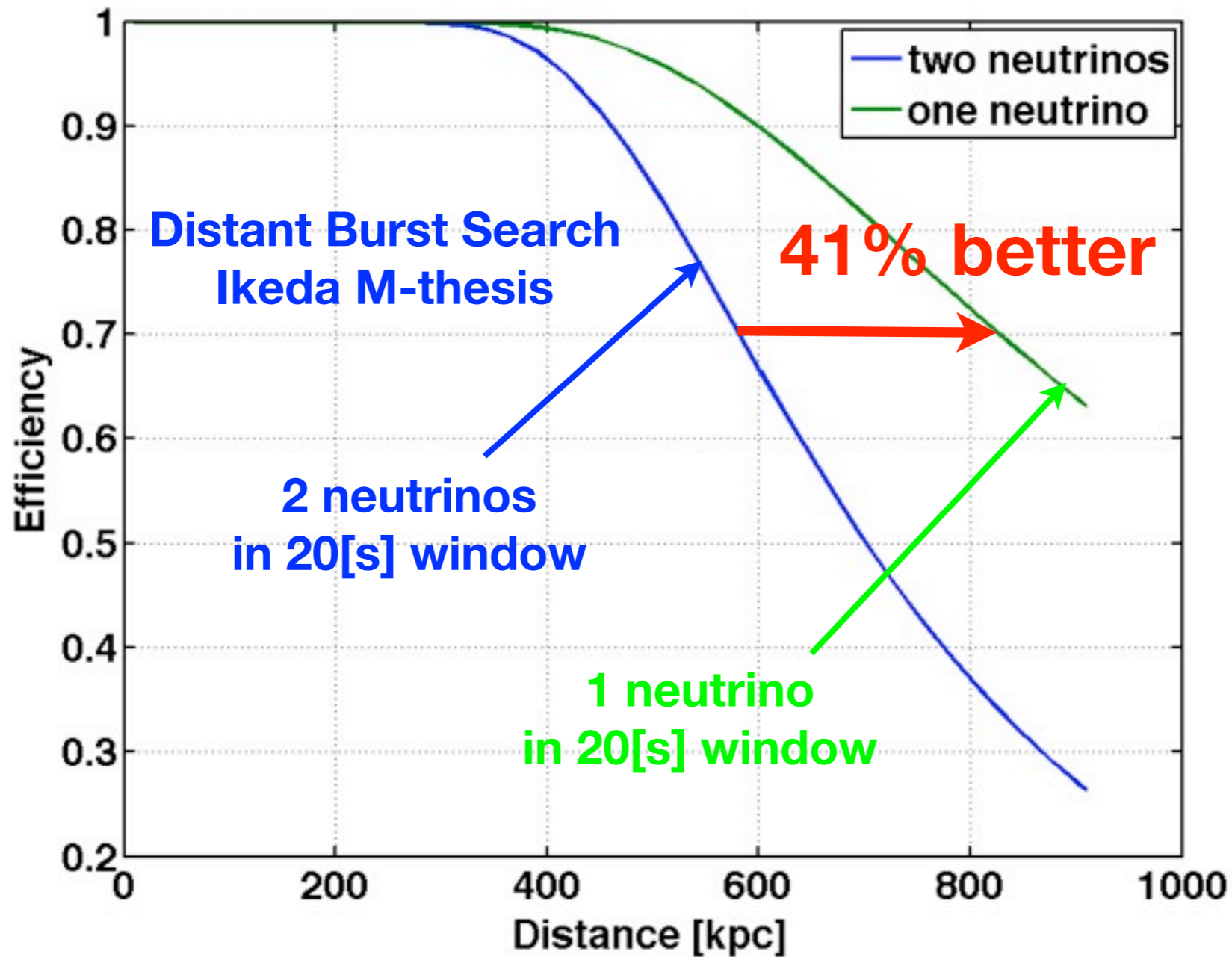




- Lower threshold extends the detectable distance to supernova.

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

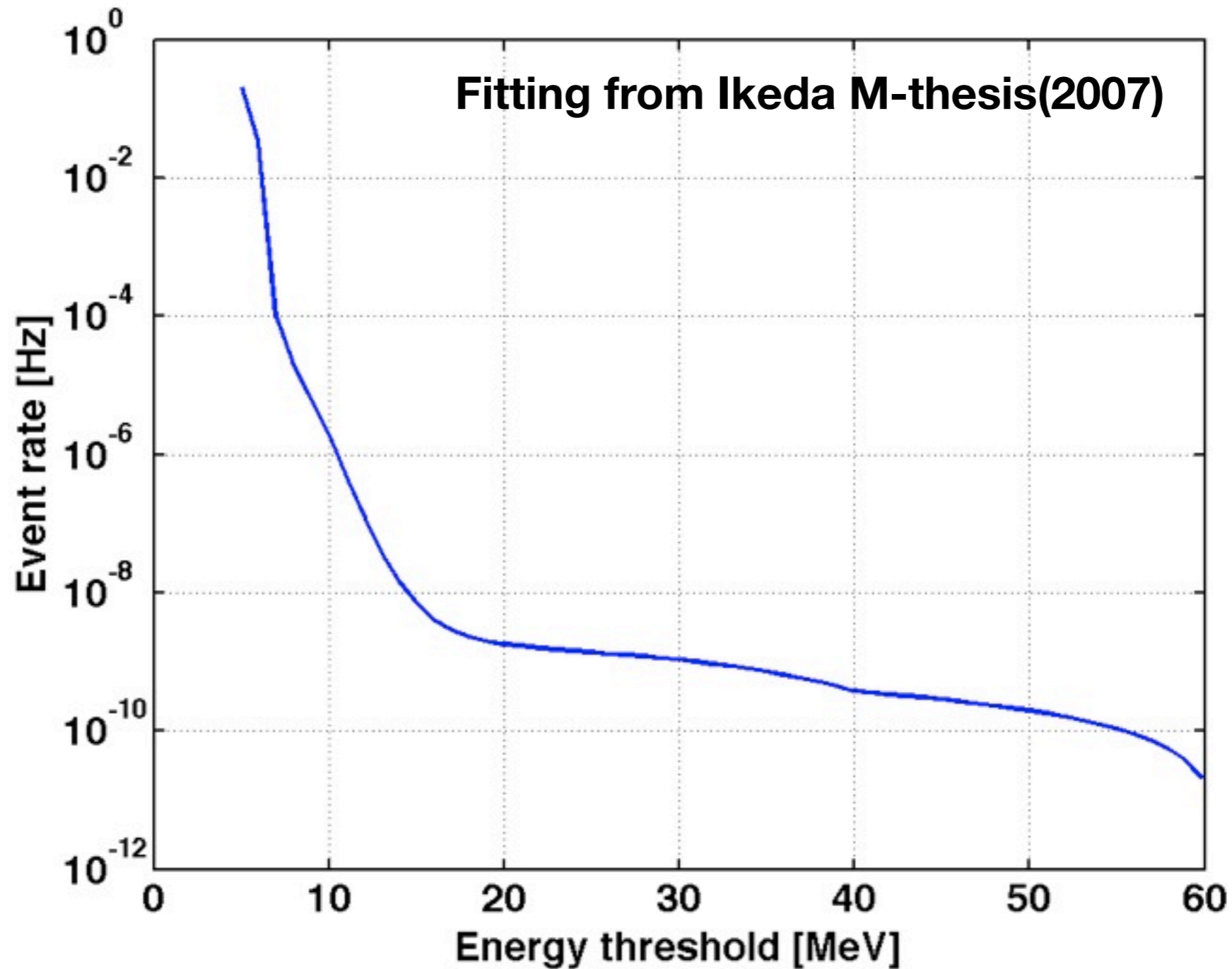
$$Eff_1 = 1 - \exp(-N)$$





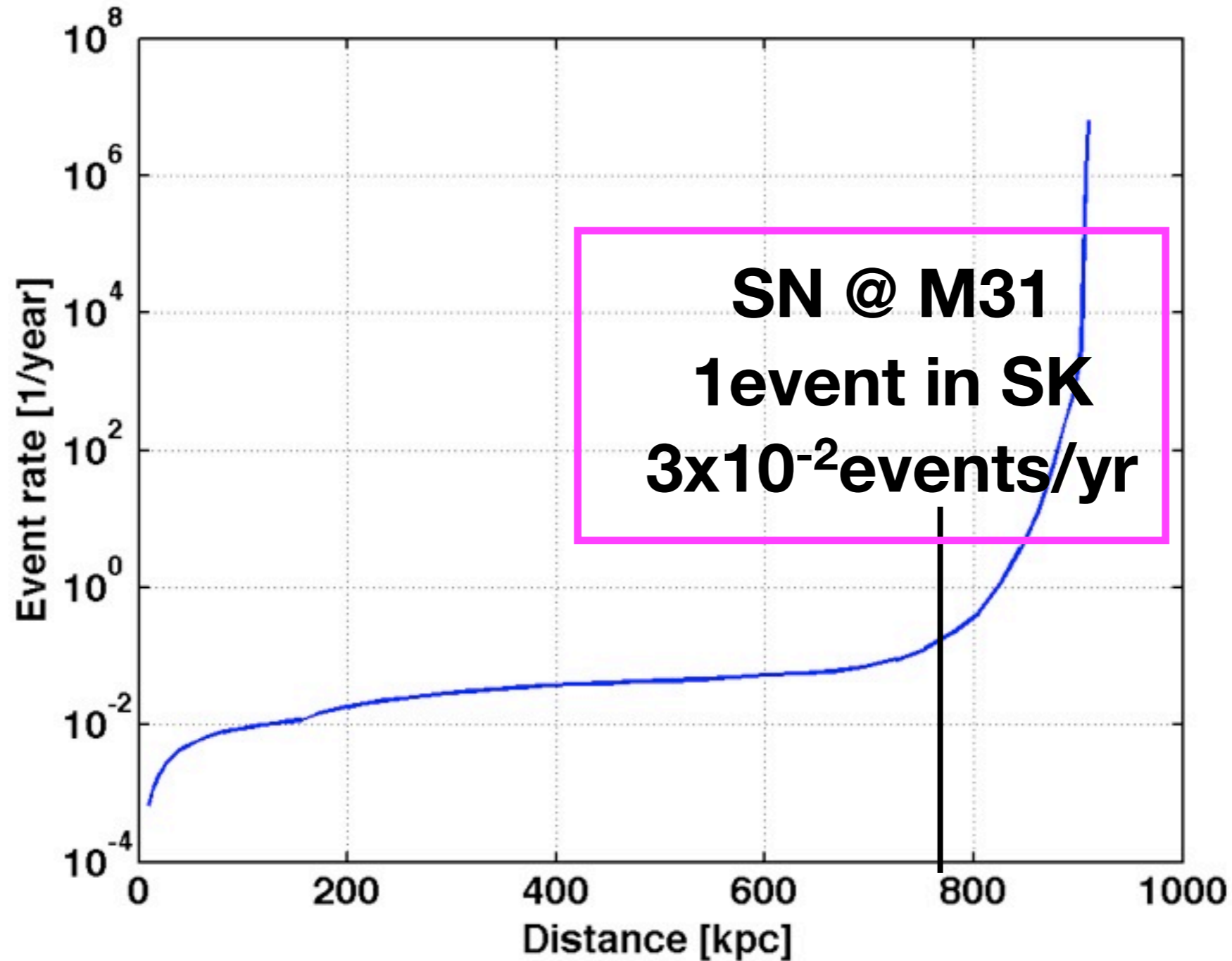


- SK background rate depends on a energy threshold.





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



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

$$P \approx N p_\nu$$

$$p_\nu = 1 - [1 + (R_\nu \times t)] \exp(-R_\nu \times t)$$

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

$R_\nu$  : Event rate of neutrinos per seconds

$R_{GW}$  : Event rate of GWs per seconds

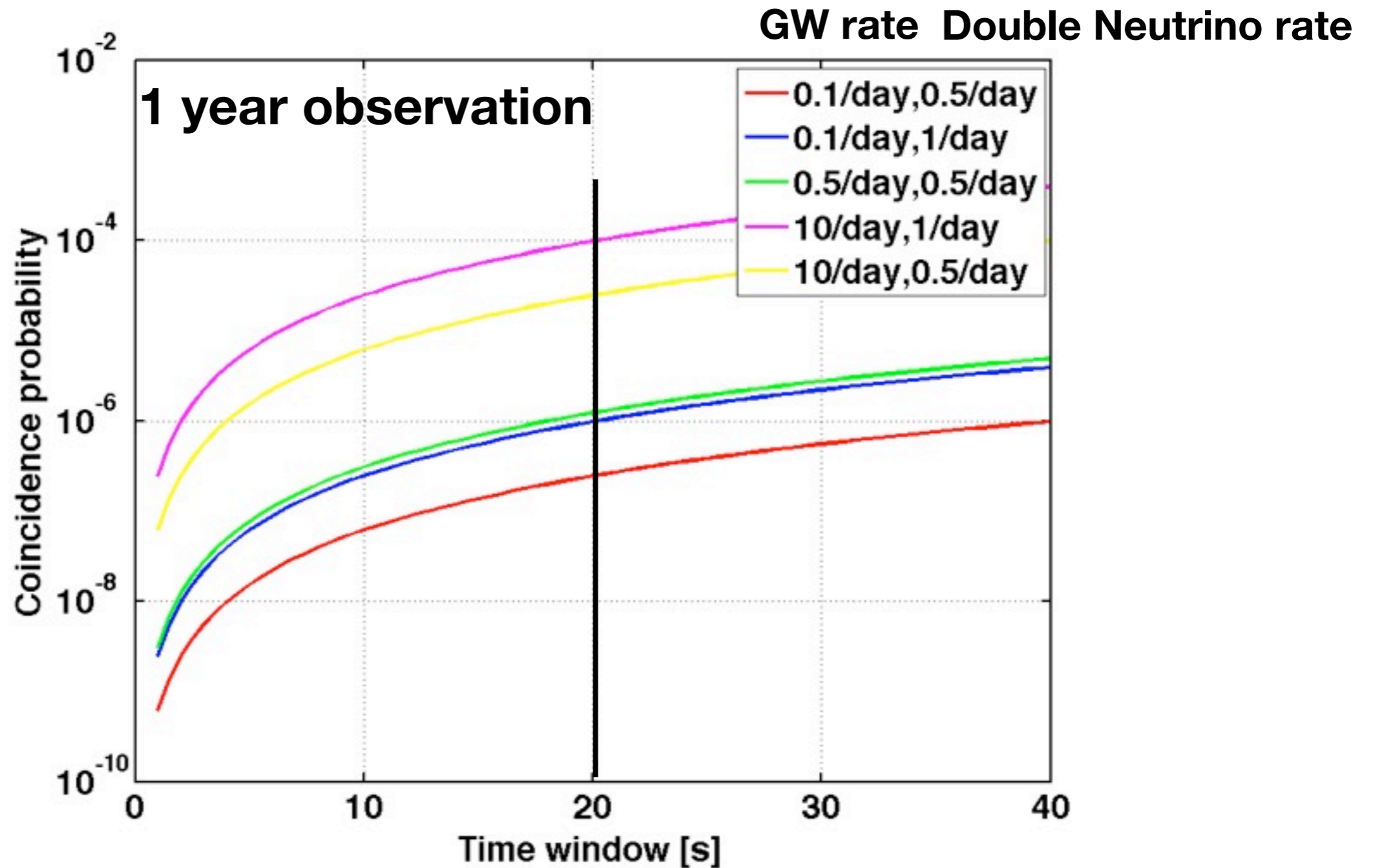
$T$  : Total live time

$t$  : coincidence time window





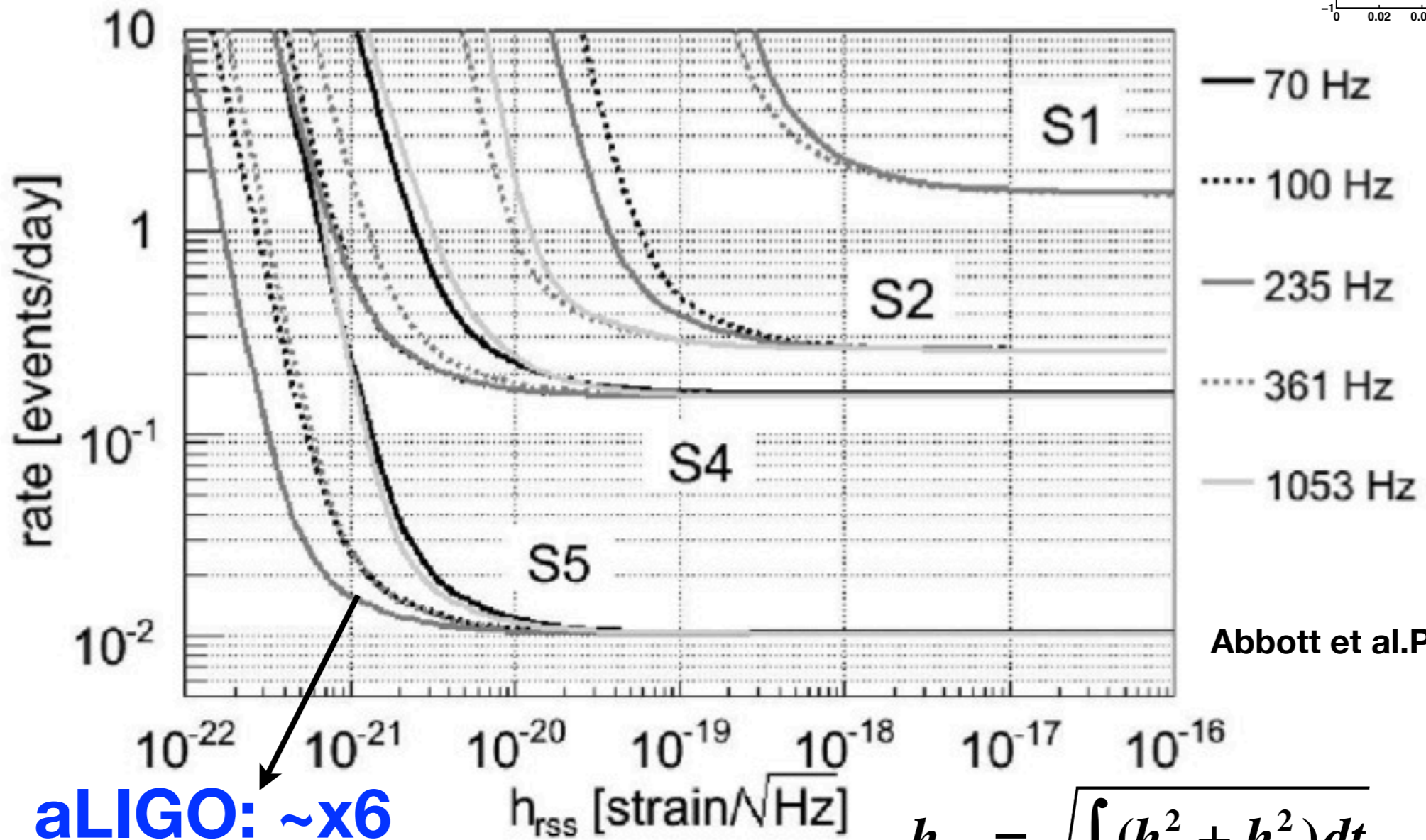
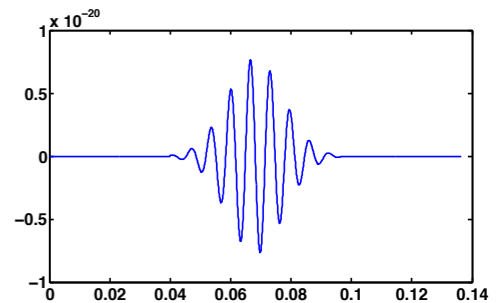
- Taking 20[s] for time window, (GW rate, Neutrino rate) = (0.1,0.5), (0.1,1), (0.5,0.5) per day can reach  $10^{-6}$ .





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

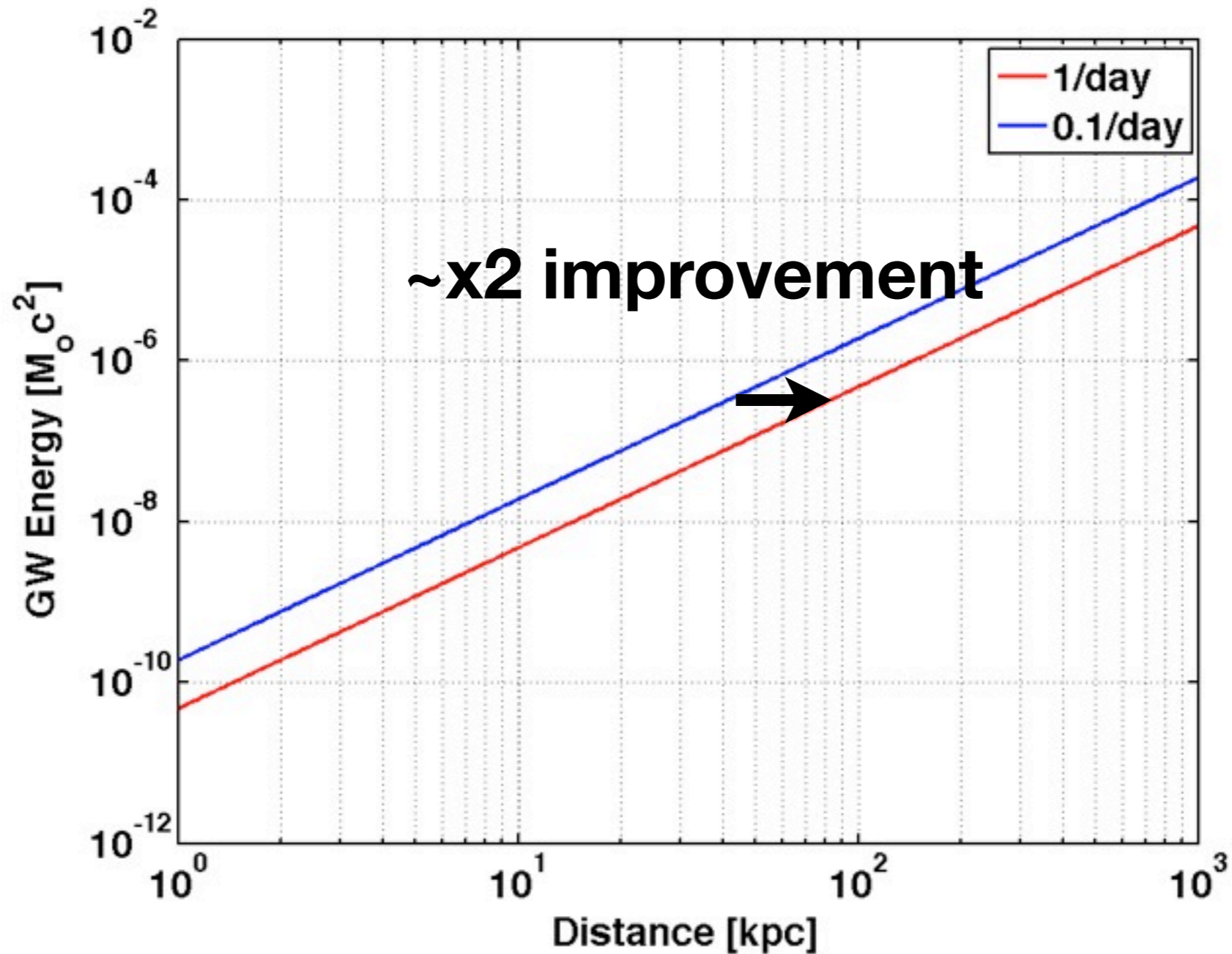
$$h_{rss} = \sqrt{\int (h_+^2 + h_x^2) dt}$$



● Assuming isotropic GW radiation:

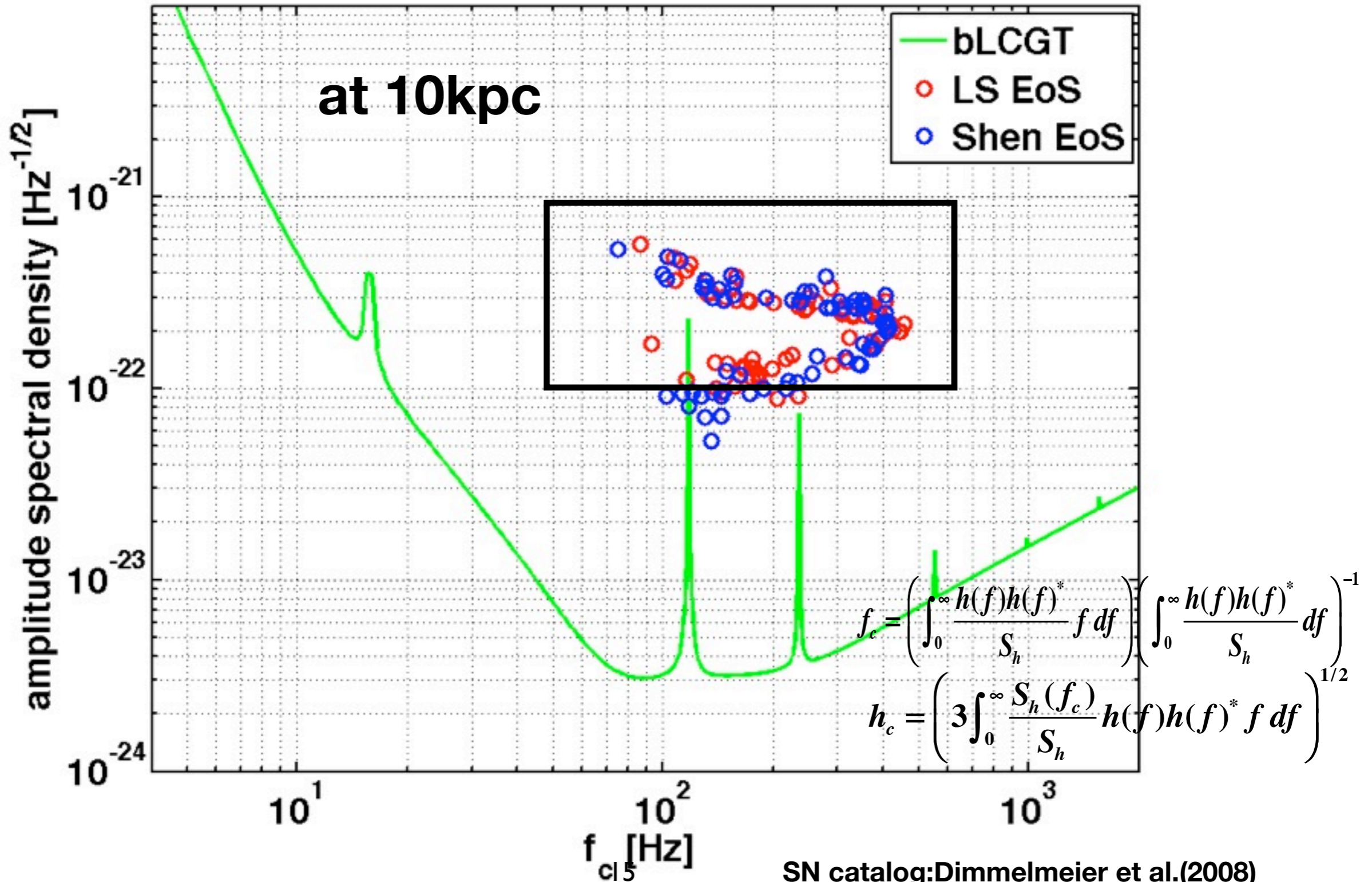
$$E_{GW} \approx \frac{\pi^2 c^3}{G} D^2 f^2 h_{rss}^2$$

GW rate



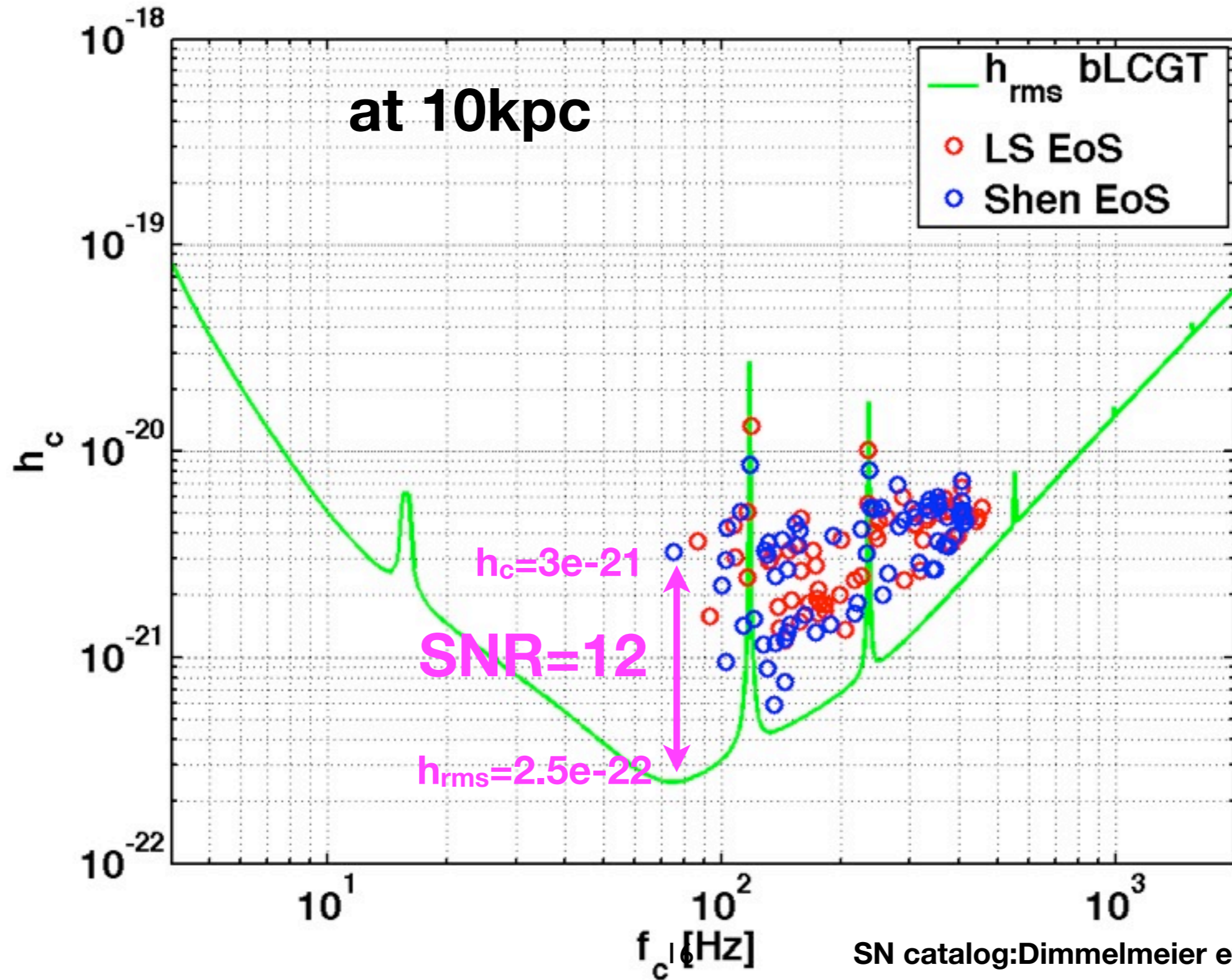


- If bLCGT reaches  $h_{\text{rSS}} = 10^{-22}$  at 0.1 event/day and SK 1 event/day, CCP satisfy  $10^{-6}$ .



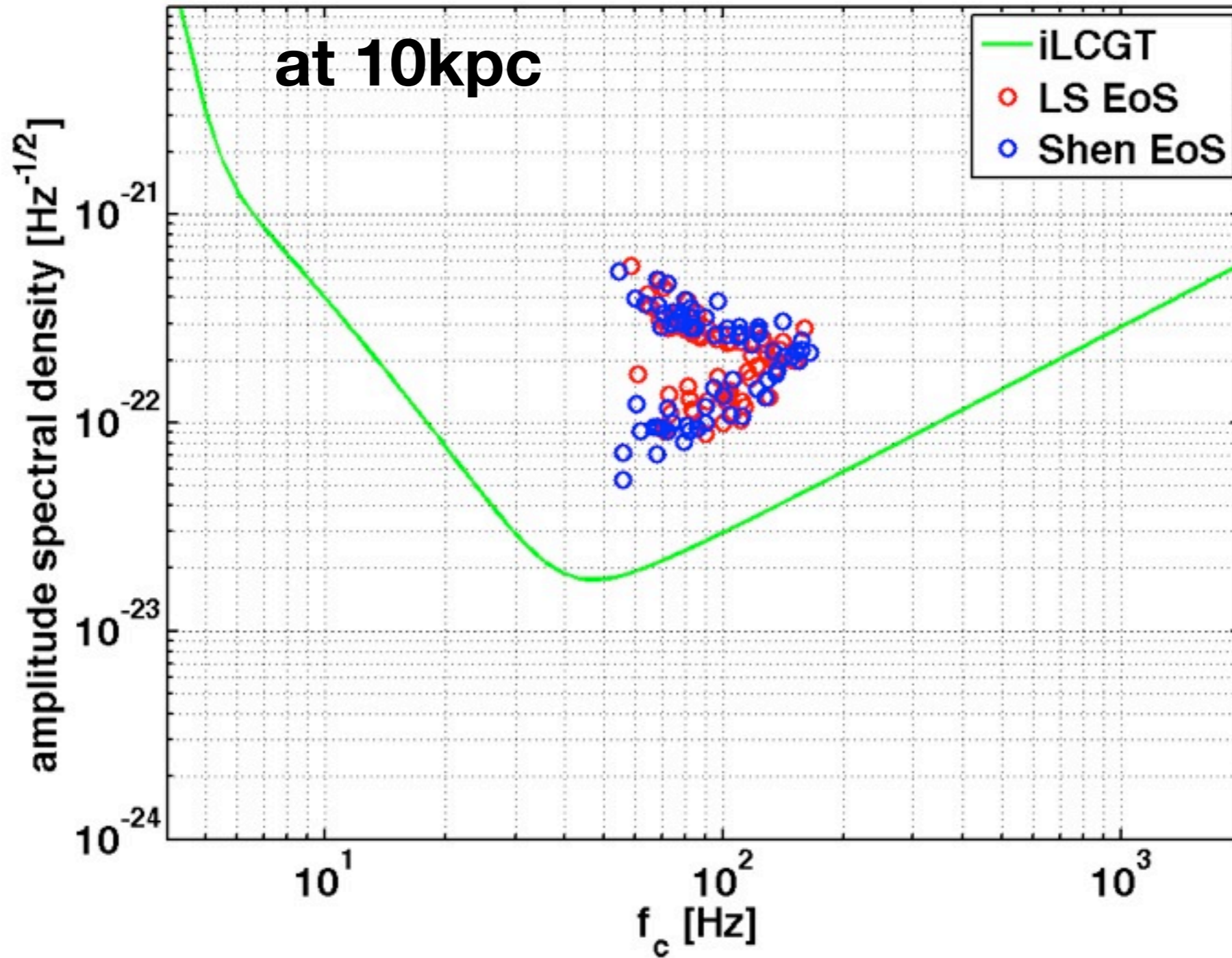


●  $h_c/h_{rms}$  is Signal-to-Noise Ratio.



SN catalog: Dimmellemeier et al. (2008)

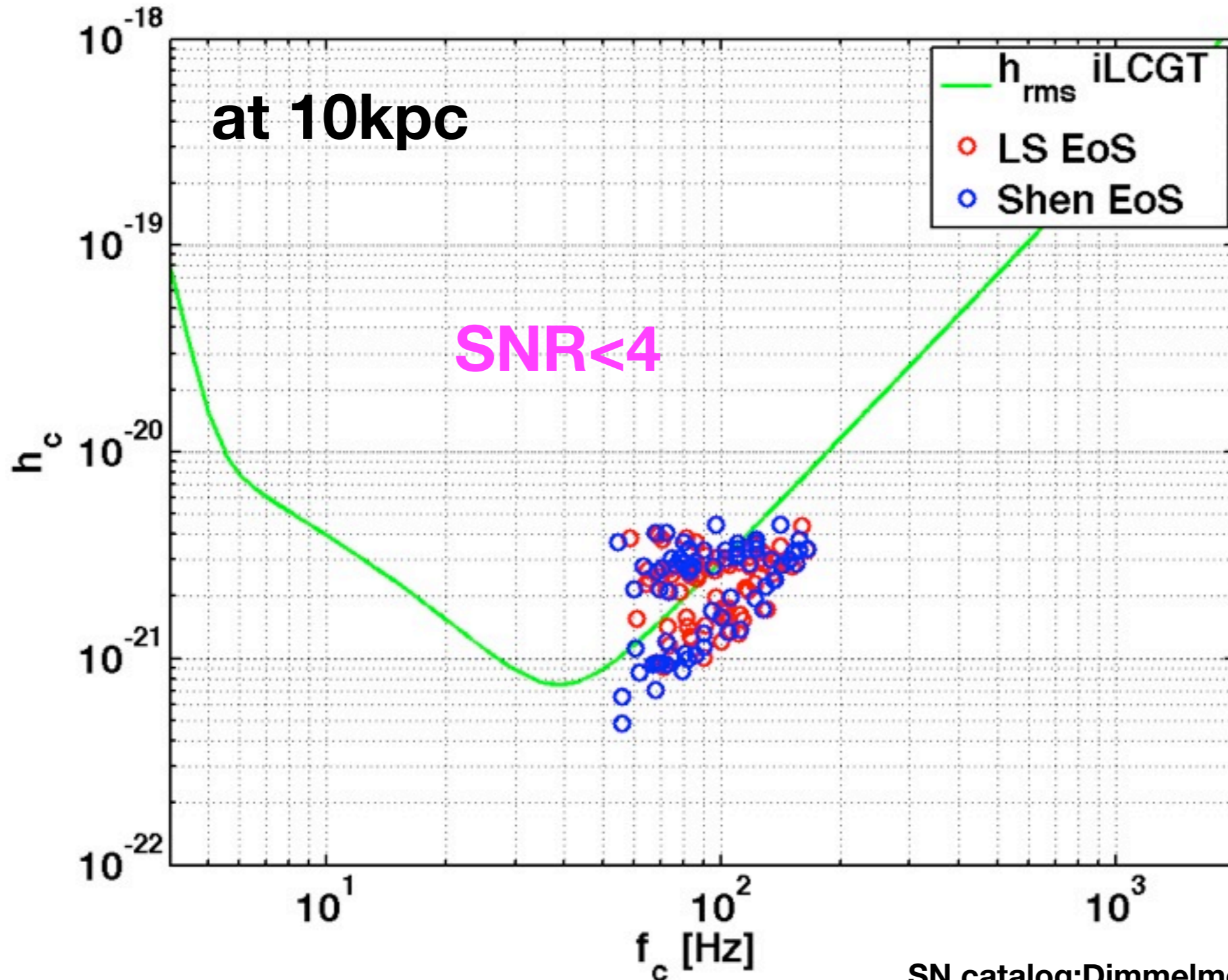








● At most SNR < 4, so lower threshold search is required.

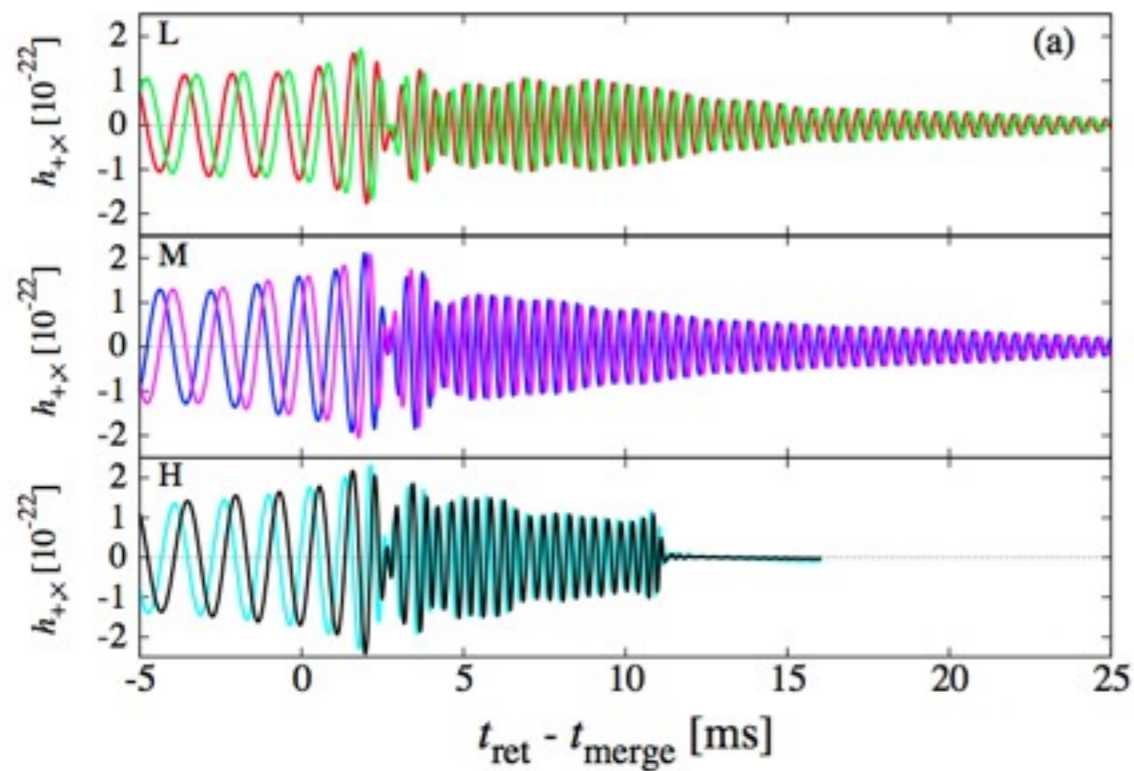


SN catalog: Dimmelmeyer et al. (2008)

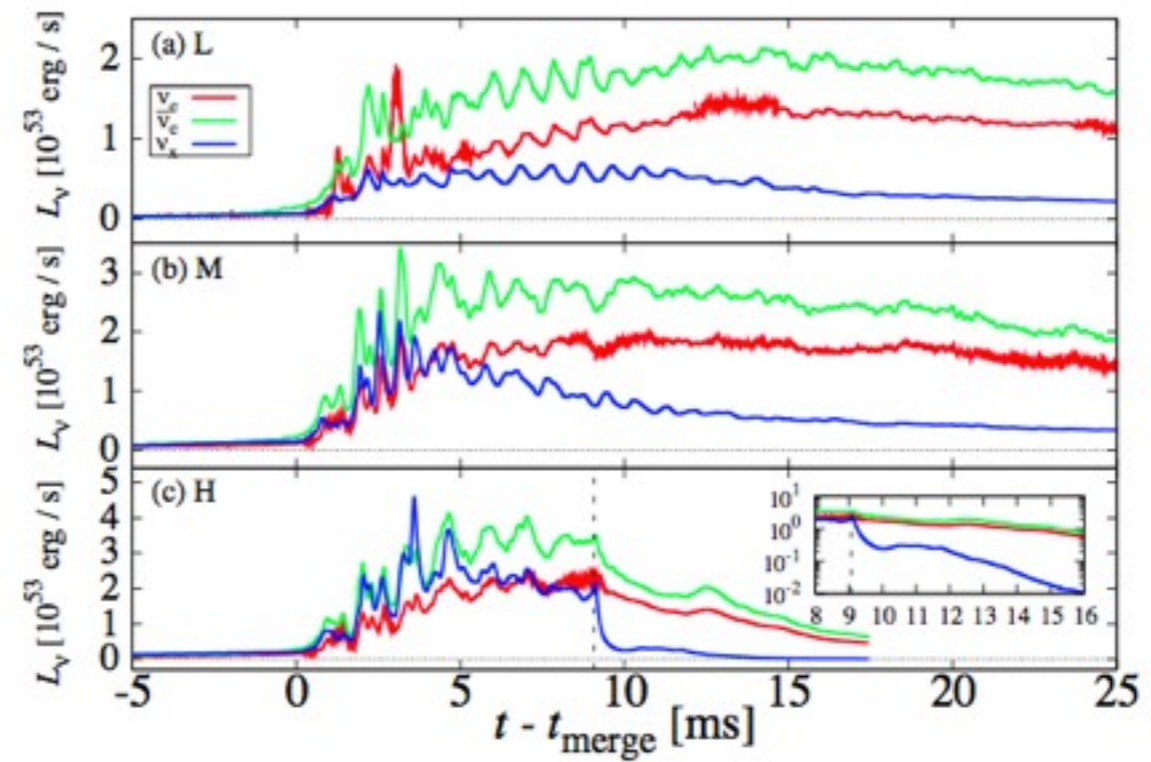


In case of compact binary coalescence : in progress.

## Compact Binary Coalescence



## Neutrino Flux



Sekiguchi et al. (2011)

- The coincidence between GW and Neutrino relaxes detection threshold
- GW: by relaxing the rate threshold from 0.1/day to 1/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.**





● Distance@neutrino event count=1

