

Multi-Messenger Observation using LCGT

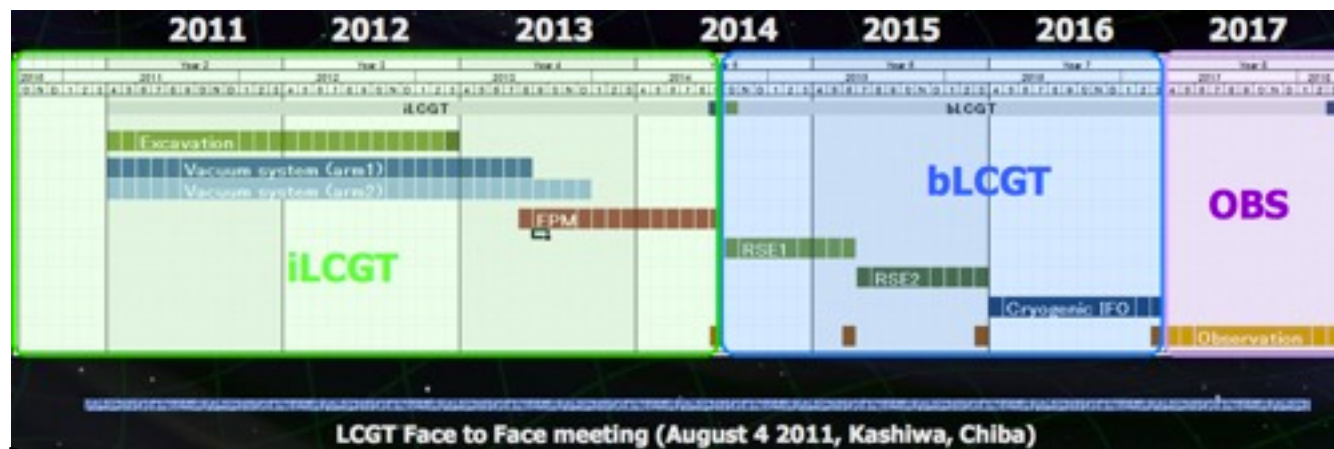
(Case study: LCGT--Super K connection)



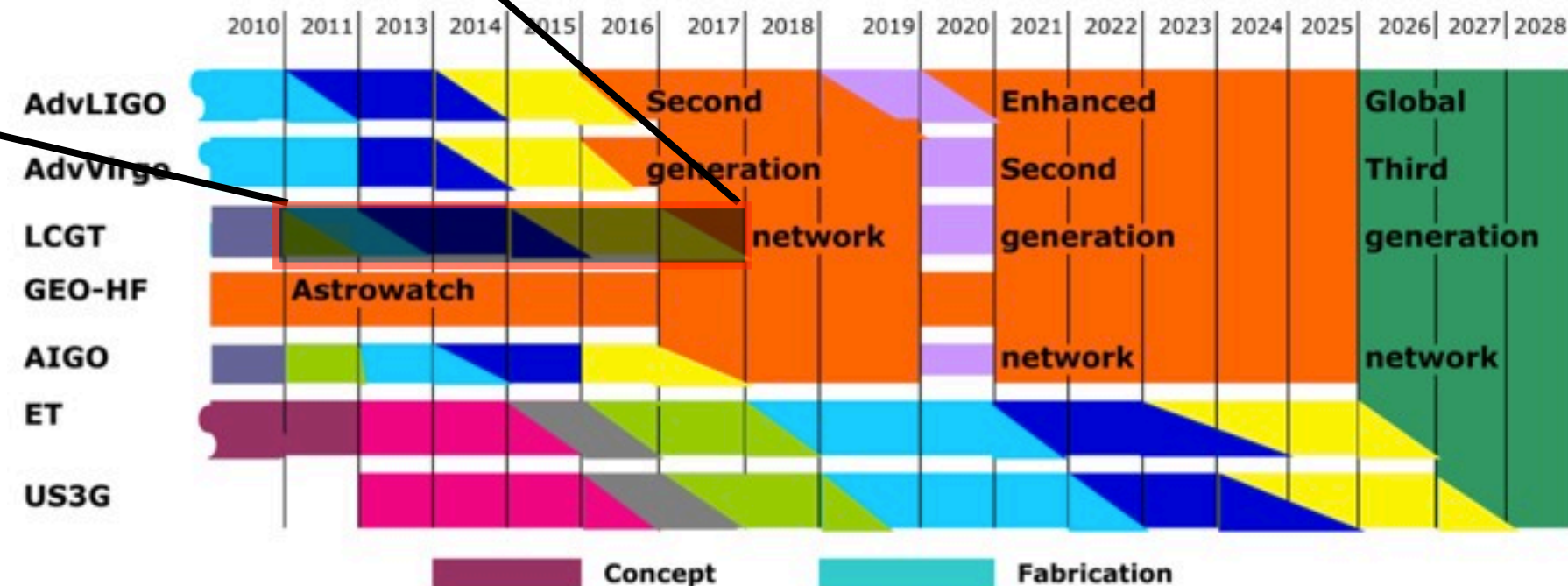
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- iLCGT : 1 month observation is planned in 2014.
- bLCGT : long duration observation is planned in 2017~
- Both LCGTs will try to make 1st detection of gravitational waves.
- ... Even only LCGT is in operation.



from GWIC Road map



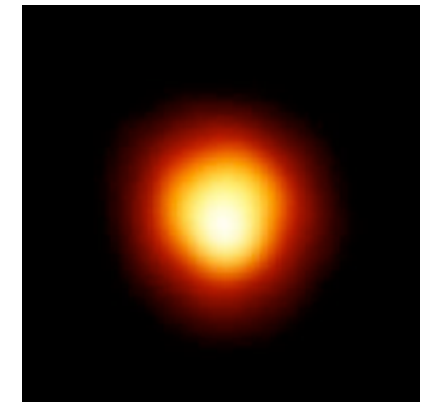
from LCGT Road map

● Core-Collapse SuperNova is one of promising sources.

● Betelgeuse -- Red supergiant star

● Distance : 196 pc

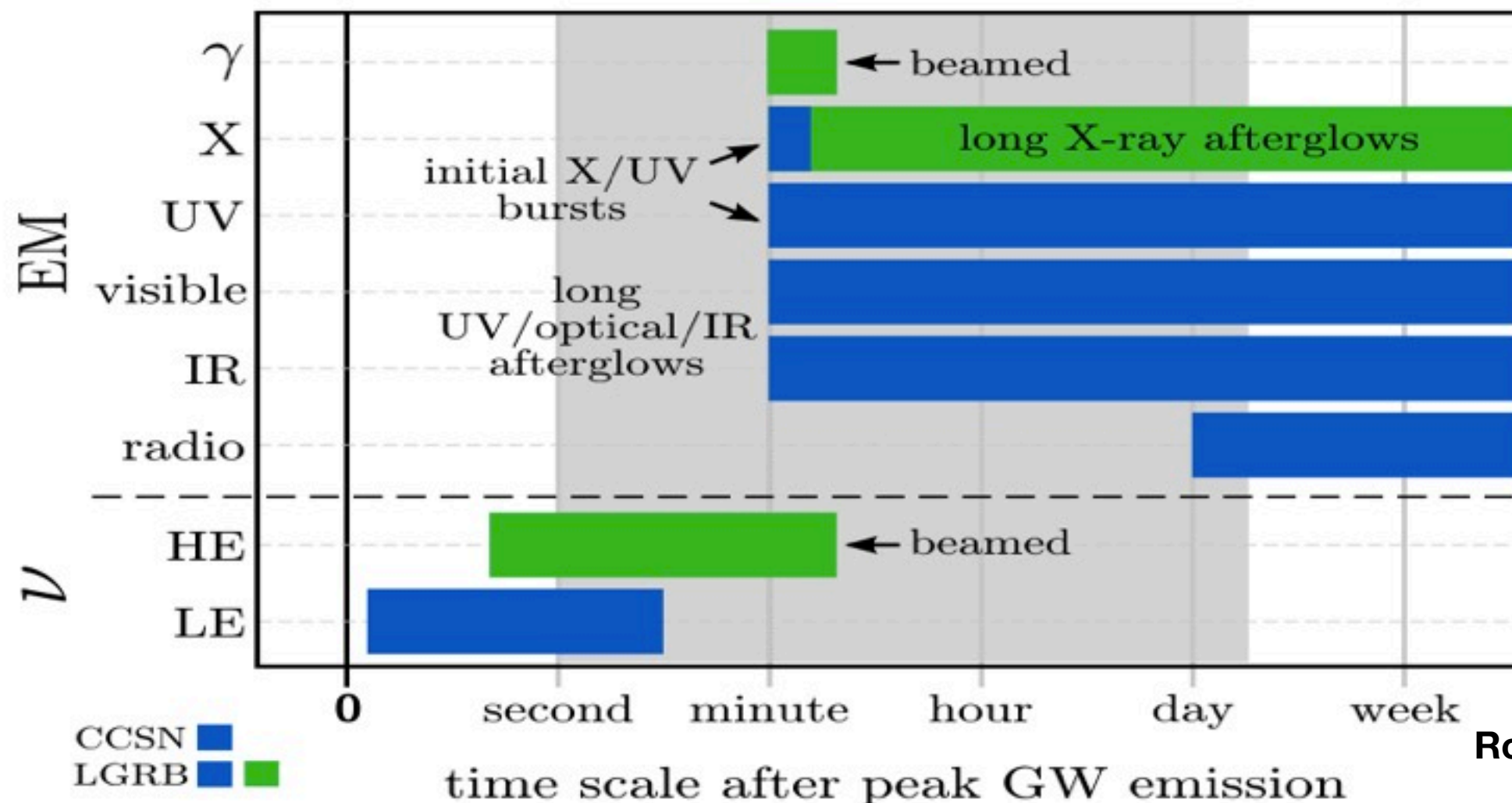
● Mass : $20 M_{\odot}$



Betelgeuse

● Besides GW, neutrino and EM wave will be radiated.

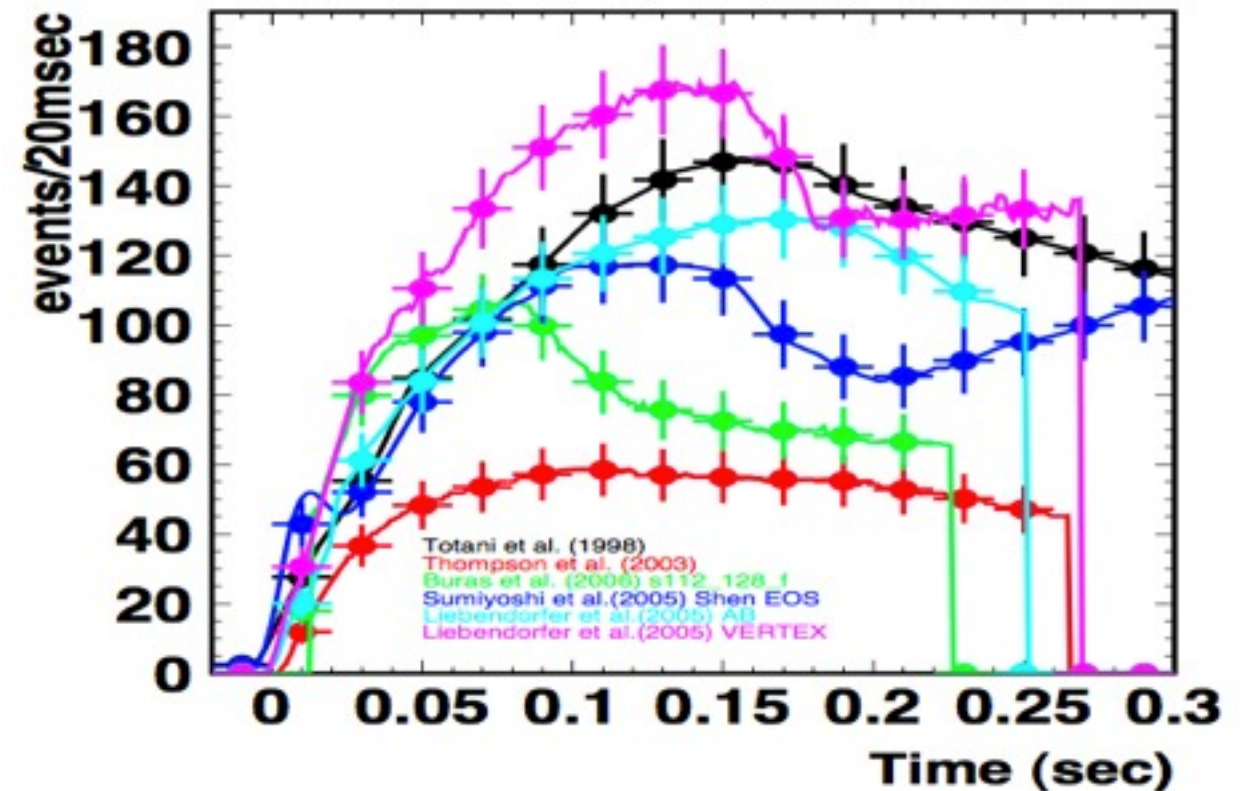
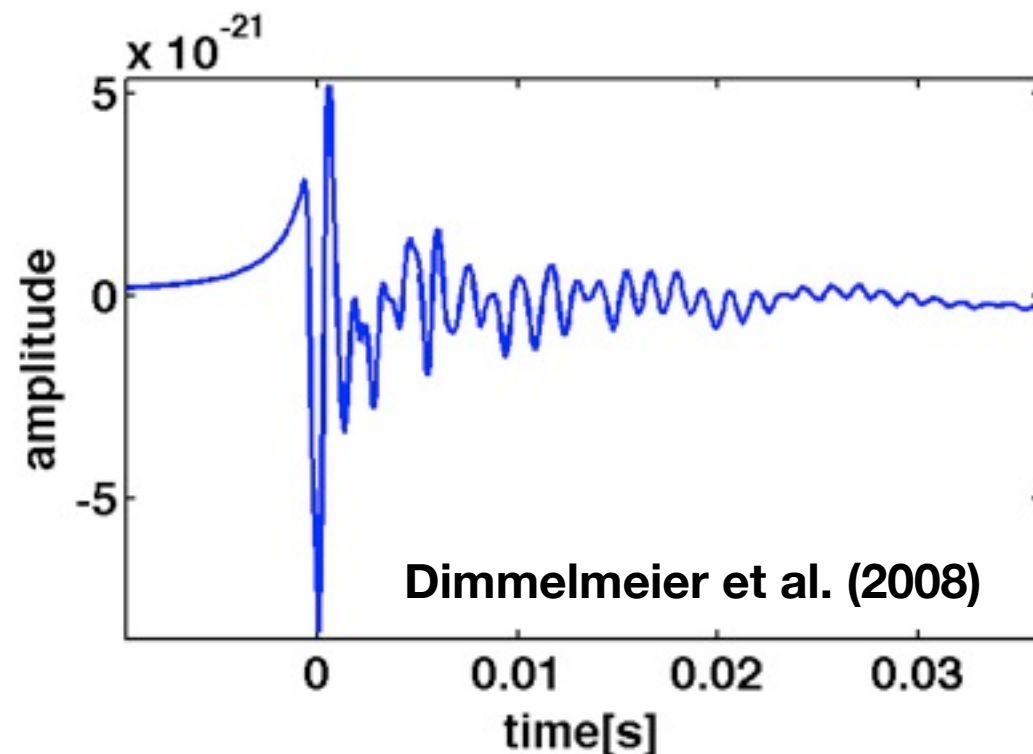
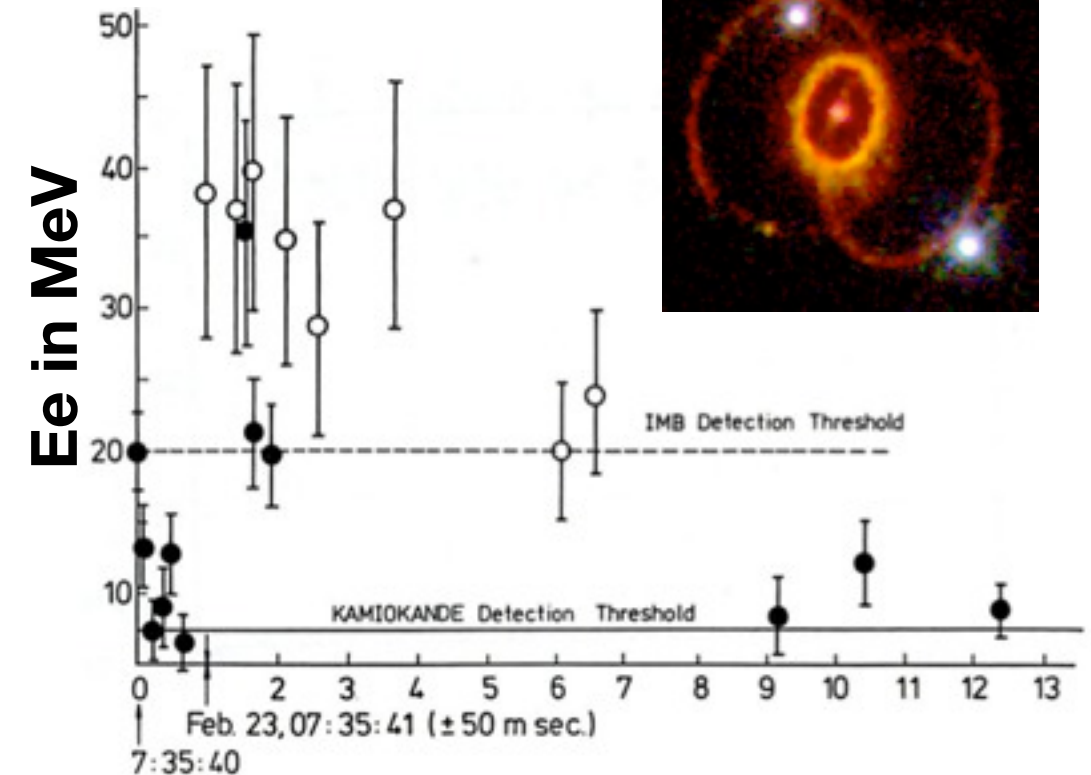
● Both GW and neutrino emission will occur within 20[s] after the core bounce. ~hours later EM emission will occur.



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

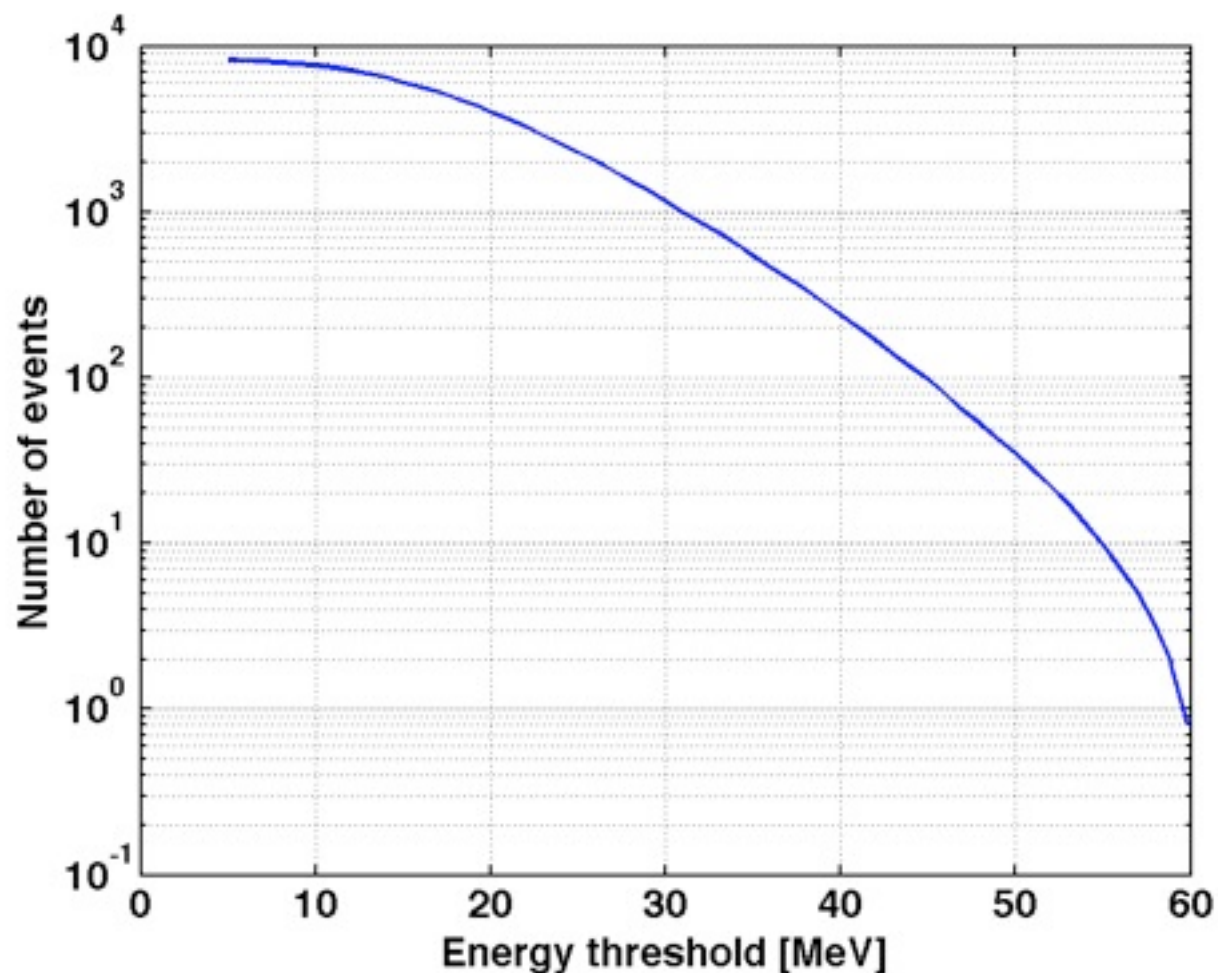


- Another way is to perform GW-neutrino coincidence analysis. Since coincidence analysis reduces false alarm rate, **we can set low threshold for both GW and neutrino search.**
- From the observation of neutrinos from SN1987A and various simulations, **the time window of the coincidence will be at most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

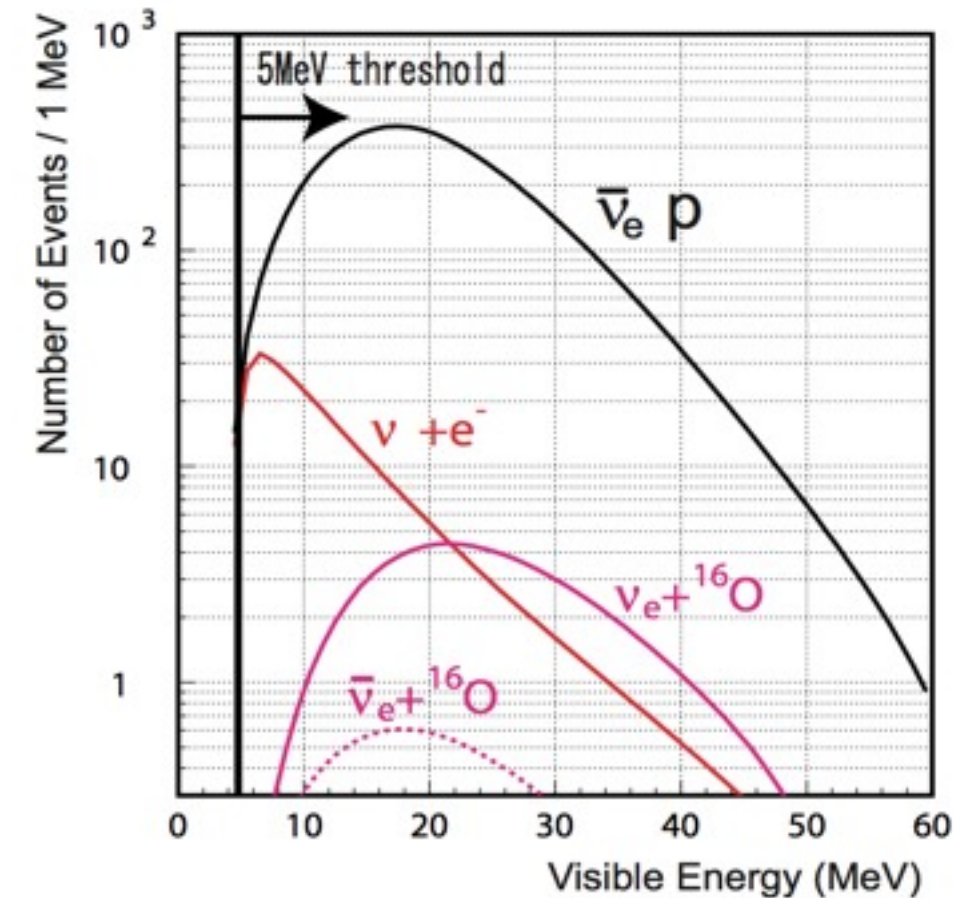


- Taking into account of all neutrino flavor, Super K will detect ~10000 events in 20 [s] when a supernova occurs at 10kpc.

Number of events from SN at 10kpc
above the threshold



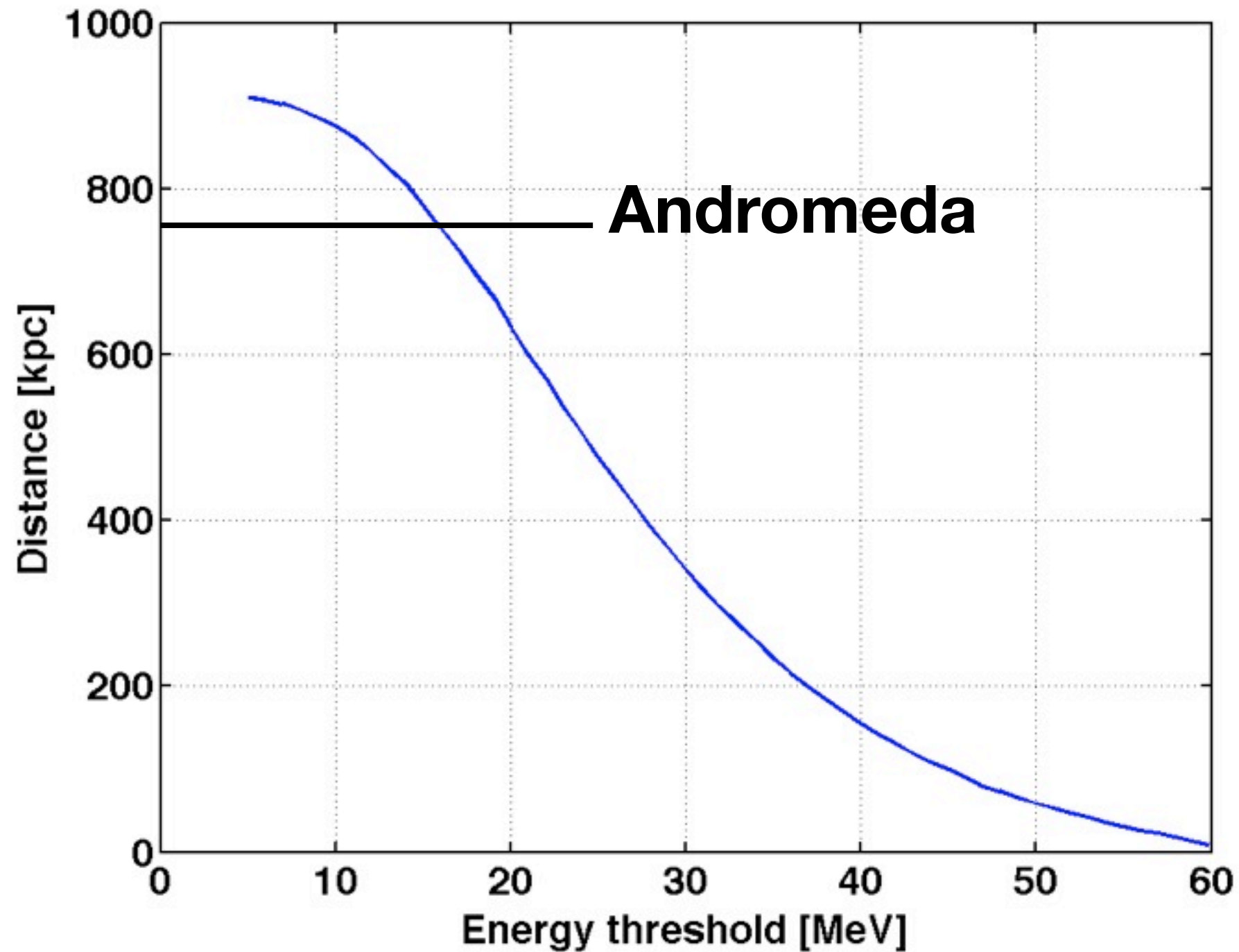
Number of events from SN at 10kpc
as energy



Ikeda et al. 2007



● Distance@neutrino event count=1

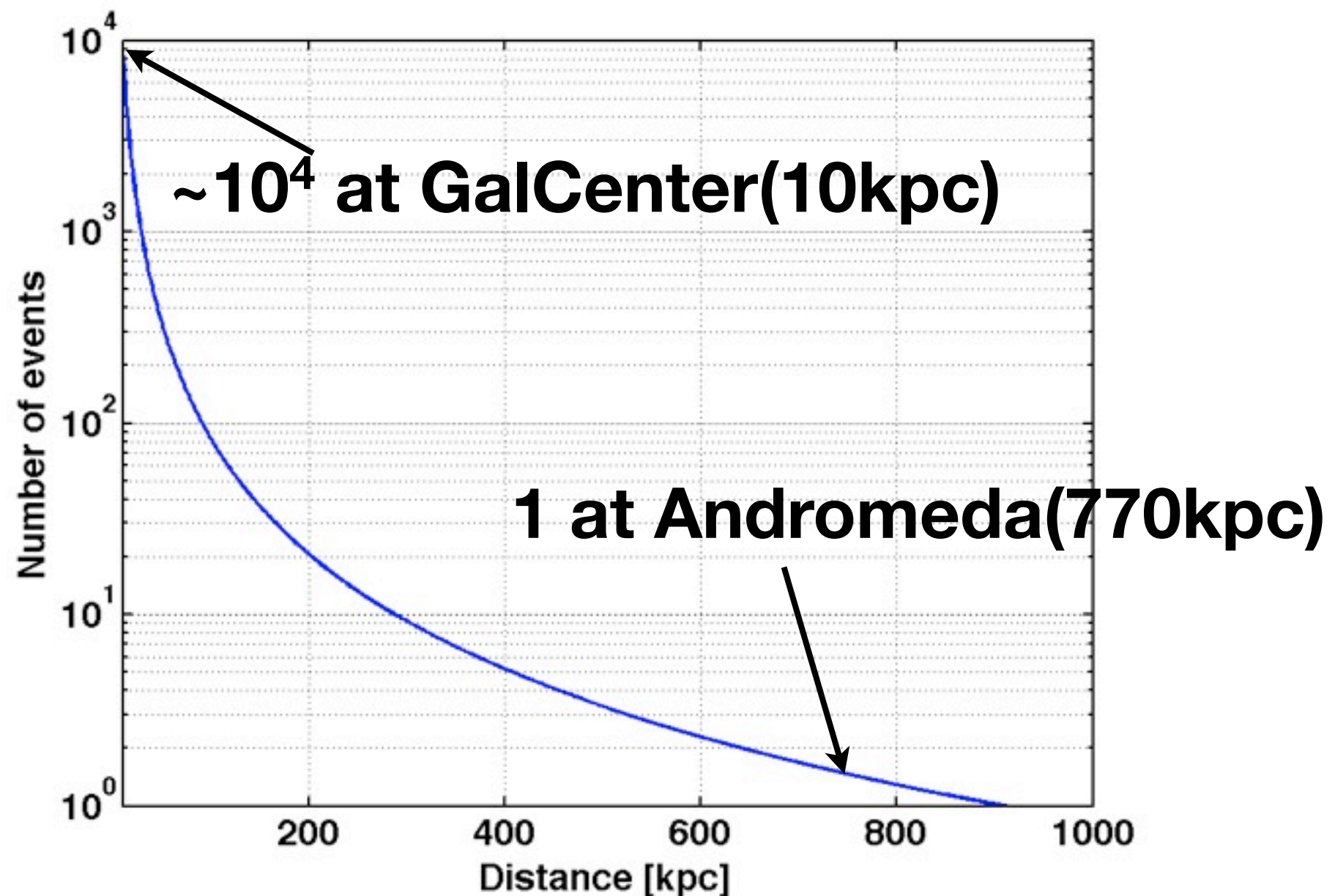




- We estimate the number of neutrino events Super-K will detect by fitting the right plot in the previous page.
- We don't apply any cut (Spallation cut etc.)
- Multiplicity of neutrinos in a given time window is subject to Poisson probability distribution.



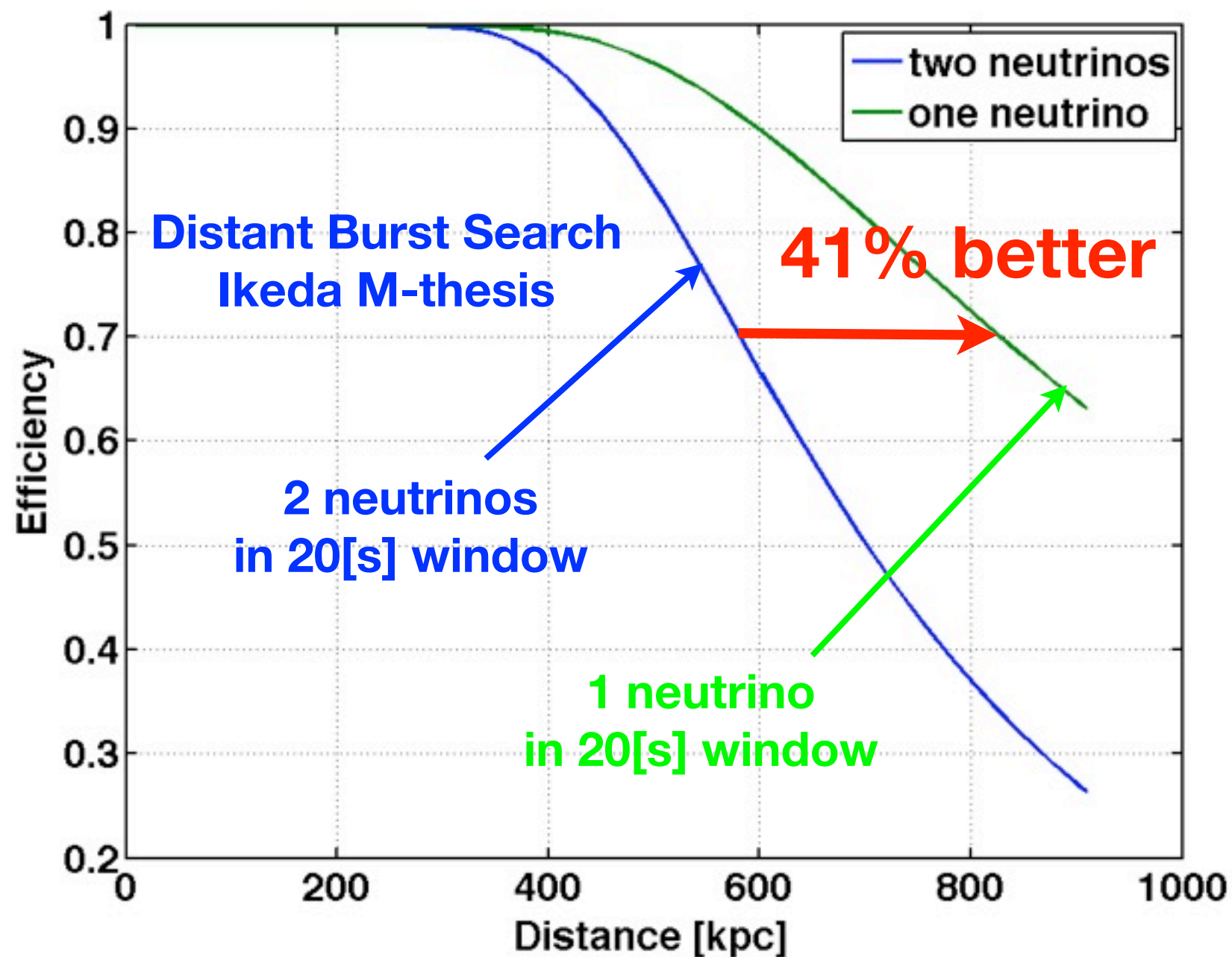
- Number of events as a function of the distance of a supernova.
- Can detect 1 event from a supernova at Andromeda.



- Lower threshold extends the detectable distance to supernova.

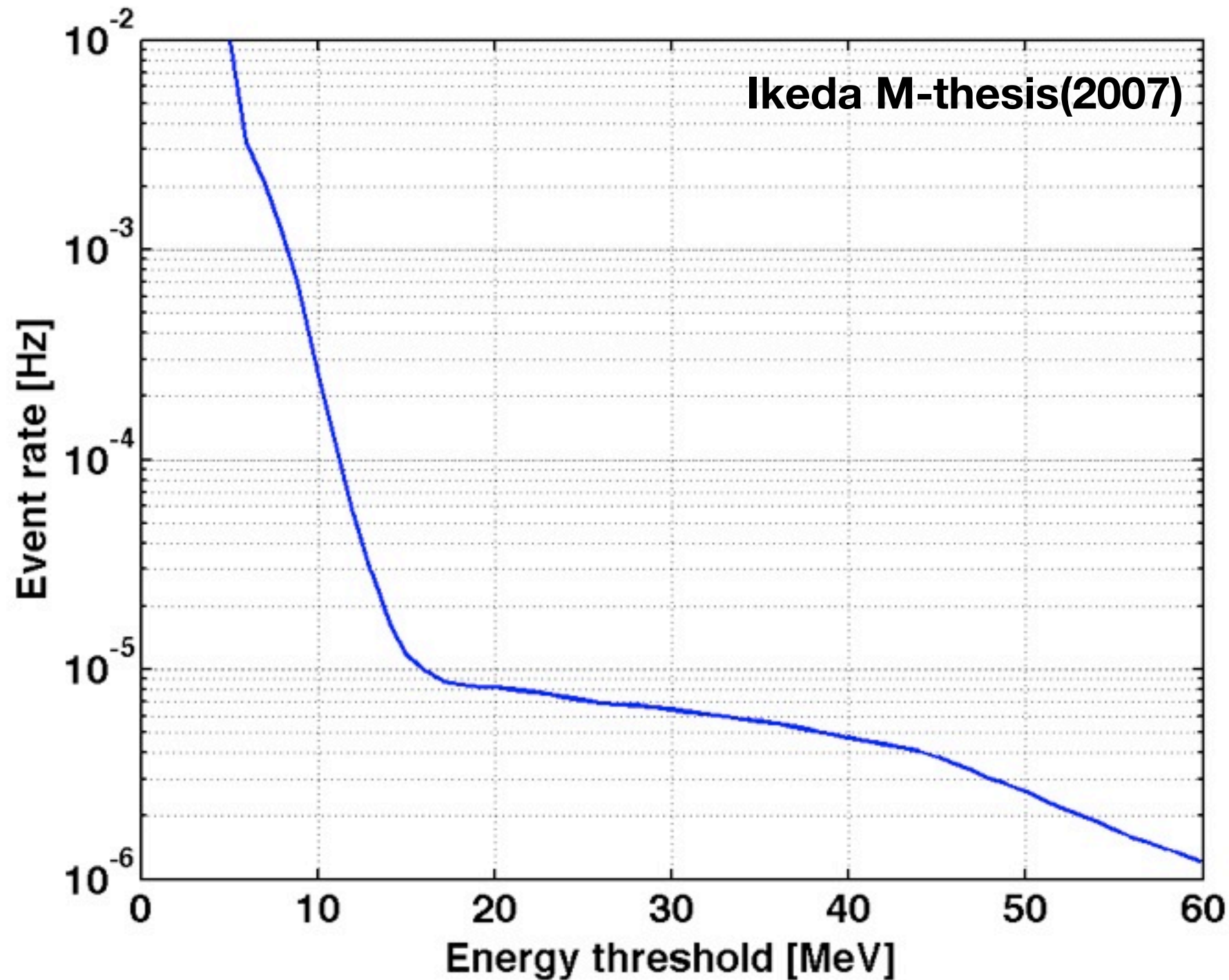
$$Eff_2 = 1 - \exp(-N) - N \exp(-N)$$

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



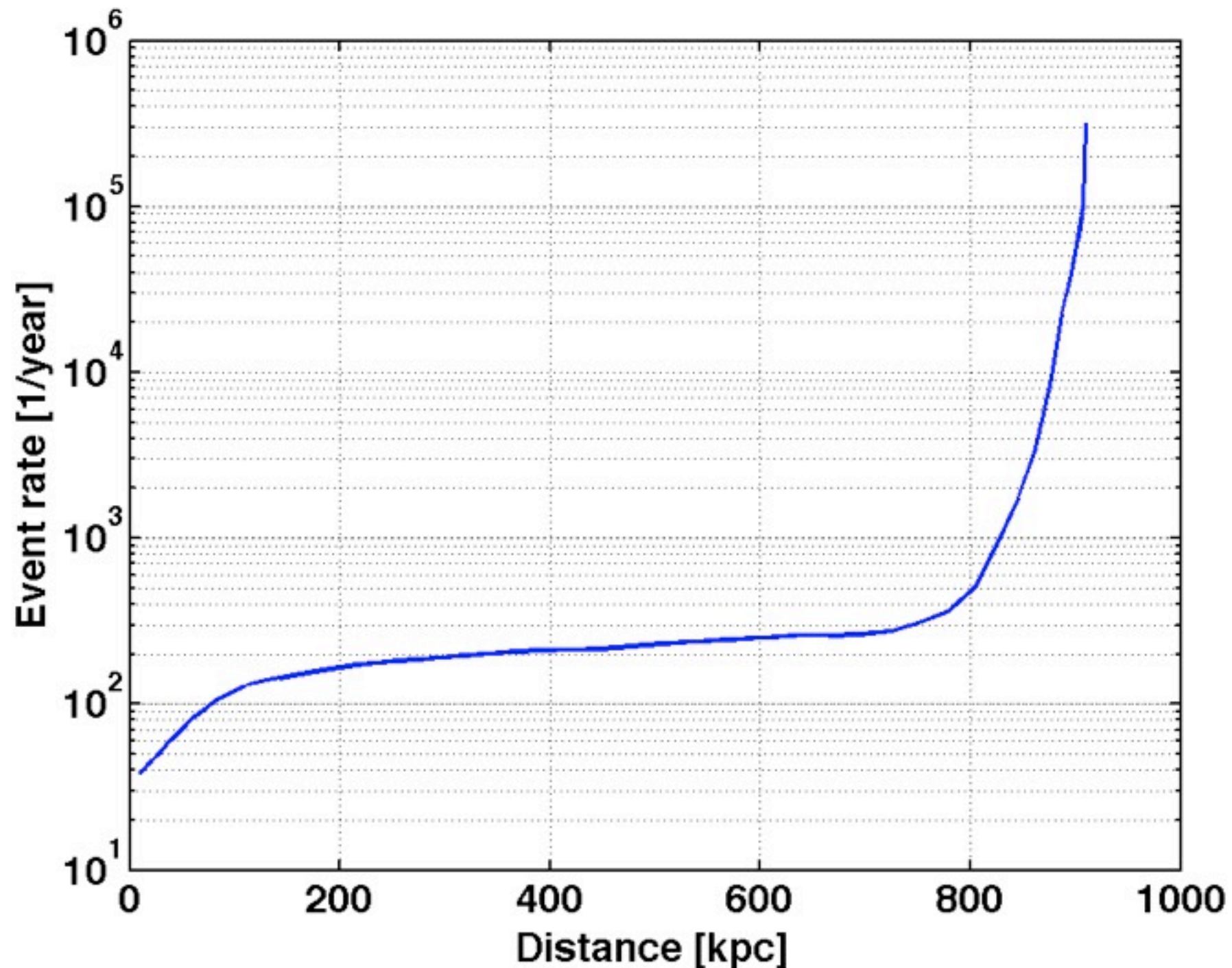


- SK background rate depends on a energy threshold.





- 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_{ν} : Event rate of neutrinos per seconds

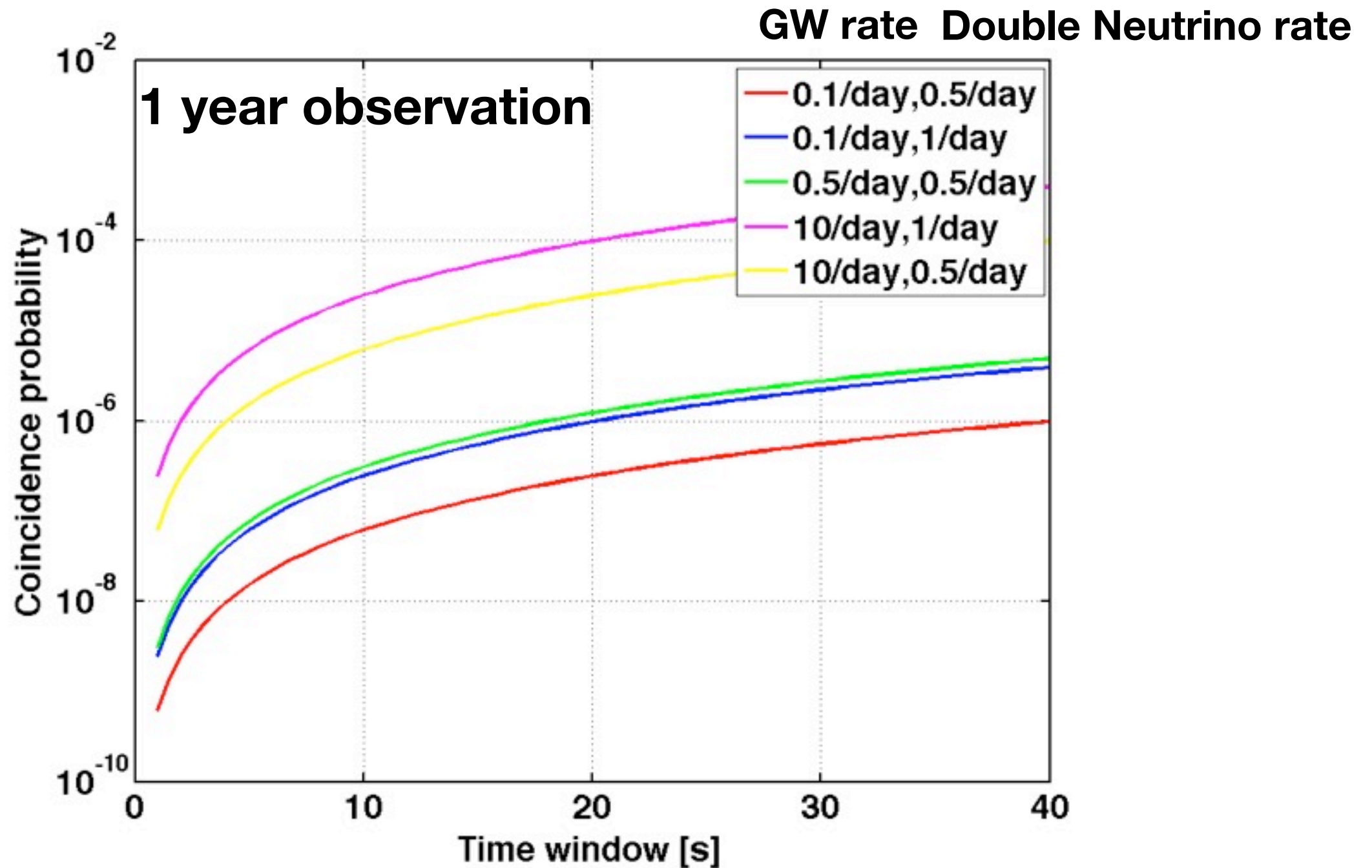
R_{GW} : Event rate of GWs per seconds

T : Total live time

t : coincidence time window

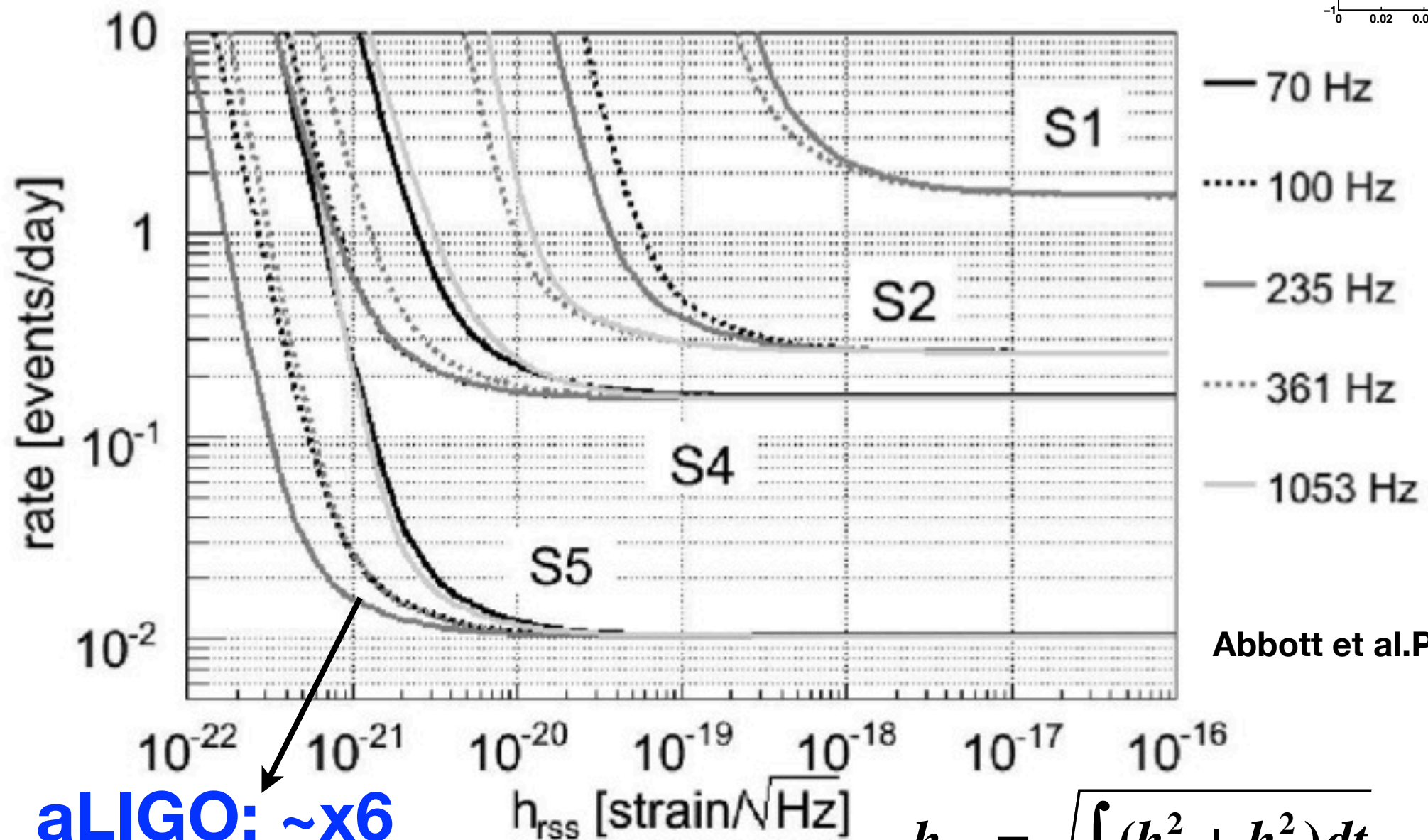
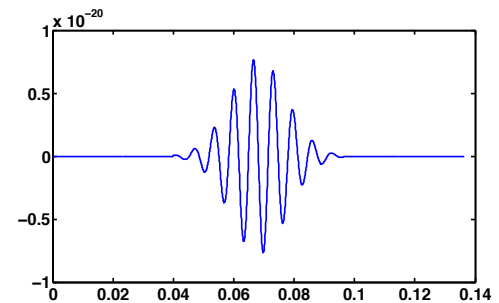


- Taking 20[s] for time window, (GW rate, Neutrino rate) = (0.1, 0.5), (0.1, 1), (0.5, 0.5) per day can reach 10^{-6} .



- 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)

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

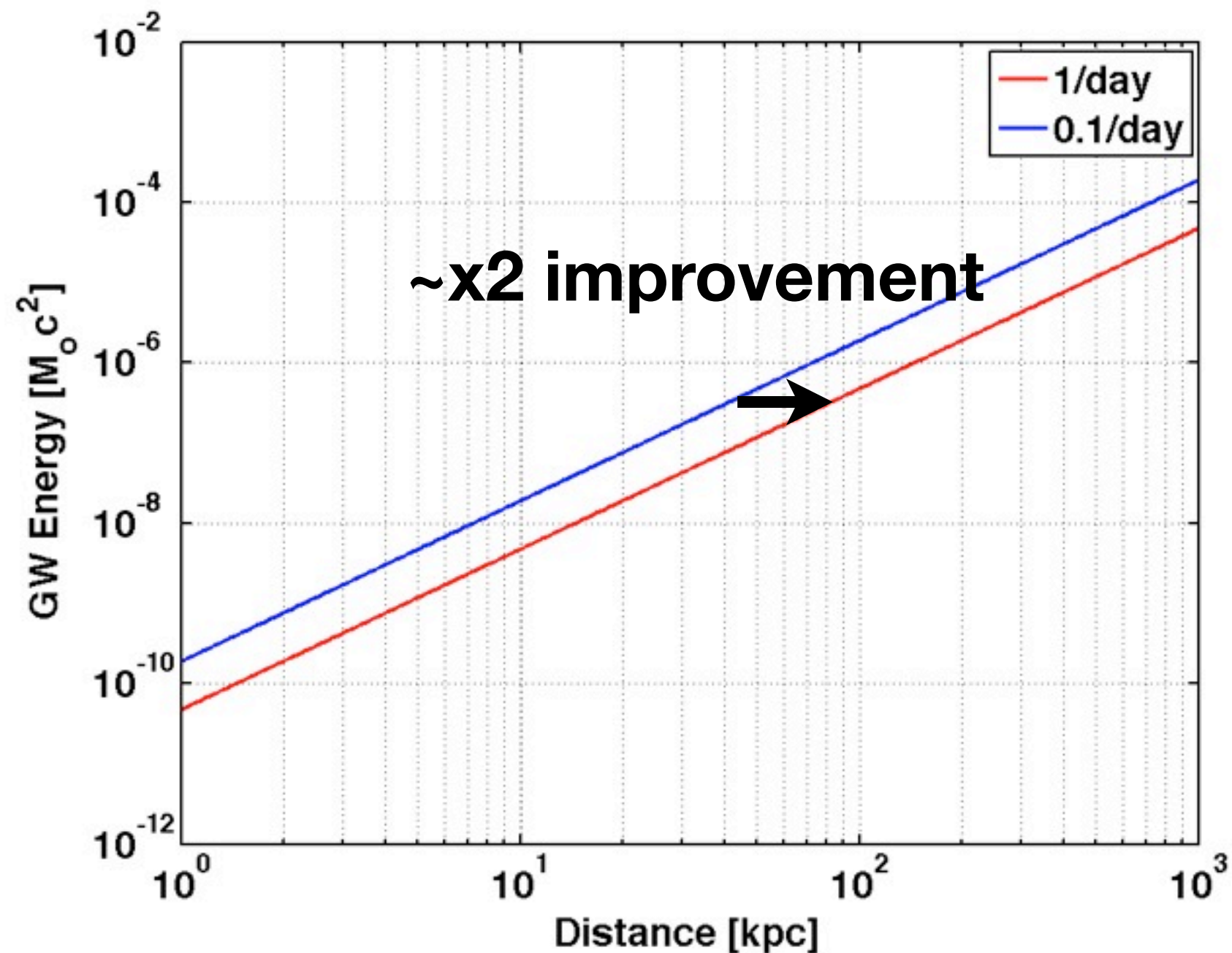
GW energy vs Distance



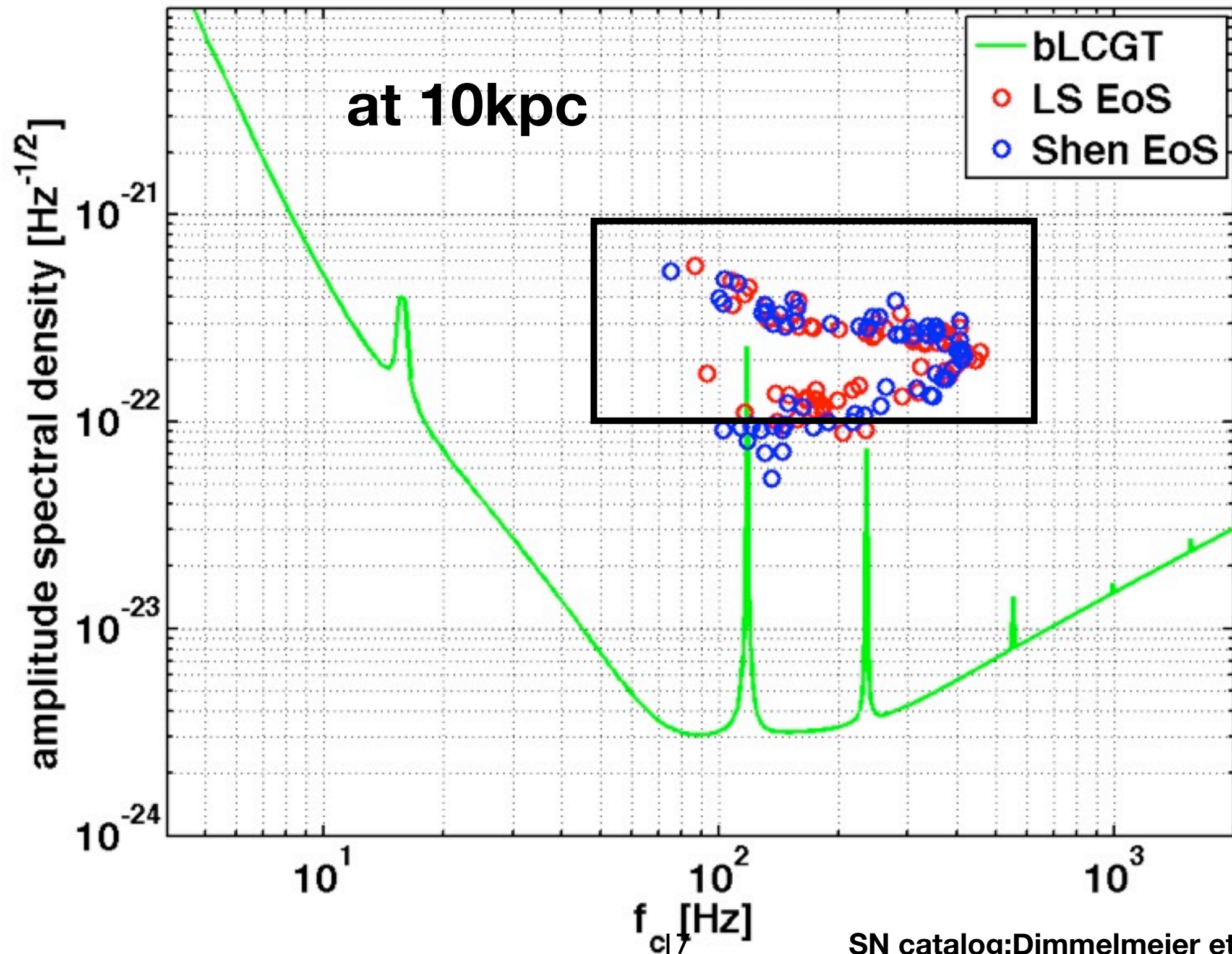
● Assuming isotropic GW radiation:

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

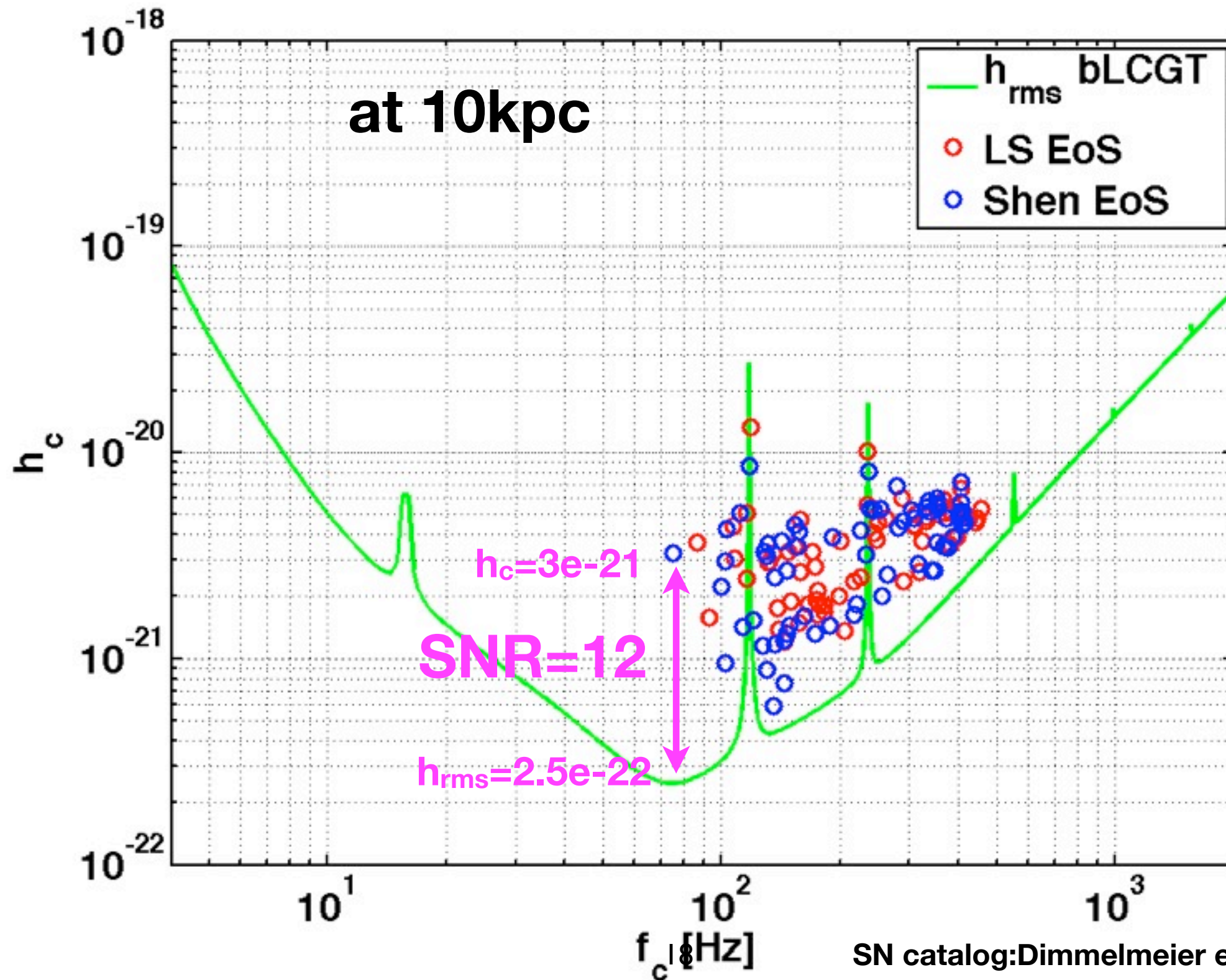
GW rate



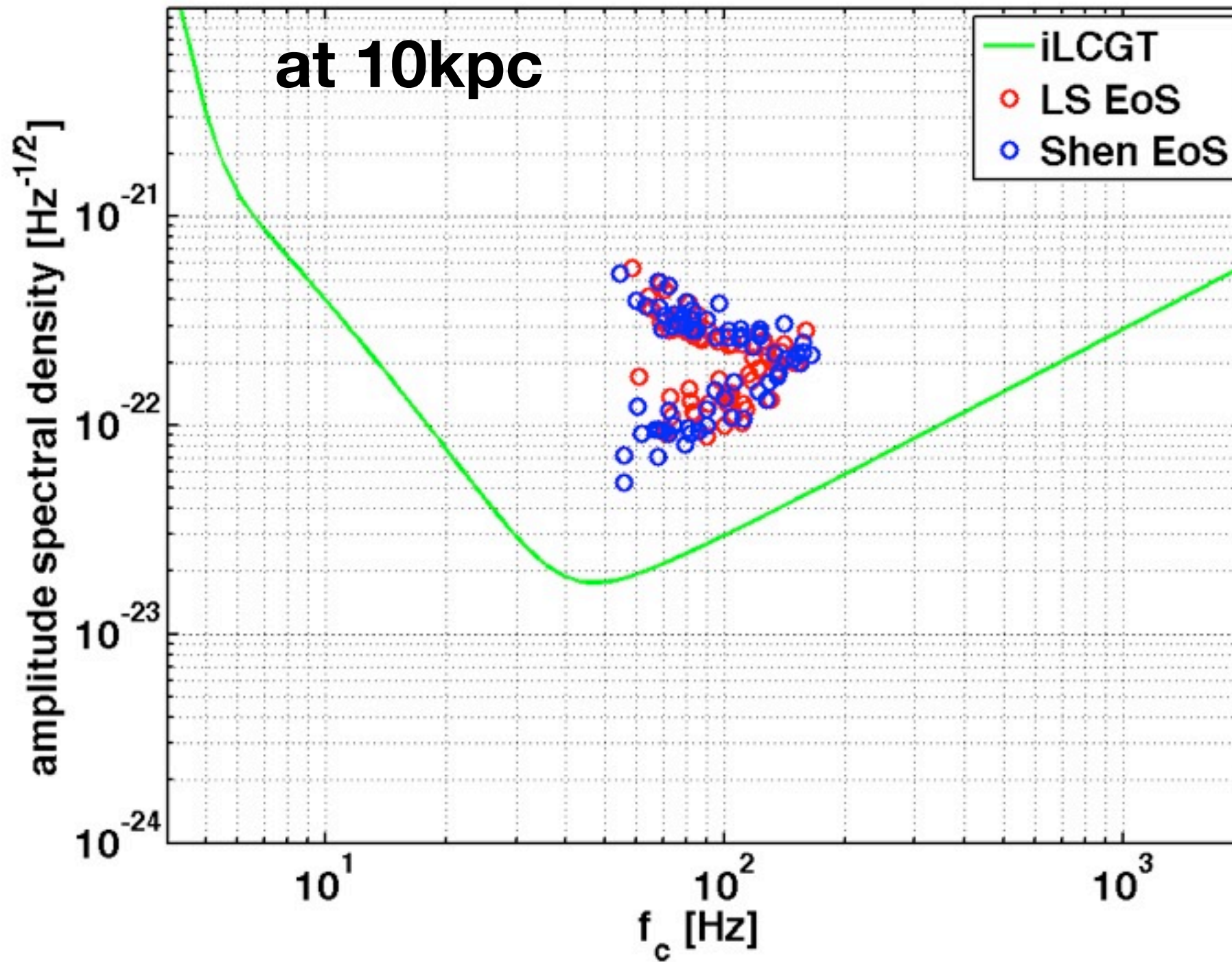
- If bLCGT reaches $h_{\text{rss}}=10^{-22}$ at 0.1 event/day and SK 1 event/day, CCP satisfy 10^{-6} .



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

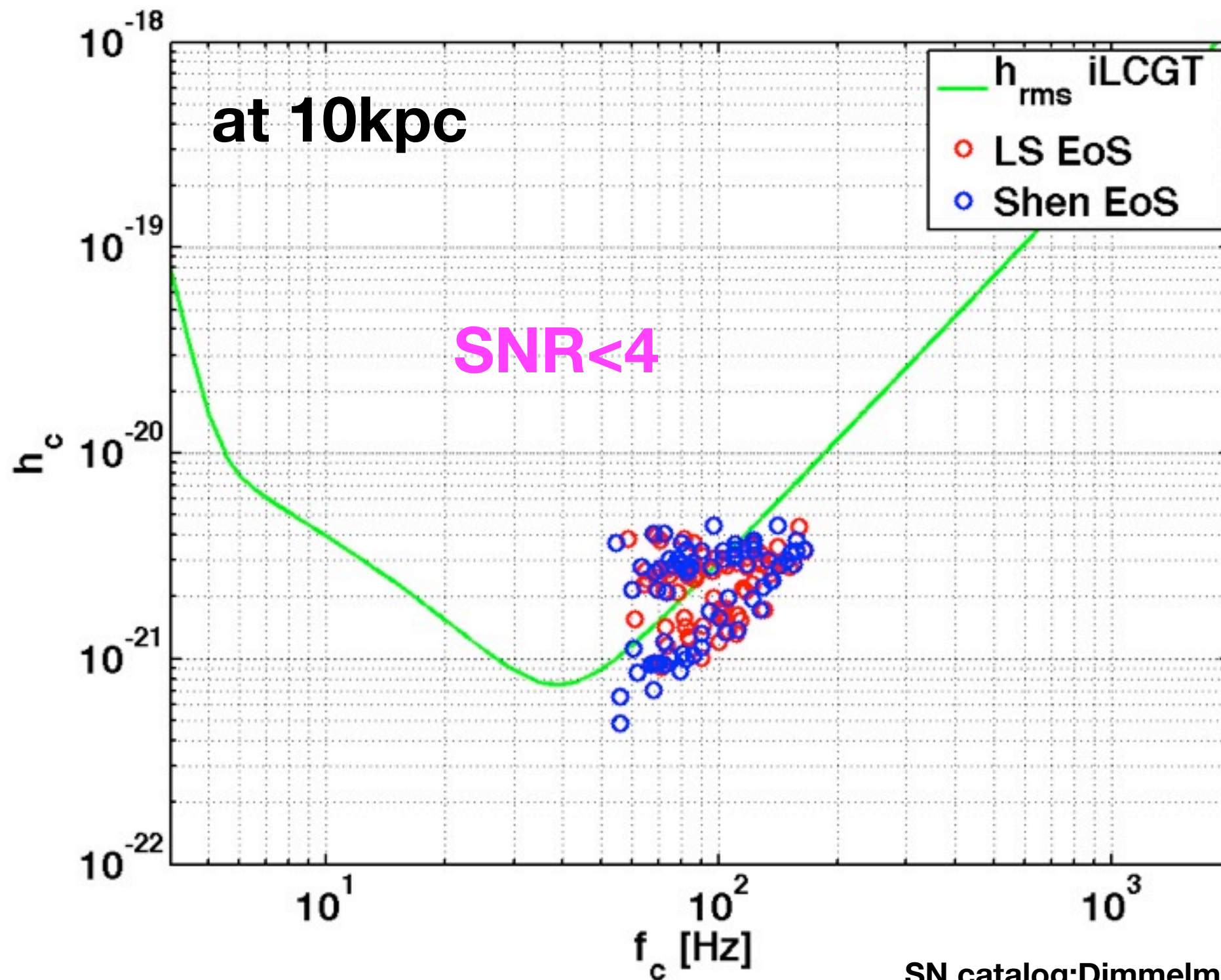


SN catalog: Dimmelmeyer et al. (2008)





- At most $\text{SNR} < 4$, so lower threshold search is required.

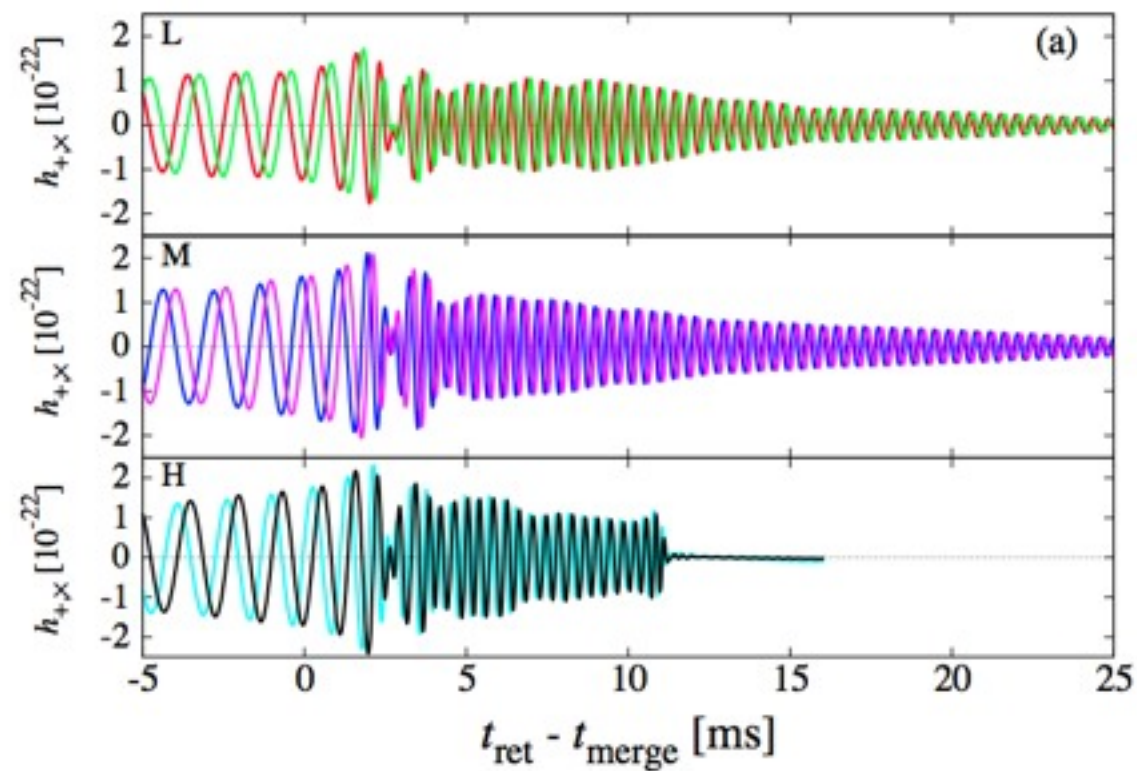


SN catalog: Dimmelmeyer et al. (2008)

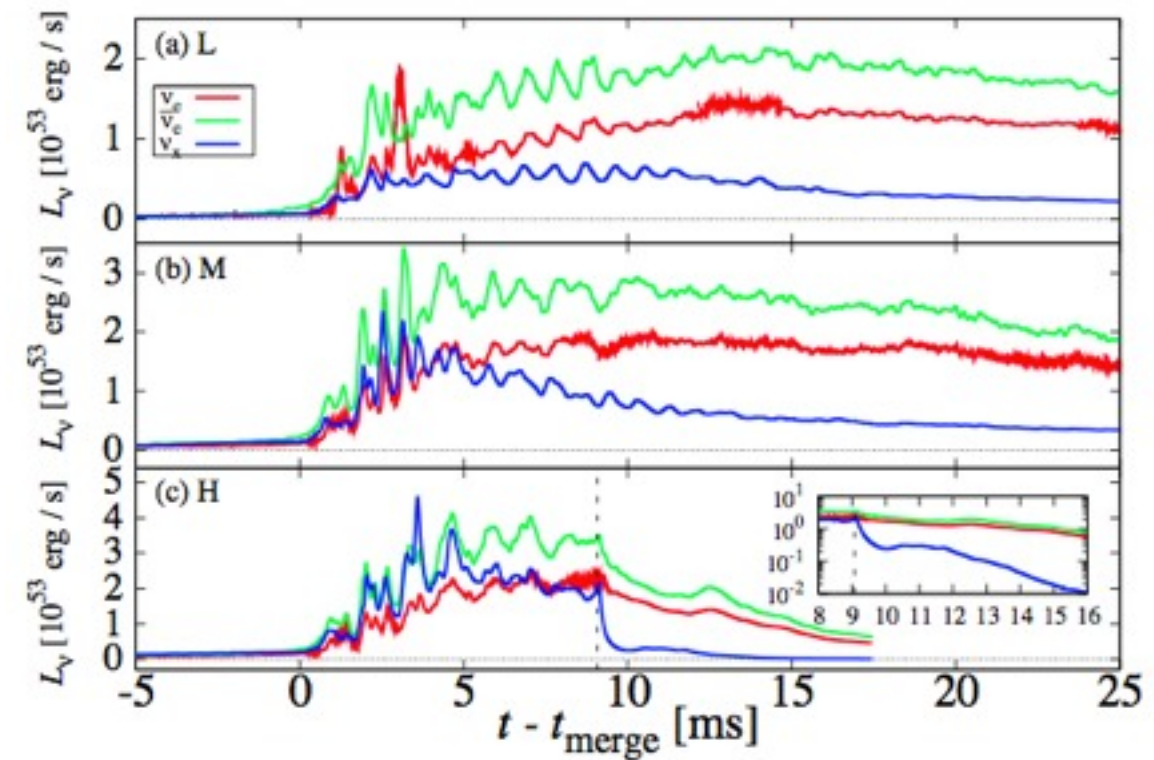


In case of compact binary coalescence : in progress.

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.**