Multi-Messenger Observation using LCGT

(Case study: LCGT--Super K connection)

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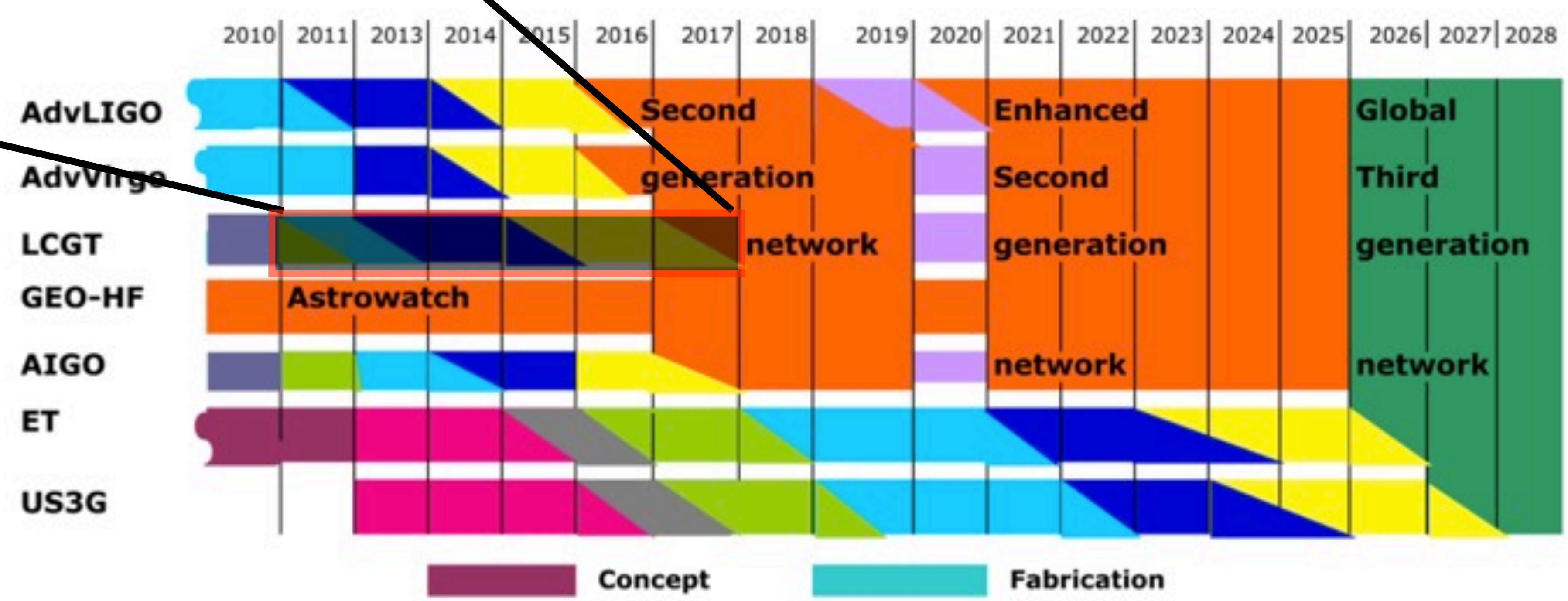
GW Observation using LCGT

- 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.

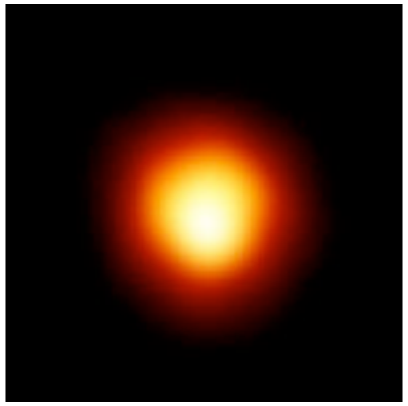
from LCGT Road map

from GWIC Road map

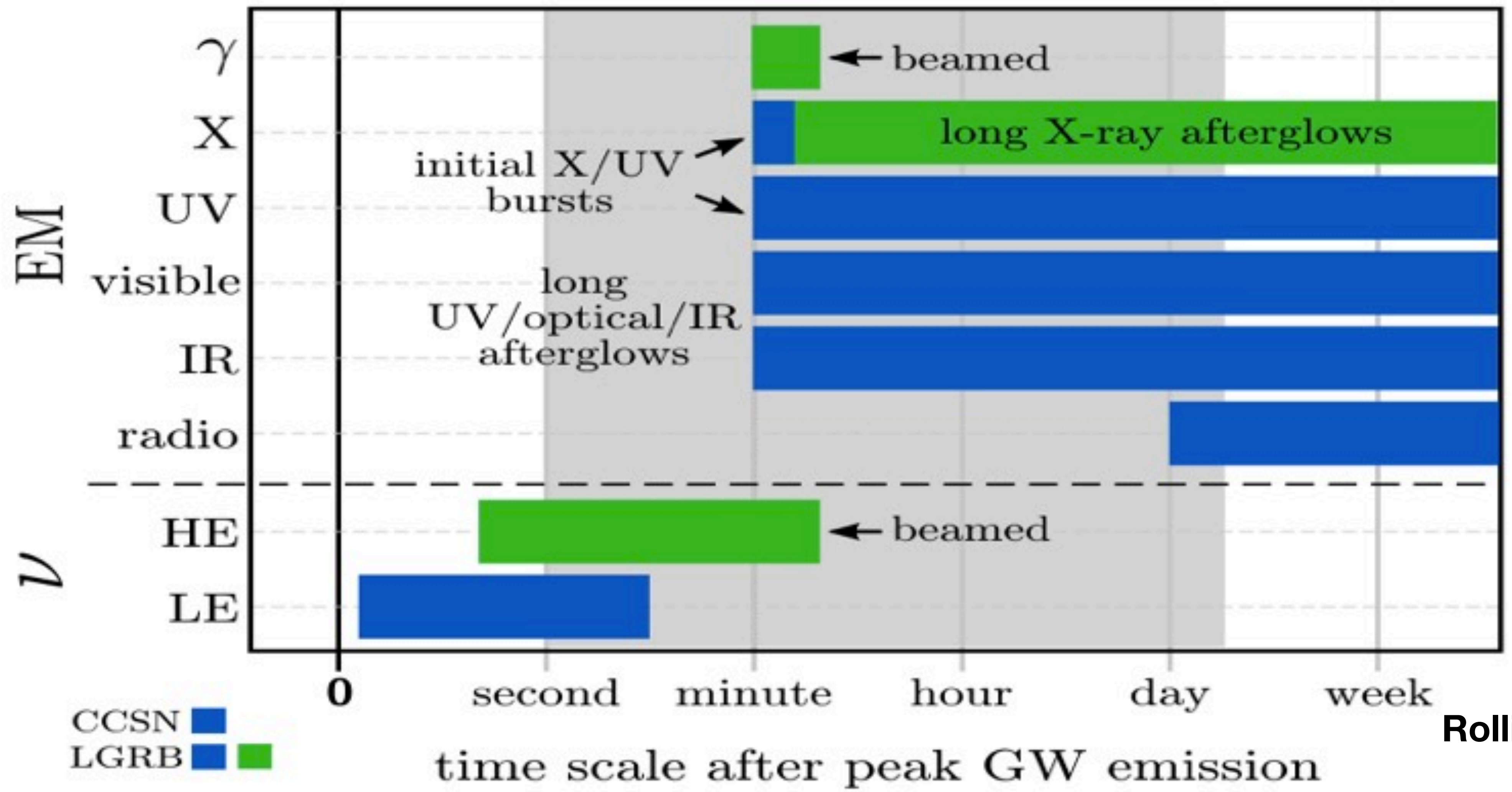


GW Sources : Supernovae

- 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

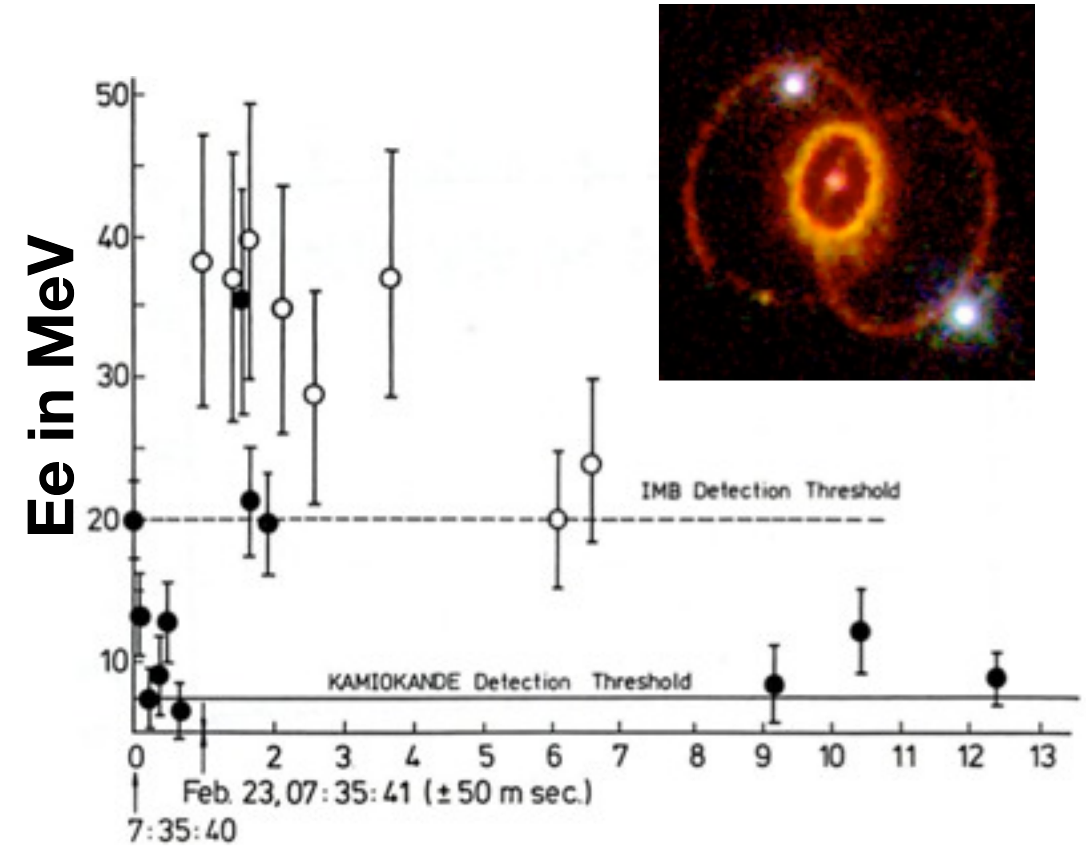


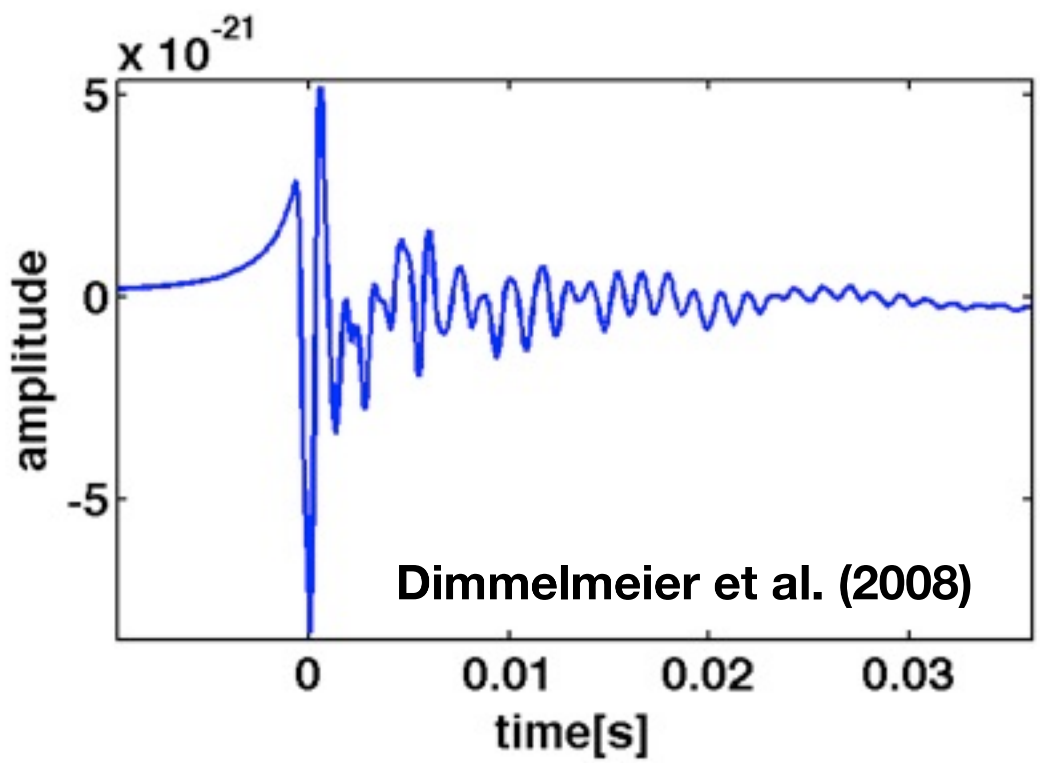
Rollins J. Thesis(2011)

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

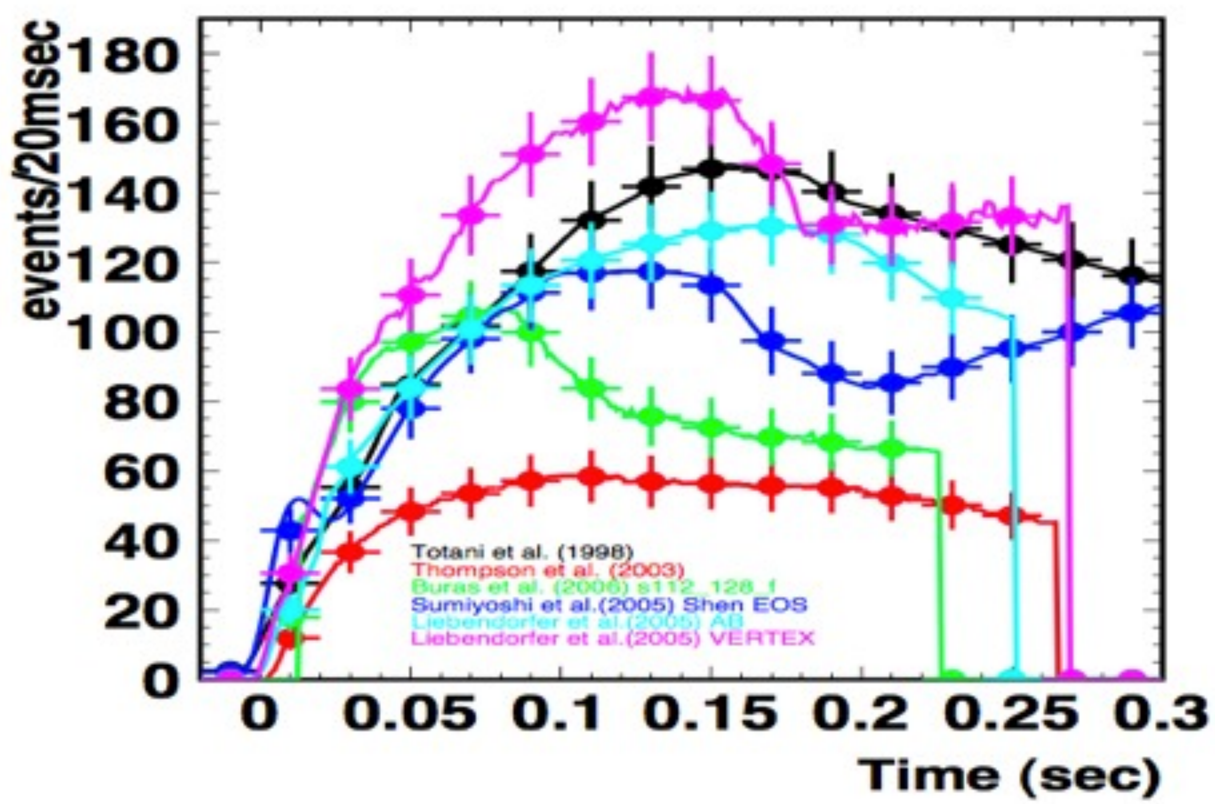
GW+Neutrino from Supernova

- 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





Dimmelmeier et al. (2008)



Nakahata (2008)

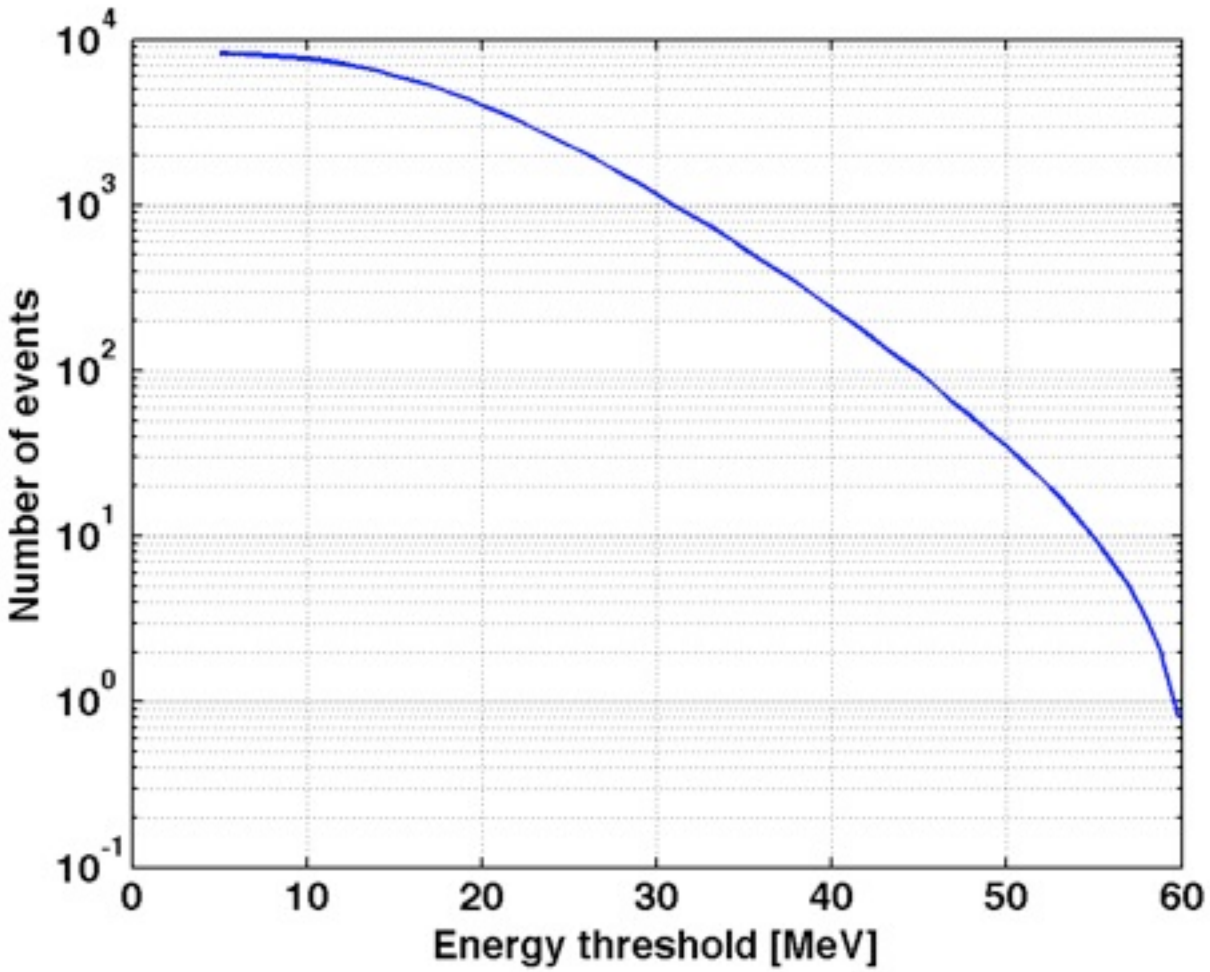
Coordinated Neutrino + GW Observation

- **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])**

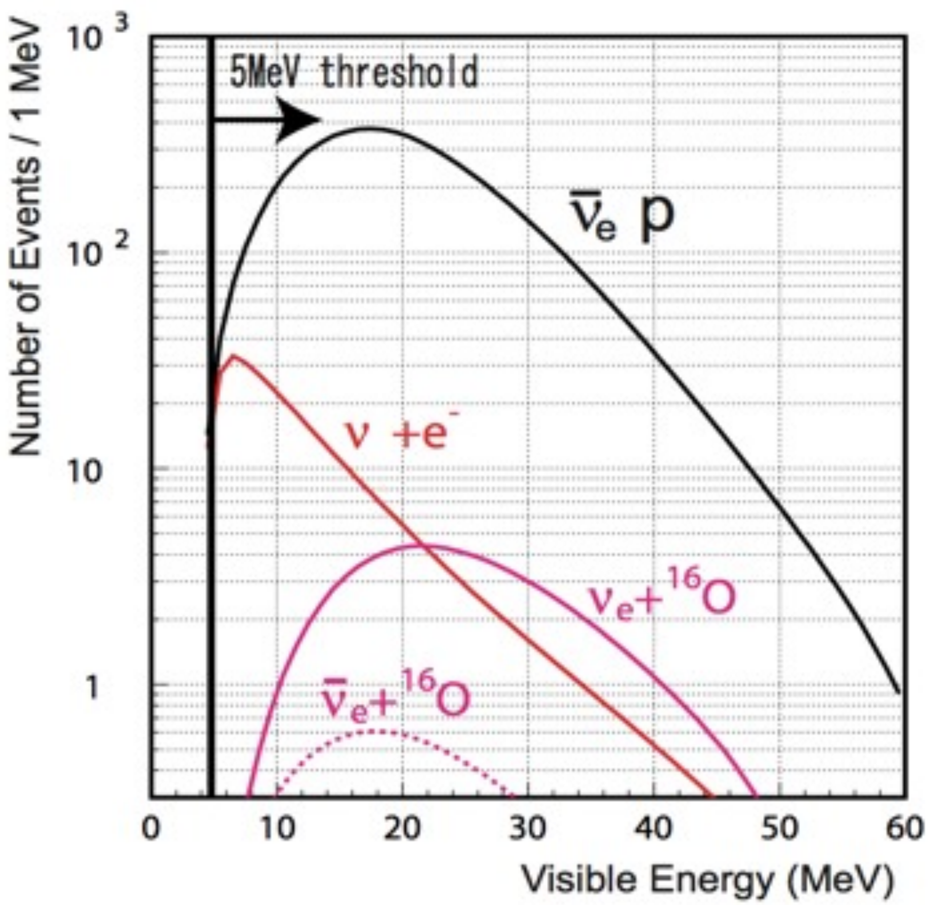
Neutrinos Super-K detecting at 10kpc

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

Number of events from SN at 10kpc above the threshold



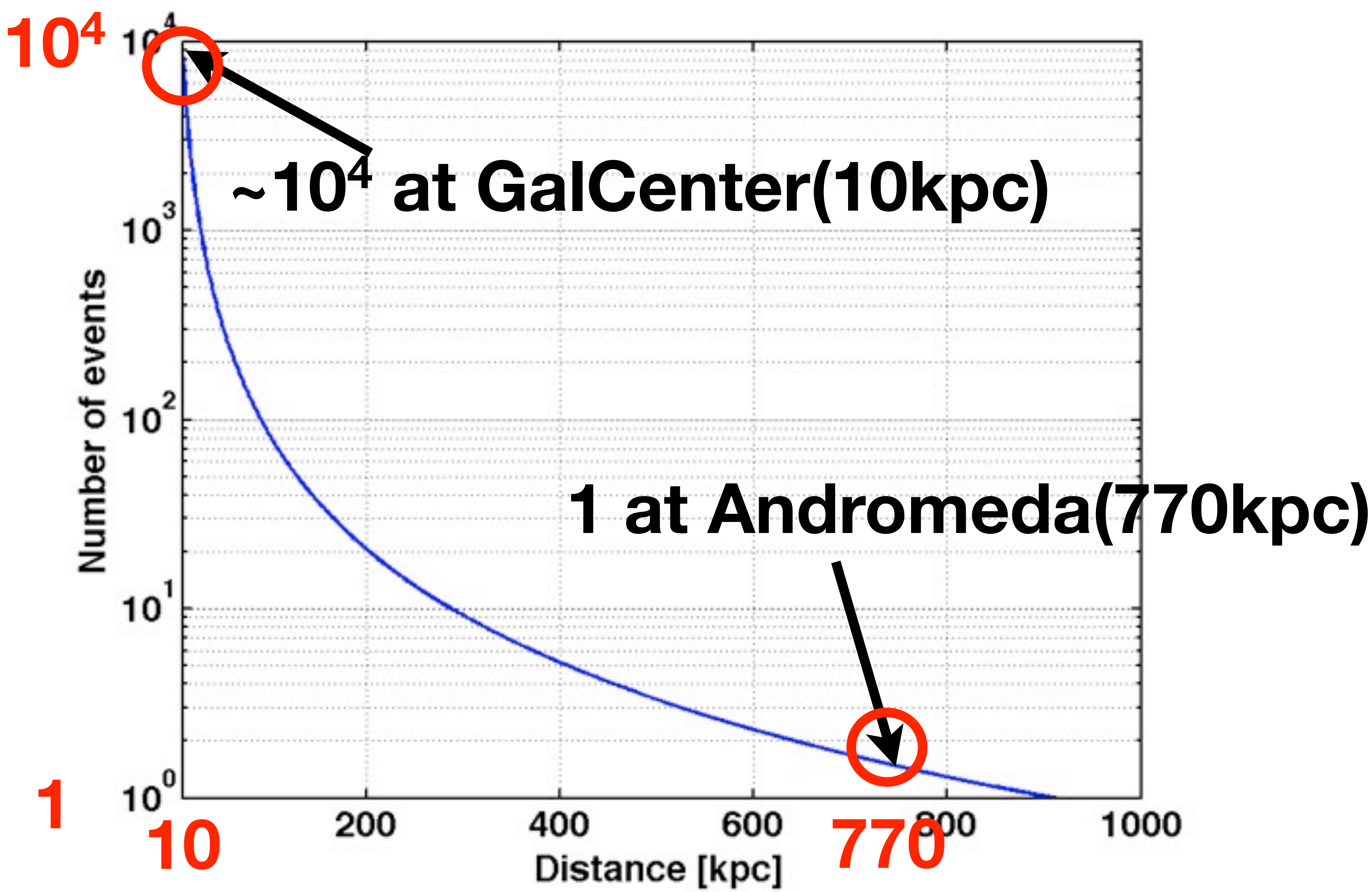
Number of events from SN at 10kpc as energy



Ikeda et al. 2007

Event number Super-K will detect

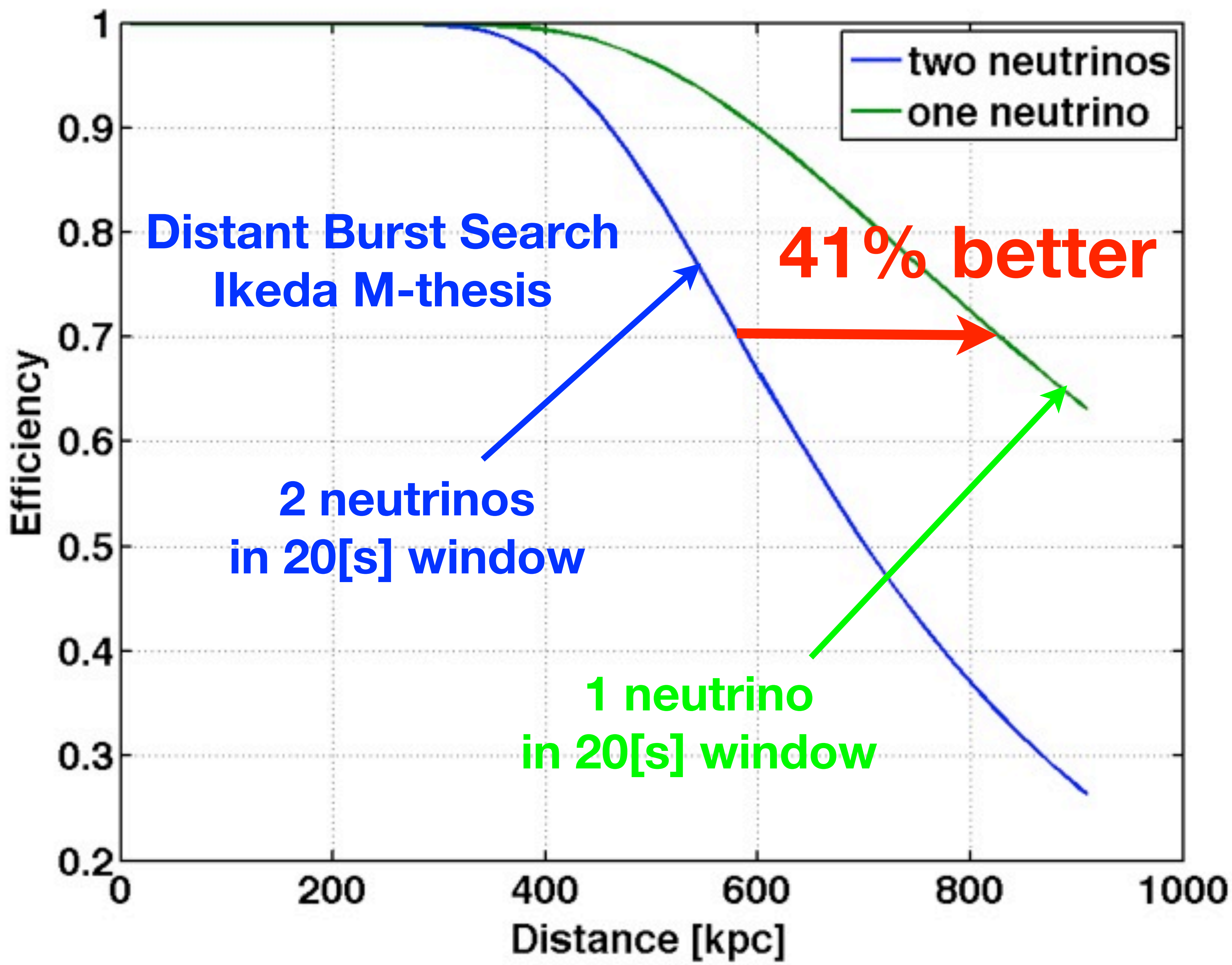
- Number of events as a function of the distance of a supernova.
- Can detect 1 event from a supernova at Andromeda.



Distant Supernova Search using Super-K

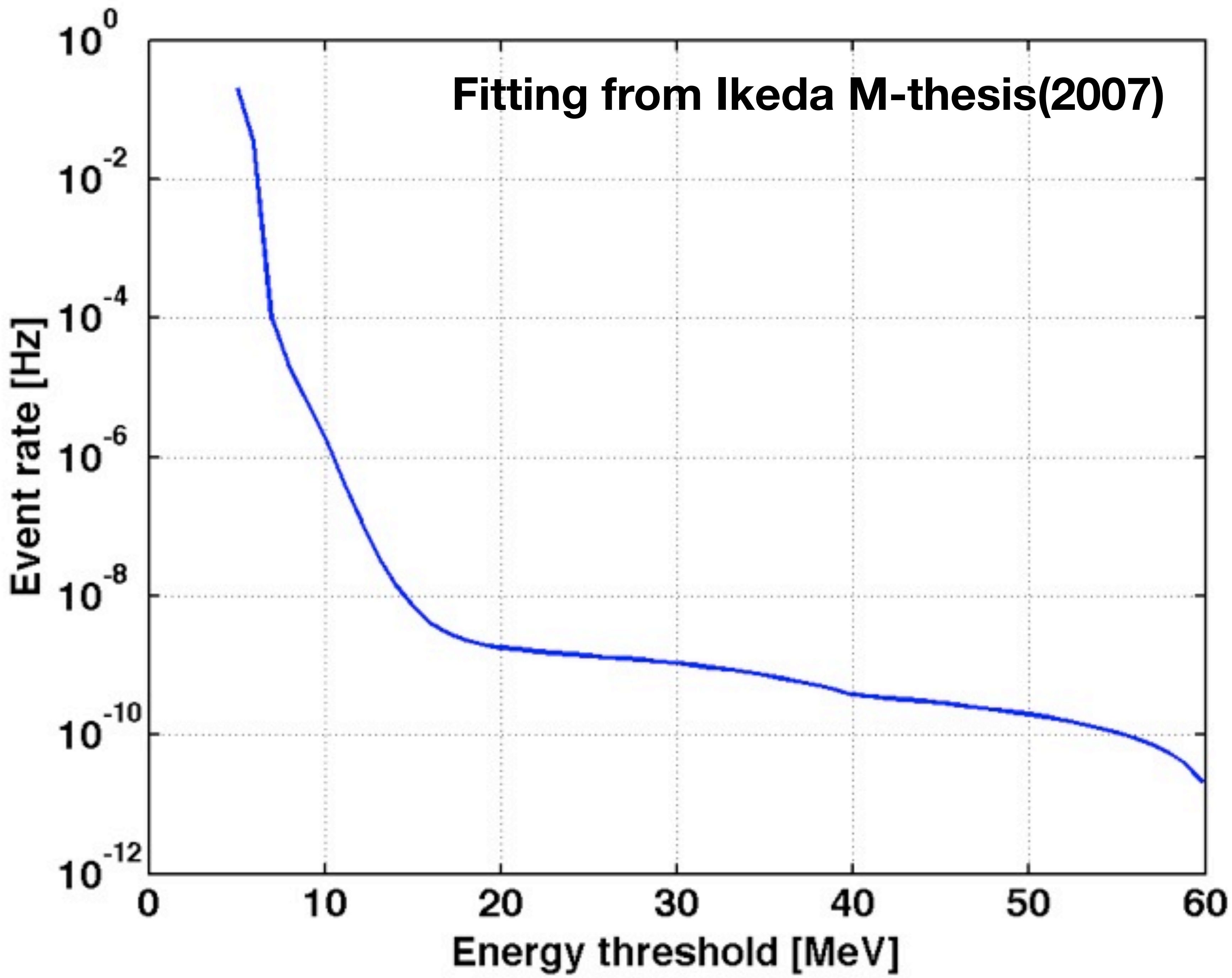
- **Lower threshold extends the detectable distance to supernova.**

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



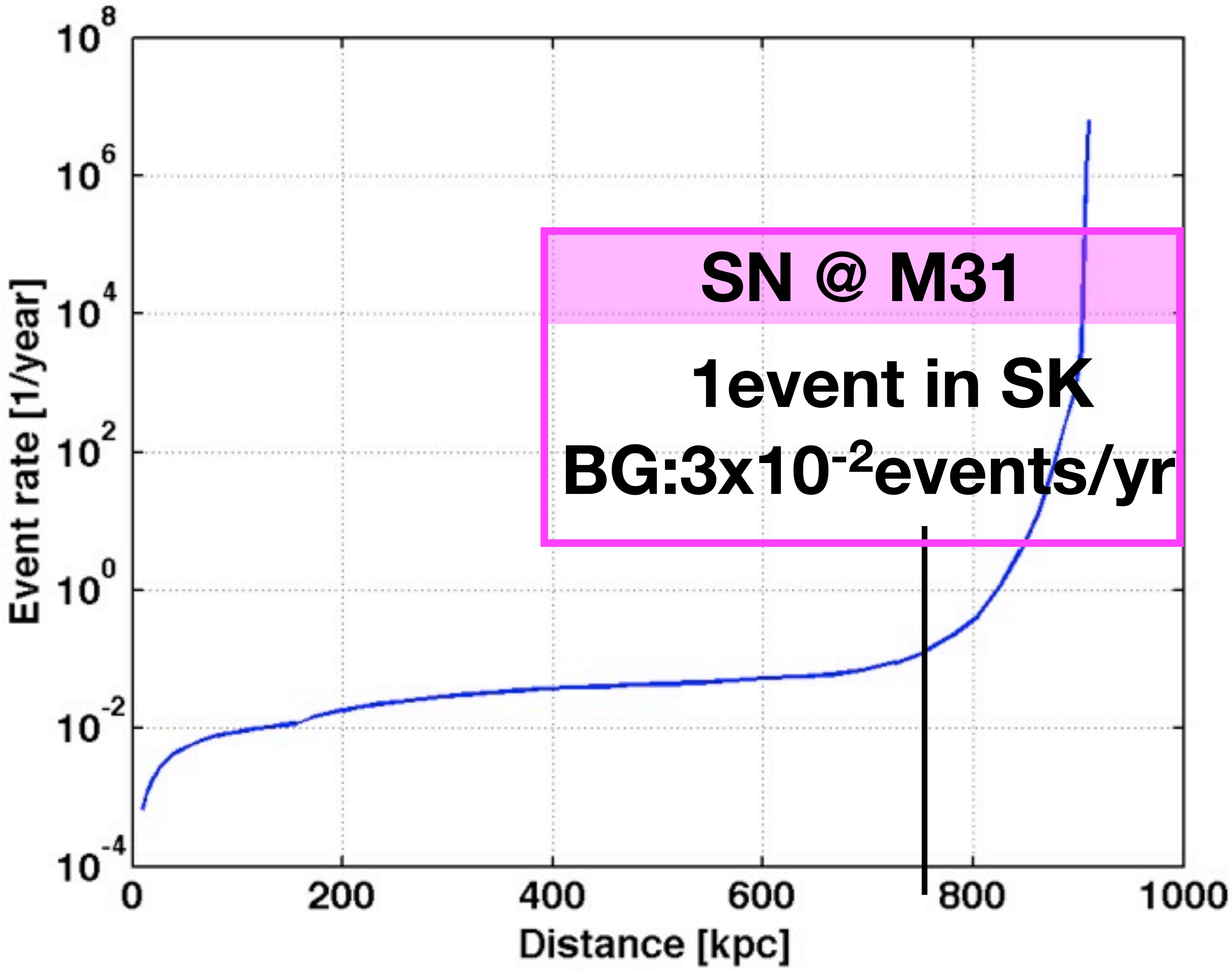
Background Event Rate

- 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

$$P \approx N p_\nu$$

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

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

R_ν : Event rate of neutrinos per seconds

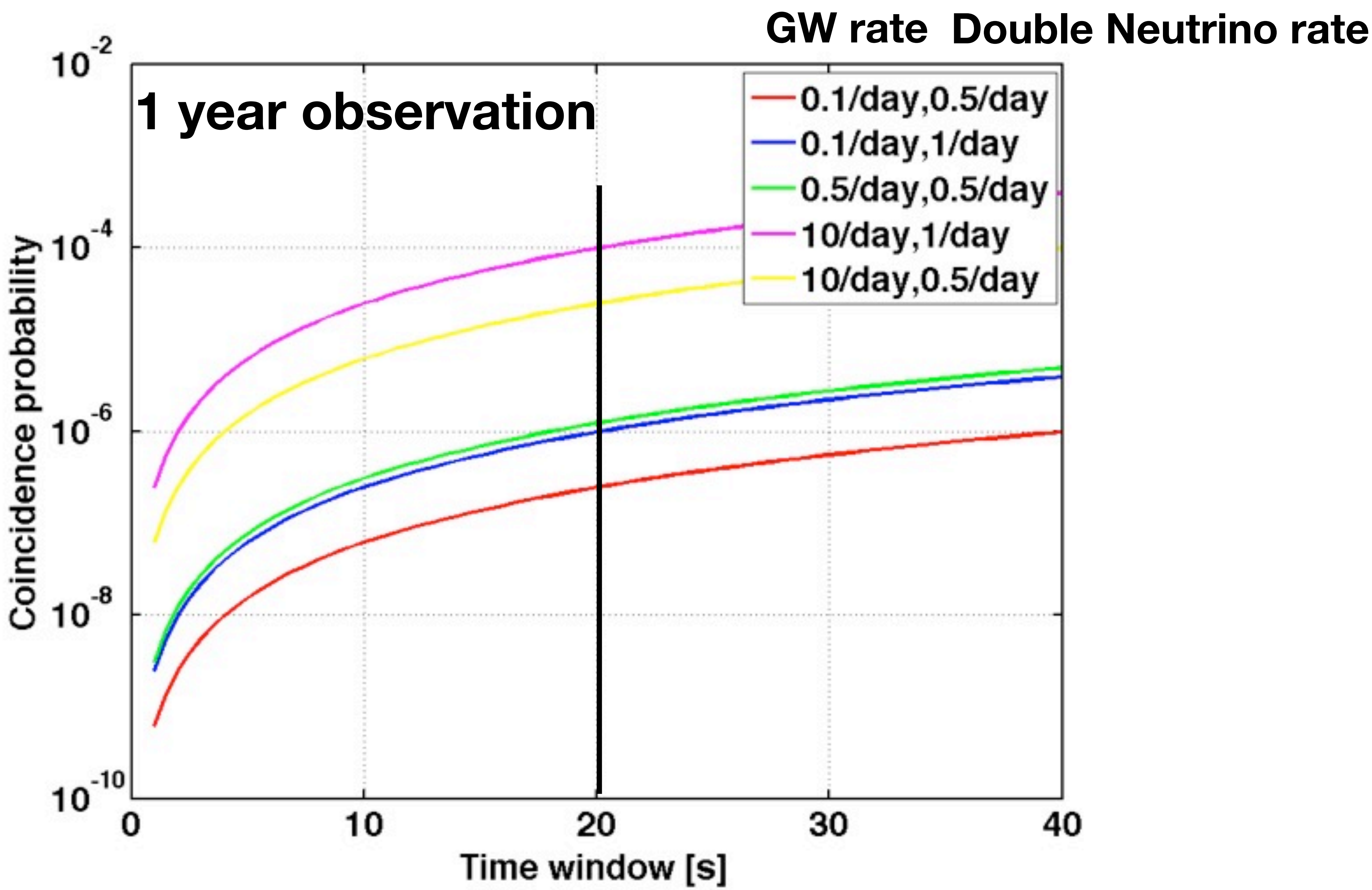
R_{GW} : Event rate of GWs per seconds

T : Total live time

t : coincidence time window

Chance Coincidence Probability

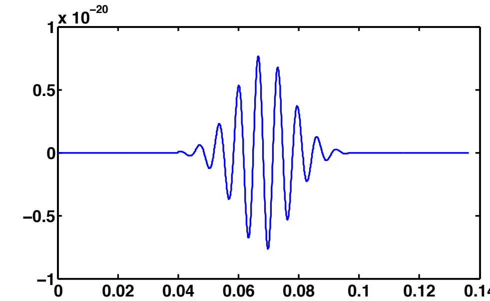
- Taking 20[s] for time window, (GW rate, Neutrino rate) =(0.1,0.5), (0.1,1),(0.5,0.5) per day can reach 10^{-6} .

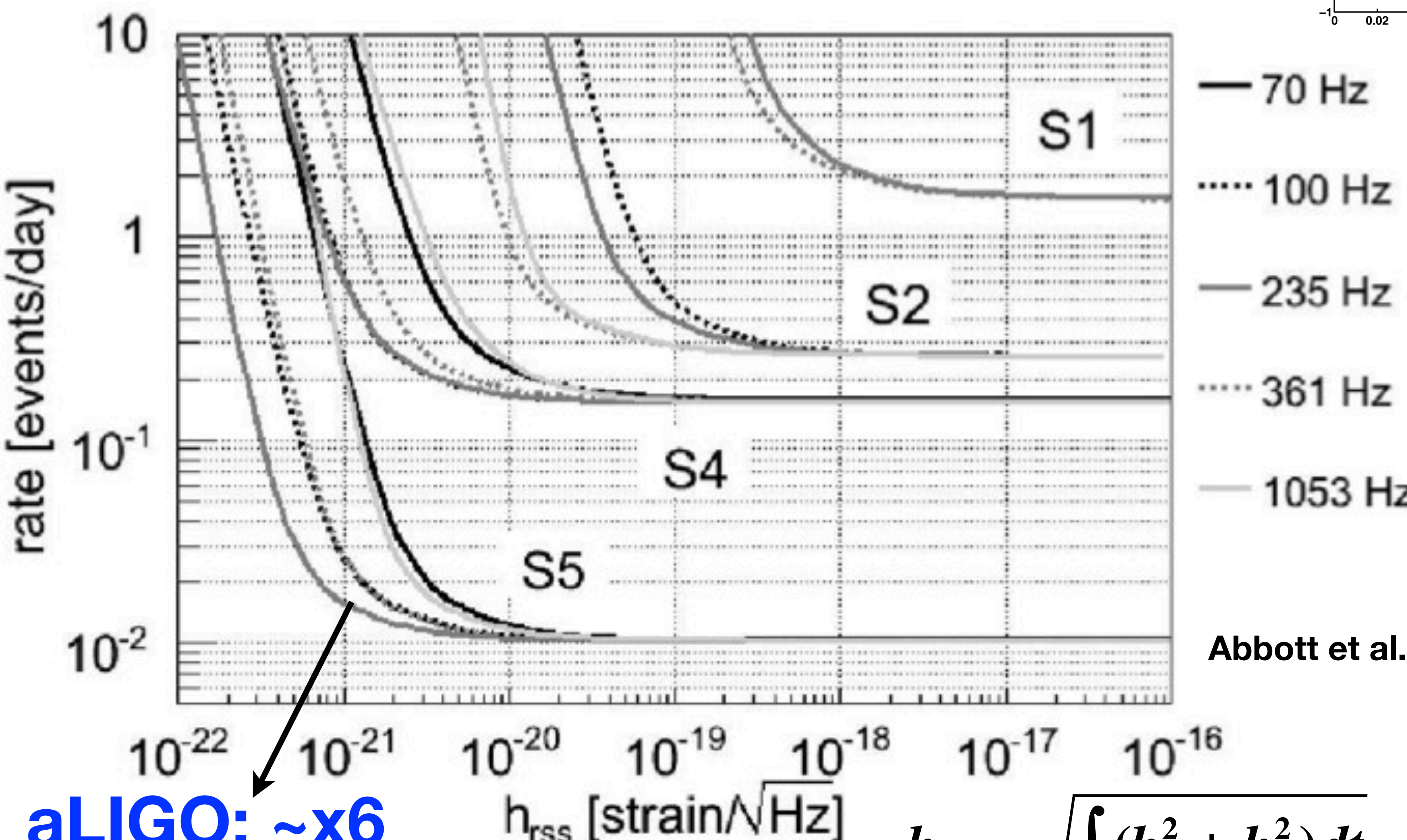


LIGO burst upper limit

- Upper limit of LIGO burst search with injection of Sine Gaussian signals.
- For SG235Q9, h_{rss}=2x10^{-22} corresponding to 1 event/day, h_{rss}=4x10^{-22}a corresponding to 0.1 event/day
- For aLIGO, very roughly h_{rss}=10^{-22} corresponding to 0.1 event/day

Sine Gaussian





aLIGO: ~x6

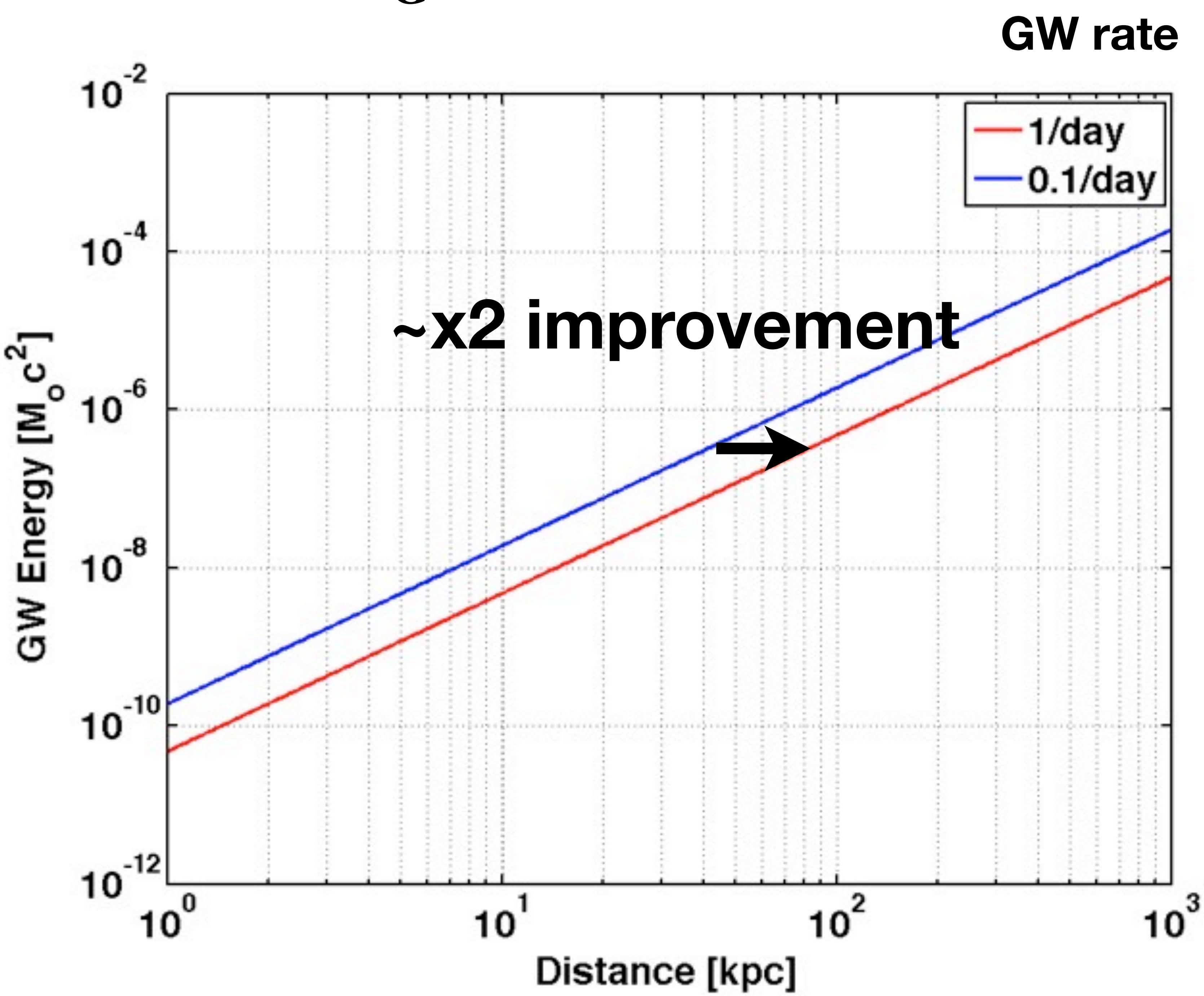
Abbott et al.PRD80(2009)

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

GW energy vs Distance

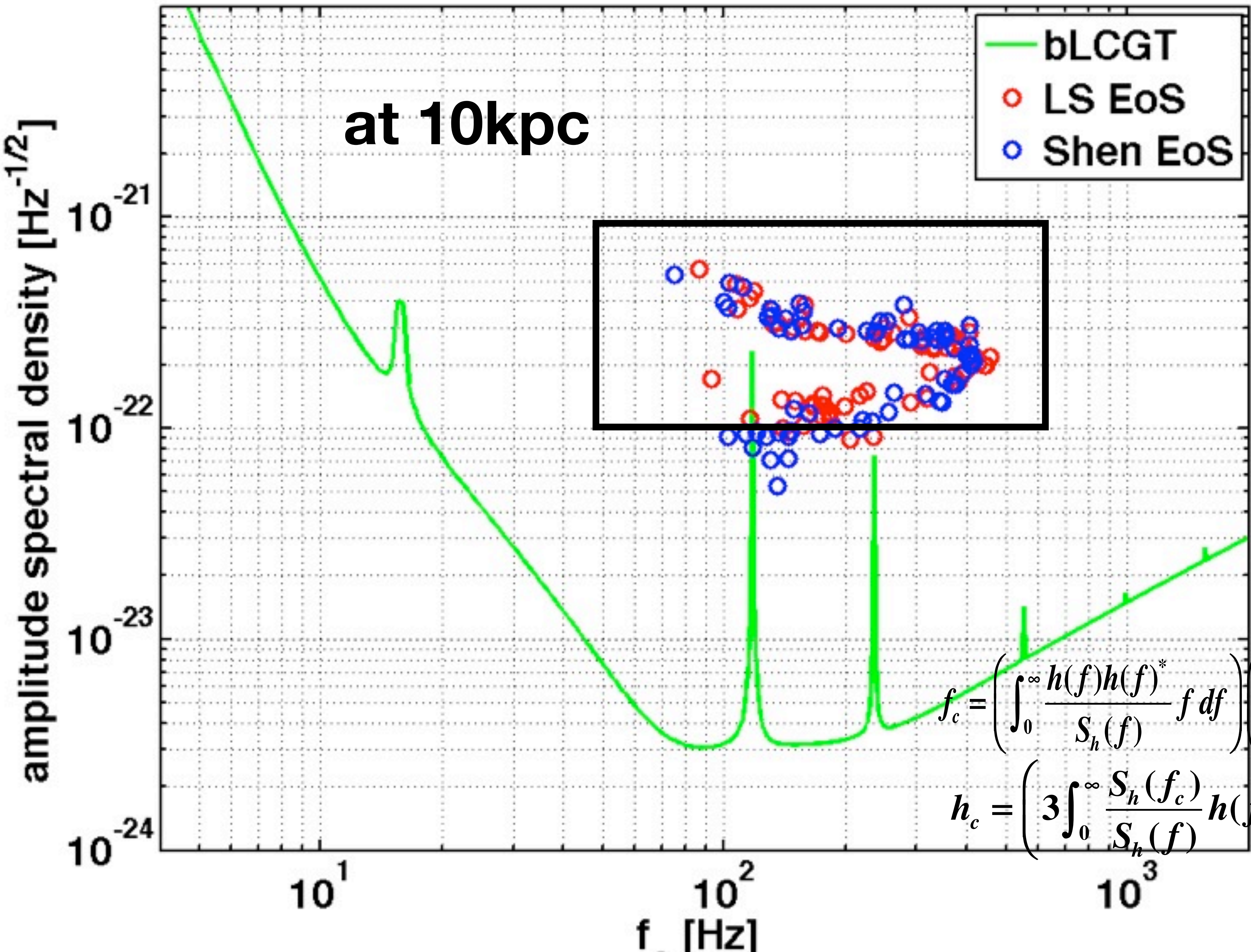
- **Assuming isotropic GW radiation:**

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



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}.



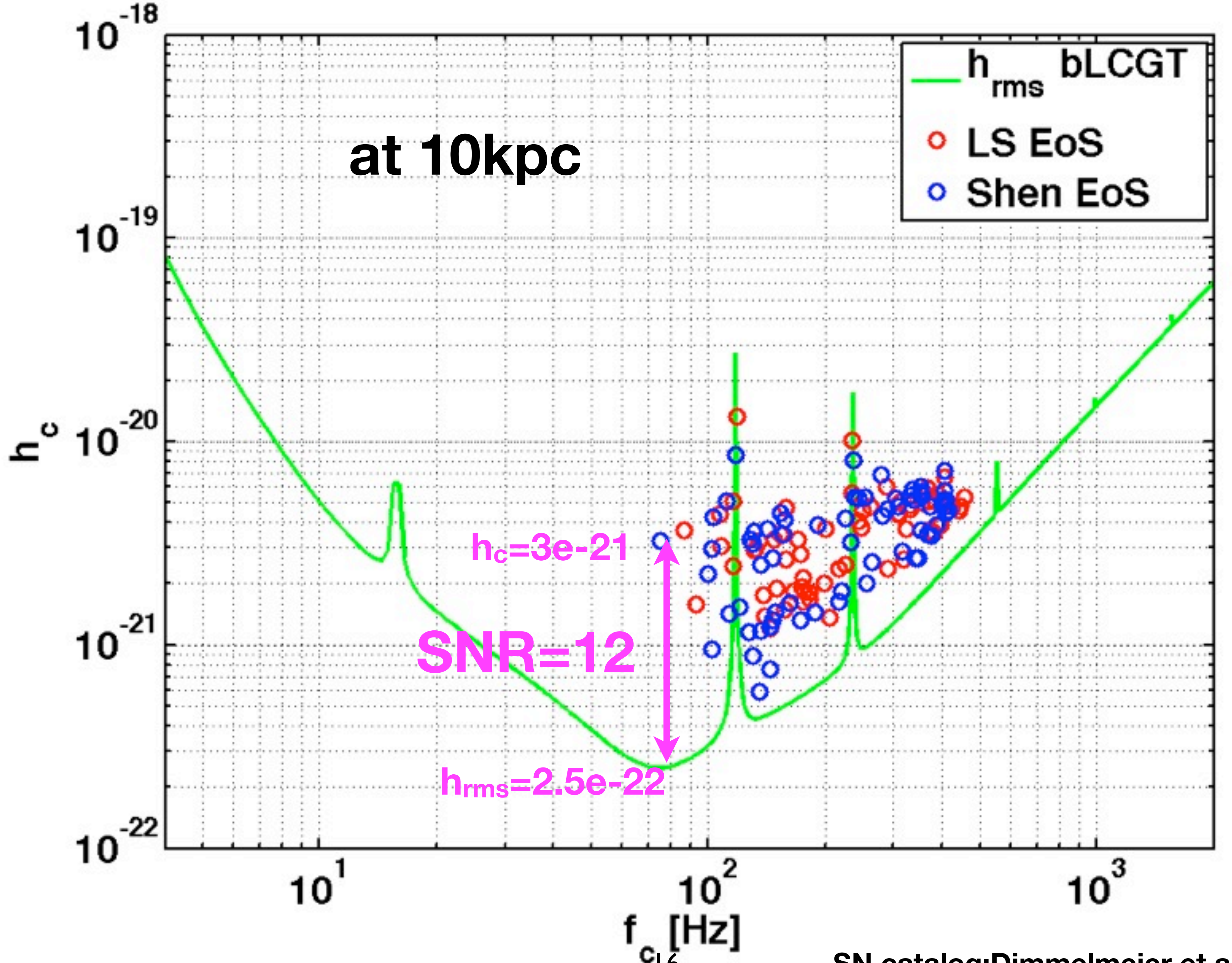
$$f_c = \left(\int_0^\infty \frac{h(f)h(f)^*}{S_h(f)} f\, df \right) \left(\int_0^\infty \frac{h(f)h(f)^*}{S_h(f)} df \right)^{-1}$$

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

SN catalog:Dimmelmeier et al.(2008)

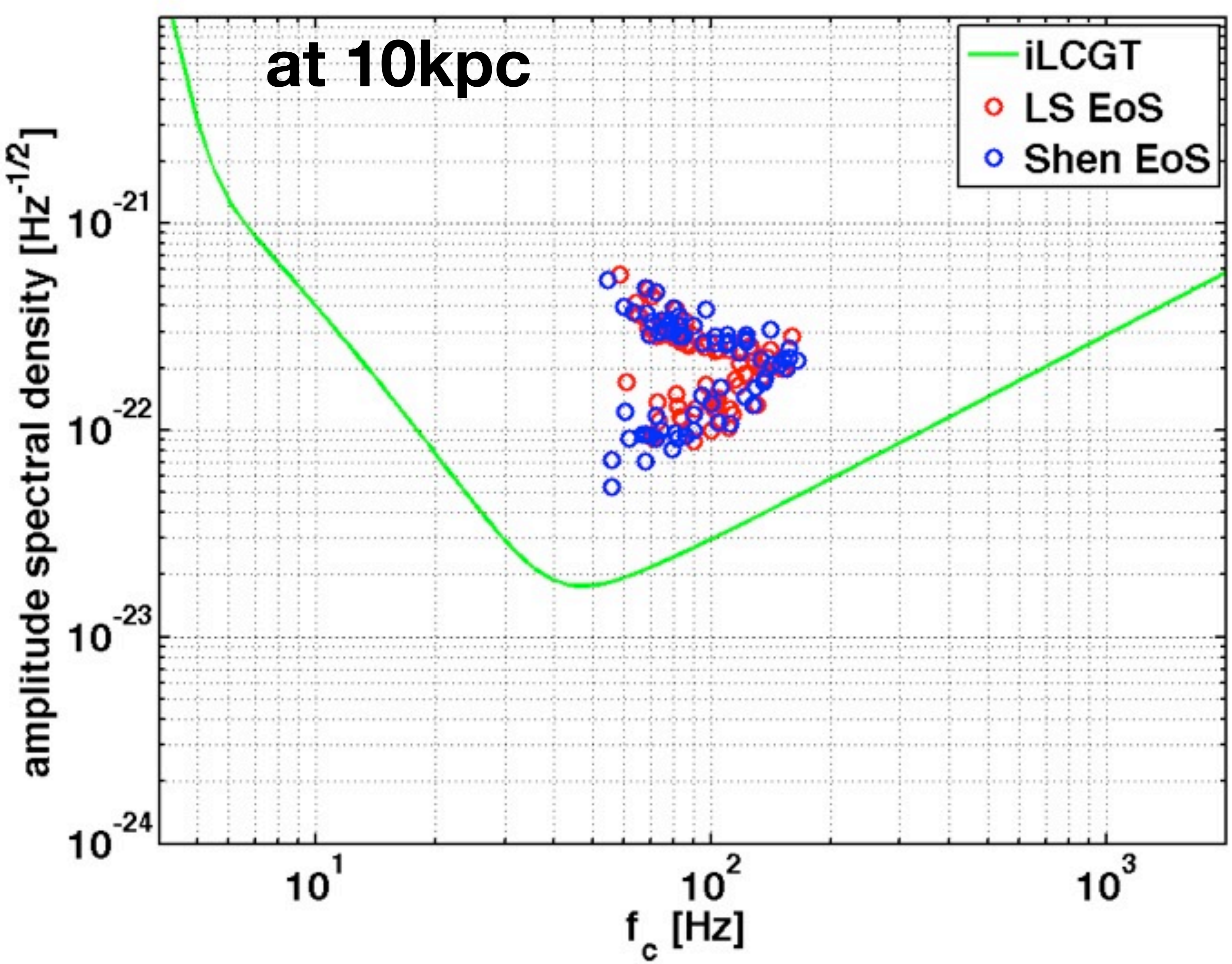
h_c vs f_c on bLCGT

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



SN catalog:Dimmelmeier et al.(2008)

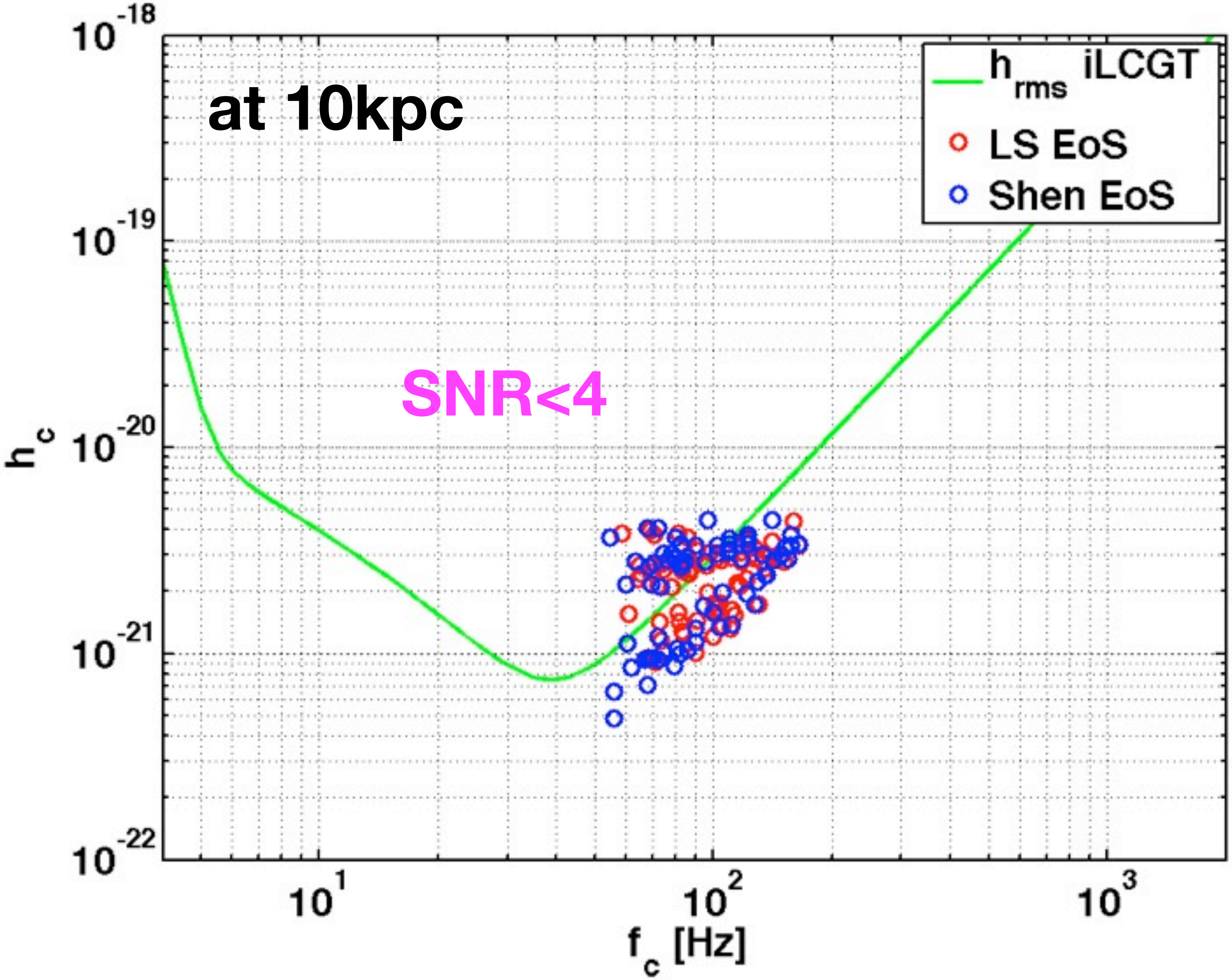
h_{rss} vs f_c on iLCGT



SN catalog:Dimmelmeier et al.(2008)

h_c vs f_c on iLCGT

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

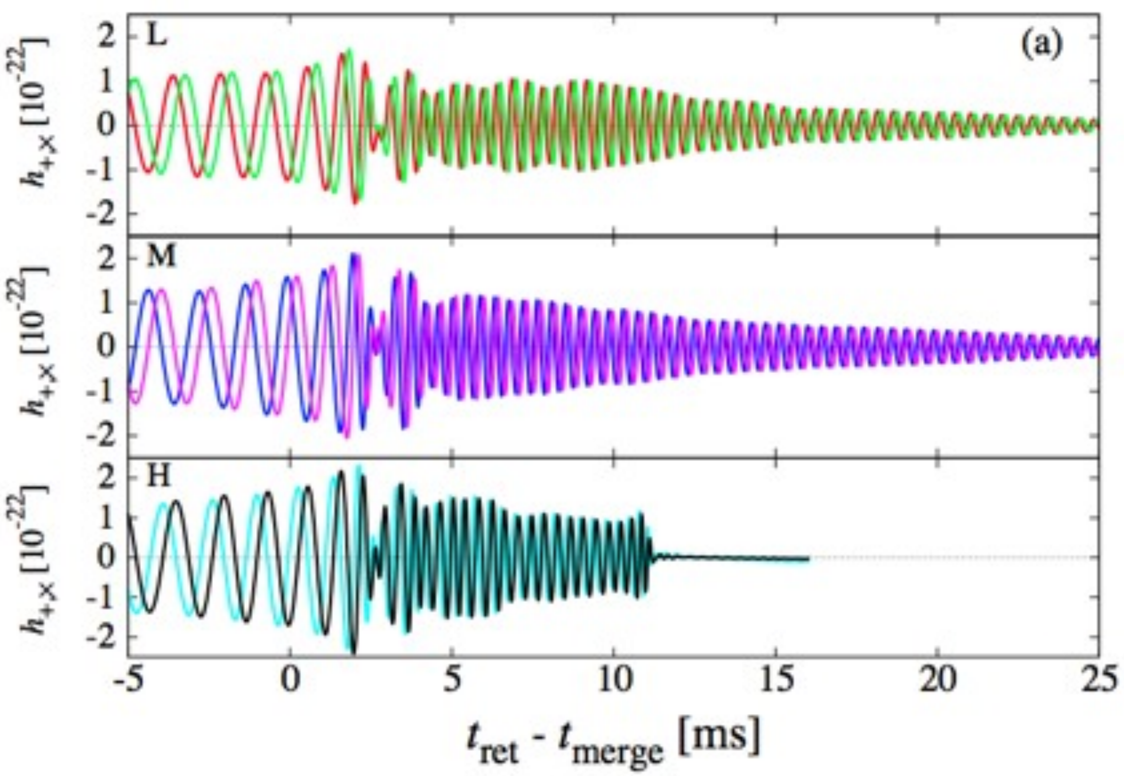


SN catalog:Dimmelmeier et al.(2008)

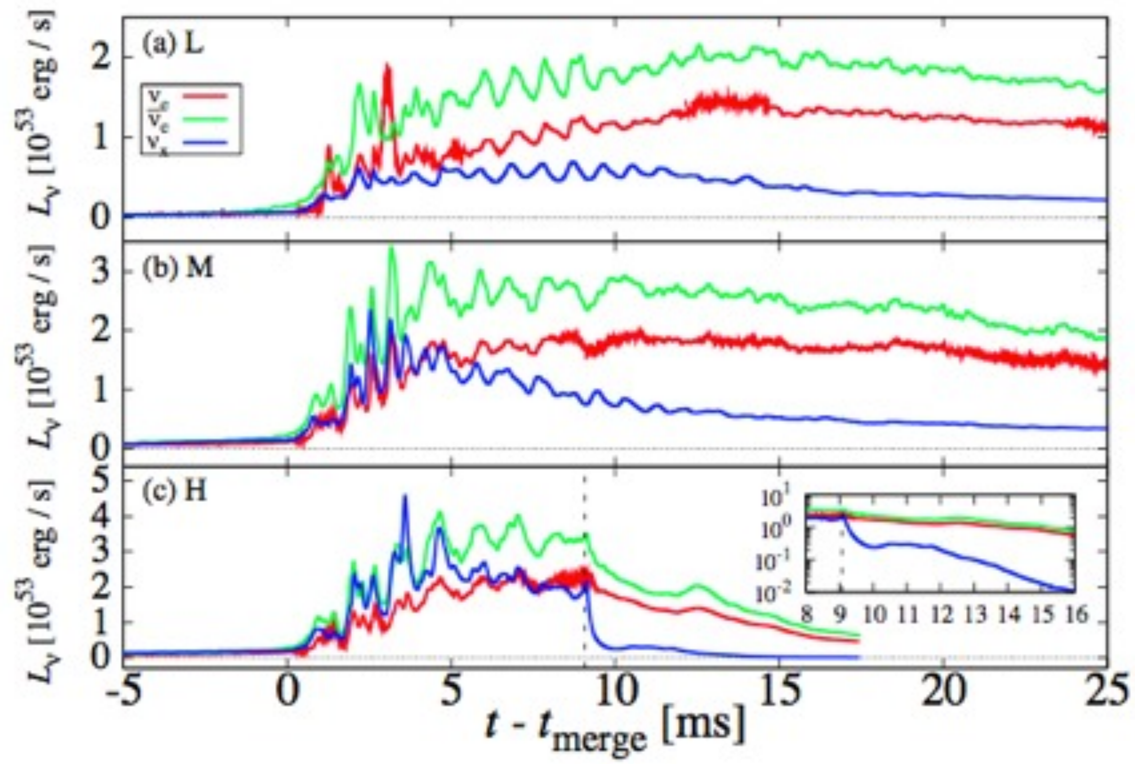
GW+Neutrino from CBC

- 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.**

Energy threshold vs Distance

- Distance@neutrino event count=1