UPPSALA UNIVERSITET

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HOW FAR CAN WE SEE CORE-COLLAPSE SUPERNOVAE USING NEUTRINOS IN ICECUBE?


SUPERNOVAE
$E_{tot} \sim 10^{53}\ erg$
ν
99% of kinetic energy!
Nucleosynthesis of heavy elements
Gives birth to neutron stars and black holes!

OUTLINE

- How are neutrinos produced in supernovae?
- How do we detect supernovae in IceCube?
- How far can we see CCSNe with high energy neutrinos?

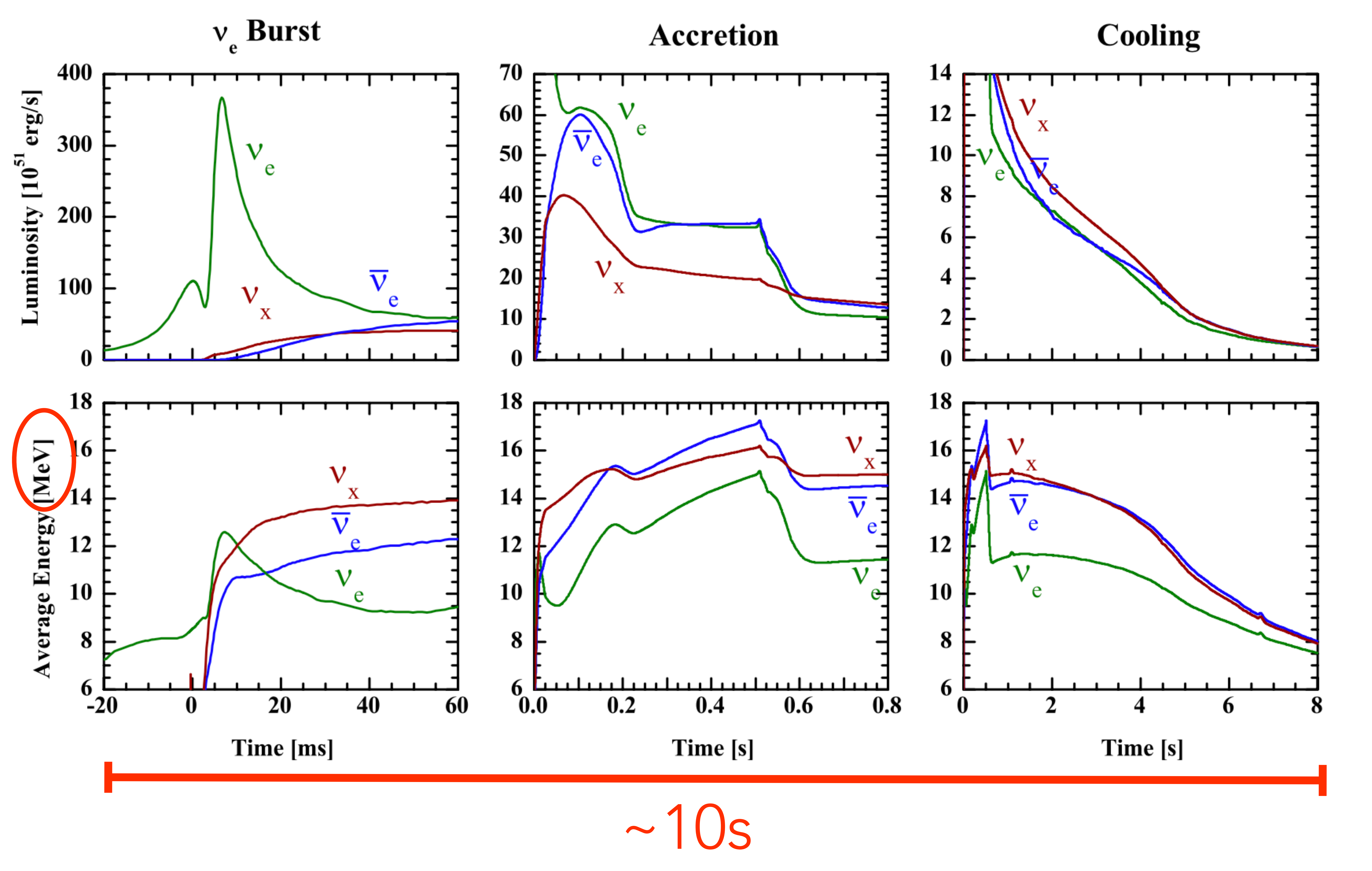
CORE COLLAPSE - LOW ENERGY NEUTRINOS

LOW ENERGY NEUTRINOS

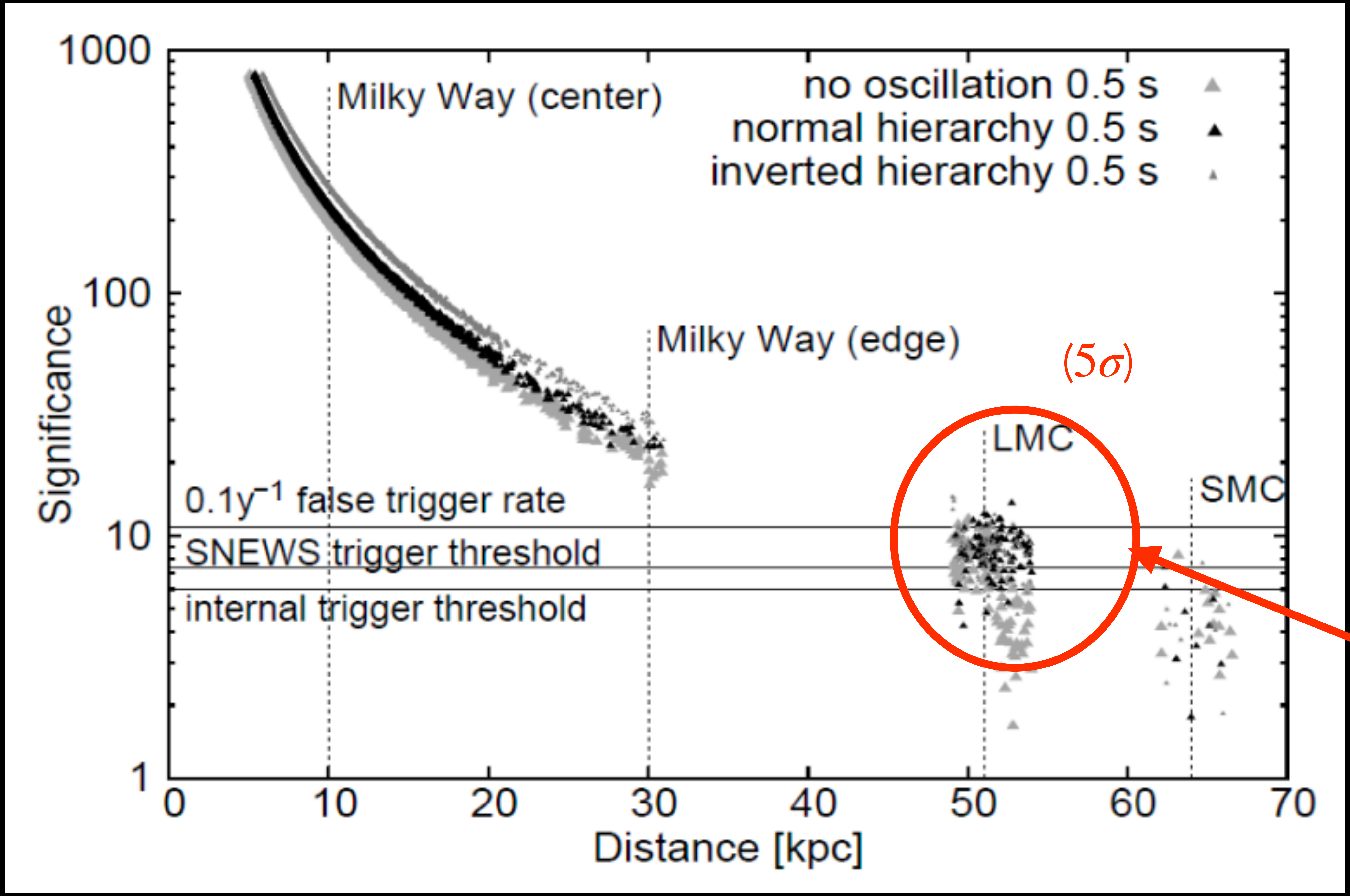
Neutrinos emitted by SN ~ 10^{58} neutrinos

IceCube observes $\bar{\nu}_e$

Oscillations will affect the spectra that IceCube observes



HOW FAR CAN WE SEE WITH LOW ENERGY NEUTRINOS?



Observational reach using low-energy neutrinos is limited to ~LMC (5σ)

HIGH-ENERGY NEUTRINOS

Progenitor star experiences mass loss prior to explosion

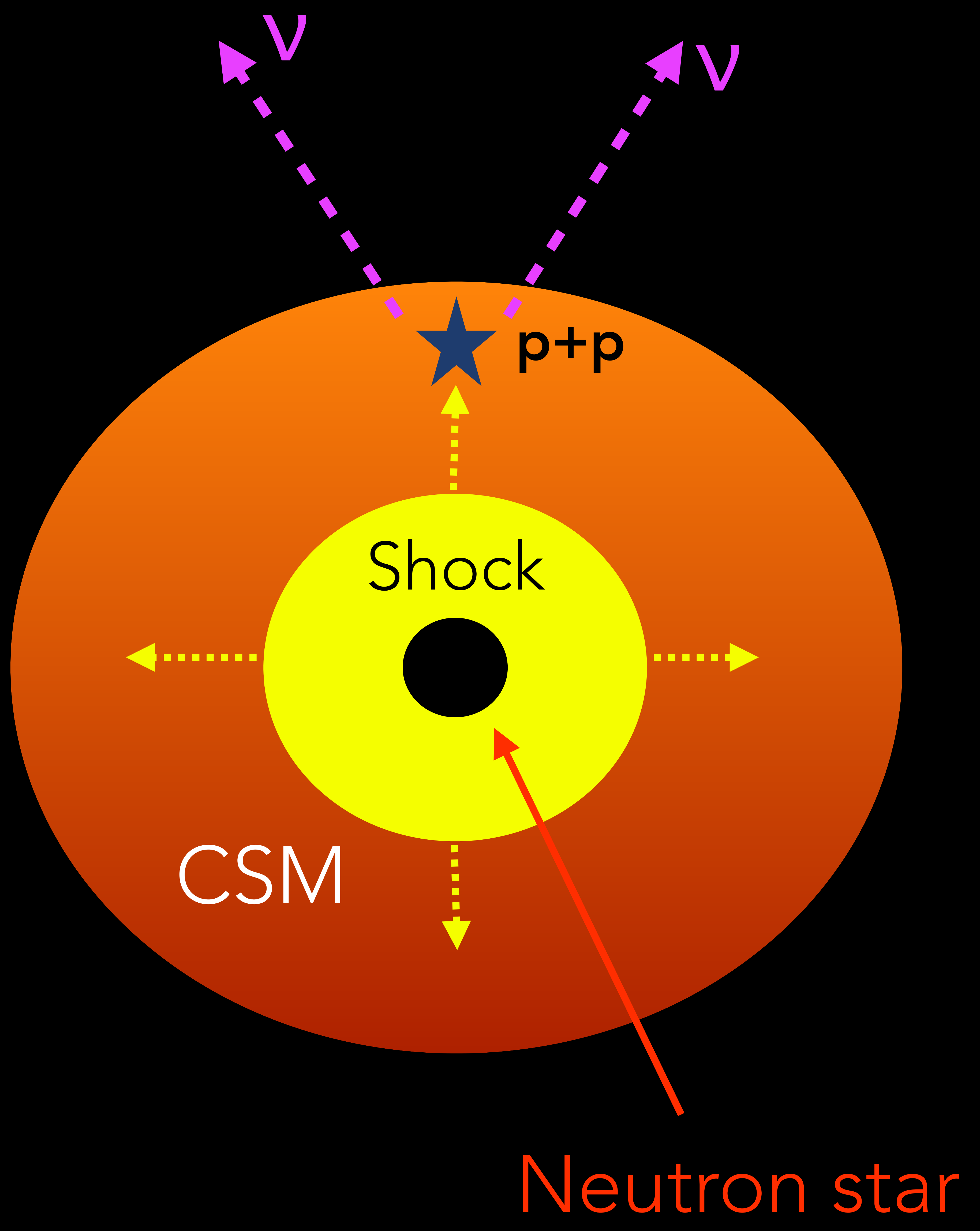
↓

Circumstellar material (CSM)

↓

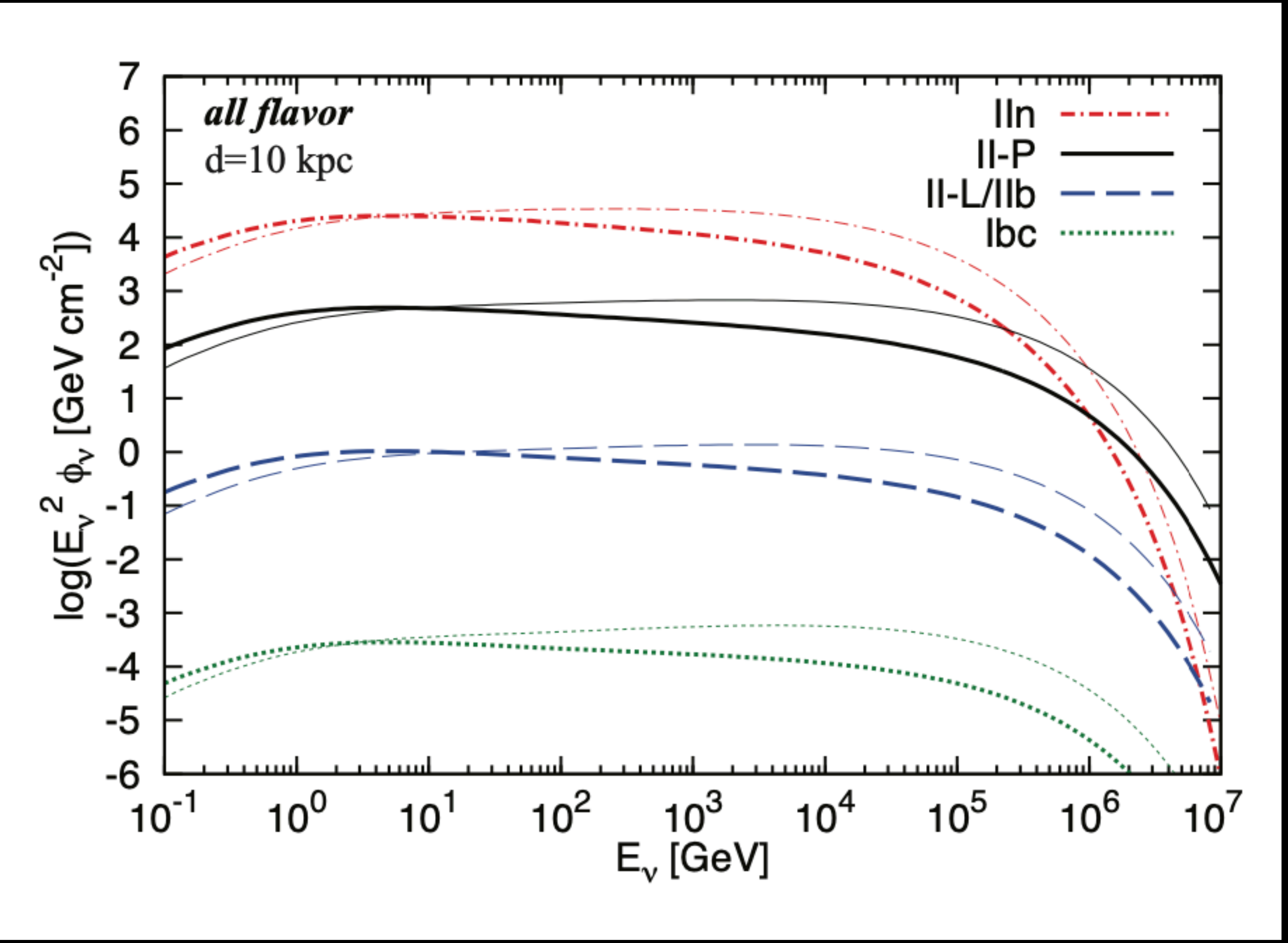
Shock interacts with CSM nucleon via inelastic pp. This can give rise to pions, which decay producing HE neutrinos.

$$p + p -> \pi^{\pm} + (X) -> \mu^{\pm} + \nu_{\mu}(\bar{\nu})_{\mu} -> e^{\pm}\nu_{e}(\bar{\nu})_{e} + \nu_{\mu}(\bar{\nu})_{\mu}$$



HIGH-ENERGY NEUTRINOS: FLUX MODEL

Energy fluences for a Galactic SN ($d = 10kpc$)



Thin line is for a model with s =2.0 and thick for s=2.2.

Observation time

Effective area: neutrino detection sensitivity. It is as a function of neutrino direction (declination) and energy.

$$N = \int_{t_{min}}^{t_{max}} \int_{E_{min}}^{E_{max}} \phi_\nu(E_\nu, t) * A_{eff}(E_\nu) * dE_\nu * dt$$

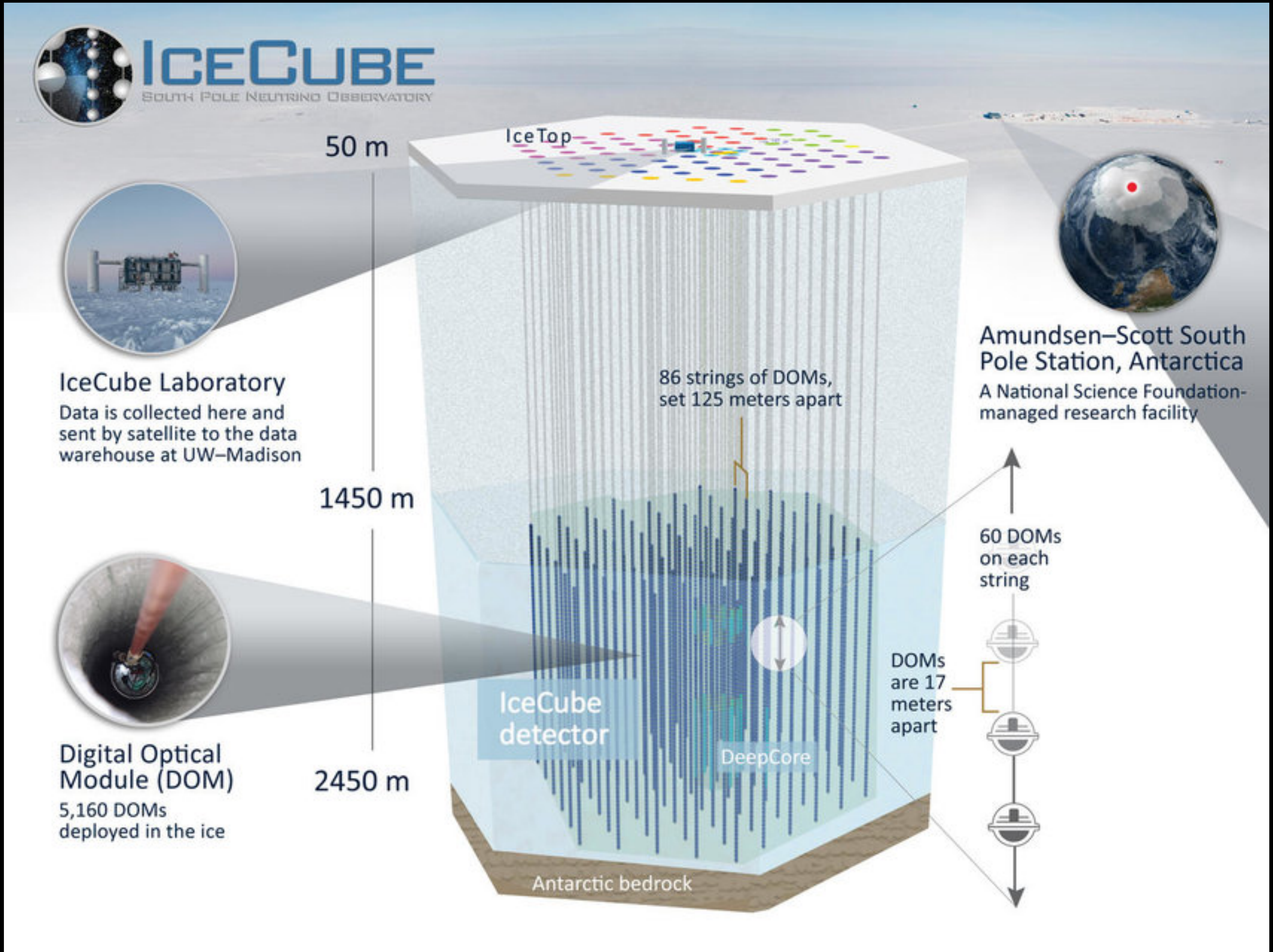
Gives the mean number of neutrinos that IceCube would observe

Neutrino energy

I have averaged the declination for northern/ southern sky.

K. Murase https://arxiv.org/abs/1705.04750v2

ICECUBE DETECTOR

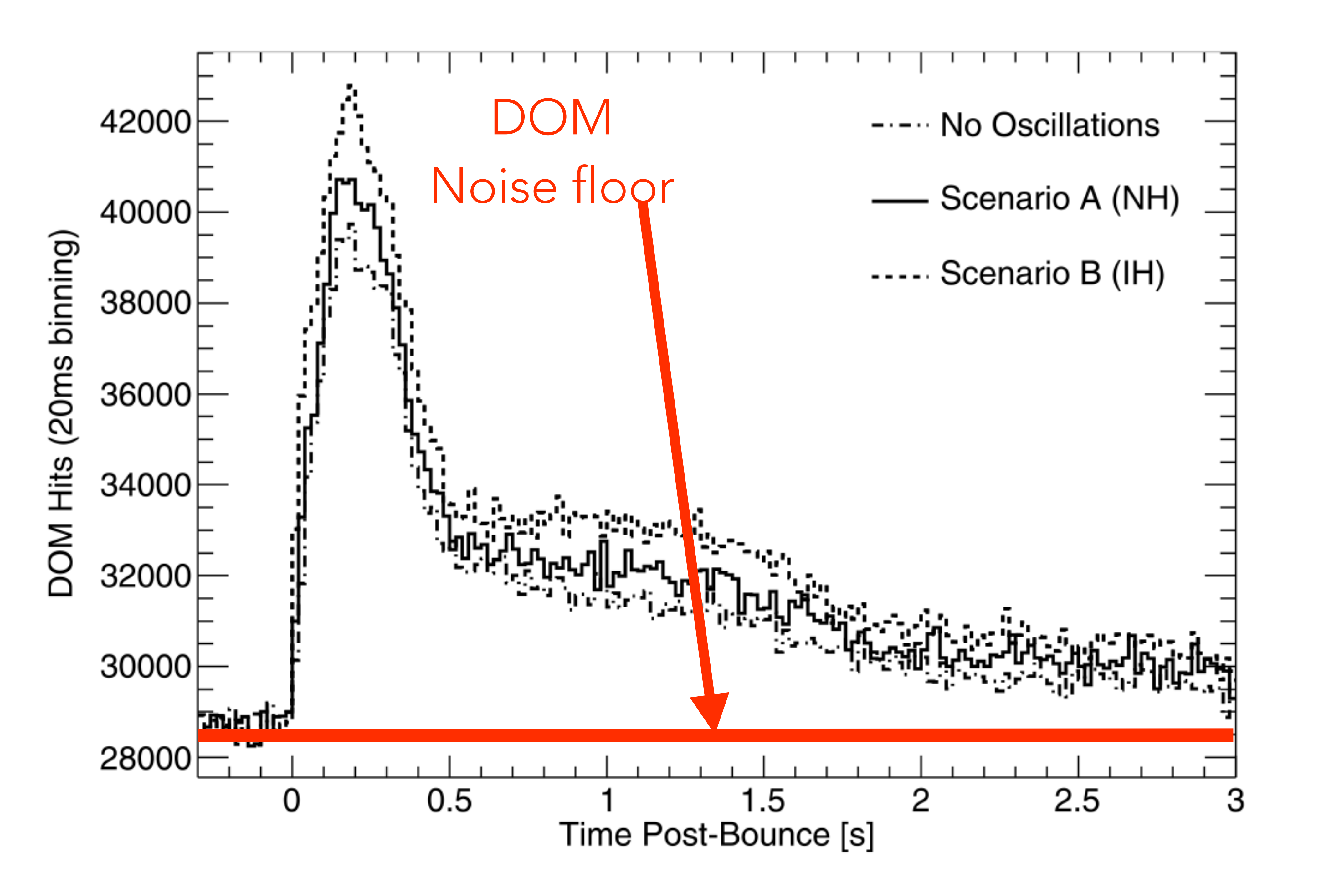


https://arxiv.org/pdf/1701.03731.pdf

HOW DOES ICECUBE OBSERVE NEUTRINOS?

Low energy (~MeV)

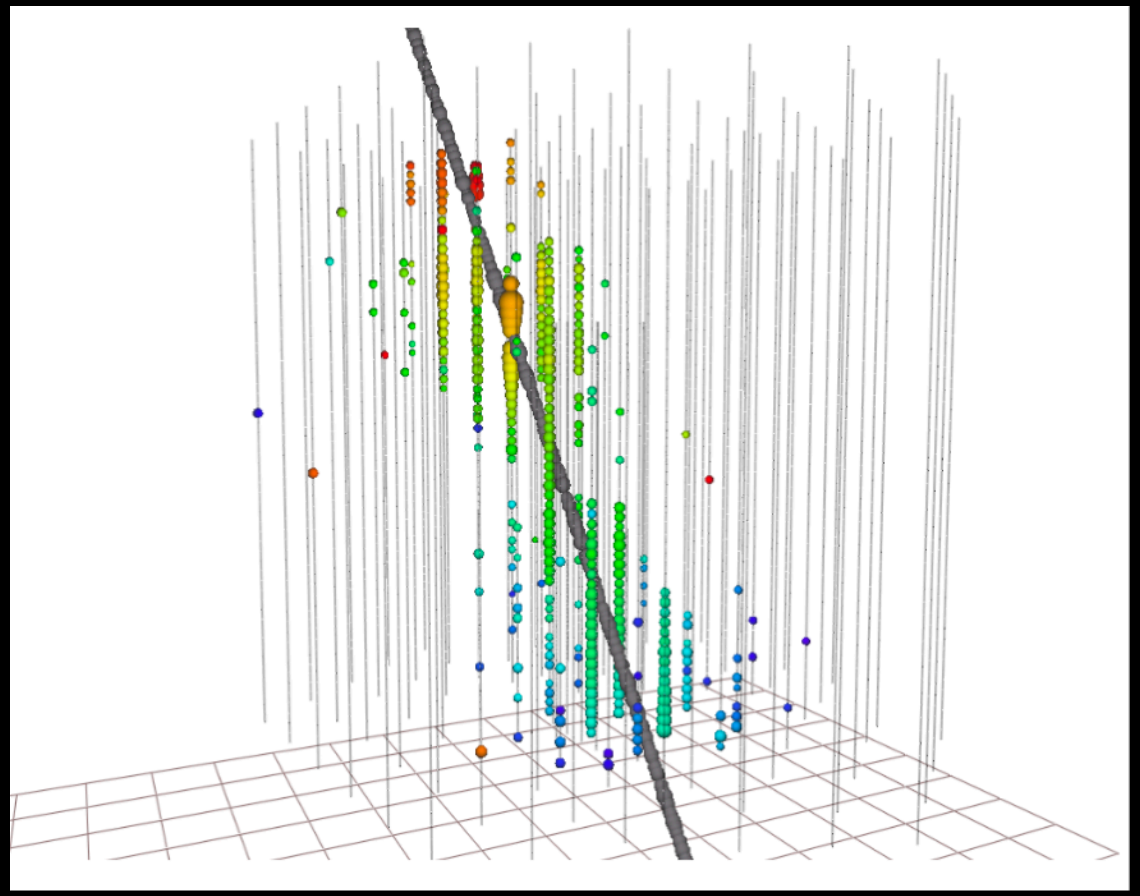
Inverse beta decay
$\bar{\nu}_e + p -> n + e^+$



Expected DOM noise rate change for a galactic SN (d~10 kpc)

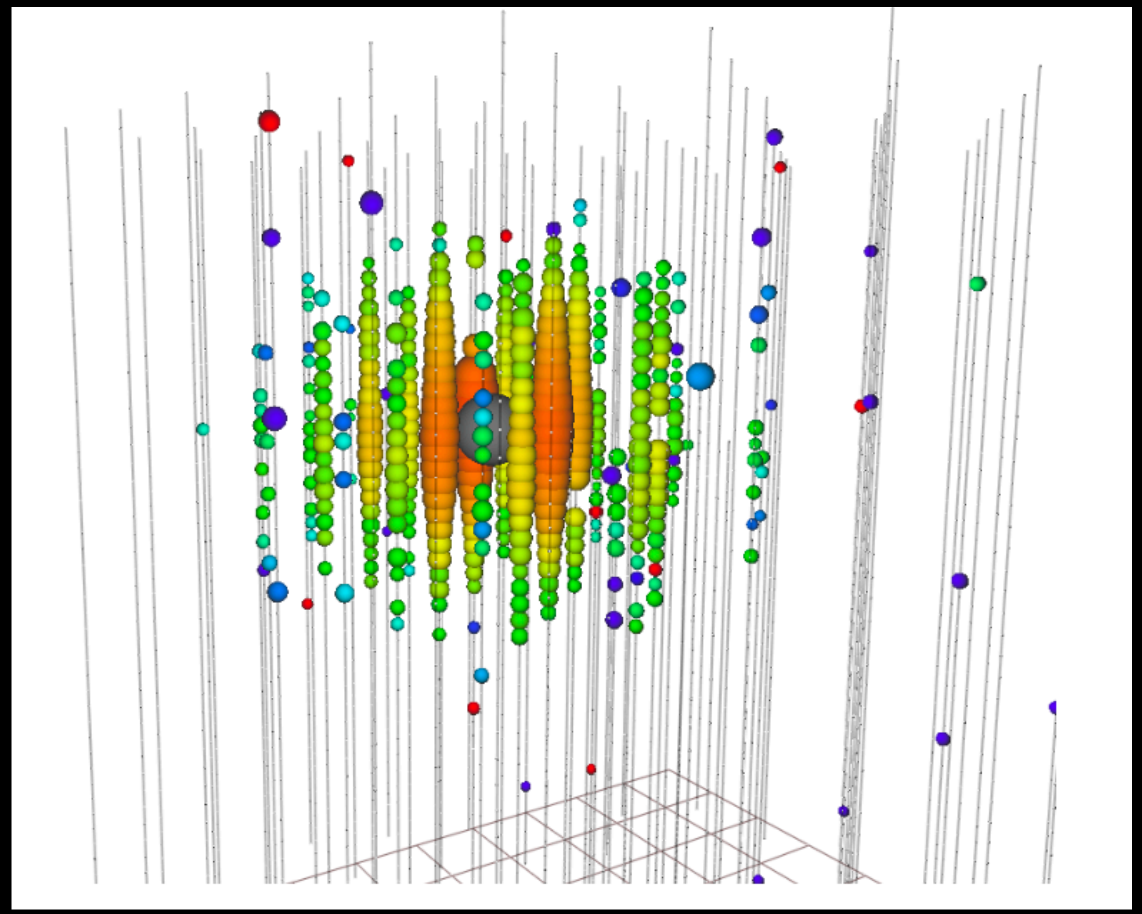
High energy (>TeV)

TRACKS



- CC: $\nu_\mu + N -> \mu + X$
- Good angular resolution (~0.5°)
- Can be difficult to estimate neutrino energy

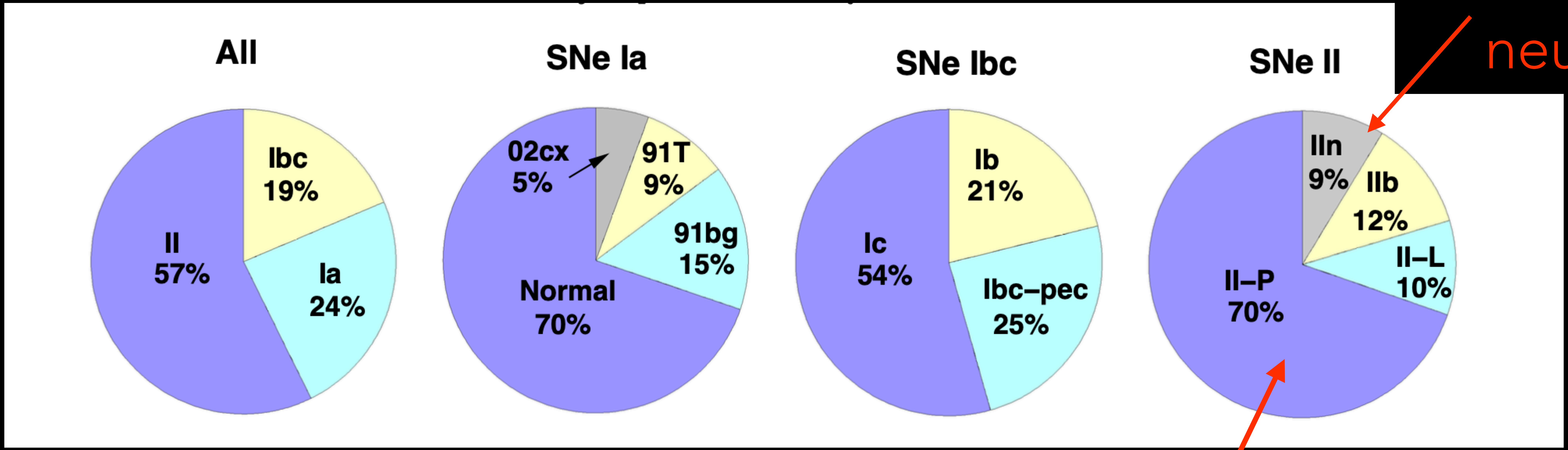
CASCADES



- CC: ν_e, ν_τ
- NC: ν_e, ν_τ, ν_μ
- Good energy reconstruction
- Not the best angular resolution (~few degrees)

SUPERNOVAE FRACTIONS

Less frequent, much larger flux of HE neutrinos



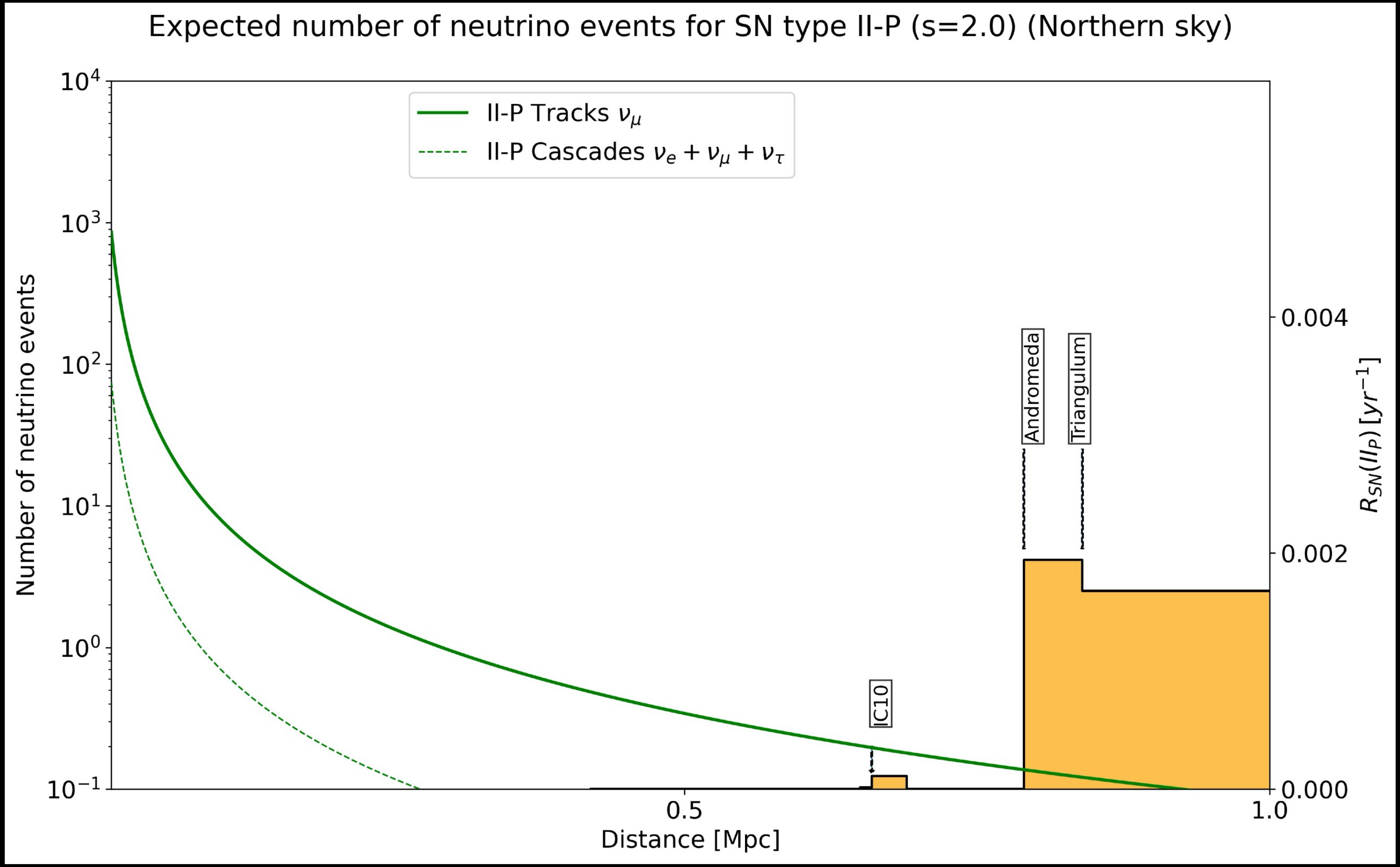
More frequent, smaller flux of HE neutrinos

https://arxiv.org/abs/1006.4612v2

ICECUBE SENSITIVITY FOR II-P (NORTHERN SKY)

Most common type of CCSNe

Gives us a limited reach

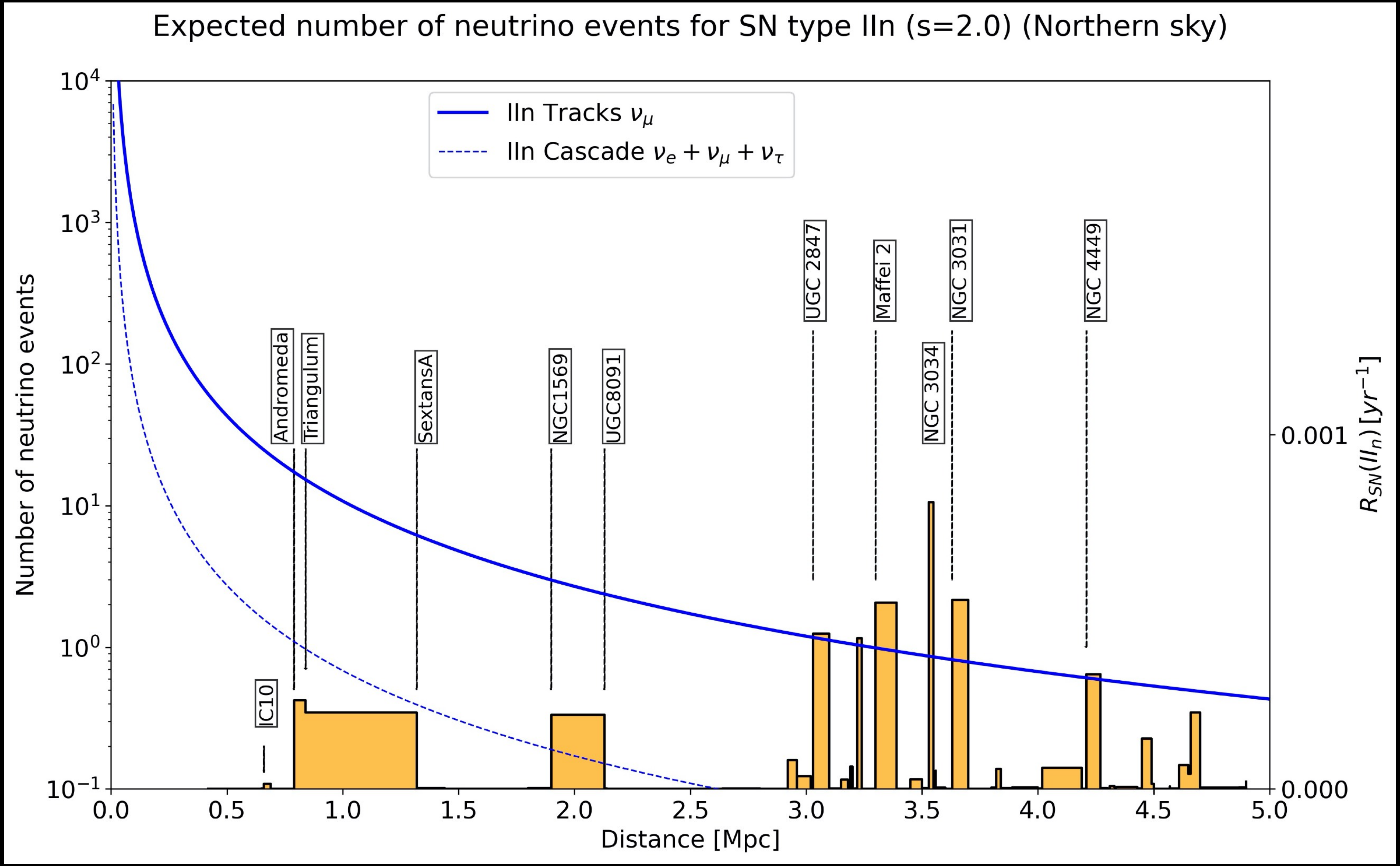


CCSNe rates: https://arxiv.org/abs/1602.03028

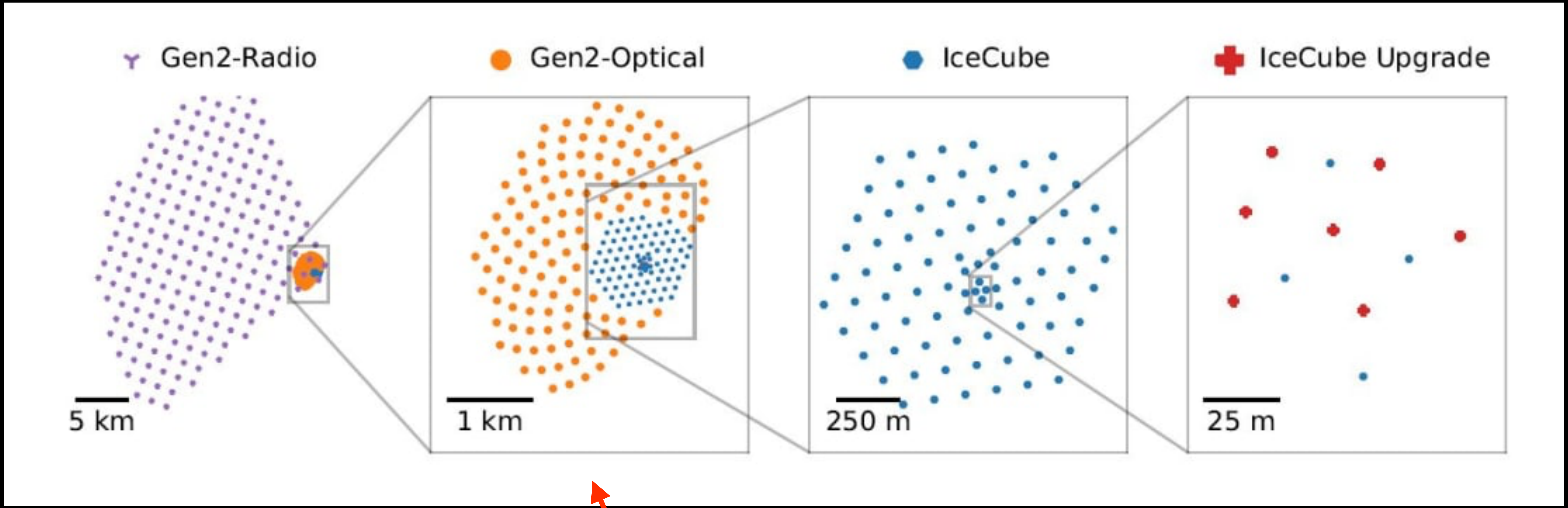
ICECUBE SENSITIVITY FOR IIN (NORTHERN SKY)

Not very common type of CCSNe

Interesting because we can reach galaxies that were previously unreachable through the low energy neutrinos.



ICECUBE GEN2



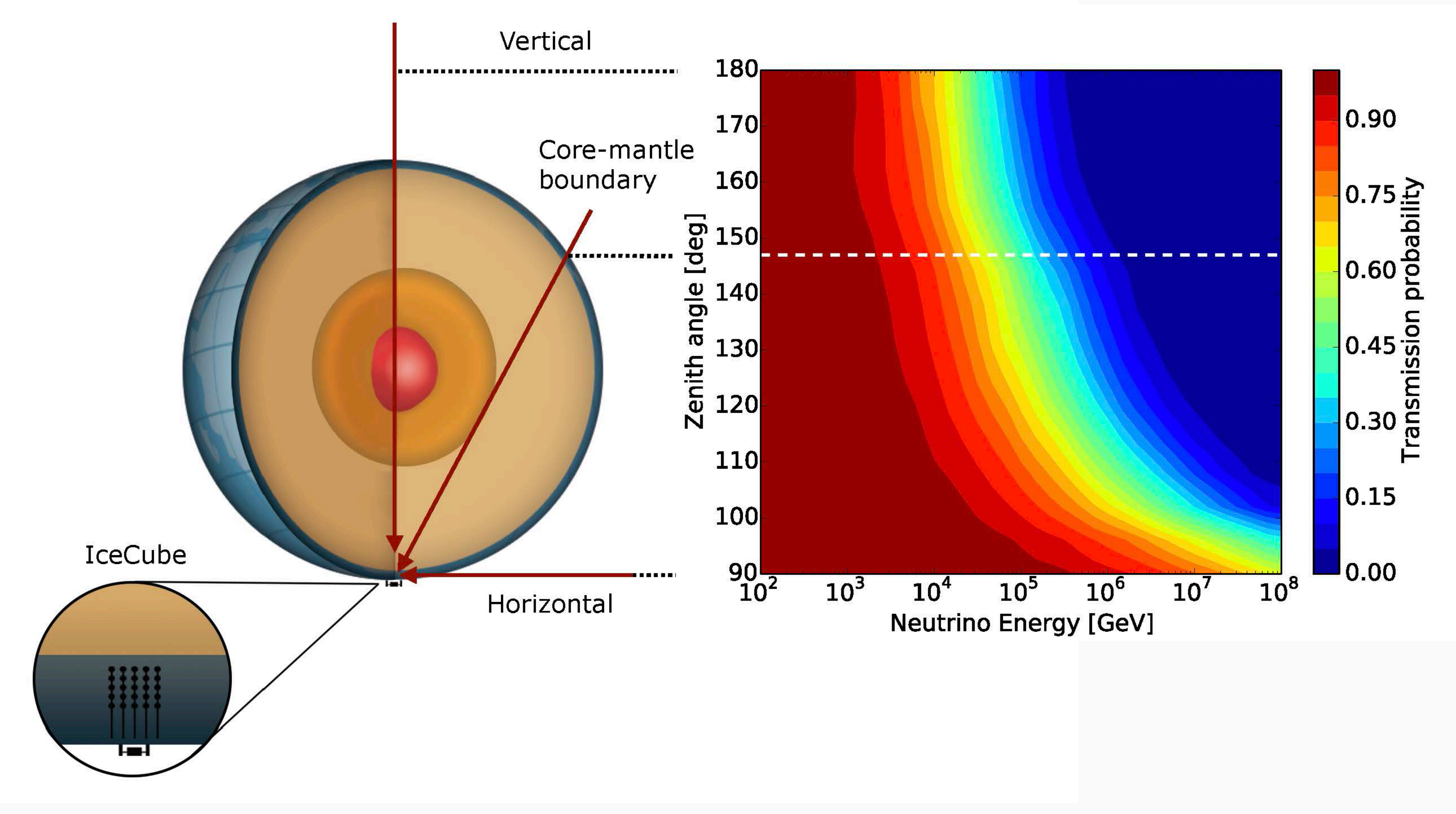
Will expand the instrumented volume by an order of magnitude. This will allow us to see further.

CONCLUSIONS

- If we look nearby using HE neutrinos from shock-CSM interaction, we could potentially have an event with a lot of neutrinos (both tracks and cascades), which could help us characterize shock dynamics. It is likely the only type of event that would give us such a flux nearby.
- For type IIn, we can extend the reach to ~ a few Mpc. This is currently the only way to see CCSNe at those distances.
- Gen-2 will further expand the reach to high energy neutrinos from CCSNe.

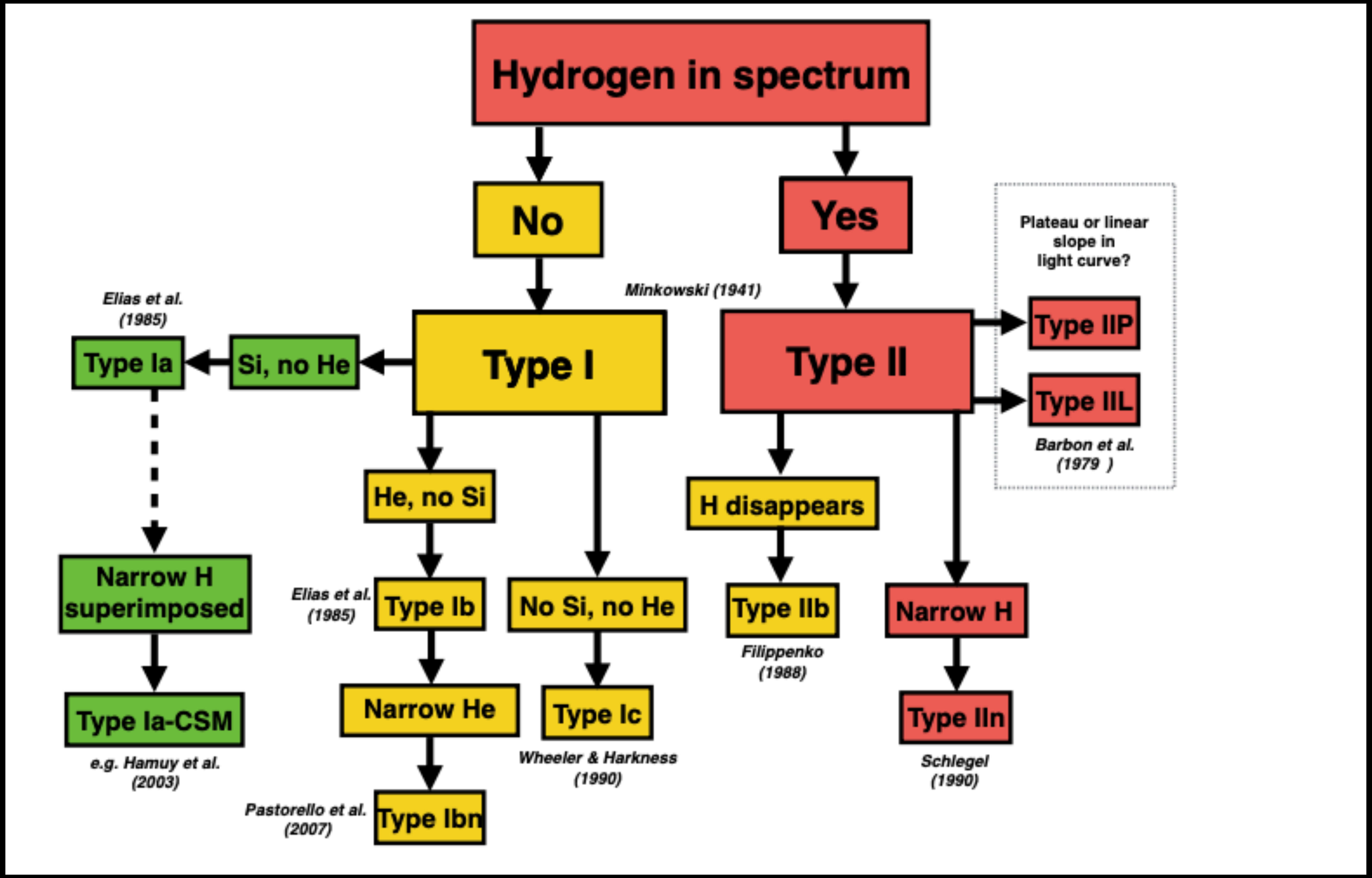
BACK UP

EFFECTIVE AREA - TRACKS



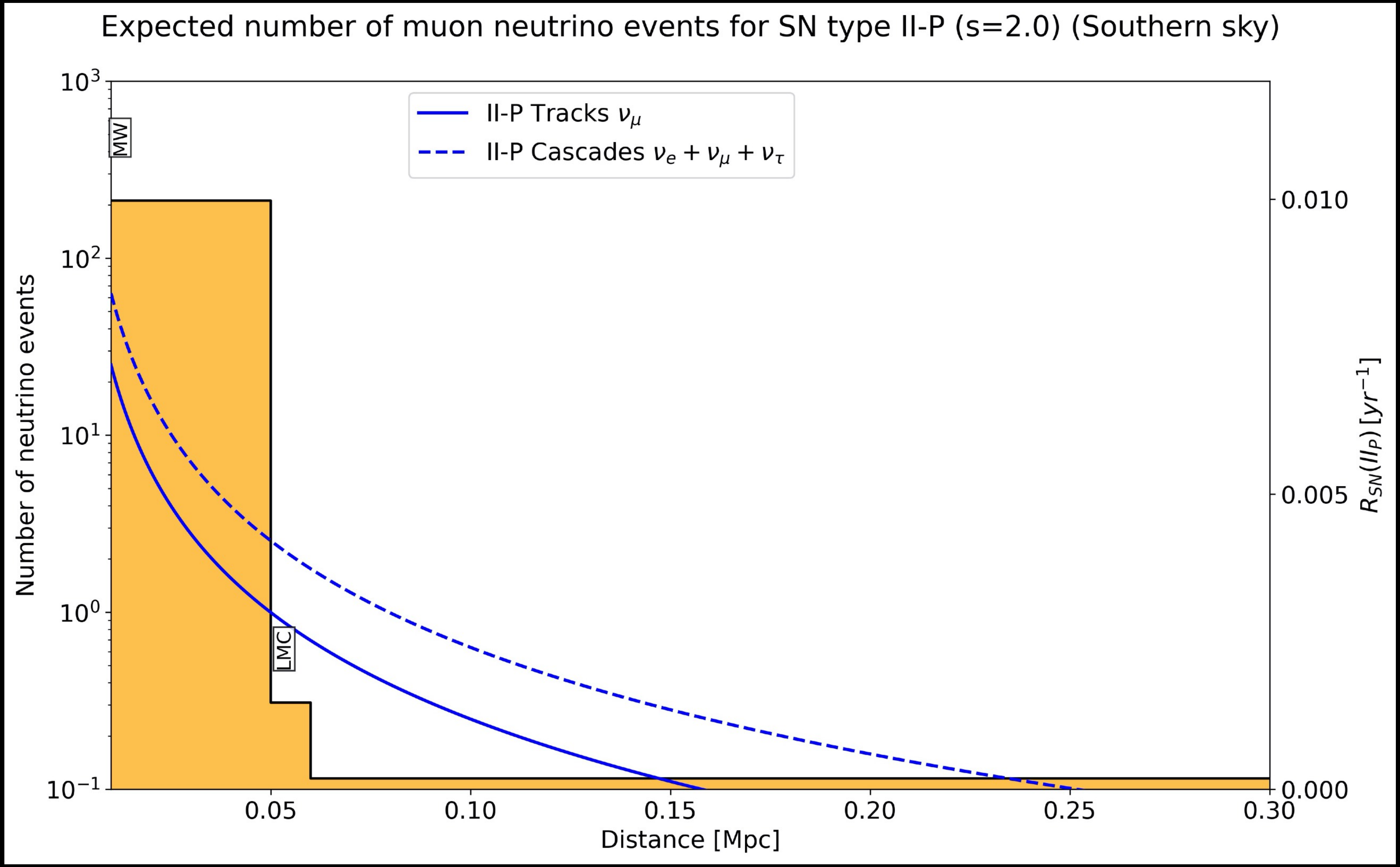
TYPES OF SUPERNOVAE

- To categorize supernovae, we need both the spectra and the light curve.
- The spectra gives us the presence of elements that helps us categorise the type of supernovae, but the light curve gives us information on the subtype of supernovae.

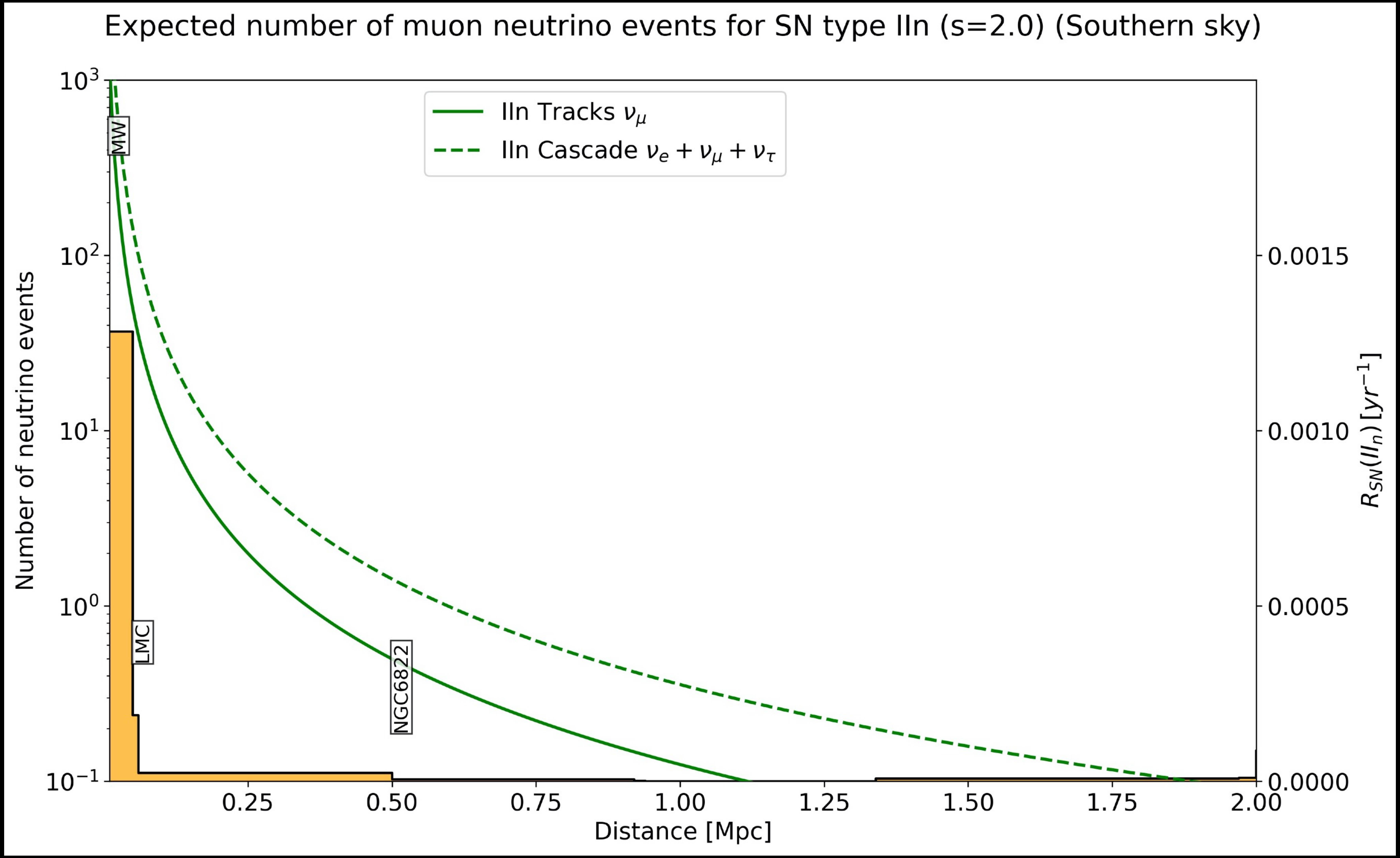


ICECUBE SENSITIVITY FOR II-P (SOUTHERN SKY)

Not many interesting galaxies in the southern sky



ICECUBE SENSITIVITY FOR IIN (SOUTHERN SKY)



MOST SENSITIVE ENERGY (TRACKS -NORTHERN SKY)