Deciphering the next supernova using neutrinos

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Partikeldagarna 2018 - Lund

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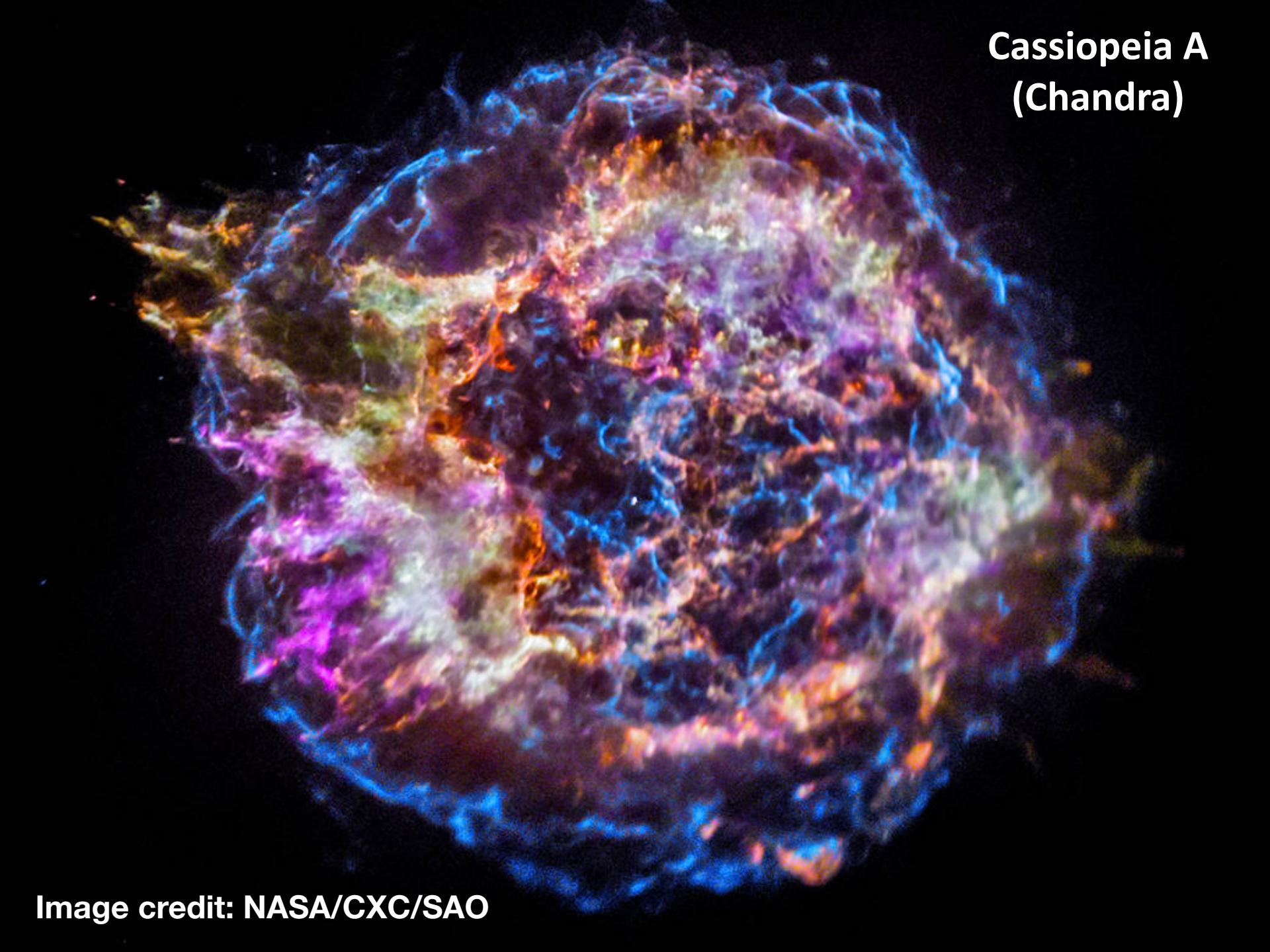
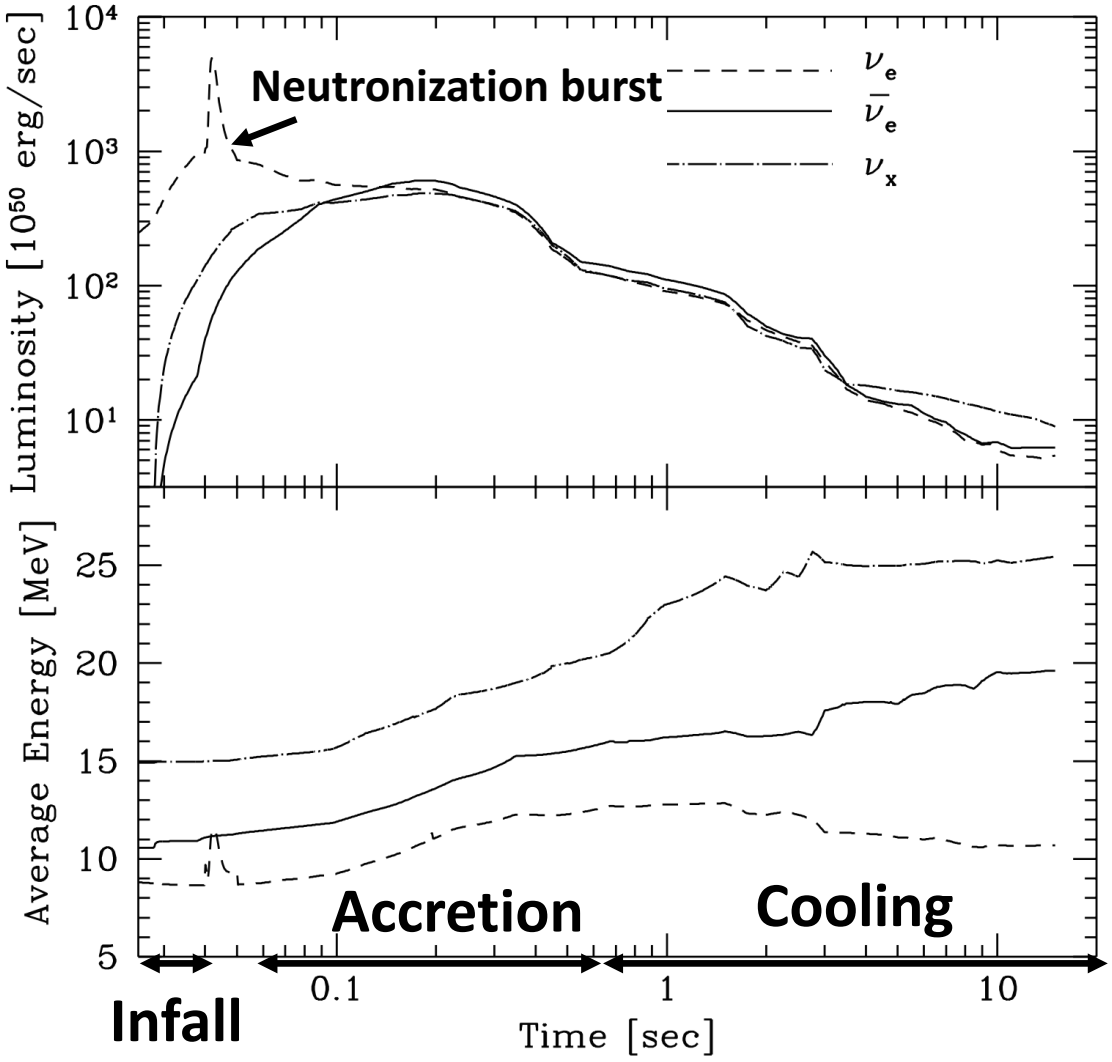
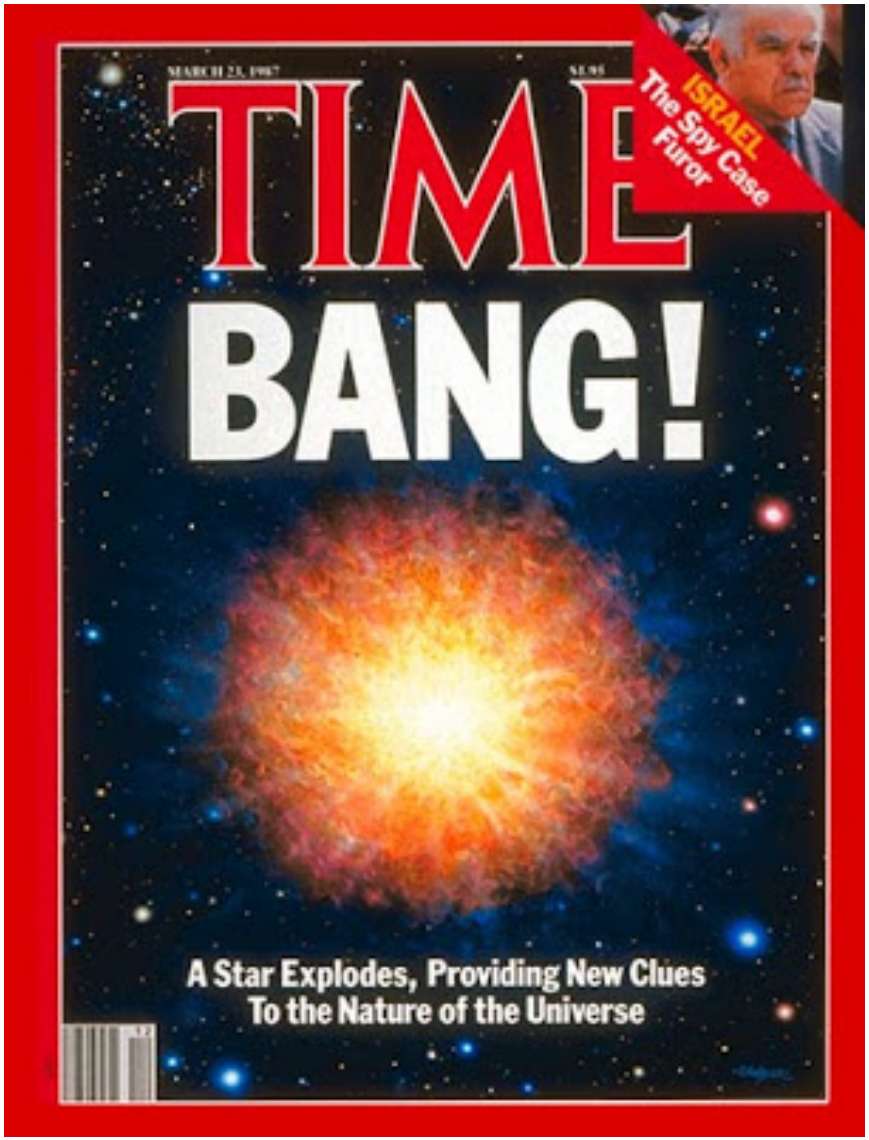
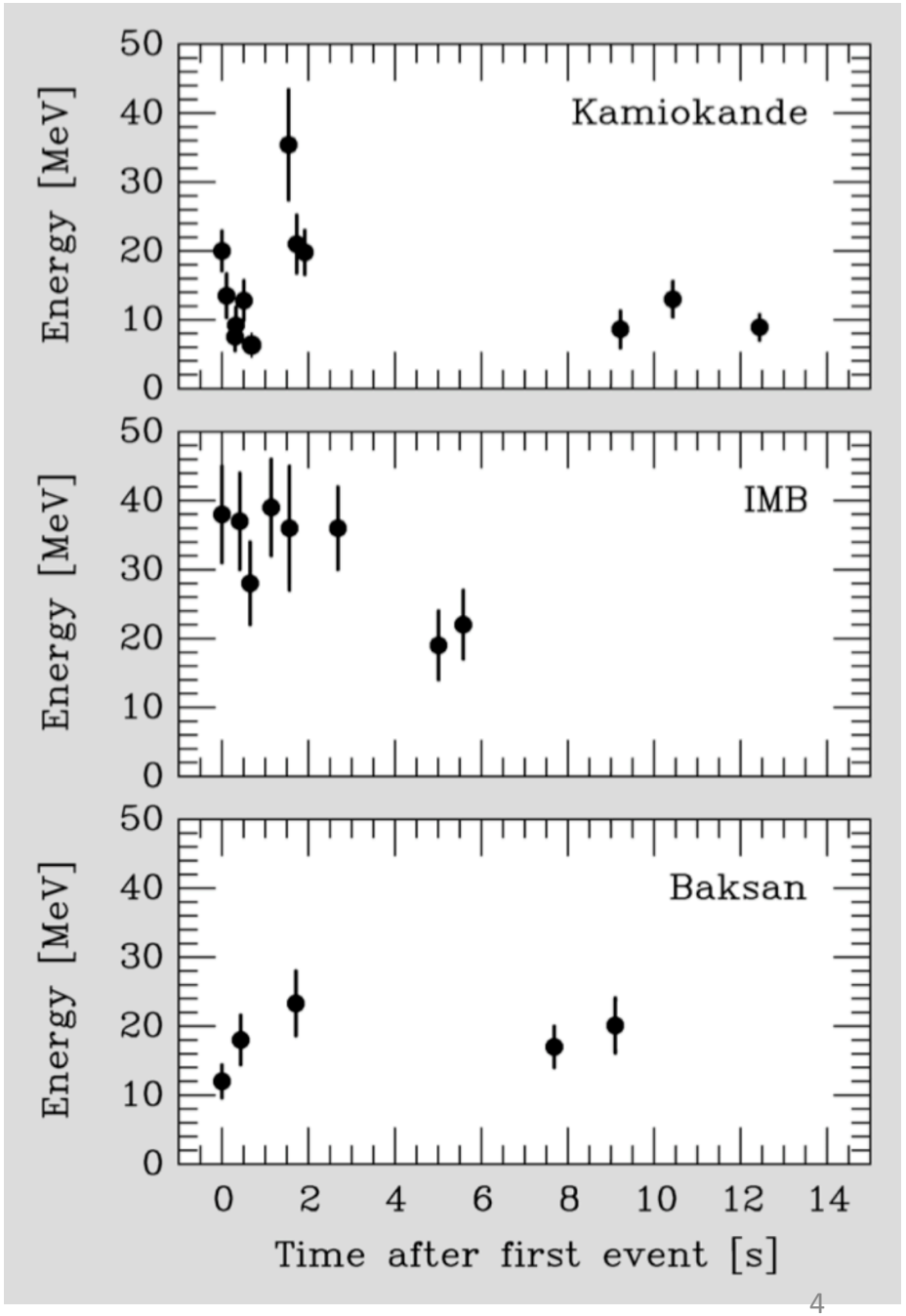

Cassiopeia A
(Chandra)
Image credit: NASA/CXC/SAO

What does the supernova neutrino signal look like?



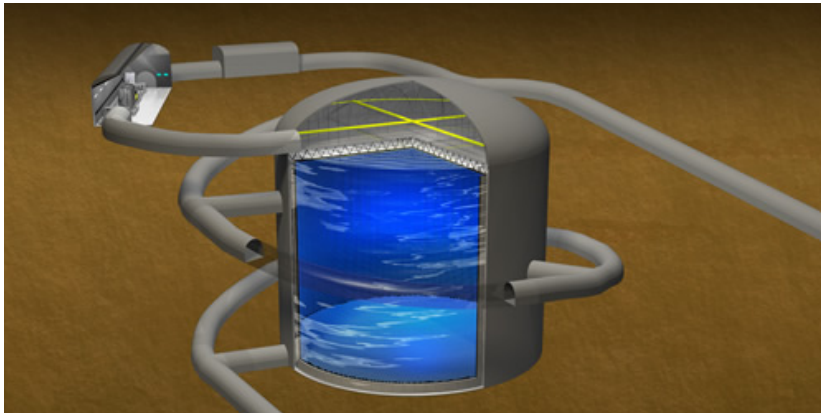
SN1987a

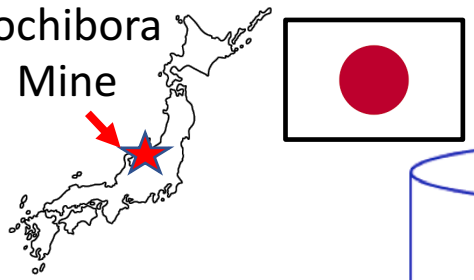

TIME
ISRAEL
The Spy Case
Furor
BANG!
A Star Explodes, Providing New Clues
To the Nature of the Universe

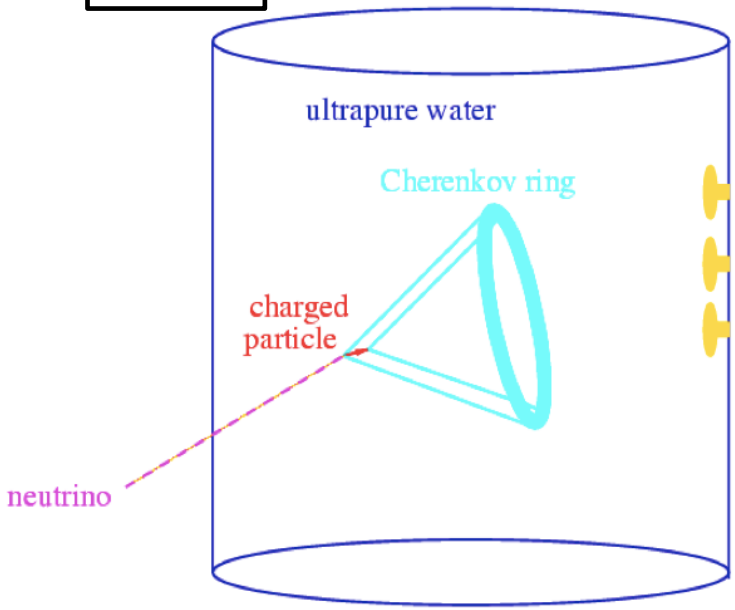

Kamiokande
IMB
Baksan
Energy [MeV]
Time after first event [s]
0
10
20
30
40
50
0
2
4
6
8
10
12
14

The Hyper-Kamiokande detector

74m (D) x 60m (H) tank
Total (fiducial) volume of 258 kT (187 kT).



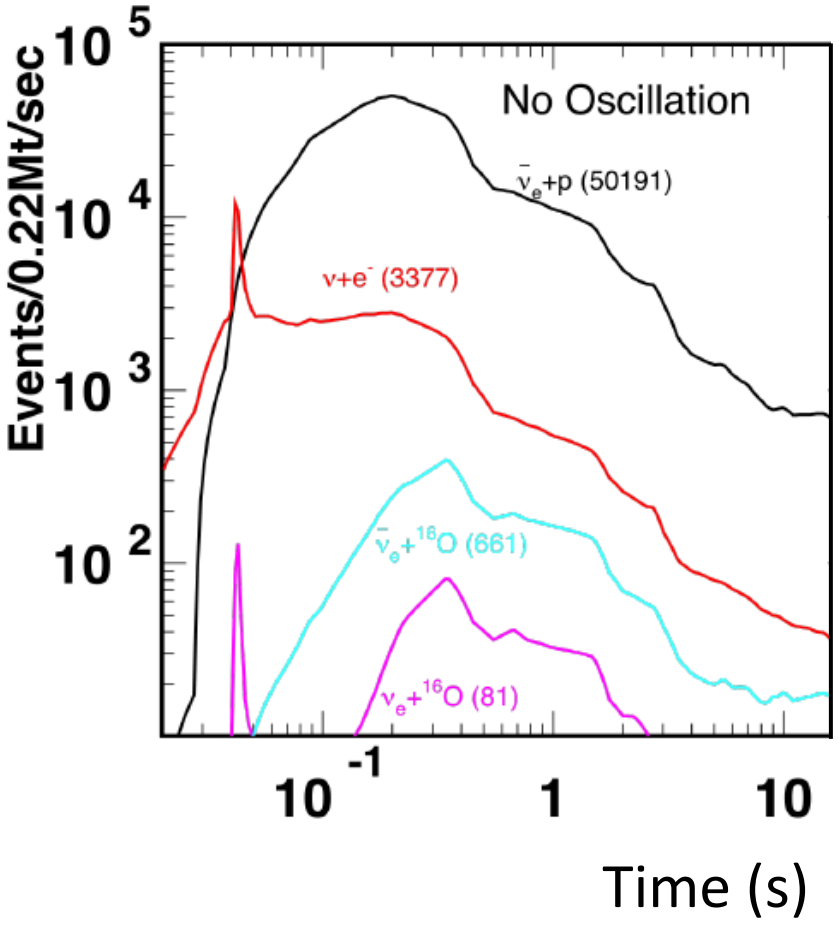




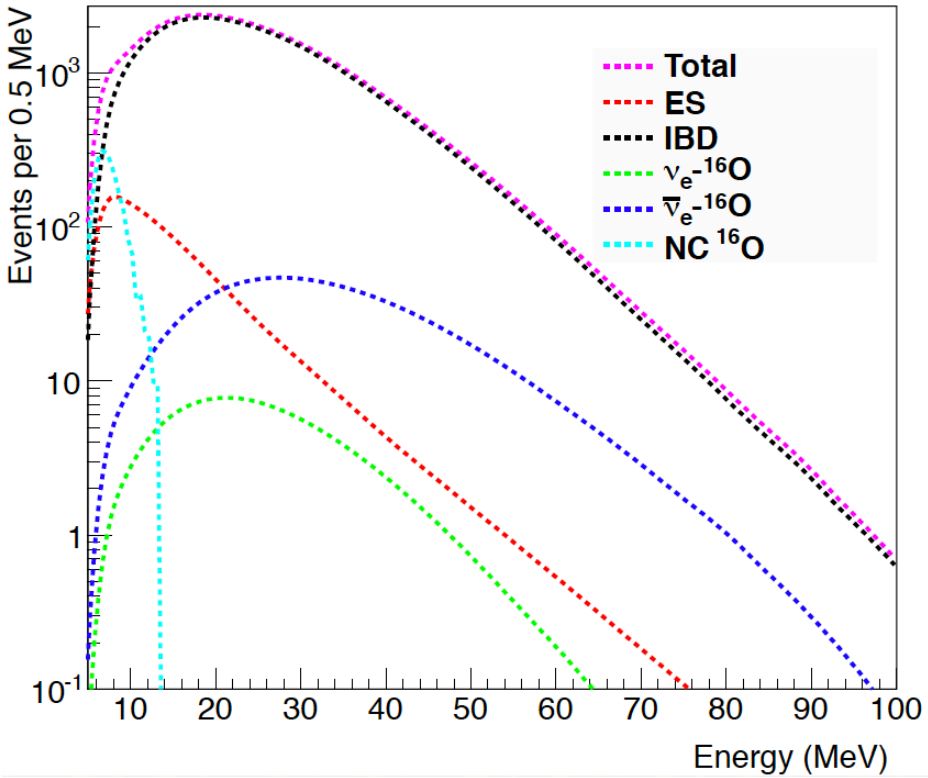
Hyper-Kamiokande will begin construction in April 2020, with data starting in 2027
See our new design report (arXiv:1805.04163)

What does a signal look like in Hyper-K?

Timing information



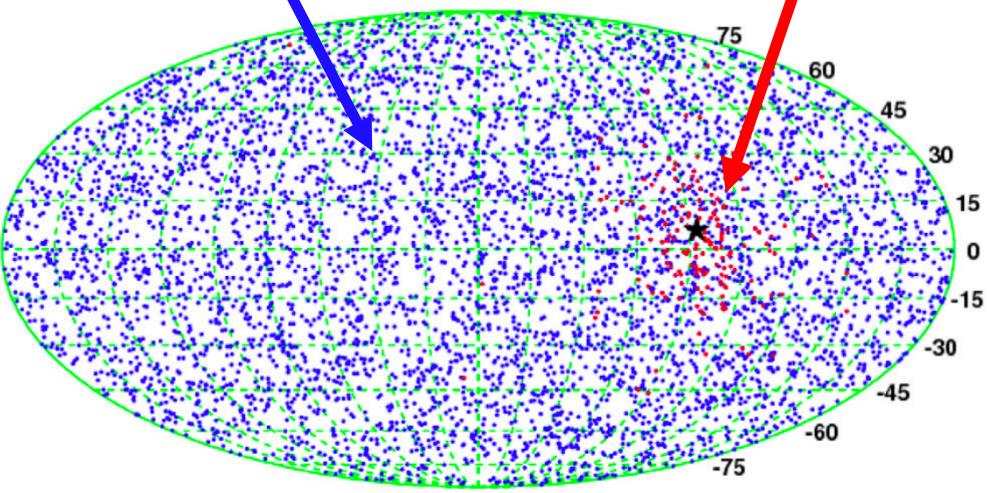
Energy information



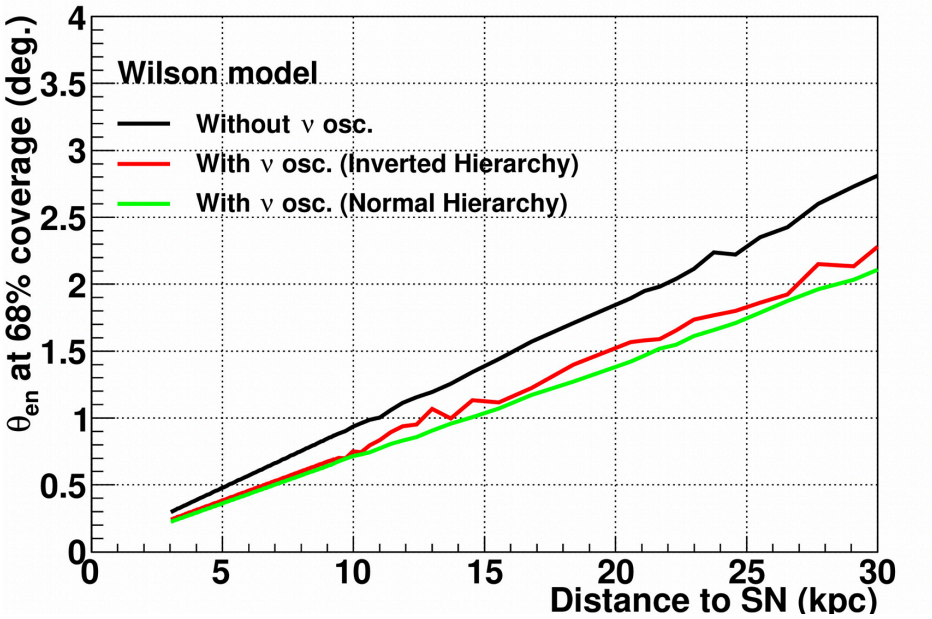
Measuring the supernova direction

$\overline{\nu}_e + p \rightarrow n + e^+$

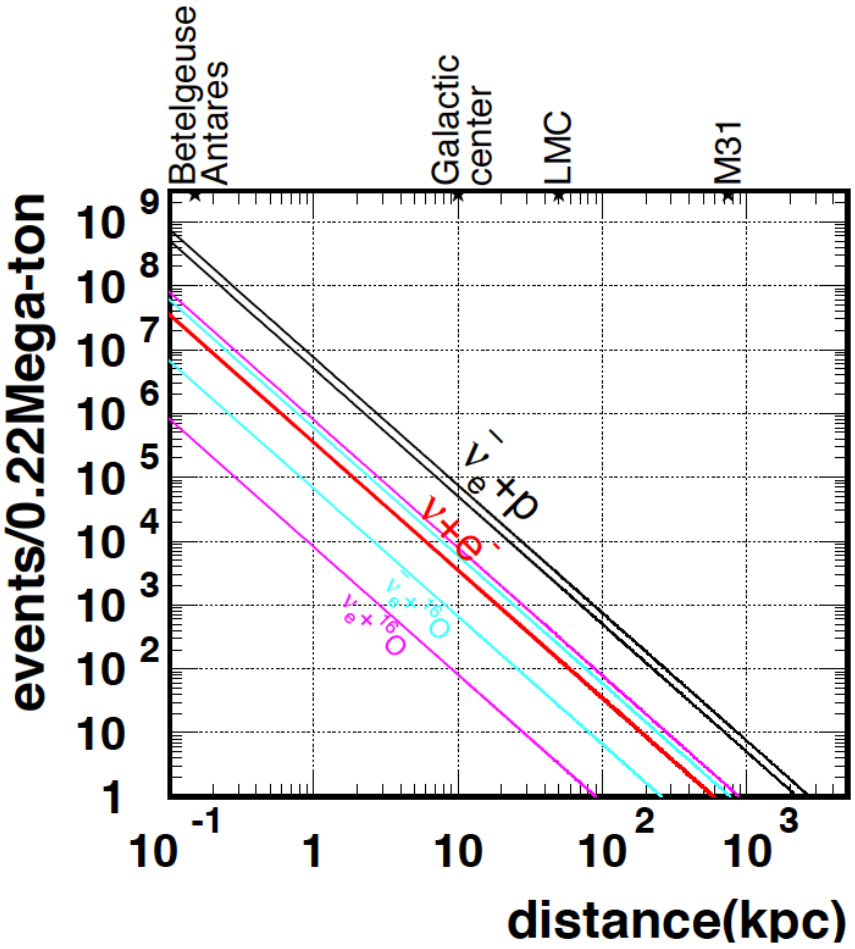
$\nu + e^- \rightarrow \nu + e^-$



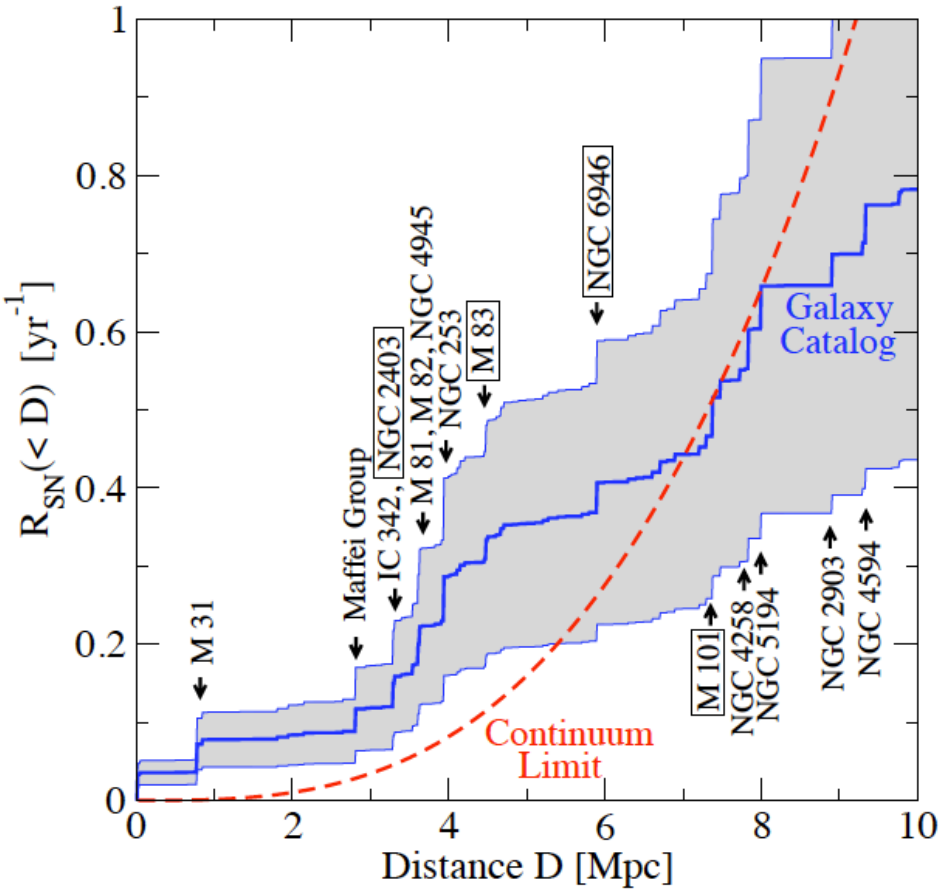
Only ~ 5% of neutrino events point back to the supernova



Hyper-K can measure the direction of a SN with half angle of 1-2°

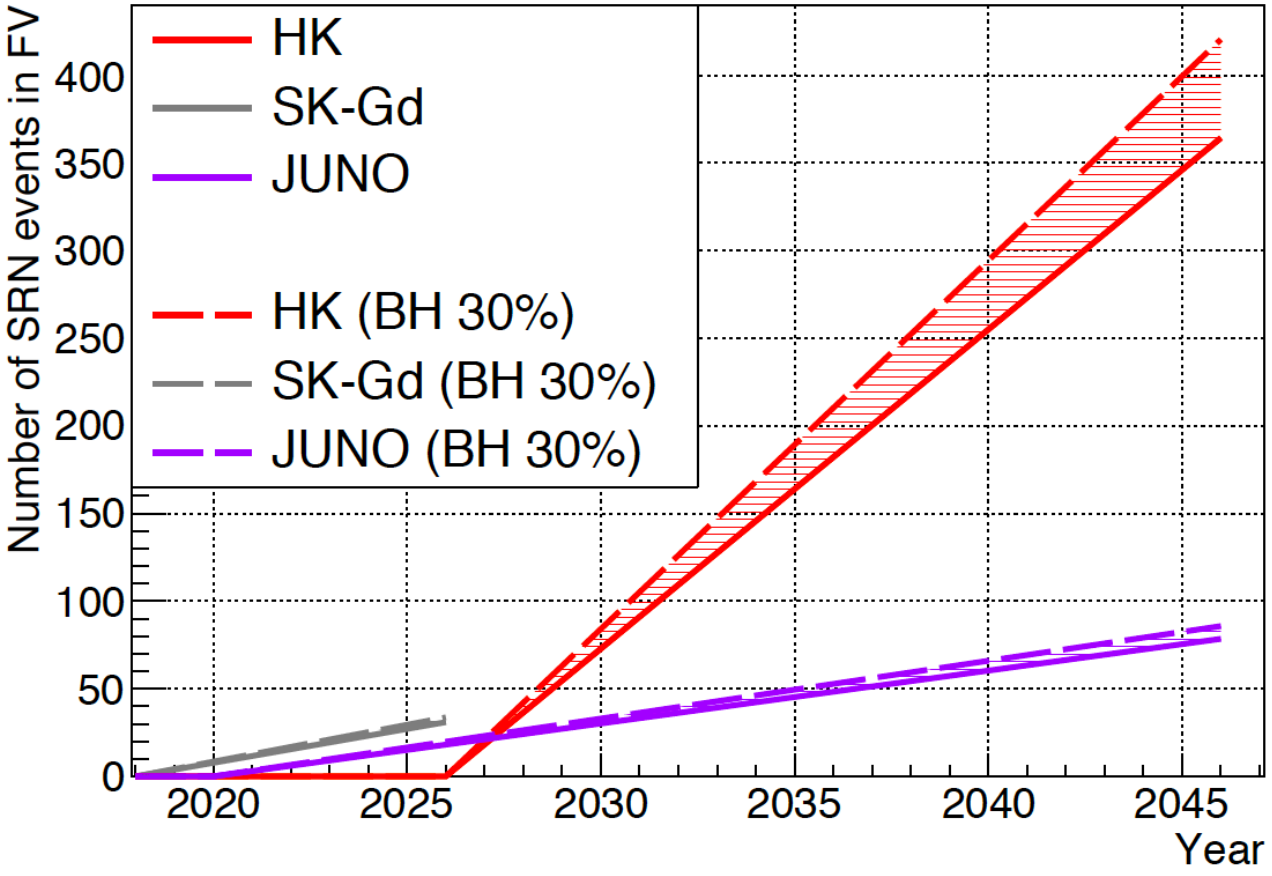


Ando, Beacom, Yüksel 05



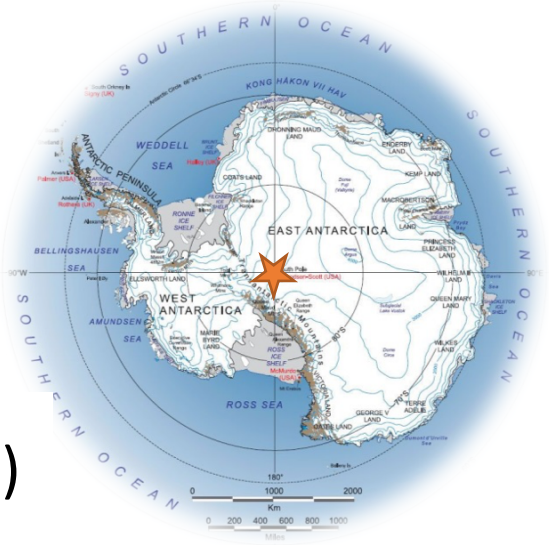
Hyper-K will probe to greater distances, where the SN rate is ~ 1/decade instead of ~2-3/century

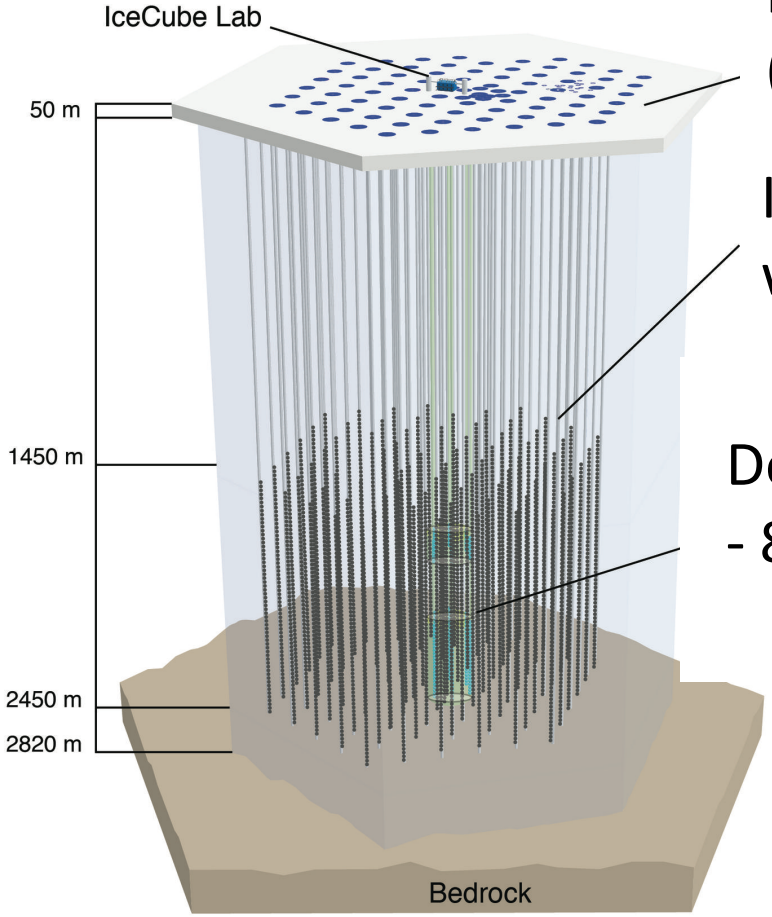
Hyper-K can make precision measurement of the diffuse supernova neutrino background



IceCube

completed 2011





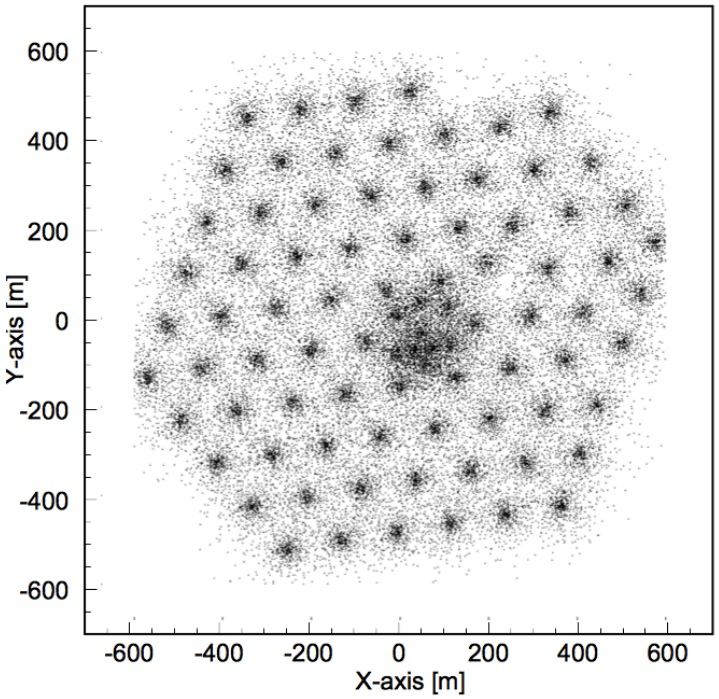
IceTop surface array
(acts as veto - 1 km^2)

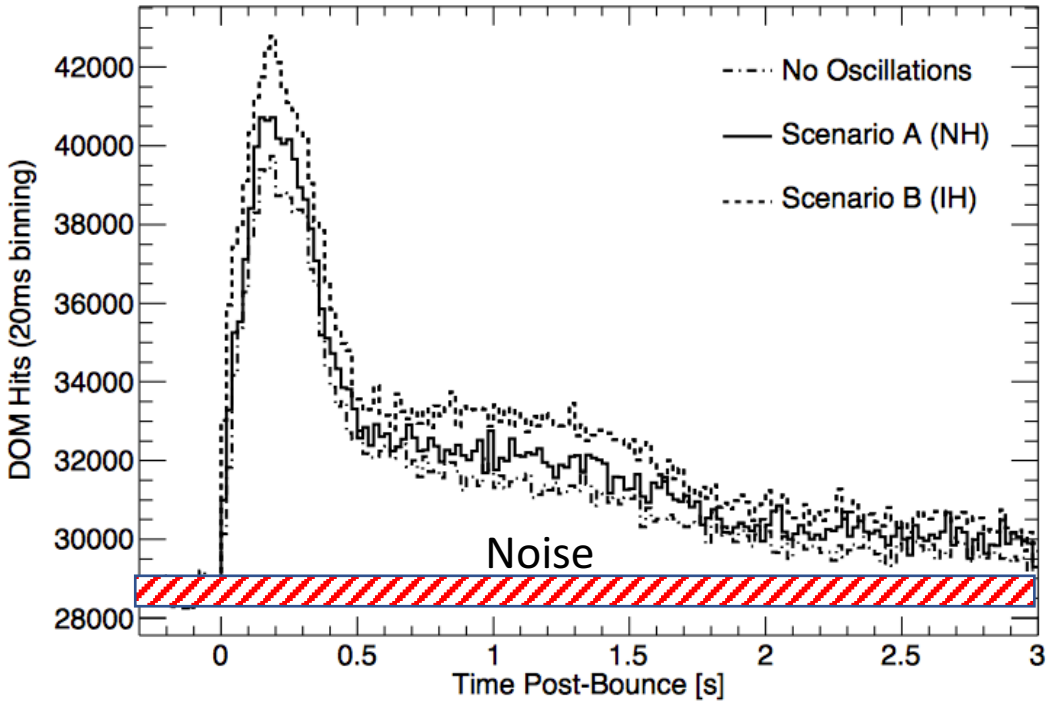
IceCube array – 86 strings
with 5160 optical modules

DeepCore
- 8 infill strings for lower energy

IceCube detects neutrinos that interact near the optical modules

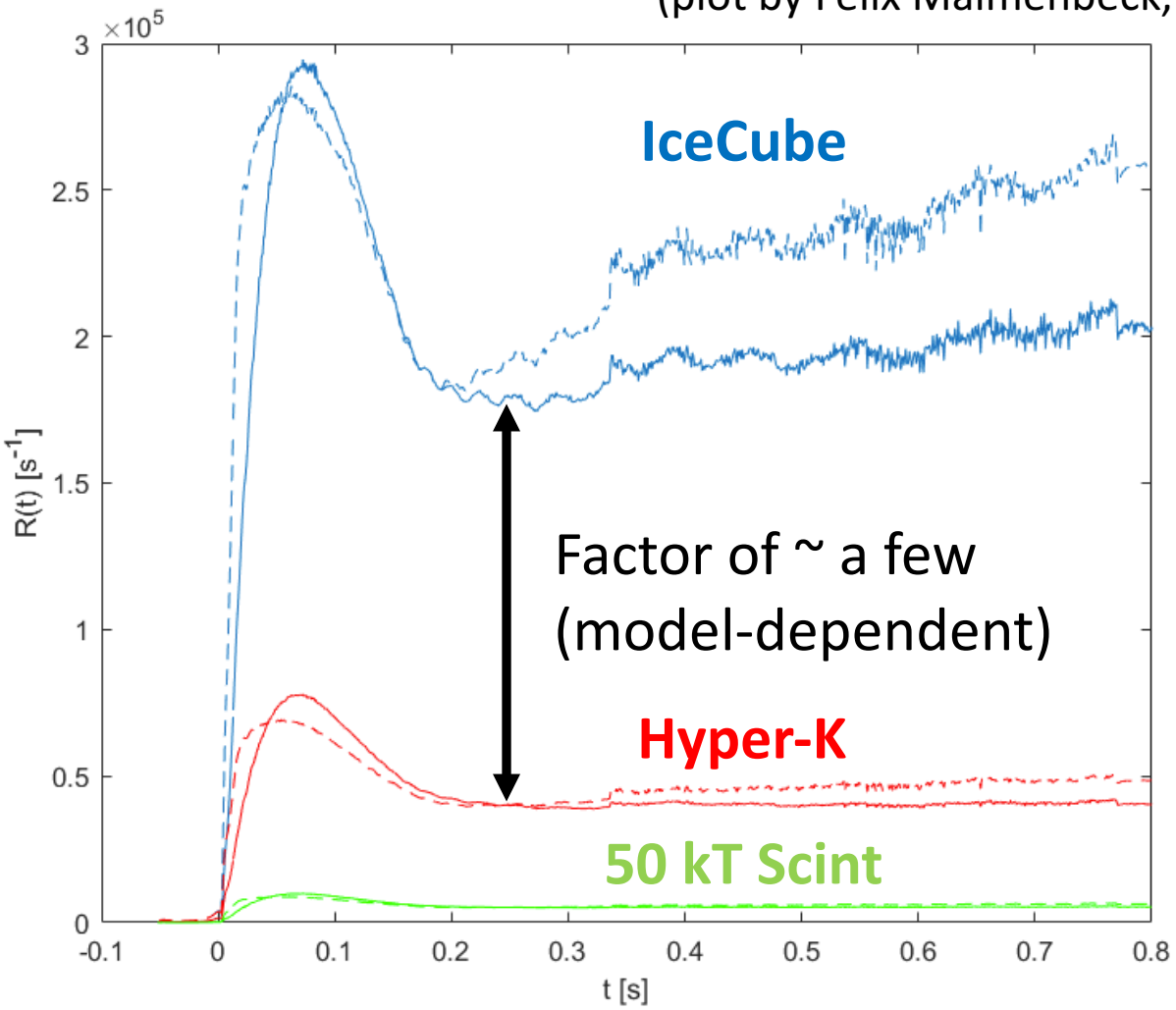
Abbasi+ 2011





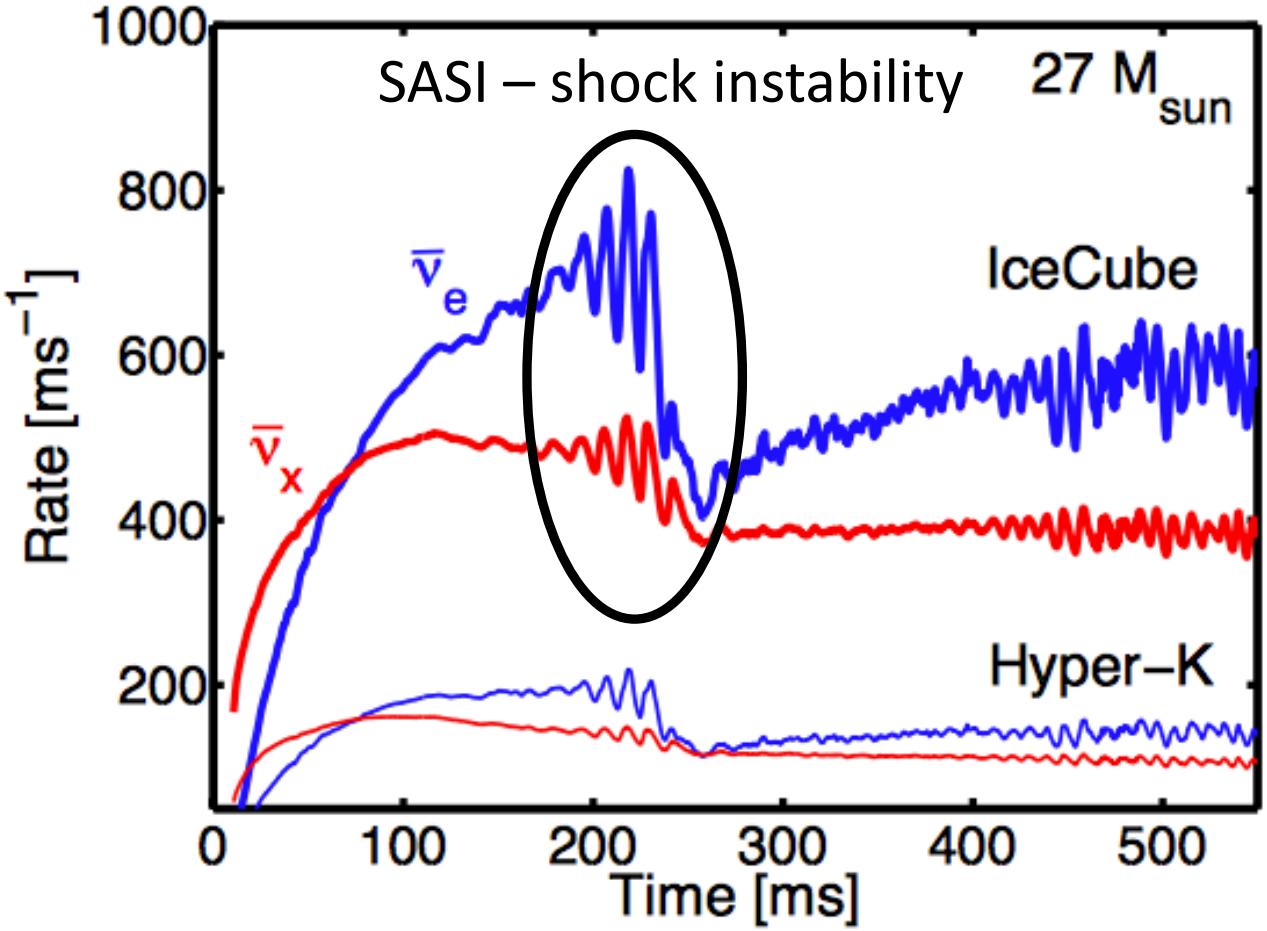
IceCube has the best neutrino rate measurement from nearby supernovae

(plot by Felix Malmenbeck, MSc@KTH)



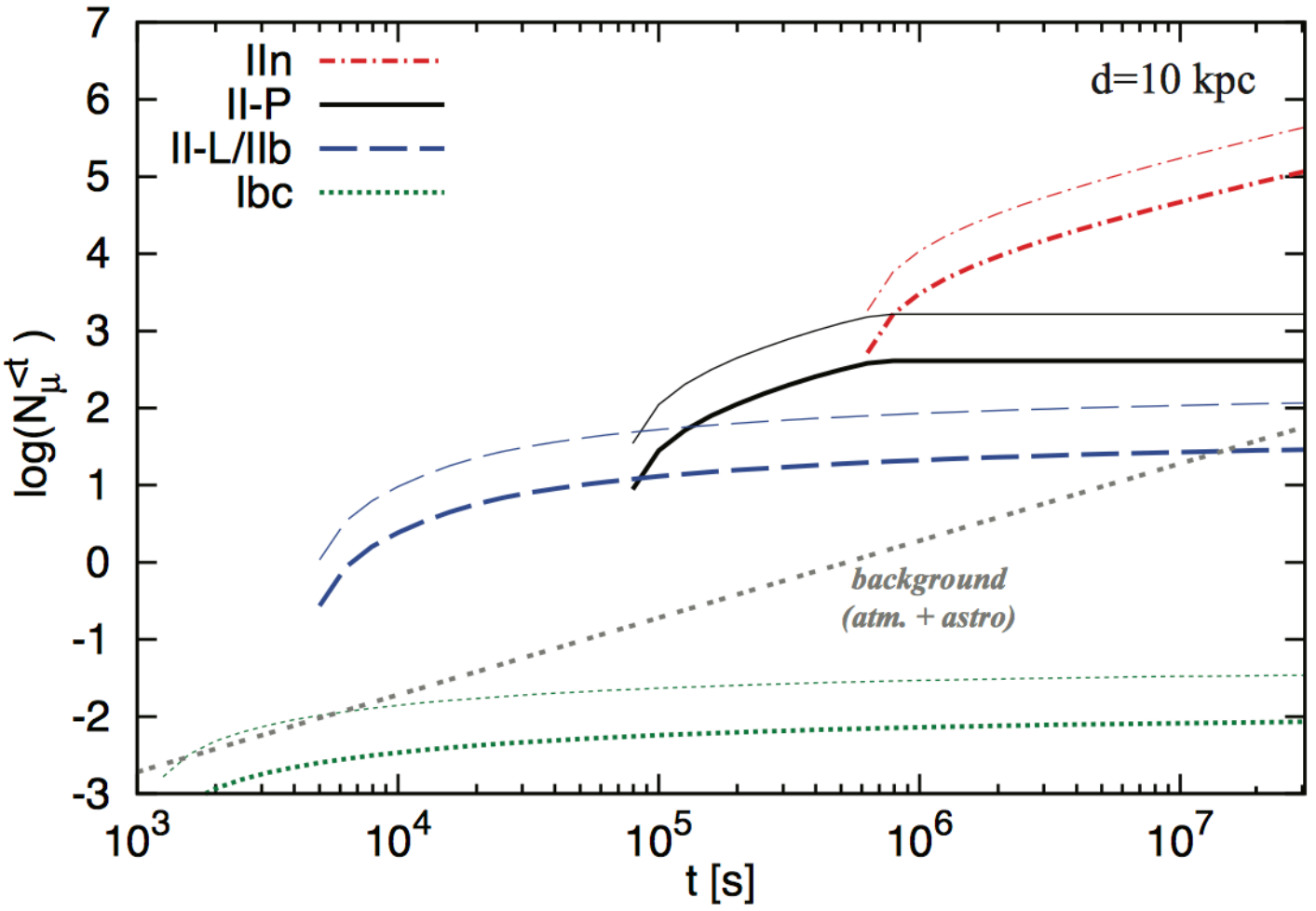
IceCube can measure features in timing structure

Tamborra+ 14



IceCube could measure high energy neutrinos from supernova shocks

Murase 18

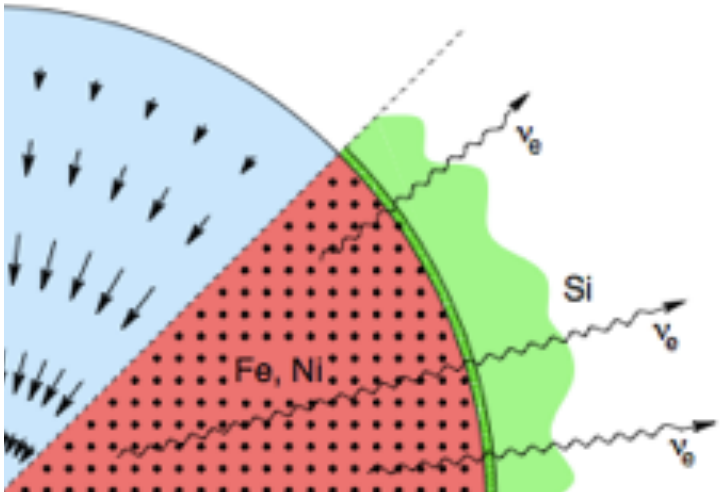


What's next? The three strategies for a supernova neutrino experimentalist

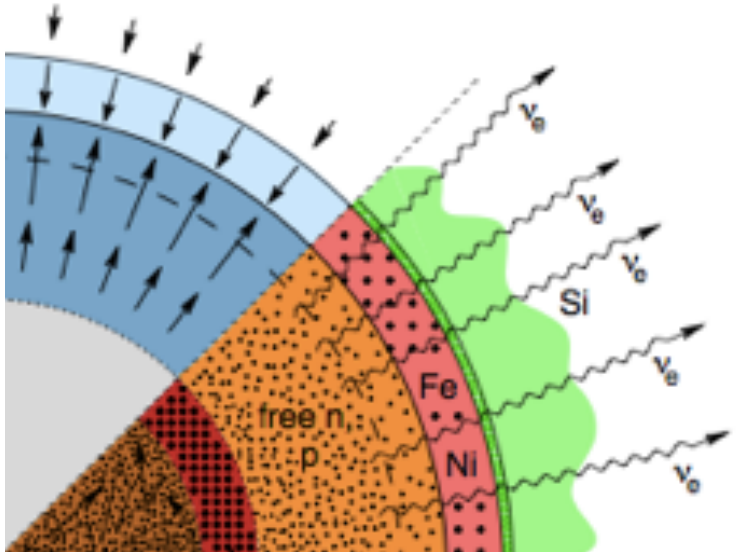
1. **We wait!** We are due for the next galactic supernova and this will give us rich astronomy and physics details about these events
2. **We expand!** Bigger detectors will allow us to reach larger distances, where the supernova rate is higher
3. **We improve!** By enhancing our capability to see supernova neutrinos, we will start to access the constant stream of diffuse supernova neutrinos constantly passing through the Earth

Only ν_e during early times

Infall



Neutronization

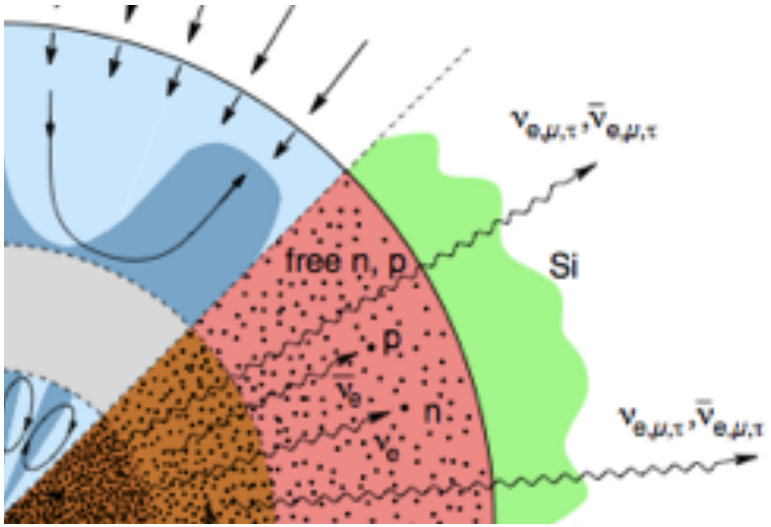


$$p + e^- \rightarrow n + \nu_e$$

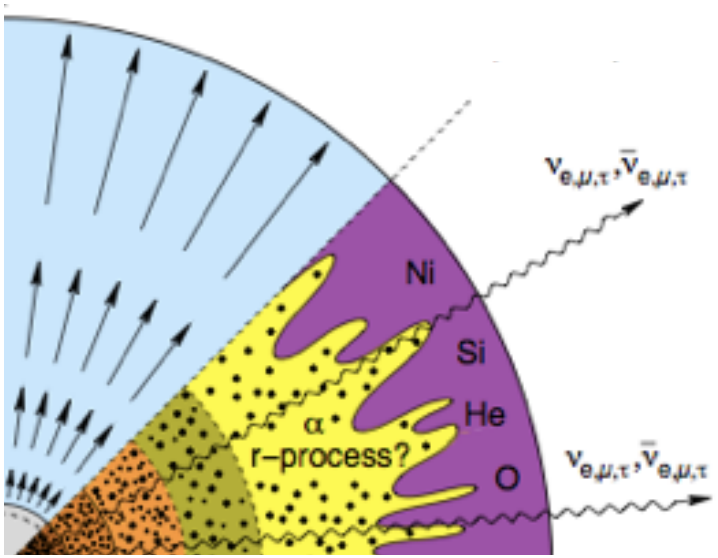
Janka+ 2007

All flavours of neutrinos at late times

Accretion

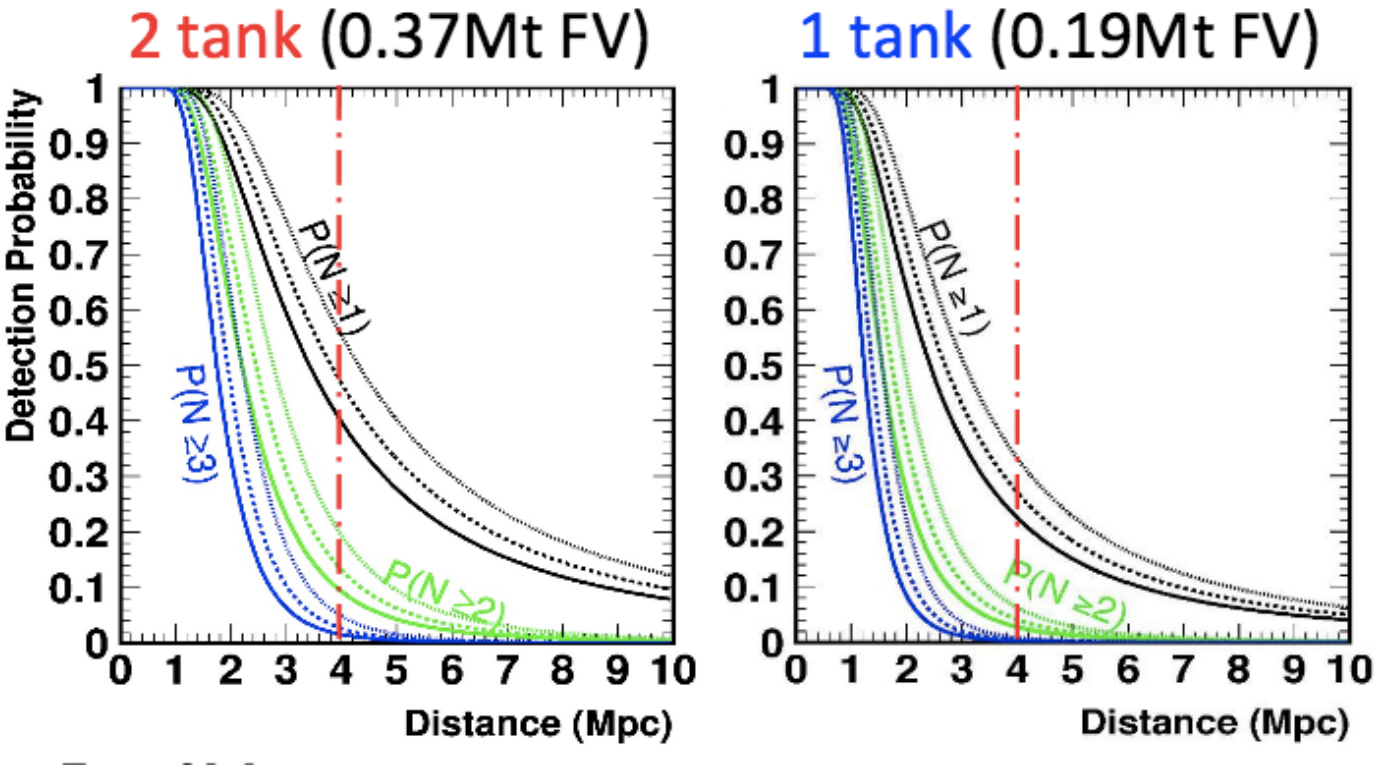


Cooling



Janka+ 2007

$n+e^+ \rightarrow p+\bar{\nu}_e$ $p+e^- \rightarrow n+\nu_e$ $e^+ + e^- \rightarrow \bar{\nu} + \nu$



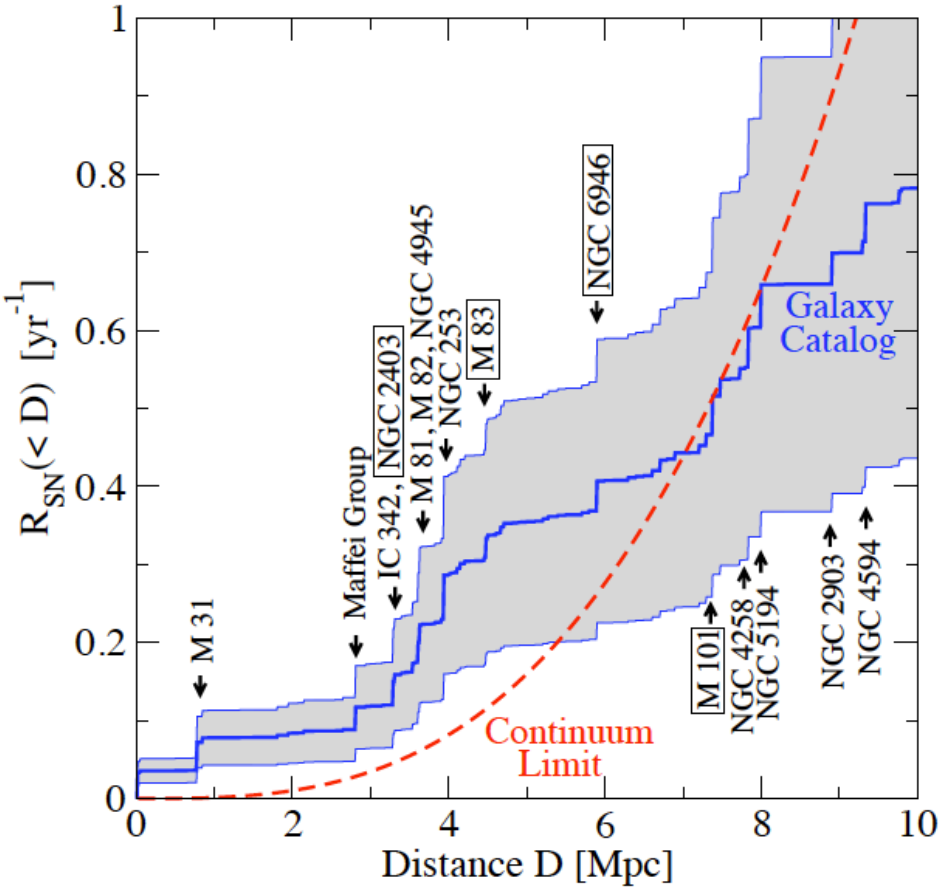
For 4Mpc supernova

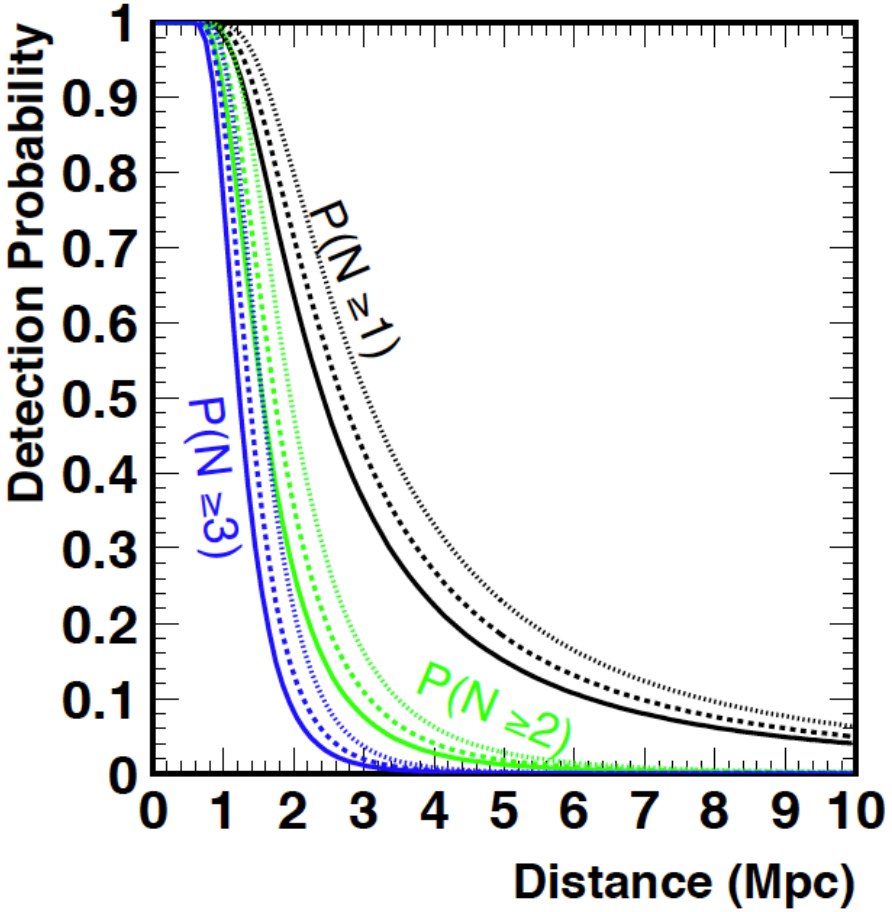
10-20 % for P(N >= 2) 3-6% for P(N >= 2)

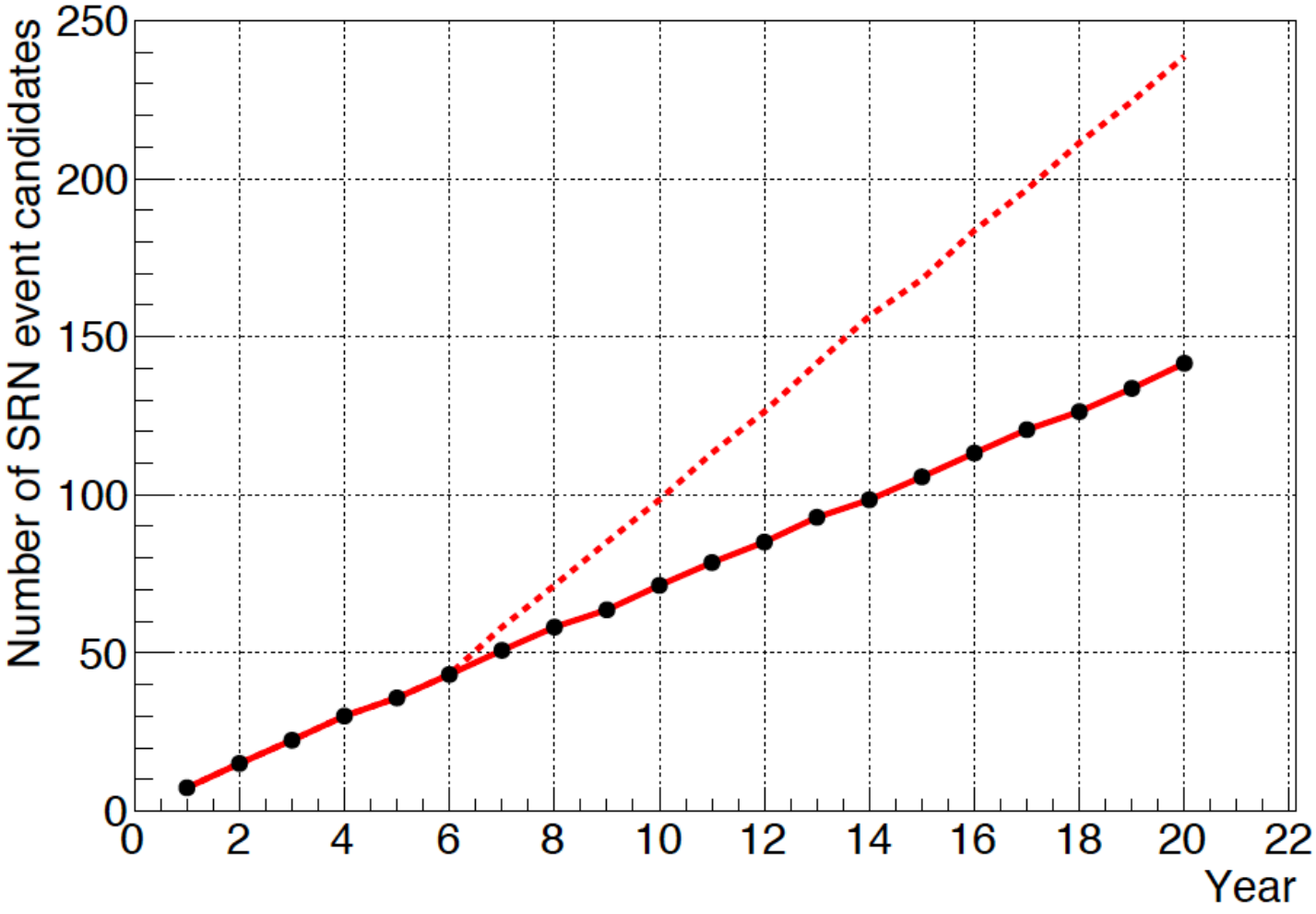
Livermore, 10 MeV threshold, expectation range from oscillation effects

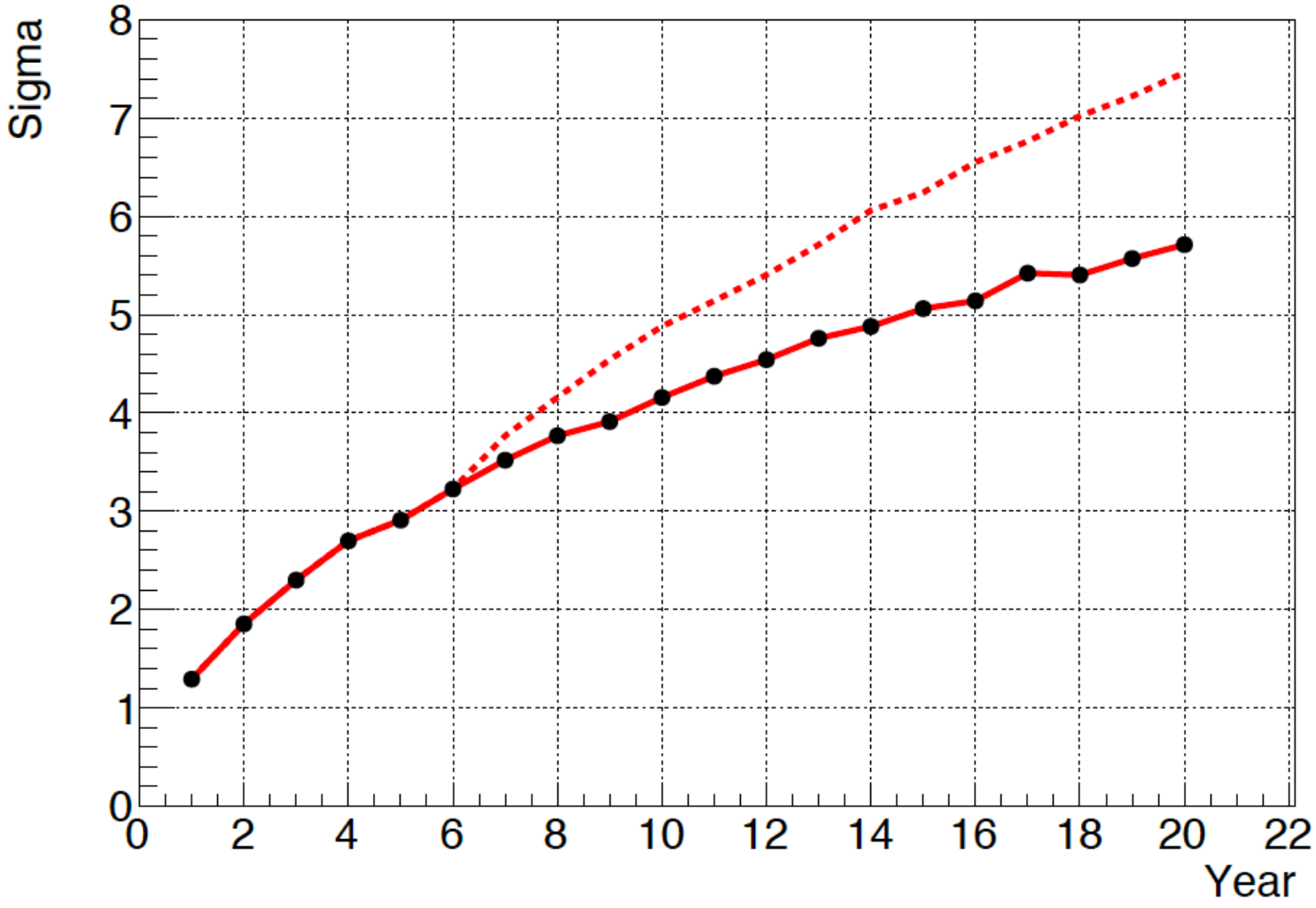
Hyper-K will probe distant SNe, where the SN rate is higher

Ando, Beacom, Yüksel 05

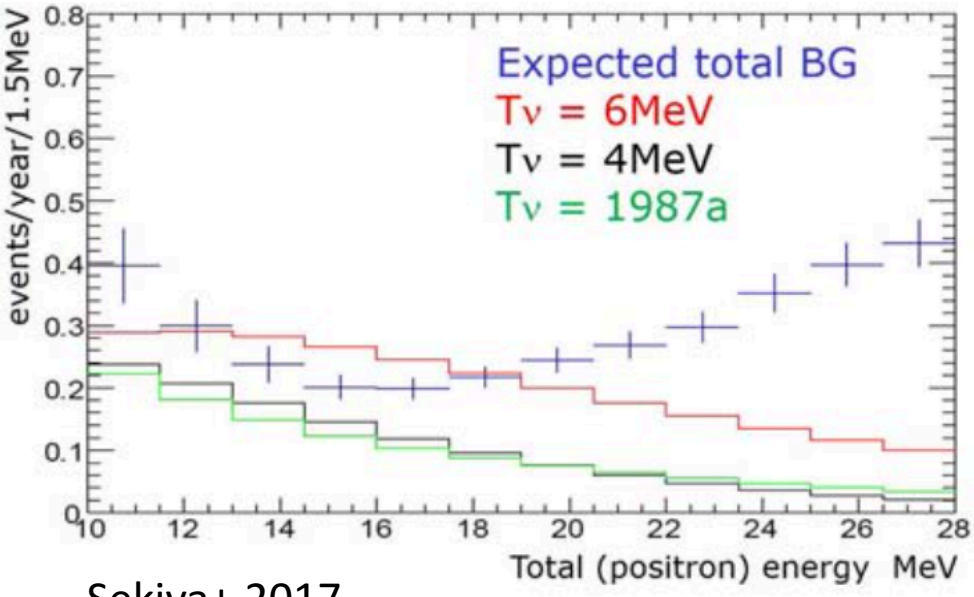





Number of SRN event candidates
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
22
Year


Sigma
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
22
Year

Super-K (+ Gd) will attempt a measurement of the DSNB



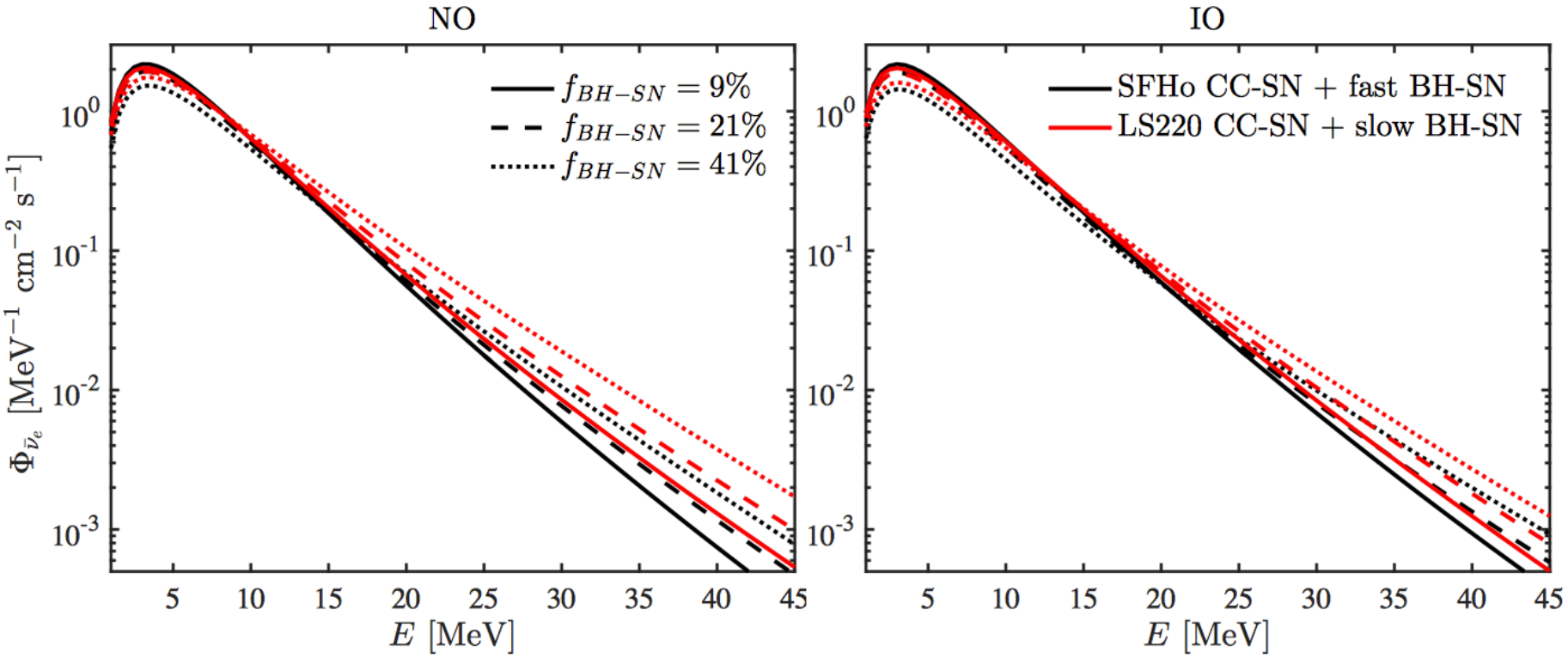
Sekiya+ 2017

Depending on the average energies of the SN neutrinos, we could see a high significance result

After 10 years

Model [16]	10-16 MeV	16-28 MeV	Total	significance
$T_{eff} = 8$ MeV	11.3	19.9	31.2	5.3σ
$T_{eff} = 6$ MeV	11.3	13.5	24.8	4.3σ
$T_{eff} = 4$ MeV	7.7	4.8	12.5	2.5σ
T_{eff} =SN1987a	5.1	6.8	11.9	2.1σ
BG	10	24	34	–

Møller+ 18


NO
IO
$f_{BH-SN} = 9\%$
$f_{BH-SN} = 21\%$
$f_{BH-SN} = 41\%$
SFHo CC-SN + fast BH-SN
LS220 CC-SN + slow BH-SN
$\Phi_{\bar{\nu}_e}$ [MeV^{-1} cm^{-2} s^{-1}]
E [MeV]
10^0
10^{-1}
10^{-2}
10^{-3}
5
10
15
20
25
30
35
40
45