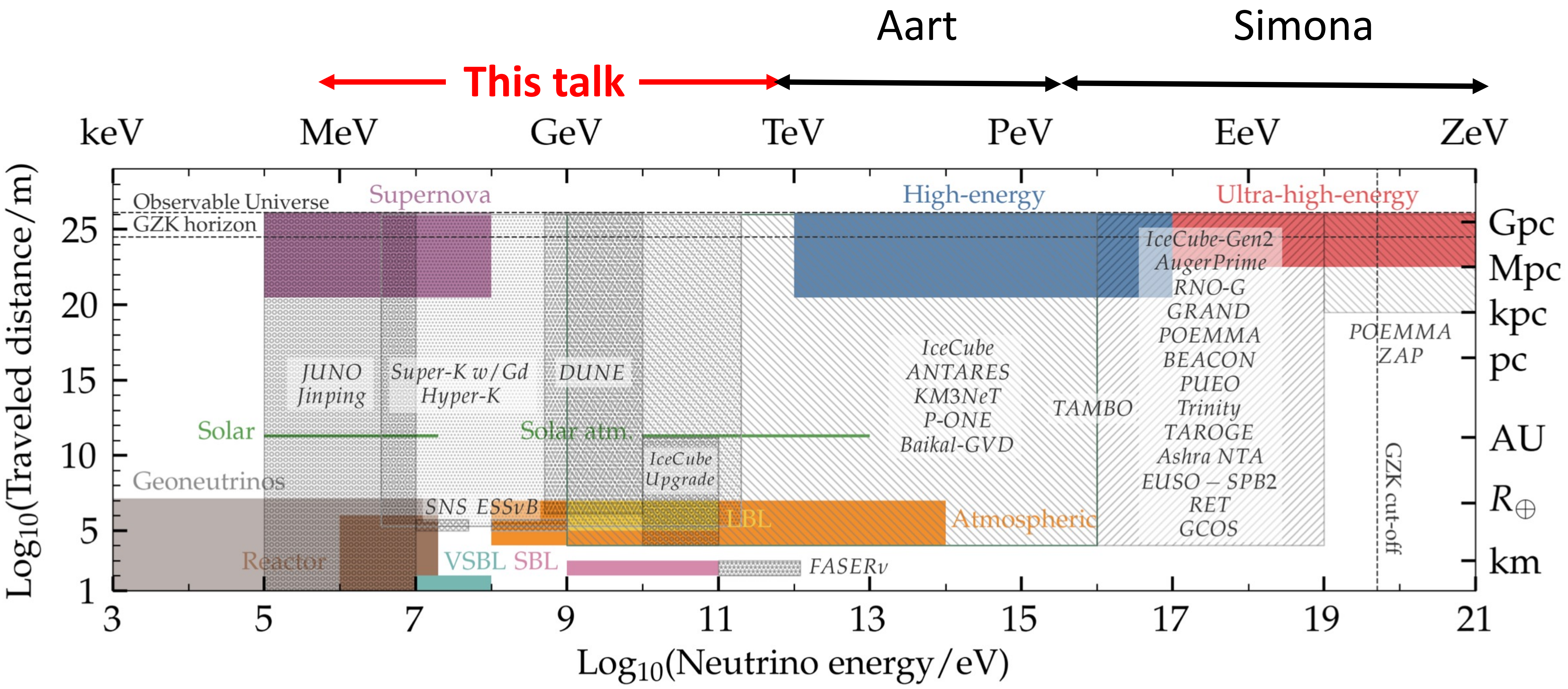
Potential of next generation MeV-TeV neutrino telescopes

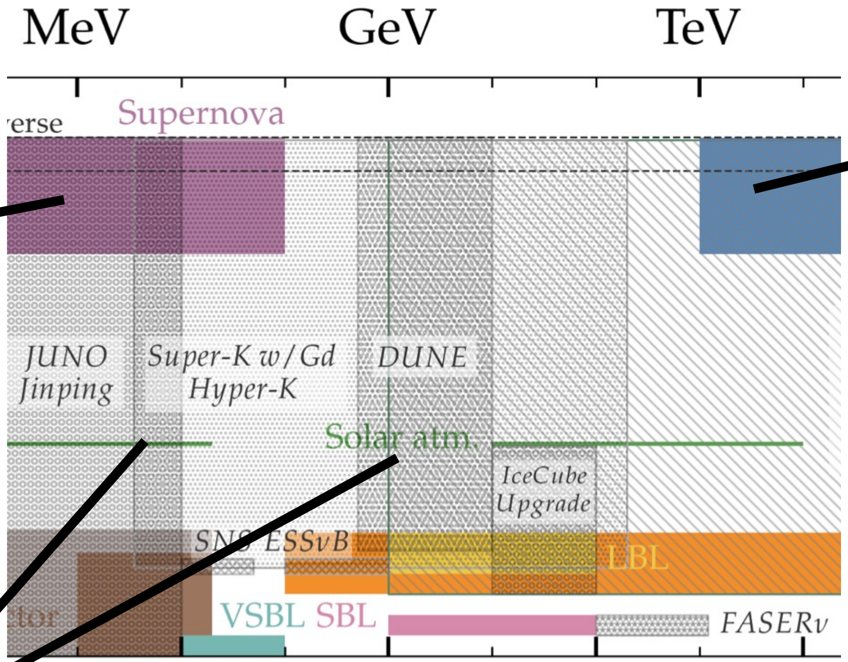
Erin O’Sullivan



Aart
Simona
This talk
keV
MeV
GeV
TeV
PeV
EeV
ZeV
Observable Universe
GZK horizon
Supernova
High-energy
Ultra-high-energy
IceCube-Gen2
AugerPrime
RNO-G
GRAND
POEMMA
BEACON
PUEO
Trinity
TAROGE
Ashra NTA
EUSO – SPB2
RET
GCOS
POEMMA
ZAP
GZK cut-off
JUNO
Jinping
Super-K w/Gd
Hyper-K
DUNE
IceCube
ANTARES
KM3NeT
P-ONE
Baikal-GVD
TAMBO
Solar
Solar atm.
IceCube Upgrade
Geoneutrinos
SNS
ESSνB
LBL
Atmospheric
Reactor
VSBL
SBL
FASERν
Gpc
Mpc
kpc
pc
AU
$R_\oplus$
km
Log_{10}(Traveled distance / m)
Log_{10}(Neutrino energy / eV)

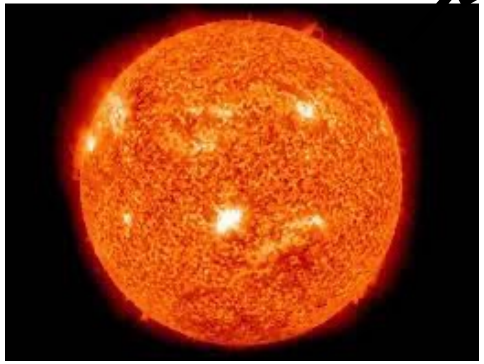
Neutrino sources in the MeV-TeV energy range

Supernova

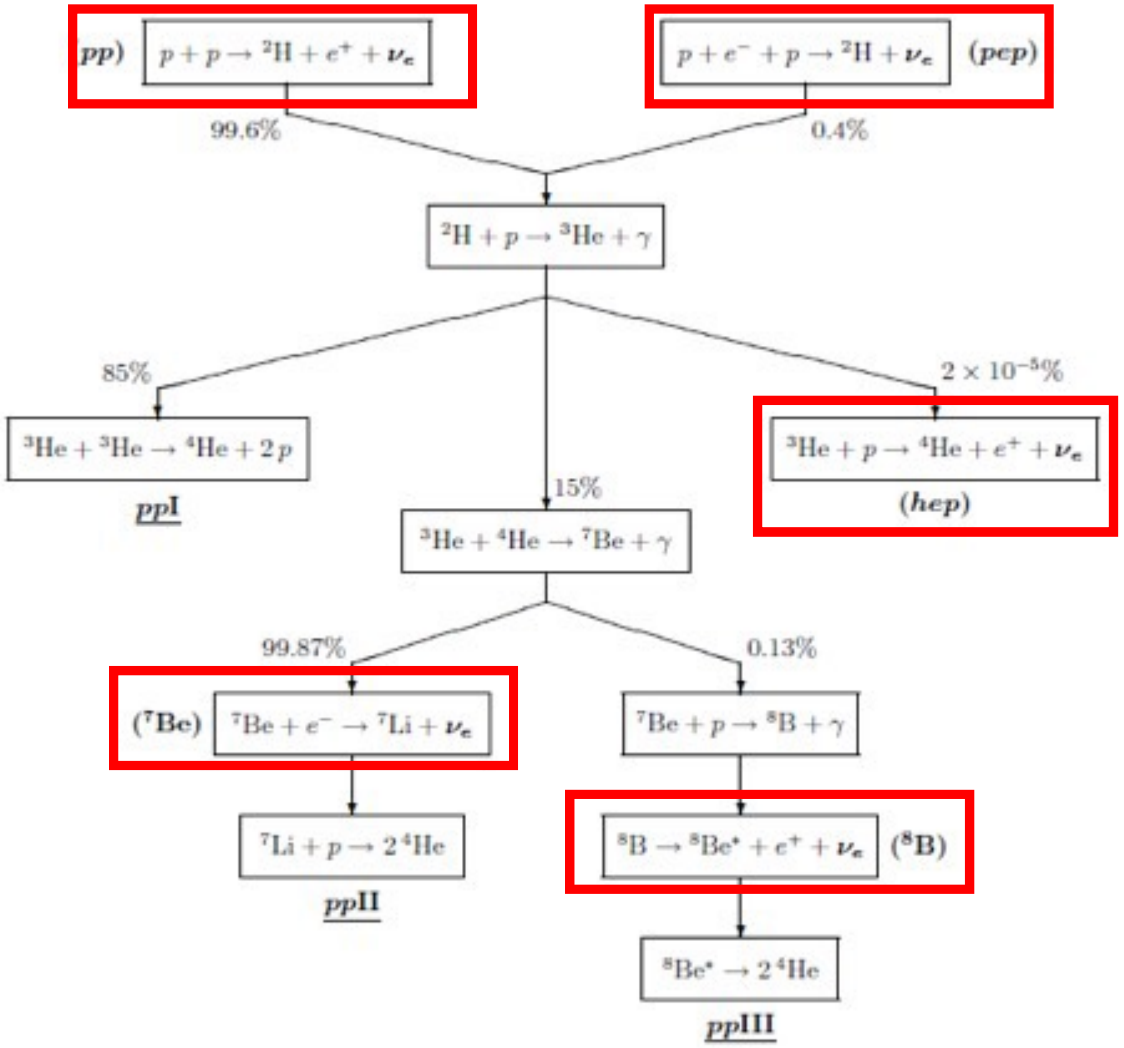


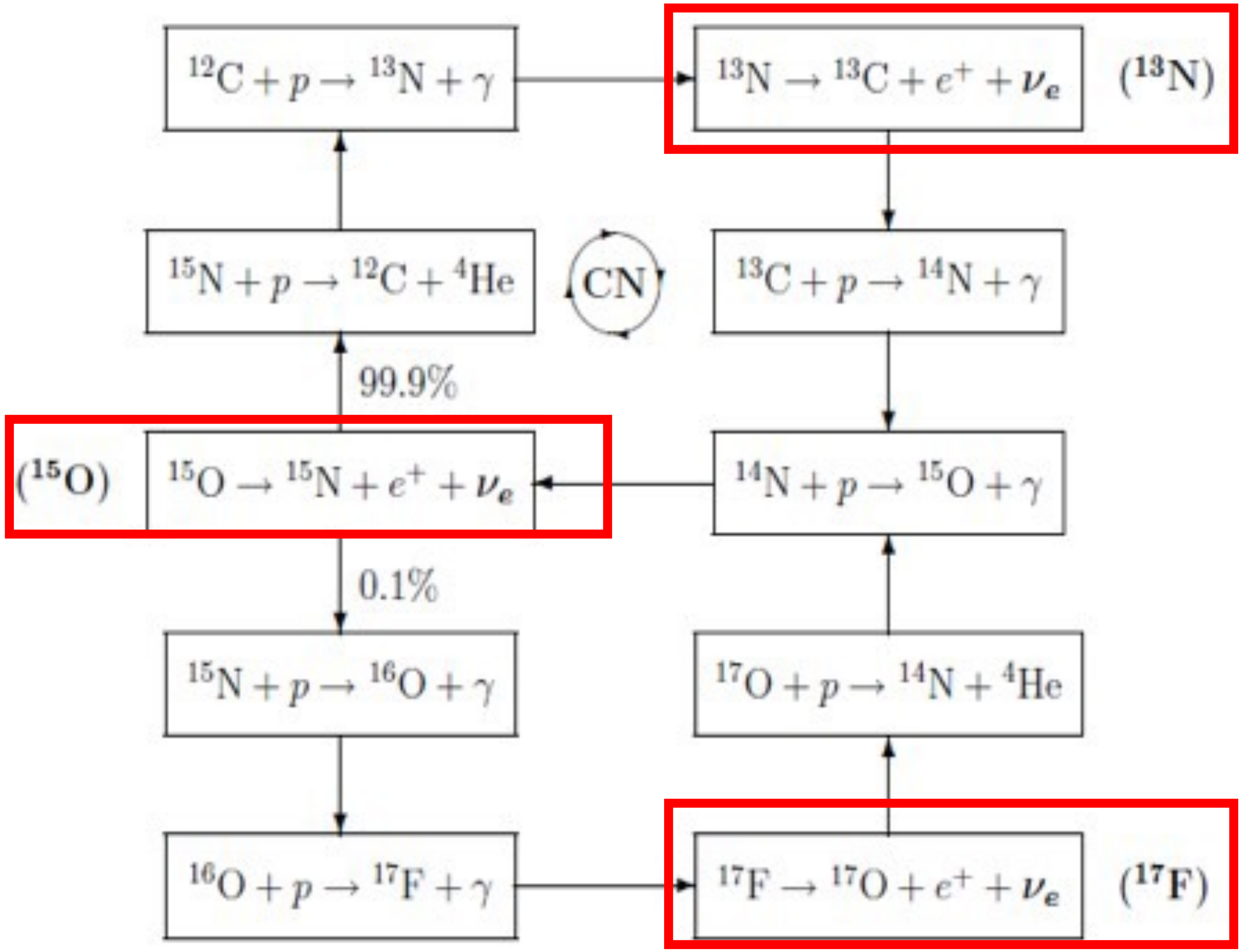
Low energy (GeV-TeV)
cosmic sources

Solar

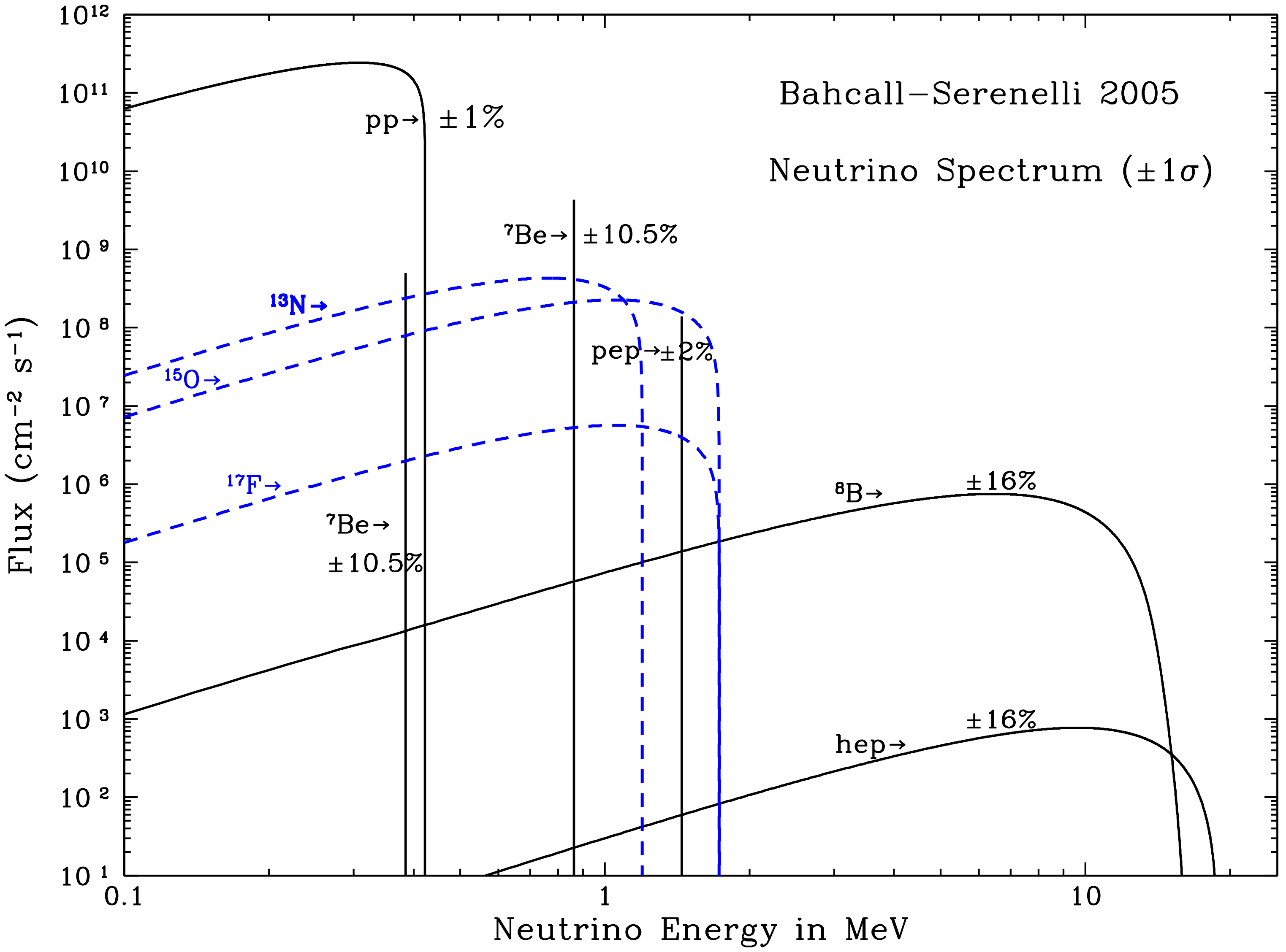


Solar


pp)
$p + p \to {}^2H + e^+ + \nu_e$
$p + e^- + p \to {}^2H + \nu_e$
(pep)
99.6%
0.4%
${}^2H + p \to {}^3He + \gamma$
85%
15%
$2 \times 10^{-5}\%$
${}^3He + {}^3He \to {}^4He + 2p$
ppI
${}^3He + p \to {}^4He + e^+ + \nu_e$
(hep)
${}^3He + {}^4He \to {}^7Be + \gamma$
99.87%
0.13%
(${}^7Be$)
${}^7Be + e^- \to {}^7Li + \nu_e$
${}^7Be + p \to {}^8B + \gamma$
${}^7Li + p \to 2\,{}^4He$
ppII
${}^8B \to {}^8Be^* + e^+ + \nu_e$
(${}^8B$)
${}^8Be^* \to 2\,{}^4He$
ppIII


${}^{12}C + p \to {}^{13}N + \gamma$
${}^{13}N \to {}^{13}C + e^+ + \nu_e$
(${}^{13}N$)
${}^{15}N + p \to {}^{12}C + {}^4He$
CN
${}^{13}C + p \to {}^{14}N + \gamma$
99.9%
(${}^{15}O$)
${}^{15}O \to {}^{15}N + e^+ + \nu_e$
${}^{14}N + p \to {}^{15}O + \gamma$
0.1%
${}^{15}N + p \to {}^{16}O + \gamma$
${}^{17}O + p \to {}^{14}N + {}^4He$
${}^{16}O + p \to {}^{17}F + \gamma$
${}^{17}F \to {}^{17}O + e^+ + \nu_e$
(${}^{17}F$)

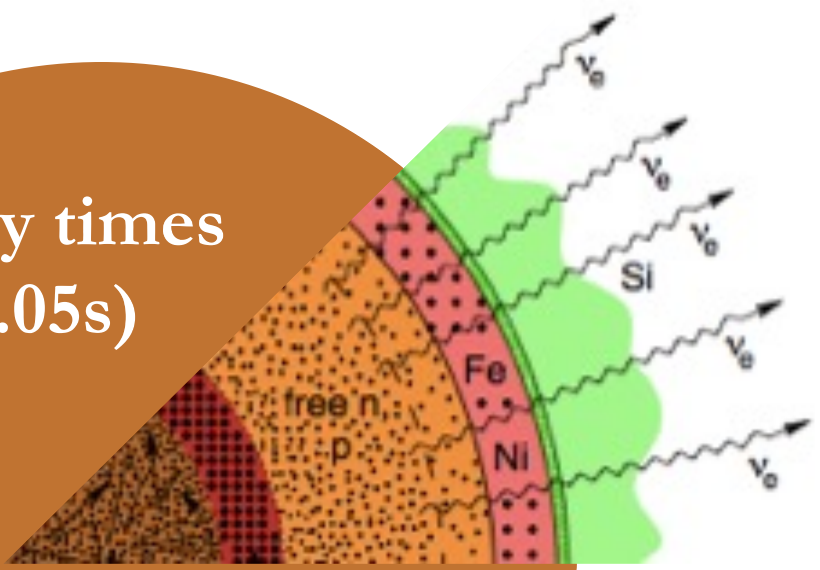
Solar



Bahcall−Serenelli 2005
Neutrino Spectrum (±1σ)
pp→ ±1%
⁷Be→ ±10.5%
¹³N→
¹⁵O→
¹⁷F→
pep→±2%
⁷Be→
±10.5%
⁸B→
±16%
hep→
±16%
Flux (cm⁻² s⁻¹)
Neutrino Energy in MeV
10¹²
10¹¹
10¹⁰
10⁹
10⁸
10⁷
10⁶
10⁵
10⁴
10³
10²
10¹
0.1
1
10

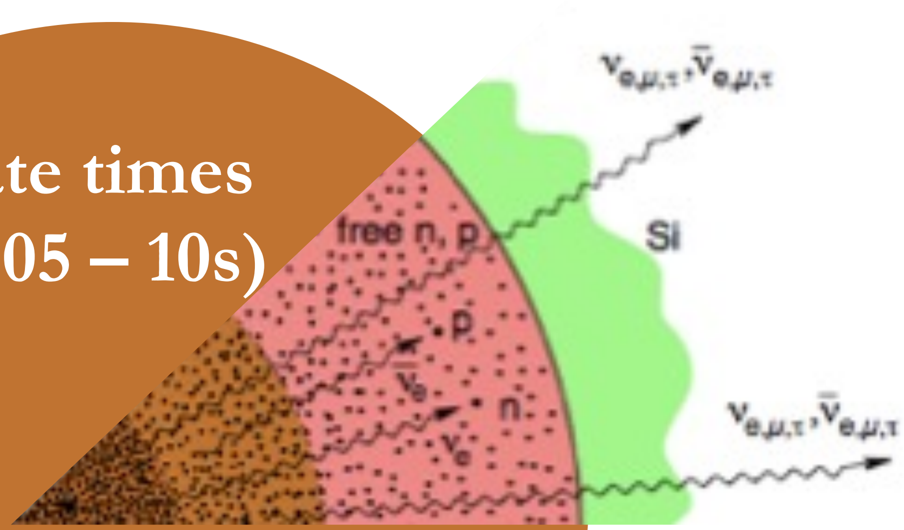
Supernova

Early times (< 0.05s)



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

Late times (0.05 – 10s)

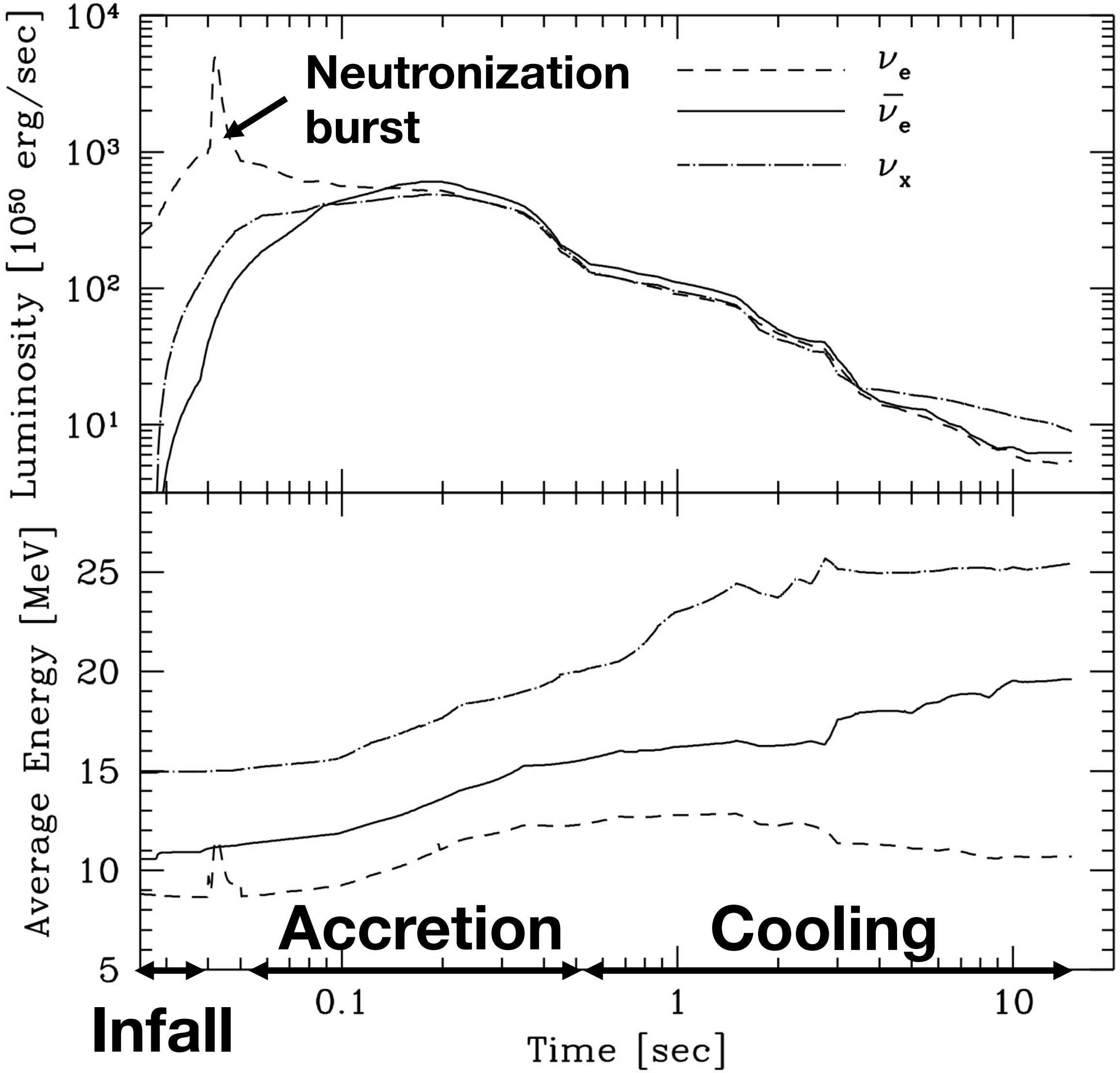


$$n+e^+ \rightarrow p+\bar{\nu}_e$$

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

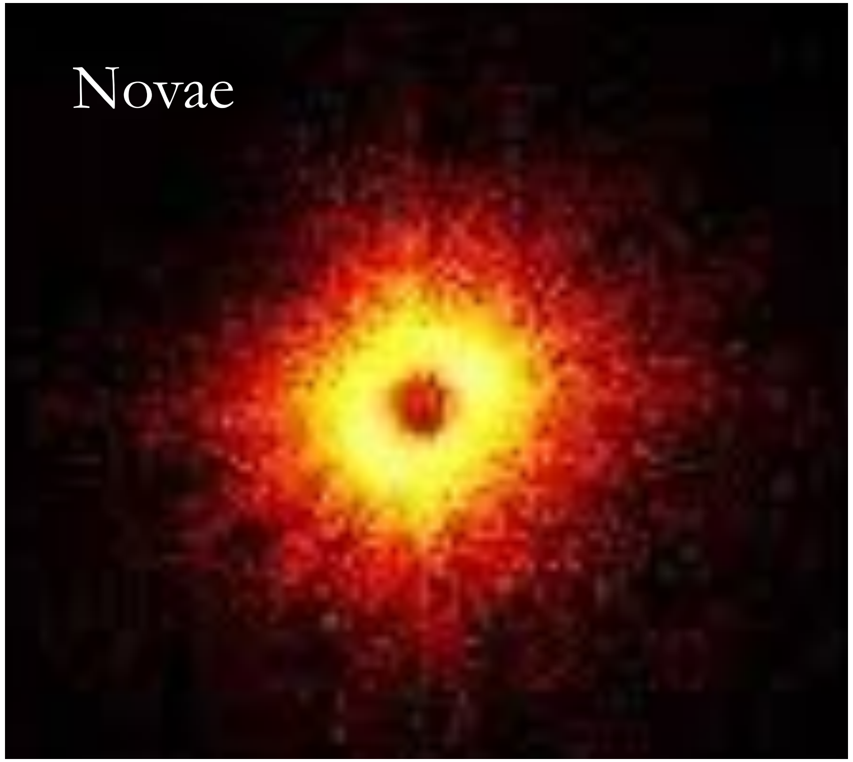
$$e^+ + e^- \rightarrow \nu + \bar{\nu}$$

Supernova

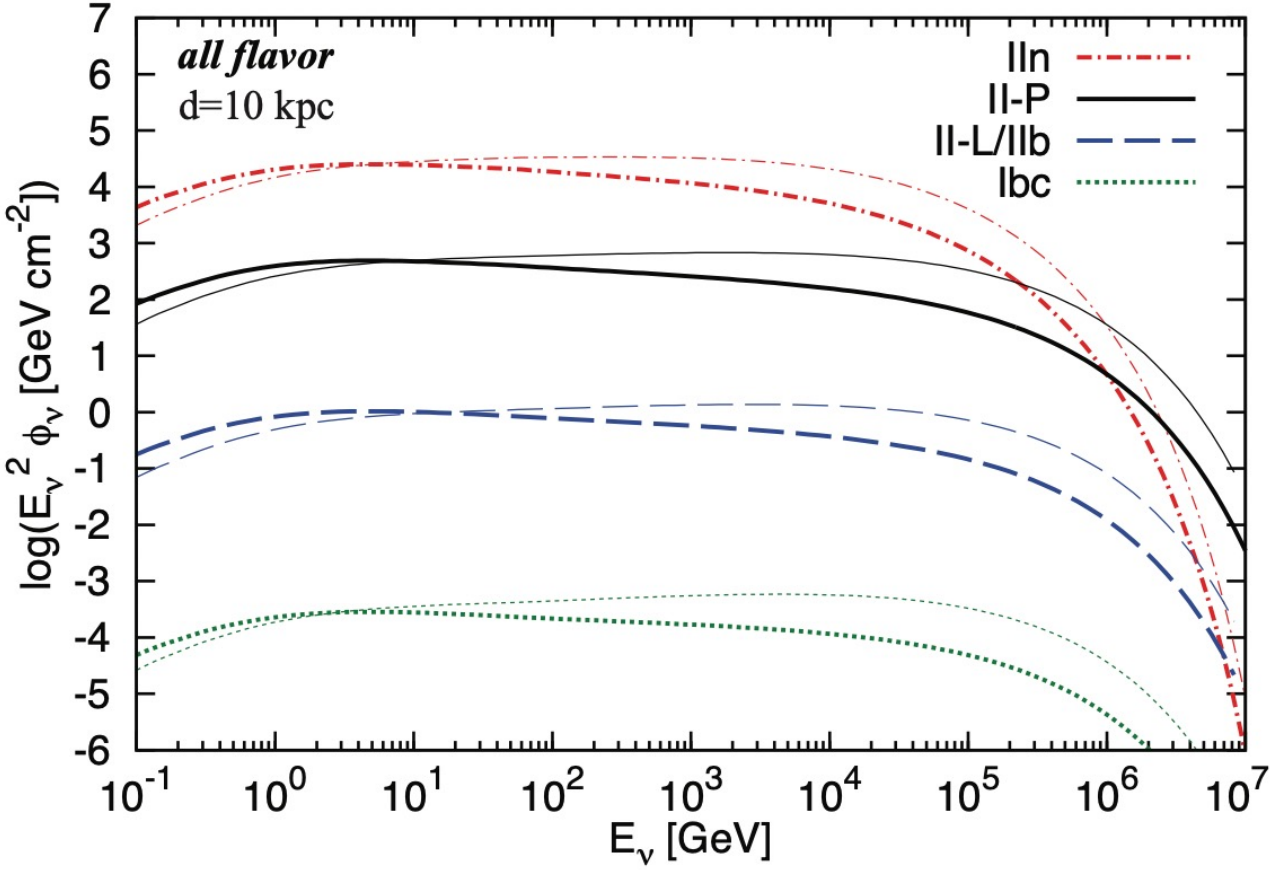


Neutronization burst
ν_e
$\bar{\nu}_e$
ν_x
Luminosity [10^{50} erg/sec]
10^4
10^3
10^2
10^1
Average Energy [MeV]
25
20
15
10
5
Accretion
Cooling
Infall
0.1
1
10
Time [sec]

Low energy (GeV-TeV) cosmic sources

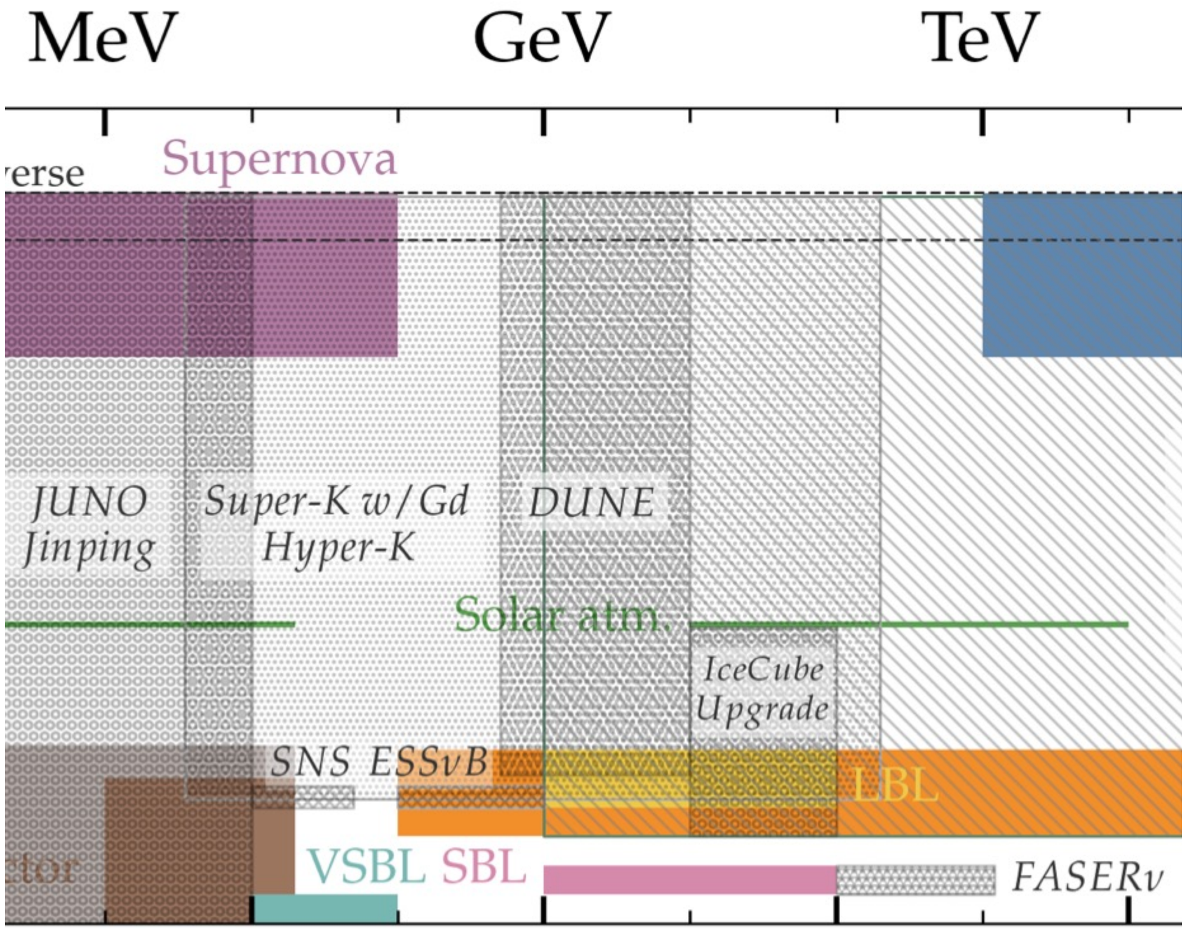


CSM supernova neutrinos

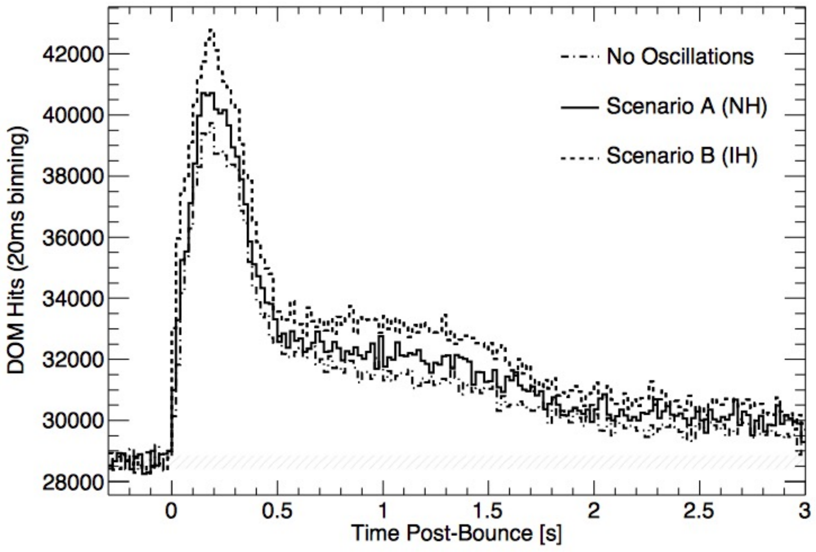


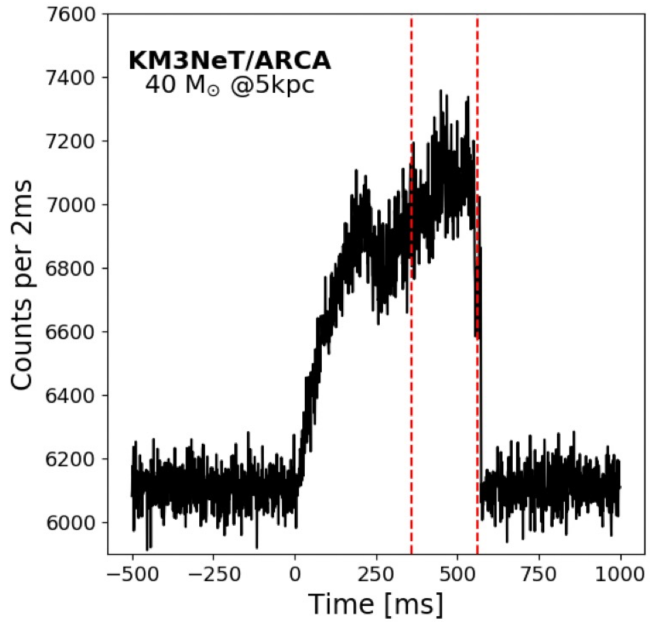
Murase 19

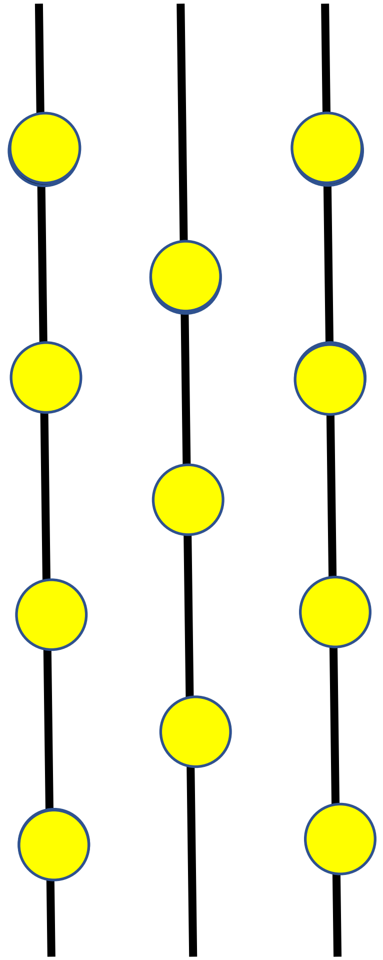
Neutrino telescopes at the MeV-TeV energy range



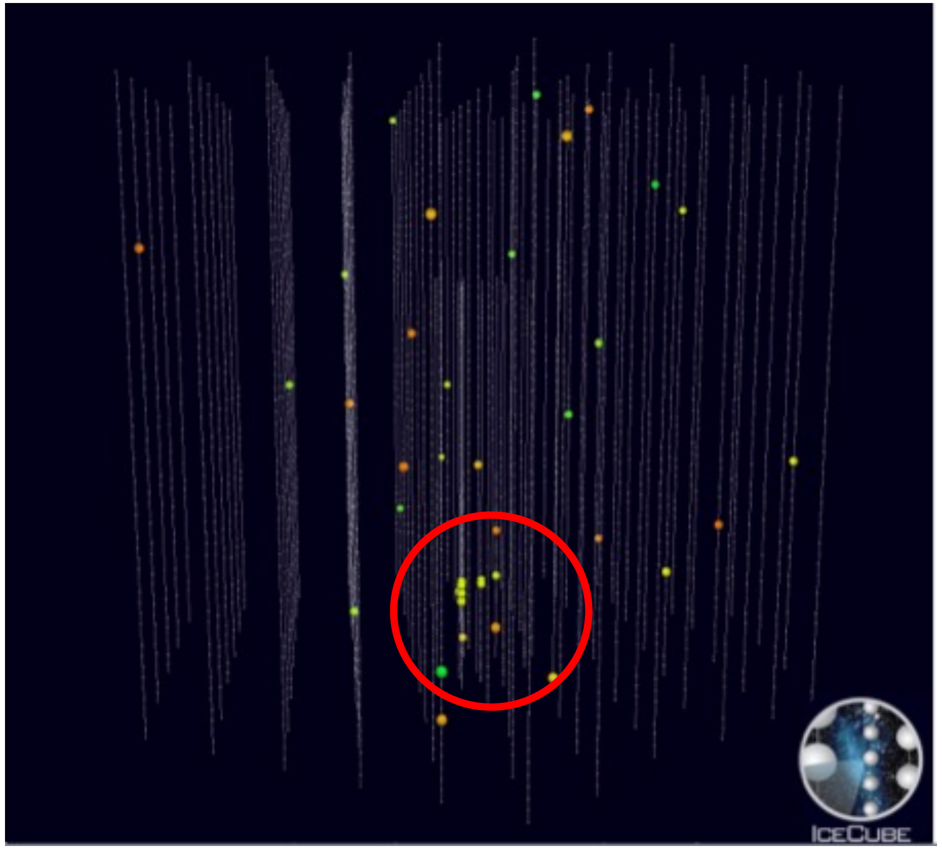
Neutrino telescope arrays will give detailed light curve for SN neutrinos

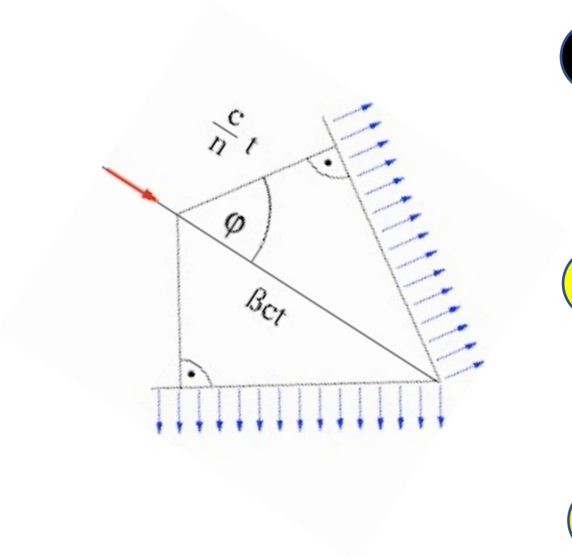


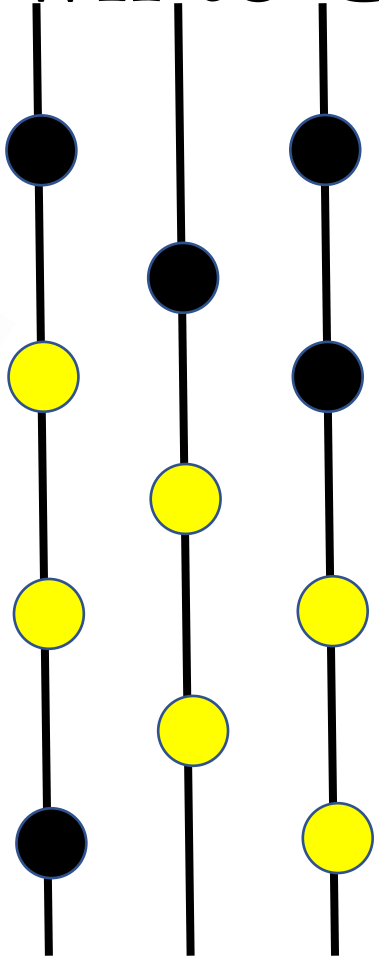




Neutrino telescope arrays are pushing the threshold down to GeV





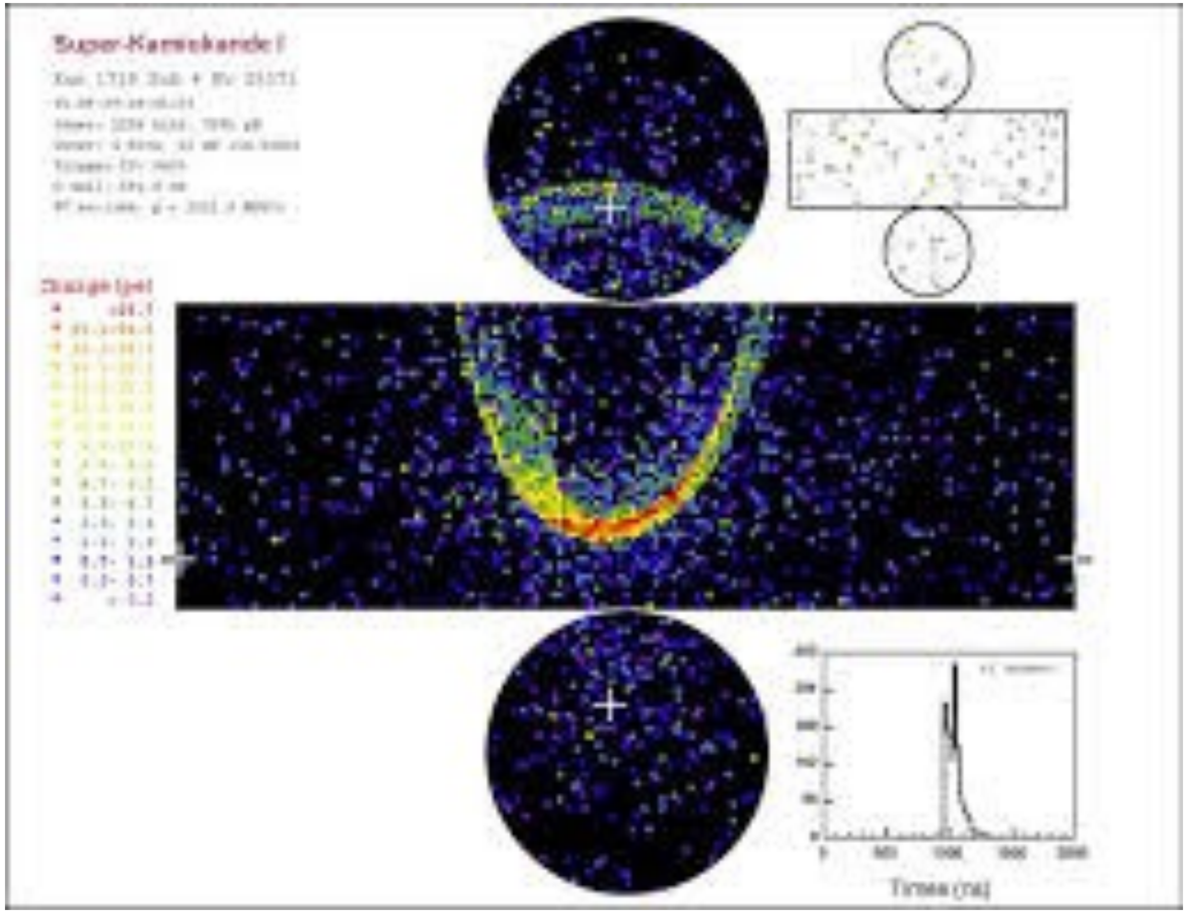


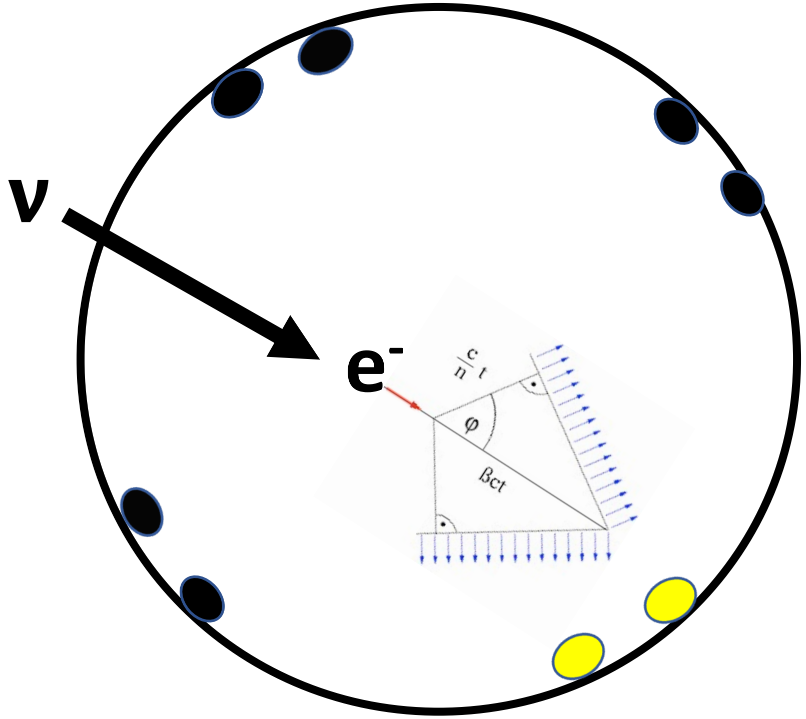
Solar

Supernova

Low energy (GeV-TeV) cosmic sources

Water Cherenkov detectors are good for detailed measurements



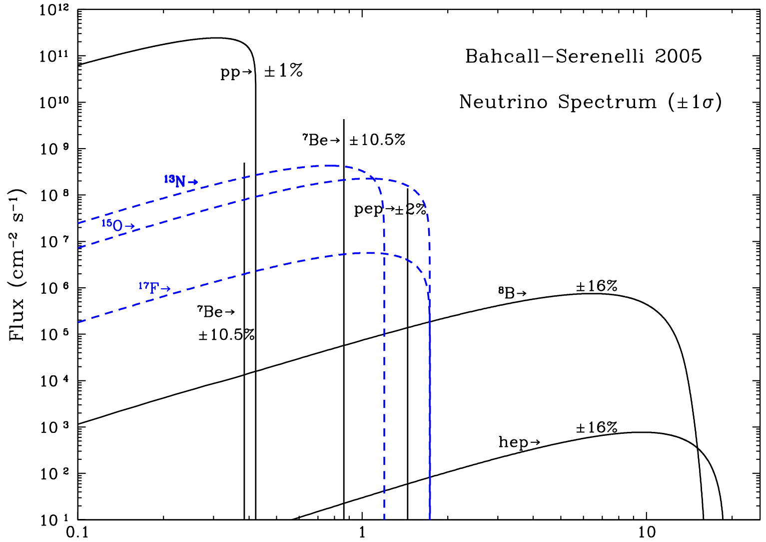


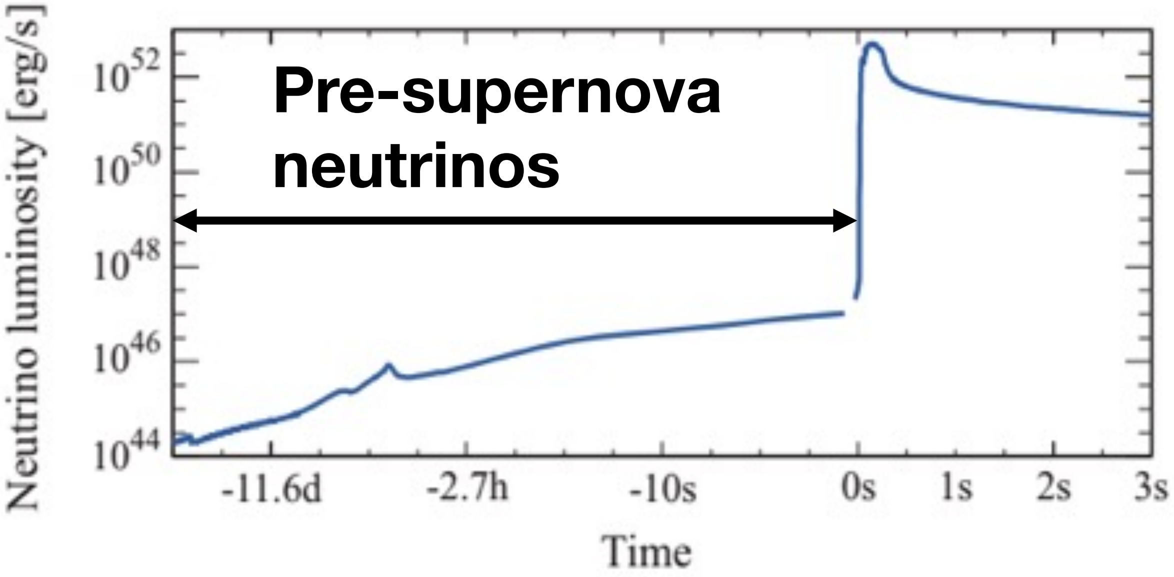
- Pointing with elastic scattering channel
- Detailed event-by-event energy information

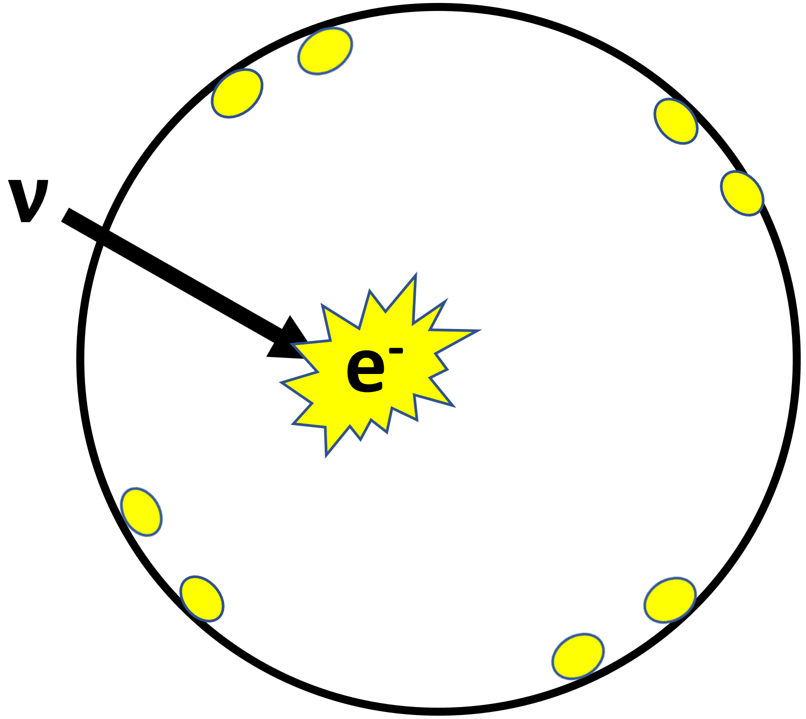
Solar

Supernova

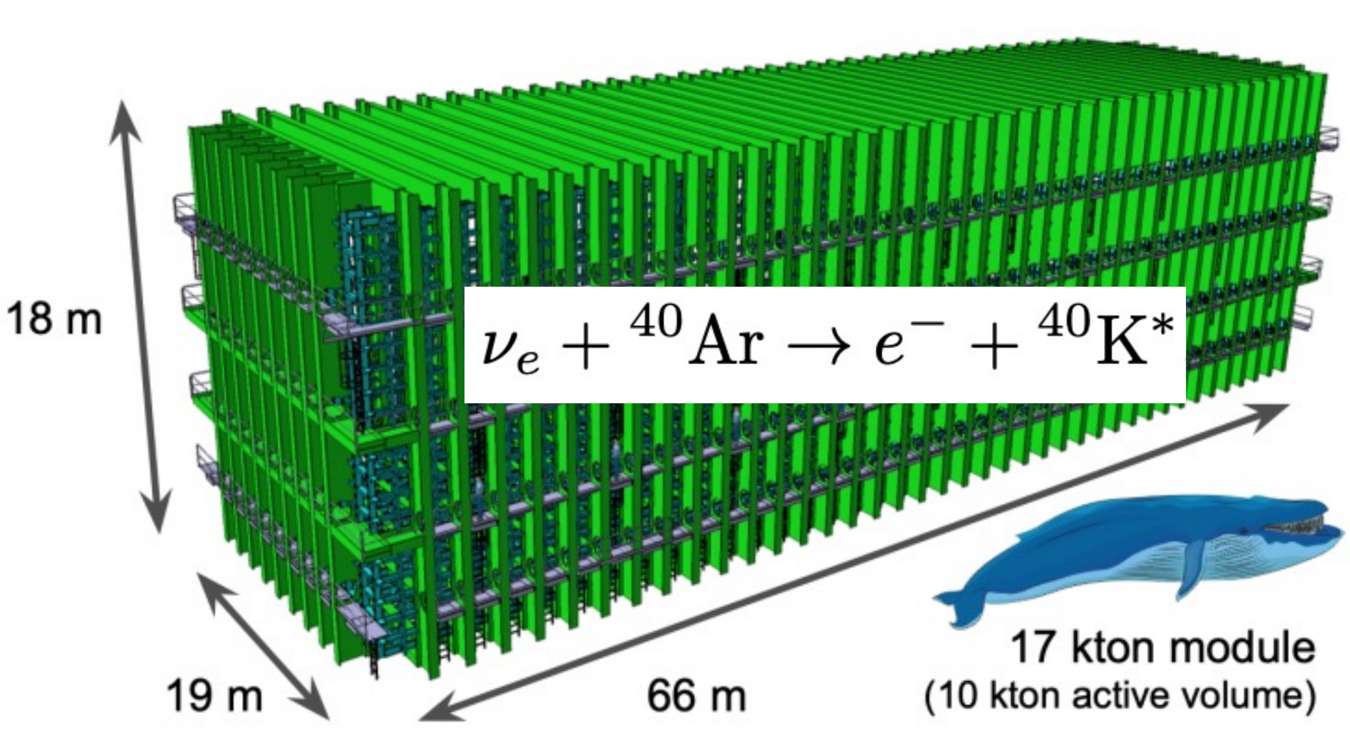
Liquid scintillator detectors can measure low energy (low-MeV)



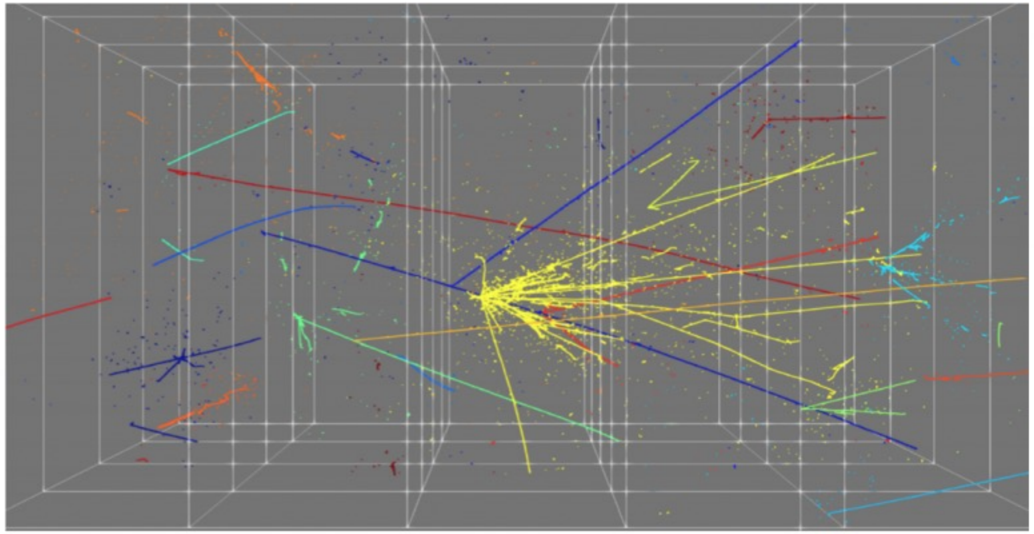


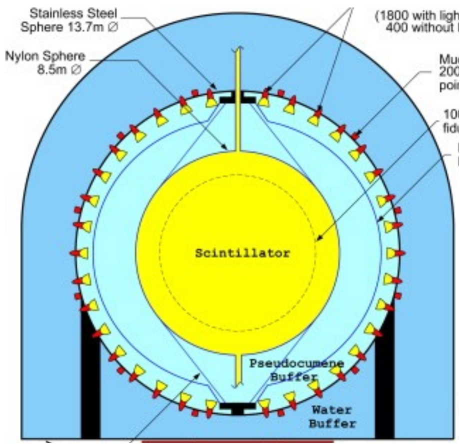


Liquid Argon (DUNE) will measure supernova neutrinos (not anti-neutrinos)



$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$



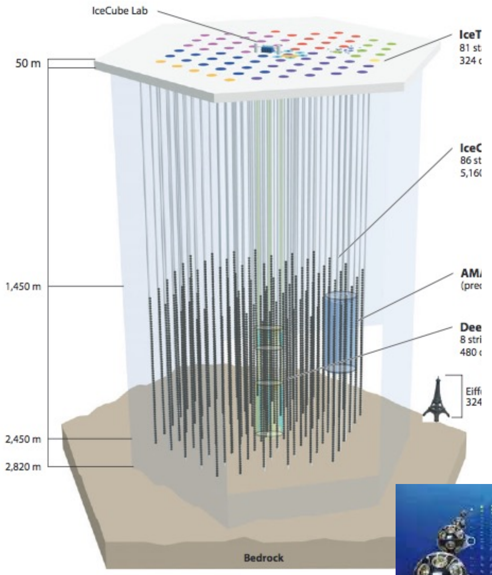


Borexino (finished)

100 Ton

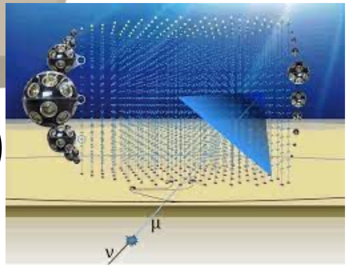
Super-Kamiokande (current)

50 kTon

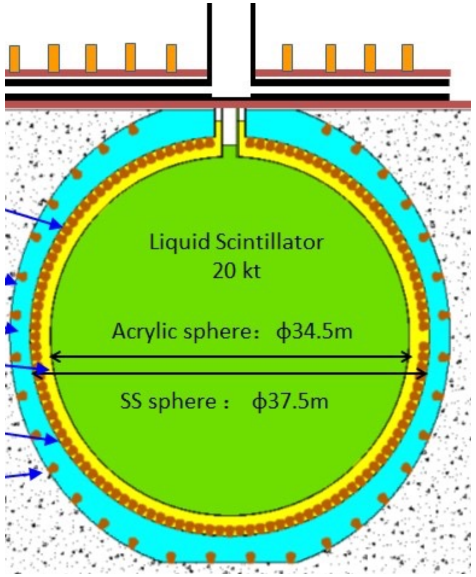


IceCube (current)

1 GTon

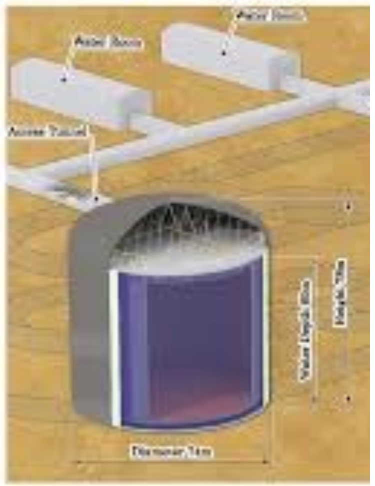


KM3Net (coming online)



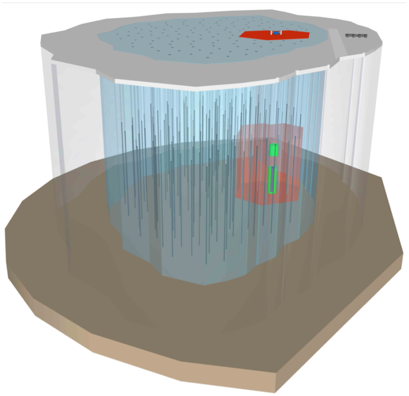
JUNO (future)

20 kTon



Hyper-Kamiokande (future)

250 kTon



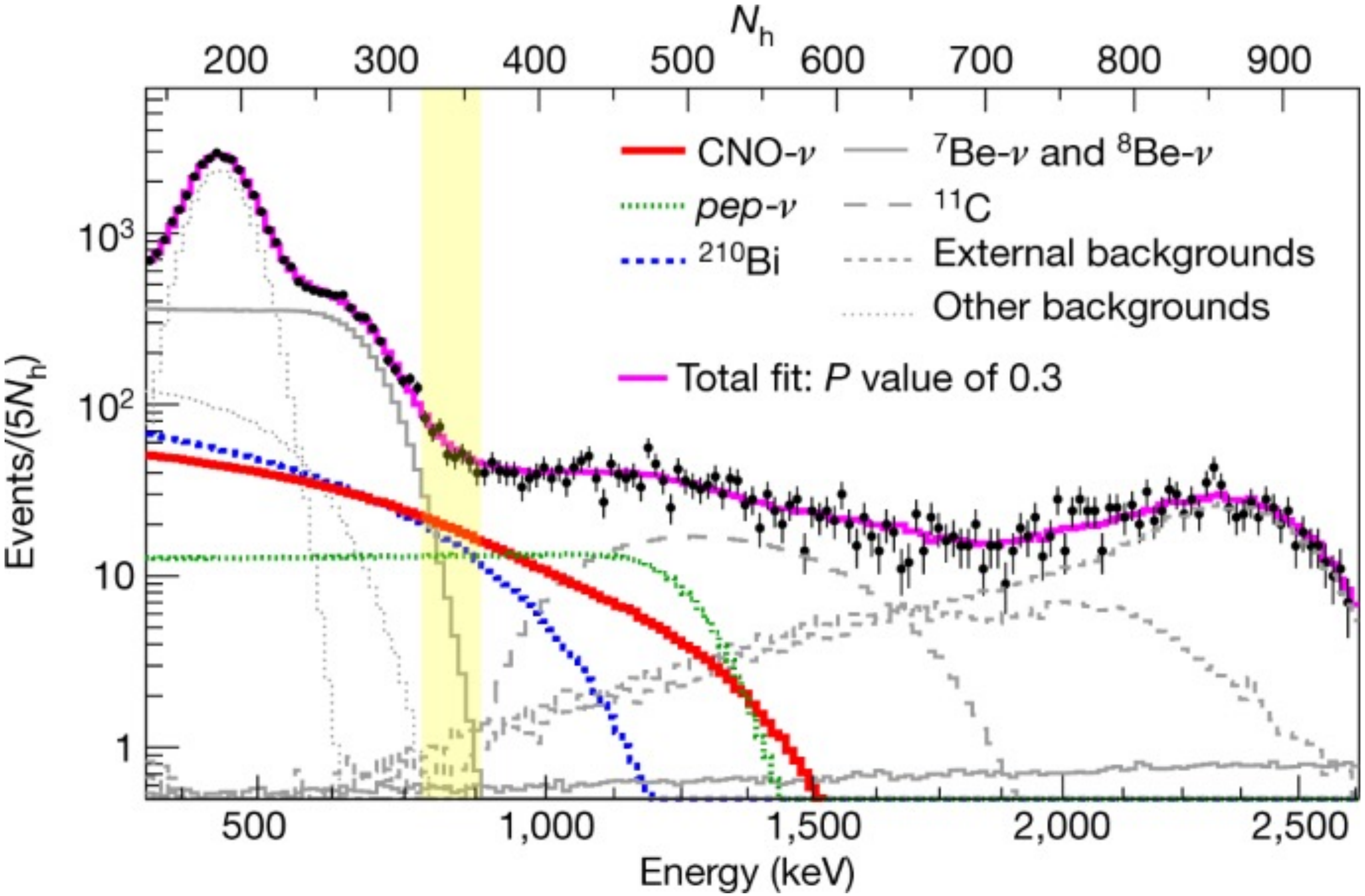
IceCube-Gen2 (future)

10 GTon

BAIKAL-GVD

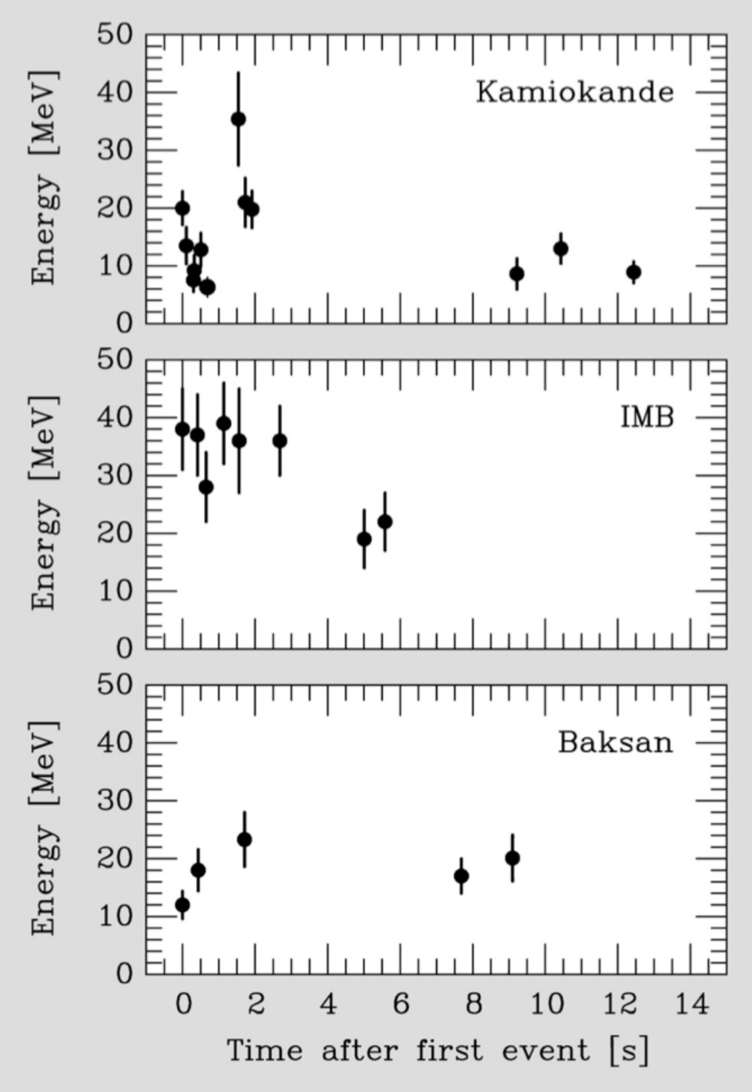
What do we know today?

Solar neutrinos (Borexino)



Nature **volume 587**, 577–582 (2020)

SN1987a

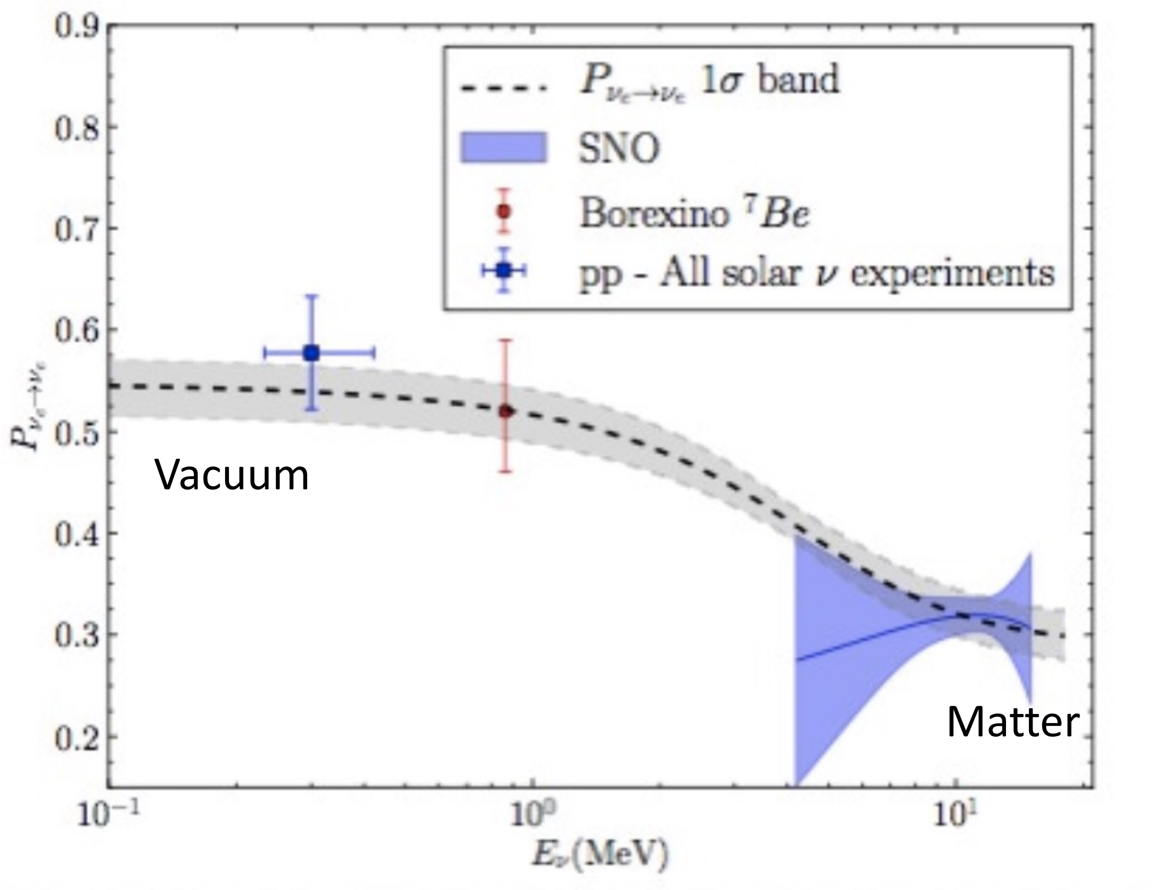


Solar neutrino astronomy goals

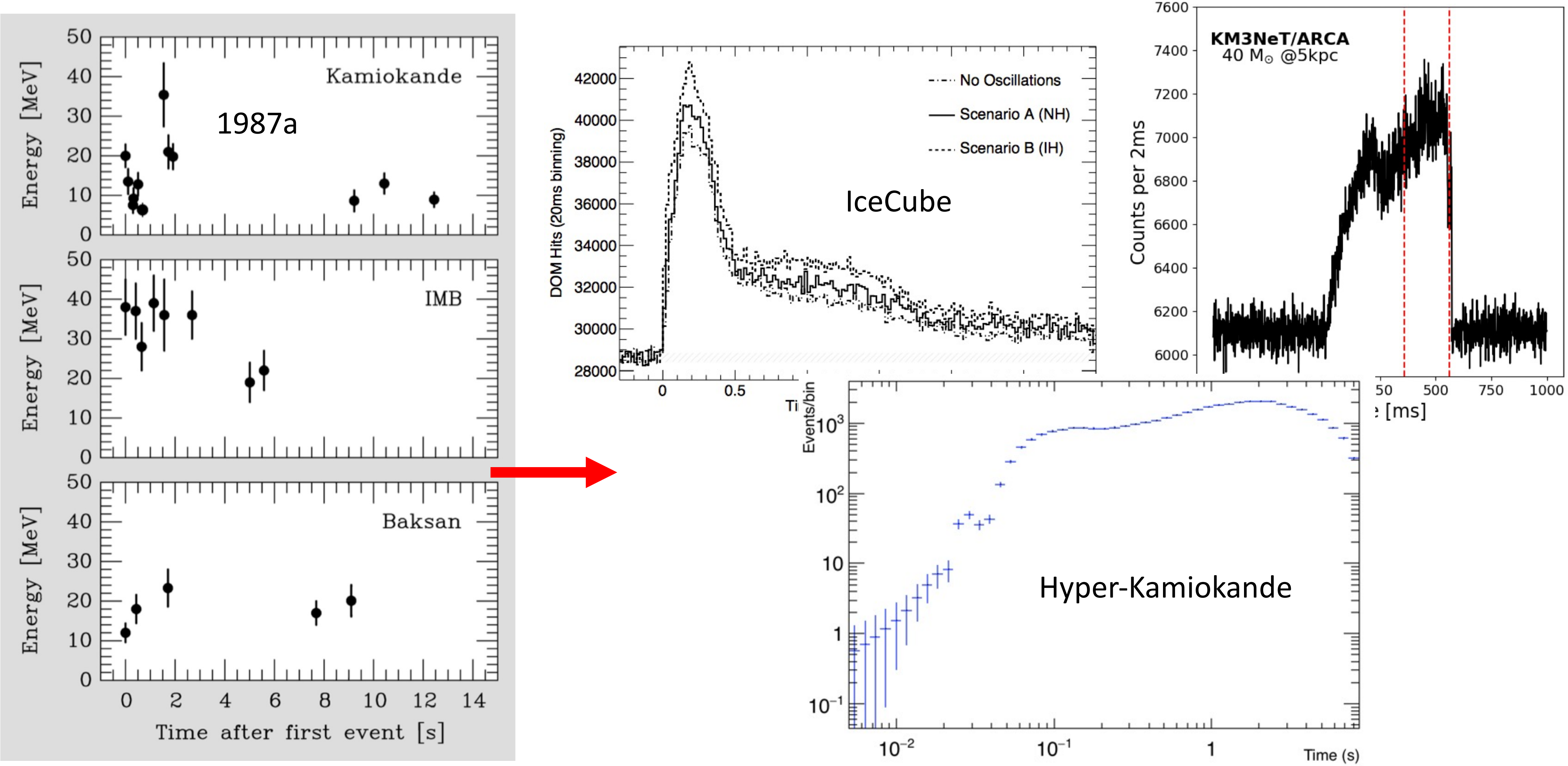
Determining the composition of our Sun with neutrinos

Source	BPS08(GS)	BPS08(AGS)	Difference
pp	$5.97(1 \pm 0.006)$	$6.04(1 \pm 0.005)$	1.2%
pep	$1.41(1 \pm 0.011)$	$1.45(1 \pm 0.010)$	2.8%
hep	$7.90(1 \pm 0.15)$	$8.22(1 \pm 0.15)$	4.1%
^{7}Be	$5.07(1 \pm 0.06)$	$4.55(1 \pm 0.06)$	10%
^{8}B	$5.94((1 \pm 0.11)$	$4.72(1 \pm 0.11)$	21%
^{13}N	$2.88(1 \pm 0.15)$	$1.89(1\ ^{+0.14}_{-0.13})$	34%
^{15}O	$2.15(1\ ^{+0.17}_{-0.16})$	$1.34(1\ ^{+0.16}_{-0.15})$	31%
^{17}F	$5.82(1\ ^{+0.19}_{-0.17})$	$3.25(1\ ^{+0.16}_{-0.15})$	44%
Cl	$8.46^{+0.87}_{-0.88}$	$6.86^{+0.69}_{-0.70}$	
Ga	$127.9^{+8.1}_{-8.2}$	$120.5^{+6.9}_{-7.1}$	

Looking for new physics in the solar upturn

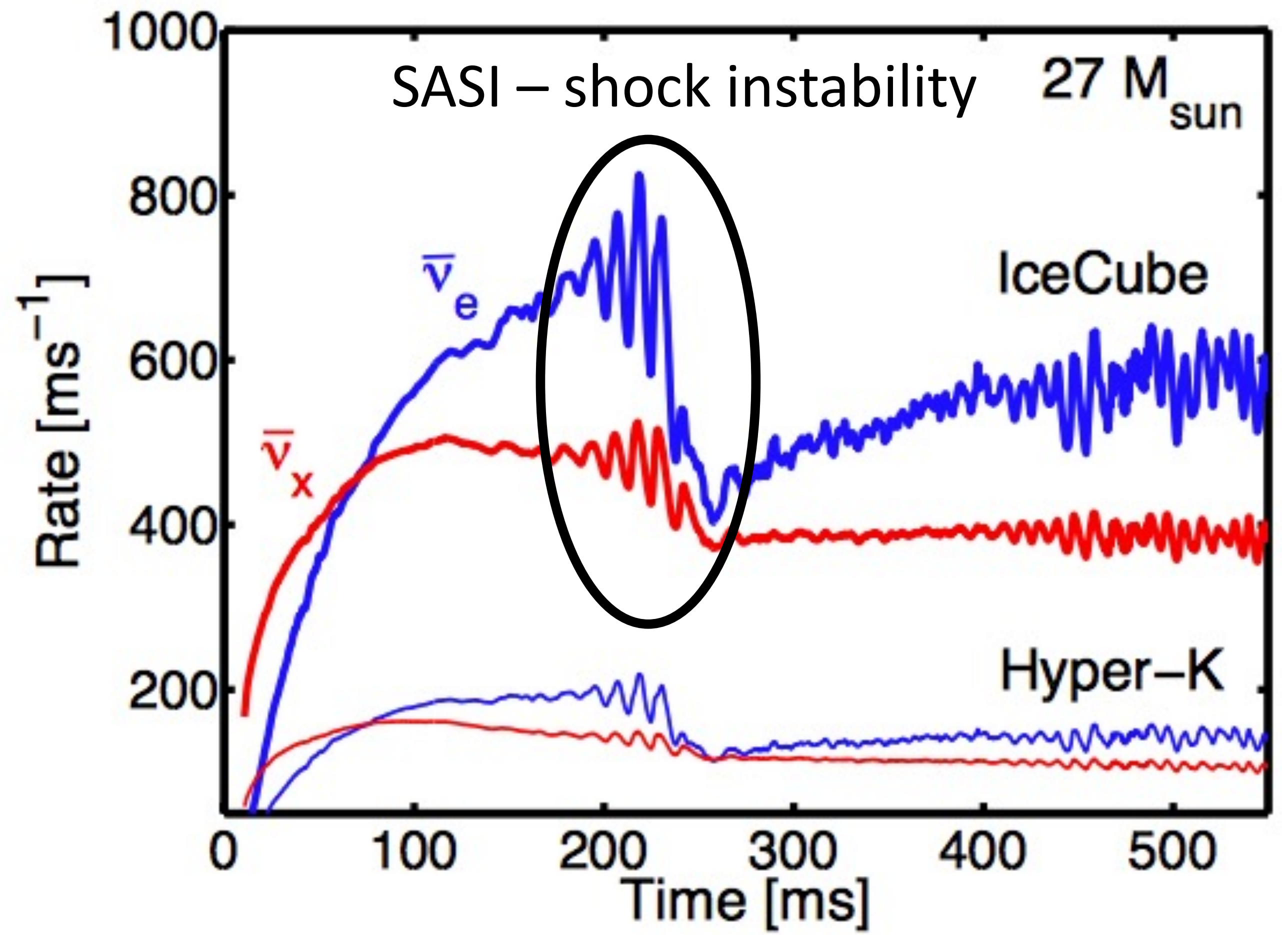


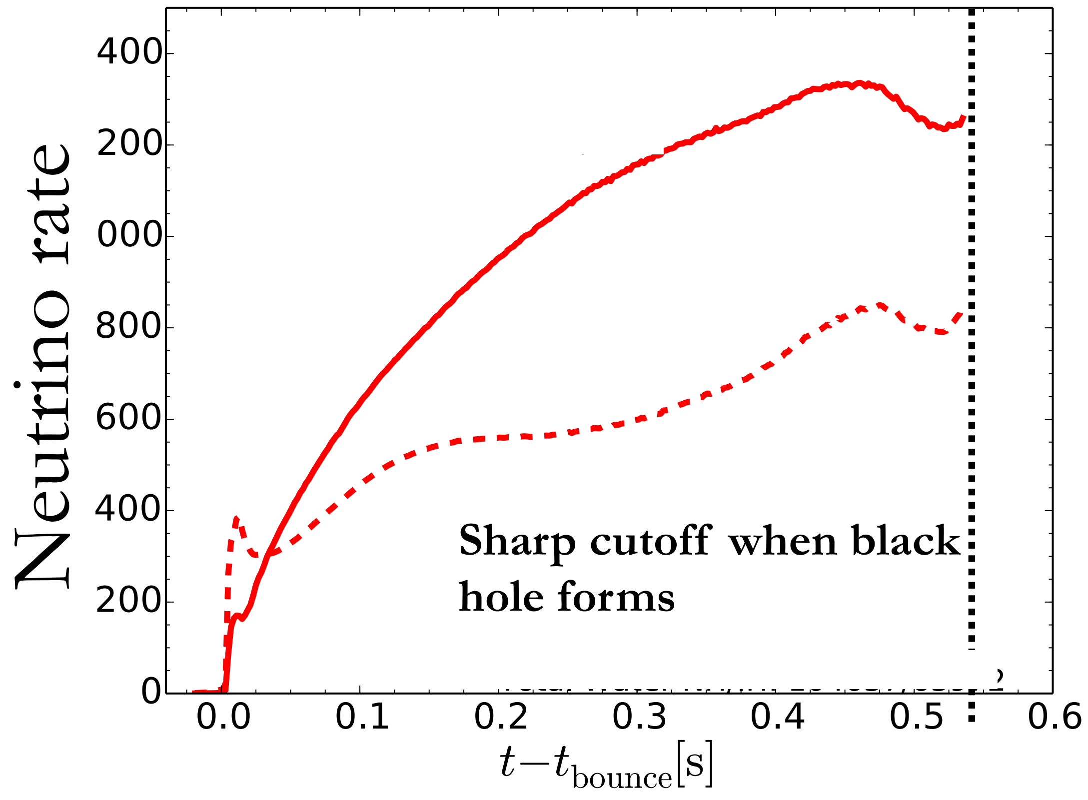
Supernova light curve in neutrinos



Why measure with better statistics?

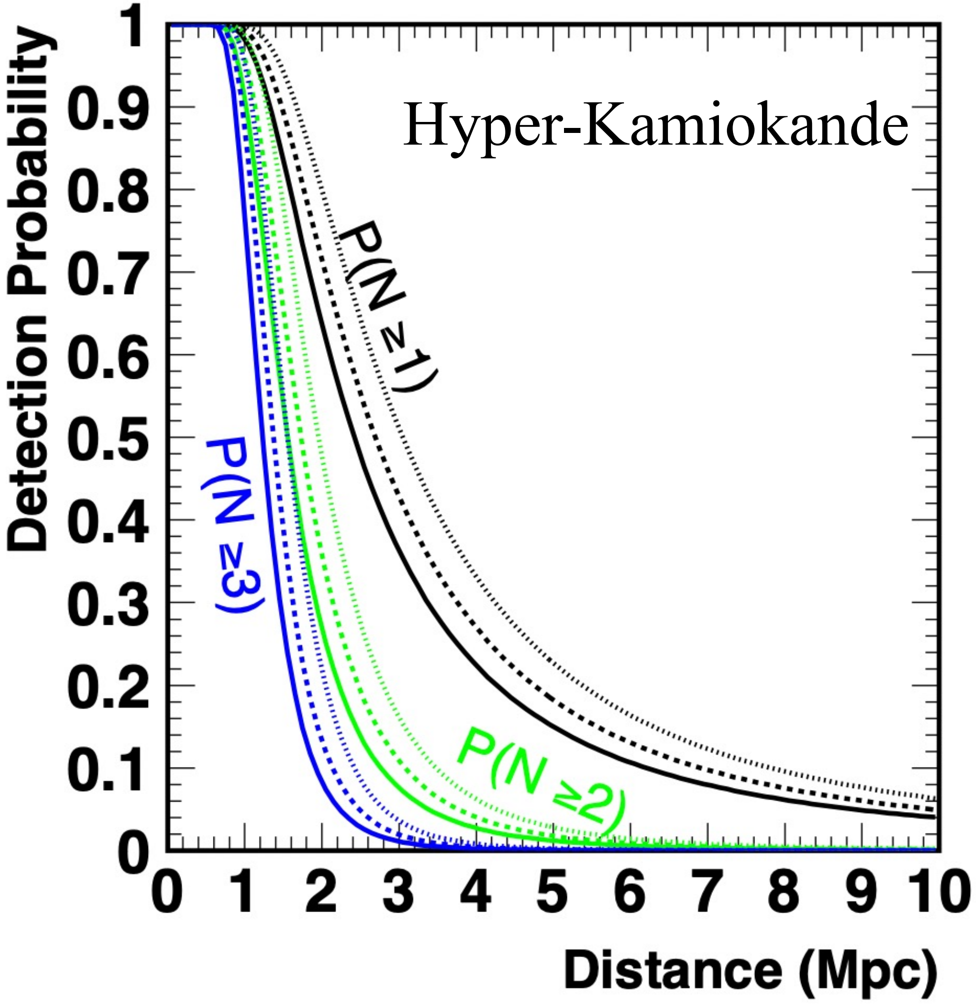
Tamborra+ 14



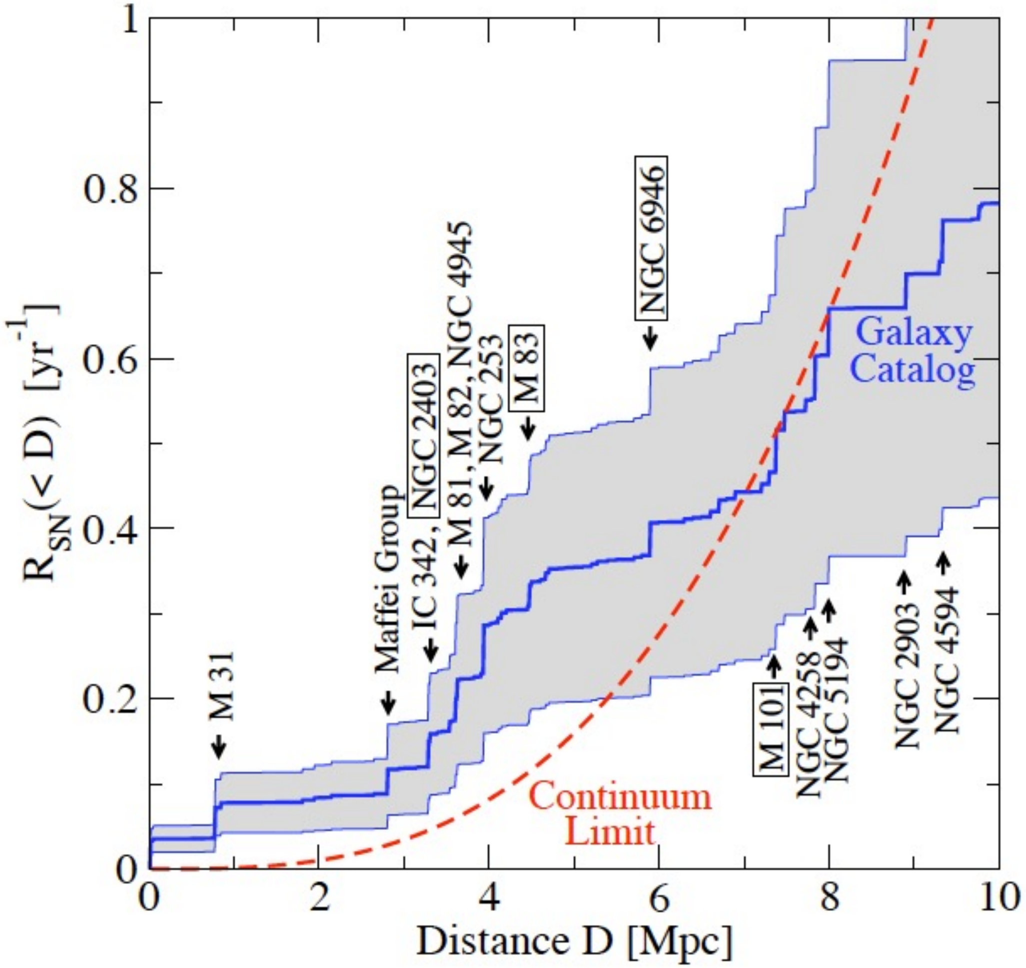


O'Connor 2015 (GR1D), 40M (1D)

Extending the horizon for supernova neutrino detection



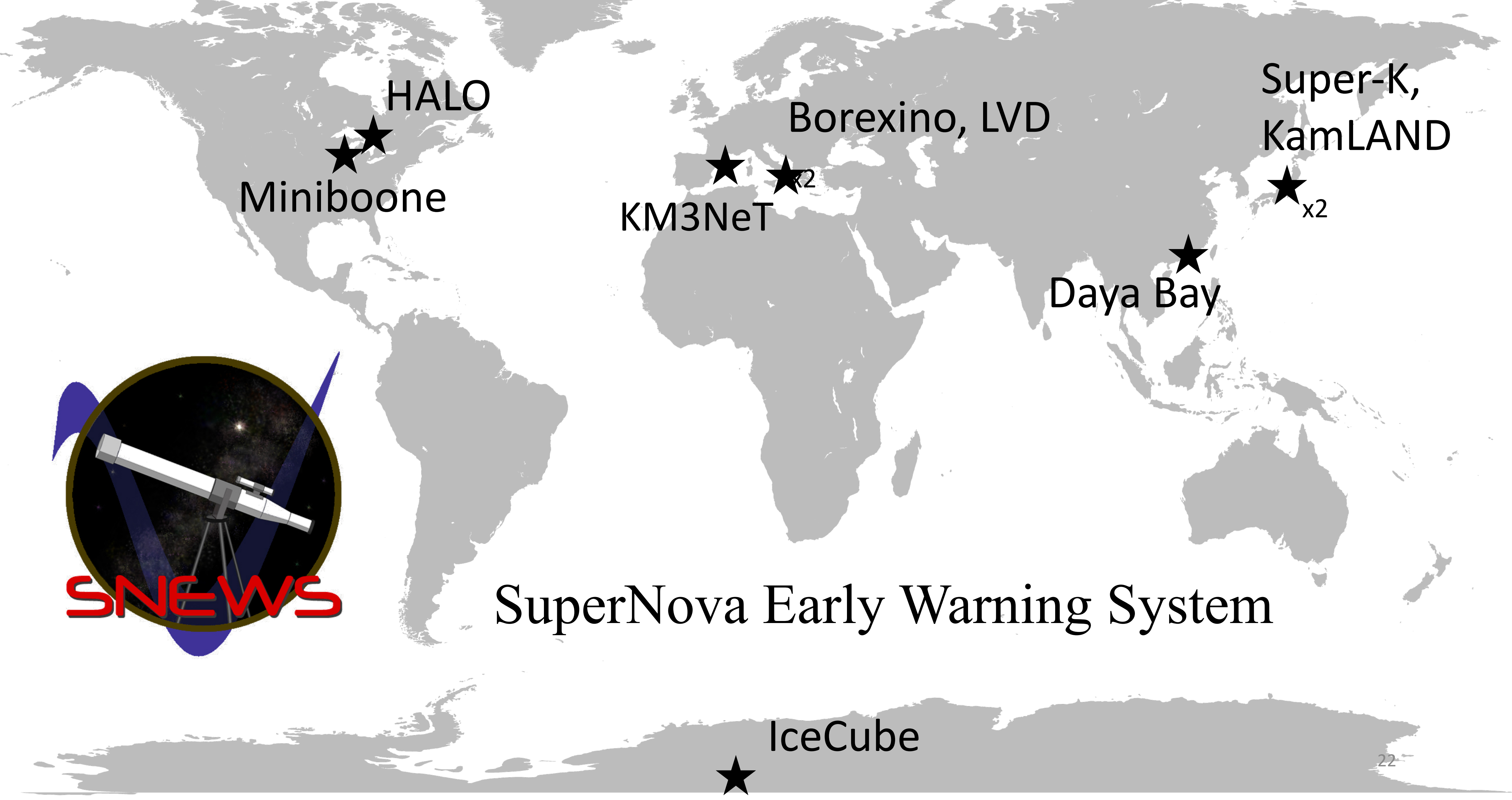
Ando, Beacom, Yüksel 05



The next supernova neutrino observation will benefit from complementary technologies

	Water	Ice/sea	Argon	Scint
$\bar{\nu}_e$	✓	✓		✓
ν_e	(✓)		✓	
ν_x				✓
Low energy				✓
Pointing	✓			
Energy info	✓		✓	✓
How many events?	Super-K 10,000	IceCube 790,000	DUNE 3,000	SNO+ 7,000

Supernova



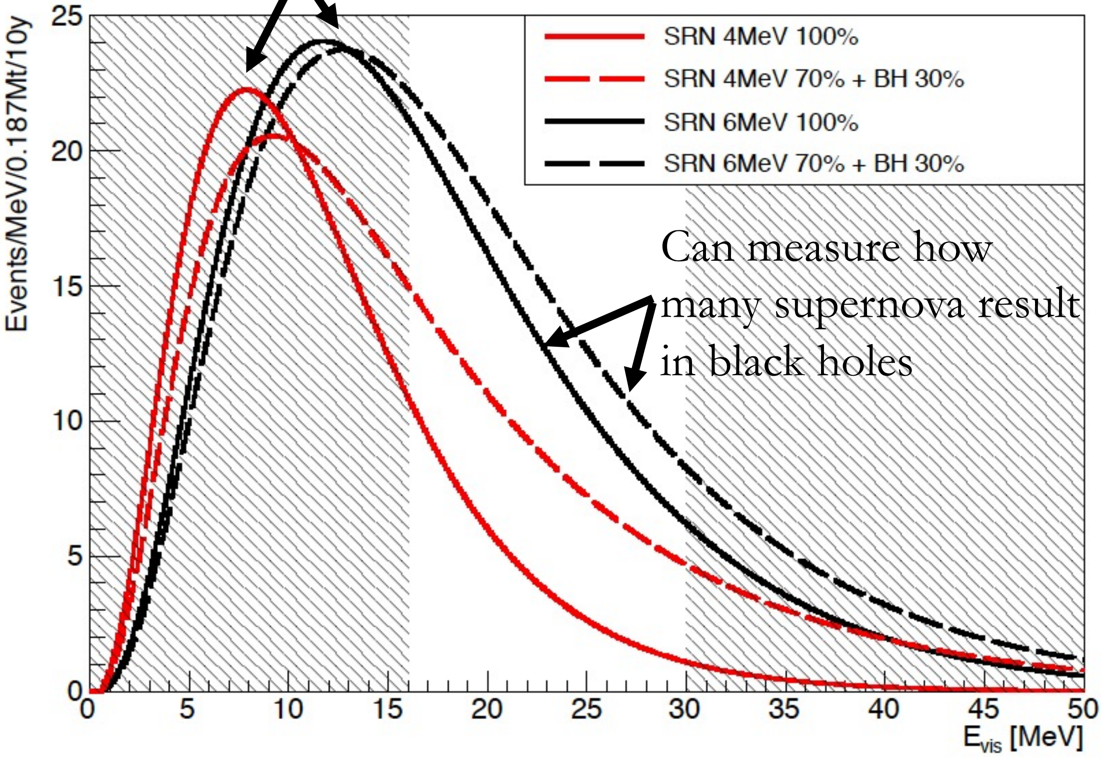
SuperNova Early Warning System

New information and capabilities with SNEWS2.0

- Pre-supernova alerts
- Triangulation for pointing
- Readiness (Fire drills)
- Discussion of multi-messenger strategy
- Lower threshold for false alarm rates

Diffuse supernova neutrino background will bring robust supernova neutrino measurements

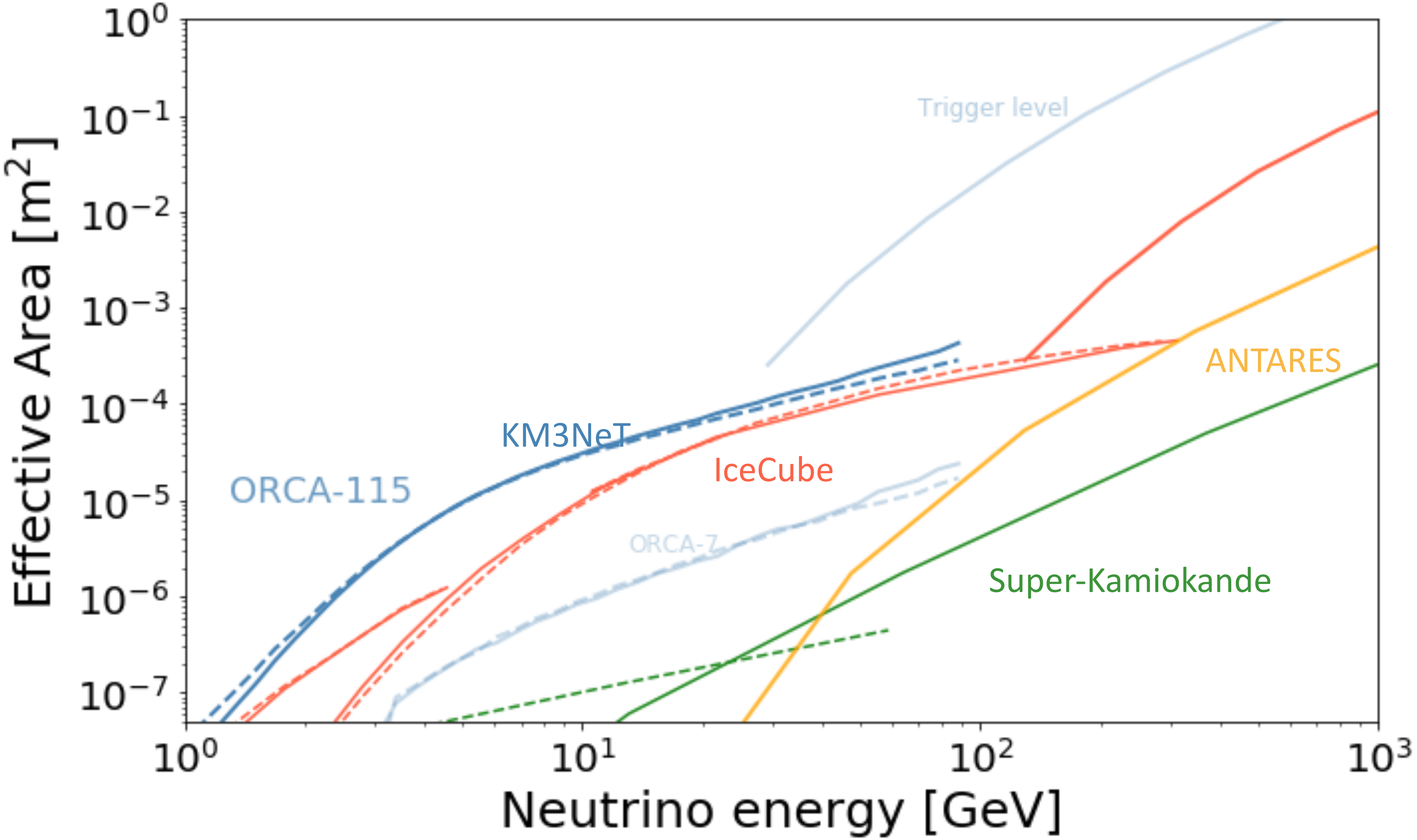
Can measure average temperature of the supernova



Can measure how many supernova result in black holes

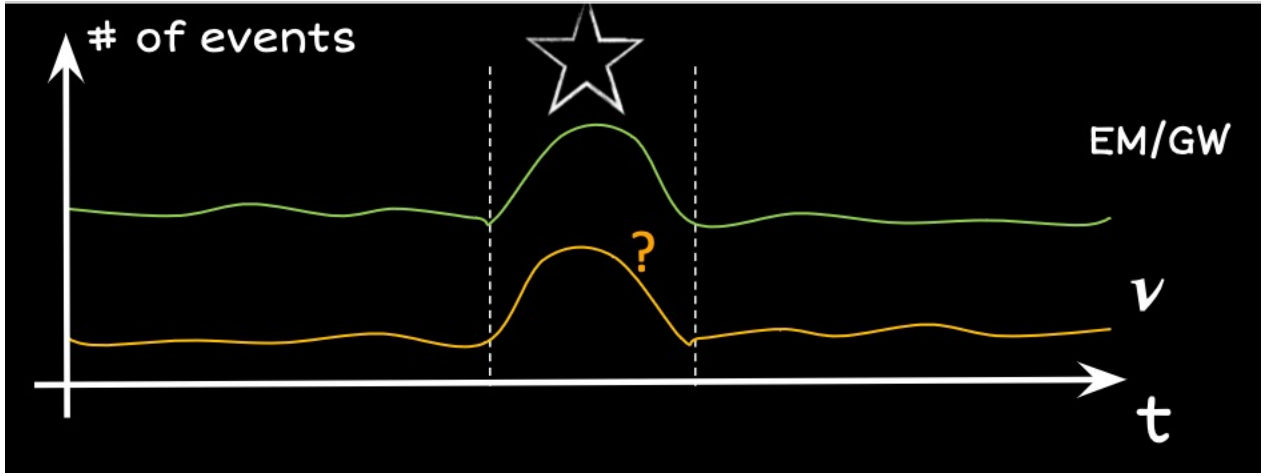
Thanks, Gwen!

GeV-TeV transients: How do we capitalize on our full energy range?

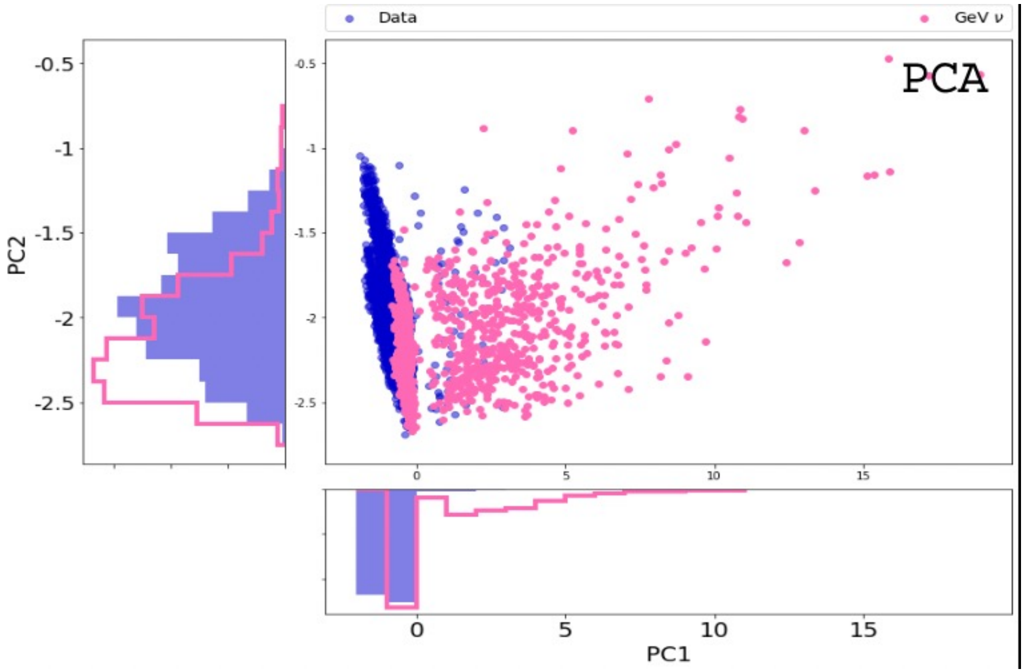


Thanks, Gwen!

Low energy (GeV-TeV) cosmic sources



Tight timing coincidence with transients
– suppress the (huge) atmospheric background



Weak and hard to reconstruct events
- Big benefit with machine learning

Summary

- Neutrino astronomy at the MeV-scale: the original multi-messenger, extragalactic neutrino events, now in the precision era
  - Solar monitoring with neutrinos
  - Supernova neutrinos (when they arrive) will allow us to probe details of inner dynamics of the system or could reveal hidden supernova (black holes)
- Neutrino astronomy at the GeV-scale is arriving.
  - Water Cherenkov experiments are still too small, but are scaling up
  - Neutrino telescopes like IceCube and KM3NeT are developing new techneques which can be sensitive to transients
- Neutrino astronomy at the GeV-TeV scale also needs special attention
  - Some sources are TeVatrons, not PeVatrons. Needs special consideration.