Towards a megaton MeV neutrino detector

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IceCube Particle Astrophysics Symposium

Madison

13. May 2013

Detecting low-energy supernova neutrinos

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Current neutrino telescopes

- Super-Kamiokande
- IceCube
- ...

➔sensitive to galactic SNe

Expect 1-2 SNe per century!

Routine SNe detection

- Goal: more than one SN / year

➔reach beyond galaxy

- Requirements

➔ ~5 Mton effective volume

➔10 MeV neutrino energy

Physics targets

- Direct probe of core collapse
  ➔e.g black hole vs. core collapse
- Total rate of SNe
  ➔no dust obscuration
- Neutrino mass hierarchy &
  QCD phase transition
- Early triggers for follow-up with other instruments
  ➔catch very early phase
- Boost coincident searches with gravitation wave detectors
- ...

100+ papers

SN 1987A

Black hole vs. neutron star

Neutrino signature

- inverse beta decay
  ➔$\nu + p \rightarrow e^+ + n$
- near-thermal profile

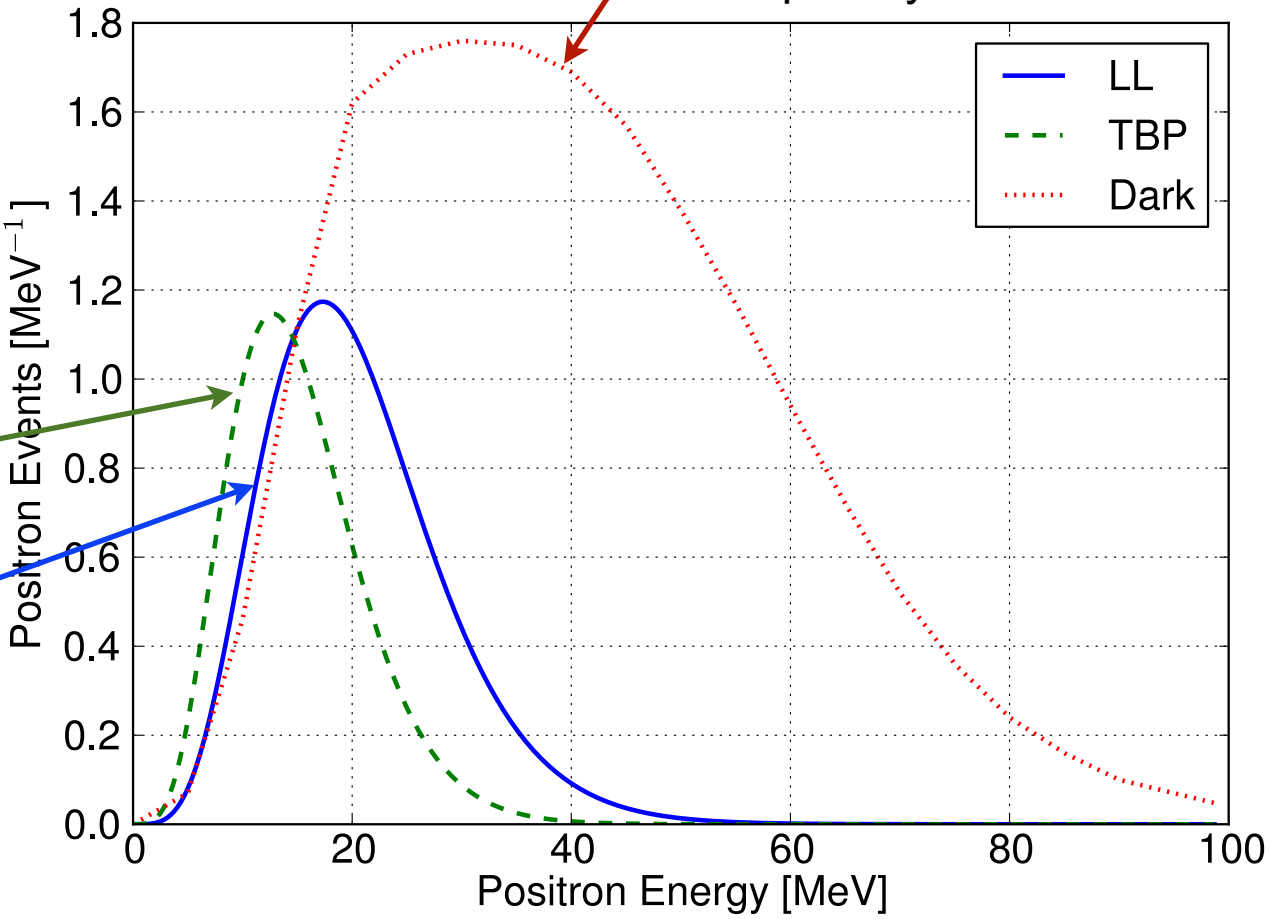
[Nakazato et al., PRD 78 (2008)]

Black hole

- failed SNe
  ➔optically dark

Neutron star formation

- TBP model
  [Thompson et al., APJ 592 (2003)]
- LL model
  [Totani et al., APJ 496 (1998) 1]



Towards a low-energy ν detector

IceCube (in operation)

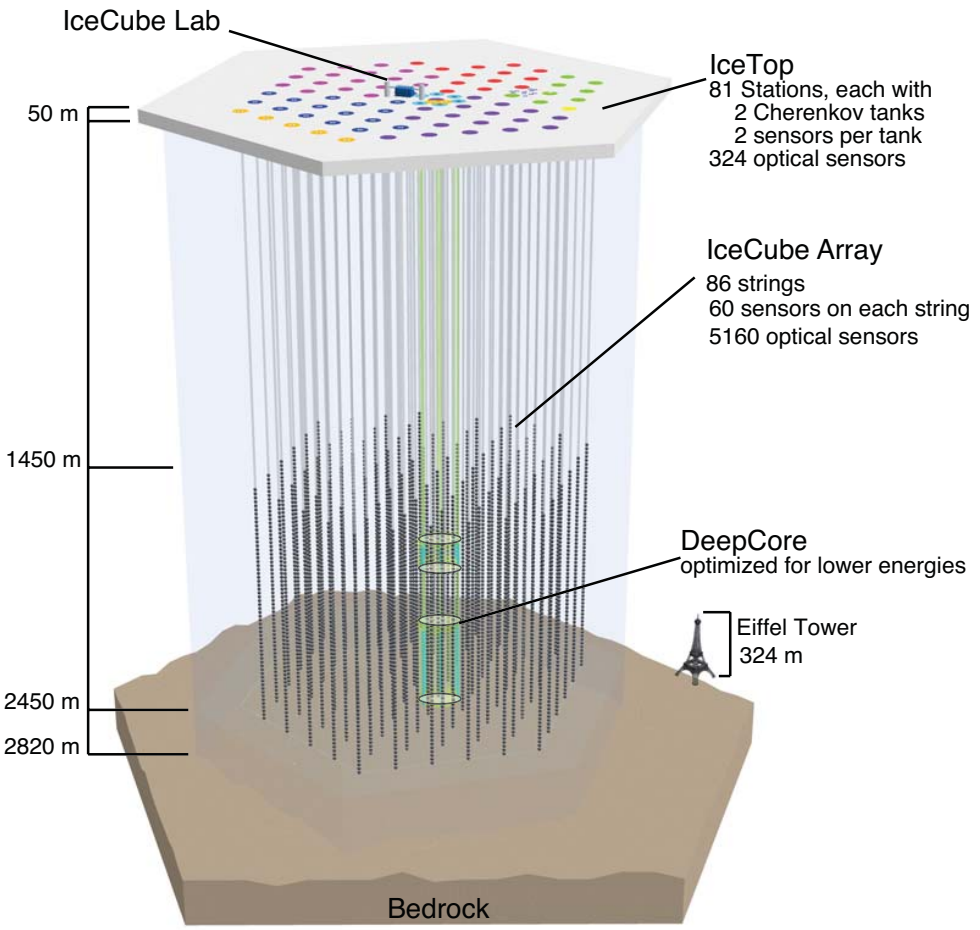
- 80 strings, 125m / 17m spacing
- E_{thresh} ~ 100 GeV

  ➔ astrophysical CR-sources

DeepCore (in operation)

- +6 strings, 72m / 7m spacing
- E_{thresh} ~ 10 GeV

  ➔WIMPs, neutrino oscillations,...



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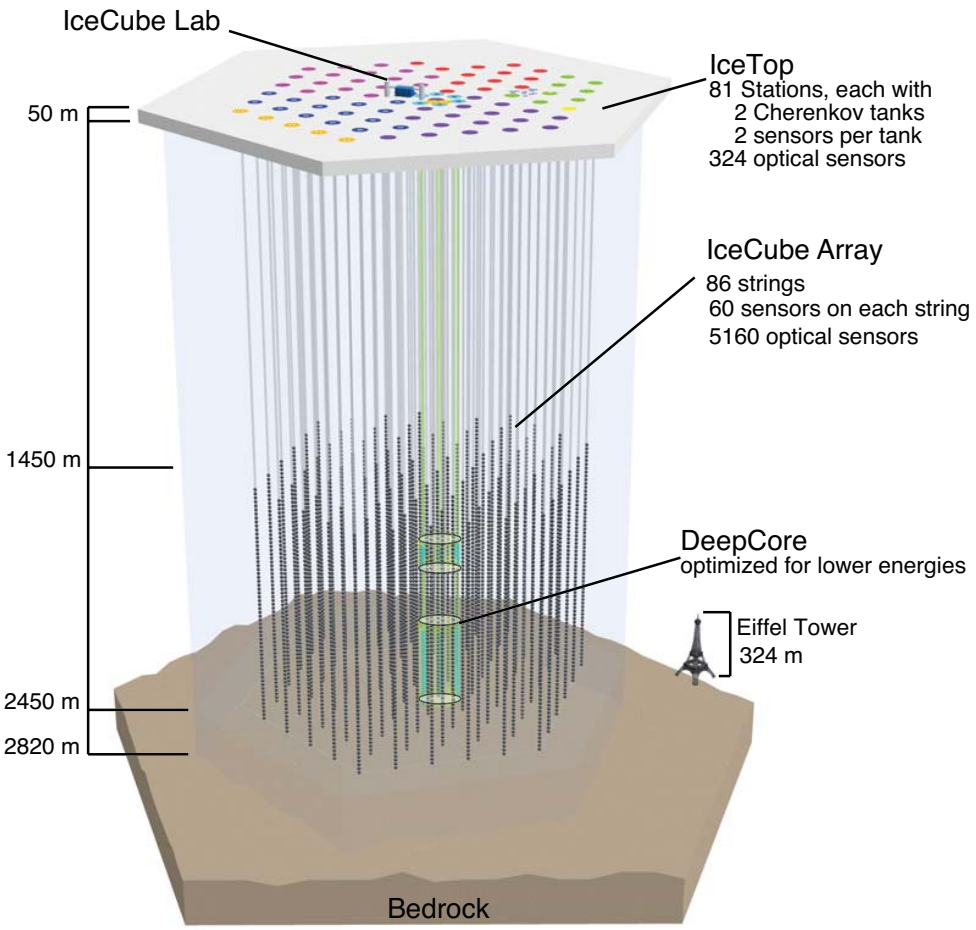

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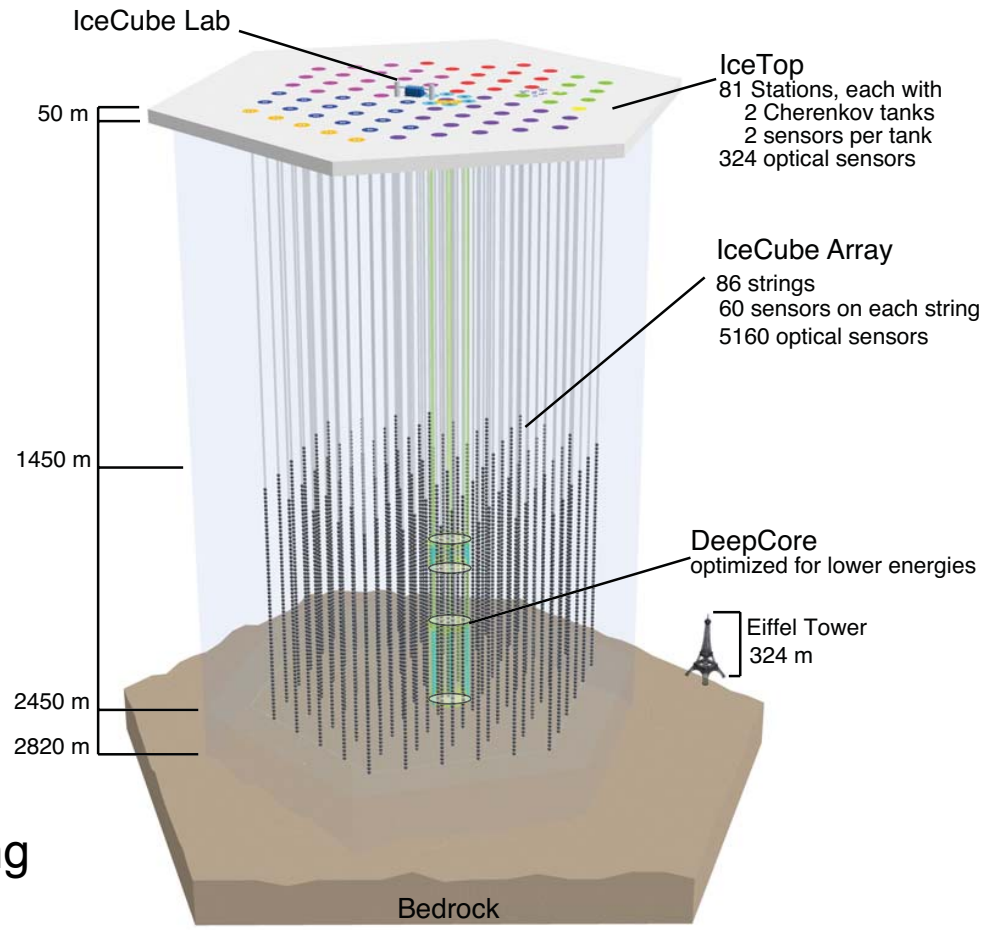
MICA (envisioned)

- +100 strings, 15-25m / 0.5m spacing
- E_{thresh} ~ few MeV

  ➔Supernova ν, proton decay,...



Why at the South Pole?

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South Pole ice cap

- very clear ($\lambda_{att} \approx 45$m)
- low radioactivity

IceCube performance

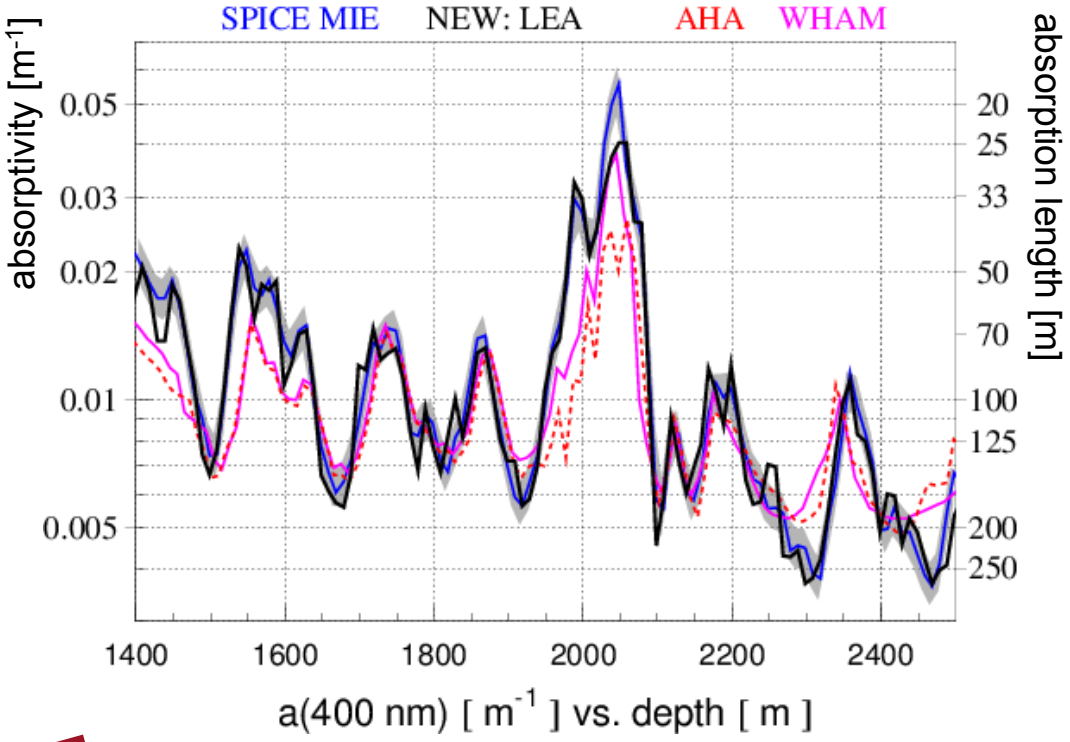
- high uptime (> 99%)
- low failure rate (< 2%)
- effective reconstruction

  ➔ 10^5 neutrinos per year

Installation

- fast & robust
- cost-effective

IceCube is a big success!

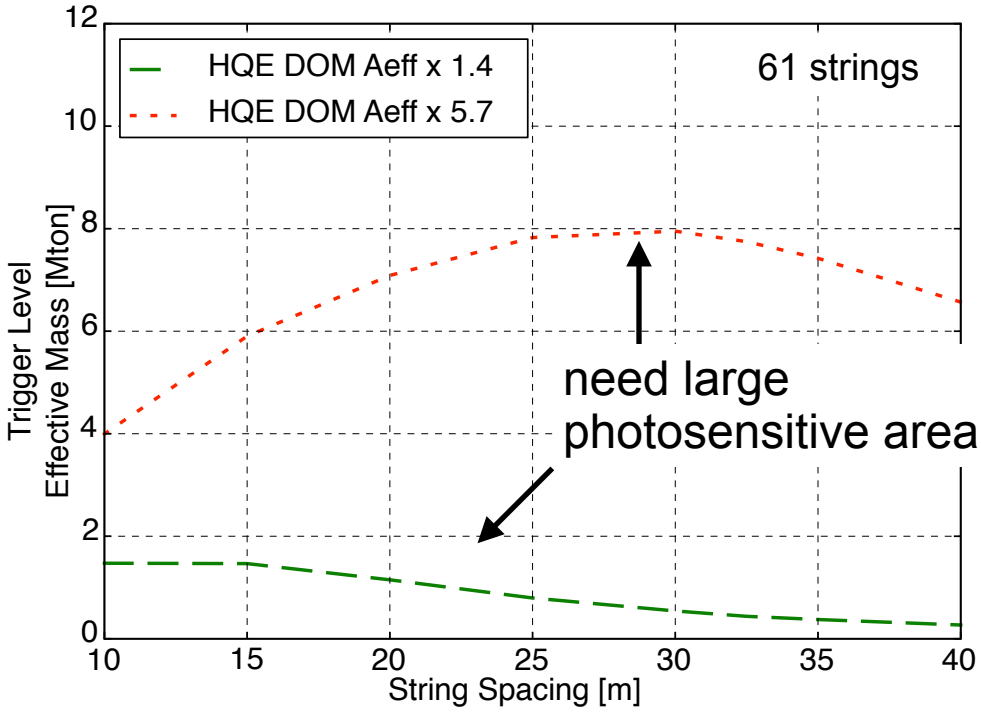


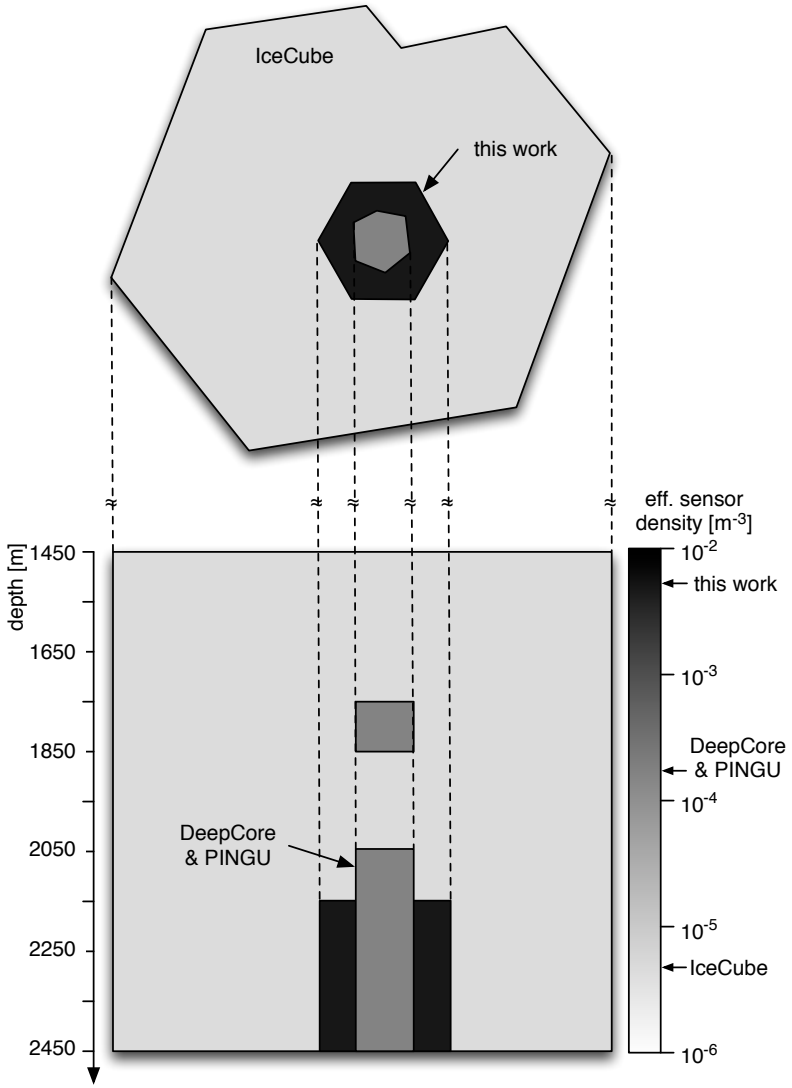
Detector optimization

Testing geometries

- 61 / 127 strings
- 2150 - 2450m depth (clearest ice)
- 300 optical sensors / string
- 35.6cm^2 photo-sensitive area
- require 5 hits / neutrino event

➔optimize string spacing





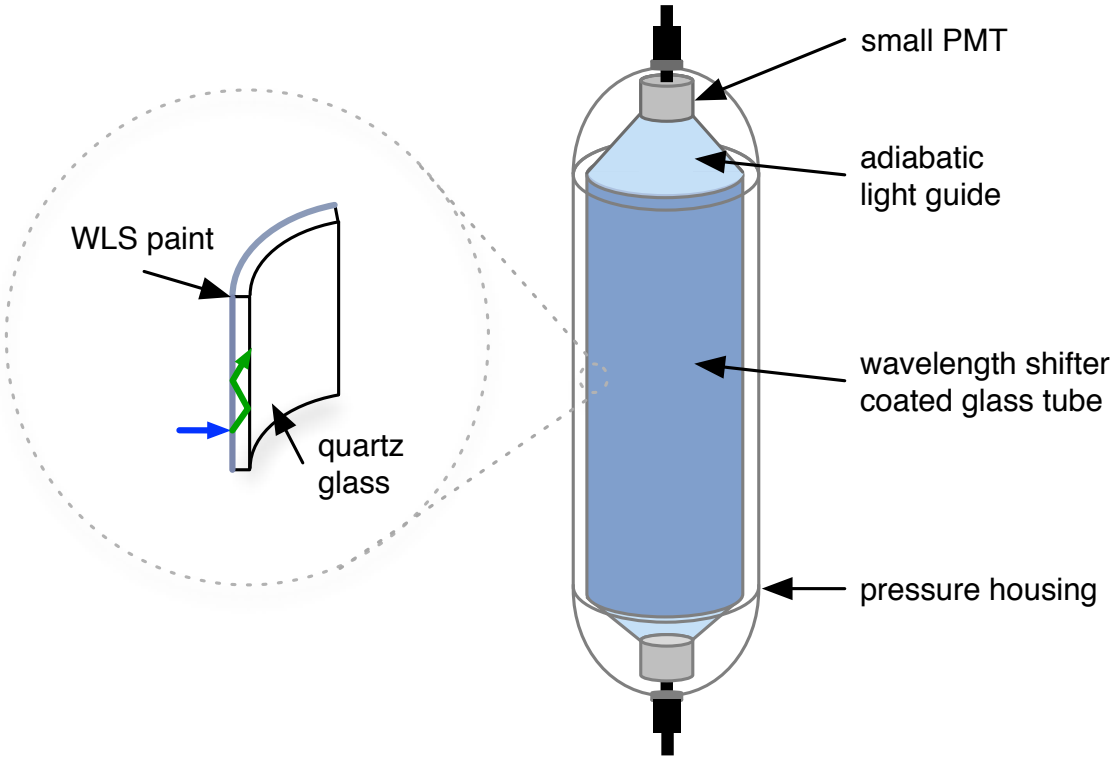
WOM: a new photo-sensor

Basic concept

- Wavelength shifters (WLS)
  ➔concentrate light

Features

- large collection area
- low noise rate (few Hz)
- better UV sensitivity
- cost effective
  ➔ prototype under development



WOM performance

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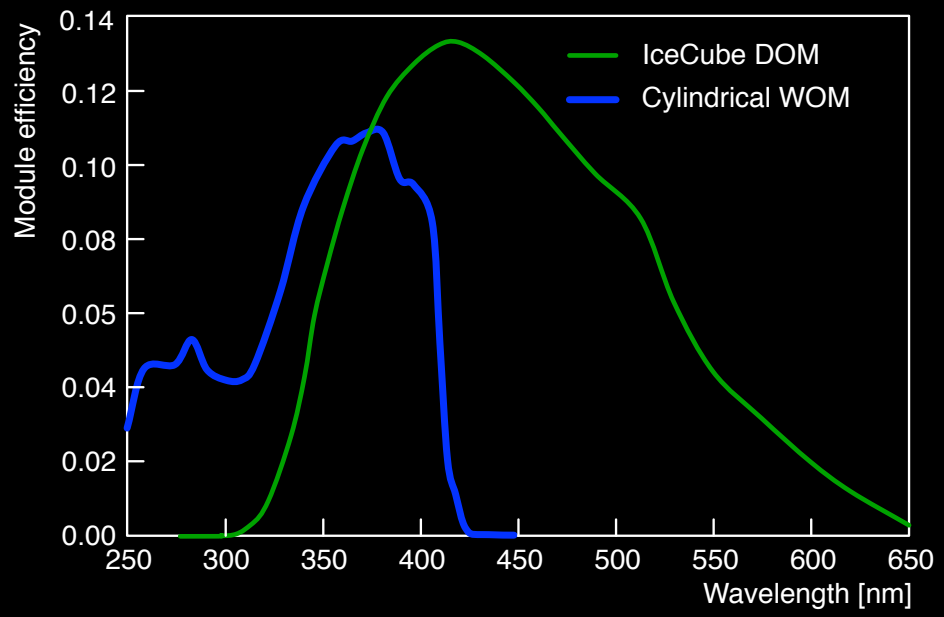
Prototype testing

- self-calibrating lab setup

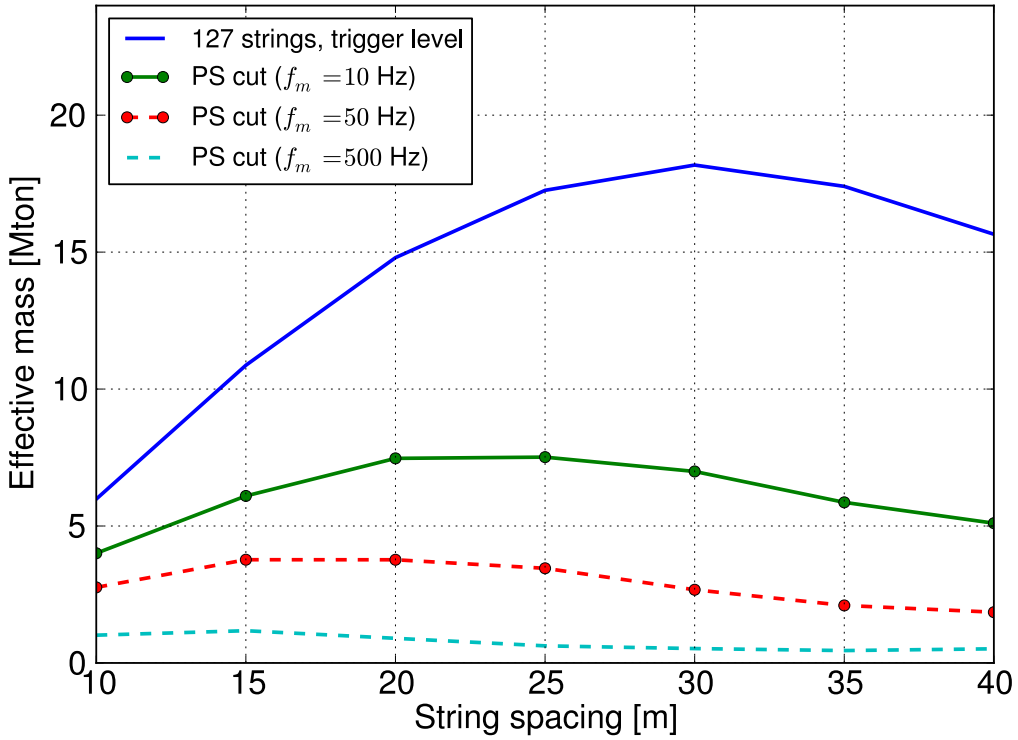


Module	Mean QE [%]	λ_{peak} [nm]	Aeff [cm^2]	Noise [Hz]
WOM	1.5	370	100-150	~10
DOM	7.10	420	18	800

Backgrounds and noise

Requirements

- SN trigger
  ➔ 3ν's in 10 sec
- want < 1 fake SN trigger / year
  ➔ need < 1 mHz fake ν's



Backgrounds	
self-noise	1.0 mHz
solar ν_e	28.2 mHz
atmo ν	0.32 mHz
Michel electrons	1.5 mHz

Lessons learned

- need large-area, low noise sensors
- solar neutrinos most challenging
  ➔use event direction (elastic scattering)

But: solar ν interesting themselves (G-modes of the sun)

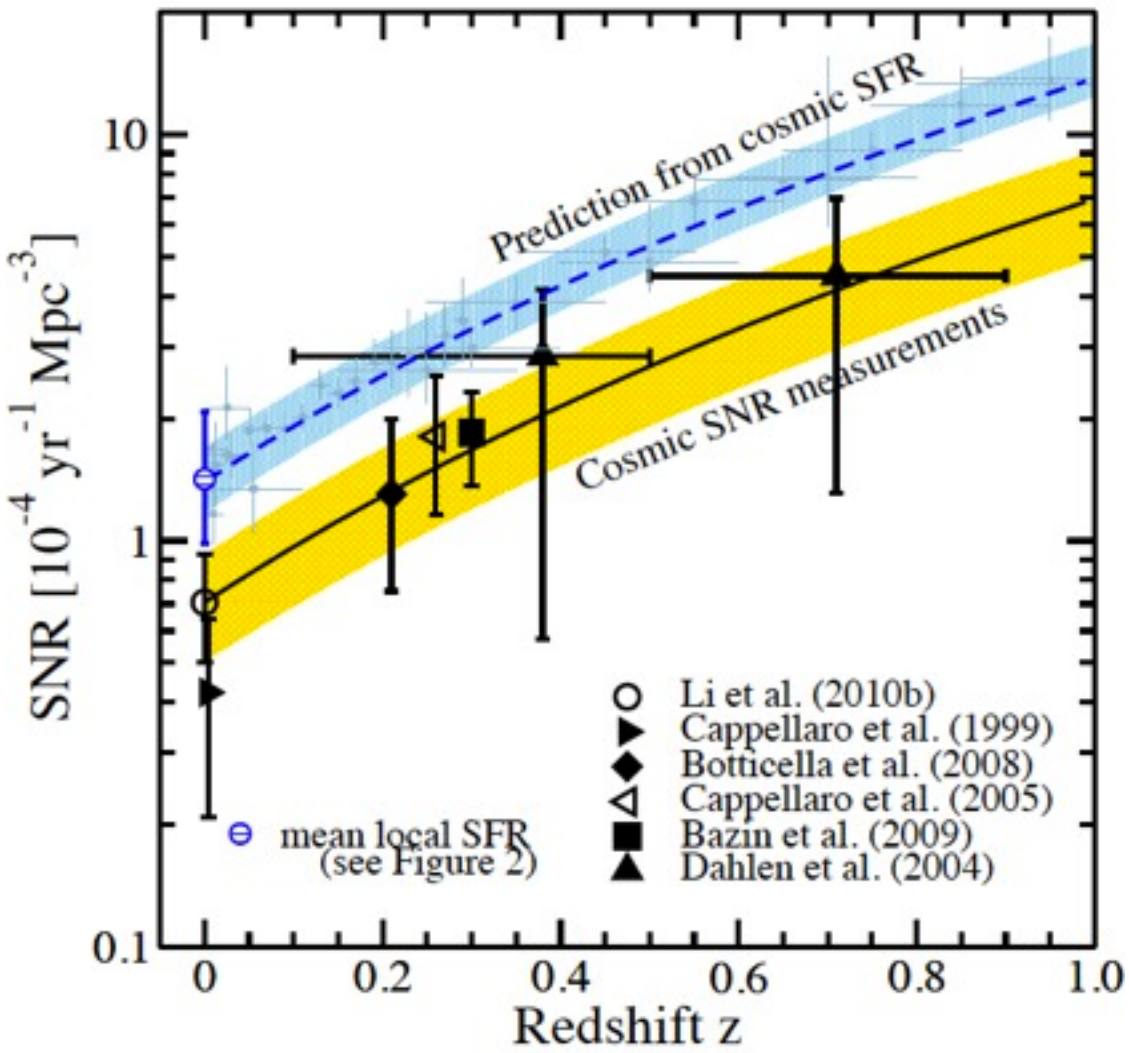
Supernova rate

Supernova rate (SNR)

- cosmological SNR
  ➔ proportional to galaxy blue luminosity
- apply to galaxy catalog

Star formation rate (SFR)

- heavy stars short-lived
  ➔ SNR ∝ SFR
- cosmic SFR
  ➔ twice as high as cosmic SNR
- many missed (e.g *dark*) SNe?



[S. Horiuchi, et al, arxiv:1102.1977v2]

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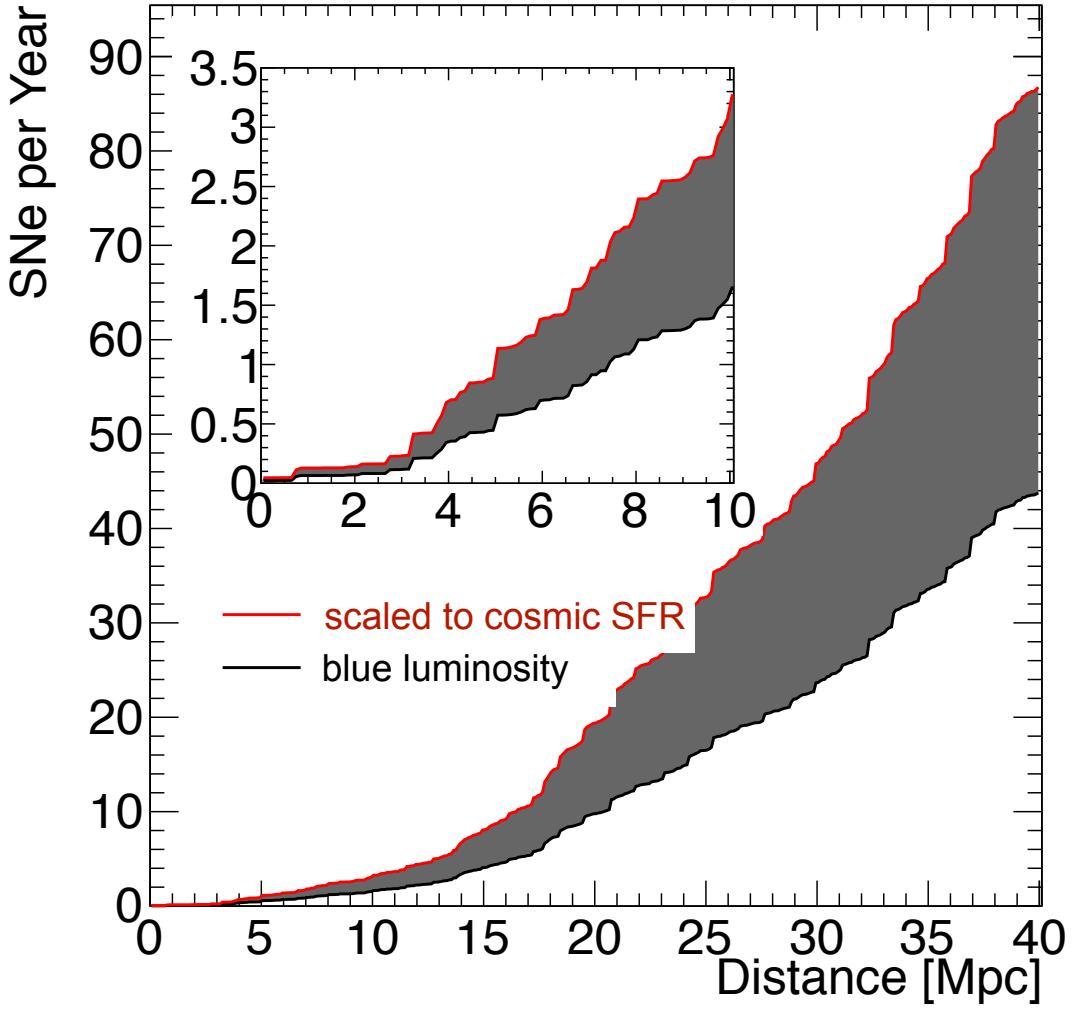
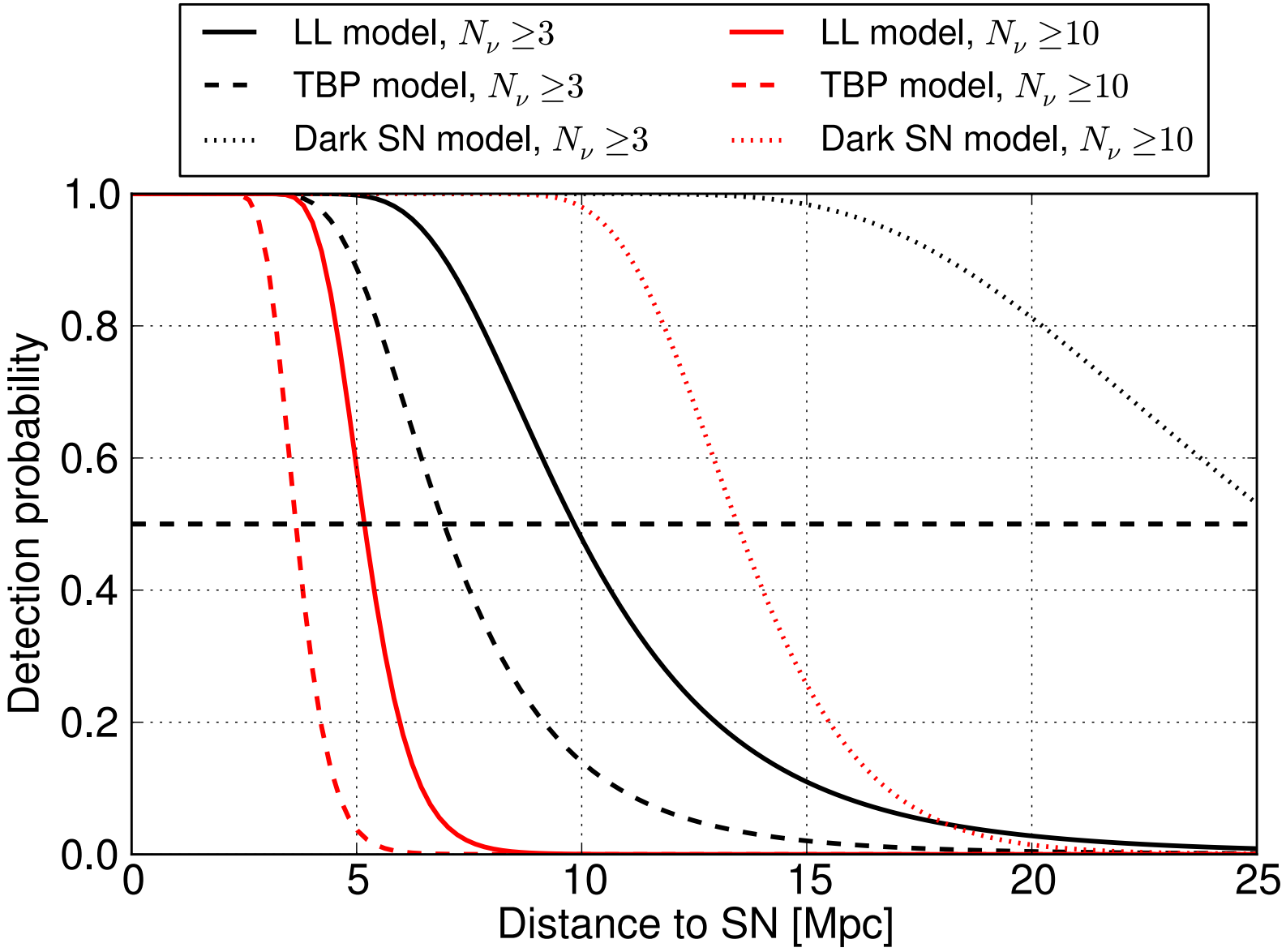
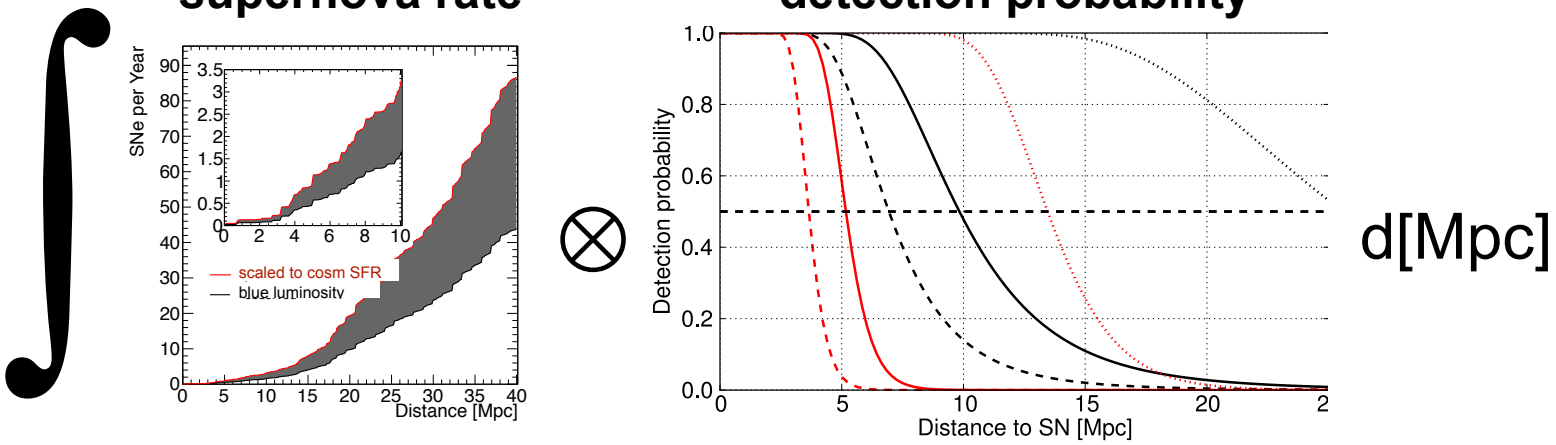


Supernova detection probability



Observed rate



observed SNe / year

=

Model	$N_v \geq 3$	$N_v \geq 10$
LL	2.34	0.55
TBP	1.13	0.26
Dark SNe*	2.03	0.34
Sum**	1.5 - 8.6	0.6 - 1.8

*Dark SN rate assumed to be 10% of total

** cosmic SFR 2x cosmic SNR

[S.B. et al, arxiv:1304.2553]

Summary

- South Pole offers a pristine environment for a very large low-energy neutrino detector
- Dense array can reach 10 Mton at a 10 MeV threshold with great scientific potential (e.g proton decay, extragalactic supernovae)
- R&D towards large, low-noise photosensor required to make this project feasible