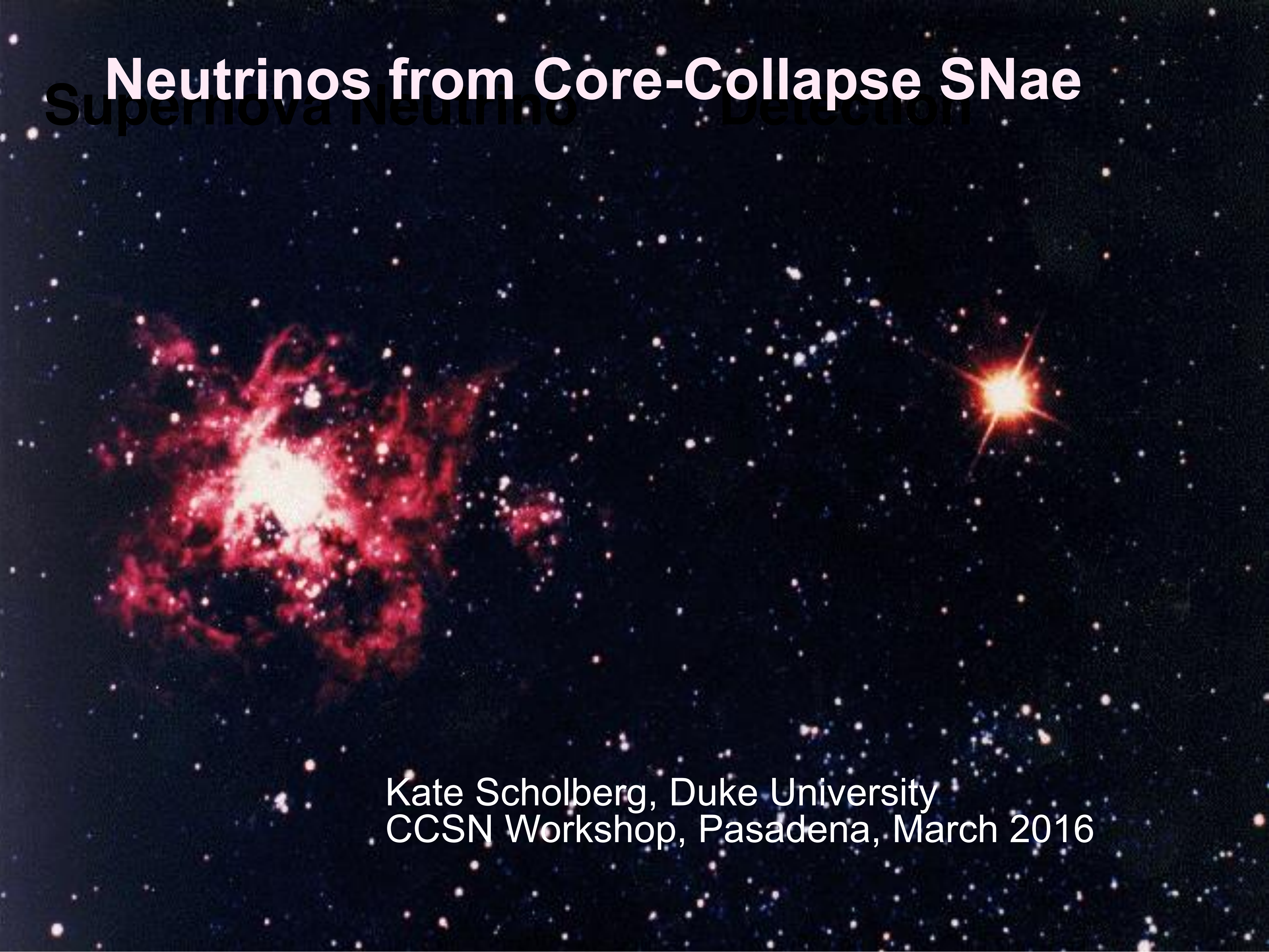
Neutrinos from Core-Collapse SNae

Supernova Neutrino Detection



Kate Scholberg, Duke University
CCSN Workshop, Pasadena, March 2016

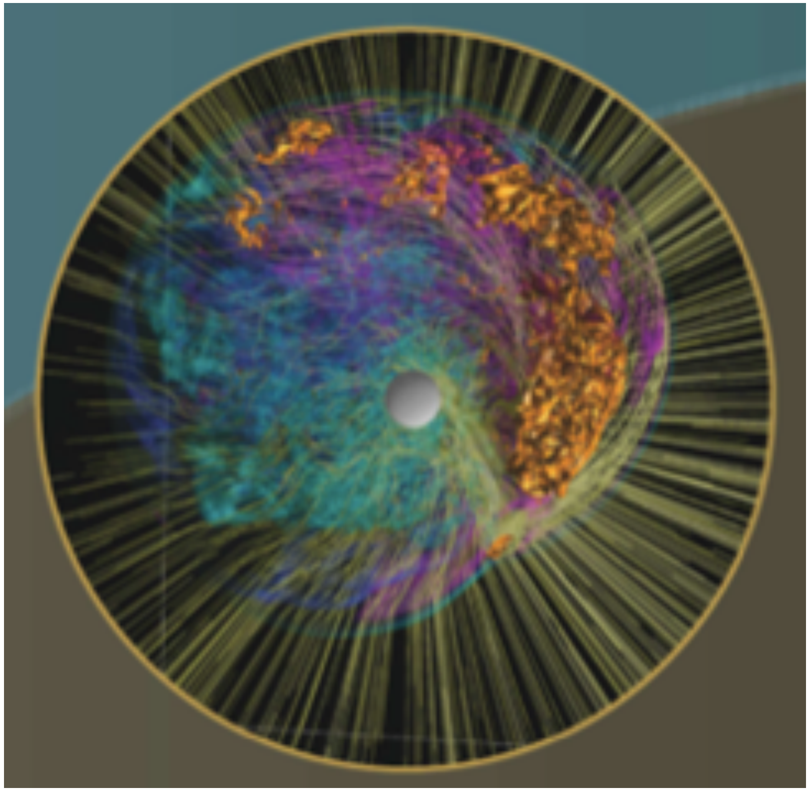
The core-collapse neutrino signal

When a star's core collapses, ~99% of the gravitational binding energy of the proto-nstar goes into ν's of *all flavors* with ~tens-of-MeV energies

(Energy *can* escape via ν's)

Mostly ν-$\bar{\nu}$ pairs from proto-nstar cooling

Timescale: *prompt* after core collapse, overall Δt~10's of seconds

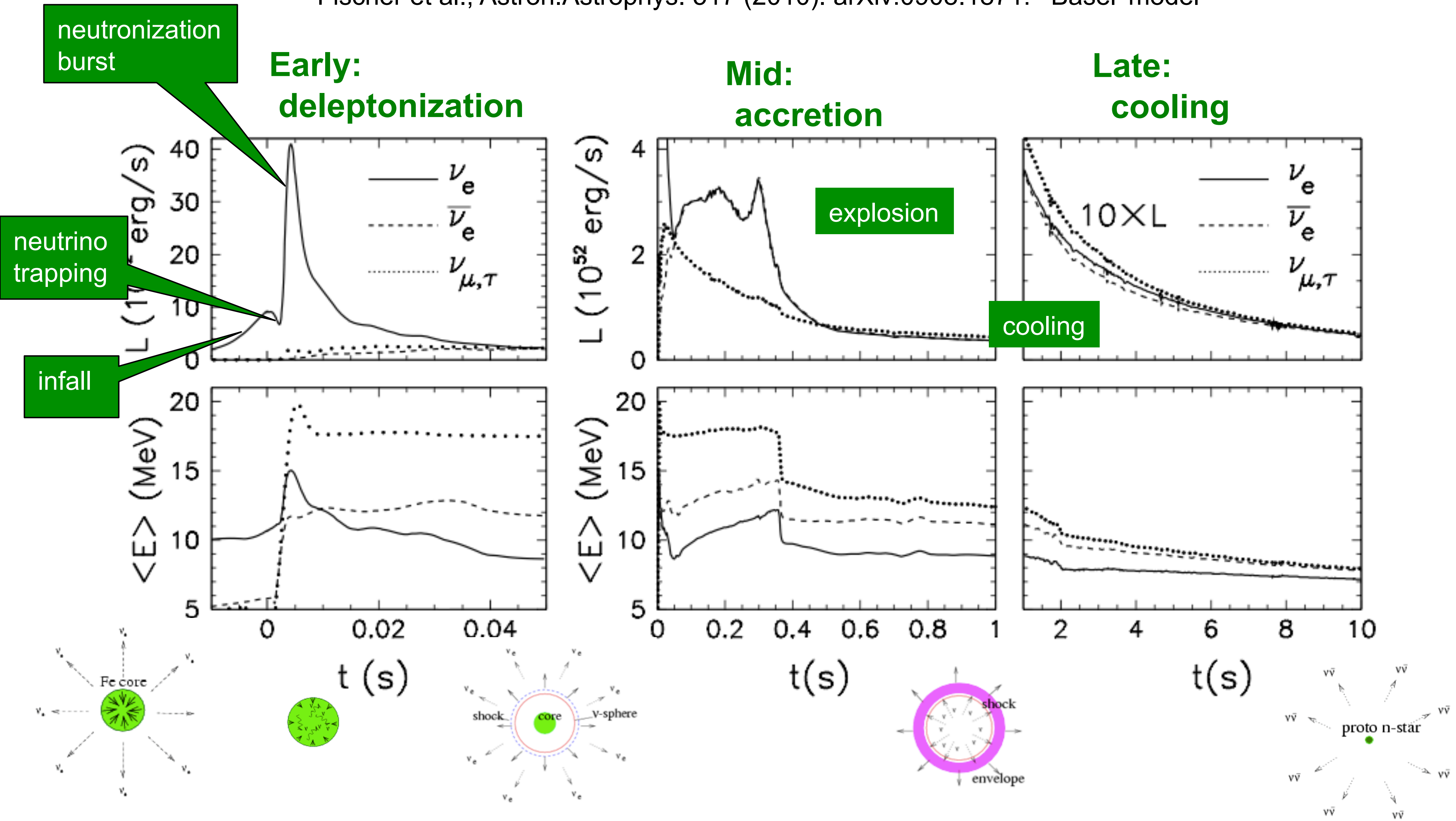


A. Mezzacappa

Expected neutrino luminosity and average energy vs time

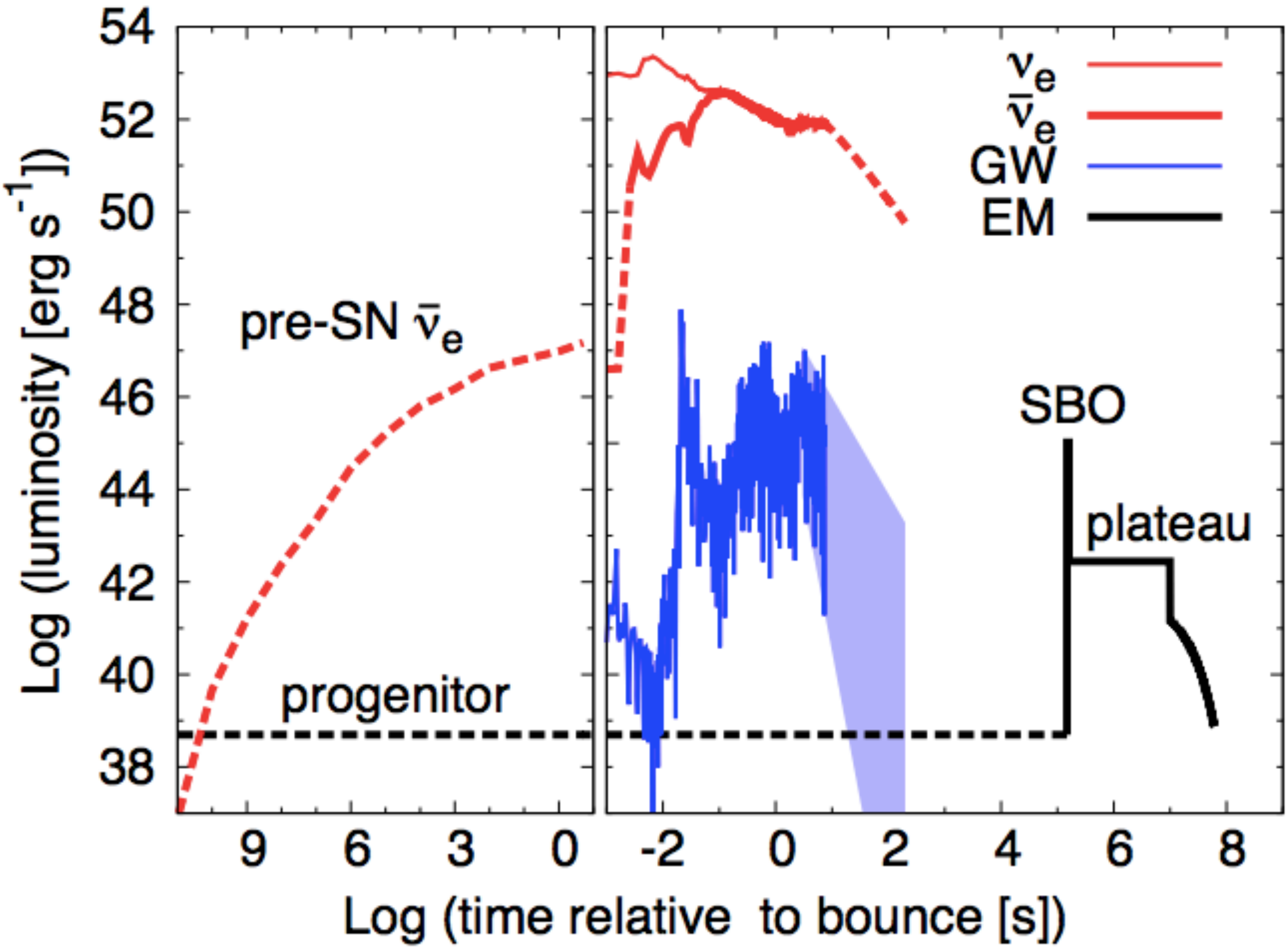
Vast information in the *flavor-energy-time profile*

Fischer et al., Astron.Astrophys. 517 (2010). arXiv:0908.1871: ‘Basel’ model



Note: visible supernova may not show up for hours or days

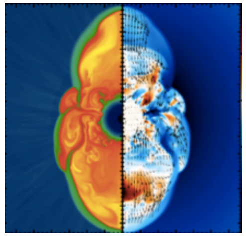
Multimessenger signals



K. Nakamura et al., MNRAS 2016

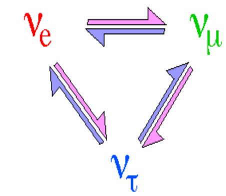
What can we learn from the next neutrino burst?

CORE COLLAPSE PHYSICS



explosion mechanism
proto nstar cooling,
quark matter
black hole formation
accretion, SASI
nucleosynthesis
....

input from neutrino experiments



from flavor, energy, time structure of burst

input from photon (GW) observations

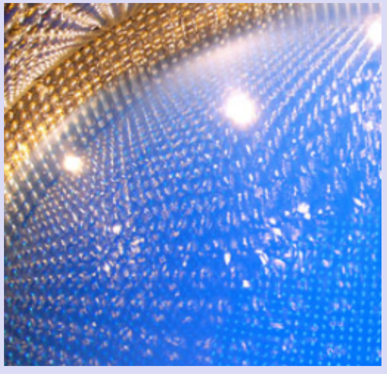
NEUTRINO and OTHER PARTICLE PHYSICS

ν absolute mass (not competitive)
ν mixing from spectra:
flavor conversion in SN/Earth
(mass hierarchy)
other ν properties: sterile ν's,
magnetic moment,...
axions, extra dimensions,
FCNC, ...

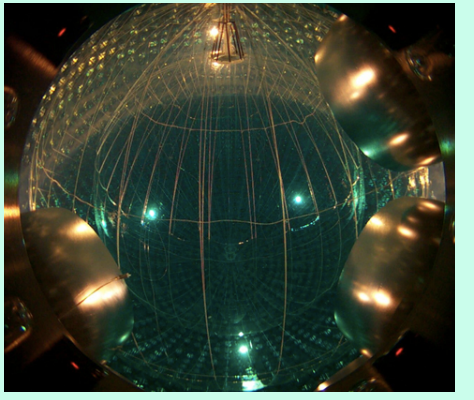
+ EARLY ALERT

Current main supernova neutrino detector types

Water



Scintillator



Argon

Lead

+ some others (e.g. DM detectors)

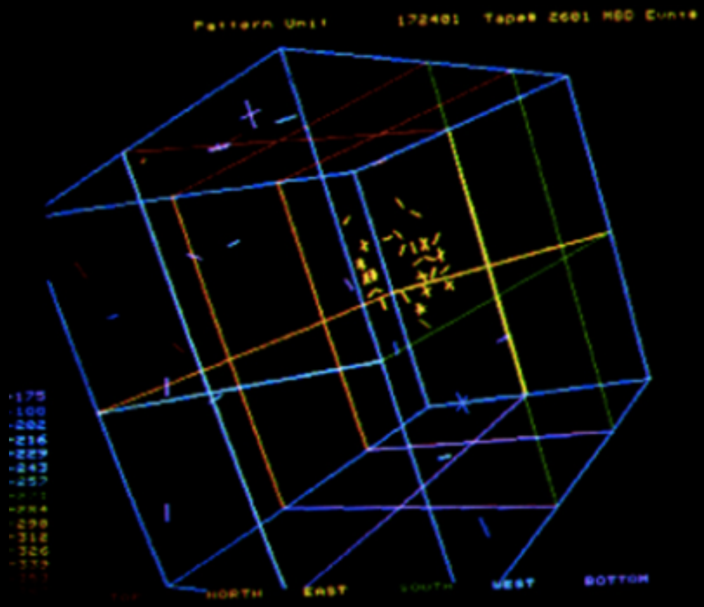
Jargon alert!

In particle physics,
an “event” is *not* this...

~$10^{52\text{-}53}$ ergs

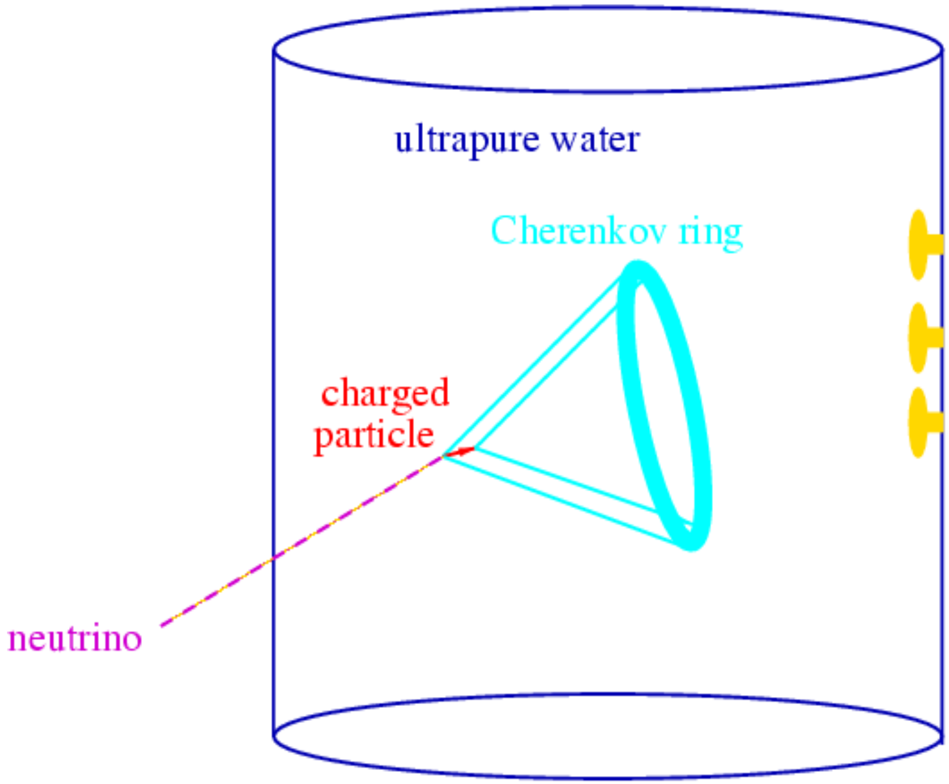
It’s an individual *recorded neutrino interaction*:

few times
10^{-5} ergs



e.g., “the IMB neutrino
detector saw 8 events
from 1987A”

Water Cherenkov detectors

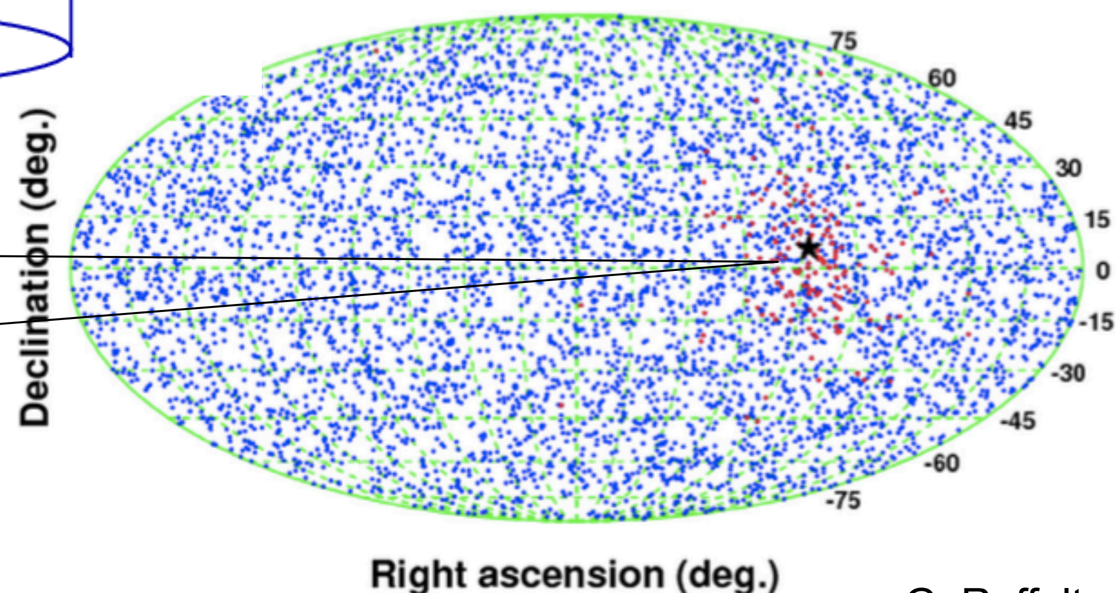


Inverse Beta Decay (CC) **dominates**

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

E_{thr}=1.8 MeV

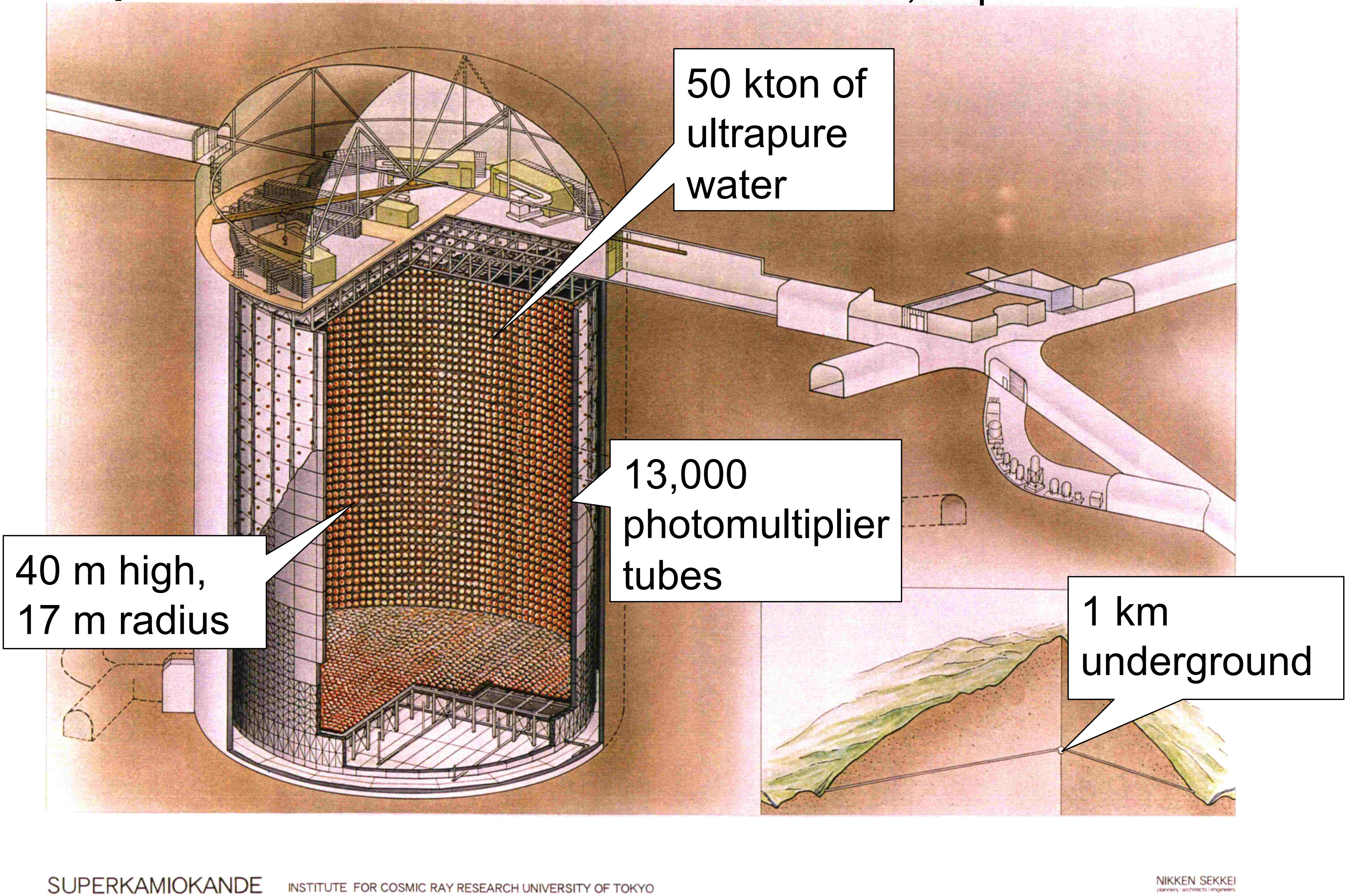
Pointing from neutrino-electron elastic scattering



G. Raffelt

Super-Kamiokande

Water Cherenkov detector
in Mozumi, Japan

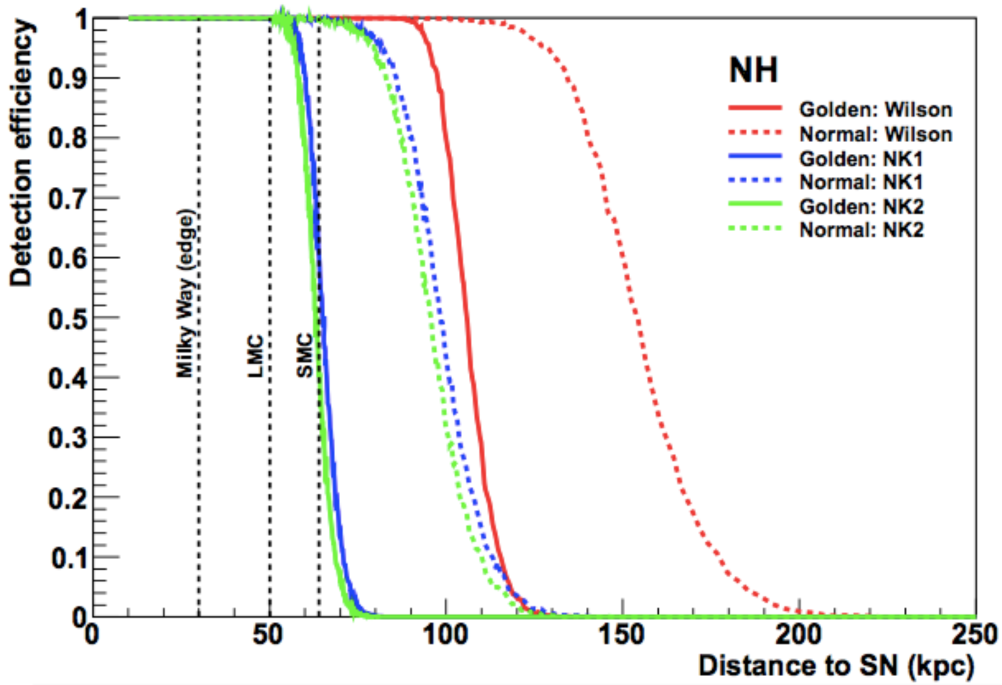


Super-Kamiokande Performance

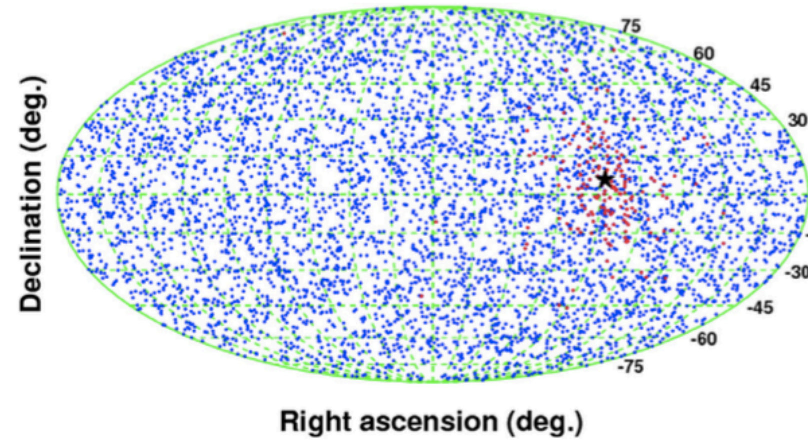
Abe et al., Astroparticle Physics 81 (2016) 39

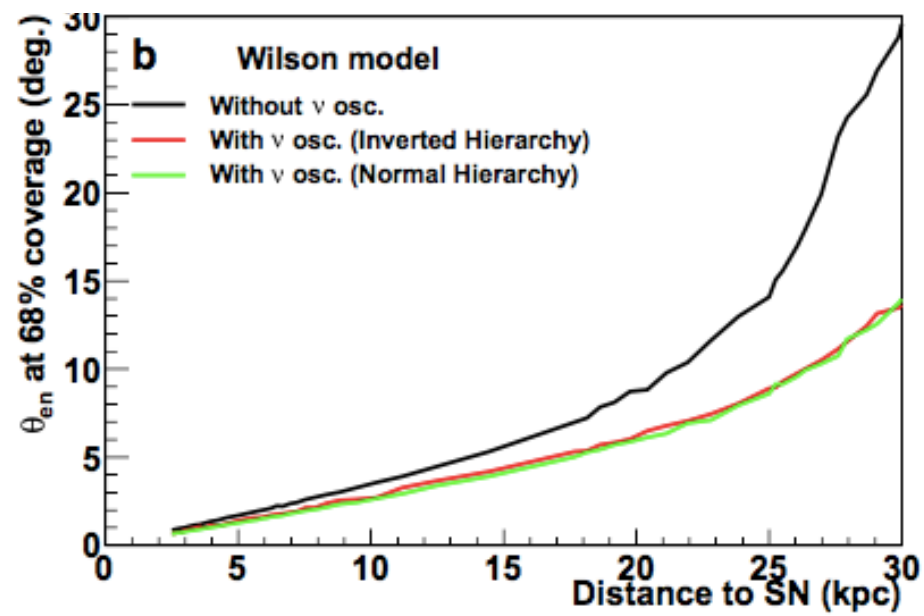
Detection efficiency

real-time monitor



Pointing*

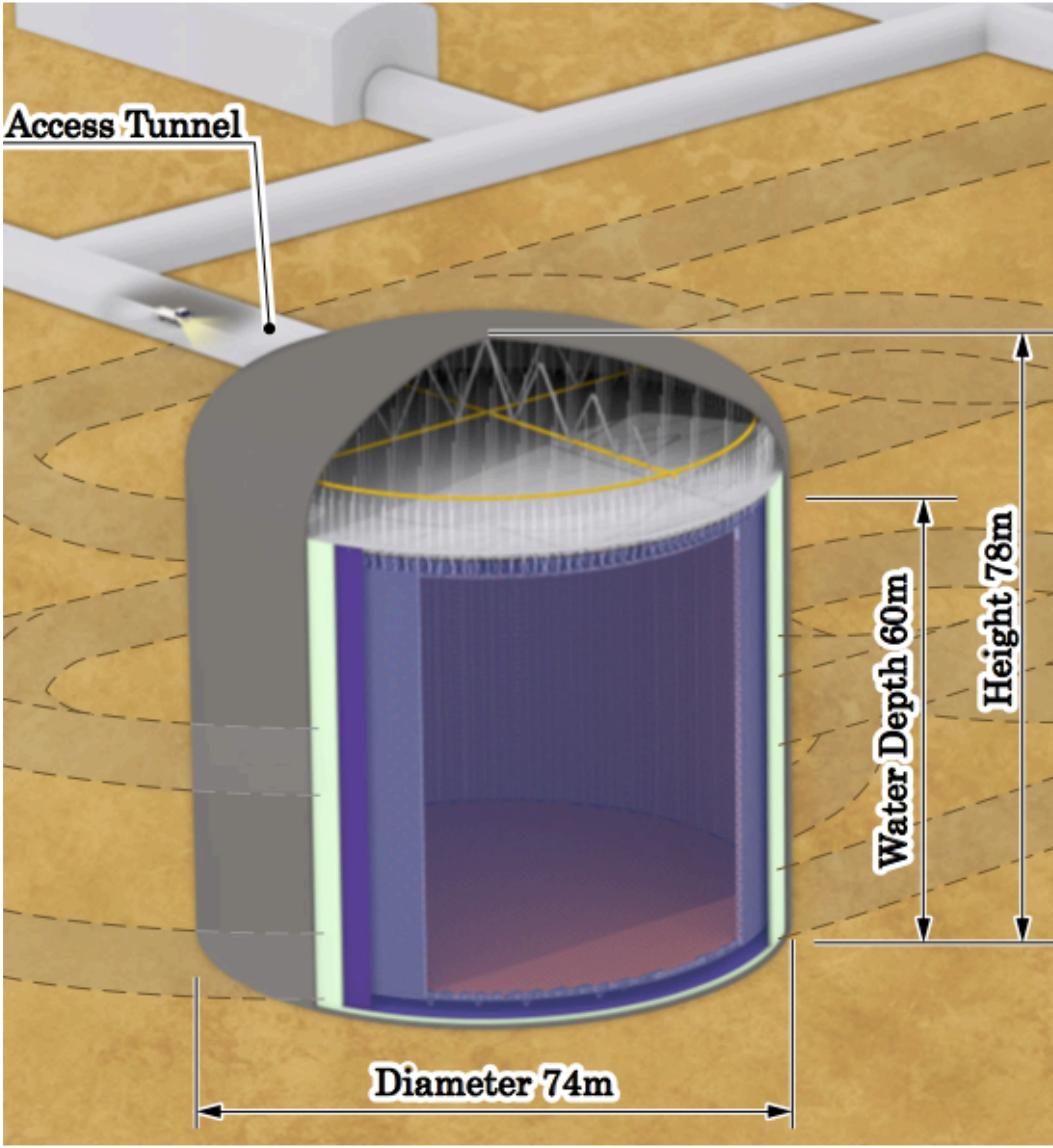




- sensitivity to full Galaxy
  (and somewhat beyond)
- few to 10^{o} pointing within this range

*SK-Gd upgrade will improve this by reducing isotropic bg

Next generation: **Hyper-Kamiokande**



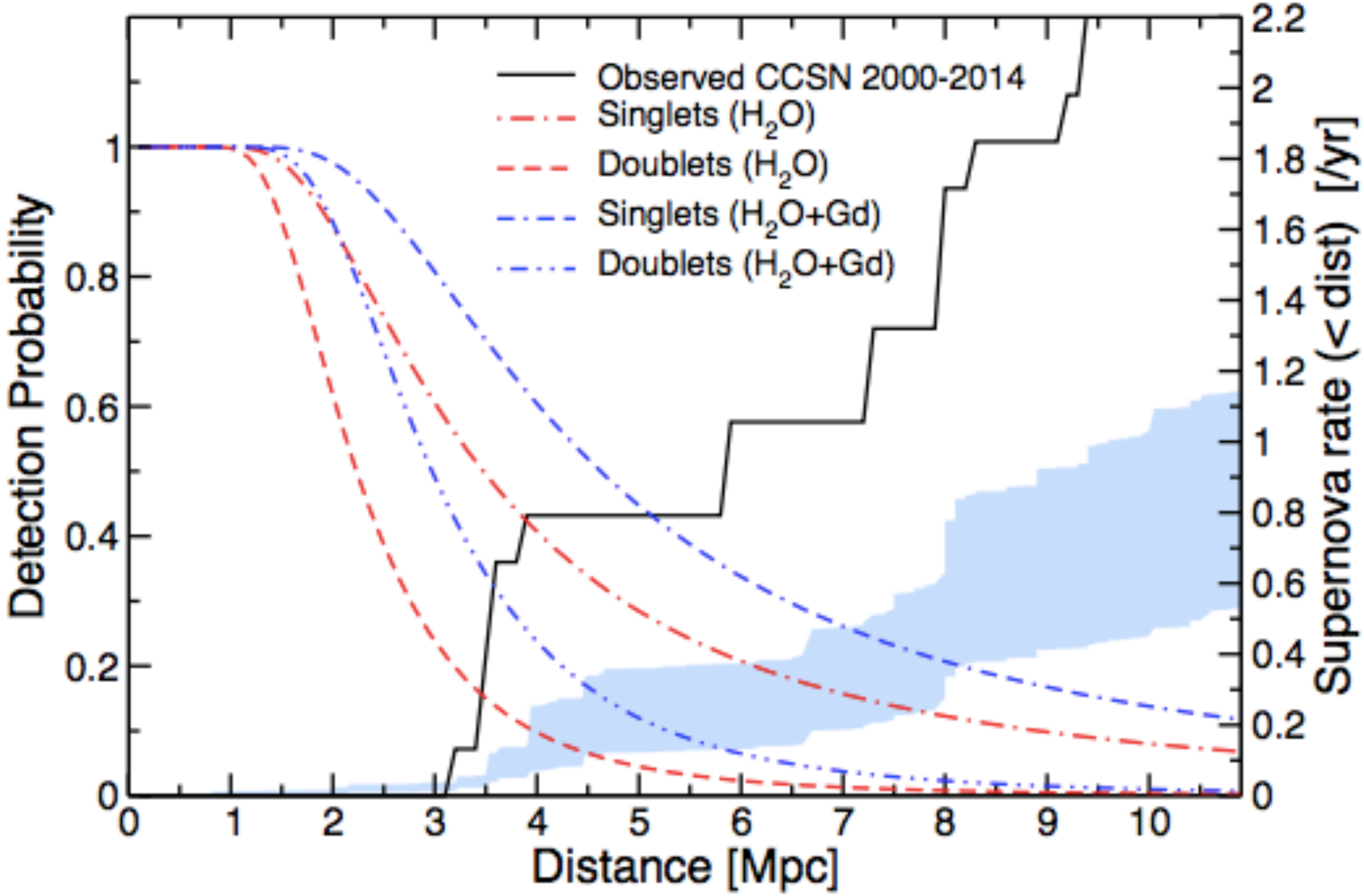
374 kton fiducial volume

Design & site-selection underway

~100,000 events!

(mostly electron antineutrinos)

Hyper-K detection probabilities



K. Nakamura et al., MNRAS 2016

Long string water Cherenkov detectors

~kilometer long
strings of PMTs
in very clear water
or ice (IceCube, ANTARES)

Nominally multi-GeV energy threshold...
but, may see burst of low energy (anti-) ν_e's as
coincident increase in single PMT count rate

Map overall time structure of burst by tracking the glow