

Core-collapse supernova neutrinos and the SuperNova Early Warning System

The background of the slide is a deep space image. On the left, there is a large, irregularly shaped nebula or supernova remnant with a bright, glowing yellow-white core and a diffuse, reddish-pink outer shell. To the right of this, there is a single, very bright star with a prominent four-pointed diffraction pattern. The rest of the background is a dark blue-black field filled with numerous small, distant stars of varying brightness.

Kate Scholberg, Duke University
Low-latency alerts and Data analysis
for Multi-messenger Astrophysics
January 13, 2022

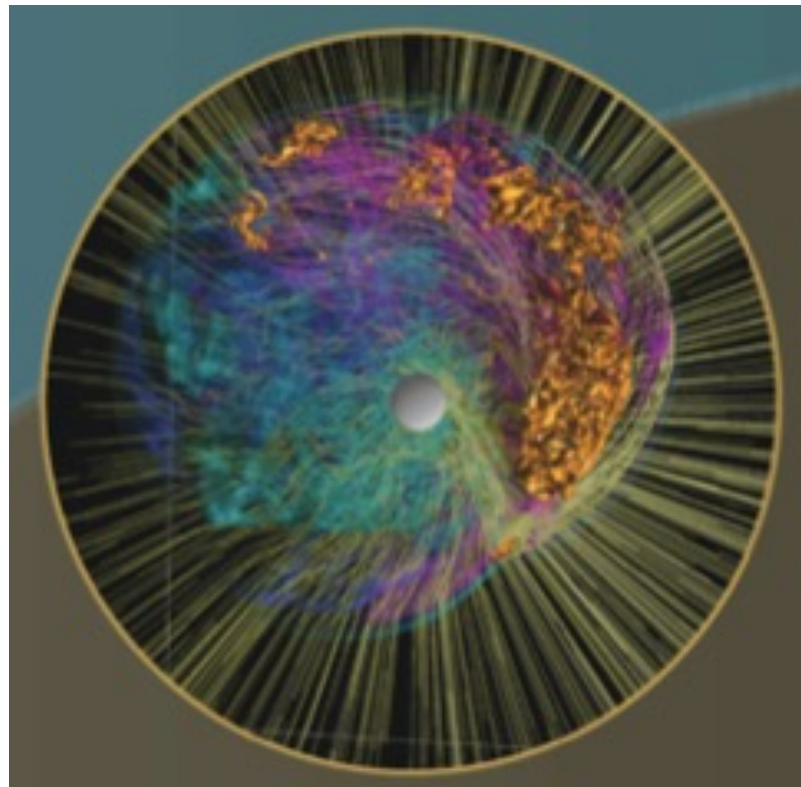
The core-collapse neutrino signal

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

(Energy *can* escape via ν 's)

Mostly ν -antiv pairs from proto-nstar cooling

Timescale: *prompt*
after core collapse,
overall $\Delta t \sim 10$'s
of seconds



A. Mezzacappa

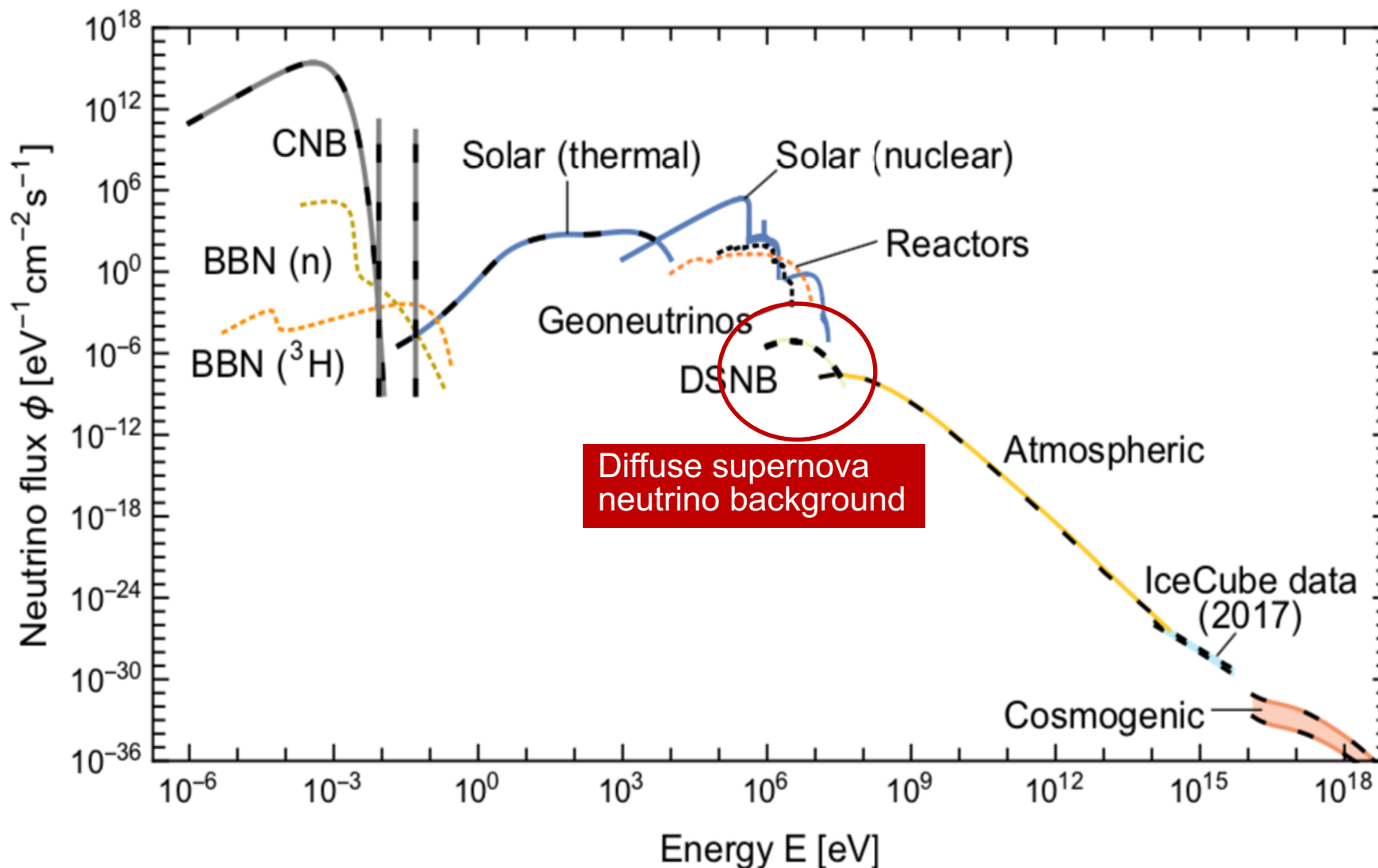
The Steady State Neutrino Spectrum @ Earth

Grand Unified Neutrino Spectrum at Earth

Edoardo Vitagliano, Irene Tamborra, Georg Raffelt. Oct 25, 2019. 54 pp.

MPP-2019-205

e-Print: [arXiv:1910.11878](https://arxiv.org/abs/1910.11878) [astro-ph.HE] | [PDF](#)



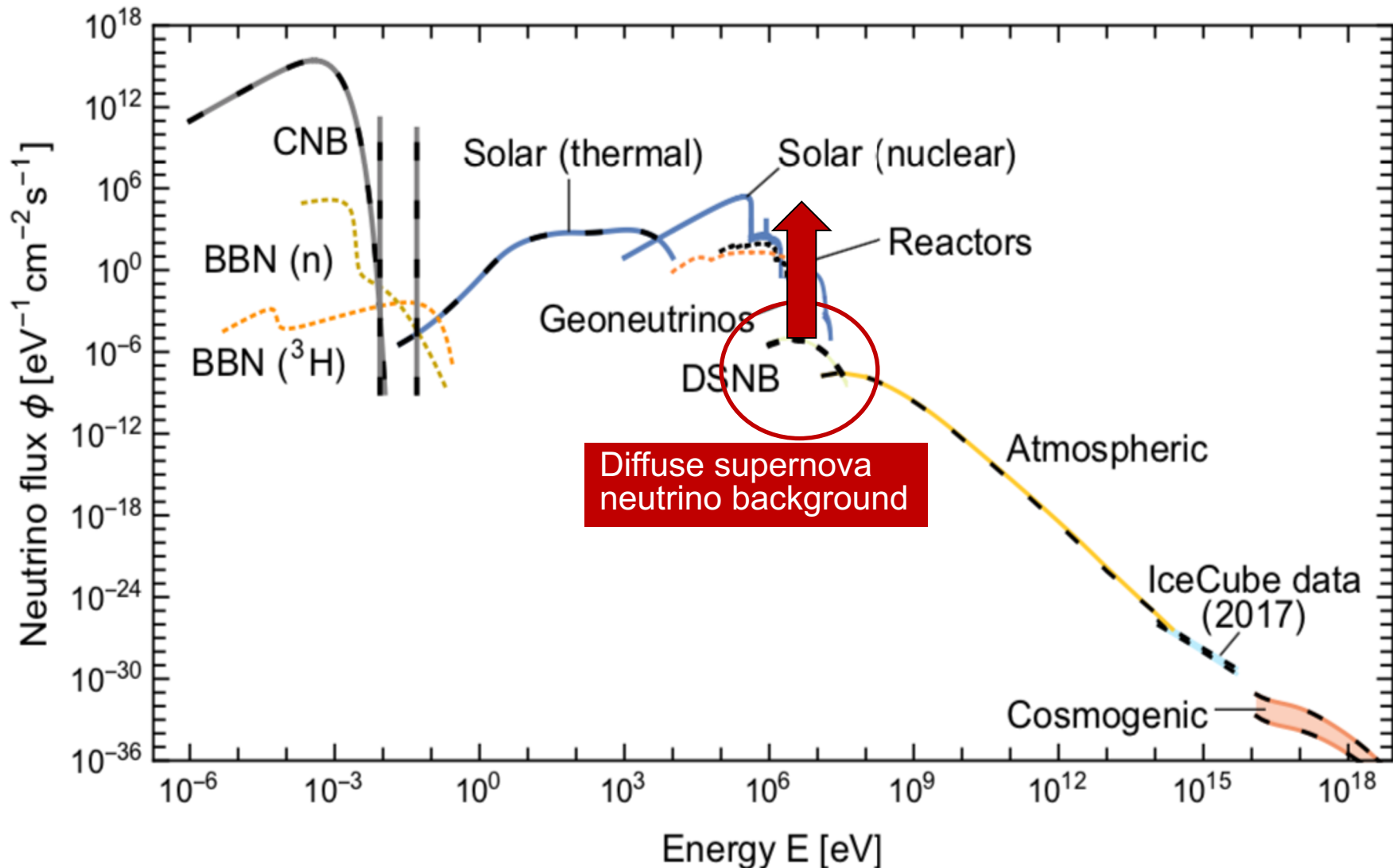
During a ~ 10 s Galactic burst,
SN flux can increase
9-10 orders of magnitude

Grand Unified Neutrino Spectrum at Earth

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MPP-2019-205

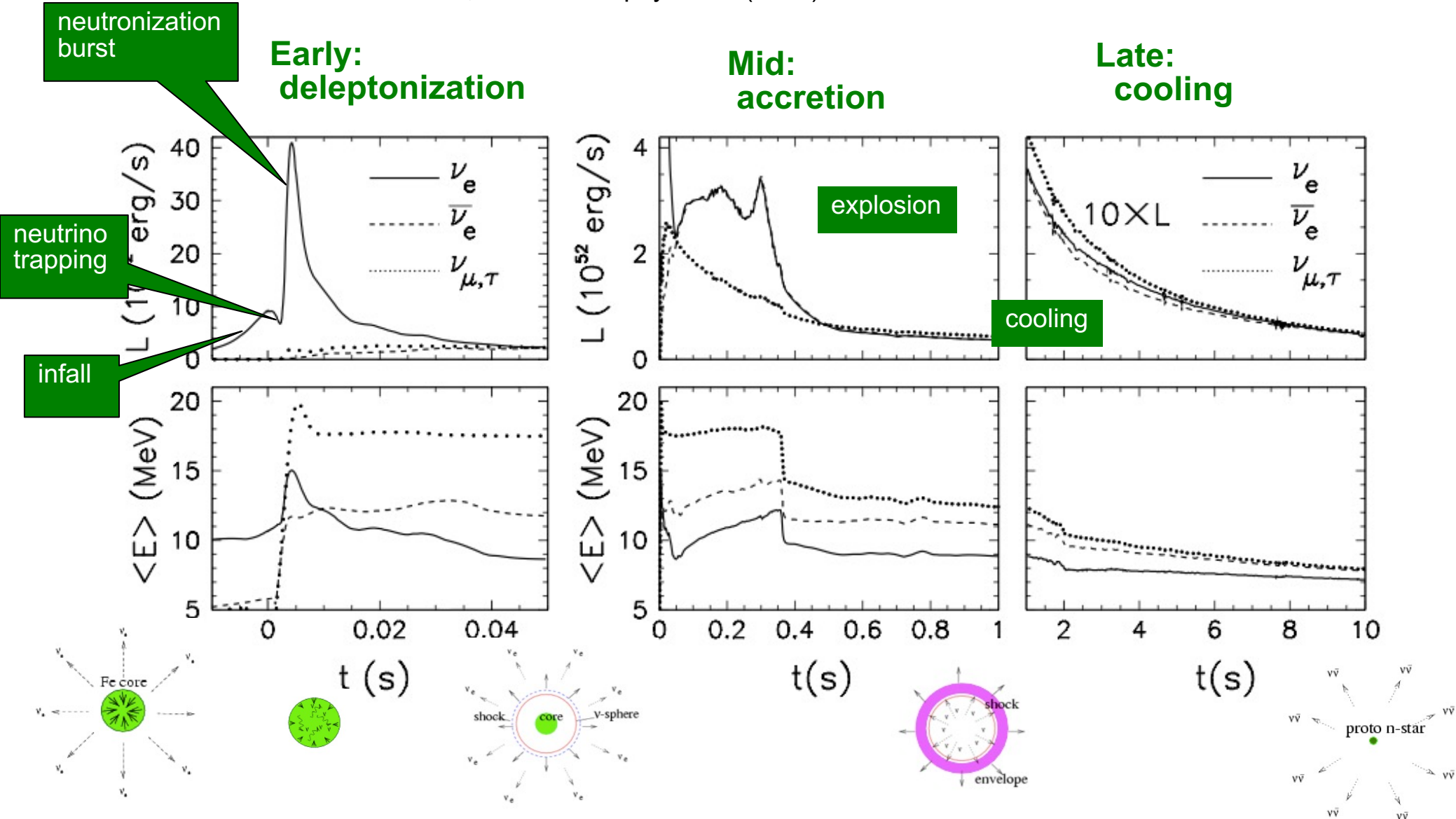
e-Print: [arXiv:1910.11878](https://arxiv.org/abs/1910.11878) [astro-ph.HE] | [PDF](#)



Expected neutrino luminosity and average energy vs time

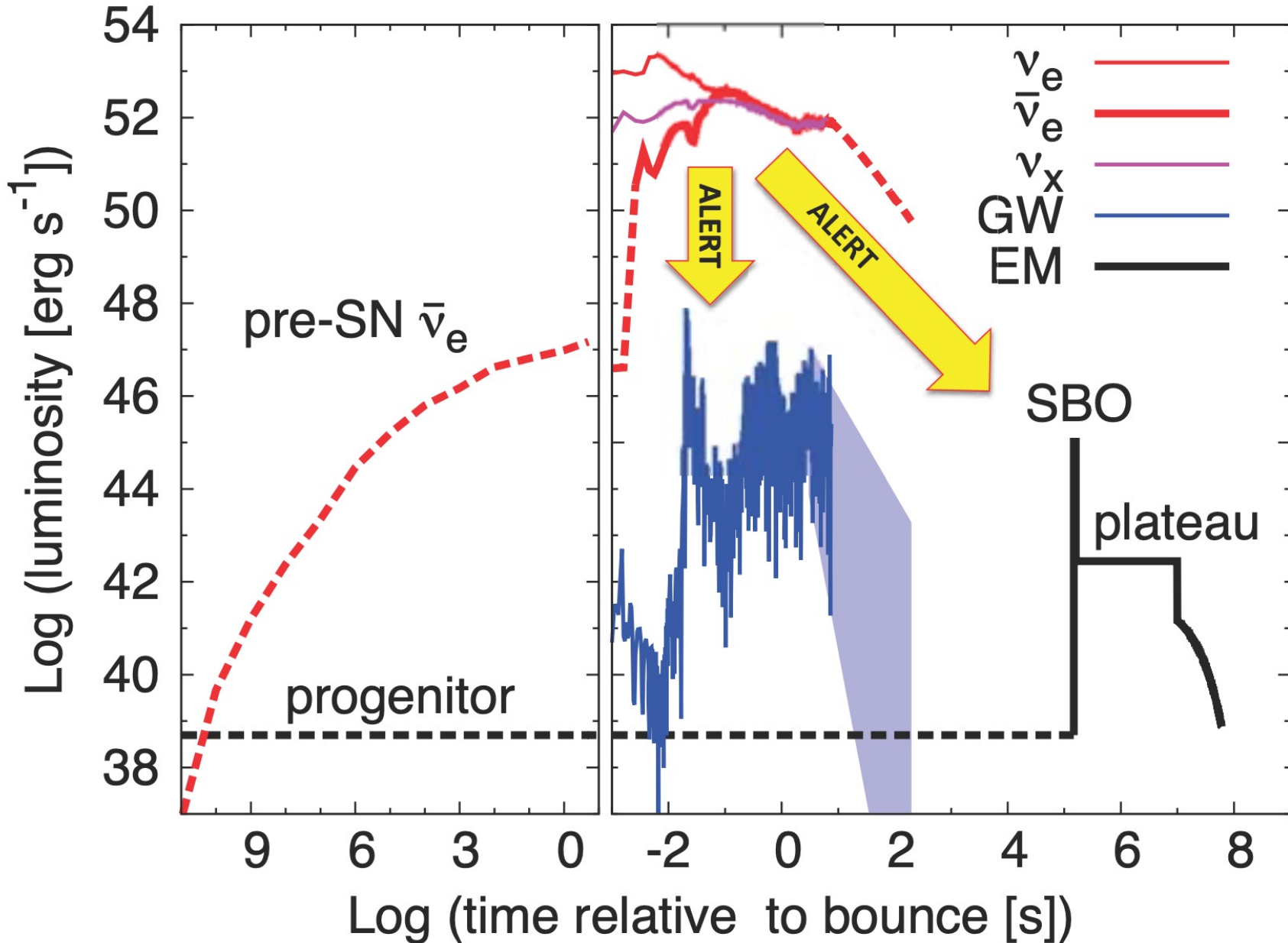
Vast information in the *flavor-energy-time* profile

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

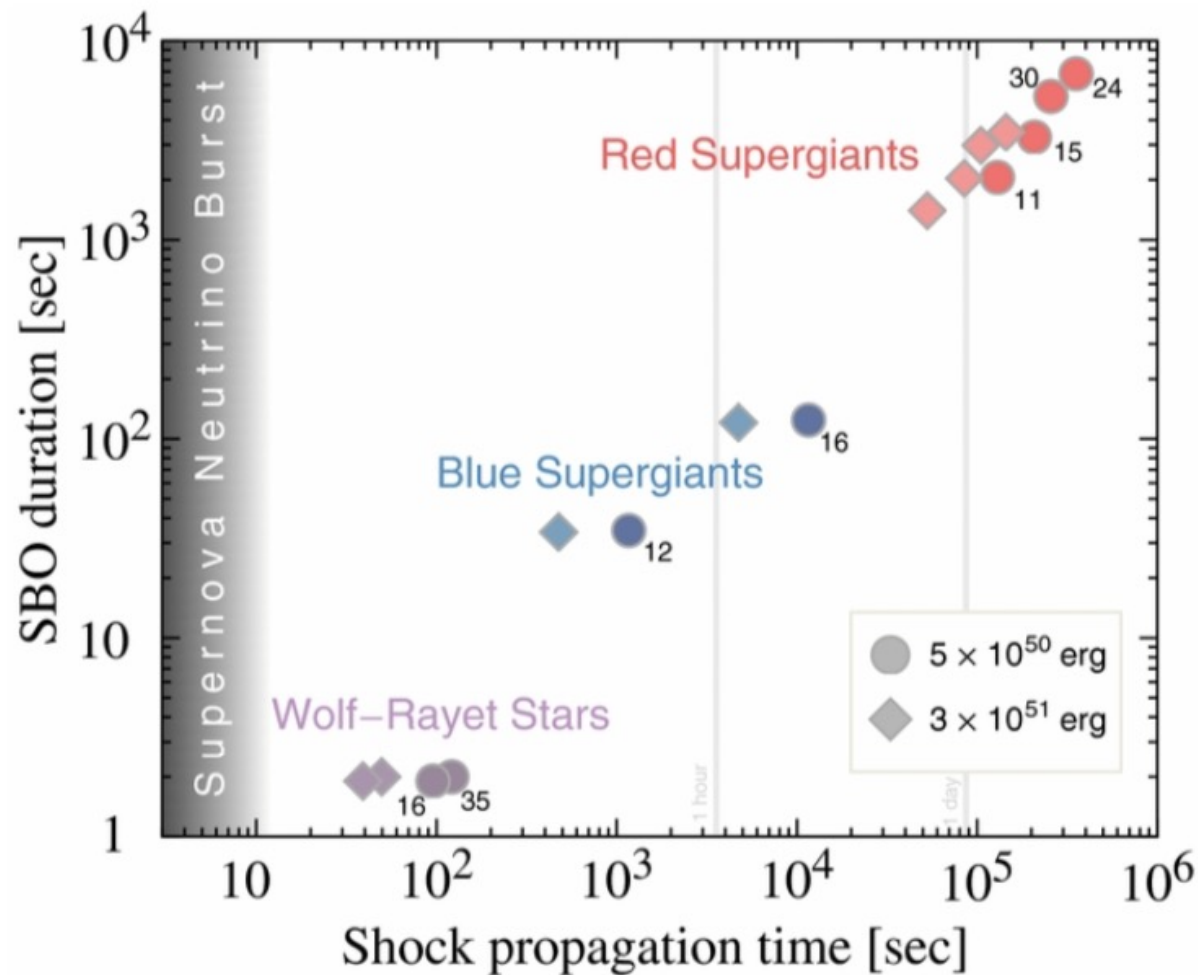


Visible supernova may not show up for hours or days

Multimessenger signals from core collapse



If we see a neutrino burst... where's the supernova??

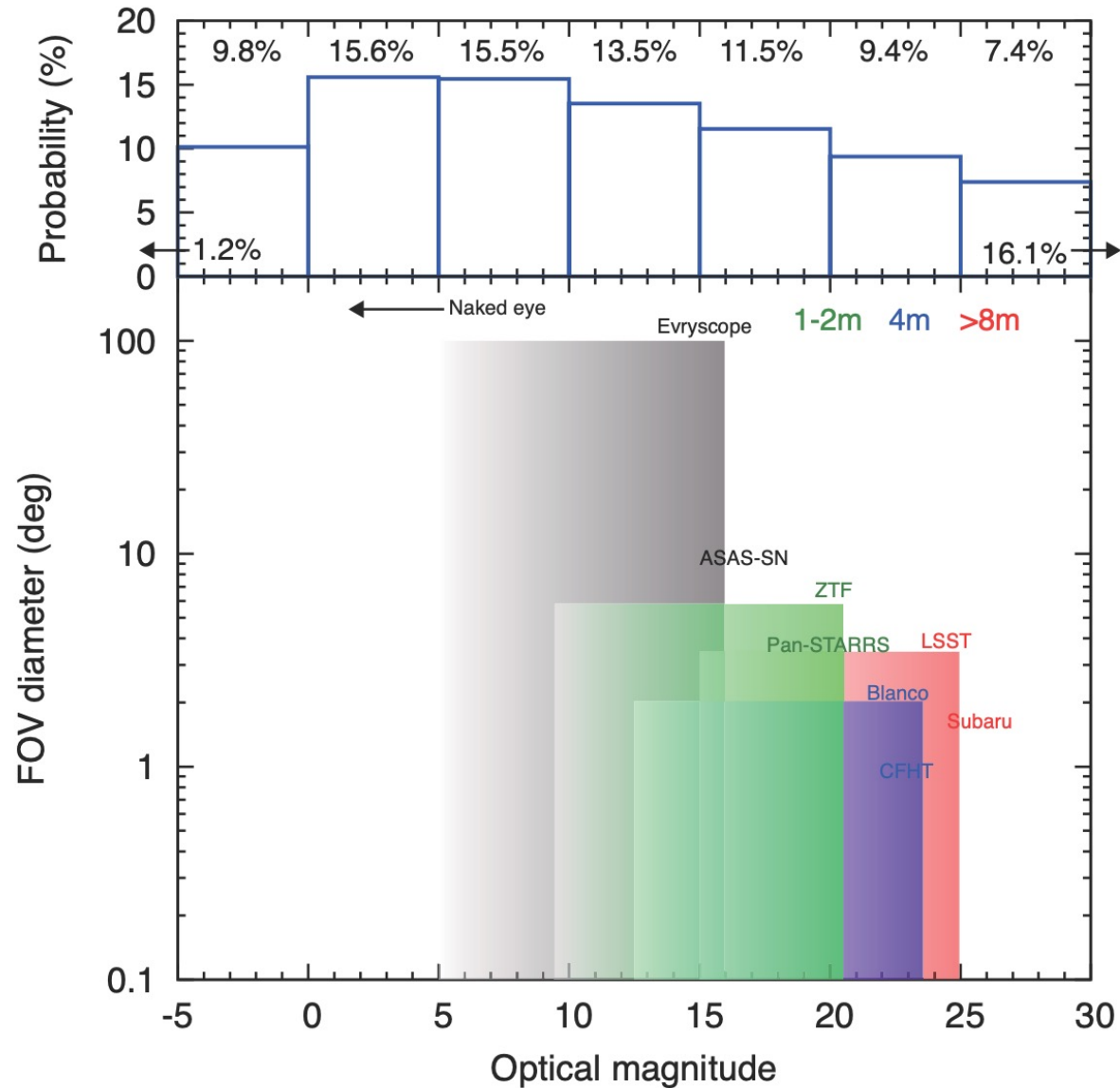


**We're racing
the shock!**

May have less than
a half hour, or even
just minutes

Matthew D. Kistler, W. C. Haxton, and Hasan Yüksel. Tomography of Massive Stars from Core Collapse to Supernova Shock Breakout. *ApJ*, 778:81, 2013, [arXiv:1211.6770](https://arxiv.org/abs/1211.6770).

Optical follow-up requirements for the next Galactic supernova



Current main supernova neutrino detector types

Water

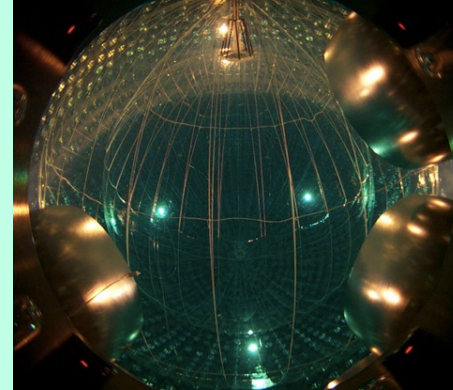


individual
 ν interactions



diffuse glow

Scintillator



Argon

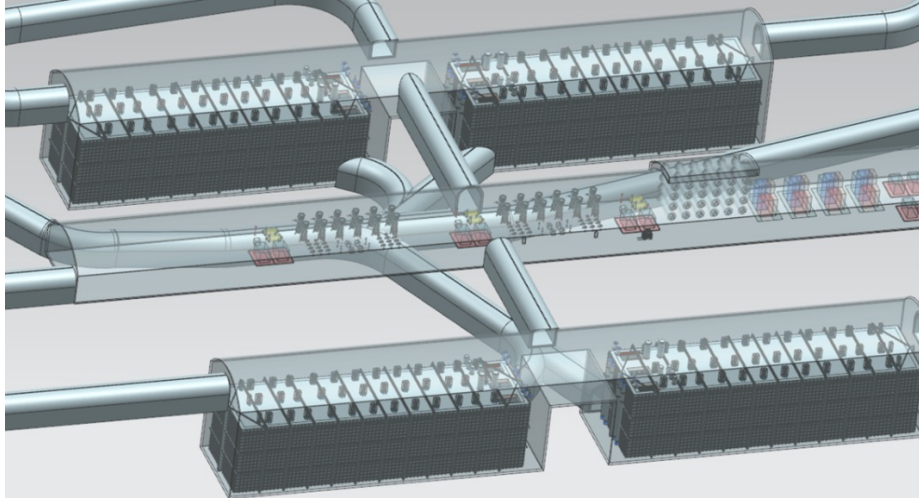


Lead

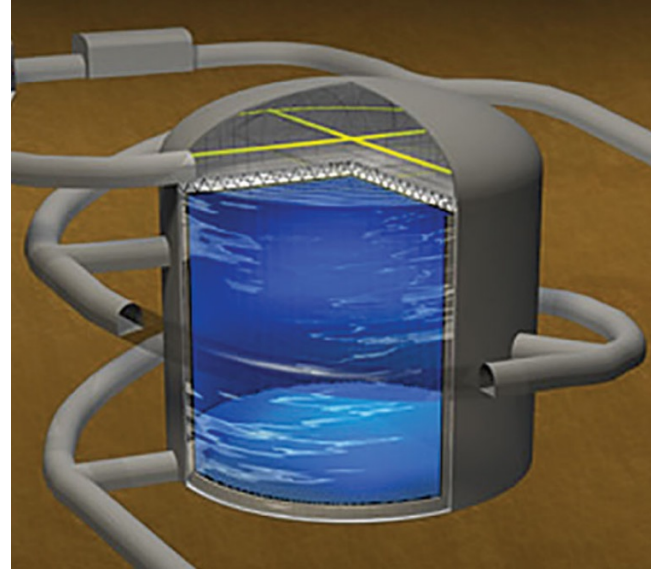


+ some others (e.g. DM detectors)

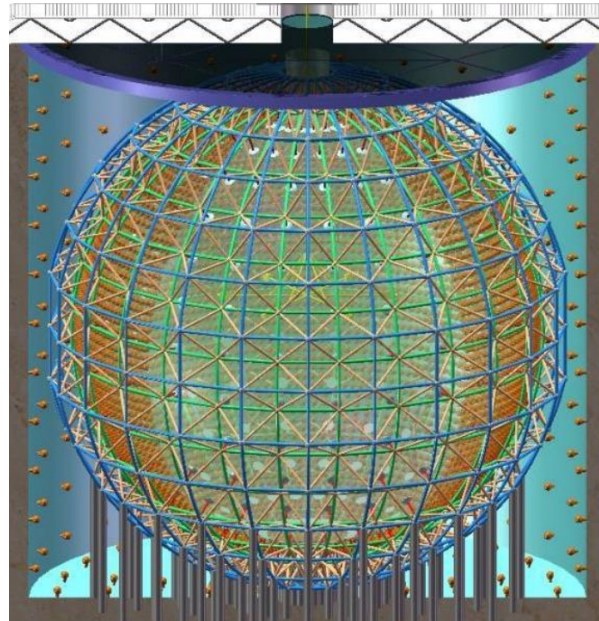
Future Supernova-Burst-Sensitive Neutrino Detectors



DUNE
40 kton argon
USA



Hyper-Kamiokande
260 kton water
Japan



JUNO
20 kton scintillator
(hydrocarbon)
China

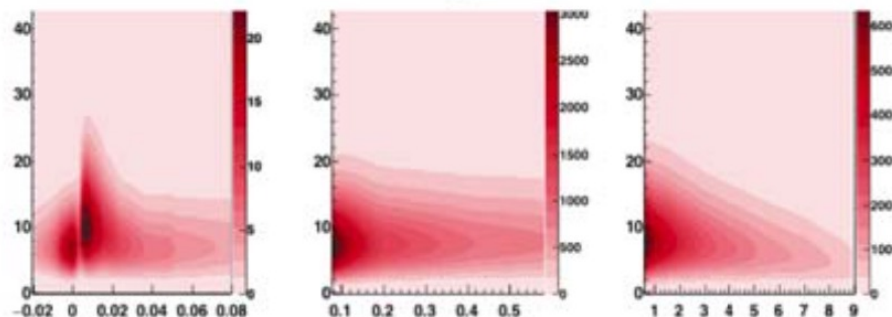
Model Spectra

Neutronization

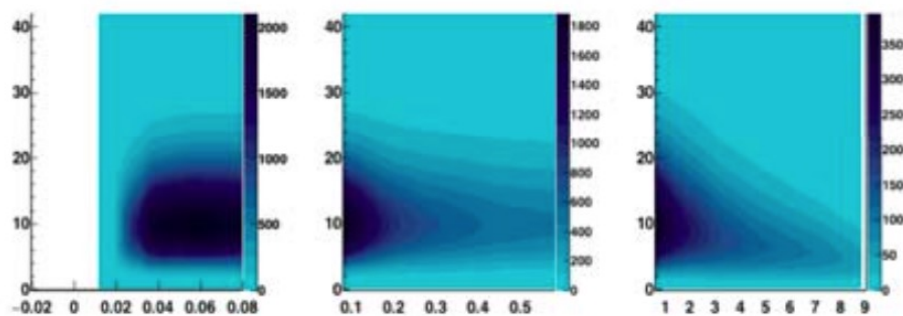
Accretion

Cooling

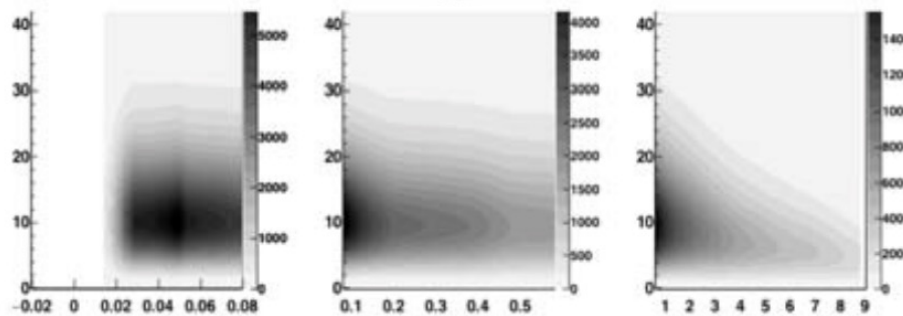
ν_e



$\bar{\nu}_e$



ν_x



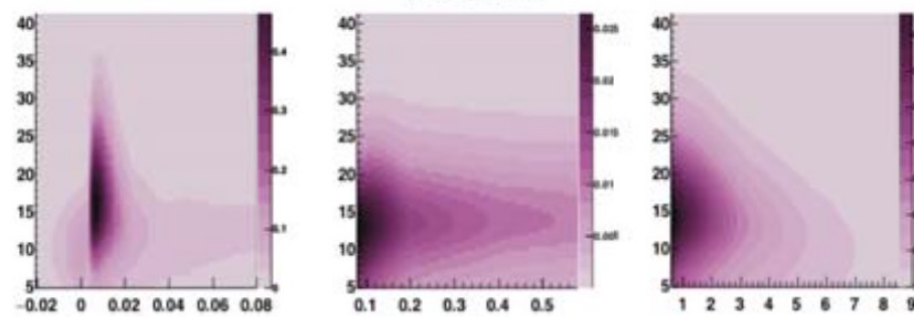
Observed Spectra

Neutronization

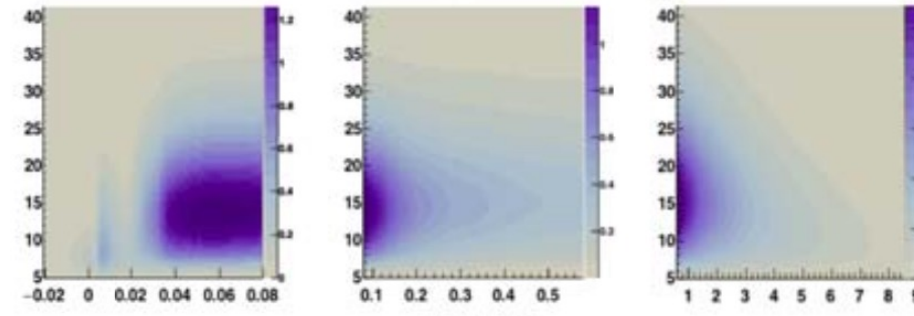
Accretion

Cooling

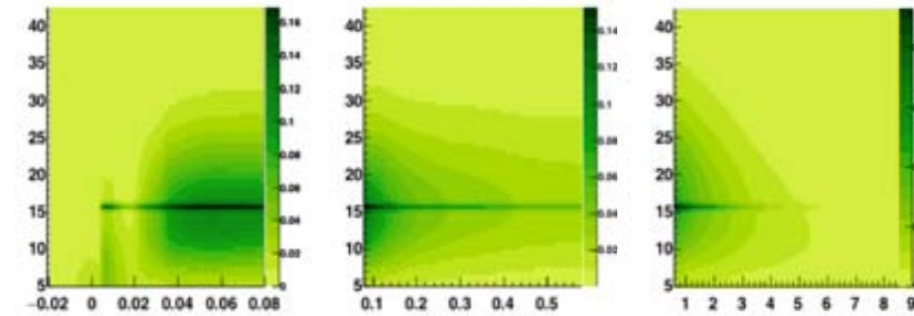
DUNE



Hyper-K



JUNO

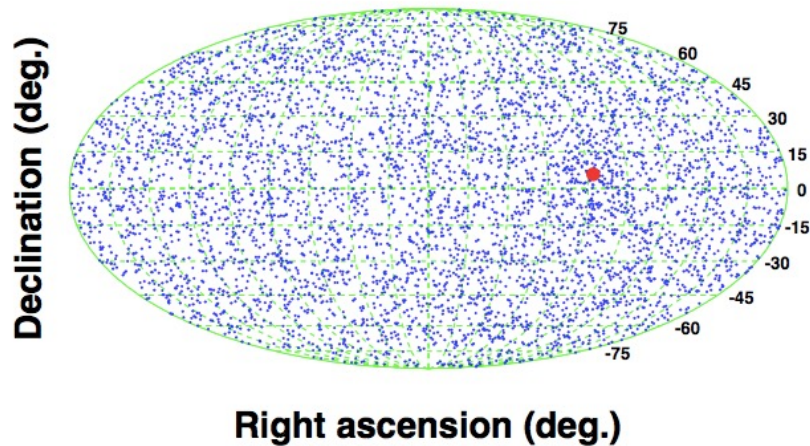


Energy (MeV)

Time (seconds)

Neutrino Pointing Approaches

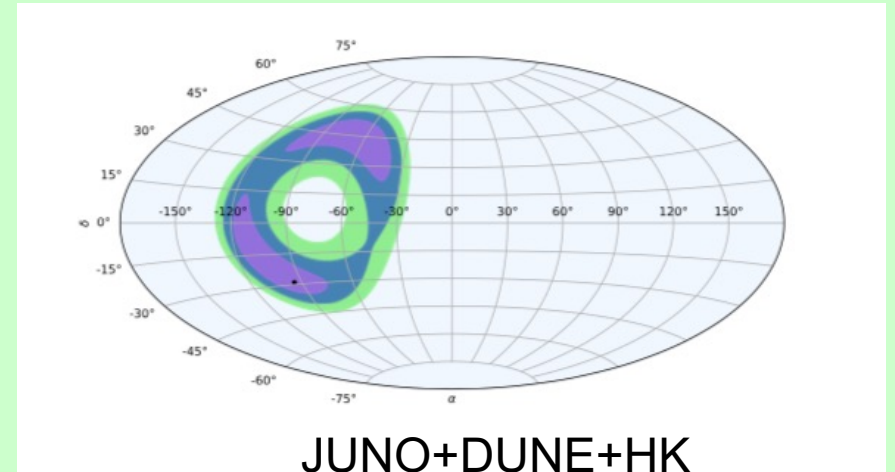
Anisotropic interactions



$$\sim \frac{25^\circ}{\sqrt{N}}$$

Likely best using
some detectors (currently, SK)

Triangulation from timing



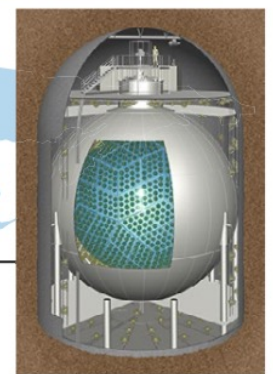
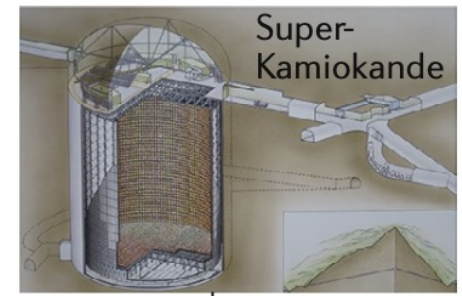
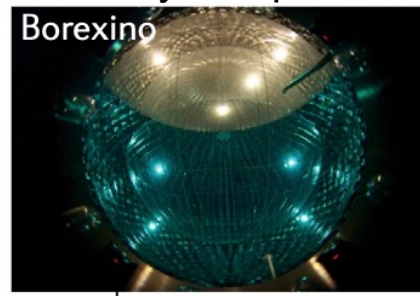
N. Linzer, KS: [arXiv:1909/03151](https://arxiv.org/abs/1909.03151)

Lower quality, but can
probably get very low latency,
with subsequent improvements

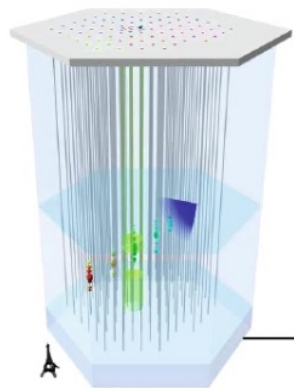
The Supernova Early Warning System 1.0



recently completed



IceCube



snews.bnl.gov

+KM3NeT, SNO+
+ NOvA, XENON

recently completed

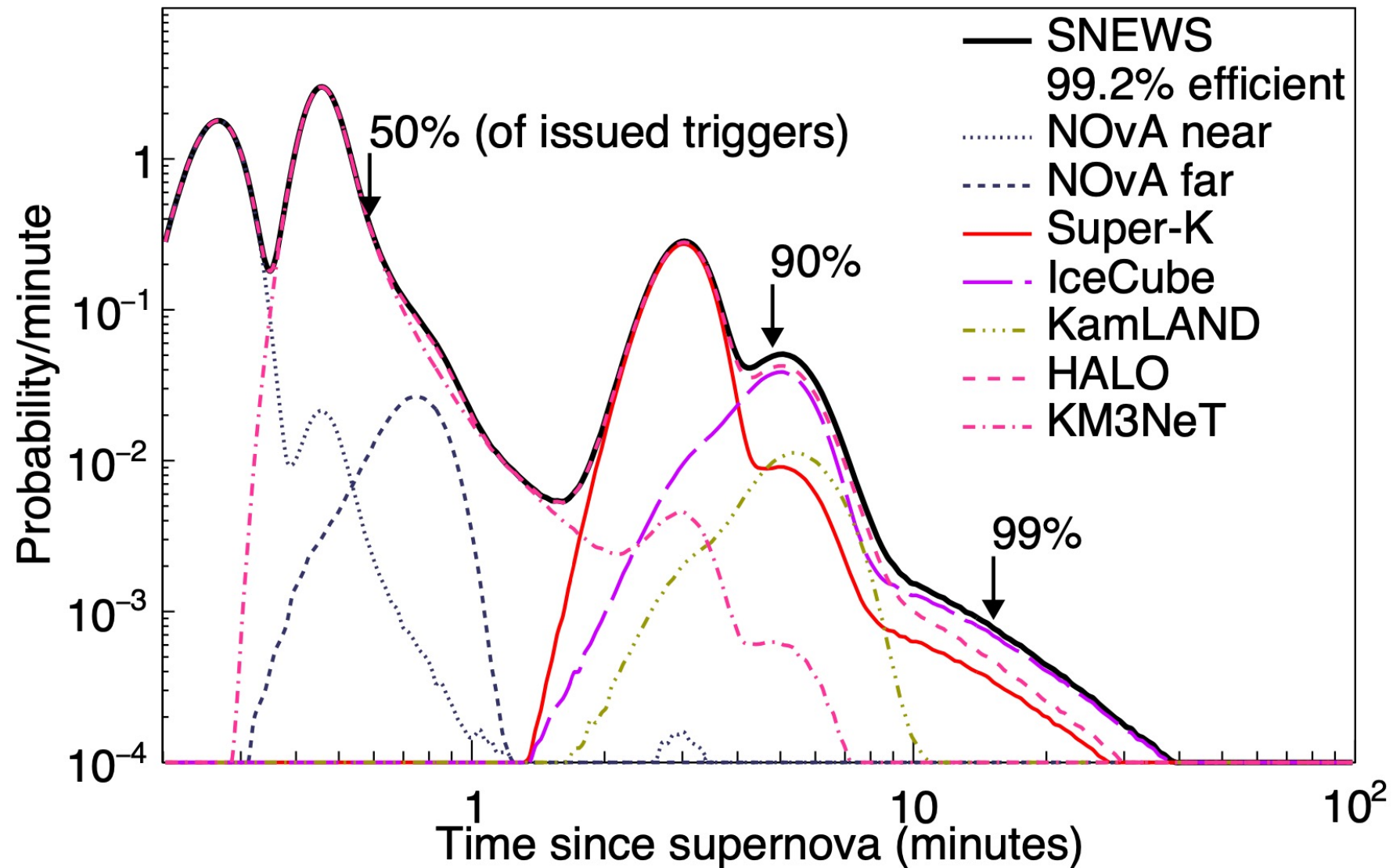


Nature Reviews

Simple 10-sec coincidence → email alert + socket connection +GCN
Running in automated mode since 2005 (no nearby CCSNe...)

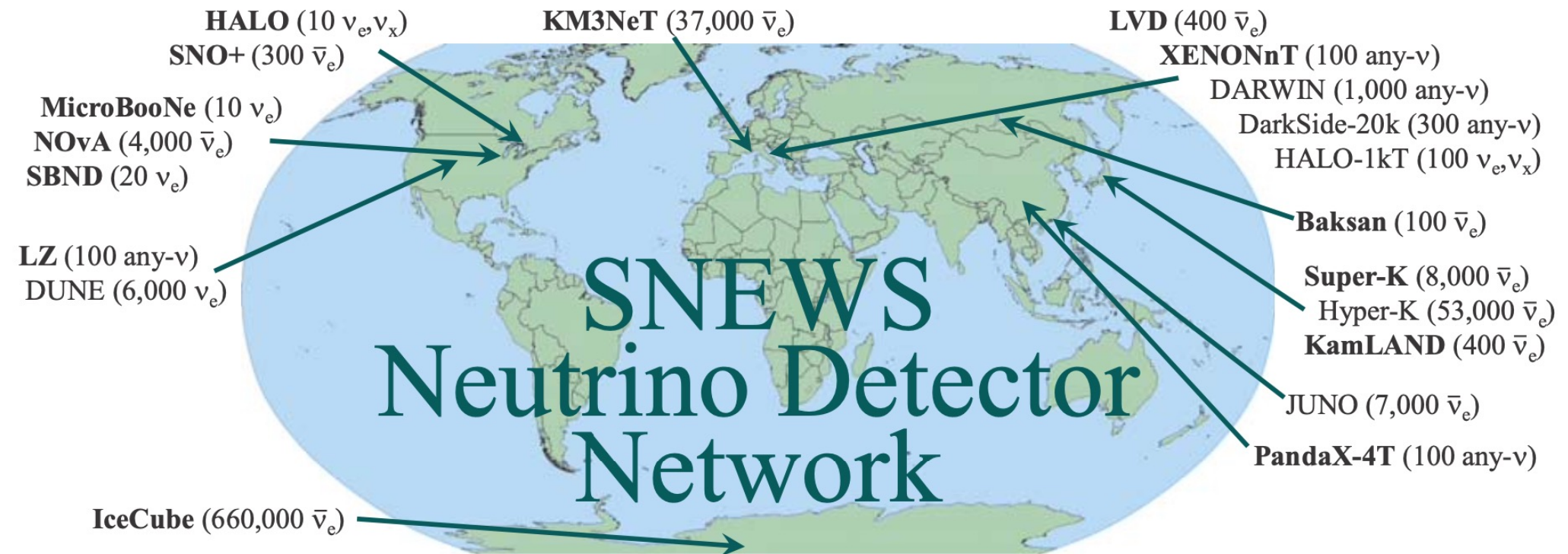
SNEWS Alert Latency

From A. Habig, M. Strait



(will improve with SNEWS 2.0)

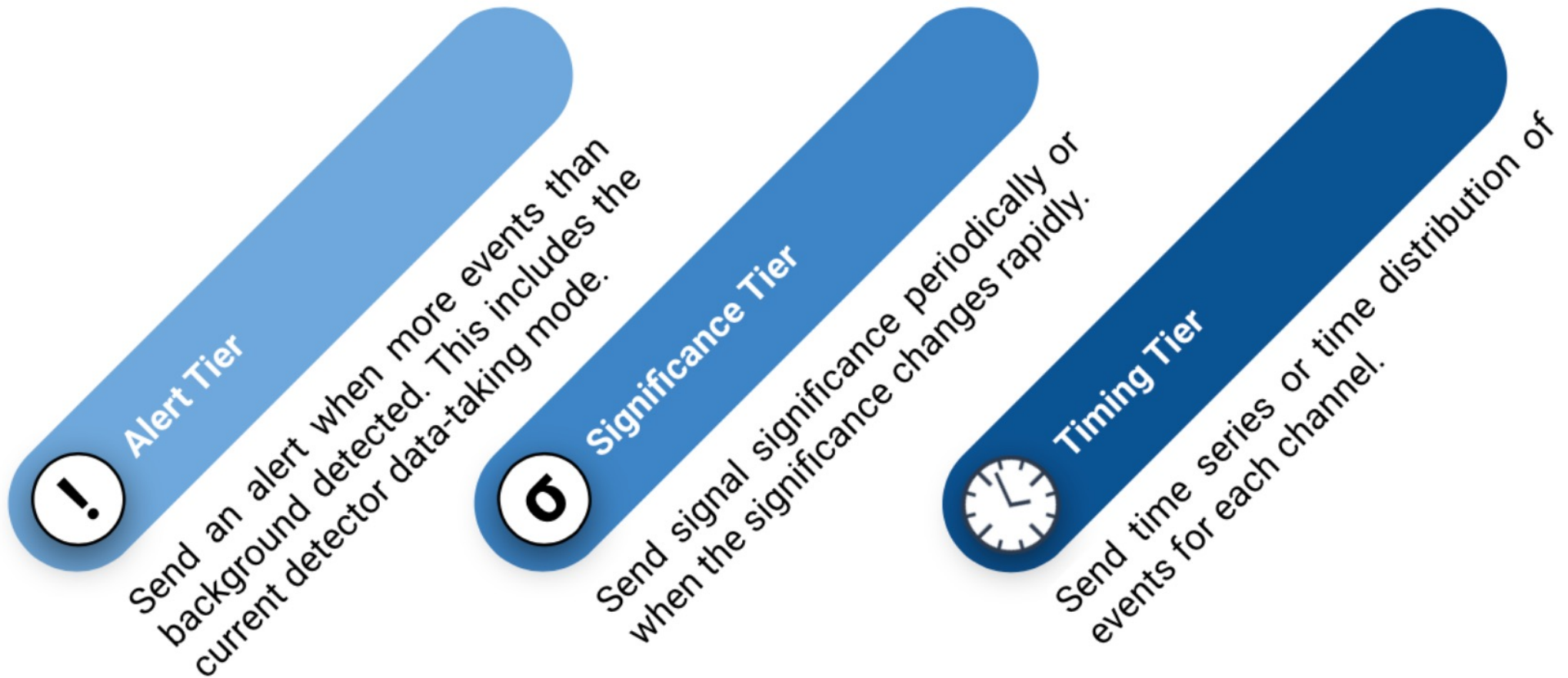
Current effort: upgrade to **SNEWS 2.0**



- improved latency
- neutrino-based pointing, including triangulation
- "fire drills"
- presupernova

snews2.org

Real-time alerts and followup



Collaborating with:
SCIMMA (using Hopskotch) (Baxter et al., CoRR, abs/2101.07779)
AMON
AAVSO, GRANDMA

WUN2K (What You Need To Know)

Core-collapse neutrinos

- ~10 second prompt burst of all flavors, few tens of MeV

Current & near future detectors:

- ~Galactic sensitivity
(SK reaches barely to Andromeda)
- can get some pointing from neutrinos
- SNEWS 1.0 network is waiting,
SNEWS 2.0 in near future

Long term future

- huge statistics: extragalactic reach
- richer flavor sensitivity (e.g. ν_e in LAr!)
- multimessenger prospects