SNEWS2.0 :
A SuperNova Early Warning System for the Multi-Messenger Era

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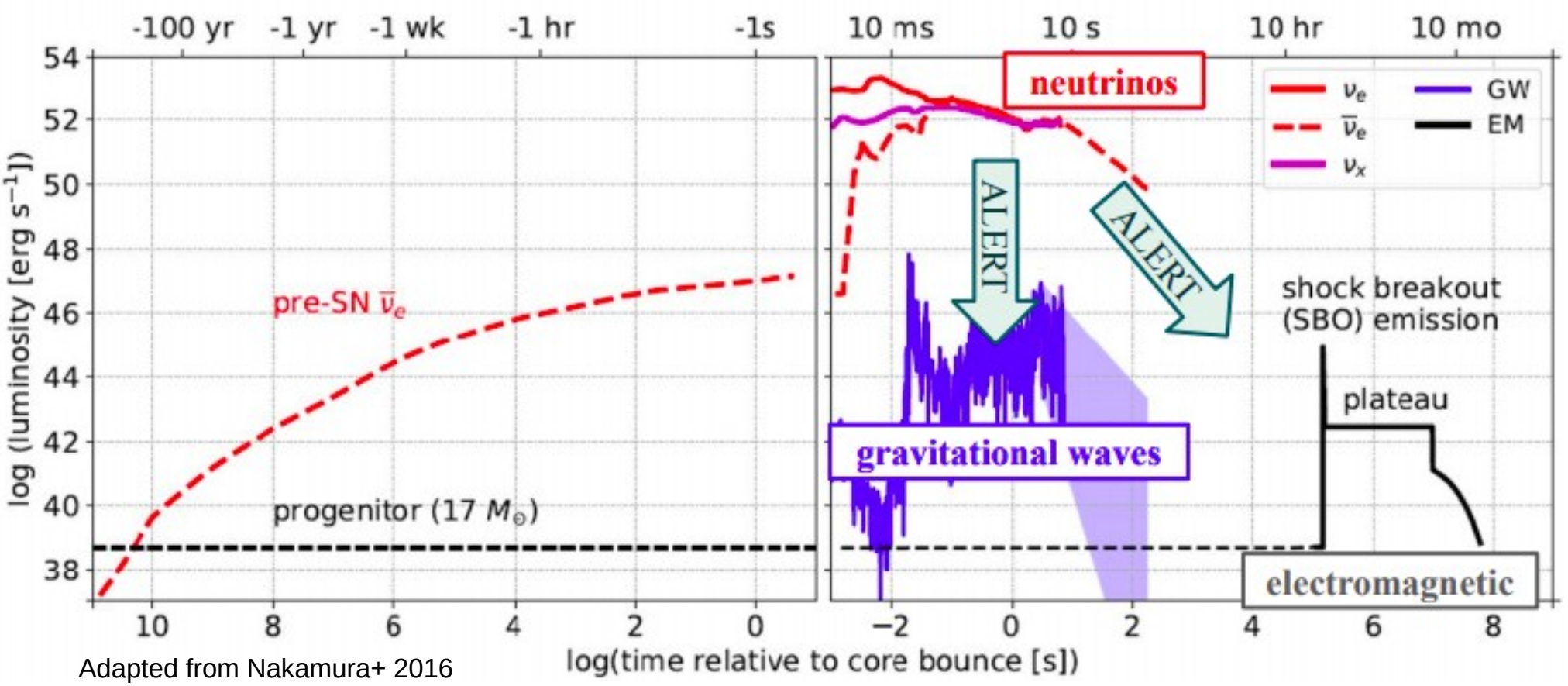
On behalf of the SNEWS Collaboration

Core-Collapse Supernova Multi-Messenger signal



Adapted from Nakamura+ 2016

- Next nearby CCSN will produce neutrinos, GWs and **EM** radiation
- Neutrinos will act as an early alert for the multi-messenger follow-up

Why/what SNEWS?

Unique insights into astro-, particle and nuclear physics under extreme conditions → Extract as much multi-messenger information as possible!

But… the expected rate of CCSN in the Milky Way is ~1.5 per century
→ **We need to be prepared!**

- Bring all neutrino detectors together → search coincident signal
- Coordination with the different EM telescope networks, GW detectors and amateur astronomers
- Early and continuous monitoring is crucial

SNEWS
SUPERNOVA EARLY WARNING SYSTEM

The goals of SNEWS

SNEWS1.0 has been guided by “the three P’s”:

- **Prompt:** provide an alert within < 1 h timescale
- **Positive**: false alert rate < 1 per century
- **Pointing**: provide supernova localisation
  (pointing not included in SNEWS1.0 alerts)

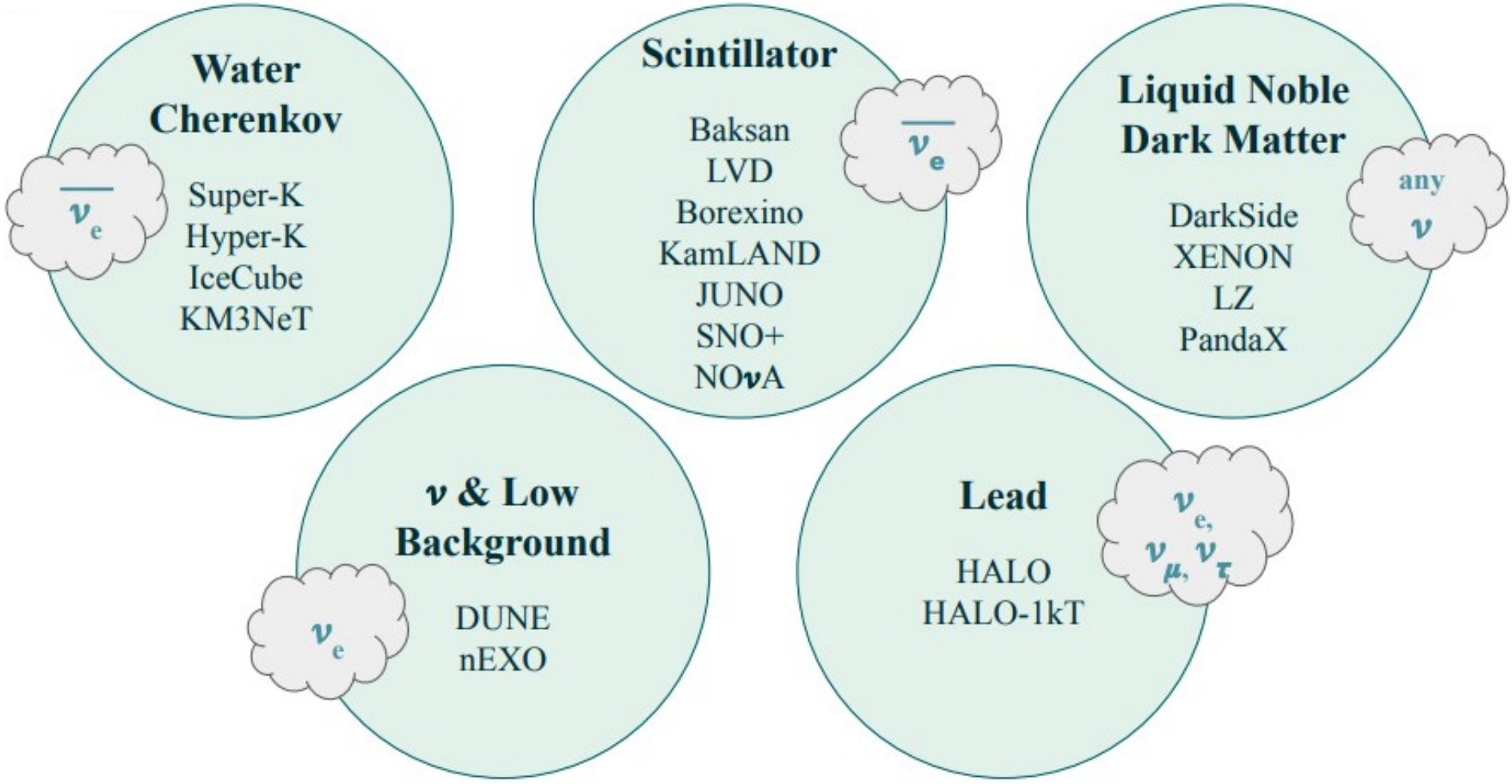
Prompt and automated alert system.

Positive signal (low FAR)

Triangulation using multiple neutrino experiments.

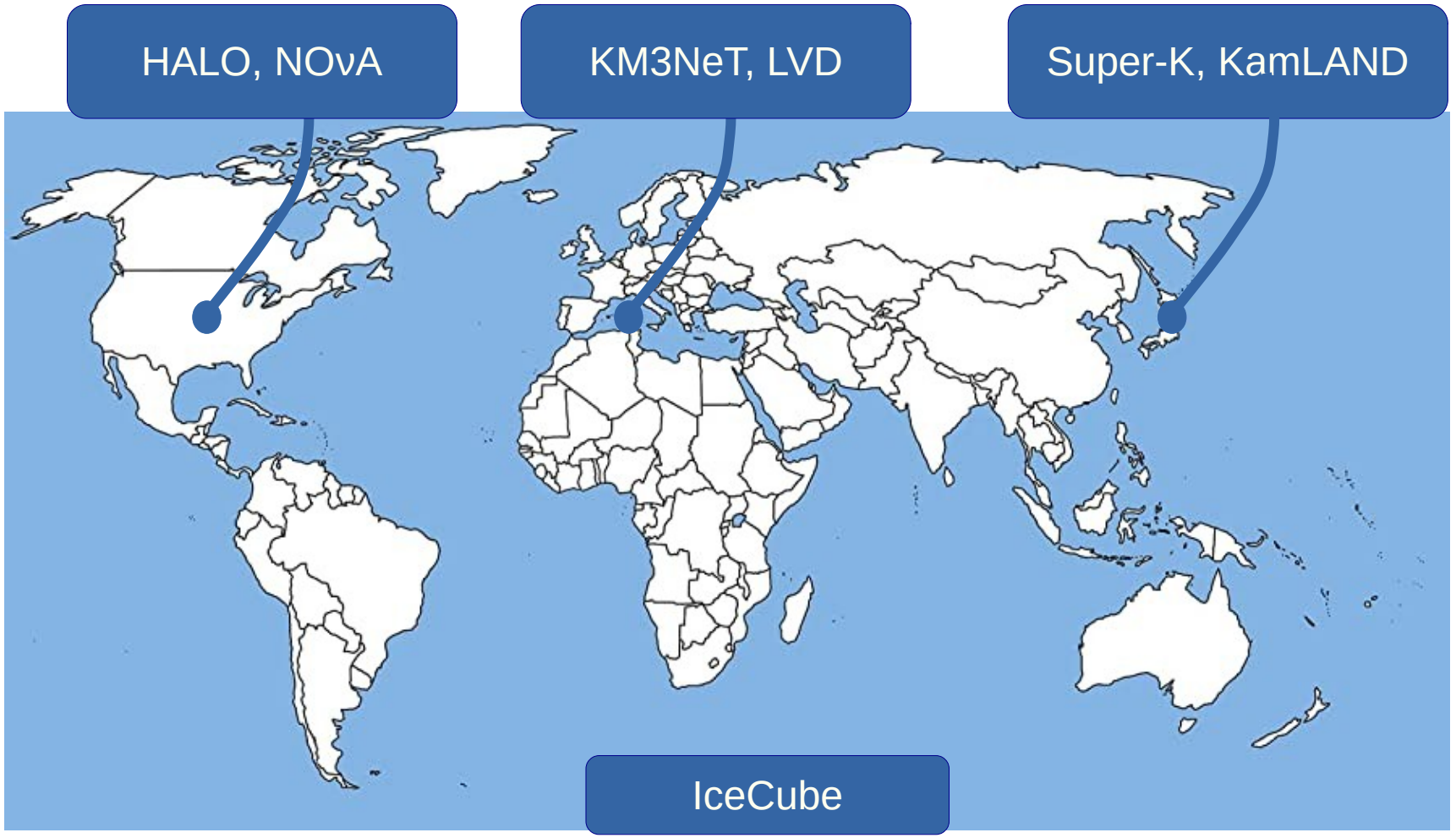
The goals of SNEWS

- Combining different detector triggers in real time allows for a positive and prompt alert + measuring the different flavor neutrino emission



SNEWS1.0

- Operating in automated mode for almost 20 years
- Currently: 7 detectors send alerts to the network

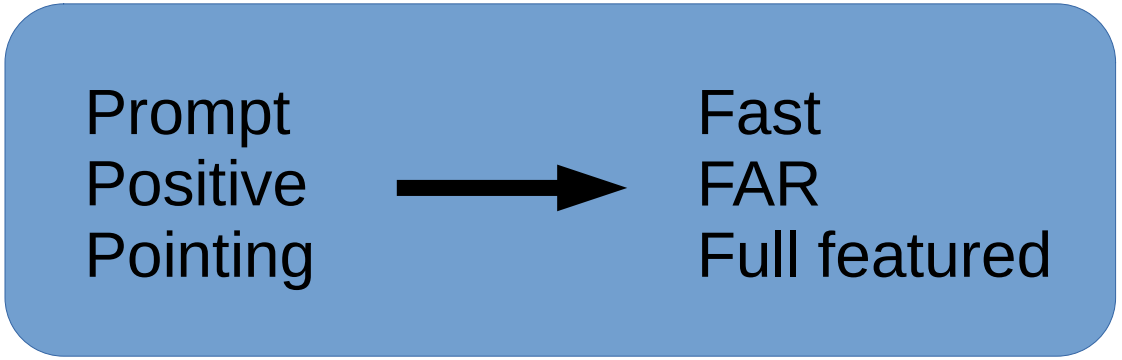


SNEWS1.0 → SNEWS2.0

→ Since 2019: Re-imagine SNEWS for today's new age of multi-messenger astronomy:
No more need to avoid false positives at all costs, we want to extract as much information as possible!

- Basic implementation almost complete
- Negotiating MoUs with experiments
- Regular "fire drills" (test alerts) already taking place

→ Move from "3P's" to "3F's" of a good alert:

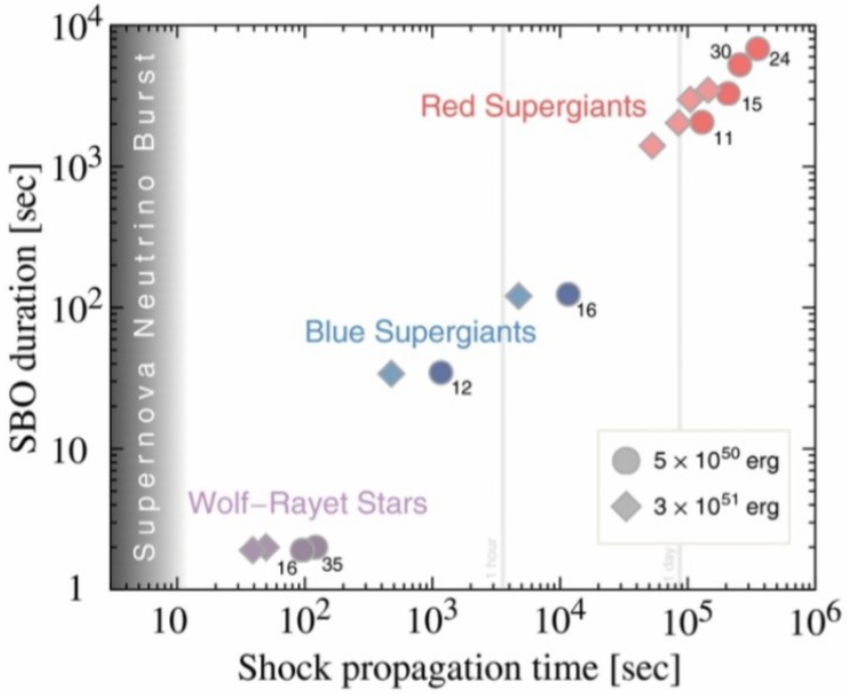


Why “Fast”?

- Neutrinos are emitted few-minutes to few-days before EM signal
  → **Telescopes might miss the EM signal otherwise**
  (bad conditions, not observing at the right moment, etc)
- Neutrinos are emitted together with gravitational waves
  → **Detection of GW counterpart difficult without neutrino alert**

Successful follow-up = rich physics outcome

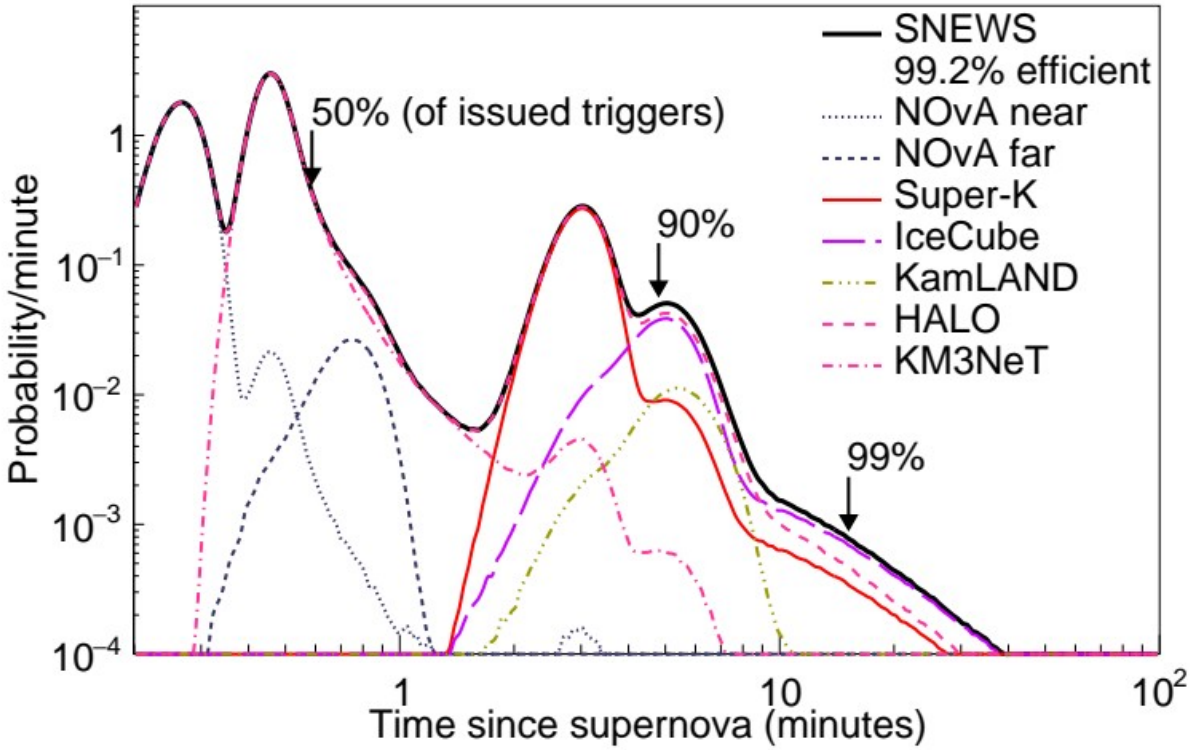
- Recording of the shock breakout (SBO): progenitor nature
- Identification of GW signal: additional physics



“Fast” alerts in SNEWS2.0

Lower latency:

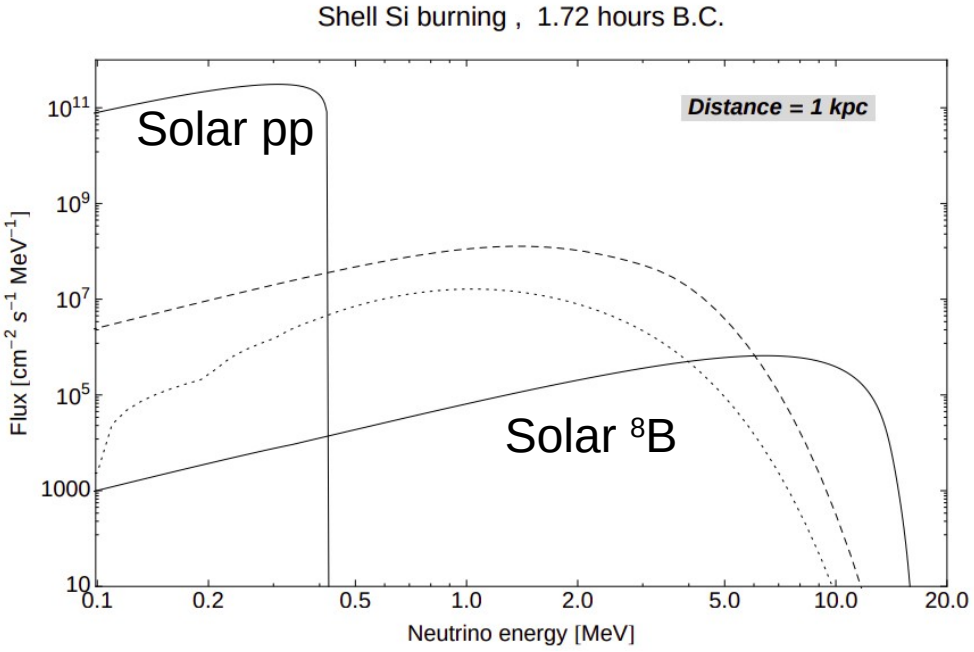
- More flexible SNEWS policy
- DAQ design of individual experiments is important



- Most current SNEWS experiments latency *O*(minutes)
- Expected server latency *O*(seconds)
- Improvement possible for various detectors in SNEWS2.0

“Fast”: Pre-supernova

- Neutrino emission previous to the explosion (during Si burning phase) detectable hours to days before the stellar collapse
- **Advance notice for neutrino and GW detectors → Fast response!**
- Difficult detection due to low-luminosity, low mean neutrino energy and longer time window of pre-supernova emission
- Low-background detectors can detect such signal for close by CCSN events (≤ 1 kpc) → KamLAND already shares significance alerts



“FAR”

When SNEWS started... only positive alerts (FAR < 1 in 100 years)

Now… it is fine to send out uncertain alerts if false alarm rate is included → GW alerts have been the best example of it

→ Allowing higher FAR enables to increase the distance horizon and the sensitivity to exotic transients

→ Astronomers can set their own FAR threshold

“Full featured”?

→ Provide as much additional information as possible for best follow-up strategy and physics outcome:

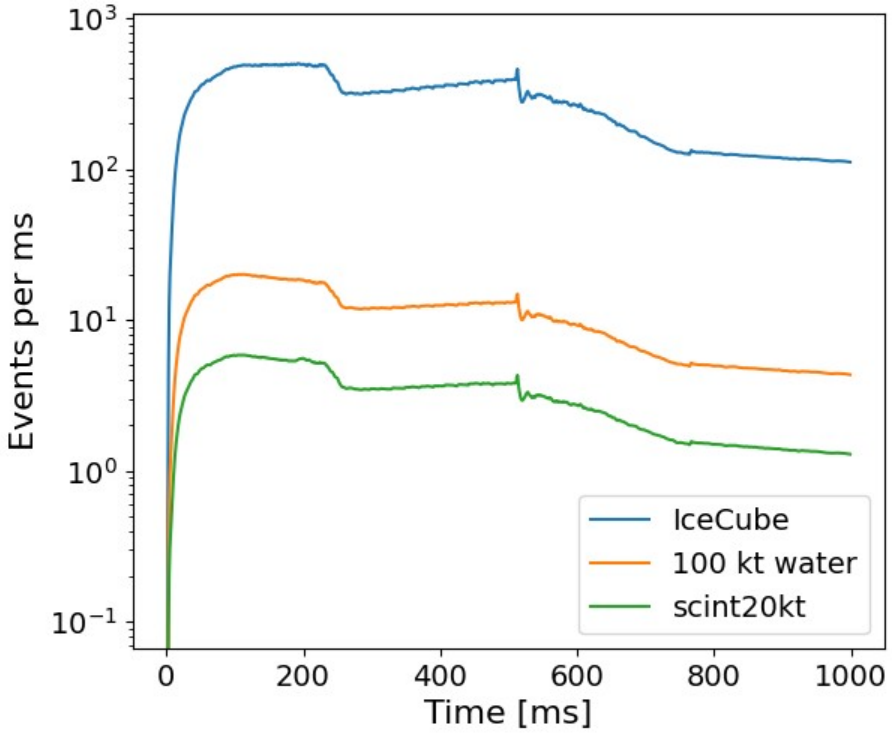
- Timing of neutrino signal
- Pointing (from the “3P’s”) → See talks by Kate and Jeff!
- Distance
- Type of event:
  - Sudden cut-off in ν signal can indicate black hole formation
  - Identify non-core-collapse events? (SN Ia, PISN, binary merger…)
  - Secondary bursts?
  - ...

  which others?

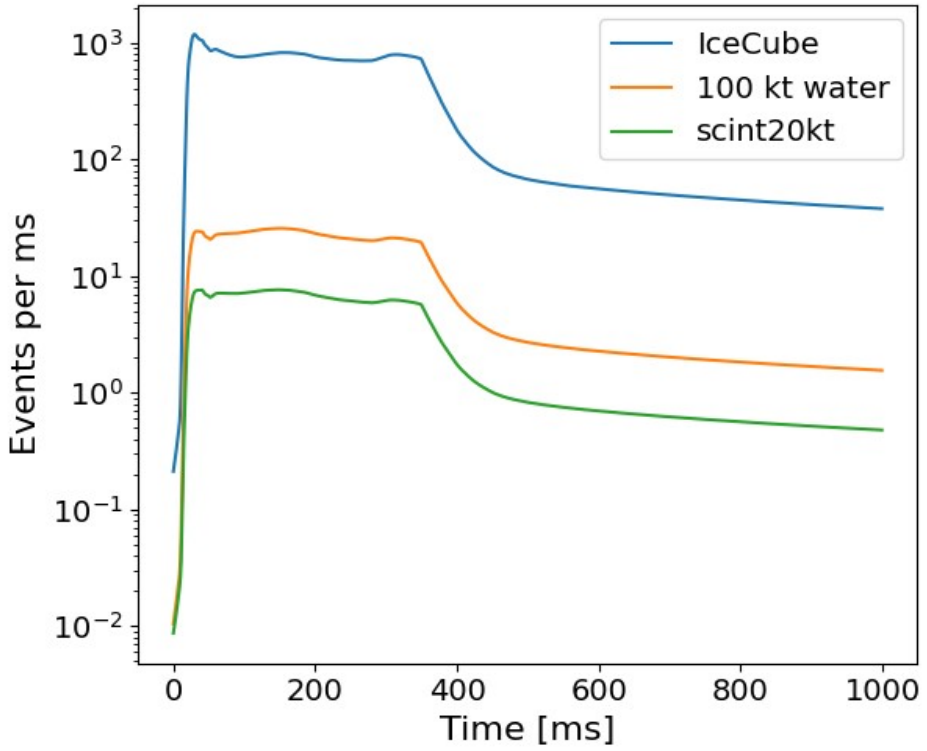
“Full featured”: Timing

➔ Neutrino time profile brings information on the CCSN physics (and about the models)

MODEL 1, progenitor 1



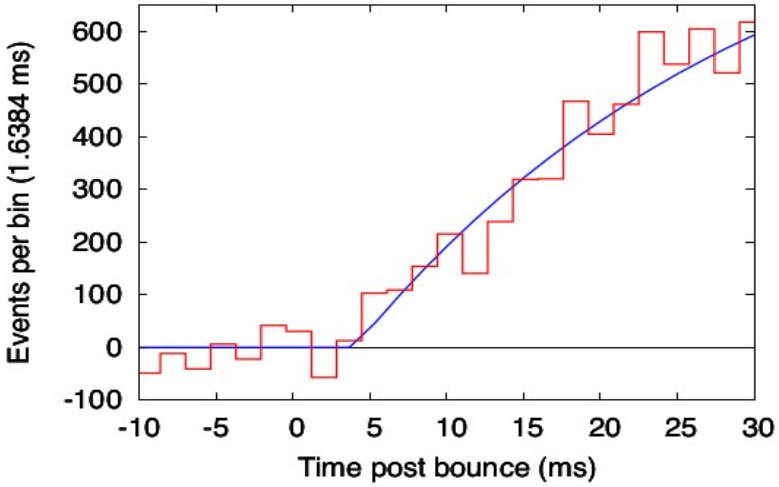
MODEL 2, progenitor 2



(Example using *snewpy*: https://github.com/SNEWS2/snewpy *and snowglobes https://github.com/SNOwGLoBES/snowglobes software*)

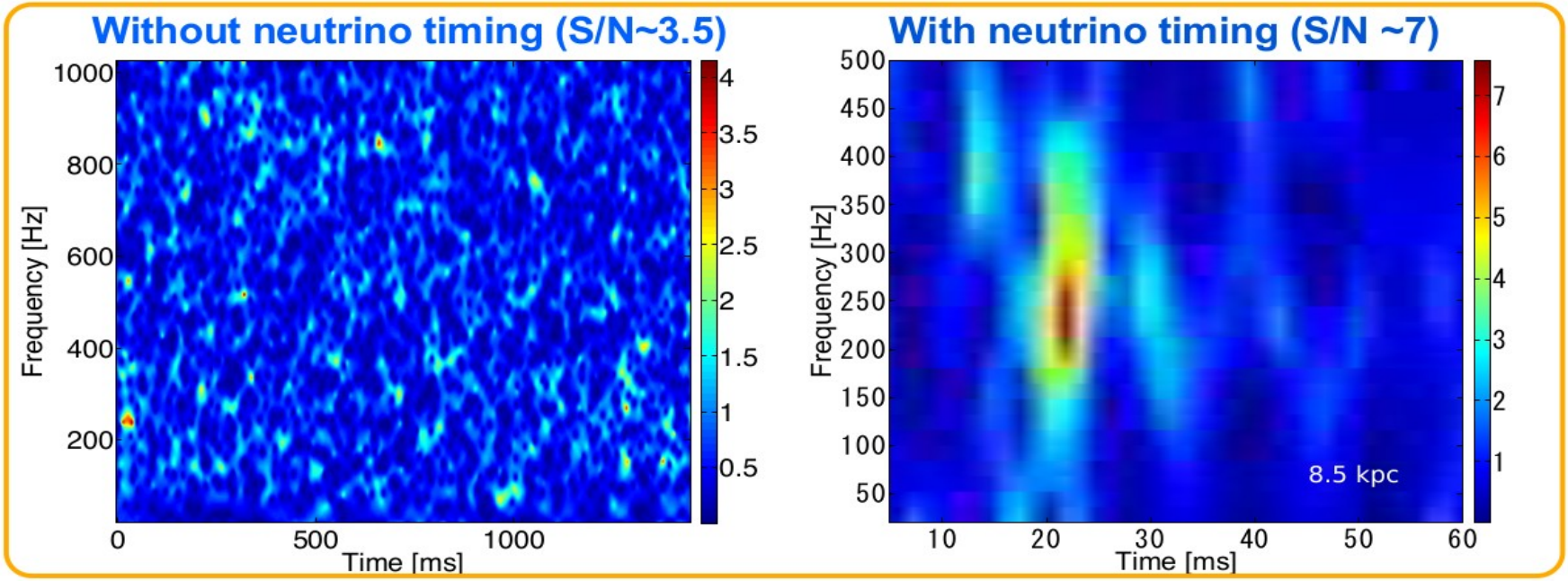
“Full featured”: Timing

- Allows to define the time window for the GW signal search



Probe core bounce time with neutrinos.

Timing for gravitational wave detection.



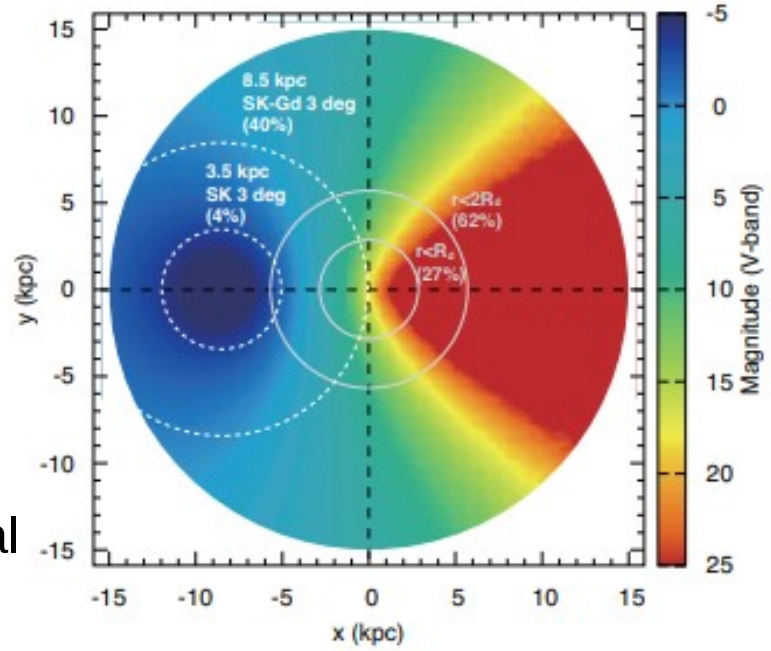
Pagliaroli+, PRL (2009), Halzen+ PRD (2009), Nakamura+, MNRAS (2016)

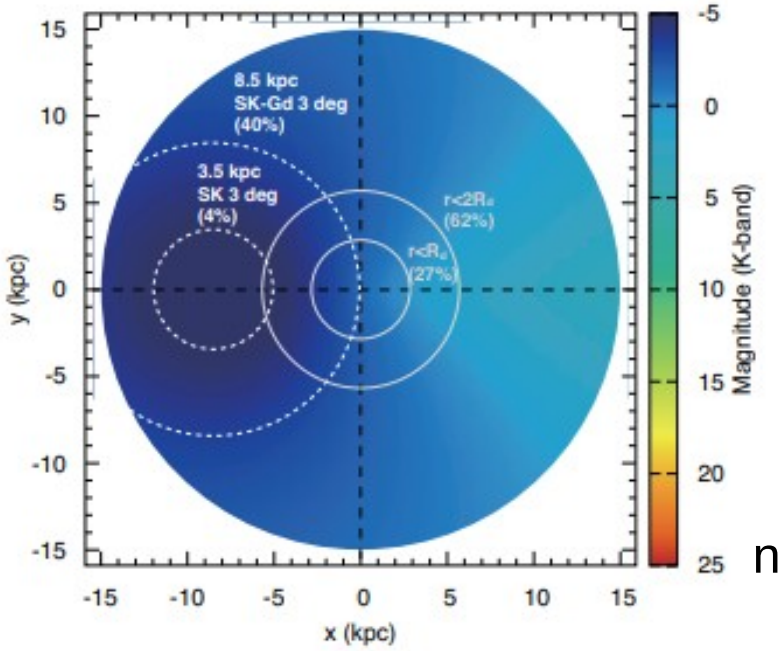
“Full featured”: Distance

- The source luminosity at different wavelengths depends on the distance
  → may affect the optimal observation strategy
- A lot of background light for Galactic source and dust obscuration near Galactic Center complicates the EM detection
- If close-by event, direction may let us create “shortlist” of candidate stars

→ Distance can be inferred using the detected neutrino event rate

optical



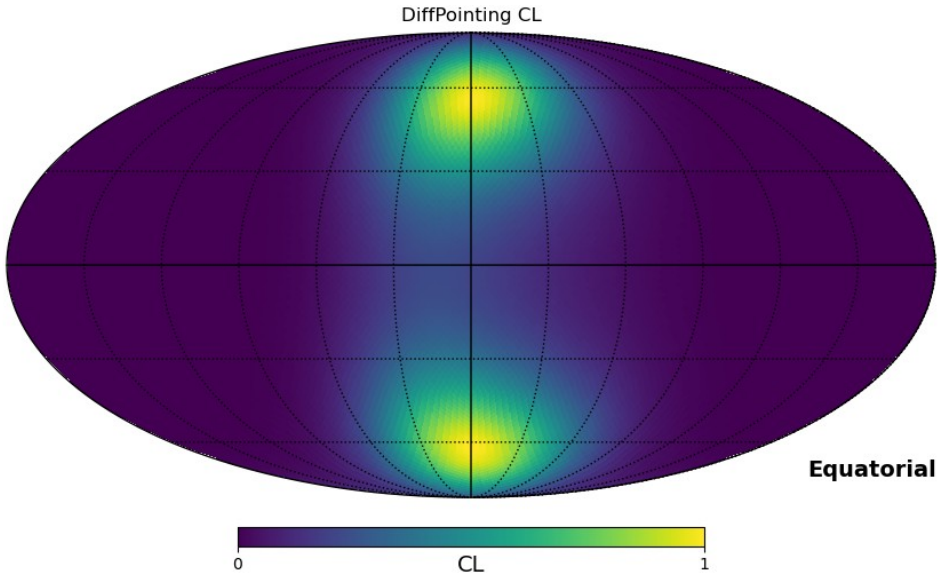


near IR

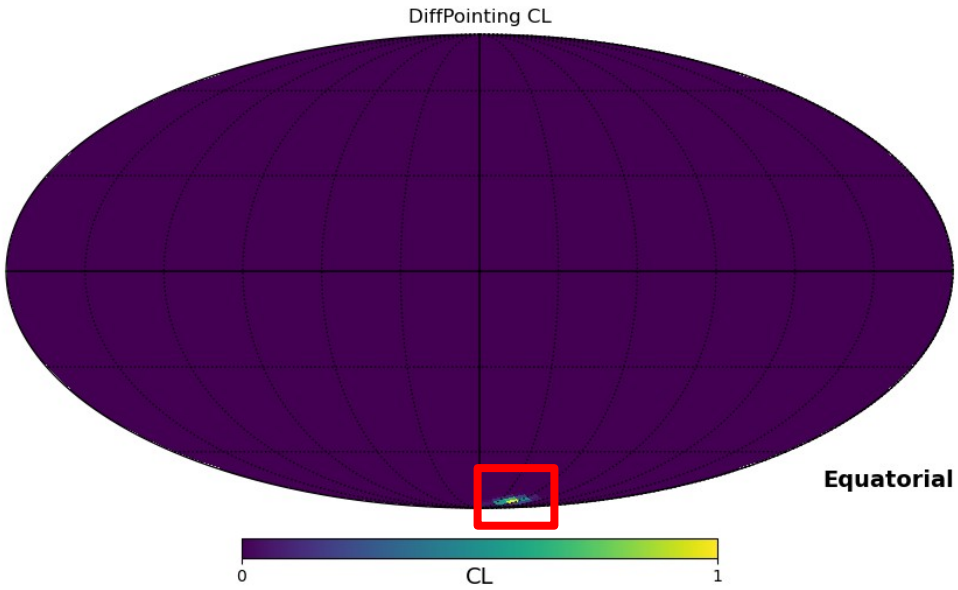
“Full featured”: Pointing

- Fast + Pointing = triangulation method (covered by Jeff later)
- First basic triangulation algorithm implemented in SNEWS
- Calculation and connection with the coincidence server has been tested in a distributed mock data challenge (fire drill):

Xenon + KamLAND + MicroBoone



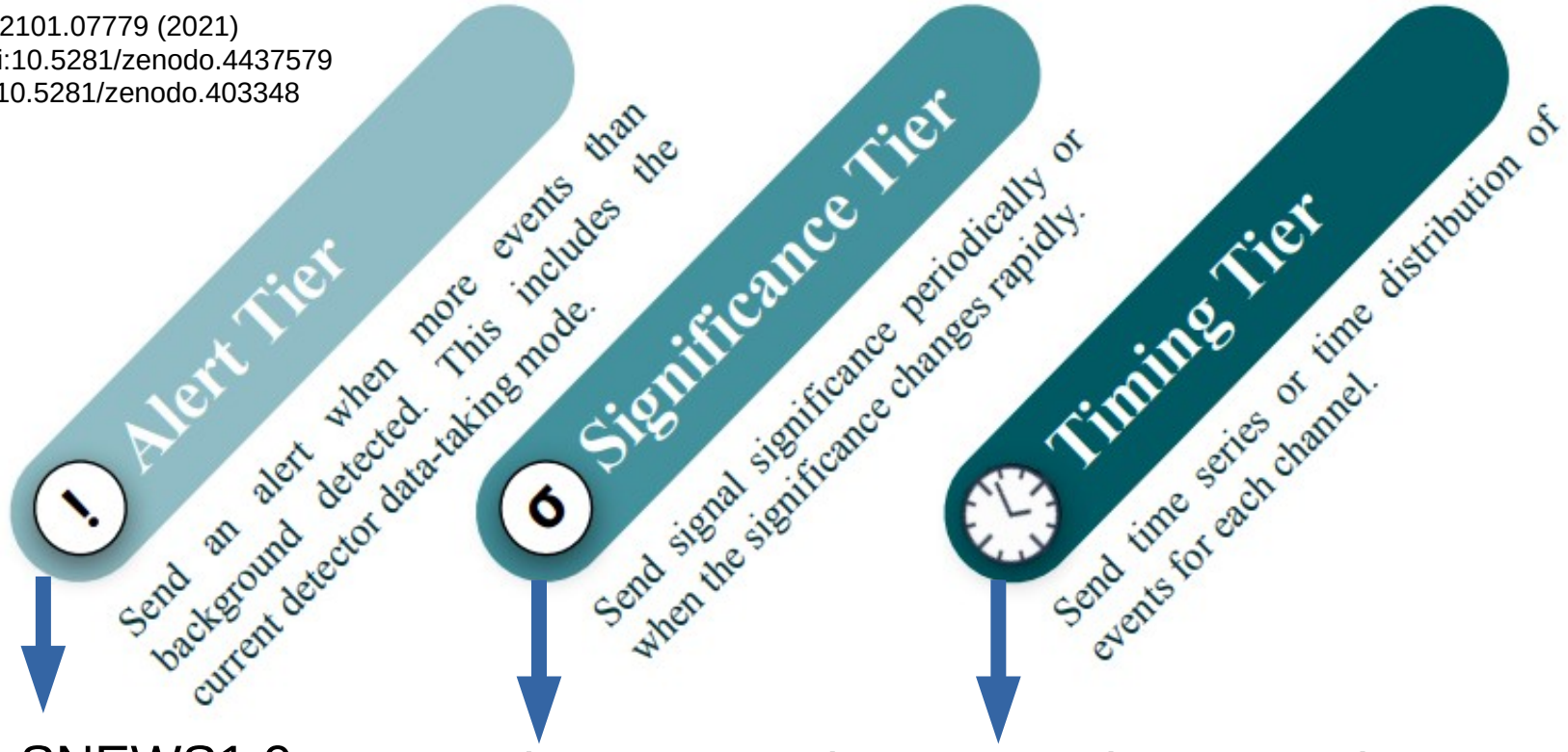
Xenon + KamLAND + MicroBoone
+ NovA + IceCube



SNEWS2.0: processing data

- Continuous data stream from detectors to SNEWS server → alert decision
- Infrastructure for message coordination and interfacing with clients
- Data exchange system relies on HOPSKOTCH (developed within SciMMA)
- Experiments can choose which degree of data they want to share and when

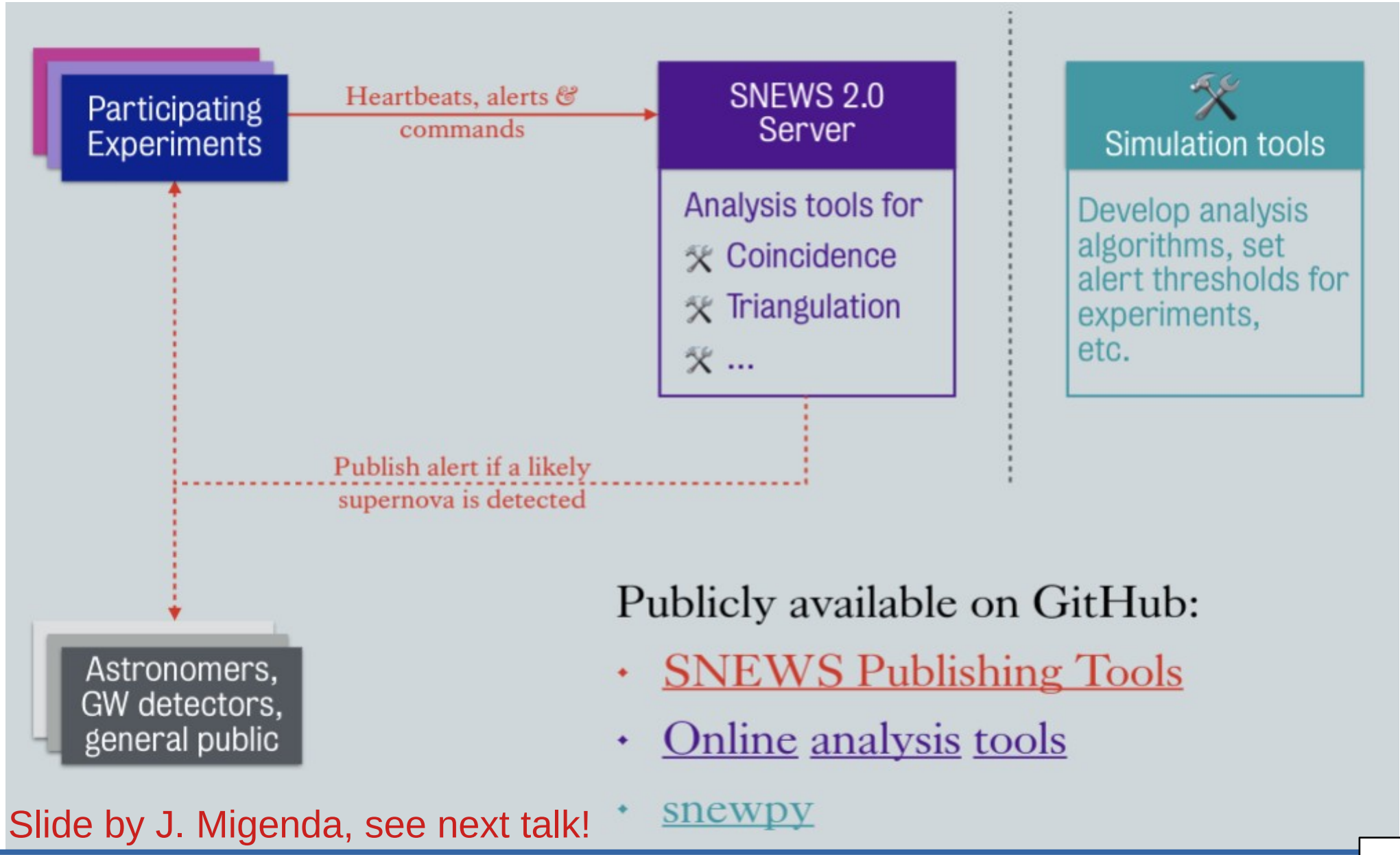
A.L Baxter+ arXiv:2101.07779 (2021)
SNEWS app→ doi:10.5281/zenodo.4437579
Hopskotch→ doi: 10.5281/zenodo.403348



Effectively SNEWS1.0

Experiments can share more data to enable new features

The SNEWS2.0 software



Slide by J. Migenda, see next talk!

“Follow-up” in the multi-messenger era

- In 2000: ATel & GCN started distributing alerts
  - Human-readable, unstructured, via mailing list
  - Good strategy for SNEWS 1.0
- Today: ~10^7 alerts per day
  - Specialized brokers distribute & filter alerts
  - Large degree of automation
  - Many robotic & fully automated telescopes

➔ SNEWS can bring neutrino & astronomy communities together to prepare follow-up strategy

→ Ensure maximal science output

Who "Follows-up" SNEWS?

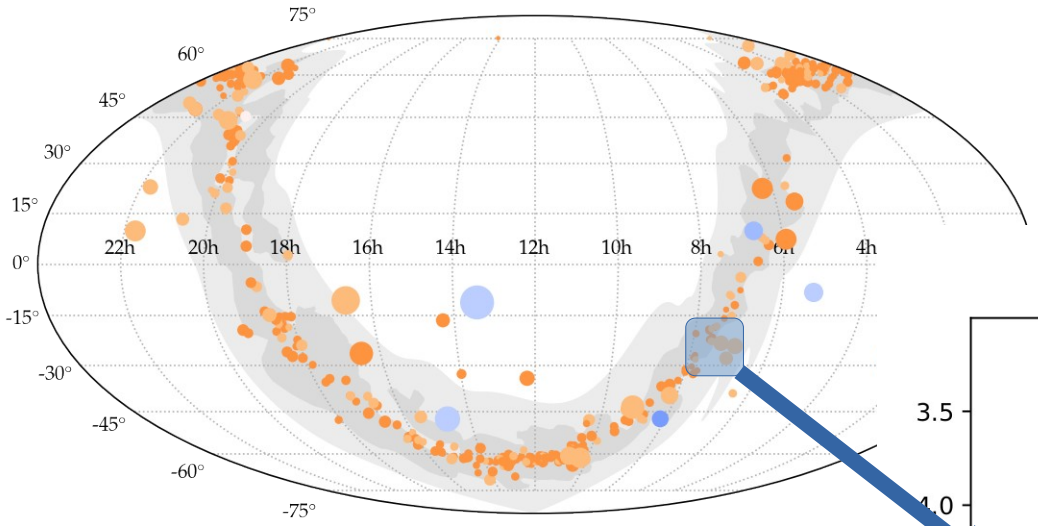
SNEWS meets the Astronomy Community

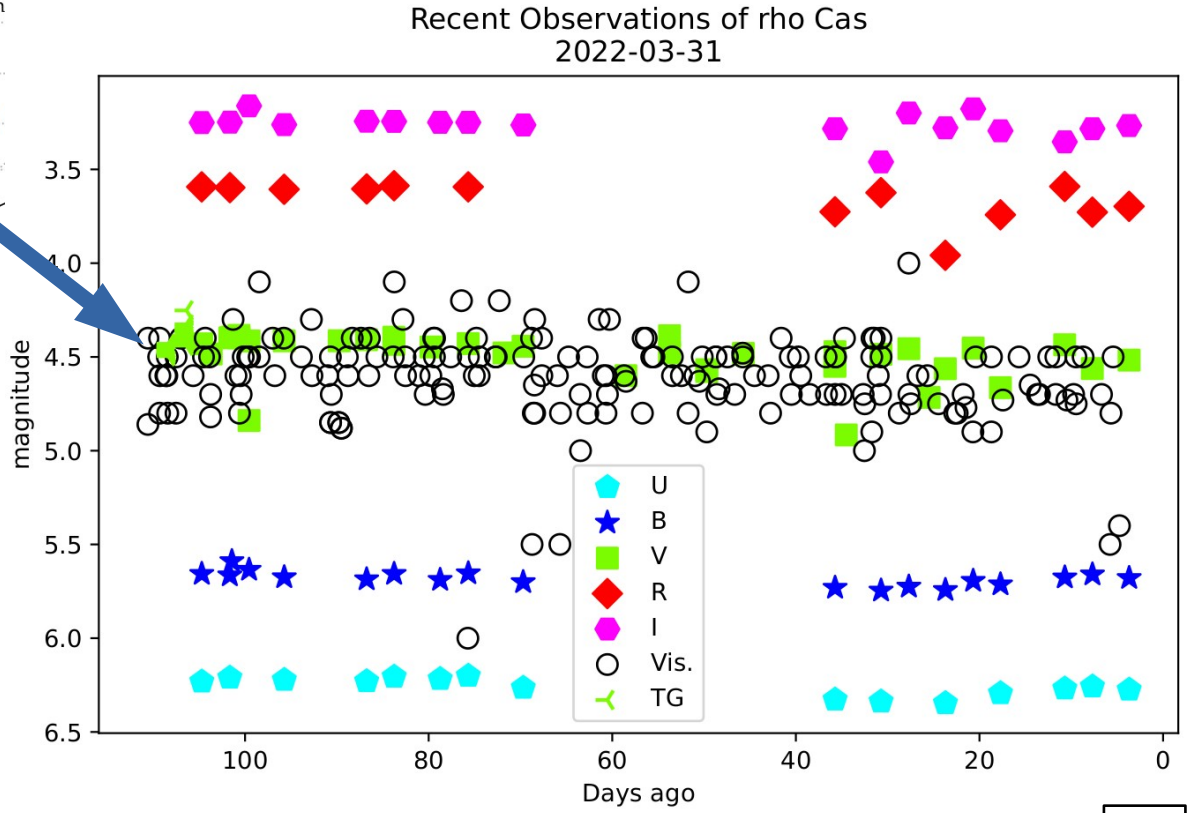
- GRANDMA (Global Rapid Advanced Network Devoted to the Multi-messenger Addicts, arXiv:2008.03962) → See talk by A. Coleiro
  - Coordinates telescope observations of transient sources with large localization uncertainties
- AAVSO (American Association of Variable Star Observers, aavso.org)
  - Network of amateur astronomers: often more flexible, large database, can send out alerts with observation requests to member
- REFITT (Recommender Engine for Intelligent Transient Tracking, arXiv:2003.08943)
  - AI-based engine to plan & coordinate follow-up taking into account available facilities (wavelengths, sensitivity, current weather, ...)

... and more!

First “Follow-up” campaign

AAVSO started campaign to regularly observe SN candidate list





Summary

- A core-collapse will produce neutrinos with GWs, and before EM radiation
  → Early warning to identify the multi-messenger signals
- SNEWS2.0 will have a larger network of neutrino detectors, with more than 15 experiments simultaneously taking data
- With SNEWS2.0, the scientific reach of the observations will be maximized
- SNEWS2.0 will help coordinating the efforts for a global multi-messenger follow-up of the next CCSN explosion
- First fire drills have taken place and we learned a lot from them