The Supernova Early Warning System (SNEWS) 2.0: a galactic SN alert in the era of Multi-Messenger Astronomy

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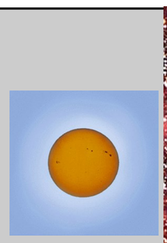
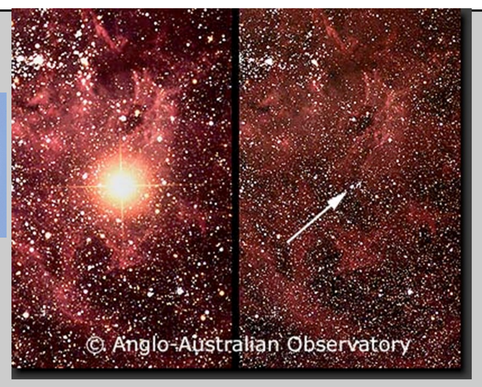
The original SNEWS

The SuperNova Early Warning System

A star is opaque to photons (*the definition of a photosphere*!) but transparent to ν: thus, the ν signal will lead the photon signal by ~hours, the time it takes the shock to cross the stellar radius: Early Warning of galactic fireworks from ν!





SN 1987A: a close enough core-collapse SN that neutrino experiments identified tens of neutrinos in their data after the initial optical discovery, confirming how Type II SN work.

To allow for a quick (*human-free*) alarm, neutrino experiments automatically send any Supernova triggers via custom SSL sockets to a central coincidence server. A real SN neutrino front will show up in more than one detector but noise will not: an automated alarm is issued in the form of PGP-signed "Supernova alarm" emails.

SNEWS was born in 1998, became operational in test mode in 2001, and has been fully operational since 2005. Still going!

But, there have been no nearby (r ~<50kpc) supernovae in that time.
(We expect 1-2 per century in our galaxy)

Other Multimessenger successes have changed astrophysics since SNEWS started:

- Bacodine/GCN followups ID "long/soft" GRBs as Hypernova (2003)
- IceCube UHE ν associated with Blazar flares (2017)
- LIGO/VIRGO GW coincidence IDs "short/hard" GRBs as colliding neutrino stars (2018)

Changed landscape: Transient Hunting is now A Thing

After GW170817 success, hundreds of GW, neutrino, and cosmic ray alerts published and followed up

→ People now expect lots of transients to chase, and aren't upset if they all aren't real.

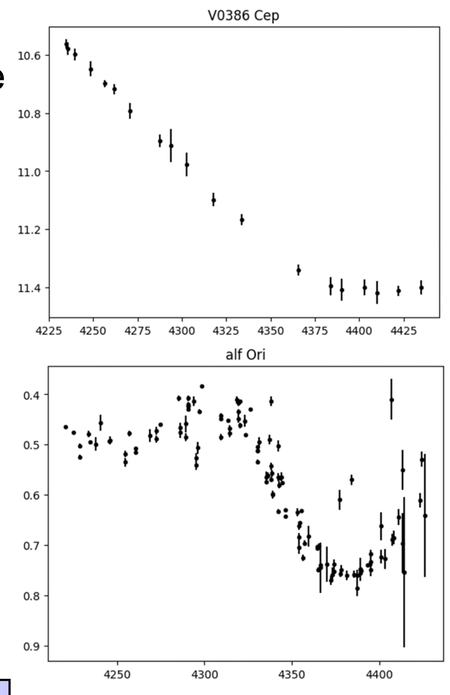
What can SNEWS do to make sure we learn as much as possible from the next galactic SN?

- Publish a fast alert to get eyes on the sky ASAP
- Figure out where the SN will appear on the sky
- Combine significances from marginal signals to increase sensitivity
- Publish less significant alarms: both "just in case" and to exercise the system
- Provide t_0 to GW antennae to help them isolate SN GW signal

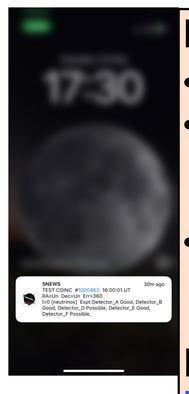
AAVSO Progenitor Campaign

- Monitor nearby progenitors so we have a baseline on what things looked like before something goes boom
- Establish working collaboration with people who will help find the eventual real SN
- The 192 brightest (< *10 mag*) nearby potential progenitors:
  - 74 now have more than 10 observations
  - 7107 total observations, 2241 in V

https://www.aavso.org/snews-campaign



AAVSO light curves in V for RSGs V0386 Cep and α Orionis



New infrastructure

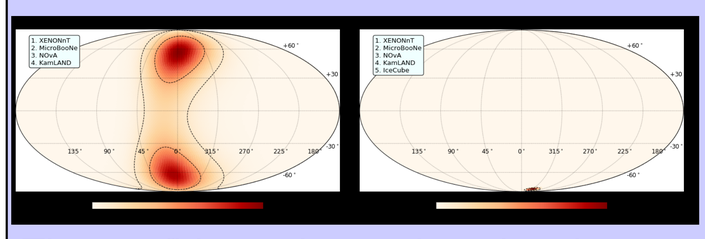
- Written in portable, maintainable Python
- Uses SCIMMA's kafka-based HOPSKOTCH network transport layer
  A.L. Baxter et al Software Pract.Exper. 52 (2022) 10, 2077-2096
- Automated observatories can subscribe: output plugins make it easily extensible for GCN, slack, email lists: even an iOS app!

Infrastructure, snewpy, and sntools code publicly available: https://github.com/SNEWS2

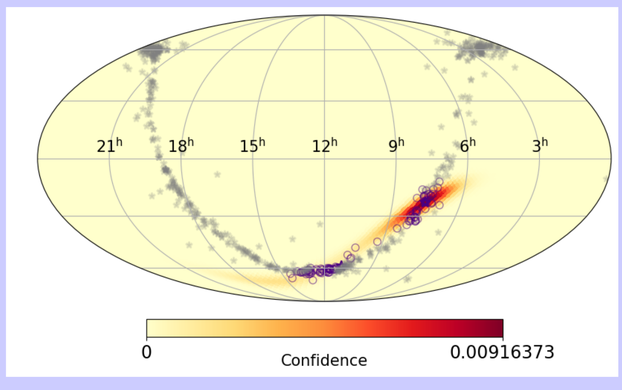
Paper describing this coming soon to arXiv

Pointing?

Individual water Cherenkov experiments can point to ~degrees with internal data analysis of ν→e scattering. Can a network help get direction faster from the arrival times of the SN ν wavefront?



The confidence interval on the sky from four smaller experiments (L), then add IceCube's high stats (R) to really zoom in



What if Red Supergiant X-46 (*113°, -22°, 7.6kpc*) explodes and SNEWS points back towards it? 105 stars are within the 90% region, 3 match when comparing distance estimates from ν flux $1/r^2$. New catalog of 640 RSG potential progenitors, from
Healy et al, Mon.Not.Roy.Astron.Soc. 529 (2024)

Pre-SN combination

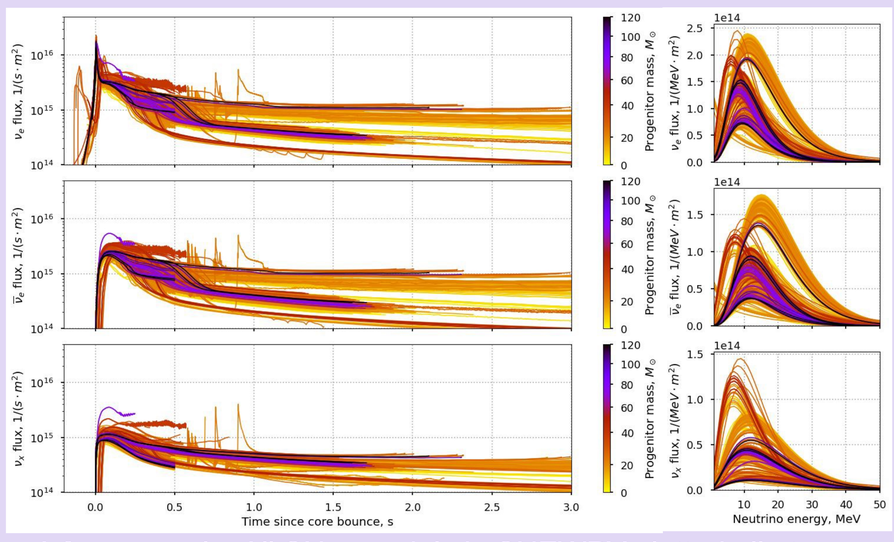
ν from the last stages of stellar evolution (O and Si shell burning) are low-energy but could give ~days warning for nearby progenitors. Currently, KamLAND and Super-K publish their candidate rate. JUNO, SNO+ and Hyper-K will also be sensitive. Low statistics means limited range (<1kpc): combining those signals would result in sensitivity to more stars. SNEWS could facilitate this.

Combining detector significances gets ~30% more range plus earlier detection for pre-SN ν.

Also can be used to combine CCSN significances from smaller experiments, but distance gained is just the void between MW and M31
A. Sheshukov et al JCAP 12 (2021) 12, 053

SNEWPY & sntools

- SNEWPY is a Python package that collects many supernova neutrino models into a uniform interface, uses SNOwGLoBES to convert ν fluence to what you'd see in a detector: *SNEWPY v2.0 coming soon!*
- Makes it easier for people to compare models
- Includes ν oscillations, MSW in SN, Earth, and shocks
- sntools generates MC events for your detector simulation
  A.L. Baxter et al Astrophys.J. 925 (2022) 2, 107
  A.L. Baxter et al J.Open Source Softw. 6 (2021) 67, 3772



A fun example: All SN ν models in SNEWPY plotted all at once

Summary:

By exchanging more information, neutrino experiments can enable:

- Better, faster pointing, try to ID potential progenitors
- Extended pre-SNe ν range
- "Fire Drills" on lower significance signals to test response
- Progenitor Monitoring campaign

SNEWS 2.0 is working towards these things.
Whitepaper is *Al Kharusi et al 2021 New J. Phys. 23 031201*

Status: replacement of OG SNEWS with new tools in beta testing, will keep running OG SNEWS in parallel for now

Sign up for an alert yourself here:

https://snews2.org

This Poster supported by NSF Grant #2209534 WoU-MMA: Collaborative Research: Advancing the SuperNova Early Warning System