Presupernova neutrinos: experiments and dicussion

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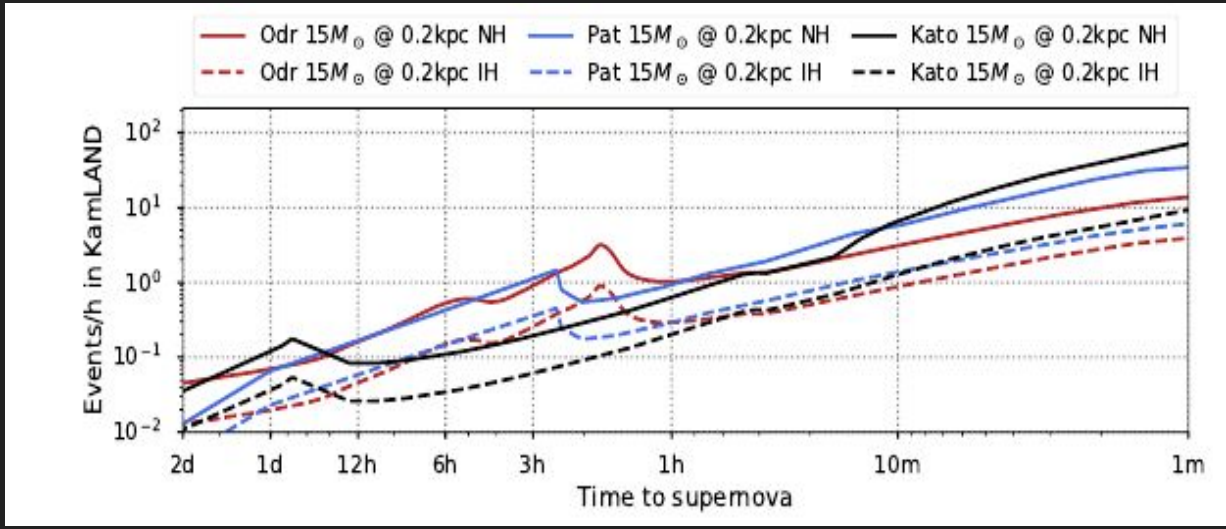
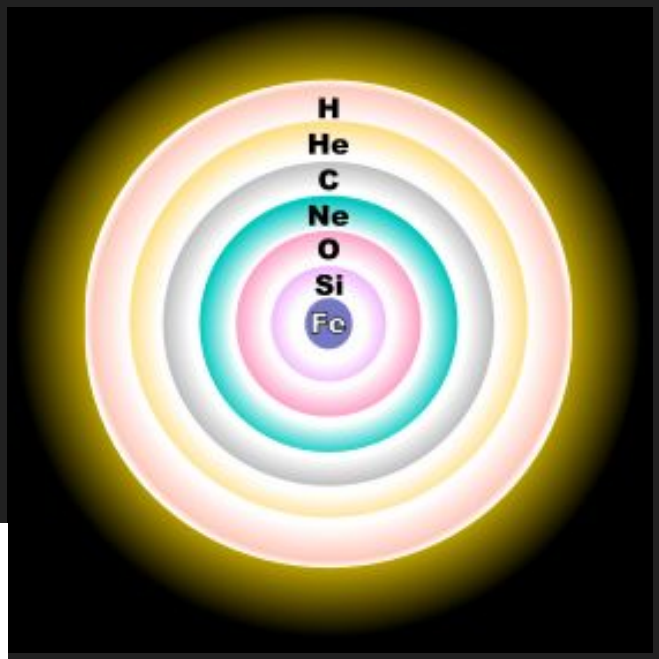
Pre-supernova neutrinos

Core-burning nuclear fusion stages for a 25-solar mass star					
Process	Main fuel	Main products	25 $M_\odot$ star[5]		
			Temperature (K)	Density (g/cm^3)	Duration
hydrogen burning	hydrogen	helium	7×10^7	10	10^7 years
triple-alpha process	helium	carbon, oxygen	2×10^8	2000	10^6 years
carbon burning process	carbon	Ne, Na, Mg, Al	8×10^8	10^6	1000 years
neon burning process	neon	O, Mg	1.6×10^9	10^7	3 years
oxygen burning process	oxygen	Si, S, Ar, Ca	1.8×10^9	10^7	0.3 years
silicon burning process	silicon	nickel (decays into iron)	2.5×10^9	10^8	5 days





Neutrinos from burning of O, Si shells: ~days before collapse

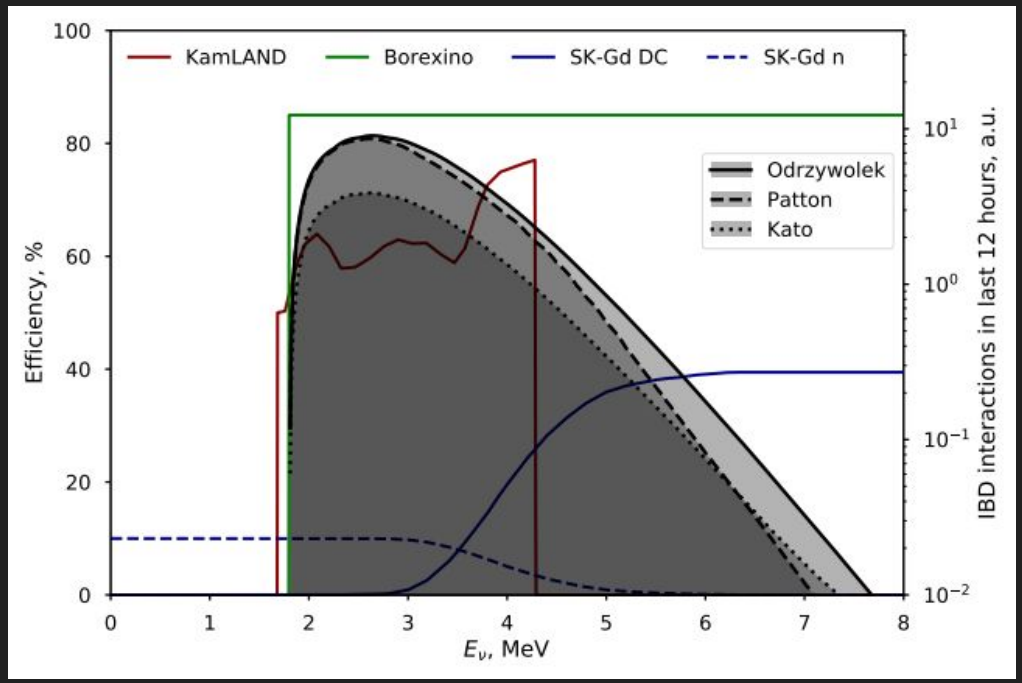
Gradually increasing flux and energy (~several MeV)

Early warning!

Pre-supernova neutrinos detection

Channels same as for CCSN, but lower energy

- Lower energy:
  ~MeVs vs ~10s MeV
- Larger signal time scale:
  days vs seconds
- Lower event rate
- More sensitive to background variations in time



Many experiments sensitive to preSN neutrinos via IBD for distances up to ~1kpc

Promising channel: CEvNS in cryogenic experiments

Next generation experinments (JUNO, Hyper-K, Dune) will make this preSN signal even more accessible

What SNEWS collaboration can offer to experiments

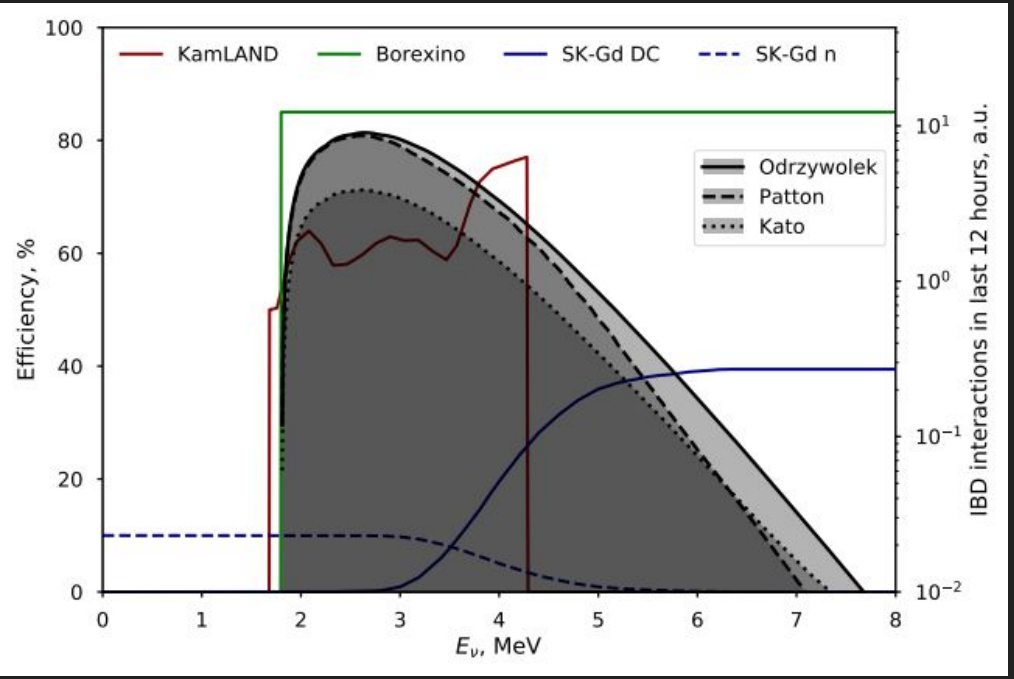
- Evaluation of preSN signal in detector: SNEWPY
  - Collection of preSN neutrino models
  - Calculation of the detector response
- Alert infrastructure: SNEWS_PT
  - Propagation of preSN alert to end users
  - Combination/coincidence of alerts
- Signal analysis: directionality?
  - No sharp signal profile → No triangulation
- Statistical methods for the signal processing: SNAP
  - Both at the experiment (client) side, and SNEWS (server) side
  - Combined measurements can make SNEWS much more sensitive than individual experiments!

Pre-supernova neutrinos detection: example

Channels same as for CCSN, but lower energy

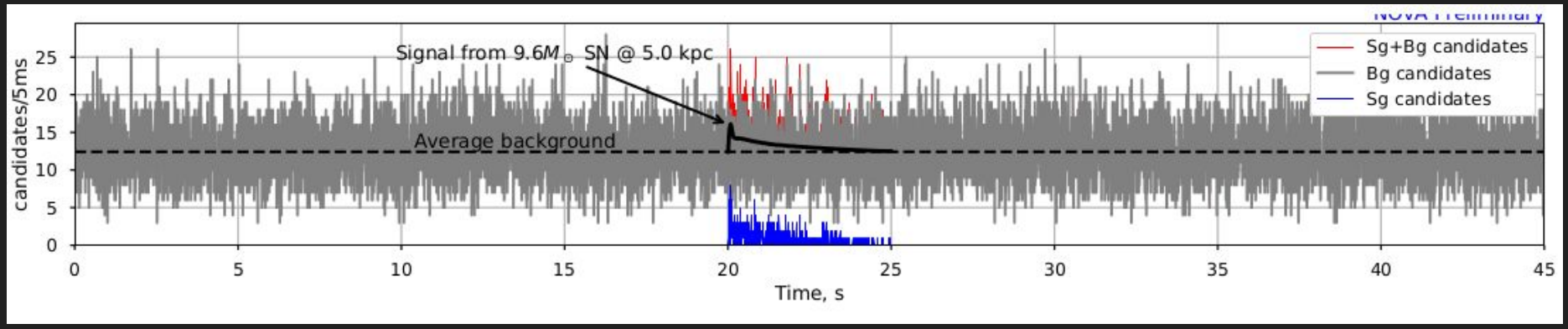
- Larger signal time scale
- Lower event rate
- More sensitive to background variations in time

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



Detector	N_{sg} in the last hour before SN			N_{bg}/hour	Counting window
	Kato15	Odr15	Pat15		
Borexino	3.95 (0.705)	1.15 (0.327)	2.11 (0.5)	0.0014	48 hours
KamLAND	7.13 (1.19)	2.4 (0.681)	4.39 (1.0)	0.0029	48 hours
SK-Gd DC	86.6 (17.5)	15.7 (4.45)	29.7 (8.13)	1	12 hours
SK-Gd neutron	42.5 (7.05)	14.8 (4.21)	26.8 (6.09)	5.5	12 hours

Signal processing and triggering: hypothesis test



Trigger system needs to distinguish between **Bg** vs **Bg+SN** hypotheses.

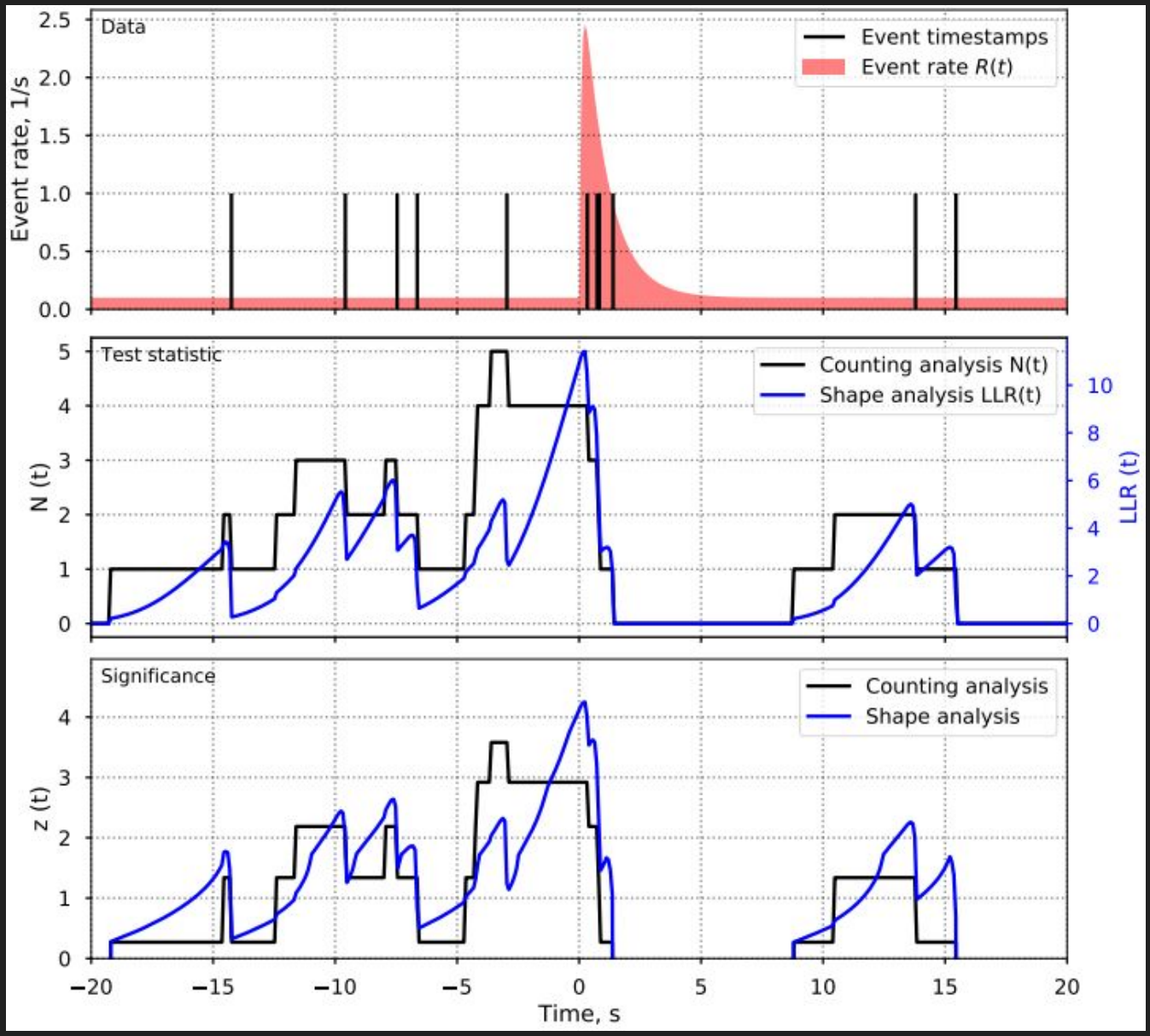
Easiest thing: just look for the N events in a sliding time window. Easy. But:

- Short window (1s): we lose a lot of signal
- Long window (10s): we gain a lot of background

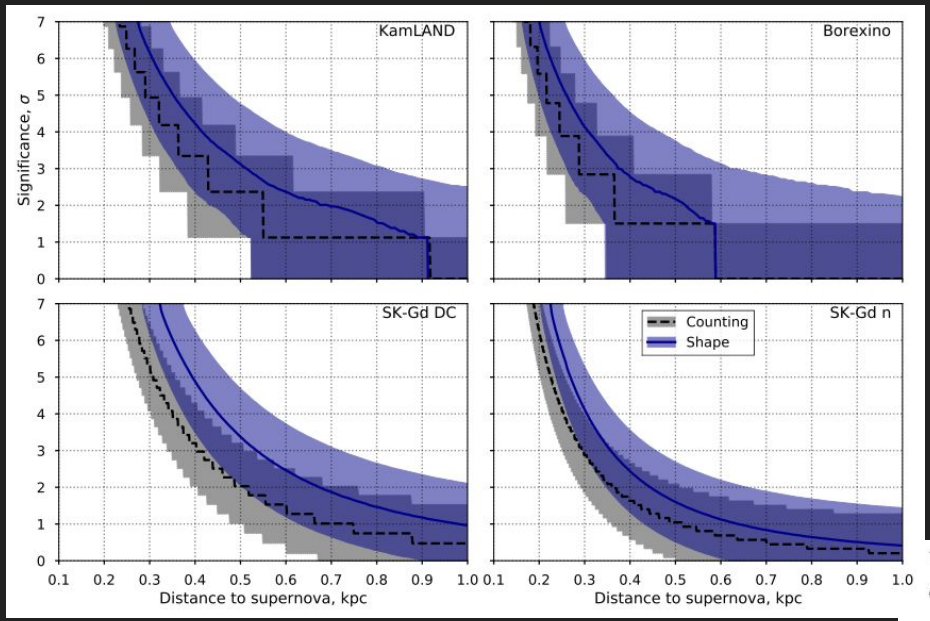
But we can use also the knowledge of the signal shape.
We use log likelihood ratio, to enhance the hypotheses discrimination:

$$\ell(\vec{n}) \equiv \log \frac{P(\vec{n}|H_1)}{P(\vec{n}|H_0)} = \sum_i n_i \cdot A_i, \quad \text{where } A_i = \log\left(1 + \frac{S_i}{B}\right)$$

Signal processing and triggering: hypothesis test



Pre supernova neutrino search: significance

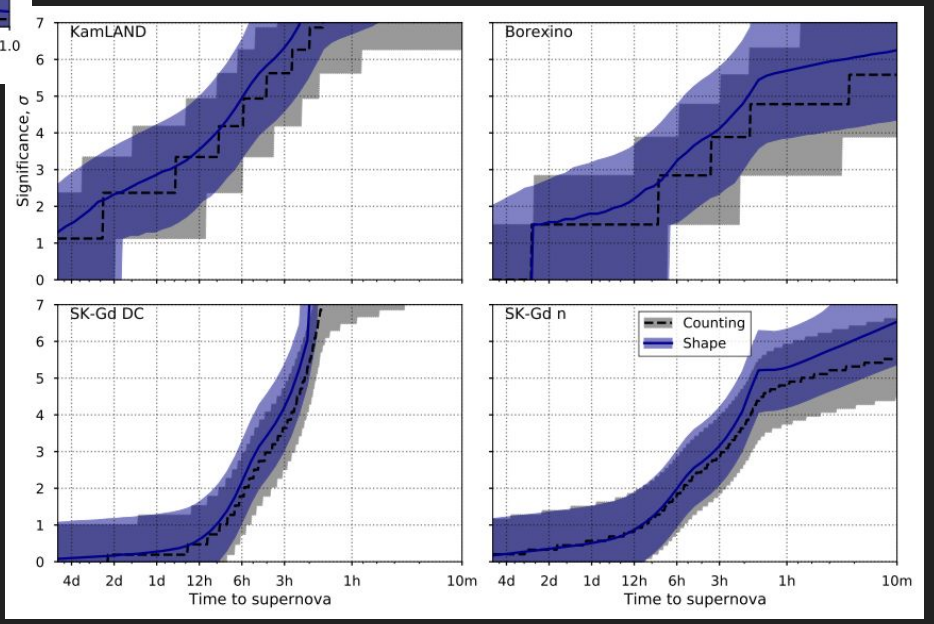


Hypothesis discrimination
(Bg vs. Bg+preSN) using:

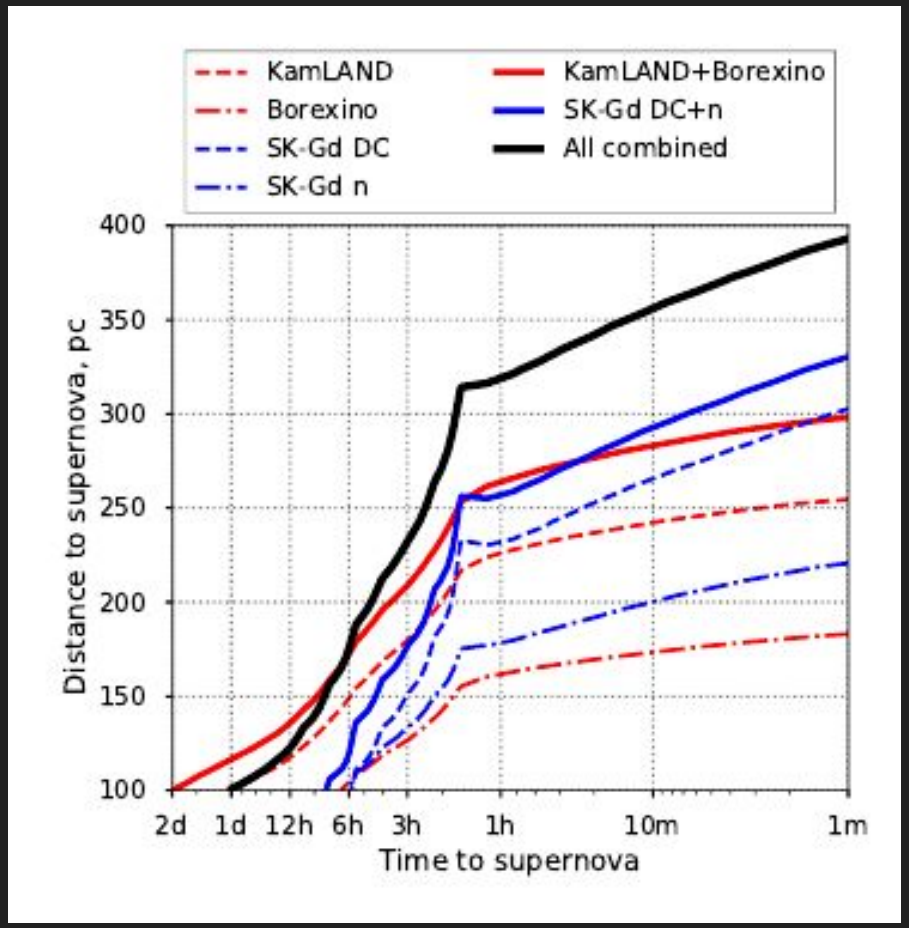
- Counting: N events in time window
- Shape: LLR with signal and background

Figures:

- Top: significance vs. distance (t=1m to SN)
- Right: significance vs. time to SN (dist = 200pc)



Pre supernova neutrino search: joint analyses



- Regions show the 5 sigma significance
- Combined analysis of preSN signals can be done both on the detector side (like SK-Gd) and on SNEWS side
- It depends on what information the experiments can share - individual events, significance?
- Directional information can be used to further improve the sensitivity

See arxiv.org/abs/2107.13172

SuperNova Async Pipeline (SNAP)

A python framework for constructing realtime data processing pipelines.

SNAP allows to easily chain the python functions/coroutines/classes.
Features:

- Allows to describe processing sources/steps
- Based on python asyncio - no need for threading
- Automatic separating event loops, where needed (i.e. buffering)
- All the configuration is separated from the code, kept in a YAML format.
- Extendable plugin system
- Can be used to construct microservices

Works for many tasks: combination, filtering, monitoring, sending alarm, visualization etc.

- Framework core: https://github.com/Sheshuk/snap-base
- SN combination: https://github.com/Sheshuk/snap-combine

Summary and discussion

- Presupernova works in SNEWS complements the main CCSN work
- SNEWS provides methods for evaluating detector response to preSN signal
- Using statistical shape analysis can benefit for preSN signal detection, improving the early warning by several hours
- SNEWS provides software packages to perform this analysis and combine the data in real time

Further development depends on experiments participation.

- What experiments can participate?
- What information they can share?
- Is there any particular desired output other than early warning?