Galactic cc-Supernova Detection with

SuperK/WIT

EGADS/HEIMDALL

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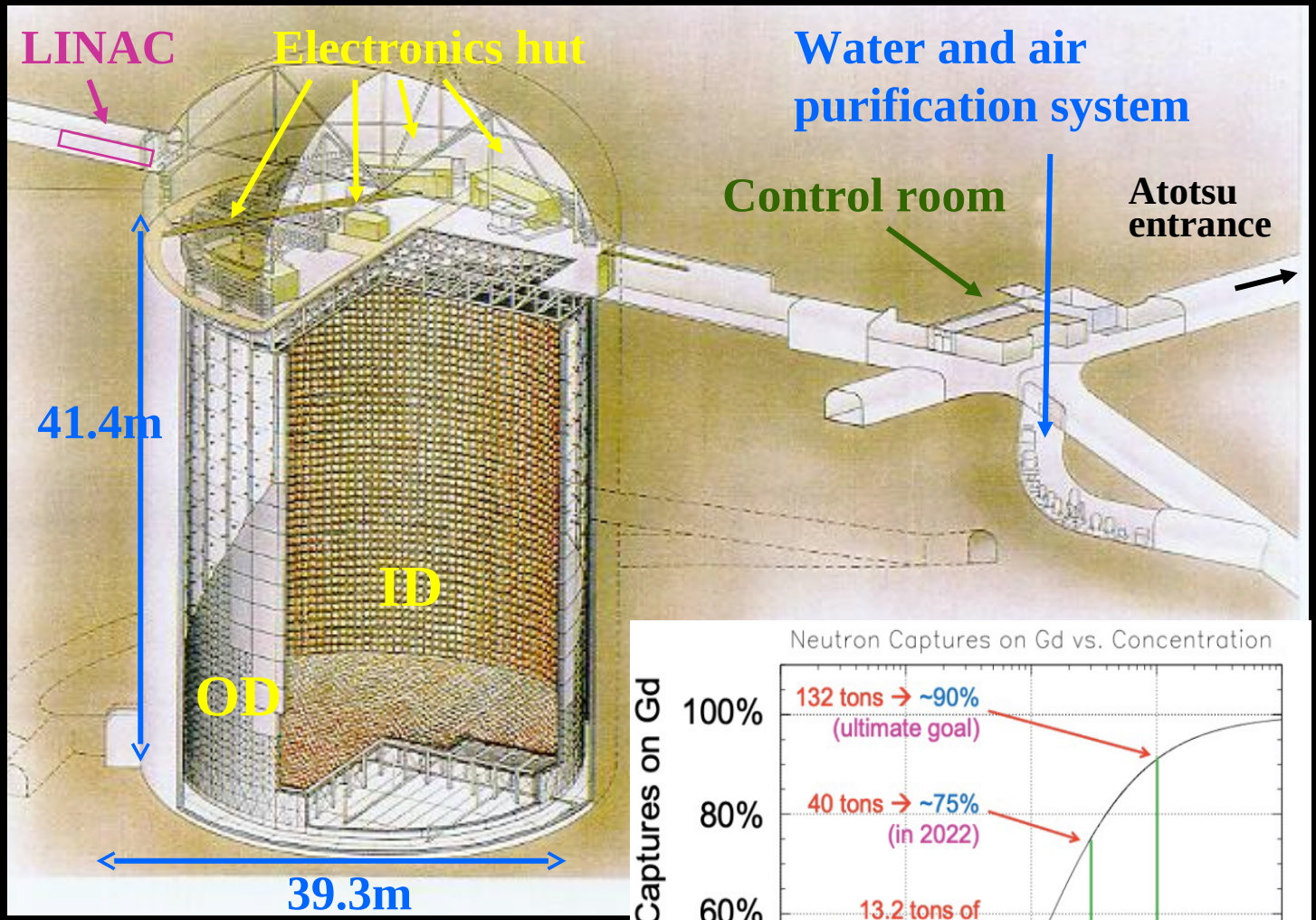
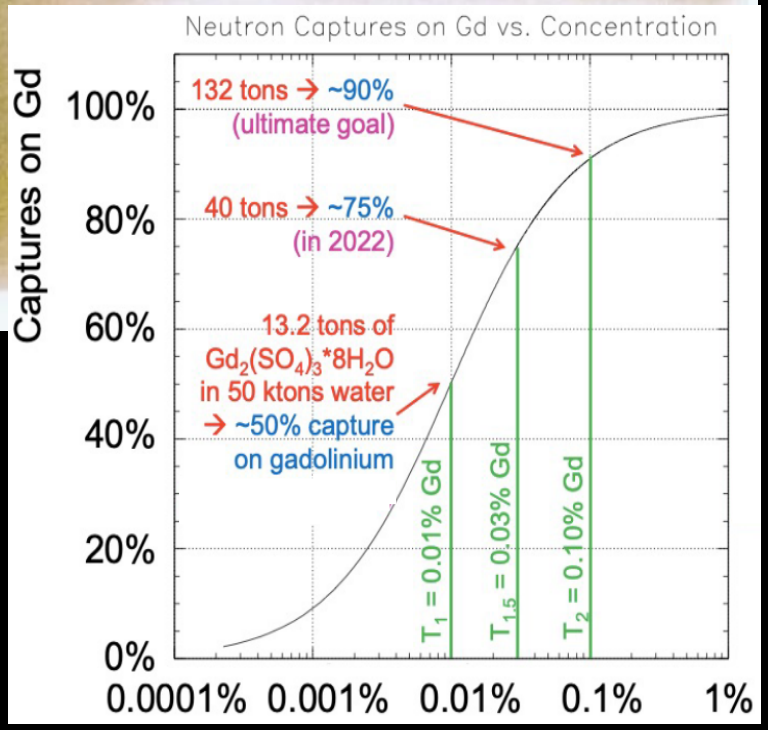
II Synergies at new frontiers, Kashiwa, Japan.
March 26th, 2024.

Super-Kamiokande Detector

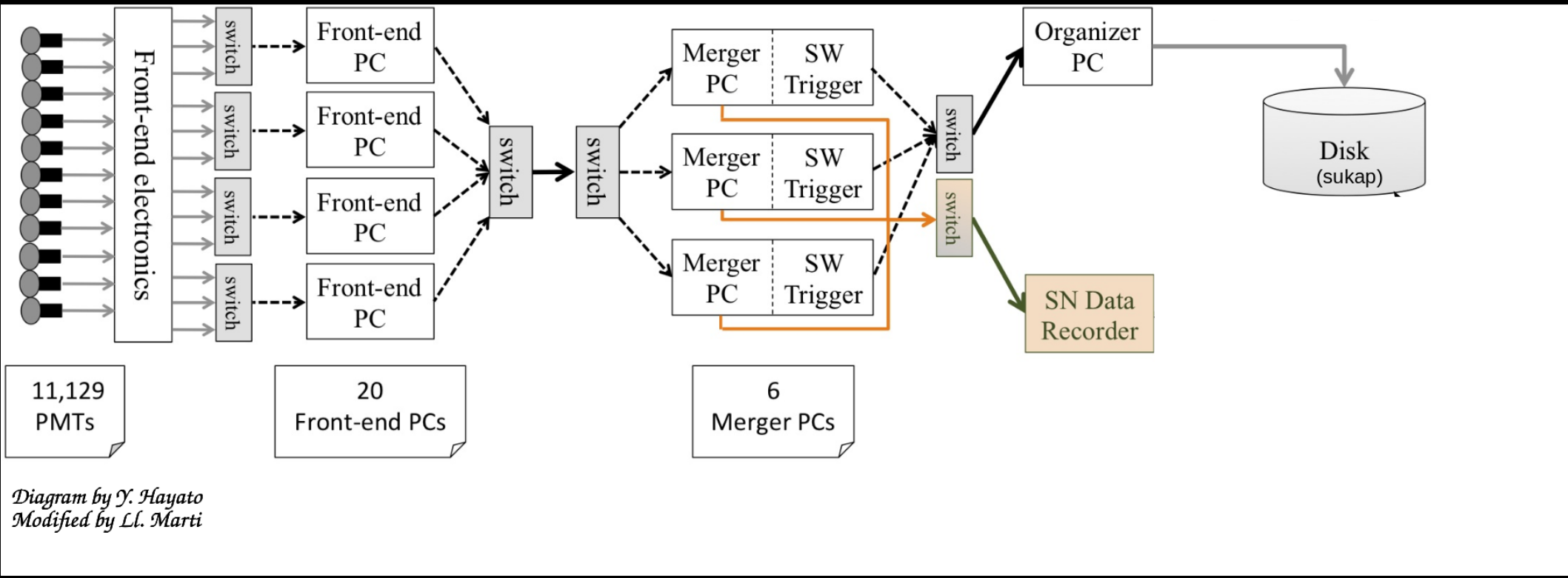




- 50 kton water
- 13+26 tons of Gd sulfate octahydrate:
  0.03% in mass
- 32 kt ID viewed by 20-inch PMTs
  > 11k PMTs
- ~2 m OD viewed by 8-inch PMTs
  ~2k PMTs

WIT System

SK's standard DAQ system:

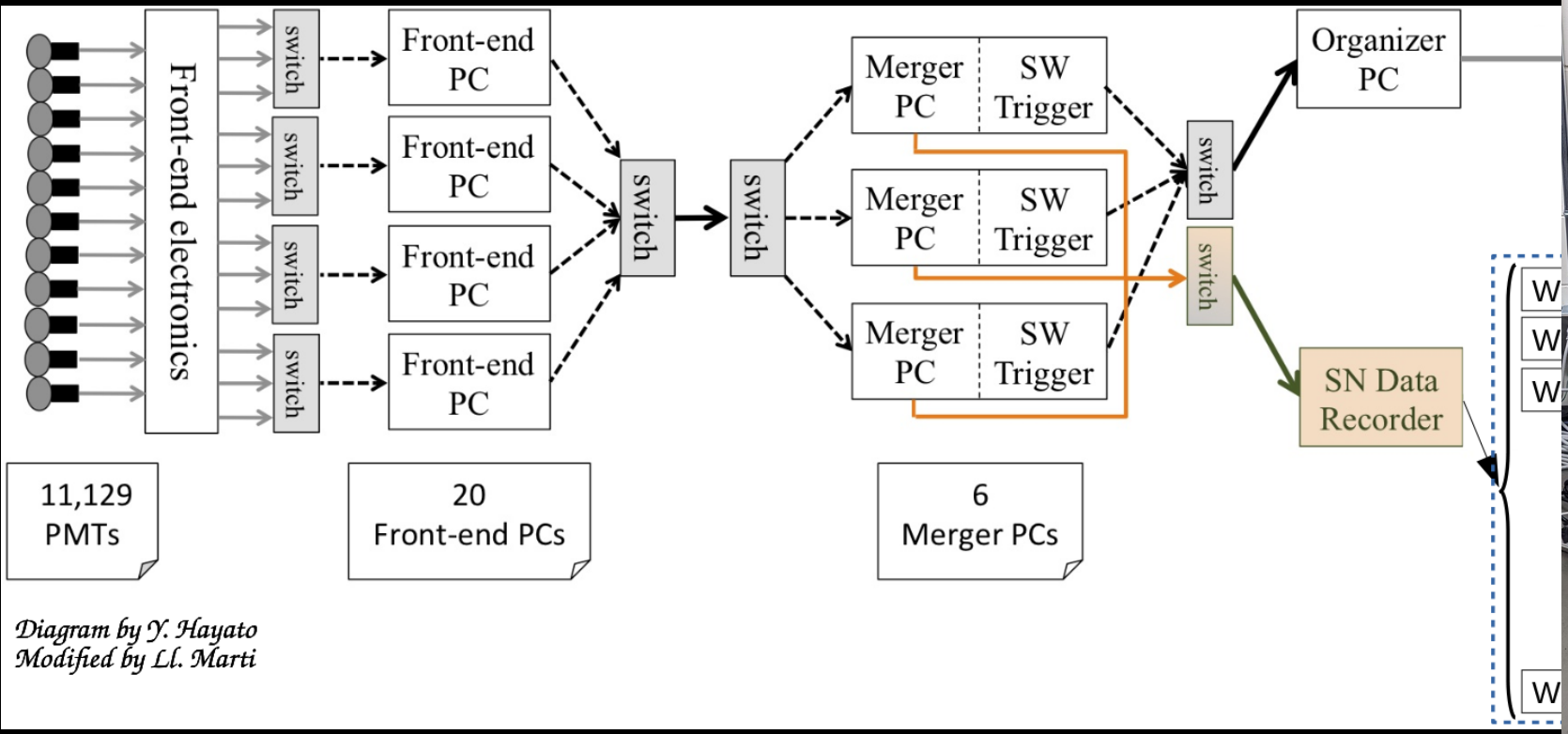


WIT System

Cluster running parallel software trigger: **W**ide-band **I**ntelligent

<u>Online machines:</u> WIT#[2-20]
Receive 23 ms data blocks
+
Event reconstruction

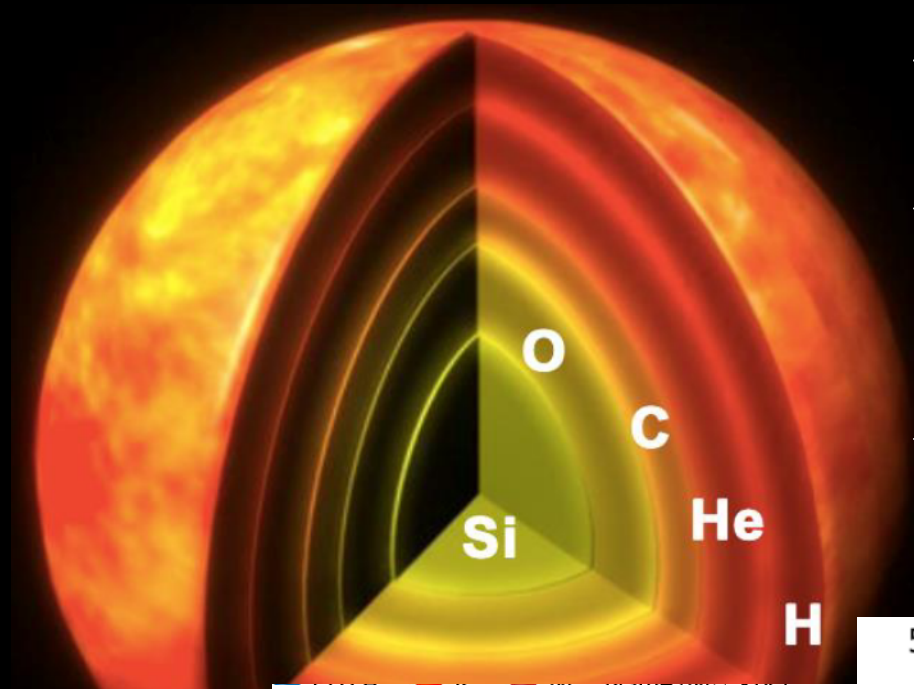
<u>Org</u>
Sorts the



<u>WIT hosts:</u>

- Triggers low energy events (electrons of E_{kin} > 2.5 MeV).
- Online pre-supernova alarm.
- Online SN burst trigger and SN-triggered raw data saving system.

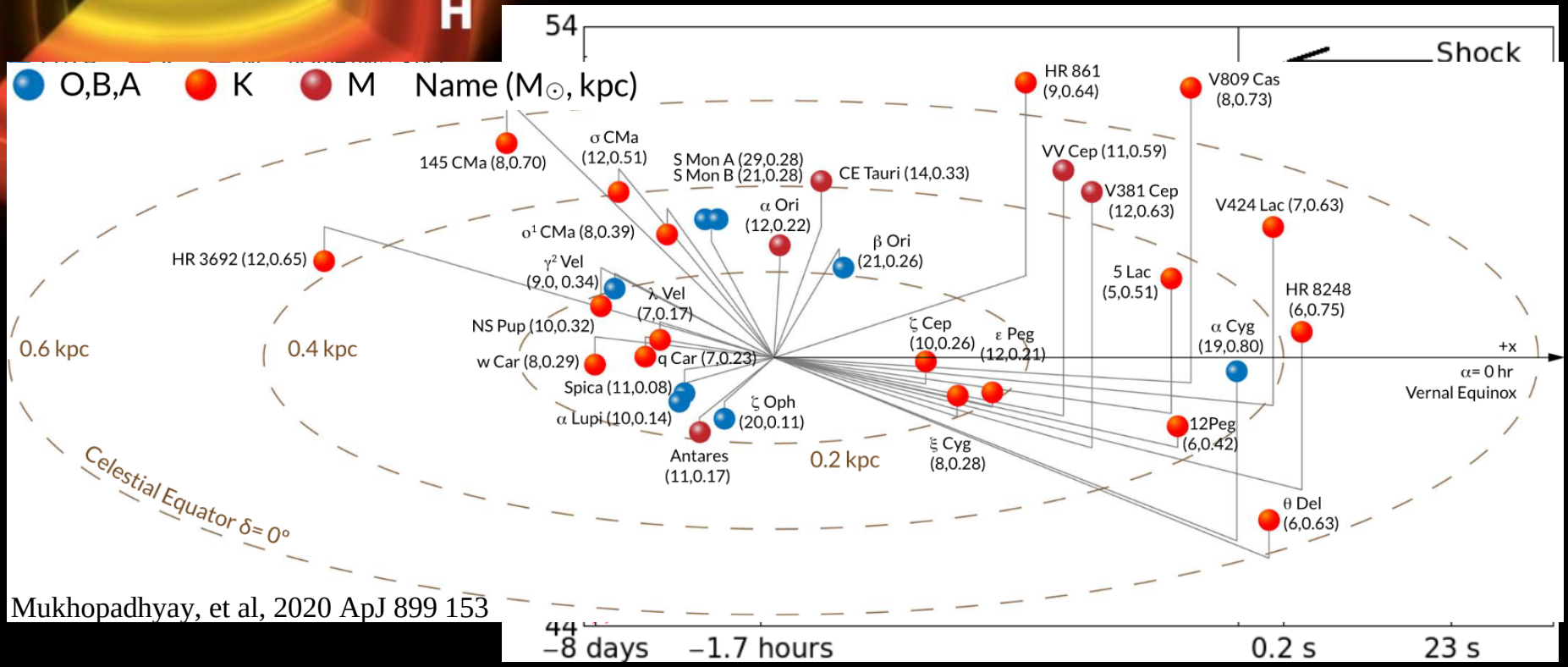
Pre-SuperNova Stars



After Carbon ignition of massive stars ($M > 8\ M_{\odot}$) neutrino emission becomes the main cooling mechanism.

Electron-positron annihilation generate thermal neutrinos:

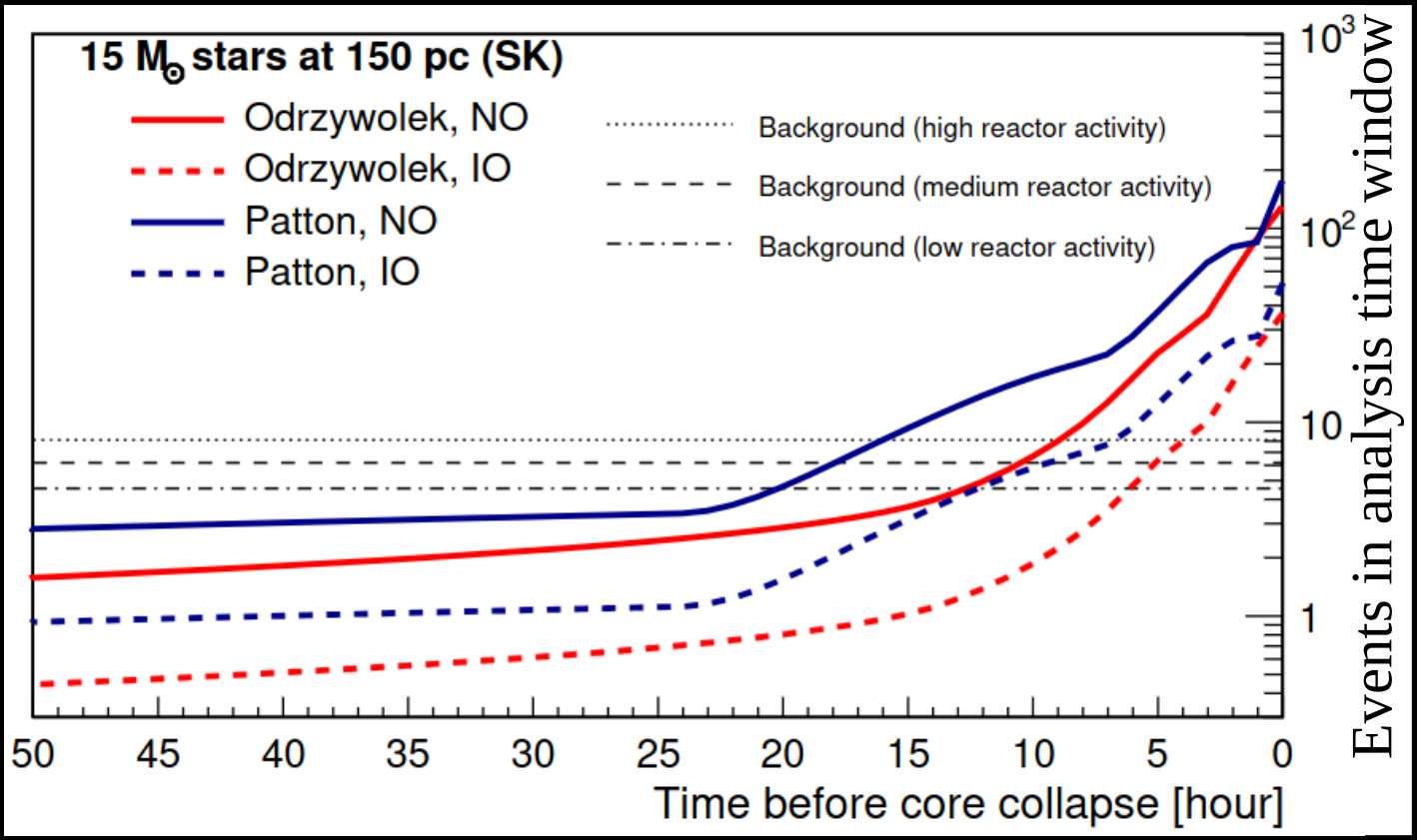
$$e^- + e^+ \longrightarrow \nu_X + \bar{\nu}_X$$



Mukhopadhyay, et al, 2020 ApJ 899 153

Astropart.Phys. 21 (2004) 303-313

SK's Pre-SuperNova WIT Alarm



Mass hierarchy sensitivity

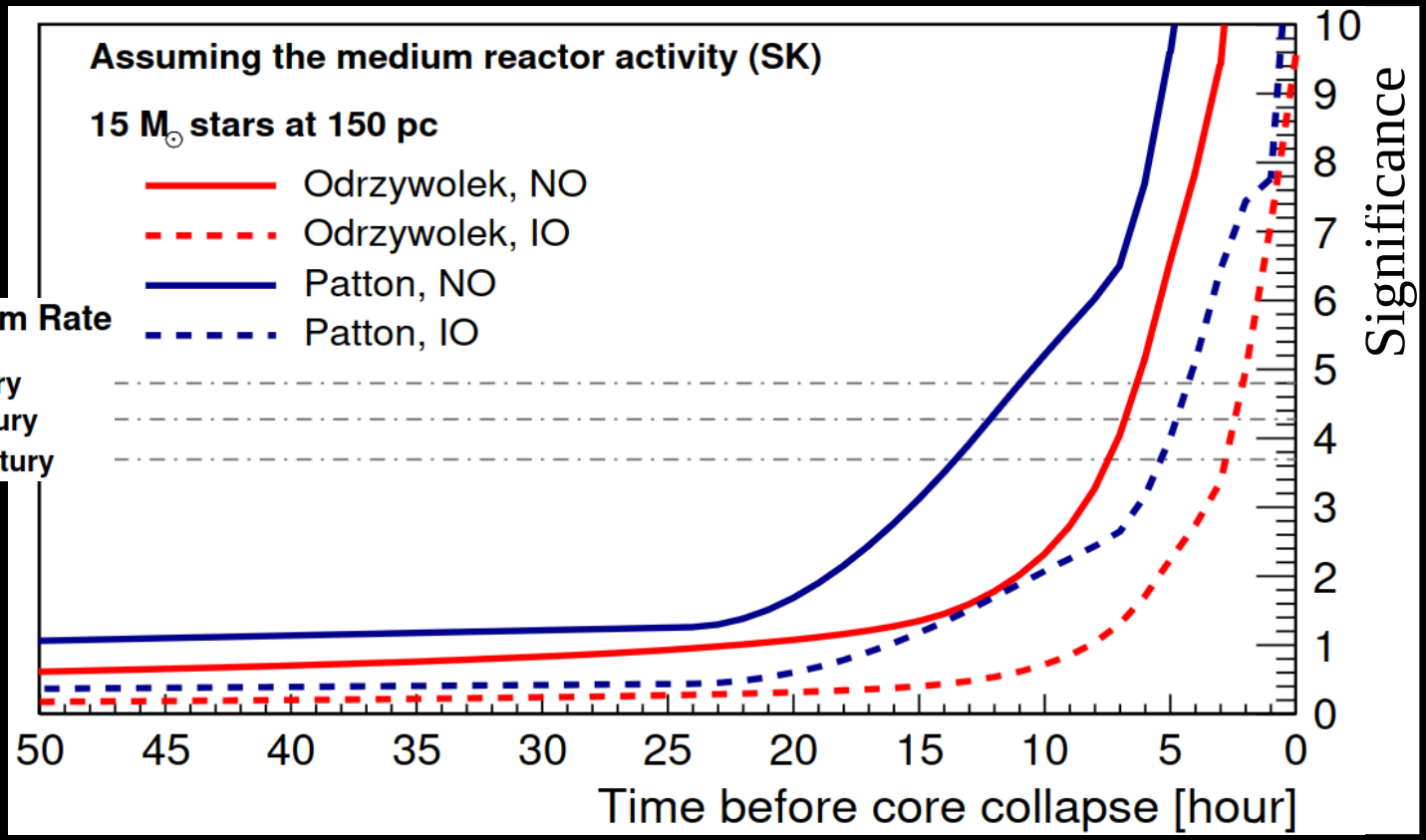
Late stage stellar evolution insight

Online BDT in WIT searching for preSN neutrinos from IBD events.

Updated number of events and significance for SK-Gd with 0.03% Gd.

L. N. Machado, Pre-supernova Alert System for Super-Kamiokande, ApJ, 935, 40 (2022)
Patton, et al 2017 ApJ 851 6

SK's Pre-SuperNova WIT Alarm



Mass hierarchy sensitivity

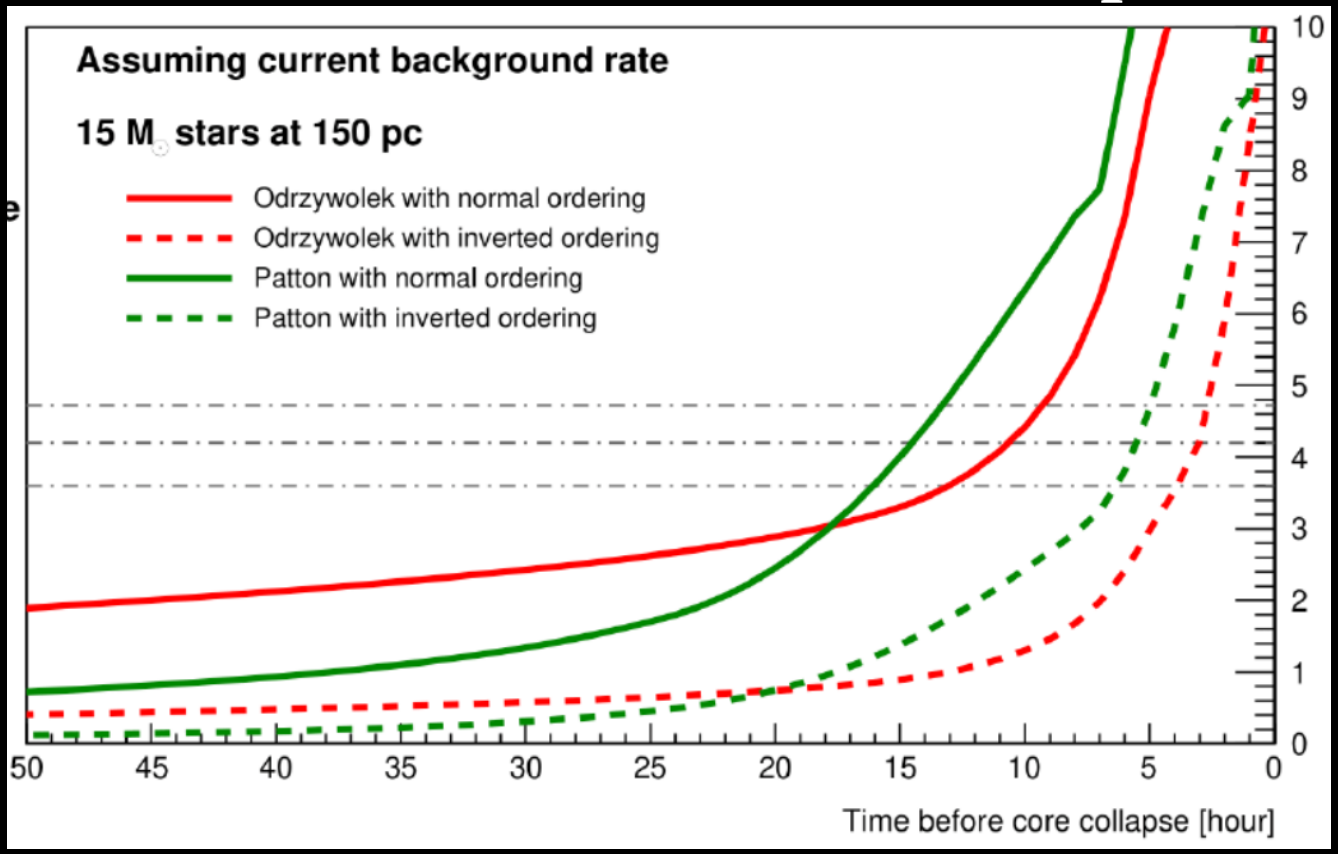
Late stage stellar evolution insight

Time to core collapse with false alarm rate at 1/100 years.
Running since 2021

Updated number of events and significance for SK-Gd with 0.03% Gd.

L. N. Machado, Pre-supernova Alert System for Super-Kamiokande, ApJ, 935, 40 (2022)
Patton, et al 2017 ApJ 851 6

SK and KamLAND Pre-SuperNova Alarm



MoU between SK & KamLAND

Paper underway!

Time to core collapse with false alarm rate at 1/100 years.

KamLAND and SK have their own pre-SN alarms since 2015 and 2021.

Reduce false alarms and increase sensitivity to close pre-SNe.

→ Assuming 150 pc and M=15 $M_\odot$ a pre-SN warning could be issued

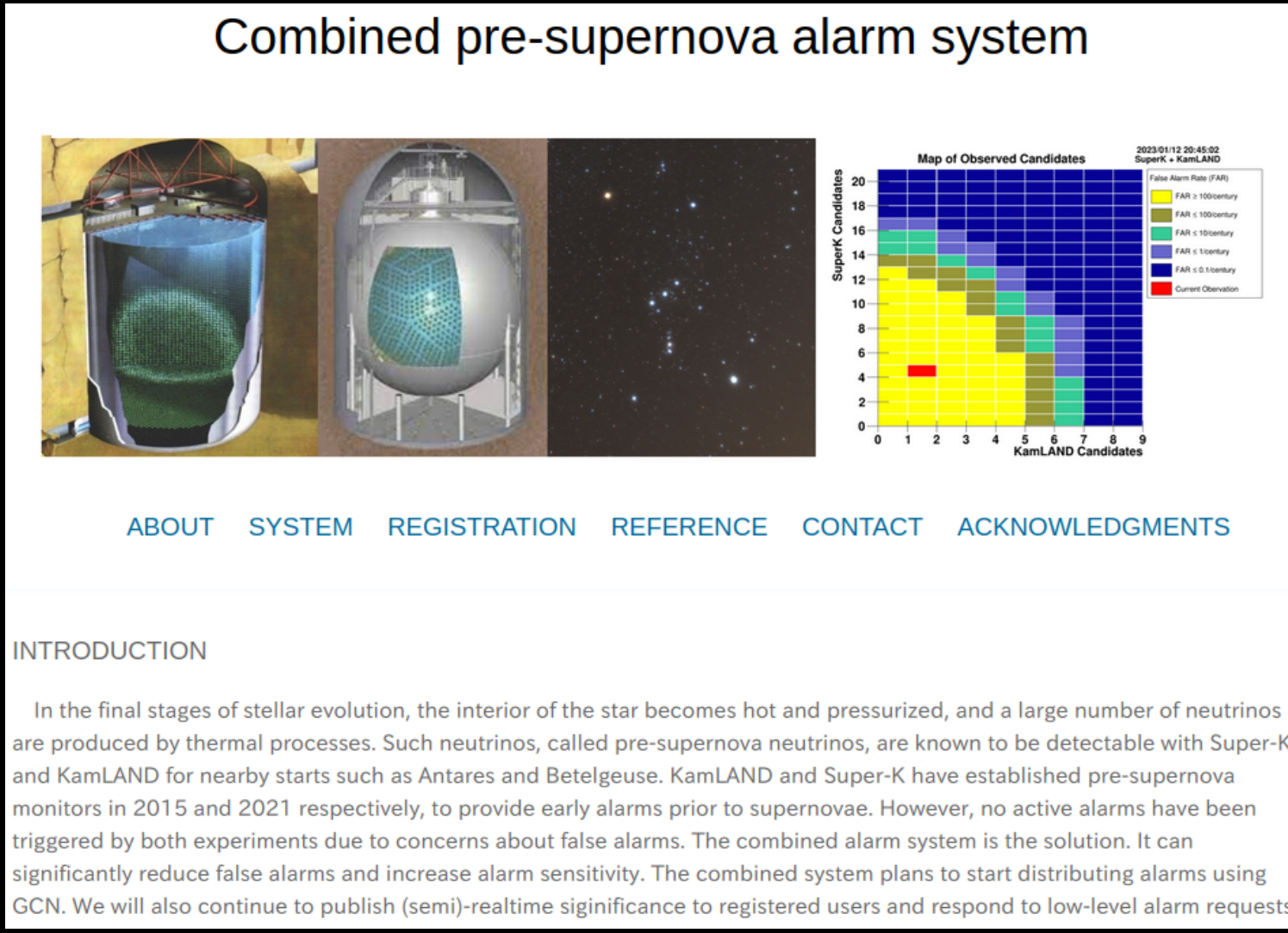
NO: ~12.4h before explosion (~1 false alarm/century)

IO: ~2.6h before explosion (~1 false alarm/century)

SK and KamLAND Pre-SuperNova Alarm

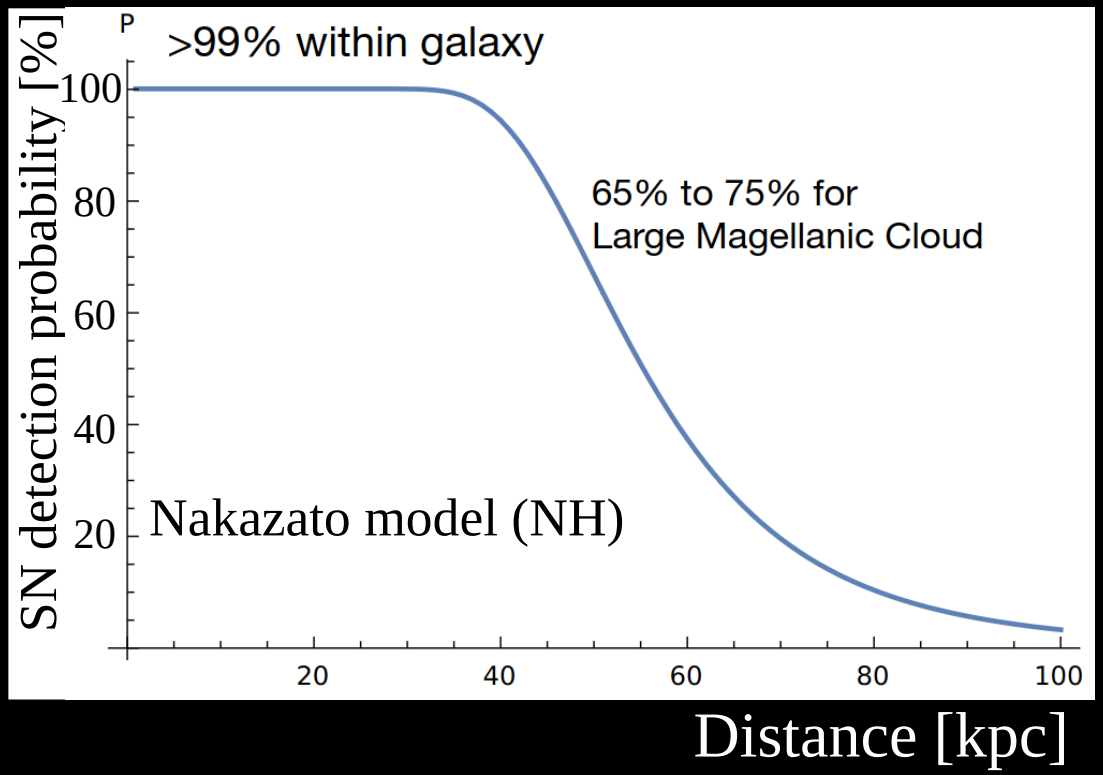
Do you want to have access to the real-time alarm status?

You can get more info and register at: https://www.lowbg.org/presnalarm/



L. N. Machado, Pre-supernova Alert System for Super-Kamiokande, ApJ, 935, 40 (2022)
K. Asakura et al., 'KamLAND Sensitivity to Neutrinos from Pre-Supernova Stars', 2016 ApJ 818 91

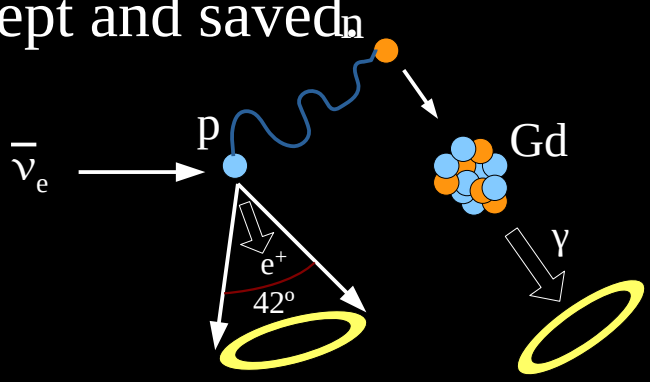
WIT online SuperNova trigger



Searches IBD candidate events in a 10 sec window.

When more than 10 candidates are found a SN alarm is issued.

Raw data for the last ~5 minutes is being kept and saved.



It can process all the SN related data in ~20 seconds even for a close SNe.

Now implementing SN direction capabilities and improving the SN detection efficiency.

It is expected to be able to deliver information such as event energy spectrum, number of events and SN direction within ~30 seconds.

Summary and information

SuperK/WIT:

→ Low energy (solar) intelligent trigger searching for SNe:
→ Gd has opened new possibilities to reduce backgrounds/enhance signals.

Pre-supernova:

→ close pre-supernova alarm running **since 2021**.
→ **Combined SK/KamLAND** since May 2023
→ no less than 2h for a Betelgeuse-like star
→ covers about 510 pc

Supernova:

→ About **25 sec to process and trigger** a ccSN
→ **Buffers raw data** and saves it after triggering a SNe.
→ coming soon: SN direction capabilities.

Useful information:

→ Combined preSN alarm: https://www.lowbg.org/presnalarm/

EGADS detector

Evaluating Gadolinium's Action on Detector Systems

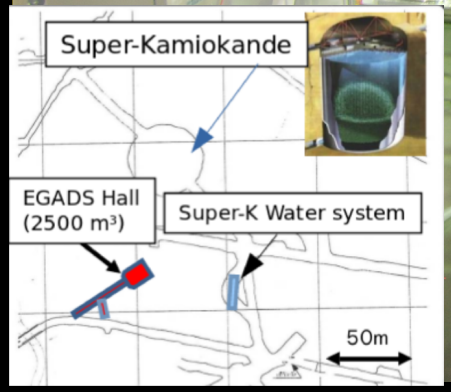
R&D test facility to prove Gd related techniques for SuperK (SK-Gd)

Dissolution and pre-treatment system

200-ton detector with 240 photomultipliers

Fast recirculation system

Selective band-pass filtration system



More infos here:

arXiv:1908.11532

arXiv:2109.00360

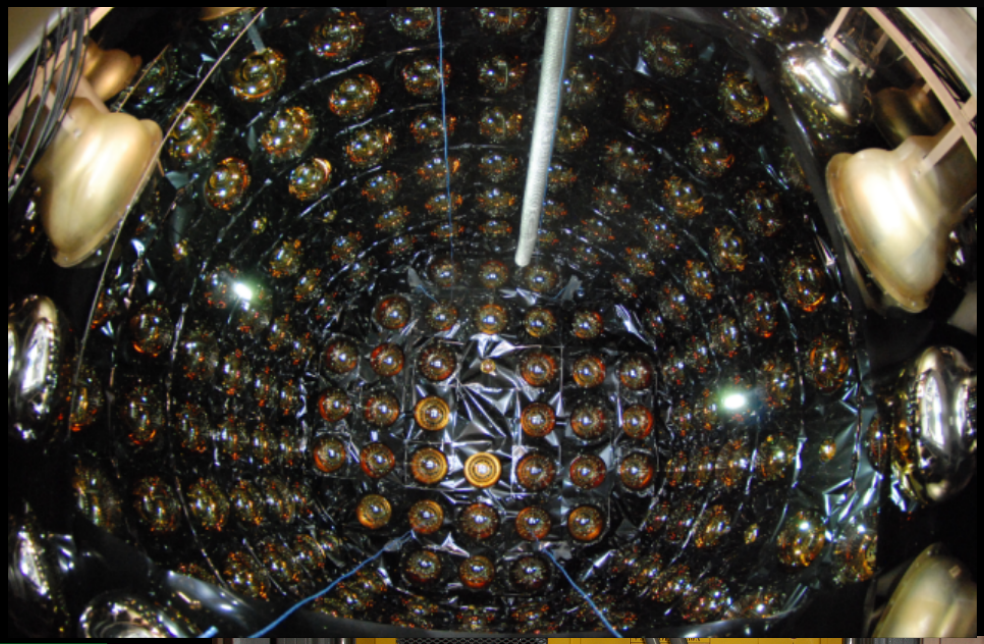
arXiv:2403.07796

PMT and electronics installation

- DAQ runs with very high livetime (> 99%).
- WW remote shifts:
  - detector compensation coils.
  - PMT HV (CAEN).
  - DAQ status.

- Automated warning emails to experts in case of problems.

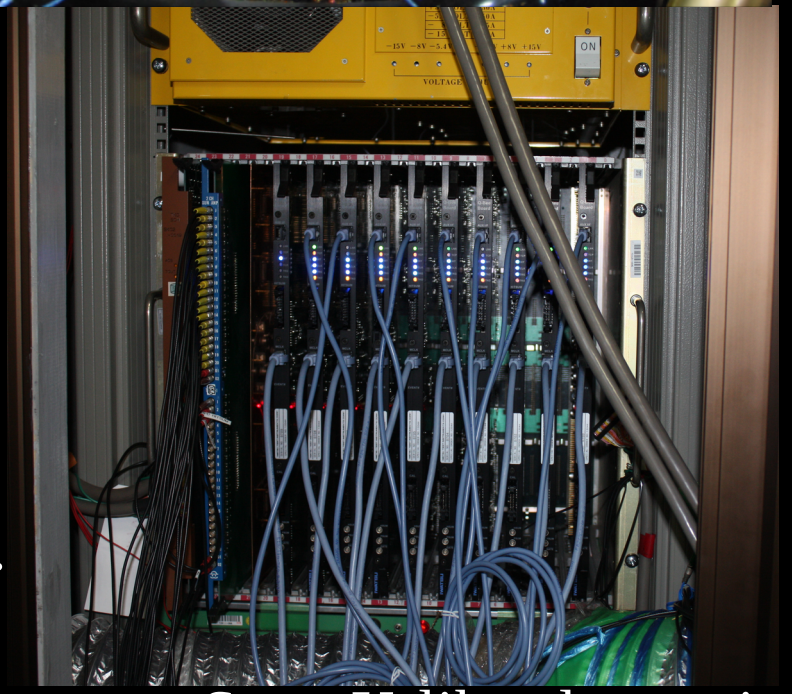
240 PMT installation



- June 2017: front-end electronics were upgraded to withstand high event rates for close SN.

→ QBEE front-end electronics:

- QTC (Charge to time converter) Based Electronics with Ethernet.
- Capability for higher event rates (~ few MHz).
- All hits can be collected.

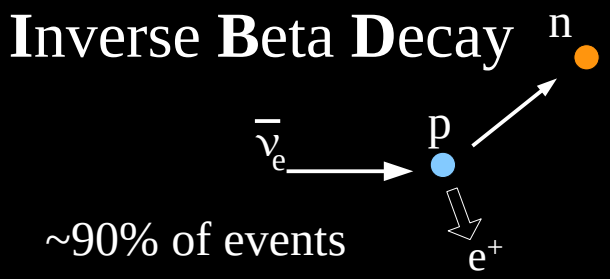


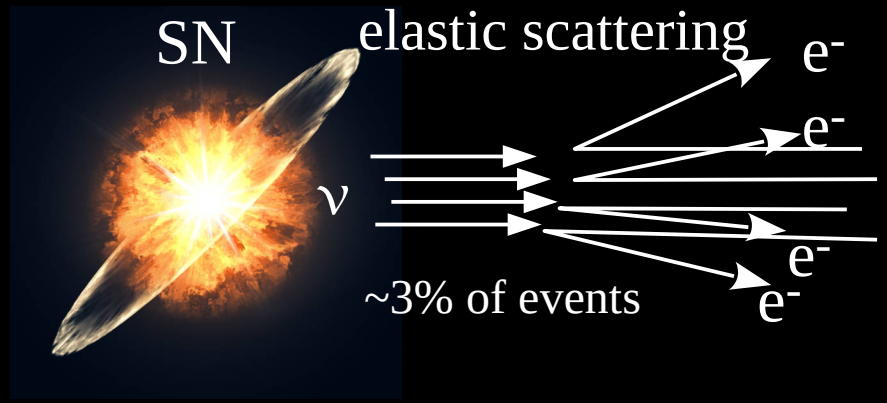
SuperK-like electronics

Detection requirements

Expected numbers for galactic SN bursts*:

Betelgeuse (~200 pc)		Galactic center (~8 kpc)	
$25\text{-}65 \cdot 10^3$	IBD	15-40	IBD
800-2000	elastic scattering	$\lesssim 1$	elastic scattering





- The event rate can be very high for a close SN:
  → Could our DAQ withstand the high rates of a close SN? **YES**
- The number of expected events decreases with distance:
  → Can we efficiently detect a SN in the far side of our galaxy? **YES**

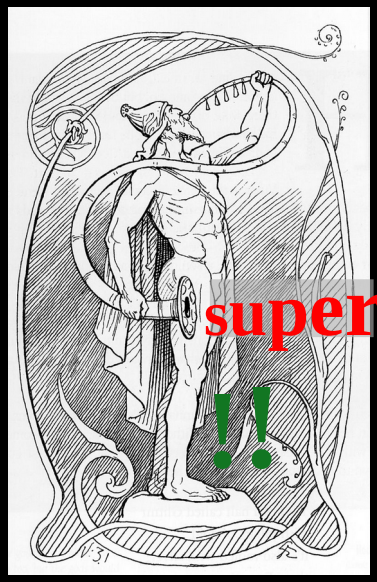
* Nakazato et al. (ApJ Supp. 205, 2 (2013)) $20M_{\odot}$

Evaluating
Gadolinium's
Action on
Detector
Systems

Employing
Gadolinium to
Autonomously
Detect
Supernovas

High **E**fficiency **I**BD **M**onitoring **D**etector and **A**utomated ca**LL**

HEIMDALL is an online machine at EGADS that searches for IBD (prompt + delayed neutron capture) events in real time:

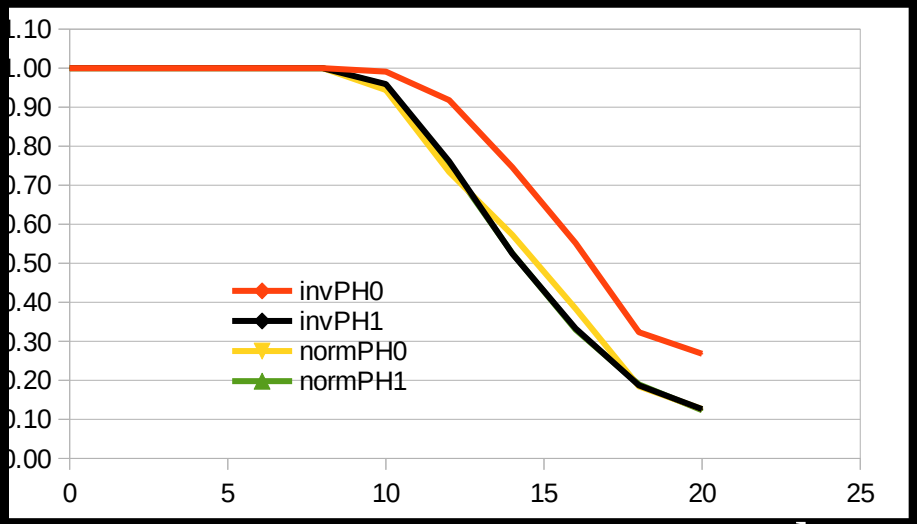


28-core/56-hyperthreaded CPU cores at 2.6 GHz. 128 GB of RAM.

SN detection efficiencies

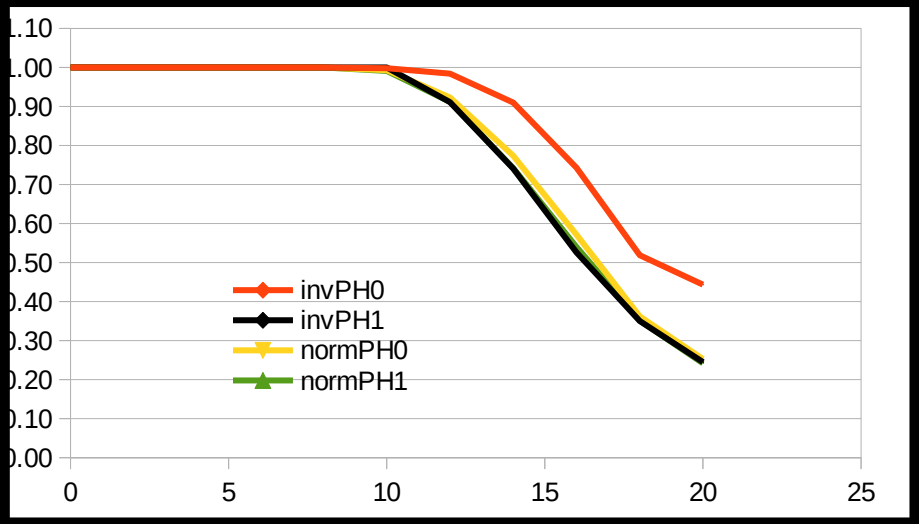
SN detection efficiency:

Gd concentration: 0.03%:



kpc

Gd concentration: 0.1%:



kpc

"inv" for inverse and "norm" for normal neutrino hierarchy.
PH: 0 adiabatic transitions, 1 w/o

Good galactic coverage already with the current concentration.

If ≥ 3 events (within 10 sec) are detected, a SN automated alarm is issued.

→ Latency time ≃ 5 seconds

→ False alarm rate: 1 per decade (at threshold).

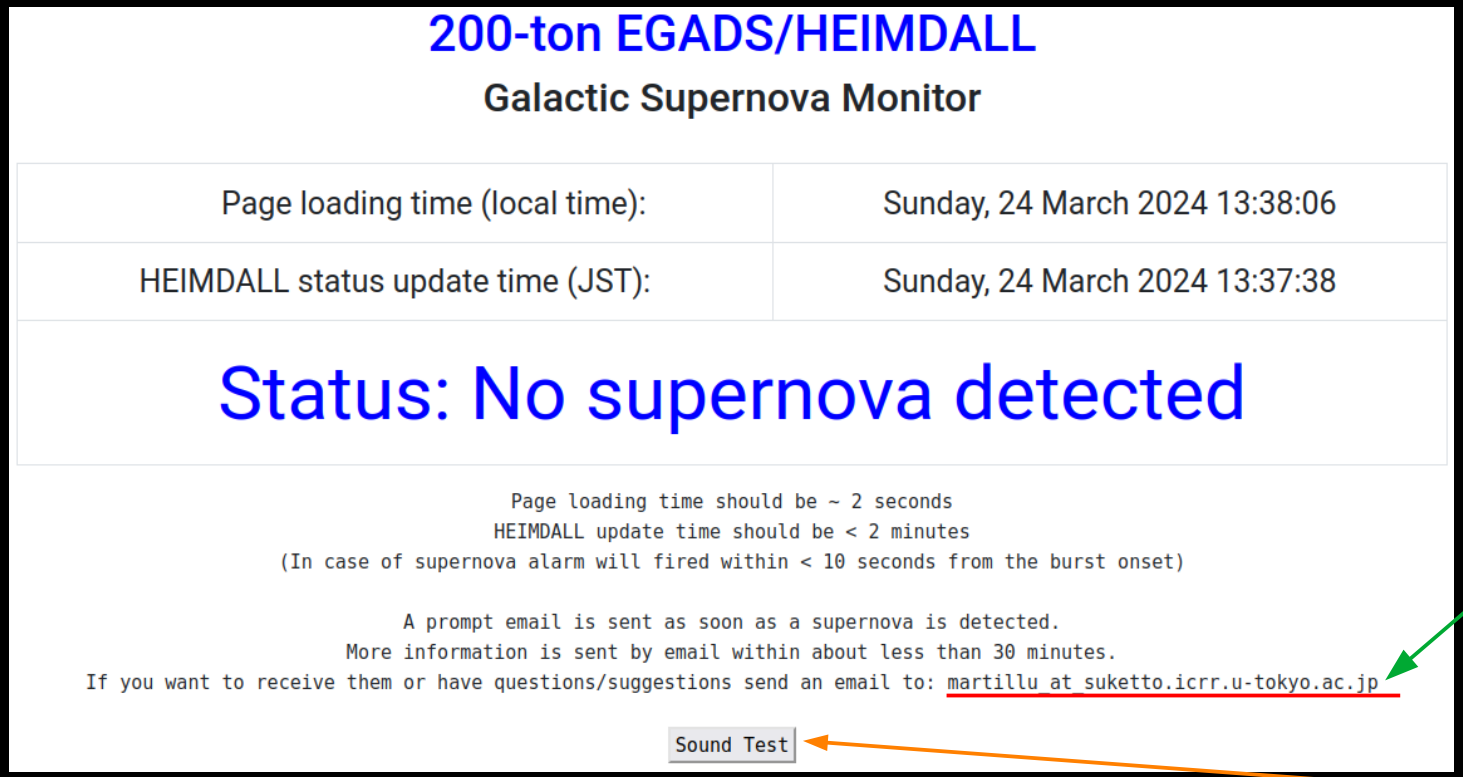
Nakazato model for: M=13, Z=0.02 trev=100 ms.

Public EGADS/HEIMDALL status

- Available for anyone.
Check: https://www-sk.icrr.u-tokyo.ac.jp/egadsSNalarm/

- The HEIMDALL status is updated within < 2 seconds

  - However, in case of SN: updated immediately after SN burst detection.
  - Includes an audible alarm.



questions/inquiries

Check the sound test !!

Check and spread the word!!

Summary and information

EGADS/HEIMDALL:

→ 200-ton Gd loaded detector with **good ccSNe coverage in our galaxy**:
→ **very short lead time** (~5 seconds from neutrino burst onset).
- Minutes can be precious for telescopes!
→ **very high life time** (> 99%).
→ coming: direction capabilities for a close ccSNe.

Useful information:

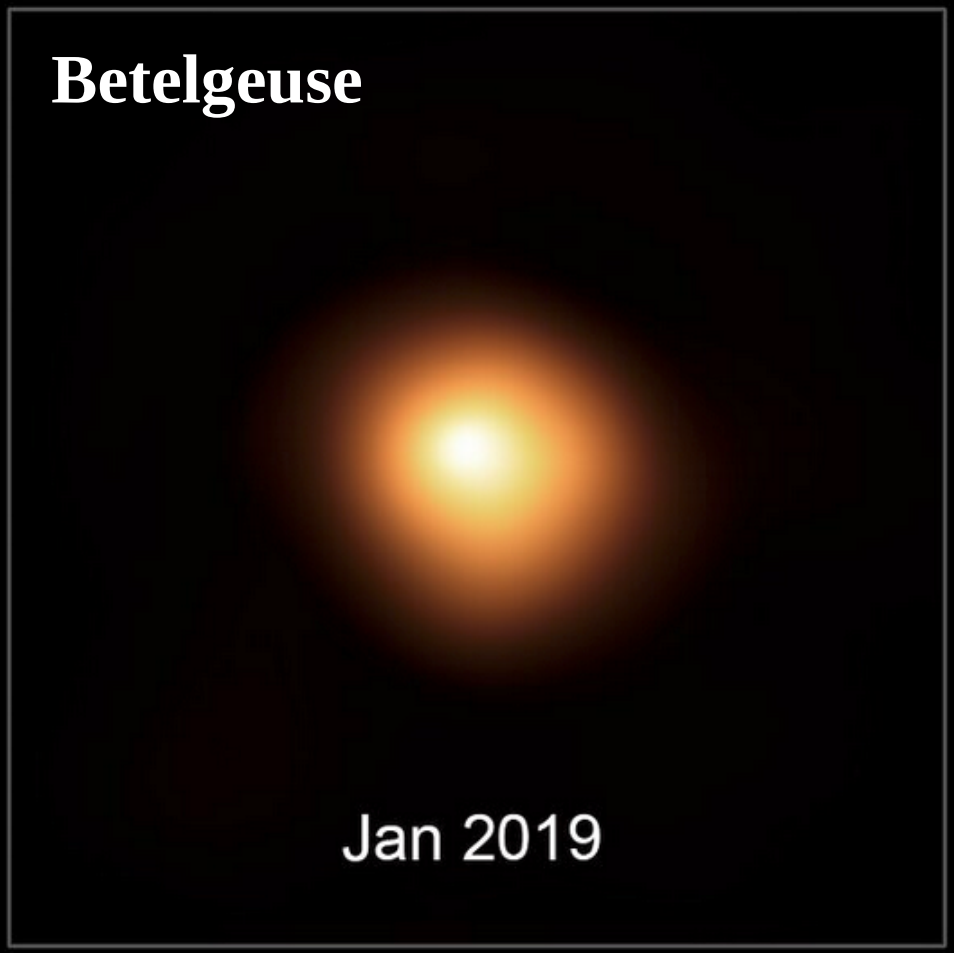
→ detection status **open to everybody**: https://www-sk.icrr.u-tokyo.ac.jp/egadsSNalarm/
→ **automated SN warning mails** : martillu_at_suketto.icrr.u-tokyo.ac.jp

Core-collapse Supernovae and goals

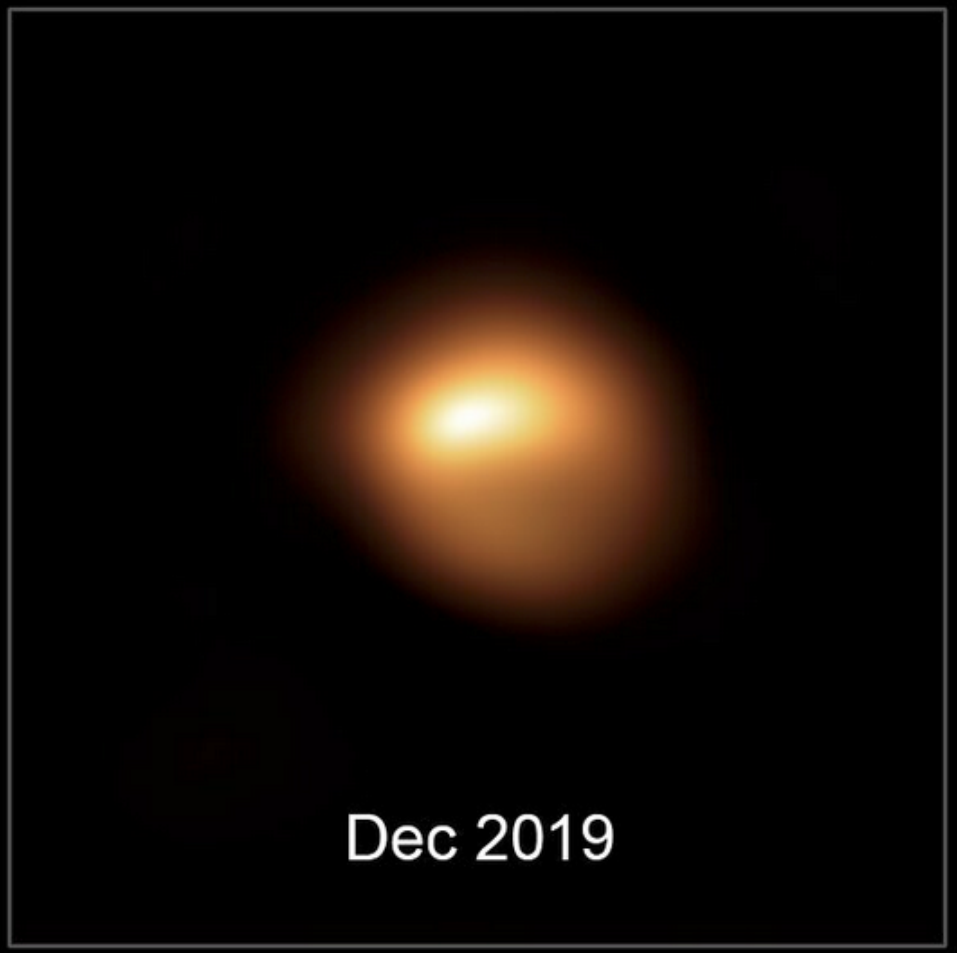
- In the last phase of nuclear fusion of massive stars

NO Hydrogen
NO Helium

Red supergiants



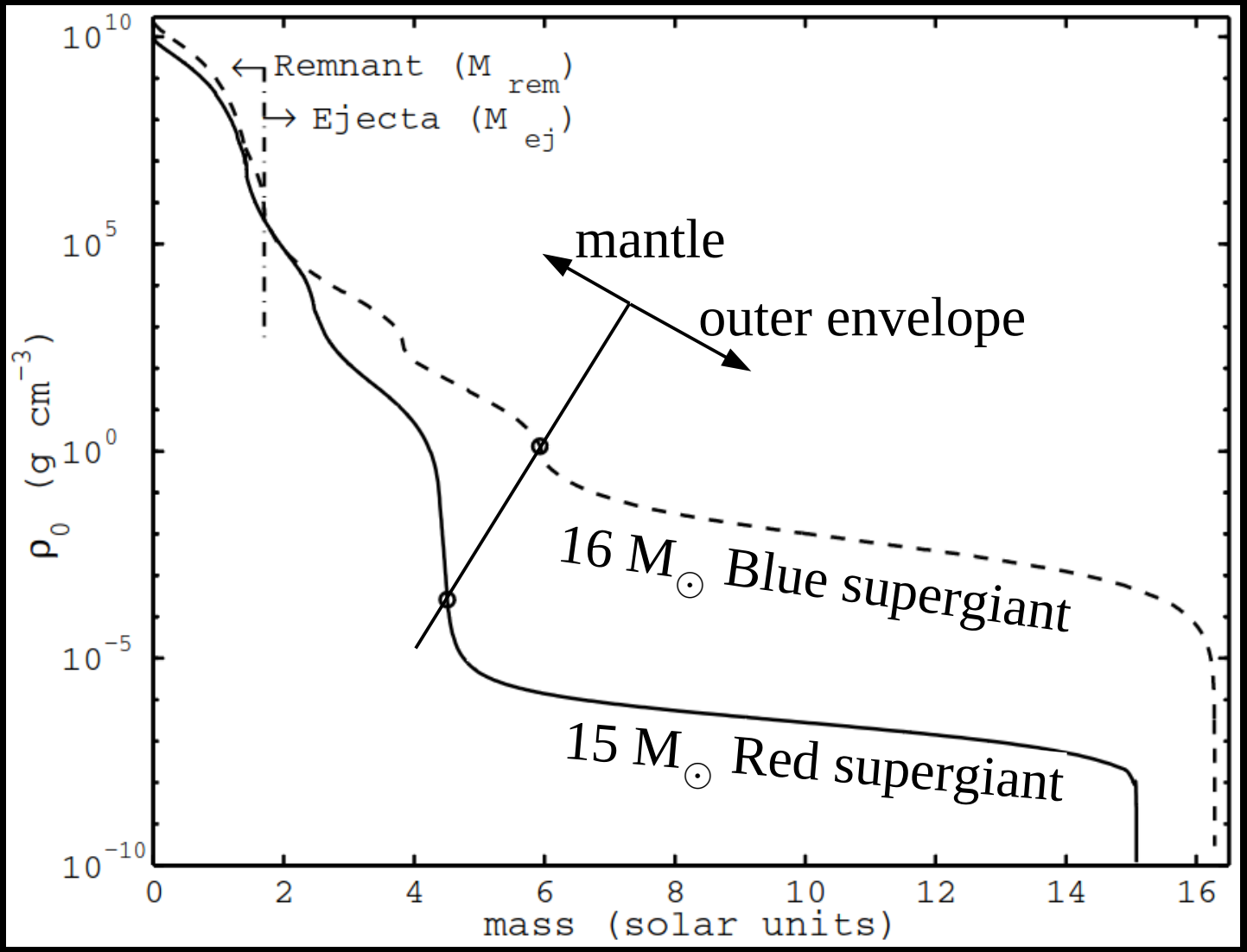
Before dimming



After dimming

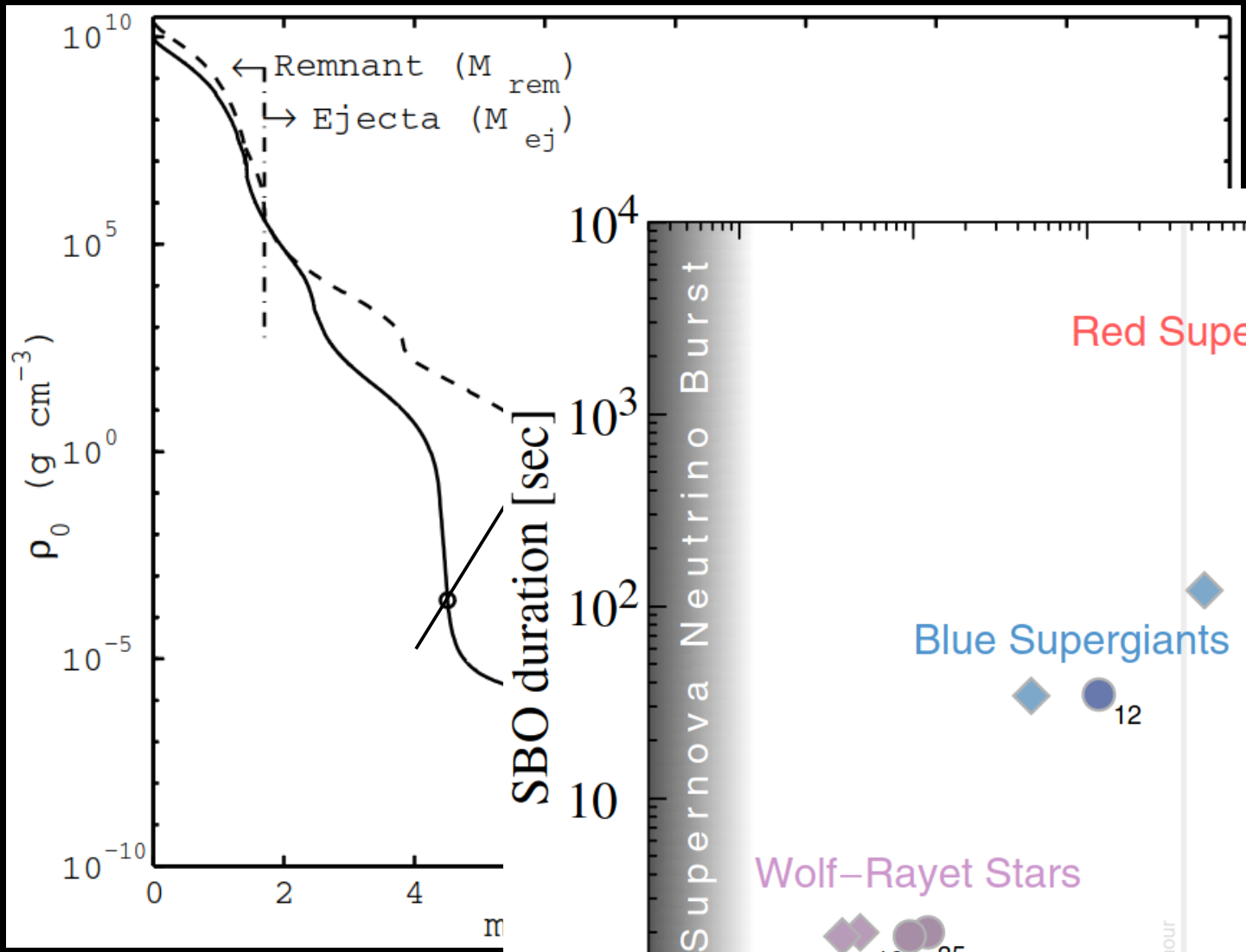
Credit: ESO/M. Montargès et al.

Core-collapse Supernovae and goals



APJ, 510: 379-403, 1999

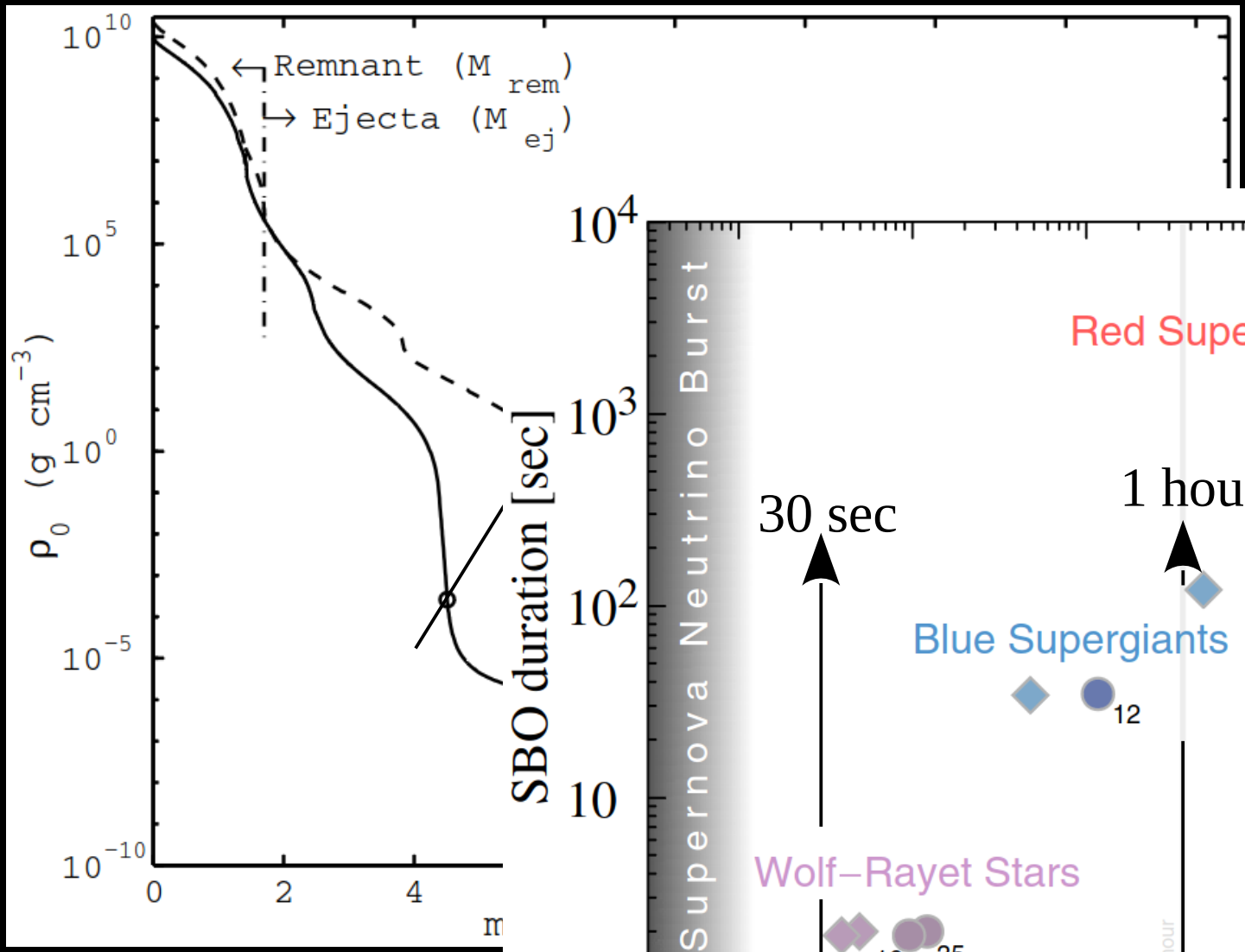
Core-collapse Supernovae and goals



APJ, 510: 379-403, 19

APJ, 778: 81, 2013

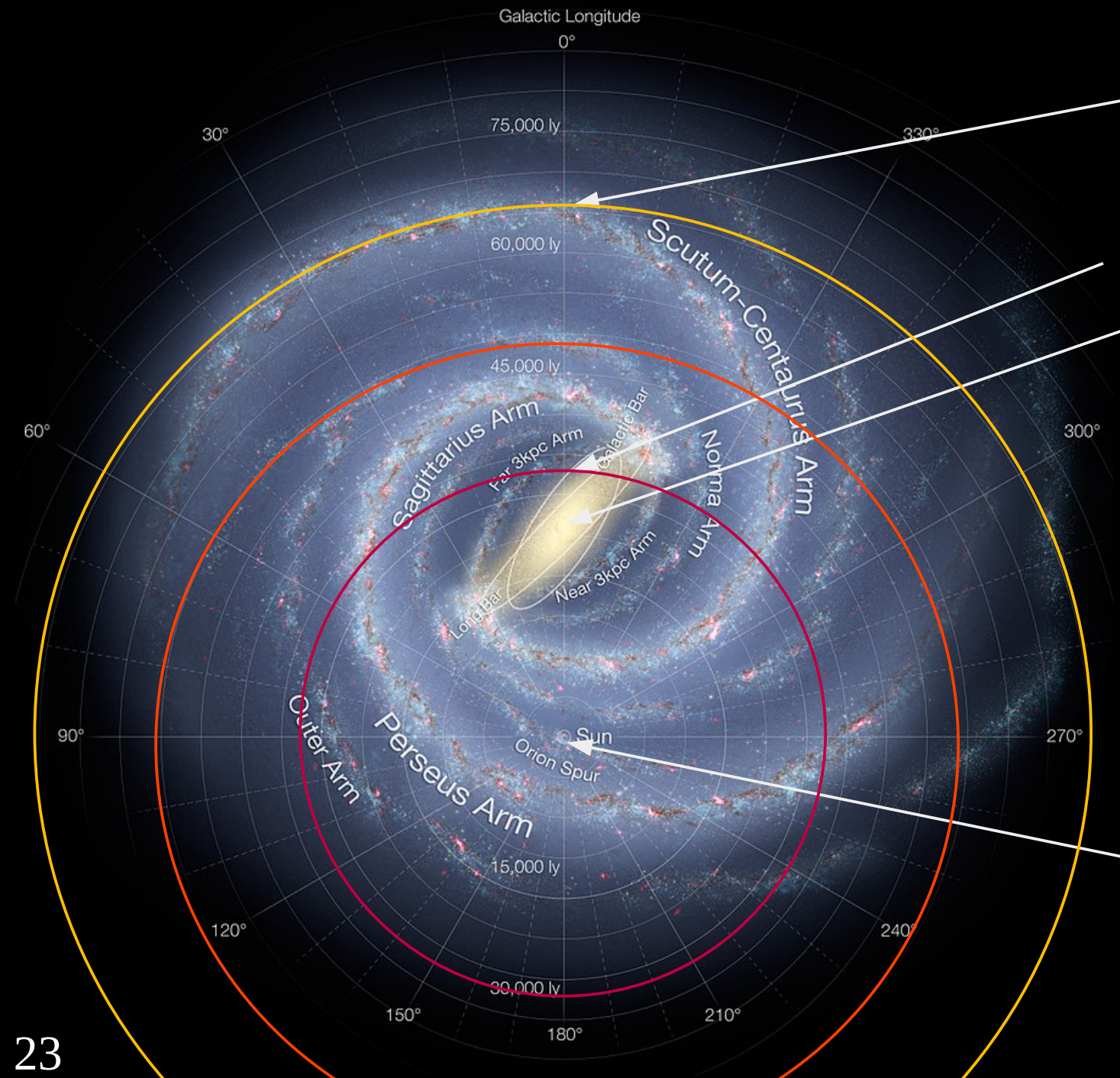
Core-collapse Supernovae and goals



APJ, 510: 379-403, 19

APJ, 778: 81, 2013

EGADS/HEIMDALL in the galaxy



20 kpc

10 kpc

Galactic center ~8 kpc

EGADS/HEIMDALL