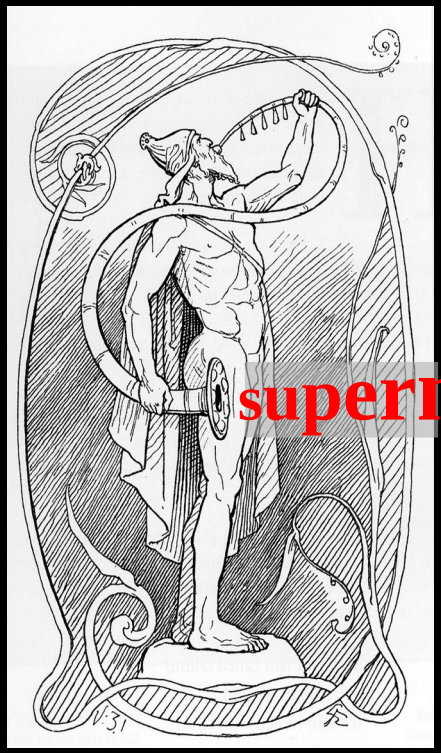
Galactic Supernova Detection with EGADS/HEIMDALL



Lluís Martí-Magro (Yokohama National University)
for the EGADS group.

Synergies at new frontiers, Kashiwa, Japan.
March 24th, 2022.

Transient events

- There are many kind of transient events:

  - Pulsating stars
  - Novae
  - Thermonuclear supernovae
  - Core collapse supernovae
  - Kilonovae
  - Black hole mergers
  - Blazars, AGNs and the like

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This will be our main topic here!

GW, photons & neutrinos: a true multi-messenger event!

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  - Core collapse supernovae ← **This will be our main topic here!**
  - Kilonovae GW, photons & neutrinos: a true multi-messenger event!
  - Black hole mergers
  - Blazars, AGNs and the like

The important ingredients towards understanding transients are:

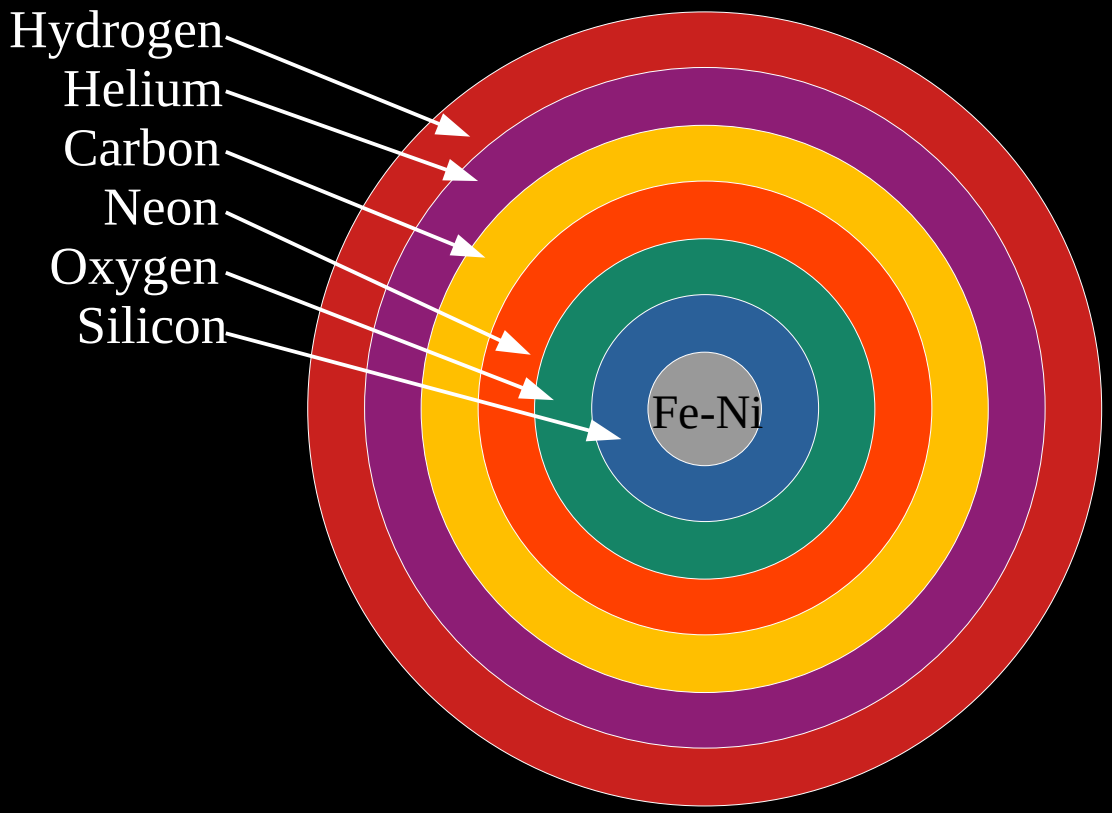
→ early observation from the onset.

→ observe them in all the possible ways: multi-messengers

→ ensure the above happens: as many detectors for all messengers and avoid dead time overlap

CC supernovae in a nutshell

- In the last phase of nuclear fusion of massive stars



At some point stellar cores are no longer supported by nuclear fusion against gravity → the core collapses

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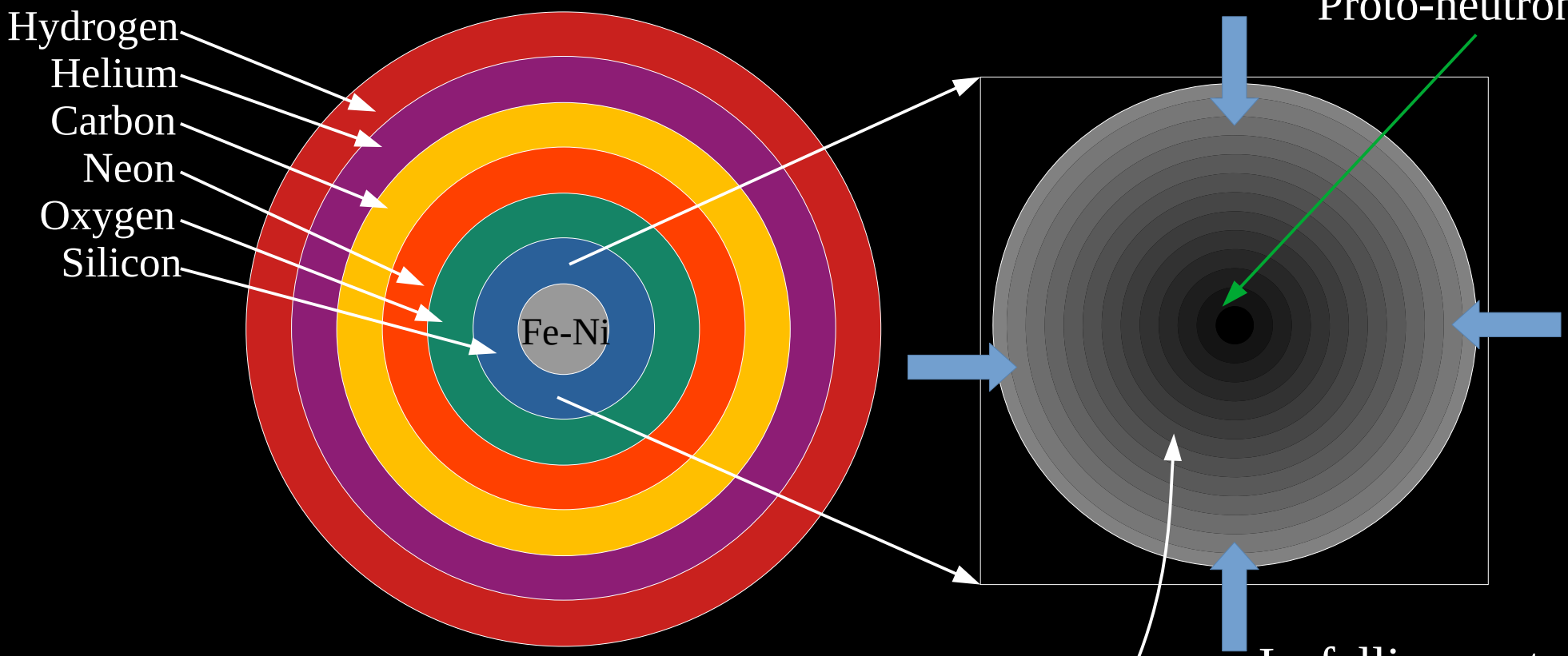

Electron capture, photodisintegration undermine the ability of the core to hold the collapse.

CC supernovae in a nutshell

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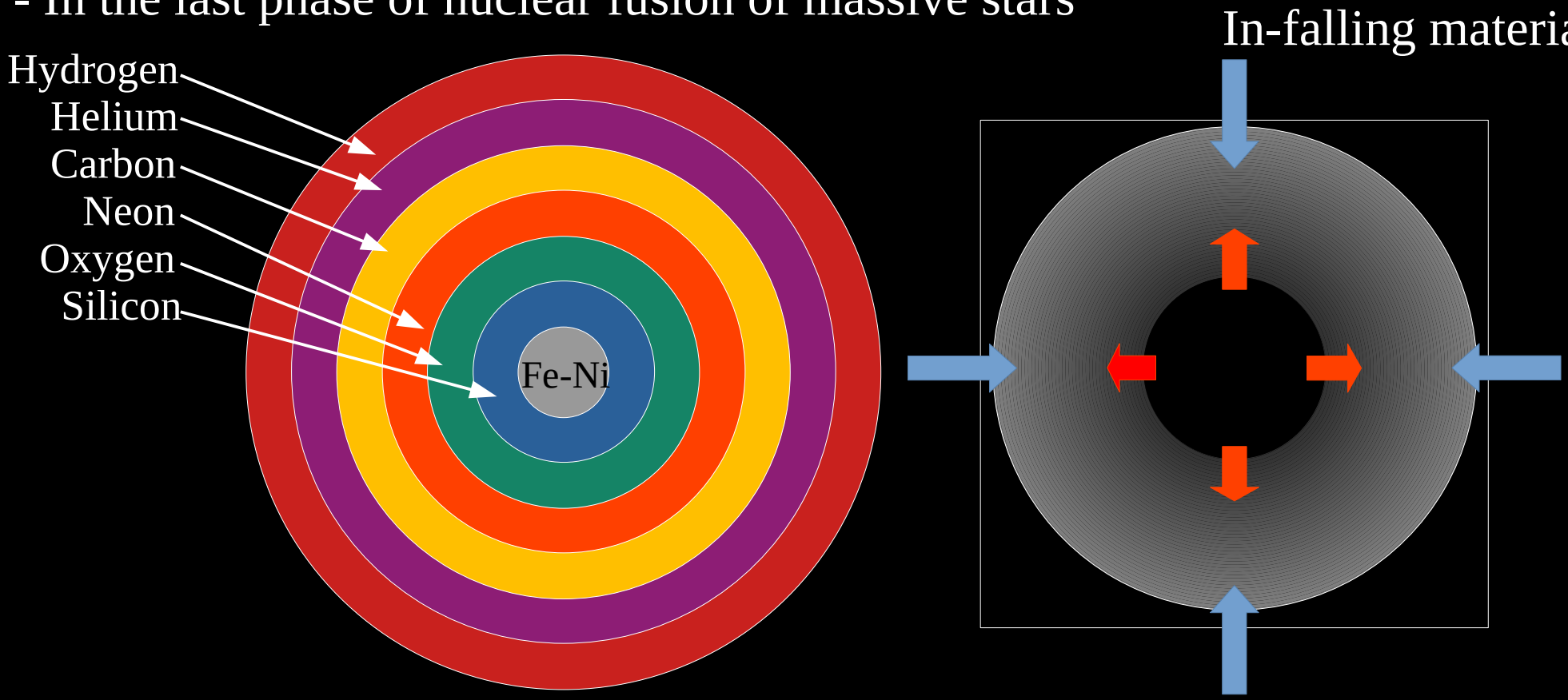


Neutron degeneracy tries to halt the collapse: in case of success a shock wave propagates to the outer layers of the star and we observe a supernova.

→ In simulations, the shock wave tends to stall:
possible mechanisms to reinvigorate it: neutrino radiation and/or aspherical hydrodinamic turbulence (convective instability and standing accretion shock instability), others (?)

And all this in about a second….

EGADS: birth of a new detector

Evaluating Gadolinium's Action on Detector Systems

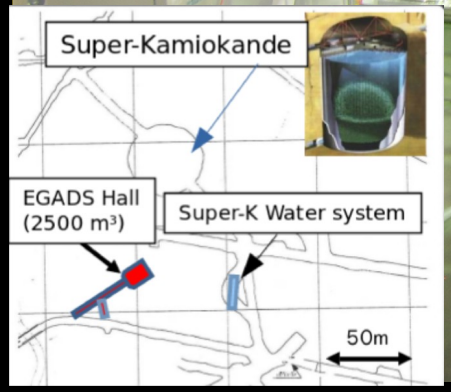
R&D test facility to prove Gd related techniques for SuperK (SK-Gd)

Dissolution and pre-treatment system

200-ton detector with 240 photomultipliers

Fast recirculation system

Selective band-pass filtration system



More infos here:

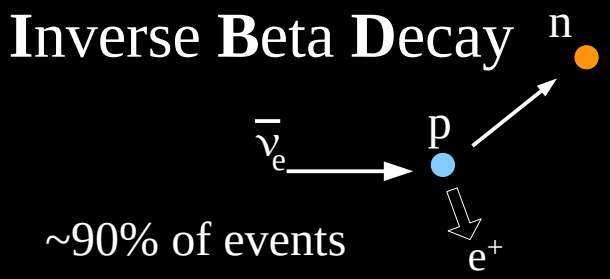
arXiv:1908.11532v1

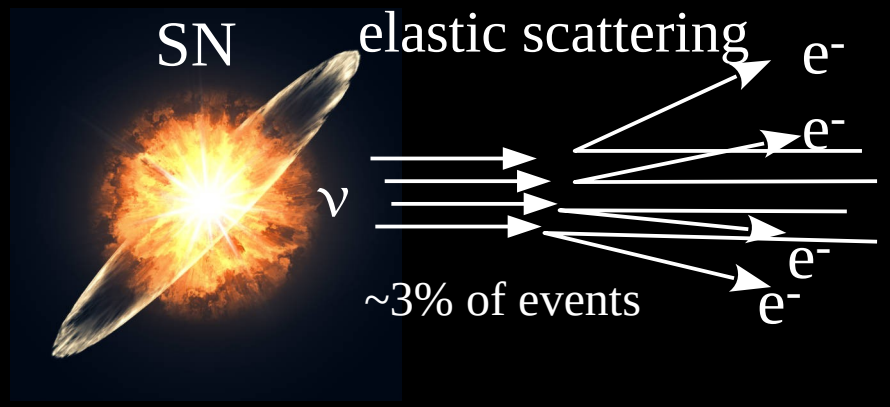
arXiv:2109.00360v3

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

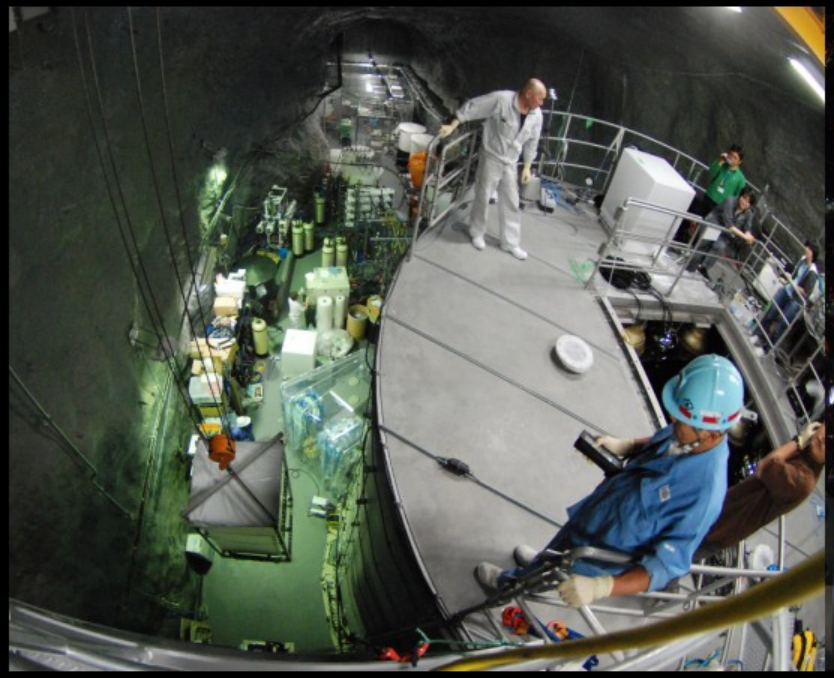


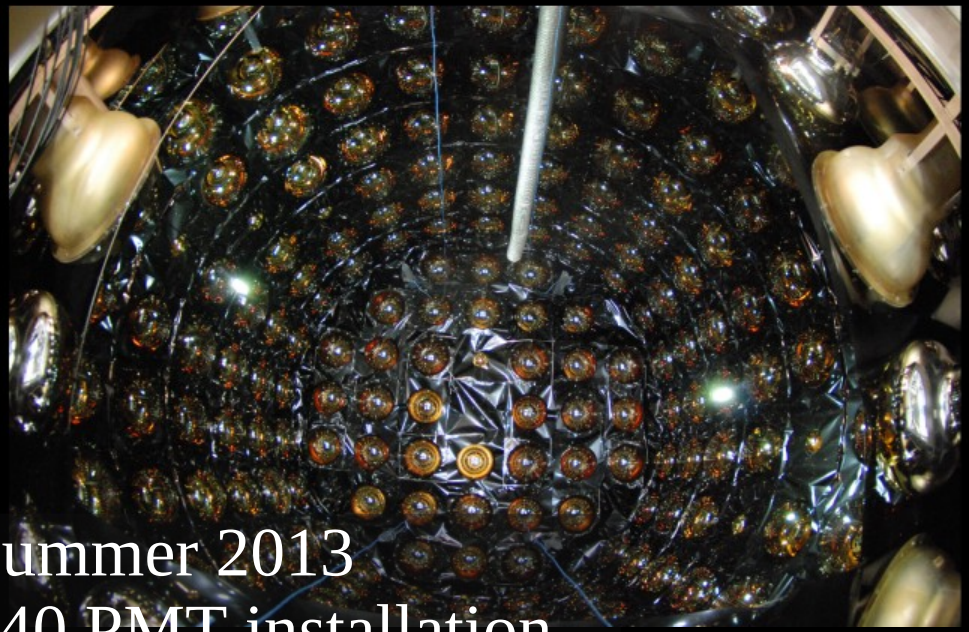


- The event rate can be very high for a close SN:
  → Could our DAQ withstand the high rates of a close SN?
- The number of expected events decreases with distance:
  → Can we efficiently detect a SN in the far side of our galaxy?

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

PMT and electronics installation





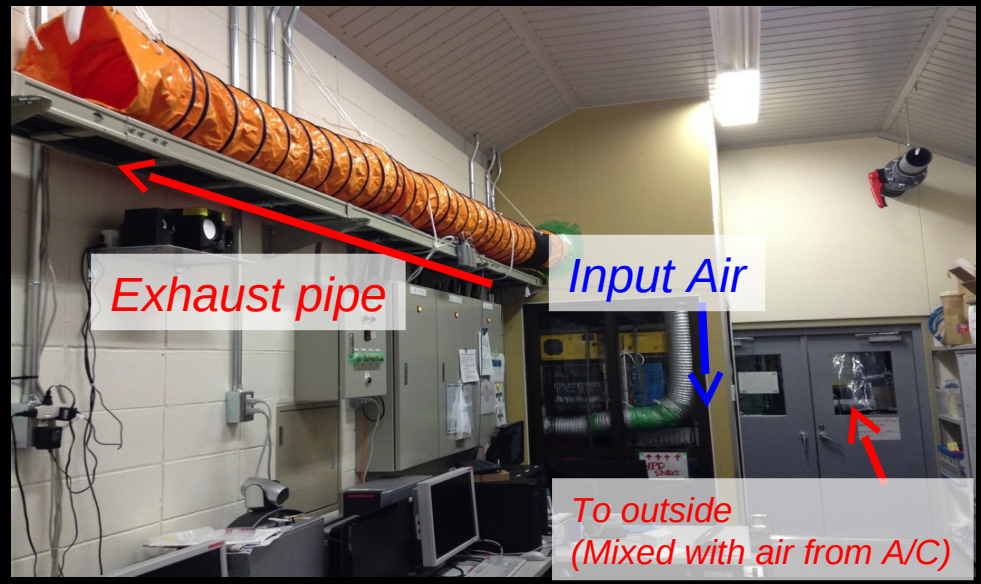
Summer 2013
240 PMT installation

PMT and electronics installation

- DAQ runs with very high livetime (> 99%).
- Temperature stable within ~1º C.

- DAQ and slow control monitor checks every 2 hours by shifters:
  - detector compensation coils.
  - PMT HV (CAEN).
  - DAQ status.

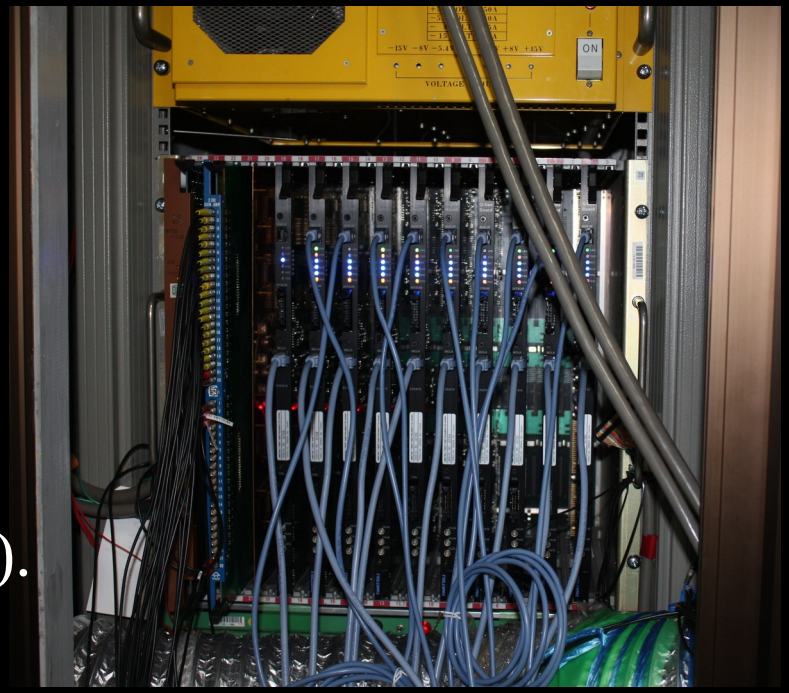
- Automated warning emails to experts in case of problems.



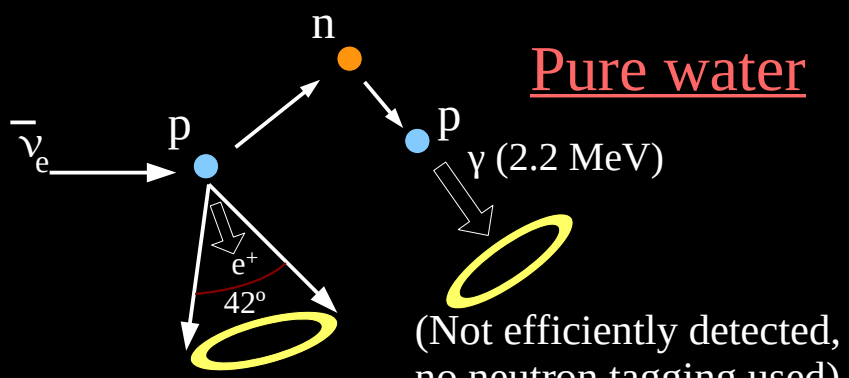
- June 2017: front-end electronics were upgraded to withstand the high event rates needed to withstand a close SN.

→ 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.



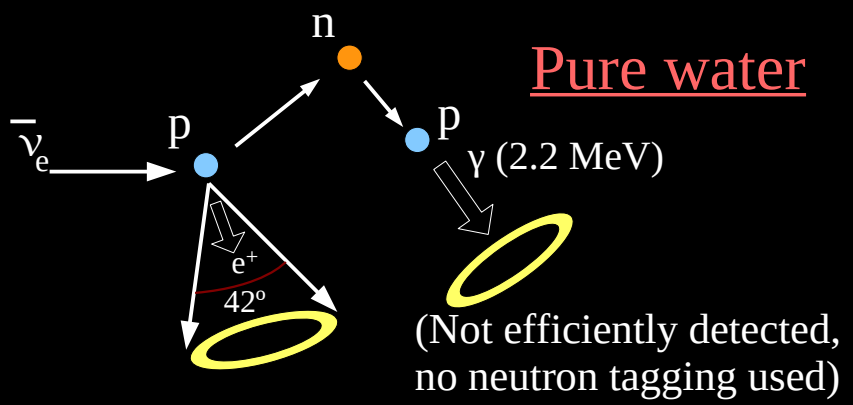
Efficient neutron tagging



Pure water

(Not efficiently detected,
no neutron tagging used)

Efficient neutron tagging



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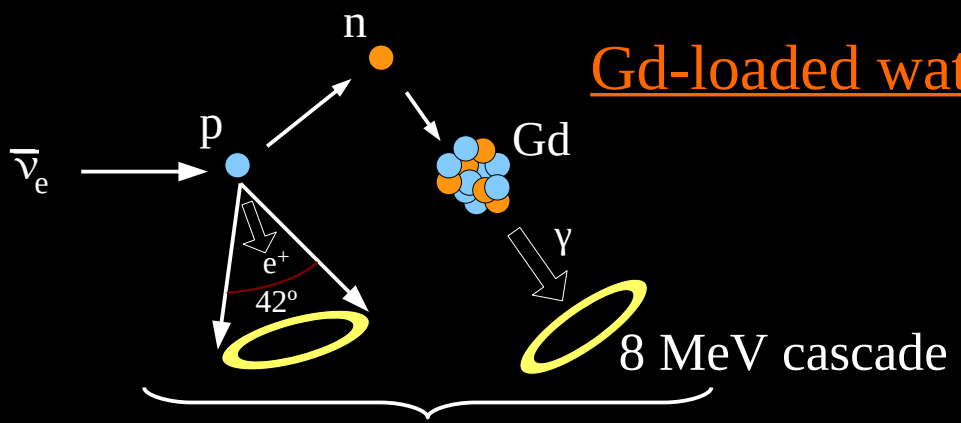


Gd-loaded water

With tight time (delayed) and position coincidence between positron and neutron capture (90% neutron capture on Gd with 0.2% $Gd_2(SO_4)_3$ concentration) we are able to reduce backgrounds*.

- Neutrinos from ccSNe are detected mostly from IBD events.
- Being able to efficiently detect neutrons reduces backgrounds.
  → Detecting a few of them are enough to trigger a SN confidently.
- EGADS current Gd concentration is 0.03% (75% of captures on Gd).
  → It will be loaded to the final concentration of 0.1% Gd in the future (90% captures on Gd).

*Idea proposed as GADZOOKS! by Beacom & Vagins PRL.93, (2004) 171101

HEIMDALL

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

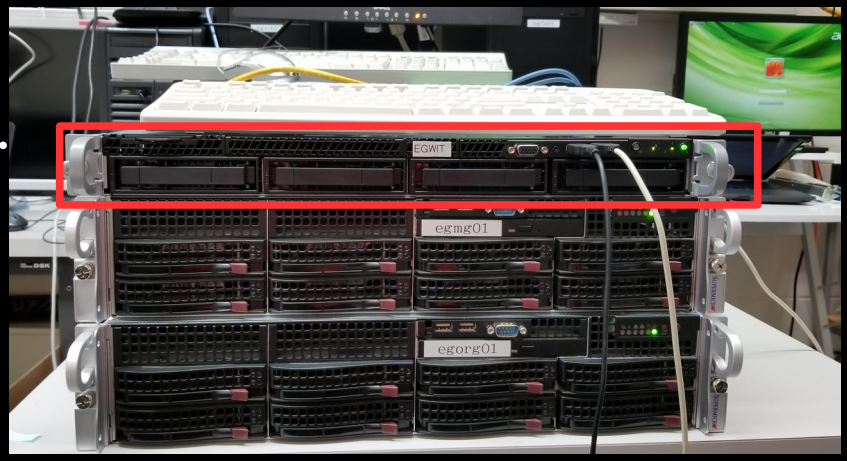
HEIMDALL is an online machine that searches for IBD (prompt + delayed neutron capture) events in real time:

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).

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



- EGADS/HEIMDALL is watching for SNe:

→ HEIMDALL watches for galactic SNe and would give an instant, automatic and independent alert to us and the community.

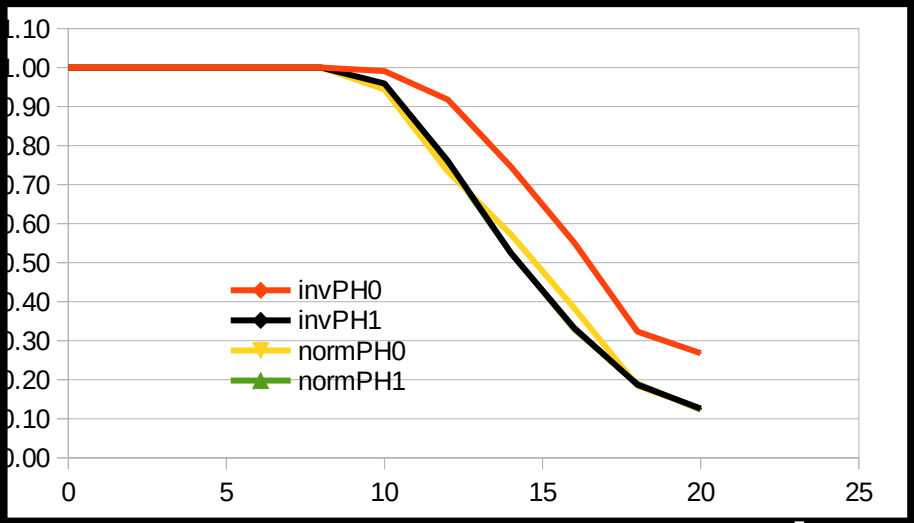
→ detection status is **open to everybody** at: http://egads.epizy.com/SNmonitor.html

→ **automated SN warning mails** at: martillu_at_suketto.icrr.u-tokyo.ac.jp

SN detection efficiencies

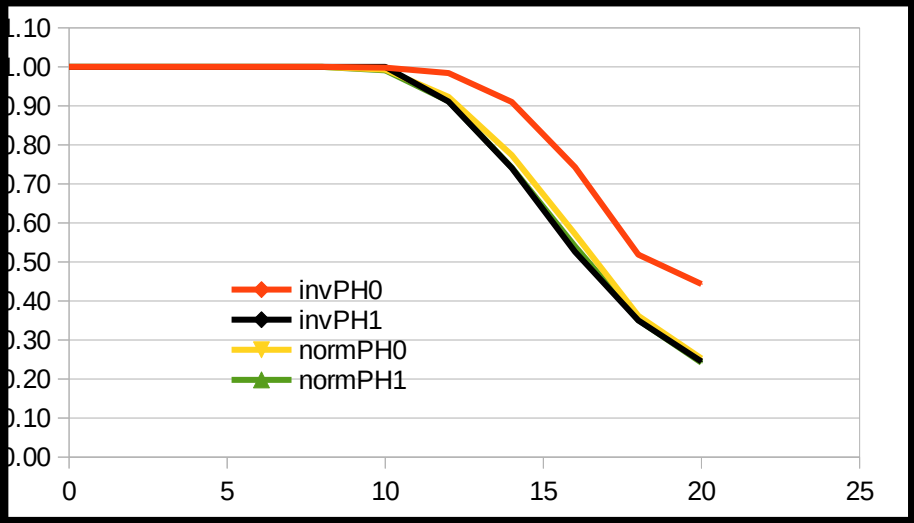
- Calculated the SN detection efficiency:
Nakazato model for: M=13, Z=0.02 trev=100 ms.
IBD in 10 sec threshold ≥ 3

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

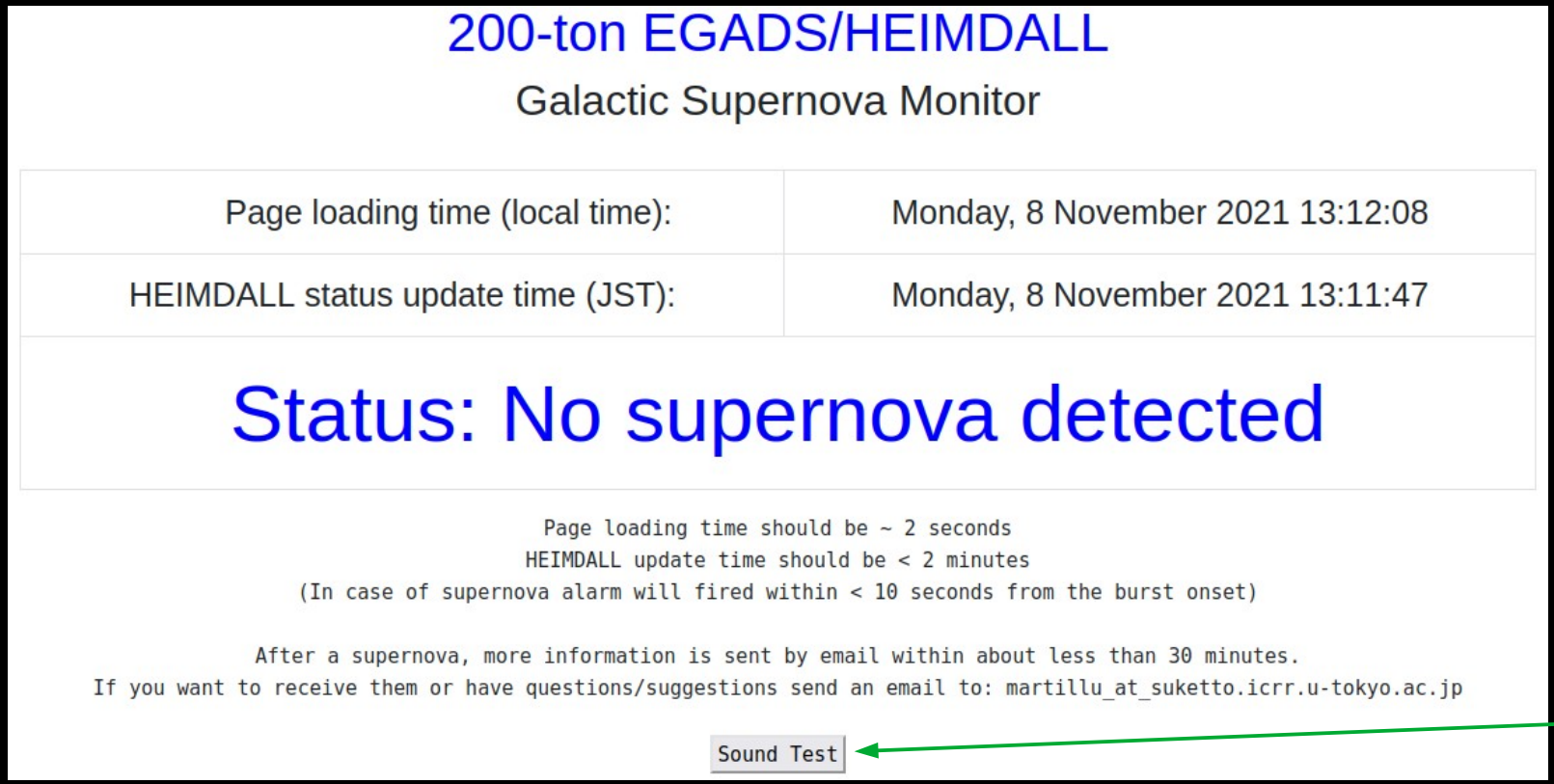
Good galactic coverage already with the current concentration.

Evaluating
Gadolinium's
Action on
Detector
Systems

Employing
Gadolinium to
Autonomously
Detect
Supernovas

Public EGADS/HEIMDALL status

- Available for anyone. Check: http://egads.epizy.com/SNmonitor.html
- The HEIMDALL status is updated within < 2 minutes
  - However, in case of SN: updated immediately after SN burst detection.
  - Includes an audible alarm.



Check the sound test !!

Feel free to check and spread the word!!

Summary and information

EGADS/HEIMDALL:

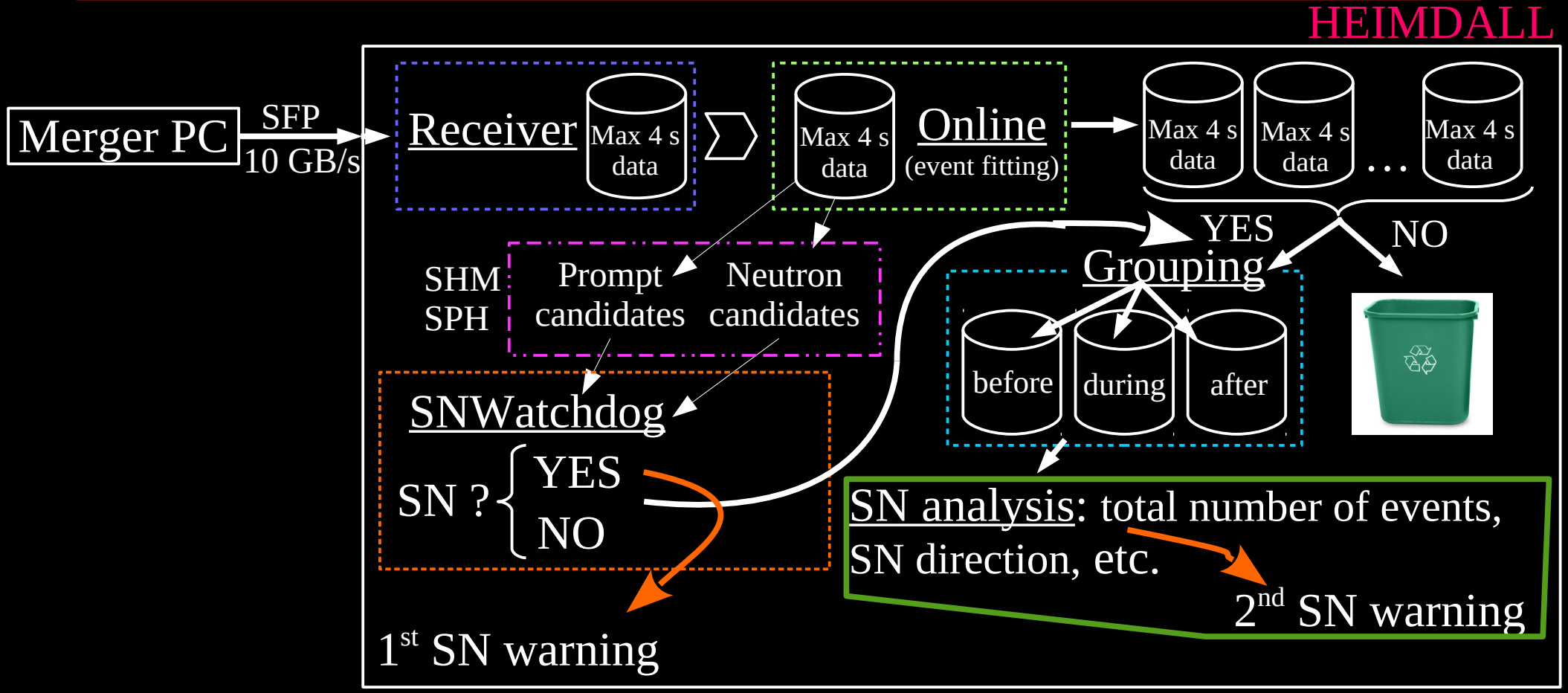
→ 200-ton Gd loaded detector with good ccSNe coverage in our galaxy:
→ can withstand the high event rates of close ccSNe.
→ high neutron high efficiency detection (thanks to Gd) enables background suppression for the most important reaction in case of ccSN (IBD).
➡ just 3 or more IBD are enough to claim detection.

→ very short lead time (~5 seconds from neutrino burst onset).
- Minutes can be precious for telescopes!
→ very high life time (> 99%).
→ coming soon: SN direction capabilities for close ccSNe.

Useful information:

→ detection status is **open to everybody** at: http://egads.epizy.com/SNmonitor.html
→ **automated SN warning mails** at: martillu_at_suketto.icrr.u-tokyo.ac.jp

HEIMDALL Data treatment

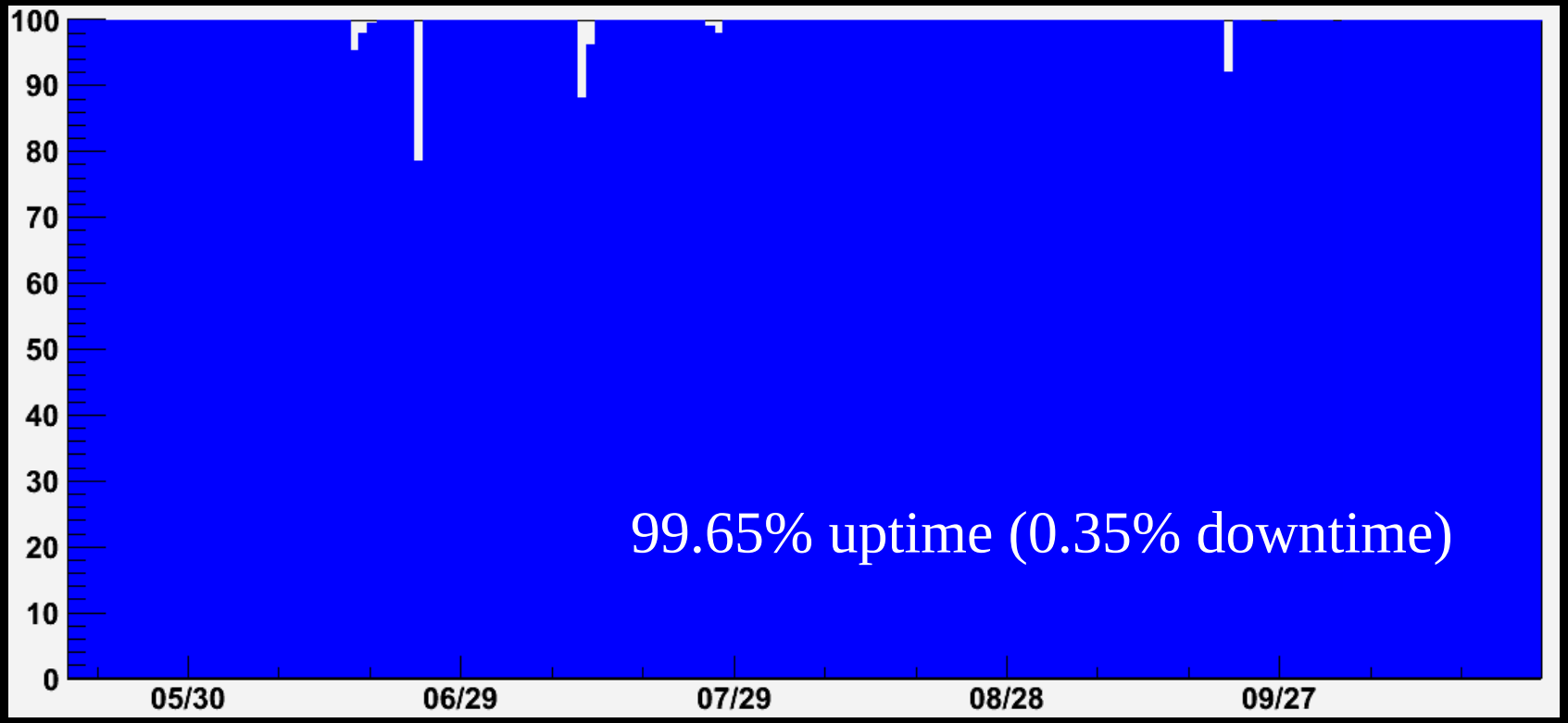


- HEIMDALL keeps ~8 minutes of raw data. In case of SN:
  - Framework for SN analysis done:
    → Number of events, number of IBD events and coarse calculation of SN direction has been implemented (equatorial coordinate system & 200x200 bins for α and δ)

→ Now, implementing a SN direction fit à la SK.

Lifetime since last CM

Very high lifetime for EGADS/HEIMDALL (May 17th – Oct 25th 2021):



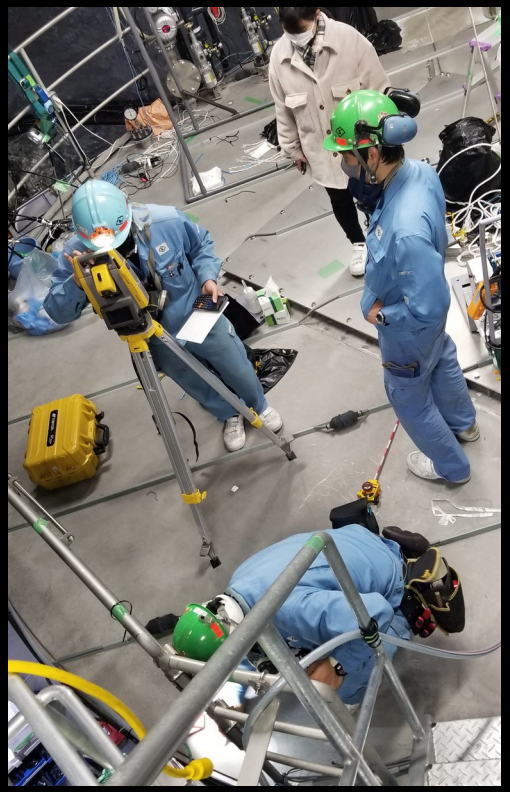
- Simultaneous HEIMDALL/SK SN downtime: 365 sec on June/18:
  Problems with EGADS channel 220 && SK ID channel 2530.

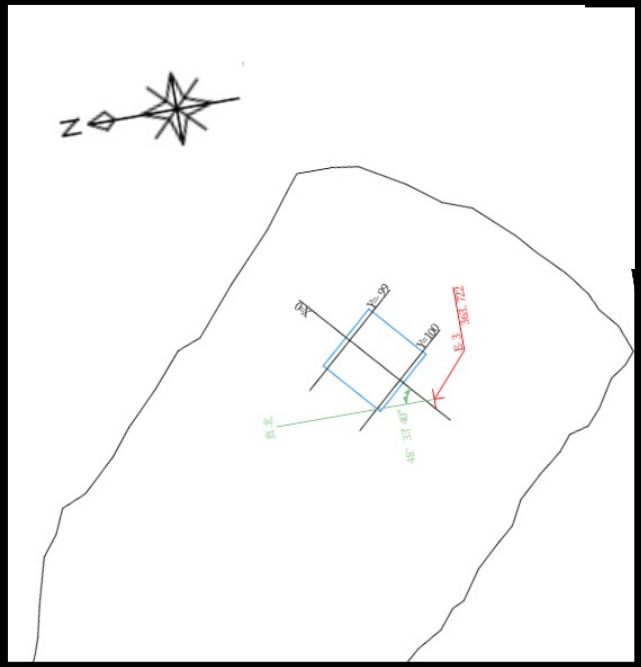
» 0.003% simultaneous HEIMDALL/SK downtime.

Pointing to SN

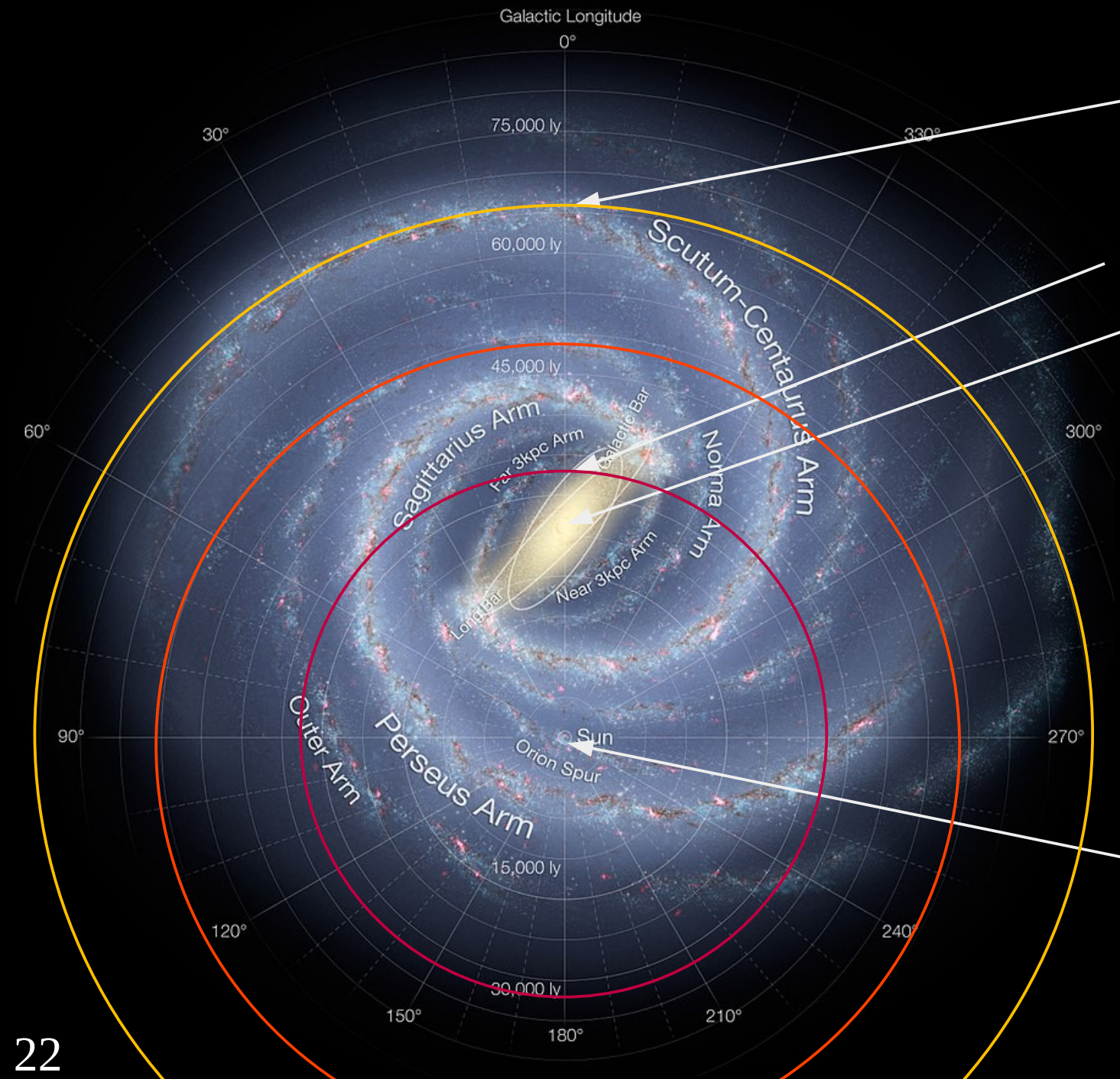
- In case of a close enough SN EGADS/HEIMDALL could point to a SN by using elastic scattering events.

- To provide this capability, we must know the relative position of the EGADS coordinate system to the celestial coordinate system:
  → Determination of the direction to the North done last February.





EGADS/HEIMDALL in the galaxy



20 kpc

10 kpc

Galactic center ~8 kpc

EGADS/HEIMDALL

HEIMDALL introduction/motivation

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

- EGADS/HEIMDALL watches in real time for galactic SNe:

→ For close SNe: new electronics allow acquisition of high event rates

→ Far SNe: neutron tagging with Gd, i.e. detecting a few IBD-compatible events will tell us a SN happened

→ HEIMDALL watches for galactic SNe and will give an instant, automatic and independent alert to us and the community

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