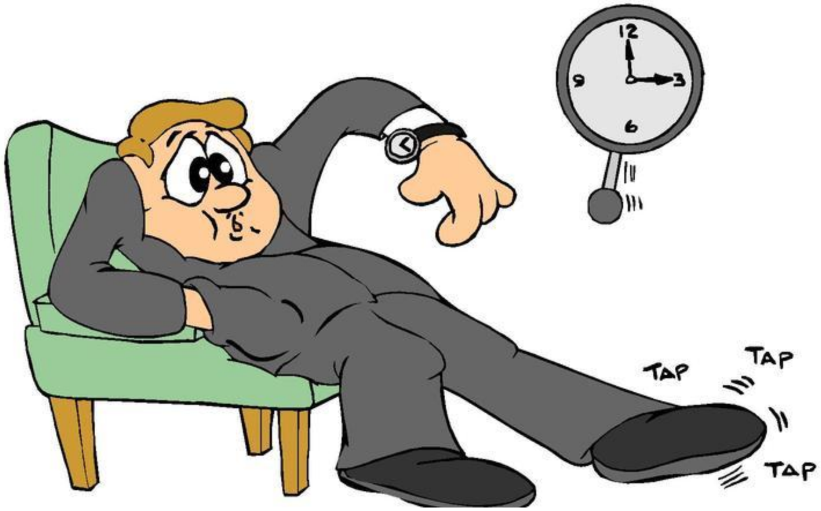
# Detection of Supernova Neutrinos



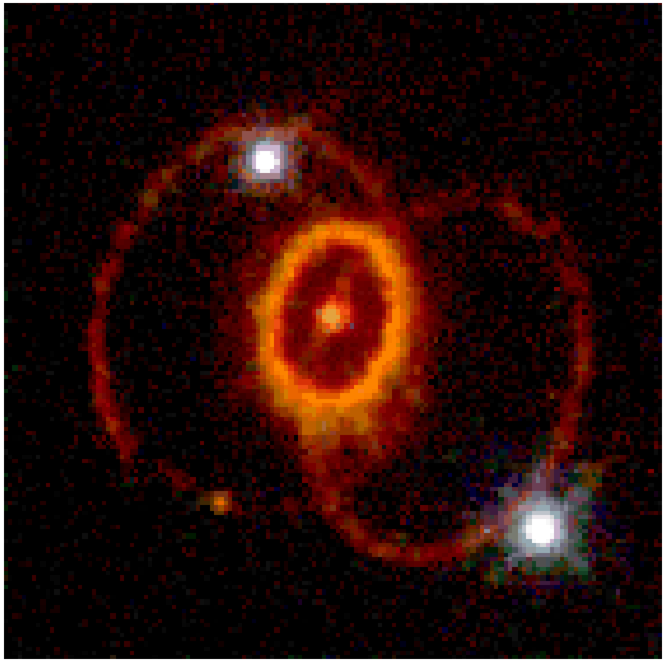

Mark Vagins
IPMU, University of Tokyo

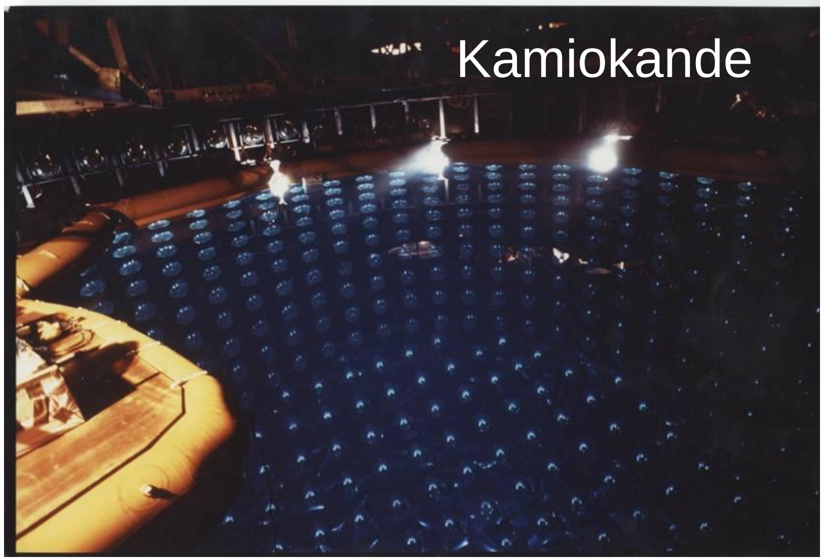
Neutrino 2010 - Athens
June 19, 2010

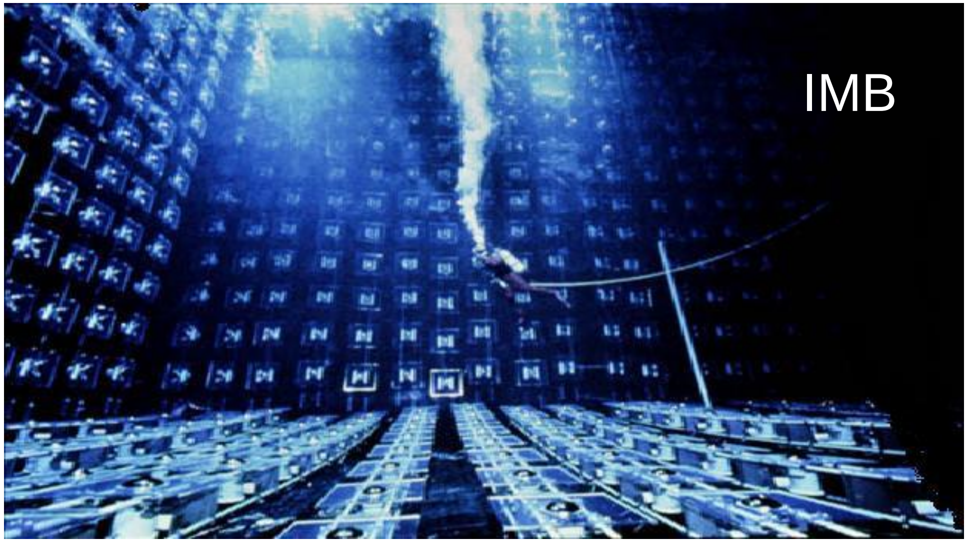
# A long time ago, in a (neighbor) galaxy far, far away…

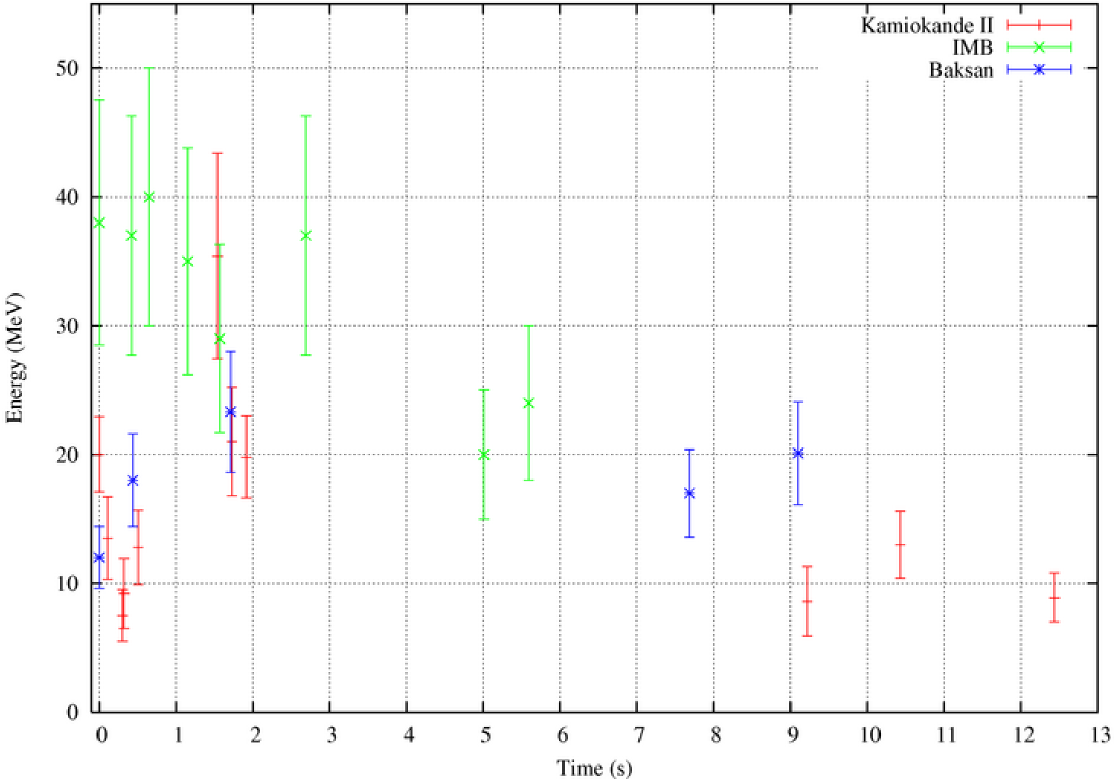
# A long time ago, in a (neighbor) galaxy far, far away…

Sandulеak $-69^{o}$ 202 was gone, but not forgotten.




Kamiokande


IMB


Kamiokande II
IMB
Baksan
Energy (MeV)
Time (s)
0
10
20
30
40
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13

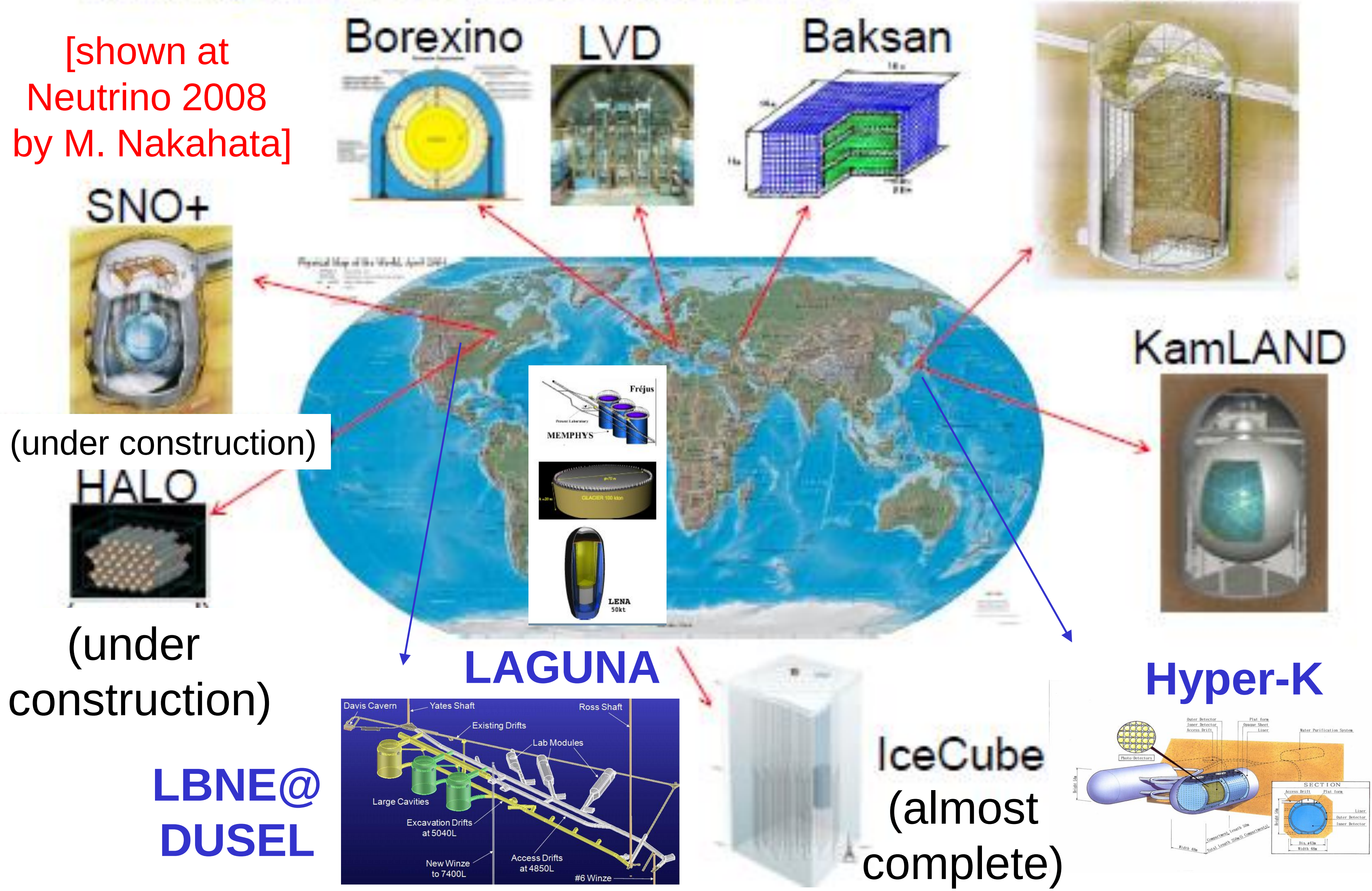

Baksan

Based on the handful of supernova neutrinos which were detected that day, approximately <u>one theory paper has been published every ten days</u>…

*….for the last <u>twenty-three years!</u>*

# Supernova detectors in the world

(running and near future experiments)



[photo courtesy C. Virtue]

HALO status as of March 2010 in SNOLAB

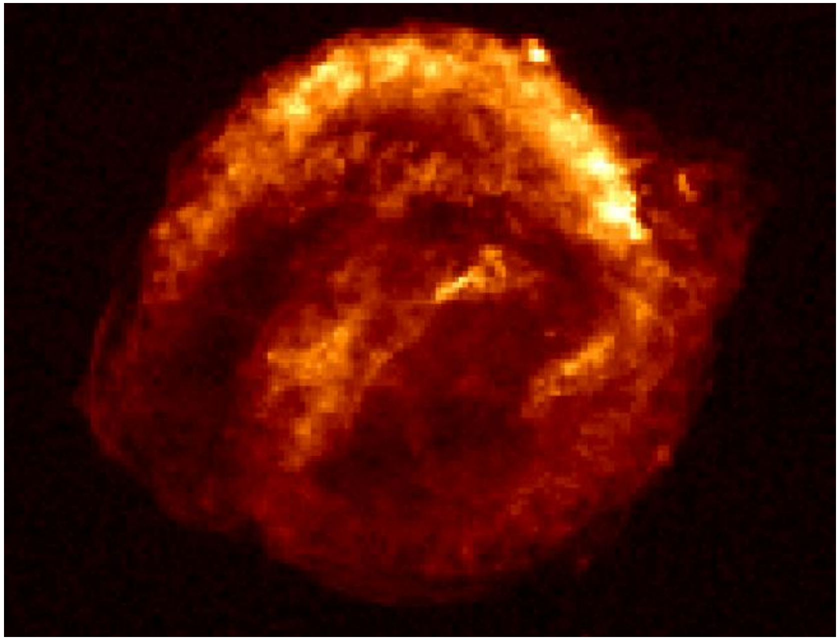
Helium And Lead Observatory

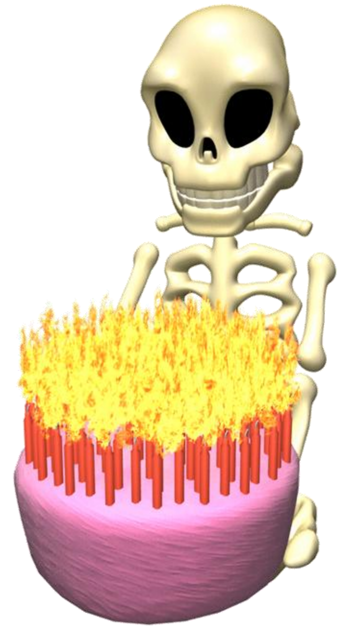
Reuses SNO $^3$He counters, plus 76 tons of existing lead

Primarily sensitive to $\nu_e$, so complementary to WC. About 50 events at 10 kpc.

*This is the first dedicated galactic SN detector since LVD in 1992!*

Should come online this year and join SNEWS in 2011.





Of course, it has been a couple of decades since SN1987A, and 405 years and 253 days since a supernova was last definitely observed within our own galaxy!

No neutrinos were recorded that mid-October day in 1604…

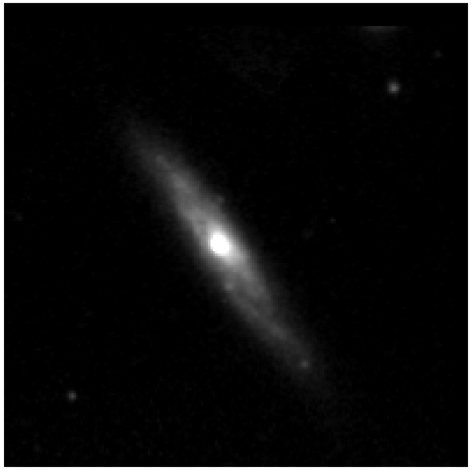
but it was probably a type Ia, anyway!

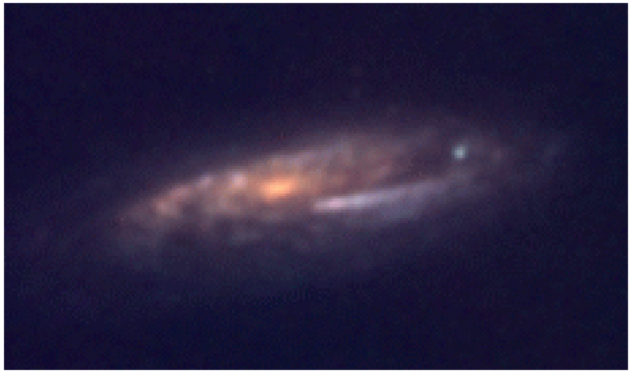
This talk is about *detecting* supernova neutrinos.

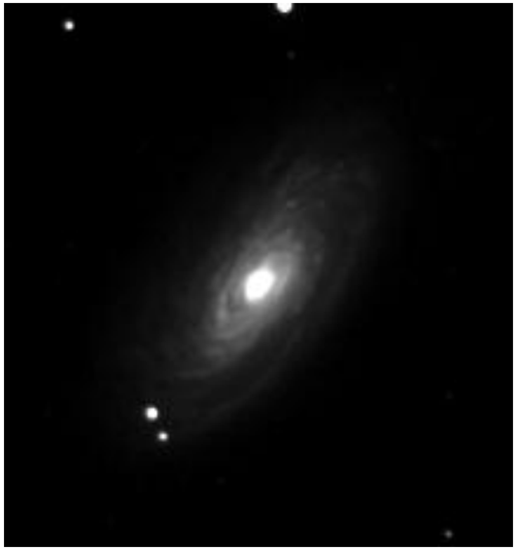
But how can we be <u>certain</u> to see some supernova neutrinos without having to wait too long?

# This is not the typical view of a supernova! Which actually… is good.

Yes, nearby supernova explosions may be rare, but supernova explosions are quite common.



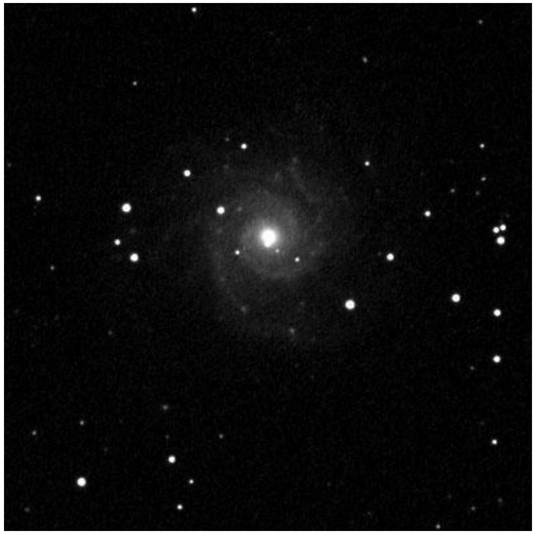




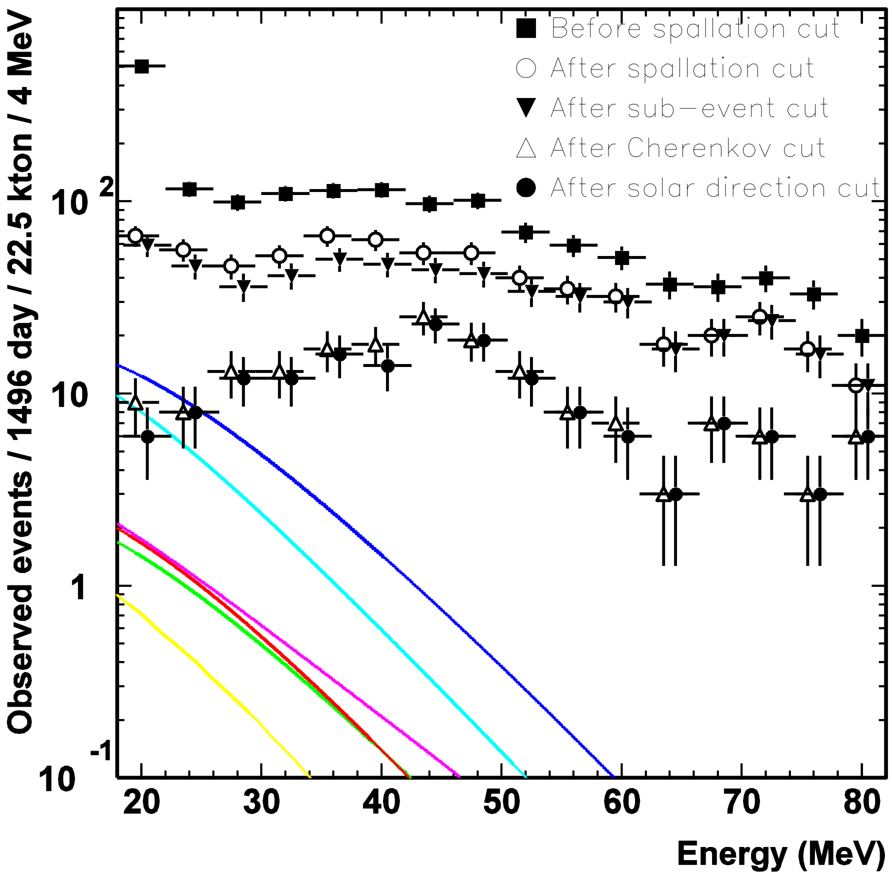
Here's how most of them look to us (video is looped).

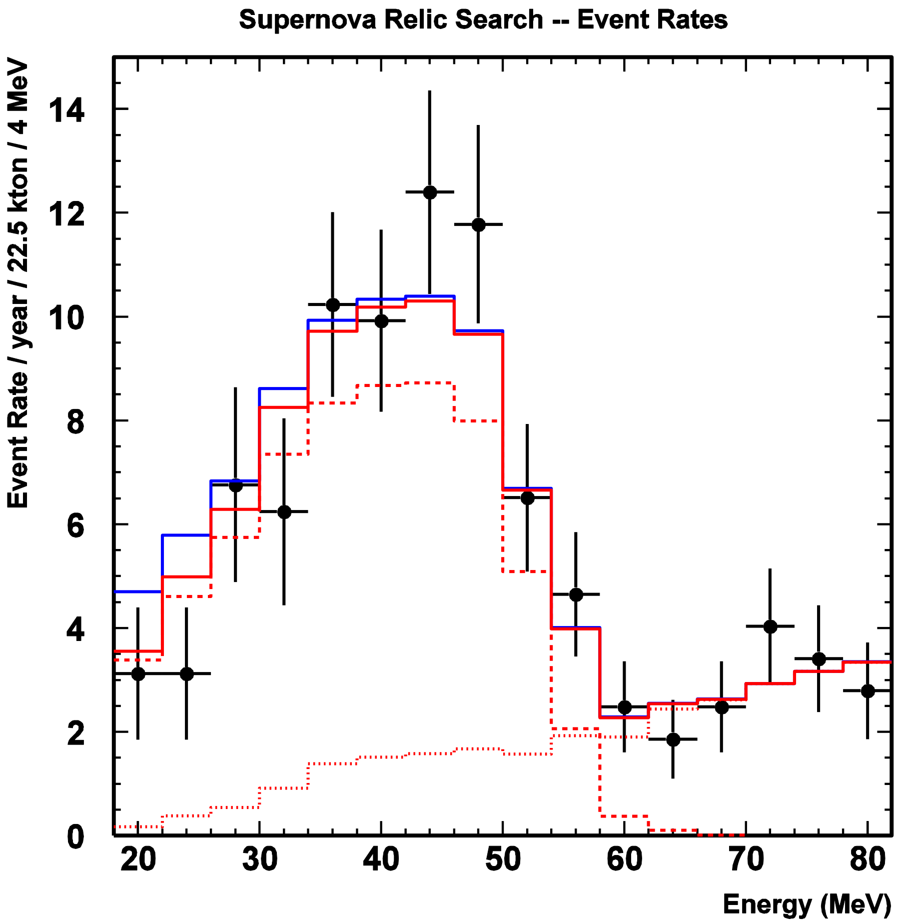
On average, there is <u>one supernova explosion each second</u> somewhere in the universe!

These produce a diffuse supernova neutrino background [DSNB], also known as the supernova relic neutrinos [SRN].



**In 2003, Super-Kamiokande published the world's best limits on this so-far unseen flux [M.Malek *et al., Phys. Rev. Lett.* 90 061101 (2003)].**

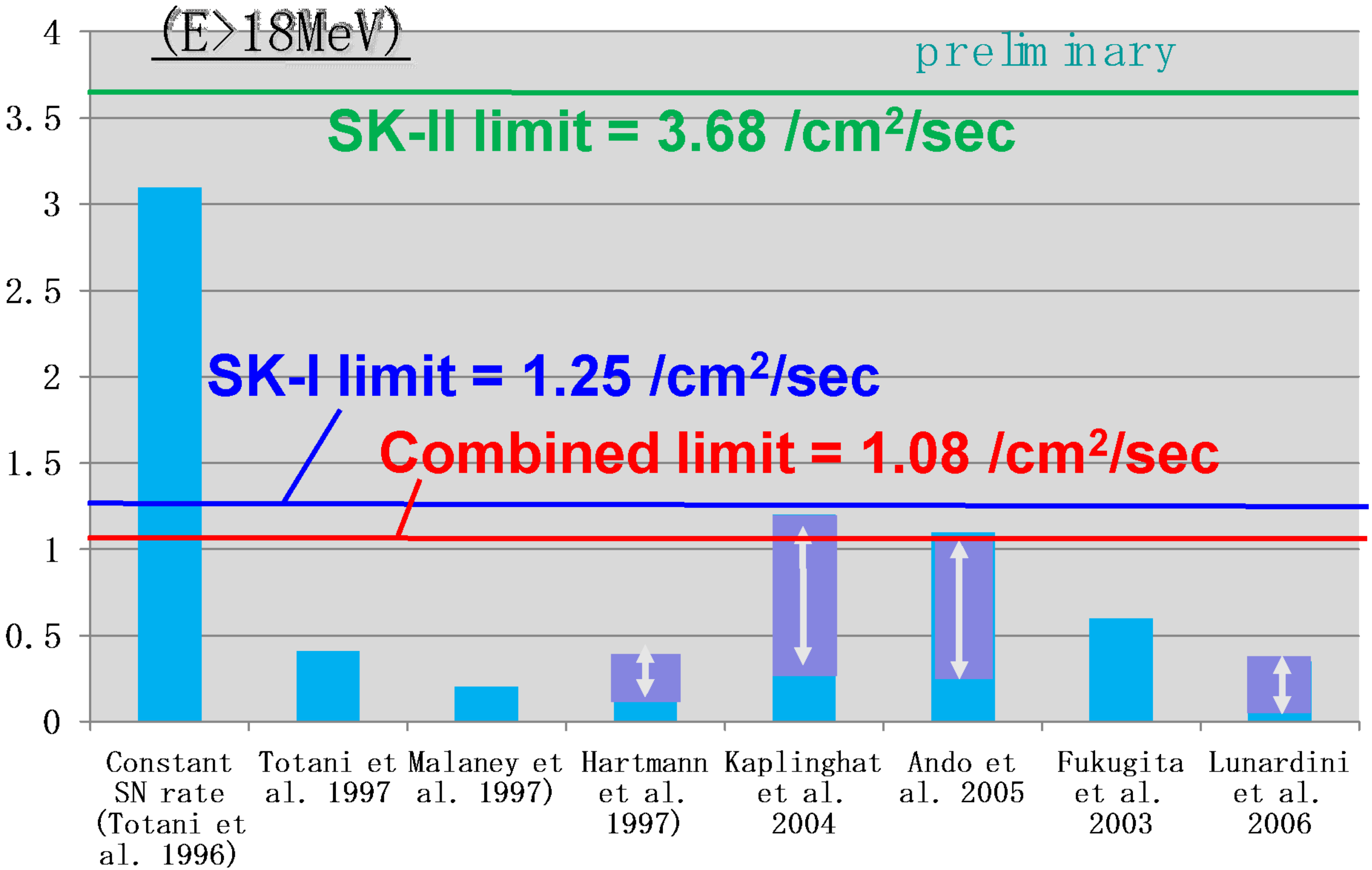



Unfortunately, the search was strongly limited by backgrounds, and no clear event excess was seen.

# Super-K I and II results:
# Flux limit vs. predicted flux

[see poster by K. Bays for SK-III status]



So, experimental DSNB limits are approaching theoretical predictions. Clearly, reducing the remaining backgrounds and going lower in energy would extremely valuable.

Note that all of the events in the present SK analysis are singles in time and space.

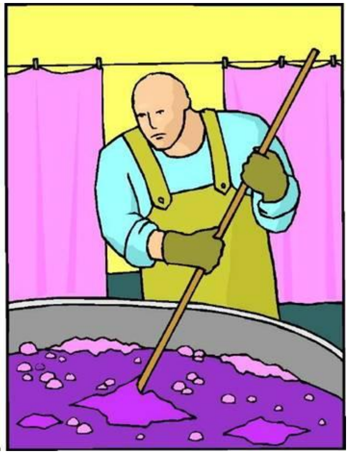
And this rate is actually very low… just three events per cubic meter per *year.*

# How can we identify neutrons produced by the inverse beta process (from supernovae, reactors, etc.) in really big water Cherenkov detectors?

$$\bar{\nu}_e + p \longrightarrow e^+ + n$$

Much beyond the kiloton scale, you can forget about using liquid scintillator, $^3$He counters, or $D_2O$!

Without a doubt, at the 50 kton+ scale the only way to go is a solute mixed into the light water...



**With this in mind, John Beacom and I wrote the original GADZOOKS!**

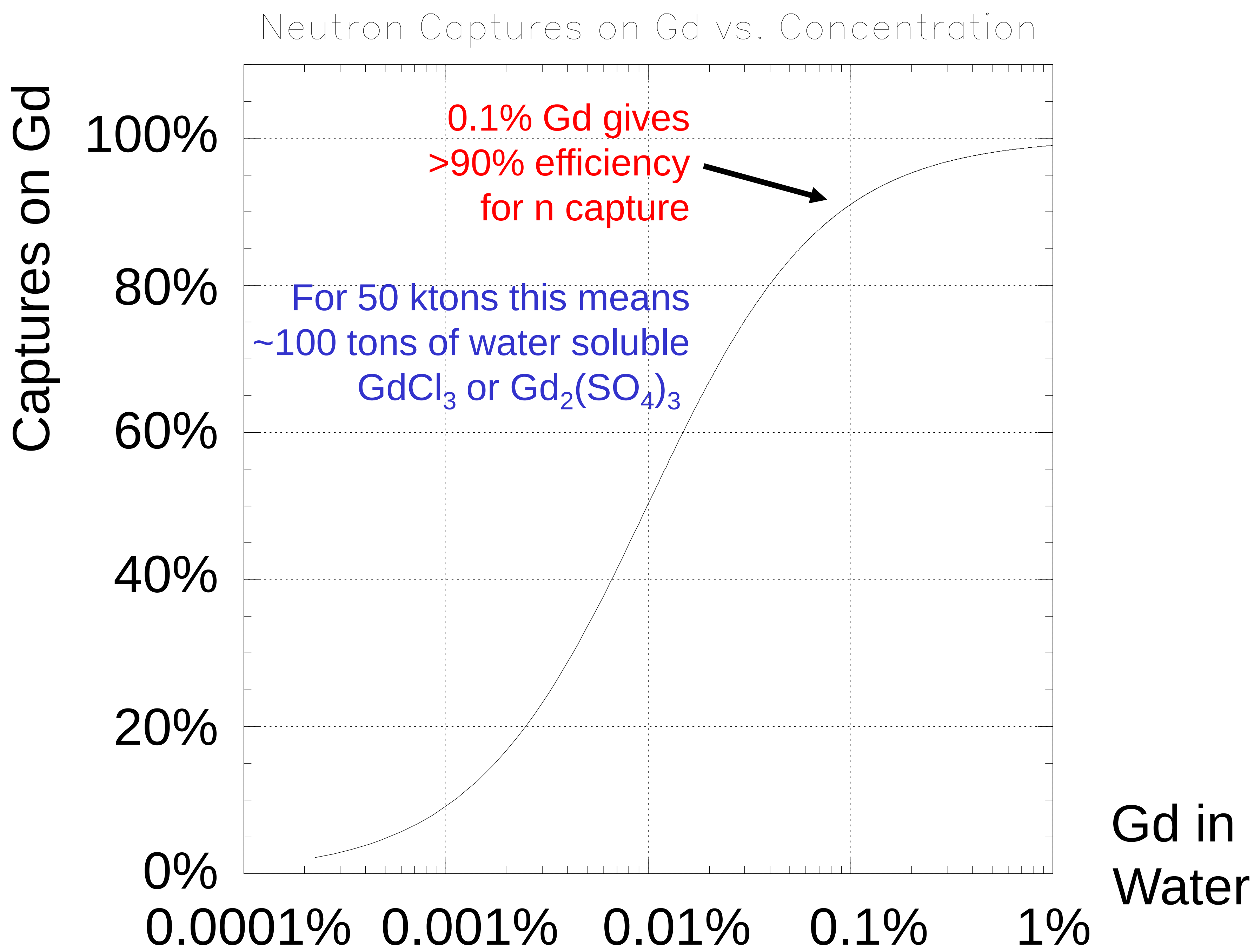
**(Gadolinium Antineutrino Detector Zealously Outperforming Old Kamiokande, Super!)**

**paper in late 2003. It was published the following year:**

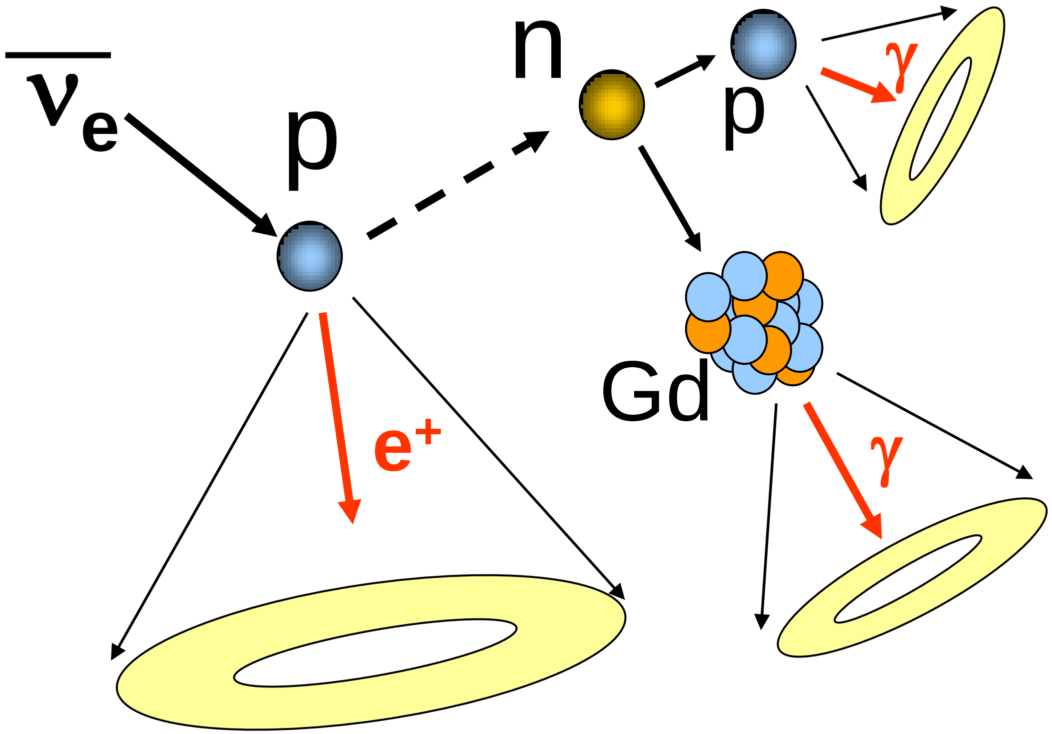
**[Beacom and Vagins, *Phys. Rev. Lett.*, 93:171101, 2004]**

# We eventually turned to the best neutron capture nucleus known – gadolinium.


- $GdCl_3$ and $Gd_2(SO_4)_3$, unlike metallic Gd, are highly water soluble
- Neutron capture on Gd emits a 8.0 MeV $\gamma$ cascade
- 100 tons of $GdCl_3$ or $Gd_2(SO_4)_3$ in Super-K (0.2% by mass) would yield >90% neutron captures on Gd
- Plus, they are easy to handle and store.


Neutron Captures on Gd vs. Concentration
Captures on Gd
100%
80%
60%
40%
20%
0%
0.0001%
0.001%
0.01%
0.1%
1%
Gd in Water
0.1% Gd gives >90% efficiency for n capture
For 50 ktons this means ~100 tons of water soluble $GdCl_3$ or $Gd_2(SO_4)_3$

# Neutron tagging in Gd-enriched WC Detector




Possibility 1: 10% or less

$n+p \rightarrow d + \gamma$

2.2 MeV γ-ray

Possibility 2: 90% or more

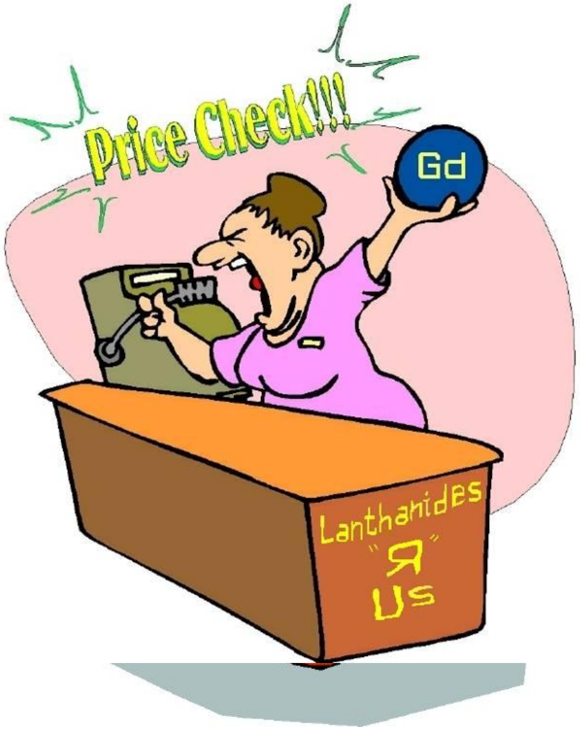
$n+Gd \rightarrow \sim 8MeV\ \gamma$

$\Delta T = \sim 30\ \mu sec$

Positron and gamma ray
vertices are within ~50cm.

$\bar{\nu}_e$ can be identified by delayed coincidence.

But, um, didn't you just say 100 *tons*?
What's that going to cost?




In 1984: $4000/kg –> $400,000,000

In 1993: $485/kg –> $48,500,000

In 1999: $115/kg –> $11,500,000

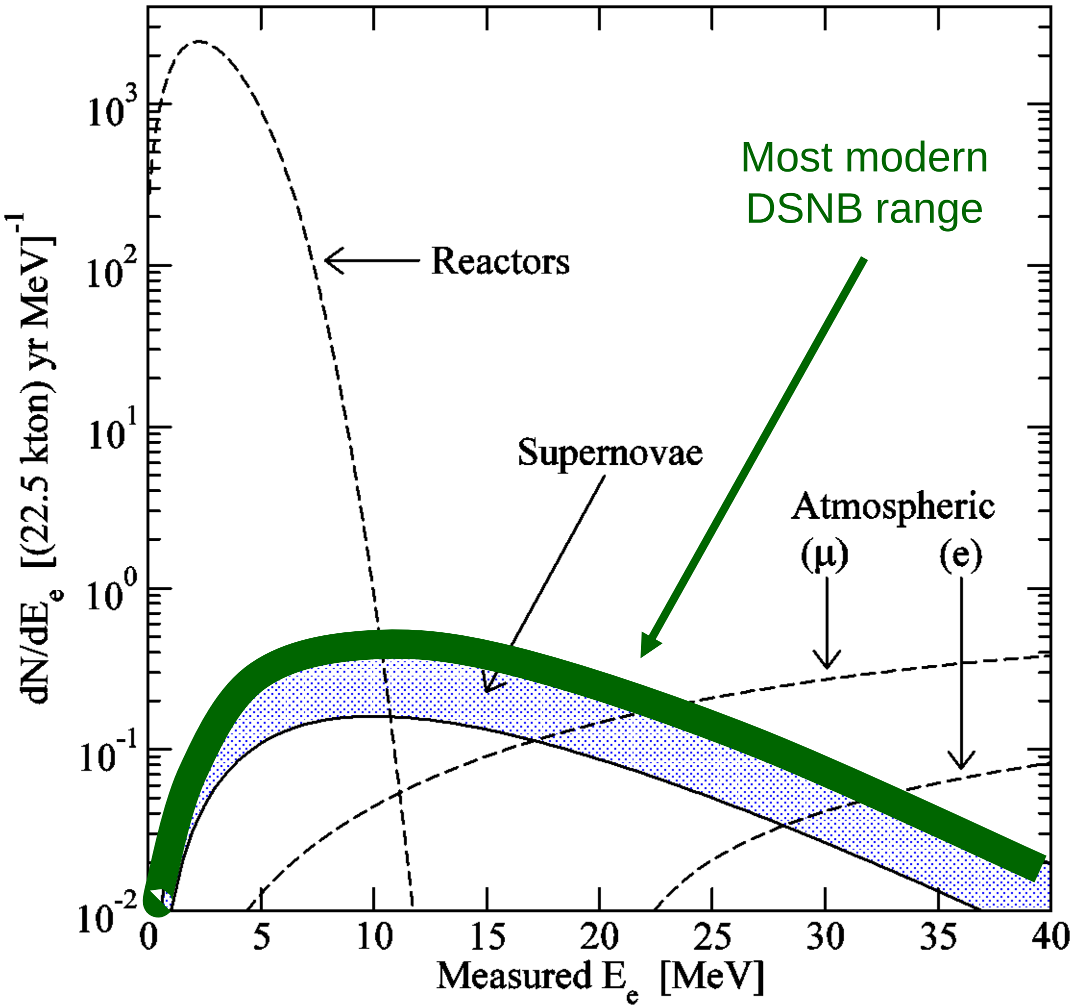
In 2010: $5/kg –> $500,000

These low, low prices are for real.

Back in 2005, \$24,000 bought me 4,000 kg of $GdCl_3$.

*Shipping from Inner Mongolia to Japan was included!*

# Here's what the coincident signals in Super-K with $GdCl_3$ or $Gd_2(SO_4)_3$ will look like (energy resolution is applied):



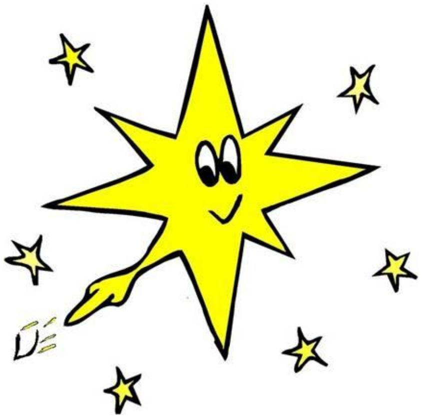

$\bar{\nu}_e + p \rightarrow e^+ + n$

spatial and temporal separation between prompt $e^+$ Cherenkov light and delayed Gd neutron capture gamma cascade:

$\lambda$=~4cm, $\tau$=~30$\mu$s

→ A few clean events/yr in Super-K with Gd

In a nutshell: adding 100 tons of soluble Gd to Super-K would provide <u>at least</u> two brand-new signals:

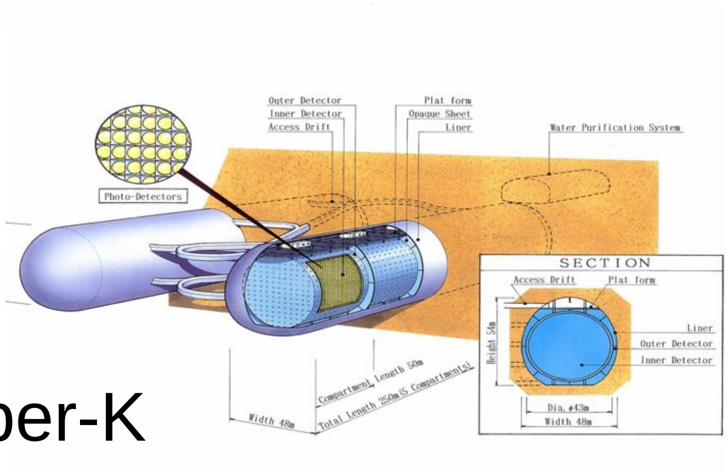



1) Discovery of the diffuse supernova neutrino background [DSNB], also known as the "relic" supernova neutrinos (up to 5 events per year)

2) Precision measurements of the neutrinos from all of Japan's power reactors (a few thousand events per year) Will improve world average precision of $\Delta m^2_{12}$

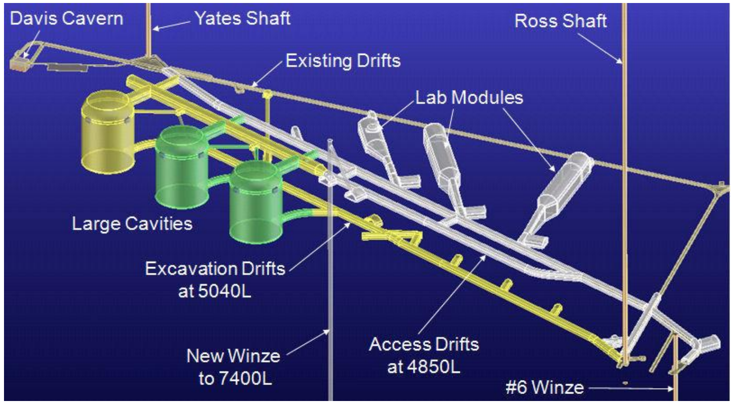
So, perhaps Super-K can be turned into a great big antineutrino detector… it would then steadily collect a handful of DSNB events every year with greatly reduced backgrounds and threshold.

Also, imagine a next generation, megaton-scale water Cherenkov detector collecting 100+ per year!




Hyper-K

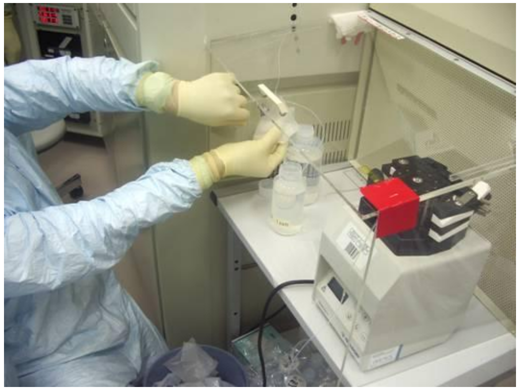
LBNE@ DUSEL

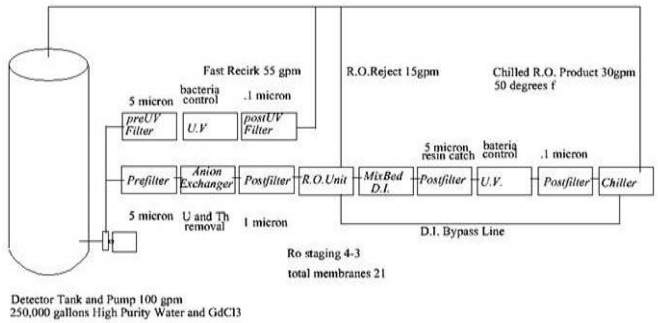



N.B.: This is the only neutron detection technique which is extensible to Mton scales, and at minimal expense, too: ~1% of the detector construction costs

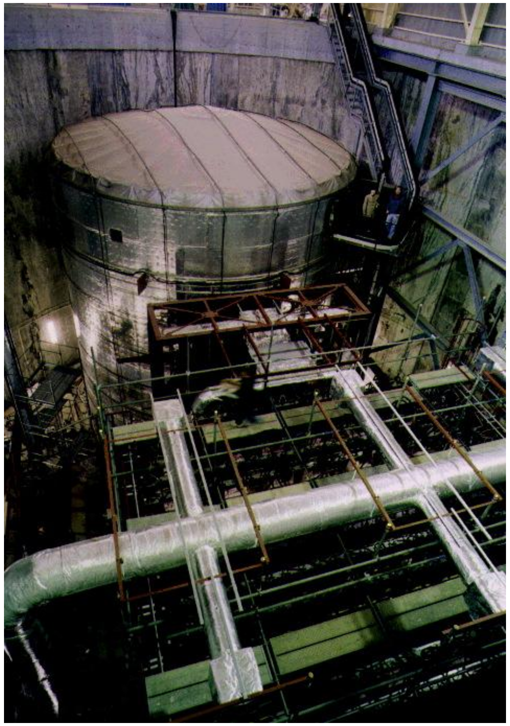
# Over the last seven years there have been a large number of Gd-related R&D studies carried out in the US and Japan:

[see poster by A. Renshaw]









## At Super-K, a calibration source using $GdCl_3$ has been developed and deployed inside the detector:

Am/Be source

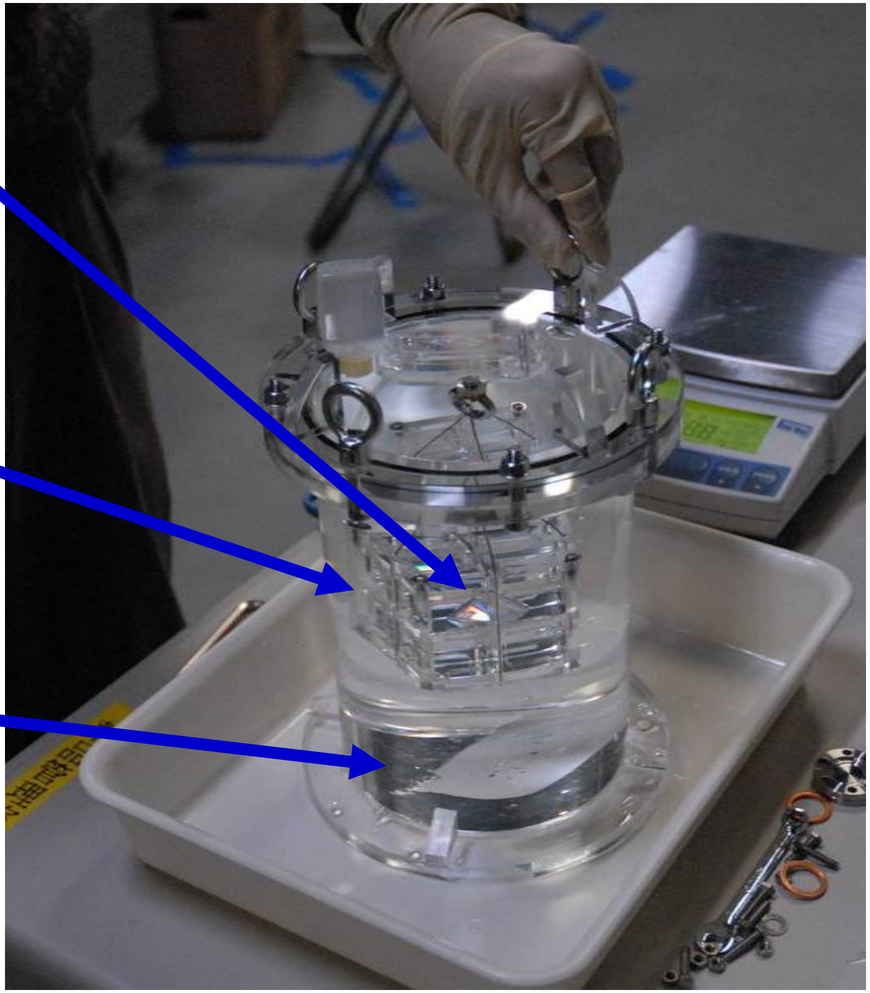
$\alpha + {}^{9}Be \rightarrow {}^{12}C^{*} + n$

${}^{12}C^{*} \rightarrow {}^{12}C + \gamma(4.4\ MeV)$

Inside a BGO crystal array

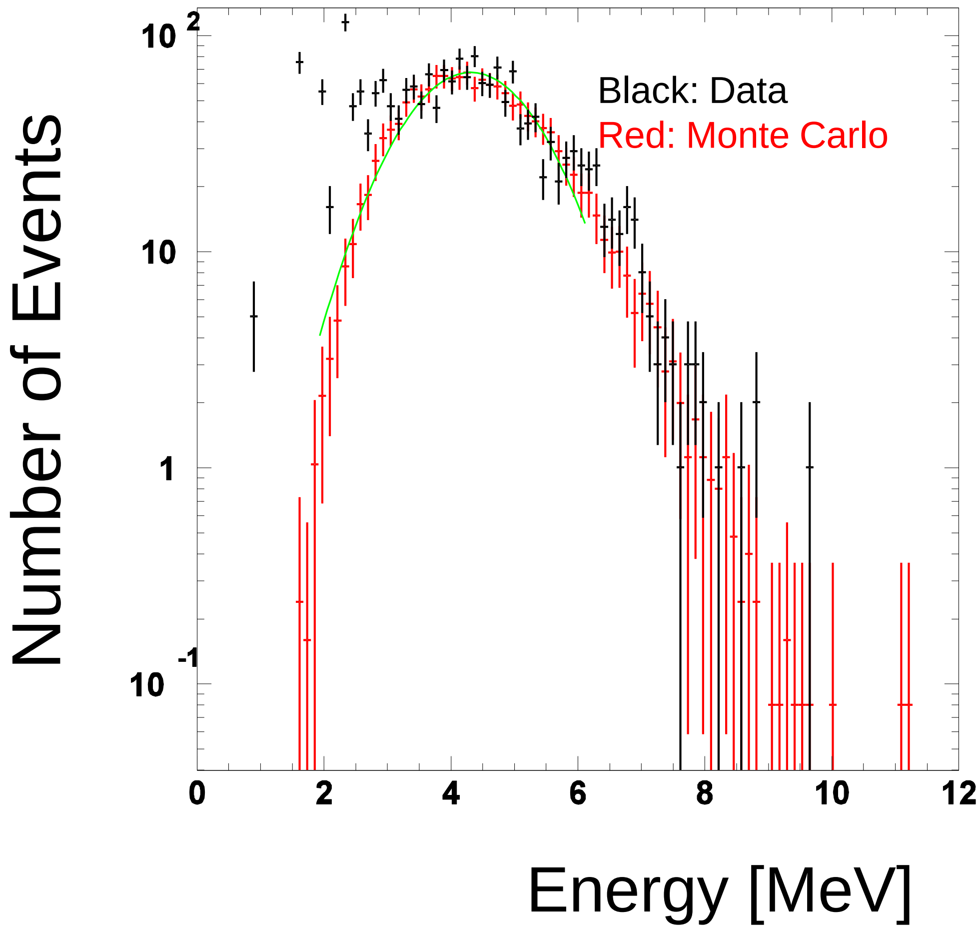
($BGO = Bi_4Ge_3O_{12}$)

Suspended in 2 liters of 0.2% $GdCl_3$ solution



Data was taken starting in early 2007.

We made the world's first spectrum of $GdCl_3$'s neutron capture gammas producing Cherenkov light:



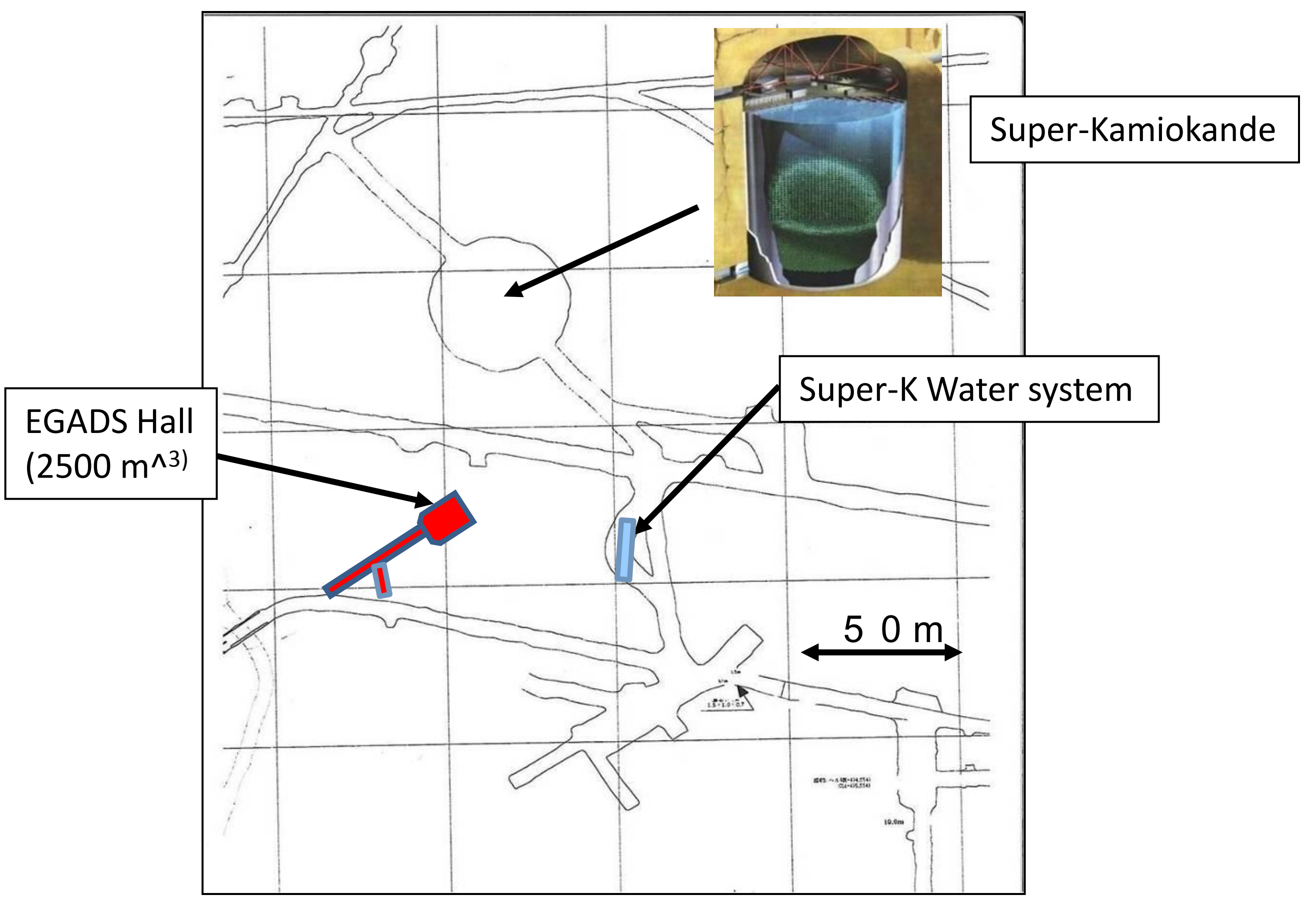

***First $GdCl_3$ "in" SK!***

**A paper on neutron tagging in Super-K, signed by the entire Collaboration, has been published:**

*Astropart.Phys **31**:320 (2009)*

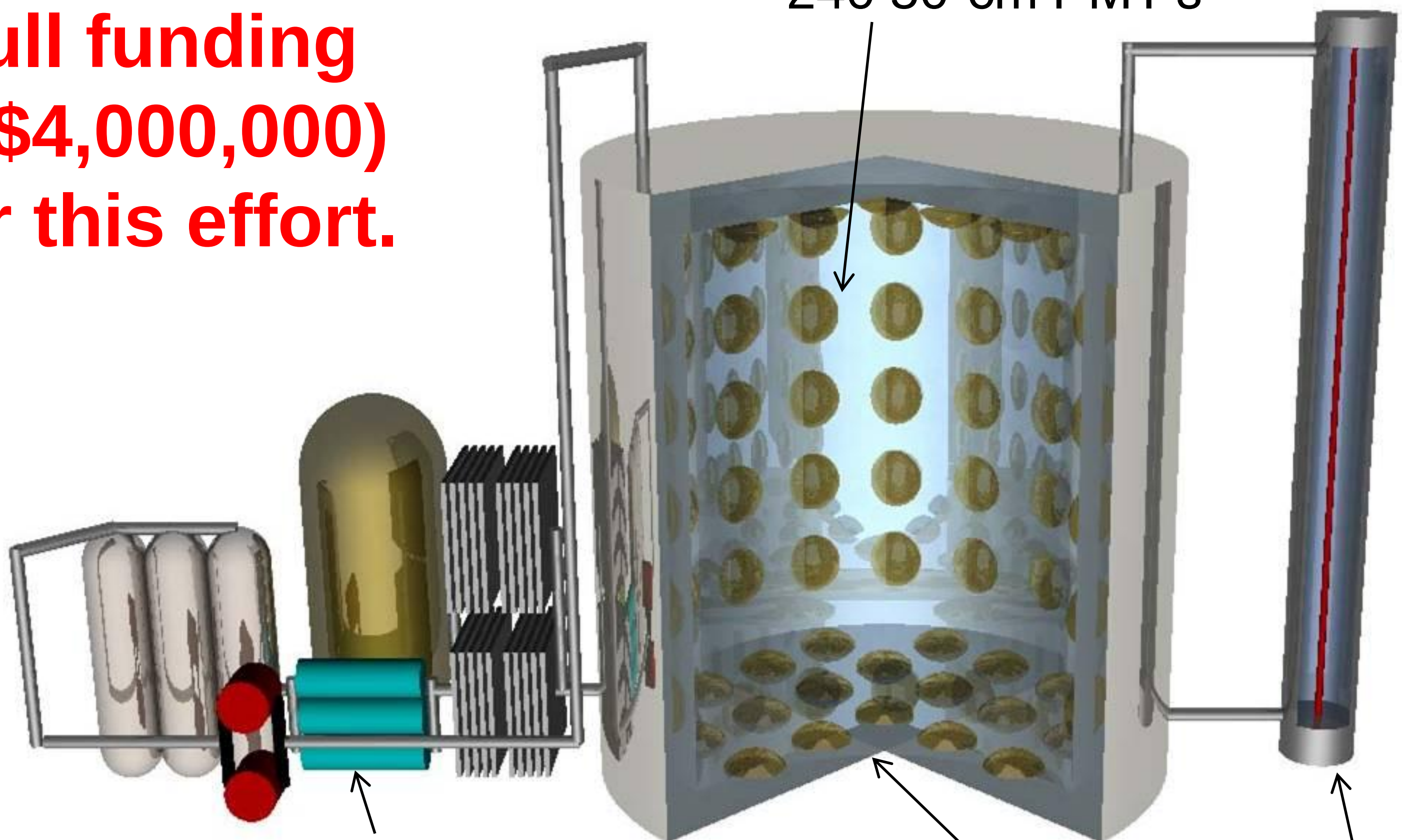
A dedicated Gd test facility is under construction in the Kamioka mine, complete with its own water filtration system, 50-cm PMT's, and DAQ electronics.

**This 200 ton-scale R&D project is called EGADS – Evaluating Gadolinium's Action on Detector Systems.**



# EGADS Facility

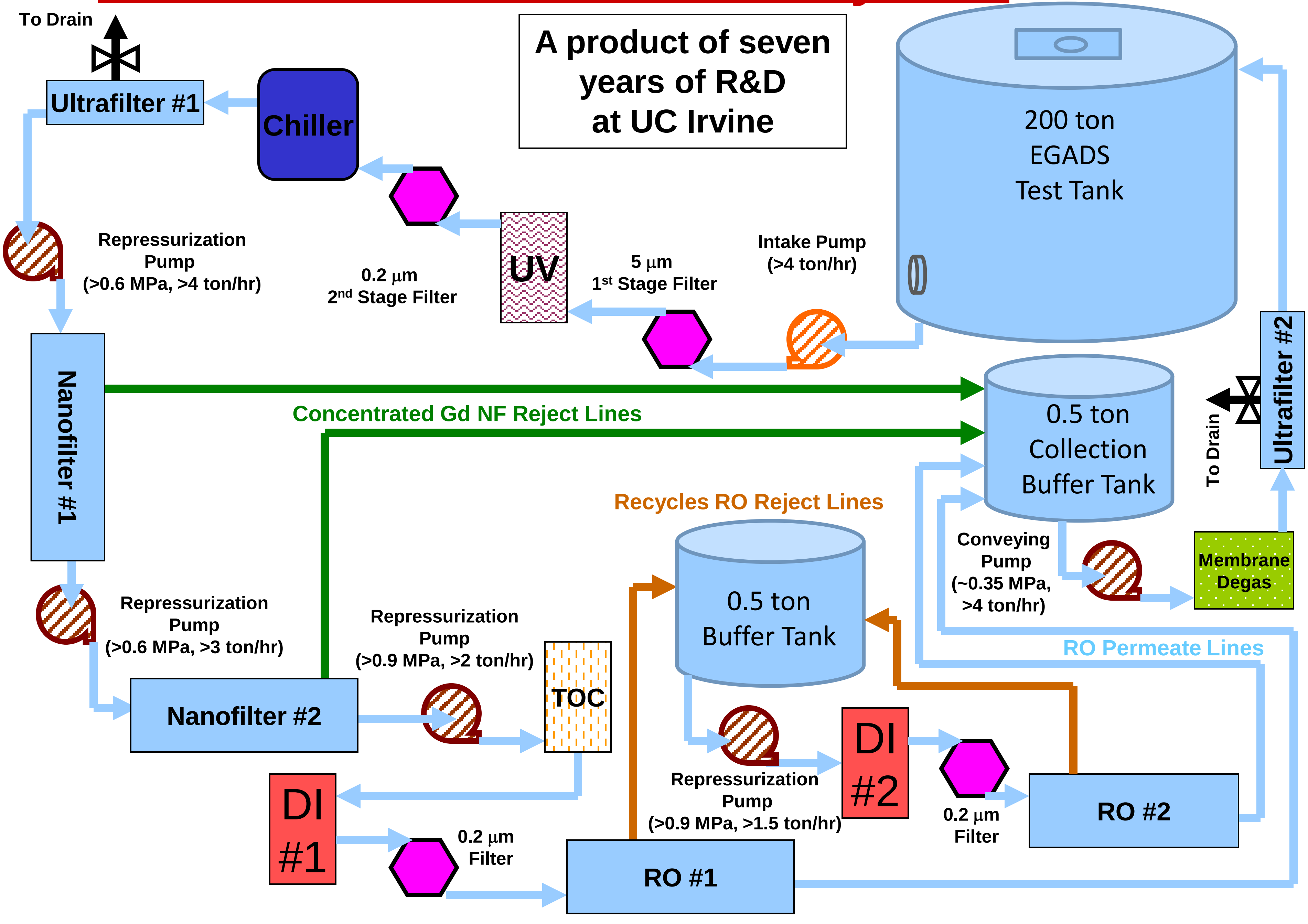
**In June of 2009 we received full funding (~$4,000,000) for this effort.**

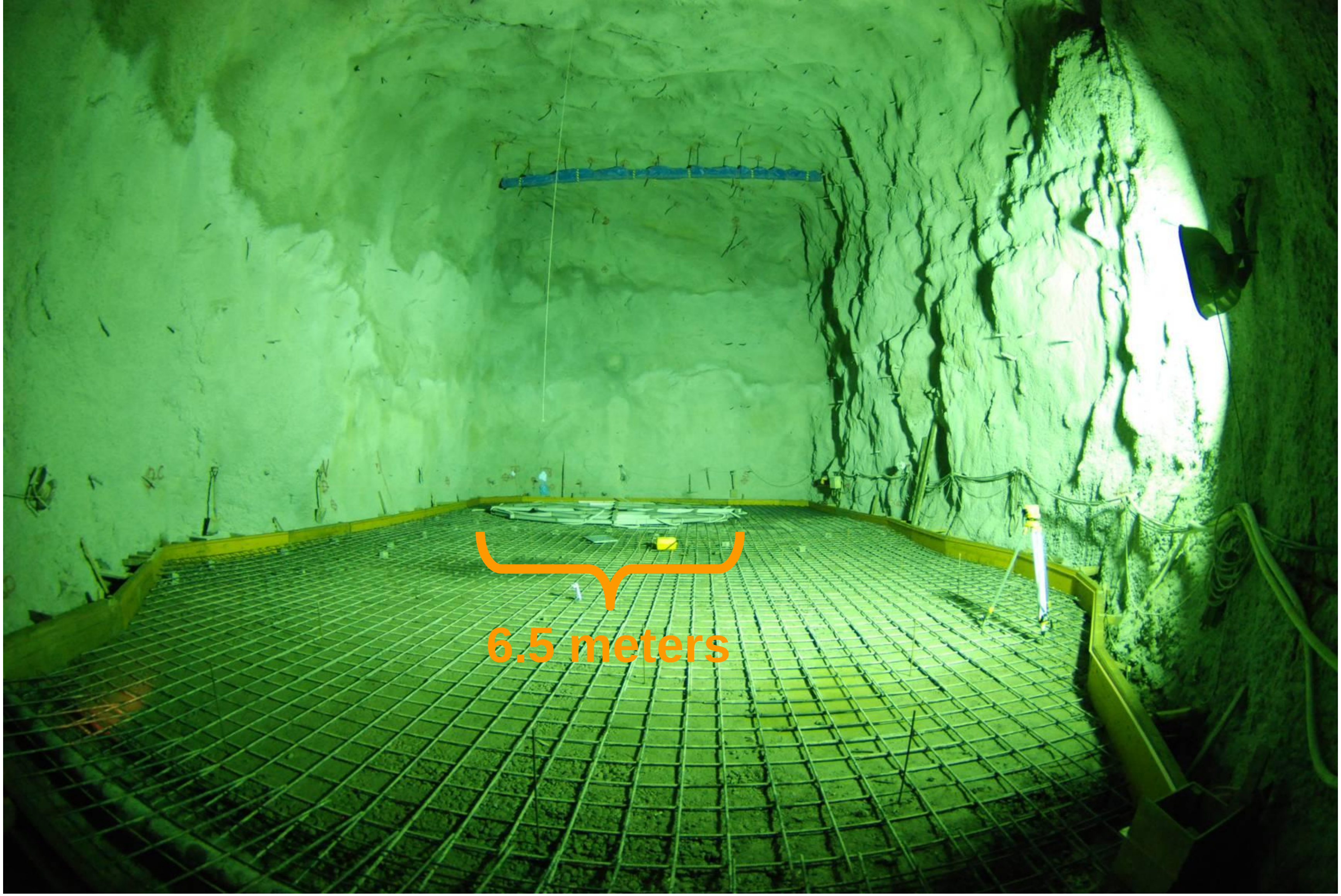



[graphic by A. Kibayashi]

# EGADS Selective Filtration System

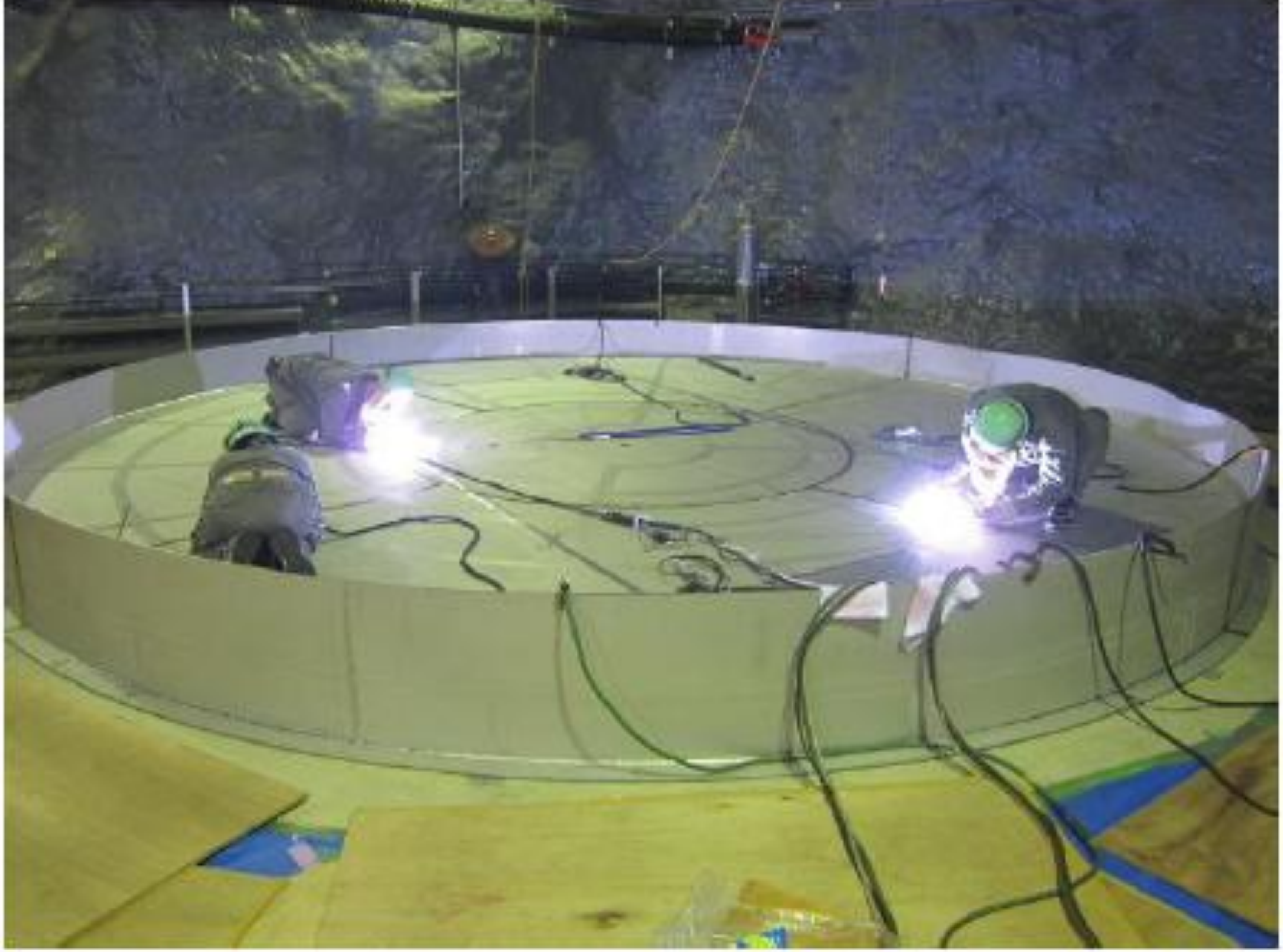
June 2010






**EGADS Cavern as of December 14, 2009**

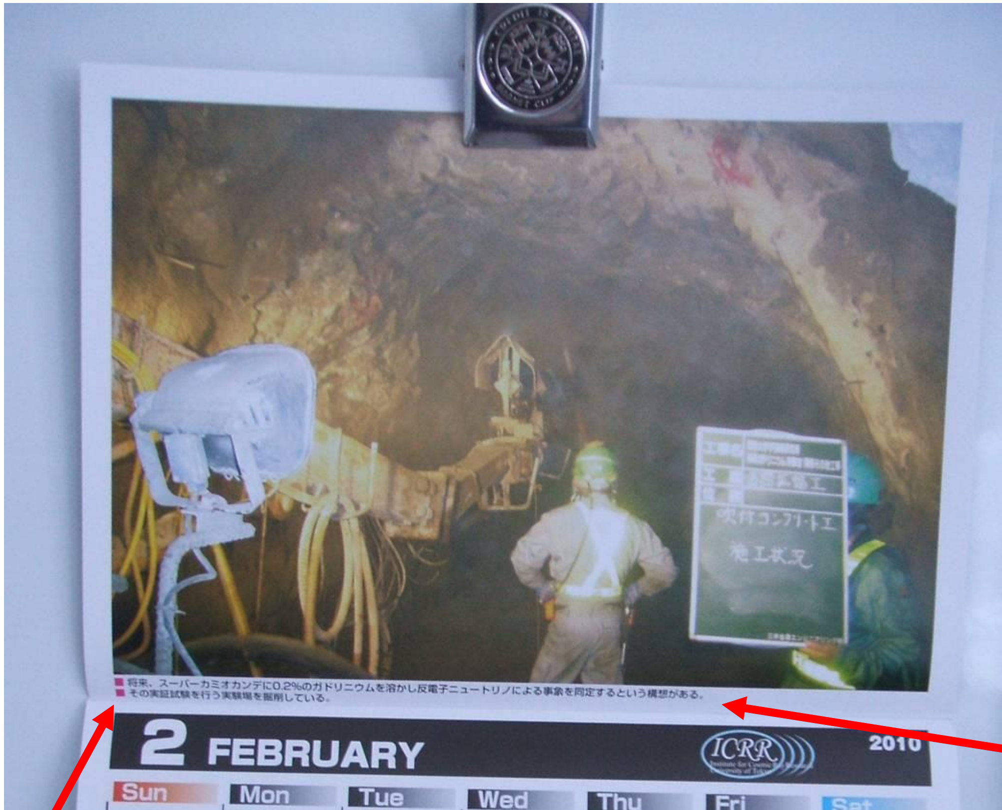
EGADS Cavern as of February 27, 2010



**EGADS Cavern as of April 16, 2010**

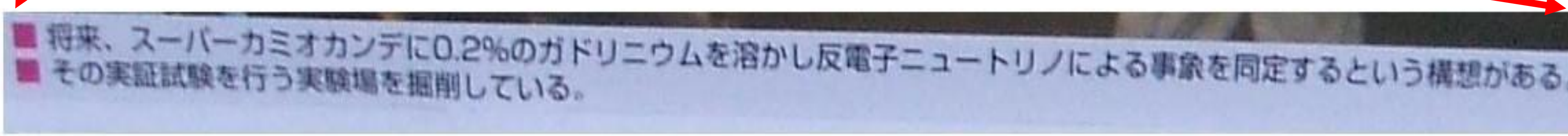
EGADS Cavern as of April 28, 2010

EGADS Cavern as of June 8, 2010




Here's the official Institute for Cosmic Ray Research [ICRR] calendar for 2010:

**EGADS is Miss February!**




# What's the schedule for EGADS?

EGADS is fully funded, and the schedule is now fixed as follows:

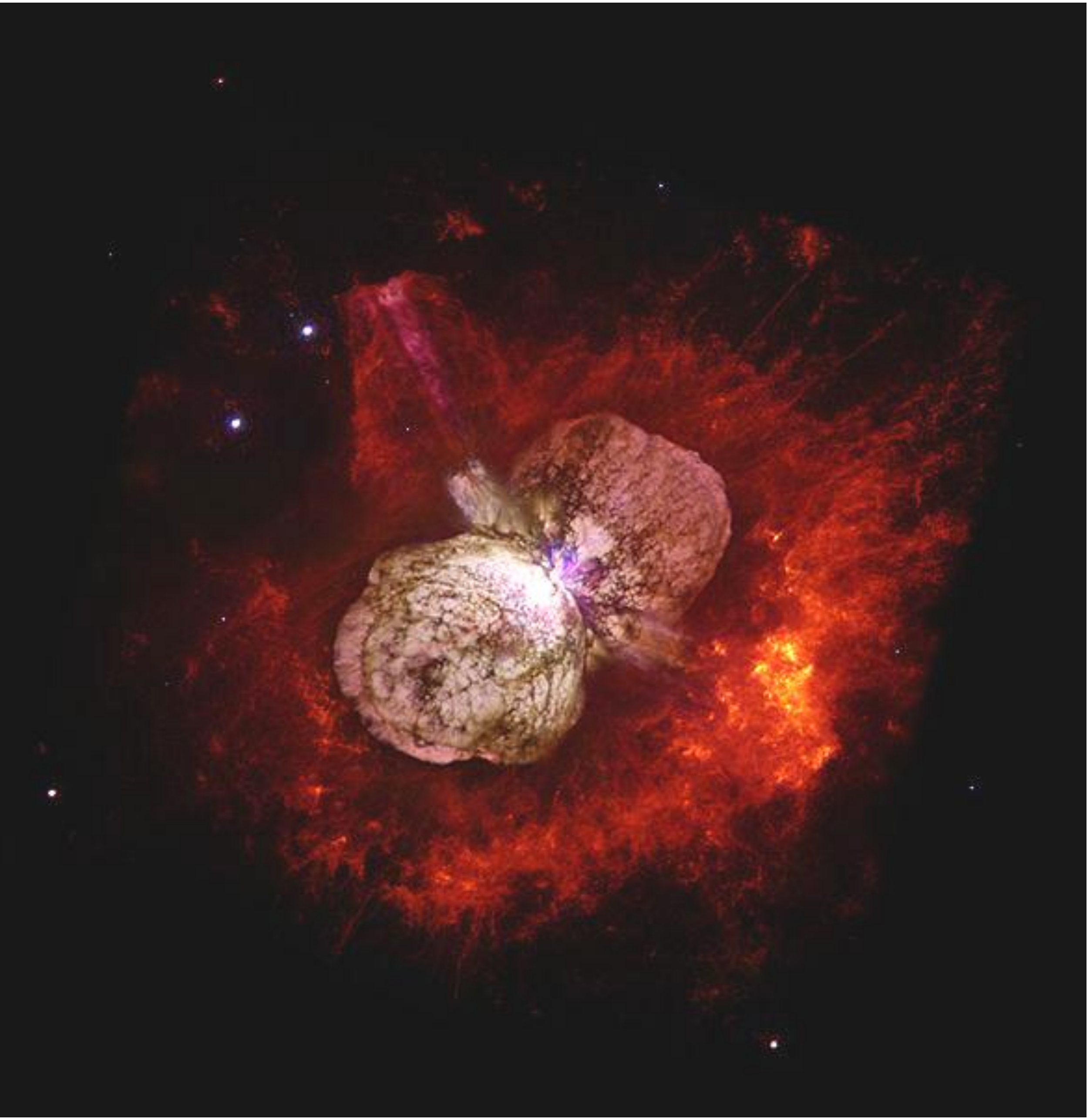
2009-10: Excavation of new underground experimental hall,
construction of stainless steel test tank and
PMT-supporting structure (completion June 2010)

2010-11: Assembly of main water filtration system,
tube prep, mounting of PMT's, installation
of electronics and DAQ computers

2011-13: Experimental program, long-term stability assessment

At the same time, material aging studies will be carried out in Japan, and transparency and water filtration studies will continue in Irvine.

**Once EGADS is shown to operate well, we will have conclusive proof that gadolinium loading will work in SK and next generation water Cherenkov detectors.**



A concluding thought:

This Gd business would work great with a closer SN, too. If Eta Carinae - which has shown recent variability - happens to explode sometime in the next few years, we would expect to see ~400 tagged supernova neutrino events…

***…in the Gd-loaded EGADS tank!***