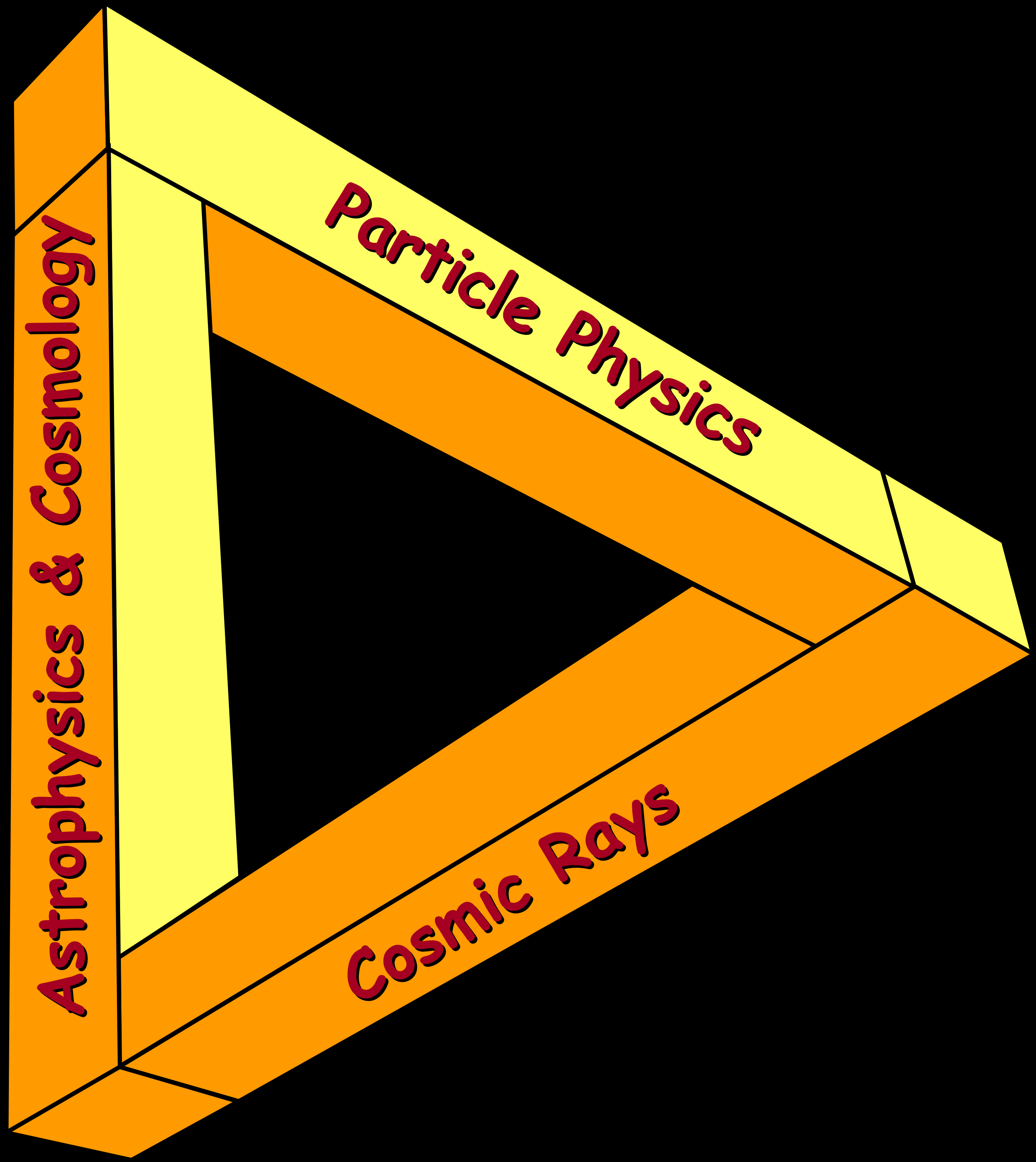
School on Neutrino Physics and Astrophysics (NEUPAST)

ICTP, Trieste, 23 September - 4 October 2002

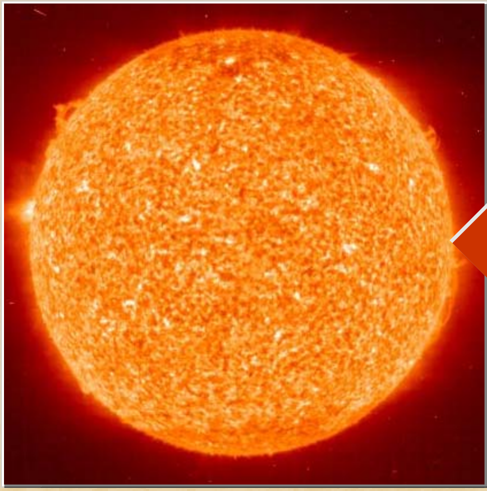
Concluding Remarks

Georg G. Raffelt
Max-Planck-Institut für Physik, München, Germany



Georg Raffelt, Max-Planck-Institut für Physik, München, Germany

Sun Glasses for Neutrinos?



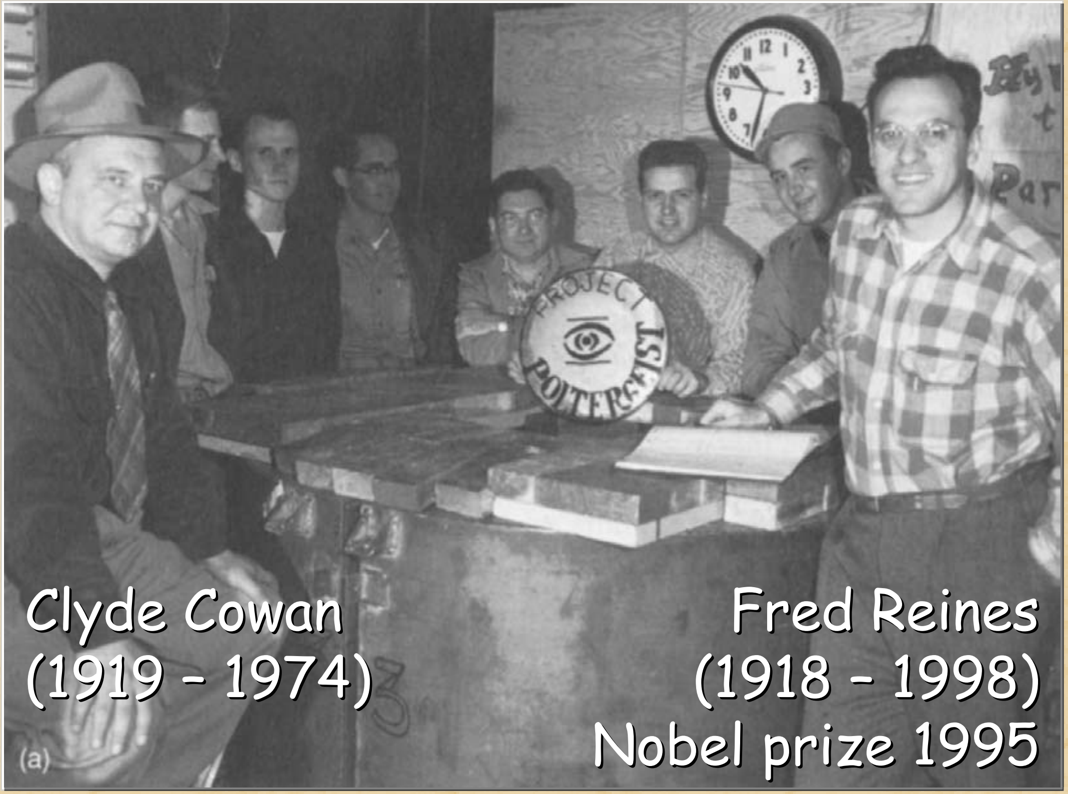
8.3 light minutes

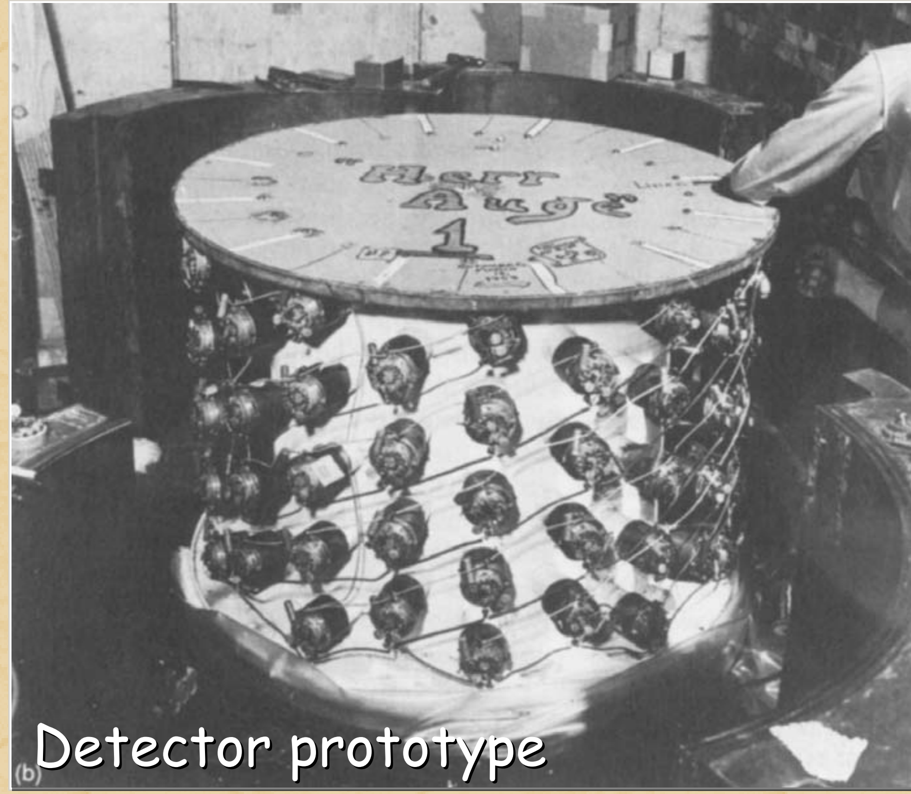
1000 light years of lead needed to shield solar neutrinos

Bethe & Peierls 1934:

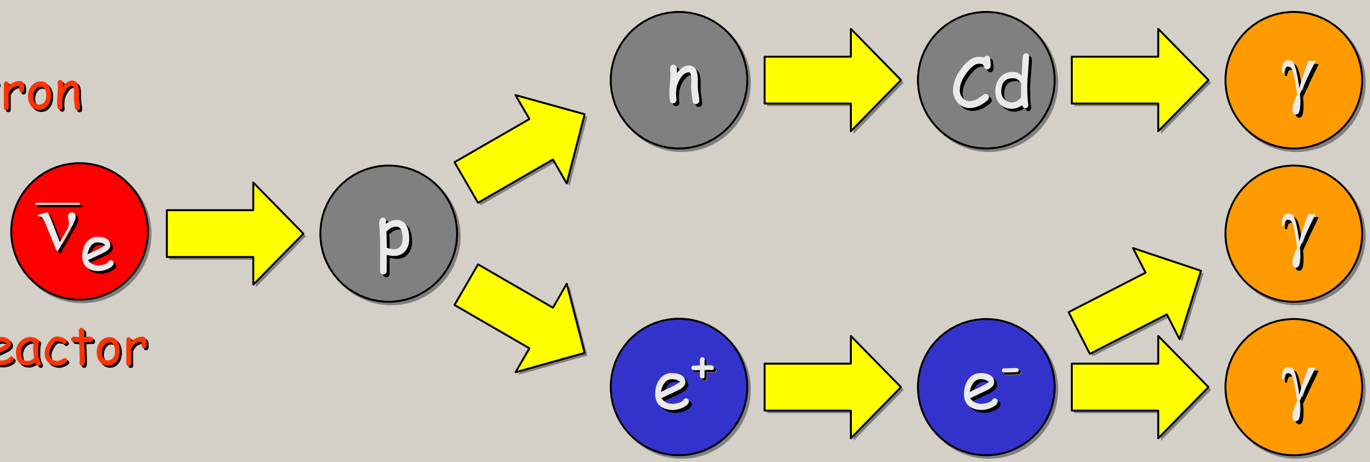
"... this evidently means that one will never be able to observe a neutrino."

First Detection (1954 - 1956)



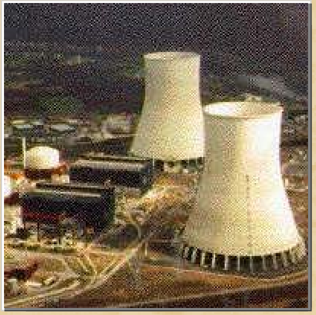


Anti-Electron Neutrinos from Hanford Nuclear Reactor



3 Gammas in Coincidence

Where do Neutrinos Appear in Nature?

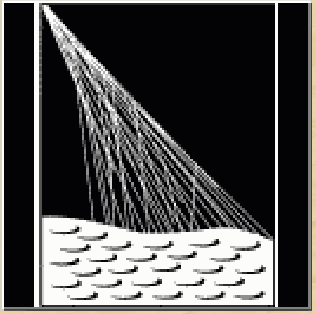


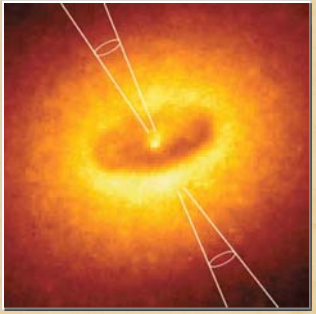
✓ Nuclear Reactors

Sun ✓

✓ Particle-Accelerators

Supernovae (Stellar Collapse)
SN 1987A ✓





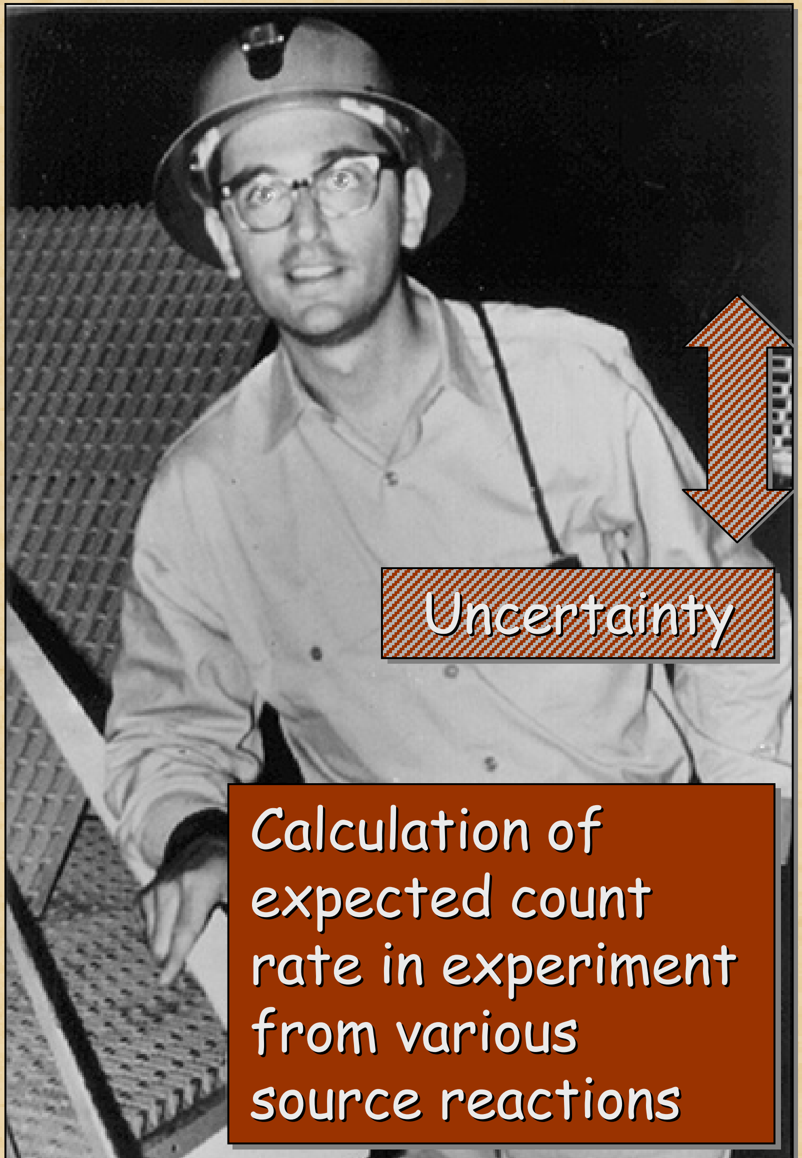
✓ Earth Atmosphere (Cosmic Rays)

Astrophysical Accelerators Soon ?

Earth Crust (Natural Radioactivity
2003 ?

Cosmic Big Bang (Today 330 ν/cm^3)
Indirect Evidence

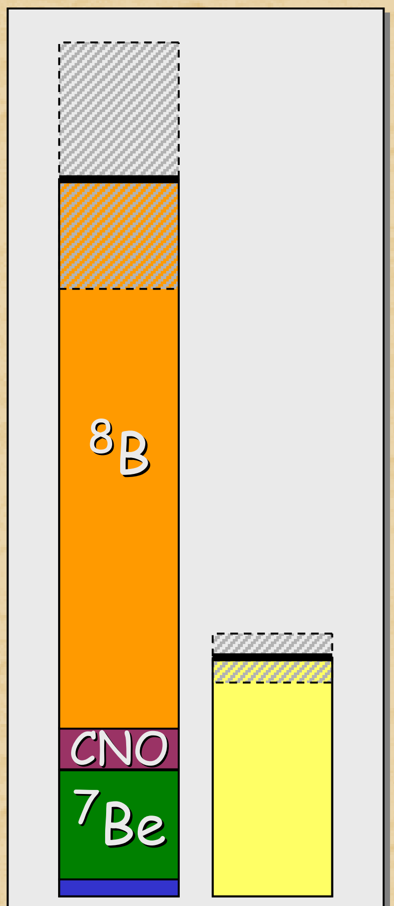
Problem of Missing Solar Neutrinos



John Bahcall

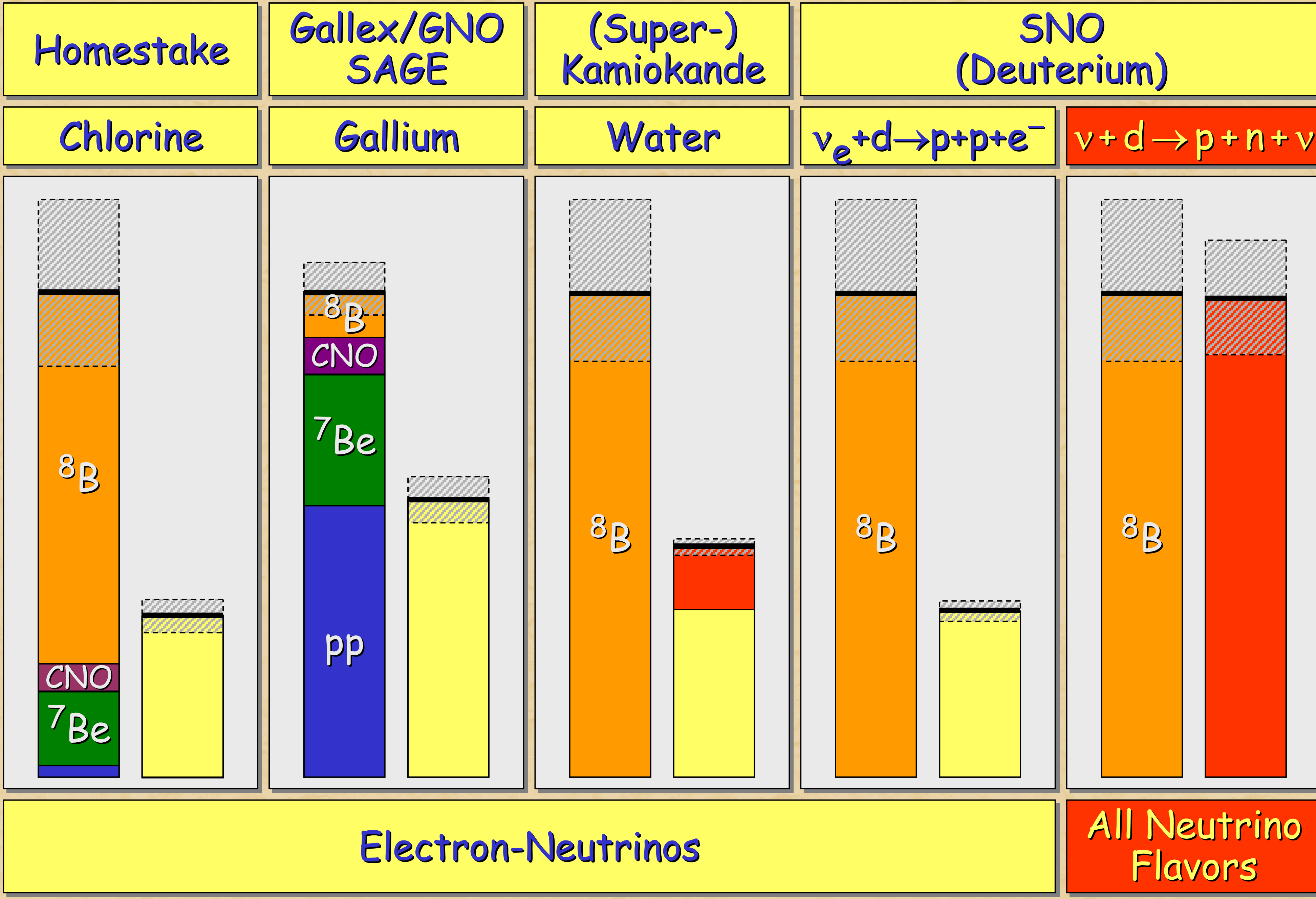
Homestake

Chlorine

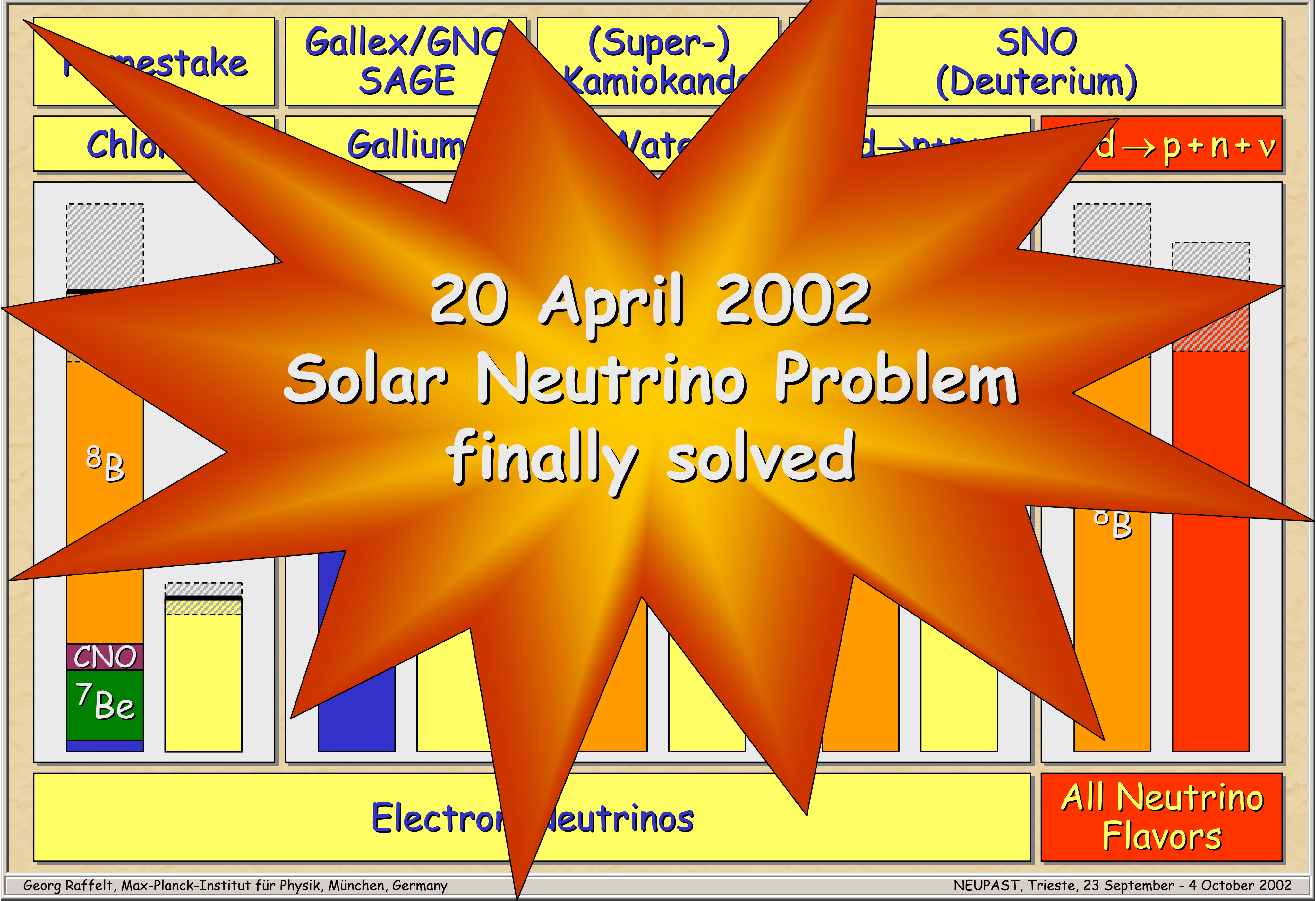


Raymond Davis Jr.

Missing Neutrinos from the Sun



Missing Neutrinos from the Sun

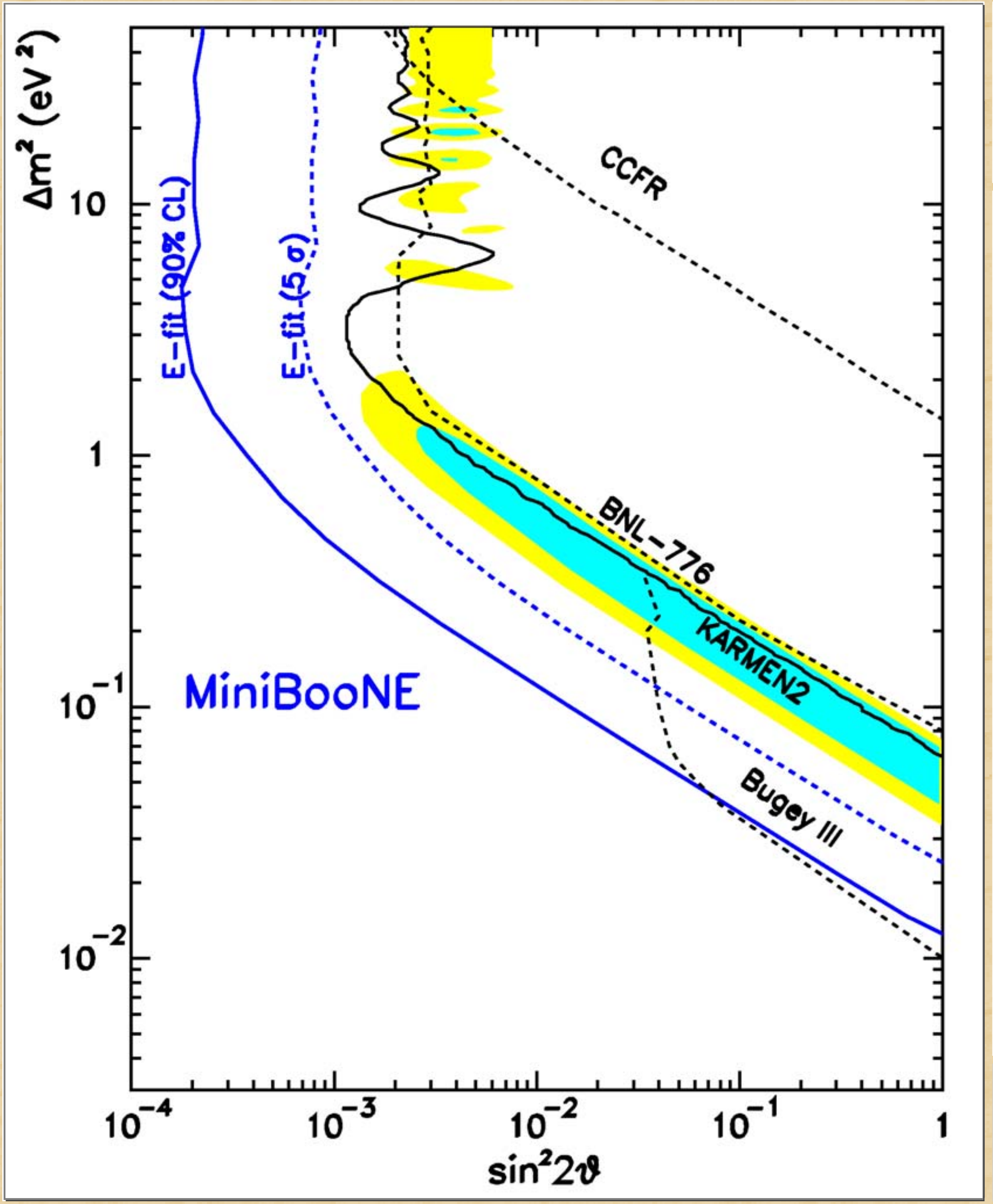


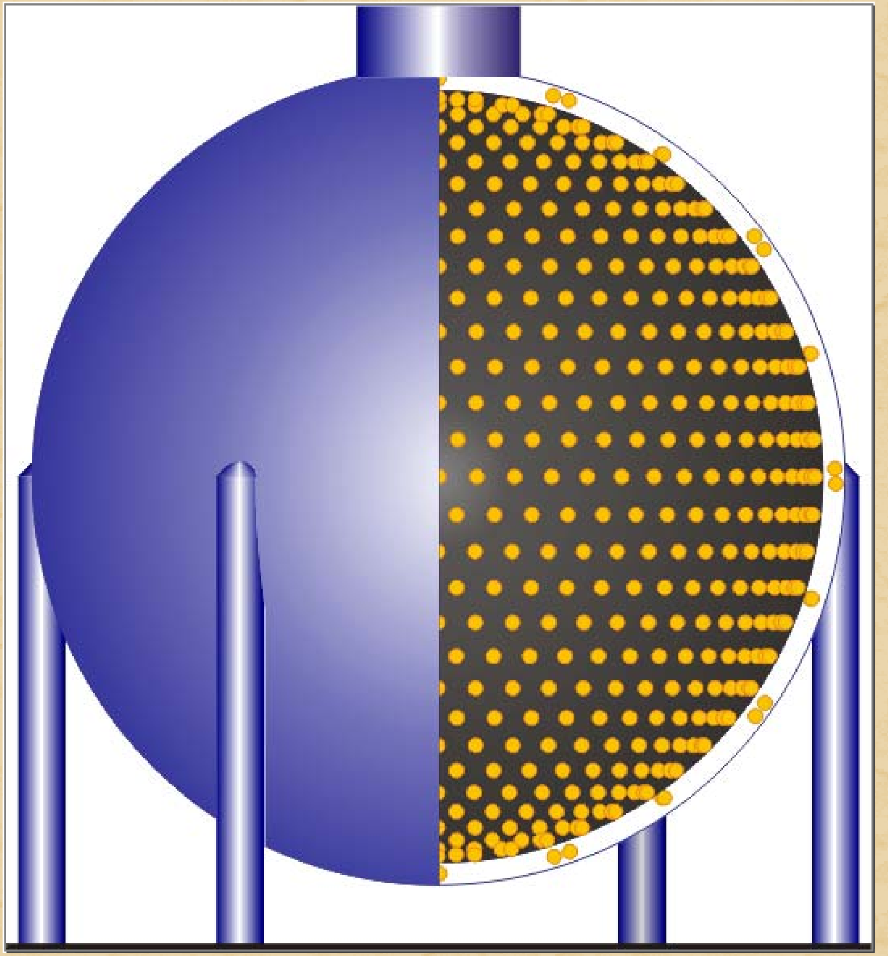
Bruno Pontecorvo
(1913 – 1993)
Invented neutrino oscillations

Status of Evidence for Neutrino Oscillations

System	Atmospheric	Solar	LSND
Channel	$\nu_\mu \to \nu_\tau$	$\nu_e \to \nu_{\mu\tau}$	$\bar{\nu}_\mu \to \bar{\nu}_e$
$\delta m^2 / eV^2$	$(1.5-4)\times 10^{-3}$	LMA $(0.2-2)\times 10^{-4}$	0.2-2 or 6.5
$\sin^2 2\theta$	0.9–1	0.2–0.6	0.001–0.03
Status	Established	Established	Unconfirmed
Test	Long Baseline (K2K)	KamLAND 2002 ?	MiniBooNE 2004 ?
Implication	Mutually inconsistent, even with a sterile neutrino Evidence for physics beyond flavor oscillations (CPT violation ...) ?		
Simplest interpre-tation	Three mass eigenstates with $m_1 \ll m_2 \ll m_3 \sim 50$ meV (hierarchical) $m_1 \sim m_2 \sim m_3 \gg 50$ meV (degenerate)		Experimental or statistical fluke

Testing LSND at MiniBooNE



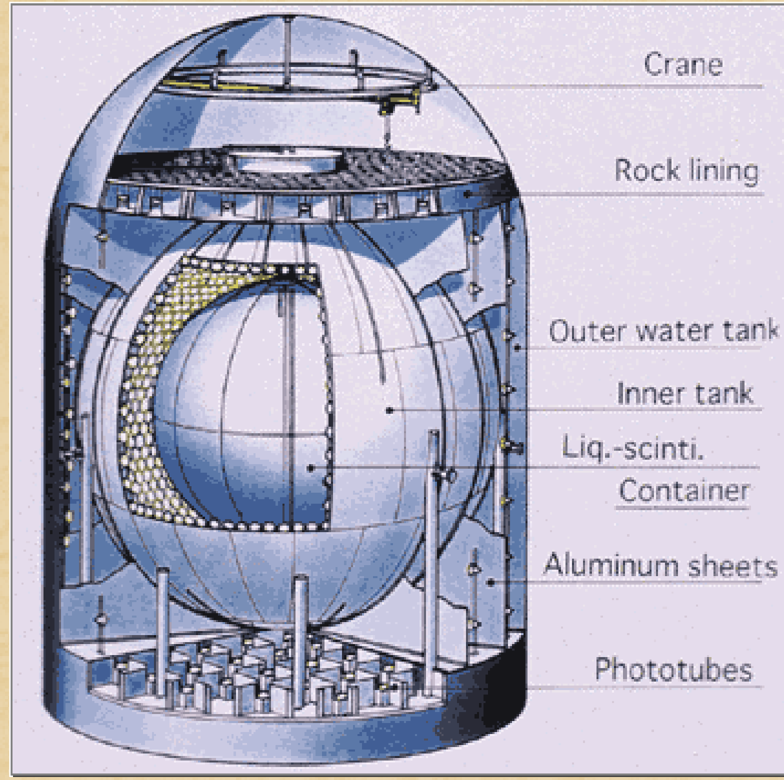


www-boone.fnal.gov

Kamland Reactor Neutrino Experiment (Japan)

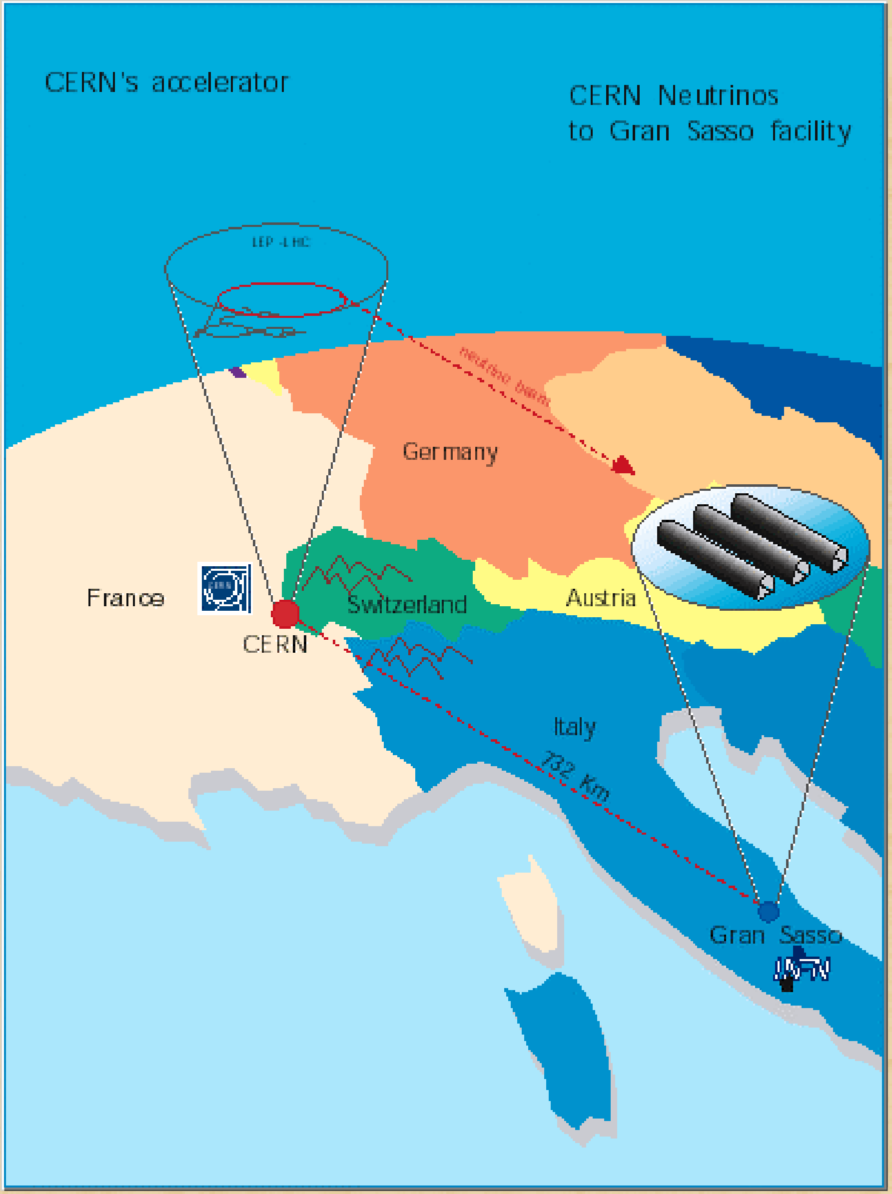
Japanese nuclear reactors
60 GW (20% world capacity)

- Witout Oscillations
  2 Neutrino captures / day
- Data taking since
  22 January 2002



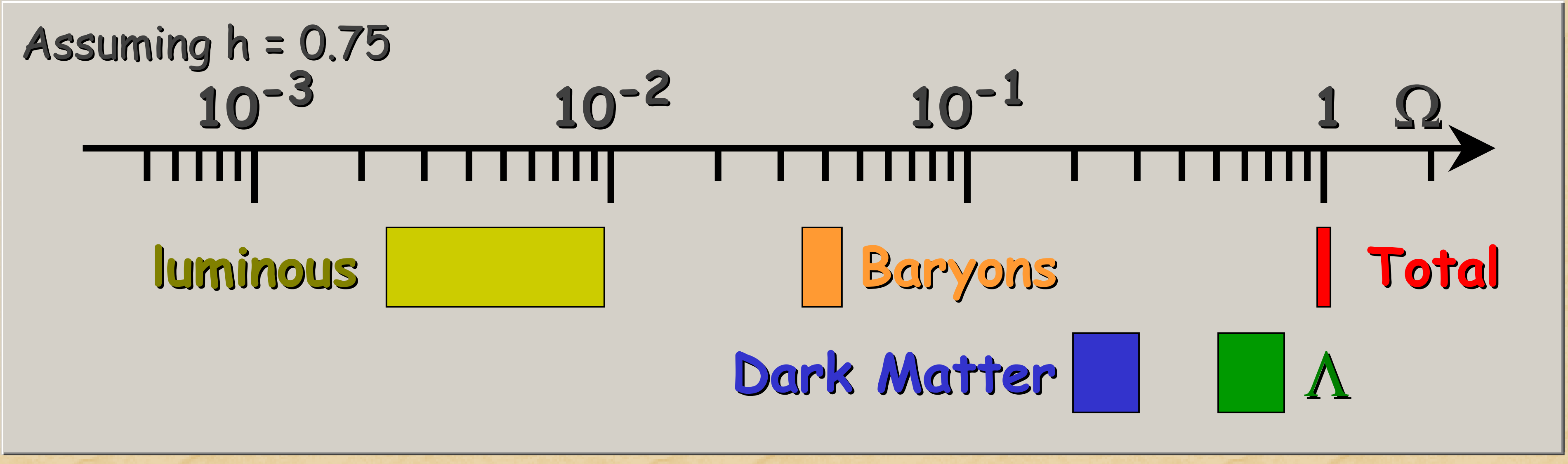
Long-Baseline Experiments

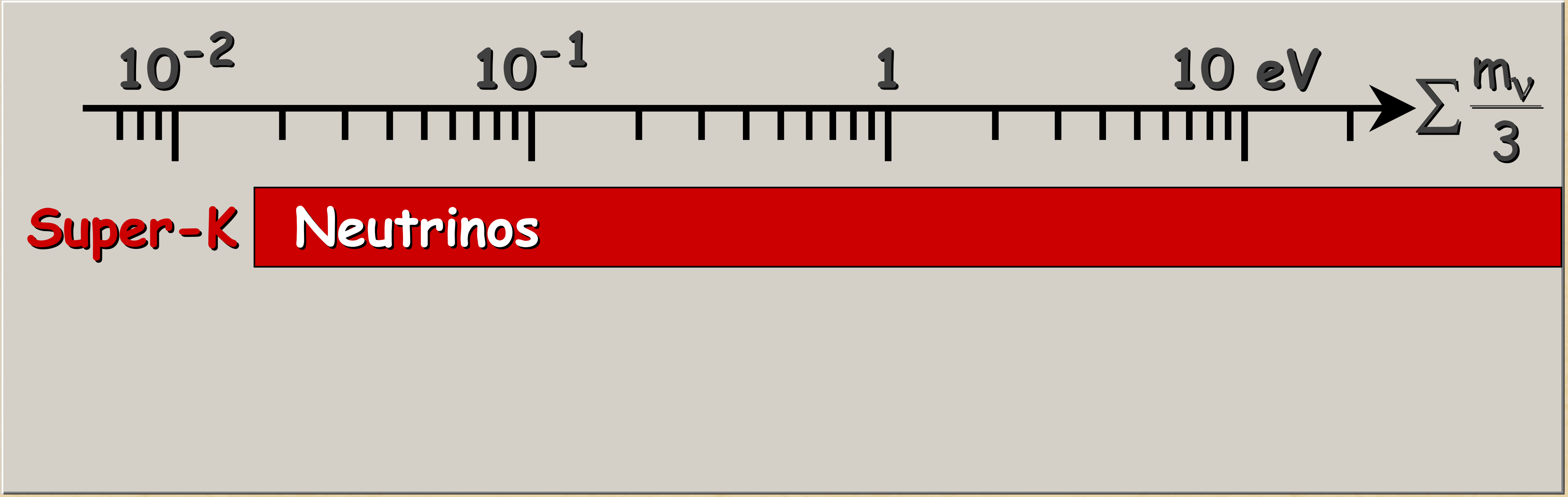
CERN - Gran Sasso



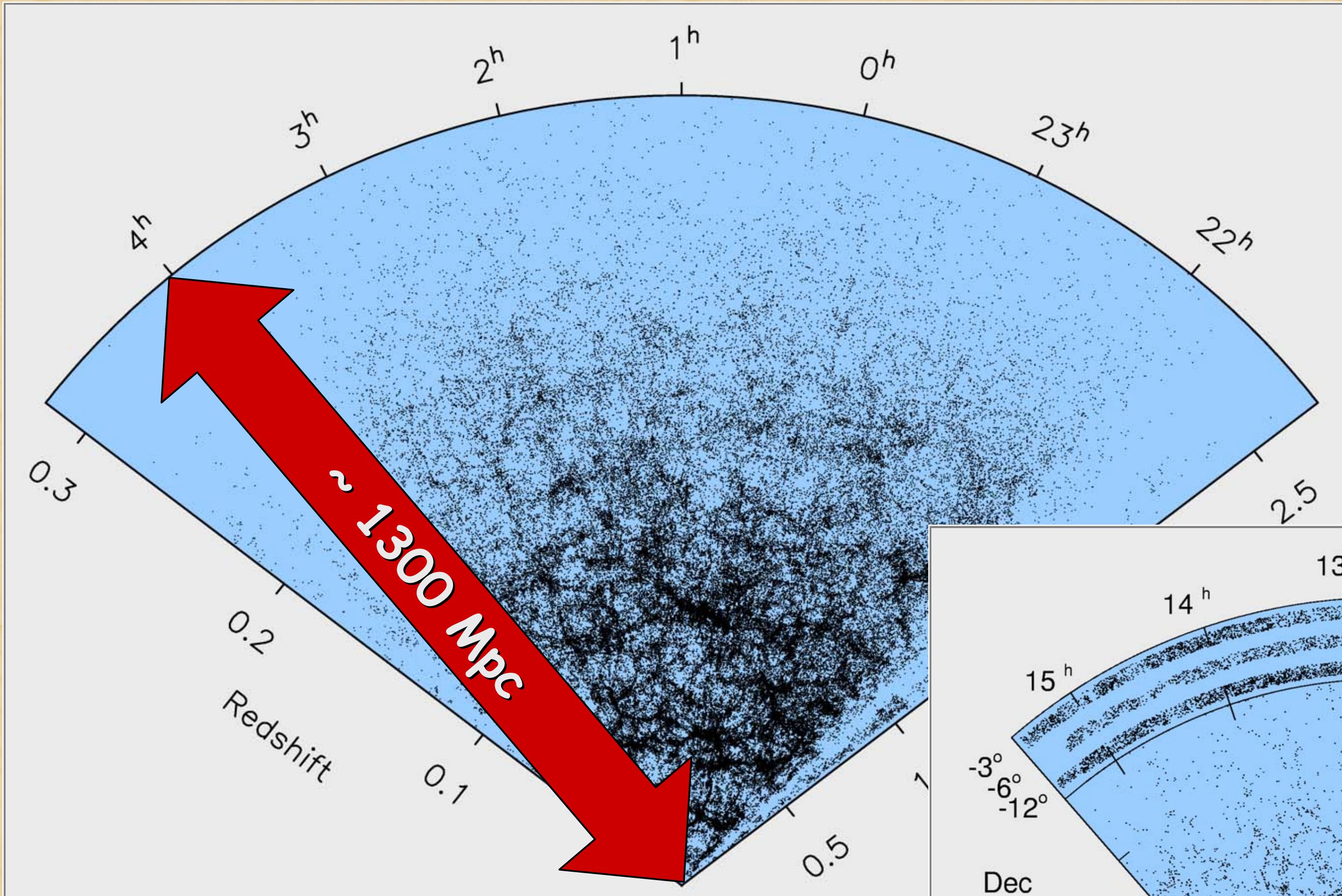
FermiLab-Soudan (MINOS)

Mass-Energy-Inventory of the Universe

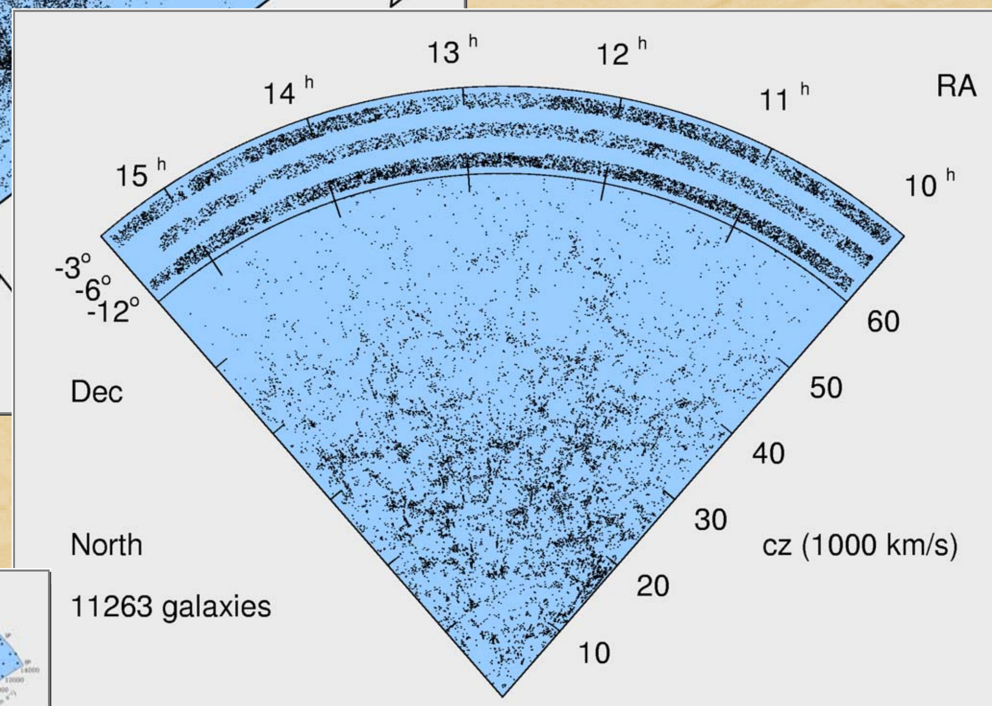




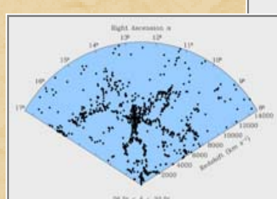
2dF Galaxy Redshift Survey (15 May 2002)



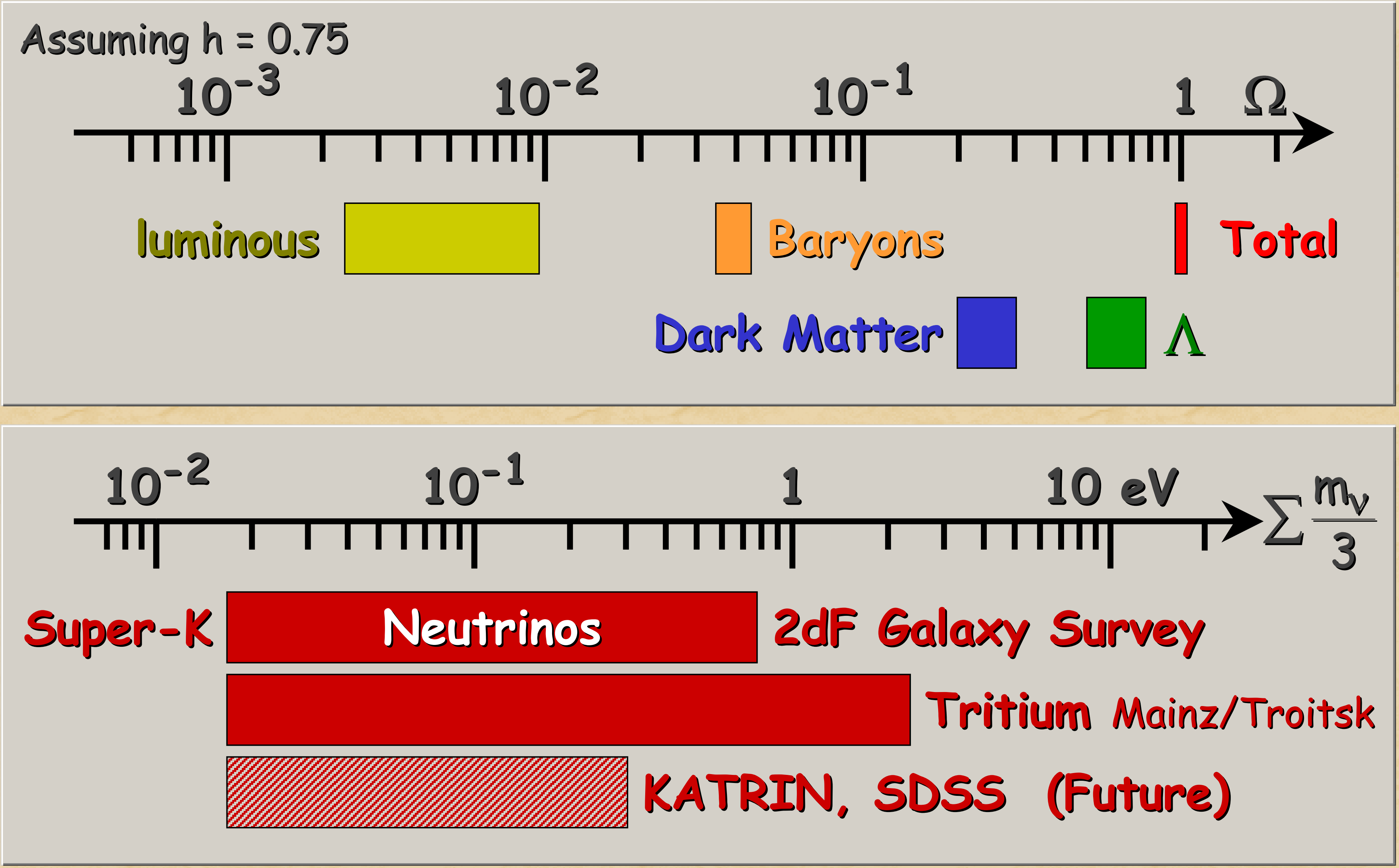
Las Campanas Redshift Survey



CfA Redshift Survey



Mass-Energy-Inventory of the Universe



Leptogenesis by Majorana Neutrino Decays

A classic paper

Volume 174, number 1 PHYSICS LETTERS B 26 June 1986

BARYOGENESIS WITHOUT GRAND UNIFICATION

M. FUKUGITA

Research Institute for Fundamental Physics, Kyoto University, Kyoto 606, Japan

and

T. YANAGIDA

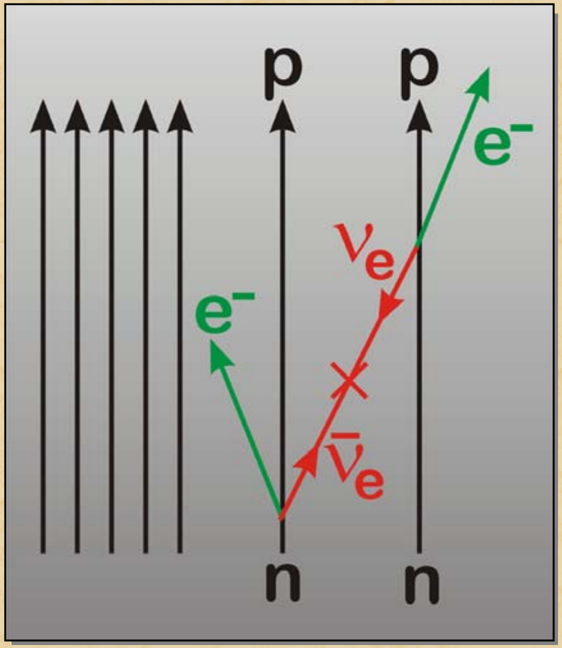
Institute of Physics, College of General Education, Tohoku University, Sendai 980, Japan and Deutsches Elektronen-Synchrotron DESY, D-2000 Hamburg, Fed. Rep. Germany

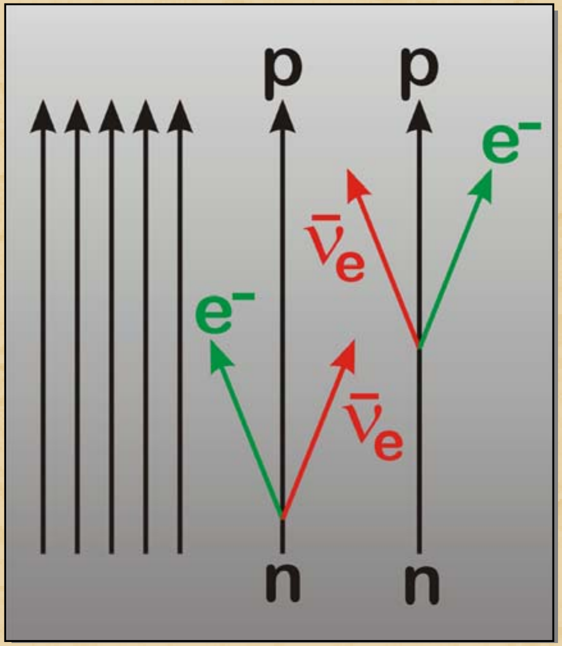
Received 8 March 1986

A mechanism is pointed out to generate cosmological baryon number excess without resorting to grand unified theories. The lepton number excess originating from Majorana mass terms may transform into the baryon number excess through the unsuppressed baryon number violation of electroweak processes at high temperatures.

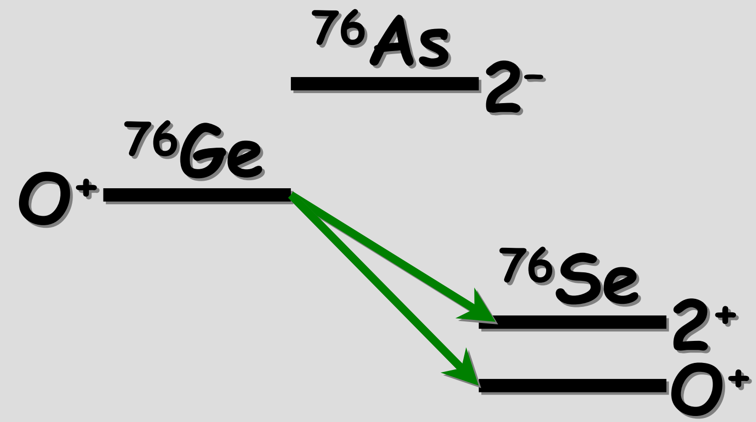
Neutrinoless ββ Decay

0ν mode, enabled by Majorana mass	2ν mode





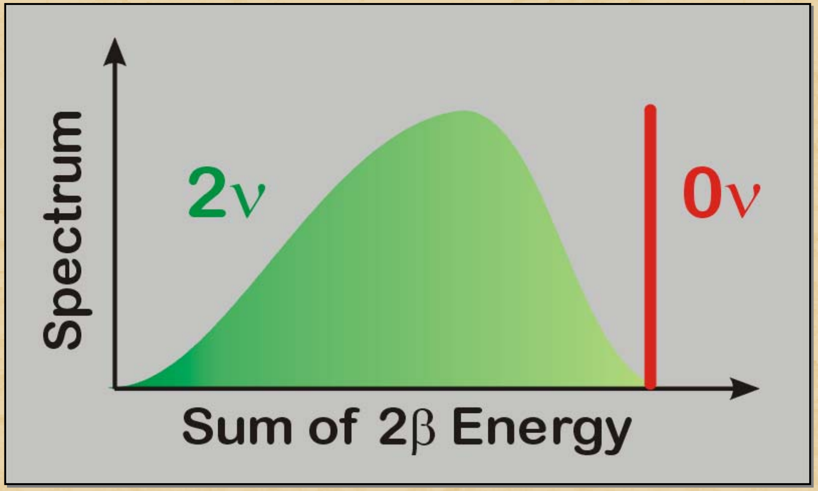
Some nuclei decay only by the ββ mode, e.g.



Half life ≈ 10^{21} yr

Measured quantity:

$$\langle m_{\nu_e} \rangle = \sum_{i=1}^{N} \lambda_i |U_{ei}|^2 m_i$$

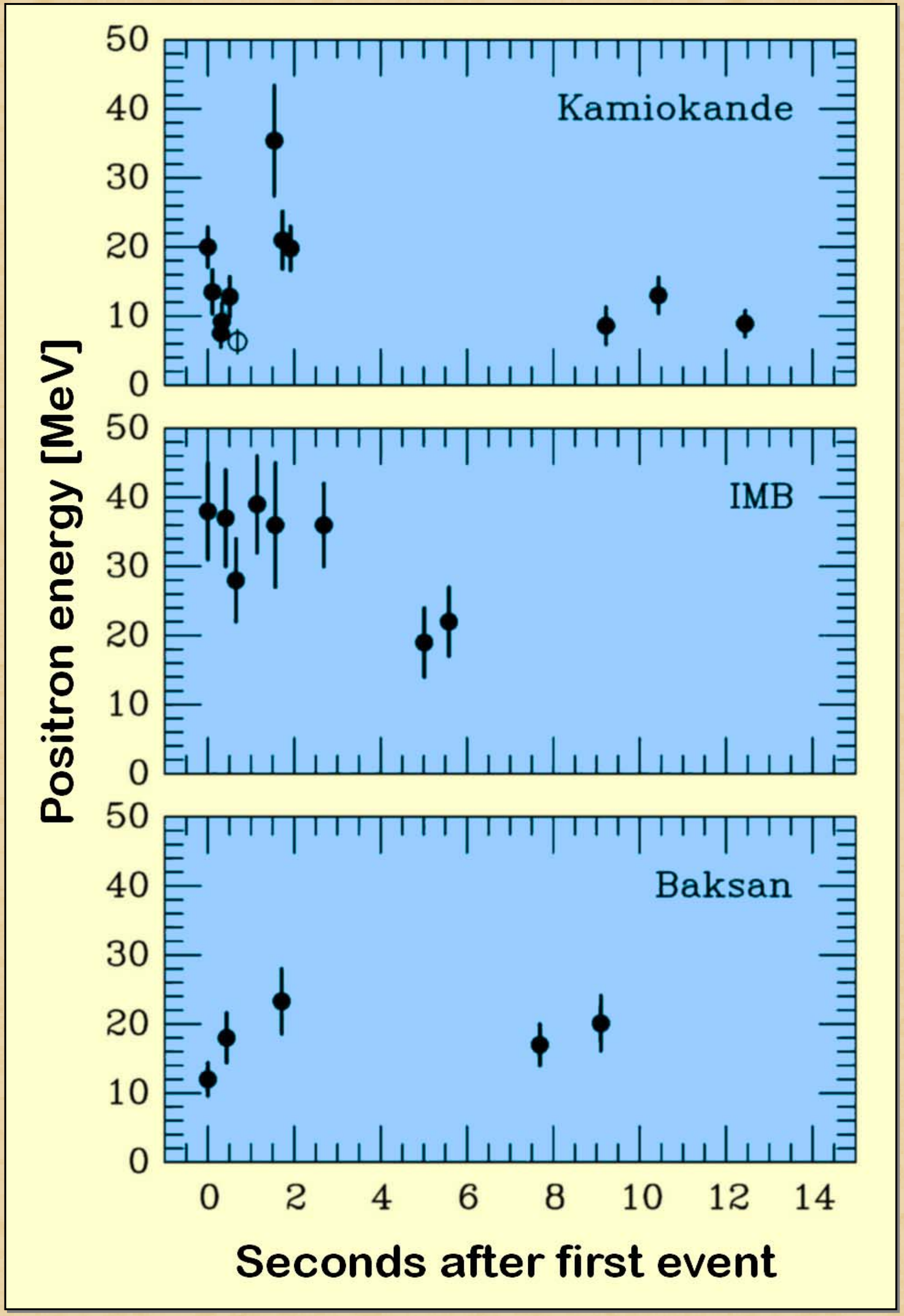


Neutrino Mass Limits and Future Sensitivity

Tritium endpoint	Mainz/Troitsk	2.2 eV
	KATRIN	0.3 eV
Supernova Nus Time-of-flight	SN 1987A	20 eV
	Super-Kamiokande	3 eV
	with black hole	2 eV
	with gravity waves	1 eV
Cosmic structure	2dF Redshift Survey	0.8 eV
	Sloan Digital Sky Survey	0.3 eV

- Assume 3 mass eigenstates with very small mass differences as indicated by atmospheric and solar neutrinos
- The cosmological limit refers to $m_\nu = \Sigma\, m_\nu/3$

Neutrino Signal of Supernova 1987A



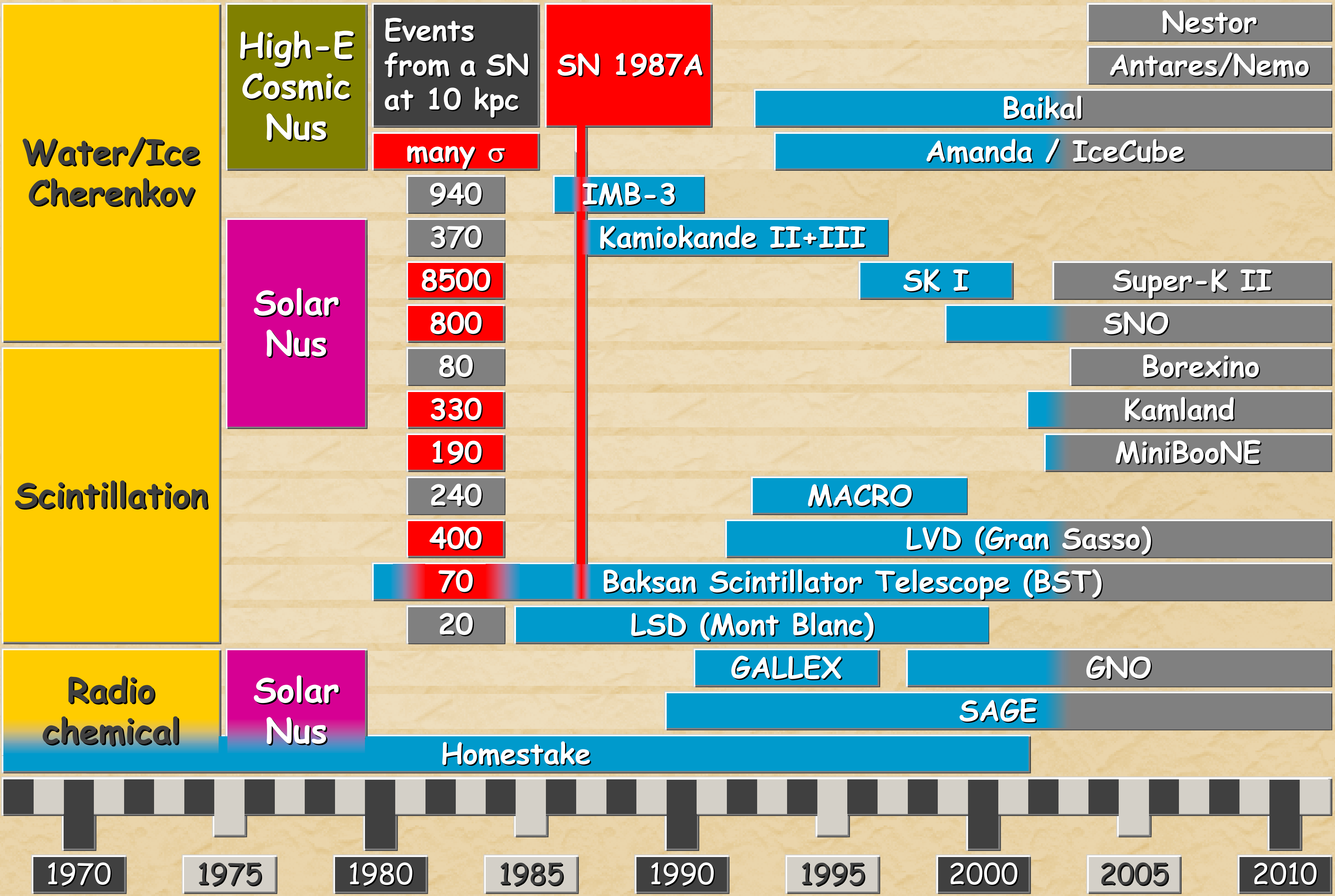
Kamiokande (Japan)
Water Cherenkov detector
Clock uncertainty ±1 min

Irvine-Michigan-Brookhaven (US)
Water Cherenkov detector
Clock uncertainty ±50 ms

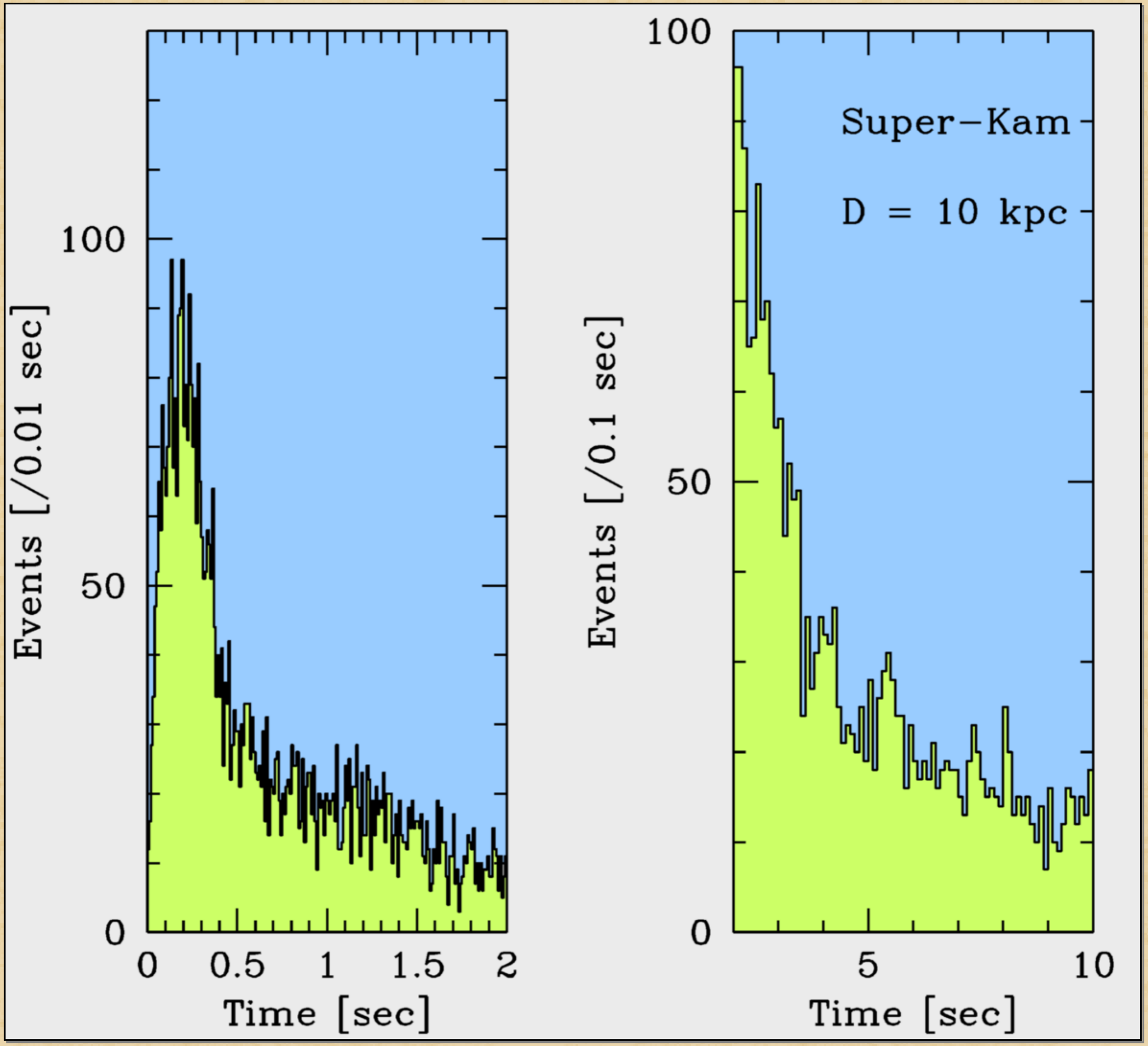
Baksan Scintillator Telescope
(Soviet Union)
Clock uncertainty +2/-54 s

Within clock uncertainties,
signals are contemporaneous

Brief History of Neutrino Astronomy



Simulated Supernova Signal in Super-Kamiokande



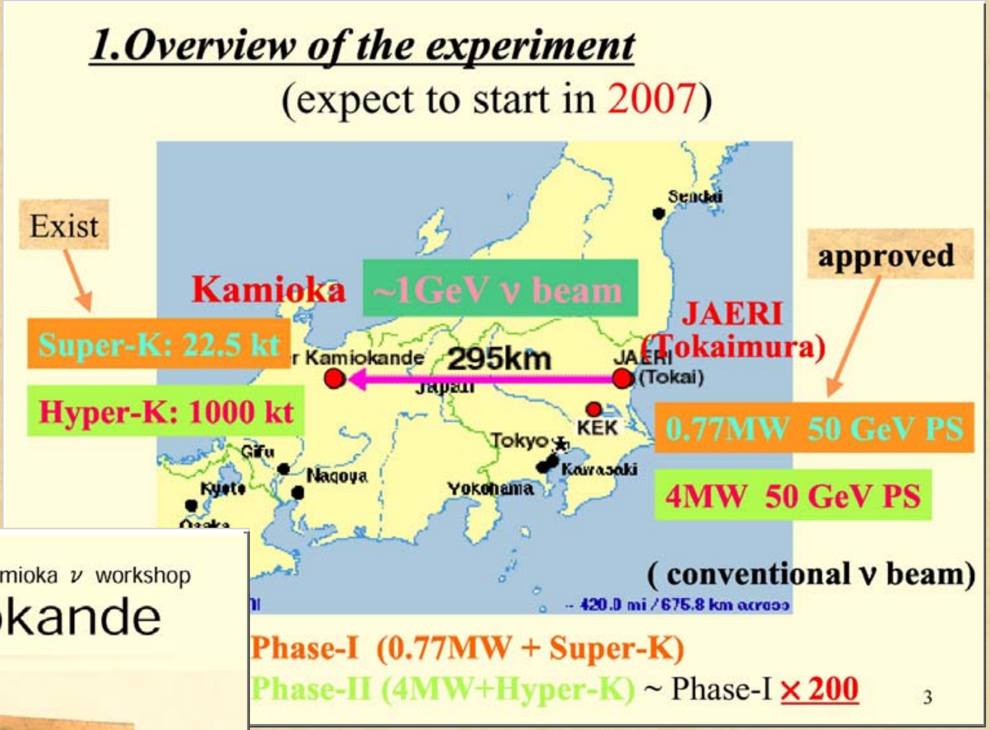
Totani, Sato, Dalhed & Wilson, ApJ 496 (1998) 216

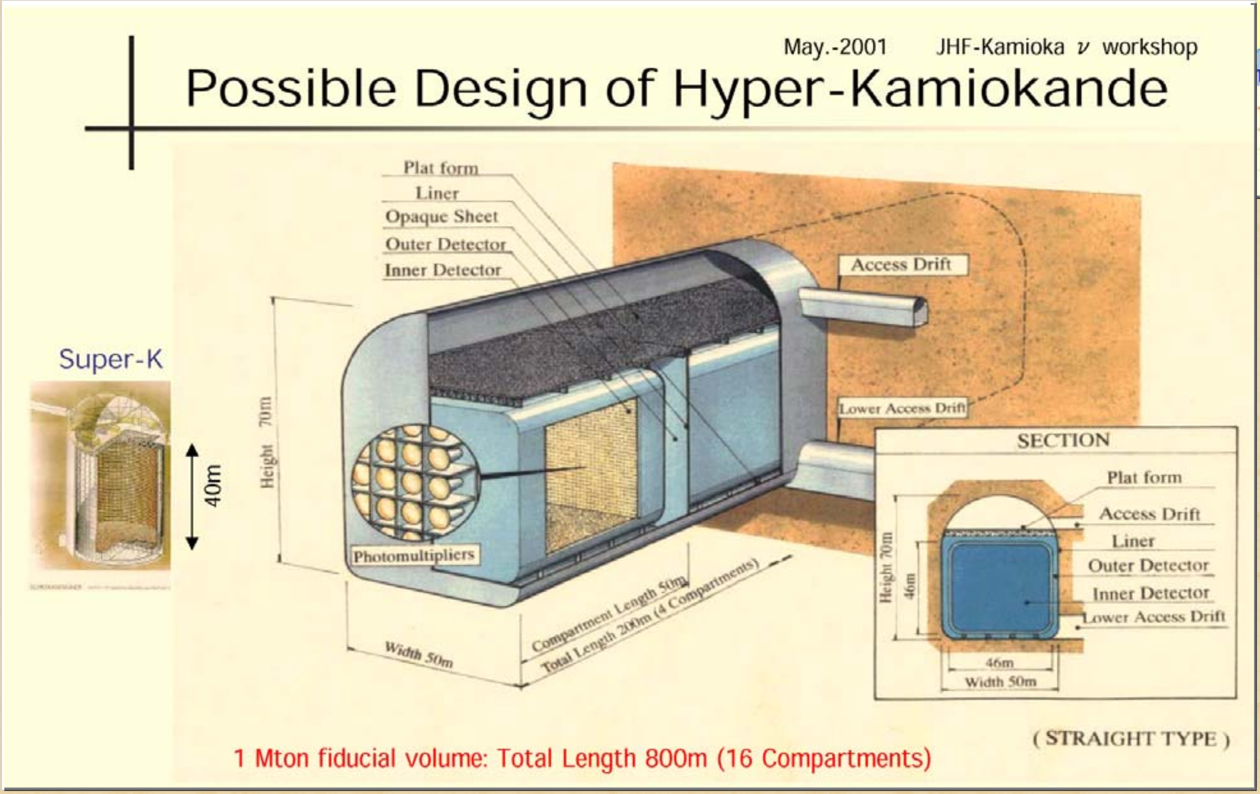
Total of about 8300 events for t < 18 s

Monte-Carlo simulation for Super-Kamiokande signal of SN at 10 kpc, based on a numerical Livermore model

The Future: A Megatonne Detector?

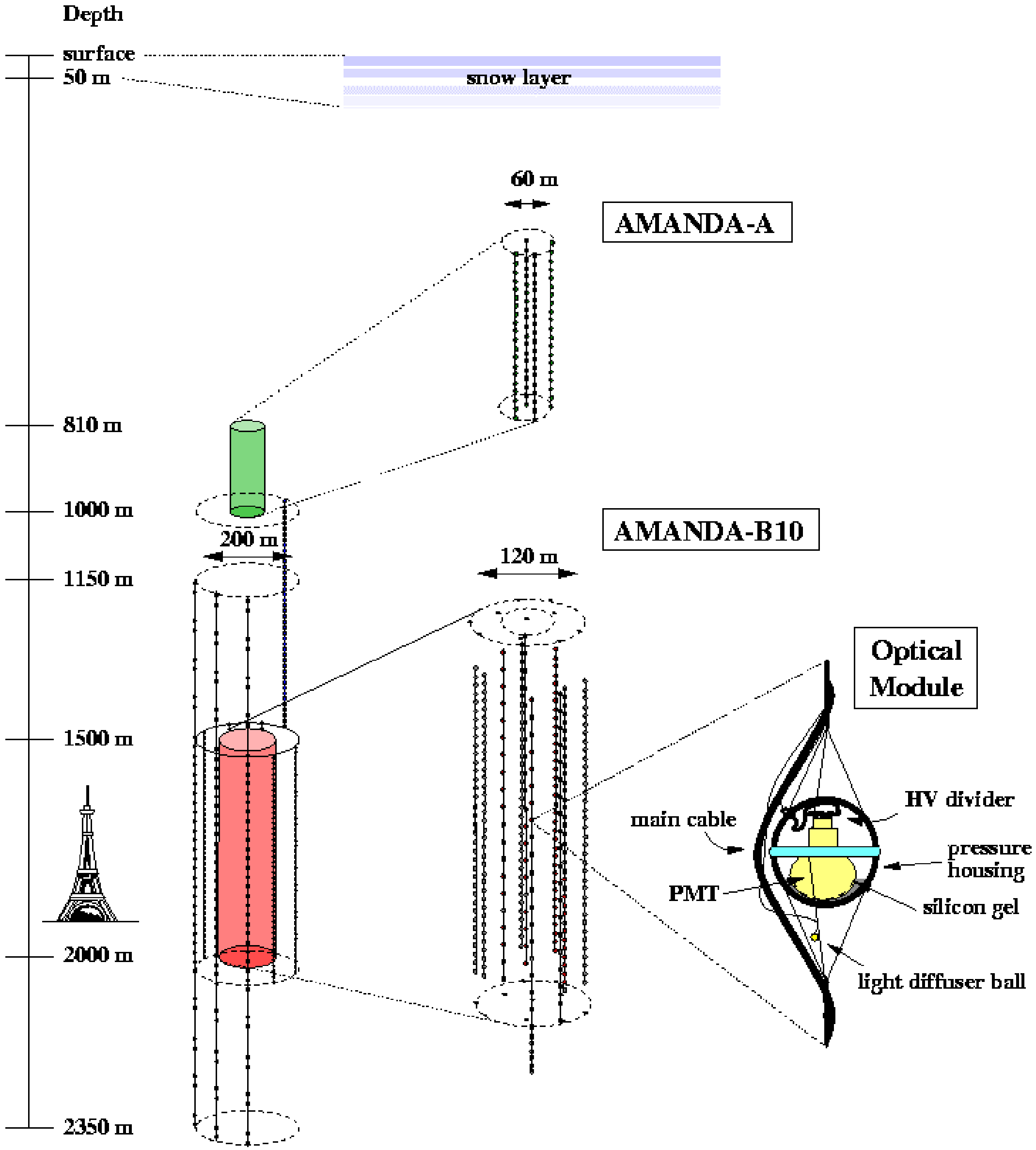
Megatonne detector motivated by
- Long baseline neutrino oscillations
- Proton decay
- Atmospheric neutrinos
- Solar neutrinos
- Supernova neutrinos
  (~10^5 events for SN at 10 kpc)





Similar discussions in
- USA (UNO project)
- Europe (Frejus Tunnel)

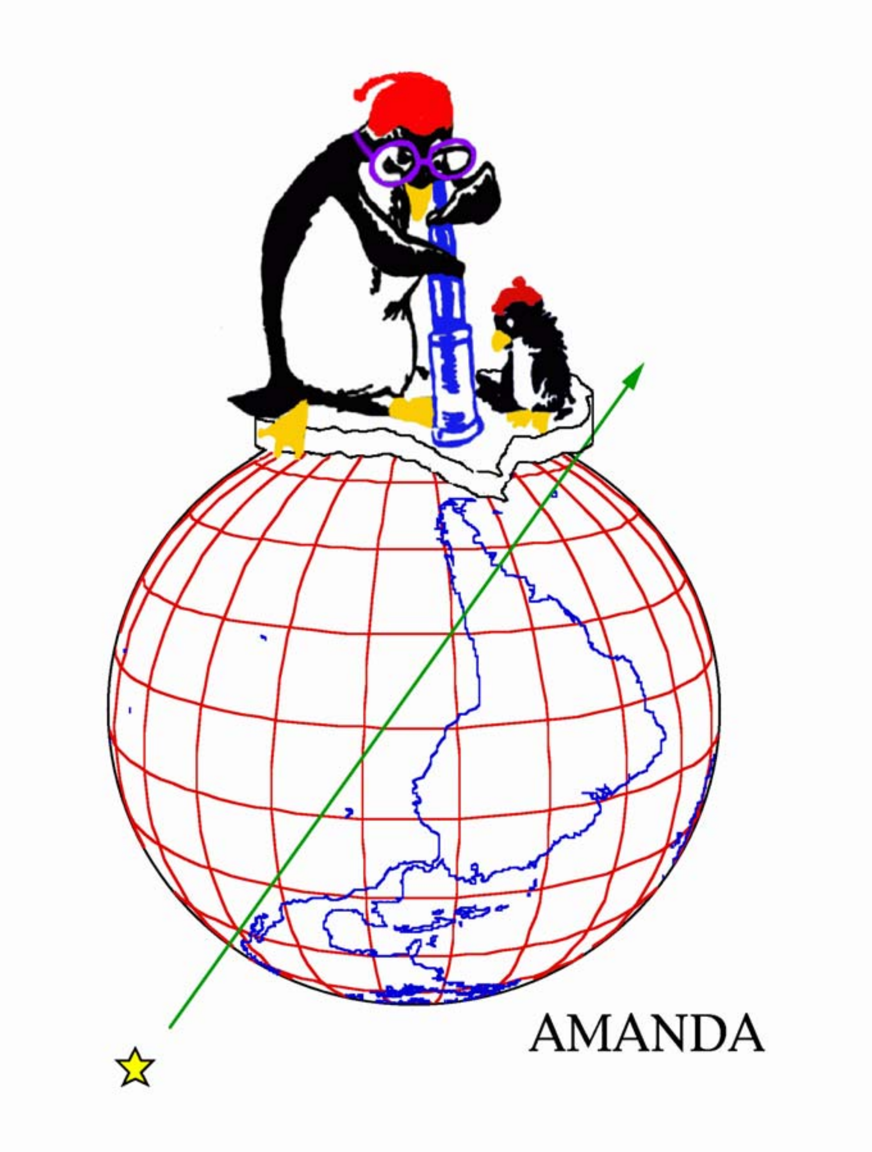
AMANDA – Neutrino Telescope at the Southpole



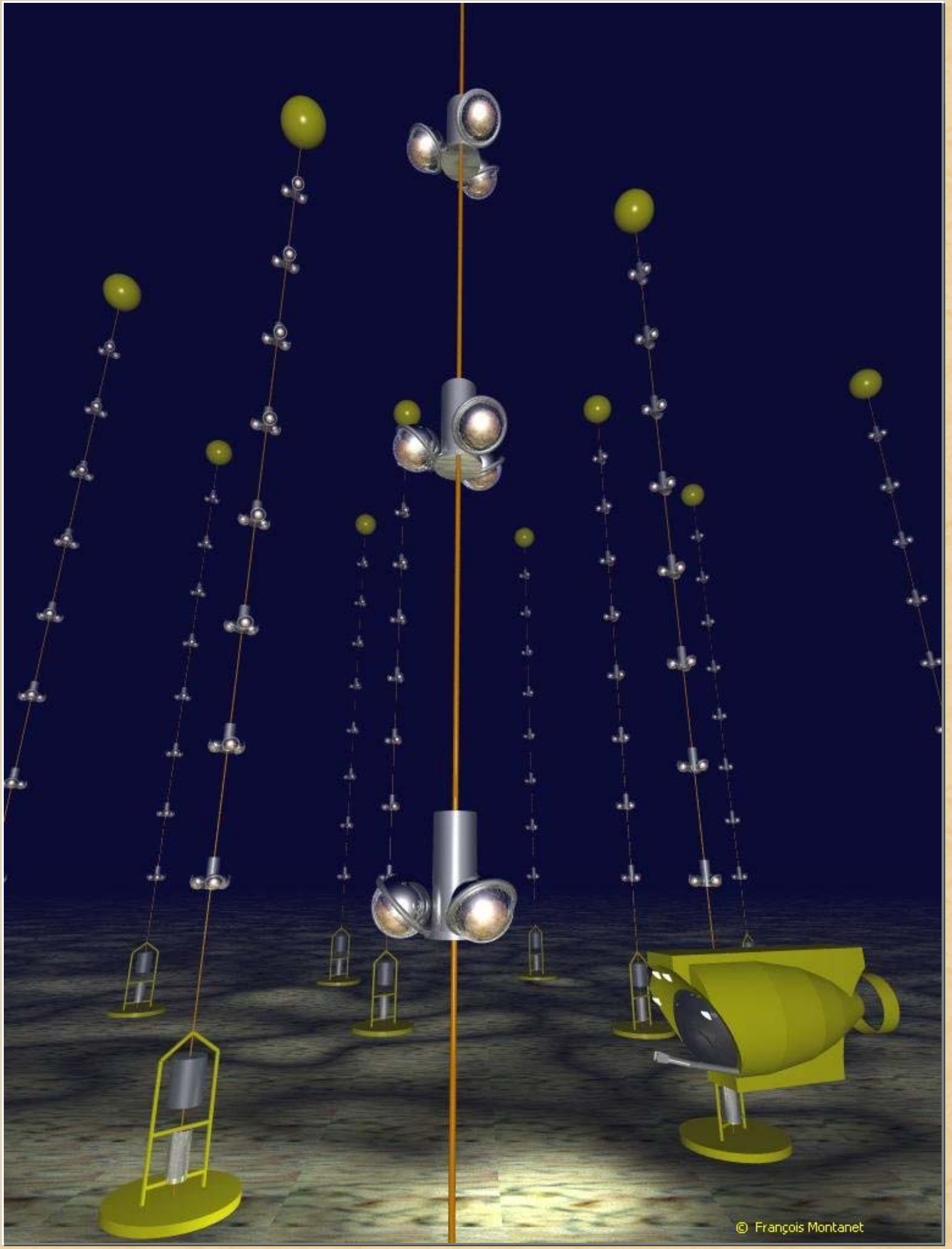
AMANDA as of 2000
Eiffel Tower as comparison
(true scaling)

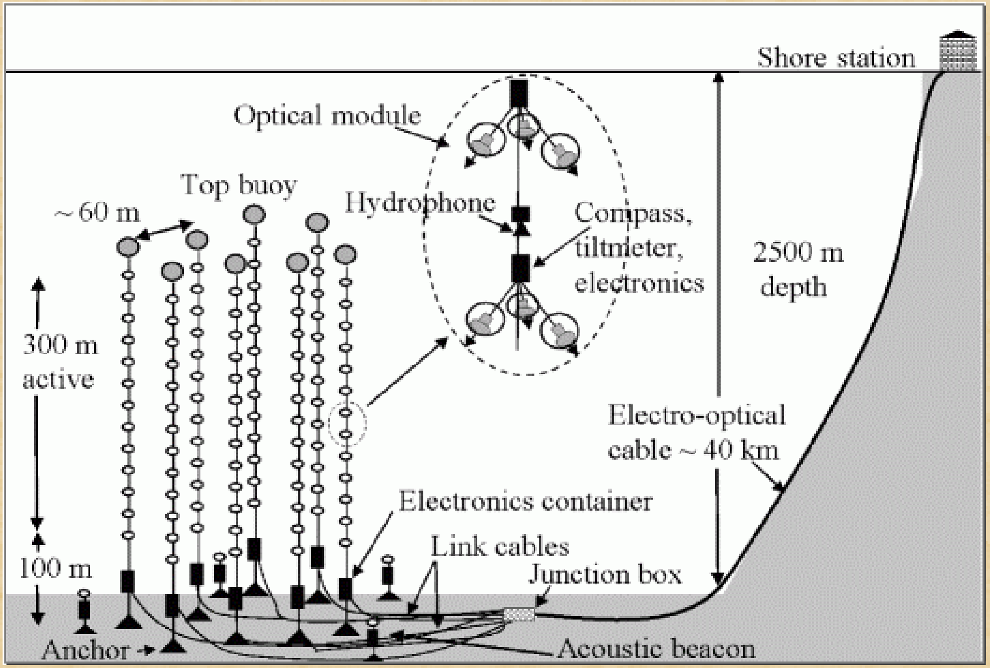
zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

zoomed in on one
optical module (OM)

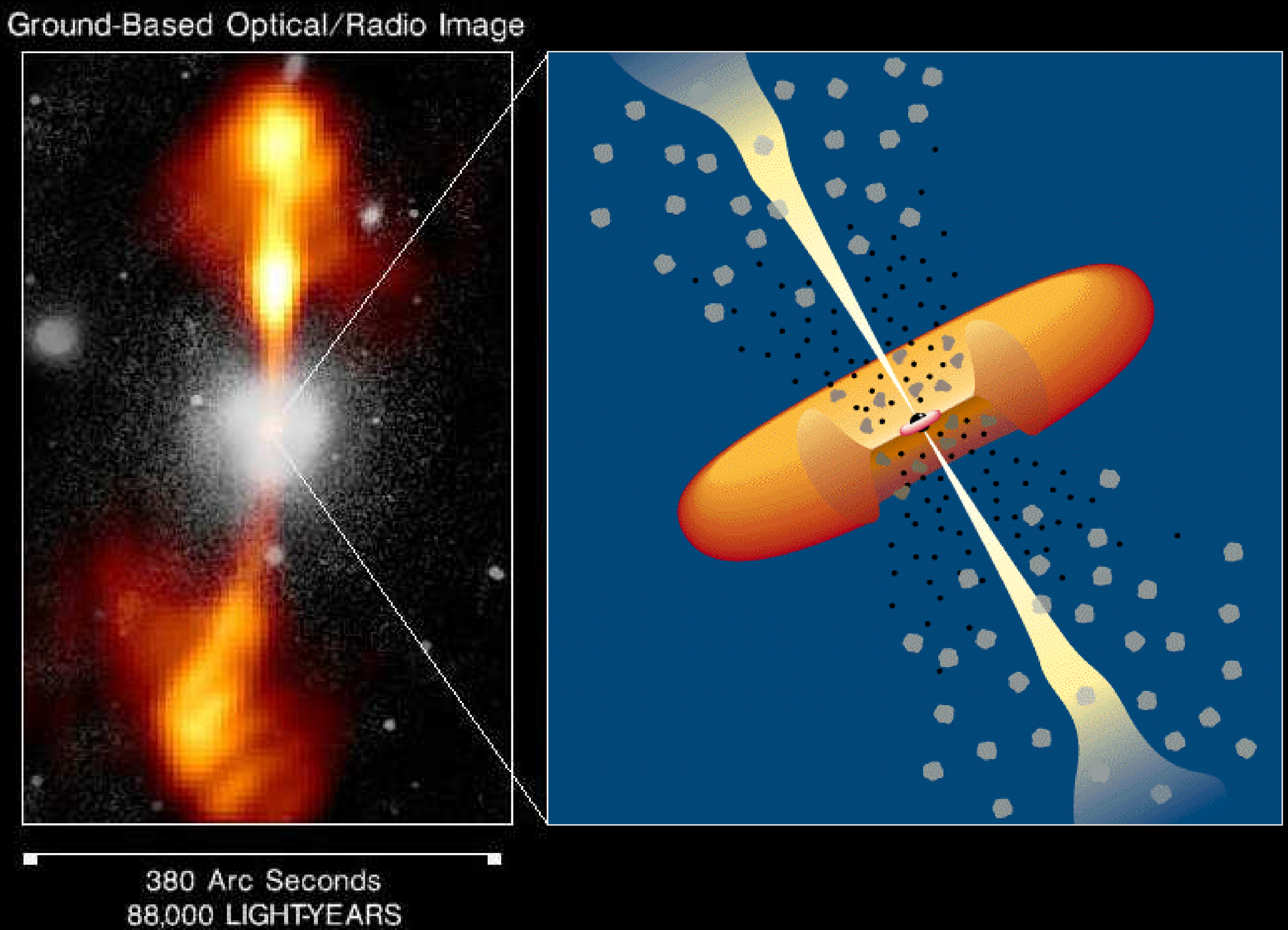


ANTARES – Neutrino Telescope in the Mediterranean

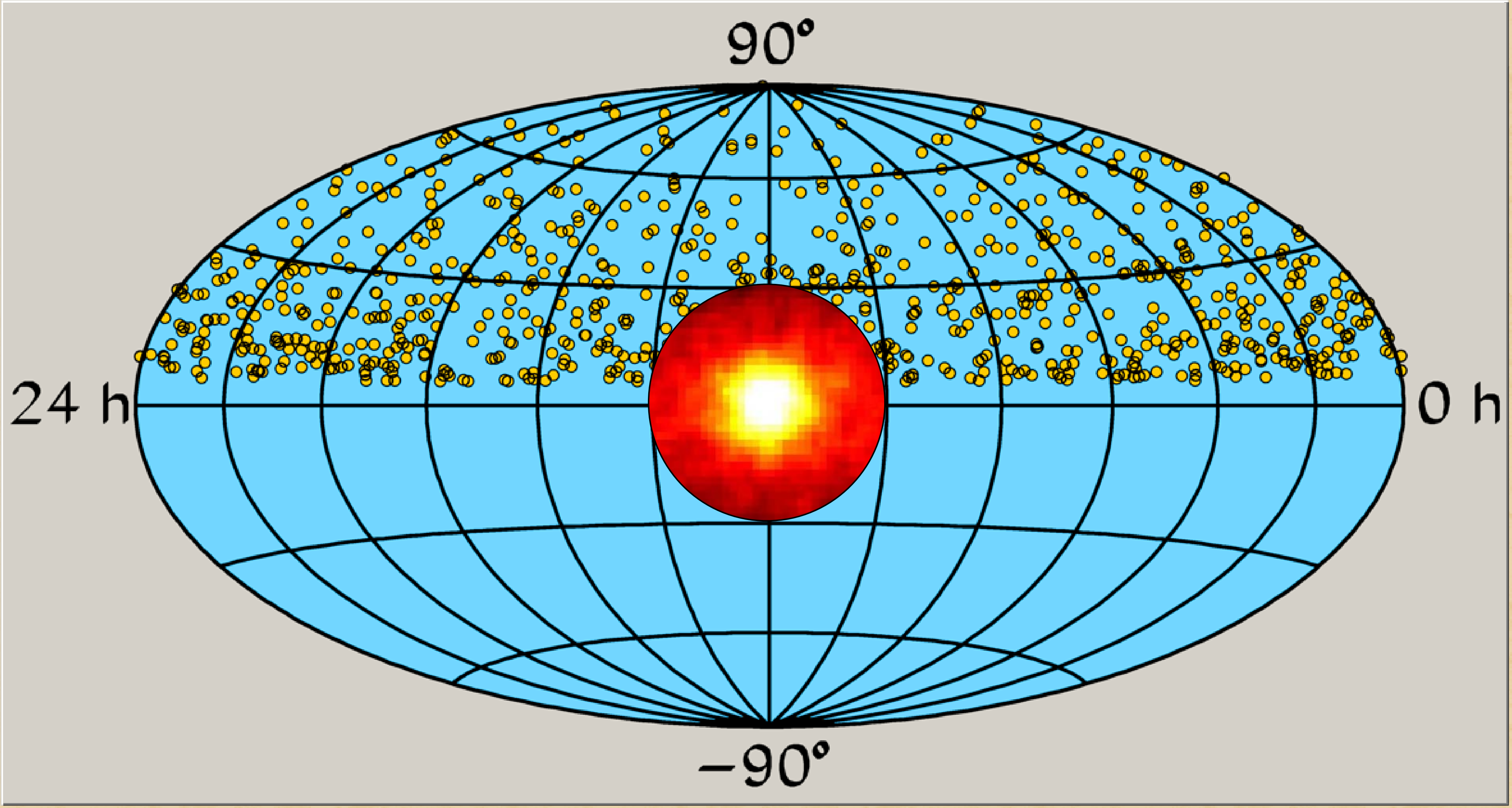




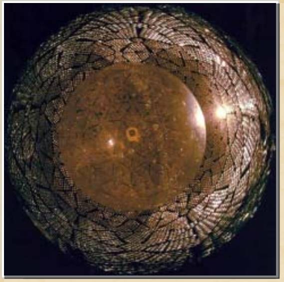
Core of the Galaxy NGC 4261



Neutrino Sky in Amanda and Super-Kamiokande



Where do we stand? Where are we going?

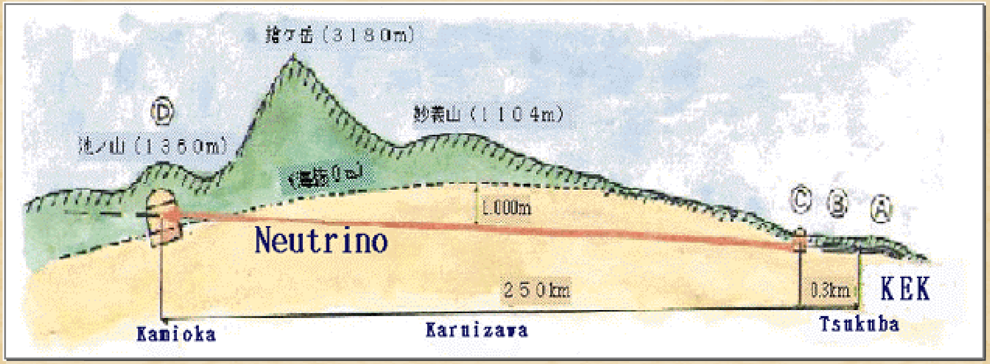


- Solar nu problem
- Atmospheric neutrino anomaly

Solved by flavor oscillations

- Very small mass differences
- Large mixing angles

Precision determination of mass & mixing matrix

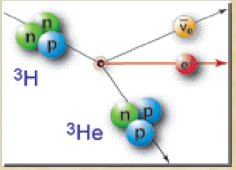


Asymmetry between nus & anti-nus ?

Absolute neutrino mass

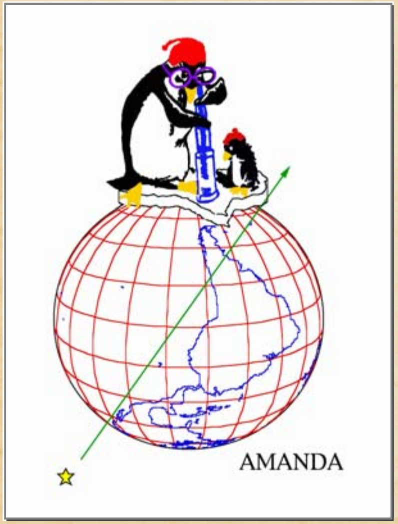
Precision cosmology

Karlsruhe Tritium Nu Experiment



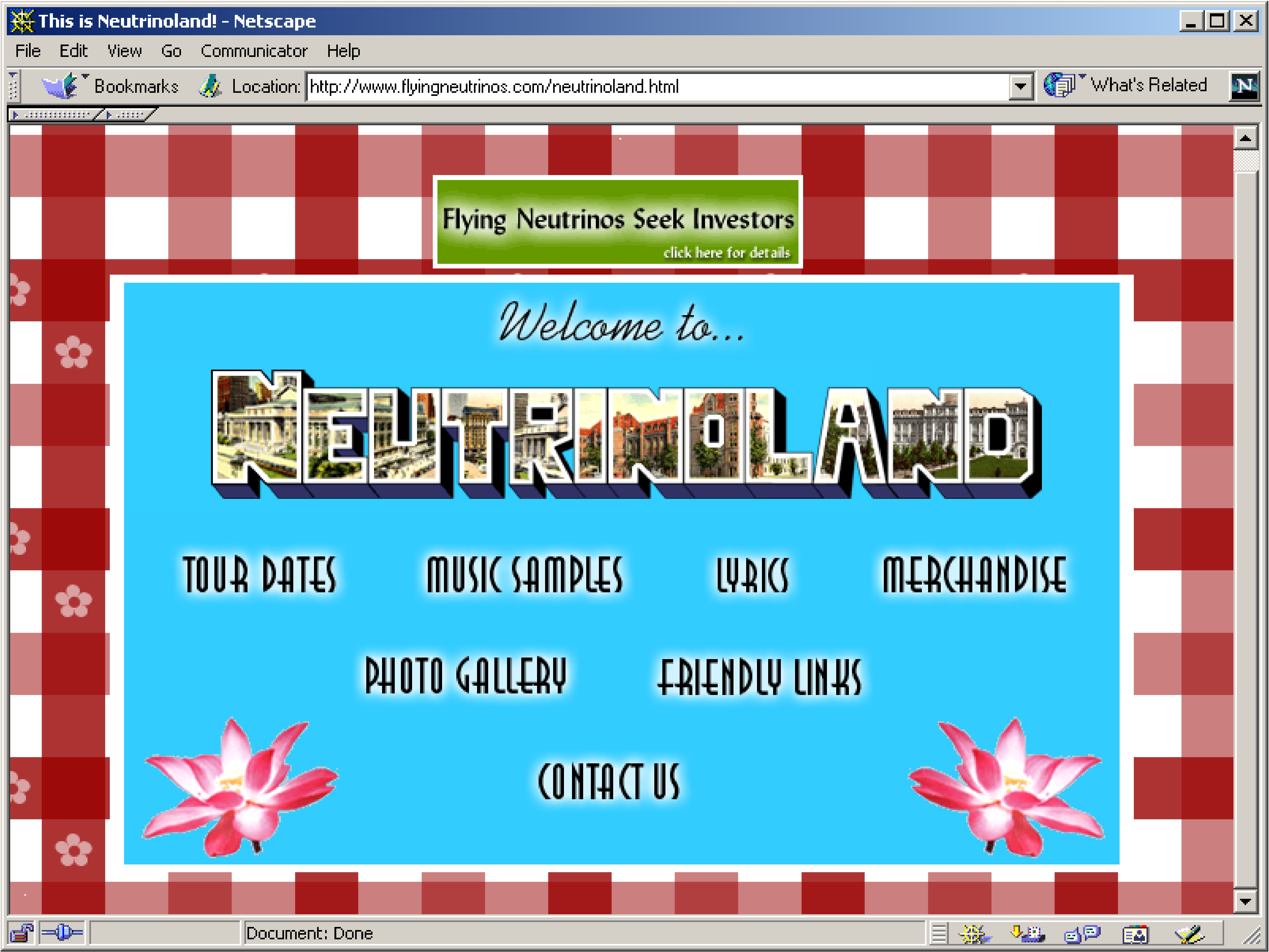
Double Beta Experiments (Genius, Majorana, Cuore, …)

Sky in the light of neutrinos



- Cosmic Accelerators
- Novel high-energy phenomena

Galactic supernova


This is Neutrinoland! - Netscape
File Edit View Go Communicator Help
Bookmarks Location: http://www.flyingneutrinos.com/neutrinoland.html
What's Related
Flying Neutrinos Seek Investors
click here for details
Welcome to...
NEUTRINOLAND
TOUR DATES
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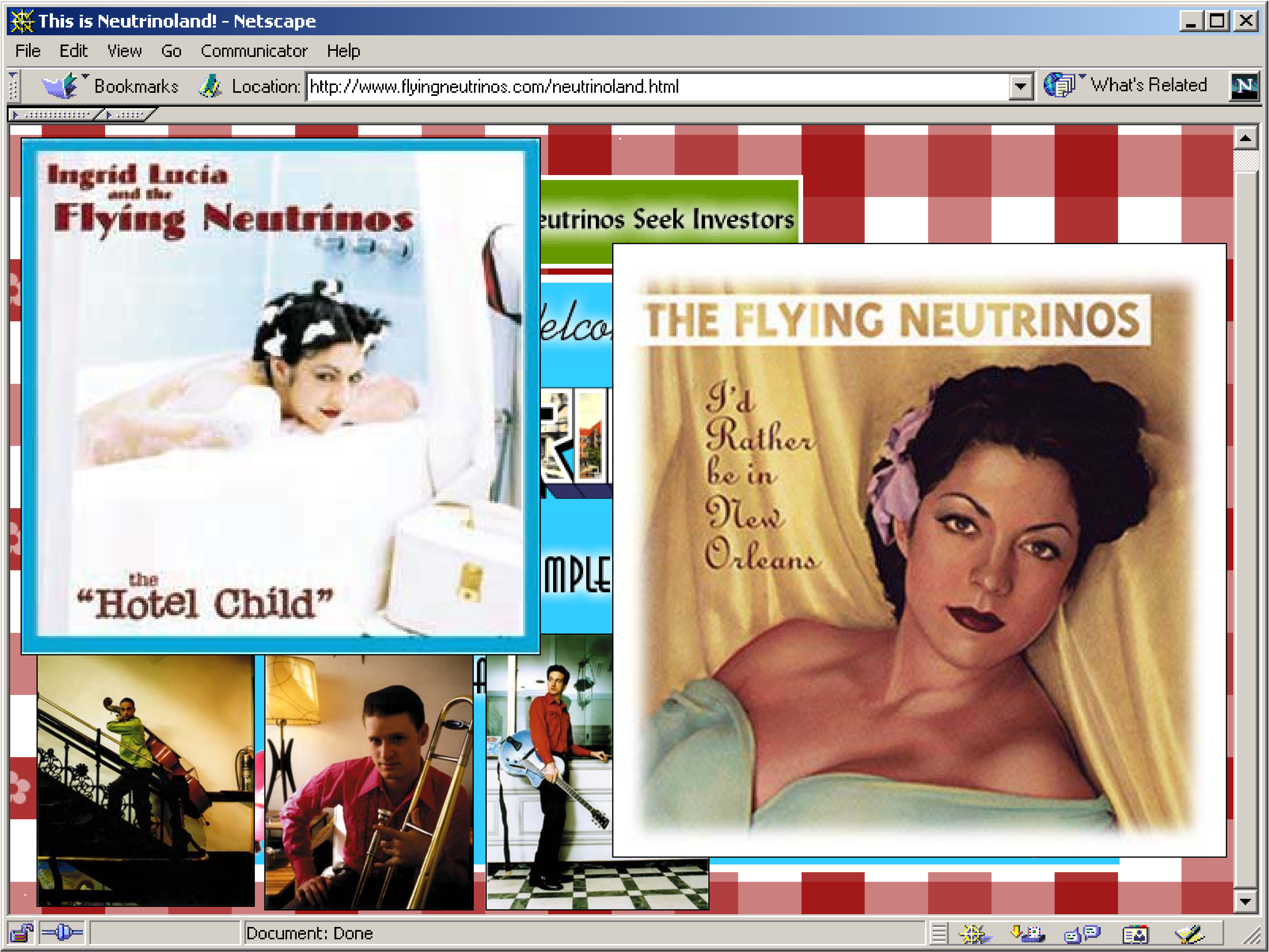
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File Edit View Go Communicator Help
Bookmarks
Location: http://www.flyingneutrinos.com/neutrinoland.html
What's Related
Ingrid Lucia and the Flying Neutrinos
the "Hotel Child"
eutrinos Seek Investors
THE FLYING NEUTRINOS
I'd Rather be in New Orleans
Document: Done


School on Neutrino Physics and Astrophysics
(NEUPAST)
ICTP, Trieste, 23 September - 4 October 2002
Thanks to
you all for coming!
Have a
safe trip home!
Georg Raffelt, Max-Planck-Institut für Physik, München, Germany