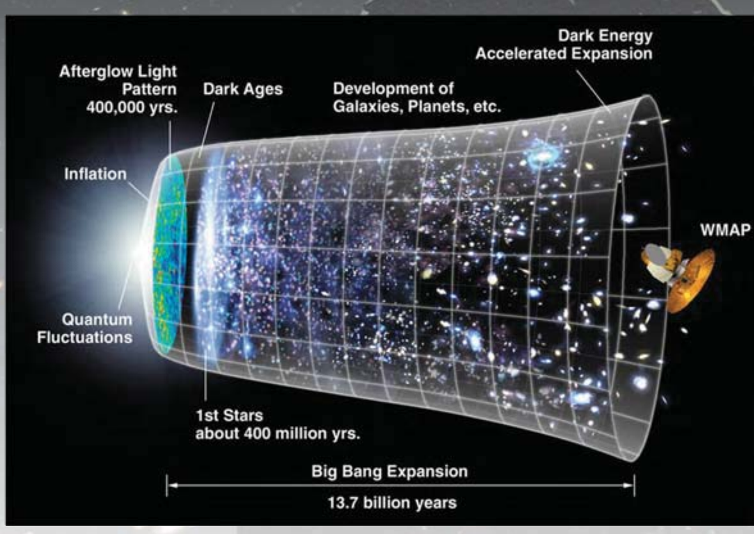
A new method to decode messages from the universe

Rolf Nahnhauer
DESY

The Universe

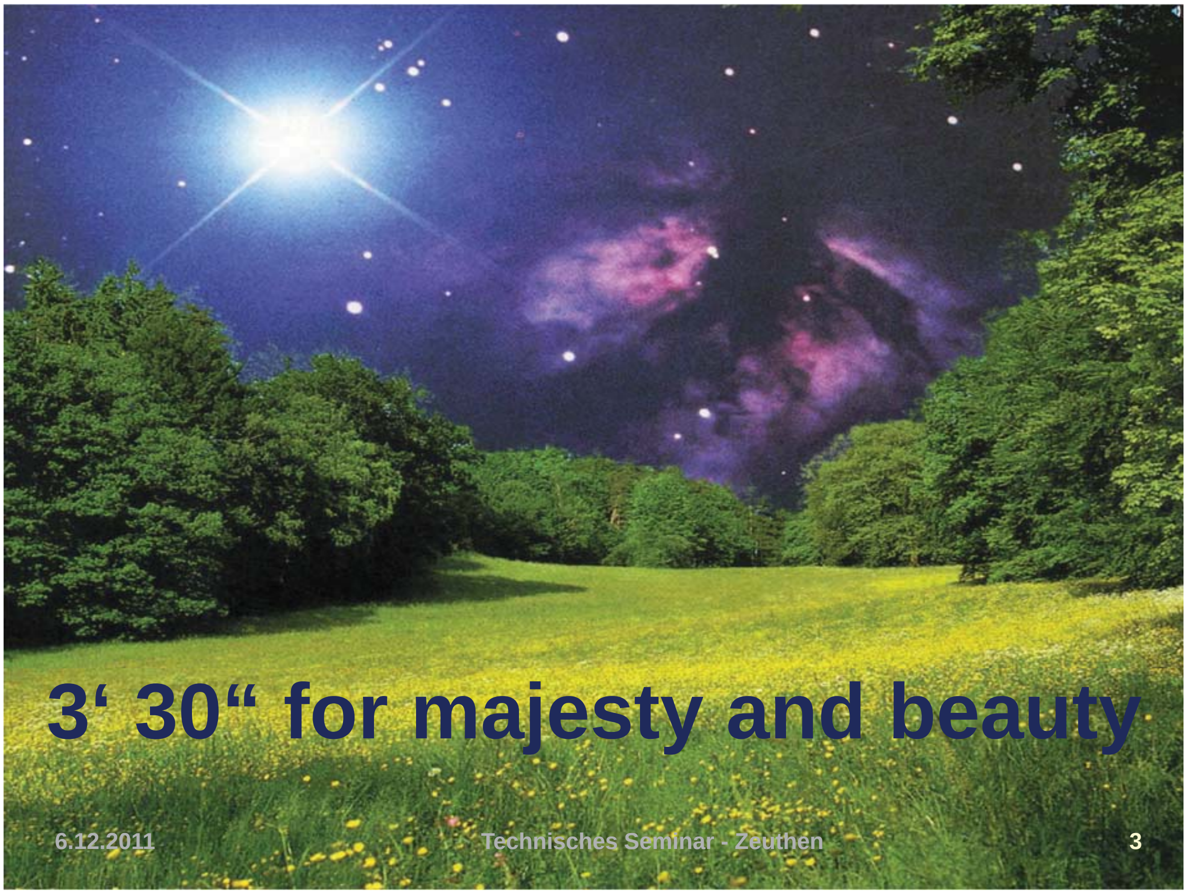


# of galaxies:
~100×10^9
#stars/galaxy:
~100×10^9
observation horizon:
~40×10^9 ly

Milky Way:
diameter: 100000 ly

Next star (Proxima Centauri):
4.2 ly

1 light year: 9.5 000 000 000 000 km = 9.5 quadrillion km

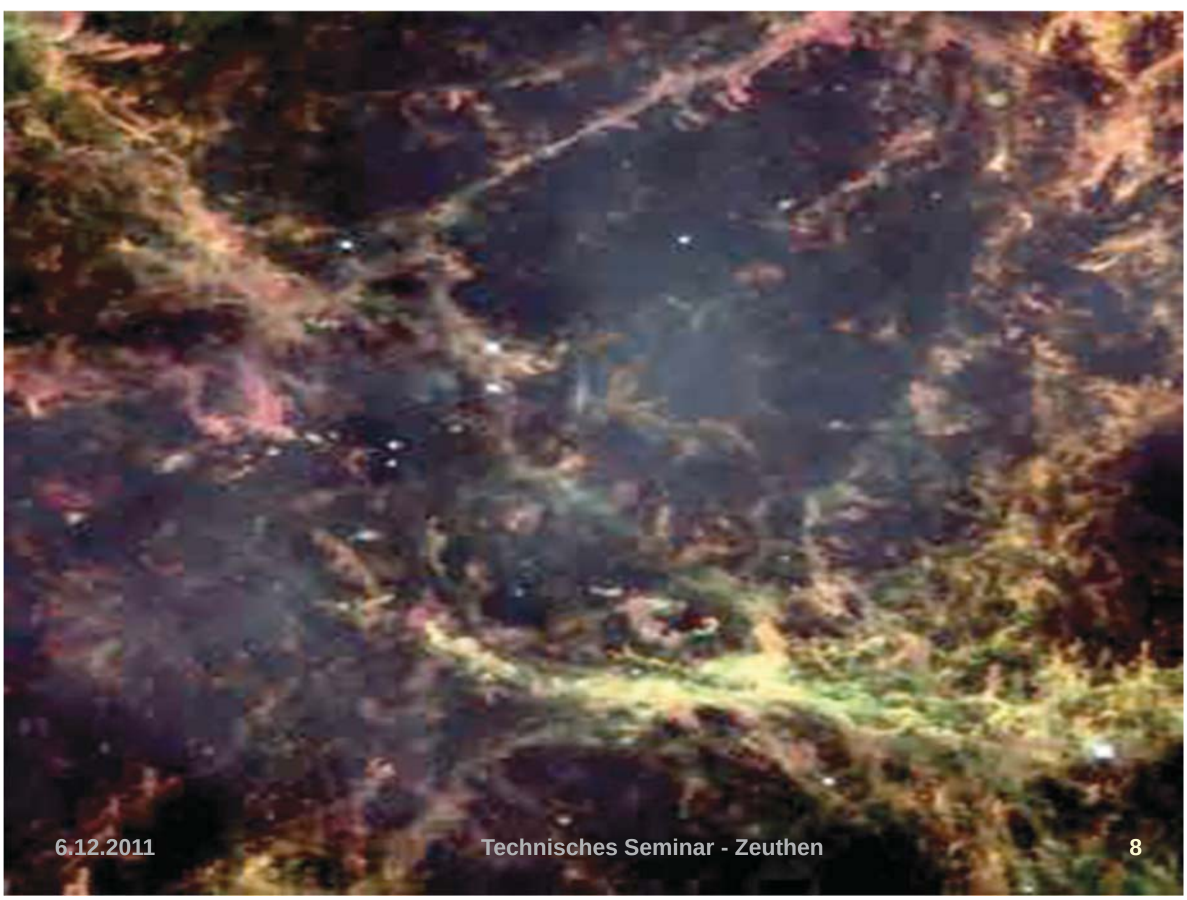

3‘ 30“ for majesty and beauty
6.12.2011
Technisches Seminar - Zeuthen
3

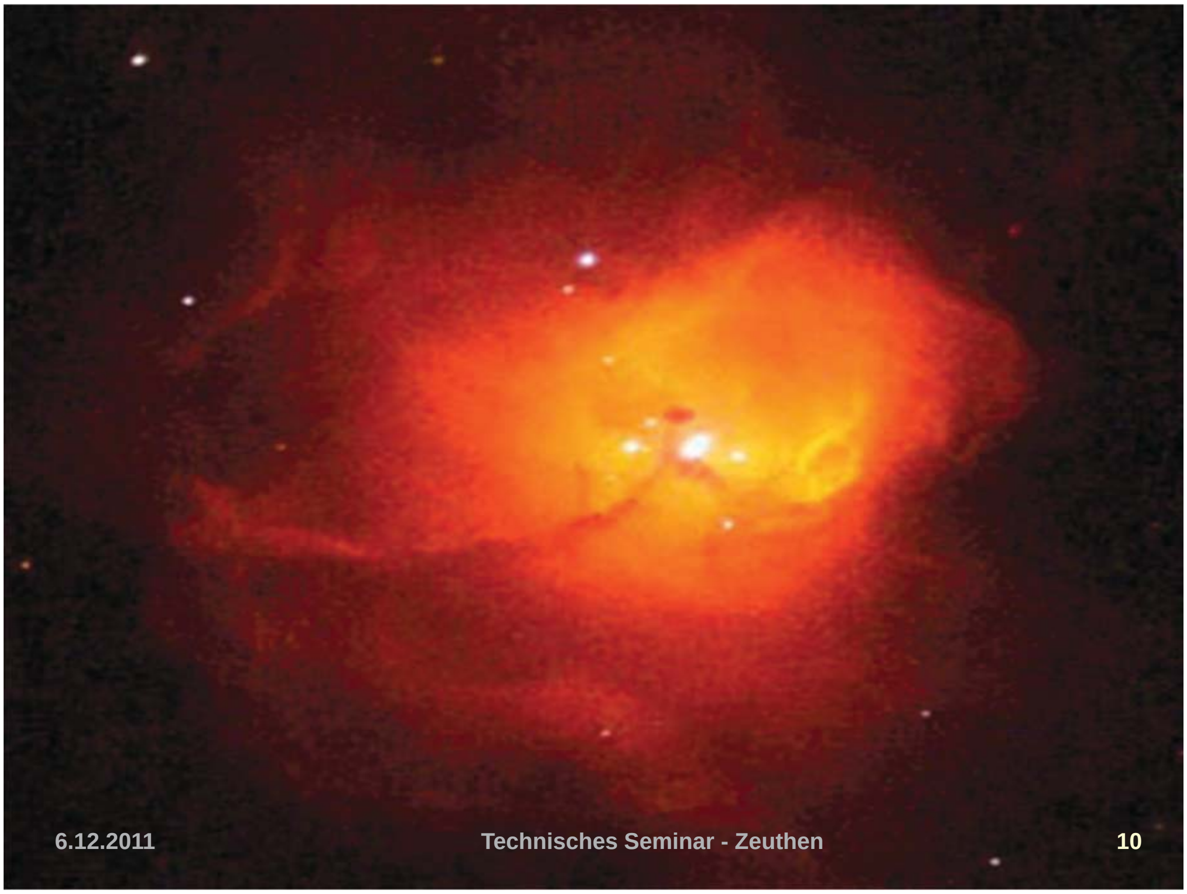

6.12.2011
Technisches Seminar - Zeuthen
4

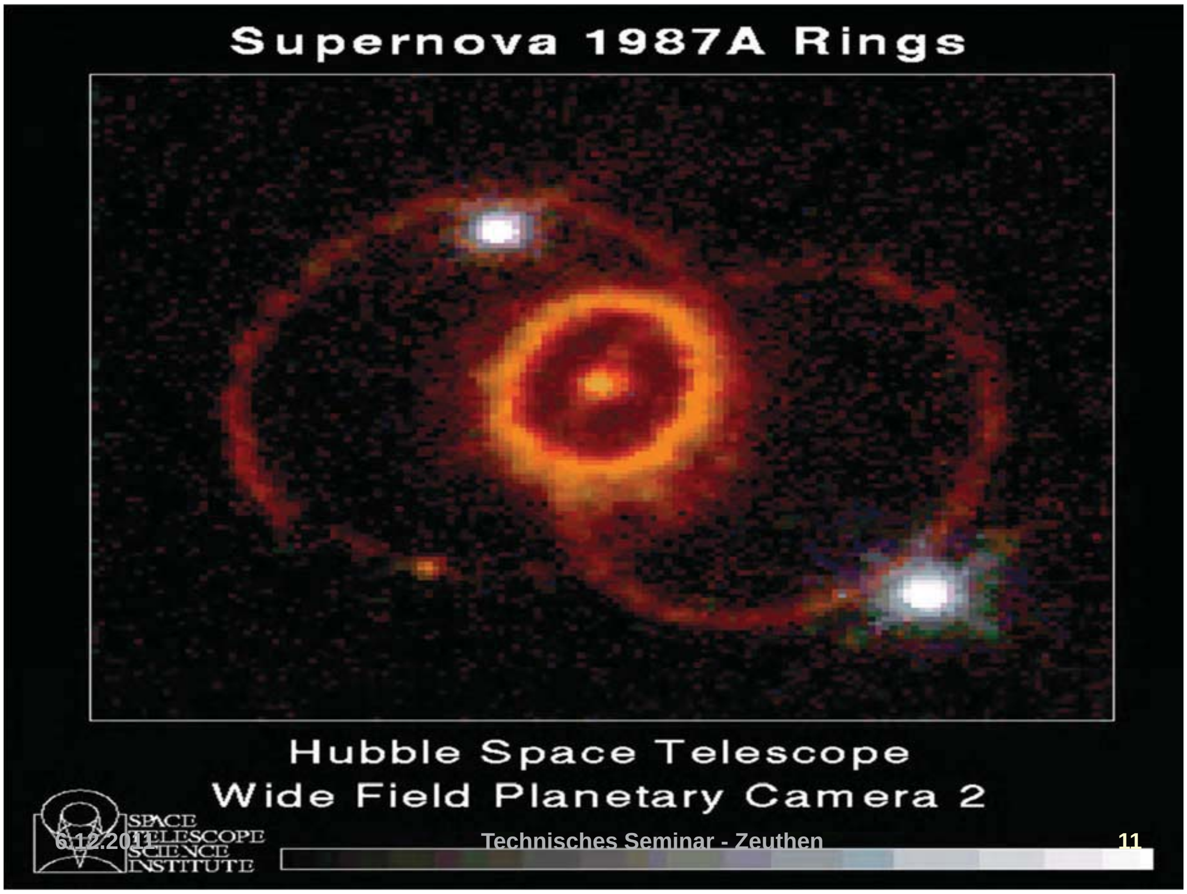

6.12.2011
Technisches Seminar - Zeuthen
5

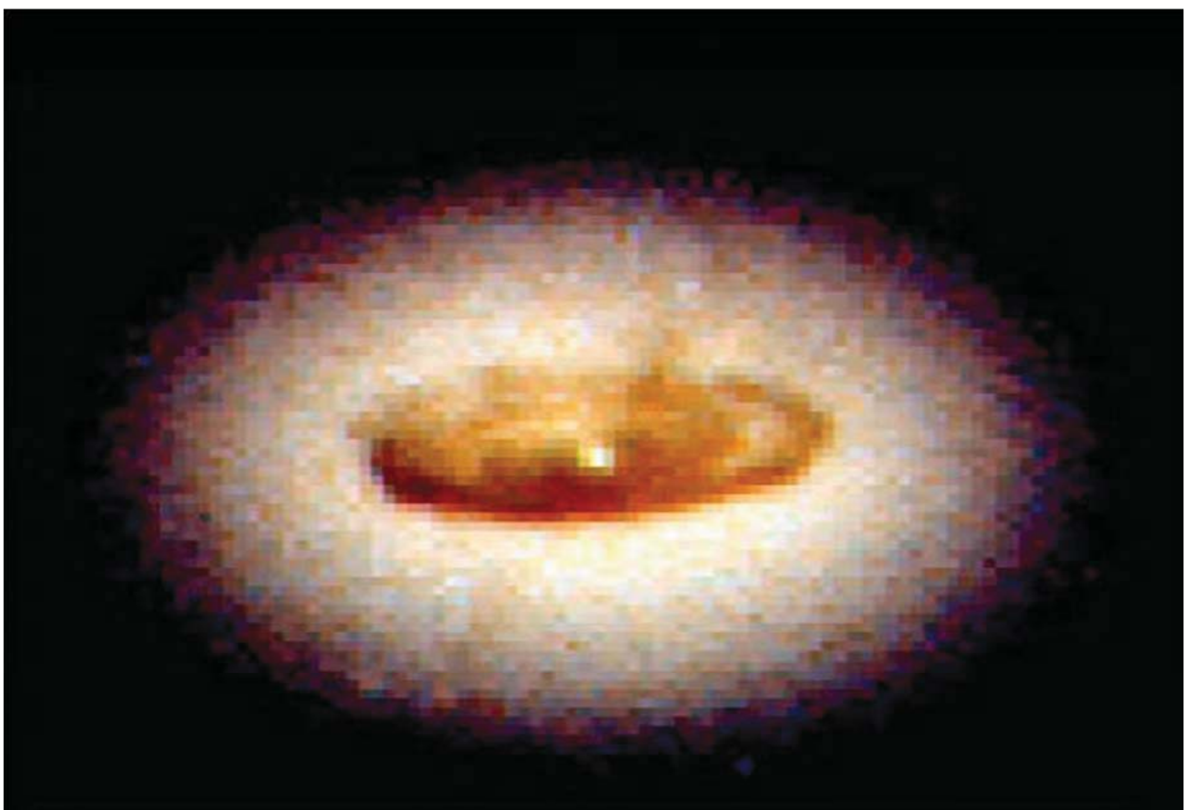

6.12.2011
Technisches Seminar - Zeuthen
6

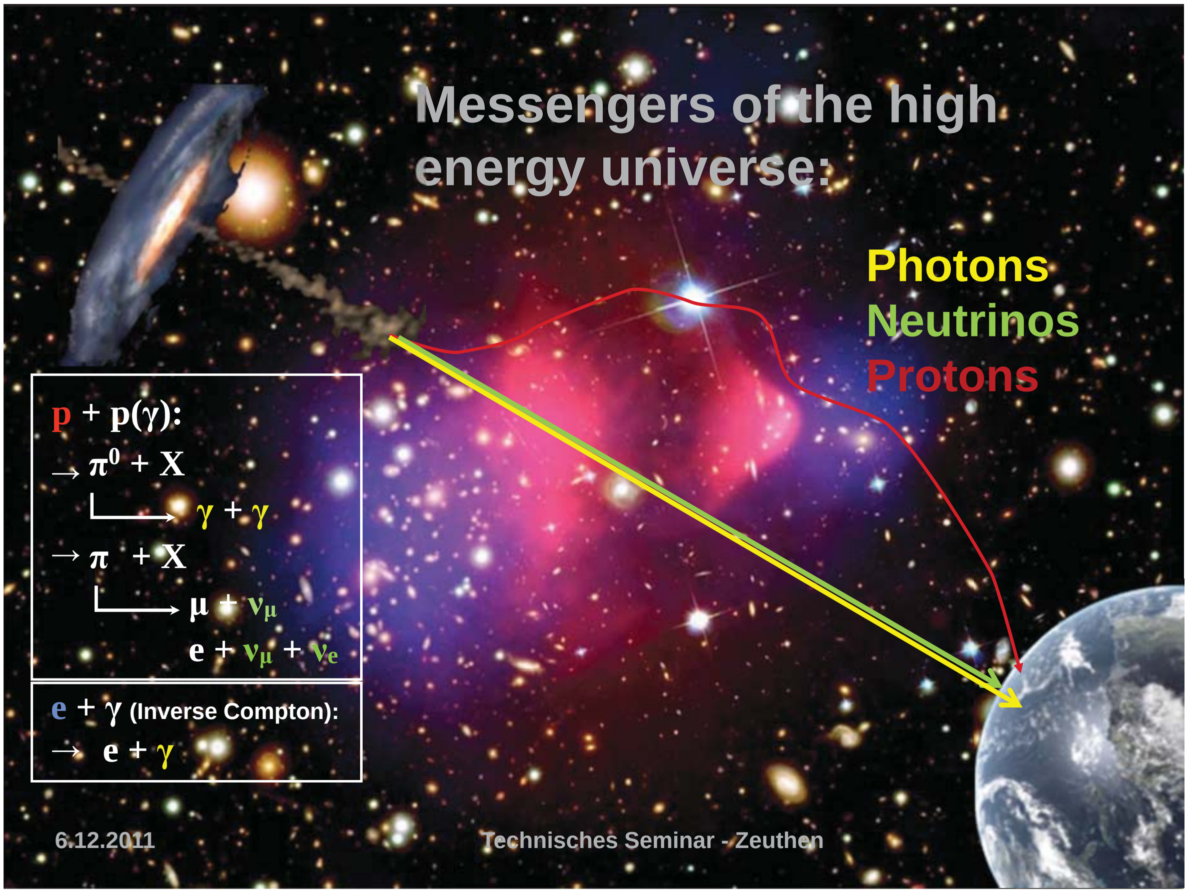

6.12.2011
Technisches Seminar - Zeuthen
7

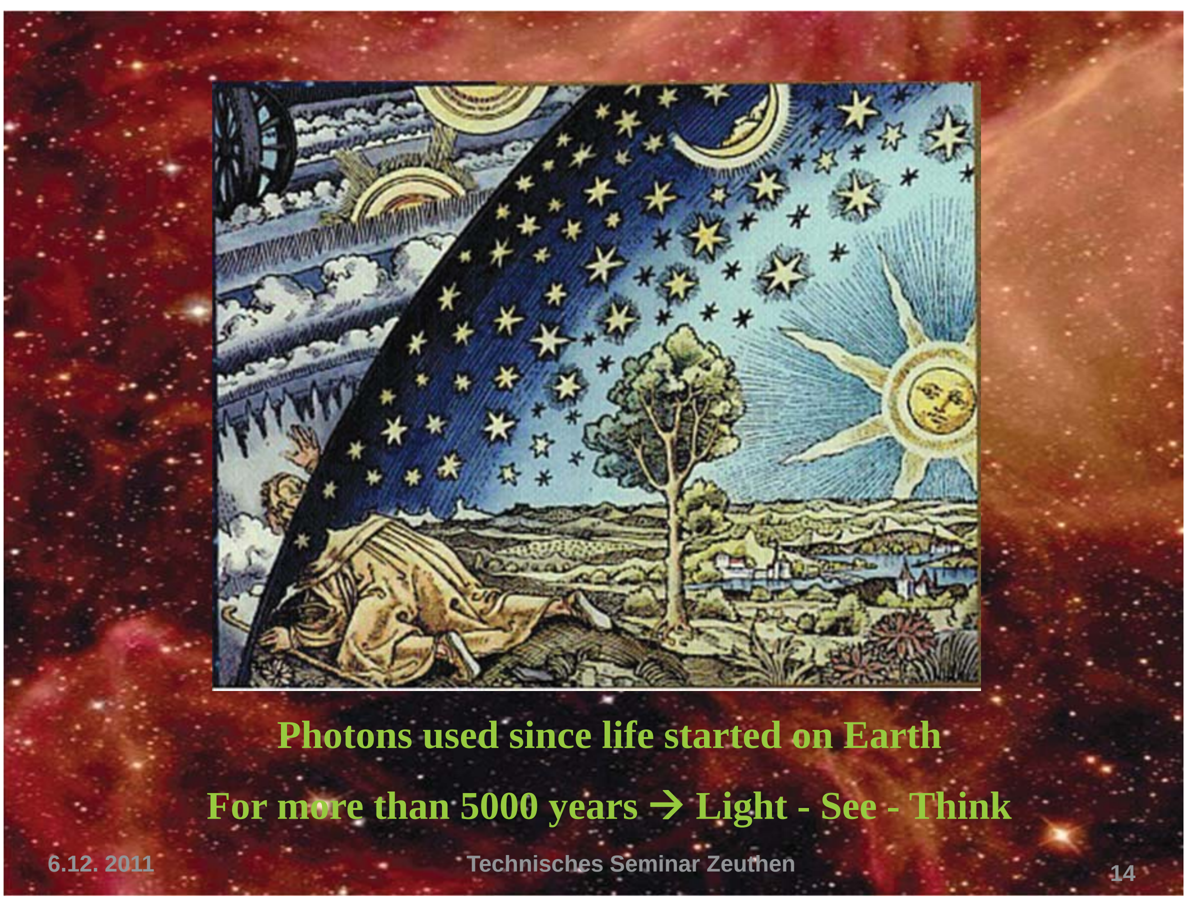

6.12.2011
Technisches Seminar - Zeuthen
8

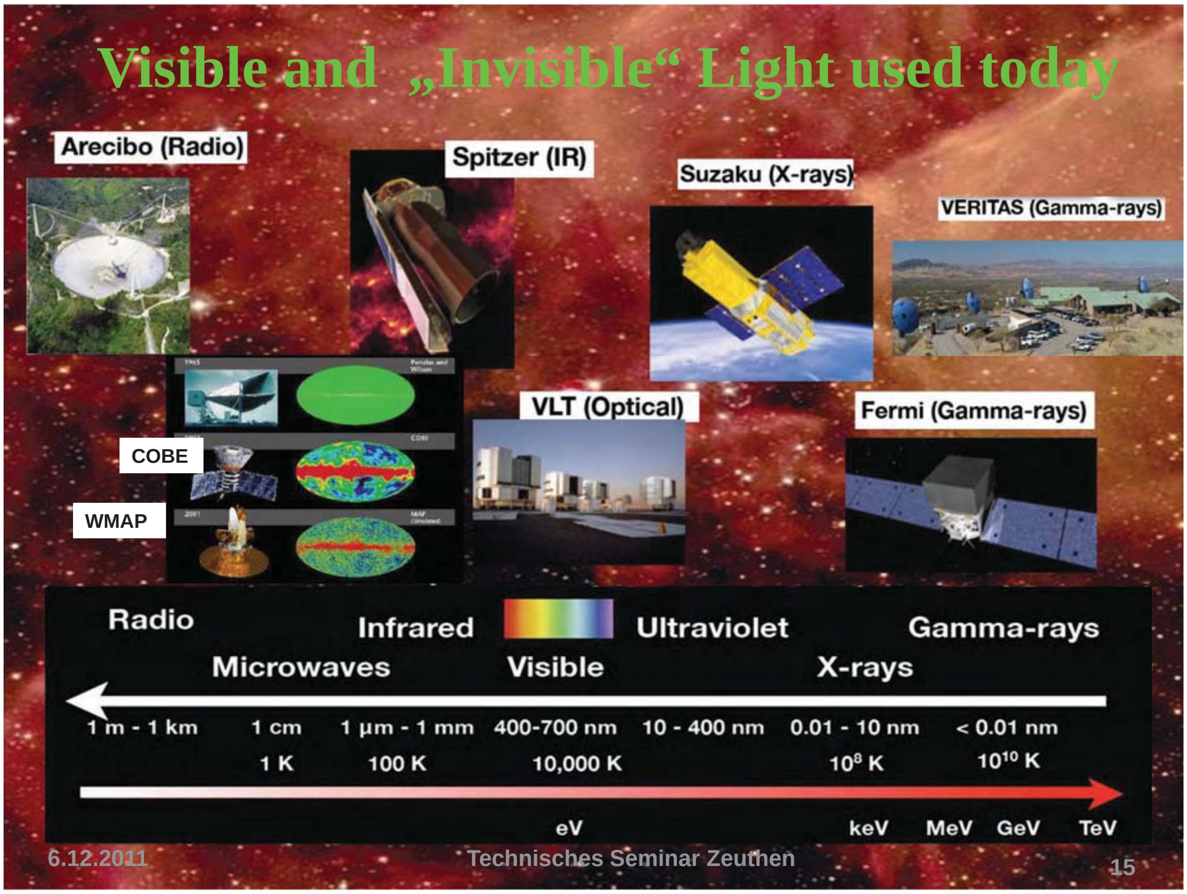



Supernova 1987A Rings
Hubble Space Telescope
Wide Field Planetary Camera 2
SPACE
TELESCOPE
SCIENCE
INSTITUTE



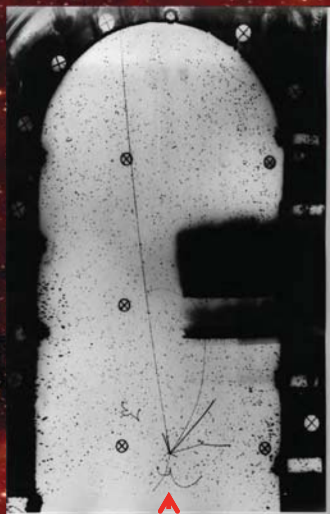

Messengers of the high energy universe:
Photons
Neutrinos
Protons
p + p(γ):
→ π0 + X
γ + γ
→ π + X
μ + νμ
e + νμ + νe
e + γ (Inverse Compton):
→ e + γ
6.12.2011
Technisches Seminar - Zeuthen


Photons used since life started on Earth
For more than 5000 years → Light - See - Think
6.12. 2011
Technisches Seminar Zeuthen
14


Visible and „Invisible“ Light used today
Arecibo (Radio)
Spitzer (IR)
Suzaku (X-rays)
VERITAS (Gamma-rays)
COBE
WMAP
VLT (Optical)
Fermi (Gamma-rays)
Radio
Infrared
Ultraviolet
Gamma-rays
Microwaves
Visible
X-rays
1 m - 1 km
1 cm
1 µm - 1 mm
400-700 nm
10 - 400 nm
0.01 - 10 nm
< 0.01 nm
1 K
100 K
10,000 K
10^8 K
10^{10} K
eV
keV
MeV
GeV
TeV
6.12.2011
Technisches Seminar Zeuthen
15


But we don‘t see neutrinos
The human senses originate from the need to increase the chances to survive in the outside world, not to do complex studies of nature
We „see“ only charged particles and their electro-magnetic radiation
Photo:: B.Koch - 19447 www.fotos.online.de
6.12.2011
Technisches bSeminar - Zeuthen
16

Make neutrino(interactions) visible:

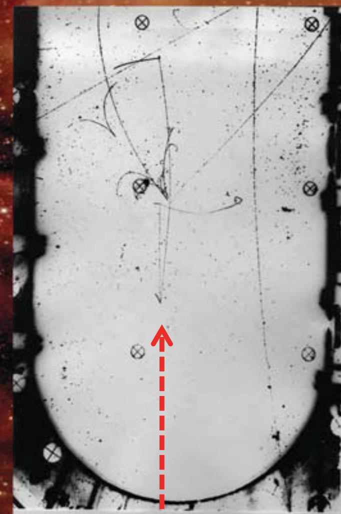


Neutral particles detectable by

➔ their decays in charged particles

➔ by the production of charged particles

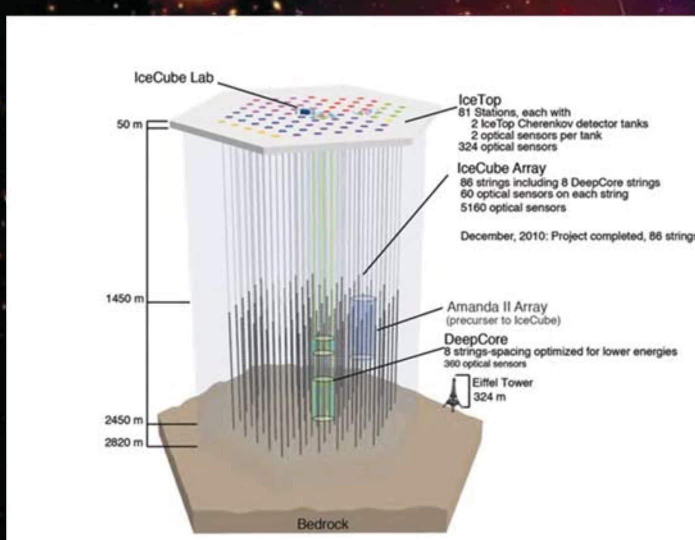
pictures from bubble chamber SKAT



$\nu_\mu N \rightarrow \mu X$

$\nu_\mu N \rightarrow \nu X$

The biggest optical neutrino detector build so far ➔ IceCube

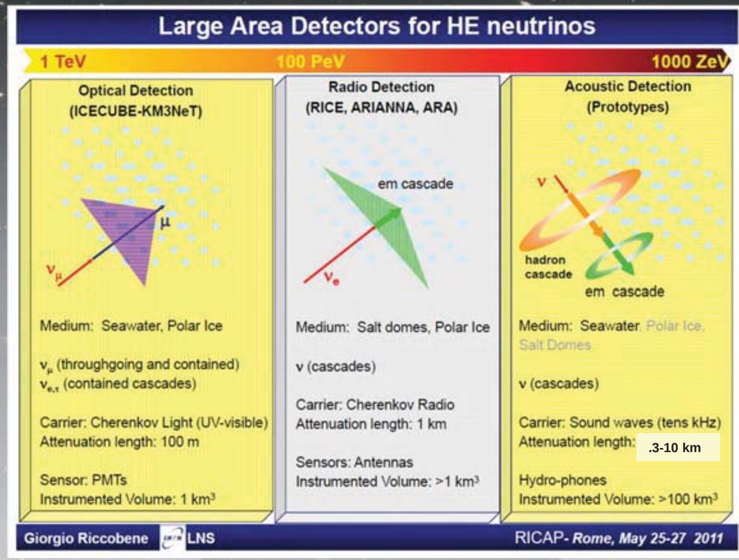


Instrumented volume:1km^3

But too small to do physics at highest neutrino energies

Need ~ 100-1000 times larger detector

Seems impossible with optical methods



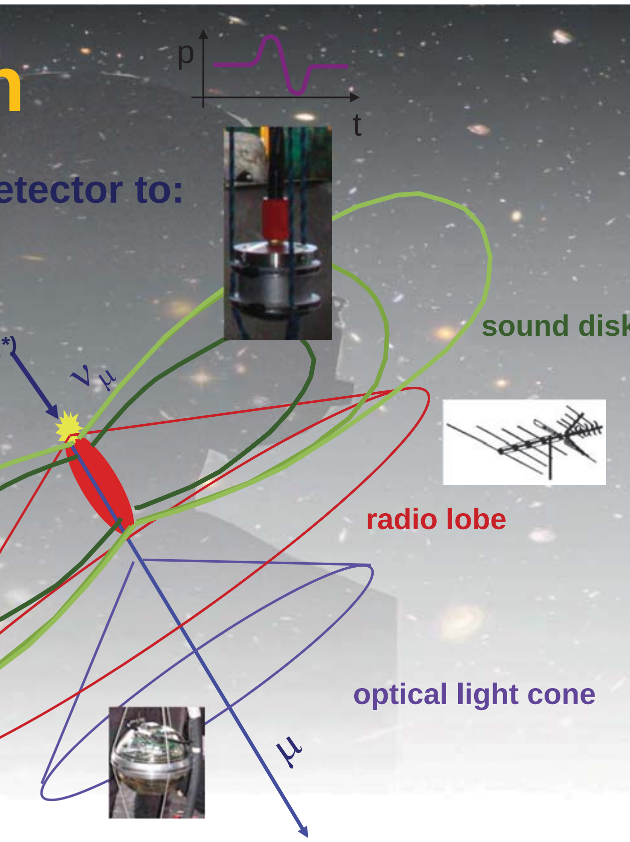
The Vision

Build > 100 km³ hybrid detector to:

Confirm GZK cutoff !

Do physics with extremely high energy cosmic neutrinos*)

- astrophysics - E > 10^{16}eV : study origin of cosmic rays - (AGN's, black holes, GZK cutoff, ...)
- particle physics - E > 10^{18}eV : study neutrino cross section (sphalerons, mini BH, ν_{strong},...)
- cosmology - E > 10^{21}eV : study relic neutrino background radiation (ν_{UHE} absorption at ν_{CBR})



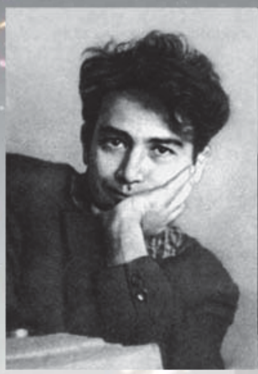
*) see e.g. R. Nahnhauer ,ARENA 2010

Some Effects of Ionizing Radiation on the Formation of Bubbles in Liquids*

DONALD A. GLASER
University of Michigan, Ann Arbor, Michigan
(Received June 12, 1952)

Nobel price 1960:
"for the invention of the bubble chamber"

Atomnaja Energija V3(1957)152



Гидродинамическое излучение от треков ионизирующих частиц в стабильных жидкостях

G. A. Askaryan

Hydrodynamic radiation from tracks of ionizing particles in stable liquids

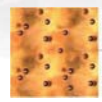
Прохождение ионизирующих частиц в жидкостях сопровождается увлечением молекул среды расталкивающимися скоплениями одноименно заряженных ионов и микровзрывами при локальных нагревах, создаваемых вблизи треков частиц. Эти

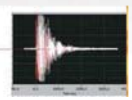
The passage of ionizing particles in liquids is accompanied by entrainment of molecules of the medium by mutually repelling accumulations of like-charge ions and microexplosions upon local heating near the particle tracks. These processes

First mentioning of an acoustic particle detection possibility

A modern application:
PICASSO - searching for Dark Matter

If a dark matter particle hits a nucleus in a tiny superheated droplet, the atom recoils and deposits its energy in a heat spike, which in turn triggers a phase transition.





First experimental detection of acoustic particle signals ?

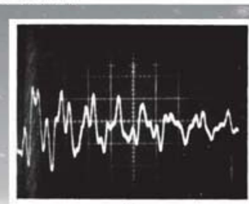
GENERATION OF MECHANICAL VIBRATIONS BY PENETRATING PARTICLES*

B. L. Beron and R. Hofstadter
Department of Physics and High Energy Physics Laboratory, Stanford University, Stanford, California 94305
(Received 11 June 1969)

Phys. Rev. Lett. 23, V4 (1969)184

Mechanical oscillations of lead-zirconate-titanate piezoelectric disks have been observed when penetrating high-energy (1.0-BeV) beams of electrons impinge on the disks. Radial and compressional modes of vibration have been observed in the frequency range 40-158 kHz. Possible applications of this observation to particle detection at very high energies are discussed. The observed phenomenon also has a possible connection with measurements of gravitational waves.

We have recently observed mechanical, or sound, vibrations in ceramic piezoelectric disks of lead-zirconate-titanate (PZT) struck by high-energy electrons. ~~Four ½-in.-thick disks of PZT~~ ~~modes~~. Electrons of energy 1.00 and 0.20 BeV were used in pulses, each lasting about 1.0 μsec and containing 10^4-10^6 electrons. The cross section of the incident 1.00-BeV beam was about 9 mm²

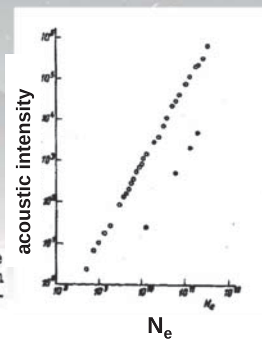


EXCITATION OF ULTRASONIC WAVES BY PASSAGE OF FAST ELECTRONS THROUGH A METAL

I.A. Borshkovskii, V.D. Volovik, I.A. Grishaev, G.P. Dubovik, I.I. Zalyubovskii, and V.V. Petrenko
Khar'kov State University
Submitted 15 April 1971
ZhETF Pis. Red. 13, No. 10, 546 - 549 (20 May 1971)

V. D. Volovik et al., Sov. JETP Lett. 13 (1971) 390

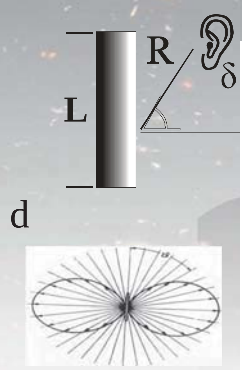
Using the electron accelerator of the Physico-technical Institute of the Ukrainian Academy of Sciences, with E₀ = 300 MeV, experiments were undertaken aimed at observing ultrasonic oscillations in solids excited by passing elec-



The Thermo-acoustic Model

First ideas presented at the 1976 DUMAND workshop independently by T. Bowen and B.A. Dolgoshein,
Proceedings not accessible (to me) but see:

G. A. Askaryan and B.Dolgoshein, JETP Lett. 25 (1977) 213
T.Bowen, Proc. 15th ICRC, Plovdiv, 1977, V6, p. 277



G.A. Askaryan et al.
NIM 164(1979) 267

In frequency domain :

P = (k/c_p) (E/R) M
M=$(f^2/2)$ (sinx/x)
f=$v_s/(2d)$, x=$(\pi L/2d)\sin\delta$

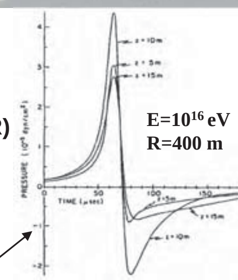
k : vol. expans. coefficient
c_p: specific heat

signal shape:
flat disk, width ~L

T. Bowen:

In time domain :

P = $(1/4\pi)(k/c_p)$ (E/R)



J. Learned,
Phys.Rew. D 19
(1979) 3293

P = $(1/\sqrt{(5.4\pi)}\ (1/4\pi)(k/c_p)\ (E/R)\ (v_s/\sigma)^2$

σ: Gaussian width of ionization distr.

Target material influence on signal strength :

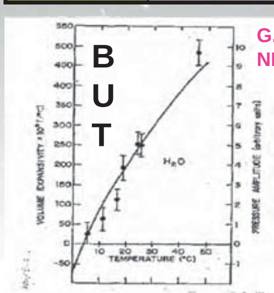
signal strength ~ Gruneisen parameter γ

	water	South Pole ice	salt
c (m/s)	1530	3880	4560
k (/K)	25.5e-5	12.5e-5	11.6e-5
C_P (J/kg/K)	3900	1720	839
$\gamma = c^2k/C_P$	0.153	1.12	2.87
f_{max} (kHz)	7.7	20	42
refraction	moderate	very small	small?
λ_{att}	> 1000 m	~300 m	> 100 m
noise	variable	stable, < 14 mPa	small?

adapted from B. Price, ARENA2005
using SPATS results

Ice is the only medium where optical, radio and acoustic signals can be used simultaneously

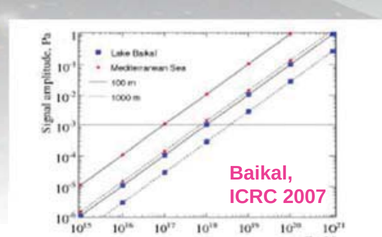
What about permafrost?
R. Nahnhauer et al.,
NIMA 587 (2008) 29



G.Sulak et al.
NIMA 161(1979)203

$T_{ANTARES}$ = 13°C
T_{Baikal} = 3°C

→



Baikal,
ICRC 2007

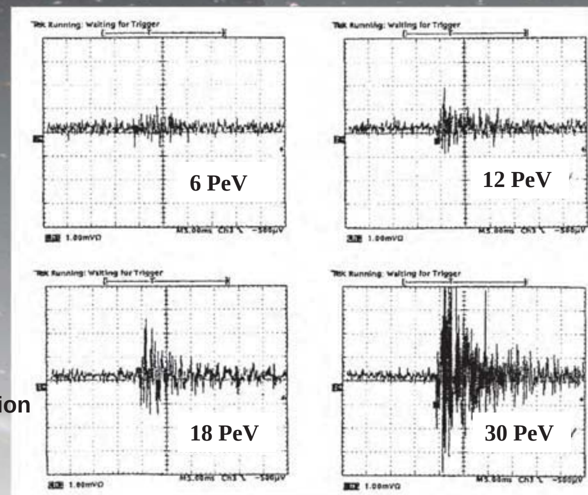
Real signal strength depends strongly on local conditions

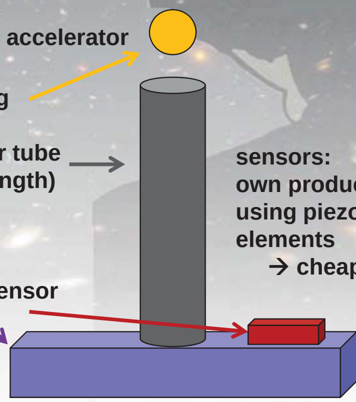
How to get PeV particles for model testing

J.Bähr,R.N.,M.Pohl
DESY Zeuthen (1996) unpulished

$E_{pot} = mgh$

m=1g, h=10cm, E=6 PeV





sensors:
own production
using piezo-
elements
→ cheap

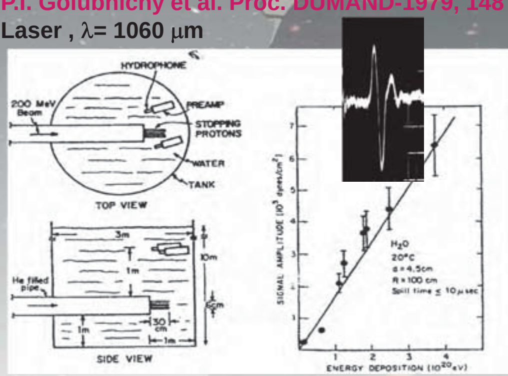
Conclusion:
- accelerator works
- basic model prediction "confirmed"

What do refined measurements say?

Early experimental checks 1979-80

Sulak et al. NIM 161(1979) 203
BNL: 200 MeV and 28 GeV protons, $E_{min} = 10^{20}$ eV
Harvard: 158 MeV Protons, $E_{min} = 10^{15}$eV

P.I. Golubnichy et al. Proc. DUMAND-1979, 148
Laser , λ= 1060 μm



Other questions studied

A= f(d), varying beam diameter
A= f(K/c_p), varying liquids
A=f(R), varying distance
A=f(p), varying static pressure

Similar studies from the last decade

V.I. Albul et al. Instr. and Exp. Techn. 44 (2001)327
125 Mev+200 MeV, p,H2O, ITEP Moscow

S. Böser et al. unpublished
(Dipl.-Thesis J.Stegmaier, Mainz2004)
177 MeV, p, ice, TSL Uppsala

K.Graf et al., Int.J.Mod.Phys. A21(2006)127
177 MeV , p, H_2O, TSL Uppsala
Laser, 1064 nm, H_2O, Erlangen

R. Nahnhauer et al., NIMA 587 (2008) 29
Laser, 1064 nm, "permafrost", Zeuthen

G.De Bonis et al.NIMA 604 (2009) 199
100 MeV+200 MeV, p, H_2O, ITEP

Conclusions

→ many Thermo-acoustic Model predictions confirmed
→ dominant mechanism is thermal expansion
→ other contributions (microbubbles, ???) can not be completely excluded

No comparison of absolute amplitude strength between data and model(s) available up to 2011

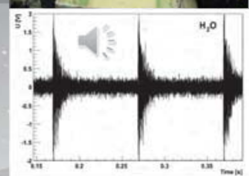
Relative comparison of signal strength

TSL Uppsala 2003

S. Böser et al. unpublished

Ice

H_2O



Beam: p, ϕ = 2cm, E = 110 PeV R = 40cm

Detectors: First generation glaciophones mounted to 13 inch IceCube glass half-spheres

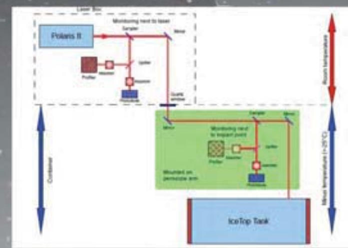
unexpectedly:

$S_{water} \geq S_{ice}$

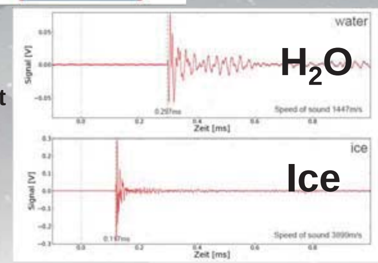
but many experimental uncertainties

Aachen Acoustic Lab.2011

D. Heinen et al. to be published



laser beam with excellent monitoring



as expected:

$S_{ice} \approx 6 * S_{water}$

Piezo-ceramic based acoustic sensors

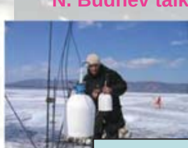
commercial production

G. Riccobene talk at ARENA2005,

AMADEUS: HTI

BAIKAL: H2020C

N. Budnev talk at ARENA2010,



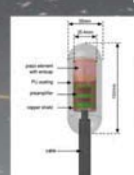
Sound absorb. hats

Typical sensitivity:

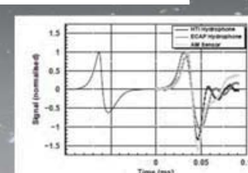
-190 → -110 dB re 1V/µPa

Special cases: military applications
RONA – ACORNE
AUTEC - SAUND

home made

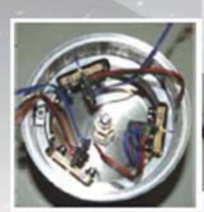


AMADEUS: Erlangen



J.A.Aguilar et al., NIMA 626-627(2011) 128

SPATS: DESY



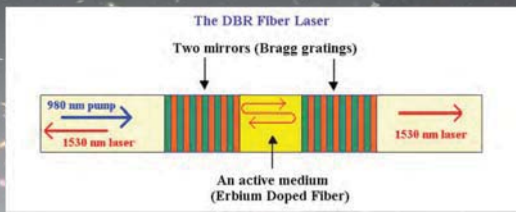
Y. Abdou et al., arXiv: 1105.4339 submitted to NIMA

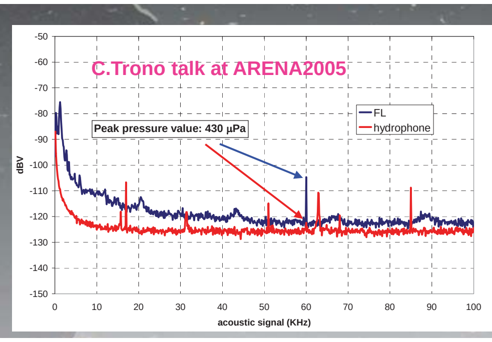
S. Böser talk at ARENA2005,

HADES: Wuppertal

“New“ sensor ideas

fibre acoustic sensors – first ideas go back more than 30 years





pressure wave on fibre :
➔ modulation of cavity size, leading to modulation of laser wavelength detectable by interferometer

Proven to work at static pressure of 35 MPa (3500 m depth) with higher sensitivity than PZT devices
P.E. Bagnoli et al., NIMA 567(2006) 515, E. Maccione et al.,NIMA 572 (2007) 490,
A.Cotrufo et al. NIMA 604 (2009) 219 (fiber wrapped on a mandrel)
For other recent publications see e.g.:
J. Wang et al., Optoelectronic letters V3 No 4 (2007) doi: 10.1007/s11801-007-6169-1
S. Goodman et al., Proc. SPIE V 7004 (2008), doi: 10.1117/12.785937
B.Guan et al. , Optics Express Vol 17 No.22 (2009)19544 and references therein

Another approach: use intensity variations instead of phase modulation

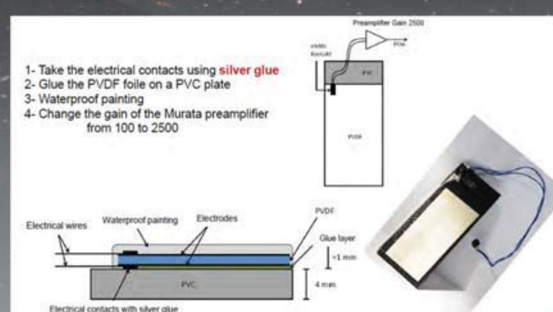
Coupled waveguide acoustooptic hydrophone

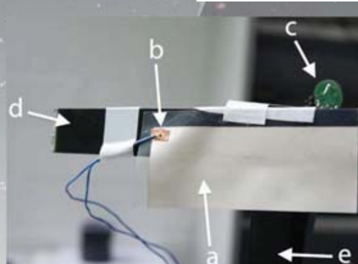
J. N. Fields
Hughes Research Laboratories, Malibu, California 90265.
Received 29 August 1979.
Sponsored by Emanuel Marom, Tel Aviv University.
0003-6935/79/213533-02$00.50/0.
© 1979 Optical Society of America.

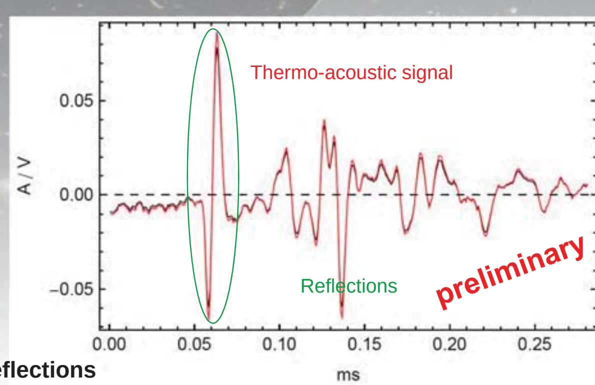
The purpose of this Communication is to propose an intensity-modulated transducer that can detect displacements several orders of magnitude smaller than the earlier scheme,[4] the new mechanism being acoustic modulation of the distance separating a pair of evanescently coupled optical waveguides.

Piezo-foils as acoustic sensors

a- PVDF foil
b- Electrical contact (Copper tape + Silver glue)
c- Preamplifier
d & e - PVC Support





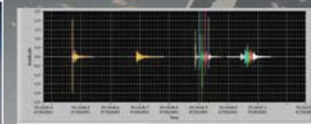


Test with laser in water tank ➔
Will be tested in ice next

Clean bipolar signal (thermo-acoustic)
Nice separation between direct signal and reflections
Frequency of the bipolar signal related to the laser beam width

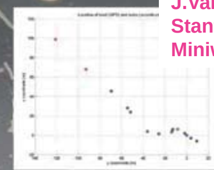
Acoustic transmitter

Saund I calibration sources



21 events per light bulb

Bulb	Depth (m)	P (kPa)	E_0 (J)
1	160	1563	234
2	107	1047	157
3	139	1360	204
4	166	1626	244
5	126	1237	186
6	101	990	148
7	86	838	126
8	135	1324	199
9	188	1842	276
10	290	2846	427



J.Vandenbroucke at Stanford Acoustic Miniworkshop ,2003

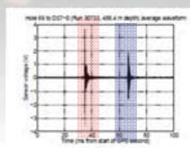
measure energy and location

SPATS transmitter:
measure sound speed, sound attenuation length, produced shear waves

own production used in ice

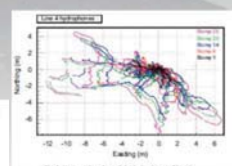
commercial ITC1001 use in water filled holes

R. Abbasi et al., APP 33(2010)277
R. Abbasi et al., APP 34(2011)382



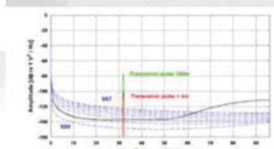
Position monitoring

Problem for all deep water optical neutrino telescopes
Solution : fix strong acoustic transmitters at known positions of the sea bed, add hydrophones to optical strings, ping every 1-2 minutes, triangulate pulses



Example: ANTARES
precision < 10 cm
M. Ardid, NIMA 602(2009)174

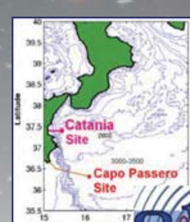
R&D for KM3NeT →
F.Ameli et al., NIMA 626(2011)211



Recent experimental test sites

ACoRNE

AMADEUS



OνDE

THE LAKE BAIKAL NEUTRINO TELESCOPE

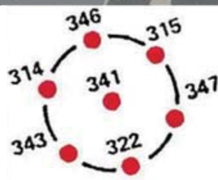
SPATS
South Pole Acoustic Test Setup

AUTEC - SAUND

Study of Acoustic Ultrahigh-energy Neutrino Detection

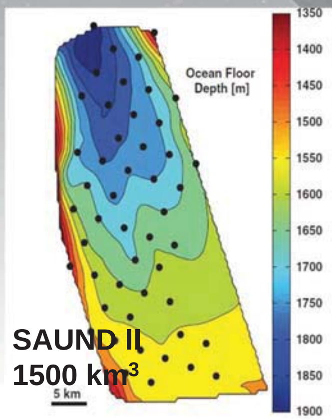
SAUND I
15 km^3

Data taking:
65 $*10^6$ trigger
in 195 days



→ first flux limit from acoustics

J. Vandenbroucke et al., Astrophys.J. 621 (2005) 301

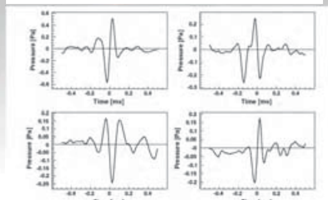


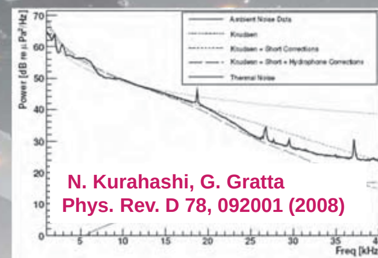
SAUND II
1500 km^3

Data taking:
328 $*10^6$ trigger
in ~130 days

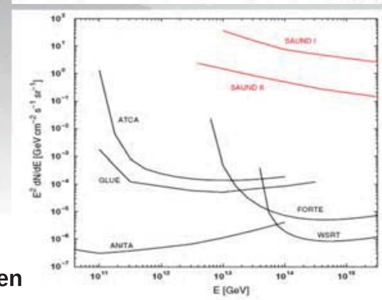
Two events after all cuts
(one example below)

N. Kurahashi et al., Phys. Rev. D 82, 073006 (2010)





N. Kurahashi, G. Gratta
Phys. Rev. D 78, 092001 (2008)

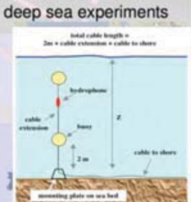


RONA - ACoRNE

Rona hydrophone array

- North-West Scotland (ranging hydrophones)
- Good test bed for future deep sea experiments

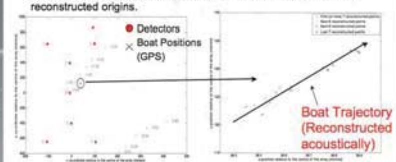
- Existing infrastructure √
- Wideband hydrophones √
- Omnidirectionality √
- Unfiltered data √
- All data to shore √
- Control over DAQ √
- No remote access X



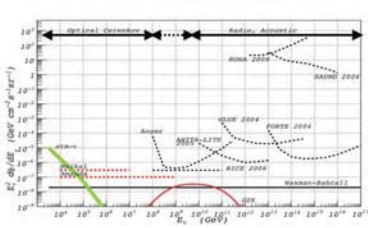
Use 8 hydrophones at sea bed

Boat Reconstruction

- Using the known detector positions and the time of arrival of the pulse on each hydrophone, each detected pulses' origin (if detected on > 4 detected) could be calculated.
- The boat, and drift, was successfully reconstructed
- Plots show the detector positions, the boat positions, and the reconstructed origins.

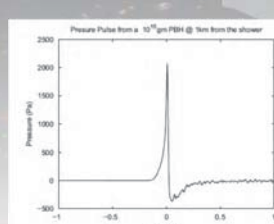


Rona Limit



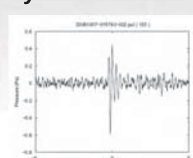
L. Thompson, ARENA2008 and S. Bevan, Theses

Search for primordial black holes



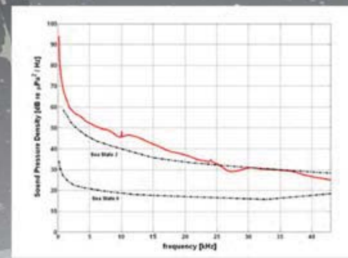
S. Danaher, ARENA2010, doi:10.1016/j.nima.2010.11.075

In 50 TB of data
81 trigger survived cuts
Only two events with "bipolar" waveform
(excluded by other reasons)



OνDE

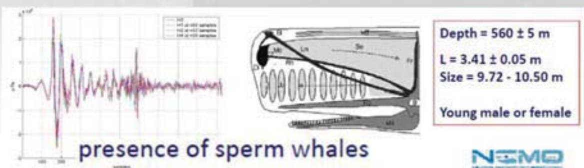
Long term measurements of acoustic background noise in very deep sea



4 hydrophones (10 Hz-40 kHz bandwidth) synchronized.
Acoustic signal digitization (24bit@96 kHz) at 2000m depth.
Data transmission on optical fibers over 28 km.
On-line monitoring and data recording on shore.
Recording 5' every hour.
Data taking from Jan. 2005 to Nov. 2006 (NEMO Phase 1 deployed).

The average noise in the [20:43] kHz band is $5.4 \pm 2.2_{stat} \pm 0.3_{syst}$ mPa

From G. Riccobene:
ARENA2008, VLVNT2009
also: arXiv: 0804.2913

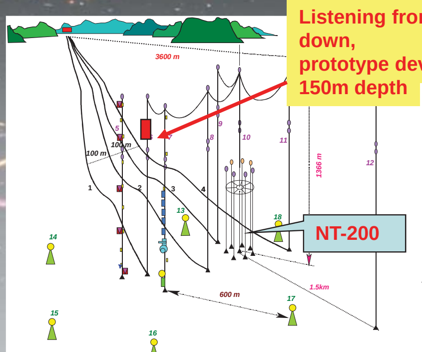


Next step:

R&D for an innovative acoustic positioning system for the KM3NeT neutrino telescope

See also G. Riccobenes talk at this conference

BAIKAL



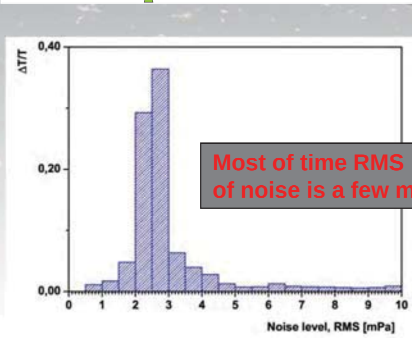
Listening from top to down, prototype device at 150m depth

March 2011 : prototype acoustic string deployed

An acoustic detector for background studies

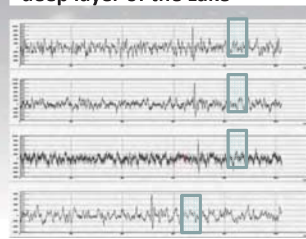
- tetrahedral antenna 1.5m
- 4 hydrophones H2020C
- 4-ch, 195kHz, 16-bit ADC
- one-plate computer
- 2 Mbit DSL modem

From N. Budnev,
ARENA 2010,
doi:10.1016/j.nima.2010.11.153



Most of time RMS of noise is a few mPa

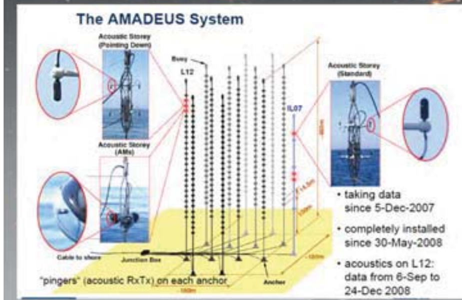
One signal from the deep layer of the Lake

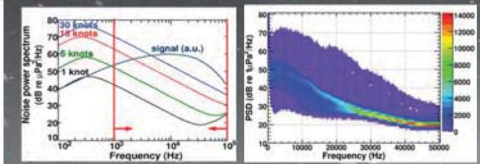


Antenna with 4 waveguide hydrophones made in Vladivostok State University

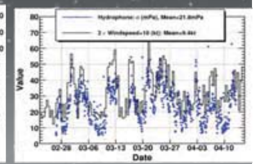
Data taking ongoing, first results soon

AMADEUS





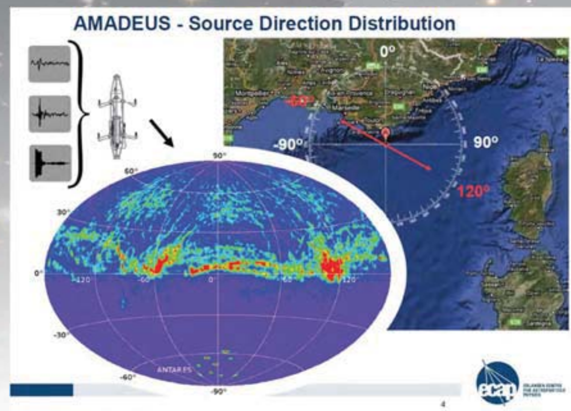
Power Spectral Density of Noise

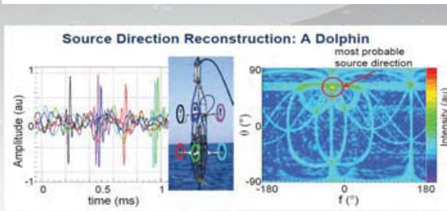


Noise strongly correlated with weather conditions

J.A.Aguilar et al., NIMA 626-627(2011) 128

36 sensors at 6 storeys
(1 – 350m distance, 34 active)
16bit @ 250kSps sampling
~ -125dB re 1V/μPa sensitivity
~85-90% uptime

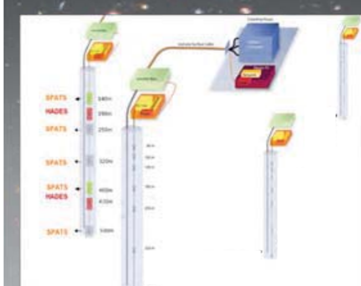




Beam forming or time difference algorithms used, uncertainty < 1 degree

R.Lahmann, ARENA2010
doi:10.1016/j.nima.2010.11.157

SPATS

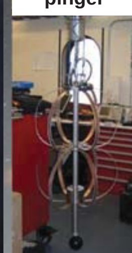


4 strings in IceCube holes

instrumented depth:
80 m - 500 m

per string:
7 stations with sensors + transmitters

pinger

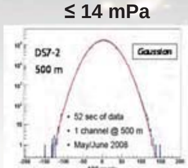


R. Abbasi et al., APP 33(2010)277
R. Abbasi et al., APP 34(2011)382
R. Abbasi et al., APP 35(2012)312

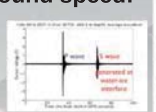
See also talk of K. Laihem at this conference

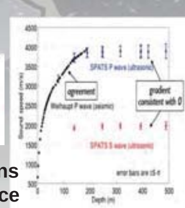
Noise conditions:
~ 2 years monitoring

Gaussian,
Stable,
Below 200 m
≤ 14 mPa



Sound speed:

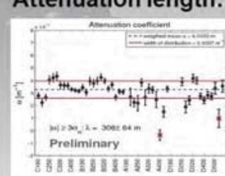




- two combinations at 125 m distance
- accuracy < 1%
- first in situ measurements for P and S waves at SP

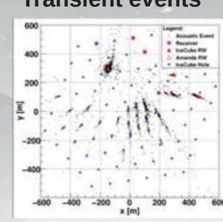
$$v_P(375m) = 3878 \pm 12 \ \ m/s$$
$$v_S(375m) = 1975.8 \pm 8.0 \ \ m/s$$

Attenuation length:



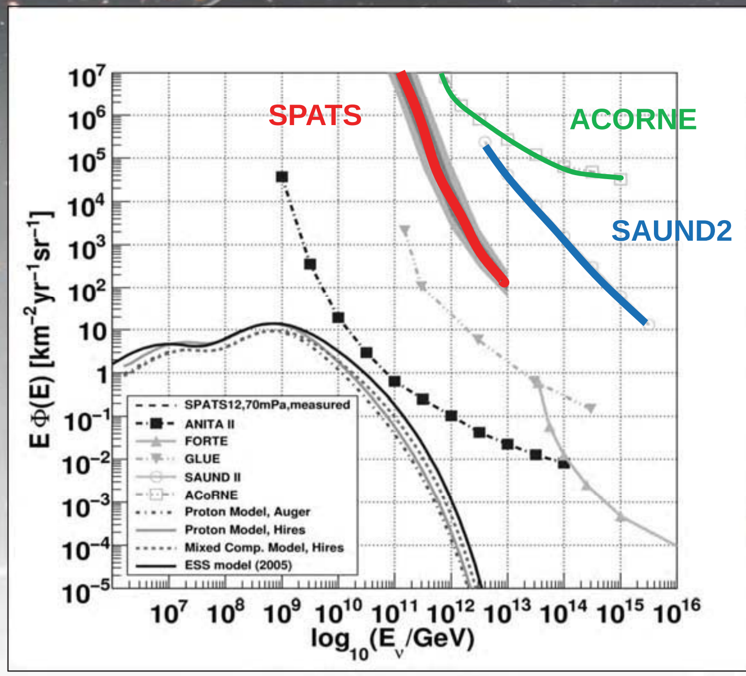
5 methods: $\lambda = 300 \pm 60\ m$
No evidence for depth or frequency dep.

Transient events



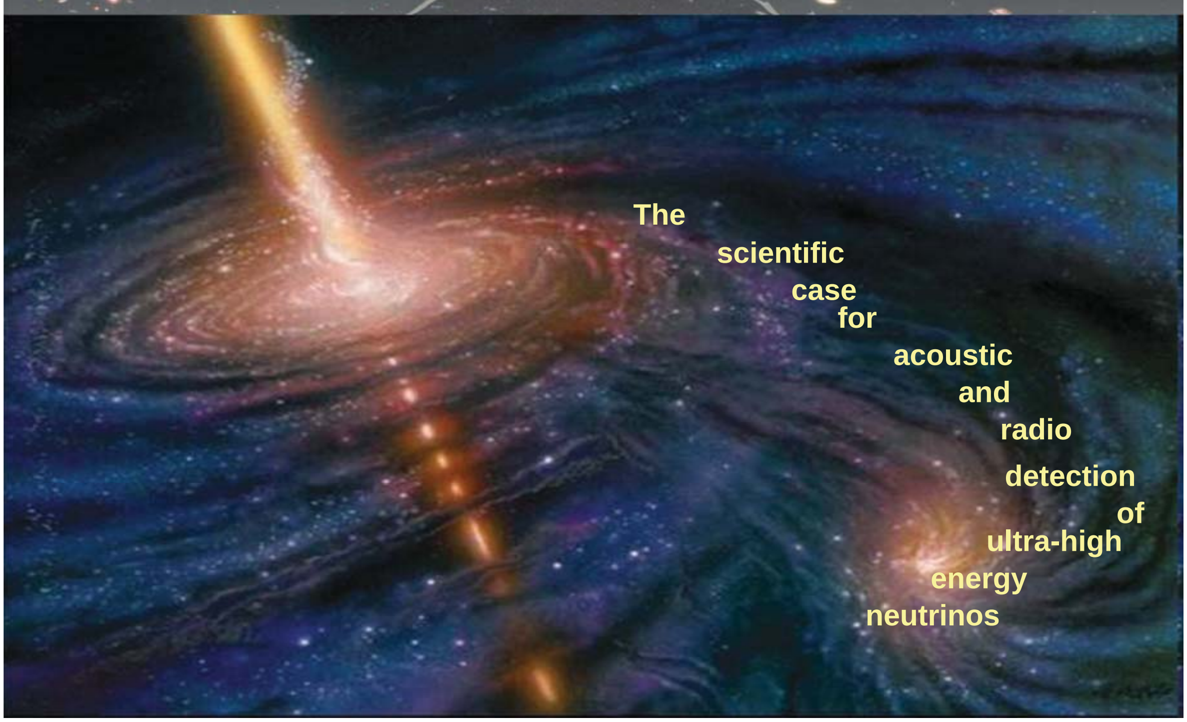
Only from identified sources, connected to IceCube detector construction

Acoustic neutrino flux limits



R. Abbasi et al.,APP 35 (2012) 312

Why all these efforts?



Get new insights from the study of ultra-high energy neutrinos above ~10^{17} eV about:

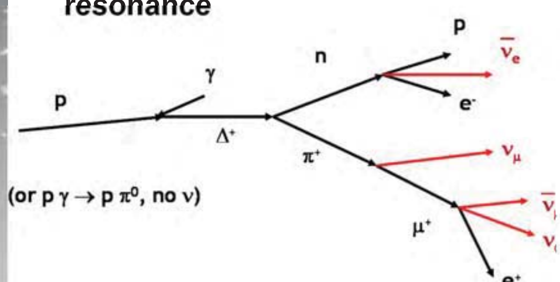
- Astrophysics
- Particle Physics
- Cosmology
- Basic symmetries

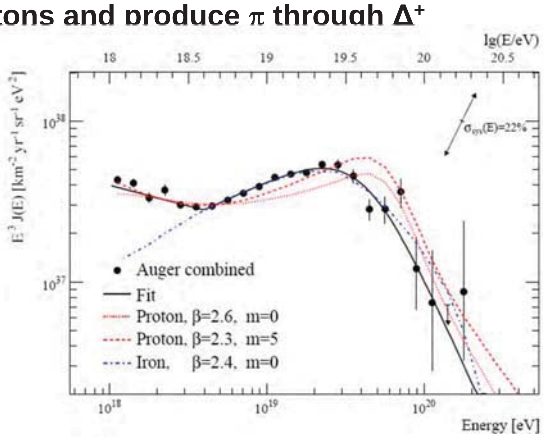
Considered sources:

- AGN's
- neutrinos from GZK-effect
- topological defects

One example – the GZK mechanism:
a guaranteed source of neutrinos

Cosmic rays interact with CMB photons and produce π through Δ^+ resonance





$$E_{th} = \frac{2m_N m_\pi + m_\pi^2}{4\varepsilon} \approx 4\cdot 10^{19}\,\mathrm{eV}$$

If UHE-CR exist they should undergo GZK mechanism
If GZK happens a neutrino flux is guaranteed
GZK neutrinos → BZ neutrinos

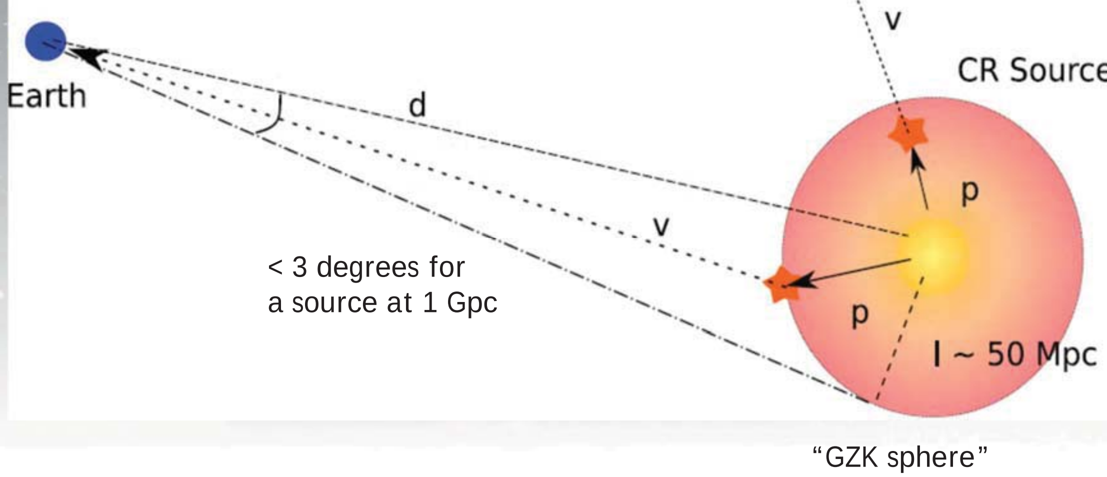
V. S. Berezinsky, G.T. Zatsepin, Phys Lett B 28 (1969)423

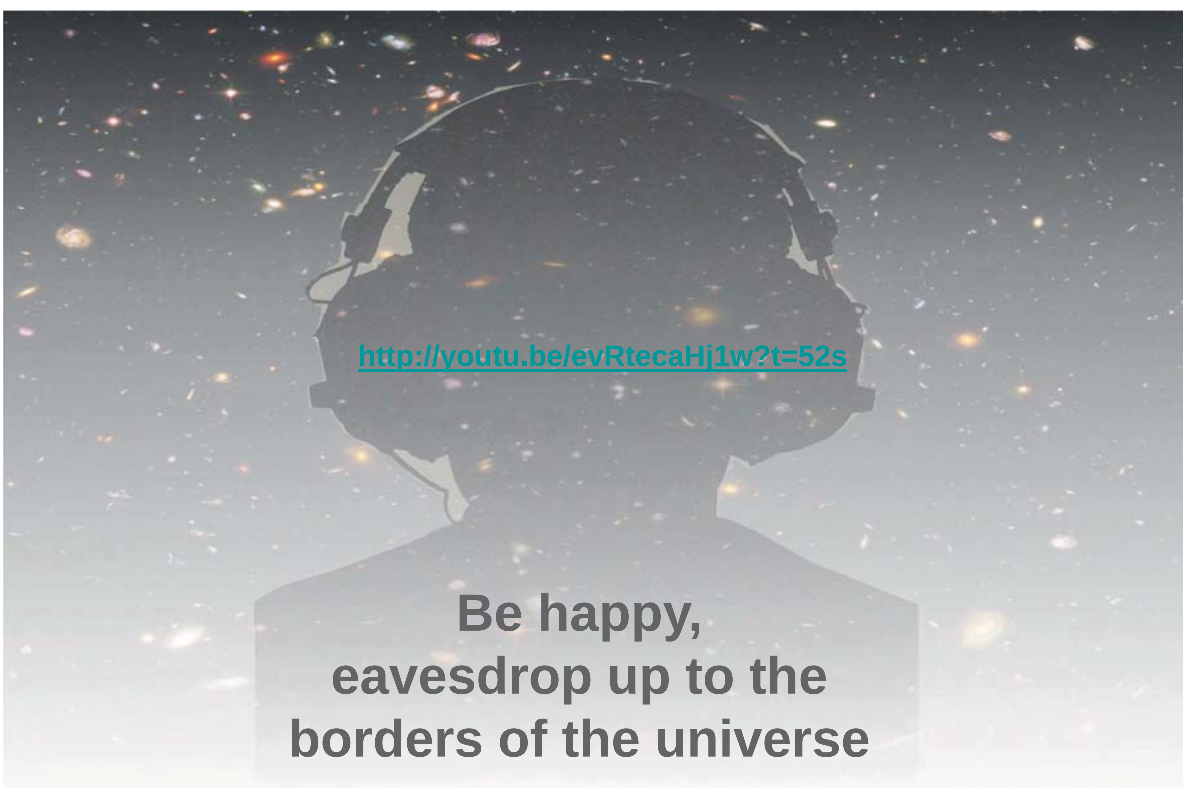
- Missing statistics?
- No more sources?
- No more power?
- or real GZK?

→ detect neutrinos

BZ neutrinos:
astronomy for UHE proton sources throughout the universe

BZ neutrinos from cosmological distances point back to the UHECR sources (within a GZK length precision)





Use for daily life? science fiction 1983

A. De Rujula, S. L. Glashow, R. R. Wilson, G. Charpak

PHYSICS REPORTS (Review Section of Physics Letters) 99, No. 6 (1983) 341–396.

THE GENIUS PROJECT

Geological Exploration by Neutrino Induced Underground Sound

use the „geotron" to send a neurino beam pulse
location and time of pulse are known
measure $V_s = f(\rho_i, \Delta d_i)$

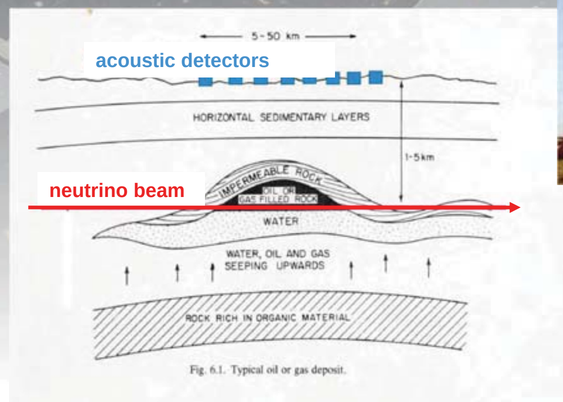
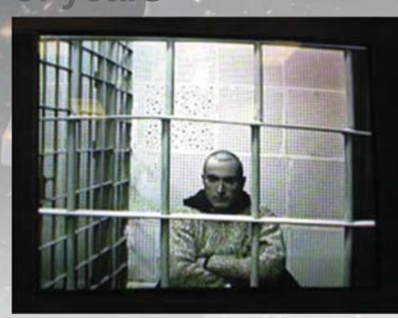


Fig. 6.1. Typical oil or gas deposit.

After successful oil digging:
→ two possibilities

Buy something fo
your pleasure:

Don't buy anything for the next couple of years



Nothing is more difficult to predict than the future !

Niels Bohr