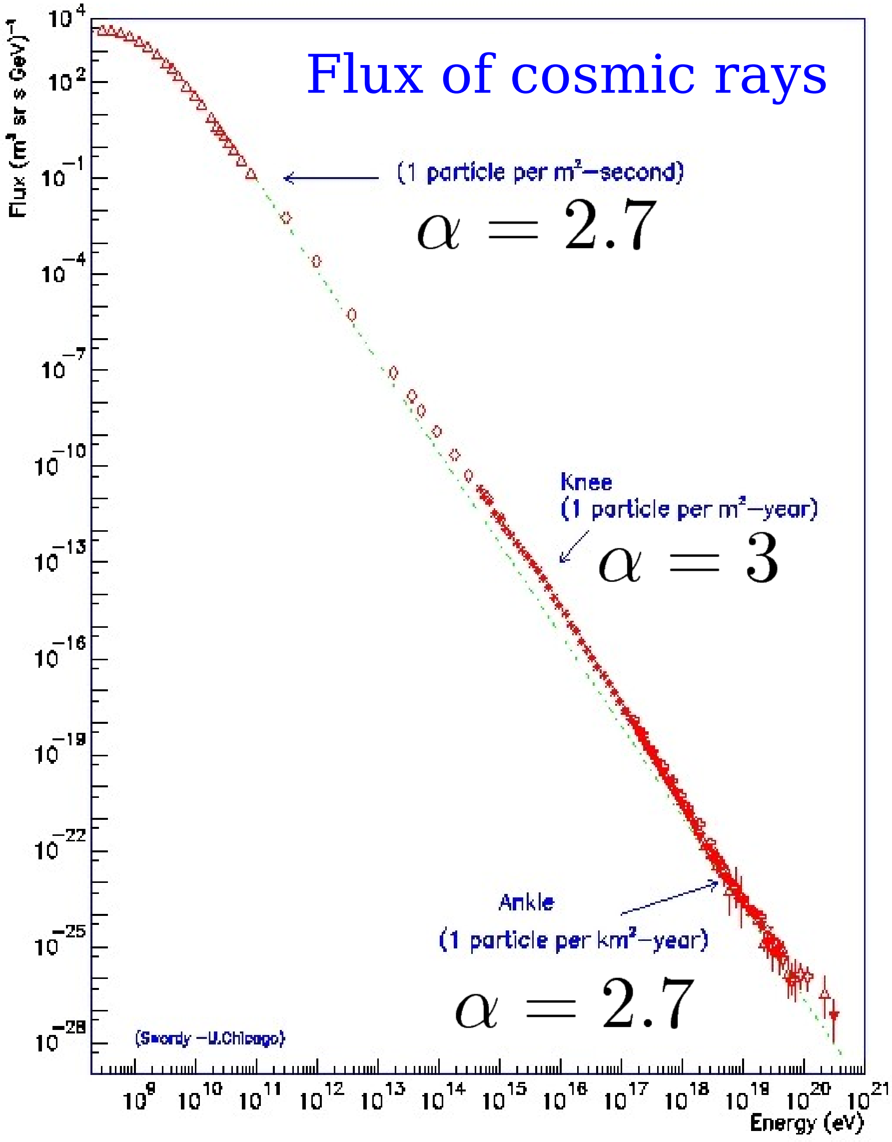
Search for neutrino emission from microquasars with ANTARES

Summary

- Neutrino astronomy
- The ANTARES detector
- Microquasars: particle accelerators in our galaxy
- Search for neutrino emission from microquasars

Neutrino astronomy

Cosmic rays (CR)



Discovered by V. Hess in 1912

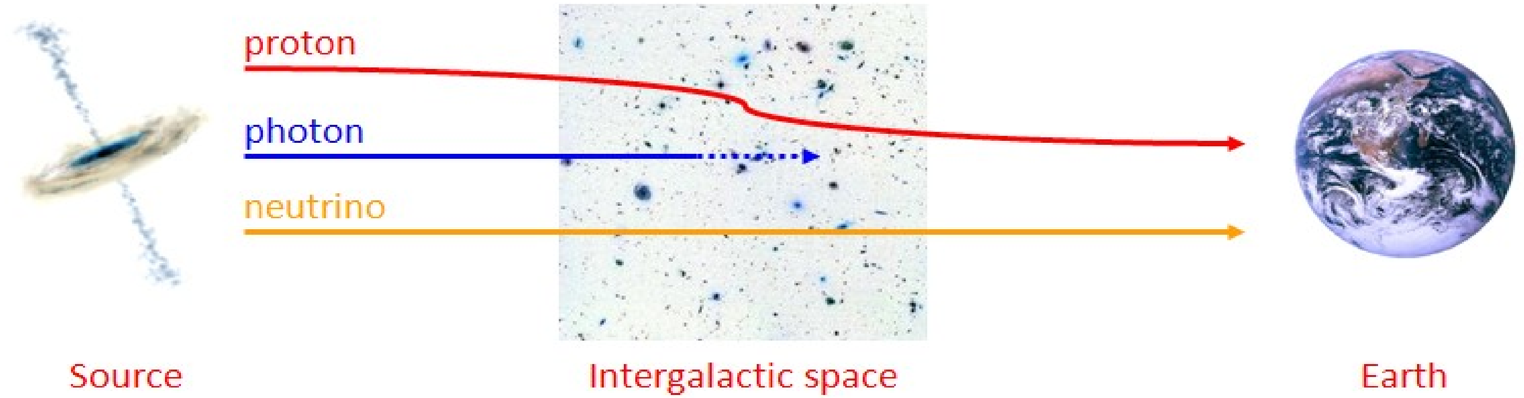
Broken power law: $\frac{dN}{dE} \propto E^{-\alpha}$

- Fermi shock acceleration at the source → $\alpha = 2$
- diffusion and leakage from the galaxy → α+= 0.6

CR energy up to 10^{20} eV:
- where are they produced?
- how are they accelerated?

Neutrino astronomy

Probing the origin of HE cosmic rays by the detection of:
• HE/VHE gamma rays (Fermi,HESS, MAGIC)
• UHE cosmic rays (AUGER)
• HE neutrino detection (ANTARES, ICECUBE)

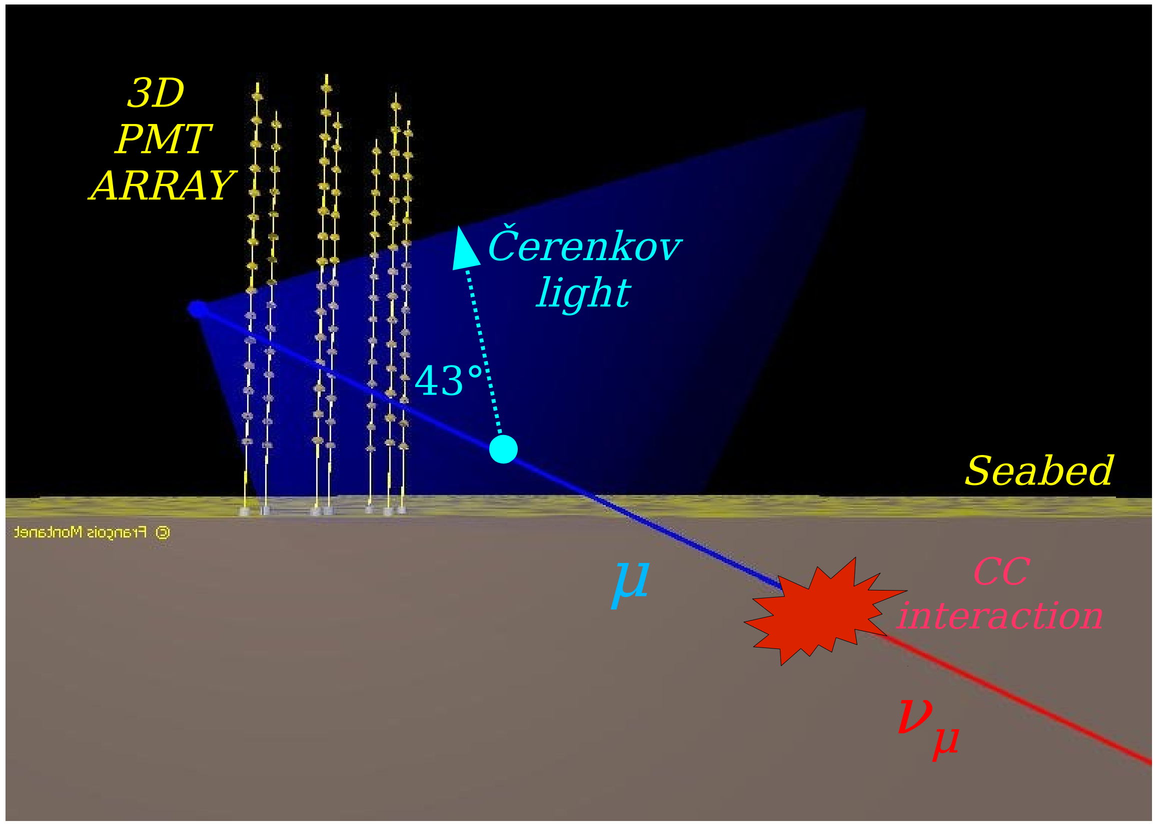


Techniques and limitations:

• galactic/exta-galactic magnetic field deviates charged particles
  • astrnomy possible at ~ 10^{19}eV
• Interaction with CMB photons limitates highest detectable energy and distance
  • ~10TeV for gamma-rays , ~ 10Mpc mean free path
  • ~ 10^{20}eV for protons , ~50Mpc mean free path
• neutrinos are produce by hadronic interactions, have no horizon nor energy threshold, but they are very hard to detect

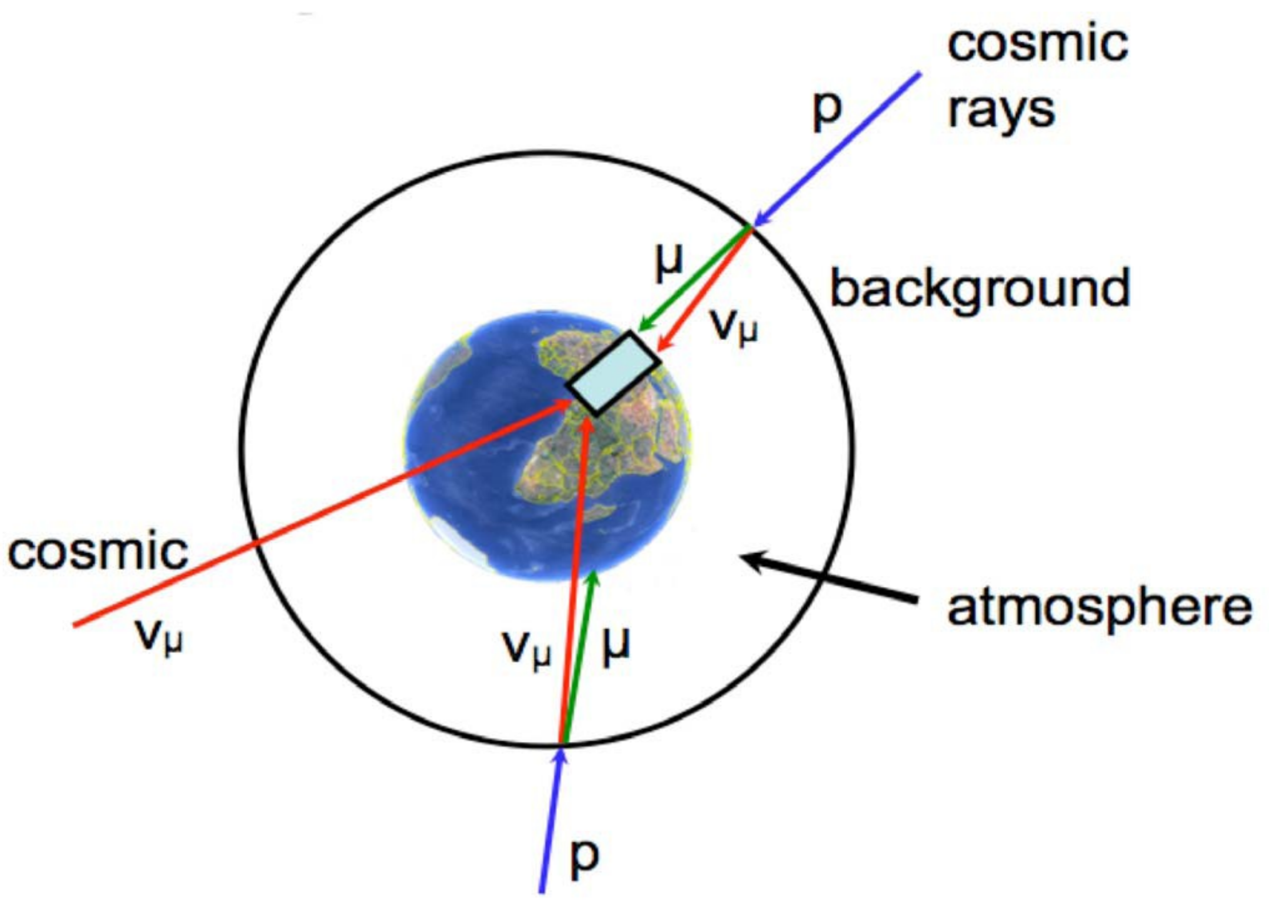
Under-water/ice neutrino detection

First conceived by Markov in 1960



Neutrinos (E > 10GeV) can be detected using the visible Cherenkov radiation produced as the high-energy charged leptons (final state of CC interactions) propagate through a transparent medium with superluminal velocity.

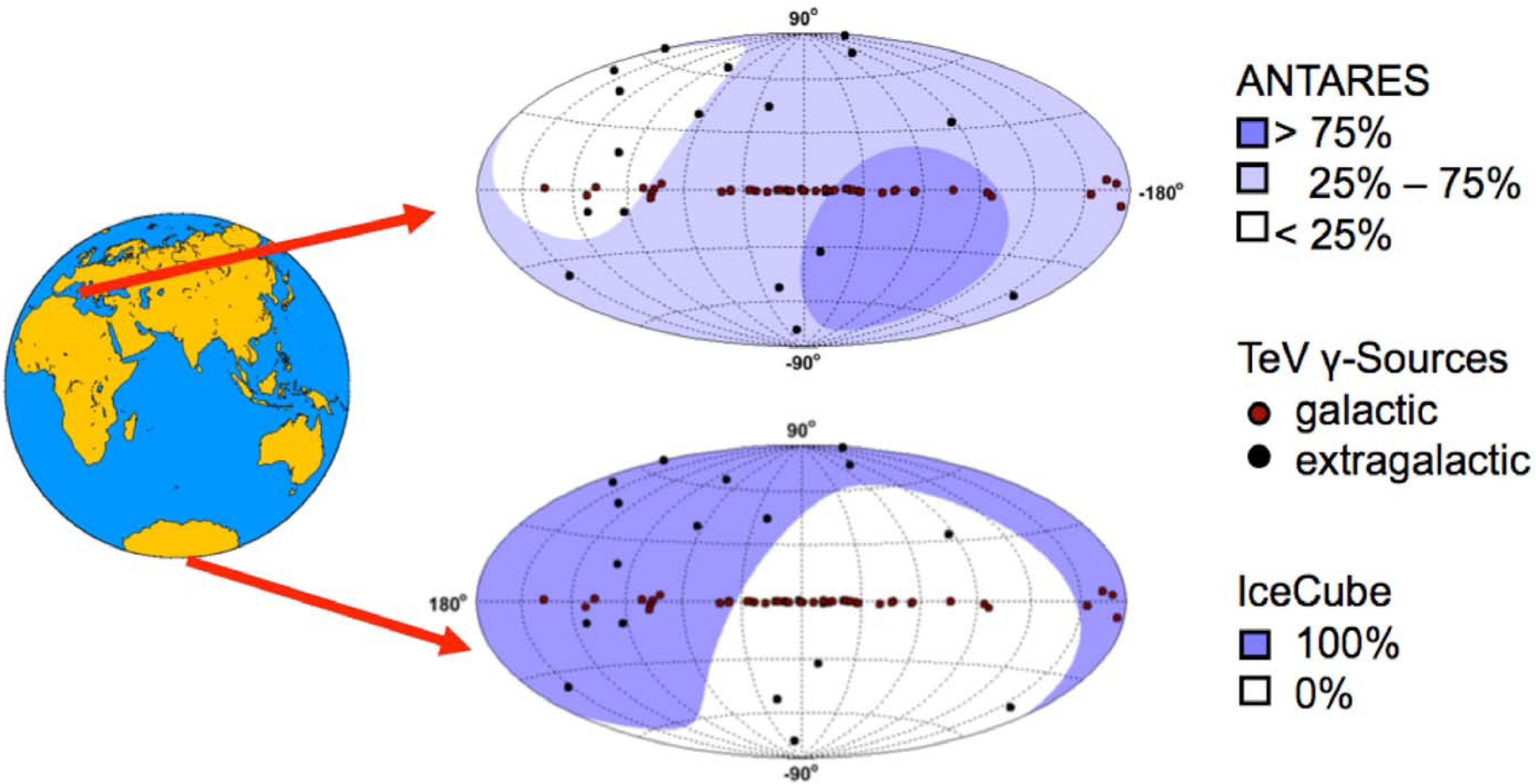
Sources of background particles



Downgoing atmospheric muons: ~10 per second
Upgoing atmospheric neutrinos: few per day

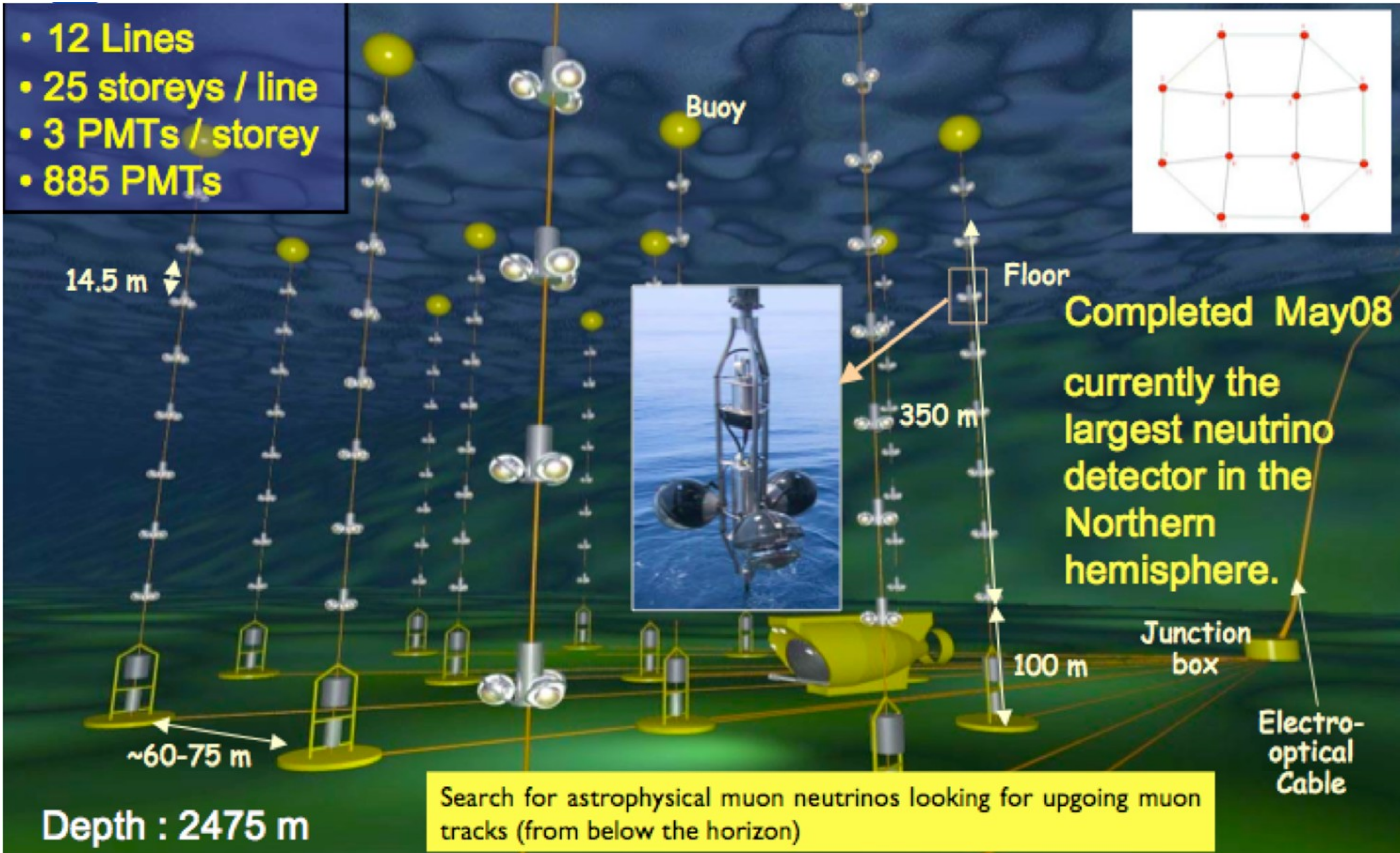
Looking for upgoing neutrinos

Neutrino telescopes

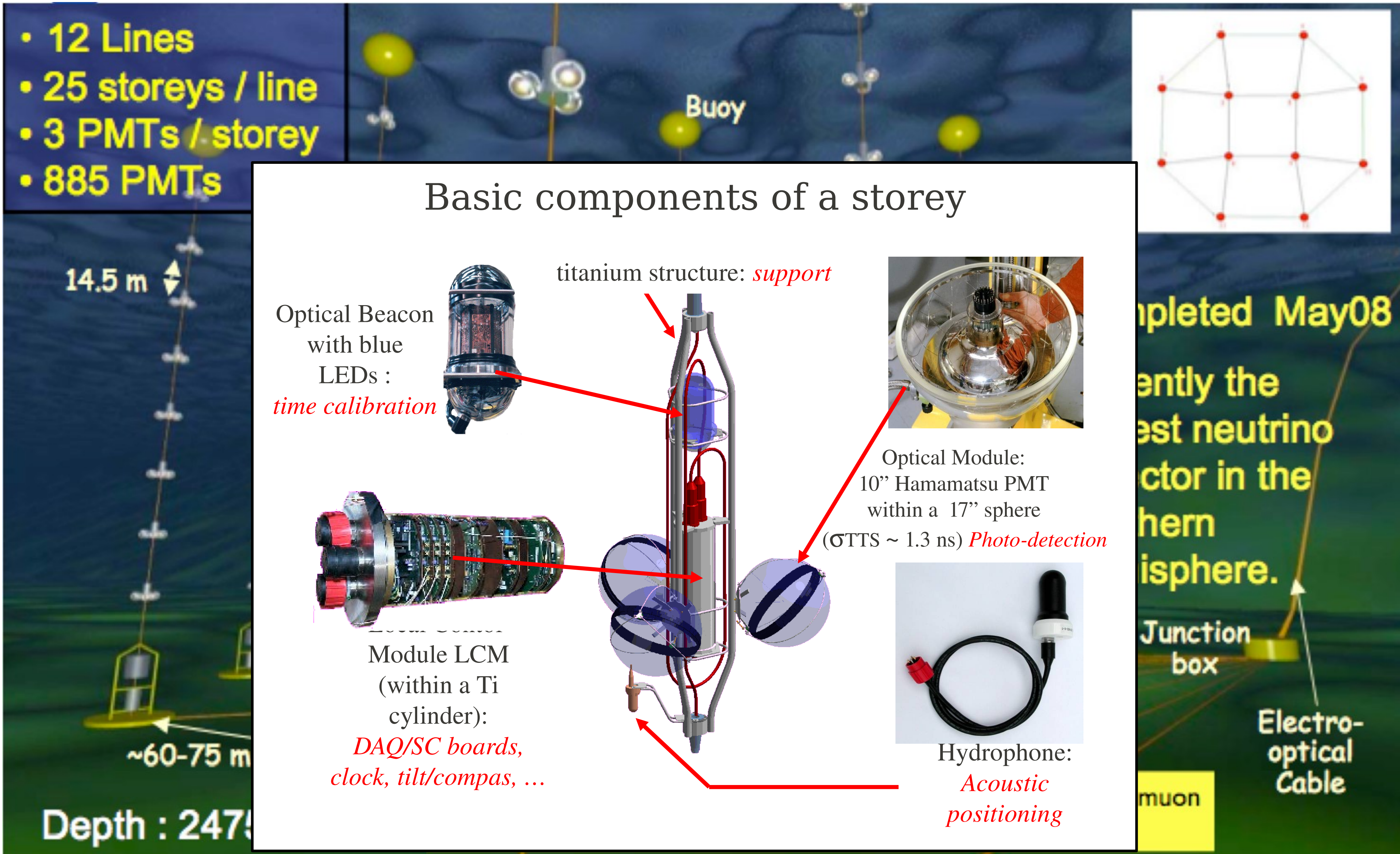


ANTARES

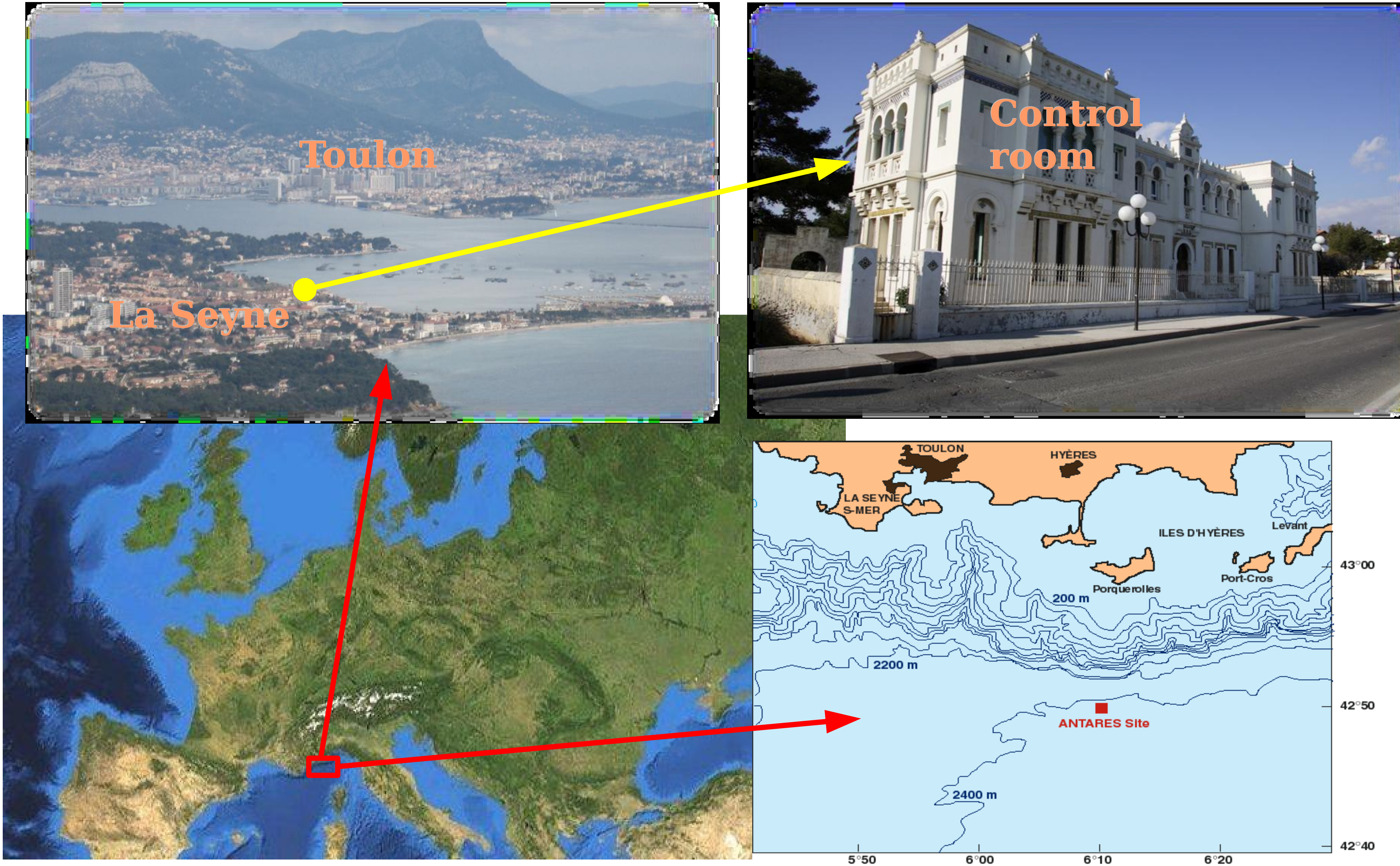
The ANTARES telescope



The ANTARES telescope

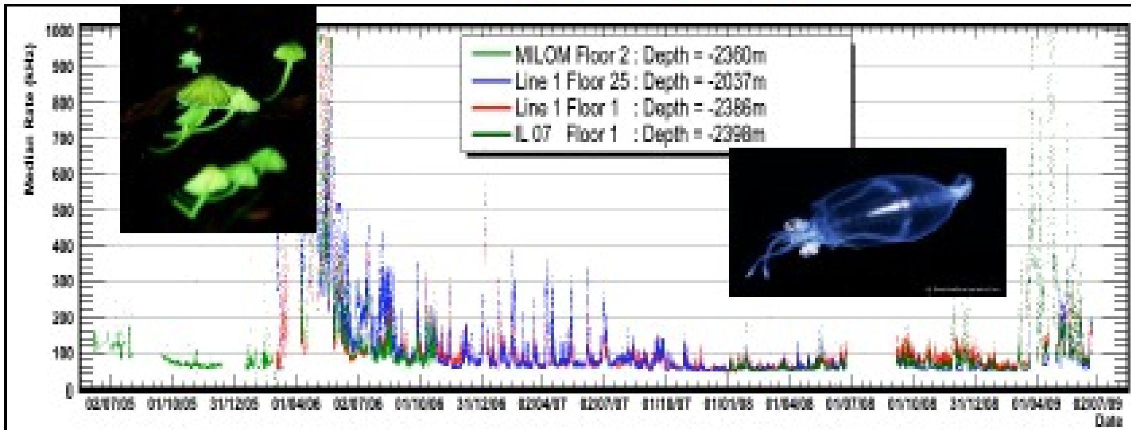


The ANTARES site

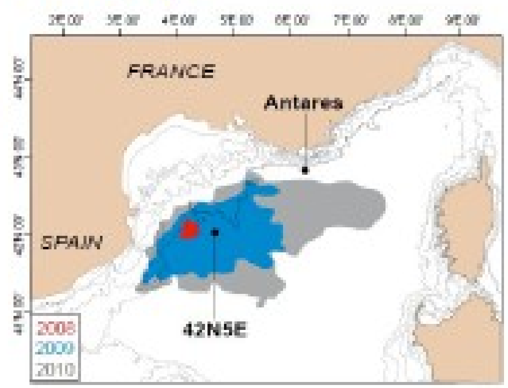


Environmental background

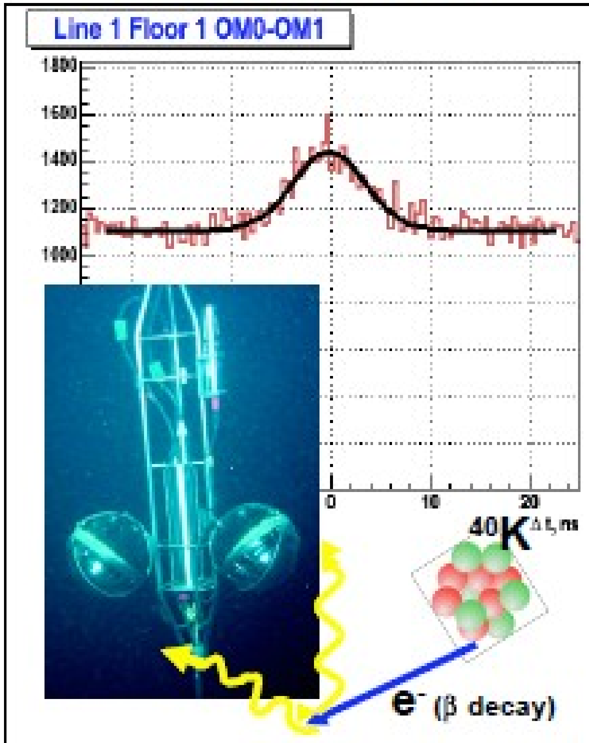
bioluminescence



- count rate dominated by bioluminescence & radioactive deyays
- K40 -> time calibration
- biolumiscense related to vertical convection events



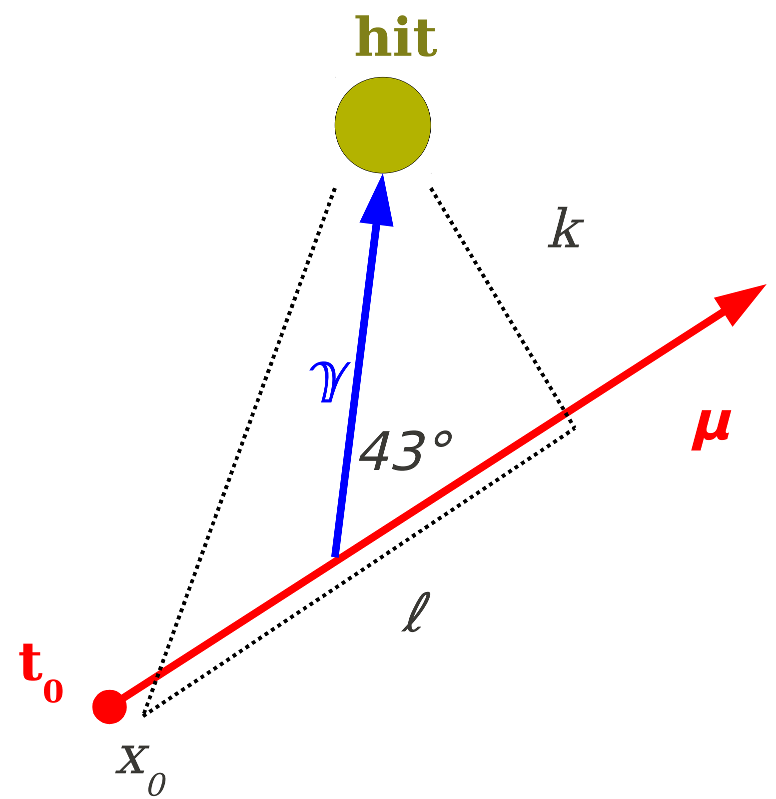
radio active decays



- **check of time calibration**
- **relative efficiency measurement**

Muon track reconstruction

- Search local hit coincidences in 20 ns time window, to reduce contribution from optical background
- Need 5 local coincidences (minimum) on 2 lines (minimum)
- Reconstruction is based on 3 main steps:
  1) Linear prefit
  2) M-Estimator maximization
  3) Refined Likelihood maximization



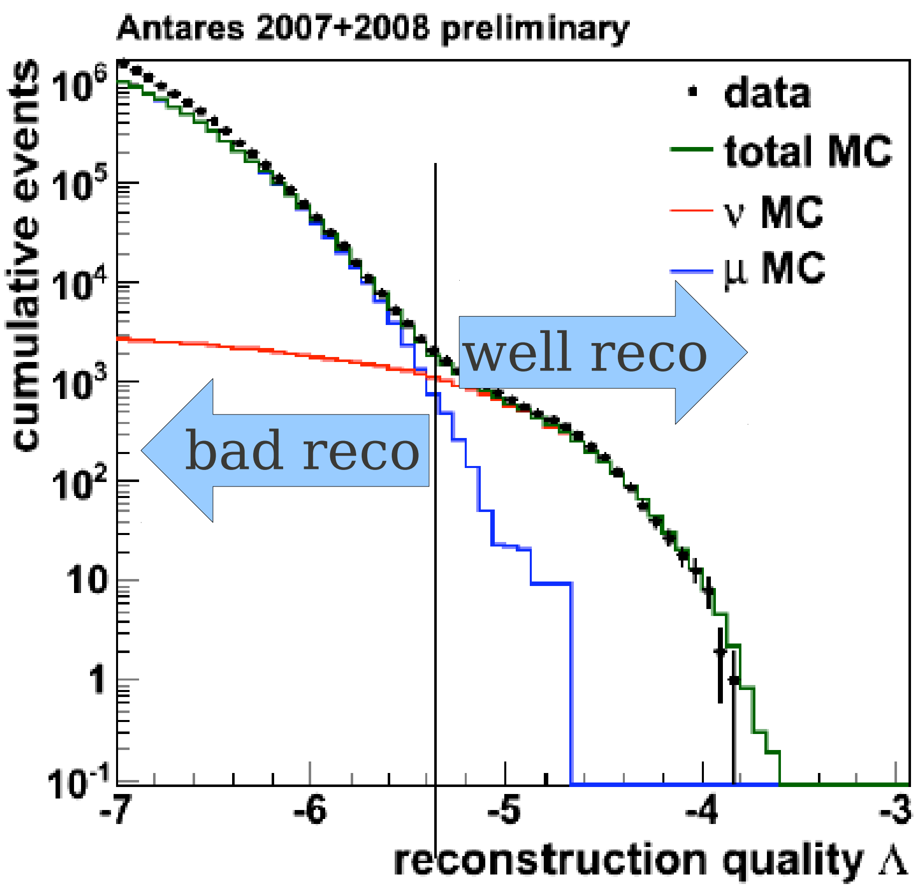
$$\Lambda = \frac{\sum_{hit} \log\left(L_{hit}\right)}{N_{NDF}}$$

$$t_{exp} = t_0 + \frac{1}{c}\left(l - \frac{k}{\tan\theta_C}\right) + \frac{1}{v_g}\left(\frac{k}{\sin\theta_C}\right)$$

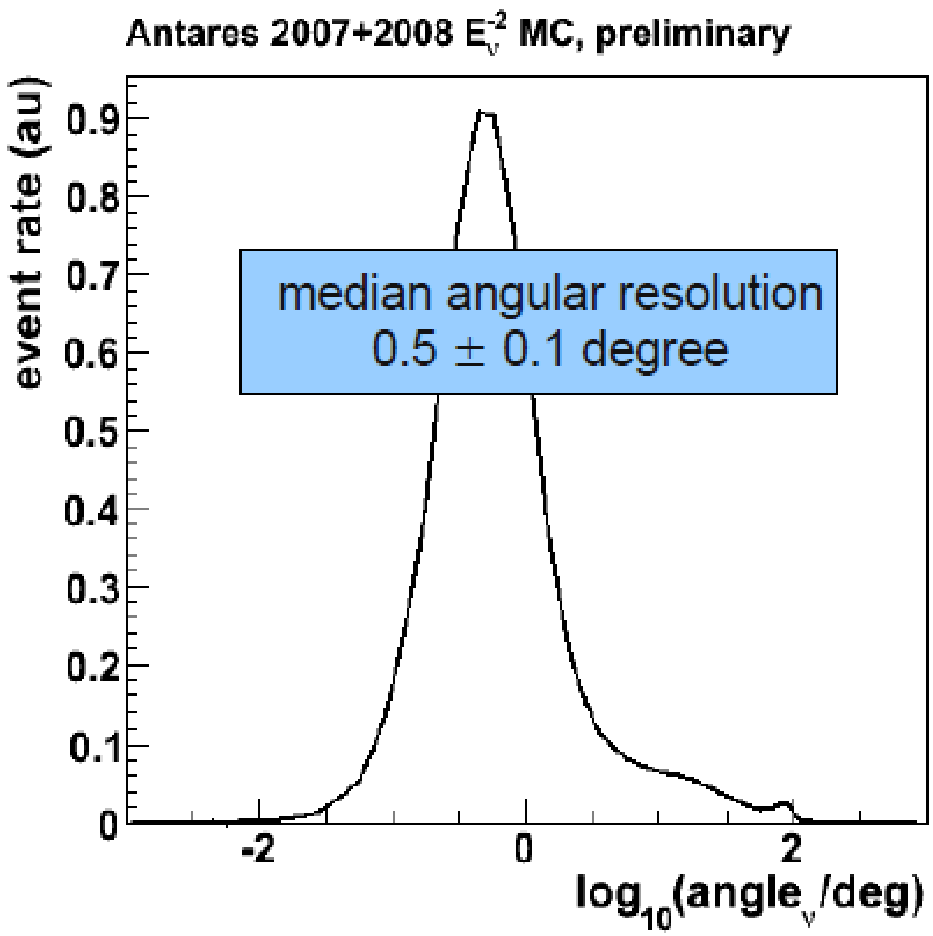
μ γ

The maximized log-likelihood Λ is used as a quality parameter

Point source search preliminary



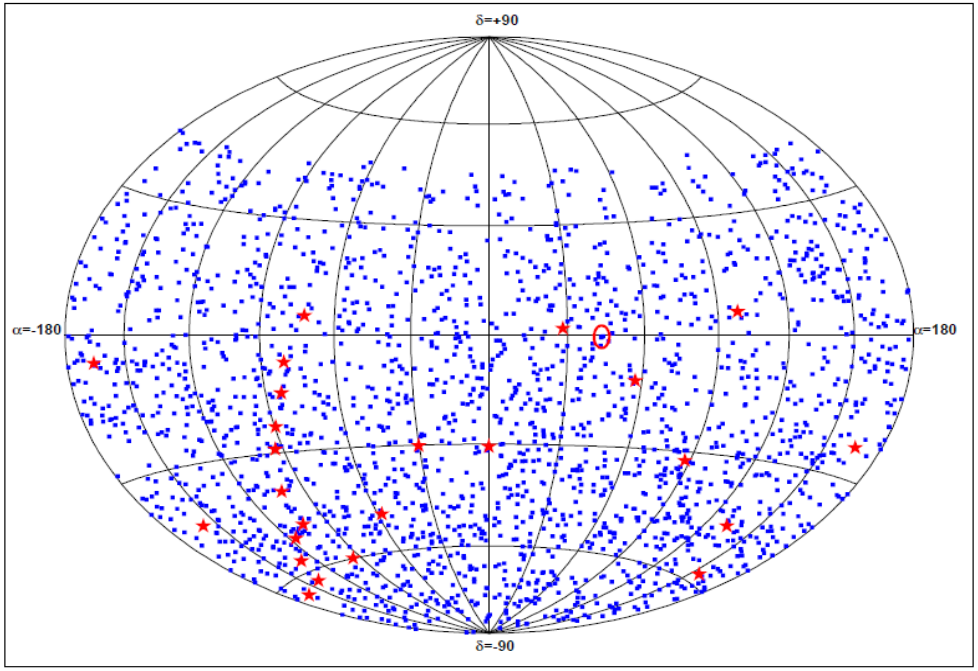
loose selection for optimal sensitivity

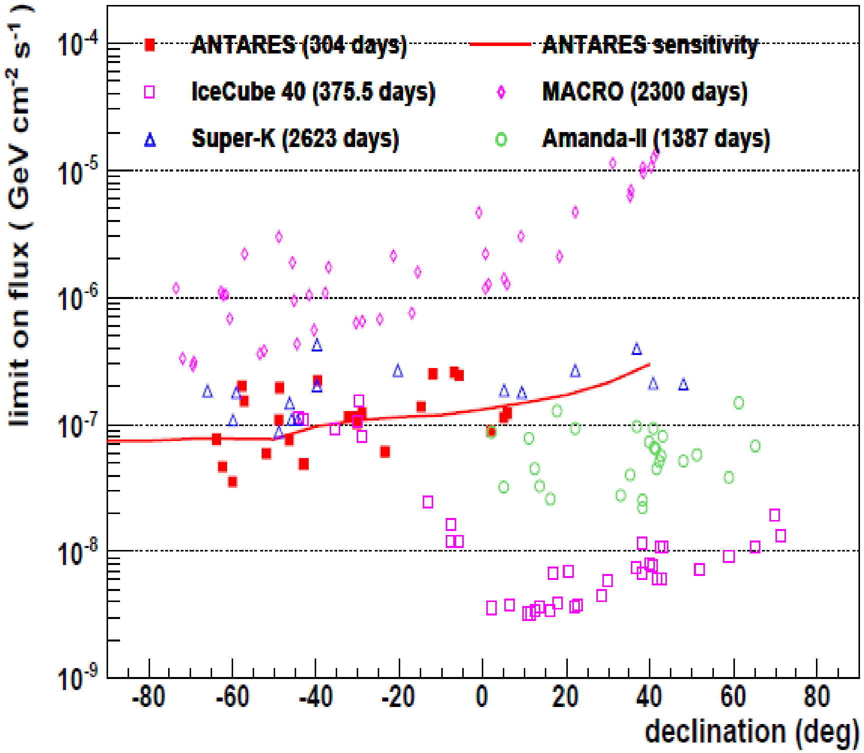


- angular resolution obtained from MC but constrained using data.
- Comparable to IceCube despite smaller detector → advantage of water over ice.

Point source search preliminary

ANTARES preliminary, 2007-2008 data
no significant sources found





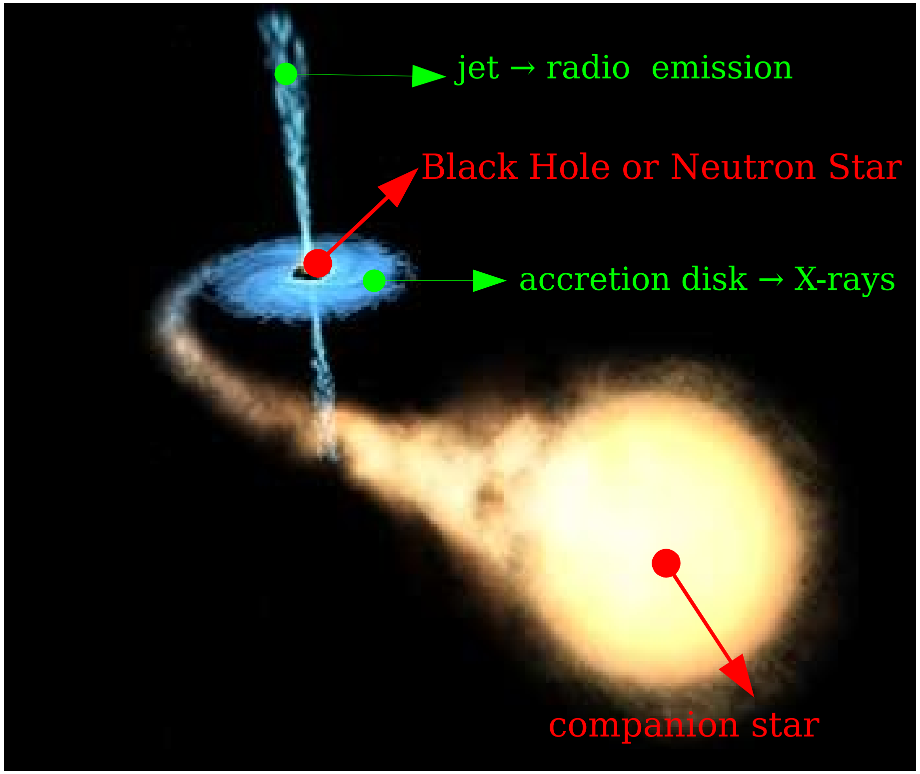
source	α_s (deg)	δ_s (deg)	N_{sig}^{fit}	Q	p-value	$\phi^{90\%CL}$
HESS J1023-575	155.83	-57.76	2.7	2.5	0.17	2.0
GX 339	-104.3	-48.79	2.2	2.1	0.26	1.9

→ microquasar

MICROQUASARS

Microquasars

X-ray binary system
compact object & companion star
+ relativistic jets



Radio emission :
non thermal synchrotron emission from resolved jets with speed 0.2-0.9*c*.
Jet acceleration → MHD models .

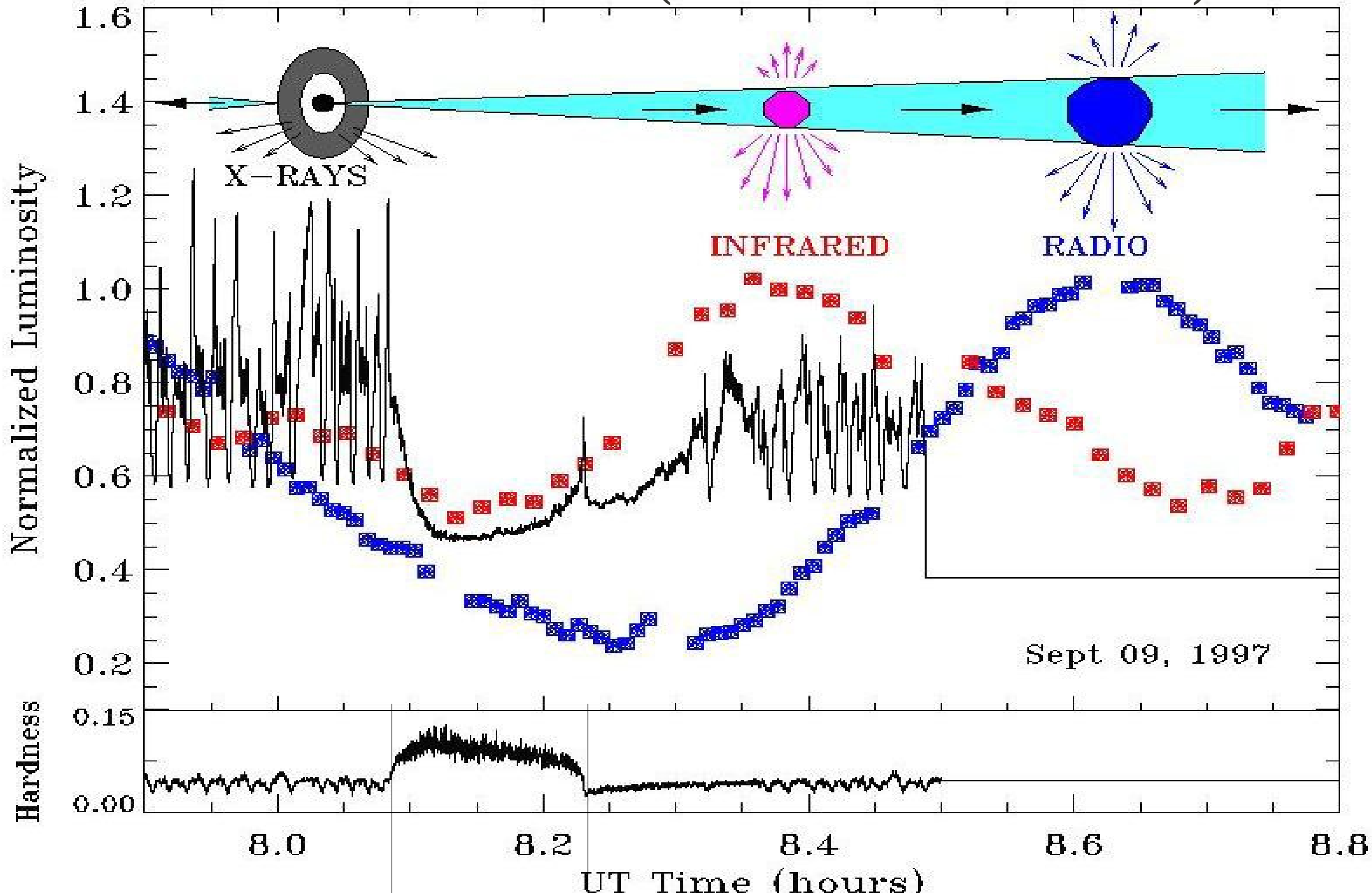
X-ray emission
- soft thermal component from accretion disk (~keV)
- hard component(s) (from comptonized corona or from the base of the jet)

GeV / TeV γ-ray emission for few of them

Time variability at different timescales depending on the source, hours to years

Jet–accretion disk coupling

GRS 1915+105 (Mirabel et al. 1998)



soft-X
disk present

hard-X
no disk
jet inj.

soft-X
disk refilled

Jet injection during hard X-ray state

Delayed peaks in infrared and radio → ejected plasma cloud gets transparent to longer wavelengths as it expands

Can use X-rays to insight particle acceleration at the source

MICROQUASAR ANALYSIS

Multimessenger approach

Search in ANTARES 2007-2010 data.

Exploit multi-wavelength information to insight the behavior of the source.

analyze only flaring periods to reduce atmospheric neutrino background

- look at sources in Hard X-ray states → jet acceleration (RXTE):
  - GX 339-4
  - Cygnus X-1
  - Circinus X-1
  - H1743-322

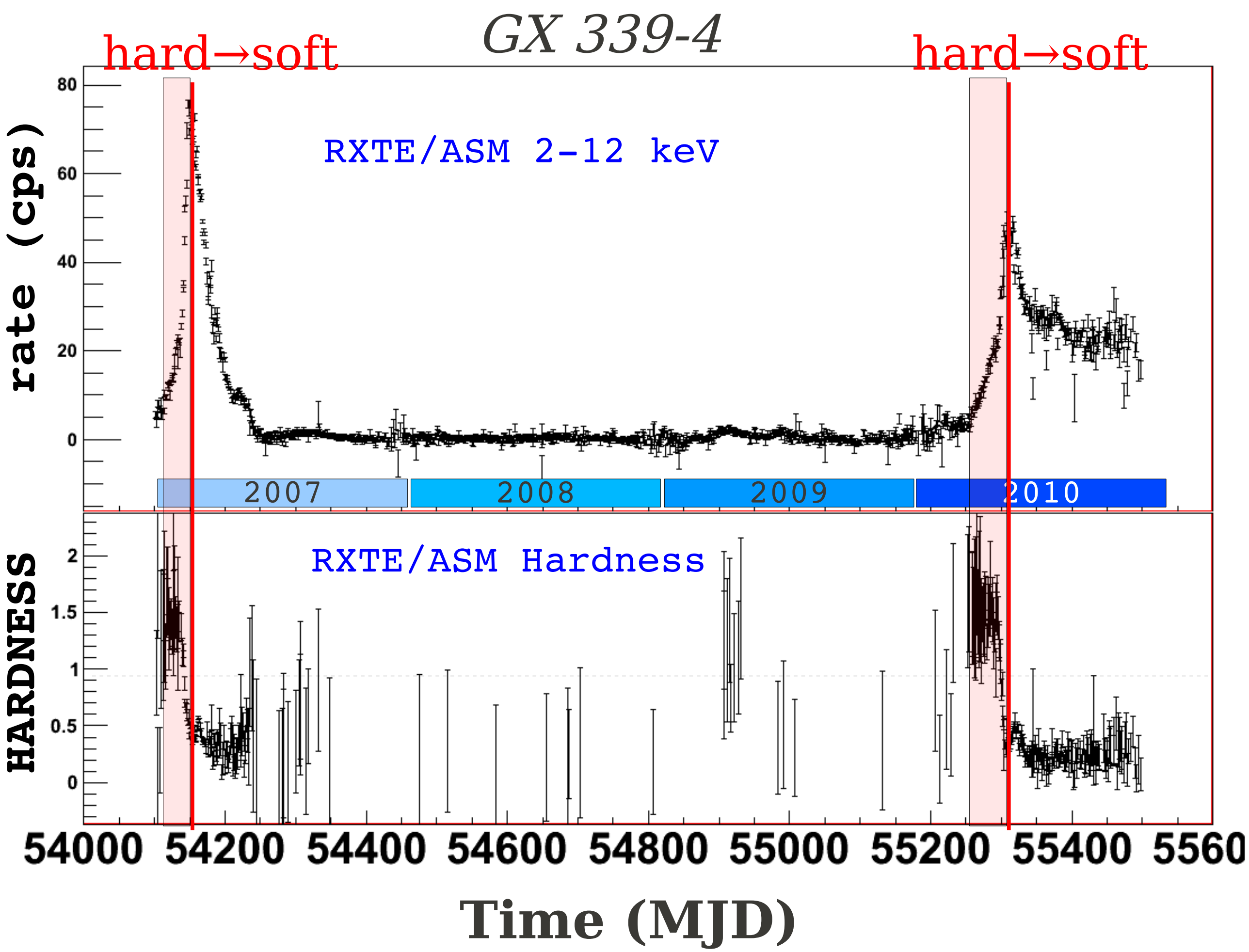
- look for γ-ray/radio flares (Fermi/Ryle):
  - Cygnus X-3

Rossi X-ray Timing Explorer

Fermi γ-ray Telescope

Ryle radio telescope

Hard X-ray state selection



RXTE lightcurve + hardness ratio

Radio observations (Atel) confirm the increasing of radio emission during hard states.

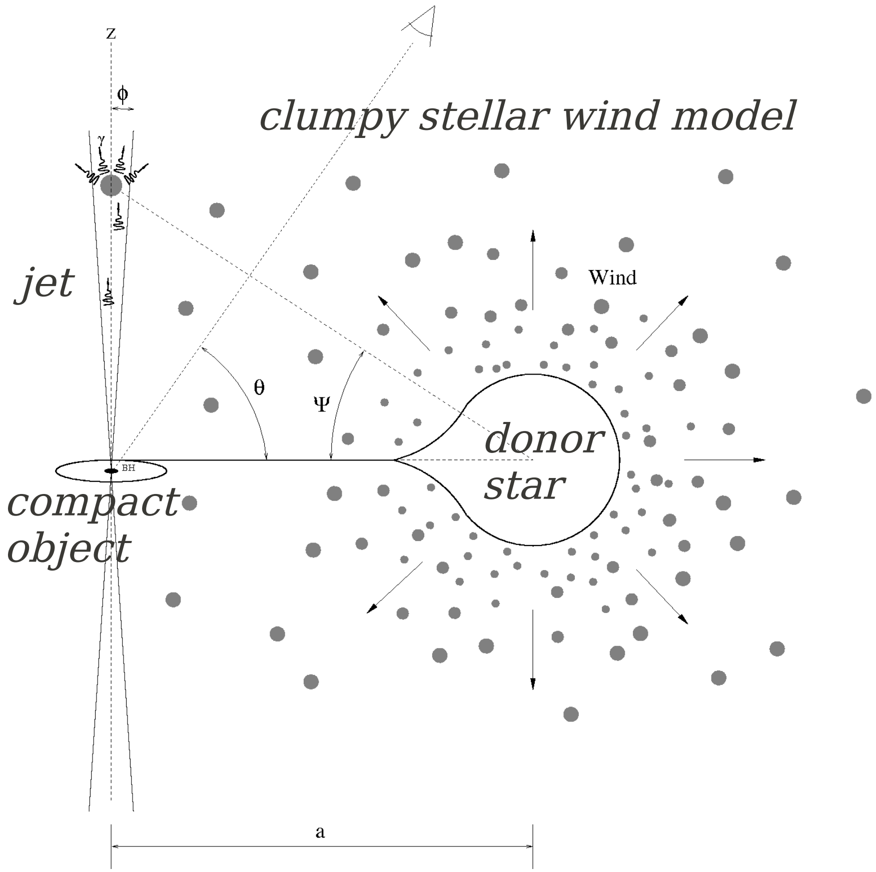
In red the periods selected for the neutrino search.

Same procedure used for 4 mi roquasars:

- GX 339-4
- Cygnus X-1
- Circinus X-1
- H1743-322

Cygnus X-3

Black Hole mass	Donor mass	Orbital period	Distance
~20 $M_\odot$	~20 $M_\odot$	4.8 h	9 kpc



High donor mass system: accretion dominated by the intense stellar wind.

Good points of CygX-3 :

– very intense jets up to ~1Jy radio fluxes

– clumps of stellar wind may provide hadronic target

– low orbital period indicates a compact system

Cygnus X-3 flares

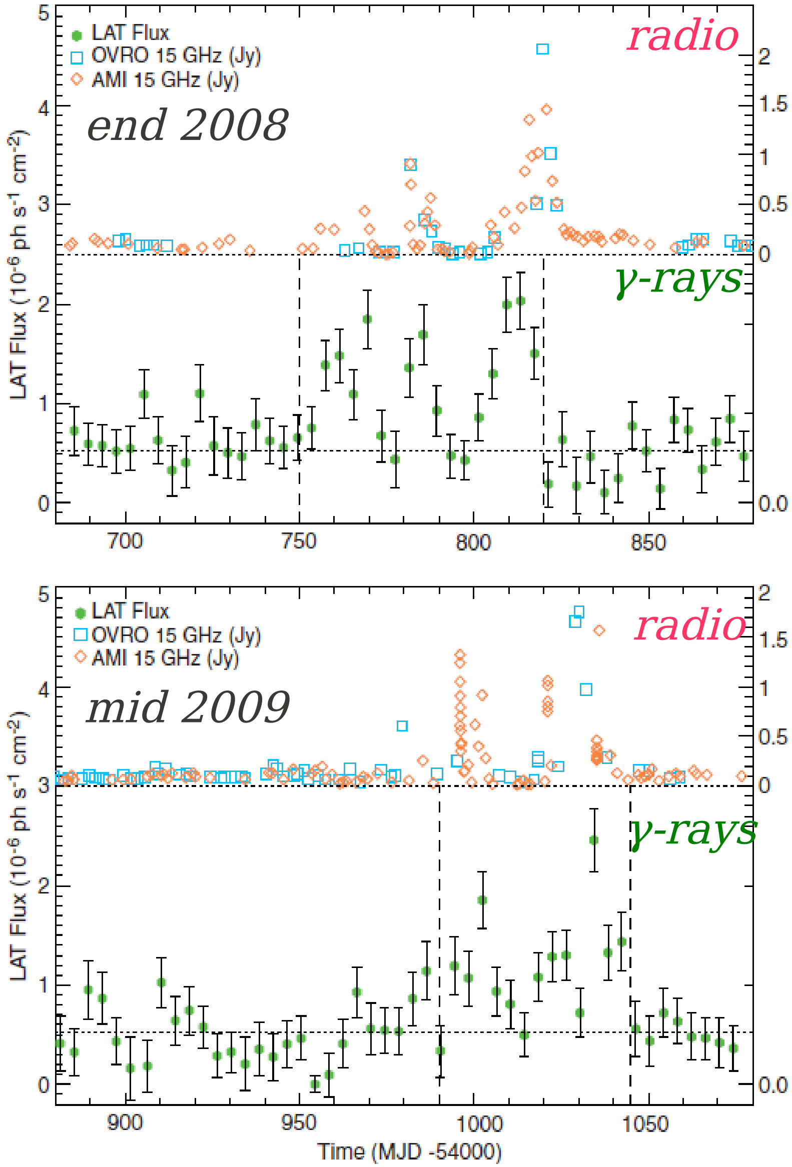
List of radio flares(from Atel):

- Jun 2007
- Apr 2008 (AGILE)
- Dec 2008 (Fermi,AGILE)
- May 2009 (Fermi,AGILE)
- May 2010 (Fermi,AGILE)

Gamma ray flares from Fermi also confirmed by AGILE observations and from radio telescopes as well.

Flare definition for Cygnus X-3 under way

Fermi (Science paper)



Selected periods

ANTARES 2007-2009 data

Total livetime: 590 days

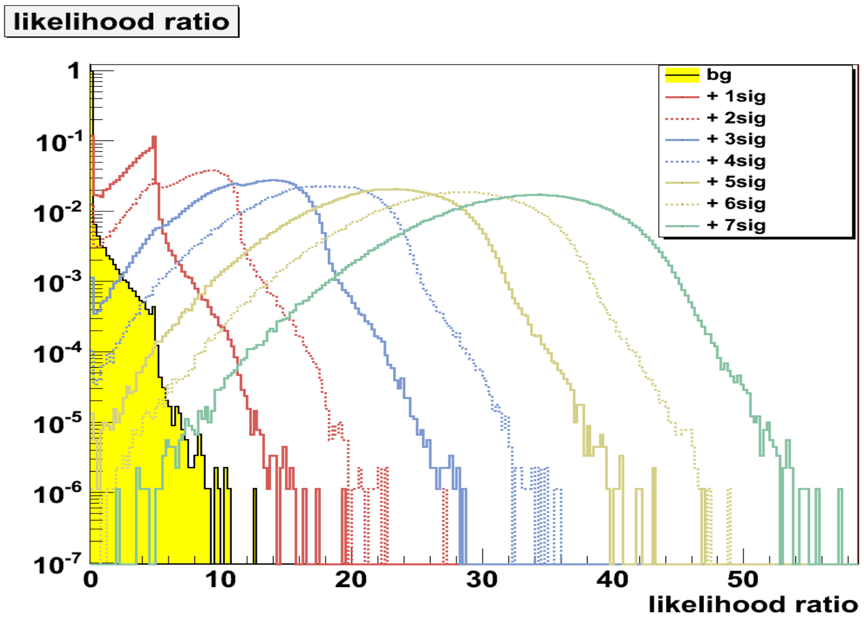
Selected days of livetime for each source taking into account source visibility.

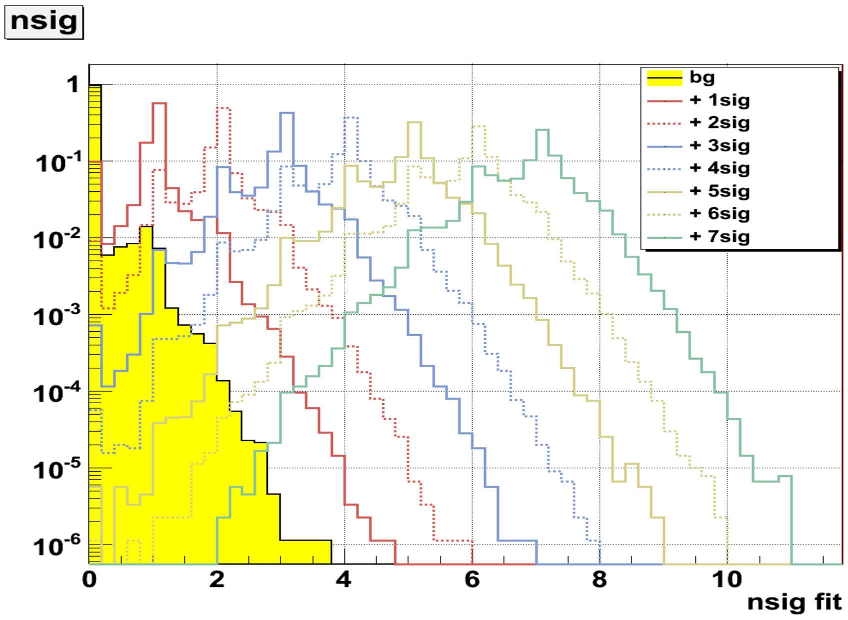
Source	selected livetime (d)	selected livetime+ visibility(d)	no. of time windows
GX339-4	8	8	2007 flare only
Cir X-1	28	28	7
H1743	26	18	2
Cyg X-1	590	163	1
Cyg X-3	70	48	2

Likelihood ratio method

- analysis is blind: neutrino arrival direction are not known to avoid bias
- backgound only and background + signal pseudo experiments are generated
- maximise likelihood to obtain fitted n_sig for each pseudo experiment
- calculate likelihood ratio = $\log(L_{sig+bg}) - \log(L_{bg})$ distribution
- can calculate critic likelihood ratios (3 sigma, 5 sigma)

results for the H1743-332 flares (18d) 9E5 pe's





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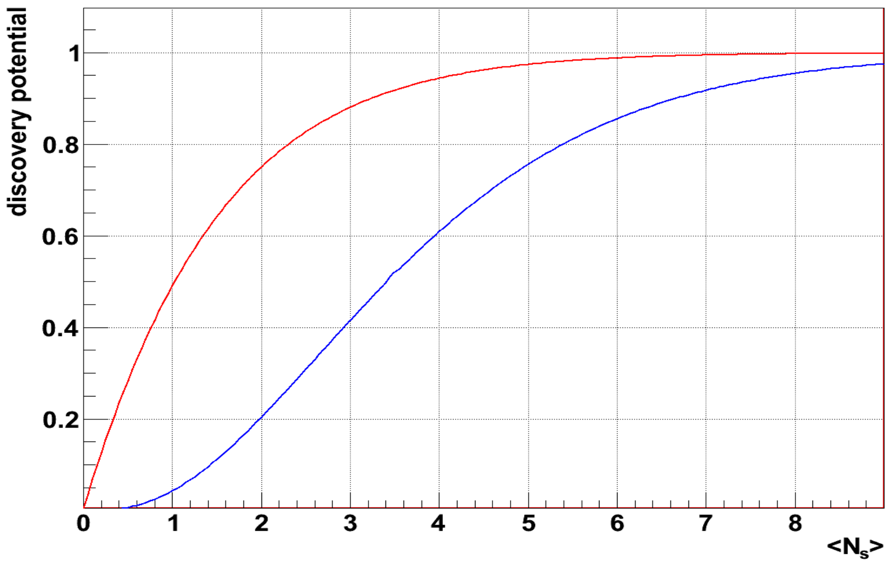
- calculate likelihood ratio = $\log(L_{sig+bg}) - \log(L_{bg})$ distribution
- can calculate critic likelihood ratios (3 sigma, 5 sigma)
- get discovery potential

results for the H1743-332 flares (18d) 9E5 pe's



3σ ~1 evt 50% C.L.
5σ ~3.5 evts 50% C.L.

Conclusions

- Neutrino astronomy with ANTARES can help to shed light over the production and acceleration of cosmic rays

- Microquasars are galactic particle accelerators and potential neutrino sources

- Multi-wavelength observation can help to select active periods to be analyzed and reduce the number of events needed for an evidence/disovery

- Analysis is ongoing