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ANTARES :
a Telescope in the Deep Sea
to study the High Energy Universe

Accueil Master 2
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Cosmic Rays

Interactions of cosmic rays in the high atmosphere produce showers of particles

Charged particles
- protons
- ions
- electrons

Neutral particles
- photons
- neutrinos

At ground level: 100 per minute and per m²

100 years after their discovery, the origin of cosmic rays is still very unclear

Flux of primary cosmic rays

Fluxes of Cosmic Rays

- (1 particle per m²-second)
- (1 particle per m²-year)
- Knee
- Extra-galactic

Neutrino Telescopes

Ankle
(1 particle per km²-year)
Why looking for neutrinos?

Pros for neutrino:
- Electrically neutral, not deviated by magnetic fields → astronomy
- No absorption → observation over cosmological distances
- Interacts VERY weakly → escapes from dense regions of the Universe

Cons:
Over 10 billions of neutrinos coming from the Sun and crossing the Earth, ONLY 1 will interact!!!
- Necessity of a HUGE detection volume
The sources of very high energy neutrinos

- Microquasars
- Active Galactic Nuclei
- SN Remnants
- Gamma-Ray Bursts
- Pulsars
- Galactic sources
- Extra galactic sources
- Dark Matter
- Exotic Physics
- Magnetic Monopoles
- Nuclearites
A new window over the Universe

High energy neutrinos emitted by cosmic accelerators

Neutrino Astronomy: skymap of the most catastrophic events of the Universe
Detection Principle of ANTARES

Cherenkov light emitted by $\mu$ coming from $\nu$ interaction. Propagation detected by PMT array. Time & position of photons allow the reconstruction of the $\mu$ ($\sim \nu$) trajectory.
Scientific Goals of Neutrino Telescopes

- Origin of Cosmic Rays
- Signatures hadronic vs. leptonic

Limitation at low energy:
- Too Short distance of muons in water
- Little amount light
- $^{40}$K background (in water)

Limitation at high energy:
Fast decrease of neutrino fluxes
$E^{-2}$, $E^{-3}$

- MeV
- GeV
- TeV
- PeV
- EeV

Volume of detector

Density of detector

Origin of Cosmic Rays
- Supernovae
- Oscillations
- Dark Matter
- Cosmic Neutrinos
- GZK, Topological Defects
The ANTARES Detector

- 12 lines
- 25 storeys/line
- 3 PMTs/storey
- 900 PMTs

Depth: 2500m
The ANTARES site

40 km long Undersea Electro-optical Cable

Toulon

Insitut M.Pacha

Site ANTARES
42 50'N, 6 10'E
Line deployment operations

- DP Ship Castor02
- Precision of ~1m on the line position at sea bottom.
- ~7 hours operation
Undersea connection of lines with ROV

• Deep Sea ROV *VICTOR* of IFREMER

• ODI wate-metable connectors with:
  4 optical fibres
  2 electrical contacts
Example of a muon event

Example of a down-going muon event, detected over the 12 detector lines
Example of a neutrino event

Example of an up-going muon event (i.e. a neutrino event) detected by 6/12 detector lines
Atmospheric Muons
500 millions per an.km³

Atmospheric Neutrinos
150000 per an.km³

Rayons Cosmiques

Atmospheric Muons
500 millions per an.km³
Cosmic Signal vs atmospheric background

**Background suppression:**
- atmospheric muons: use reconstruction quality
- atmospheric neutrinos: isotropic + lower energy spectrum

**Signal:**
- distribution concentrated for point source + harder energy spectrum

Point Source  Diffuse Flux
Search for cosmic neutrino sources: 2007-2012: 5516 neutrinos

Most significant cluster at:
$RA = -46.8^\circ, \delta = -64.9^\circ$

6 (14) neutrinos within 1° (2°)

Analysis of 2007-2012 data → best world limits in South sky

Combined analysis ANTARES-IceCube

5 sigma discovery

Combined IC22 Antares
ANTARES analyses at CPPM

- **Search for transient sources (GRBs, μQuasars, AGN flares...):**
  - Search for time coincidences with $\gamma$ or X observations

**Search with 6 microquasars**

- 2007-2010 data set (813 days)
- Microquasars with ($x/\gamma$)-ray outbursts
- Likelihood ratio method (no energy proxy)
- No events detected in coincidence
- Flux limit above predictions

**Recent search with 41 blazars**

- 2008-2011 data (750 days livetime)
- 86 flaring periods 2FGL+Fermi Flare Advocates
- Improved likelihood with energy proxy (Nhits)

PRELIMINARY

- Lowest p-value (12%) 3C279 (2 events)
  - Compatible with background fluctuation

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ANTARES analyses at CPPM

- Analysis of optical images triggered by TAToO neutrino alerts:
  - Search for optical counterparts to high energy neutrino candidates coming from a GRB or a SuperNova

- Large sky coverage, high duty cycle
- No hypothesis on the nature of the source
- Sensitivity improved: 1 doublet is 3σ evidence, 1 triplet is 5σ!
- System active since 2009 with optical telescopes, now extended to SWIFT/XRT

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- **Search for neutrinos produced by Dark Matter annihilations:**

  - Relic WIMPs gravitationally trapped via elastic collisions (Sun, Earth, Galactic Center)

  $$\langle E_\nu \rangle \sim M_\chi / 3$$
ANTARES analyses at CPPM

- Search for diffuse flux of Ultra High Energy neutrinos (GZK,...):

- Measurement of neutrino mass and mixing parameters using atmospheric neutrino oscillations:

![Graphical representations of ANTARES analyses](image)
Existing Neutrino Telescopes

- **BAIKAL (1989)**: Lake Baikal, Sibérie
- **DUMAND**: Hawaii (canceled in 1995)
- **AMANDA**: South Pole, Antarctica
- **IceCube**
- **NESTOR (1991)**: Grèce
- **ANTARES (1996)**: France
- **NEMO (2000)**: Italie
- **KM3Net (2003)**: Mediterranean Sea
IceCube is located at the South Pole and composed of 86 lines of 60 optical modules spread over 1 km x 1km x 1km in the ice at a depth of -2500m + 80 surface stations.

Prototype: 1993-2005
Deployment: 2004-2011
Region of Sky Observable by Neutrino Telescopes

IceCube (South Pole)
- (ice: \(\sim 0.6^\circ\))

ANTARES (43° North)
- Angular resolution
- (water: \(\sim 0.3^\circ\))

**Galactic Centre**
- Vela
- CRAB
- SS433
- Mkn 501
- RX J1713.7-39
- GX339-4
- Mkn 421
- IceCube (South Pole)
- ANTARES (43° North)

Angular resolution
Ice Cube:
First signal of cosmic neutrinos!!
The European project KM3NeT in the Mediterranean Sea

A neutrino detector at least 50 time larger than ANTARES

R&D Phase:
- Characterisation of new multi PMs photodetectors
- Optimisation of detector geometry
- Optimisation of detector installation (deployment, costs, ...)
- Conception and construction of new deep-sea infrastructure
A single KM3NeT Building Block (115 strings)

Phase 1 (funded): 2 sites (Toulon, Capo Passero). 31 strings
Phase 1.5: 2 sites 1 block each → Measurement of IceCube signal
Phase 2: 2 (3 Greece?) sites with 6 blocks → Neutrino astronomy
ORCA: measurement of the neutrino mass hierarchy with a dense undersea neutrino telescope

Measurement of the Daya Bay experiment in Spring 2012: $\sin^2 2\theta_{13} = 0.109 \pm 0.03 \pm 0.025$

→ Sensitivity to neutrino mass hierarchy with oscillations of atmospheric neutrinos of few GeV interacting with the Earth

→ On-going feasibility study of such measurement with a dense undersea neutrino telescope (ORCA)
The Neutrino Astronomy group at CPPM

• 8 permanent physicists
• 1 PhD student

Data analysis of the ANTARES neutrino telescope:
- Searches for cosmic neutrino point sources (AGNs, SNRs, µQuasars, …)
- Multi-messenger searches for transient sources (GRBs, SNs, …)
- Indirect searches for Dark Matter
- Measurements of neutrino oscillations

Construction and operation of the second generation neutrino telescope in the Mediterranean Sea (KM3NeT), analysis of its first data

Study of the neutrino mass hierarchy measurement (ORCA)

Lots of New, Rich and Great Physics!

→ Join the Adventure!!