FISICA e TECNOLOGIA per un telescopio sottomarino di 1 Km3 nel mediterraneo per lo studio dei neutrini cosmici.

G.C. Barbarino
DSF e INFN

Raggi cosmici E≥10^{20} eV, un problema ...

Spettro Raggi cosmici

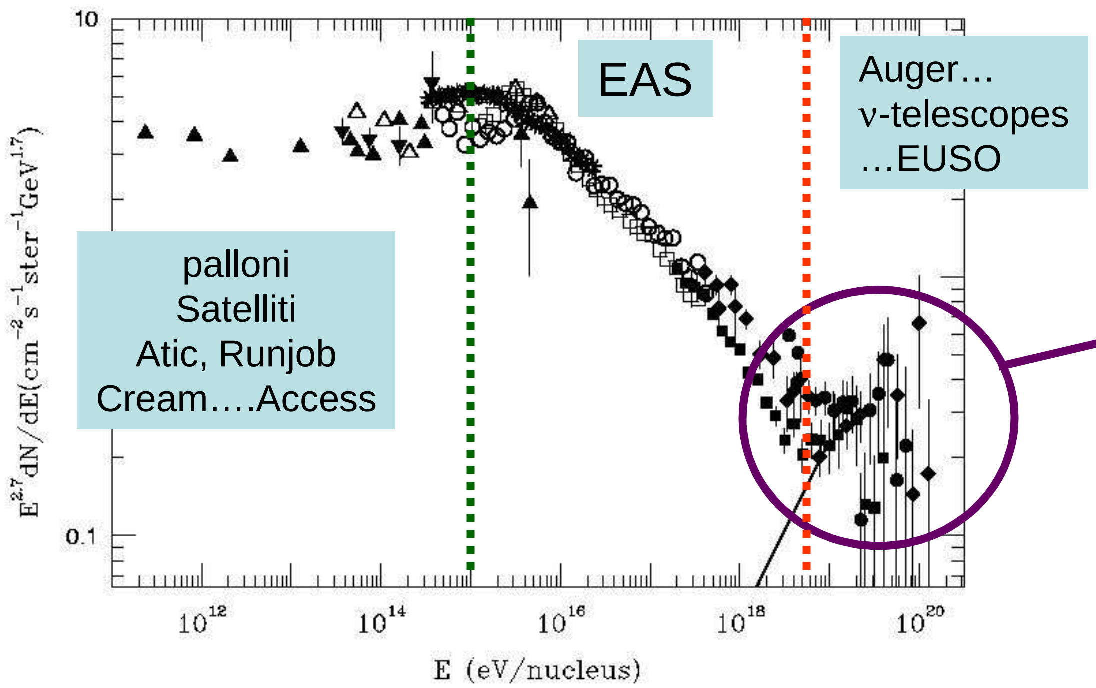
acceleratori cosmici

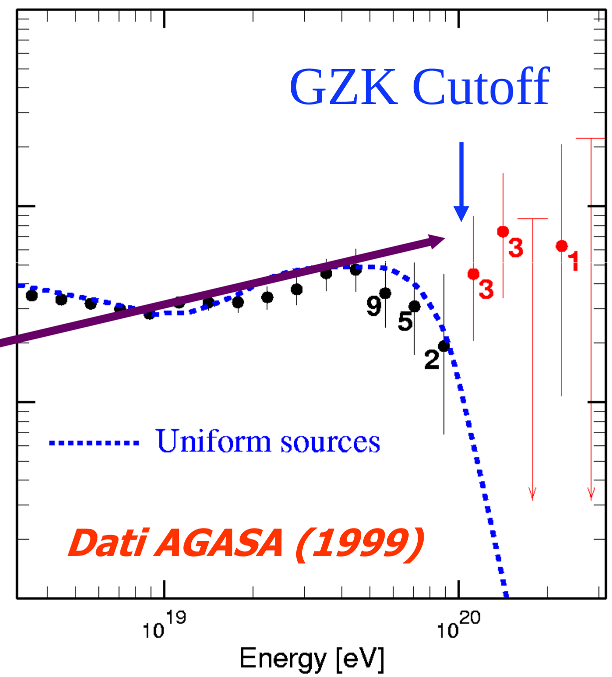
10^{20} eV ≈ 17 Joules

origine galattica

origine galattica ed extragalattica ?

origine sconosciuta





Photomeson interaction (GZK cutoff 2.7K°)

$N\gamma_{CMBR} \rightarrow N\pi$

pair production

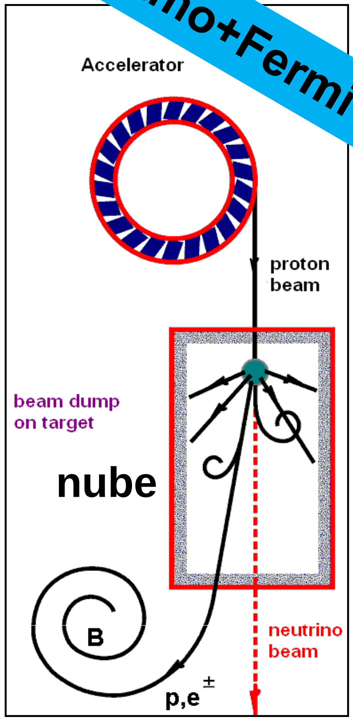
$\gamma\gamma_{IR,MW} \rightarrow$ e+e-

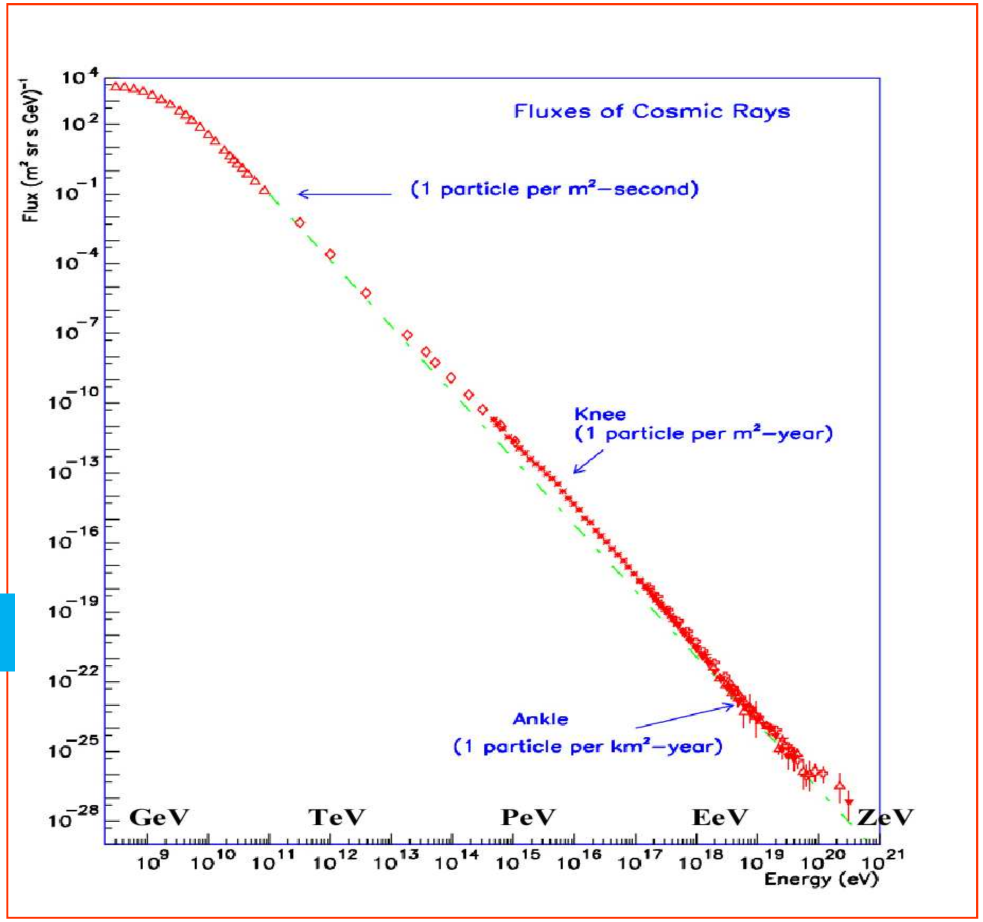
Intergalactic space not trasparent

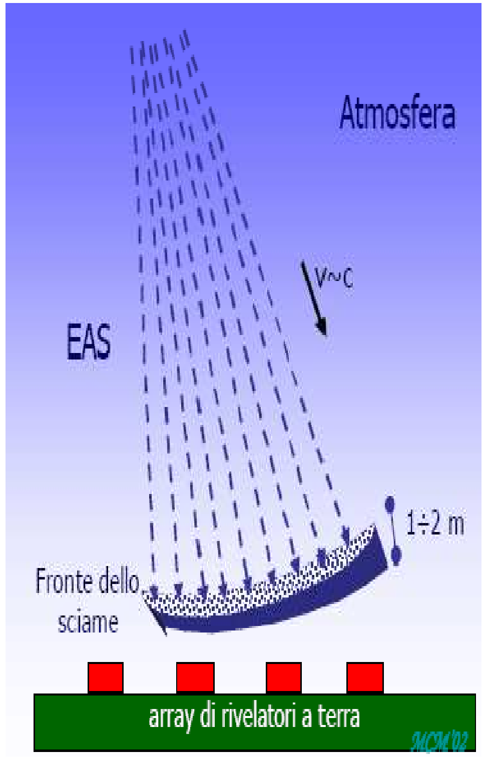
Dinamo+Fermi

Motori

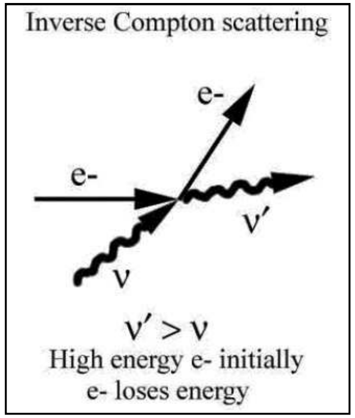
Grandi quantita' di energia trasportata dalla radiazione elettromagnetica e corpuscolare (raggi cosmici)







Compton inverso

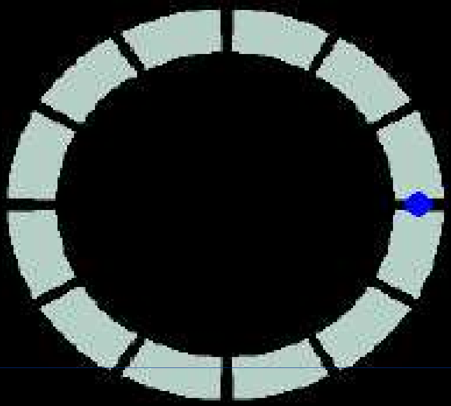


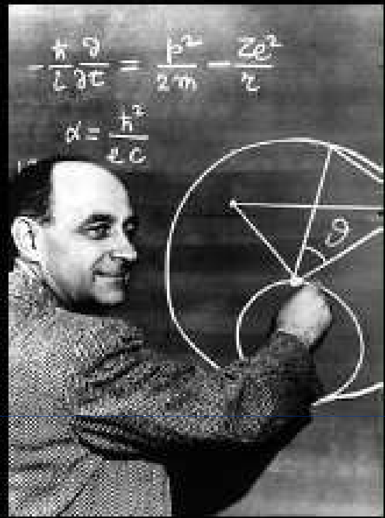
Meccanismi di accelerazione
Elettromagnetici ?
Nucleari ?

How might such cosmic accelerators work?

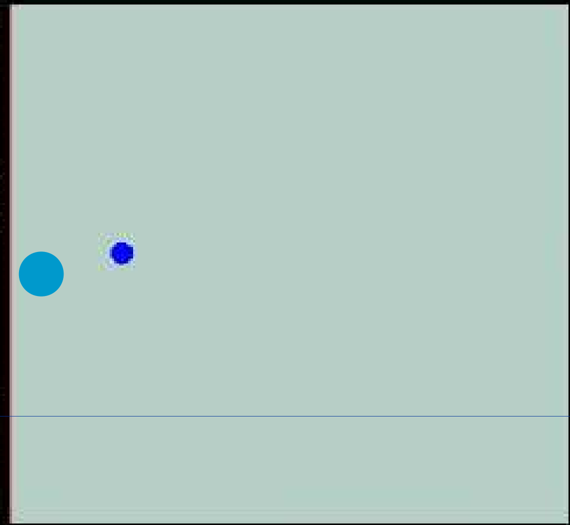
Man-made accelerators

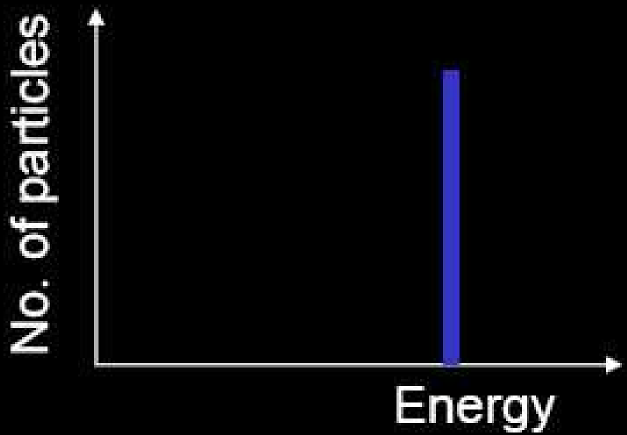
Nature's accelerators

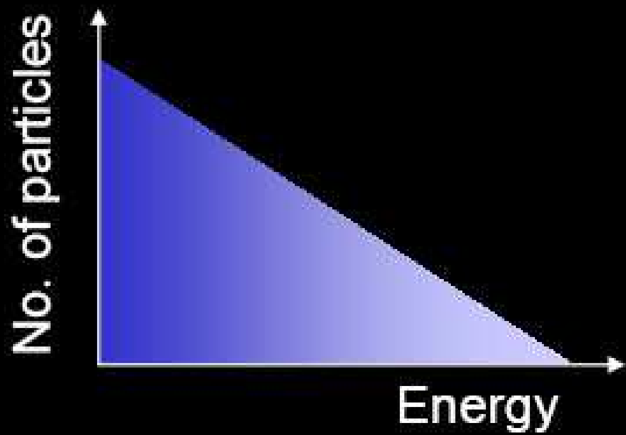




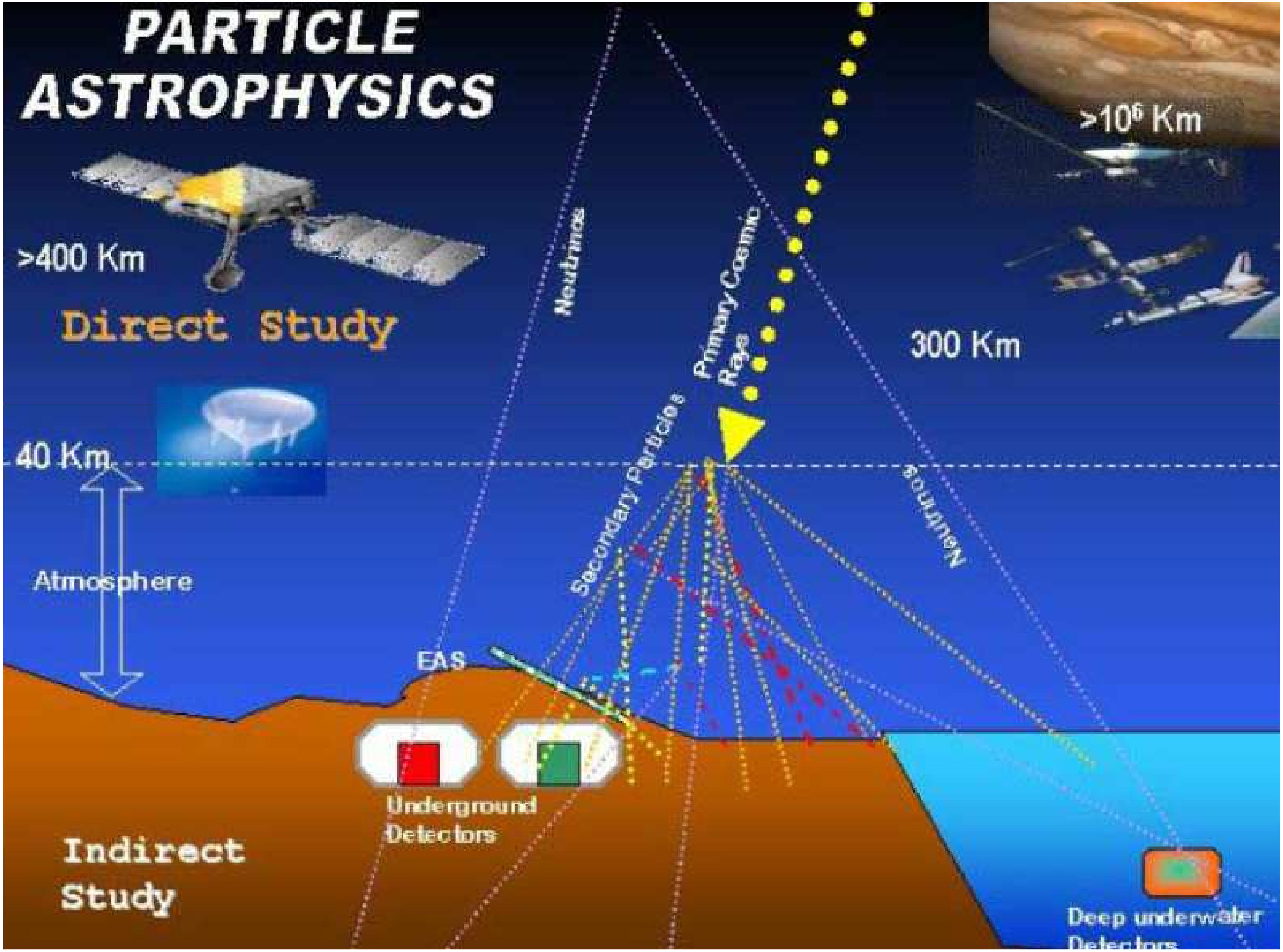
Enrico
Fermi



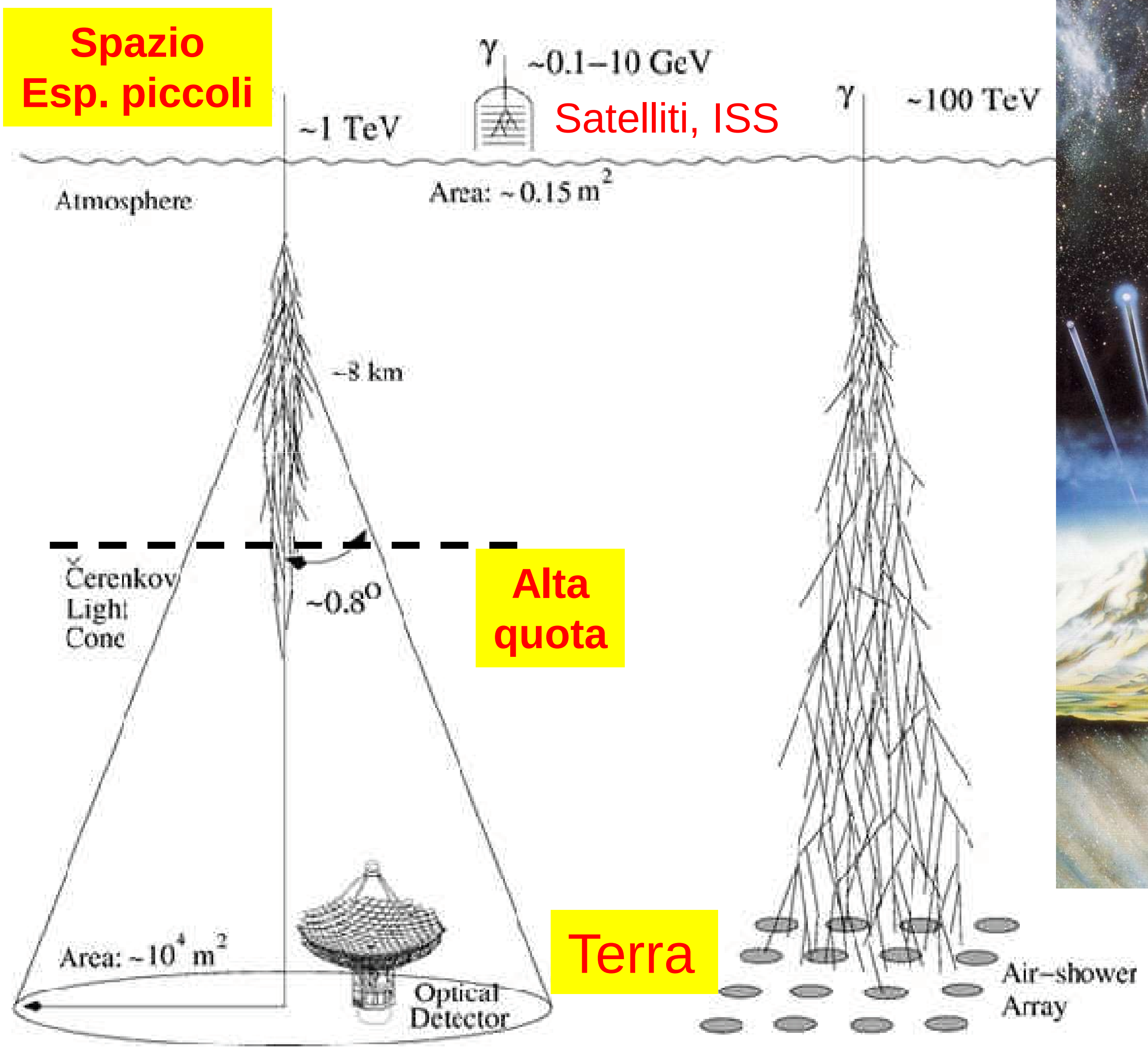


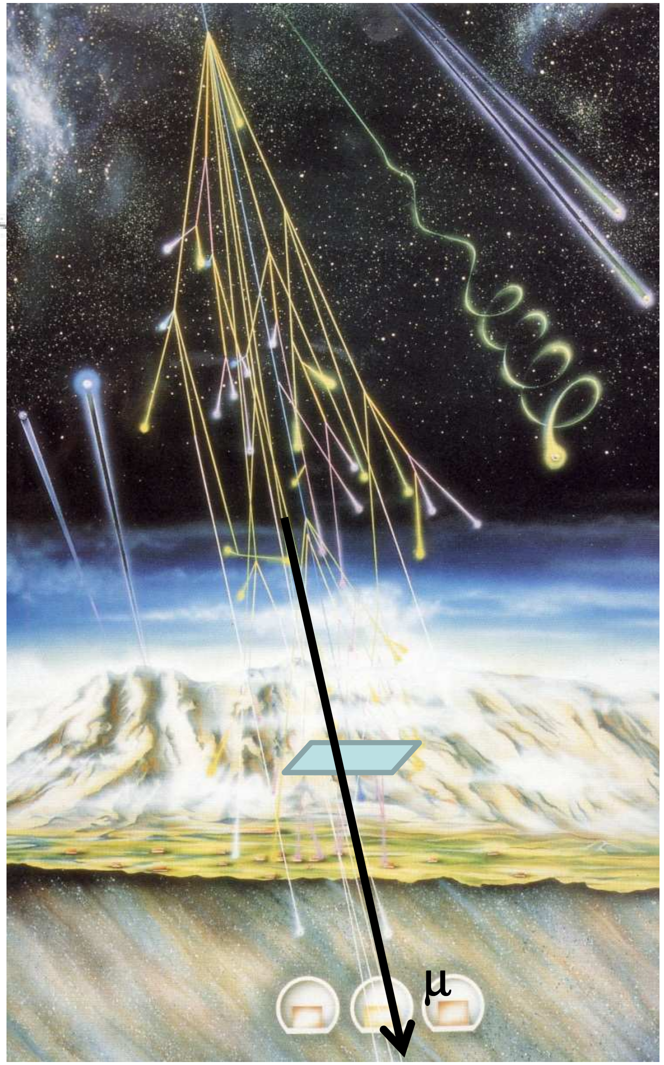


Il laboratorio cosmico



Gamma misurati in tutto l'ambiente Cosmico: Terra e spazio





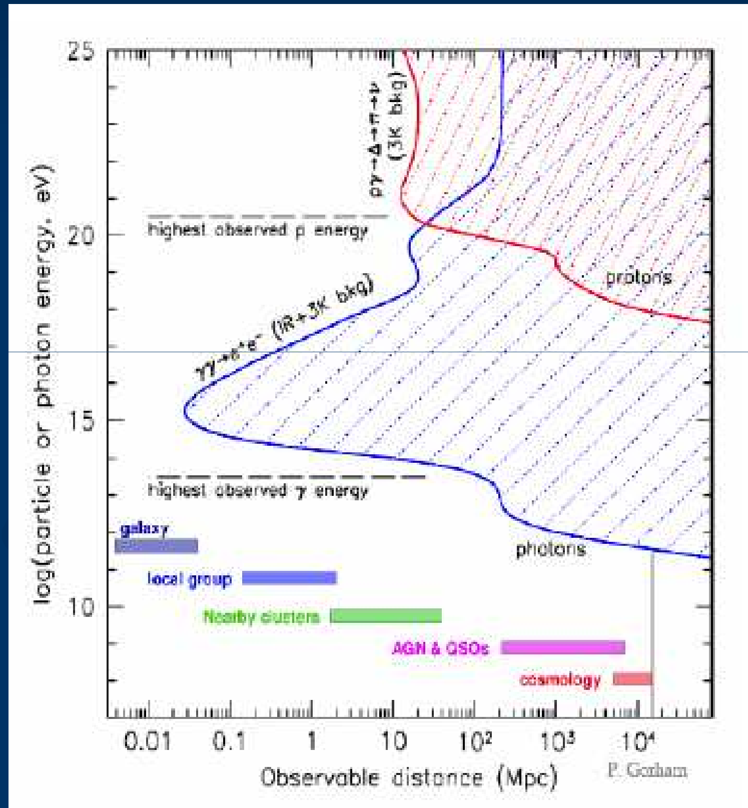
Probes for high energy astronomy

The Universe is not "transparent" for HE photons and protons

$$\gamma + \gamma_{CMB} \rightarrow e^{+} + e^{-}$$

$$p + \gamma_{CMB} \rightarrow \Delta^{+}$$
$$\rightarrow n + \pi^{+}$$
$$\rightarrow \mu^{+} + \nu_{\mu}$$

GZK effect



Protons with $E < 10^{19}$eV are deflected by magnetic fields

Need neutrinos to observe the distant Universe at high energy GZK

Lo spettro di osservazione dei processi astrofisici

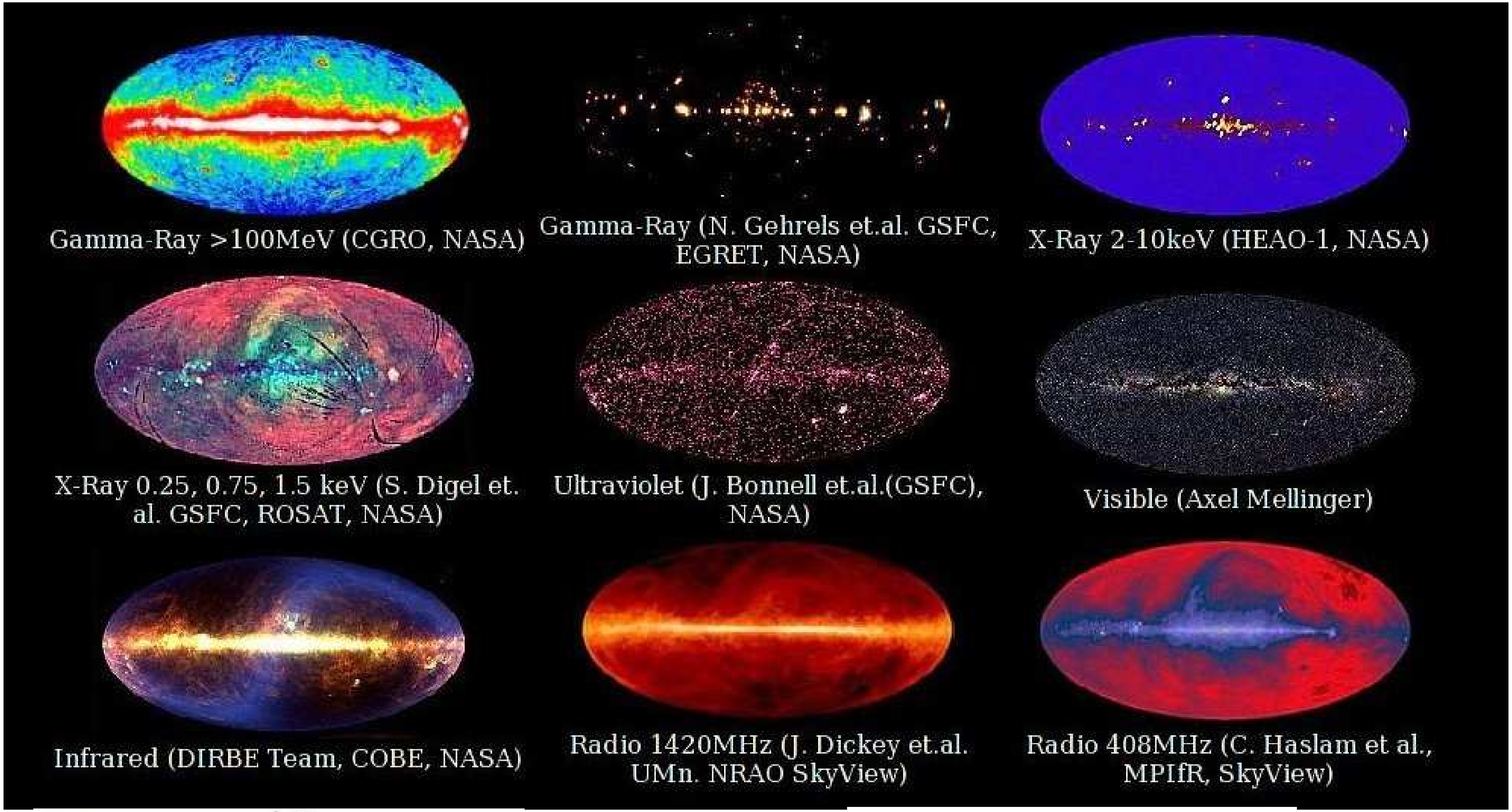
Il cielo appare diverso a seconda dello spettro elettromagnetico osservato

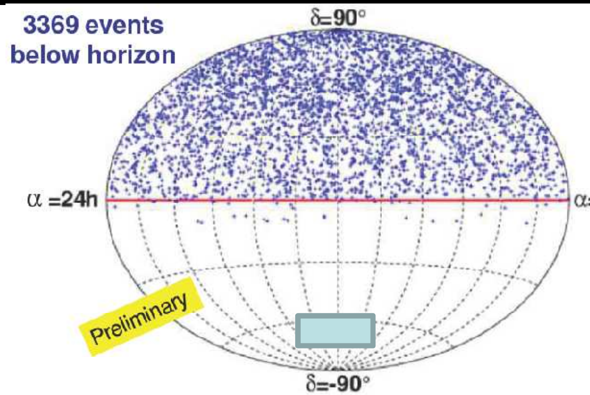
Esistono numerose fasi evolutive stellari non visibile nell'ottico tipicamente fasi turbolente invisibili ai nostri occhi

L'Astronomia visibile osserva la parte piu' "tranquilla e stabile dell'Universo"
Luce emessa dalle superfici delle sorgenti (galassie, stelle) fasi stabili

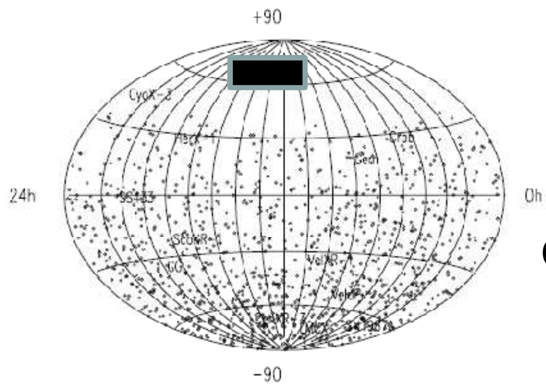
Astronomia infrarossa studia il debole calore emesso dalle grandi distese di gas interstellare. Materia fredda che collassa a formare galassie e stelle.
Basse energie: grandi regioni di polvere interstellare

Produzione di raggi X, γ, ν coinvolgono enormi energie. Queste astronomie studiano regioni tormentate che sono e furono sedi di esplosioni.
Alte energie = fenomeni locali intensi (VITA DI UNA STELLA)





Neutrini
Amanda/Ice Cube
Polo sud

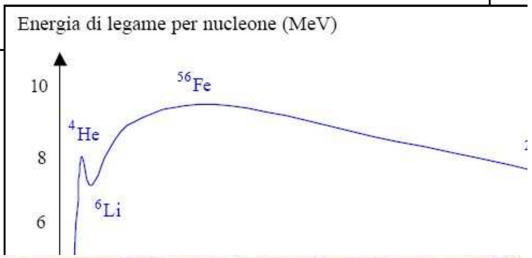


Neutrini
Macro
Gran Sasso

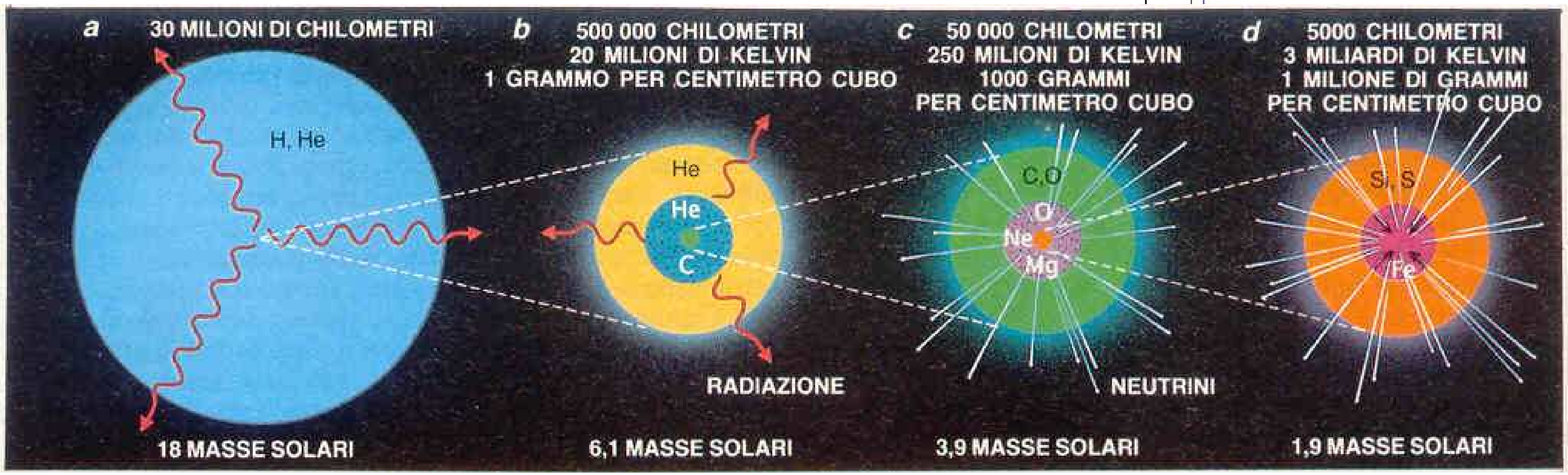
Le fasi finali della evoluzione stellare diventano sorgenti di radiazione elettromagnetica e corpuscolare (Motori)

Stelle: nascono da contrazioni di nubi molecolari: gas e polveri. Le regioni piu' dense collassano per gravita': regioni di emissione radio,microonde, infrarosso 10-20 K°.

per gravita' la densita' aumenta, il gas diventa opaco e la temperatura sale. Inizio reazioni di fusione nucleare H, He. Per T= 10^6 K. Equilibrio fra forza gravitazionale e e pressione interna di riscaldamento.

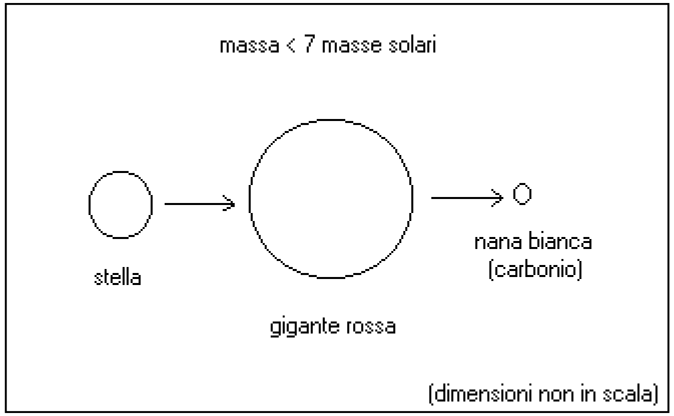


Motori

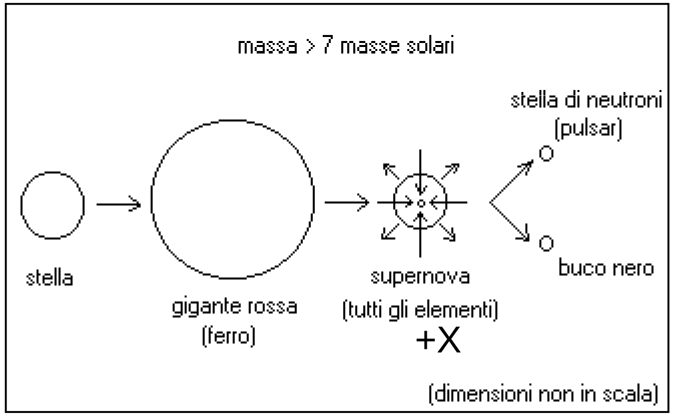


Successive evoluzioni stellari

3 tipi di evoluzione legati alla massa della stella



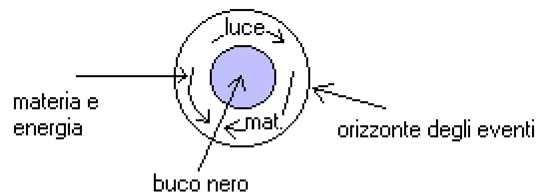
Stelle da 1-4 masse Sole: Fusione fino a Carbonio, Ossigeno, NANE BIANCHE stabilita' data dalla pressione di elettroni 1,4 Masse Sole. Emissione X e materia



Stelle da 4-10 masse Sole: Fusione fino a Ferro e Nichel e gusci di elementi leggeri, H, He. Se La massa > 1.4 masse Sole, forte contrazione, $p + e^- \Rightarrow n + \nu_e$ neutronizzazione, riduzione pressione elettronica, alta temperatura, rottura nuclei Fe, stella di neutroni, implode, T sale, esplosione. Emissione particelle, N, X, γ

Motori

Momento angolare,Erot.,B



$\nabla \times E = \delta \mathbf{B} / \delta t$

Stelle da 5-10 masse Sole. Nucleo con massa Residua > 3 masse Sole. Continua collasso. Altissima energia tale da formare materia-antimateria Annichilazione o assorbimento di una componente. Emissione particelle X, γ

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On the Origin of the Cosmic Radiation

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(Received January 3, 1949)

A theory of the origin of cosmic radiation is proposed according to which cosmic rays are originated and accelerated primarily in the interstellar space of the galaxy by collisions against moving magnetic fields. One of the features of the theory is that it yields naturally an inverse power law for the spectral distribution of the cosmic rays. The chief difficulty is that it fails to explain in a straightforward way the heavy nuclei observed in the primary radiation.

I. INTRODUCTION

IN recent discussions on the origin of the cosmic radiation E. Teller[1] has advocated the view that cosmic rays are of solar origin and are kept relatively near the sun by the action of magnetic fields. These views are amplified by Alfvén, Richtmyer, and Teller.[2] The argument against the conventional view that cosmic radiation may extend at least to all the galactic space is the very large amount of energy that should be present in form of cosmic radiation if it were to extend to such a huge space. Indeed, if this were the case, the mechanism of acceleration of the cosmic radiation should be extremely efficient.

I propose in the present note to discuss a hypothesis on the origin of cosmic rays which attempts to meet in part this objection, and according to which cosmic rays originate and are accelerated primarily in the interstellar space, although they are assumed to be prevented by magnetic fields from leaving the boundaries of the galaxy. The main process of acceleration is due to the interaction of cosmic particles with wandering magnetic fields which, according to Alfvén, occupy the interstellar spaces.

Such fields have a remarkably great stability because of their large dimensions (of the order of magnitude of light years), and of the relatively high electrical conductivity of the interstellar space. Indeed, the conductivity is so high that one might describe the magnetic lines of force as attached to the matter and partaking in its streaming motions. On the other hand, the magnetic field itself reacts on the hydrodynamics[3] of the interstellar matter giving it properties which, according to Alfvén, can pictorially be described by saying that to each line of force one should attach a material density due to the mass of the matter to which the line of force is linked. Developing this point of view, Alfvén is able to calculate a simple formula for the velocity V of propagation of magneto-elastic waves:

$$V = H/(4\pi\rho)^{\frac{1}{2}}, \qquad (1)$$

where H is the intensity of the magnetic field and ρ is the density of the interstellar matter.

One finds according to the present theory that a particle that is projected into the interstellar medium with energy above a certain injection threshold gains energy by collisions against the moving irregularities of the interstellar magnetic field. The rate of gain is very slow but appears capable of building up the energy to the maximum values observed. Indeed one finds quite naturally an inverse power law for the energy spectrum of the protons. The experimentally observed exponent of this law appears to be well within the range of the possibilities.

The present theory is incomplete because no satisfactory injection mechanism is proposed except for protons which apparently can be regenerated at least in part in the collision processes of the cosmic radiation itself with the diffuse interstellar matter. The most serious difficulty is in the injection process for the heavy nuclear component of the radiation. For these particles the injection energy is very high and the injection mechanism must be correspondingly efficient.

II. THE MOTIONS OF THE INTERSTELLAR MEDIUM

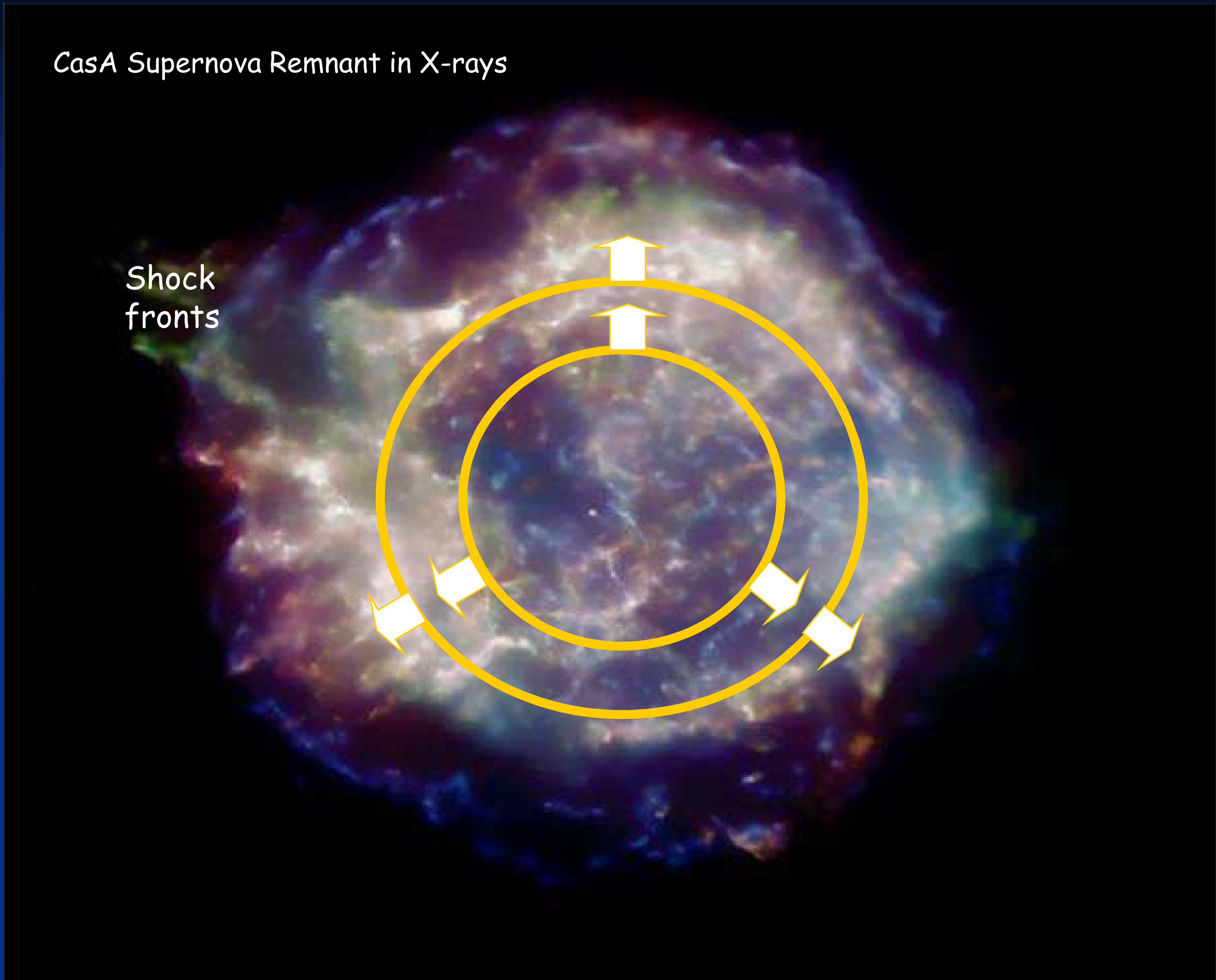
It is currently assumed that the interstellar space of the galaxy is occupied by matter at extremely low density, corresponding to about one atom of hydrogen per cc, or to a density of about 10^{-24} g/cc. The evidence indicates, however, that this matter is not uniformly spread, but that there are condensations where the density may be as much as ten or a hundred times as large and which extend to average dimensions of the order of 10 parsec. (1 parsec. $= 3.1\times10^{18}$ cm $= 3.3$ light years.) From the measurements of Adams[4] on the Doppler effect of the interstellar absorption lines one knows the radial velocity with respect to the sun of a sample of such clouds located at not too great distance from us. The root mean square of the radial velocity, corrected for the proper motion of the sun with respect to the neighboring stars, is about 15 km/sec. We may assume that the root-mean-square velocity

[1] Nuclear Physics Conference, Birmingham, 1948.
[2] Alfvén, Richtmyer, and Teller, Phys. Rev., to be published.
[3] H. Alfvén, Arkiv Mat. f. Astr., o. Fys. 29B, 2 (1943).
[4] W. S. Adams, A.p.J. 97, 105 (1943).

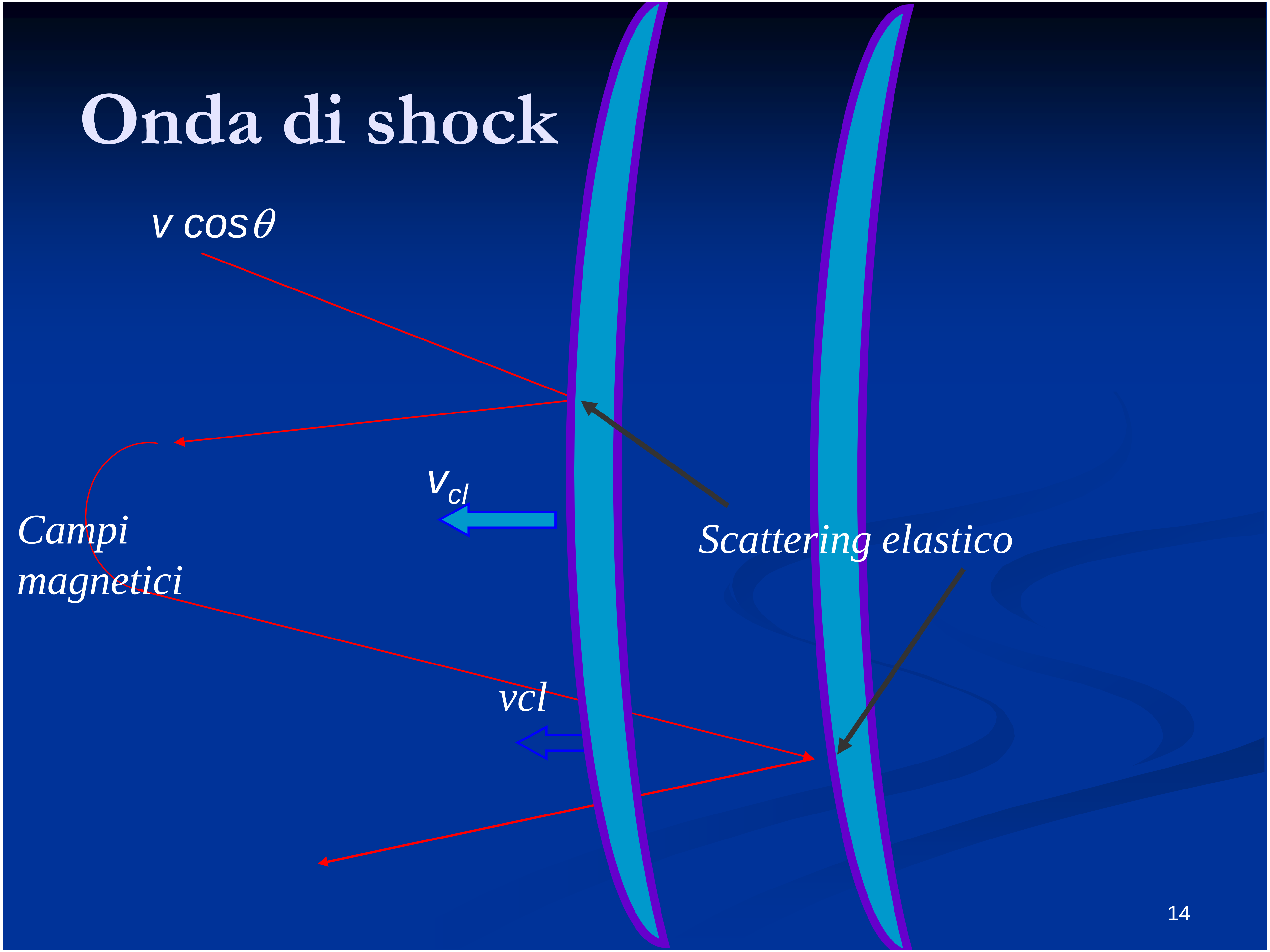
4.2 Il meccanismo di Fermi

Il meccanismo “idrodinamico” descrive accelerazione stocastica di RC da parte di ripetuti urti delle particelle con un’onda di shock, ad esempio emessa dall’esplosione di una SN. Un gran numero di collisioni possono far crescere l’energia fino a valori molto elevati. Guadagno di energia per collisione:

$$\Delta E/E = \varepsilon$$


CasA Supernova Remnant in X-rays
Shock
fronts

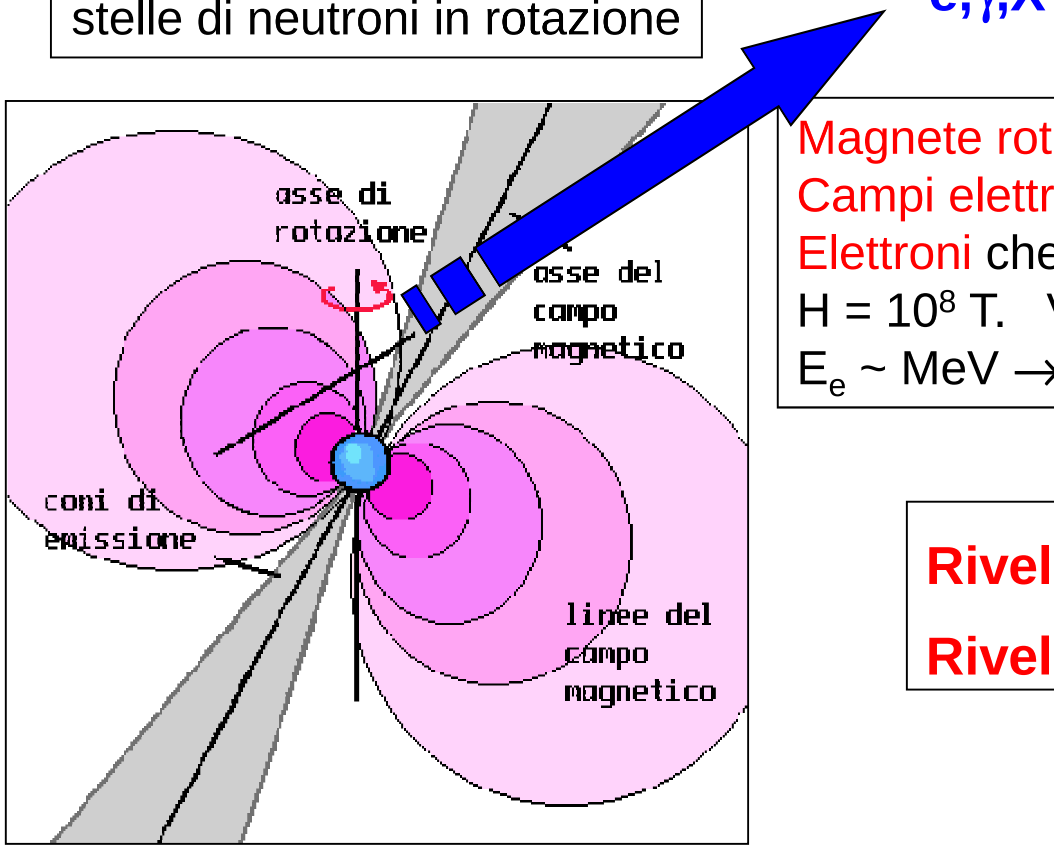
Onda di shock



- Tra i siti possibili di accelerazione dei raggi cosmici dobbiamo includere (ad energia crescente):
  - i venti stellari
  - le esplosioni di Supernovae
  - le "remnants" di tali esplosioni: stelle di neutroni ruotanti, pulsar con nebulose, …
  - Modello non sufficiente per giustificare RC con $E>10^{19}$ eV
  - altri oggetti esotici, quali i "mini-black holes", se esistono.
  - I raggi cosmici osservati con energie $E>10^{19}$ eV, potrebbero essere stati accelerati da meccanismi extragalattici, quali jets di nuclei Galattici attivi o GRB

Acceleratore cosmico 1

PULSAR ISOLATE
stelle di neutroni in rotazione



Magnete rotante non allineato: dipolo magnetico
Campi elettrici indotti intensi+FERMI
Elettroni che sfuggono a jets.
$H = 10^8$ T. $V = 10^{16}$ V.
$E_e \sim$ MeV $\rightarrow \gamma \rightarrow e^+ e^- \rightarrow \gamma\gamma$ ....

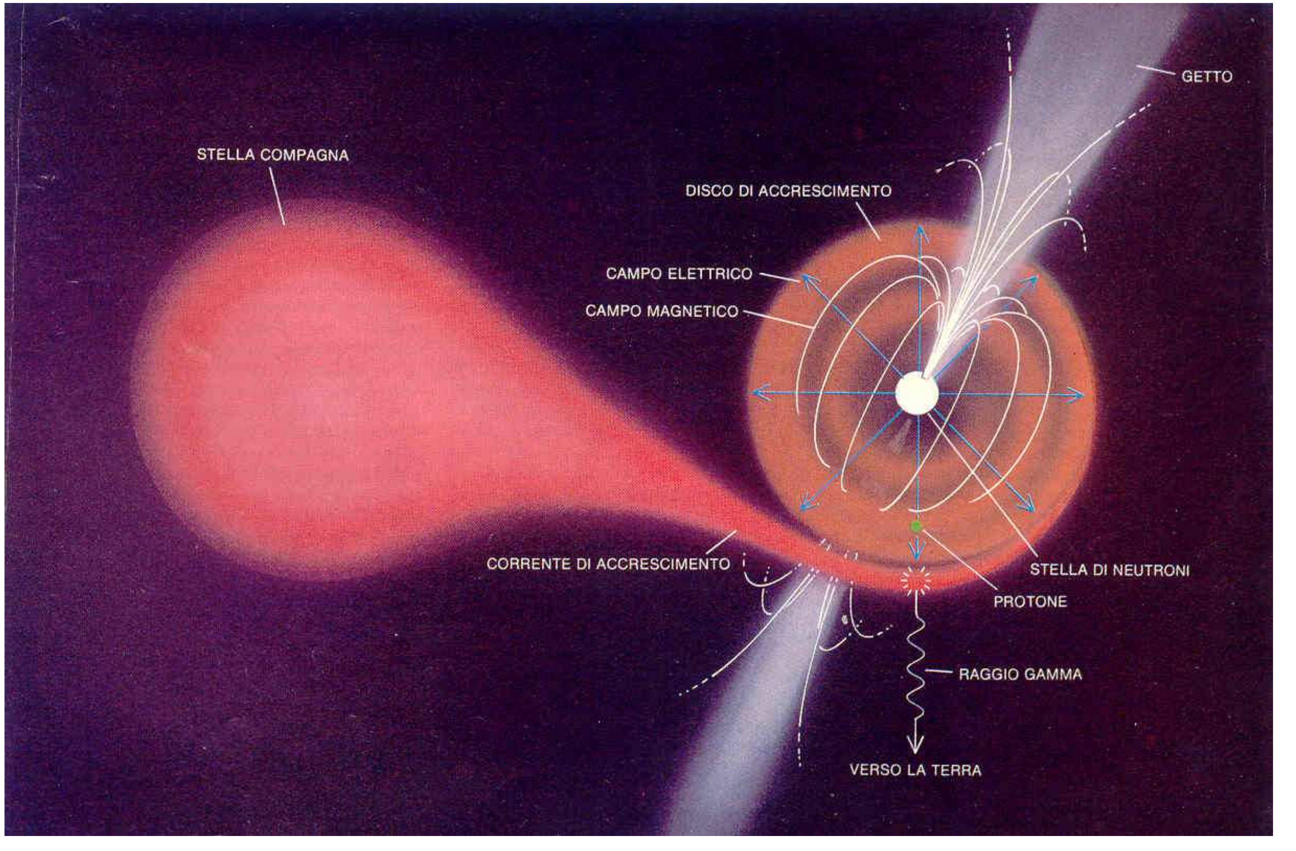
Rivelazione X: palloni, satelliti

Rivelazione γ : satelliti, esp. a terra

Parte espulsa dalla stella: esplosione di supernova
Emissioni di particelle accelerate e, p, nuclei
+ accelerazione di FERMI nei resti di supernova

Acceleratore cosmico 2

SISTEMI BINARI



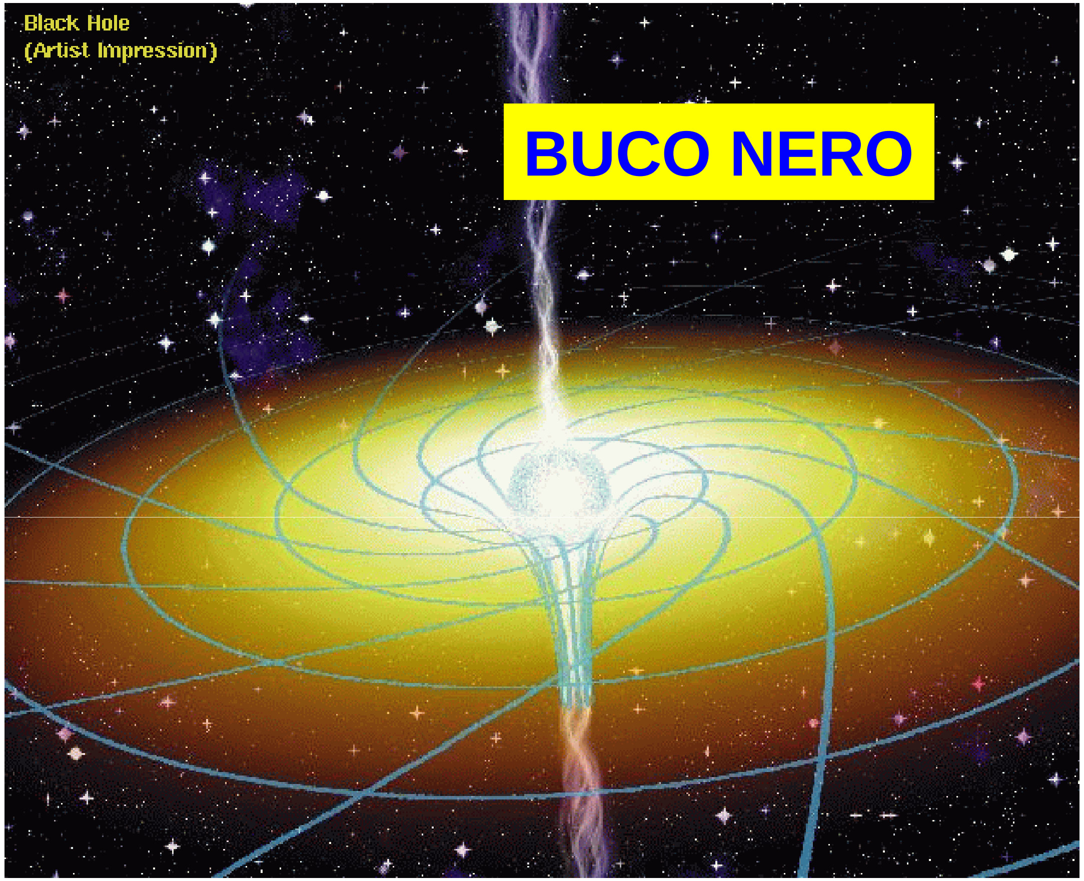
sorgenti di raggi **e,γ,X,ν**

associati a trasferimento di materia dalla stella primaria

attraverso i poli magnetici della stella di neutroni (alte temperature, X).

Spiegano $\gamma \sim 10^{12}$eV processi elettromagnetici? X e compton inverso ?

Acceleratore cosmico 3



Processo simile alla formazione delle pulsars.

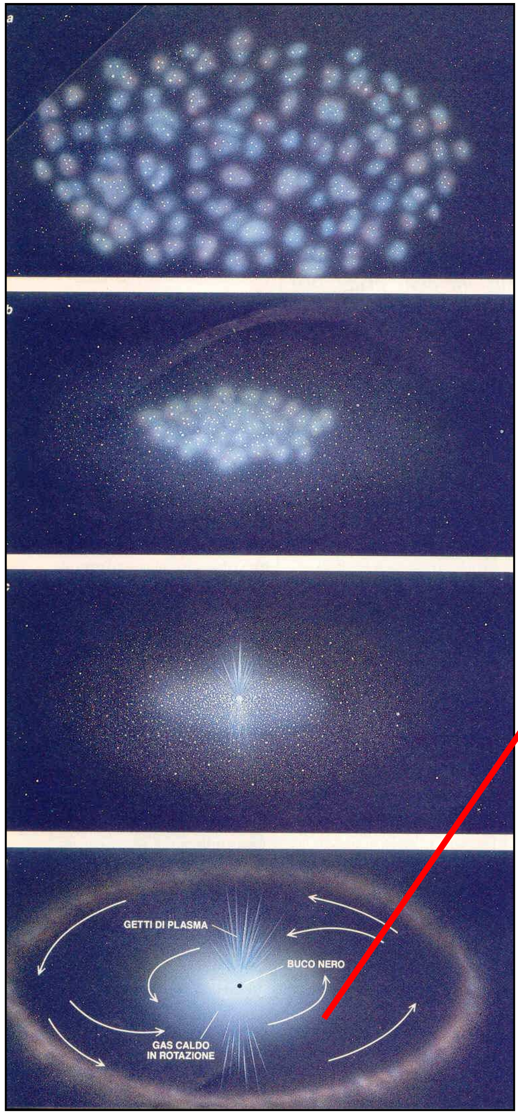
Fine del processo di evoluzione stellare

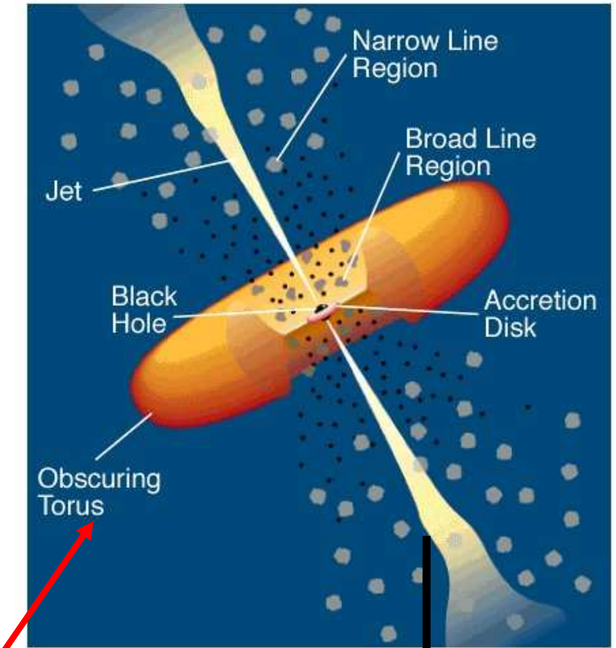
Generato da supernovae con nucleo con massa > 3 M sole
oltre lo stadio di stella di neutroni

Formazione di coppie particella Antiparticella un assorbita e una espulsa

Il buco nero attira materia circostante formando un disco di accrescimento
La caduta di materia ad alta temperatura genera emissione X

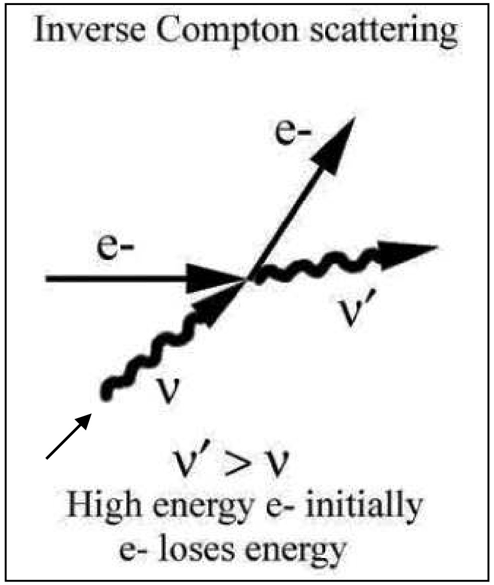
Modello simile per AGN (nucleo galattico attivo)





Processi di accelerazione

1)



2)

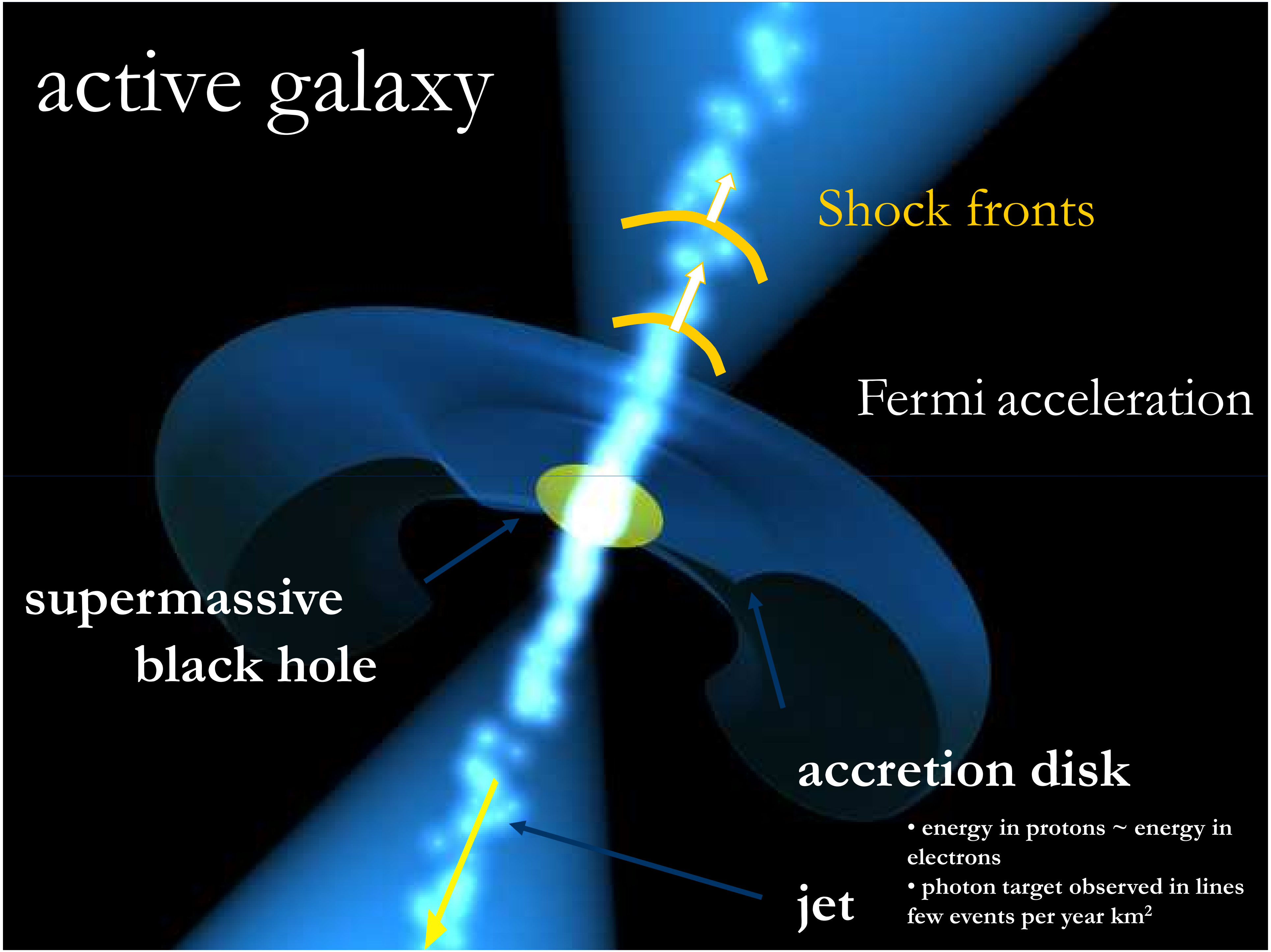
Jets di radiazione e particelle Dinamo+Fermi

+

$$p + N_{gas} \rightarrow \pi^0 + \pi^{\pm} + \cdots$$

$\pi^0 \rightarrow \gamma\gamma$ $\quad \pi^{\pm} \rightarrow \mu\ e\ \nu\ \nu$

Buco nero di grande massa che acquista materia da stelle e gas che orbitano attorno. E rot. +B

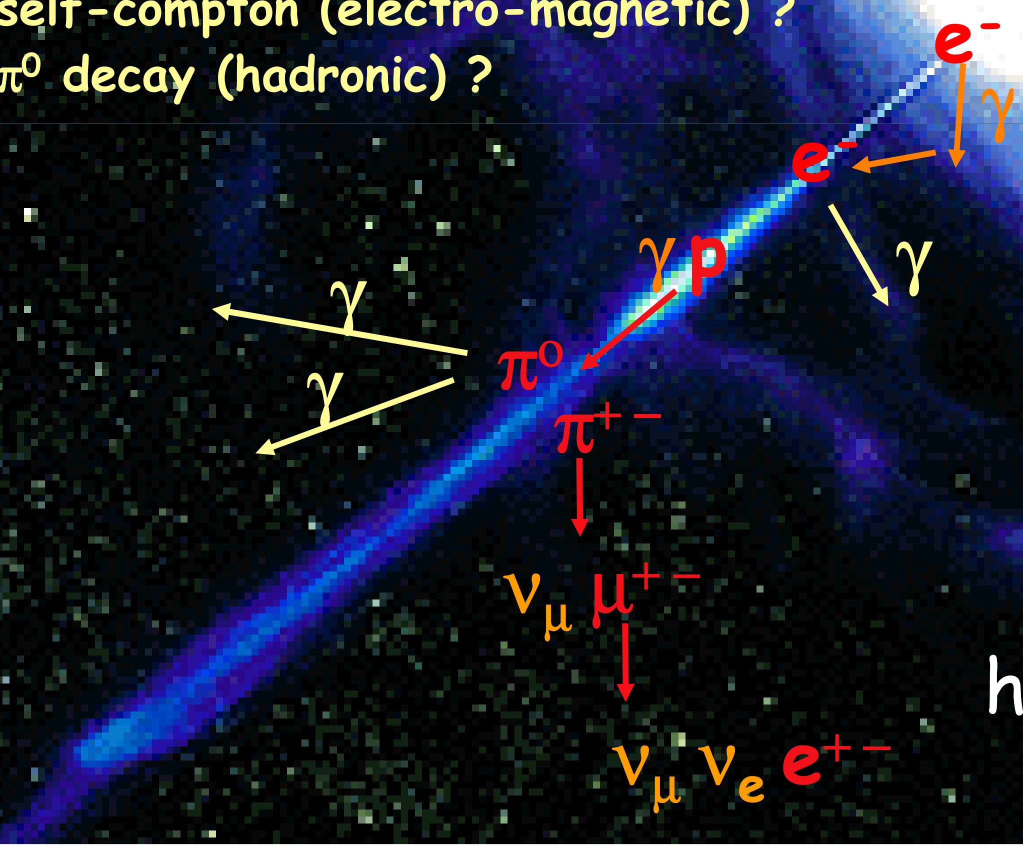

active galaxy
Shock fronts
Fermi acceleration
supermassive
black hole
accretion disk
jet
• energy in protons ~ energy in electrons
• photon target observed in lines
few events per year km²

Charged Particles Accelerated

Neutral particles secondary products

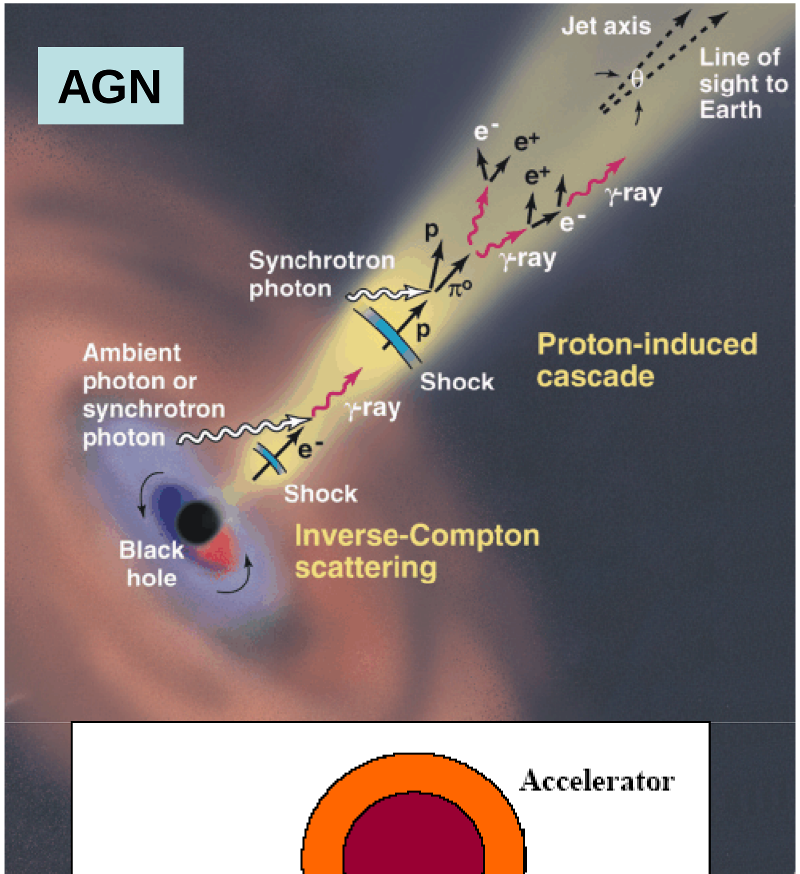
Low energy emission (X-ray) :
Synchrotron emission of e^- in jet

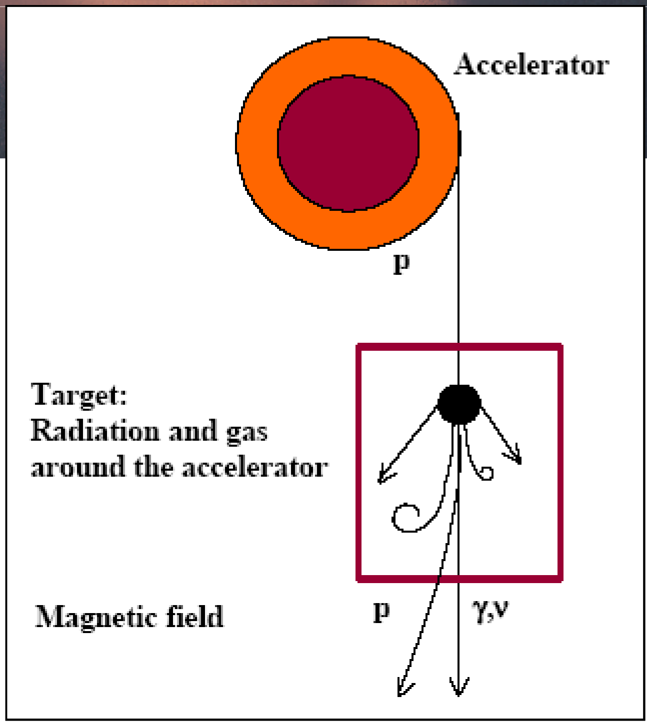
High energy emission (γ-ray):
- self-compton (electro-magnetic) ?
- π^0 decay (hadronic) ?

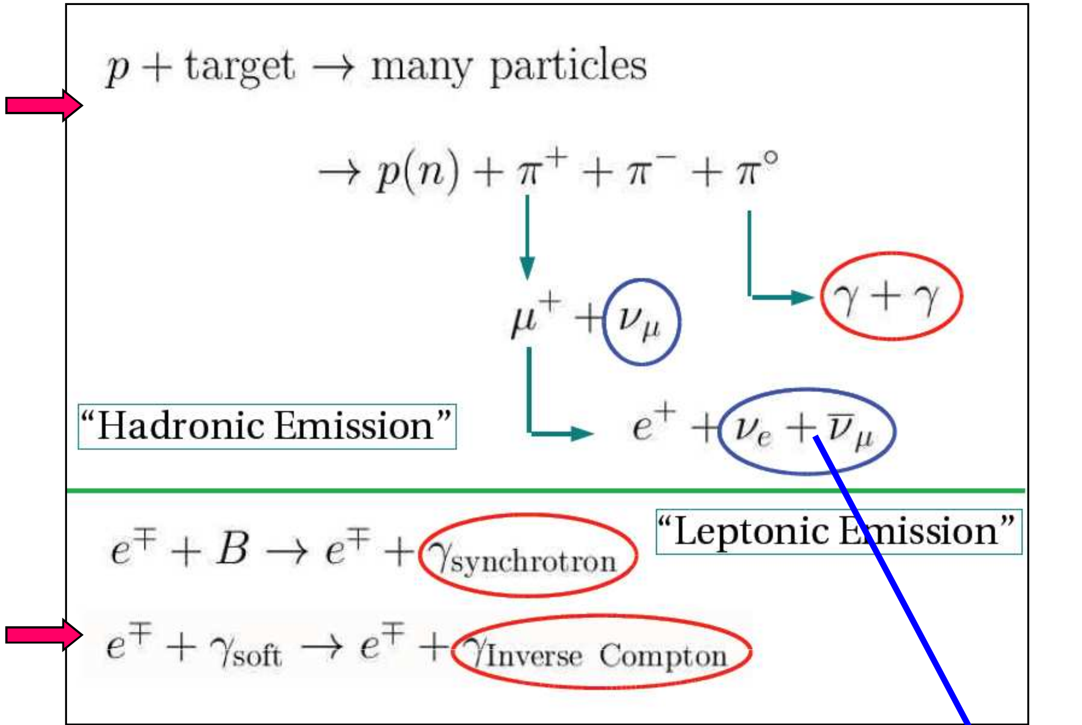


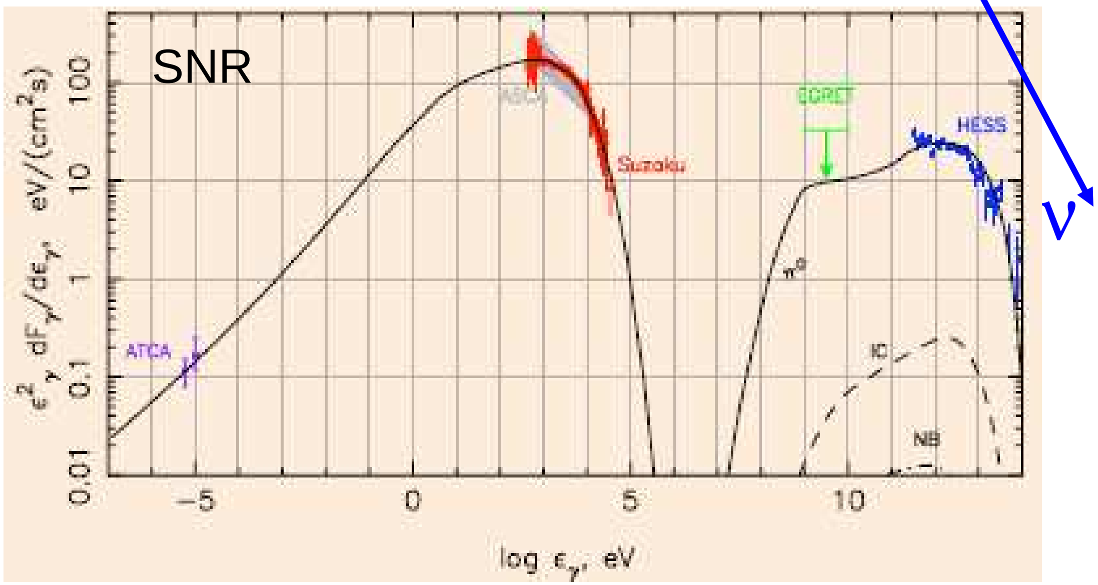
Need both
γ and ν probes
to distinguish
hadronic and leptonic
acceleration

Cosmic accelerators









Gamma Ray burst dal cosmo

-Intensa radiazione gamma di durata variabile msec-100 sec mai nello stesso punto
-presenza di afterglow nell'ottico, X-ray, radio dopo ore-settimane.
-la maggior parte dei GRB durano 2-10 sec e presentano afterglow.

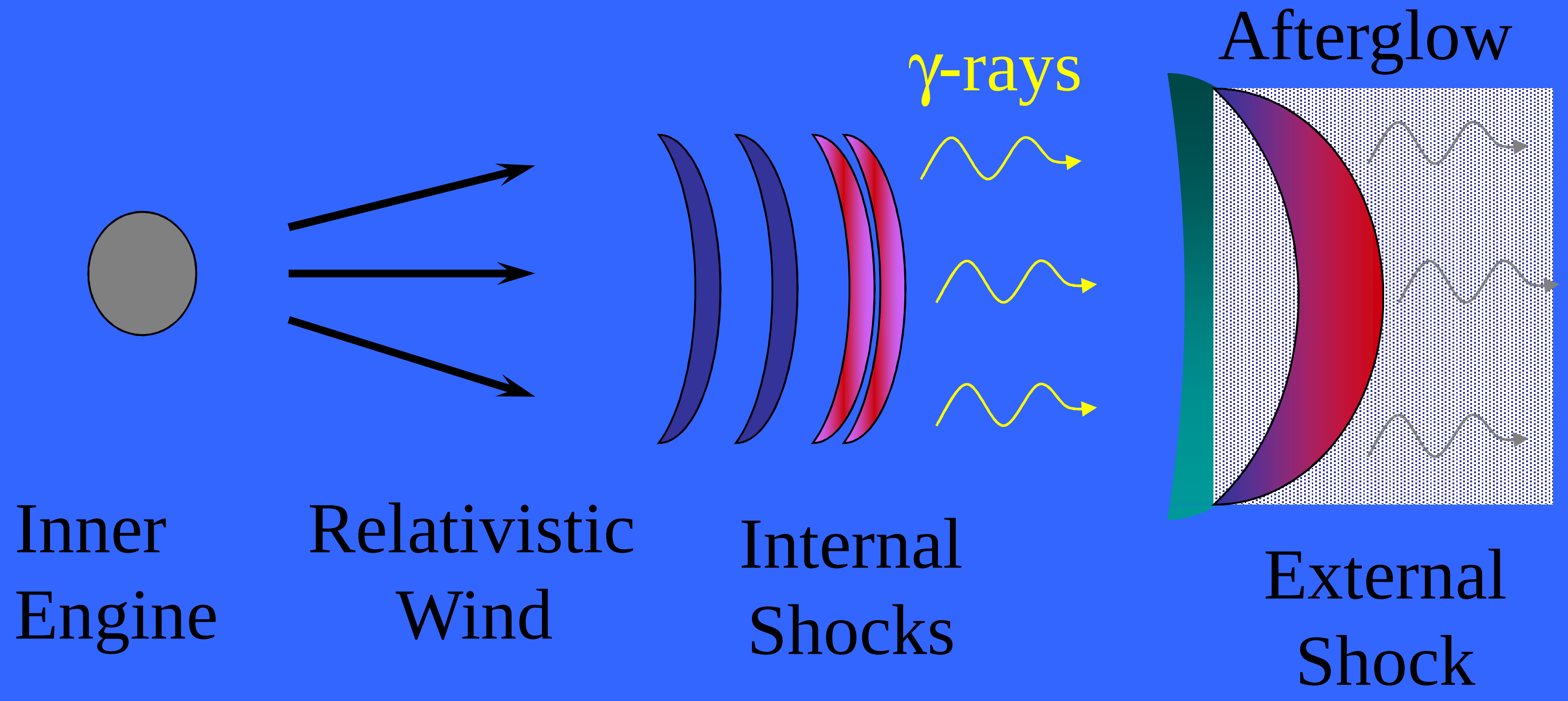
Fenomeni che originano i GRB

-Collisione di due stelle di neutroni o buchi neri (GRB di breve durata < 2 sec.)
-Fusione di un buco nero ed una stella di neutroni. (NS-NS), (BH-NS).
-Evento catasrofico, accelerazione di particelle cariche.
-Trasformazione materia-energia.
-Studi di afterglow nell'X per capire l'origine sulla base dell'assorbimento o meno.

GRB: energia > 100 volte Supernova e 10^{11} volte energia del Sole in un anno.

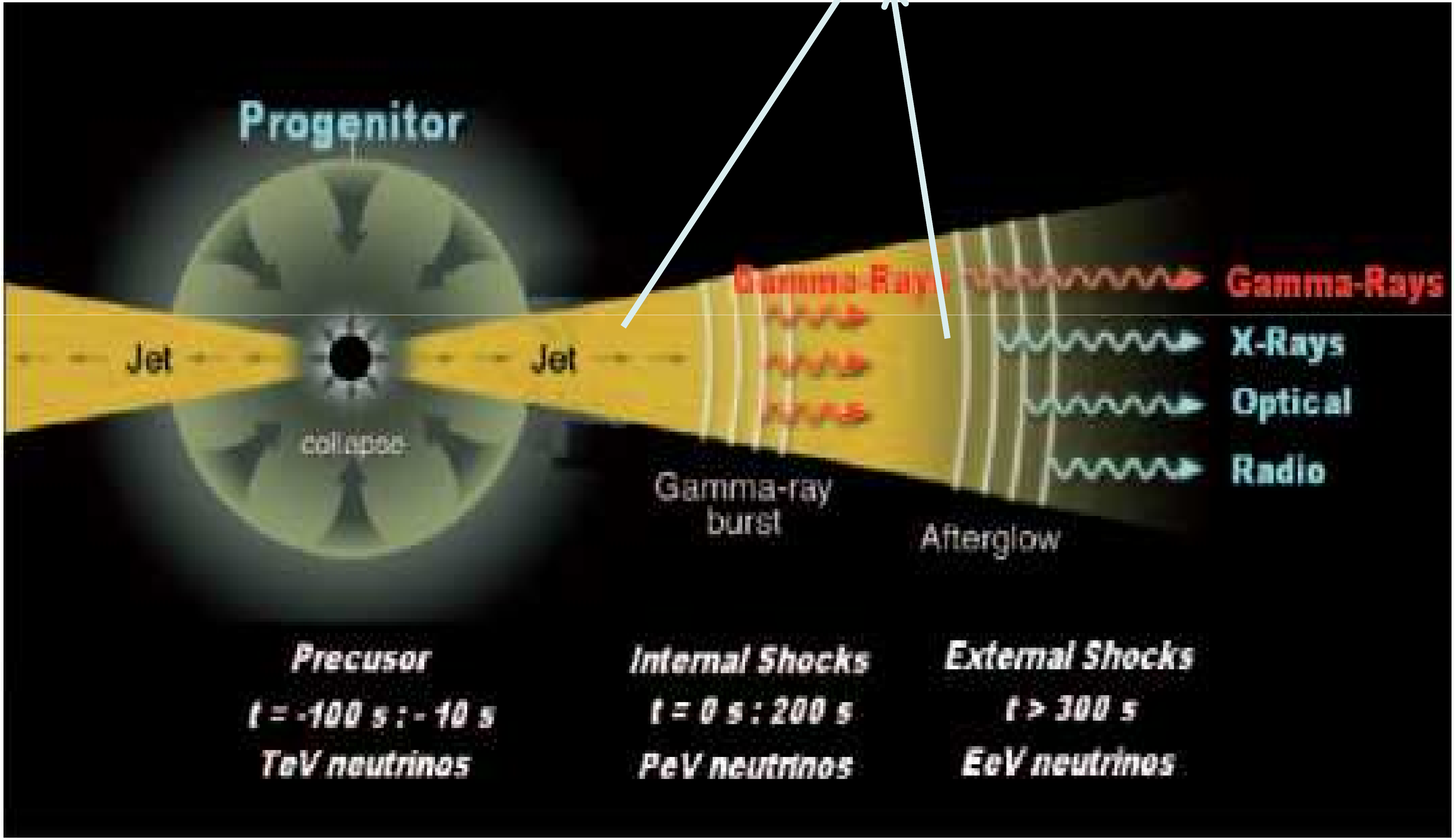
Circa uno al giorno con energia stimata di 10^{52} erg
In pochi sec
=
sole 3000 miliardi di anno o galassia in 100 anni

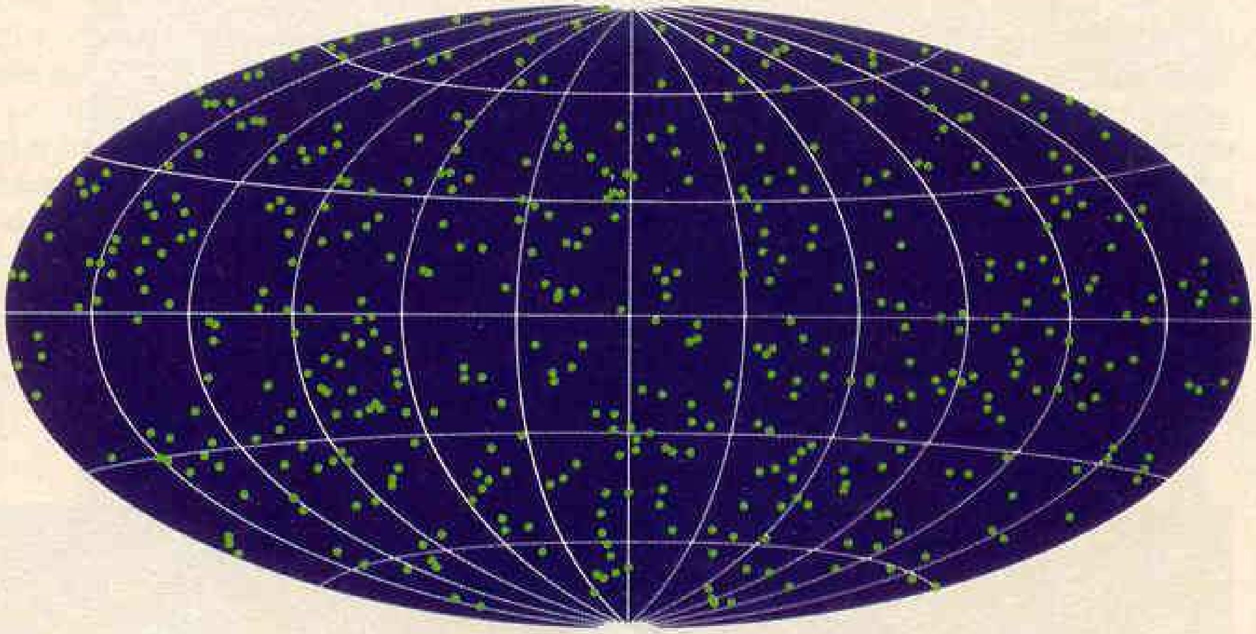
The Internal-External Fireball Model



There are <u>no direct observations</u> of the inner engine. The <u>γ-rays light curve</u> contains the <u>best evidence</u> on the inner engine's activity.

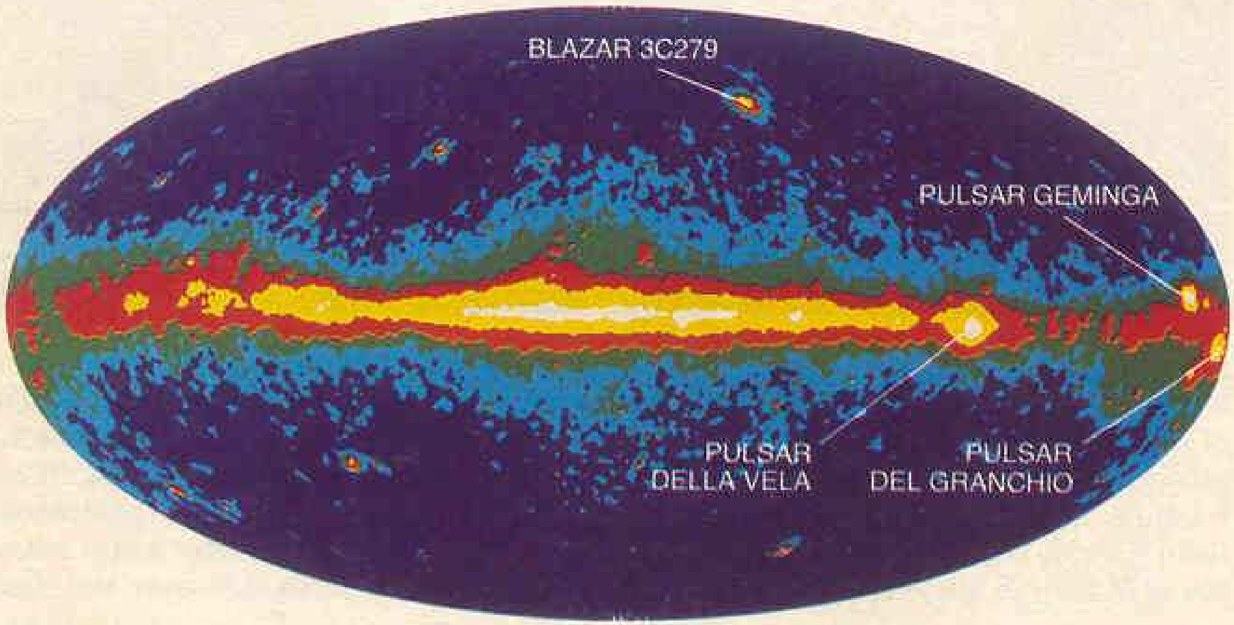
adroni+FERMI+pp/pγ





Distribuzione
di sorgenti
rivelata da BATSE

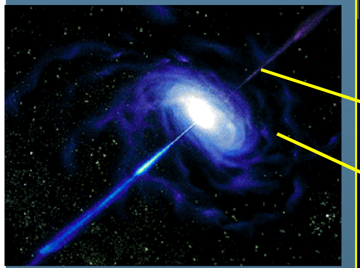
-isotropa
-galassie lontane

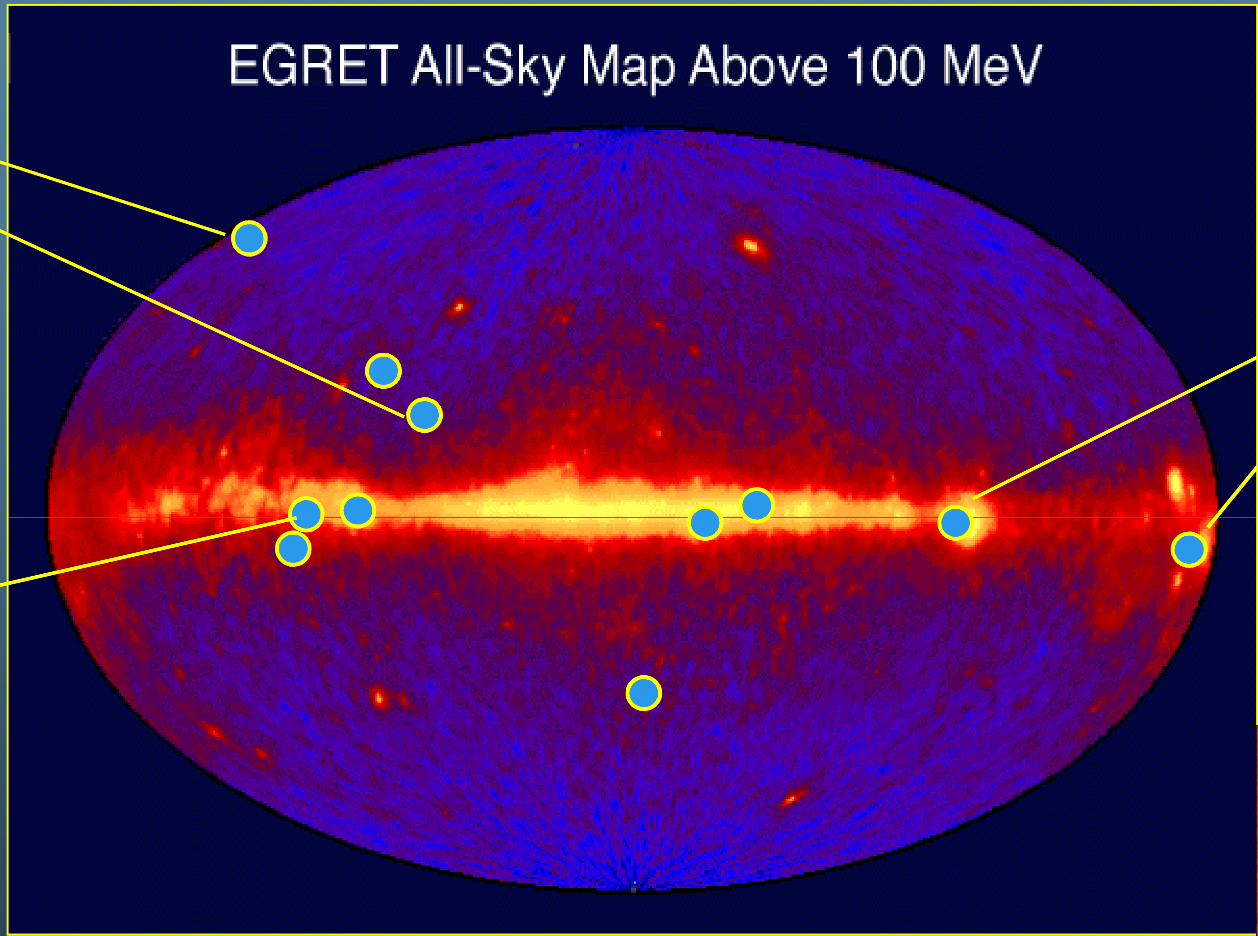


Gamma di alta
Energia rivelati da
EGRET

Examples of Astrophysical Objects

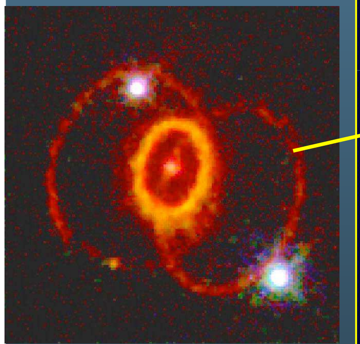
AGN



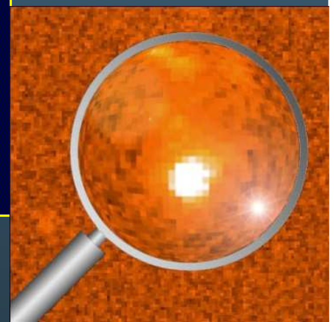


Pulsar

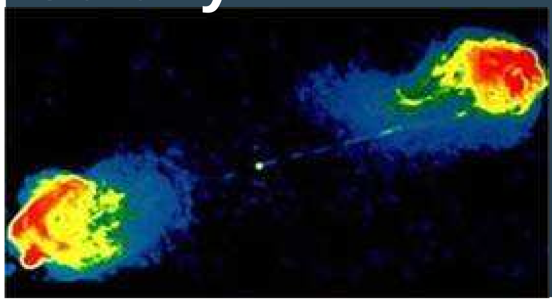
SNR



GRB

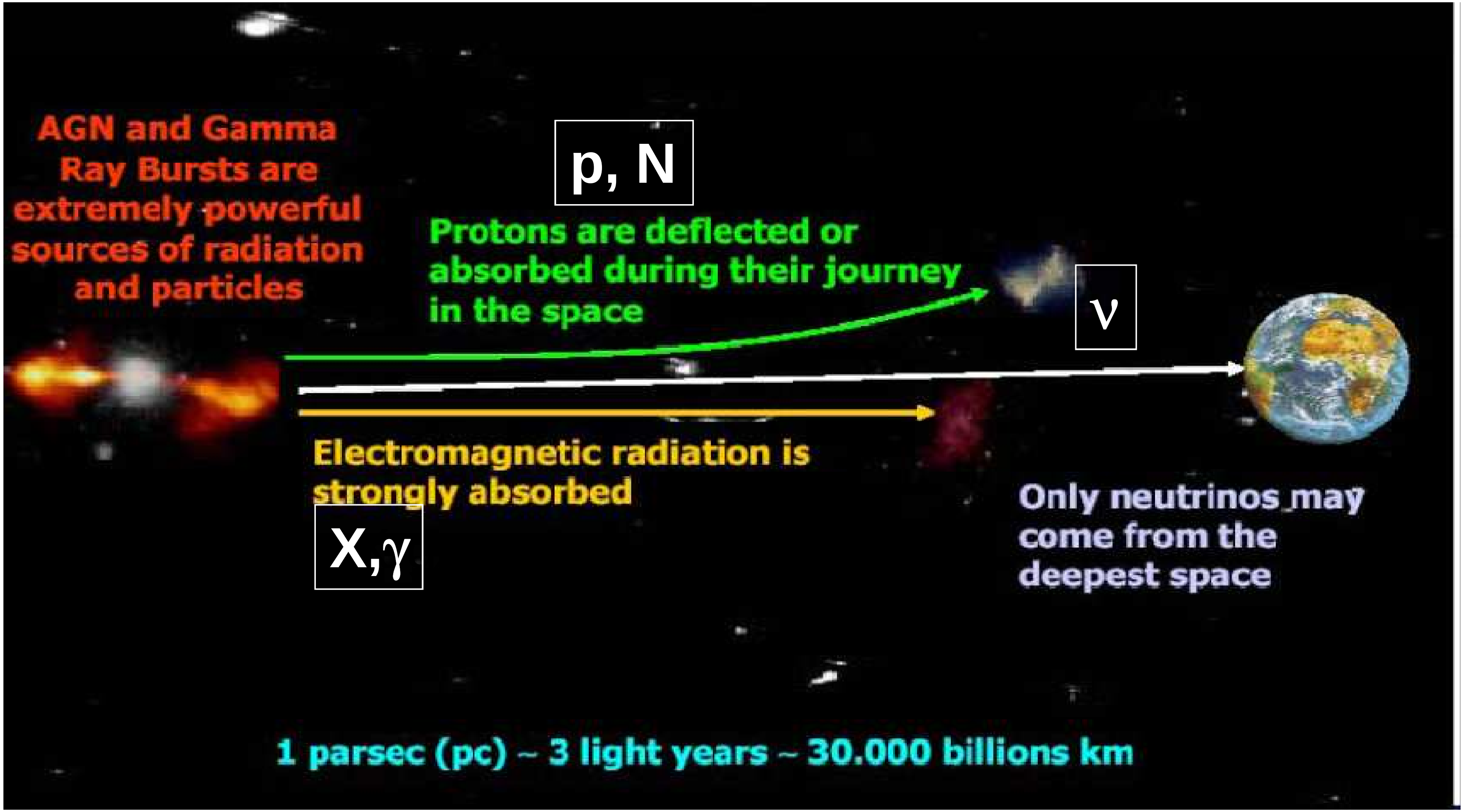


Radio Galaxy

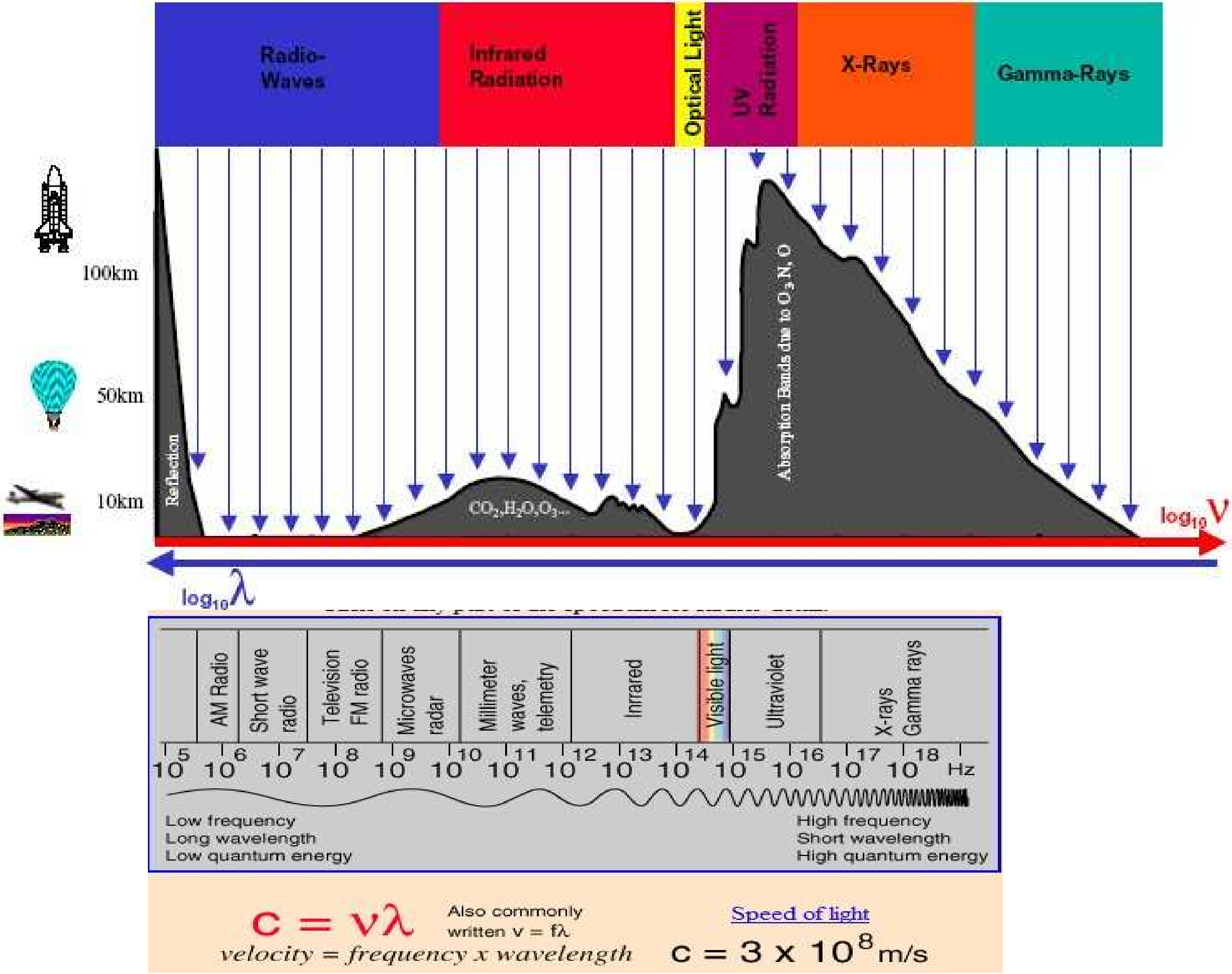


Colliding galaxies

Come cerchiamo queste sorgenti cosmiche ?



Influenza dell'atmosfera sulla sperimentazione con telescopi Radio, Infrarossi, Ultravioletti, Raggi X, Raggi γ



Intimate Relation between :

Cosmic Ray Physics

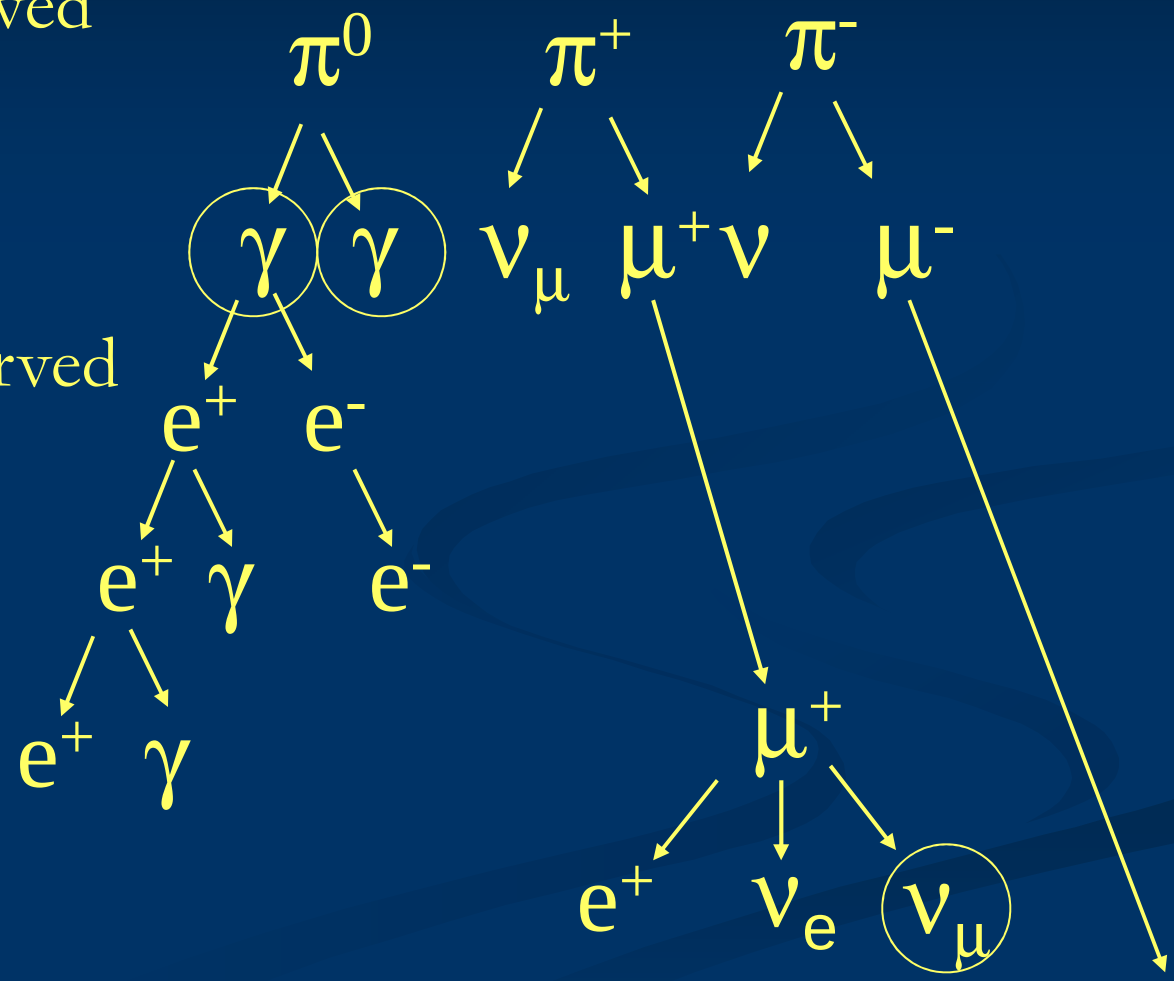
High Energy Gamma Astronomy

Neutrino Astronomy

ν and γ beams

neutral pions are observed
as gamma rays

charged pions are observed
as neutrinos



$2\,\nu_\mu \sim \gamma$

Fundamental Idea:

Technique:

Instrument a Large Volume of Water/Ice with Cherenkov Photon detectors (PMT's) to Detect High Energy Astrophysical Neutrinos.

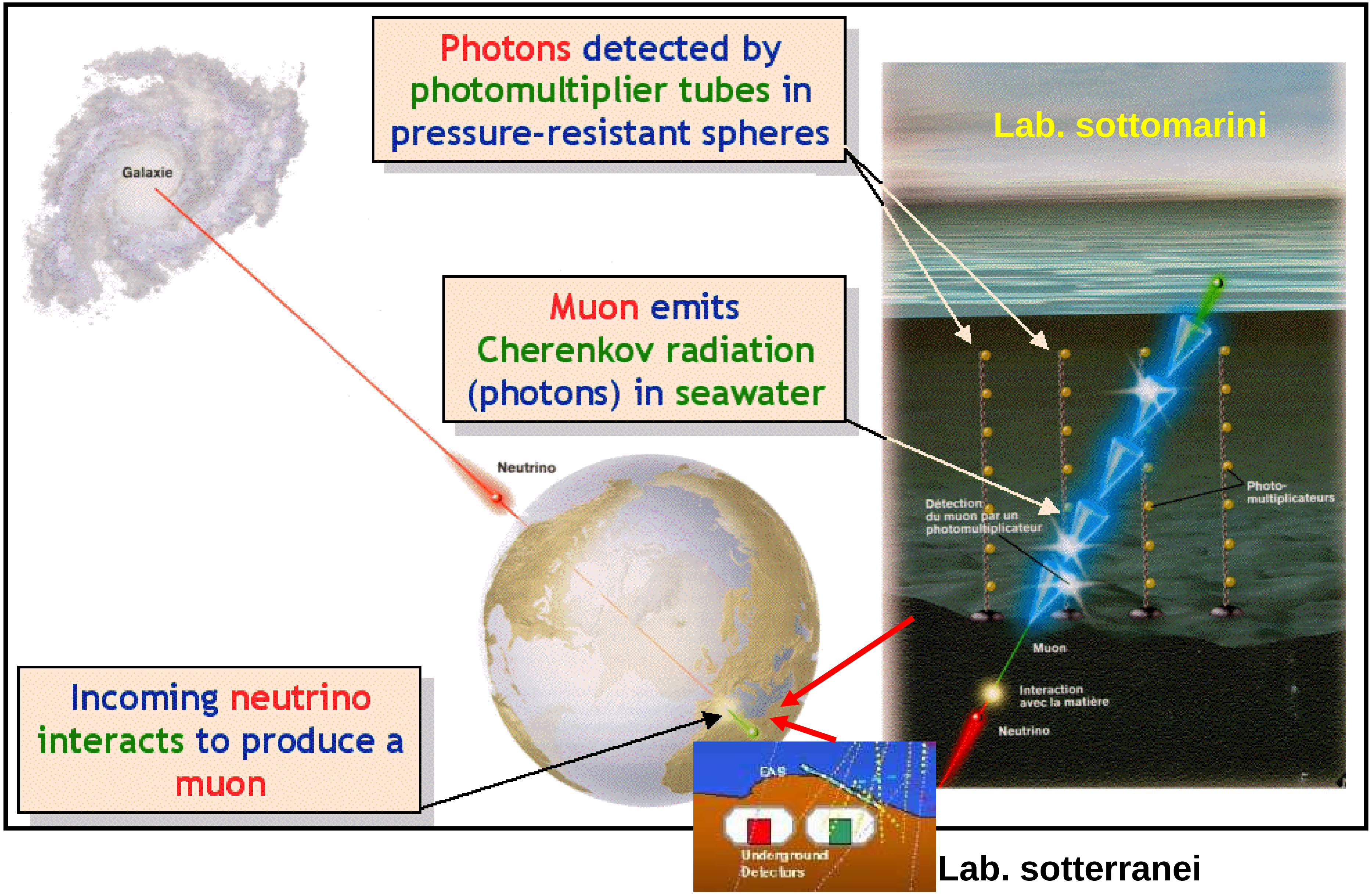
Size:

Identification of the dimension of a

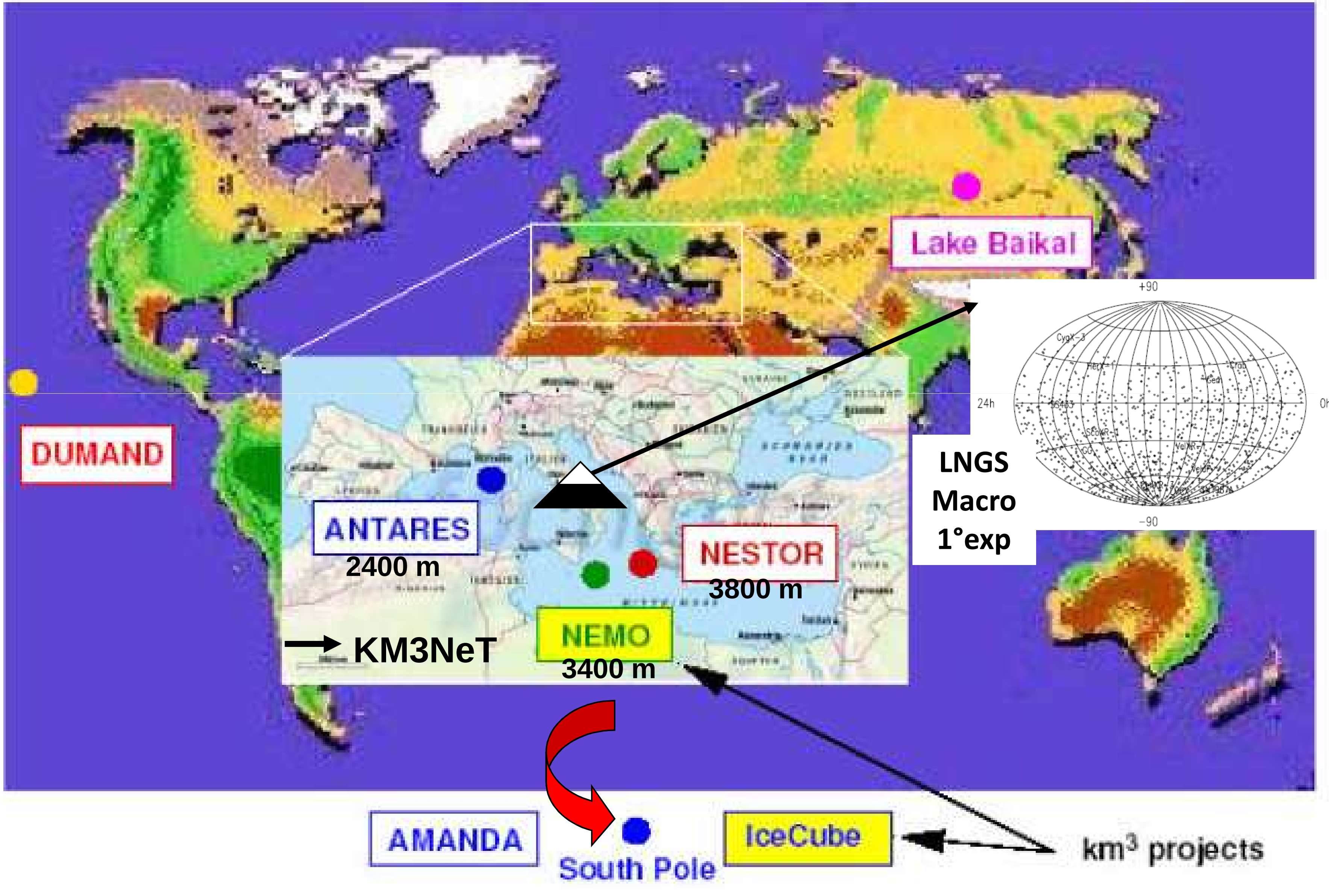
Cubic Kilometer

as the "Natural Size" for such a detector considering the Expected Fluxes

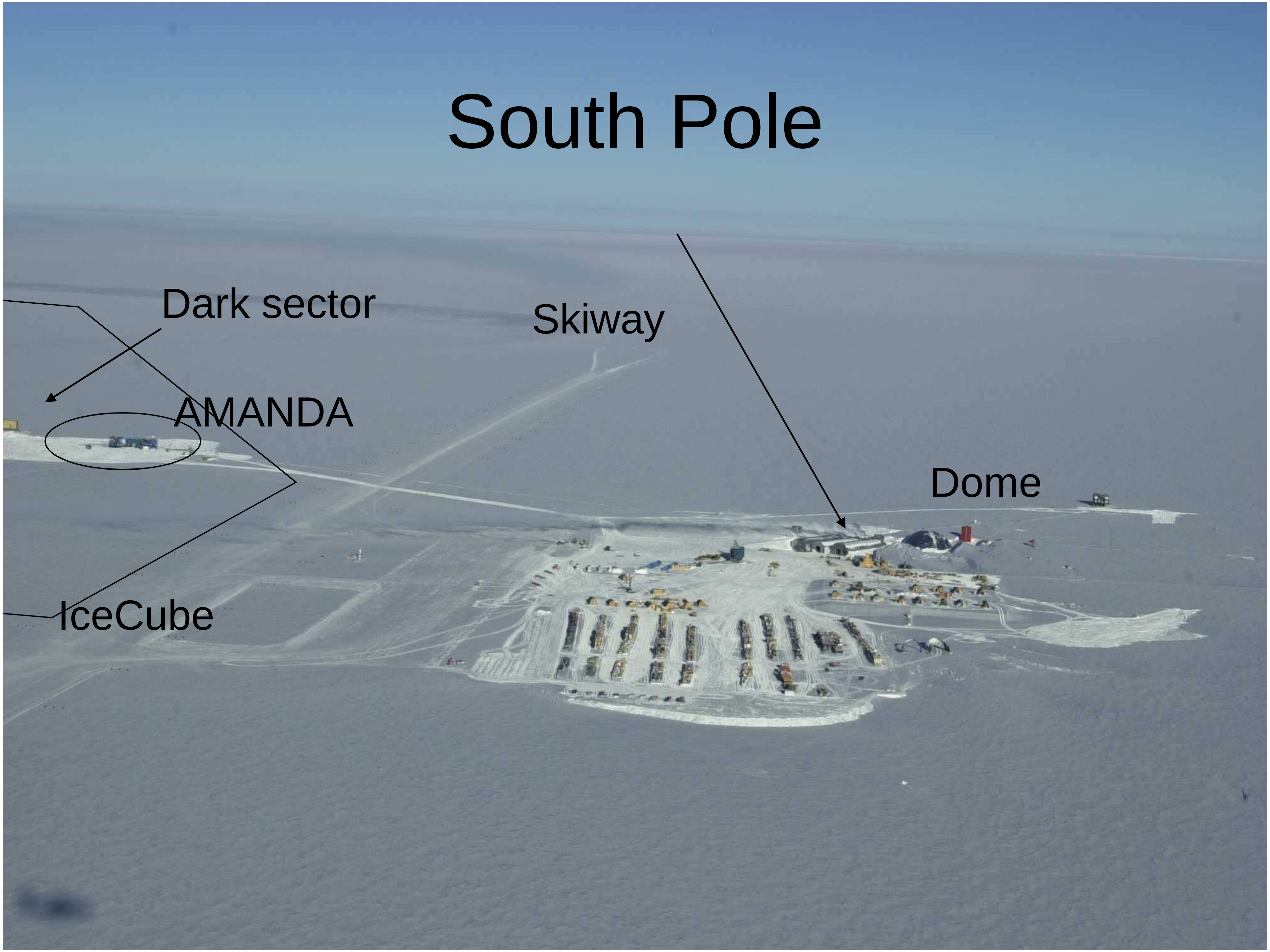
Neutrini da acceleratori cosmici



The Neutrino Telescope world map

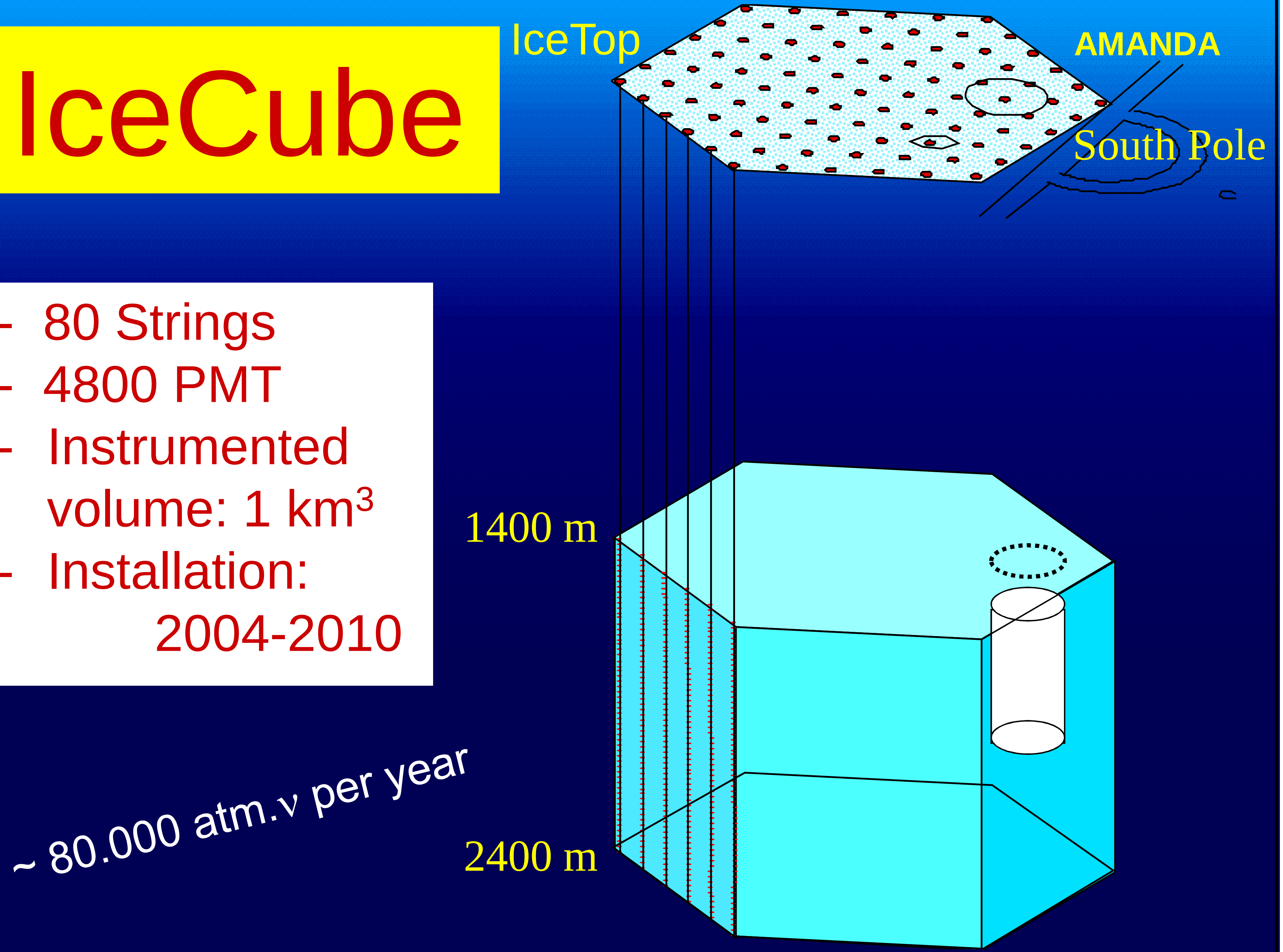


South Pole



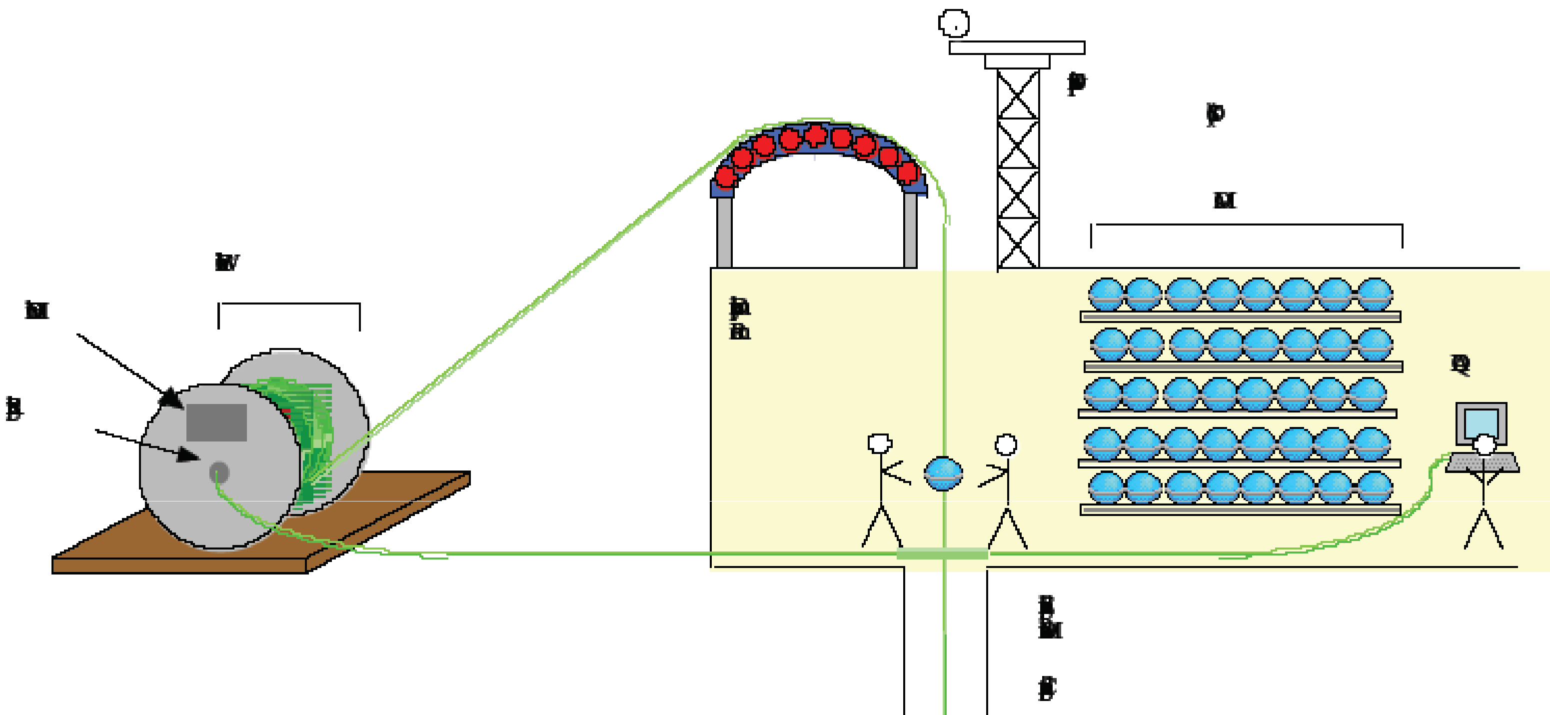
IceCube

- 80 Strings
- 4800 PMT
- Instrumented volume: 1 km^3
- Installation: 2004-2010



Deployment of the strings

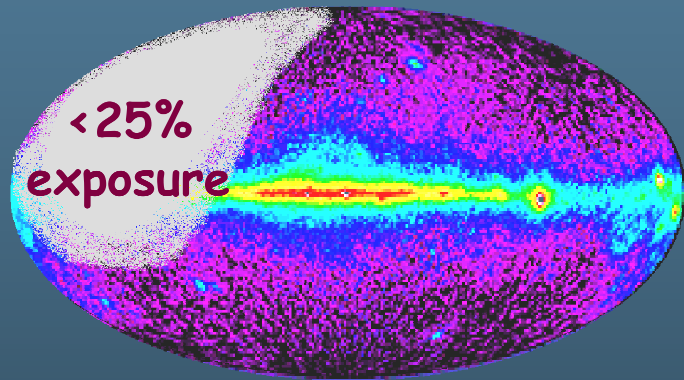
In-Door deployment



Neutrino Telescopes

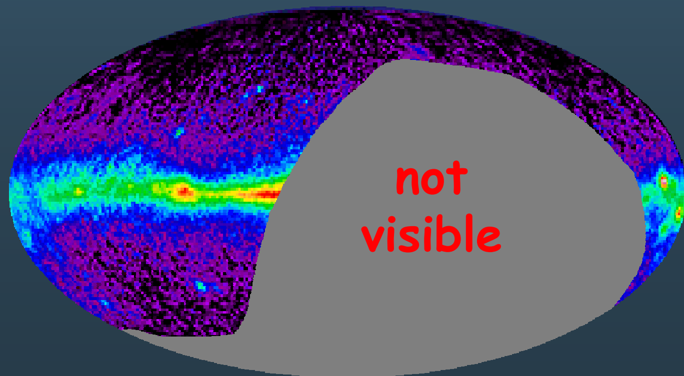
Better angular resolution (~0.2°)

ANTARES, NEMO, NESTOR,KM3
Mediterranean Sea, 43° N



Less Background light

AMANDA , ICECUBE
(South pole)



ICE versus WATER

Advantages ICE

No Radioactivity ^{40}K
No bioluminescence
No sedimentation

Advantages WATER

Detector recoverable
(reconfiguration possible)

Larger Depth possible

Longer Absorption Length
(but More Scattering)

L_{abs} 100 m

$L_{eff\text{-}scat}$ 20 m

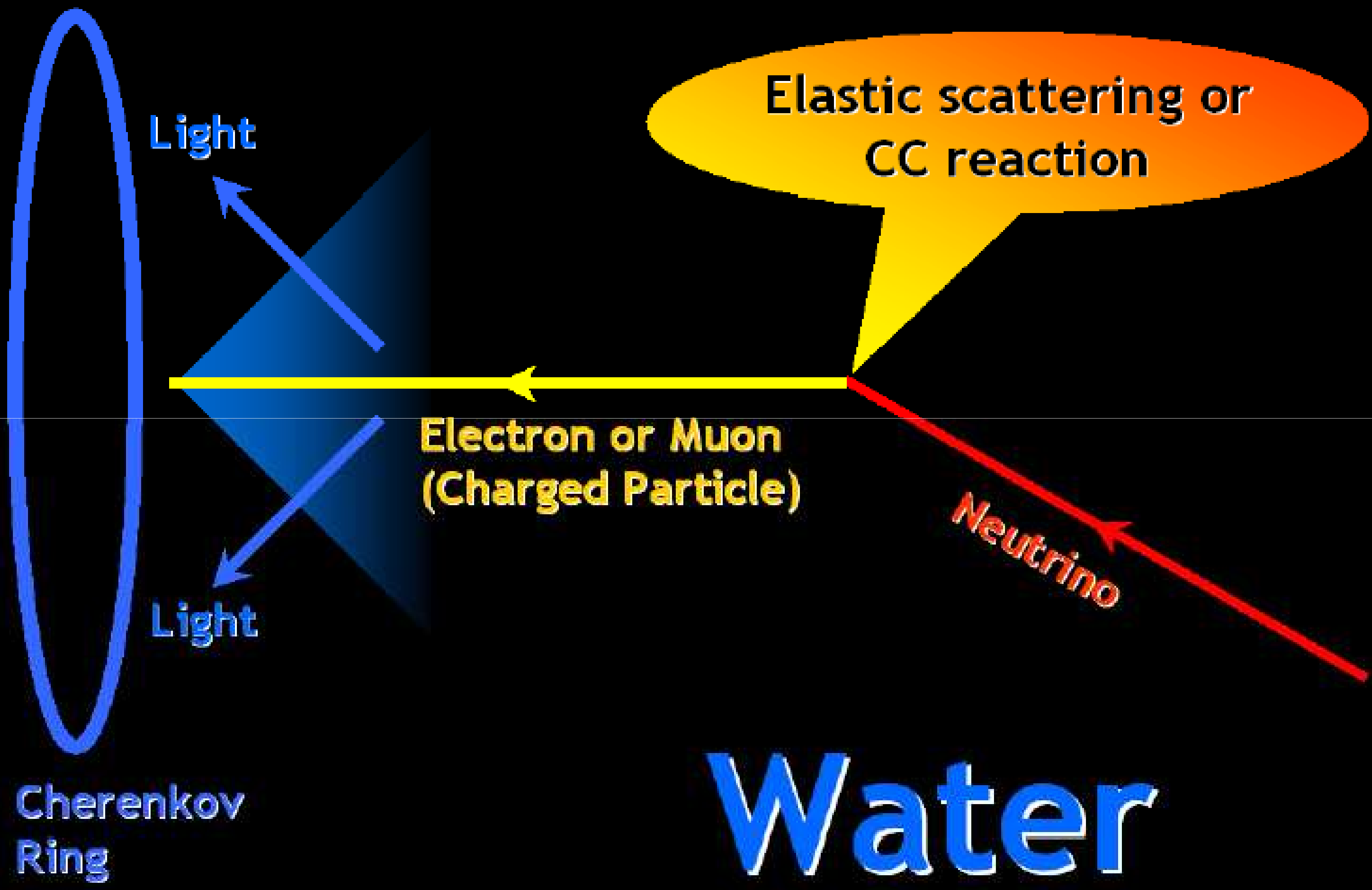
Less Scattering Length
(but more absorption)

L_{abs} 70 m

L_{scat} > 100 m

The two Detectors See
DIFFERENT PARTS of the SKY

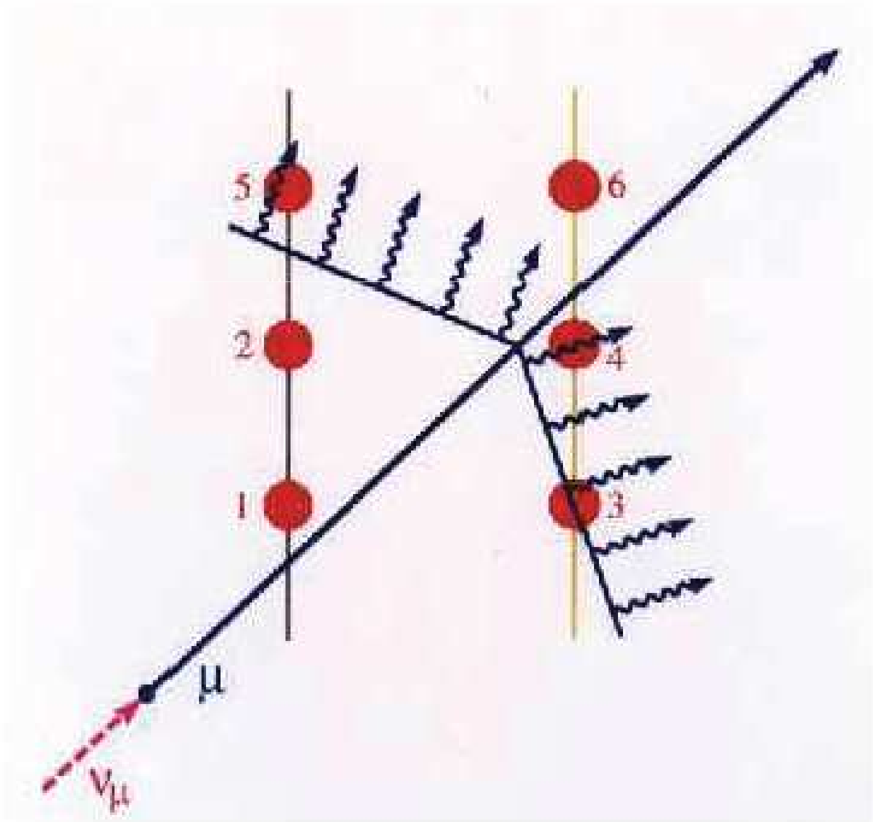
Cherenkov Effect

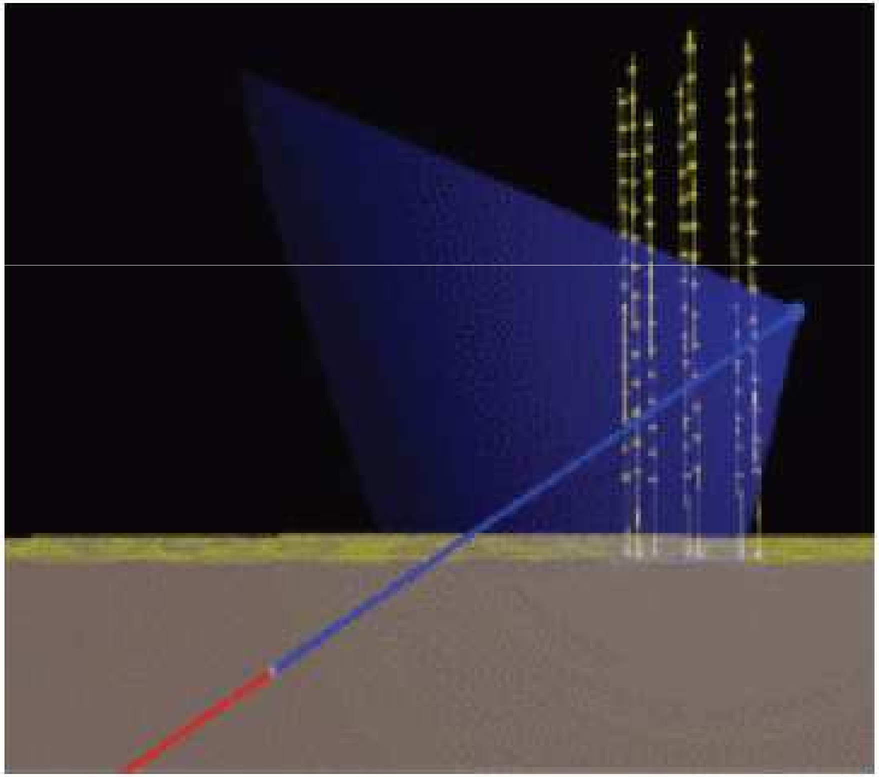


Neutrino Telescopes

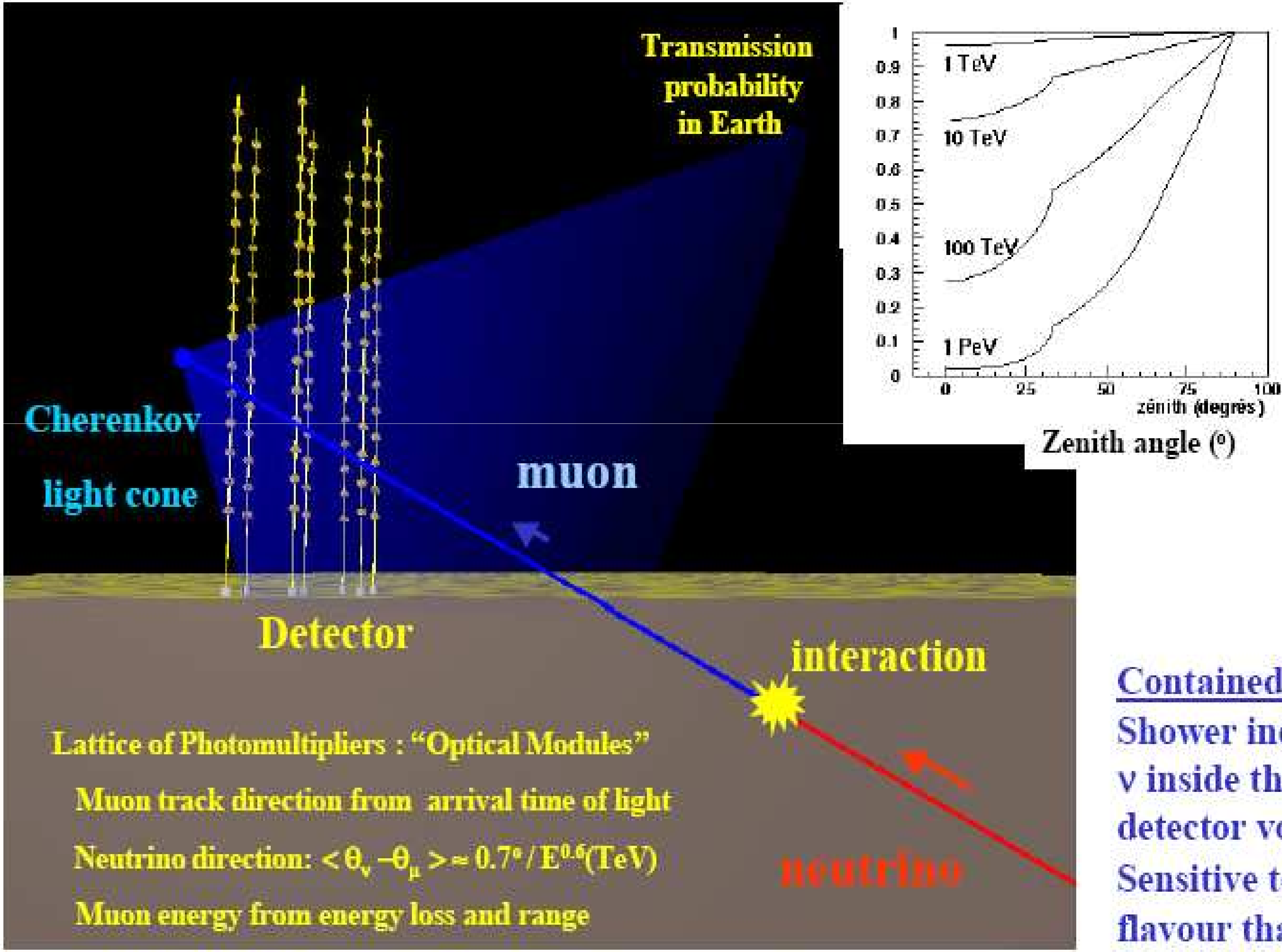
Detection concept

Antares, Nemo, Nestor
Amanda, Ice-cube





Using Earth as Detector Media



Contained showers

Shower induced by ν inside the detector volume

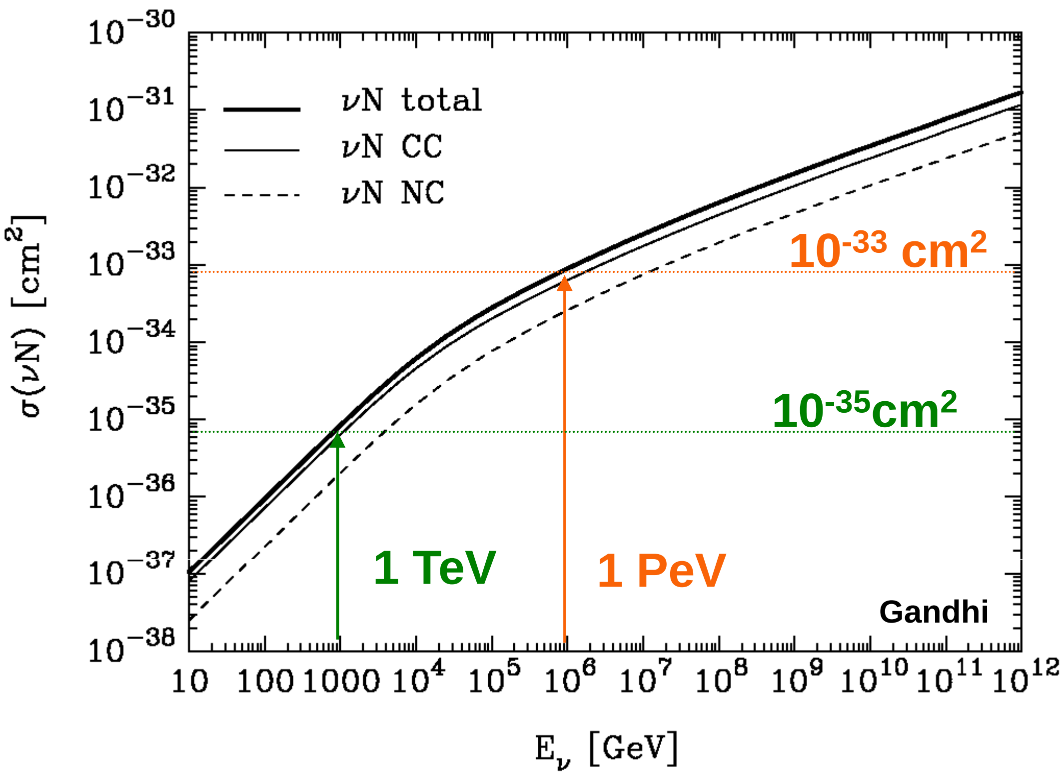
Sensitive to other ν flavour than ν_μ

Neutrino cross section

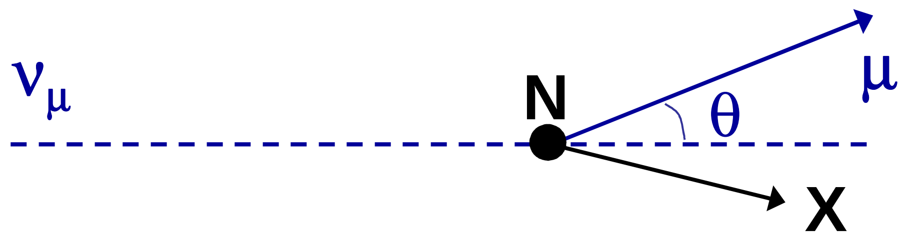
Neutrinos are detected indirectly, following a DIS on a target nucleus N:

$$\nu_\ell + N \rightarrow \ell^- + X$$

$$\sigma_{\nu N} \begin{cases} \propto E_\nu & E_\nu \leq 5\,\text{TeV} \\ \propto E_\nu^{0.4} & E_\nu > 5\,\text{TeV} \end{cases}$$



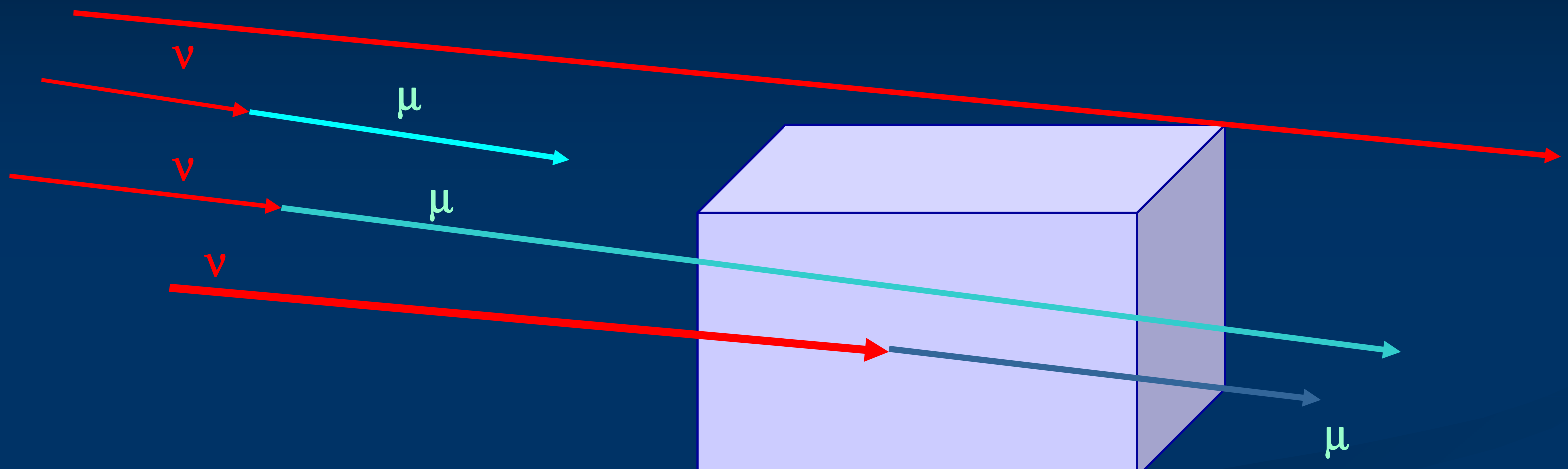
At >TeV energies the muon and the neutrino are co-linear



$$\langle\theta\rangle \approx \frac{1.5^\circ}{\sqrt{E_\nu\,[\text{TeV}]}}$$

Reconstruction of the μ trajectory allows the identification of the ν direction

Telescopio di neutrini = rivelatore muoni



Rivelatore “instrumentato” $D<R_\mu$

$$\frac{N_\mu\left(E_{\mu,min},\vartheta\right)}{AT} = \int_{E_{\mu,min}}^{E_\nu} dE_\nu \Phi_\nu\left(E_\nu,\vartheta\right) \cdot P_{\nu\mu}\left(E_\nu,E_{\mu,min}\right) \cdot e^{-\sigma_{tot}(E_\nu)N_A Z(\vartheta)}$$

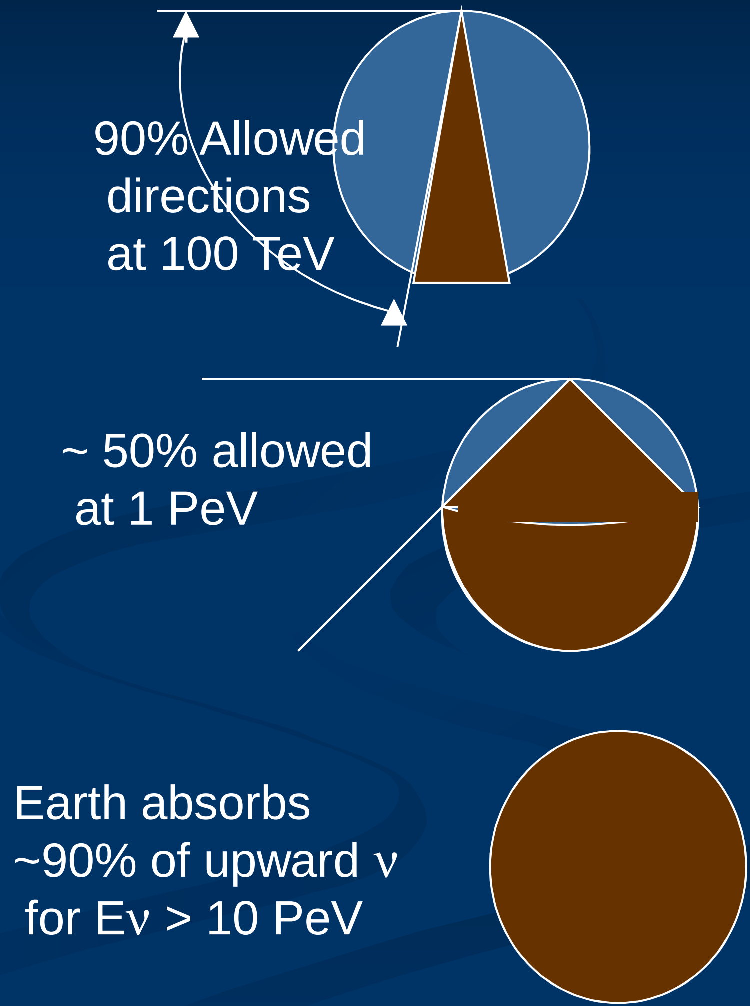
Spettro energetico dei neutrini

Probabilità di rivelare il muone indotto

Probabilità di assorbimento dei n dalla Terra

ν Propagation in the Earth

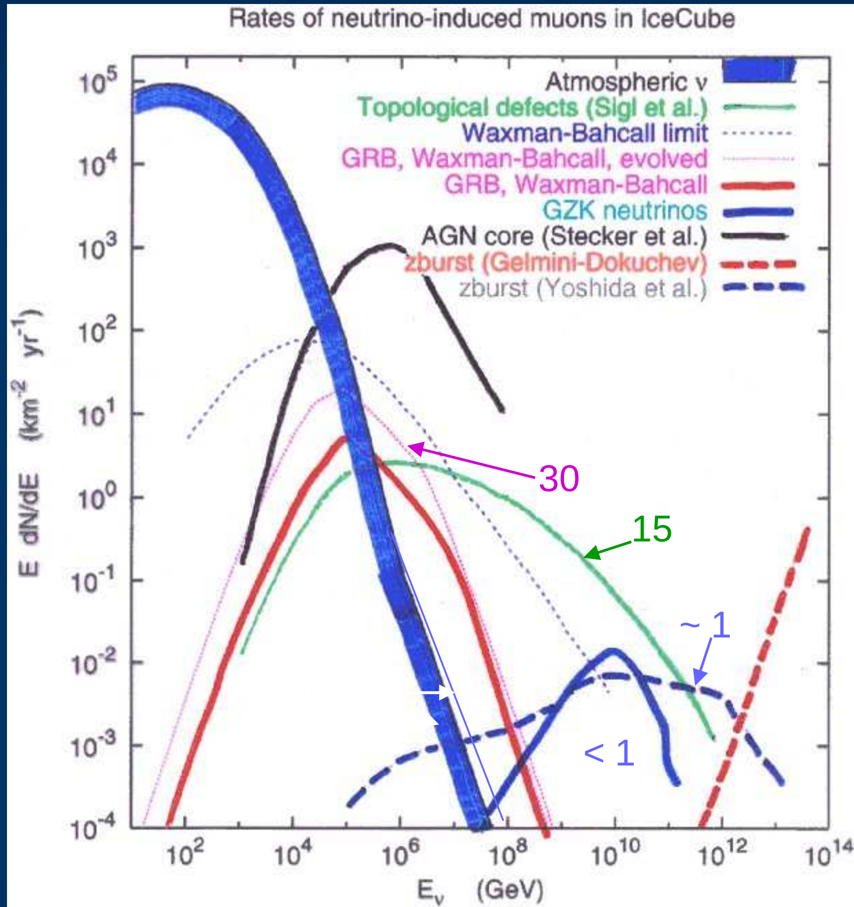
- Lower hemisphere 50% opaque for $E_\nu \sim$ PeV
- Regeneration of ν_τ
  - $\nu_\tau \rightarrow \tau \rightarrow \nu \rightarrow$ cascade:
  - Look for excess of upward cascades between 0.1 and 10 PeV
- For $E_\nu >$ PeV can use downward neutrinos as well as upward



Expected signals in km^3

- Possible point sources:
  - Galactic
    - SNR 0 - 10 events / yr
    - μ-quasars 0.1 - 5 / burst
    - ~ 100 / yr, steady source
  - Extra-galactic
    - AGN jets 0-100 / yr
    - GRB precursor (~100 s)
      - ~ 1000 bursts / yr
      - ~ 0.2 events / burst
    - GRB jet after breakout
      - smaller mean signal / burst
    - Nearby bursts give larger signal in both cases

Diffuse (unresolved) sources--signature:
- **hard spectrum**
- **charm background uncertain**



Site selection criteria

- **Depth**

  Reduction of atmospheric muon flux
- **Water optical transparency**

  Optimisation of detector performances (efficiency and angular resolution)
- **Weak and stable deep sea currents**

  Reduce stresses on mechanical structures

  Reduce stimulation of bioluminescent organisms
- **Low optical noise**

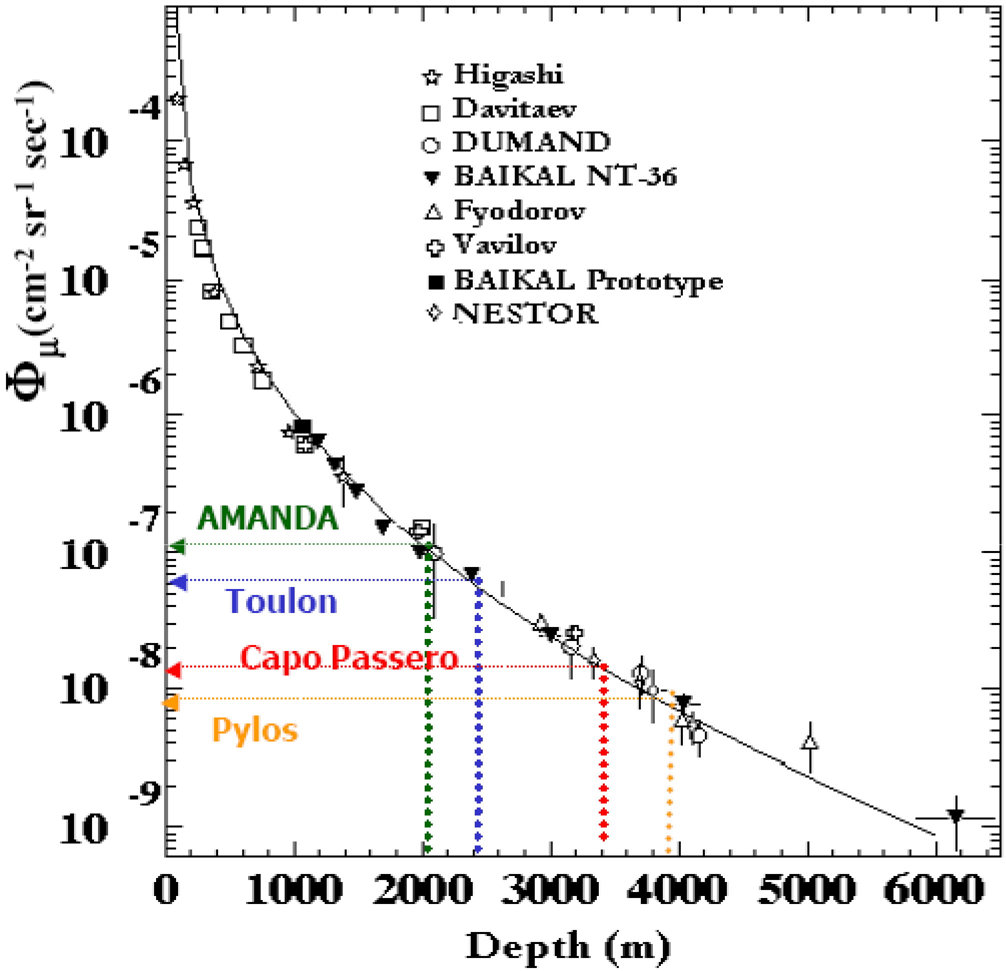
  Low optical background (40K + bioluminescence) ⇒ detector performances
- **Low biofouling and sedimentation**
- **Distance from the shelf break and from canyons**

  Installation safety
- **Proximity to the coast and to existing infrastructures**

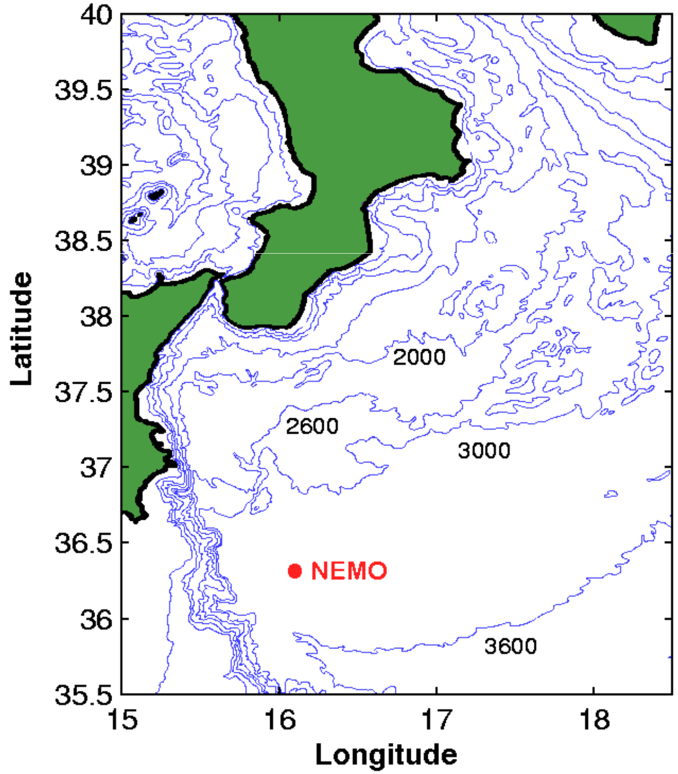
  Easy access for sea operations

  Reduction of costs for installation and maintenance

Depth and muon flux reduction



Down-going muon background is reduced as a function of water depth allowing the selection capability of up-going tracks



Depth in Capo Passero is about 3400 m (equivalent to Gran Sasso and Kamioka)

Investigated many Mediterranean sites with depth >3300m

NEMO @ Km3

100 Km cavo elettroottico

3500 metri di profondita

Migliori qualita' marine:

- **Sedimentazione**
- **Correnti**

Proprieta' ottiche:

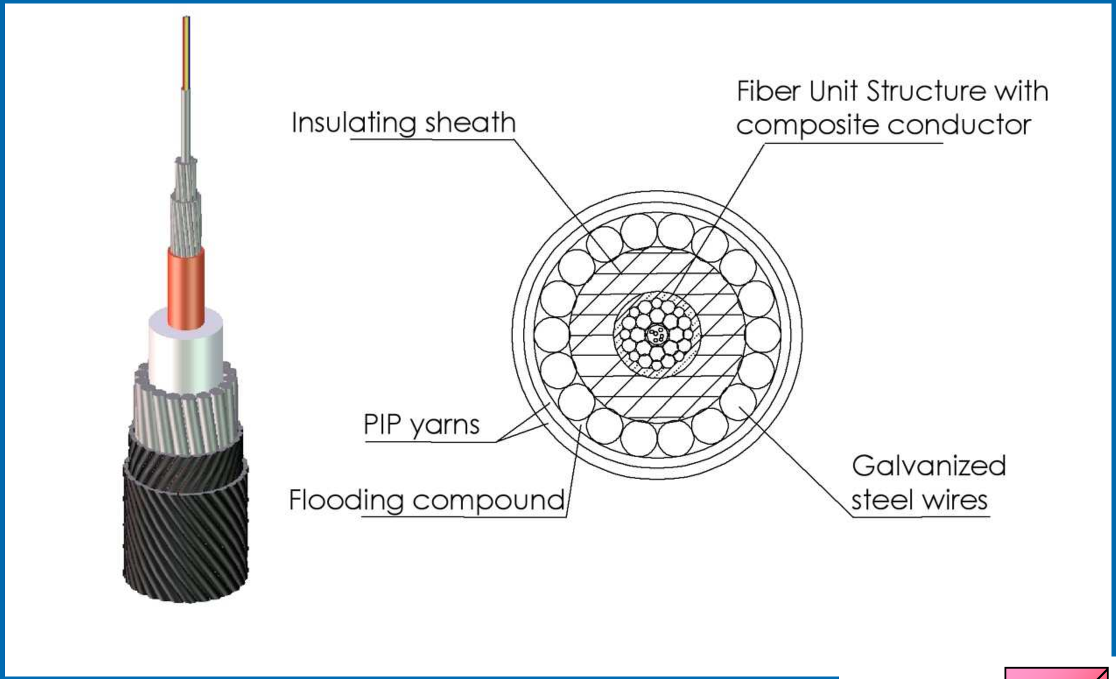
- **Biofouling**
- **Fondo da K40**
- **Assorbimento**
- **scattering**

← **Lab. Capo Passero**

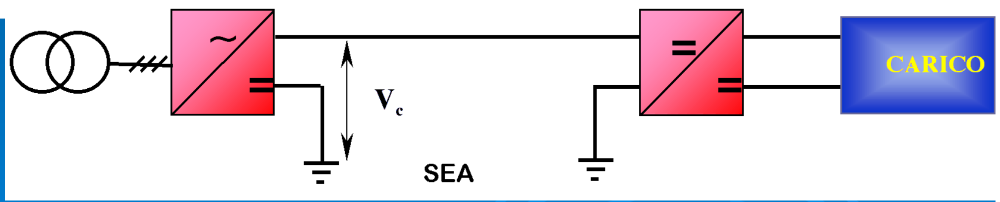

VINI

The NEMO/KM3 electro-optical cable

DC solution with sea return



Terminata la posa del cavo definitivo: Test di potenza in corso



Working Voltage 10 kV
Power up to 100 kW
Optical fibres 20

Converter
Vin 10 kV DC
Vout 400 DC
+
Splitter ottico

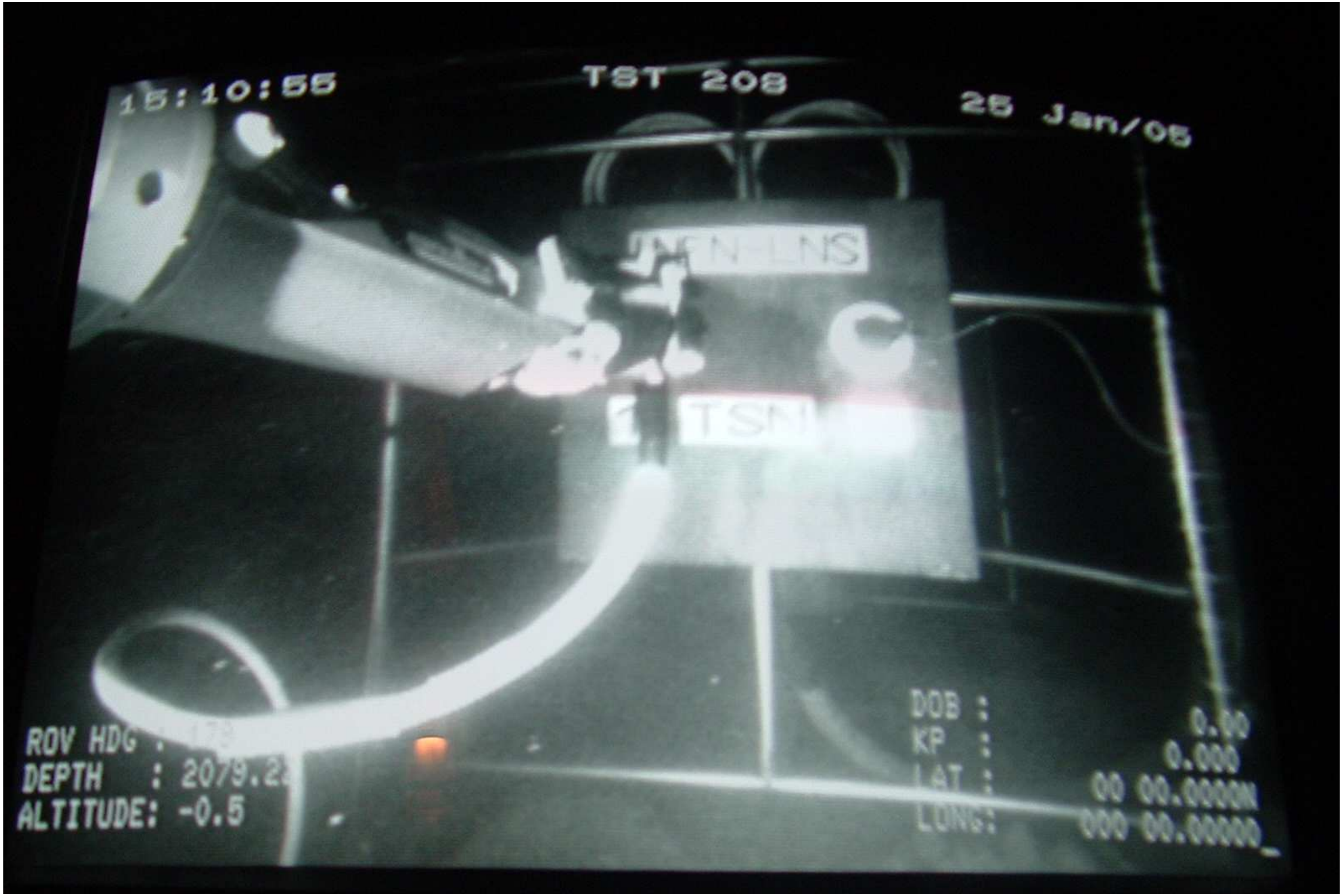
Test di deployment del telaio

La procedura di deployment del telaio di terminazione del cavo EO è stata testata in acqua bassa con la Nave Certamen

Test di deployment del telaio

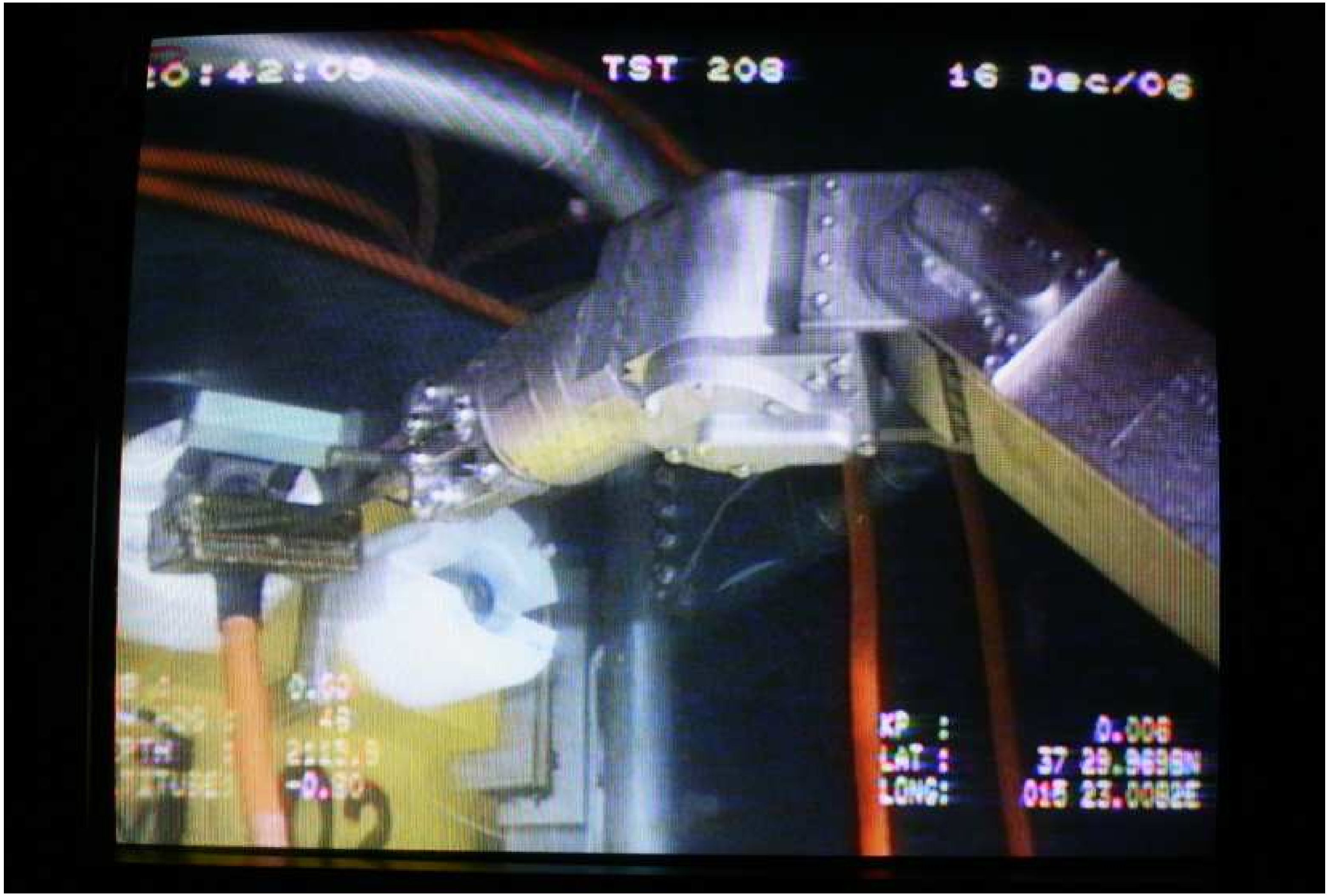
Immersione del telaio

Frame deployment
20-26 jan 2005



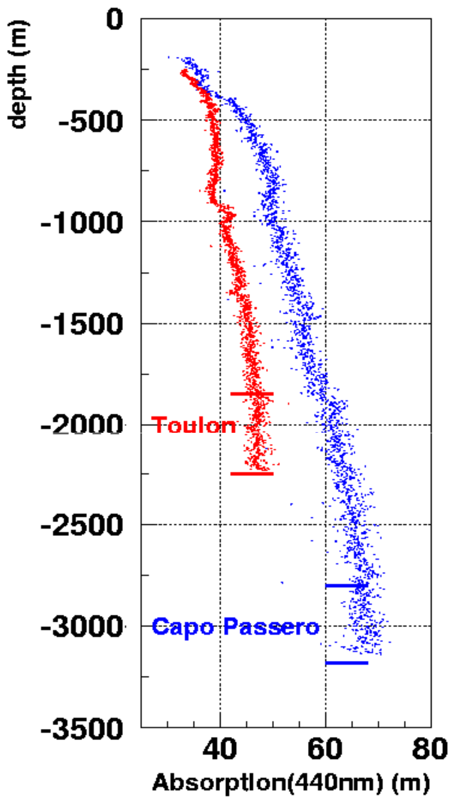
NEMO Phase-1 installation

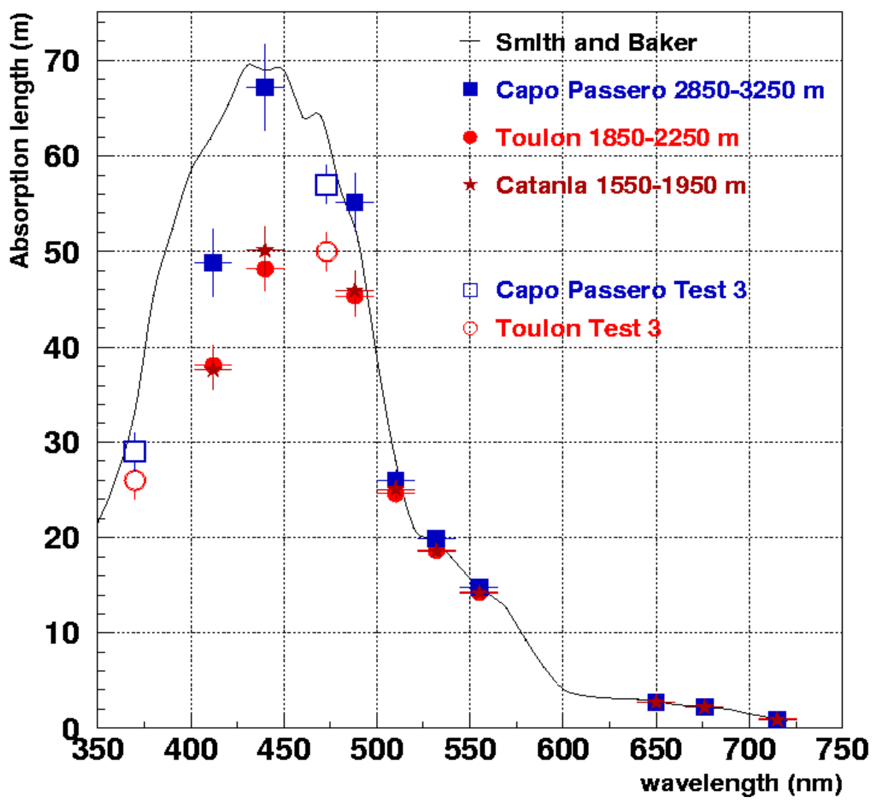
December 16 2006 *Connection of the tower to the JB*



Water Optical Properties

Optical water properties measured in joint 2002 NEMO-ANTARES campaigns





Absorption: a(λ)

Scattering: b (λ)

Attenuation: c(λ)

(c=a+b)

$$I_{a,b,c}(x,l)=I_0 exp(-x\cdot L_{a,b,c})$$

Light absorpion coefficient (λ) ⟶ n° of Cherenkov photons on PMT
Light scattering coefficient (λ) ⟶ timing of Cherenkov photons on PMT

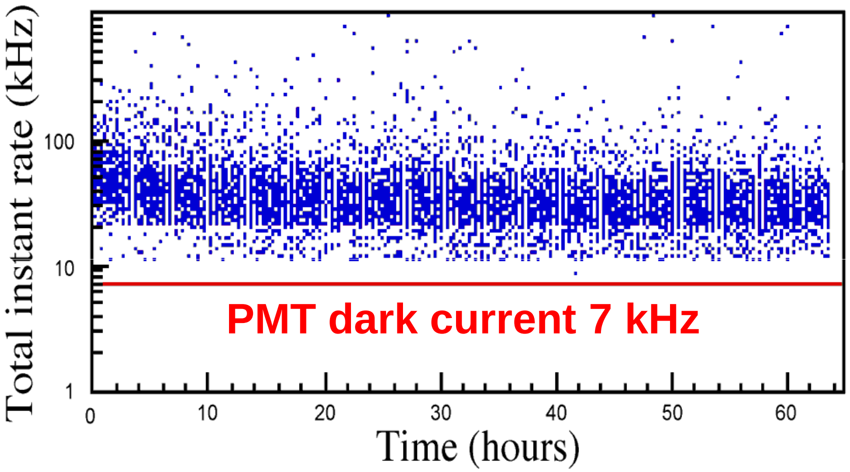
Optical background in Capo Passero and Toulon-1

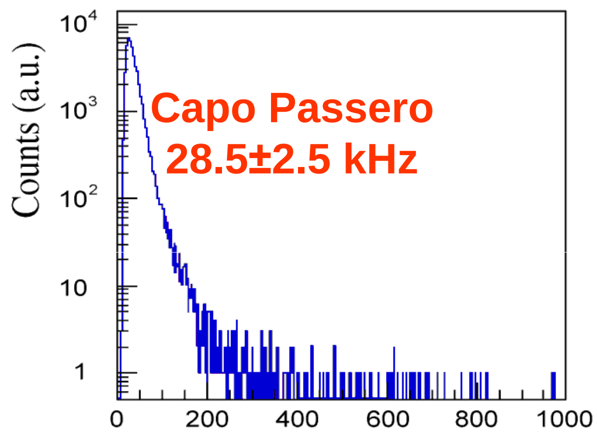
A joint NEMO-ANTARES measurement

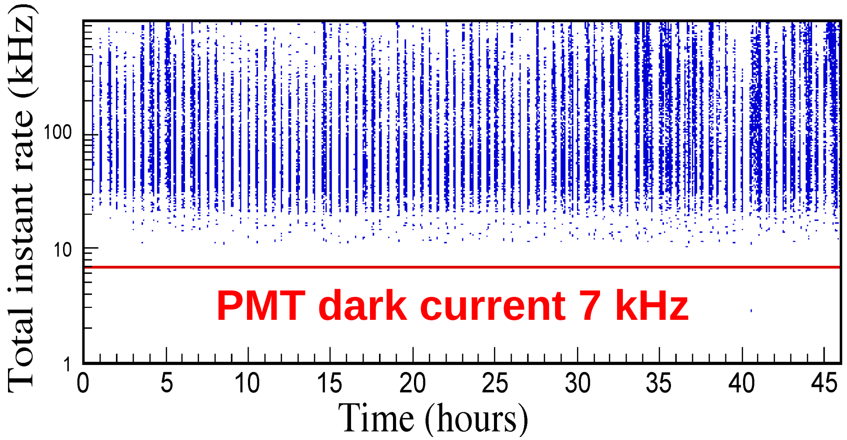
^{40}K

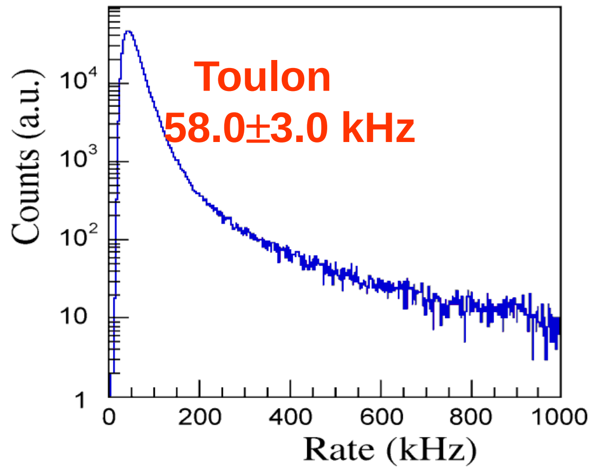
NEMO device (8'' PMT at 0.3 spe)

Decay of radioactive elements (mainly ^{40}K)
$\rightarrow$ stable frequency noise ($\approx$30 kHz)



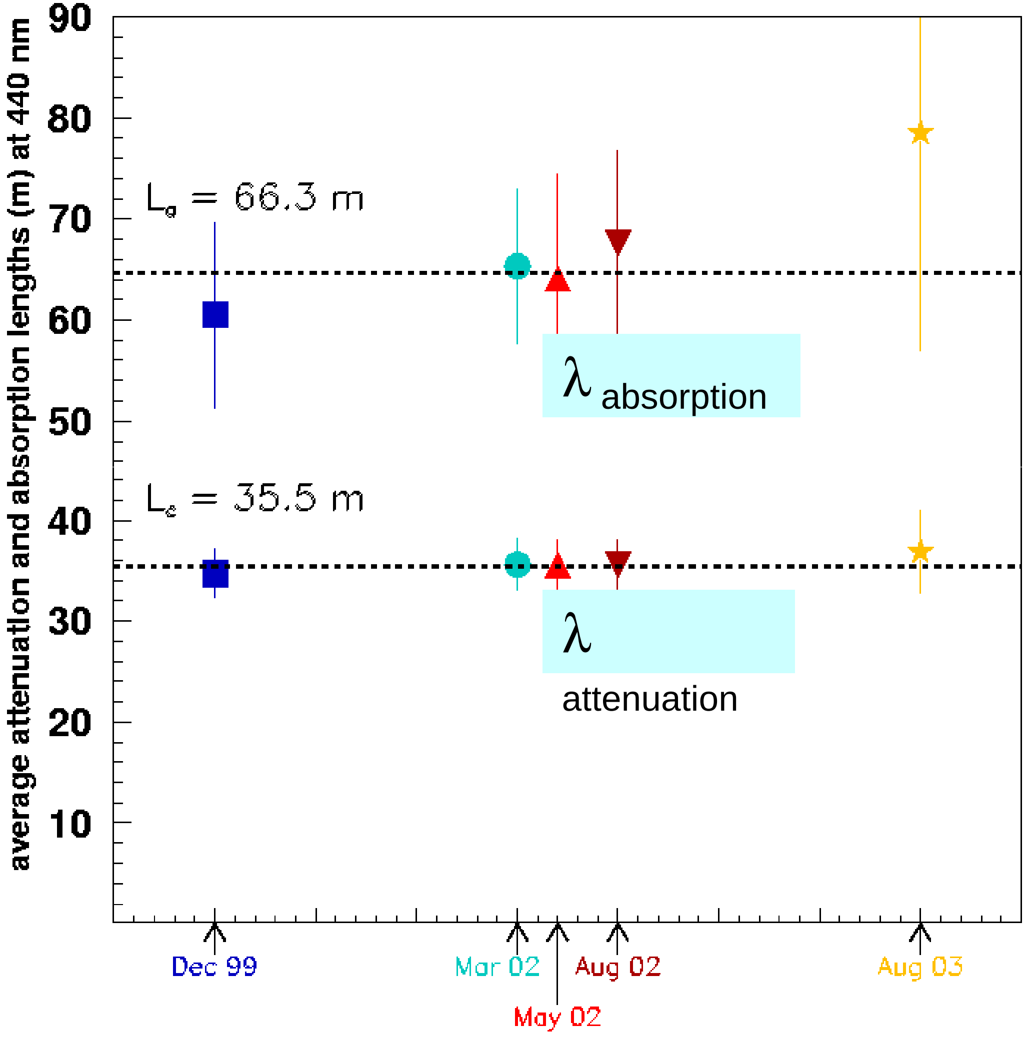






Seasonal dependence of optical properties in Capo Passero

Average absorption and attenuation lengths, for λ=440nm, in different periods



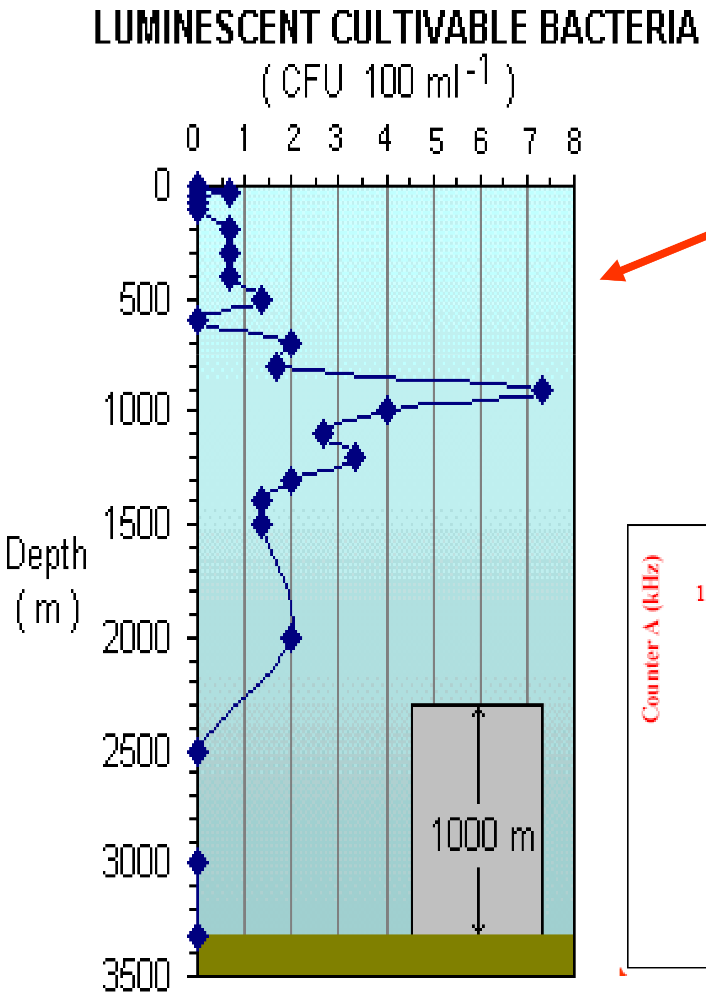
Capo Passero 2850-3250 m

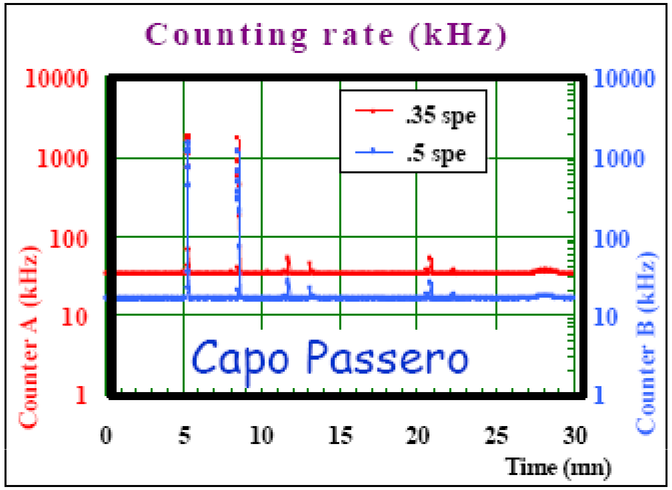
No seasonal dependence observed

Optical background in Capo Passero and Toulon-2

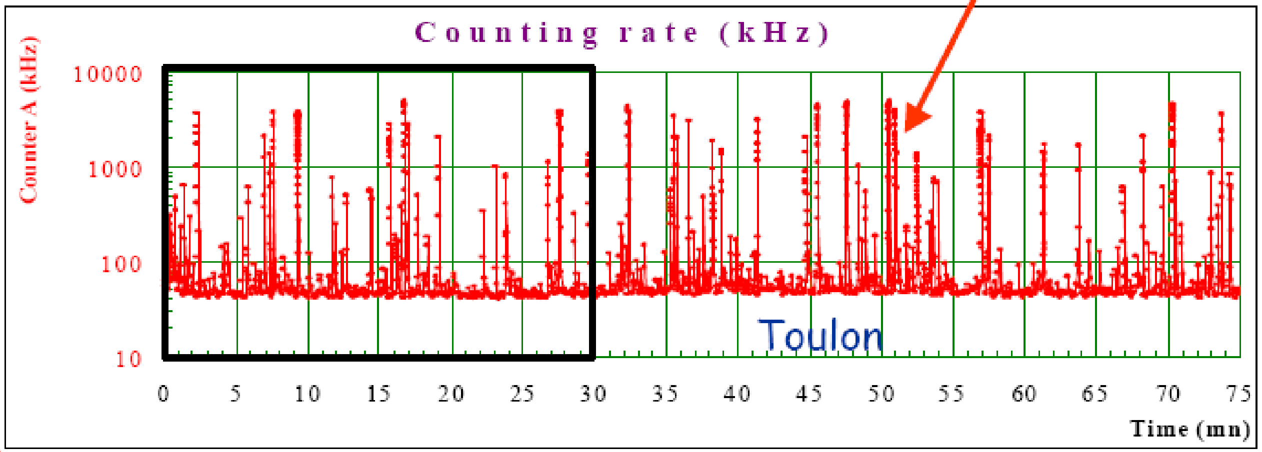
bioluminescence

No luminescent bacteria have been observed in Capo Passero at depth > 2500 m

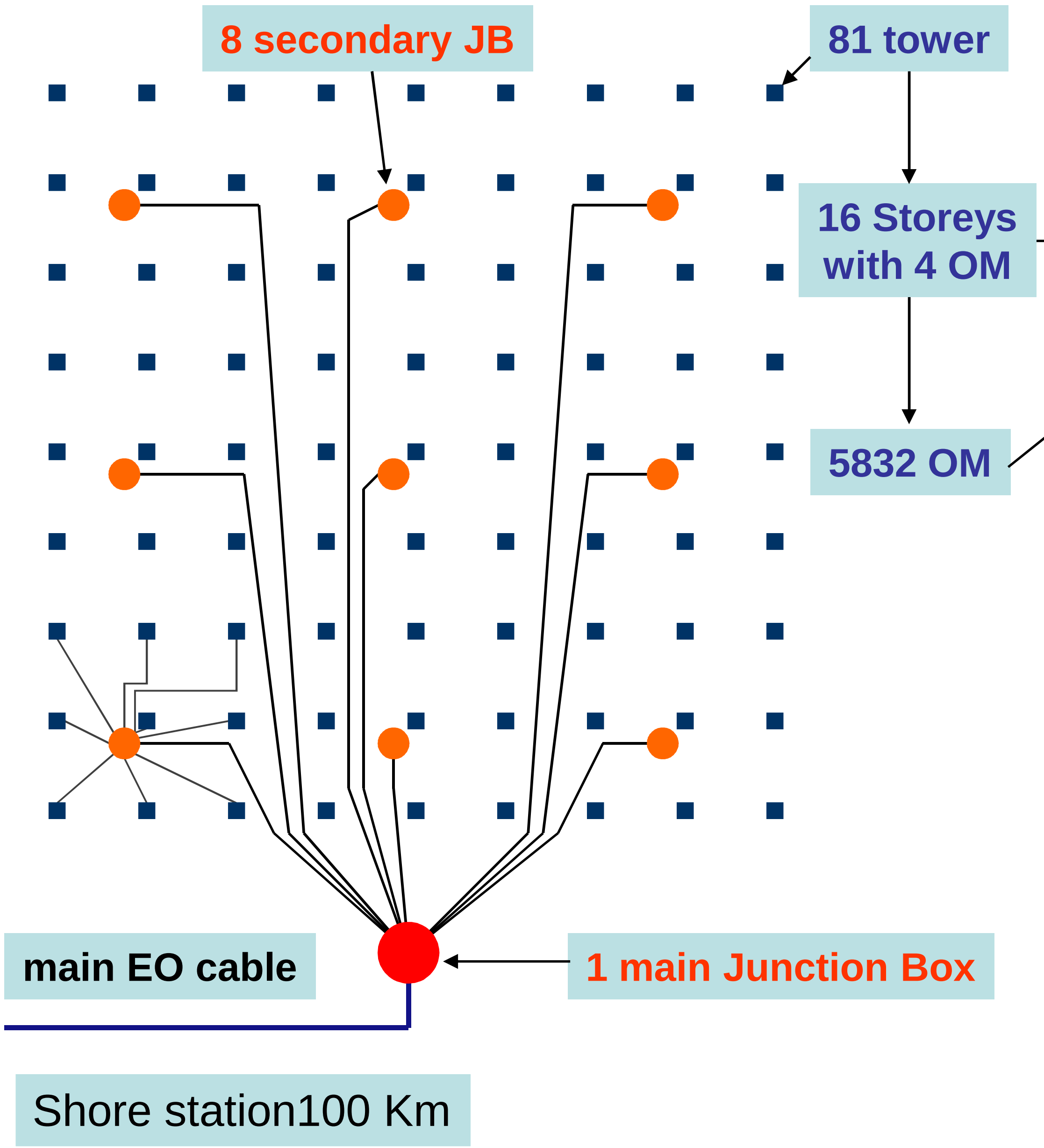


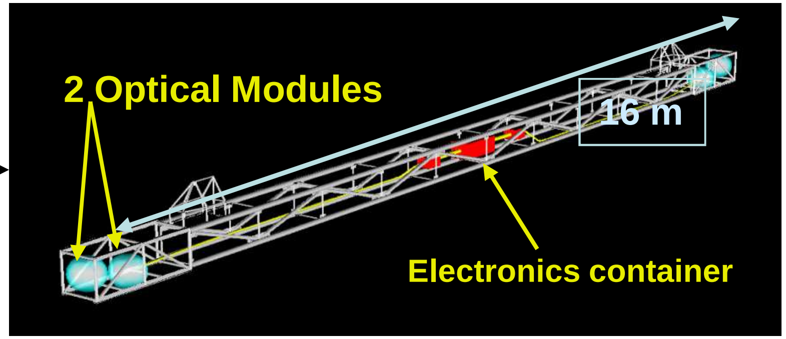


Bioluminescence bursts



NEMO: a project for a Km3 neutrino telescope





Detector geometry:

- *5832 PMTs*
- *81 towers arranged in 9x9 lattice*
- *140 m between towers*
- *20 m storey length*
- *40 m vertical spacing*
- *4 down-horizontal PMT/storey*

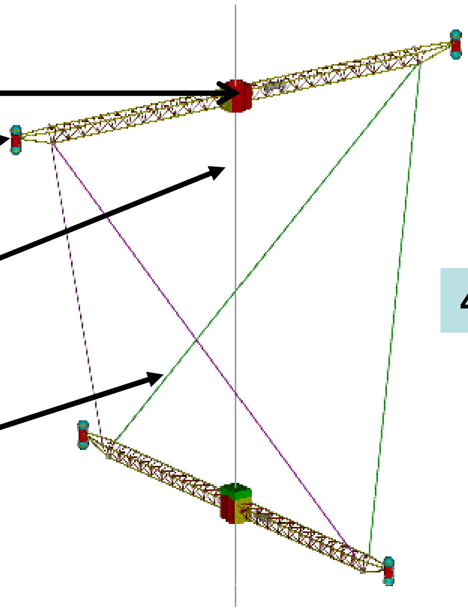
The NEMO "Tower"

Electronics module

Optical Module

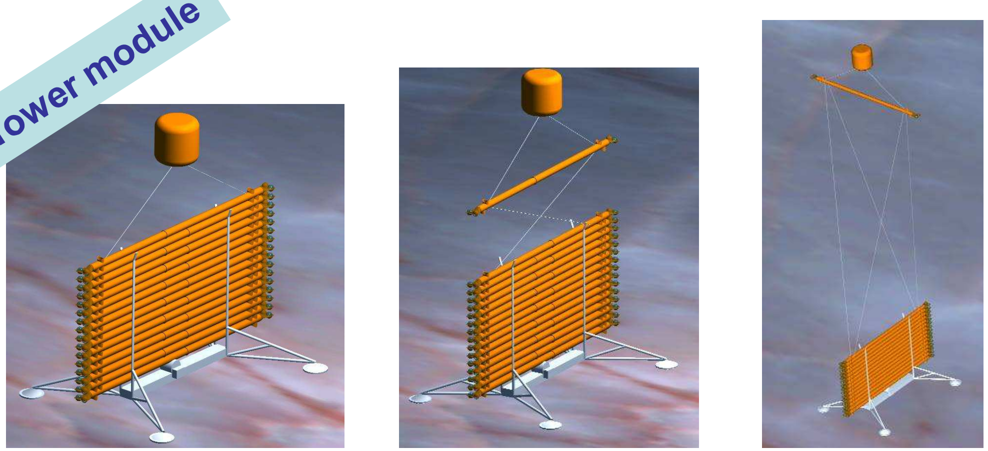
Electro optical cable
Non mechanical!

Dynema fiber
tensioning cable



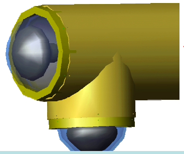
40 m

Tower module



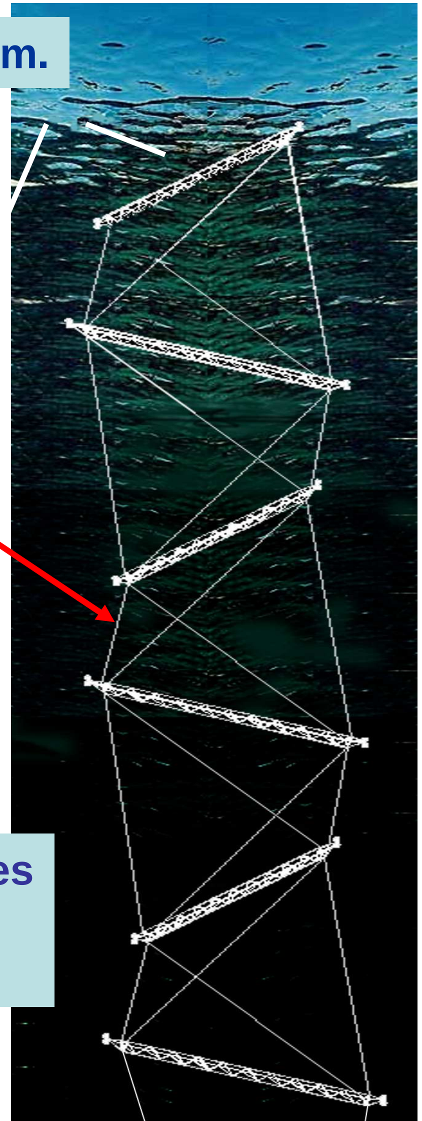
Full height 750 m.

Sequence of Storeys 90° rotated



2 down-horizontal PMT

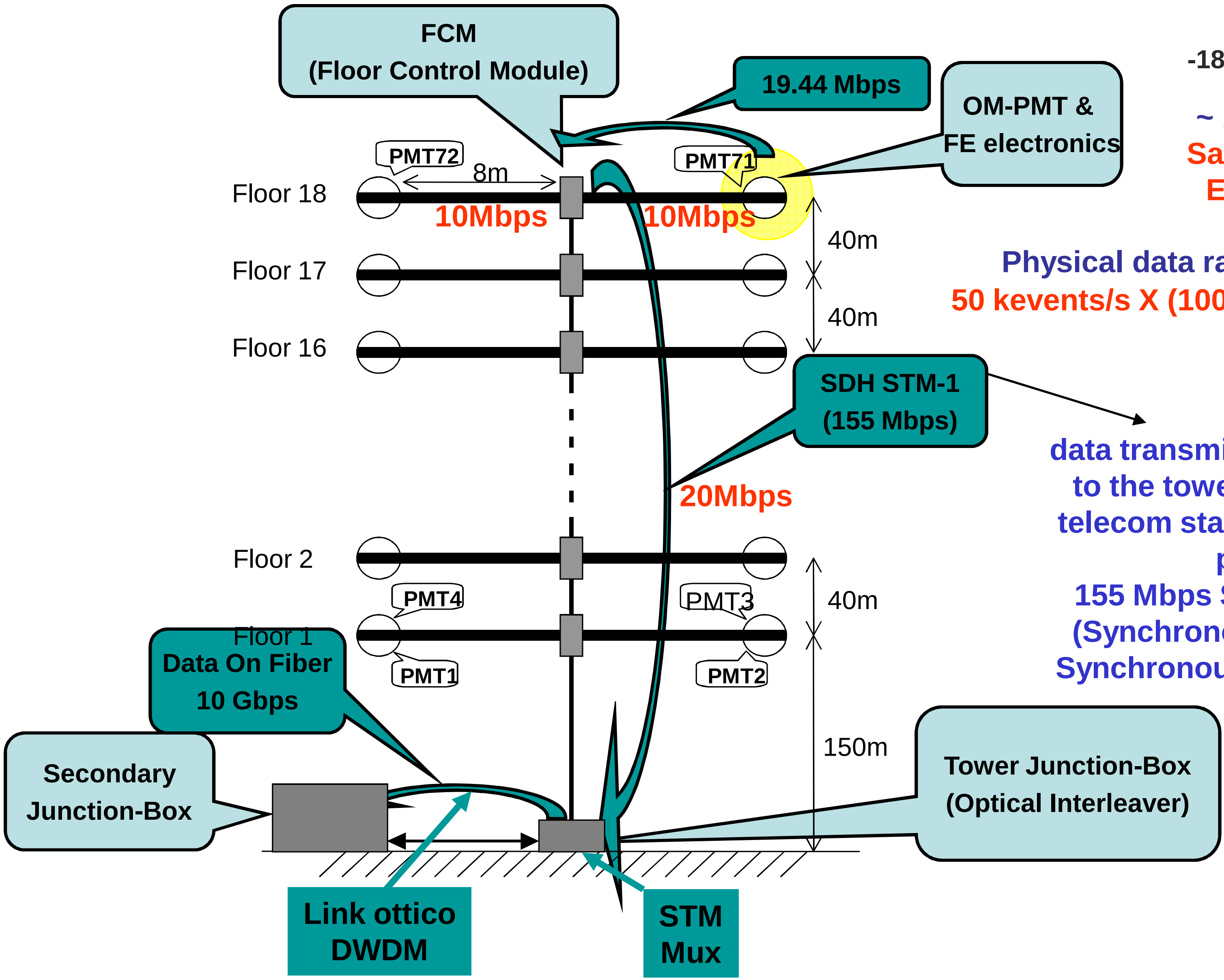
Few structures to reduce connectins



150 m from seabed

Deployment and unfurling technique tested in shallow waters
The structure can be packed for transportation and deployment
Connections operated by a submarine remotely operated vehicles

The NEMO Tower



PMT Dynamics:

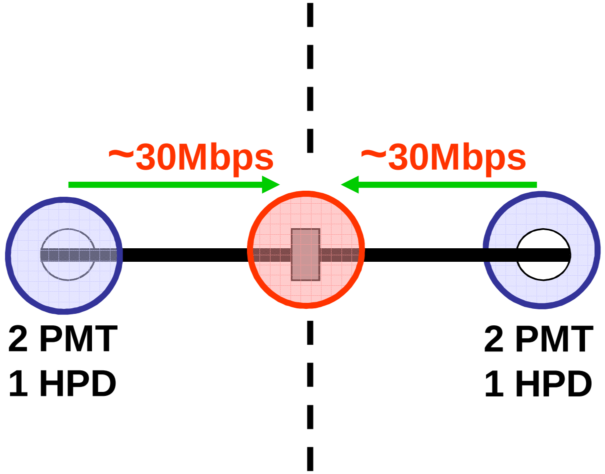
(-40V /-18mV)
-18mV=(~1/4 phe 13"PMT)

~ 1300 → 2048 (11 bit)
Sampling rate:200MHz
Event length: ~50ns

Physical data rate (due to ^{40}K):
50 kevents/s X (100 bit/event) ~ 5Mbps

data transmission from the floor to the tower junction box is a telecom standard synchronous protocol:
155 Mbps STM-1SDH/SONET
(Synchronous Over NETwork
Synchronous Digital Hierarchy)

Floor readout electronics



Inside Optical Module (OM)..x 4

~ 50kHz

~10Mbps/PMT

Hamamatsu 10" R7081 SEL

Front-end electronics

2 PMT

2 PMT

Tower Junction Box

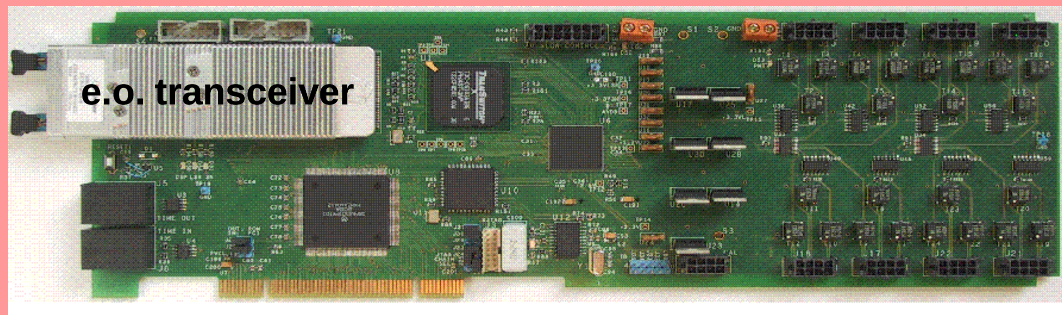
Secondary Junction Box

.....x 18 floors

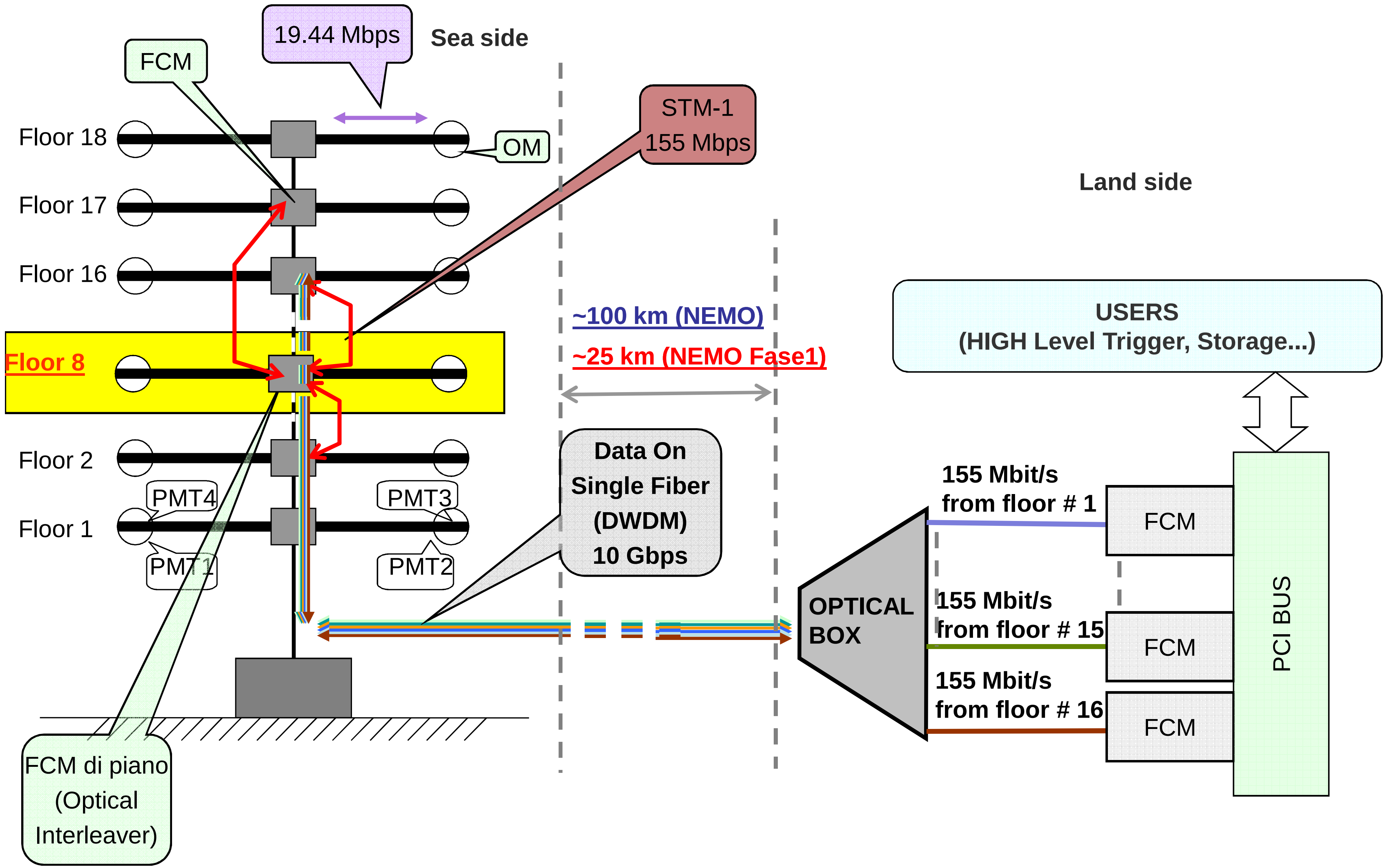
Inside Floor Control Module (FCM)

Floor Control Module Interface:

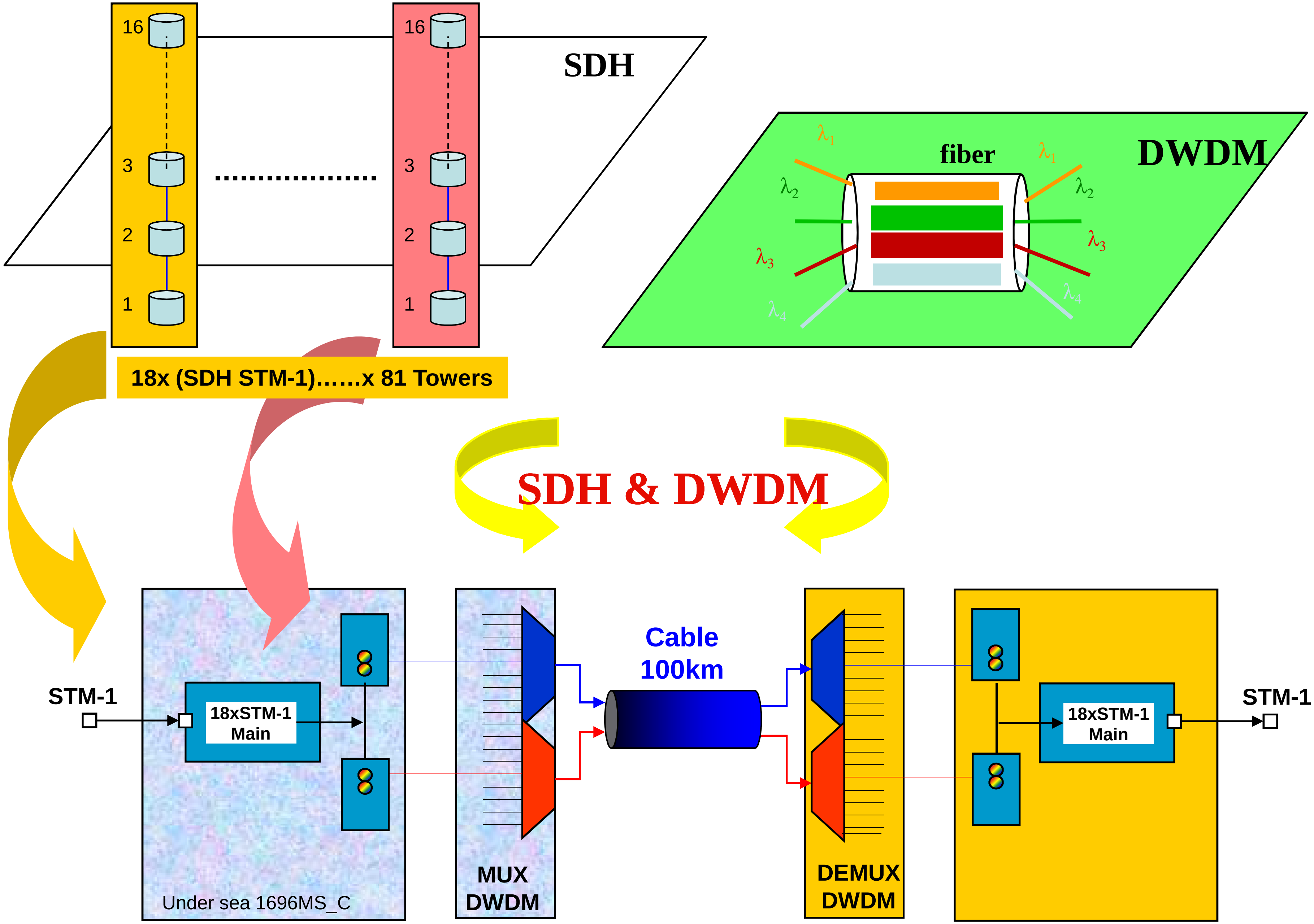
Transmit OM and Slow Control data (water parametres, OM position, internal sensors) to shore through Optical Fibre (DWDM technology)



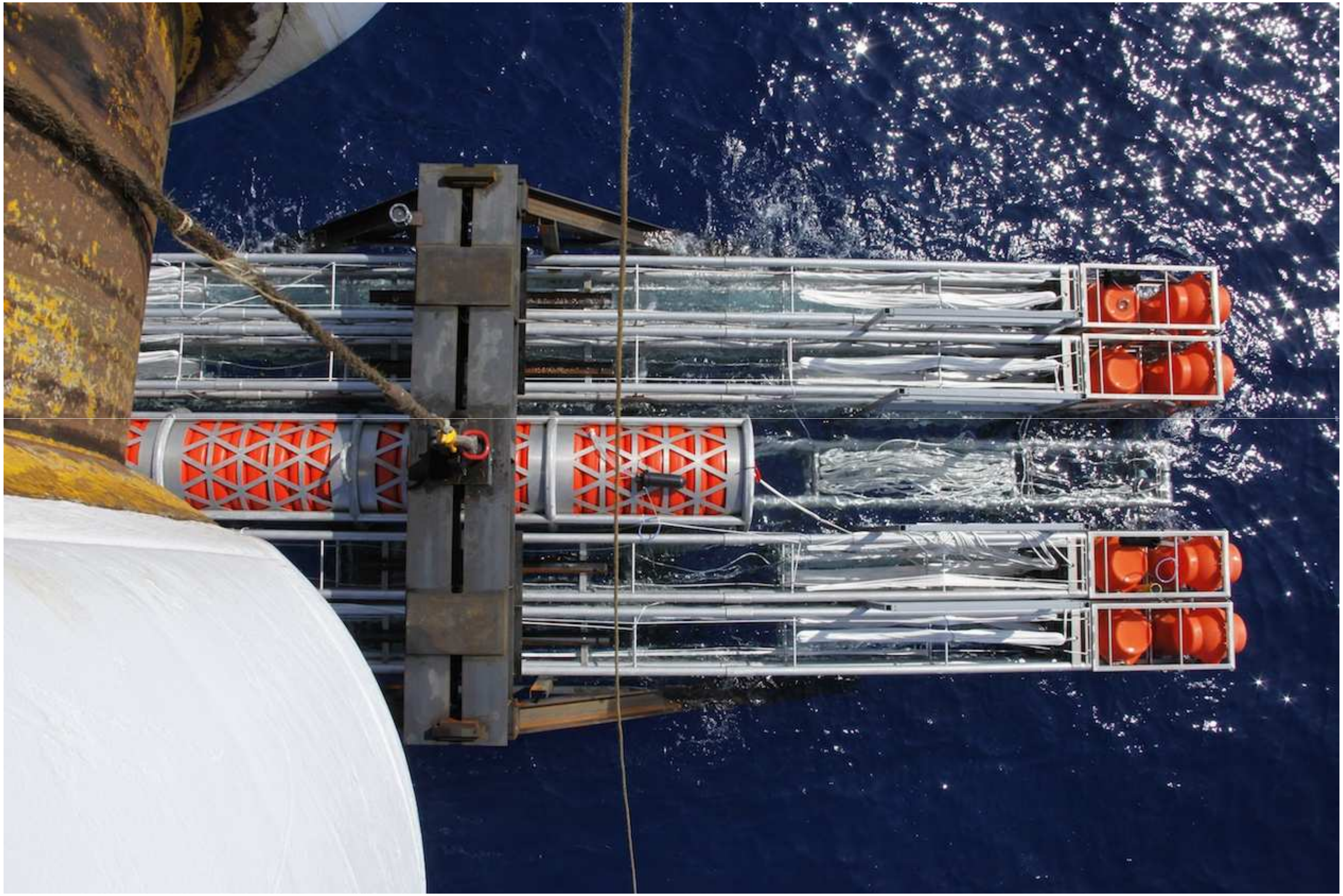
NEMO tower and data collection



NEMO data transport: SDH and DWDM tecnologies



Recupero della torre



Buon viaggio a LNS !!