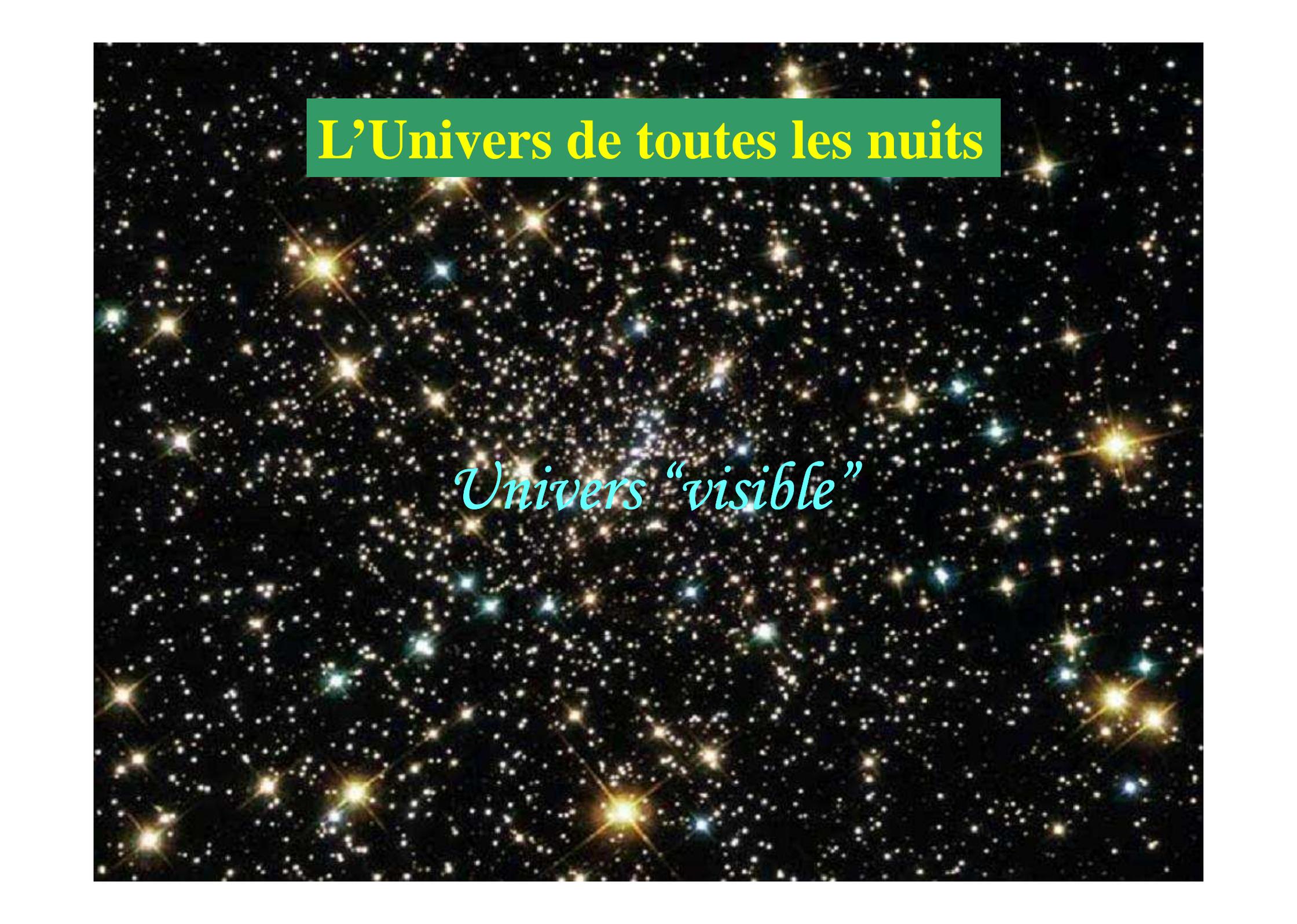




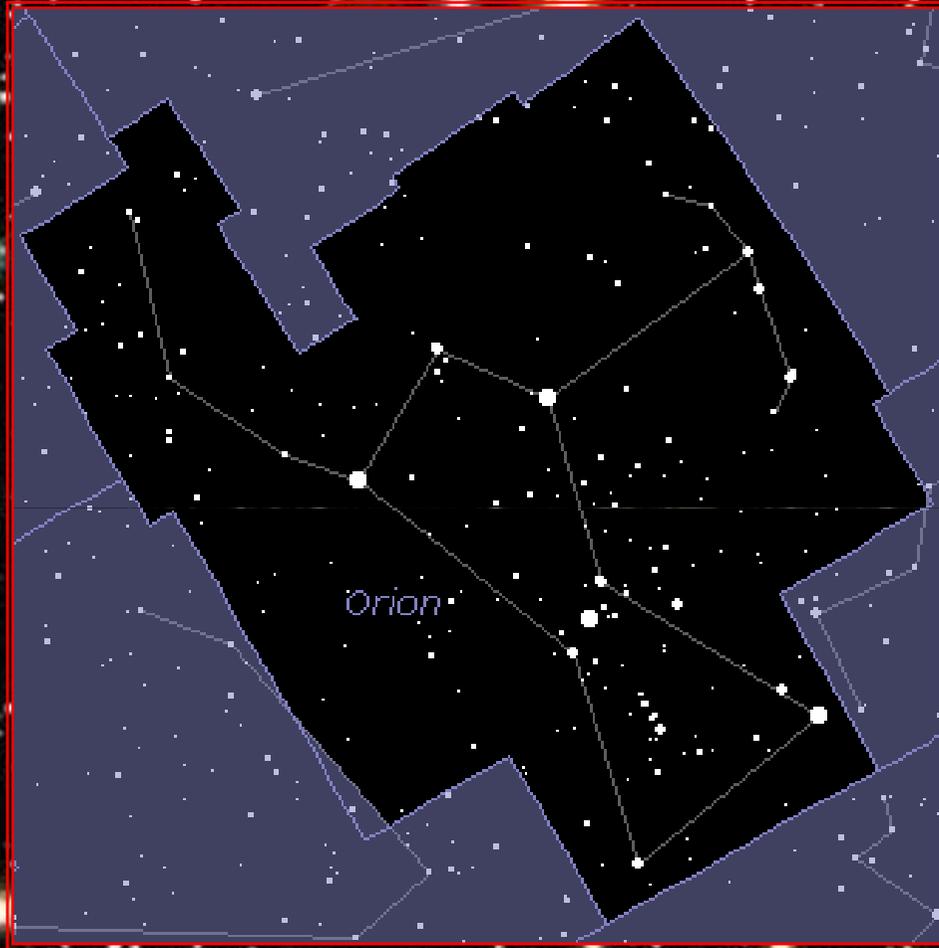
Astronomie Neutrino
une nouvelle fenêtre sur l'Univers



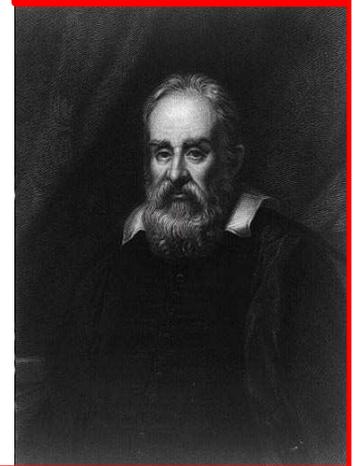
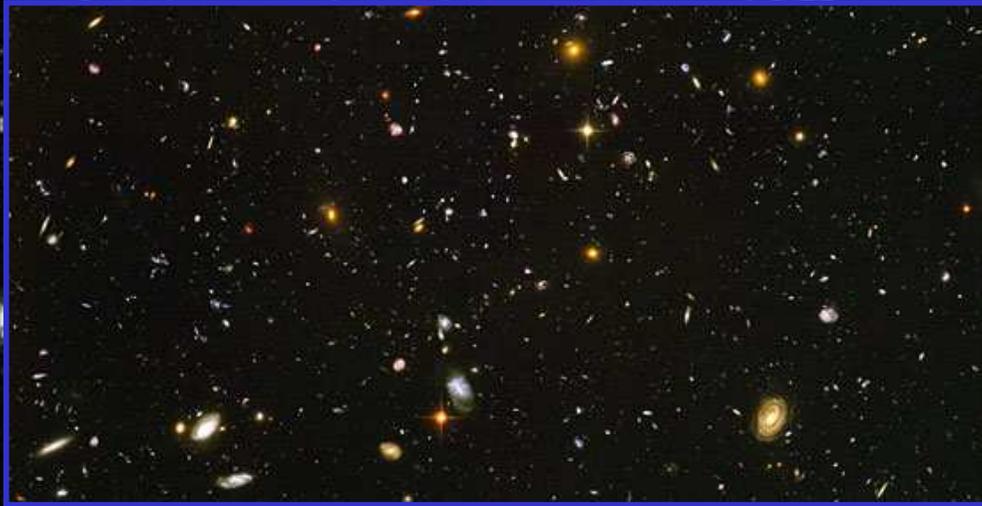
L'Univers de toutes les nuits

Univers "visible"

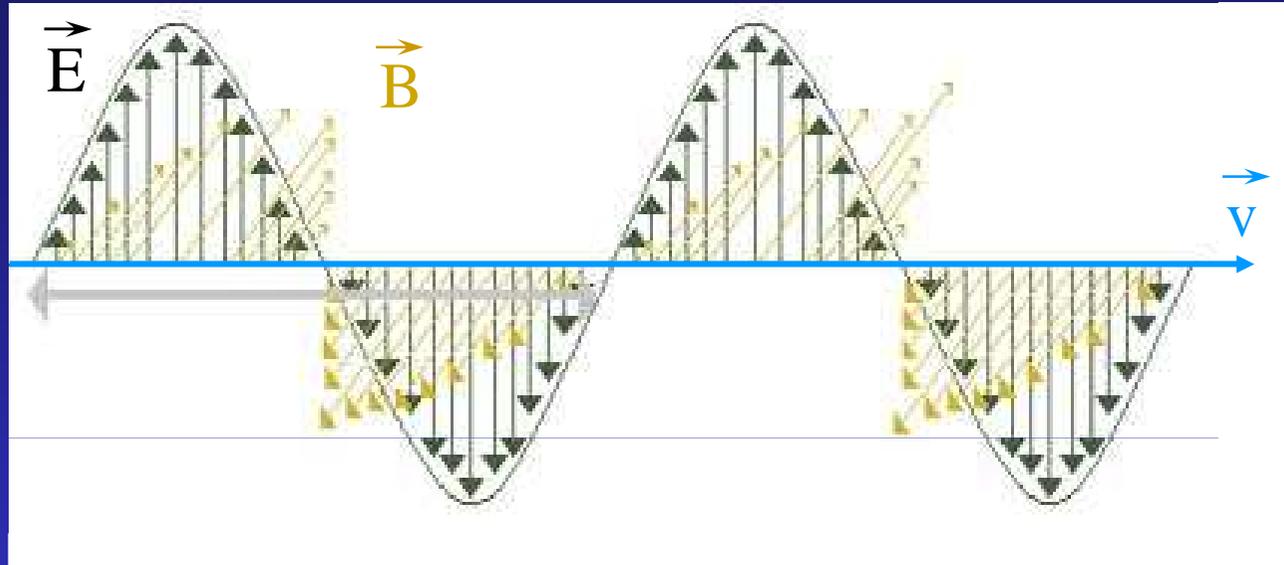
sans télescope



avec télescope

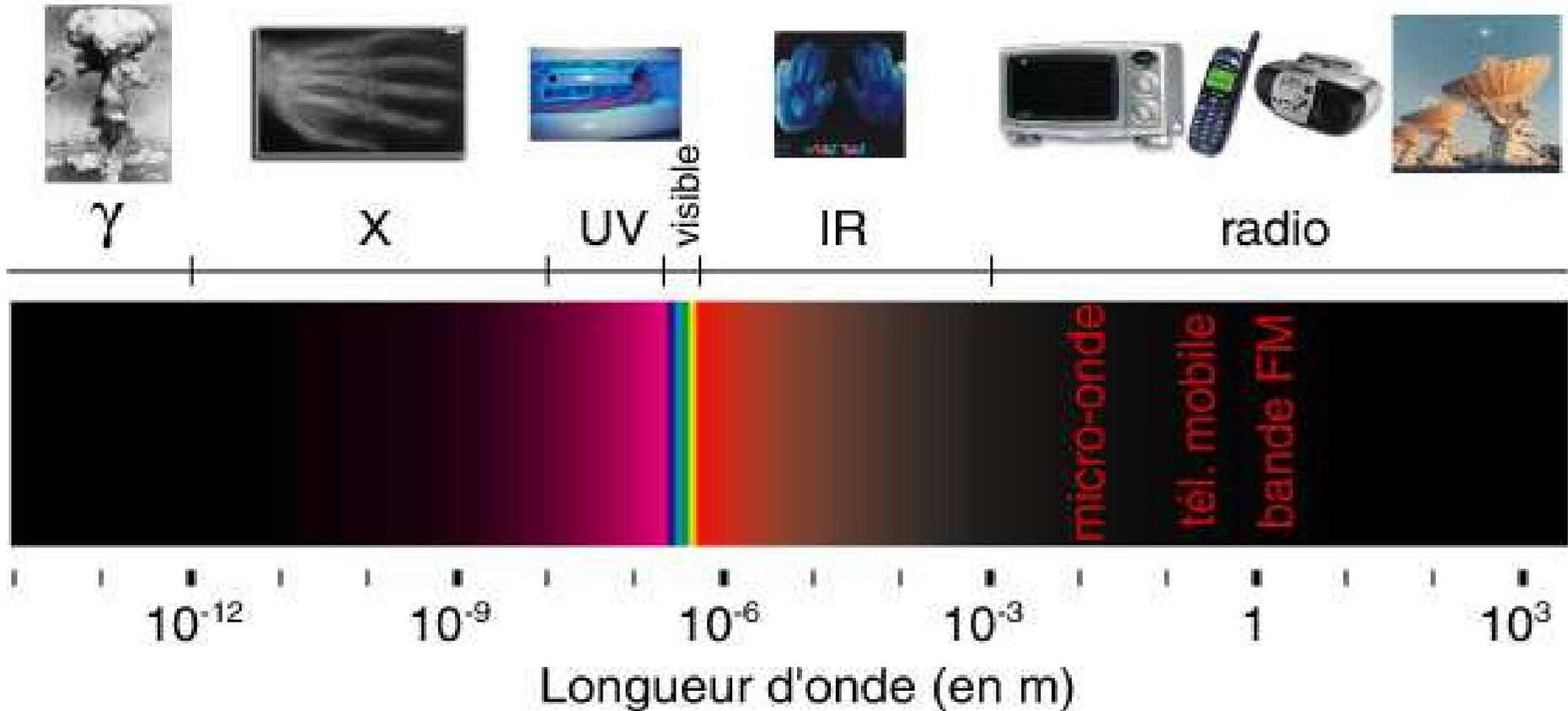


Lumière = Onde Electro-magnétique

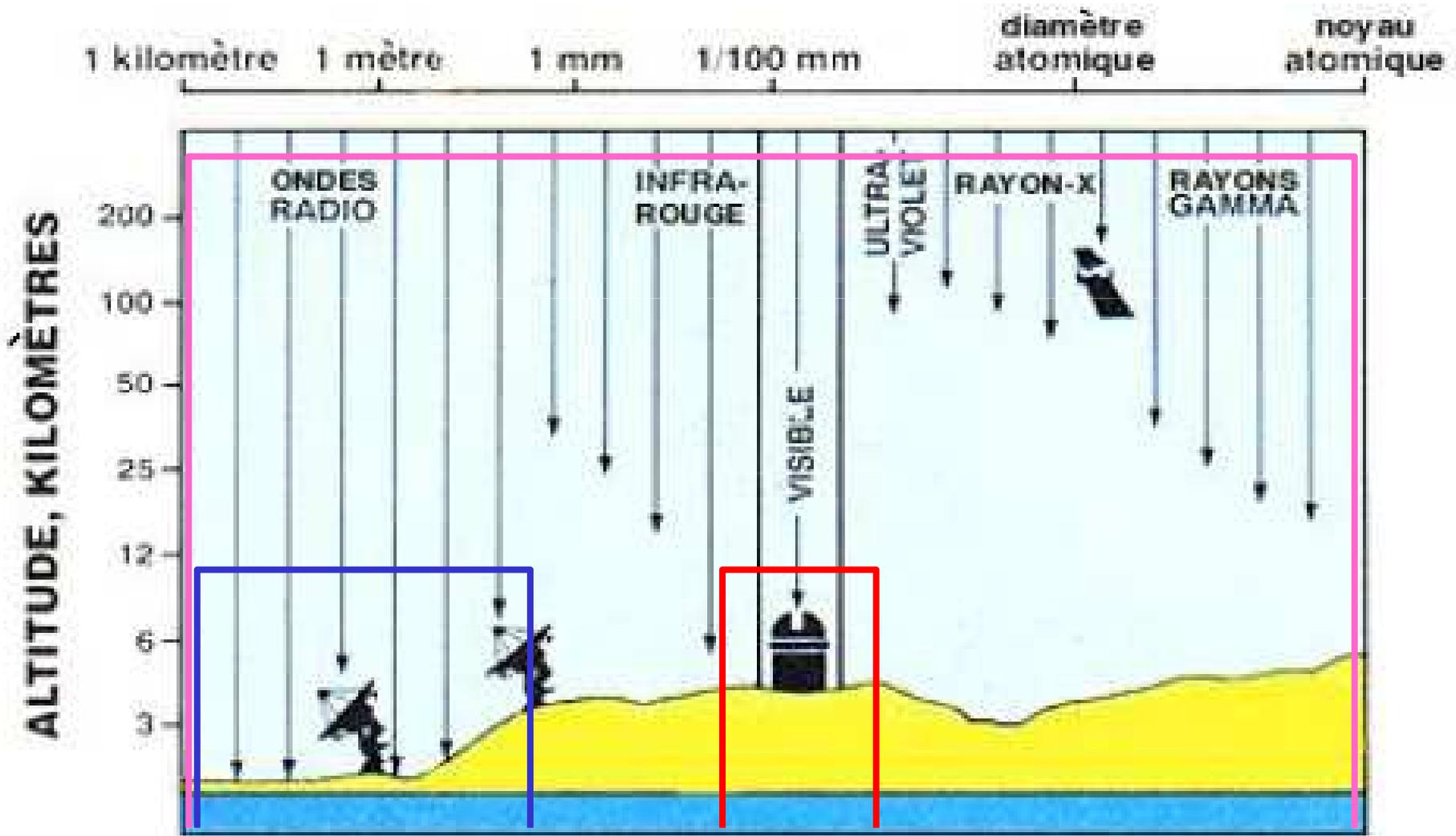


- Longueur d'onde: $\lambda = c/\nu$
- Fréquence: ν (Hz)
- Energie : $E = h \nu$ (photon = grain de lumière)
(Mécanique quantique)

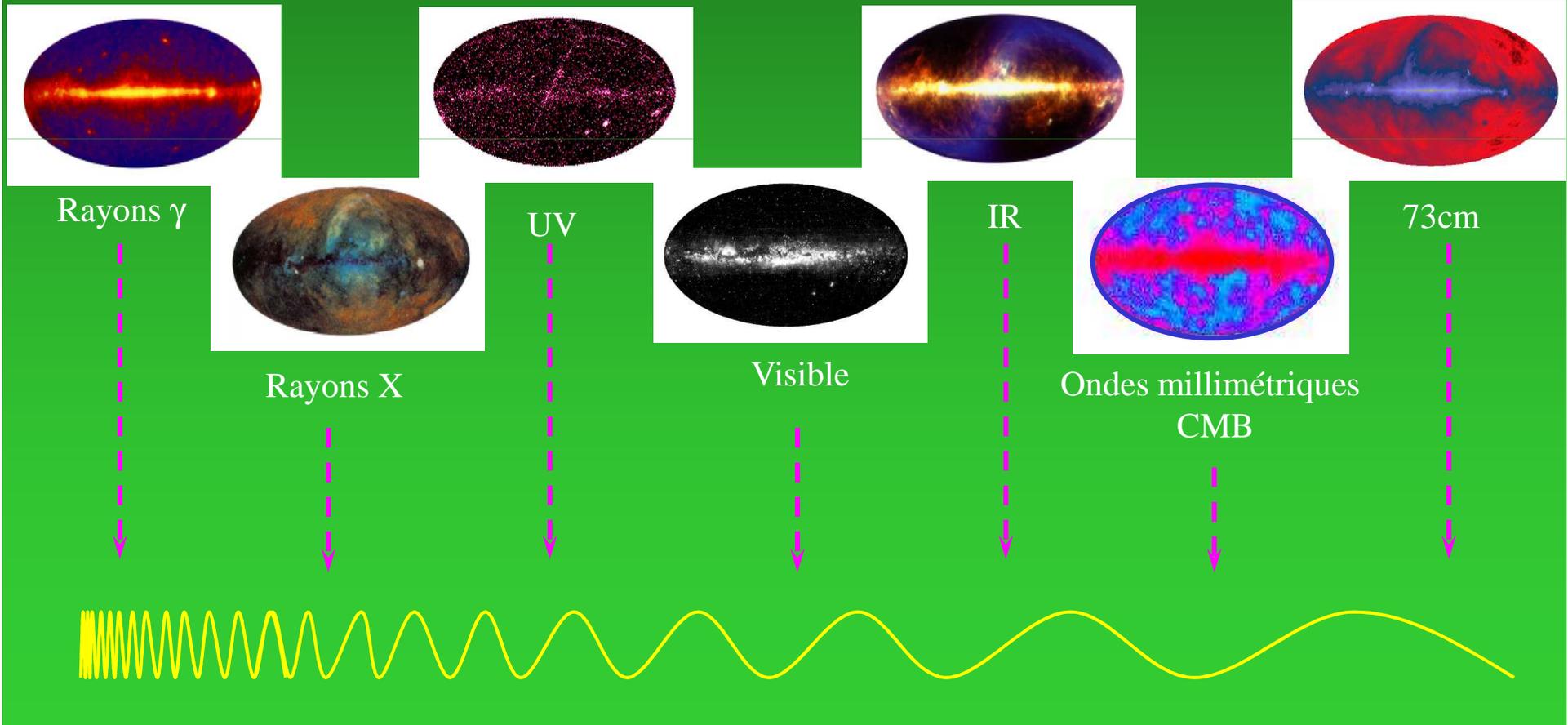
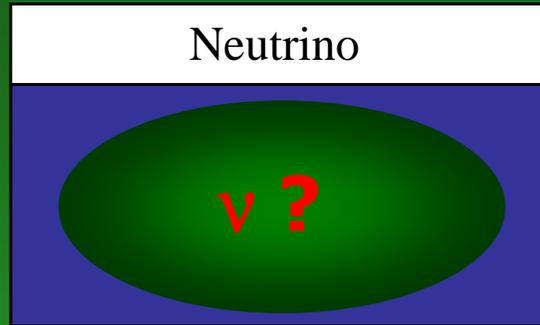
L'Univers à travers les ondes EM



Le filtre atmosphérique



Multiples fenêtres ouvertes à l'Univers

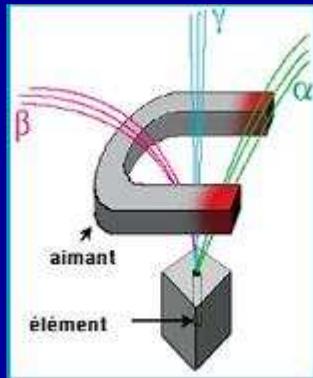


Le Neutrino

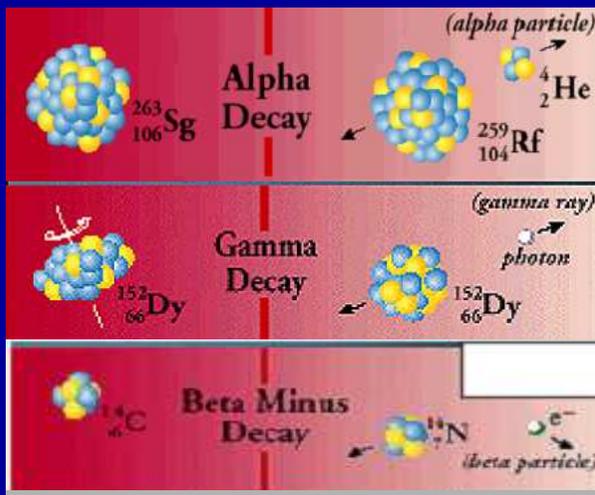
Préhistoire du neutrino

1896 Découverte de la radioactivité

3 processus d'instabilité de la matière : α , β , γ



α : charge positives
 β : charge negative
 γ : neutre



Avant

Après

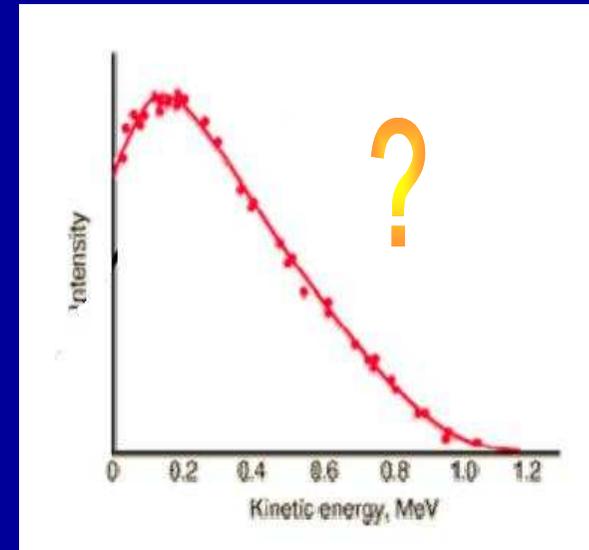
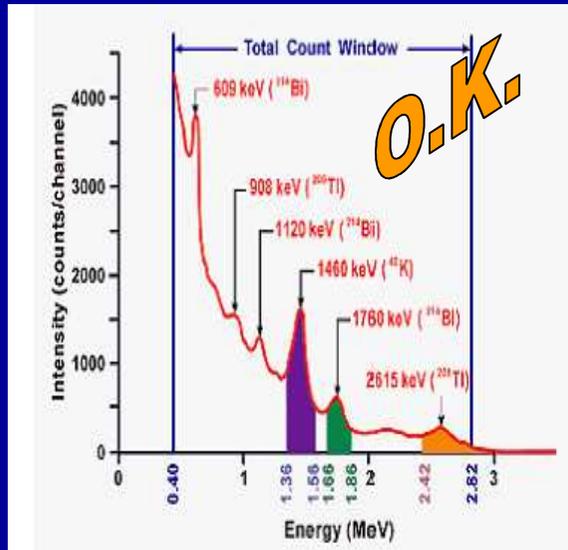
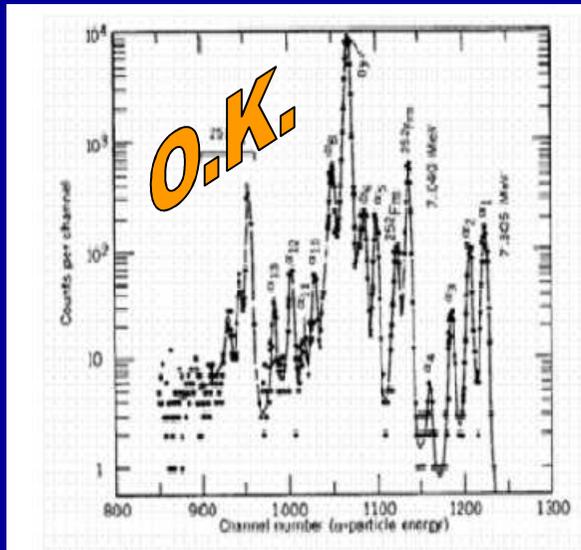


Conservation de l'énergie
 Conservation de l'impulsion } **Spectre discret**

α

γ

β



La solution désespérée

Lettre de Pauli du 4 Decembre 1930



- L'électron est accompagné par une nouvelle particule avec laquelle il partage son énergie
- Cette particule doit être très difficile à détecter car elle n'a jamais été observée

$$\Rightarrow m_\nu \sim 0$$

$$\Rightarrow Q_\nu = 0$$

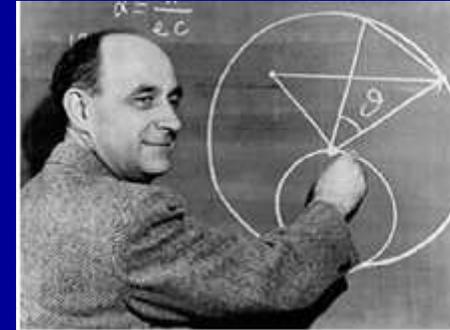
$$\Rightarrow \mu_\nu \sim 0$$

Le neutrino entre dans le monde des physiciens

Théoriquement

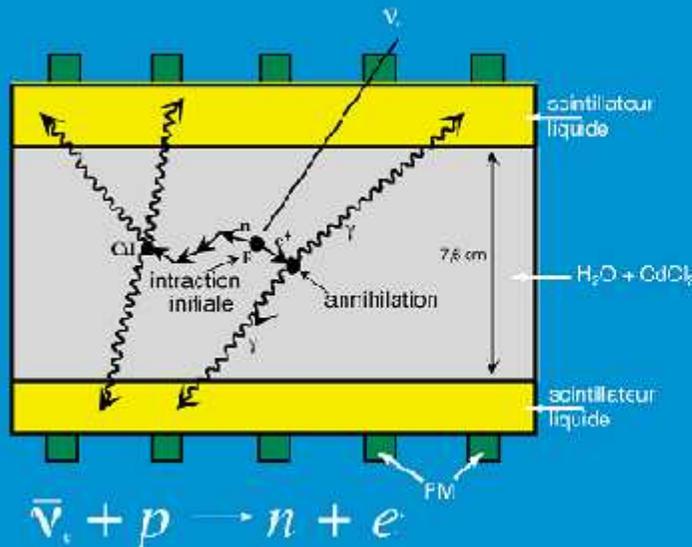
1934 E. Fermi

Théorie de la désintégration bêta



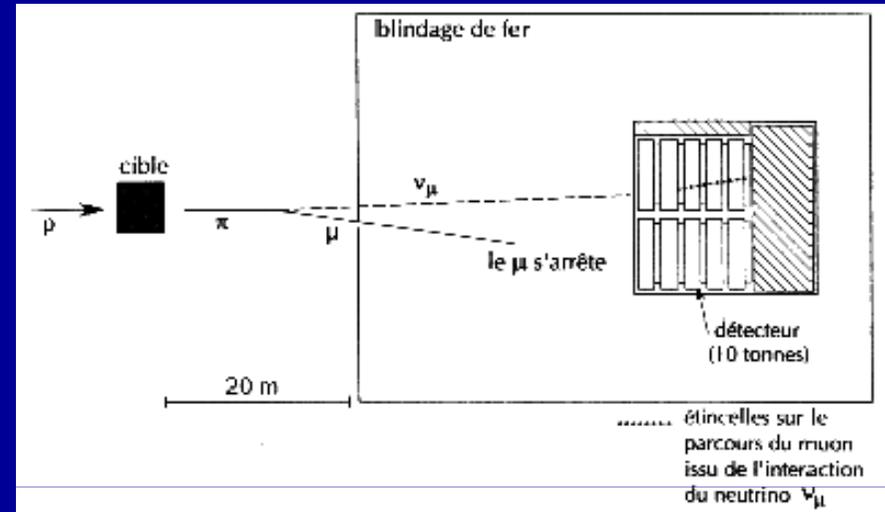
Expérimentalement

1956 Expérience de Reines et Cowan : Centrale nucléaire
Sahavana River



Découverte
du
neutrino
électronique

1963 : découverte du neutrino muonique

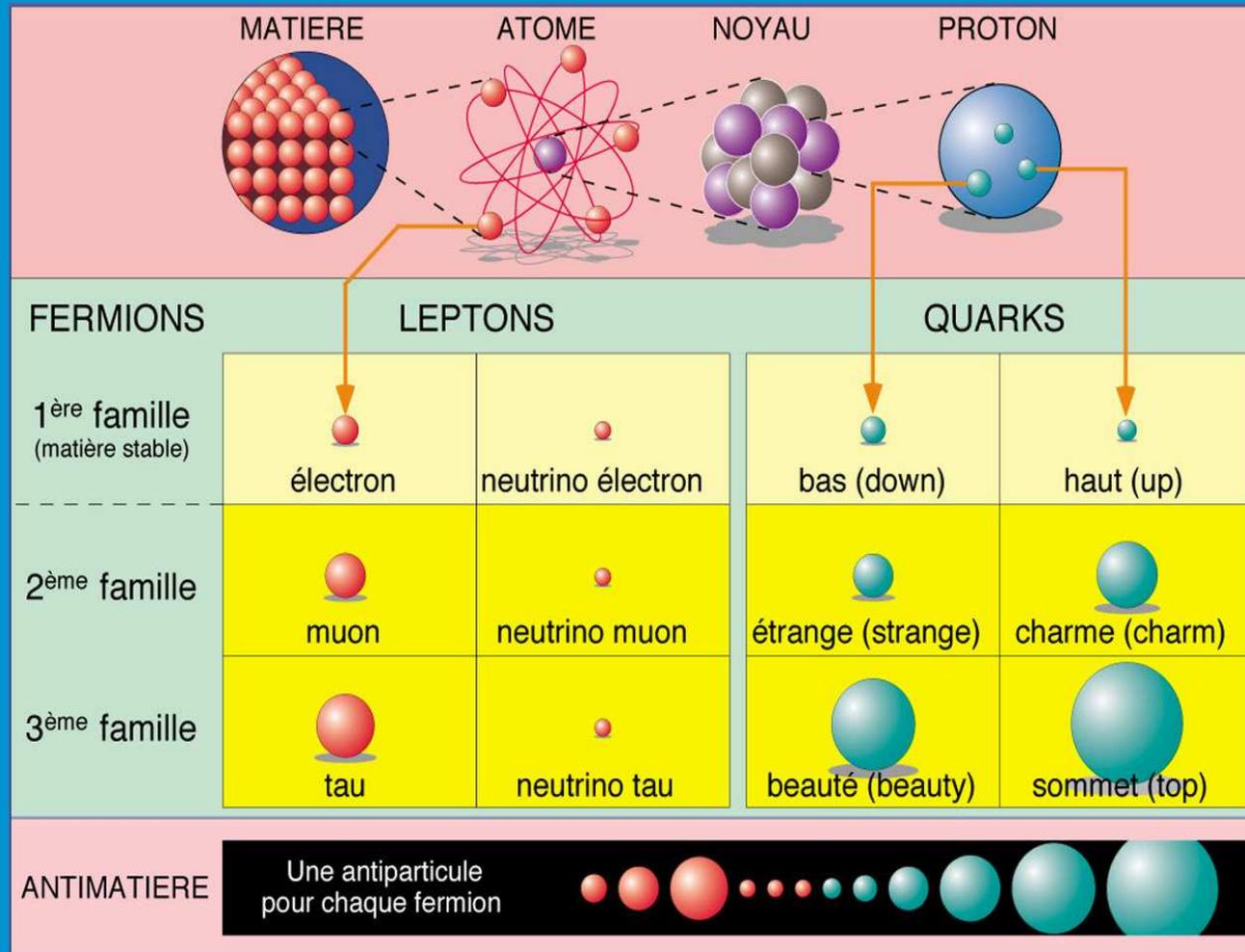


2000: découverte du neutrino de Tau



Collaboration DONUT, Fermi Lab.

Les constituants élémentaires de la matière



3 neutrinos ν_e , ν_μ , ν_τ

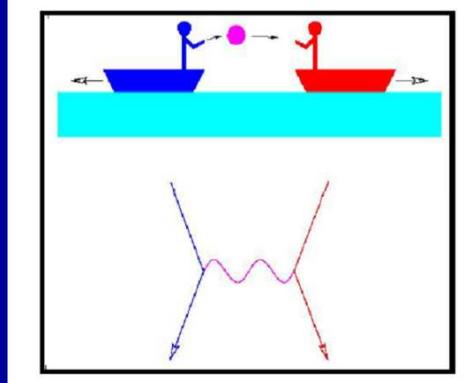
Le Modele Standard

M
A
T
I
E
R
E

QUARKS

u	d
s	c
b	t

Quanta des Forces



LEPTONS

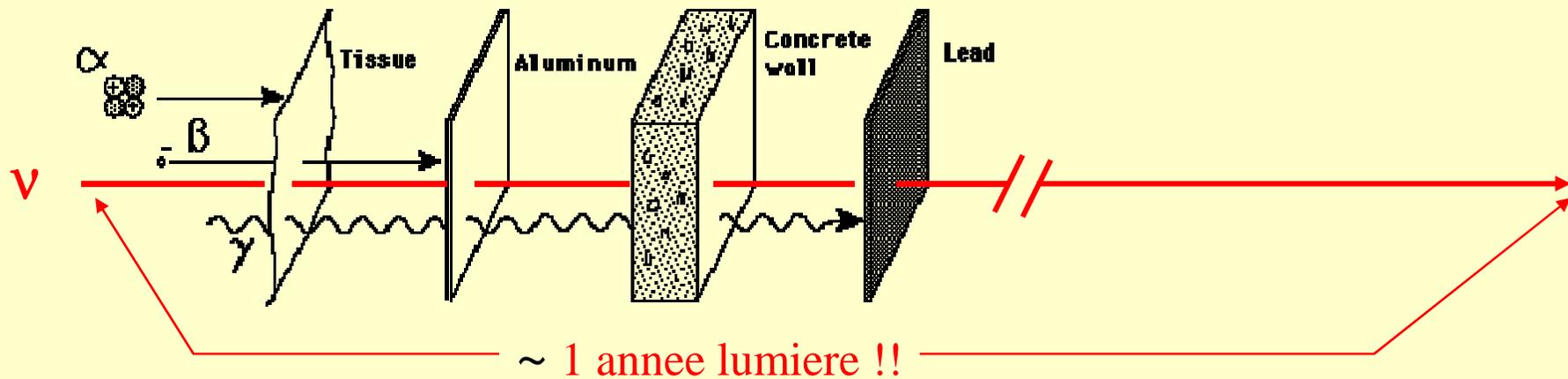
e	ν_e
μ	ν_μ
τ	ν_τ

F
O
R
C
E
S

F O R C E S Q U A N T A	Gravité	Electro- magnétisme	Force Faible	Force Forte
	Graviton	Photon	bosons W et Z	Gluon
	Portée : infinie	infinie	10^{-18} cm	10^{-13} cm
	Intensité : 10^{-38}	10^{-2}	10^{-7}	1

Le neutrino ne "sent" que l'interaction faible !

Le neutrino, particule passe-muraille

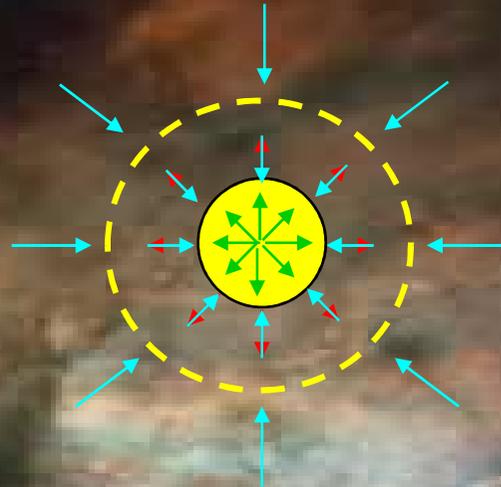


- Le neutrino peut sonder les régions les plus reculées de l'Univers
- Le neutrino peut sonder les régions le plus intimes des objets cosmiques

A full-disk image of the Sun captured in the 171 Å iron emission line by the Solar and Heliospheric Observatory (SOHO). The image shows the solar surface with various magnetic features, including sunspots and active regions, appearing as bright blue and white structures against a dark blue background. The text "Les neutrinos du Soleil" is overlaid in yellow in the center of the image.

Les neutrinos du Soleil

SOHO, 171A Fe emission line



Gravitation

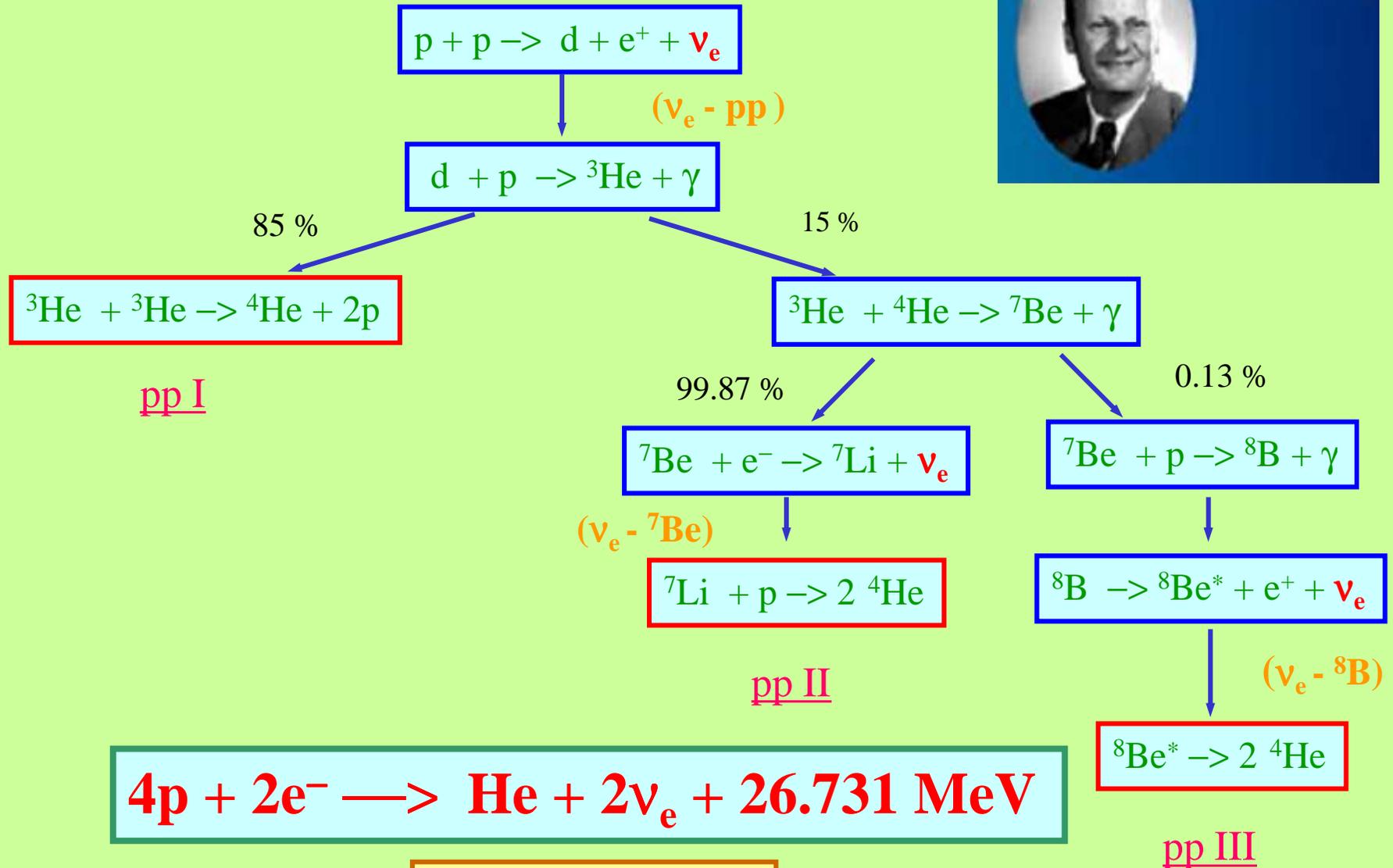
Radiation

Fusion nucléaire

Gravitation

Equilibre dynamique
 $T \sim 14$ Millions de °K

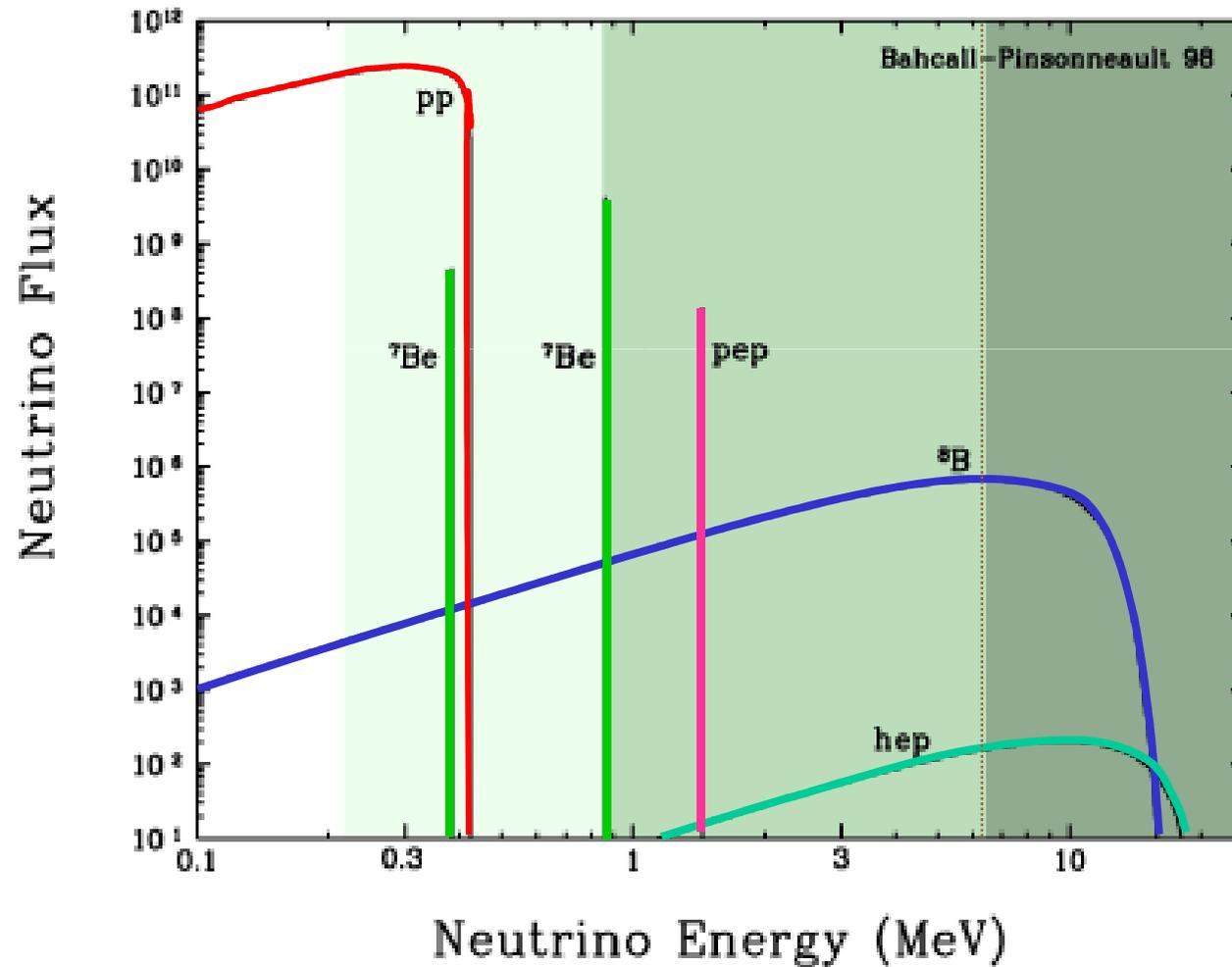
Comment cela marche ?



$$4p + 2e^- \rightarrow \text{He} + 2\nu_e + 26.731 \text{ MeV}$$

$$N\nu \sim 2 \cdot 10^{38} \text{ s}^{-1}$$

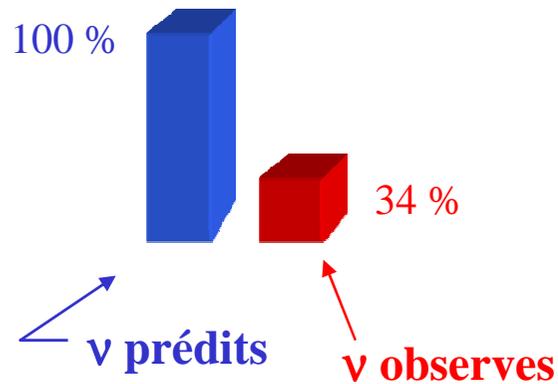
Spectre neutrinos



1964 Ray Davis propose de detecter les ν du soleil

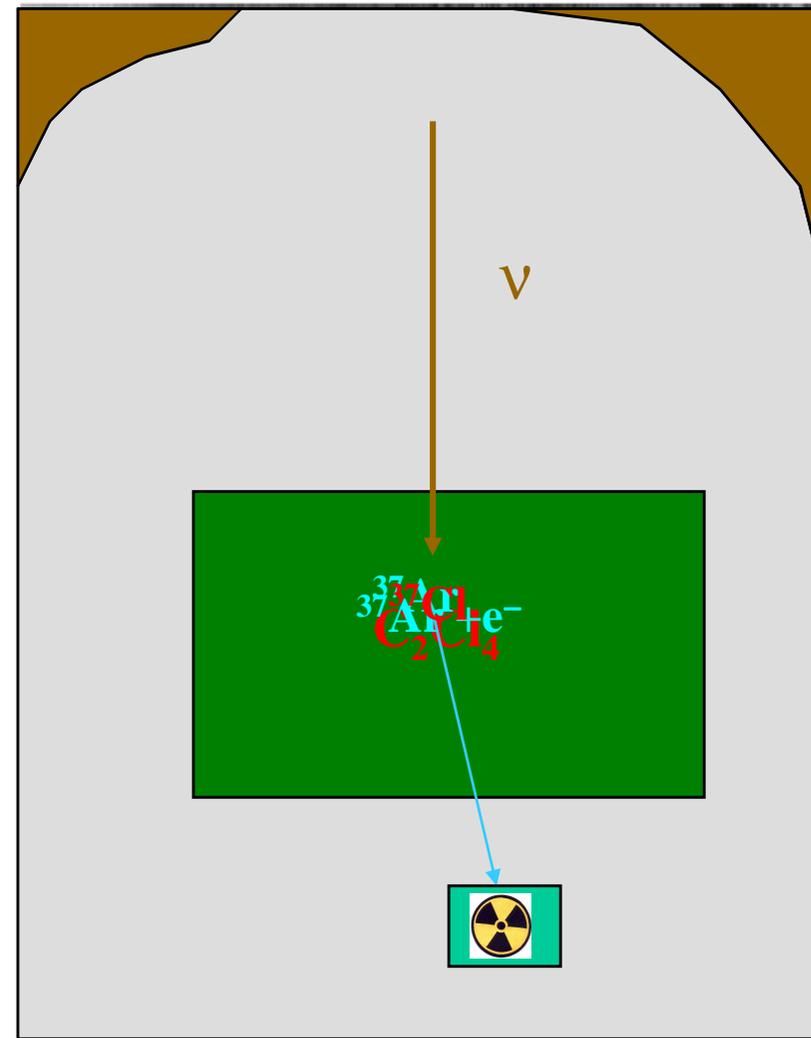


1968 : seulement
34 % des neutrinos attendus !



Problème du neutrino solaire

Mine de Homestake

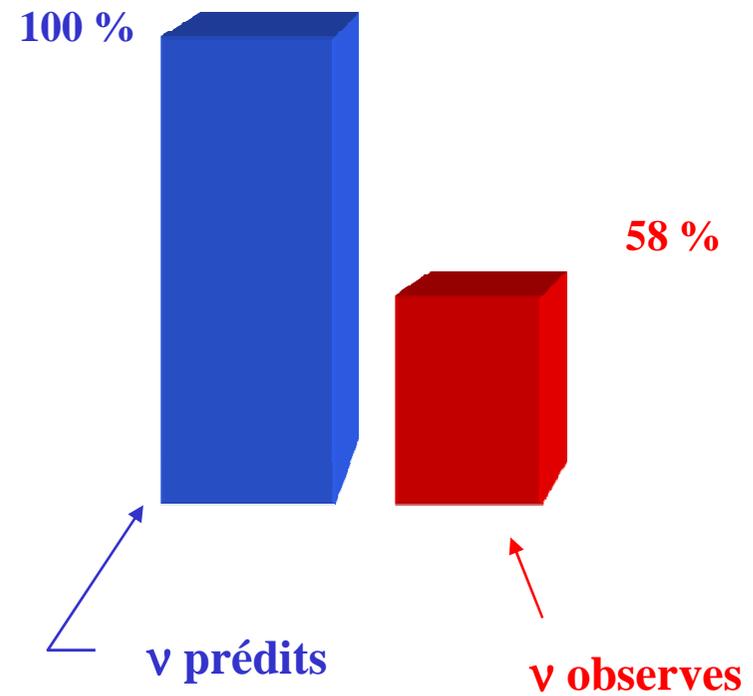
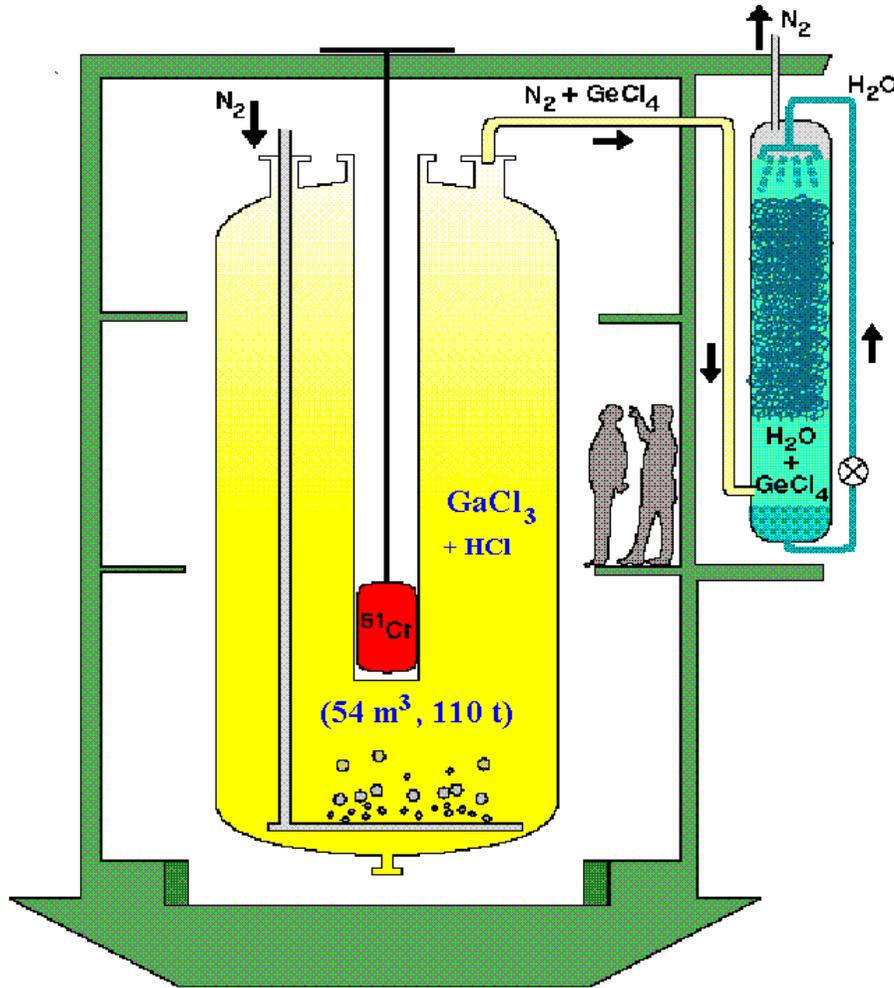




GALEX

(1991 – 1997)

Confirme le résultat de Davis



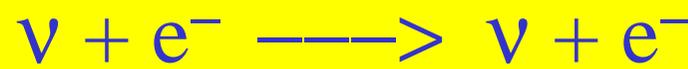
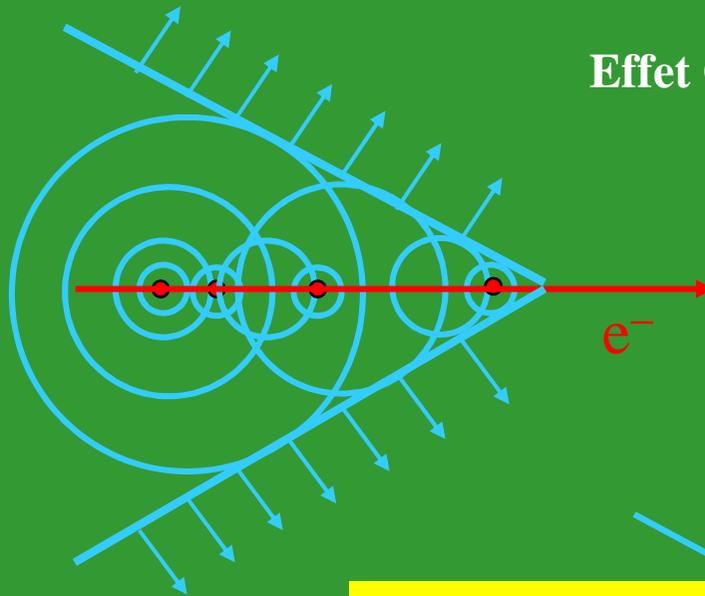
Mais, ils sont “solaires” ces neutrinos ?

Détection directe des neutrinos

Déplacement d'une particule chargée dans un milieu transparent

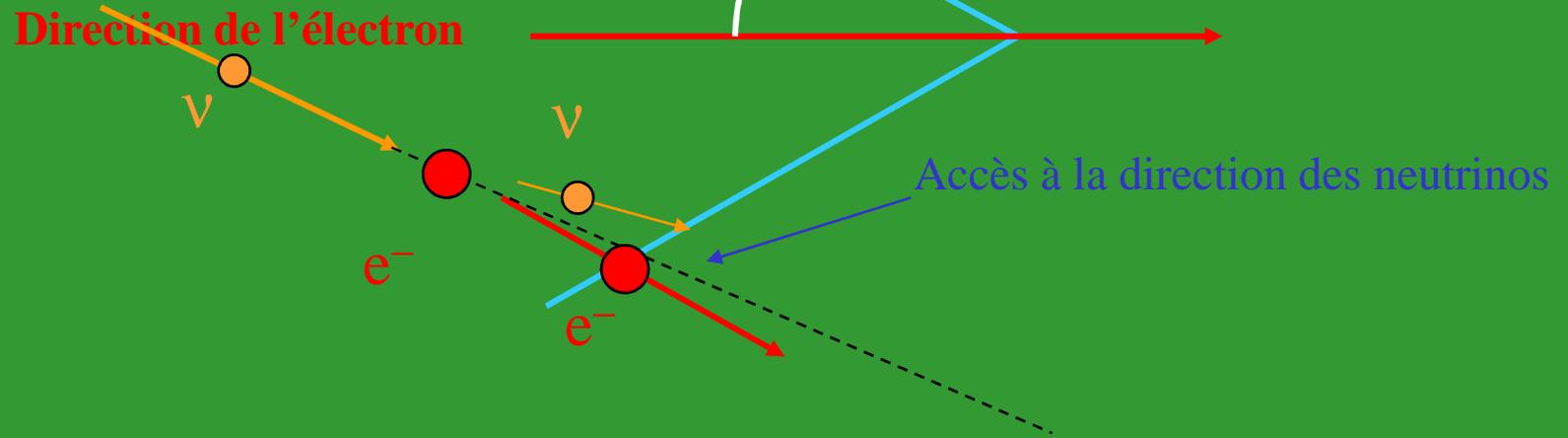
Effet Cherenkov

$$V_{e^-} > V_{lumiere} \text{ (dans le milieu)}$$



dans l'eau

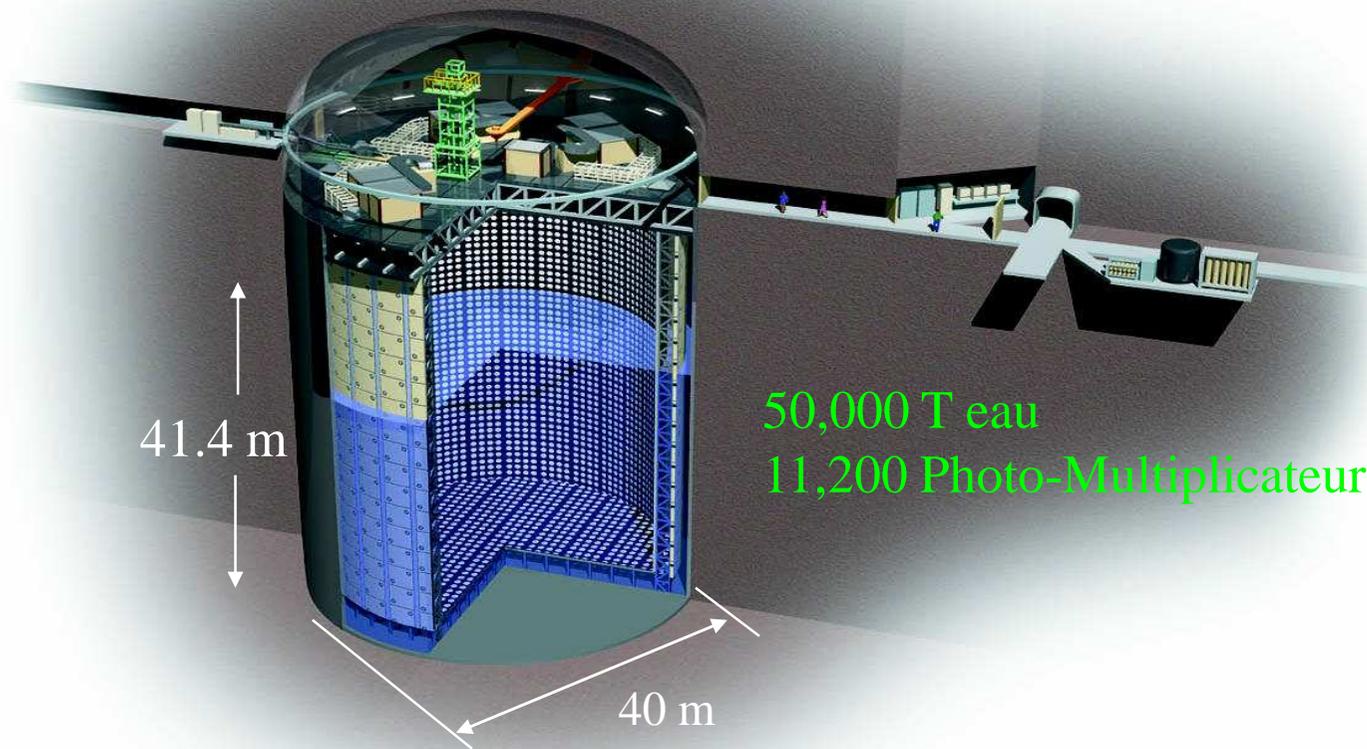
Direction de l'électron



Kamiokande → Super Kamiokande

(1987 -)

(vie moyenne du proton)



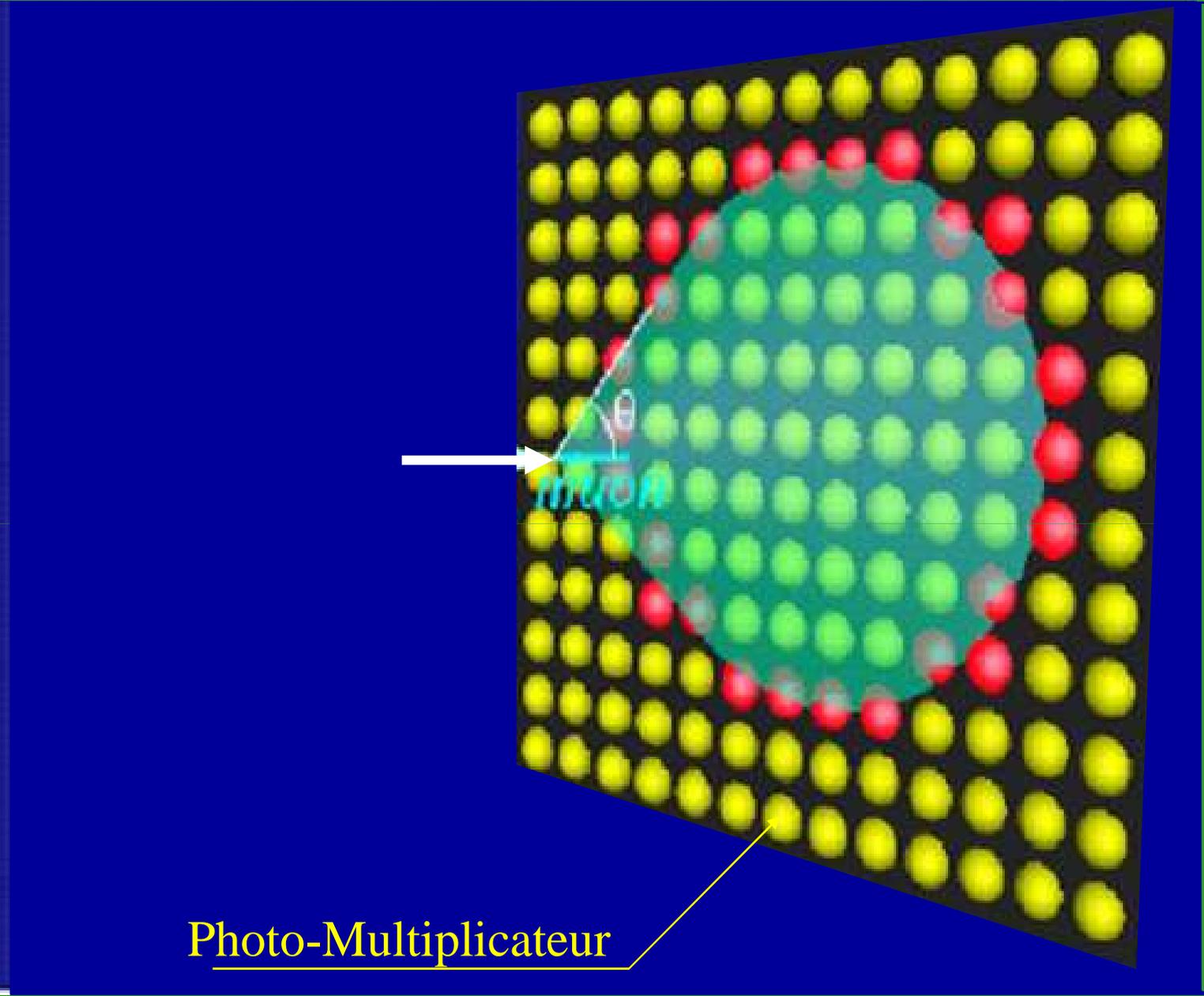
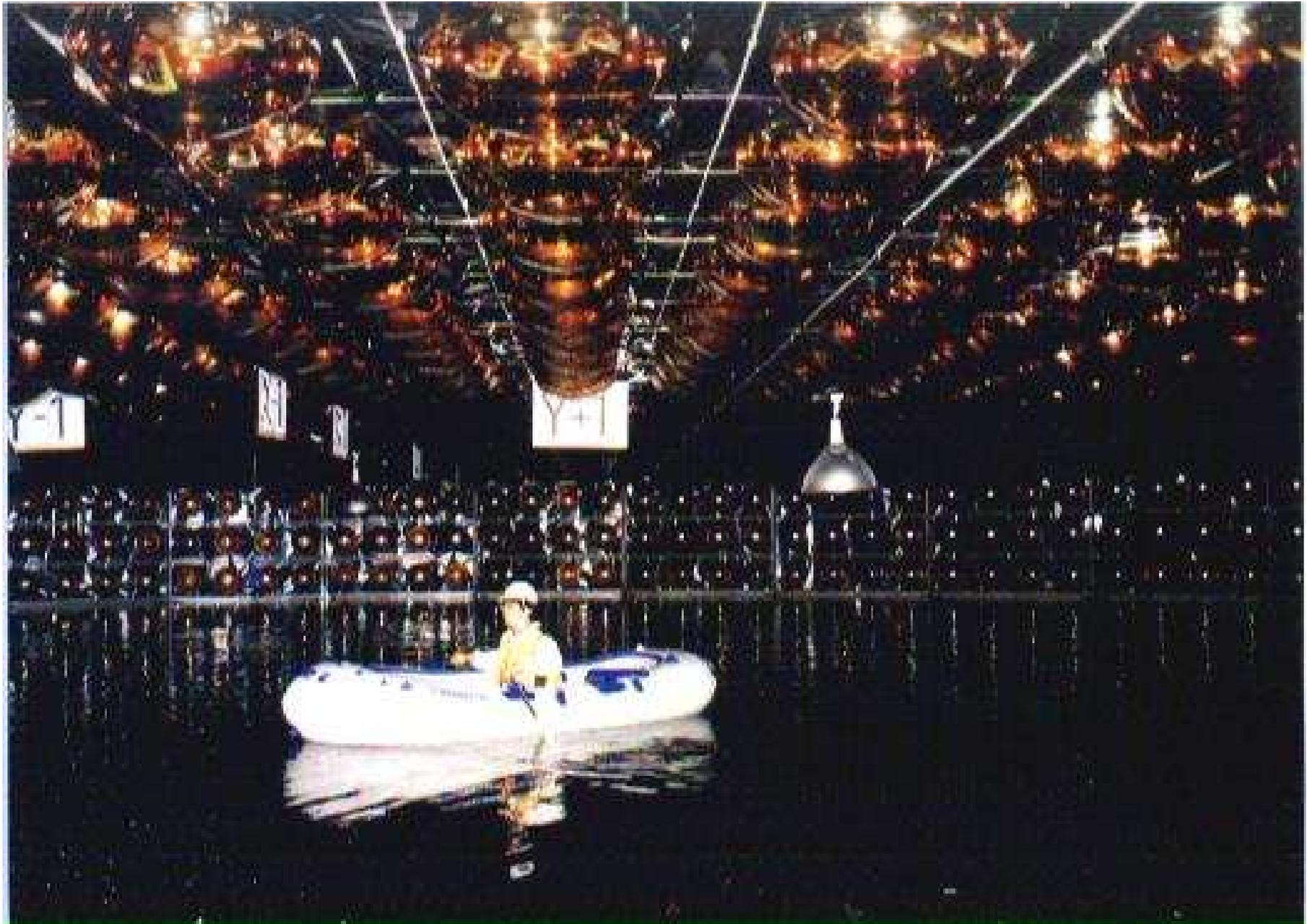
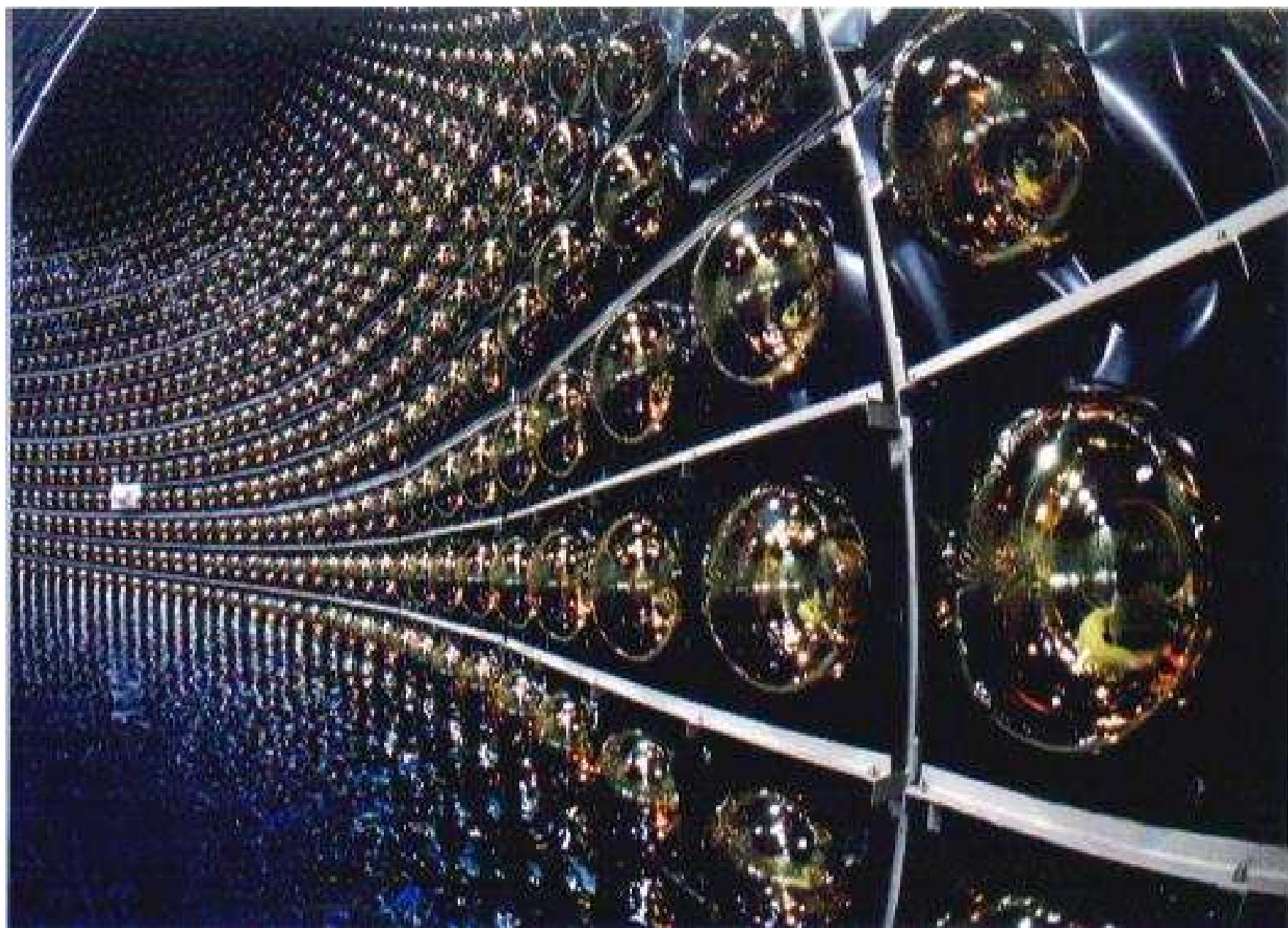
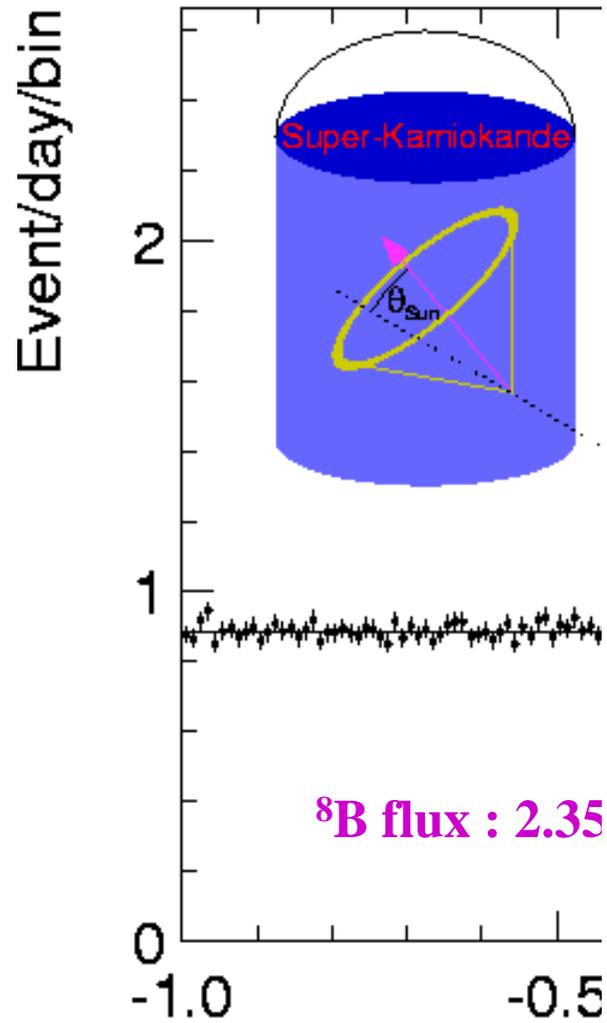


Photo-Multiplicateur

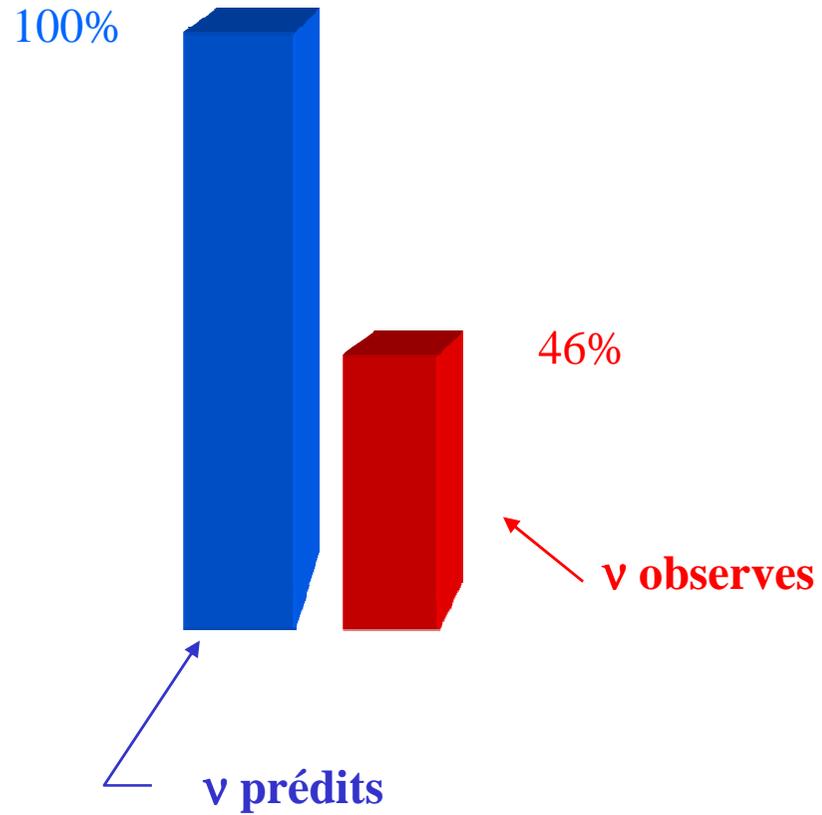




Resultat 31/0



Le problème des ν solaire persiste



Une expérience dans une météorite

Détecteur SNO

2092 m to Surface

18 m Diameter
Support Structure
for 9500 PMTs,
60% coverage

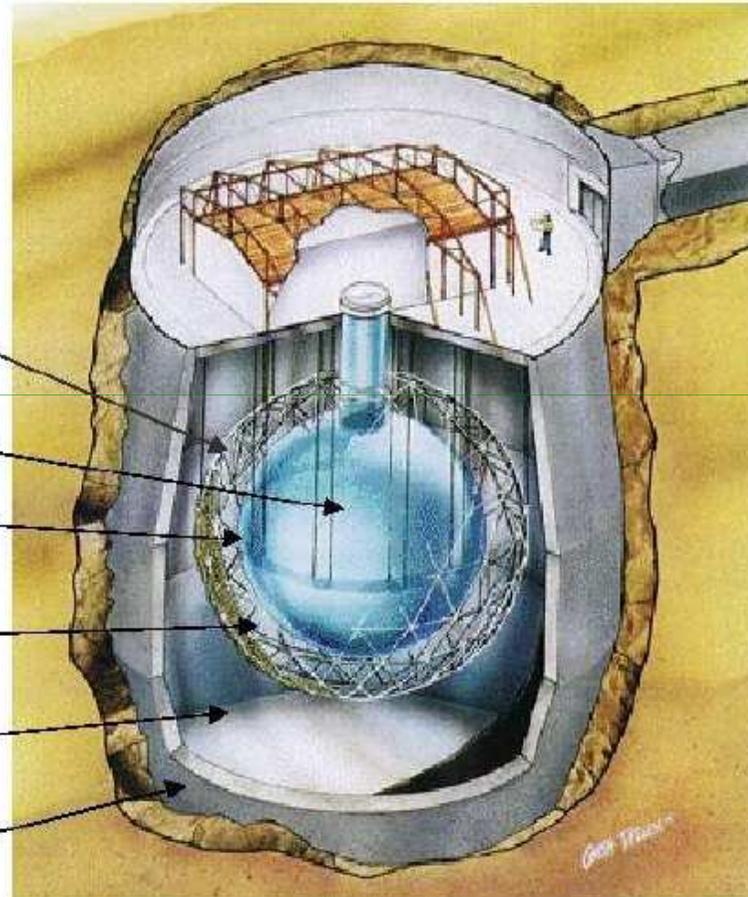
1000 Tonnes D_2O

12 m Diameter
Acrylic Vessel

1700 Tonnes Inner
Shielding H_2O

5300 Tonnes Outer
Shield H_2O

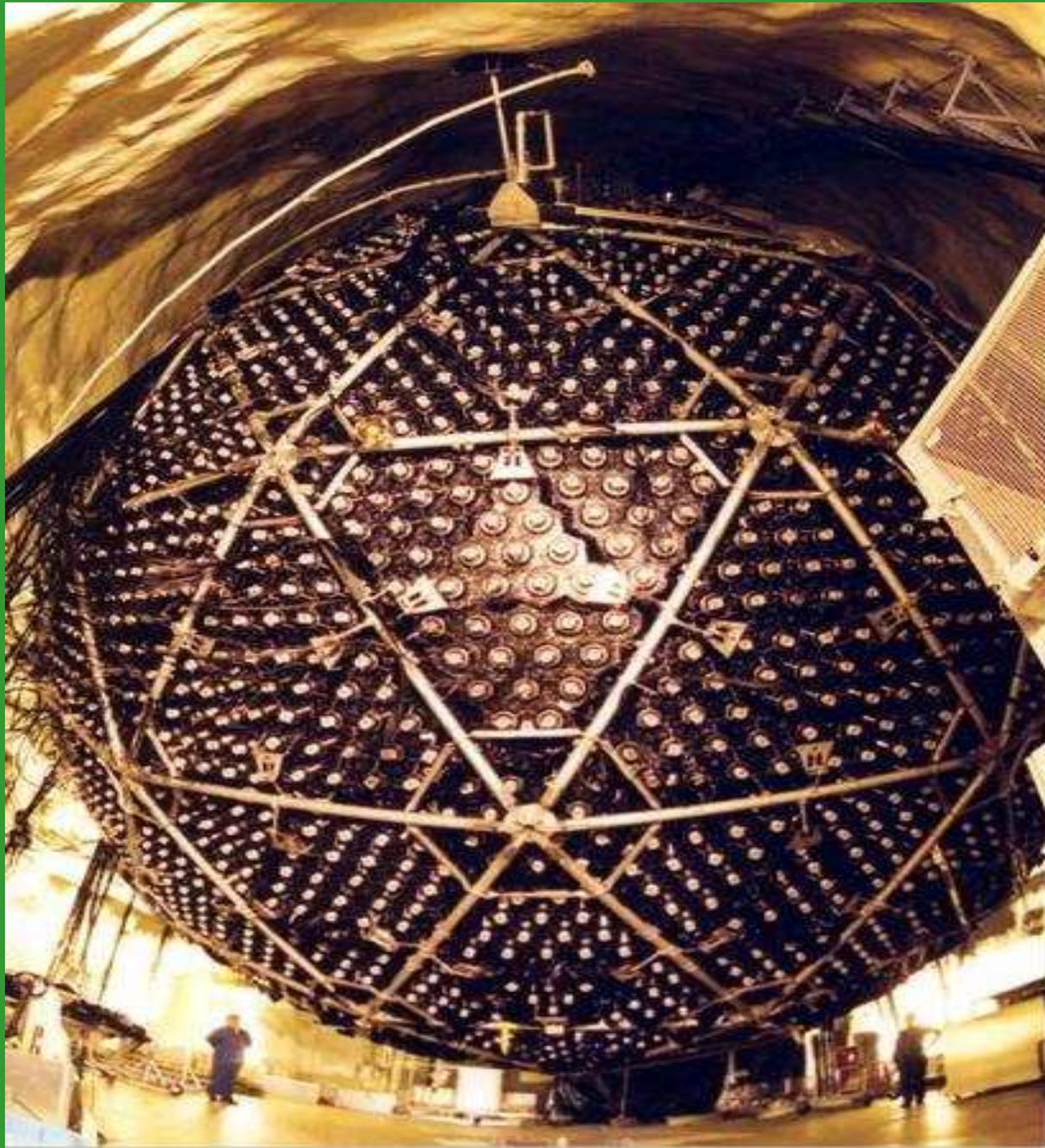
Urylon Liner and
Radon Seal



Départ 1999

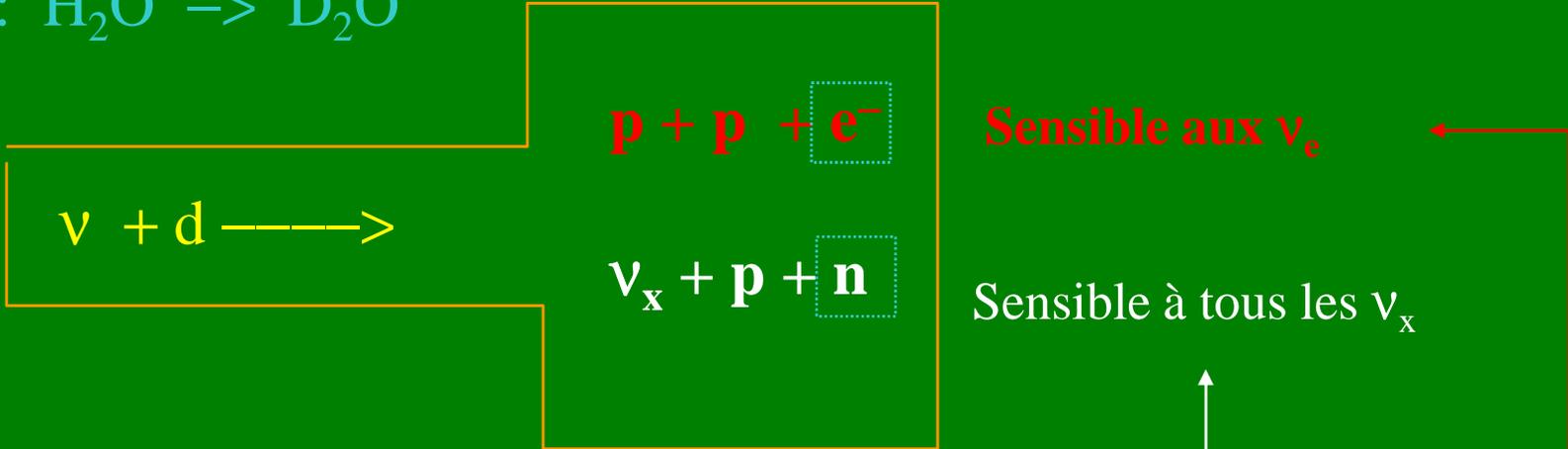
Oser ICHEP 2002



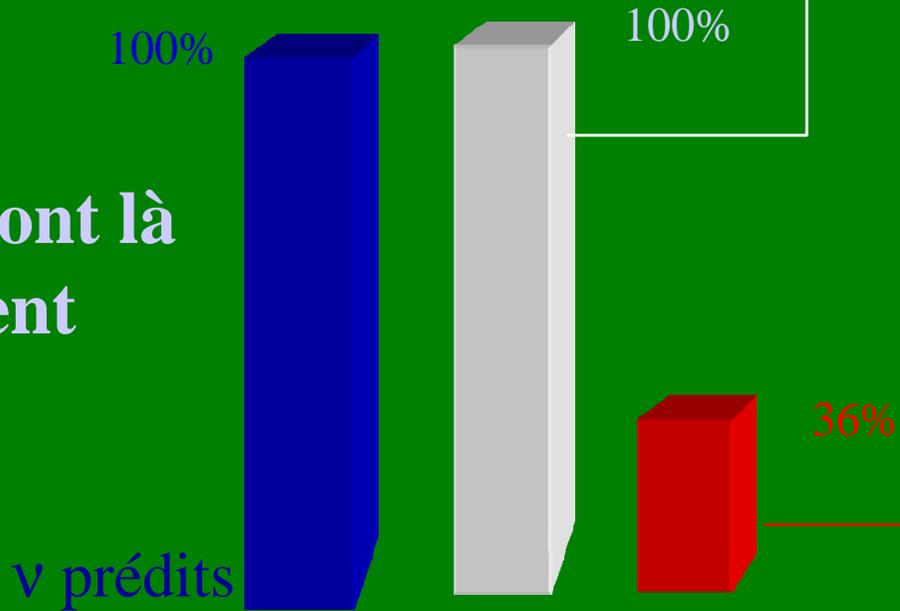


La détection de neutrinos dans SNO

SNO : $\text{H}_2\text{O} \rightarrow \text{D}_2\text{O}$



Tous le neutrinos sont là
mais les ν_e manquent

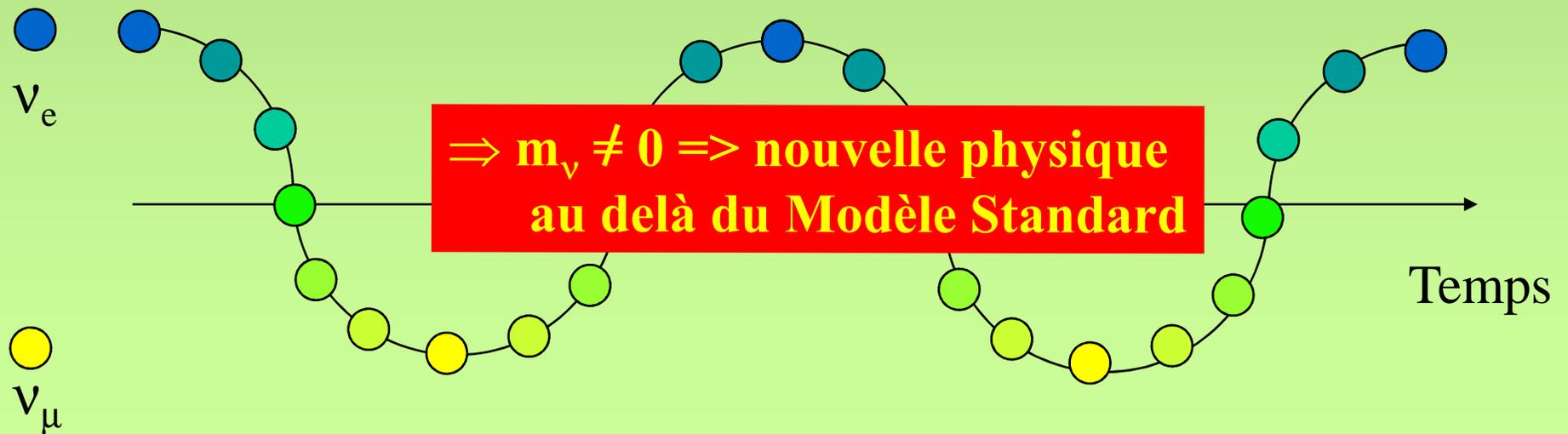


Où sont passés les neutrinos ?

Oscillations des neutrinos

Si le neutrino possède une masse il peut changer de saveur dans le temps

Exemple très chromatique de l'oscillation de neutrinos entre deux saveurs



La période dépend de l'énergie



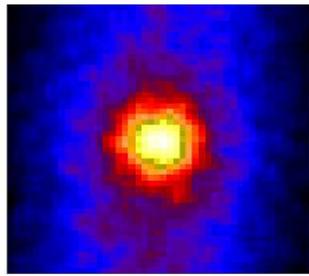
The Nobel Prize in Physics 2002



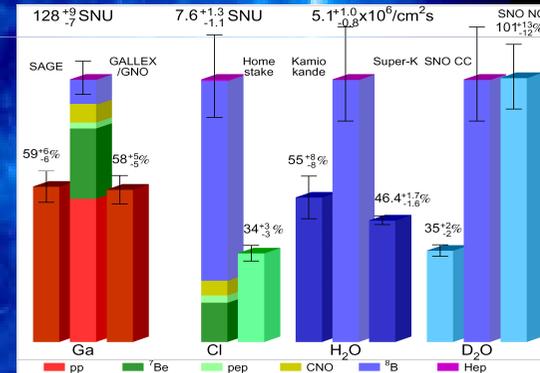
Raymond Davis Jr.



Masatoshi Koshihara



Super- K (Japan) image of the sun using neutrinos



=> neutrino oscillation

SOHO, 171A Fe emission line

Astronomie neutrino au delà du soleil

23 fevrier 1987, Grand Nuage de Magellan (150000 a.l.)



Tarantula Nebula in LMC (constellation Dorado, southern hemisphere)
size: ~2000ly (1ly ~ 6 trillion miles), distance: ~180000 ly

Supernovae
1987A

Encore plus sur les étoiles

Etoile : 75% H et 25% He

Fusion "lente" de l'hydrogene



$3 {}^4\text{He} \rightarrow {}^{12}\text{C} + 7.656 \text{ MeV}$: Geante Rouge --> Naine Blanche

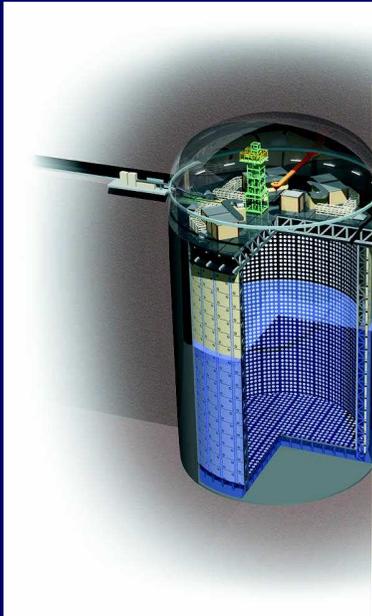
Si plus de 8 masse solaire



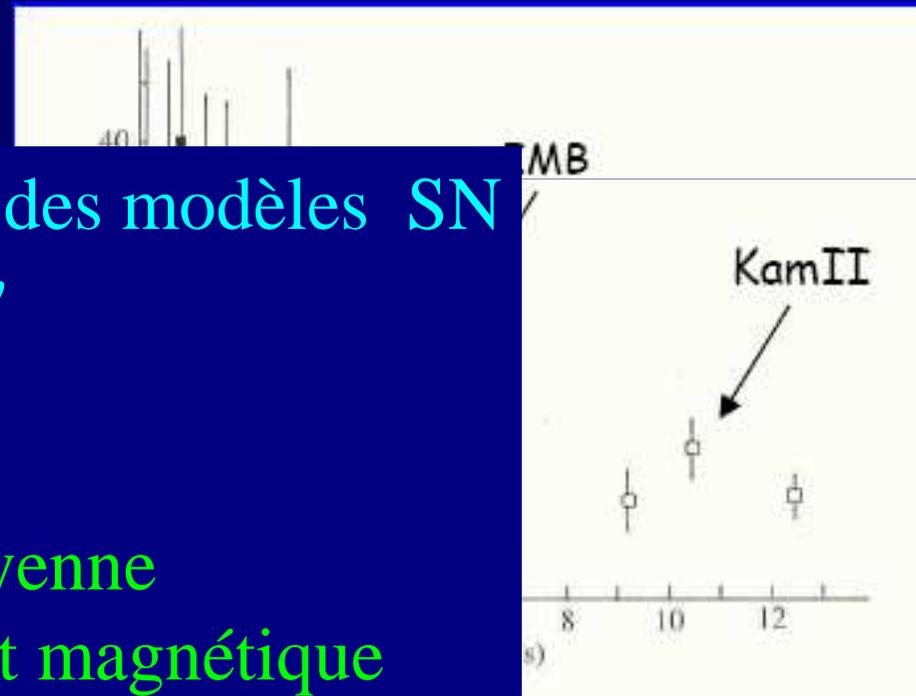
Au delà, réactions endothermiques => fin du combustible



On a vu les neutrinos de la SN !

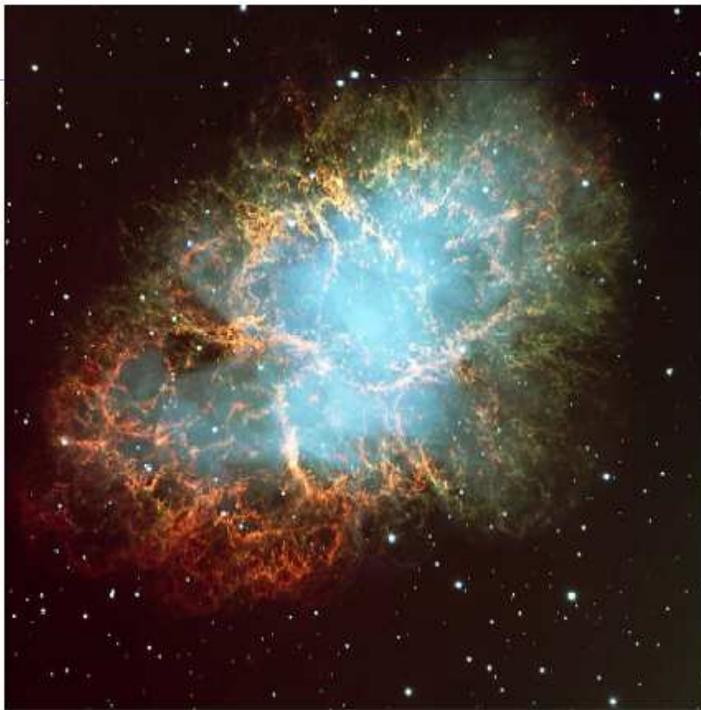


- Confirmation des modèles SN
- Physique du ν
 - masse
 - charge
 - vie moyenne
 - moment magnétique
 - etc



Les supernovae "historiques"

Nebuleuse du Crabe



The Crab Nebula in Taurus (VLT KUEYEN + FORS2)

ESO PR Photo 40/99 (17 November 1999)

© European Southern Observatory



an

185

369

1006

Chinois

1054

1181

1572 Tycho Brahe

1604 Kepler

1987A

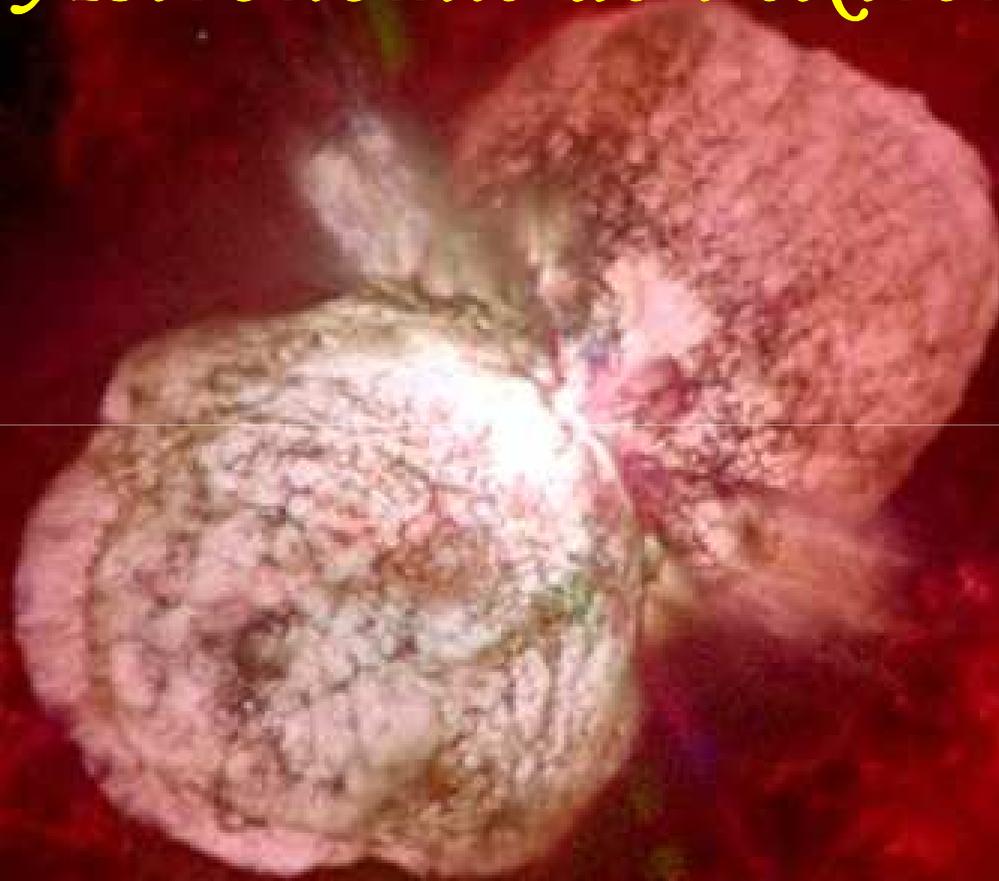
→ Première (et seule) observée en v

Betelgeuse
(20 Mo, 310 a.l.)



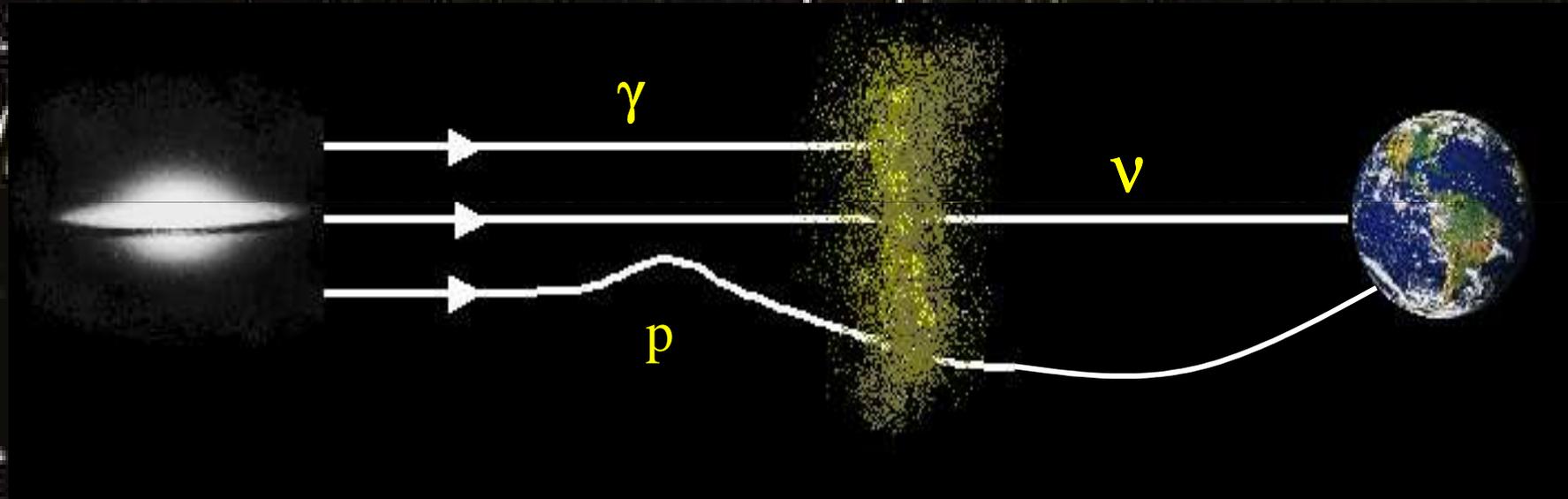
et “prochainement”

Astronomie de l'extrême



Astronomie Haute énergie

Messagers : γ , p , ν



Origine des neutrinos haute énergie

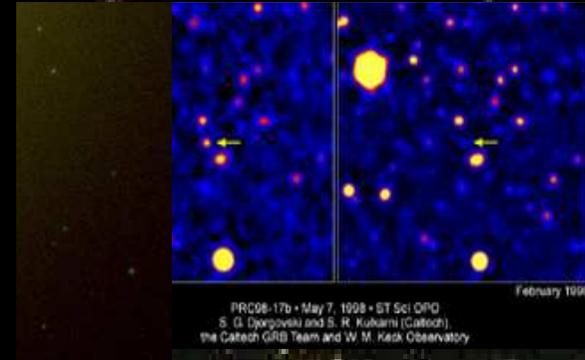
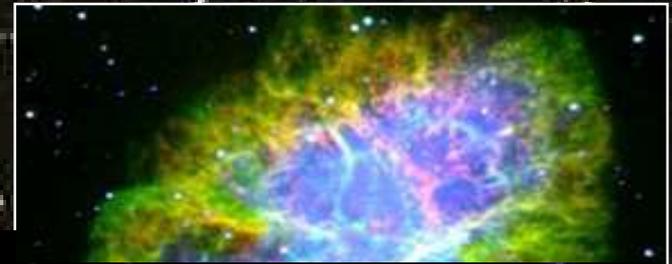
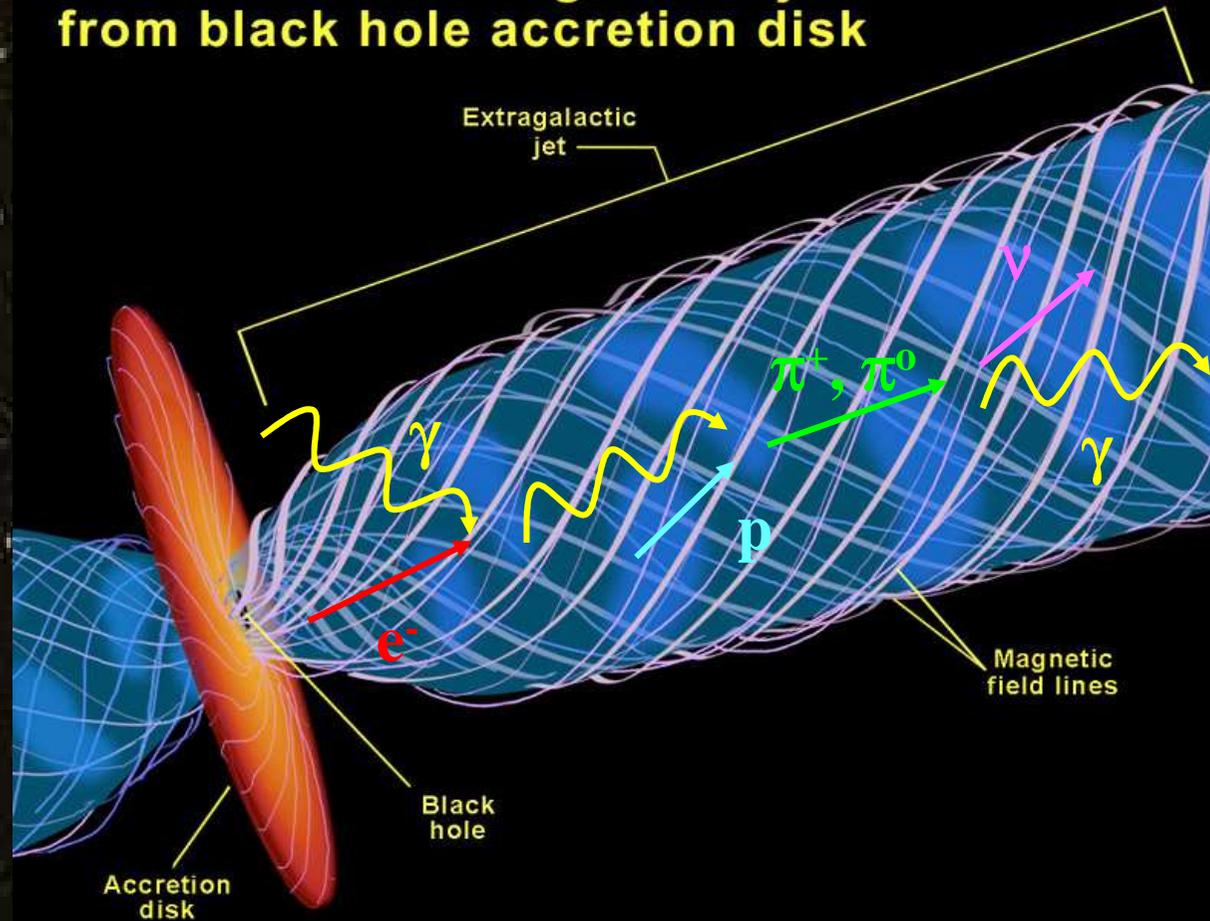
$$p + A \longrightarrow \pi^{+-} + \dots$$

$$\pi^{+-} \longrightarrow \bar{\nu}_{\mu} + \mu$$

$$\mu \longrightarrow \nu_{\mu} + \nu_e + e$$

Les sources

Formation of extragalactic jets from black hole accretion disk



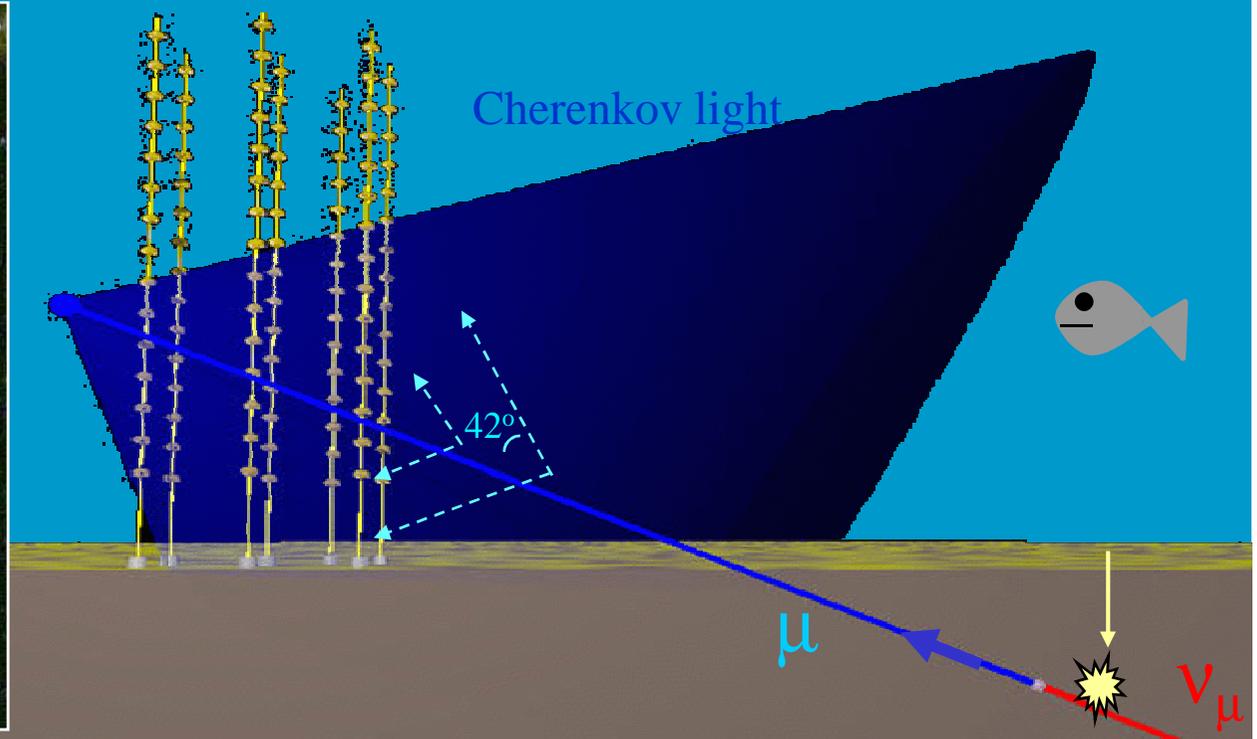
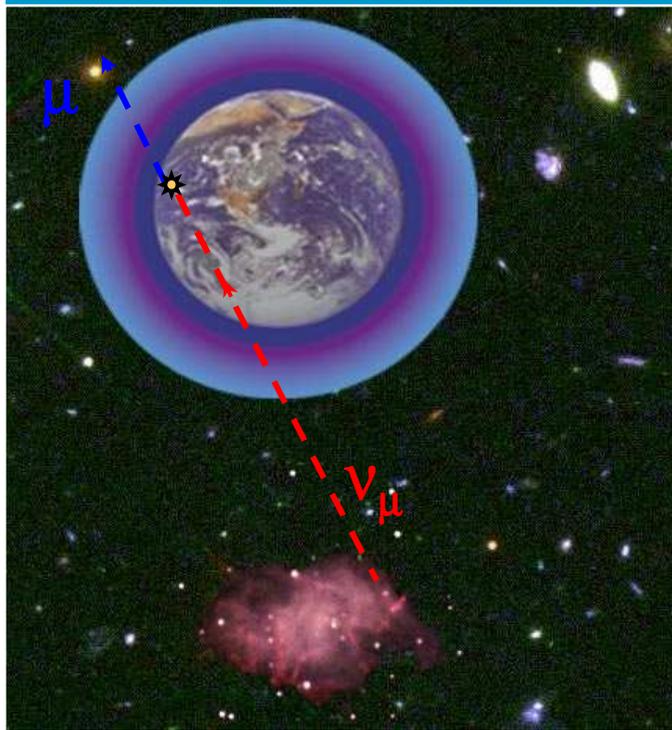
3C273

GRB 971214

Comment détecter les ν haute énergie

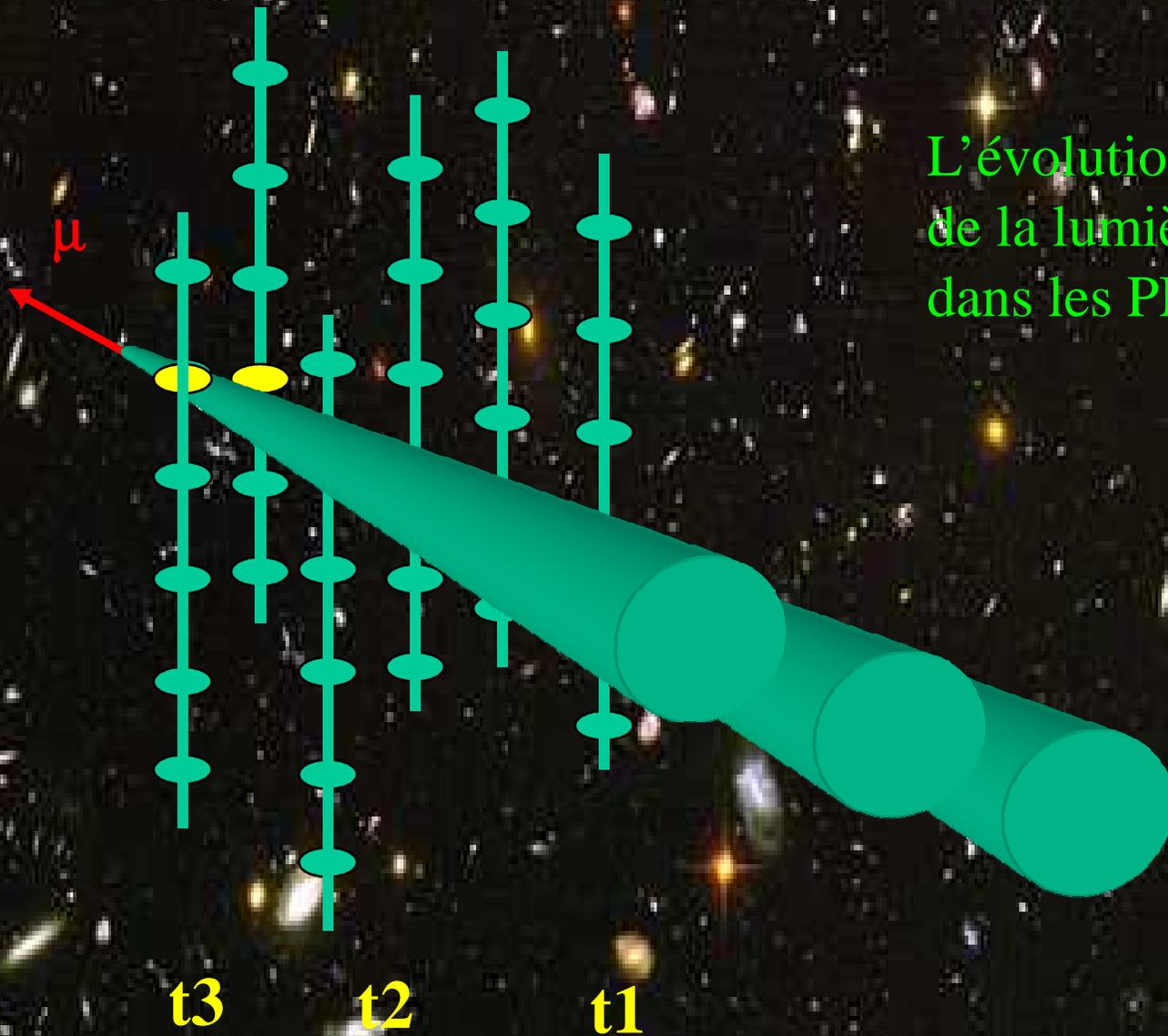
Très faibles flux => très grand détecteurs => Détecteur "naturel"

- Lumière Cherenkov dans l'eau de mer ou la glace
- Produite par les muons issus des neutrinos muoniques



Reconstruction de la trajectoire

L'évolution en temps
de la lumière Cherenkov
dans les PM donne la direction



ANTARES collaboration

1996 Collaboration formed



Sheffield
Leeds



NIKHEF
Amsterdam



Erlangen



ITEP
Moscow



IFREMER, Brest
DAPNIA, Saclay
IReS, Strasbourg
Mulhouse
CPPM, Marseille
IFREMER, Toulon
COM, Marseille
OCA, Nice



IFIC
Valencia

Pisa

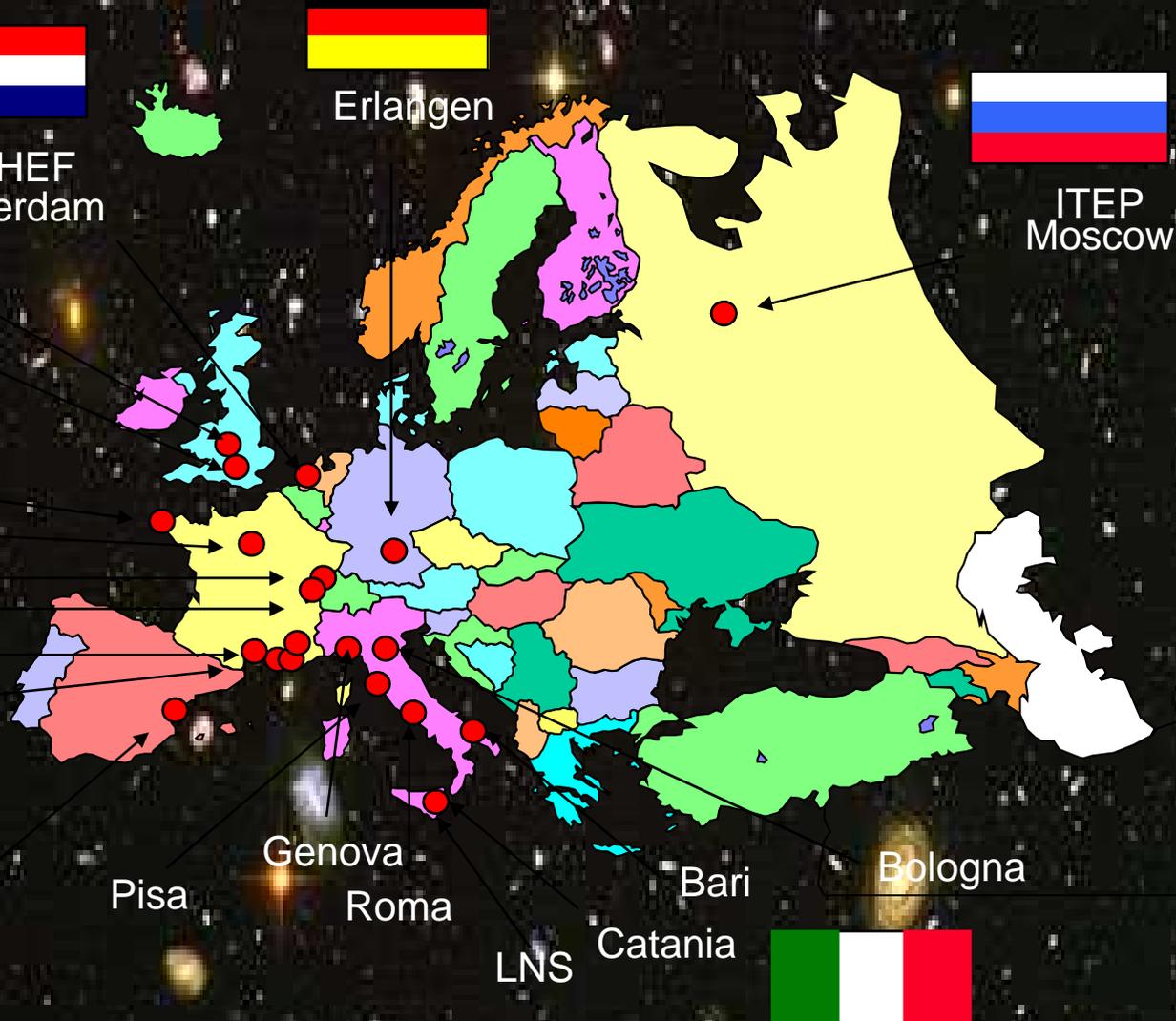
Genova

Roma

LNS

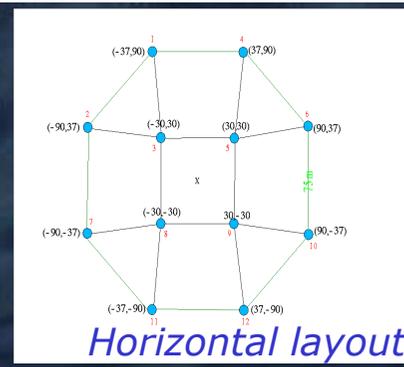
Bari

Bologna



The ANTARES telescope

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



a storey

14.5 m

350 m

to be deployed by 2005-2007

100 m

40 km to shore

2500m depth

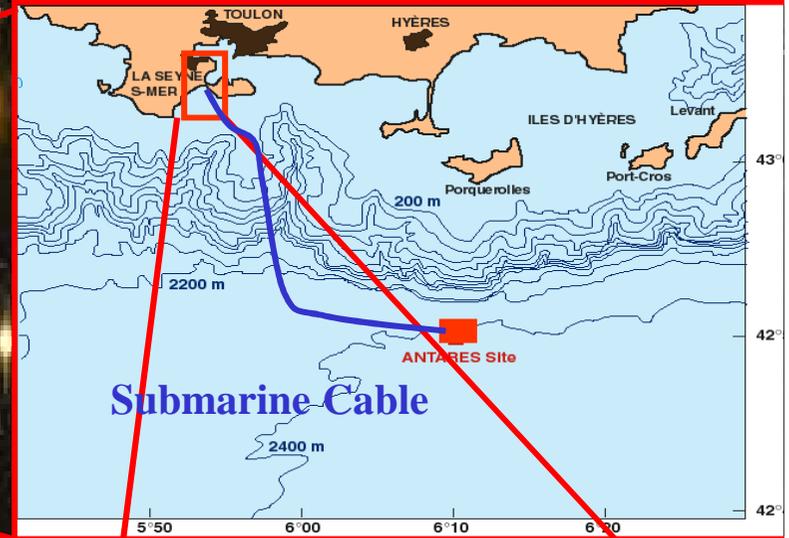
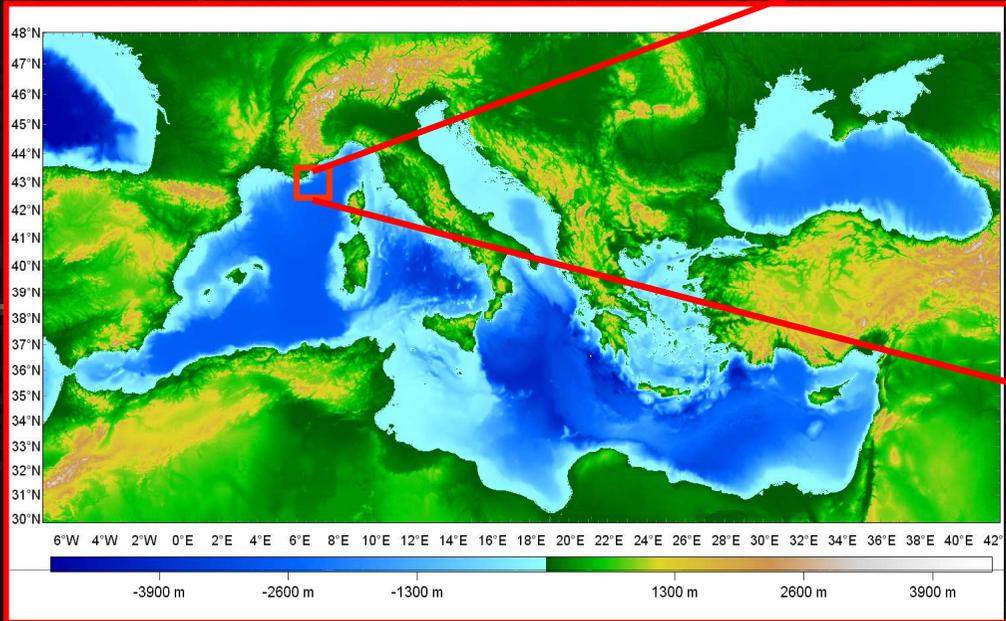
Junction Box

~70 m

Anchor/line socket

Submarine links

ANTARES Site



1996-1999 : R&D + Site Evaluation



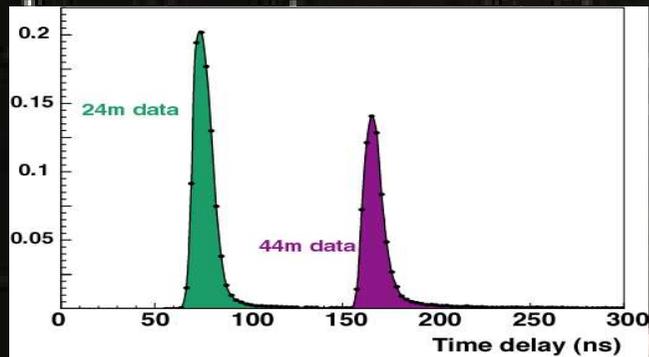
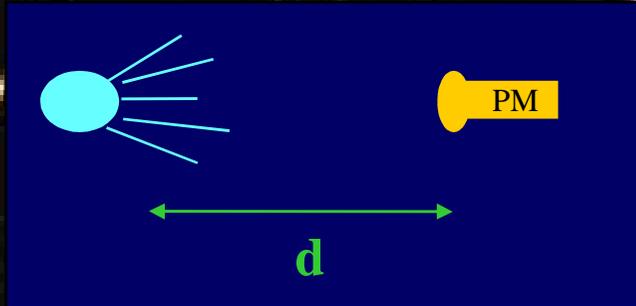
Institut Michel Pacha

Shore Station



Evaluation du site

Transparence de l'eau

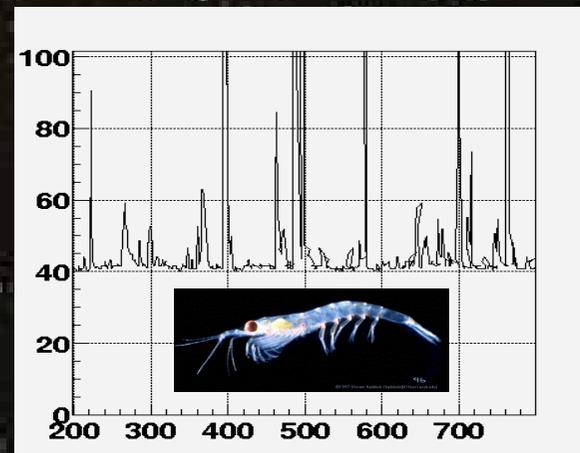
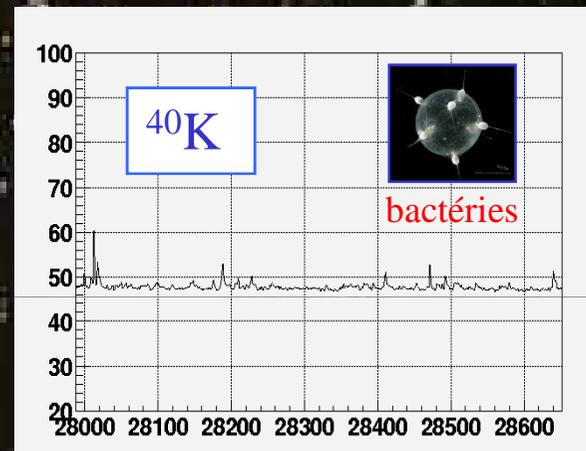


- Lumière bleue (470 nm)

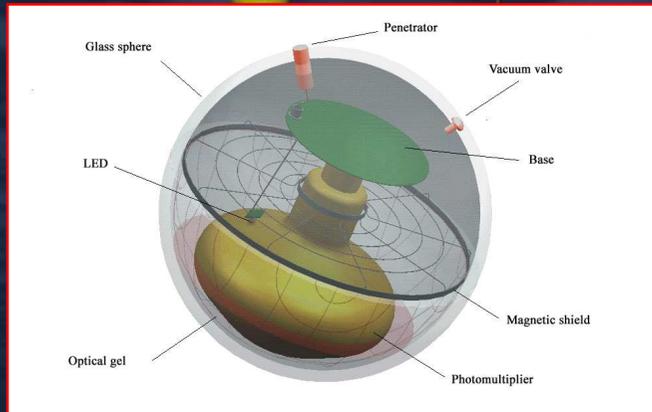
$$\lambda_{\text{abs}} \sim 60 \pm 8 \text{ m}$$

$$\lambda_{\text{scat eff}} \sim 260 \text{ m}$$

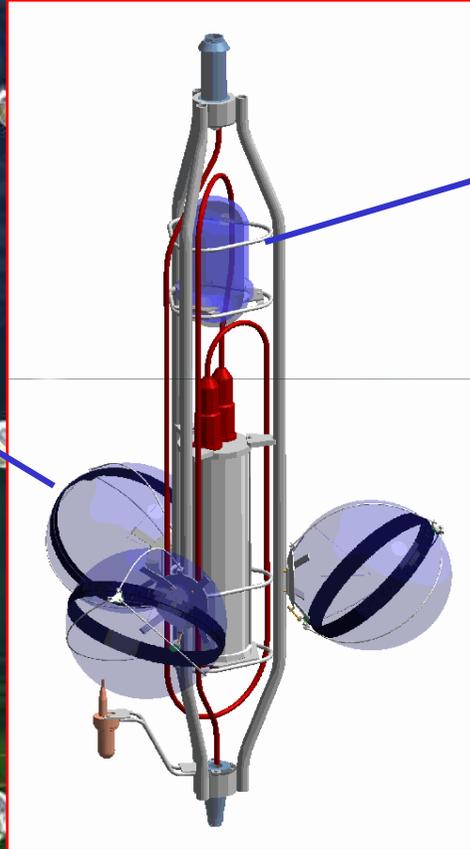
Bioluminescence



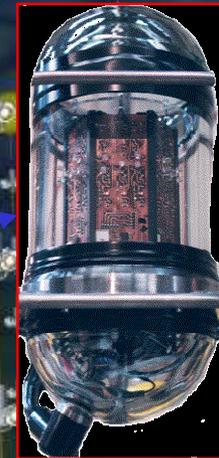
Constituants du télescope



Module optique :
PM de 10" dans
sphères Bentos
supportant 300 bar.

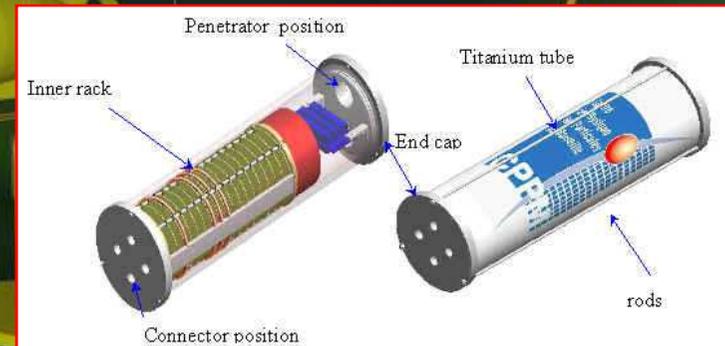


The storey



Balise optique :
étalonnage du
détecteur avec
LED bleu

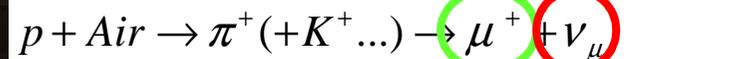
The Local Control Module :
gestion des signaux et
positionnement



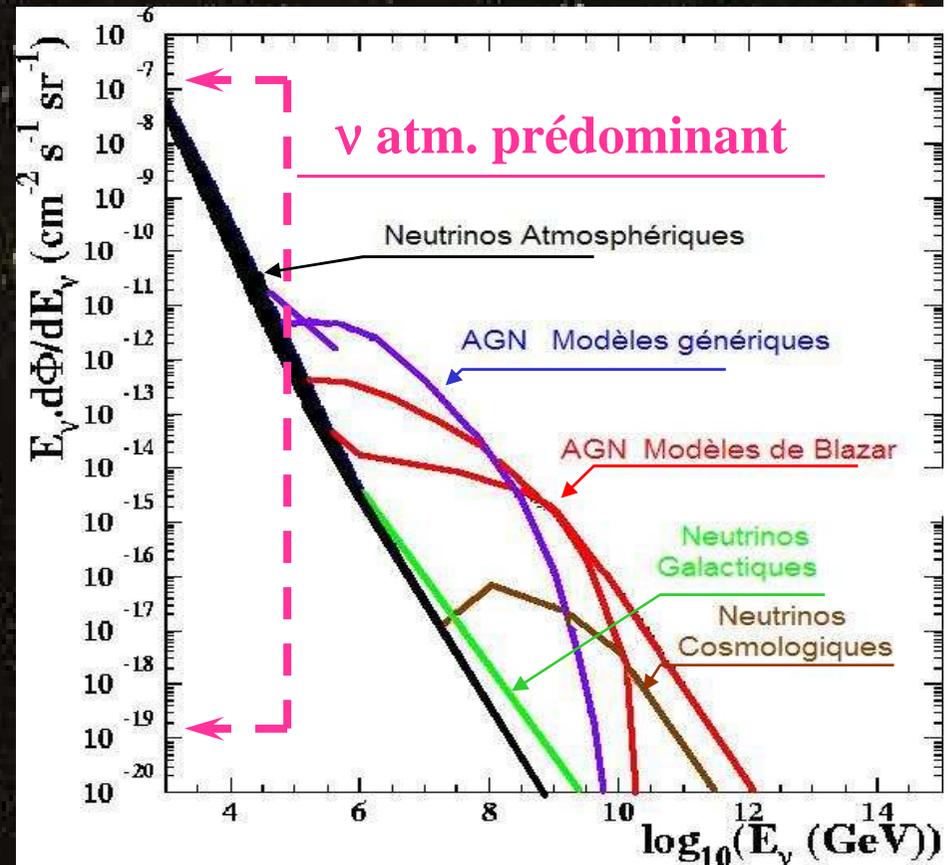
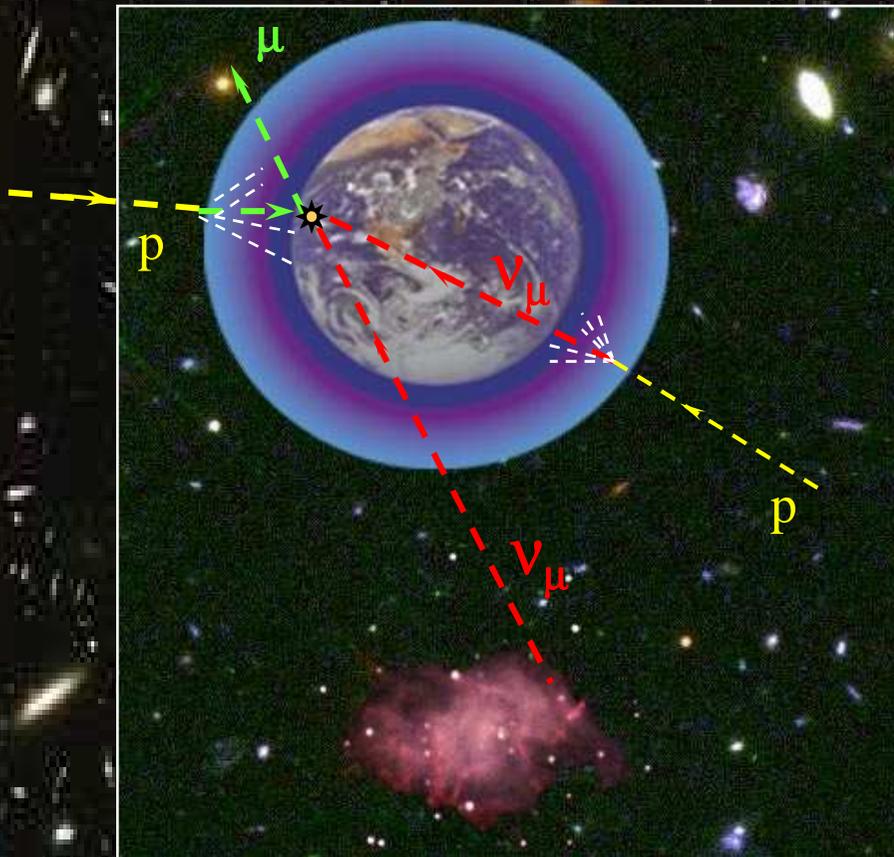


Bruit de fond physique

Le bruit de fond physique provient de l'interaction du rayonnement cosmique avec l'atmosphère.



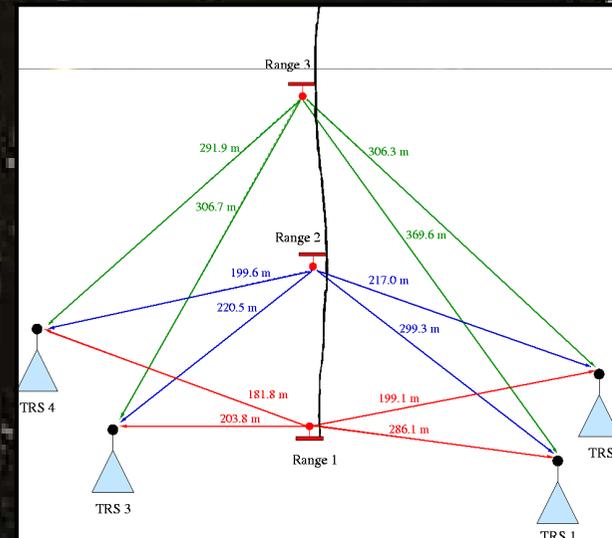
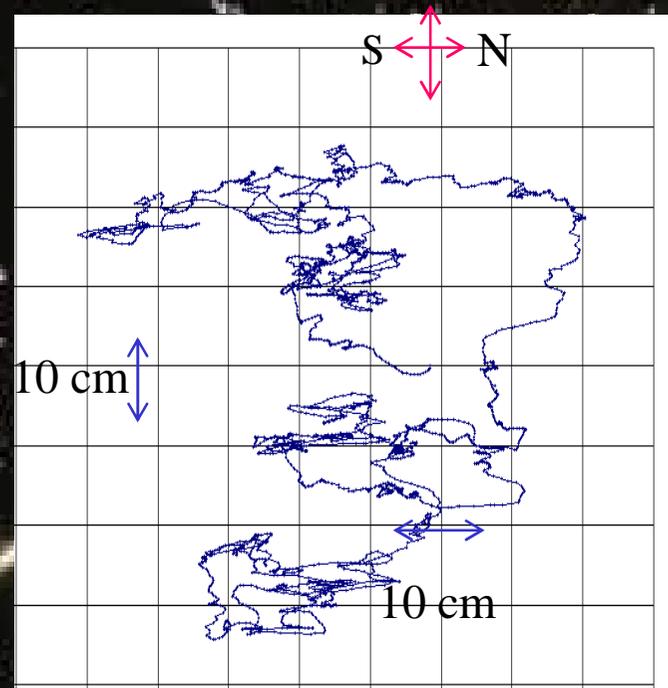
“Il faut regarder vers le bas et à haute énergie”



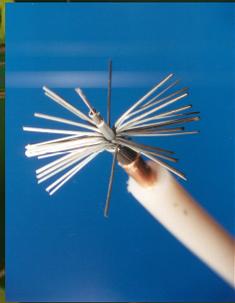
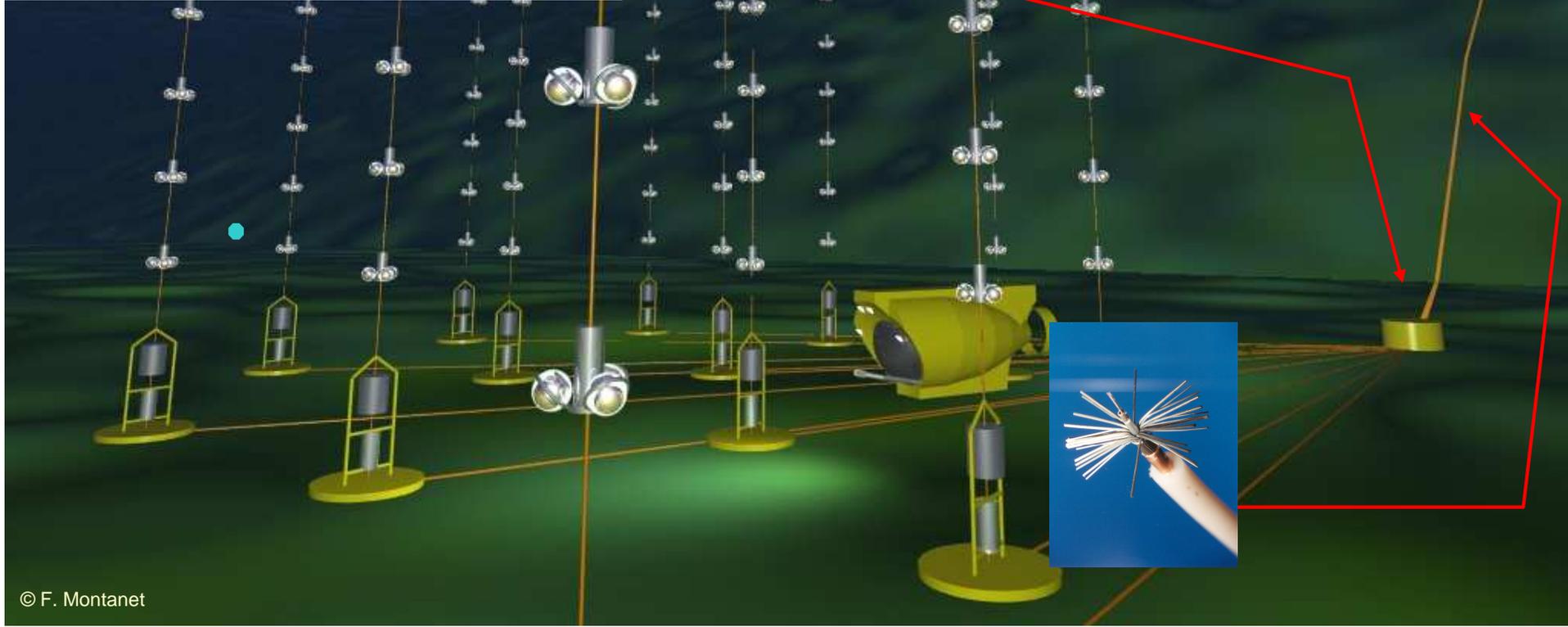
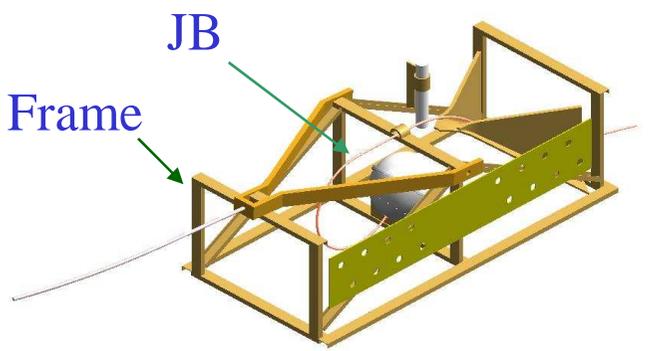
Positionnement de la ligne



Triangulation avec balise
acoustique et hydrophones
Précision ~5 cm



2000 - 2002



2000 – 2002

- Surveillance du site



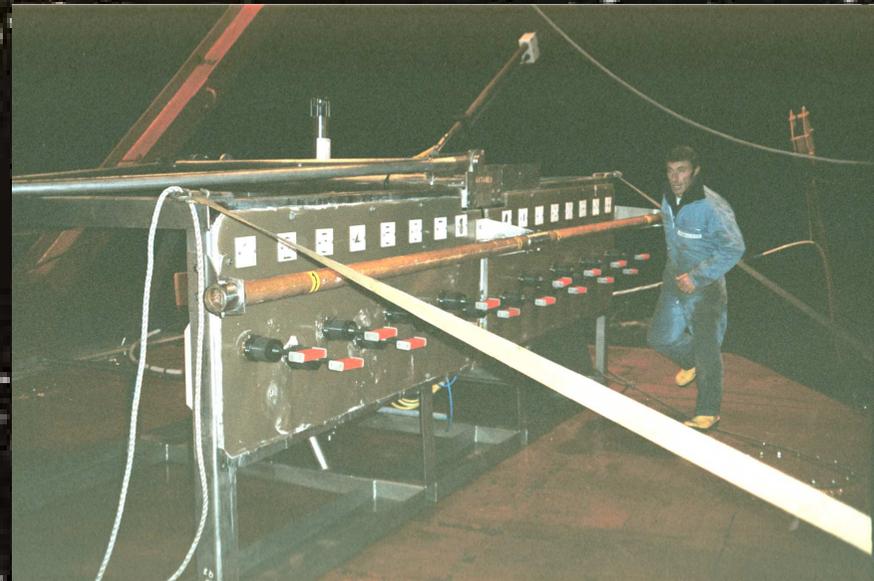
- Approximately 1 big object per ha
- All objects around detector location measured

- Déploiement du câble électro-optique



- Déploiement de la boîte de jonction

2000 – 2002



Detailed knowledge of large objects on site

Prototype sector line PSL & MIL

April 2003 – July 2003

**Prototype
Sector
Line
(PSL)
Dec 2002**

**Mini
Instrumentation
Line
(MIL)
Feb 2003**

PLS : 1/5 of a complete line

5 Storeys of
Optical Modules

Probe for
Sound velocity

Profiler for
Sea current
(ADCP)

Probe for salinity and
temperature (CTD)

LED Beacon

hydrophone

Junction Box

hydrophones

**Junc Box
Dec 2002**

Seismograph

Anchor with
electronics
containers

March 2003

Laser Beacon

Link Cables

**EO cable
Oct 2001**

PSL deployment and connection



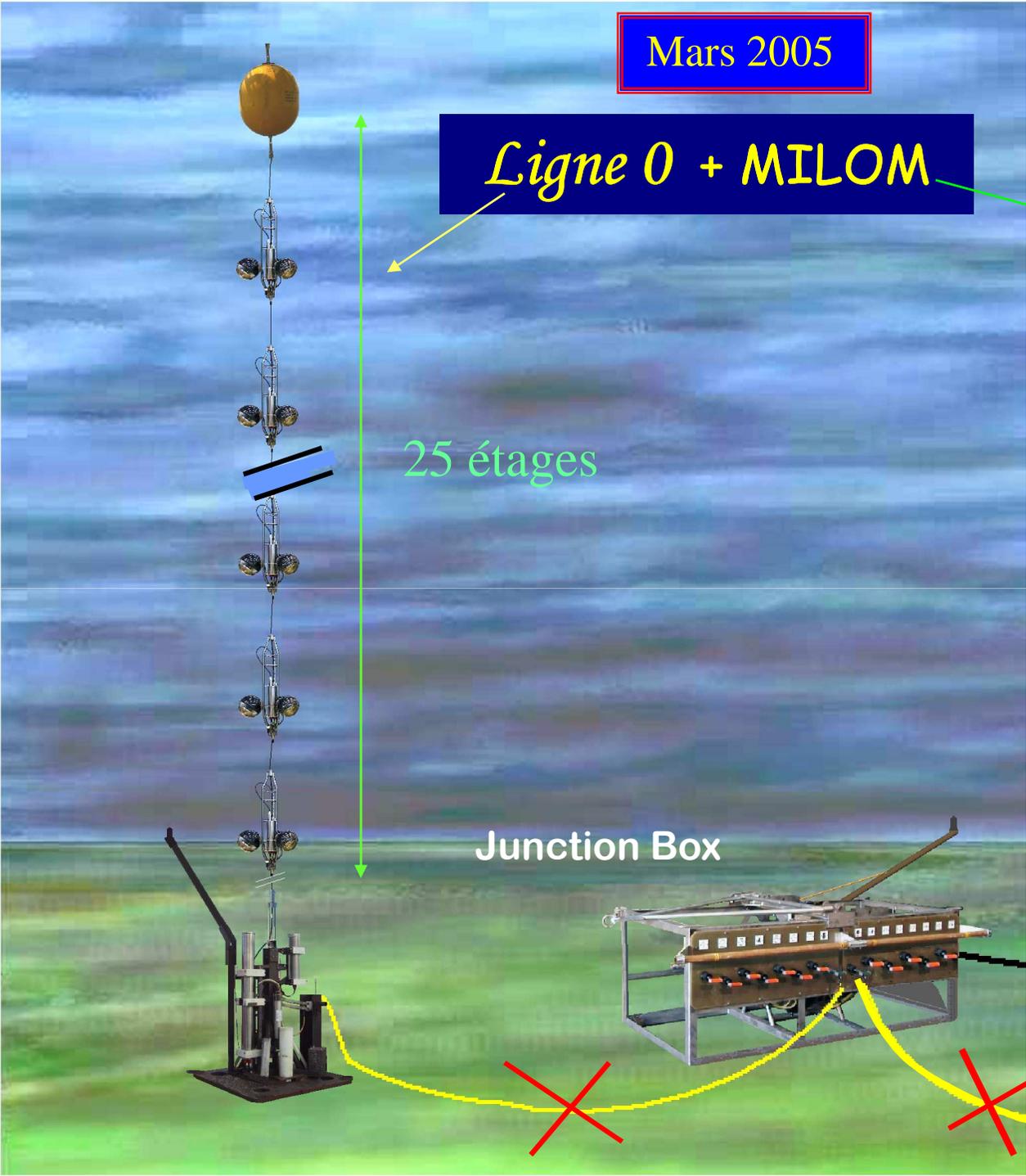
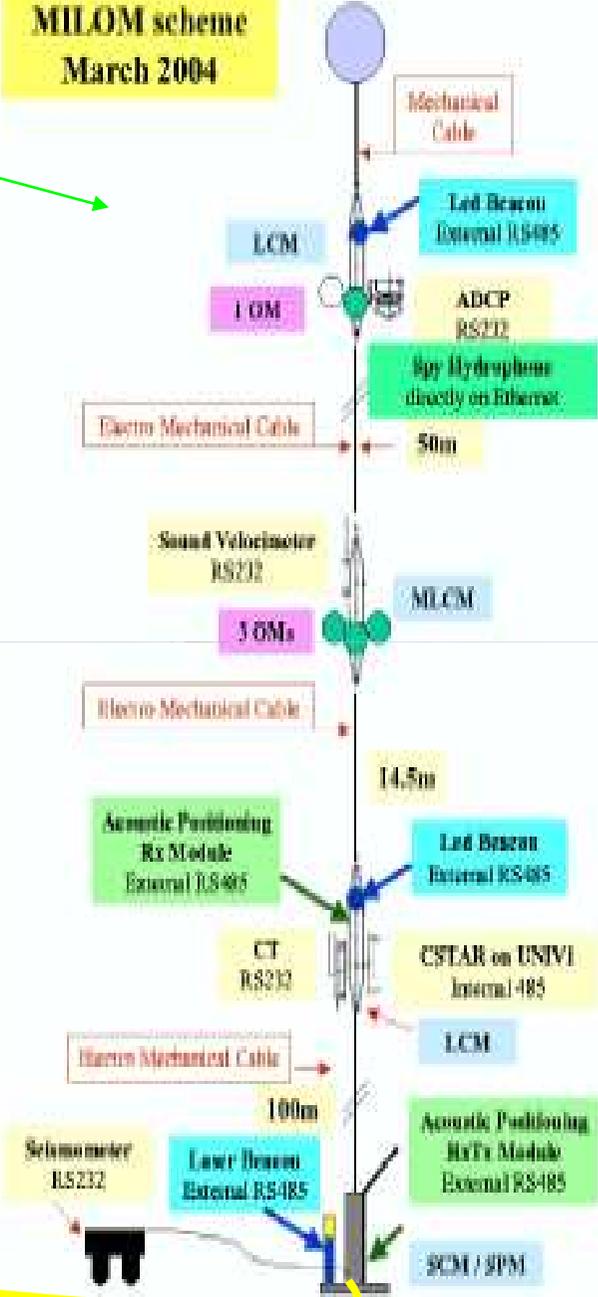
Mars 2005

Ligne 0 + MILOM

25 étages

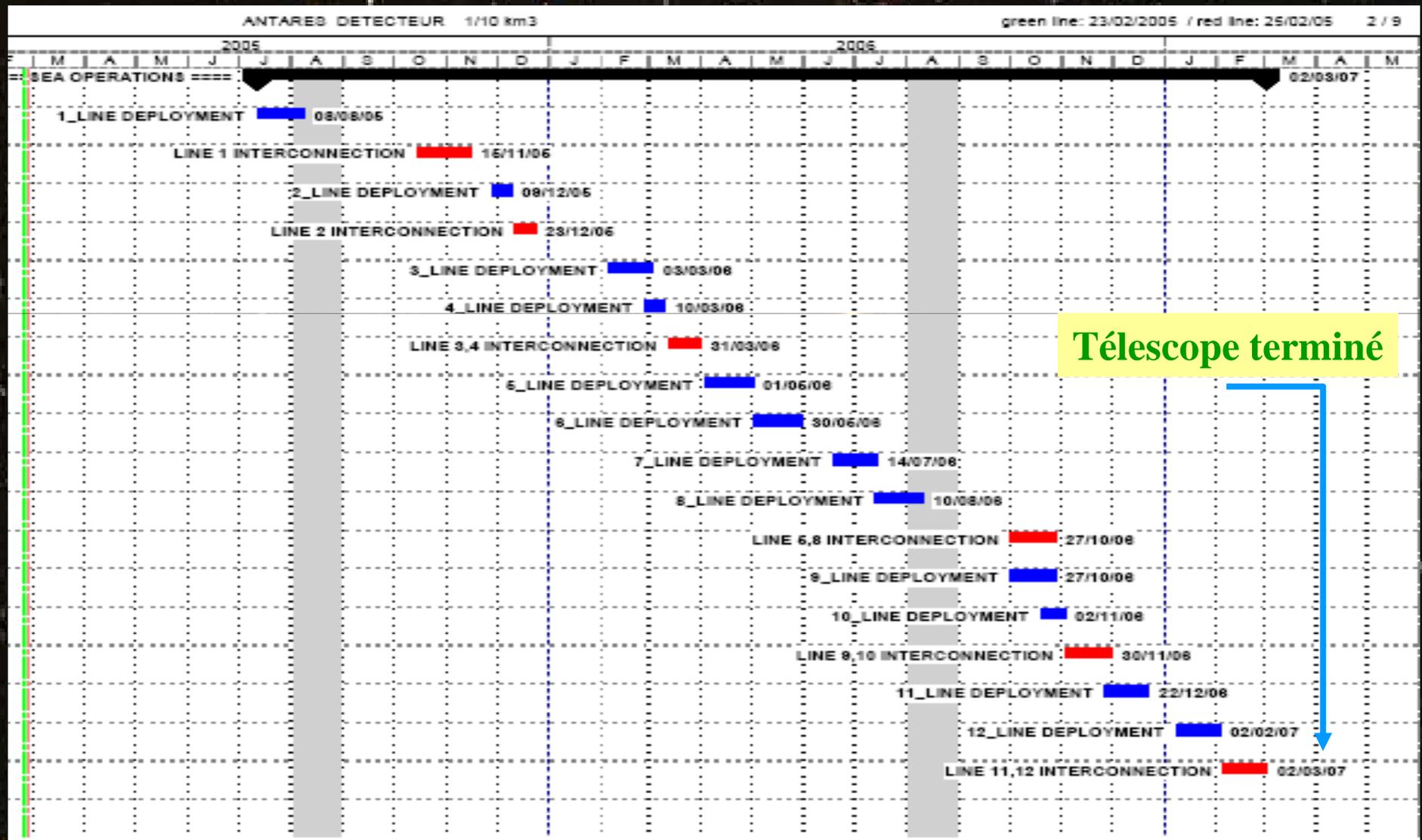
Junction Box

MILOM scheme
March 2004

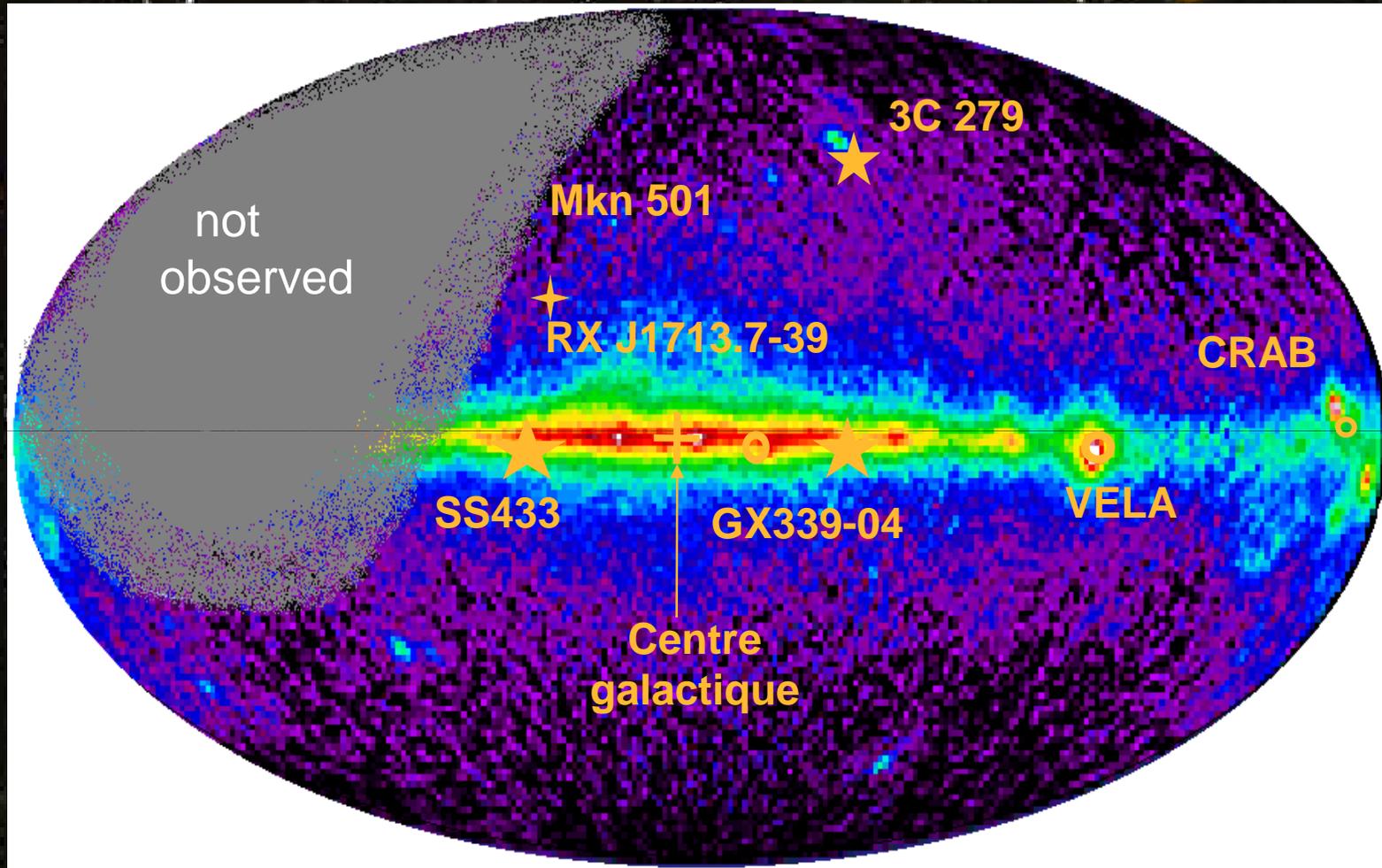


Avenir pour ANTARES

Juillet 2005 - 2007



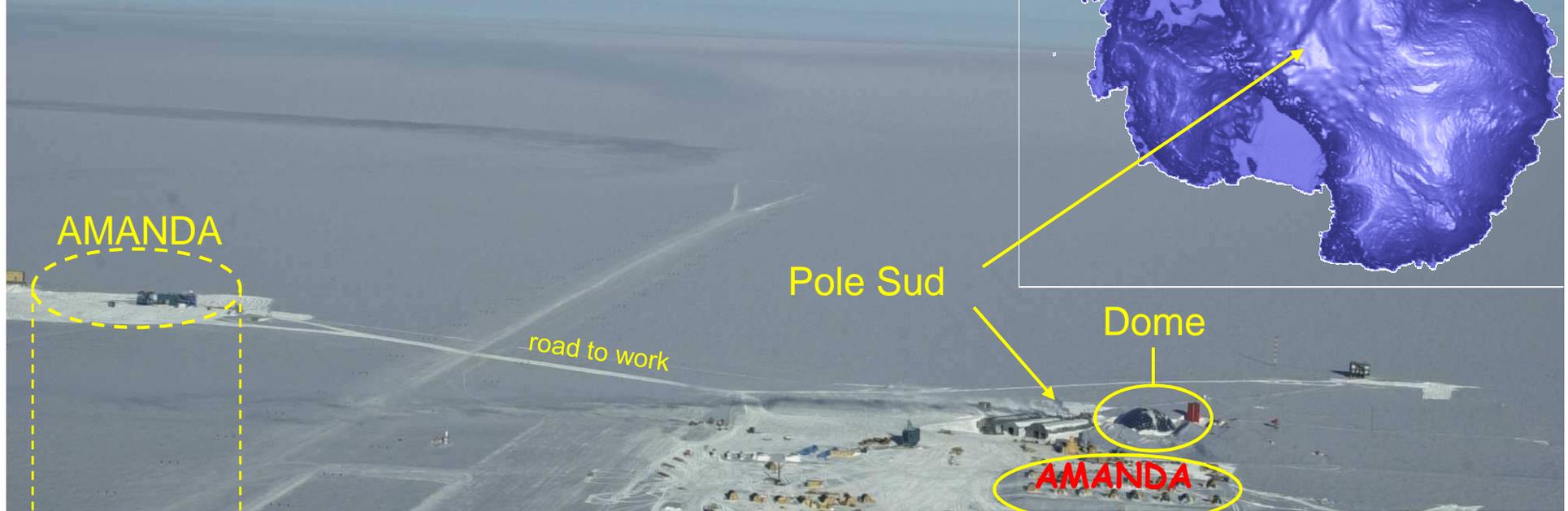
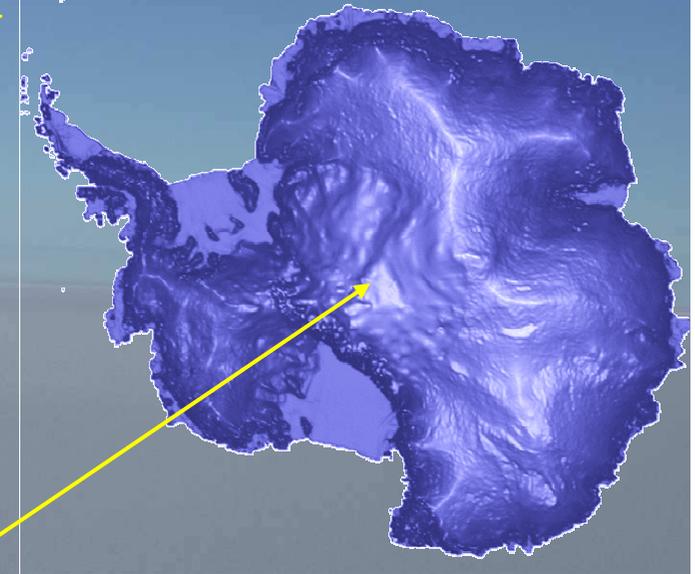
Le ciel vu par ANTARES



Sources γ bon candidats

Astronomie neutrino au pôle sud

AMANDA



AMANDA

Pole Sud

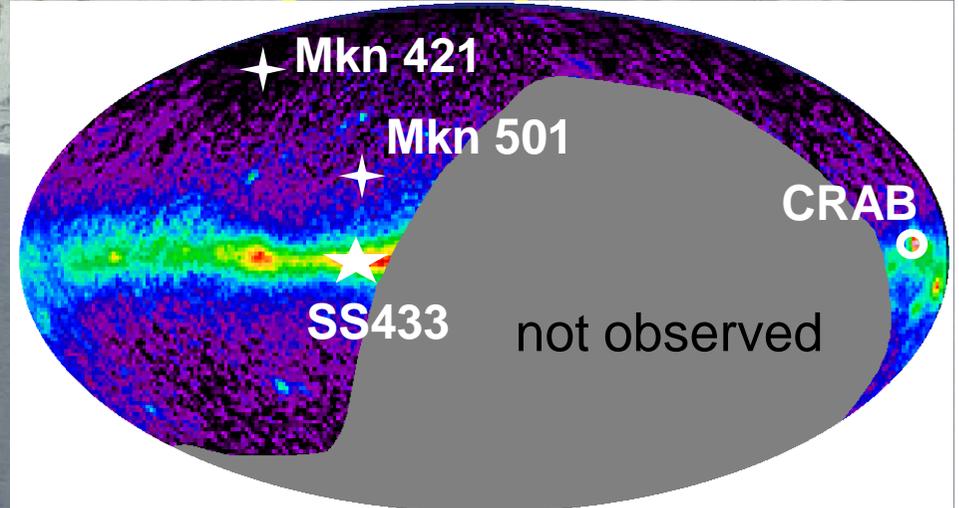
Dome

AMANDA

1500 m

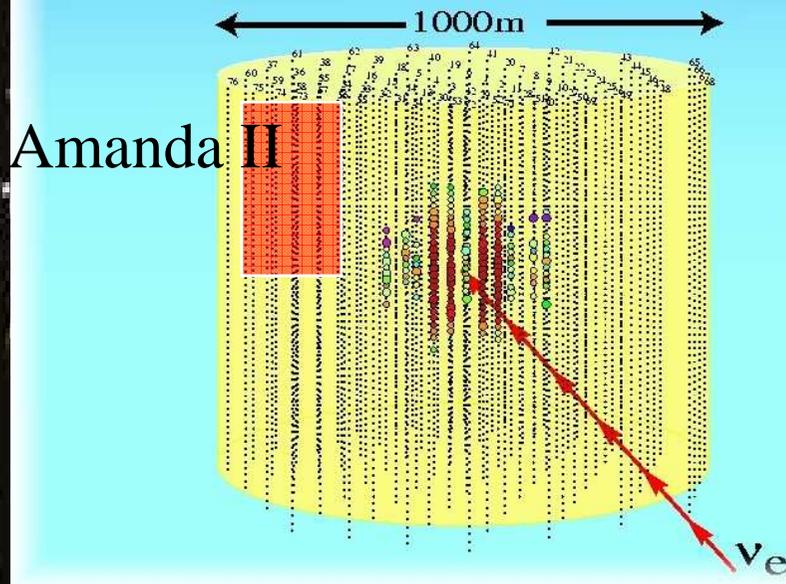
2000 m

[not to scale]



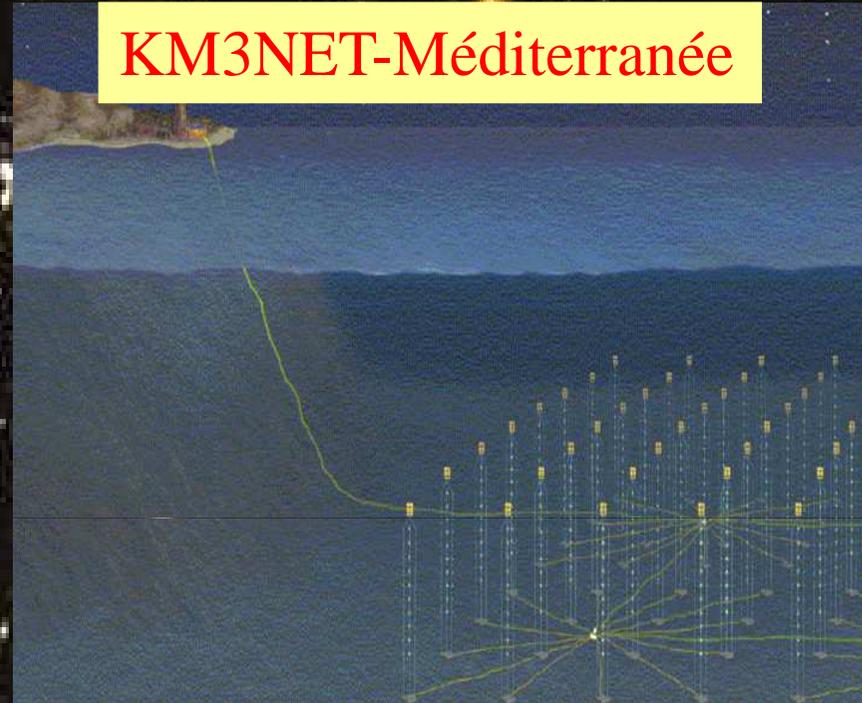
Prochaine Génération: KM3

ICECUBE-Pole Sud



- Finance en place (NSF)
- 80 lignes, 60 PM/ligne: 4800 PMs total
- $V \approx 1 \text{ km}^3$, $E_{\text{th}} \sim 0.5\text{-}1\text{TeV}$
- Fin construction ~2011?

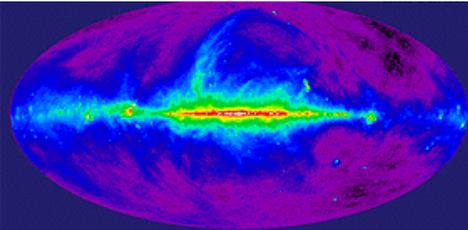
KM3NET-Méditerranée



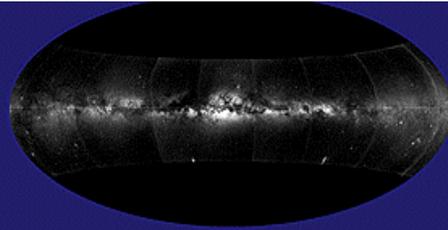
- EU FP6 design study (2006-2008)
- lignes/tours? ~5000 PMs
- $V \approx 1\text{km}^3$, $E_{\text{th}} \sim 0.5 \text{ TeV}$
- Construction ~5ANS

Conclusion

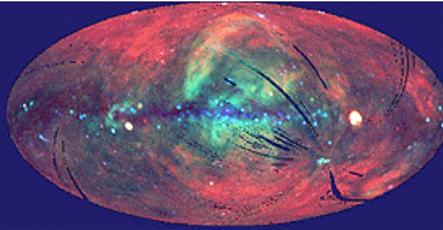
Radio



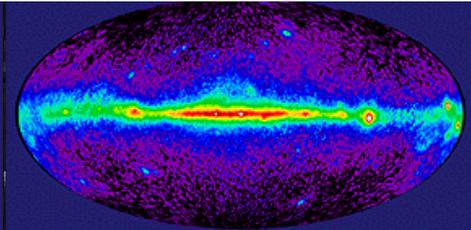
Lumière visible



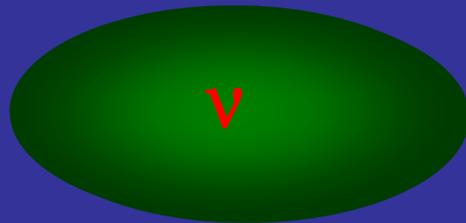
Rayon X

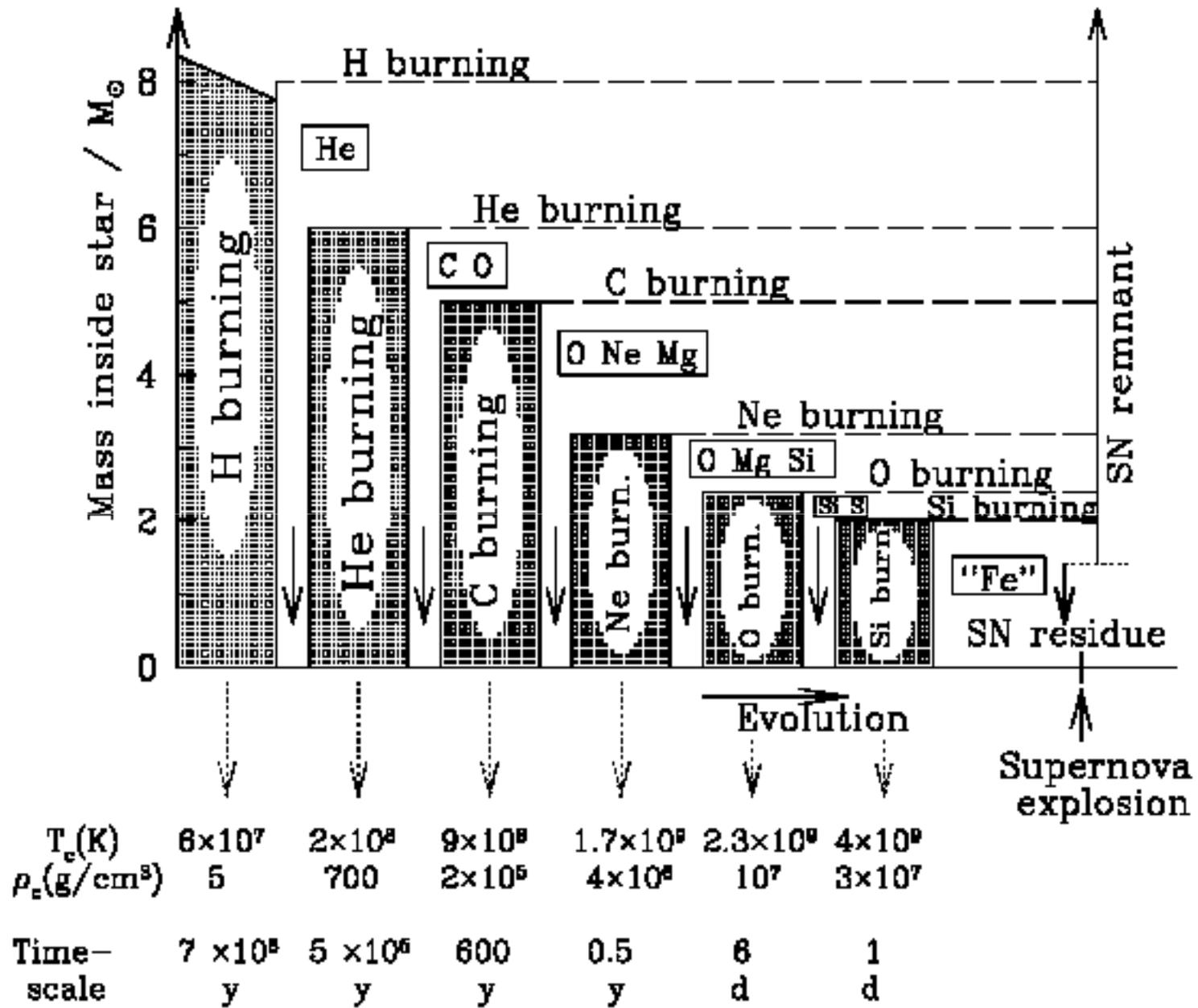


Rayon gamma

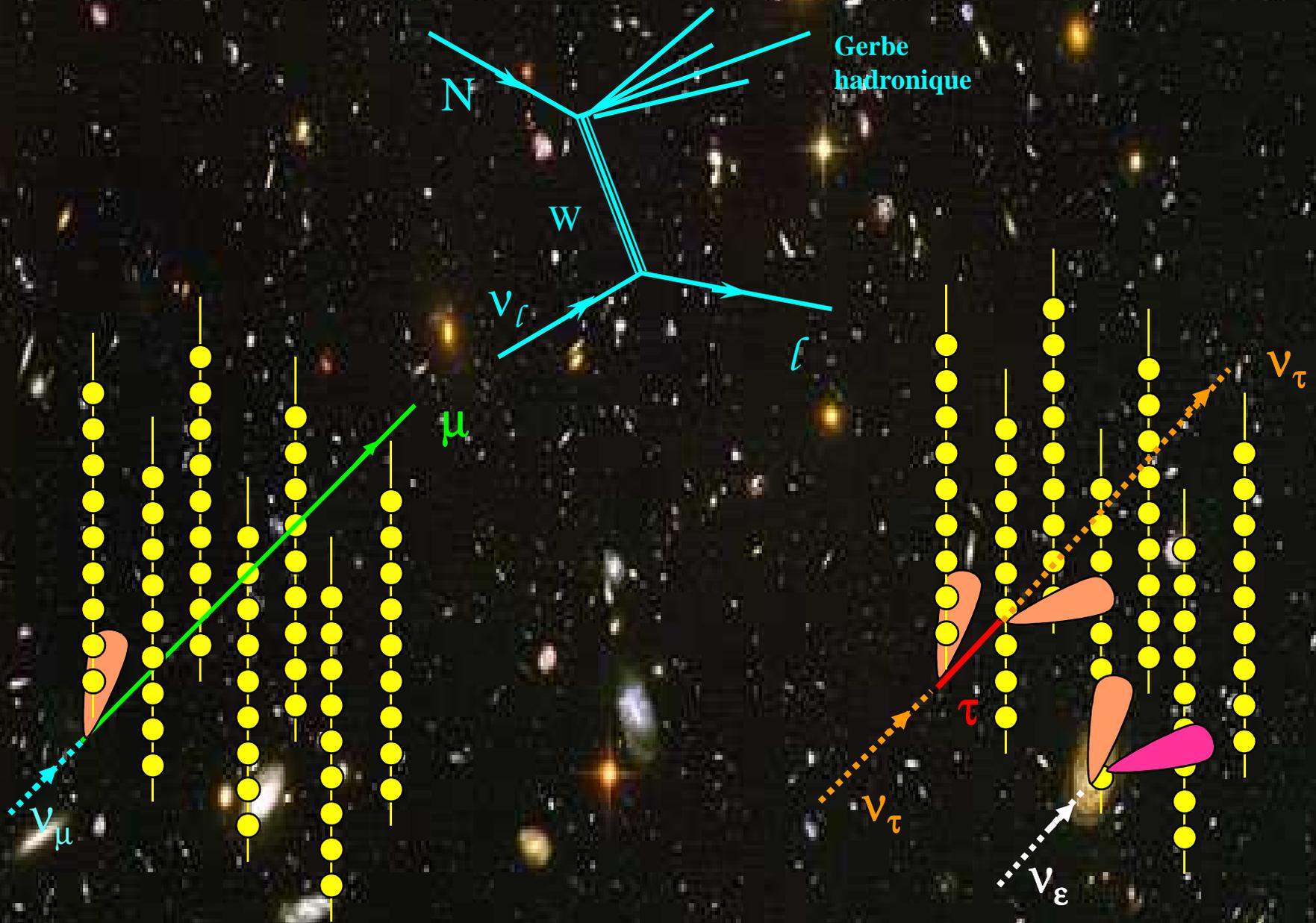


Neutrino

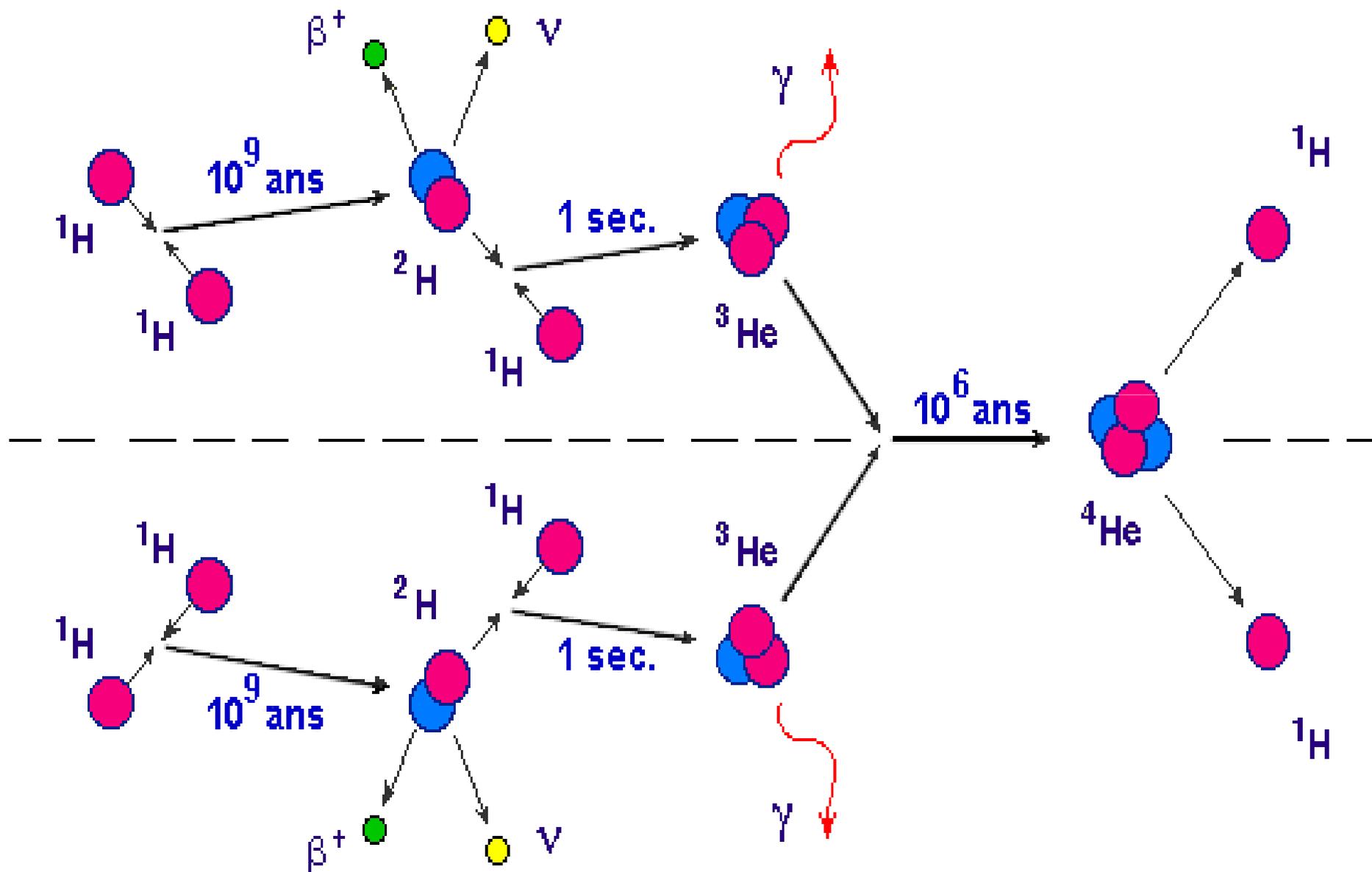




Différents type d'événements

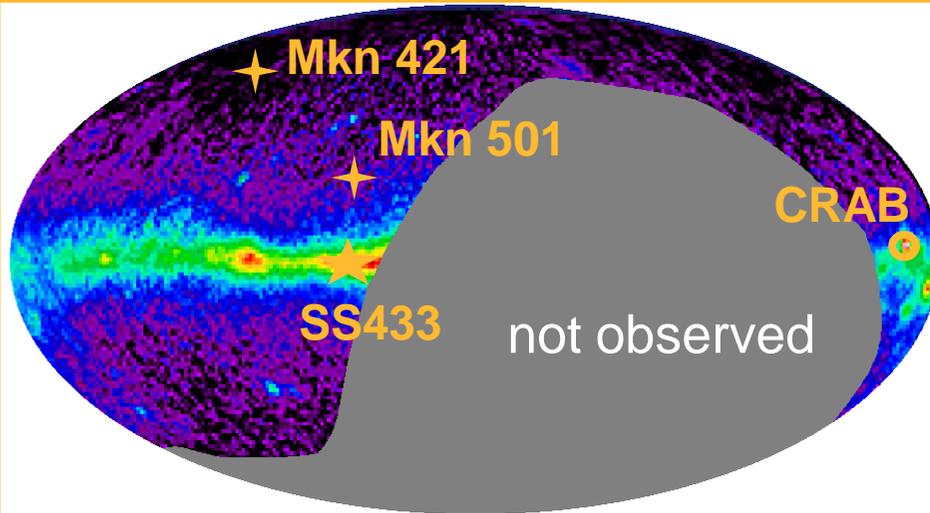


Dépendance en temps

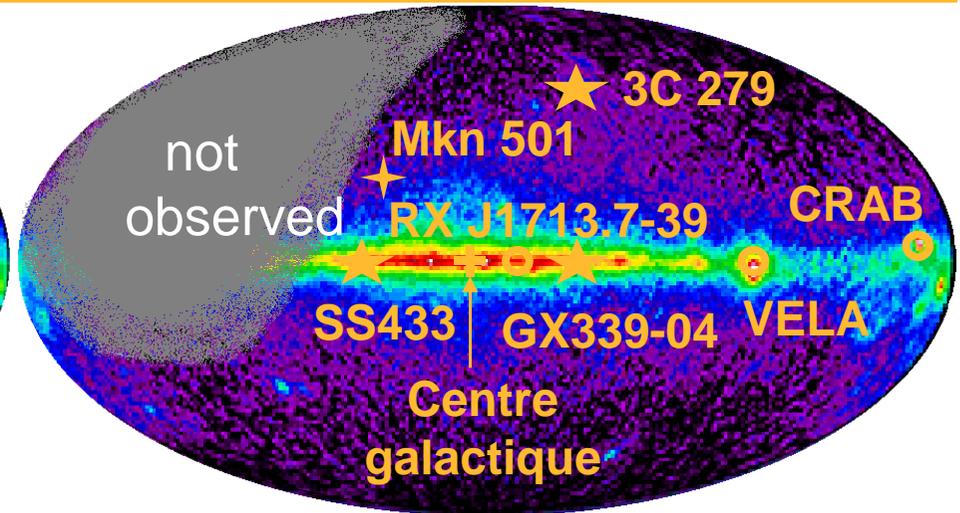


Most promising sources

AMANDA



ANTARES



EGRET Source Type	number of sources	seen by Antares	seen by Amanda
All	271	89%	43%
AGN	94	86%	52%
Pulsars	5	100%	40%
Unidentified Gal. Plane	55	93%	36%
Unidentified off Gal. Plane	116	90%	40%

Microquasars:

SS433 →

GX339 →

	Signal	atm. nu's
Antares 1 year	4.3	0.3
Amanda 1 year (*)	2.0	4.4
Amanda observed (*)	0	2.4
Antares 1 year	6.5	0.3
Amanda	invisible	—

Predictions. Galactic sources

Source Type	Distance (kpc)	E_ν (GeV)	$N_{\nu\mu}$ ($\text{km}^{-2} \text{yr}^{-1}$)	Ref.
Supernovae Shocks pulsars	10	$< \sim 10^3$ $\sim 10^2 - 10^6$ $\sim 10^5 - 10^8$ $\sim 10 - 10^8$	~ 100 50 – 1000 $\sim 100 - 1000$ $< \sim 1000$	Waxman & Loeb 2001 Protheroe et al. 1998 Beall & Bednarek 2002 Nagataki 2004
Plerions Crab	0.5 – 4.4 2	$< 10^3 - 10^5$ $\sim 10^3 - 5 \cdot 10^5$ $\sim 10^3 - 5 \cdot 10^5$ $\sim 10^3 - 5 \cdot 10^5$ 10–10 ⁶	$\sim 1 - 12$ $< \sim 1$ a few ~ 1 $\sim 4 - 14$	Guetta & Amatto 2003 Bednarek 2003 Bednarek & Protheroe 1997 Bednarek 2003 Amato et al. 2003
Shell SNRs SNR RX J1713.7-3946 Sgr A East	6 8	$< \sim 10^4$ $< \sim 10^5$	~ 40 ~ 140	Alvarez-Muñiz & Halzen 2002
Pulsars + Clouds Galactic Centre Cygnus OB2	8 1.7	$10^4 - 10^7$ $> \sim 10^3$ $10^4 - 10^7$ $< \sim 10^6$	$\sim 2 - 30$ a few ~ 0.5 ~ 4	Bednarek 2002 Torres et al. 2004 Bednarek 2003 Anchordoqui et al. 2003
Binary systems A0535+26	2.6	$3 \cdot 10^2 - 10^3$	a few	Anchordoqui et al. 2003
Microquasars	1 – 10	$10^3 - 10^5$	1 – 300	Distefano et al. 2002
Magnetars	3 – 16	$< \sim 10^5$	1.7 (0.1/ $\Delta\Omega$) (5/d ²)	Zhang et al. 2003

Supernova 1987A Rings



Hubble Space Telescope
Wide Field Planetary Camera 2

