

Les nouveaux instruments pour sonder le Cosmos et la Matière

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Festival les deux infinis 26 Juin 2012



Archaelogie des deux infinis: lier la compréhension du cosmos à l'étude de sa texture

✓ Thalès: d'une cosmogonie anthropomorphique (Hésiode) vers une cosmologie hylémorphique. Le cosmos émerge du neutre par différentiation des opposées. Pourquoi cette transition? L'article neutre de la langue grecque? L'invention de la monnaie?

✓ Anaximandre: le premier fragment « ce n'est ni l'eau ni aucun autre des prétendus éléments, mais une substance différente de ceux-ci, qui est infinie (l'« apeiron », l'informe), et de laquelle procèdent tous les cieux et les cosmos qu'ils renferment. Et les choses retournent à ce dont elles sont sorties « «comme il est prescrit ; car elles se donnent réparation et satisfaction les unes aux autres de leur injustice, suivant le temps »».

✓ Suivent d'autres réductions théoriques

✓ *Pythogore:* au nombre

✓ *Platon:* à la géométrie

✓ *Aristote:* les catégories et la logique

(« archai » : principes, commencements)

(arithmétique, harmonies célestes)

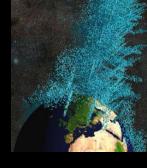
(éléments les 5 polyèdres, les Idées)

(physique-métaphysique, langue)

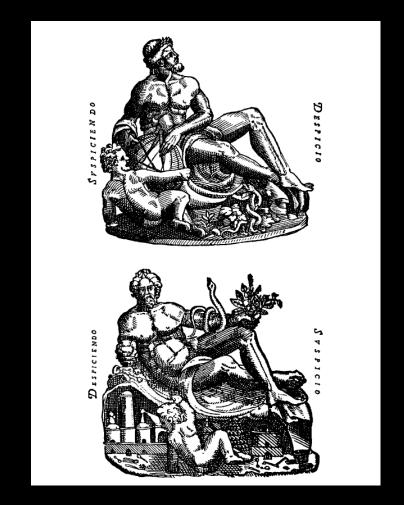
- ✓ Mais selon Aristote, le premier théoricien des deux infinis fut Platon (la dyade):
 - ✓ « Platon lui aussi a imaginé les infinis au nombre de deux, pour cette raison qu'il semble qu'on dépasse une limite et qu'on aille à l'infini à la fois par augmentation et par réduction »



Les deux infinis à la Renaissance: frontispiece de l'Uranienborg de Tyho Brahe



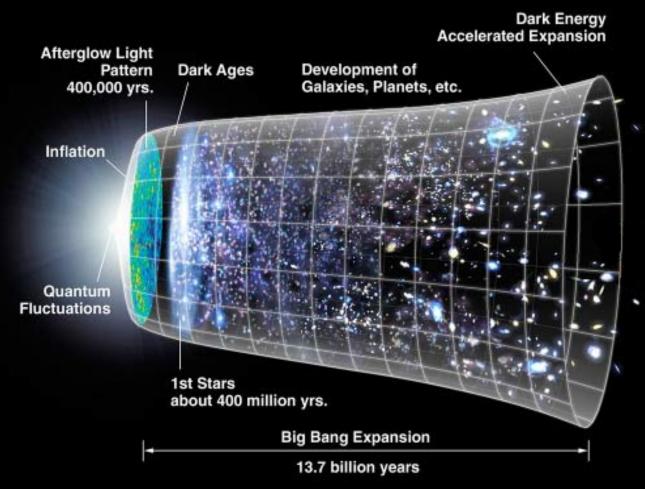
Suspiciendo despicio



Despiciendo Suspicio



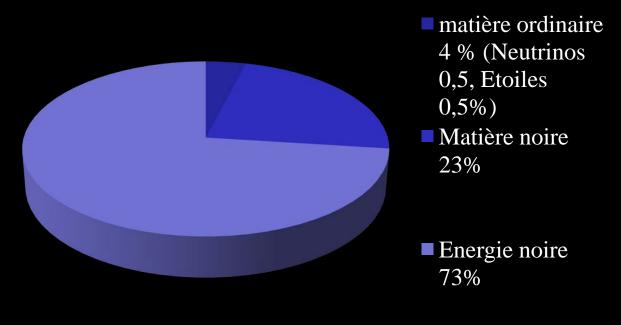
Le modèle standard de la Cosmologie

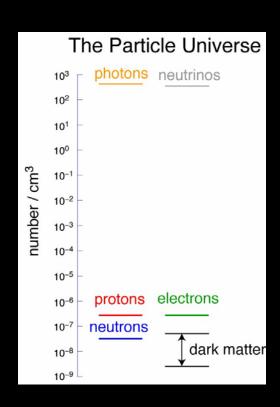




Questions ouvertes de la cosmologie





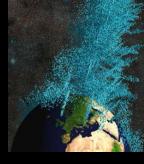


- Quelle est la nature de l'énergie noire ? (champ ou modification de la RG?)
- Quelle est la nature de la matière noire? (particule ou modification de la RG?)
- Quand et comment la matière a dominé sur l'antimatière ?
- Comment la structure (étoiles) a émergé parmi les 99,5% d'autres choses ?

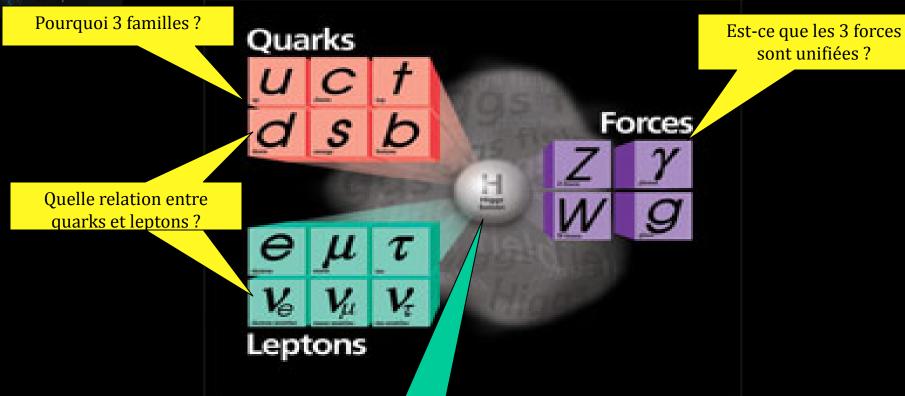




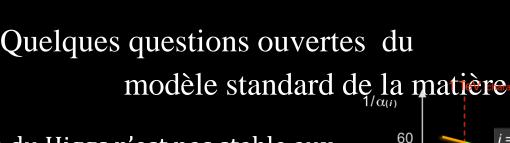
Le modèle standard de la matière



sont unifiées?



Higgs at 125 GeV?



✓ La masse du Higgs n'est pas stable aux corrections quantiques, sauf fine-tuning.

→ Supersymétrie

✓ La particule sypersymétrique la plus légère est candidate de matière noire

→ WIMP*

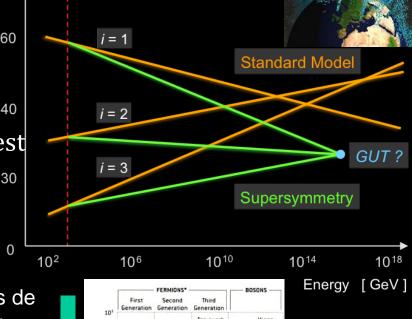
✓ Supersymétrie aide à l'unification.

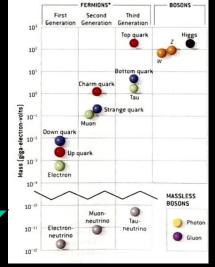
→ désintégration du proton

→ relations entre quarks et leptons

11 ordres de grandeur

- ✓ Pourquoi la masse des neutrinos est si différente des masses des autres particules?
- →Partenaire « lourd » du neutrino « standard » responsable de la masse légère de ce dernier par effet balançoire...
- → Leptogenèse → Baryogenèse → Brisure de la symétrie matière antimatière FF



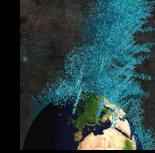


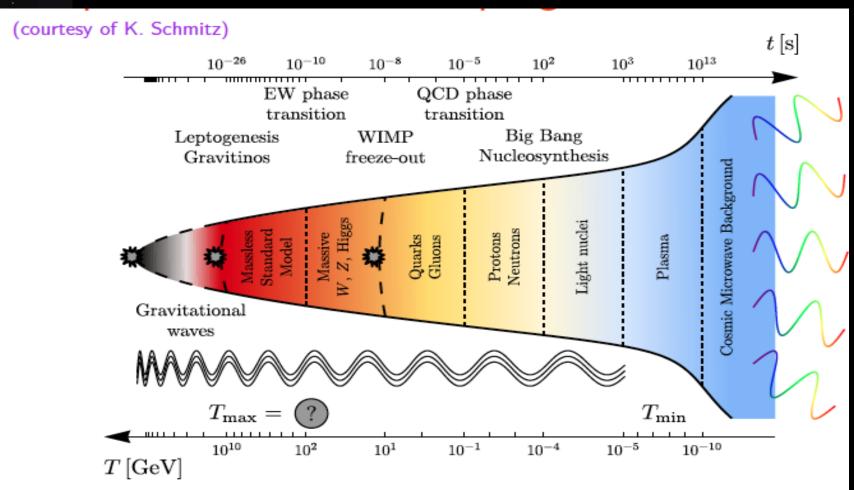
EFFETS d'un HIGGS 125 GEV?

^{*} Dimensions supplémentaires prédictions similaires



Le Big Bang du point de vue de la physique des particules



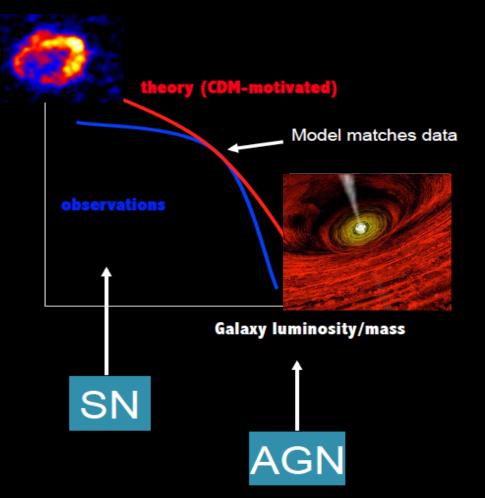




Un sujet à l'interface des deux modèles standards: les accélérateurs cosmiques

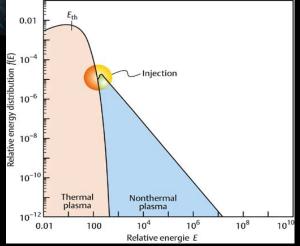
L'hypothèse des particules de matière noire ne suffit pas simuler la formation des structures

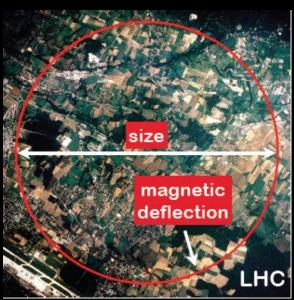
→ Trop des galaxies nains et géants



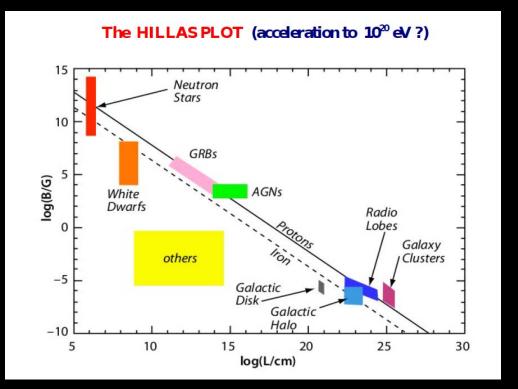
Les phénomènes violents régulent la formation des structures par feedback

Modèles d'accélération



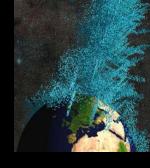


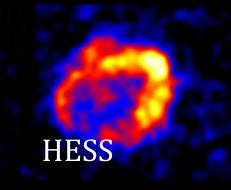
- L'accélération est très probablement continue
- Il faut des champs magnétiques pour confiner les particules
- L'énergie maximal dépend du champ magnétique et des dimensions de l'accélérateur





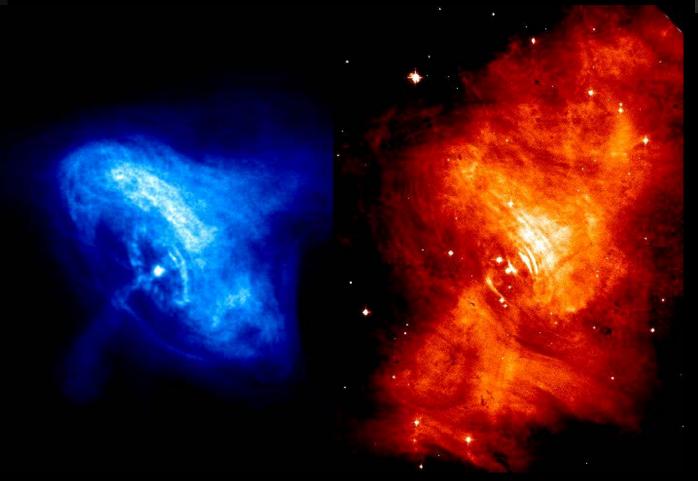
Phénomènes violents: exemple 1: Supernova



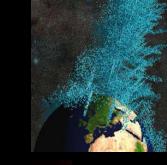


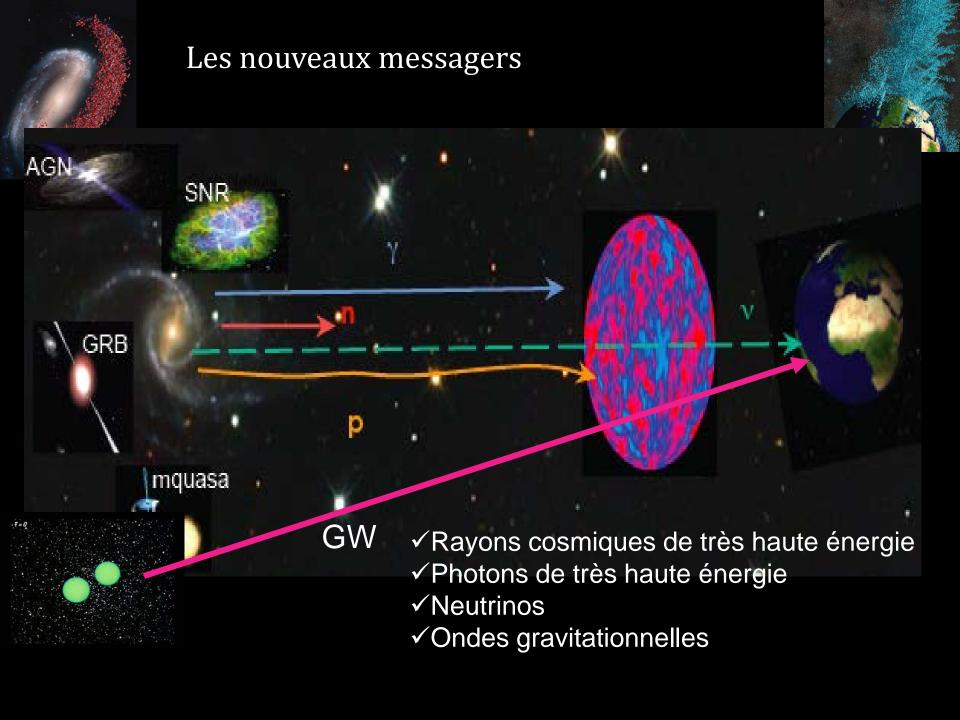


Phénomènes violents: exemple 2: Pulsars

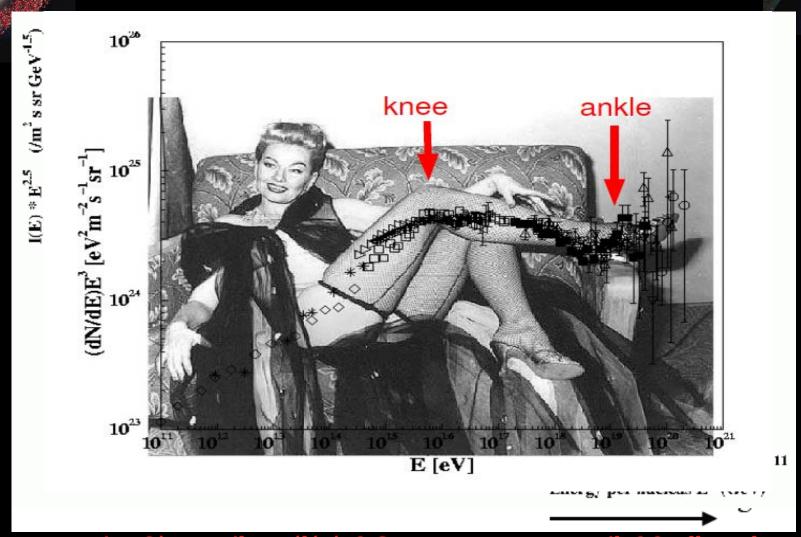


Phénomènes violents: exemple 3: Fusion de trous noirs ou étoiles à neutrons





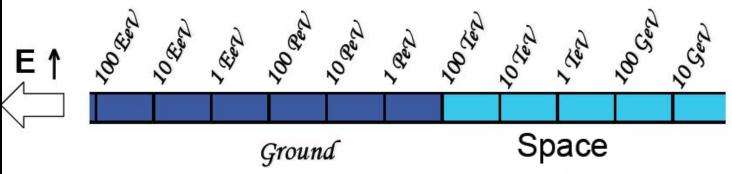
Le spectre des rayons cosmiques



Enigme centenaire: Où sont -ils accélérés? Comment se propagent-ils? Quelle est leur composition? 2 infinis mieux comprendre leur partie astrophysique pour déceler des traces de nouvelle physique

Charged cosmic rays

Crédit : J. Paul







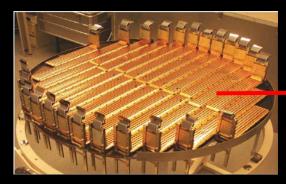
Un détecteur de particules à l'ISS: AMS 1 an sur la station spatiale 17 milliards de RC collectés



Transition Radiation Detector (TRD)



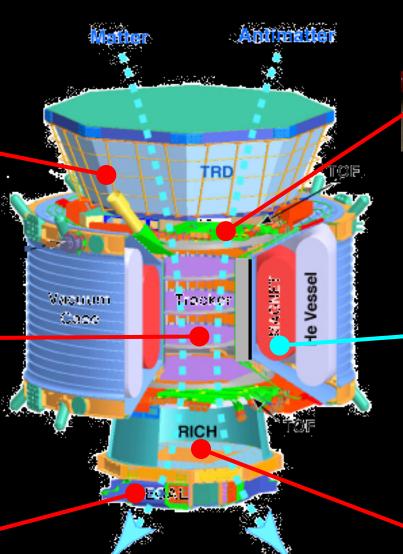
Silicon Tracker



Calorimeter (ECAL)



Détecteur AMS

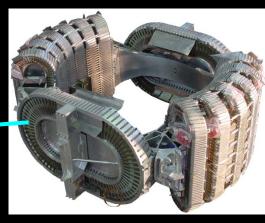


Résultats à l'automne

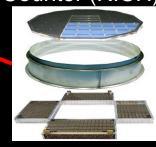
Time of Flight Detector (TOF)



Magnet



Ring Image Cerenkov Counter (RICH)



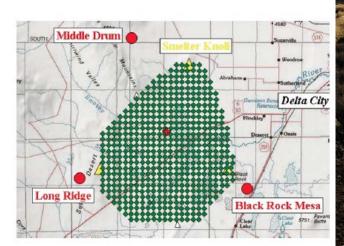
The Pierre Auger Observatory

Located in Argentina, province of Mendoza, Malargue Total area 3000 km²

- Surface Detector array (SD)
 - water Cherenkov detectors
 - ❖ 1660 in 1.5 km grid
 - 61 in 0.75 km grid (infill low energies $\sim 3 \times 10^{17} \text{eV}$)
 - ♦100% duty cycle
- Fluorescence Detector (FD)
 - ❖ 4 Fluorescence sites + I (Heat low energies ~ IO¹⁷eV)
 - ♦ 6 telescopes per site (3 for Heat)
 - ❖ ~ I 4% duty cycle (moonless nights)
- Atmospheric monitoring
 - **❖**Lidars
 - **CLF**
- Muon detectors(AMIGA)
- Radio detectors (Mhz & GHz)



Telescope Array (Hybrid, Northern hemisphere)



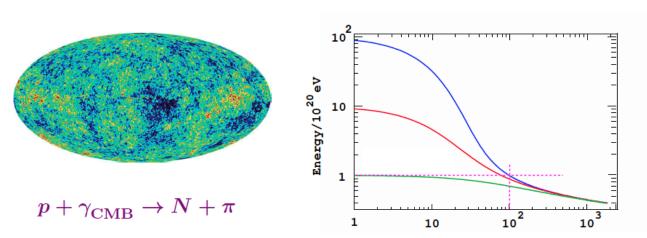
- 507 SD's
 1.2 km spacing, 700 km²
- 3 FD's



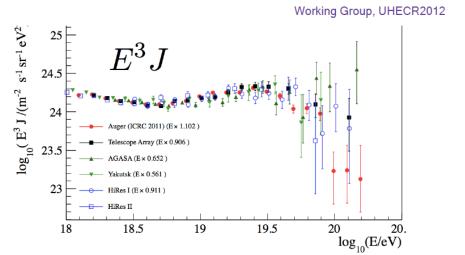


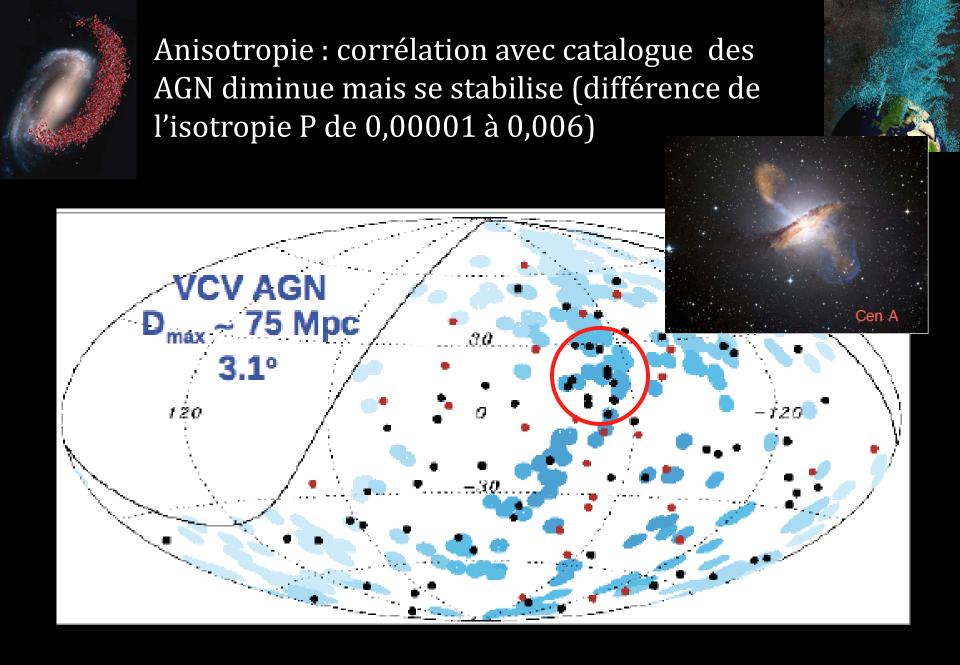
Enigme résolu(?): Supression de flux où on attend l'interaction avec le fonds diffus cosmologique (GZK)

Greisen-Zatsepin-Kuzmin Effect



Pas de photons de haute énergie ou neutrinos de haute énergie qui serait la signature des processus anormaux

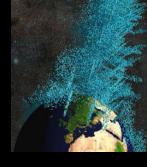




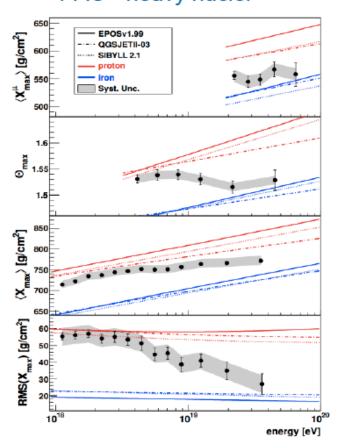
Corrélation avec Cen A (P = 4%)? Hors champ pour TA



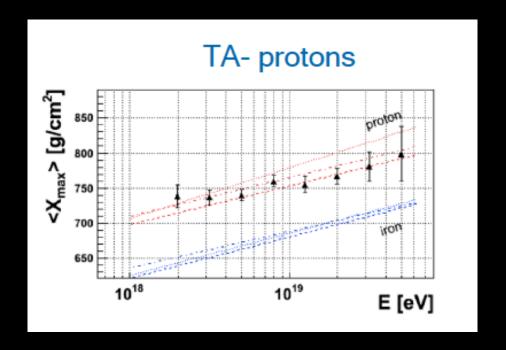
Nouveau énigme: indices de changement de composition aux hautes énergies (p→ Fe)





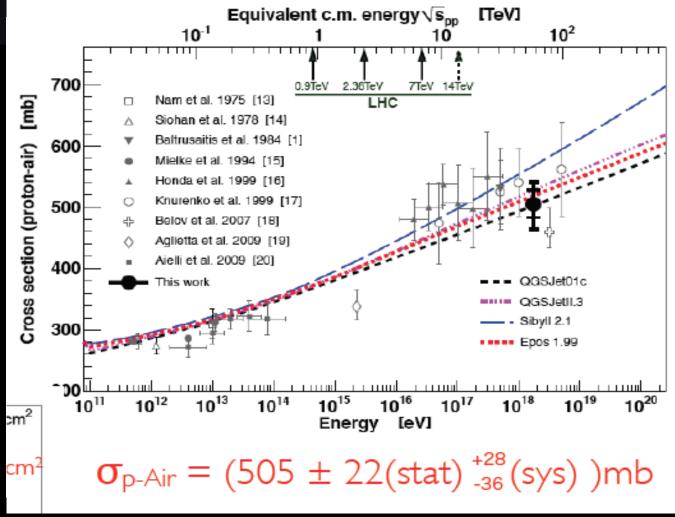


Désaccord avec les résultats de Telescope Array



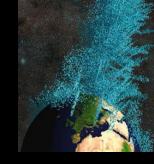


Auger et LHC

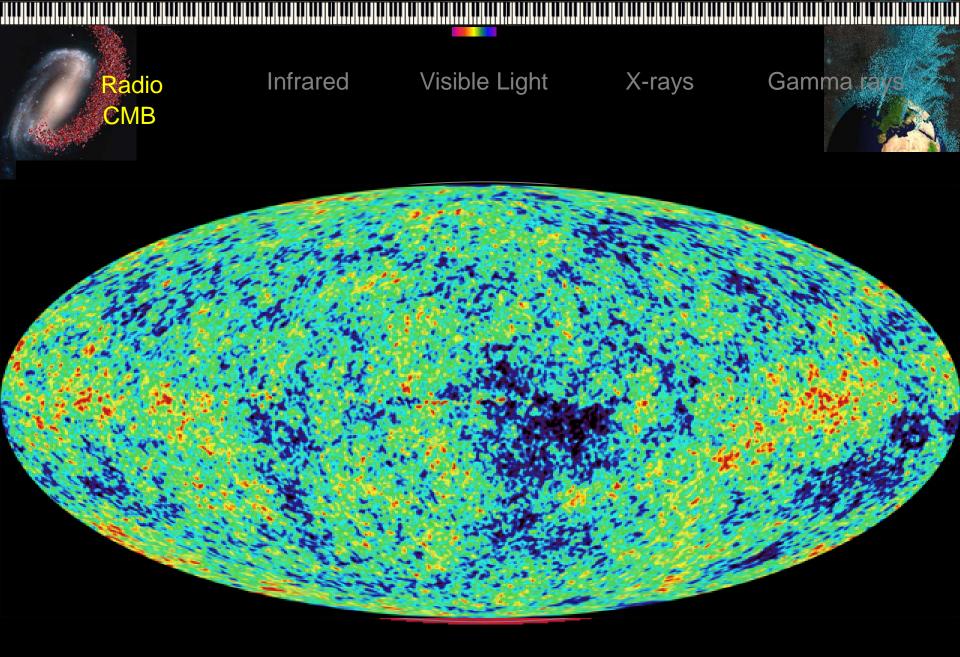


Mesure de la section efficace des protons aux 57 TeV

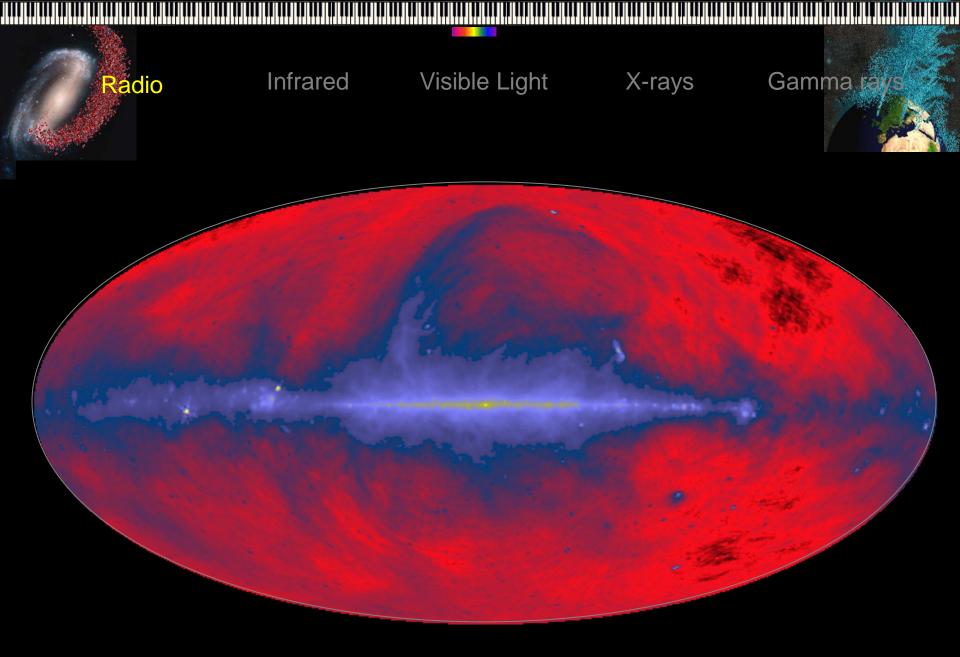




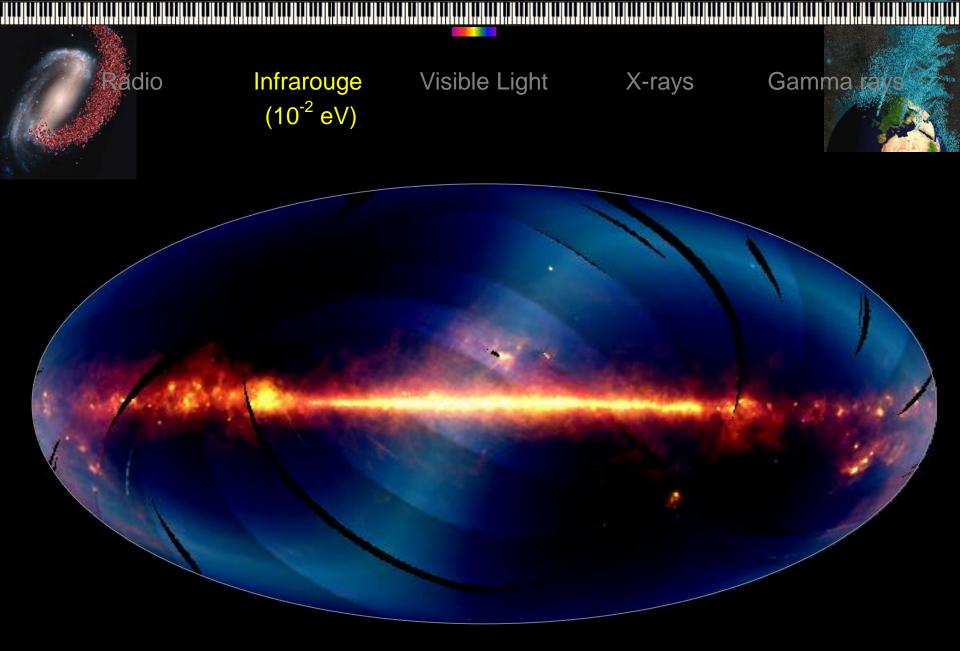
L'Univers électromagnétique



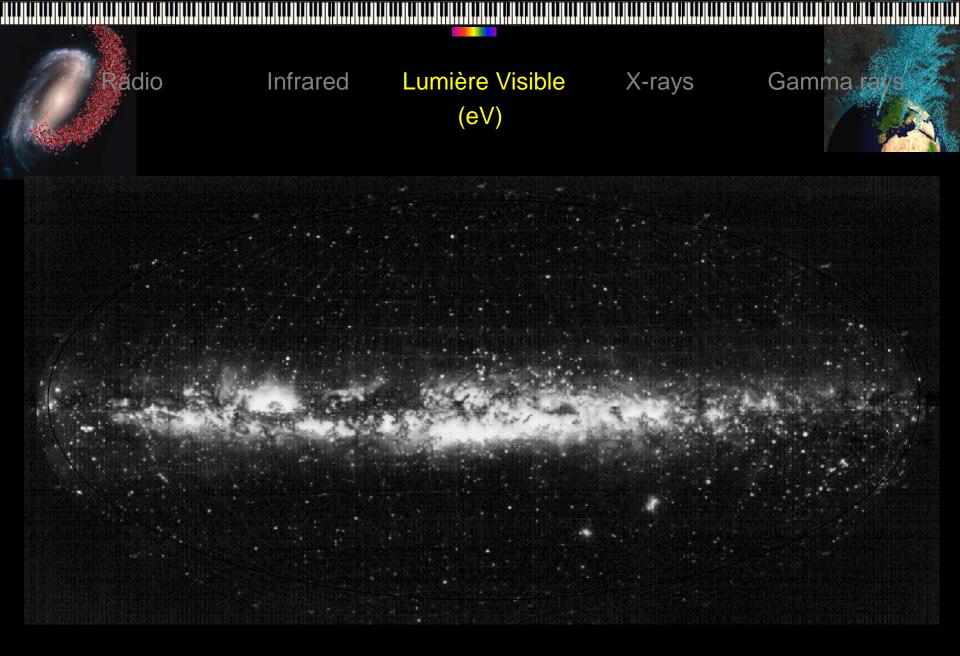
La sphère céleste examinée sous plusieurs longueurs d'onde



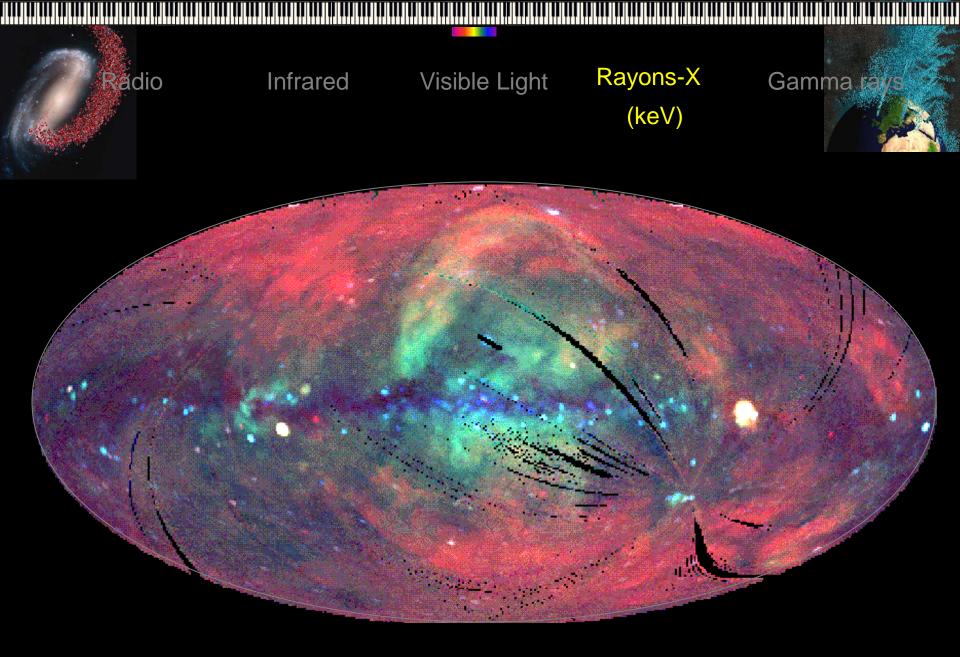
La sphère céleste examinée sous plusieurs longueurs d'onde



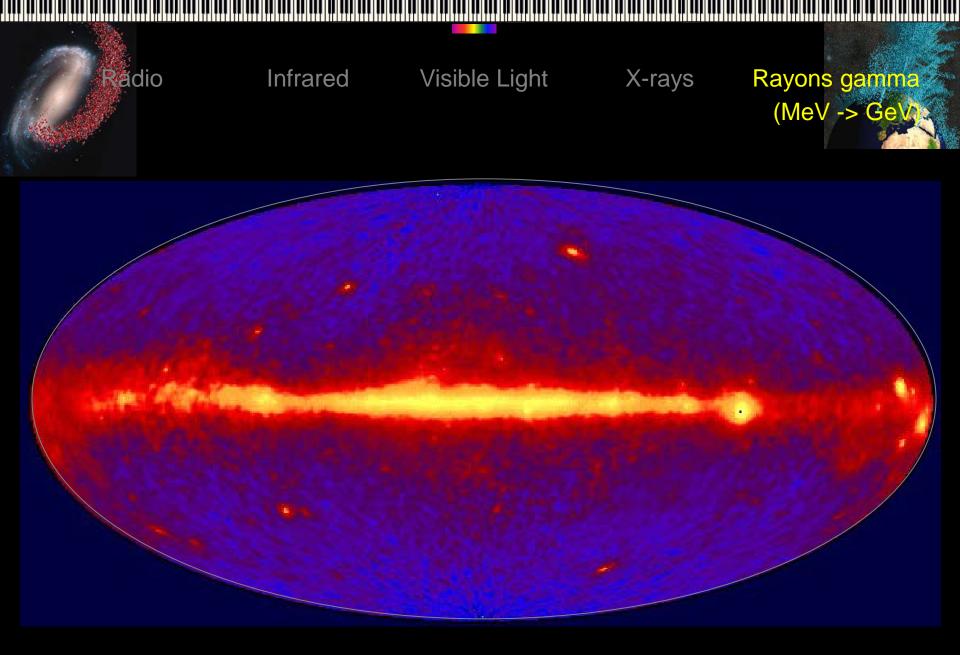
La sphère céleste examinée sous plusieurs longueurs d'onde



La sphère céleste examinée sous plusieurs longueurs d'onde



La sphère céleste examinée sous plusieurs longueurs d'onde



La sphère céleste examinée sous plusieurs longueurs d'onde



La radiogalaxie Centaurus A vue dans les domaines X, optique, infrarouge et radio (échelle : 15, 7.5, 10, et 12.5 minutes)



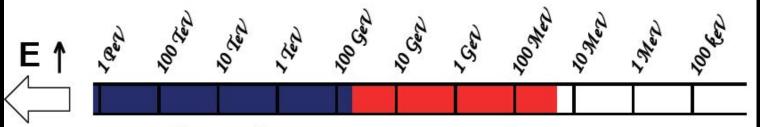
L'approche multi-longueur d'onde donne une vision globale d'un objet astronomique complexe.

Pourquoi aller vers le multimessager?

Etudier en profondeur (neutrinos, GW), mieux comprendre les mécanismes d'accélération (CR, neutrino)

High-energy gamma-rays

Crédit : J. Paul



Ground

Space





кауоп ү

100 MeV - 100 GeV

Radio AGN AGN-Blazar

AGN-Non Blazar

Infrared

Visible Light 1,873 sources

X-rays **Galaxy**

* Starburst Galaxy

Radio Galaxy

Seyfert Galaxy



based on integrated exposure (100 MeV to 100 GeV) from August 4, 2008, to July 31, 2010. TS > 25

- Unassociated
- Possible Association with SNR and PWN

2FGL Catalog

PSR w/PWN

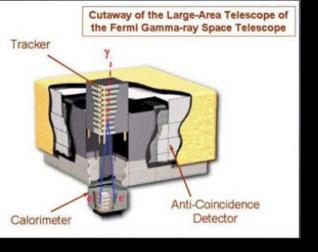
PSR

SNR

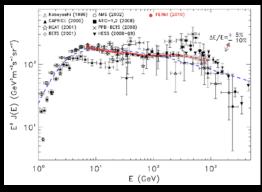
Nova

PWN

Globular Cluster + HMB

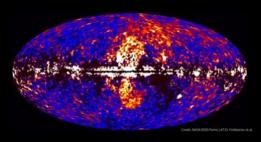


Some FERMI « highlights »

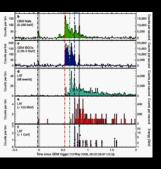


e⁺e⁻ spectrum to 1 TeV

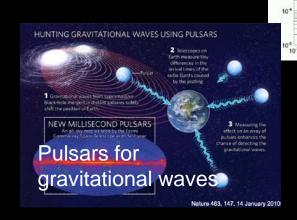
detection of nearly 1,000 blazar AGNs



©-ray emitting bubbles extending 25,000 light-years north and south of the galactic center



high-energy emission from both long and short duration ©ray bursts Lorenz violation

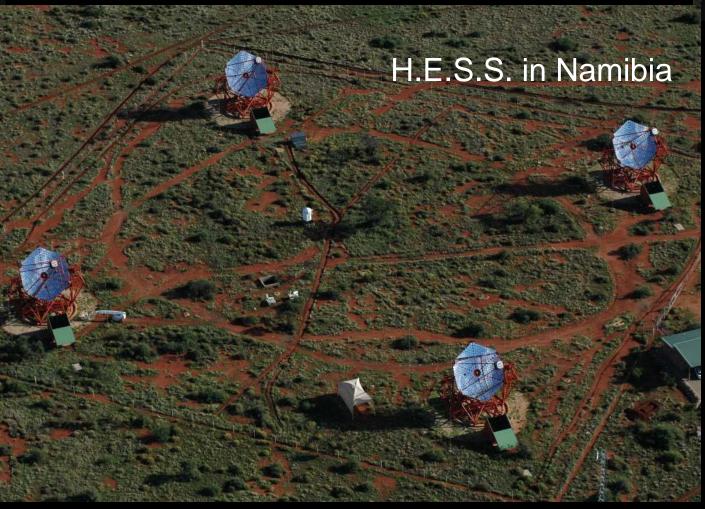


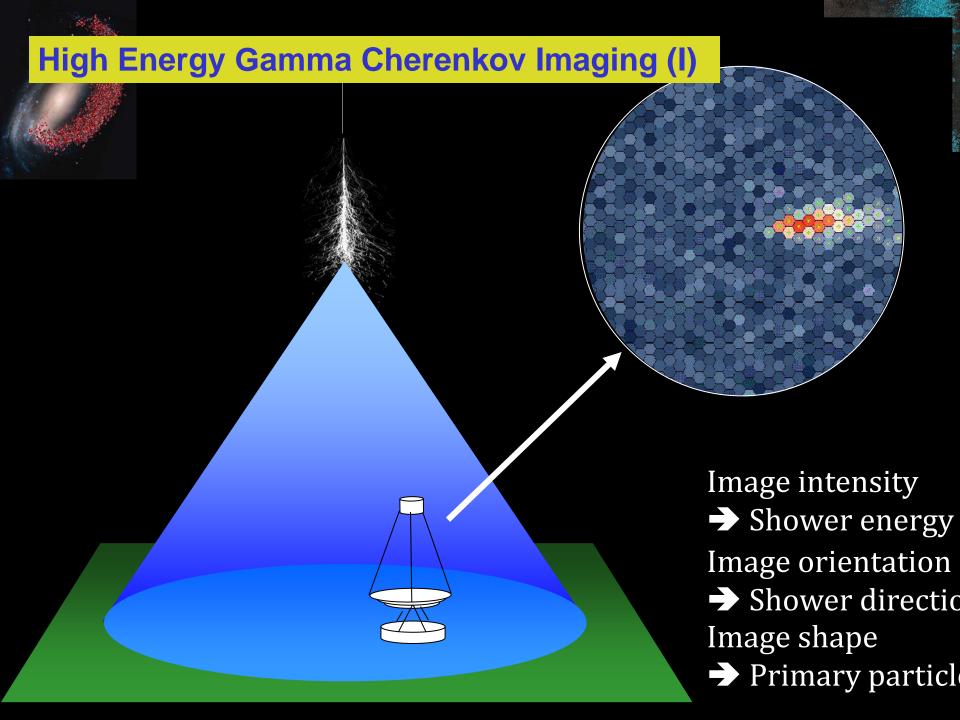
measurement of spectrum of high-energy isotropic radiation to more than 100 GeV

Fermi LAT - Abdo et al. 2010

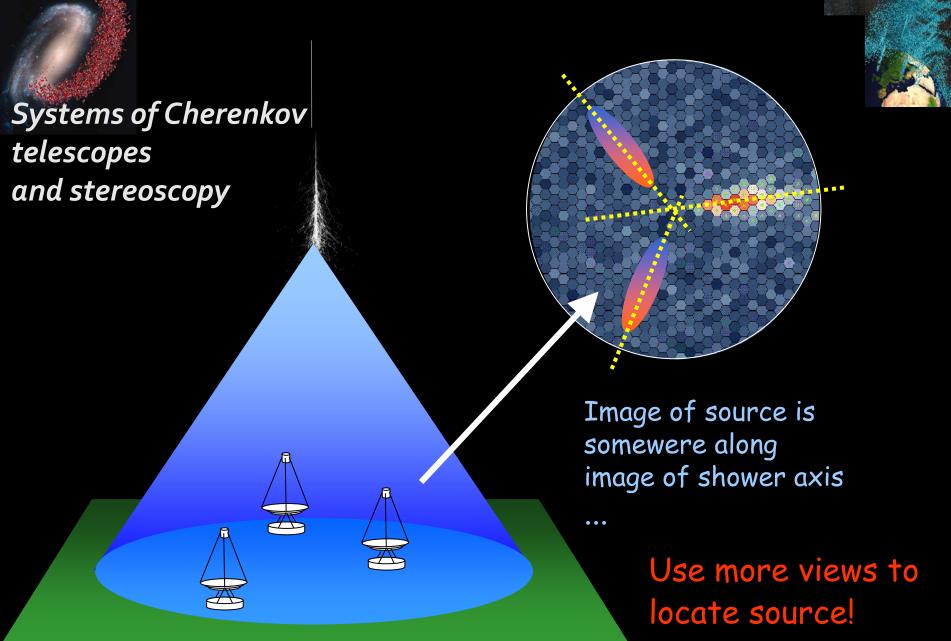


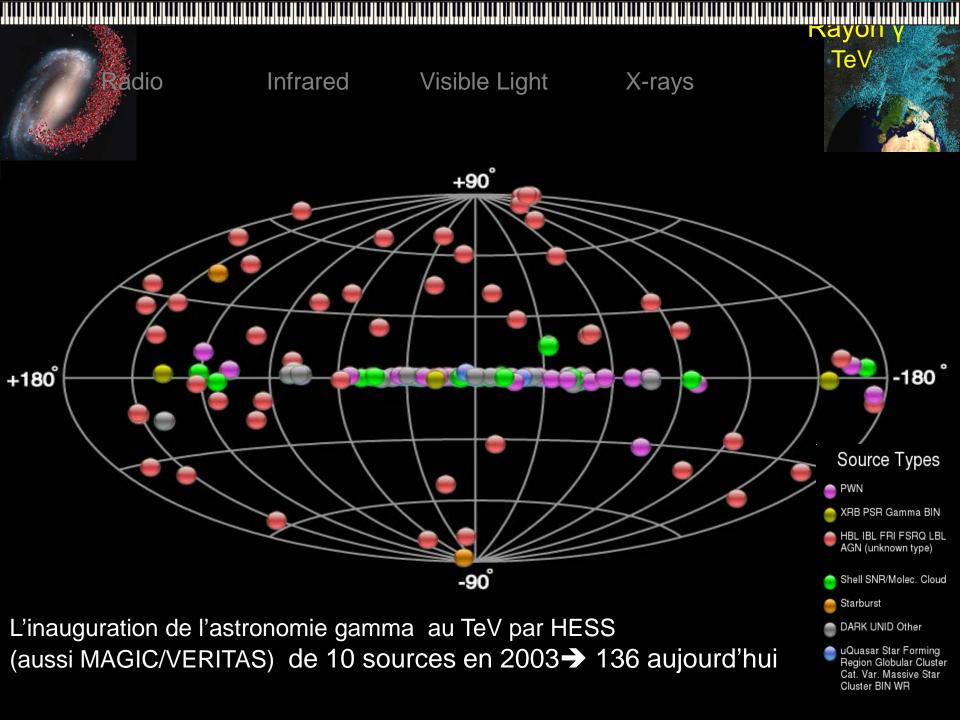
From HESS to HESS2





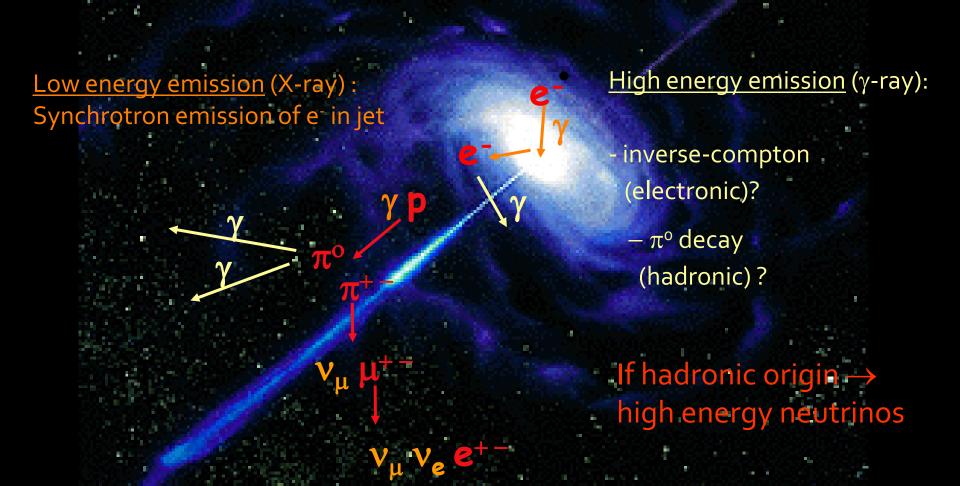
High Energy Gamma Cherenkov Imaging (II)

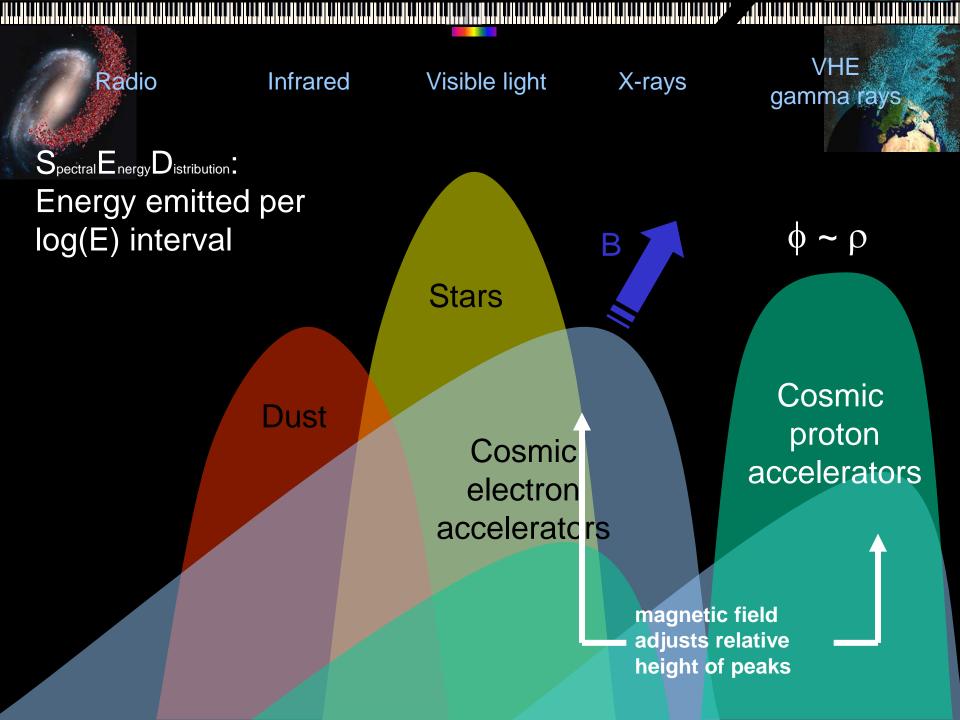






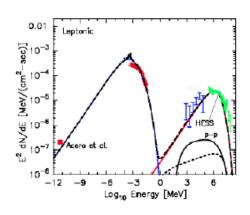
Phénomènes violents: exemple 4: Trous noirs supermassifs au centre des galaxies (AGN)





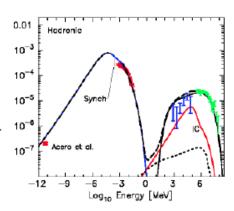
Ex: SNR RXJ1713.7-3946

«Leptonic» model best fits



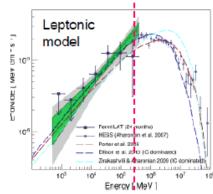
D. C. Ellison et al. ApJ, 712, 287 (2010)

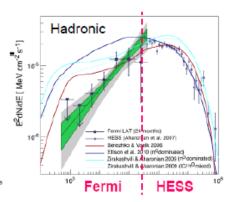




Observations from FERMI now favour ICS production of γ

Abdo et al. ApJ, 734, 28, 2011

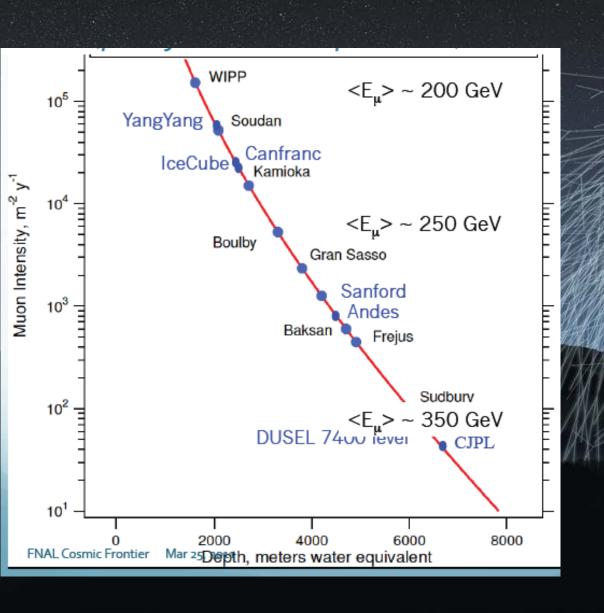


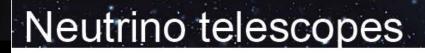




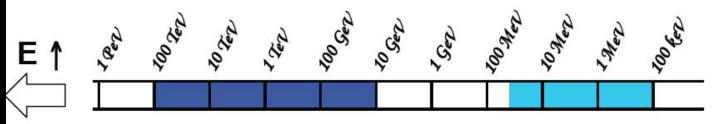


Eviter les rayons cosmiques



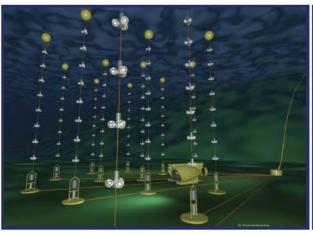


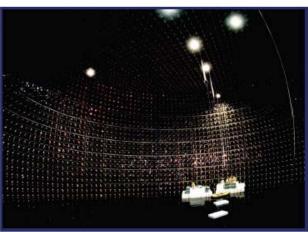
Crédit : J. Paul



Deep Sea/Ice

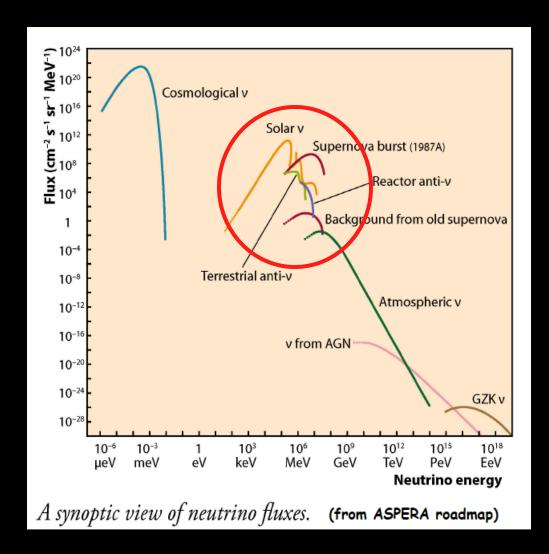
Underground







Neutrinos cosmiques Basse énergie





Core-Collapse Supernovae:

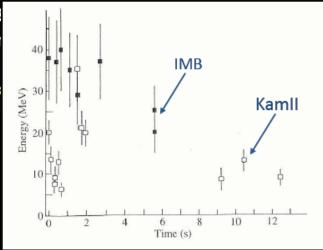
Explosions of Massive Stars, $M > 8-10 M_{Sun}$



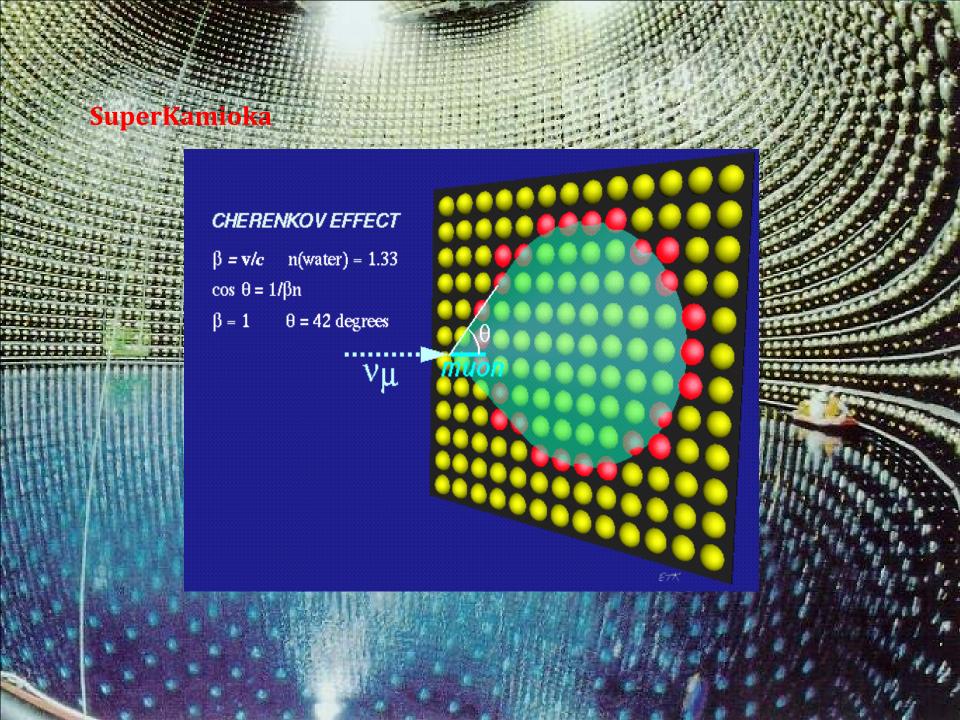
- © Anglo-Australian Observatory
- 1 SN/s/universe
- 1 SN/yr/@10 Mpc
- 1 SN/(40-100 yrs)/Milky Way



Supernova 198 Large Magellar Progenitor: BSG Sanduleak



L'acte de naissance de l'Astroparticule ?



Laguna-LBNO: Large Apparatus for Grand Unification and Neutrino Astrophysics

Long Baseline Neutrino Oscillations

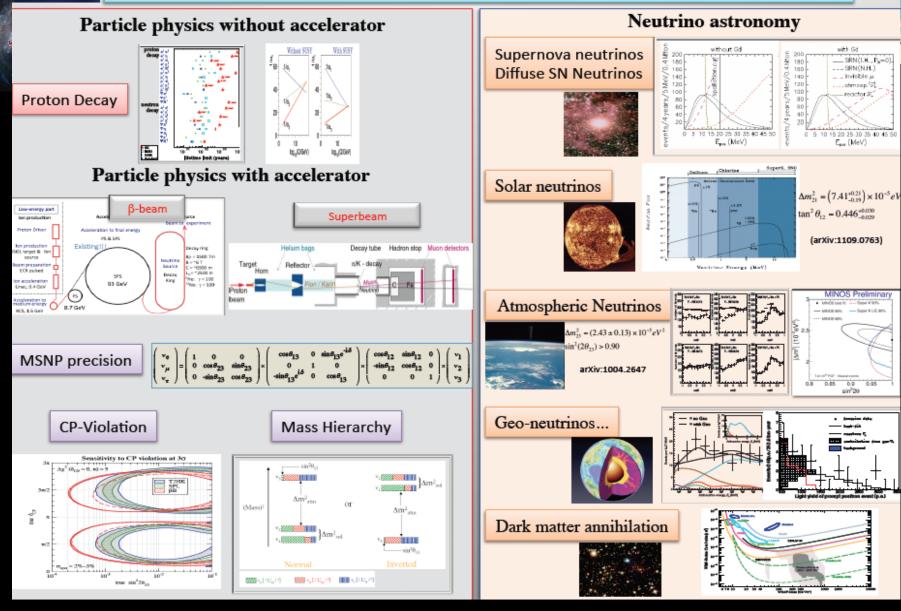
SBN (I.H., P_e=0 --- SRN(N.H.)

_ invisible µ

..... obmosp. 📆

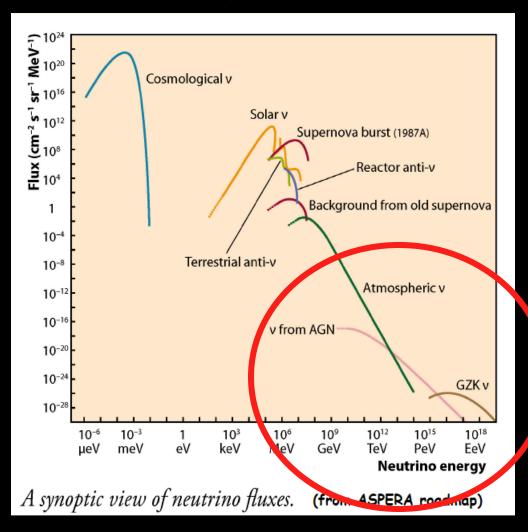
E_{ee} (MeV)

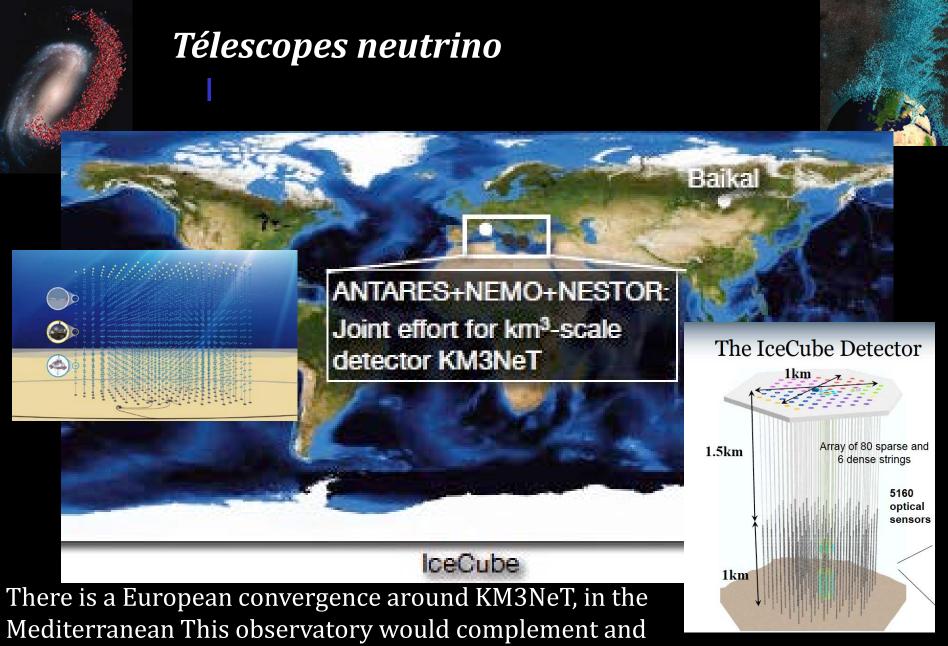
0.85 0.9





Neutrinos cosmiques Haute energie



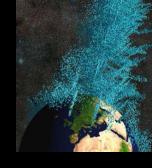


Mediterranean This observatory would complement and extend the results from IceCube, which has started taking data at South Pole.



Le principe de détection

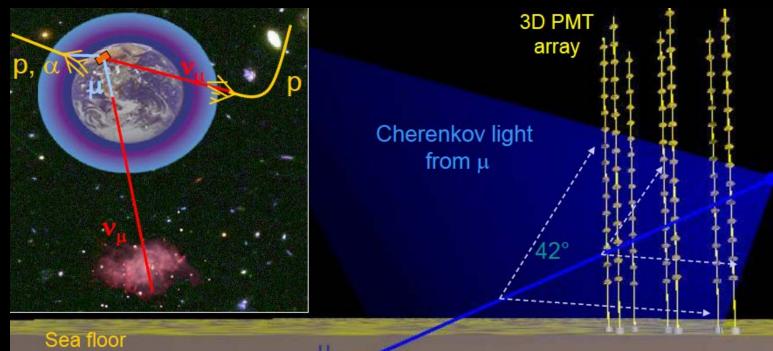
interaction



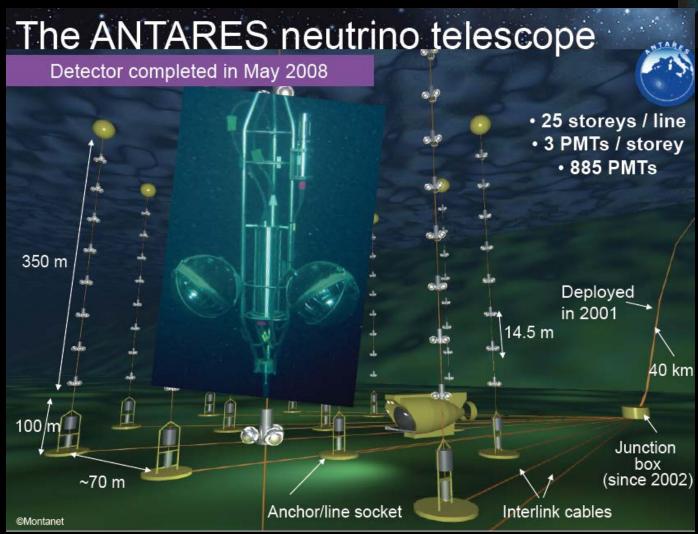
The reconstruction is based on local

coincidences compatible with the

Cherenkov light front







Potential extragalactic sources

Starburst galaxies

S

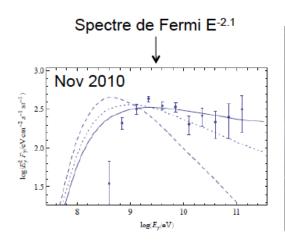
The Galactic center region

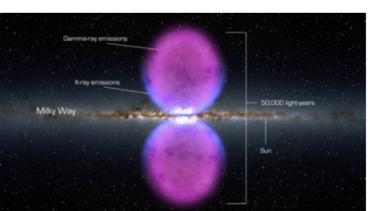
Fermi Bubbles

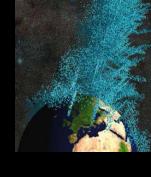
"Giant, Multi-Billion-Year-Old Reservoirs of Galactic Center Cosmic Rays"

M. Crocker and F. Aharonian Phys. Rev. Lett. 106 (2011) 11102

"Bilateral 'bubbles' of emission centered on the core of the Galaxy and extending to around 10 kpc above and below the Galactic plane. These structures are coincident with a non-thermal microwave 'haze' found in WMAP data and an extended region of X-ray emission detected by ROSAT."

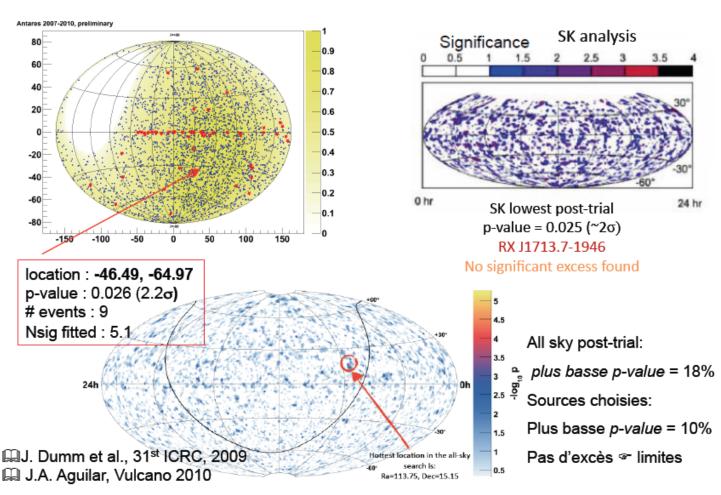






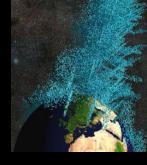
sources
potentielles
de
neutrinos
de très
haute
énergie

Sky maps

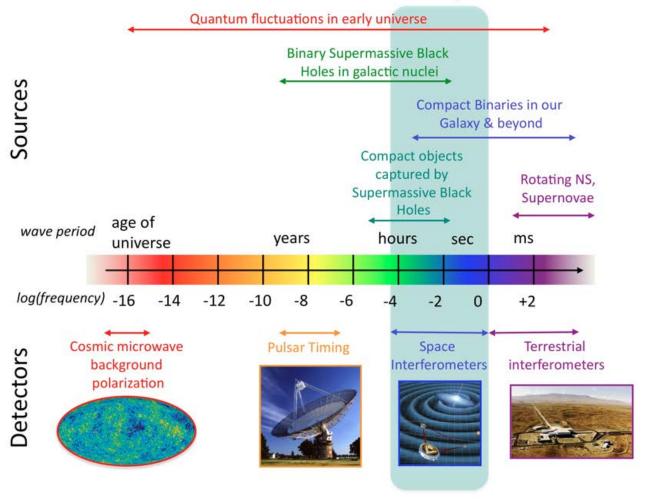




Communication au fond de la mer par bioluminescence

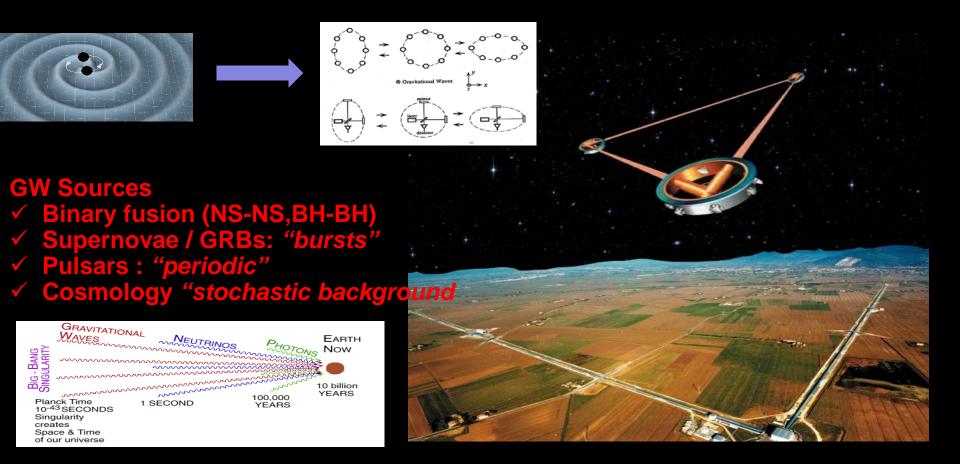


The Gravitational Wave Spectrum



Gravitational waves

✓ Today, there is a strong expectation that success will finally be achieved during the next ten years, using a network of second-generation (or "advanced") laser interferometers in the United States, Europe, Japan and India



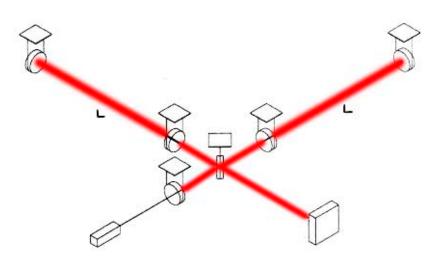


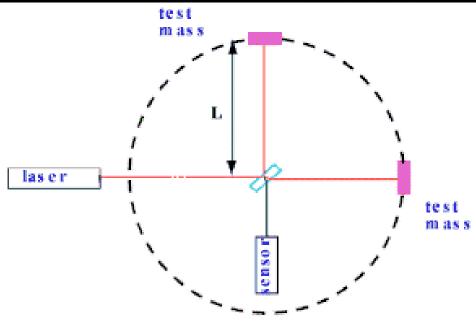
The quadrupolar nature of the GW makes the Michelson interferometer a "natural" GW detector

$$\delta L \approx \frac{h}{2} \cdot L_0$$

 $L_0 \sim 10^3$ m in terrestrial detectors

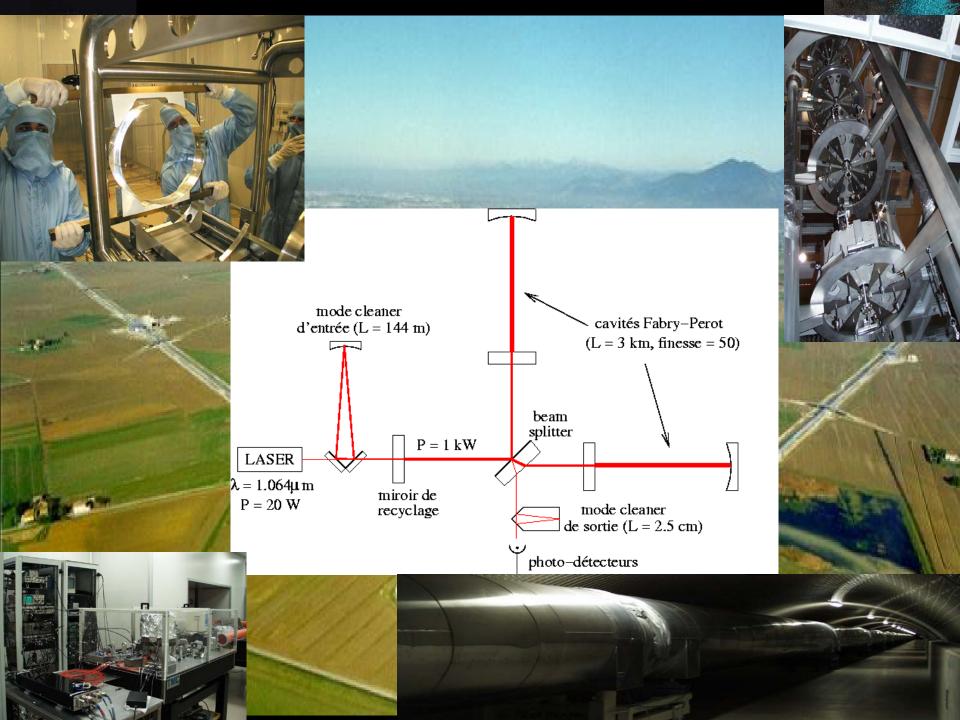
We use a "trick" to build
 ~100km long detectors on the
 Earth





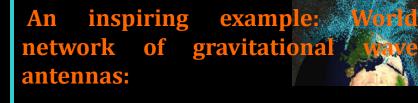
Effective length:

$$L' = L_0 \times \frac{2F}{\pi}$$

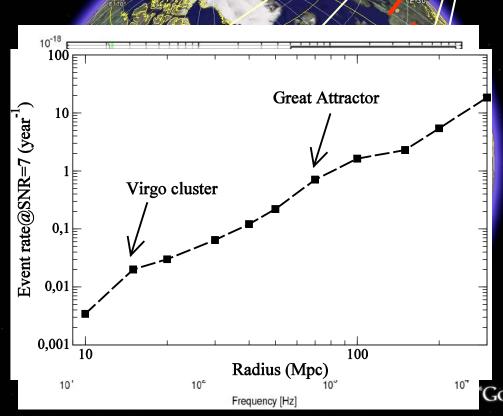


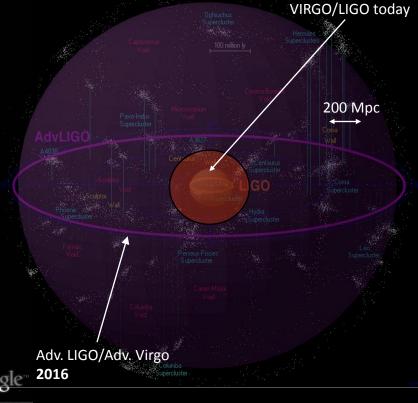
Gravitational waves: LIGO-VIRGO common runs

The scientific community pioneered a network between the gravitational wave antennas in Europe and in the United States, with sharing of information and techniques, coordinated data-taking and joint publication of results. Other ground-based antennae are expected to come on-line (KAGRA in Japan, INDIGO in India) and expected to join the network.



Sensitivity increase
Source direction determination
Polarizations measurement

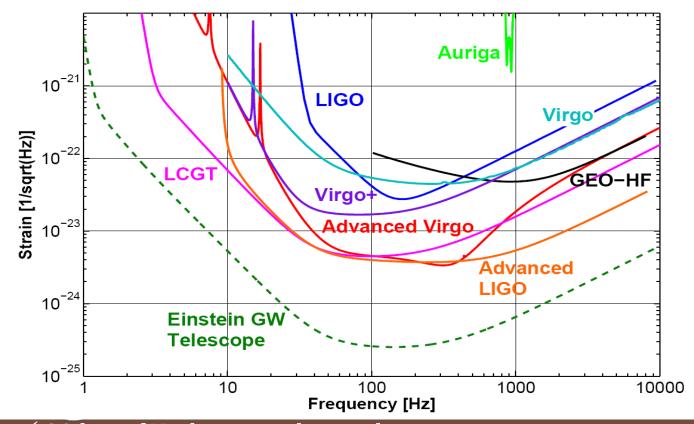






Gravitational waves: Einstein Telescope (ET)

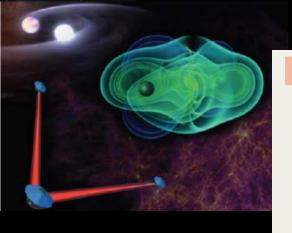
EU funded Design Study Einstein Telescope completed



√ 30 km of Underground tunnels

The path for research in gravitational waves beyond the advanced detectors foresees two projects of a very large scale: the Earth-bound **Einstein Telescope (ET)** and the space-bound e**LISA/NGO** project. ET construction would start at the end of this decade, after the first detection of gravitational waves with the advanced detectors and following successful R&D. The LISA project, for which preparatory work in on-going, would eventually rely on the success of the technological mission LISA-Pathfinder

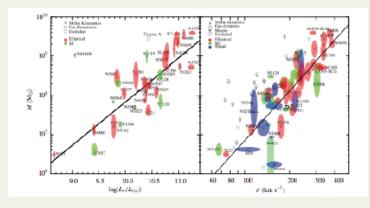




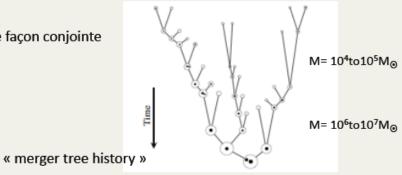
Science	NGO
Galactic binaries	Expected: about 3000 Verification binaries: > 8
Astrophysical BH mergers	Expected rate: 10 to 100/yr Expected number (2yr mission): 20 to 200
Extreme Mass Ratio Inspiral	Expected rate: 1 to 100/yr Expected number (2yr): 10 to 20
Testing GR	Capability of observing 50% of all z≈2 coalescing binary systems consisting of objects with masses between 10 ⁵ and 10 ⁶ M _☉
Cosmology	Capability of detecting gravitational wave backgrounds from cosmic strings or phase transitions

Trous noirs massifs

Il existe une relation profonde entre les galaxies et leur trou noir central

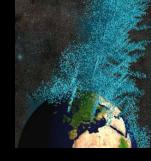


ce qui laisse penser qu'ils ont évolué de façon conjointe





Suspiciendo descpicio



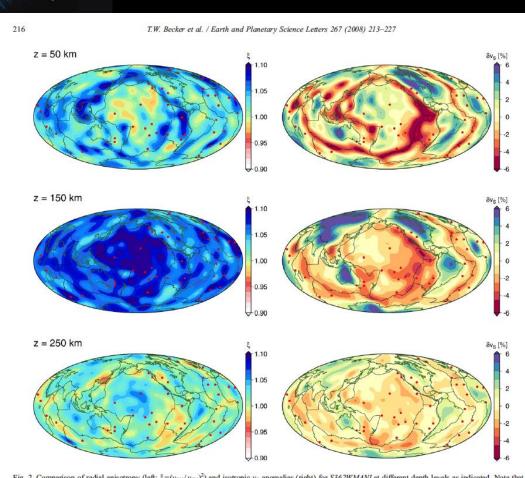


Fig. 2. Comparison of radial anisotropy (left; $\xi = (v_{SH}/v_{SV})^2$) and isotropic v_S anomalies (right) for S362WMANI at different depth levels as indicated. Note that ξ includes the (non-PREM like) average $\langle \xi \rangle$ of S362WMANI as shown in Fig. 1a. Red circles are hotspot locations from the compilation of Steinberger (2000).

- ✓ Auger peut déployer un réseau de sismomètres dense
- ✓ANTARES/KM3 peut étendre le réseau sismométrique à la mer ✓VIRGO aurait des sensitivités extraordinaires

pour les mouvements du

noyau

✓ Les grands détecteurs neutrino (Borexino) peuvent détecter les geoneutrinos Leçon inaugurale de Barbara Romanowicz Au CdF

Le rayon cosmique ultime: particules de matière noire

Counting Nuclear Recoils: Types of Signals

heat, vibration

Germanium, Silicon

CaWO₄, sapphire

light

NaI, CsI, CaWO4

Liquid Ar, Xe

high pressure Xe

charge

Germanium, Silicon

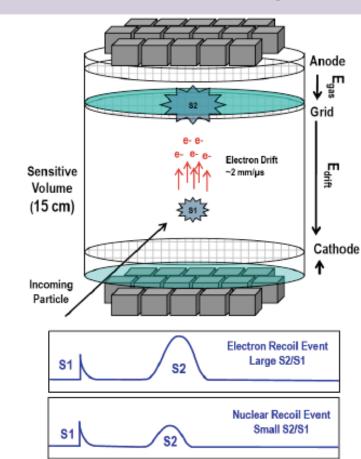
Liquid Ne, Ar, Xe

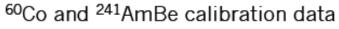
Gas: Ne, Xe, Ar, C₂H₆, CF₄ etc...

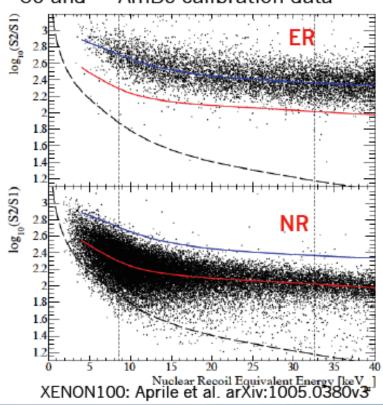
Priscilla Cushman

<u>Ionization + Scintillation: Two-Phase Noble Liquids</u>

Time Projection Chamber technology





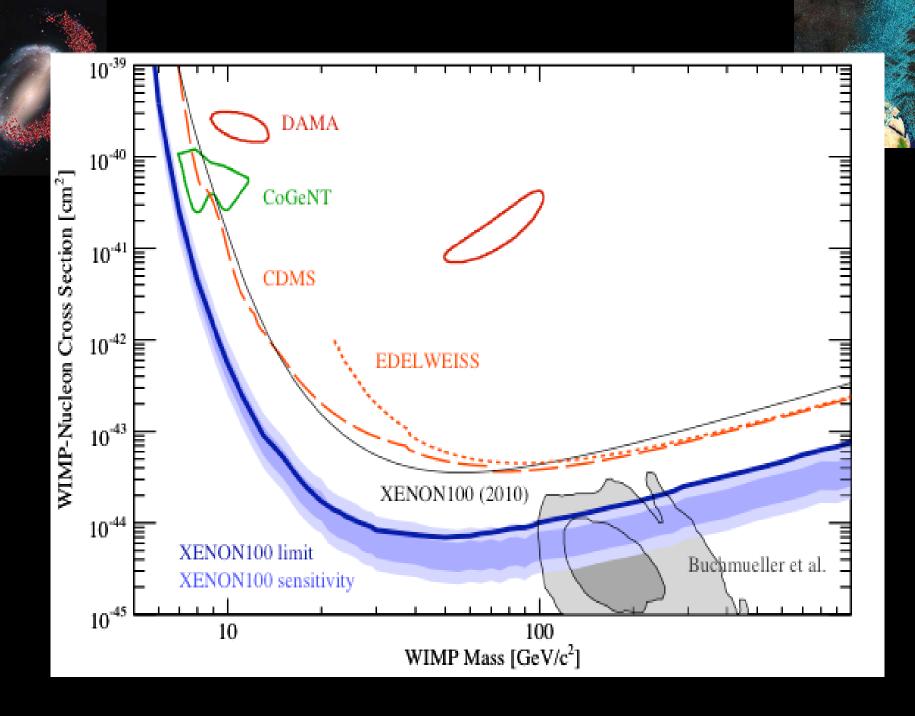


400 keV]



Dark matter worldwide distribution of experiments







Non, la supersymétrie n'est pas encore morte au LHC (exemple pMSSM)

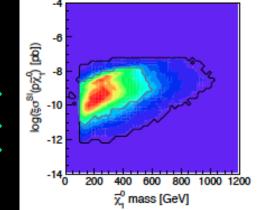
S. Kraml

-68% BCR ---95% BCF

p(0 I CMS)

Spin independent

We are here 10⁻⁹ pb 1 ton 10⁻¹¹ pb 10 ton 10⁻¹² pb



Spin dependent

We are here 10⁻⁴ pb (ANTARES/ICECUBE)

P(θ | CMS)

-68% BCR -95% BCR

-95% BCR

-95% BCR

-95% BCR

-95% BCR

-95% BCR

-95% BCR

-95% BCR

-95% BCR

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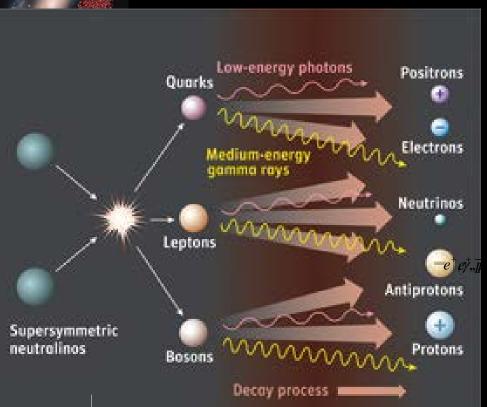
-95% BCR

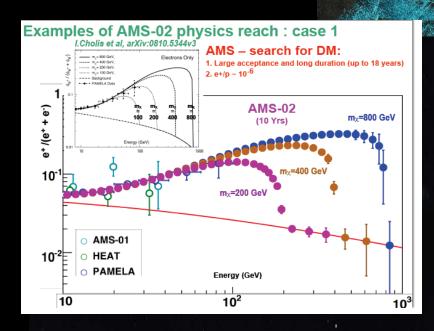
-95% BCR

-95%

Complementarité

Recherches indirectes de matière noire

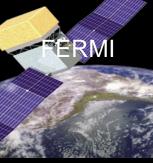




Pulsar ou matière noire?



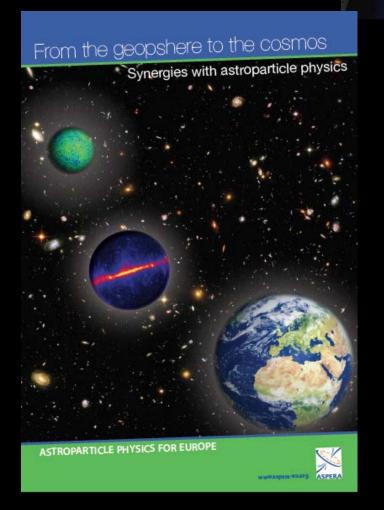






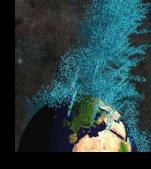
Un moment de publicité:

Astroparticle physics The European Roadmap OECD Global Science Forum Report of the Working Group on Astroparticle Physics **MARCH 2011** 2011





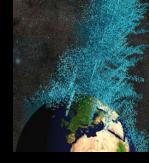
Organising the Astroparticle From ApPEC to ASPERA and back



- **✓** Astroparticle Physics European Coordination (ApPEC) since 2001
- **✓** AStroparticle Physics ERAnet ASPERA (2006- 2012)
 - ✓ ASPERA -1 (FP6, 2006-2009)
 - ✓ Definition of the field → the Seven Magnificent Roadmap
 - ✓ Many other actions: census, common calls, national days, linking
 - ✓ ASPERA-2 (FP7, 2009-2012)
 - ✓ Update of the roadmap → action plan
- **✓** Astroparticle Physics European Consortium (ApPEC) (2012-...)
 - ✓ Signature of the MoU defining the consortium June 29 2012 in Berlin



Cosmos, archéologie du concept



- ✓ La première apparition du mot « cosmos » dans l'Iliade 180, chant XIV: « Après quoi Héra revêt une robe divine qu'Athéna a ouvrée et lustrée pour elle, en y ajoutant nombre d'ornements. Elle se ceint d'une ceinture... Aux lobes percés de ses deux oreilles, elle enfonce des boucles.... Sa tête enfin la toute divine la couvre d'un voile... blanc comme le soleil. À ses pieds luisants, elle attache des belles sandales. Enfin, quand elle a ainsi autour de son corps disposé tout son cosmos, elle sort se sa chambre » .
- ✓ La racine du mot monde a des origines similaires.
- ✓ «Pythagore emprunta le premier la notion de cosmos pour décrire la totalité des choses » **Aetius**
- ✓ Le concept de cosmos, contient le hasard et la violence :
 - ✓ « Un détritus par le hasard abandonné le plus bel cosmos » Héraclite
 - ✓ « Les baccantes au réveil un miracle d'eucosmie » Euripide
- ✓ Que le monde soit cosmos fut une des décisions constitutives de notre histoire intellectuelle H. Blumenberg

10⁻³⁰⁻³³ cm

v mass, proton decay

Les deux infinis

Event horizon Inflation, Dark energy/matter

10²⁸ cm

10⁻²⁴⁻²⁷ cm

High Energy processes, SUSY, Higher Dim

10⁻²¹ cm

LHC physics

10⁻¹⁵⁻¹⁸ cm

Nuclear physics

10⁻⁵ cm

Astroparticle infrastructures help study ocean floor biodiversity

GZK horizon 10²⁶ cm HE CR,γ, ν, GW

Galaxy 10^{22} cm Supernova HE γ , ν , Origin of CR,

Solar system 1015 cm Nucleosynthesis Solar v

Astroparticle detectors use the geosphere as detecting medium

Astroparticle helps us understand our origins



The 3 questions of Astroparticle Physics (APIF/OECD definition)

1. What is the role of high energy phenomena in the formation of cosmic structures?

Multi-messenger studies (γ , CR, ν , GW)

Origin of Cosmic Rays, Search for new particles (dark matter, antimatter) Limits of fundamental laws.

AdvVIRGO/LIGO, CTA, KM3net

2. What is the Universe made of?

Nature of dark matter and energy

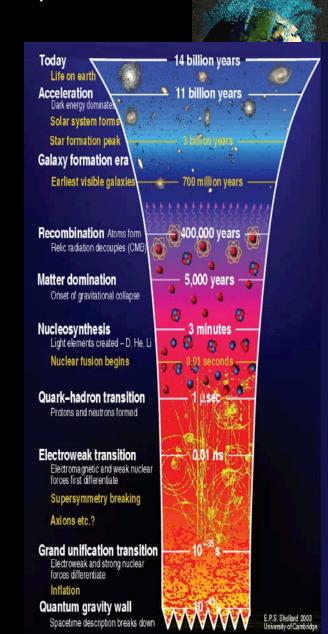
Probe EW scale, Gravitation
LSST/EUCLID 1 ton dark matter detector

3. Probe matter and interactions at the highest energies.

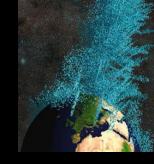
Rare decays: proton lifetime, neutrino properties

Access GUT scales

LAGUNA1 ton neutrino mass detector







MERCI