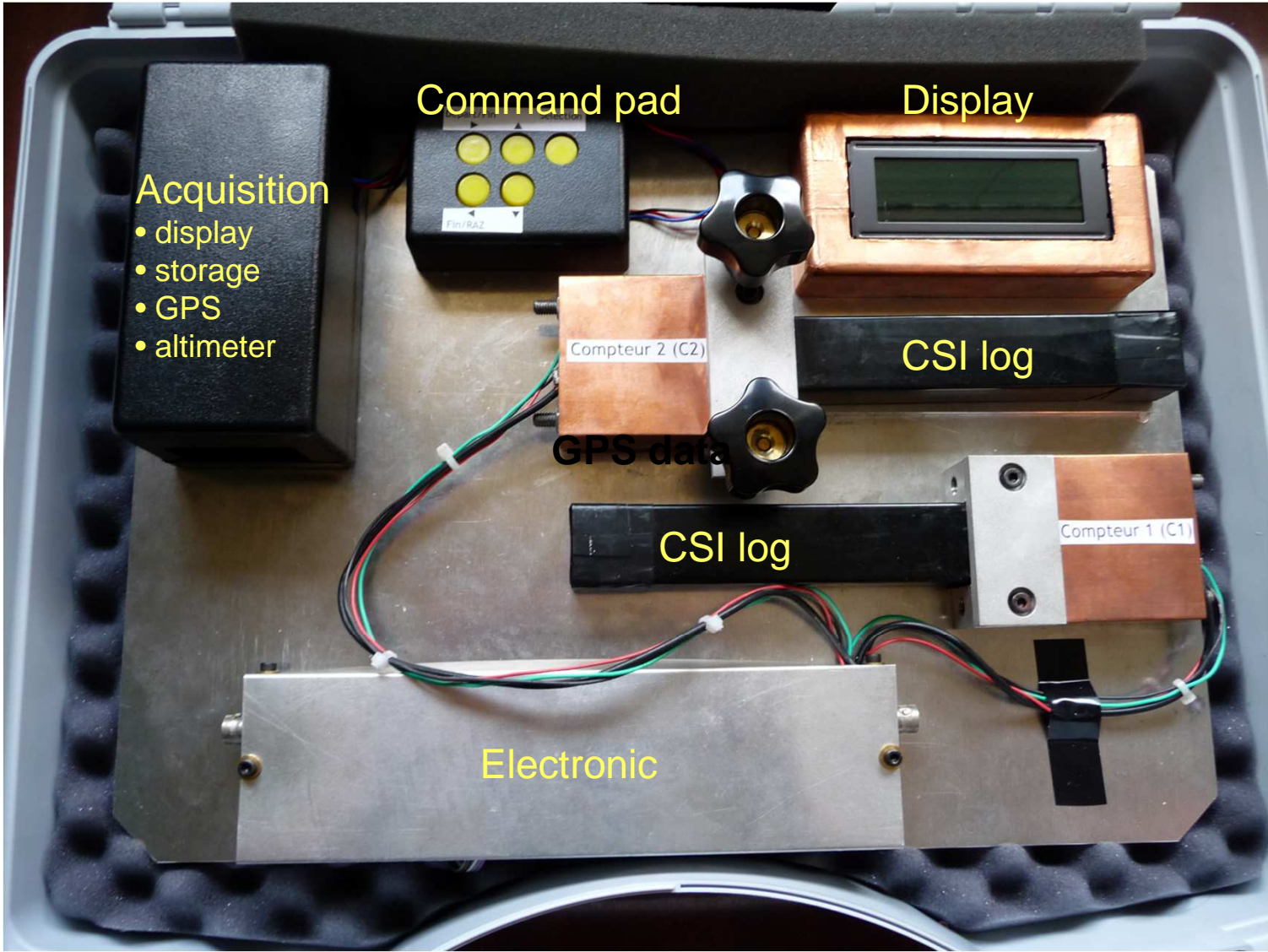


# *The Cosmix project*

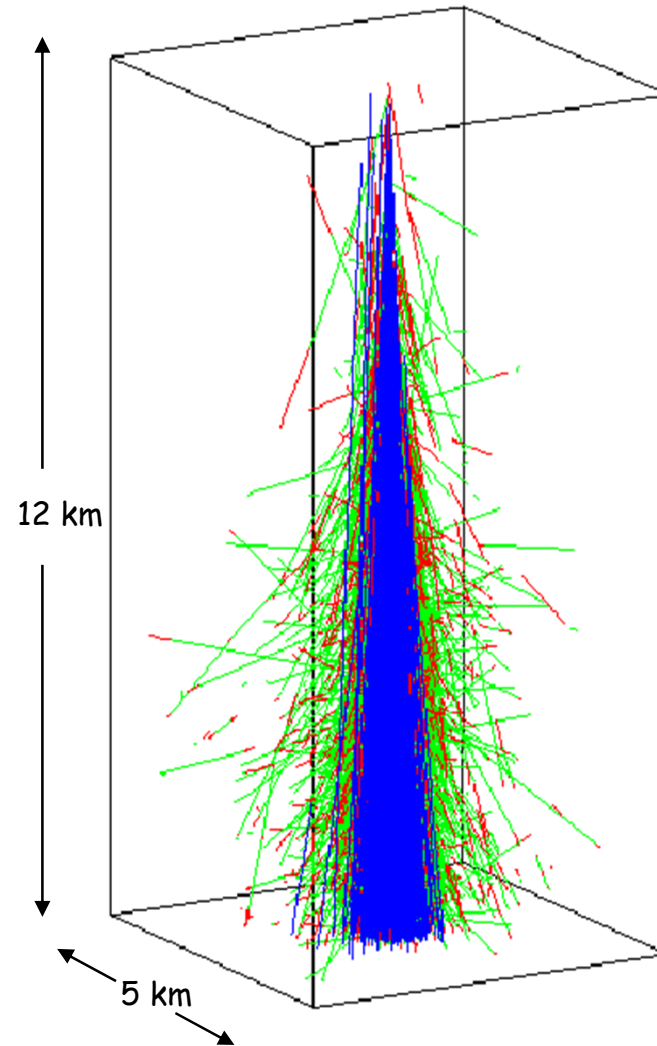
# The COSMIX kit



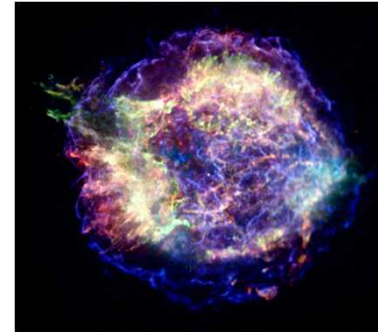
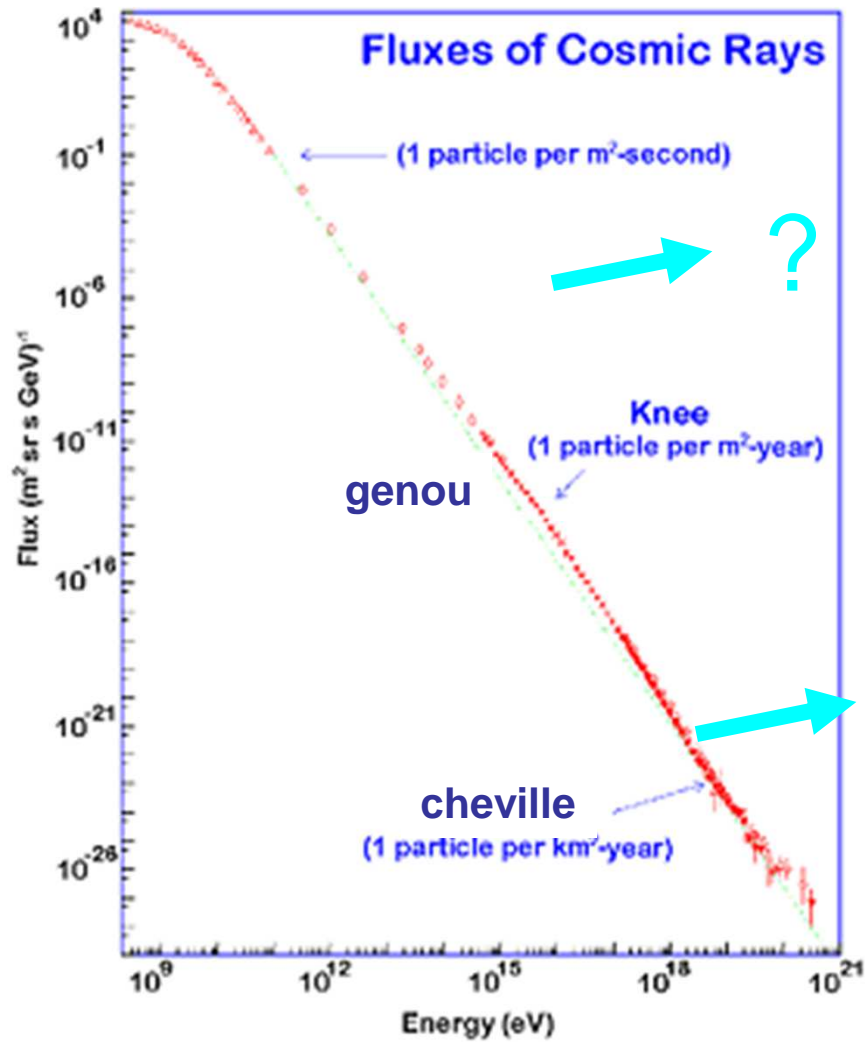
# Cosmic rays

---

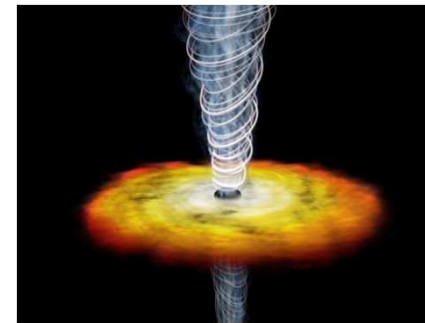
- discovered in 1912 (V. Hess)
- composition: mostly protons
- isotropic!!! Can't be used to do astronomy!
- discovery of positron (1932), muon (1937), pion (1947)
- up to  $10^{20}$  eV
- at least two different origins



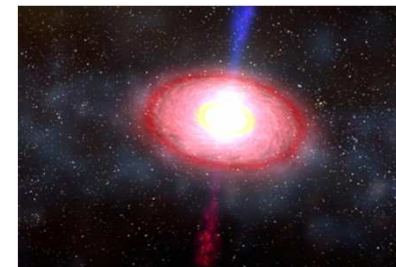
# The origin of cosmic rays



Supernova remnants



Active Galactic Nuclei



Gamma-ray bursts

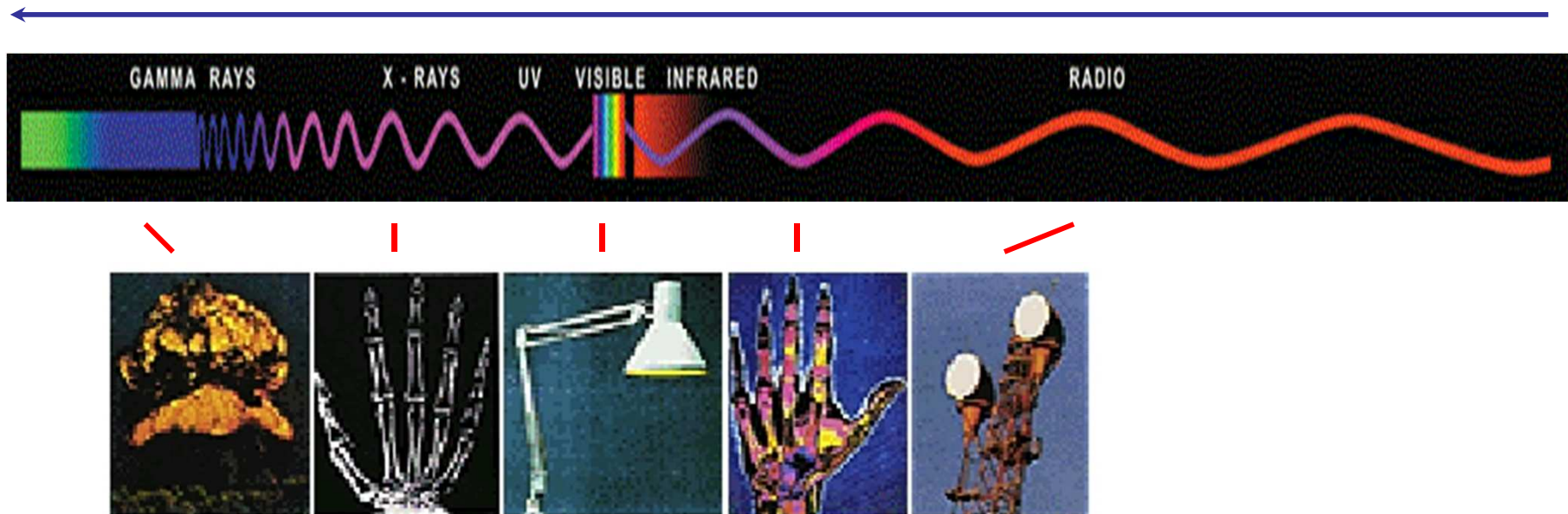
# The electromagnetic spectrum

---

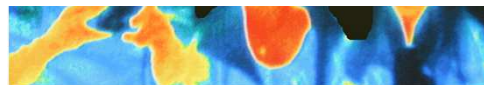
3 equivalent notions: frequency, wavelength, energy

$$E = h\nu = hc/\lambda$$

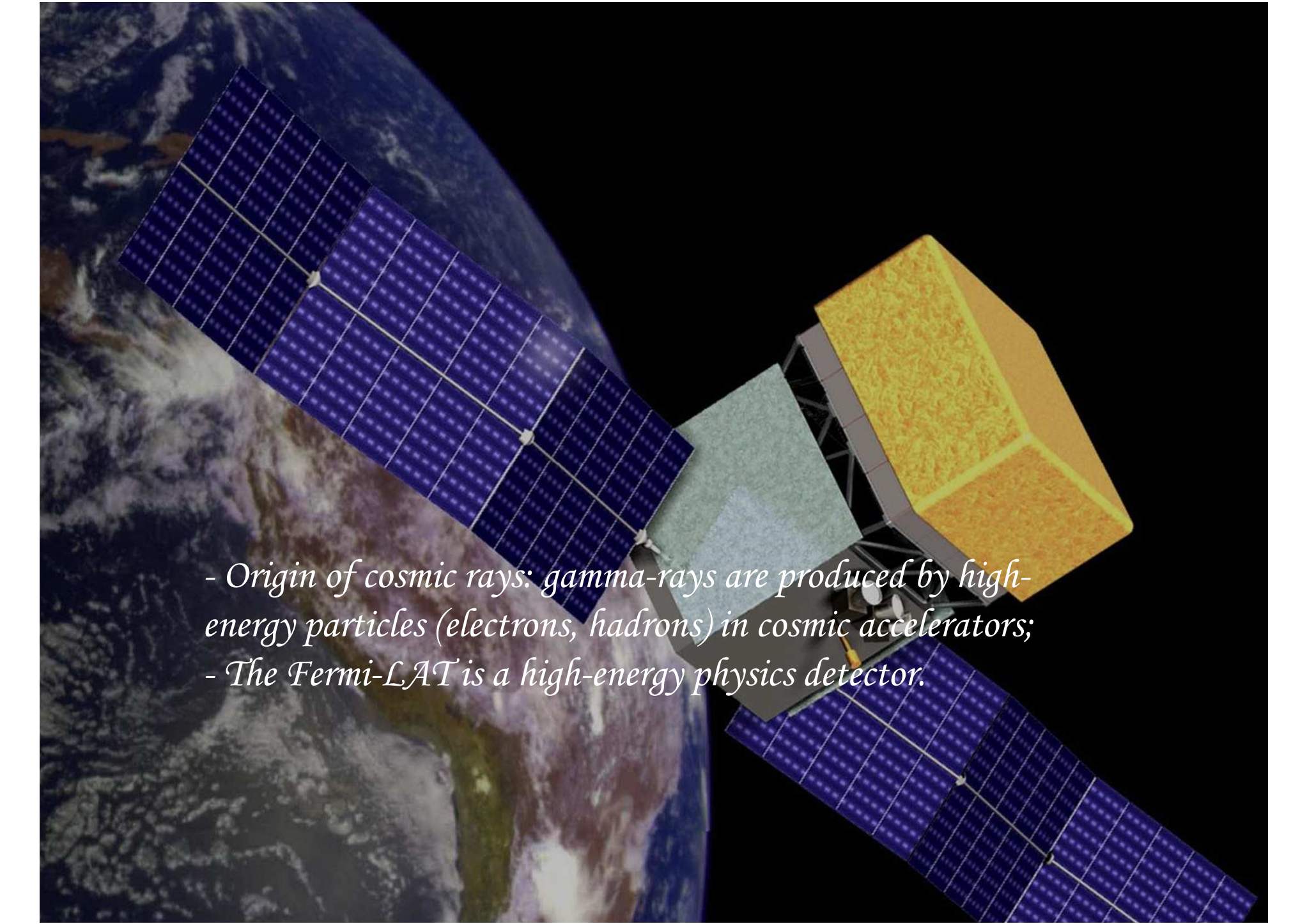
E and  $\nu$  increase,  $\lambda$  decreases



Gamma-rays are produced by high-energy particles interacting with magnetic fields, matter or other photons

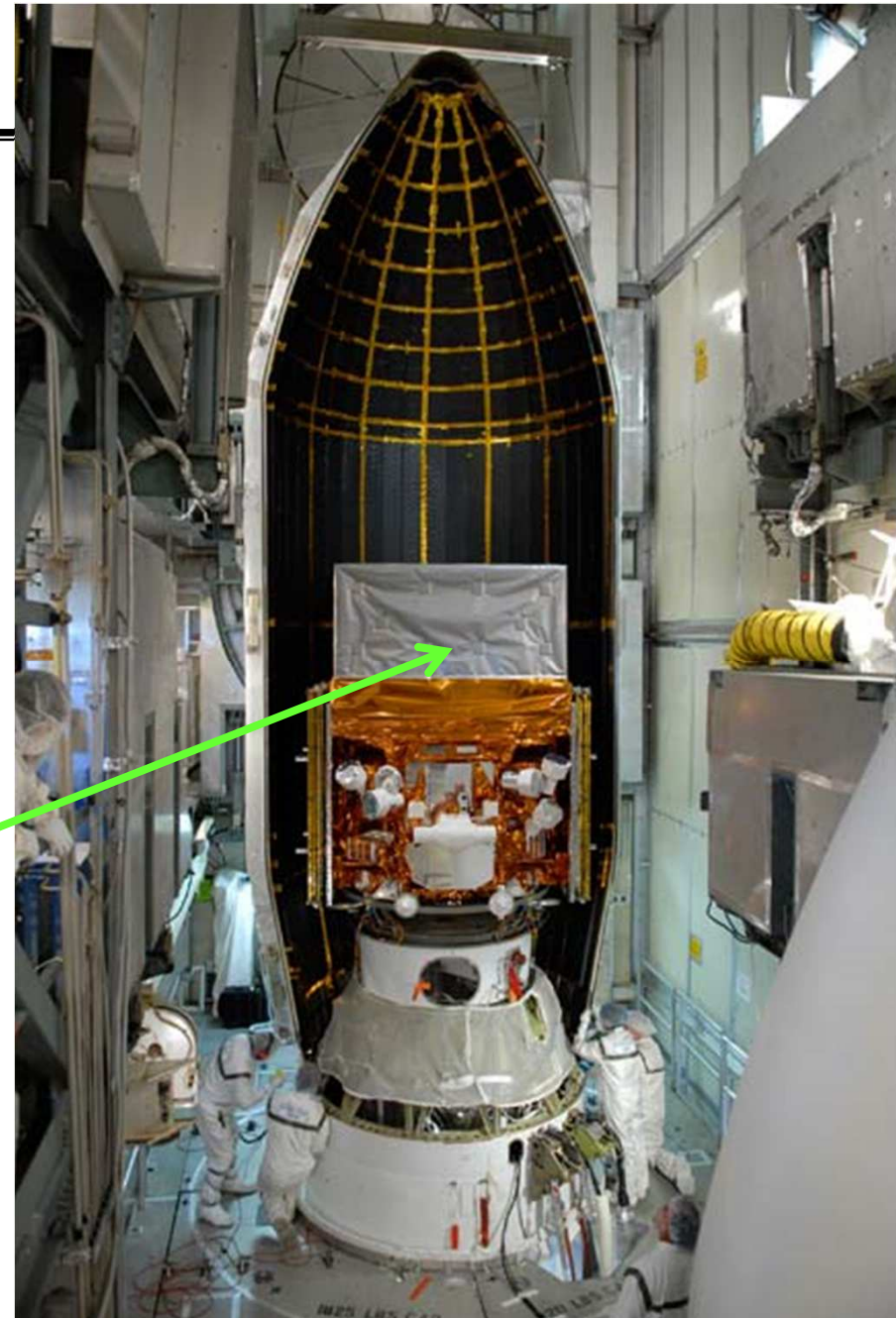
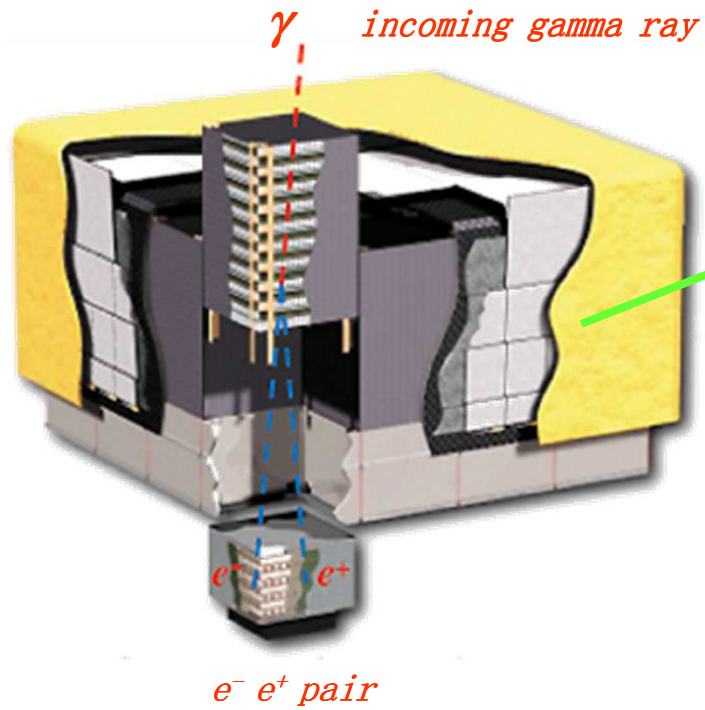
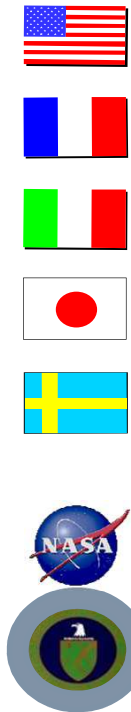




- 
- *Origin of cosmic rays: gamma-rays are produced by high-energy particles (electrons, hadrons) in cosmic accelerators;*
  - *The Fermi-LAT is a high-energy physics detector.*

# The Large Area Telescope (LAT) on board the Fermi satellite

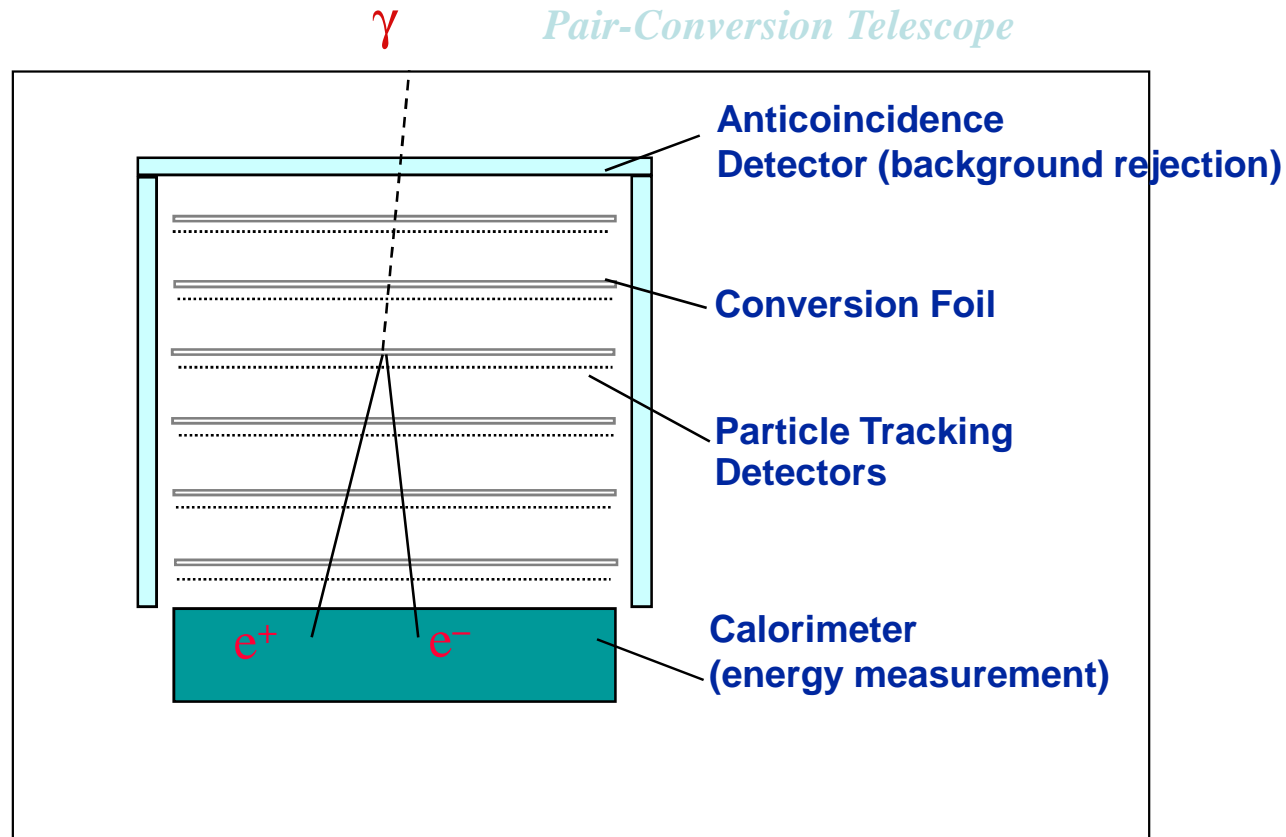
(launch: June 11, 2008)





# Fermi Large Area Telescope (LAT)

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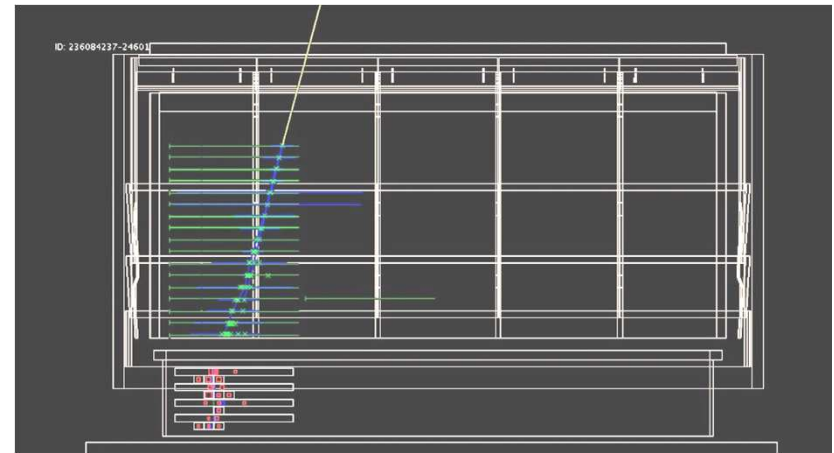
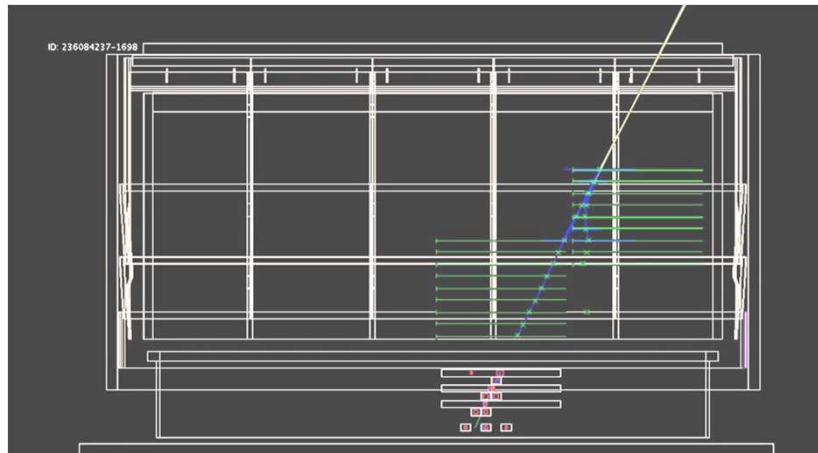
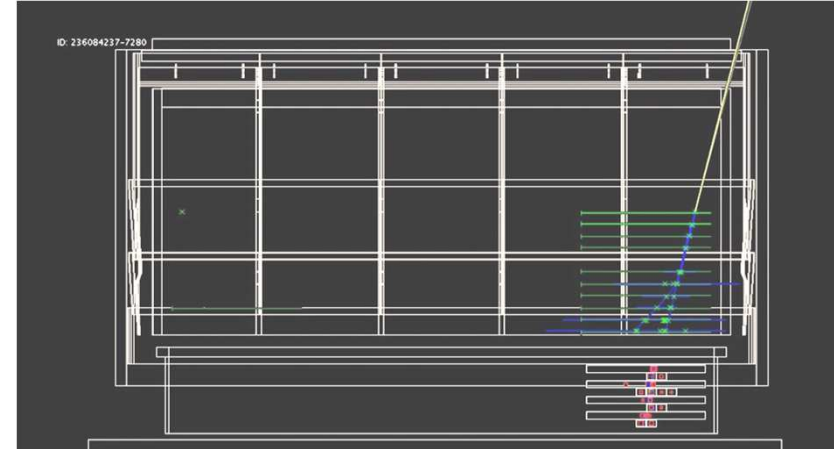
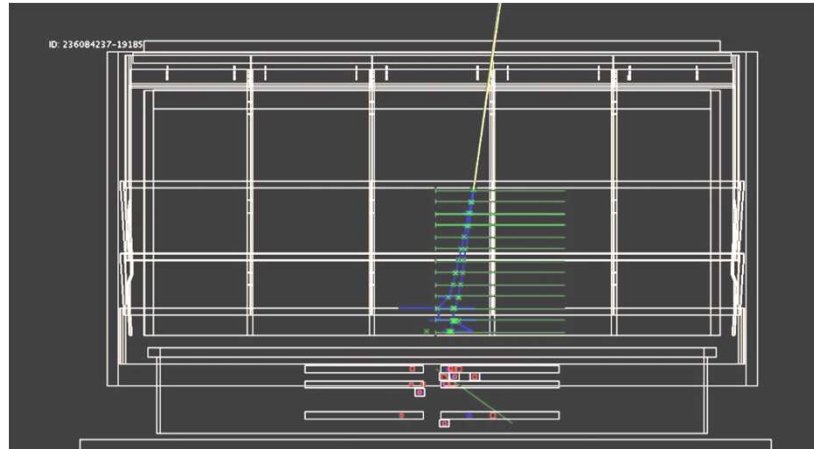


The gamma-ray photons gamma interact with matter and materialize into an electron-positron pair. The LAT is a High-Energy Physics detector.



# Gamma-ray photons in the LAT

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# Fermi LAT data

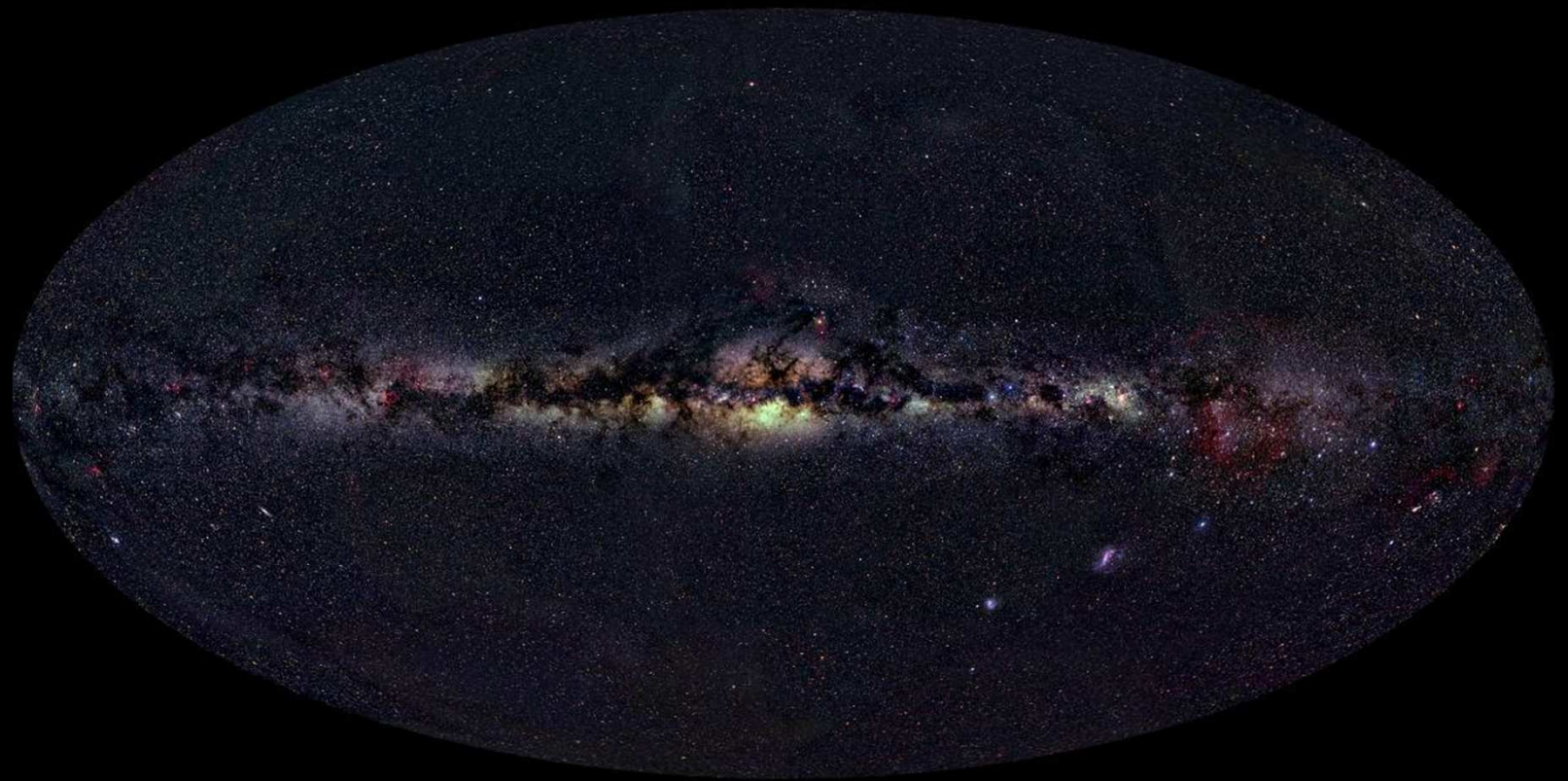
The screenshot shows a software interface with two main windows. The top window, titled "fv: Summary of lat\_photon\_weekly\_w015\_p130\_v001\_flt.fits in /home/local1/fits\_file/", displays a table of FITS files. The bottom window, titled "fv: Binary Table of lat\_photon\_weekly\_w015\_p130\_v001\_flt.fits[1] in /home/local1/fits\_f", displays a binary table of data with columns for Index, Energy (E), RA, DEC, L, B, and THETA.

**Summary of FITS Files:**

Index	Extension	Type	Dimension	View
<input type="checkbox"/> 0	Primary	Image	0	Header Image Table
<input type="checkbox"/> 1	EVENTS	Binary	22 cols X 282496 rows	Header Hist Plot All Select
<input type="checkbox"/> 2	GTI	Binary	2 cols X 108 rows	Header Hist Plot All Select

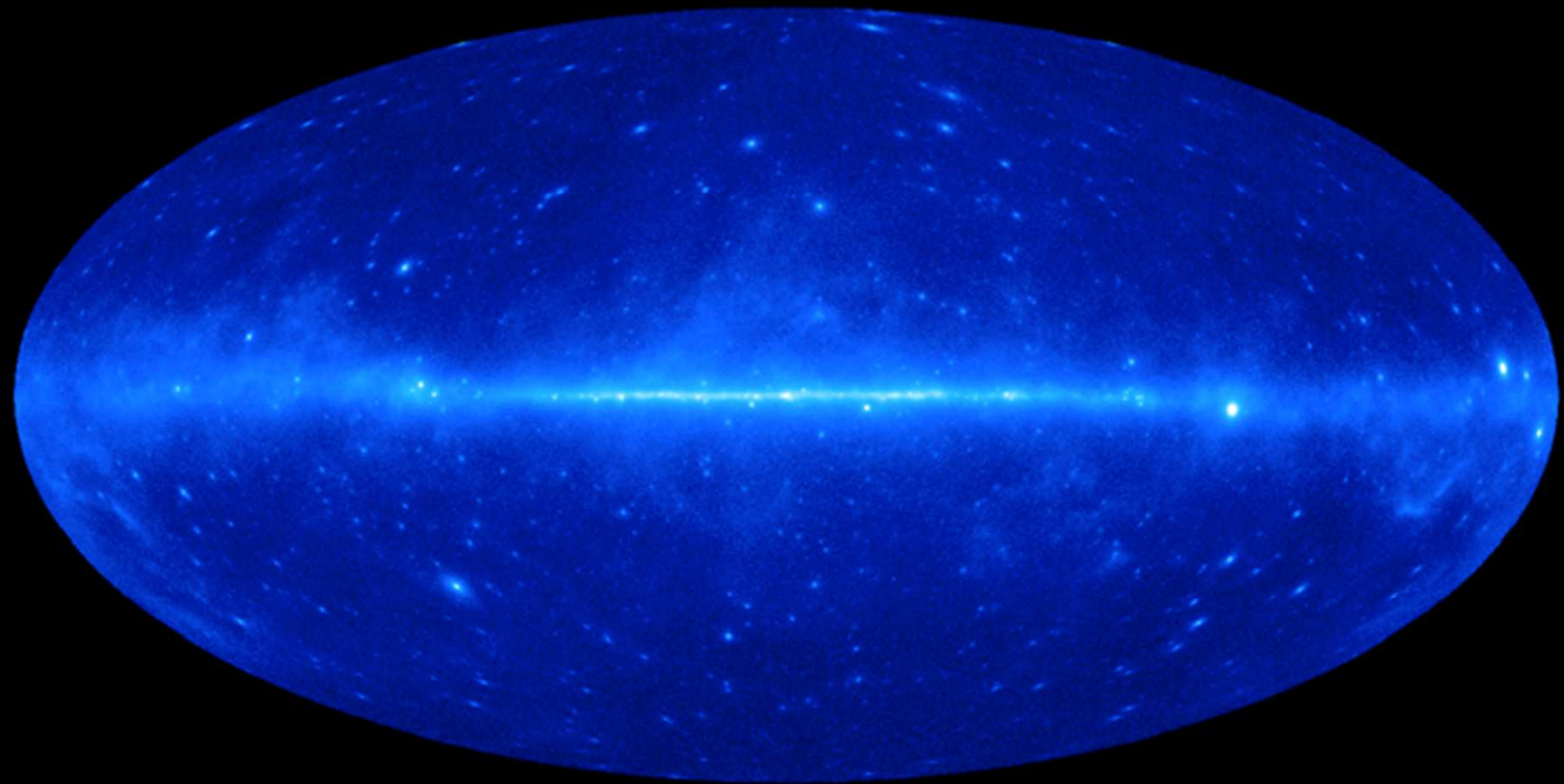
**Binary Table of Data:**

Select	ENERGY	RA	DEC	L	B	THETA
<input type="checkbox"/> All	E	E	E	E	E	E
<input type="checkbox"/> Invert	MeV	deg	deg	deg	deg	deg
	Modify	Modify	Modify	Modify	Modify	Modify
1	5.948376E+02	3.190671E+02	-3.705634E+01	6.410967E+00	-4.397406E+01	7.043832E+01
2	3.559989E+02	5.263270E+01	2.587974E+01	1.622107E+02	-2.460732E+01	4.078584E+01
3	4.958988E+02	3.013696E+02	3.537136E+01	7.224776E+01	1.923293E+00	6.550476E+01
4	2.561439E+02	4.725511E+00	6.717871E+01	1.197768E+02	4.506552E+00	5.332901E+01
5	3.140352E+02	3.761794E+01	-4.568155E+01	2.628327E+02	-6.298319E+01	6.428506E+01
6	4.192114E+02	5.025957E+01	5.157824E+01	1.451875E+02	-4.710841E+00	4.850283E+01
7	2.660367E+02	7.625768E+01	3.367800E+00	1.969225E+02	-2.178014E+01	6.450130E+01
8	7.746436E+02	4.434700E+01	2.130900E+01	1.582946E+02	-3.277552E+01	3.153118E+01
9	4.046572E+02	6.938319E+01	3.018223E+01	1.702534E+02	-1.125100E+01	5.469625E+01
10	1.369719E+02	5.213140E+01	3.194742E+01	1.578145E+02	-2.008077E+01	4.040837E+01
11	3.997244E+02	3.530521E+02	1.858325E+01	9.797916E+01	-4.041833E+01	1.891041E+01
12	1.658488E+02	3.066959E+02	4.506220E+01	8.256982E+01	3.941032E+00	6.277695E+01
13	4.585629E+03	1.083242E+01	3.266071E+01	1.209584E+02	-3.017991E+01	1.832021E+01
14	3.793775E+02	4.164798E+01	1.037430E+01	1.634978E+02	-4.324523E+01	2.875199E+01
15	1.526924E+02	3.383994E+02	1.378288E+01	7.933768E+01	-3.716058E+01	3.307420E+01
16	1.013430E+02	3.353424E+02	1.529149E+01	7.774402E+01	-3.410194E+01	3.591610E+01
17	1.856867E+02	3.167148E+01	2.925471E+01	1.420531E+02	-3.080777E+01	2.286978E+01
18	2.878818E+02	3.101717E+02	3.919566E+01	7.939149E+01	-1.622287E+00	5.984022E+01
19	5.396586E+02	3.551581E+02	5.789342E+01	1.136128E+02	-3.691428E+00	4.532473E+01
20	2.429480E+02	5.011462E+01	5.818341E+01	1.415458E+02	8.026558E-01	5.125824E+01



© 2000, Axel Mellinger

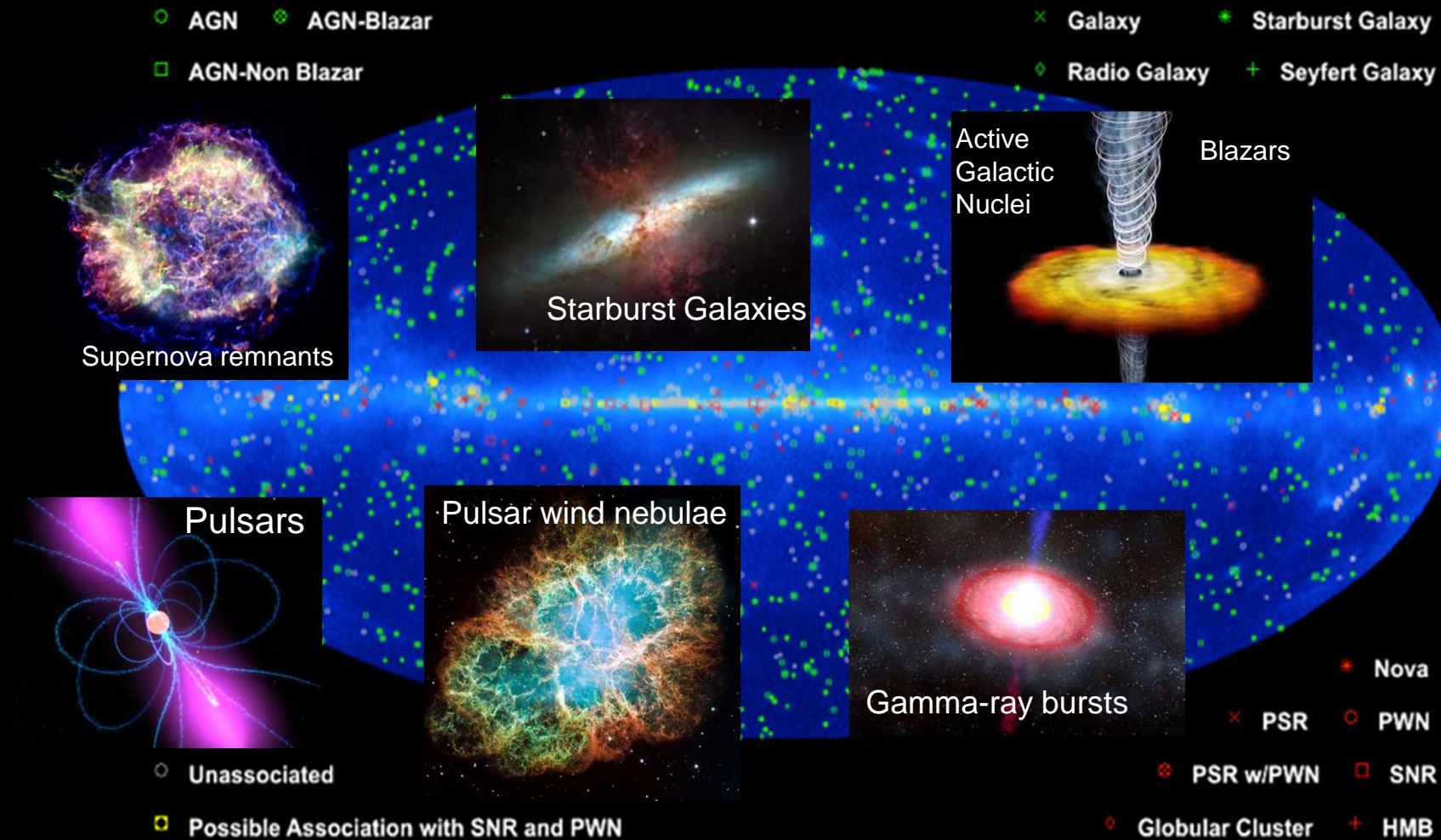




Credit: Fermi Large Area Telescope Collaboration



# Fermi Large Area Telescope 2FGL catalog



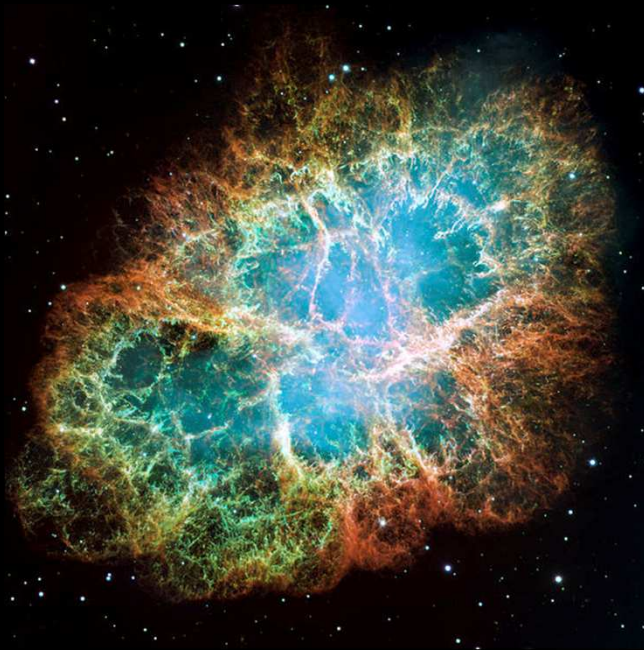
1873 sources with  $TS > 25$

The Fermi collaboration, Nolan, P. L. et al. 2012, ApJS, 199, 31

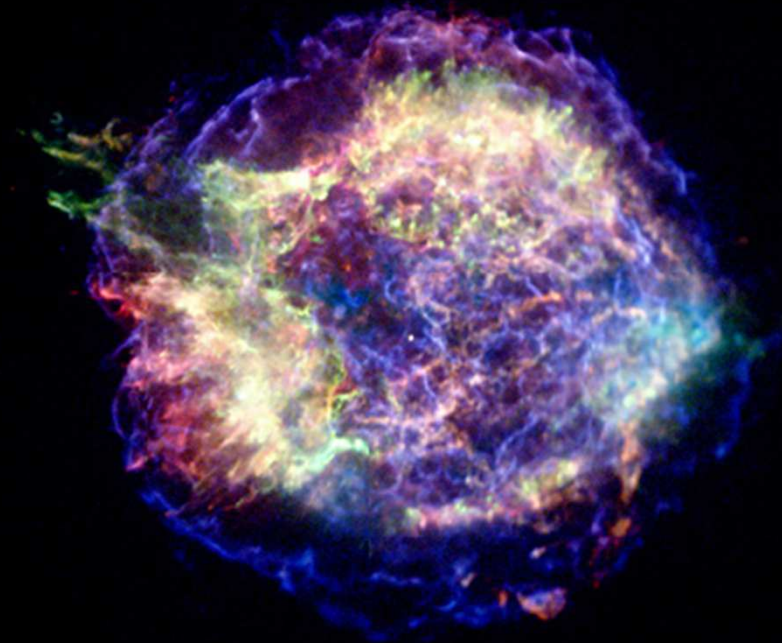
Publication de 2012 la plus citée en Astrophysique

Credit: Fermi Large Area Telescope Collaboration

## Supernova Remnants



Crab nebula (Hubble)



Cassiopeia A (Chandra)

# « Fermi acceleration »

---



# « Fermi acceleration »

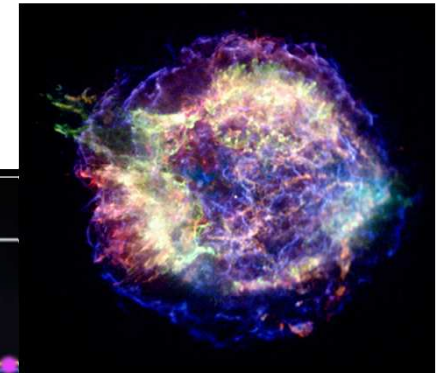
---



This process provides a power-law energy distribution for the accelerated particles (« non-collisional » process):  $N(E) \propto E^{-\alpha}$



# Shell supernova remnants

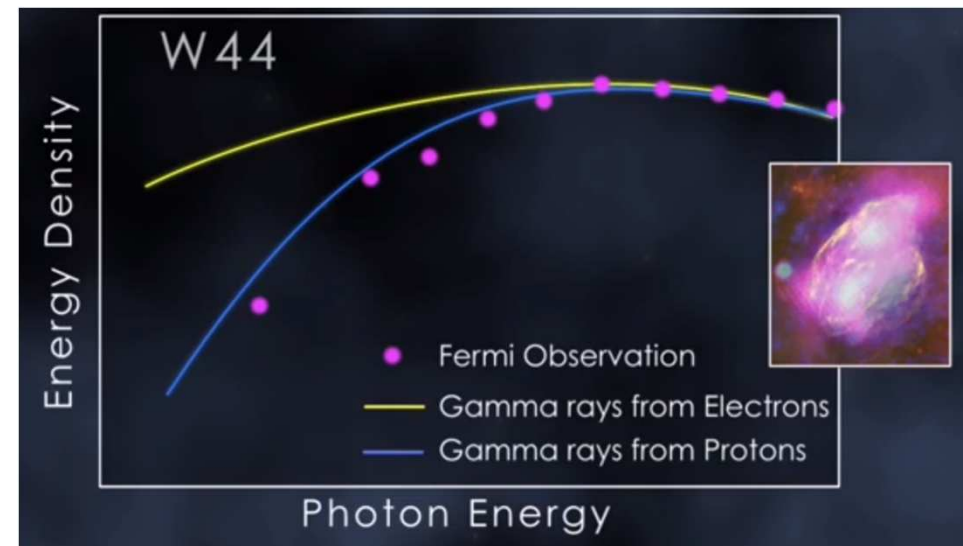
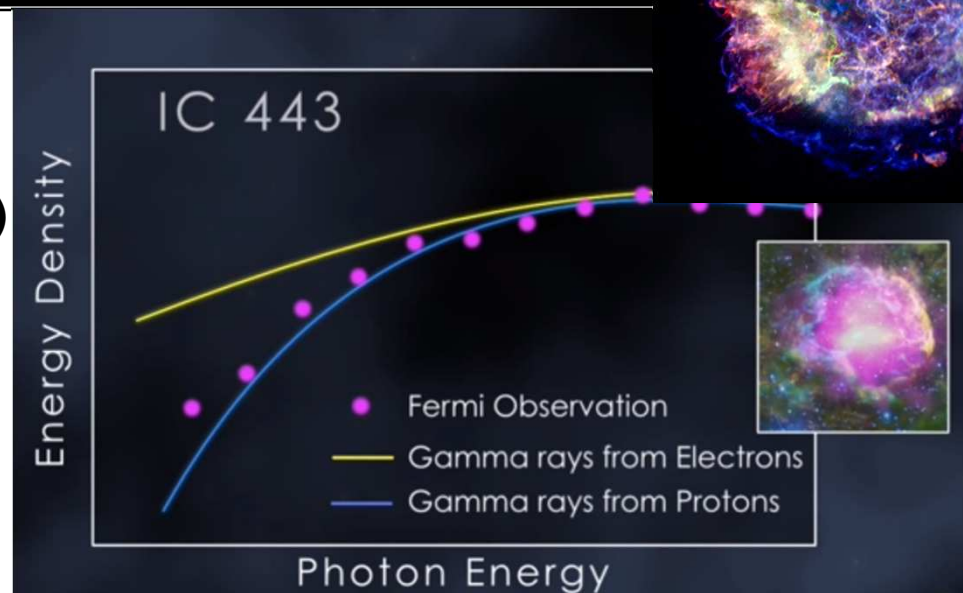


Aged remnants interacting with molecular clouds (« dense » matter) target nuclei in nuclear interactions (protons) or Bremsstrahlung (electrons)

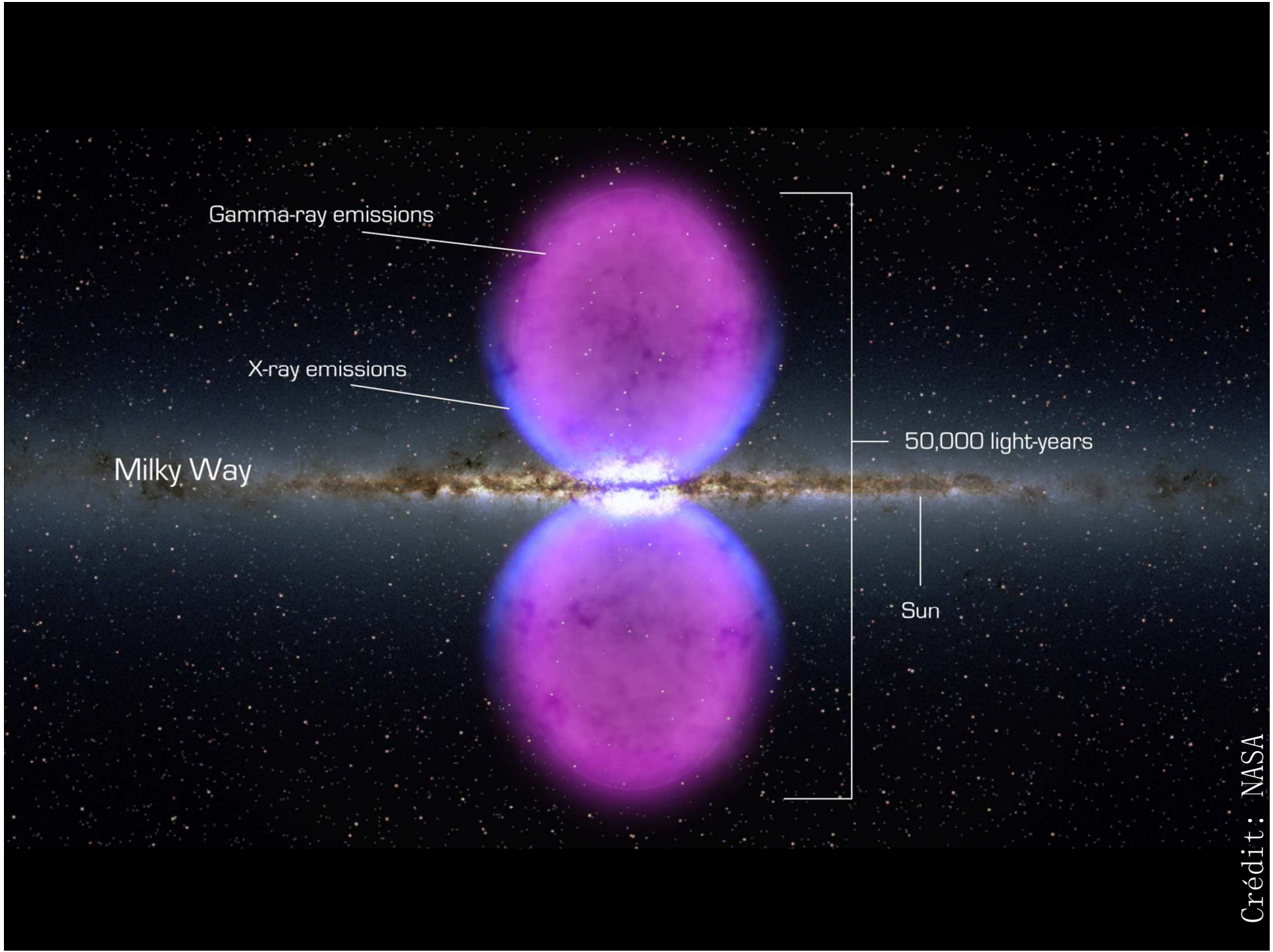
Gamma-ray emitters  
→ cosmic accelerators  
electrons or protons?

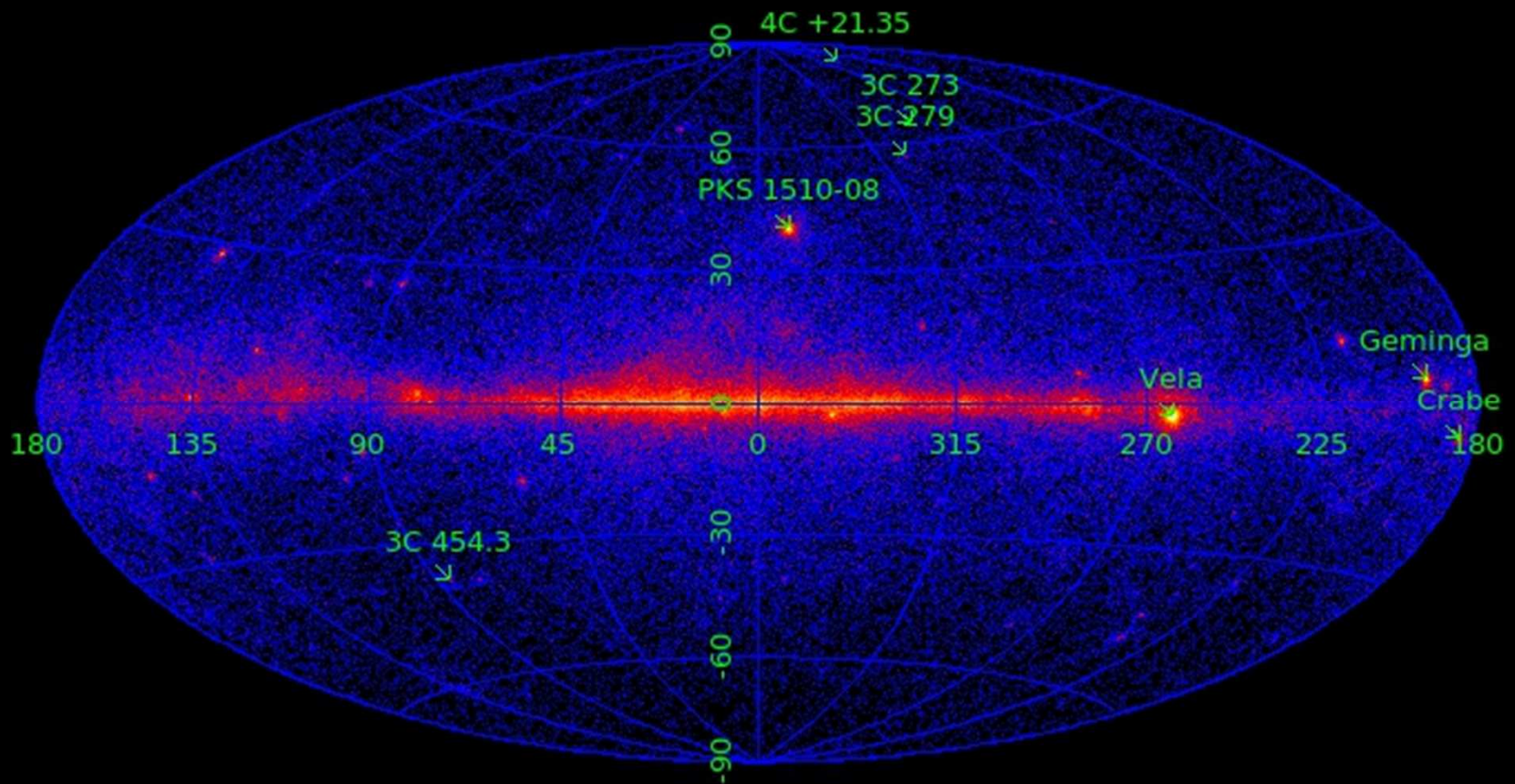
Gamma-ray Fermi-LAT spectra  
→ protons!

Confirmed sites of acceleration for Galactic cosmic rays



One of 10 top scientific results in 2013 according to Science





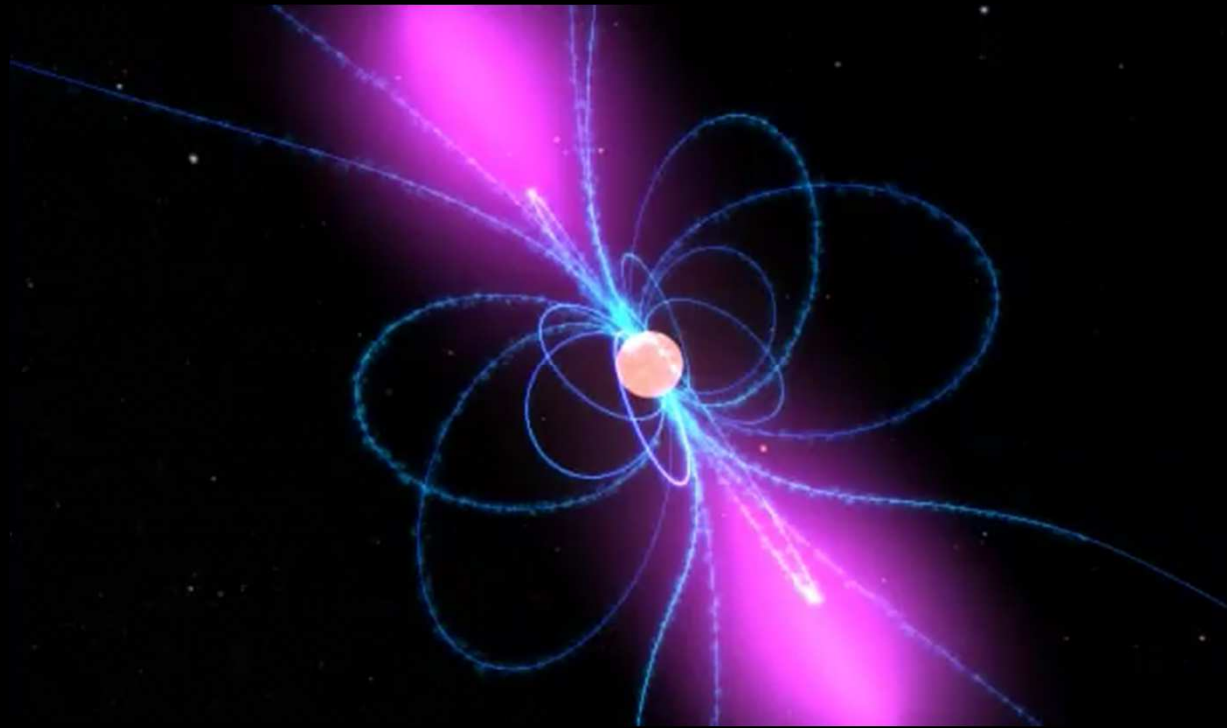


# Pulsars

“Pulsating star”: fast-spinning neutron star (up to 30 rotations/s)  
Collapsed-core of an exploded massive star (supernova)

>150 detected by Fermi

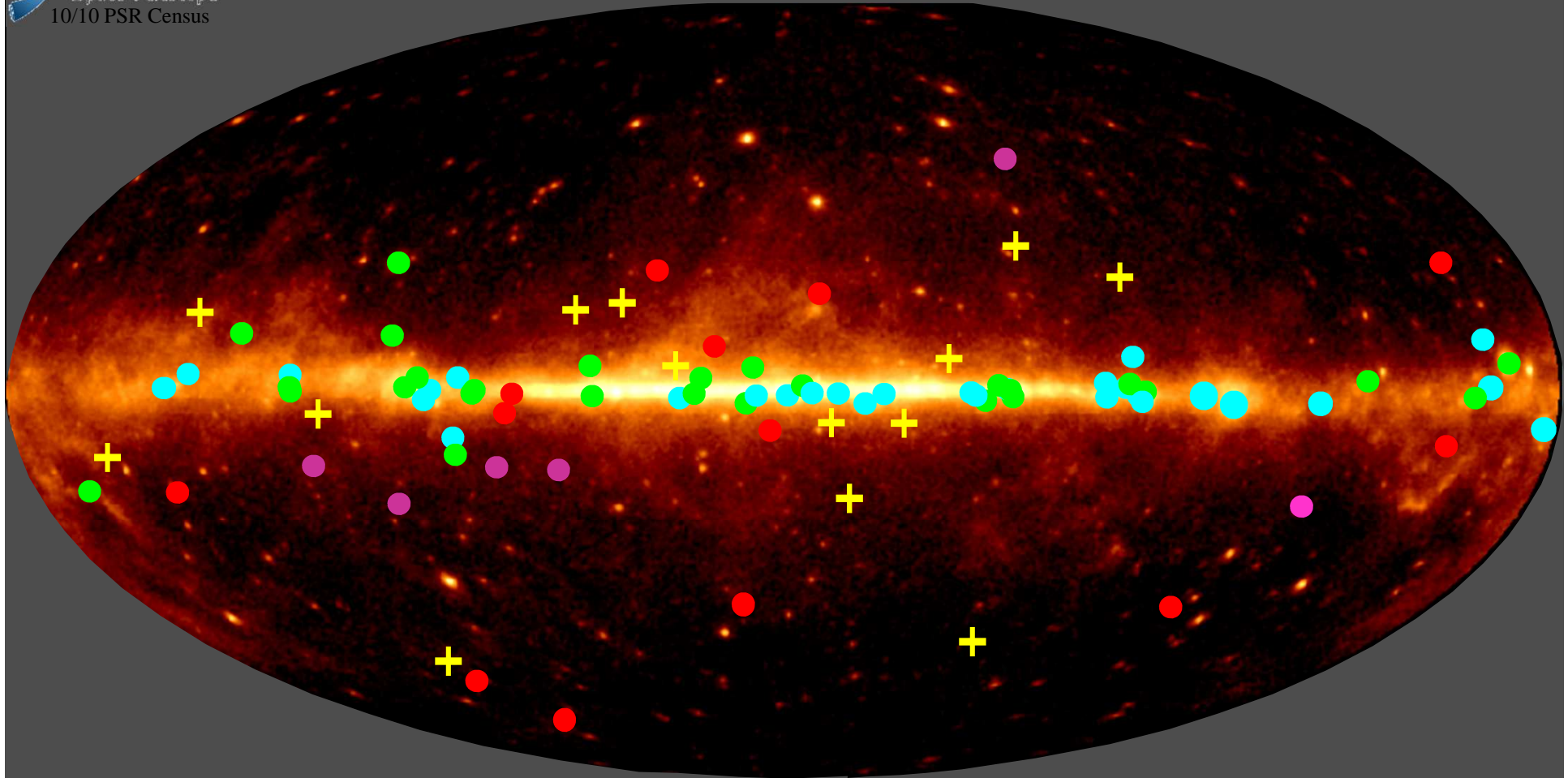
$p+e \rightarrow n+\nu_e$        $M \sim M_{\text{soleil}}$      $R \sim 10 \text{ km}$      $\rho \sim 10^{15} \text{ kg/l}$      $B = 10^{12} \text{ G}$





# The LAT Pulsar Sky

Pulses at 1/10<sup>th</sup>  
Real Rate



30 Young Radio-selected

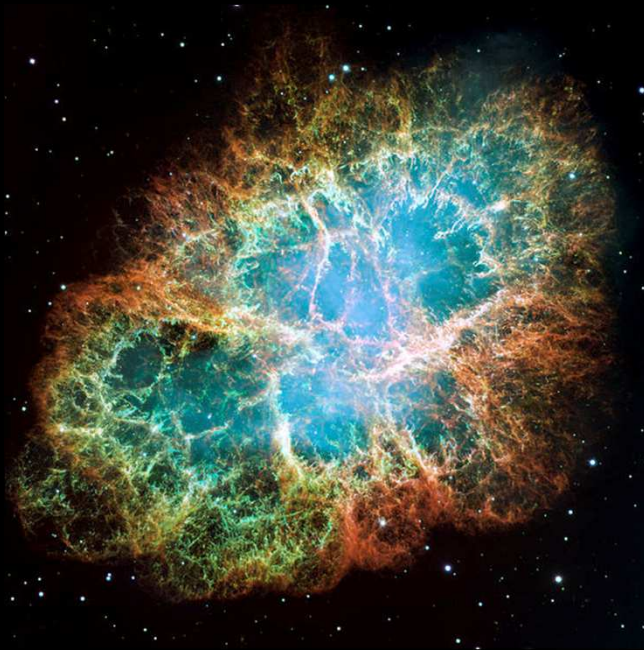
13 MSP Radio-selected

25 Young  $\gamma$ -selected

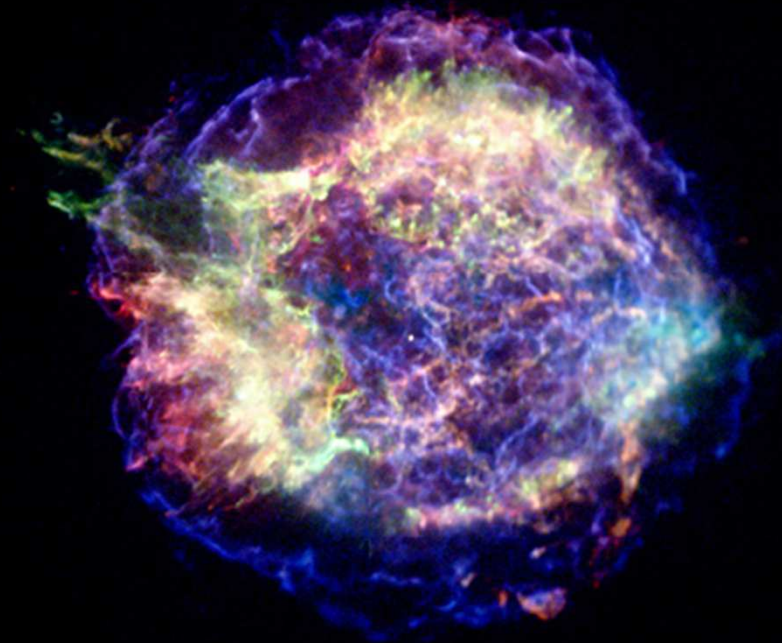
6  $\gamma$ -sel MSP  $\gamma$ /R pulse

14  $\gamma$ -sel MSP R pulse

## Supernova Remnants



Crab nebula (Hubble)



Cassiopeia A (Chandra)

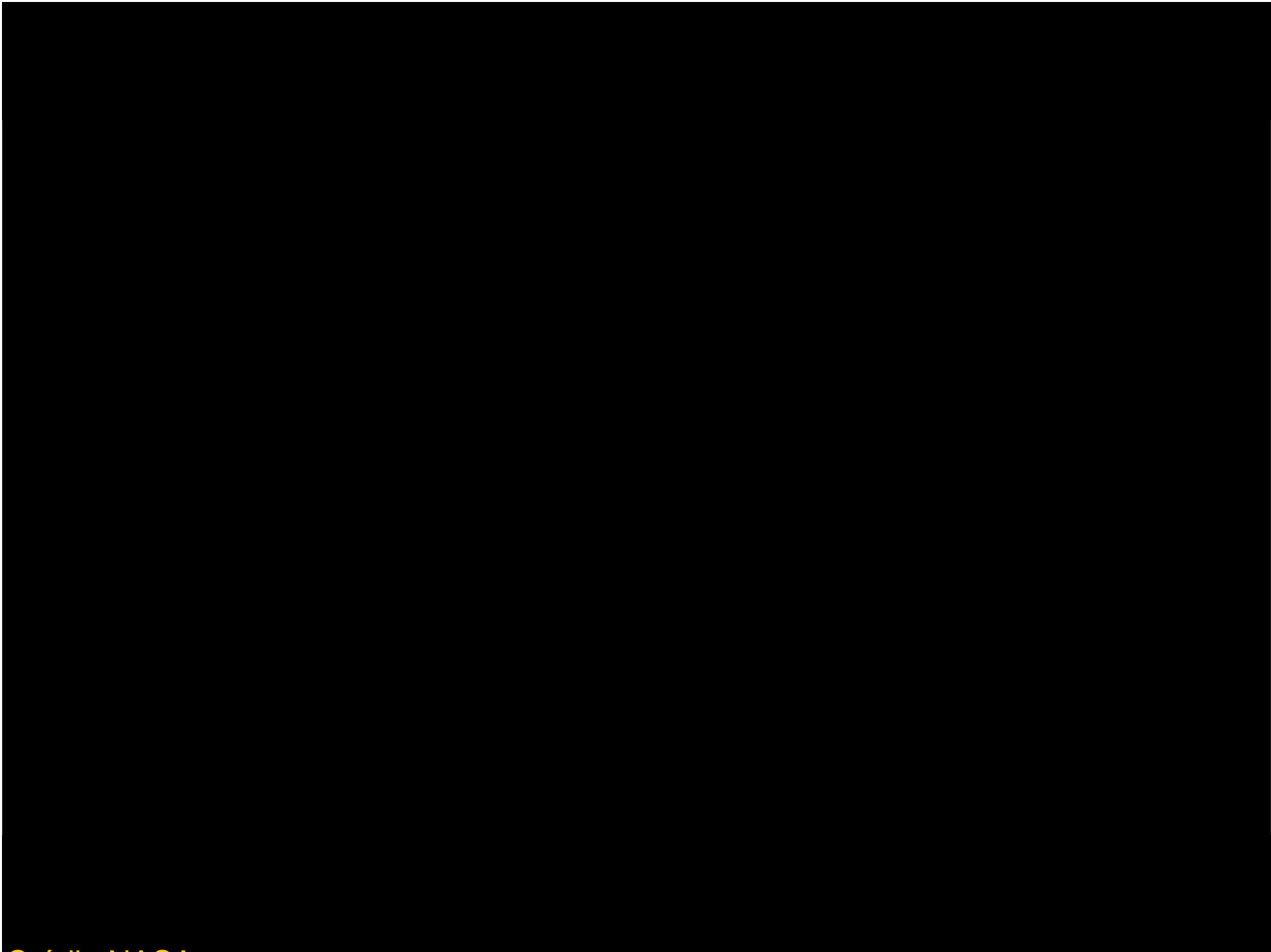


Centaurus A Radio Galaxy (VLT KUEYEN + FORS2)

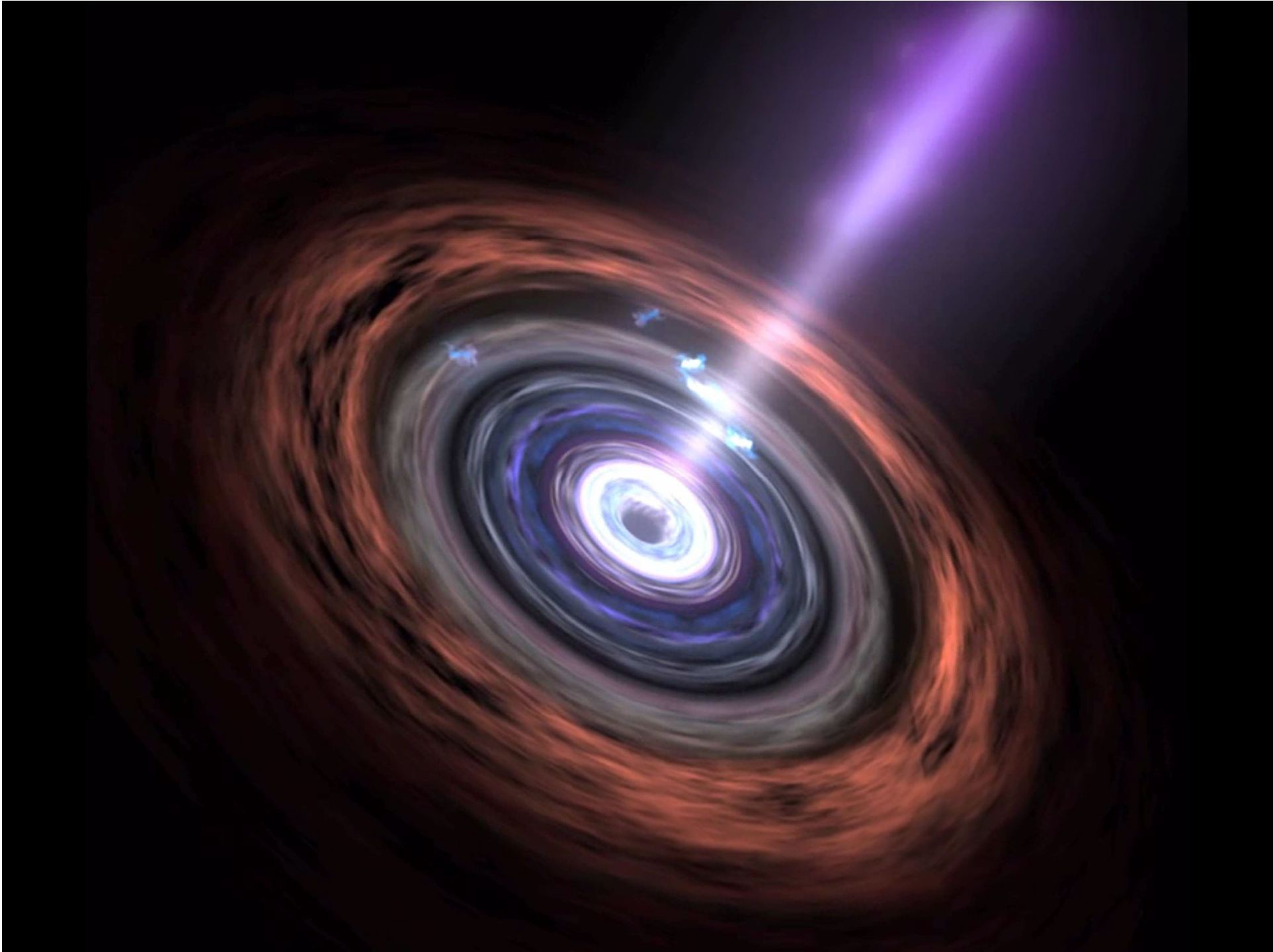
ESO PR Photo 05b/00 (8 February 2000)

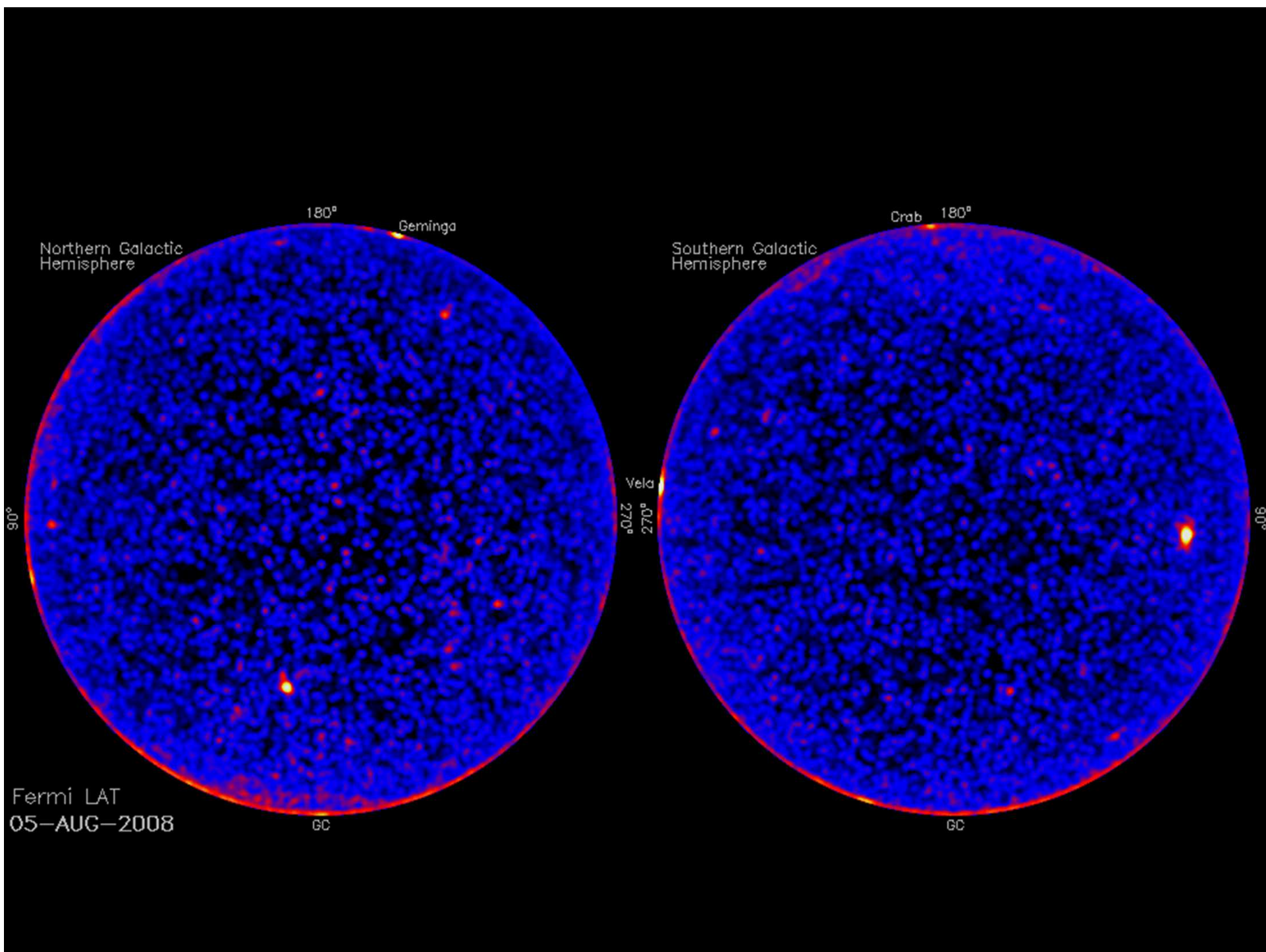
© European Southern Observatory



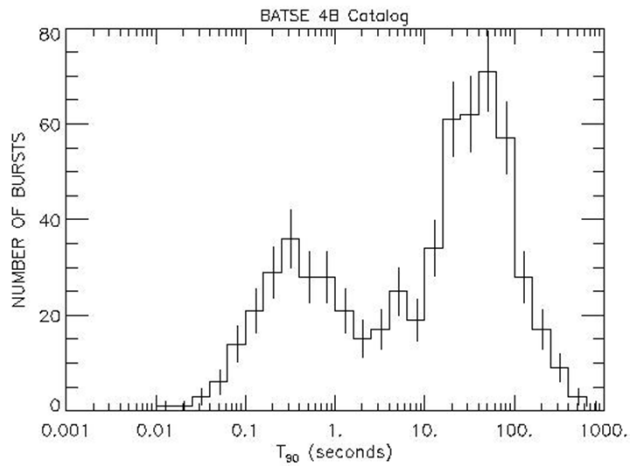




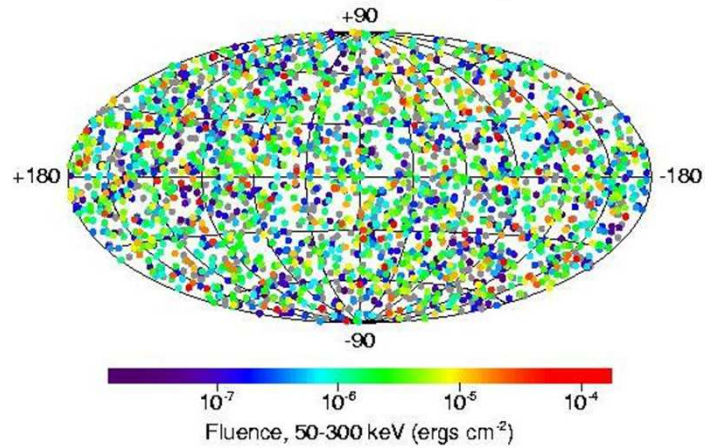




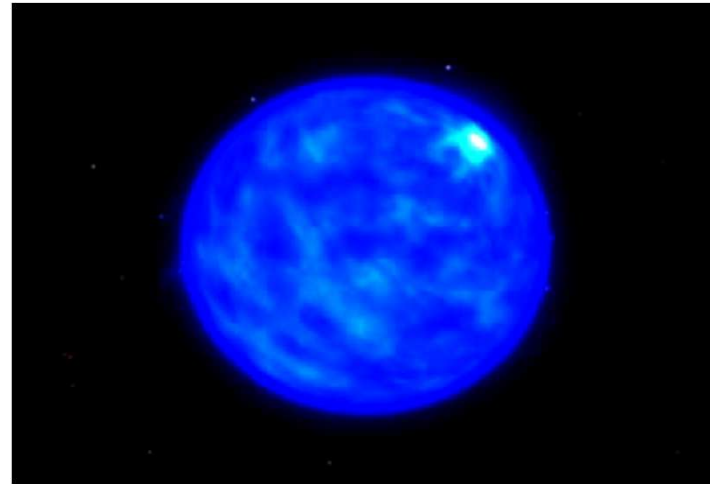
# Sursauts gamma



2704 BATSE Gamma-Ray Bursts



longs: hypernova/collapsar



courts: coalescence d'objets compacts





# COSMIX

<http://www.cenbg.in2p3.fr/Les-rayons-cosmiques-au-Lycee,970>

---

Designed by CEN-Bordeaux Gradignan

Case usable by an physics teaching without any specific training

Simple: no tuning

Cost effective: material recycling

Portable: USB powered

Data free of background

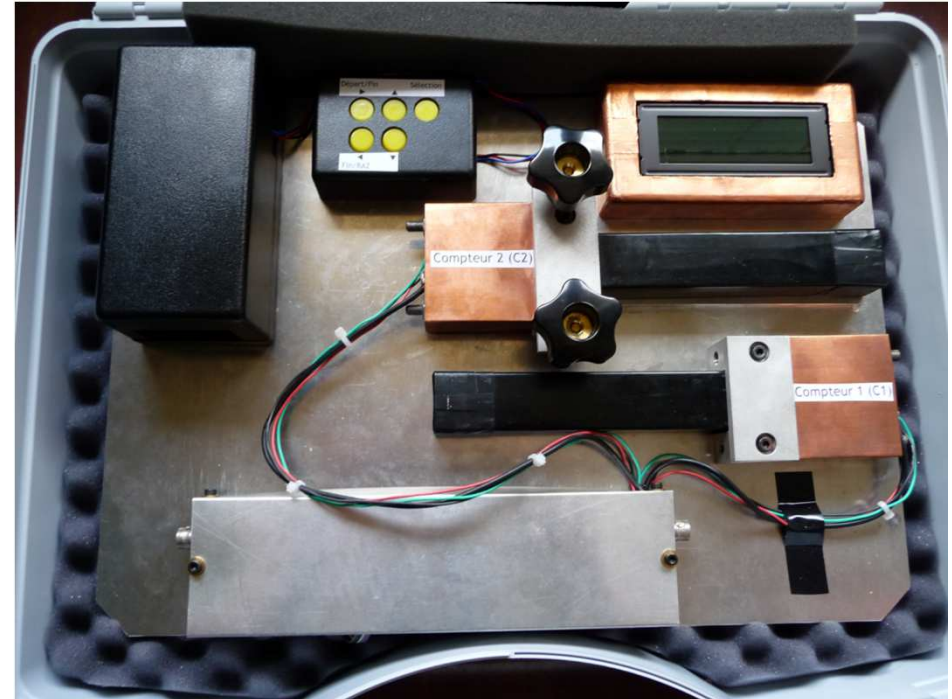
Allows the existence of atmospheric muons to be demonstrated

Visualisation of pulses with a simple oscilloscope – Buzzer

Counting and data logging via arduino and SD card

Fitted with a GPS and altimeter

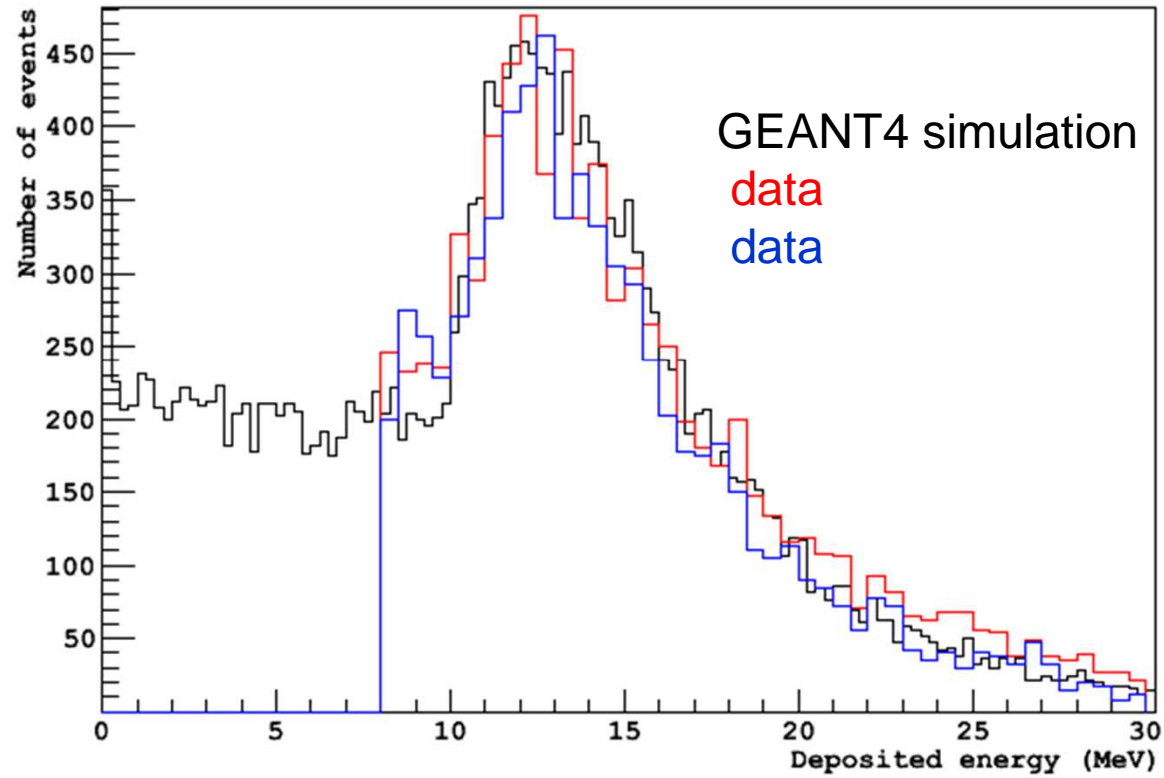
Status: 48 kits built, 24 of which circulating in high-schools





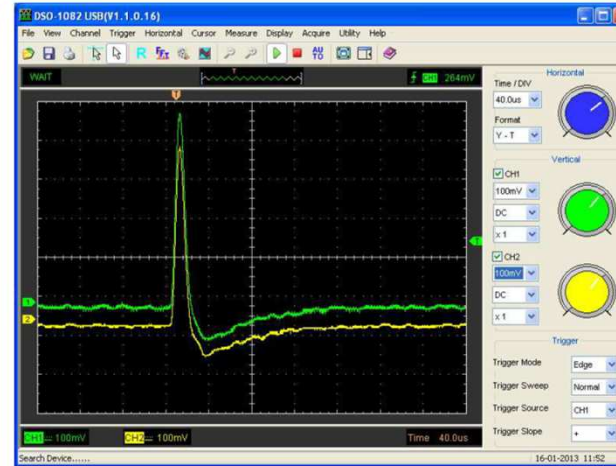
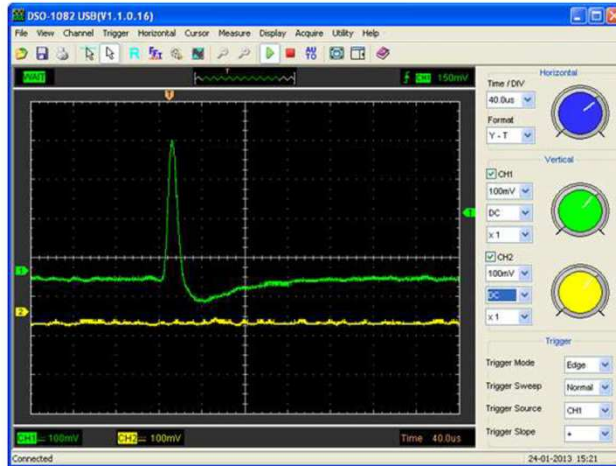
# Deposited-energy distribution

---

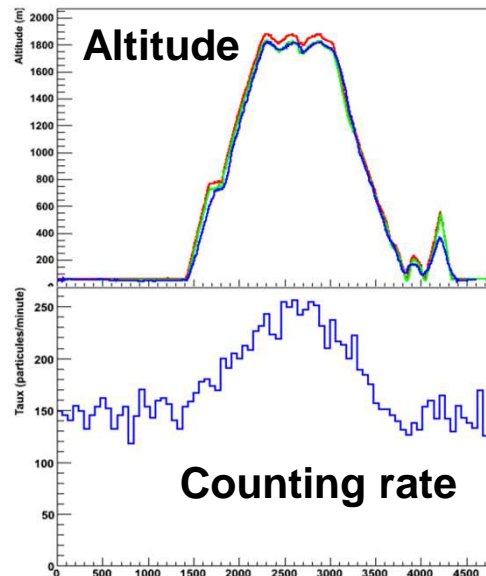


# Examples of measurements

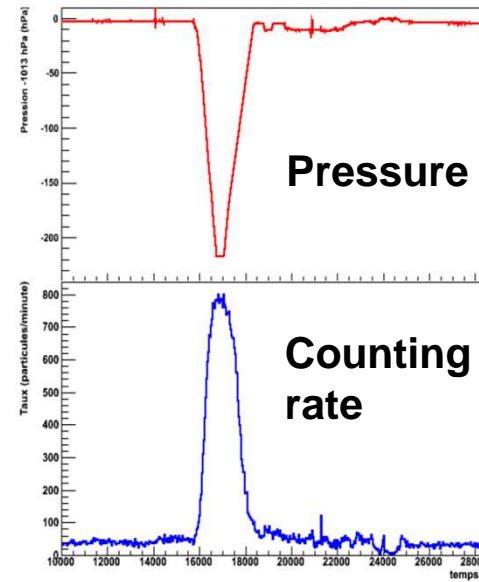
- **Scope signals** – a single counter coincidence between two counters



- **Flights**



on a general aviation airplane (up to 1800 m)



on an airliner

# In a tunnel...

---

Experiments looking at rare decays done in tunnels to reduce muon background  
(overburden of 4 km equivalent water)

Ex: Tunnel de Modane between France and Italy

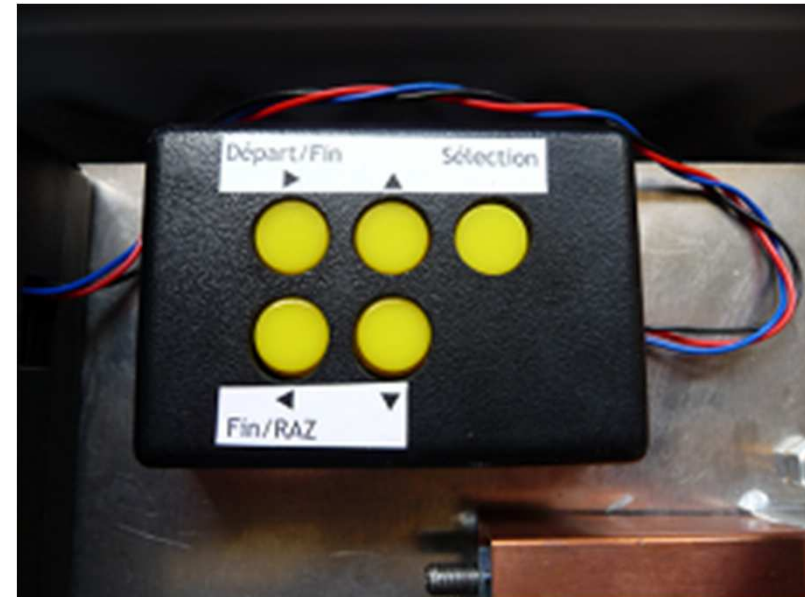
Conting rate in single reduced by 100  
in coincidence by 300000 (1 count in 4 days)

# Commands

---

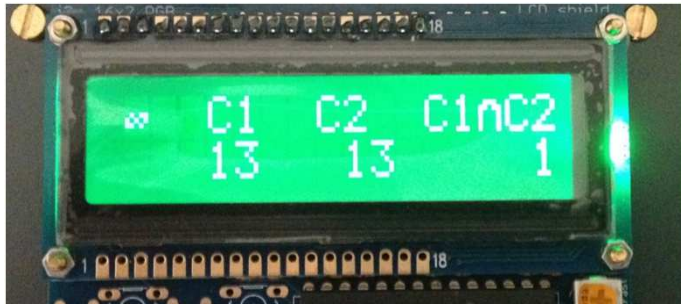
Button pad allows one to scroll through a menu:

- start/stop/reset counting
- predefine a run duration
- turn on/off buzzer
- Display: counting, time, GPS data....





# Menu



Nominal counting

Temperature  
Pressure data



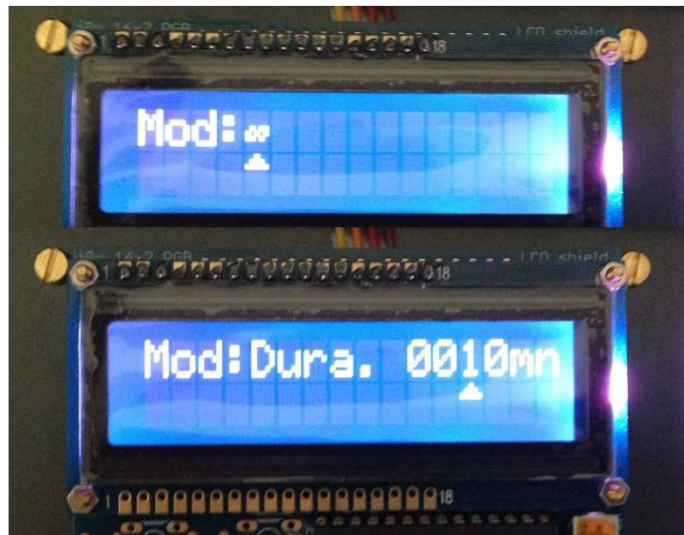
GPS data



Date



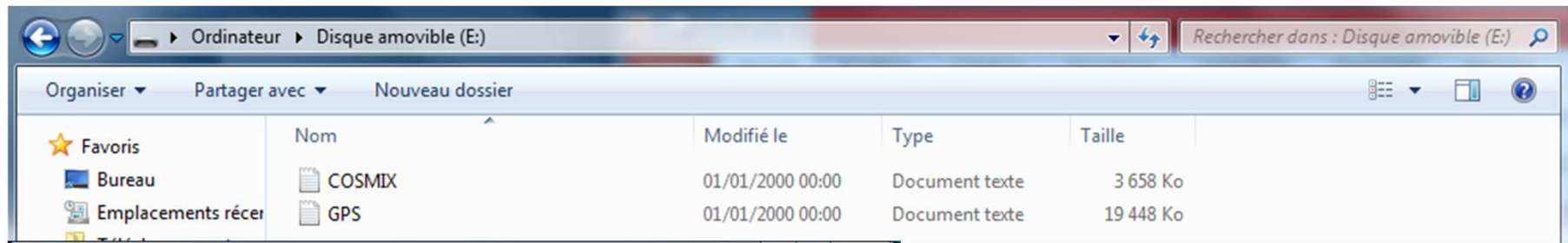
Turning  
Buzzer ON/OFF



Setting the run duration



# Data format



```

COSMIX - Bloc-notes
Fichier Edition Format Affichage ?
2015,07,14,14,07,57.00,(*),110540,46.230419,6.55180,515,28.7,96749,0,1,0,104,88,0
2015,07,14,14,08,00.00,(8),112125,46.230380,6.55160,510,28.7,96743,0,1,0,104,89,0
-----
New Run
Mod: continuous          Clock System : UTC
2015,07,15,07,15,10.00,(*),7294,-999.0,-999.0,-999,27.6,96947,0,1,0,1,1,0
2015,07,15,07,15,10.00,(*),7500,-999.0,-999.0,-999,27.6,96938,1,0,0,1,1,0
2015,07,15,07,15,12.00,(*),9054,-999.0,-999.0,-999,27.7,96938,0,1,0,1,2,0
2015,07,15,07,15,12.00,(*),9445,-999.0,-999.0,-999,27.6,96944,0,1,0,1,3,0
2015,07,15,07,15,12.00,(*),9908,-999.0,-999.0,-999,27.7,96941,1,0,0,2,3,0
2015,07,15,07,15,14.00,(*),11808,-999.0,-999.0,-999,27.7,96949,0,1,0,2,4,0
2015,07,15,07,15,15.00,(*),12018,-999.0,-999.0,-999,27.7,96944,0,1,0,2,5,0
2015,07,15,07,15,16.00,(*),13331,-999.0,-999.0,-999,27.7,96944,0,1,0,2,6,0
2015,07,15,07,15,16.00,(*),13742,-999.0,-999.0,-999,27.7,96944,1,0,0,3,6,0
2015,07,15,07,15,17.00,(*),14005,-999.0,-999.0,-999,27.7,96944,0,1,0,3,7,0
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2015,07,15,07,15,19.00,(*),16924,-999.0,-999.0,-999,27.7,96941,0,1,0,6,10,0
2015,07,15,07,15,20.00,(*),17080,-999.0,-999.0,-999,27.7,96932,1,0,0,6,10,0
2015,07,15,07,15,21.00,(*),18565,-999.0,-999.0,-999,27.7,96938,1,0,0,7,10,0
2015,07,15,07,15,22.00,(*),19296,-999.0,-999.0,-999,27.7,96938,1,0,0,8,10,0
2015,07,15,07,15,22.00,(*),19450,-999.0,-999.0,-999,27.7,96932,1,0,0,9,10,0
2015,07,15,07,15,22.00,(*),19917,-999.0,-999.0,-999,27.7,96946,1,0,0,10,10,0
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2015,07,15,07,15,23.00,(*),20849,-999.0,-999.0,-999,27.7,96941,1,1,0,11,12,0
2015,07,15,07,15,24.00,(*),21651,-999.0,-999.0,-999,27.7,96941,1,0,0,12,12,0
2015,07,15,07,15,24.00,(*),21920,-999.0,-999.0,-999,27.7,96943,0,1,0,12,13,0
2015,07,15,07,15,25.00,(*),22187,-999.0,-999.0,-999,27.7,96946,0,1,0,12,14,0
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2015,07,15,07,15,26.00,(*),23149,-999.0,-999.0,-999,27.7,96938,0,1,0,13,15,0
Clock Adjustment 1 seconds
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2015,07,15,07,15,28.00,(*),24941,46.228691,6.55129,8,27.7,96940,0,1,0,13,17,0
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2015,07,15,07,15,30.00,(*),26956,46.228721,6.55319,-18,27.7,96940,0,1,0,13,19,0
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2015,07,15,07,15,32.00,(*),29016,46.229621,6.54790,379,27.7,96932,1,0,0,14,21,0
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GPS - Bloc-notes
Fichier Edition Format Affichage ?
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2015,07,15,07,49,01.00,(8),2038443,46.229759,6.54490,448,30.8,96929
2015,07,15,07,49,01.00,(8),2038733,46.229759,6.54490,448,30.8,96929
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y, mo, d, hr, min, s, 1/100 s, (GPS sat.), long, lat, alt (m), T(°C), P(Pa)

y, mo, d, hr, min, s, 1/100 s, (GPS sat.), long, lat, alt (m), T(°C), P(Pa), Tr1, Tr2, Tr1∩Tr2, C1, C2, C1∩C2