Cadaveri stellari

raggi gamma, onde gravitazionali
& morti stellari "violente"

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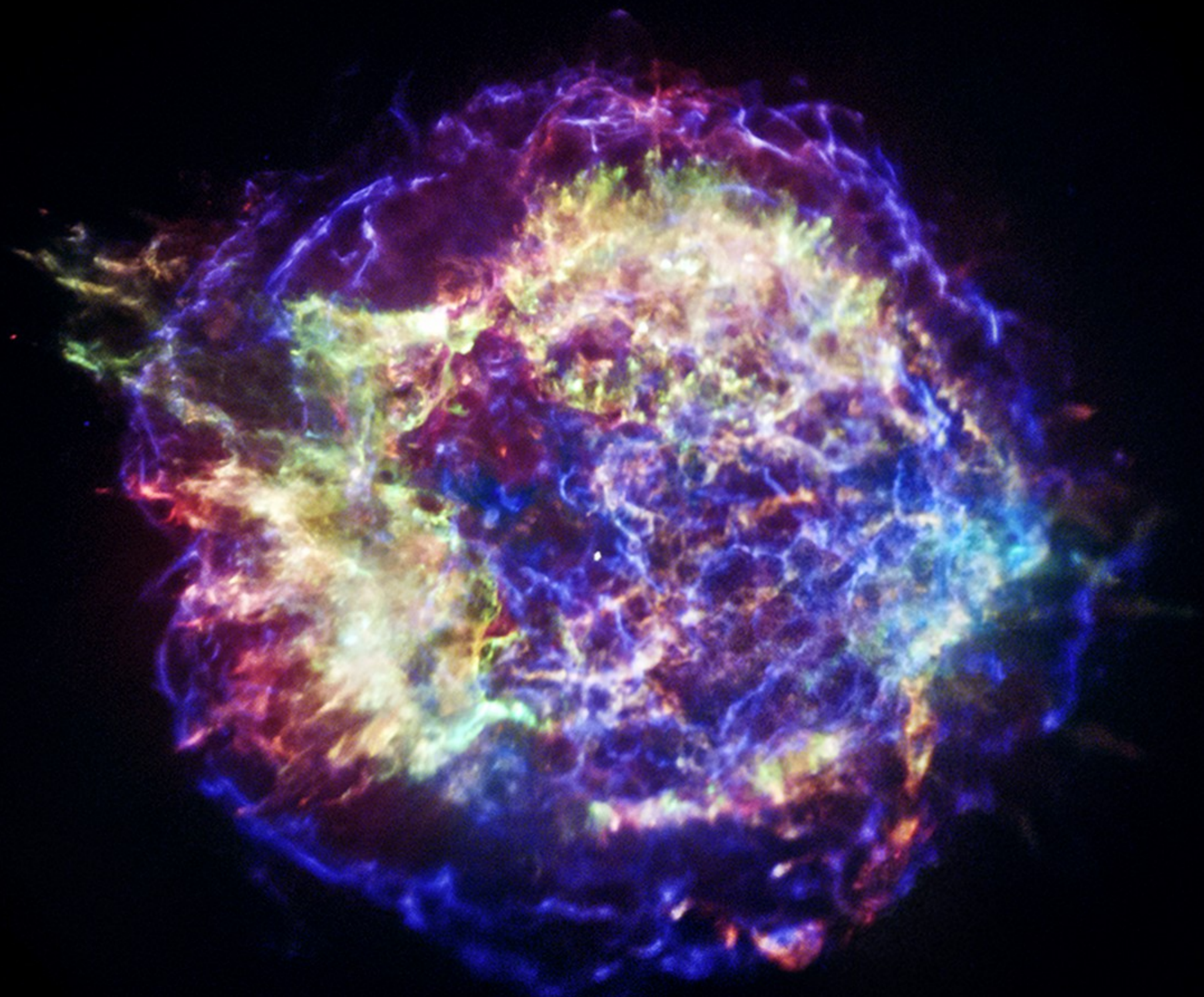
11/03/2015

CSI Cassiopea



Cassiopeia A

Raggi X

11 mila anni luce

“Morti” violente

- Stella massiva

- Lampo gamma
- Gamma Ray Burst

- Supernova

- Resto di supernova
- (Cas A)

- Stella di neutroni

- Buco nero

- Lampo gamma
- (se in sistemi binari)

Perchè studiare i “cadaveri stellari”?

Fenomeni energetici

- Enormi quantità di energie (es. 10^{50} erg)
- Astrofisica delle alte energie

Laboratori naturali

- Condizioni estreme di gravità, campi em, densità, ecc
- Fisica fondamentale (gravitazione, eq di stato, etc)

Non solo fotoni!

- Emissione di neutrini e raggi cosmici
- Onde gravitazionali
- Astronomia “multi-messaggero”

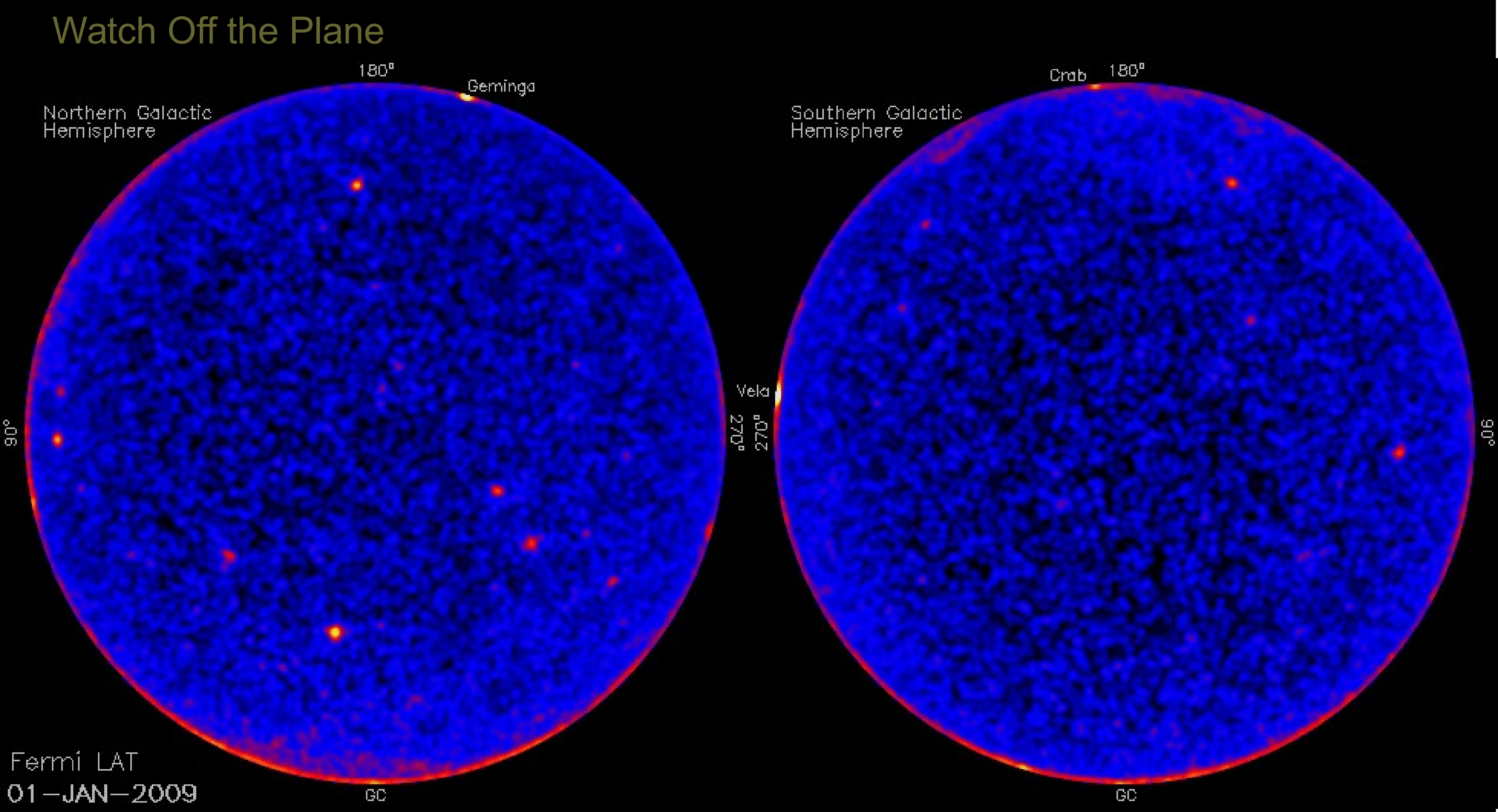
…e a Pisa?

Fisica spaziale con raggi gamma (Fermi)

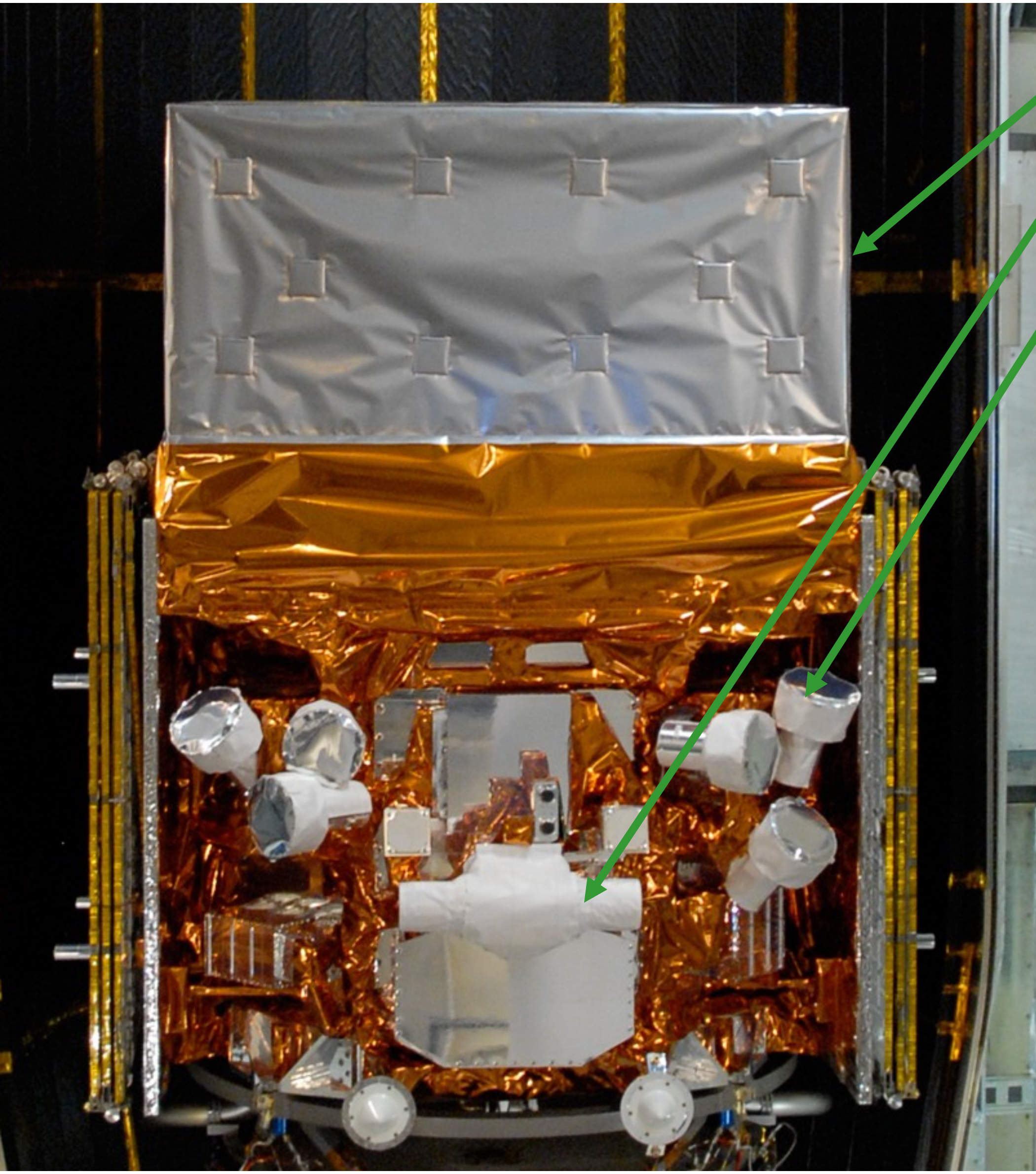
Fisica delle onde gravitazionali (Virgo)

Neutrini, raggi cosmici, e fisica gamma da terra (Antares, AMS, MAGIC/CTA)

Gamma-ray sky: the movie



The Fermi Observatory



Large Area Telescope (LAT)
20 MeV - >300 GeV

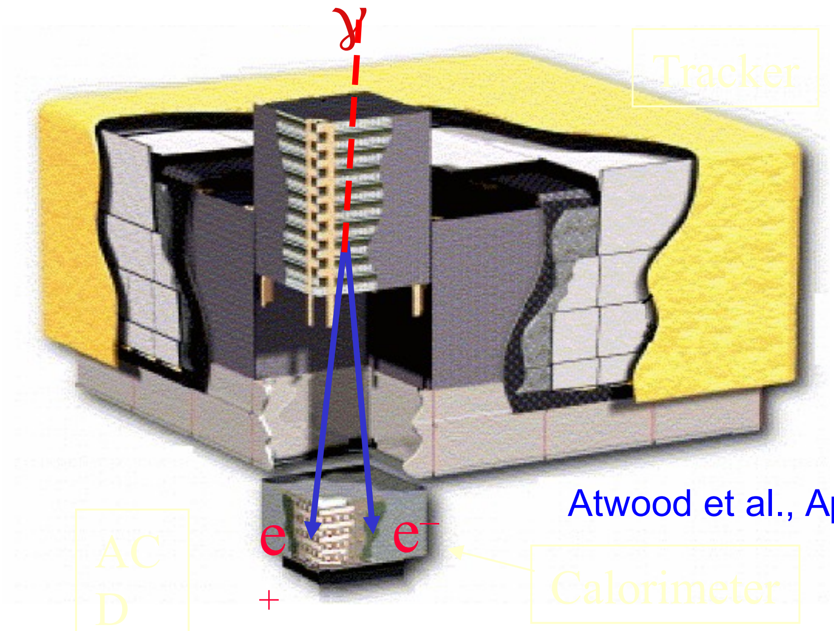
Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 30 MeV

KEY FEATURES

- Huge field of view
  - LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
- Huge energy range, including largely unexplored band 10 GeV - 100 GeV. Total of >7 energy decades!
- Large effective area
- Large leap in all key capabilities. Great discovery potential.

The Large Area Telescope (LAT)

- International collaboration: USA, Italy, France, Germany, Sweden, Japan
- PI: Peter Michelson (Stanford University)
- Italy involvement through ASI, INFN, INAF and many Universities

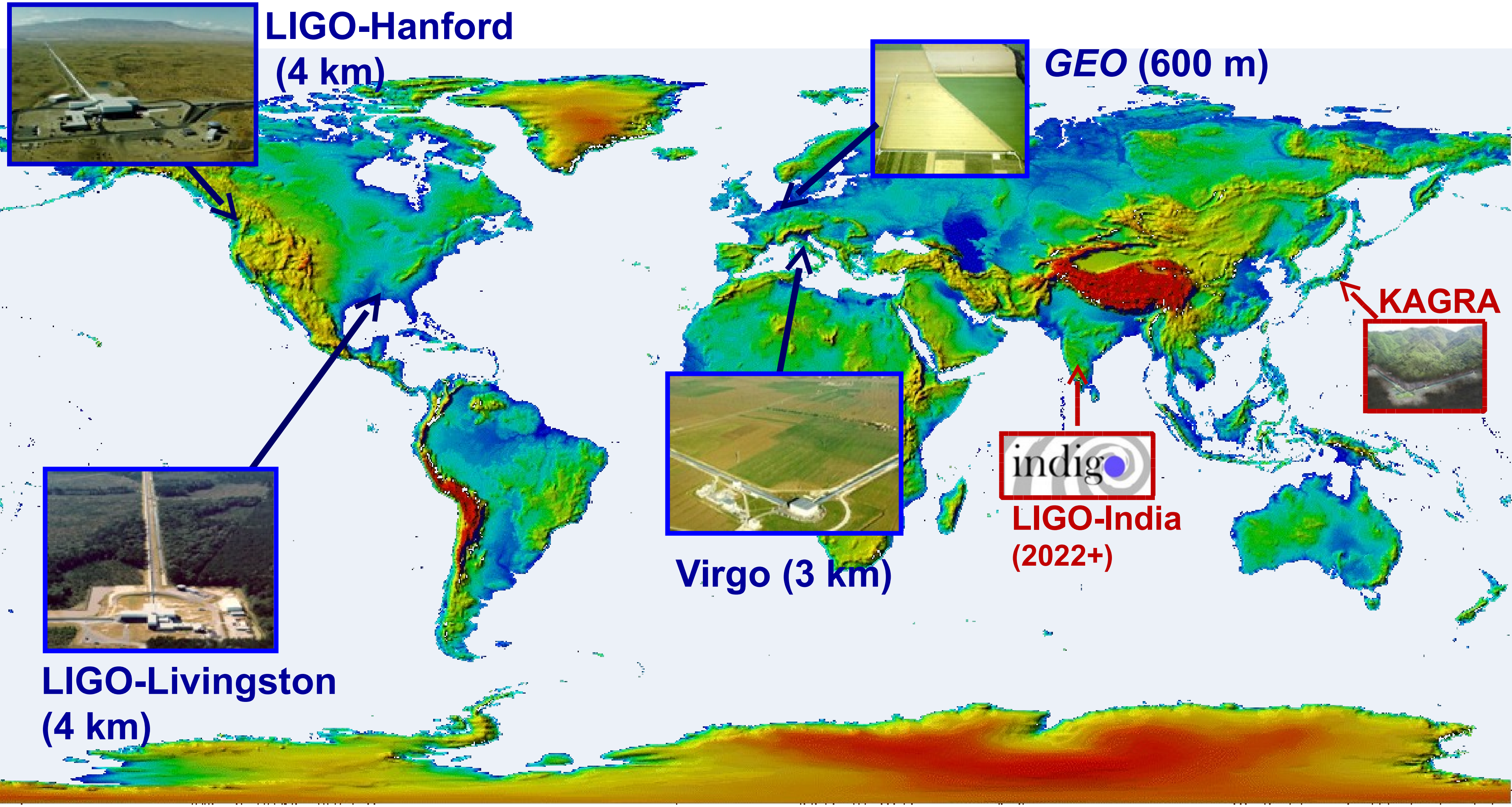


Atwood et al., ApJ, 2009

- Electron-positron pair conversion
- 4x4 modularity
- Redundancy
- Weight 3000 kg, Power 650 W

- Main LAT subsystems
  - Silicon microstrip tracker
  - CsI hodoscopic calorimeter
  - Anticoincidence detector

A network of Gravitational Wave detectors



LIGO and Virgo currently under upgrade
They will observe the sky (10-1000 Hz) as a single network
aiming at the first direct detection of GWs

The Virgo interferometer

- Advanced gravitational interferometers coming online in the next years (Virgo/LIGO)
- Mergers are the most promising GW sources, but also continuous signal from pulsars
- Gravitational-electromagnetic synergy is crucial

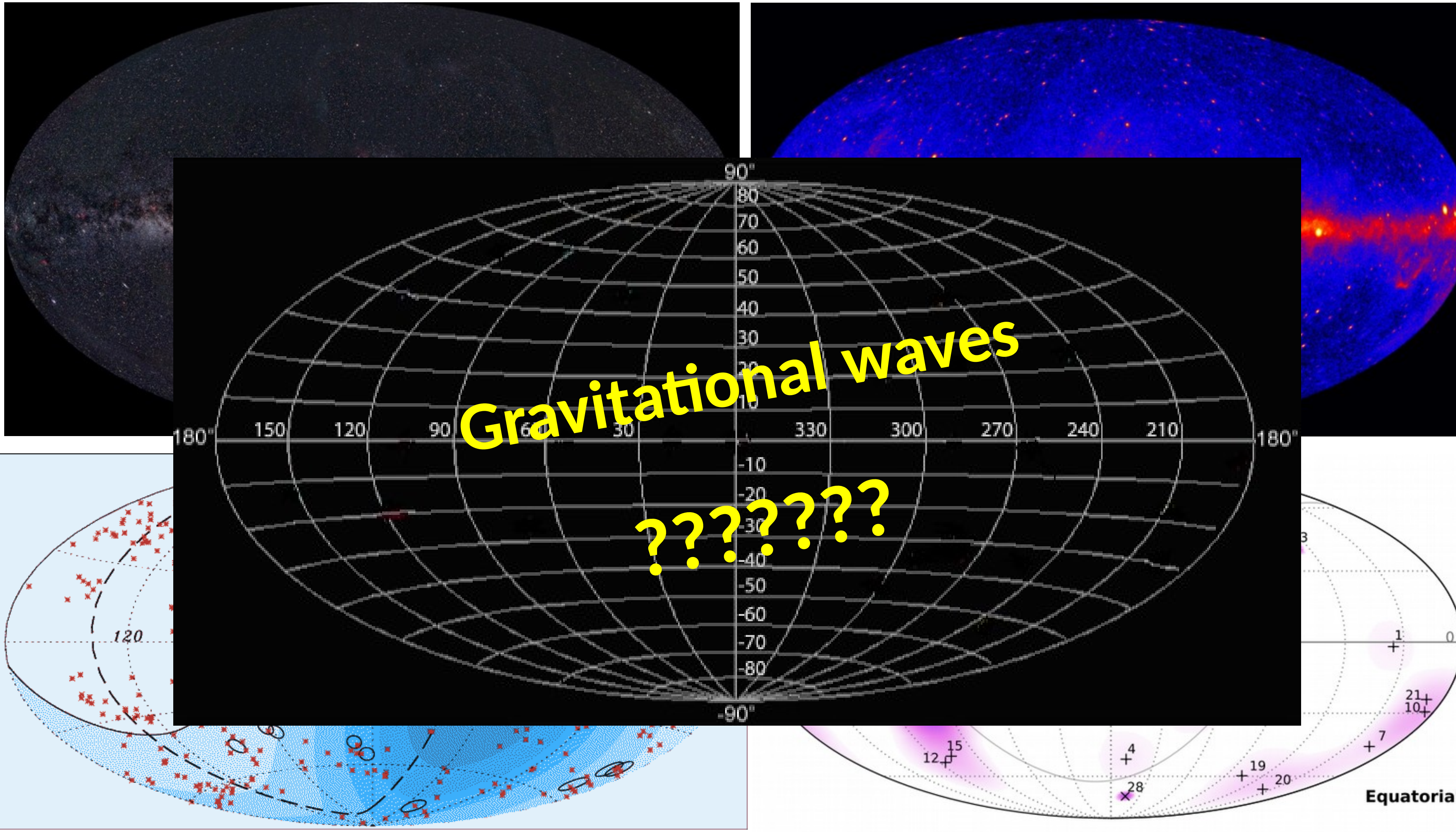
Virgo
1 x 3km (Cascina, Pisa, Italy)
www.virgo.infn.it

LIGO
2 x 4 km (Richland, WA + Livingston, LA)
www.ligo.caltech.edu

A multi-messenger sky

Optical (APOD)

Gamma rays > 0.1 GeV (Fermi-LAT, 2013)

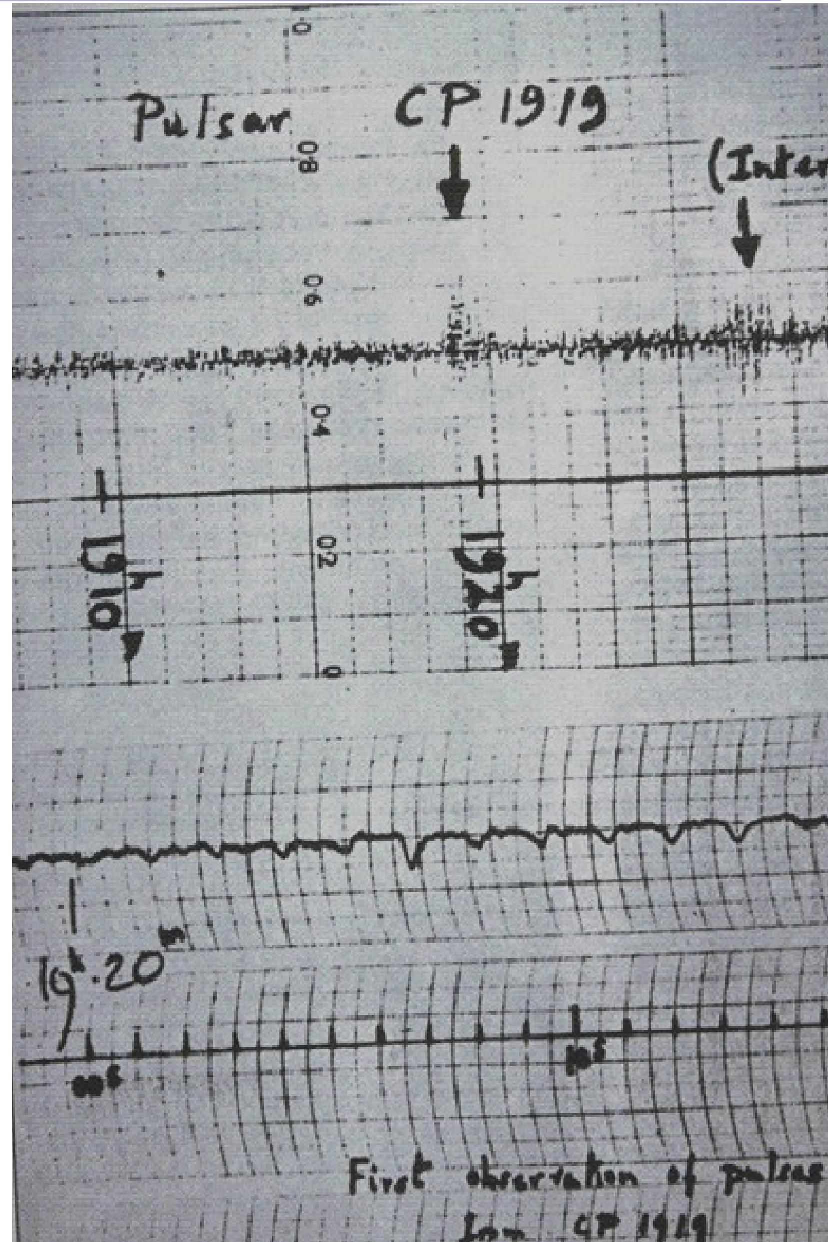


Cosmic rays > 57 Eev (Auger, 2007)

Neutrinos > 30 Tev (Icecube, 2013)

M. Razzano

Stelle di neutroni e pulsar



Jocelyn Bell
&
Anthony Hewish
(1967)

Premio Nobel 1974

What is a pulsar?

Pulsars are rotating, highly-magnetized neutron stars, emitting radiation that is pulsed due to rotation and powered by rotational energy

Some numbers…

Mass: ~1.4 M_{sol} (from X-rays binaries, e.g. see Stairs 2004)

Radius ~ 10 Km;

Periods: ~0.0015 s – ~8.5 s;

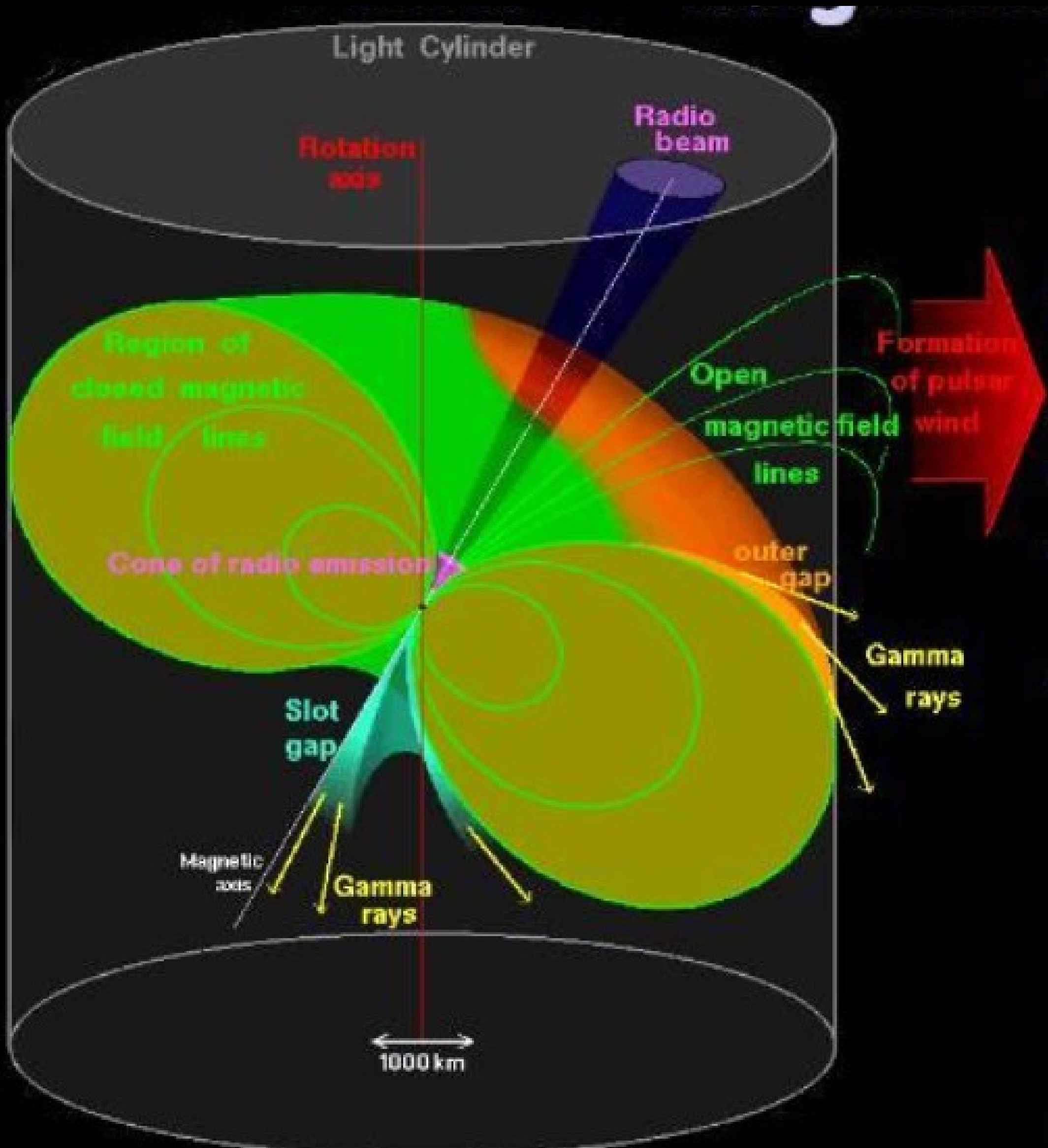
Moment of inertia: 10^{45} g cm^2;

Density: 10^{15} g/cm^3 at the center;

Magnetic field: ~ 10^8G-10^{14}G

Spin down luminosity: ~ 10^{30}-10^{38} erg/s

The “basic” picture



High-E particles + B-fields
→ gamma rays

Where is the acceleration zone?

Polar Cap models:
above the magnetic poles;

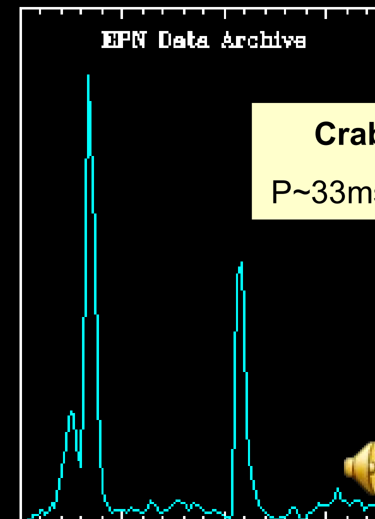
Outer Gap models:
between the last closed lines and the null surface (i.e. $\Omega \cdot B = 0$)

Slot Gap models:
along the last closed field lines

Wind models:
external regions

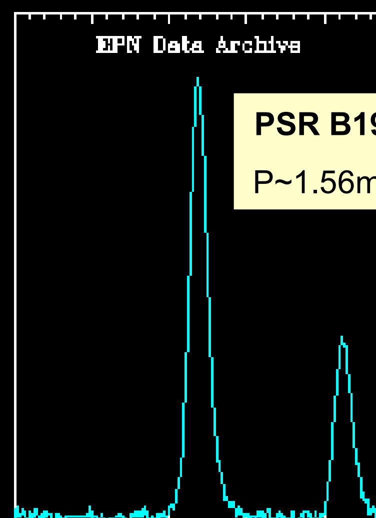
Il "suono" delle pulsar

Jodrell bank:
http://www.jb.man.ac.uk/~pulsar/Education/Sounds/sounds.html
Princeton group:
http://pulsar.princeton.edu/pulsar/multimedia.shtml



Crab

P~33ms



PSR B1937+21

P~1.56ms

Pulsar e raggi gamma

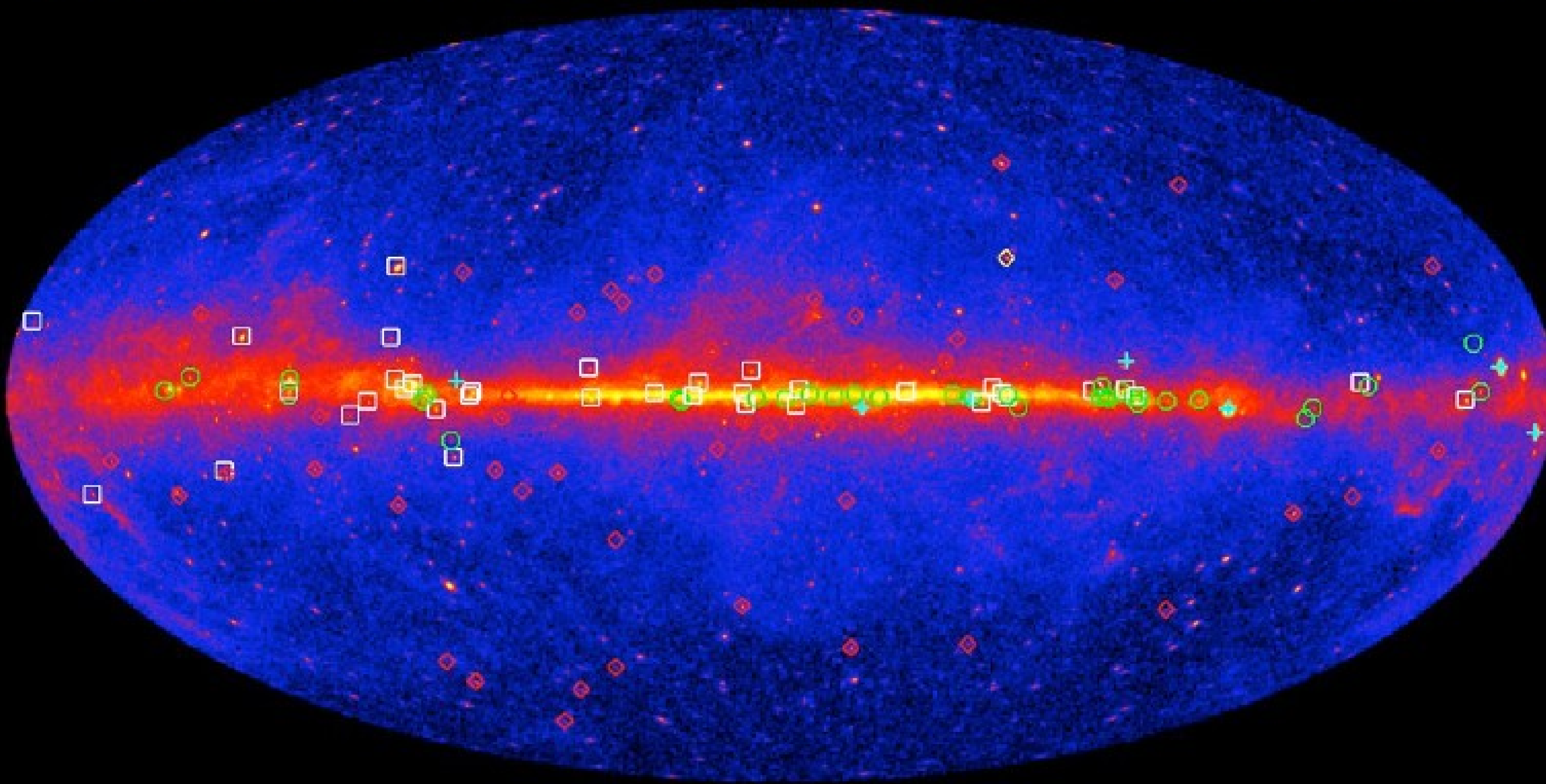
- Efficiency
  - Radio emission is a negligible fraction of the energy budget
  - Gamma ray efficiency can be as high as 10%
  - → Probes of primary acceleration processes in the magnetosphere

- "Magnetic" science
  - Gamma rays are beamed along B field lines with small pitch angles
  - → Can track magnetic field structure

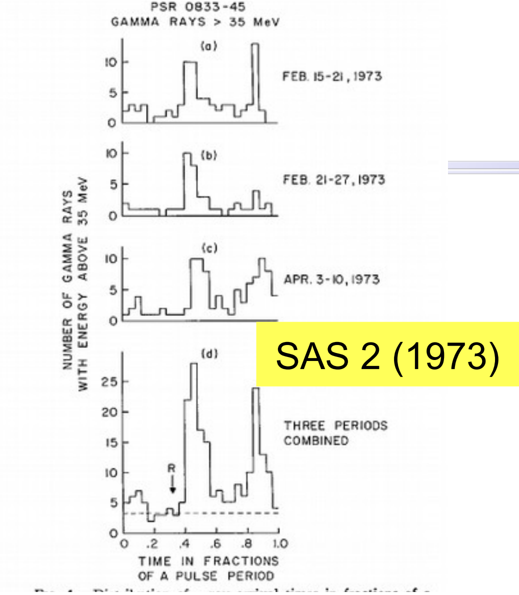
- Beam structure
  - Very different from radio
  - → Gamma rays can track different pulsar populations

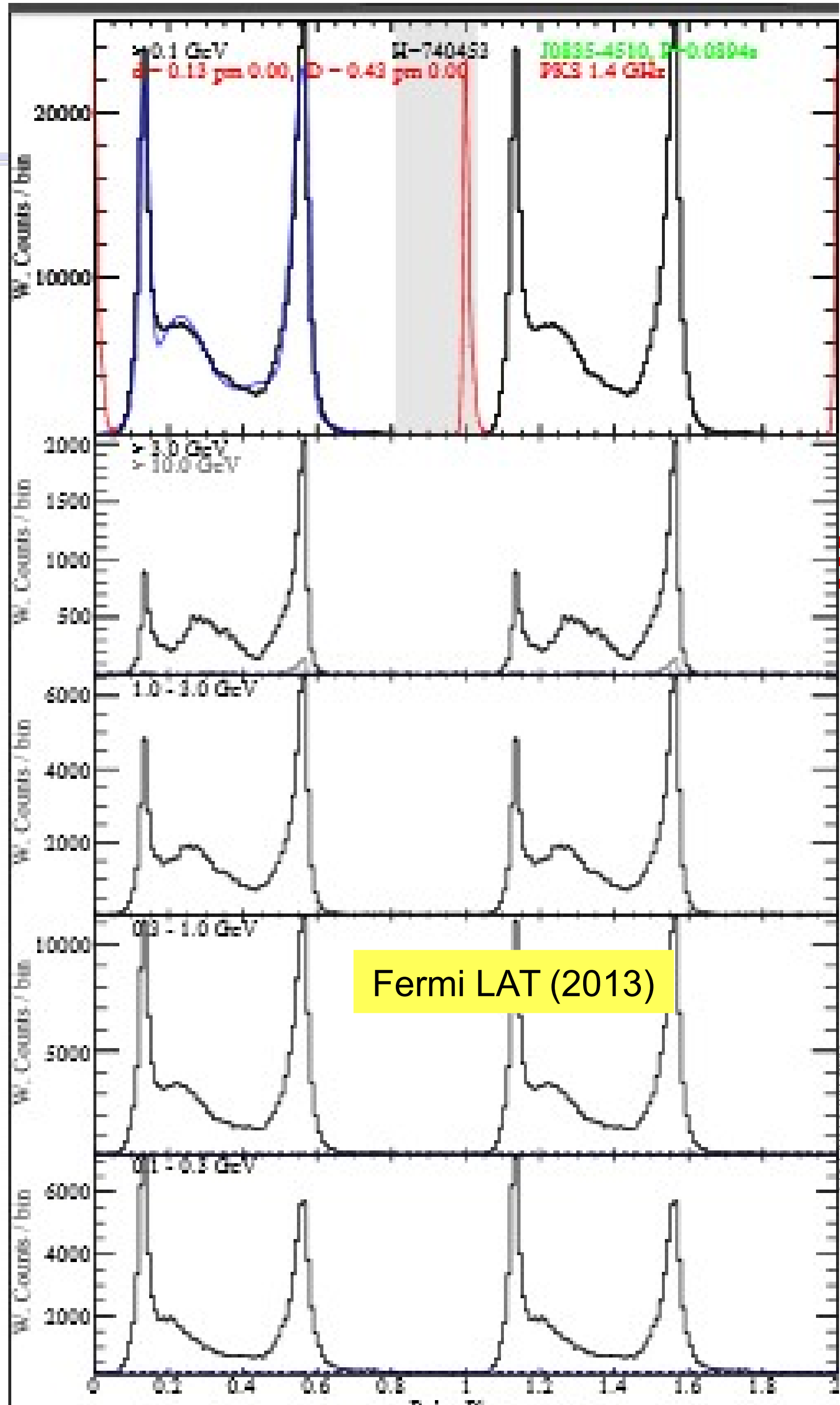
160 pulsar a raggi gamma

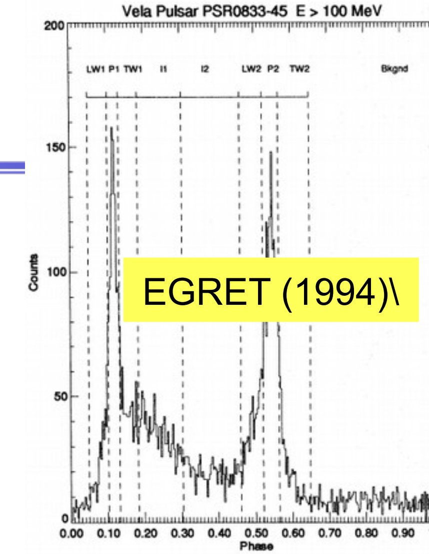
https://confluence.slac.stanford.edu/display/GLAMCOG/Public+List+of+LAT-Detected+Gamma-Ray+Pulsars

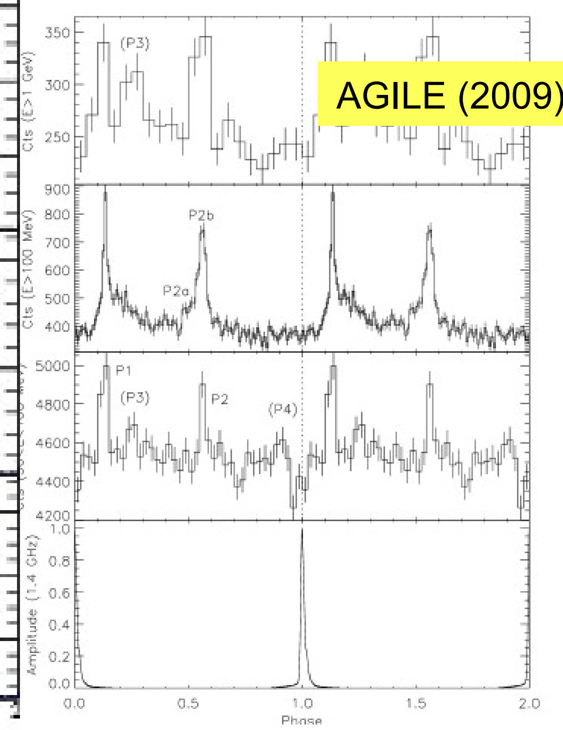


42 young radio- and X-ray-selected (green circles, cyan crosses)
36 young γ-ray-selected (white squares)
46 radio-selected MSPs (red diamonds) + 1 γ-ray-selected MSP (yellow diamond)
(+20 to be published!)


PSR 0833-45
GAMMA RAYS > 35 MeV
FEB. 15-21, 1973
FEB. 21-27, 1973
APR. 3-10, 1973
THREE PERIODS COMBINED
NUMBER OF GAMMA RAYS WITH ENERGY ABOVE 35 MeV
TIME IN FRACTIONS OF A PULSE PERIOD
SAS 2 (1973)

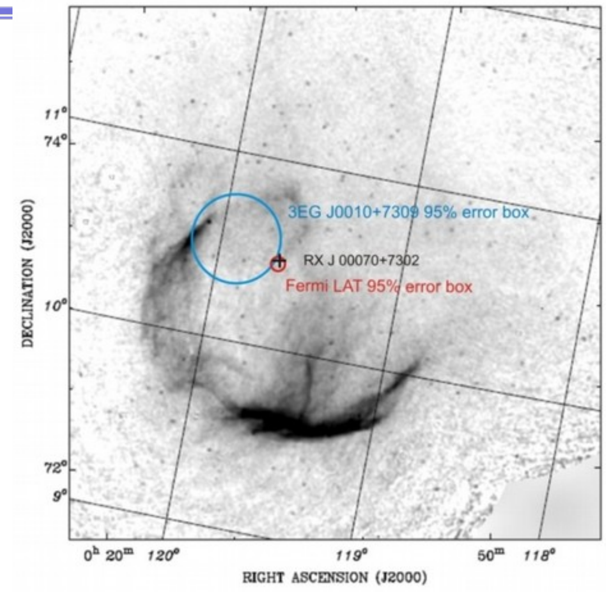

> 0.1 GeV
> 3.0 GeV
> 10.0 GeV
1.0 - 3.0 GeV
W. Counts / bin
PKS 1.4 GHz
Fermi LAT (2013)

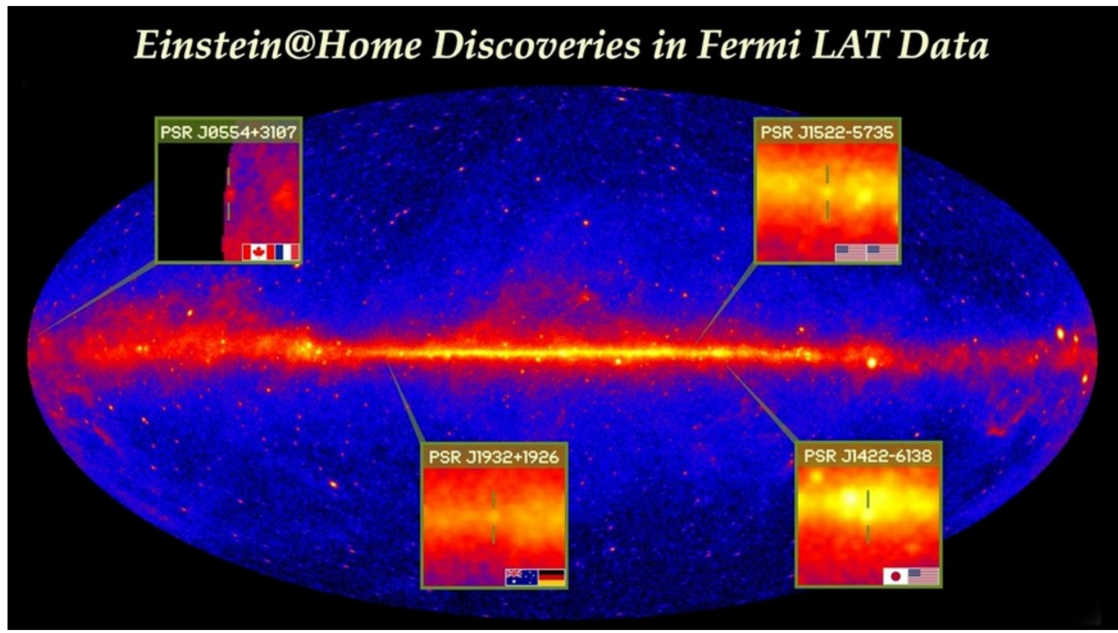

Vela Pulsar PSR0833-45 E > 100 MeV
LW1 P1 TW1 I1 I2 LW2 P2 TW2 Bkgnd
Counts
Phase
EGRET (1994)\


(P3)
P2b
P2a
P1
P2
(P4)
Amplitude (1.4 GHz)
Phase
AGILE (2009)

Pulsar blind searches

- Why "blind"
  - We don't know frequency, etc..
  - We don't know position
  - Is it binary?
- Search is difficult
  - Gamma rays are sparse (1 ph/100 periods)
  - N_{trials} huge (>>10^{10})
  - CPU intensive
- So?
  - Time-differencing technique
  - (Atwood+06, Ziegler+08)

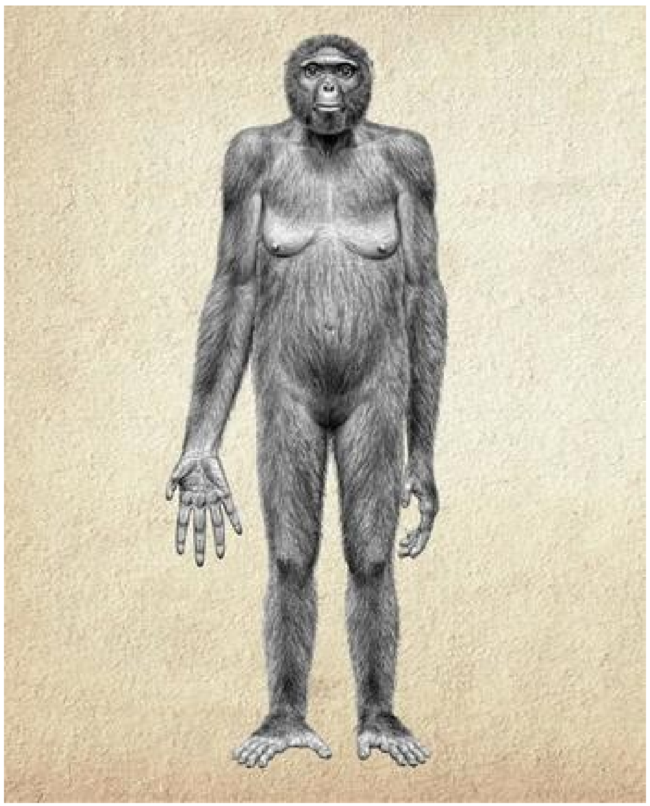




http://einstein.phys.uwm.edu/

«2nd most relevant discovery in 2009»
(Science)

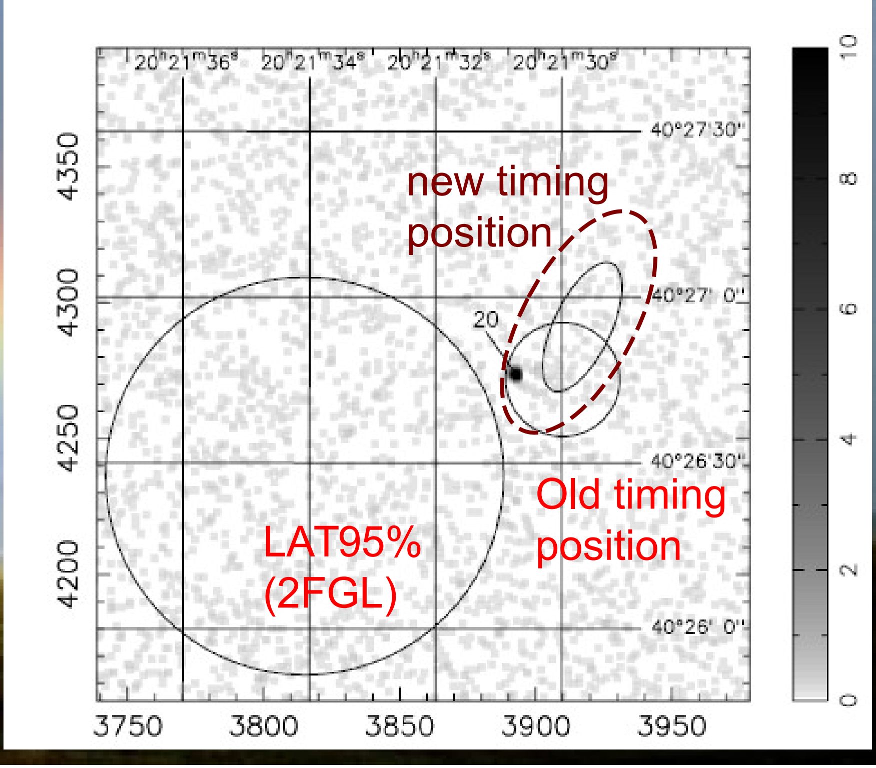
And the winner is…



(Arditpitecus)

Pulsars in multicolor

- **Multiwavelength follow ups are extremely important for pulsars:**
- **To discover new pulsars**
  - **Detect modulation at other energies (e.g. radio)**
  - **Find point sources for blind searches (e.g. X-rays)**
  - **Unveil orbital modulation of a companion (e.g. optical)**
- **To investigate known pulsars**
  - **Build spectrum**
  - **Multi-λ light curves**
  - **Detect proper motion**

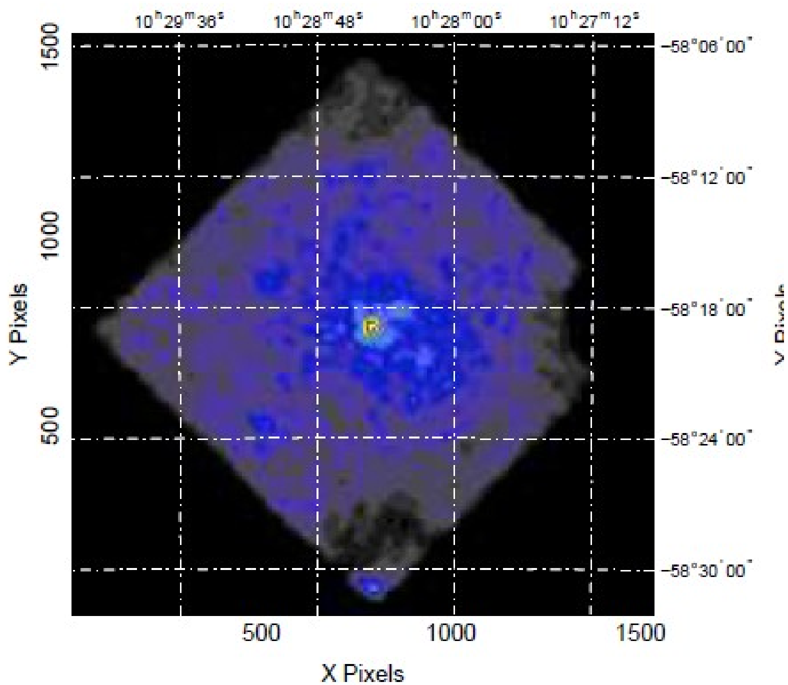


Example: Identification of the long-debated X-ray counterpart of Gamma Cyg PSR with Chandra

(Weisskopf,Romani,**Razzano** et al. ,ApJ,2011)

Optical observations of pulsars

- < 10 pulsars have been identified in optical (4 with pulsations)
- Optical emission is very faint (mv>26). 8-m telescopes are required
- Upper limits and spectra to constrain emission models (e.g. synchrotron)



VLT + Suzaku observations of PSR J1028-5819
(Mignani, **Razzano** et al. 2012,A&A 234,543)

New VLT observations of PSR J1048-5932
(**Razzano** et al. 2012, MNRAS submitted)

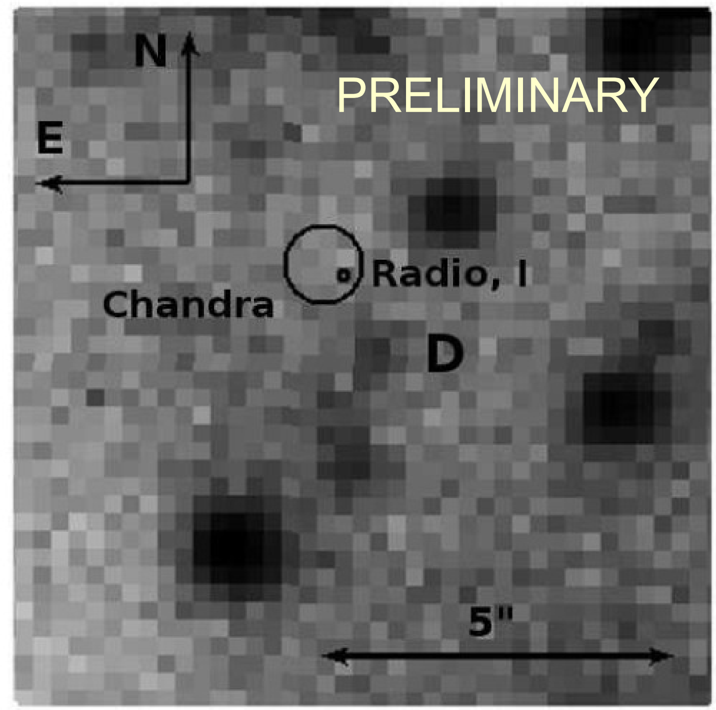
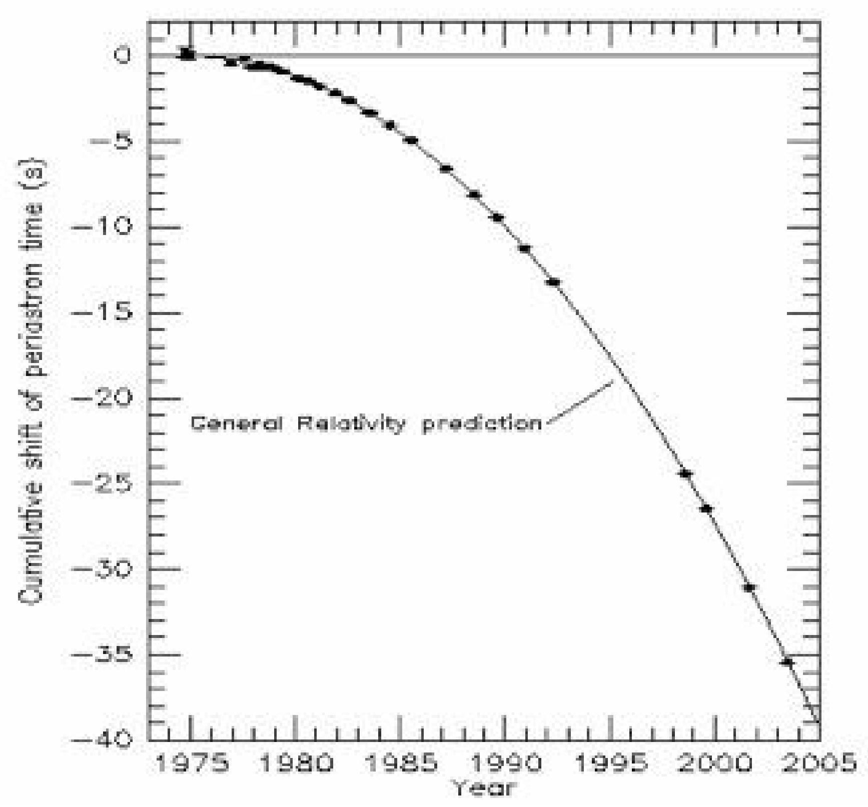


Figure 1. VLT/FORS2 image of the PSR J1048−5832 field (R band; 13797.7 s). The *Chandra* (Gonzalez et al. 2006) and radio interferometry (Stappers et al. 1999) positions are shown as circles. The star closest to the *Chandra* position is Star D of Mignani et al. (2011).

Pulsar e onde gravitazionali

…between pulsars and gravitational waves

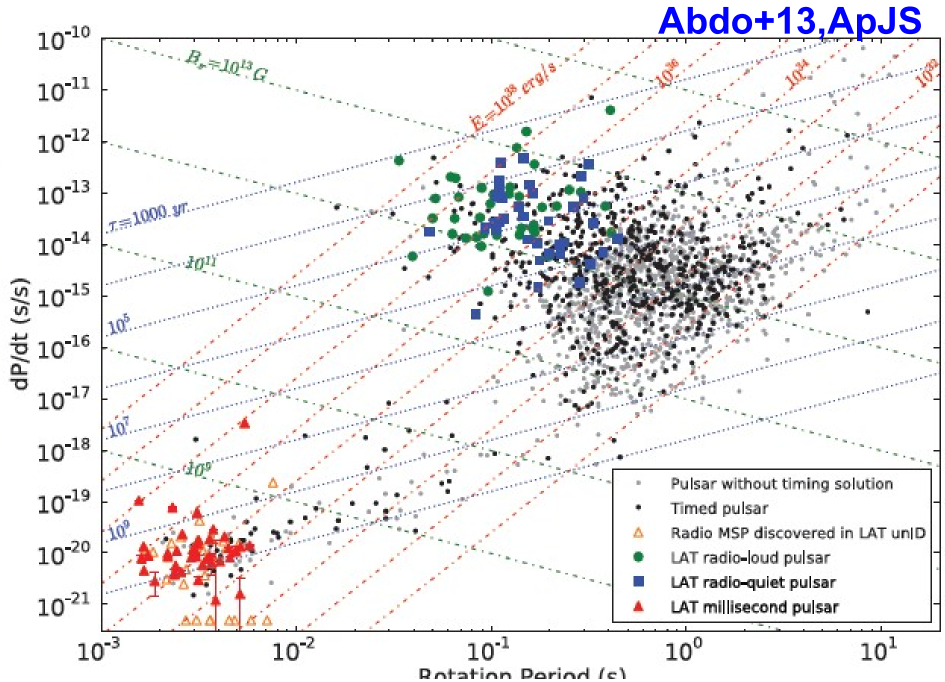
- PSR B1913+16 (1974)
- Discovered by Russel Hulse and Joseph Taylor
- Binary ! 59-ms pulsar + neutron star, orbit of 77 hrs
- Orbital decay consistent with GW emission
- L_{GW} = 7x10^{24} W (1.4% L_{sun})
- (Nobel prize in 1993)

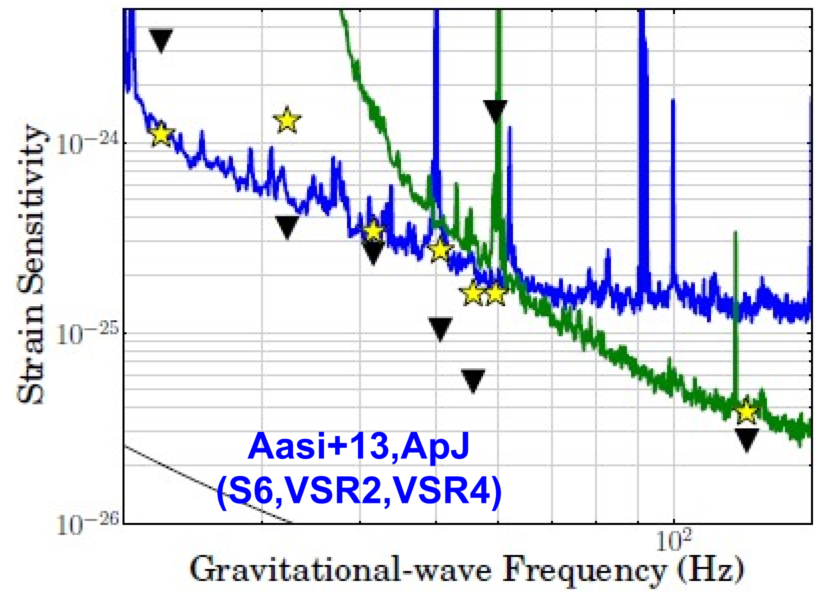


However, this was an indirect observation of GWs…

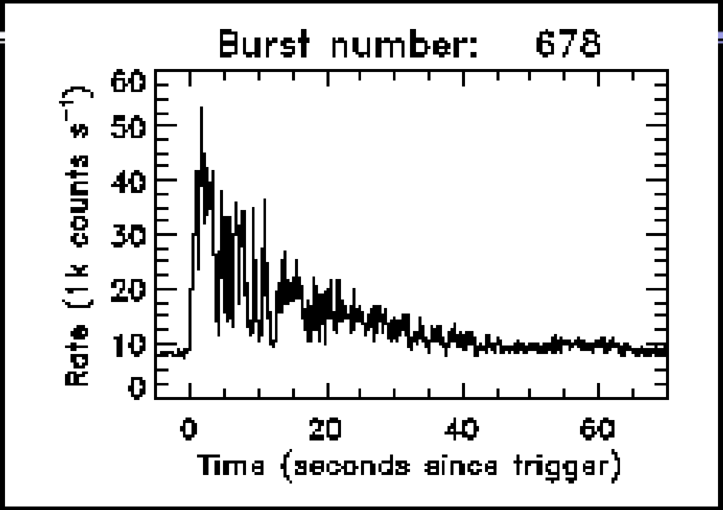
The pulsar connection

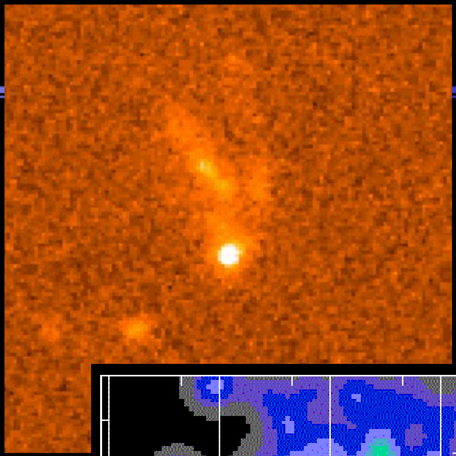
- **Quadrupole momentum from oblate neutron stars**
- **Periodic continuous GW signal**
- **Complementary information**
  - GWs from neutron star
  - Gamma rays from magnetosphere
- **EM →GW**
  - Many Fermi pulsars are young, energetic, and relatively nearby, i.e. good GW candidates
  - Fermi continuously monitors pulsars, providing timing solutions
  - Fermi is the only instrument capable of timing most radio-quiet pulsars

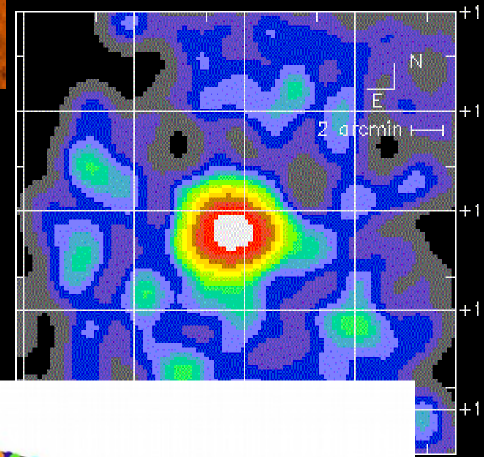


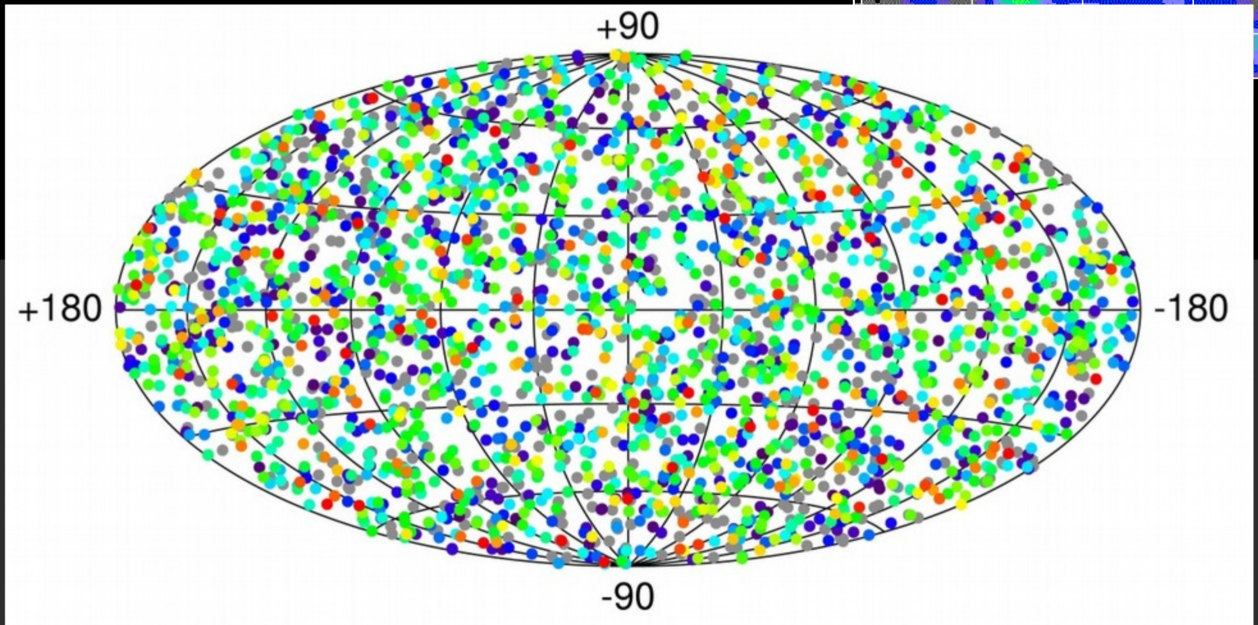


Gamma Ray Bursts









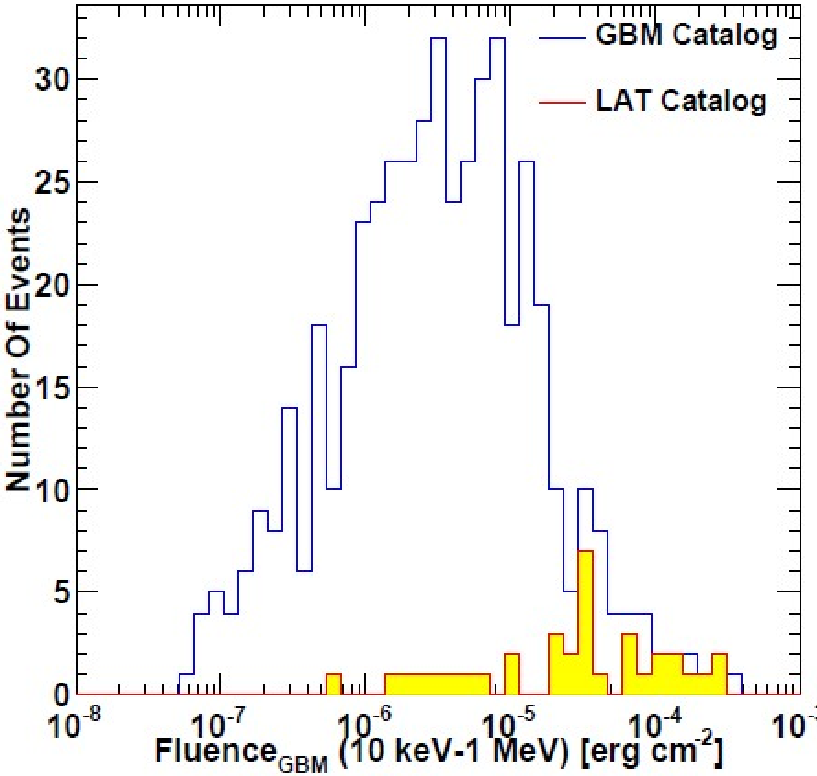
GRBs in the Fermi era

- First LAT GRB Catalog (Ackermann+13, ApJS)

- 35 GRBs detected by the LAT (28 >100 MeV)
- 5 of them are short GRBs ($T_{90,GBM}$ < 2 s)
- 733 detected by the GBM

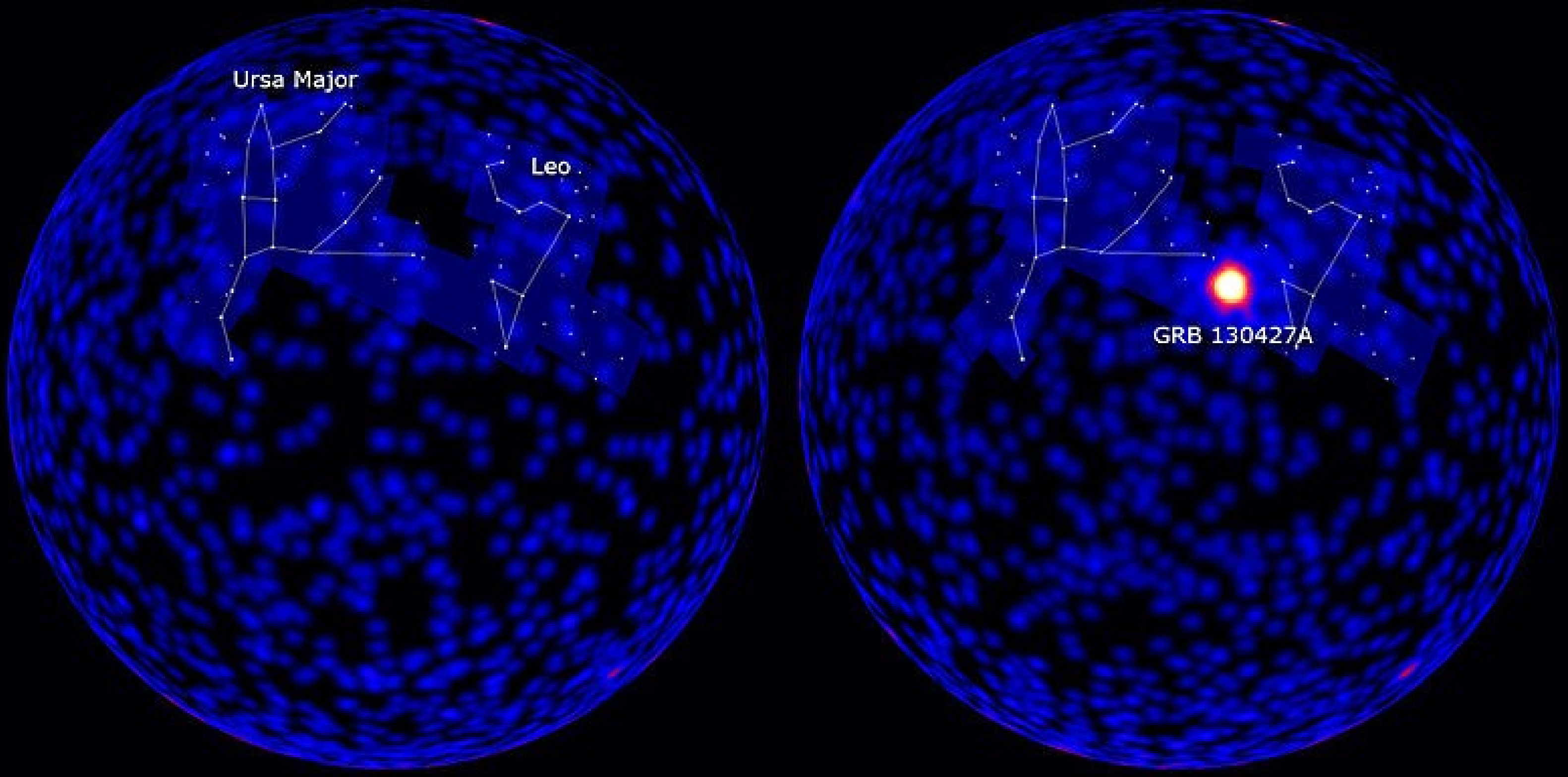
Main results:

- Spectra:
  - Deviation from Band function at low E
  - Additional power law at high-E
  - High-E photons by the LAT (e.g. 95 GeV from GRB130427A)
  - High-E cutoff
  - Temporally-extended high-E emission
- LAT GRBs among the brightest ones



See also: GBM 2-yr catalog (Goldstein+12, ApJS)

13 aprile: un GRB "spaventoso'

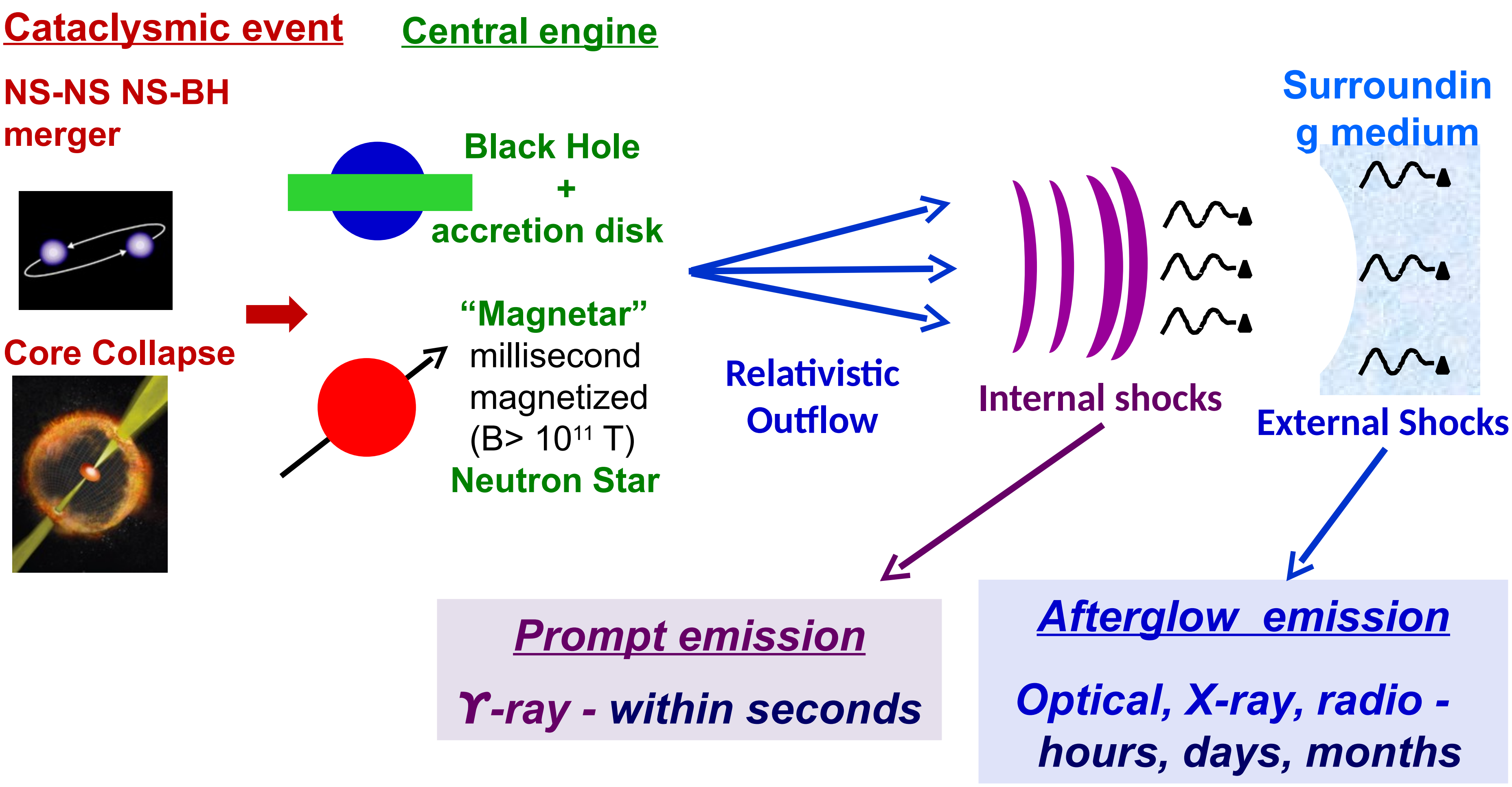


Before and after Fermi LAT views of GRB 130427A, centered on the north galactic pole

3.6 miliardi di anni luce

94 GeV

GRBs emission - Fireball Model



Transient sources: Gamma Ray Bursts

Merger of NS-NS / NS-BH

Core collapse of massive star

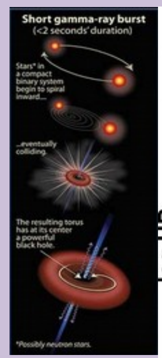
Gamma-Ray Burst: flashes of gamma-rays

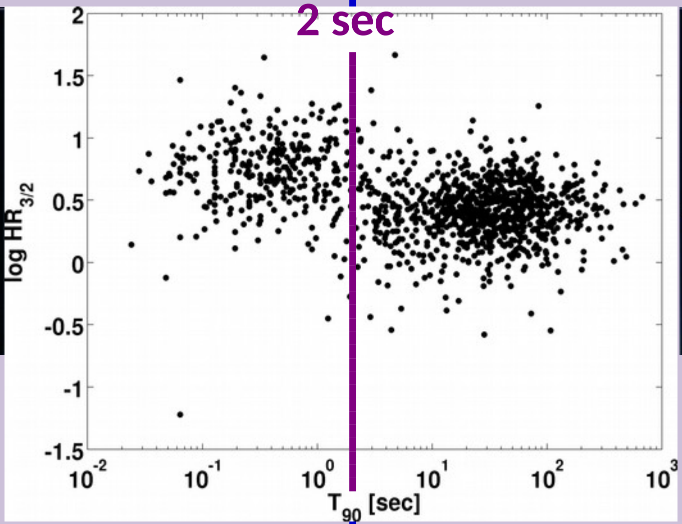
isotropic-equivalent energy up to 10^{53} erg

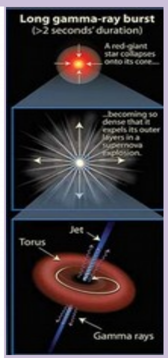
Short Hard GRB

Progenitor indications:

- lack of observed SN
- association with older stellar population
- larger distance from the host galaxy center (~ 5-10 kpc)







Long Soft GRB

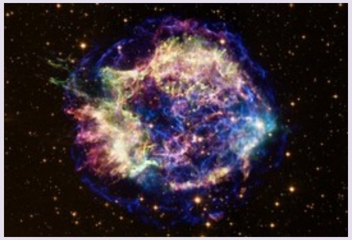
Progenitor strong evidence: observed Type Ic SN spectrum

Kilonovae

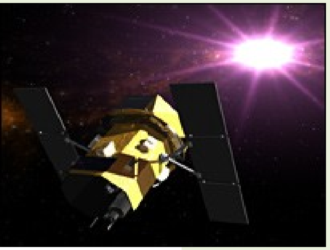
(Optical/IR, radio remnant)

Supernovae

Type II, Ib/c



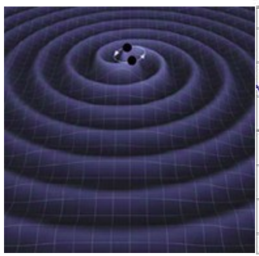
GRB prompt emission TRIGGERED GW SEARCH

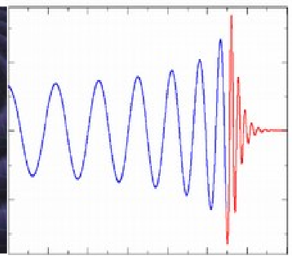


Known **GRB event time** and **sky position:**

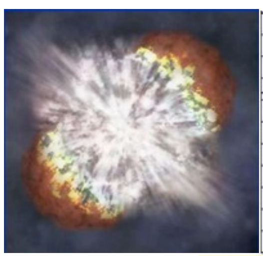
- **reduction in search parameter space**
- **gain in search sensitivity**

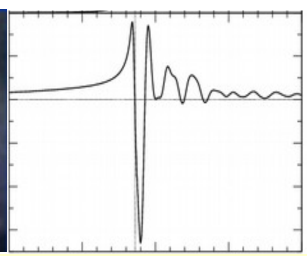
GW transient searches



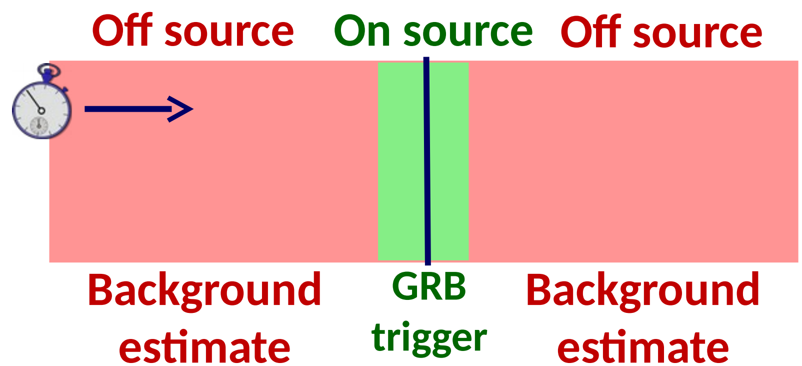


Unmodeled GW burst
(< 1 sec duration)
Arbitrary waveform
 Excess power





Compact Binary Coalescence
Known waveform
 Matched filter



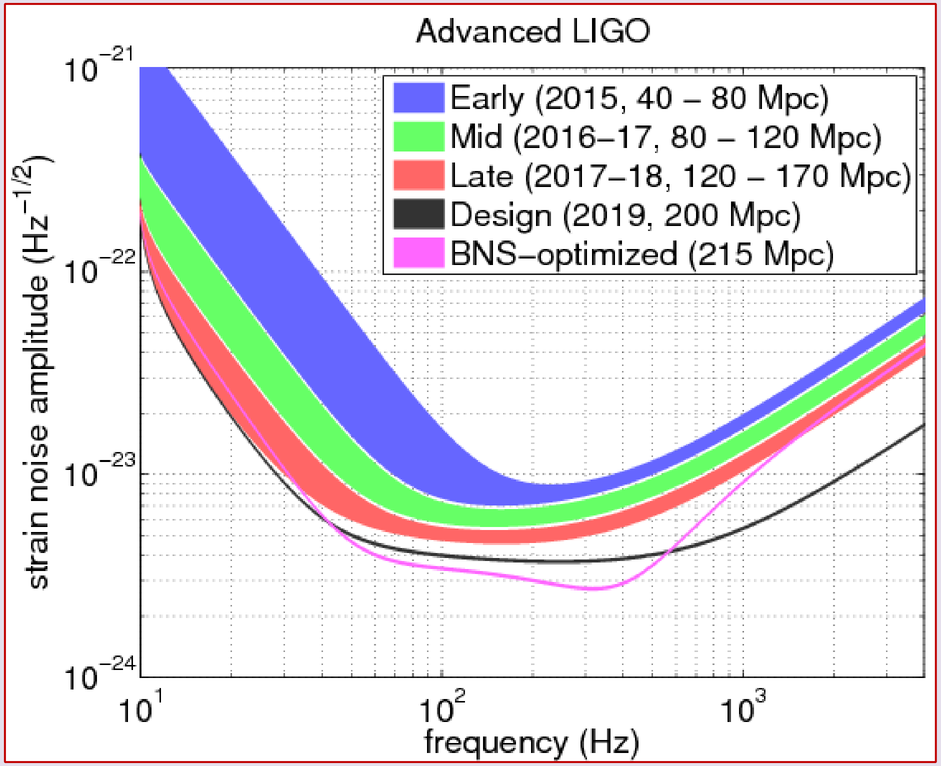
Analyzed 154 GRBs detected by gamma-ray satellites during **2009-2010** while 2 or 3 LIGO/Virgo detectors were taken good data

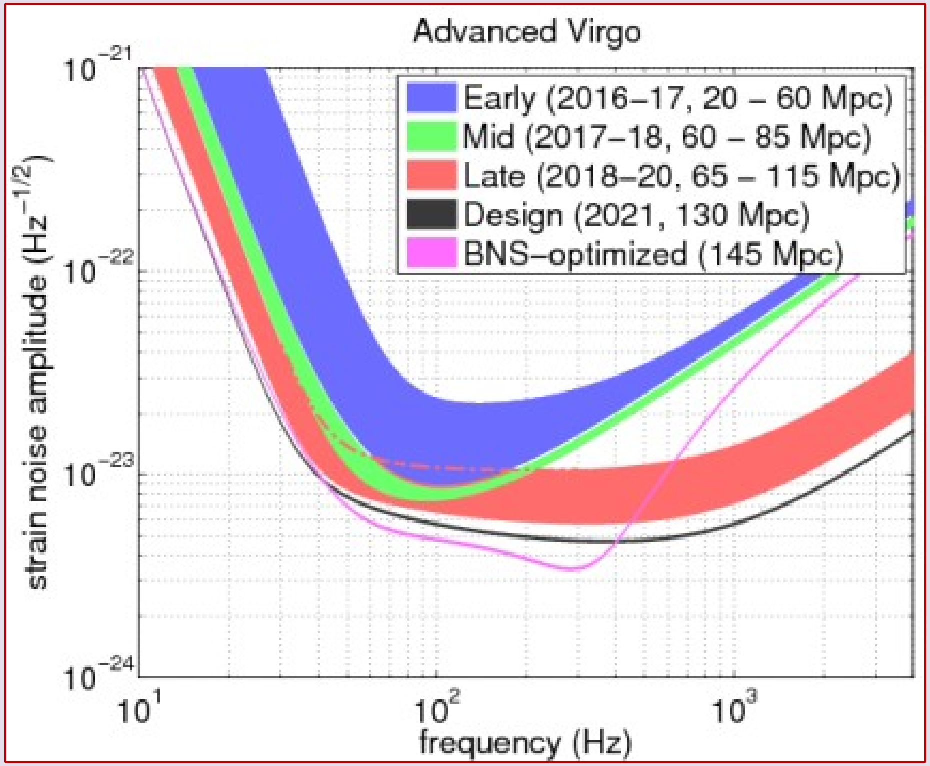
No evidence for gravitational-wave counterparts Abadie et al. 2012, ApJ, 760

Advanced GW Detectors: Observing scenario

LSC & Virgo Collaborations, arXiv:1304.0670

Progression of sensitivity and range for Binary Neutron Stars





Larger GW-detectable Universe

Una nuova finestra sul cosmo

- GW and photons provide complementary information
    - Multimessenger observations extremely promising
- Multimessenger approach is key to study the most extreme objects in the Universe
    - Natural laboratories to probe fundamental physics
    - Transients (e.g. GRBs)
    - Also, other sources (e.g. neutron stars)
- Virgo and LIGO are undergoing major upgrades
    - Increased sensitivity → Larger volumes to probe
    - Joint observations planned for 2016
- Fermi still in orbit and working smoothly (NASA extension)
    - High-energy telescope
    - Continuous monitoring of the sky

Per maggiori informazioni

- Finanziamento da progetto MIUR (@Pisa M.R.)
- Gruppo di ricercatori Dipartimento & INFN
- Collaborazione internazionale (Europa, USA)
- Lavoro su dati astrofisici (gamma, X, ottico) e onde gravitazionali

- **Nuovo corso Laurea Specialistica "Fisica delle Onde Gravitazionali"**
- **Possibilità di tesi**

- **Contatti**

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