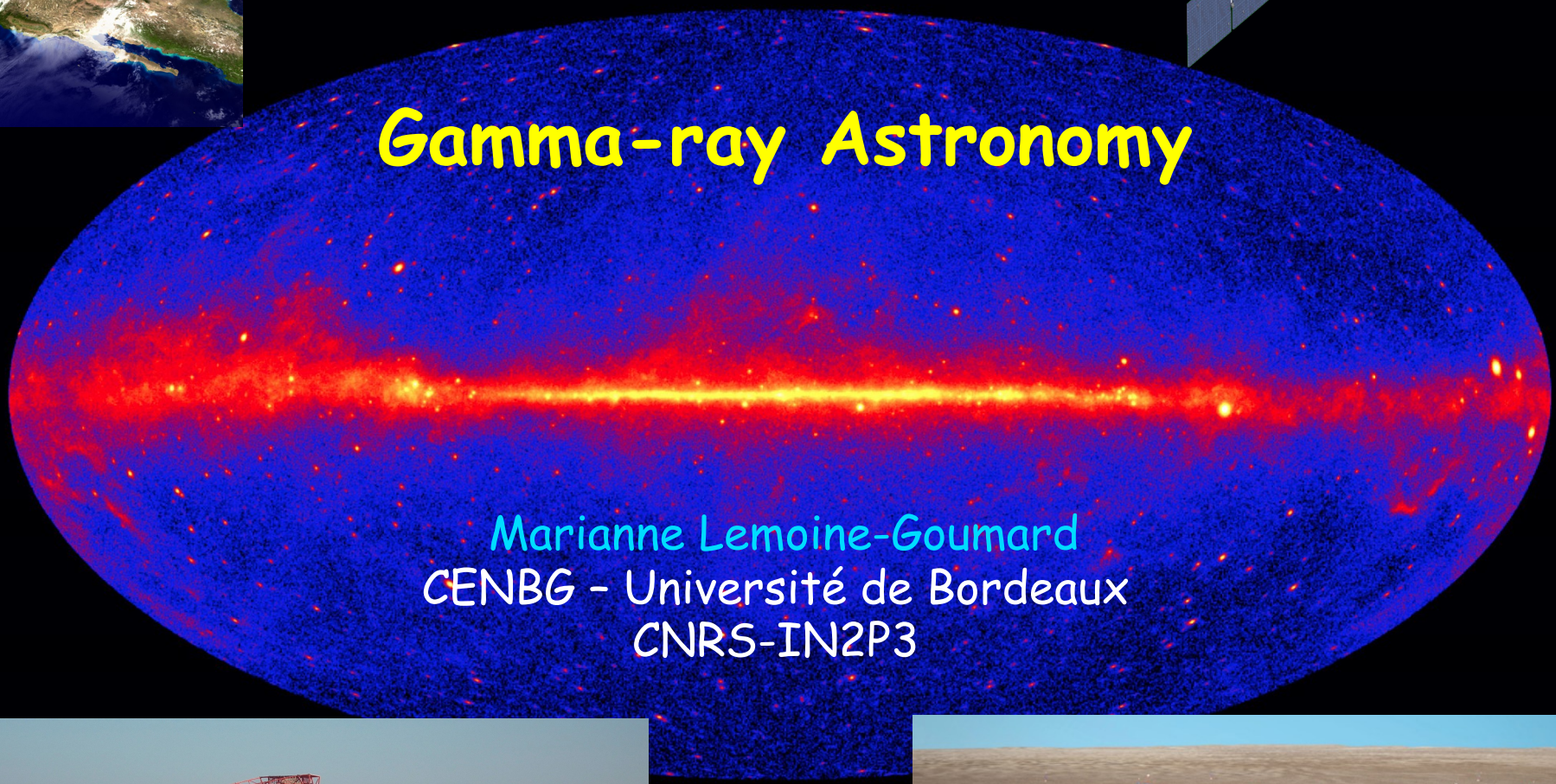
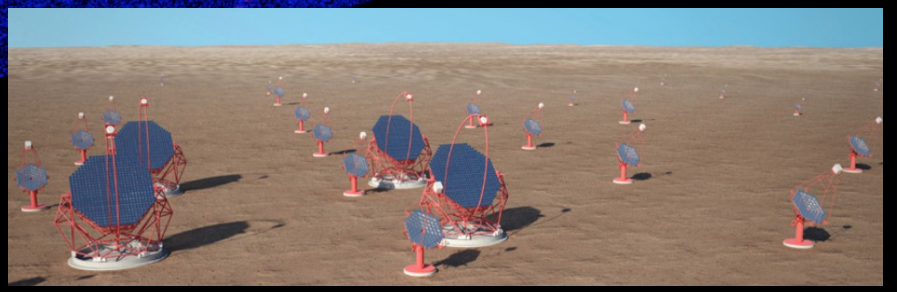
Gamma-ray Astronomy



Marianne Lemoine-Goumard
CENBG – Université de Bordeaux
CNRS-IN2P3



Disclaimer

Many great results + on-going and future projects

- I won't be able to summarize everything: apologies to everyone
- Focuse on the french community and the interest for our Program
- Try to highlight some of our strengths for the future

=> Large part of materials presented at our previous meeting in 2014

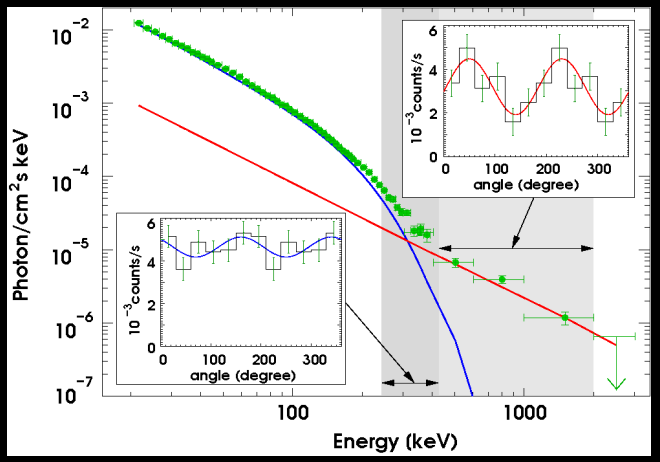
Operating Space-based missions

Fermi
Launched Jun 11 2008
Mission extended thru FY 2016
LAT (20 MeV - > 300 GeV)
GBM (8 keV – 30 MeV)

INTEGRAL
Launched Oct 7 2002
Mission extended thru 2016
IBIS (15 keV - 10 MeV)
SPI (20 keV – 8 MeV)

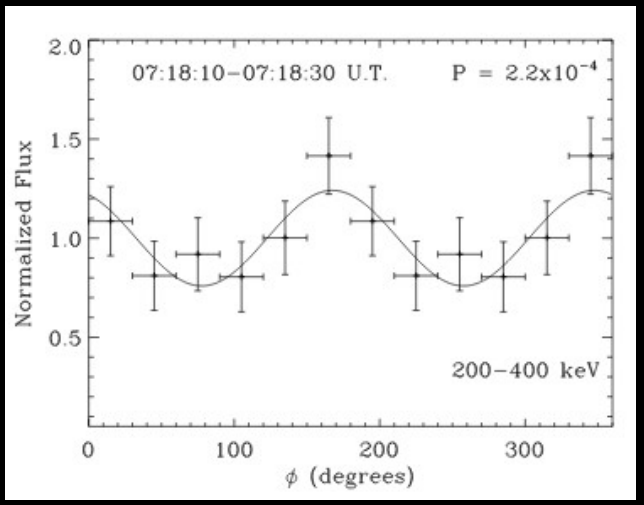
AGILE
Launched April 23 2007
Spinning mode since 10/2009
30 MeV – 50 GeV
+ SuperAGILE for GRBs

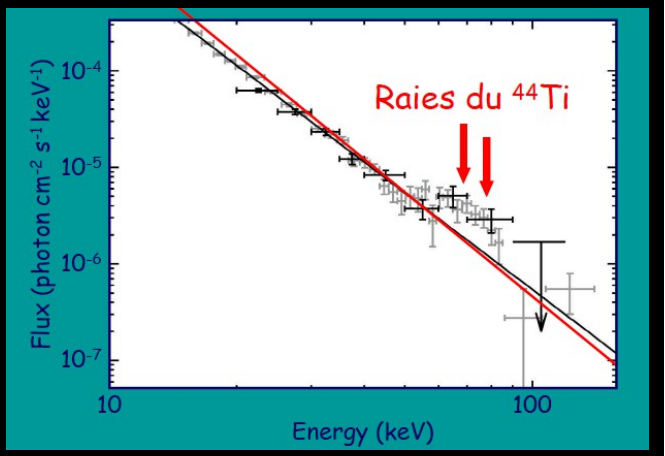
Some Highlights from INTEGRAL



First evidence of polarised soft γ-ray photons from a stellar mass black hole : Cygnus X
(Laurent et al., Science, 2011, 332, 438)

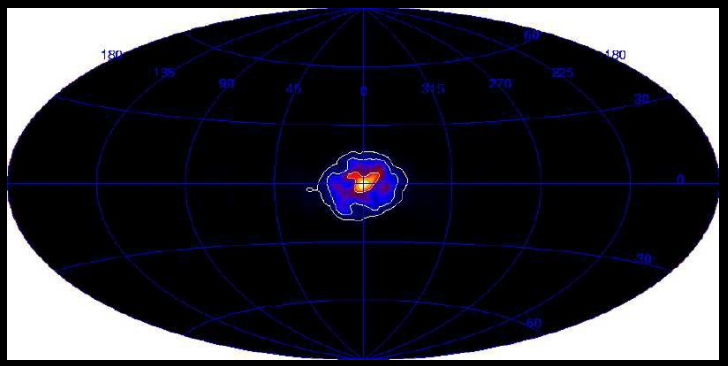
GRB 140206A: the most distant polarized Gamma-Ray Burst
+ Constraint on the Lorentz invariance violation
(Götz et al., MNRAS, 2014, 444, 2776)



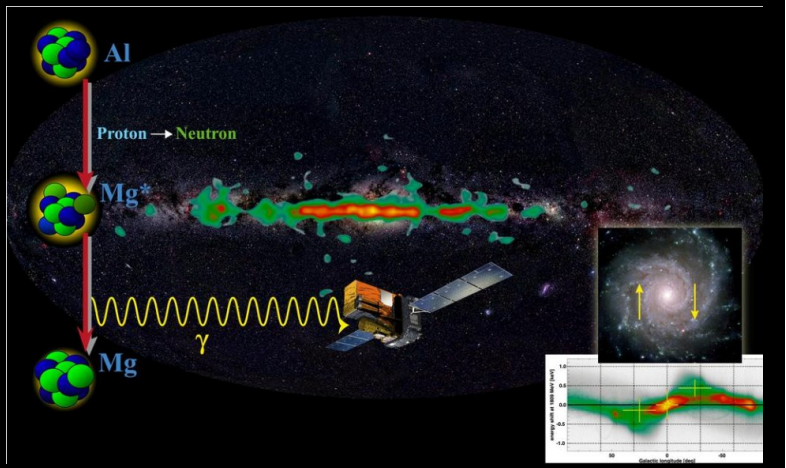


The detection of ^{44}Ti γ-ray lines from supernova Cas A
(Renaud et al., ApJ, 2006, 647, L41)

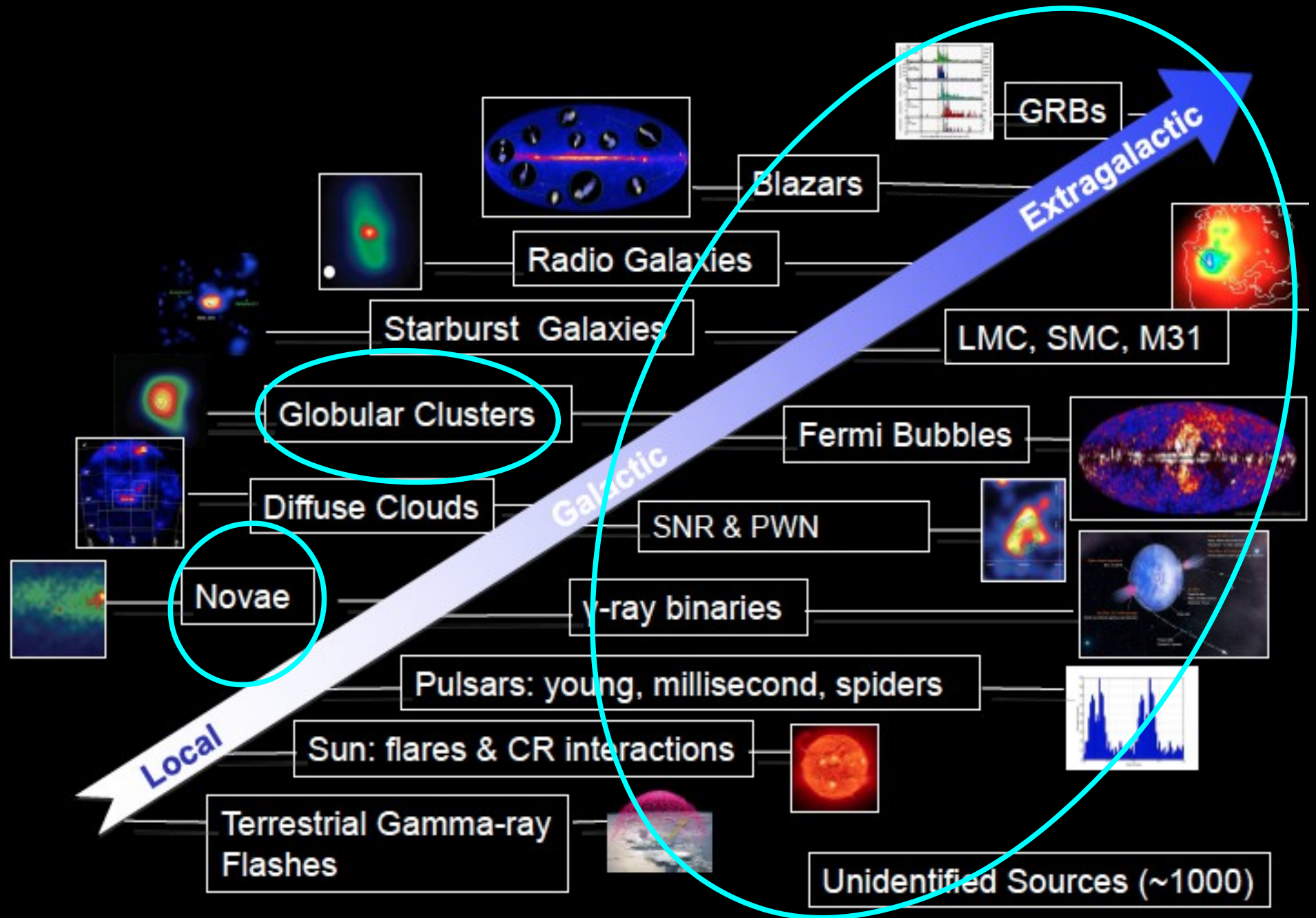
First large-scale sky-map at 511 keV
(Knödlseder et al., A&A, 2005, 441, 513)



Radioactive 26Al from massive stars in the Galaxy
(Diehl et al., 2006, Nature, 439, 45)



Science with Fermi



Highlights & Surprises offered by Fermi (& AGILE)

- Pulsars are everywhere ! 160 announced and many more to come
- The Crab Nebula is not a steady source : flare of 30 times the average flux
- Novae emit gamma-rays
- A cocoon of young cosmic-rays : the case of Cygnus cocoon
- The Fermi bubbles
- The Galactic Center excess
- Individual source study outside the Milky Way : the case of the LMC
- Several catalogs of interest for a large community :
    - Whole sky and data : 1FGL, 2FGL, 3FGL
    - High Energy : 1FHL, 2FHL
    - AGNs : 1LAC, 2LAC, 3LAC
    - SNR : SNRCat

Bridging the gap with the TeV energy range

Fermi between 100 MeV and 100 GeV :

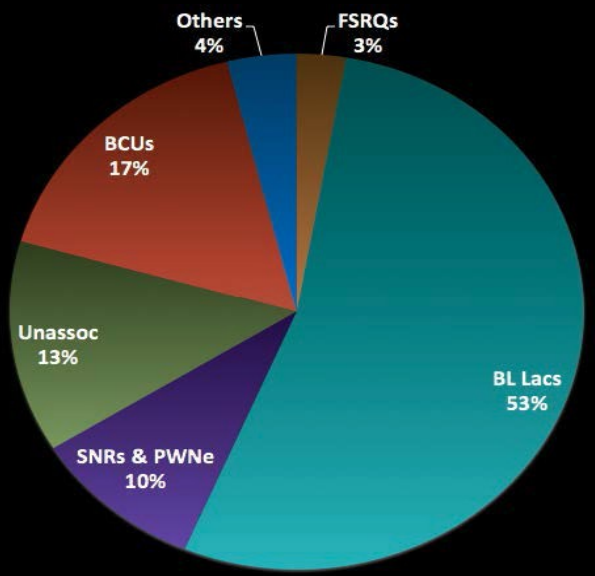
3033 sources detected ; 80% being extragalactic

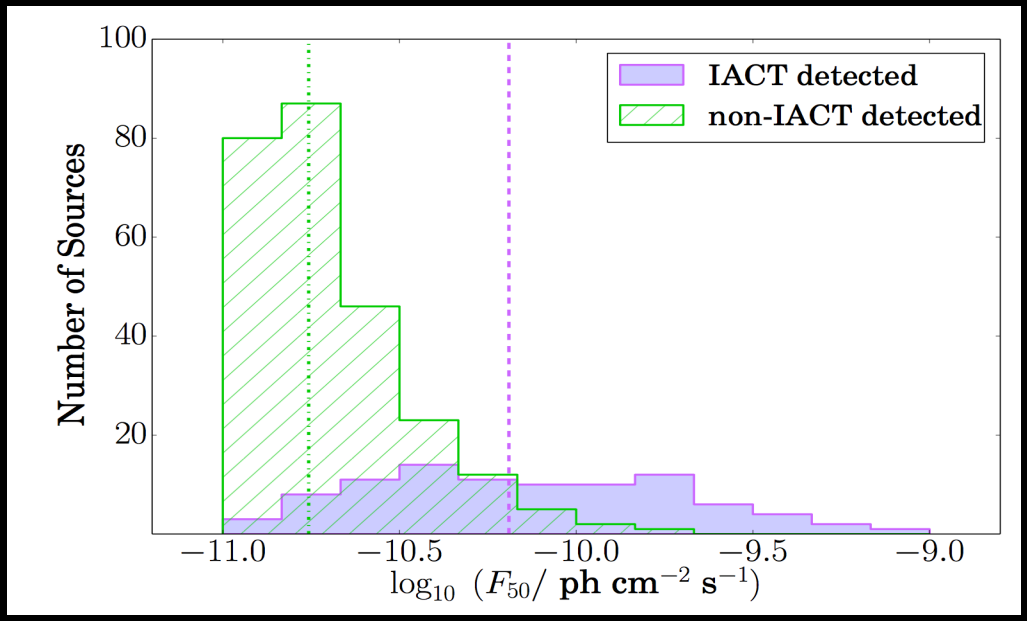
Fermi between 50 GeV and 2 TeV :

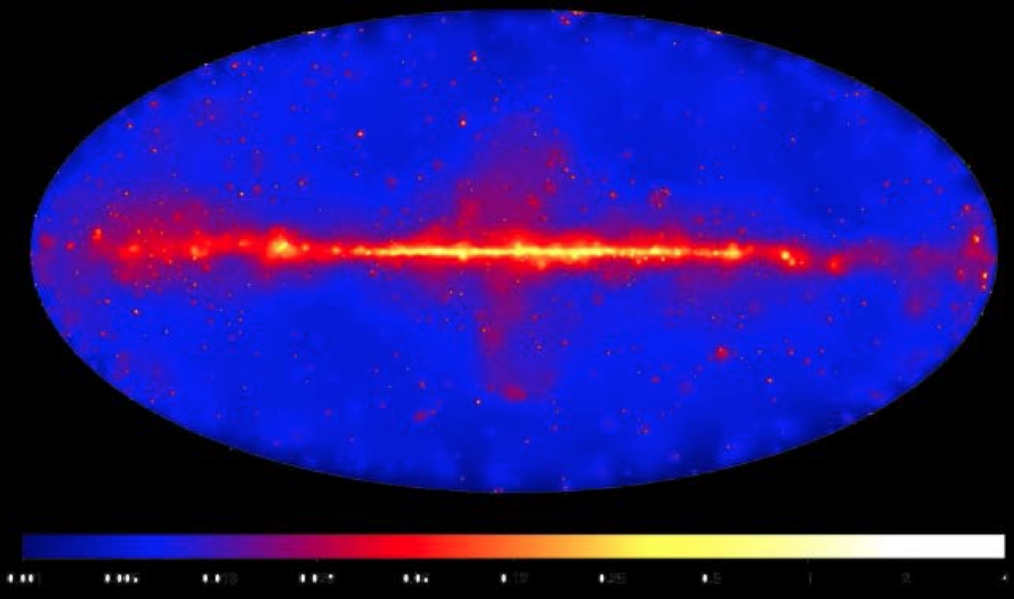
360 sources detected ; 74% being extragalactic

Cherenkov telescopes between 100 GeV and several TeV :

165 sources detected ; 43% being extragalactic





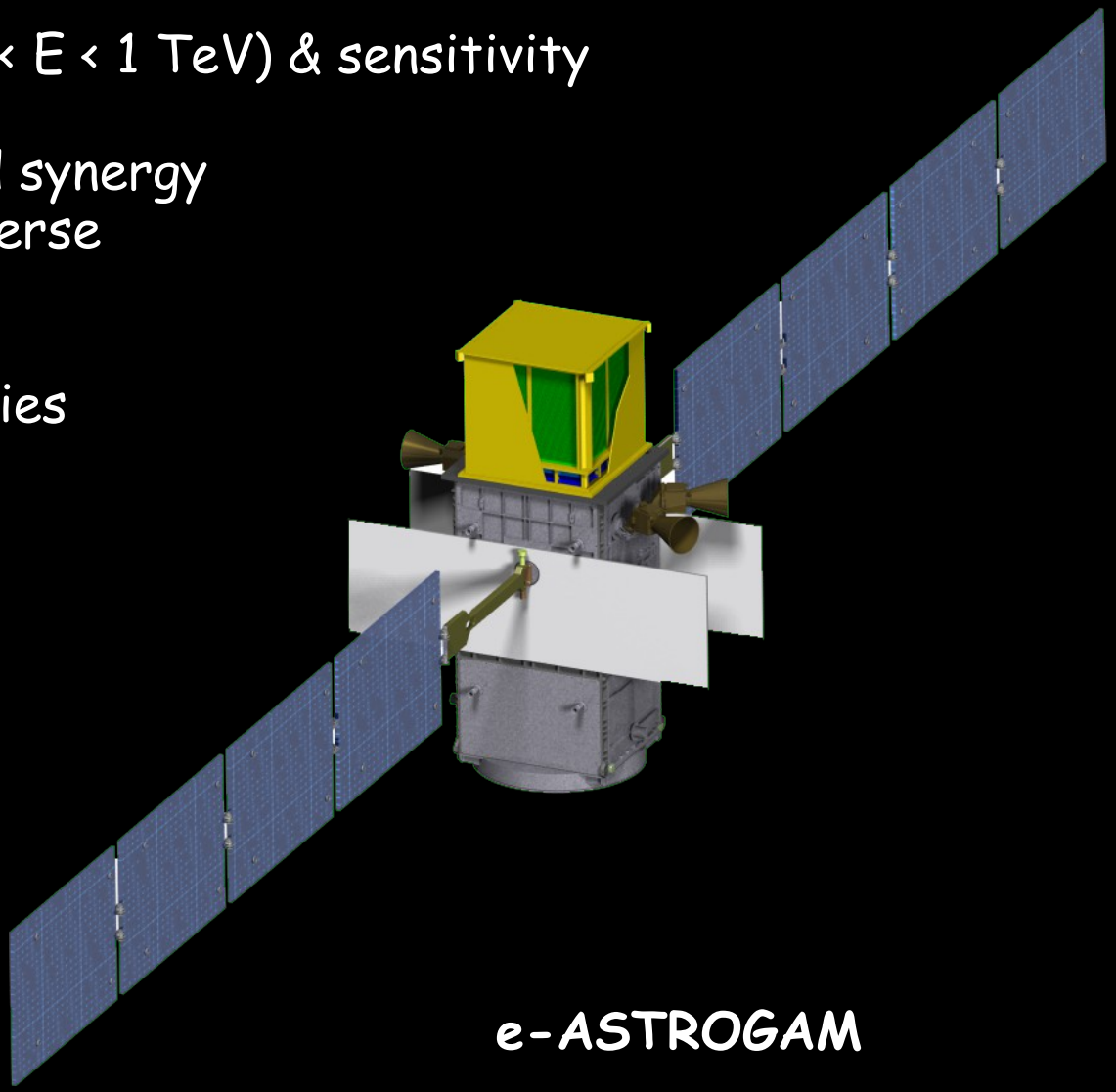


THE FUTURE for space-based missions

- New events
  Extended energy range (1 MeV < E < 1 TeV) & sensitivity

- Multi-messenger Astrophysics and synergy
  A whole new window on the Universe

- New capabilities
  Polarisation at gamma-ray energies



e-ASTROGAM

Near Future with Hitomi-SGD

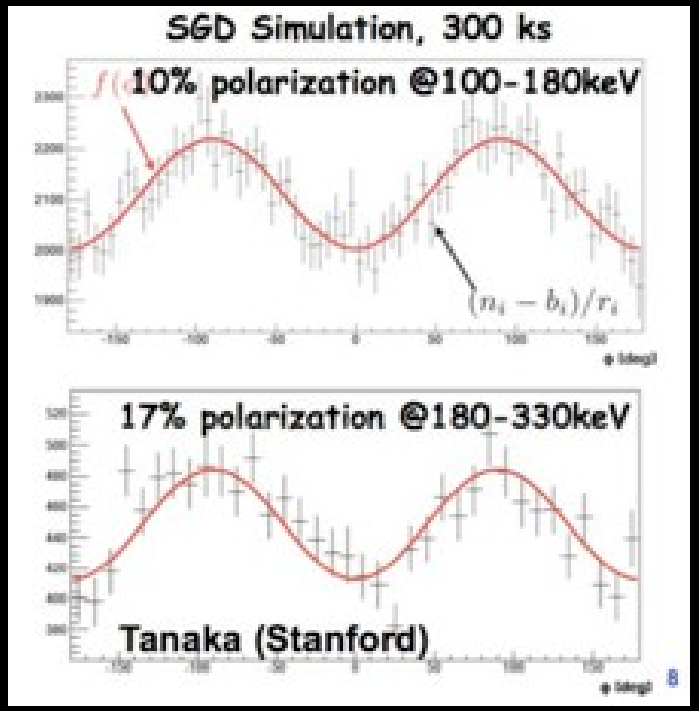
Successful launch

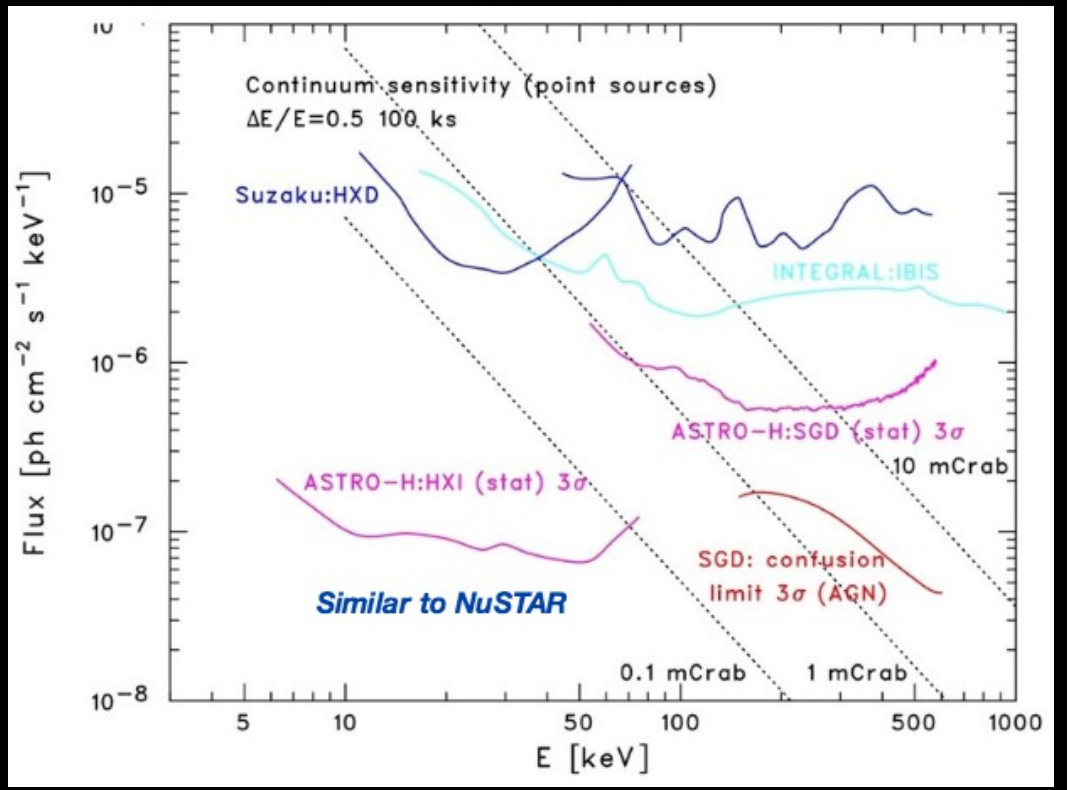
Science operations will be similar to those of Suzaku with pointed observations of each target until the observing time is accumulated

Soft Gamma-ray Detector (4-600 keV) : Si/CdTe Compton camera

Vast improvement in the sensitivity between 10 keV and 600 keV

Energy dependent polarization capabilities above 100 keV





Near Future with INTEGRAL

Collaboration currently writing science case to be running up to 2017-2018 :

- INTEGRAL is the only mission observing the gamma-ray sky between 600 keV and 10 MeV for the foreseeable future!
- New multiwavelength-multimessenger opportunities have opened up
- Omni-directional view of the INTEGRAL/SPI-ACS is excellent for GW follow-up

  => Savchenko et al. 2016 : « non-detection by SPI-ACS disfavors a cosmic origin of the Fermi/GBM excess » & « INTEGRAL UL is …. the tightest limit that can be set on GW150914 with any modern instrument in the gamma- ray energy range »
- Study of nucleosynthesis in our Galaxy

Near-Future with Fermi

Fermi is the only mission in its waveband for the foreseeable future!

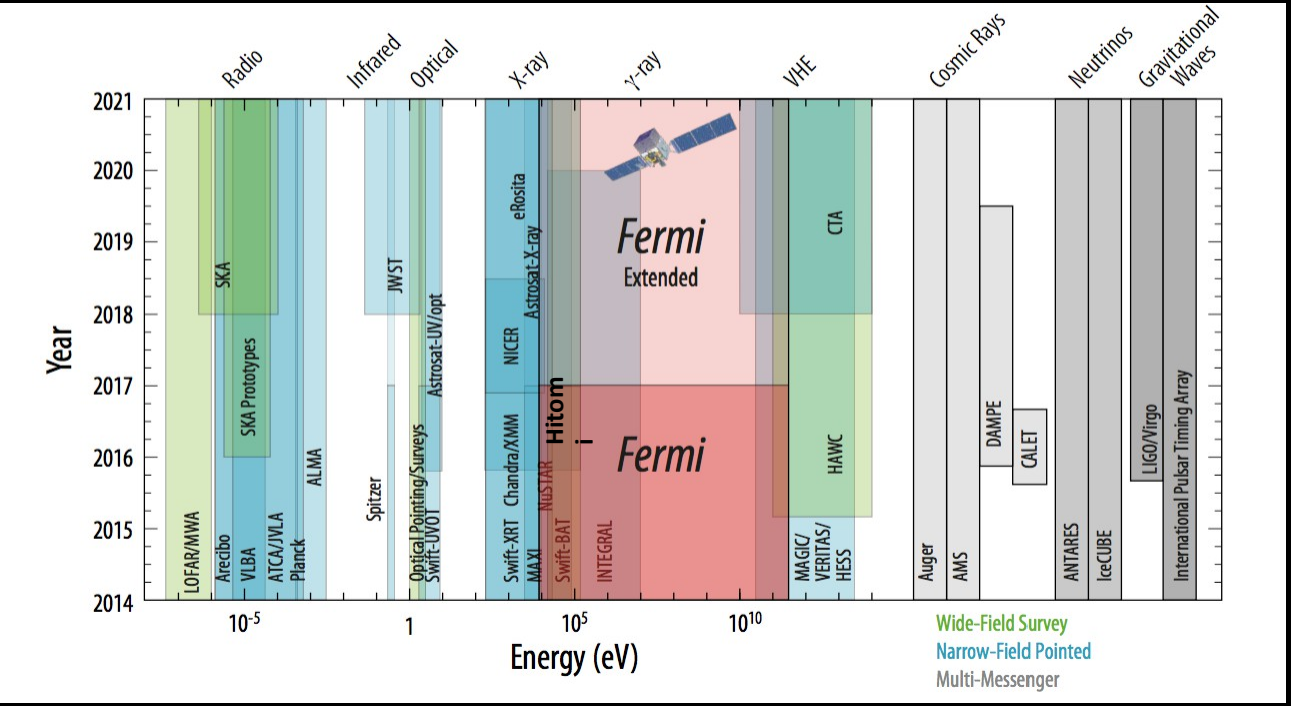
New multiwavelength-multimessenger opportunities have opened up

2014 Panel Report :

- « The Fermi Observatory…is a unique asset to the NASA portfolio »
- « The SRP recommends continuation of the Fermi extended mission through 2018 »

2016 Senior Review Proposal due by January 22, 2016:

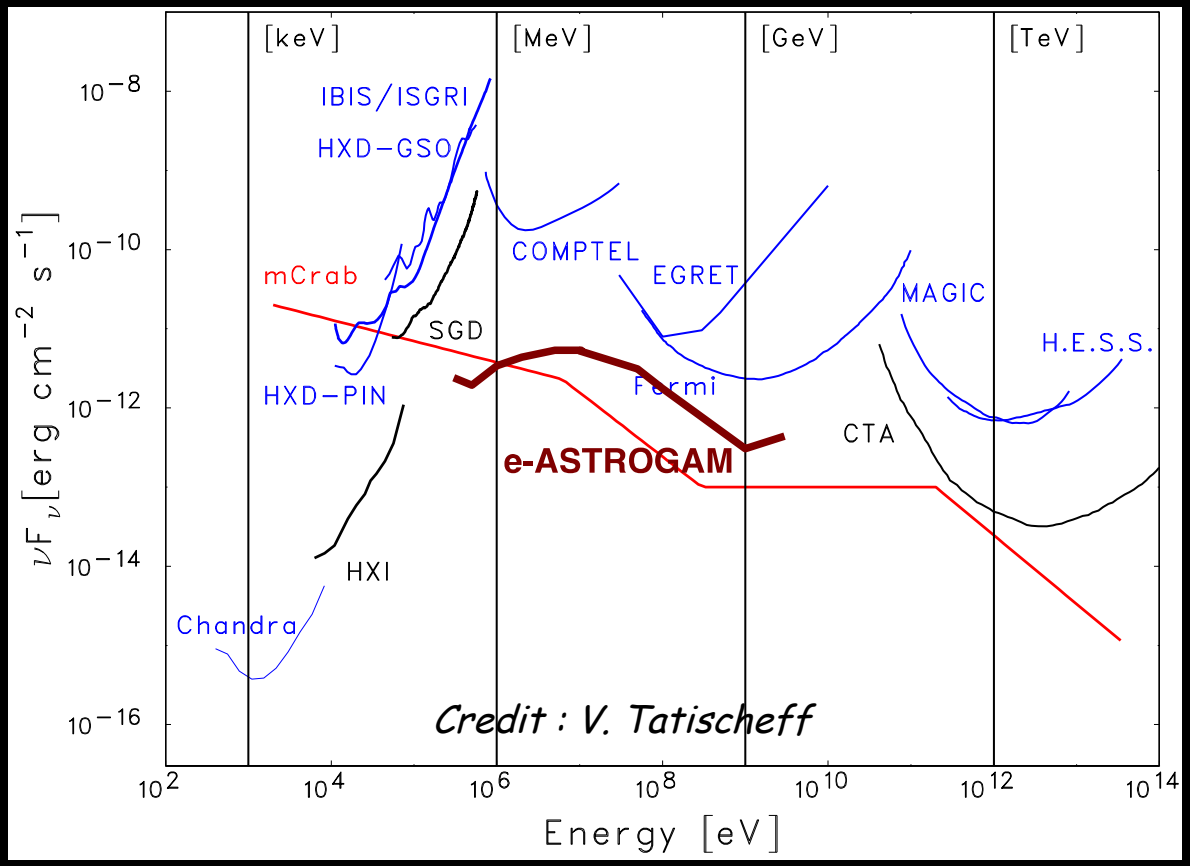
- Propose to extend the Fermi mission through to 2020

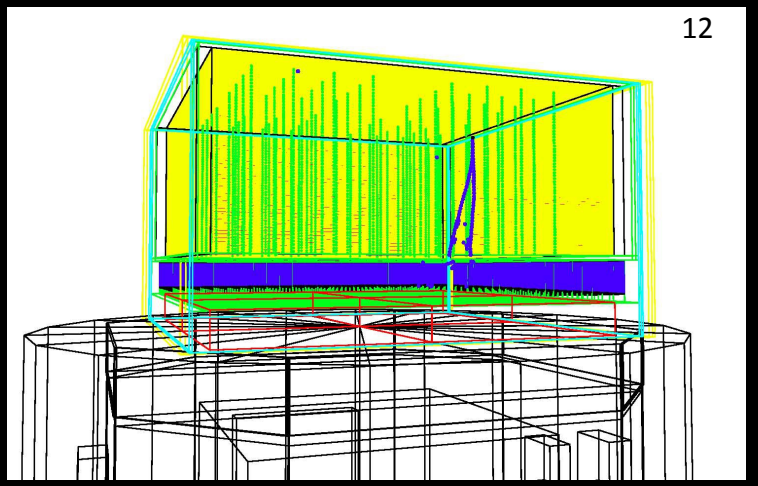


At more longer term : e-ASTROGAM

Objective : Improve sensitivity by a factor of about 50 in the **mostly unexplored energy range 0.3 - 100 MeV** (continuum and line detection)

e-ASTROGAM performance evaluated with **MEGAlib** and **Bogemms** (both based on Geant4) and a detailed mass model of the instrument





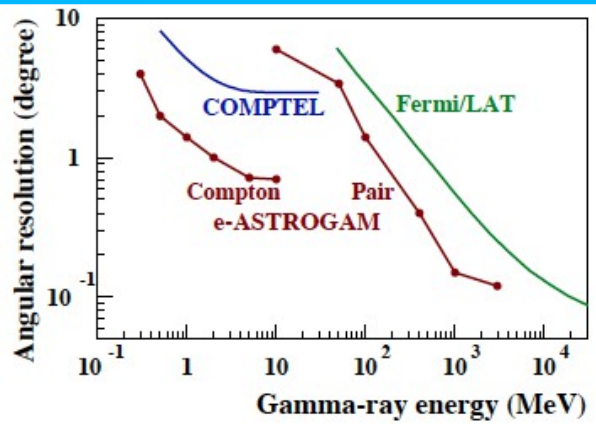
Adapted from Takahashi et al. (2013)

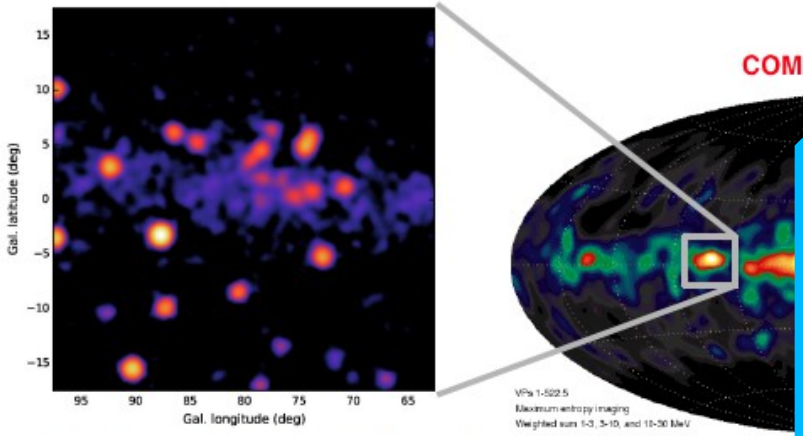
- **ASTRO-H/SGD**: S(3σ) for 100 ks exposure of an isolated point source
- **COMPTEL** and **EGRET**: sensitivities accumulated during the whole duration of the CGRO mission (9 years)
- **Fermi/LAT**: 5σ sensitivity for a high Galactic latitude source and after 1 year observation in survey mode
- **e-ASTROGAM** - 3σ/5σ sensitivity for a 1-year effective exposure of a high Galactic latitude source

e-ASTROGAM : Angular resolution & Polarization

- Improve angular resolution close to the Compton physical limits

Simulation of the Cygnus region in the 1 – 3 MeV energy band using the e-ASTROGAM PSF, from an extrapolation of the 3FGL source spectra to low energies

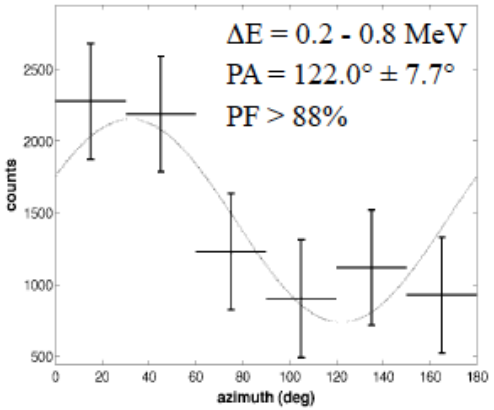




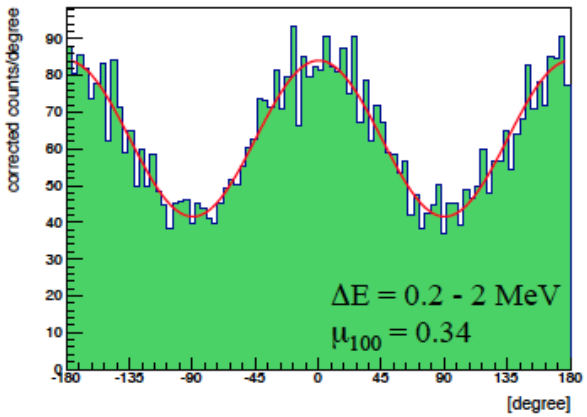
V. Tatischeff for the e-ASTROGAM Collaboration

28th Texas Sym

- γ-ray polarization in **objects emitting jets** (Blazars, GRBs, X-ray binaries) or with **strong magnetic field** (pulsars, magnetars) can pose strong constraints on the magnetic field structure and the nature of the γ-ray emission process
- γ-ray polarization from **cosmological sources** (Blazars, GRBs) will address fundamental questions related to Lorentz Invariance (vacuum birefringence)



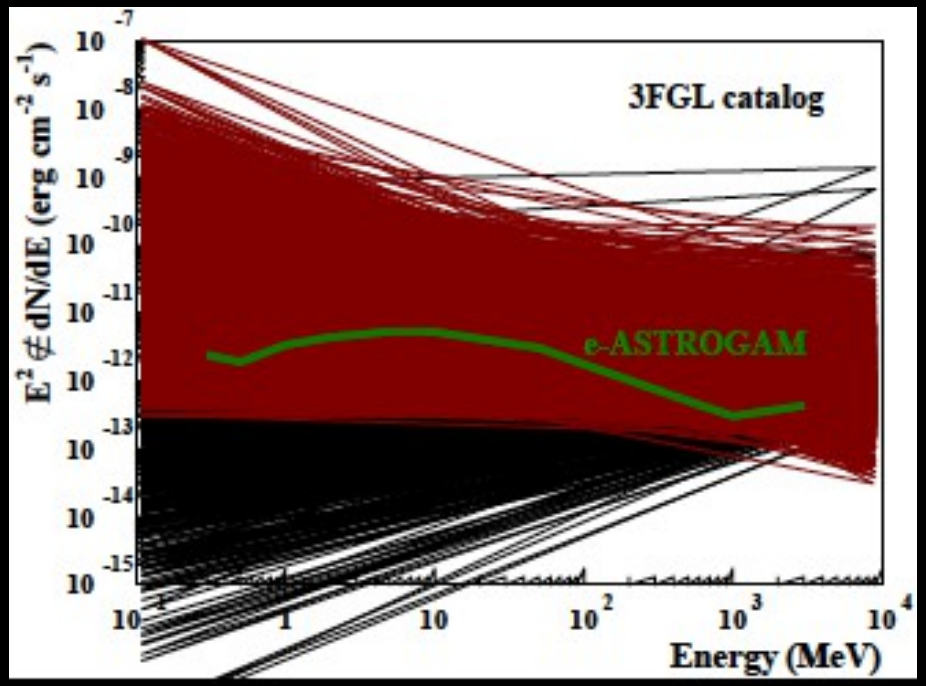
INTEGRAL/IBIS polarigramme for the Crab emission in the off-pulse and bridge intervals (Forot et al. 2008)

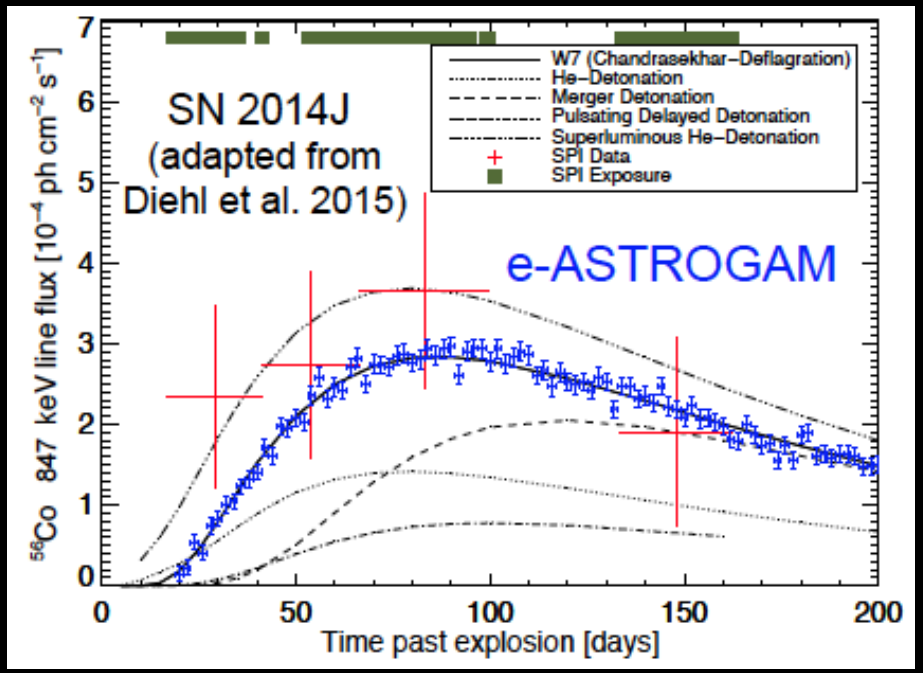


e-ASTROGAM polarization response for a 100% polarized, 10 mCrab-like source observed on axis for 10^6 s

e-ASTROGAM : prospects

- Unprecedented sensitivity and capability for measuring polarization
  => e-ASTROGAM has the potential for many foundational discoveries
- e-ASTROGAM payload is innovative in many respects, but technology is ready
- French labs very well represented in the collaboration
- e-ASTROGAM will be proposed in 2016 as ESA's M5 Medium-size mission





Other future missions of interest for our community

HARPO : instrument concept based on a time projection chamber allowing high angular resolution and polarisation between 3 MeV & 3 GeV
Demonstrator successfully tested - potential space mission still to be defined

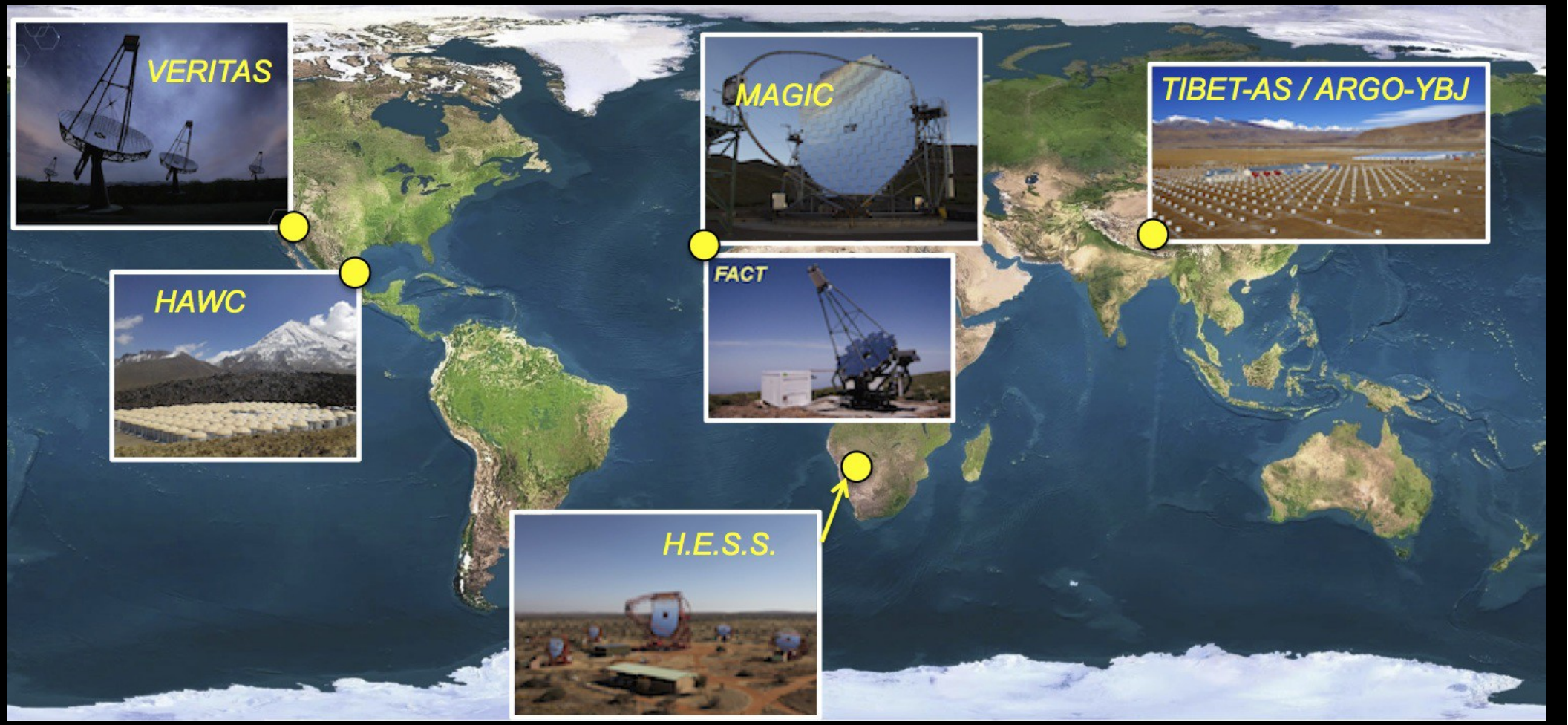
GAMMA-400 : Russian-led project for a gamma-ray telescope optimized for energies around 100 GeV. Still in the design and early development phase

PANGU : conversion pair gamma-ray telescope based on an innovative Silicon strip tracker (10 MeV – 1 GeV) optimized for high angular resolution.
Proposed as an ESA-CAS joint Small Science Mission

Parameter	AdEPT	e-ASTROGAM	CALET	DAMPE	GAMMA-400	HARPO	HERD	PANGU
Context	R&D	M5?	ISS	China	Russia	R&D	China	ESA/CAS?
Launch date	–	2029?	2015	2015	$\sim$ 2021	–	$>$ 2020	2021?
Energy range (GeV)	0.005 - 0.2	0.0003 - 3	0.02 - 10000	2 - 10000	0.1 - 3000	0.003 - 3	0.1 - 10000	0.01 - 5
Ref. energy (GeV)	0.07	0.1	100	100	100	0.1	100	1
$\Delta E/E$	30%	30%	2%	1.5%	1%	10%	1%	30%
A_{eff} (cm^2)	500	1500	t.b.d.	3000	5000	2700	t.b.d.	180
Sensitivity (mCrab)	10	10	1000	100	100	1	10	t.b.d.
Field of view (sr)	t.b.d.	2.5	1.8	2.8	1.2	t.b.d.	t.b.d.	2.2
Angular resolution	1°	1.5°	0.1°	0.1°	0.02°	0.4°	0.1°	0.2°
MDP (10 mCrab)	10%	20%	–	–	–	t.b.d.	–	t.b.d.
Technology	TPC	Si+CsI	fib.+$PbWO_4$	Si+BGO	Si+CsI	TPC	Si+LYSO	Si (fib.)+B

Credit : Knödlseder, 2016

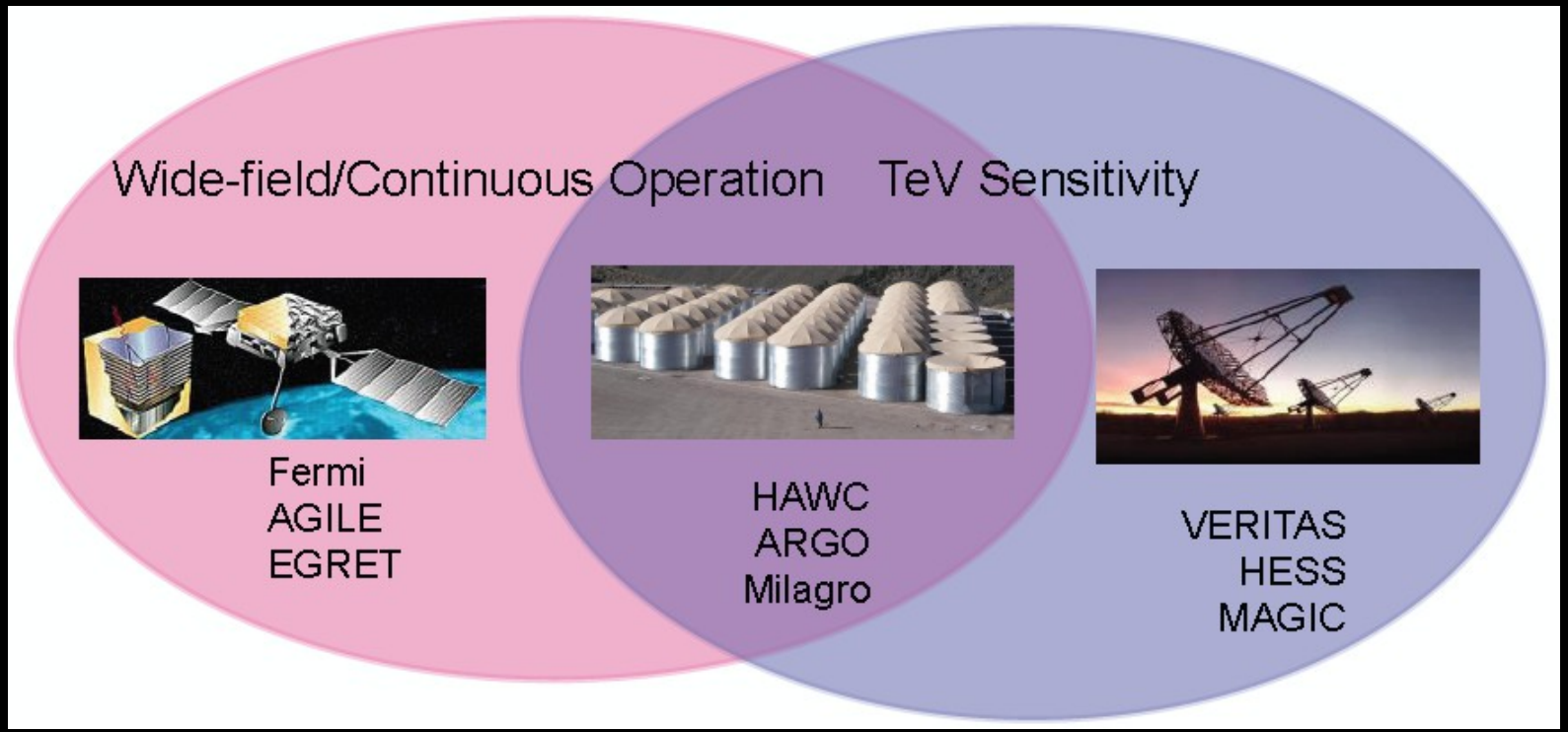
OPERATING GROUND-BASED INSTRUMENTS



Complementarity of gamma-ray instruments

- Space-based detectors - continuous full (large)-sky coverage from MeV to GeV

- Ground-based detectors have TeV sensitivity
  - Current Imaging Atmospheric Cherenkov Telescopes (IACTs) have excellent energy and angle resolution, but FoV of 0.003 sr and duty cycle of 10%
  - Particle detectors have an aperture > 2 sr and duty cycle of 90% but angular resolution of ~0.6° (@ 1 TeV)



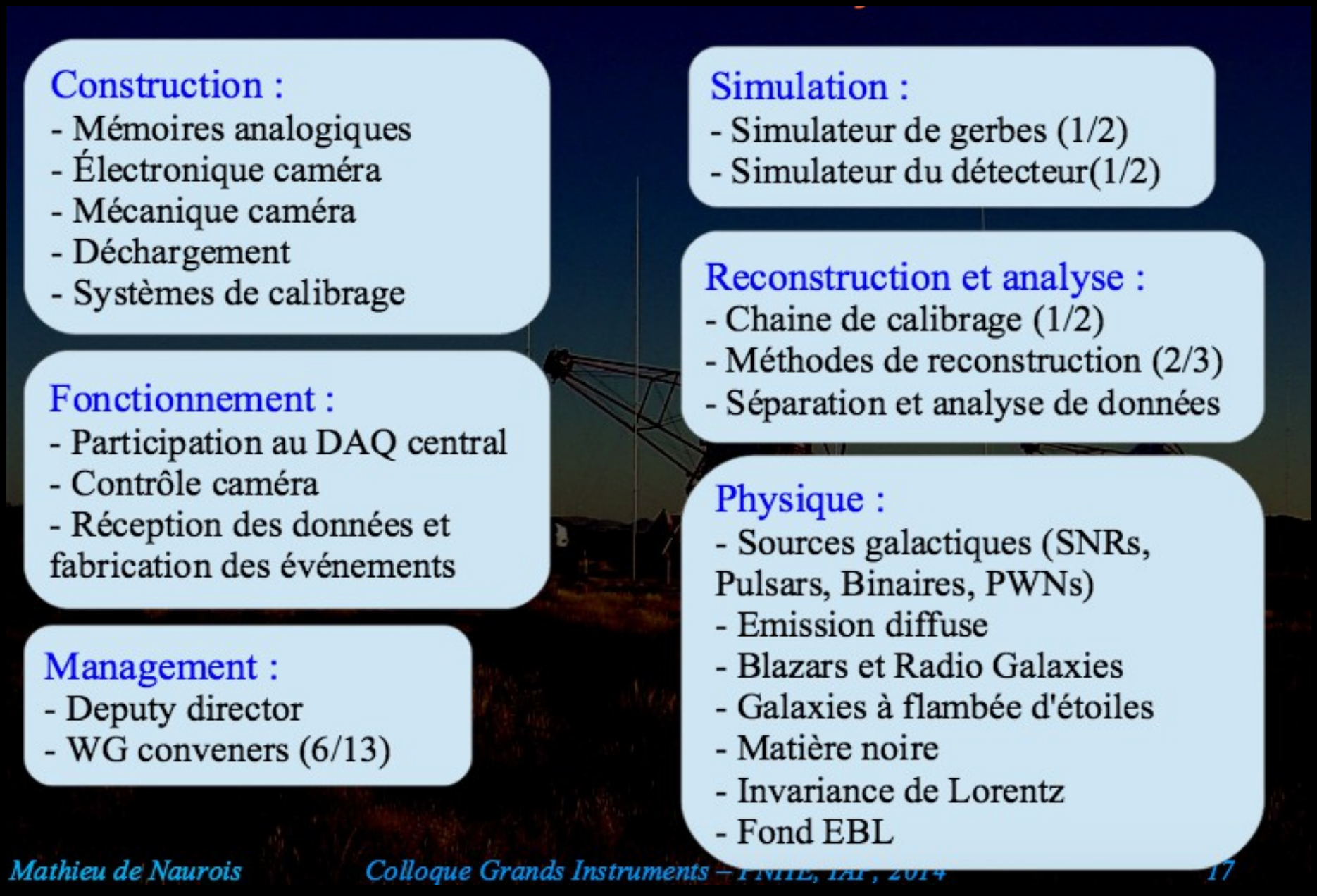
H.E.S.S.

HESS is an array of four 12m IACTs + one 28m telescope (CT5, FoV ~ 3.5°)

CT5 is operationnal since 2012
Energy range from 30 GeV to 100 TeV
Focus system of CT5 under study => Focusing close to the altitude of shower maximum maximizes the γ-ray acceptance close to the energy threshold

Major upgrade of HESS I camera from 2015-2016: reducing the dead time of the cameras, improving the overall performance of the array and reducing the system failure rate related to aging

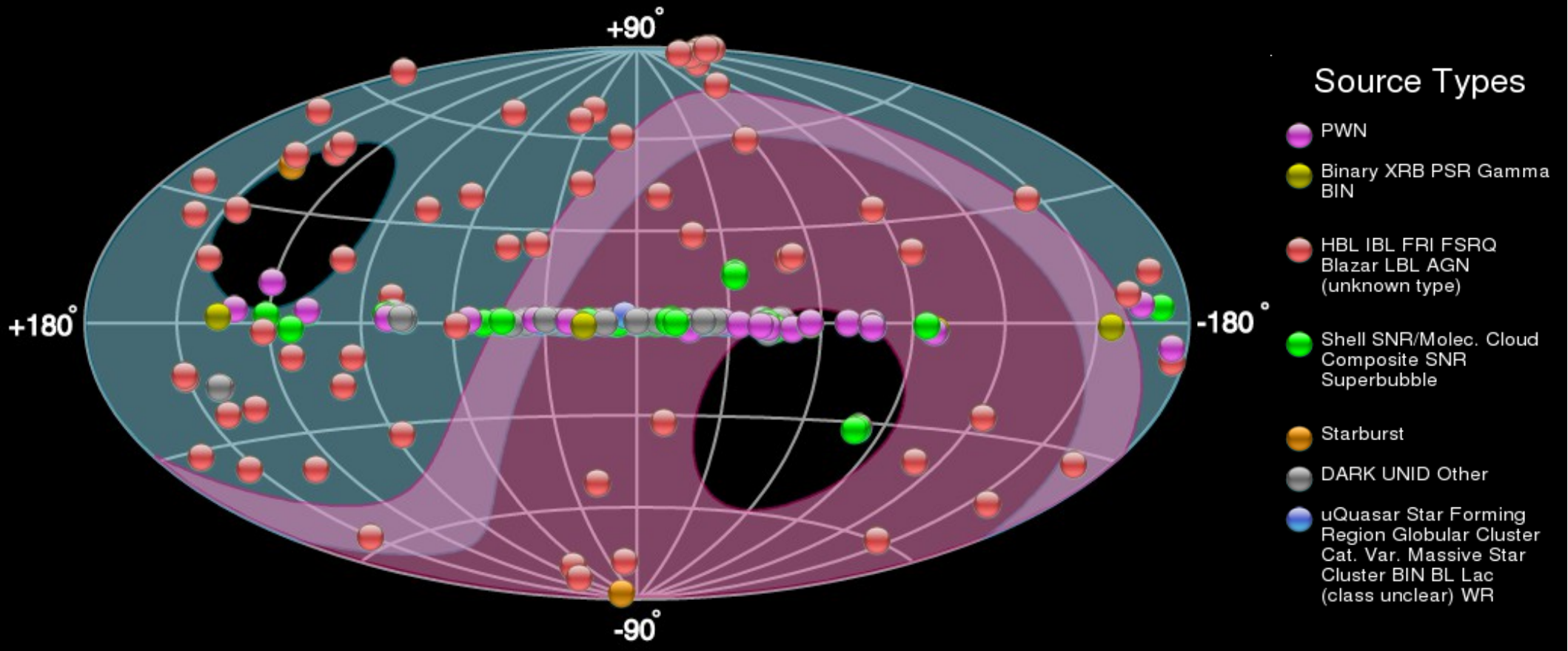
French contributions : from A to Z !



M. Lemoine-Goumard, Journées PNHE, March 31, 2016

The TeV sky today: a large variety of sources

Already 162 detected sources reported in the TeV Catalog as of December 2015 !
65 sources are extragalactic – 70 are Galactic – 27 UNID

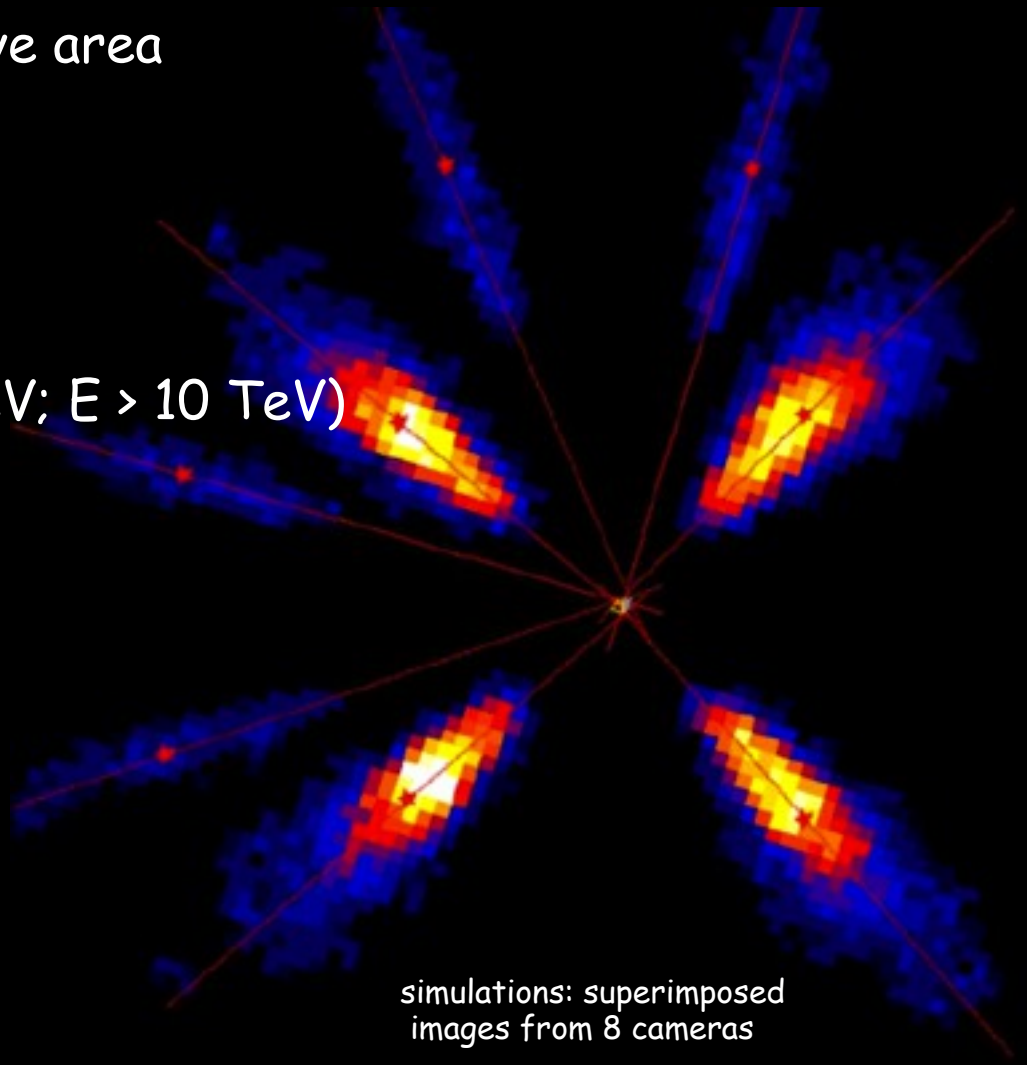


THE FUTURE for ground based detectors

- More events
  More photons from larger effective area

- Better events
  Better reconstruction

- New events
  Extended energy range (E < 50 GeV; E > 10 TeV)



simulations: superimposed images from 8 cameras

Near Future with H.E.S.S.-II

Pulsars :

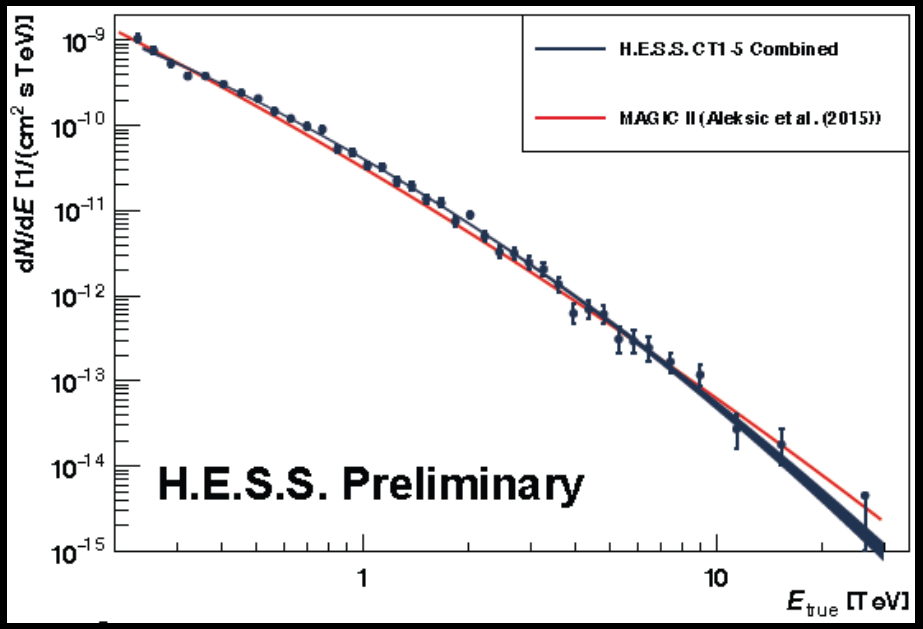
- Detection of the Vela Pulsar above 20 GeV by HESS
- Other bright Fermi PSRs are priority targets (eg. PSR J1709-4429)

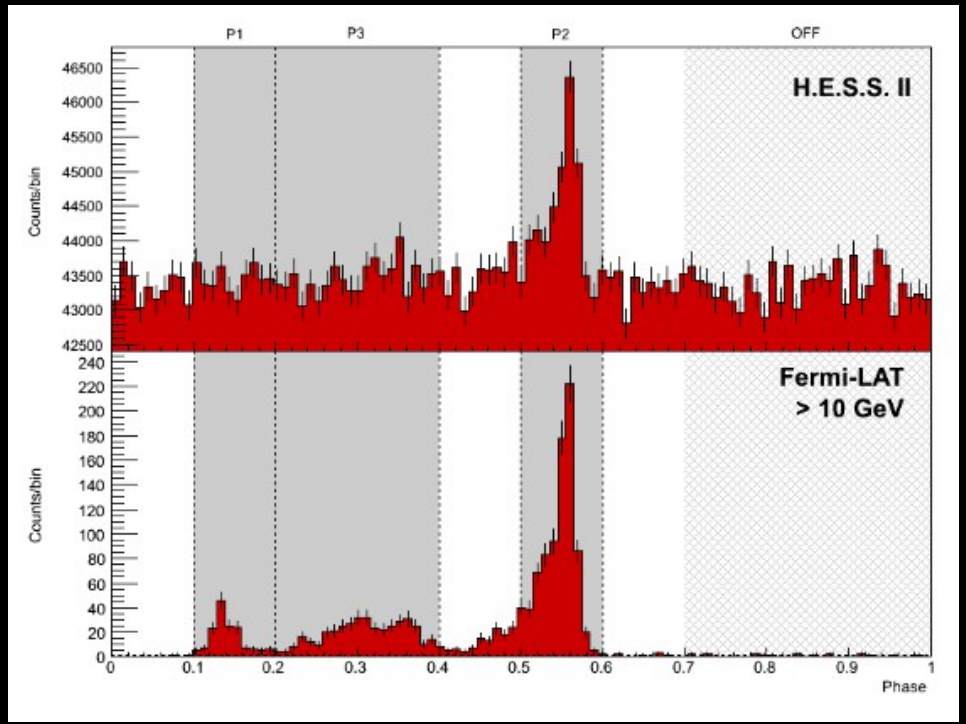
GRBs : Rapid repointing system

- CT5 drive is significantly updated + CT5 can point in reverse-mode + fully automatic ToO observation system implemented

First step and science towards CTA

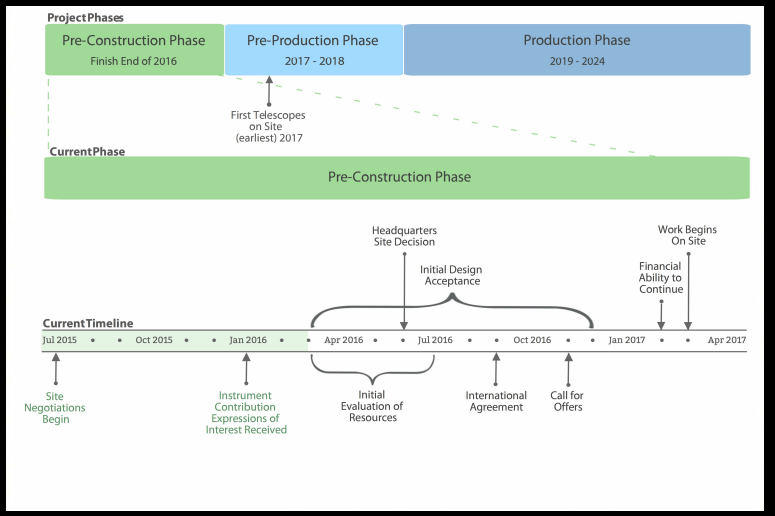
first hybrid IACT array

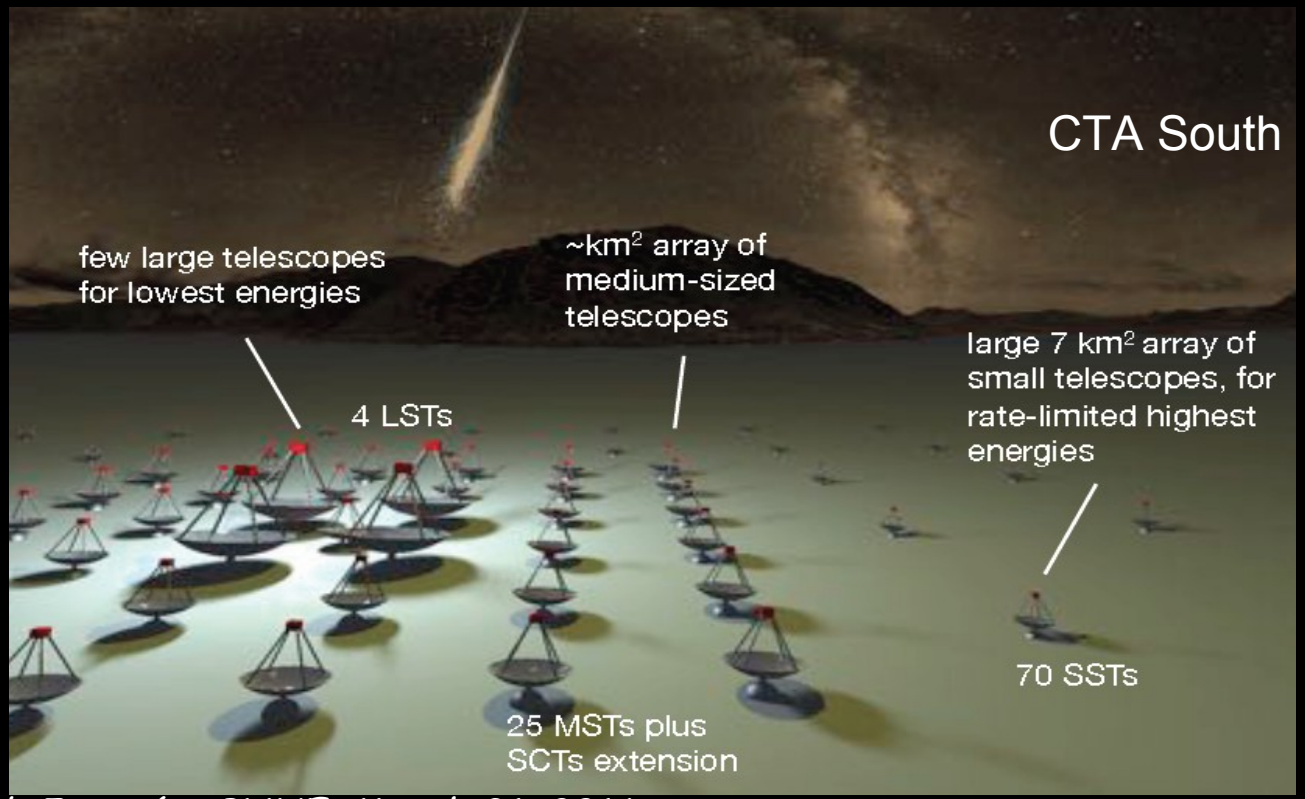




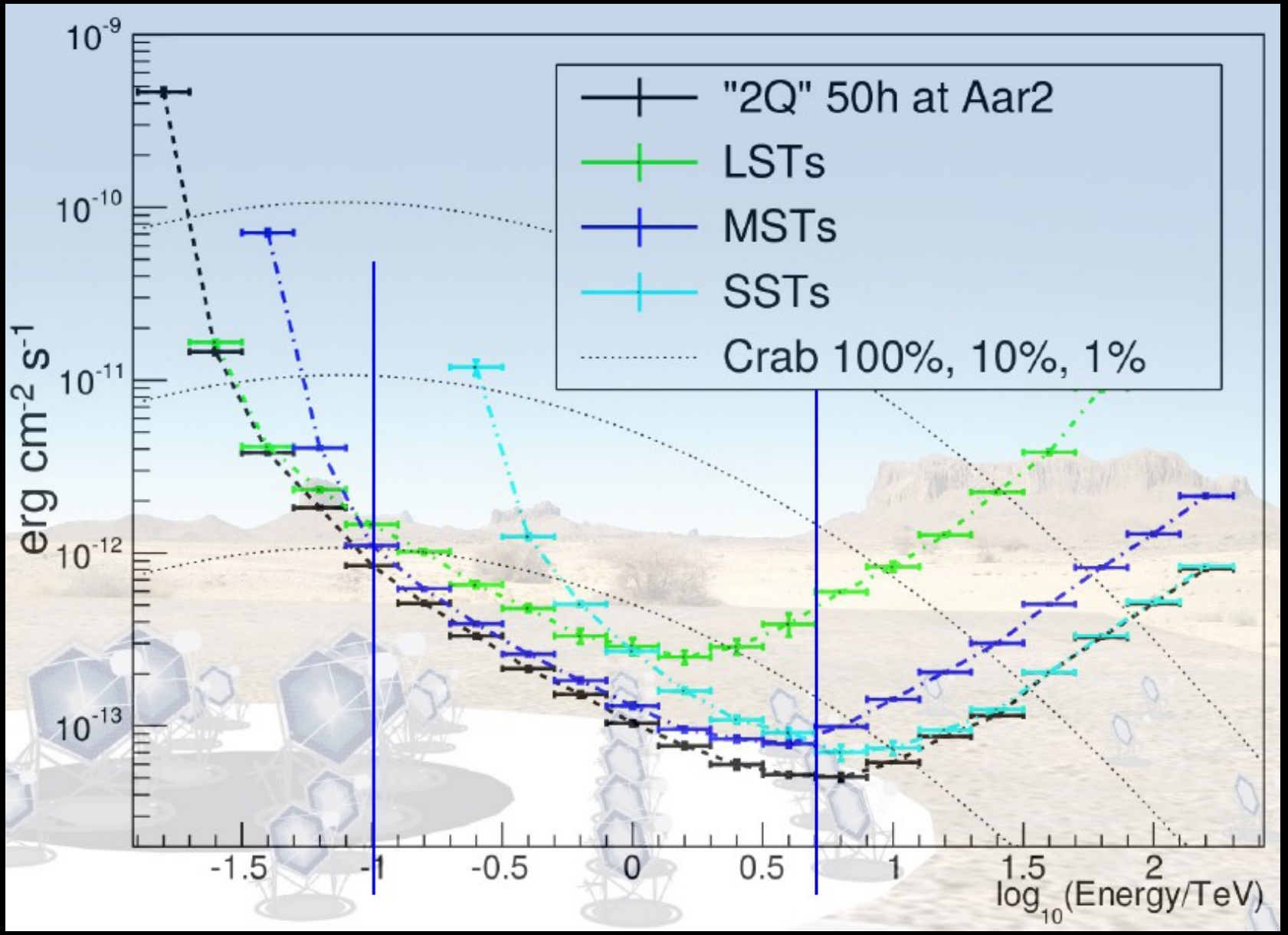
The Cherenkov Telescope Array (CTA)

- > 1200 members
  - 194 Institutes from 31 countries
- 2 sites selected:
  - North (La Palma, Spain)
  - South (Paranal, Chile)
- 3 Telescope sizes
- ~120 Telescopes in total +
- South US extension with ~25 Telescopes

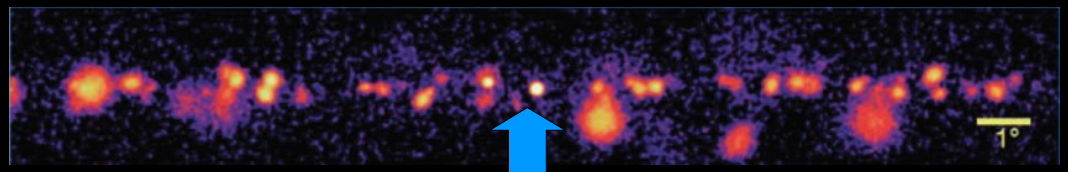




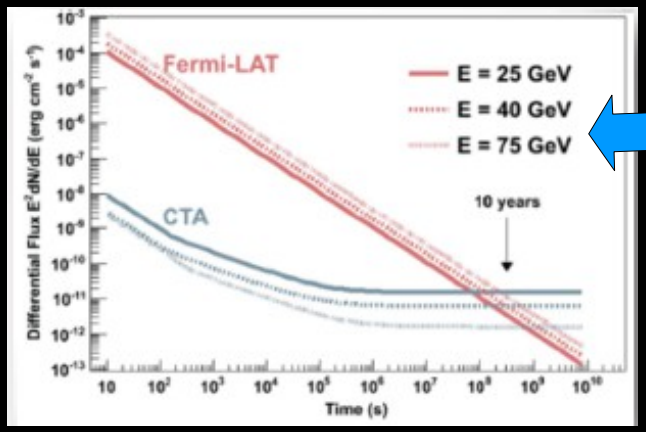
CTA telescopes contribution



CTA science prospects

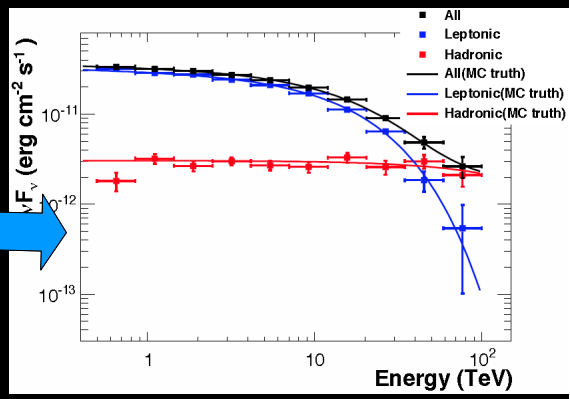


8° FoV => Surveys

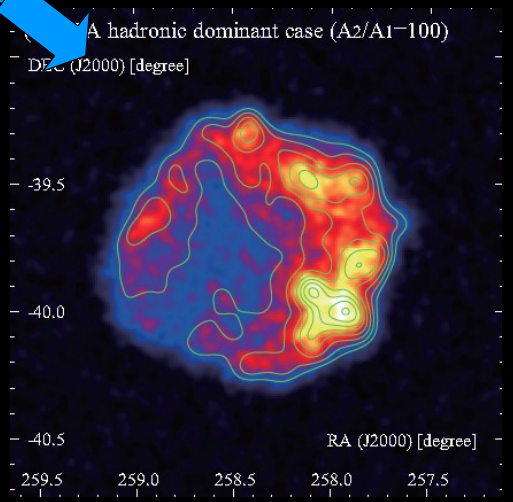


Fast slewing => Transients

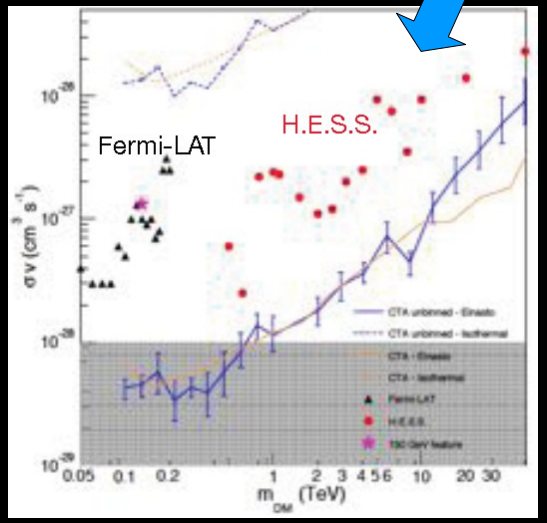
Energies up to 300 TeV
=> PeVatron



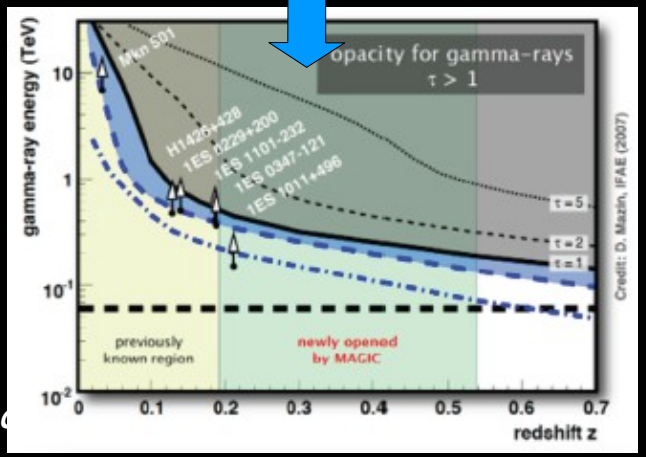
Excellent angular resolution
=> Morphology



Excellent energy resolution => Lines



Energies down to 20 GeV
=> Cosmology



The Large High Altitude Air Shower Array (LHAASO)

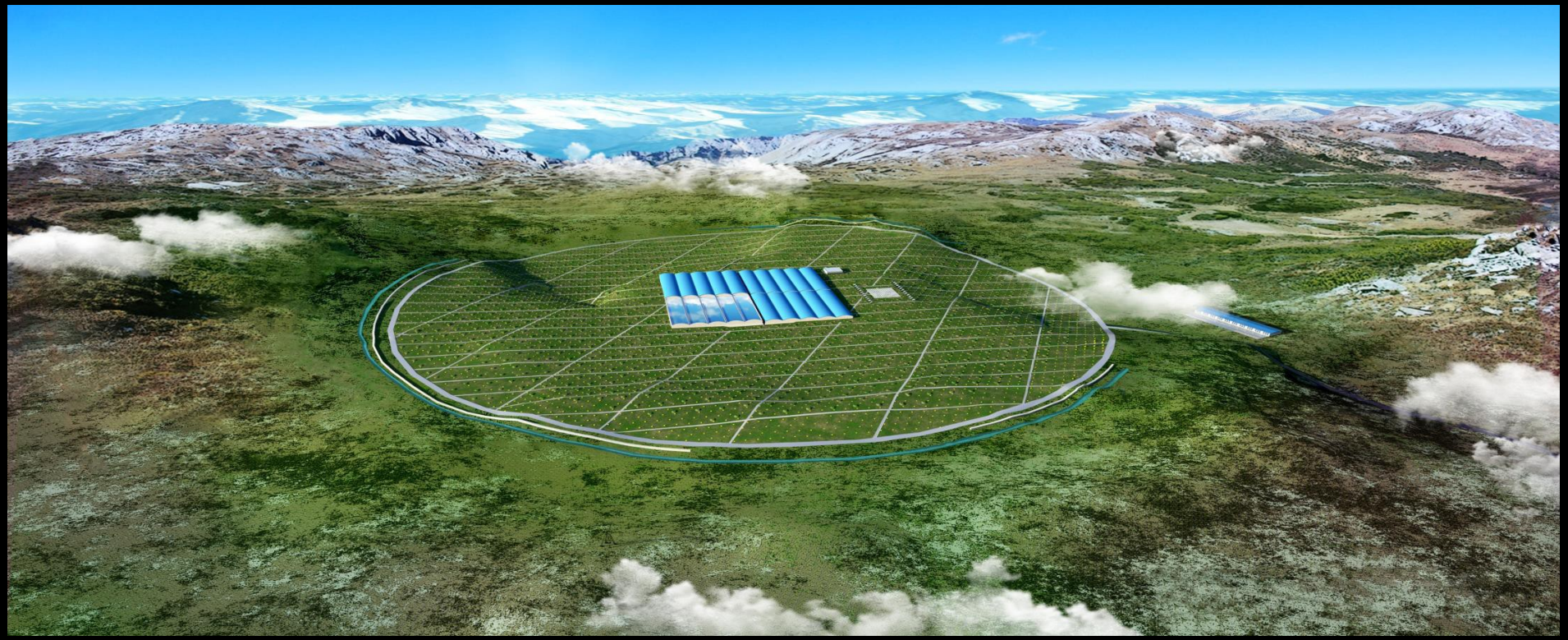
LHAASO detectors:

- air shower array of 1 km^2

. 75 000 m2 Water Cherenkov Detector Array (WCDA)

- 12 Wide-field Cherenkov telescopes (WFCTA)
- Infilled shower core detectors

Engineering at ARGO site (~1% LHAASO in operation for > 2 years)



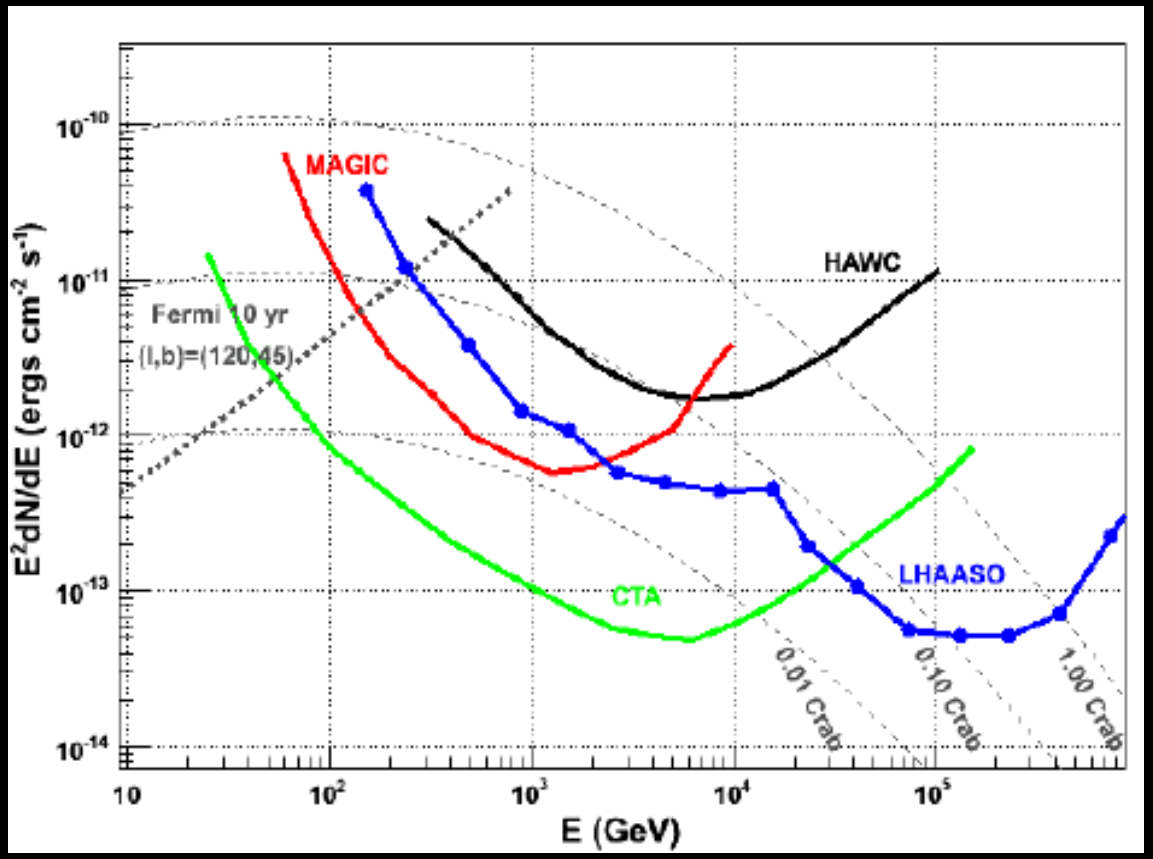
Performances and prospects of LHAASO

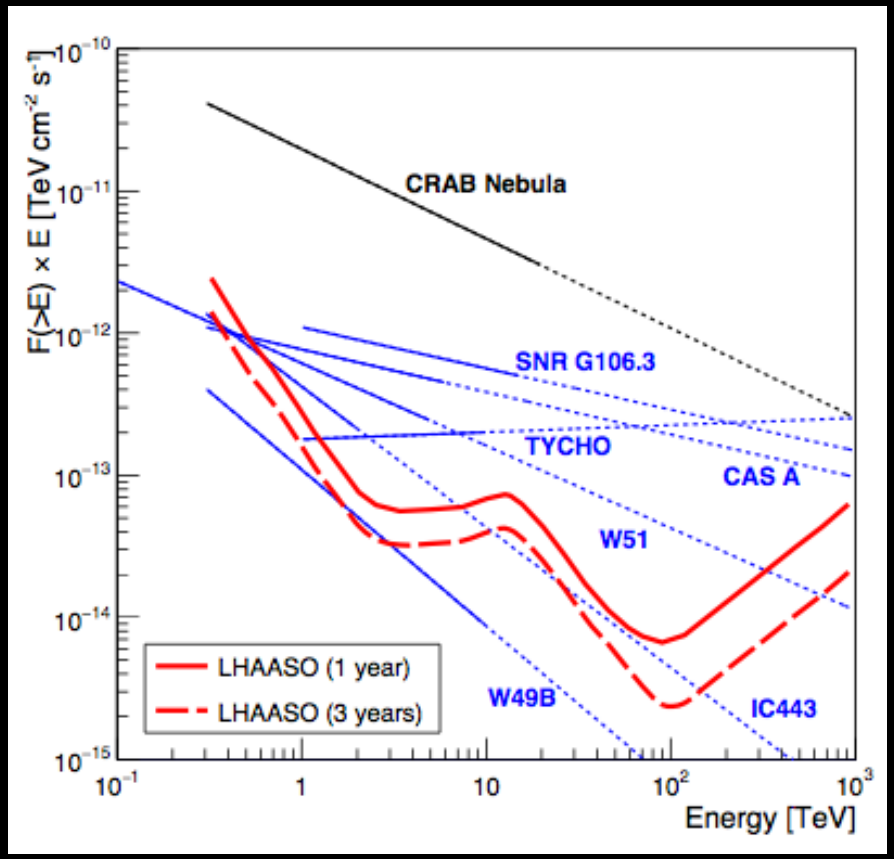
Better sensitivity than CTA for E > 30 TeV

Official approval for funding from agency in China

LHAASO infrastructure construction has started at Mt. Haizi, Sichuan

The detector deployment will start by the end of this year





Summary

Many great results and projects led by our community

e-ASTROGAM and CTA are the experiments involving the largest part of our colleagues but several other projects might be of interest : HARPO, PANGU, LHAASO...

The next few years promise more fruitful science (number of sources is not the limiting factor) while new observatories are being developed

« It's a great time for gamma-rays. In terms of mapping gamma rays, we have barely opened our eyes. »
E. Hays