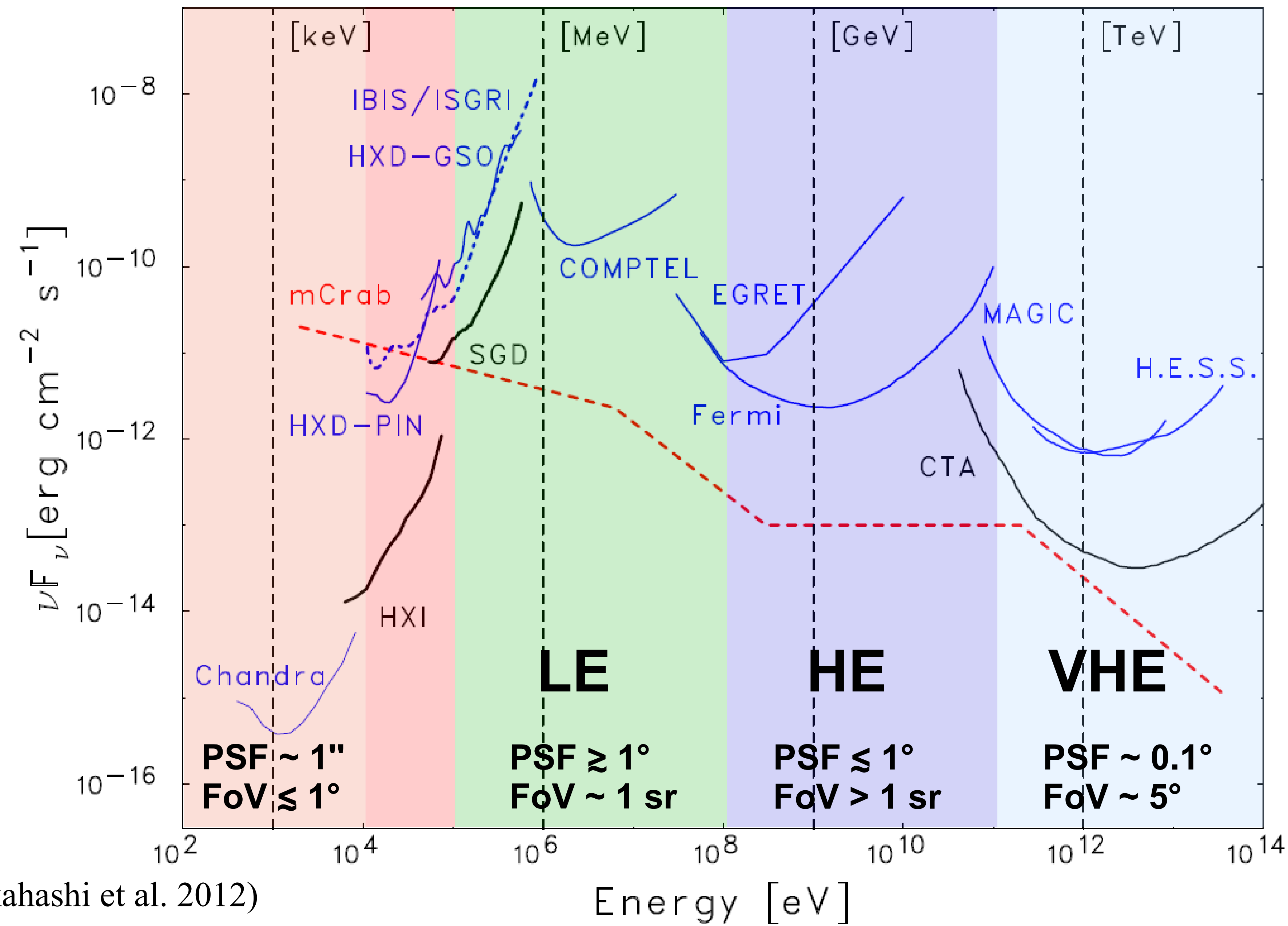
Synergies between X-ray and gamma-ray domains

M. Renaud

LUPM, CNRS/IN2P3 – Univ. Montpellier 2, France

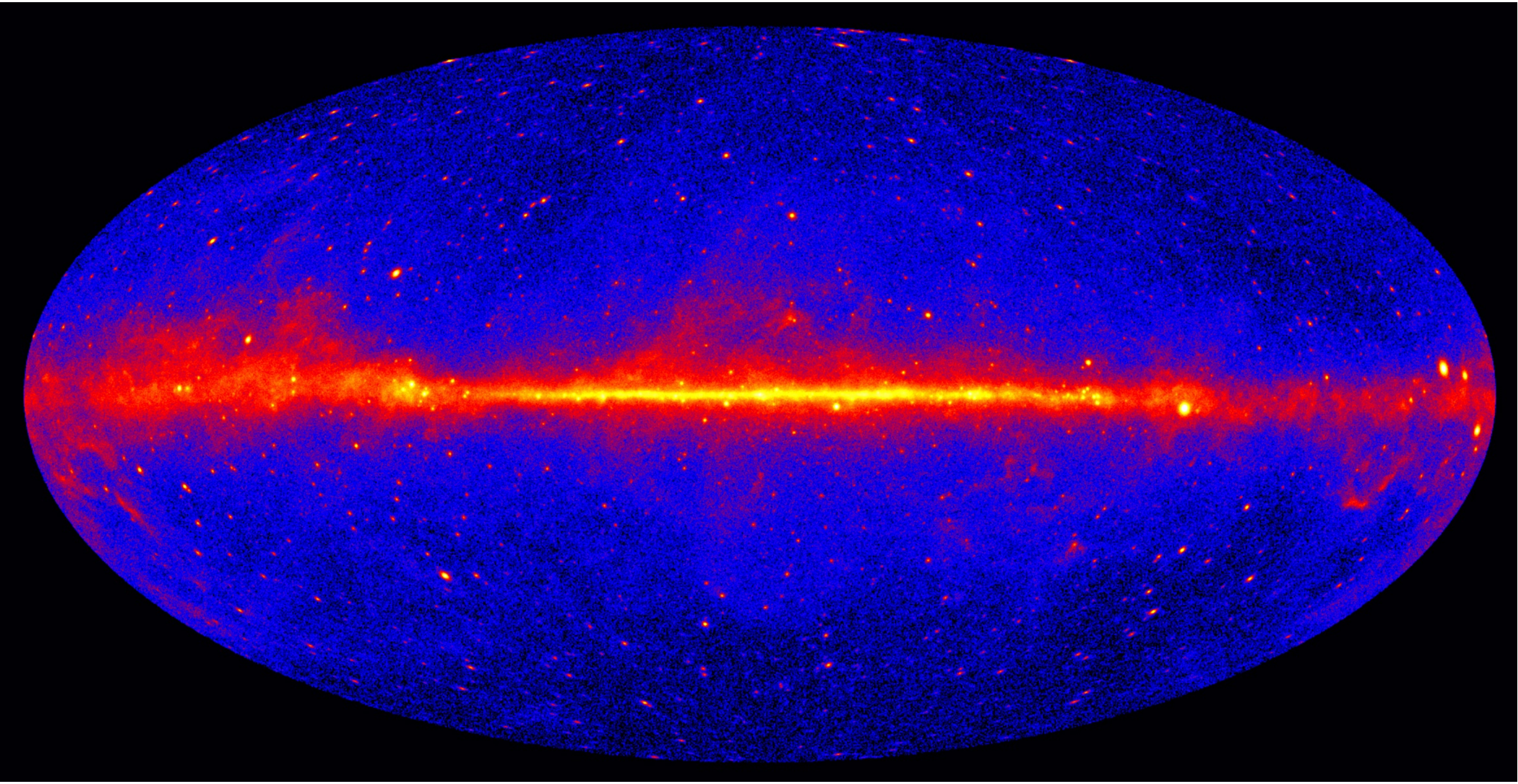
with the help from J.-P. Lenain & P. Martin in particular,
and many others through their work, articles, reviews...

X-rays & gamma-rays in a nutshell



(Takahashi et al. 2012)

HE sky from *Fermi*/LAT

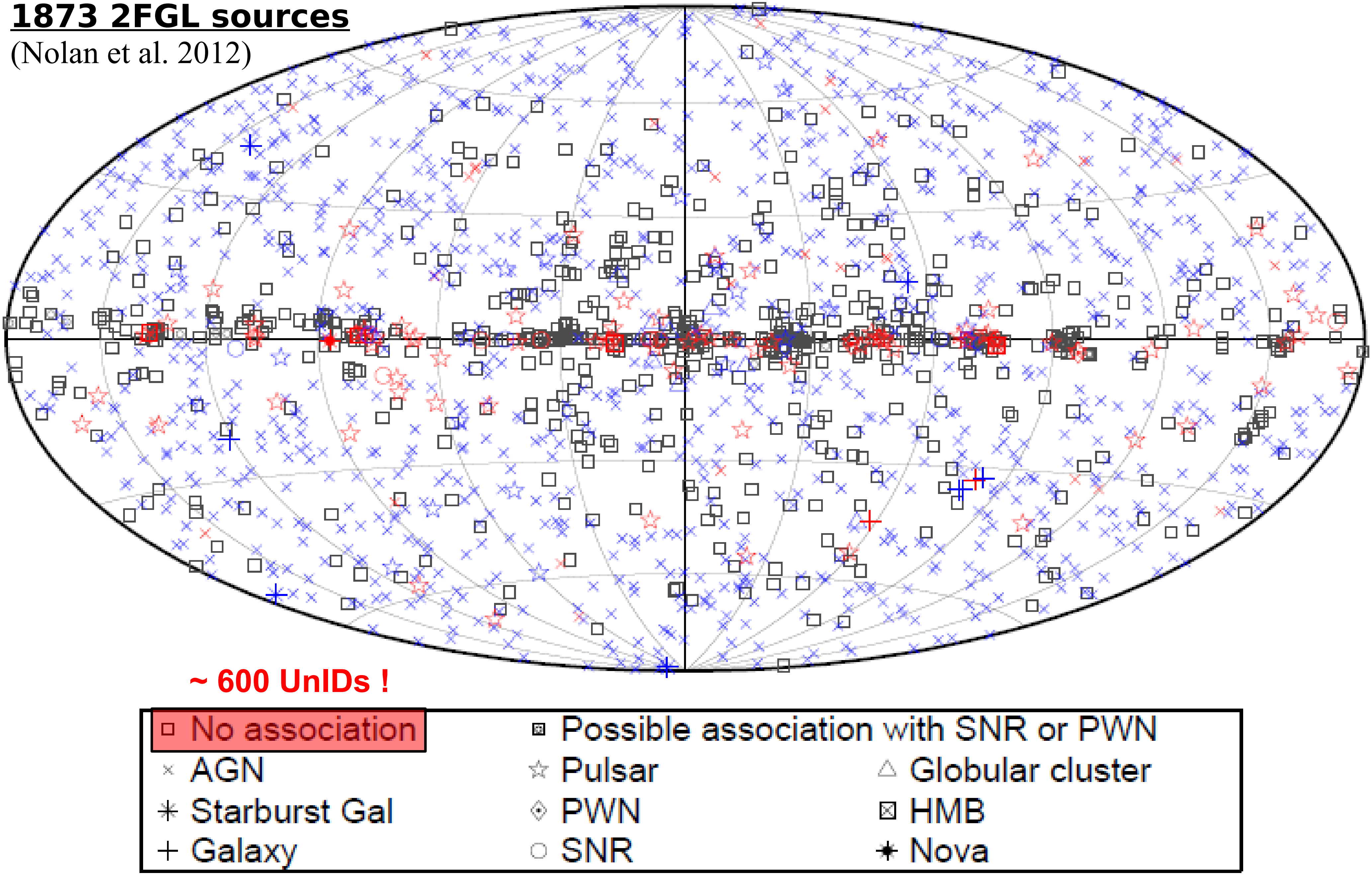


Fermi/LAT 5-yr all-sky image at E > 1 GeV

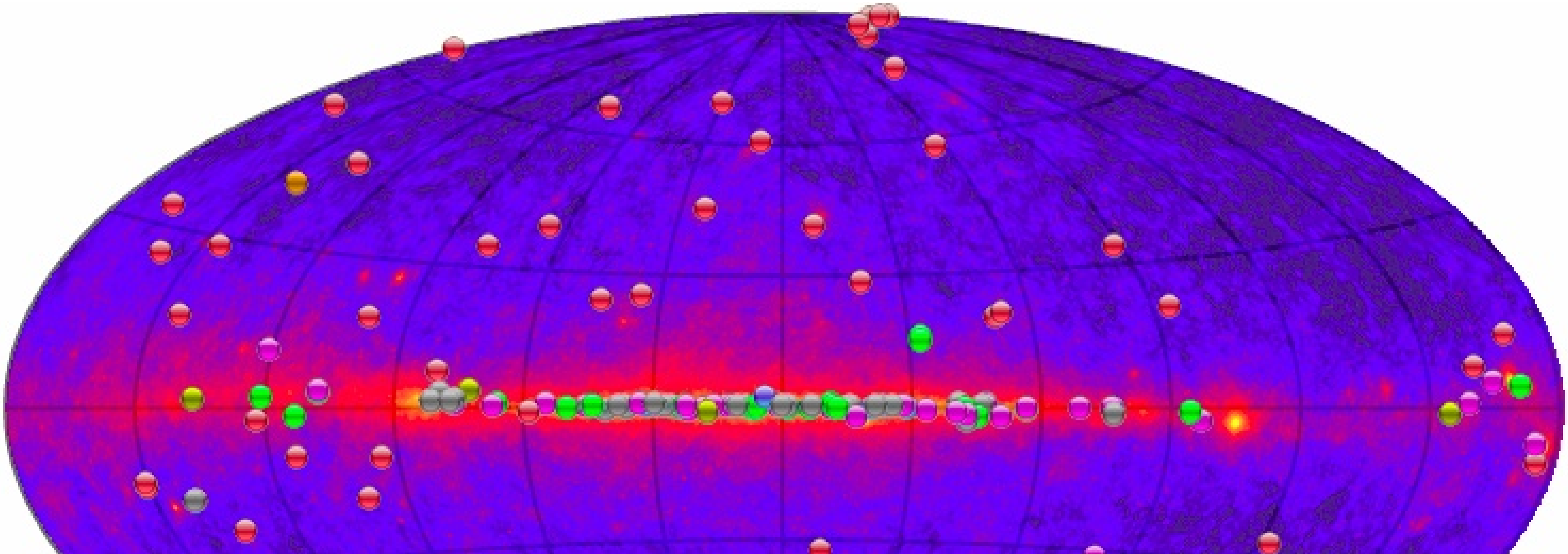
HE sky from *Fermi*/LAT

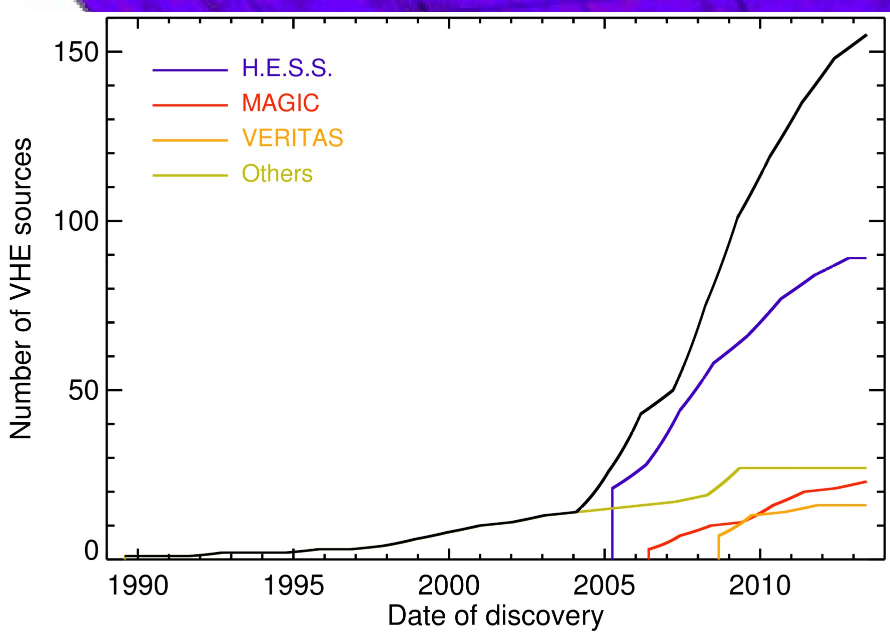
1873 2FGL sources

(Nolan et al. 2012)



VHE sky from IACTs

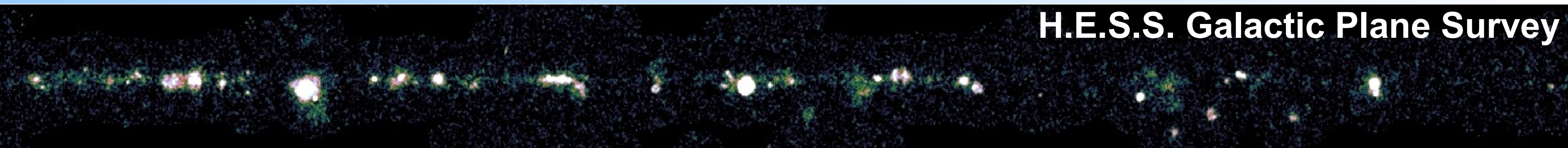


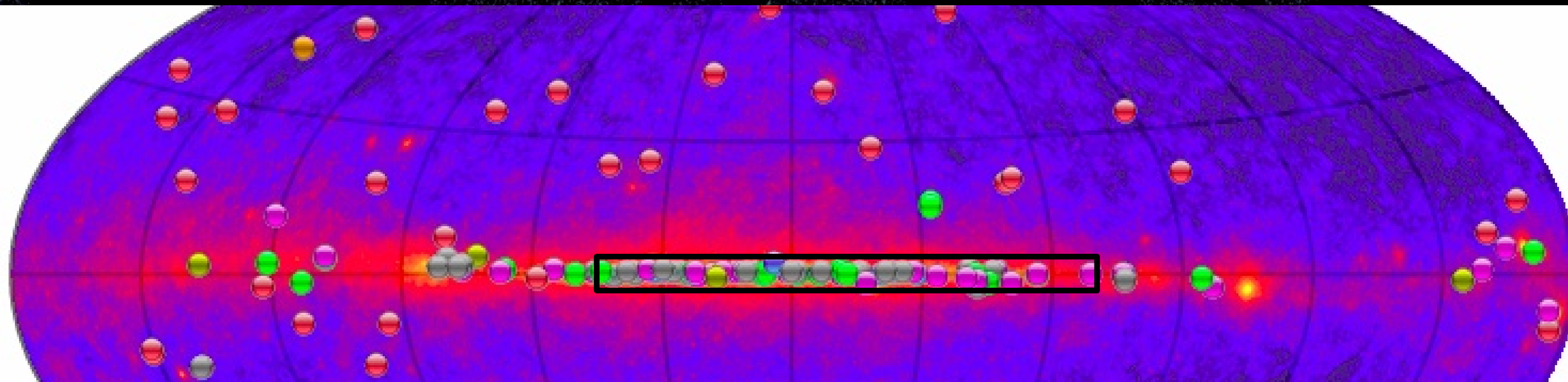


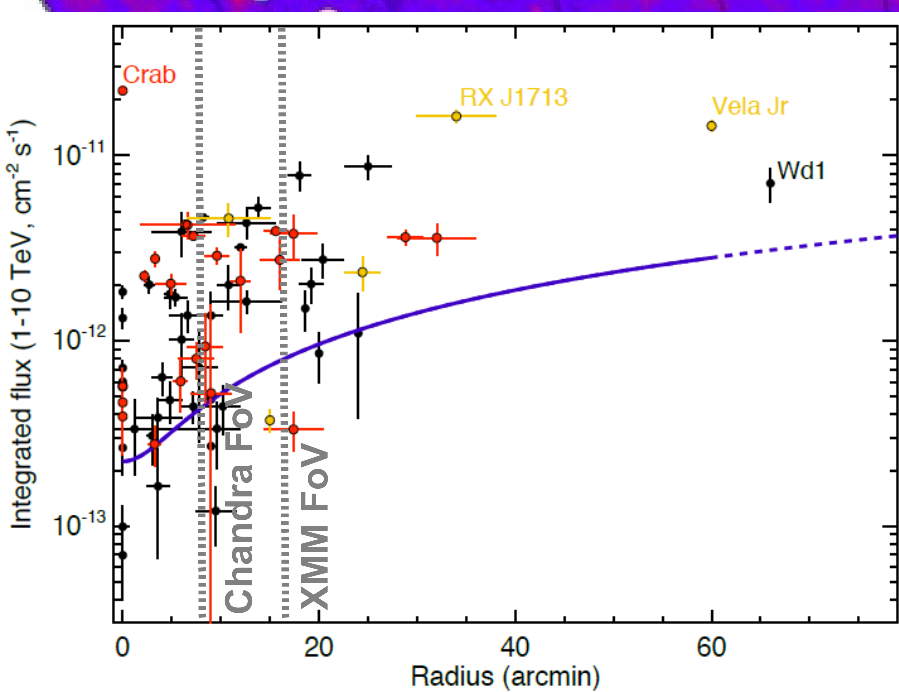
http://tevcat.uchicago.edu/

155 sources as of june 2013

VHE sky from IACTs



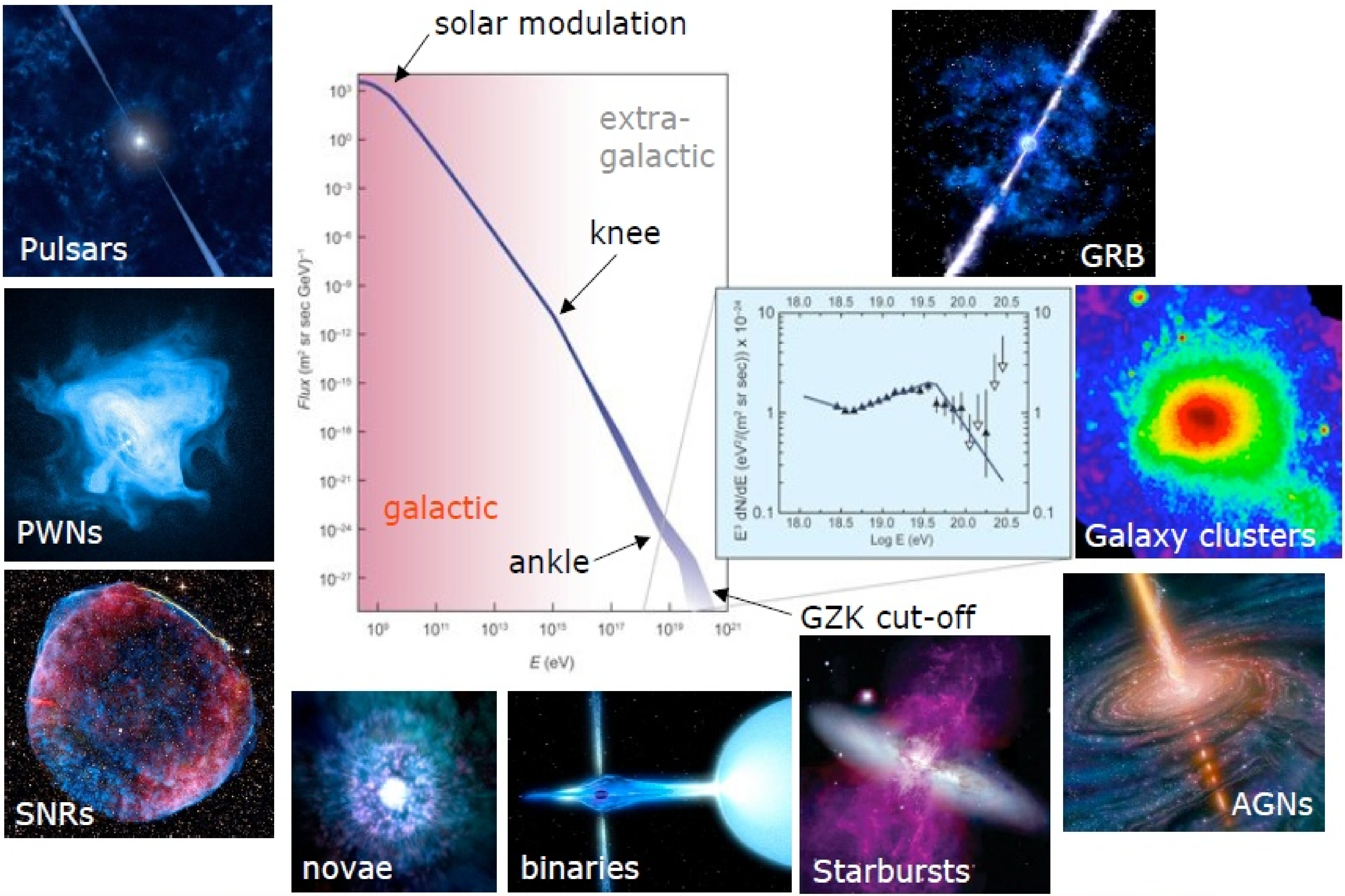




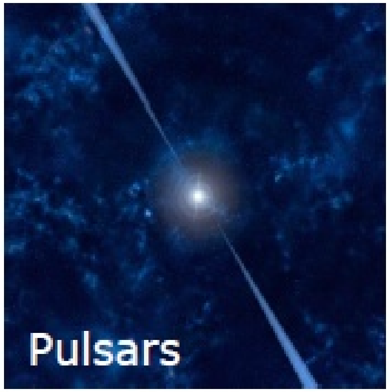
http://tevcat.uchicago.edu/

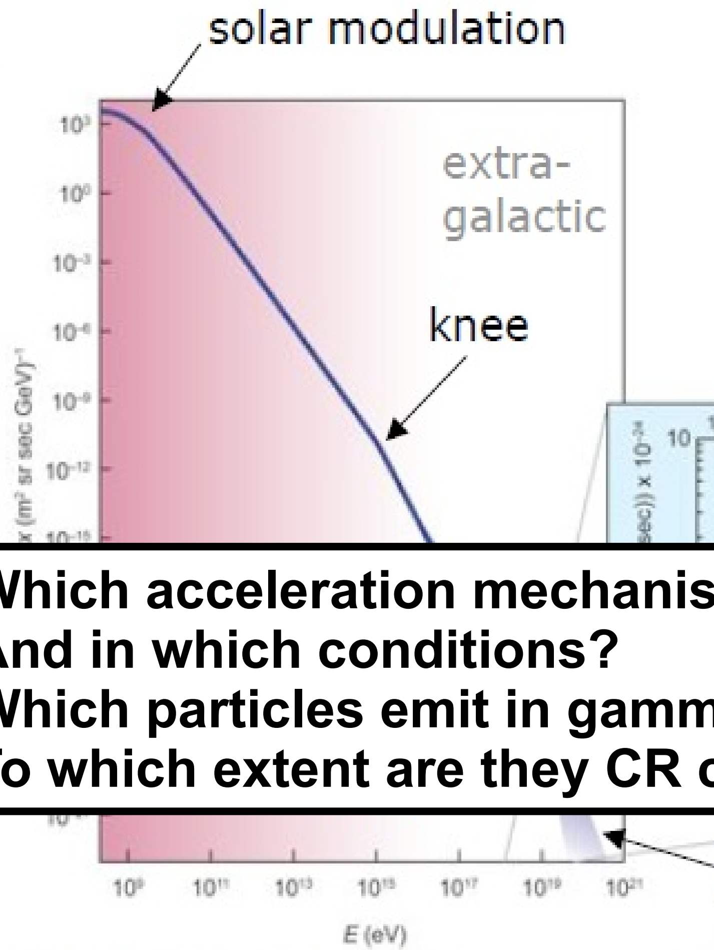
155 sources
as of june 2013

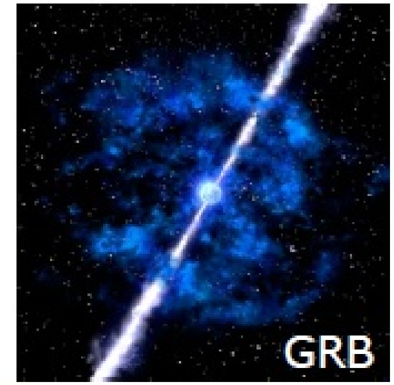
Seeking the cosmic-ray sources...

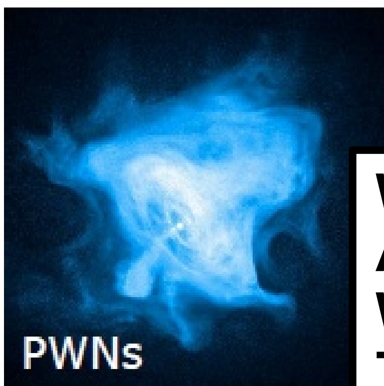


Seeking the cosmic-ray sources...

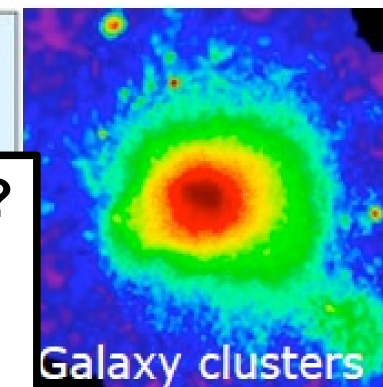


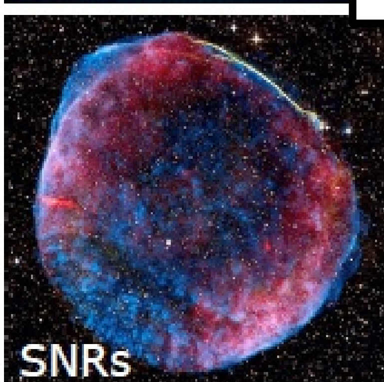


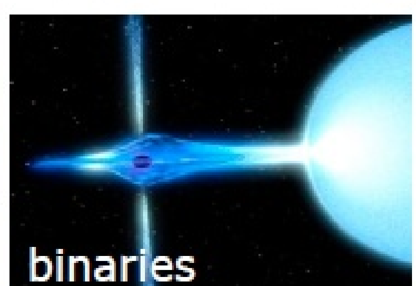




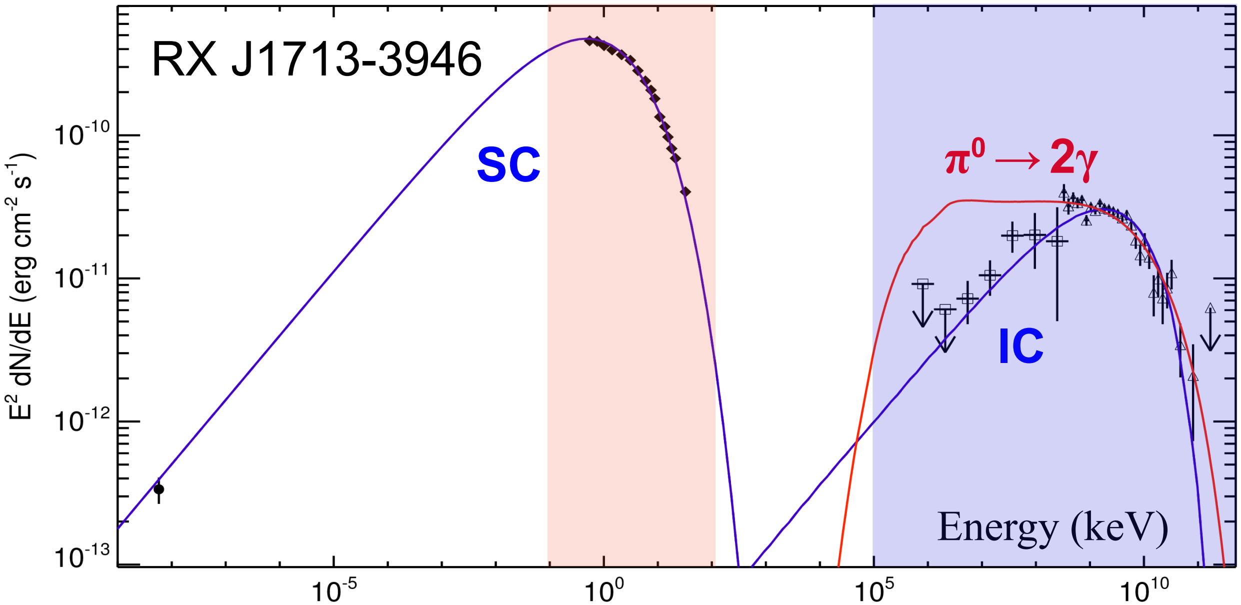
Which acceleration mechanisms are at play?
And in which conditions?
Which particles emit in gamma-rays?
To which extent are they CR contributors?

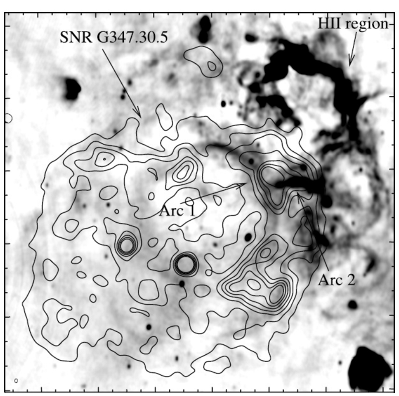


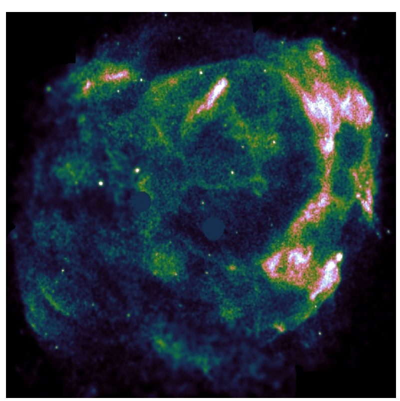


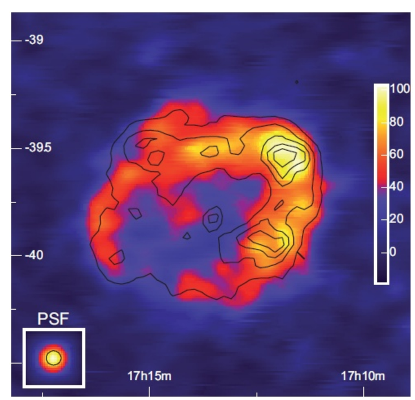


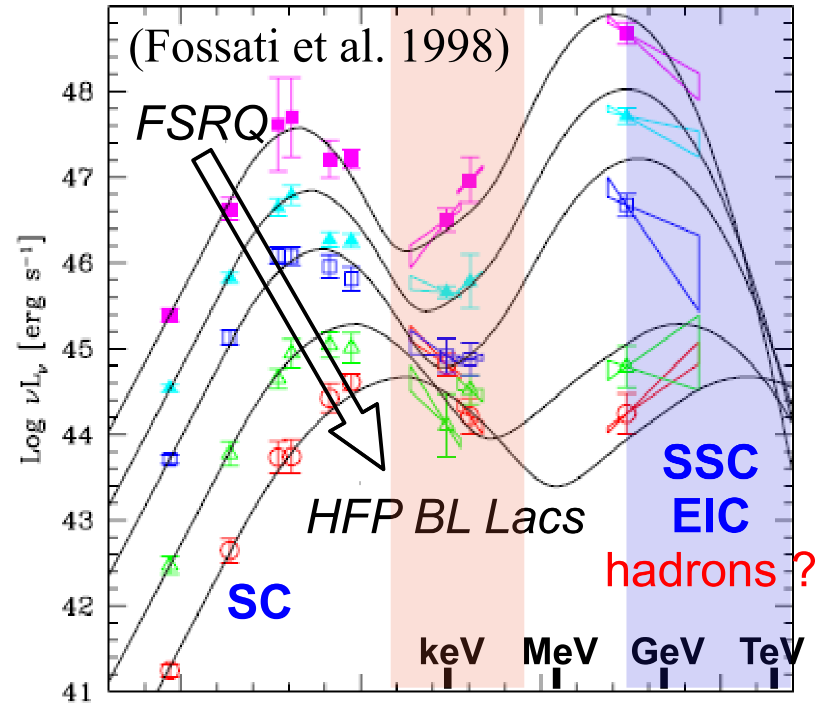
...and the link between X-rays & gamma-rays

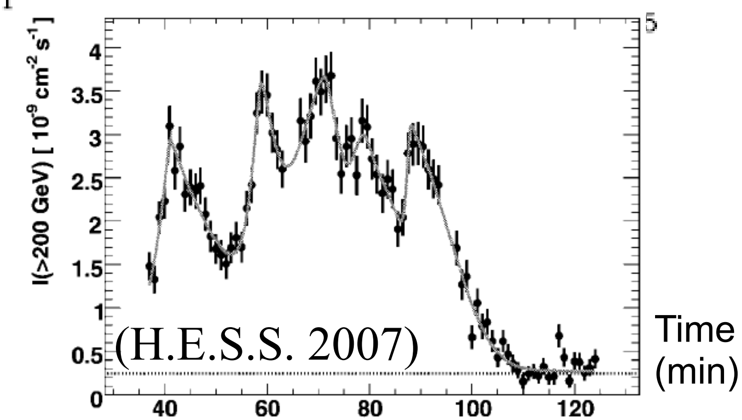












SNRs, PWNe, «Dark sources» :
Spectro-imaging capabilities

AGNs, PSRs, binaries, novae :
Time-resolved spectra

...and the link between X-rays & gamma-rays

Object	Discovered	Year	Type	Method
Crab Nebula	Whipple	1989	PWN	Position
Crab Pulsar	MAGIC	2008	Pulsar	Periodicity
RX J1713.7−3946	CANGAROO	2000	SNR	Morphology
Cassiopeia A	HEGRA	2001	SNR	Position
RX J0852.0−4622	CANGAROO	2005	SNR	Morphology
G0.9+0.1	H.E.S.S.	2005	SNR	Position
HESS J1825−137	H.E.S.S.	2005	PWN	ED Morphology
MSH 15−52	H.E.S.S.	2005	PWN	Morphology
LS 5039	H.E.S.S.	2005	γ-ray binary	Periodicity
HESS J1303−631	H.E.S.S.	2005	PWN	ED Morphology
PSR B1259−63	H.E.S.S.	2005	γ-ray binary	Variability
Vela X	H.E.S.S.	2006	PWN	Morphology
LS I+61 303	MAGIC	2006	γ-ray binary	Periodicity
Kookaburra (Rabbit)	H.E.S.S.	2006	PWN	Morphology
Kookaburra (Wings)	H.E.S.S.	2006	PWN	Morphology
HESS J0632+057	H.E.S.S.	2007	γ-ray binary	Periodicity
HESS J1731−347	H.E.S.S.	2007	SNR	Morphology
RCW 86	H.E.S.S.	2008	SNR	Morphology
SN 1006	H.E.S.S.	2009	SNR	Morphology
Tycho	VERITAS	2010	SNR	Position

(Funk 2012)

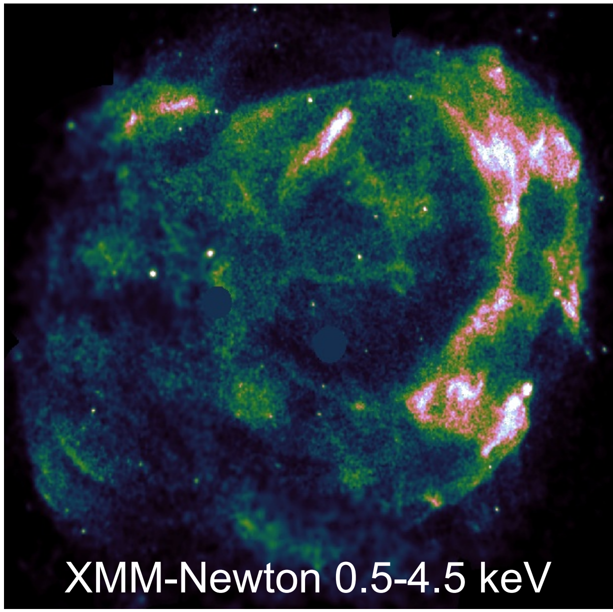
Table 1: Firmly identified Galactic TeV objects.

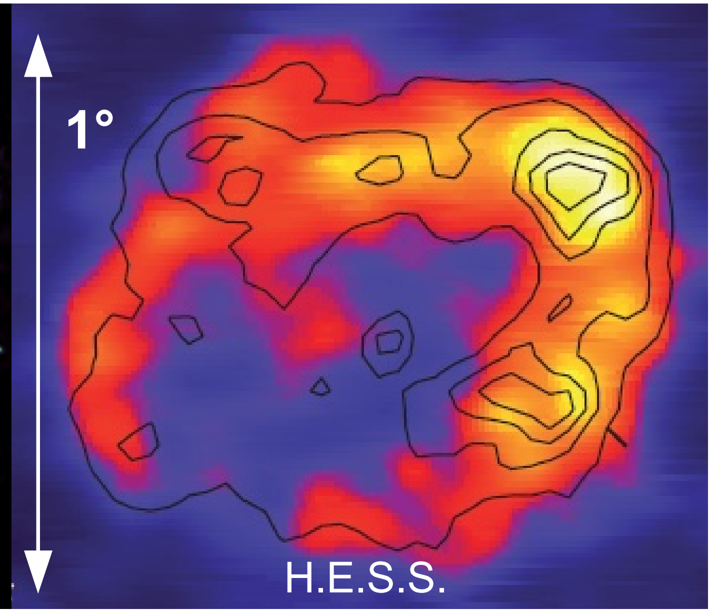
SNRs, PWNe, «Dark sources» : Spectro-imaging capabilities

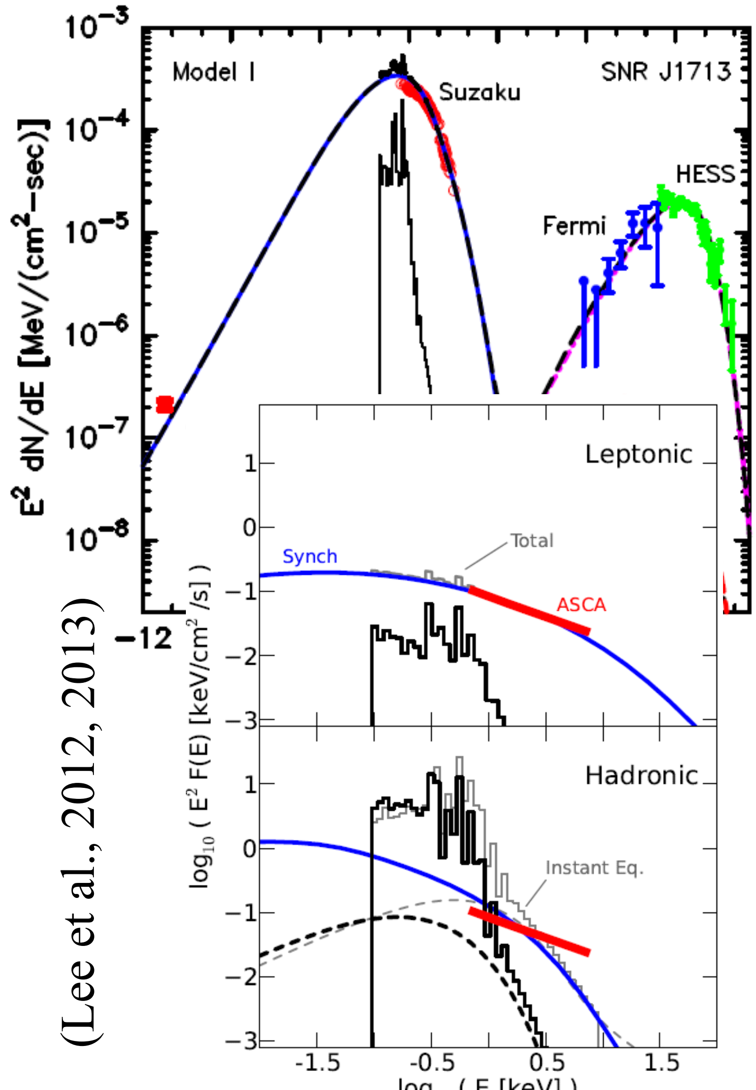
AGNs, PSRs, binaries, novae : Time-resolved spectra

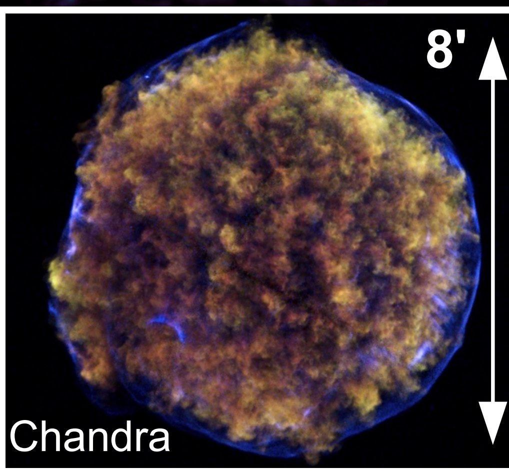
X-ray / gamma-ray synergies

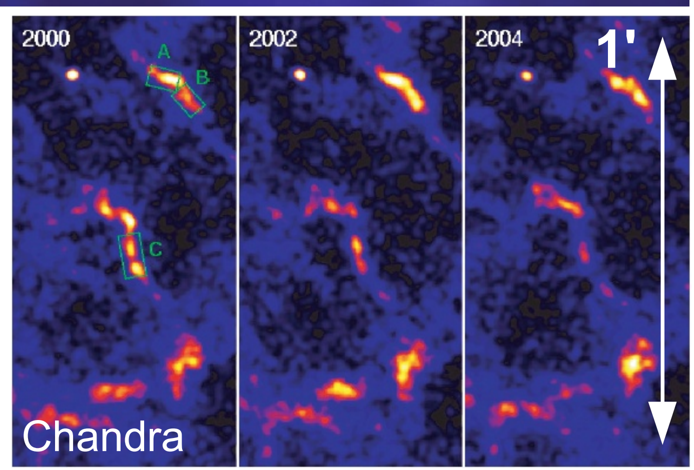
Supernova remnants : *detailed broadband studies*









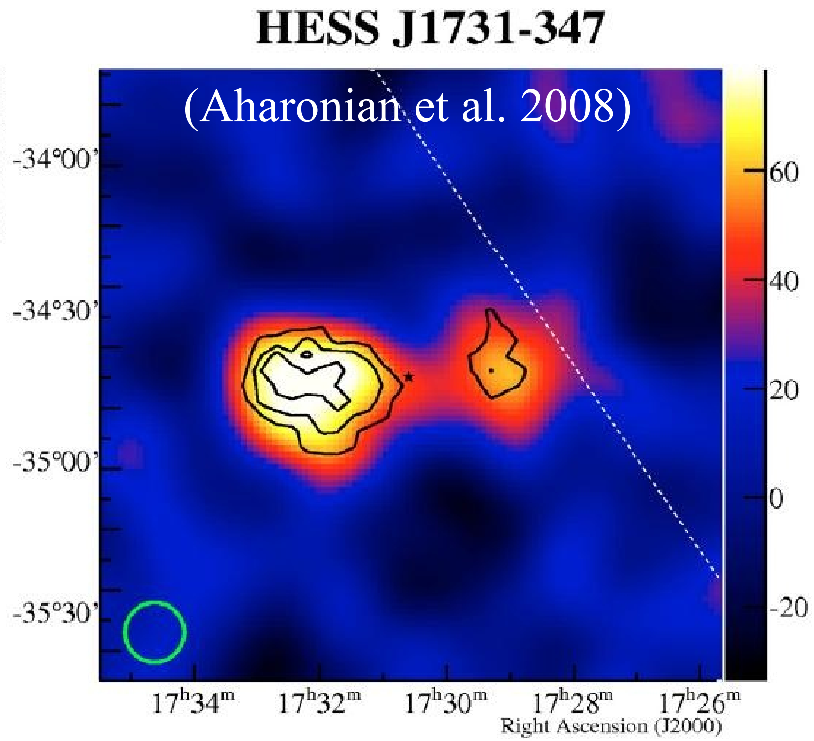


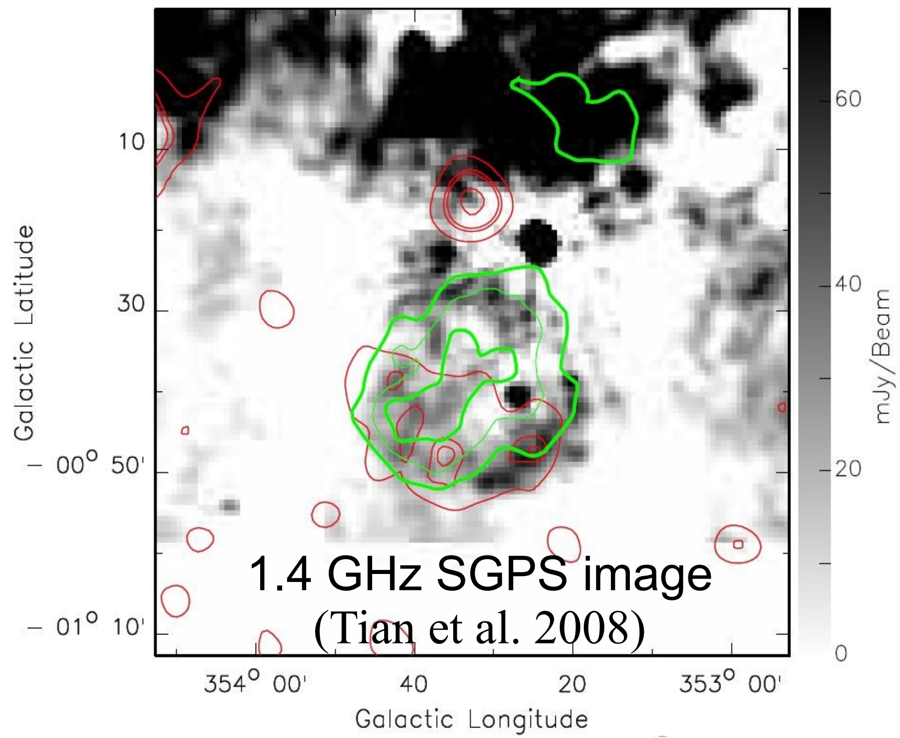
Thermal emission → hydrodynamical conditions
Small-scale structures → B-field → CR acceleration
Nonthermal spectrum → diffusion regime

Origin of γ-ray emission ↔ E_{max}, ε_{CR}
SNRs ↔ main CR sources ?

X-ray / gamma-ray synergies

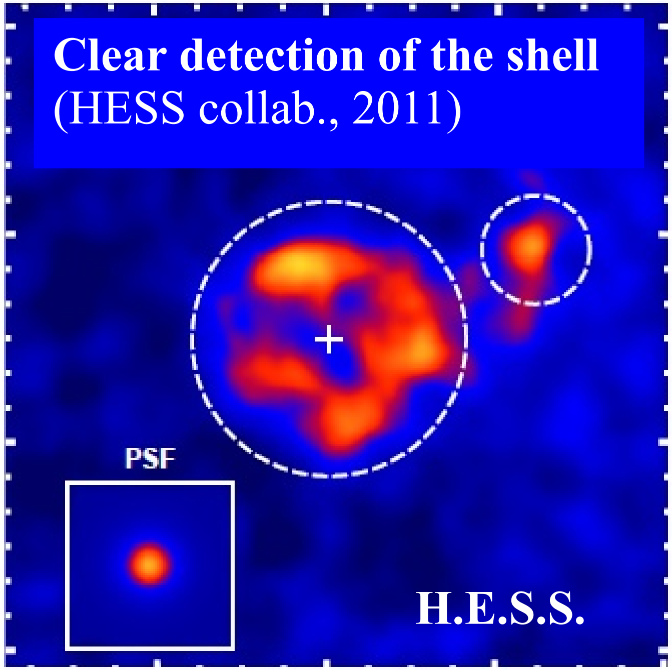
Supernova remnants : *search for new SNRs*

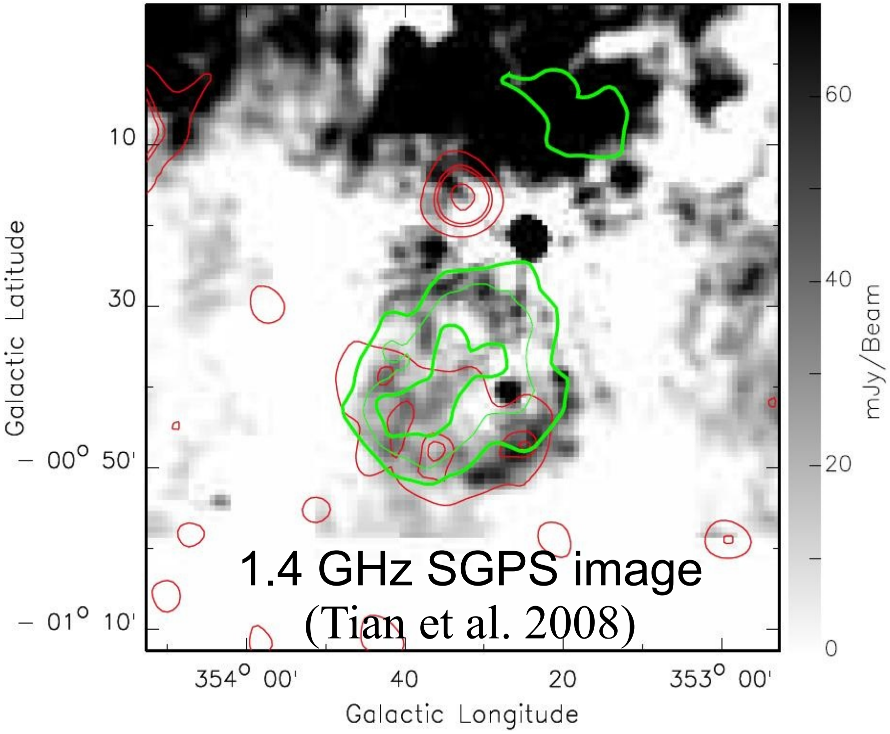




X-ray / gamma-ray synergies

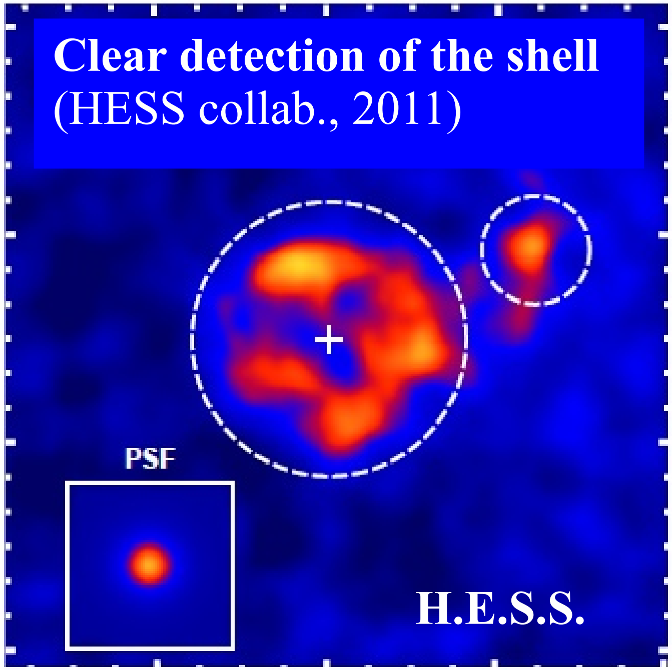
Supernova remnants : *search for new SNRs*

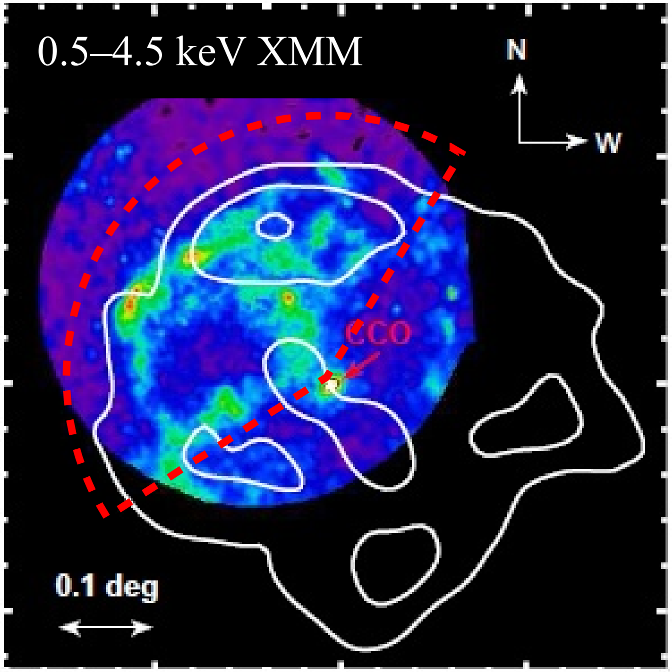


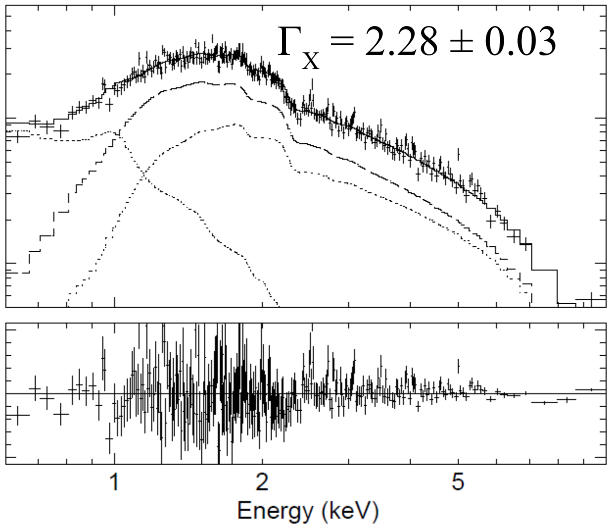


X-ray / gamma-ray synergies

Supernova remnants : *search for new SNRs*

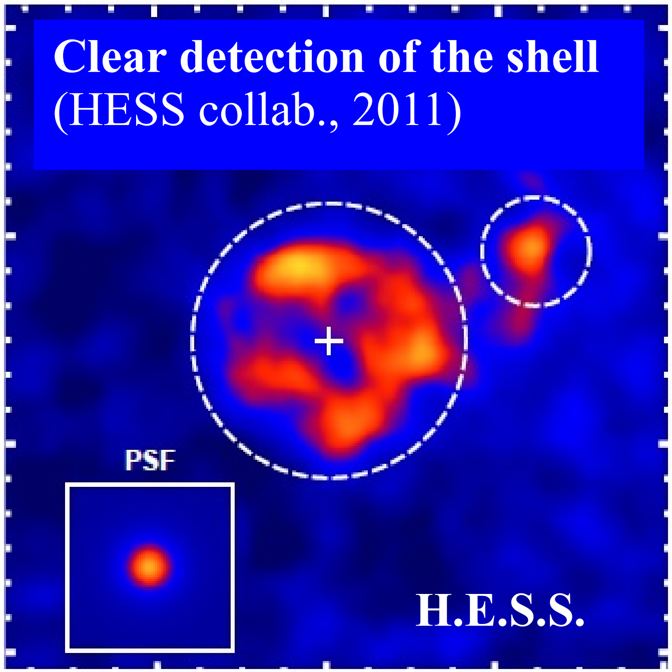


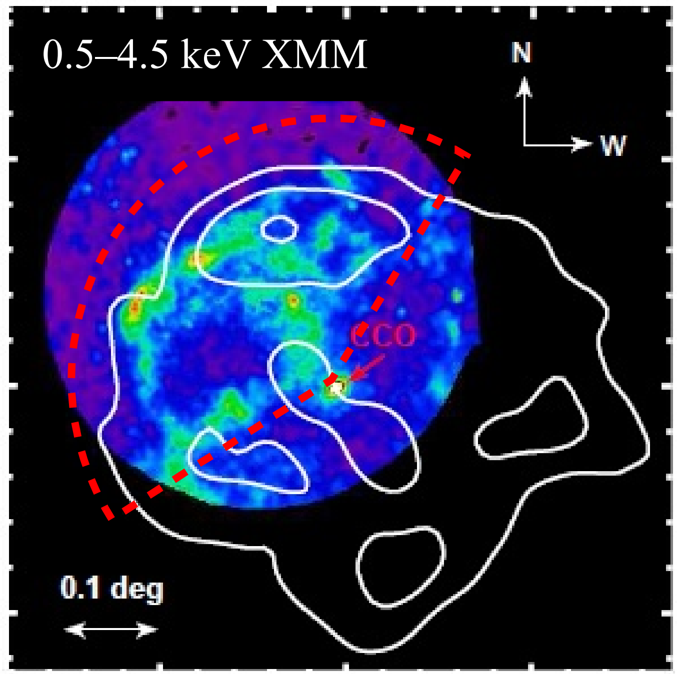


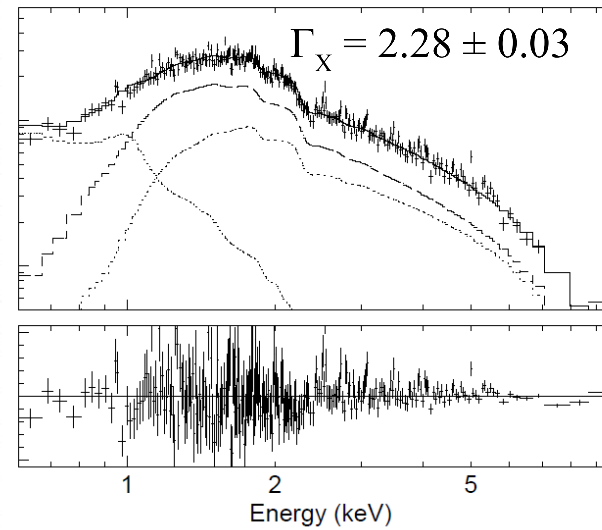


X-ray / gamma-ray synergies

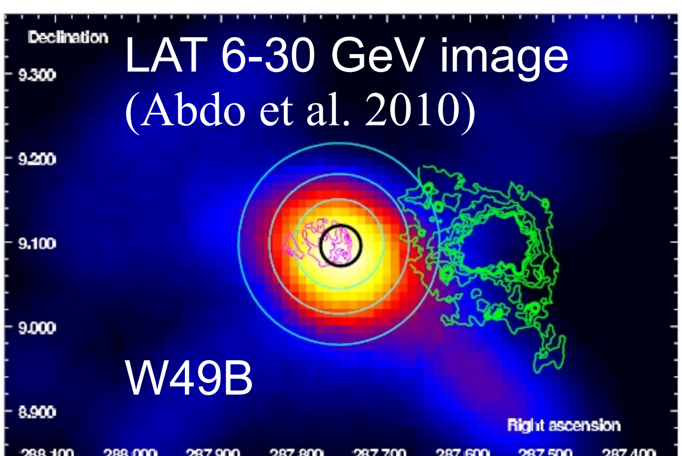
Supernova remnants : *search for new SNRs*





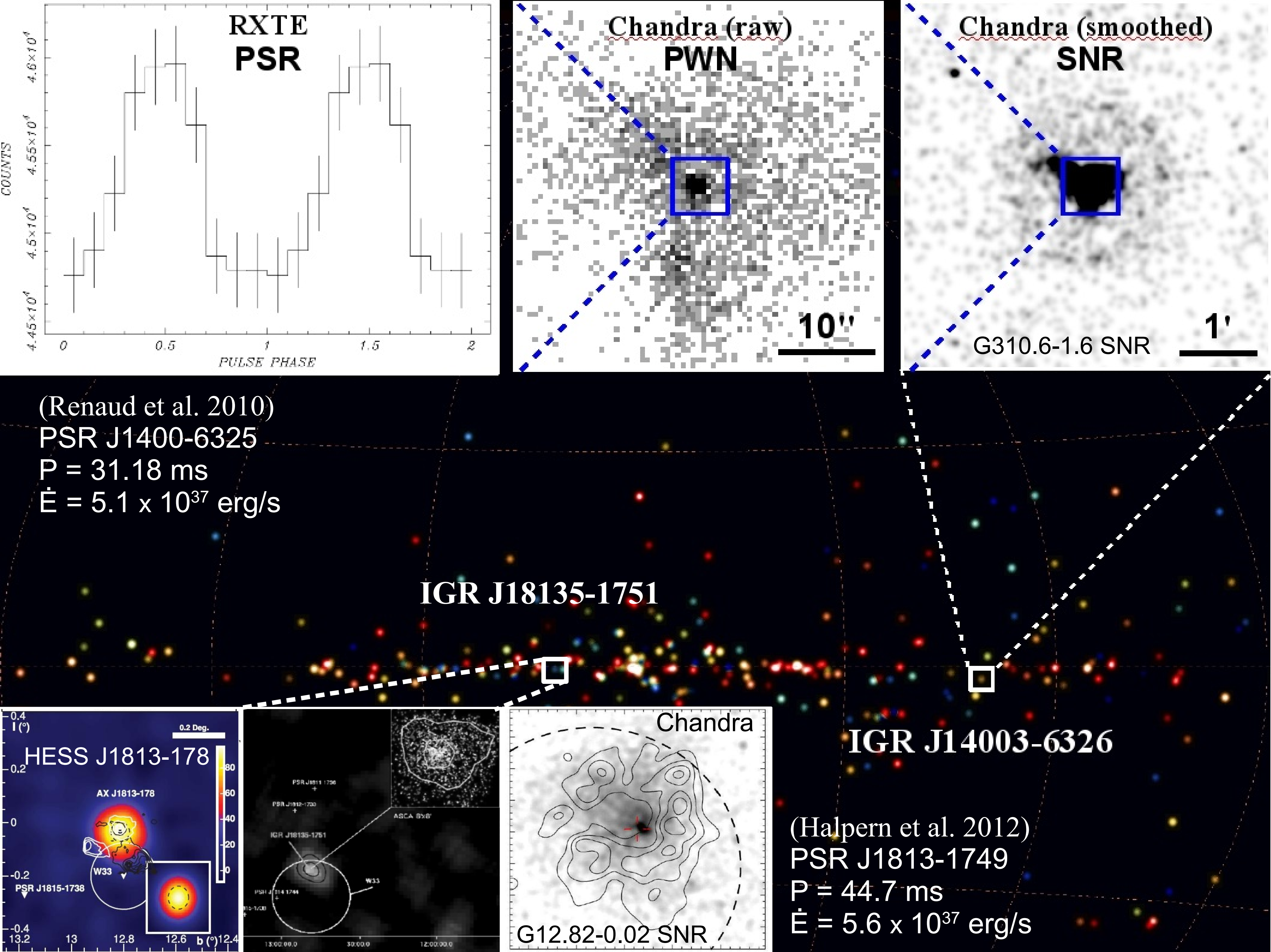


Sensitivity	XXX
Energy range	XXX
PSF	XXX
ΔE/E	XX
FoV	XXX
Timing capabilities	X
Fixed-time observations	X



Young SNRs interacting with MCs

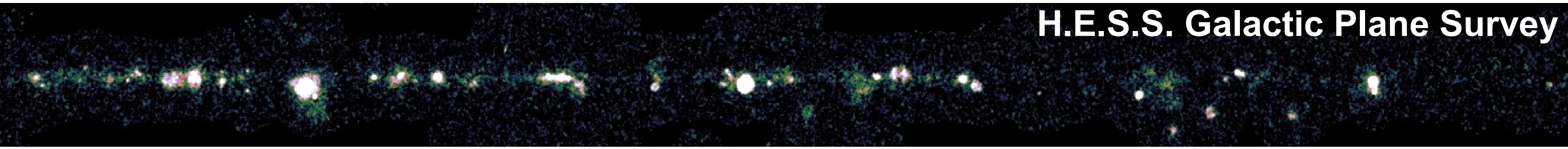
Probing the hadronic origin of γ-rays through X-rays from p-p $\rightarrow \pi^{+/-} \rightarrow e^{+/-}$?

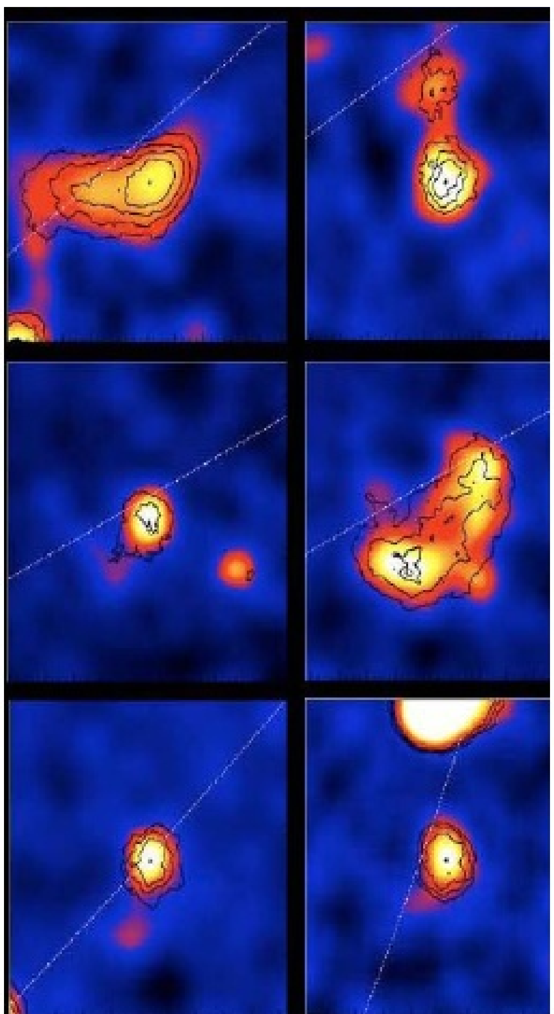


RXTE
PSR
COUNTS
PULSE PHASE
Chandra (raw)
PWN
10''
Chandra (smoothed)
SNR
G310.6-1.6 SNR
1'
(Renaud et al. 2010)
PSR J1400-6325
P = 31.18 ms
Ė = 5.1 x 10^37 erg/s
IGR J18135-1751
IGR J14003-6326
HESS J1813-178
0.2 Deg.
AX J1813-178
W33
PSR J1815-1738
IGR J18135-1751
ASCA 8x8'
Chandra
G12.82-0.02 SNR
(Halpern et al. 2012)
PSR J1813-1749
P = 44.7 ms
Ė = 5.6 x 10^37 erg/s

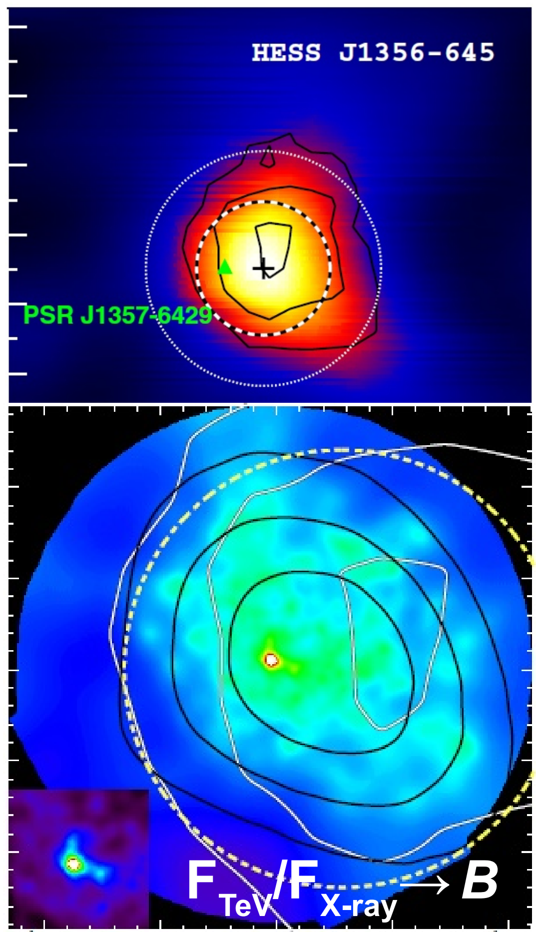
X-ray / gamma-ray synergies

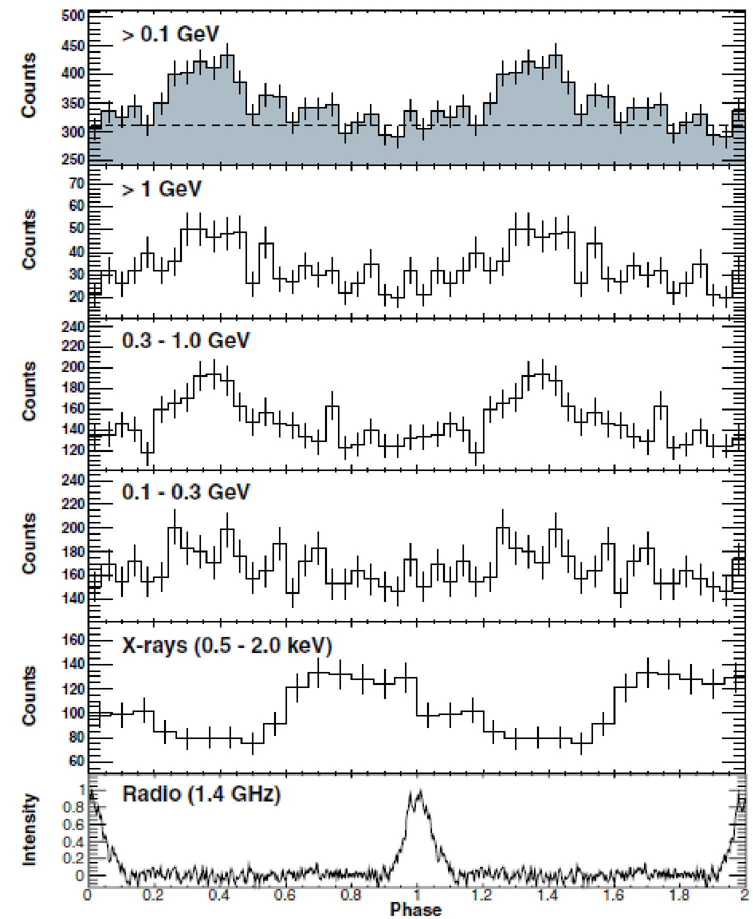
Pulsar wind nebulae *and the « dark » TeV sources*





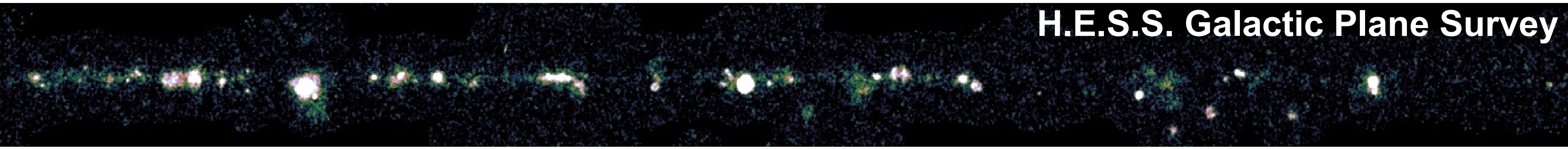
HESS J1356-645 (Abramowski et al. 2011, Lemoine-Goumard et al. 2011)

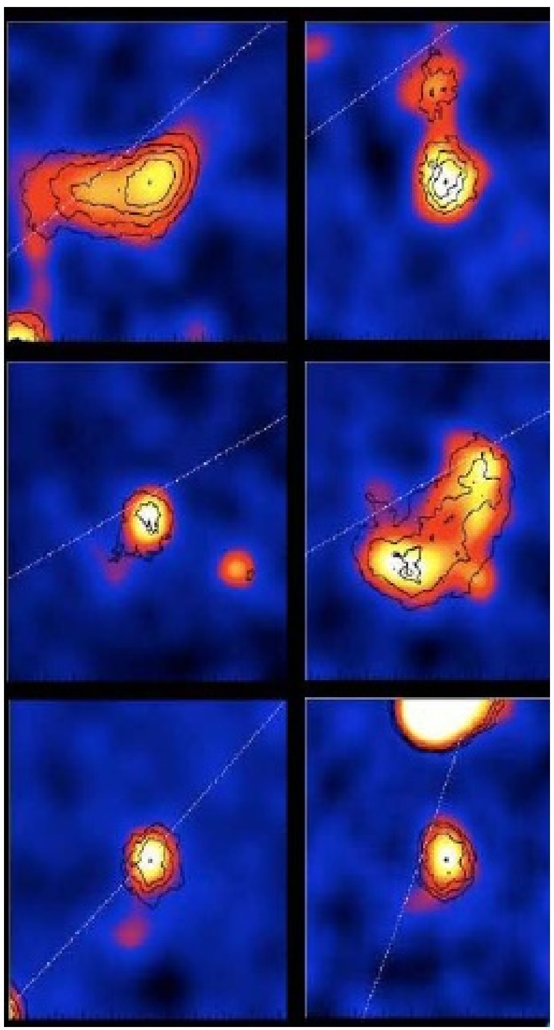




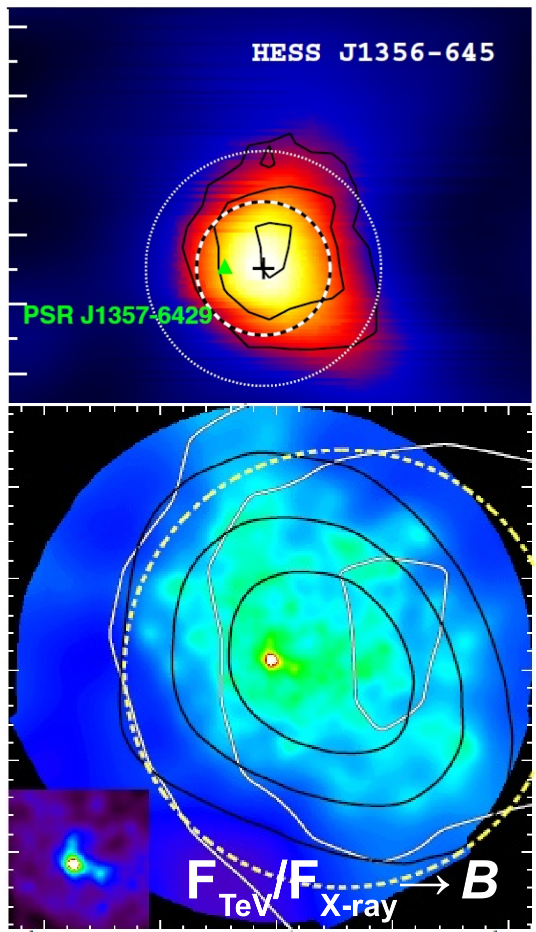
X-ray / gamma-ray synergies

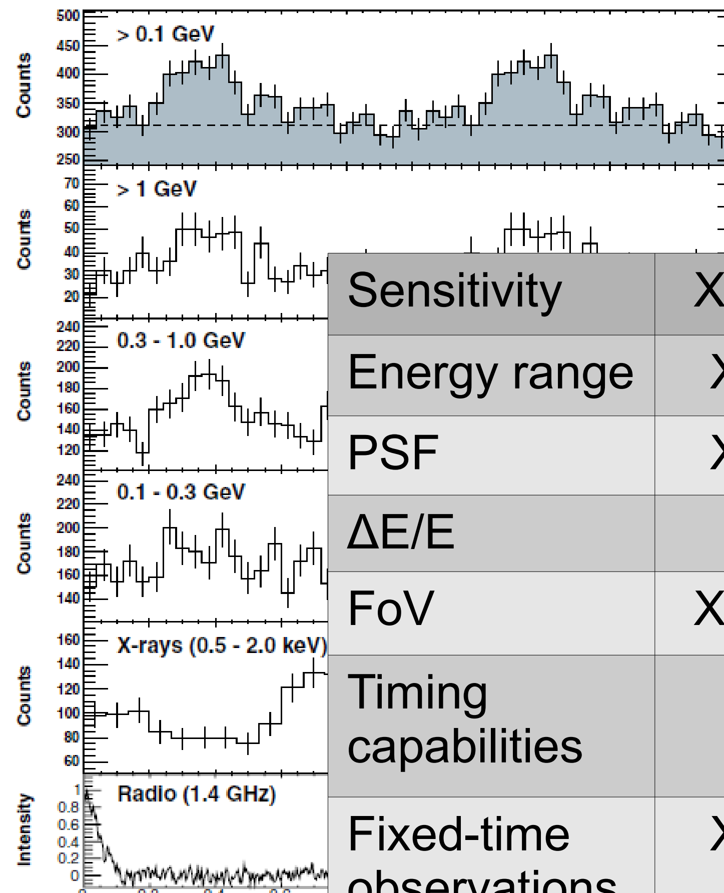
Pulsar wind nebulae *and the « dark » TeV sources*





HESS J1356-645 (Abramowski et al. 2011, Lemoine-Goumard et al. 2011)

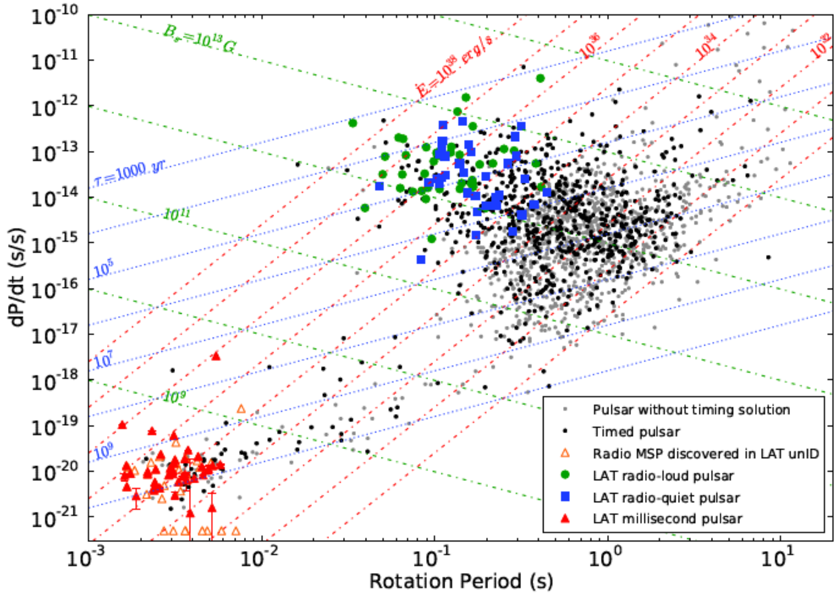


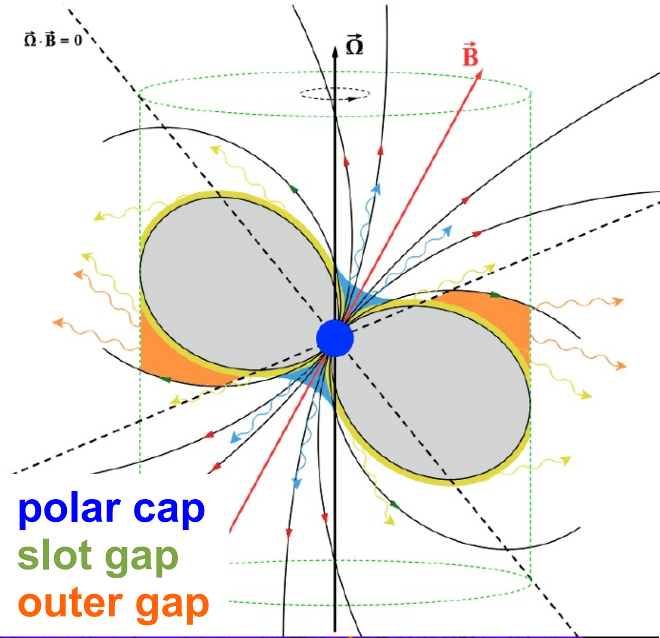


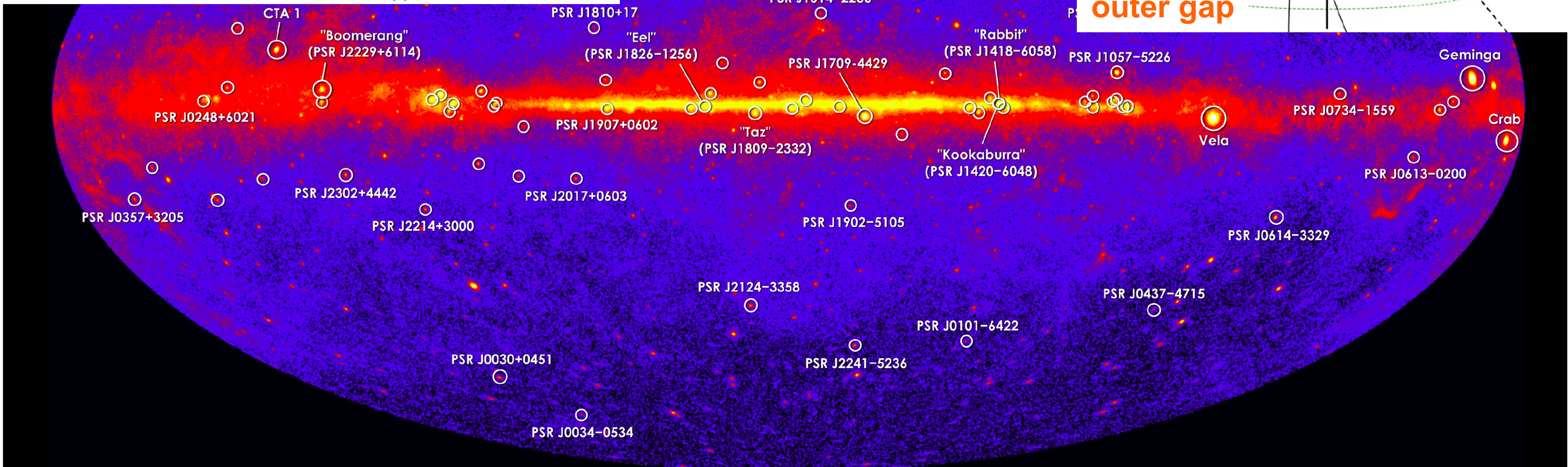
Sensitivity	XXX
Energy range	XX
PSF	XX
ΔE/E	X
FoV	XXX
Timing capabilities	X
Fixed-time observations	XX

X-ray / gamma-ray synergies

Pulsars *avec le LAT*



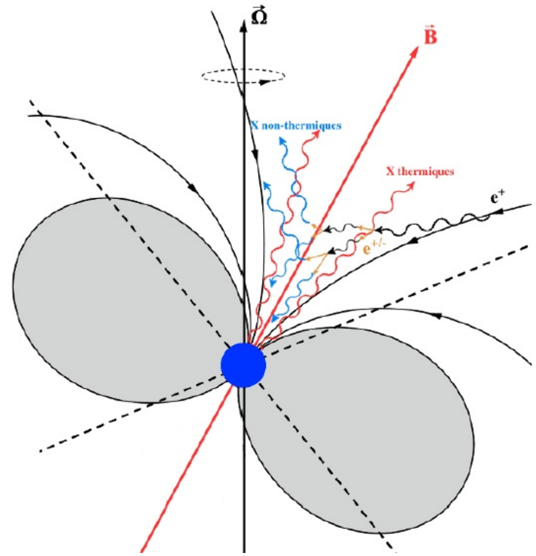


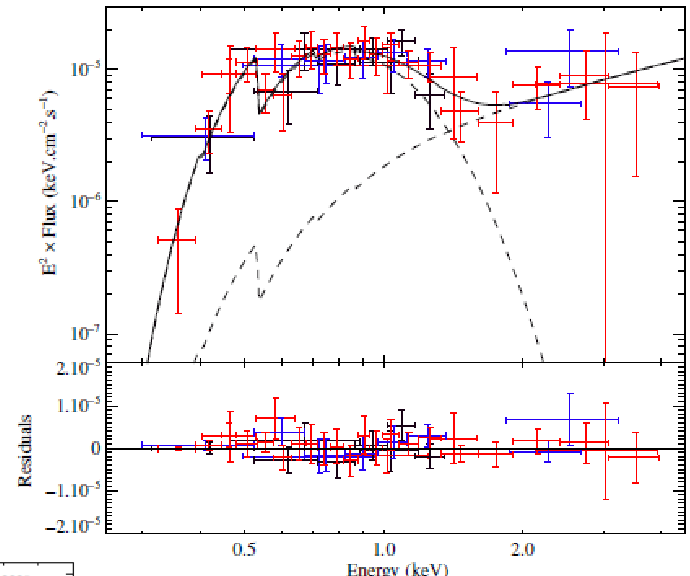


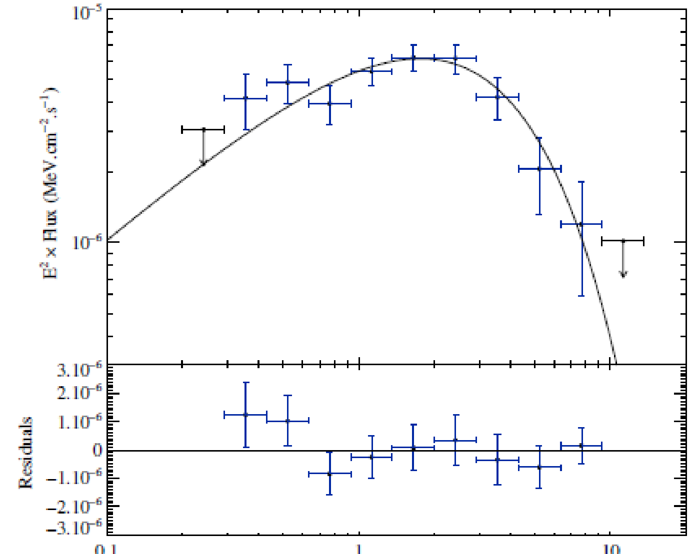
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2nd_PSR_catalog/ (Abdo et al. 2013)

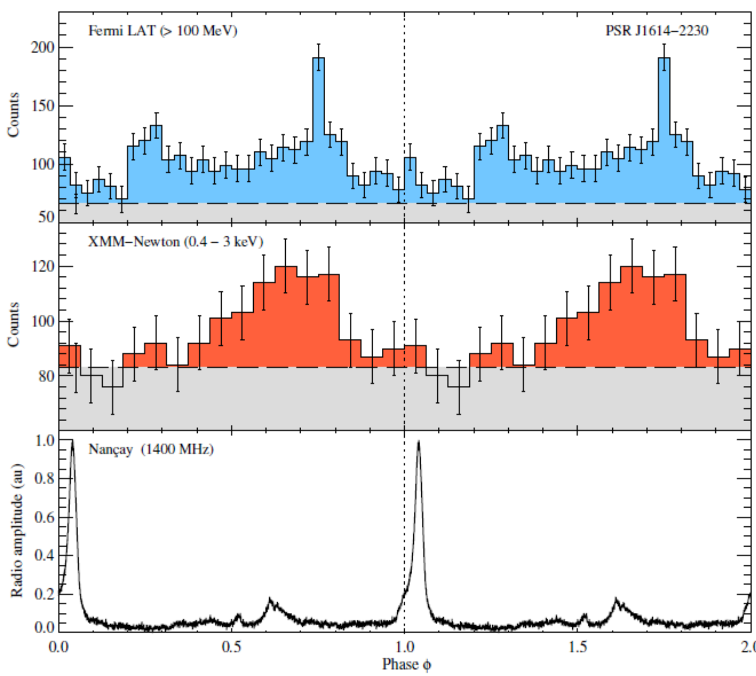
X-ray / gamma-ray synergies

Pulsars : *observations X et γ des ms PSRs*









PSR J1614-2230
(Pancrazi et al. 2012)

Origin of nonthermal X-rays...
common to the γ-ray emission?

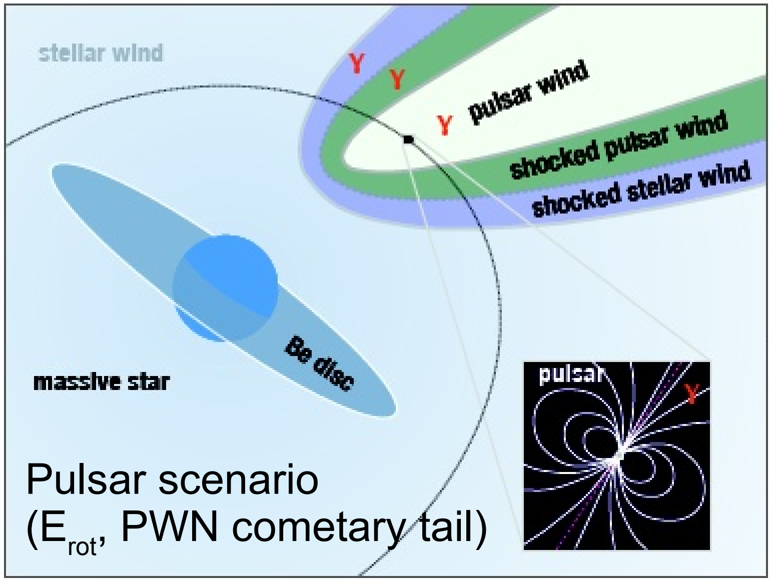
Phasogram of thermal X-rays
→ constraints on (M, R, α, ζ)
(Pancrazi PhD 2011)

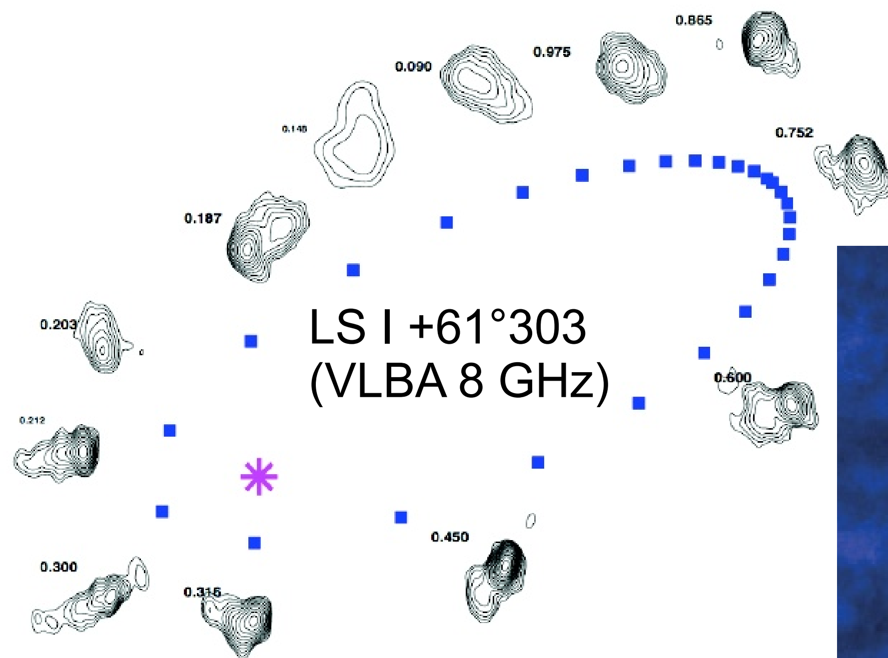
Sensitivity	XXX
Energy range	XXX
PSF	X
ΔE/E	XX
FoV	X
Timing capabilities	XXX
Fixed-time observations	XX

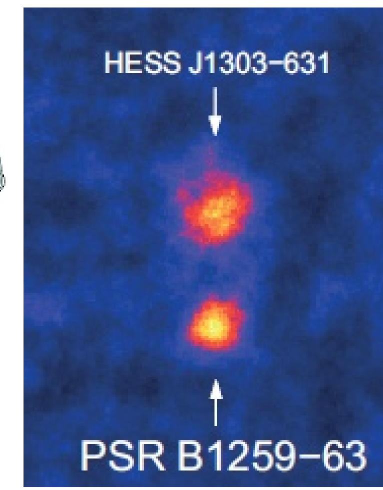
X-ray / gamma-ray synergies

Binary systems

«Gamma-ray binaries & related systems» (Dubus 2013)







<u>Gamma-ray binaries</u>

→ TeV point-like, peak in νF_ν > MeV

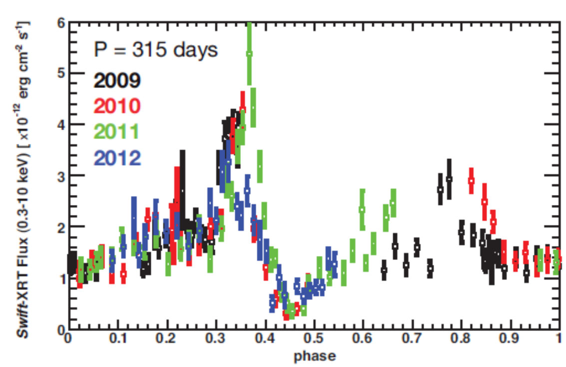
→ modulated mwl emission on $\tau_{orbital}$

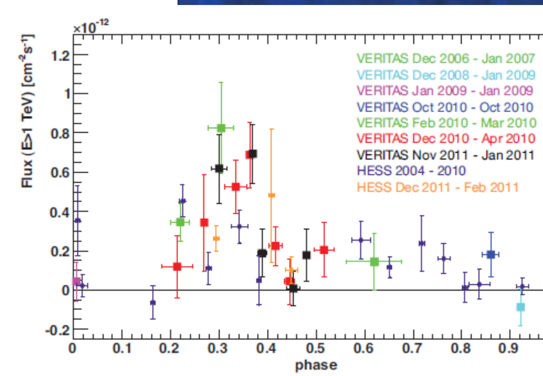
→ extended structure in radio

→ 5 systems known so far :

PSR B1259-63, LS 5039, LS I +61°303[(x)]
HESS J0632+057[(*)], 1FGL J1018.6-5856

[(x)] magnetar-like burst found in X-rays
[(*)] orbital period discovered in X-rays

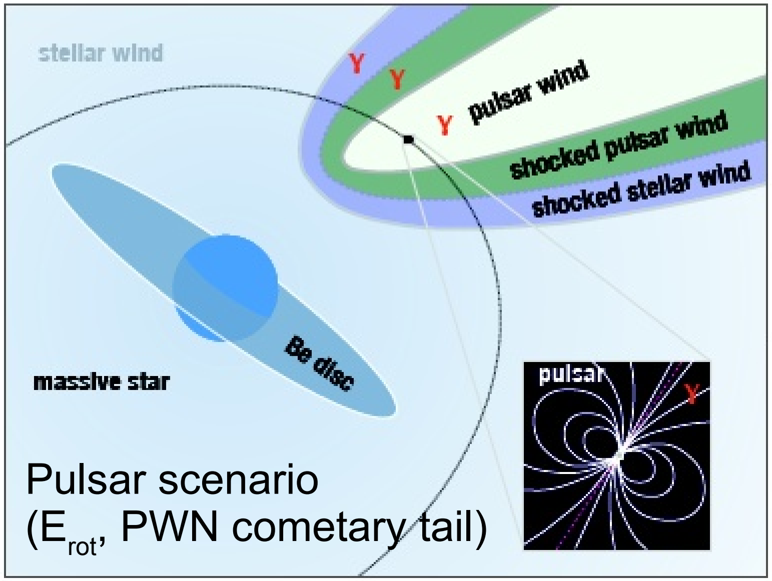




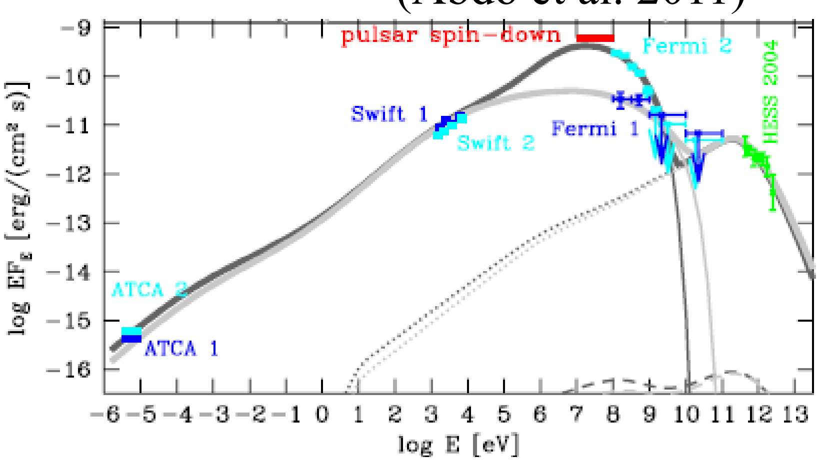
HESS J0632+057

X-ray / gamma-ray synergies

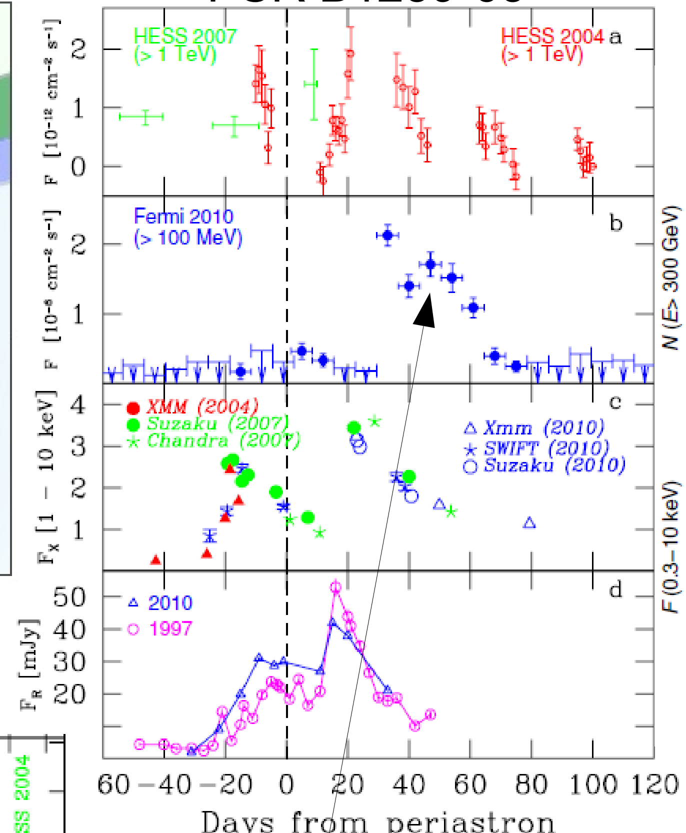
Binary systems



(Abdo et al. 2011)

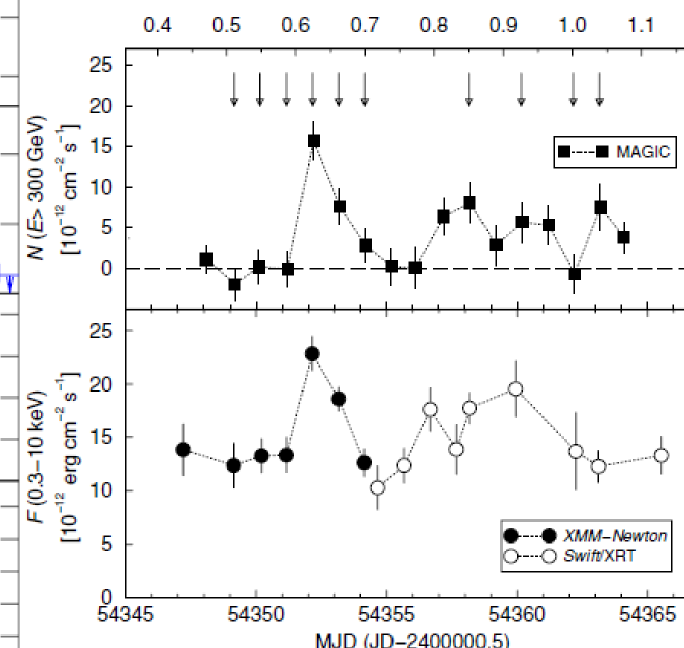


PSR B1259-63



Episodic event ?
Crab-like flare ?

LS I +61°303
(Anderhub et al. 2009)



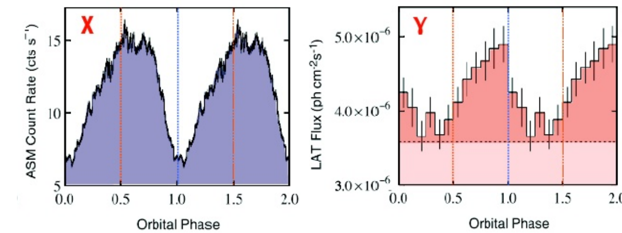
X-ray/VHE correlation

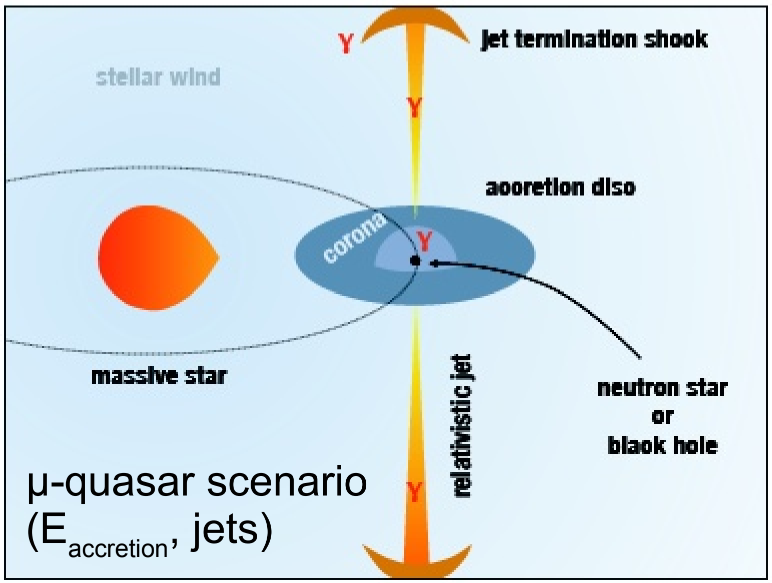
↓

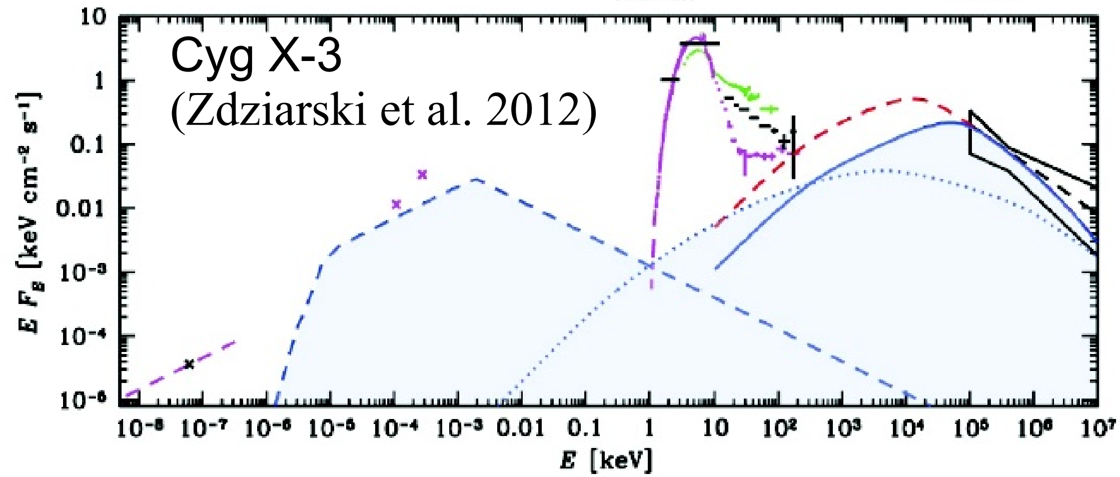
same electron population emitting SC and IC ?
(see Acciari et al. 2011)

X-ray / gamma-ray synergies

Binary systems

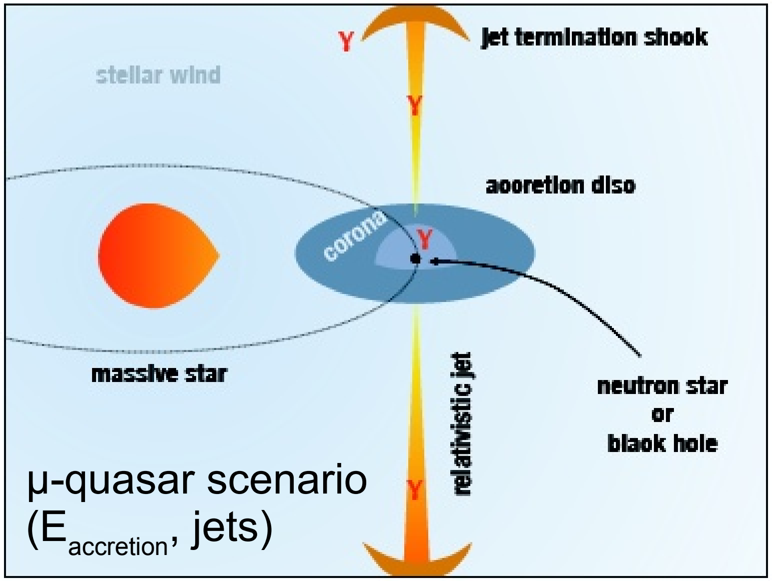


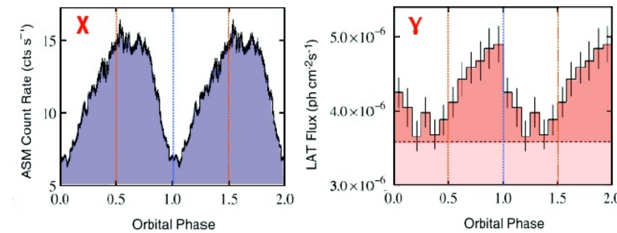


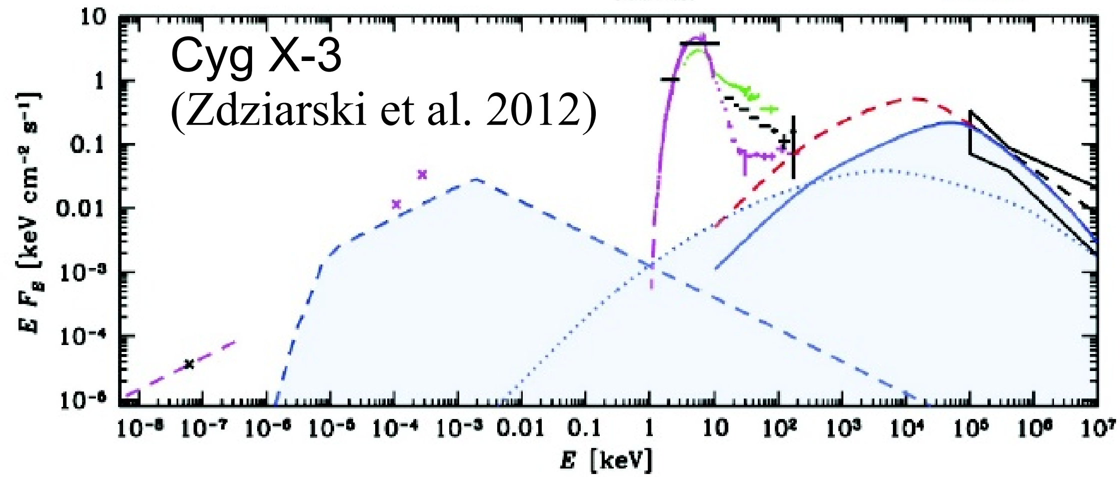


X-ray / gamma-ray synergies

Binary systems







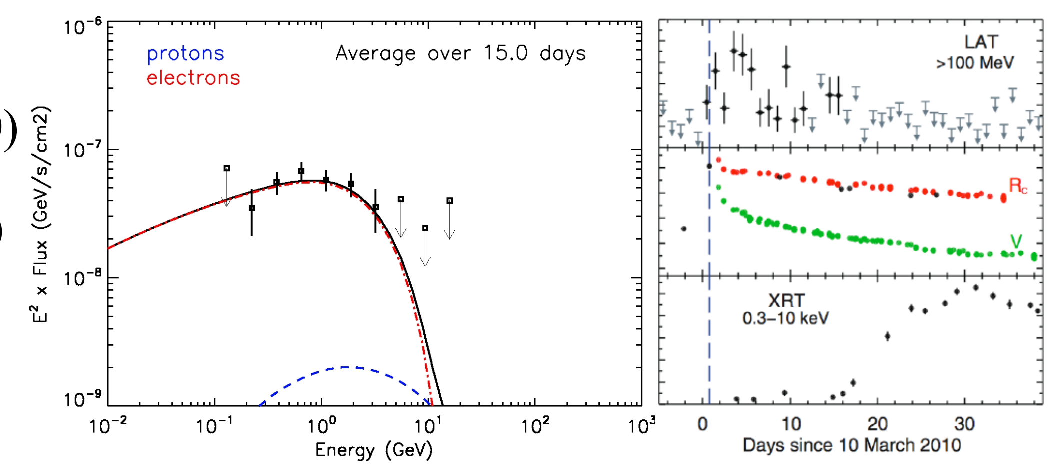
Other binary systems detected in gamma-rays :

– **colliding wind binaries** (η Car, Abdo et al. 2010)

– **novae** (Martin & Dubus 2013, Cheung et al. 2013)

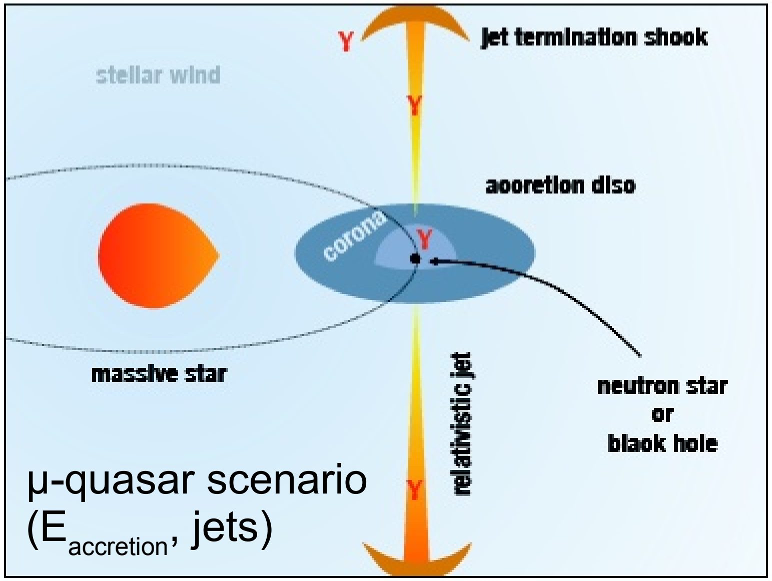
Scaled-down / fast-forward version of SNRs ?

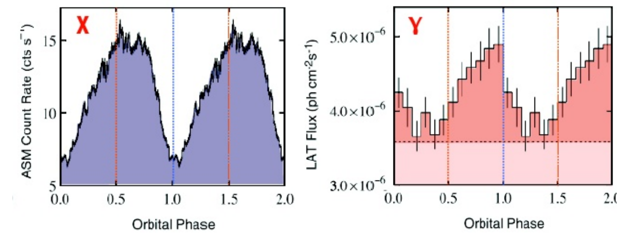
X-ray observations to constrain :
1- hydrodynamics of ejecta in complex CBM
2- how much material is swept-up and injected

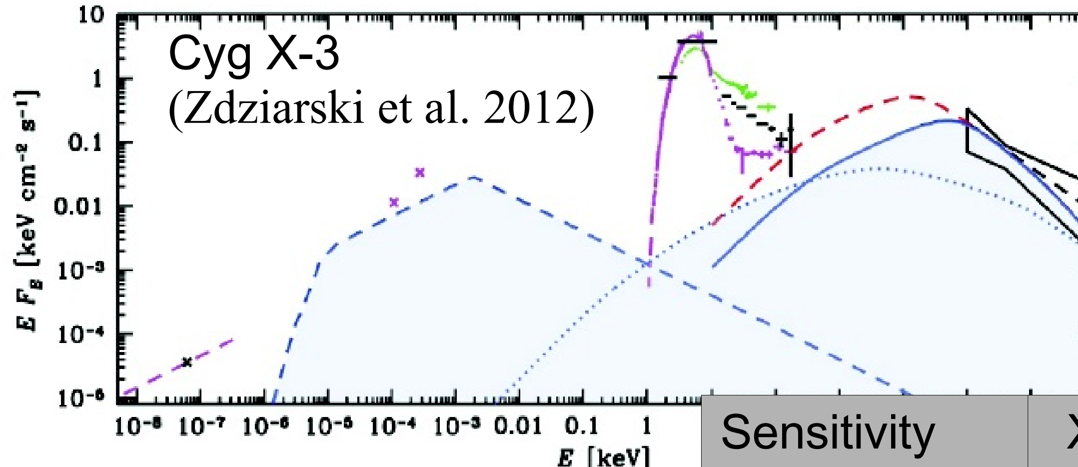


X-ray / gamma-ray synergies

Binary systems







Sensitivity	XXX
Energy range	XXX
PSF	X
ΔE/E	XX
FoV	X
Timing capabilities	XX
Fixed-time observations	XXX

Other binary systems detected in gamma-rays :

– **colliding wind binaries** (η Car, Abdo et al. 2010)

– **novae** (Martin & Dubus 2013, Cheung et al. 2013)

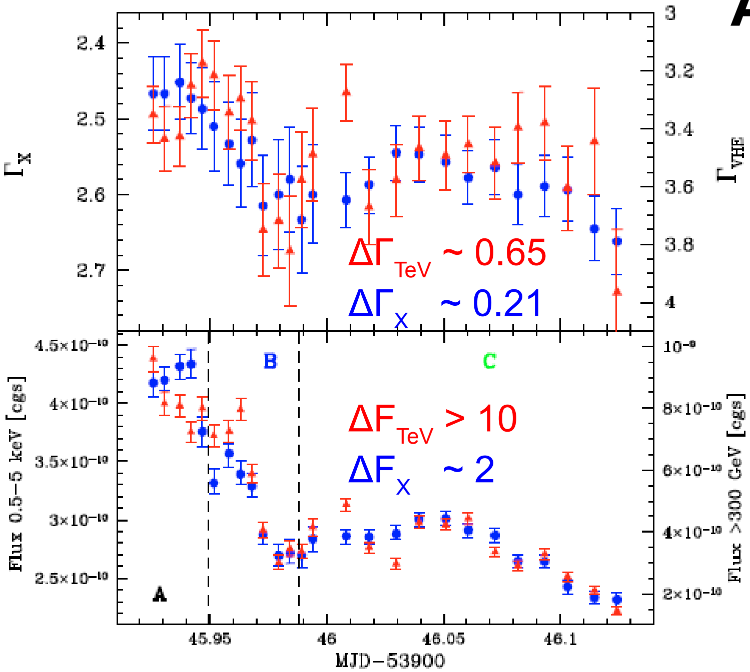
Scaled-down / fast-forward version of SNRs ?

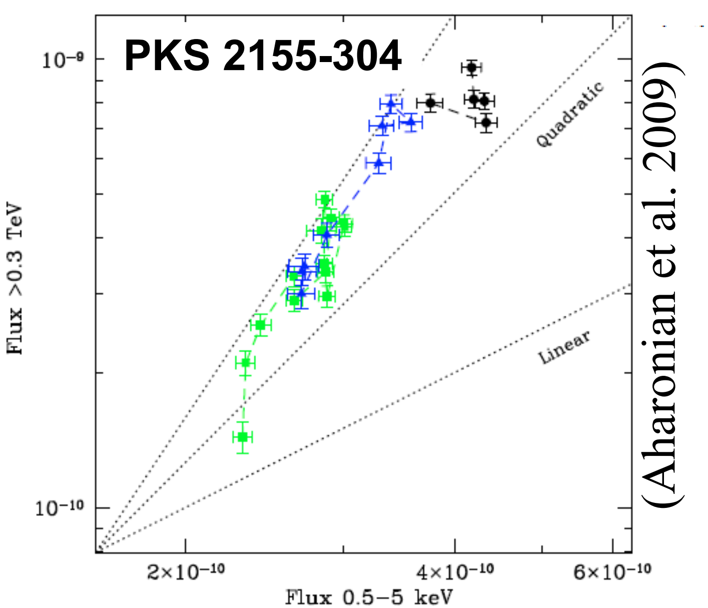
X-ray observations to constrain :

1- hydrodynamics of ejecta in complex CBM
2- how much material is swept-up and injected

X-ray / gamma-ray synergies

Active Galactic Nuclei



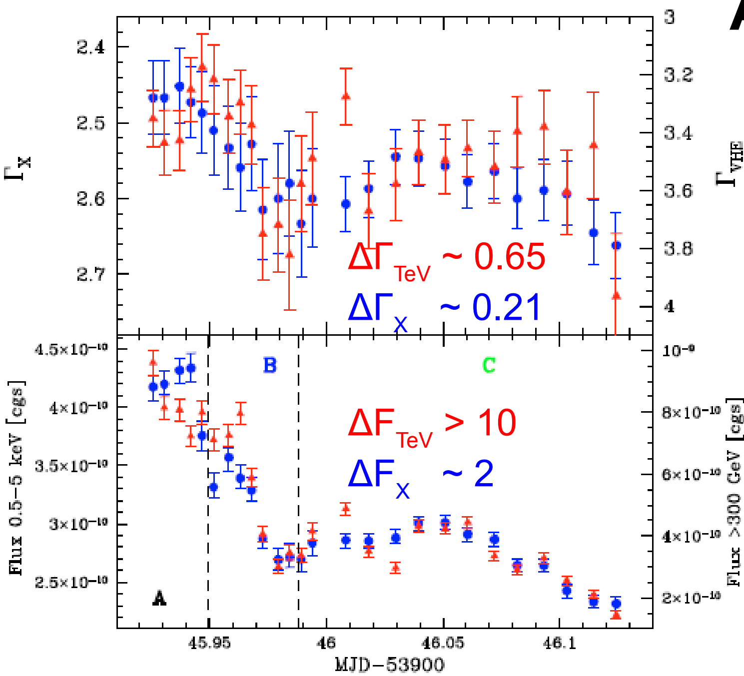


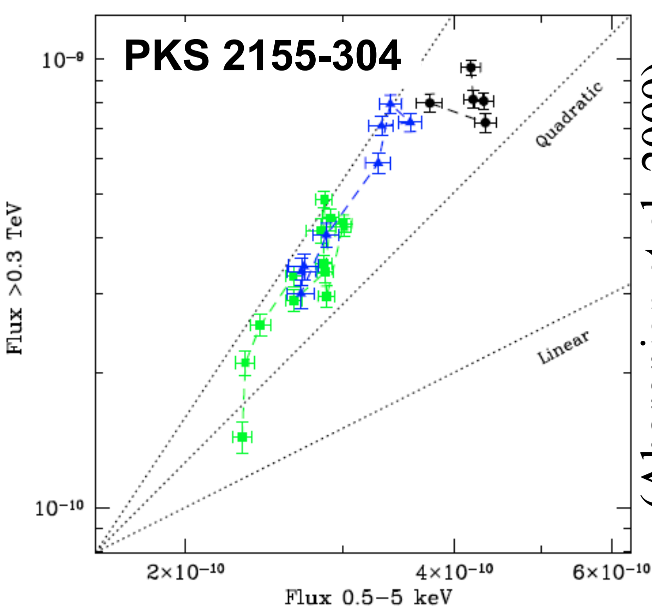
(Aharonian et al. 2009)

Strong X-TeV correlation
→ one-zone SSC, but :
$F_{TeV} \alpha F_X^{\alpha}$ with **α > 2**
→ **multi-zone SSC**

X-ray / gamma-ray synergies

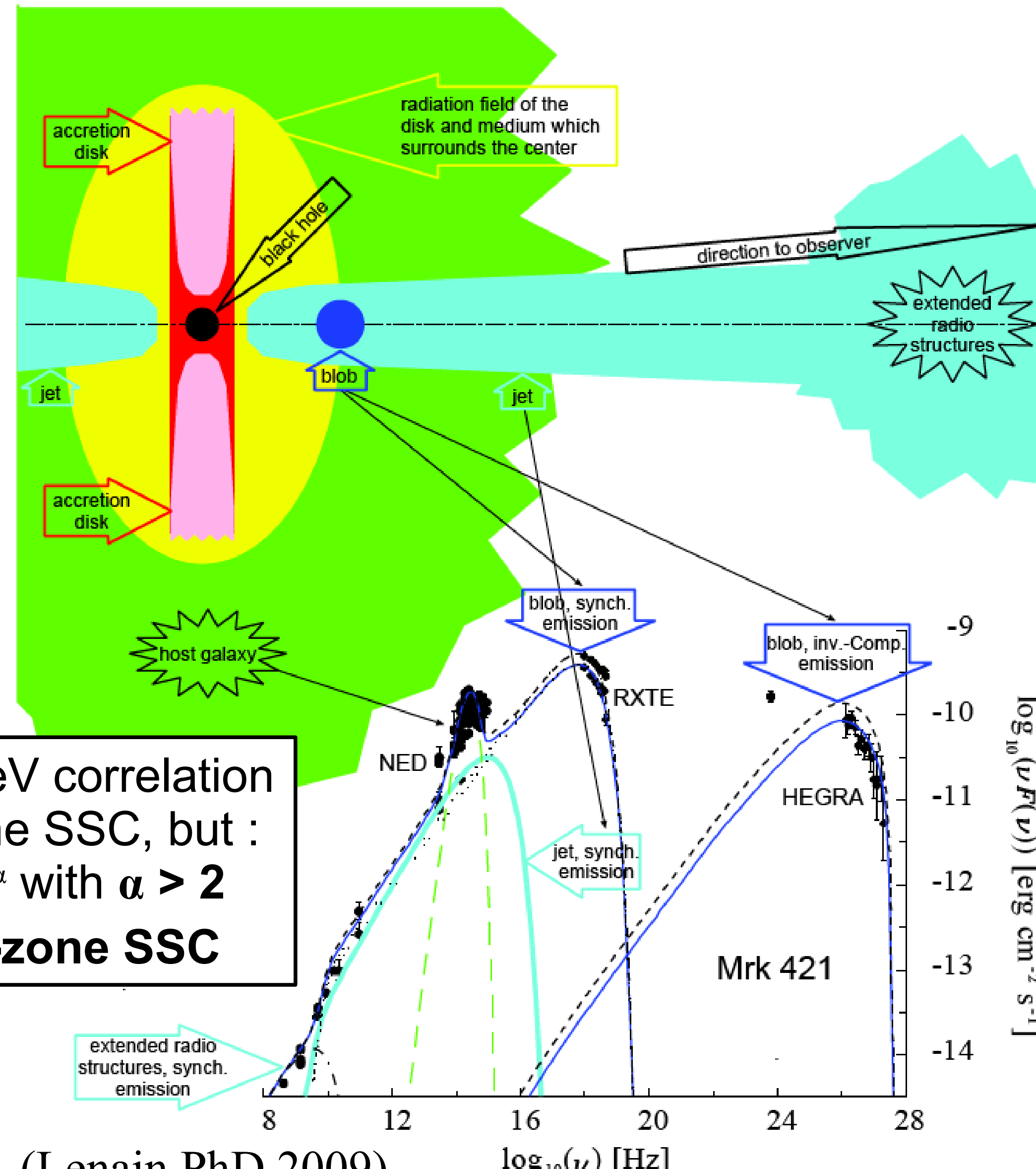
Active Galactic Nuclei





(Aharonian et al. 2009)

Strong X-TeV correlation
→ one-zone SSC, but :
F_{TeV} α F_X^{α} with **α > 2**
→ **multi-zone SSC**

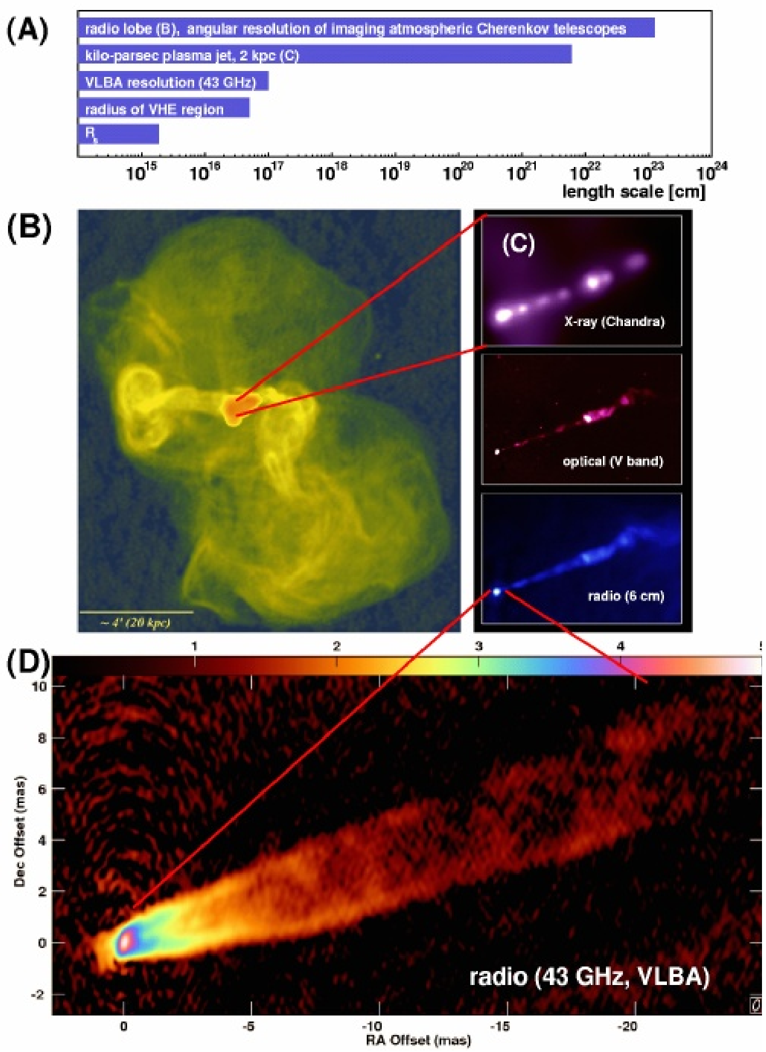


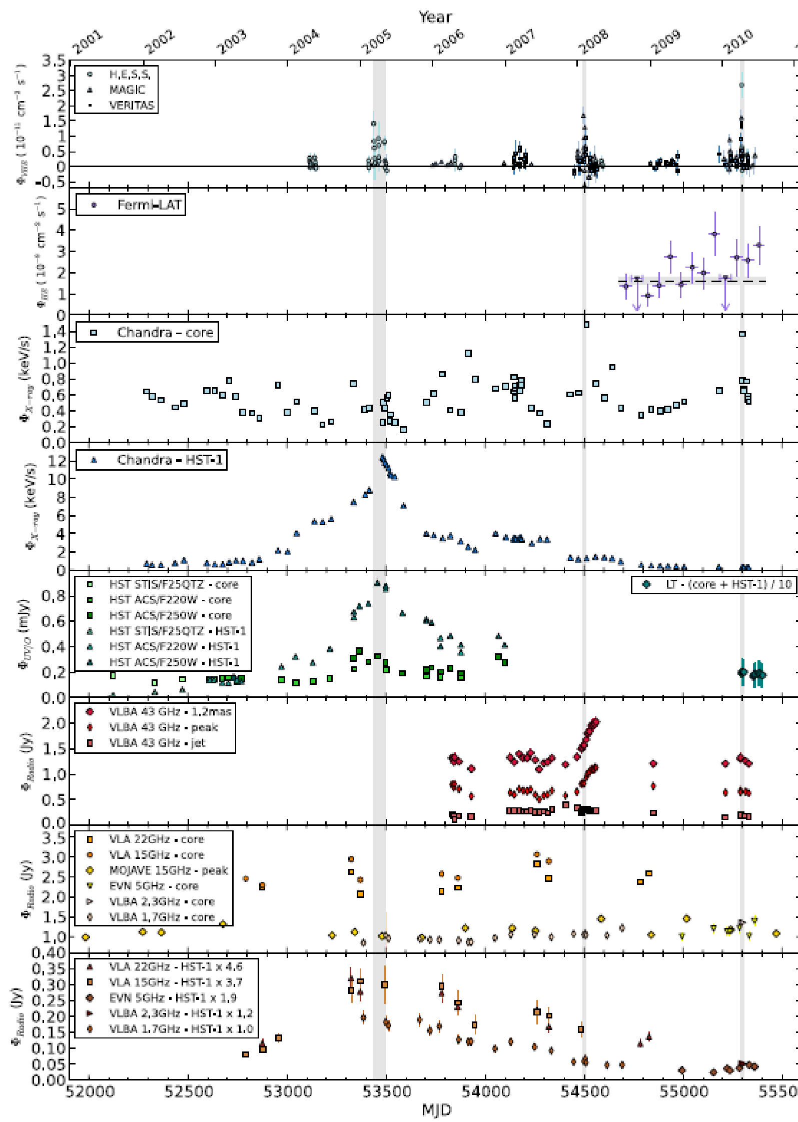
(Lenain PhD 2009)

X-ray / gamma-ray synergies

Active Galactic Nuclei

Origin of the M87 2005/2008/2010 flares (Acciari et al. 2009, Abramowski et al. 2012)



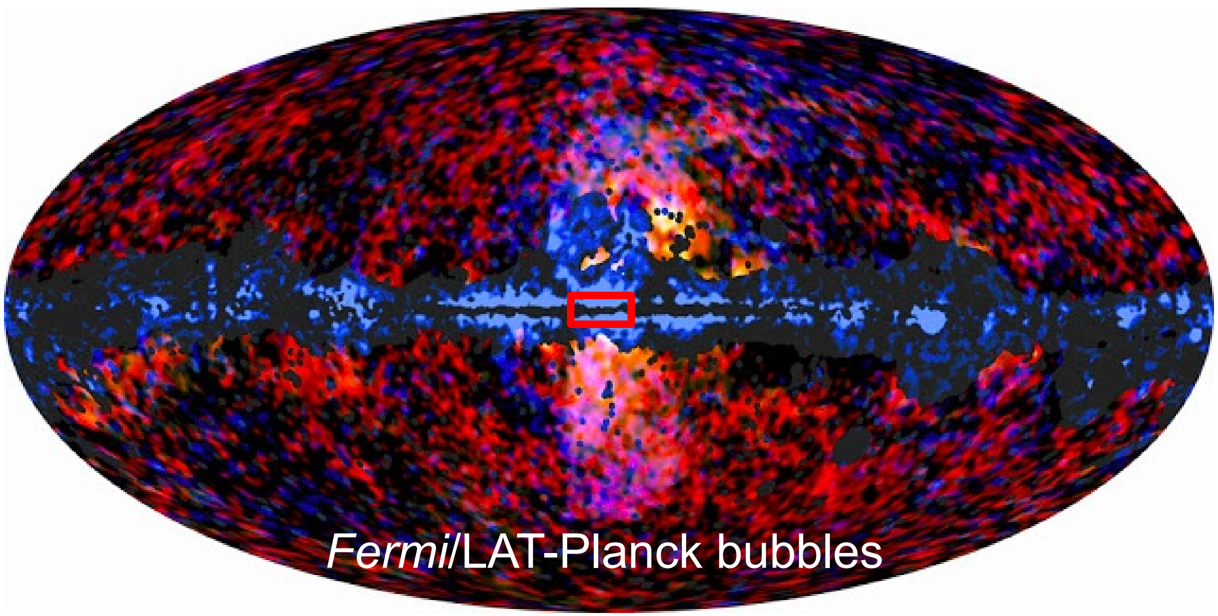


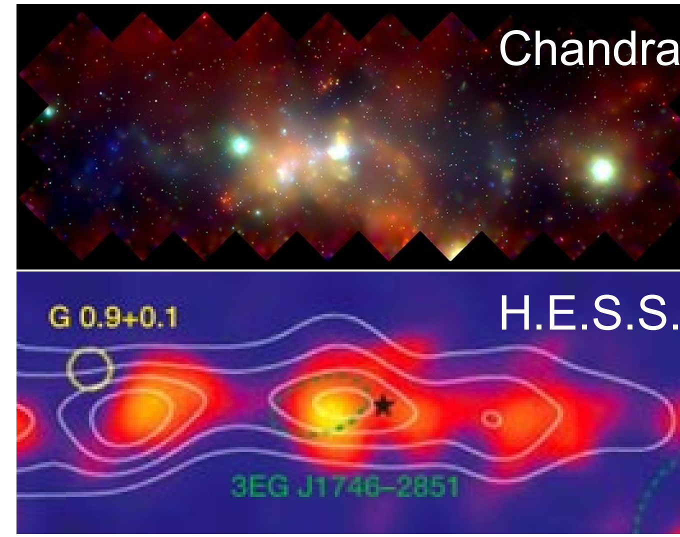
τ_{TeV} ~ day

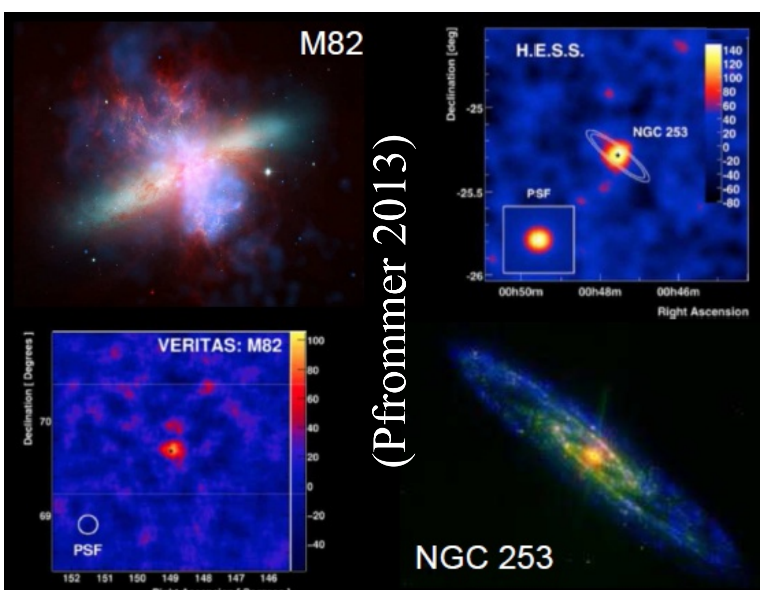
Sensitivity	XX
Energy range	XXX
PSF	X
ΔE/E	X
FoV	X
Timing capabilities	XX
Fixed-time observations	XXX

X-ray / gamma-ray synergies

Other galaxies… and the Galactic Center!







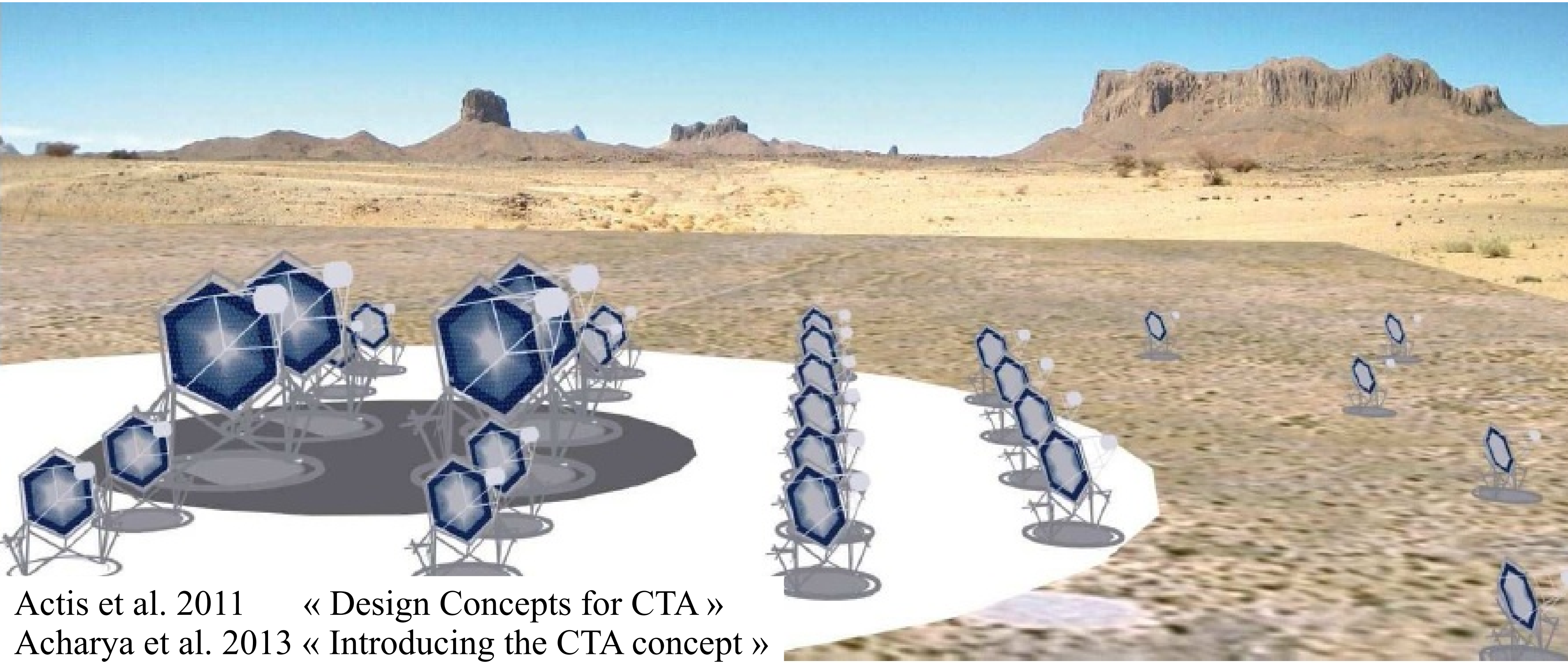
Everything at once ! Potential γ-ray emitters lying in ~1deg^2 :

– SMBH (G2 gas cloud)
– MCs and stellar clusters
– Radio filaments
– SNRs, PWNe
– Magnetar (SGR 1745-2900)
– Binaries

Sensitivity	XXX
Energy range	XXX
PSF	XXX
ΔE/E	XXX
FoV	XXX
Timing capabilities	XXX
Fixed-time observations	XXX

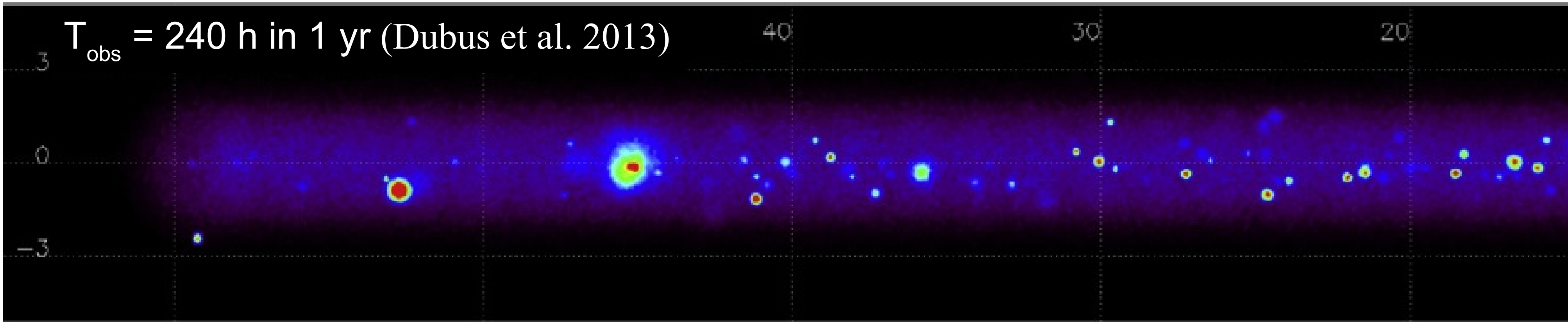
The CTA project

Higher sensitivity	→ 1000 sources? Pop. studies	mCrab, 5σ, 50h @TeV
Wider energy coverage	Spectro(-imaging) capabilities	30 GeV – 300 TeV
Better angular resolution	Source identification, morphology	~3 arcmin @TeV
Better energy resolution	Cutoffs & spectral features	rms < 10% @TeV
Wider field-of-view	Extended sources & survey	6 – 8 degrees

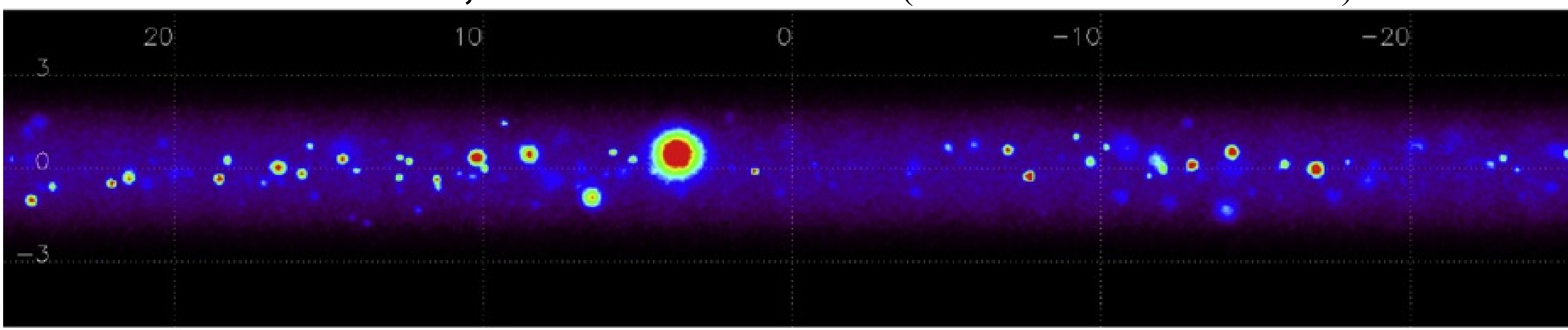


Actis et al. 2011 « Design Concepts for CTA »
Acharya et al. 2013 « Introducing the CTA concept »

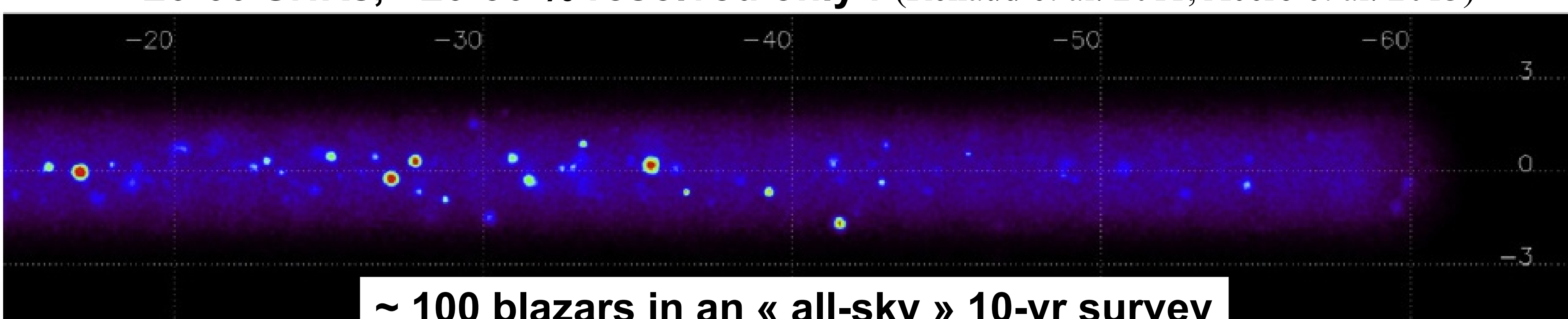
CTA surveys



~ 500 PWNe, ~30-50 % confused ! (de Ona-Wilhelmi et al. 2013)



~ 20-60 SNRs, ~20-30 % resolved only ! (Renaud et al. 2011, Acero et al. 2013)



~ 100 blazars in an « all-sky » 10-yr survey

Conclusion

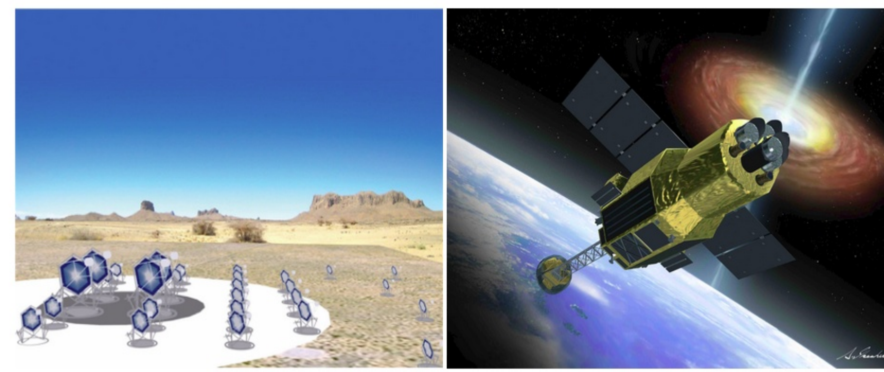
	SNRs	PWNe	PSRs	Binaries	AGNs
Sensitivity	XXX	XXX	XXX	XXX	XX
Energy range	XXX	XX	XXX	XXX	XXX
PSF	XXX	XX	X	X	X
ΔE/E	XX	X	XX	XX	X
FoV	XXX	XXX	X	X	X
Timing capabilities	X	X	XXX	XX	XX
Fixed-time observations	X	XX	XX	XXX	XXX

66th Fujihara Seminar

X-raying the Gamma-Ray Universe
-- CTA-X-ray LINK Meeting --

4 (Mon) - 6 (Wed) Nov. 2013
Yumoto Fujiya Hotel, Hakone-Yumoto, Kanagawa-ken, Japan

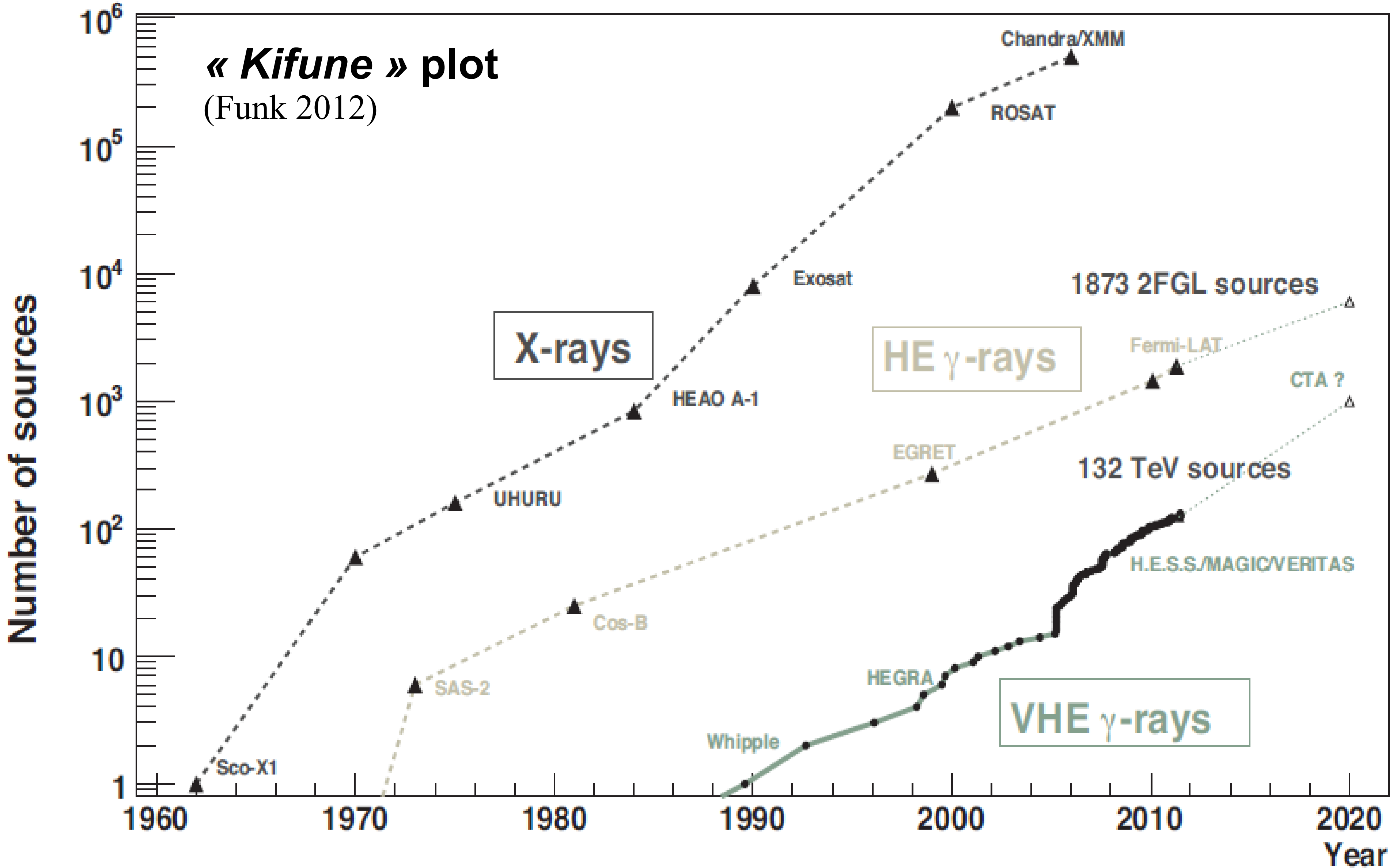
Top | Overview | Registration | Program | Participants | Venue



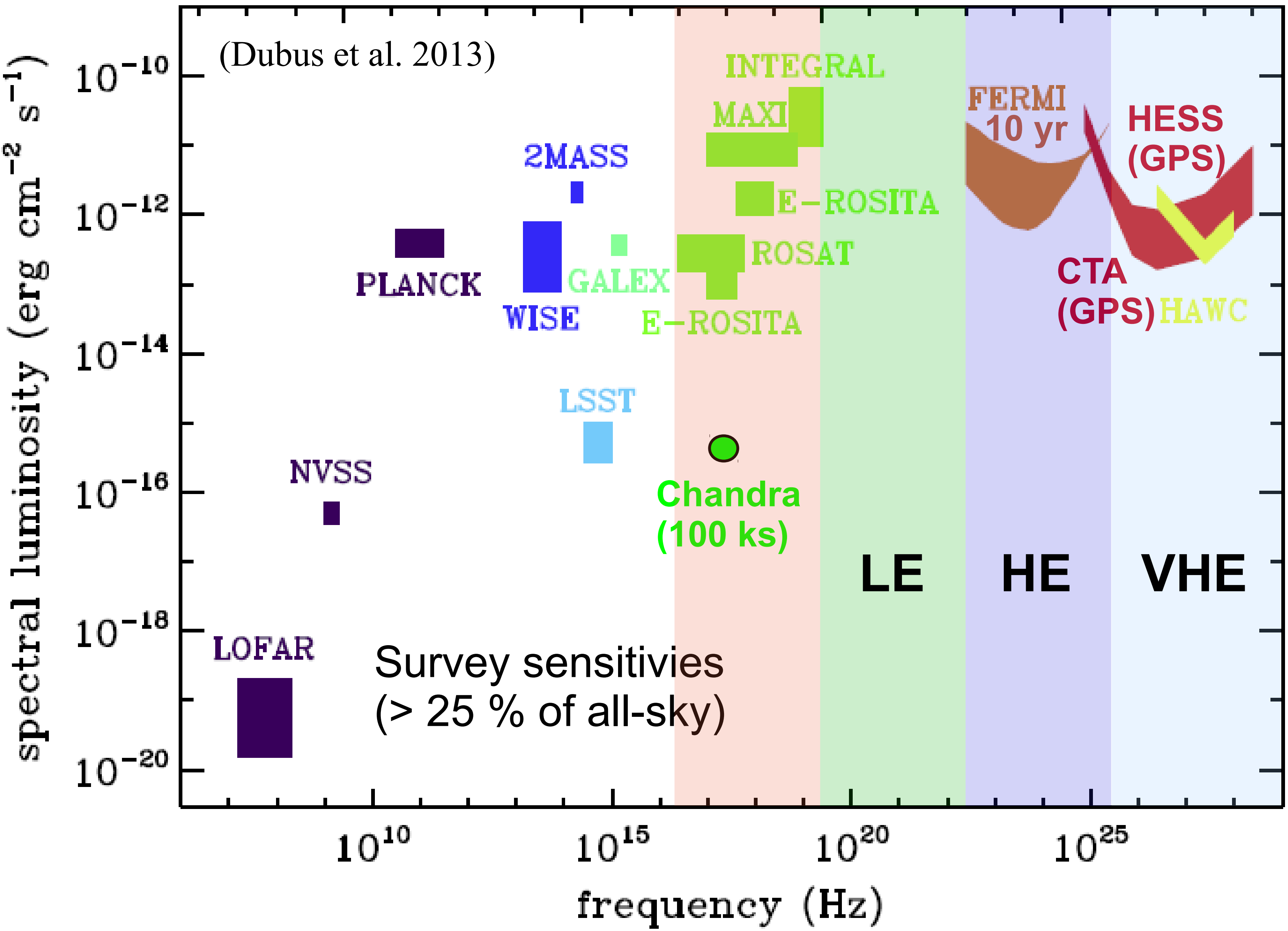
Requirements for the next X-ray instrument :

– High collective area over an energy range as broad as possible
– FoV (grasp) is critical for studying extended Galactic HE/VHE sources
– Operating mode (ToO response) optimized to allow fast pointing on alert

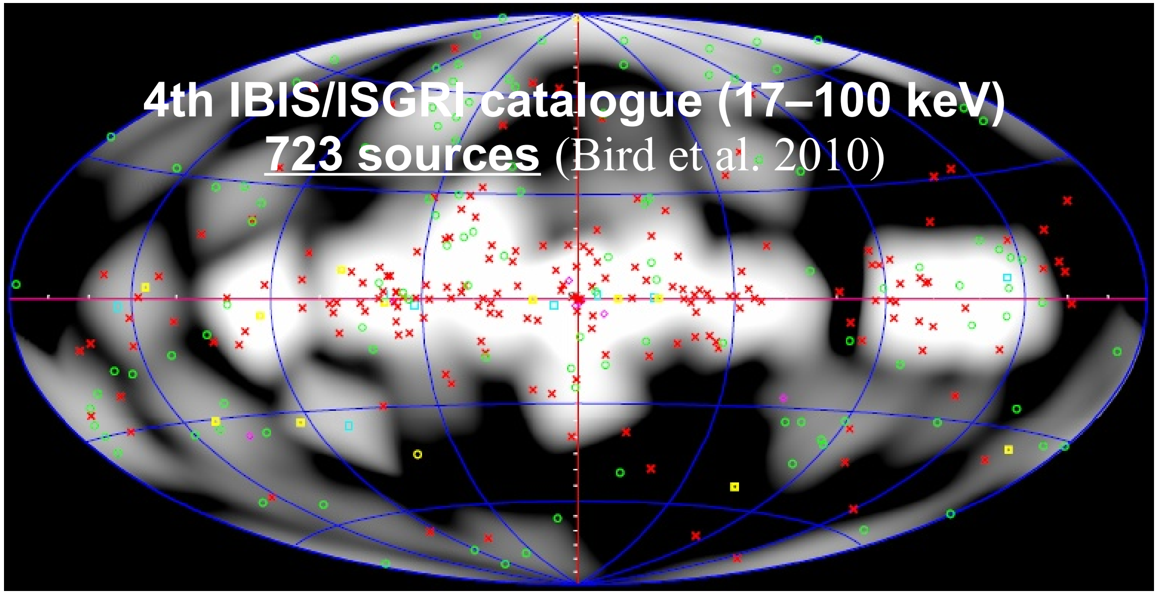
X-rays & gamma-rays in a nutshell

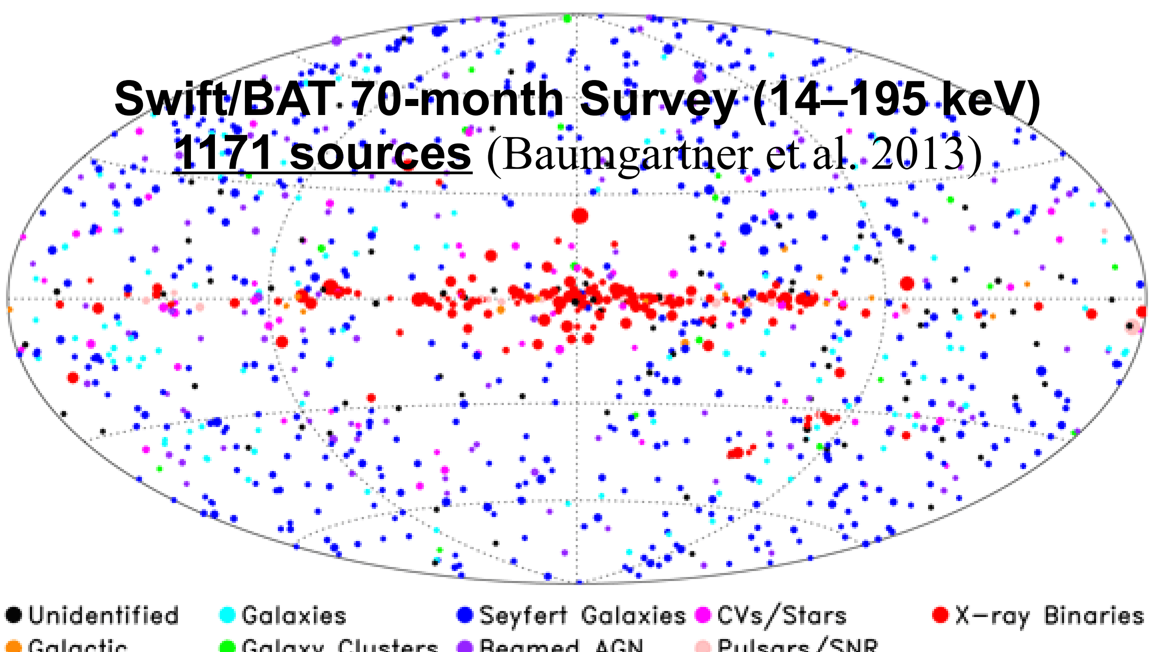


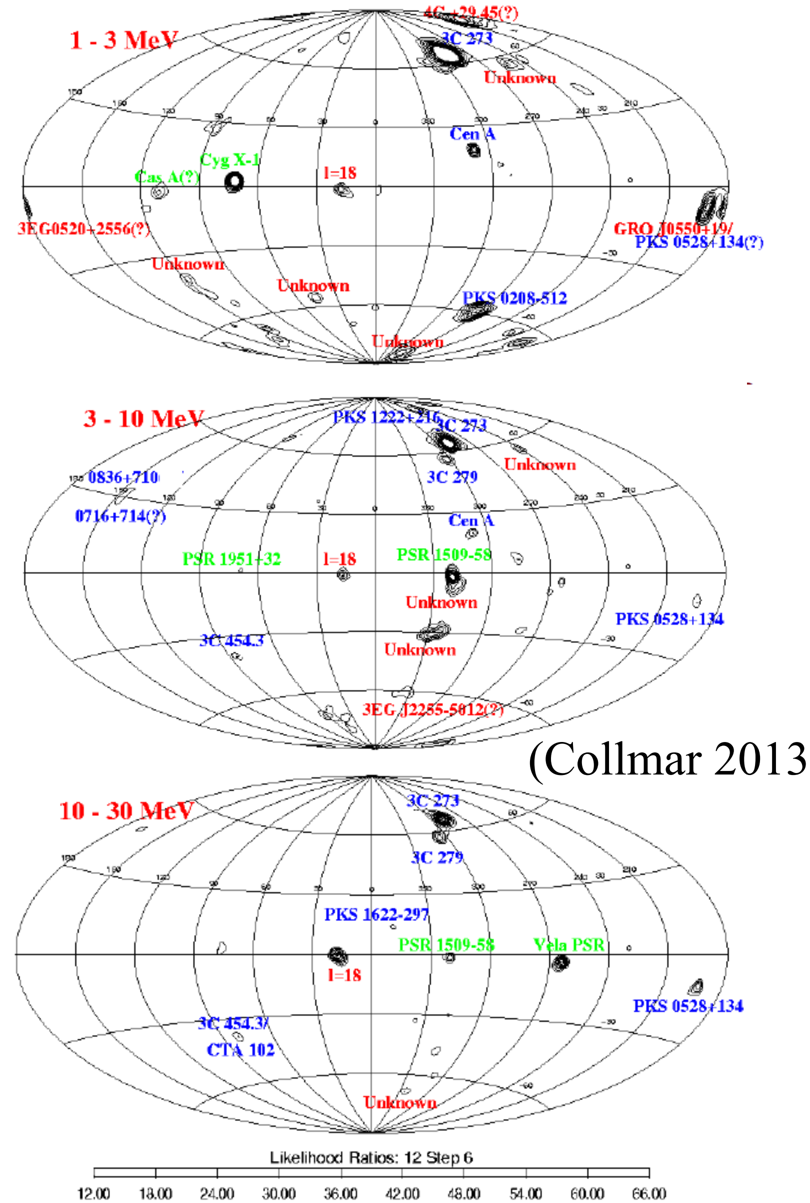
X-rays & gamma-rays in a nutshell



LE sky from *Swift*, *INTEGRAL*, *GRO*/COMPTEL



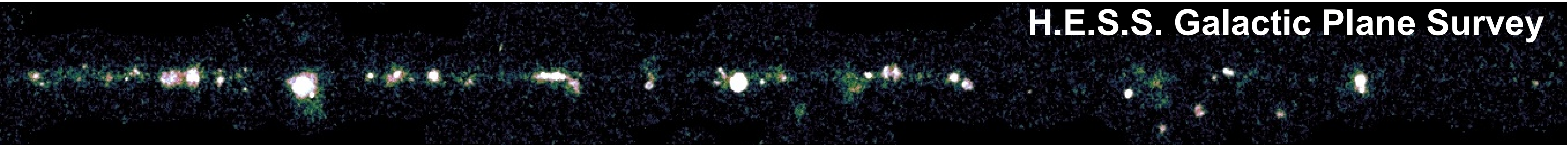


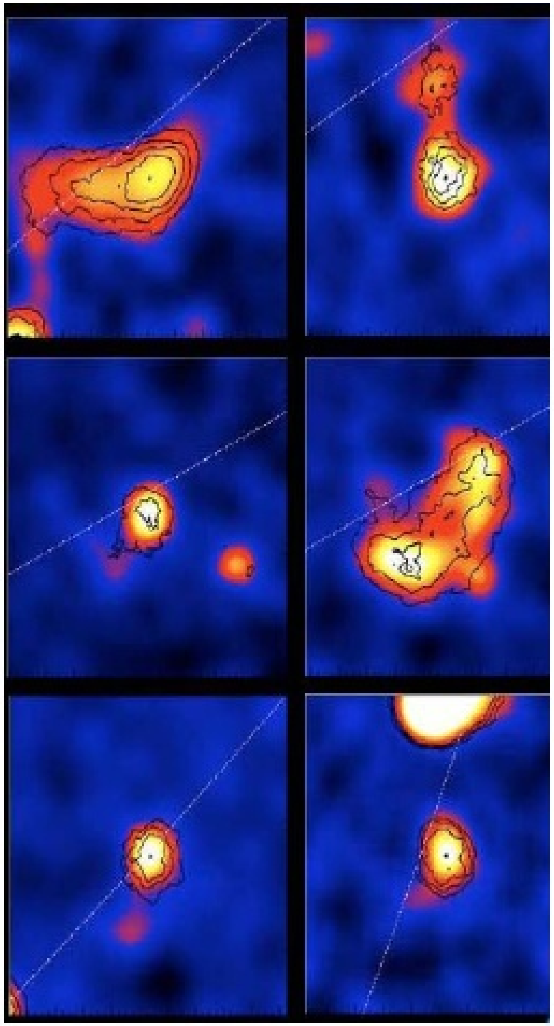


COMPTEL 9-yr all-sky → 45 sources

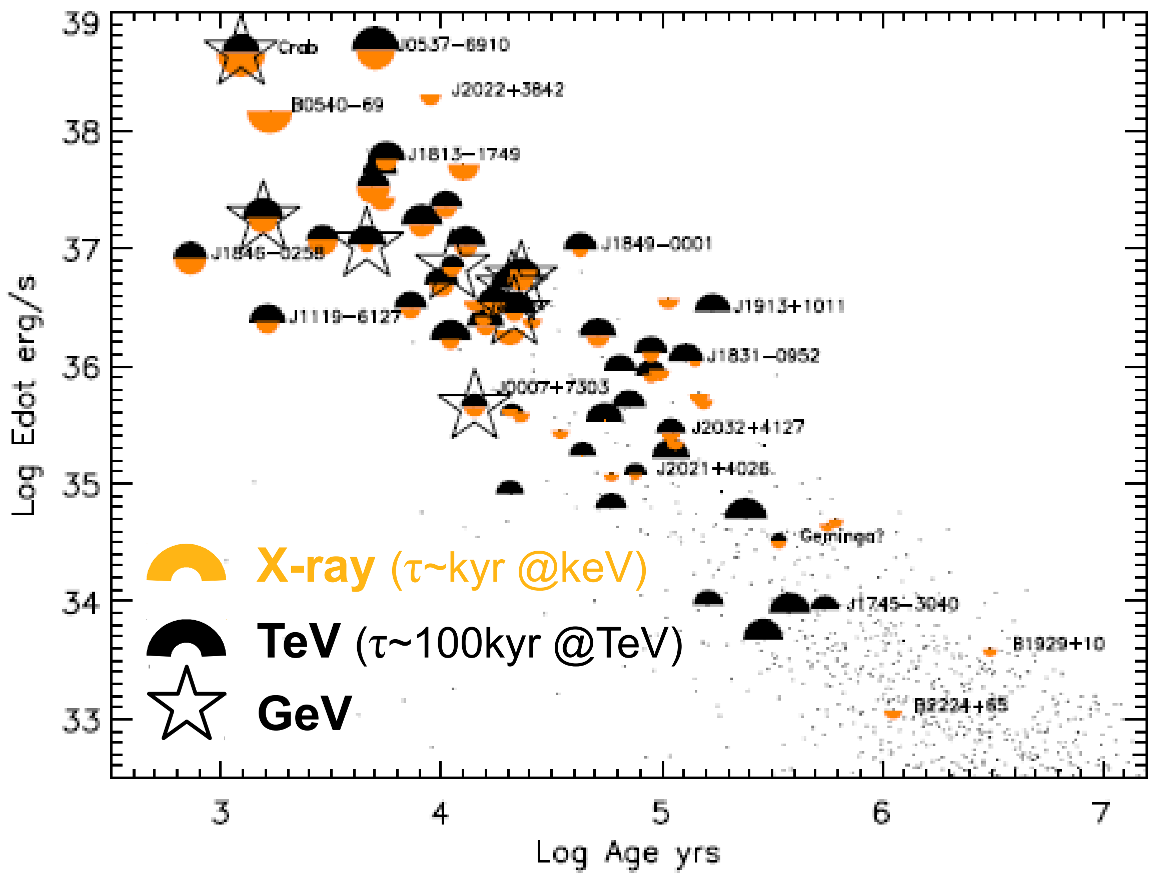
X-ray / gamma-ray synergies

Pulsar wind nebulae *and the « dark » TeV sources*





30+ TeV PWNe & candidates from middle-aged (~10^4 y) PSRs



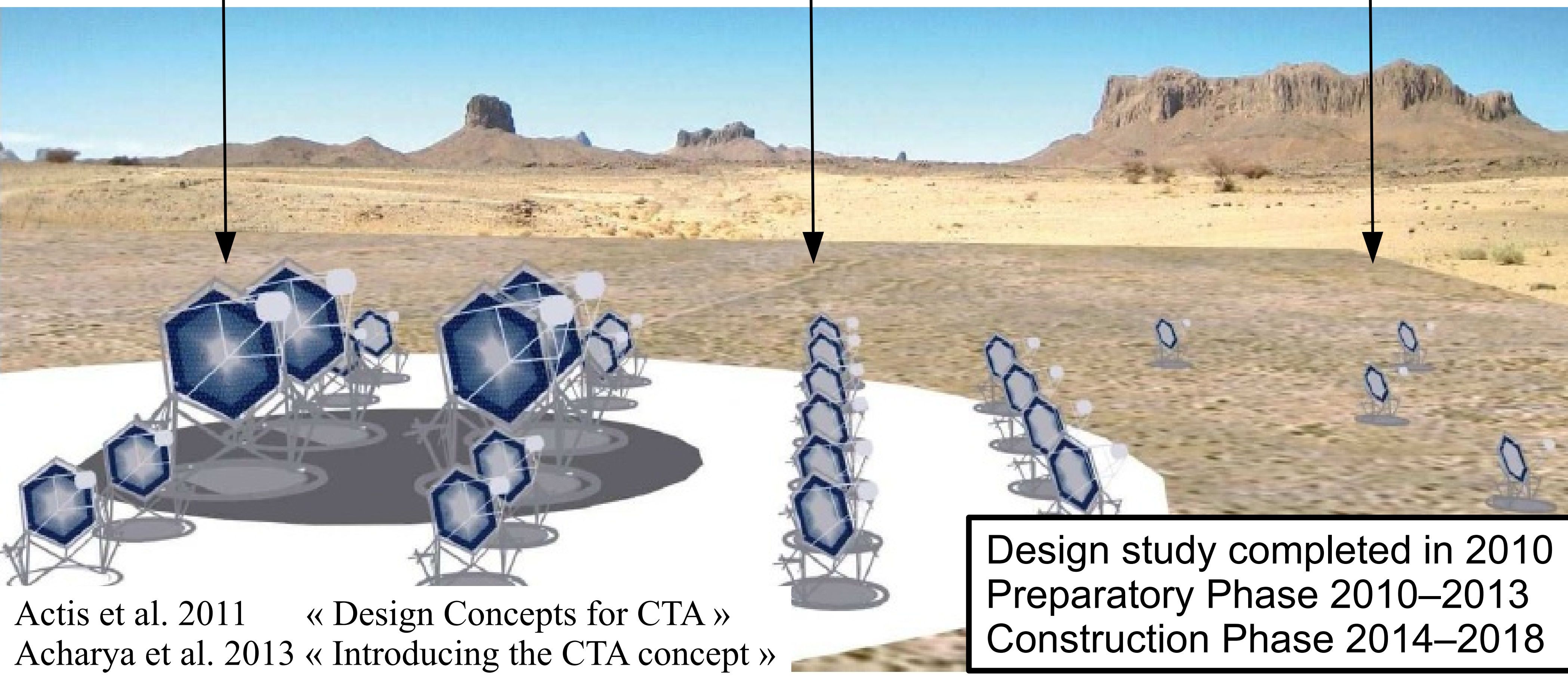
(Kargaltsev, Rangelov & Pavlov 2013)

The CTA project

LSTs (a few)
Low-energy section
energy threshold
of ~ 20–30 GeV
20-30 m telescopes

MSTs (~25)
Medium energies
mcrab sensitivity
~100 GeV–10 TeV
10-15 m telescopes

SSTs (~70)
High-energy section
~10 km^2 area at
multi-TeV energies
5-8 m telescopes



Design study completed in 2010
Preparatory Phase 2010–2013
Construction Phase 2014–2018

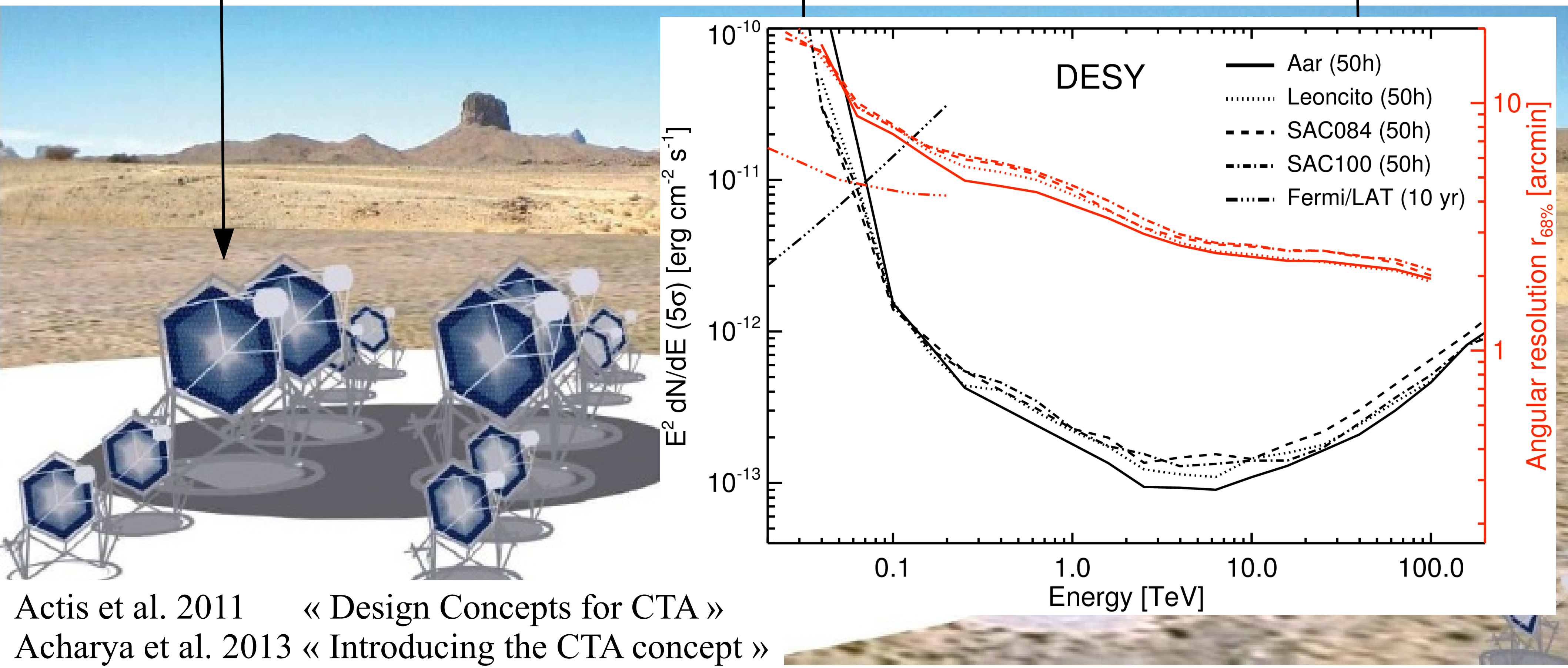
Actis et al. 2011 « Design Concepts for CTA »
Acharya et al. 2013 « Introducing the CTA concept »

The CTA project

LSTs (a few)
Low-energy section
energy threshold
of ~ 20–30 GeV
20-30 m telescopes

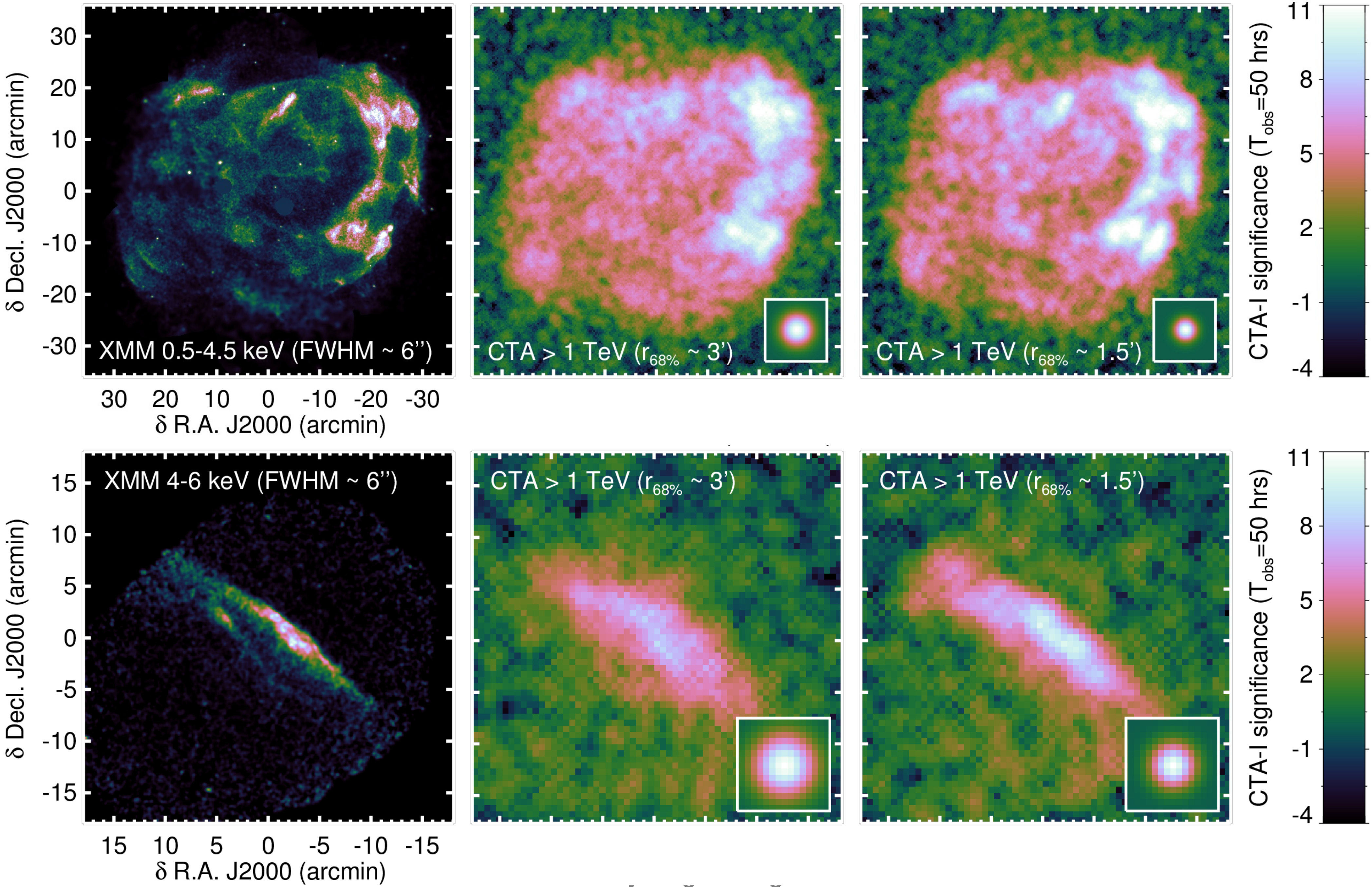
MSTs (~25)
Medium energies
mcrab sensitivity
~100 GeV–10 TeV
10-15 m telescopes

SSTs (~70)
High-energy section
~10 km^2 area at
multi-TeV energies
5-8 m telescopes



Actis et al. 2011 « Design Concepts for CTA »
Acharya et al. 2013 « Introducing the CTA concept »

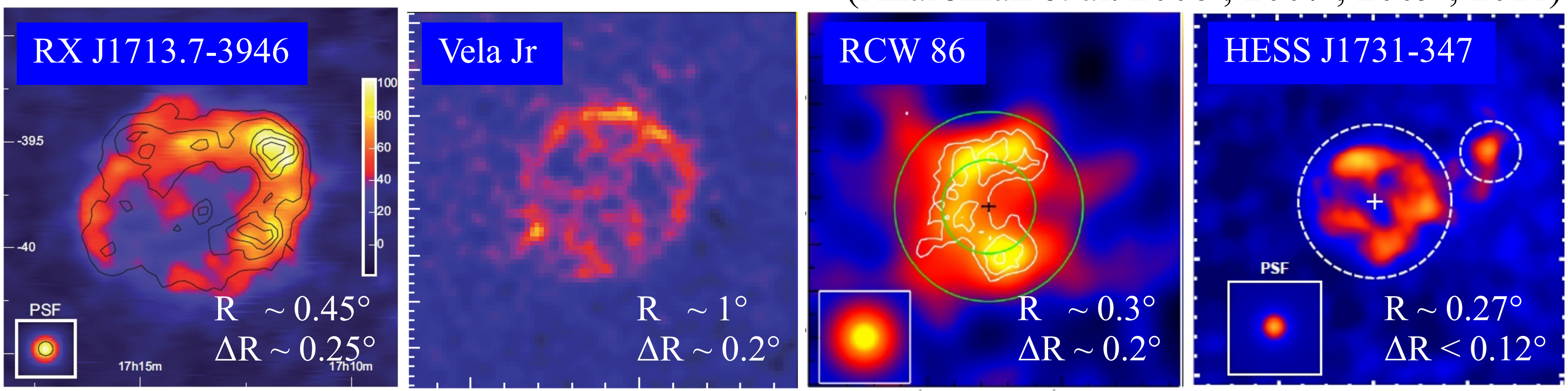
Prospects on SNRs with CTA

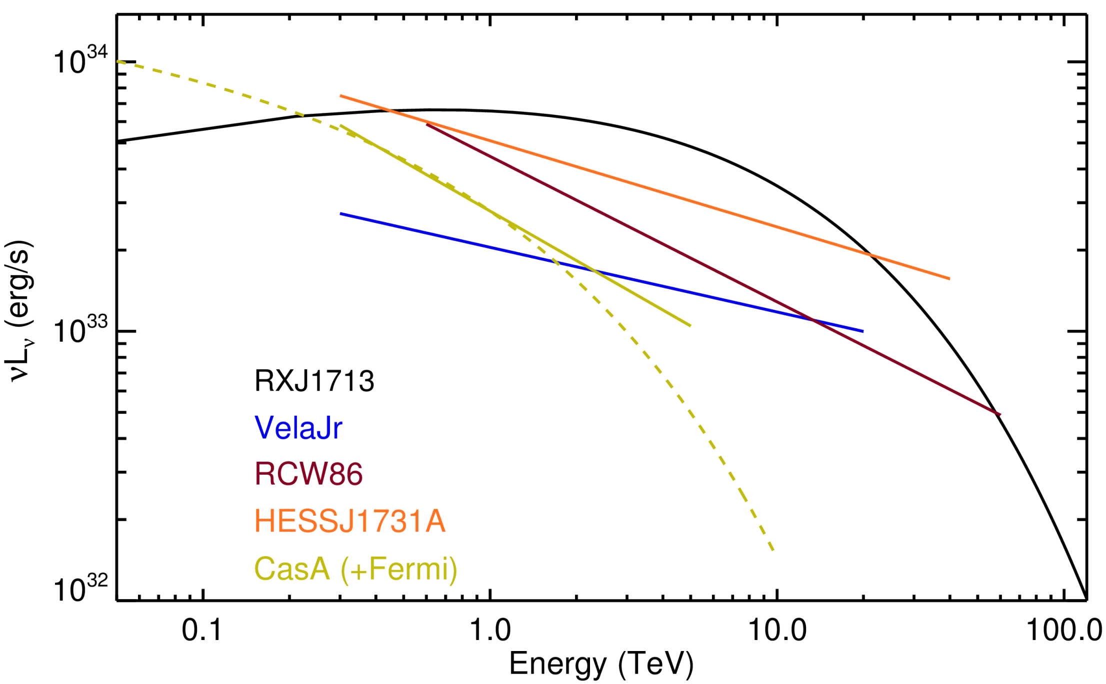


Prospects on SNRs with CTA

Population studies

(Aharonian et al. 2006 ; 2007 ; 2009 ; 2011)





CTA simulations of RX J1713-, Vela Jr-, RCW86-, HESS J1731-like SNRs with their spectral and morphological properties as measured with H.E.S.S.

Horizons of :

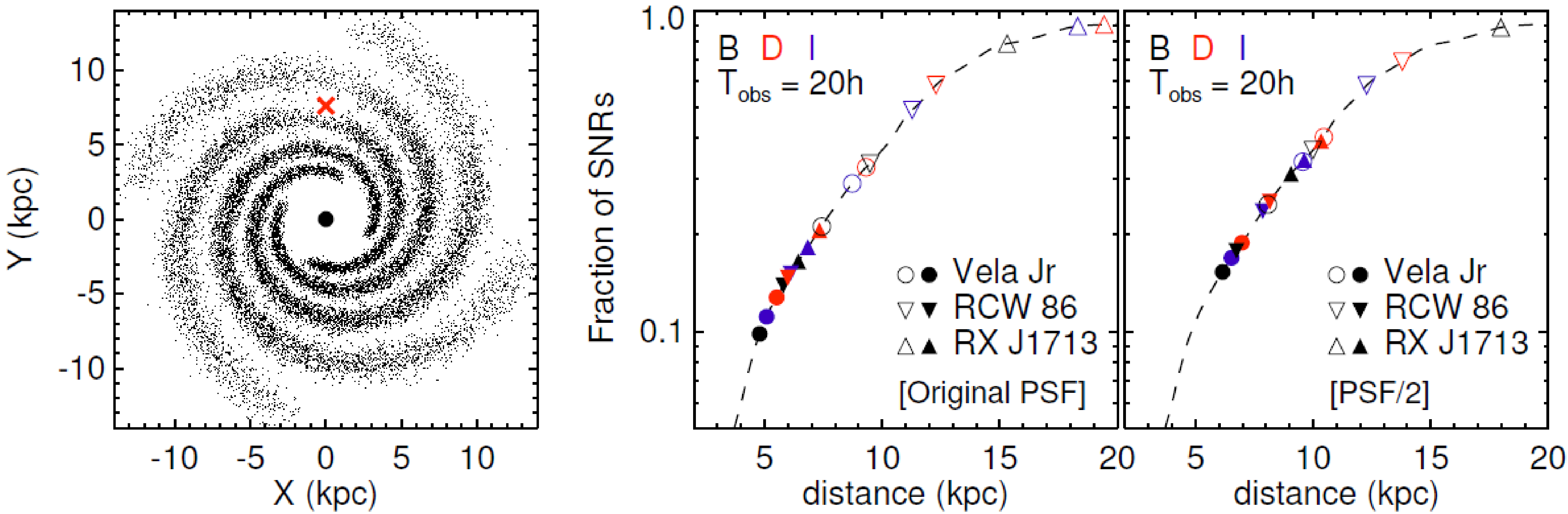
Detectability → d / S/N = 5σ
Resolvability → d / Shell favored over Gaussian fit

Prospects on SNRs with CTA

Population studies (Acero et al. 2013)

Simulate Galactic (core-collapse) SNR distribution :

Assume R_{gal} distribution of Case & Bhattacharya (1998)
Concentrated around spiral arms as given by Vallée (2008)
With arm dispersion as in dust model of Drimmel & Spergel (2001)



If all SNRs shine ~3000 yr in TeV → ~ 60 TeV-emitting SNRs
~ 20–55 would be **detectable** but only **~ 6–12** would be **resolvable** with CTA

If CTA PSF improved by a factor of 2 → almost 2× more resolvable SNRs!