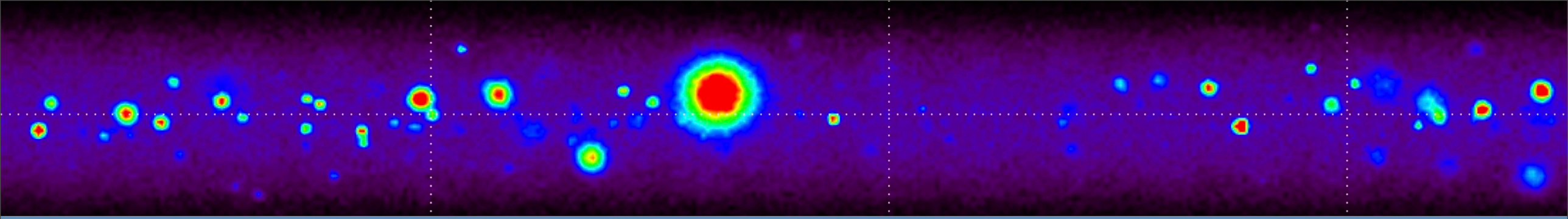


Surveying the sky with the Cherenkov Telescope Array

Guillaume Dubus

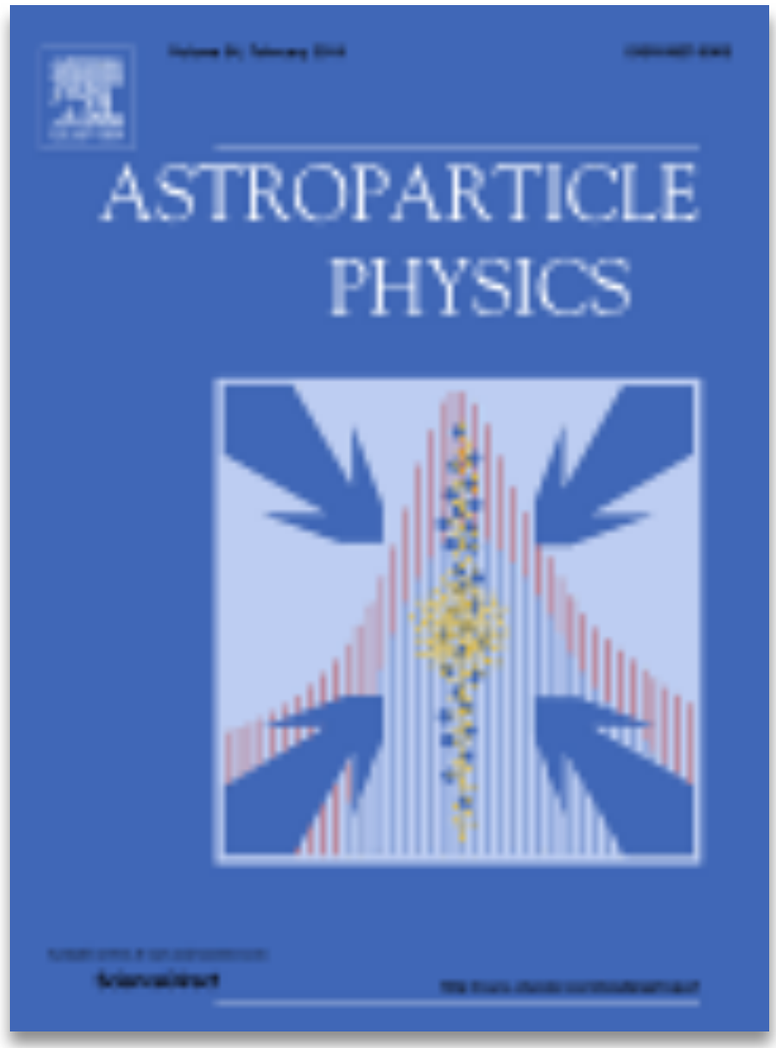
Fermi School 2014, Lewes DE

Institut de Planétologie et d'Astrophysique de Grenoble

Surveys with the Cherenkov Telescope Array

G. Dubus, J. Contreras, S. Funk, Y. Gallant, T. Hassan, J. Hinton, Y. Inoue, J. Knödlseder, P. Martin, N. Mirabal, M. de Naurois, M. Renaud, **for the CTA consortium**

Astroparticle Physics (2013) 43, 317

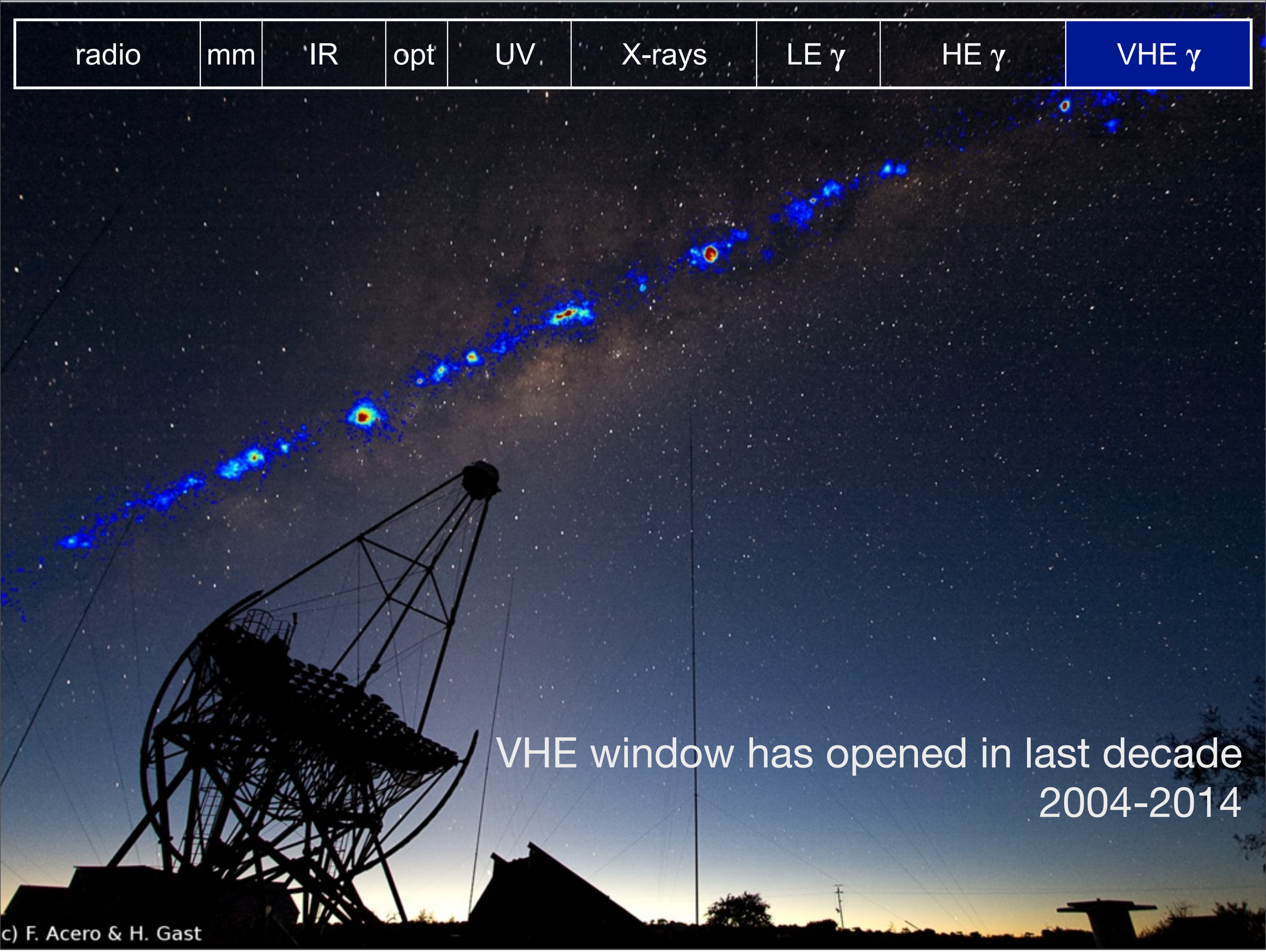


special issue

Seeing the High-Energy Universe with the Cherenkov Telescope Array

see also Funk, Hinton, Digel 2008

radio	mm	IR	opt	UV	X-rays	LE γ	HE γ	VHE γ

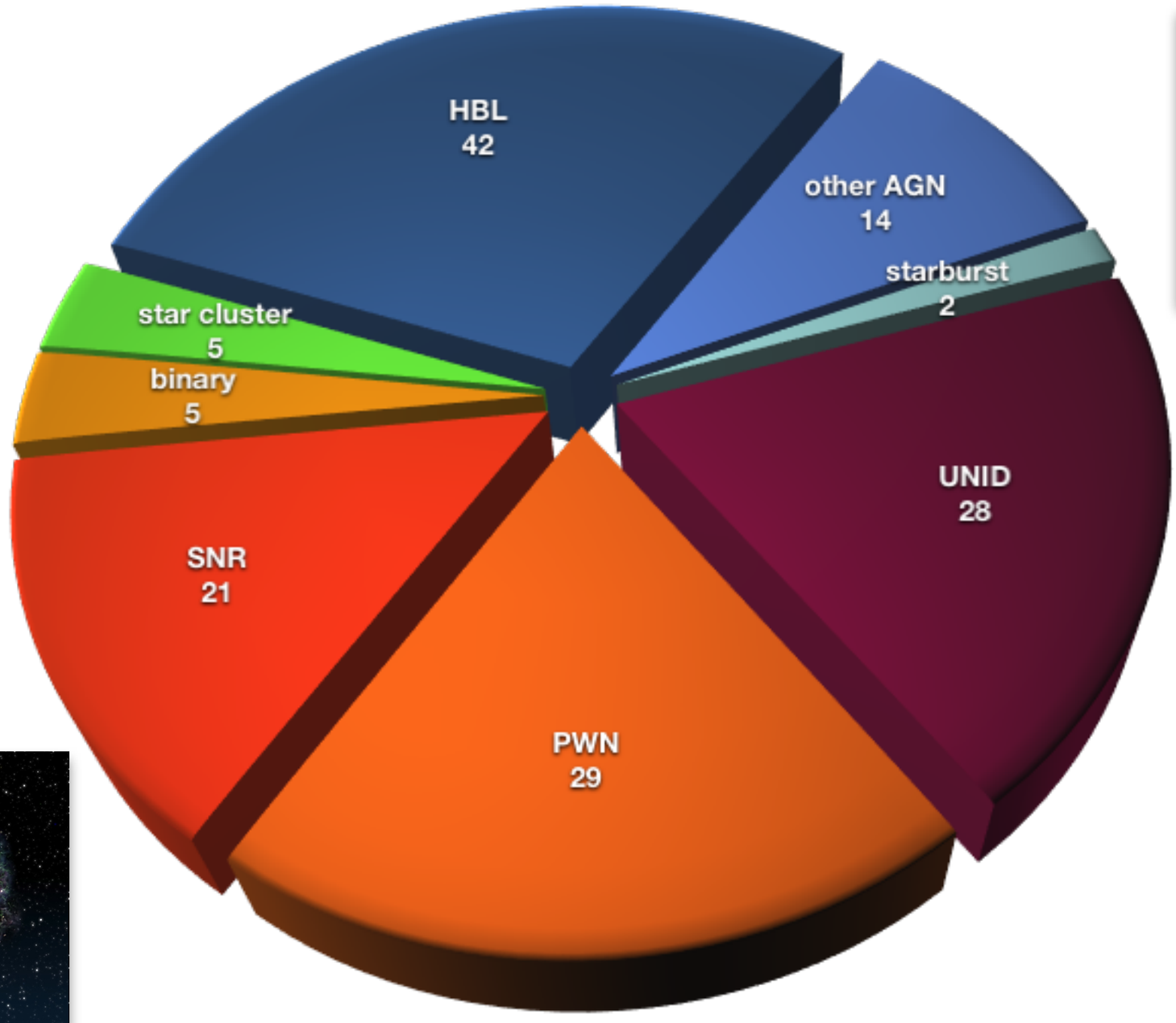


VHE window has opened in last decade
2004-2014

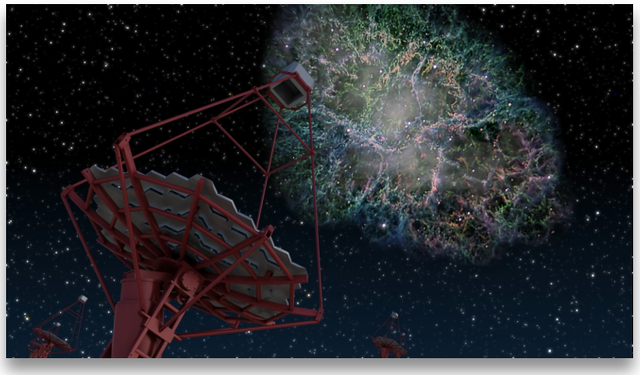
What's in the VHE γ-ray sky ?

TeVCat online catalog

extragalactic ≈ 60 sources

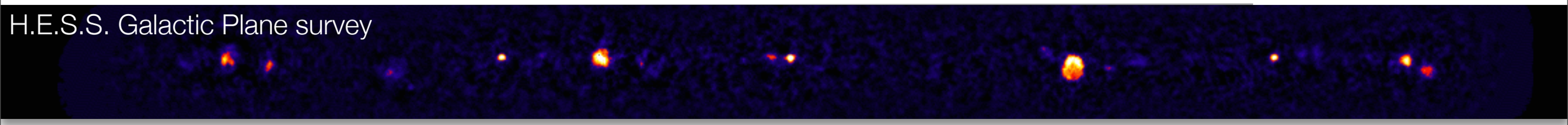


galactic
≈ 60 sources

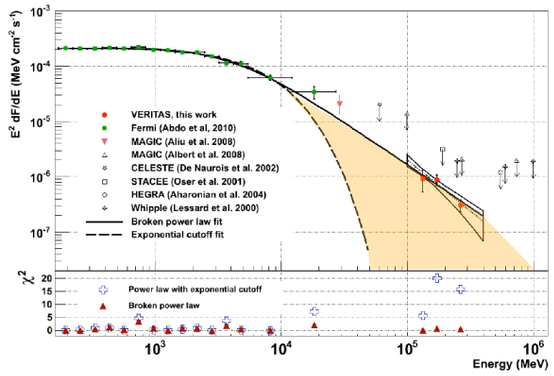


unidentified
≈ 30 sources

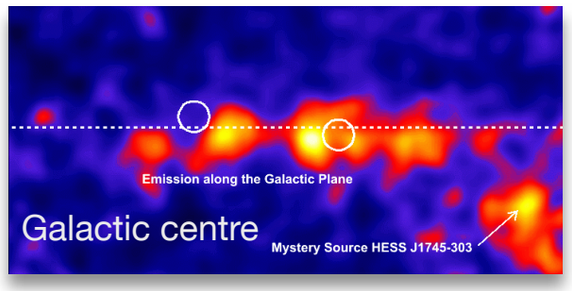
A selection of VHE γ-ray highlights



- A population of accelerators in Galaxy

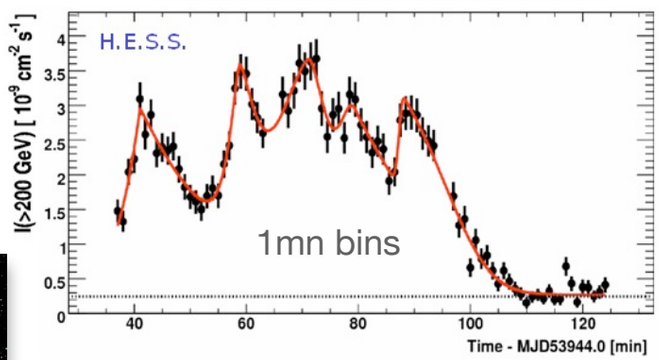


- VHE pulsed emission in Crab

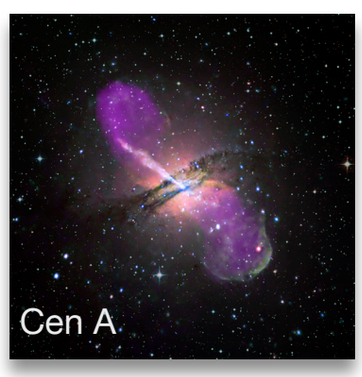


- Cosmic ray overdensities near SNR, GC, starburst

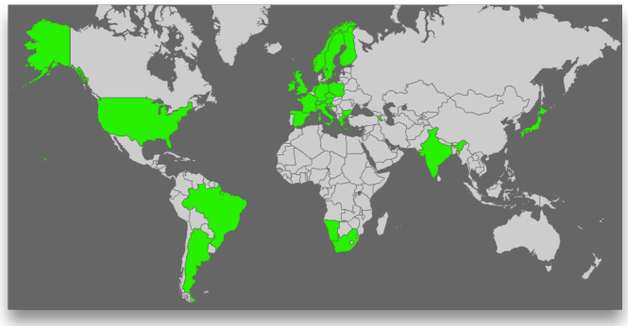
- Variability ≤ light-crossing time of black hole horizon



- VHE emission from AGNs with misaligned jet



CTA consortium

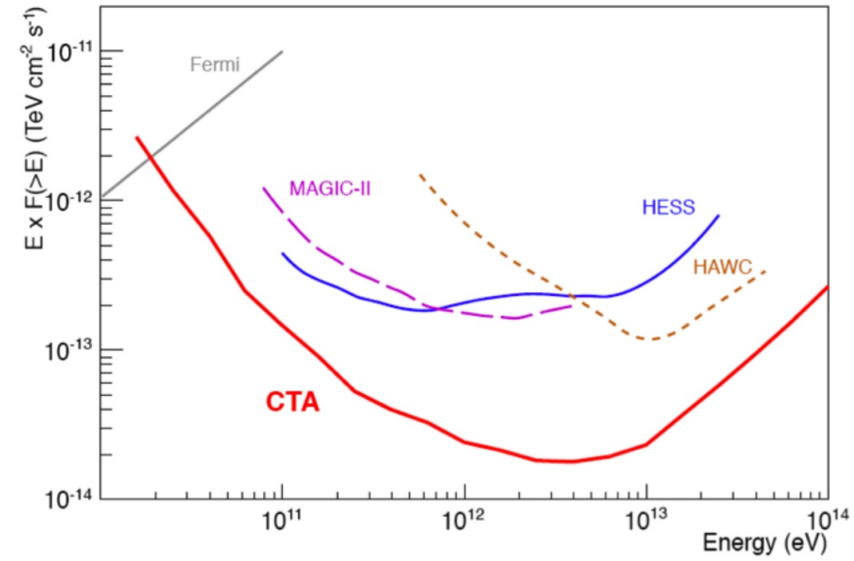


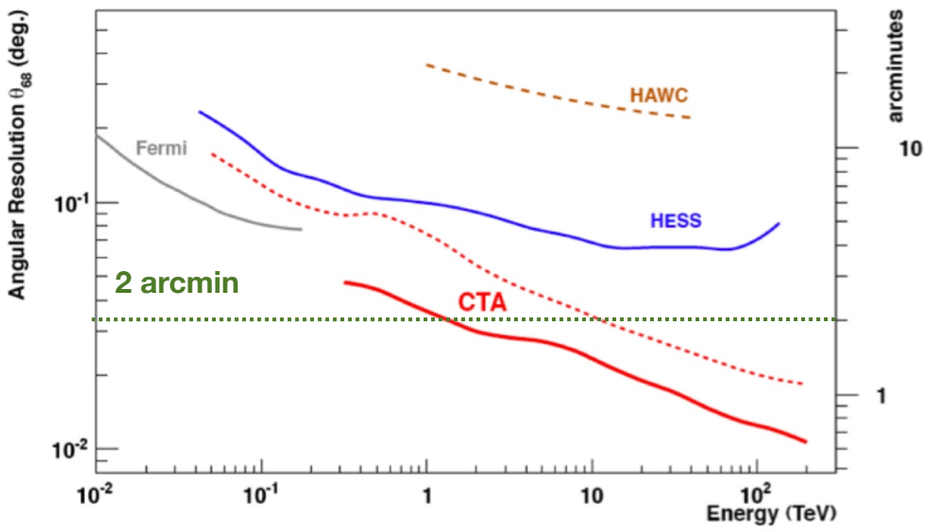
Unites worldwide VHE community to

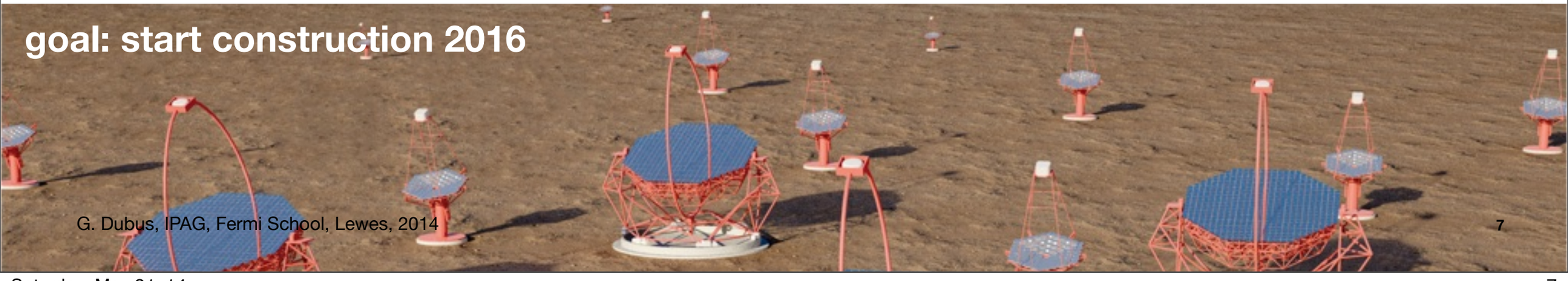
- **understand origin & role of cosmic rays**
  - Where are the sites of particle acceleration ?
  - How much energy do the particles carry ?
  - What feedback on star formation, galaxy evolution ?
- **probe extreme environments**
  - What mechanisms accelerate particles and let them escape ?
  - How is this linked with relativistic outflows ?
- **investigate VHE emission on cosmological scales**
  - How does VHE activity evolve with time ?
  - Does VHE γ-ray propagation influence the IGM ?
  - Is dark matter annihilating in gamma rays ?
- **explore the frontiers of physics**
  - Is c constant with photon energy ?
  - Do axions exist ?

An **open observatory** with

- **factor 10 gain in sensitivity**
  - access VHE population across whole Galaxy
  - sample fast variability (GRB, AGN...)
- **field-of-view ≥ 8º**
  - diffuse emission
  - faster surveys
- **improved angular resolution (2'@1 TeV)**
  - resolve extended sources (SNR, starbursts...)
- **wide energy coverage**
  - ≤ 100 GeV to reach higher redshifts
  - ≥ 10 TeV to search for PeVatrons





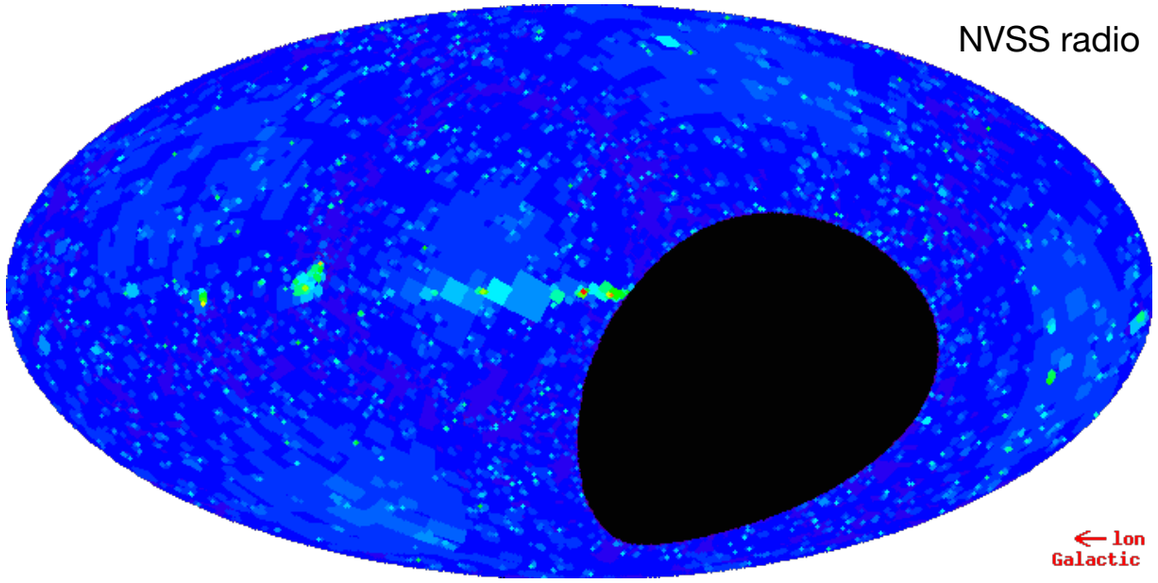


G. Dubus, IPAG, Fermi School, Lewes, 2014

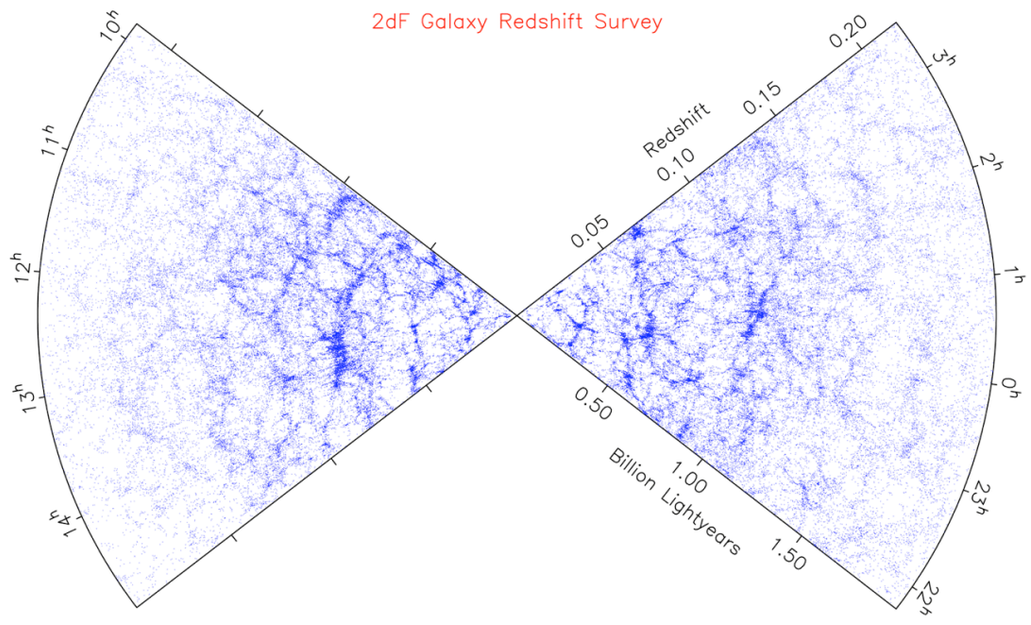
Why survey ?

- **reference**
- **map all that's there**
- **specific scientific goals**

well-defined, systematic method



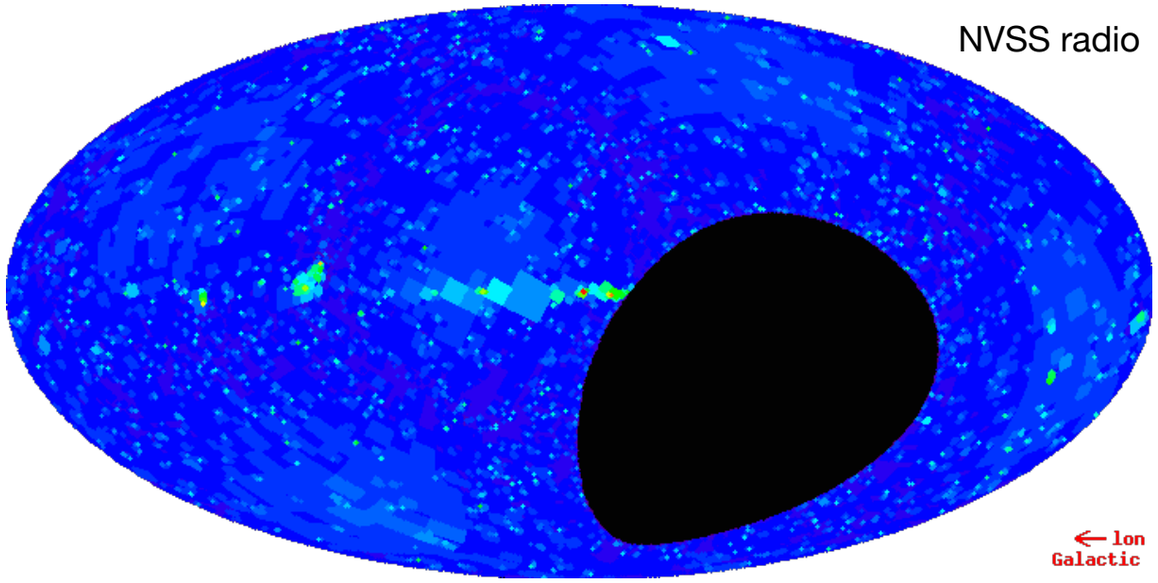
star catalogues



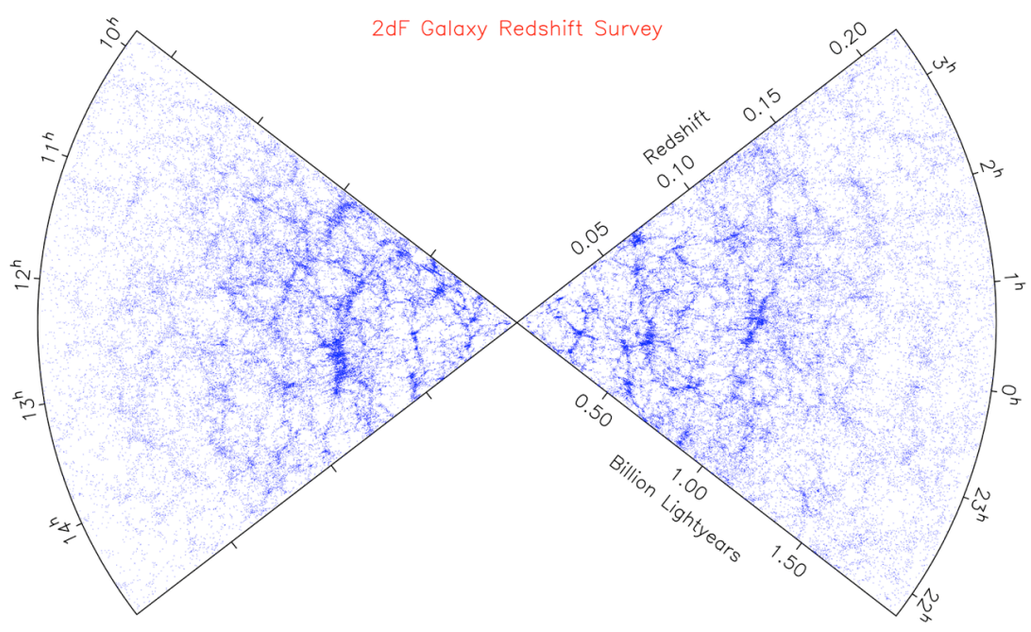
2dF galaxies

Advantages of surveys ?

- **unbiased**
- **legacy**
- **optimize**



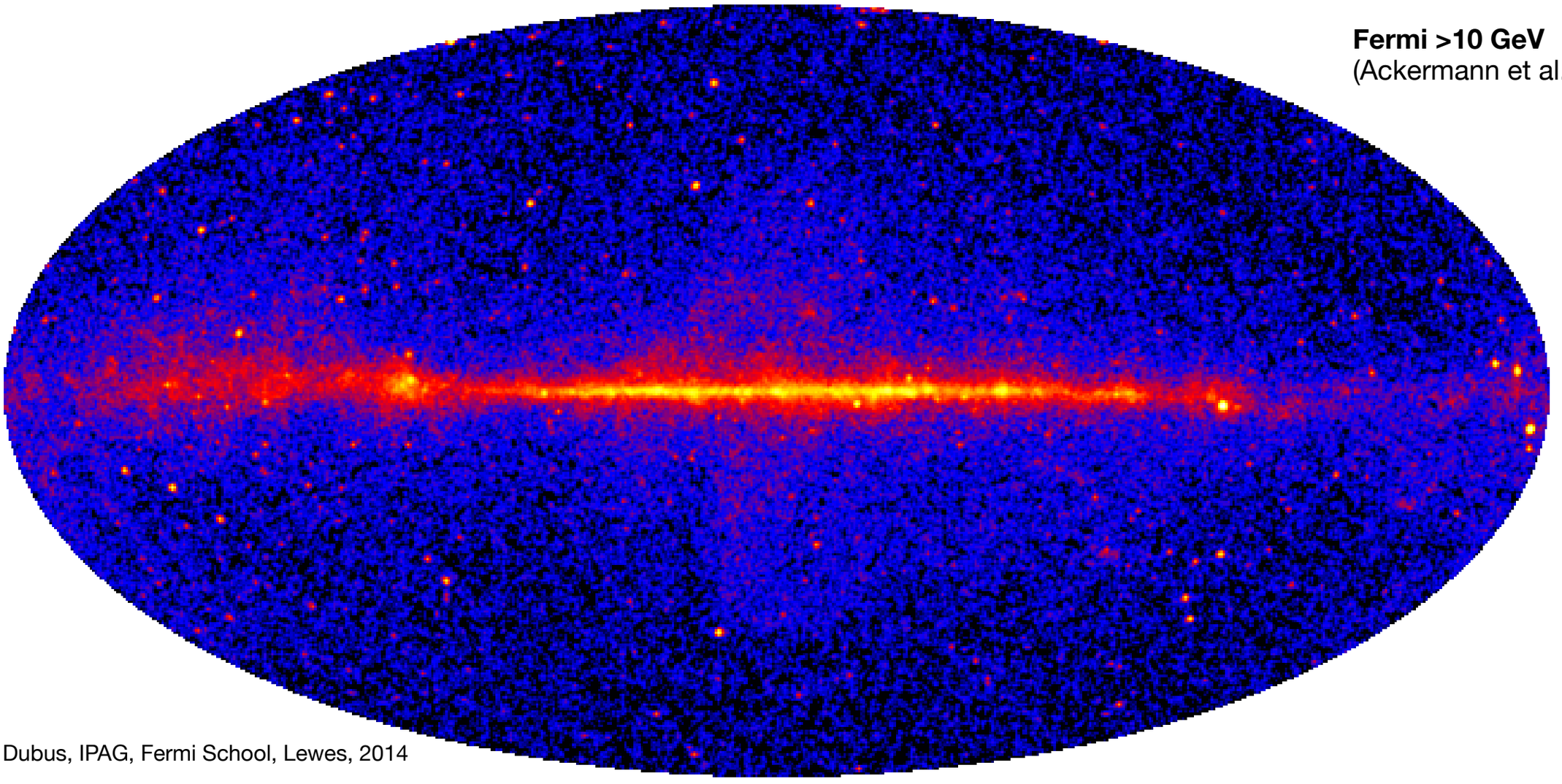
star catalogues



2dF galaxies

CTA is an **observatory**

- Provide open access to datasets of wide interest.
- Assist community to formulate open time proposals.
- Surveys as a key science project of the consortium (under discussion).



Fermi >10 GeV
(Ackermann et al. 2014)

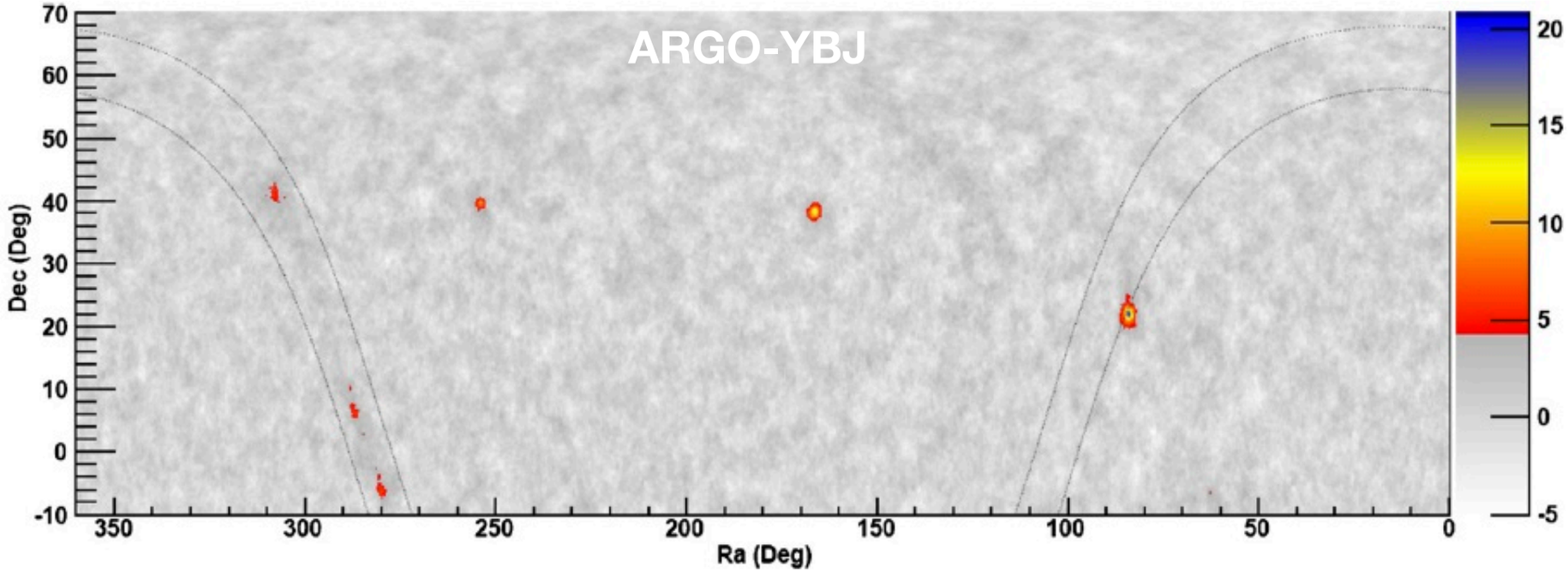
VHE surveys [1] EAS

MILAGRO 1° to 80°, >275 mCrab (>1 TeV) 2 (8) sources

ARGO-YBJ -10° to 70° >250 mCrab (>0.3 TeV) 6 sources

Atkins et al. 2004, Abdo et al. 2007

Bartoli et al. 2013



HAWC

median energy few TeV

1° resolution

50 mCrab in 1 year

high duty cycle

VHE surveys [2] IACTs

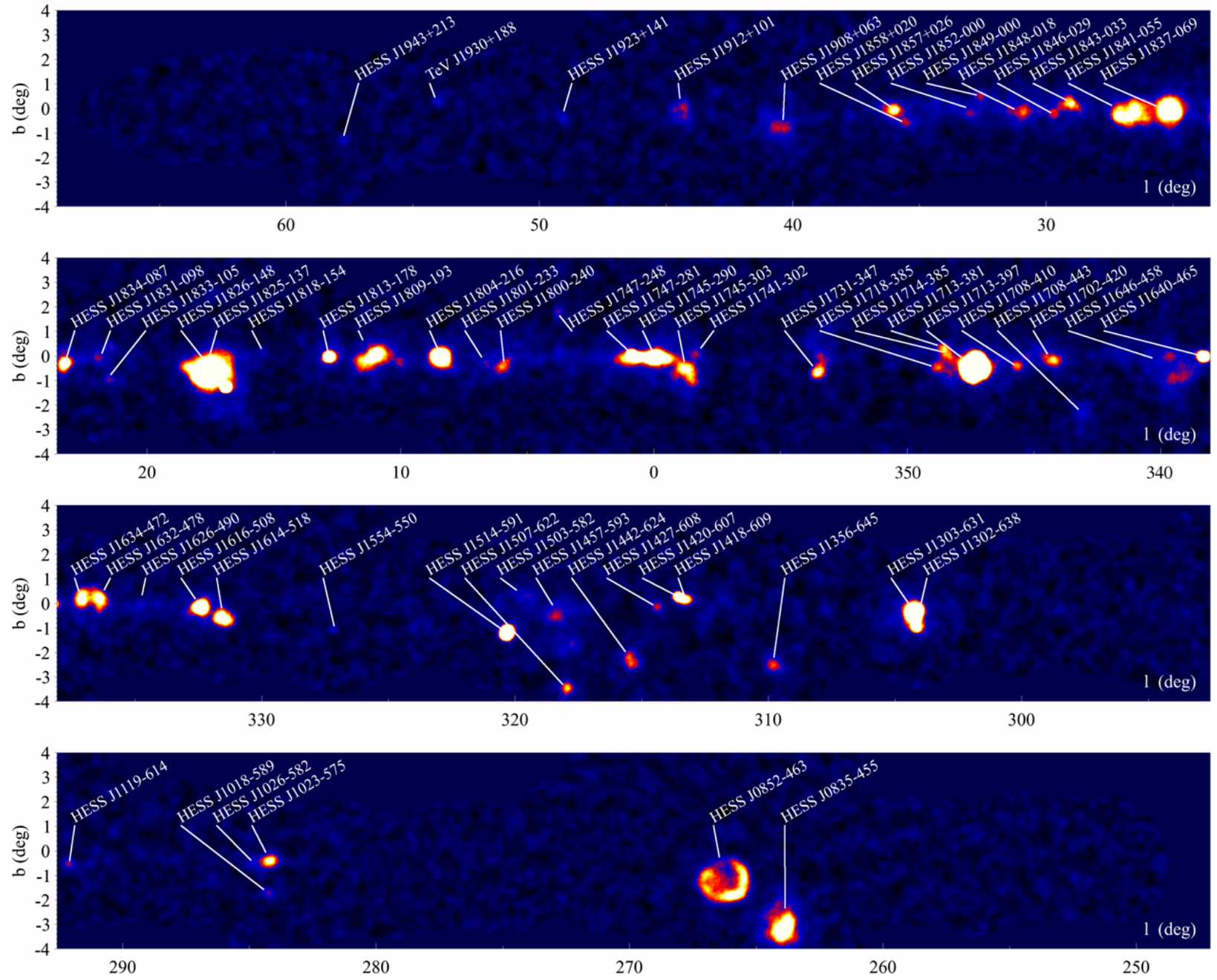
H.E.S.S. Galactic Plane survey

Gast et al. 2012

l=-80° to 60° |b|<3°
(2% of the sky)
>60 sources
0.1° resolution
~20 mCrab (>100 GeV)

[*VERITAS Cygnus region*
(0.2% of the sky)
2 sources
~40 mCrab (>200 GeV)]

[*All-sky serendipitous*:
very rough estimate
~20 mCrab, 5% of sky ?]

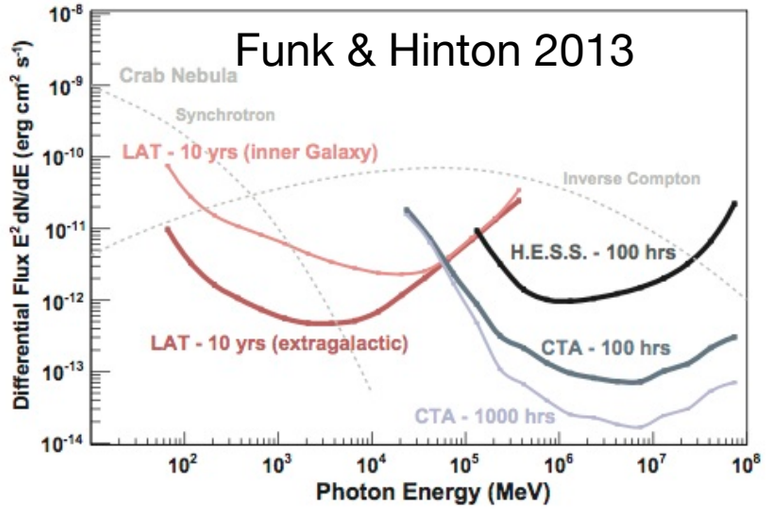


VHE surveys [3] *Fermi*

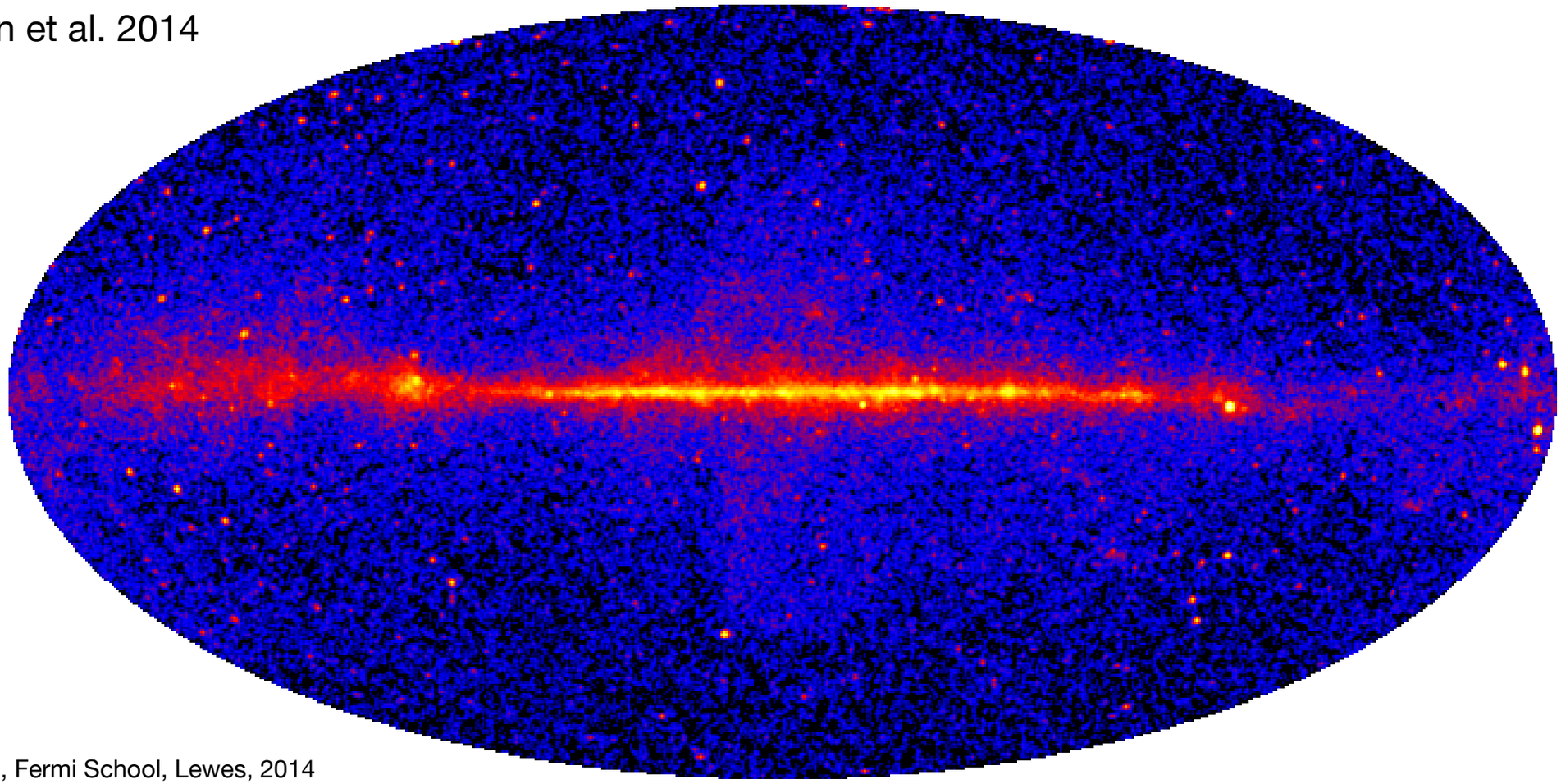
***Fermi*-LAT** all-sky above 10 GeV

10-100 GeV, 0.2º-0.3º resolution
~500 sources: 75% AGN, 5% pulsar, 10% unidentified

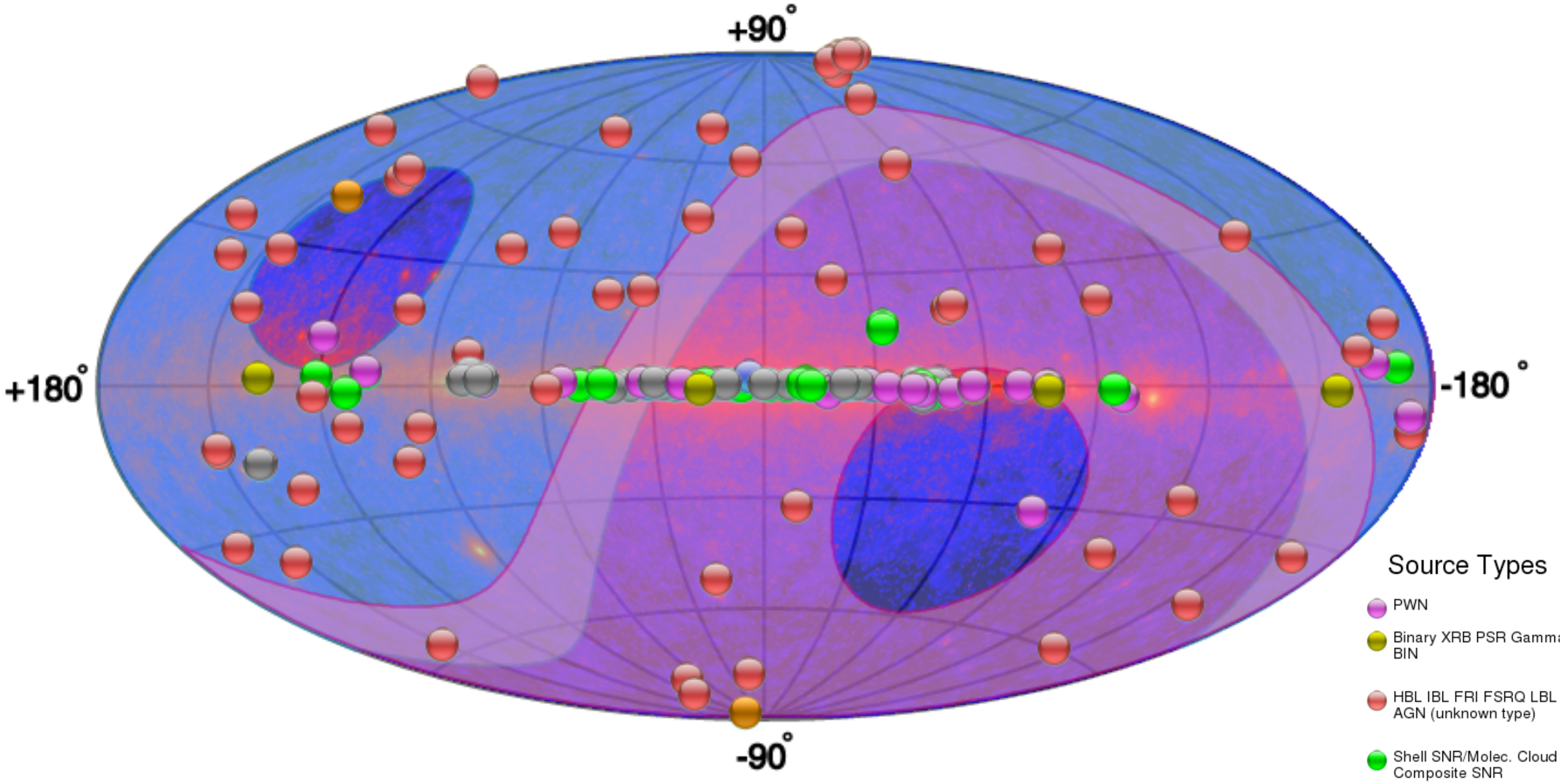
10 years ~10 mCrab (>10 GeV), ~50 mCrab (>100 GeV)



Ackermann et al. 2014



Distribution of VHE sources



G. Dubus, IPAG, Fermi School, Lewes, 2014

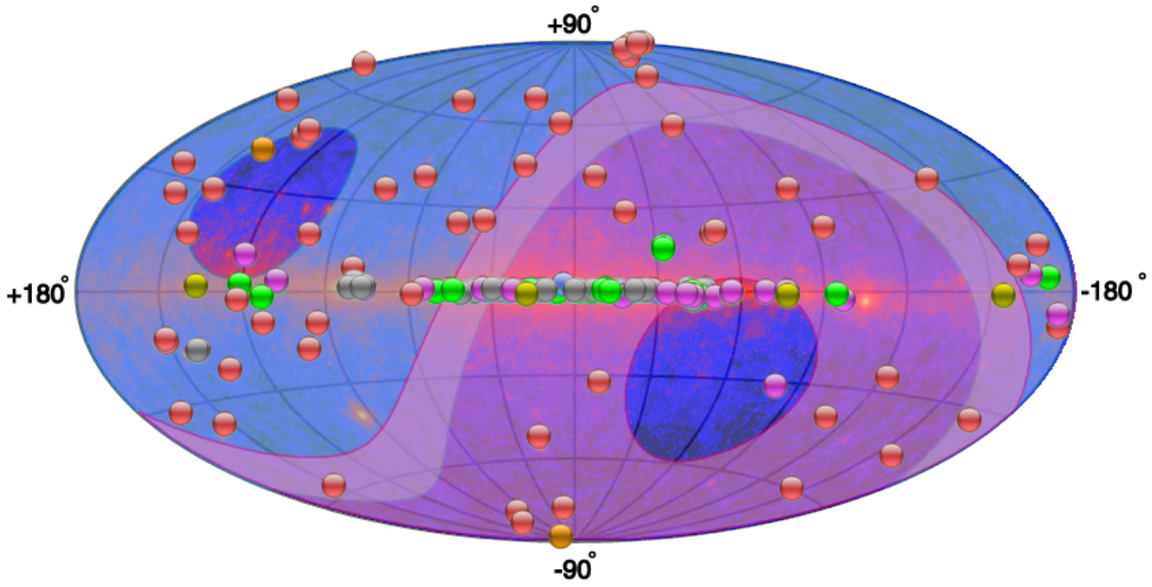
Surveys with CTA: examples

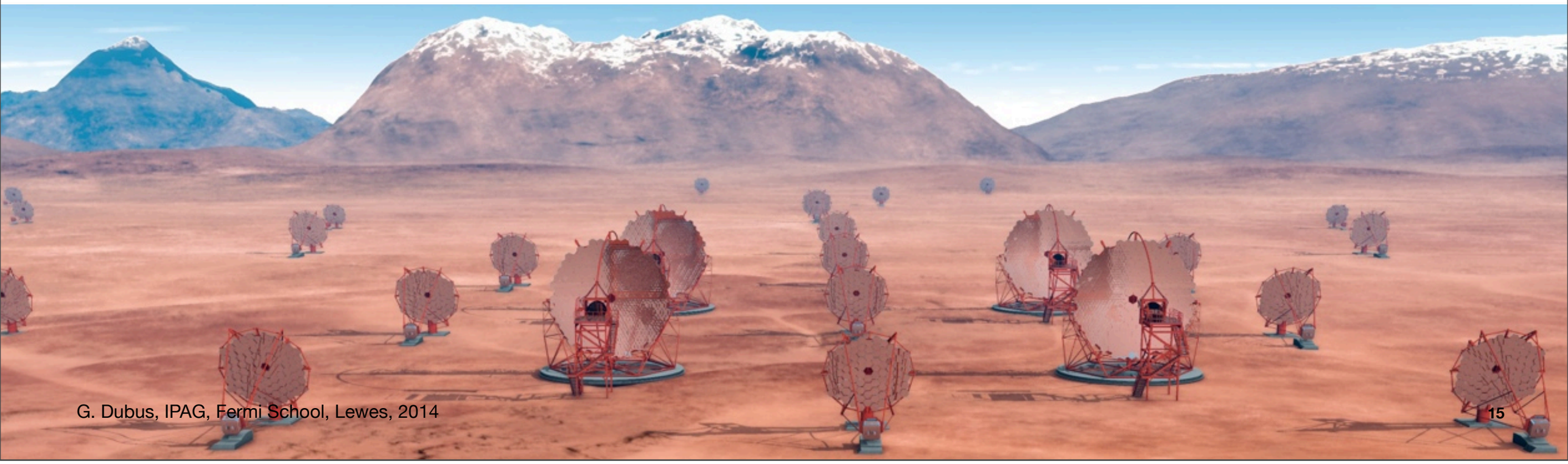
Survey of the Galactic Plane

- half of VHE sources within |l|<60º, |b|<3º
- how deep ?
- what science ?

“All-sky” survey

- can it be done ?
- how does it compare to EAS arrays ?
- what science ?



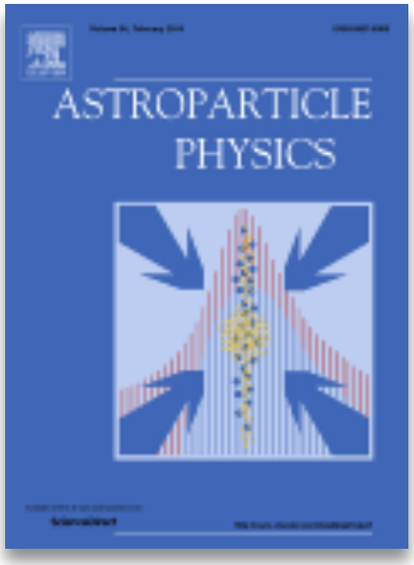


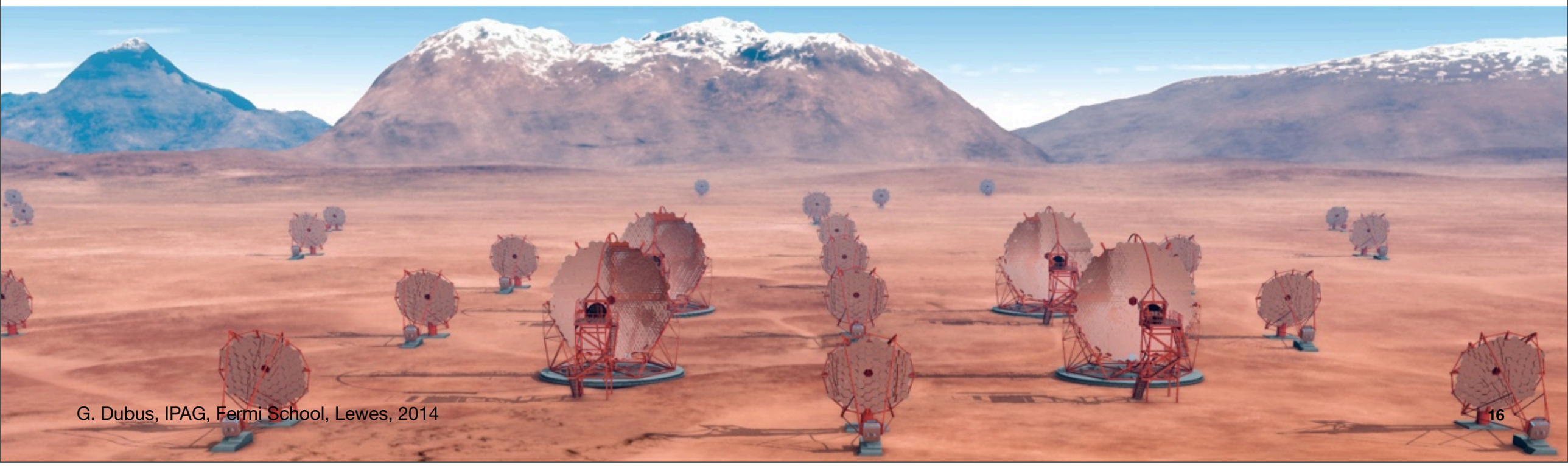
G. Dubus, IPAG, Fermi School, Lewes, 2014

Surveys with CTA: examples

Feasibility study *P. Martin & J. Knödlseder*

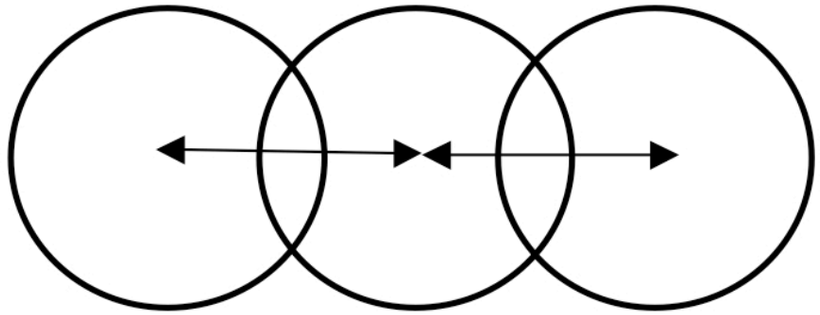
- mock dataset of reconstructed events using MC files
- fit background & source model using ctools (gamma lib)
- no Galactic diffuse
- no astronomical visibility
- A_{eff} gaussian with θ^2 with $\sigma=3^o$
- 20^o zenith angle
- sensitivities 0.1-100 TeV with $\Gamma=2.5$



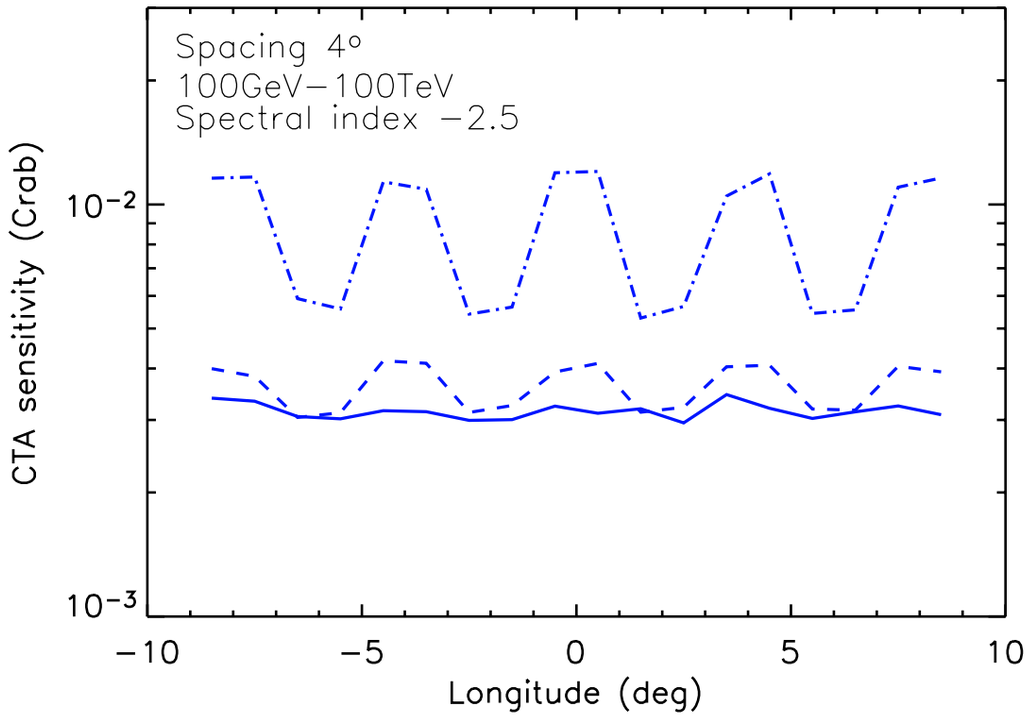


Survey of inner Galactic Plane

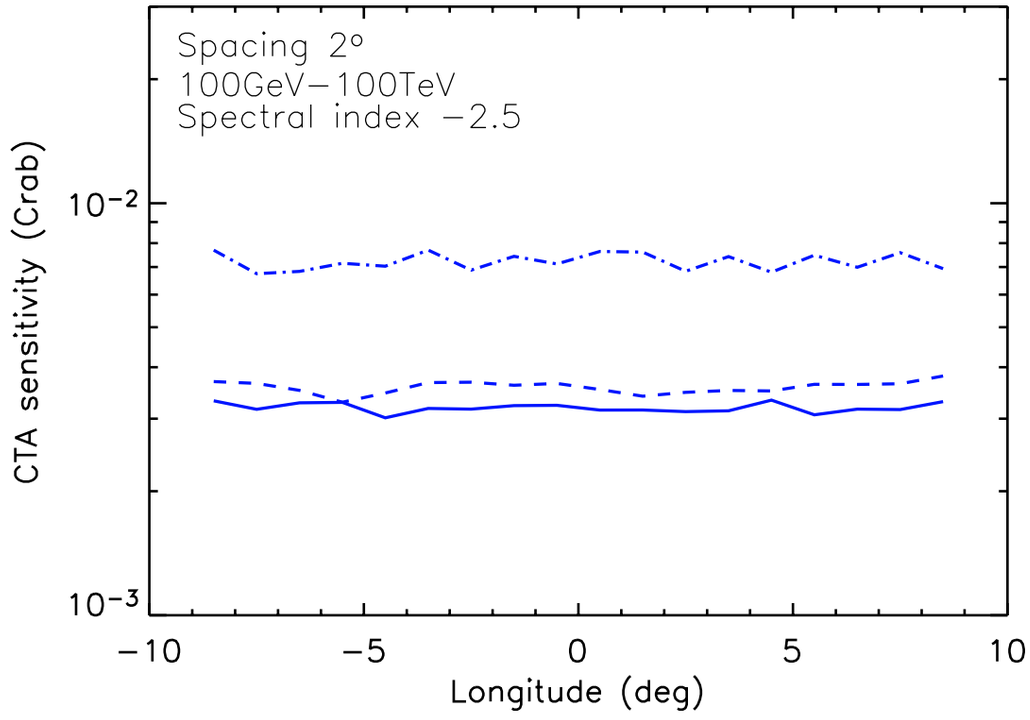
- single row of pointings |l|<60º
- 60 x 4h pointings = **240 hours**
- **3 mCrab** at b=0º



spacing 4º



2º



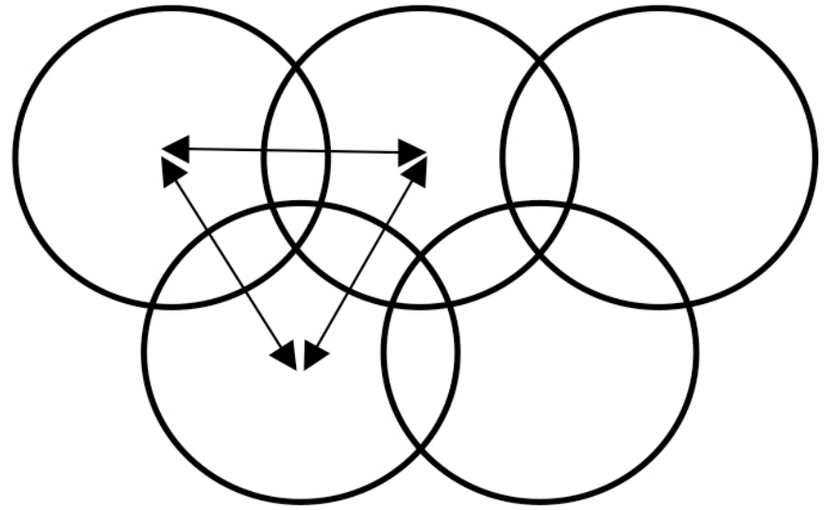
b=2º

b=1º

b=0º

“All-sky” survey

- **π survey** (1/4th sky at zenith <60º)
  - 7408 x 0.5 hr per pointing = **370 hours**
  - **22 mCrab** > 100 GeV
  - 38 mCrab > 1 TeV
  - 10 % variations in sensitivity (4º spac.)



$$N\left[>F(t_{\rm fov})\right]=N_0\left(\frac{t_{\rm fov}}{t_0}\right)^{-n/2}\times\pi\frac{\theta_{\rm fov}^2}{4}\frac{t_{\rm obs}}{t_{\rm fov}}\propto t_{\rm obs}\theta_{\rm fov}^2 t_{\rm fov}^{-1/4}$$ *(Y. Inoue)*

- **divergent pointing ?** *(J. Hinton, Lucie Gérard)*

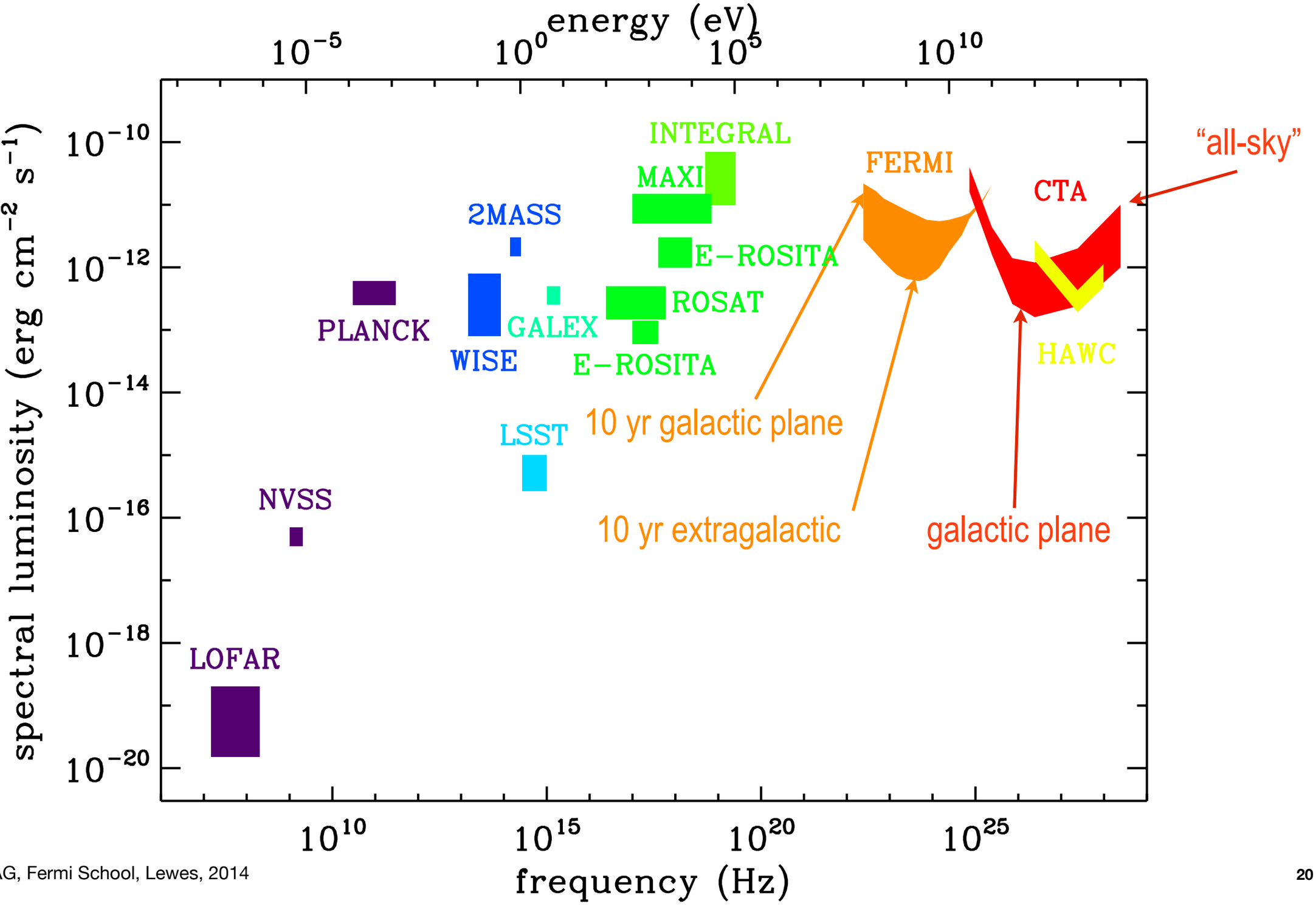
Divergent pointing

- telescopes do not all point at same spot but cover a 20°x 20° patch
- multiplicity 2-3 per event

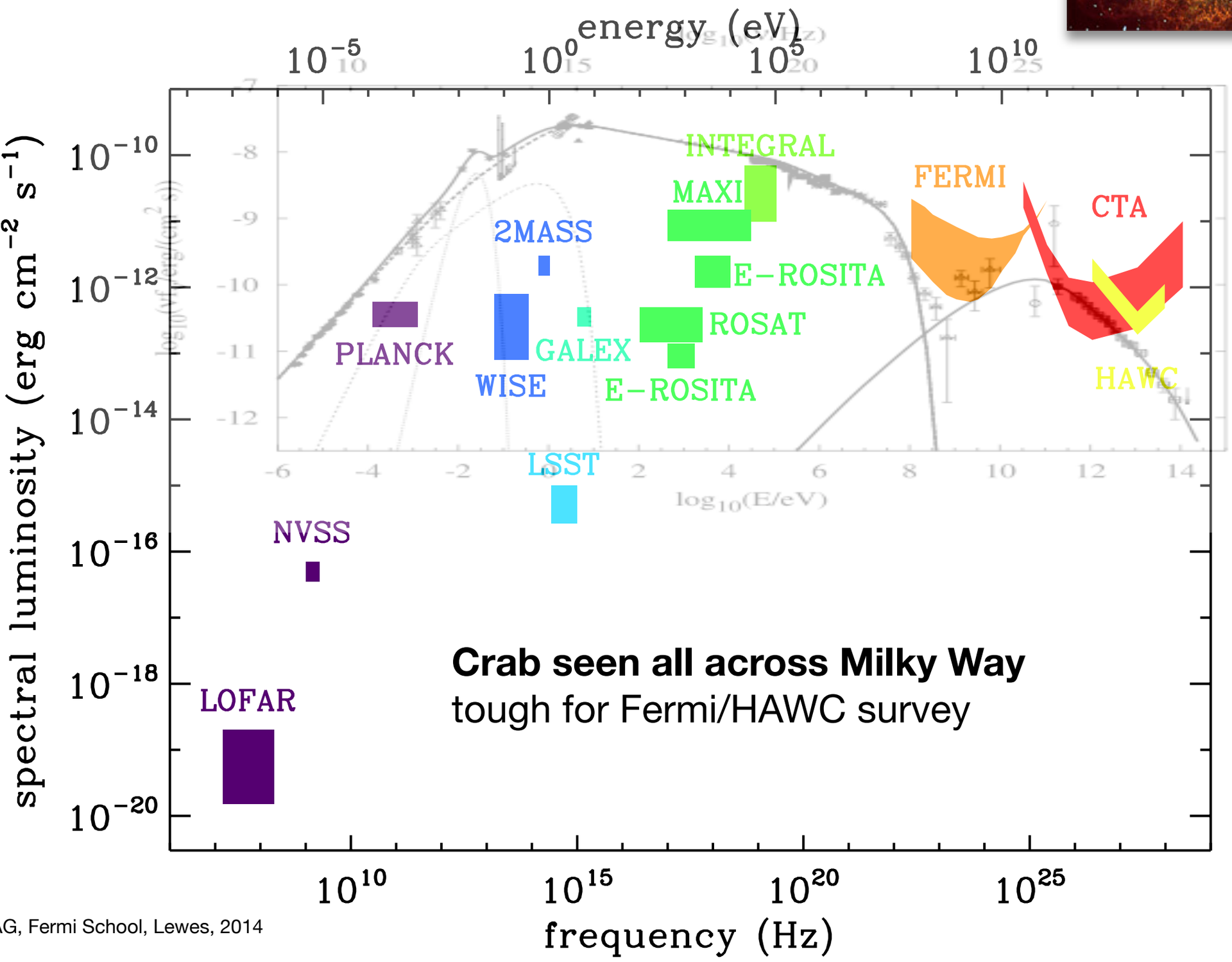
- trade energy range, resolution, sensitivity for field-of-view
- needs dedicated analysis
- also useful for counterparts in big error boxes (GW, ν)

- gain if FoV increases faster than time to get same target sensitivity
  → *studies underway*

Surveys in a spectral energy diagram

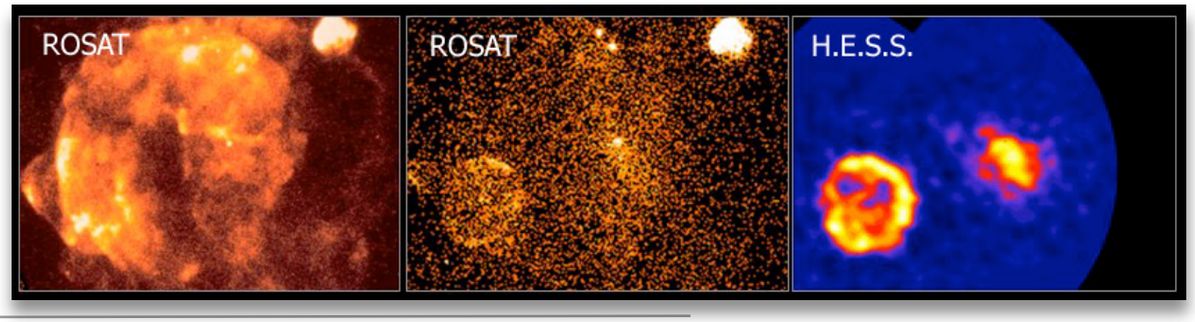


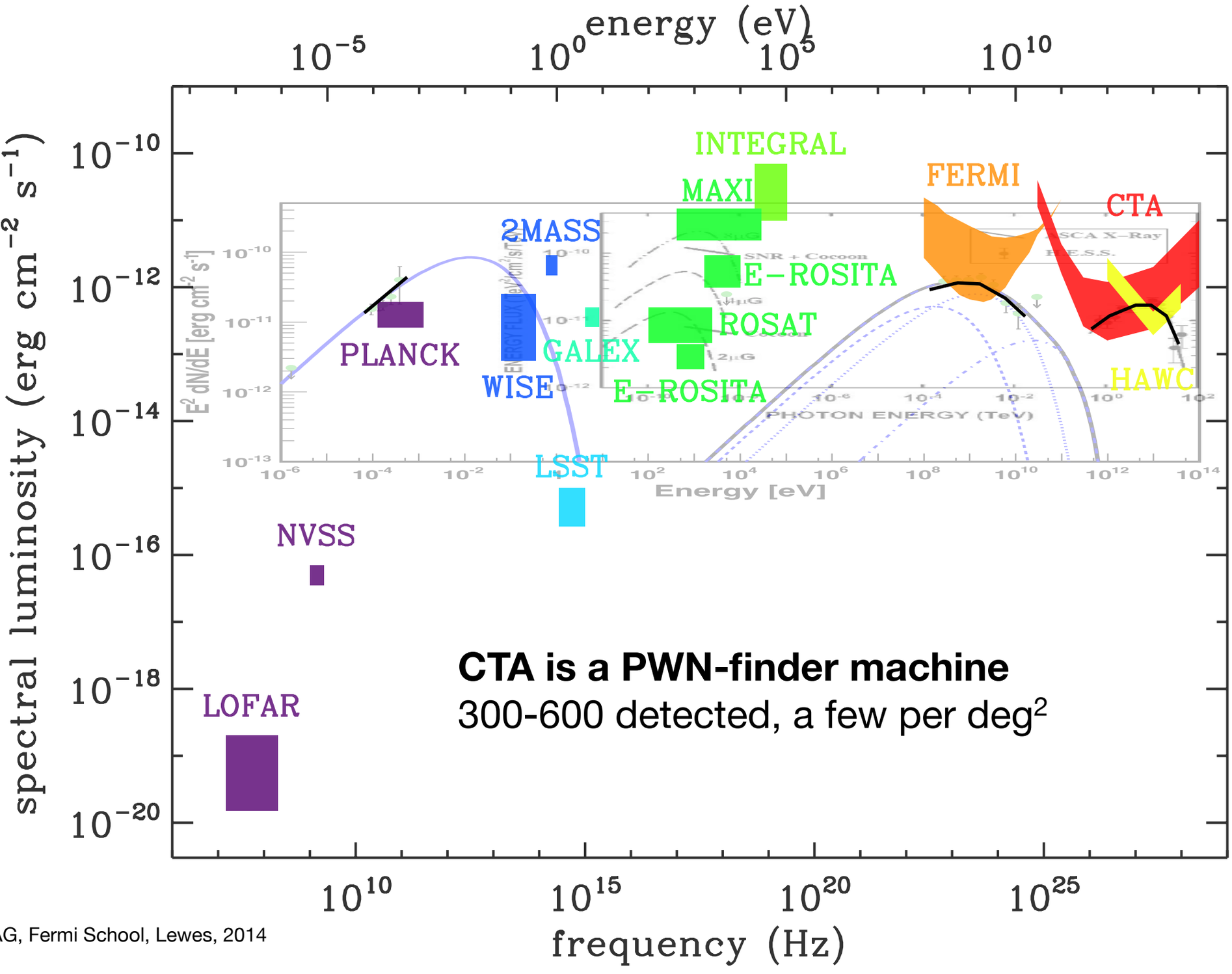
PWNe: Crab 100 x fainter



Crab seen all across Milky Way
tough for Fermi/HAWC survey

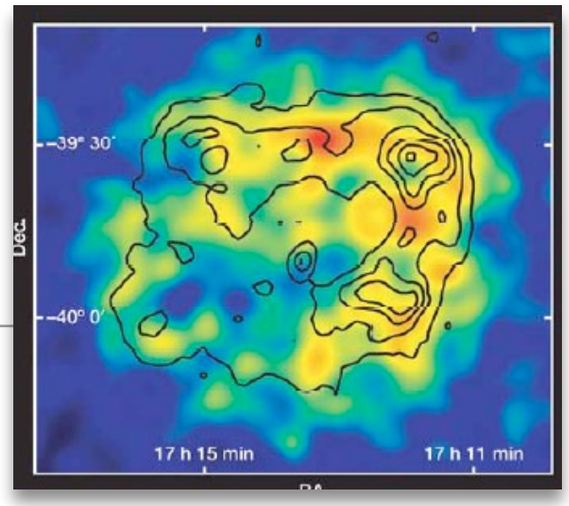
PWNe: Vela X, 30 x fainter

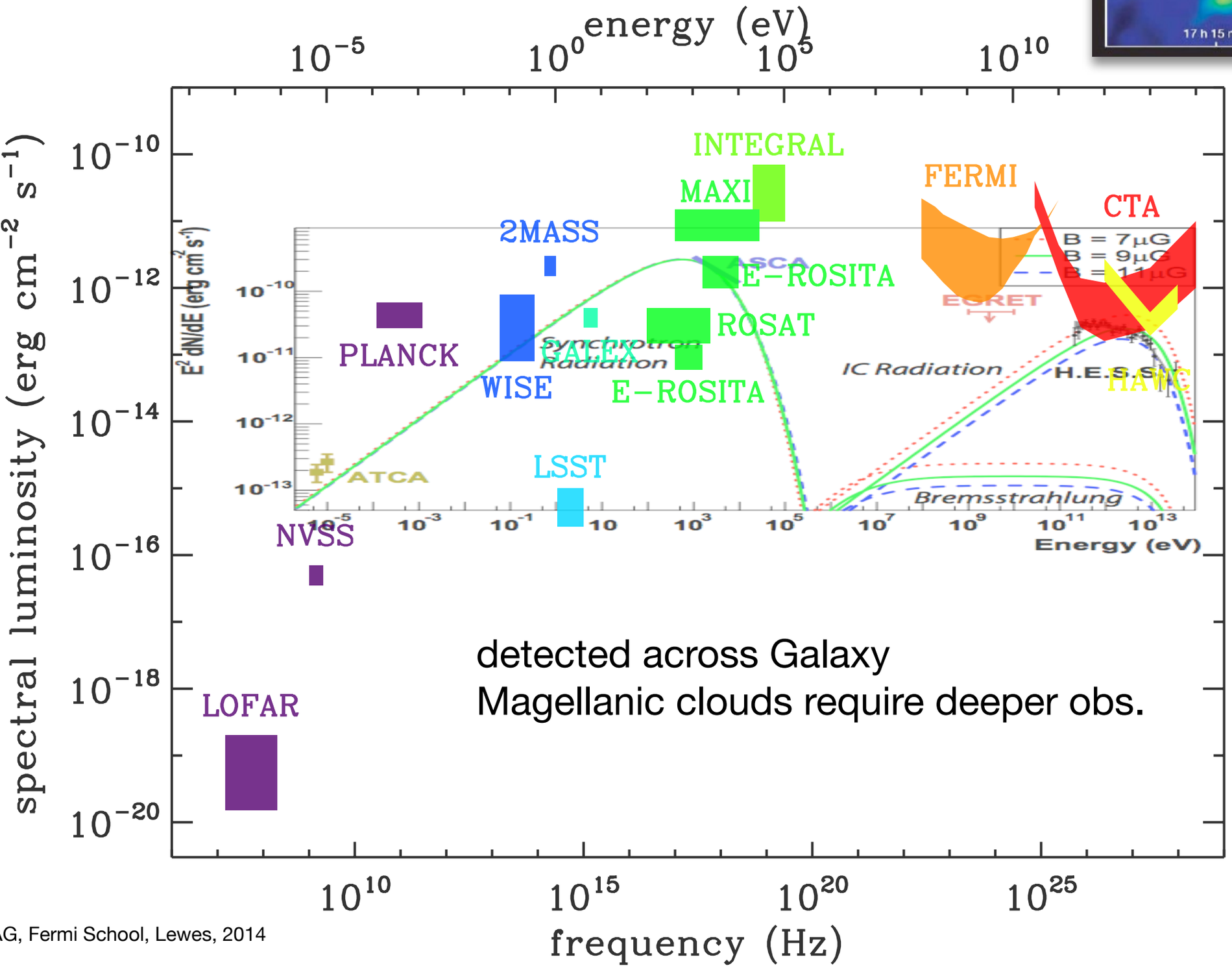




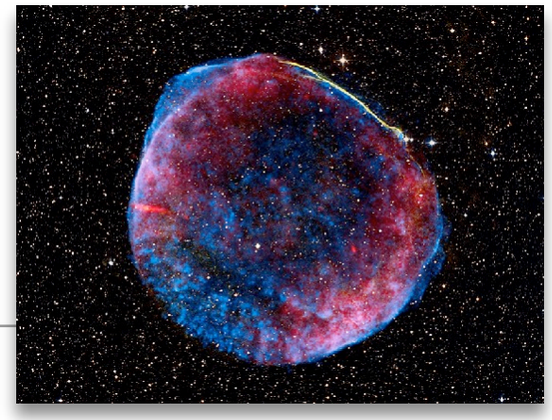
G. Dubus, IPAG, Fermi School, Lewes, 2014

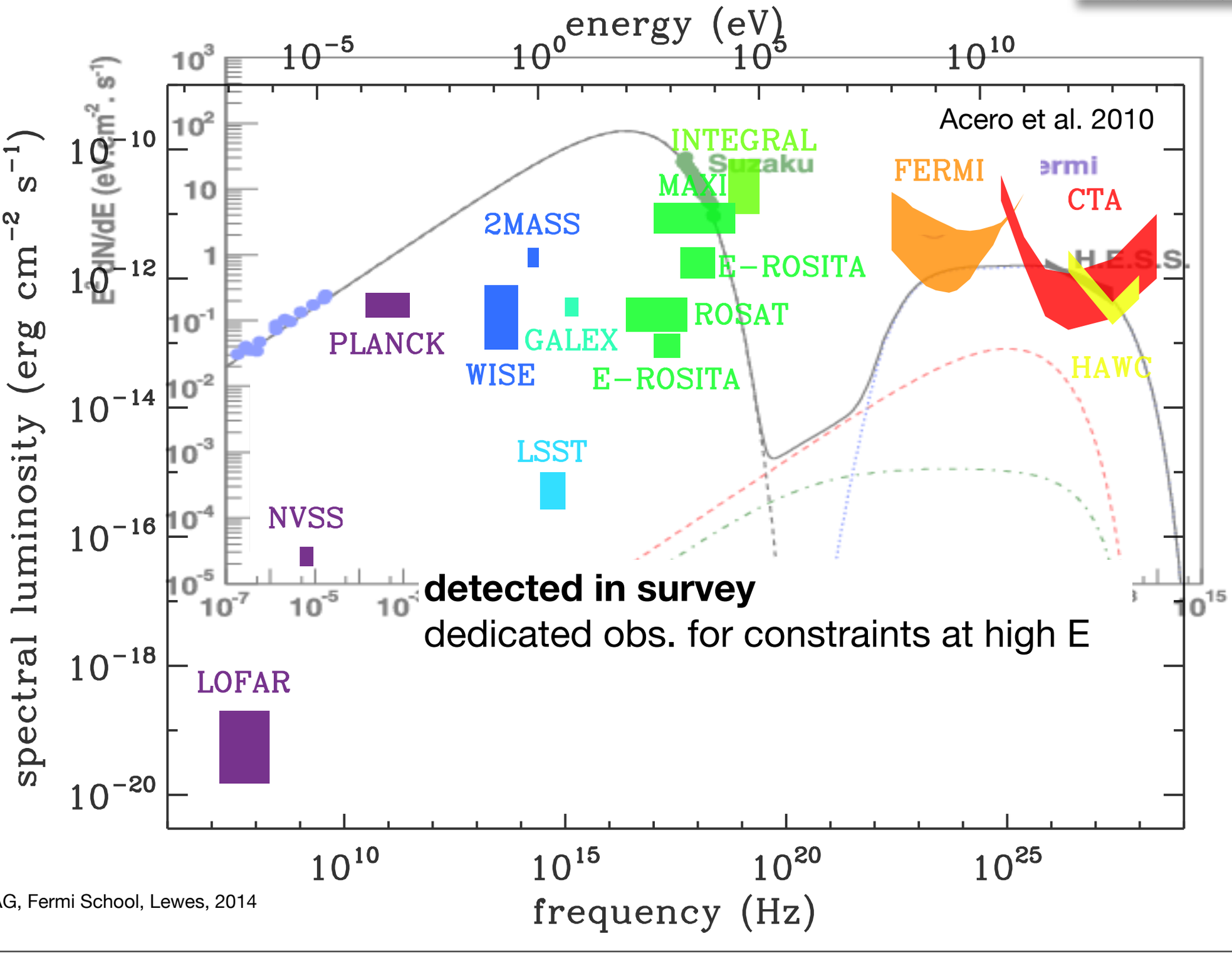
SNR: RXJ 1713.7-3946, 100 x fainter



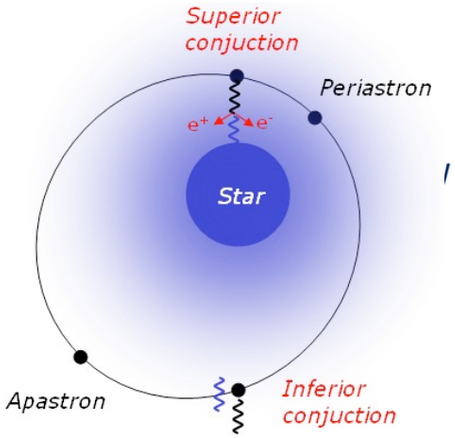


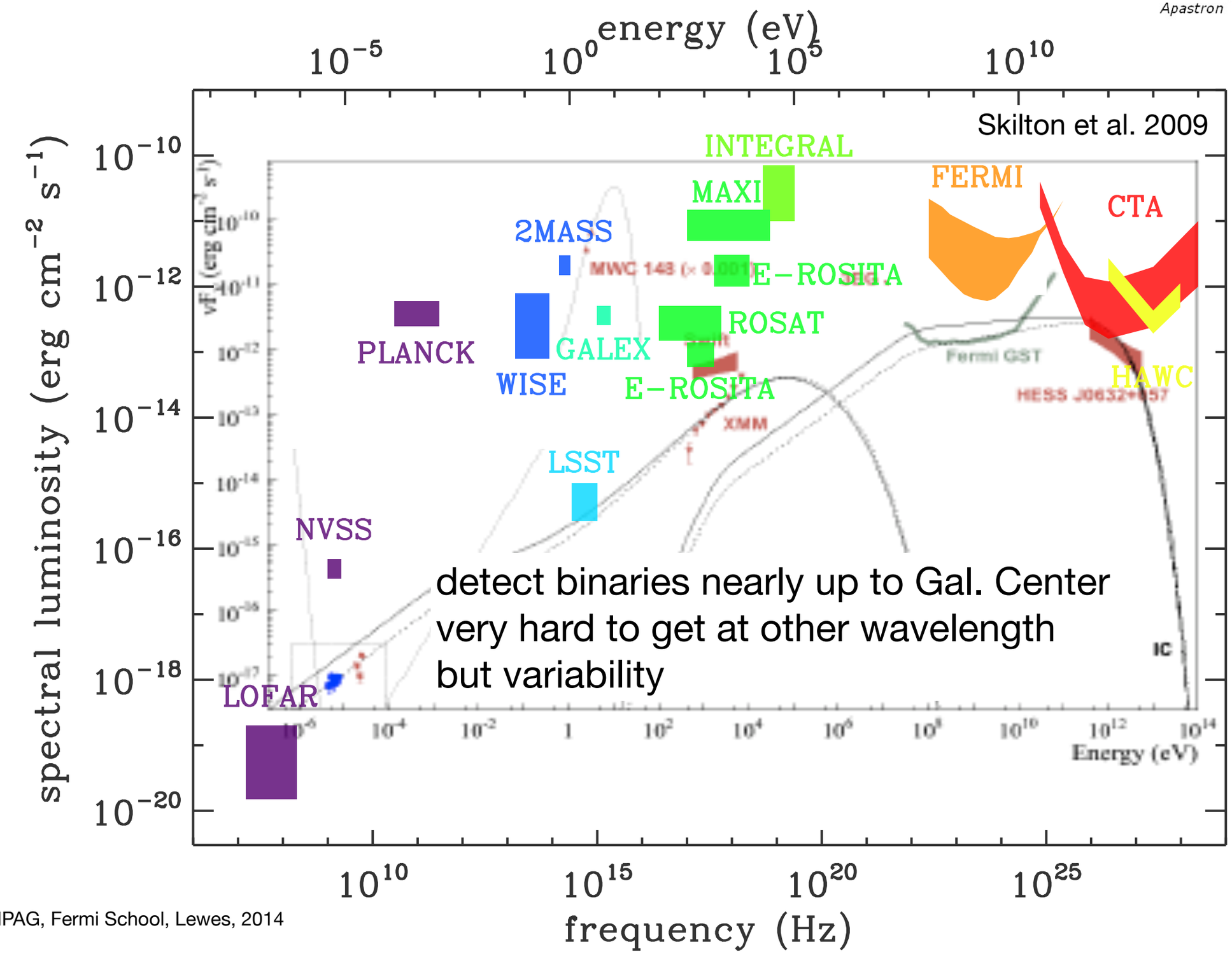
SNR: SN 1006




energy (eV)
spectral luminosity (erg cm^{-2} s^{-1})
frequency (Hz)
E dN/dE (eV cm^{-2} s^{-1})
Acero et al. 2010
INTEGRAL
Suzaku
MAXI
2MASS
E−ROSITA
FERMI
CTA
H.E.S.S.
PLANCK
GALEX
ROSAT
WISE
E−ROSITA
HAWC
LSST
NVSS
LOFAR
detected in survey
dedicated obs. for constraints at high E

Gamma-ray binary: HESS J0632 x 10 faint

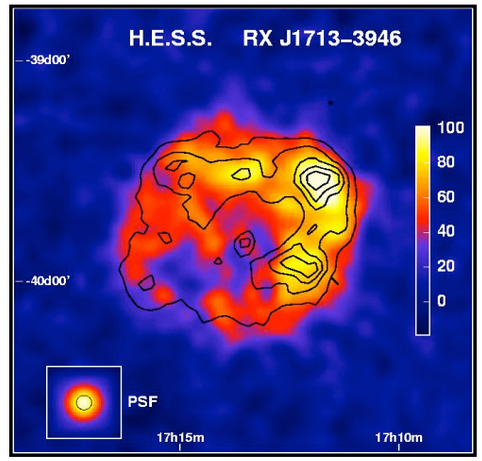


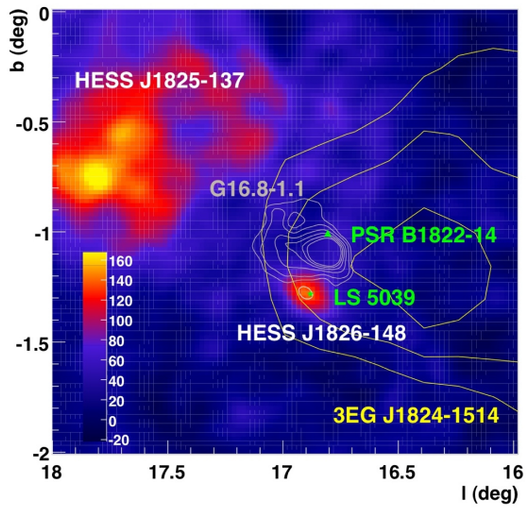


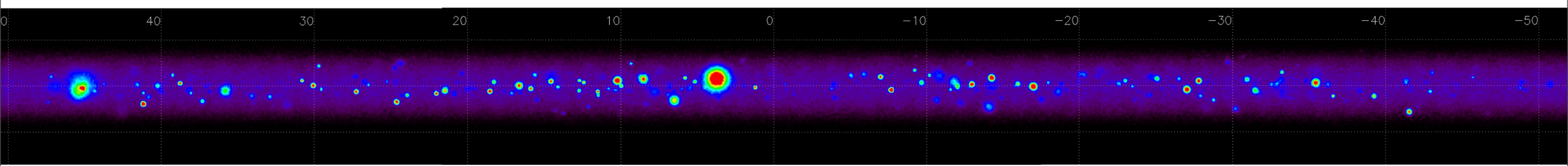
(inner) Galactic Plane survey

- **Several hundred sources accessible**
  - 300-600 PWNe population study
  - 20-70 SNR (only 7-15 resolved): PeVatron candidates
  - 20-30 binaries (optimise visit strategy for variability)
  - >70 sources based on extrapolation from Fermi-LAT
  - passive molecular clouds up to ~1 kpc
  - follow-up for morphology, spectra, variability

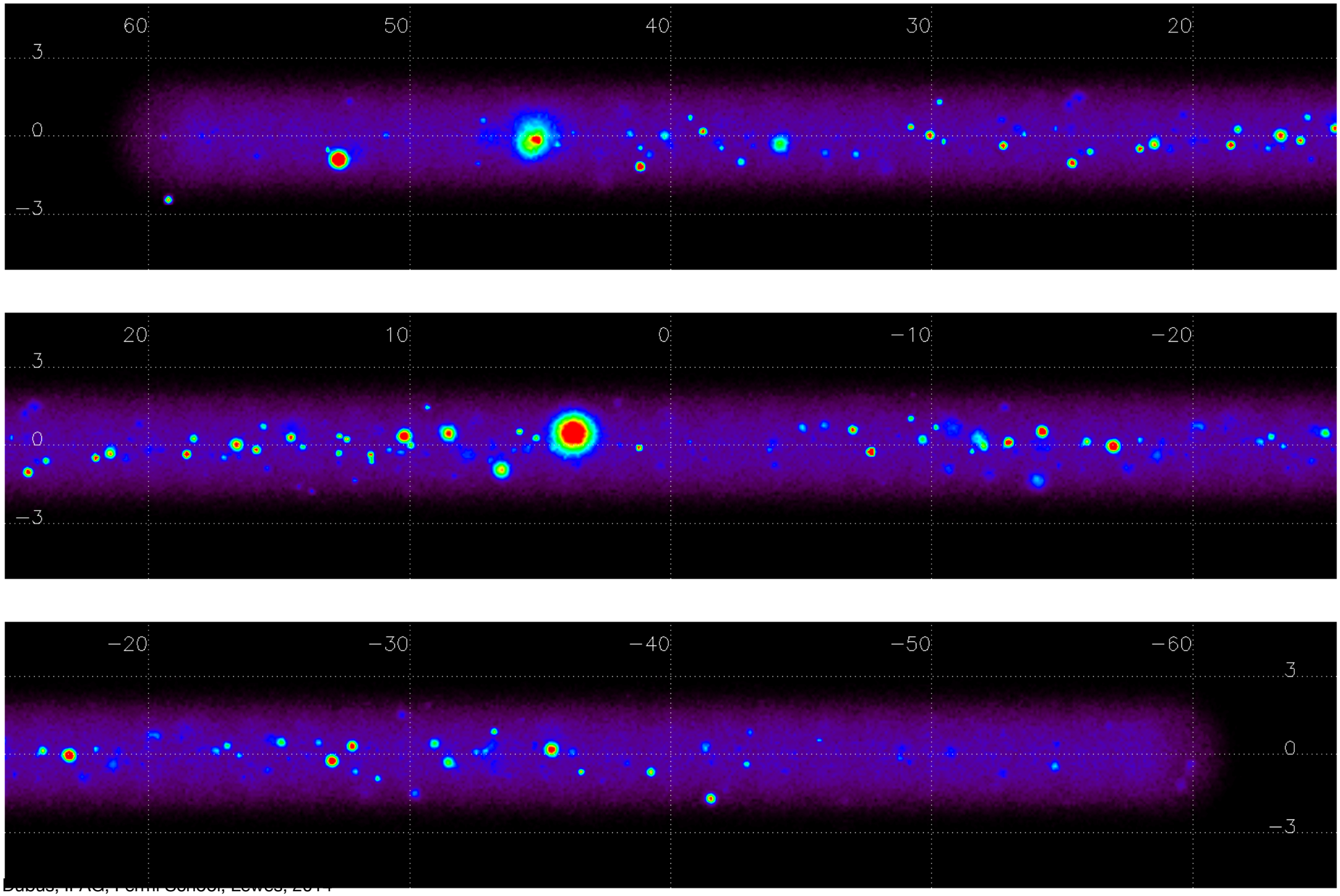
- **Source confusion**
  - ~3 sources per square degree
  - nearly all sources are extended





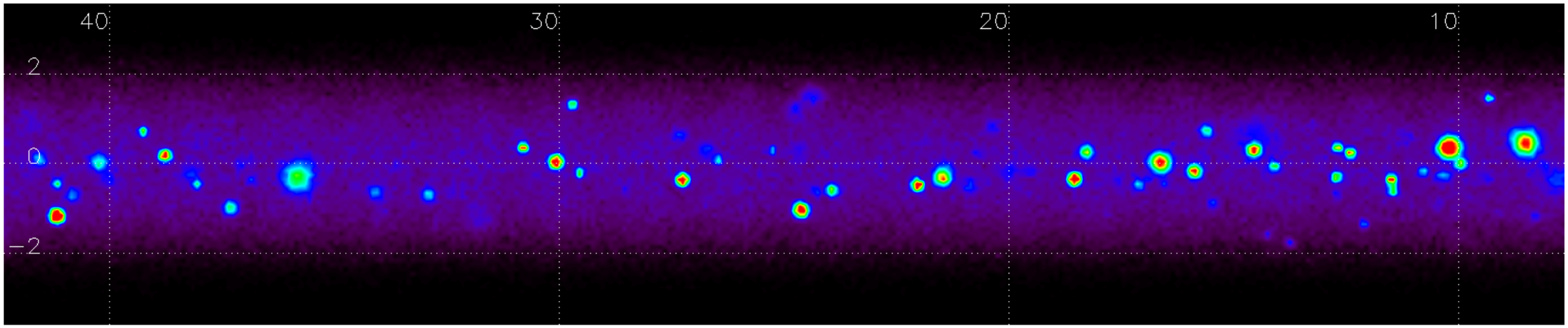


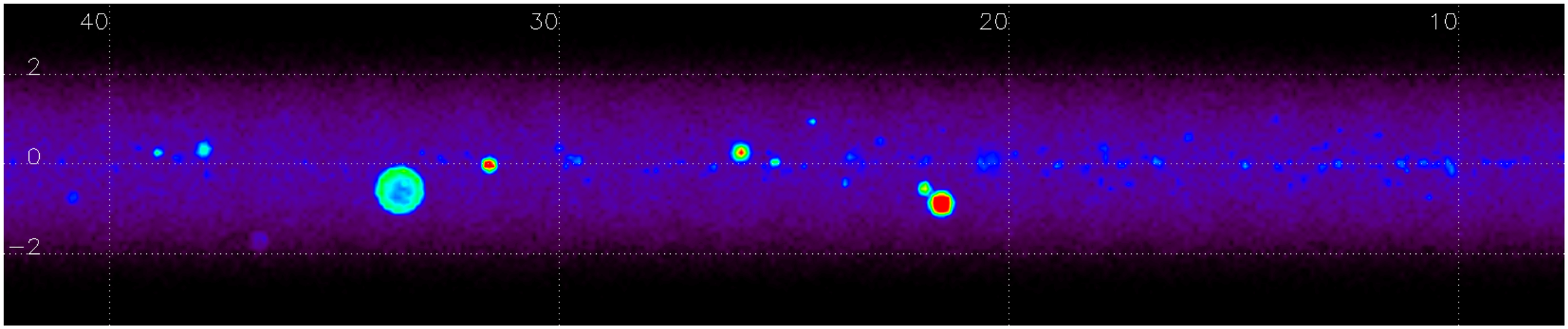
Simulated survey of Galactic Plane



Comparison different population inputs

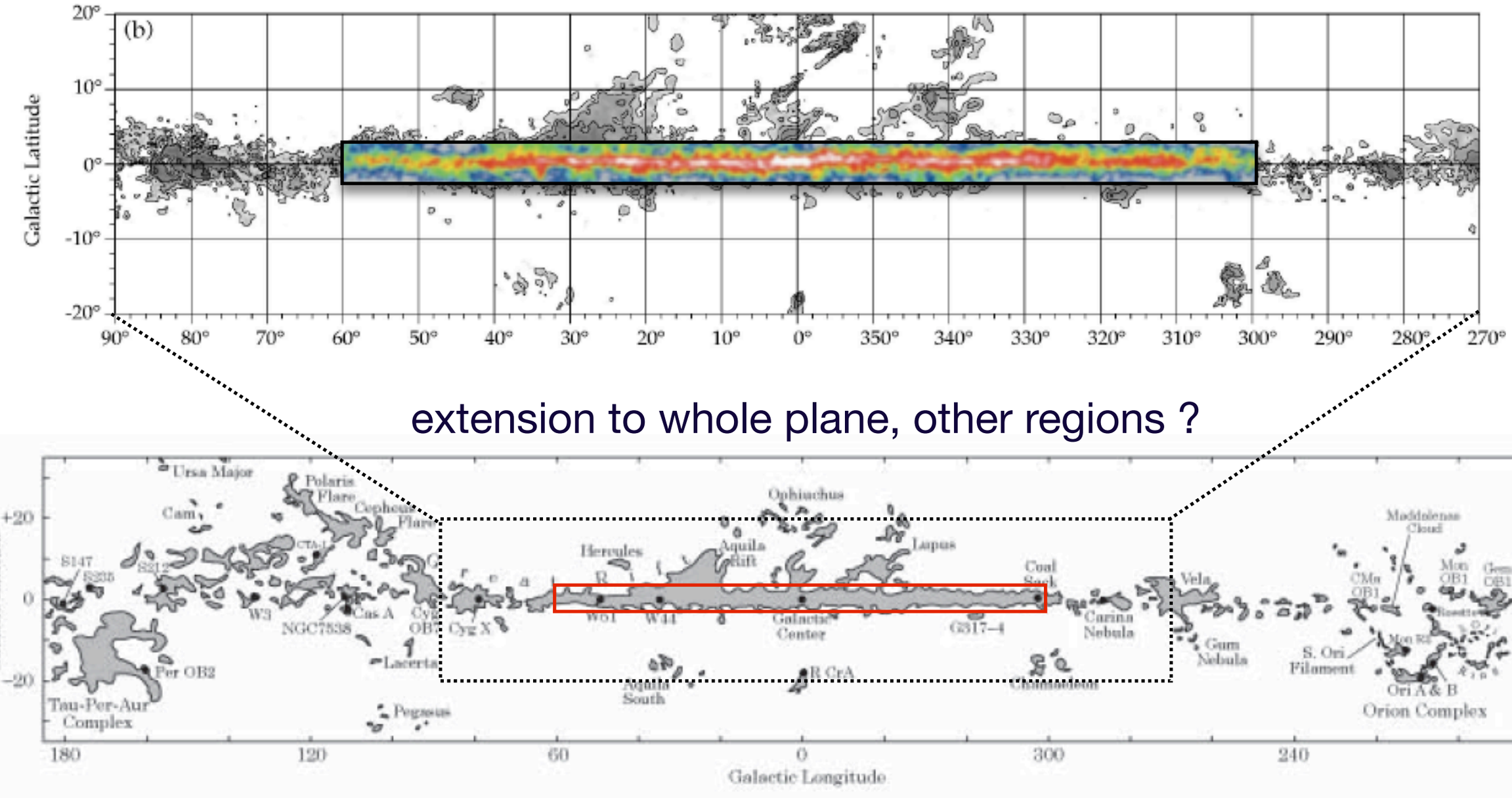
PWNe population input *M. Renaud et al.*





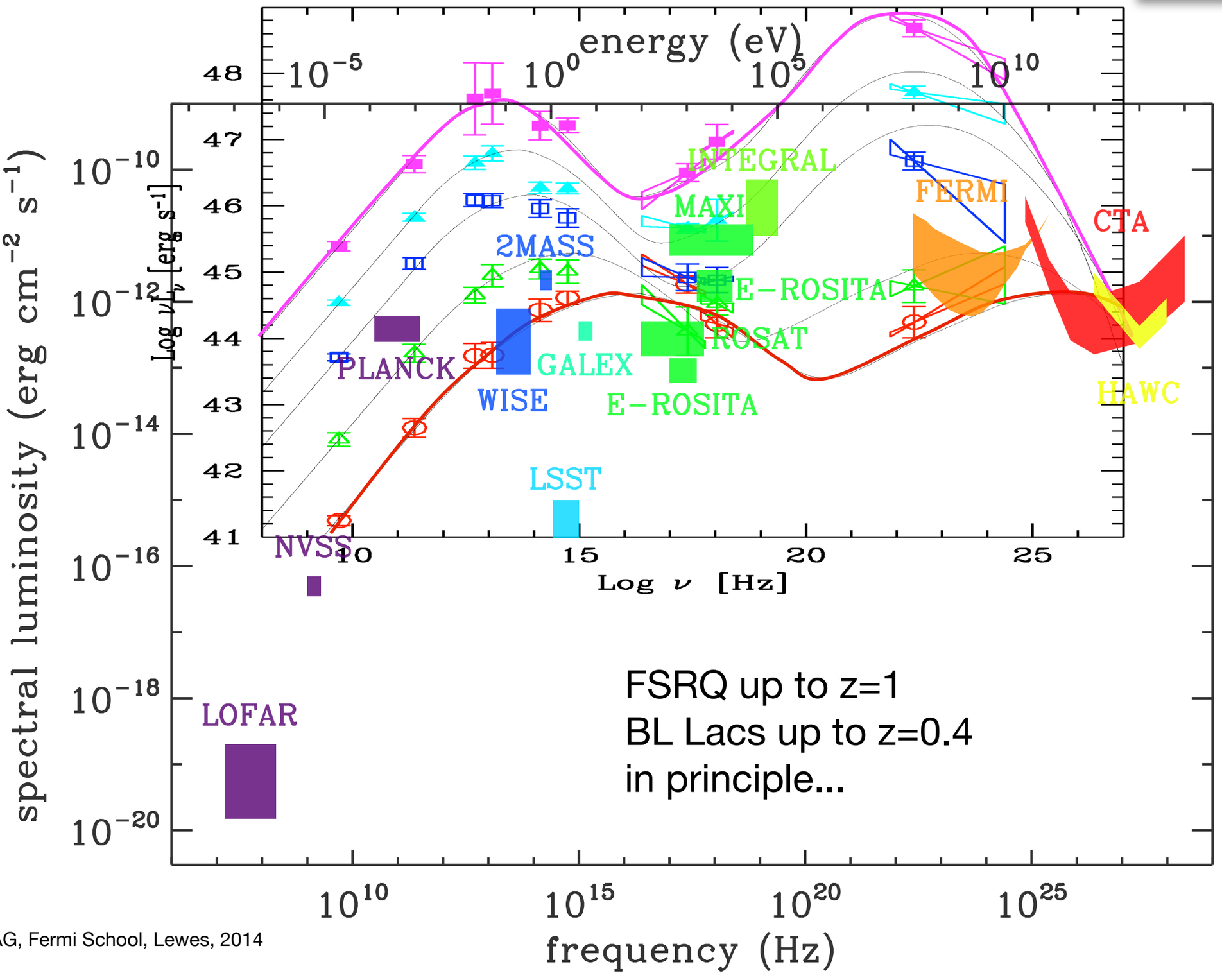
SNR+PWNe population input *S. Funk et al.*

(inner) Galactic Plane Survey in context



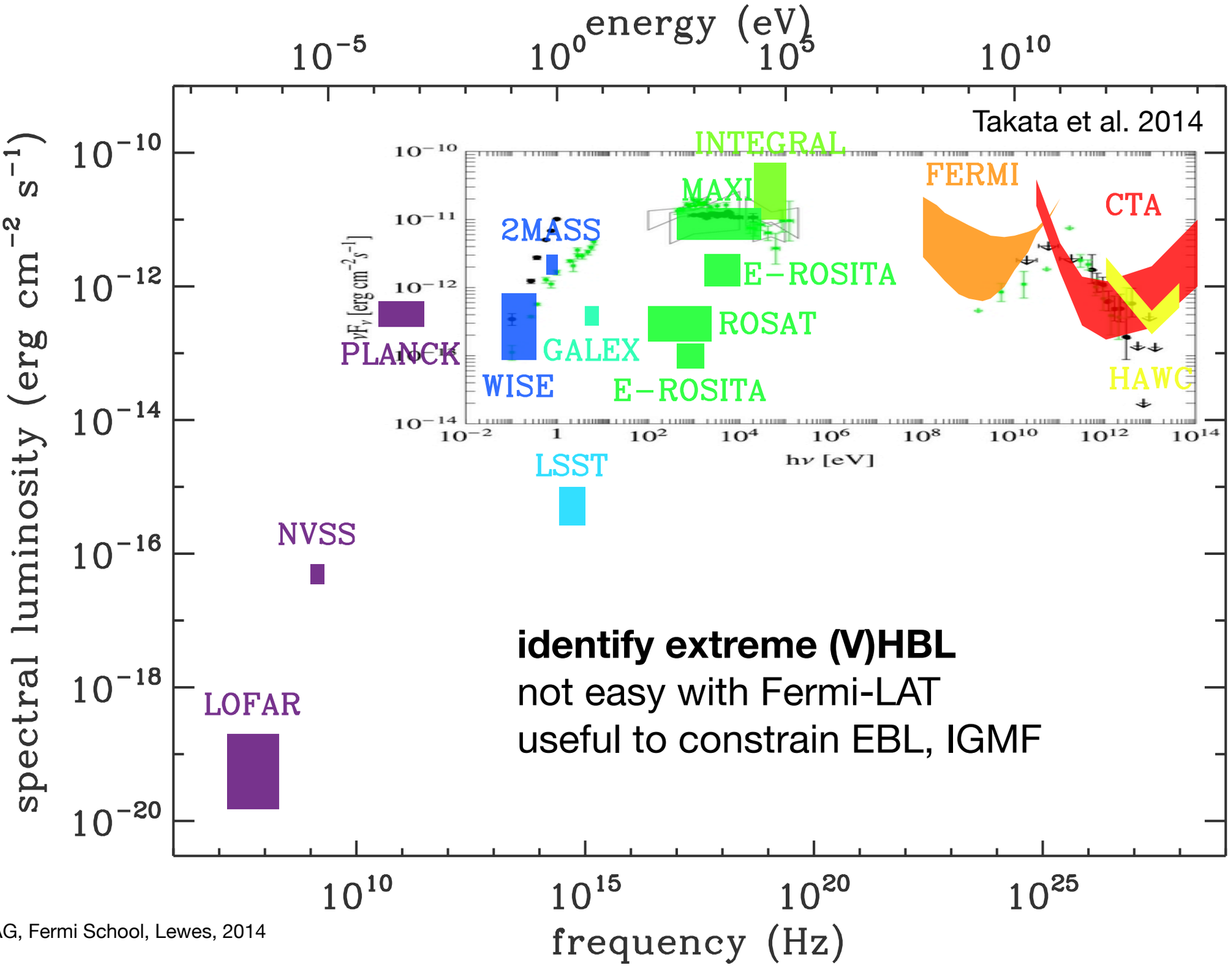
Dame et al. 2001 CO map

Blazar sequence



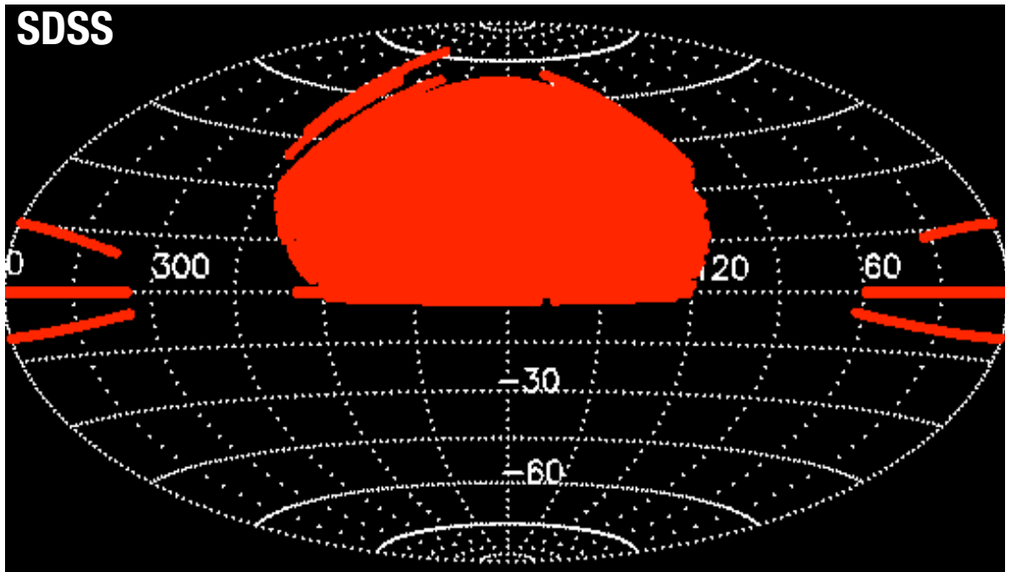
FSRQ up to z=1
BL Lacs up to z=0.4
in principle...

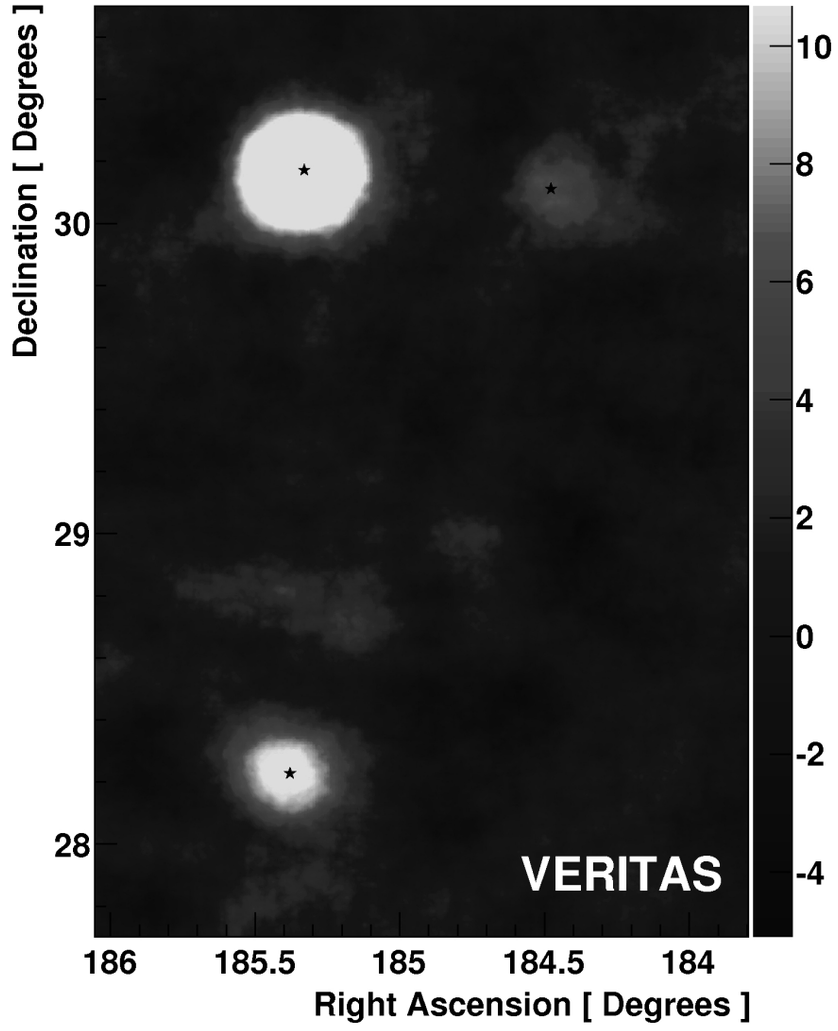
Extreme HBL: 1ES 0347-121



All-sky (“π”) survey

- **25% of the sky**
  - >2500 (50) AGN with z<0.2 (0.01)
  - ~2 Fermi-LAT sources per field





3 sources in same VHE extragalactic field (Benbow et al. 2011)

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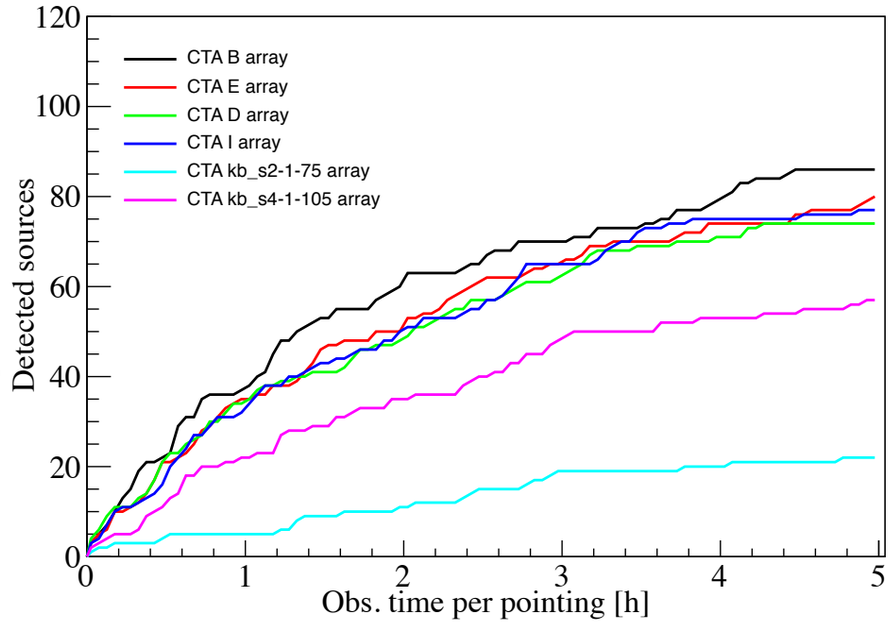

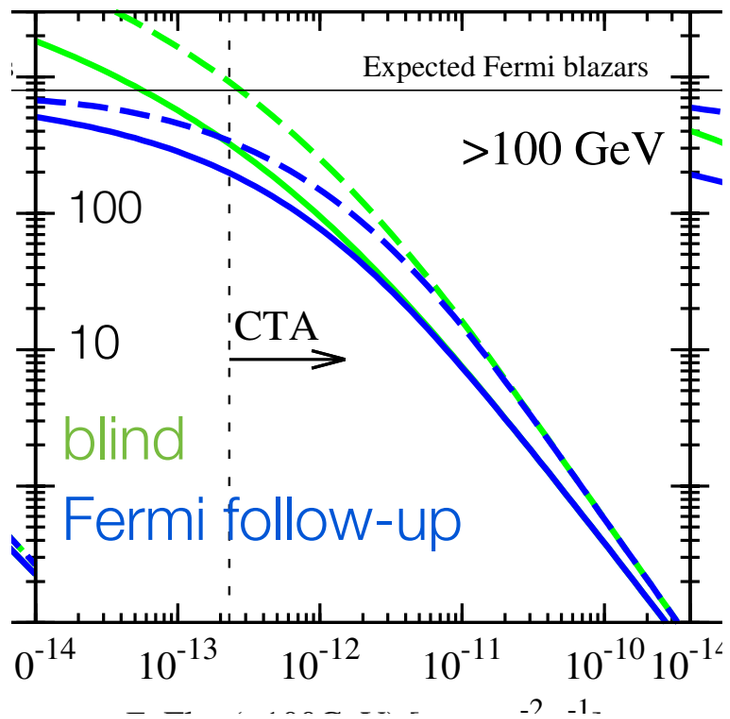

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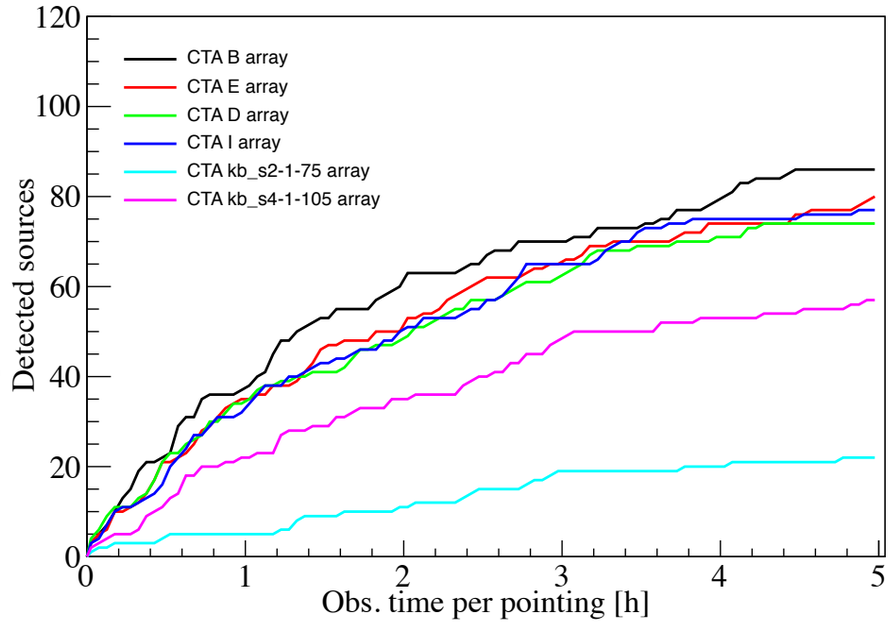

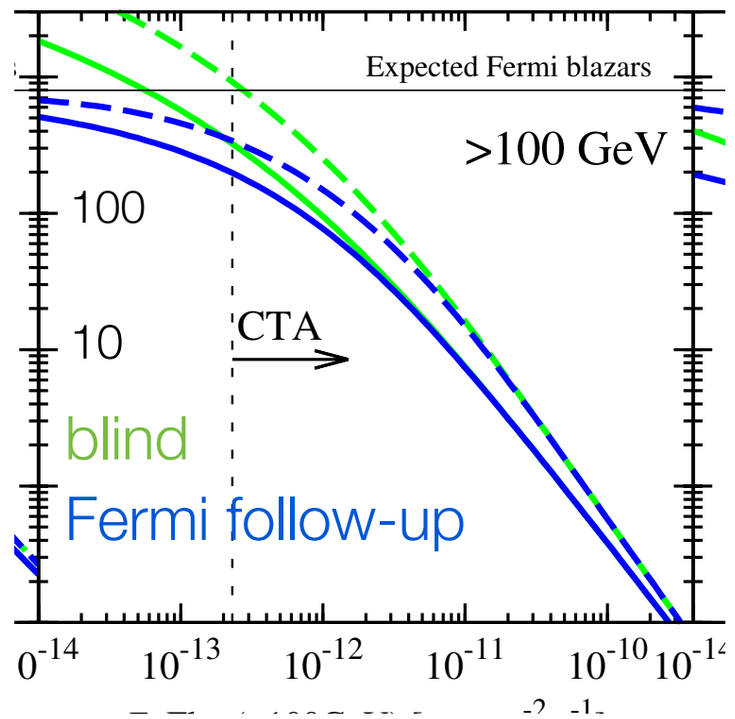

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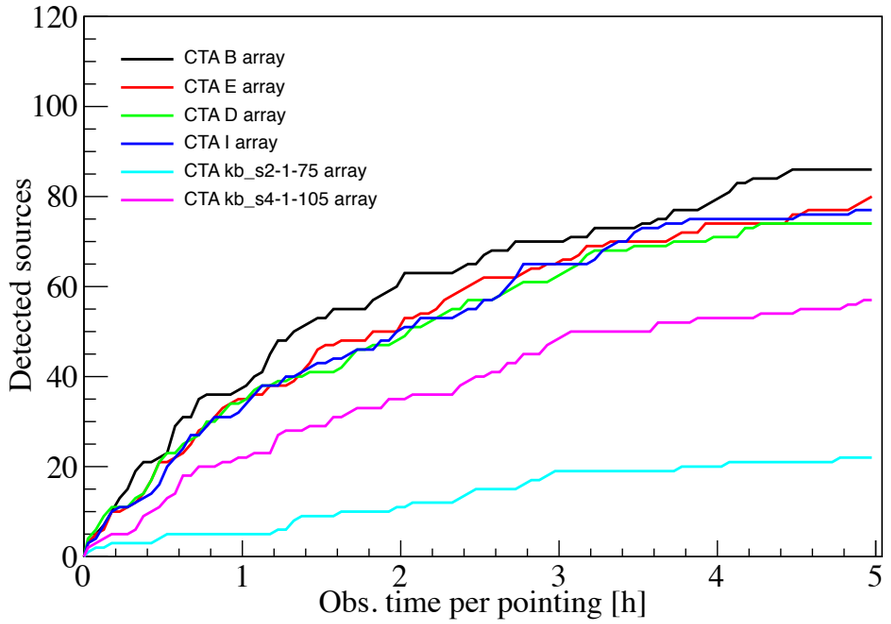
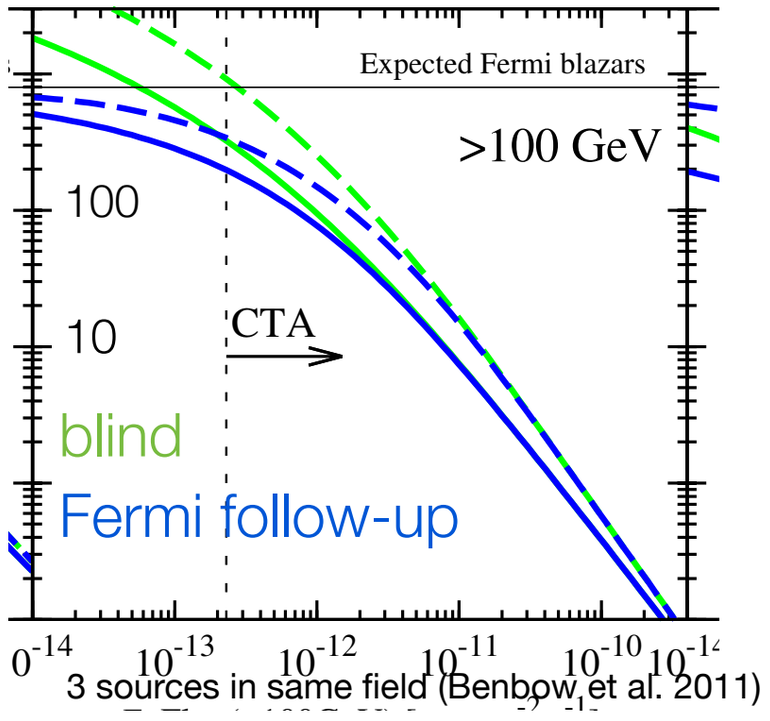
  - ⇒ **targeted surveys**

- need dedicated for clusters, starbursts, Magellanic
- no variability ⇒ HAWC

high-risk high-gain





3 sources in same field (Benbow et al. 2011)

Surveying the sky with

- **Surveys likely to be part of key science program of CTA**
  - best done by consortium
  - helps with open time proposals

- **“inner” Galactic plane**
  - down to 3 mCrab in 240 hr (prod1), 10x improvement
  - (very) high density of sources
  - PWN population study, candidate PeVatrons, binaries...
  - extend to full plane, other regions (Cygnus, Magellanic clouds,...) ?

- **All-sky “π” survey**
  - can be done, 22 mCrab in 370 hr (prod1), complement Fermi, HAWC
  - high-risk high-gain ⇒ mitigate cost with divergent pointing ?

currently under discussion