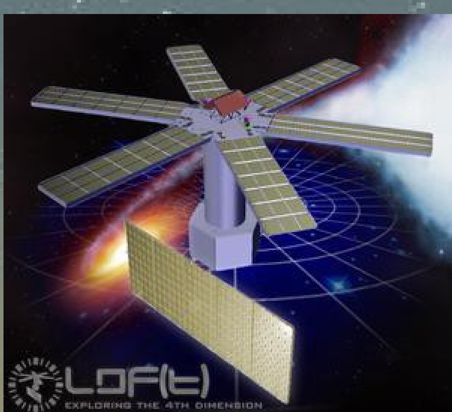
From high energy to highest energy: gamma-ray astronomy and LOFT

Rhaana Starling
University of Leicester

with thanks to
Richard White, Jim Hinton, Stefan Ohm and Paul O'Brien



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THE ROYAL SOCIETY

Production mechanisms include

- IC scattering of energetic electrons on soft photons
- Decay of neutral pions created during interactions of accelerated protons and nuclei
- Bremss emission when electrons interact with surrounding medium

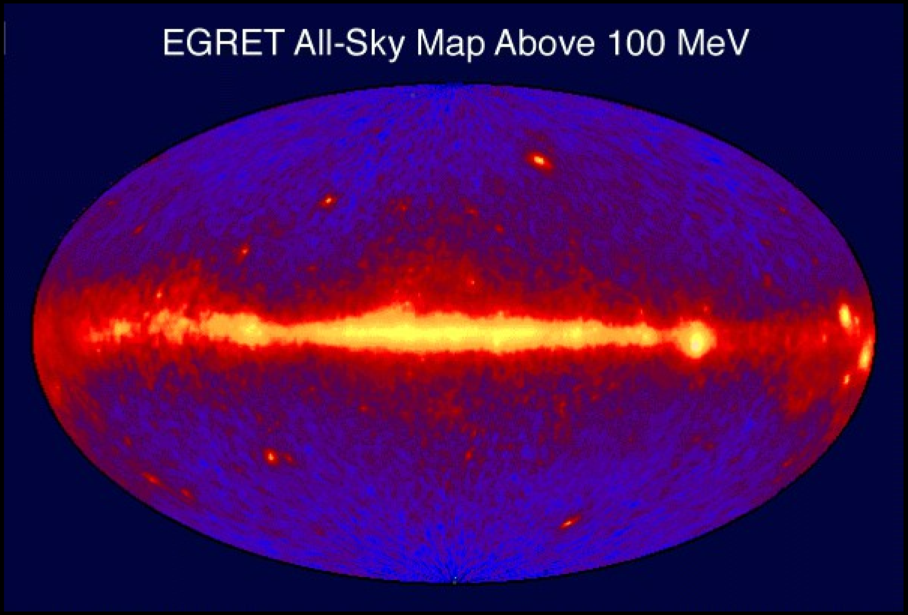
i.e. protons as well as electrons are probed via HE gamma-rays

VHE neutrinos (eg IceCube) and UHE protons (eg Pierre Auger) also probe HE phenomena

image: IoP

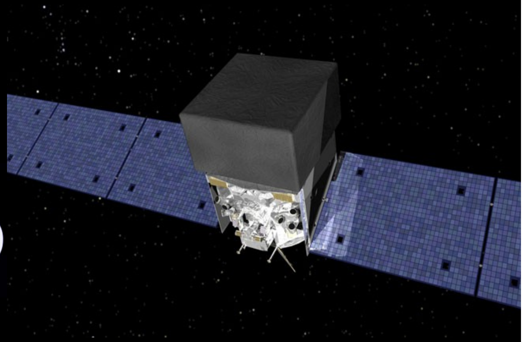
The 'high energy' gamma-ray sky

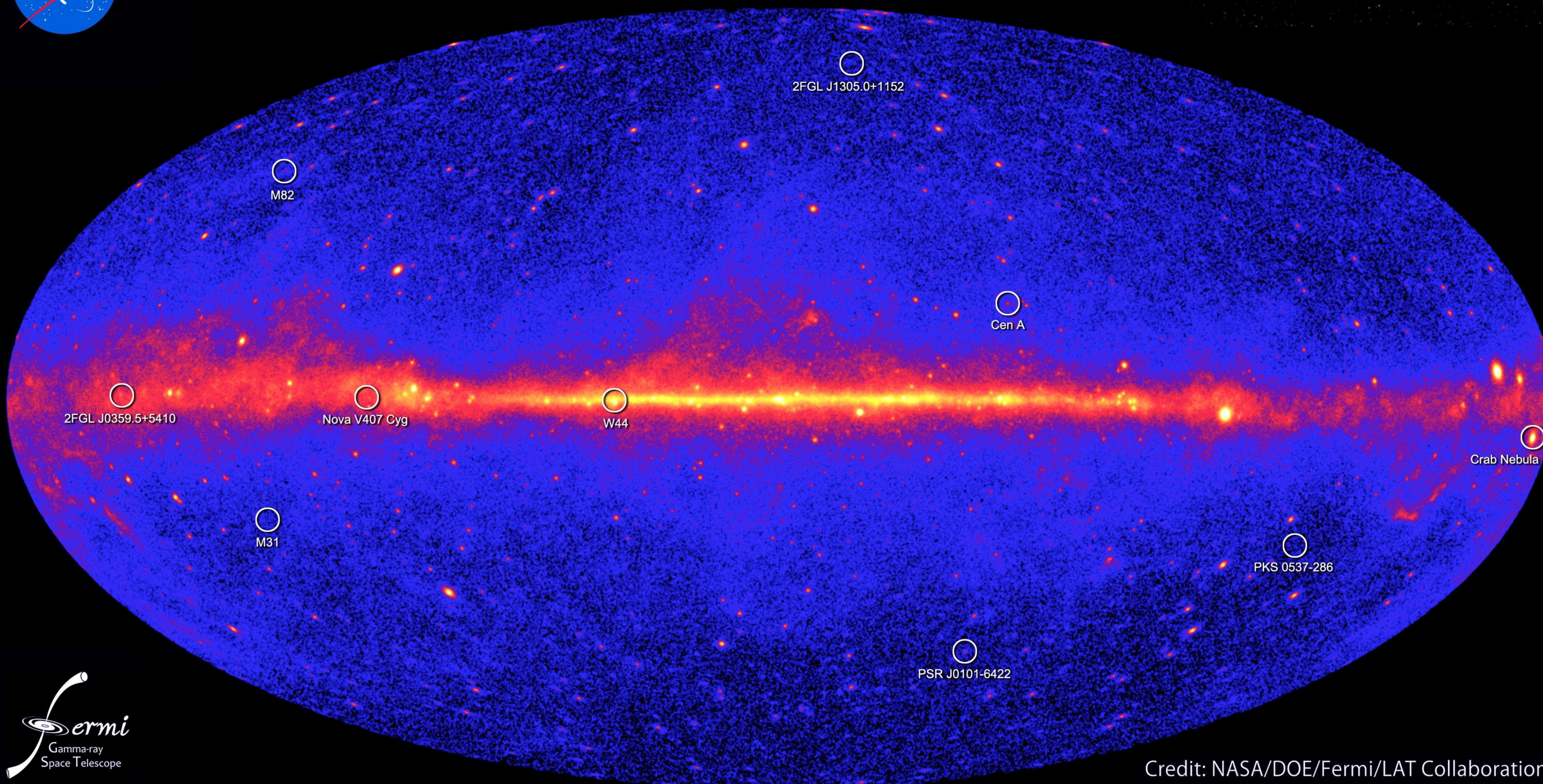
Observed since 60's but field took off in 90's with the first >100 MeV all-sky map by EGRET



Large Area Telescope (LAT) since 2008
100 MeV-100 GeV

Fermi two-year all-sky map



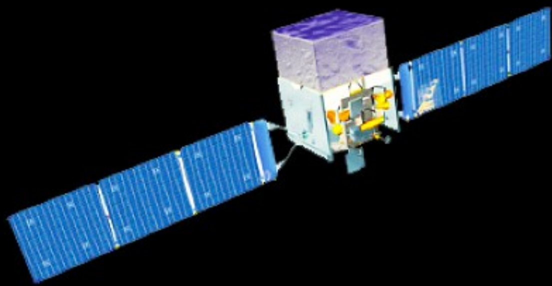


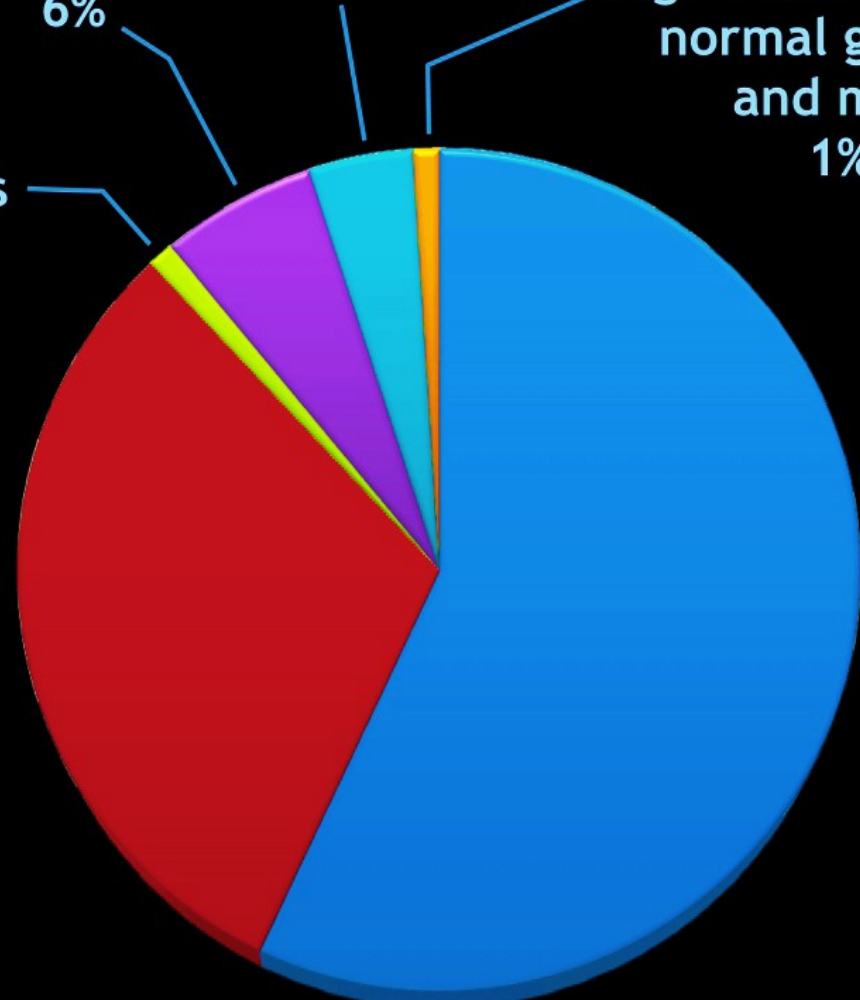
Fermi
Gamma-ray
Space Telescope

Credit: NASA/DOE/Fermi/LAT Collaboration

Nolan et al. 2012, ApJS, 199, 31
1873 point sources, 100 MeV – 100 GeV
>50% AGN; many transients incl. GRBs

What has Fermi found: The LAT two-year catalog



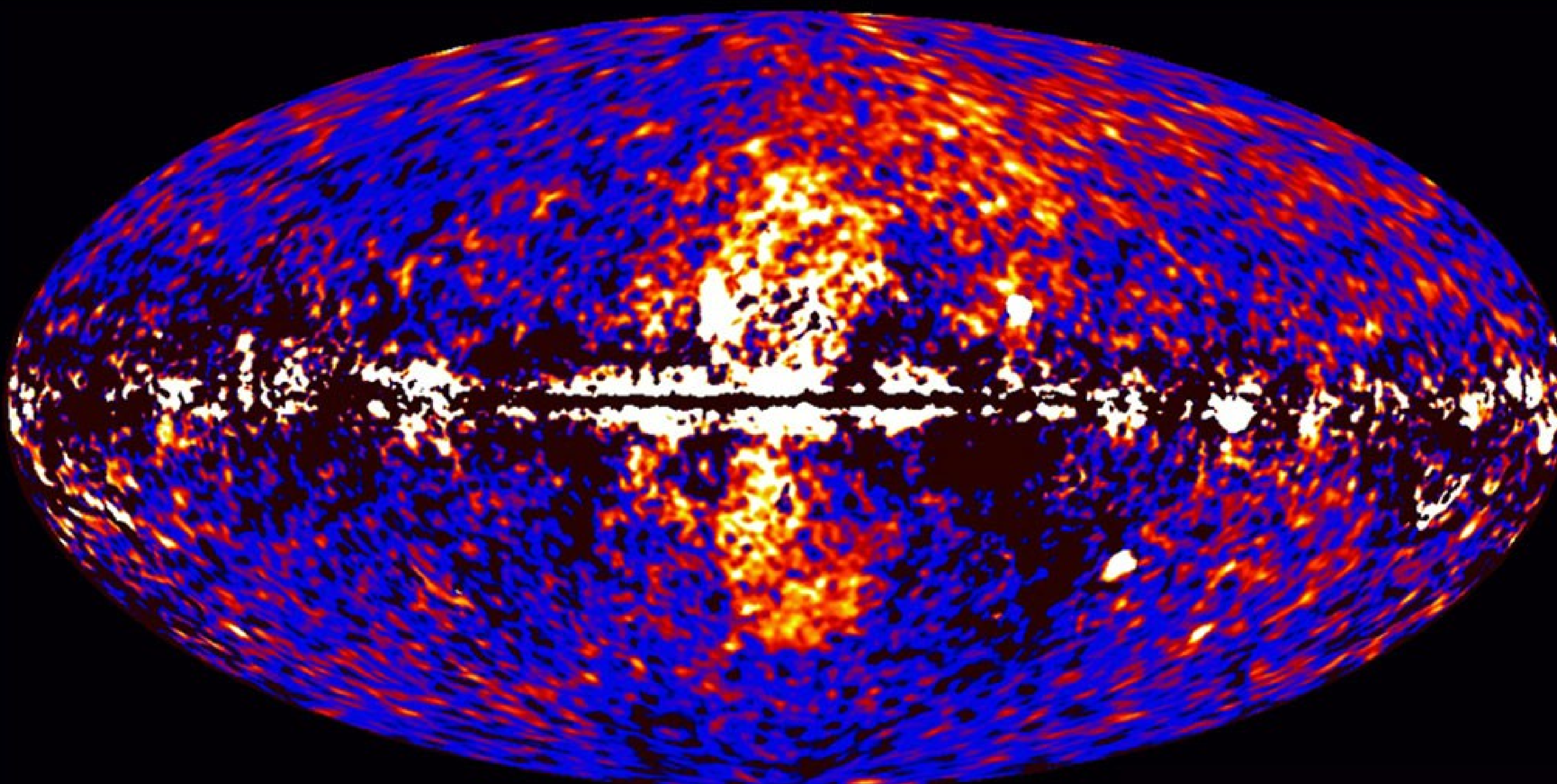


Credit: NASA/Goddard Space Flight Center

Fermi bubbles

giant gamma-ray lobes from the Milky Way

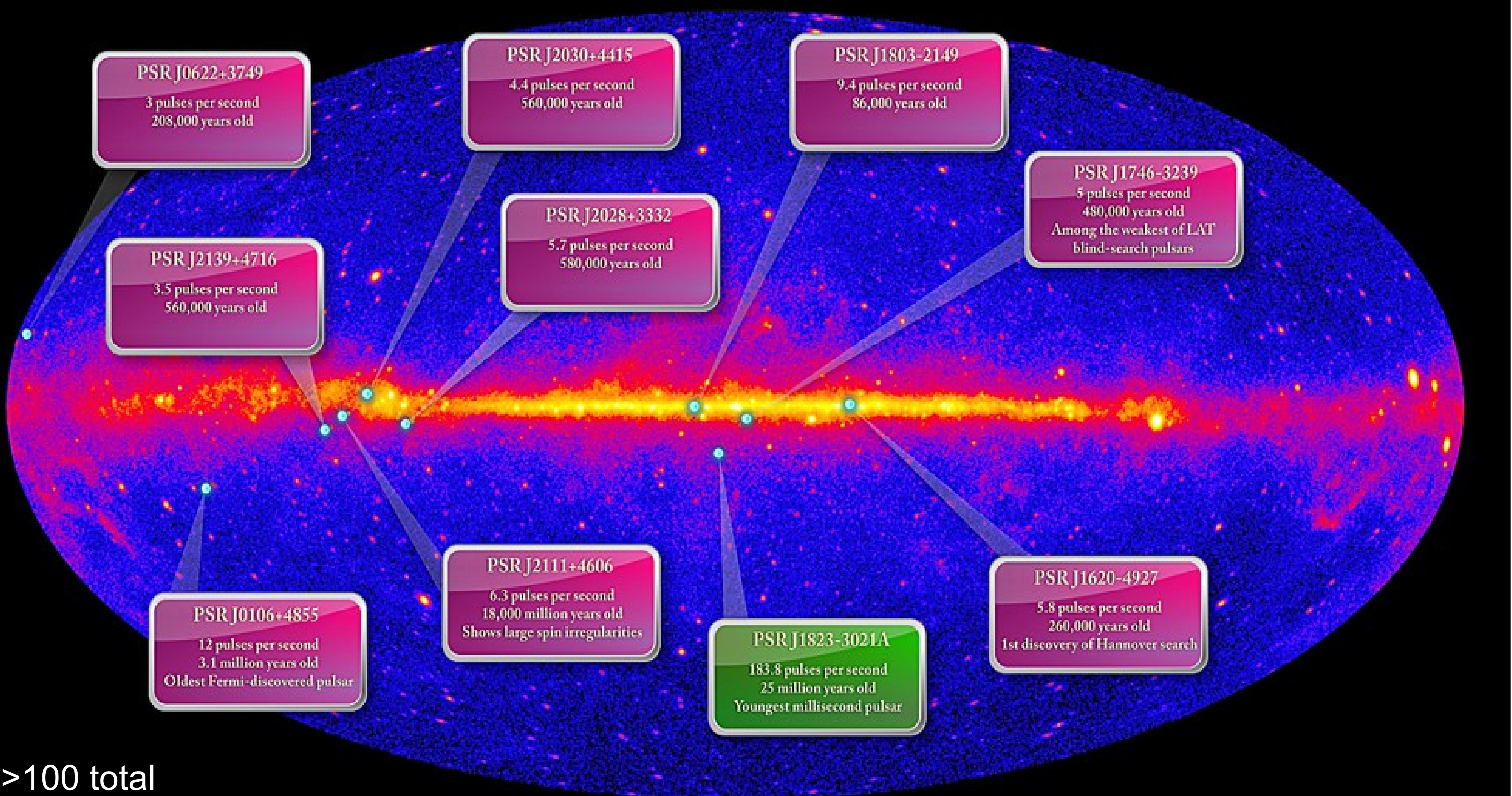
edges visible in ROSAT and radio
<10 million years old
sudden impulsive event: star formation or AGN activity?



Credit: NASA/DOE/Fermi LAT/
D. Finkbeiner et al.

Timing key to resolving brightest regions of the sky

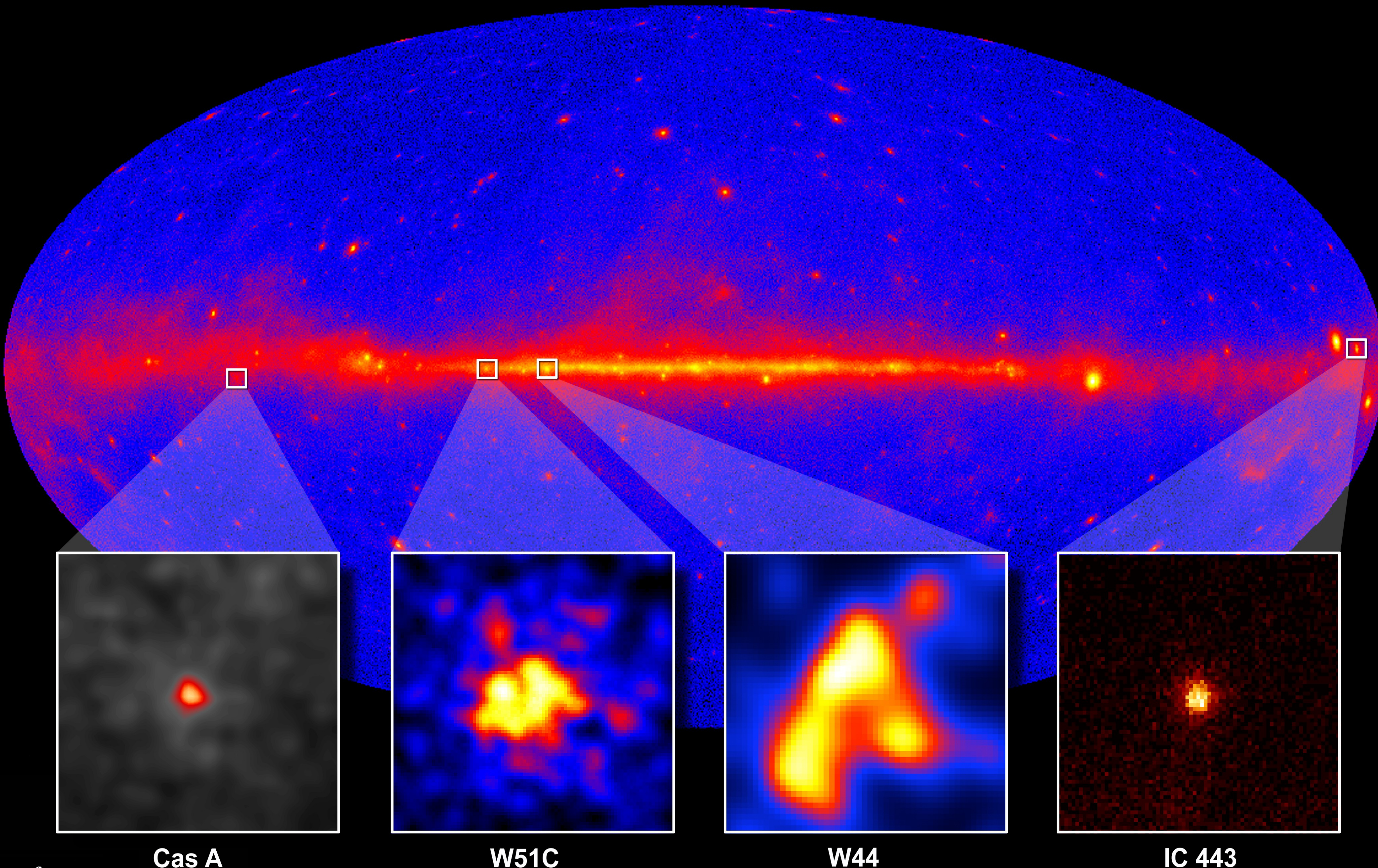
Fermi's 9 Newest Pulsars and the Youngest Millisecond Pulsar Known



>100 total
About ½ seen in X-rays

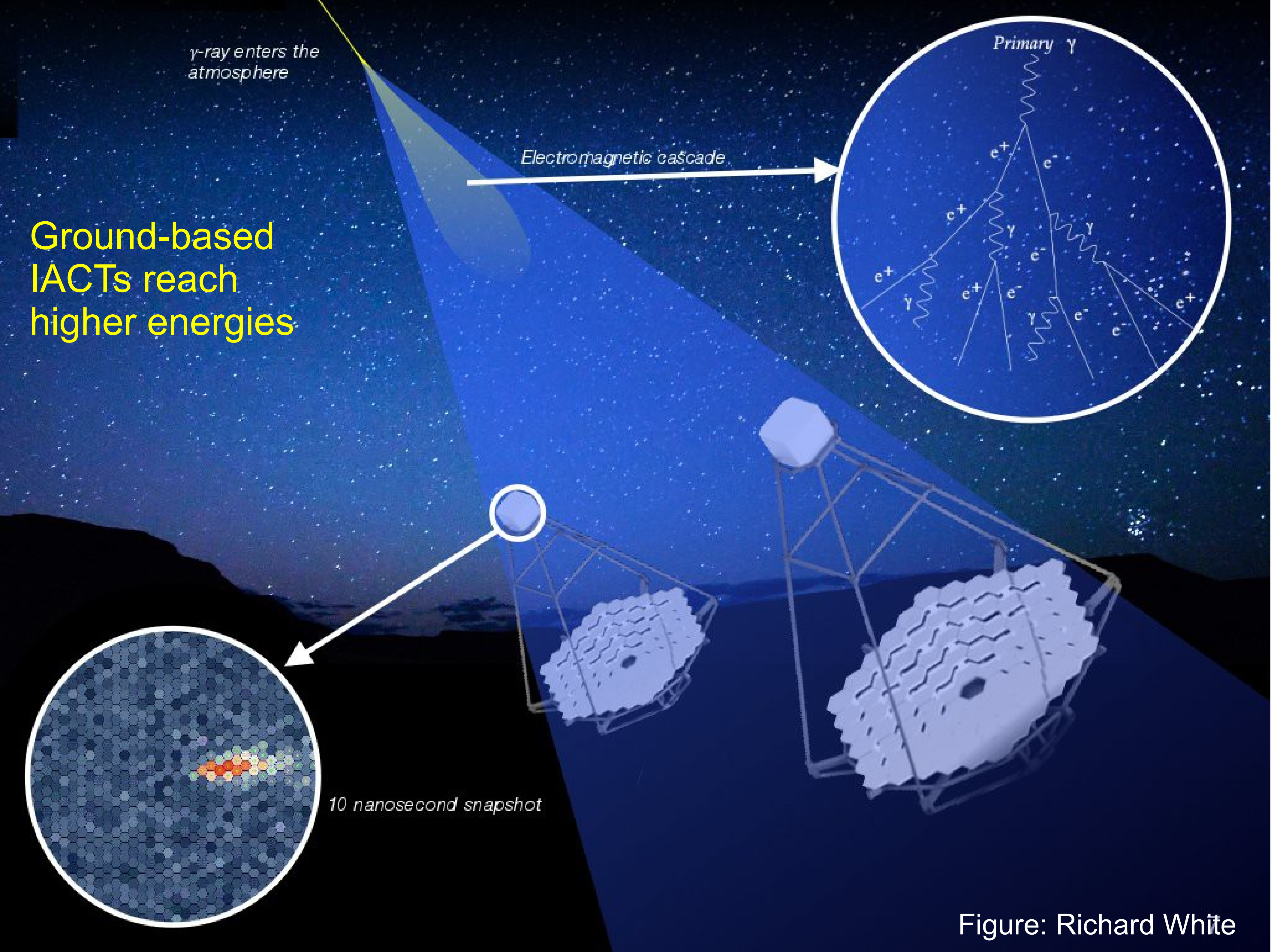
Credit: NASA/DOE/Fermi LAT

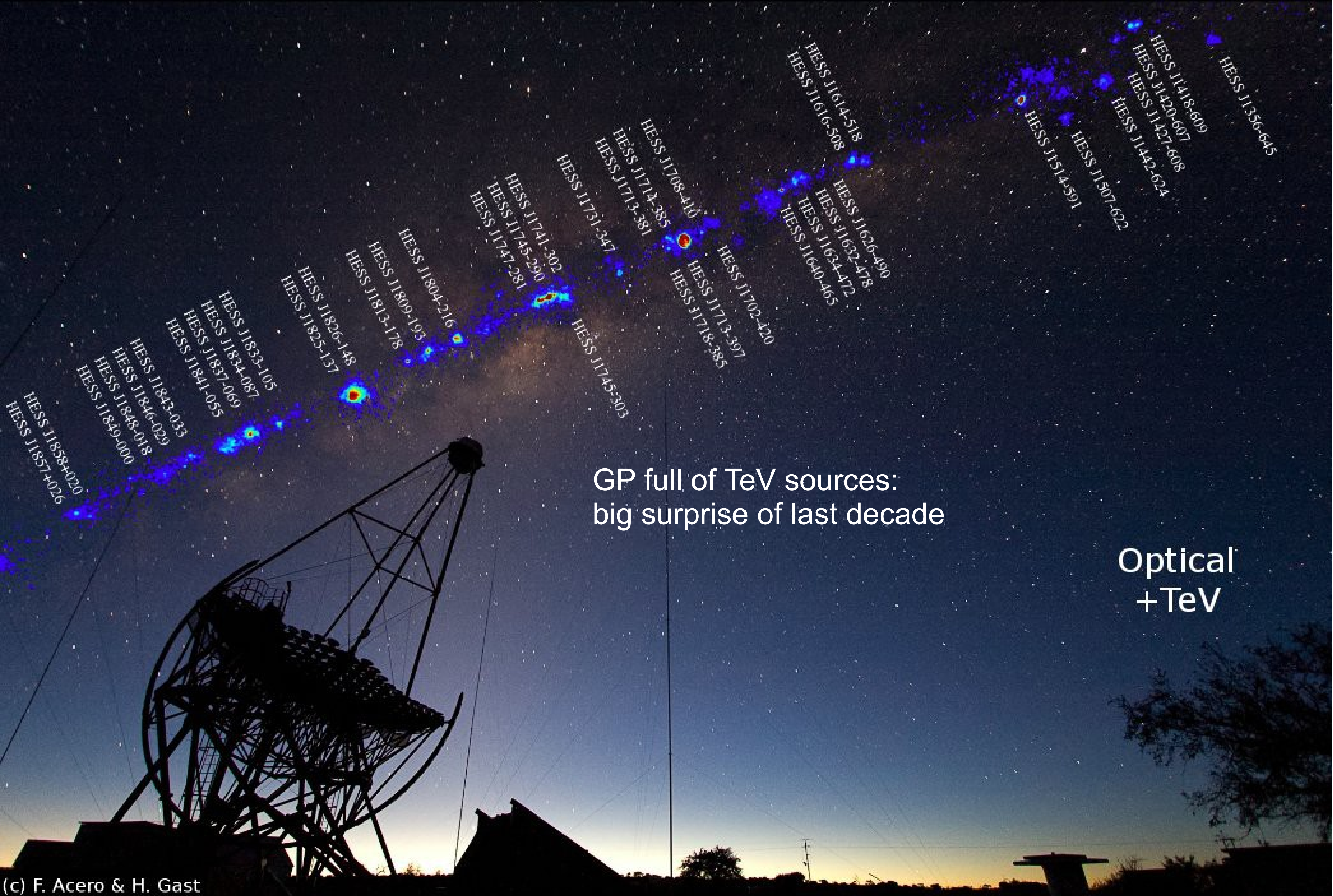
NASA's Fermi telescope resolves supernova remnants at GeV energies



Discovering the sites of cosmic ray acceleration in our MW

Credit: NASA/DOE/
Fermi LAT


Ground-based IACTs reach higher energies
γ-ray enters the atmosphere
Electromagnetic cascade
Primary γ
e+
e-
γ
10 nanosecond snapshot
Figure: Richard White


HESS J1857+026
HESS J1858+020
HESS J1849-000
HESS J1848-018
HESS J1846-029
HESS J1843-033
HESS J1841-055
HESS J1837-069
HESS J1834-087
HESS J1833-105
HESS J1825-137
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HESS J1813-178
HESS J1809-193
HESS J1804-216
HESS J1747-281
HESS J1745-290
HESS J1741-302
HESS J1745-303
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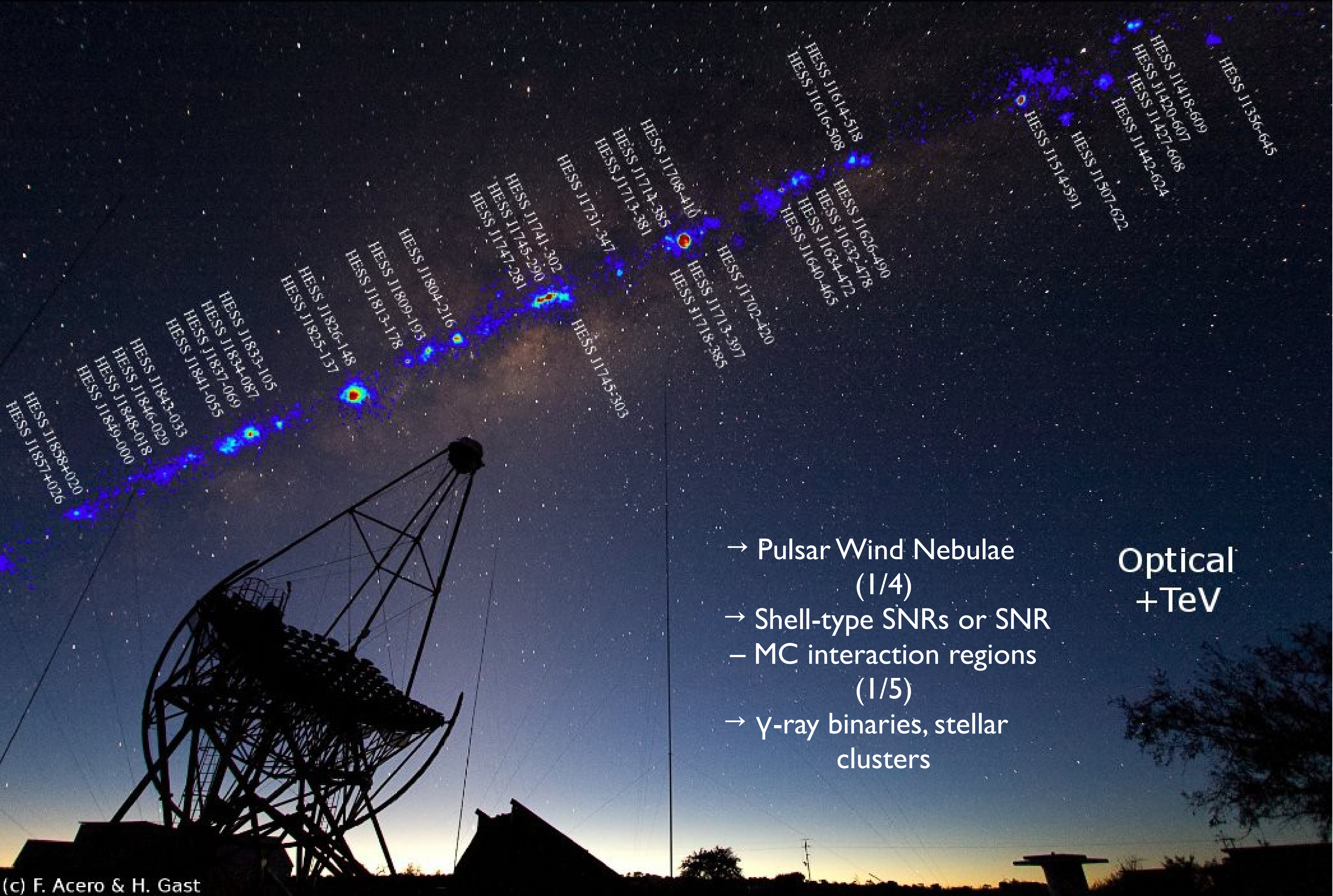
HESS J1714-385
HESS J1708-410
HESS J1718-385
HESS J1713-397
HESS J1702-420
HESS J1640-465
HESS J1634-472
HESS J1632-478
HESS J1626-490
HESS J1616-508
HESS J1614-518
HESS J1514-591
HESS J1507-622
HESS J1442-624
HESS J1427-608
HESS J1420-607
HESS J1418-609
HESS J1356-645
GP full of TeV sources:
big surprise of last decade
Optical
+TeV
(c) F. Acero & H. Gast



HESS J1356-645
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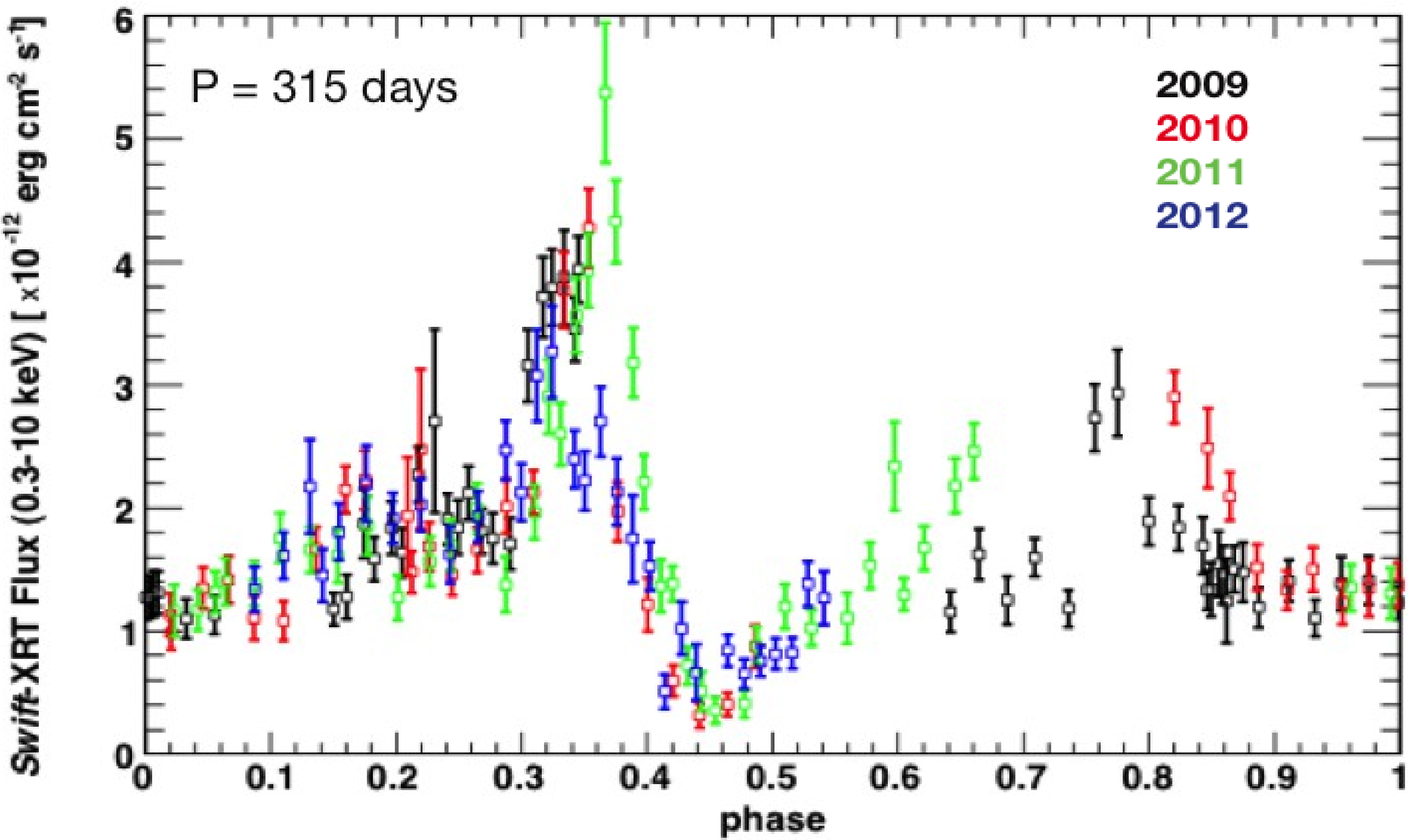
HESS J1846-029
HESS J1848-018
HESS J1849-000
HESS J1858+020
HESS J1857+026
→ Pulsar Wind Nebulae (1/4)
→ Shell-type SNRs or SNR – MC interaction regions (1/5)
→ γ-ray binaries, stellar clusters
Optical +TeV
(c) F. Acero & H. Gast

HESS J0632+057: first binary detected via VHE gamma-rays

- Compact object + Be star binary
- TeV point source discovered by HESS
- Swift follow-up showed long time-scale periodic behaviour in X-rays
- joint campaign with HESS and VERITAS confirmed this

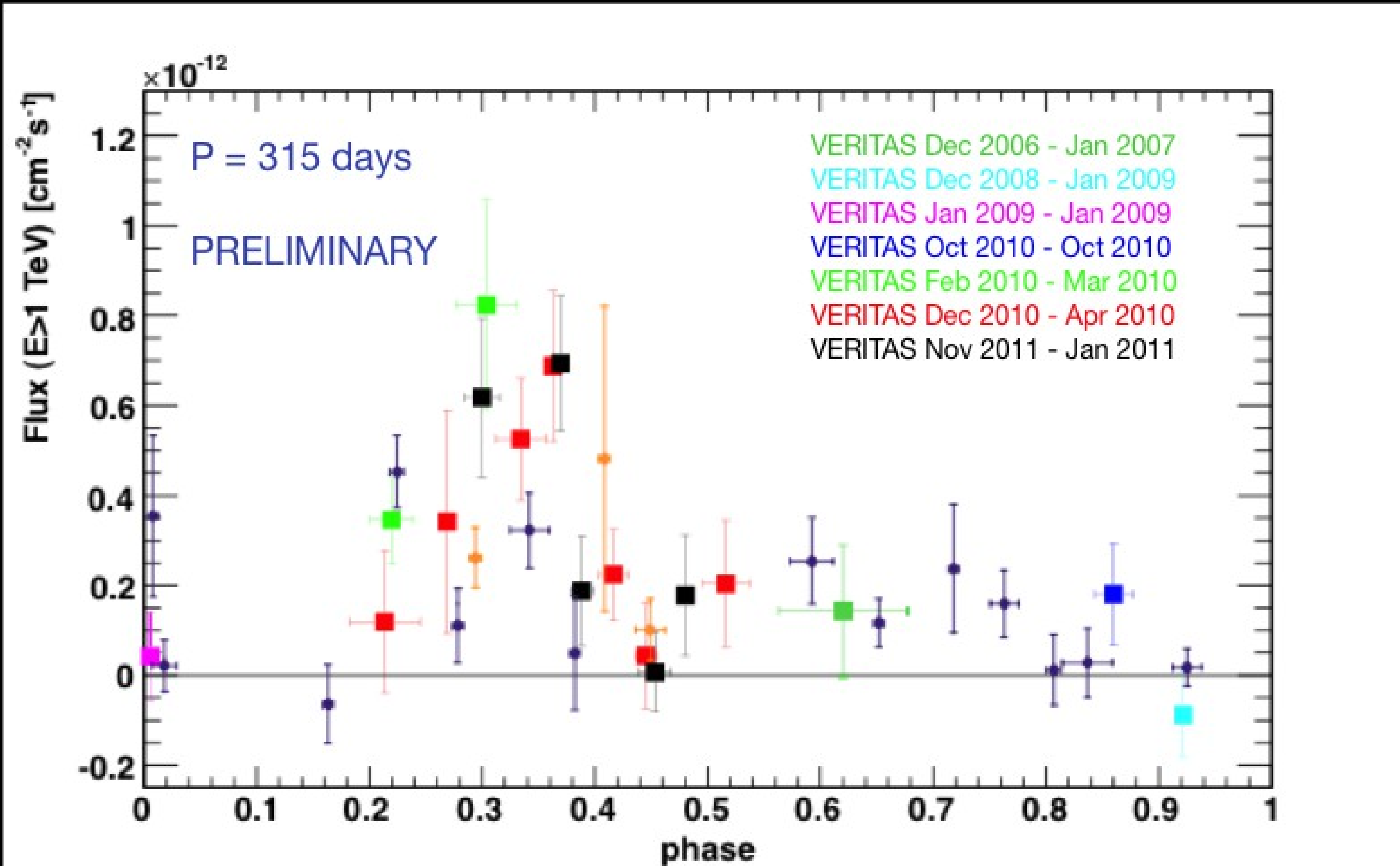
Only a handful of TeV binaries known: TeVs may come from pulsar winds driving shock acceleration or accretion driving a microquasar jet

HESS J0632+057: Swift XRT monitoring



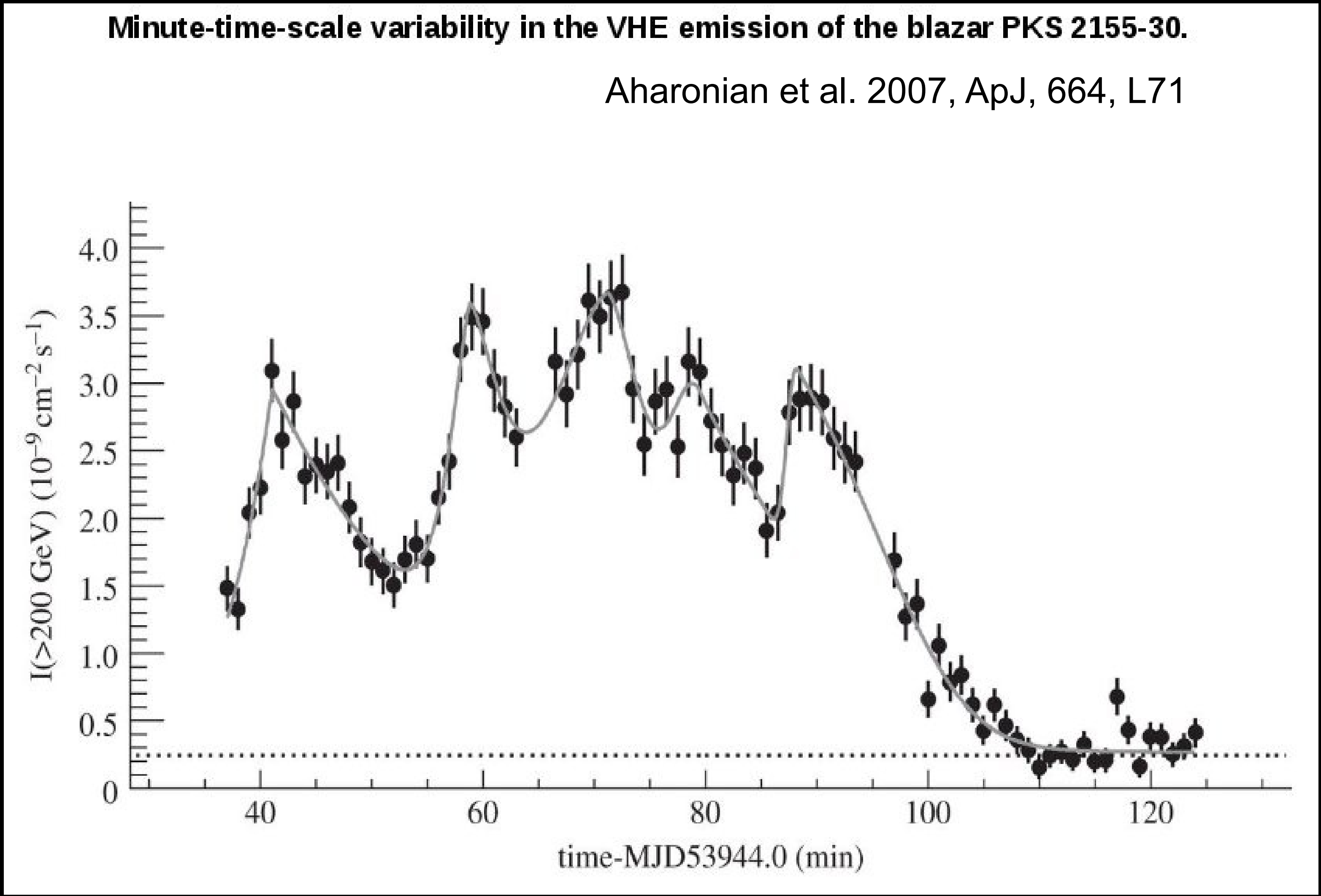
Adapted from Bongiorno et al. 2011, ApJ, 737, L11

HESS J0632+057: HESS+VERITAS monitoring

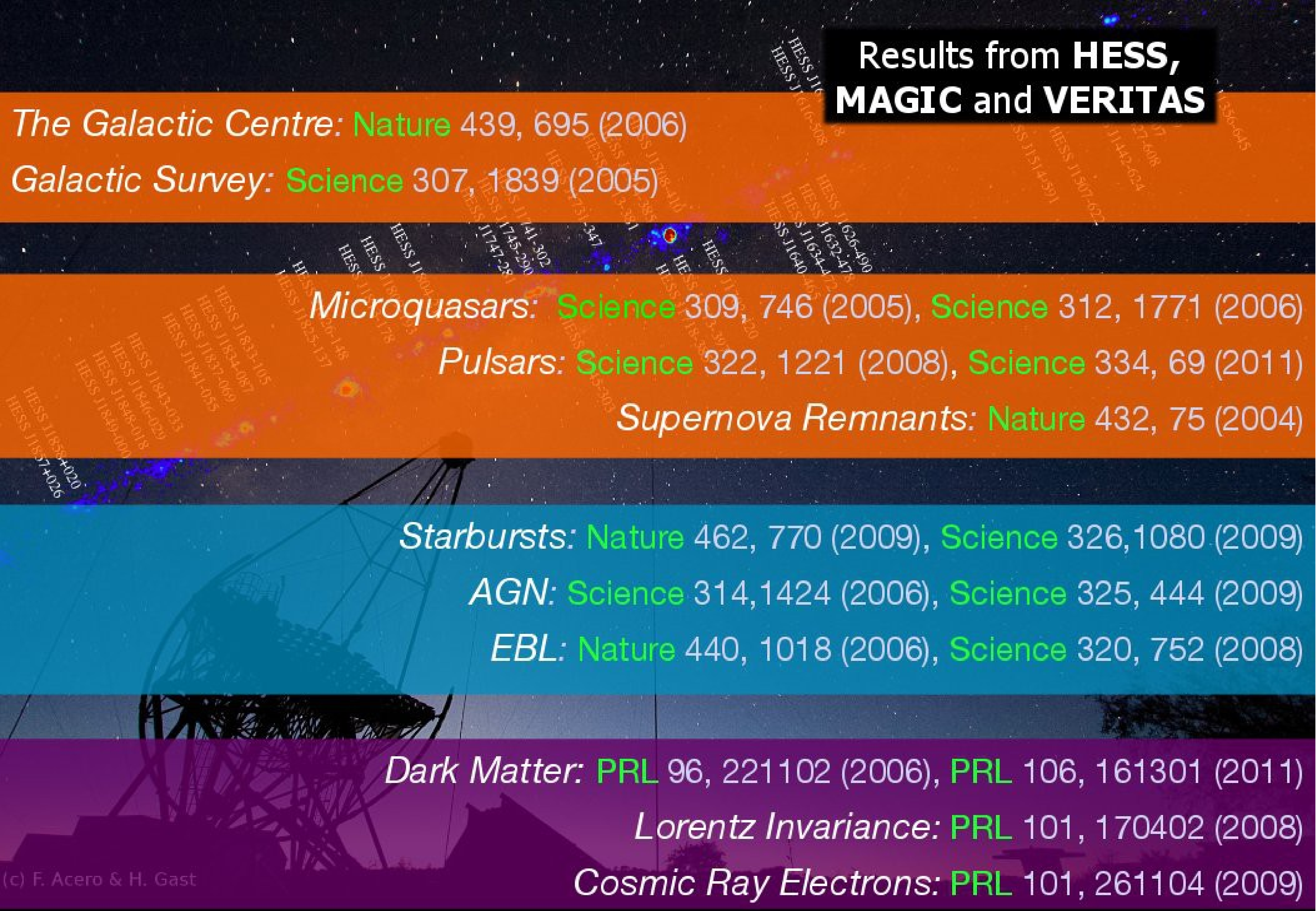


Slide from Stefan Ohm & collaborators

High frequency peaked BL Lac PKS 2155



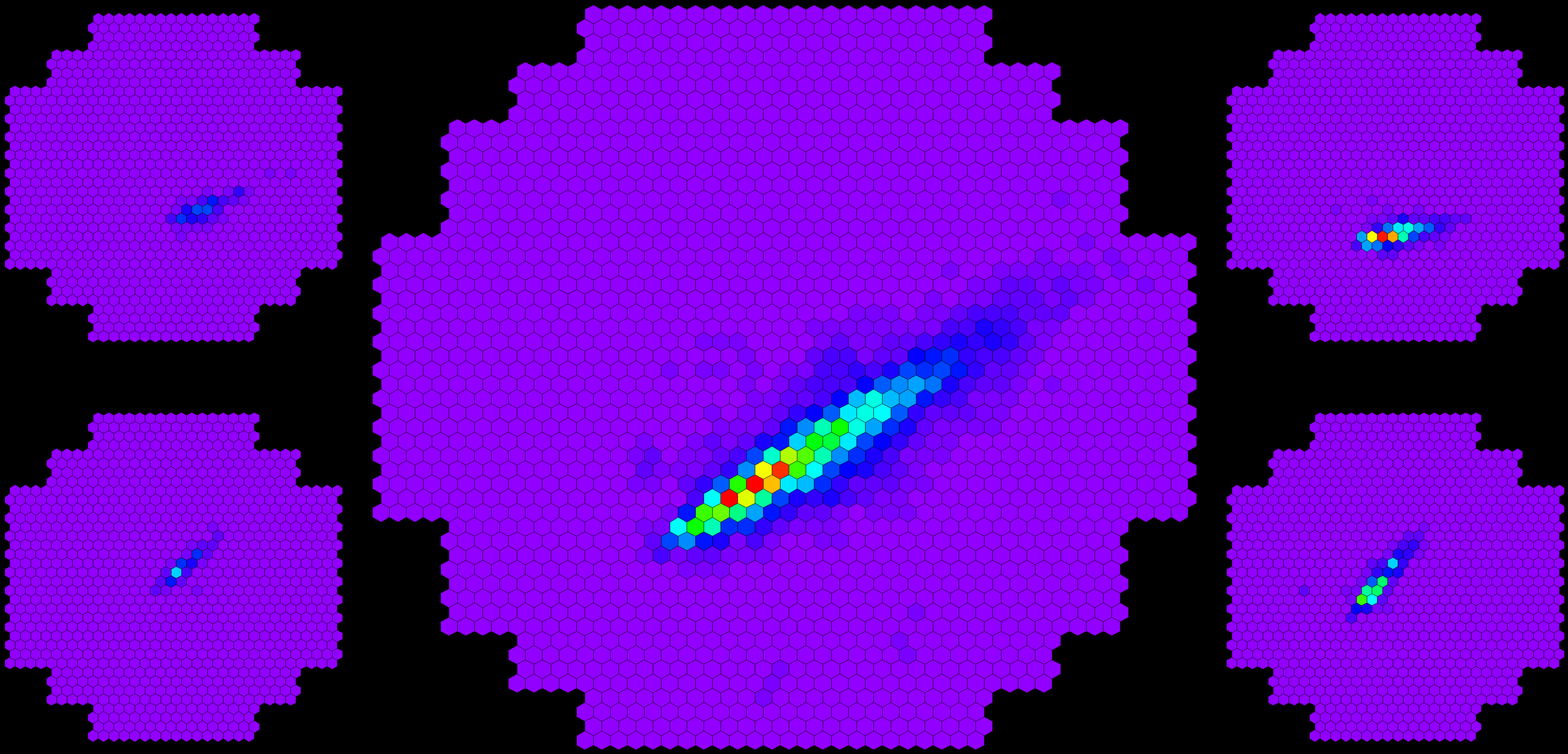
Well-known gamma-ray emitter but average flux in the bright flare reached a spectacular 7xCrab >200 GeV.


Results from **HESS, MAGIC** and **VERITAS**
The Galactic Centre: Nature 439, 695 (2006)
Galactic Survey: Science 307, 1839 (2005)
Microquasars: Science 309, 746 (2005), Science 312, 1771 (2006)
Pulsars: Science 322, 1221 (2008), Science 334, 69 (2011)
Supernova Remnants: Nature 432, 75 (2004)
Starbursts: Nature 462, 770 (2009), Science 326,1080 (2009)
AGN: Science 314,1424 (2006), Science 325, 444 (2009)
EBL: Nature 440, 1018 (2006), Science 320, 752 (2008)
Dark Matter: PRL 96, 221102 (2006), PRL 106, 161301 (2011)
Lorentz Invariance: PRL 101, 170402 (2008)
Cosmic Ray Electrons: PRL 101, 261104 (2009)
(c) F. Acero & H. Gast

THE STATE OF THE ART:

HESS-2

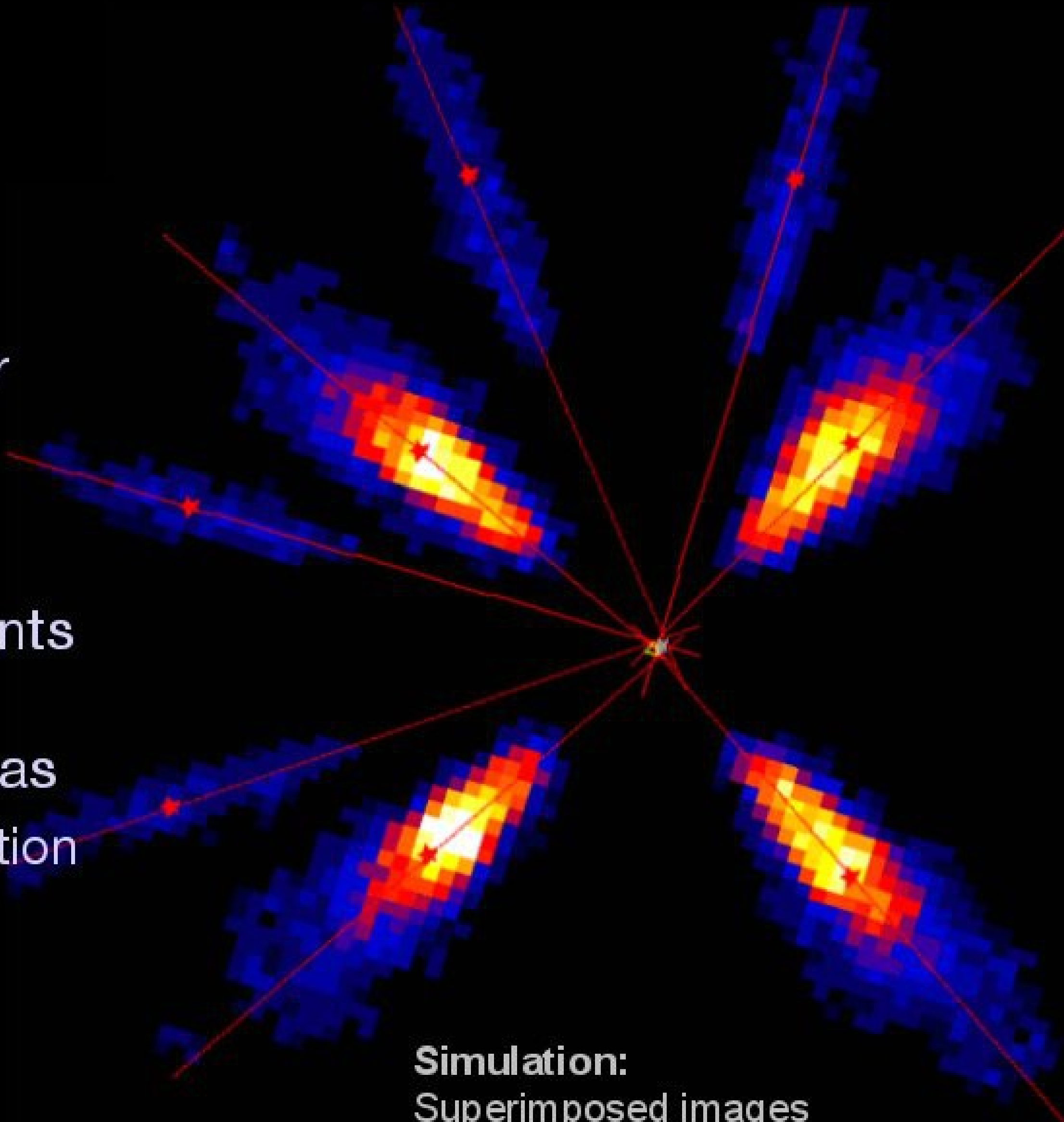
HESS-1: 4 x 12m tels
HESS-2: +28m tel.
Began operations mid-2012



HESS-2: one of first air showers seen by new 5-telescope set-up.
Courtesy of the HESS Collaboration.

How to do better?

- More events
  - More photons = better spectra, images, fainter sources
    - Larger collection area for gamma-rays
- Better events
  - More precise measurements of atmospheric cascades and hence primary gammas
    - Improved angular resolution
    - Improved background rejection power
- => More Telescopes!



Simulation:
Superimposed images from 8 cameras

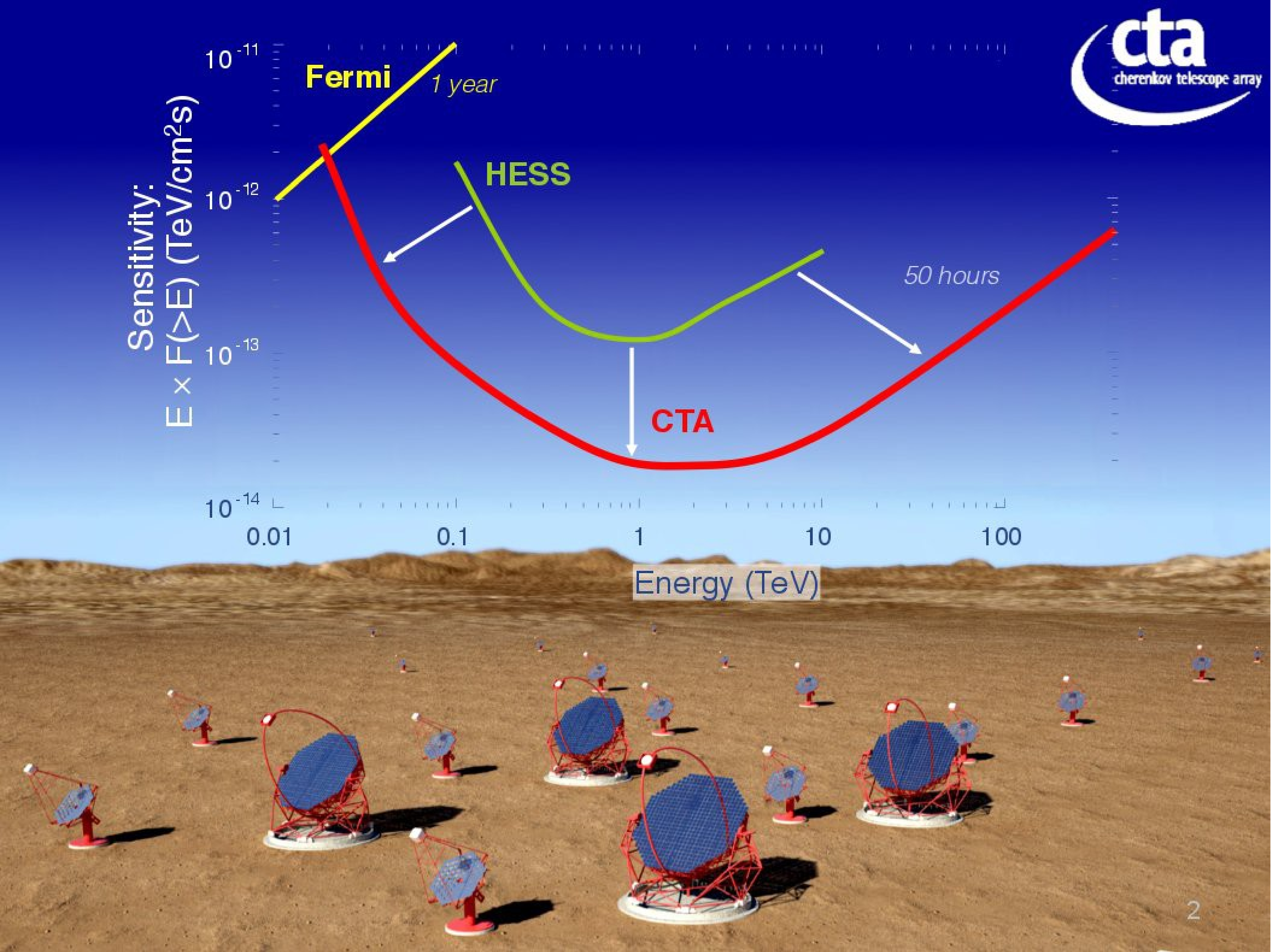
Figure: Jim Hinton

The Cherenkov Telescope Array

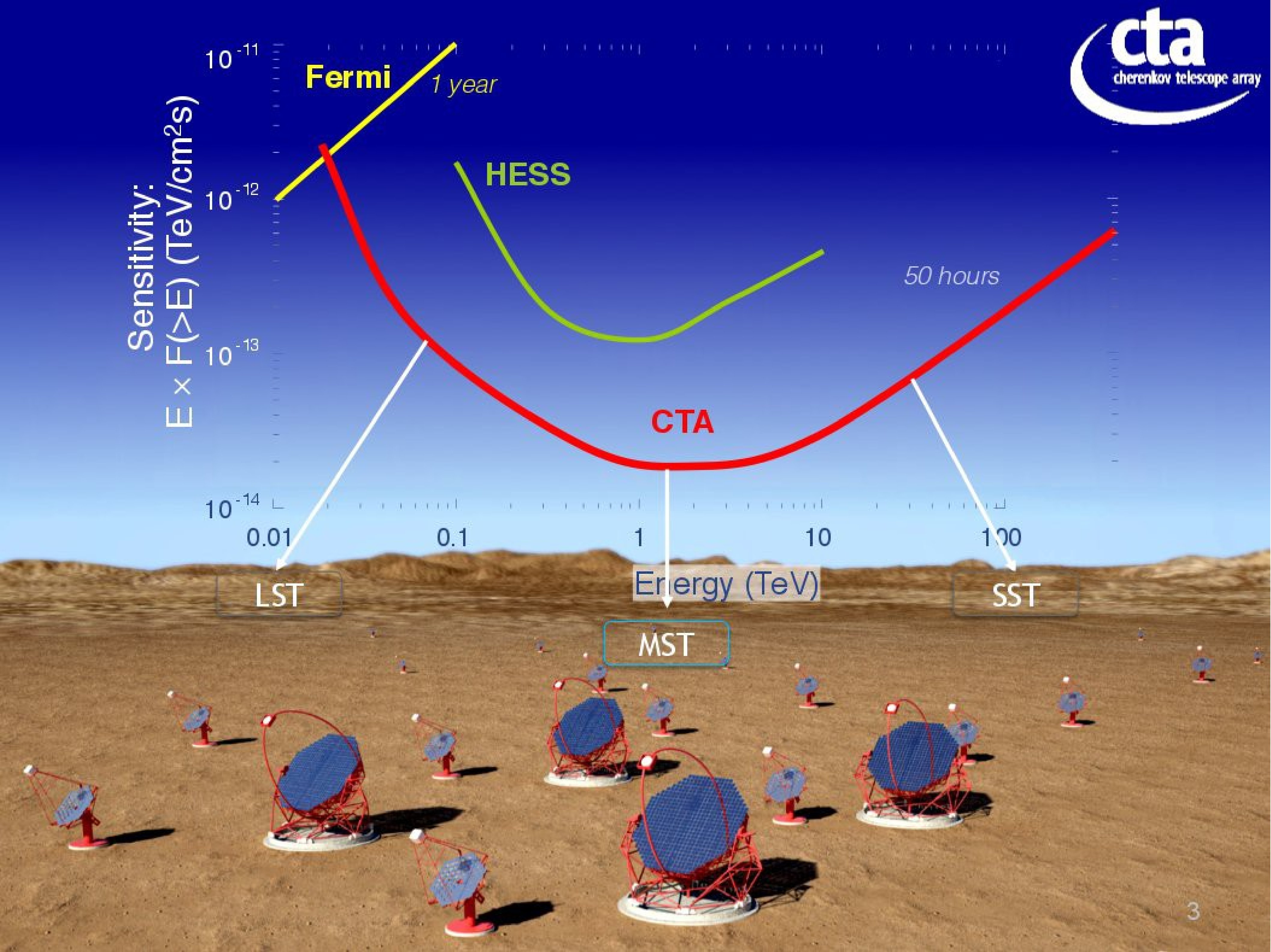
- A huge improvement in all aspects of performance
  - A factor ~10 in sensitivity, much wider energy coverage, much better resolution, field-of-view, full sky, …
- A user facility / proposal-driven observatory
  - With two sites and a total of >100 telescopes
- A global ~€200M project
  - Including everyone from HESS, MAGIC and VERITAS

www.cta-observatory.org.uk

First Science: ~2016
Completion: ~2020



cta
cherenkov telescope array
Sensitivity:
E × F(>E) (TeV/cm²s)
10^-11
10^-12
10^-13
10^-14
Fermi
1 year
HESS
50 hours
CTA
0.01
0.1
1
10
100
Energy (TeV)



Sensitivity:
E × F(>E) (TeV/cm²s)
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
Fermi
1 year
HESS
50 hours
CTA
0.01
0.1
1
10
100
Energy (TeV)
LST
MST
SST
cta
cherenkov telescope array

The Cherenkov Telescope Array

>1000 PEOPLE IN 27 COUNTRIES

The Cherenkov Telescope Array

The British Contribution
Positioning the UK for early CTA science

- CHEC (Compact High Energy Camera)
  - Prototype camera for the SST
  - Leicester-led effort with collaborators from UK + US and Japan
  - Funding in place for 2 prototype cameras
    - UK funding from STFC and U. Leicester

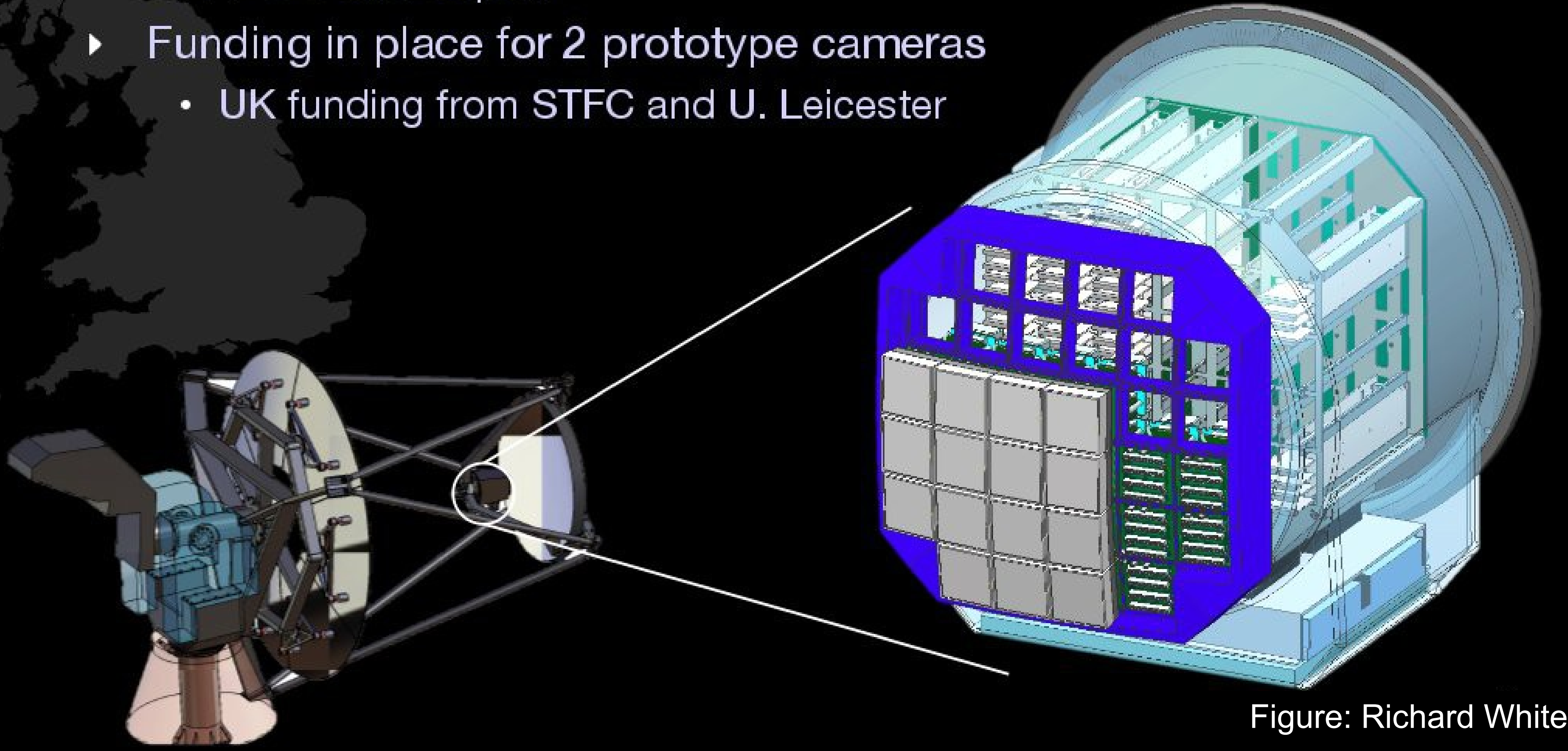
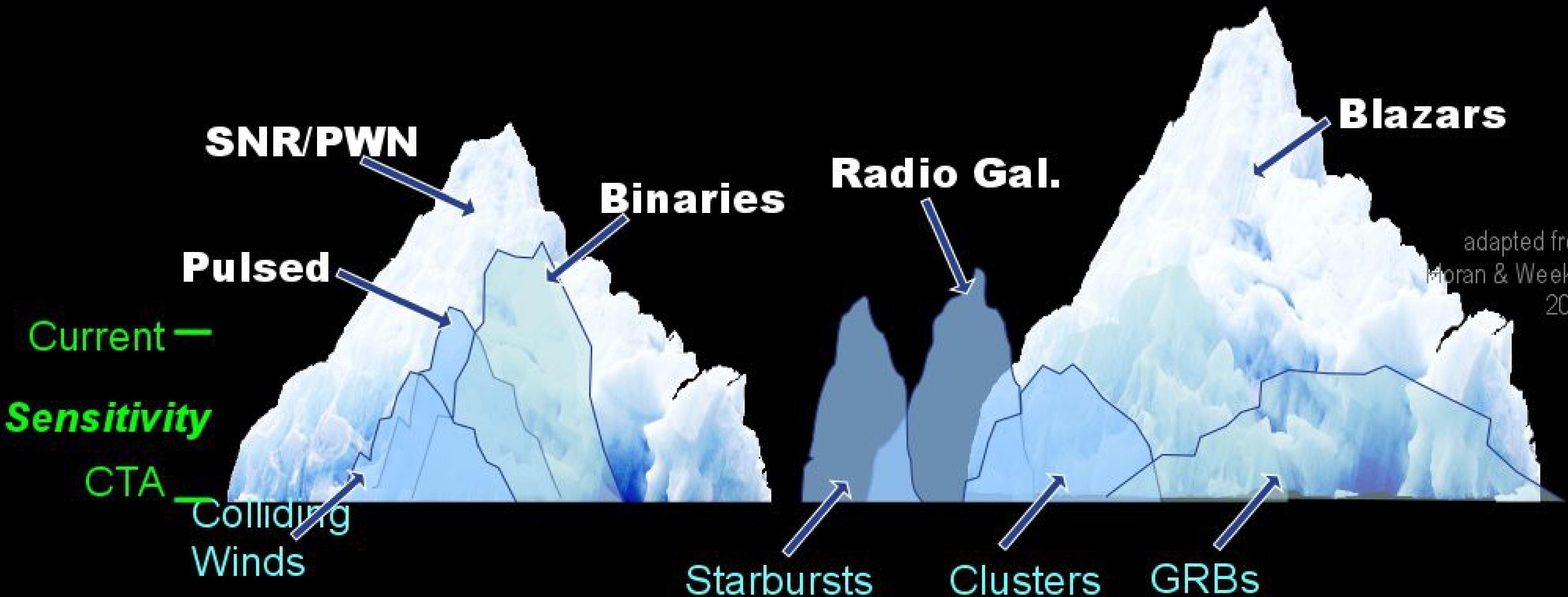


Figure: Richard White

CTA Science Targets
the non-thermal universe



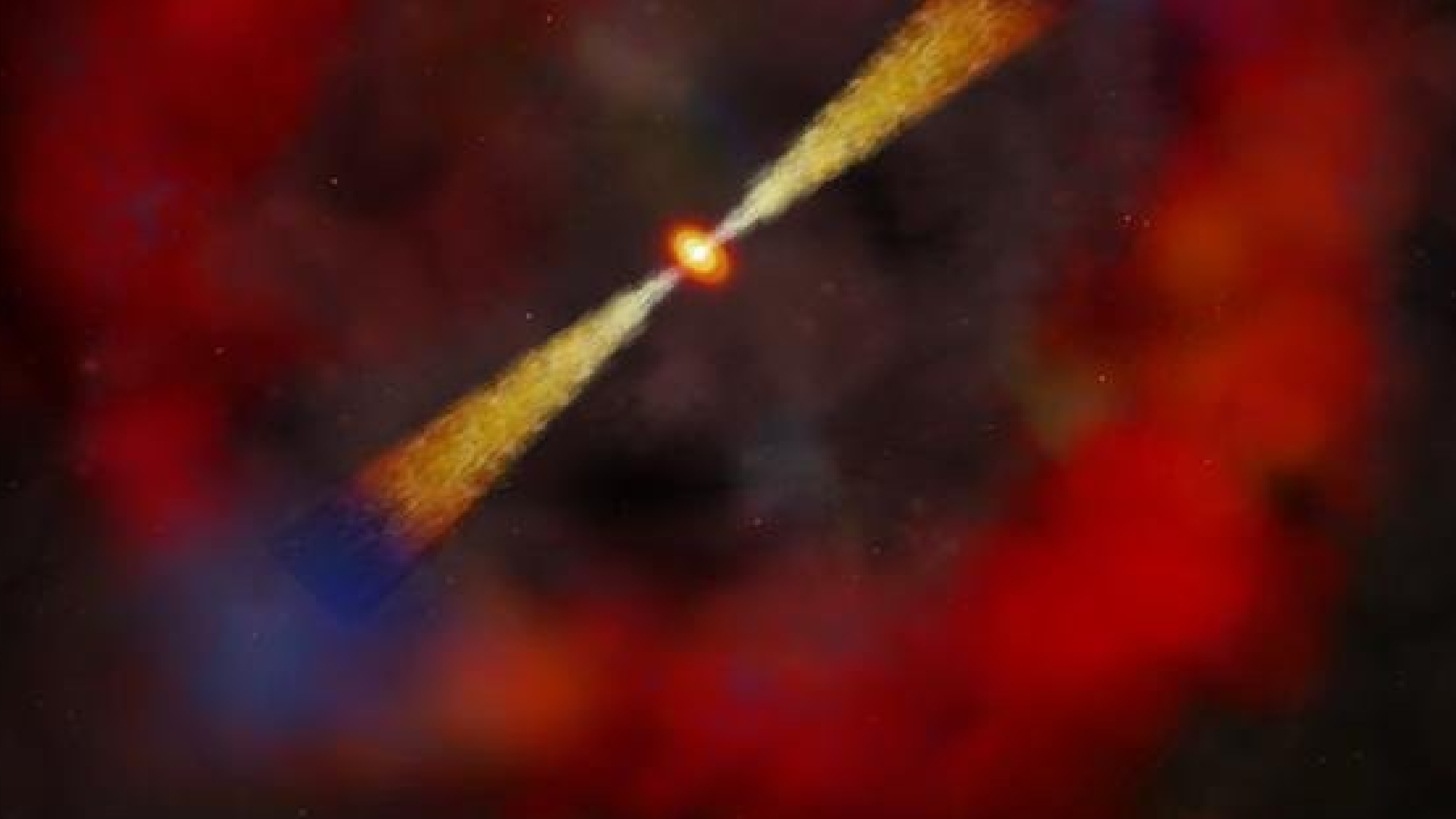
- Guaranteed astrophysics
  - Current generation detections are the tip of the iceberg
- Major discovery potential!

CTA Science

- Shocks, Jets and Particle Acceleration
  - The how/where/what of particle acceleration
  - Physics of strong shocks and relativistic outflows
  - GRBs, AGN jets and lobes, PWN, SNRs, Colliding winds +++
- Relativistic Particle Feedback
  - Impact of accelerated particles on their environments
  - from ISM to ICM scales
- Gamma-rays as Probes
  - Probes of cosmic radiation fields and magnetic fields
- Fundamental Physics
  - Dark Matter indirect detection
  - Speed-of-light measurements → LIV

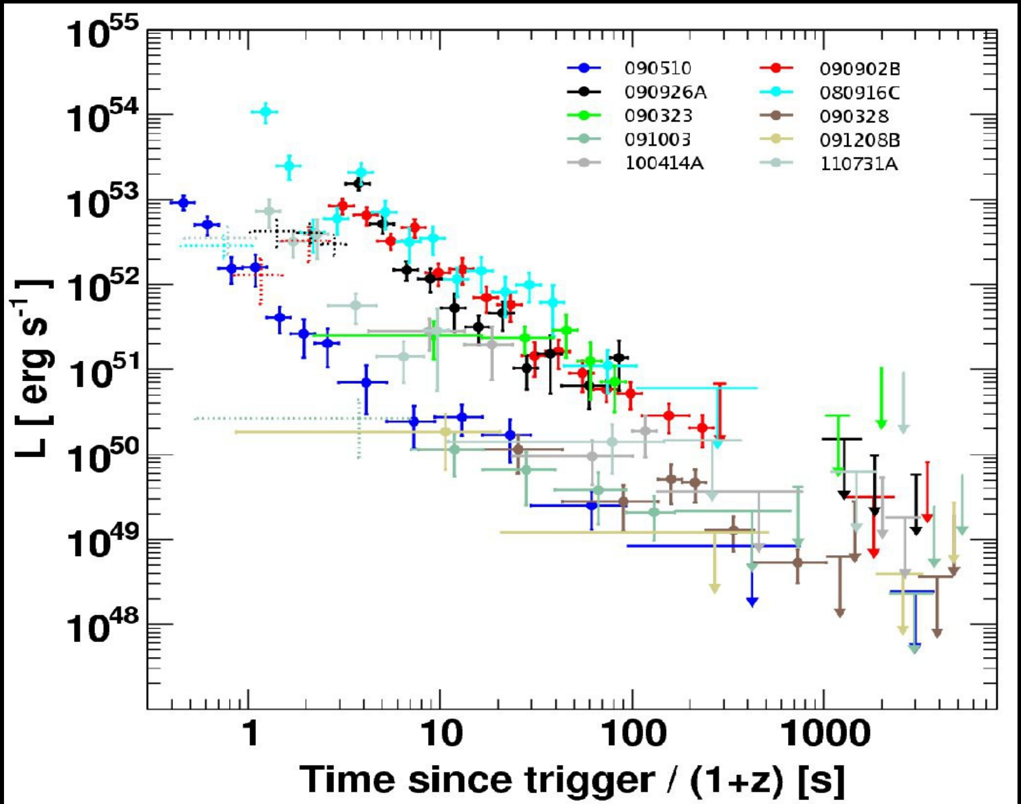
CTA will rapidly respond to ToO triggers, e.g. gamma-ray bursts

GRBs are relativistic jet sources: gamma-rays produced in shocks

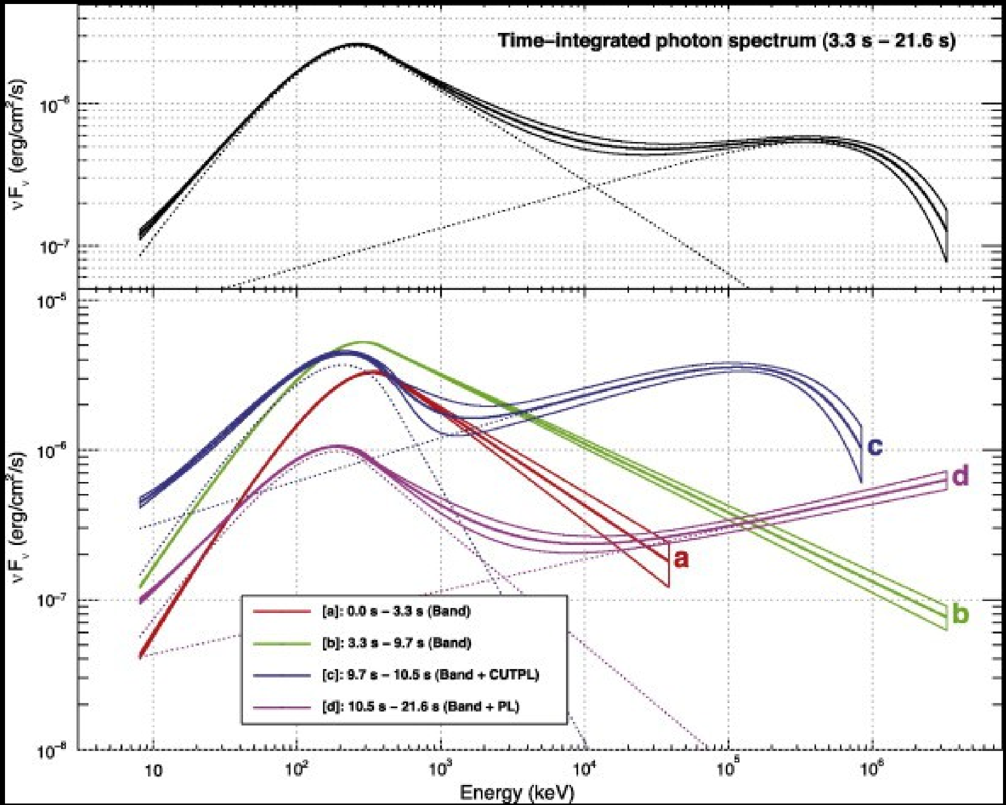


Fermi LAT GRBs show delayed and extended HE emission, and for some an 'extra' spectral component beyond the extrapolation from keV: more opportunity to catch them in action.

28 GRBs seen at >100 MeV, 7 at >20 GeV in 3 years (only 8% of all Fermi GRBs – are HE-emitting bursts special?)



Ackermann et al. 2013 arXiv:1303.2908



e.g. GRB 090926A Ackermann et al. 2011 ApJ, 729, 114

CTA predicted to catch prompt and afterglow of several GRBs/yr, including both 'long' and 'short' bursts (S. Inoue et al. 2013, Astropart. Phys. 43, 252).

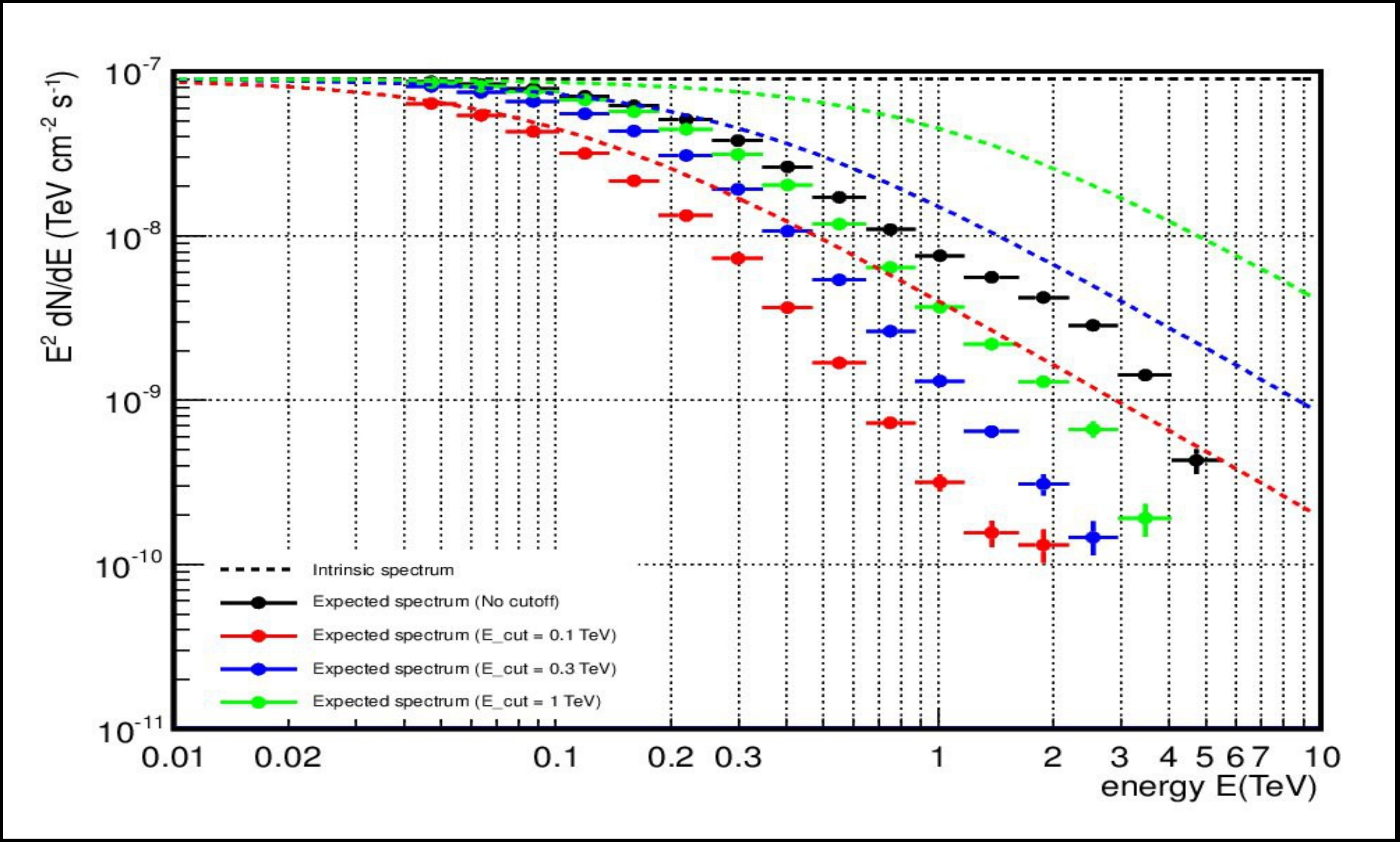
Predicted spectra for the recent GRB 130427A are spectacular, and it could have been seen for over a week...

Prompt Phase:

t=100s
50s exposure

Extrapolation from Tam et al. 1305.3217 EBL model Y. Inoue et al. 2013

>100000 cts



Courtesy CTA-GRB group, in particular S. Inoue, V. Connaughton, P. O'Brien, J. Granot

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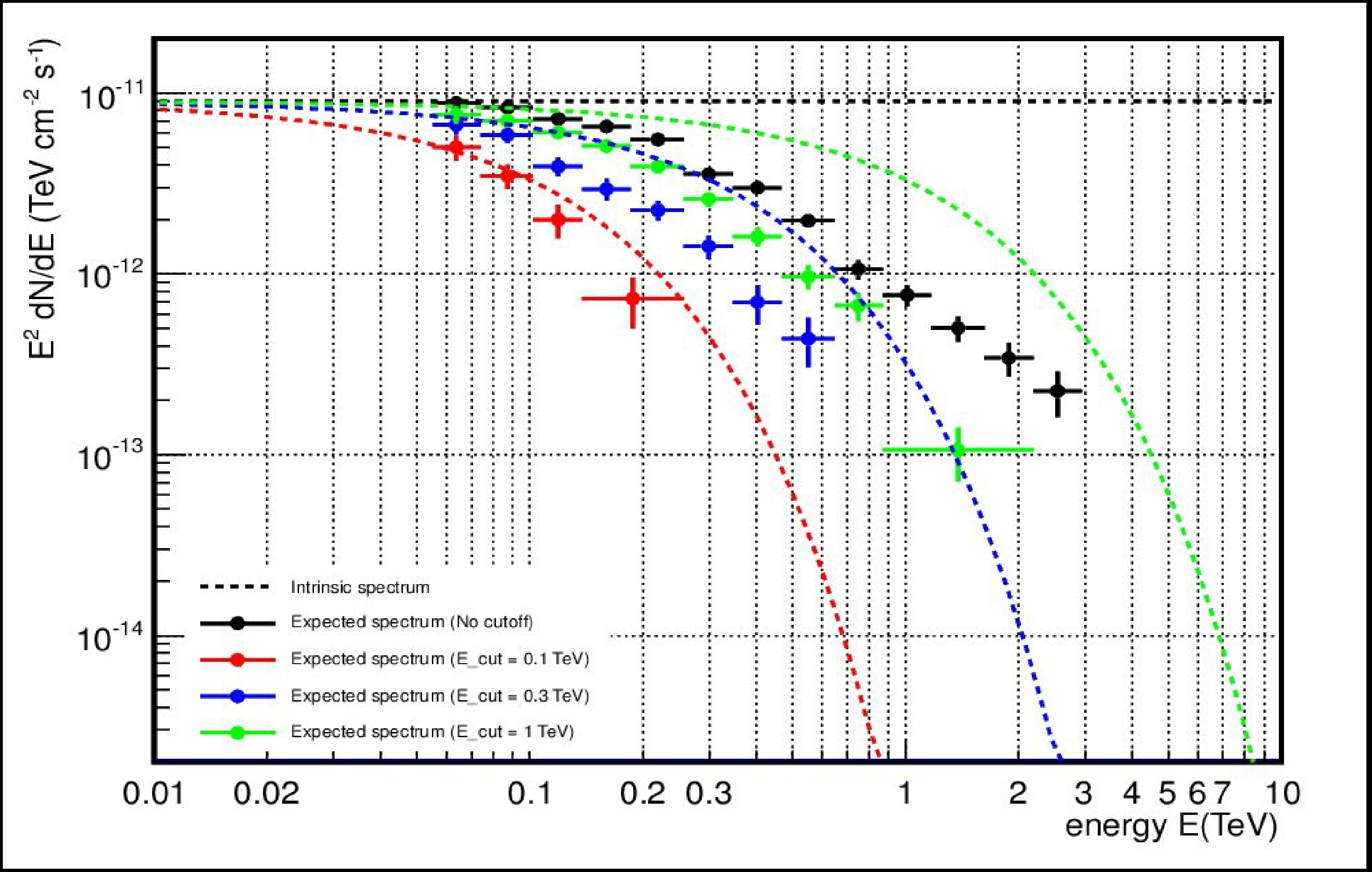
Afterglow Phase:

t=10 days
15h exposure

Extrapolation from Tam et al. 1305.3217
EBL model Y. Inoue et al. 2013

>1000 cts



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CTA predicted to catch prompt and afterglow of several GRBs/yr, including both 'long' and 'short' bursts (S. Inoue et al. 2013, Astropart. Phys. 43, 252).

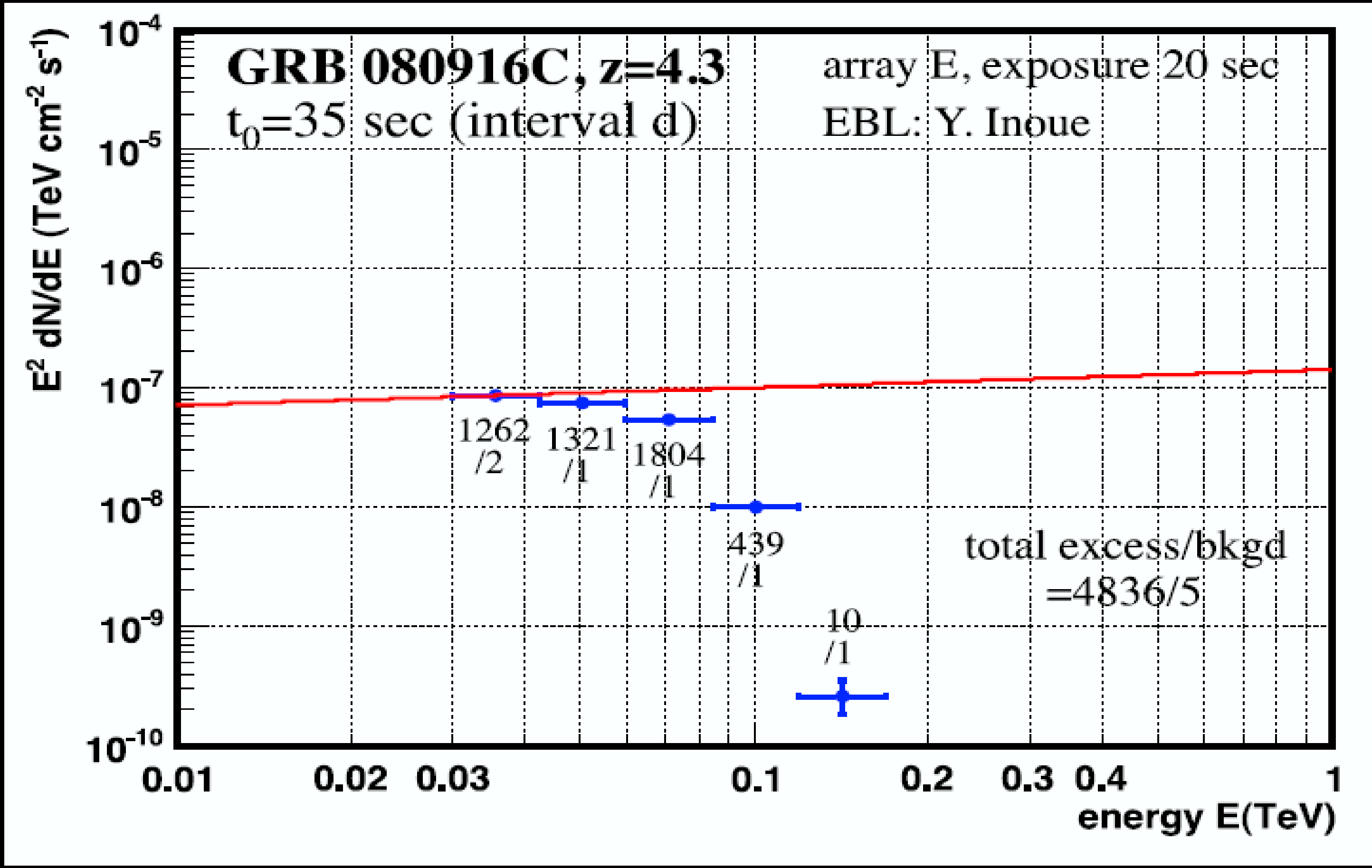
Predicted spectra for the z=4.3 GRB 080916C shows that high redshift is accessible with CTA

Prompt Phase:

t=35s
20s exposure

EBL model Y. Inoue et al. 2013

>1000 cts
for z>4 GRB

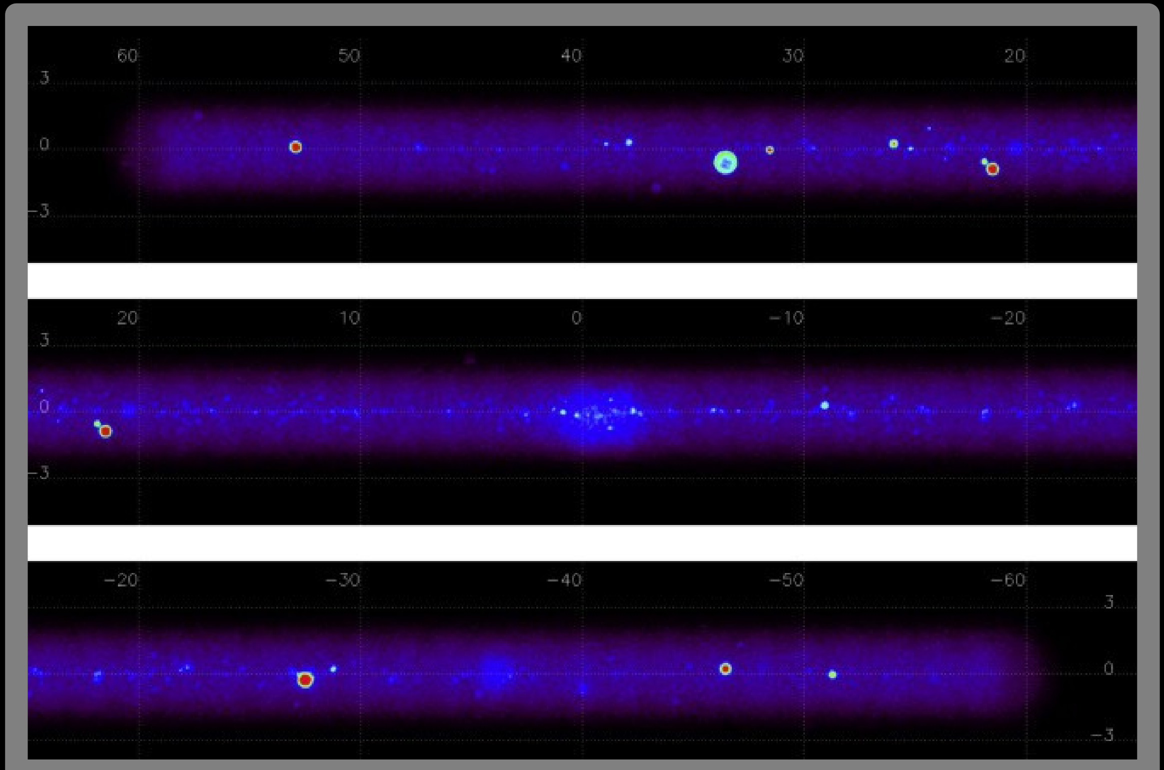


S. Inoue et al. 2013

CTA can accept urgent triggers for LOFT discoveries

and

CTA survey modes may produce triggers that LOFT can follow-up (NB 31% of LAT sources unidentified)



CTA: simulation of a 240h Galactic Plane Survey (Dubus et al. 2013, Astropart. Phys. 43, 317)

From high energy to highest energy: gamma-ray astronomy and LOFT

LOFT operations will overlap with CTA if both are built: CTA should be complete and 'experienced' in 2020+

Broadband coverage from keV to GeV-MeV-TeV

The high energy gamma-ray sky comprises many of the source-types LOFT will capture, and science within the 'extreme Universe' theme at sites of particle acceleration: jets, shocks, winds

Each may act as a trigger for the other in rapid transient science