POPULATIONS OF *GAMMA-RAY* POINT SOURCES

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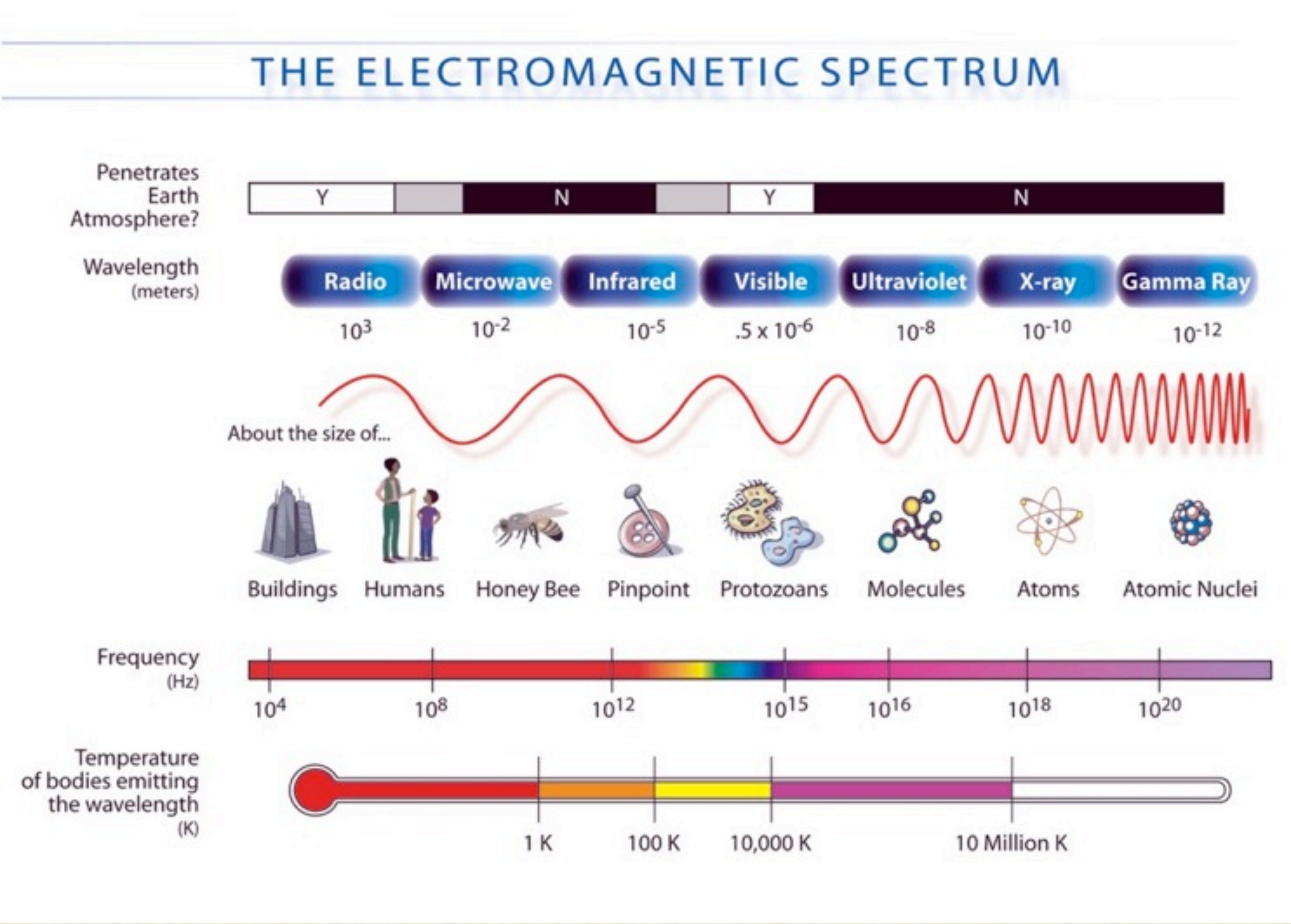
OUTLINE

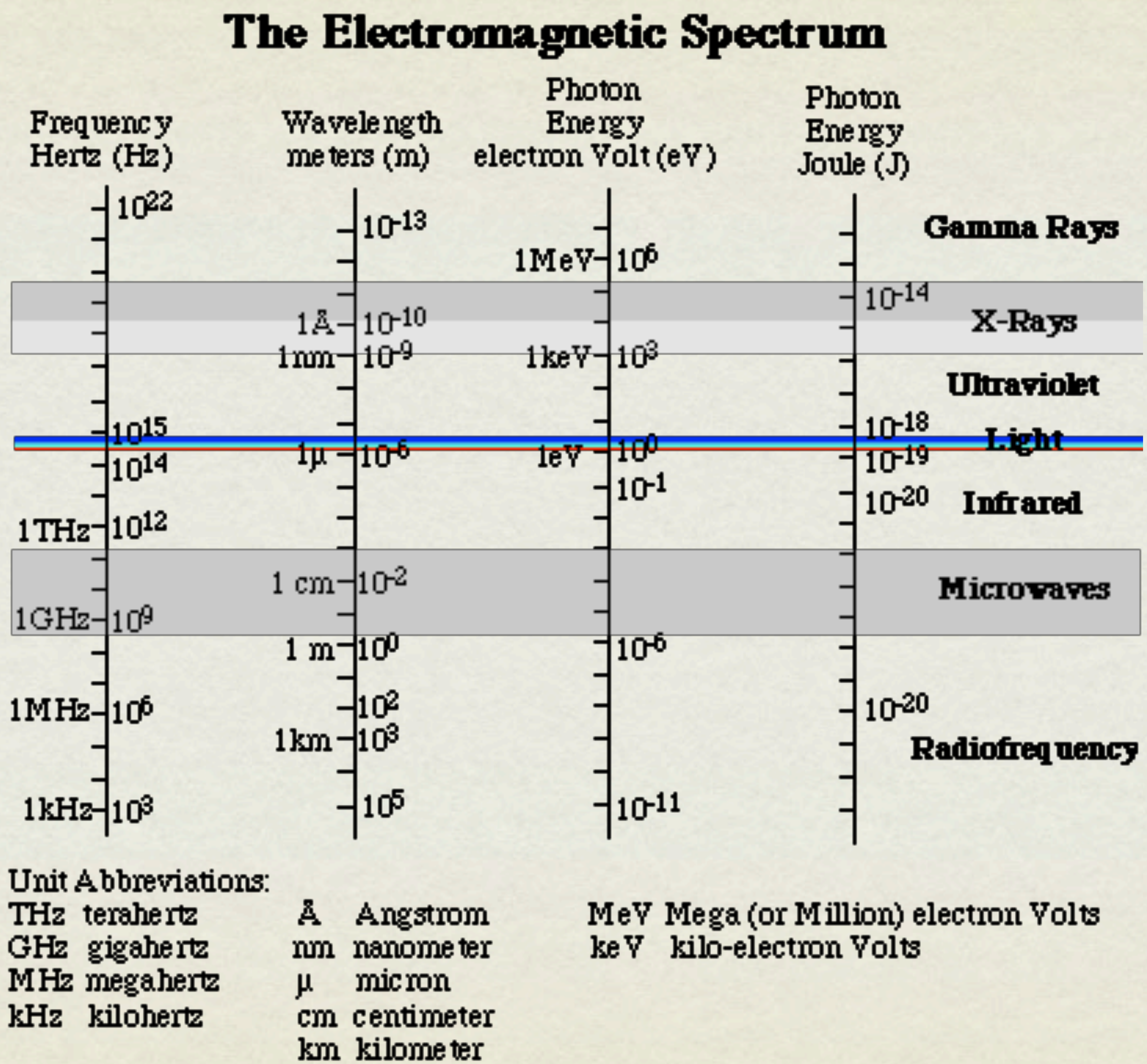
- Gamma-ray in Astronomy
- Emission Mechanisms
- Instruments Development
- Populations of Gamma-ray sources
- Catalogues

GAMMA-RAY?



THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^3
10^-2
10^-5
.5 x 10^-6
10^-8
10^-10
10^-12
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^12
10^15
10^16
10^18
10^20
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K

GAMMA-RAY?



The Electromagnetic Spectrum
Frequency Hertz (Hz)
Wavelength meters (m)
Photon Energy electron Volt (eV)
Photon Energy Joule (J)
Gamma Rays
X-Rays
Ultraviolet
Light
Infrared
Microwaves
Radiofrequency
10^{22}
10^{15}
10^{14}
1THz 10^{12}
1GHz 10^{9}
1MHz 10^{6}
1kHz 10^{3}
10^{-13}
1Å 10^{-10}
1nm 10^{-9}
1µ 10^{-6}
1 cm 10^{-2}
1 m 10^{0}
10^{2}
1km 10^{3}
10^{5}
1MeV 10^{6}
1keV 10^{3}
1eV 10^{0}
10^{-1}
10^{-6}
10^{-11}
10^{-14}
10^{-18}
10^{-19}
10^{-20}
10^{-20}
Unit Abbreviations:
THz terahertz
GHz gigahertz
MHz megahertz
kHz kilohertz
Å Angstrom
nm nanometer
µ micron
cm centimeter
km kilometer
MeV Mega (or Million) electron Volts
keV kilo-electron Volts

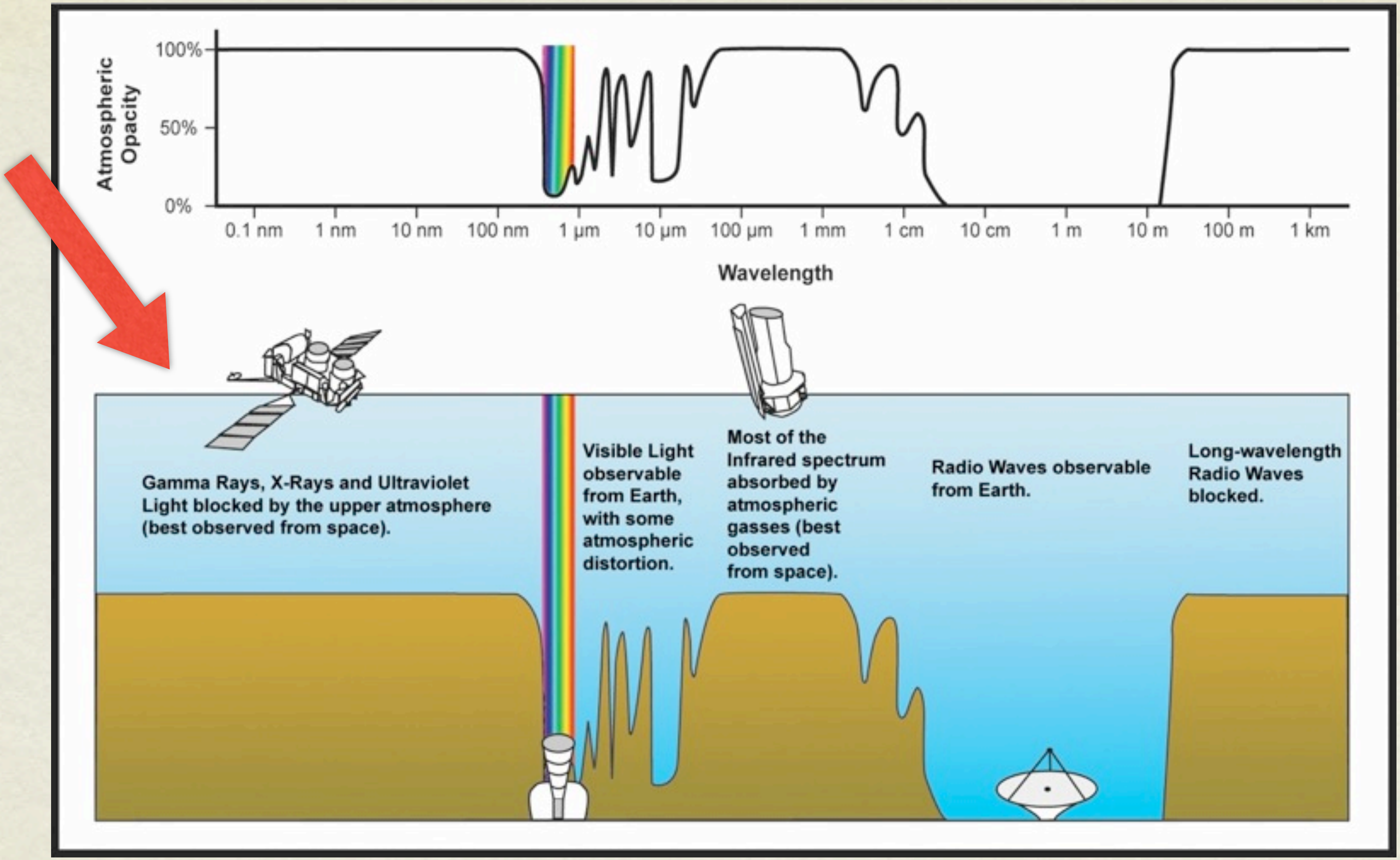
GAMMA-RAY?

- Highest energy photons, a few hundred keV to TeV.
- Probe nuclear and elementary particles.
- Probe the most violent/relativistic activities, or extreme environments in Astronomy.

GAMMA-RAY IN ASTRONOMY?

- Producing gamma-rays
  - ➙ Blackbody with temperature higher than 2×10^{9} K
  - ➙ Compton scattering
  - ➙ Nuclear transition
  - ➙ Decays, Annihilation
  - ➙ Changed particles + Electric fields/Magnetic fields
    Synchrotron radiation, Bremsstrahlung radiation
- Gamma-rays interact with environments

DETECT GAMMA-RAY



- High energy photons are **blocked** by our Earth's atmosphere.

DETECT GAMMA-RAY

- Small effective area (aperture) compared to that in other wavelengths.

- Ground-based (higher energy regime: 10 GeV to TeV)
  ➙ Cherenkov cascade
  ➙ Optical detectors

- Balloon/Space-borne (lower energy regime: MeV to GeV/TeV)
  ➙ Pair production
  ➙ Inverse Compton scattering
  ➙ Gamma-ray detectors

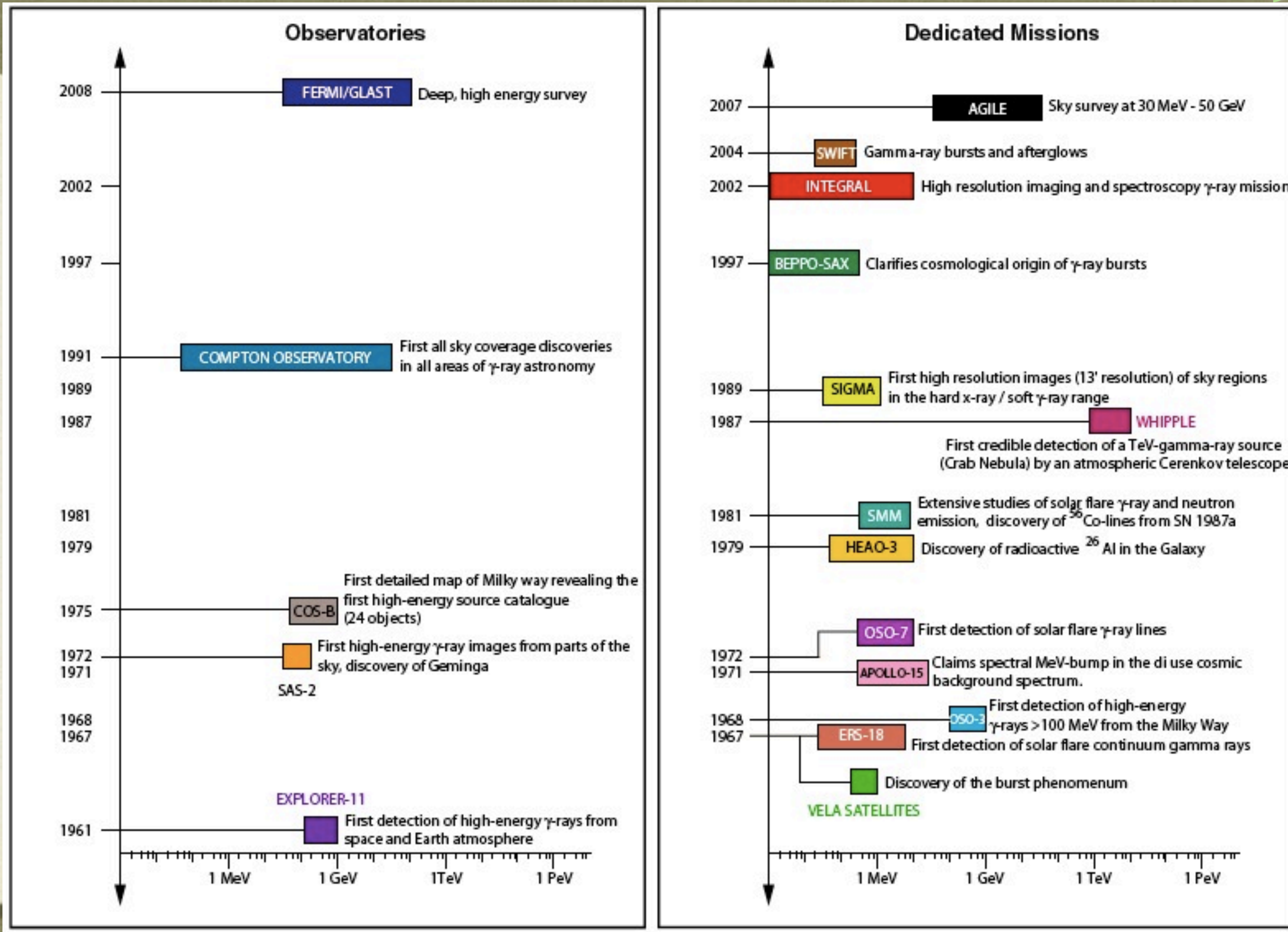
GAMMA-RAY TELESCOPE.SATELLITE

- Started Since 1960s.
  ➙ Gamma-ray bursts were first detected by the U.S. military satellites (Vela satellites) in the late 1960s.
  ➙ SAS-II & COS-B provided the first accurate maps of the Milky Way, and discovered Geminga.
  ➙ HEAO-C first discovered radioactive ^{26}Al line (1.809 MeV).

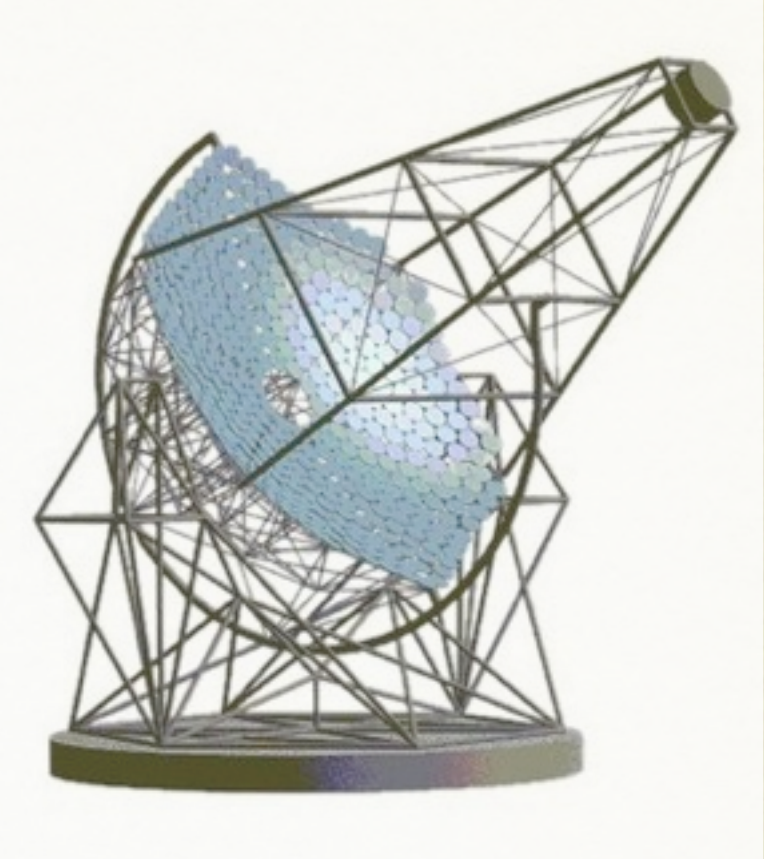
- Matured from 1990s
  ➙ SIGMA provided the first high resolution images of X-ray novae and microquasars.
  ➙ Compton Observatory provided the first all-sky survey.
  ➙ WHIPPLE Telescope detect the first secured TeV source, Crab.

TIMELINE

Pinkau 2009



High Energy Stereoscopic System



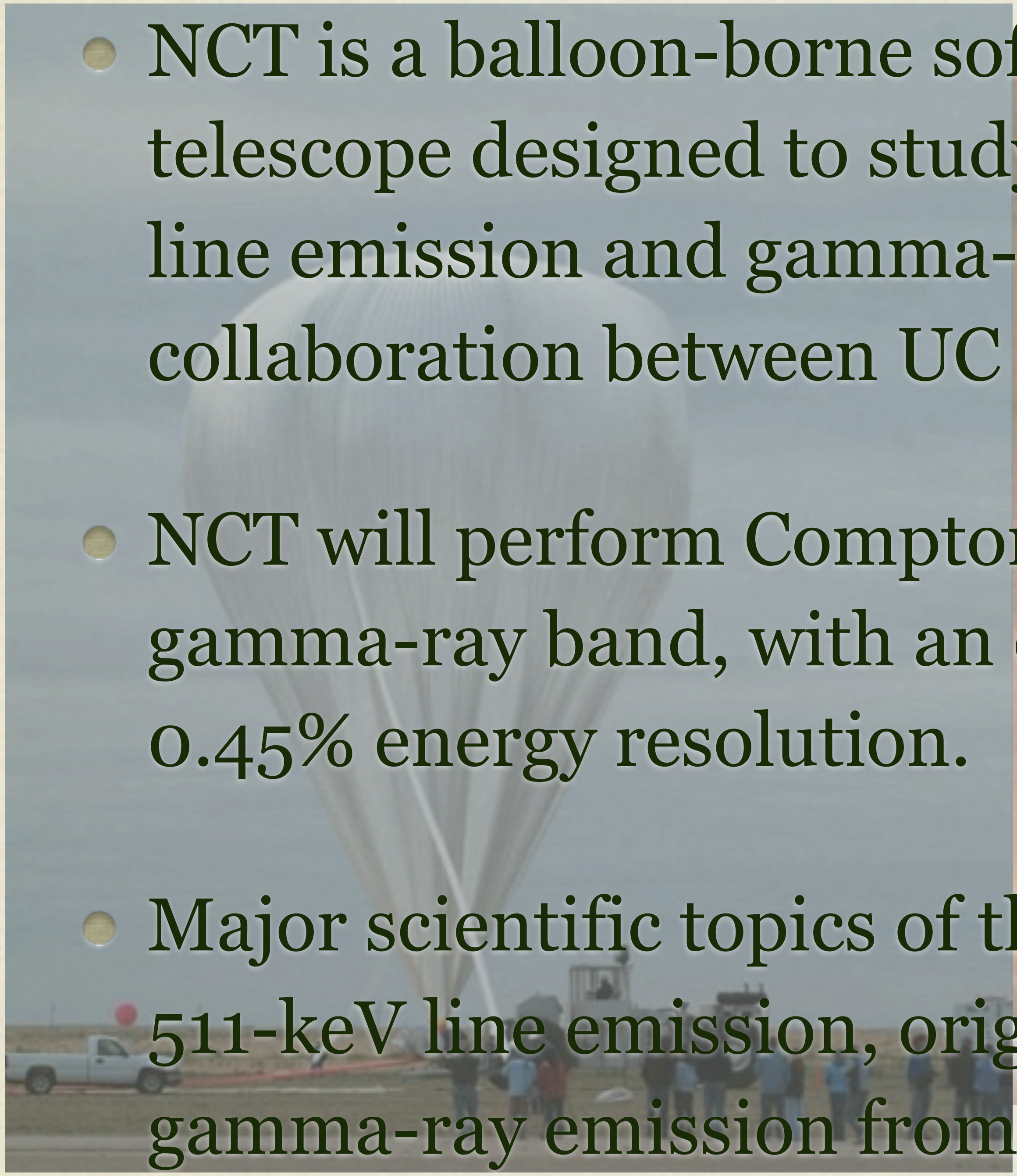
- Cherenkov telescope, 100 GeV to 100 TeV.
- Total mirror area is 108 m^2 per telescope;
  5^o field of view; Diameter 12 m;
  Focal length 15 m (f/d ~1.2);
  PSF 0.03^o (rms) on axis, 0.06^o for rays 2^o off axis;
  Energy Resolution ~15%;
  Time Required for a 5σ Detection at 20^o
  ~ 0.01 Crab in ~25 hrs (1Crab=1.75×10^{-11}(erg/TeV)$^{-1.62}$ cm^{-2} s^{-1})
- Phase I: 4 telescopes separated by 120 m.
  Phase II: an single huge dish with about 600 m^2 mirror area will be added at the center of the array, increasing the energy coverage, sensitivity and angular resolution of the instrument.

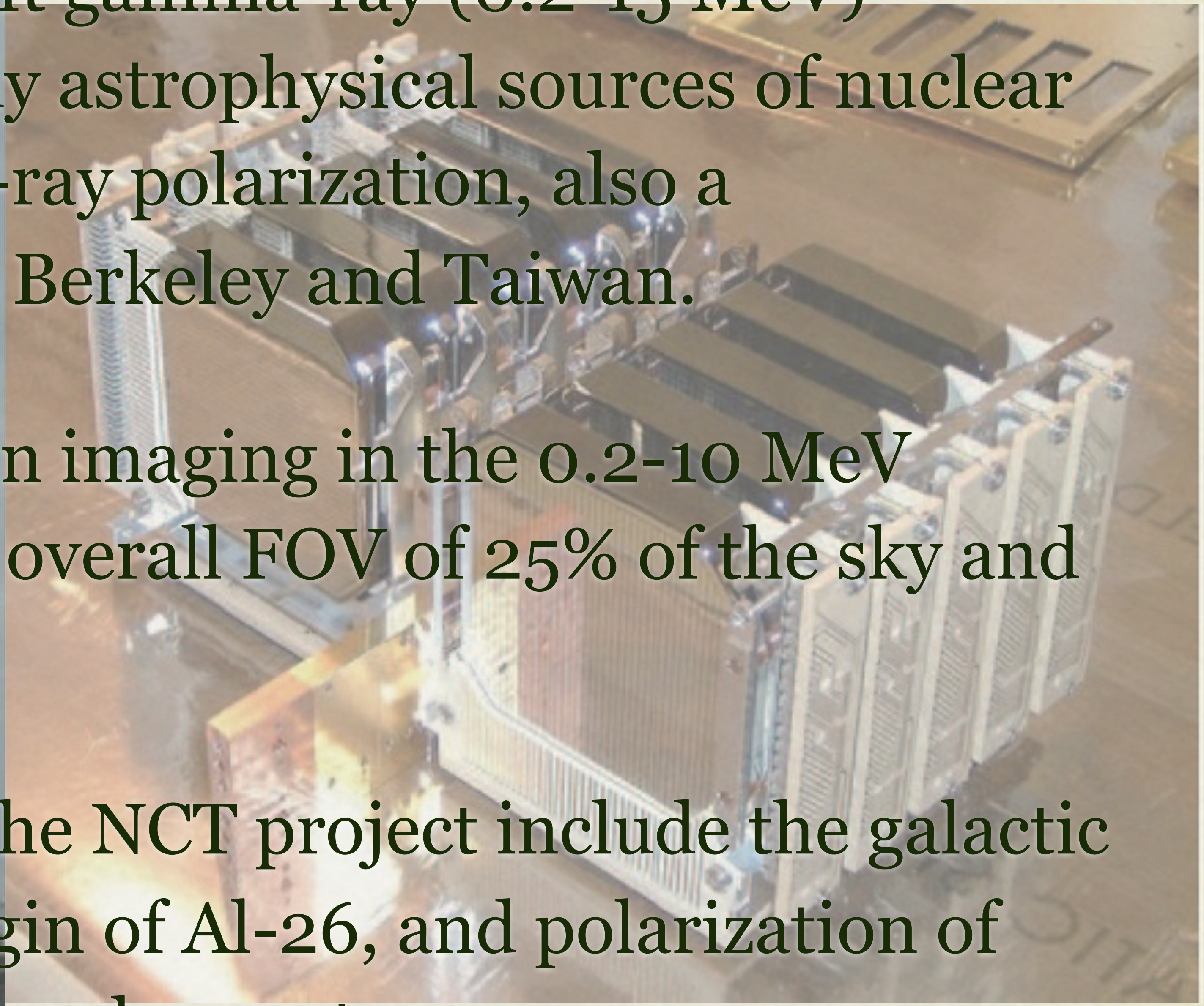
NUCLEAR COMPTON TELESCOPE

- NCT is a balloon-borne soft gamma-ray (0.2-15 MeV) telescope designed to study astrophysical sources of nuclear line emission and gamma-ray polarization, also a collaboration between UC Berkeley and Taiwan.

- NCT will perform Compton imaging in the 0.2-10 MeV gamma-ray band, with an overall FOV of 25% of the sky and 0.45% energy resolution.

- Major scientific topics of the NCT project include the galactic 511-keV line emission, origin of Al-26, and polarization of gamma-ray emission from pulsars, etc.





FERMI GAMMA-RAY SPACE TELESCOPE

Quantity	LAT (Minimim Spec.)	EGRET
Energy Range	20 MeV - 300 GeV	20 MeV - 30 GeV
Peak Effective Area[1]	> 8000 cm^2	1500 cm^2
Field of View	> 2 sr	0.5 sr
Angular Resolution[2]	< 3.5° (100 MeV) < 0.15° (>10 GeV)	5.8° (100 MeV)
Energy Resolution[3]	< 10%	10%
Deadtime per Event	< 100 μs	100 ms
Source Location Determination[4]	< 0.5'	15'
Point Source Sensitivity[5]	< 6×10^{-9} cm^{-2} s^{-1}	~ 10^{-7} cm^{-2} s^{-1}

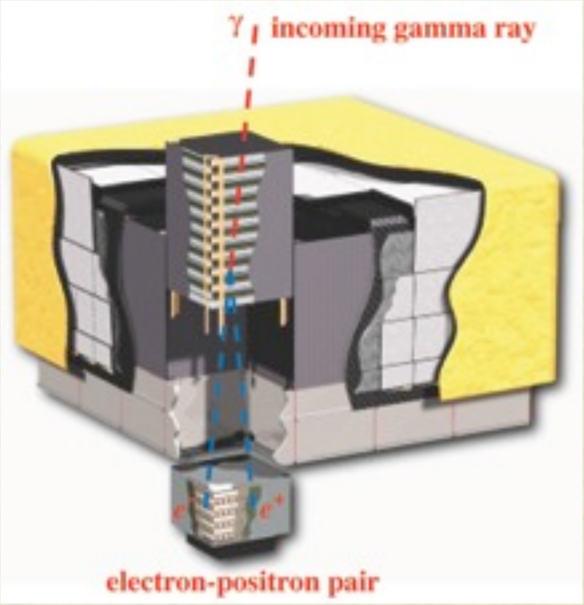
[1] After background rejection

[2] Single photon, 68% containment, on-axis

[3] 1-σ, on-axis

[4] 1-σ radius, flux 10^{-7} cm^{-2} s^{-1} (>100 MeV), high |*b*|

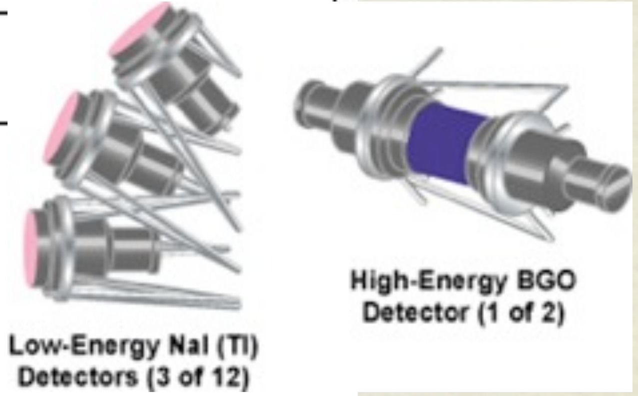
[5] > 100 MeV, at high |*b*|, for exposure of one-year all sky survey, photon spectral index -2



Pair production

FERMI GAMMA-RAY SPACE TELESCOPE

Quantity	GBM (Minimum Spec.)	BATSE
Energy Range	< 10 keV - > 25 MeV	25 keV - 10 MeV
Field of View	all sky not occulted by the Earth	4π sr
Energy Resolution[1]	< 10%	< 10%
Deadtime per Event	< 15 μs	
Burst Sensitivity[2]	< 0.5 $cm^{-2}\ s^{-1}$	0.2 $cm^{-2}\ s^{-1}$
Alert GRB Location[3]	~ 15°	~ 25°
Final GRB Location[4]	~ 3°	1.7°



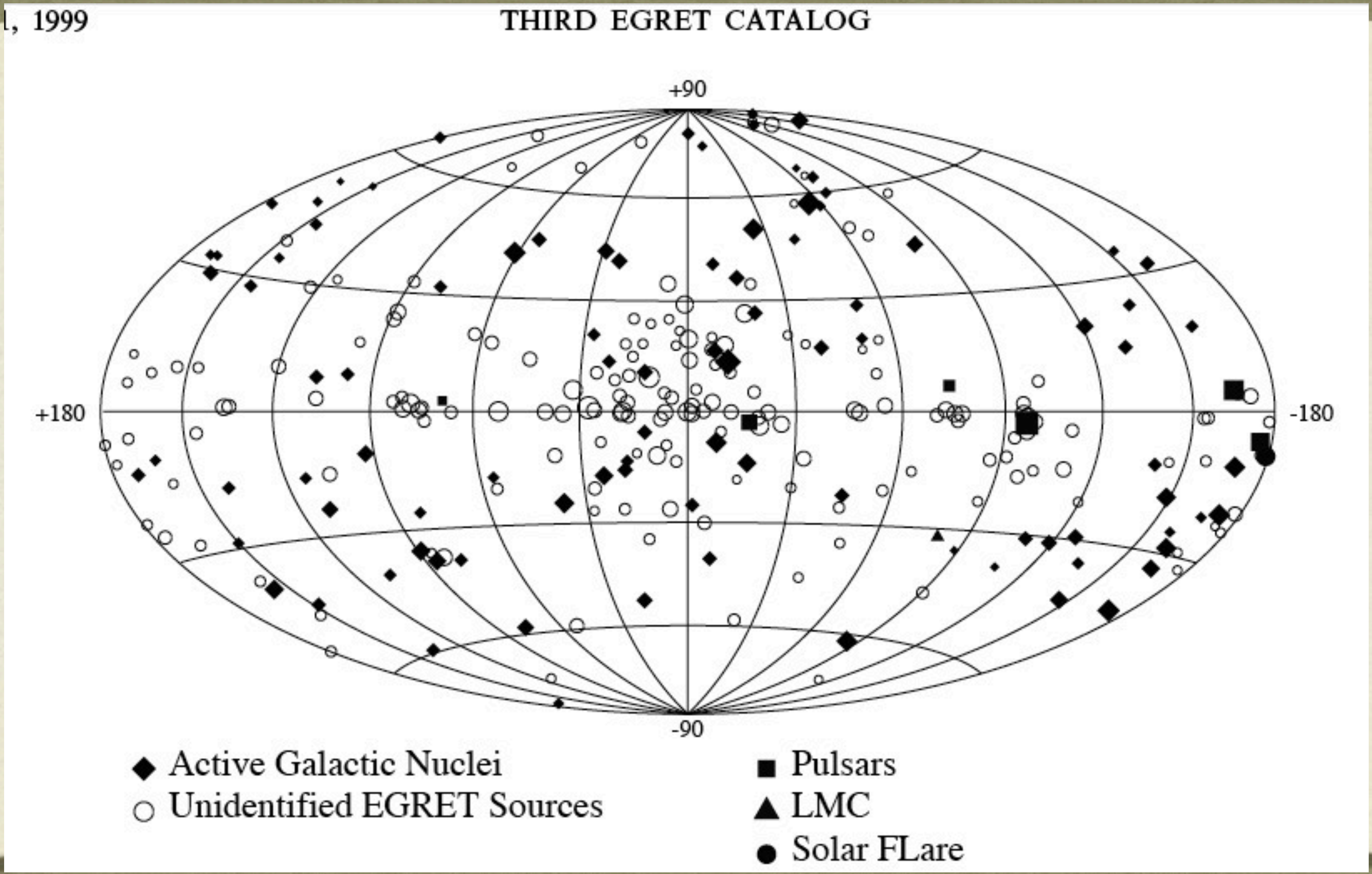
[1] 1-σ, 0.1 - 1 MeV

[2] 50 - 300 keV

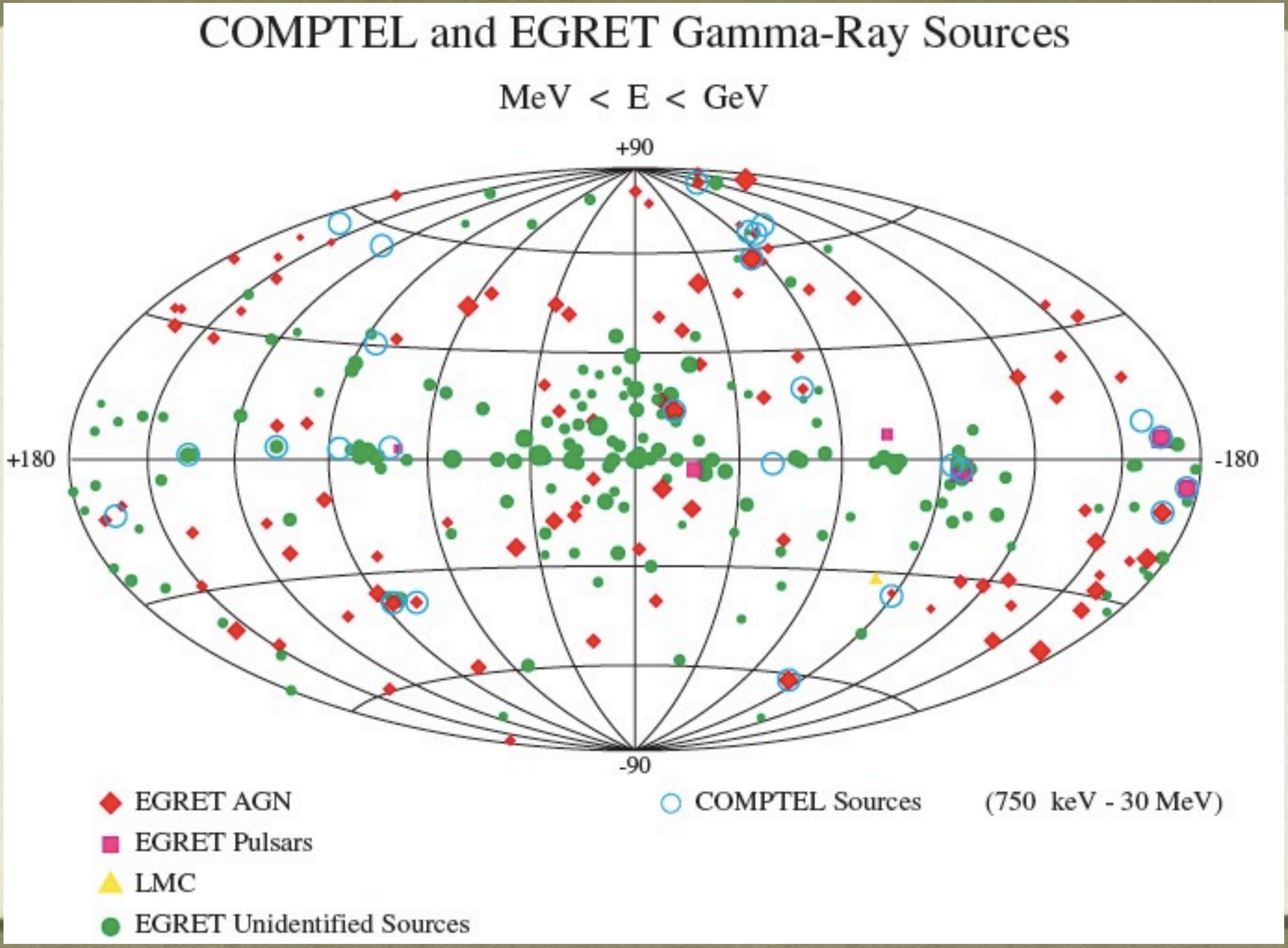
[3] Calculated on-board; 1 second burst of 10 photons $cm^{-2}\ s^{-1}$, 50 - 300 keV

[4] Final ground computed locations; 1 second burst of 10 photons $cm^{-2}\ s^{-1}$, 50 - 300 keV

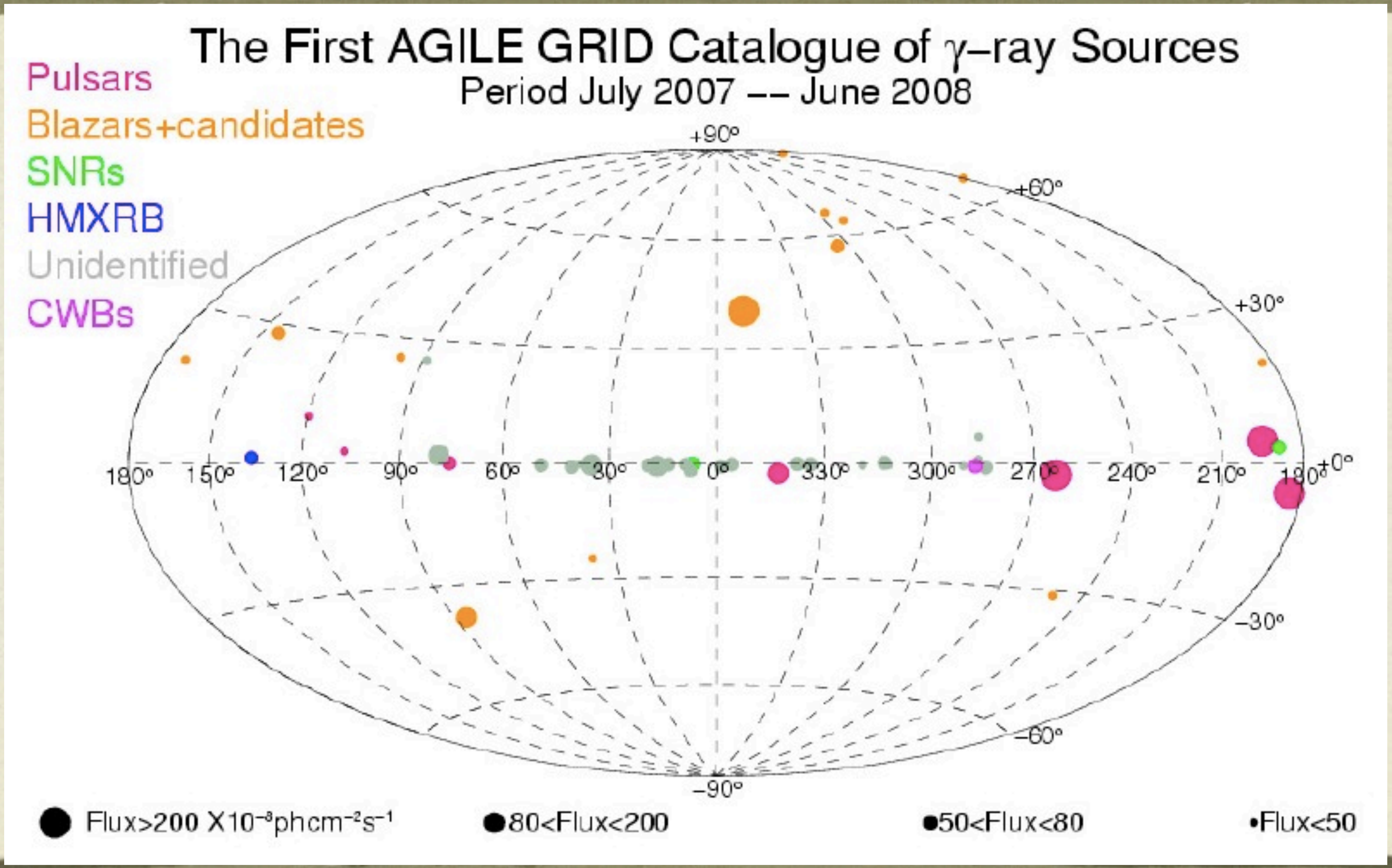
GAMMA-RAY SKY



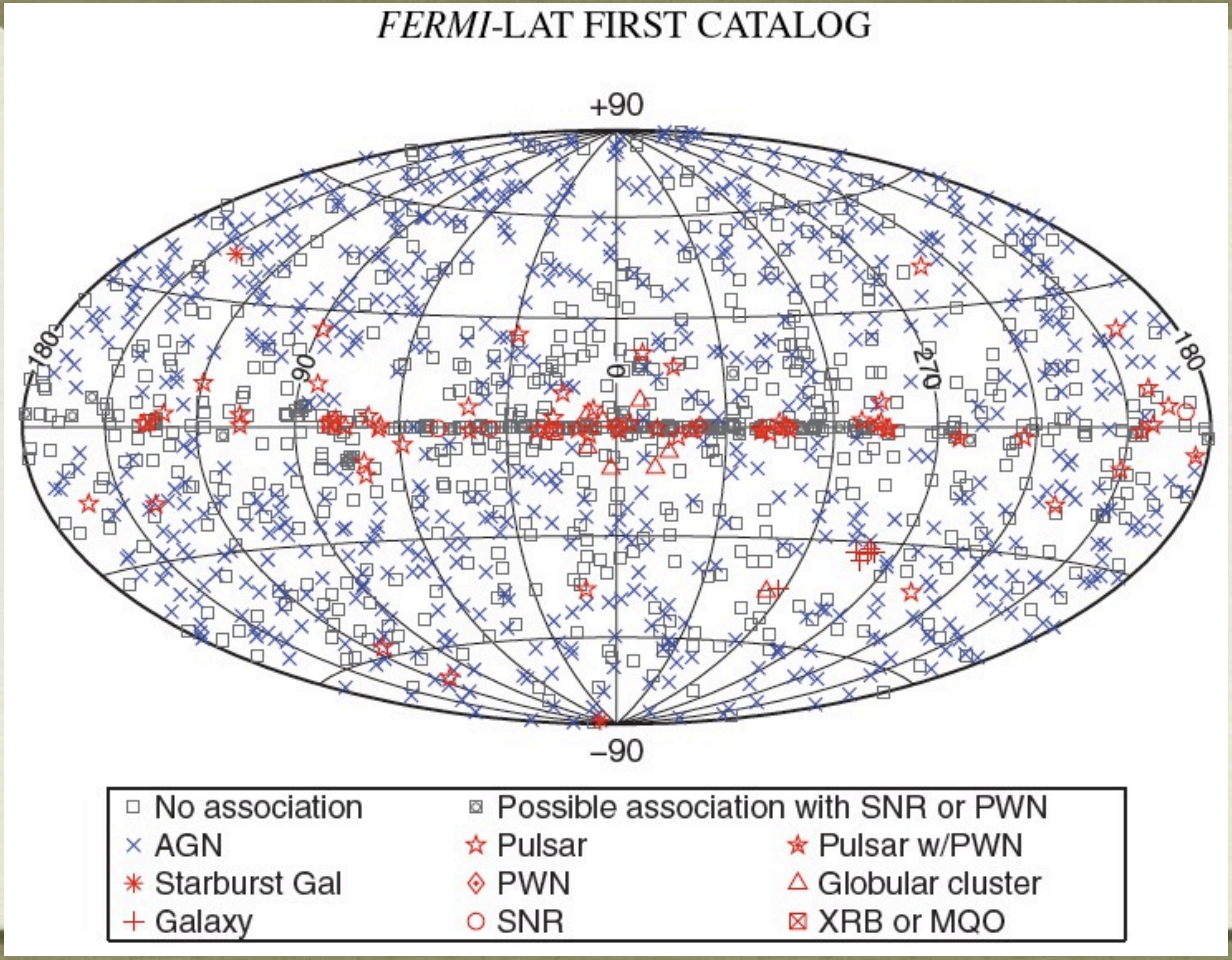
GAMMA-RAY SKY



GAMMA-RAY SKY



GAMMA-RAY SKY



POPULATIONS OF GAMMA-RAY SOURCES

- Pulsars
- X-ray binaries (HMXB, microquasar)
- Galaxies (Active Galactic Nuclei, Blazar)
- Supernovae explosion/remnant
- Gamma-ray burst
- Other issues
- Unidentified sources

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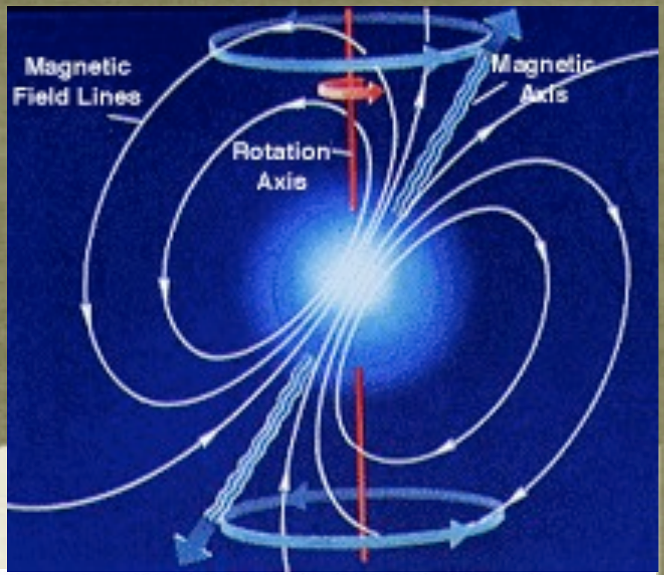
PULSAR



- A neutron star which emits beams of radiation that sweep through the line of sight, and show pulses in their light curves.

- High speed electrons interact with magnetic fields.

- Spin-powered pulsar & accretion-powered pulsar.
  ➙ radio pulsar, X-ray pulsar, gamma-ray pulsar
  ➙ milli-second pulsar

- Gamma-ray observations could help distinguish different pulsar models.

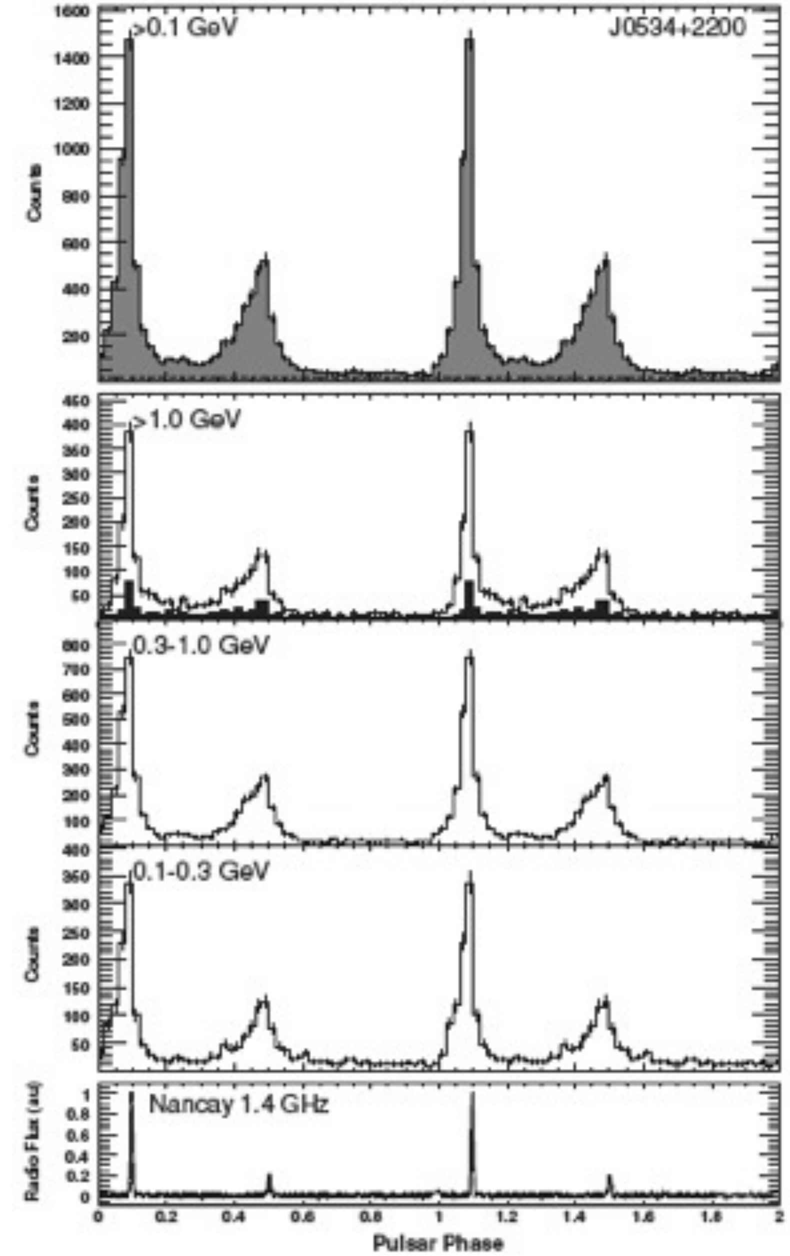
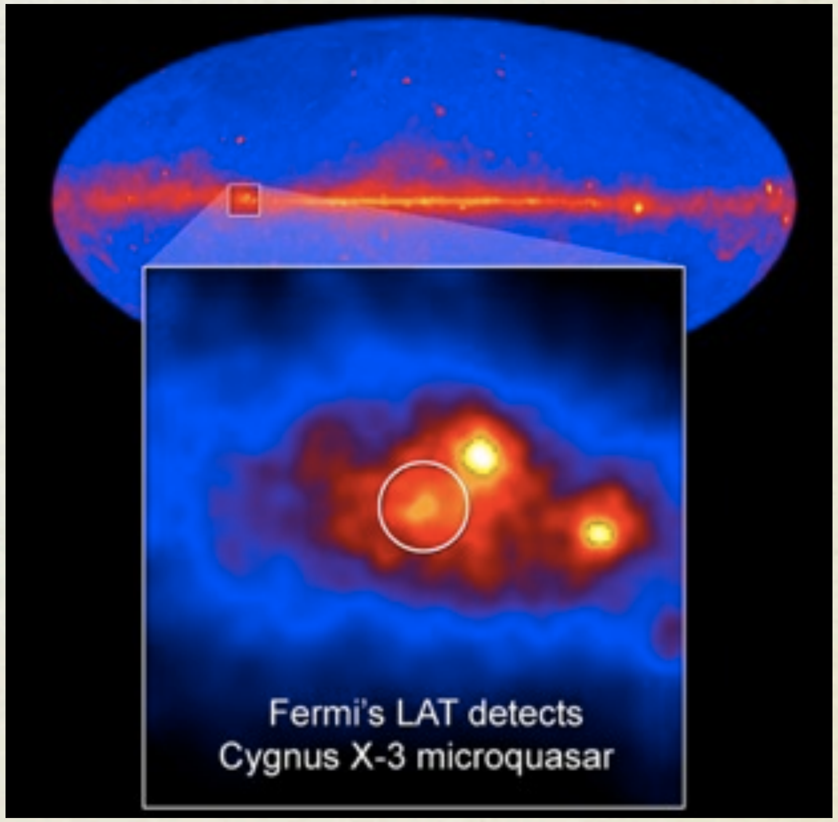


Figure A8. Light curves for PSR J0534+2200 (P = 33.1 ms, Crab pulsar). The zero of phase is set to the radio precursor.

X-RAY BINARIES

- Composed of a compact object and a normal star companion.
- High Mass X-ray Binaries (HMXBs) with a high mass companion
- Microquasar
  ➙ Black hole/neutron star HMXB
  ➙ gamma-rays from jets or pulsar winds
  ➙ eg., Cyg-X3



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GALAXIES


An artists conception of an AGN

- Active Galactic Nuclei (AGN)
  - ➙ scaled-up microquasar
  - ➙ super-massive black holes accreting materials
  - ➙ Blazars: jet-on AGNs
  - ➙ Quasars: very distant AGNs
- Inverse Compton generated Gamma-rays from jets

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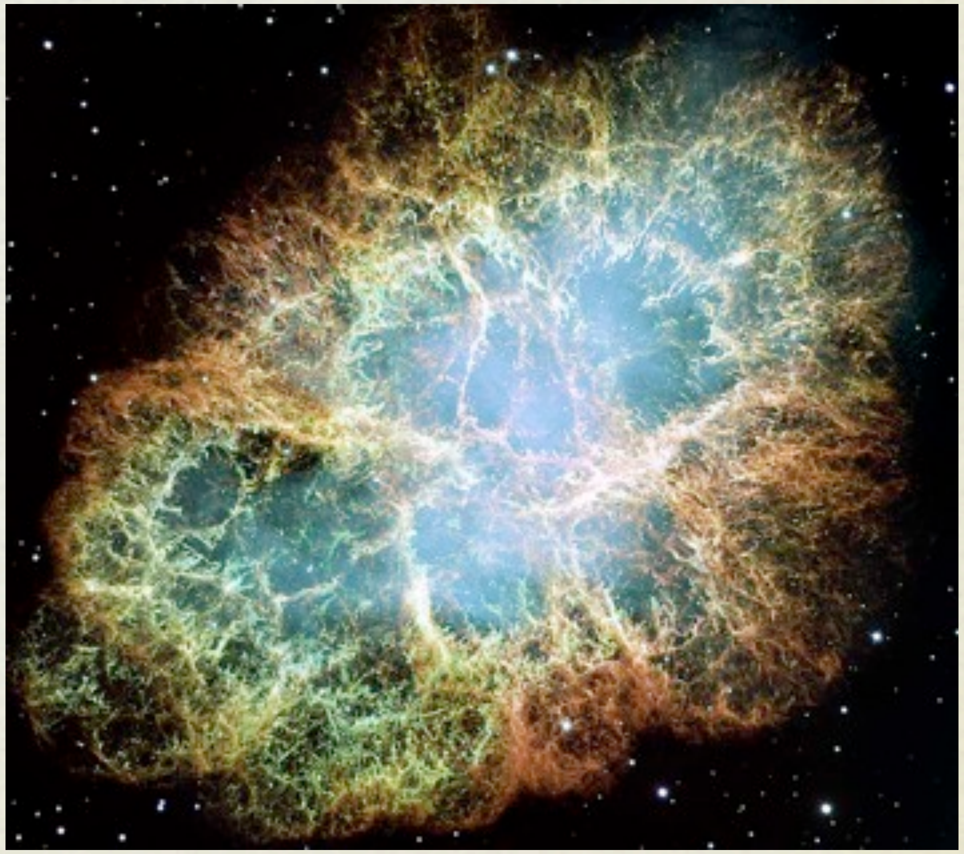
SUPERNOVAE

- Explosion of massive stars and their remnants.
- Shocks, particle acceleration and interactions with environment, synchrotron radiation.
- Supernovae remnants are often associated with pulsar wind nebulae, eg., Crab and Vela.
- Possible sources of Cosmic rays and Gamma-ray burst.



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GAMMA-RAY BURST

- Extra-galactic source;
  two distinct type ➙ long GRB and short GRB.
- A relativistic fireball model.
- Core collapse of massive stars (SNe).
- Mergers of two compact objects.
- Stellar collisions in globular clusters?

OTHER ISSUES

- Dark matter annihilation search
  Weakly interacting massive particles annihilate to produce gamma-rays

- Clusters of Galaxies?
  Ackermann et al. 2010, arXiv:1006.0748vi

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DISCOVERIES FROM CATALOGUES

Aharonian et al. 2005, Science

- New gamma-ray population?

At least two of eight newly-discovered HESS sources have no identified counterpart in radio or x-rays, which suggests the exciting possibility of a new class of “dark” nucleonic particle accelerators. The HESS catalog provides insights into particle acceleration in our Galaxy and adds a piece to the long-standing puzzle of cosmic-ray origin.

REPORTS

A New Population of Very High Energy Gamma-Ray Sources in the Milky Way

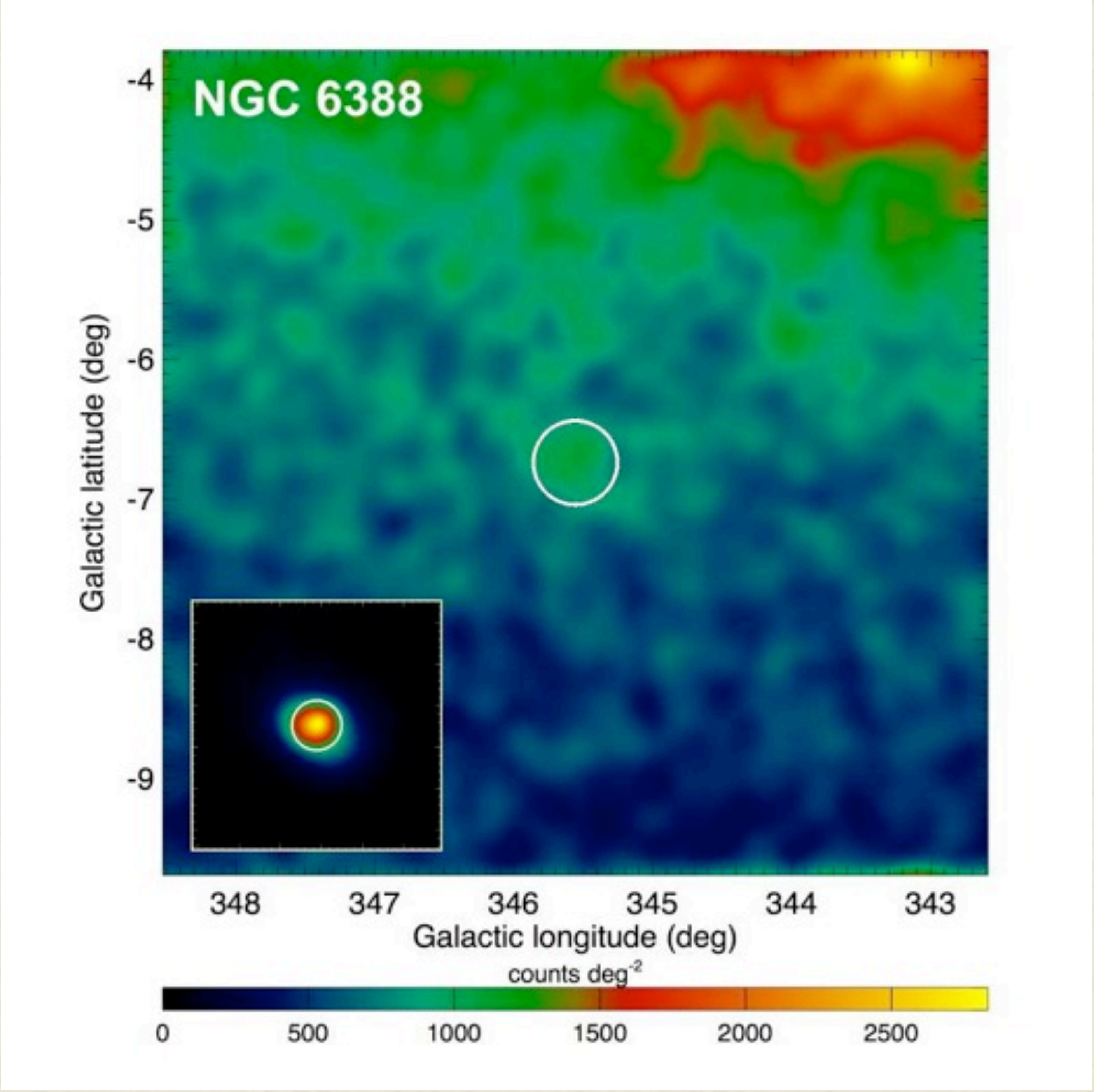
F. Aharonian,[1] A. G. Akhperjanian,[2] K.-M. Aye,[3] A. R. Bazer-Bachi,[4] M. Beilicke,[5] W. Benbow,[1] D. Berge,[1] P. Berghaus,[6*] K. Bernlöhr,[1,7] C. Boisson,[8] O. Bolz,[1] C. Borgmeier,[7] I. Braun,[1] F. Breitling,[7] A. M. Brown,[3] J. Bussons Gordo,[9] P. M. Chadwick,[3] L.-M. Chounet,[10] R. Cornils,[5] L. Costamante,[1] B. Degrange,[10] A. Djannati-Ataï,[6] L. O'C. Drury,[11] G. Dubus,[10] T. Ergin,[7] P. Espigat,[6] F. Feinstein,[9] P. Fleury,[10] G. Fontaine,[10] S. Funk,[1]† Y. A. Gallant,[9] B. Giebels,[10] S. Gillessen,[1] P. Goret,[12] C. Hadjichristidis,[3] M. Hauser,[13] G. Heinzelmann,[5] G. Henri,[14] G. Hermann,[1] J. A. Hinton,[1] W. Hofmann,[1] M. Holleran,[15] D. Horns,[1] O. C. de Jager,[15] I. Jung,[1,13]‡ B. Khélifi,[1] Nu. Komin,[7] A. Konopelko,[1,7] I. J. Latham,[3] R. Le Gallou,[3] A. Lemière,[6] M. Lemoine,[10] N. Leroy,[10] T. Lohse,[7] A. Marcowith,[4] C. Masterson,[1] T. J. L. McComb,[3] M. de Naurois,[16] S. J. Nolan,[3] A. Noutsos,[3] K. J. Orford,[3] J. L. Osborne,[3] M. Ouchrif,[16] M. Panter,[1] G. Pelletier,[14] S. Pita,[6] G. Pühlhofer,[1,13] M. Punch,[6] B. C. Raubenheimer,[15] M. Raue,[5] J. Raux,[16] S. M. Rayner,[3] I. Redondo,[10]§ A. Reimer,[17] O. Reimer,[17] J. Ripken,[5] L. Rob,[18] L. Rolland,[16] G. Rowell,[1] V. Sahakian,[2] L. Saugé,[14] S. Schlenker,[7] R. Schlickeiser,[17] C. Schuster,[17] U. Schwanke,[7] M. Siewert,[17] H. Sol,[8] R. Steenkamp,[19] C. Stegmann,[7] J.-P. Tavernet,[16] R. Terrier,[6] C. G. Théoret,[6] M. Tluczykont,[10] D. J. van der Walt,[15] G. Vasileiadis,[9] C. Venter,[15] P. Vincent,[16] B. Visser,[15] H. J. Völk,[1] S. J. Wagner[13]

DISCOVERIES FROM CATALOGUES

Gamma-Rays from

Globular Clusters

Abdo et al. 2010, arXiv:1003.3588v1



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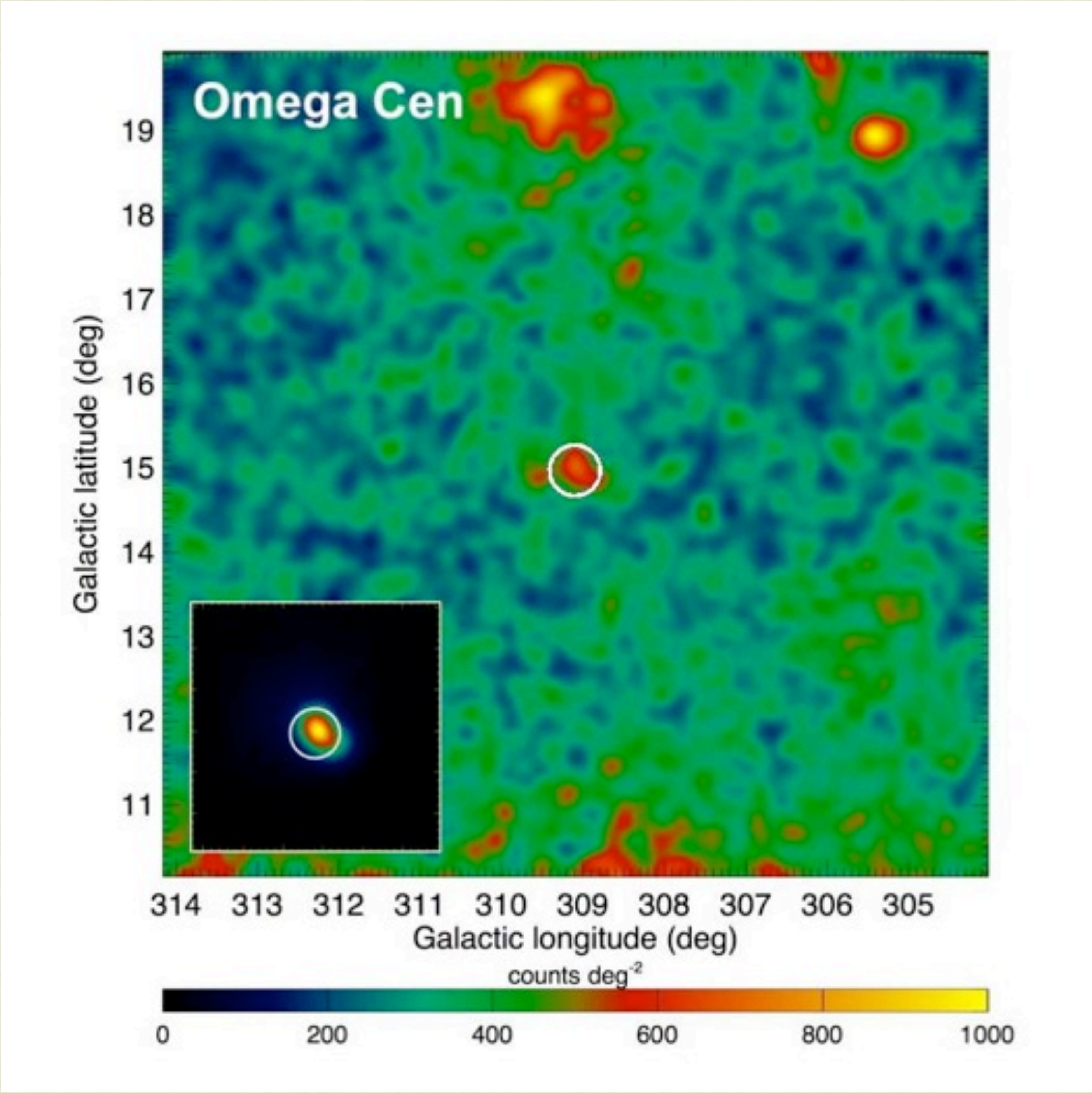

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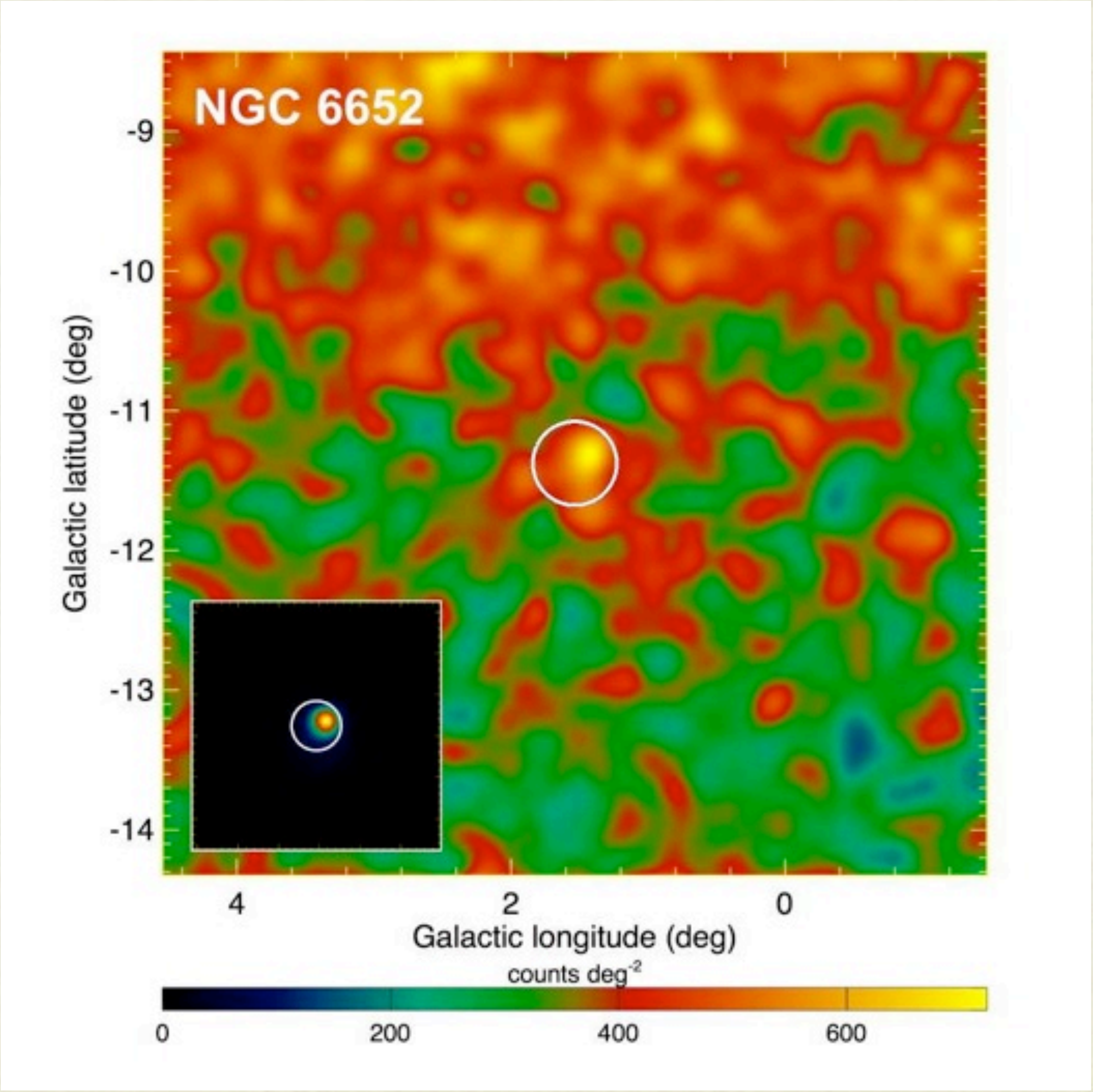

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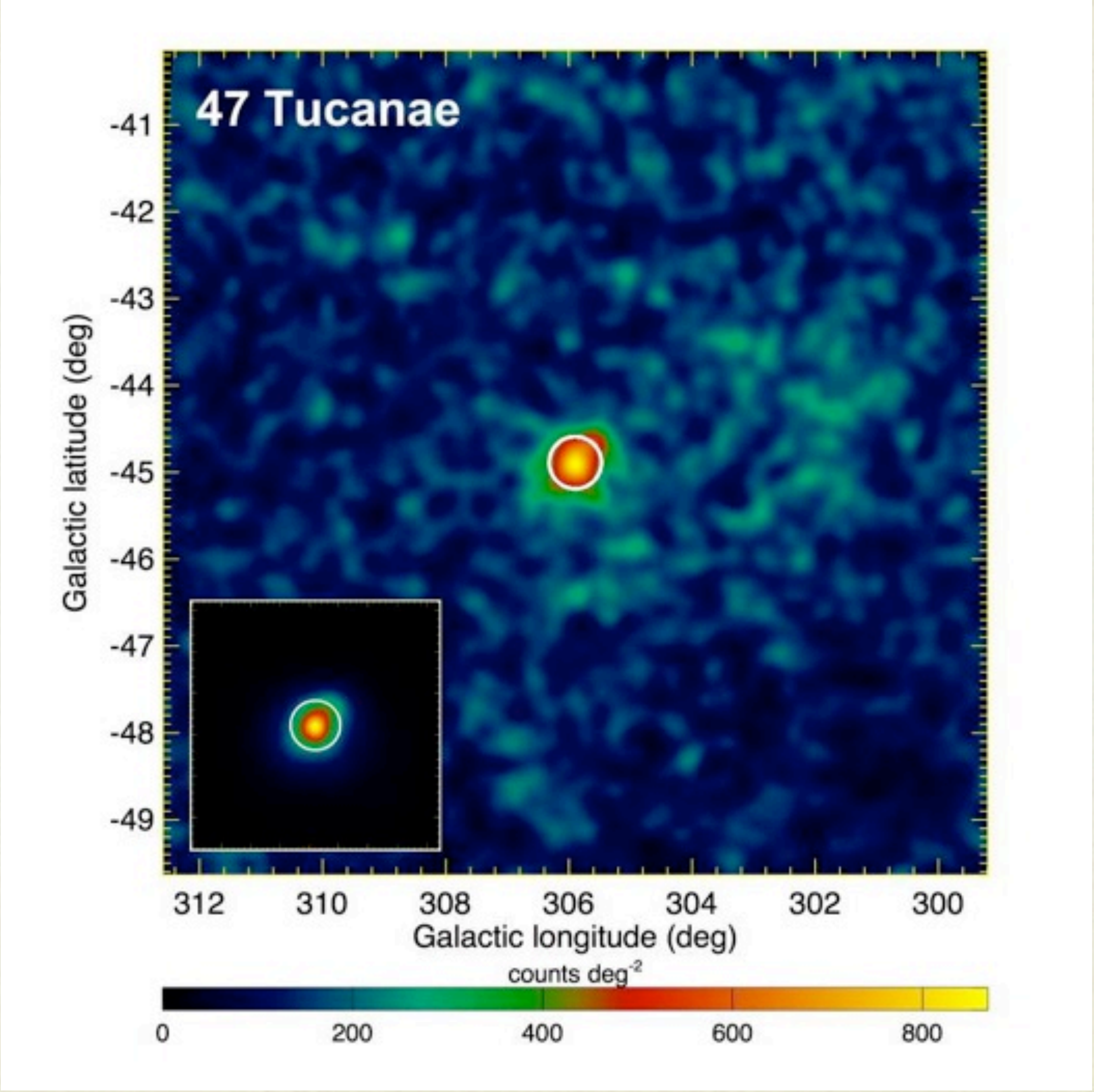

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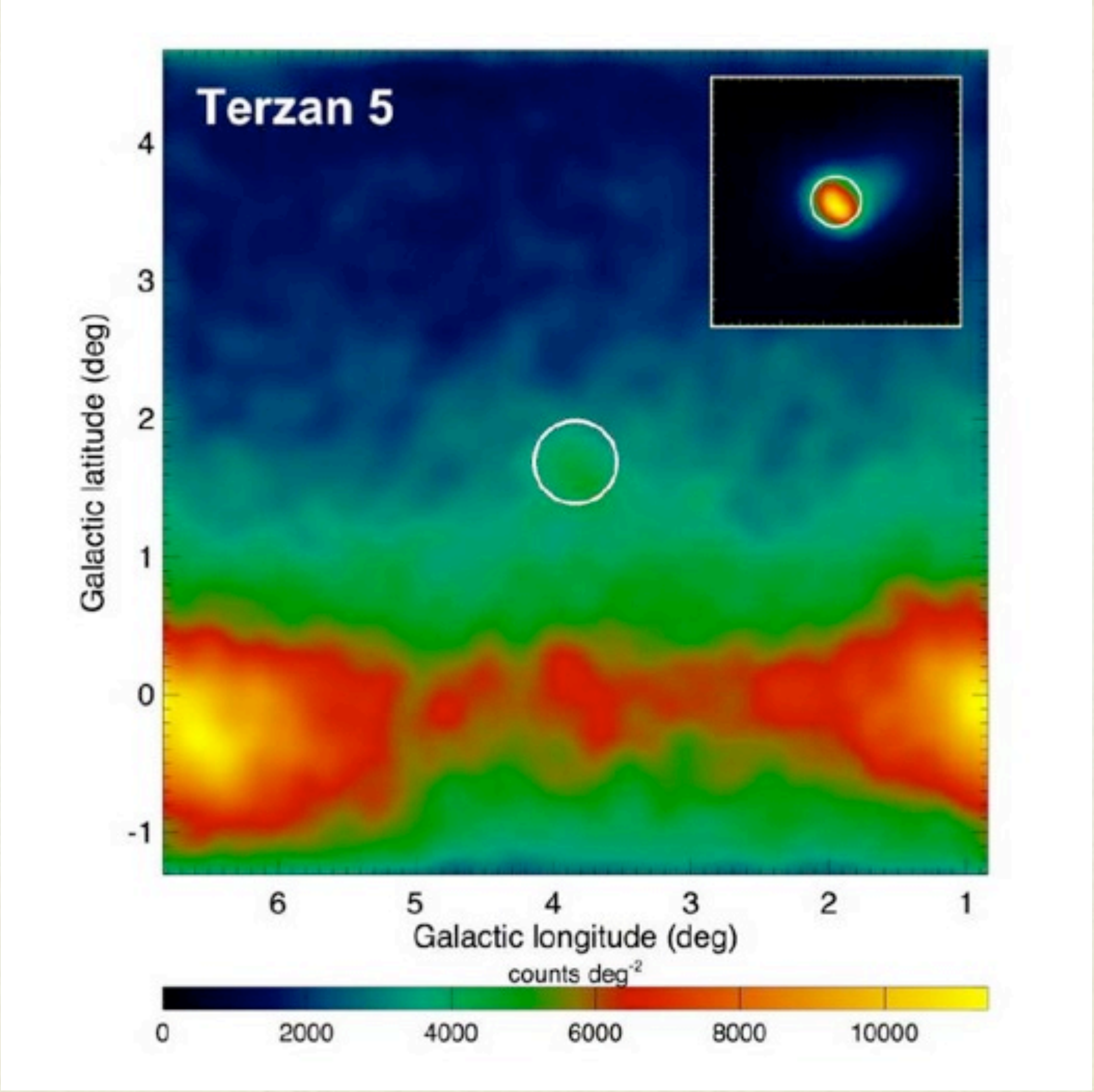

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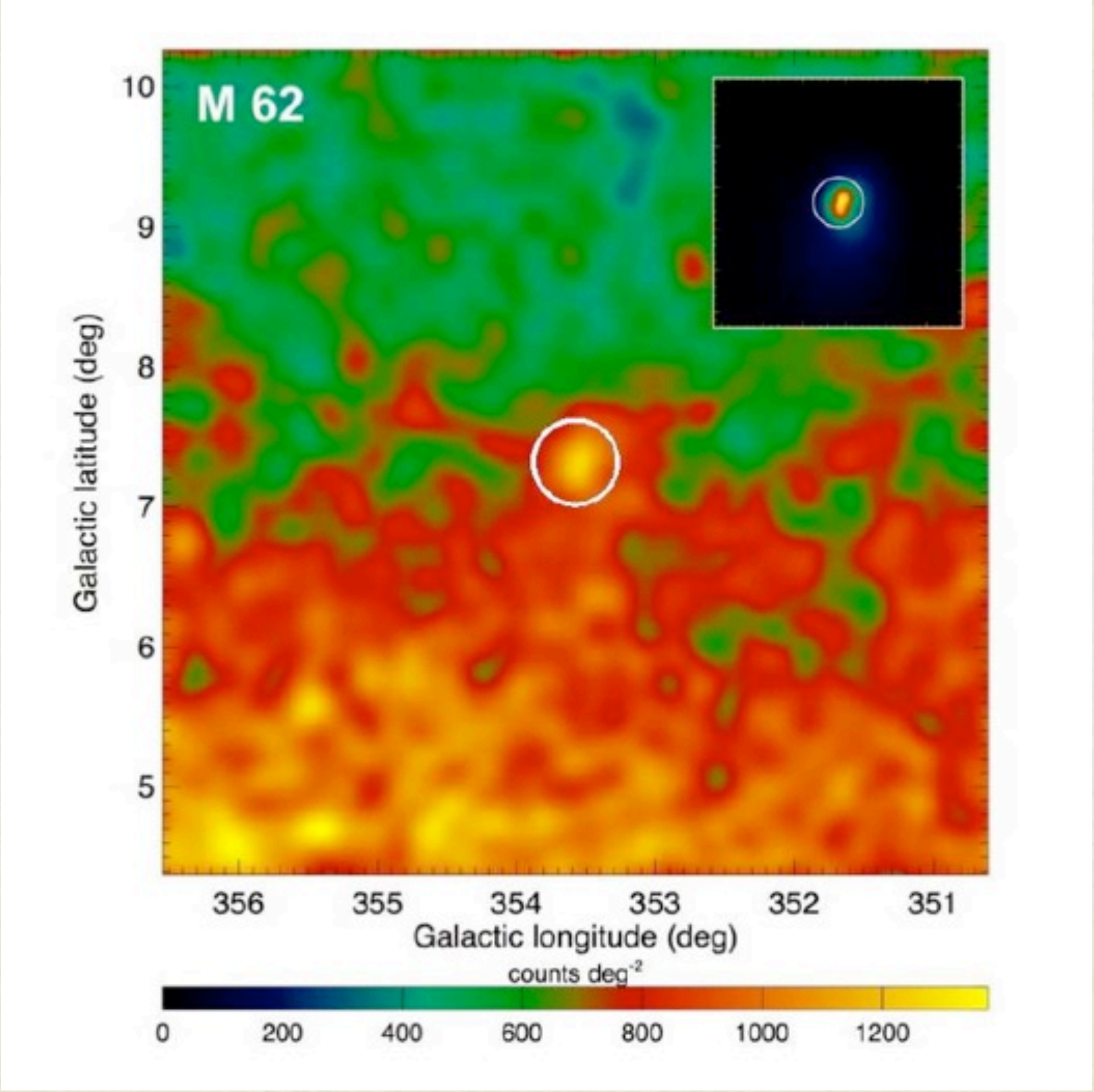

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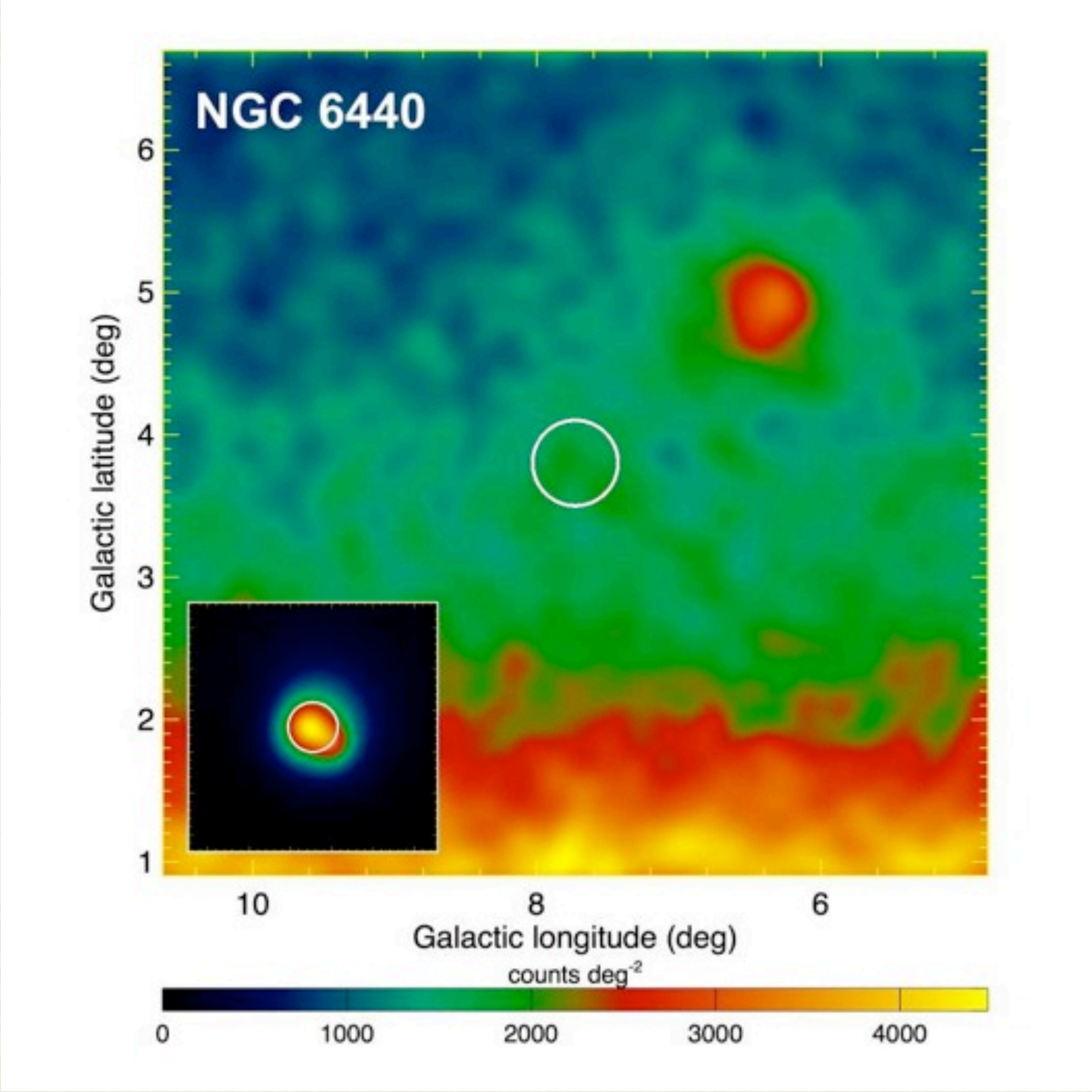

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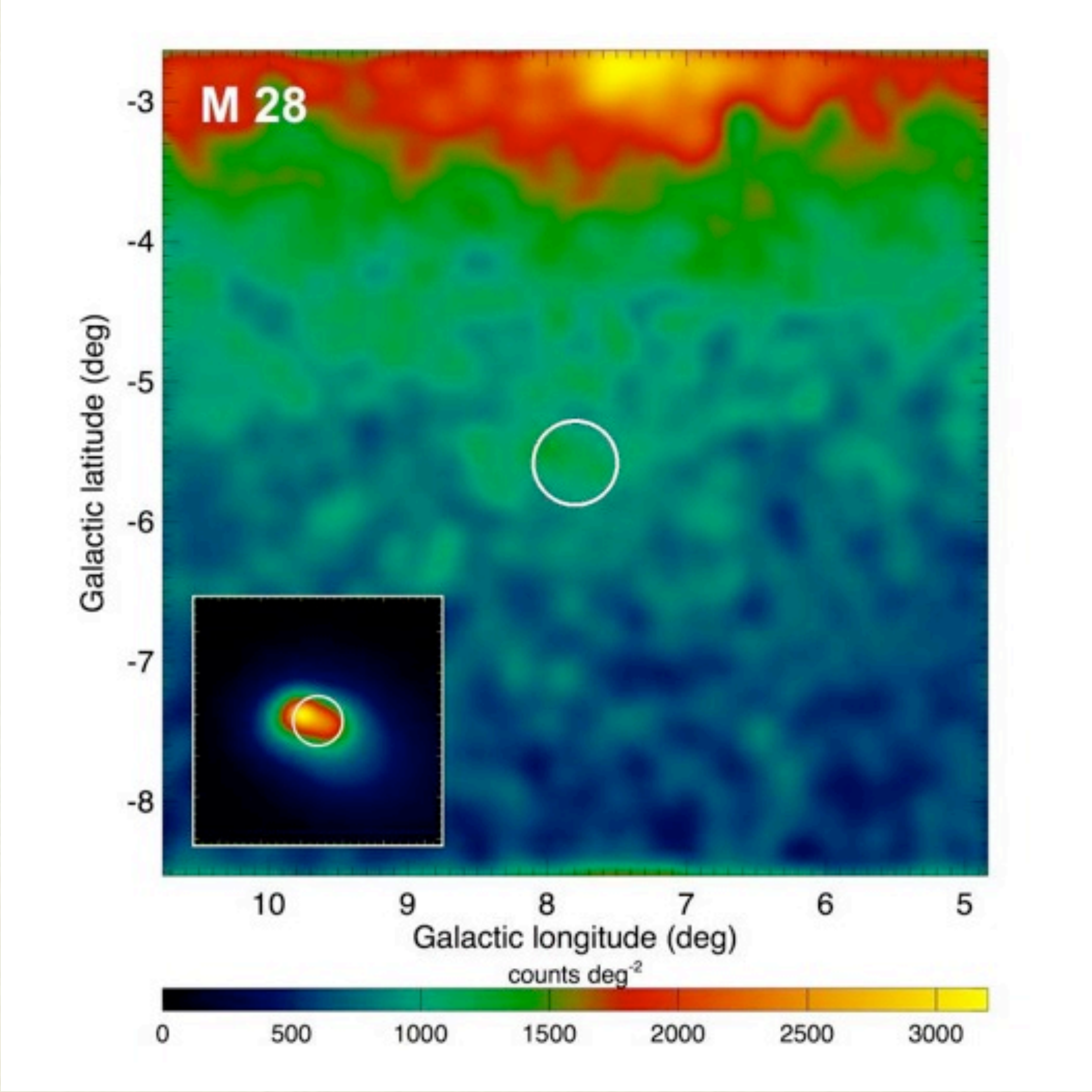

DISCOVERIES FROM CATALOGUES

Abdo et al. 2010, arXiv:1003.3588v1

Table 3. Gamma-ray characteristics of globular clusters.

Name	α_{J2000}	δ_{J2000}	r_{95}	σ_{ext}	TS	χ^2_{month}	Photon flux	Energy flux	Γ	E_c	s_c
47 Tucanae	$00^h23.8^m$	$-72°04'$	$3.3'$	$< 4.8'$	603.3	9.6	$2.9^{+0.6+0.4}_{-0.5-0.3}$	$2.5^{+0.2+0.2}_{-0.2-0.2}$	$1.4^{+0.2+0.2}_{-0.2-0.2}$	$2.2^{+0.8+0.3}_{-0.5-0.2}$	5.6
Omega Cen	$13^h26.5^m$	$-47°29'$	$7.5'$	$< 8.4'$	50.0	14.6	$0.9^{+0.5+0.3}_{-0.4-0.2}$	$1.0^{+0.2+0.1}_{-0.2-0.1}$	$0.7^{+0.7+0.4}_{-0.6-0.4}$	$1.2^{+0.7+0.2}_{-0.4-0.2}$	4.0
M 62	$17^h01.1^m$	$-30°08'$	$4.4'$	$< 7.2'$	107.9	16.0	$2.7^{+1.0+1.9}_{-0.9-0.8}$	$2.1^{+0.3+0.5}_{-0.3-0.1}$	$1.7^{+0.3+0.4}_{-0.3-0.5}$	$4.4^{+3.8+17.7}_{-1.8-1.8}$	2.5
NGC 6388	$17^h35.9^m$	$-44°41'$	$5.7'$	$< 9.0'$	86.6	13.8	$1.6^{+1.0+2.0}_{-0.6-0.6}$	$1.6^{+0.3+0.6}_{-0.3-0.2}$	$1.1^{+0.7+0.8}_{-0.5-0.8}$	$1.8^{+1.2+1.8}_{-0.7-0.6}$	3.3
Terzan 5	$17^h47.9^m$	$-24°48'$	$2.9'$	$< 9.0'$	341.3	25.5	$7.6^{+1.7+3.4}_{-1.5-2.2}$	$7.1^{+0.6+1.0}_{-0.5-0.5}$	$1.4^{+0.2+0.4}_{-0.2-0.3}$	$2.6^{+0.7+1.2}_{-0.5-0.7}$	7.1
NGC 6440	$17^h48.8^m$	$-20°21'$	$5.2'$	$< 8.4'$	65.7	5.9	$2.9^{+2.7+4.4}_{-1.3-1.1}$	$2.2^{+0.9+1.2}_{-0.5-0.2}$	$1.6^{+0.5+0.6}_{-0.5-0.8}$	$3.1^{+3.3+\infty}_{-1.4-1.1}$	1.4
M 28	$18^h24.4^m$	$-24°51'$	$8.0'$	$< 15.6'$	77.9	20.6	$2.6^{+1.3+2.2}_{-1.0-0.9}$	$2.0^{+0.4+0.6}_{-0.3-0.3}$	$1.1^{+0.7+0.6}_{-0.5-0.7}$	$1.0^{+0.6+0.4}_{-0.3-0.2}$	4.3
NGC 6652	$18^h35.7^m$	$-33°01'$	$7.5'$	$< 9.6'$	54.8	9.8	$0.7^{+0.5+0.2}_{-0.3-0.1}$	$0.8^{+0.2+0.1}_{-0.1-0.1}$	$1.0^{+0.6+0.3}_{-0.5-0.3}$	$1.8^{+1.2+0.4}_{-0.6-0.3}$	3.2
NGC 6541	$18^h07.9^m$	$-43°41'$	$20.1'$	–	12.0	–	< 1.1	< 0.8	(1.4)	(1.6)	–
NGC 6752	$19^h10.3^m$	$-59°56'$	$6.3'$	–	13.7	–	< 0.7	< 0.5	(1.4)	(1.6)	–
M 15	$21^h29.4^m$	$+12°06'$	$6.9'^*$	–	5.4	–	< 0.6	< 0.5	(1.4)	(1.6)	–

- Sources in globular clusters; New milli-second pulsars!?

KEEP WORKING, FIND SOMETHING.

Thank you!