Laboratory for Space Research

Where are all the MeV gamma-ray pulsars?

Pablo Saz Parkinson

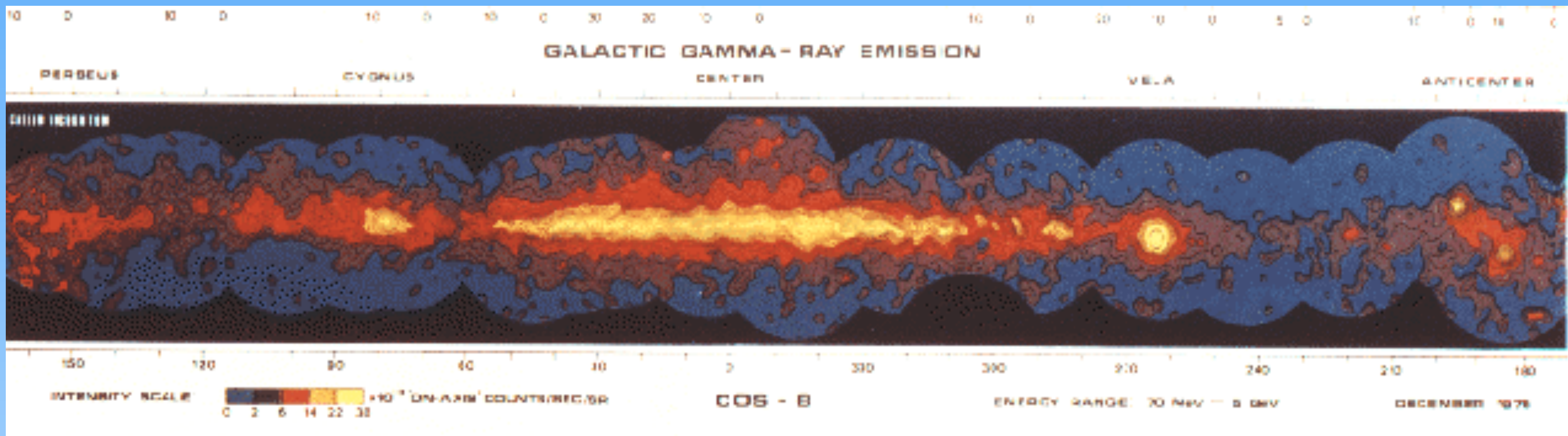
Department of Physics and Laboratory for Space Research

University of Hong Kong

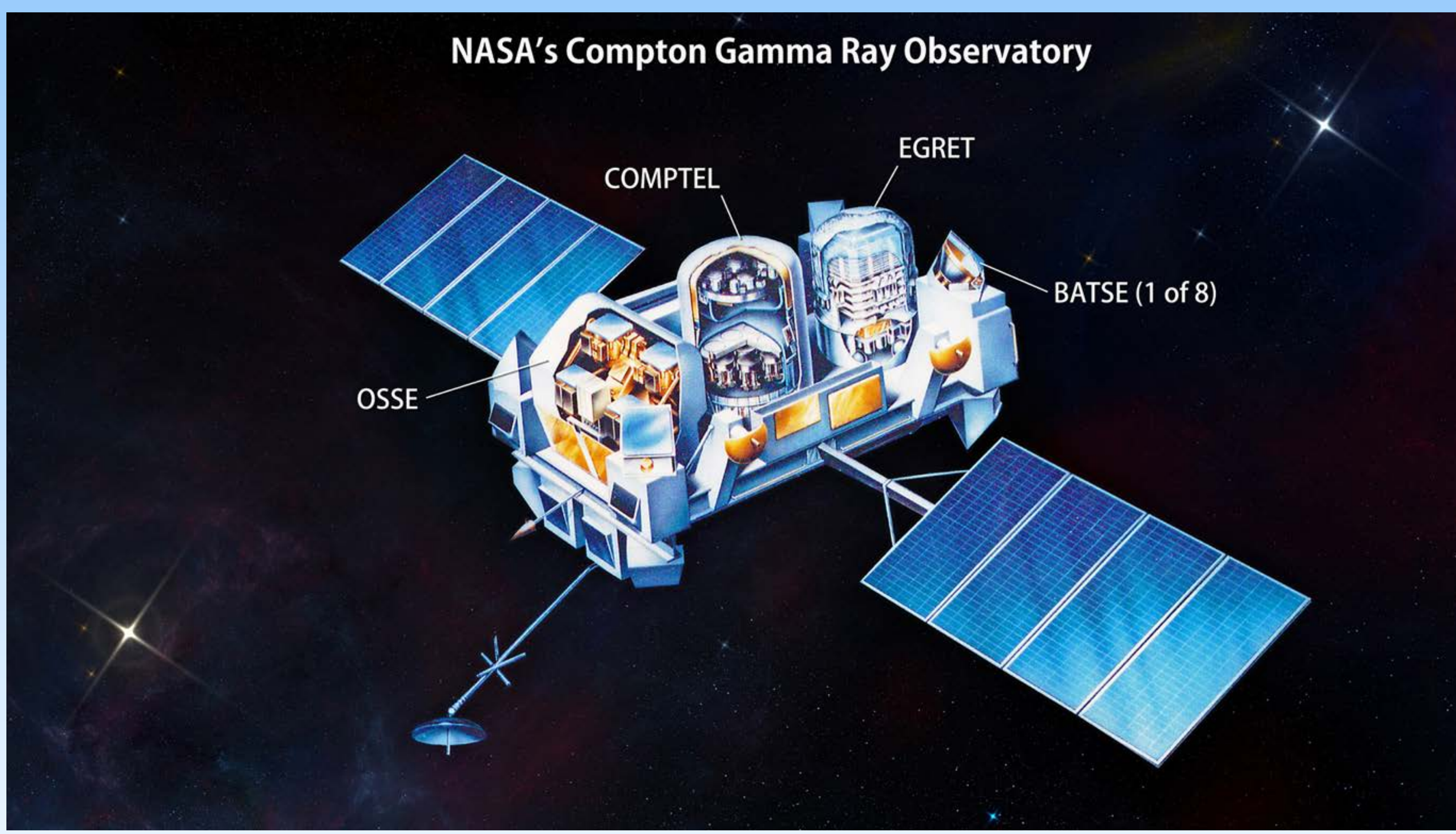
ESAC Science Seminar

12 December 2019

Gamma-ray astronomy



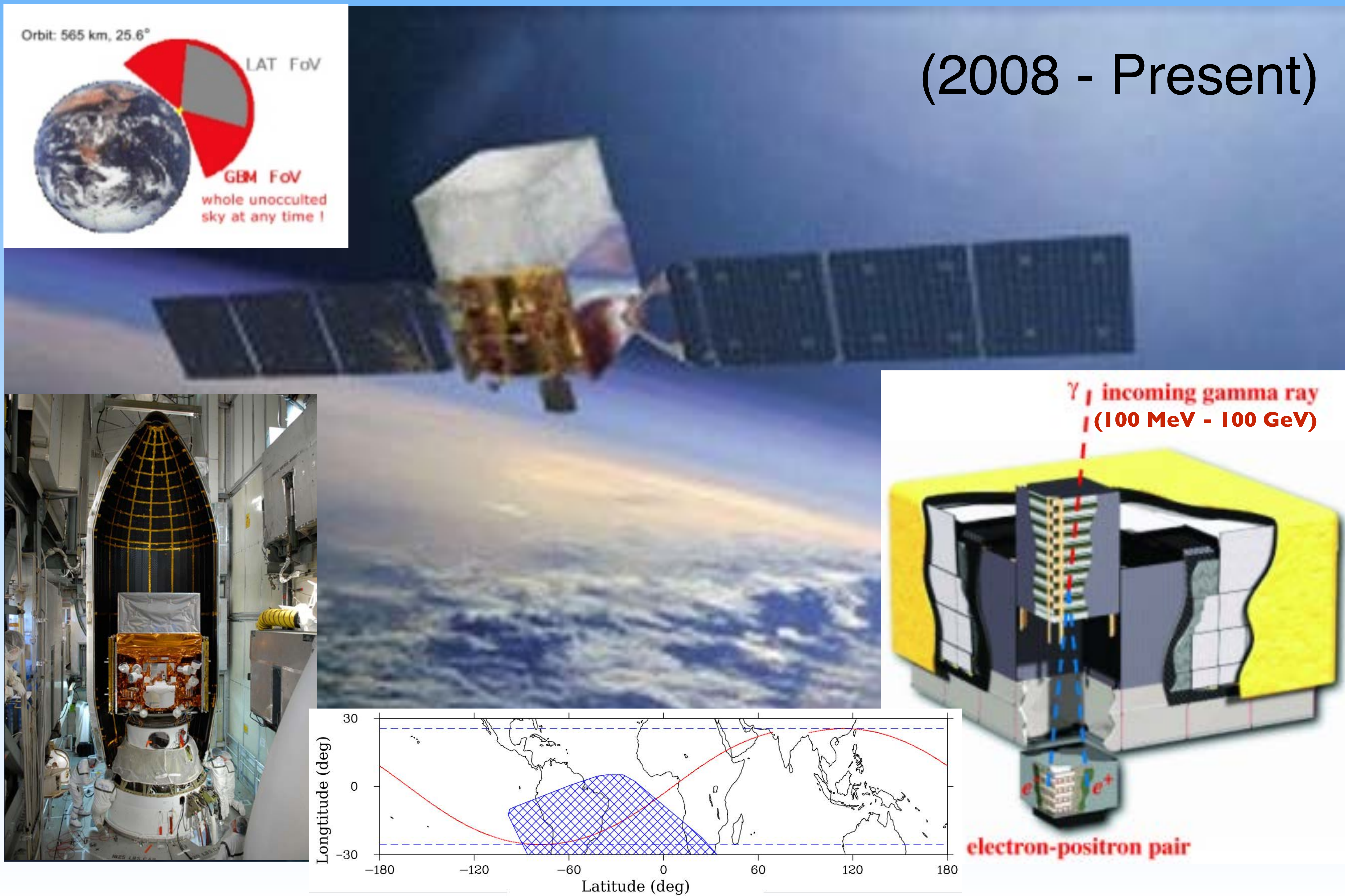
COS-B (1975-1982):
~200,000 photons



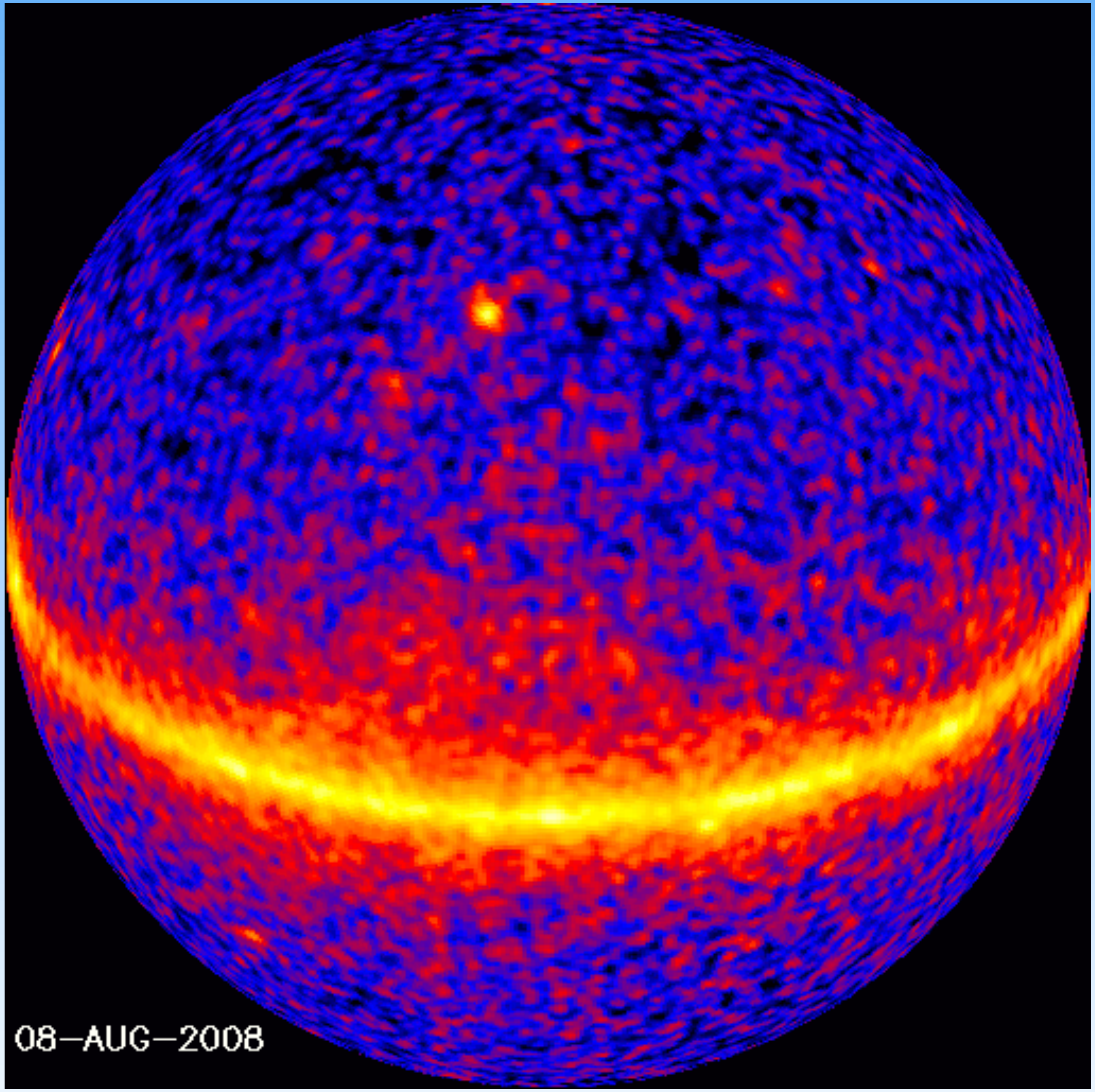
EGRET (1991-2000): 1.4E6 photons, ~300 sources

SAS-2 (1972-1973): ~8000 photons

Fermi gamma-ray space telescope

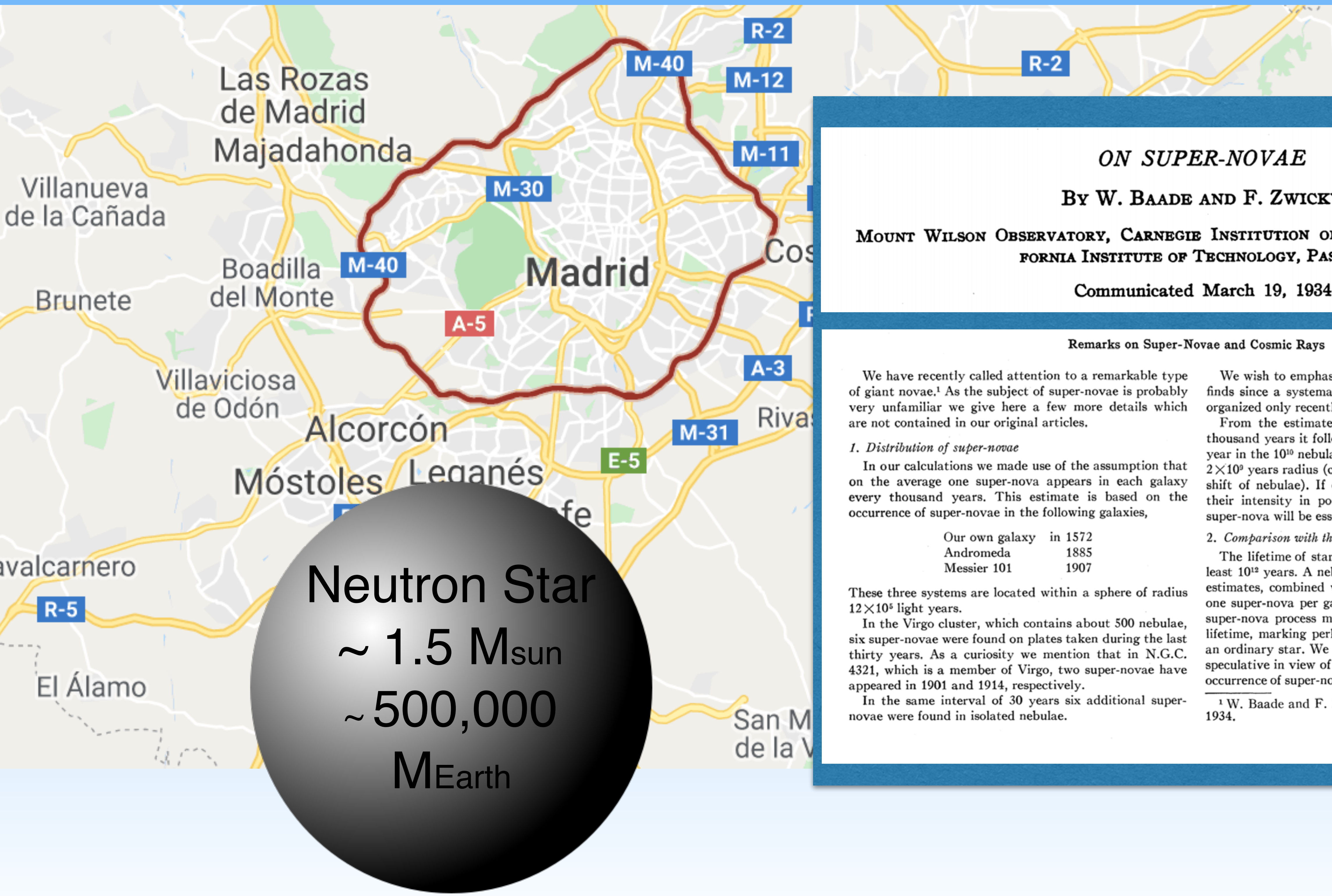


Fermi gamma-ray sky



> 3 billion photons (and counting)

Neutron stars



ON SUPER-NOVAE

By W. Baade and F. Zwicky

Mount Wilson Observatory, Carnegie Institution of Washington and California Institute of Technology, Pasadena

Communicated March 19, 1934

Remarks on Super-Novae and Cosmic Rays

We have recently called attention to a remarkable type of giant novae.[1] As the subject of super-novae is probably very unfamiliar we give here a few more details which are not contained in our original articles.

1. Distribution of super-novae

In our calculations we made use of the assumption that on the average one super-nova appears in each galaxy every thousand years. This estimate is based on the occurrence of super-novae in the following galaxies,

Our own galaxy	in 1572
Andromeda	1885
Messier 101	1907

These three systems are located within a sphere of radius 12×10^5 light years.

In the Virgo cluster, which contains about 500 nebulae, six super-novae were found on plates taken during the last thirty years. As a curiosity we mention that in N.G.C. 4321, which is a member of Virgo, two super-novae have appeared in 1901 and 1914, respectively.

In the same interval of 30 years six additional super-novae were found in isolated nebulae.

We wish to emphasize that all of these finds are chance finds since a systematic search for super-novae has been organized only recently.

From the estimate of one super-nova per galaxy per thousand years it follows that 10^7 super-novae appear per year in the 10^{10} nebulae which are contained in a sphere of 2×10^9 years radius (critical distance derived from the red shift of nebulae). If cosmic rays come from super-novae their intensity in points far away from any individual super-nova will be essentially independent of time.

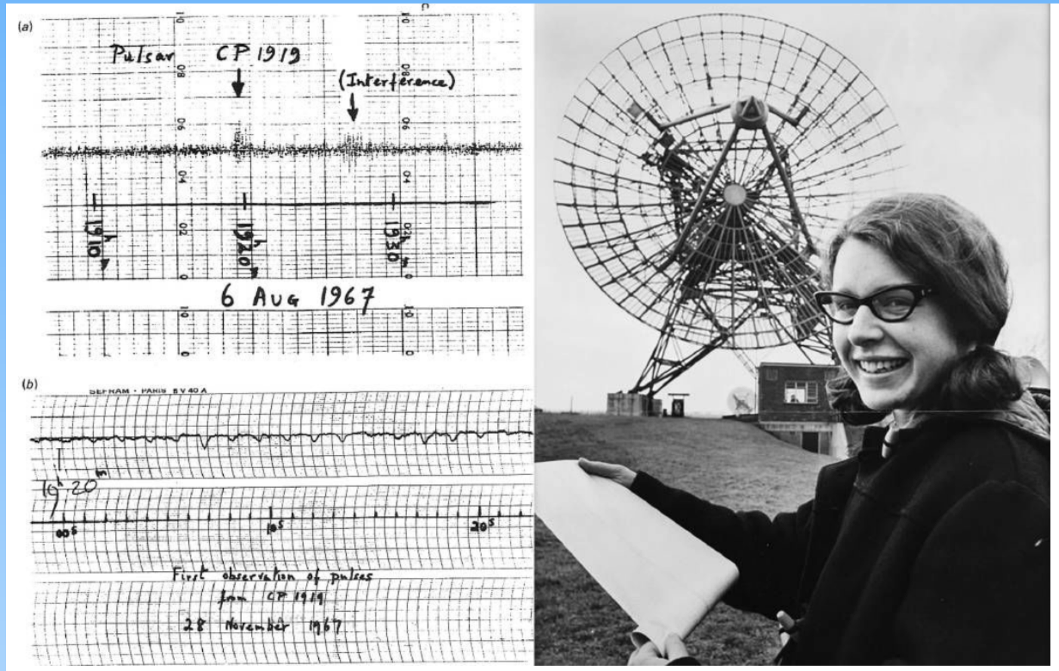
2. Comparison with the lifetime of stars

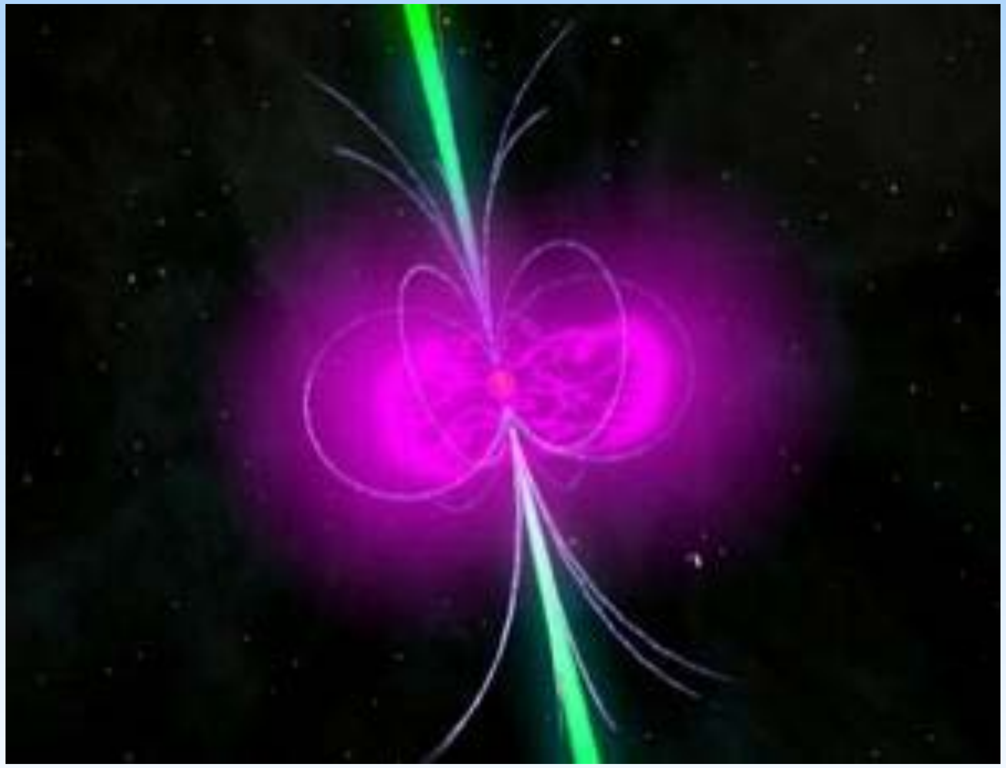
The lifetime of stars is supposed to be of the order of at least 10^{12} years. A nebula contains about 10^9 stars. These estimates, combined with the frequency of occurrence of one super-nova per galaxy per 10^3 years suggest that the super-nova process might occur to every star once in its lifetime, marking perhaps the cessation of its existence as an ordinary star. We realize that this suggestion is highly speculative in view of the possibility that the frequency of occurrence of super-novae may depend on time and in view

[1] W. Baade and F. Zwicky, Proc. Nat. Acad. Sci. May, 1934.

Pulsar Basics

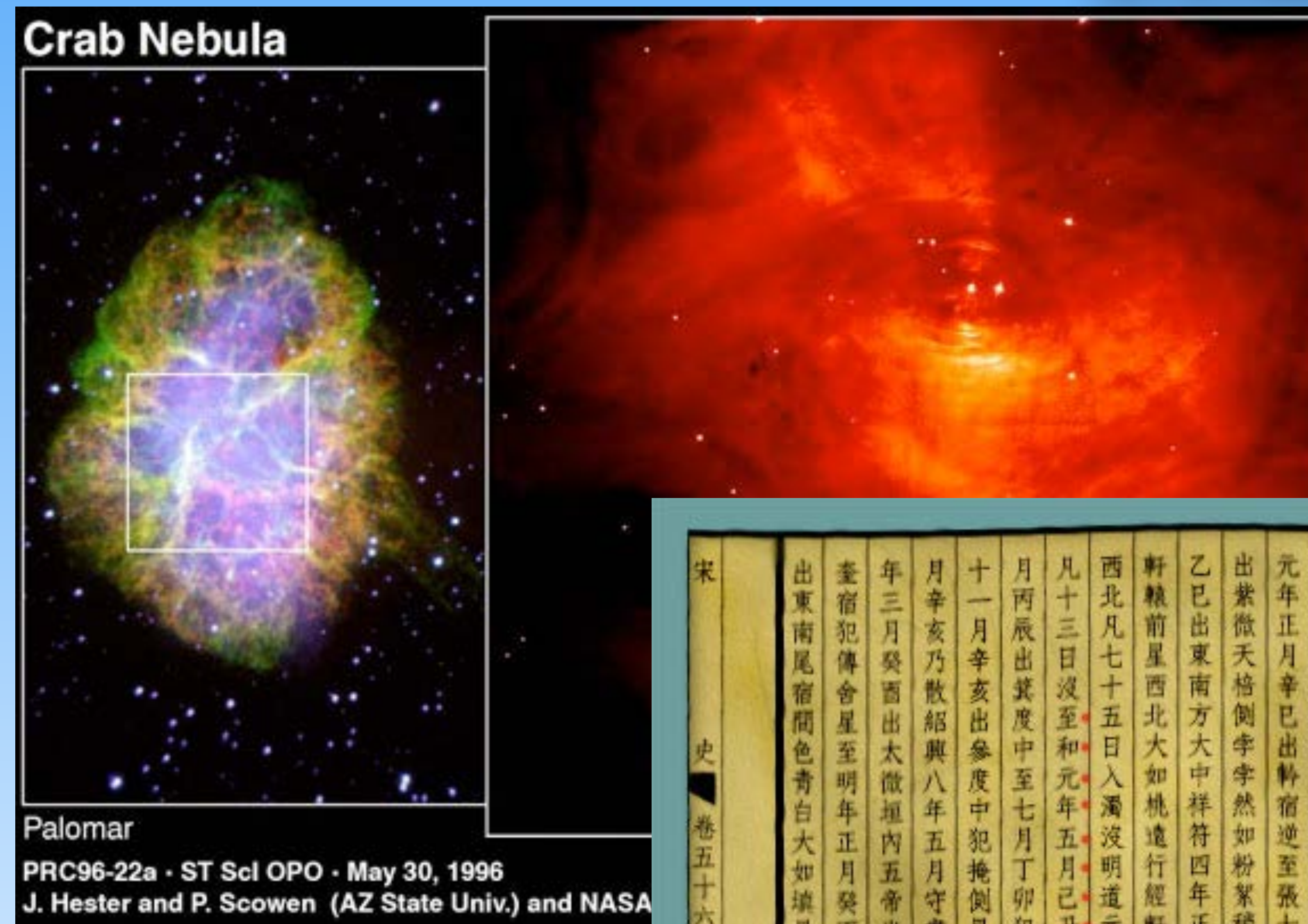
- Discovered ~ 50 years ago but still not completely understood
- Rapidly-spinning (0.1 Hz - 700 Hz),
- highly-magnetised (1E9 to 1E15 G)
- neutron star (R ~ 10 km, M ~ Sun)
- ~2500 known pulsars
- Two main "varieties": young and millisecond pulsars
- multi-wavelength emission (over 20 decades)

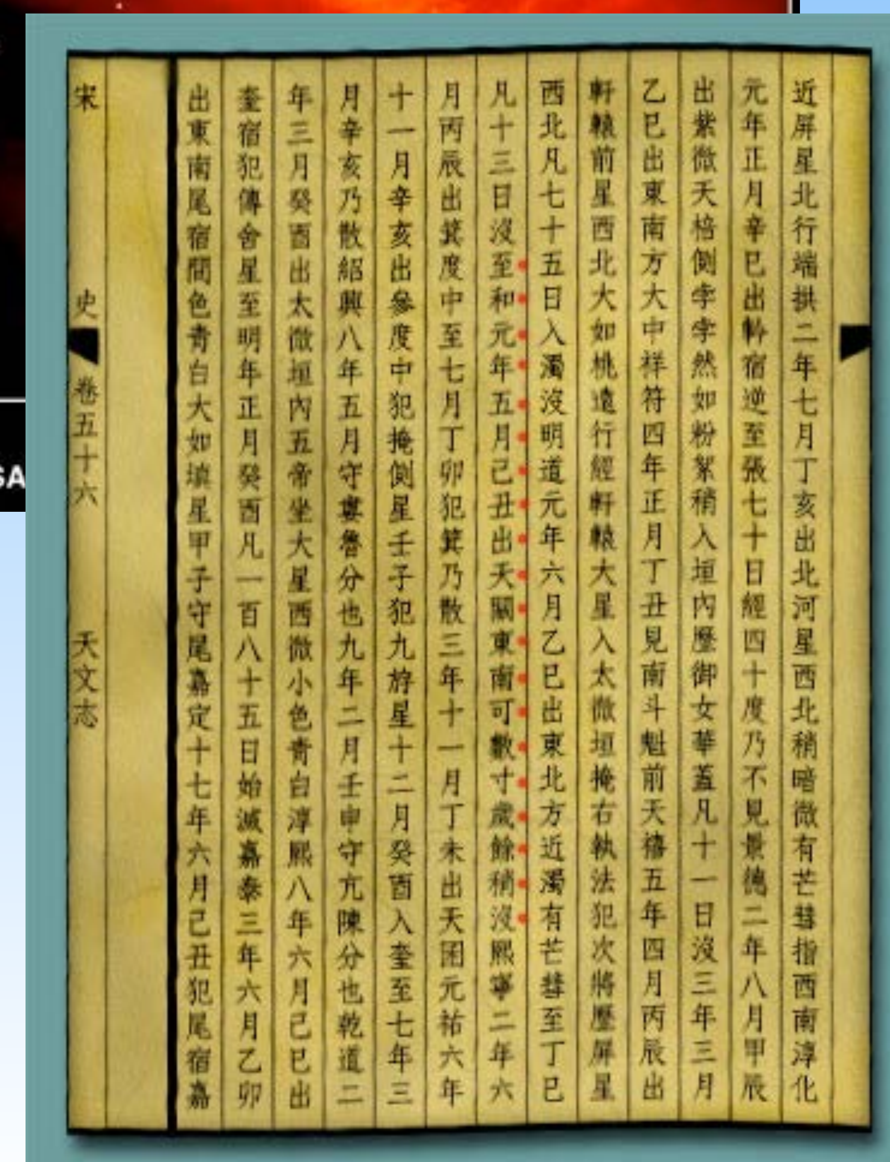




The Crab pulsar

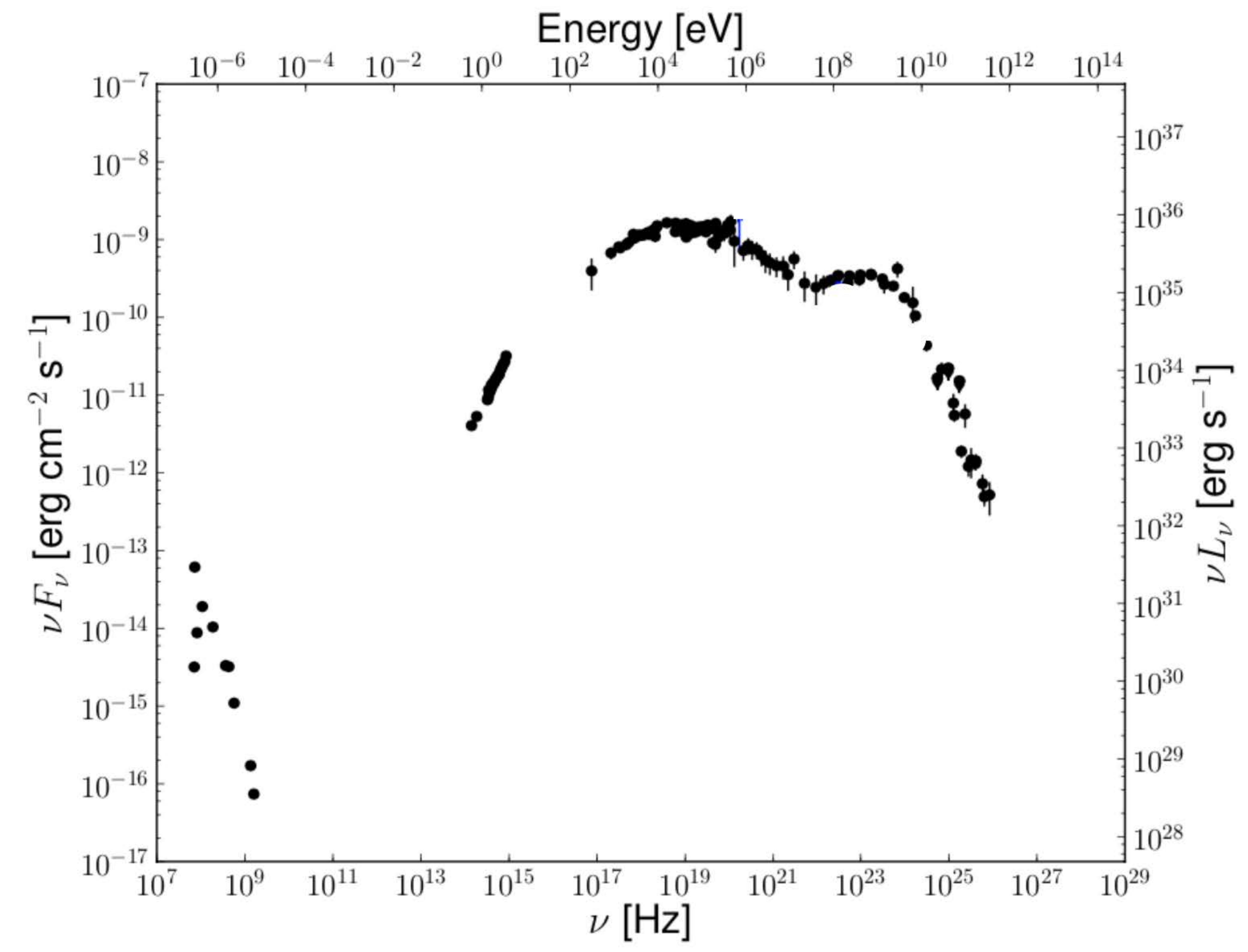
- Remnant of SN 1054 AD (recorded by Chinese astronomers in the Song Dynasty)
- One of the youngest (and the *most* energetic) known pulsars




近屏星北行端拱二年七月丁亥出北河星西北稍暗微有芒彗指西南淳化
元年正月辛巳出軫宿逆至張七十日經四十度乃不見景德二年八月甲辰
出紫微天棓側孛孛然如粉絮稍入垣內歷御女華蓋凡十一日沒三年三月
乙巳出東南方大中祥符四年正月丁丑見南斗魁前天禧五年四月丙辰出
軒轅前星西北大如桃遶行經軒轅大星入太微垣掩右執法犯次將歷屏星
西北凡七十五日入濁沒明道元年六月乙巳出東北方近濁有芒彗至丁巳
凡十三日沒至和元年五月己丑出天關東南可數寸歲餘稍沒熙寧二年六
月丙辰出箕度中至七月丁卯犯箕乃散三年十一月丁未出天囷元祐六年
十一月辛亥出參度中犯掩側星壬子犯九斿星十二月癸酉入奎至七年三
月辛亥乃散紹興八年五月守婁魯分也九年二月壬申守亢陳分也乾道二
年三月癸酉出太微垣內五帝坐大星西微小色青白淳熙八年六月己巳出
奎宿犯傳舍星至明年正月癸酉凡一百八十五日始滅嘉泰三年六月乙卯
出東南尾宿間色青白大如填星甲子守尾嘉定十七年六月己丑犯尾宿嘉

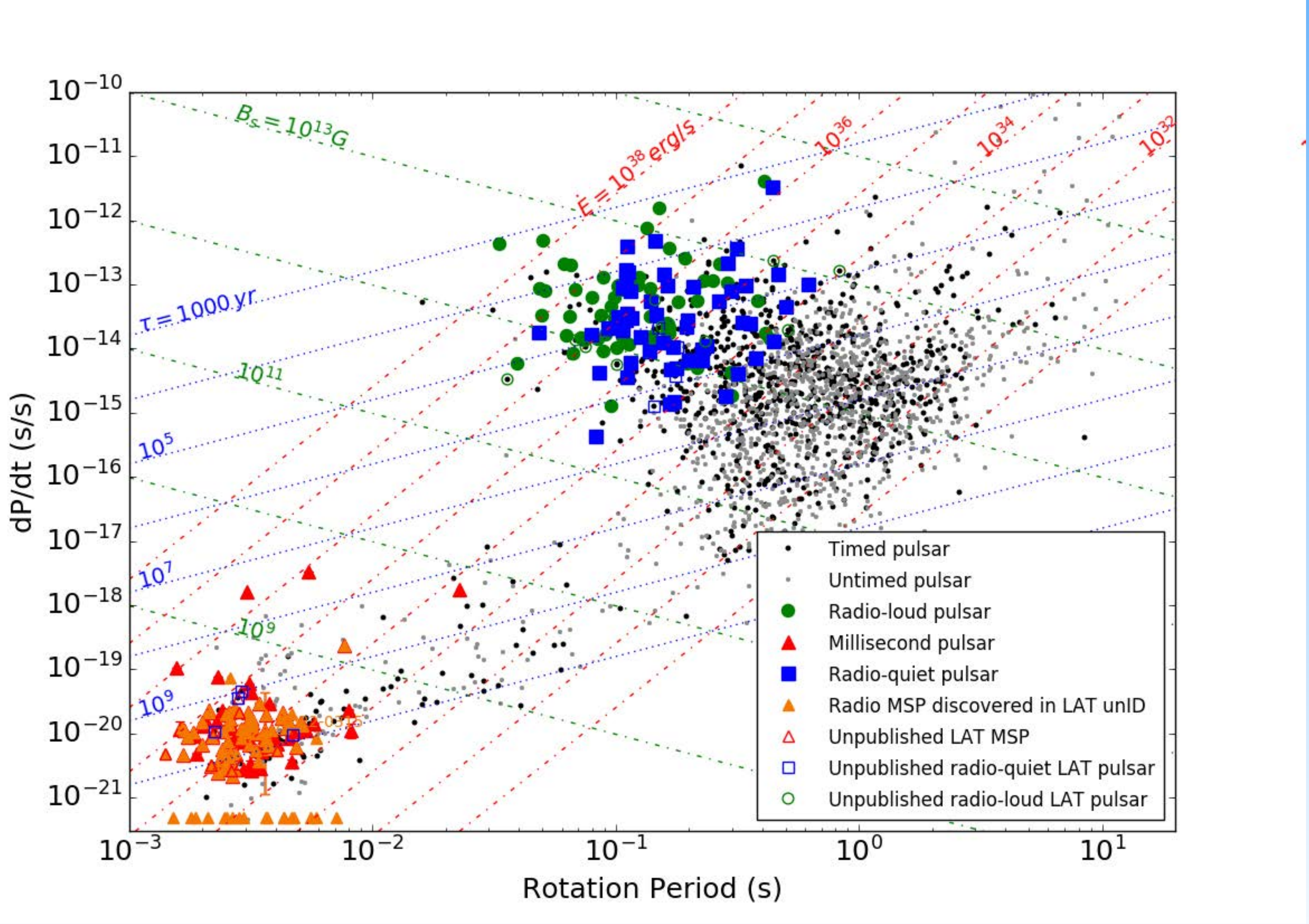
宋史 卷五十六 天文志

The Crab pulsar



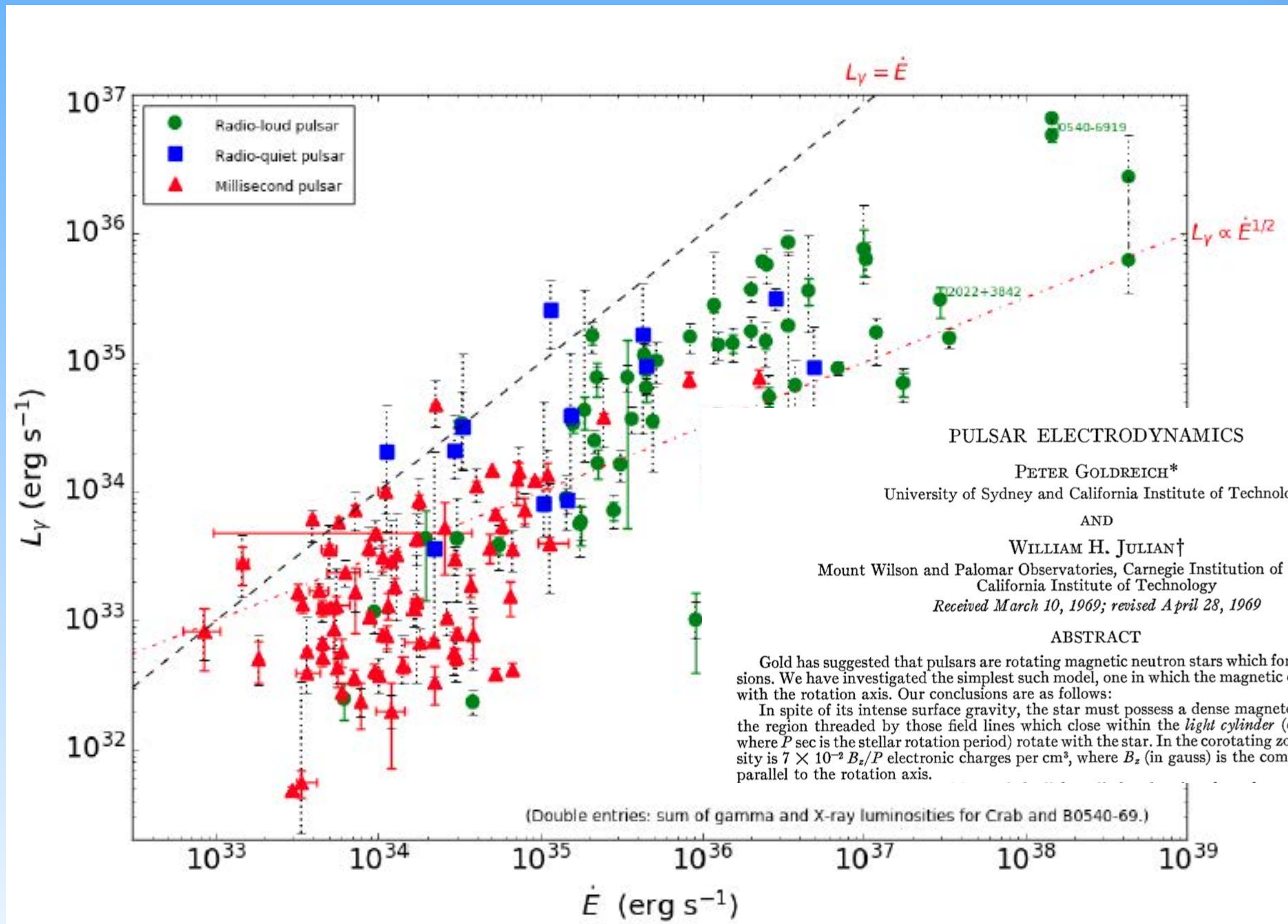
Bühler & Blandford 2014

The pulsar population



Abdo et al. 2013 (2PC)

Gamma-ray efficiency



Abdo et al. 2013 (2PC)

PULSAR ELECTRODYNAMICS

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AND
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Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology

Received March 10, 1969; revised April 28, 1969

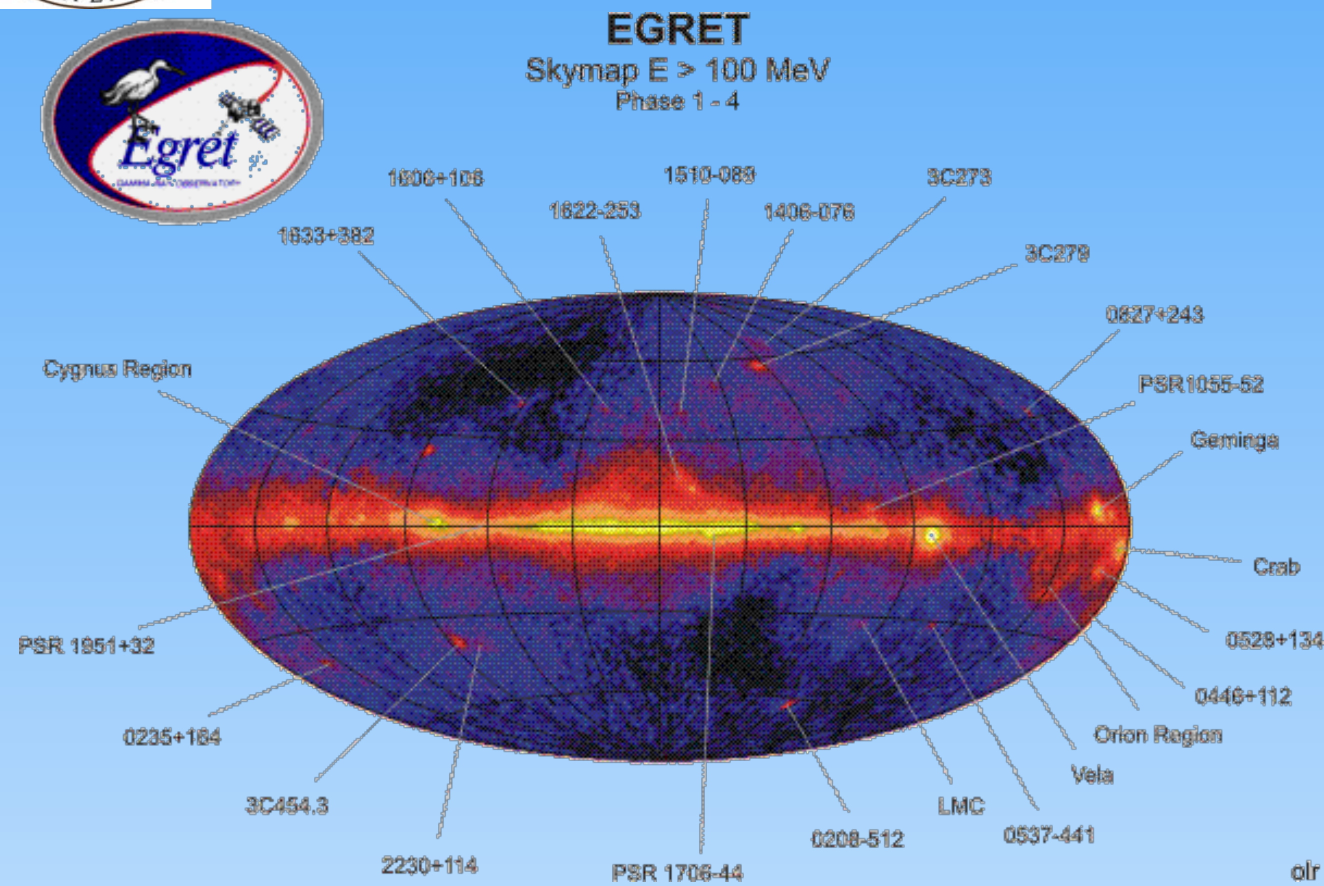
ABSTRACT

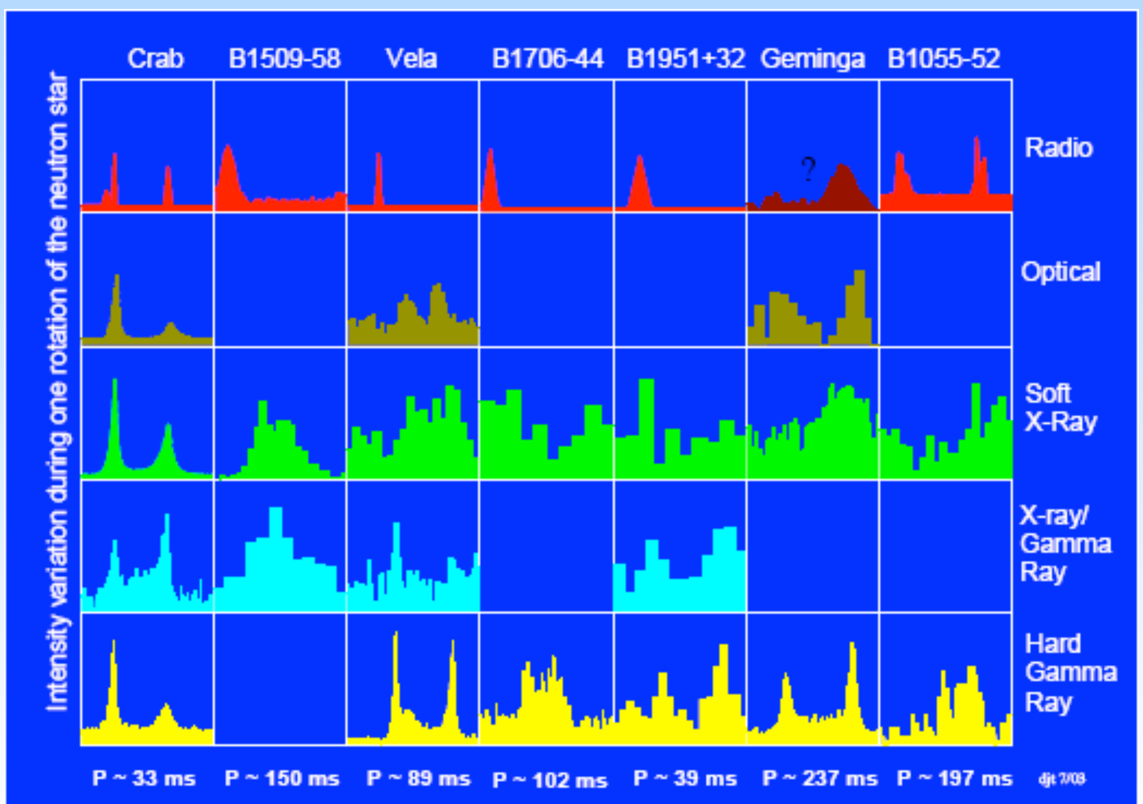
Gold has suggested that pulsars are rotating magnetic neutron stars which formed in supernova explosions. We have investigated the simplest such model, one in which the magnetic dipole moment is aligned with the rotation axis. Our conclusions are as follows:

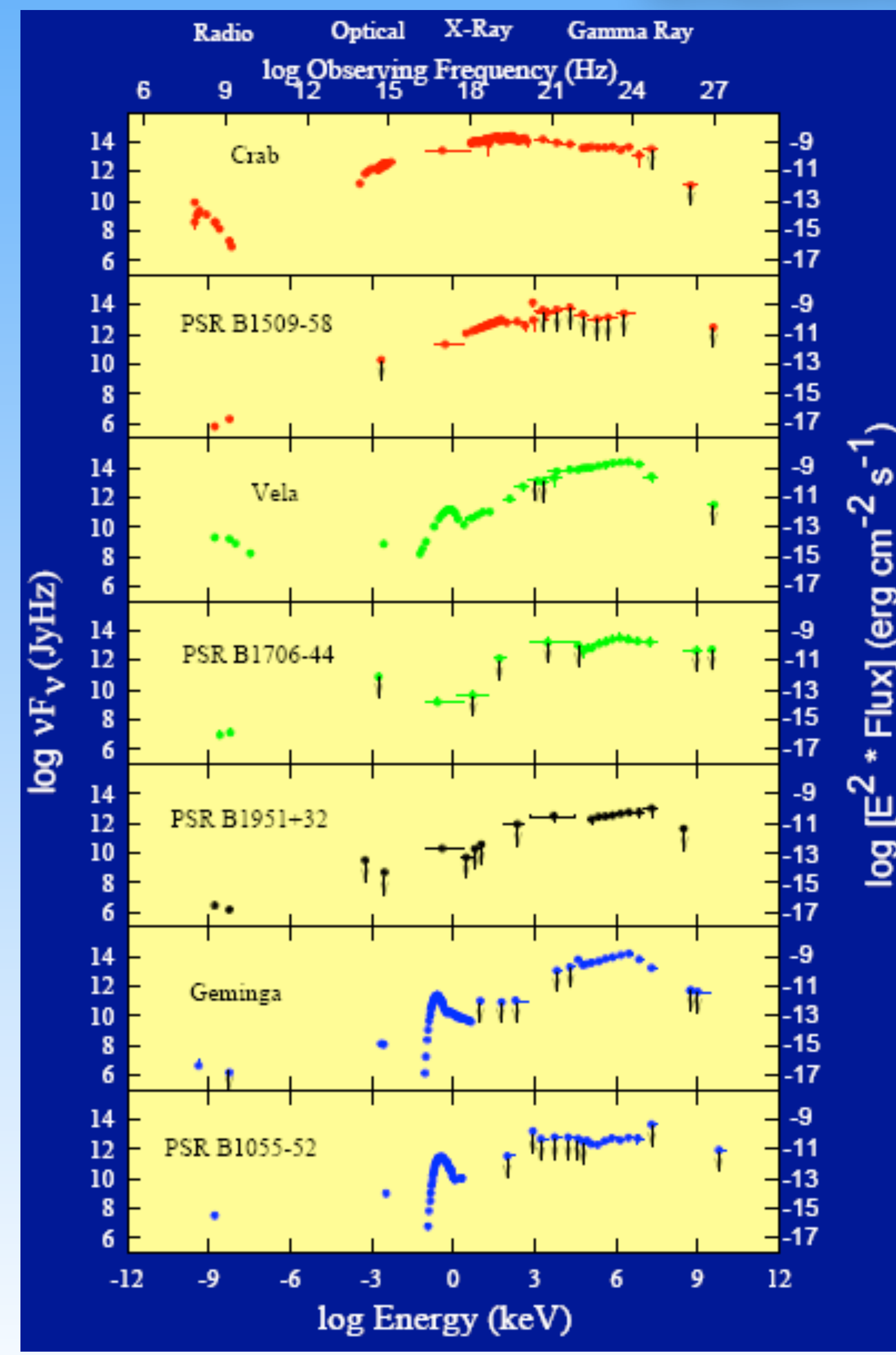
In spite of its intense surface gravity, the star must possess a dense magnetosphere. The particles in the region threaded by those field lines which close within the *light cylinder* (of radius $5 \times 10^9\ P$ cm, where P sec is the stellar rotation period) rotate with the star. In the corotating zone the space-charge density is $7 \times 10^{-2}\ B_z/P$ electronic charges per cm^3, where B_z (in gauss) is the component of magnetic field parallel to the rotation axis.

$$\dot{N}_{GJ} = n_{GJ} A_{PC}$$
$$\simeq 1.4 \times 10^{38}\, \dot{P}^{\frac{1}{2}}\, P^{-3/2} \mathrm{s}^{-1}.$$

Gamma-ray pulsars pre-Fermi







Credit: Dave Thompson (2004)

Fermi LAT Pulsars

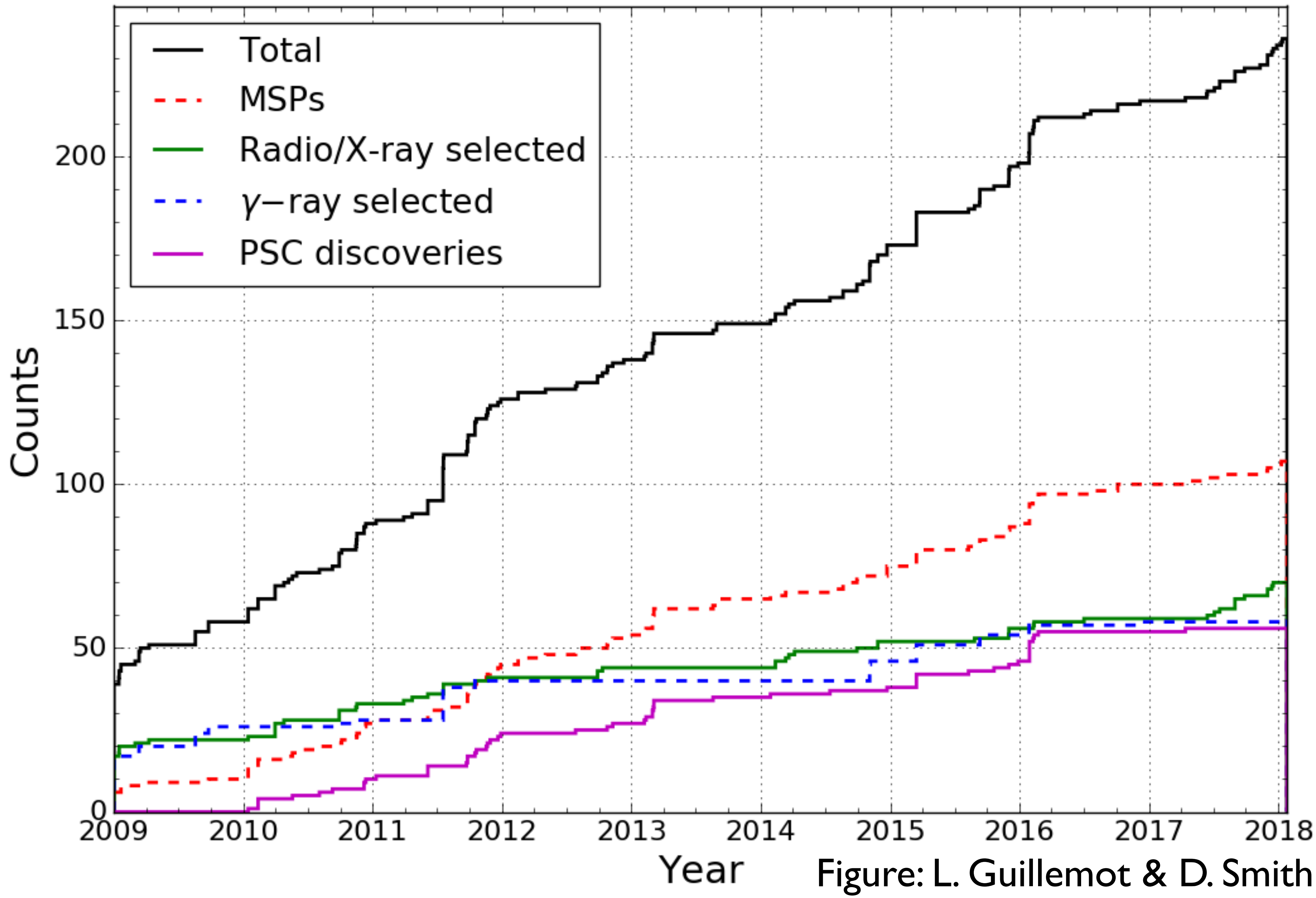
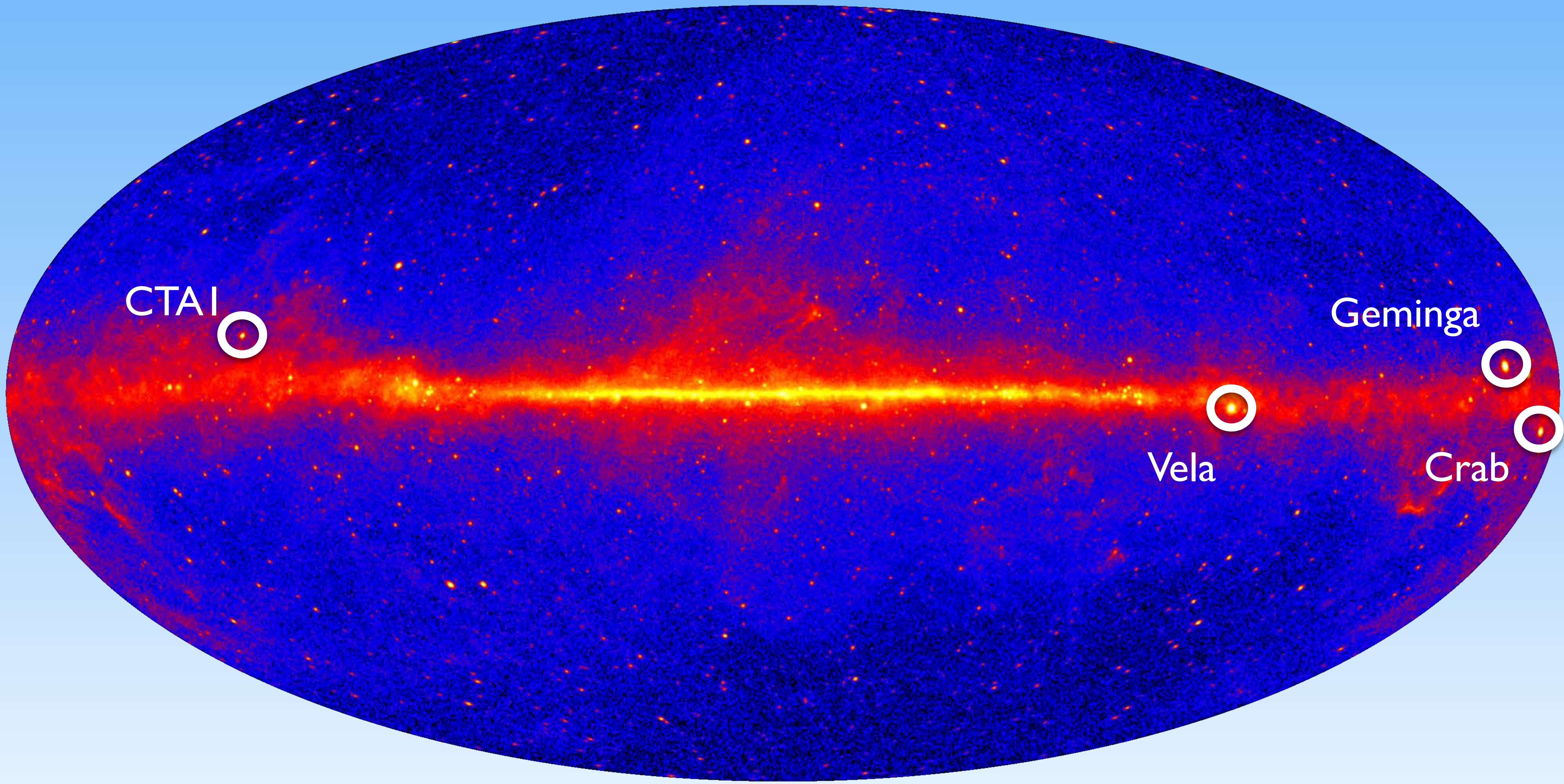


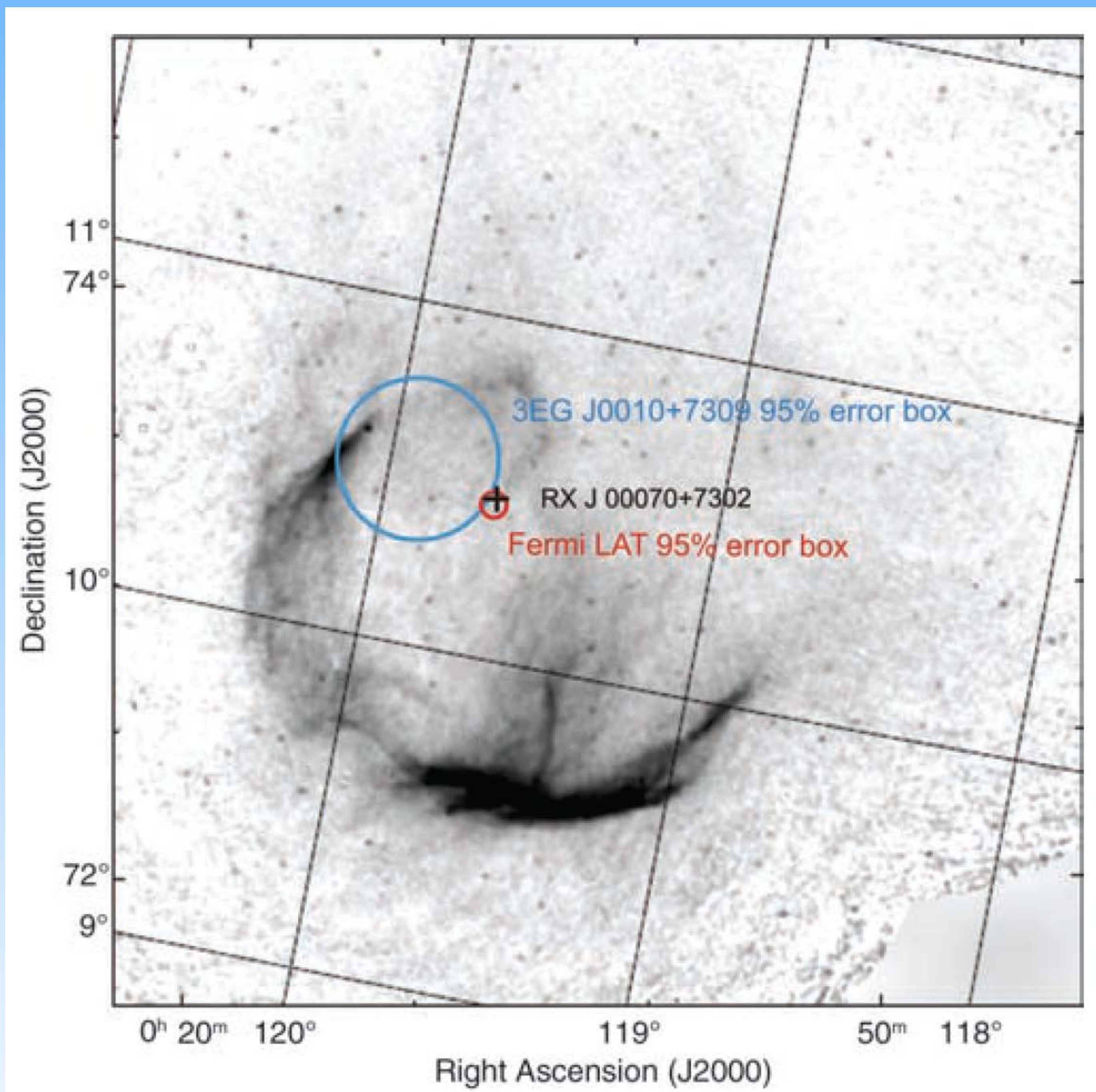
Figure: L. Guillemot & D. Smith

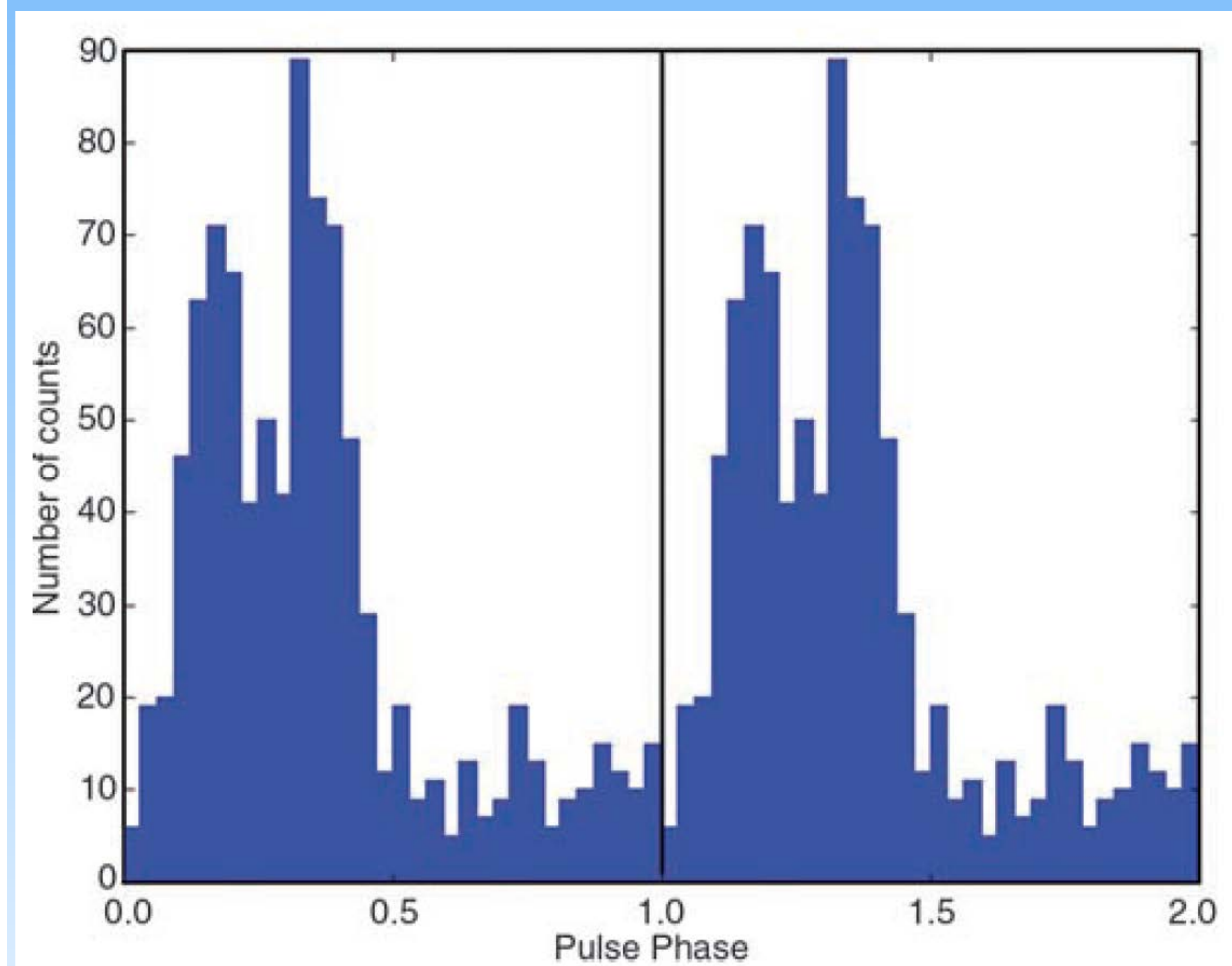
http://tinyurl.com/fermipulsars

Fermi gamma-ray sky



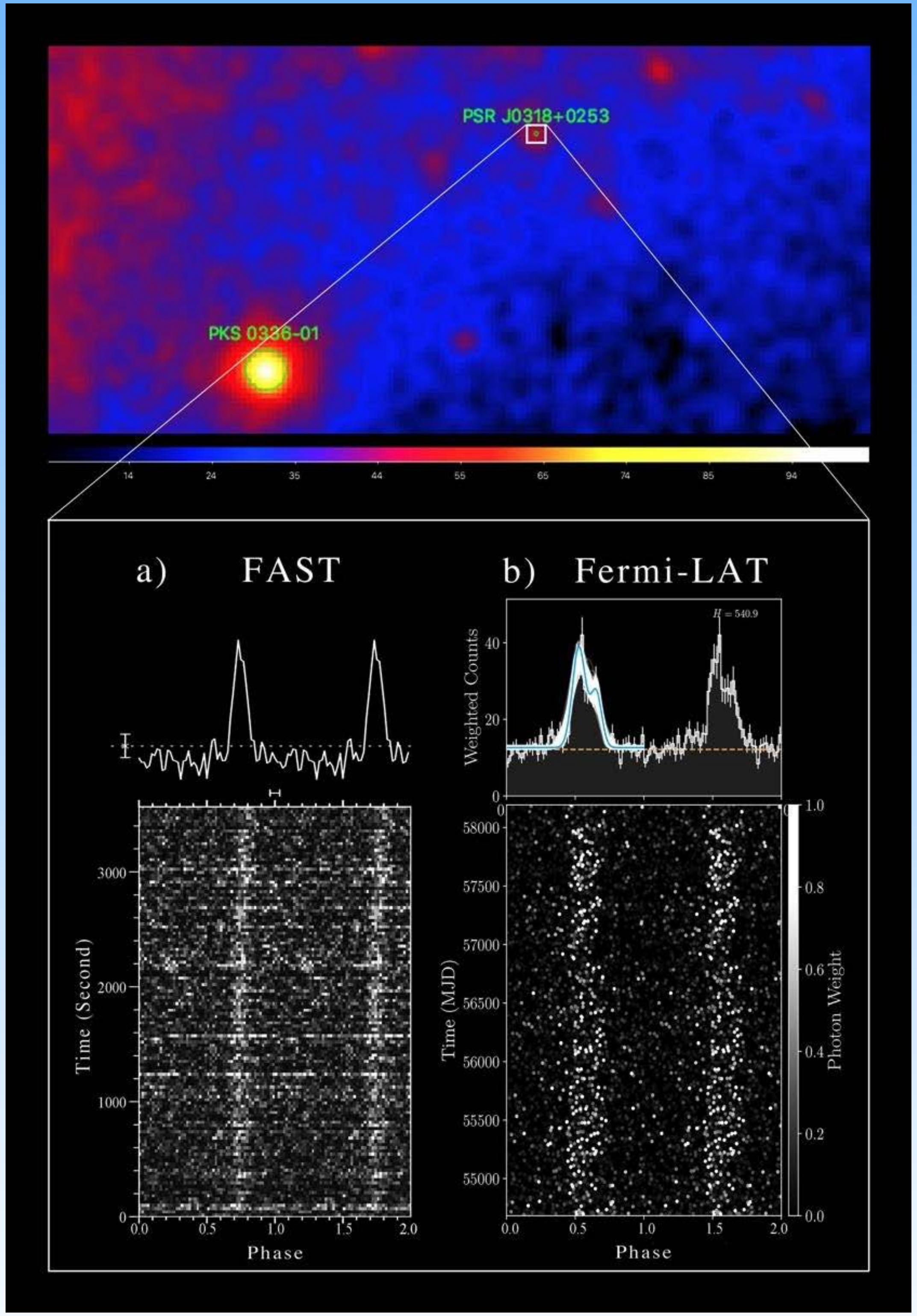
First Fermi-LAT discovery





Science **322** (5905), 1218-1221.
DOI: 10.1126/science.1165572originally published online October 16, 2008

Searching for FAST Pulsars



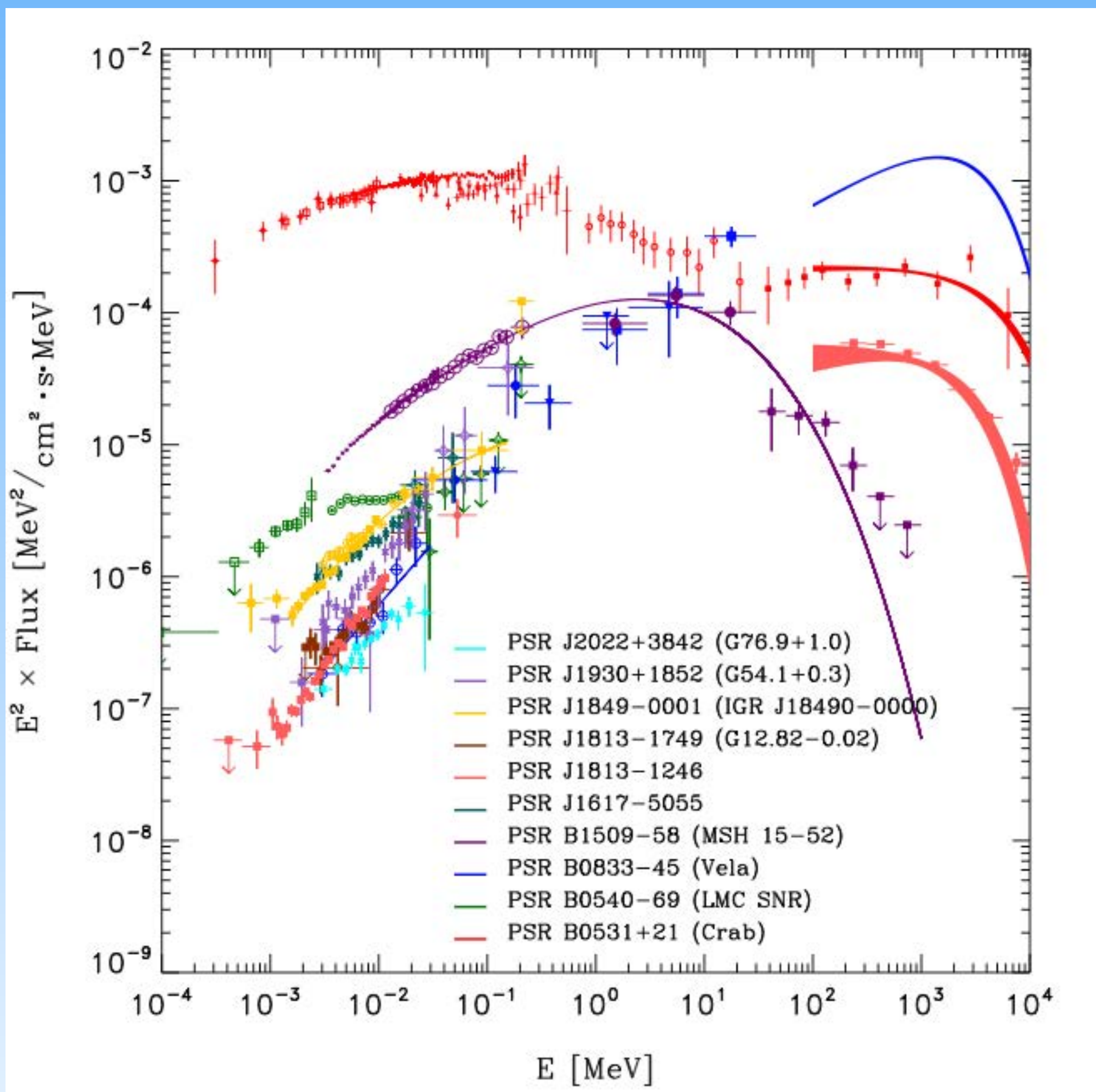
ATel #11584; *Pei Wang, Di Li, Weiwei Zhu, Chengmin Zhang, Jun Yan (National Astronomical Observatories, Chinese Academy of Sciences), Xian Hou (YunNan Observatories, Chinese Academy of Sciences), Colin J. Clark (Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy, University of Manchester), Pablo M. Saz Parkinson (Department of Physics and Laboratory for Space Research, University of Hong Kong & Santa Cruz Institute for Particle Physics), Peter F. Michelson (Stanford University), Elizabeth C. Ferrara (UMCP/CRESST/GSFC), David J. Thompson, (NASA/GSFC), David A. Smith (Universite ? Bordeaux 1, CNRS/IN2P3/CENBG), Paul S. Ray, Matthew Kerr (Space Science Division, Naval Research Laboratory), Zhiqiang Shen (Shanghai Astronomical Observatory), Na Wang (Xinjiang Astronomical Observatory), on behalf of FAST and the Fermi-LAT Collaboration.Â*

on 28 Apr 2018; 04:43 UT

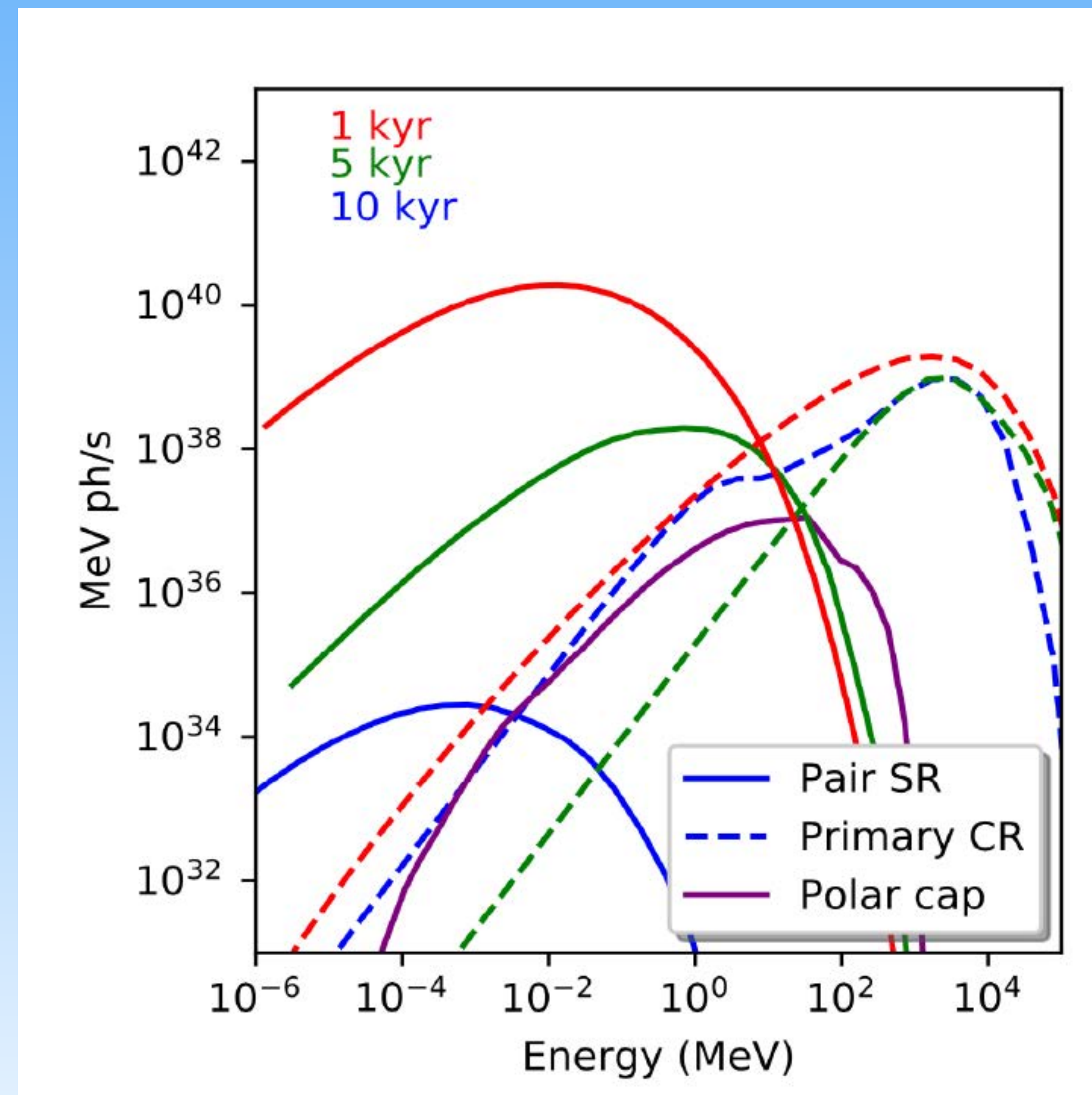
Credential Certification: Di Li (dili@nao.cas.cn)

Subjects: Radio, Gamma Ray, Pulsar

Why the MeV range?



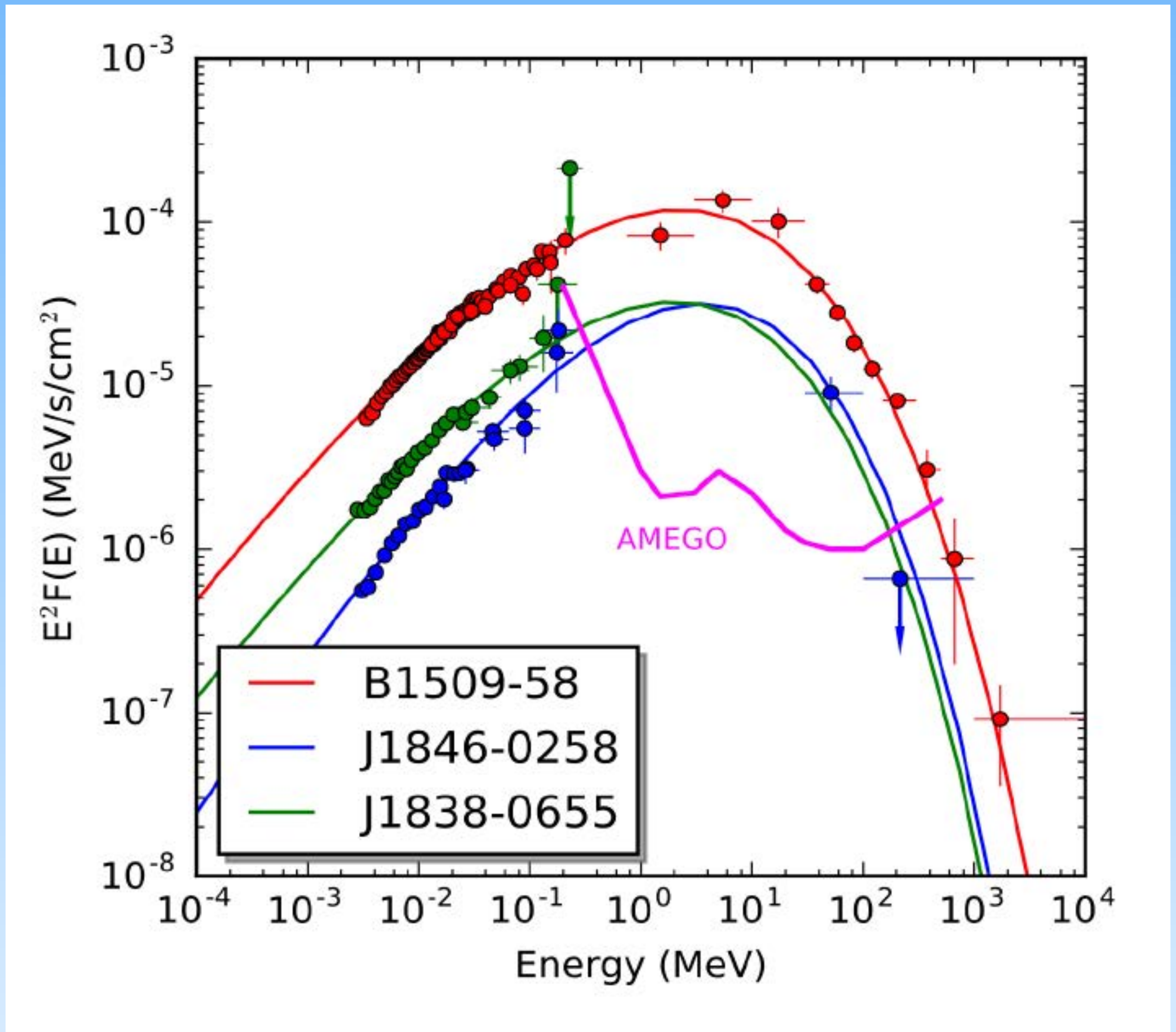
Kuiper & Hermsen (2015)



Harding et al. (2015)

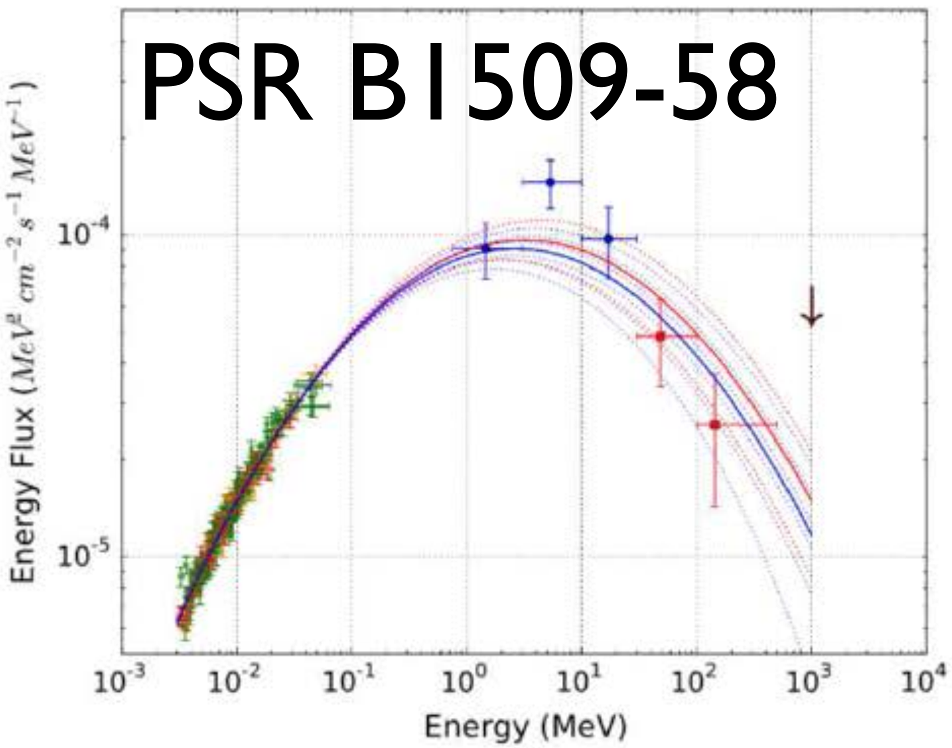
MeV pulsars

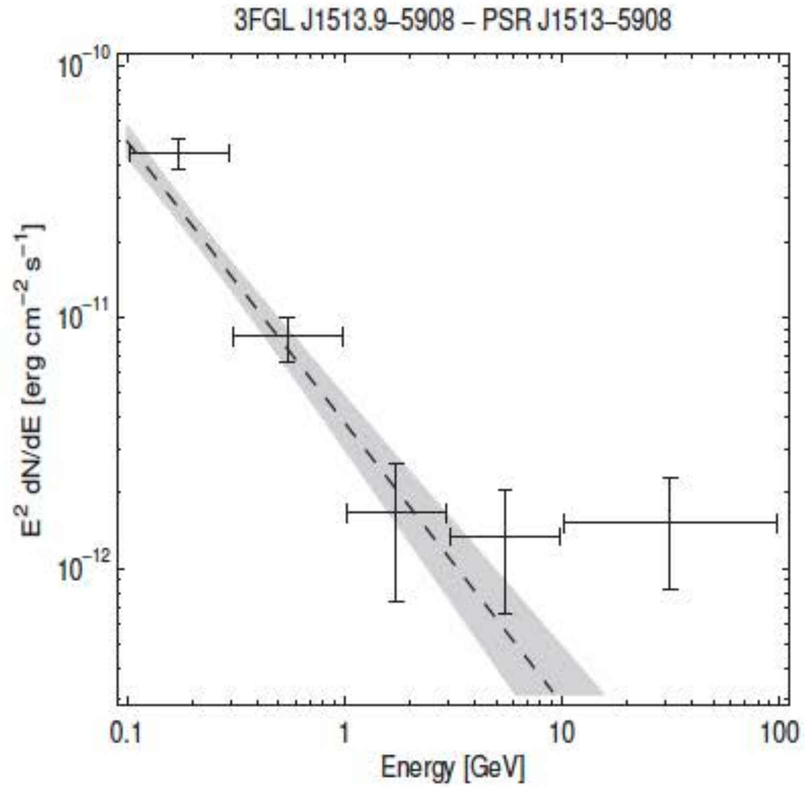
- Peak of emission below 1 GeV
- Typically young and very energetic, high B-field
- Often associated with SNRs, TeV sources
- Very few detected by Fermi LAT

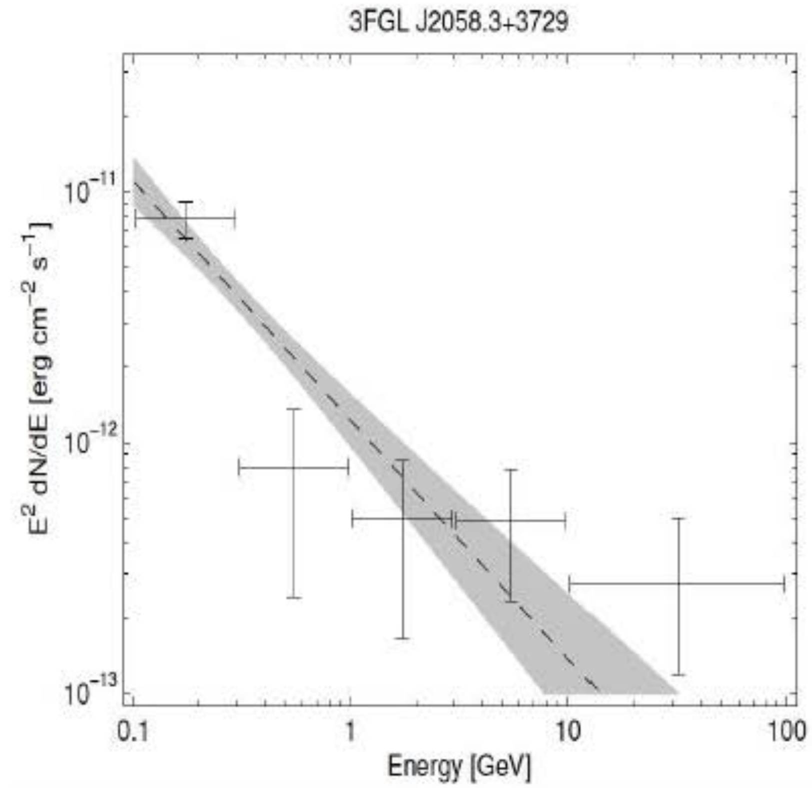


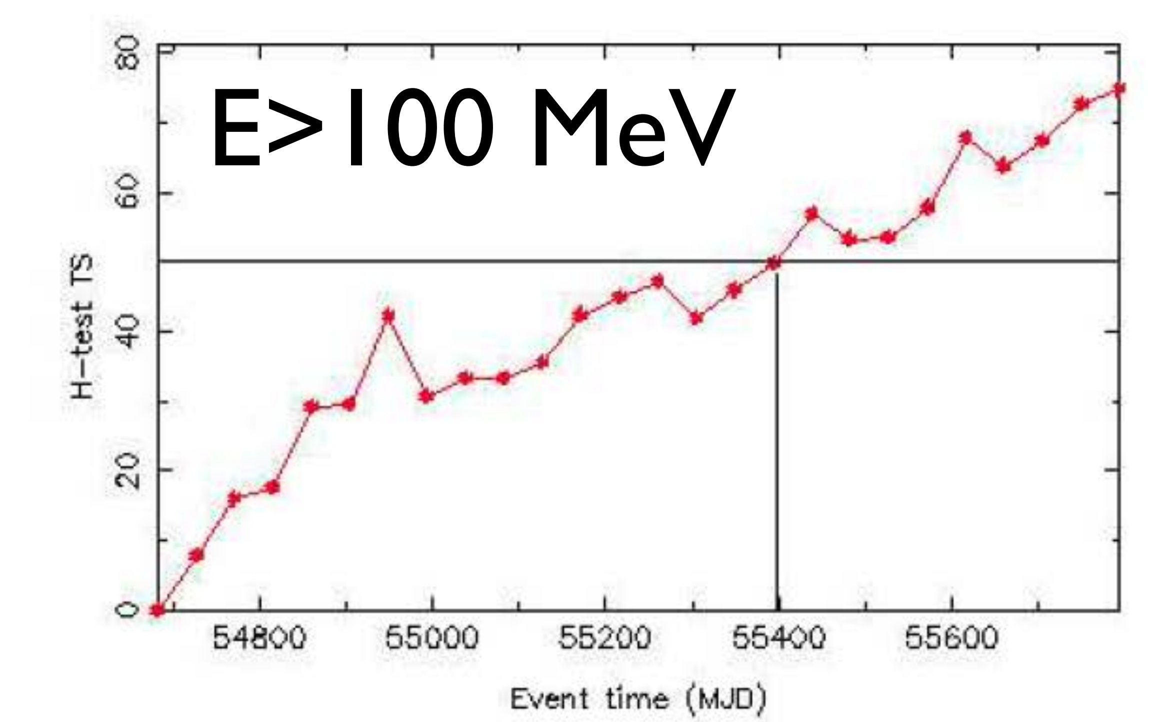
Kuiper & Hermsen (2018)

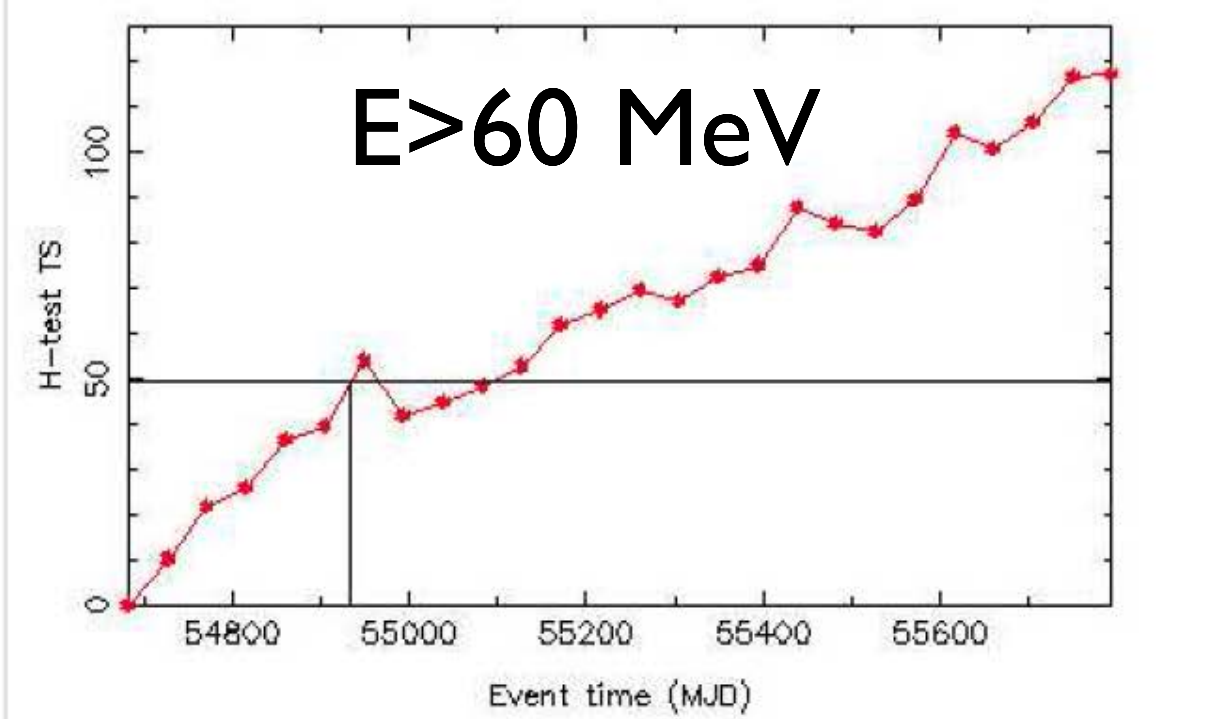
LAT detections of MeV pulsars



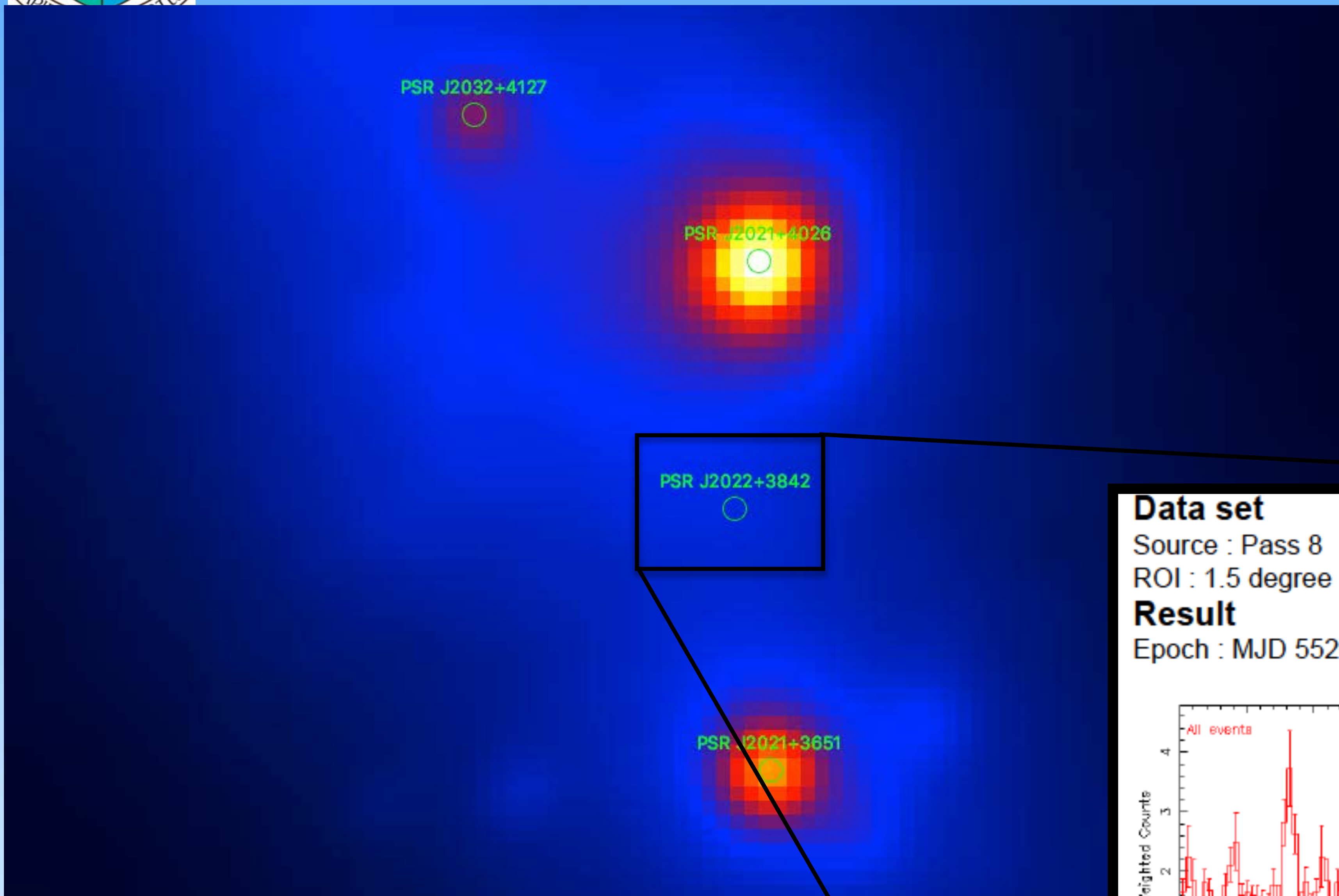




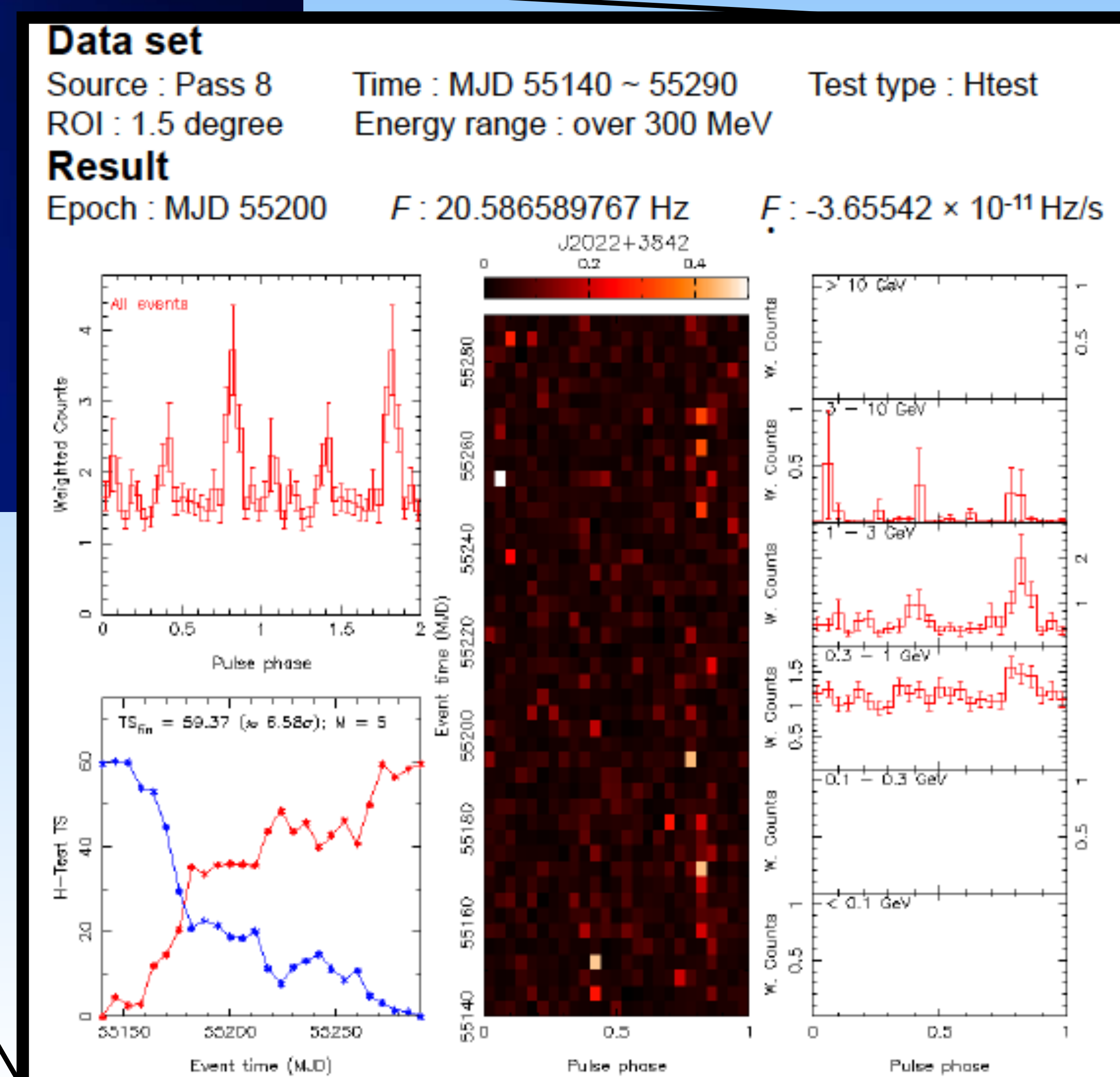




PSR J2022+3842



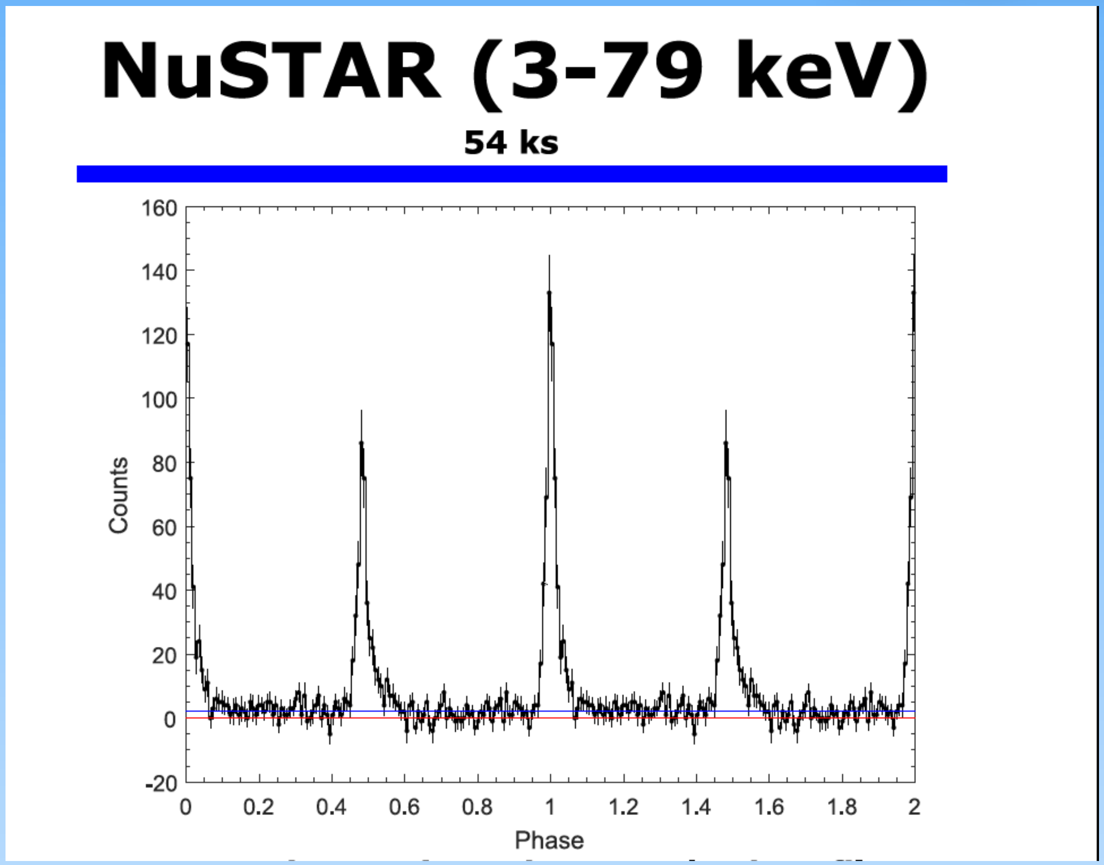
Ohuchi et al. 2015
(Fermi Symposium)

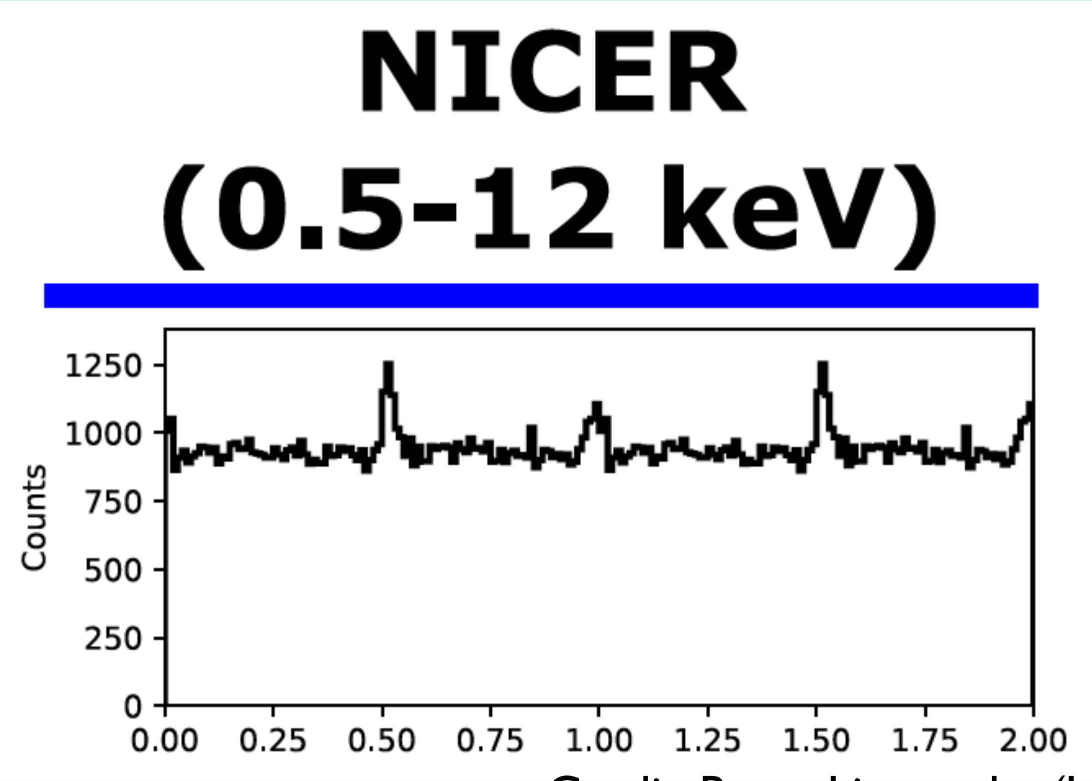


Discovered in X-rays
(Chandra/XMM)
Associated with SNR G76.9+1.0
Arzoumanian et al. (2011)

PSR J2022+3842

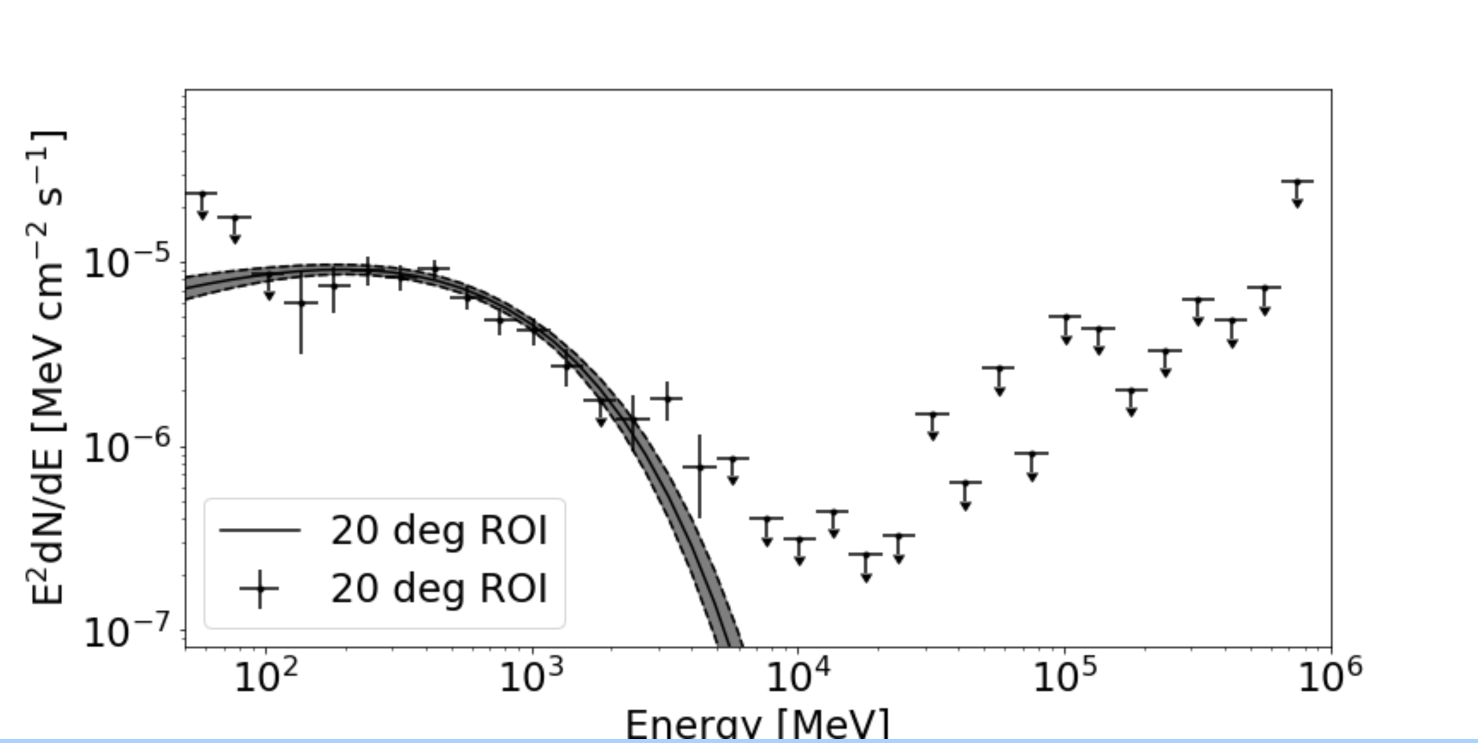
- Young (< 10 kyr), energetic (3E37 erg/s)
- Associated with G76.9+1.0
- Very noisy
- Bright in X-rays, but radio faint

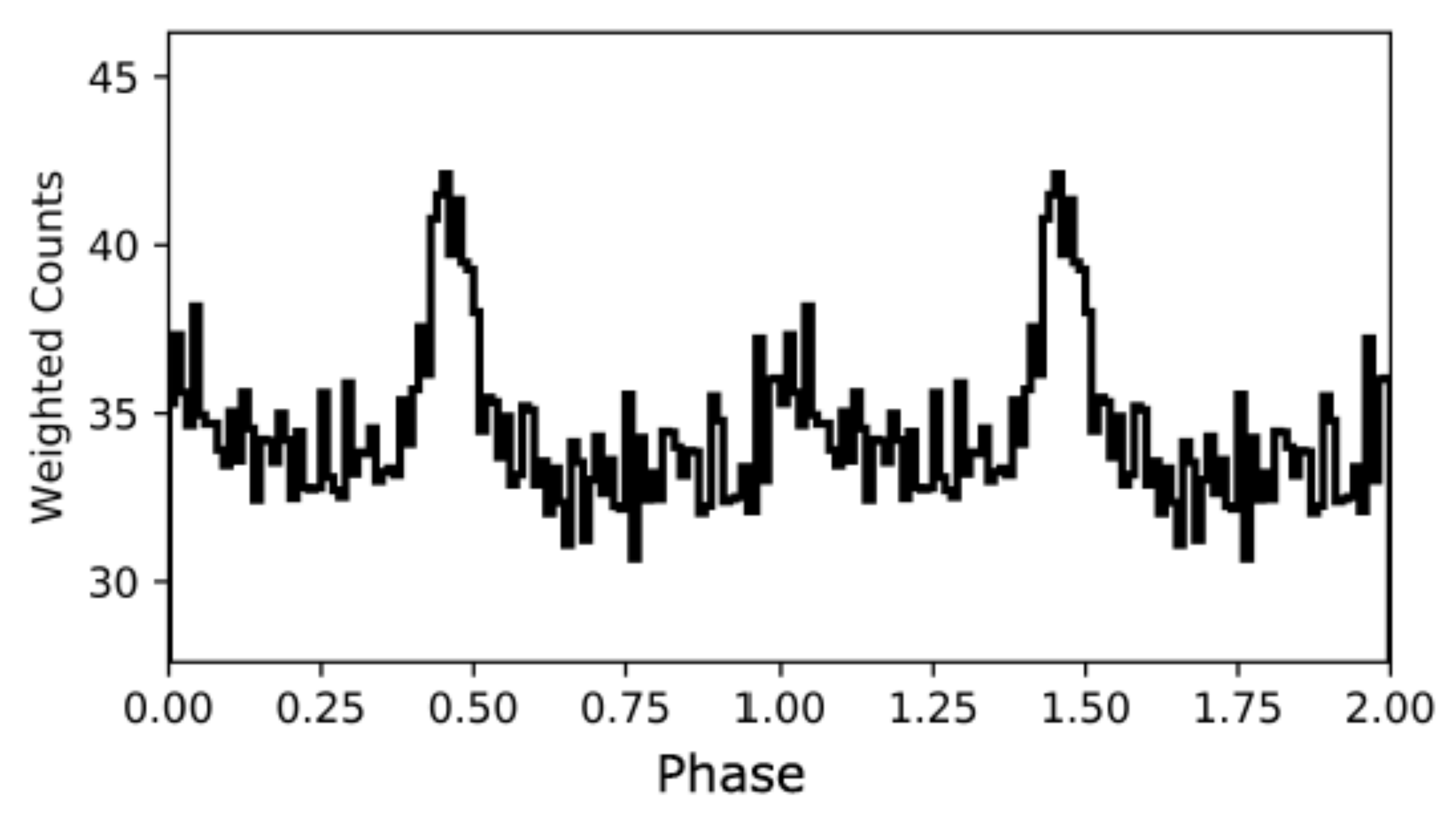




Credit: Brent Limyansky (UCSC)

PSR J2022+3842 (LAT)

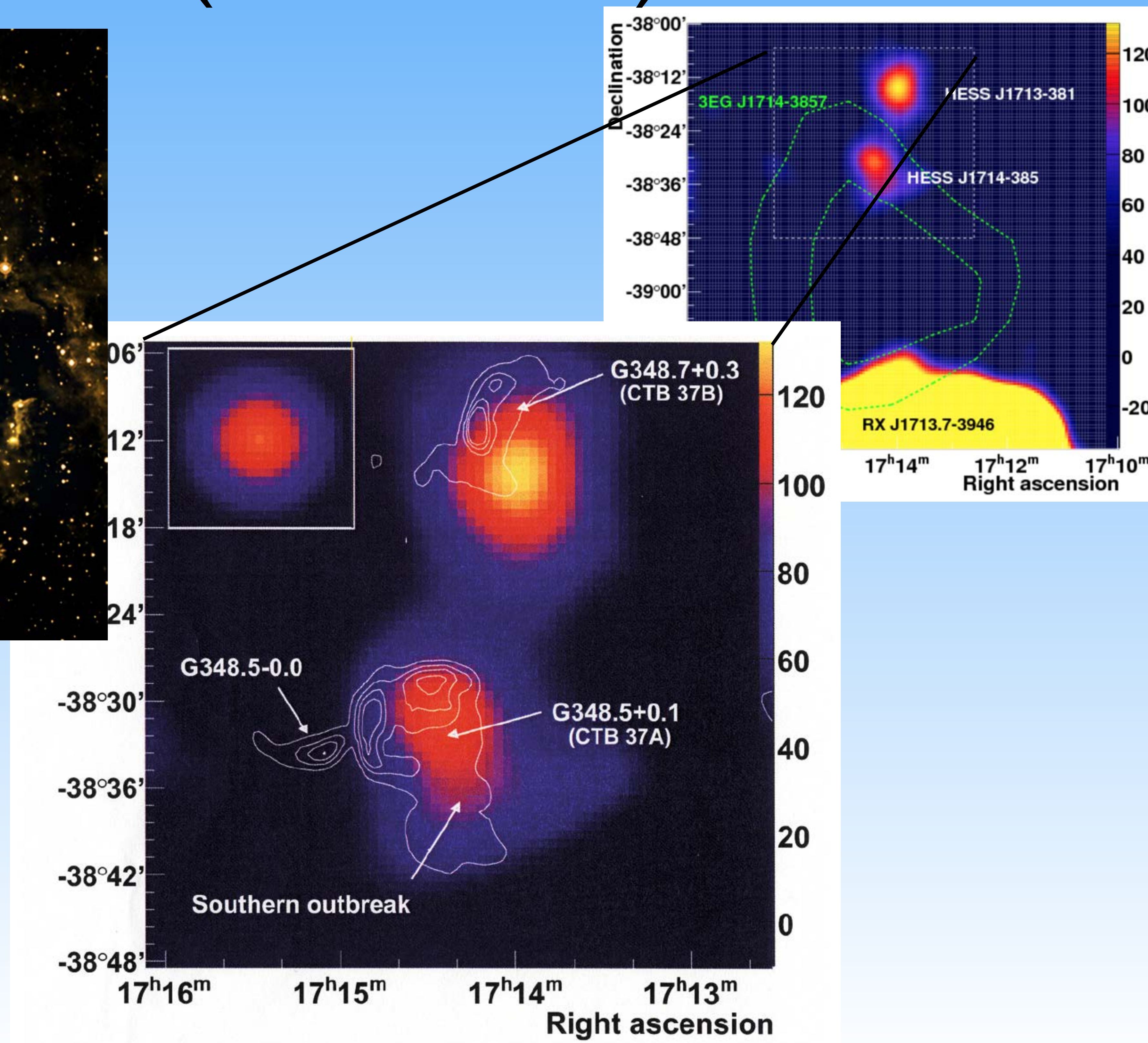




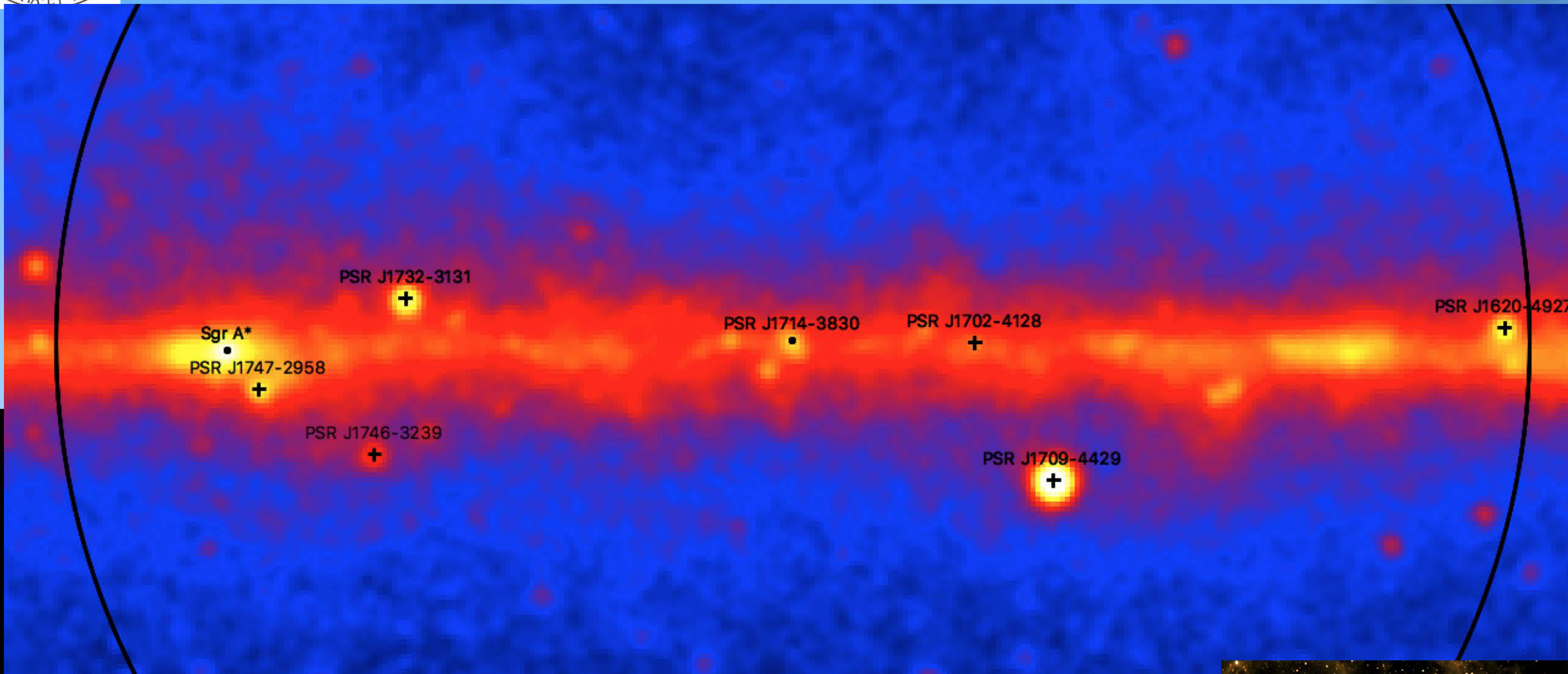
Credit: Brent Limyansky (UCSC)

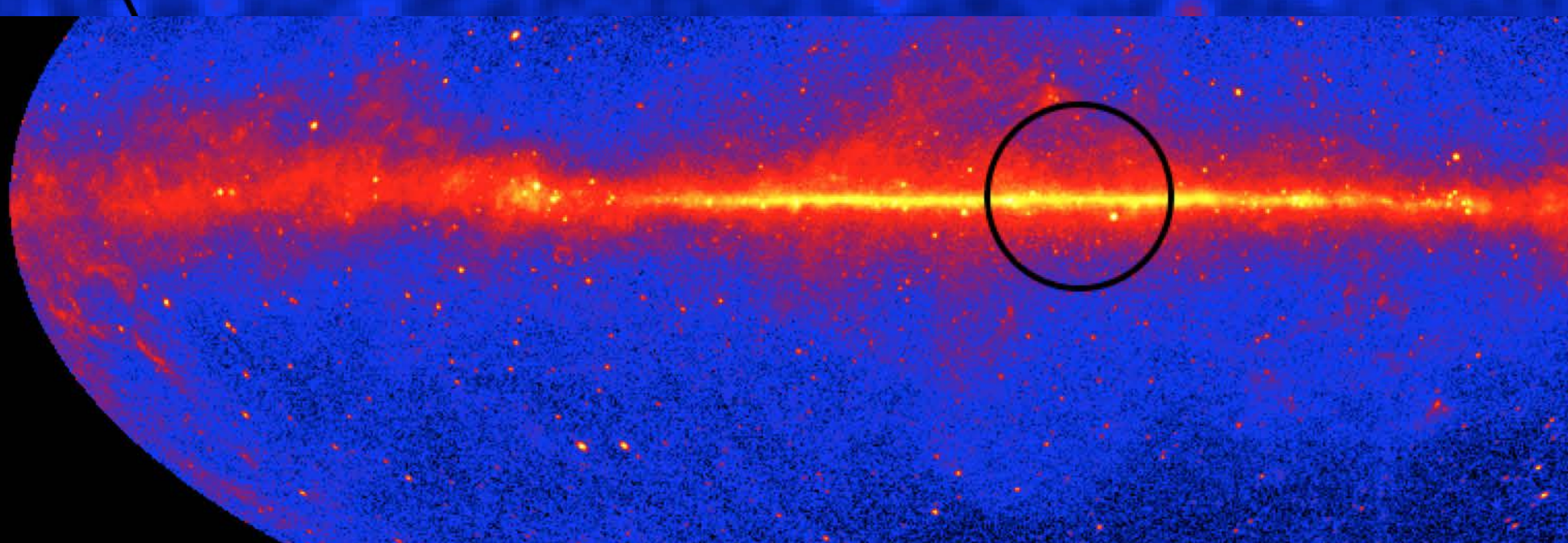
Multi-wavelength view of SNRs (CTB 37A)

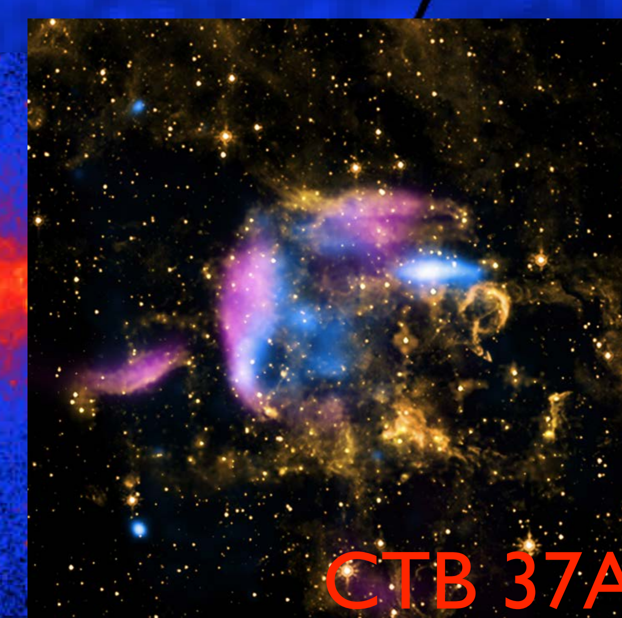
Image credit: X-ray: NASA/CXC/Morehead State Univ/T.Pannuti et al; Radio: Molonglo Obs. Synthesis Tel.; Infrared: NASA/JPL-Caltech



PSR J1714-3830







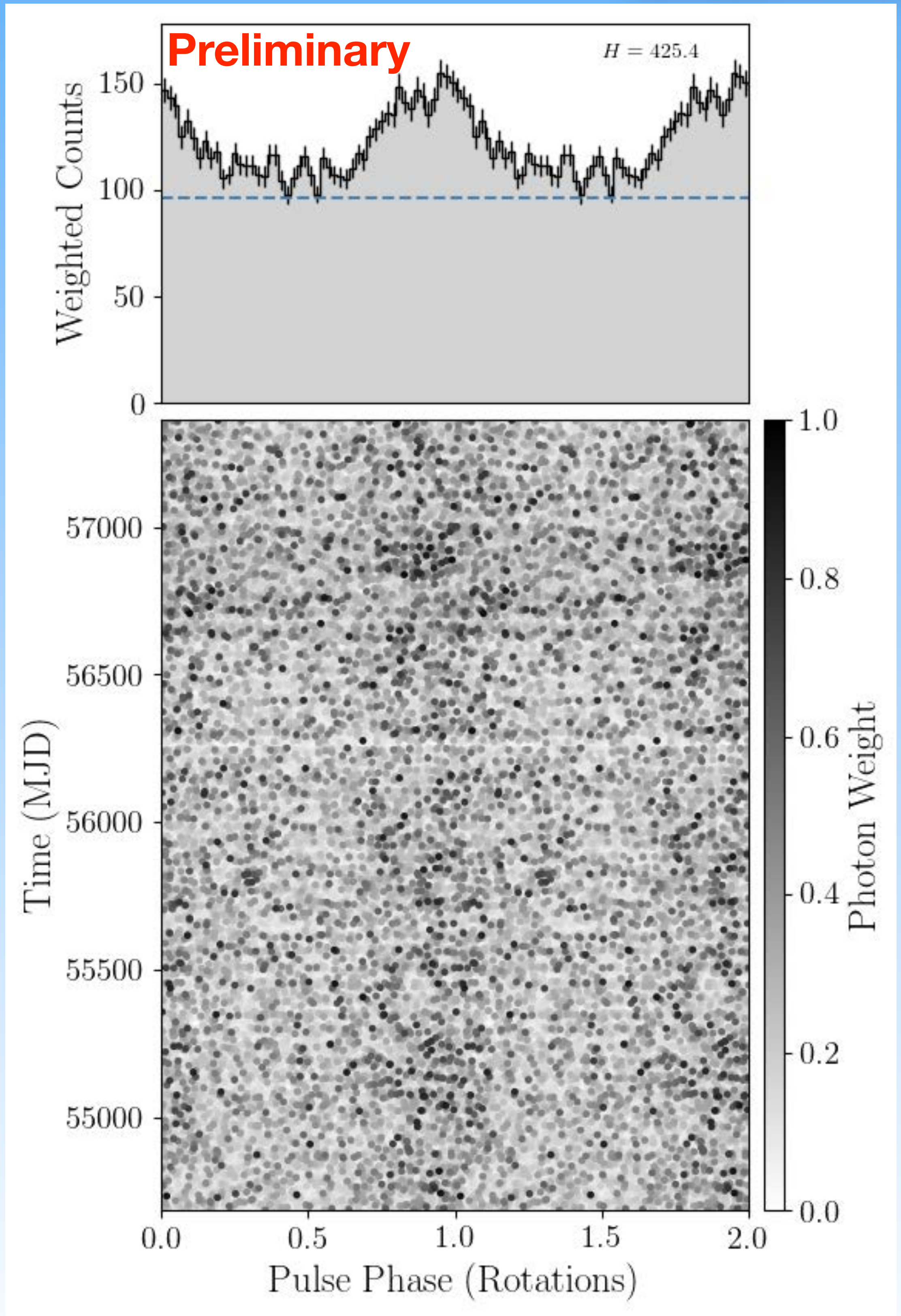
PSR J1714-3830

Derived properties:

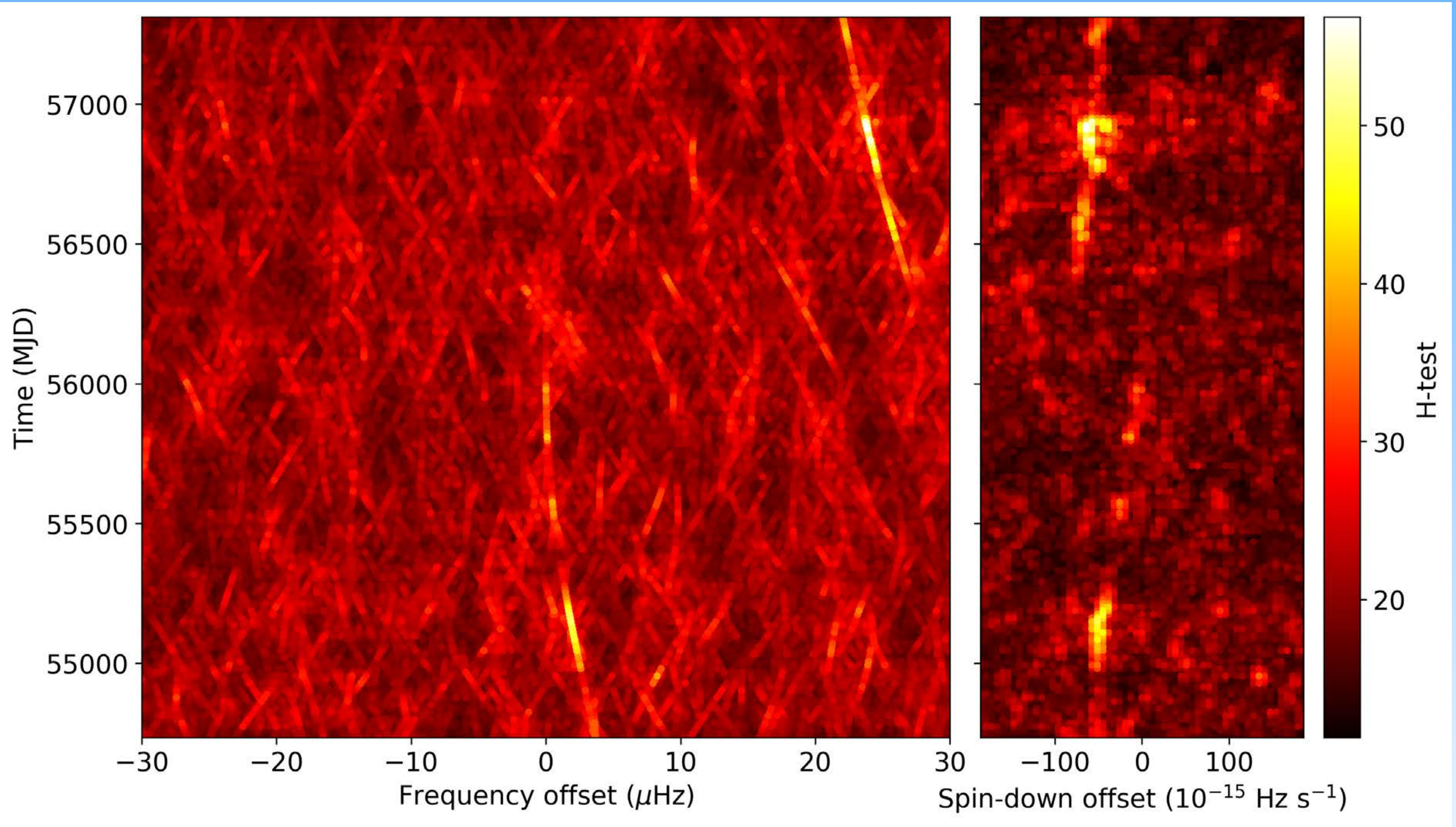
$$\dot{E} \sim 5 \times 10^{36} \mathrm{erg\,s}^{-1}$$

$$B_s \sim 2.5 \times 10^{12}\,\mathrm{G}$$

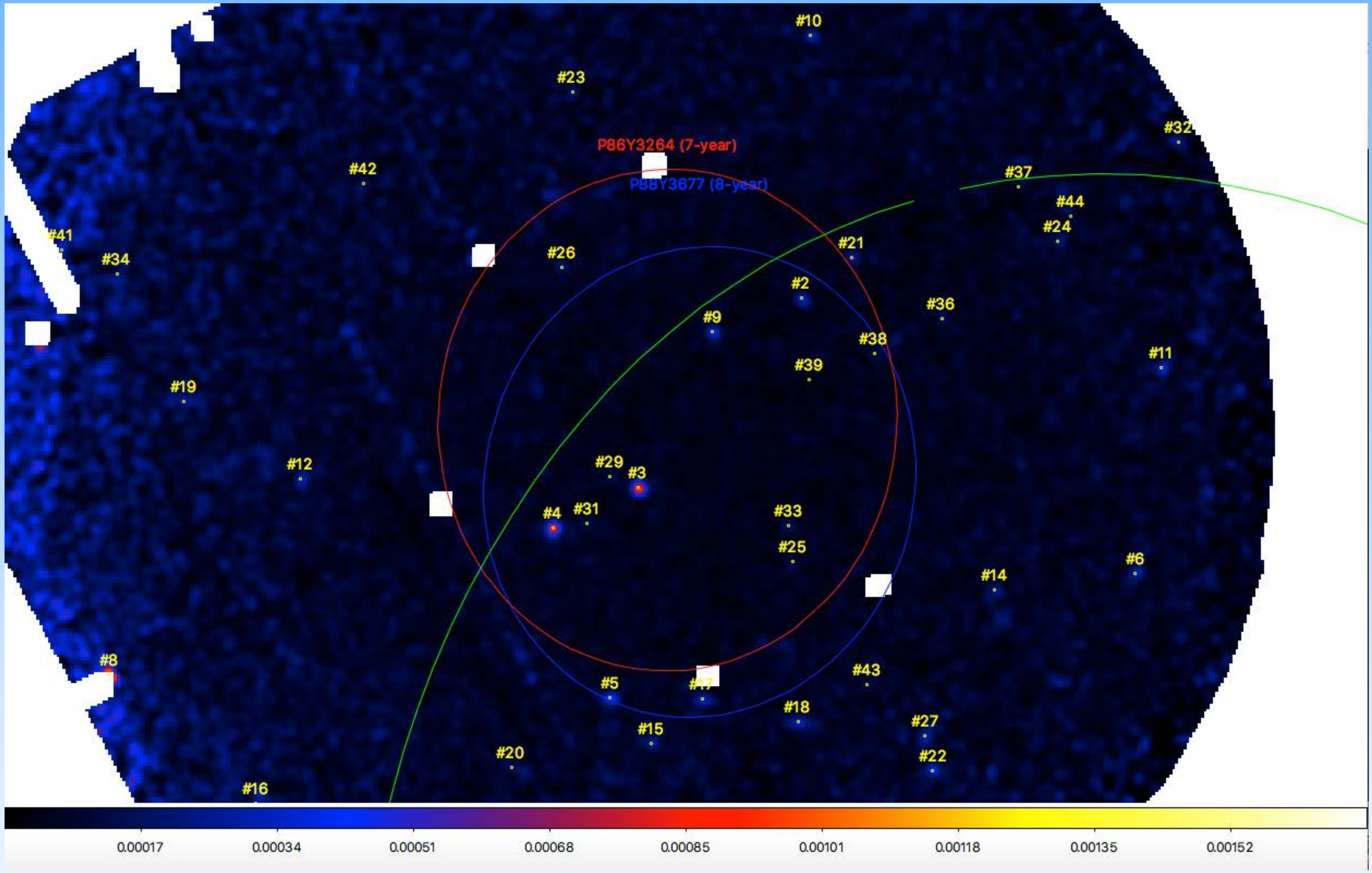
$$\tau \sim 20\,\mathrm{kyr}$$



Glitches in PSR J1714-3830



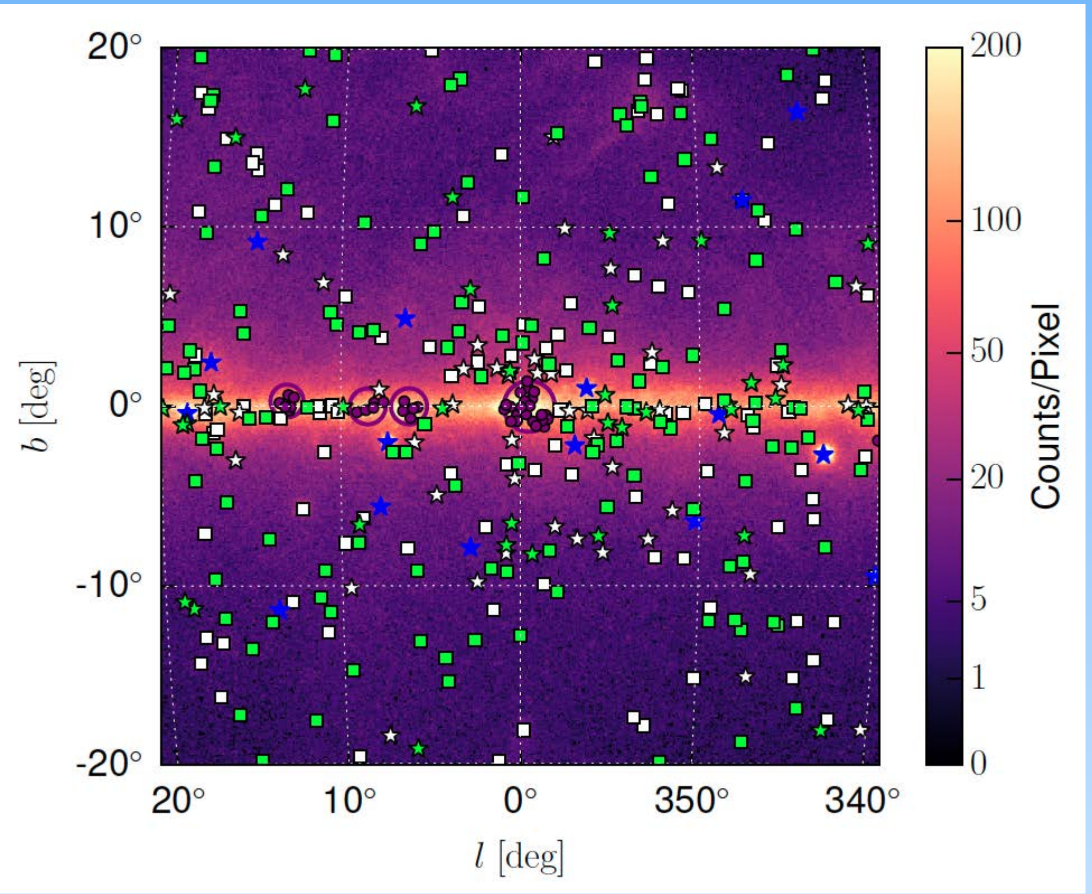
Uncovering soft gamma-ray pulsars with X-ray telescopes



XMM Observation of Fermi LAT Unassociated Source

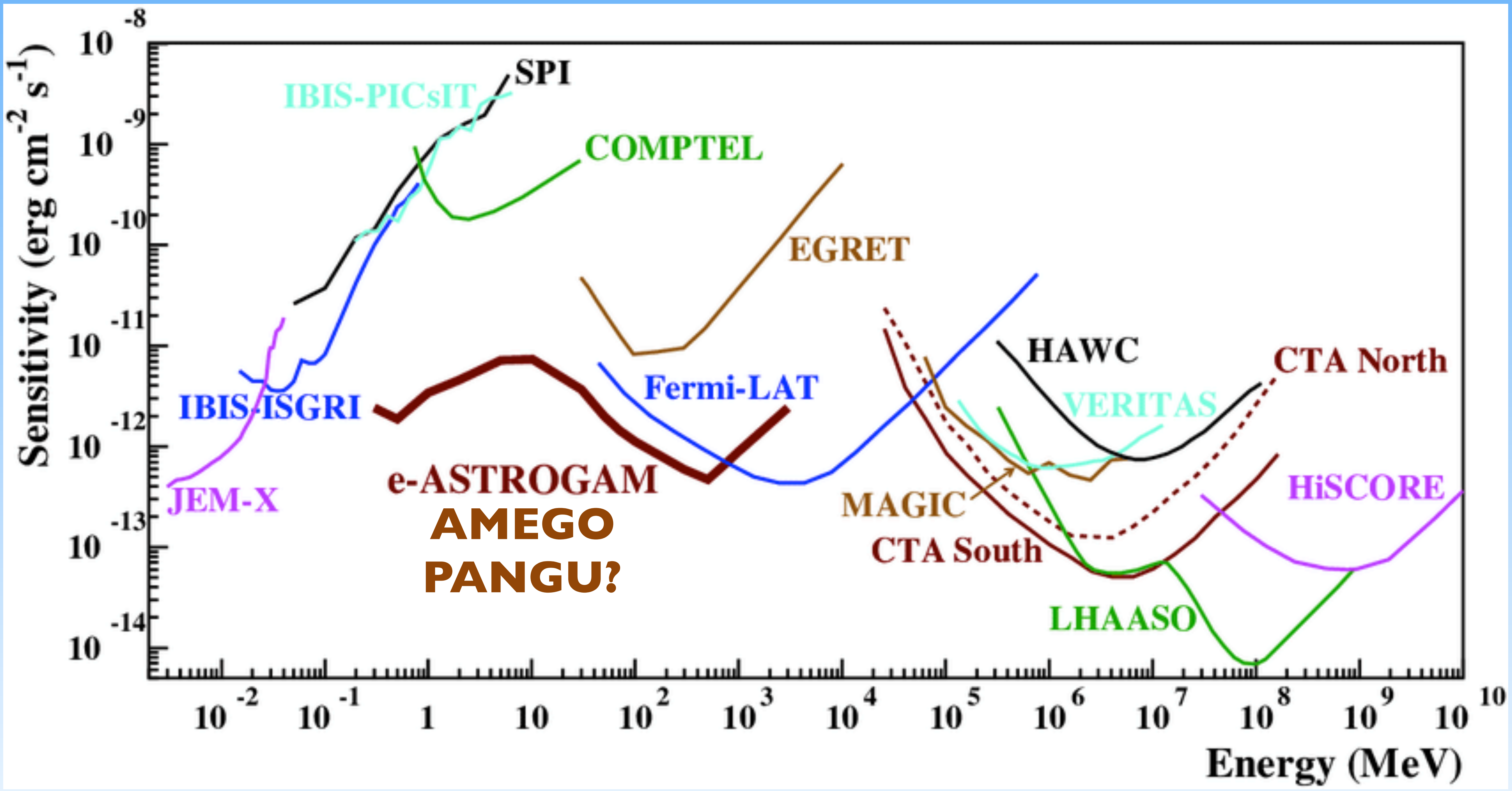
Galactic Center

- Bright gamma-ray source (known since 70s)
- Source confusion (diffuse emission)
- PSRs and DM predicted
- 2FIG Catalog: ~400 sources, including dozens of likely pulsars
- GC excess can be due to 800-3600 bulge PSRs



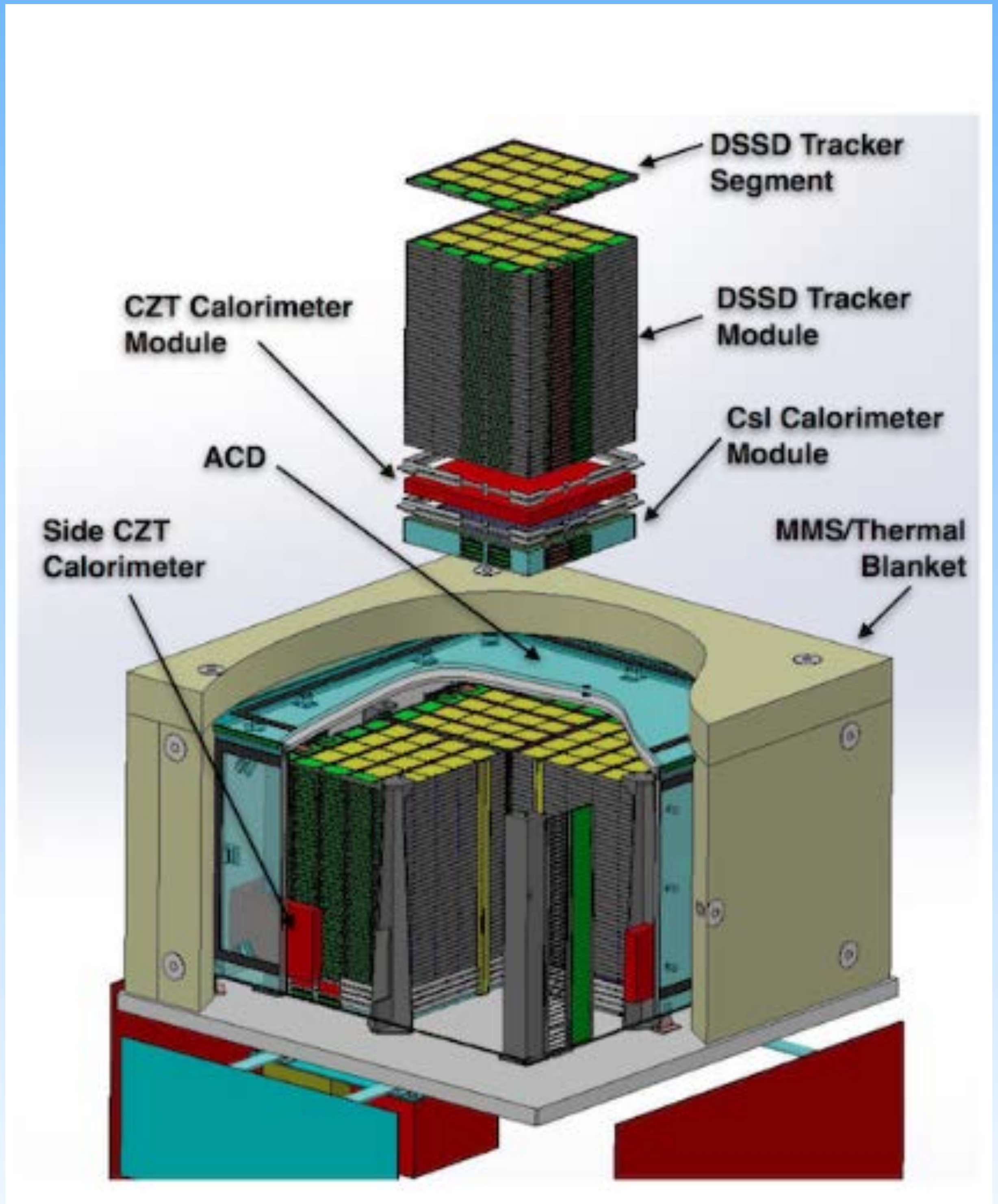
7.5 yr of data 0.3-500 GeV
Ajello et al. 2018

The MeV gap



Sensitivity (erg cm^{-2} s^{-1})
Energy (MeV)
SPI
IBIS-PICsIT
COMPTEL
EGRET
IBIS-ISGRI
JEM-X
e-ASTROGAM
AMEGO
PANGU?
Fermi-LAT
HAWC
CTA North
VERITAS
MAGIC
CTA South
LHAASO
HiSCORE

MeV telescopes



https://asd.gsfc.nasa.gov/amego/

Joint ESA-CAS proposal

Joint Scientific Space Mission

Chinese Academy of Sciences (CAS) – European Space Agency (ESA)

PROPOSAL

PANGU: A High Resolution Gamma-Ray Space Telescope

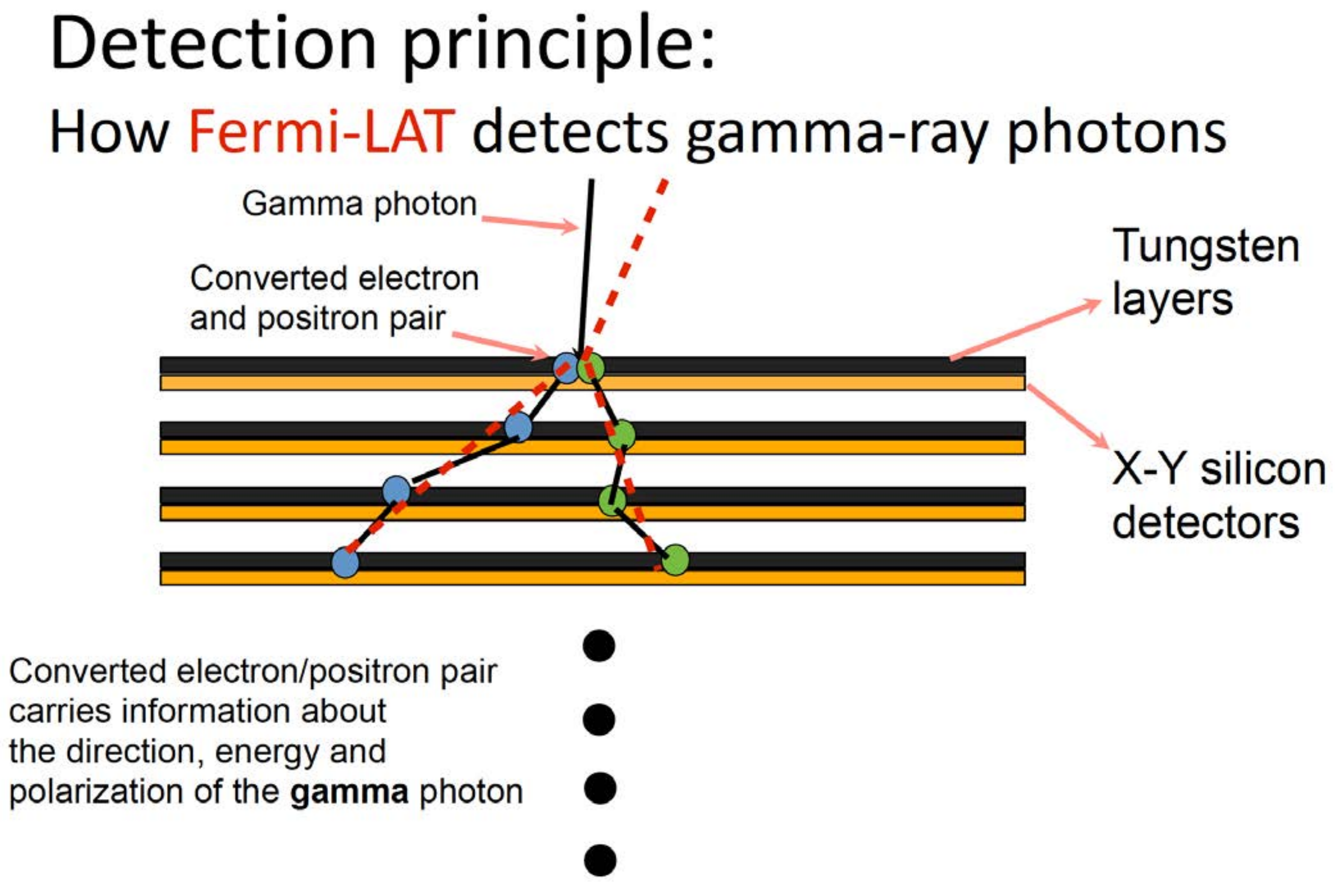
Co-PIs:	**Xin Wu**	**Jin Chang**
Signature:		
Affiliation:	**Department of Nuclear and Particle Physics University of Geneva Geneva, Switzerland**	**Purple Mountain Observatory Chinese Academy of Sciences Nanjing, China**
Email:	**xin.wu@unige.ch**	**chang@pmo.ac.cn**

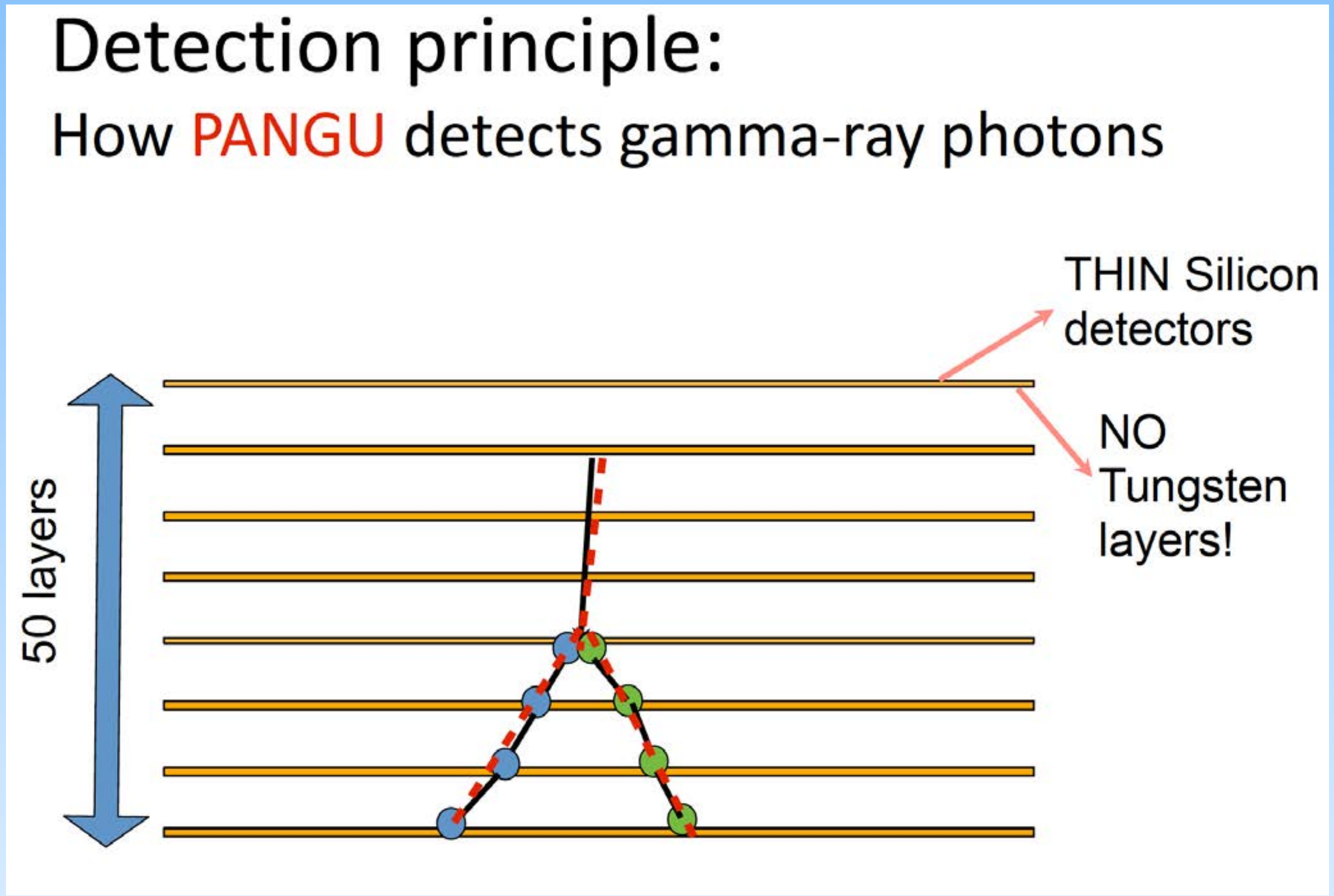
The PANGU Collaboration

- A growing international collaboration from China, Europe and US
  - 64 members from 21 Chinese institutes
  - 17 members from 10 European institutes (Switzerland, Italy, Germany, France, Netherlands)
  - 4 members from 4 US institutes

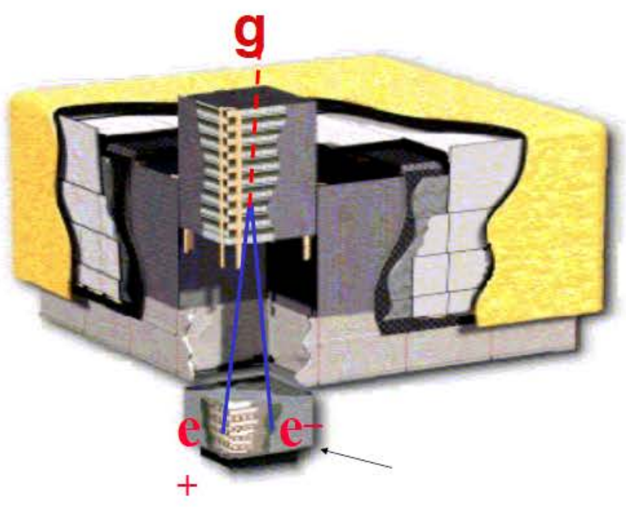
Strong interest and broad support from the Chinese and European astrophysics communities

PANGU vs Fermi LAT





PANGU v.s. Fermi



4300 kg (2789 kg payload for LAT)

30 MeV 300 MeV 3 GeV 30 GeV 300 GeV

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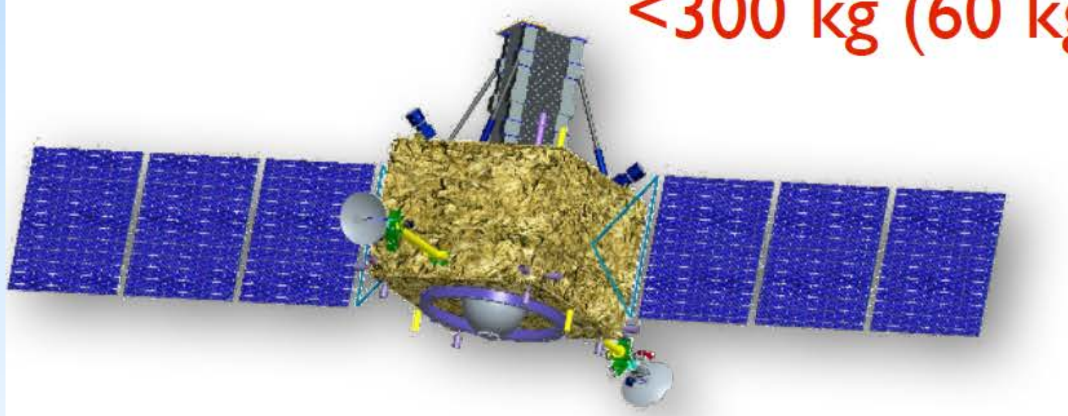
<300 kg (60 kg payload) -> up to 400 kg payload?



PANGU 2019

- Support from Chinese Space Agency: SAST-Shanghai is looking for a science instrument on a planned satellite
- In July 2019, at the JICSS meeting (joint-lab w/ 18 Chinese Universities and HKU in Hong Kong) in Shanghai, a PANGU was selected
- A PANGU science "white book" is being re-written
- Work on updating the design study
- PANGU Science meeting held in Zhuhai (Oct 2019)
- HKU is revamping PANGU: enlisting international collaborators

Summary

- Over 50 years after their discovery, we still don't completely understand pulsars, however …
- Much of the recent progress in our understanding is coming from the numerous results from gamma-ray astronomy, primarily from Fermi-LAT.
- It is very challenging for Fermi-LAT to discover (or even detect) pulsars below 100 MeV … but we try.
- The population of MeV pulsars may help us address a number of questions about pulsars and astrophysics in general. We need a new MeV telescope.