First Year Results from the Fermi Gamma-ray Space Telescope

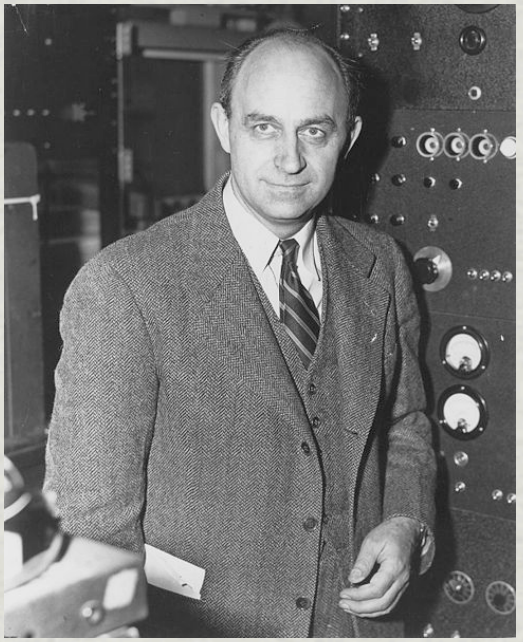
(This version was edited for online post)

Yasunobu Uchiyama
(Panofsky Fellow of SLAC)
on behalf of the Fermi LAT collaboration

Contents

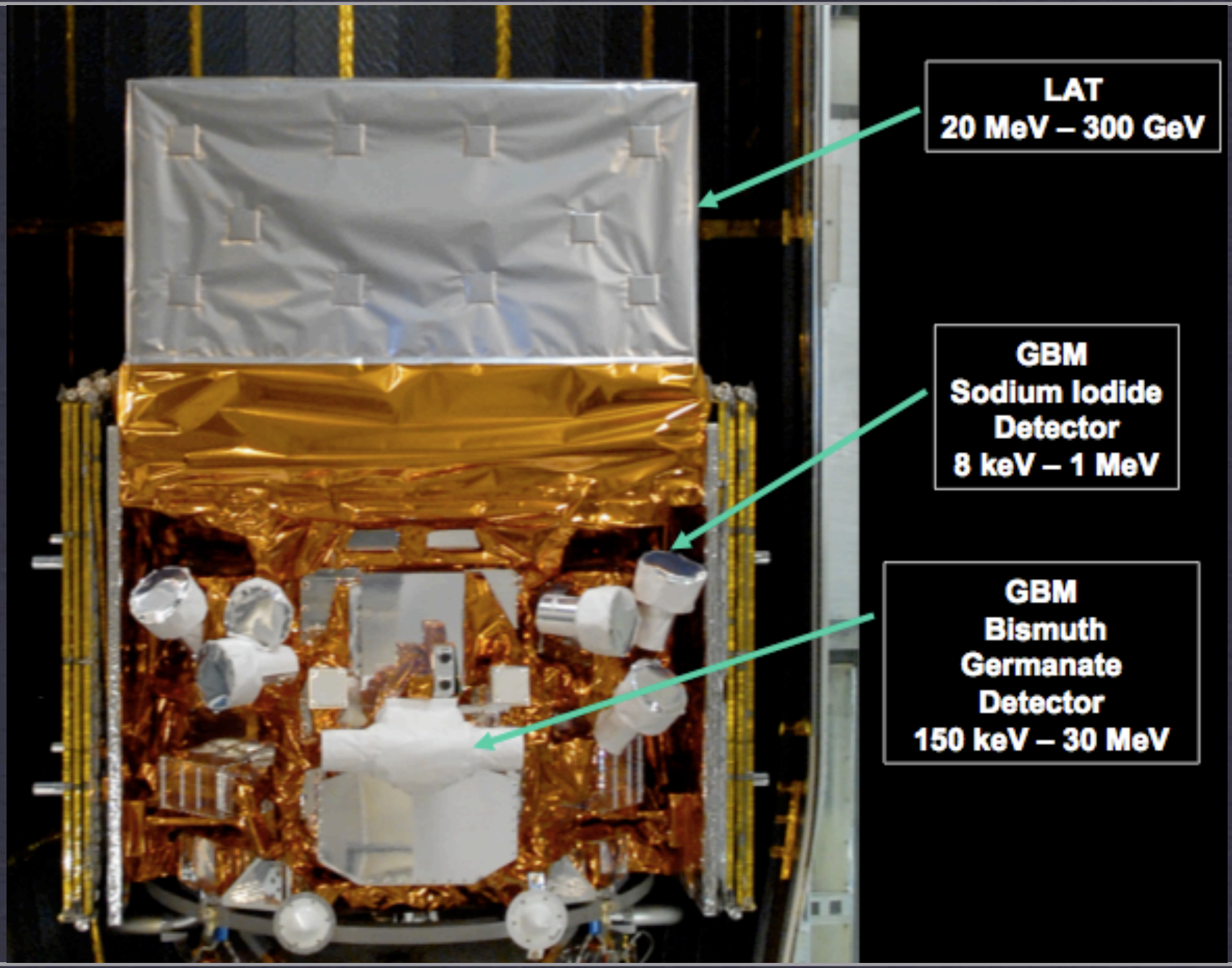
- **Large Area Telescope** (LAT) onboard **Fermi**
- **Galactic** Sources
  - Pulsars, Pulsar Wind Nebulae
  - Binaries
  - Supernova Remnants
- **Extragalactic** Sources
  - Blazars, Radio Galaxies
  - Magellanic Clouds, Starburst Galaxies
  - Gamma-ray Bursts (Talk by Asano-san)
- **Backgrounds**
  - Cosmic-ray Electrons/Positrons
  - Galactic Diffuse Emission
  - Extragalactic Gamma-ray Background
- **[Solar Objects]** (Sun, Moon, ...)
- **[Dark Matter Search]**

Enrico Fermi

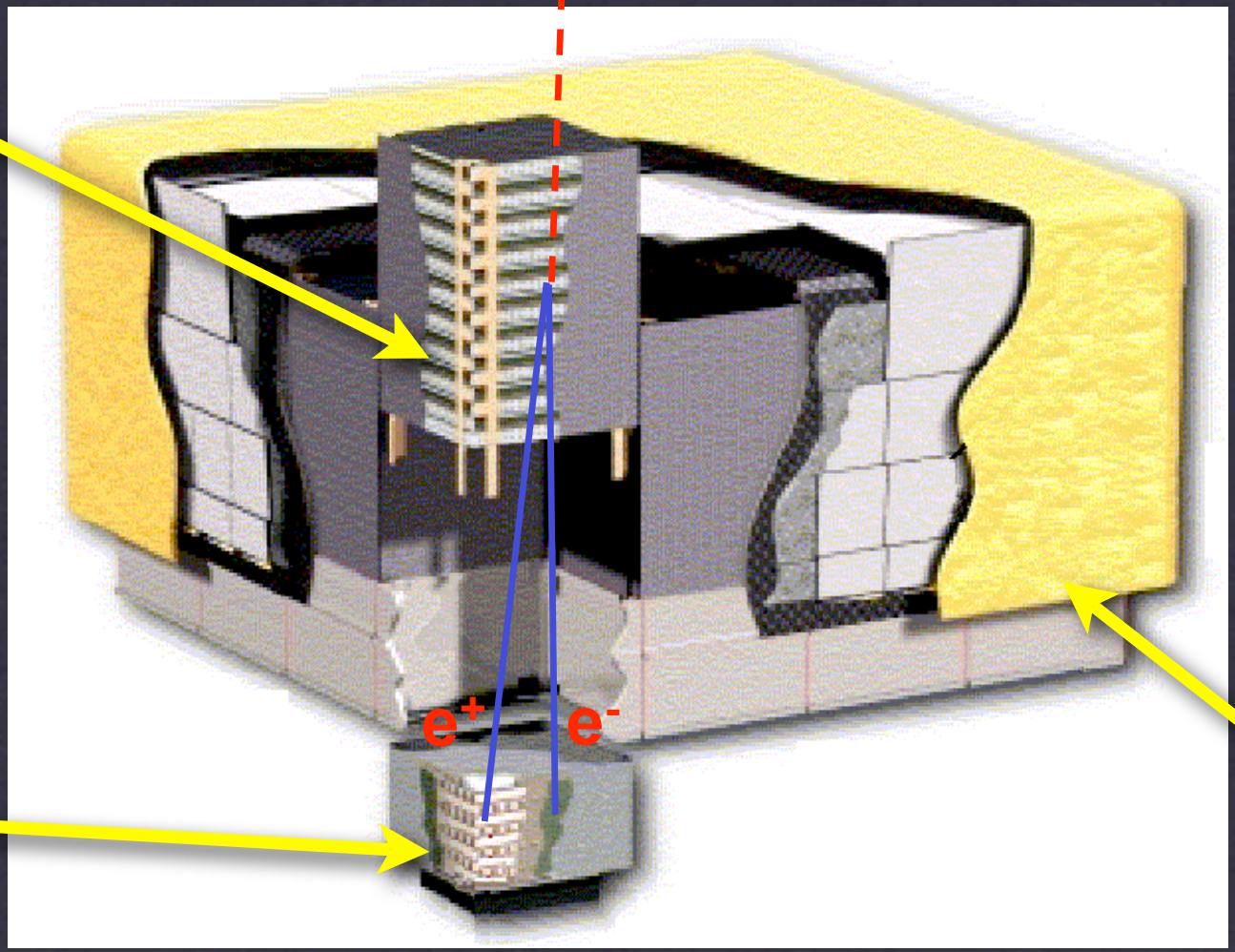


Launch!

* June 11, 2008
* Delta II Heavy launch vehicle
* Low-Earth orbit 565 km (96 min period)
* Inclination 25.6 deg



LAT and GBM onboard Fermi

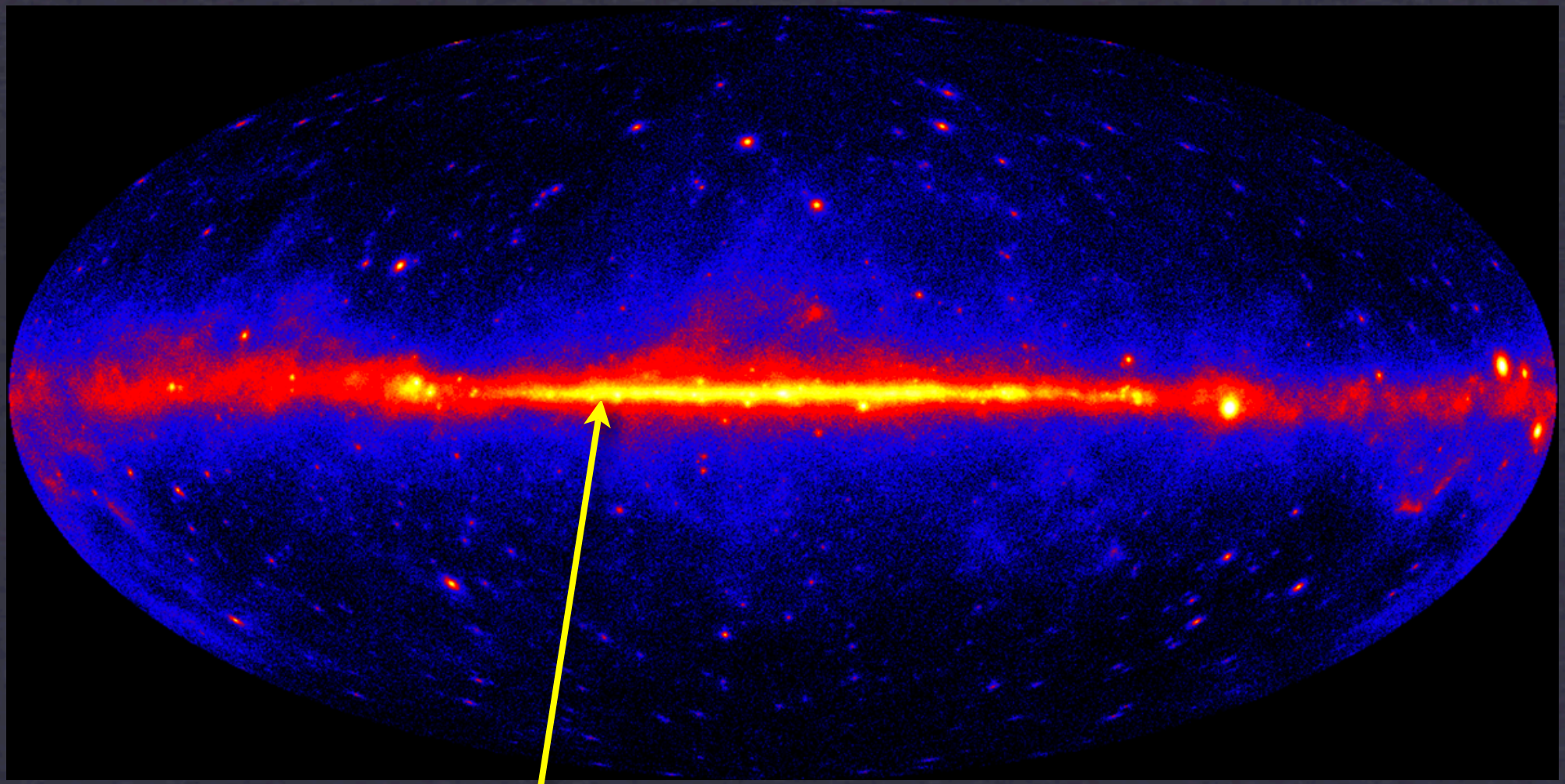


LAT: 4x4 modular array
3000 kg, 650 W

Large Area Telescope (LAT)

LAT All Sky Map (1 yr)

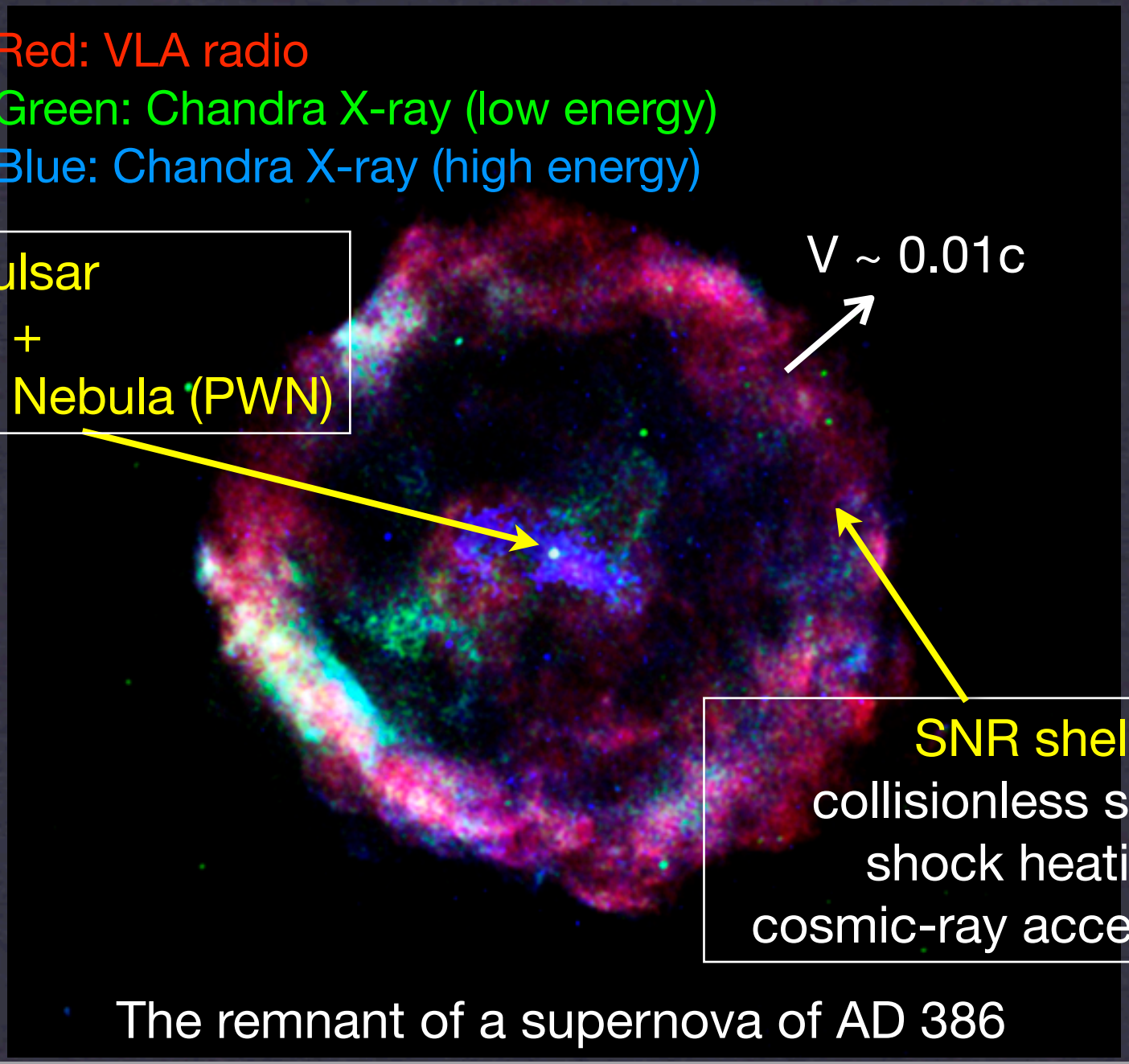
> 1000 LAT sources



Milky Way (Galactic Cosmic Rays)

Part 1: Galactic Sources

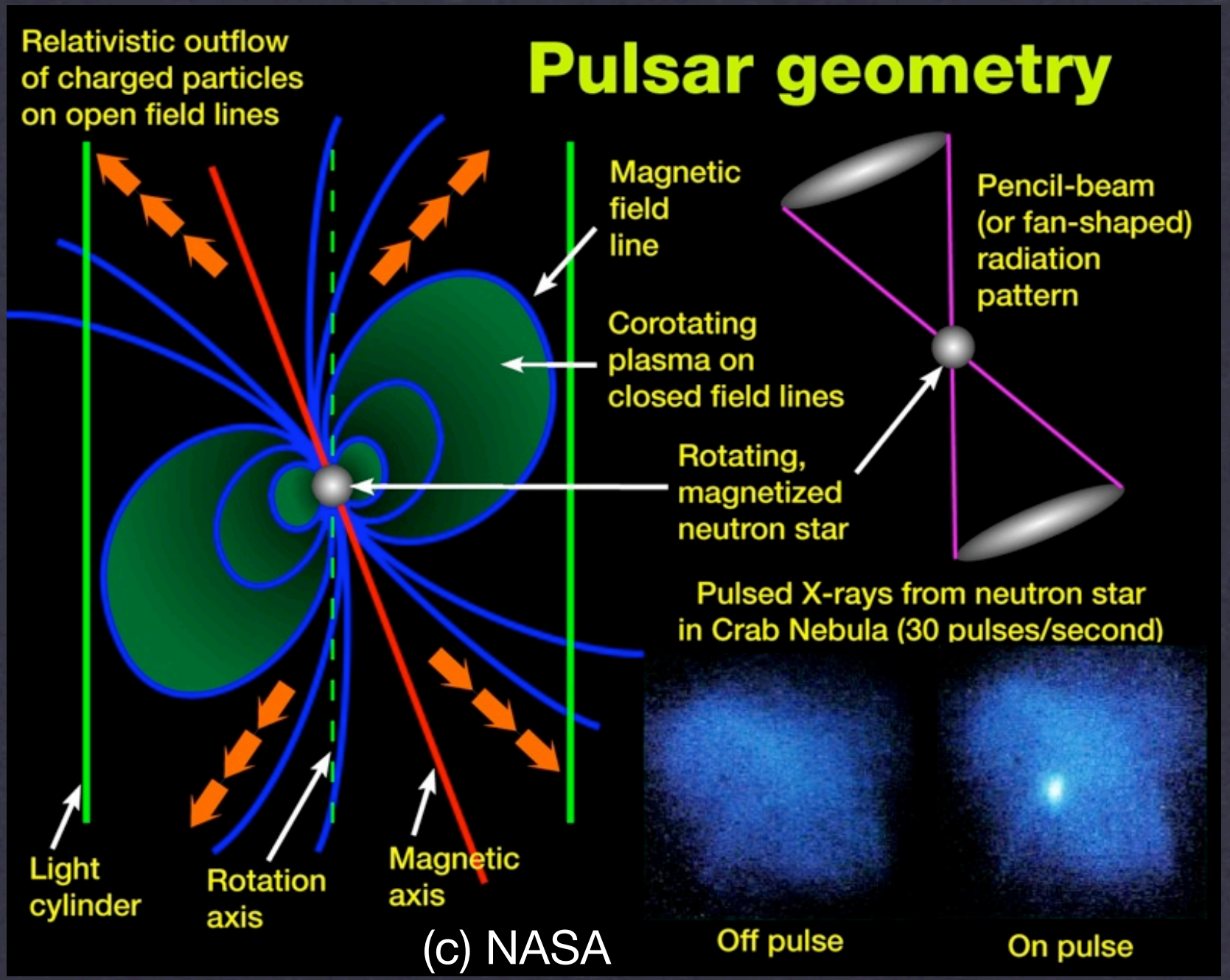
- Pulsar
- Pulsar Wind Nebula (PWN)
- Supernova Remnant (SNR)
- Binary (Neutron star/Black hole + Massive star)



Supernova Remnant G11.2-0.3

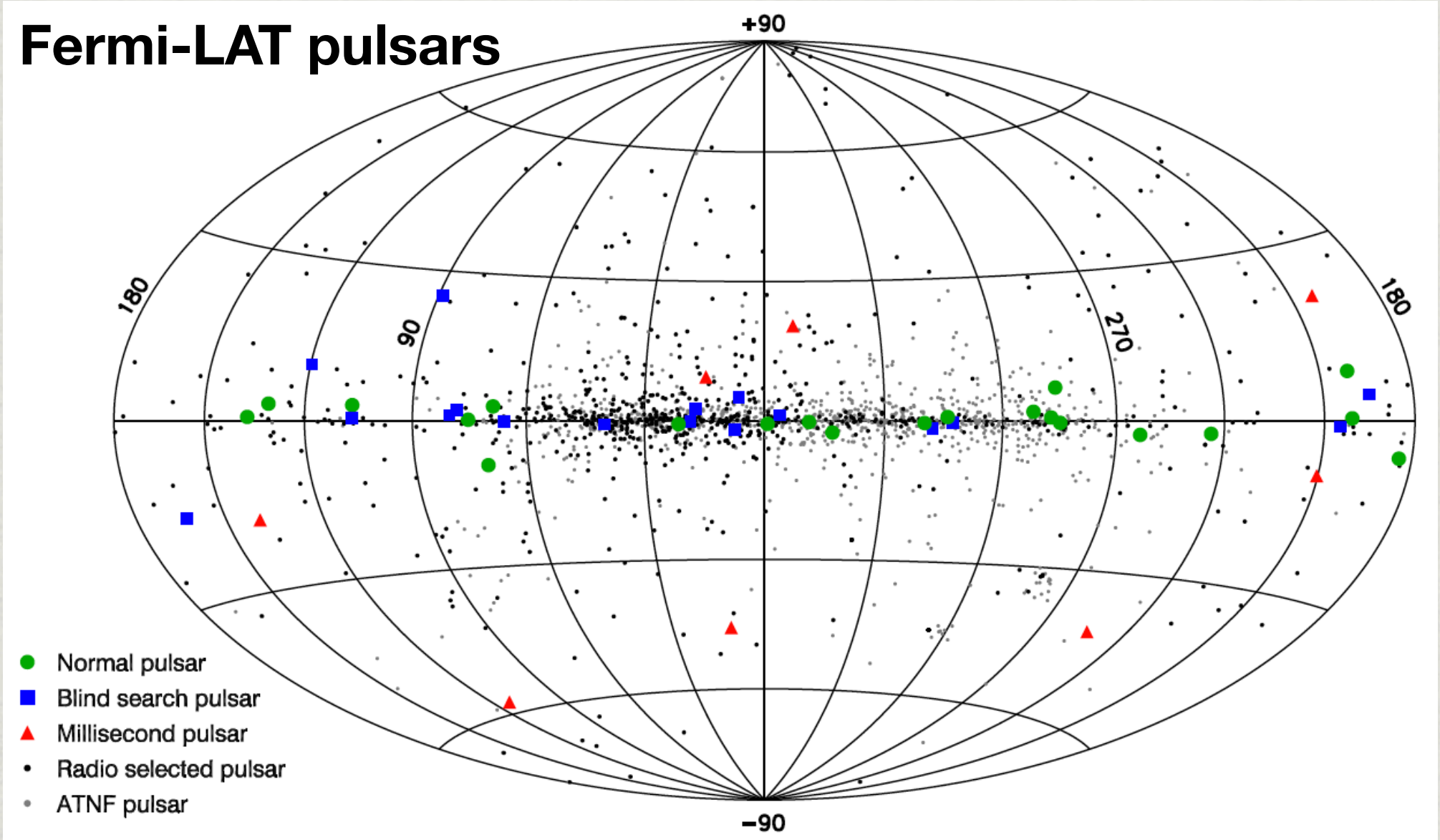
Pulsar, PWN, and SNR

Pulsar's Magnetosphere

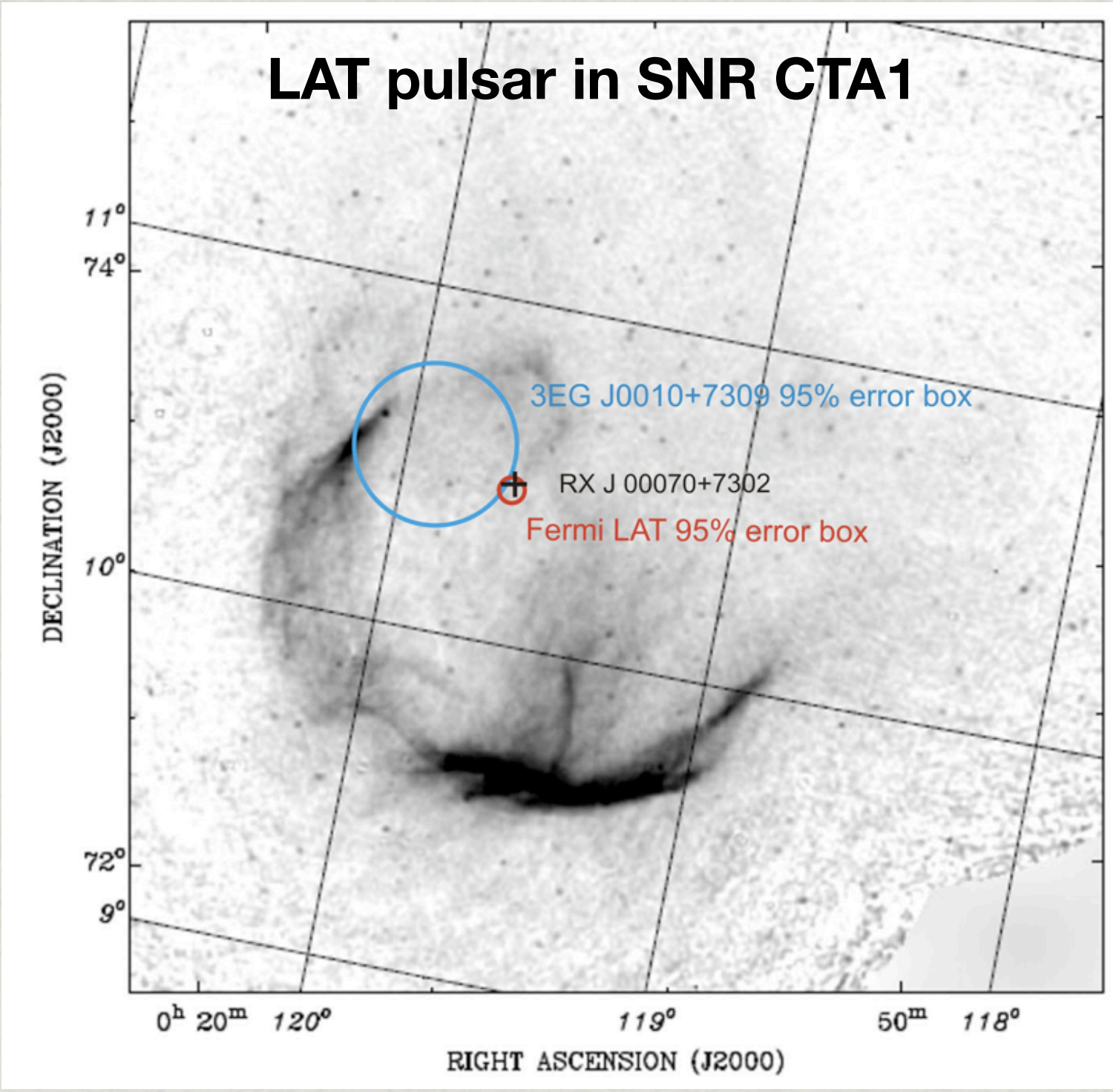


Pulsars

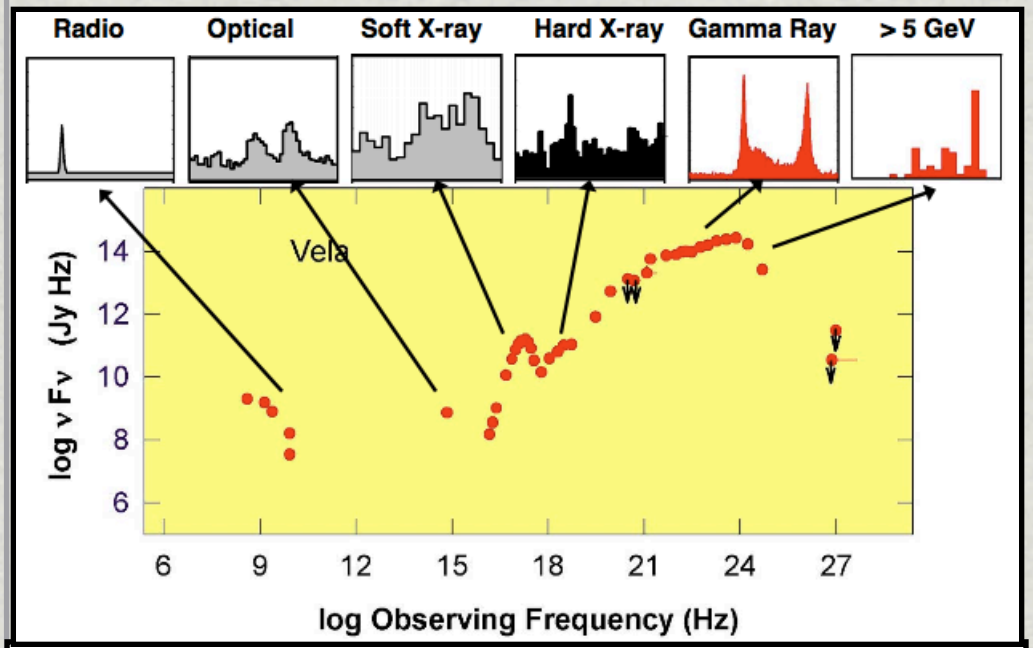
EGRET **6** pulsars → LAT **46** pulsars

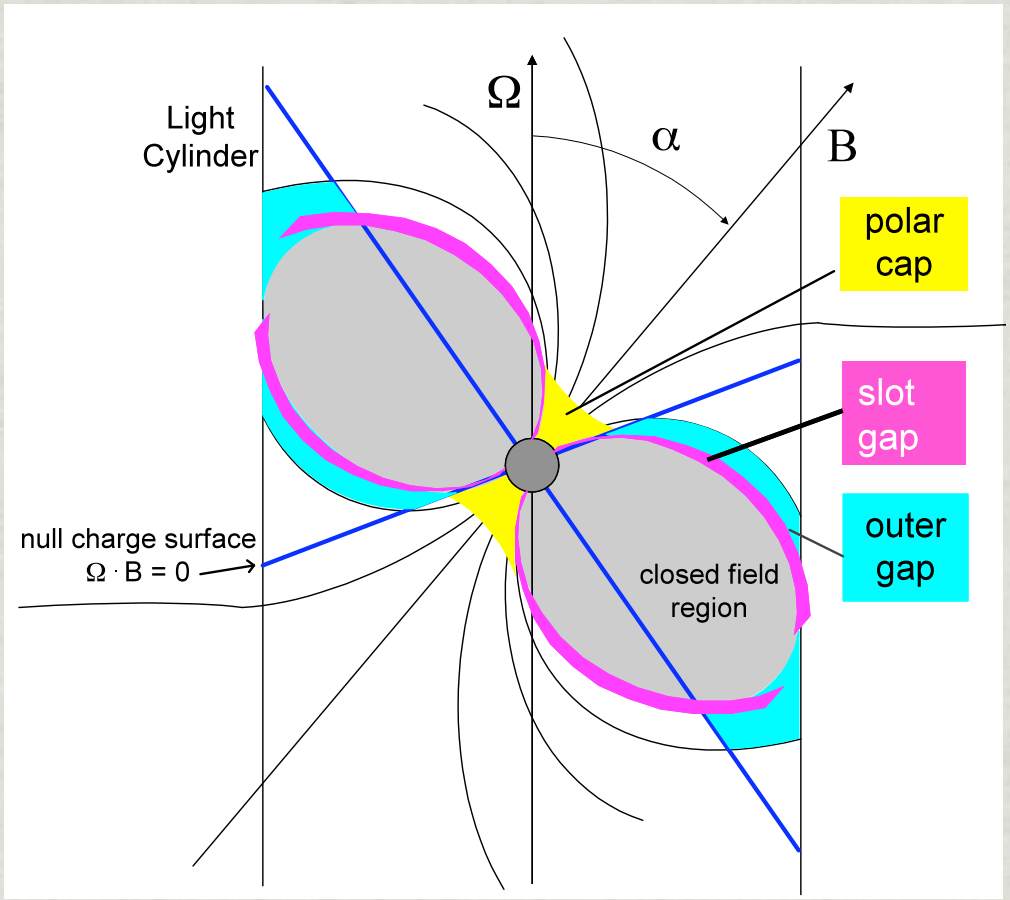


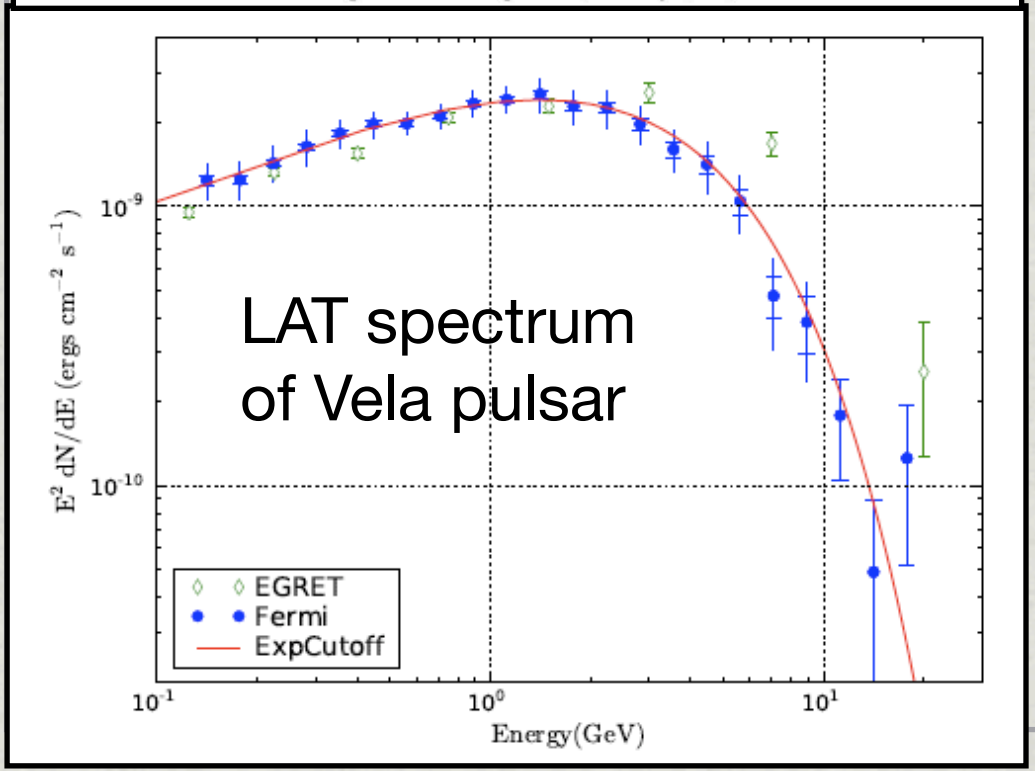
LAT pulsar in SNR CTA1



Gamma-ray Emission Zone



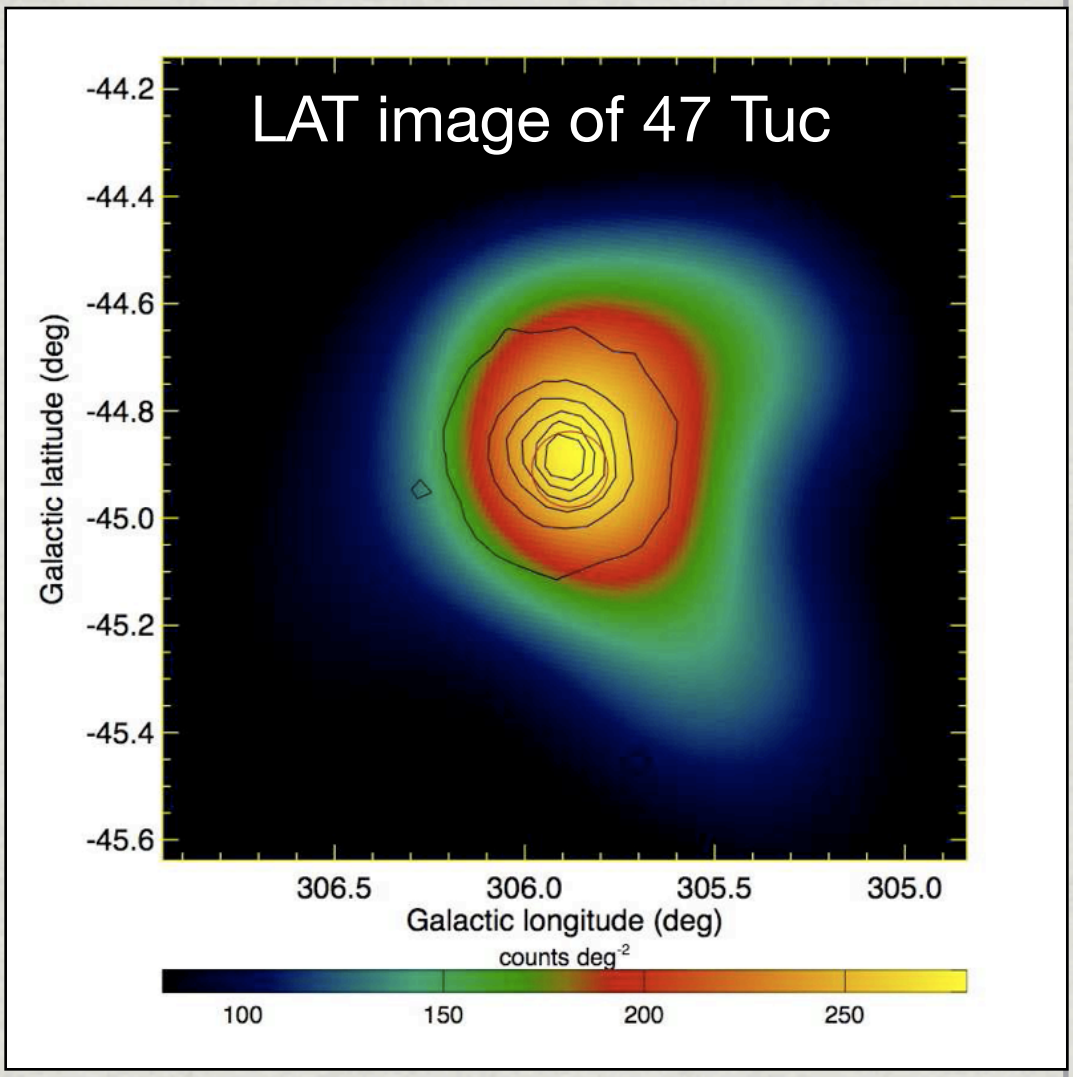




LAT spectrum
→ Inconsistent with Y-B pair attenuation
→ **Polar Cap** excluded

LAT Detection of the Globular Cluster 47 Tucanae

- Millions of stars
- 120 light-year diameter
- 13 billion years old



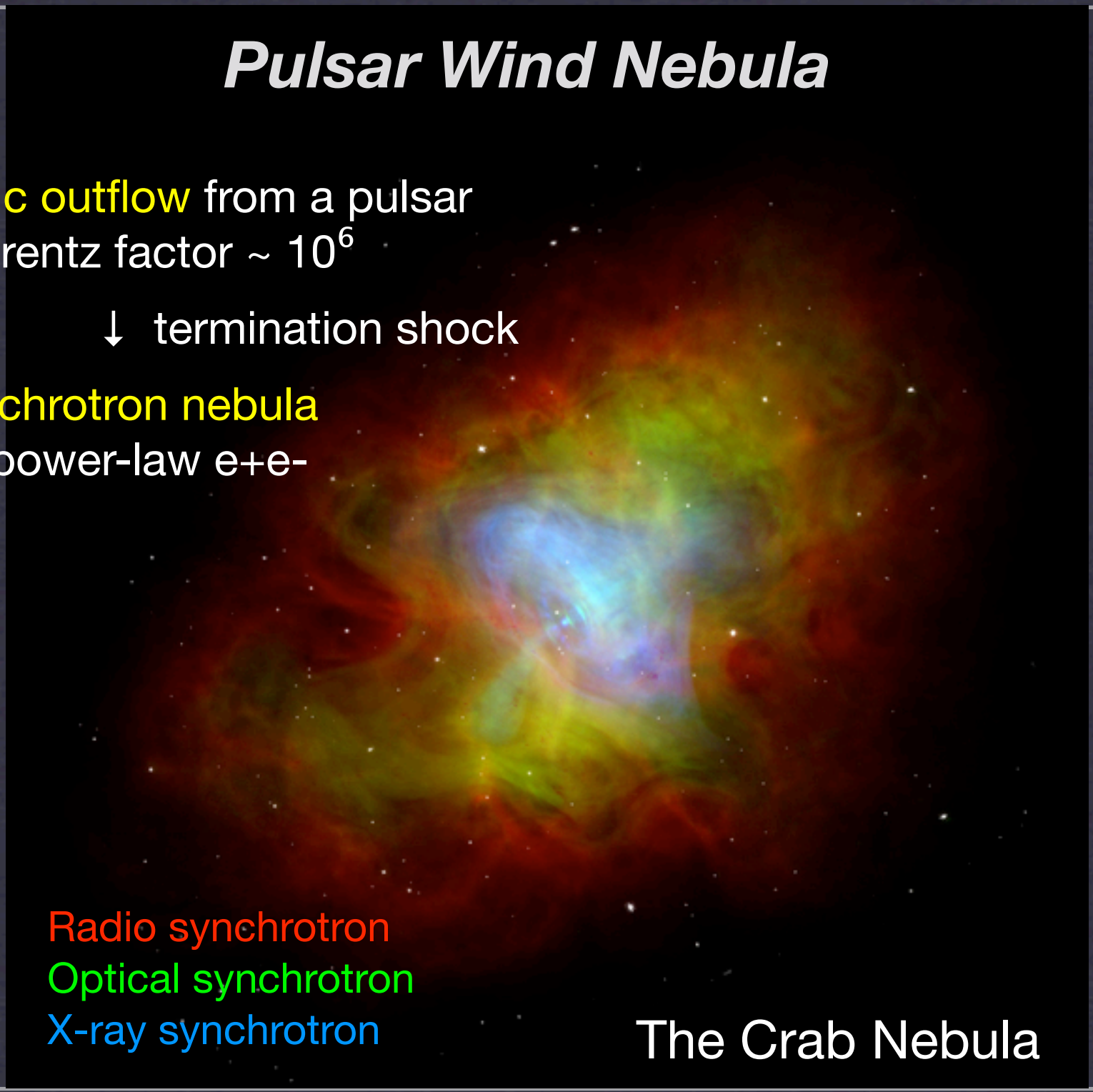
50-60 Millisecond Pulsars

Pulsar Wind Nebula

relativistic outflow from a pulsar
bulk Lorentz factor ~ 10^6

↓ termination shock

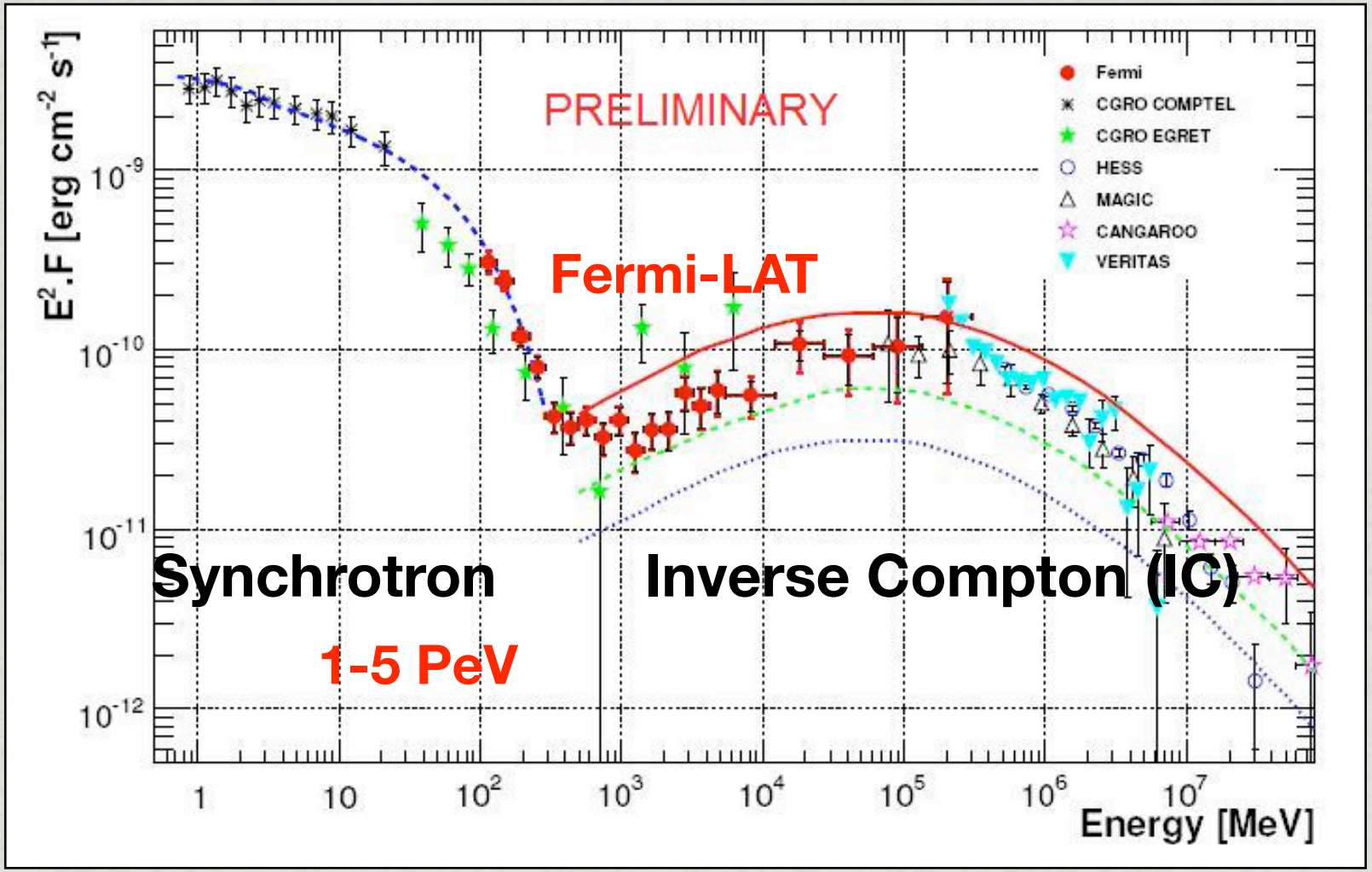
synchrotron nebula
by power-law e+e-



Radio synchrotron
Optical synchrotron
X-ray synchrotron

The Crab Nebula

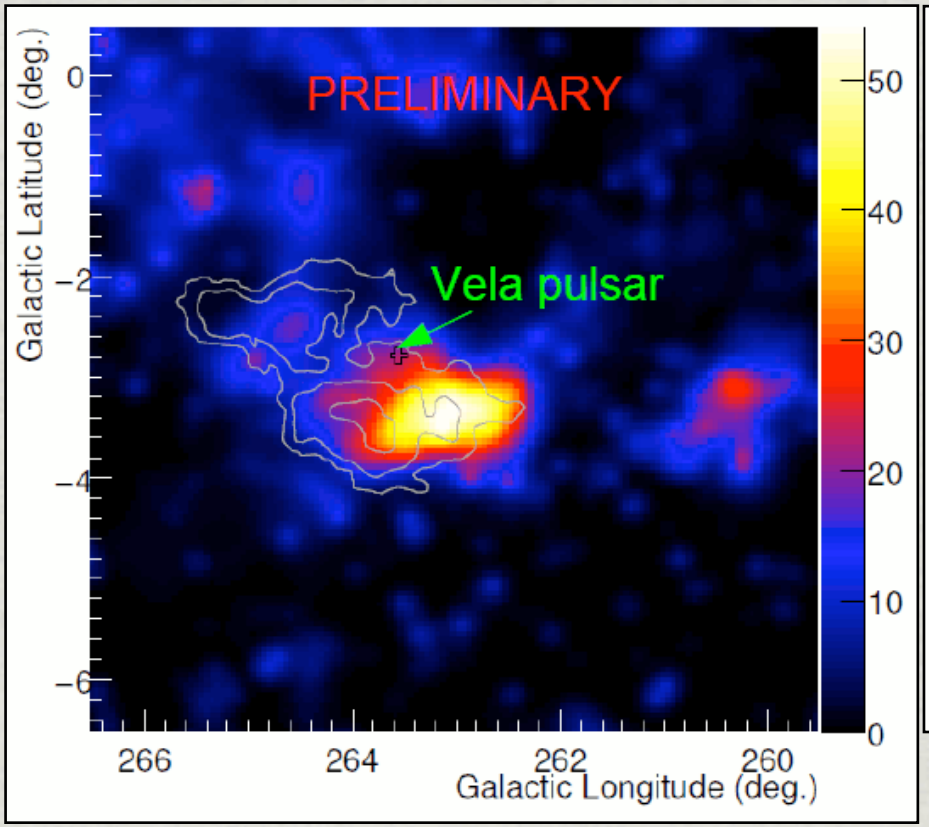
The Crab Nebula: Gamma-ray Spectrum



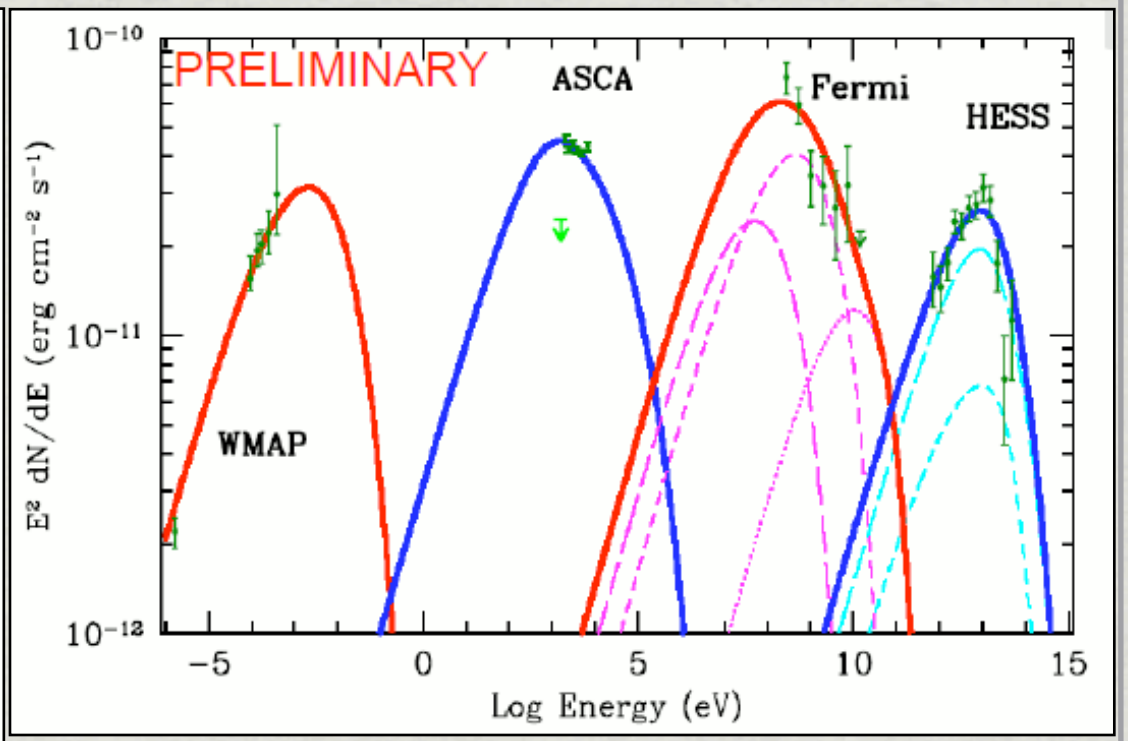
IC level controlled by B-field → **B= 0.1-0.2 mG**

Vela X PWN

Fermi-LAT (significance map)



SED of Vela X



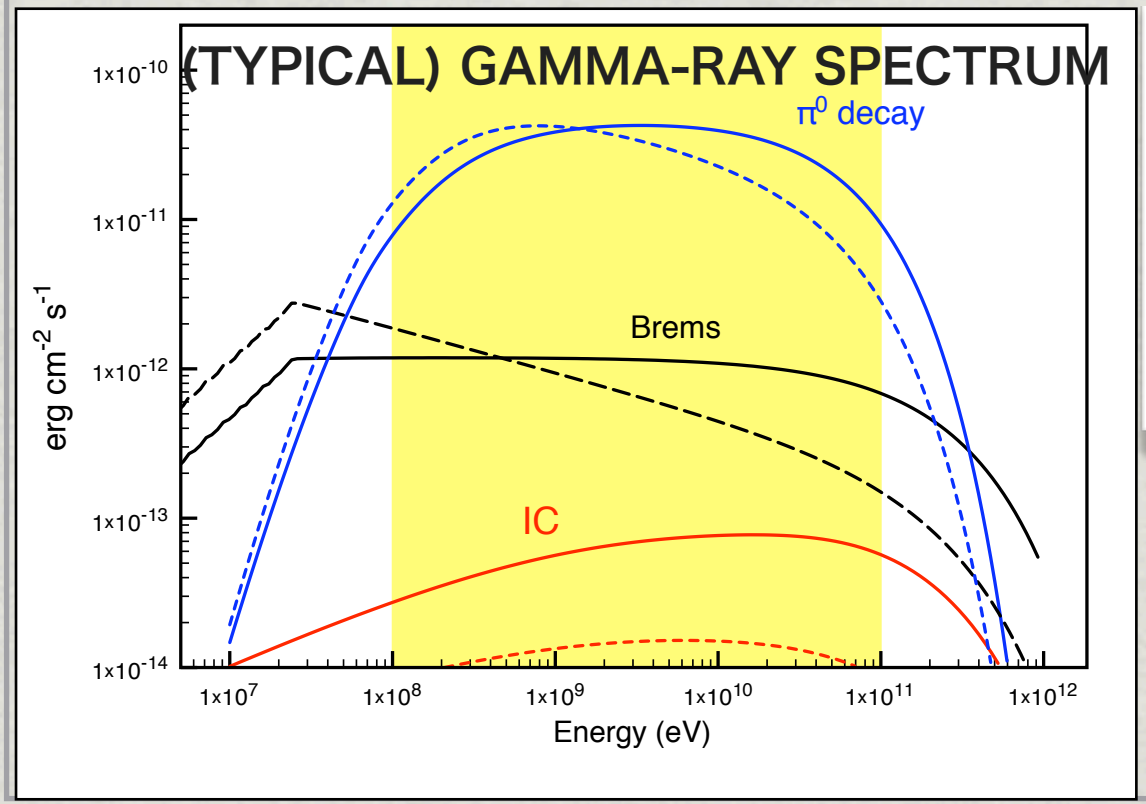
Off-pulse of Vela pulsar →
Detection of extended gamma-rays

IC level controlled by B-field
→ **B ~ 4 μG**

D = 290 pc: one of the closest pulsar known

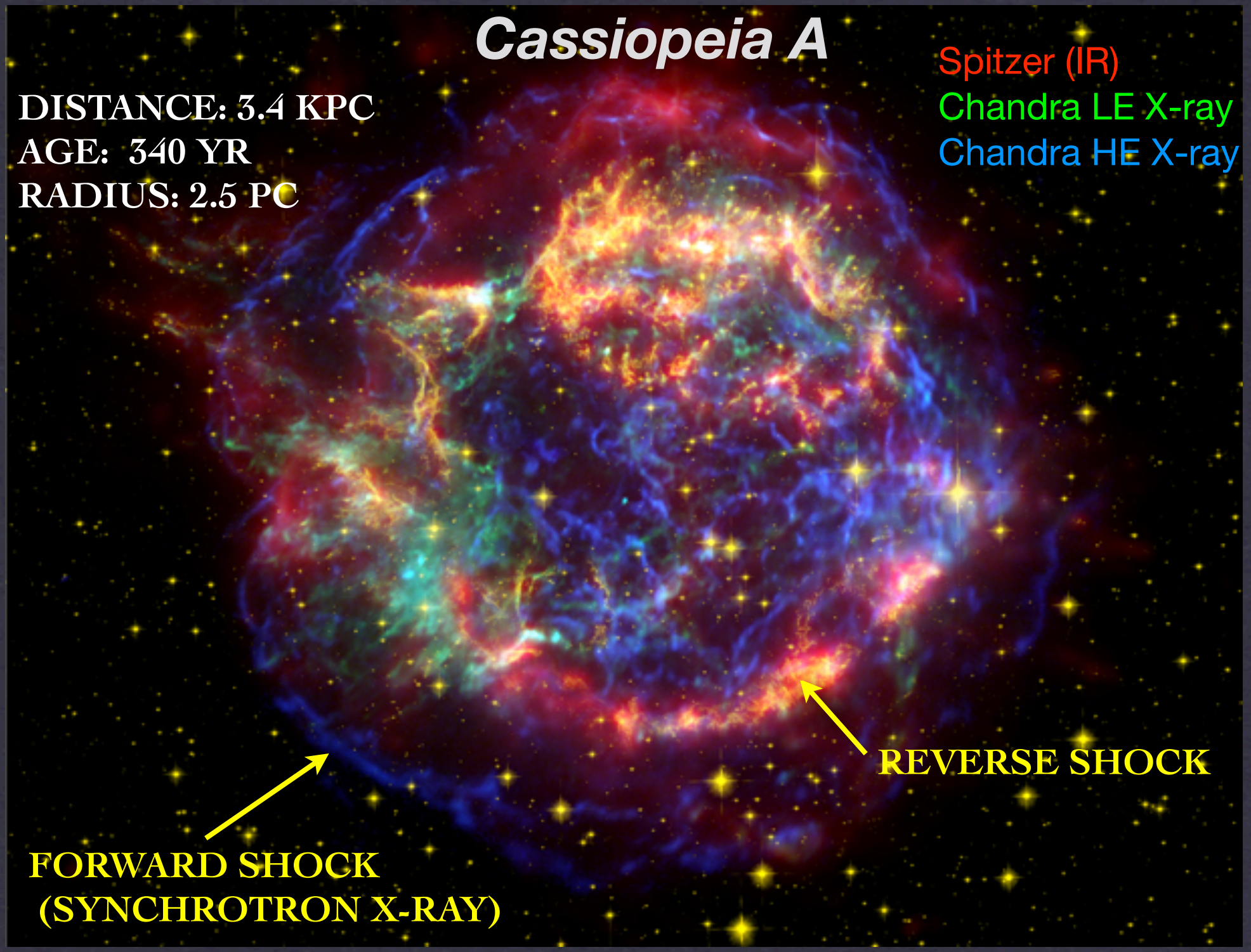
Supernova Remnants

- **Diffusive Shock Acceleration** (1st order **Fermi Acceleration**) at expanding supernova shells is the most-favored explanation for **the origin of galactic cosmic rays (CRs)**.
  - Key issues to be addressed by **Fermi LAT**:
    - Searching for **pion-decay** signatures,
    - Measuring total **CR energy content** per SNR,
    - Measuring **CR spectrum**,
    - Learning how CRs are **released** into ISM.



- **D = 3 kpc**
- **$n = 100\ cm^{-3}$**
- **$W_p = 10^{49}$ erg**
- **$W_e = 10^{47}$ erg**
- **$E_{p,max} = E_{e,max} = 0.5$ TeV**
- **Particle index = 2.0 (solid)**
- **Particle index = 2.3 (dashed)**

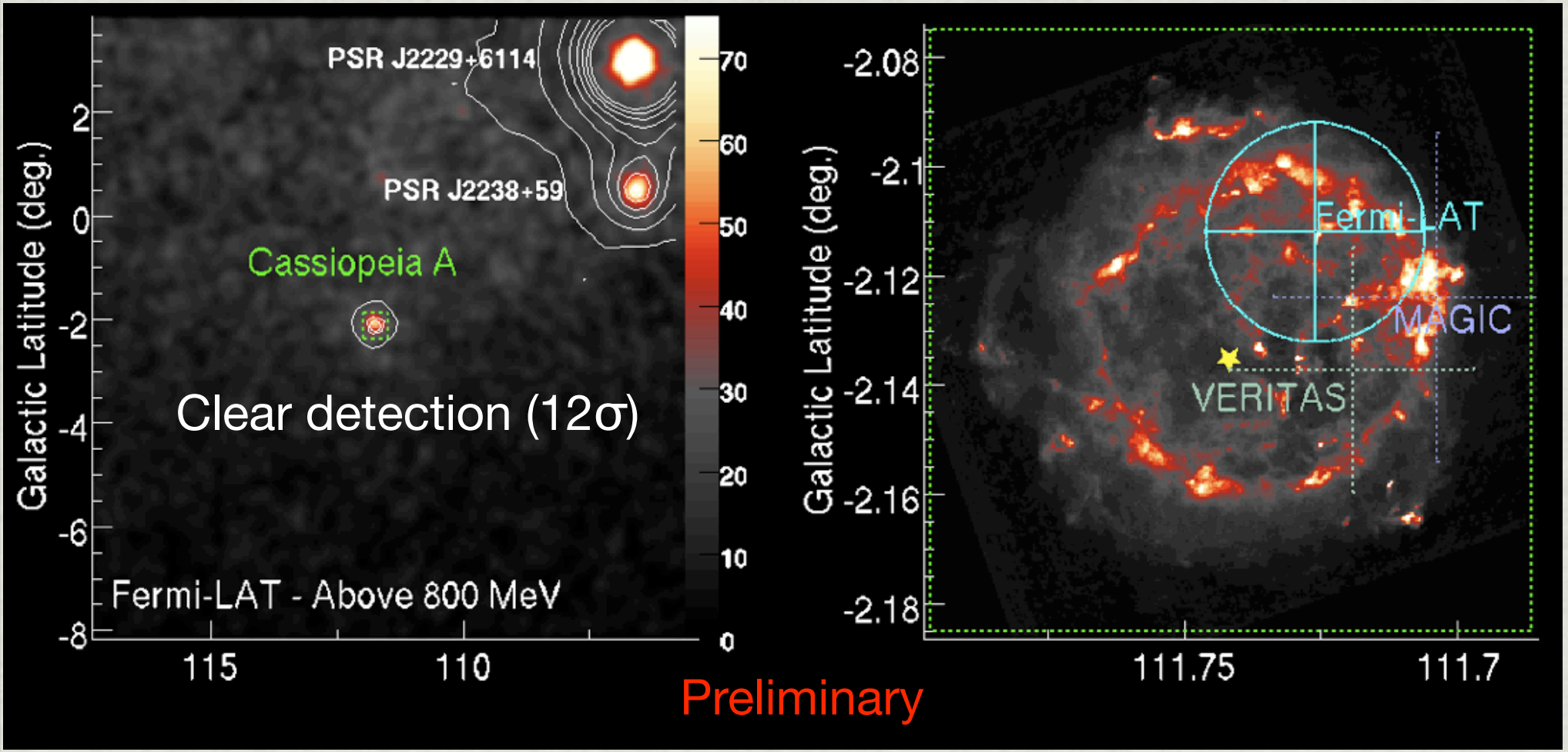
Interaction with molecular cloud enhances Pion-decay/ Bremsstrahlung.


Cassiopeia A
DISTANCE: 3.4 KPC
AGE: 340 YR
RADIUS: 2.5 PC
Spitzer (IR)
Chandra LE X-ray
Chandra HE X-ray
REVERSE SHOCK
FORWARD SHOCK
(SYNCHROTRON X-RAY)

Fermi-LAT Detection of Cas A

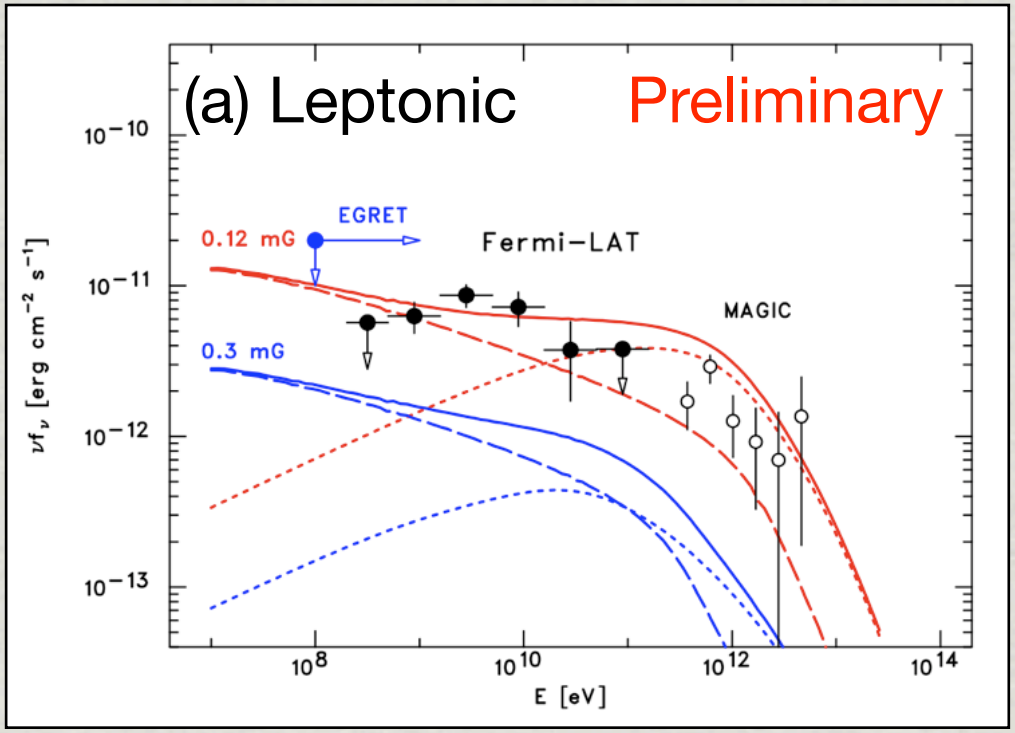
Fermi-LAT

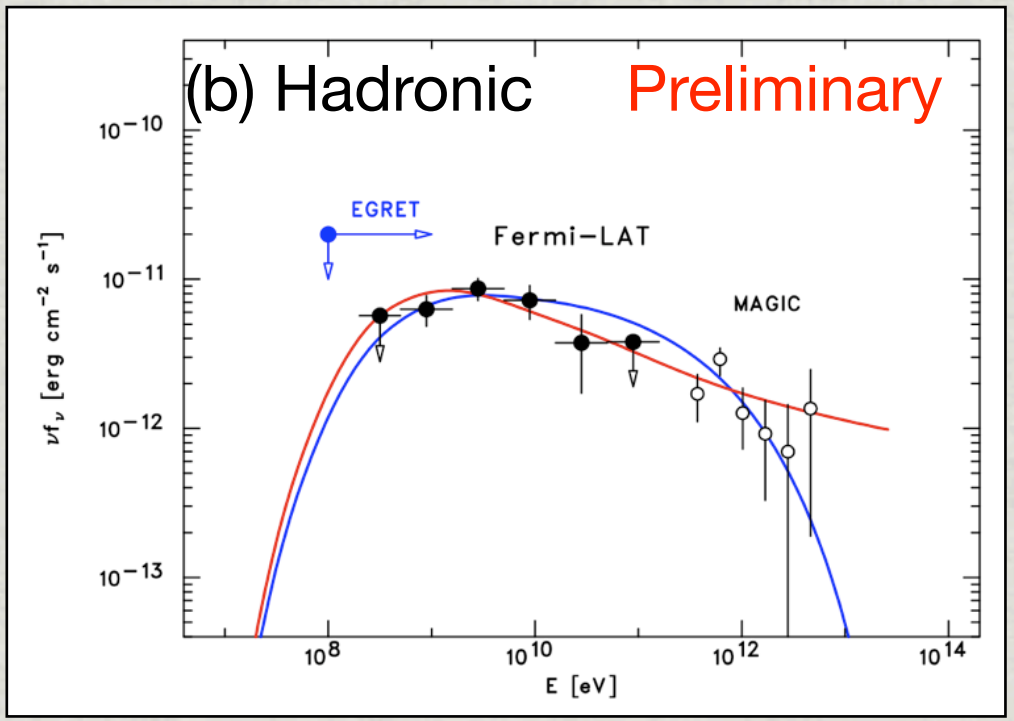
VLA radio map



First clear detection of historical SNR

The position does not match with CCO (neutron star)





Cas A Spectrum

(a) Leptonic (Bremsstrahlung + IC)

B = 0.12 mG

We = 1×10^{49} erg

(total electron energy content)

(b) Hadronic (π^0 decay)

B > 0.12 mG

Wp = 4×10^{49} erg

(total proton energy content)

New evidence for

B-field amplification, but

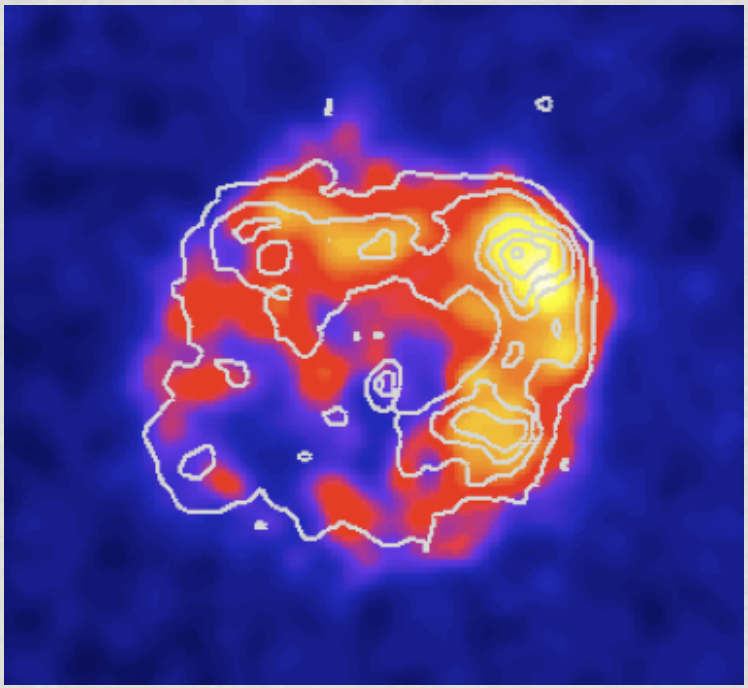
Wcr(1-4x10^{49} erg) << Esn(2x10^{51} erg)

SNR RXJ1713.7-3946: Brightest keV/TeV sources

TeV Gamma: Hadronic or Leptonic origin?

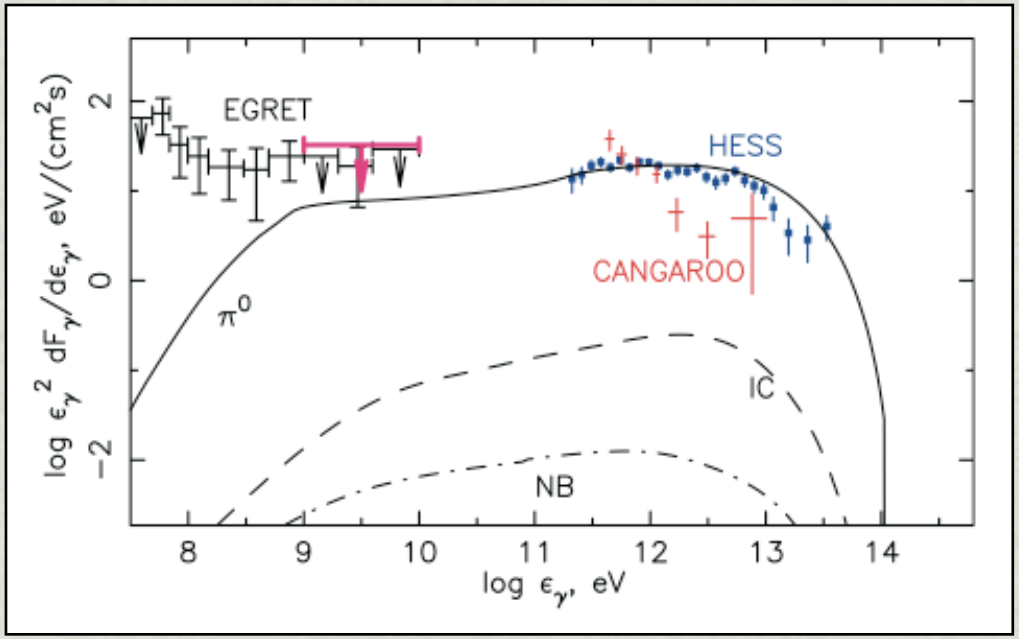
Gamma-ray emission mechanism is under active debate.

SNR RXJ1713.7-3946



X-RAY (ASCA) VS TEV (HESS)

NON-LINEAR ACCELERATION BEREZHKO&VÖLK 2006

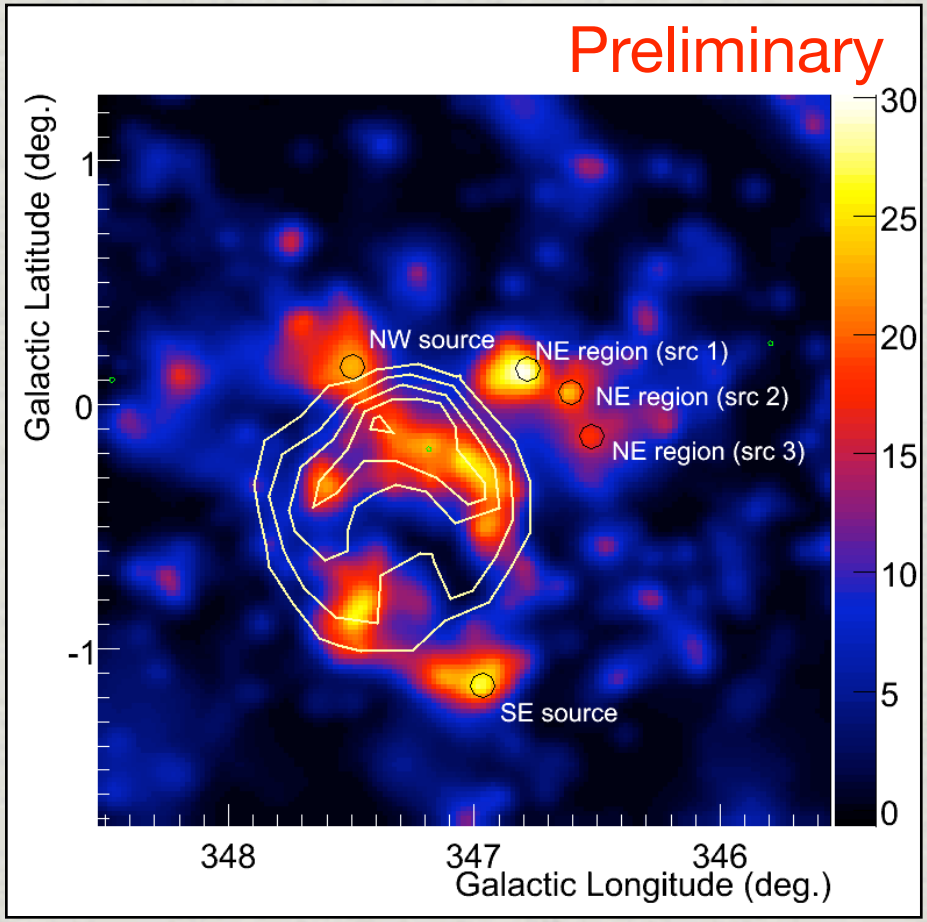


Synchrotron X-ray variability : B ≈ 0.1 - 1 mG

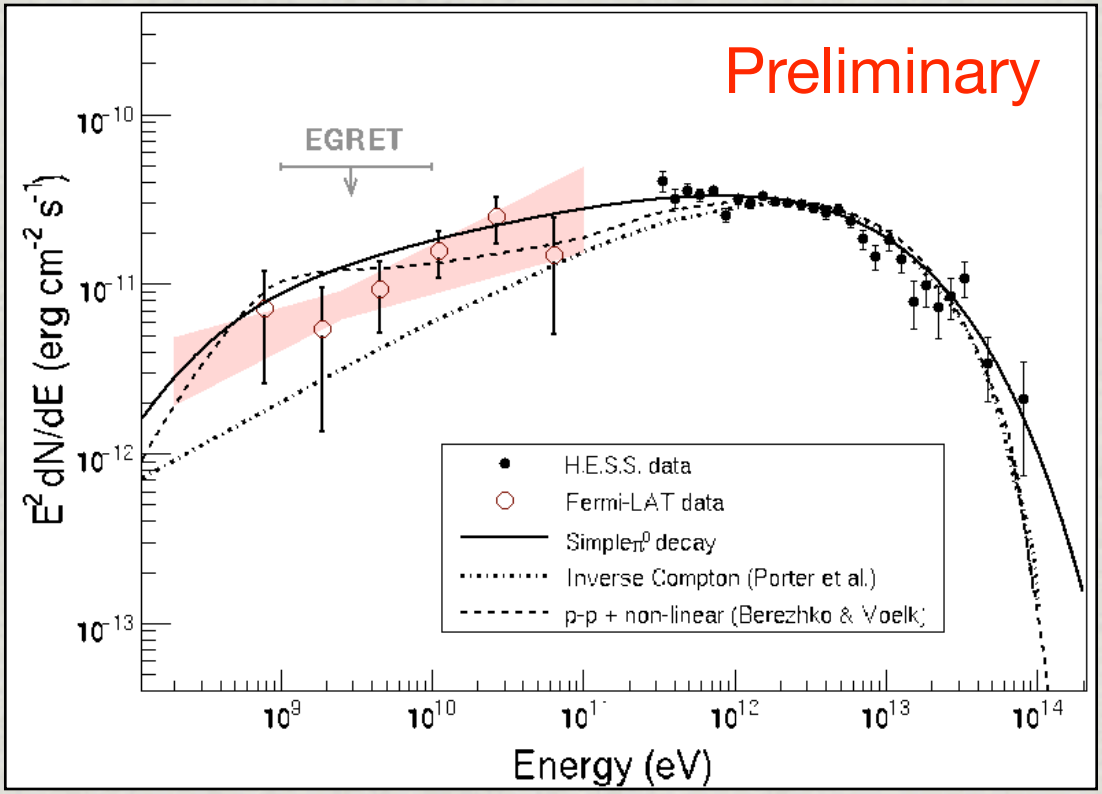
UCHIYAMA+2007

SNR RXJ1713.7-3946
Fermi LAT Results (Preliminary)

Fermi-LAT (significance map)

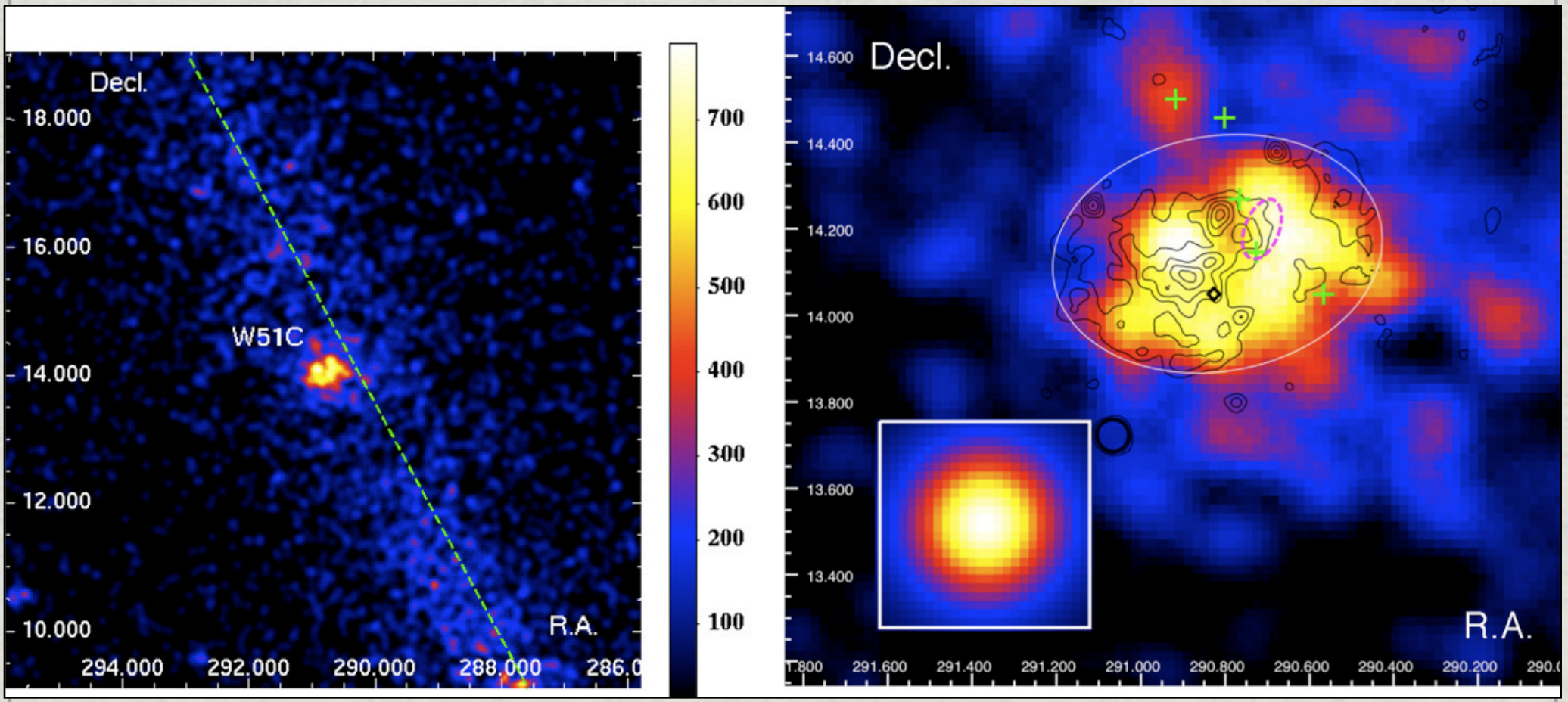


LAT + HESS Spectrum



SNR interacting with Molecular Cloud: (1) SNR W51C

- Middle-aged (~ 3×10^4 yr) Distance: ~ 6 kpc
- Radio shell, thermal X-ray (black contours)

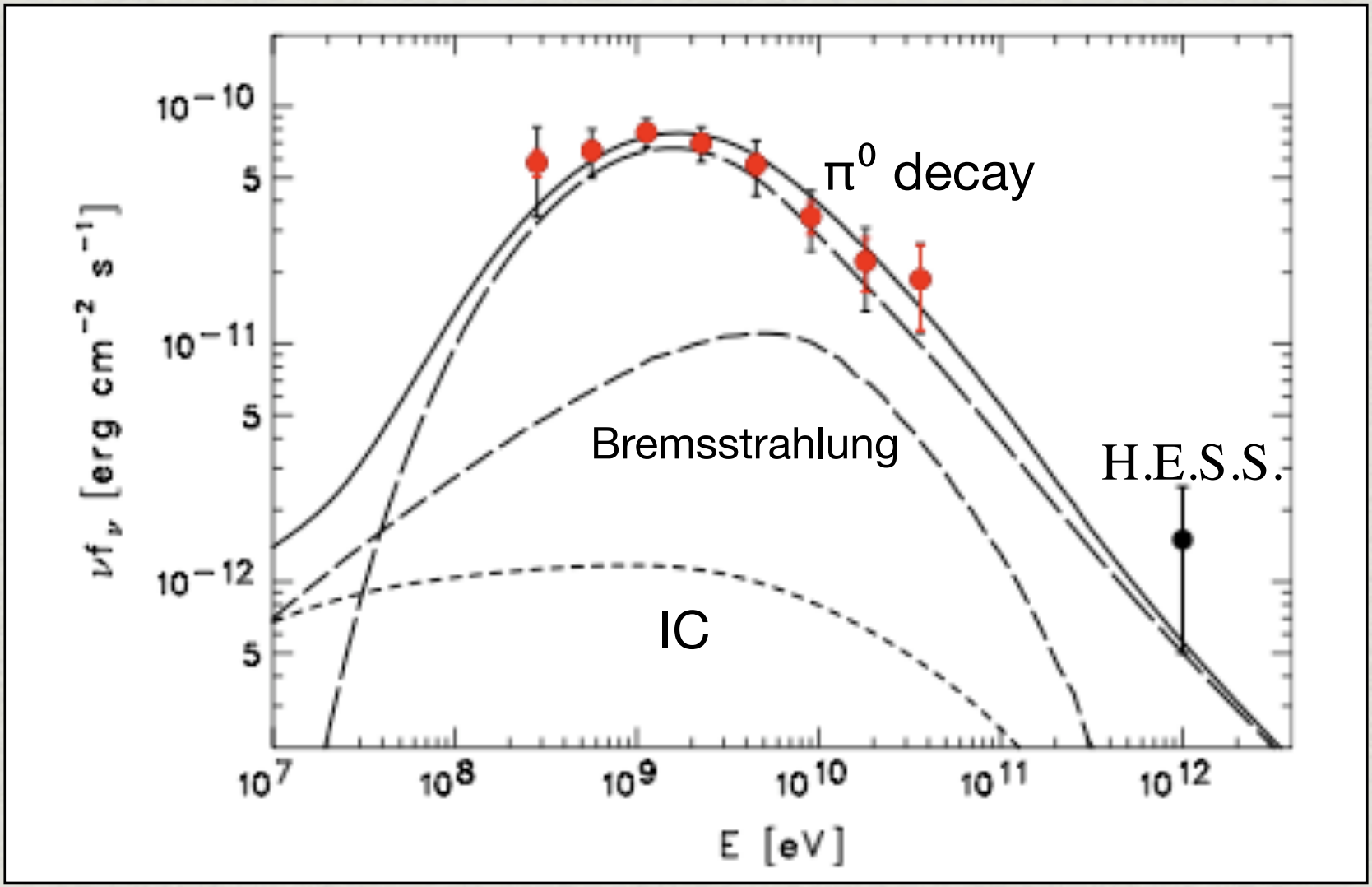


Fermi-LAT Count Map (Front Events; 2–10 GeV)

SNR W51C

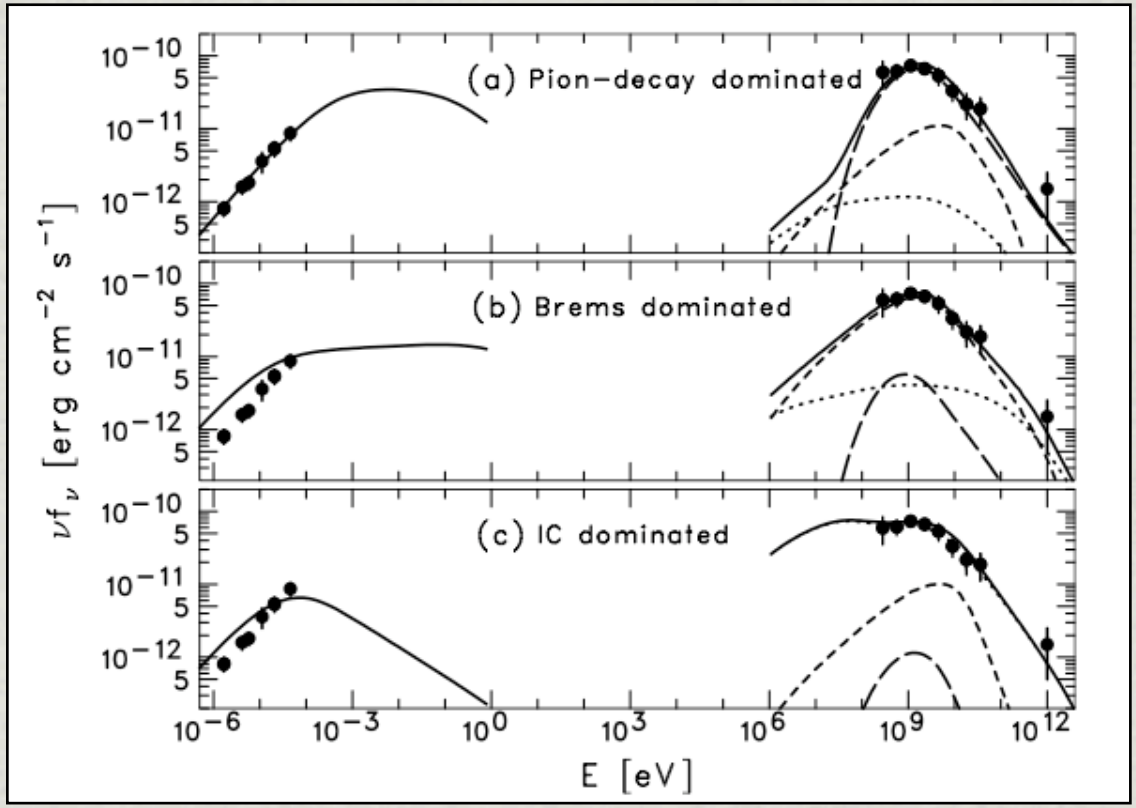
CR proton sources are finally found?

Fermi-LAT Spectrum



Molecular cloud interaction enhances π^0 -decay emission

SNR W51C: SED modeling



π^0 decay : OK

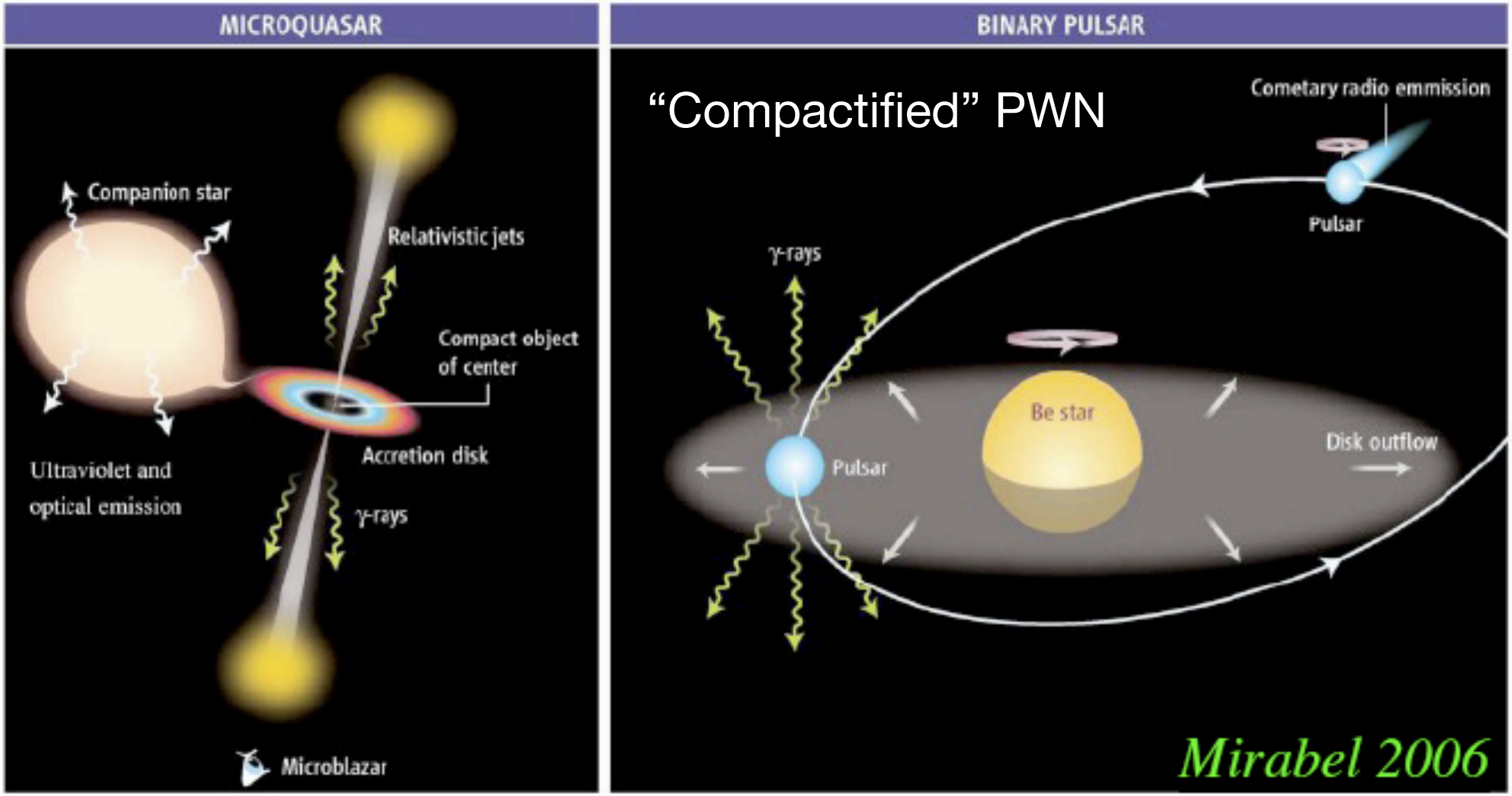
brems : unlikely but not fully excluded

IC : very unlikely

Model	Parameters					Energetics	
	a_e/a_p	Δs	p_{br} (GeV c^{-1})	B (μG)	$\bar{n}_H$ (cm^{-3})	W_p (10^{50} erg)	W_e (10^{50} erg)
(a) π^0 decay	0.02	1.4	15	40	10	5.2	0.13
(b) Bremsstrahlung	1.0	1.4	5	15	10	0.54	0.87
(c) Inverse Compton	1.0	2.3	20	2	0.1	8.4	11

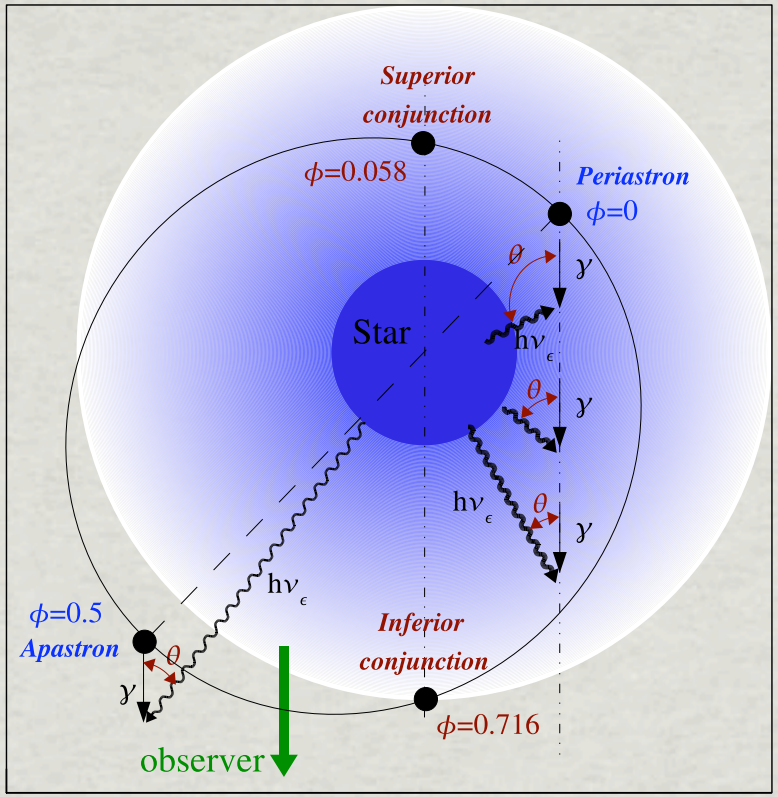
Notes. Seed photons for IC include the CMB ($kT_{CMB} = 2.3 \times 10^{-4}$ eV, $U_{CMB} = 0.26$ eV cm^{-3}), infrared ($kT_{IR} = 3 \times 10^{-3}$ eV, $U_{IR} = 0.90$ eV cm^{-3}), and optical ($kT_{opt} = 0.25$ eV, $U_{opt} = 0.84$ eV cm^{-3}). The total energy content of radiating particles, $W_{e,p}$, is calculated for $p > 10$ MeV c^{-1}.

Gamma-ray Binaries



Gamma-ray Binary (1): LS 5039

- Orbital period 3.9 day (e~0.3)
- Orbital radius ~ 0.1 AU
- Distance ~2.5 kpc
- companion star: O6.5V (~ 20 Msun)
- compact object: BH/NS (1.5-5 Msun)
- Relativistic outflow (v~0.2c) L~1000 AU
- No emission from accretion disc



Gamma-ray Production: Anisotropic Inverse Compton (IC)

TeV Gamma: IC Klein-Nishina regime

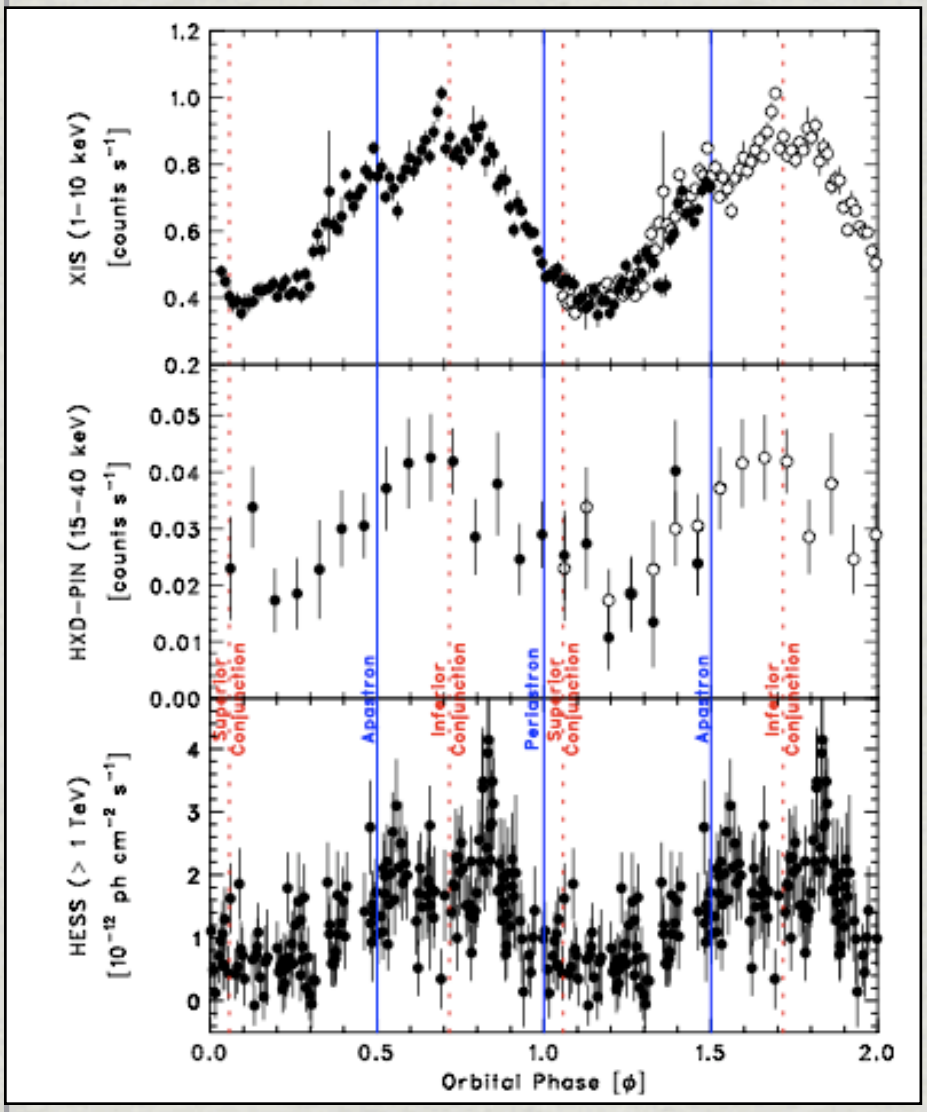
γγ absorption (with stellar photons)

GeV Gamma: IC Thomson regime

~~γγ absorption~~

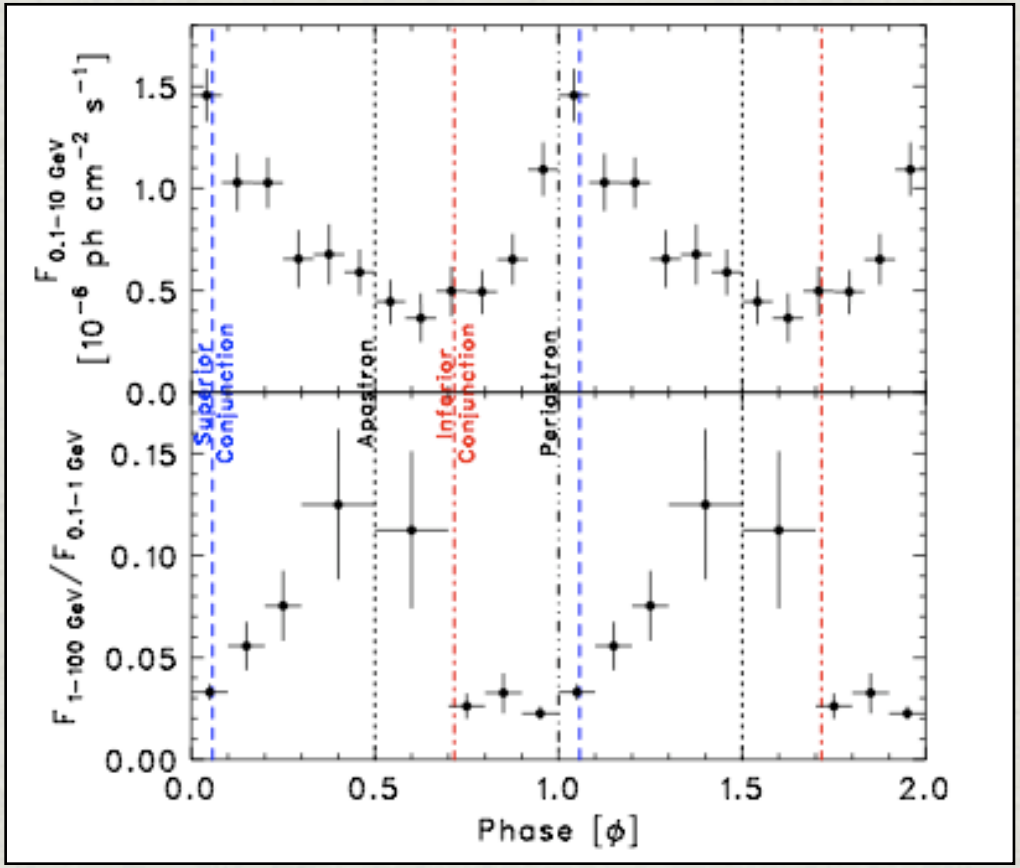
Gamma-ray Binary (1): LS 5039

Suzaku X-ray (synchrotron?)



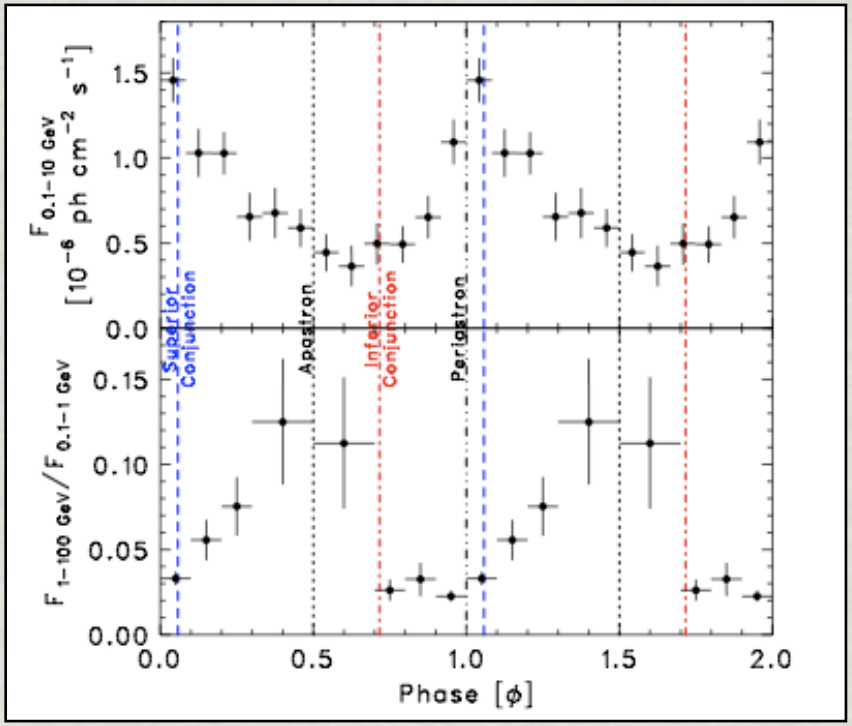
H.E.S.S. (IC in KN)

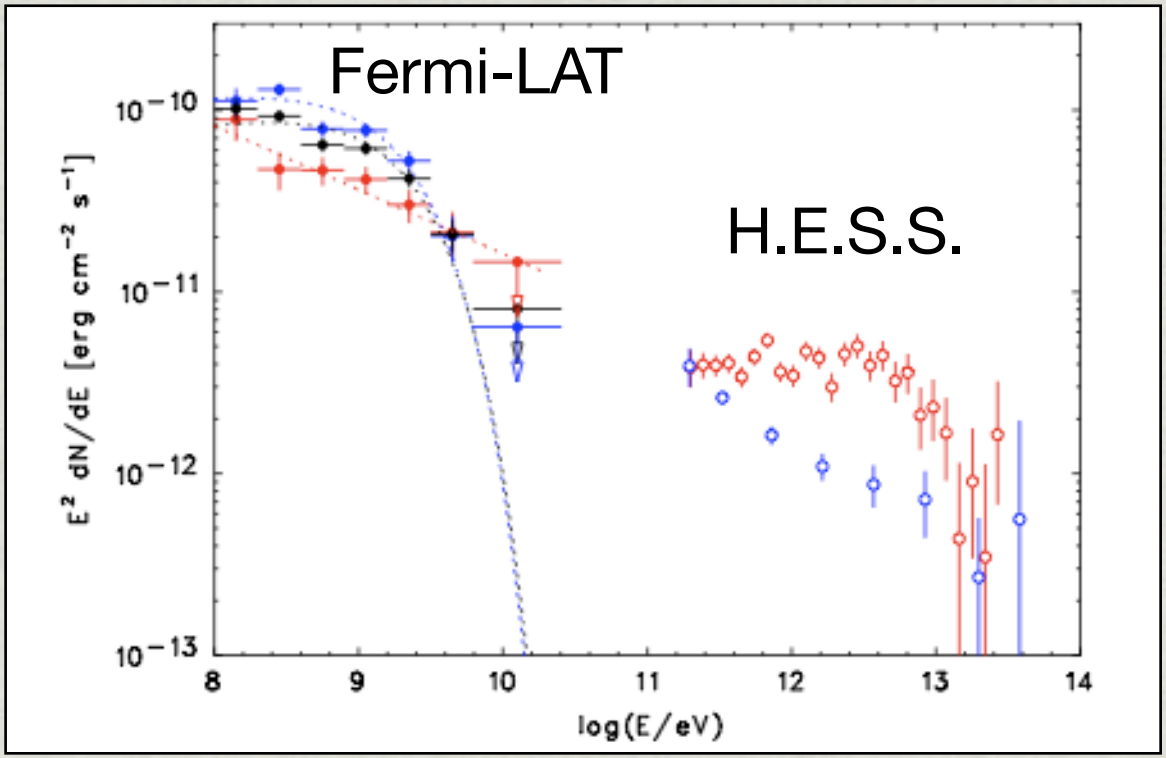
Fermi-LAT



Fermi-LAT modulation
is consistent with IC interpretation

Gamma-ray Binary (1): LS 5039



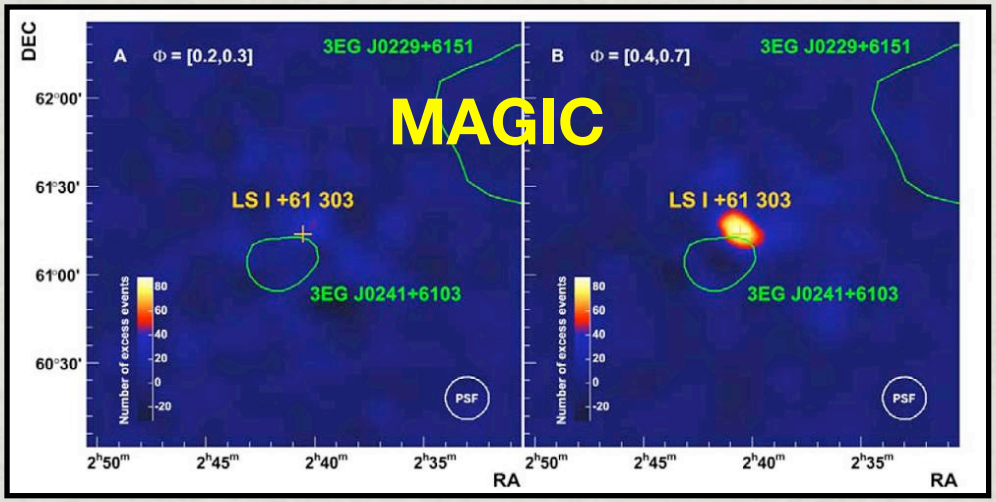


Fermi-LAT spectrum (early cutoff)
is **NOT** consistent with IC interpretation

↓

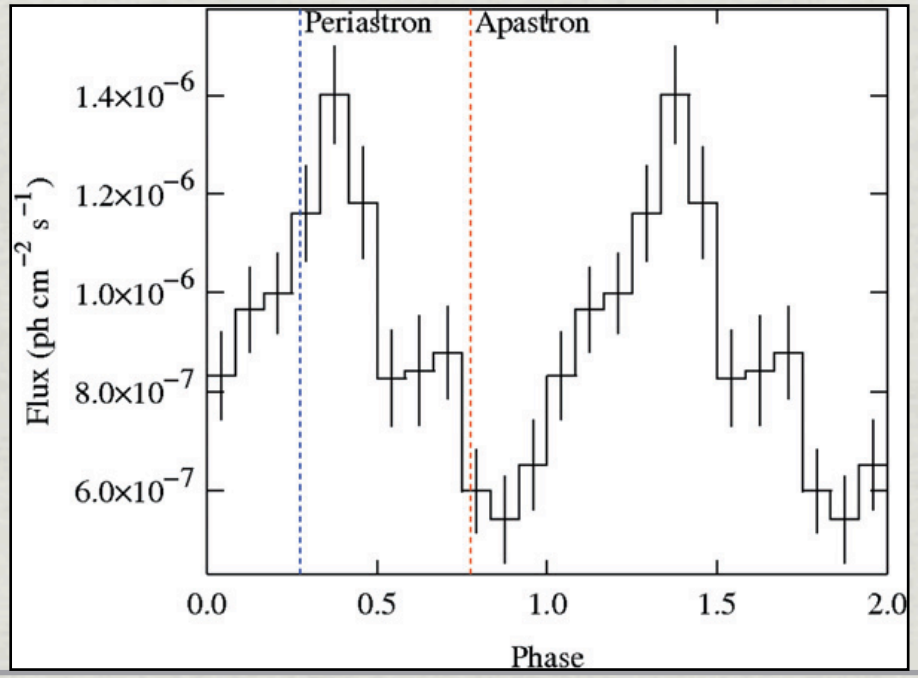
Magnetospheric radiation?
(modulation has to be explained)

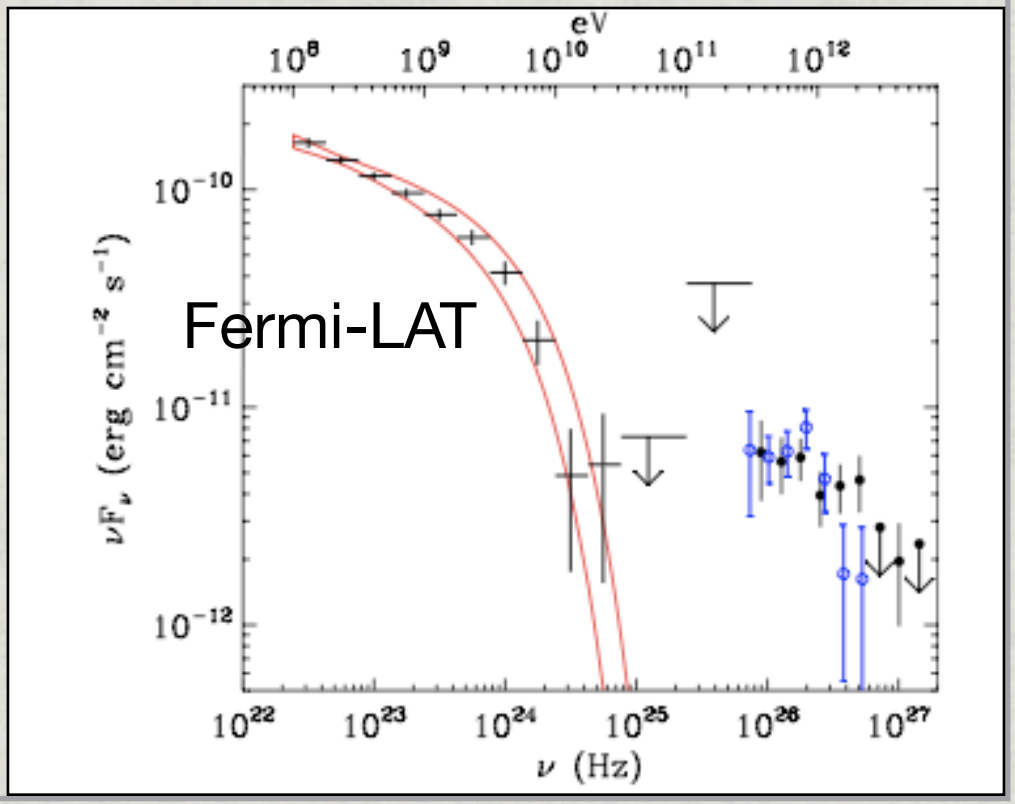
Gamma-ray Binary (2): LSI+61 303



- Orbital period 27 day (e~0.6)
- companion star: Be star (circumstellar disc)
- compact object: BH/NS
- Relativistic outflow
- No emission from accretion disc

Fermi-LAT orbital modulation





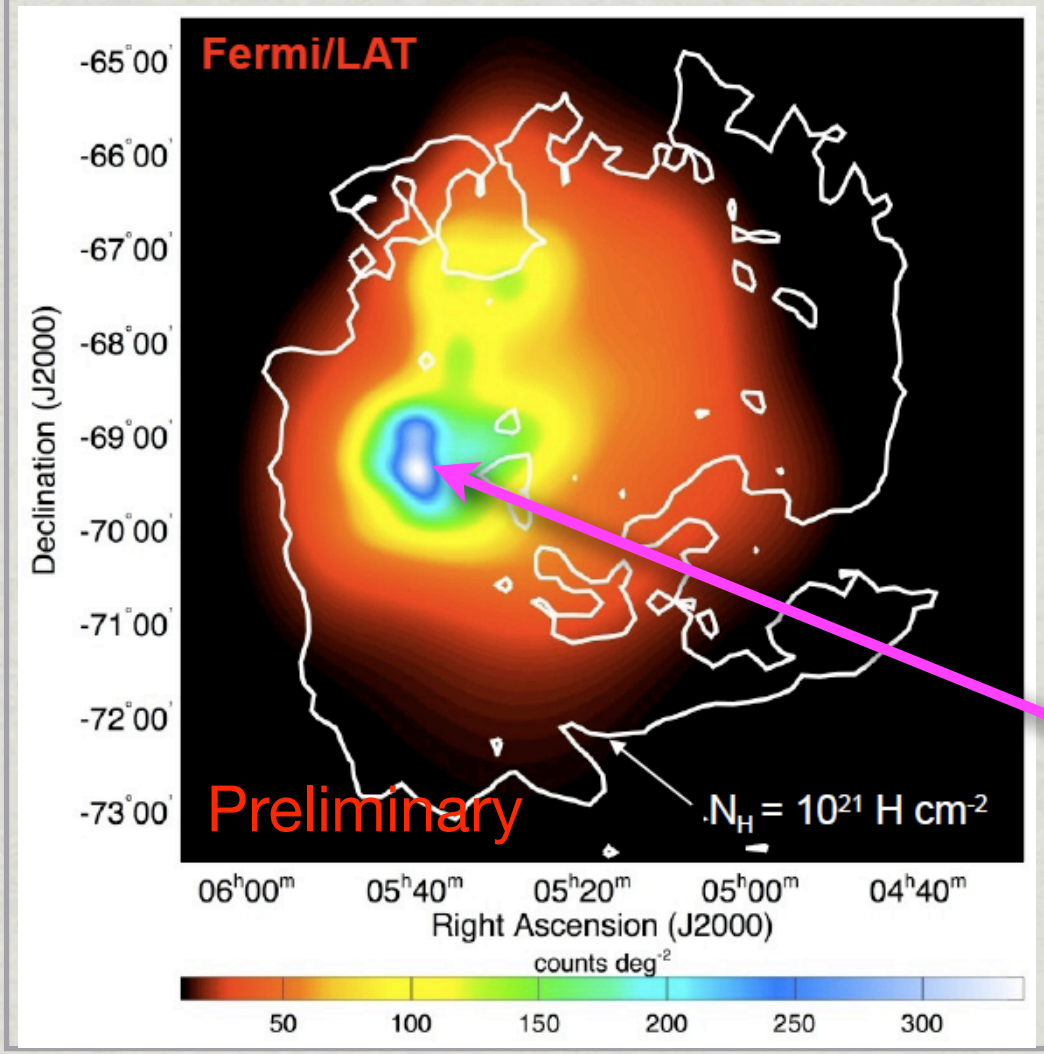
Part 2: Extragalactic Sources

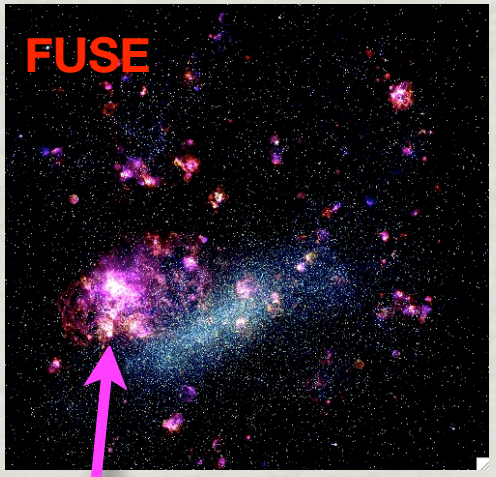
- ~~Blazars~~, Radio Galaxies
- Large Magellanic Cloud, Starburst Galaxies
- ~~Gamma-ray Bursts~~

Large Magellanic Cloud (LMC)

Probe Cosmic-Ray (CR) distribution in a galaxy
LMC: D~50 kpc, i~20-30 deg (~face-on), 8 deg diameter

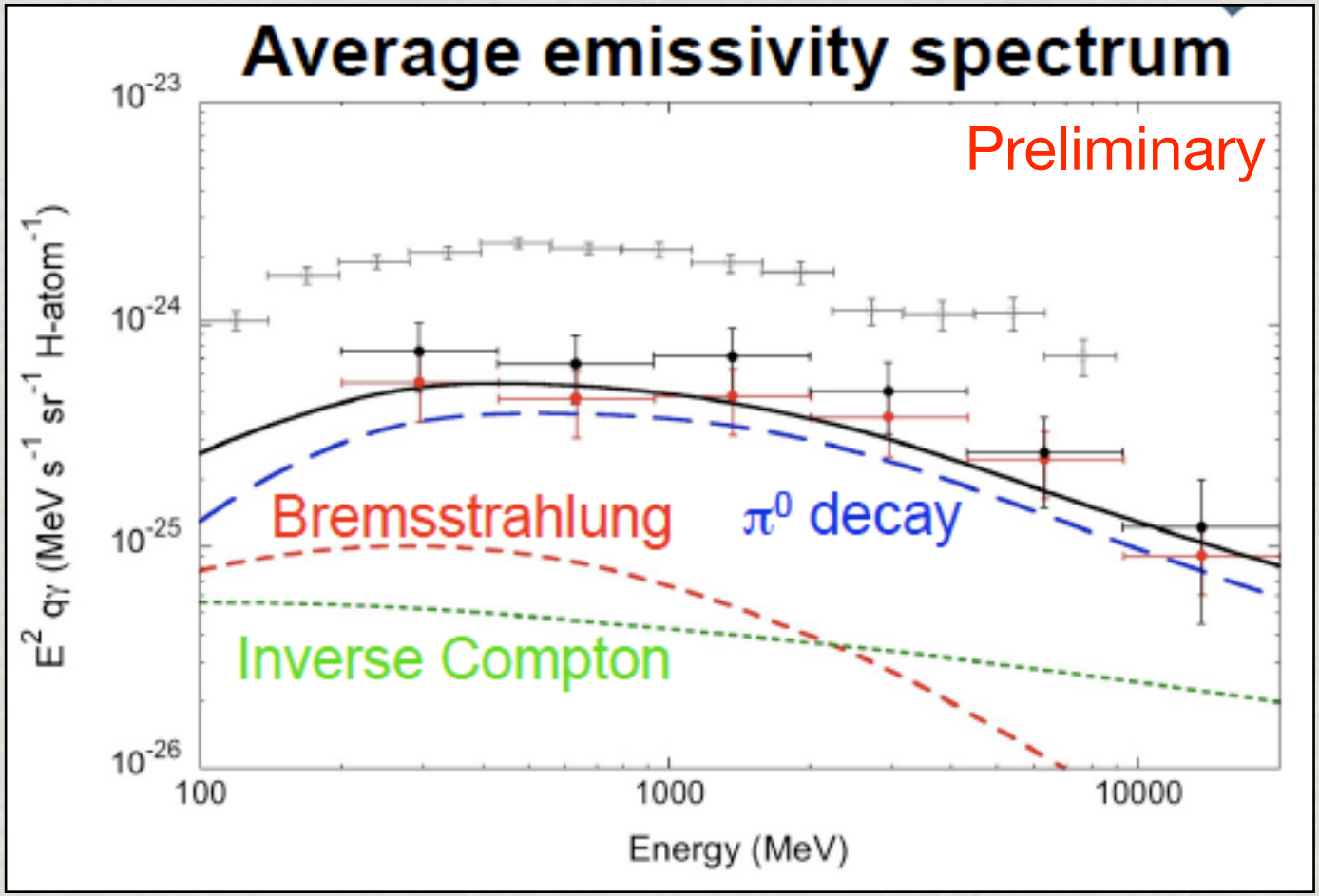
First resolved gamma-ray map of LMC





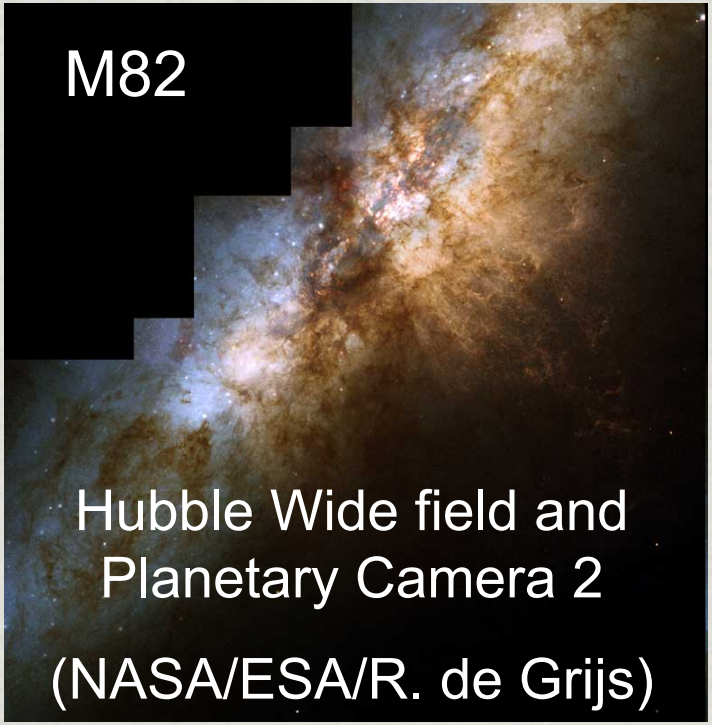
"30 Doradus" star-forming region

Large Magellanic Cloud (LMC)



CR density (LMC) ~ 0.2-0.3 x Galactic value
(consistent with relative SN rate)

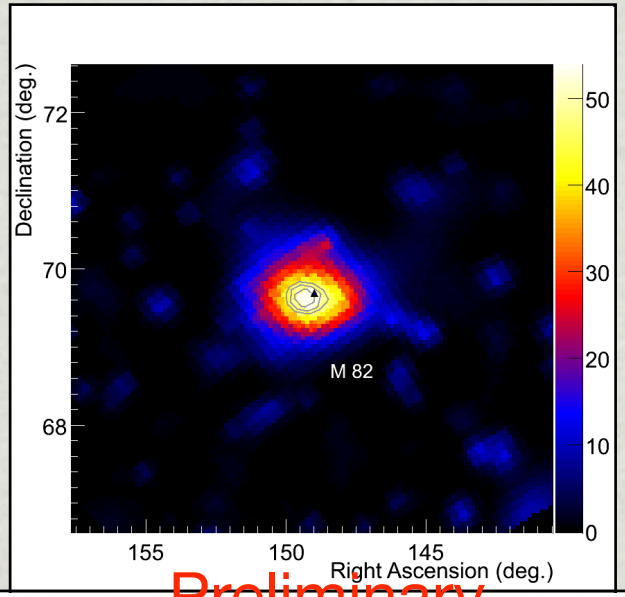
Starburst Galaxies



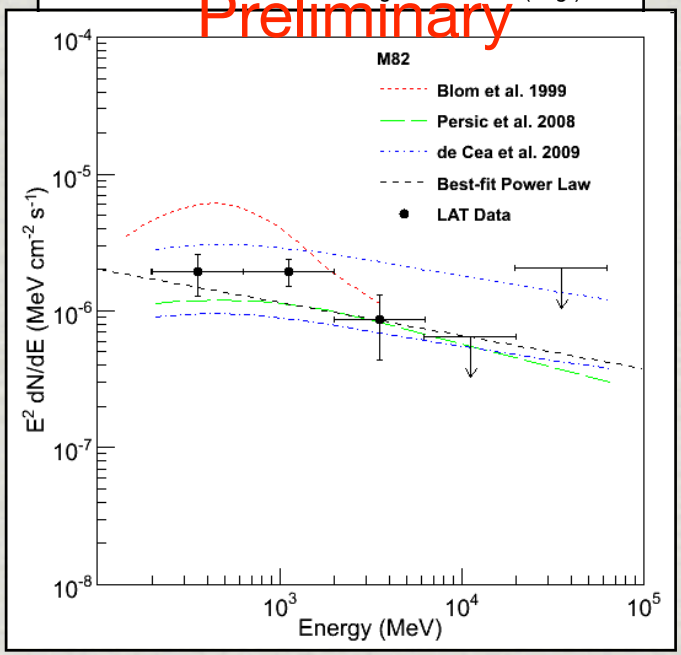
- **Two closest starburst galaxies (~3 Mpc)**
- **Edge-on viewing angles**
- **Small (~100 pc scale) starburst regions**
- **Star formation rate ~10 × Milky Way rate**
- **Lack active nuclei**

Detection of M82 and NGC253

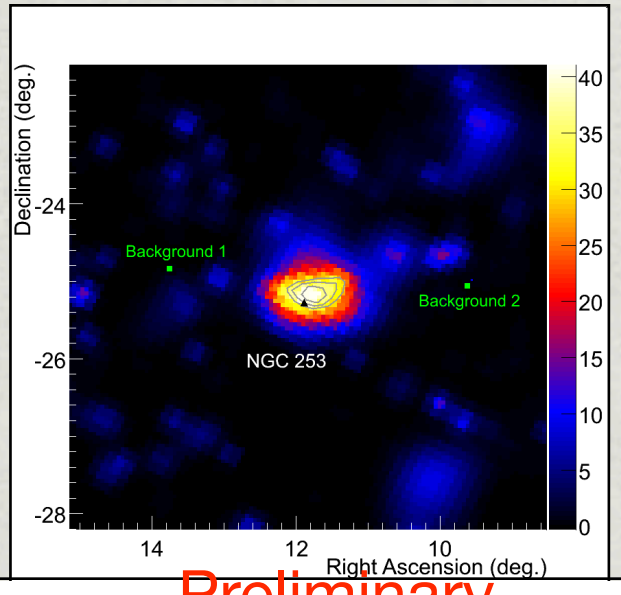
M82: 6.8σ



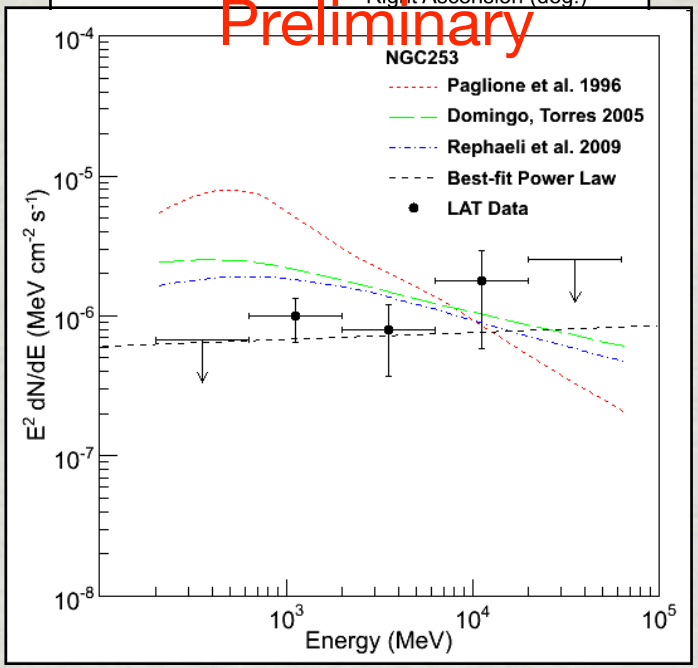
Preliminary



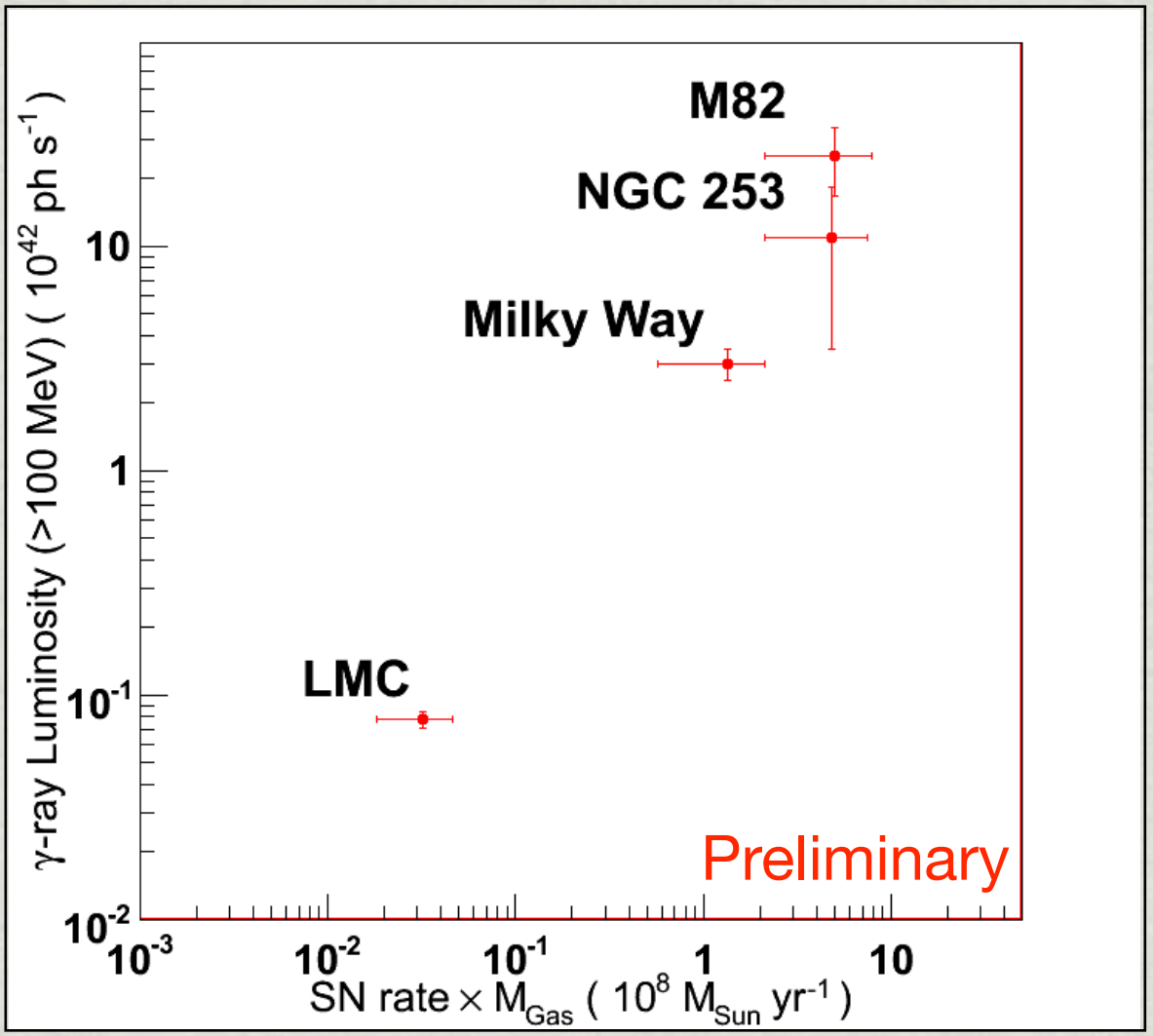
NGC253: 4.8σ



Preliminary



Gamma-ray Luminosity of Galaxies

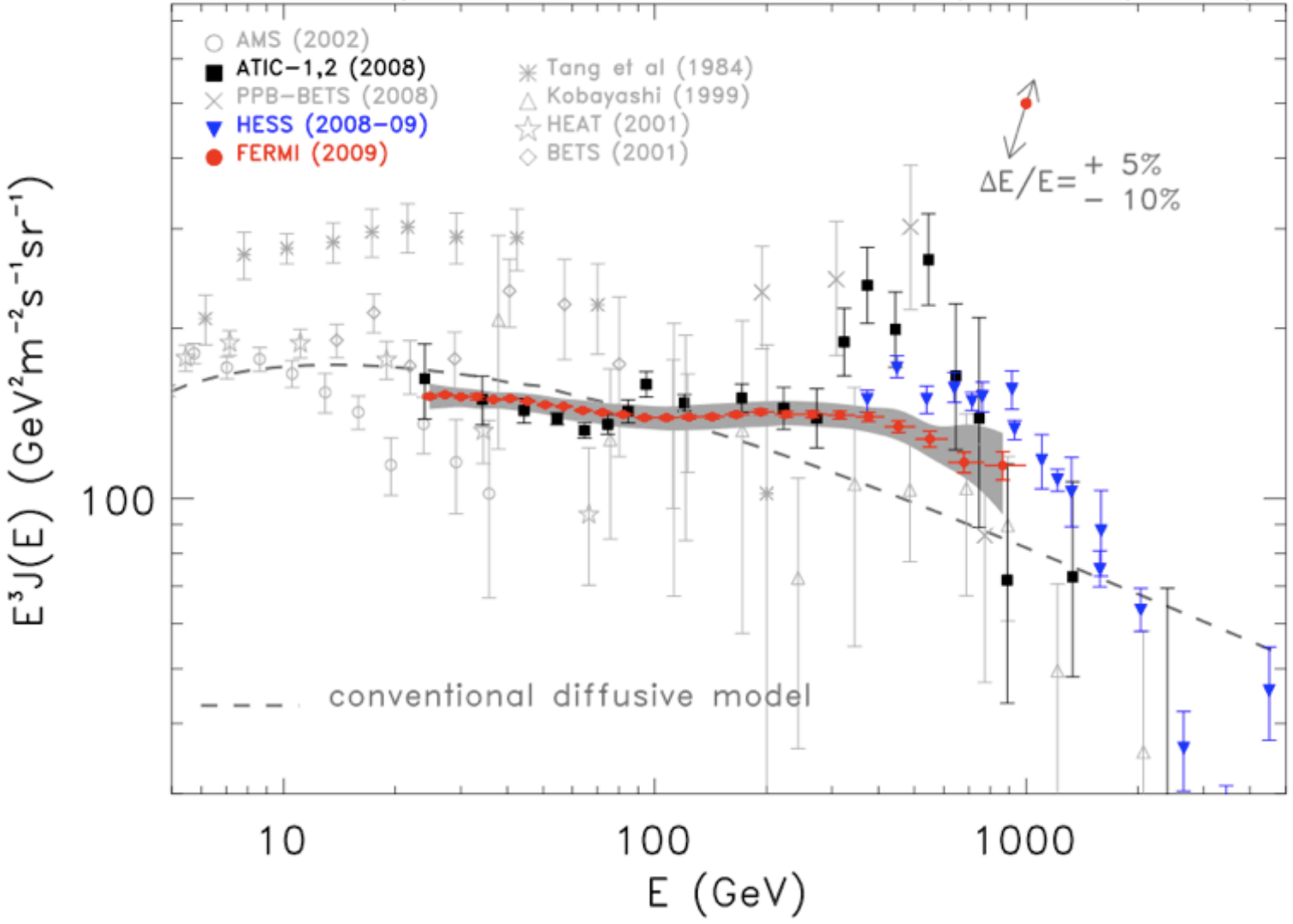


Part 3: Backgrounds

- Cosmic-ray Electrons/Positrons
- ~~Galactic Diffuse Emission~~
- Extragalactic Gamma-ray Background

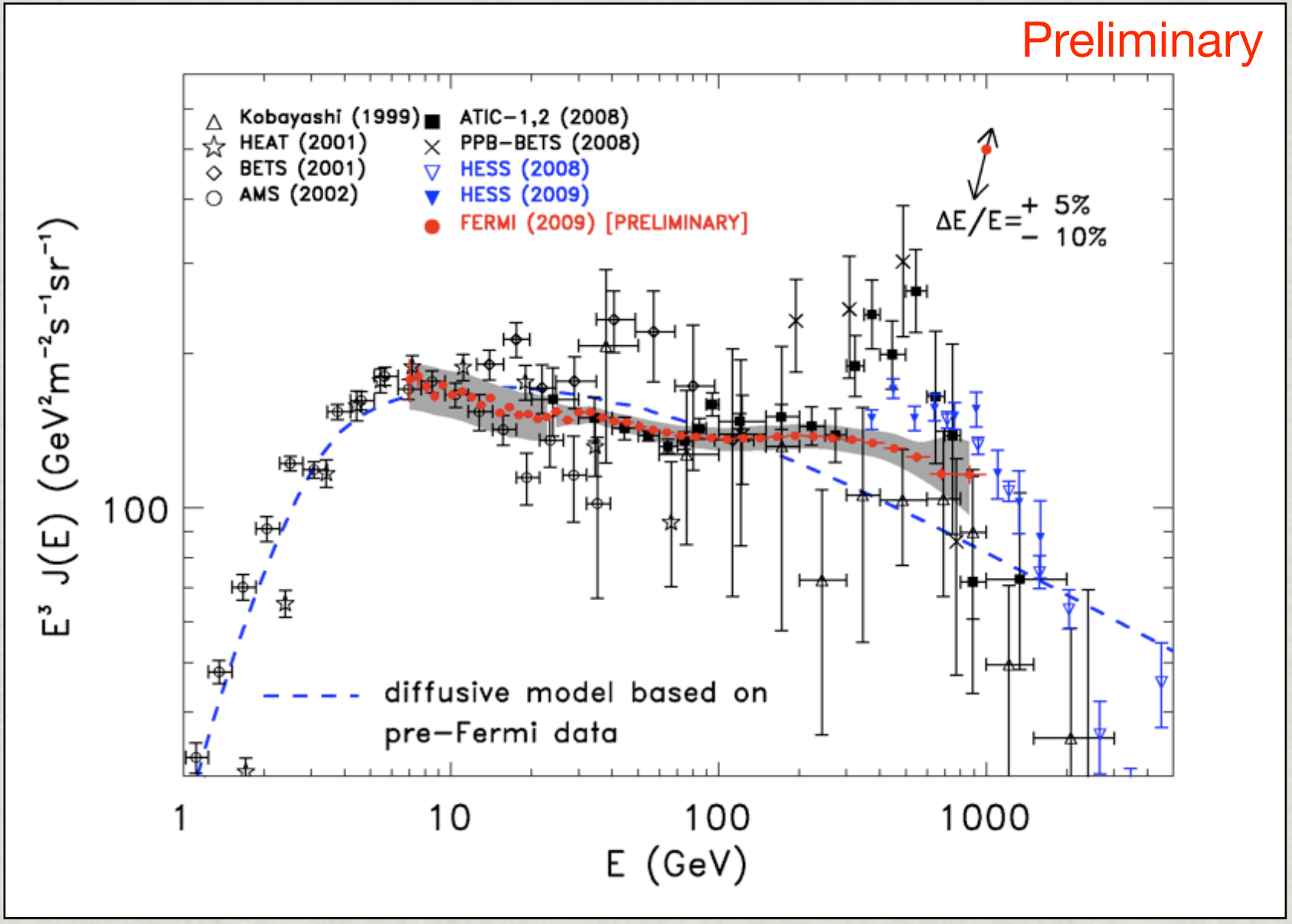
Cosmic-ray Electron/Positron

Abdo et al. (Fermi LAT collaboration) PRL (2009)

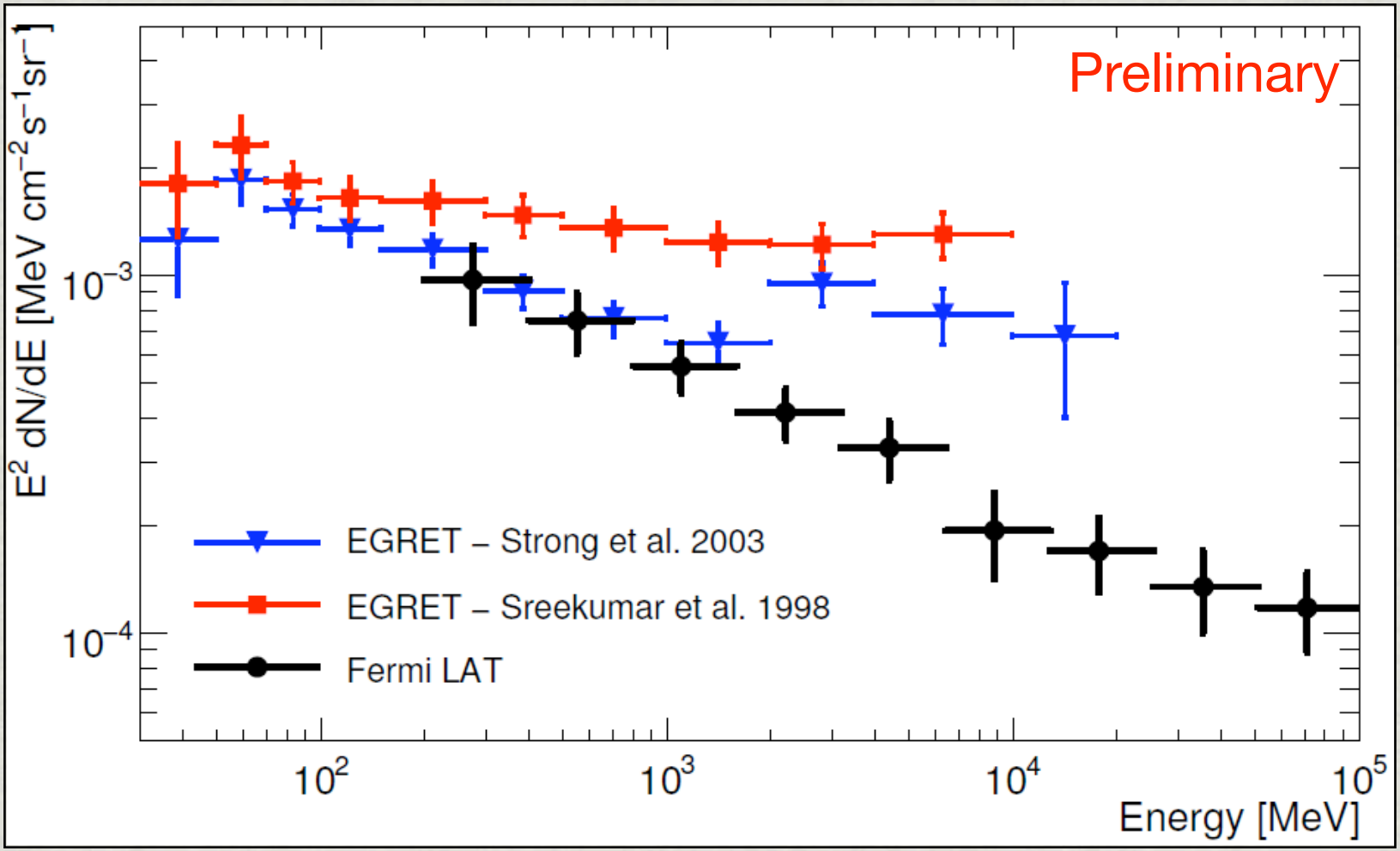


Many many **Dark Matter** papers....

Cosmic-ray Electron/Positron LE extension



Extragalactic Gamma-ray Background



Summary :

Fermi meets the high prelaunch expectation

Special Thanks to **KEK** (for financial support)