Fermi Large Area Telescope

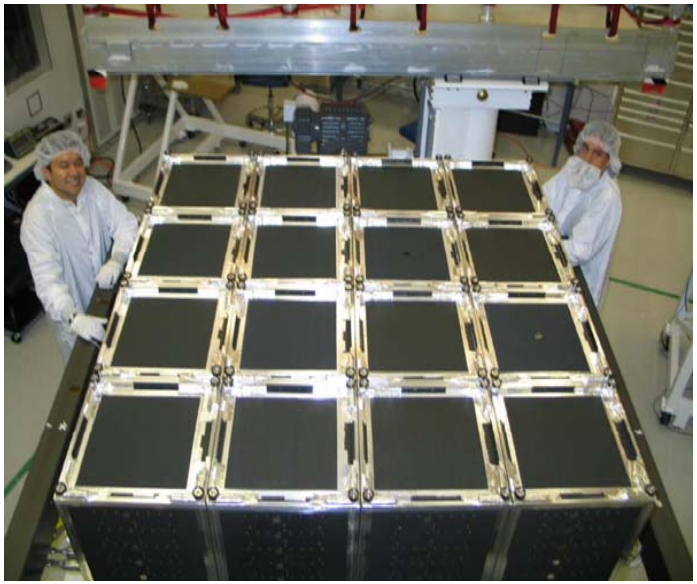
US-Japan 30 Year Anniversary
October 20, 2010

Tuneyoshi Kamae
SLAC/KIPAC, Stanford University
(University of Tokyo)

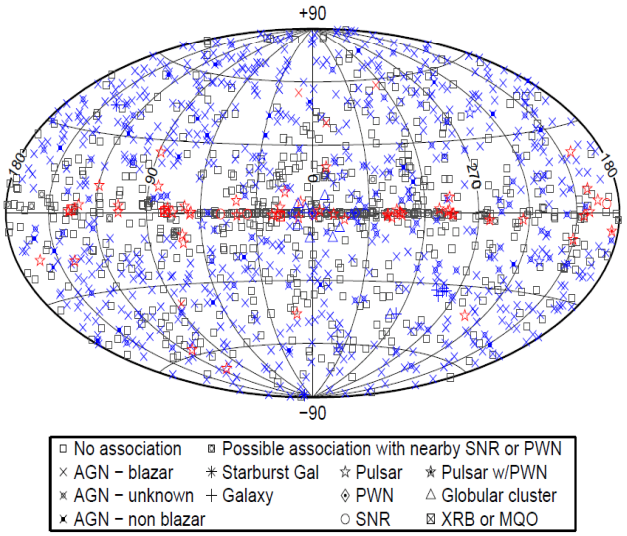
US-Japan: GLAST / Fermi Large Area Telescope

- Large Area Telescope coll. formed in 1995 and Japan joined in 1997
- LAT coll. won the NASA Announcement of Opportunity in 2001
- LAT assembled and tested in 2006 and integrated with the satellite in 2007
- Lauched on June 11, 2008
- Science operation started on August 4, 2008
- Surveyed the entire sky over 120k orbits and recorded 3.5×10^8 γ-rays by Oct 2010.
- Found 1400 point (or point-like) sources detected with >4σ significance March 2010

Oct 2005:Si Tracker completed
US-Japan + INFN + DOE



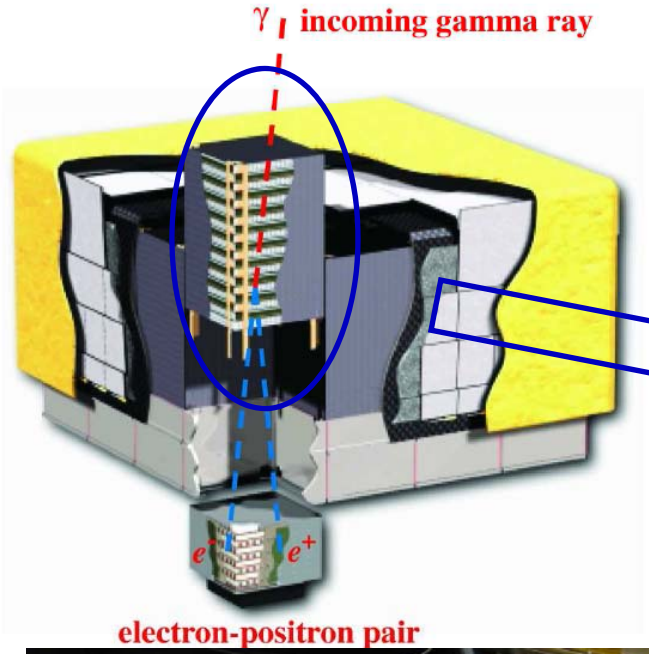
Mar 2010:1400+ sources

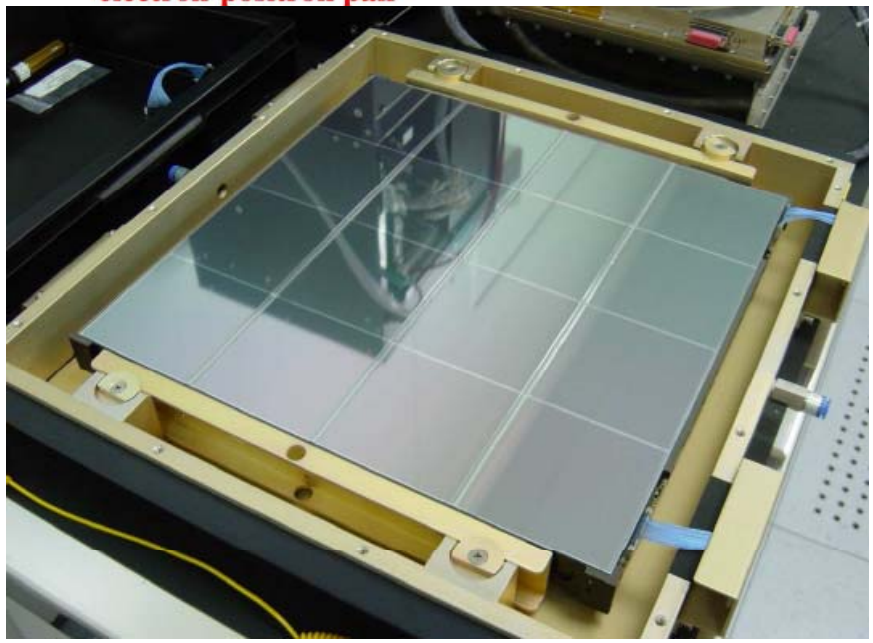


Contributions to Particle Astrophysics

- Successful coll. between HEP and astro community
  - Hybrid culture nurtured: Hiroshima U. and Japanese at SLAC
  - Inter-disciplinary activities: HEP, CR, X, radio, IR and optical
- Exploration vast unexplored territories in particle astrophysics
  - Gamma-ray signals from Dark Matter annihilation / decay
  - Cosmic-ray spectra and Dark Matter annihilation / decay
  - Tests on Lorentz invariance using Gamma-Ray Bursts
  - Particle accelerators in the Universe
  - Long-term variability in the Universe
- US-Japan funding has been used most effectively in GLAST/Fermi
  - R/D fund: In early days when space agencies were not onboard.
  - Travel fund: Frequent (and long term) visits to SLAC.

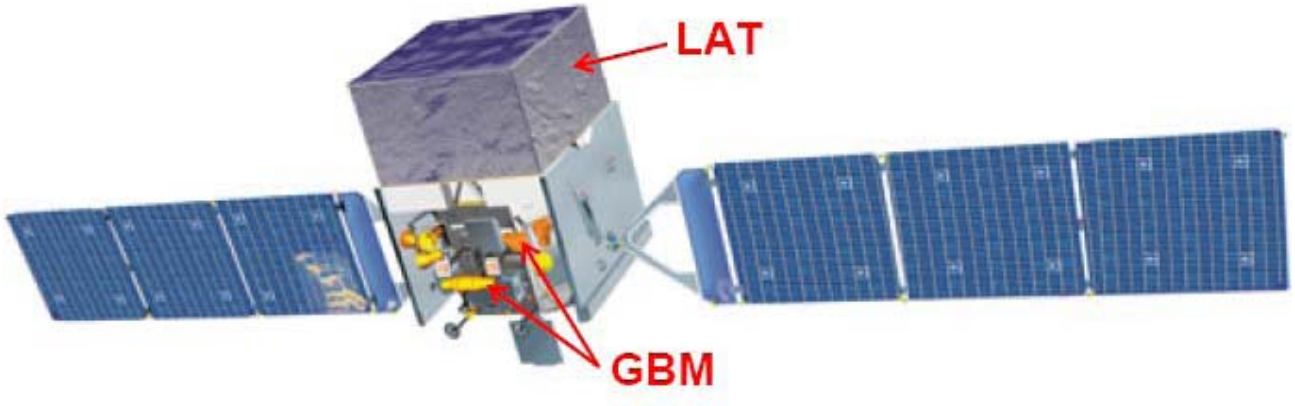
Silicon Tracker





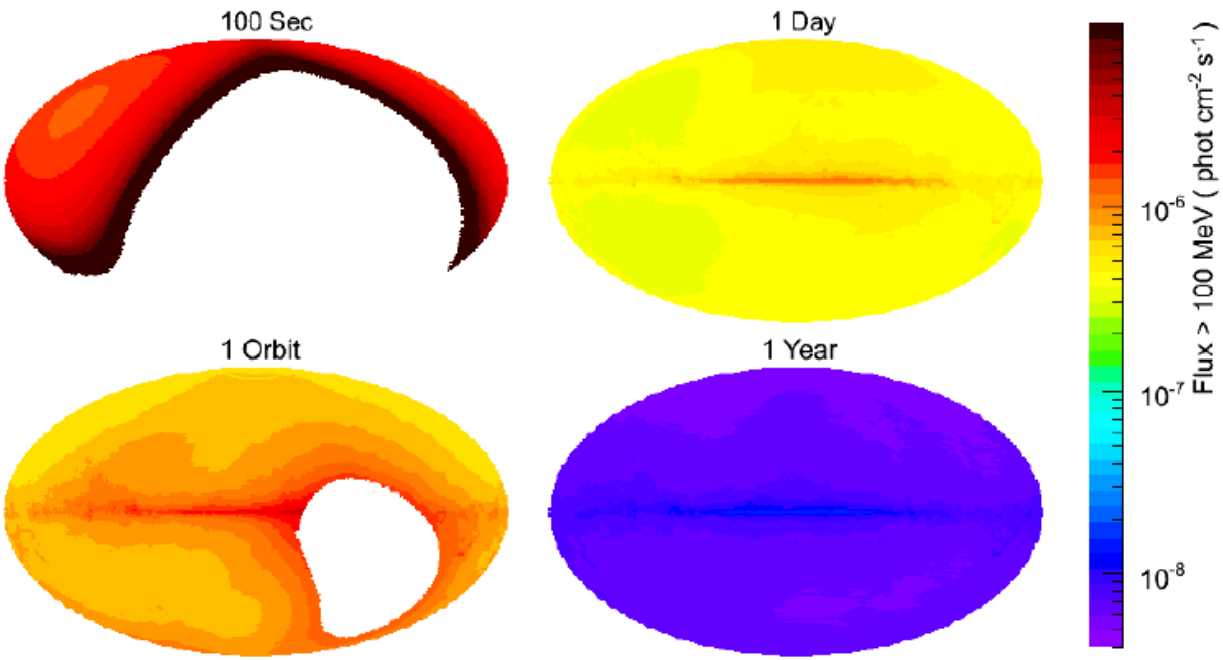
US-Japan + INFN + DOE

Fermi Observatory



Spectral coverage

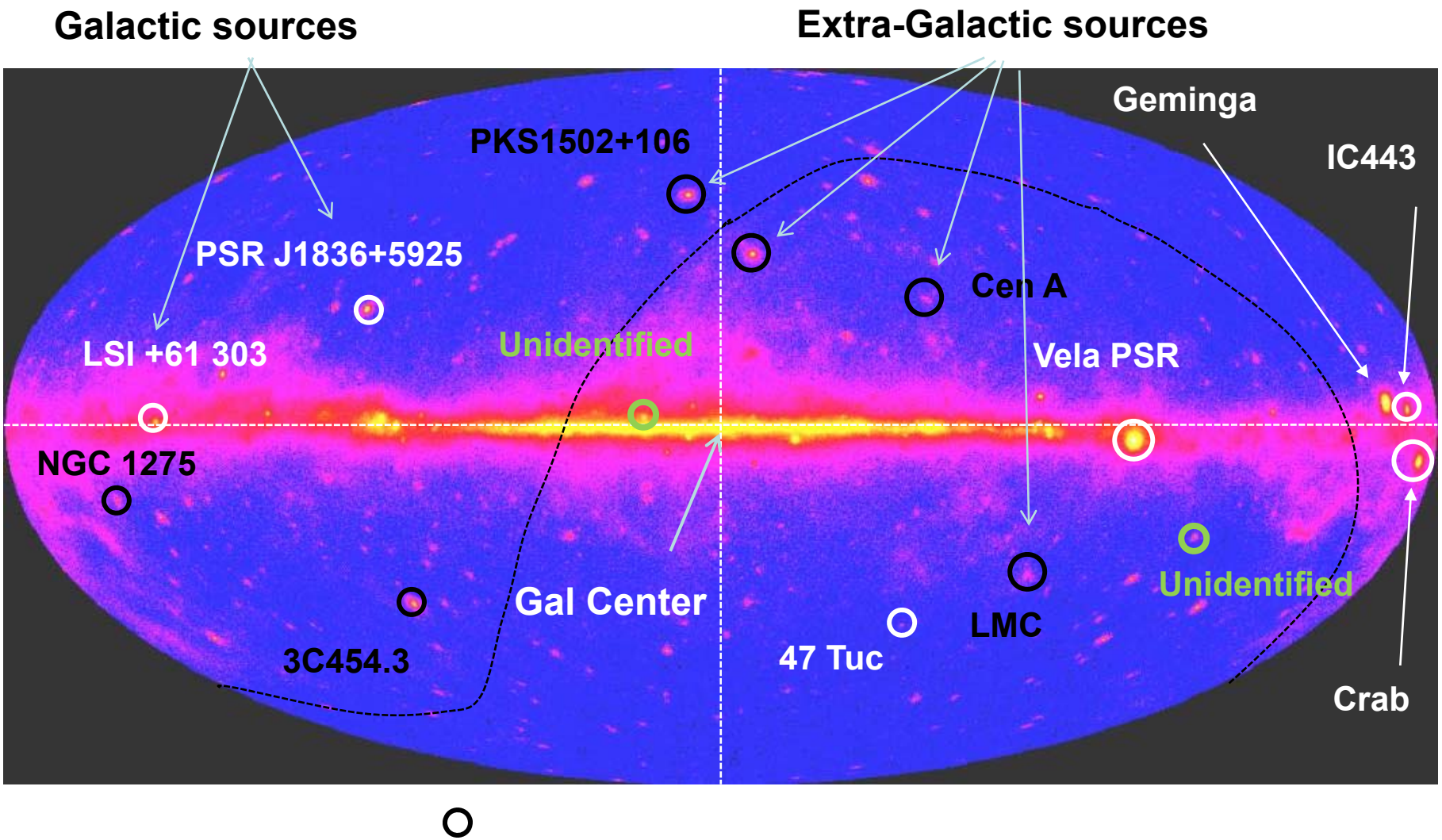
- LAT:~20MeV-300GeV
- GBM: 8keV-40MeV



LAT survey capability

- Orbit height~560km
- Orbit time:~90 min
- FOV: ~ 2.4sr
- Pointing rocked to make exposure uniform over all sky.

Gamma-ray Sky: What do we see?
- Point Sources -

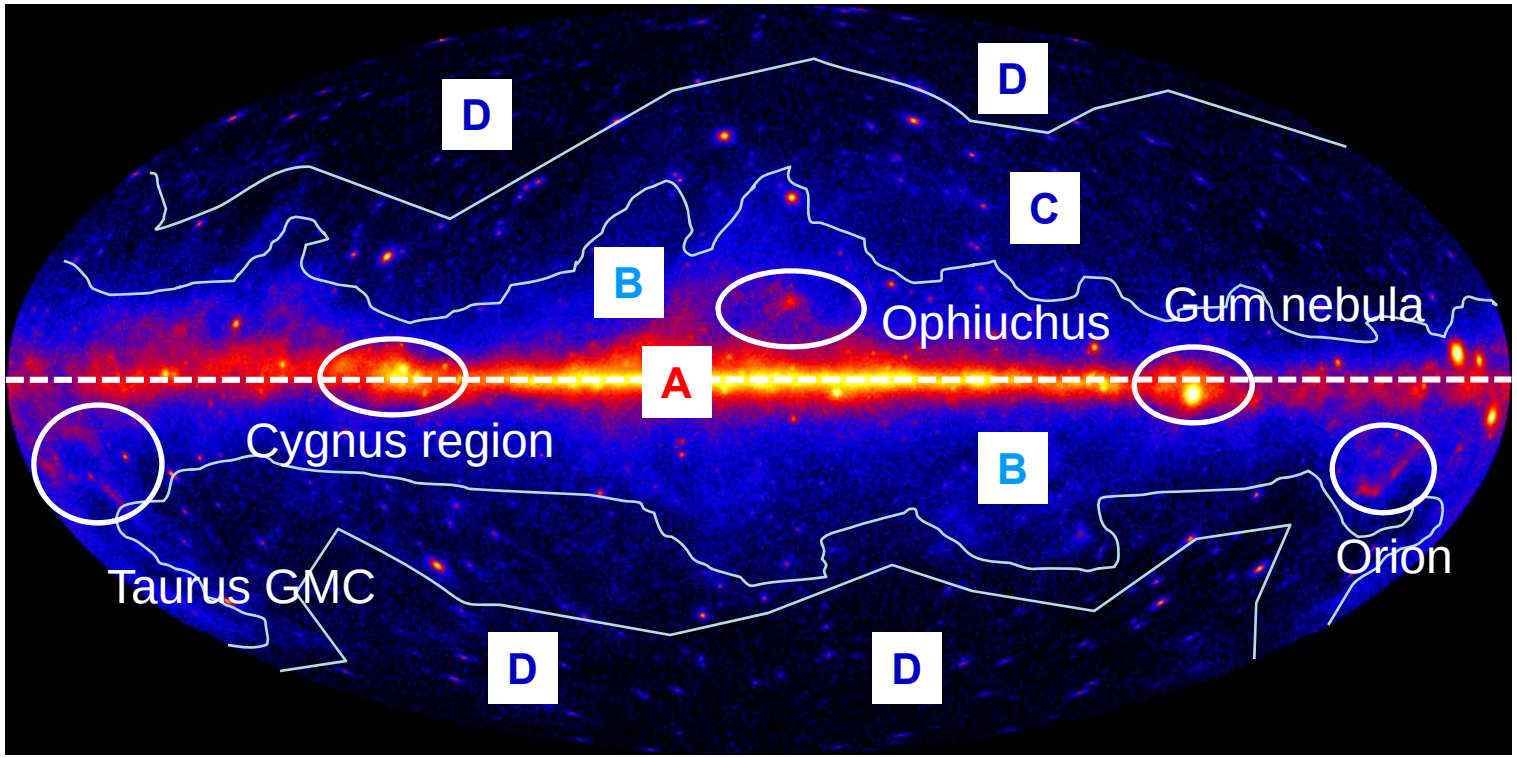


Gamma-ray Sky: What do we see?
- Extended Sources -

A) H2 gas in the inner Galaxy
B) Gas structure near the solar system
C)Atomic H gas in Galactic halo & outer Galaxy
D)Extra-Galactic "diffuse" emission

Mizuno, Kamae

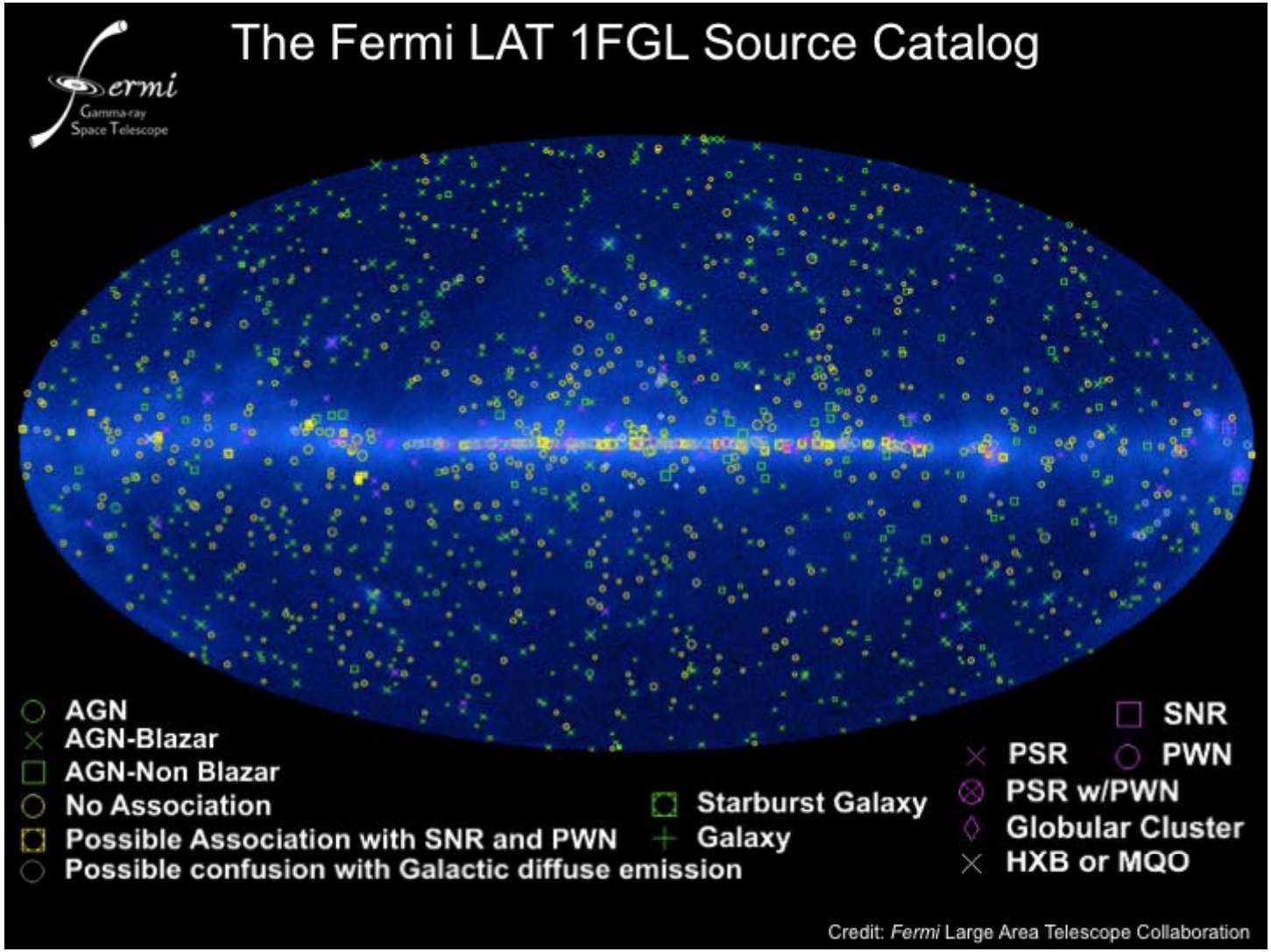
Gal Plane



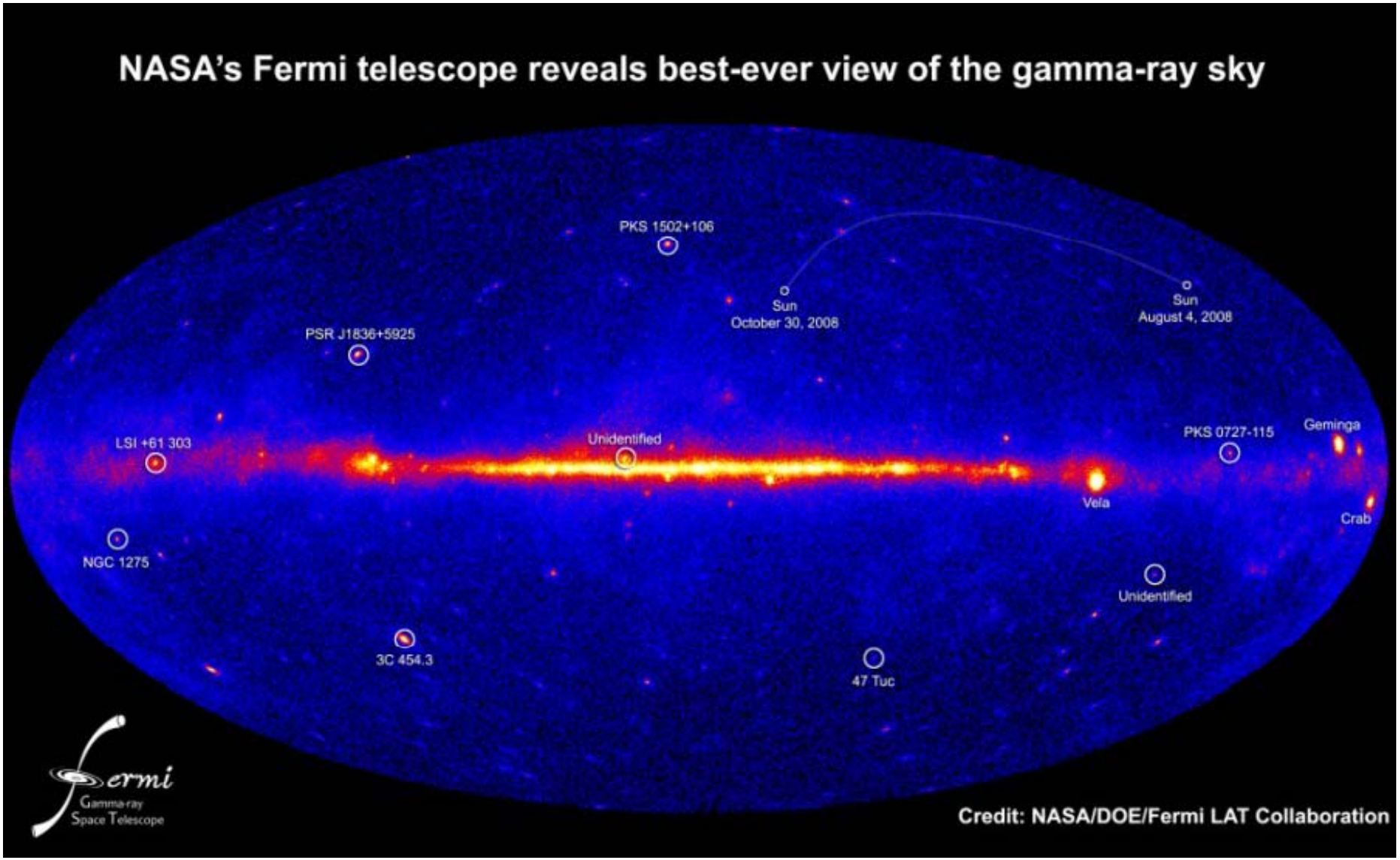
First Fermi Source Catalog

- ~1400 Point Sources -

Still 40% is un-id



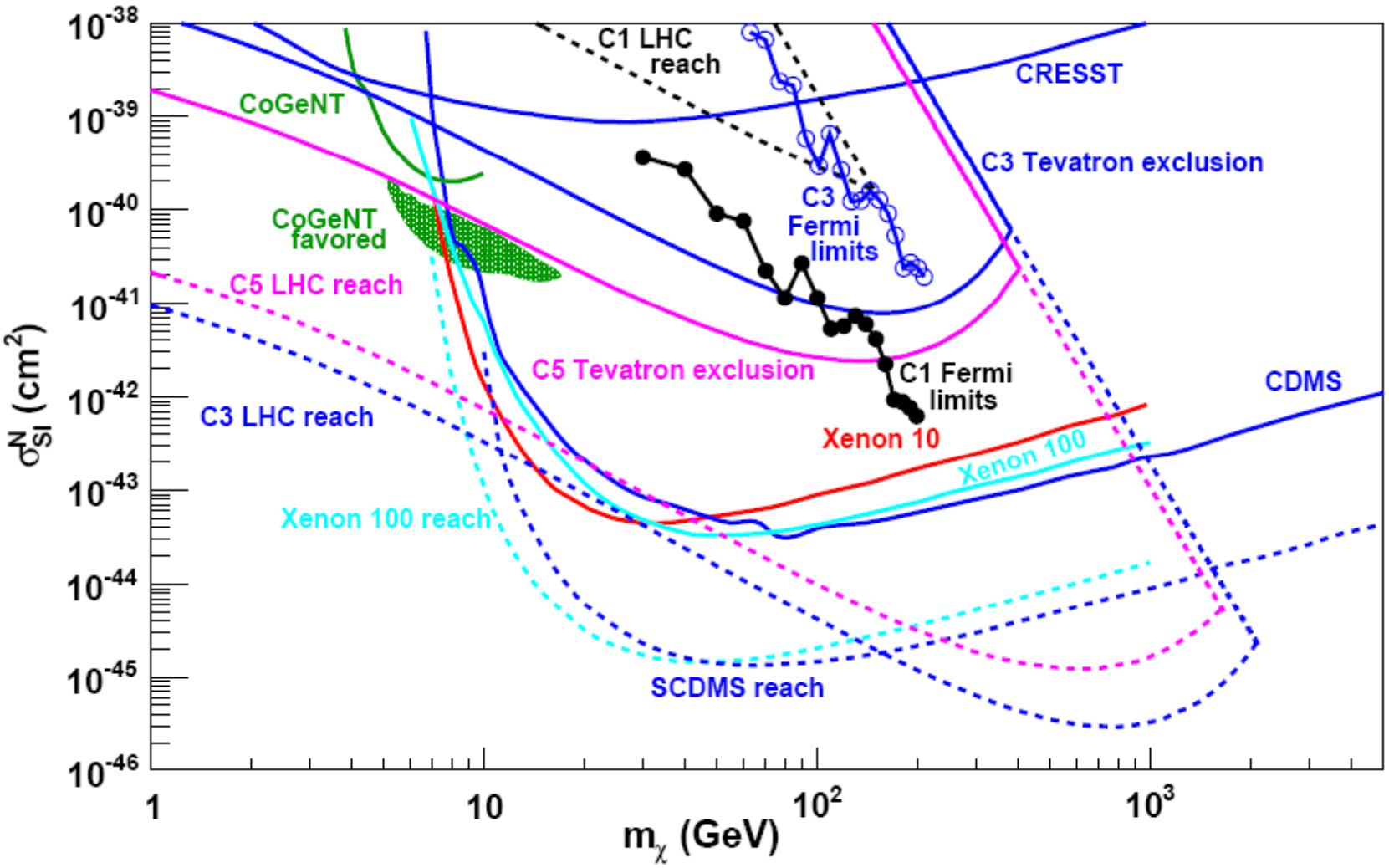
We see Sun and Moon in γ-rays



Gamma-Ray Signals from Dark Matter Annihilation/Decay

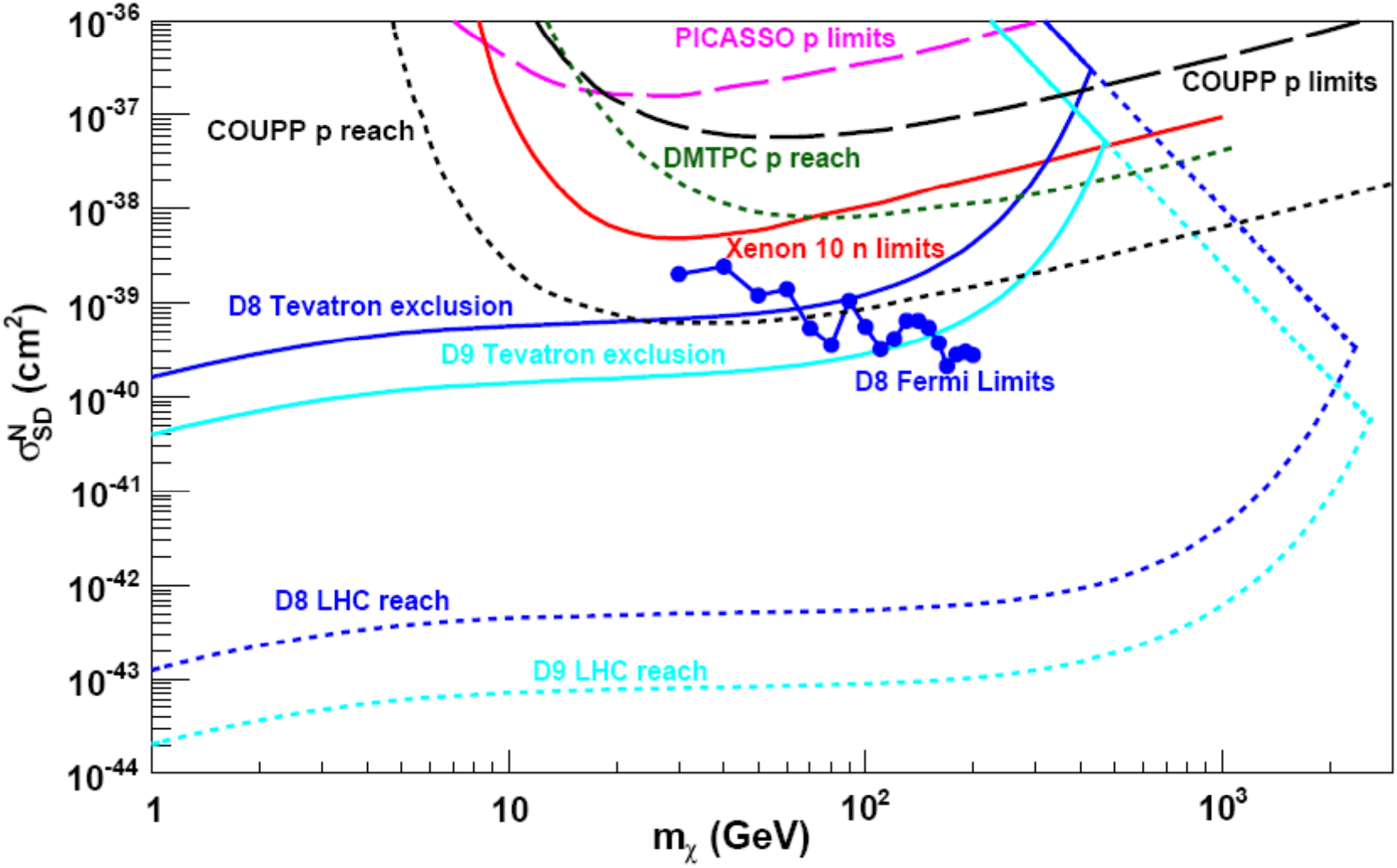
Constraint on WIMP: Spin Independent

Goodman et al., arXiv:1009.0008v1 Aug 31,2010



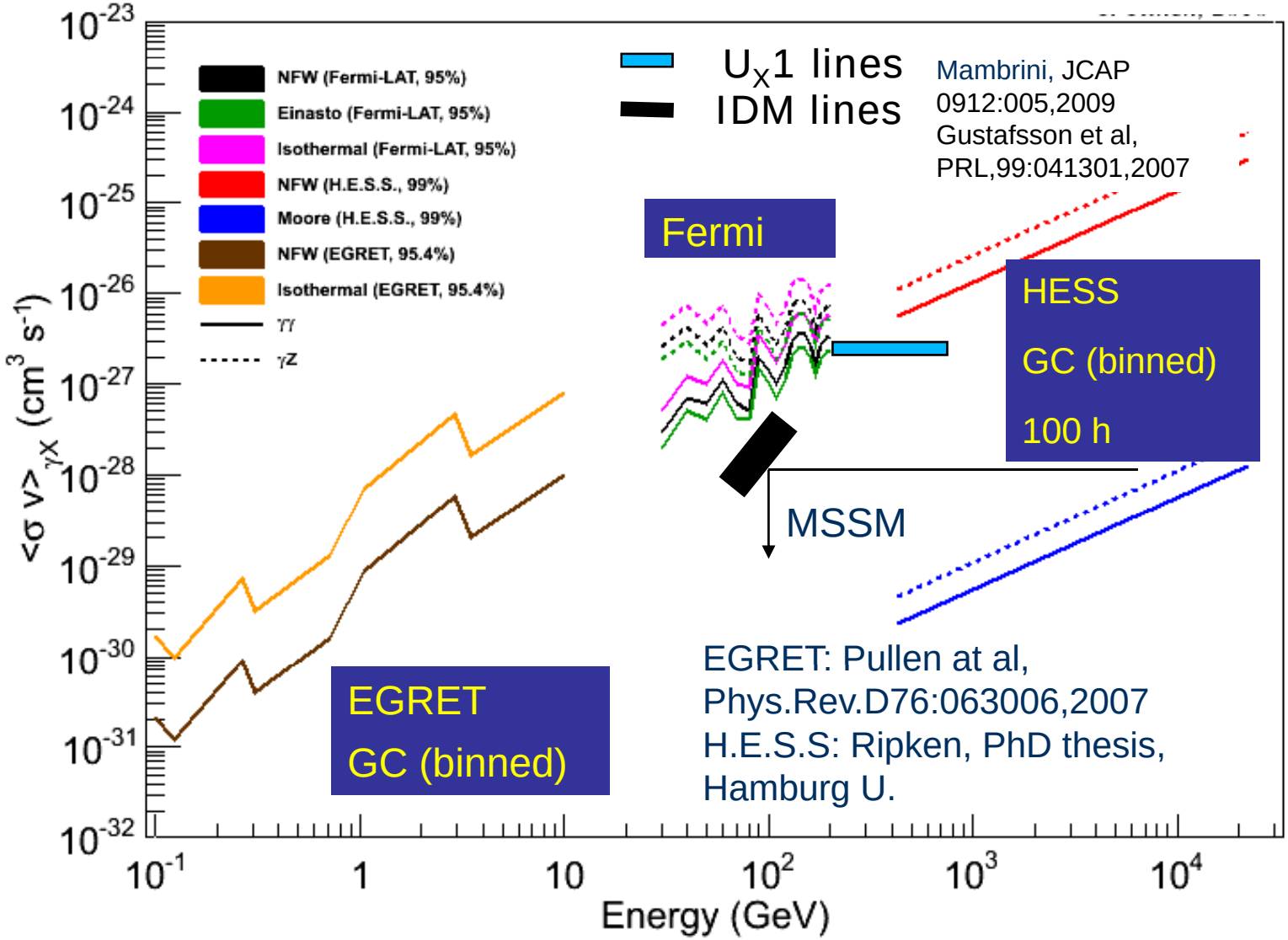
Constraint on WIMP: Spin Dependent

Goodman et al., arXiv:1009.0008v1 Aug 31,2010



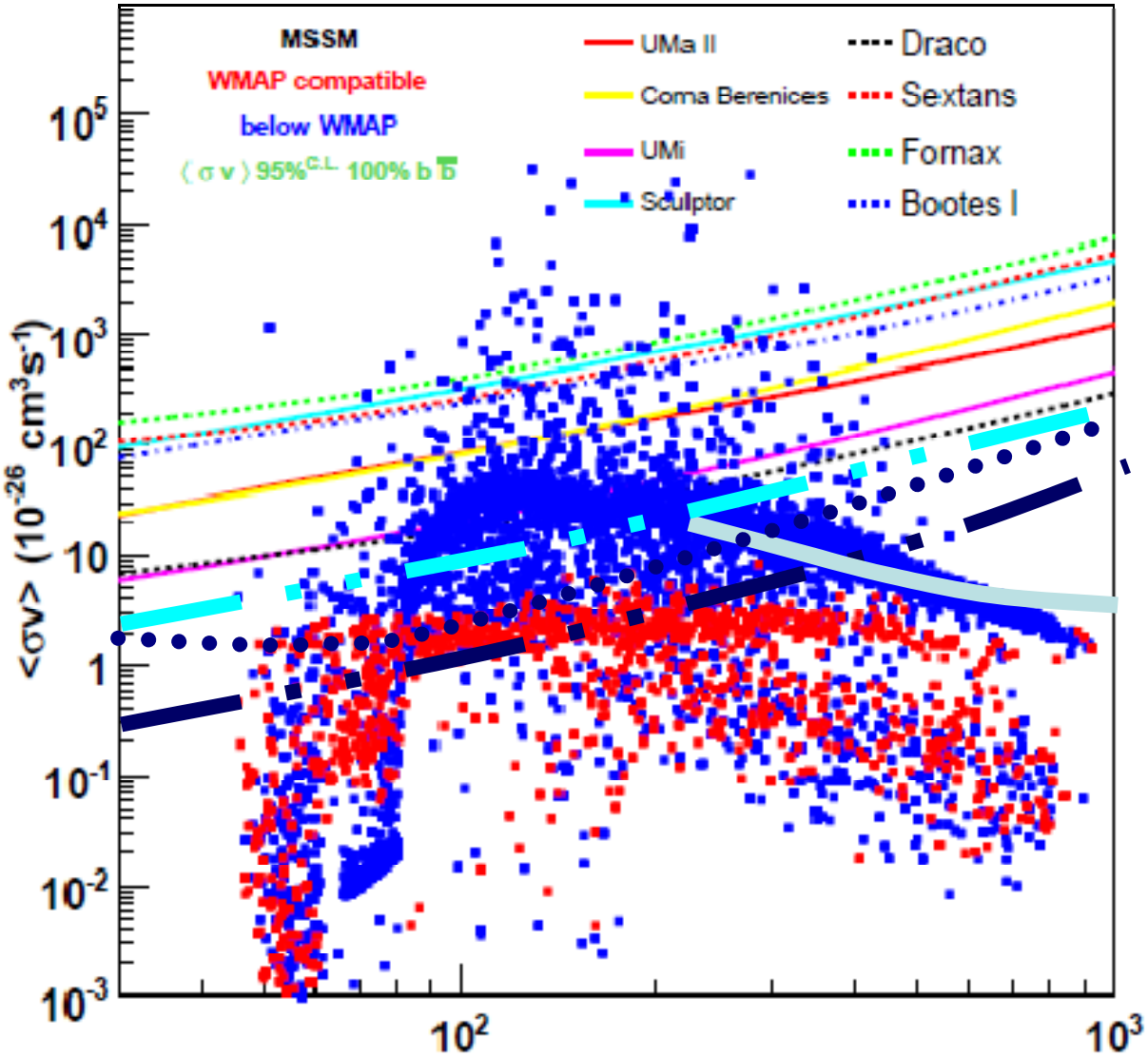
Constraint on Line Emission

T. Ylinen PhD 2010



Summary: γ-ray Signals from DM Annihilation

From Jan Conrad



Fermi 1 yr dwarfs

Fermi 5 yr combined dwarfs

Fermi 5 yr halo, no substructure

Cyan: indicating diffuse bg range.

H.E.S.S.

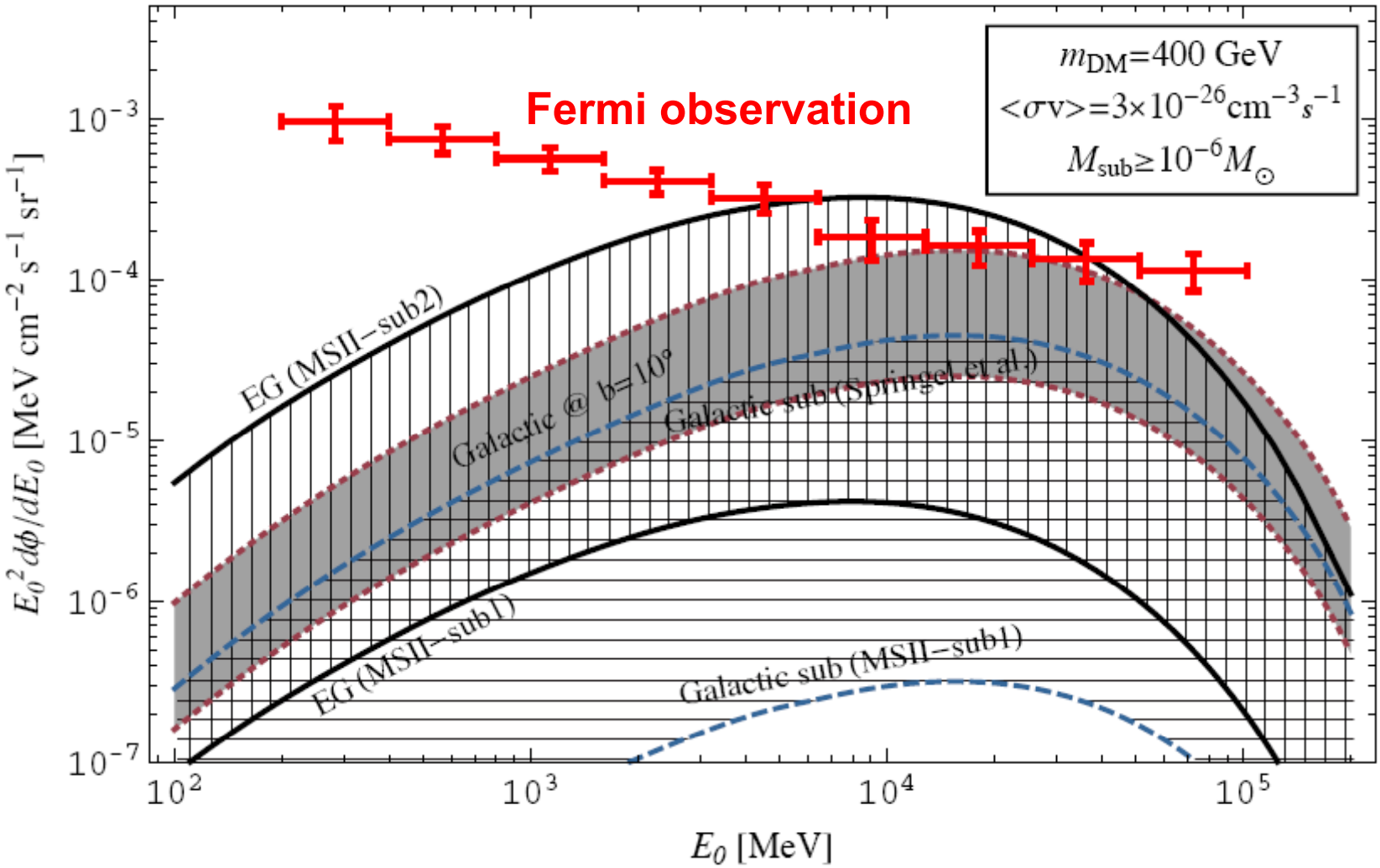
+ energy range, event selection (Fermi)
+ news from othe exps. AMS,LHC(?)

10^{-27} .... with some work and ideas ....

Summary: γ-ray Signals from DM

Fermi Coll, arXiv:1002.4415v1

Gamma-ray flux from outside of our Galaxy

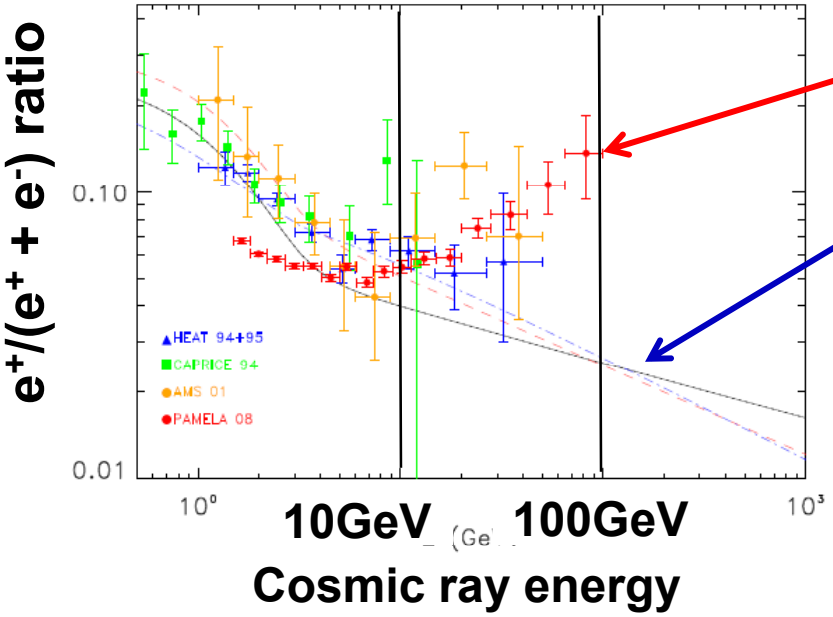


Cosmic-Ray Spectra and Dark Matter Annihilation/Decay

PAMELA Measurement on comic ray

- Positron Excess? -

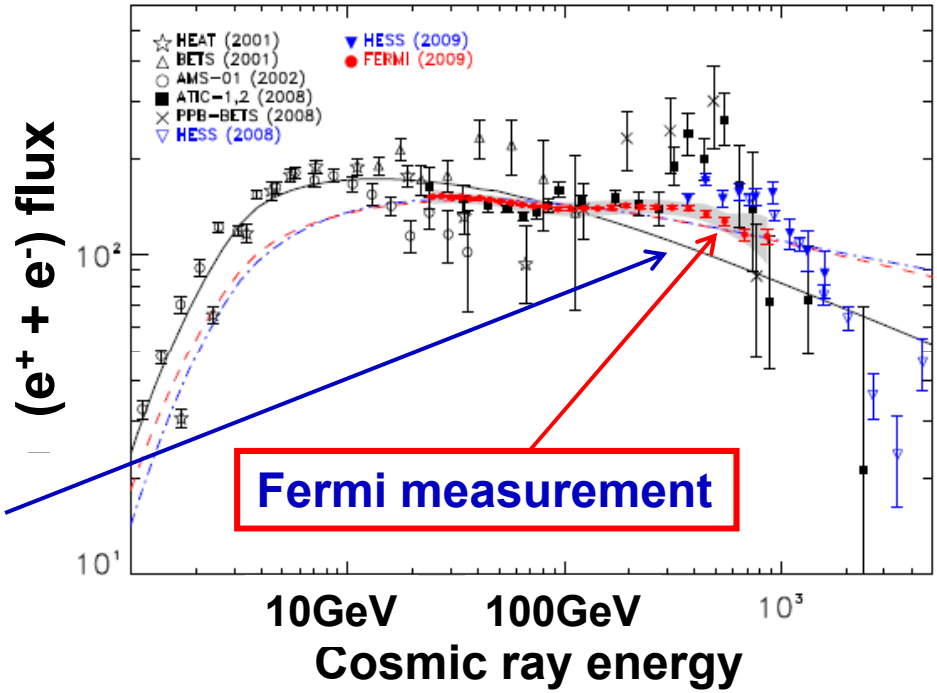
Positron/(electron+positron)



PAMELA measurement

Predictions based on naive models

Flux of (electron + positron)

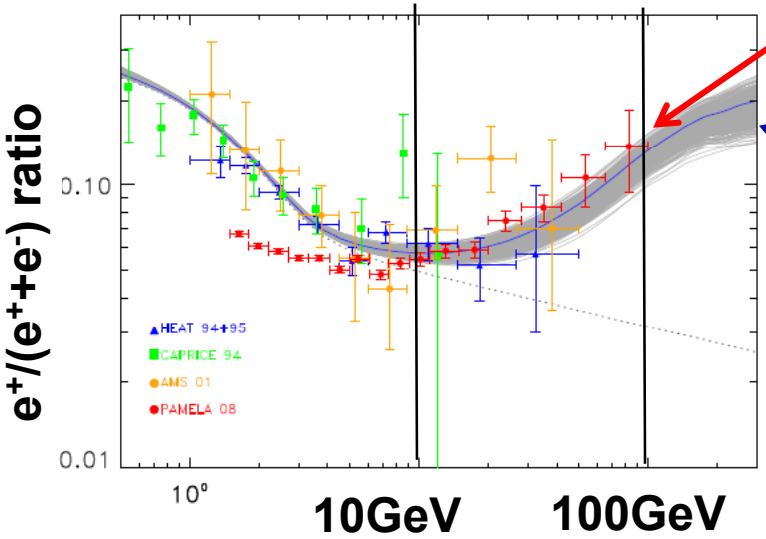


Fermi measurement

Predictions based on naive models

PAMELA Results: Nearby e^+ Source(s)?

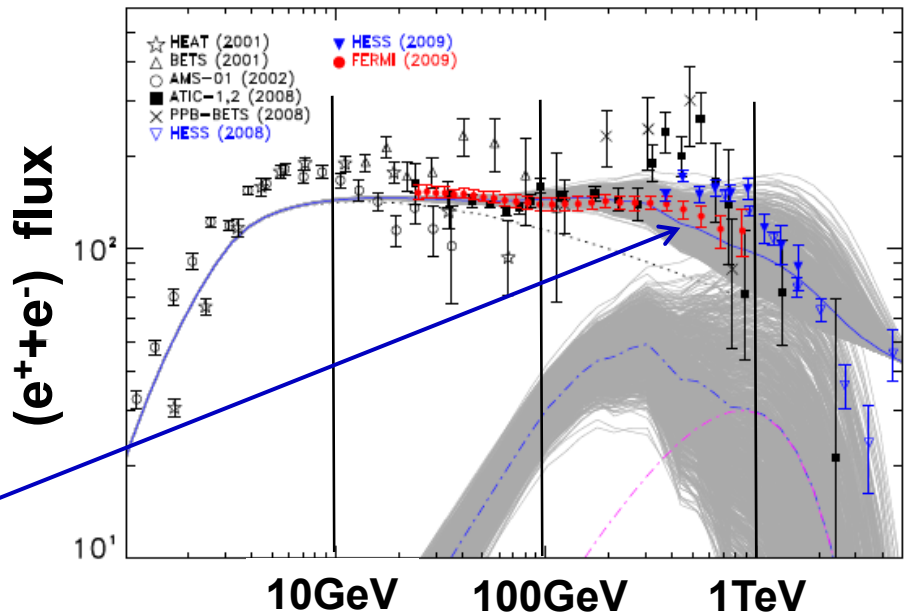
Positron/(electron+positron)



PAMELA result

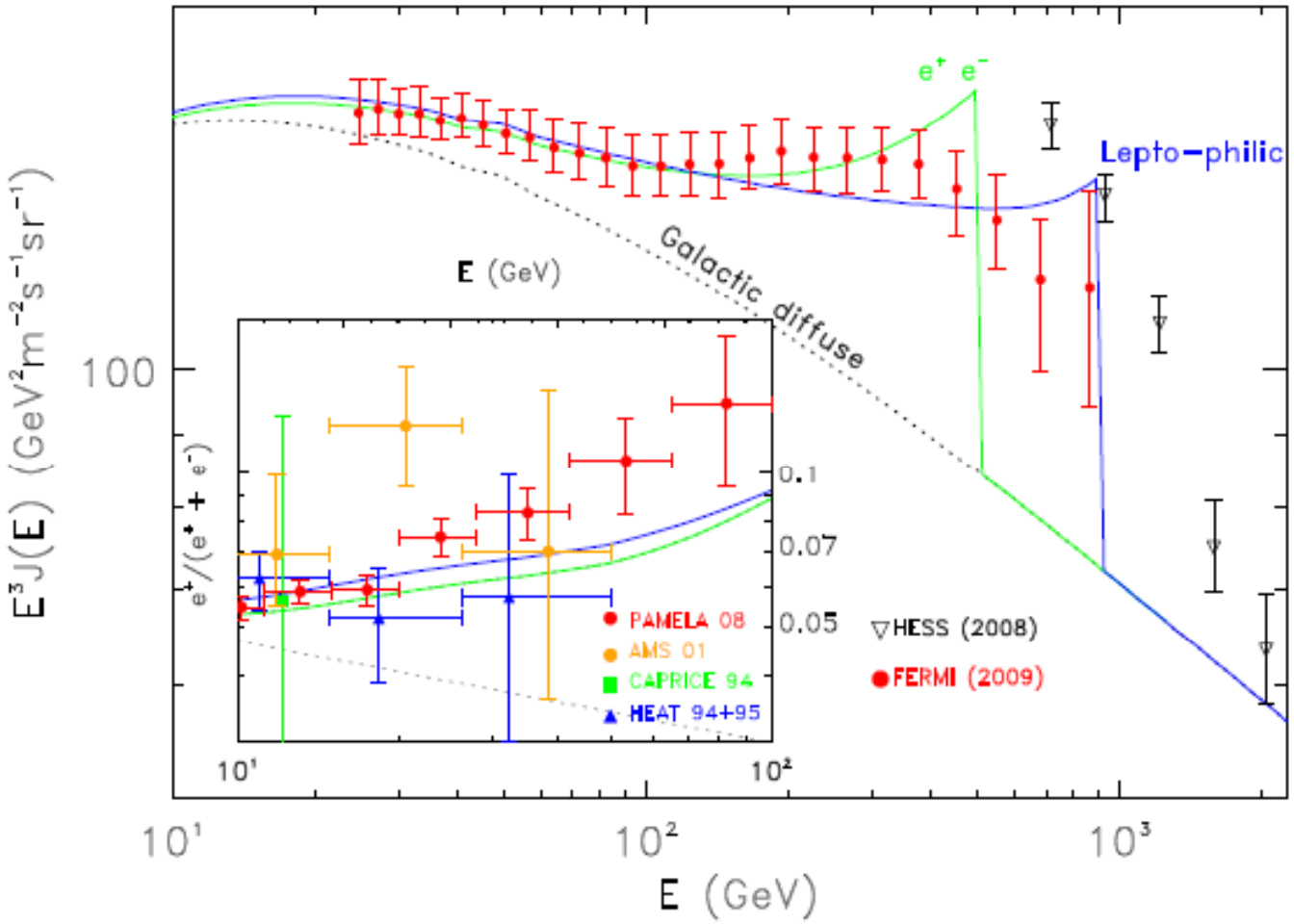
Possible contribution of nearby pulsars

Flux of (electron + positron)



Possible contribution of nearby pulsars

PAMELA Results: Dark Matter?

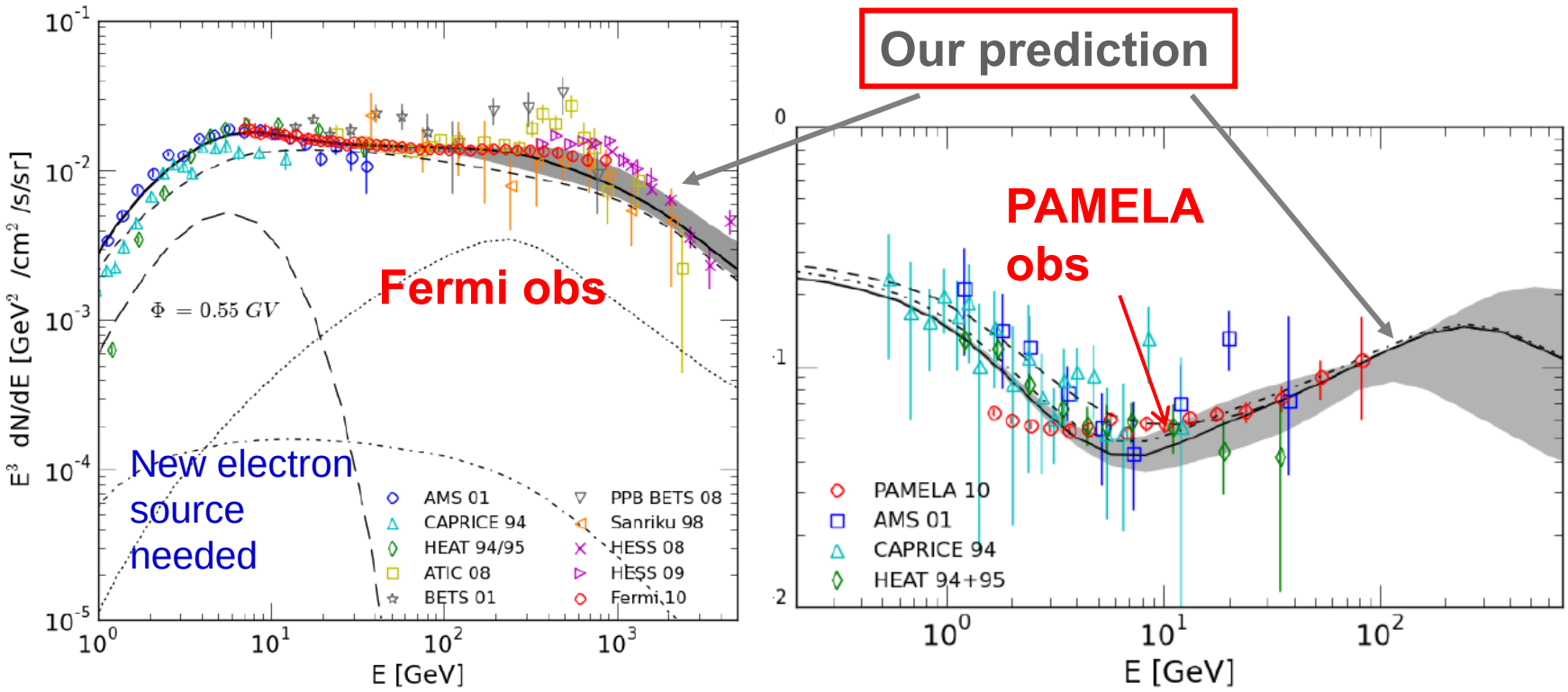


PAMELA Positron Ratio and Fermi γ-ray Obs

- γ-rays trace CR propagation -

Kamae, Lee, et al., arXiv:1010.3477 Oct 2010
(Kamae, Tanaka, Uchiyama)

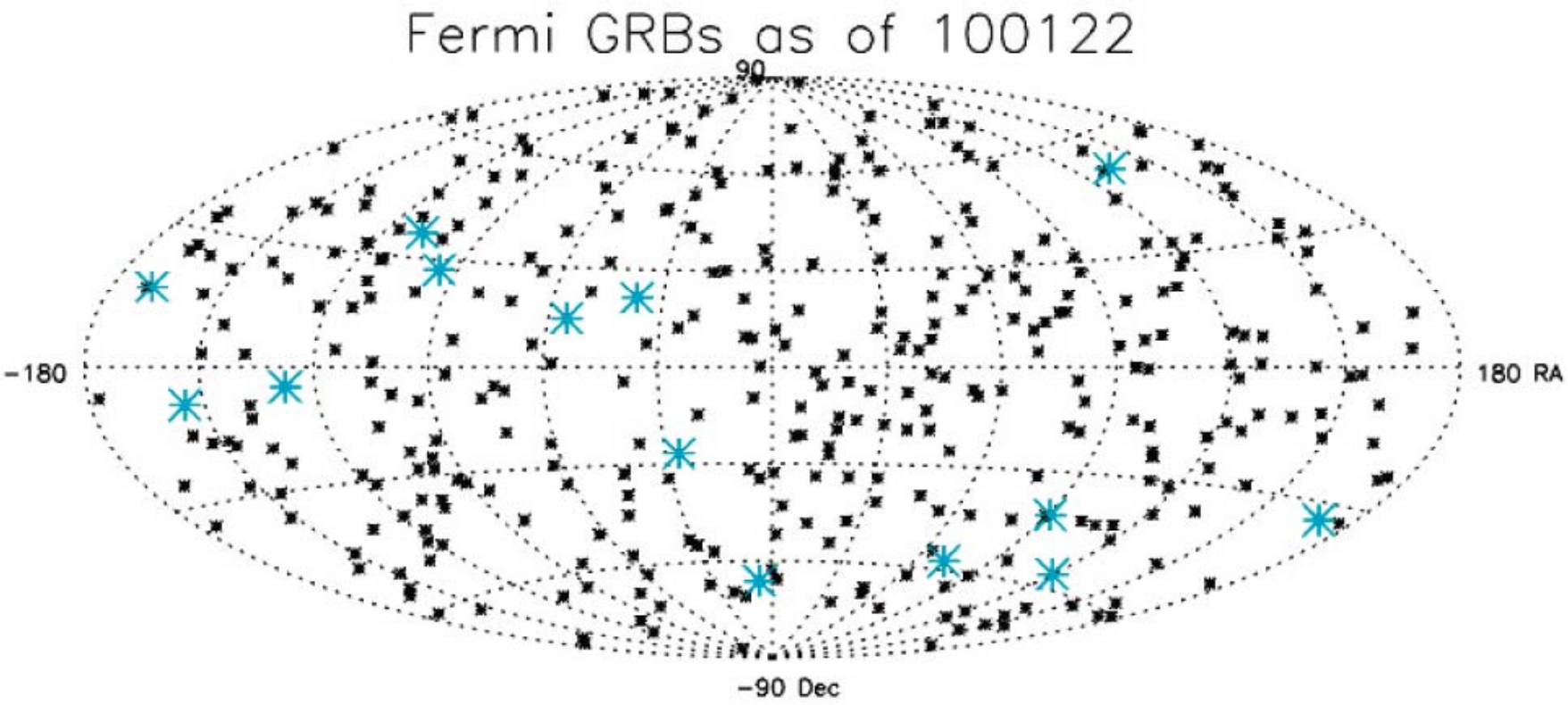
PAMELA $e^+/(e^+ + e^-)$ is reproduced without calling for new positron source(s).



Tests on Lorentz Invariance using Gamma-Ray Bursts (GRB)

Summary of Fermi-LAT Detection of GRBs

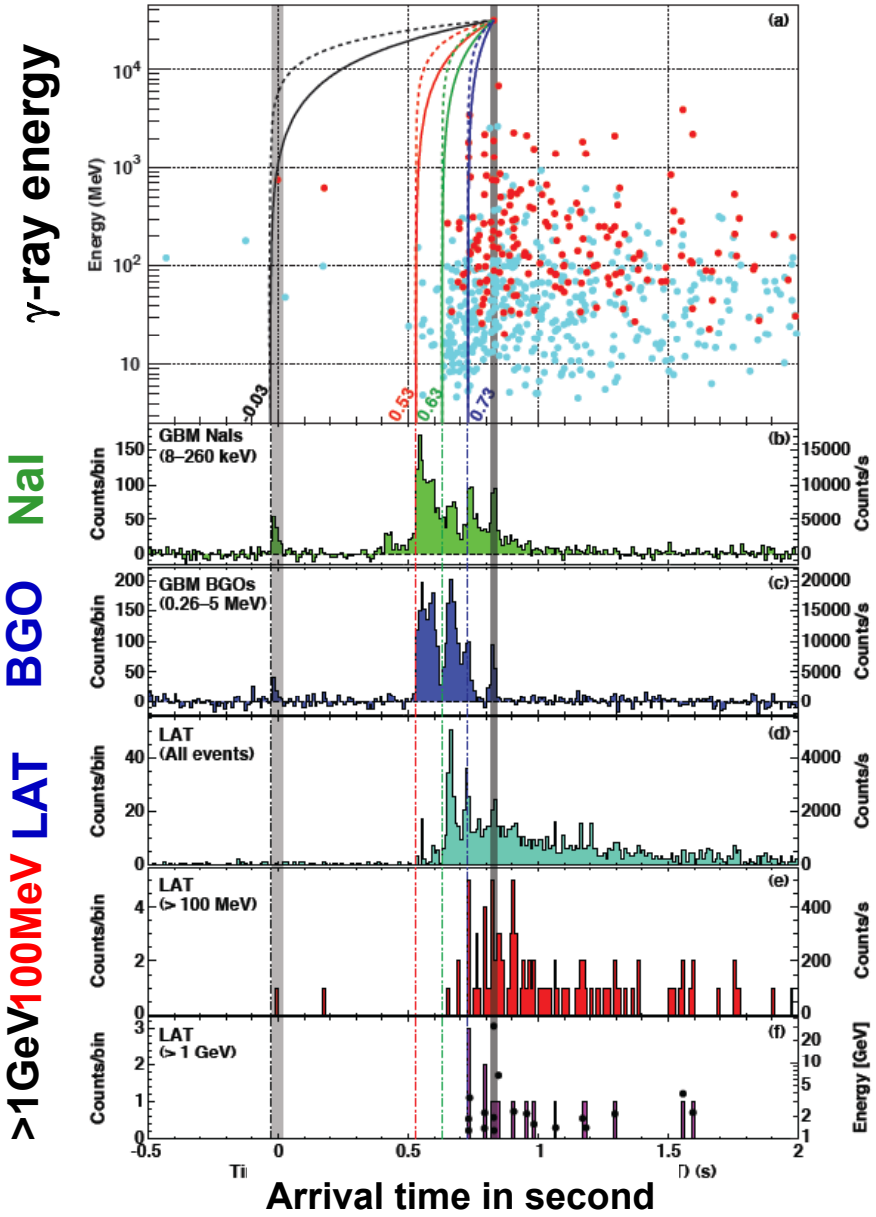
Tajima, Ohno, Kawai



241 GRBs detected by Fermi GBM
Blue (14) detected by LAT

Test on Lorentz Invariance

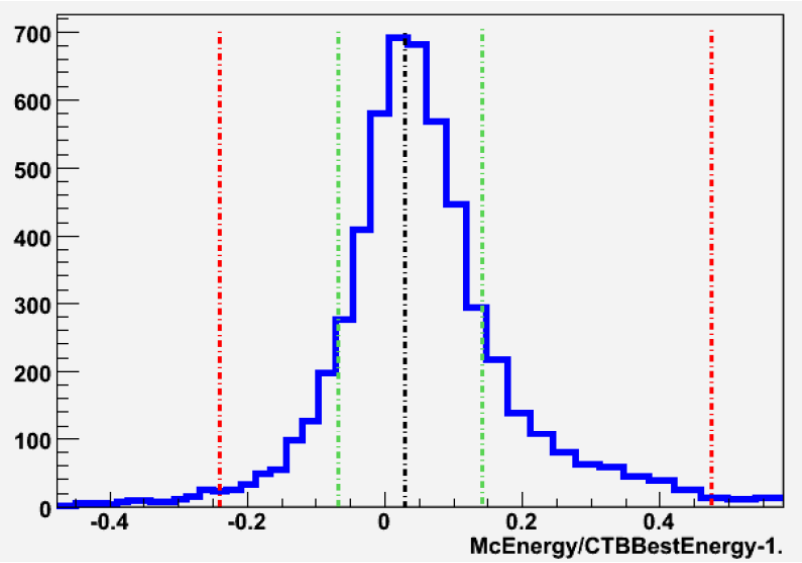
GRB 090510 at z=0.903 with one 31GeV γ-ray



Abdo, A. A. et al. 2009, Nature, 462, 331
(Tajima, Ohno, Kawai)

Difference in arrival times of γ-rays

Energy measurement



$M_{QG,1} > 1.0 \times M_{Planck}$ (n=1)

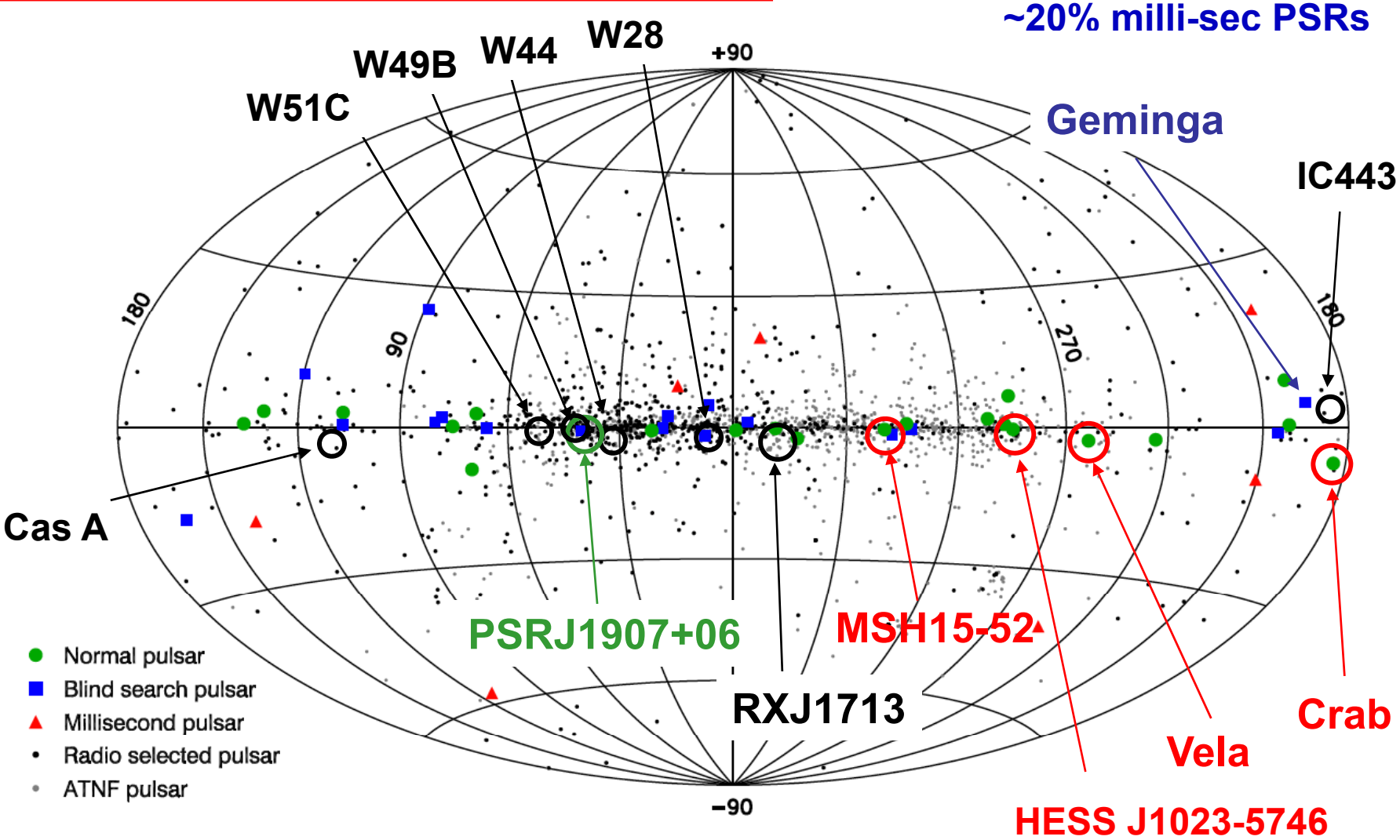
Particle Accelerators in the Universe

Galactic Cosmic Ray Sources

Abdo et al. 2010 ApJS 187, 460

59 PSRs detected:
~30% γ-ray loud
~50% radio-loud
~20% milli-sec PSRs

~7 Supernova Remnants (SNR) studied
~4 Pulsar Wind Nebulae (PWN) studied



Discovery by Fermi

- Galaxy is filled with Pulsars -

Abdo et al. 2010 ApJS 187, 460

Kawai

- ❑ **Many γ-ray pulsars have been hidden.**
- ❑ **Millisecond pulsars are good accelerators**

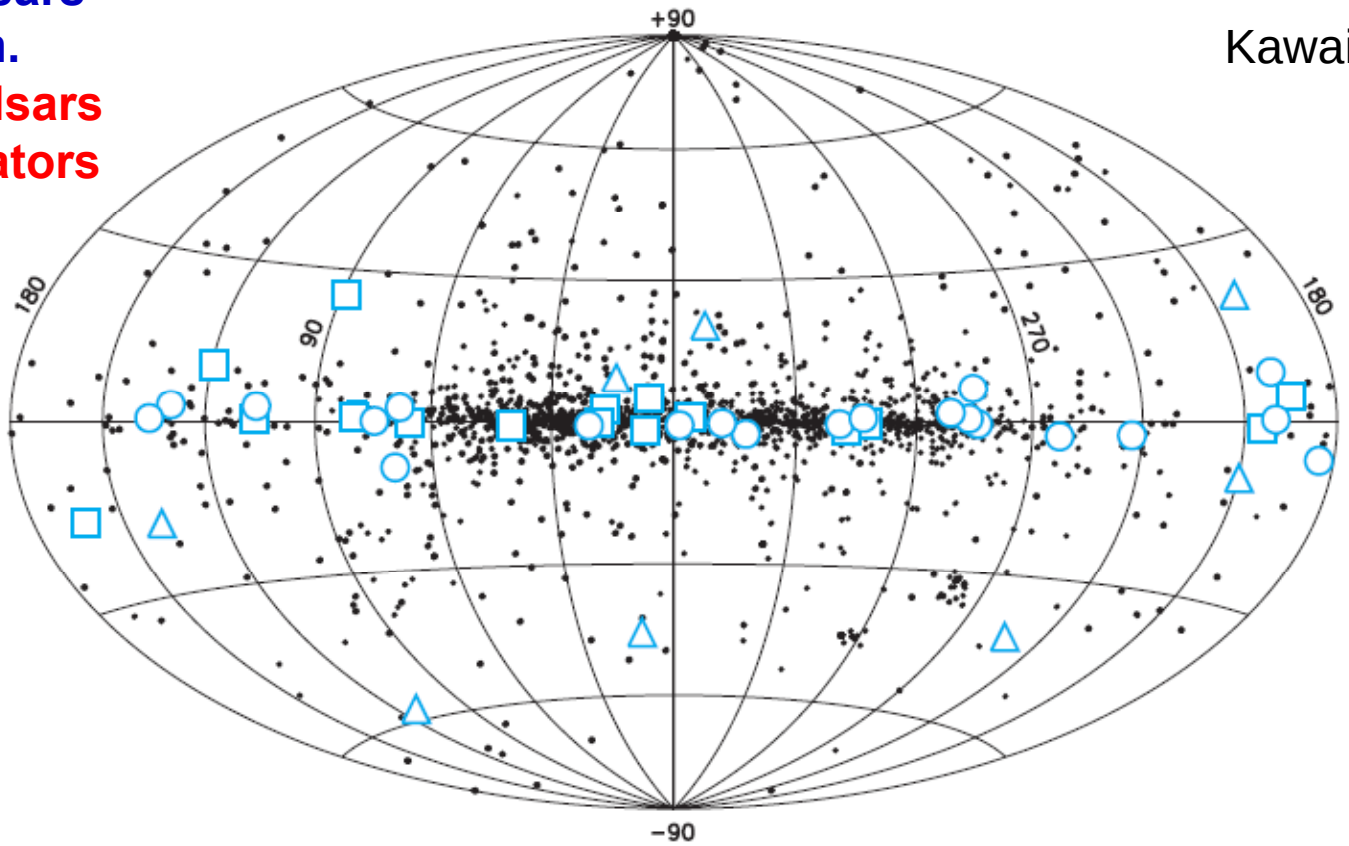
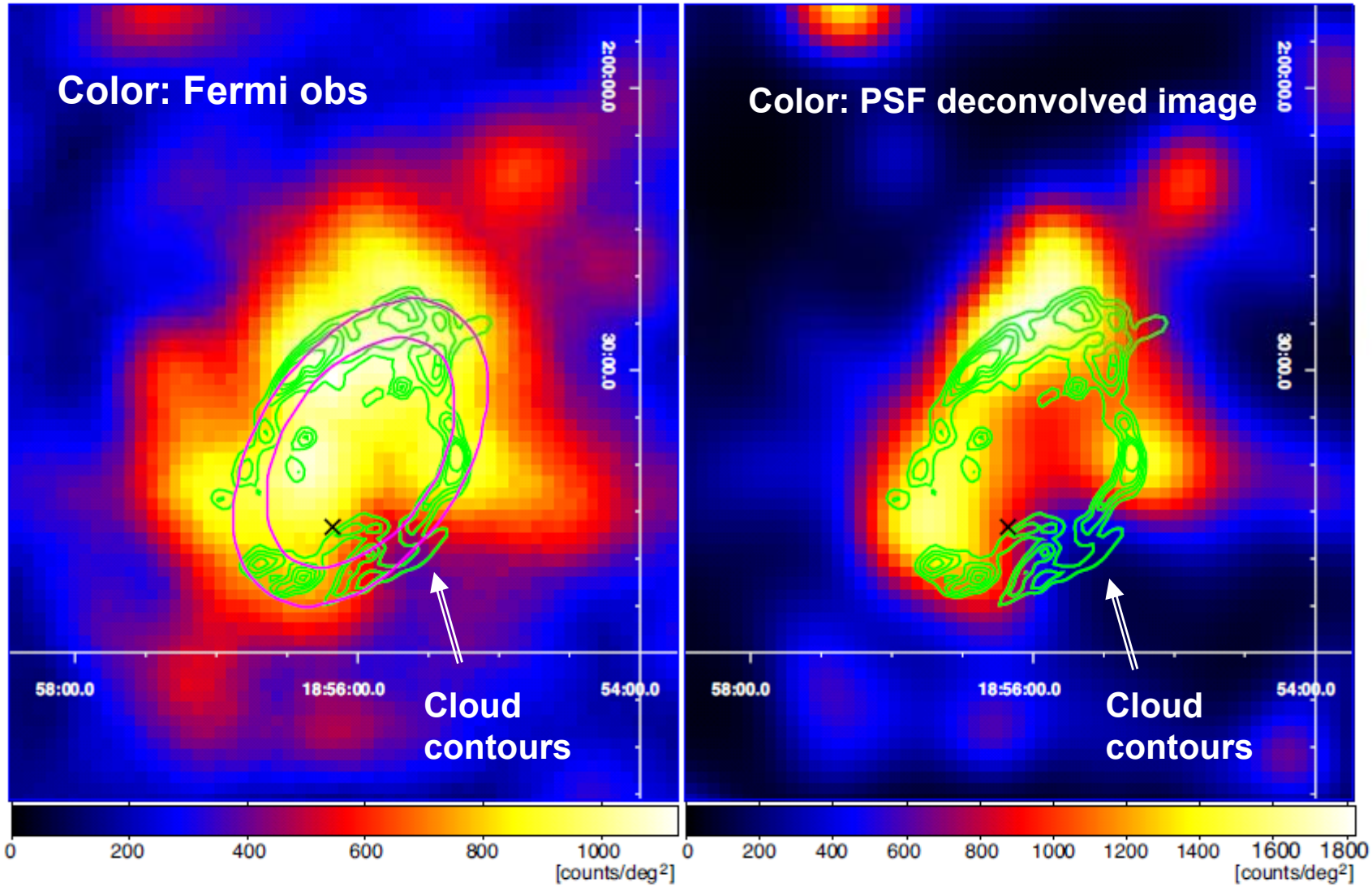


図 1: LAT が検出したパルサーの銀河座標上分布 [8]。丸：電波パルサー、四角：ガンマ線で見つかったパルサー、三角：ミリ秒パルサー。黒点は既知の電波パルサーの位置。

Discovery by Fermi

Many SNRs are Interacting with molecular clouds

Fermi 2010, Science Express 7 Jan 2010, 1182787 (Tajima, Kamae, Tanaka, Uchiyama)

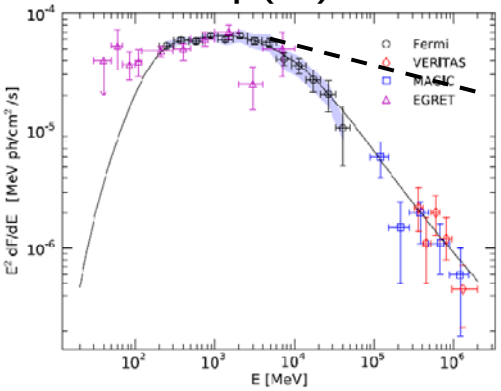


Discovery by Fermi: CR proton spectra roll down

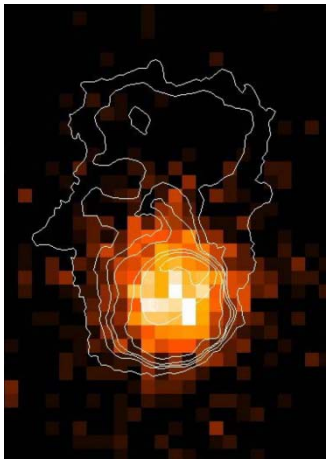
(Kamae, Tajima, Tanaka, Uchiyama)

- **CR spectra break at 10-100 GeV**
- **A large fraction of energy（W_p ~ $10^{48\text{-}50}$ ergs) is kept for ~30kyr**

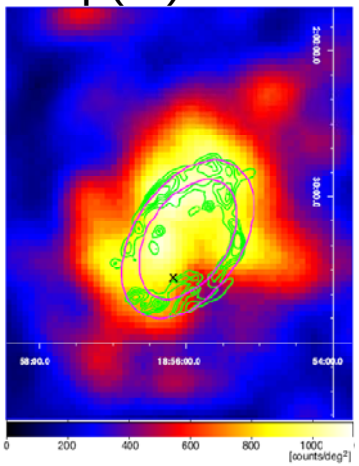
IC443: Ep(br)=**70GeV**

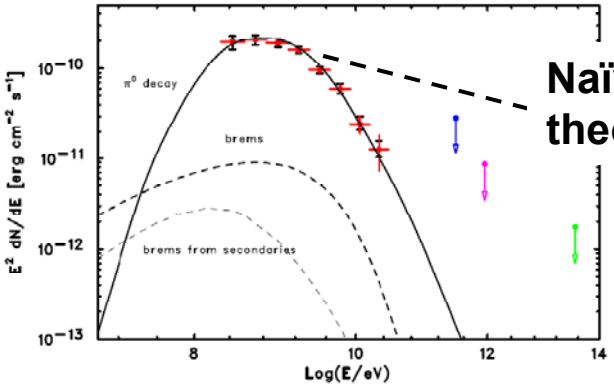


Naïve theory



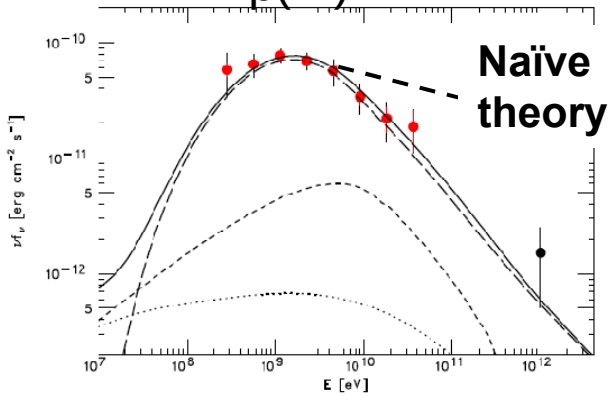
W44: Ep(br)=**7-10GeV**



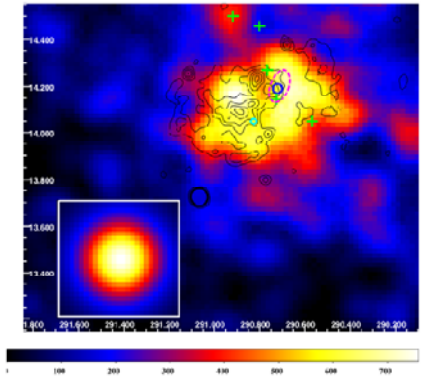


Naïve theory

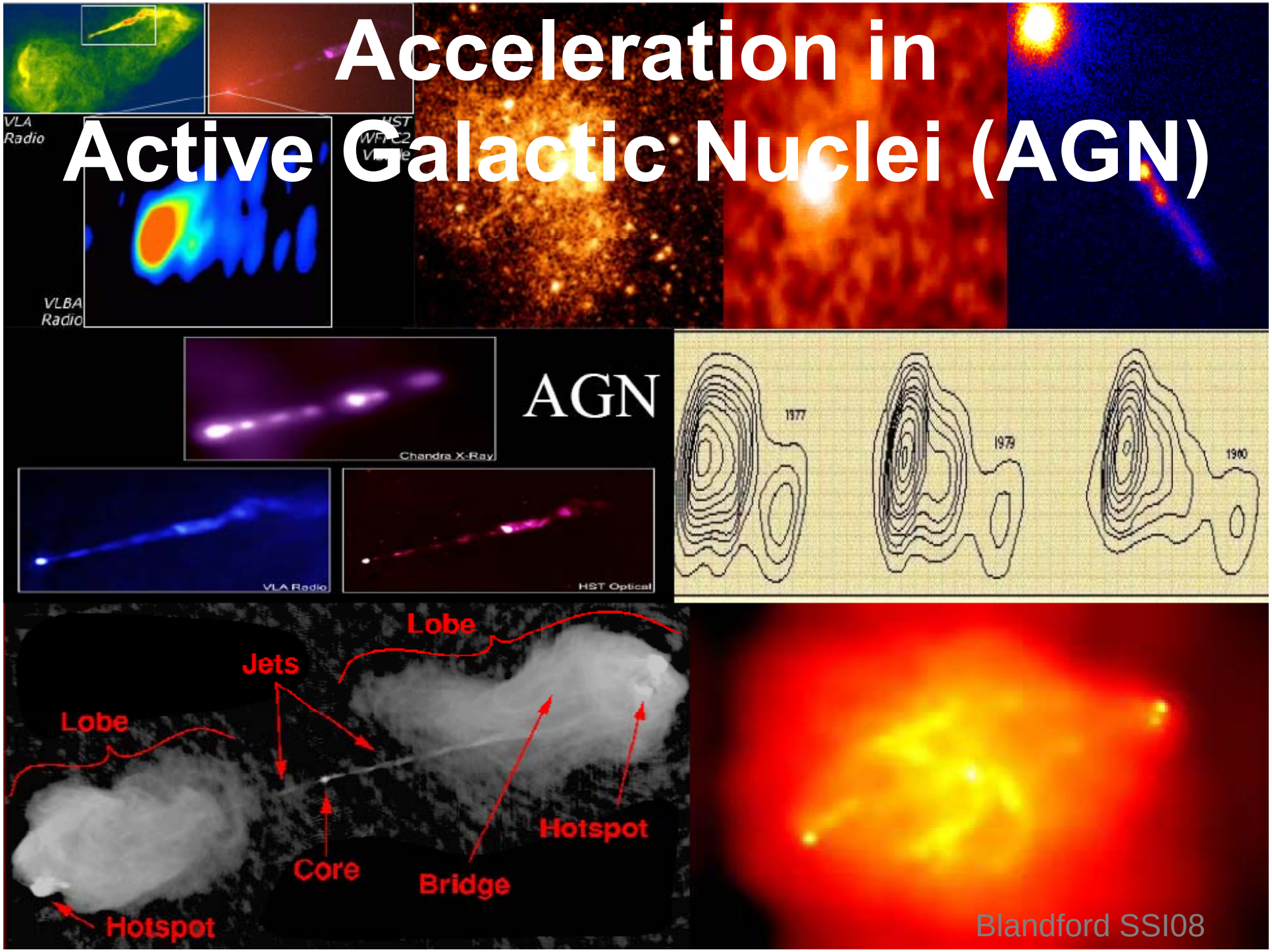
W51C: Ep(br)=**10-30GeV**



Naïve theory

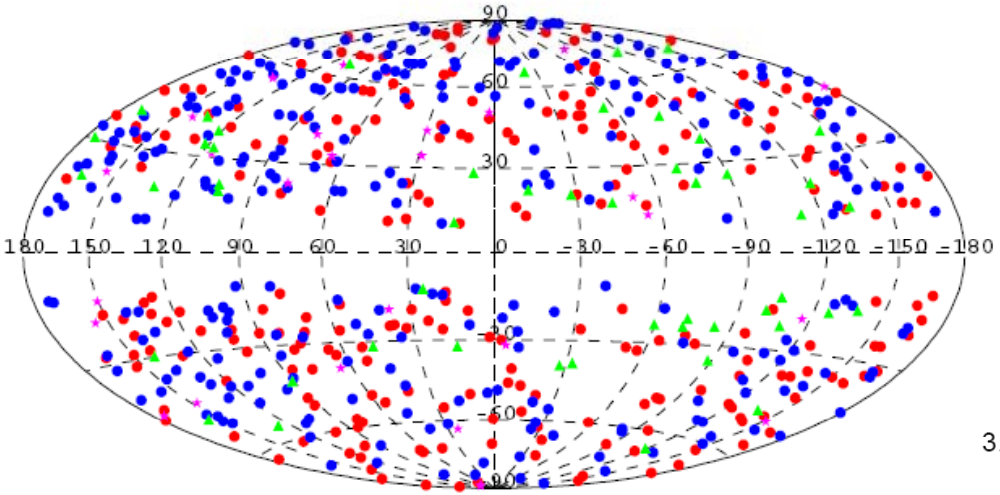


Acceleration in Active Galactic Nuclei (AGN)



Fermi Discovery

Thousands of γ-ray bright AGNs in early universe

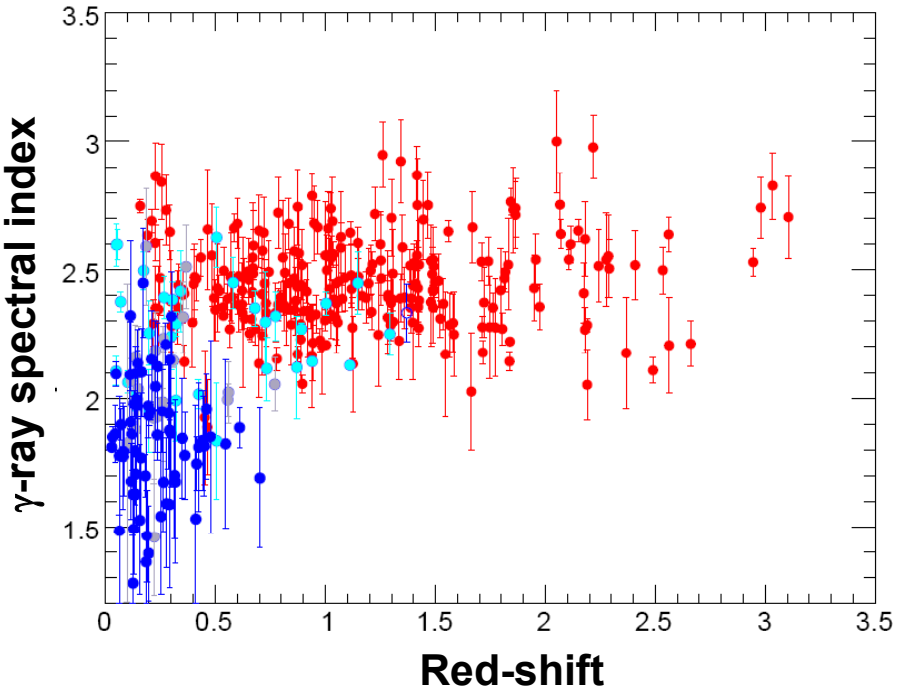


Abdo et al. 2010 ApJ 715, 429
(Fukazawa, Kataoka, Hayashida)

Galactic plane excluded

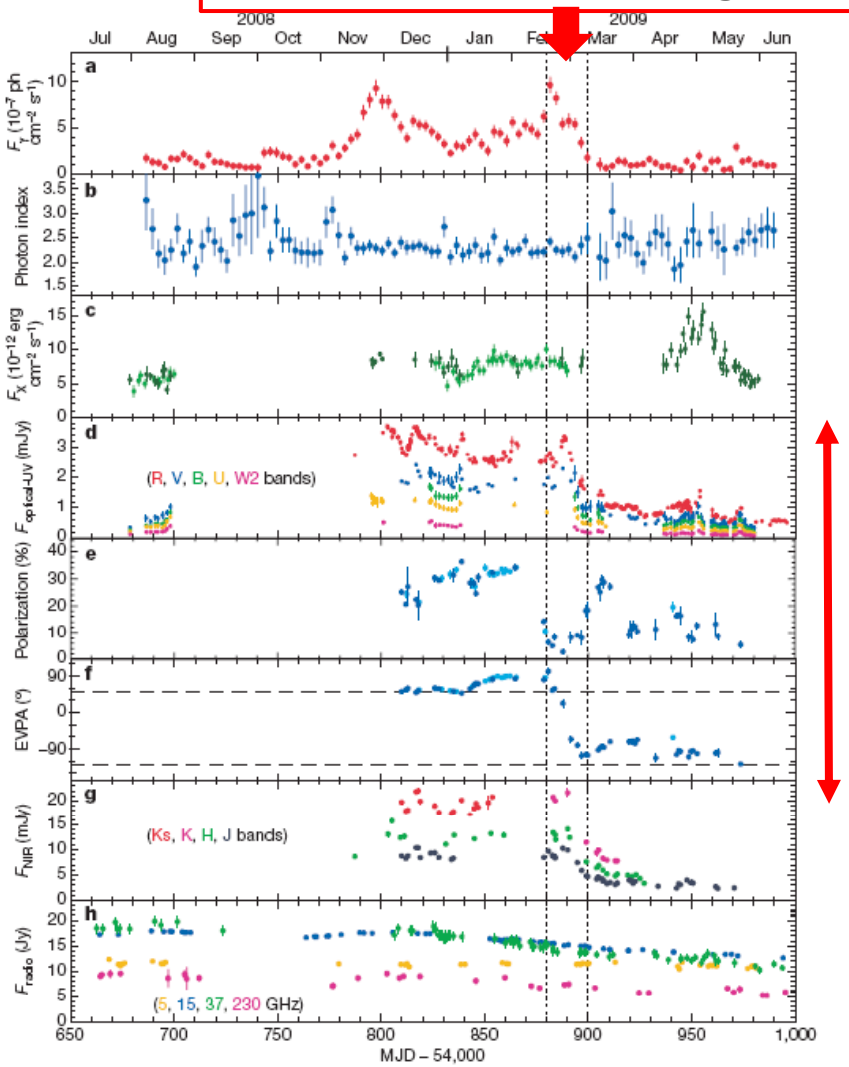
AGN classes
red: FSRQs
cyan: LSP-BL Lacs
gray: ISP-BL Lacs
blue: HSP-BL Lacs

Red-shift distribution



Fermi Discovery: Magnetic Structure in Jet

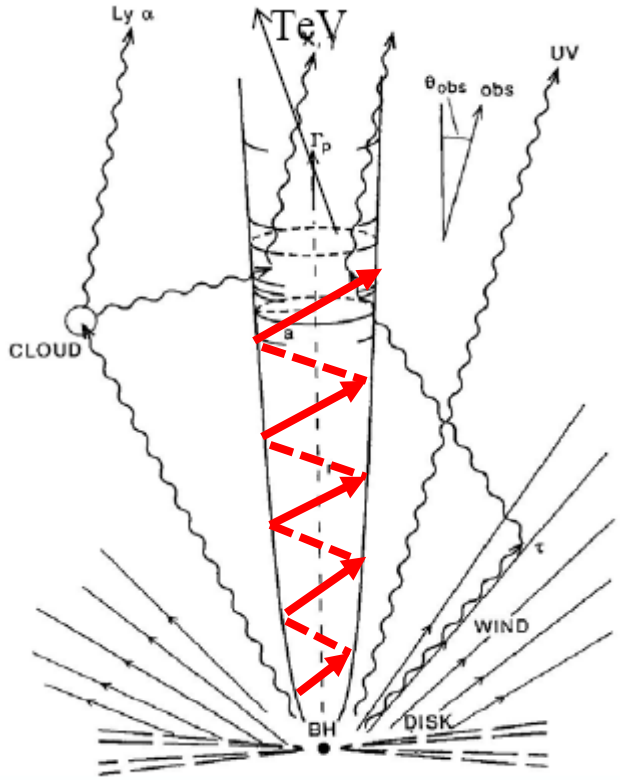
Polarization flip during a flare in 3C279



Abdo et al., Nature 463, 919-923 (2010)
Hayashida, Fukazawa, Kataoka

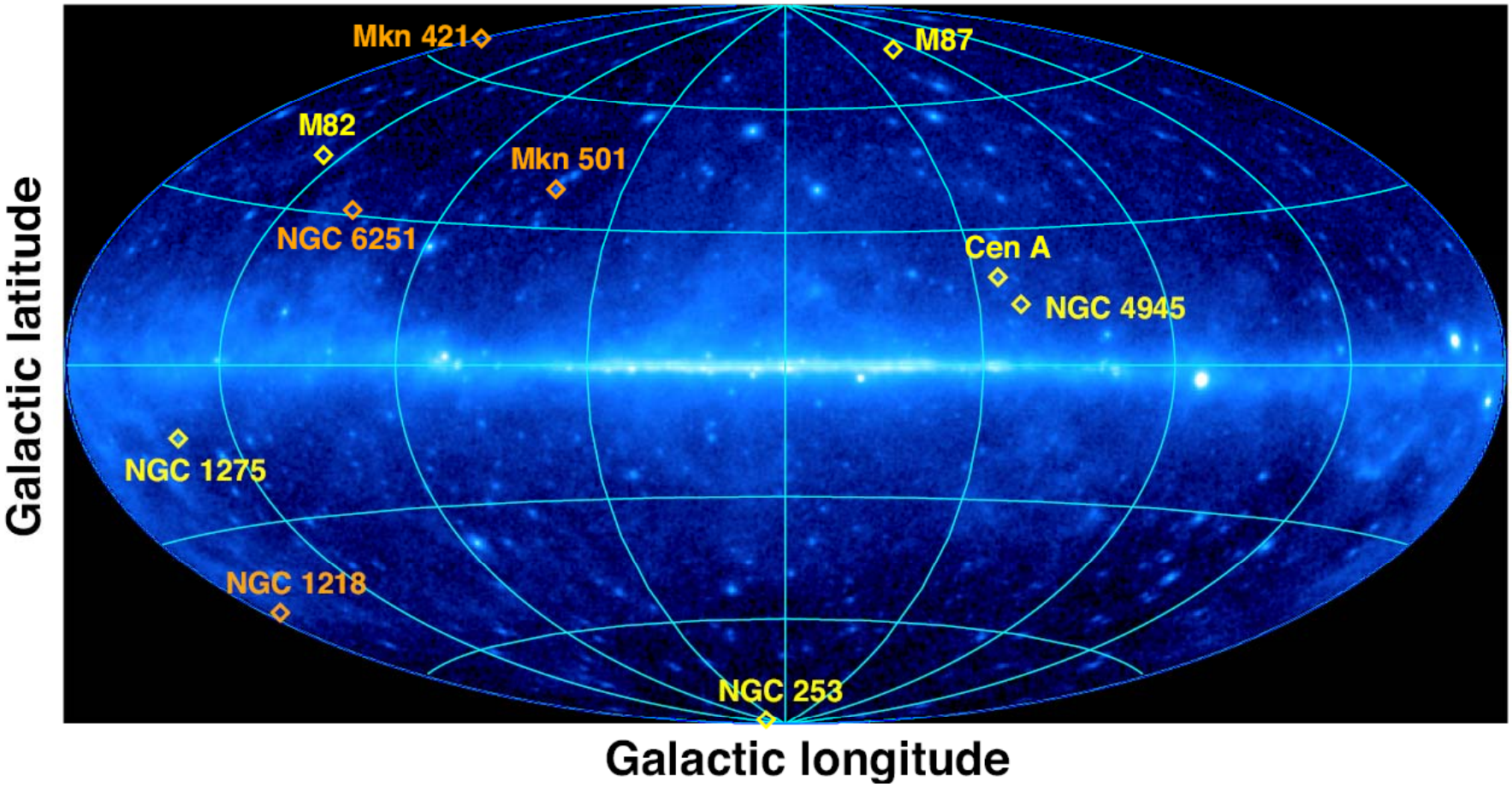
Polarization meas by **Kanata Telescope**

Spiral Magnetic Field?



Nearby AGNs: Possible Sources of UHECRs

- About 10 Sources are within the GZK radius (100Mpc) -



UHECR: Ultra HighEnergy Cosmic Ray ($E>10^{18}$eV)

Fermi γ-ray Obs Constrain Origin of UHECR

- Dermer & Razzaque, arXiv:1004.4249 Sep 2010 -

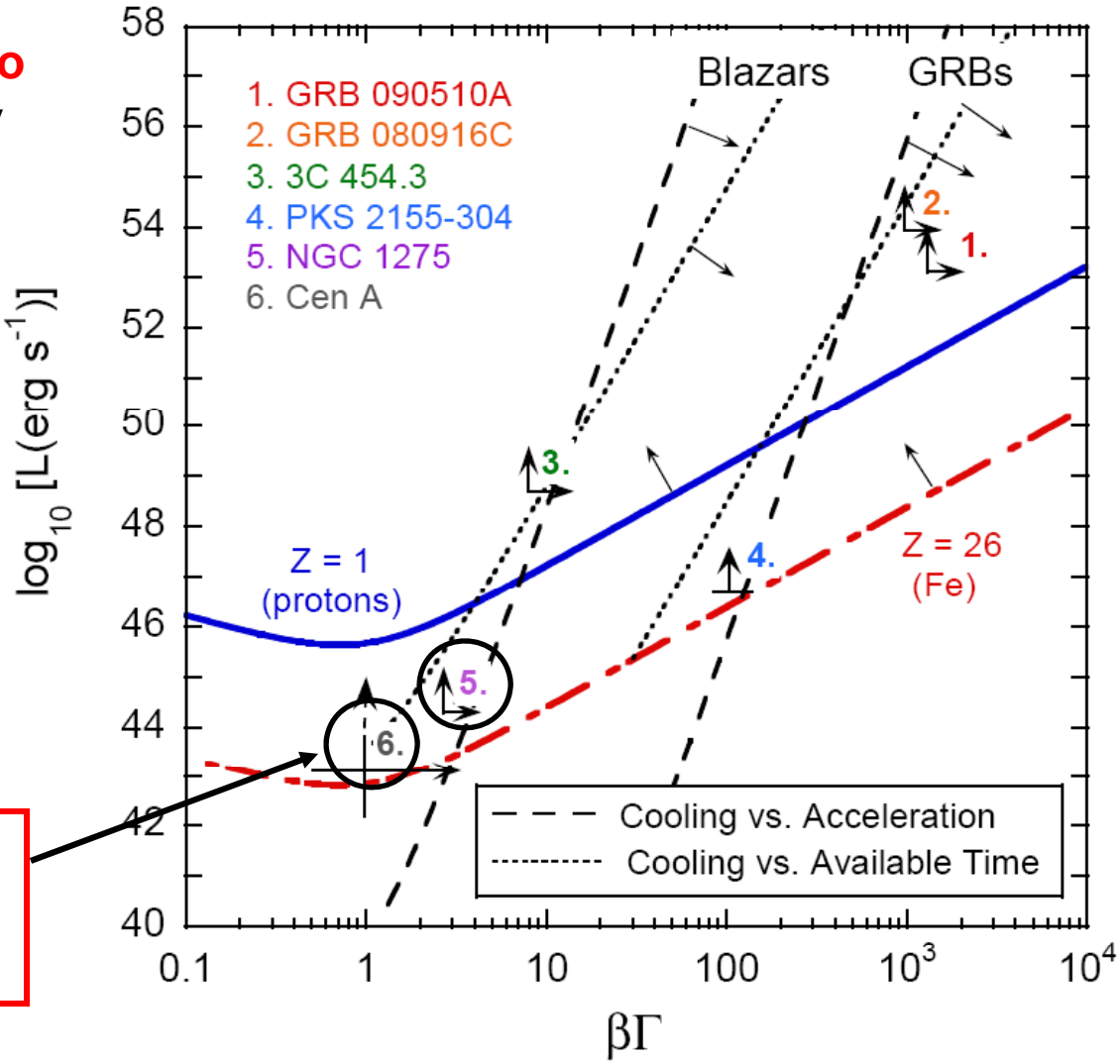
In the **internal shock scenario** and **γγ opacity** argument, they derive following equation:

Fermi obs. =>
γ-ray luminosity L_γ and bulk Lorentz factor Γ

$$E_{max} \propto 2\times10^{20}(Z/\Gamma)\sqrt{L_\gamma}$$

Energetic GRBs (1,2,3) can accelerate both proton and Fe to 10^{20}eV

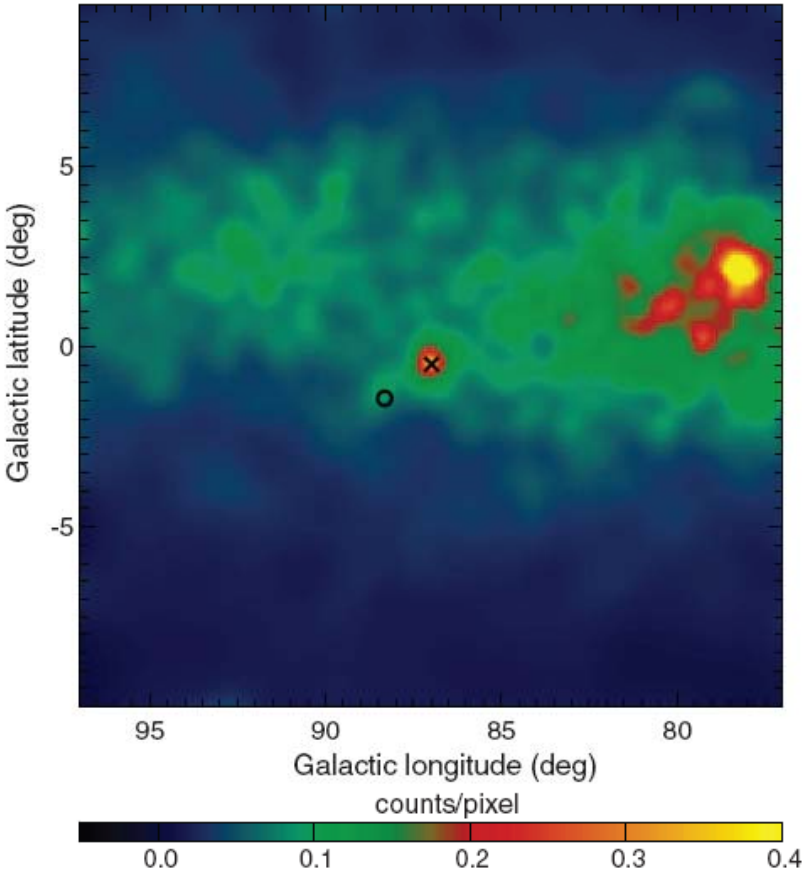
AGNs within GZK cutoff (5,6) can accelerate Fe, but not proton, to ~10^{20}eV



Flare in Nova: V407 γ-Cygni

Abdo et al. **SCIENCE** VOL 329 13 AUGUST 2010

H. Takahashi



Discovered by Japanese “amateur” astronomers => Found in Fermi data

9. K. Nishiyama, F. Kabashima, International Astronomical Union Central Bureau for Astronomical Telegrams, reported by H. Maehara, no. 2199 (2010).

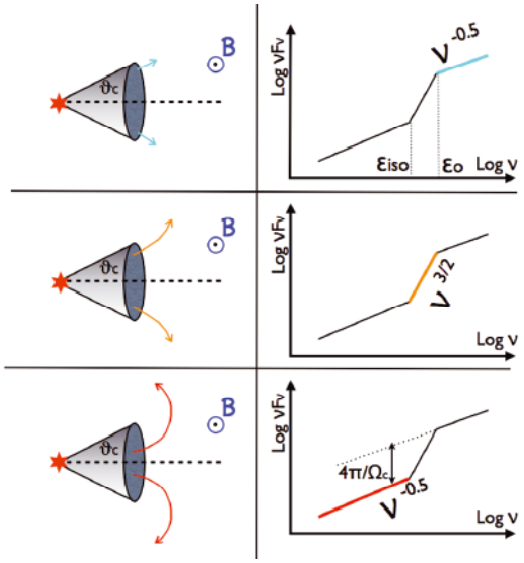
New Developments and Future Prospects

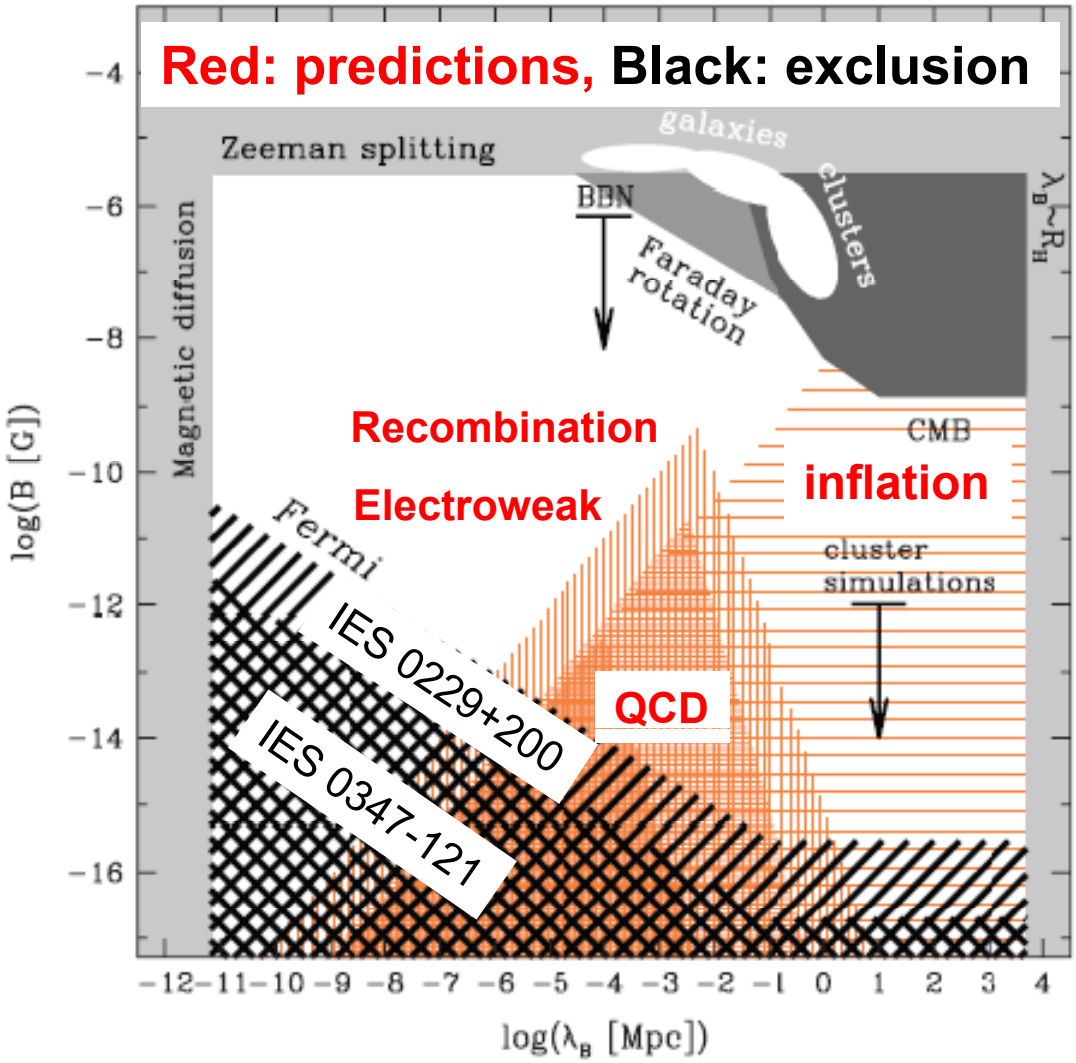
Fermi Constrains Cosmological B-Field

Andrii Neronov* and Ievgen Vovk
SCIENCE VOL 328 2 APRIL 2010

Neronov, A. & Semikoz, D. V., Phys Rev D, 80, 123012 (2009)

B-field in cosmological space is large:
B > ~10^{-16} Gauss





Conclusions

Particle physicists inherit the genes from pioneers who have

- built quantum mechanics,
- invented particle accelerators,
- found thousands of particles,
- established the Standard Model and
- **are exploring beyond the Standard Model**.

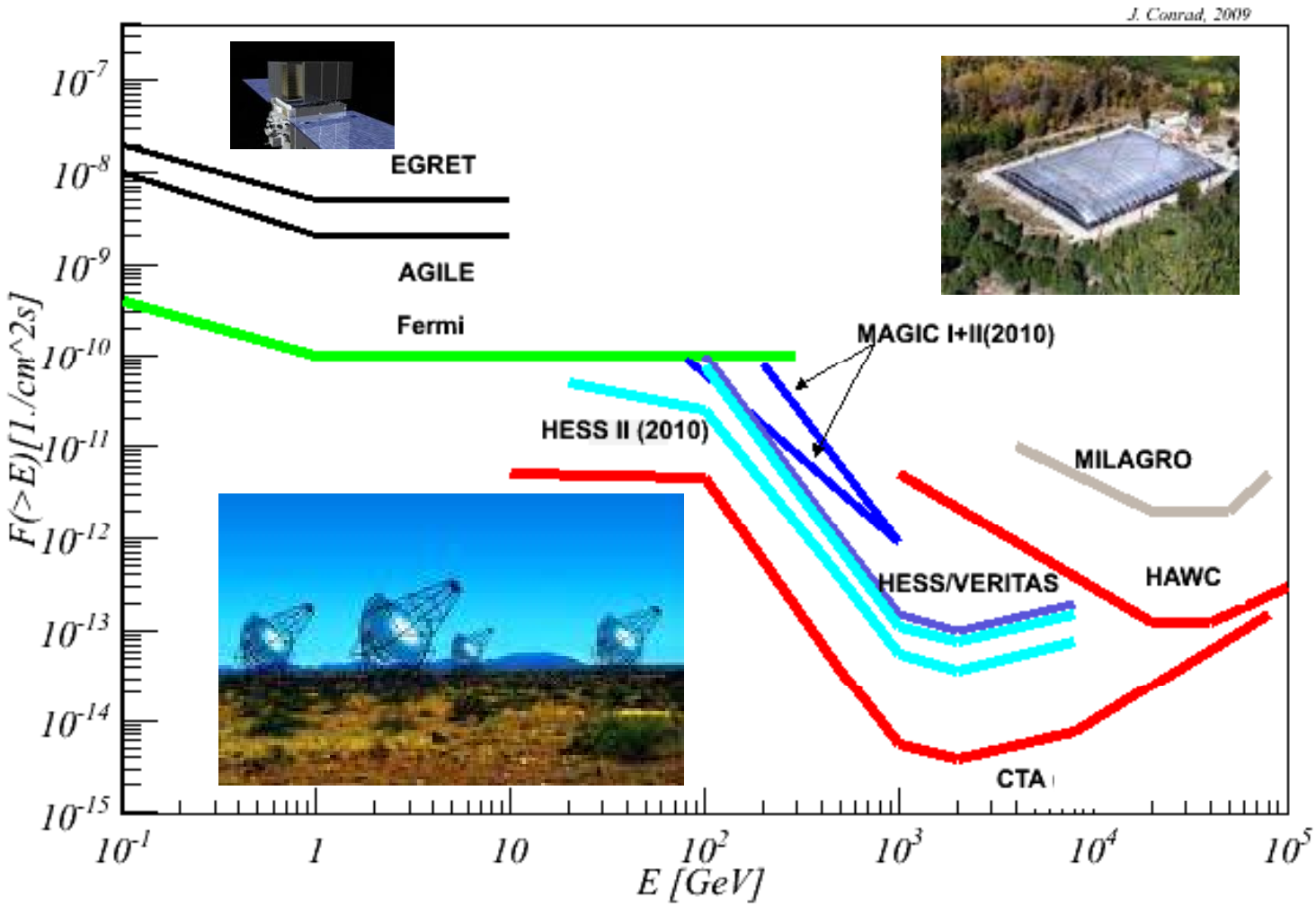
The field is outgrowing beyond the largest man-built accelerator, **leaving many fundamental physics issues unanswered.**
The Universe offers many exciting possibilities of discoveries.

US-Japan should fully embrace emerging fields of **particle astrophysics and cosmology.**

Fermi Gamma-ray Space Telescope and **Sloan Digital Sky Survey** have proven that **particle physicists are called for to lead major projects in the new fields.**

Have courage to jump into new fields as our "sensei" had before us!

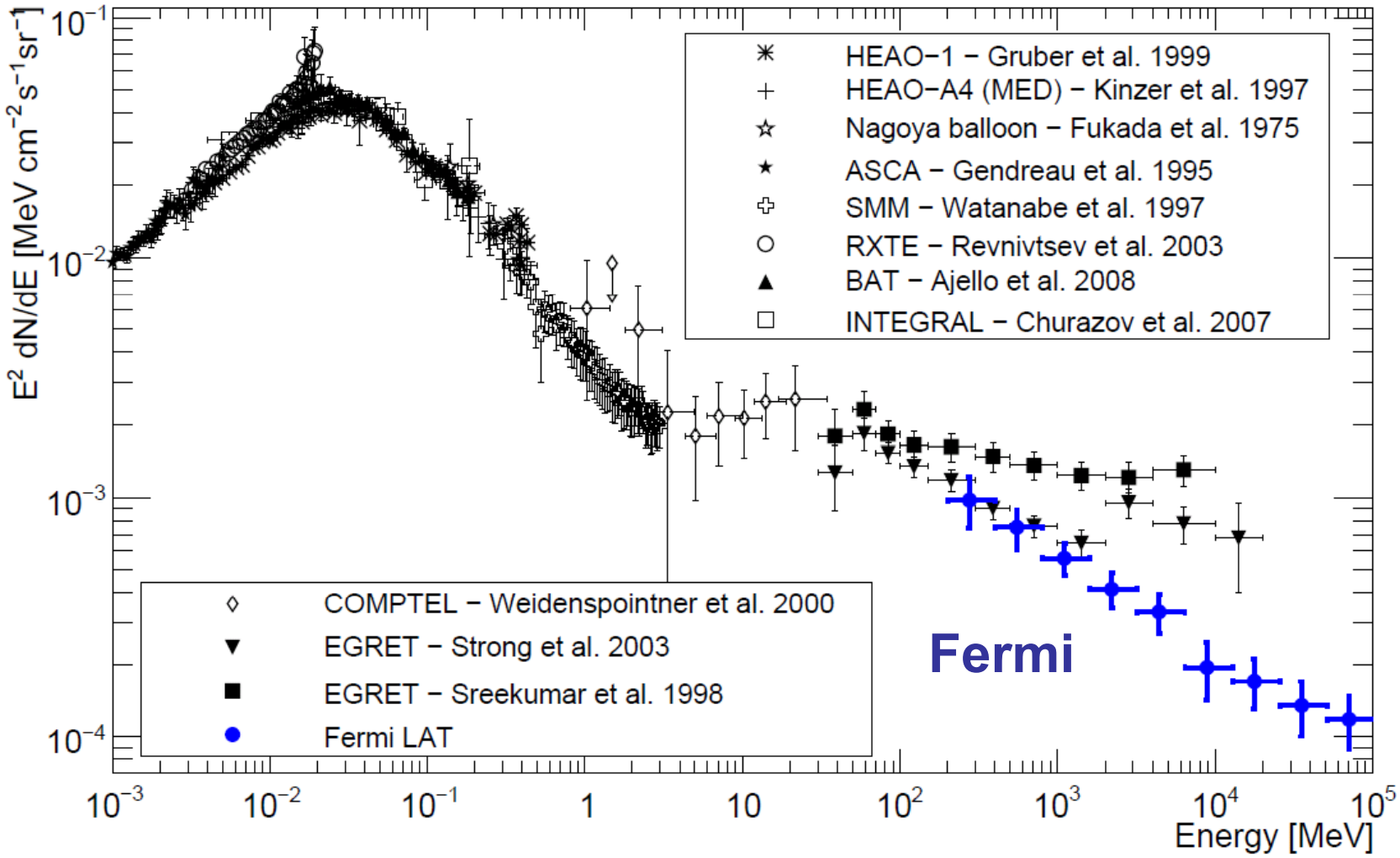
Future Projects



Backups

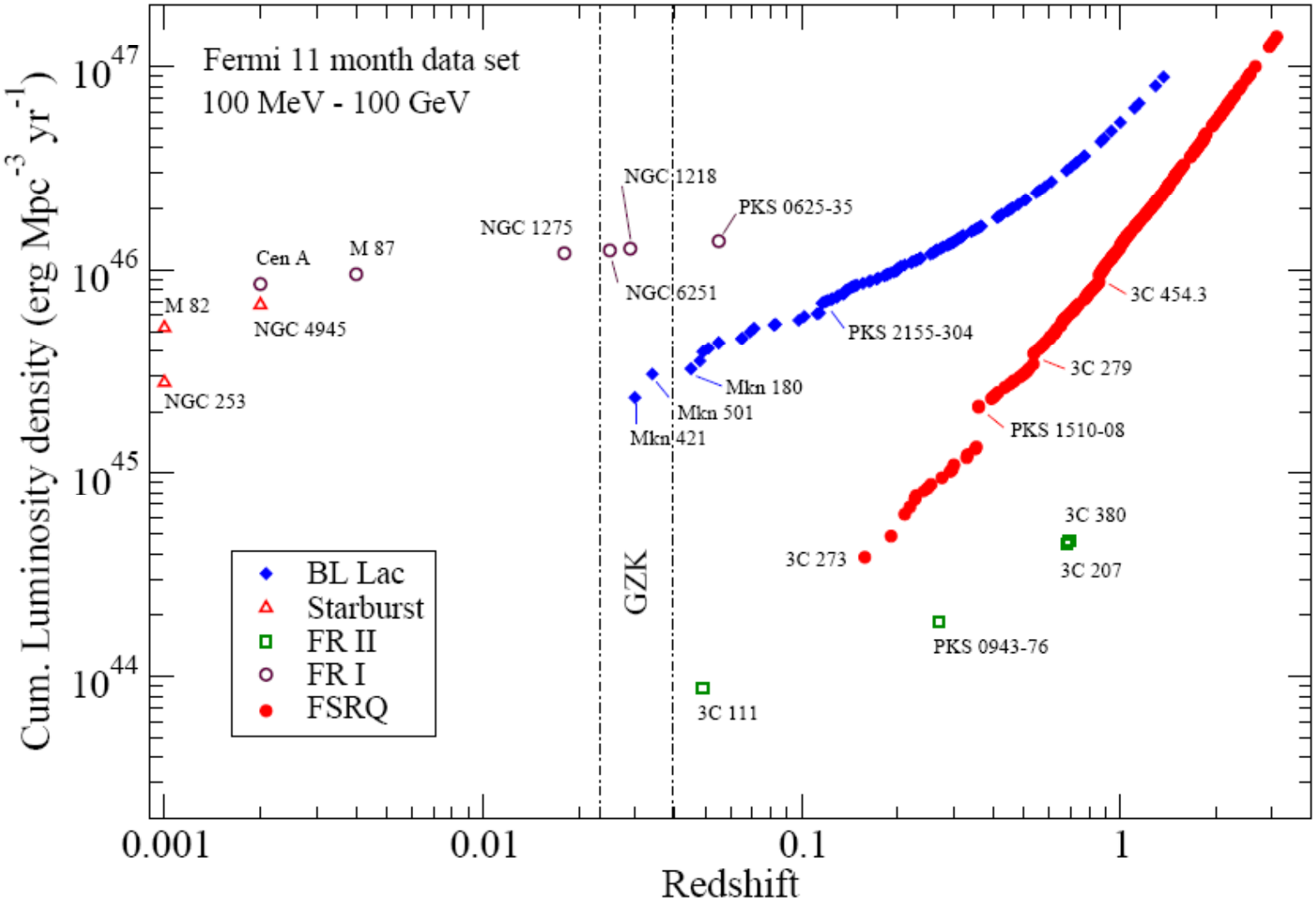
Extragalactic Diffuse γ-rays by Fermi

aka “extragalactic γ-ray background: γ-rays not associated with identified sources



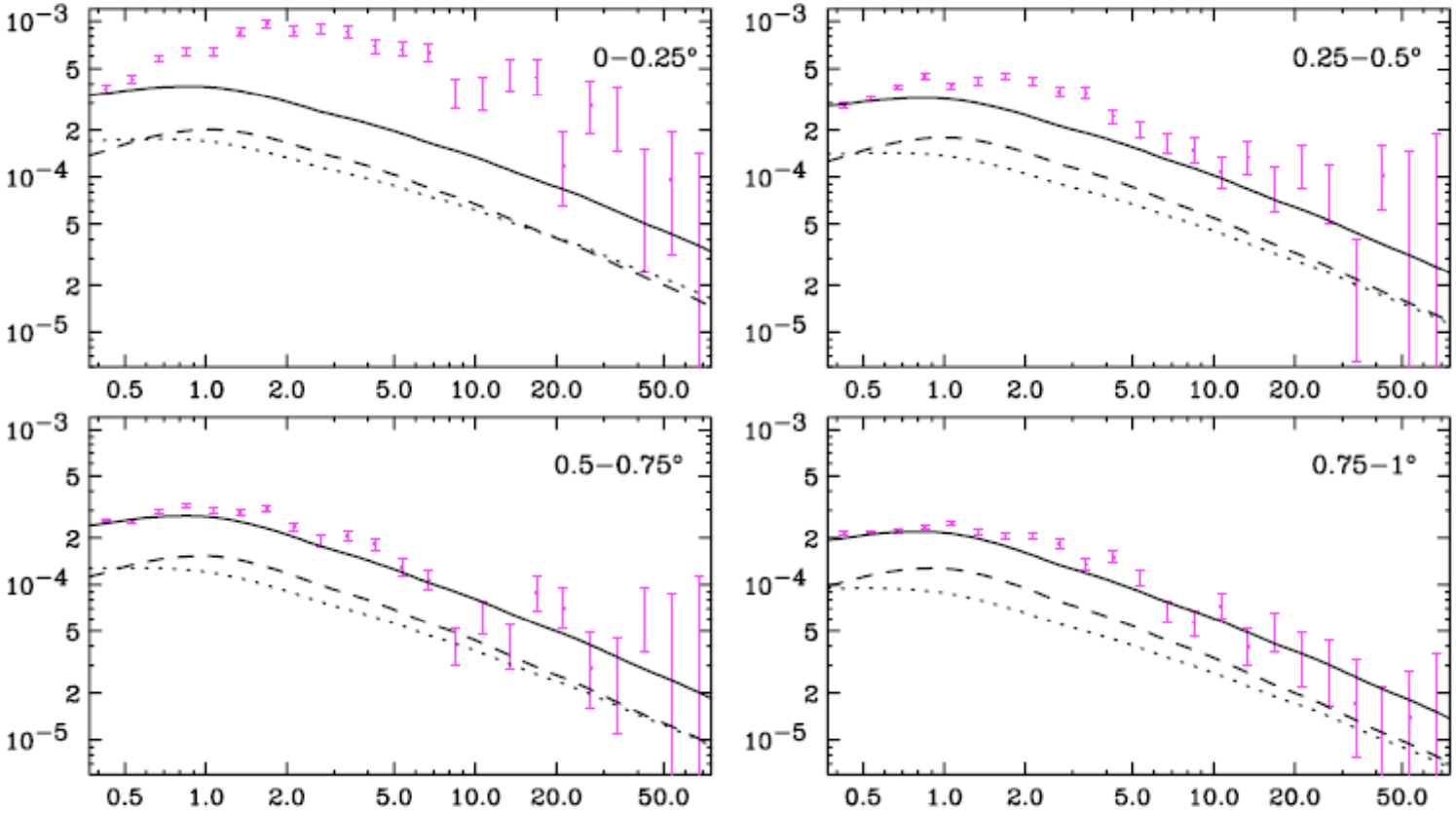
Fermi γ-ray Obs Constrain Origin of UHECR

- Dermer & Razzaque, arXiv:1004.4249 Sep 2010 -



Hooper Goodenough

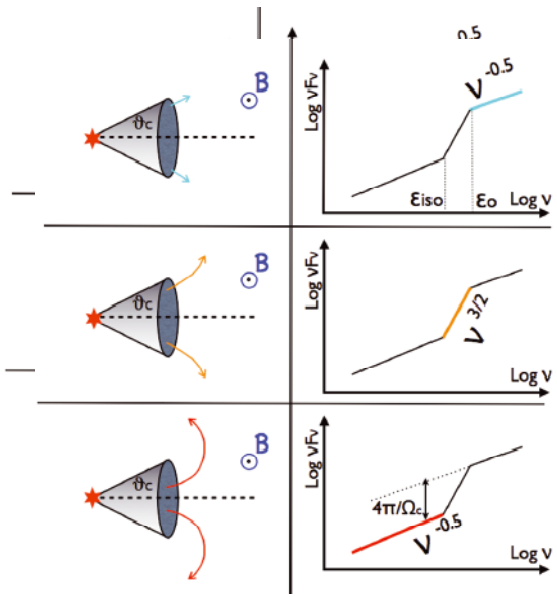
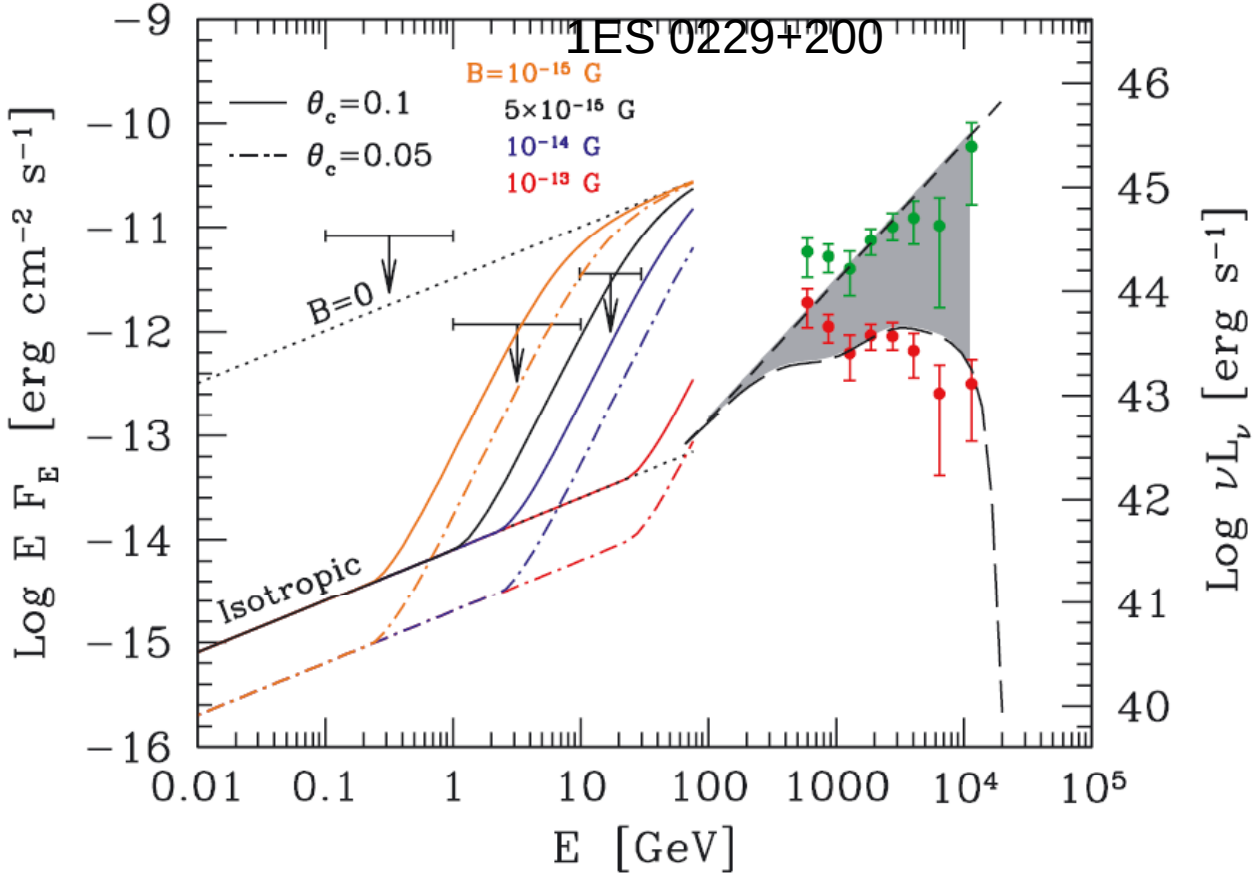
arXiv:1010.2752v1 (Oct. 13, 2010)



Spectral Model of Halo Emission

Tavecchio et al. (2010a,b)

Mon. Not. R. Astron. Soc. **406**, L70–L74 (2010)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