the animated GeV sky by Fermi

Isabelle Grenier
Université Paris Diderot & CEA Saclay

on behalf of the Fermi-LAT collaboration
Fermi instruments

- launched in June 2008
  - lifetime 5 + 5 years

- Large Area Telescope (LAT)
  - 20 MeV – 300 GeV

- GLAST Burst Monitor (GBM)
  - 8 keV – 30 MeV
  - all sky not occulted by Earth
γ-ray bursts
γ-ray bursts
a short one

so far: > 160 GBM events, > 5 LAT events

GRB081024B

- first short GRB with $\gamma > \text{GeV}$
- delayed and longer-lasting emission at high energy
- single Band spectrum
- $\gamma + \gamma \rightarrow e^{\pm}$ constraints
  $\Gamma > 150$ at $z = 0.1$
  $\Gamma > 900$ at $z = 3.0$

- origin of lasting HE $\gamma$ rays?
- why with 2nd GBM peak?
- why delayed after sub-MeV?
GRB080916C: $z = 4.35 \pm 0.15$ (GROND)

- delayed and 23mn-lasting $\gamma$ rays
- Band spectrum $E_{\gamma} \leq 13$ GeV ($E_{\text{rest}} \leq 170$ GeV)
- $E_{\text{iso}} = 8.8 \times 10^{47}$ J = 4.9 $M_\odot c^2$
- beamed: $\Gamma > 890 \pm 20$
- X-ray afterglow after 17h
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the animated GeV sky
the LAT telescope

- PSF HWHM
  - for $E^{-2}$ source
  - 0.1-1 GeV band: 0.6°
  - 1-100 GeV: 0.05°
- 2.4 sr (20% sky)
with old EGRET eyes
sharper Fermi eyes

Cygnus region: 0.1-1 GeV, 3 months
energy-dependent eyes

Cygnus region 1 to 100 GeV
better localization

0FGL sources, 95% error circles
twinkling sky

- what sensitivity and smooth exposure can do
  - < 30% exposure variations (SAA)
- whole sky every 3 hours
- variability: minutes, hours, days, months
source detection

- wavelet detection
- max-likelihood: TS evaluation, spectrum characterization
- interstellar emission model needs improvement
205 bright sources

- significance > 10 $\sigma$ (point-sources, not flux limited)
  - compared to 31 3EG sources > 10 $\sigma$ over 9 years
  - 1/3 sources at $|b|<10^\circ$ (inner Galaxy), 2/3 off the plane
  - $\sim$ weekly flux measurements and $X^2$ test ($\Delta F/F_{\text{pulsar}} \leq 3\%$)

- 1/3 variable sources, mostly off the plane ($P_{\text{chance}} < 1\%$)
Fermi versus EGRET

40% LAT sources off the plane with no EGRET counterpart = variable

better LAT PSF ⇒ less confusion with ISM and neighbours in the plane
205 bright sources

LAT PSF $\Rightarrow$ localization $> 2.4'$ and 6'-20' near threshold

$\Rightarrow$ multi-$\lambda$ studies

identified:
15 radio-X PSR
14 radio-quiet PSR
1 HMXB
+ 3 BZB + 3 BZQ
Sun & Moon

associated:
1 hmxb
43 bzb + 59 bzq
11 bzu
Cen A + NGC1275
LMC
47 Tuc

unidentified:
38
with weak associations for
11 SNR, 4 radio psr, 2 pwn
active galactic nuclei
L_{bol} = 10^{38-41} W radio-loud

(f_{core} >> f_{extended}, S_v \propto v^\alpha, \alpha > -0.5)

high dL/dt, polar > 3%
often giant elliptical galaxy

smaller M_{BH}
larger L_{acc} and L_{jet}, L \leq L_{Edd}
bright lines+superlum

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bright lines+superlum
BLR in polarized light

BL Lac

accretion disk

BLR

dust+gas torus

FSRQ, OVV, HPQ

FR II

FR I

BLR in polarized light

dust+gas torus

NLR

smaller $M_{\text{BH}}$

larger $L_{\text{acc}}$ and $L_{\text{jet}}, L \leq L_{\text{Edd}}$

bright lines+superlum

$L_{\text{bol}} = 10^{38-41}$ W radio-loud

($f_{\text{core}} >> f_{\text{extended}}, S_\nu \propto \nu^\alpha, \alpha > -0.5$)

high $dL/dt$, polar > 3%

often giant elliptical galaxy

larger $M_{\text{BH}}$

smaller $L_{\text{acc}}$ and $L_{\text{jet}}, L \ll L_{\text{Edd}}$

weak lines +superlum
Fermi AGN at $|b| > 10^\circ$

- 106 high-confidence (> 90%) associations
- 57 FSRQ, 42 Bl Lac, 5 uncertain
  - 40% Bl Lac (23% for EGRET)
  - 7 HBL (only 3+1 for EGRET)
- 2 radiogalaxies: Cen A, NGC1275
- 33/116 LAT sources at $|b| > 10^\circ$ seen by EGRET

$\theta_{95} \sim 0.14^\circ$ (EGRET 0.62°)
SED with blazar type

blazar sequence
Fermi AGN

- flux and hardness
  - ⇒ many more soon
- trend for fainter, harder Bl Lacs

PRELIMINARY
red and blue blazars

more powerful, softer FSRQ

\[ \langle E^{-2.33 \pm 0.01} \rangle \]

\[ \langle E^{-1.99 \pm 0.01} \rangle \]
spectral curvatures

IC curvature showing up for bright sources

3C454.3 (FSRQ)  AO 0235+165 (interm. BL)  Mkn501 (HBL)

PRELIMINARY
3C454.3

- spectral break at $E = 2.4 \pm 0.3$ GeV
- not a cooling break ($\Delta \alpha > 0.5$)
- $\gamma + \gamma_{\text{disc}}$ or $\gamma_{\text{corona}} \rightarrow e^\pm$ unlikely (very close to BH and no cascading in X rays detected)
- intrinsic electron break?

### Graphs

- Plot showing $v F_v [\text{erg cm}^{-2} \text{s}^{-1}]$ vs frequency [Hz] for various telescopes and periods.
- Graph showing $v F_v [\text{erg cm}^{-2} \text{s}^{-1}]$ vs $E$ (MeV).

**E - 2.27 ± 0.03**

**E - 3.5 ± 0.3**

**PRELIMINARY**
blazars with redshift

Fermi-LAT

FSRQ
BI Lac
unknown
radiogal

PRELIMINARY
blazar evolution?

logN-logS slope:
- all: $2.50 \pm 0.12$ (euclidian)
- FSRQ: $2.55 \pm 0.12$
- Bl Lac: $2.32 \pm 0.15$

$V/V_{\text{max}}$:
- $V_{\text{comoving}}$ where source / $V_{\text{maximum}}$ available for its detection
- 0.5 for uniform, non-evolving distribution in euclidian space
- all: $0.512 \pm 0.031$
- FSRQ: $0.645 \pm 0.043$ (more in past?)
- Bl Lac: $0.473 \pm 0.046$ (no evolution)
FSRQ variability

- PKS1502+106 ($z = 1.84$)
- rapid variability
- multi-λ campaign
  - γ-X: correlated no time lag
  - UV-opt: 4-day lag
  - mm: 1 month lag?
  - radio: 3 month lag?

PRELIMINARY
short flare, γ and X co-spatial, $E_{\text{rest frame}} \leq 140 \text{ GeV}$, $\tau_{\gamma\gamma} \propto \delta^{-5} L/\Delta t \Rightarrow \delta...$

- after ejection of VLBI core knot
- and E-field ordering

ExC (disc, BLR) emission or SSC...

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![Graph showing $E_\gamma \text{ [MeV]}$ vs $\log_{10}(\nu F_\nu) \text{ [erg s}^{-1}\text{ cm}^{-2}]$](image)
Bl Lac variability

PKS2155-304 (z = 0.12) in a low state
- 12-day multi-\(\lambda\) campaign
- SSC single zone, 3 power-law electron spectrum
  - \(E_e(X) > 120\) GeV
  - \(10 < E_e(\text{GeV-TeV}) < 120\) GeV
  - TeV is K-N dominated
- \(\Rightarrow\) \(X-\gamma\) time correlation
  - none expected, none seen
  - unlike in flare state
- \(\Rightarrow\) opt-TeV time correlation
  - none expected, but seen
  - \(\Rightarrow\) not SSC optical seeds
- \(\Rightarrow\) muti-zone model
$L_{\text{bol}} = 10^{36-38} \text{ W}$

radio-quiet or weak

spiral galaxy

NLR clouds? or jet/ISM interaction?

BLR in polarized light

Seyfert I

Seyfert II

QSO

BLRG

NLRG

accretion disk

dust+gas torus

$3 R_s$

$10^5 R_s$

lightdays

QSO

BLRG

NLRG

Seyfert I
accretion disk
dust+gas torus
BLR
BLR in polarized light
Seyfert I
Seyfert II
$L_{\text{bol}} = 10^{36-38} \text{ W}$
radio-quiet or weak
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NLR clouds? or jet/ISM interaction?
3 $R_s$
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lightdays
QSO
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NLRG
Seyfert II
Seyfert I
dust+gas torus
accretion disk
radio-loud Seyfert in γ rays!

- PMN J0948+0022 (Sey1 lines + radio-loud variable core, z = 0.58)
  - δ > 2.5 and θ < 22°
  - SED similar to FSRQ
    - confirms jet presence
    - Γ = 10, δ = 18
    - exC on BLR dominates
    - low-power FSRQ
- low-mass black hole
  - ⇒ low power
- high L/L_Edd = 0.4
  - ⇒ active jet
- any other?
NGC 1275

- nearby radiogalaxy (alias Perseus A or 3C84) in the Perseus cluster
- with blazar-like radio core
- piercing jets
NGC1275

- detected by LAT
- stable over 4 months, but variable between COS-B, EGRET, and LAT
  - γ-ray source = AGN, not the Perseus cluster or dark matter
- γ rays at large angle from slow+fast beams or decelerating jet
  - Ghisellini ’05 and Georganopoulos & Kazanas ’03
  - enhanced IC emission from the interaction of the two zones
pulsars
EGRET pulsars in a few days

PSR J1952+3252

PSR J1709-4429

PSR J1057-5226
pulsars: > 25 radio-loud (> 7 ms psr), > 14 radio-quiet
identified pulsars = 40% of the bright sources at low latitude
blind search: CTA 1

- $P = 316.86$ ms
- close peaks $\Delta \Phi \sim 0.2$, as in PSR B1706-44
- age $\approx 10$ kyr consistent with SNR and X-ray PWN
identified sources

3EG J1826-1302 (Eel)
3EG J1420-6038 (Rabbit)
3EG J1734-3232
3EG J1741-2050
3EG J0631+0642
3EG J1958+2909
3EG J1908+06
3EG J2020 γ Cyg
3EG J0357+32
3EG J2238+58
Cygnus region

Cyg OB2

LAT 95%

PSR J2021+4026

3 month survey
E > 450 MeV

PSR J2031+4026

dragonfly

PSR J2032+4119
ms pulsars

- many nearby ms pulsars detected
  - ⇒ large beaming fraction
  - J0218+4232 at 3.2 kpc confirmed
  - 6 with D < 500 pc, large É/D^2
  - a variety of shapes
accelerator sites

Vela: simple exponential cut-off ($b = 1$, $b = 2$ rejected at 16.5 $\sigma$)

- $\Rightarrow$ no evidence for $\gamma + B \rightarrow e^\pm$
- $\Rightarrow$ medium- to high-altitude accelerator gap

\[ N(E) = N_0 E^\Gamma e^{-\left(\frac{E}{E_c}\right)^b} \]

\[ \Gamma = -1.51^{+0.05}_{-0.04} \]

\[ E_c = 2.9 \pm 0.1 \text{ GeV} \]
different “antenna” patterns
- slot gap
- radio cone
- outer gap
- impact on true $L_\gamma/E_{\text{psr}}$ efficiency
sharp caustic peaks

ex:

- Vela (< 0.3 ms):
- Dragonfly:

- PSR J1028-5819:

\[ \delta \phi_{\gamma - \text{radio}} = 0.16 \pm 0.01 \text{ (improved systematic from DM)} \]

\[ \delta \phi_{\gamma} = 0.468 \]
multi-\(\lambda\) sub-structures

ex: Vela
phase separation and shifts

- a variety of $\Delta \phi(\gamma \text{ peaks})$ and $\Delta \phi(\text{radio-}\gamma)$
  - with age, luminosity...
  - ex: J2229+6114

![Graph showing phase separation and shifts](image)
phase-resolved spectroscopy

on its way...

ex: dragonfly
population studies

- simulations of $10^6$ pulsars for polar, slot, outer gap
- confrontation to observations

![Graphs showing Edot vs. Age and Fermi Pulsar Detections]
pulsar wind nebulae

Crab

Gamma-ray phase histogram above 100 MeV (50 bins)

PRELIMINARY

Spectral energy distribution of the Crab Nebula

on-going search for extended emission around pulsars
also toward IC 443, W44, W28...
other Galactic sources
inner Galaxy
inner Galaxy
massive stars

- unidentified source in Westerlund 2
- other WR coincidences toward crowded and confused Gal. center and Carina regions
- WR 140 & WR 147 not bright sources
LMC and 30 Doradus

- extended source + hot spot on 30 Doradus
- extension correlated with HI
systematic orbital modulation searches for many binaries

- LSI +61°303 source
  - modulated \( \Rightarrow \) identified

- LS 5039 under study

\( \gamma \)-ray binaries
26.5 day modulation

average spectrum $\approx E^{-2.41 \pm 0.03 \pm 0.17}$

non simultaneous spectra
47 Tuc

- ms pulsars? binaries?

- ok with 23 ms pulsars and 10% efficiency
fast transients

- bright & fast transients
  - released by ATels
  - http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/
  - 2 bright transients detected at low latitude (ATels 1771 & 1788)
- Swift, Chandra, and VLA follow-up observations in place
the stable GeV sky: the Milky Way
interstellar emission

- 80% of LAT photons
- no GeV excess
interstellar medium

gas

HI (LAB) Kalberla '05

HII <<

CO (CfA) Dame '01

dust

I(100 µm) IRAS Schlegel '98

dark gas Grenier '05

IR emission → N_{dust}: temperature correction
interstellar medium

gas

HI (LAB) Kalberla '05

HII <<

CO (CfA) Dame '01

dust

E(B-V) Schlegel '98

dark gas Grenier '05

IR emission $\rightarrow N_{dust}$: temperature correction
dark gas
dark gas

photons - IC
$E > 150\text{MeV}$

linear scale

HI

photons - IC - HI - CO

CO

$E(B-V)_{\text{res}}$
dark gas

- photons - IC
- E > 150 MeV
- linear scale
- HI
- CO
- E(B-V)_res
comparable N(H) column-densities in the 3 phases

problems with linear combination of ISM tracers in the Galactic plane...
more tomorrow

Fermi Science Support Center (http://fermi.gsfc.nasa.gov/ssc/)
W28

HII W28A2