Fermi-LAT gamma-ray observations of the Supernova remnant HB21

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on behalf of the Fermi Large Area Telescope Collaboration

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We present the analysis of Fermi Large Area Telescope (LAT) γ-ray observations of HB21, a mixed-morphology shell-type supernova remnant. Such supernova remnants are characterized by an interior thermal X-ray plasma, surrounded by a wider nonthermal shell emitting at radio frequencies. HB21 has a large angular size, making it a good candidate for detailed morphological and spectral studies with the LAT. The radio extension is 2°x1°, compared to the LAT 68% containment angle of ~1° at 1 GeV. To understand the origin of γ-ray emission, we compare LAT observations with other wavelengths that trace non-thermal radio synchrotron, nearby molecular clouds, shocked molecular clumps, and the central X-ray plasma. Finally, we model possible hadronic and leptonic emission mechanisms. We conclude that gamma-rays from HB21 are likely the result of electron bremsstrahlung or proton-proton collisions with an enhanced density due to interaction with the nearby clouds.

HB21 (G89.0+4.7)

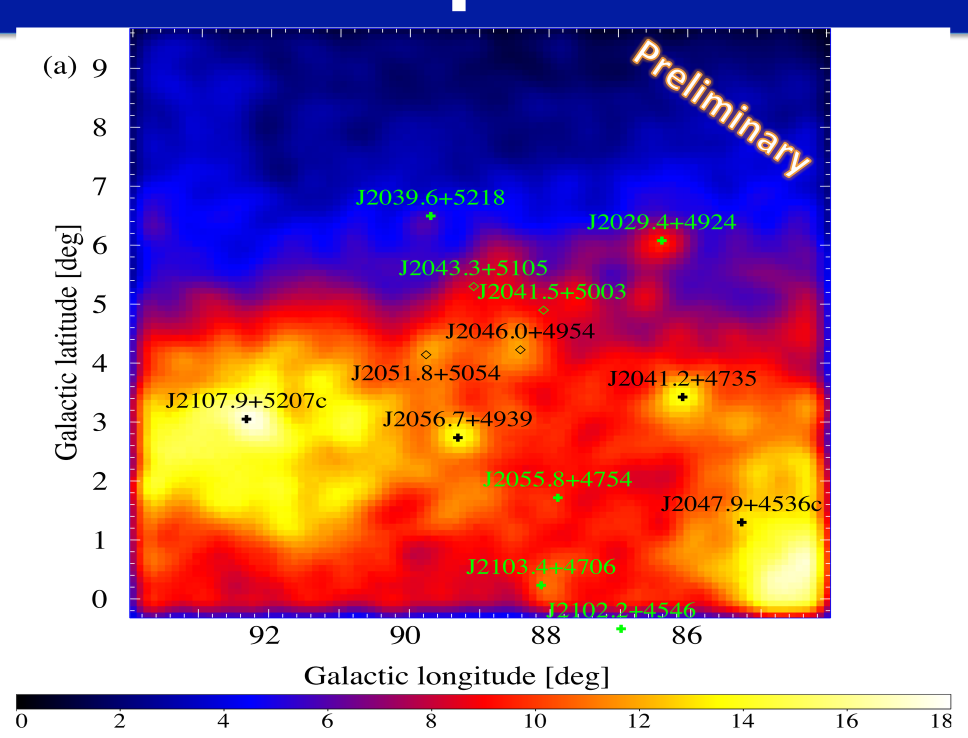
Characteristics:

- Mixed morphology, shell type SNR
- Radio coordinates: (89.0,+4.7) [1]
- Radio extension: 2°×1° [1]
- Age ~$4 \cdot 10^4$ yr [2]
- distance ~1.7 kpc [3]
- SN progenitor: Type Ib or II[4]

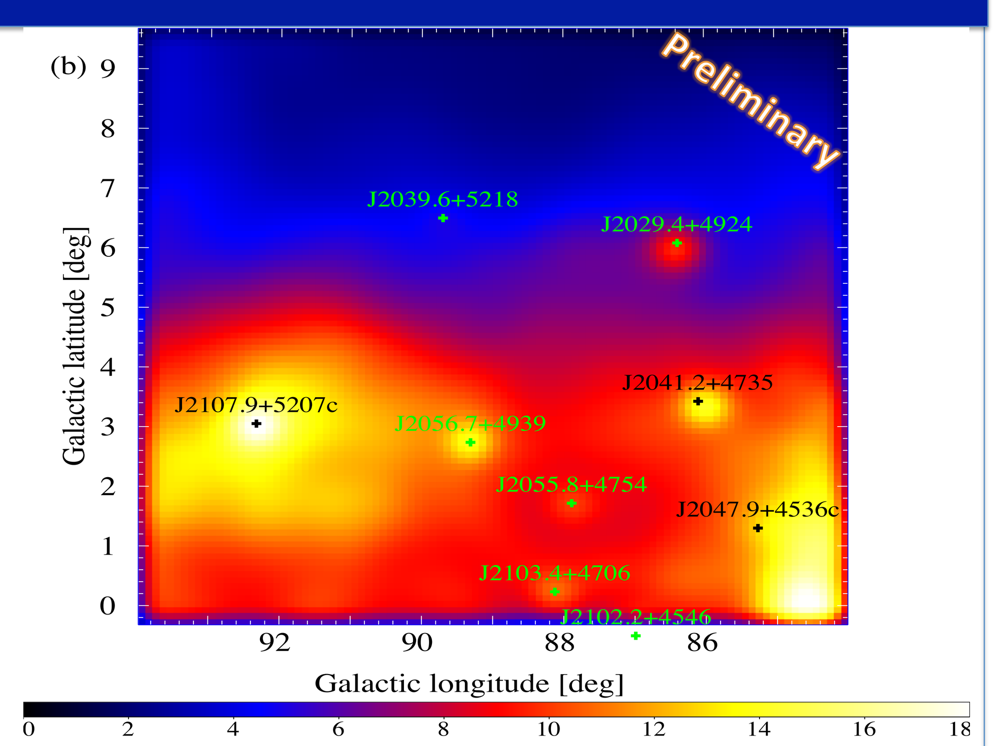
Data selection:

- ✓ Energy: 100 MeV – 300 GeV (SED)
  1 GeV – 300 GeV (morphology)
- ✓ Time: 08/04/2008 15:43:37
  06/14/2012 02:47:10
- ✓ Region of interest 10°×10°
- ✓ P7SOURCE selection, irfs P7V6

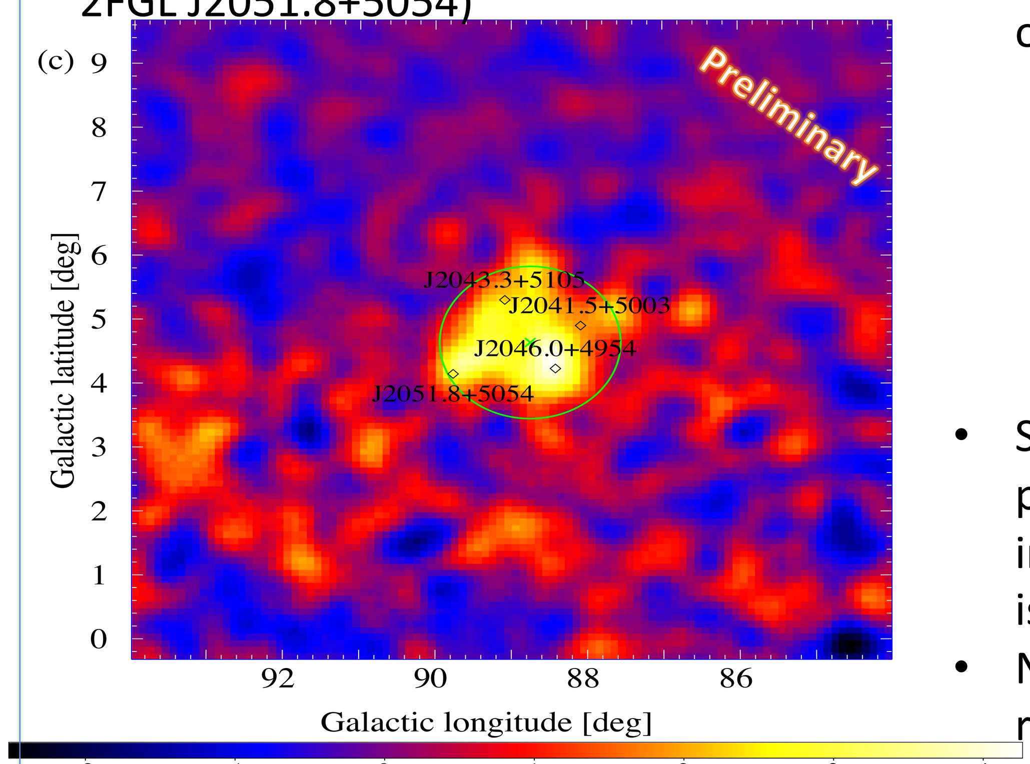
Counts maps



Counts map E>1GeV. Overlaid sources from 2FGL catalog (crosses= background sources, diamonds= three sources associated with the remnant and 2FGL J2051.8+5054)

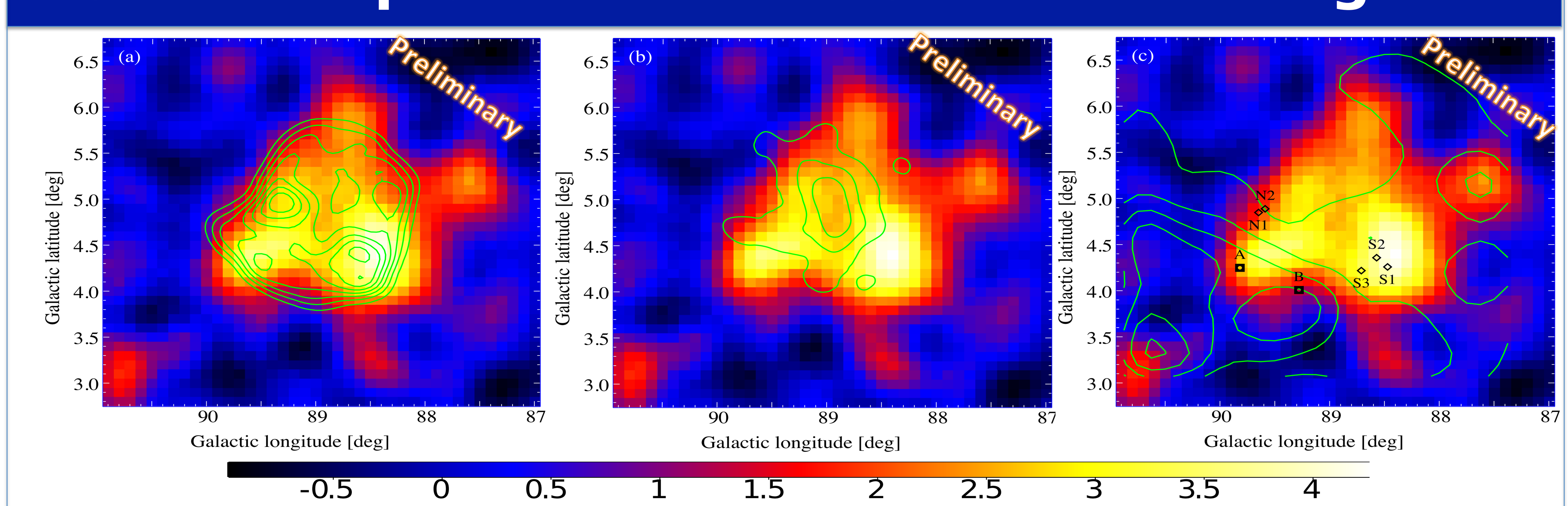


Background model map



- Remaining emission associated with HB21 (~29σ) overlaied with:
  - ✧ the positions of the four point sources above
  - ✧ best-fit disk determined from the LAT data centered at (l,b)=(88.75° ± 0.04°, 4.65° ± 0.05°) with radius = 1.19° ± 0.06°
- Systematic errors: disk shifted toward north-western part (shifts in longitude between 0.19° and 0. 24°, and in latitude between 0. 06° and 0. 09°), and the radius is smaller by 0. 18°– 0.24°
- No spectral variations found splting the disk into two regions
- Emission modeled with a disk (2FGL J2051.8+5054 not considered as separate source)

Counts map overlaid with other wavelengths



Radio emission at 6 cm (Sino-German 6 cm Polarization Survey of the Galactic Plane)[6]. Seven contour levels are linearly spaced from 0 Jy arcmin^{-2} to 322 Jy arcmin^{-2}

Background-subtracted X-ray emission (ROSAT). Three contour levels linearly spaced form 0.36×10^{-3} to 2.13×10^{-3} counts s^{-1} arcmin^{-2}

Intensities of the 2.6 mm CO line (Dame et al 2001-2011) integrated in the velocity range between –20 km s^{-1} and +20 km s^{-1}. Six contour levels linearly spaced from 1.5 K km s^{-1} to 28 K km s^{-1}. Cloud A appears from 9 km s^{-1} to -6 km s^{-1} and cloud B appears from 1 km s^{-1} to -9 km s^{-1}. Diamonds are shocked molecular clouds[5].

γ-ray emission

✧ is brighter than X-ray emitting plasma

✧ compares well with radio shell even if it extends beyond the radio shell in a region where molecular clouds are present

Systematic errors study

see F.de Palma's poster: A Method for Estimating Galactic Diffuse Systematics: Application to the Fermi-LAT SNR Catalog

Effective area (EA) errors: 10% @ 100MeV, 5% @ 516 MeV and 10% above 10 GeV[7]

Interstellar emission model (ISM)

Compare results obtained with 8 differents models ♭ changing

- ✧ spin temperature of atomic hydrogen (150 K and 105 K)
- ✧ height of CR propagation halo (4 kpc and 10 kpc)
- ✧ CR source distribution in the Galaxy (Lorimer (2006) and SNR distribution by Case&Bhattacharya (1998))

Models have 4 more degrees of freedom (compared to 1 dof of the standard background):

- 2 d.o.f. for atomic hydrogen maps
- 1 d.o.f. for molecular hydrogen (traced by CO) map
- 1 d.o.f. for Inverse Compton map

Total error calculation

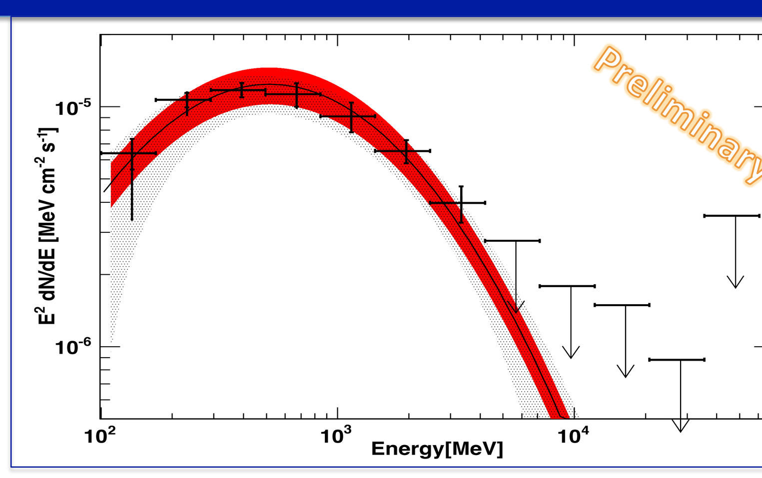
Systematic error: standard deviation approach

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n_{alternative}} (x_{alternative} - x_{standard})^2}{n_{alternative}}}$$

Total systematic error: $\sigma_{total} = \sqrt{\sigma_{EA}^2 + \sigma_{ISM}^2}$

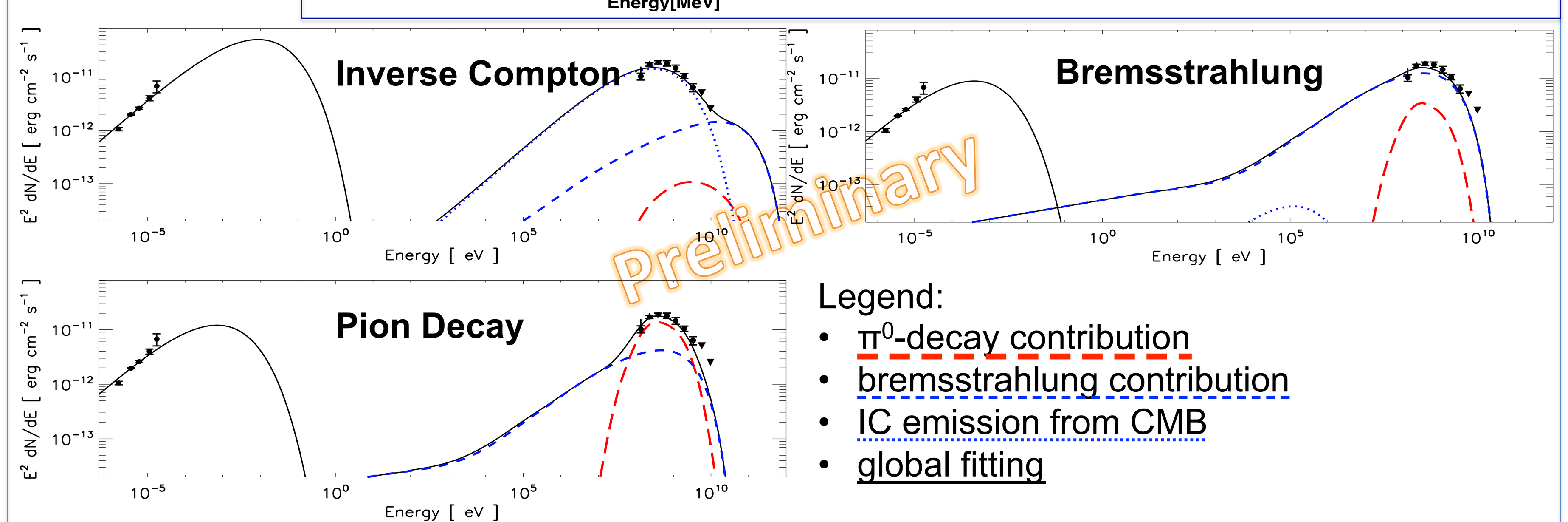
Spectral energy distribution modeling

Spectrum fitted with logParabola because it is preferred at 9σ



Legend:

- T bars: statistic errors
- bars: total systematic errors
- upper limits: statistical errors
- black line: global fit
- statistic error on global fit
- total systematic error on global fit



Legend:

- π^0-decay contribution
- bremsstrahlung contribution
- IC emission from CMB
- global fitting

model	Index	p_{max} [GeV/c]	n_H [cm^{-3}]	B_{tot} [μG]	η_e/η_p	W_p [erg]	W_e [erg]
IC	1.76	200	0.1	3	1	1×10^{49}	4×10^{49}
Brems.	1.76	4	10	100	0.1	5×10^{49}	4×10^{49}
π^0-decay	1.76	6	10	100	0.01	2×10^{49}	1×10^{49}

total γ-ray luminosity above 100 MeV: $(3.3\pm1.5)\times10^{34}$ erg s^{-1}

Conclusions

- ✓ γ-ray emission originated from collision of shock-accelerated particles with interstellar matter. Hypothesis supported by:
  - emission modeled with a disk
  - γ-ray emission may extend beyond the radio shell
  - brightest γ-ray emission coincides with known shocked molecular clumps
  - no spectral variations found
- ✓ γ-emission dominated both by π^0 decay due to nuclei or by bremsstrahlung from energetic electrons (IC disfavoured because of the low interstellar density needed)
- ✓ total energy:
  hadronic-dominated scenario: ~2×10^{49} ergs
  leptonic-dominated scenario: electrons ~4×10^{49} ergs

References and notes

1) Green D.A., 2009, Bulletin of Astronomical Society of India, 37,45
2) Pannuti et al., 2011, The Astronomical Journal, 140, 1787
3) Byun at al., 2006, The Astrophysical Journal, 637, 283
4) Knödlseder et al., 1996, Astronomy & Astrophysics, 4, 120
5) Koo et al., 2001, The Astrophysical Journal, 552, 175
6) Xiao L. et al., 2011, Astronomy and Astrophysics, 529
7) M.Ackermann et al. 2012, ApJS, 203, 4

♭) alternative models developed by: F. de Palma, G. Johannesson, L. Tibaldo, T. J. Brandt, J. Ballet, J. W. Hewitt, and F. Acero.