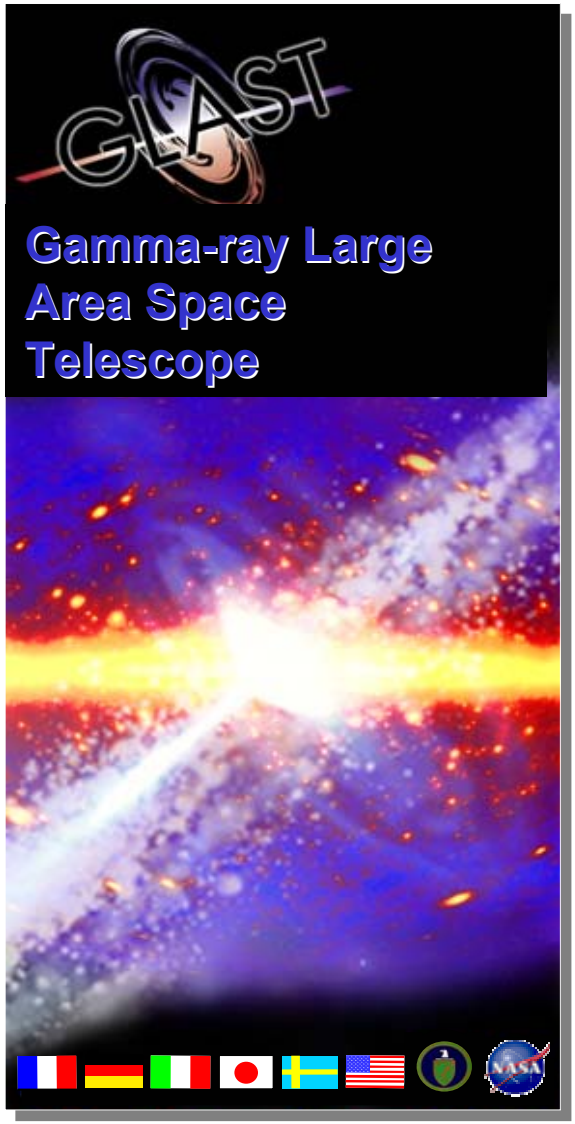

Multifrequency Strategies for the Identification of Gamma-Ray Sources

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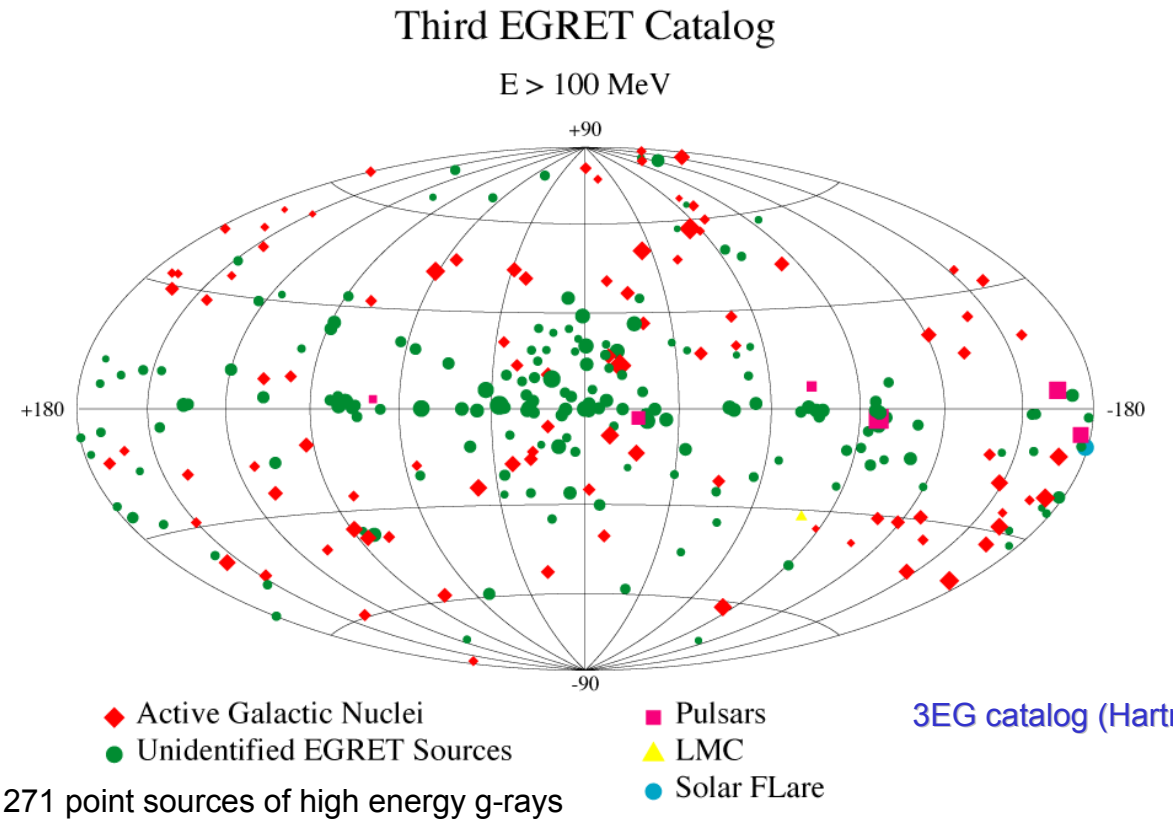
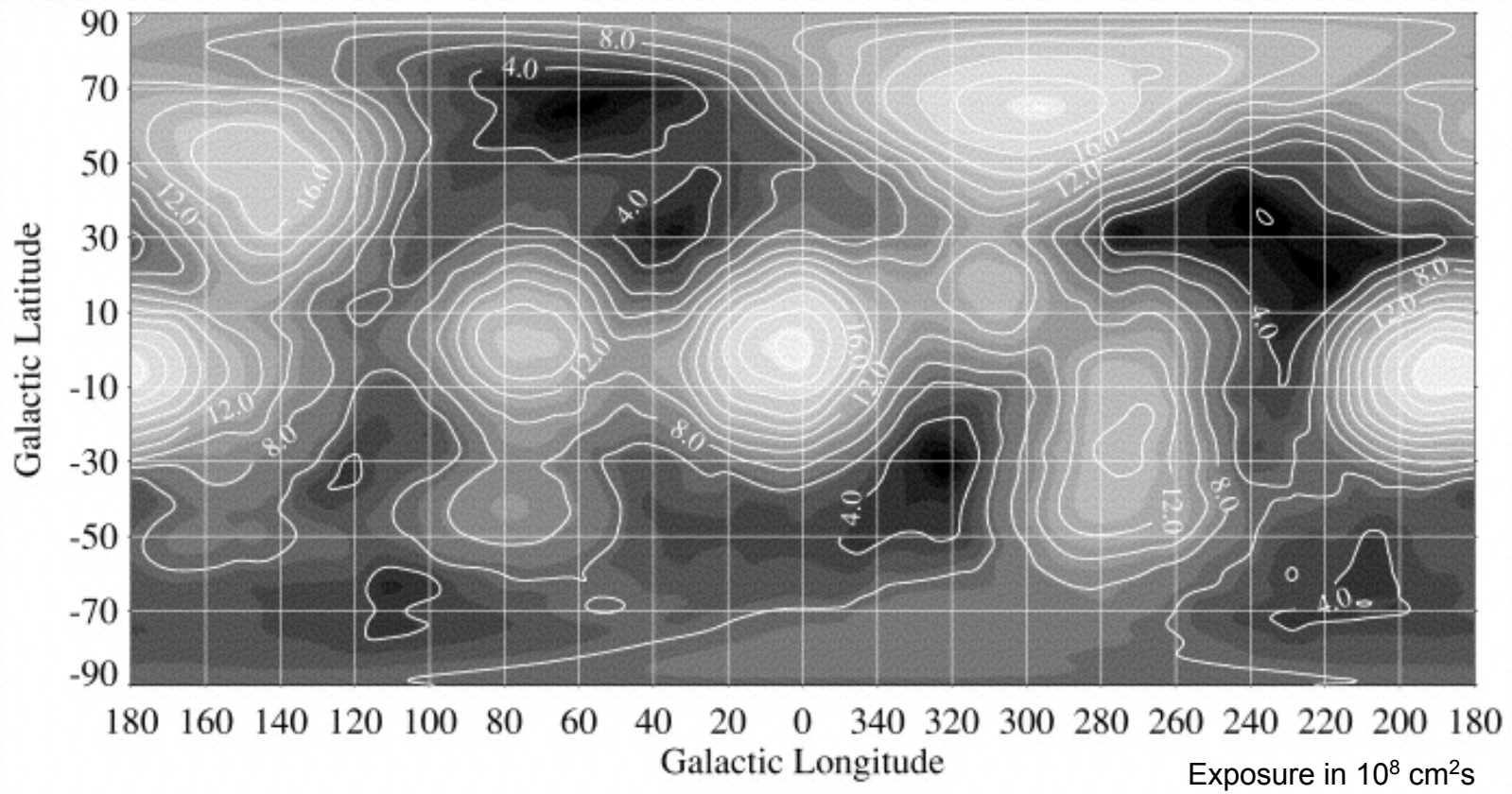
3EG catalog



3EG catalog (Hartman et al. 1999)

271 point sources of high energy g-rays
5 pulsars
1 solar flare
66 high-confidence blazar identifications
27 possible blazar identifications
1 likely radio galaxy (Cen A)
1 normal galaxy (LMC)
170 unidentified sources.

EGRET source sensitivity



Significance of detection S ~ F $\sqrt{E/B}$ (F=flux, E=exposure, B=background)
Two criteria for source detection:
5σ for |b| < 10º and 4σ for |b| > 10º

Challenges in the identification process

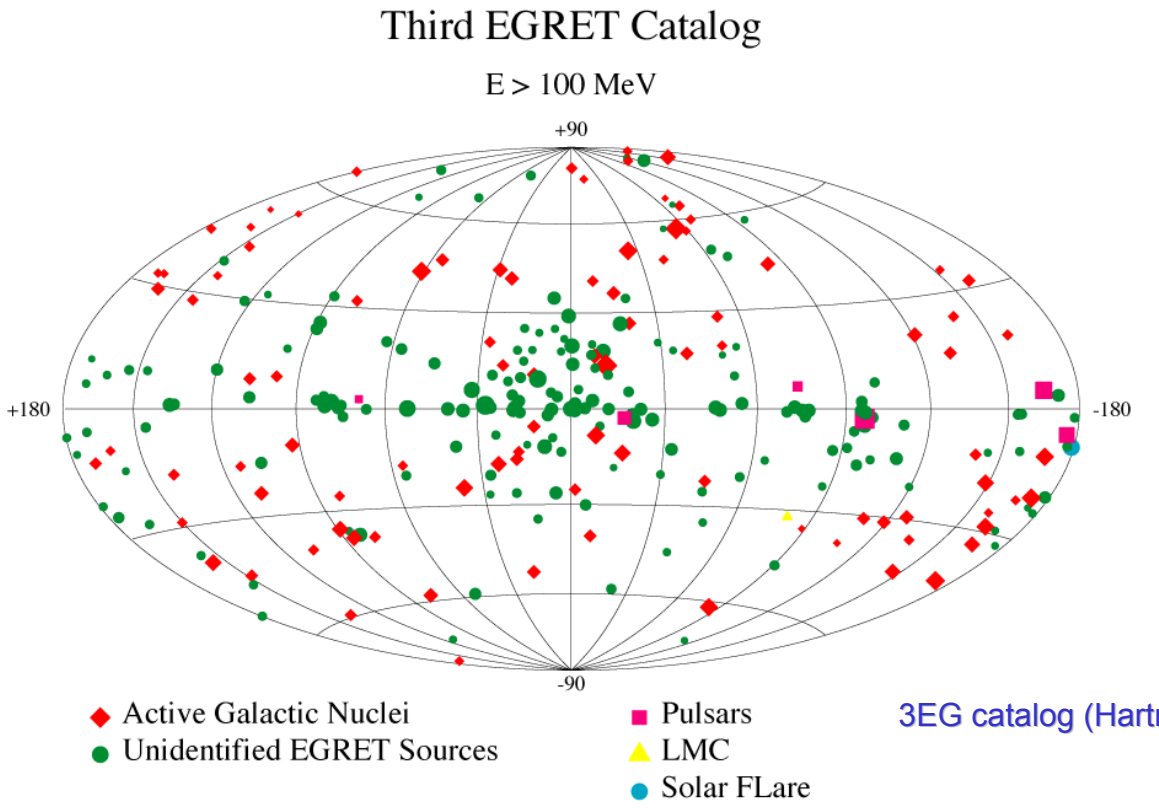
The error box of a typical egret source is large ~ 0.5º - 1º

The identification of Low latitude sources gets hampered by the bright Galactic diffuse emission along the plane.

Lack of correlation between the γ-ray flux and for example X-ray flux

Counterpart searches of γ-ray sources usually start with looking for “more of the same” kinds of sources.

3EG catalog



3EG catalog (Hartman et al. 1999)

- All pulsars detected by EGRET are at low latitudes
- Blazars are isotropic on the sky

Characteristics of EGRET Balzars

The blazars seen by EGRET all share several common characteristics:

- radio-loud (> 500 mJy)

- flat spectrum with radio spectral indices $0.6 > \alpha > -0.6$

- they have a continuum spectrum that is non-thermal

- characterized by strong variability

- optical polarization

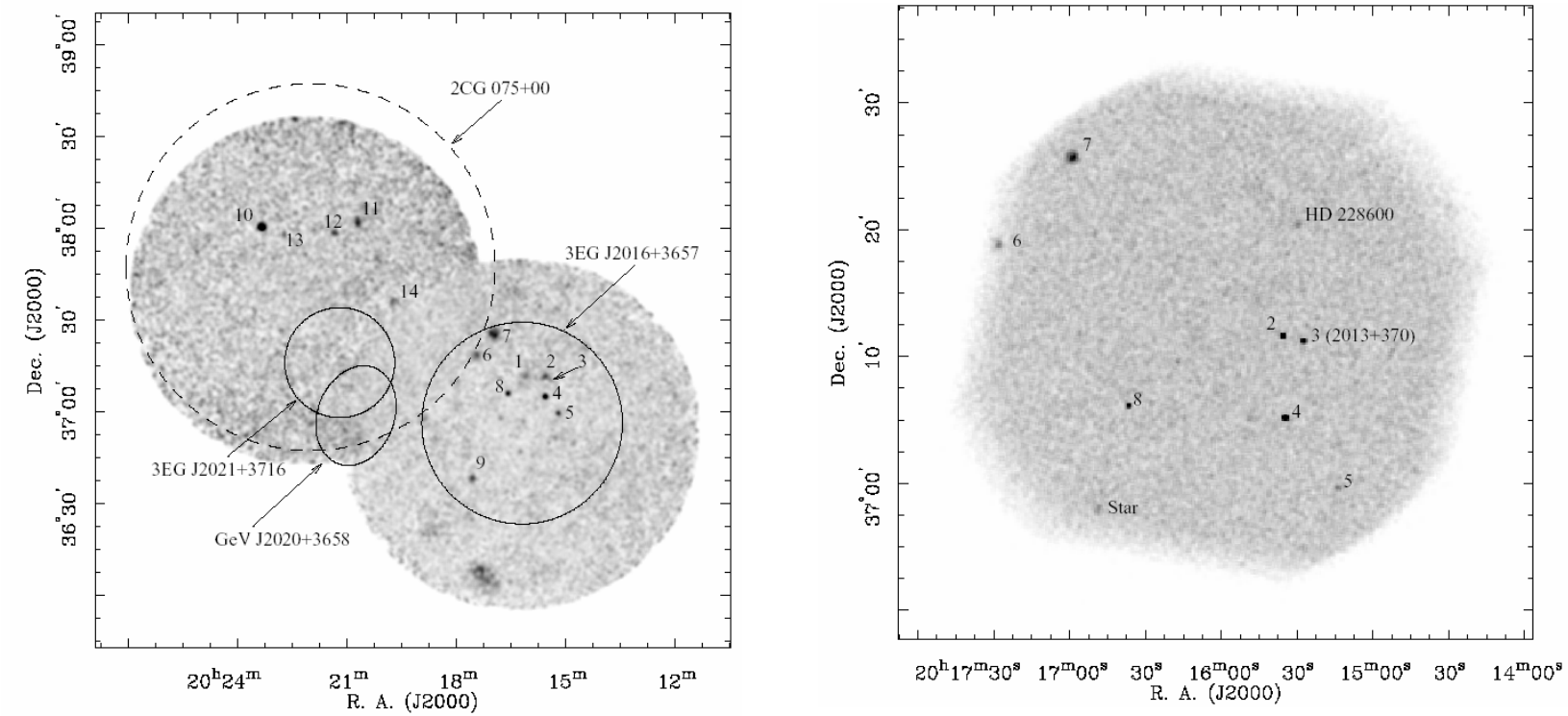
A Blazar counterpart for 3EG J2016+3657

This is a low-latitude EGRET source

3EG J2016+3657 & 3EG J2021+3719 are two sources in the Cygnus region probably associated with the unidentified COS-B source 2CG 075+00 (Pollack et al. 1985).

The error circles of both 3EG J2016+3657 & 3EG J2021+3716 are covered by archival X-ray imaging observations with ROSAT (PSPC and HRI) and ASCA, as well as Einstein IPC (Wilson 1980).

ROSAT soft X-ray image



(Left): ROSAT soft X-ray image of 3EG J2016+3657 and 3EG J2021+3716. The circles for the two 3EG sources correspond to the ~95 % confidence contours. The dashed circle corresponds to the COS-B source 2CG 075+00. The GeV Catalog source (Lamb & Macomb 1997) is also shown. The minimum detectable intrinsic flux for the ROSAT image was 6.5 x 10^{-13} erg cm^{-2} s^{-1}.
(Right): ROSAT HRI X-ray image of the field around 3EG J2016+3657. The image shows the sources 2 and 3 (B2013+370) as clearly resolved point sources. Both figures are from Mukherjee et al. (2000).

Optical identification of X-ray sources

Optical observations with the MDM 2.4m and the KNO 2.1m provided optical identification of all X-ray sources.

Other than source #1 and #3, the sources in the EGRET fields are either cataclysmic variables (CVs) or Wolf-Rayet stars or binary O stars. All unlikely to be γ-ray emitters.

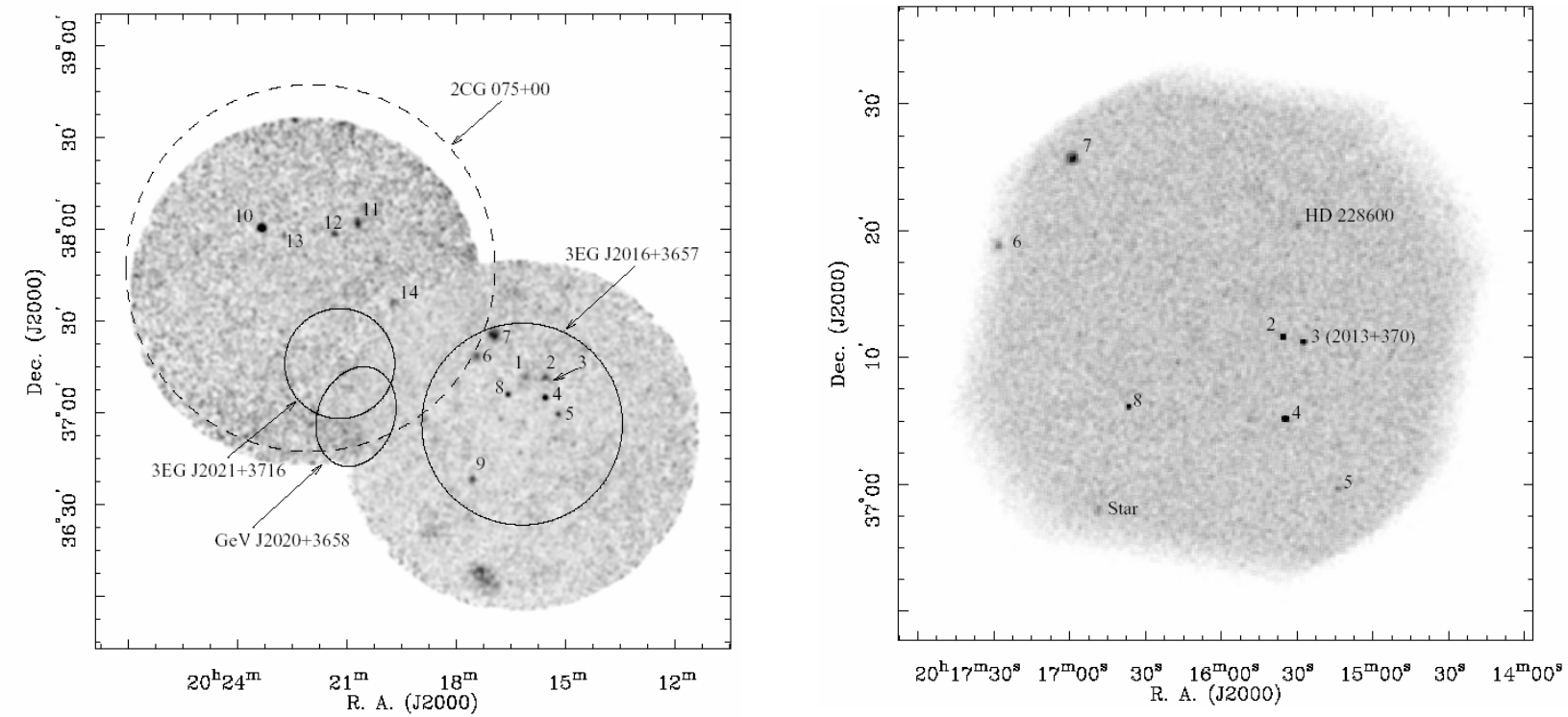
source #1:
supernova remnant (SNR) CTB 87
- too weak and too far away => disfavored

source #3:
blazar-like radio source B2013+370
=> favored counterpart

Other characteristics of B2013+370 support identification with 3EG J2016+3657
- compact, extragalactic, non-thermal radio source
- variable at optical and mm
- a 5 GHz flux of 2 Jy.

The spectral energy distribution (SED) of 3EG J2016+3657 is characterized by a synchrotron peak at lower energies, a Compton peak at higher energies, with most of the power output in γ-rays.

ROSAT soft X-ray image



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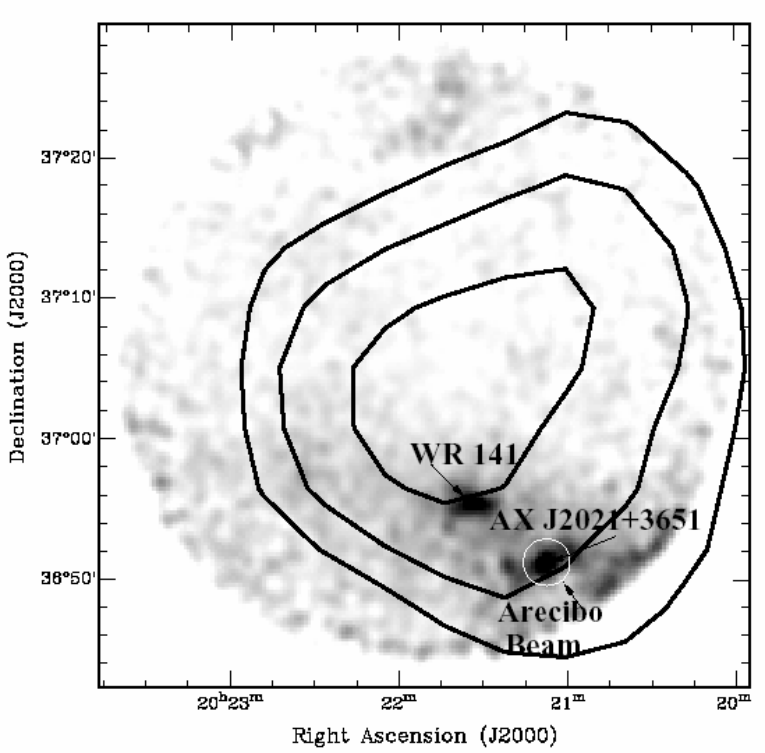
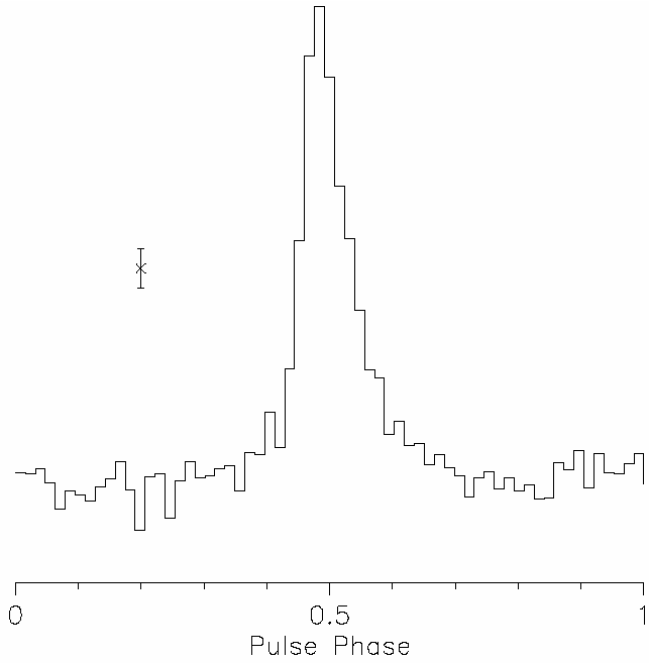
3GE J2021+3716: The young radio pulsar PSR J2021+3651



ASCA GIS image (2- 10 keV) of the error box of the γ-ray source GeV J2020+3658. The contours correspond to 68%, 95% and 99% confidence levels. The position of the ASCA unidentified hard X-ray source, suggested as the counterpart of the EGRET source, is shown.

Roberts et al. (2002) observed AX J2021.1+3651 with the Wideband Arecibo Pulsar Processor (WAPP) and discovered a new young and energetic pulsar PSR J2021.1+3651, which they argue is the counterpart to the EGRET source GeV J2020+3658.

3GE J2021+3716: The young radio pulsar



Pulsar profile of PSR J2021+3651 at 1.4 GHz.
Figure fromRoberts et al. (2002)

The positional coincidence of the pulsar with GeV J2020+3658, the hard spectrum of the EGRET source, and its low variability, and the fact that Roberts et al. (2002) find high inferred spin down luminosity for the pulsar strongly argue that the two sources are related.

3EG J2027+3429: An other blazar behind the galactic plane?

3EG J2027+3429, also in the Cygnus region,

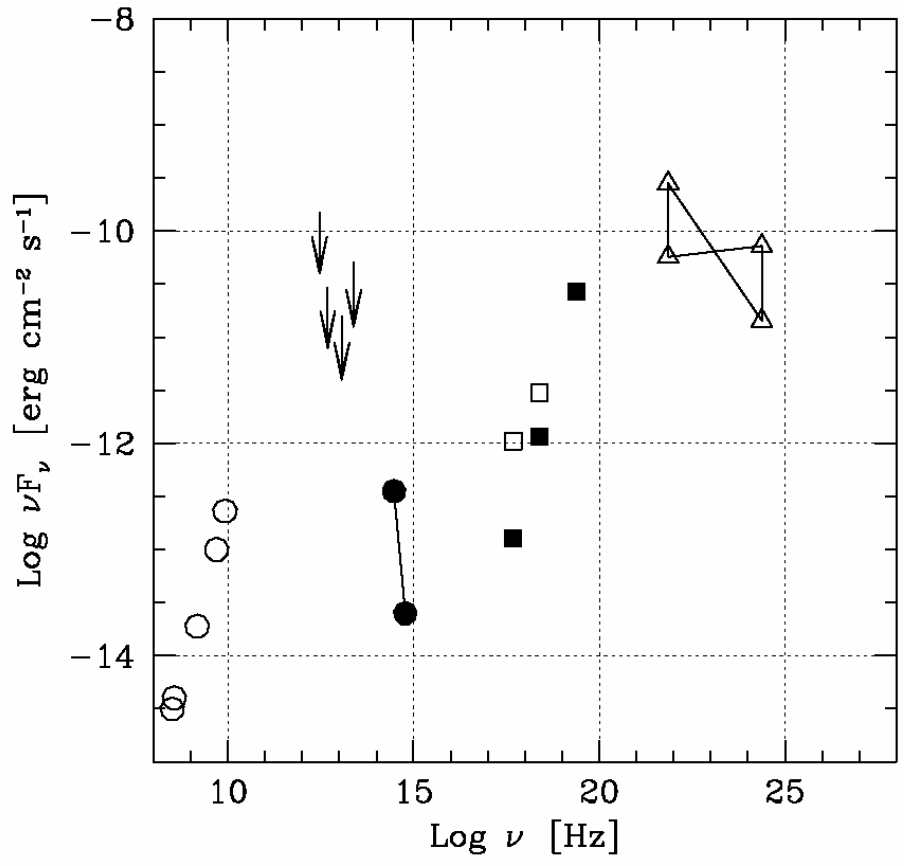
Using a multiwavelength strategy, Sguera et al. (2003) have suggested the BeppoSAX X-ray source WGA J2025.1+3342, to be associated with the EGRET source.

WGA J2025.1+3342 is highly variable at X-ray energies, has a at spectrum in the range 1-100 keV.

At radio wavelengths, the source was found to have a flat spectrum in the range 0.3-10 GHz, and is a bright, compact object.

Optical observations of the source by Sowards-Emmerd et al. (2003) suggest that the spectrum has emission lines of the Balmer series, and is therefore a quasar at z = 0.219.

Spectral energy distribution (SED)



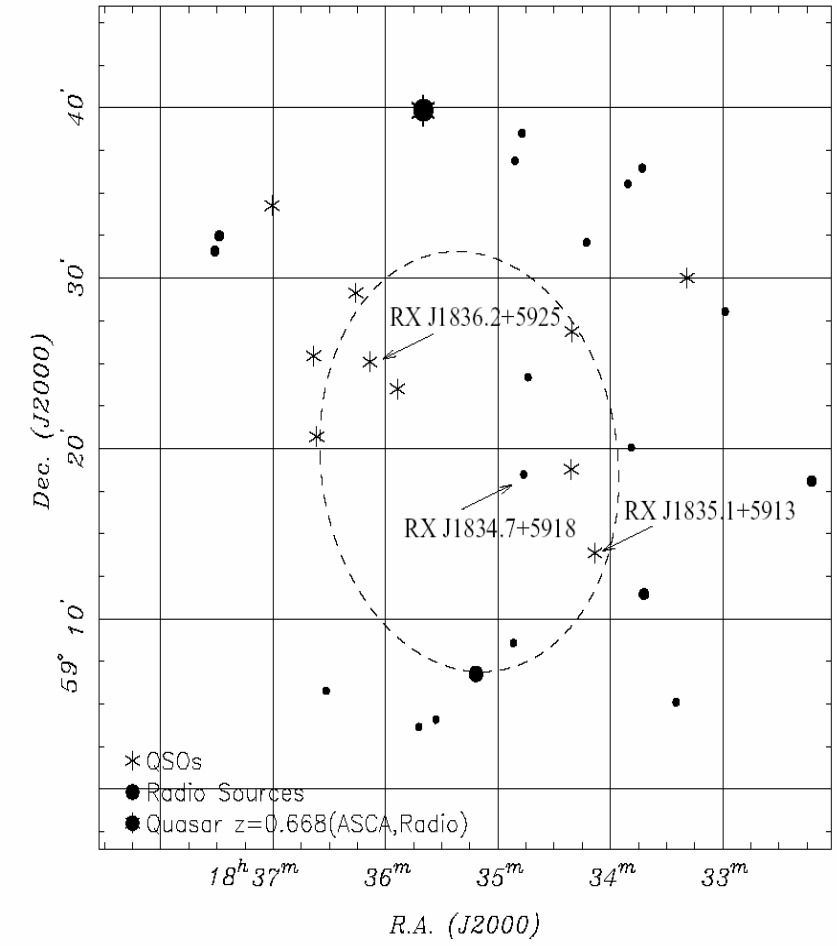
Spectral energy distribution (SED) of 3EG J2027+3429, assuming that it is associated with the X-ray source WGA J2025.1+3342. The symbols are as follows: open circles - radio, filled circles - optical, open and filled squares - BeppoSAX, triangles - EGRET. The arrows correspond to IRAS upper limits. Note the synchrotron and inverse Compton humps characteristic of EGRET blazars. Figure from Sguera et al. (2003).

3EG J1835+5918: A Radio quiet neutron star

3EG J1835+5918 is the brightest and most accurately positioned unidentified EGRET source.

- location is at high Galactic latitude l = 88.74º, b = 25.07º
- localized within a radius of 12’ at 99% confidence
- spectral index in the 70 MeV to 4 GeV range of -1.7
- no strong evidence of variability

Analysis of radio data



RX J1835.1+5913
brightest quasar

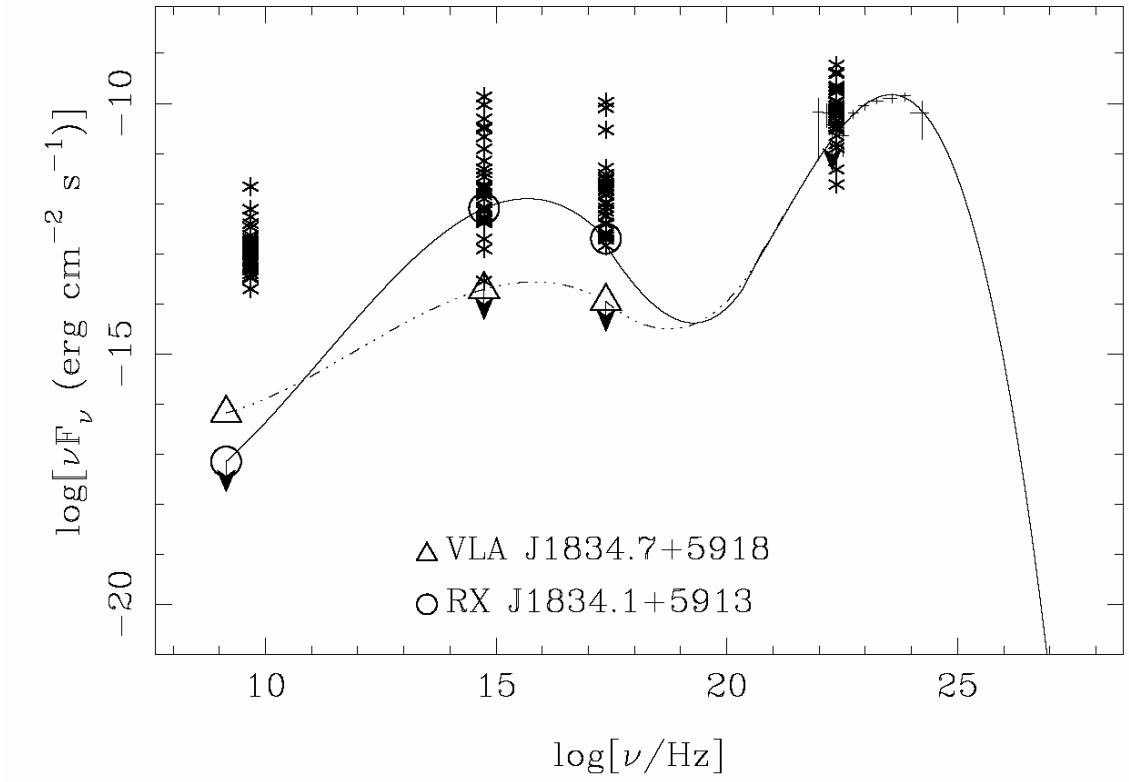
VLA J1834.7+5918
brightest of three weak radio sources

RX J1836.2+5925
has no optical counterpart

Positions of quasars (*asterisks*) and radio sources (*filled circles*) in the field of 3EG J1835+5918. Radio sources have been drawn in proportion to their 1.4 GHz fluxes.

Multiwavelength parameters

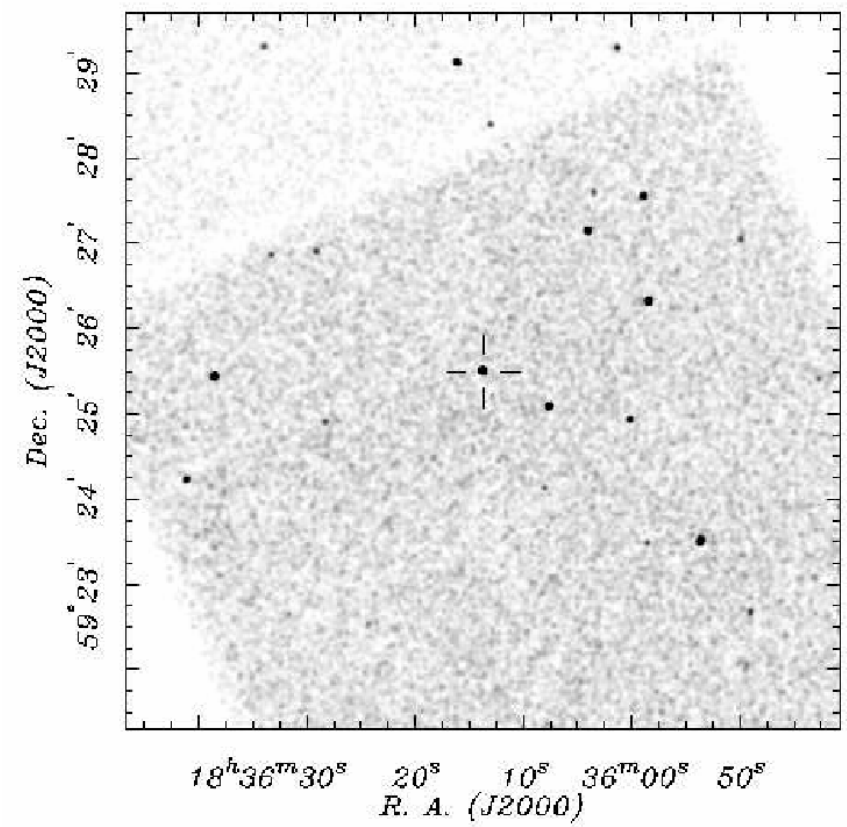
Radio, optical, X-ray and γ-ray fluxes for well identified blazars



Both candidates are at the faint end of the distribution

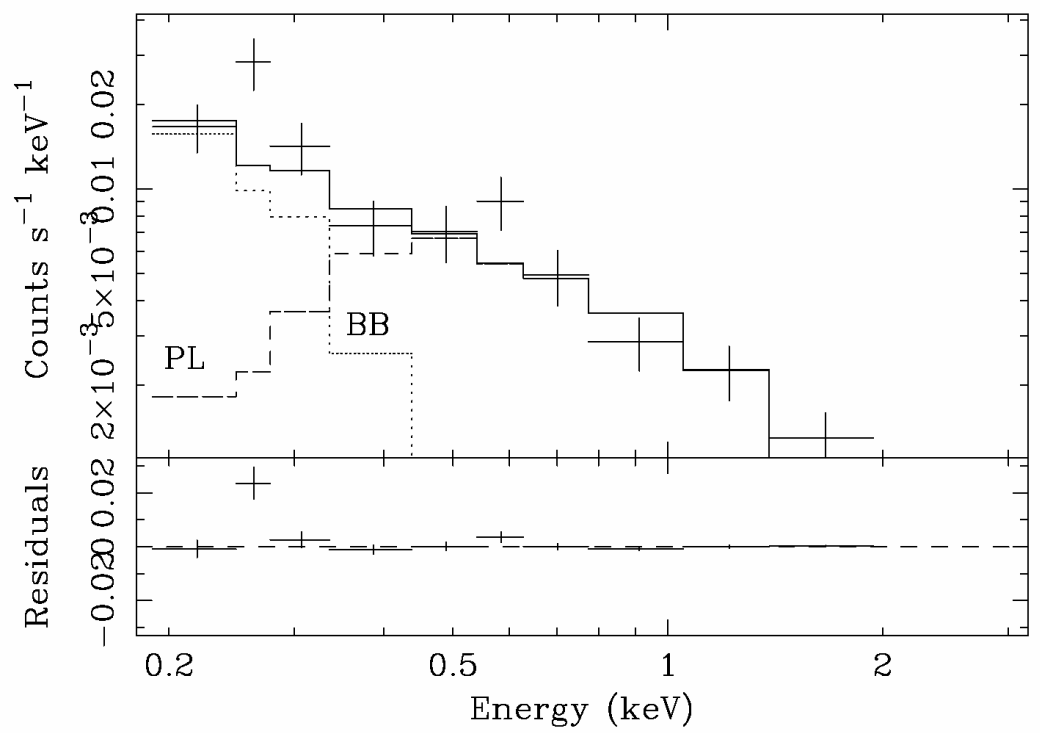
➡ unlikely that 3EG J1835+5918 is a blazar

Chandra image



Smoothed *Chandra* ACIS-S3 image centered on the source
RX J1836.2+5925 (*cross*).

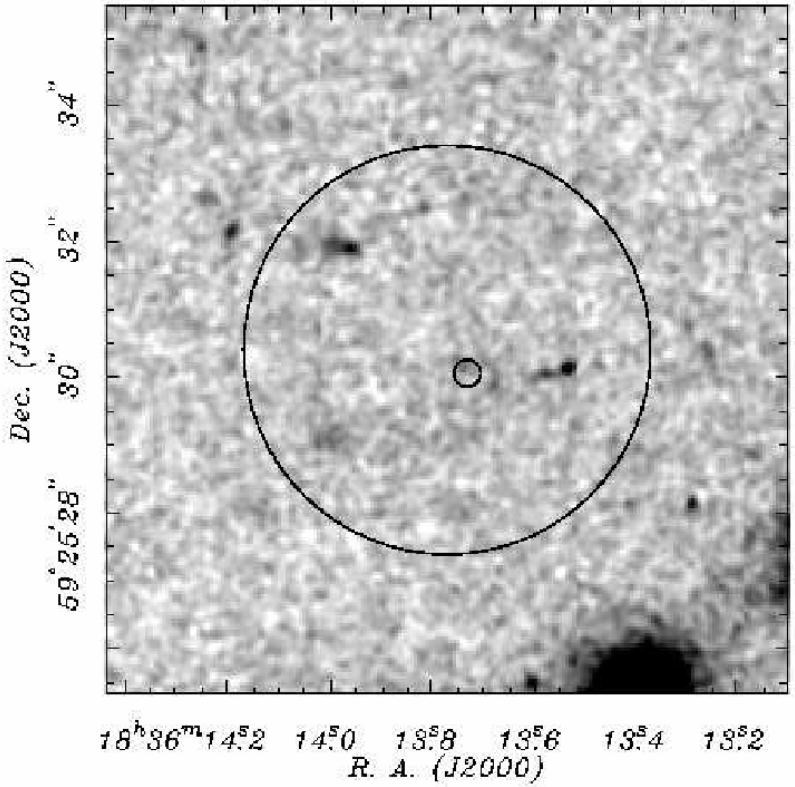
Chandra ACIS-S3 spectrum



Precise astrometry of the ACIS image in the USNO-A2.0 optical reference frame was achieved by registration of four previously identified, “bright” X-ray sources with their optical counterparts on the MDM 2.4m *V*-band CCD image *Chandra* ACIS-S3 spectrum of RX J1836.2+5925, the neutron star counterpart of 3EG J1835+5918. *Top panel*: Data (*crosses*) and best-fit model (*thick line*) for an assumed *N*H = 4.6×1020 cm-2 (see text). Contributions of the blackbody (*dotted line*) and power law (*dashed line*) components are shown. *Bottom panel*: Difference between data and model, in the same units as the top panel.

=> Spectrum of an ultra soft source

HST STIS CCD Imaging



Smoothed, open filter *HST* STIS image centered on the X-ray source RX J1836.2+5925. The 3″ radius error circle from the *ROSAT* HRI, and the 0.″2 radius *Chandra* error circle are shown. The limiting magnitude of this image is equivalent to $V = 28.8$.

At the northeast edge of the *Chandra* error circle there is only a marginal source of V 29.0±0.4 in the STIS 50CCD image.

Since this is not even a 3σ detection, we consider that the X-ray source is formally undetected optically,

The absence of an optical detection places additional constraints on the distance and temperature of the neutron star RX J1836.2+5925
***d* > 250 pc**.

Conclusions for 3EG J1835+5918

The results of these deep X-ray, optical, and radio observations are quite revealing of the properties of RX J1836.2+5925.

Without exception they support the hypothesis that it is an older and possibly more distant cousin of the Geminga pulsar, and readily identifiable with the EGRET source 3EG J1835+5918

The X-ray source, which is primarily an ultra soft blackbody of $T_\infty = 3\times10^5$ K, is significantly cooler than the oldest "ordinary" γ-ray pulsar Geminga $T_\infty = (5.6\pm0.6)\times10^5$ K.

At the same time, the difference in temperature is not sufficient to account for the factor of 40 difference in soft X-ray flux between Geminga and RX J1836.2+5925, so the latter may be as far away as 800 pc, as compared to $d \sim 200$ pc for Geminga.