PSR J1907+0602: A Radio-Faint Gamma-Ray Pulsar Powering A Bright TeV PWN

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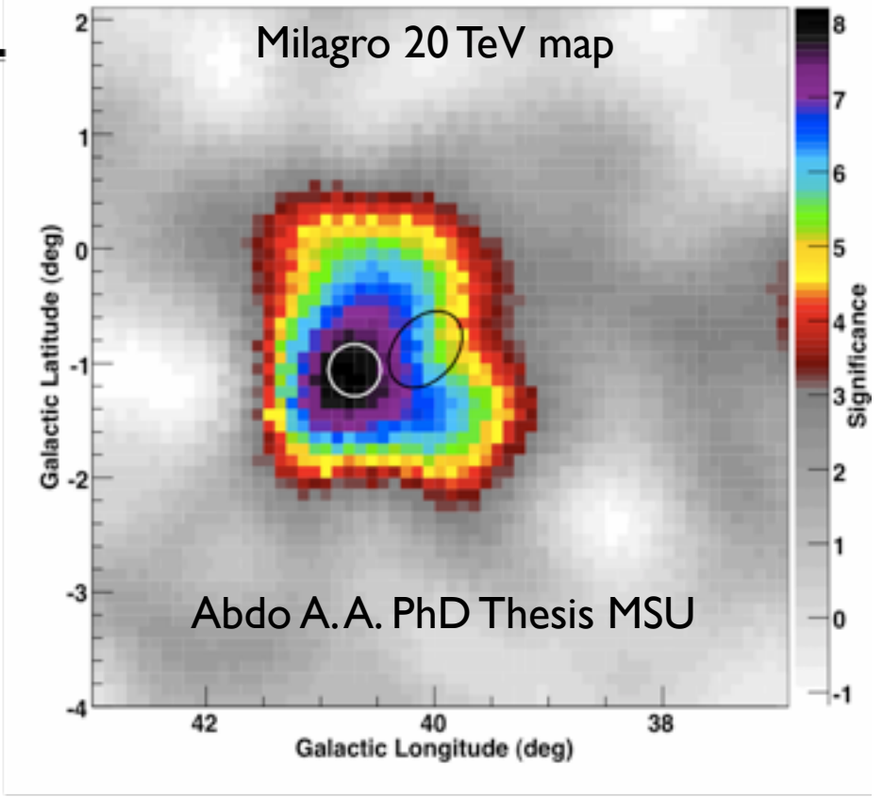
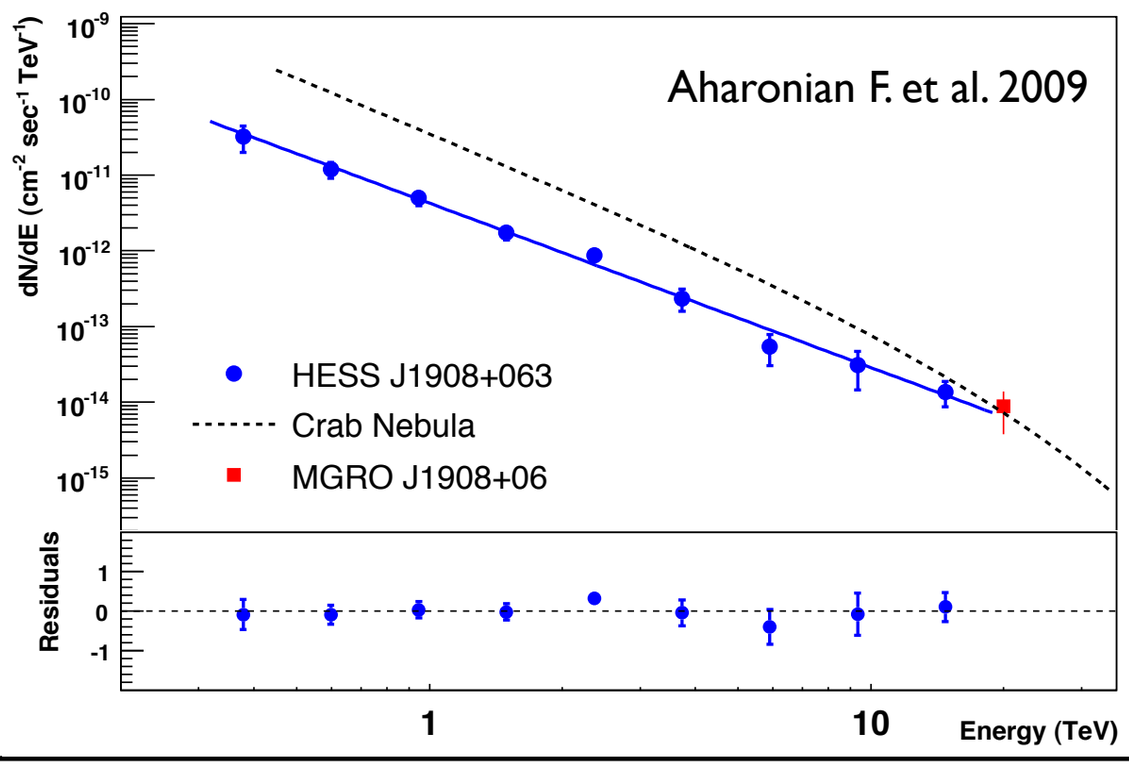
A Quick Summary

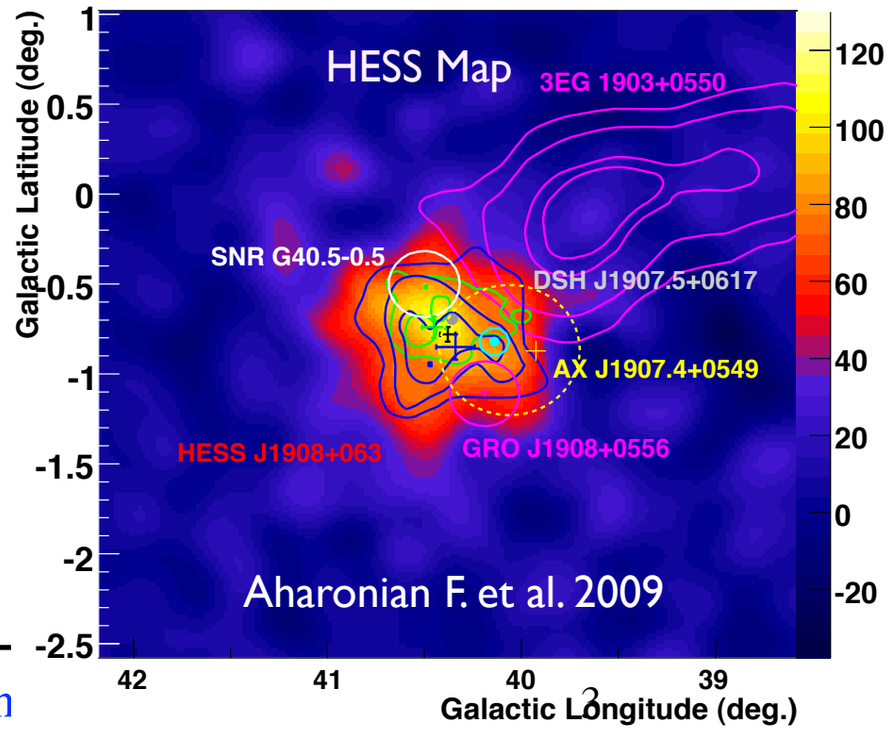
- History
  - MGRO J1908+06, an extended TeV source discovered with Milagro at median energies of 20 TeV.
  - Spectrum measured by other ground-based TeV telescopes at lower energies (0.3 - 20 TeV) (HESS and VERITAS)
- What's new here?
  - We have discovered a pulsar in a blind search with the *Fermi* LAT within the Milagro source.
  - Detected an X-ray source with Chandra with spectrum consistent with neutron star.
  - Detected weak radio pulsations with the Arecibo radio telescope.
  - Submitted to ApJ

TeV Observations

- Extended TeV gamma-ray emission with ~0.3 degree extension.
- Photon index of 2.1 and a flux at 20 TeV 80% that of the Crab nebula.



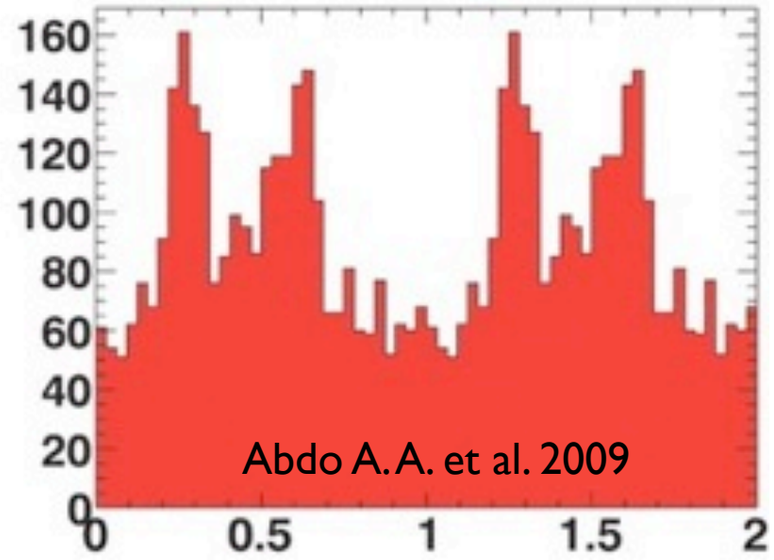


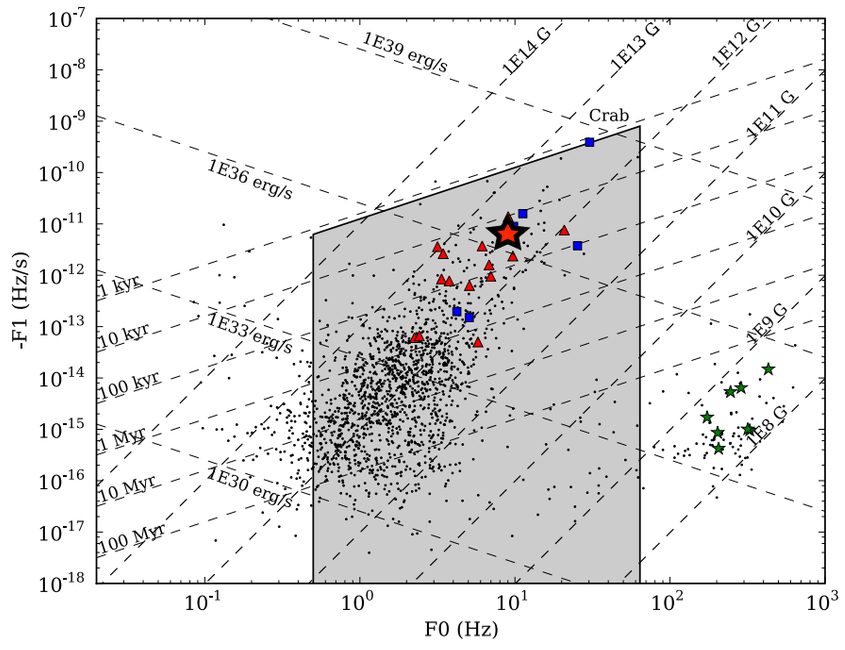


Discovery of the Pulsar

- We discovered a 106.6 ms pulsar in a blind period search of LAT data.
- 19,000 year spin-down age
- 3.1 x 10^{12} gauss
- 2.8 x 10^{36} ergs s^{-1}
- best fit location of RA= 286.965 , DEC = 6.022

~5 months of data





Localization

- Improved analysis techniques allow us to fit for position when timing the pulsar.
- This gives a very accurate position determination down to few arcsecond accuracy.
- This is crucial for multi wavelength follow-up observations.

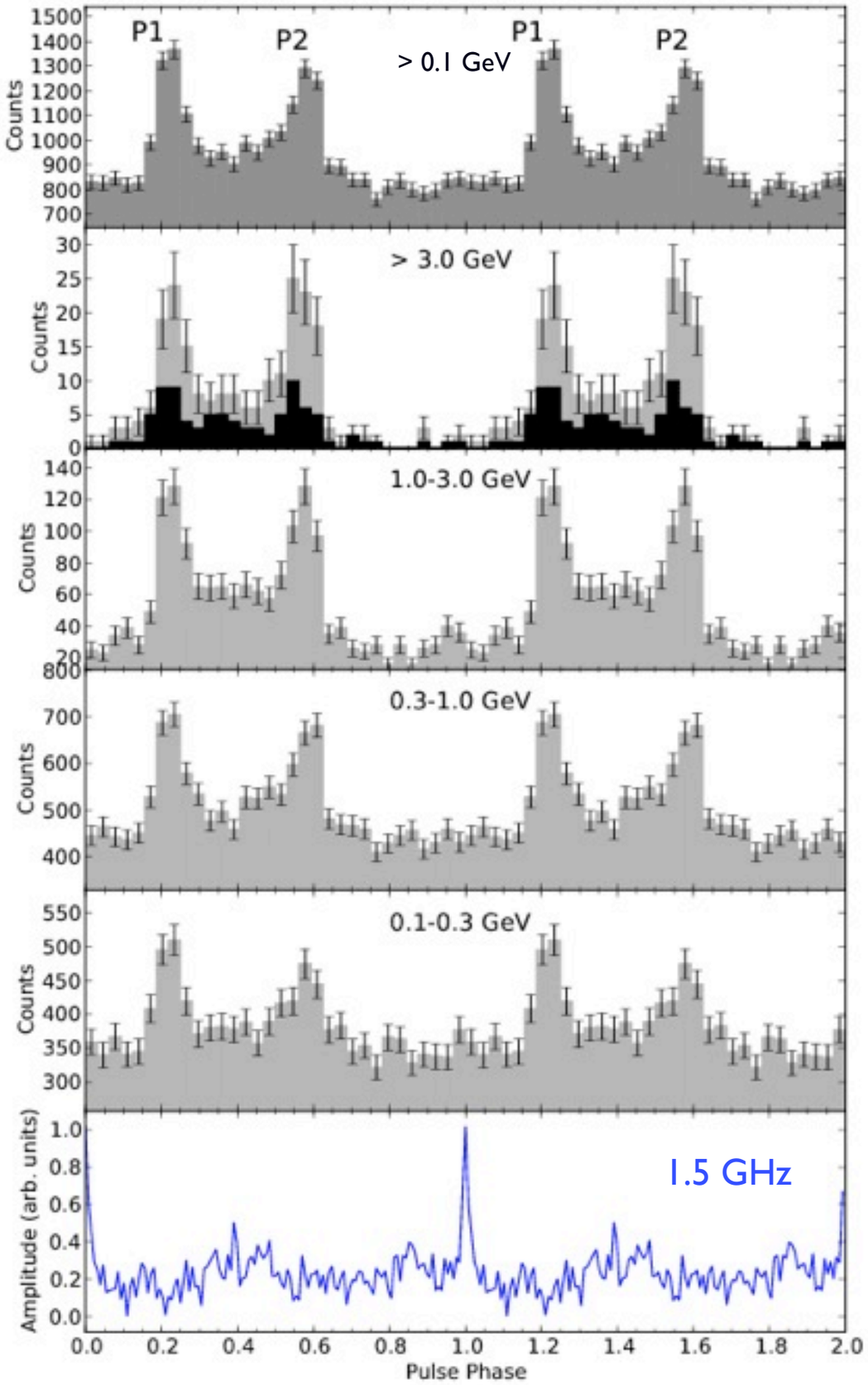
Radio Detection

Using the LAT timing position and ephemeris

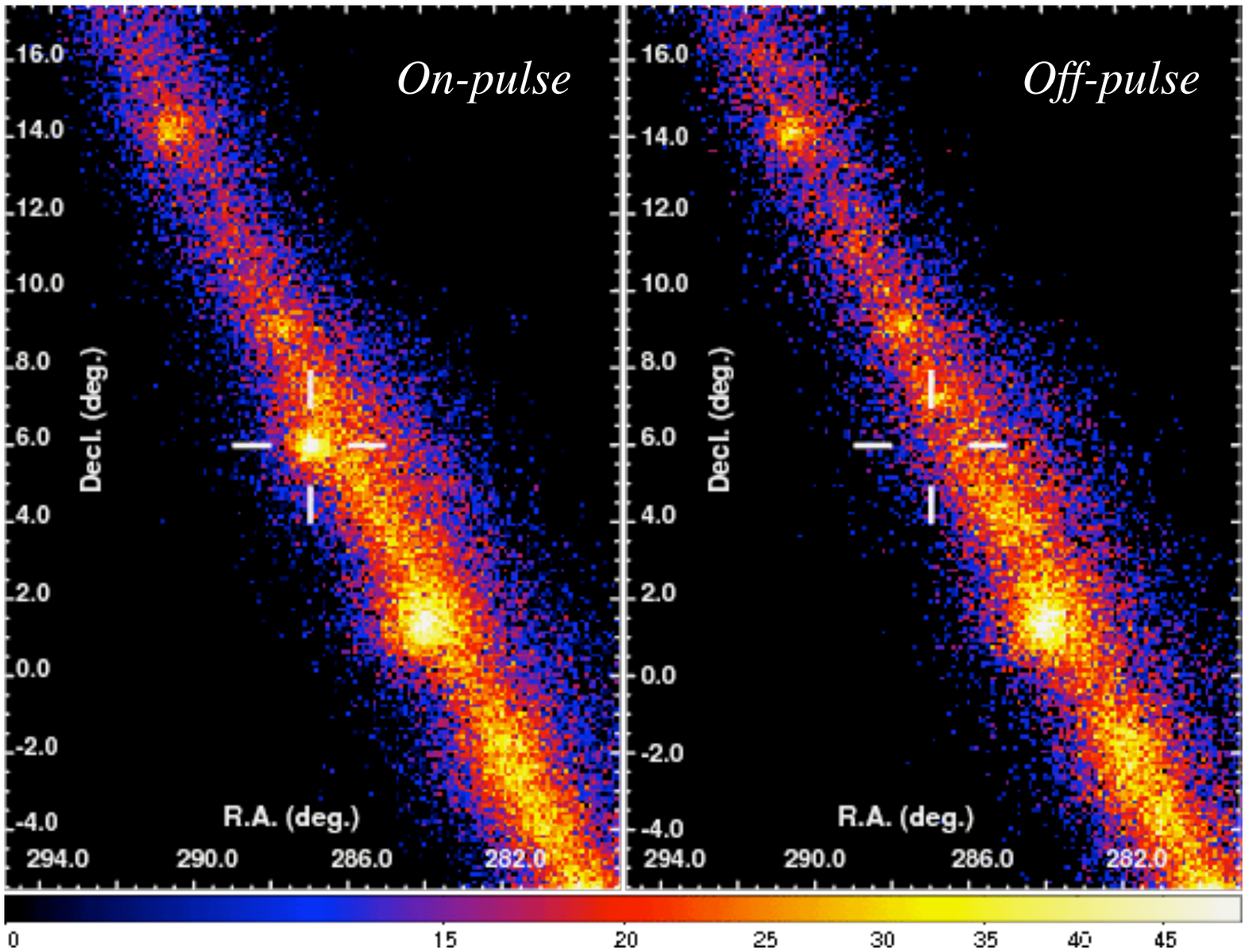
- Very faint radio pulsations detected at 1.5 GHz with Arecibo (Paulo Freire)
- Flux density of 3.4 uJy
- DM distance of 3.2 kpc
- Extremely low radio luminosity, but not the lowest ever :
  - Pseudo-luminosity of 0.035 mJy kpc^2. Smaller than the least luminous young pulsar (< 100,000 yrs) in the ATNF catalog (PSR J0205+6449 with 0.46 mJy kpc^2 at 1.4 GHz)
  - More luminous than PSRJ1741-2054 (0.025 mJy) first discovered by Fermi and later found in deep radio searches.

Pulse Profile

- Gamma rays:
  - Two distinct peaks with $\Delta = 0.36$
  - Pulsations detected at E > 5 GeV
  - No significant evolution in shape of P1/P2 with energy
- Radio lead $\delta = 0.22$ and Δ are in good agreement with the correlation predicted for outer magnetosphere models.



Fermi LAT Counts Map



Complex and busy region of the Galaxy that must be treated with care in the spectral analysis

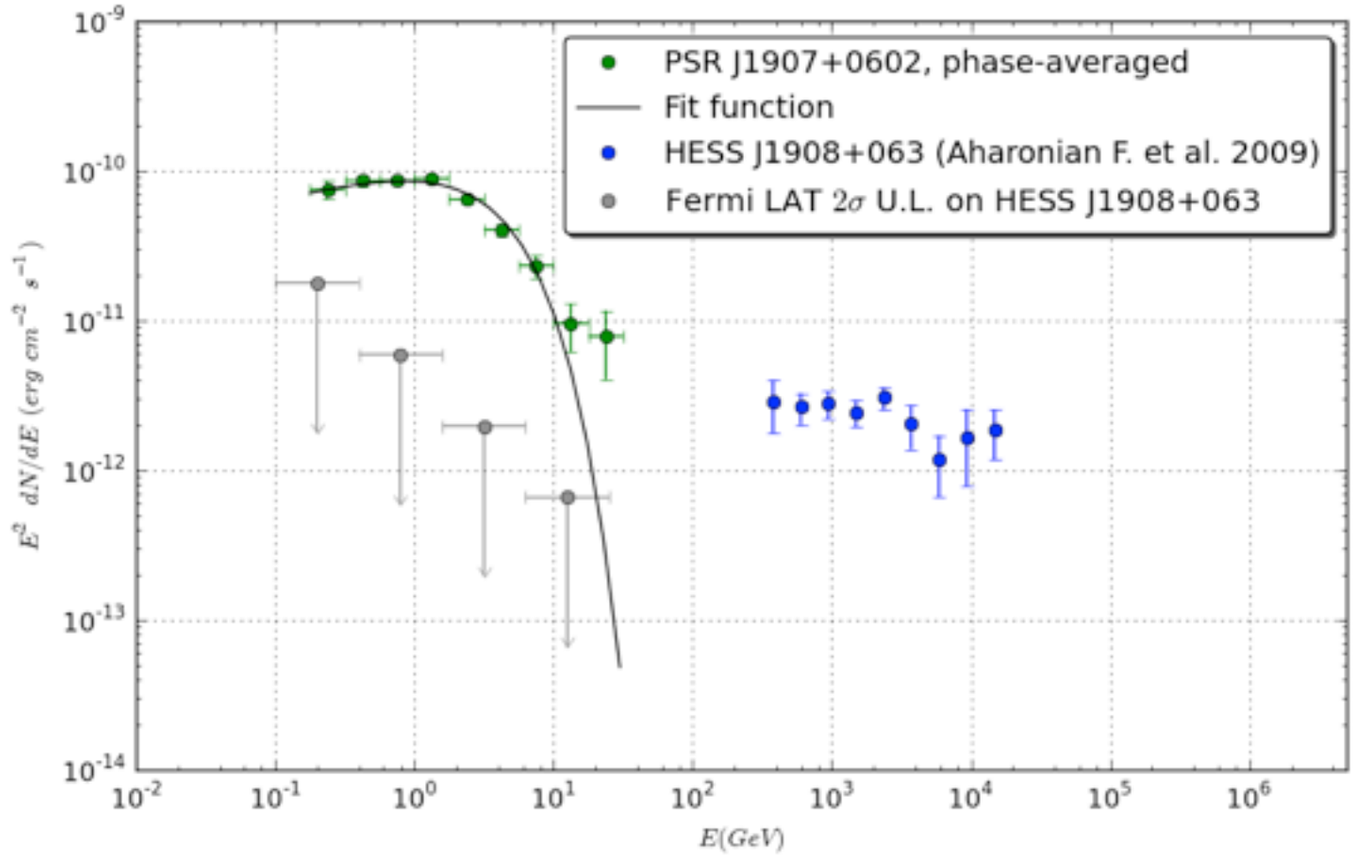
Spectral Energy Distribution

- LAT upper limits on emission from the TeV PWN requires a turnover between 20 and 300 GeV.
- We constrain the overall GeV-TeV PWN flux to be < 25% that of the pulsed flux.
- Very efficient in generating pulsed gamma-rays (13%).

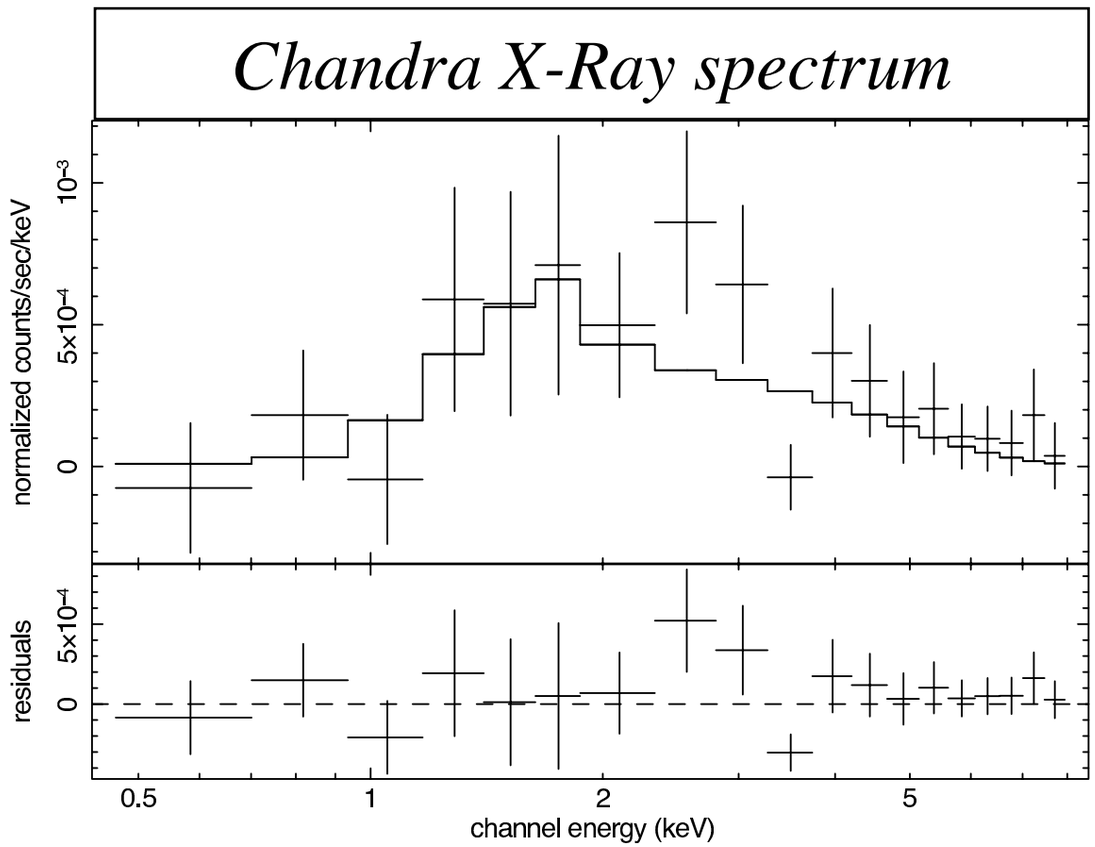
Power law with exponential cutoff

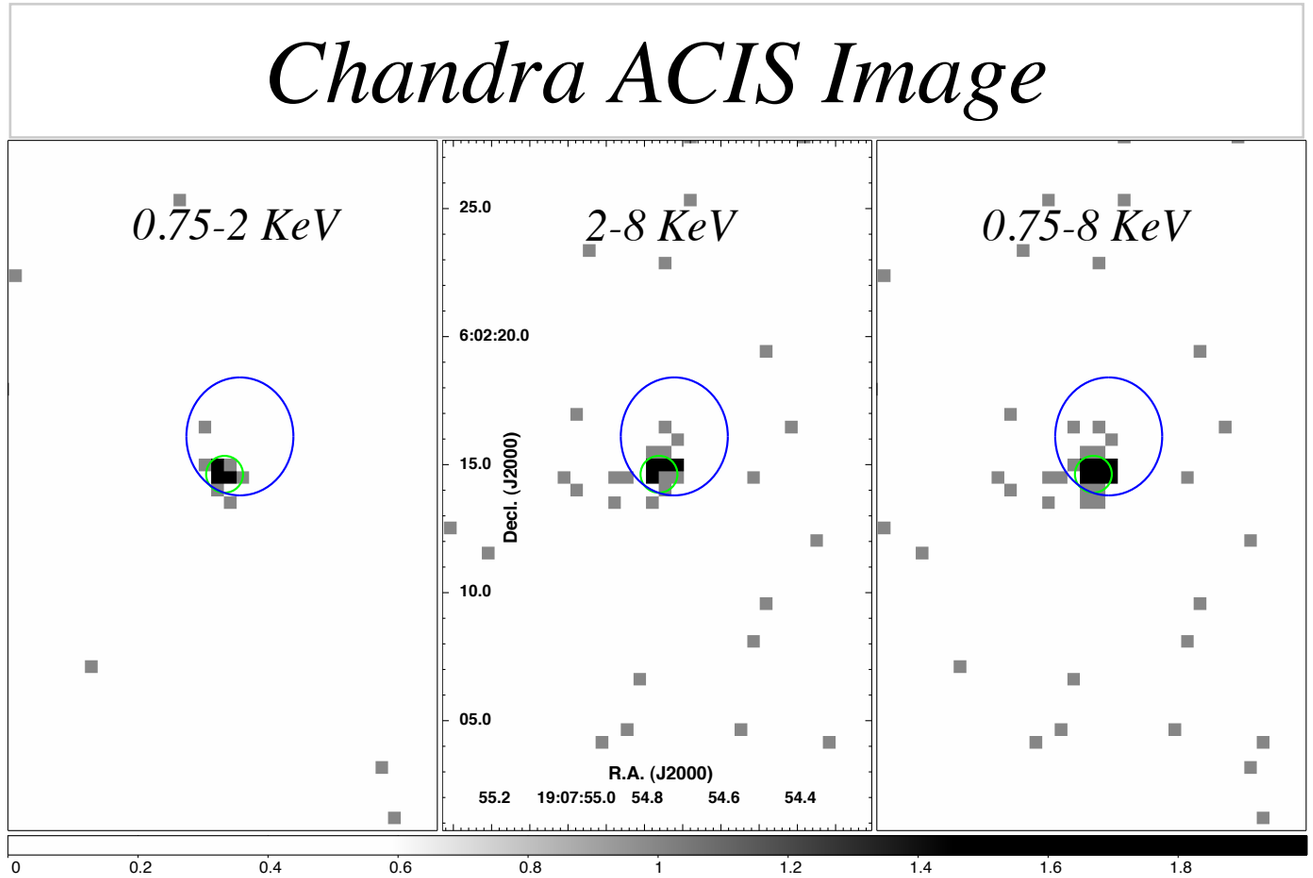
$$\frac{dN}{dE} = (7.06 \pm 0.43_{stat.} + (^{+0.004}_{-0.064})_{sys.}) \times 10^{-11} E^{-\Gamma} e^{-E/E_c} \,\gamma\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{MeV}^{-1}$$

$$\Gamma = 1.76 \pm 0.05_{stat.} + (^{+0.271}_{-0.287})_{sys.} \qquad E_c = 3.6 \pm 0.5_{stat.} + (^{+0.72}_{-0.36})_{sys.}\ \mathrm{GeV}$$



Chandra X-Ray Counterpart





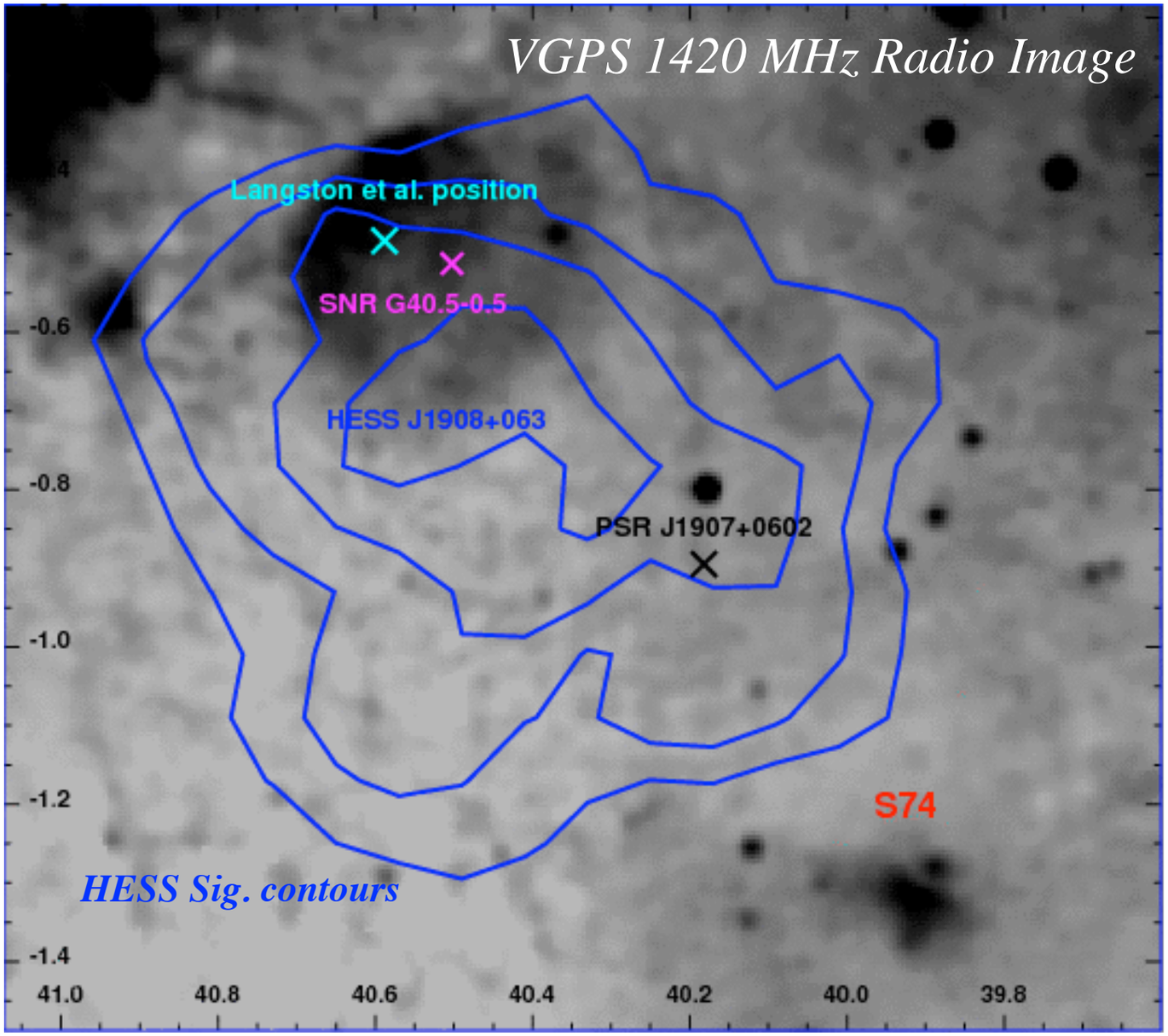
- 19 ksec exposure
- No flux < 1 keV and significant flux > 2 keV
- Non-thermal emission mechanism
- Hint of spatial extent for harder emission.
- Very low X-ray flux suggests DM distance is not an overestimate.

- Fermi LAT timing position

- Chandra source CXOU J190754.7+060214

Birthplace of the Pulsar

- The bulk of the TeV PWN is between SNR G40.5-0.5 and the pulsar.
- Age and distance estimates of the SNR are in agreement with those of the pulsar.
- Distance between G40.5-0.5 and PSRJ1907+0602 is 28 pc
  - At 3.2 kpc, this requires a 1400 km/s transverse velocity for the pulsar.
  - Any associated X-ray or radio PWN should have a bow-shock and a trail pointing back to the SNR.
- Lower velocities would be required if the pulsar was born at the center of the TeV PWN.



Summary

- PSR J1907+0602:
  - A very faint radio pulsar.
  - Very efficient in generating pulsed gamma-rays.
  - X-ray counterpart: *CXOU J190754.7+060214*
- The TeV source is plausibly the wind nebula of PSR J1907+0602.
  - The derived timing position of PSR J1907+0602 is well inside the extended TeV source.
  - The energetics work out. Pulsar can power the PWN:
    - Overall GeV-TeV PWN flux is <= 25% of the pulsed flux.
  - LAT U.L. suggest PWN spectrum to have a low energy turnover between 20 and 300 GeV.
- This nebula is more luminous than the Crab at 20 TeV.
- See talk by Michael Dormody on PSR J1022-5746 , another Fermi blind search pulsar that seems to be powering a TeV source

Fermi LAT Residual Counts map