G32.64+0.53 Analysis

Sarah Silverman, Alan Nguyen
March 23, 2022

Motivation

- **Is G32.64+0.53 a PeVatron?**
  - possible association with LHAASO J1849-0003 (Zhen et al. 2021)
  - E_{max}(PeV)= .35 +/- 0.07
- **leptonic or hadronic?**
  - G32.64+0.53 is likely a leptonic accelerator (Sudoh et al. 2021)
  - location in giant molecular cloud could favor hadronic scenario
- **multi-wavelength analysis:**
  - morphology study and SED
- **x-ray morphology and TeV detection tell similar story to our other PeVatron candidates**
  - comparison to several other middle-aged TeV PWNe

Article | Published: 17 May 2021

Ultrahigh-energy photons up to 1.4 petaelectronvolts from 12 γ-ray Galactic sources

Zhen Cao, F. A. Aharonian, ... X. Zuo + Show authors

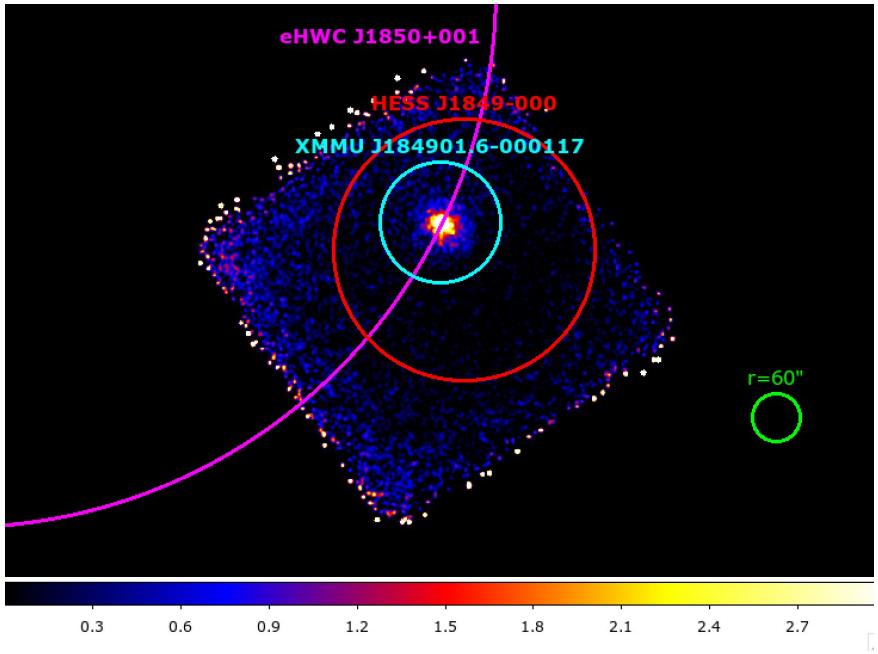
Nature **594**, 33–36 (2021) | Cite this article

14k Accesses | **29** Citations | **686** Altmetric | Metrics

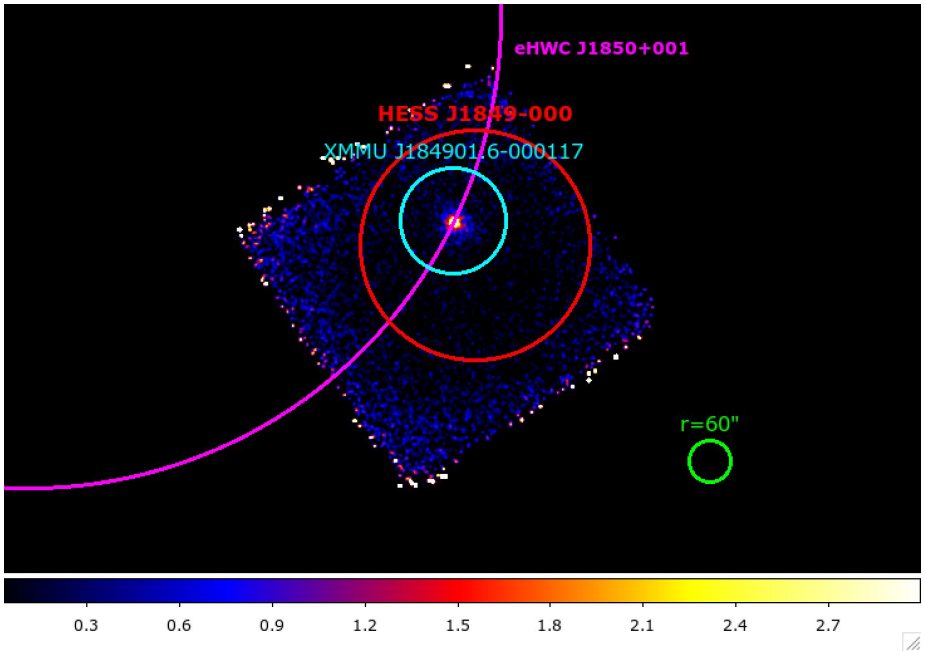
Prior Detections

- first discovered by INTEGRAL in 2003 (Molkov et al.)
- data from the HESS Galactic Plane Survey (2004-2013) was analyzed by Terrier et al. (2008)
  - HESS J1849-000 found to be coincident with IGR J18490-0000
- observed by Chandra three times, XMM-Newton two times
- observed by HAWC twice
- observed by NuSTAR in November 2020

G32.64+0.53 NuSTAR Images



3-10 keV



10-30 keV

- eHWC J1850+001 (magenta), HESS J1849-000 (red), XMMU J184901.6-000117 (cyan) centroid and 1-sigma extension overlayed
- eHWC extension > 56 TeV = .37°

Background on G32.64+0.53

- **Distance**: 7 kpc
- **Location**: Scutum arm tangent region (W 43)
- **Age**: 42.9 kyr
- no associated SNR
- Center: $18^h49^m01^s.59$ $-00^o01'17".73$
- no radio emission detected

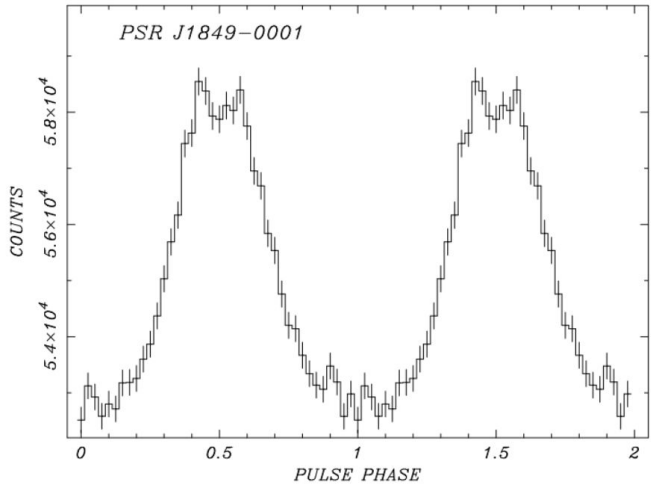
Powered by X-ray Pulsar: PSR J1849-0001

- τ_C= 42.9 kyr
- E=9.8 x 10^{36} erg s^{-1}

Gotthelf et al. (2011):

- timing analysis with 2010 RXTE data revealed a highly significant signal of P= 38.52 ms
- $\dot{P}$= 1.42 x 10^{-14} s s^{-1}

no GeV or radio emission detected

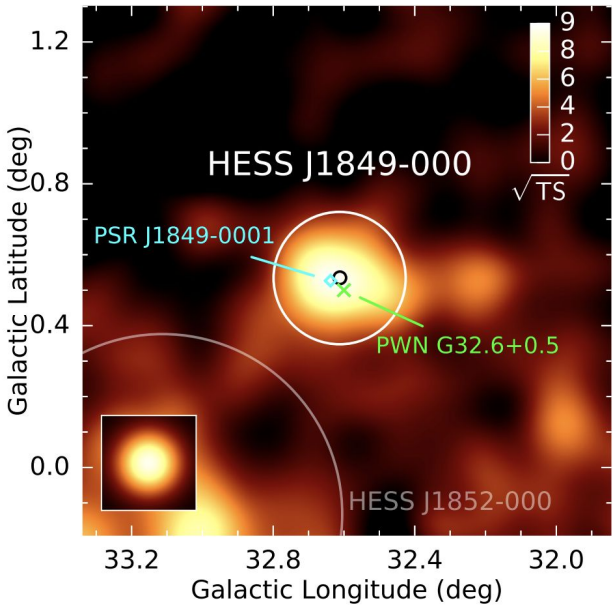


X-ray pulse profile of PSR J1849-0001 (2-20 keV) using RXTE data (Gotthelf et al. 2011)

VHE TeV γ-ray Emission

- HESS:
  - HESS J1849-000: .09° VHE extent (Abdalla et al. 2018)
- HAWC:
  - 2HWC J1849+001: .11° from IGR J18490-0000, .2° from HESS J1849-0000
  - one of nine sources emitting above >56 TeV (Abeysekara et al. 2020)

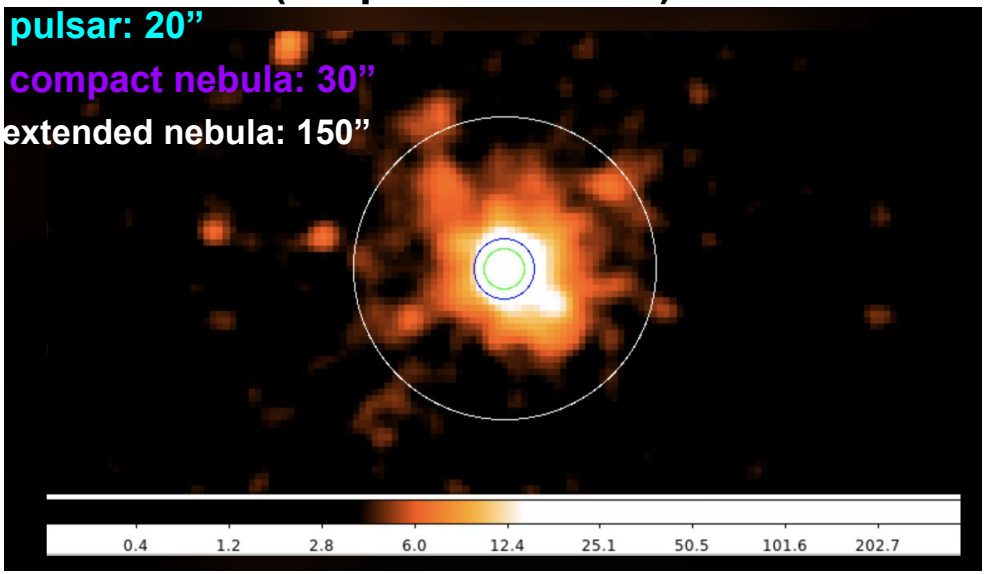
"likely candidate for the >50 TeV energy emission seen by HAWC" (Brisbois et al. 2021)



VHE γ-ray image of HESS J1849-000
Abdalla et al. (2018)

X-ray emission: 3 Components

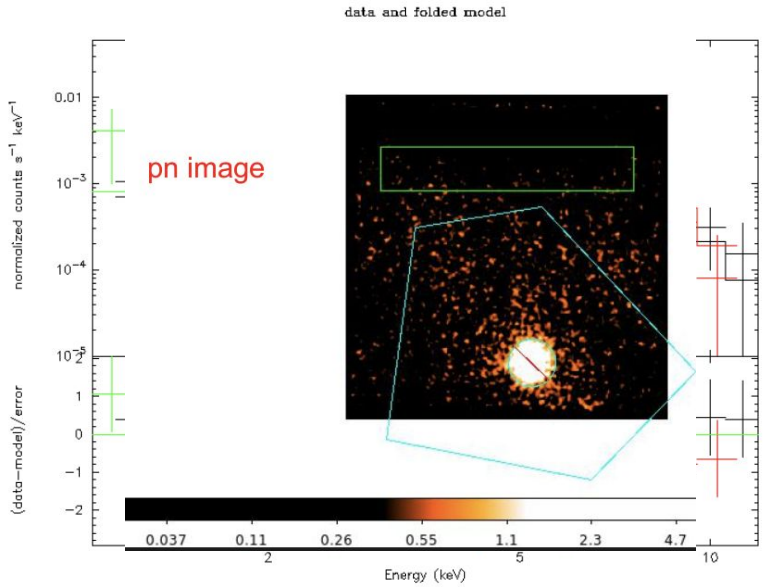
1. **X-ray pulsar**
   a. **pulsation detected by RXTE (Gotthelf et al. 2011), XMM and Chandra (Kuiper et al. 2015), and NuSTAR**
   b. **20” point source (Gotthelf et al. 2011; Vleeschower Calas et al. 2018)**
2. **compact PWN**
   a. **23ks ACIS-S Chandra observation: ≤30” in 2-10 keV band (Bogdanov et al. 2019)**
   b. **NuSTAR: 60” (hard x-ray emission up to 30 keV)**
3. **diffuse, extended PWN**
   a. **XMM: 75”-150” (Kuiper et al. 2015)**

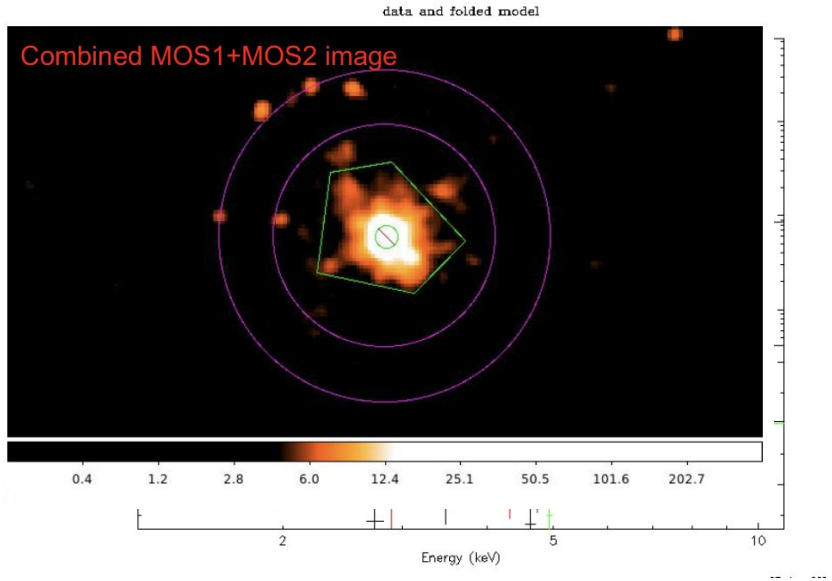


Similar to Eel PWN which has both:

- **compact nebula (~40”)**
- **diffuse nebula (6’ x 2’)**

XMM-Newton analysis by Alan





	PWN	Pulsar
Photon Index	1.73 +/- .11	1.14 +/- .05
X^2_ν (d.o.f)	1.07 (130)	1.13 (162)
N_H, 10^{22} cm^{-2}	7.6 +/- .54	6.62 +/- .21

Alan analyzed archived XMM data from a 2011 observation (53.6 ks). Both his timing and spectral analysis were consistent with results cited in prior papers (Gotthelf et al. 2011 and Kuiper et al. 2015 (timing); Vleeschower Calas et al. 2018 (spectral))

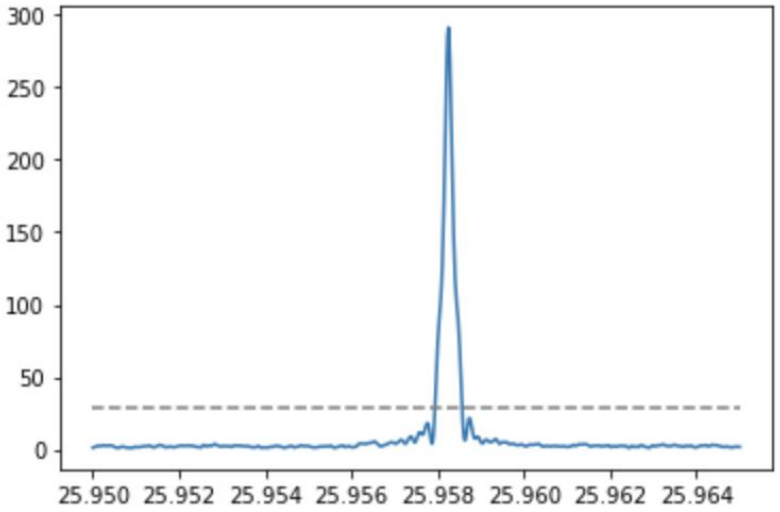
NuSTAR

NuSTAR Analysis

Timing, Imaging, and Spectral Analysis

NuSTAR Timing Analysis

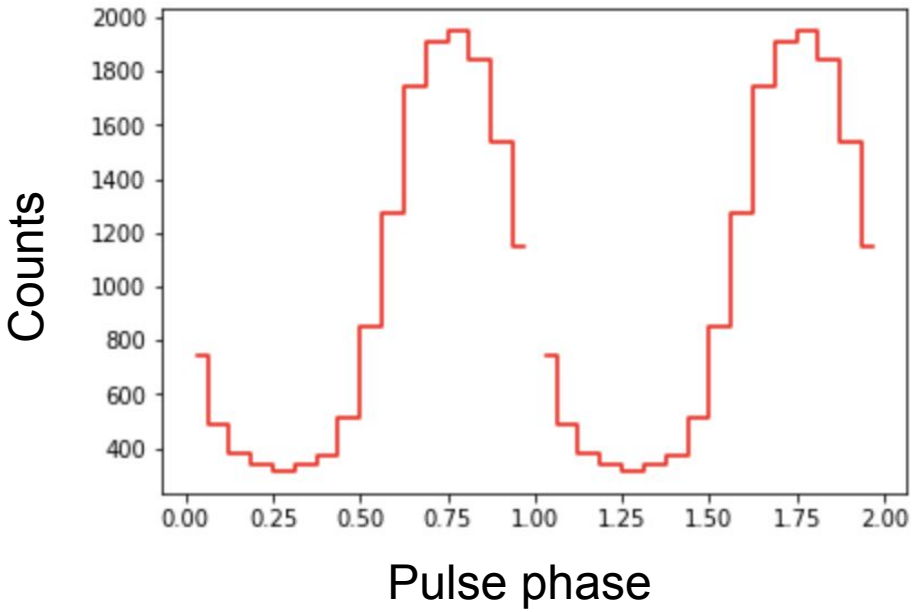
60” source extraction region



- Z^2 -test yielded very significant signal at ν_{max}= 25.9582 +/- .0006 Hz (P=.0385234 s)
  - gray line indicates 5-sigma detection

- there has been **no glitch** in pulsation since the observation cited in Gotthelf et al. (2011)

Pulse Profile using NuSTAR Data



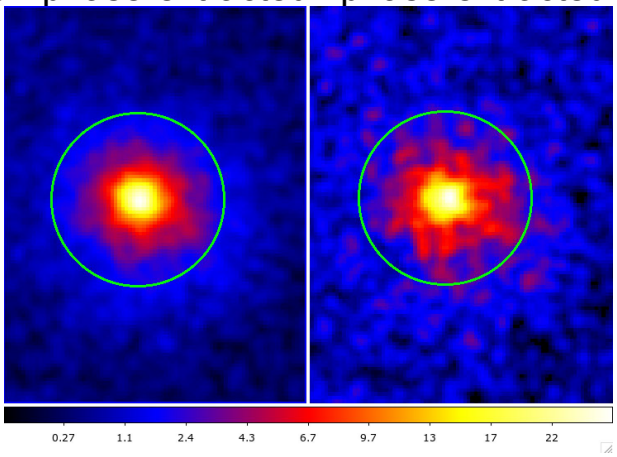
- focused exclusively on the 0-.5 phase range for PWN analysis

Pulsar-PWN vs. PWN-only in ds9 (3-30 keV)

60” radius regions shown

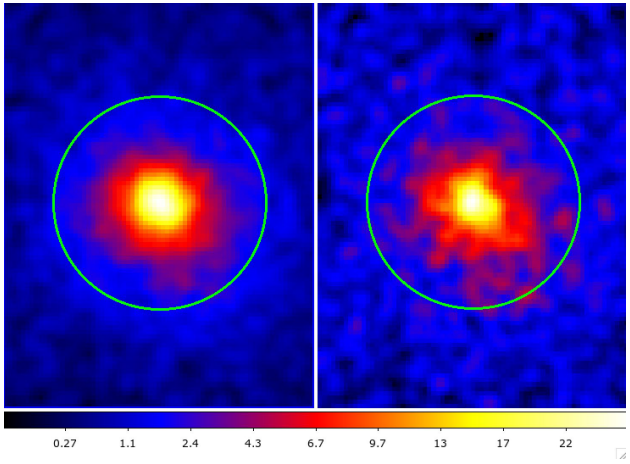
FPMA

non-phase-extracted phase-extracted



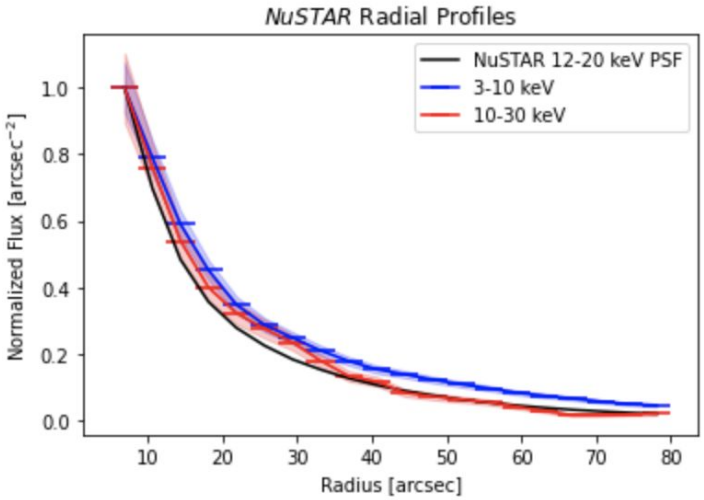
FPMB

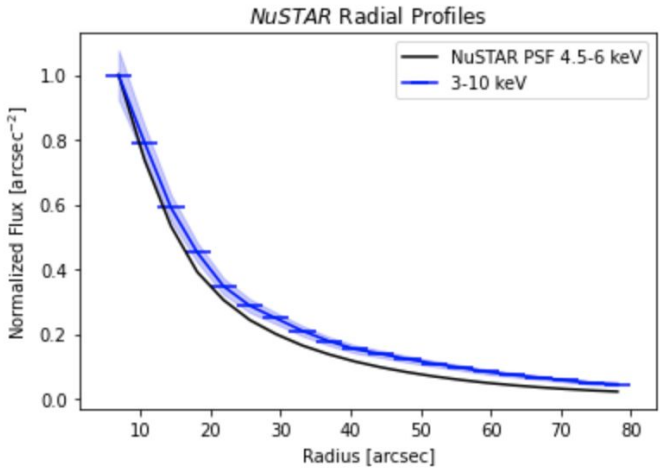
non-phase-extracted phase-extracted

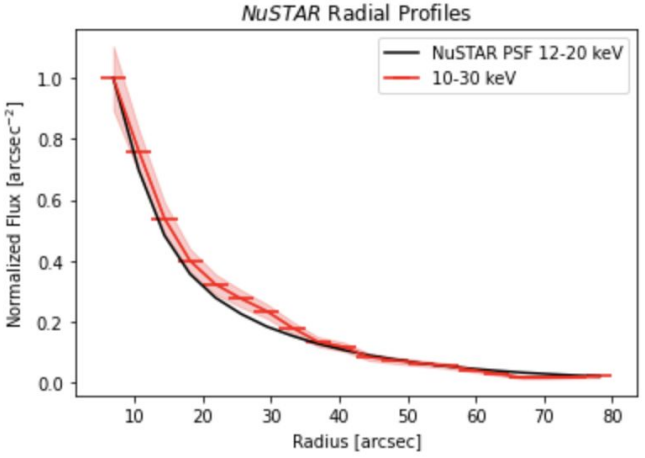


Imaging Analysis

Comparing radial profiles to NuSTAR's 1.5 arcmin off-axis PSF







- 3-10 keV and 10-30 keV radial profiles for exposure-corrected, ONTIME-scaled, smoothed, and background-subtracted images
- 20 annuli with R_{Inner}=5" and R_{outer}=80"
- **compact pwn is too small for NuSTAR to spatially resolve**

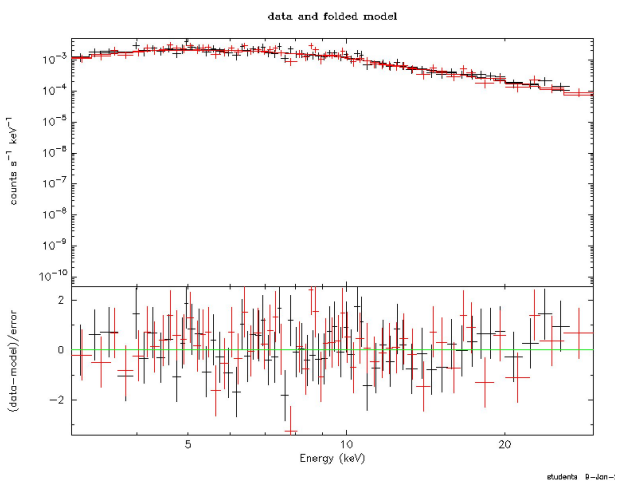
NuSTAR Spectral Analysis

Object	PWN-Pulsar	PWN	PWN	PWN	Pulsar
Region	60” circle NuSTAR	40” circle NuSTAR	40”-60” Annulus NuSTAR	60” circle NuSTAR	60” circle NuSTAR
Net Counts	14556	2167	771	2927	8753
Photon Index	1.49 ± .03	1.45 ± .06	1.69 ± .11	1.53 ± .04	1.44 ± .03
X^2_ν (d.o.f)	1.08 (377)	.78 (116)	.97 (38)	1.0 (141)	1.05 (354)
N_H, 10^{22} cm^{-2}	4.3 (frozen)	4.3 (frozen)	4.3 (frozen)	4.3 (frozen)	4.3 (frozen)

- background dominates ~30 keV
- absorbed power-law model
- 3-sigma binning
- Joint fit w/ XMM (in progress…)

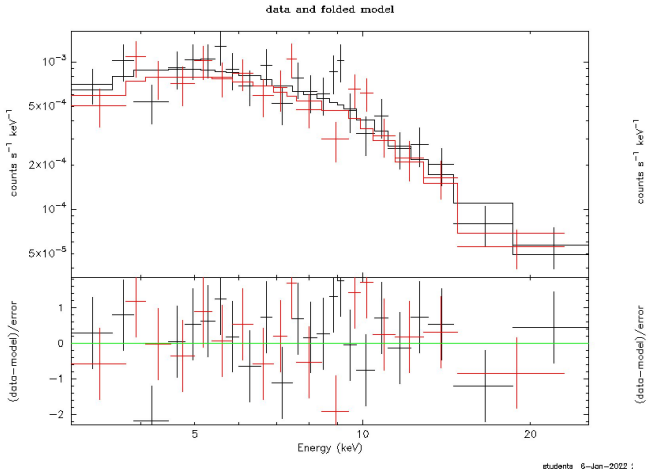
in more detail…

40” PWN



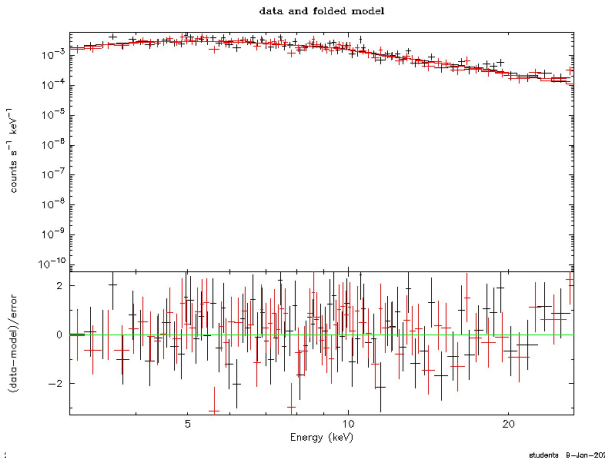
Photon Index: 1.45 ± .06
X^2_ν (d.o.f): .78 (116)
N_H: 4.3x10^{22} cm^{-2}

40”-60” PWN



Photon Index: 1.69 ± .11
X^2_ν (d.o.f): .97 (38)
N_H: 4.3x10^{22} cm^{-2}

60” PWN



Photon Index: 1.53 ± .04
X^2_ν (d.o.f): 1.0 (141)
N_H: 4.3x10^{22} cm^{-2}

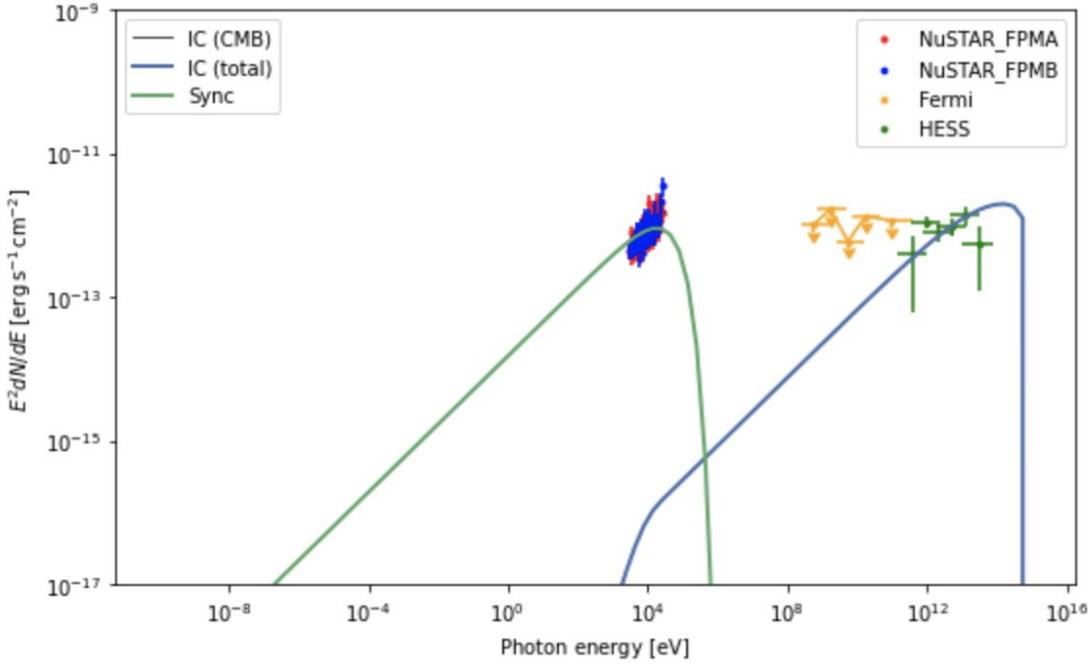
SED FITTING

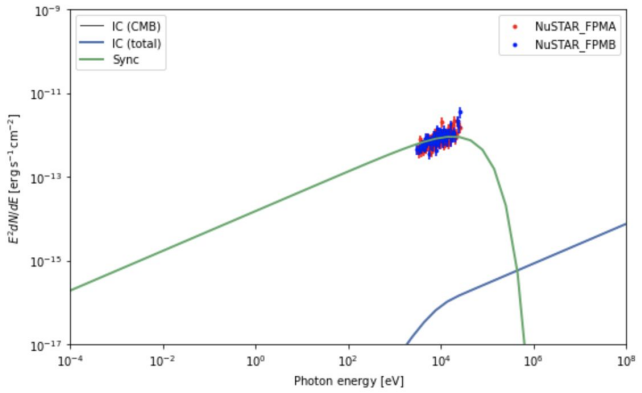
Using Naima

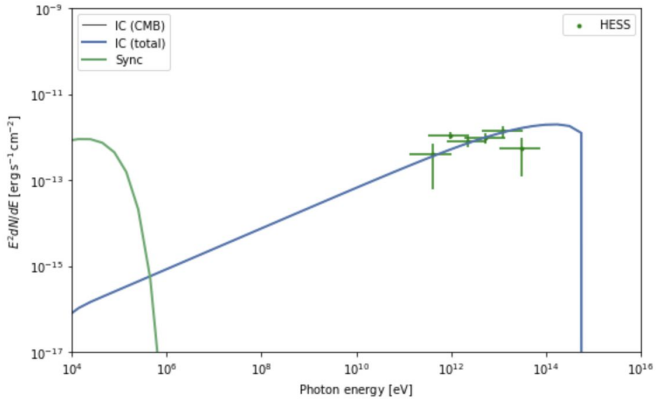
SED Fit in NAIMA: Pure Leptonic, PL

B-field: 0.8 microgauss
Spectral index: 2.05
seed photon field:
CMB-only

- including diffuse emission detected by xmm would raise the synchrotron flux by factor of ~3





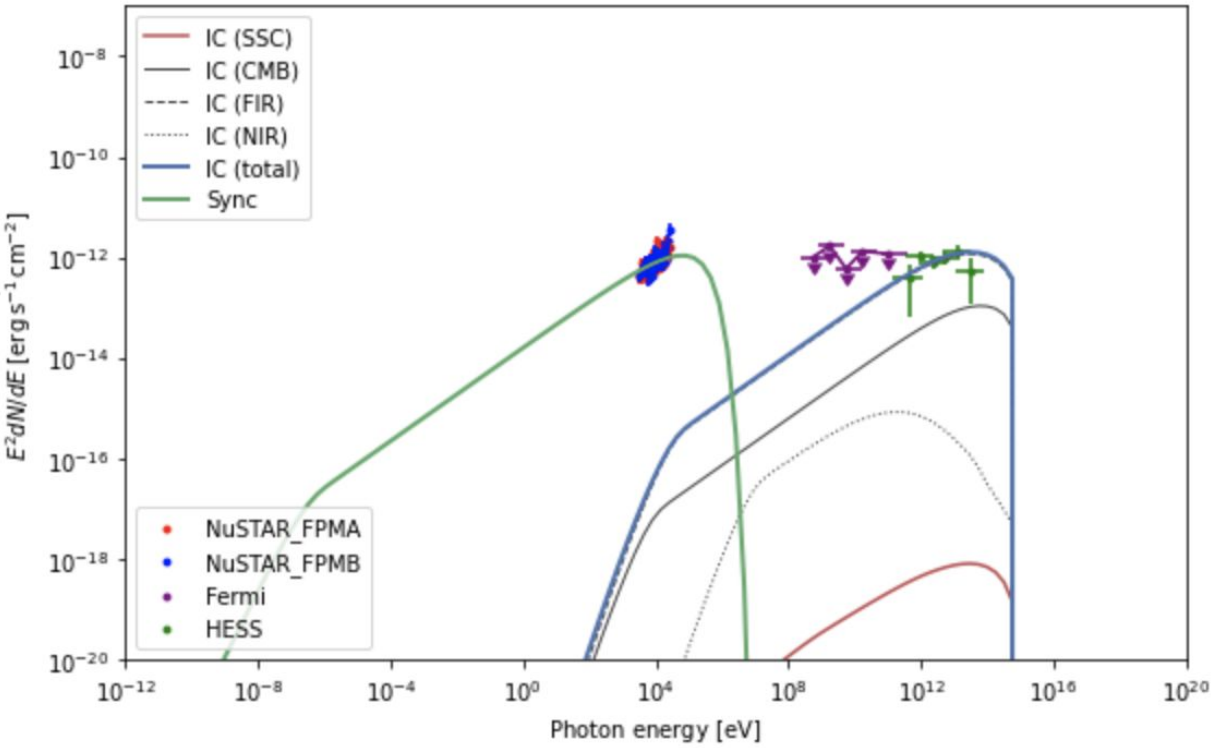


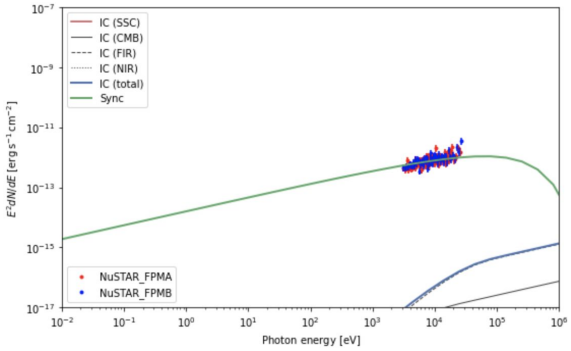
SED Fit in NAIMA: Pure Leptonic, ECPL

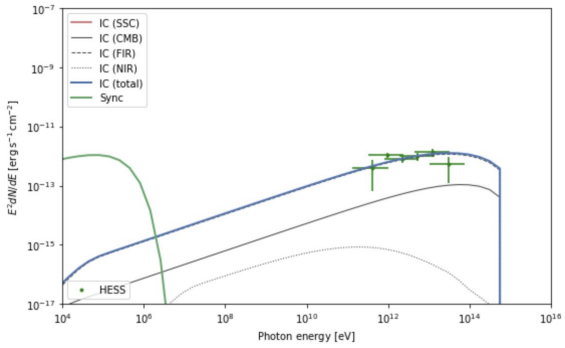
Components of fit:

- Synchrotron, synchrotron self-Compton, far infrared ICS, near infrared ICS, CMB

B-field: 4.4 microgauss
Spectral index: 2.07
cutoff energy: 1 PeV
Dust temperature: 12 K (Carlhoff et al. 2013)
FIR photon field: 9 eV/cm^3

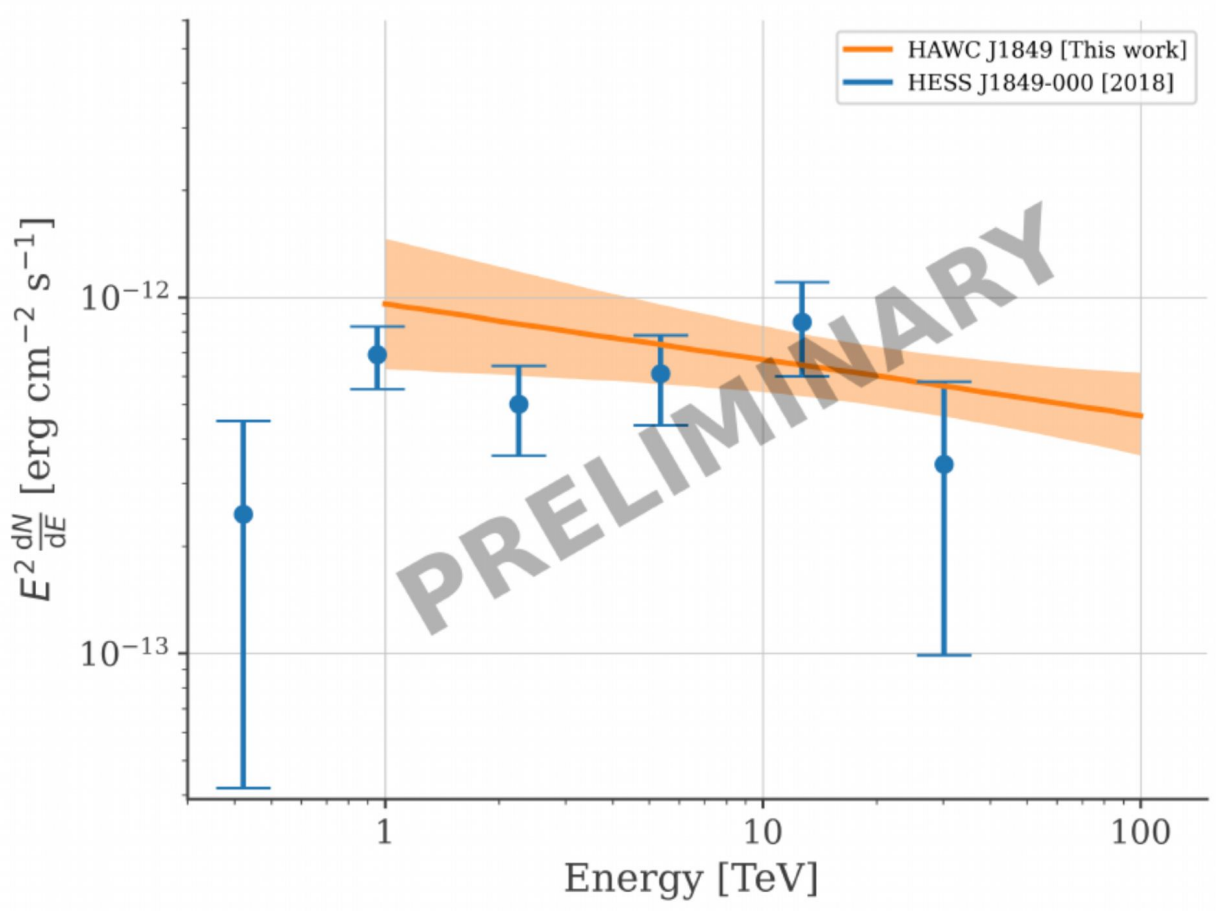






HESS vs. HAWC Data

data provided by Dr. Kelly Malone



Brisbois et al. 2021

Seeing that HAWC detected this source up to 100 TeV, including HAWC data will be important for constraining E_{cutoff}

Summary

- G32.64+0.53 has a compact component ≤30” as seen by Chandra and diffuse extended component out to 150” seen by XMM
- NuSTAR is unable to spatially resolve the compact PWN
- past XMM results confirmed by Alan
- So far, I have tried two different leptonic scenarios for the SED, but a hadronic scenario has not been ruled out

Next Steps:

- joint fit (XMM, NuSTAR)
- continue with SED fitting
  - include diffuse extended emission from xmm data
  - include HAWC data
  - try hadronic scenario
- work with Yosi’s dynamic PWN model