Supernova Remnants and Pulsar Wind Nebulae with VERITAS

http://apod.nasa.gov/apod/ap060602.html
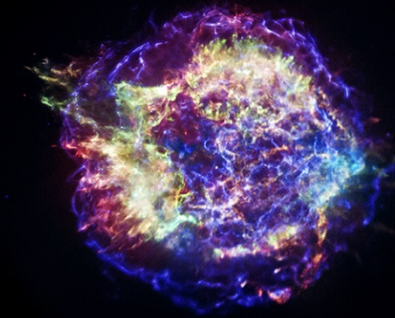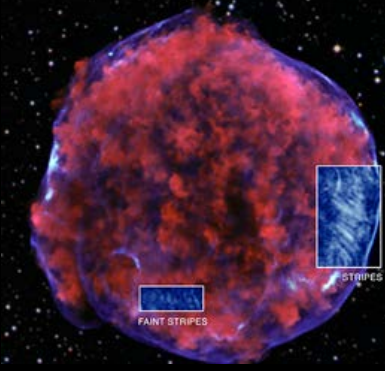
Amanda Weinstein

for the VERITAS Collaboration

TeVPA 2017

Overview

- VERITAS /Overview

- Pulsar wind nebulae

- Middle-aged SNRs

- Young Historical SNRs (Tycho and Cas A)

VERITAS in a Nutshell

Specifications:
- Energy range: 85GeV to > 30 TeV
- Energy resolution ~ 15 % at 1 TeV
- Angular resolution (68% containment): 0.1^o at 1 TeV, 0.14^o at 200 GeV
- Source location accuracy: <50 arcseconds

Instrument design:
- Electromagnetic calorimetry with atmosphere
- Four 12-m imaging atmospheric Cherenkov telescopes
- 499-pixel cameras (3.5° FoV
- FLWO Mt. Hopkins, Az (1268 m)

T4

T3

109 m

T2

T1
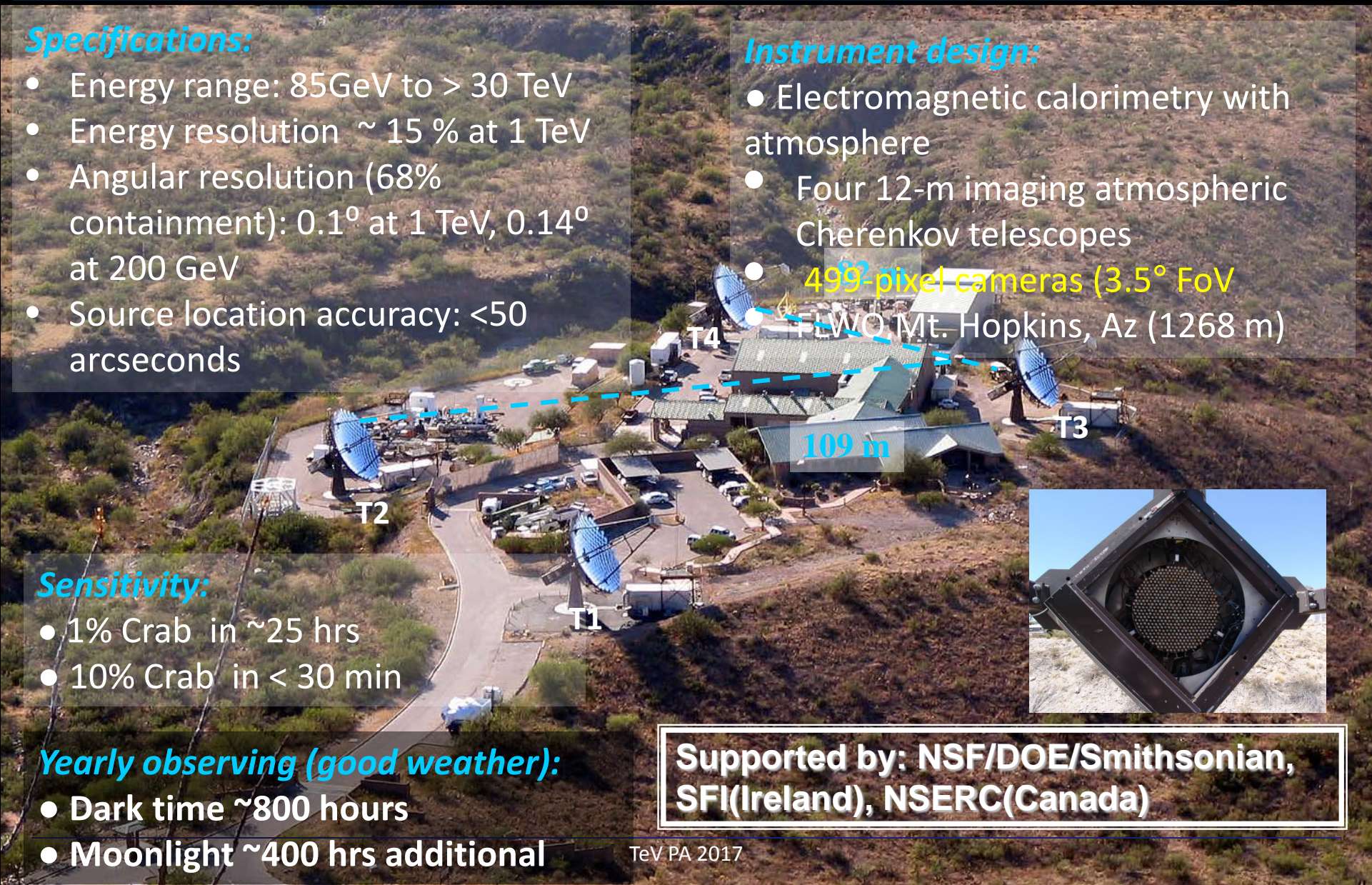
Sensitivity:
- 1% Crab in ~25 hrs
- 10% Crab in < 30 min

Supported by: NSF/DOE/Smithsonian, SFI(Ireland), NSERC(Canada)

Yearly observing (good weather):
- Dark time ~800 hours
- Moonlight ~400 hrs additional

TeV PA 2017

Program Overview

Young SNR:
Hunting for PeVatrons
(maximal proton energy)
Cas A
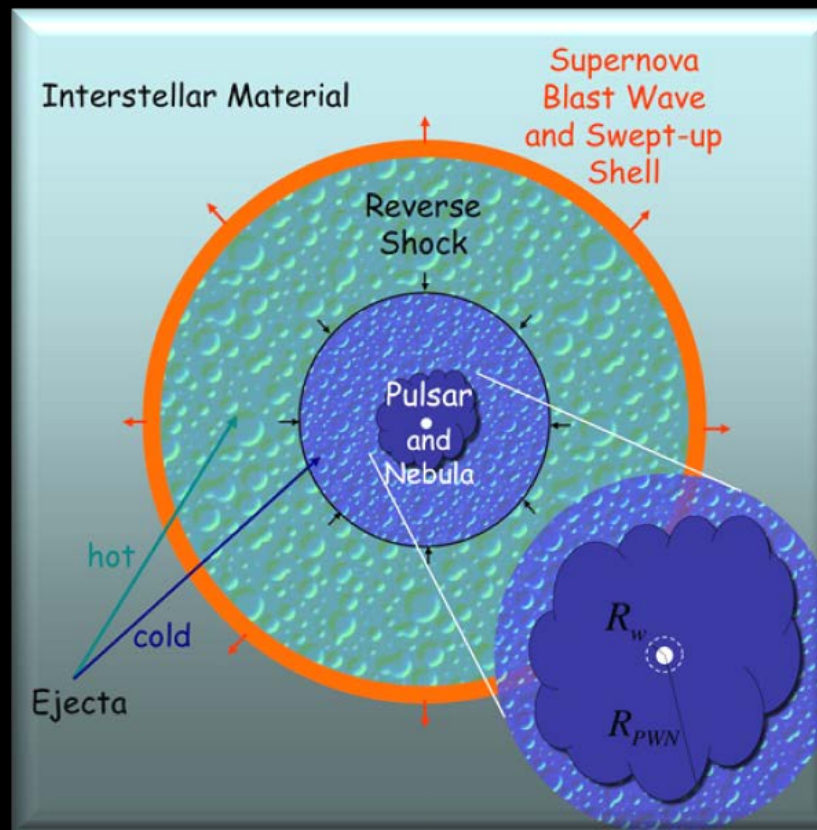Tycho's SNR

Middle-aged SNRs:
Gamma Cygni
IC 443

Resolved morphology
Particle diffusion and
escape

Hadrons and leptons

Pulsar Wind Nebulae
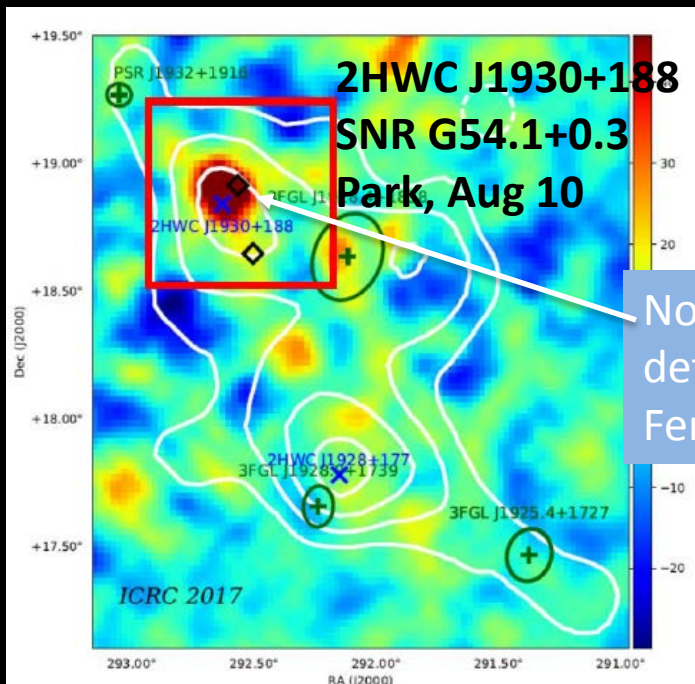
e+/e- production

Inverse Compton
and synchrotron

- PWNe upper limits

- Recent PWNe from HAWC follow-up (see Park)
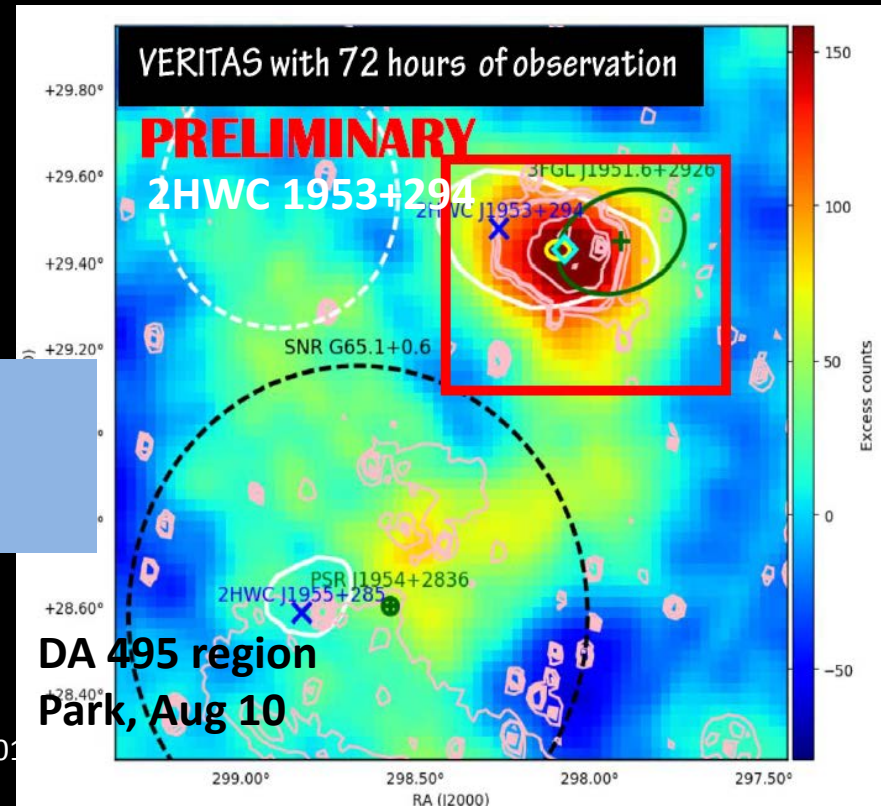
- TeV J2032+4130

PULSAR-WIND NEBULAE

PWN Highlight I: HAWC follow-up

- HAWC reported 19 new sources with 507 days of exposure
- High-angular resolution follow-up with Fermi-LAT (E >10 GeV) and VERITAS (E > 85 GeV; see Park, Hui)
  - 12 not detected by VERITAS, 1 known and 1 new 1 likely TeV PWN
  - Some sources (e.g. Geminga) not included as pose unique technical challenges for VERITAS (see Brantseg, Aug. 10)
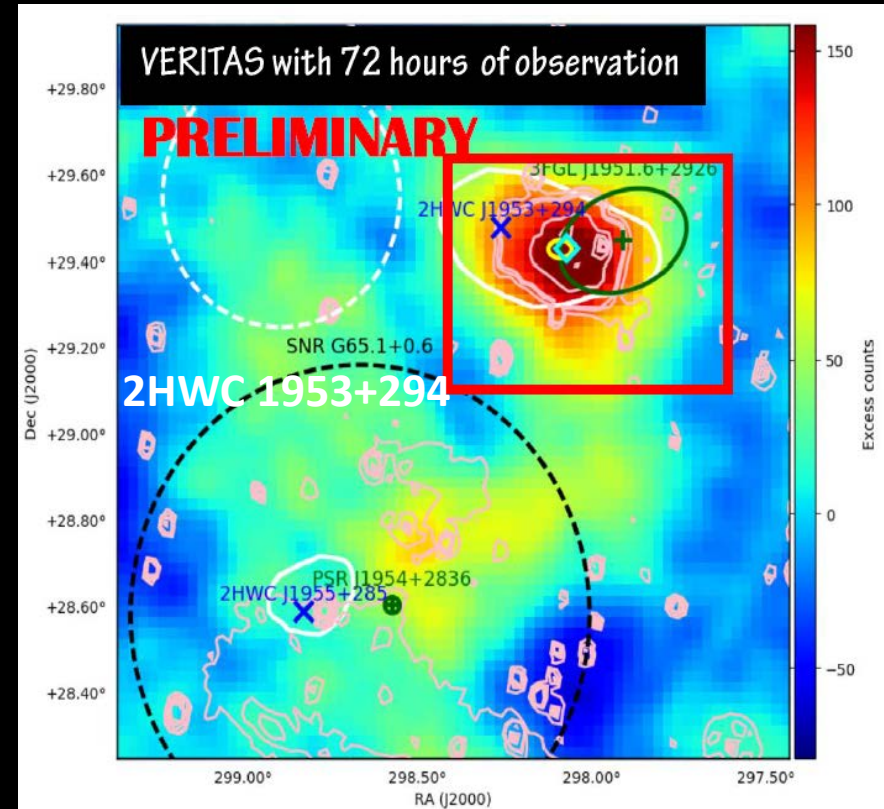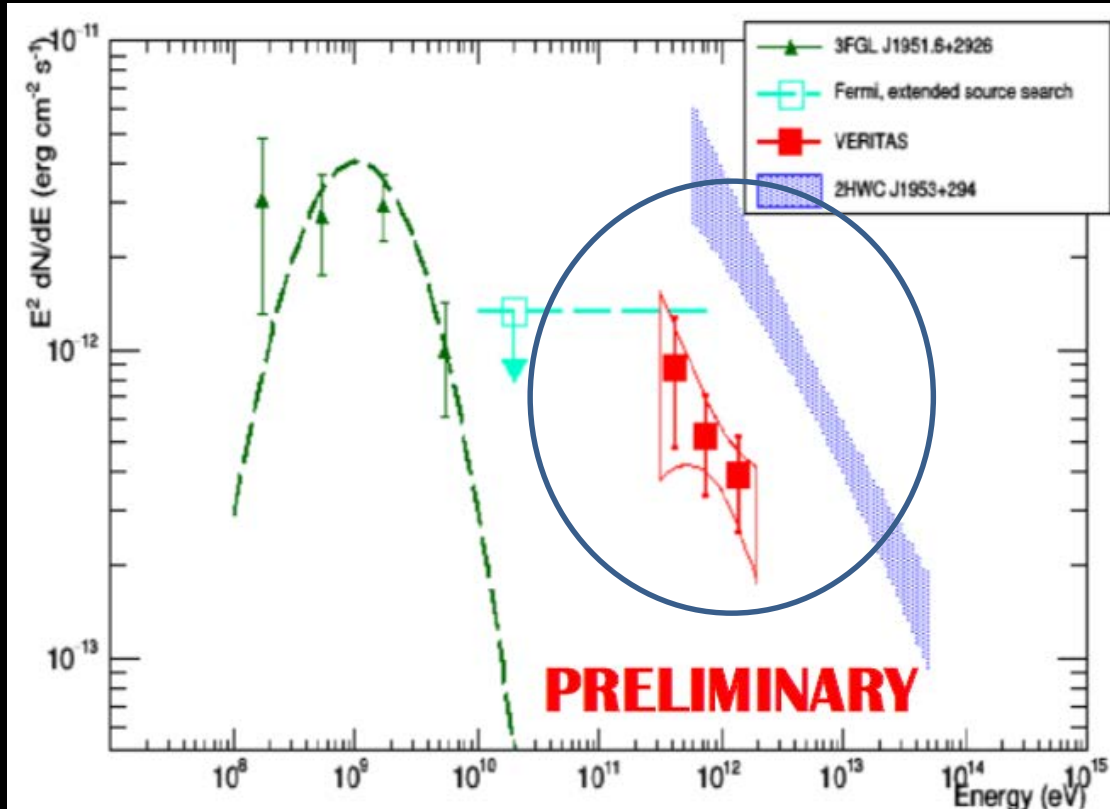

2HWC J1930+188
SNR G54.1+0.3
Park, Aug 10

Now also detected by Fermi-LAT

ICRC 2017

VERITAS with 72 hours of observation

PRELIMINARY
2HWC 1953+294

DA 495 region
Park, Aug 10

TeV PA 201

- Just the tip of the iceberg…?
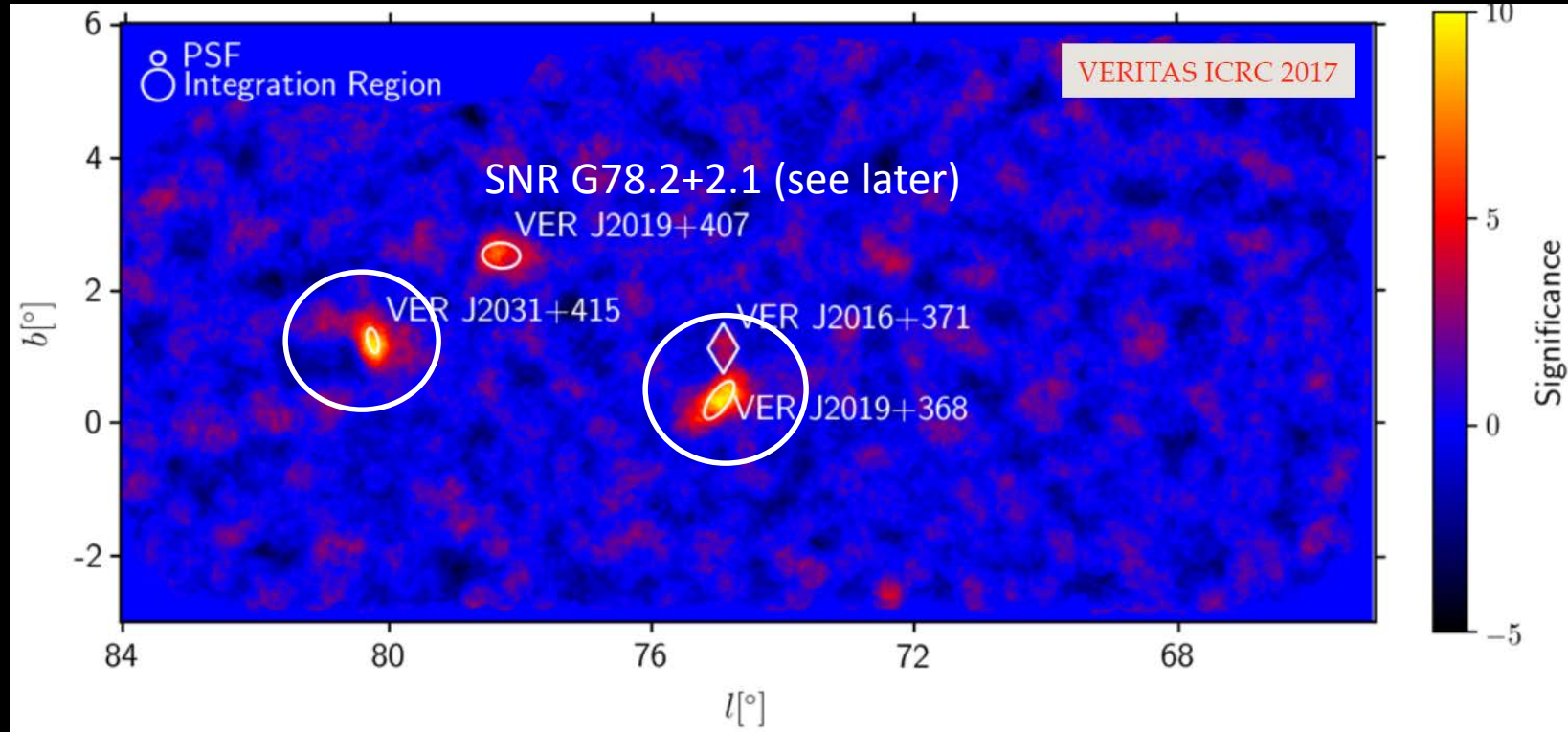
- From the update of the Cygnus region survey (300 hrs of data)
- Two regions (one with a hint of multiple source contributions) where PWNe may form counterparts
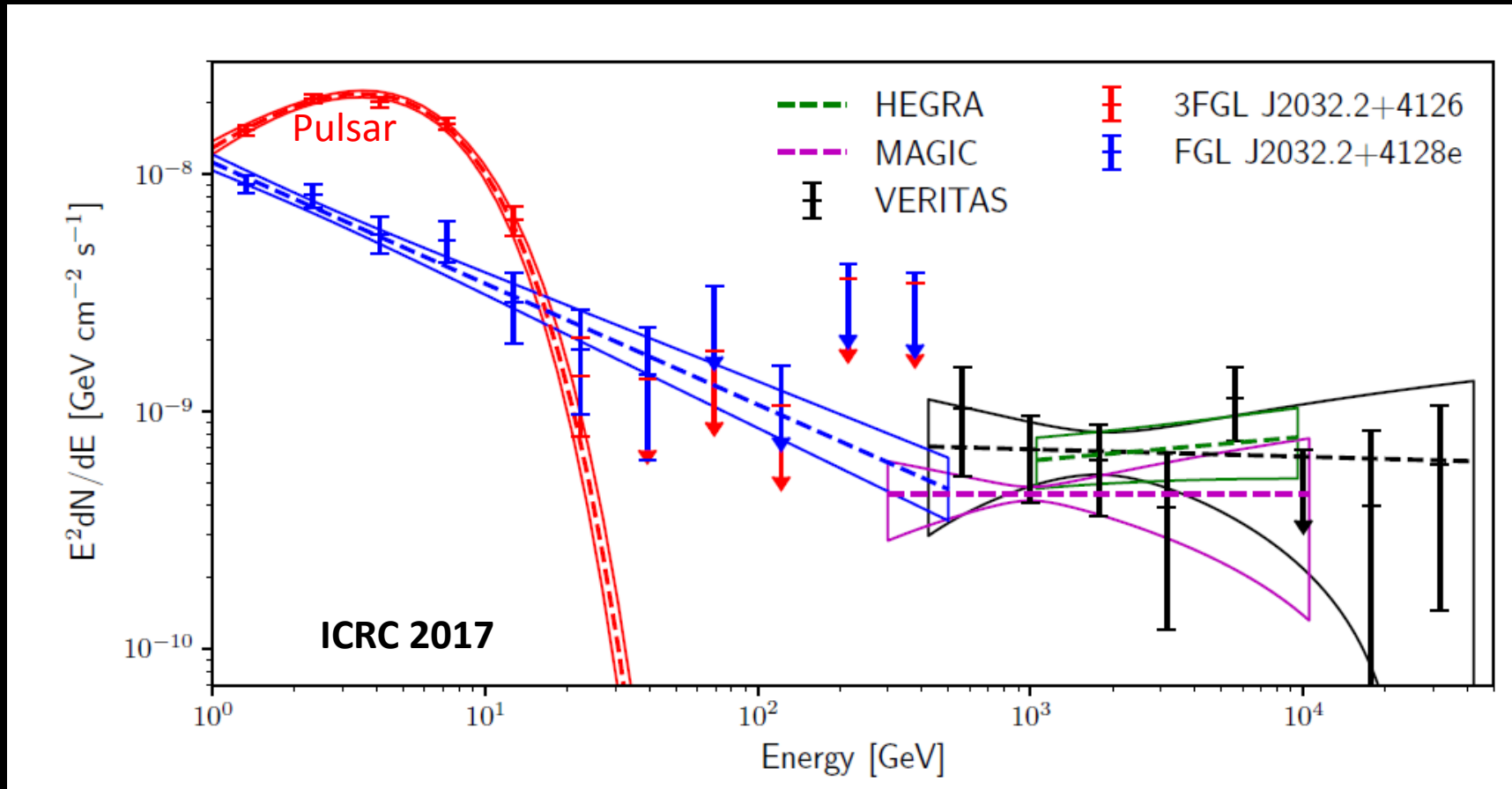
PWN (?)Highlights II: TeV J2032+4130

- Well known extended TeV source surrounding a gamma-ray pulsar

- Extended excess seen by both Fermi-LAT and VERITAS

- Overlaps more extended regions of emission seen by Fermi-LAT and HAWC

- Pulsar now known to be part of a long-period binary
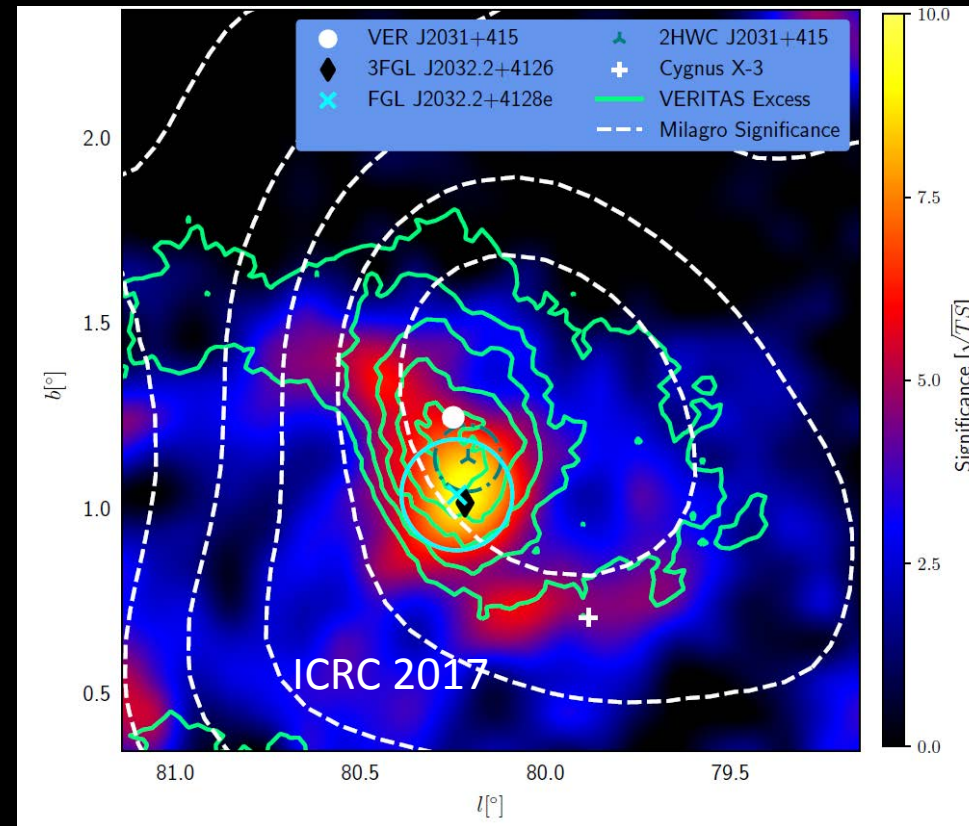
Fermi-LAT significance map with VERITAS contours overlaid (green)

PWN? Lack of spectral break at high energies..
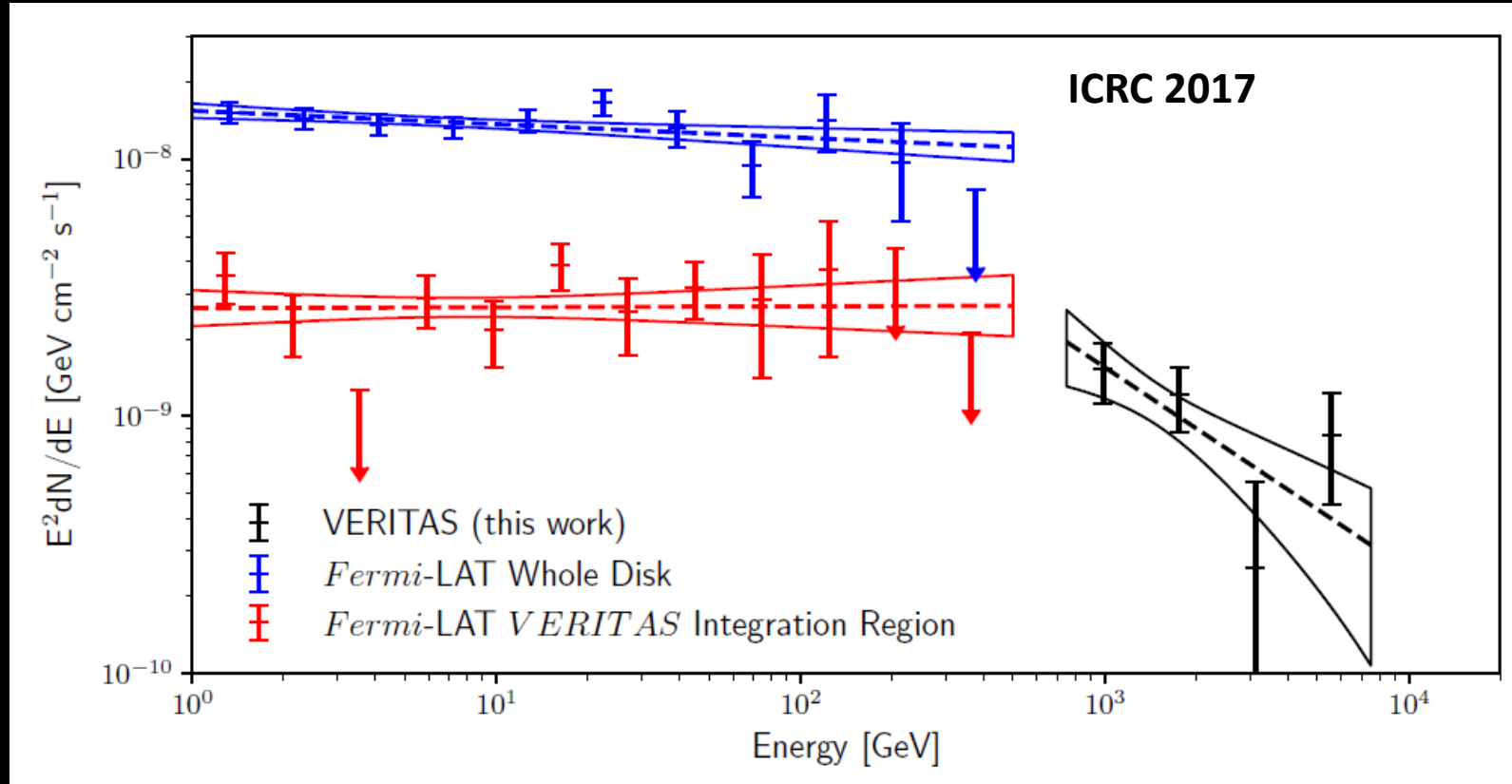
TeV PA 2017

MIDDLE-AGED REMNANTS

Gamma Cygni (VER J2019+407)

- Updated results (Cygnus Region Survey)
- Fermi-LAT emission remains more extended than that seen by VERITAS
- However, emission on northern rim matches well
- HAWC claims full remnant at displaced position

- VERITAS: Asymm Gaussian

$$0.29 \pm 0.02° \text{ by } 0.19 \pm 0.01°$$
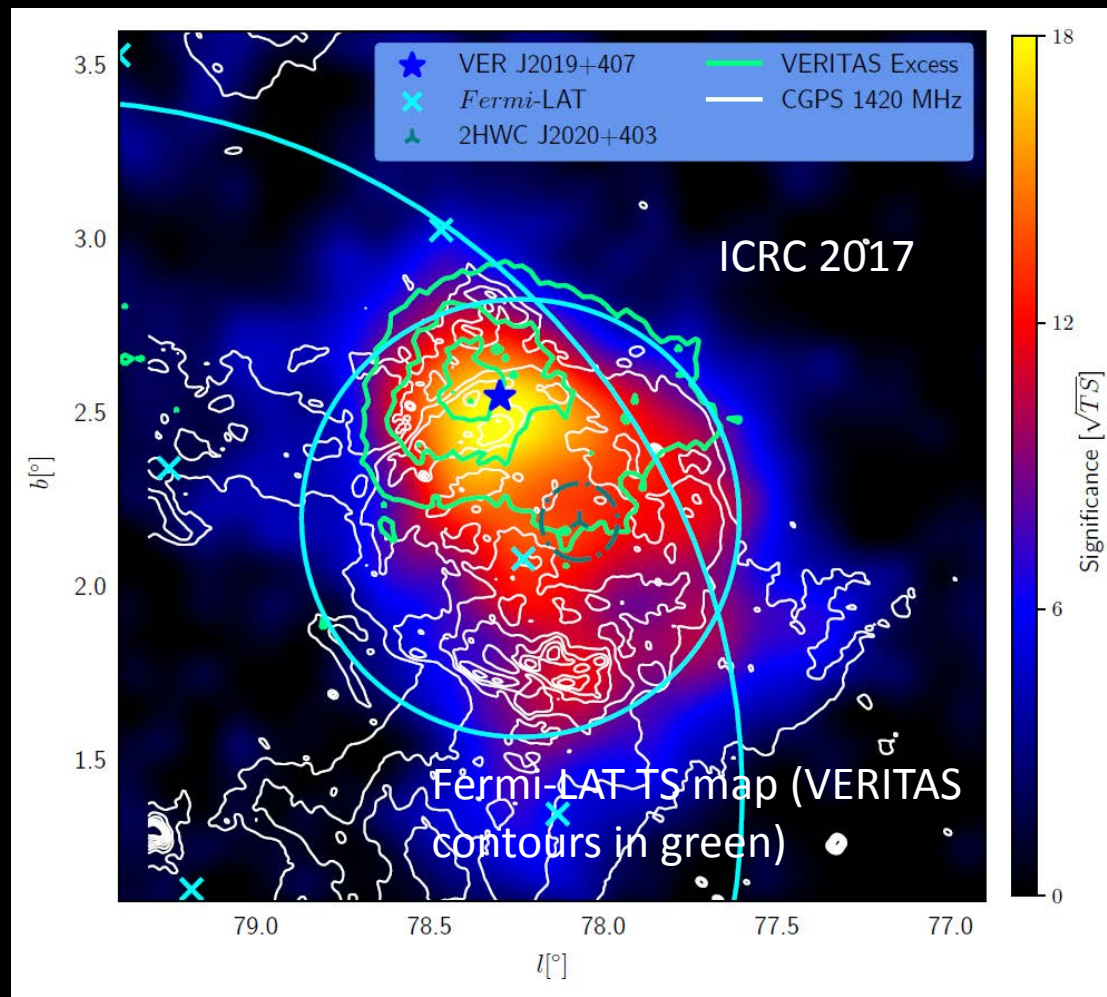
Gamma Cygni (VER J2019+407)

- Fermi-LAT emission consistent with constant index across remnant, flux enhancement at VERITAS location

- Joint fit with BPL, $I_1 = 1.97\pm0.07$, $I_2 = 2.79\pm0.22$, $E_b = 405$ GeV, $N0 = (1.93\pm0.50)$E-14 GeV-1 cm-2 s-1.

ICRC 2017

VERITAS (this work)
Fermi-LAT Whole Disk
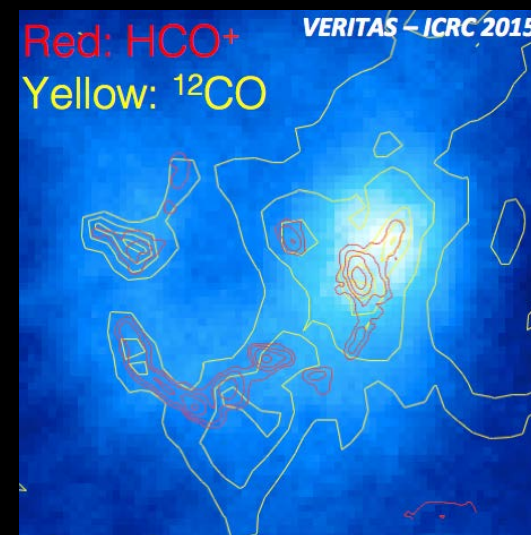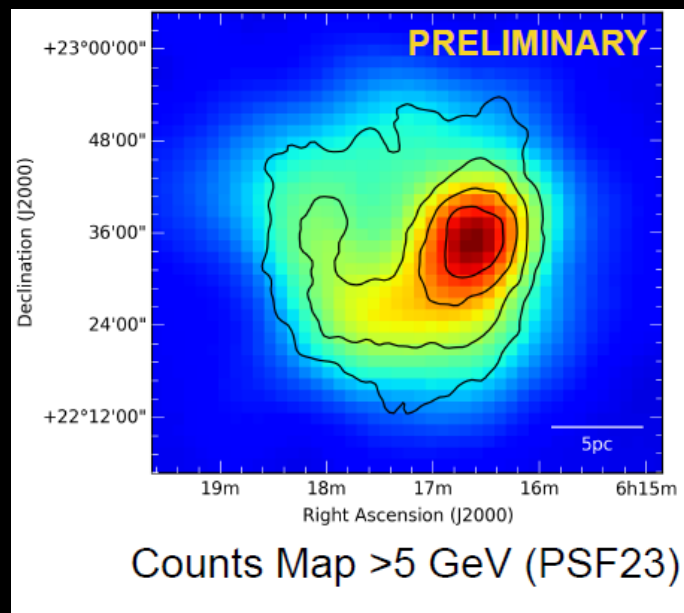Fermi-LAT VERITAS Integration Region

Resolving IC443

- Middle-aged SNR interacting with a molecular cloud
- Clear signature of pion decay in Fermi-LAT data (Ackermann et al. 2013)
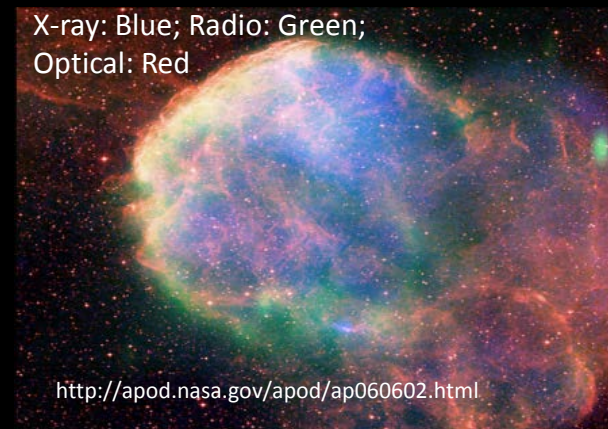
VERITAS emission (black contours) matches remarkably with Fermi-LAT

Resolving gamma-ray emission zones on 5 pc scale
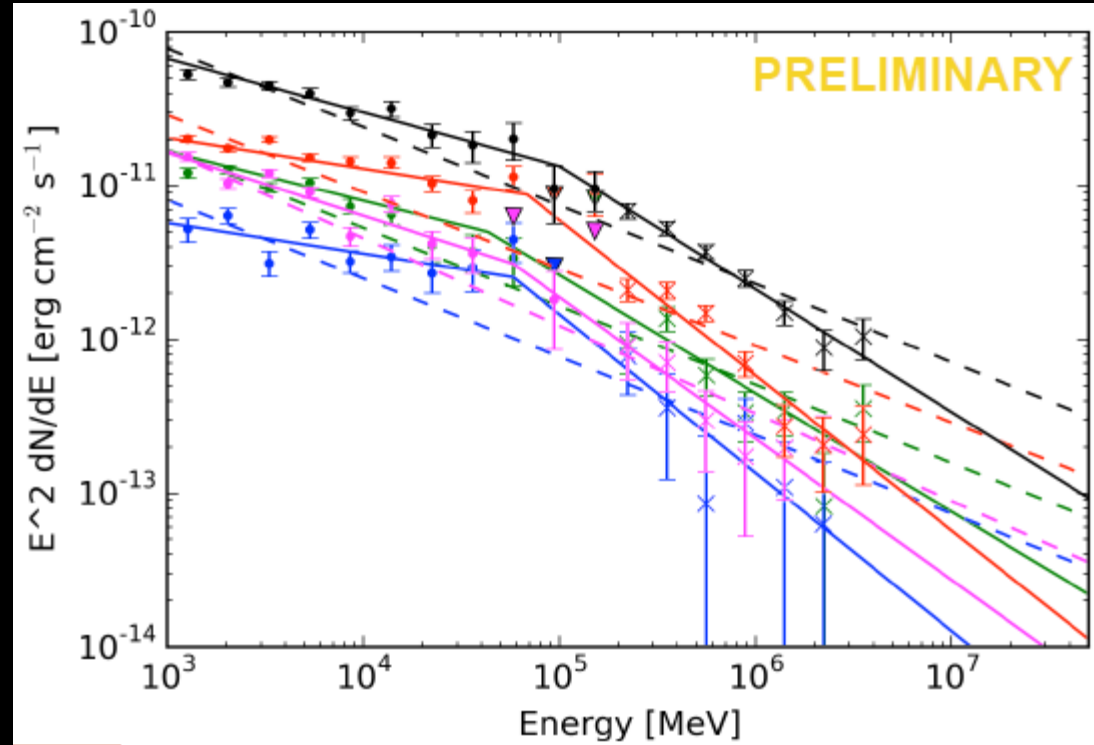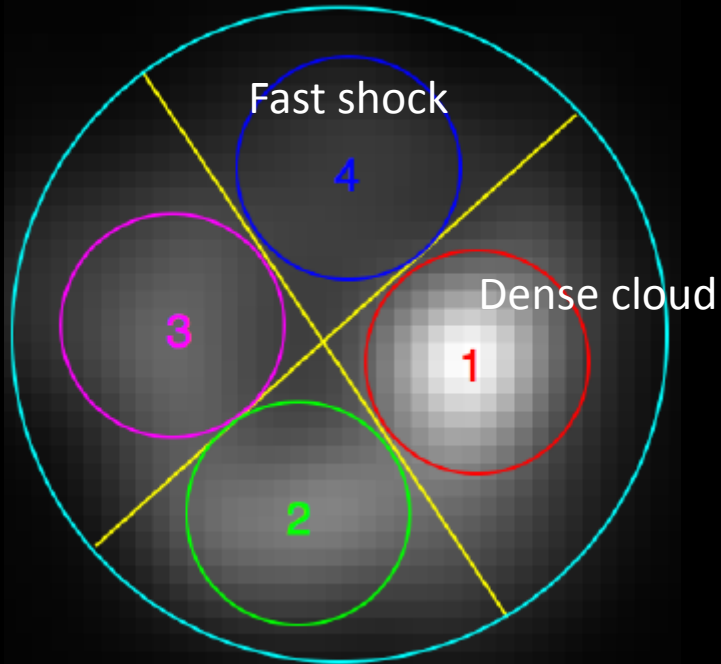

X-ray: Blue; Radio: Green; Optical: Red

http://apod.nasa.gov/apod/ap060602.html

PRELIMINARY

Counts Map >5 GeV (PSF23)

Red: HCO+
Yellow: ^{12}CO

VERITAS – ICRC 2015

VERITAS map; shocked gas contours

TeV PA 2017

Comparing regions

- Broken PL fits for all regions : Γ_1~2.3, Γ_2~2.9, break energy ~ 60 GeV

- Strong differences in environment but no clear differences in spectral shape!
- Order of magnitude variation in intensity but TeV/GeV integral flux ratios consistent within errors.

IC 443 in Context

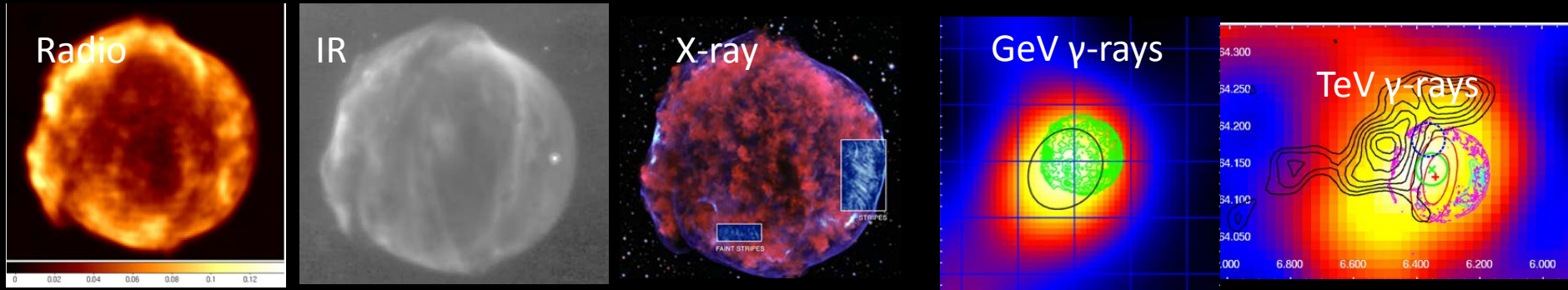Ackermann et al 2017
arXiv:1702.00476
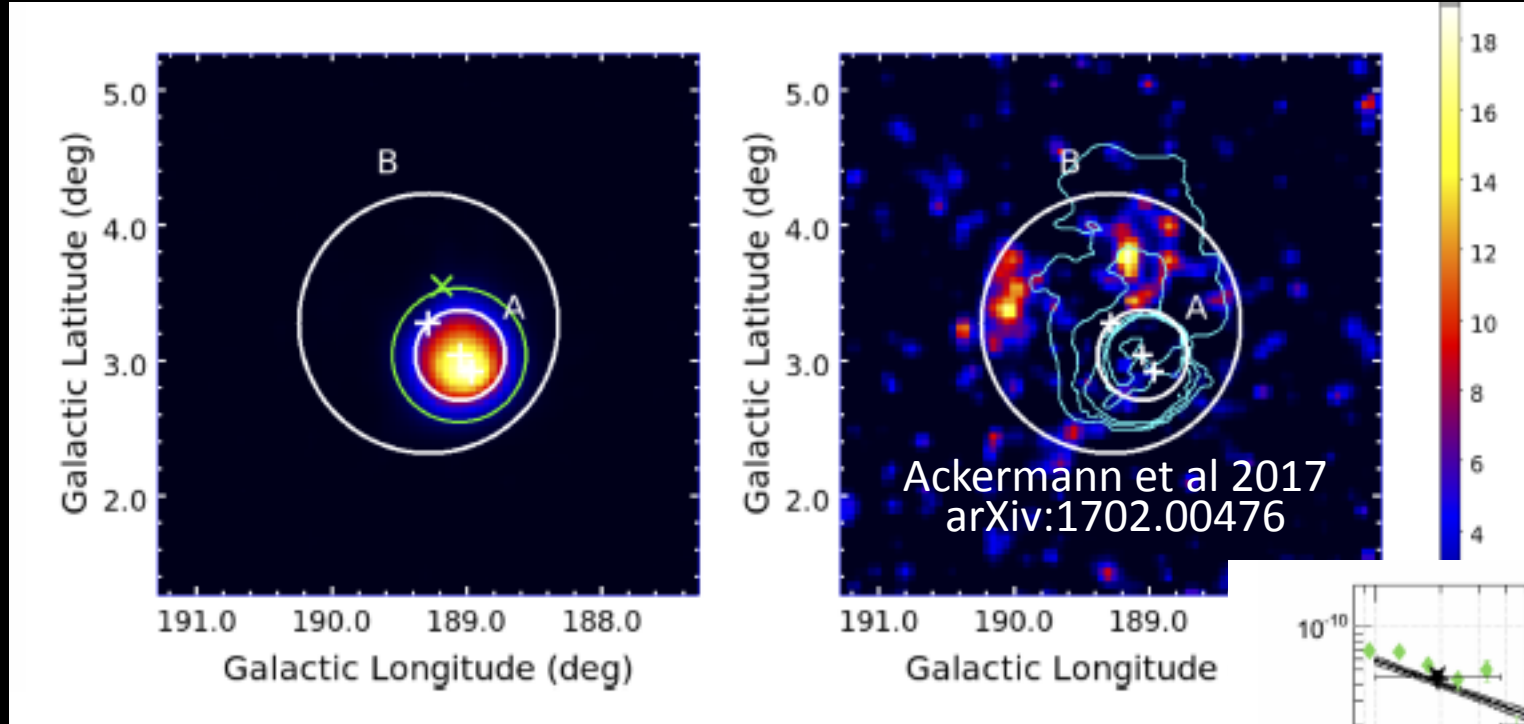
- Fermi-LAT now reports a second, hard-spectrum extended source encompassing IC 443 (FGES J0617.2+2235,)

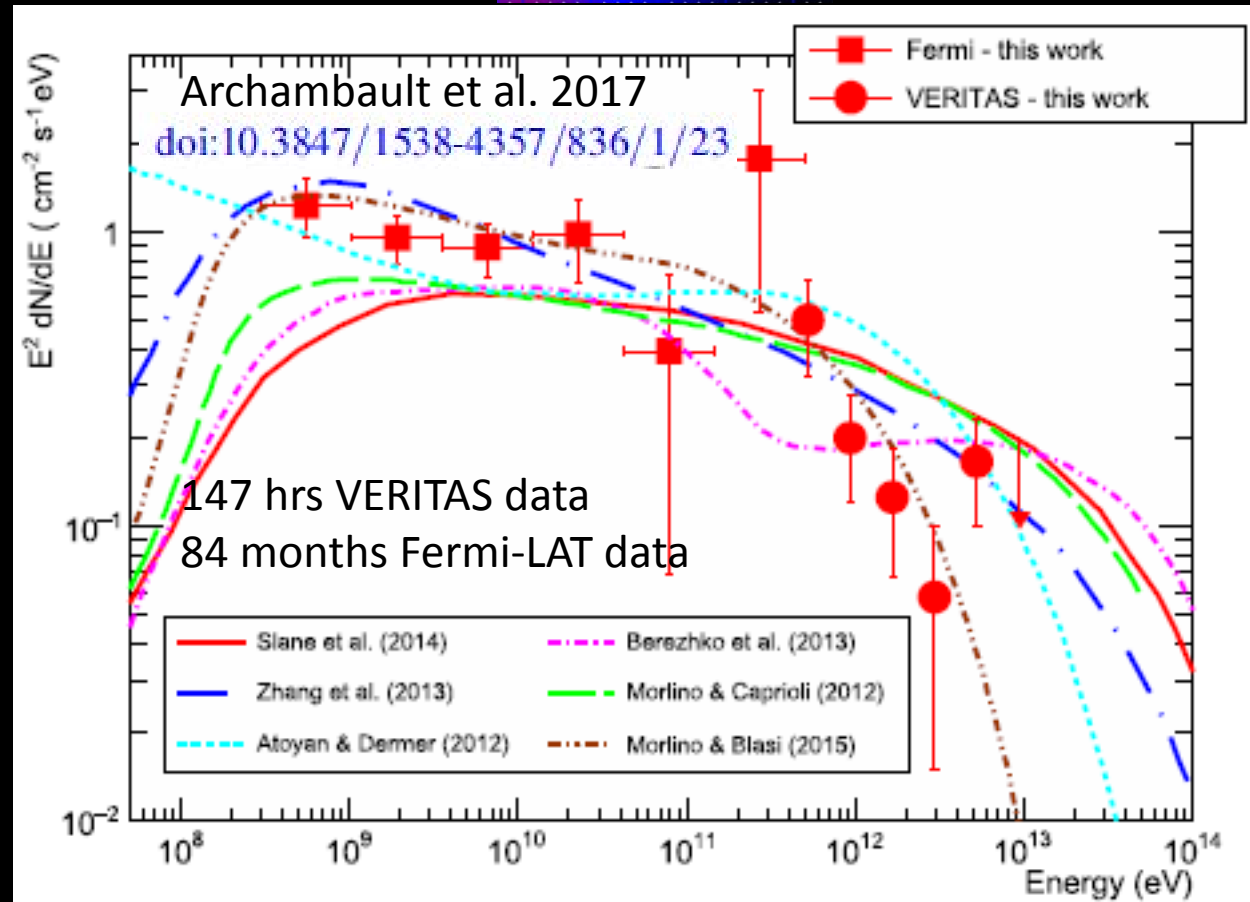- Escape signature? What will we see with IACTs?
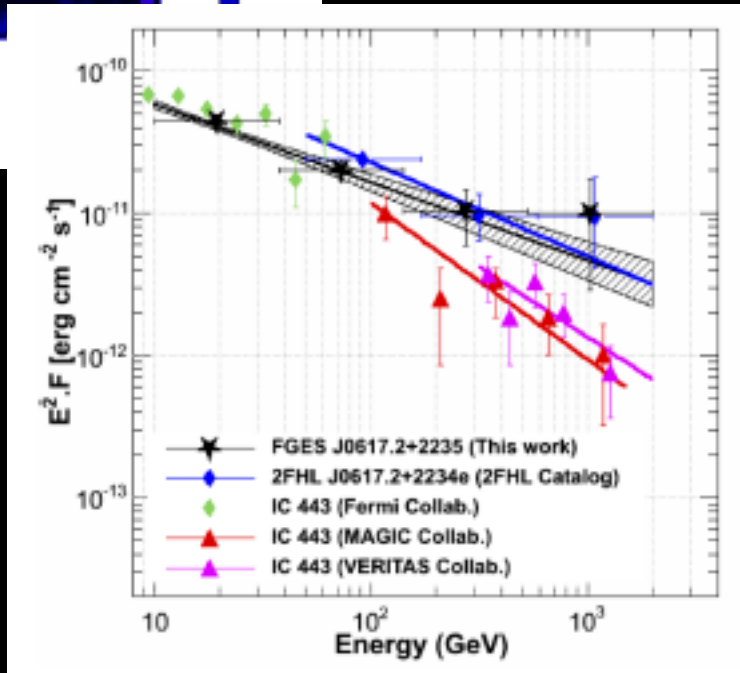
YOUNG SUPERNOVA REMNANTS

Tycho's SNR

Radio

IR

X-ray

GeV γ-rays

TeV γ-rays

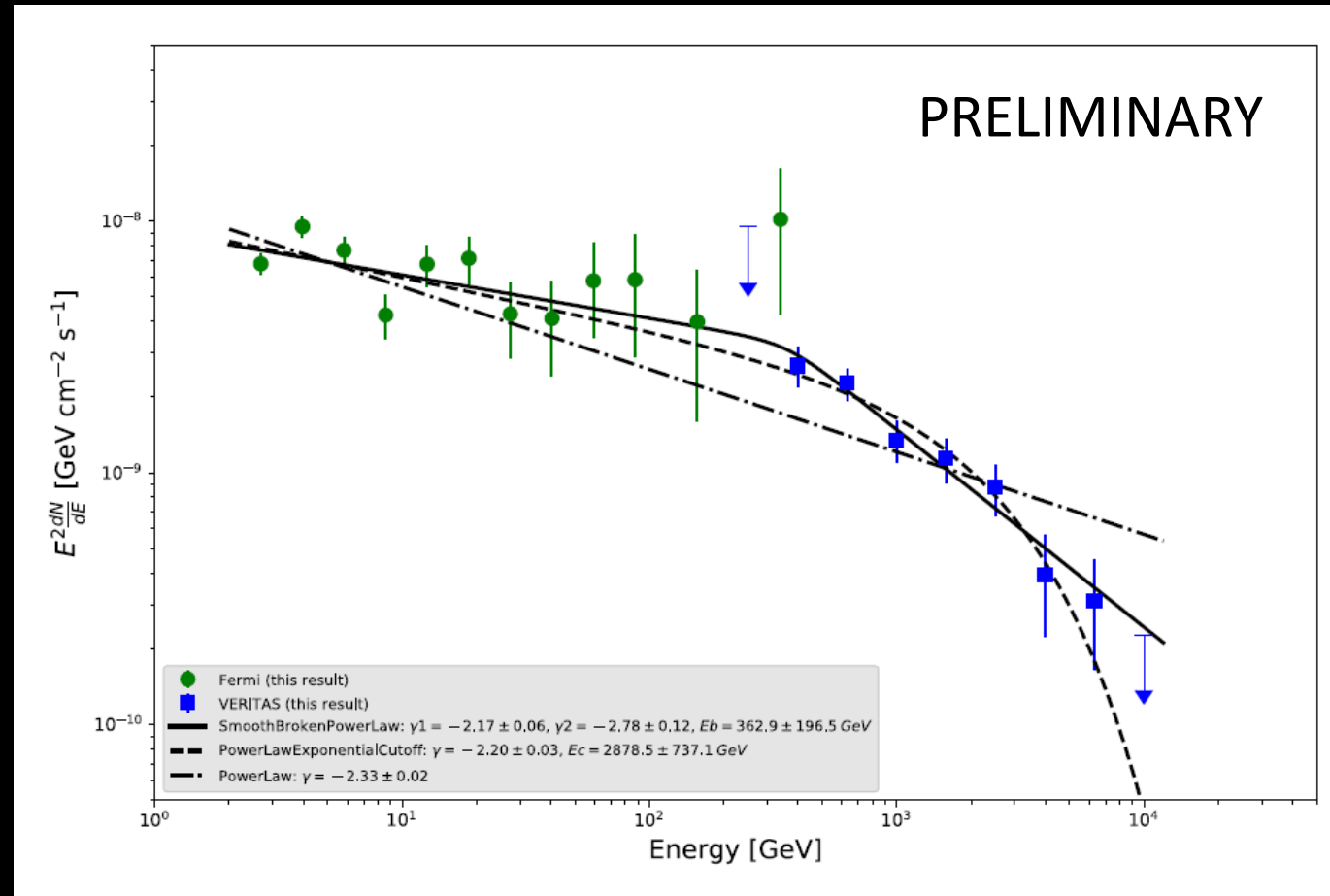- Historical Type 1a SNR (age: 445 yr; distance: 2-5 kpc)

- Most models support predominantly hadronic emission

- New (softer) spectrum suggests lower max. proton energy than models developed to describe previous GeV-TeV spectrum

- Morphology tests rule out emission dominated by MC or SW quadrant

Archambault et al. 2017
doi:10.3847/1538-4357/836/1/23

147 hrs VERITAS data
84 months Fermi-LAT data

Cas A

- 350 yr old core-collapse supernova remnant

- 3-4 kpc

- Broken power law, exponential cutoff models favored over a single power law (~3.5 σ after accounting for syst. uncertainties)

- Modeling in process---extension to lower and higher energies promise strong constraints on models.

Summary

- Broad VERITAS program studying SNR and PWNe and their relationship to cosmic rays

- PWNe remain the most populous TeV source class, but some examplars (e.g. TeV J2032+4130) hold surprises

- No PeVatrons..but model-constraining high-stats spectra of young SNR!

- Middle-aged SNR are starting to yield up interesting results about particle acceleration and diffusion
  - Morphological match between GeV and TeV gamma-ray pictures generally improves with increased integration times
  - Adding HAWC information at high energies will help---but disentangling multiple contributions at these energies is key!

- Trend towards deep observations, multi-instrument studies, and disentangling complex regions of emission