Galactic Sources with HAWC

http://www.webcamsdemexico.com/webcam-pico-de-orizaba.html 8/8/2017

Petra Huentemeyer

petra@mtu.edu

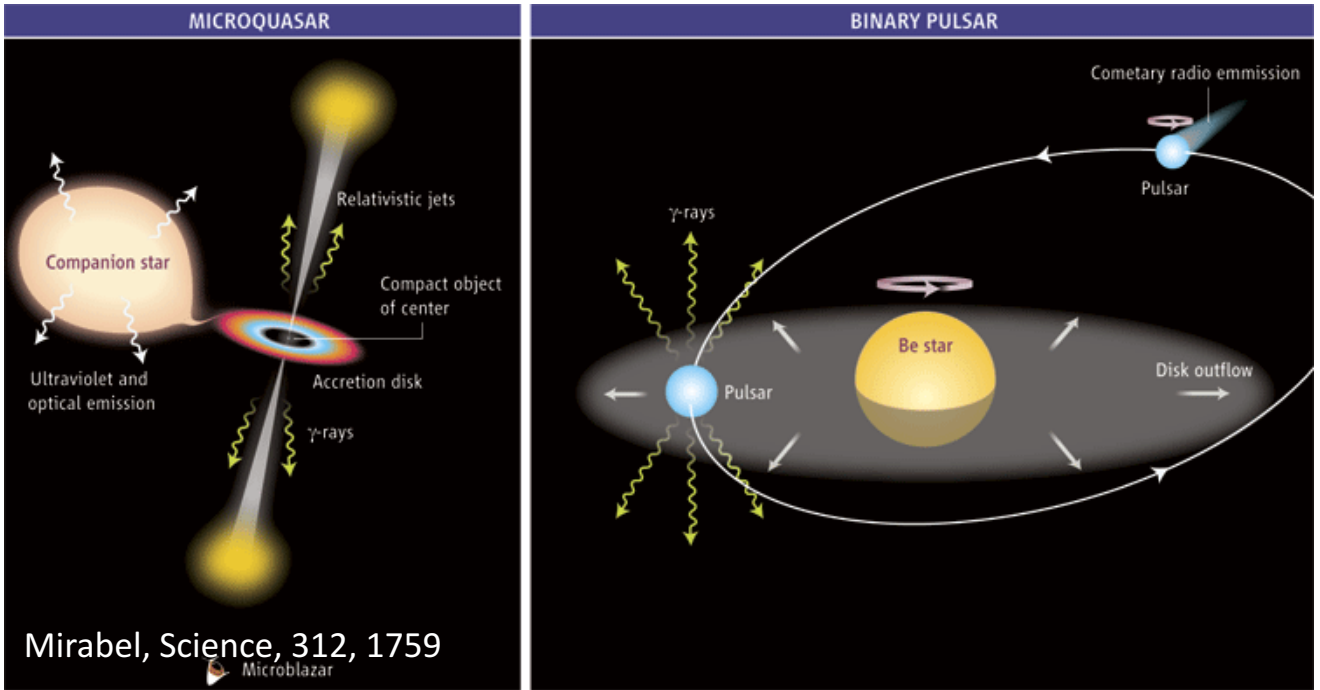
Galactic HAWC Observations

- Transients
  - TeV Binaries
  - Flares
- Highest energy accelerators
- Extended emission
  - Diffuse emission
  - Fermi bubbles
  - Molecular clouds
  - Nearby PWNe
  - SNRs

- High Duty Cycle
- Sensitivity and angular resolution > ~ 10 TeV
- Wide field of view and angular resolution (1^o-0.2^o, 68% cont.)

Transients – TeV Binaries

- **Unusual, rare** to have a natural mechanism repeatedly accelerating particles
- **Many** confirmed **radio and X-ray binaries** but **only 5 γ-ray binaries:** PSR B1259-63, LS 5039, LS I +61 303, HESS J0632+057, 1FGL J1018.6-5856, HESS J1832-093(?)
- All 5 γ-ray binaries observed in TeV are **point-like sources**
- γ-ray binaries: **compact objects** in orbit with **massive companion stars**
- mechanism of γ-ray production not fully understood → **mismatches** in observations at **different energy bands** unexplained
- **Unbiased survey** of our Galaxy could lead to more **discoveries allowing source-class studies**



Mirabel, Science, 312, 1759

Transients – TeV Binaries

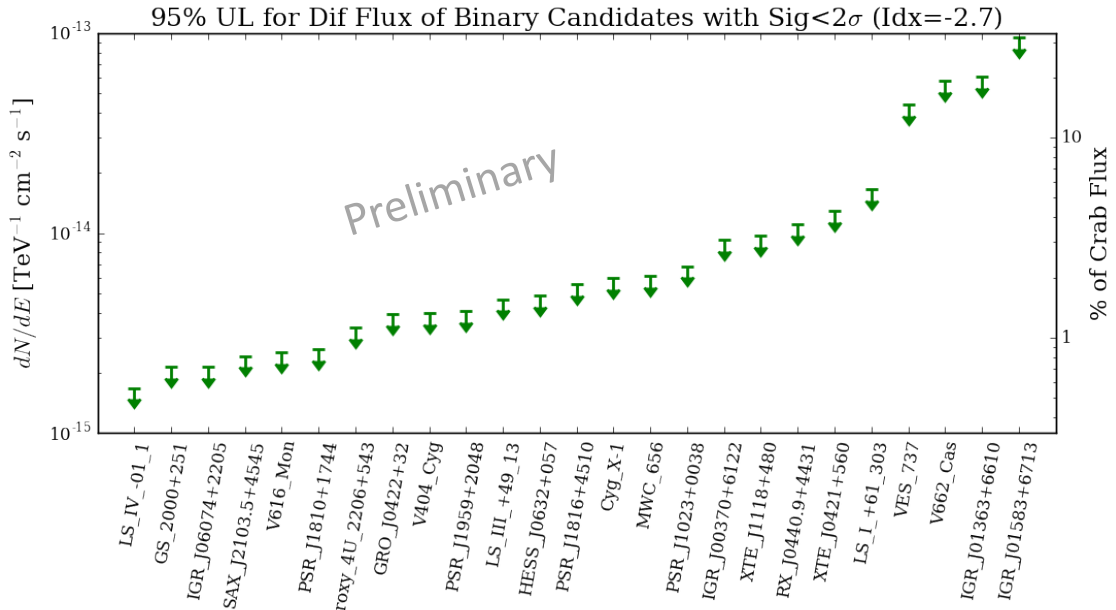
ICRC2017, Contrib. [369] [GA033] Searching for TeV Gamma-ray Emission from Binary Systems with HAWC – **Chang Rho, UR**

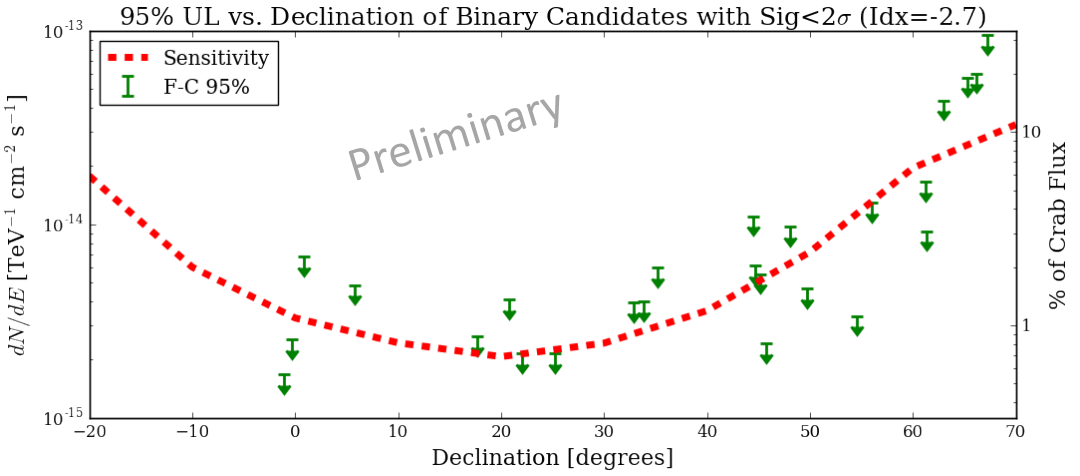
Source	RA	Dec	Type	d [kpc]	τ [day]	TS	Signif. [post-trial]	Dif Flux @ 7 TeV [$\mathrm{TeV}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$]
IGR J00370+6122	00:37	$+61°21'$	HMXB	3.4	15.67	0.00	$< 2\sigma$	$9.21 \cdot 10^{-15}$
V662 Cas	01:18	$+65°17'$	HMXB	6.5	11.60	0.15	$< 2\sigma$	$5.75 \cdot 10^{-14}$
IGR J01363+6610	01:36	$+66°11'$	HMXB	2.0	–	0.00	$< 2\sigma$	$6.03 \cdot 10^{-14}$
IGR J01583+6713	01:58	$+67°13'$	XB	4.1	–	0.26	$< 2\sigma$	$9.51 \cdot 10^{-14}$
VES 737	02:20	$+63°01'$	Bin	5.0	–	0.26	$< 2\sigma$	$4.38 \cdot 10^{-14}$
LS I +61 303	02:40	$+61°13'$	HMXB	2.0	26.50	0.00	$< 2\sigma$	$1.66 \cdot 10^{-14}$
XTE J0421+560	04:19	$+55°59'$	HMXB	2.0	19.41	0.04	$< 2\sigma$	$1.29 \cdot 10^{-14}$
GRO J0422+32	04:21	$+32°54'$	LMXB	2.0	0.21	1.43	$< 2\sigma$	$3.93 \cdot 10^{-15}$
RX J0440.9+4431	04:40	$+44°31'$	HMXB	2.9	–	7.41	$< 2\sigma$	$1.10 \cdot 10^{-14}$
IGR J06074+2205	06:07	$+22°05'$	HMXB	4.5	–	0.01	$< 2\sigma$	$2.15 \cdot 10^{-15}$
V616 Mon	06:22	$-00°20'$	LMXB	1.1	0.33	0.00	$< 2\sigma$	$2.54 \cdot 10^{-15}$
HESS J0632+057	06:32	$+05°48'$	HMXB	1.6	315 ± 5	2.39	$< 2\sigma$	$4.85 \cdot 10^{-15}$
PSR J1023+0038	10:23	$+00°53'$	LMXB	1.3	–	5.27	$< 2\sigma$	$6.83 \cdot 10^{-15}$
XTE J1118+480	11:18	$+48°02'$	LMXB	1.7	0.17	1.84	$< 2\sigma$	$9.71 \cdot 10^{-15}$
LS IV -01 1	17:07	$-01°05'$	Star	0.3	–	0.00	$< 2\sigma$	$1.68 \cdot 10^{-15}$
PSR J1810+1744	18:10	$+17°41'$	MSP	2.0	–	0.25	$< 2\sigma$	$2.62 \cdot 10^{-15}$
PSR J1816+4510	18:16	$+45°10'$	MSP	4.0	0.36	0.15	$< 2\sigma$	$5.53 \cdot 10^{-15}$
LS 5039	18:26	$-14°50'$	HMXB	2.9	3.90	139.97	11.54σ	$6.37 \cdot 10^{-14}$
4U 1907+09	19:09	$+09°49'$	HMXB	4.0	8.37	10.87	2.17σ	$7.08 \cdot 10^{-15}$
SS 433	19:12	$+04°59'$	XB	5.5	13.10	17.27	3.29σ	$8.51 \cdot 10^{-15}$
IGR J1914+0951	19:14	$+09°52'$	HMXB	5.0	13.56	80.40	8.58σ	$1.50 \cdot 10^{-14}$
Cyg X-1	19:58	$+35°12'$	HMXB	2.2	5.60	4.99	$< 2\sigma$	$5.96 \cdot 10^{-15}$
PSR J1959+2048	19:59	$+20°48'$	Bin	2.5	–	3.10	$< 2\sigma$	$4.08 \cdot 10^{-15}$
GS 2000+251	20:02	$+25°14'$	LMXB	2.7	0.35	0.00	$< 2\sigma$	$2.14 \cdot 10^{-15}$
V404 Cyg	20:24	$+33°52'$	LMXB	2.4	6.47	0.98	$< 2\sigma$	$3.97 \cdot 10^{-15}$
EXO 2030+375	20:32	$+37°38'$	HMXB	5.0	46.02	16.85	3.23σ	$9.54 \cdot 10^{-15}$
Cyg X-3	20:32	$+40°57'$	HMXB	7.0	0.20	77.54	8.41σ	$2.15 \cdot 10^{-14}$
LS III +49 13	20:56	$+49°40'$	BH	0.1	–	0.00	$< 2\sigma$	$4.67 \cdot 10^{-15}$
SAX J2103.5+4545	21:03	$+45°45'$	HMXB	6.5	12.68	0.00	$< 2\sigma$	$2.43 \cdot 10^{-15}$
4U 2206+543	22:07	$+54°31'$	HMXB	2.6	9.57	0.00	$< 2\sigma$	$3.36 \cdot 10^{-15}$
MWC 656	22:42	$+44°43'$	HMXB	2.6	–	0.40	$< 2\sigma$	$6.10 \cdot 10^{-15}$

- γ- ray binary candidates:
  - 3 known γ-ray binaries in HAWC FOV (red)
  - 5 unconfirmed locations with TS > 10
  - 28 XRBs with short orbital periods
- TS fitting a power law with idx = -2.7 and E_{piv} = 7 TeV.
- Post-trial significances for each of the sources (< 2σ UL; > 2σ LC).

Transients – TeV Binaries

ICRC2017, Contrib. [369] [GA033] Searching for TeV Gamma-ray Emission from Binary Systems with HAWC – **Chang Rho, UR**





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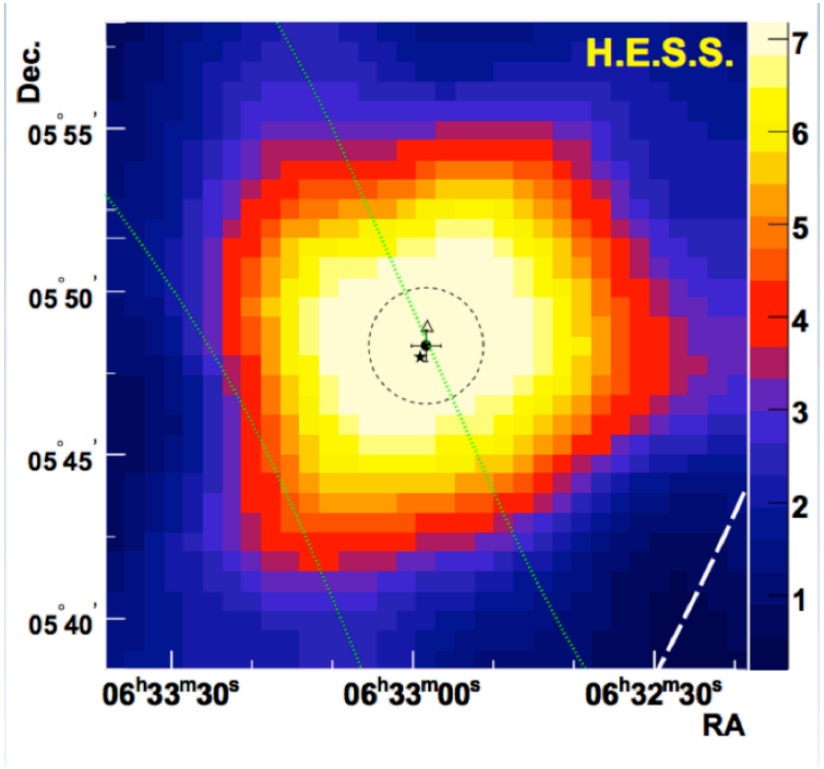

HESS J0632+057

- First discovered as a TeV source by H.E.S.S. in 2007.
- Variability later found in X-rays (P_{orb} = 321 ± 5 days) then also observed in TeV (P_{orb} = 315 ± 5 days).
- Only γ-ray binary observed by all three major IACTs (H.E.S.S., VERITAS & MAGIC).
- Binary system with a nearby Be star, MWC 148.
- No HE observation by Fermi/LAT.

Transients – TeV Binaries

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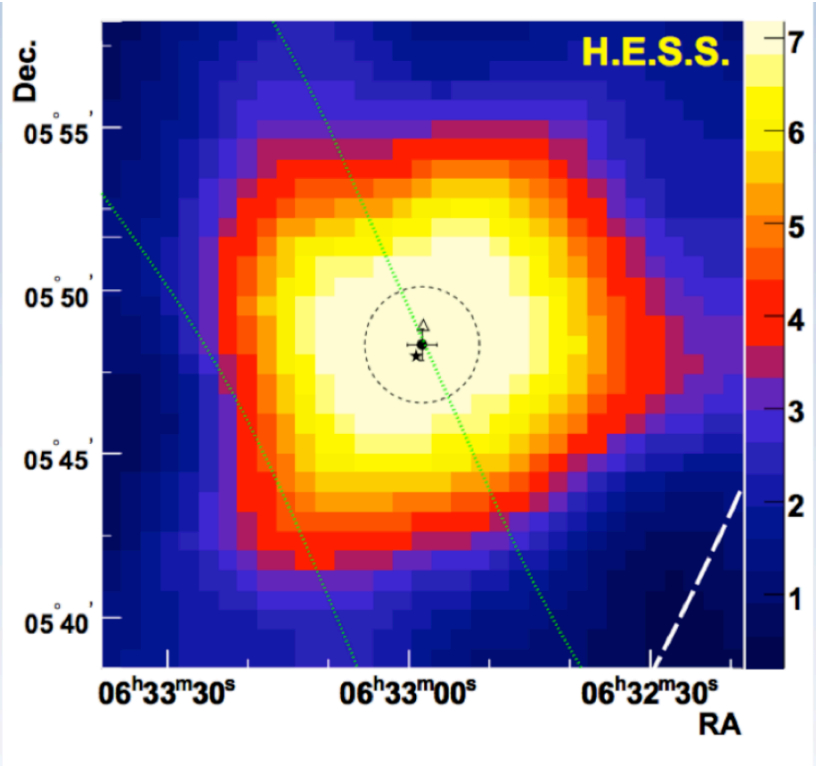

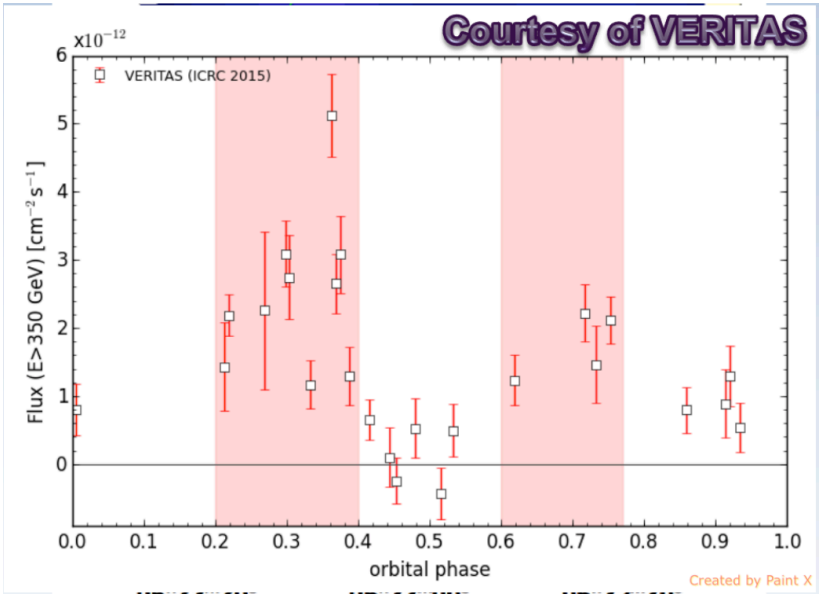

HESS J0632+057

Transients – TeV Binaries

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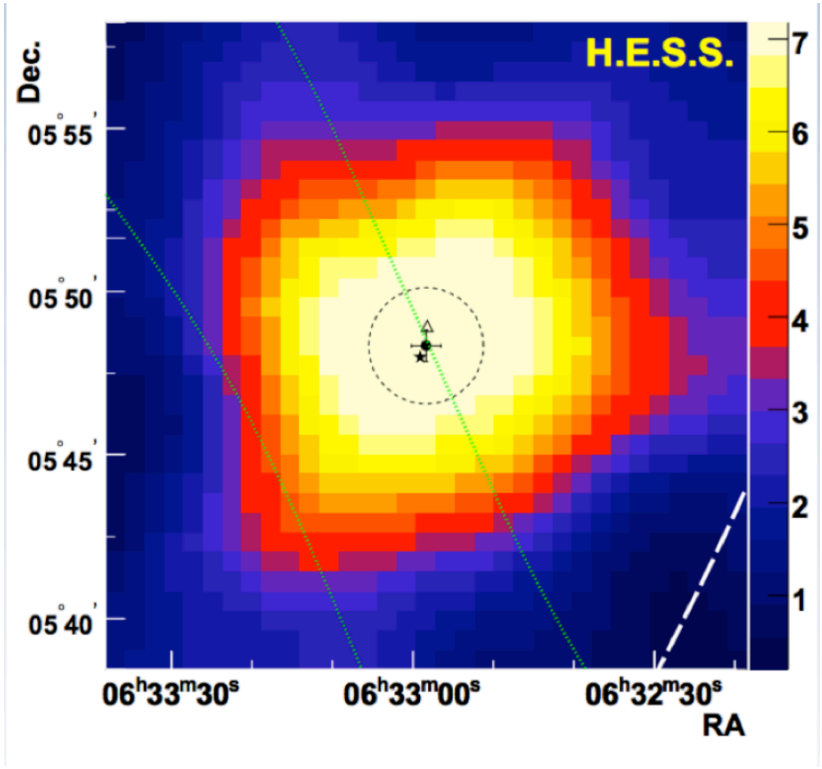

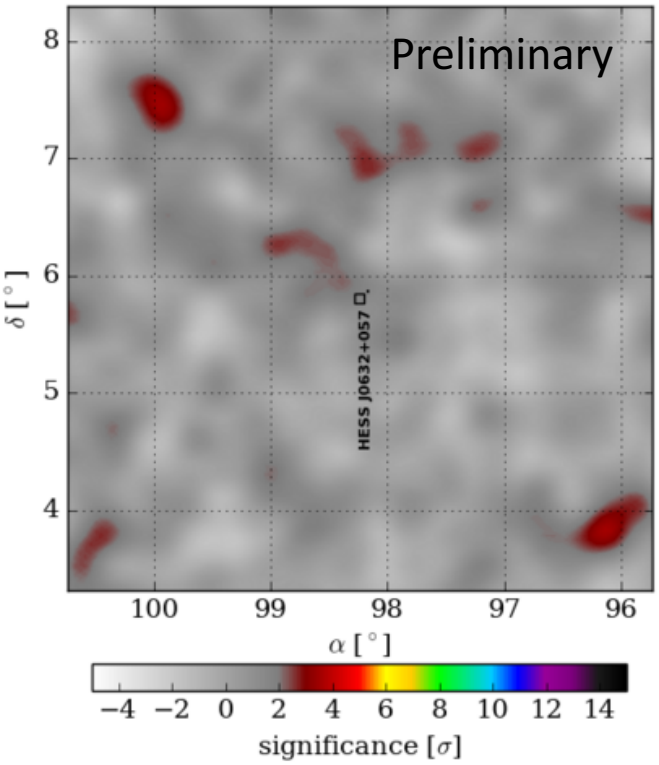

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Transients – TeV Binaries

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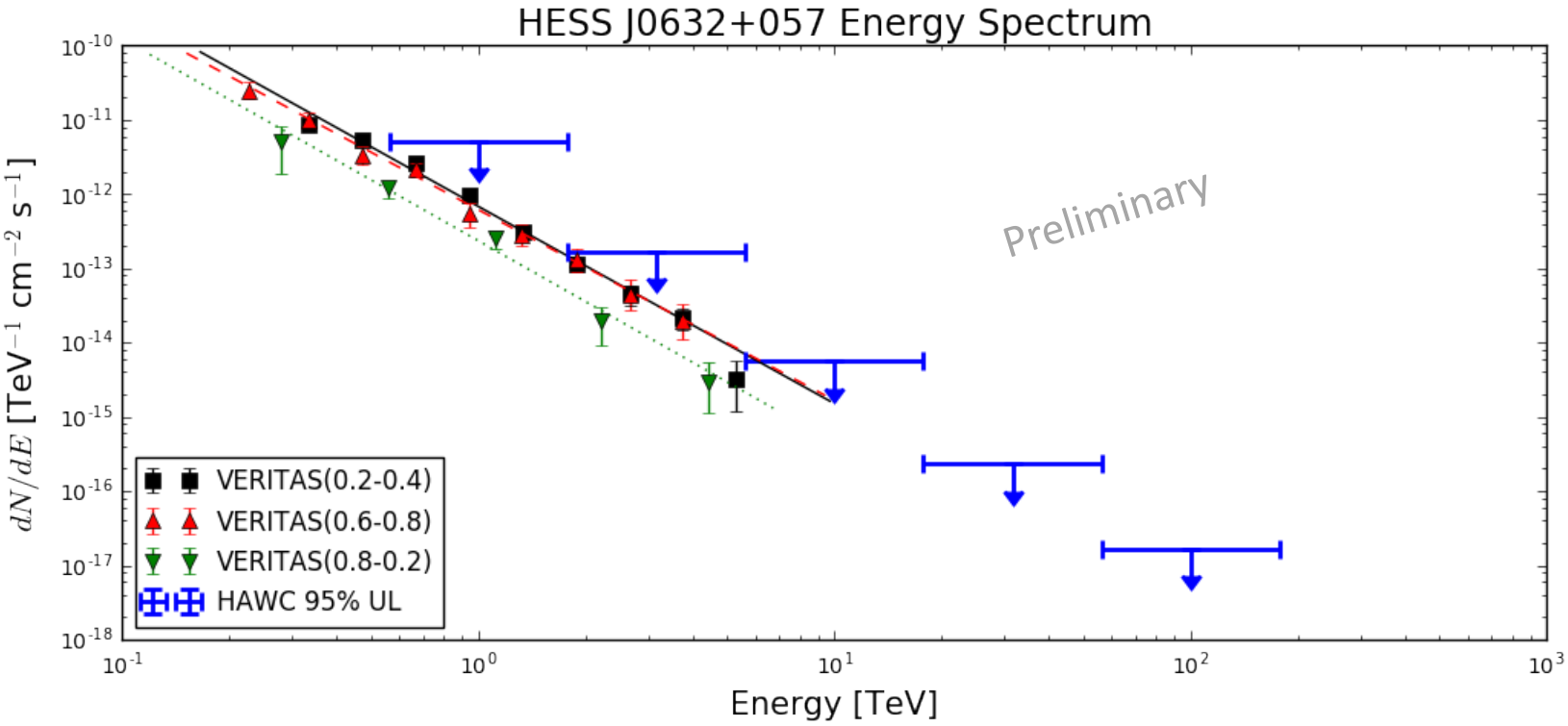
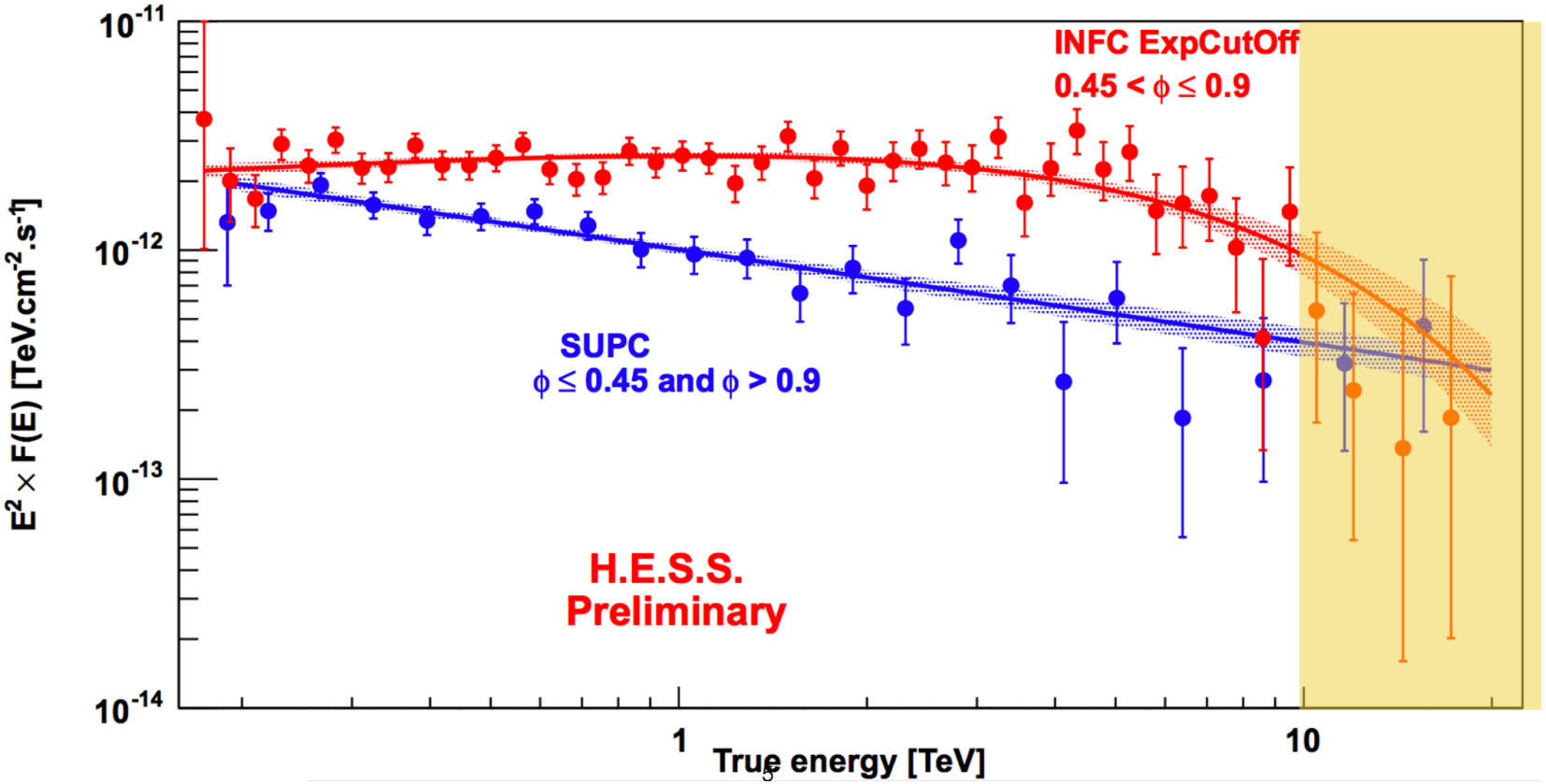


Expect **detection** with **~3 years** of data (**power law**), ~8 years of data (**cutoff @ 5 TeV**).

Transients – TeV Binaries: LS5039

ICRC2017, Contrib. [896] [GA231] A First Look at Periodicity in HAWC with TeV Binaries – **Chad Brisbois, MTU**

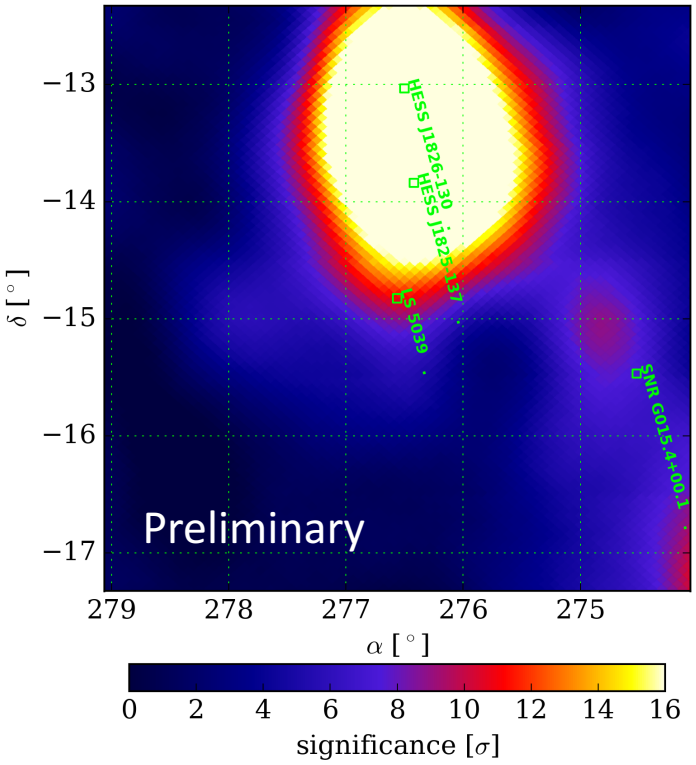


P. Bordas *et al.* [H.E.S.S. Collaboration], AIP Conf. Proc. 1792, no. 1, 040017 (2017) doi:10.1063/1.4968921 [arXiv:1610.03264 [astro-ph.HE]]

What happens above 10 TeV?

Transients – TeV Binaries: LS 5039

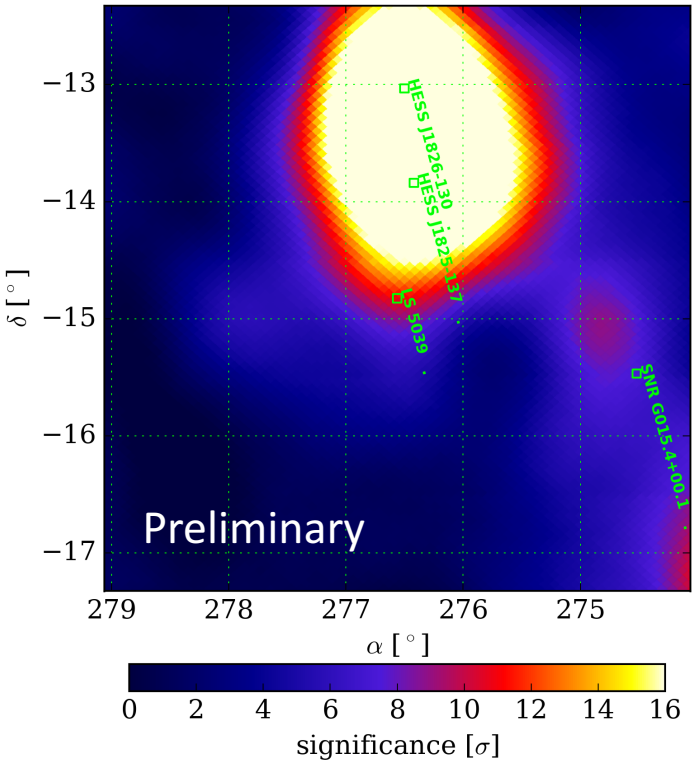
ICRC2017, Contrib. [896] [GA231] A First Look at Periodicity in HAWC with TeV Binaries – **Chad Brisbois, MTU**



- LS 5039
  - High-Mass X-ray binary O star - $23M_{\odot}$
  - Compact Companion - $3.7M_{\odot}$
  - 3.9 day period
- Challenge: Located in a busy region, near HESS J1825-137 & HESS J1826-130. Both are extended sources!

Transients – TeV Binaries: LS 5039

ICRC2017, Contrib. [896] [GA231] A First Look at Periodicity in HAWC with TeV Binaries – **Chad Brisbois, MTU**



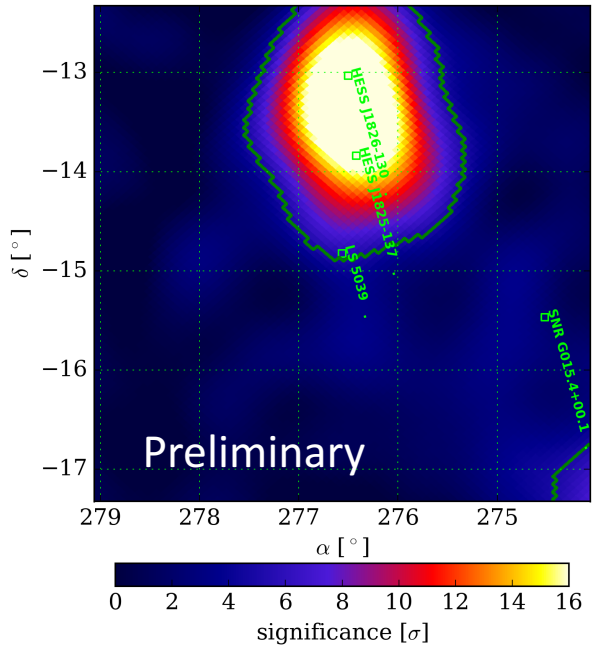
- Method:
  1. Split dataset according to phase of LS 5039
  2. Fit normalization with a fixed index (-2.0)
  3. Subtract high flux map from low flux map
  4. Perform same procedure with high/low energy bins
  5. Check for significant difference between the flux

$$\mathfrak{S} = \frac{F_{high} - F_{low}}{\sqrt{\sigma_{high}^2 + \sigma_{low}^2}}$$

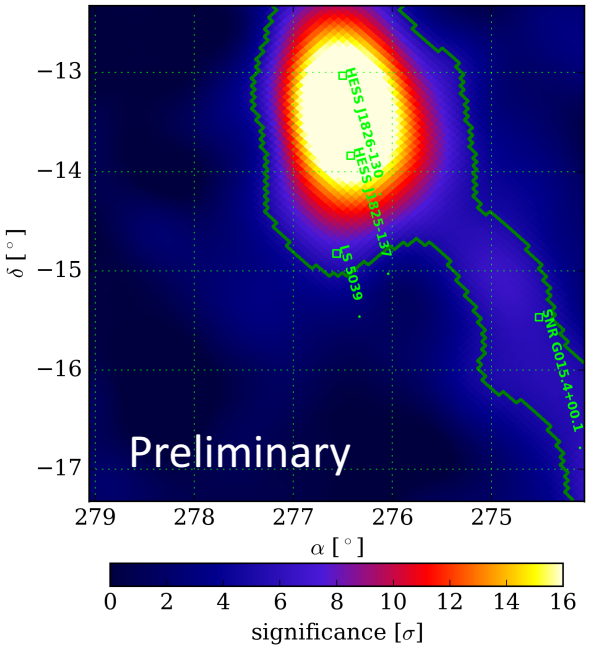
Transients – TeV Binaries: LS 5039

ICRC2017, Contrib. [896] [GA231] A First Look at Periodicity in HAWC with TeV Binaries – **Chad Brisbois, MTU**

High State – 342 days



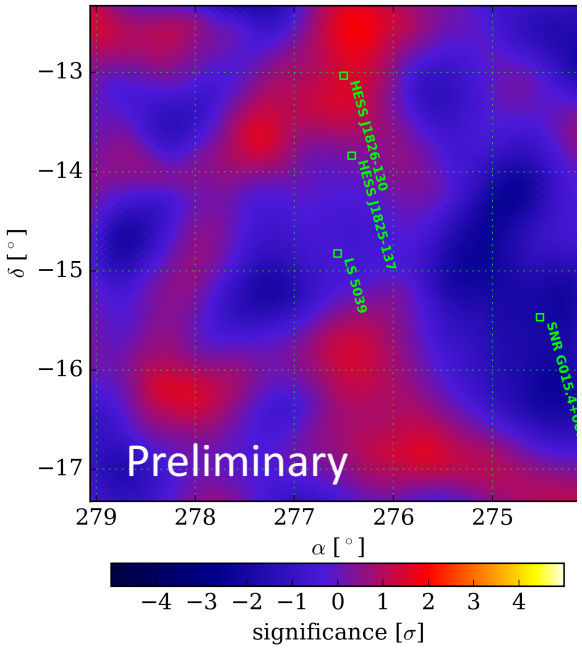
Low State – 418 days



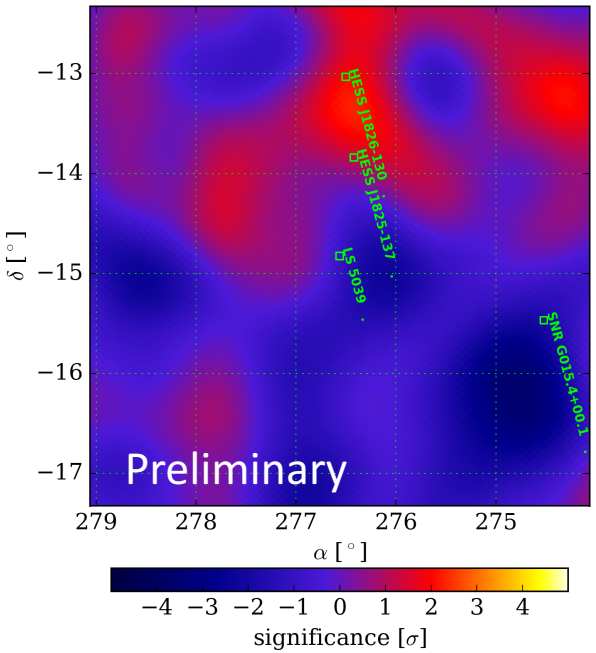
Transients – TeV Binaries: LS 5039

ICRC2017, Contrib. [896] [GA231] A First Look at Periodicity in HAWC with TeV Binaries – **Chad Brisbois, MTU**

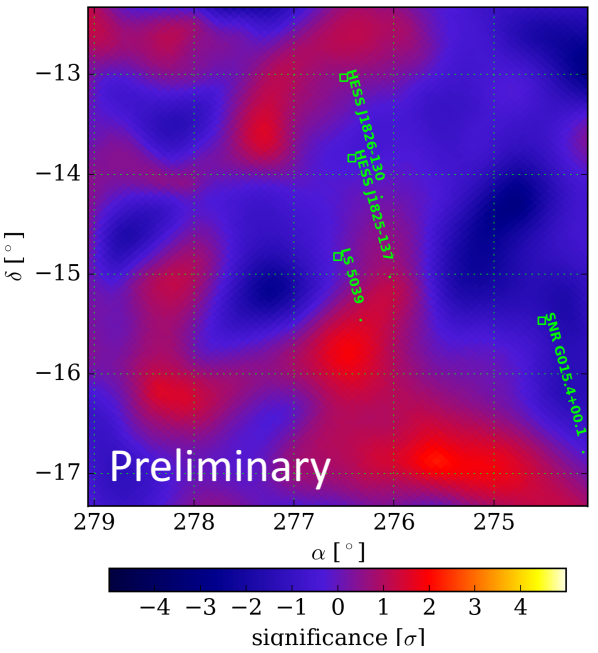
Full Energy Range



< ~ 10 TeV



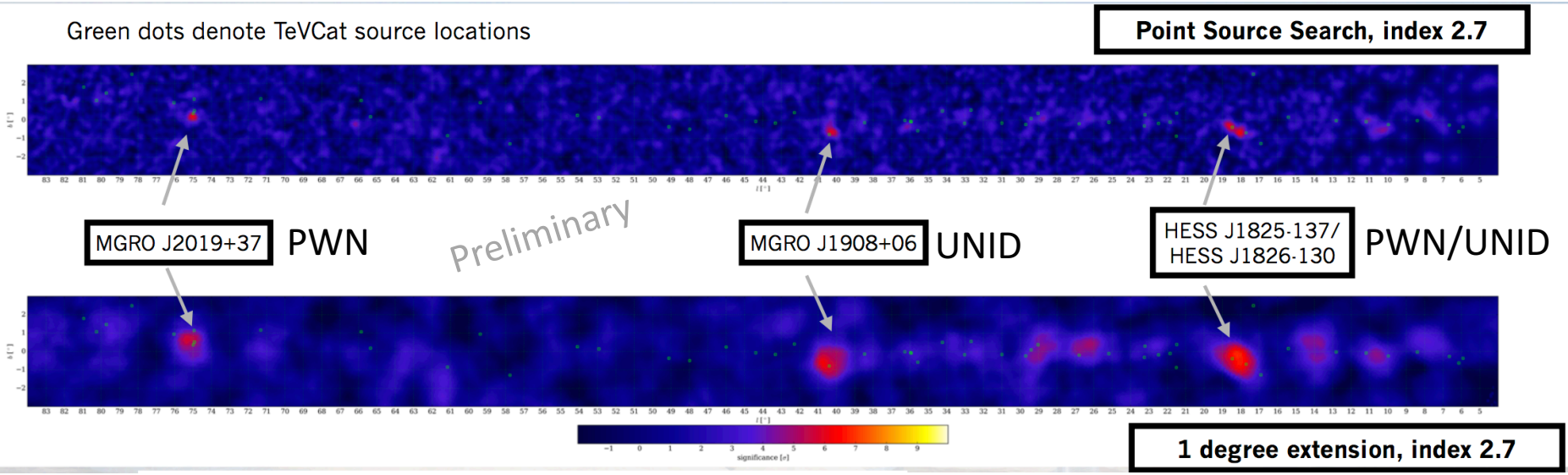
> ~ 10 TeV



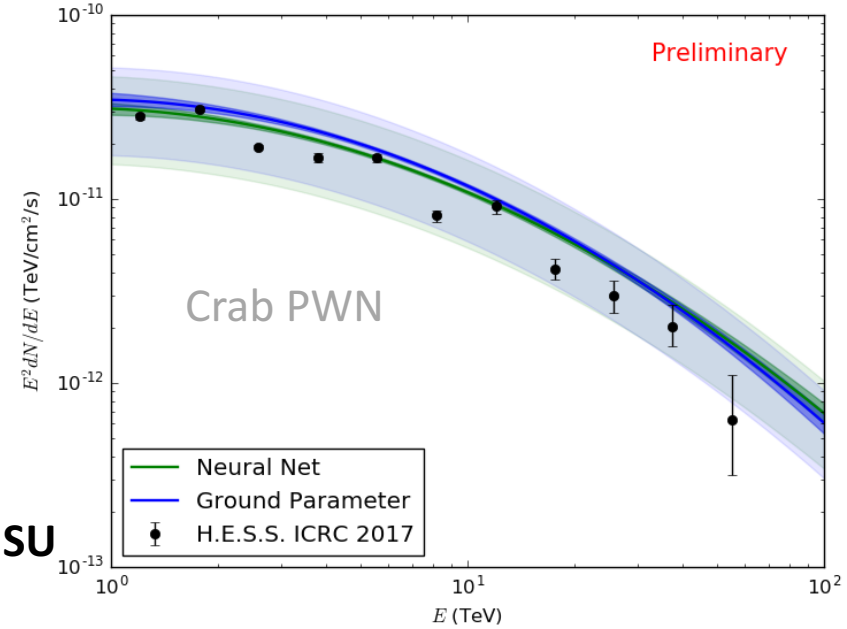
Map	Flux ($10^{-14}\ TeV^{-1}cm^{-2}s^{-1}$)
High State	1.13 ± 0.25
Low State	1.32 ± 0.24
Difference	-0.19 ± 0.35

Flux Difference ($10^{-15}\ TeV^{-1}cm^{-2}s^{-1}$)		$\mathfrak{S}$
Full	-0.59 ± 3.2	-0.18
< ~ 10 TeV	-6.2 ± 8.4	-0.75
> ~ 10 TeV	-2.0 ± 3.5	-0.54

Highest Energy Accelerators



TeVPA2017, A First Look at the Very High Energy Gamma-Ray Sky from HAWC – **Kelly Malone, PSU**

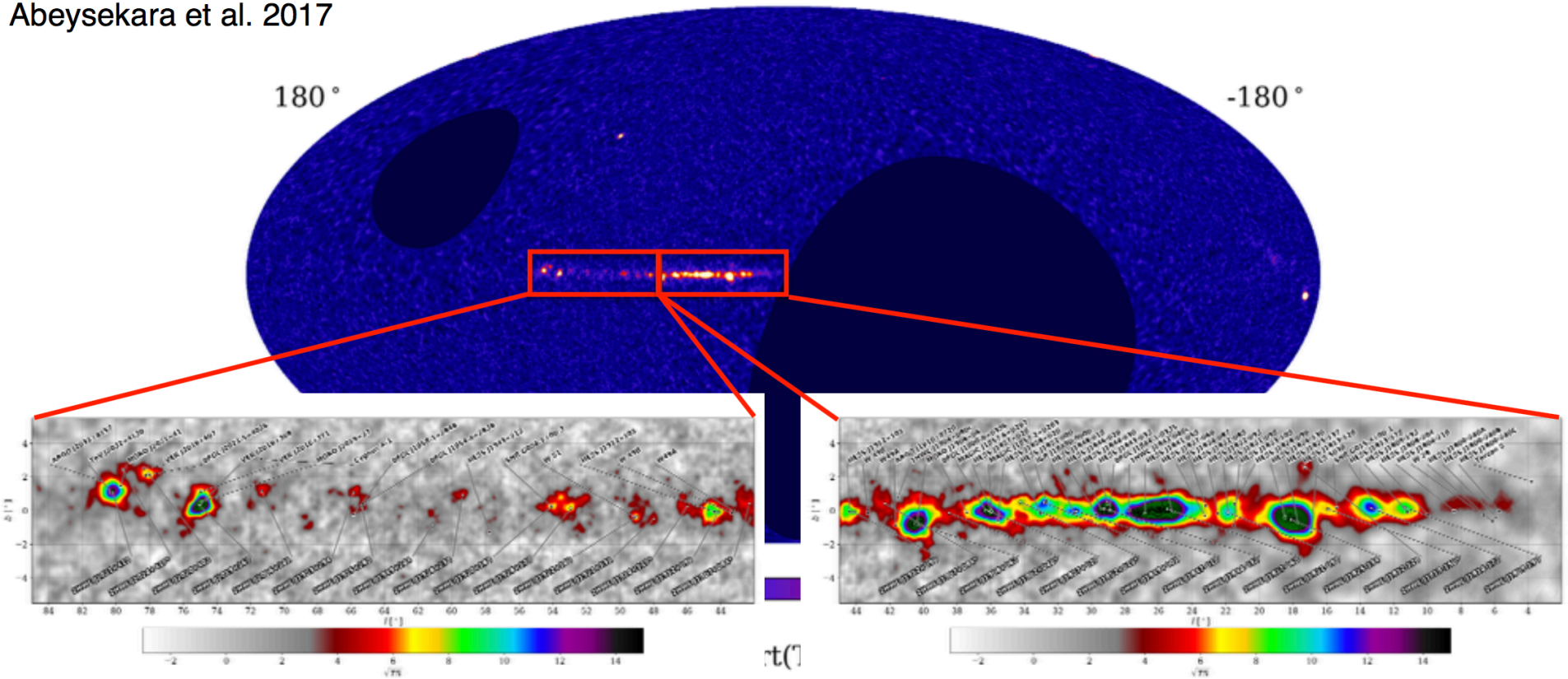


TeVPA2017, Measuring High Energy Spectra with HAWC– **Sam Marinelli, MSU**

Extended Emission – Diffuse Emission

ICRC2017, Contrib. [436] [GA251] Probing Galactic Diffuse TeV Gamma-Ray Emission with the HAWC Observatory – **Hao Zhou, LANL**

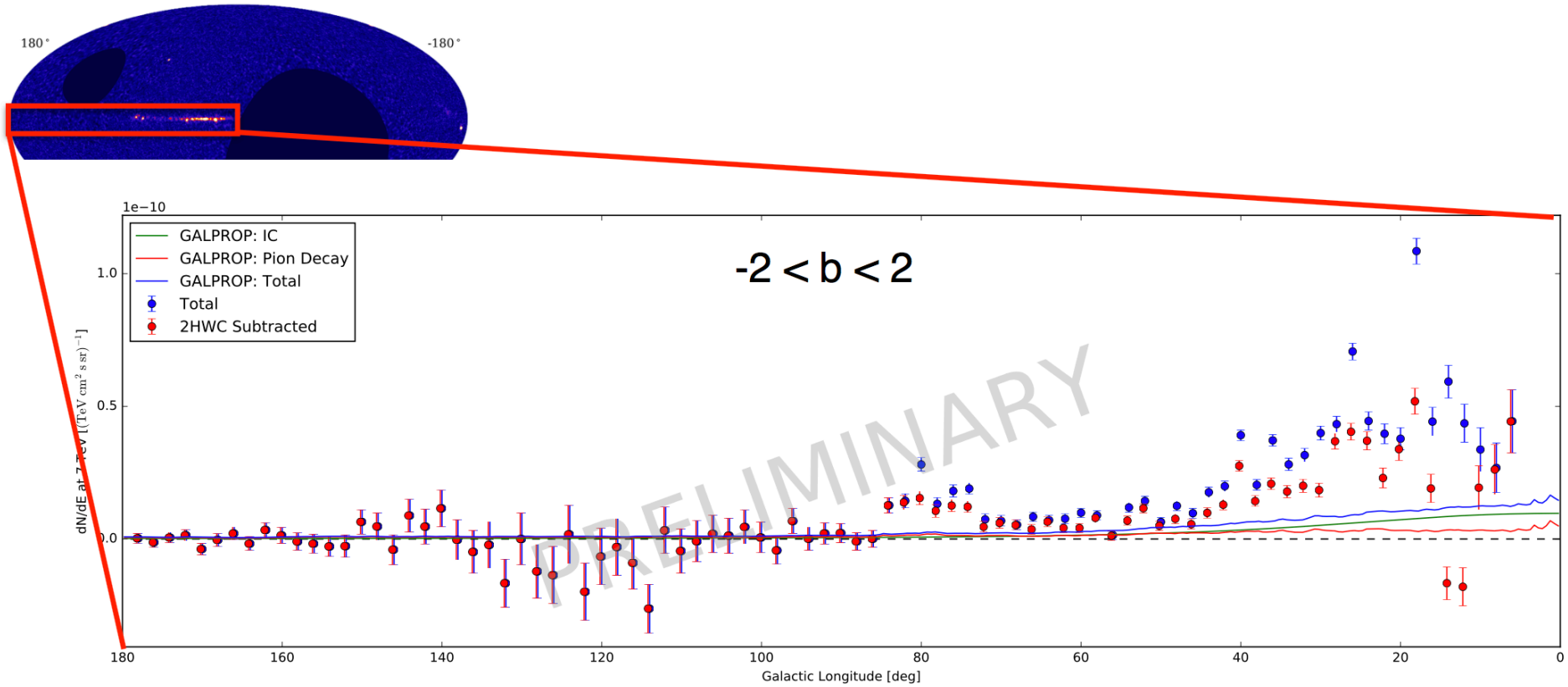
2HWC Catalog
Abeysekara et al. 2017



Challenge: @ TeV energies, gamma-ray emission from localized sources (resolved and unresolved) dominates over truly diffuse emission

Extended Emission – Diffuse Emission

ICRC2017, Contrib. [436] [GA251] Probing Galactic Diffuse TeV Gamma-Ray Emission with the HAWC Observatory – **Hao Zhou, LANL**

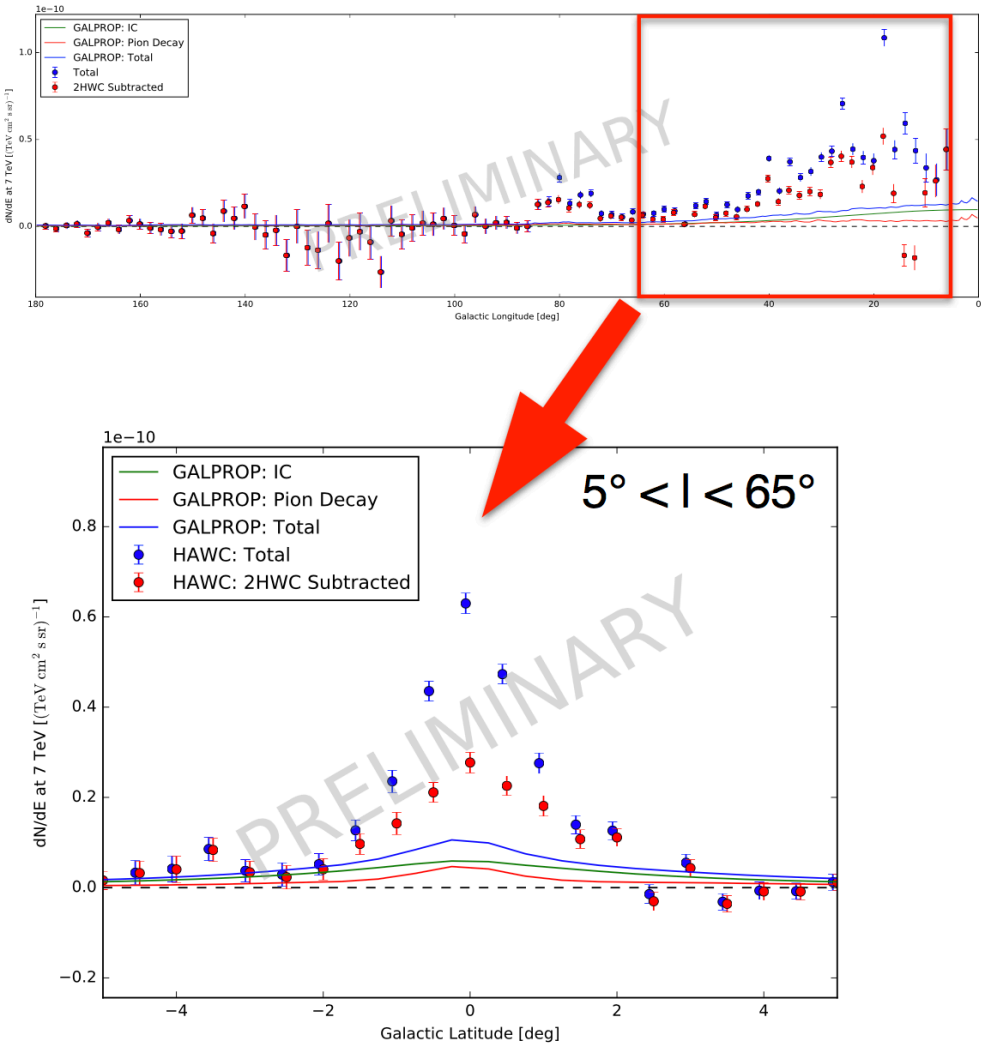


Red Points: Combination of

- **Extended emission** of 2HWC sources not accounted for in the catalog
- **Unresolved** sources below the detection threshhold
- **Galactic diffuse emission**

Extended Emission – Diffuse Emission

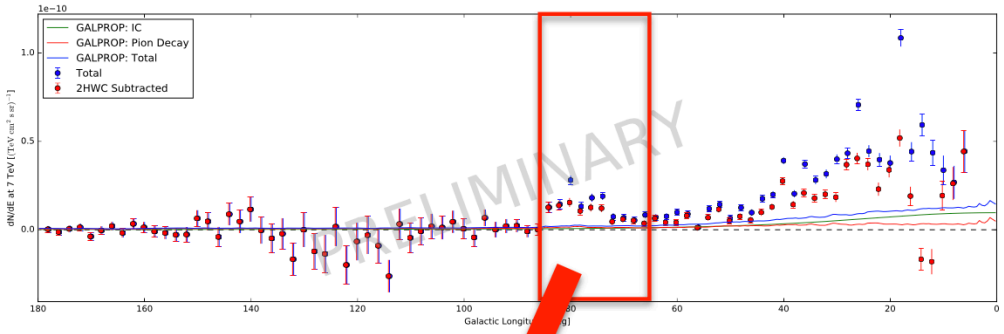
ICRC2017, Contrib. [436] [GA251] Probing Galactic Diffuse TeV Gamma-Ray Emission with the HAWC Observatory – **Hao Zhou, LANL**

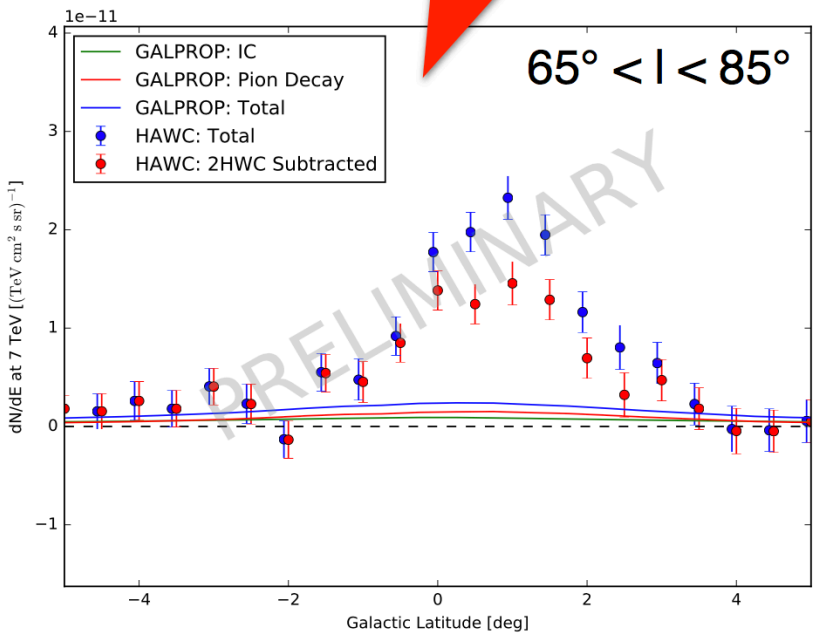


- **24** 2HWC sources
- **Resolved** sources account for ~ **1/3** of the total emission
- Source-subtracted emission is **2-3 times** of the emission predicted by **GALPROP** (Strong et al. 2010)

Extended Emission – Diffuse Emission

ICRC2017, Contrib. [436] [GA251] Probing Galactic Diffuse TeV Gamma-Ray Emission with the HAWC Observatory – **Hao Zhou, LANL**

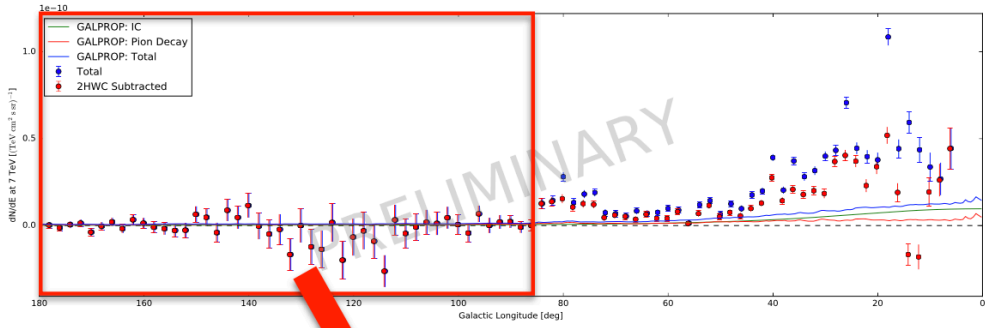


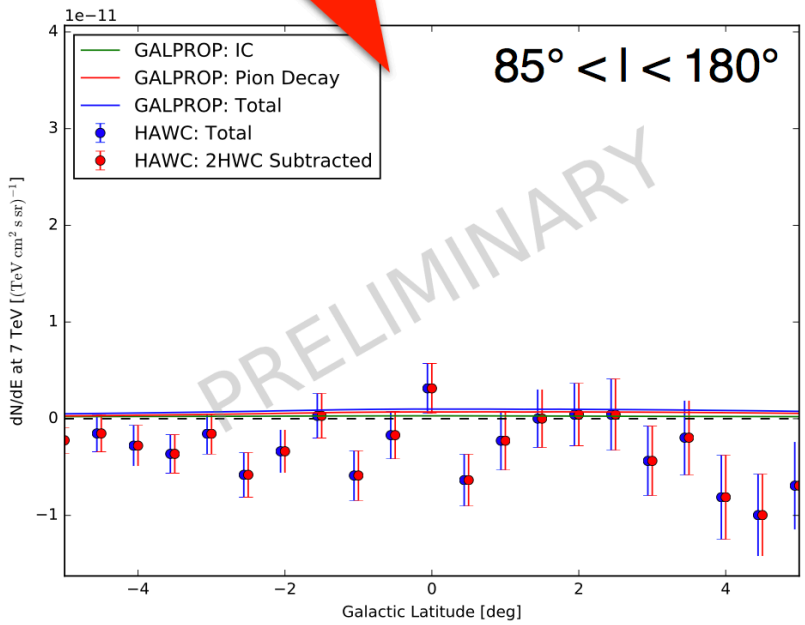


- **7** 2HWC sources
- **Resolved** sources account for ~ **1/5** of the total emission
- Source-subtracted emission is an **order of magnitude higher** than the emission predicted by **GALPROP** (Strong et al. 2010)

Extended Emission – Diffuse Emission

ICRC2017, Contrib. [436] [GA251] Probing Galactic Diffuse TeV Gamma-Ray Emission with the HAWC Observatory – **Hao Zhou, LANL**

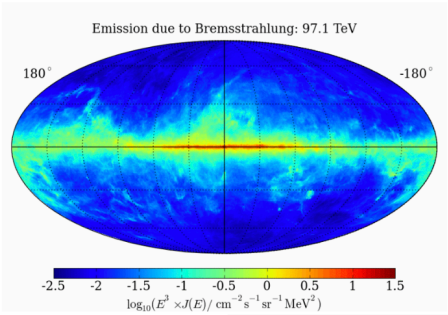


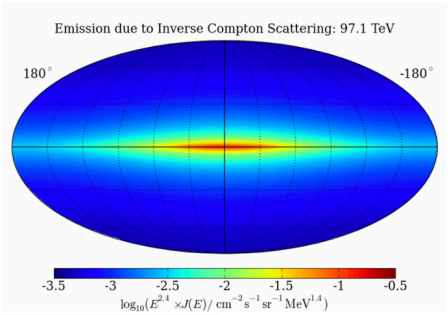


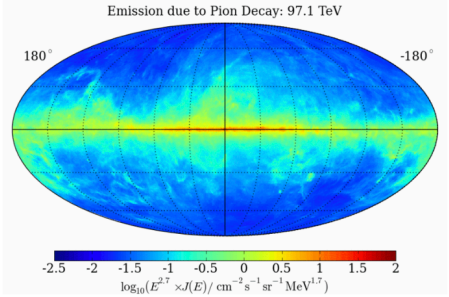
- **No** 2HWC sources
- **No** significant gamma-ray emission

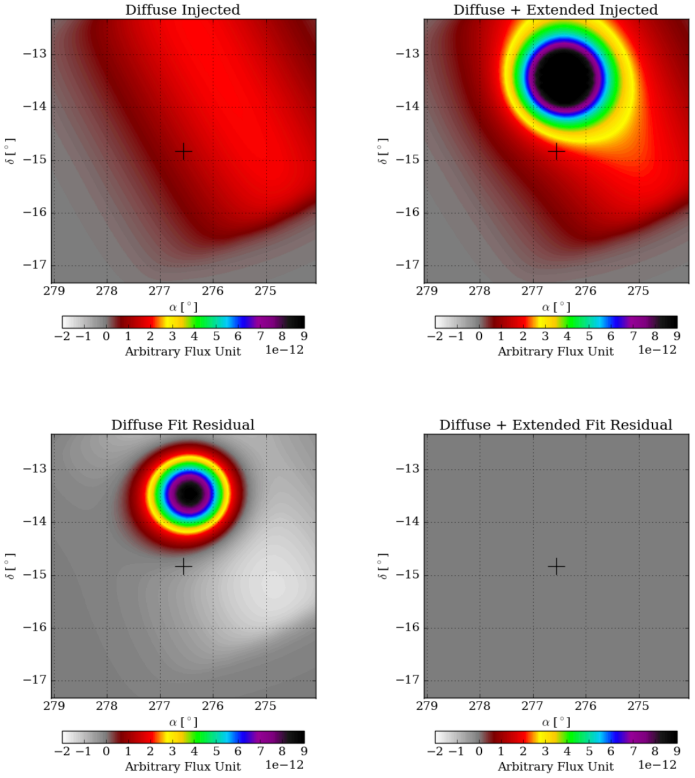
Extended Emission – Diffuse Emission

ICRC2017, Contrib. [916] [GA034] Techniques for Measuring Galactic Diffuse Emission Flux and their Preliminary Results in Confused Regions – **Chang Rho, UR**









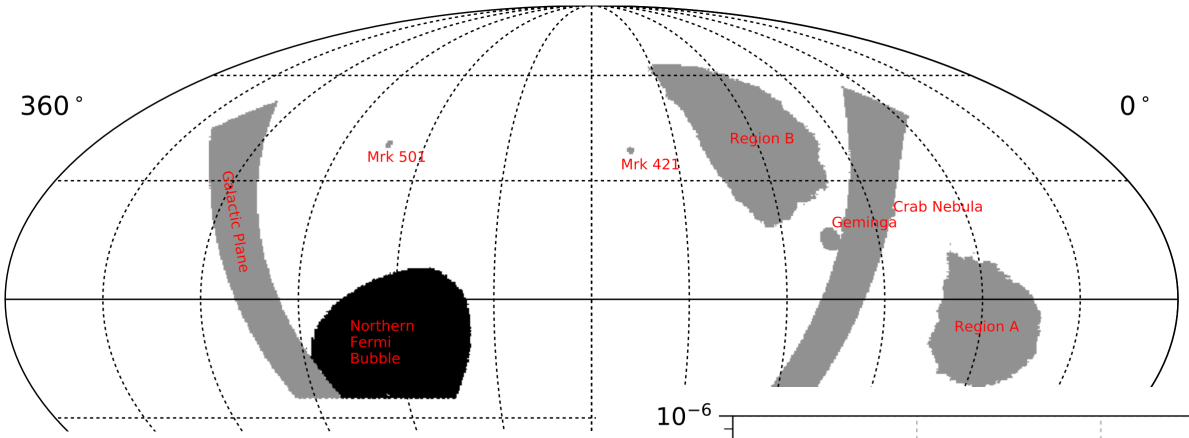
Preliminary

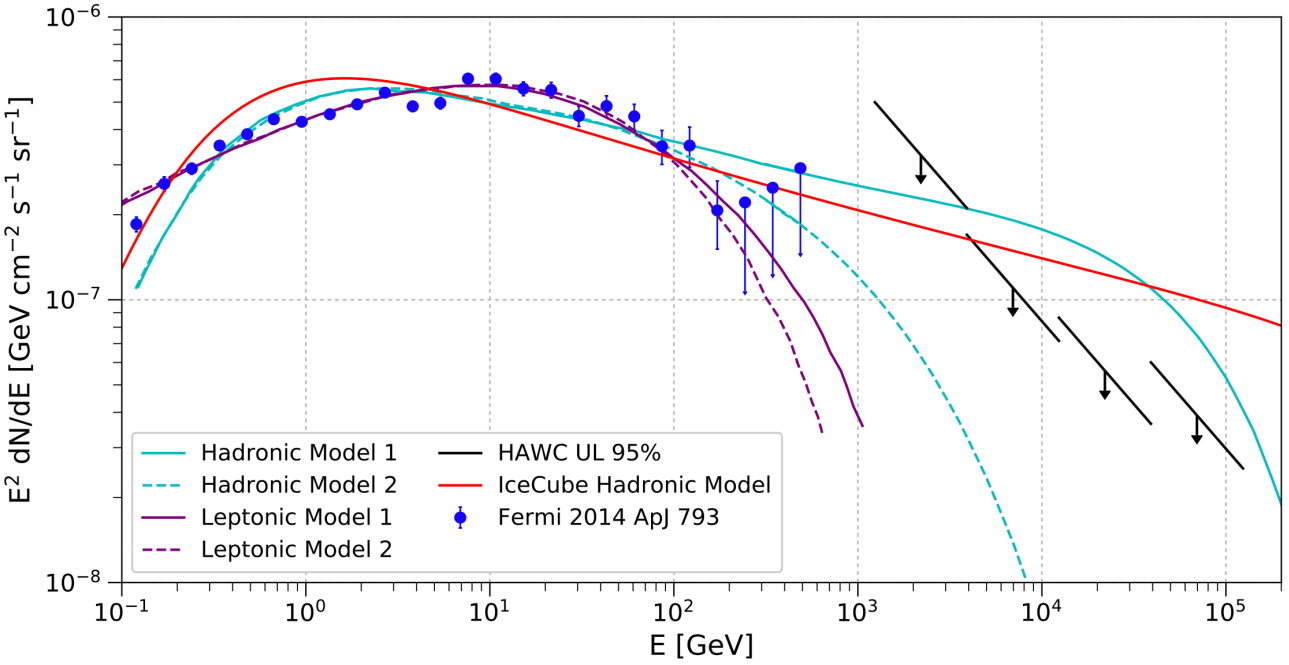
GALPROP-like template or…

$$F = Ke^{\frac{-b^2}{2\sigma_b^2}}$$

Extended Emission – N. Fermi Bubble

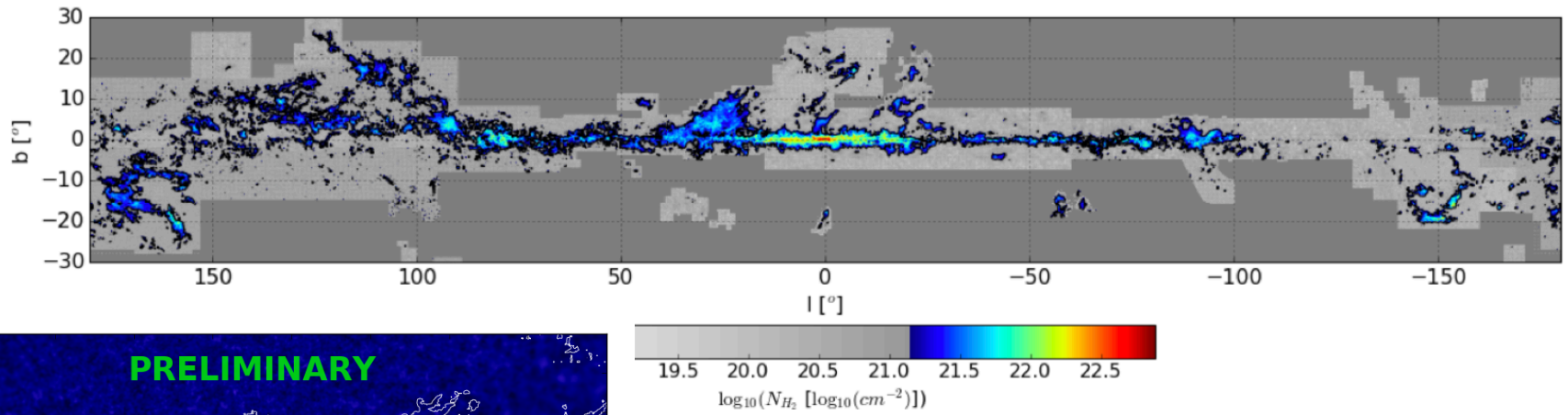
A.U. Abeysekara et al 2017, ApJ 842 85



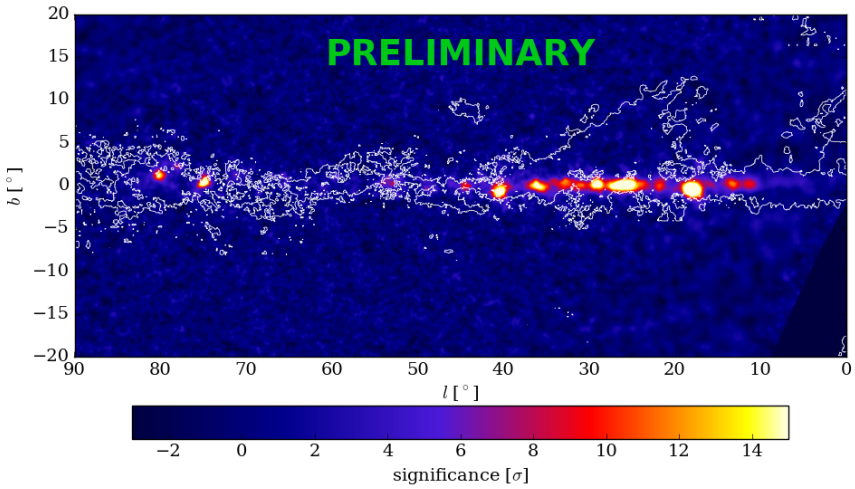


Extended Emission – This Session

TeVPA2017, Searching for Gamma-Ray Signal from Giant Molecular Clouds with HAWC – **Hugo Ayala, PSU**



CfA-Chile survey mapping the CO distribution in the galaxy (Dame et al. 2001). Photo © Luis Argerich https://flic.kr/p/eHZVB8



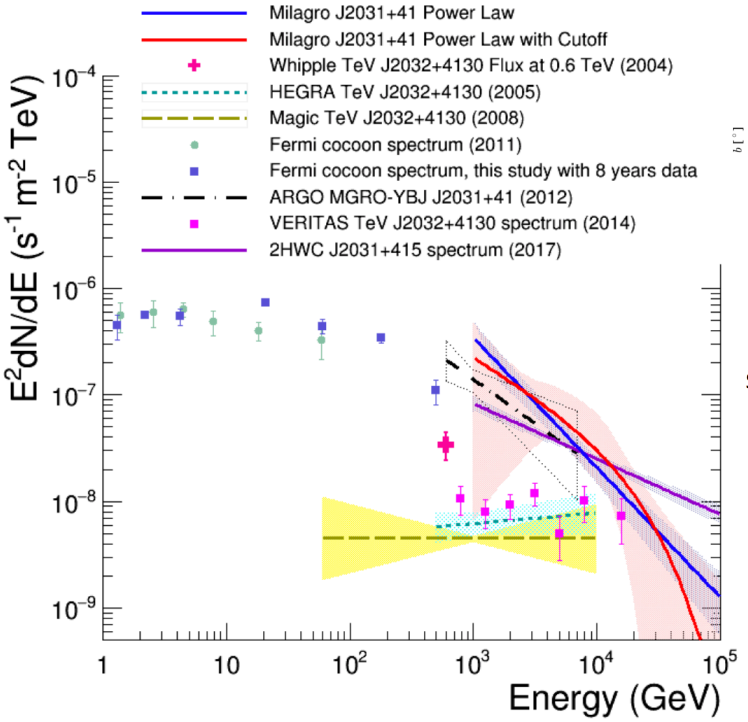
"Molecular Clouds as Cosmic-Ray Barometers"
Casanova et al. Publ.Astron.Soc.Jap.62:769-777,2010

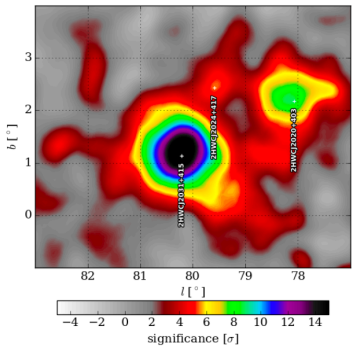
Aharonian 1990

$$F_\gamma = \begin{cases} 1.45 \times 10^{-13} E_{\rm TeV}^{-1.75} (M_5/d_{\rm kpc}^2)\,{\rm cm}^{-2}\,{\rm s}^{-1} & 100\,{\rm MeV} < E_\gamma < 1\,{\rm TeV} \\ 2.85 \times 10^{-13} E_{\rm TeV}^{-1.6} (M_5/d_{\rm kpc}^2)\,{\rm cm}^{-2}\,{\rm s}^{-1} & E_\gamma > 1\,{\rm TeV} \end{cases}$$

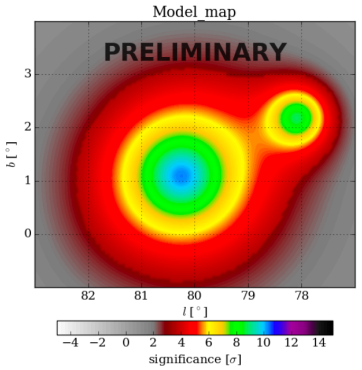
Extended Emission – This Session

TeVPA2017, Study of Gamma-Ray Emission at the Cygnus Cocoon Region
– **Binita Hona, MTU**

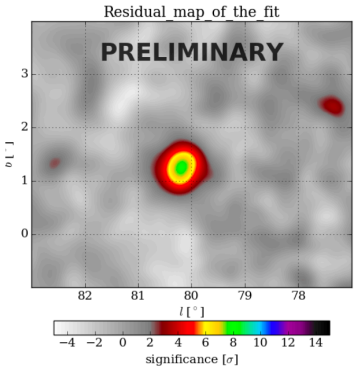




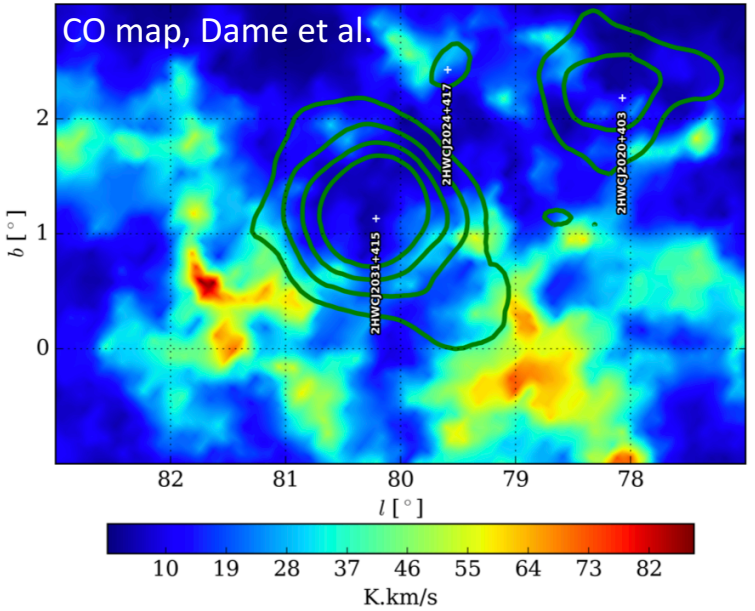
Significance Map of Cocoon Region



Model Map



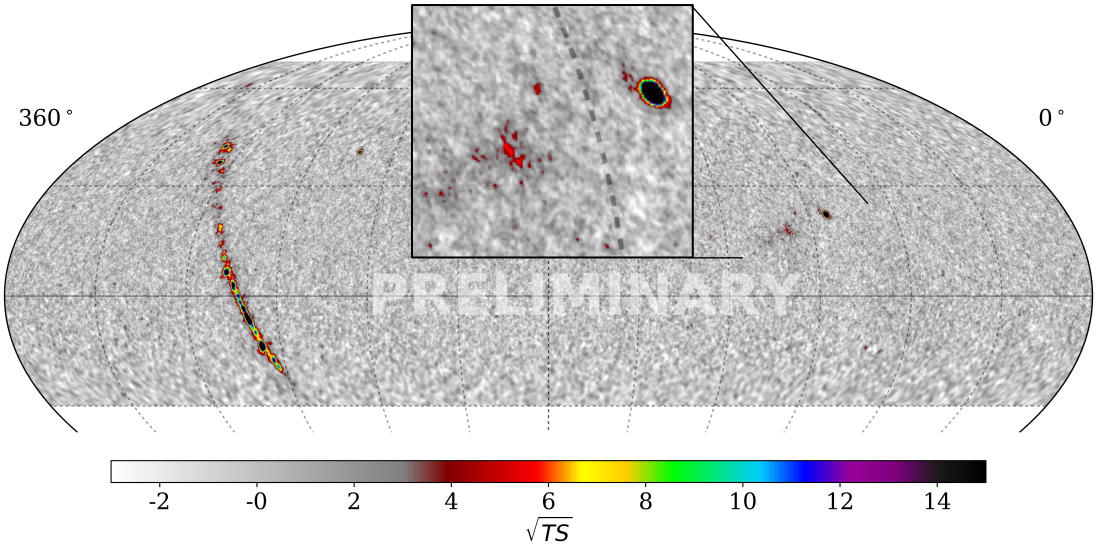
Residual Map of the Fit

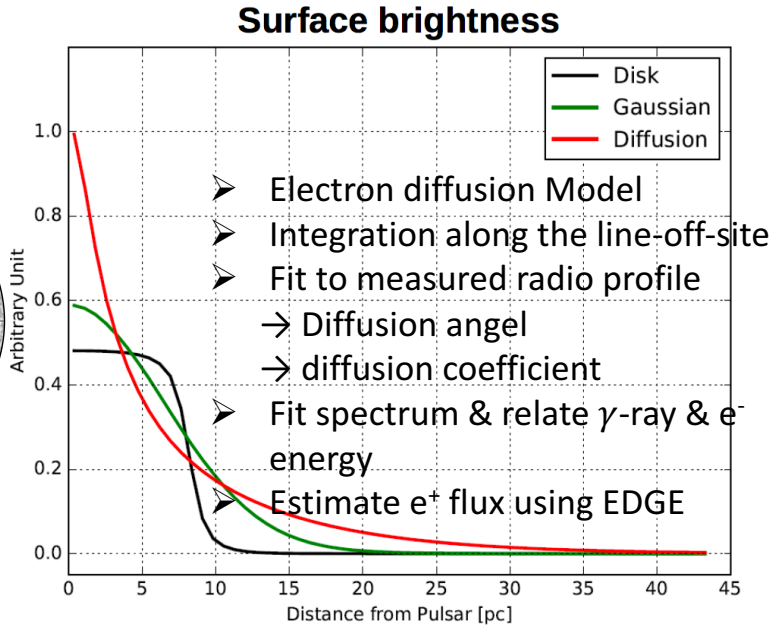


Multisource fits and morphological models
Disentangle emission components

Extended Emission – This Session

TeVPA2017, Constraints from Observations of Geminga and Monogem – **Jim Linnemann, MSU**





ICRC2017, Contrib. [922] [GA250] Constraining the Diffusion Coefficient with HAWC TeV Gamma Ray Observations of Two Nearby Pulsar Wind Nebulae – **Hao Zhou, LANL**

ICRC2017, Contrib. [900] [GA065] EDGE: a code to calculate diffusion of cosmic-ray electrons and their gamma-ray emission – **Rubén Lopéz-Coto, MPIK**

ICRC2017, Contrib. [510] [GA122] Constraining the Origin of Local Positrons with HAWC TeV Gamma-Ray Observations of Two Nearby Pulsar Wind Nebulae – **Francisco Salesa Greus, IFJ-PAN**

Multi-Instrument, Wavelengths, Messenger, and Alerts

- **TeVPA2017, Tuesday**: IceCube Search for Galactic Neutrinos Using the HAWC 2HWC Catalog – Josh Wood, UW-Mad
- **TeVPA2017, this session**: VERITAS and Fermi-LAT Observations of TeV Gamma-Ray Sources from the second HAWC catalog – Nahee Park
- **TeVPA2017, this session**: Follow-up VERITAS and NuSTAR Observations of Galactic HAWC Gamma-Ray Sources

Outlook

Looking forward to

- More data
- Better understanding of systematics
- More cross-observatory collaboration
- More joint analyses