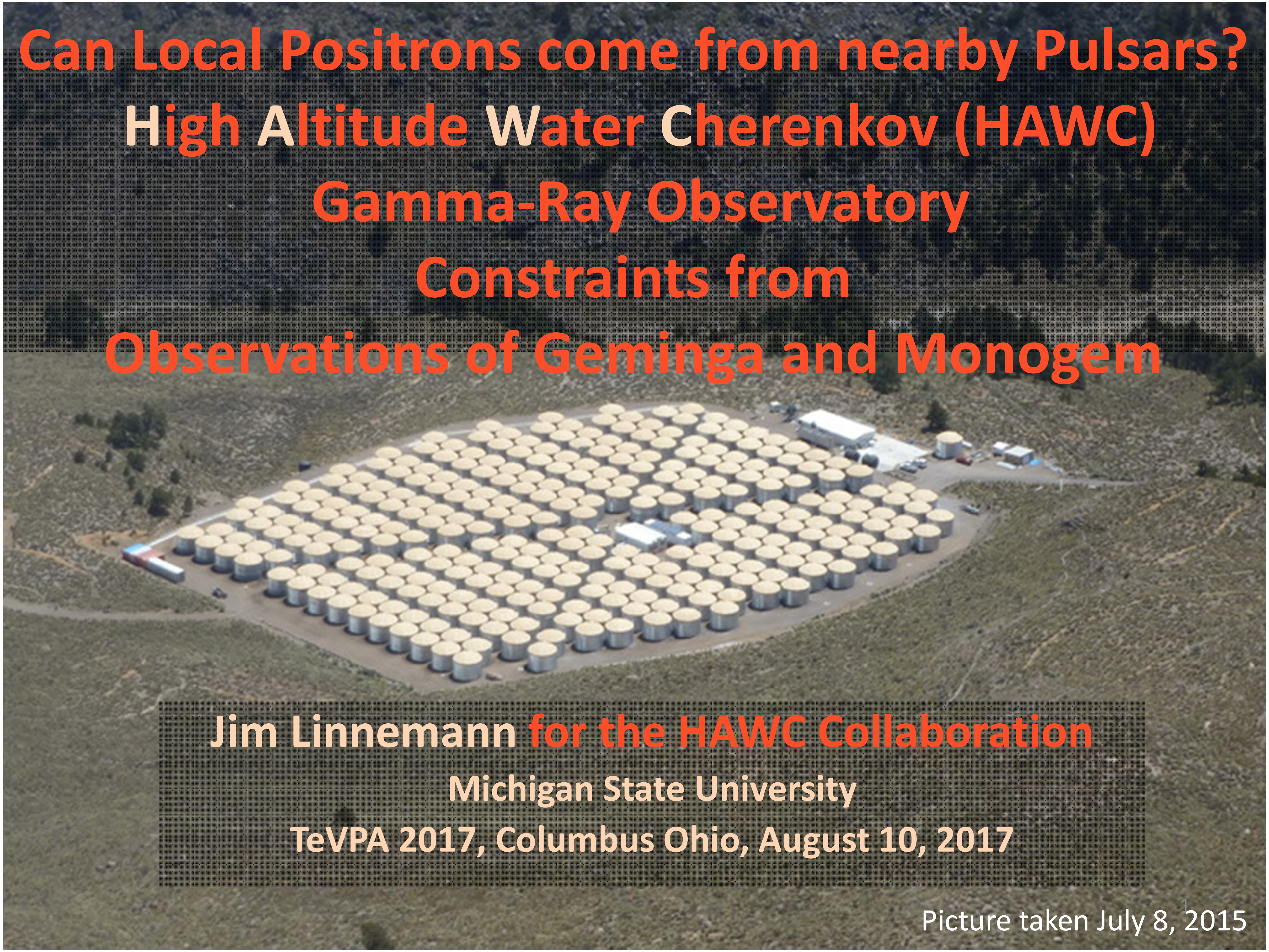
Can Local Positrons come from nearby Pulsars?

High Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory Constraints from Observations of Geminga and Monogem



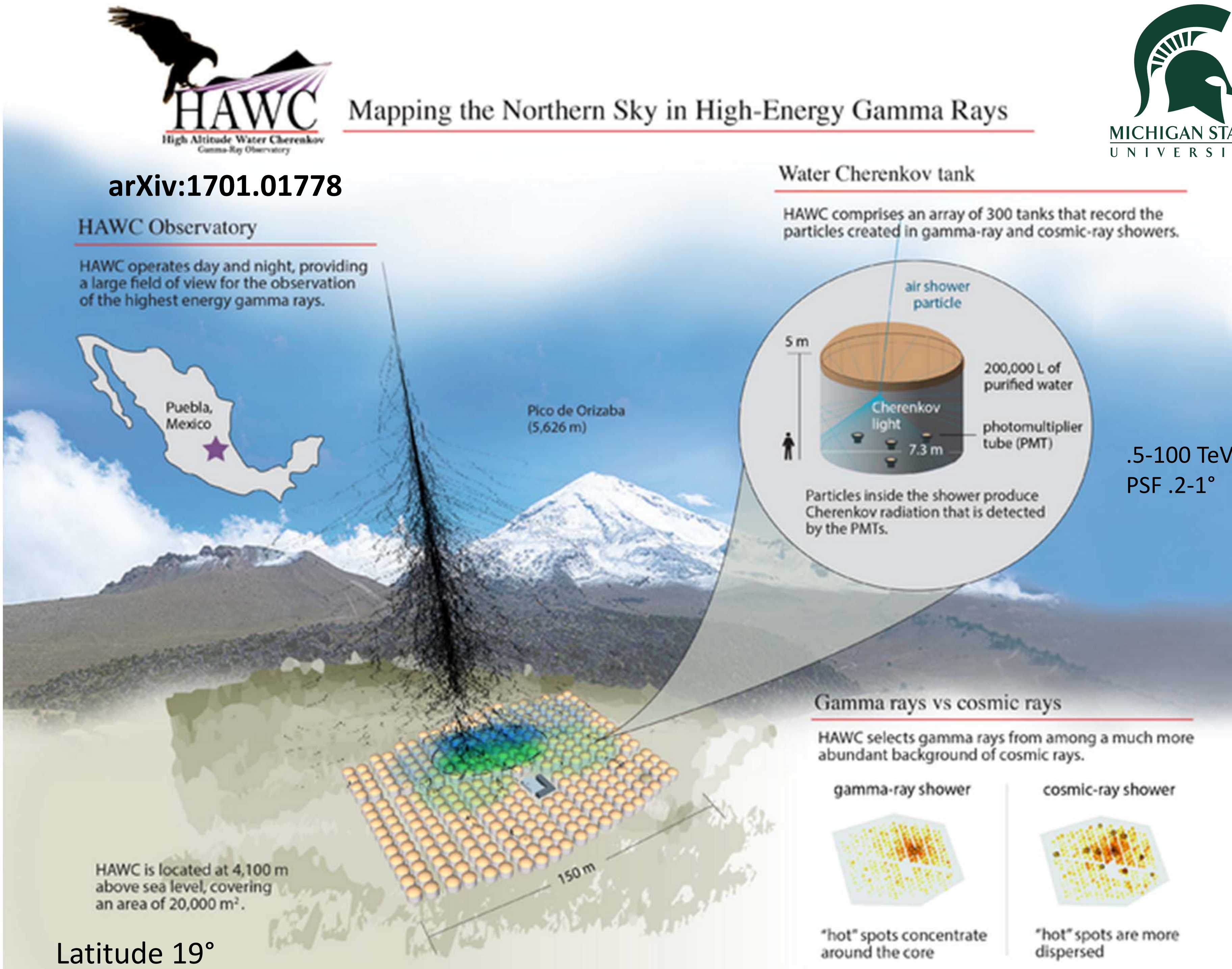
Jim Linnemann for the HAWC Collaboration

Michigan State University

TeVPA 2017, Columbus Ohio, August 10, 2017

Picture taken July 8, 2015

arXiv:1701.01778



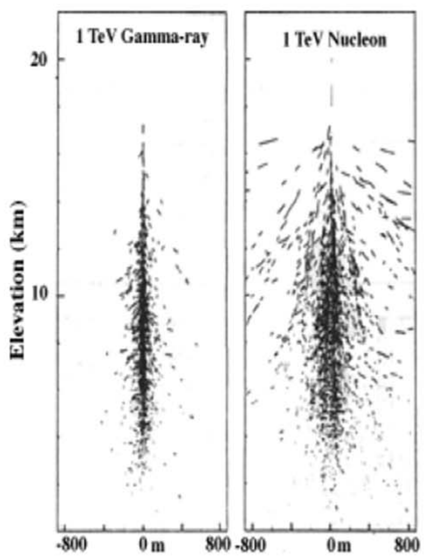
.5-100 TeV
PSF .2-1°

Latitude 19°

Gamma-Hadron Separation

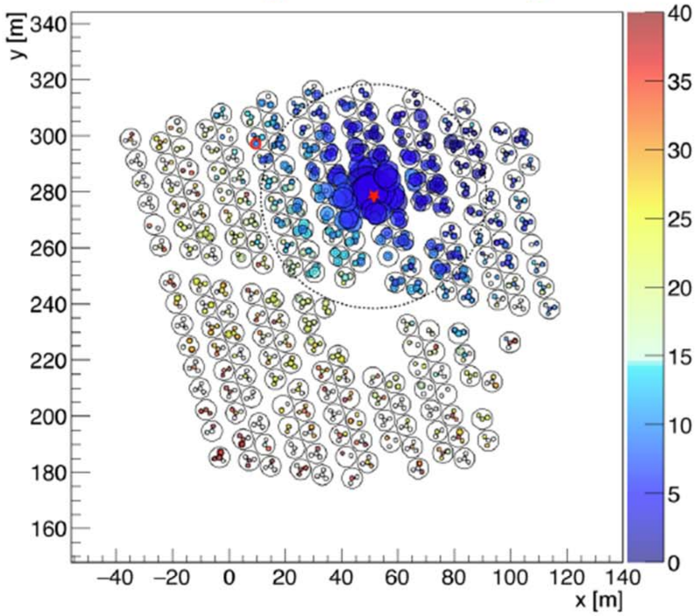
Simulation

Gamma Hadron



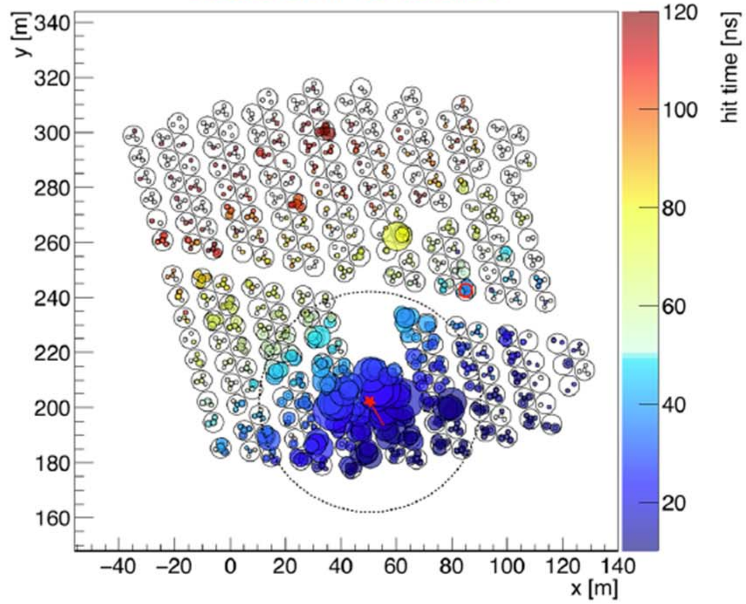
HAWC Data

Likely Gamma Ray



HAWC Data

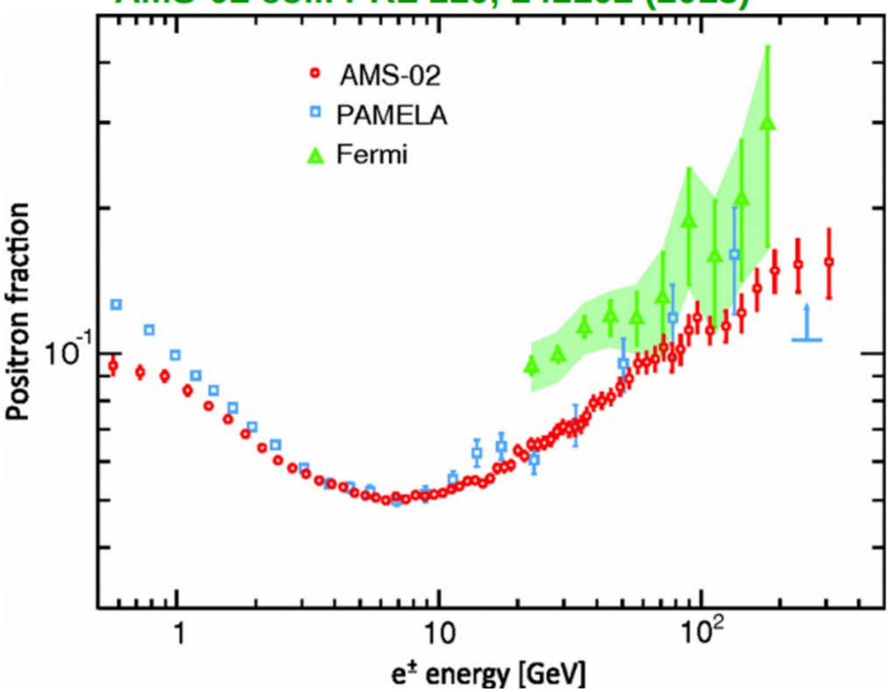
Hadron Shower



- Main background is hadronic CR, e.g. 400 γ/day from the Crab vs 15k CR/s.
- Gamma/hadron can be discriminated based on the event footprint on the detector: gamma-ray showers are more compact, cosmic rays showers tend to "break apart".

Cosmic-Ray Positron Excess

- In 2009 PAMELA satellite reported an excess of positrons for energies above 10 GeV [**Adriani et al. Nature 458, 607 (2009)**].
- The excess is unexpected from conventional propagation of CR [**Moskalenko & Strong ApJ 493, 694 (1998)**].
- The positron excess has been confirmed by Fermi-LAT and AMS-02 (with high-precision). **AMS-02 coll. PRL 110, 141102 (2013)**



- The origin of the excess is unknown.
- Theorized to be originated by nearby sources, dark matter or new models of CR propagation.
- Near middle-aged **pulsars are good candidates** to be the sources:
  - Close enough so e^+e^- can make it to the Earth.
  - Old enough so e^+e^- had time to reach us.
  - Still energetic to produce high-energy particles.

Nearby Northern Sky Pulsars

ATNF Pulsar Catalogue

Catalogue Version: 1.56

#	NAME		RAJD (deg)	DECJD (deg)	DIST (kpc)	AGE (Yr)	EDOT (ergs/s)
1	J0633+1746	hh92	98.47564	17.77025	0.25	3.42e+05	3.2e+34
2	B0656+14	mlt+78	104.95056	14.23931	0.29	1.11e+05	3.8e+34
3	J0835-3707	mlc+01	128.76283	-37.13097	0.55	8.77e+05	2.4e+33
4	B0922-52	mlt+78	141.03621	-53.04561	0.51	3.33e+05	3.4e+33
5	B0940-55	wvl69	145.56596	-55.88119	0.30	4.61e+05	3.1e+33
6	B0941-56	mlt+78	145.72692	-56.96207	0.41	3.23e+05	3.0e+33
7	J0954-5430	mlc+01	148.52517	-54.51486	0.43	1.71e+05	1.6e+34
8	B1001-47	mlt+78	150.83992	-47.78389	0.37	2.2e+05	3.0e+34
9	B1055-52	vl72	164.49569	-52.44896	0.09	5.35e+05	3.0e+34
10	J1732-3131	aaa+09c	263.13975	-31.52306	0.64	1.11e+05	1.5e+35
11	J1741-2054	aaa+09c	265.48846	-20.89917	0.30	3.86e+05	9.5e+33
12	B1742-30	kac+73	266.48464	-30.67311	0.20	5.46e+05	8.5e+33
13	B1822-09	dls72	276.37762	-9.58953	0.30	2.32e+05	4.6e+33

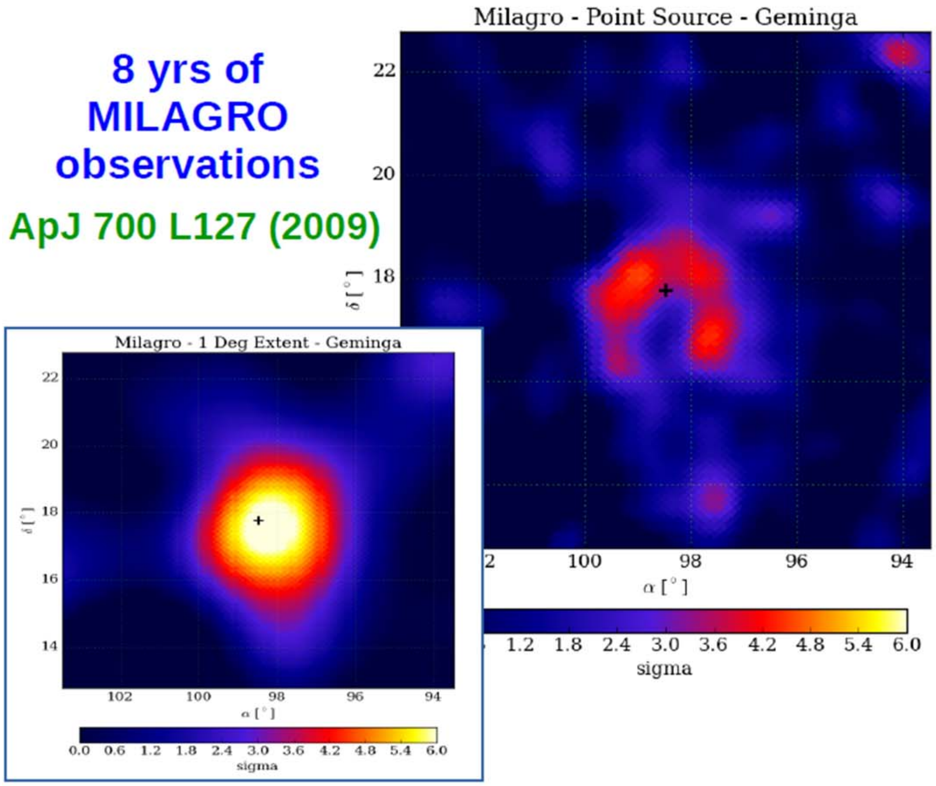
Geminga

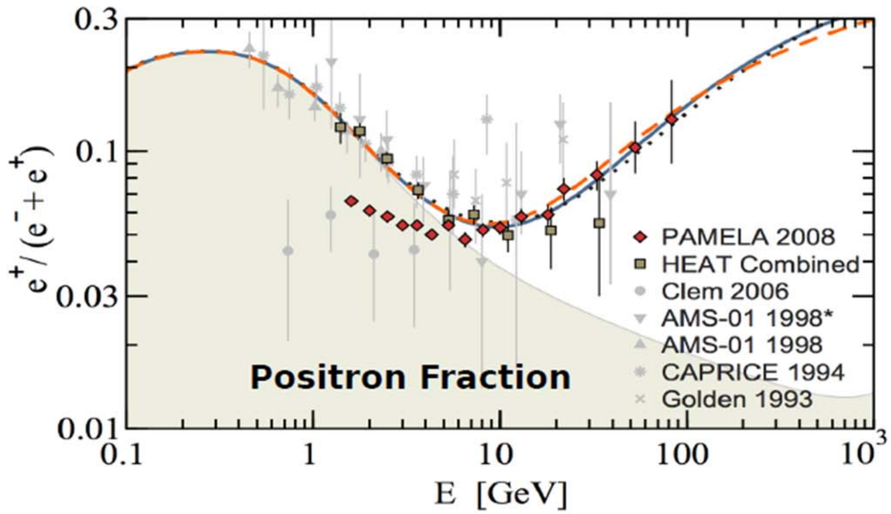
“Monogem”

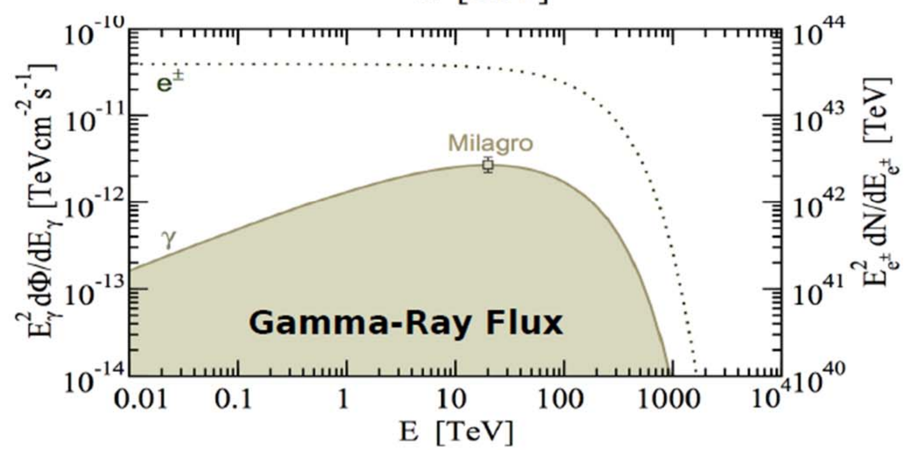
The Geminga Case

8 yrs of MILAGRO observations

ApJ 700 L127 (2009)







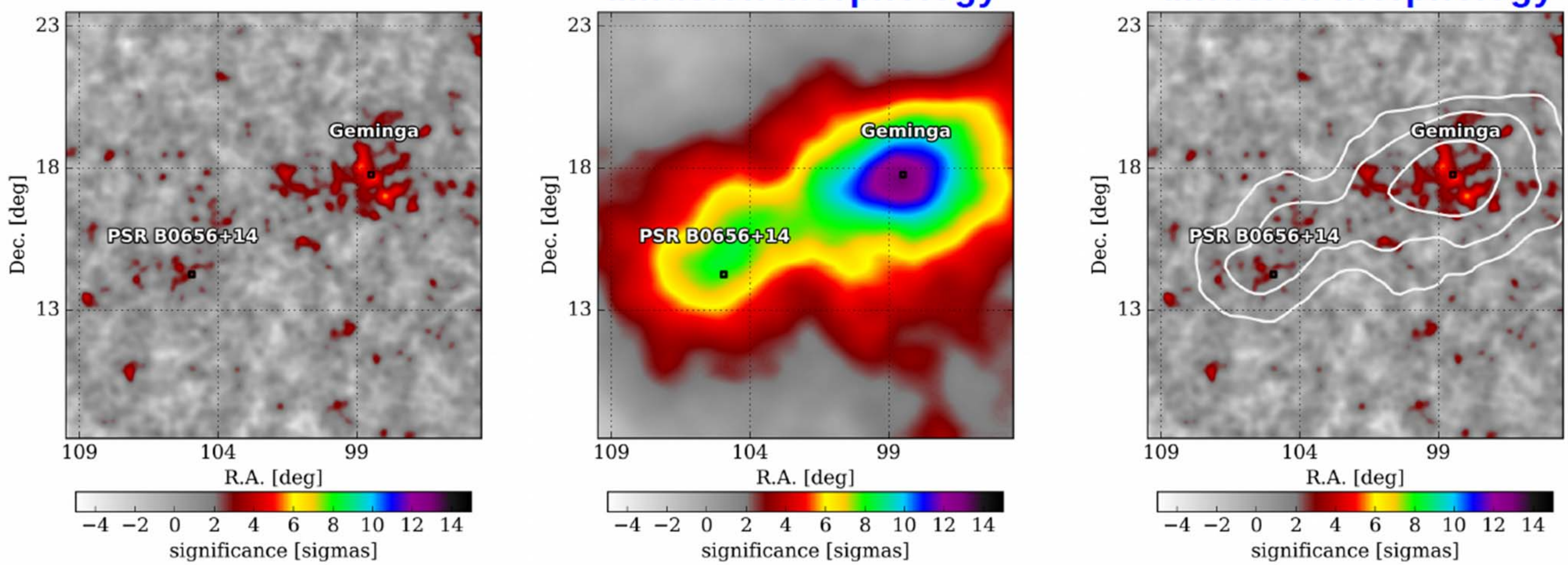
- Extended TeV emission (>2°) discovered by Milagro.
- Much more extended than the X-ray emission.
- Not detected (yet) by IACT.
- Proposed as a main contributor to positron excess.

Yuksel et al. PRL 103, 051101 (2009)

HAWC observations of TeV γ emission near Geminga and Monogem Pulsars

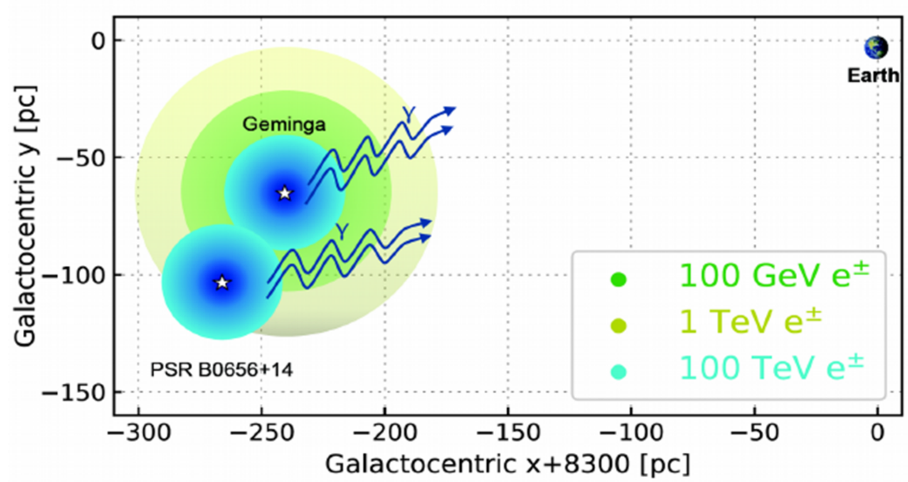
- Gamma-rays sources coincident with **Geminga** and **B0656+14** pulsars were reported in the 2[nd] HAWC catalog as 2HWC J0635+180 and 2HWC J0700+143 [HAWC coll. ApJ 843:40 (2017)].
- Extended TeV gamma-ray emission from PSR B0656+14 is a new discovery by HAWC.
- Both sources show a clear increase in significance for an extended morphology assumption.
- The gamma-ray measurement of both sources can constrain the expected positron flux from them.

convolved with the PSF | **convolved with the diffusion morphology** | **5, 7, 10 σ contours from diffusion morphology**



Electron Diffusion Model

- We assume a model where e^+e^- pairs diffuse into the ISM around the pulsar.
- The **radial distribution of e^+e^-**, at a given time **t**, distance **r** from the source is: [**Atoyan et al. Phys. Rev. D52, 3265 (1995)**]



Continuous injection of e^+e^-

$$f(t,r,E_e) = \frac{Q_0 E_e^{-\Gamma}}{4\pi D(E_e) r}\,\mathrm{erfc}(r/r_d)$$

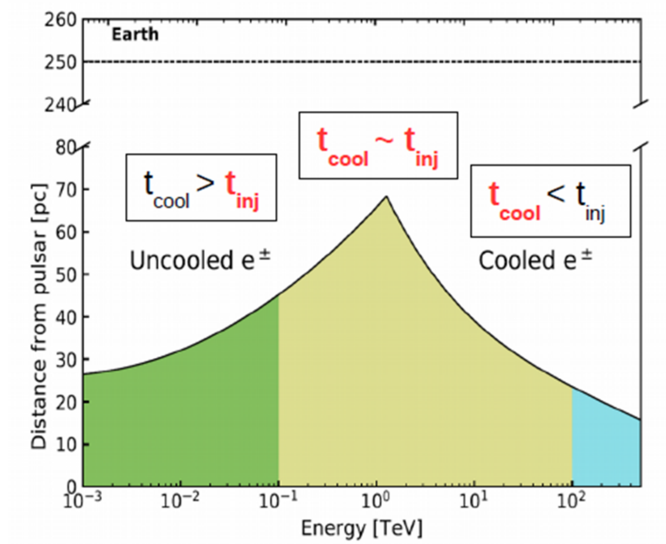
$$D(E_e) = D_0(E_e/10\ \mathrm{GeV})^{\delta}$$ Diffusion coefficient

$$r_d = 2\sqrt{D(E_e)t_E}$$ Diffusion radius

t_E = min (t_{cool}, t_{inj}), where t_{inf} = t_{age} ~3.4 x 10^5 yr

t_{cool} = f(E), for E=100TeV, t_{cool} ~ 10^4 yr

- We assume diffusion coefficient index (δ) fixed to 0.33



Erfc gives strong d/r_d dependence: e^+ flux very peaked near 1 TeV

TeV Gamma-Ray Profile

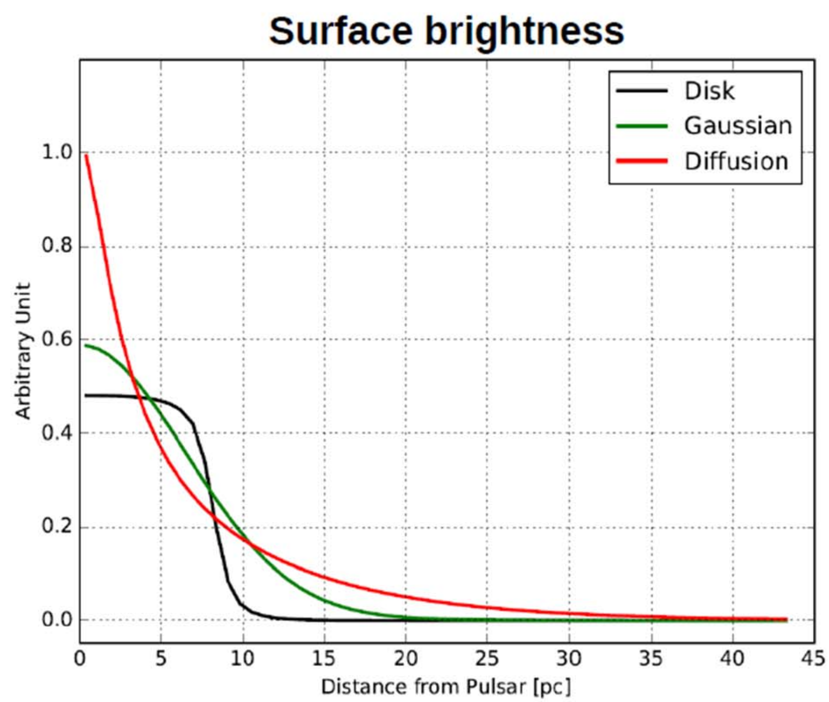
Integrating the **radial distribution** along the observer line-of-sight:

$$f_\theta = \frac{1.2154}{\pi^{3/2}\theta_\mathrm{d}(\theta + 0.06 \cdot \theta_\mathrm{d})} \exp(-\theta^2/\theta_\mathrm{d}^2)$$

$$\theta_\mathrm{d} \equiv \frac{180^\circ}{\pi} \cdot \frac{r_\mathrm{d}}{d_\mathrm{src}}$$ Diffusion angle

- The gamma-rays are produced through **inverse Compton scattering** of CMB, IR, and Optical photons.
- The relation between the electron and gamma-ray energy:

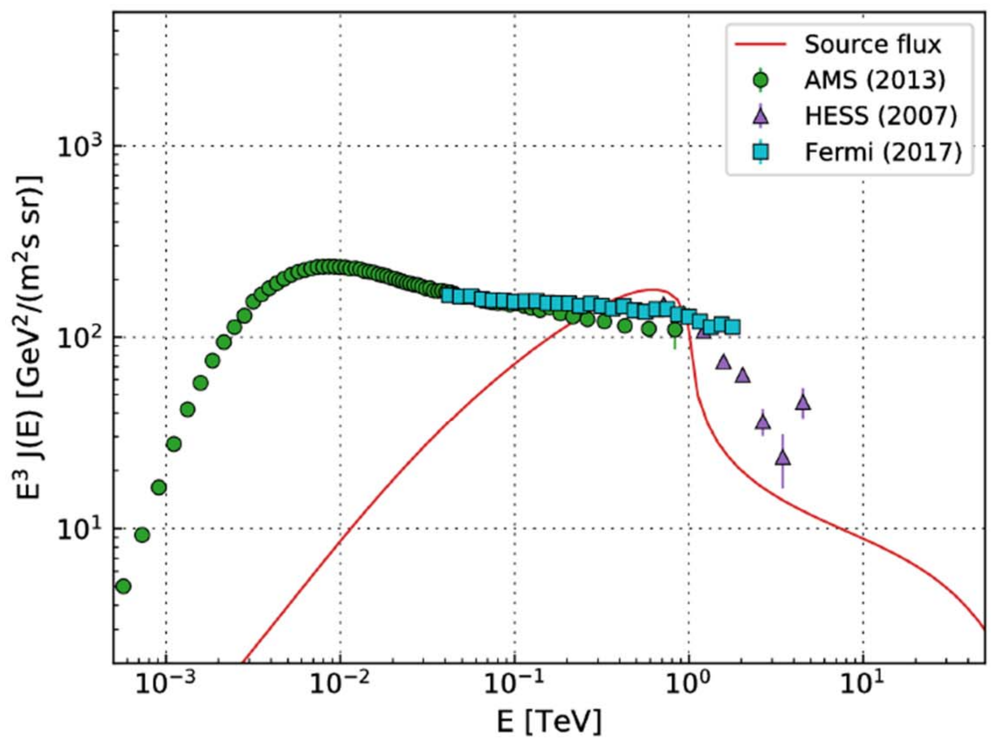
$$< E_e > \approx 17 < E_\gamma >^{0.54+0.046\log_{10}(<E_\gamma>/\ \mathrm{TeV})}$$



- The morphology based on “diffusion propagation model” fits better the HAWC data (using a likelihood analysis) compared to other morphologies tested (Disk and Gaussian).
- We fitted a **power law (N, index)** and a **diffusion morphology (diffusion angle)** to HAWC data.
- Paper under review, the **results of the fit are not public yet**.

Positron Flux Estimation Code

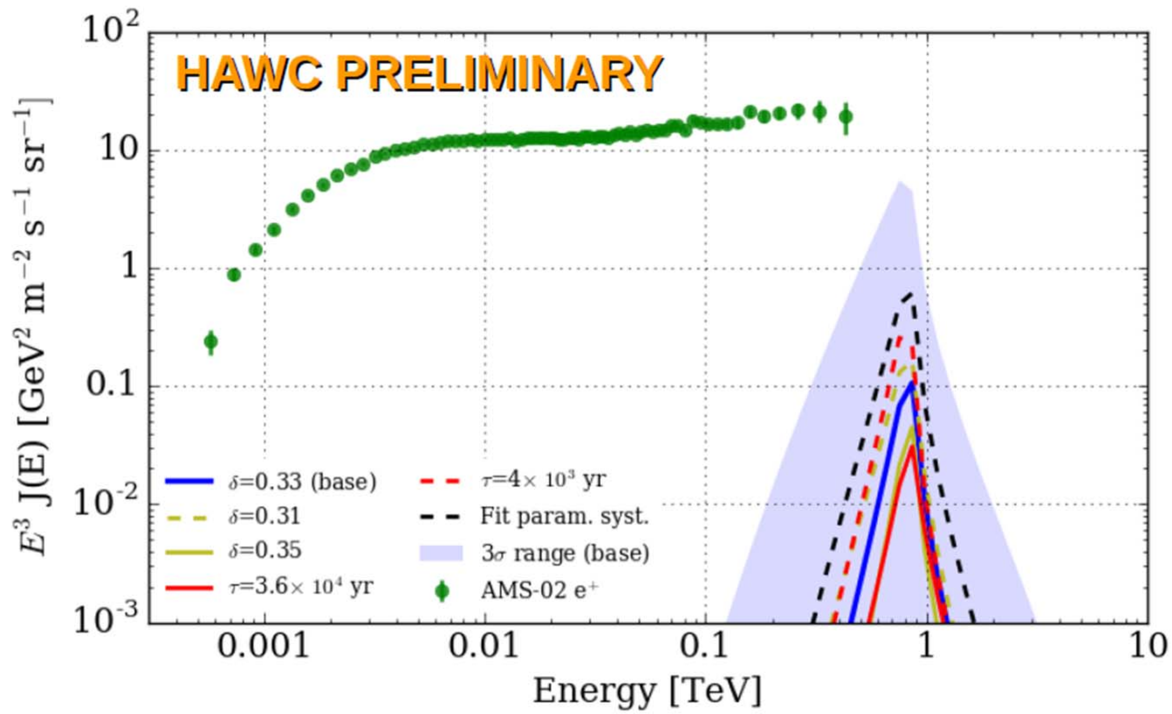
- A flexible code (**EDGE**) with dependencies on the GAMERA package [J.Hahn, ICRC2015] is used to estimate the positron flux produced in the sources.
- The code assumes that the pulsars are pure dipole radiators. The luminosity goes as $\mathbf{L=L_0\ (1+t/\tau)^{-2}}$.
- The code computes the energy density of electrons for every energy and every point in the space at a time equals to the age of the source.



Total e+ e- flux for a simulated source using the EDGE code.

Derived Positron Flux at Earth

- The fitted parameters using HAWC data are used as input to the **EDGE** code allowing the **estimation of the positron flux** from both sources.
- The 3σ range is based on statistical uncertainties from simulations.
- Systematics uncertainties include: systematics in the fit parameters, pulsar characteristic initial spin-down timescale (τ), and spectral index of the diffusion coefficient (δ).
- PSR B0656+14 is several orders of magnitude lower than Geminga and out of scale in the plot.



AMS-02 points from
PRL 113, 121102 (2014)

Monogem: farther away, younger. lower total electron energy deposit

Summary

Electron Diffusion near Geminga and Monogem:

HAWC has reported an extended TeV gamma-ray emission from Geminga (confirmation of Milagro observations) and B0656+14 (discovery) pulsars.

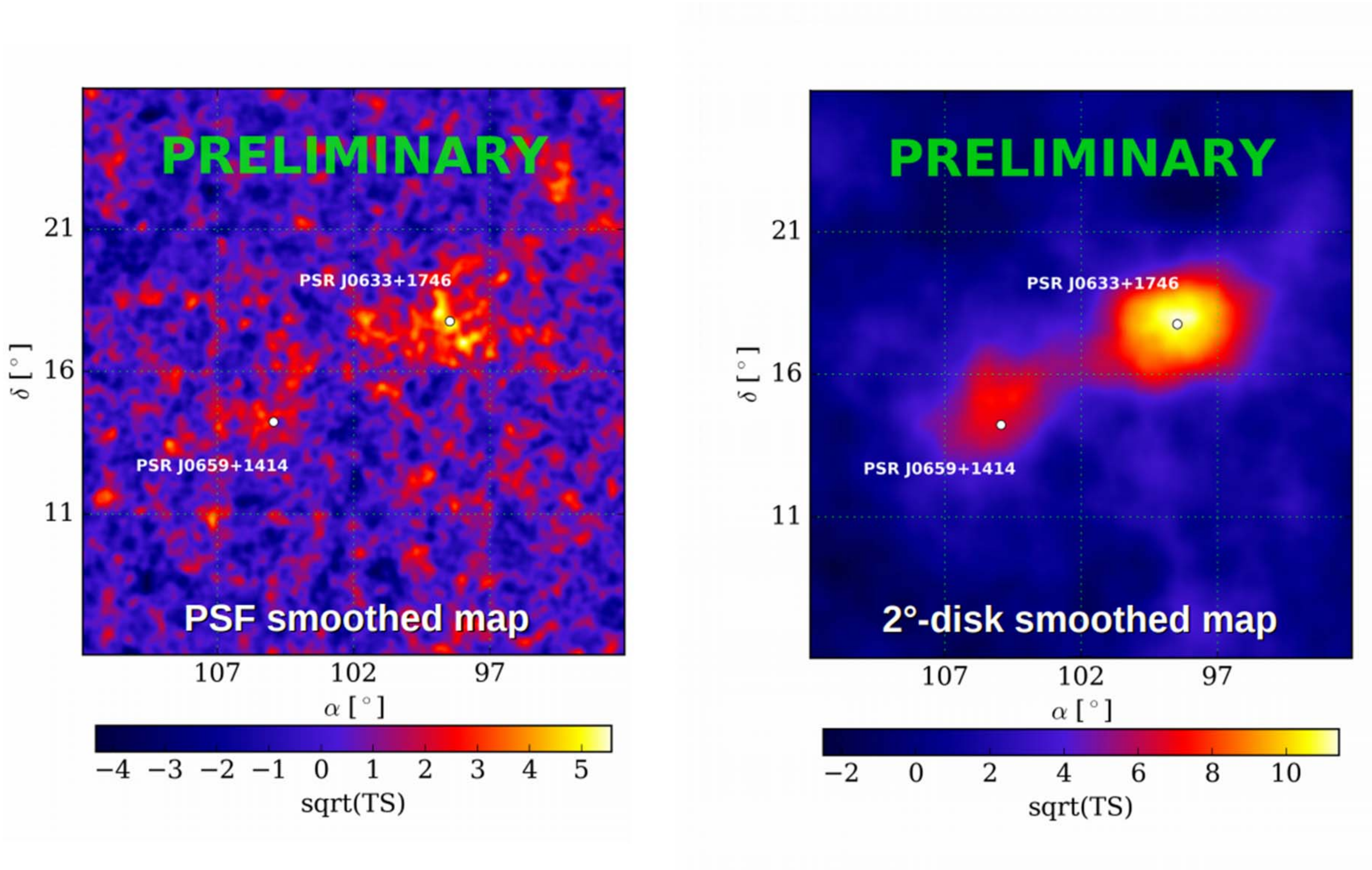
Under the assumption of isotropic and homogeneous diffusion these two pulsars are **unlikely to be the dominant source of the positron flux excess** above 10 GeV reported by satellites.

Full analysis details will be public soon.

Thanks for slides to: F. Salesa Greus and collaborators:
S. Casanova, B. Dingus, R. Lopez-Coto, Hao Zhou

Extras

Geminga Region (Disk)



Diffusion Comments

Does D change once away from pulsars?

- Pulsars 50pc apart; D is compatible
- Geminga has moved 70pc since birth (probably outside its snr)
- Energy density injected by the pulsar is orders of magnitude lower than ISM -> little effect on ISM conditions > few pc

direction to Earth perpendicular to the spiral arms

- likely lower B correlation length

diffusion coefficient likely depends on height above galactic disk

- D(e+) could well differ from CR average

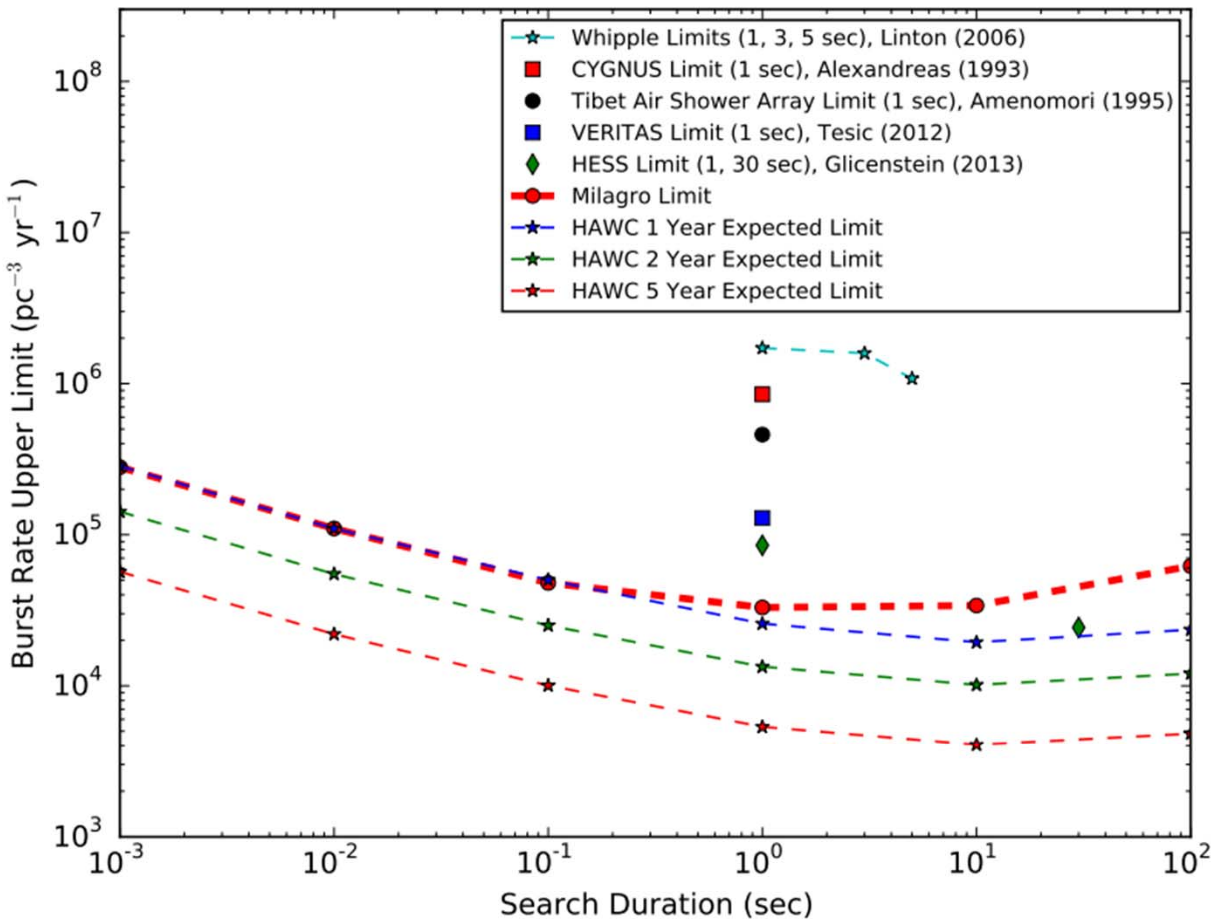
Hard to get many low E e+ to Earth unless D changes near pulsars

Possible non-uniformity of D:

Both pulsars may be inside Monogem ring?

Local bubble ~ 50pc near earth: .1 ISM density: D higher near Earth?

PBH Limits (HAWC in progress)

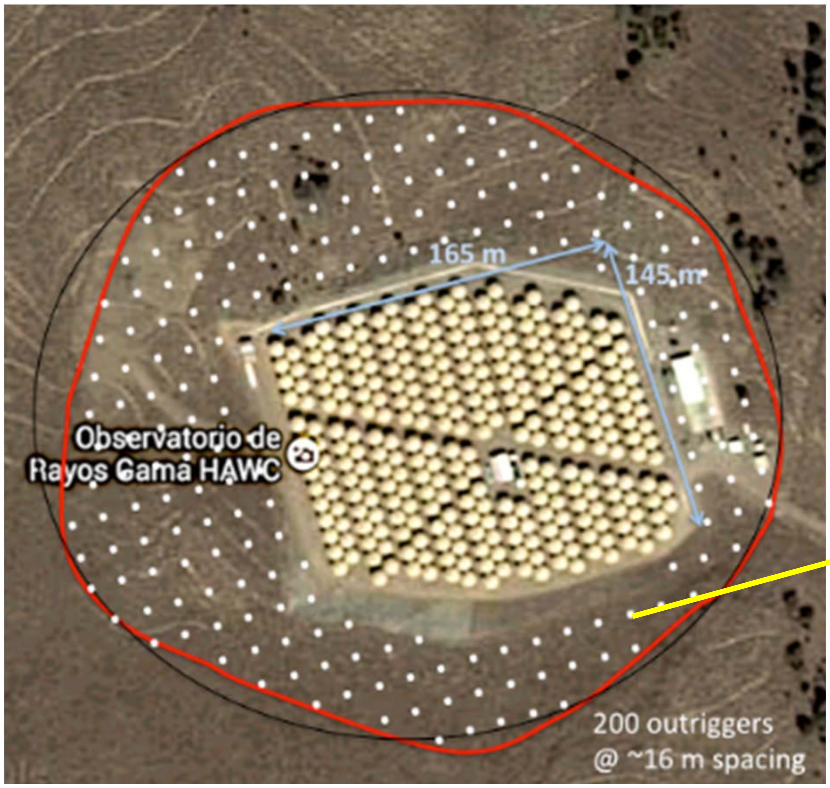


Arxiv 1510.04372

Figure 20: Published PBH burst rate density 99% CL upper limits and sensitivities for various experiments [13; 7; 8; 9; 10; 11; 12]. The upper limits and sensitivities shown are derived using the Standard Emission Model description for the PBH emission spectra.

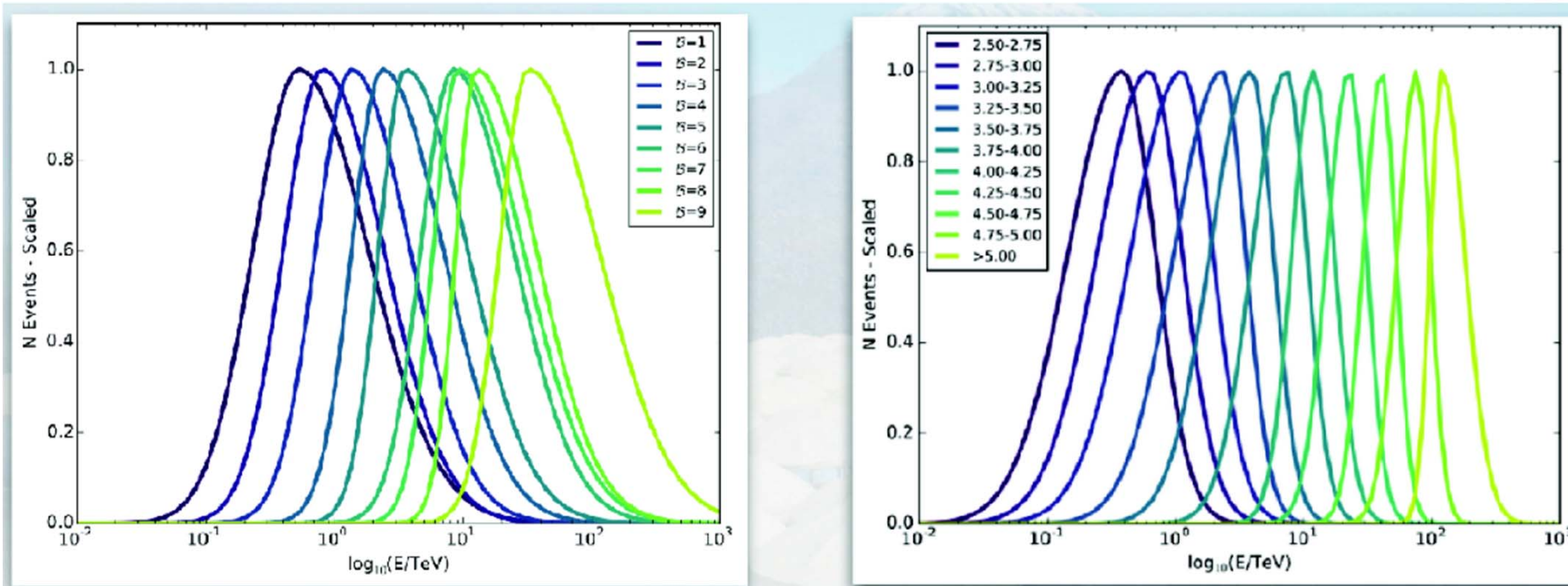
Upgrades and Southern Sky Survey

Enhance sensitivity > 10 TeV with **Outrigger** tanks



- No TeV Survey of the Southern Sky – **YET!**
- Workshop planned in Puebla, MX for Nov. 10-12. For details see: http://events.icecube.wisc.edu/conferenceDisplay.py?confId=81

Bin Energy (current vs EE)



Old method arXiv: 1701.01778v1

New method