Status of the paper on neutron searches

Editorial Board: Lorenzo Caccianiga, Lorenzo Cazon, Danelise de Oliveira Franco Federico Maria Mariani, Geraldina Golup, Esteban Roulet, Paul Sommers

Method

We are searching for event excesses that could indicate a neutron flux

Probability density method: we assign a weight to each event representing the probability density of an event coming from a target direction

$$w_i = \frac{1}{2\pi\sigma_i^2} \exp\left(-\frac{\xi_i^2}{2\sigma_i^2}\right)$$

ξ_i : angular distance

$\sigma_i \longrightarrow$ parameterized Angular Uncertainty (not Angular Resolution)!

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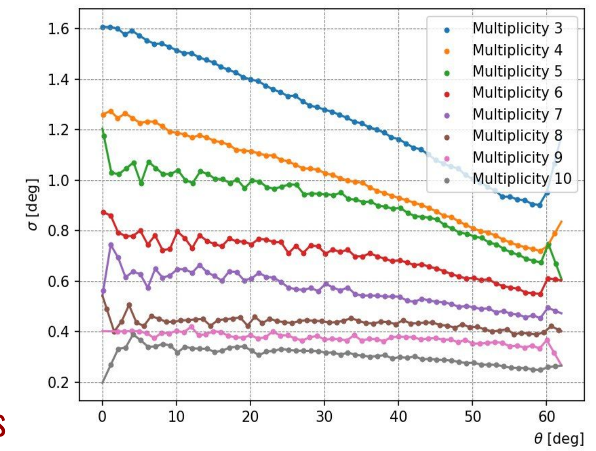
For each target direction:

$$\rho_{\mathrm{obs}} = \sum_i^N w_i \quad \Longleftrightarrow \quad \rho_{\mathrm{scr}}$$

Angular uncertainty

So far defined as $$\sqrt{(\Delta\theta)^2 + (\Delta\phi \sin\theta)^2},$$



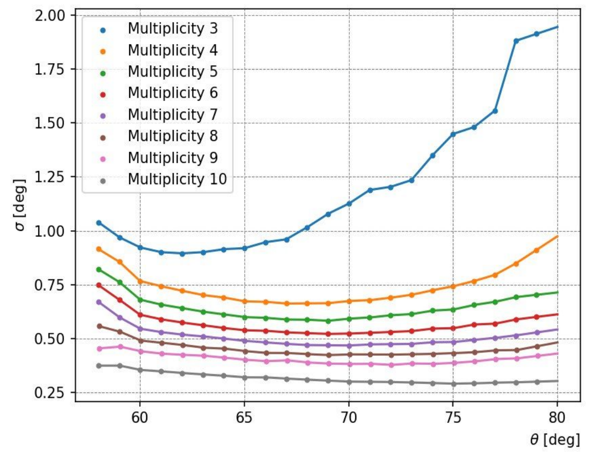
Doubt by Darko: are we overestimating it? -> check compatibility with moon shadow results

AR parameterization: zenith angle, multiplicity, dataset of origin

For the scramble technique we sampled 2 events:

simulated event

- Event 1: UTC
- Event 2: θ, origin dataset σ →
- An azimuth angle from a uniform distribution between 0 and 2π



Data and target sets

SD events from January 01, 2004 and December 31, 2022

SD-1500		SD-750	
1≤E<2	2’009’321	0.1≤E<0.2	1’069’076
2≤E<3	382’576	0.2≤E<0.3	236’367
E≥3	262’677	0.3≤E<1	149’725
E≥1	2’654’574	0.1≤E<1	1’455’168

E [EeV]

Target sets

See GAP 2023-039

12 catalogs, **888** candidate sources (**167** with dist.<1kpc)

Doubt by me: two new catalogs of LMXB and HMXB have gotten out recently. Should we use them instead of the old (20ish years) ones? Problem: they don’t provide a flux information

Energy range: $E \geq 1\,\mathrm{EeV}$ (SD-1500)								
Class	**R.A [deg].**	**Dec. [deg]**	ρ_{obs} [deg^{-2}]	ρ_{exp} [deg^{-2}]	**Flux U.L.** [km^{-2} yr^{-1}]	**E-flux U.L.** [eV cm^{-2} s^{-1}]	p	p^*
msec PSRs	277.12	6.42	66.53	57.47	0.029	0.21	0.0028	0.55
γ-ray PSRs	296.63	−54.05	140.10	124.20	0.021	0.15	5.4e-05	0.014
LMXB	236.98	−62.57	142.84	132.05	0.016	0.11	0.0090	0.60
HMXB	308.11	40.95	11.35	7.00	0.13	0.92	0.013	0.54
H.E.S.S. PWN	128.75	−45.60	126.47	117.16	0.015	0.11	0.0066	0.17
H.E.S.S. other	98.25	5.79	64.39	58.40	0.023	0.17	0.032	0.77
H.E.S.S. UNID	305.02	40.76	11.89	7.25	0.13	0.92	0.011	0.47
Microquasars	308.11	40.96	11.33	6.99	0.13	0.93	0.013	0.18
Magnetars	162.53	−59.89	132.76	128.49	0.010	0.076	0.15	0.99
LHAASO	292.25	17.75	43.10	36.58	0.038	0.27	0.021	0.17
Crab	83.63	22.01	28.12	29.47	0.018	0.13	0.67	0.67
Gal. Center	266.42	−29.01	100.12	104.15	0.0050	0.037	0.89	0.89

Energy range: $E \geq 1\,\mathrm{EeV}$ (SD-1500)								
Class	**R.A [deg].**	**Dec. [deg]**	ρ_{obs} [deg^{-2}]	ρ_{exp} [deg^{-2}]	**Flux U.L.** [km^{-2} yr^{-1}]	**E-flux U.L.** [eV cm^{-2} s^{-1}]	p	p^*
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γ-ray PSRs	296.63	−54.05	140.10	124.20	0.021	0.15	5.4e-05	0.014
LMXB	236.98	−62.57	142.84	132.05	0.016	0.11	0.0090	0.60
HMXB	308.11	40.95	11.35	7.00	0.13	0.92	0.013	0.54
H.E.S.S. PWN	128.75	−45.60	126.47	117.16	0.015	0.11	0.0066	0.17
H.E.S.S. other	98.25	5.79	64.39	58.40	0.023	0.17	0.032	0.77
H.E.S.S. UNID	305.02	40.76	11.89	7.25	0.13	0.92	0.011	0.47
Microquasars	308.11	40.96	11.33	6.99	0.13	0.93	0.013	0.18
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LHAASO	292.25	17.75	43.10	36.58	0.038	0.27	0.021	0.17
Crab	83.63	22.01	28.12	29.47	0.018	0.13	0.67	0.67
Gal. Center	266.42	−29.01	100.12	104.15	0.0050	0.037	0.89	0.89

SD-1500 data set									
Class	No.	Weighted combined p-value P_ω				Unweighted combined p-value P_ω			
		$E \geq$ 1 EeV	1 – 2 EeV	2 – 3 EeV	$E \geq$ 3 EeV	$E \geq$ 1 EeV	1 – 2 EeV	2 – 3 EeV	$E \geq$ 3 EeV
msec PSRs	283	0.50	0.75	0.024	0.78	0.86	0.59	0.34	1.0
γ-ray PSRs	261	0.034	0.0063	0.41	0.66	0.17	0.14	0.43	0.86
Crab	1	0.67	0.49	0.26	0.94	0.67	0.49	0.27	0.94
Gal. Center	1	0.89	0.82	0.71	0.72	0.89	0.81	0.71	0.71
LMXB	102	0.26	0.77	0.48	0.073	0.57	0.83	0.15	0.53
HMXB	60	0.35	0.19	0.70	0.51	0.47	0.48	0.34	0.71
H.E.S.S. PWN	28	0.0054	0.0082	0.015	0.61	0.30	0.53	0.063	0.63
H.E.S.S. other	45	0.19	0.52	0.31	0.13	0.59	0.80	0.15	0.48
H.E.S.S. UNID	56	0.79	0.96	0.65	0.22	0.67	0.90	0.56	0.42
Microquasars	15	0.81	0.86	0.80	0.39	0.35	0.57	0.42	0.52
Magnetars	27	0.97	0.93	0.71	0.83	0.99	0.99	0.79	0.65
LHAASO	9	0.35	0.64	0.35	0.31	0.17	0.32	0.49	0.26

Energy range: $E \geq 0.1\,\mathrm{EeV}$ (SD-750)								
Class	**R.A [deg].**	**Dec. [deg]**	ρ_{obs} [deg^{-2}]	ρ_{exp} [deg^{-2}]	**Flux U.L.** [km^{-2} yr^{-1}]	**E-flux U.L.** [eV cm^{-2} s^{-1}]	p	p^*
msec PSRs	250.91	−12.42	59.25	54.73	2.0	15.0	0.042	0.66
γ-ray PSRs	288.35	10.33	19.97	15.90	5.2	38.0	0.0029	0.28
HMXB	116.85	−53.33	85.56	78.24	2.0	14.0	0.010	0.077
H.E.S.S. PWN	284.30	2.63	33.65	30.94	2.5	18.0	0.092	0.38
H.E.S.S. other	288.20	10.15	20.66	16.25	5.3	39.0	0.0017	0.019
Magnetars	274.71	−15.99	62.50	58.99	1.7	13.0	0.098	0.34

Energy range: $E \geq 0.1\,\mathrm{EeV}$ (SD-750)								
Class	**R.A [deg].**	**Dec. [deg]**	ρ_{obs} [deg^{-2}]	ρ_{exp} [deg^{-2}]	**Flux U.L.** [km^{-2} yr^{-1}]	**E-flux U.L.** [eV cm^{-2} s^{-1}]	p	p^*
msec PSRs	250.91	−12.42	59.25	54.73	2.0	15.0	0.042	0.66
γ-ray PSRs	288.35	10.33	19.97	15.90	5.2	38.0	0.0029	0.28
HMXB	116.85	−53.33	85.56	78.24	2.0	14.0	0.010	0.077
H.E.S.S. PWN	284.30	2.63	33.65	30.94	2.5	18.0	0.092	0.38
H.E.S.S. other	288.20	10.15	20.66	16.25	5.3	39.0	0.0017	0.019
Magnetars	274.71	−15.99	62.50	58.99	1.7	13.0	0.098	0.34

SD-750 data set									
Class	No.	Weighted combined p-value P_ω				Unweighted combined p-value P_ω			
		$E \geq$ 0.1 EeV	0.1 – 0.2 EeV	0.2 – 0.3 EeV	$E \geq$ 0.3 EeV	$E \geq$ 0.1 EeV	0.1 – 0.2 EeV	0.2 – 0.3 EeV	$E \geq$ 0.3 EeV
msec PSRs	25	0.58	0.49	0.91	0.092	0.75	0.39	0.83	0.57
γ-ray PSRs	113	0.96	0.93	0.86	0.37	0.55	0.74	0.43	0.31
HMXB	8	0.17	0.69	0.36	0.021	0.26	0.57	0.25	0.16
H.E.S.S. PWN	5	0.80	0.91	0.77	0.12	0.30	0.66	0.11	0.24
H.E.S.S. other	11	0.54	0.73	0.24	0.53	0.031	0.50	0.047	0.26
Magnetars	4	0.099	0.26	0.13	0.22	0.33	0.59	0.29	0.35

Pulsar J1946-5403

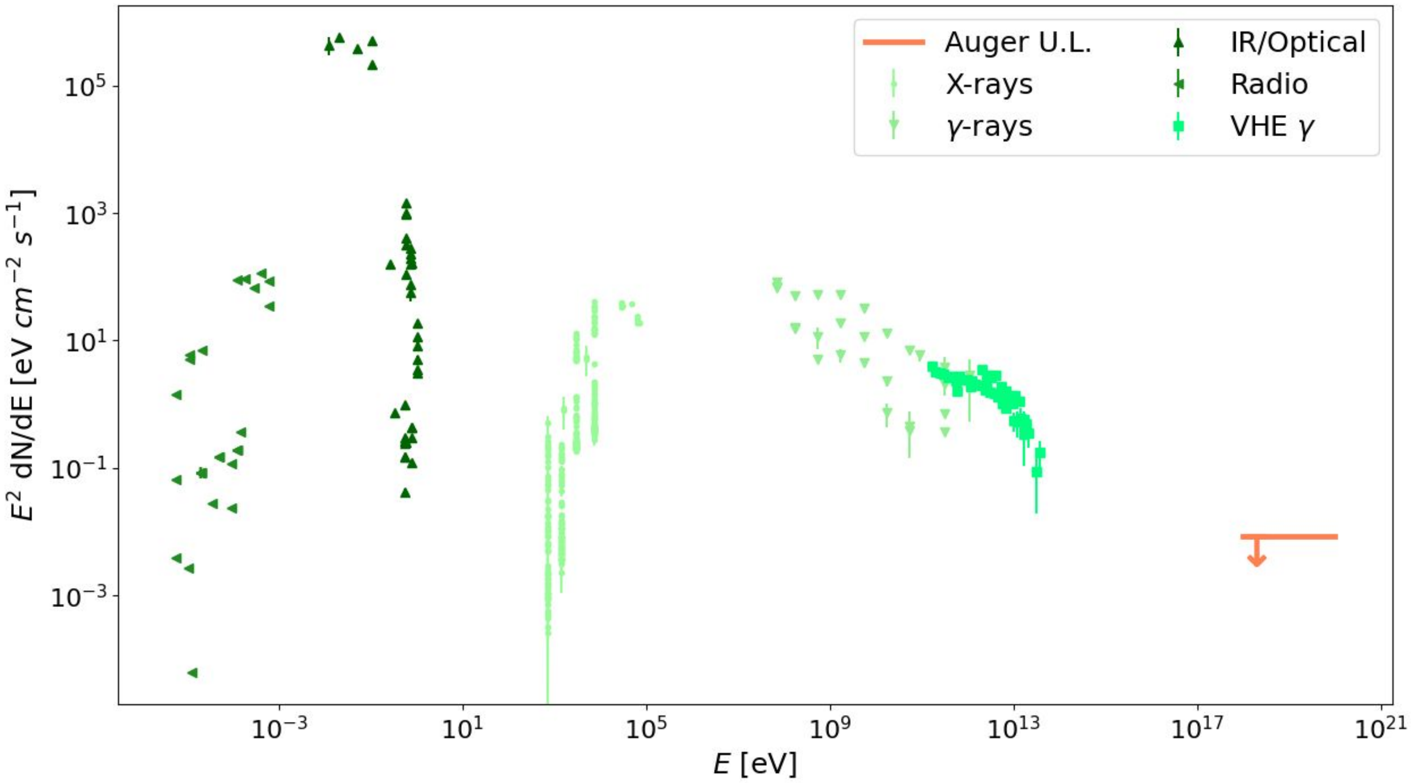
In the literature we found two different distance estimates for this γ-ray pulsar

- From ATNF pulsar catalog: 1.15 kpc
- From *F. Camilo et al 2015 ApJ 810 85* : 0.9 kpc

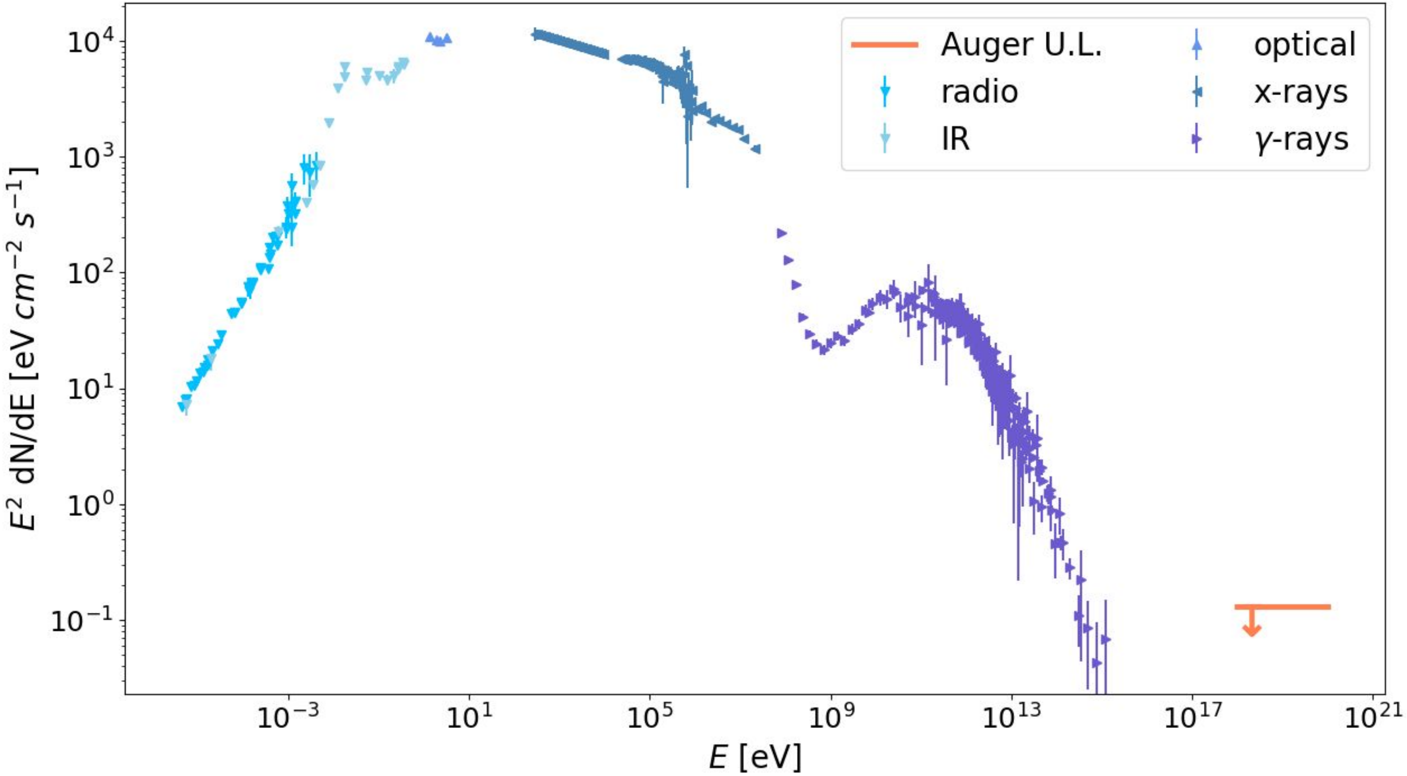
We studied the feasibility of testing it with the SD-750 and it turned out that it would likely give a result there too if the excess in the SD-1500 were true (see GAP2024_052)

Class	R.A. [deg]	Dec. [deg]	ρ^{obs} [deg^{-2}]	ρ^{exp} [deg^{-2}]	Flux U.L. [km^{-2} yr^{-1}]	E-flux U.L. [eV cm^{-2} s^{-1}]	p-value	p-value (penalized)
PSR J1946-5403	296.63	-54.05	81.11	77.82	1.4	9.9	0.14	0.14

SED for notable sources - Galactic Center



SED for notable sources - CRAB nebula



Conclusions and outlook

Paper is written (already passed two rounds of proofs from the EB)

Open questions:

1) **check the angular uncertainty (and add a short note commenting the difference between AR and our estimate)**
2) **Understand what to do with LMXB and HMXB**
3) **Prepare the tables with all the results as supplementary materials**
4) **So far, the target is ApJL, if we want to add the plots of the parametrization, we need to switch to ApJ**

Perspective:

1) **we want to proceed with a blind analysis producing a map of the cosmic ray density in each point in the sky with which we’ll look both for point sources and for excesses along the galactic Plane with the help from the GSSI group**
2) **perform a search for space-time correlation with transient events (and/or blind)**
3) **decide what to do with the HiRes-TA BLLac claim**

BACKUP

Energy range: $1 \leq E/\mathrm{EeV} < 2$ (SD-1500)								
Class	**R.A [deg].**	**Dec. [deg]**	ρ_{obs} [deg^{-2}]	ρ_{exp} [deg^{-2}]	**Flux U.L.** [km^{-2} yr^{-1}]	**E-flux U.L.** [eV cm^{-2} s^{-1}]	p	p^*
msec PSRs	285.50	3.01	54.88	48.26	0.027	0.19	0.0042	0.70
γ-ray PSRs	296.63	−54.05	105.26	94.94	0.019	0.14	0.00030	0.075
LMXB	140.65	−63.29	108.80	101.17	0.016	0.11	0.012	0.72
HMXB	285.90	3.19	54.24	48.00	0.026	0.19	0.0053	0.27
H.E.S.S. PWN	128.75	−45.60	96.67	89.40	0.016	0.12	0.0036	0.096
H.E.S.S. other	128.84	−45.18	95.72	89.17	0.015	0.11	0.0089	0.33
H.E.S.S. UNID	305.02	40.76	8.90	5.11	0.14	1.0	0.0057	0.27
Microquasars	308.11	40.96	7.18	4.92	0.11	0.80	0.048	0.52
Magnetars	248.97	−47.59	93.64	90.96	0.010	0.074	0.17	0.99
LHAASO	292.25	17.75	31.09	26.40	0.038	0.28	0.018	0.15
Crab	83.63	22.01	20.64	20.66	0.024	0.17	0.49	0.49
Gal. Center	266.42	−29.01	77.45	79.70	0.0056	0.041	0.81	0.81

Energy range: $2 \leq E/\mathrm{EeV} < 3$ (SD-1500)								
Class	**R.A [deg].**	**Dec. [deg]**	ρ_{obs} [deg^{-2}]	ρ_{exp} [deg^{-2}]	**Flux U.L.** [km^{-2} yr^{-1}]	**E-flux U.L.** [eV cm^{-2} s^{-1}]	p	p^*
msec PSRs	286.37	4.00	13.25	8.93	0.0089	0.065	0.0025	0.51
γ-ray PSRs	290.36	1.61	13.21	9.41	0.0078	0.057	0.0060	0.79
LMXB	259.70	−32.18	20.11	15.00	0.0061	0.044	0.0012	0.12
HMXB	223.21	−59.82	22.62	18.10	0.0049	0.036	0.011	0.49
H.E.S.S. PWN	279.41	−6.95	13.54	11.02	0.0053	0.038	0.040	0.68
H.E.S.S. other	245.49	−50.27	20.53	16.91	0.0045	0.033	0.015	0.50
H.E.S.S. UNID	284.58	2.09	11.93	9.33	0.0064	0.047	0.033	0.85
Microquasars	262.75	−26.00	17.56	14.15	0.0049	0.036	0.011	0.16
Magnetars	245.69	−49.85	20.01	16.85	0.0041	0.030	0.030	0.56
LHAASO	308.05	41.05	2.41	1.23	0.028	0.21	0.11	0.64
Crab	83.63	22.01	5.97	5.22	0.0071	0.052	0.27	0.27
Gal. Center	266.42	−29.01	13.77	14.57	0.0019	0.014	0.71	0.71

Energy range: $E \geq 3\,\mathrm{EeV}$ (SD-1500)								
Class	**R.A [deg].**	**Dec. [deg]**	ρ_{obs} **[deg^{-2}]**	ρ_{exp} **[deg^{-2}]**	**Flux U.L. [km^{-2} yr^{-1}]**	**E-flux U.L. [eV cm^{-2} s^{-1}]**	p	p^*
msec PSRs	302.69	−13.40	13.88	8.33	0.0046	0.034	0.0025	0.51
γ-ray PSRs	266.40	10.29	10.51	5.25	0.0071	0.052	0.0039	0.64
LMXB	247.01	−49.20	16.09	11.38	0.0031	0.023	0.011	0.69
HMXB	299.59	35.20	3.86	1.61	0.013	0.097	0.050	0.95
H.E.S.S. PWN	292.63	18.87	7.57	3.99	0.0075	0.055	0.022	0.47
H.E.S.S. other	224.44	−59.47	16.45	12.33	0.0028	0.020	0.031	0.75
H.E.S.S. UNID	278.69	−8.76	10.62	7.79	0.0033	0.024	0.053	0.95
Microquasars	265.29	−29.70	12.83	9.94	0.0027	0.020	0.050	0.53
Magnetars	275.57	−16.07	12.64	8.58	0.0037	0.027	0.014	0.31
LHAASO	299.05	28.07	4.63	2.57	0.0084	0.061	0.077	0.51
Crab	83.63	22.01	1.50	3.58	0.0020	0.015	0.94	0.94
Gal. Center	266.42	−29.01	8.90	9.88	0.0012	0.0085	0.71	0.71

Energy range: $0.1 \leq E/\mathrm{EeV} < 0.2$ (SD-750)								
Class	**R.A [deg].**	**Dec. [deg]**	ρ_{obs} [deg^{-2}]	ρ_{exp} [deg^{-2}]	**Flux U.L. [km^{-2} yr^{-1}]**	**E-flux U.L. [eV cm^{-2} s^{-1}]**	p	p^*
msec PSRs	140.50	−52.04	62.81	58.86	1.7	12.0	0.051	0.73
γ-ray PSRs	164.24	−58.88	61.57	56.36	2.0	14.0	0.014	0.80
HMXB	116.85	−53.33	62.60	58.64	1.6	12.0	0.054	0.36
H.E.S.S. PWN	284.30	2.63	23.50	21.65	2.4	18.0	0.11	0.43
H.E.S.S. other	224.91	−60.78	58.23	55.21	1.6	11.0	0.11	0.72
Magnetars	270.25	−22.95	51.81	49.92	1.4	10.0	0.20	0.59

Energy range: $0.2 \leq E/\mathrm{EeV} < 0.3$ (SD-750)								
Class	**R.A [deg].**	**Dec. [deg]**	ρ_{obs} **[deg^{-2}]**	ρ_{exp} **[deg^{-2}]**	**Flux U.L. [km^{-2} yr^{-1}]**	**E-flux U.L. [eV cm^{-2} s^{-1}]**	p	p^*
msec PSRs	259.79	−14.63	10.66	8.87	0.58	4.2	0.057	0.77
γ-ray PSRs	284.58	−22.28	13.05	9.91	0.70	5.1	0.0051	0.44
HMXB	102.02	−44.32	13.73	11.80	0.46	3.4	0.068	0.43
H.E.S.S. PWN	98.12	17.37	2.38	1.53	1.6	11.0	0.043	0.20
H.E.S.S. other	288.20	10.15	5.92	3.84	1.2	8.7	0.0058	0.062
Magnetars	274.71	−15.99	10.36	9.05	0.48	3.5	0.12	0.40

Energy range: $E \geq 0.3\,\mathrm{EeV}$ (SD-750)								
Class	**R.A [deg].**	**Dec. [deg]**	ρ_{obs} [deg^{-2}]	ρ_{exp} [deg^{-2}]	**Flux U.L.** [$\mathrm{km^{-2}\,yr^{-1}}$]	**E-flux U.L.** [$\mathrm{eV\,cm^{-2}\,s^{-1}}$]	p	p^*
msec PSRs	358.96	0.85	5.50	3.93	0.43	3.1	0.074	0.85
γ-ray PSRs	187.91	−51.27	10.75	7.48	0.36	2.6	0.013	0.78
HMXB	190.71	−63.06	10.91	7.51	0.36	2.6	0.015	0.12
H.E.S.S. PWN	277.85	−9.90	7.53	5.18	0.41	3.0	0.030	0.14
H.E.S.S. other	224.91	−60.78	9.67	7.57	0.28	2.0	0.075	0.58
Magnetars	118.93	−29.56	8.15	6.68	0.27	2.0	0.12	0.41

Cosmic-ray intensity (km^{-2} yr^{-1} sr^{-1})			
Energy range	**Vertical**	**Inclined**	**Total**
$E \geq 1\,\mathrm{EeV}$	26.67	25.31	51.98
$1 \leq E/\mathrm{EeV} < 2$	21.00	19.93	40.93
$2 \leq E/\mathrm{EeV} < 3$	3.26	3.10	6.36
$E \geq 3\,\mathrm{EeV}$	2.41	2.29	4.70

Cosmic-ray intensity (km^{-2} yr^{-1} sr^{-1}) - SD-750 data set	
Energy range	**Cosmic-ray intensity [km^{-2} yr^{-1} sr^{-1}]**
$E \geq 1\,\mathrm{EeV}$	4820.44
$1 \leq E/\mathrm{EeV} < 2$	3854.55
$2 \leq E/\mathrm{EeV} < 3$	599.26
$E \geq 3\,\mathrm{EeV}$	366.63