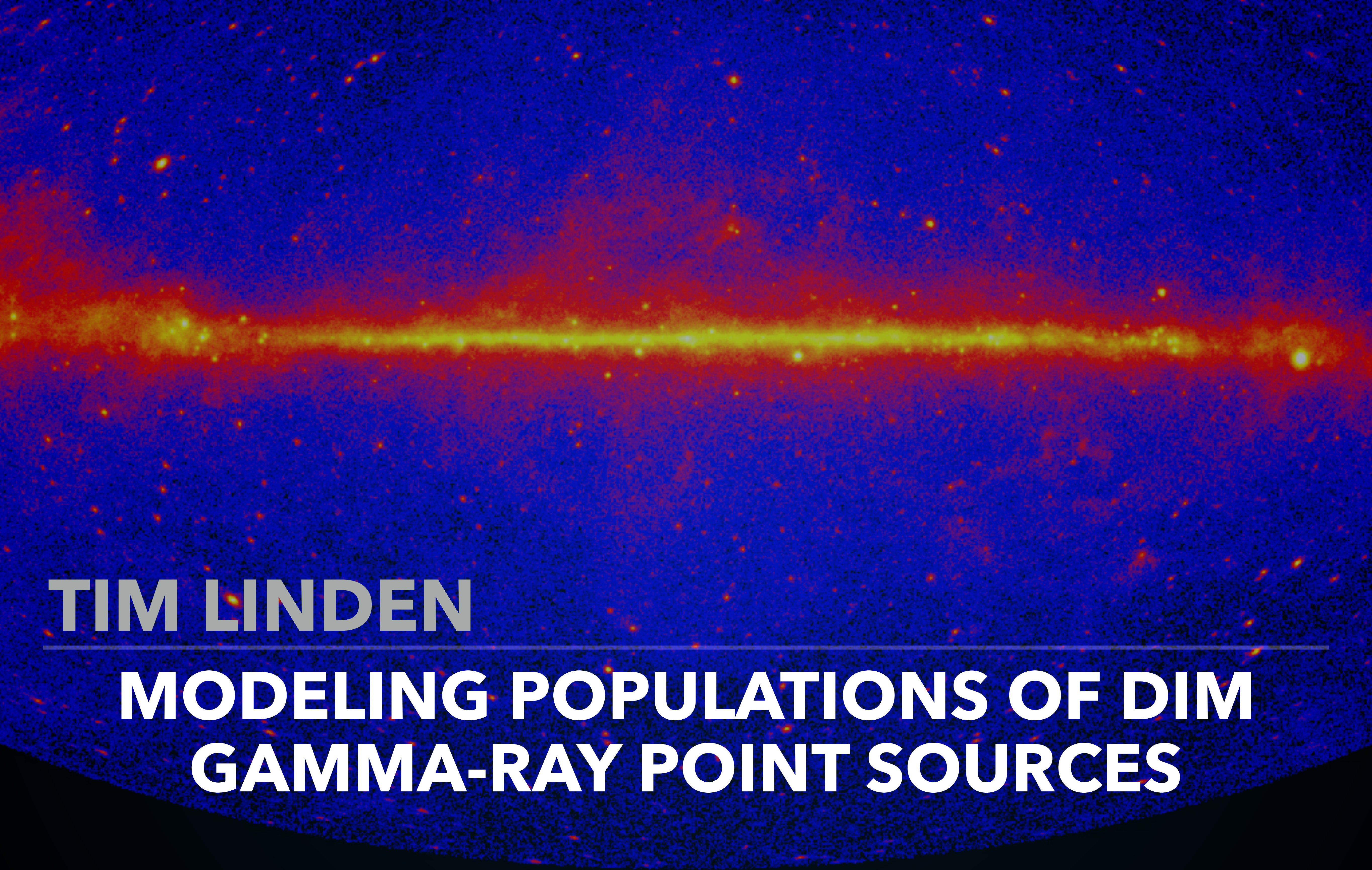


TIM LINDEN

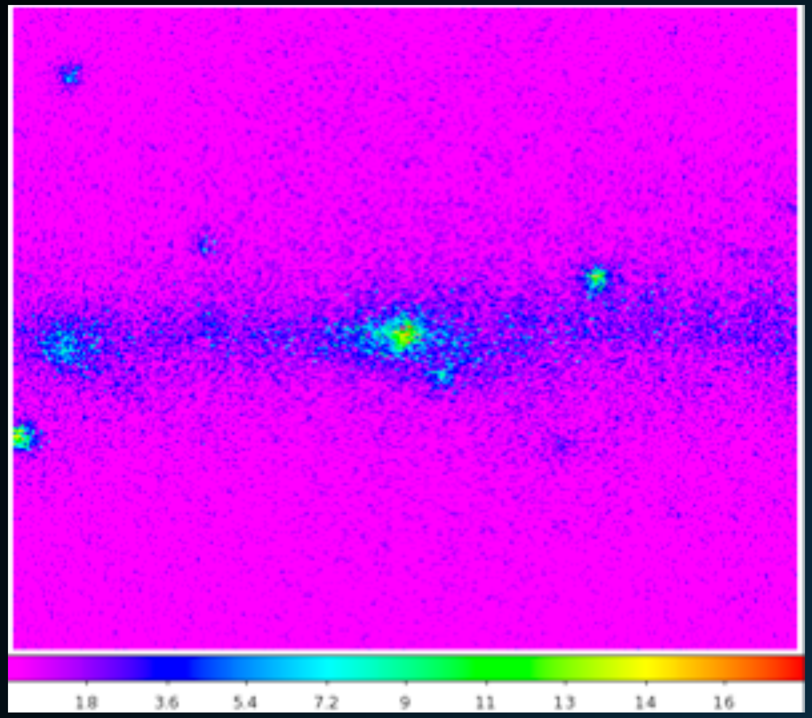
MODELING POPULATIONS OF DIM GAMMA-RAY POINT SOURCES

AstroStat Meeting

June 27, 2017

THE OHIO STATE UNIVERSITY
CENTER FOR COSMOLOGY AND ASTROPARTICLE PHYSICS

GAMMA-RAY DATA ANALYSIS

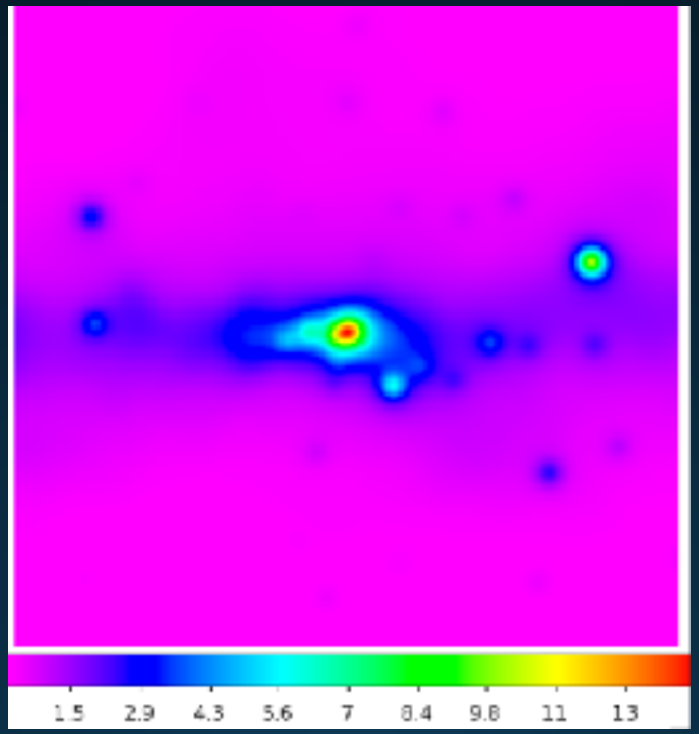


Data (15° x 15°)

~1 GeV

Best PSF

−

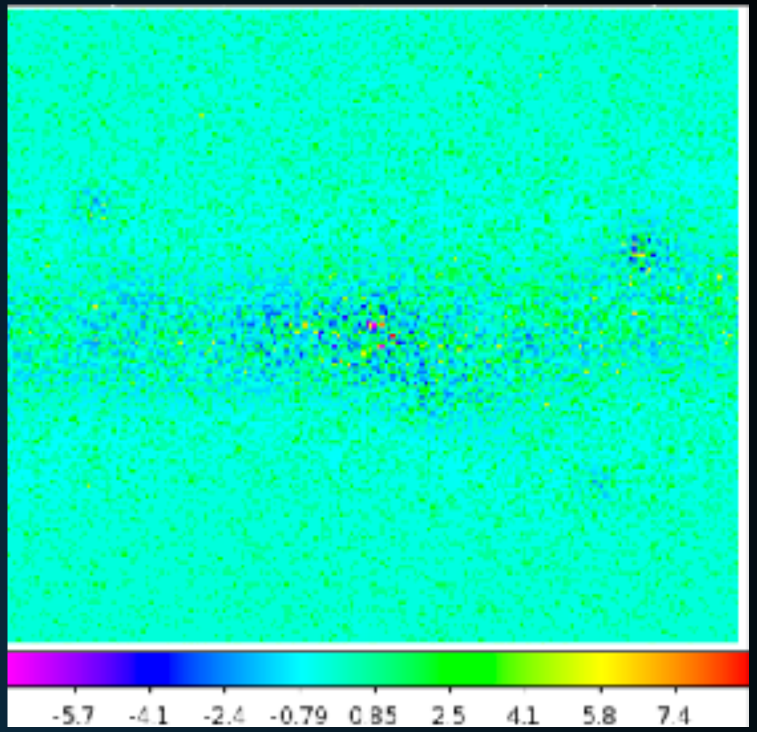


Model

Diffuse

Point Sources

=



Residual

Calculate the fit to the data by calculating the Poisson probability of observing X photons in each bin given the model.

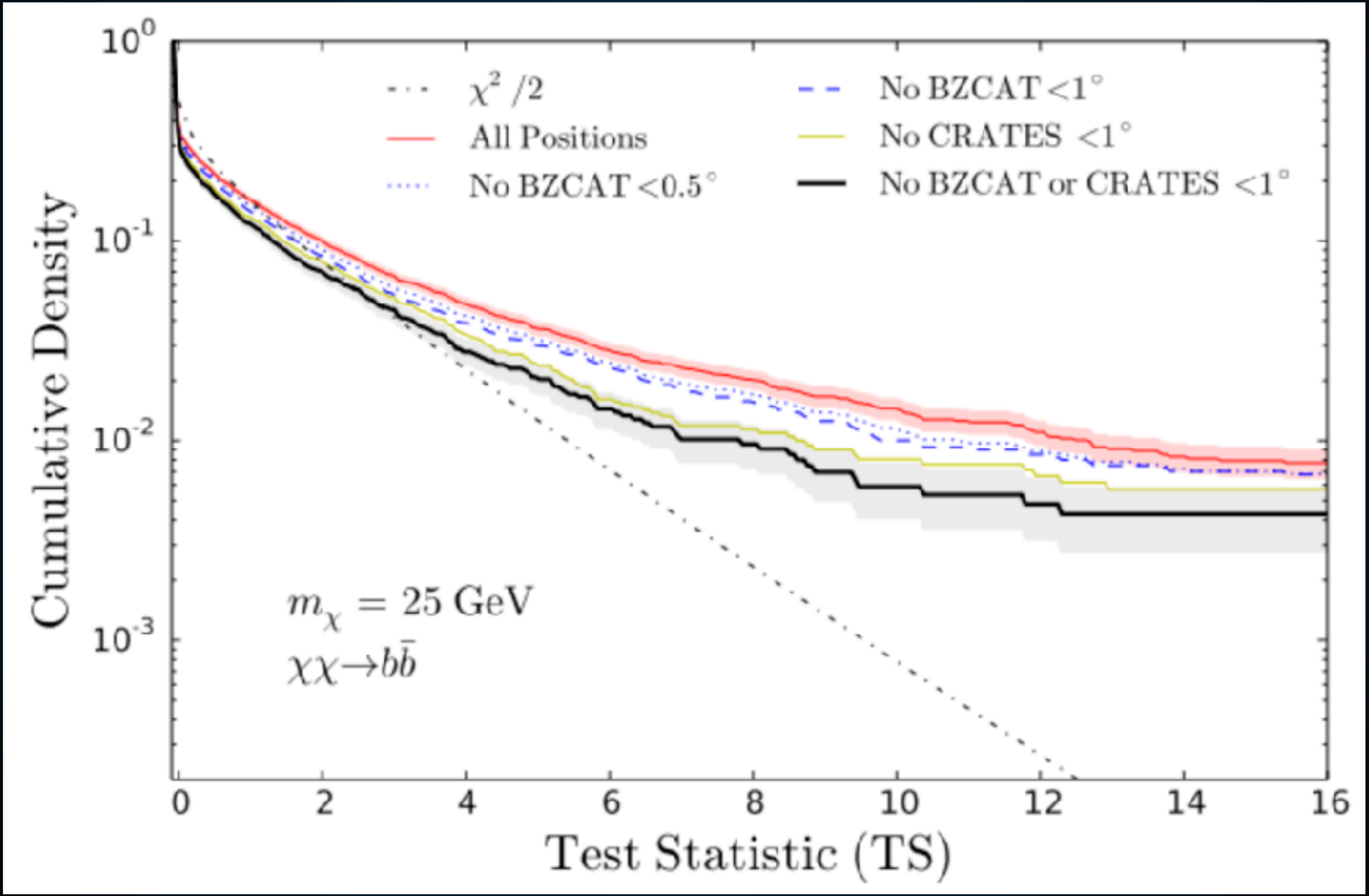
Can calculate the improvement to the fit by adding additional point sources into the model.

GAMMA-RAY DATA ANALYSIS

- Advantages:
  - Nearly equivalent coverage of the full sky.
  - Universe nearly transparent to GeV gamma-rays
- Disadvantages:
  - Not much energy information
  - Poor PSF (~1° PSF; ~0.1° localization of bright sources)

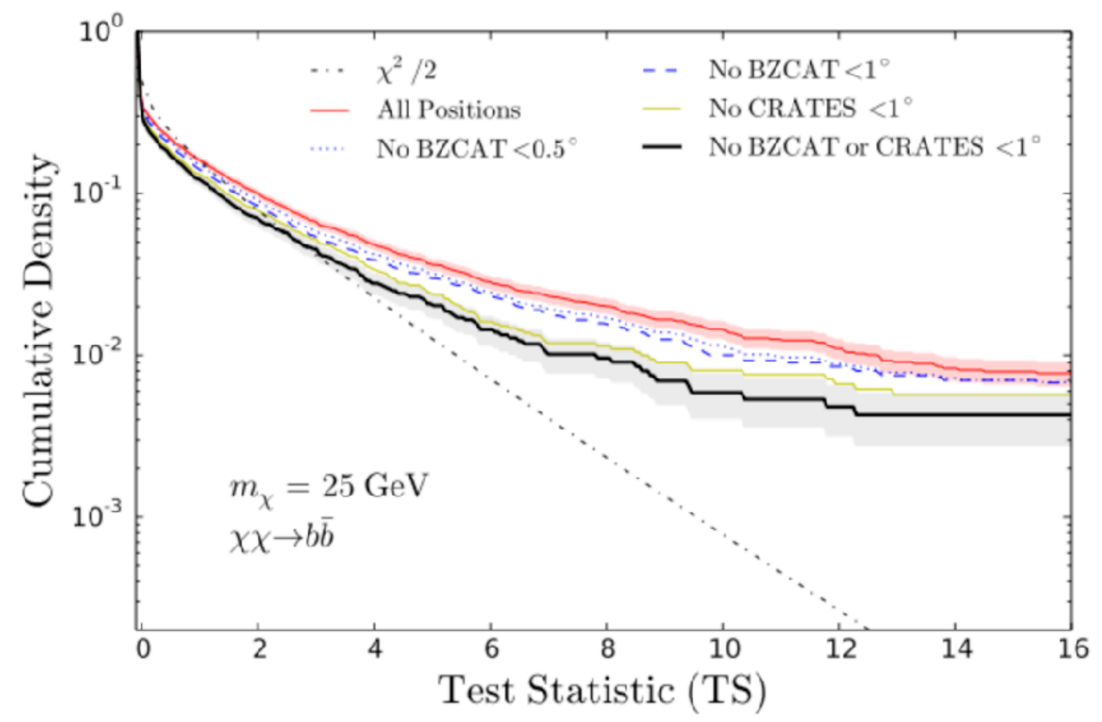
BACKGROUND MODELING ISSUES

- **Background fluctuations not Poisson Statistics:**



BACKGROUND MODELING ISSUES

- Employ “blank sky locations” to characterize the background.



- Accounts for known and unknown systematic issues and point source properties.

- Computationally intensive, hard to understand rare events.
- Background changes based on source model.
- Can have global changes in model - e.g. galactic plane.

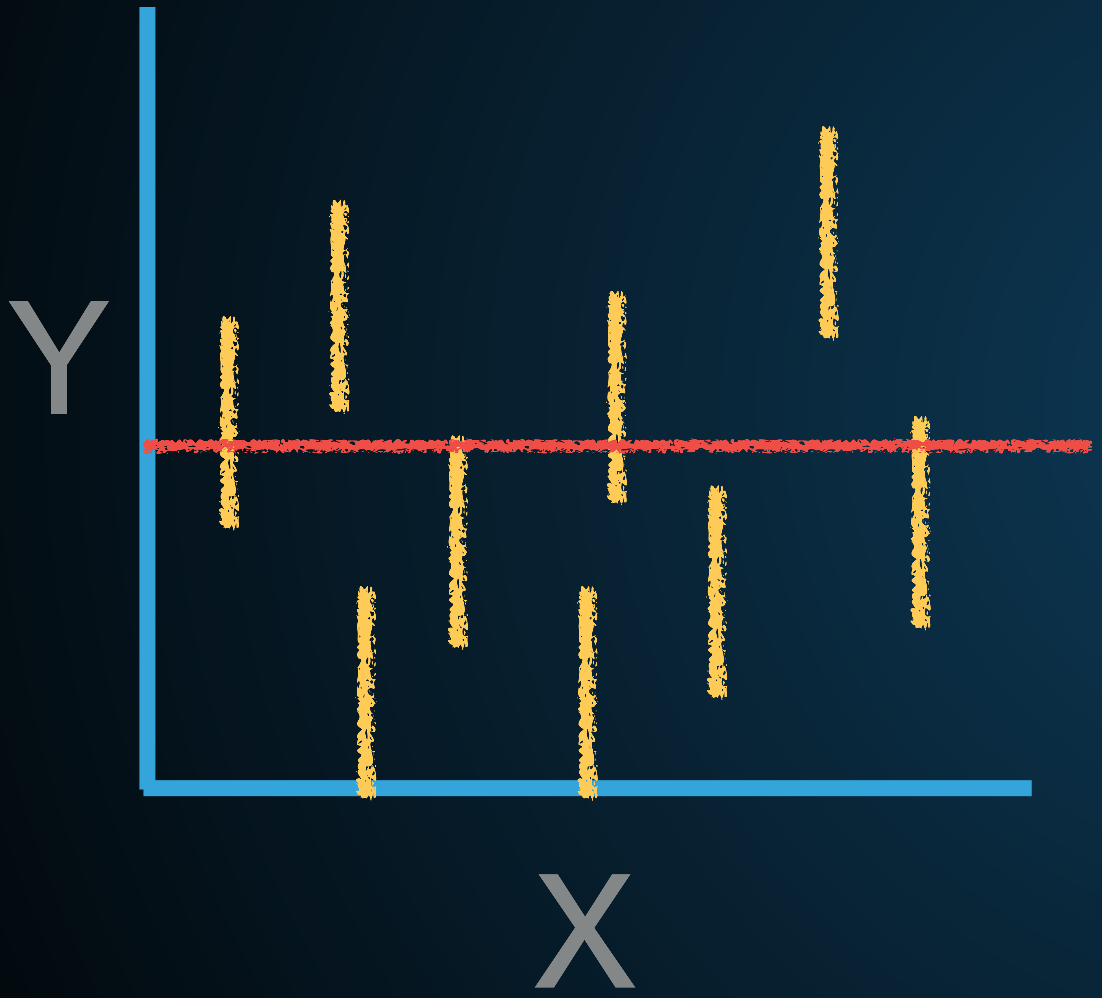
USING LOW ENERGY INFORMATION

Determine the gamma-ray luminosity of a population of point sources

- Advantages:
  - Know where sources are, and approximately how bright they should be (model dependent)
- Disadvantages:
  - Flux fluctuations in the background often larger than individual source fluxes.

USING LOW ENERGY INFORMATION

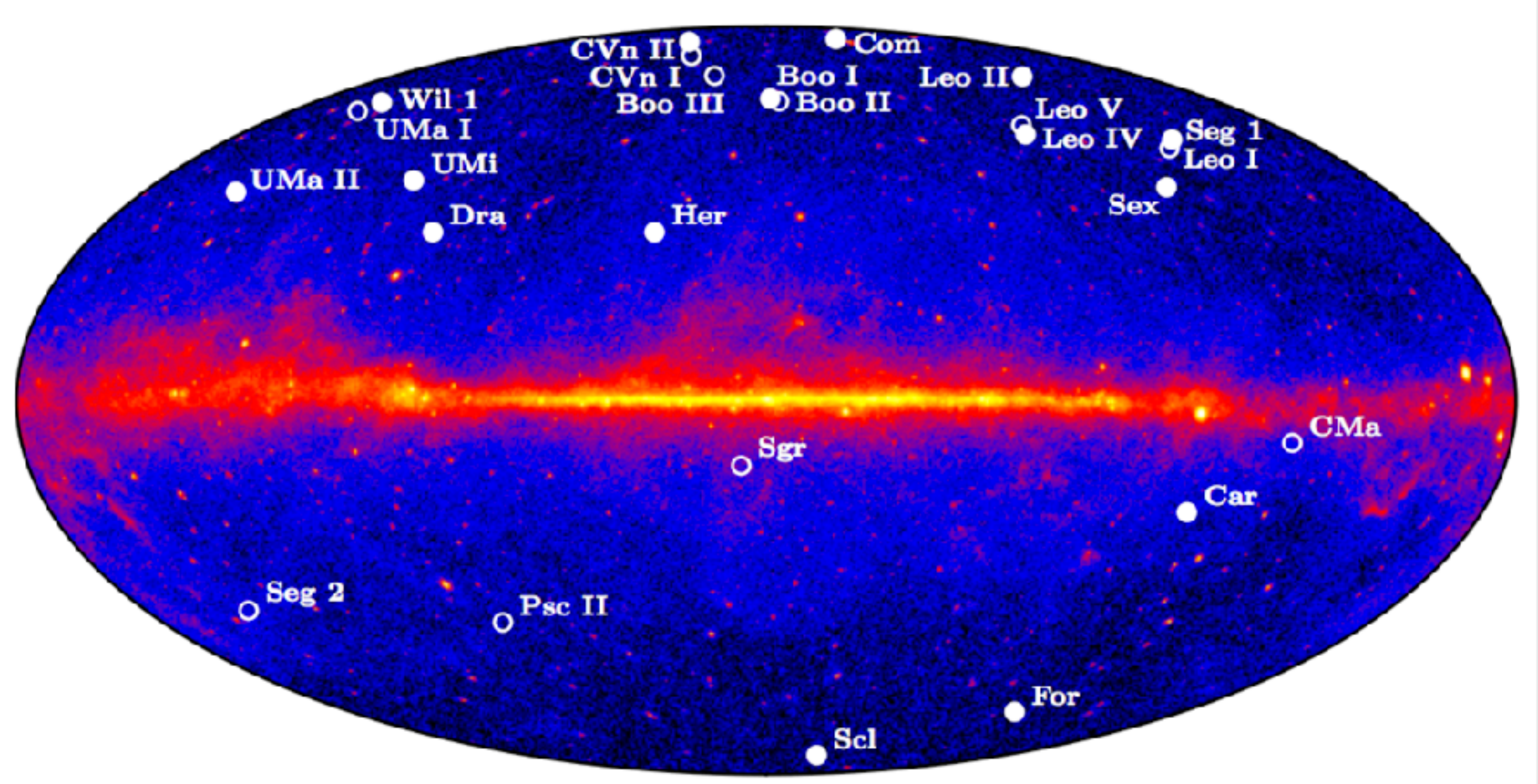
Determine the gamma-ray luminosity of a population of point sources



vs.

EXAMPLE - DWARF SPHEROIDAL GALAXIES

- **Dark Matter Annihilation in Dwarf Galaxies**



EXAMPLE - DWARF SPHEROIDAL GALAXIES

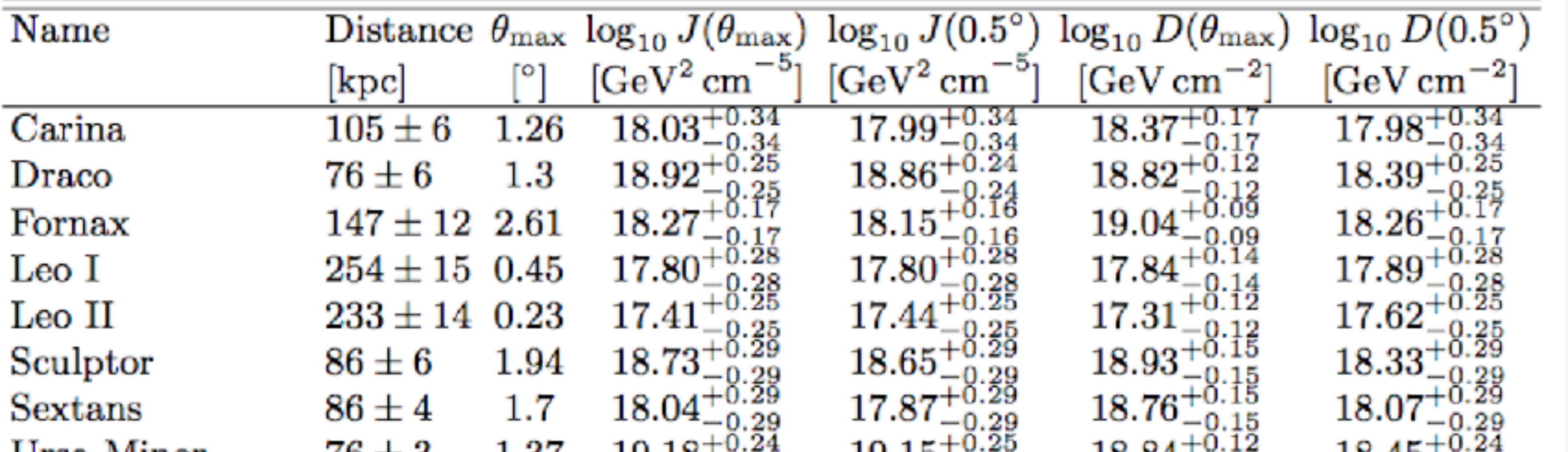
- **Dark Matter Annihilation in Dwarf Galaxies**

$$\phi_s(\Delta\Omega) = \underbrace{\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\mathrm{DM}}^2}\int_{E_{\min}}^{E_{\max}}\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma}\mathrm{d}E_\gamma}_{\Phi_{\mathrm{PP}}} \cdot \underbrace{\int_{\Delta\Omega}\left\{\int_{\mathrm{l.o.s.}}\rho^2(\boldsymbol{r})\mathrm{d}l\right\}\mathrm{d}\Omega'}_{\text{J-factor}}$$

Normalization Factor | **Dwarf Environment**

Common to all dwarfs | **Optical Observations**

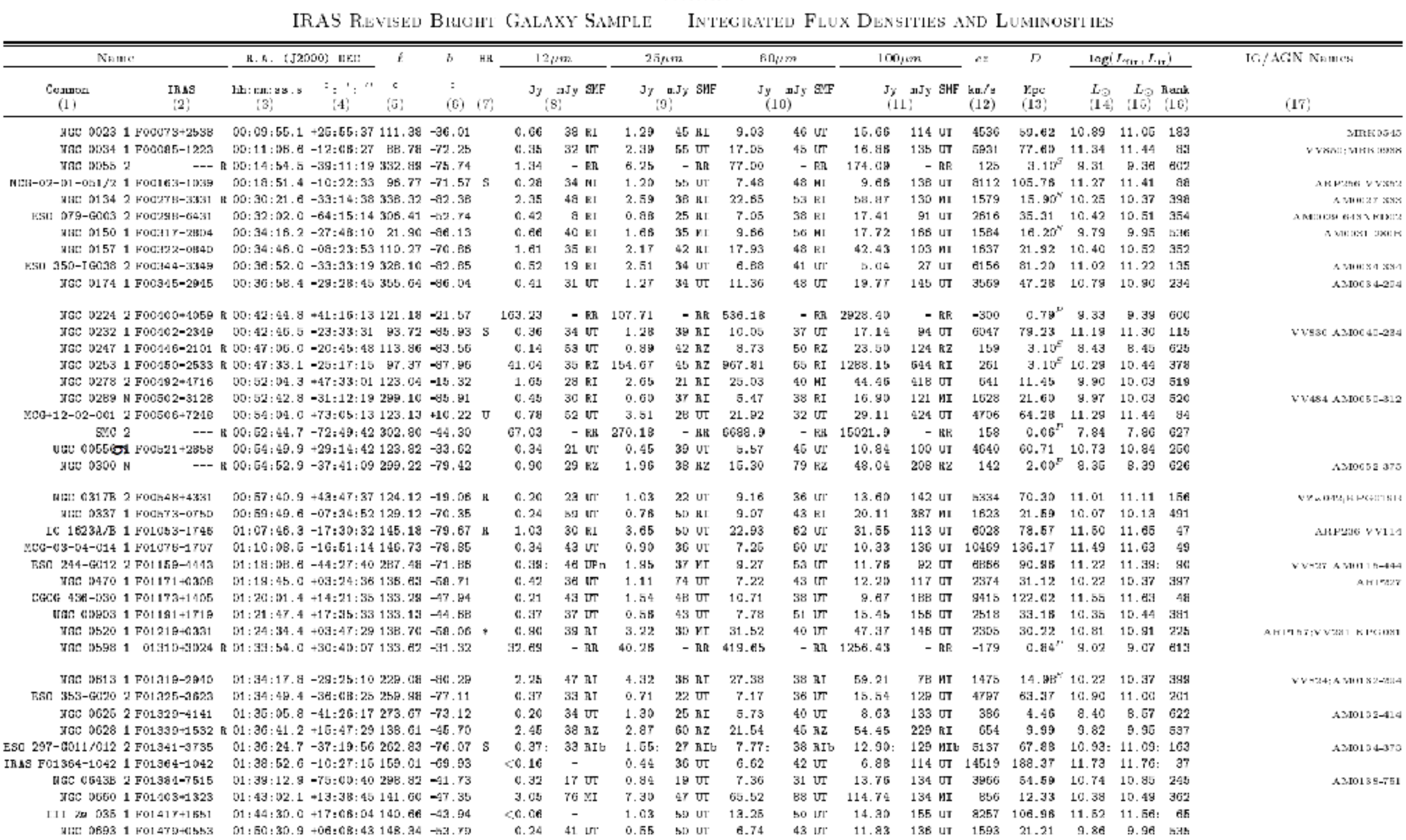
Want to test if it is non-zero. | **Have Uncertainties**



Name	Distance [kpc]	$\theta_{\max}$ [°]	$\log_{10} J(\theta_{\max})$ [GeV^2 cm^{-5}]	$\log_{10} J(0.5°)$ [GeV^2 cm^{-5}]	$\log_{10} D(\theta_{\max})$ [GeV cm^{-2}]	$\log_{10} D(0.5°)$ [GeV cm^{-2}]
Carina	105 ± 6	1.26	$18.03^{+0.34}_{-0.34}$	$17.99^{+0.34}_{-0.34}$	$18.37^{+0.17}_{-0.17}$	$17.98^{+0.34}_{-0.34}$
Draco	76 ± 6	1.3	$18.92^{+0.25}_{-0.25}$	$18.86^{+0.24}_{-0.24}$	$18.82^{+0.12}_{-0.12}$	$18.39^{+0.25}_{-0.25}$
Fornax	147 ± 12	2.61	$18.27^{+0.17}_{-0.17}$	$18.15^{+0.16}_{-0.16}$	$19.04^{+0.09}_{-0.09}$	$18.26^{+0.17}_{-0.17}$
Leo I	254 ± 15	0.45	$17.80^{+0.28}_{-0.28}$	$17.80^{+0.28}_{-0.28}$	$17.84^{+0.14}_{-0.14}$	$17.89^{+0.28}_{-0.28}$
Leo II	233 ± 14	0.23	$17.41^{+0.25}_{-0.25}$	$17.44^{+0.25}_{-0.25}$	$17.31^{+0.12}_{-0.12}$	$17.62^{+0.25}_{-0.25}$
Sculptor	86 ± 6	1.94	$18.73^{+0.29}_{-0.29}$	$18.65^{+0.29}_{-0.29}$	$18.93^{+0.15}_{-0.15}$	$18.33^{+0.29}_{-0.29}$
Sextans	86 ± 4	1.7	$18.04^{+0.29}_{-0.29}$	$17.87^{+0.29}_{-0.29}$	$18.76^{+0.15}_{-0.15}$	$18.07^{+0.29}_{-0.29}$

EXAMPLE - STAR FORMING GALAXIES

- Nearby Star-Forming Galaxies



IRAS Revised Bright Galaxy Sample — Integrated Flux Densities and Luminosities

Name Common (1)		Name IRAS (2)		R.A. (J2000) hh:mm:ss.s (3)	DEC °:′:″ (4)	ℓ ° (5)	b ° (6)	RR (7)	12μm Jy (8)	12μm mJy	12μm SMF	25μm Jy (9)	25μm mJy	25μm SMF	60μm Jy (10)	60μm mJy	60μm SMF	100μm Jy (11)	100μm mJy	100μm SMF	cz km/s (12)	D Mpc (13)	log(L_{FIR}) $L_\odot$ (14)	log(L_{IR}) $L_\odot$ (15)	Rank (16)	IG/AGN Names (17)
NGC 0023	1	F00073+2538		00:09:55.1	+25:55:37	111.38	-36.01		0.66	38	RI	1.29	45	RI	9.03	46	UT	15.66	114	UT	4536	59.62	10.89	11.05	183	MRK0545
NGC 0034	1	F00085-1223		00:11:06.6	-12:06:27	88.78	-72.25		0.35	32	UT	2.39	55	UT	17.05	45	UT	16.86	135	UT	5931	77.60	11.34	11.44	83	VV850;MRK0938
NGC 0055	2	---	R	00:14:54.5	-39:11:19	332.88	-75.74		1.34	-	RR	6.25	-	RR	77.00	-	RR	174.09	-	RR	125	3.10^{S}	9.31	9.36	602	
MCG-02-01-051/2	1	F00163-1039		00:18:51.4	-10:22:33	96.77	-71.57	S	0.28	34	MI	1.20	55	UT	7.48	48	MI	9.68	136	UT	8112	105.78	11.27	11.41	88	ARP256 VV352
NGC 0134	2	F00278-3331	R	00:30:21.6	-33:14:38	338.32	-82.38		2.35	48	RI	2.59	36	RI	22.65	53	RI	58.87	130	MI	1579	15.90^{N}	10.25	10.37	398	AM0027-333
ESO 079-G003	2	F00298-6431		00:32:02.0	-64:15:14	306.41	-52.74		0.42	8	RI	0.88	25	RI	7.05	38	RI	17.41	91	UT	2616	35.31	10.42	10.51	354	AM0029-643 NED02
NGC 0150	1	F00317-2804		00:34:16.2	-27:48:10	21.90	-86.13		0.66	40	RI	1.68	35	RI	9.66	56	MI	17.72	166	UT	1584	16.20^{N}	9.79	9.95	536	AM0031-280B
NGC 0157	1	F00322-0840		00:34:46.0	-08:23:53	110.27	-70.86		1.61	35	RI	2.17	42	RI	17.93	48	RI	42.43	103	MI	1637	21.92	10.40	10.52	352	
ESO 350-IG038	2	F00344-3349		00:36:52.0	-33:33:19	326.10	-82.85		0.52	19	RI	2.51	34	UT	6.68	41	UT	5.04	27	UT	6156	81.20	11.02	11.22	135	AM0034-334
NGC 0174	1	F00345-2945		00:36:58.4	-29:28:45	355.64	-86.04		0.41	31	UT	1.27	34	UT	11.36	48	UT	19.77	145	UT	3569	47.28	10.79	10.90	234	AM0034-294
NGC 0224	2	F00400+4059	R	00:42:44.8	+41:16:13	121.18	-21.57		163.23	-	RR	107.71	-	RR	536.18	-	RR	2928.40	-	RR	-300	0.79^{P}	9.33	9.39	600	
NGC 0232	1	F00402-2349		00:42:45.5	-23:33:31	93.72	-85.93	S	0.36	34	UT	1.28	39	RI	10.05	37	UT	17.14	94	UT	6047	79.23	11.19	11.30	115	VV830 AM0040-234
NGC 0247	1	F00446-2101	R	00:47:06.0	-20:45:48	113.86	-83.56		0.14	53	UT	0.89	42	RZ	8.73	50	RZ	23.50	124	RZ	159	3.10^{E}	8.43	8.45	625	
NGC 0253	1	F00450-2533	R	00:47:33.1	-25:17:15	97.37	-87.96		41.04	35	RZ	154.67	45	RZ	967.81	65	RI	1288.15	644	RI	261	3.10^{E}	10.29	10.44	378	
NGC 0278	2	F00492+4716		00:52:04.3	+47:33:01	123.04	-15.32		1.65	28	RI	2.65	21	RI	25.03	40	MI	44.46	418	UT	641	11.45	9.90	10.03	519	
NGC 0289	N	F00502-3128		00:52:42.8	-31:12:19	299.10	-85.91		0.45	30	RI	0.60	37	RI	5.47	38	RI	16.90	121	MI	1628	21.60	9.97	10.03	520	VV484 AM0050-312
MCG+12-02-001	2	F00506+7248		00:54:04.0	+73:05:13	123.13	+10.22	U	0.78	52	UT	3.51	28	UT	21.92	32	UT	29.11	424	UT	4706	64.28	11.29	11.44	84	
SMC	2	---	R	00:52:44.7	-72:49:42	302.80	-44.30		67.03	-	RR	270.18	-	RR	6688.9	-	RR	15021.9	-	RR	158	0.06^{F}	7.84	7.86	627	
UGC 00556	1	F00521+2858		00:54:49.9	+29:14:42	123.82	-33.62		0.34	21	UT	0.45	39	UT	5.57	45	UT	10.84	100	UT	4040	60.71	10.73	10.84	250	
NGC 0300	N	---	R	00:54:52.9	-37:41:09	299.22	-79.42		0.90	29	RZ	1.96	38	RZ	15.30	79	RZ	48.04	208	RZ	142	2.00^{F}	8.35	8.39	626	AM0052-375
NGC 0317B	2	F00548+4331		00:57:40.9	+43:47:37	124.12	-19.06	R	0.20	23	UT	1.03	22	UT	9.16	36	UT	13.60	142	UT	5334	70.30	11.01	11.11	156	[illegible]
NGC 0337	1	F00573-0750		00:59:49.6	-07:34:52	129.12	-70.35		0.24	59	UT	0.78	50	RI	9.07	43	RI	20.11	387	MI	1623	21.59	10.07	10.13	491	
IC 1623A/B	1	F01053-1746		01:07:46.3	-17:30:32	145.18	-79.67	R	1.03	30	RI	3.65	50	UT	22.93	62	UT	31.55	113	UT	6028	78.57	11.50	11.65	47	ARP236 VV114
MCG-03-04-014	1	F01076-1707		01:10:08.5	-16:51:14	146.73	-78.85		0.34	43	UT	0.90	36	UT	7.25	60	UT	10.33	136	UT	10469	136.17	11.49	11.63	49	
ESO 244-G012	2	F01159-4443		01:18:08.6	-44:27:40	287.48	-71.86		0.38:	46	UPn	1.95	37	MT	9.27	53	UT	11.78	92	UT	6886	90.98	11.22	11.38:	90	VV827 AM0116-444
NGC 0470	1	F01171+0308		01:19:45.0	+03:24:36	136.63	-58.71		0.42	36	UT	1.11	74	UT	7.22	43	UT	12.20	117	UT	2374	31.12	10.22	10.37	397	ARP227
CGCG 436-030	1	F01173+1405		01:20:01.4	+14:21:35	133.28	-47.94		0.21	43	UT	1.54	48	UT	10.71	38	UT	9.67	188	UT	9415	122.62	11.55	11.63	48	
UGC 00903	1	F01191+1719		01:21:47.4	+17:35:33	133.13	-44.68		0.37	37	UT	0.58	43	UT	7.78	51	UT	15.45	156	UT	2518	33.18	10.35	10.44	381	
NGC 0520	1	F01219+0331		01:24:34.4	+03:47:29	138.70	-58.06	*	0.86	39	RT	3.22	30	MT	31.52	40	UT	47.37	146	UT	2305	30.22	10.81	10.91	225	ARP157;VV231 KPG031
NGC 0598	1	01310+3024	R	01:33:54.0	+30:40:07	133.62	-31.32		32.69	-	RR	40.28	-	RR	419.65	-	RR	1256.43	-	RR	-179	0.84^{H}	9.02	9.07	613	
NGC 0613	1	F01319-2940		01:34:17.8	-29:25:10	229.08	-80.29		2.25	47	RT	4.32	36	RT	27.38	38	RT	59.21	78	MT	1475	14.98^{N}	10.22	10.37	398	VV824;AM0132-294
ESO 353-G020	2	F01325-3623		01:34:49.4	-36:08:25	259.98	-77.11		0.37	33	RT	0.71	22	UT	7.17	36	UT	15.54	129	UT	4797	63.37	10.90	11.00	201	
NGC 0625	2	F01329-4141		01:35:05.8	-41:26:17	273.67	-73.12		0.20	34	UT	1.30	25	RI	5.73	40	UT	8.63	133	UT	386	4.46	8.40	8.57	622	AM0133-414
NGC 0628	1	F01339+1532	R	01:36:41.2	+15:47:29	138.61	-45.70		2.45	38	RZ	2.87	60	RZ	21.54	45	RZ	54.45	229	RI	654	9.99	9.82	9.95	537	
ESO 297-G011/012	2	F01341-3735		01:36:24.7	-37:19:56	262.83	-76.07	S	0.37:	33	RIb	1.55:	27	RIb	7.77:	38	RIb	12.90:	129	MIb	5137	67.88	10.93:	11.09:	163	AM0134-373
IRAS F01364-1042	1	F01364-1042		01:38:52.6	-10:27:15	159.01	-69.93		<0.16	-		0.44	36	UT	6.62	42	UT	6.88	114	UT	14519	188.37	11.73	11.76:	37	
NGC 0643B	2	F01384-7515		01:39:12.9	-75:00:40	298.82	-41.73		0.32	17	UT	0.84	19	UT	7.36	31	UT	13.76	134	UT	3966	54.59	10.74	10.85	245	AM0138-751
NGC 0660	1	F01403+1323		01:43:02.1	+13:38:45	141.60	-47.35		3.05	76	MI	7.30	47	UT	65.52	88	UT	114.74	134	MI	856	12.33	10.38	10.49	362	
III Zw 035	1	F01417+1651		01:44:30.0	+17:06:04	140.66	-43.94		<0.06	-		1.03	59	UT	13.25	50	UT	14.30	155	UT	8257	106.98	11.52	11.56:	65	
NGC 0693	1	F01479+0553		01:50:30.9	+06:08:43	148.34	-63.79		0.24	41	UT	0.55	59	UT	6.74	43	UT	11.83	136	UT	1593	21.21	9.86	9.96	535	

EXAMPLE - STAR FORMING GALAXIES

- Believe that star-formation leads to supernovae, and that supernovae produce gamma-rays:

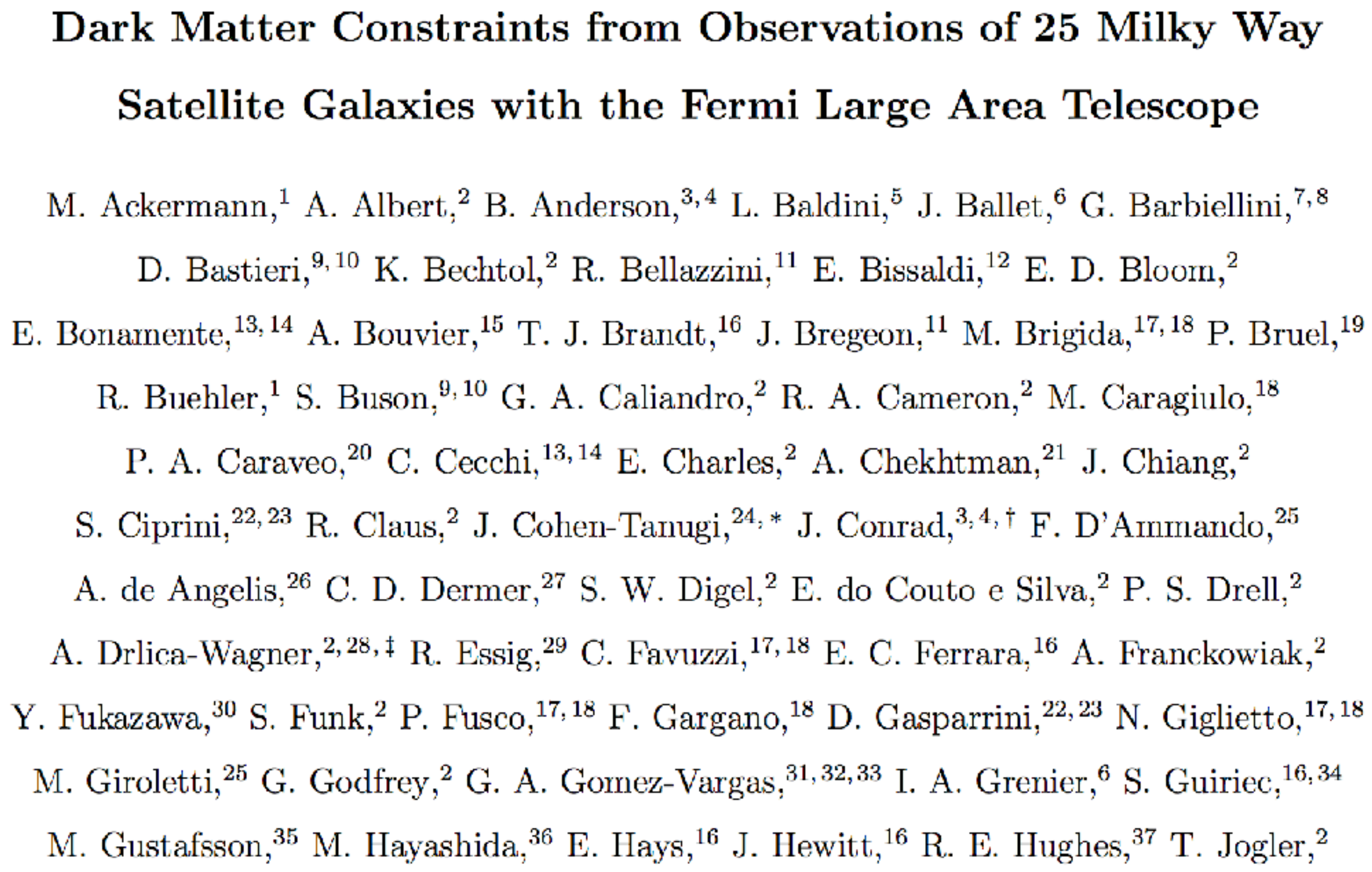
$$\log_{10}\left(\frac{L_\gamma}{\mathrm{erg\ s^{-1}}}\right) = \alpha \log_{10}\left(\frac{L_{IR}}{10^{10} L_\odot}\right) + \beta$$

- If there is uncertainty in the efficiency of gamma-ray production from star formation:

$$P_c\left(L_{\gamma,c}\right) = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{\log(L_{\gamma,c}) - \alpha \log L_{IR} - \beta}{2\sigma^2}\right)$$

$$\phi_c = \frac{1}{4\pi d_{SFG}^2} L_{\gamma,c}$$

PREVIOUS METHOD (ACKERMANN ET AL. 2014 + MANY OTHERS)

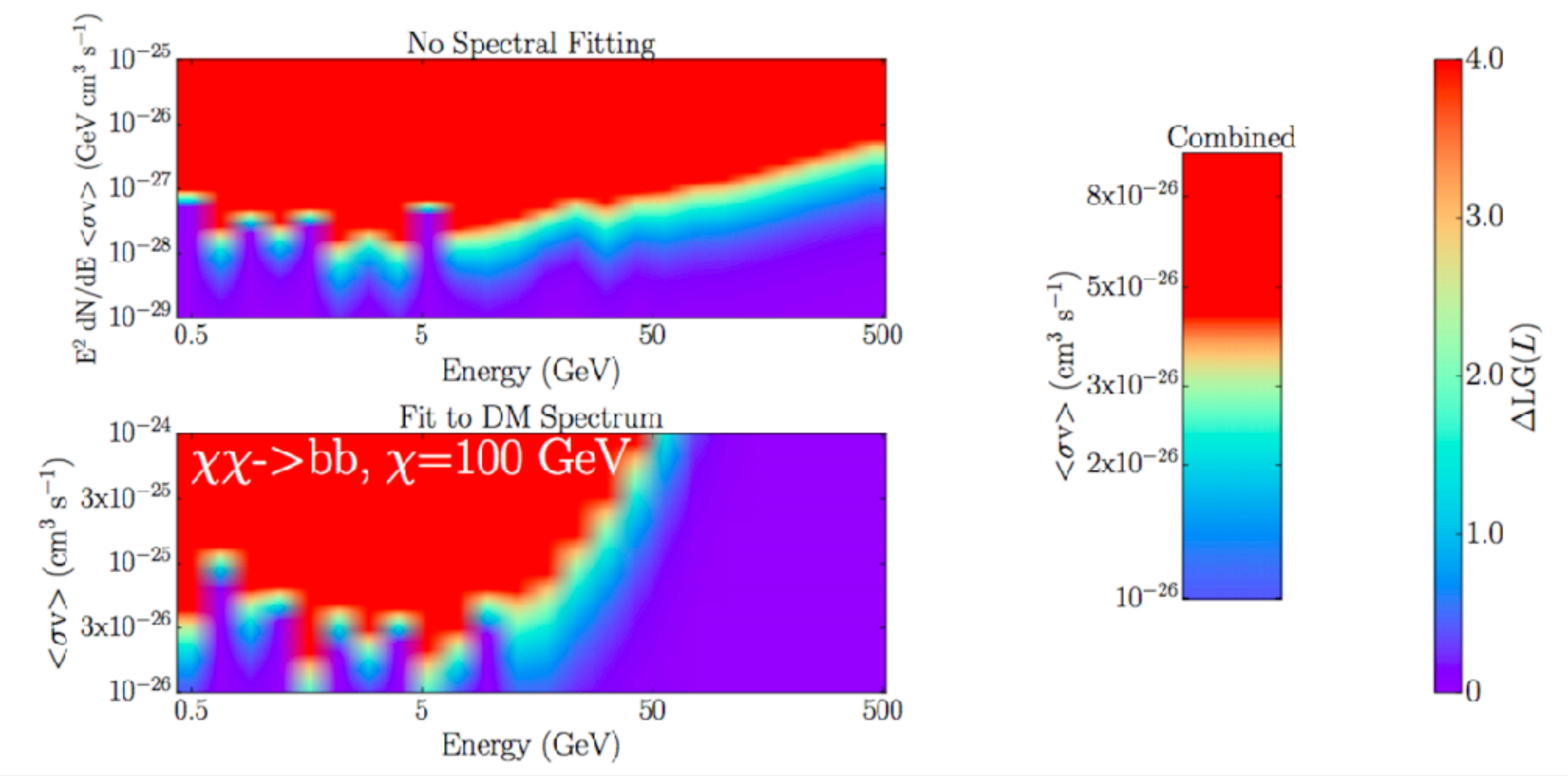


Dark Matter Constraints from Observations of 25 Milky Way Satellite Galaxies with the Fermi Large Area Telescope

M. Ackermann,[1] A. Albert,[2] B. Anderson,[3,4] L. Baldini,[5] J. Ballet,[6] G. Barbiellini,[7,8]
D. Bastieri,[9,10] K. Bechtol,[2] R. Bellazzini,[11] E. Bissaldi,[12] E. D. Bloom,[2]
E. Bonamente,[13,14] A. Bouvier,[15] T. J. Brandt,[16] J. Bregeon,[11] M. Brigida,[17,18] P. Bruel,[19]
R. Buehler,[1] S. Buson,[9,10] G. A. Caliandro,[2] R. A. Cameron,[2] M. Caragiulo,[18]
P. A. Caraveo,[20] C. Cecchi,[13,14] E. Charles,[2] A. Chekhtman,[21] J. Chiang,[2]
S. Ciprini,[22,23] R. Claus,[2] J. Cohen-Tanugi,[24,*] J. Conrad,[3,4,†] F. D'Ammando,[25]
A. de Angelis,[26] C. D. Dermer,[27] S. W. Digel,[2] E. do Couto e Silva,[2] P. S. Drell,[2]
A. Drlica-Wagner,[2,28,‡] R. Essig,[29] C. Favuzzi,[17,18] E. C. Ferrara,[16] A. Franckowiak,[2]
Y. Fukazawa,[30] S. Funk,[2] P. Fusco,[17,18] F. Gargano,[18] D. Gasparrini,[22,23] N. Giglietto,[17,18]
M. Giroletti,[25] G. Godfrey,[2] G. A. Gomez-Vargas,[31,32,33] I. A. Grenier,[6] S. Guiriec,[16,34]
M. Gustafsson,[35] M. Hayashida,[36] E. Hays,[16] J. Hewitt,[16] R. E. Hughes,[37] T. Jogler,[2]

PREVIOUS METHOD (ACKERMANN ET AL. 2014 + MANY OTHERS)

Carpenter et al. 2016



- First Fit the Flux of a Individual point source in a number of energy bin, assuming a given spectrum.

PREVIOUS METHOD (ACKERMANN ET AL. 2014 + MANY OTHERS)

$$\mathrm{TS} = -2\ln\left(\frac{\mathcal{L}(\boldsymbol{\mu}_0, \hat{\boldsymbol{\theta}} \,|\, \mathcal{D})}{\mathcal{L}(\hat{\boldsymbol{\mu}}, \hat{\boldsymbol{\theta}} \,|\, \mathcal{D})}\right).$$

null $(\boldsymbol{\mu} = \boldsymbol{\mu}_0)$

alternative hypotheses $(\boldsymbol{\mu} = \hat{\boldsymbol{\mu}})$

- Calculate the improvement in log-likelihood by adding a source with a given flux at a specific sky position.

$$\phi_s(\Delta\Omega) = \underbrace{\frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{\mathrm{DM}}^2}\int_{E_{\min}}^{E_{\max}}\frac{\mathrm{d}N_\gamma}{\mathrm{d}E_\gamma}\mathrm{d}E_\gamma}_{\Phi_{\mathrm{PP}}} \cdot \underbrace{\int_{\Delta\Omega}\left\{\int_{\mathrm{l.o.s.}}\rho^2(\boldsymbol{r})\mathrm{d}l\right\}\mathrm{d}\Omega'}_{\text{J-factor}}$$

- Assume a particle physics model (blue)

improvement in fit from adding a dwarf with a given flux

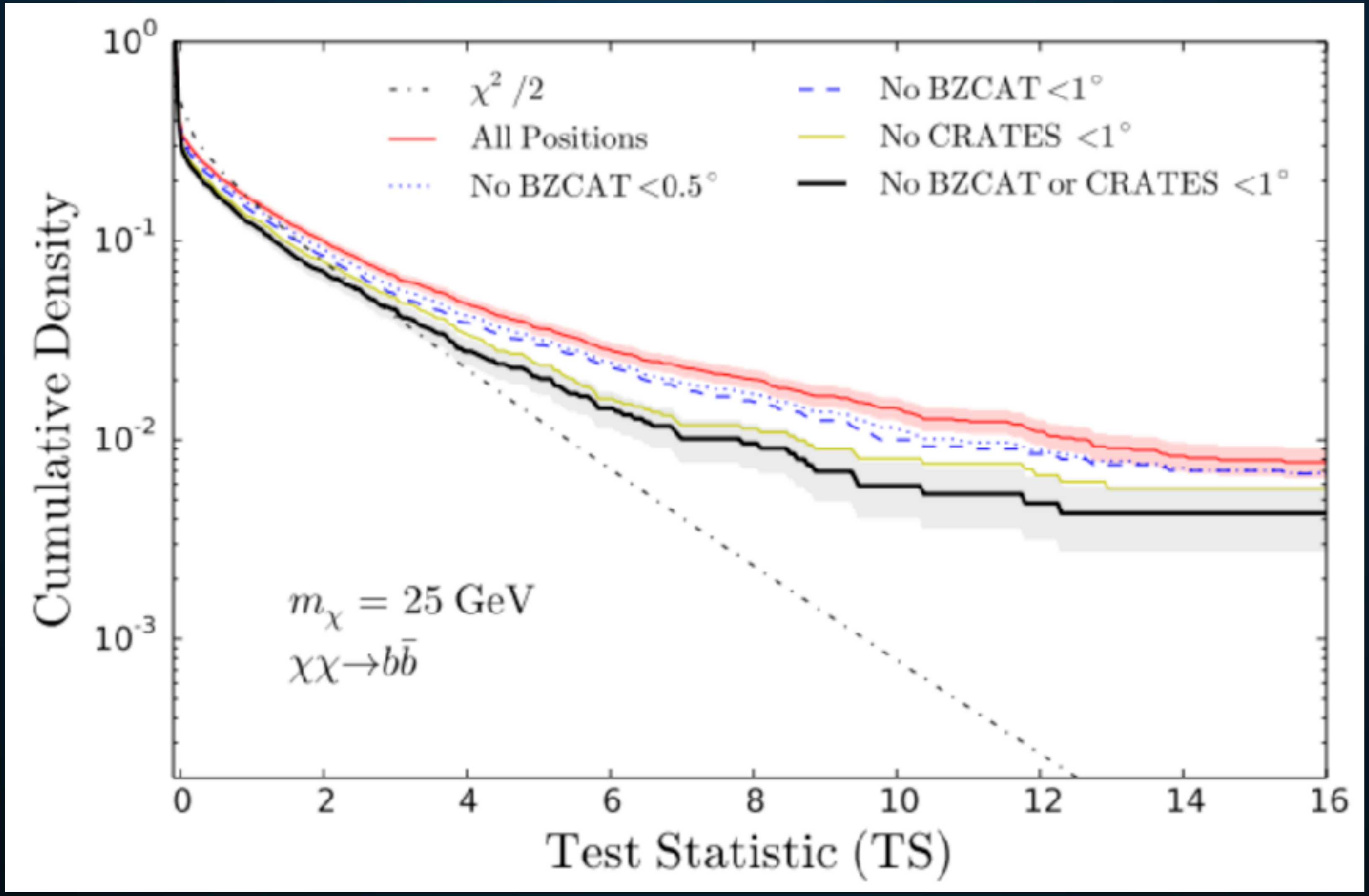
$$\tilde{\mathcal{L}}_i(\boldsymbol{\mu}, \boldsymbol{\alpha}_i \,|\, \mathcal{D}_i) = \mathcal{L}_i(\boldsymbol{\mu}, \hat{\boldsymbol{\theta}}_i \,|\, \mathcal{D}_i) \times \frac{1}{\ln(10) J_i \sqrt{2\pi}\sigma_i} e^{-(\log_{10}(J_i) - \overline{\log_{10}(J_i)})^2/2\sigma_i^2}$$

cost from modifying the J-factor of the dwarf to accommodate that flux in a certain model

PREVIOUS METHOD (ACKERMANN ET AL. 2014 + MANY OTHERS)

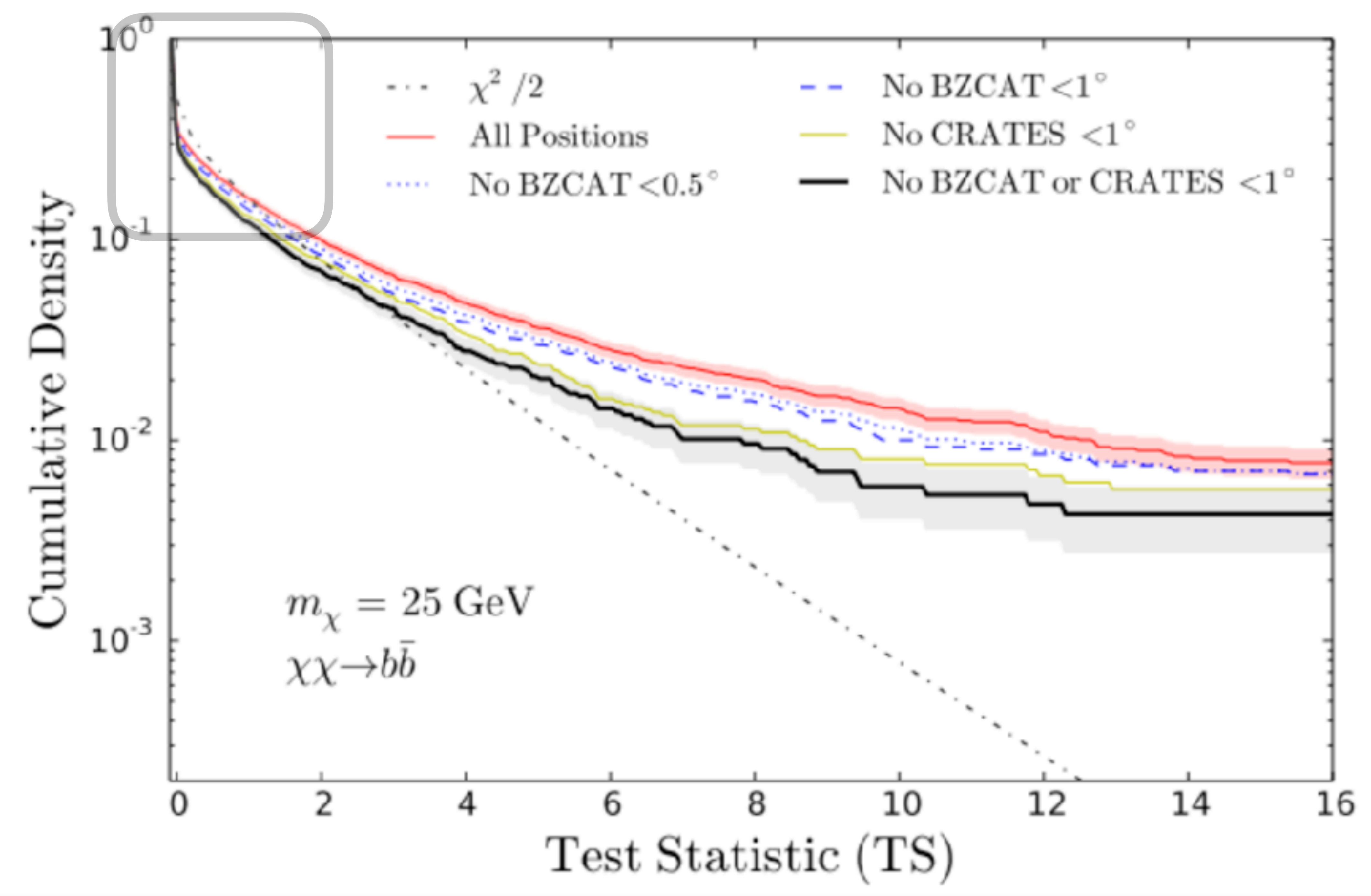
$$\tilde{\mathcal{L}}(\boldsymbol{\mu}, \{\boldsymbol{\alpha}_i\} \,|\, \mathcal{D}) = \prod_i \tilde{\mathcal{L}}_i(\boldsymbol{\mu}, \boldsymbol{\alpha}_i \,|\, \mathcal{D}_i)$$

- **Find the total likelihood as the product of the individual likelihoods, and then correlate with a given probability by comparing with blank sky locations:**



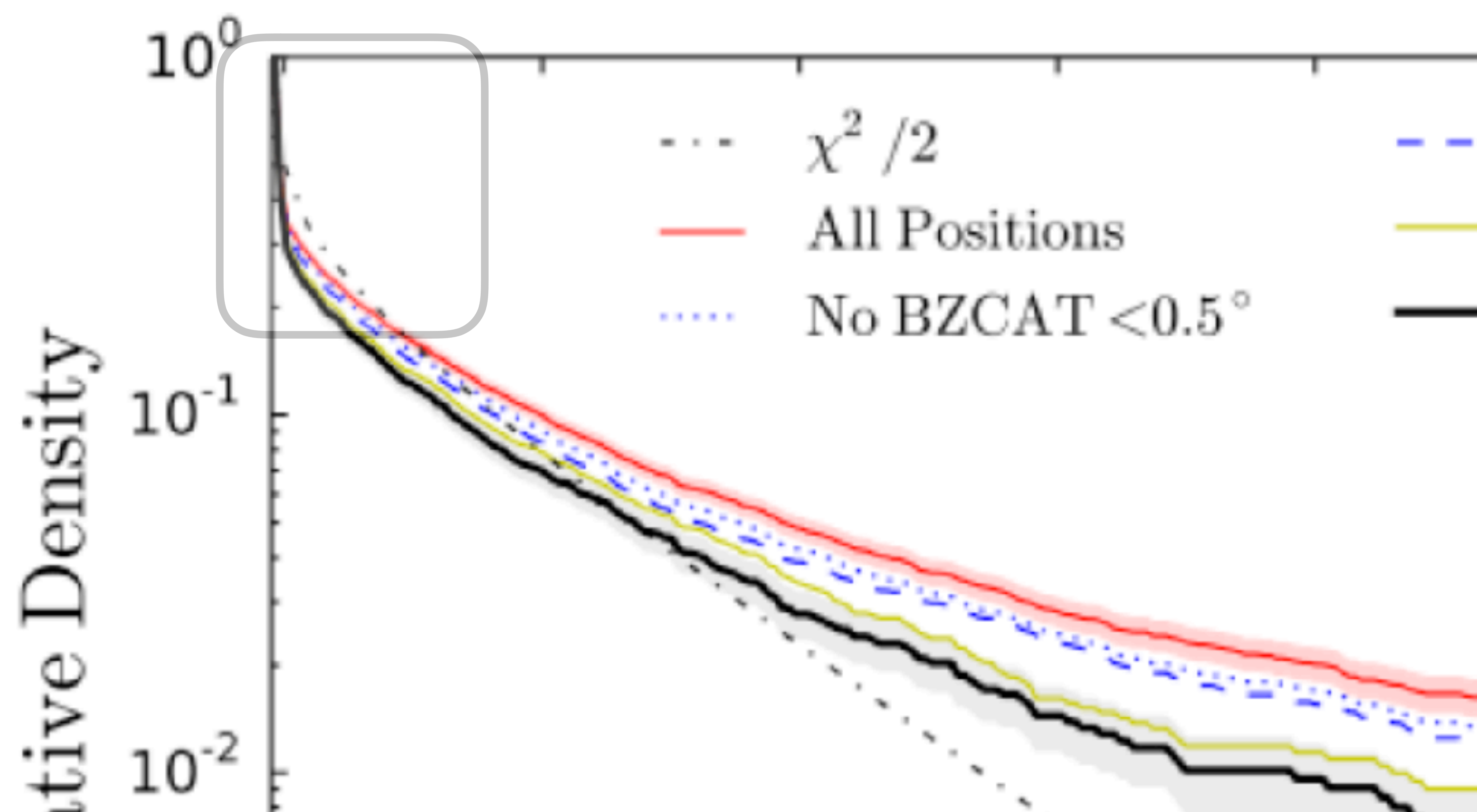
NEGATIVE BACKGROUND FLUCTUATIONS

- **Another problem with this model is seen for the 50% of sources with almost no TS.**



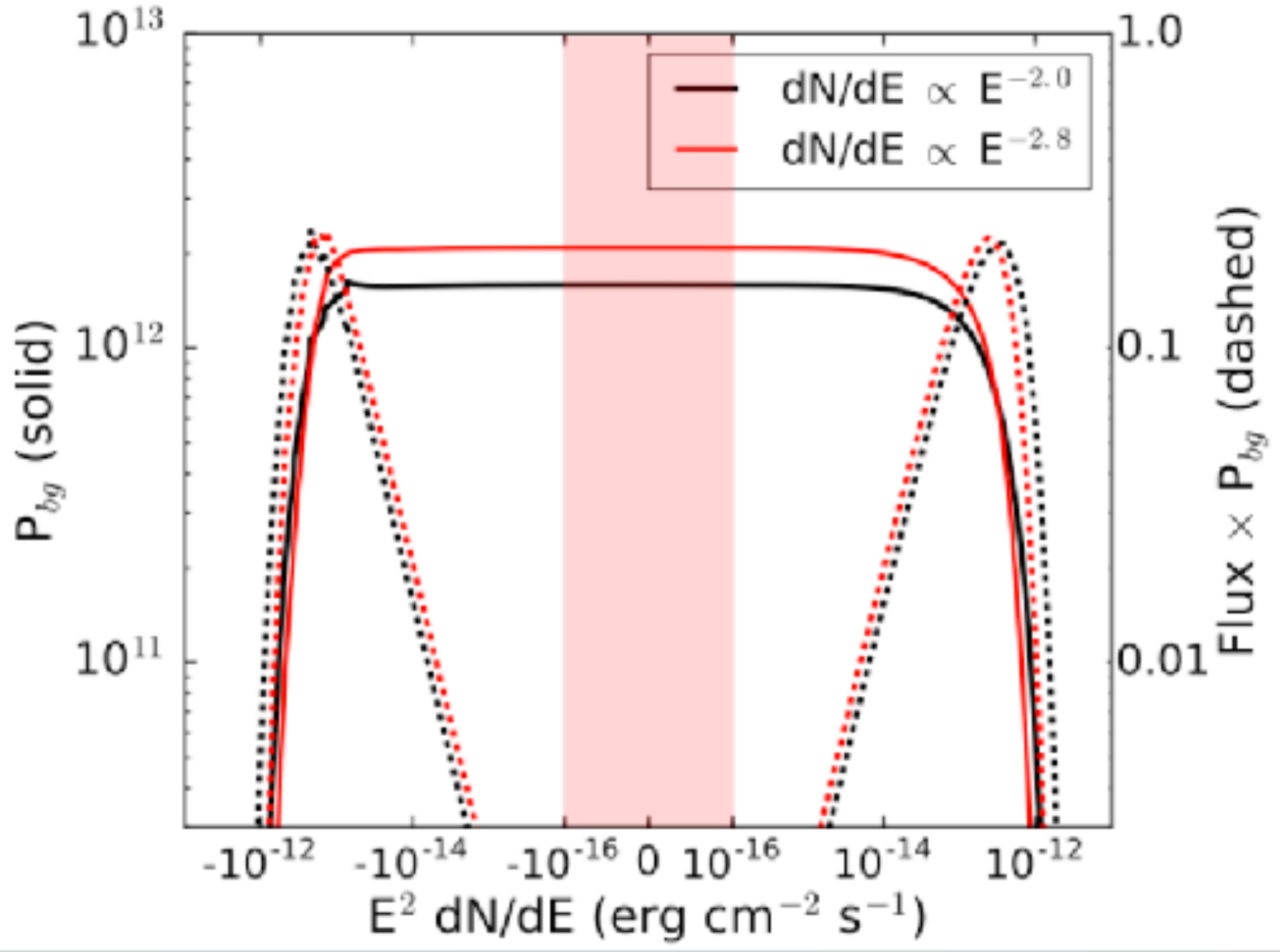
NEGATIVE BACKGROUND FLUCTUATIONS

- **Another problem with this model is seen for the 50% of sources with almost no TS.**



DIFFICULTIES: NEGATIVE BACKGROUND FLUCTUATIONS

- Background fluctuations are almost as likely to be negative as positive.
- These background fluxes can be much brighter than individual sources – which will then appear to have no flux.



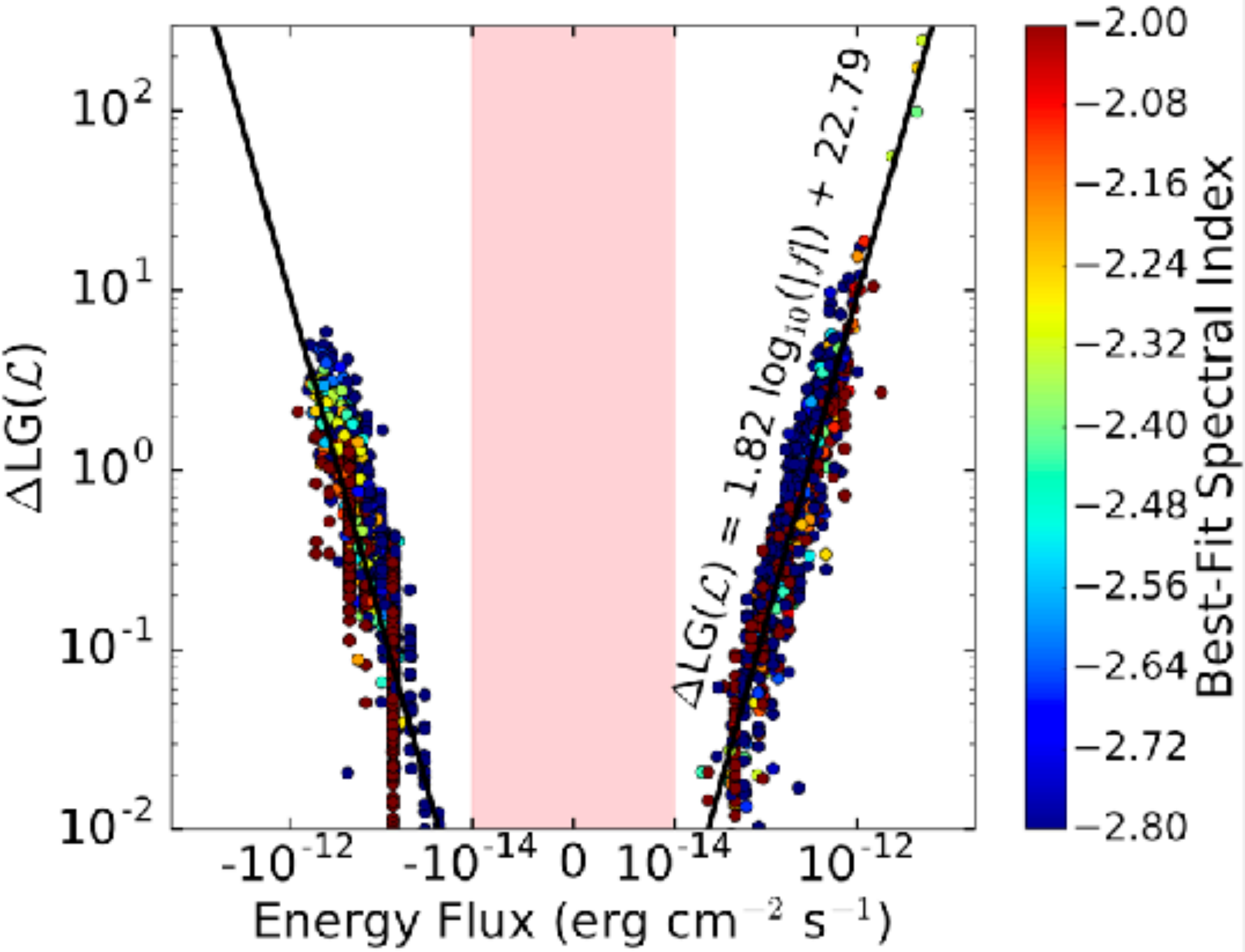
- Need a solution that can find a correlation even in the limit of significant negative background fluctuations.

CORRELATION BETWEEN FLUX AND LG(L)

- TS is a photon counting statistic:

$$P(k \text{ events in interval}) = e^{-\lambda}\frac{\lambda^k}{k!}$$

- The LG(L) change produced by a point-source scales directly with its flux.

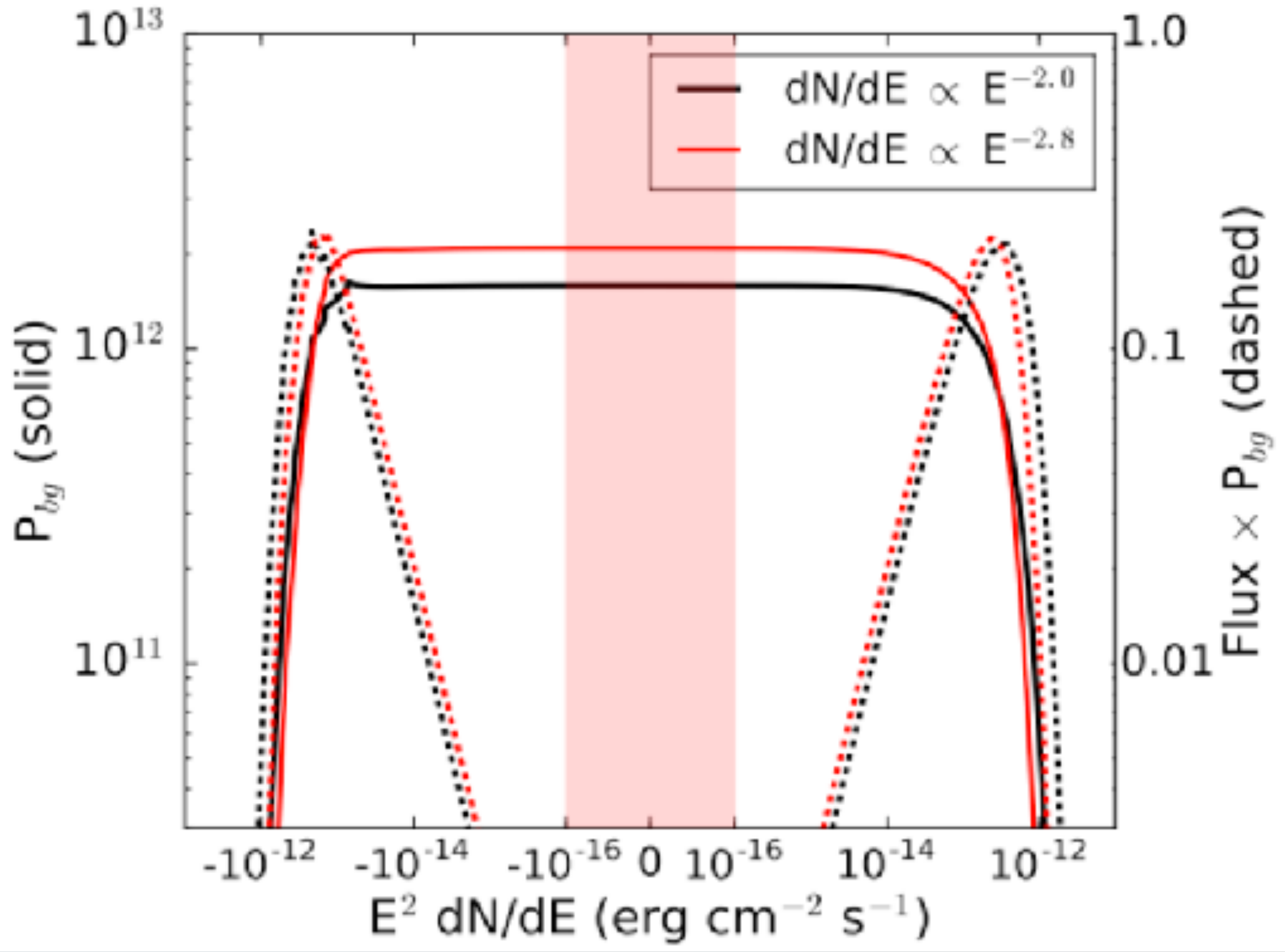


- Can compute the correlation between fluxes and LG(L) and compute the likelihood of having a point source at a specific value directly in flux space.
- Don’t need to directly use this relation.

CORRELATION BETWEEN FLUX AND LG(L)

- The probability of having a background sky location with a given flux is:

$$P_{bg}(\phi_{bg}) = \frac{1}{N}\sum_i A_i \exp\left(-\mathrm{LG}(\mathcal{L}(\phi_{bg}))\right)$$



- Can go through and test the point source flux at each sky position for every possible choice of background fluctuation.

CORRELATION BETWEEN FLUX AND LG(L)

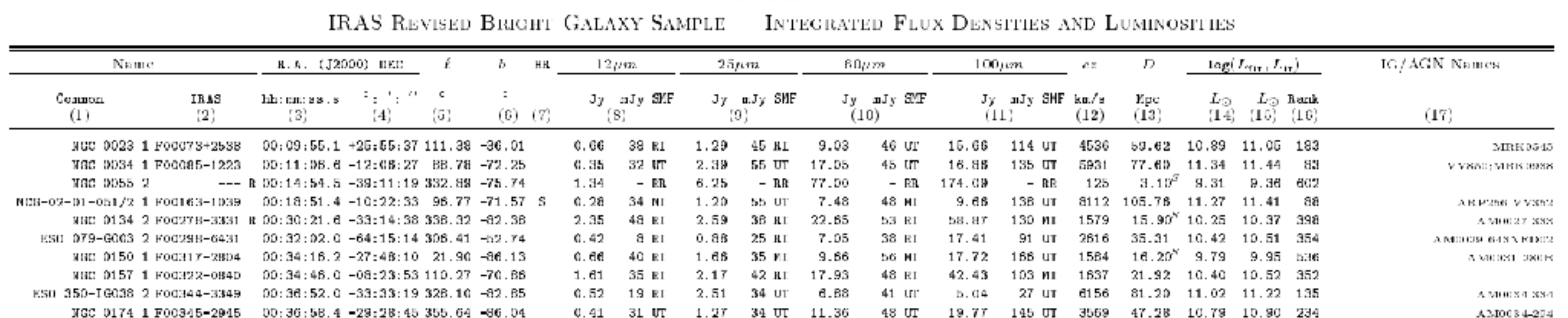
- While the probability of having a source with a given flux comes from the correlation function:

$$\log_{10}\left(\frac{L_\gamma}{\text{erg s}^{-1}}\right) = \alpha \log_{10}\left(\frac{L_{IR}}{10^{10} L_\odot}\right) + \beta$$

- And can be calculated by:

$$P_c\left(L_{\gamma,c}\right) = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{\log(L_{\gamma,c}) - \alpha \log L_{IR} - \beta}{2\sigma^2}\right)$$

$$\phi_c = \frac{1}{4\pi d_{SFG}^2} L_{\gamma,c}$$



IRAS Revised Bright Galaxy Sample Integrated Flux Densities and Luminosities

Name				R.A. (J2000)	DEC	ℓ	b	RR	12μm			25μm			60μm			100μm			cz	D	log(L_{FIR}, L_{IR})			IG/AGN Names
Common (1)		IRAS (2)		hh:mm:ss.s (3)	°:′:″ (4)	° (5)	° (6)	(7)	Jy (8)	mJy	SMF	Jy (9)	mJy	SMF	Jy (10)	mJy	SMF	Jy (11)	mJy	SMF	km/s (12)	Mpc (13)	$L_\odot$ (14)	$L_\odot$ (15)	Rank (16)	(17)
NGC 0023	1	F00073+2538		00:09:55.1	+25:55:37	111.38	-36.01		0.66	38	RI	1.29	45	RI	9.03	46	UT	15.66	114	UT	4536	59.62	10.89	11.05	183	MRK0545
NGC 0034	1	F00085-1223		00:11:06.6	-12:06:27	88.78	-72.25		0.35	32	UT	2.39	55	UT	17.05	45	UT	16.86	135	UT	5931	77.60	11.34	11.44	83	VV850;MRK0938
NGC 0055	2	---	R	00:14:54.5	-39:11:19	332.88	-75.74		1.34	-	RR	6.25	-	RR	77.00	-	RR	174.09	-	RR	125	3.10^{S}	9.31	9.36	602	
MCG-02-01-051/2	1	F00163-1039		00:18:51.4	-10:22:33	96.77	-71.57	S	0.28	34	MI	1.20	55	UT	7.48	48	MI	9.68	138	UT	8112	105.78	11.27	11.41	88	ARP256 VV352
NGC 0134	2	F00278-3331	R	00:30:21.6	-33:14:38	338.32	-82.36		2.35	48	RI	2.59	36	RI	22.65	53	RI	58.87	130	MI	1579	15.90^{N}	10.25	10.37	398	AM0027-333
ESO 079-G003	2	F00298-6431		00:32:02.0	-64:15:14	306.41	-52.74		0.42	8	RI	0.88	25	RI	7.05	38	RI	17.41	91	UT	2616	35.31	10.42	10.51	354	AM0030-643 KDG2
NGC 0150	1	F00317-2804		00:34:16.2	-27:48:10	21.90	-86.13		0.66	40	RI	1.68	35	MI	9.66	56	MI	17.72	166	UT	1584	16.20^{N}	9.79	9.95	536	AM0031-280B
NGC 0157	1	F00322-0840		00:34:46.0	-08:23:53	110.27	-70.86		1.61	35	RI	2.17	42	RI	17.93	48	RI	42.43	103	MI	1637	21.92	10.40	10.52	352	
ESO 350-IG038	2	F00344-3349		00:36:52.0	-33:33:19	328.10	-82.85		0.52	19	RI	2.51	34	UT	6.88	41	UT	5.04	27	UT	6156	81.20	11.02	11.22	135	AM0034-334
NGC 0174	1	F00345-2945		00:36:58.4	-29:28:45	355.64	-86.04		0.41	31	UT	1.27	34	UT	11.36	48	UT	19.77	145	UT	3569	47.28	10.79	10.90	234	AM0034-294

CORRELATION BETWEEN FLUX AND LG(L)

- **Then the total probability of some correlation with {α,β,σ}**

product over all SFGs

Probability of a given flux from the background and point source improving the fit to the data

$$P(\alpha,\beta,\sigma) = \prod_j \int_{-\infty}^{\infty}\int_{0}^{\infty} \exp(-\mathrm{LG}(\mathcal{L}(\phi_c+\phi_{bg})))\times$$
$$\times\, P_{bg}(\phi_{\gamma,bg})\, P_c\,(\phi_c,\alpha,\beta,\sigma)\; \mathrm{d}\phi_{\mathrm{c}}\, \mathrm{d}\phi_{\mathrm{bg}}$$

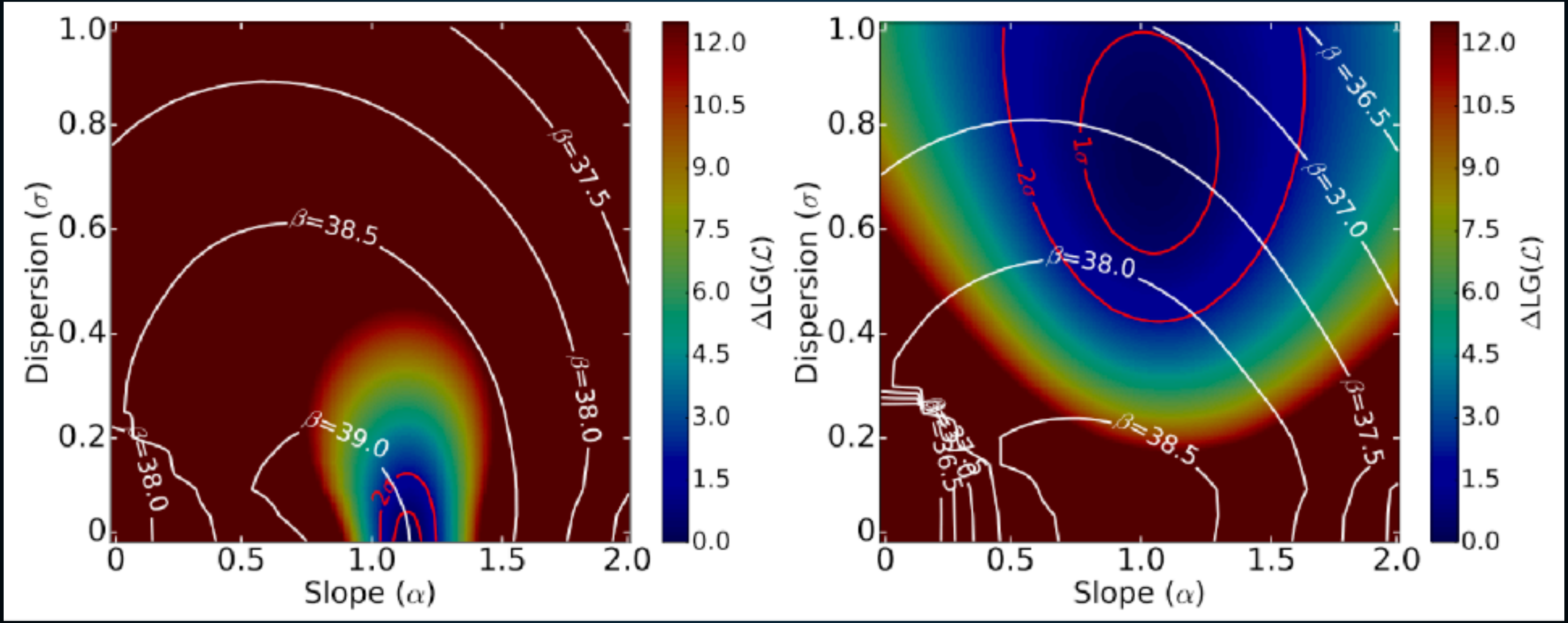
probability of this background fluctuation

probability of this point source flux.

CORRELATION BETWEEN FLUX AND LG(L)

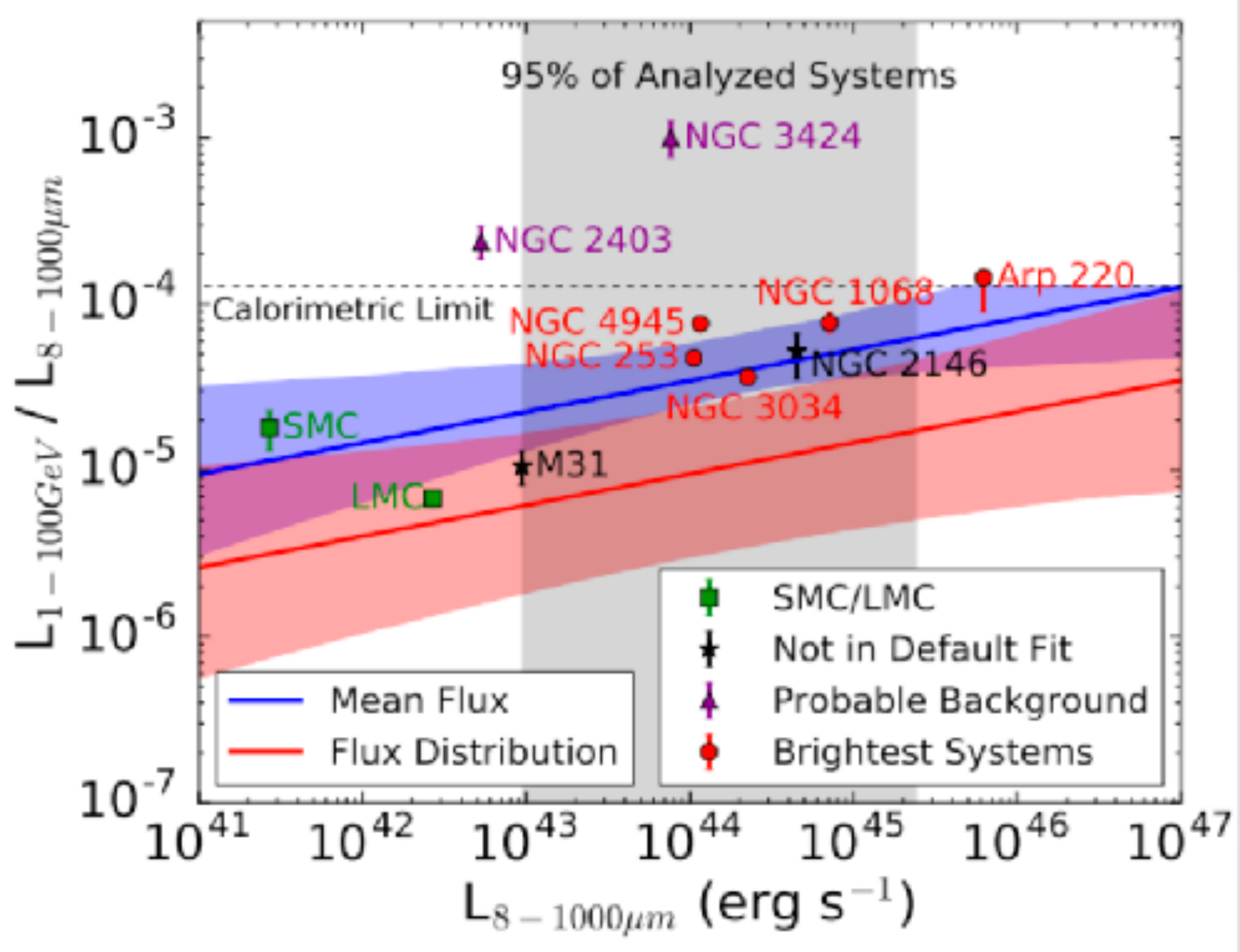
- **Injected signal with:**

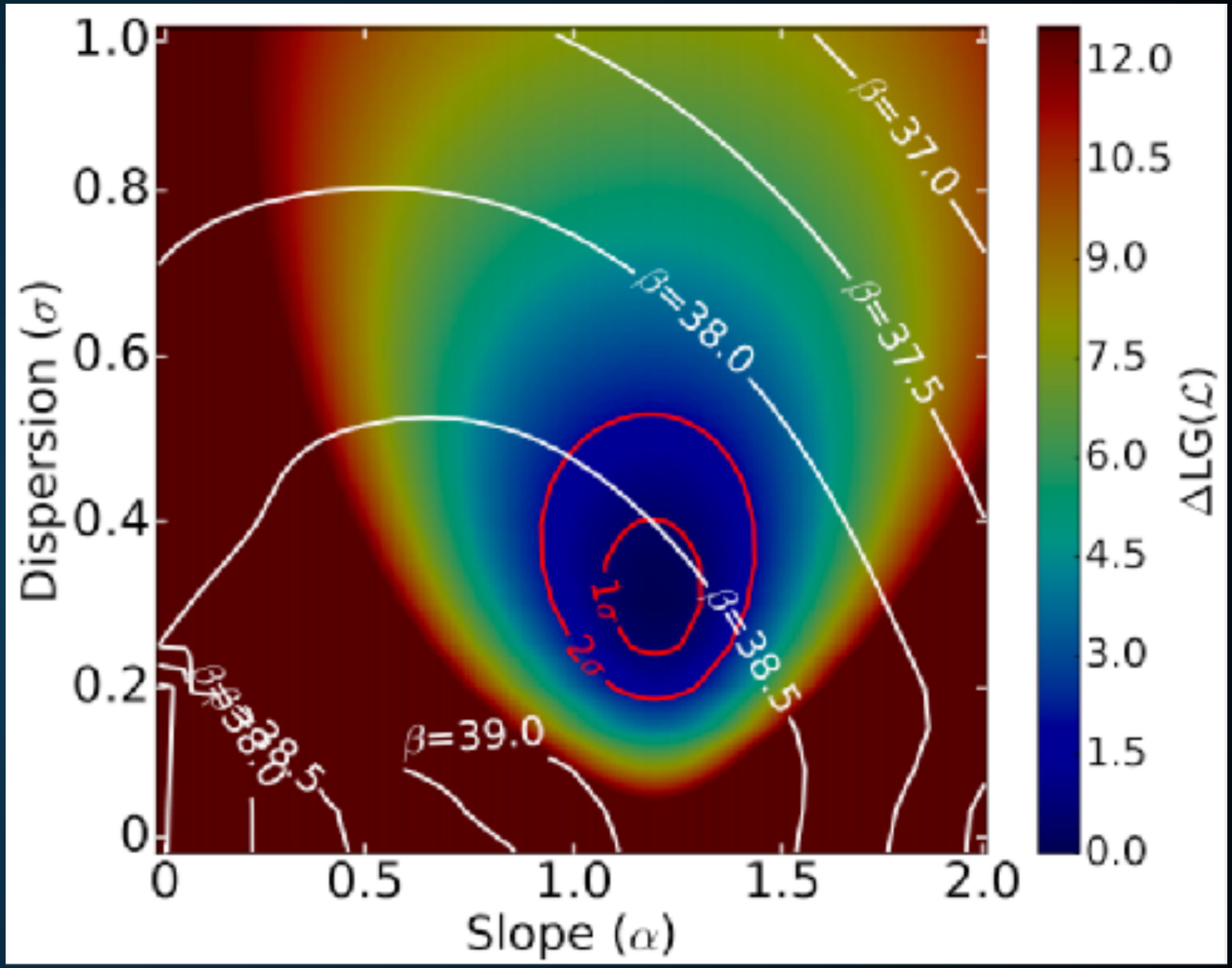
$$\log_{10}(L_\gamma\ /\ (\mathrm{erg\ s^{-1}})) = 1.17\ \log_{10}(L_{IR}/\ 10^{10}L_\odot) + 38.985$$



RESULTS

- Looking at science results momentarily:

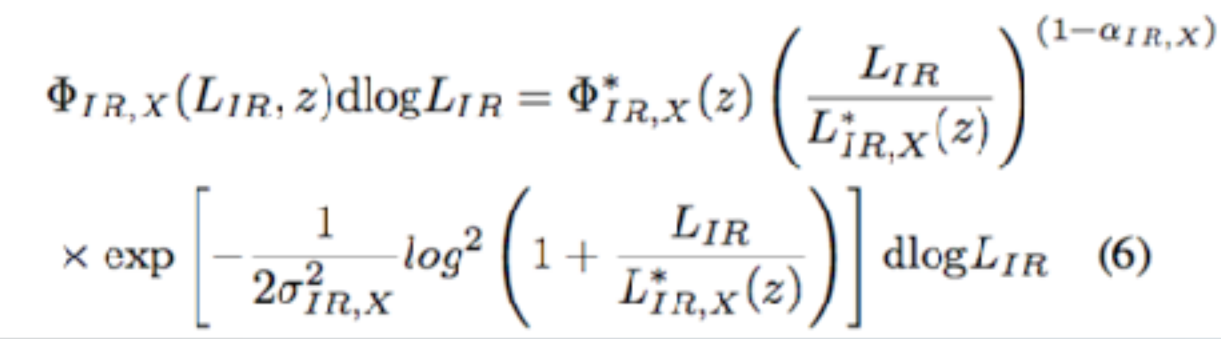




- Have a model that predicts the luminosities of the brightest star forming galaxies, while remaining consistent with the population of dimmer systems.

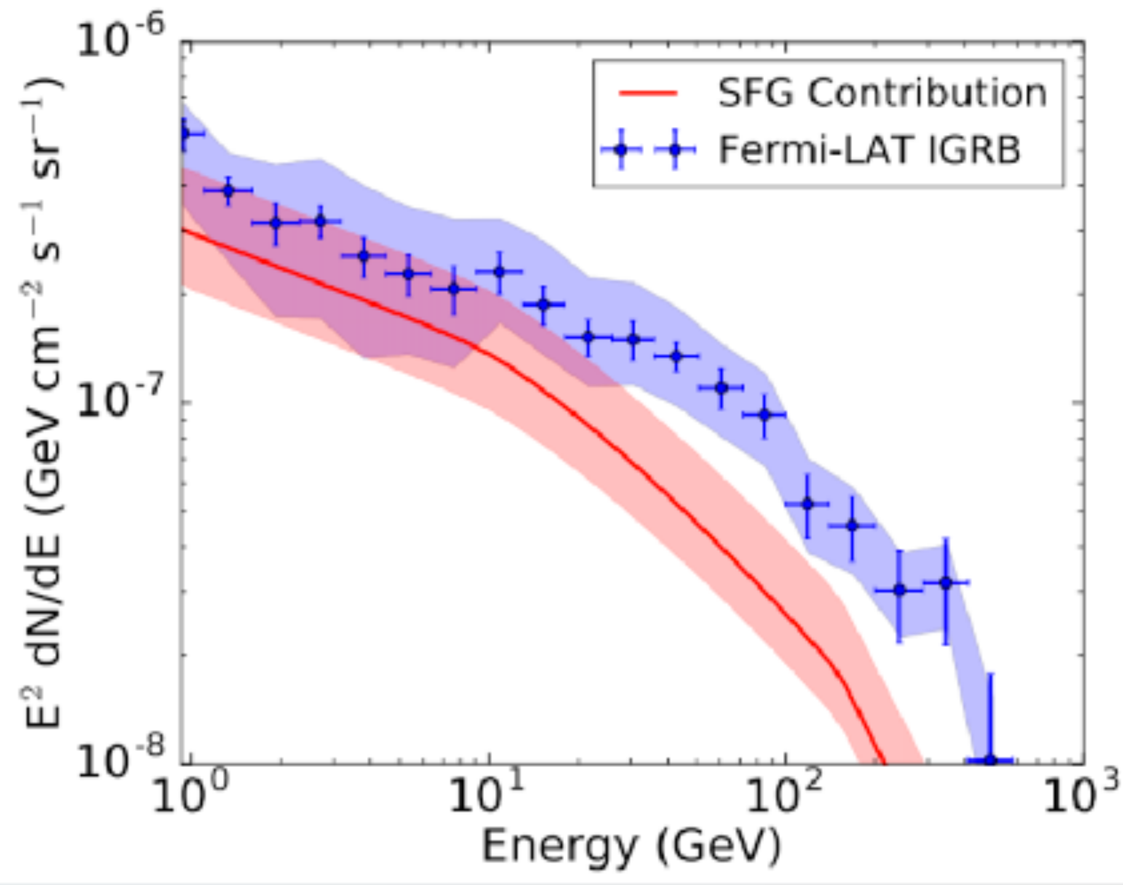
EXTRAPOLATION TO DIM SOURCES

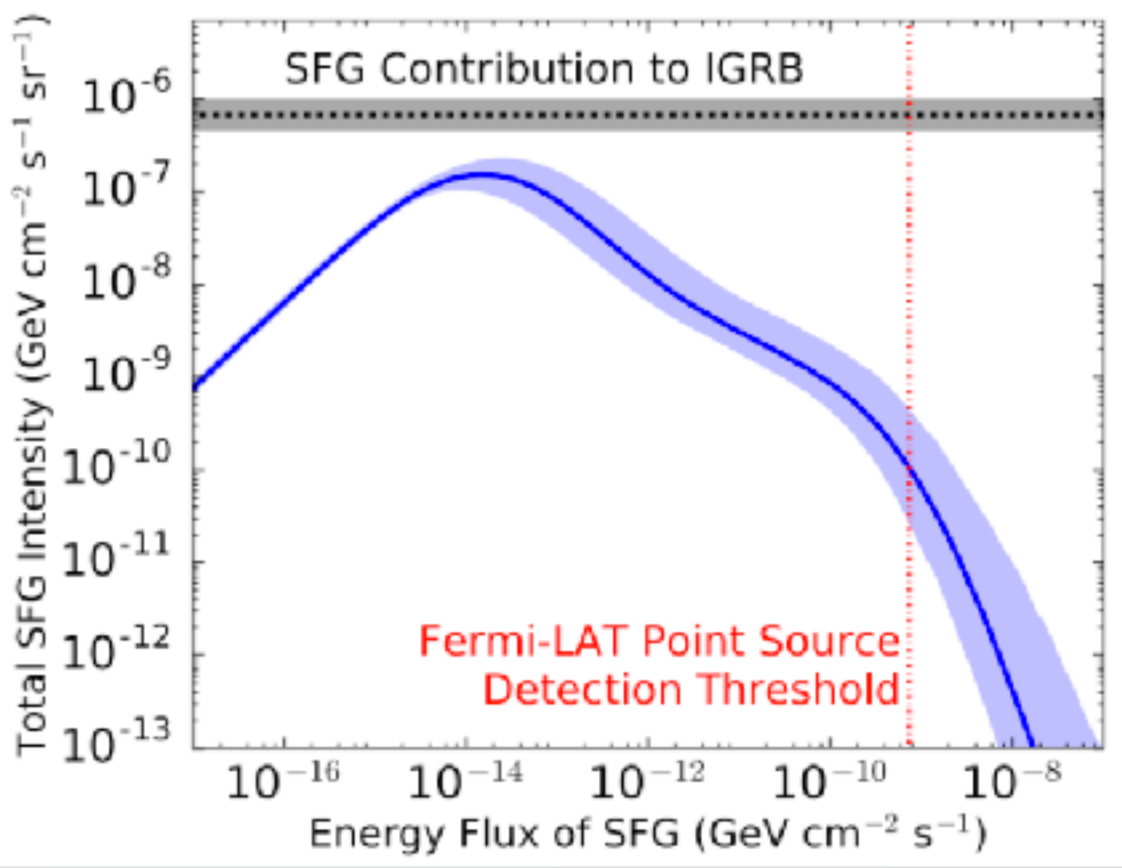
- Extrapolation to dim point sources in FIR observations:



$$\Phi_{IR,X}(L_{IR},z)\,\mathrm{dlog}L_{IR} = \Phi^*_{IR,X}(z)\left(\frac{L_{IR}}{L^*_{IR,X}(z)}\right)^{(1-\alpha_{IR,X})} \times \exp\left[-\frac{1}{2\sigma^2_{IR,X}}log^2\left(1+\frac{L_{IR}}{L^*_{IR,X}(z)}\right)\right]\mathrm{dlog}L_{IR} \qquad (6)$$

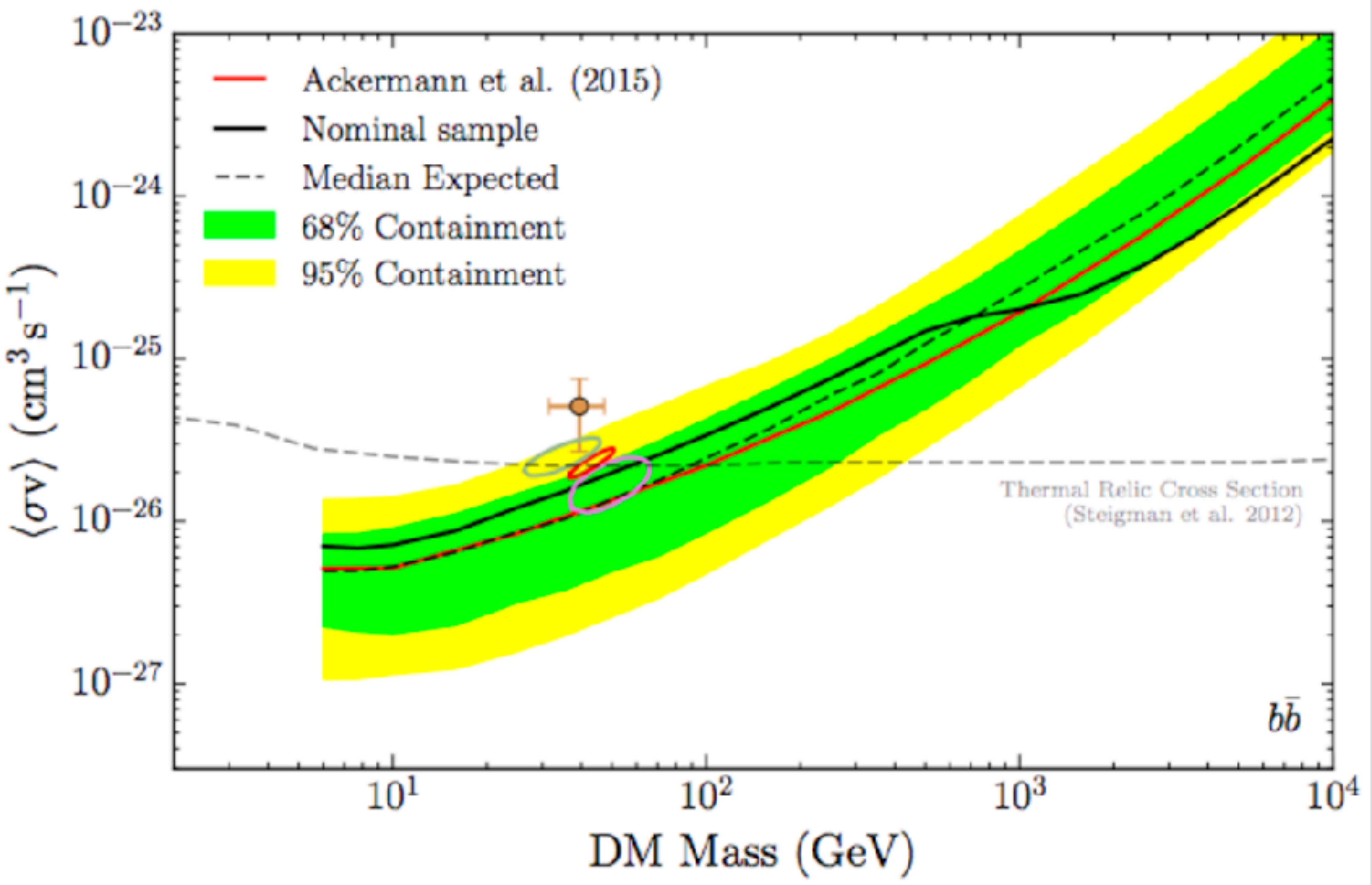
- We can now calculate the total contribution of all star-forming galaxies to the totally isotropic gamma-ray flux.





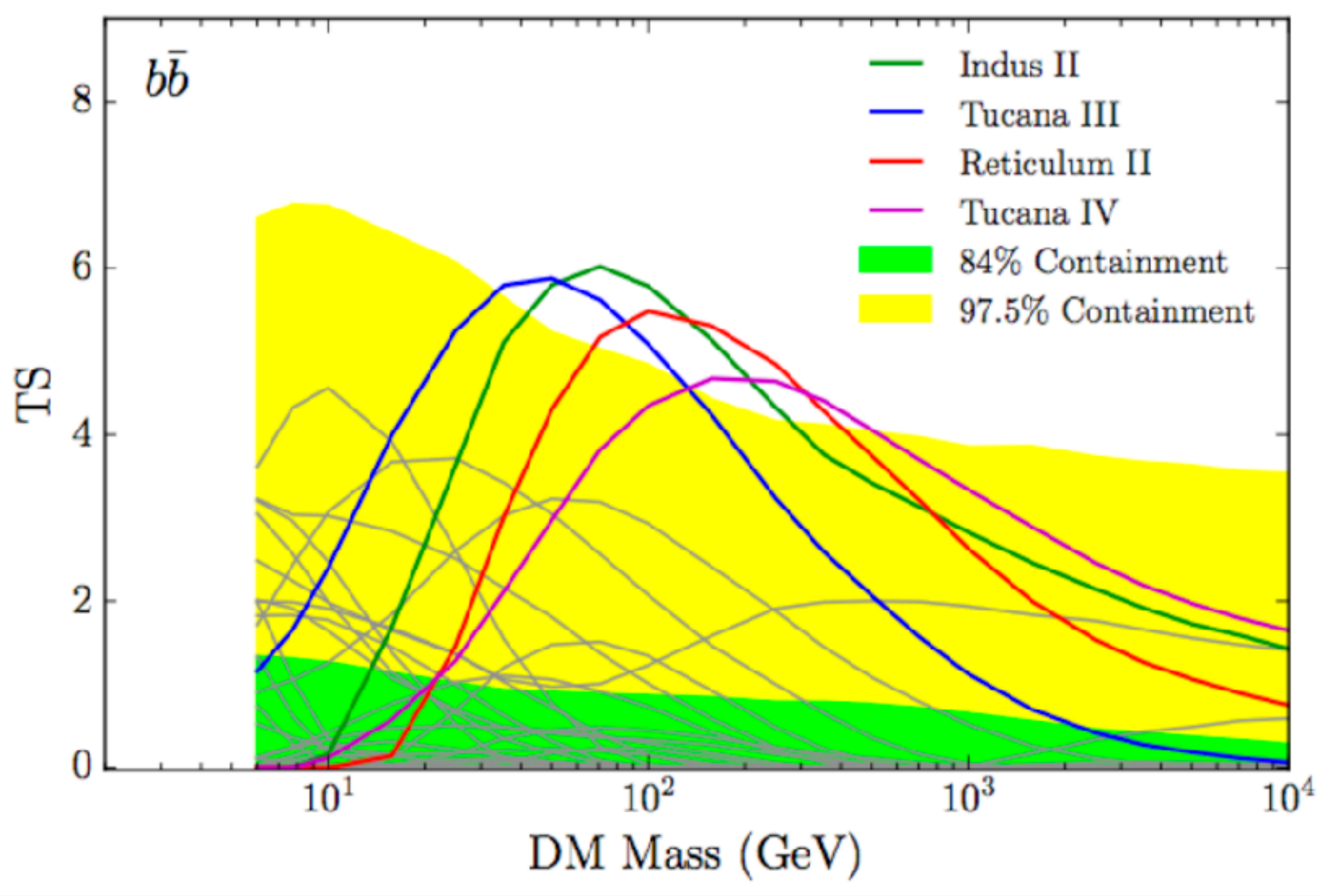
DWARF SPHEROIDAL GALAXIES

- Transferring this analysis to dwarf galaxies is straightforward.
- Analysis potentially has a very high impact



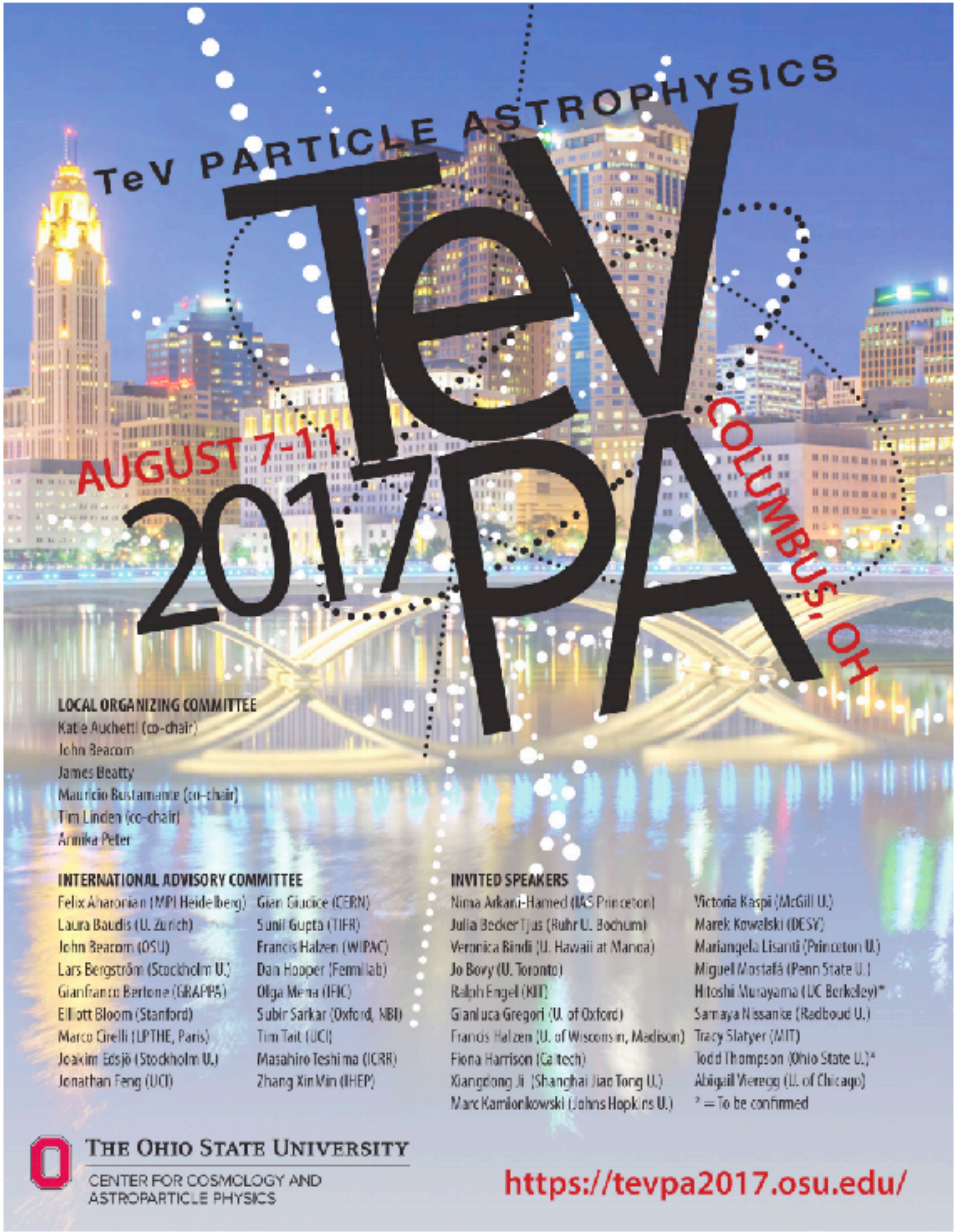
DWARF SPHEROIDAL GALAXIES

- **Transferring this analysis to dwarf galaxies is straightforward.**
- **Analysis potentially has a very high impact**



TeVPA 2017

tevpa2017.osu.edu



LOCAL ORGANIZING COMMITTEE

Katie Auchetti (co-chair)
John Beacom
James Beatty
Mauricio Bustamante (co-chair)
Tim Linden (co-chair)
Annika Peter

INTERNATIONAL ADVISORY COMMITTEE

Felix Aharonian (MPI Heidelberg)
Laura Baudis (U. Zurich)
John Beacom (OSU)
Lars Bergström (Stockholm U.)
Gianfranco Bertone (GRAPPA)
Elliott Bloom (Stanford)
Marco Cirelli (LPTHE, Paris)
Joakim Edsjö (Stockholm U.)
Jonathan Feng (UCI)
Gian Giudice (CERN)
Sunil Gupta (TIFR)
Francis Halzen (WIPAC)
Dan Hooper (Fermilab)
Olga Mena (IFIC)
Subir Sarkar (Oxford, NBI)
Tim Tait (UCI)
Masahiro Teshima (ICRR)
Zhang XinMin (IHEP)

INVITED SPEAKERS

Nima Arkani-Hamed (IAS Princeton)
Julia Becker Tjus (Ruhr U. Bochum)
Veronica Bindi (U. Hawaii at Manoa)
Jo Bovy (U. Toronto)
Ralph Engel (KIT)
Gianluca Gregori (U. of Oxford)
Francis Halzen (U. of Wisconsin, Madison)
Fiona Harrison (Caltech)
Xiangdong Ji (Shanghai Jiao Tong U.)
Marc Kamionkowski (Johns Hopkins U.)
Victoria Kaspi (McGill U.)
Marek Kowalski (DESY)
Mariangela Lisanti (Princeton U.)
Miguel Mostafá (Penn State U.)
Hitoshi Murayama (UC Berkeley)*
Samaya Nissanke (Radboud U.)
Tracy Slatyer (MIT)
Todd Thompson (Ohio State U.)*
Abigail Vieregg (U. of Chicago)
* = To be confirmed

THE OHIO STATE UNIVERSITY
CENTER FOR COSMOLOGY AND
ASTROPARTICLE PHYSICS

https://tevpa2017.osu.edu/

- August 7–11, Columbus, OH
- Registration and abstract submission are open
- Pre-meeting mini-workshops on Sunday, August 7

DISCUSSION AND CONCLUSIONS

- Some Challenges:
  - Still need to analyze blank sky locations
    - Extremely expensive
    - Only ~10^5 independent locations
  - How to deal with negative model expectations?
  - Need to assume that the flux/likelihood correlation is similar in blank sky locations and in sources.