
# Search for Spatially Extended *Fermi*-LAT Sources Using Two Years of Flight Data

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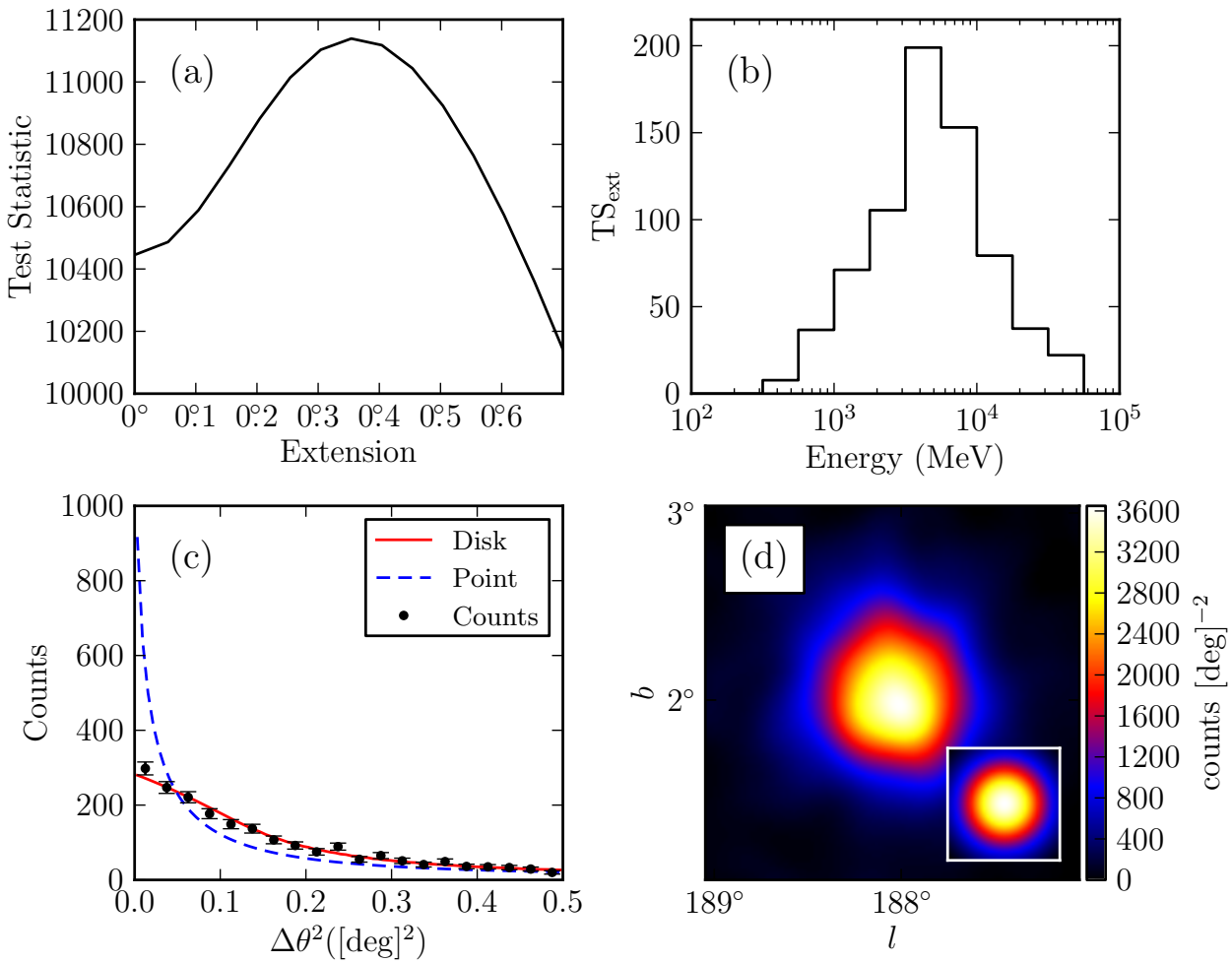
# Overview

- Category II Paper
- Contact Authors: J. Lande, M. Ackermann, S. Funk
- Full author list being finalized
- Internal Referees: Marianne Lemoine-Goumard and Johann Cohen-Tanugi
- Target Journal: ApJ
- Status (something about being submitted to internal referees XXXX)

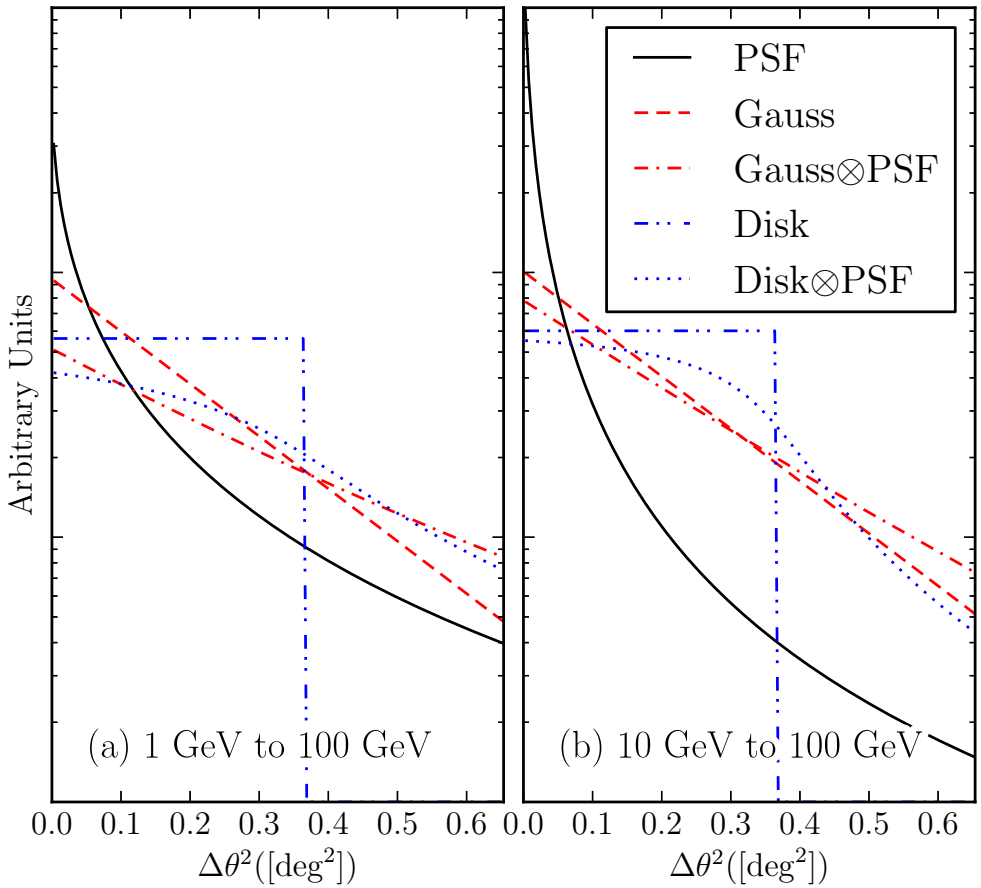
# Paper Outline

- Description/validation of a new method (`pointlike`) for analyzing extended sources.
- Calculation of the LAT's sensitivity to spatially extended sources
- Presentation of a new search for spatially extended sources:
  - reanalyzing the extension of the 12 extended sources in 2FGL
  - testing AGN from 2LAC for extension to validate the analysis
  - presenting on the discovery/interpretation of several new extended sources not in 2FGL.

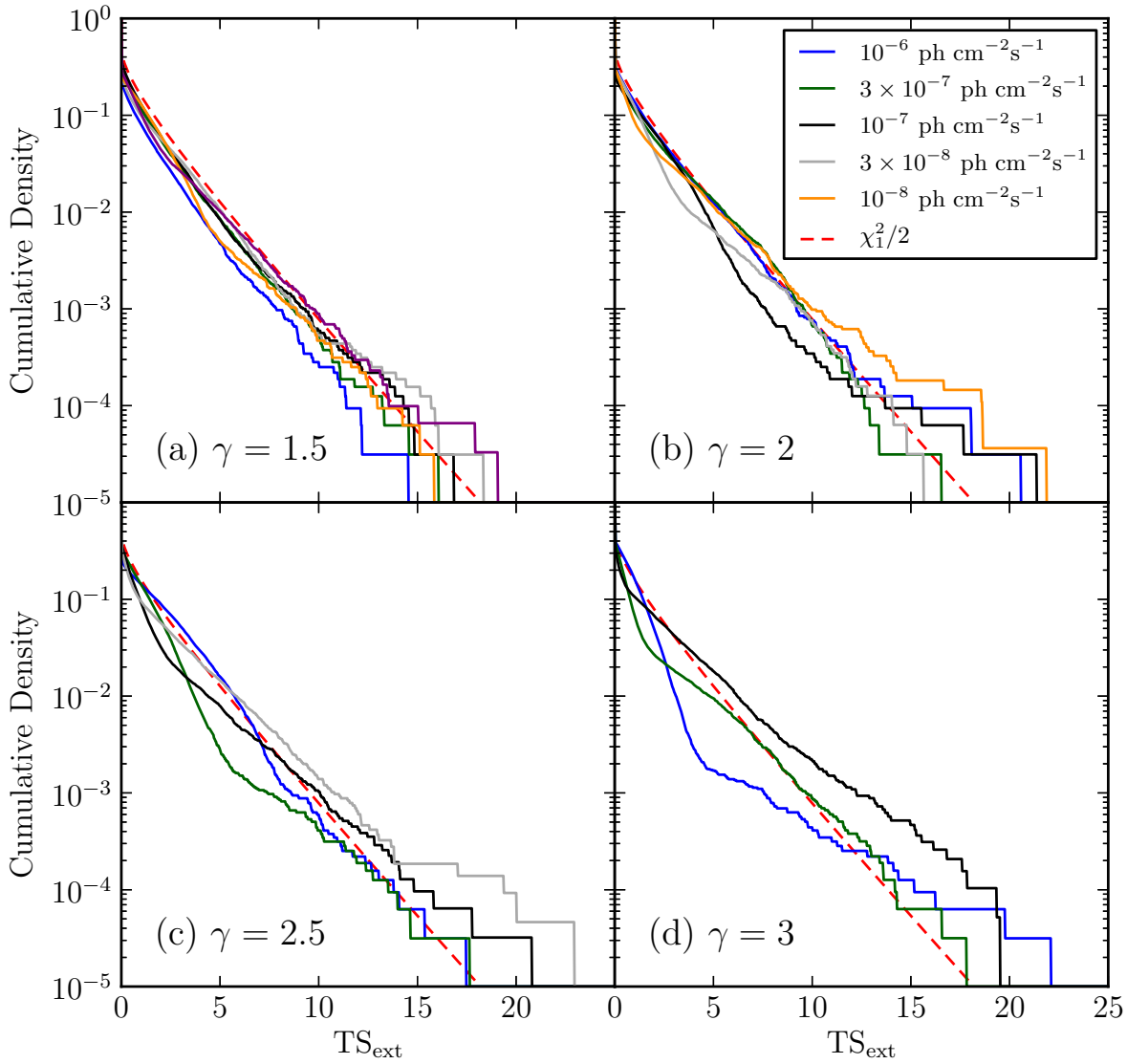
# Fig. 1


(a)
Test Statistic
Extension
11200
11000
10800
10600
10400
10200
10000
0°
0.1
0.2
0.3
0.4
0.5
0.6
(b)
TS$_{ext}$
Energy (MeV)
200
150
100
50
0
$10^2$
$10^3$
$10^4$
$10^5$
(c)
Disk
Point
Counts
Counts
$\Delta\theta^2$([deg]$^2$)
1000
800
600
400
200
0
0.0
0.1
0.2
0.3
0.4
0.5
(d)
$b$
$l$
3°
2°
189°
188°
3600
3200
2800
2400
2000
1600
1200
800
400
0
counts [deg]$^{-2}$

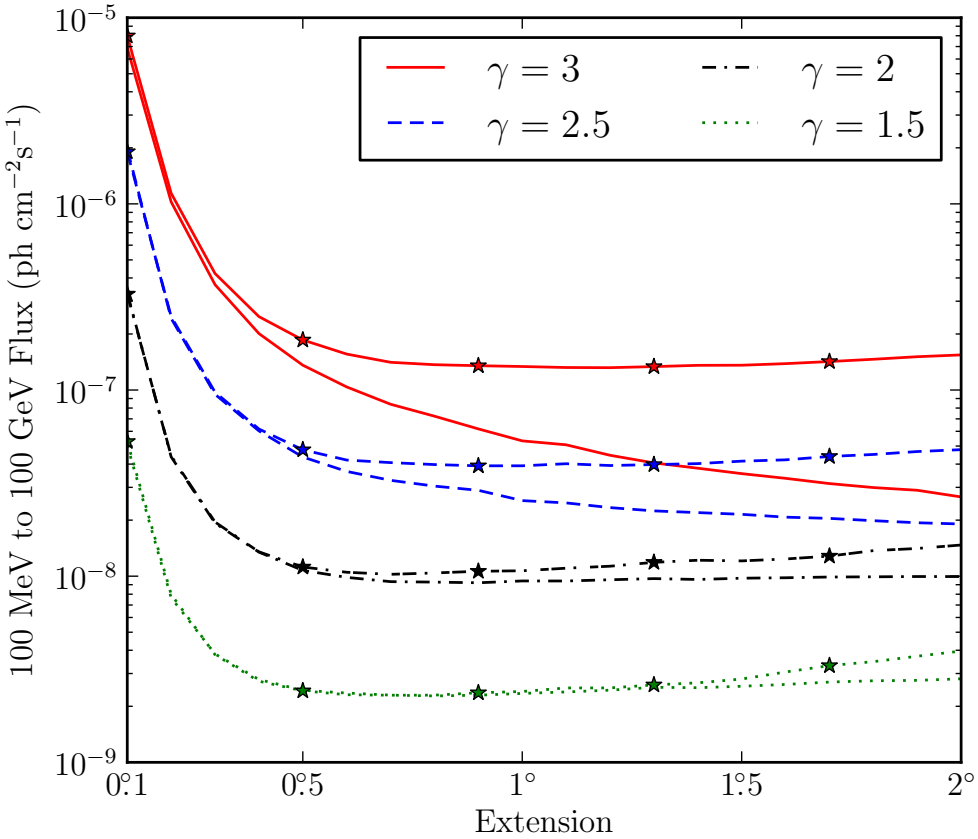
# Fig. 2


PSF
Gauss
Gauss⊗PSF
Disk
Disk⊗PSF
Arbitrary Units
(a) 1 GeV to 100 GeV
(b) 10 GeV to 100 GeV
0.0 0.1 0.2 0.3 0.4 0.5 0.6
$\Delta\theta^2([\mathrm{deg}^2])$

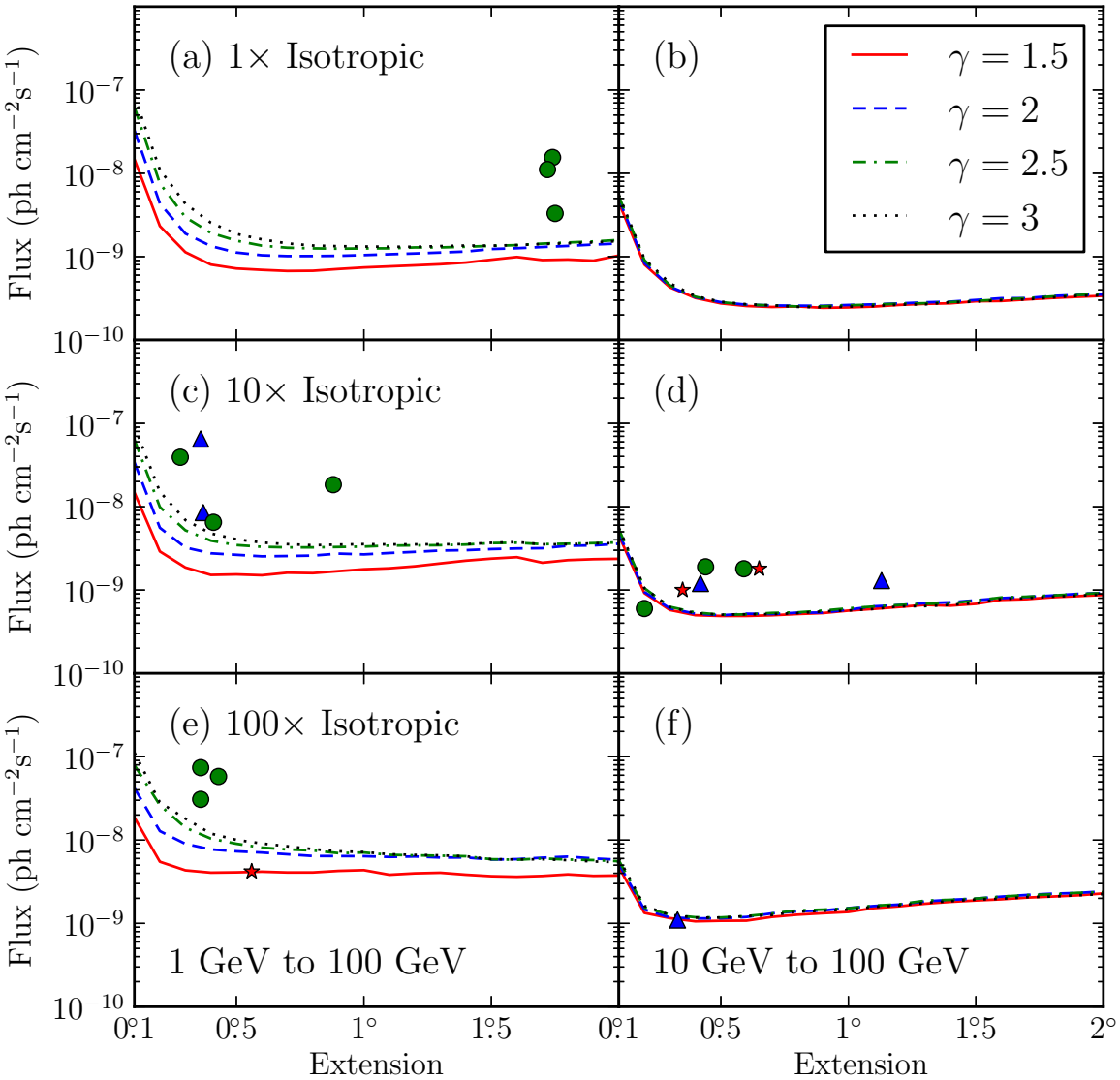
# Fig. 3


Cumulative Density
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
(a) $\gamma = 1.5$
(b) $\gamma = 2$
(c) $\gamma = 2.5$
(d) $\gamma = 3$
$10^{-6}$ ph cm$^{-2}$s$^{-1}$
$3 \times 10^{-7}$ ph cm$^{-2}$s$^{-1}$
$10^{-7}$ ph cm$^{-2}$s$^{-1}$
$3 \times 10^{-8}$ ph cm$^{-2}$s$^{-1}$
$10^{-8}$ ph cm$^{-2}$s$^{-1}$
$\chi^2_1/2$
0
5
10
15
20
25
$TS_{ext}$

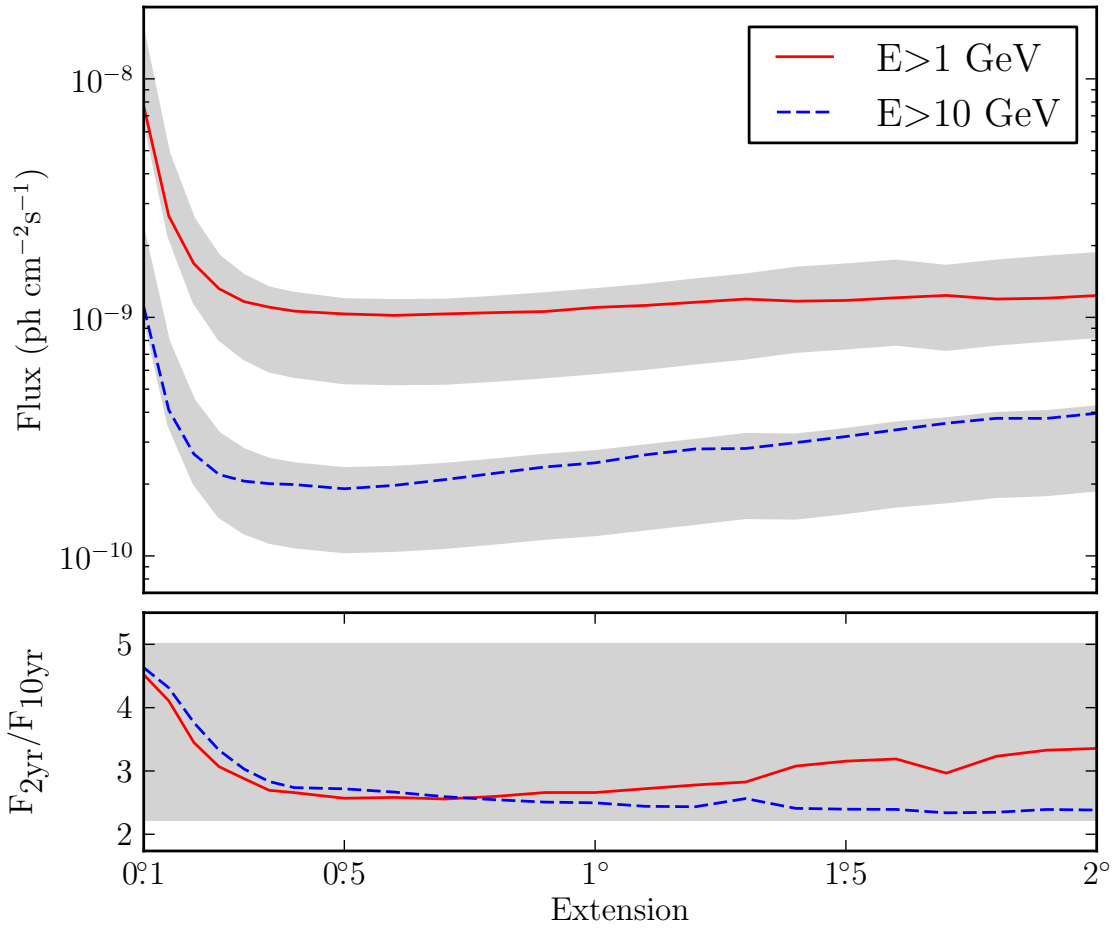
# Fig. 4


$\gamma = 3$
$\gamma = 2$
$\gamma = 2.5$
$\gamma = 1.5$
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
100 MeV to 100 GeV Flux (ph cm$^{-2}$s$^{-1}$)
0.1
0.5
1°
1.5
2°
Extension

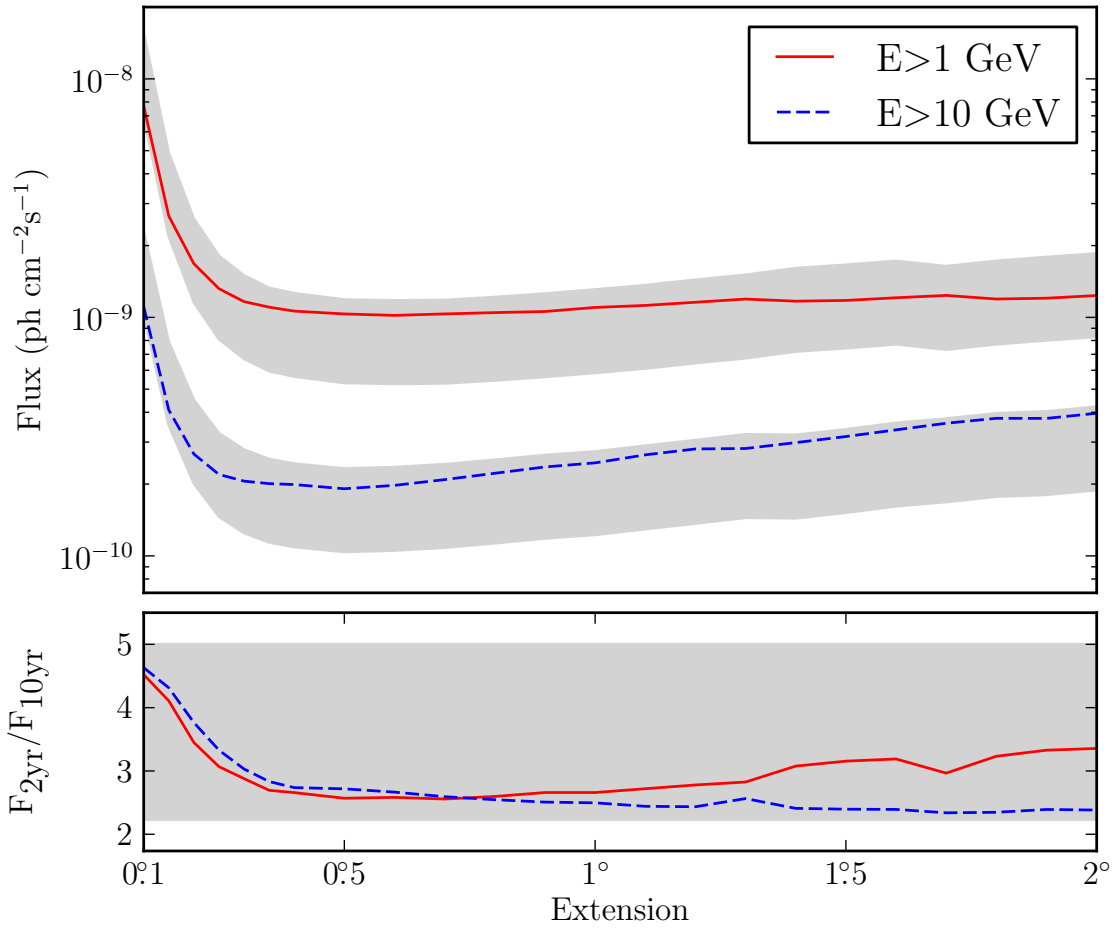
# Fig. 5


(a) 1× Isotropic
(b)
(c) 10× Isotropic
(d)
(e) 100× Isotropic
(f)
$\gamma = 1.5$
$\gamma = 2$
$\gamma = 2.5$
$\gamma = 3$
Flux (ph cm$^{-2}$s$^{-1}$)
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
1 GeV to 100 GeV
10 GeV to 100 GeV
0.1
0.5
1°
1.5
2°
Extension

# Fig. 6


E>1 GeV
E>10 GeV
$10^{-8}$
$10^{-9}$
$10^{-10}$
Flux (ph cm$^{-2}$s$^{-1}$)
$F_{2yr}/F_{10yr}$
5
4
3
2
0.1
0.5
1°
1.5
2°
Extension

# Fig. 6


E>1 GeV
E>10 GeV
$10^{-8}$
$10^{-9}$
$10^{-10}$
Flux (ph cm$^{-2}$s$^{-1}$)
$F_{2yr}/F_{10yr}$
5
4
3
2
0.1°
0.5°
1°
1.5°
2°
Extension

| Name | GLON (deg.) | GLAT (deg.) | $\sigma$ (deg.) | TS | $TS_{ext}$ | Pos Err (deg.) | Flux[(a)] (ph $cm^{-2}\,s^{-1}$) | Index |
|---|---|---|---|---|---|---|---|---|
| | | | E>1 GeV | | | | | |
| SMC | 302.68 | -44.81 | $1.75 \pm 0.07 \pm 0.02$ | 94.8 | 67.4 | 0.12 | $3.3 \pm 0.4$ | $2.41 \pm 0.17$ |
| LMC | 279.10 | -32.61 | $1.74 \pm 0.05 \pm 0.13$ | 1101.3 | 860.5 | 0.05 | $15.5 \pm 0.6$ | $2.48 \pm 0.06$ |
| IC443 | 189.05 | 3.04 | $0.36 \pm 0.01 \pm 0.04$ | 10719.8 | 510.4 | 0.01 | $64.8 \pm 1.2$ | $2.23 \pm 0.02$ |
| Vela X | 263.34 | -3.11 | 0.88 | | | | | |
| Centarus A | 309.52 | 19.42 | $\sim 10$ | | | | | |
| W28 | 6.50 | -0.27 | $0.43 \pm 0.02 \pm 0.03$ | 1324.8 | 177.4 | 0.01 | $58.0 \pm 1.8$ | $2.63 \pm 0.03$ |
| W30 | 8.61 | -0.20 | $0.36 \pm 0.02 \pm 0.02$ | 465.4 | 73.3 | 0.02 | $30.7 \pm 1.6$ | $2.59 \pm 0.04$ |
| W44 | 34.69 | -0.38 | $0.36 \pm 0.01 \pm 0.02$ | 1903.3 | 217.7 | 0.01 | $73.6 \pm 1.8$ | $2.68 \pm 0.02$ |
| W51C | 49.13 | -0.45 | $0.28 \pm 0.02 \pm 0.05$ | 1819.5 | 115.7 | 0.01 | $39.3 \pm 1.3$ | $2.35 \pm 0.03$ |
| Cygnus Loop | 74.22 | -8.46 | $1.72 \pm 0.05 \pm 0.07$ | 356.5 | 356.5 | 0.06 | $11.1 \pm 0.7$ | $2.53 \pm 0.11$ |
| | | | E>10 GeV | | | | | |
| MSH 15−52 | 320.38 | -1.22 | $0.20 \pm 0.04 \pm 0.03$ | 76.2 | 6.5 | 0.03 | $0.6 \pm 0.7$ | $2.27 \pm 0.73$ |
| HESS J1825−137 | 17.56 | -0.46 | $0.65 \pm 0.03 \pm 0.01$ | 83.6 | 55.9 | 0.05 | $1.8 \pm 0.2$ | $1.74 \pm 0.19$ |

| Name | GLON (deg.) | GLAT (deg.) | $\sigma$ (deg.) | TS | $TS_{ext}$ | Pos Err (deg.) | Flux[(a)] (ph $cm^{-2}\,s^{-1}$) | Index | Counterpart |
|---|---|---|---|---|---|---|---|---|---|
| | | | | E>1 GeV | | | | | |
| 2FGL J0823.0−4246 | 260.32 | -3.28 | $0.37 \pm 0.03 \pm 0.02$ | 320.9 | 46.3 | 0.02 | $8.5 \pm 0.7$ | $2.20 \pm 0.09$ | Puppis A |
| 2FGL J1627.0−2425c | 353.08 | 16.78 | $0.41 \pm 0.05 \pm 0.02$ | 144.5 | 31.1 | 0.04 | $6.5 \pm 0.6$ | $2.49 \pm 0.14$ | Ophiuchus |
| 2FGL J1712.4−3941 | 347.25 | -0.54 | $0.56 \pm 0.04 \pm 0.01$ | 75.0 | 39.6 | 0.05 | $4.2 \pm 0.9$ | $1.47 \pm 0.12$ | RX J1713.7−3946 |
| | | | | E>10 GeV | | | | | |
| 2FGL J0851.7−4635 | 266.29 | -1.43 | $1.13 \pm 0.08 \pm 0.05$ | 116.1 | 87.2 | 0.07 | $1.3 \pm 0.2$ | $1.76 \pm 0.21$ | Vela Jr. |
| 2FGL J1615.0−5051 | 332.38 | -0.14 | $0.33 \pm 0.04 \pm 0.01$ | 53.4 | 16.3 | 0.04 | $1.1 \pm 0.2$ | $2.24 \pm 0.28$ | HESS J1616−508 |
| 2FGL J1615.2−5138 | 331.66 | -0.66 | $0.42 \pm 0.03 \pm 0.01$ | 76.6 | 48.0 | 0.05 | $1.2 \pm 0.2$ | $1.77 \pm 0.24$ | HESS J1614−518 |
| 2FGL J1632.4−4753c | 336.41 | 0.22 | $0.44 \pm 0.04 \pm 0.03$ | 127.8 | 64.5 | 0.04 | $1.9 \pm 0.2$ | $2.29 \pm 0.21$ | HESS J1632−478 |
| 2FGL J1837.3−0700c | 25.08 | 0.13 | $0.35 \pm 0.08 \pm 0.03$ | 46.2 | 18.8 | 0.07 | $1.0 \pm 0.2$ | $1.63 \pm 0.29$ | HESS J1837−069 |
| 2FGL J2021.5+4026 | 78.18 | 2.19 | $0.59 \pm 0.03 \pm 0.02$ | 222.2 | 116.4 | 0.04 | $1.8 \pm 0.2$ | $2.31 \pm 0.19$ | $\gamma$-Cygni |

| Name | $TS_{\texttt{pointlike}}$ | $TS_{\texttt{gtlike}}$ | $TS_{\text{alt,diff}}$ | $TS_{\text{ext}\texttt{pointlike}}$ | $TS_{\text{ext}\texttt{gtlike}}$ | $TS_{\text{ext alt,diff}}$ | $\sigma$ (deg.) | $\sigma_{\text{alt,diff}}$ (deg.) | $\sigma_{\text{alt,psf}}$ (deg.) | $TS_{\text{inc}}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | E>1 GeV | | | | | | |
| 2FGL J0823.0−4246 | 350.9 | 320.9 | 352.5 | 66.0 | 46.3 | 53.6 | 0.37 | 0.39 | 0.38 | 22.1 |
| 2FGL J1627.0−2425c | 170.2 | 144.5 | 112.6 | 43.9 | 31.1 | 23.9 | 0.41 | 0.40 | 0.39 | 20.0 |
| 2FGL J1712.4−3941 | 80.9 | 75.0 | 43.4 | 47.4 | 39.6 | 22.2 | 0.56 | 0.56 | 0.54 | 6.4 |
| | | | | E>10 GeV | | | | | | |
| 2FGL J0851.7−4635 | 116.7 | 116.1 | 122.3 | 87.1 | 87.2 | 90.4 | 1.13 | 1.16 | 1.17 | 16.1 |
| 2FGL J1615.0−5051 | 52.4 | 53.4 | 55.6 | 17.5 | 16.3 | 17.4 | 0.33 | 0.32 | 0.32 | 11.9 |
| 2FGL J1615.2−5138 | 76.3 | 76.6 | 86.3 | 44.0 | 48.0 | 52.6 | 0.42 | 0.43 | 0.43 | 37.0 |
| 2FGL J1632.4−4753c | 126.6 | 127.8 | 120.7 | 63.9 | 64.5 | 64.1 | 0.44 | 0.44 | 0.47 | 40.6 |
| 2FGL J1837.3−0700c | 45.4 | 46.2 | 39.0 | 18.5 | 18.8 | 16.6 | 0.35 | 0.34 | 0.38 | 12.6 |
| 2FGL J2021.5+4026 | 234.3 | 222.2 | 235.6 | 135.9 | 116.4 | 121.4 | 0.59 | 0.60 | 0.60 | 24.3 |