GLAST: Data Challenge 1

Source Detection with Voronoi Tessellations and Bayesian Blocks

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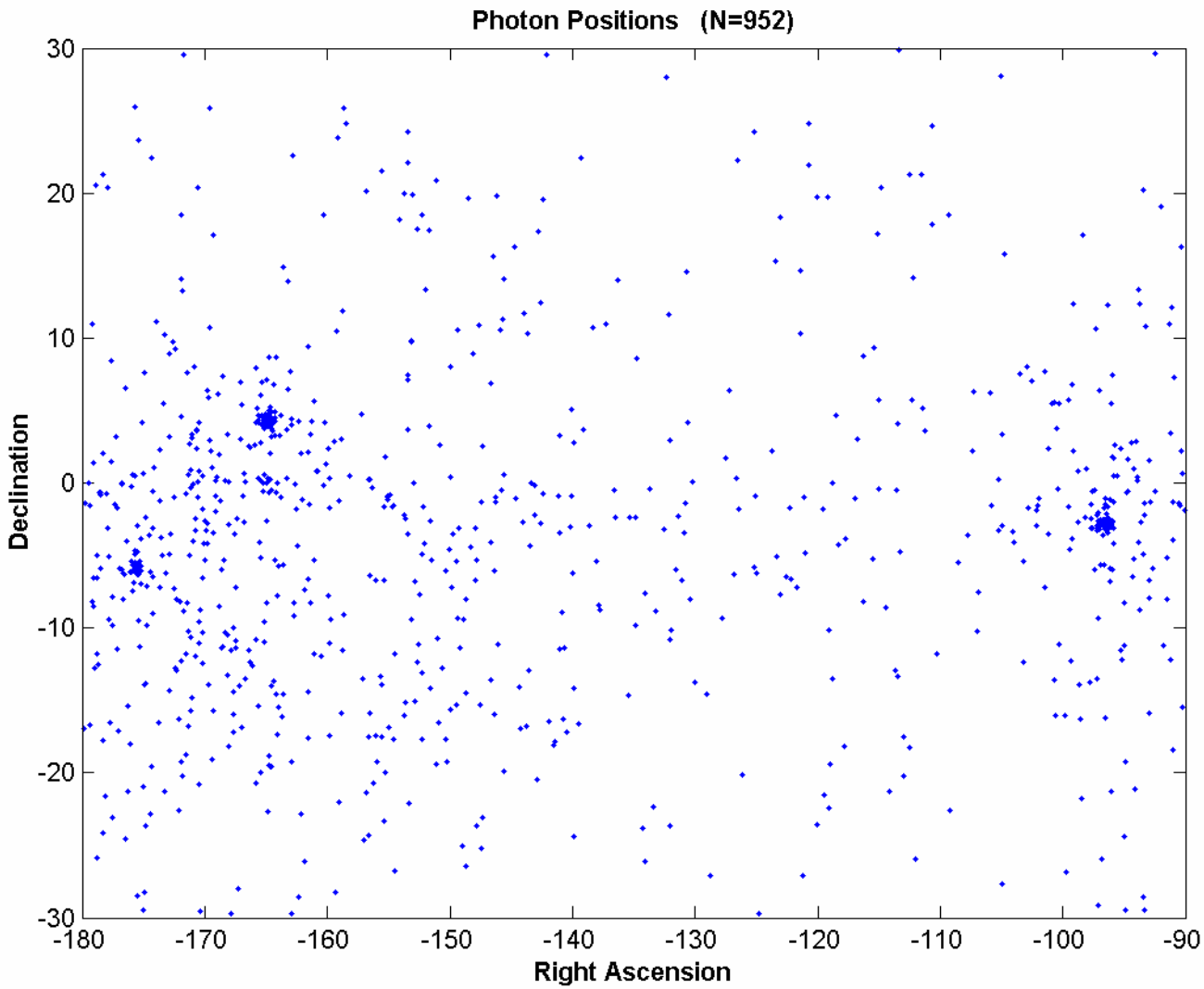
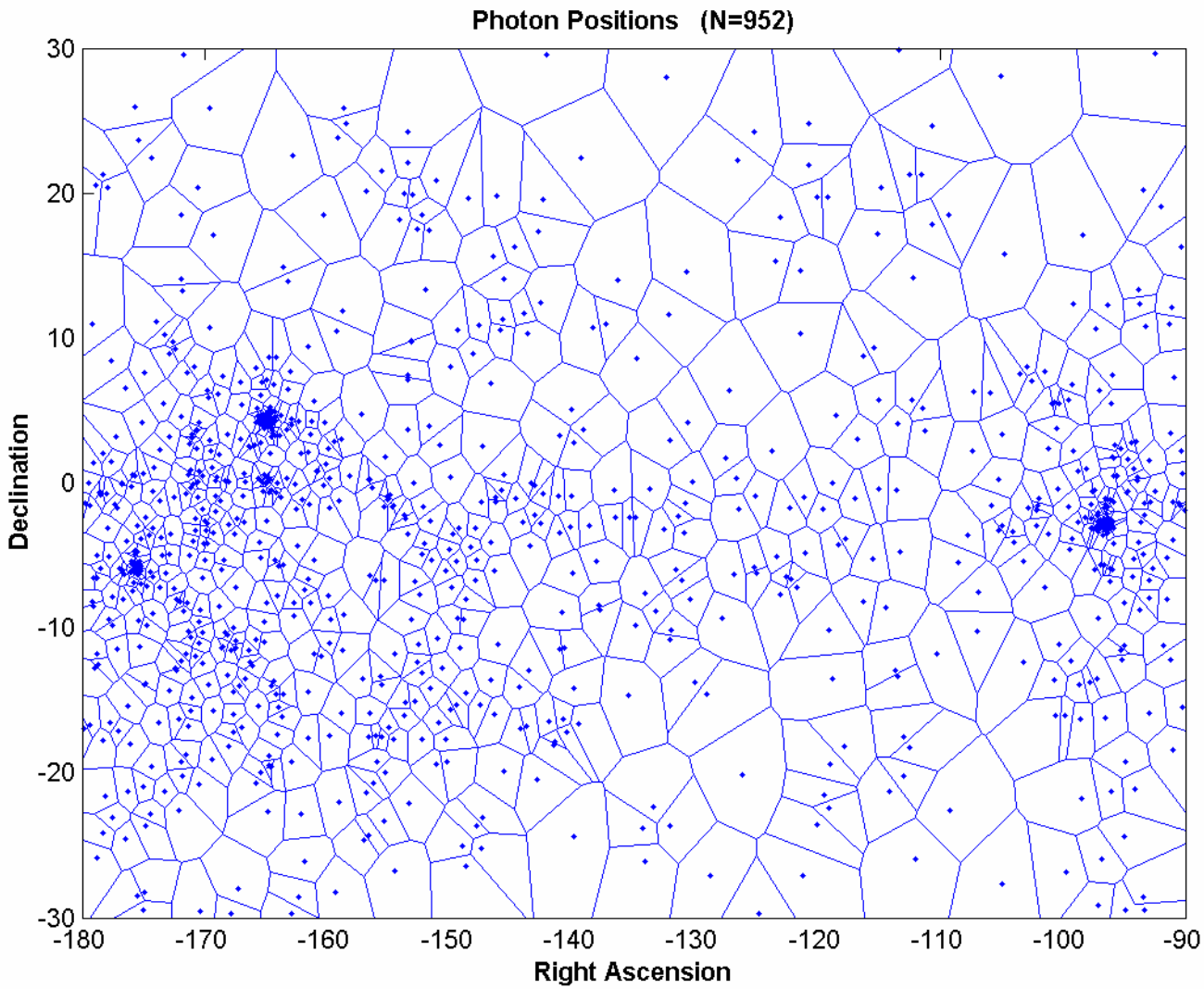
The Basic Ideas

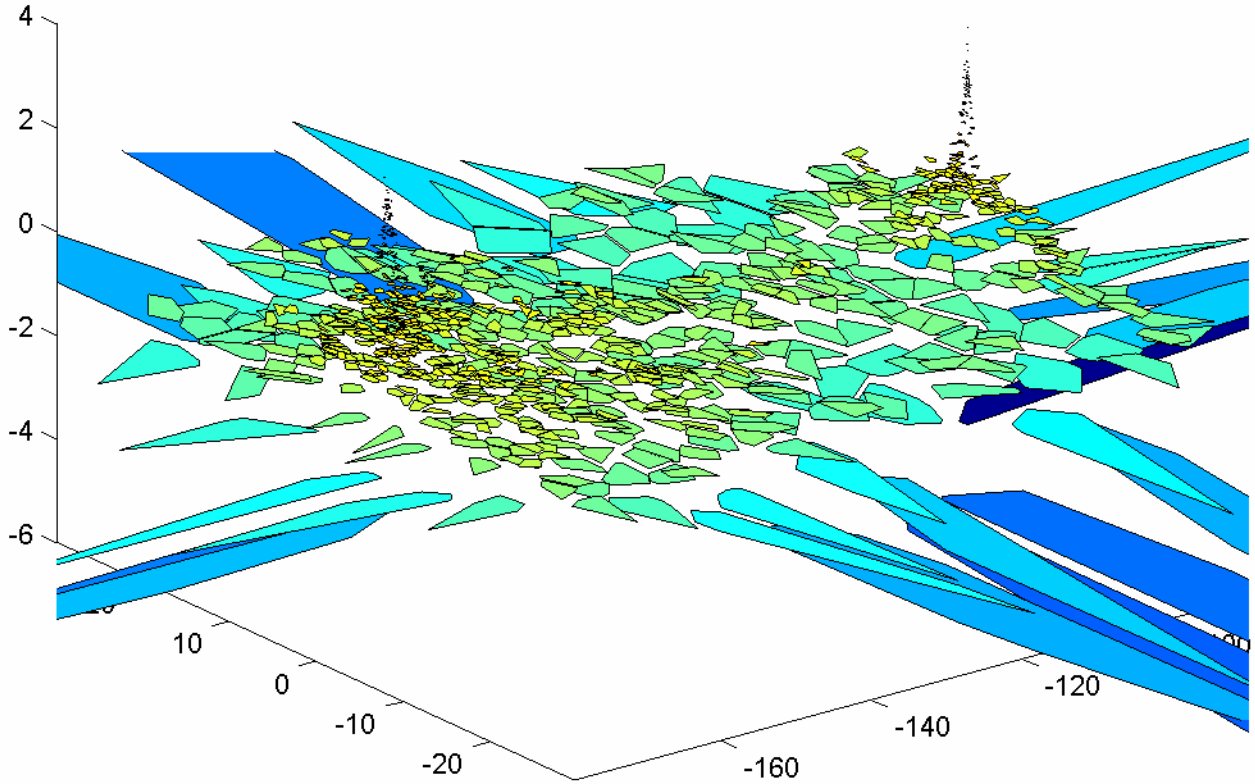
- Two-step process:
  - Nonparametric Density Estimation
  - Identify Sources as Density Maxima
- Voronoi Tessellation
  - Voronoi Cells as Photon Surrogates
  - 1/Area of cell ~ local photon density
  - Cell geometry → local density gradient
- Ignore Exposure & Spread (PSF) for now
- Treat Energy Dependence Approximately
- Optimal Segmentation: *Bayesian Blocks*
- Results with DC1 Data (cf. wavelet results)

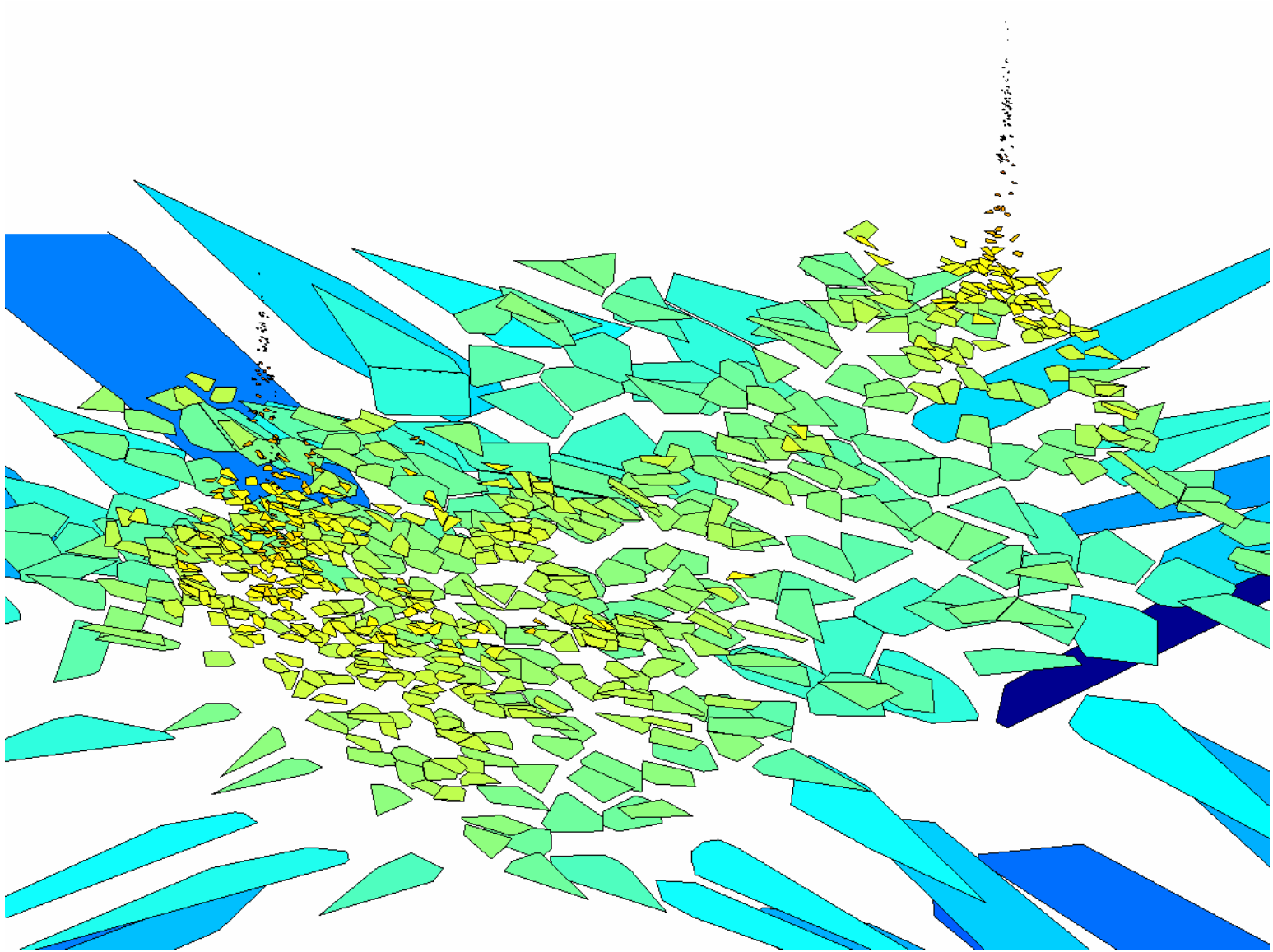

Photon Positions (N=952)
Declination
Right Ascension
30
20
10
0
-10
-20
-30
-180
-170
-160
-150
-140
-130
-120
-110
-100
-90

Construct Voronoi cells to represent local photon density:

density ~ 1 / cell area

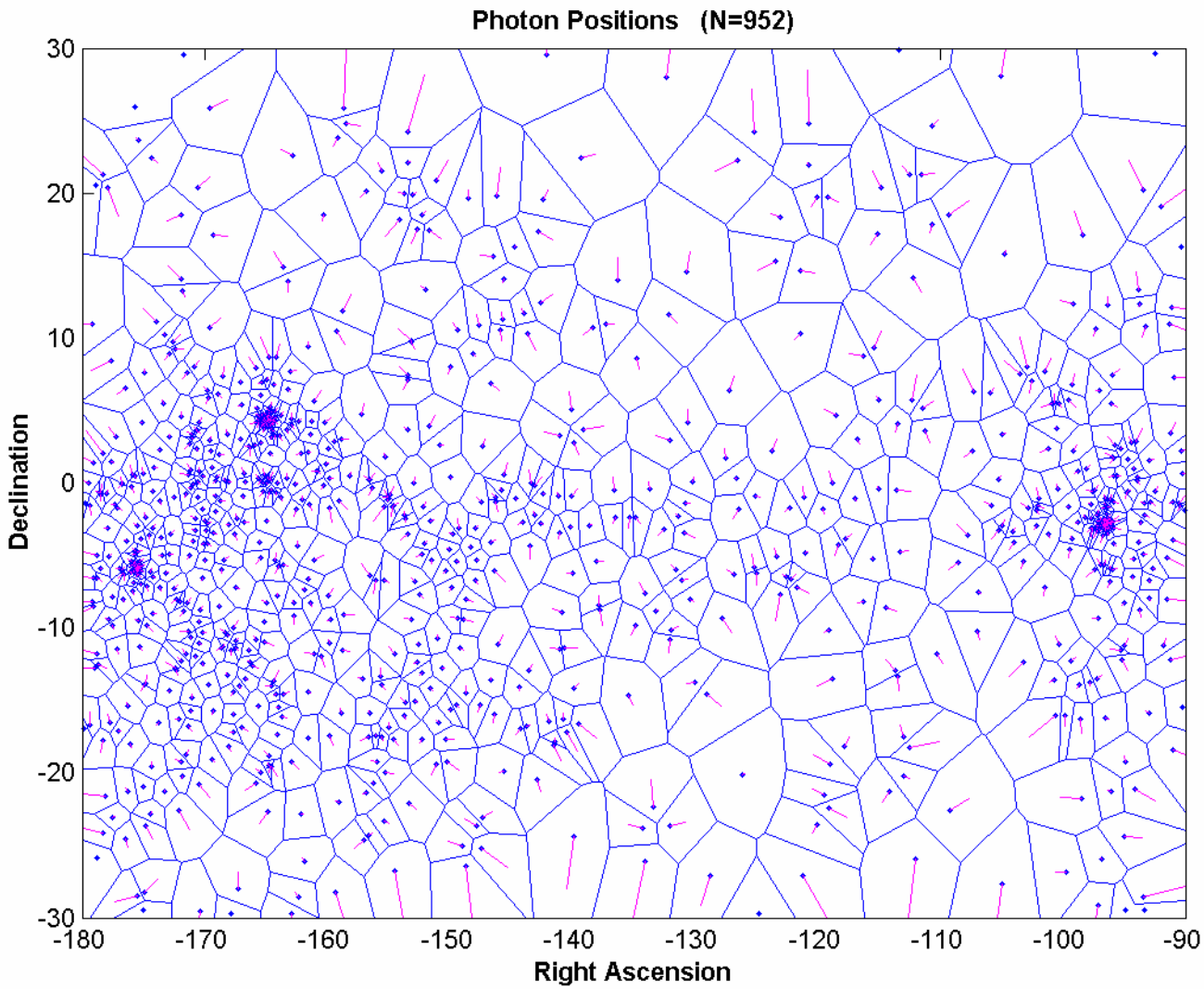

Photon Positions (N=952)
Declination
Right Ascension
30
20
10
0
-10
-20
-30
-180
-170
-160
-150
-140
-130
-120
-110
-100
-90

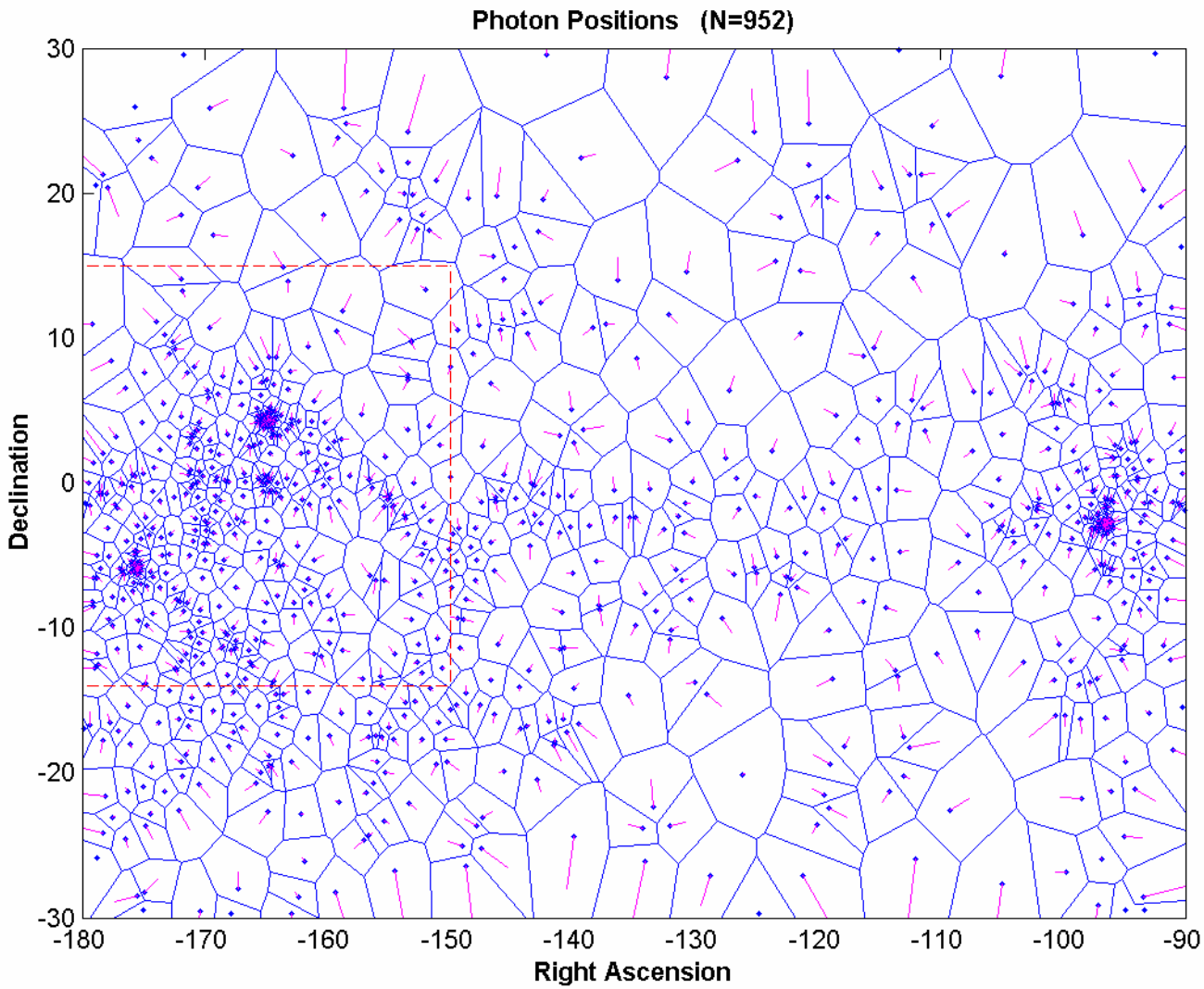

4
2
0
-2
-4
-6
10
0
-10
-20
-120
-140
-160

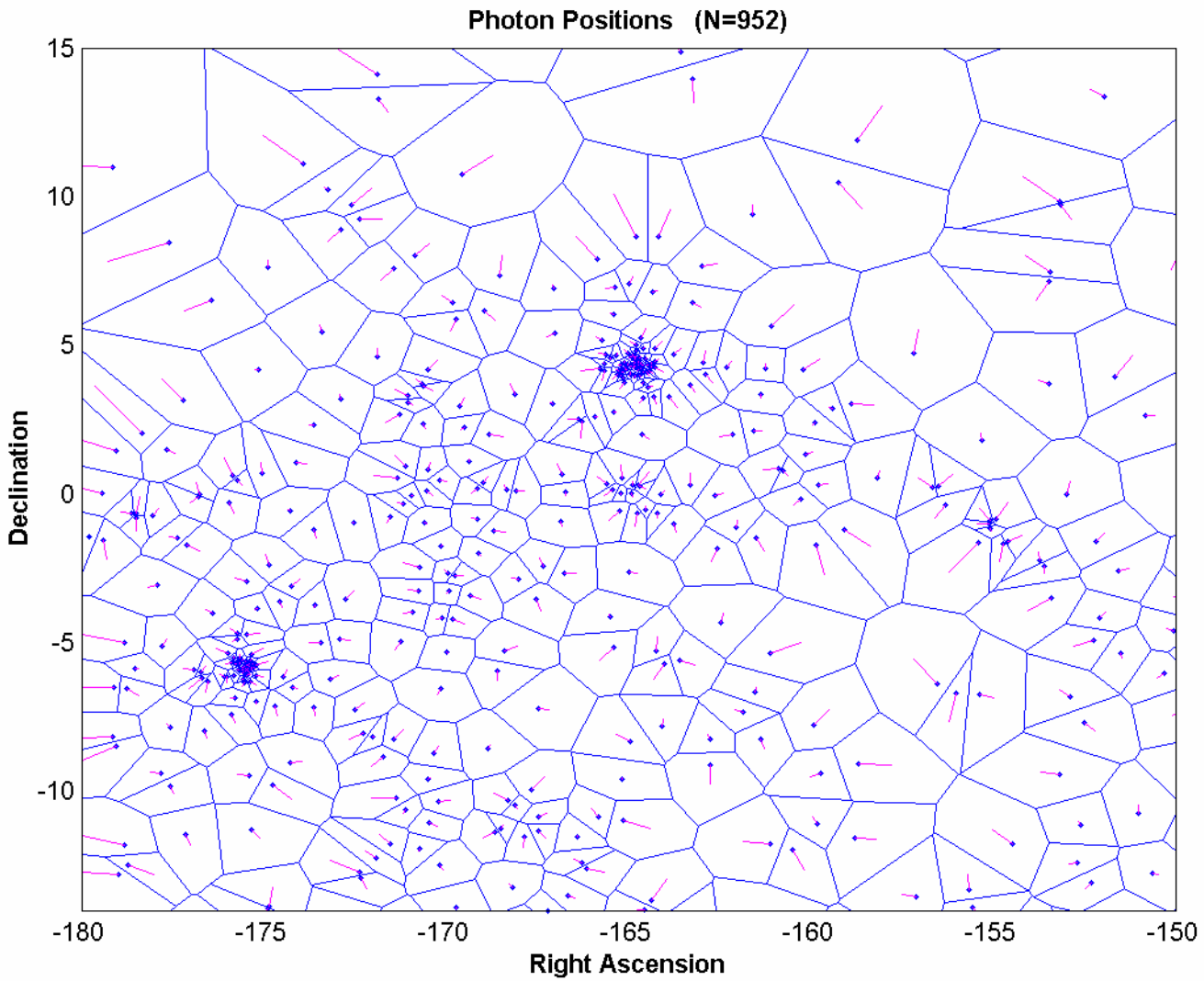


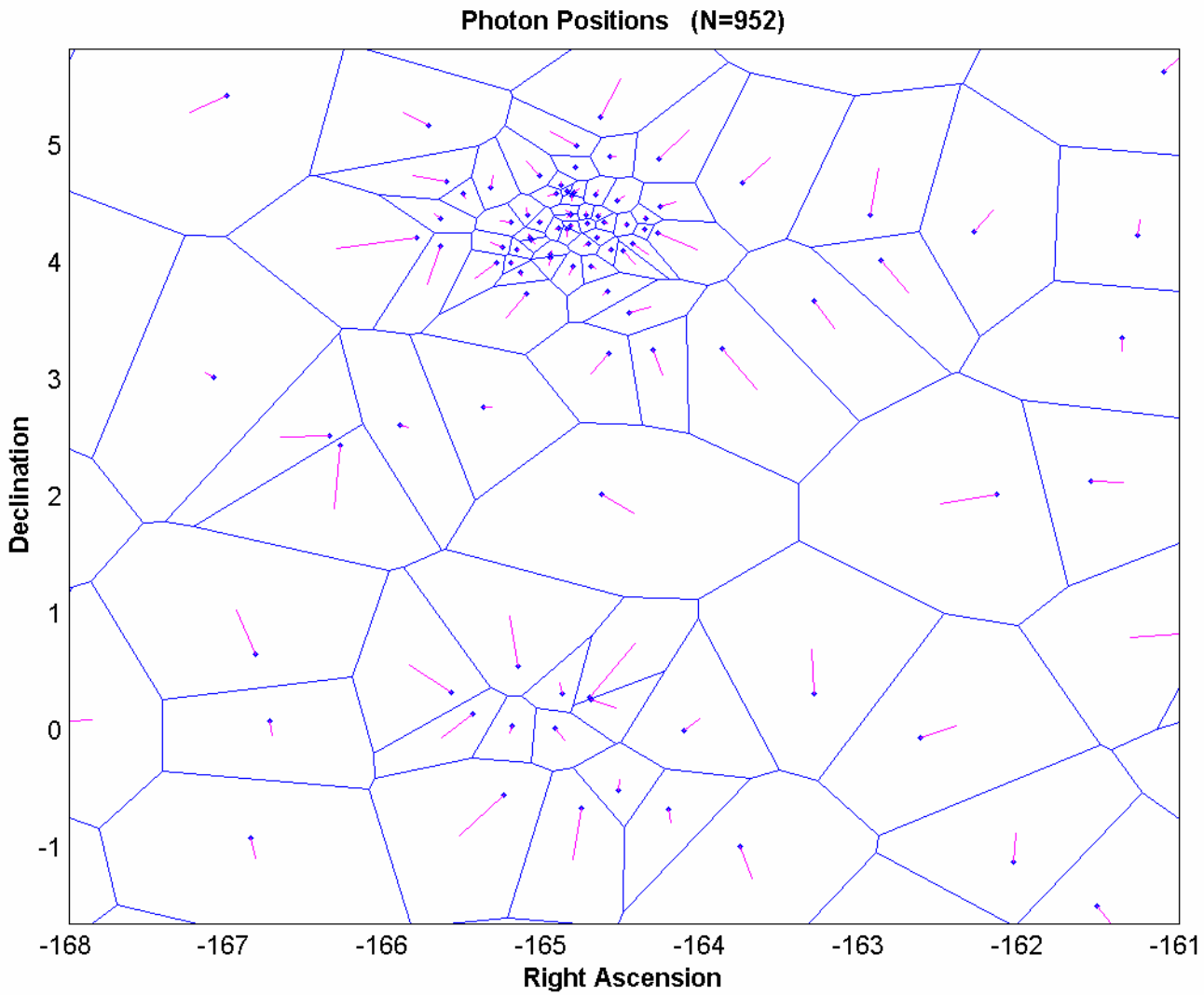
Voronoi cells also represent local photon density gradients

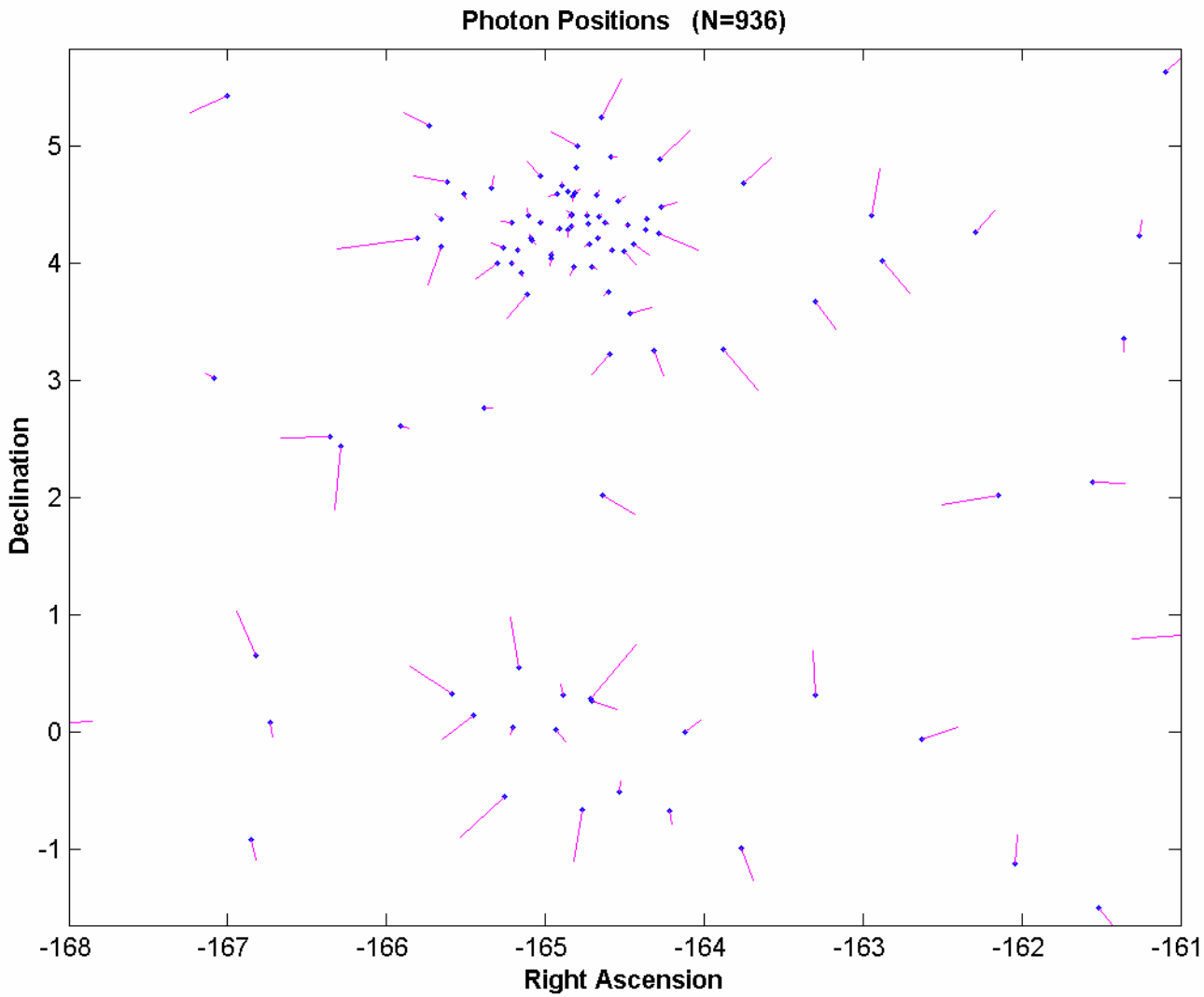
…


Photon Positions (N=952)
Declination
Right Ascension
30
20
10
0
-10
-20
-30
-180
-170
-160
-150
-140
-130
-120
-110
-100
-90

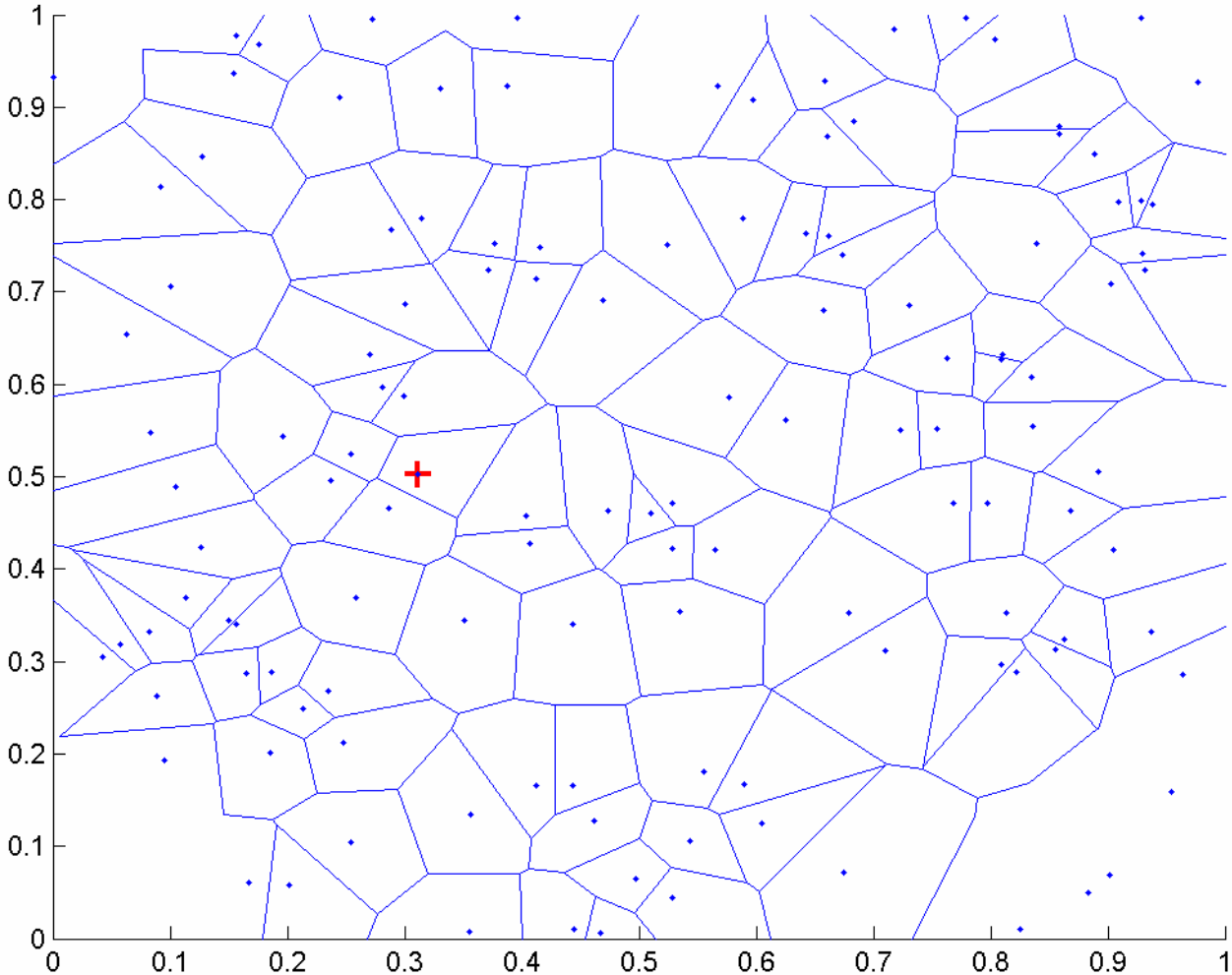

Photon Positions (N=952)
Declination
Right Ascension
30
20
10
0
-10
-20
-30
-180
-170
-160
-150
-140
-130
-120
-110
-100
-90

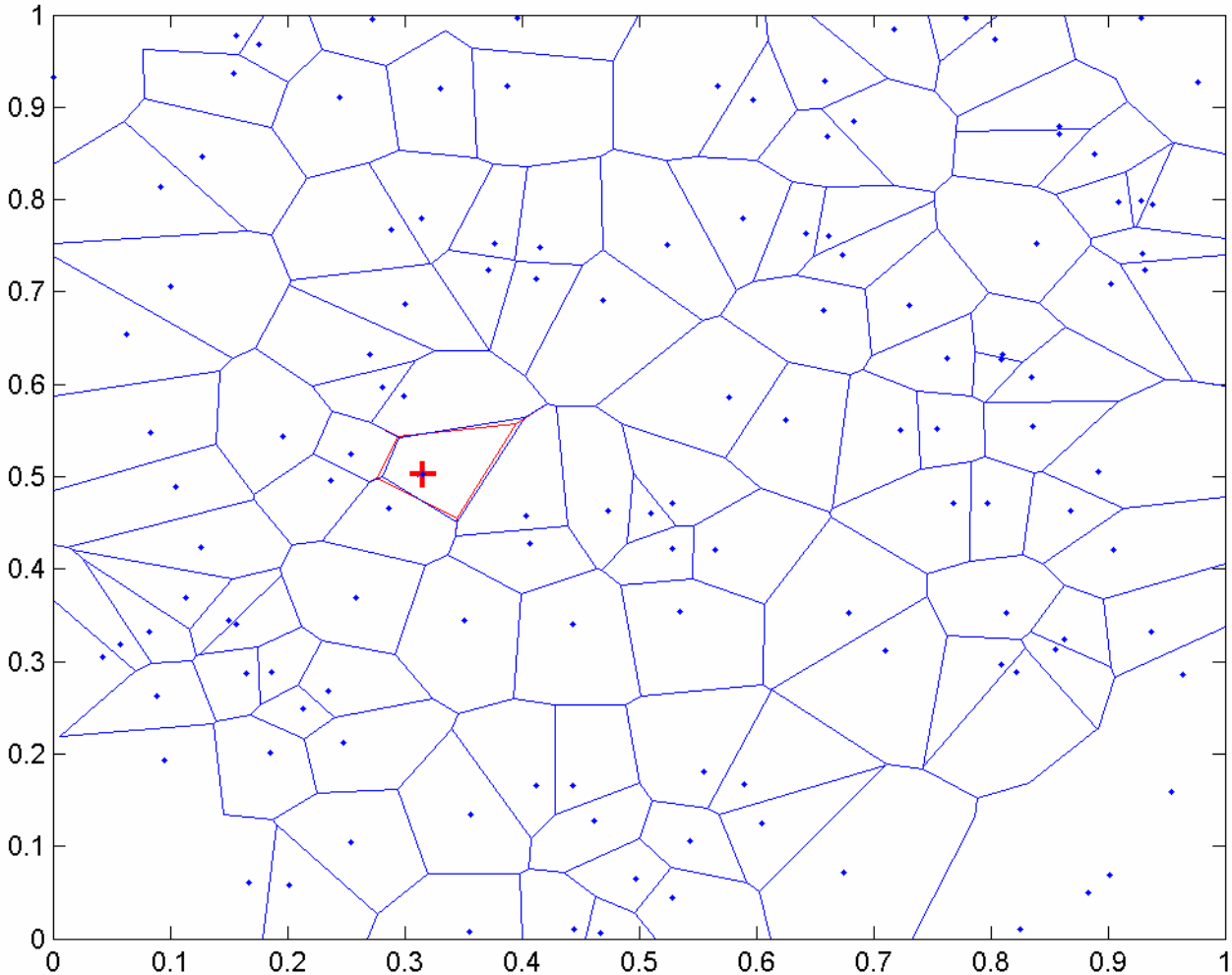

Photon Positions (N=952)
Declination
Right Ascension
15
10
5
0
-5
-10
-180
-175
-170
-165
-160
-155
-150

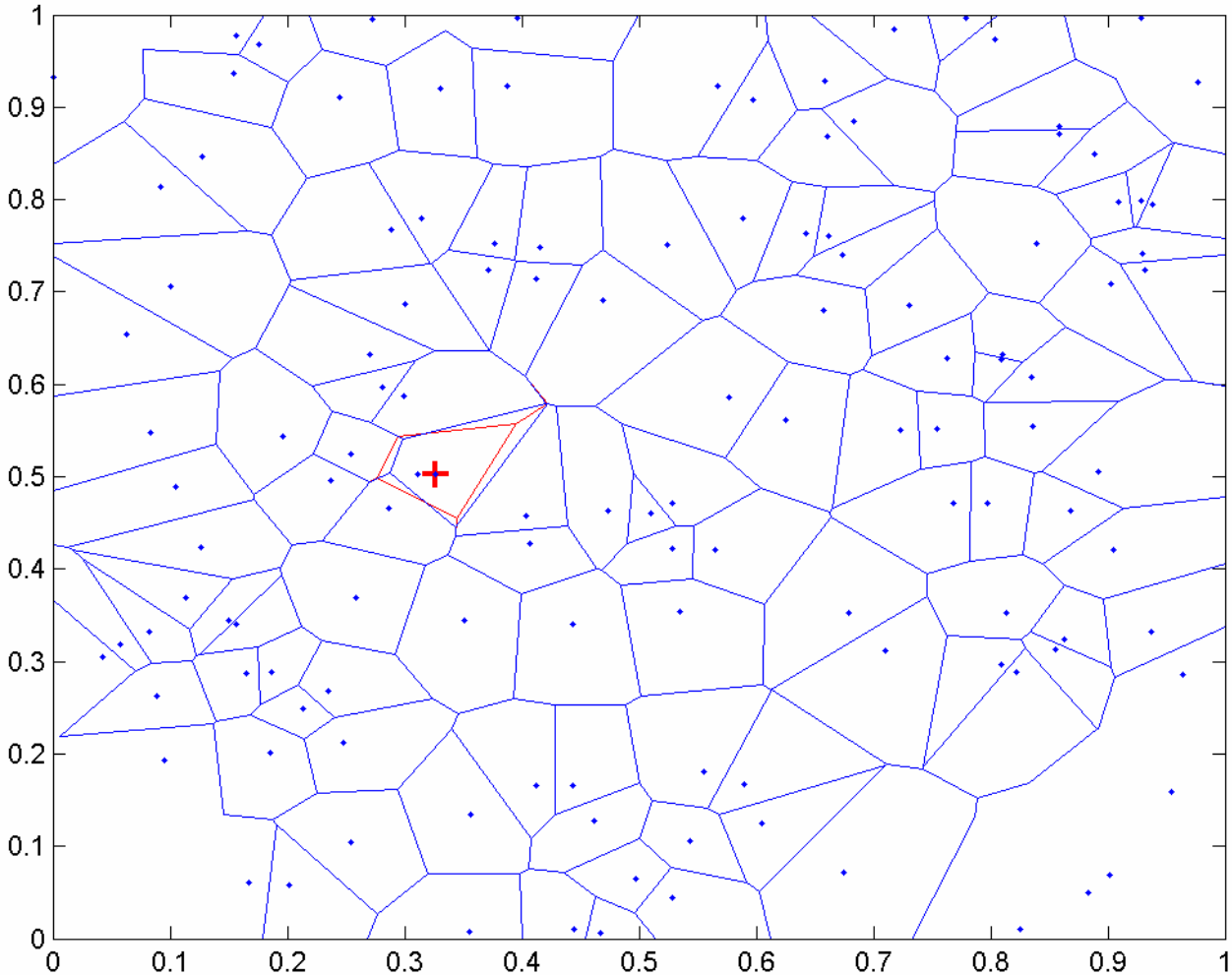

Photon Positions (N=952)
Declination
Right Ascension
5
4
3
2
1
0
-1
-168
-167
-166
-165
-164
-163
-162
-161

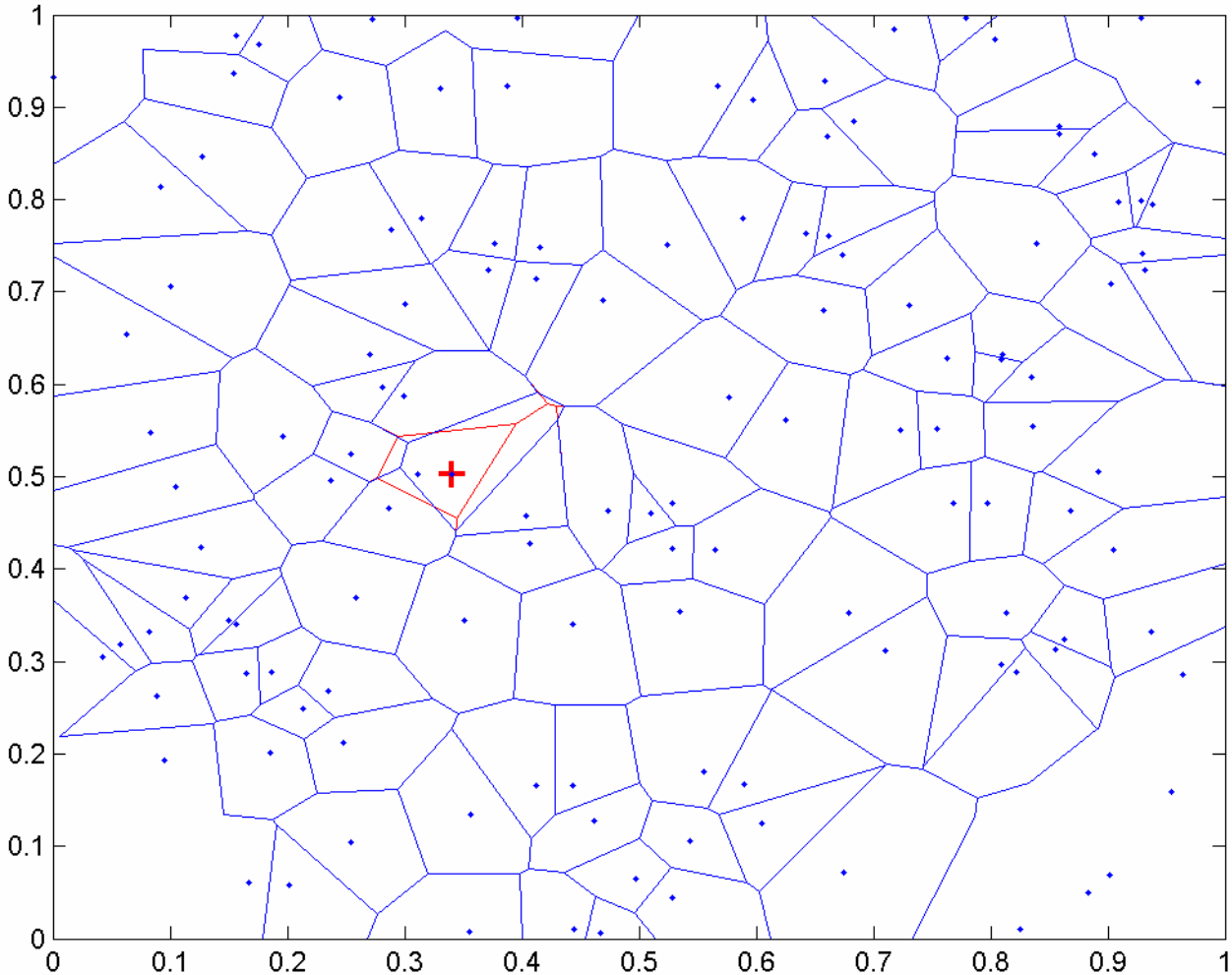

Photon Positions (N=936)
Declination
Right Ascension
5
4
3
2
1
0
-1
-168
-167
-166
-165
-164
-163
-162
-161

The Voronoi cells are a *local* representation of the data …


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


1
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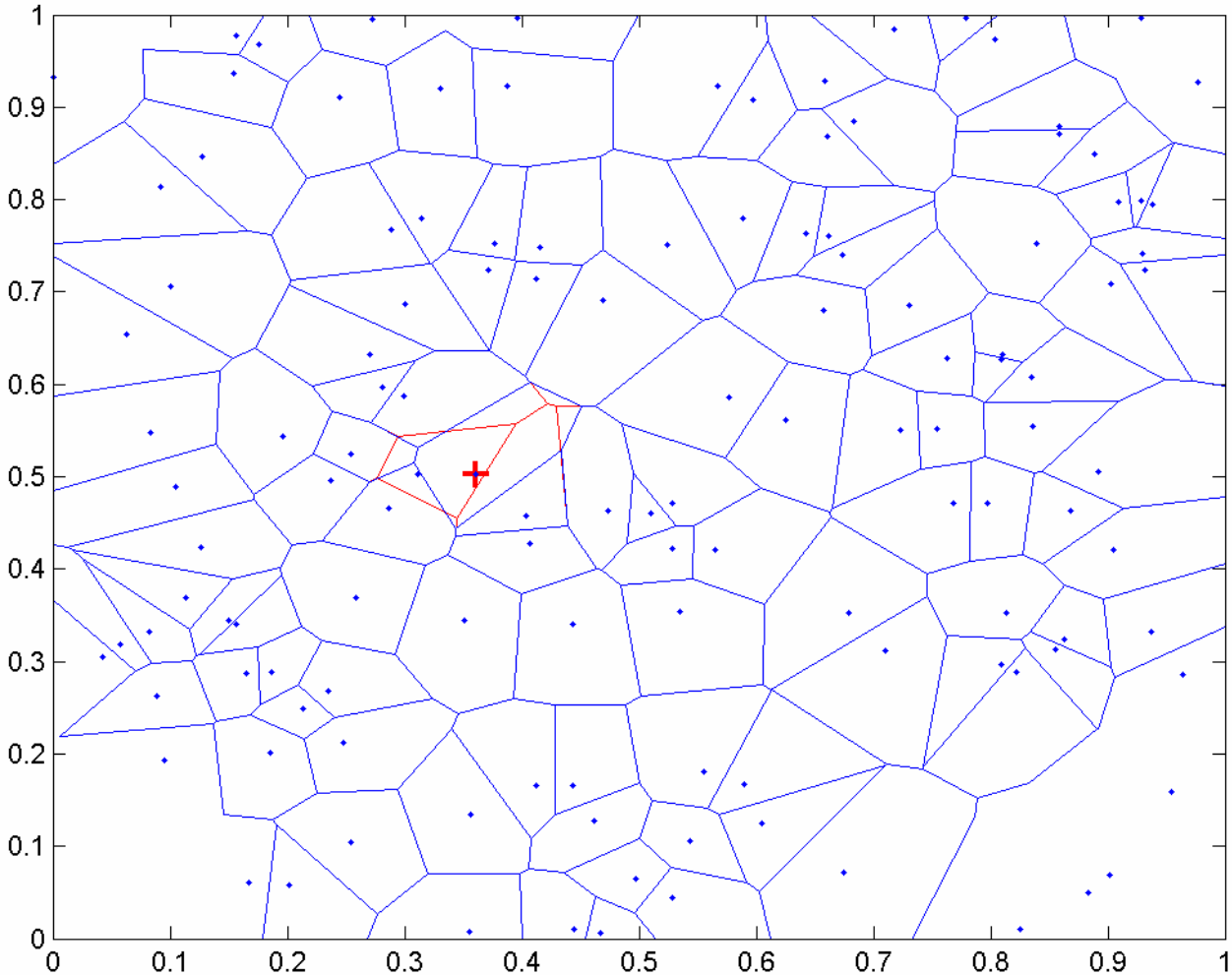
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


1
0.9
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0.6
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0.2
0.1
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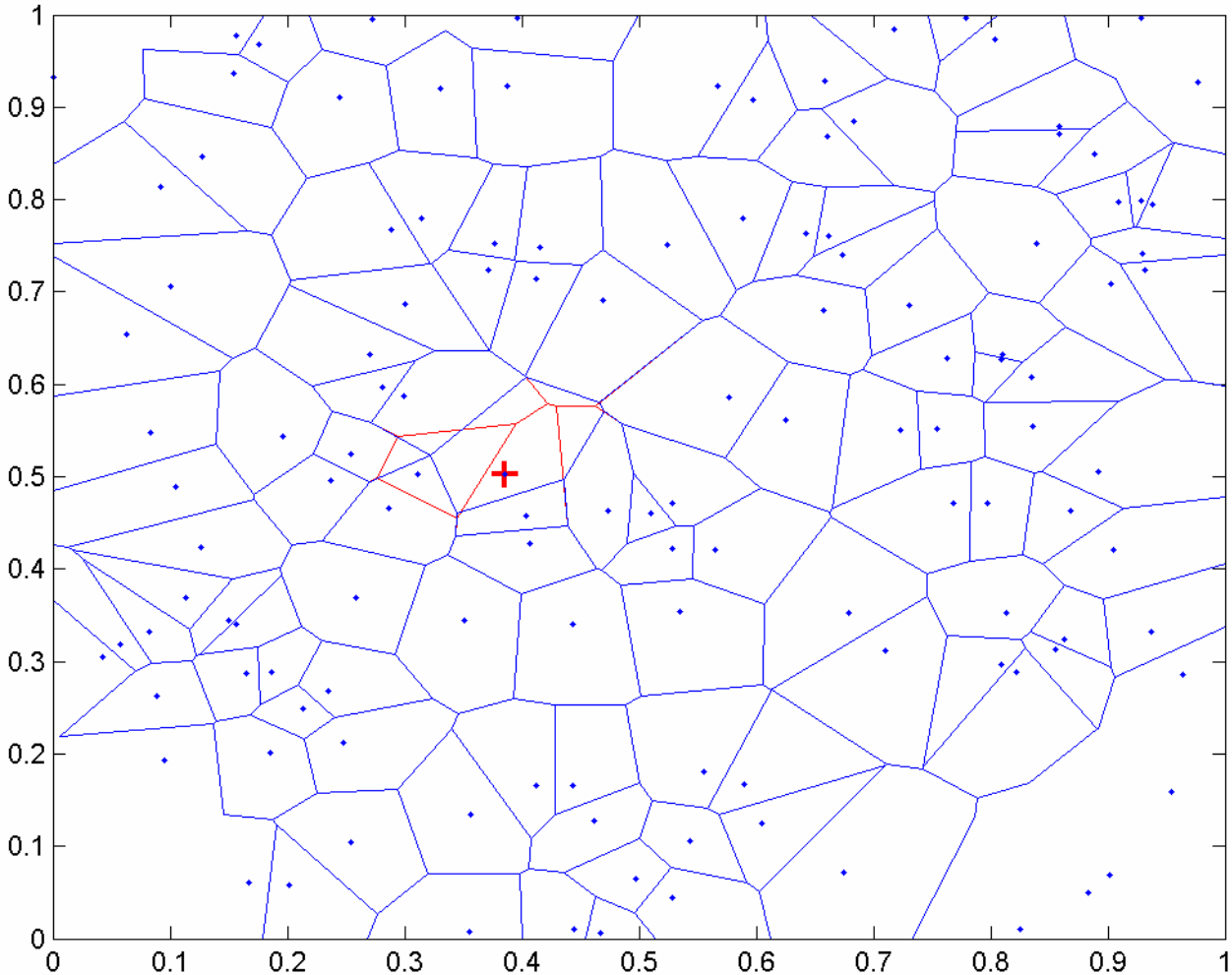
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


1
0.9
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0.7
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0.2
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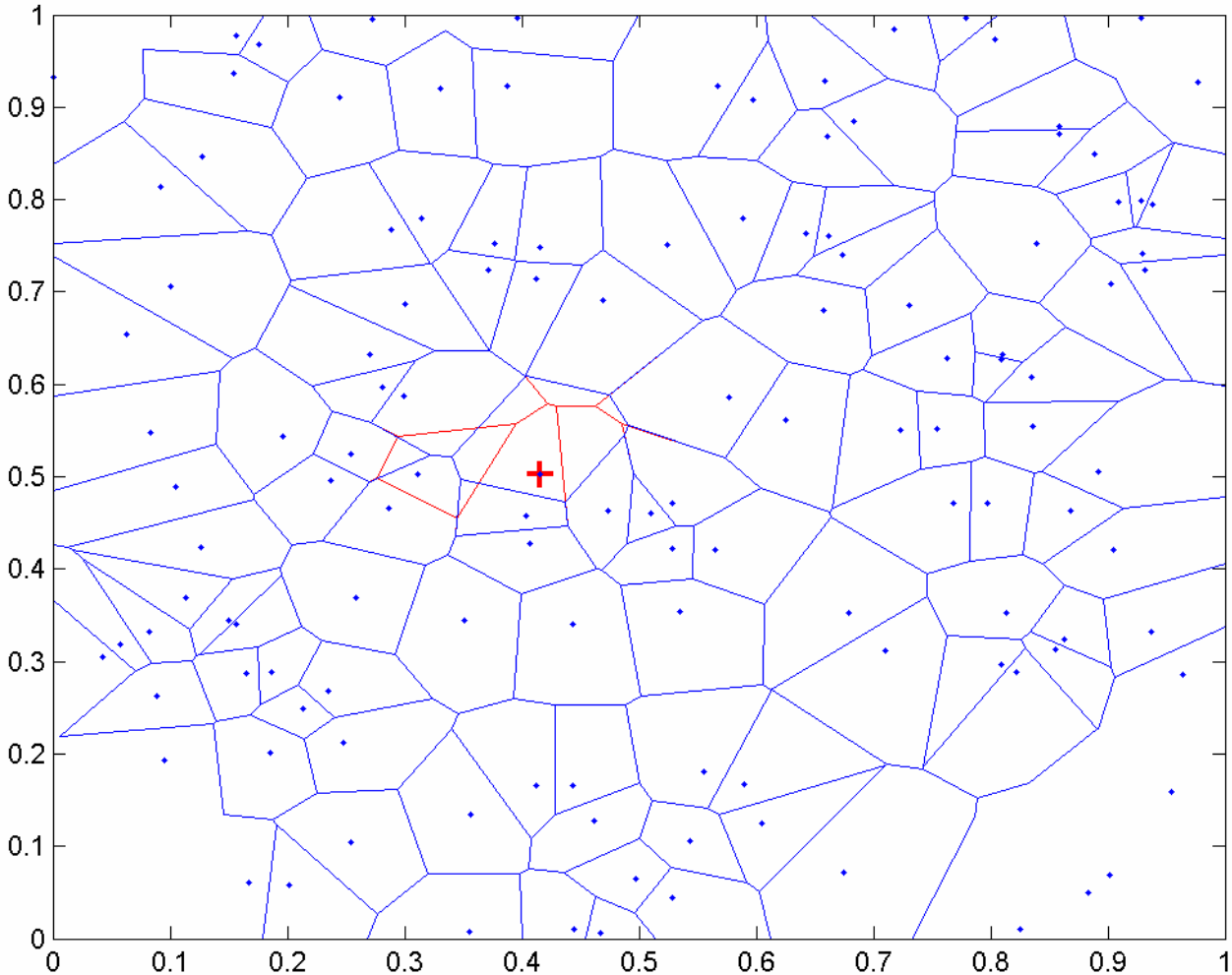
0.4
0.5
0.6
0.7
0.8
0.9
1


1
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0.6
0.5
0.4
0.3
0.2
0.1
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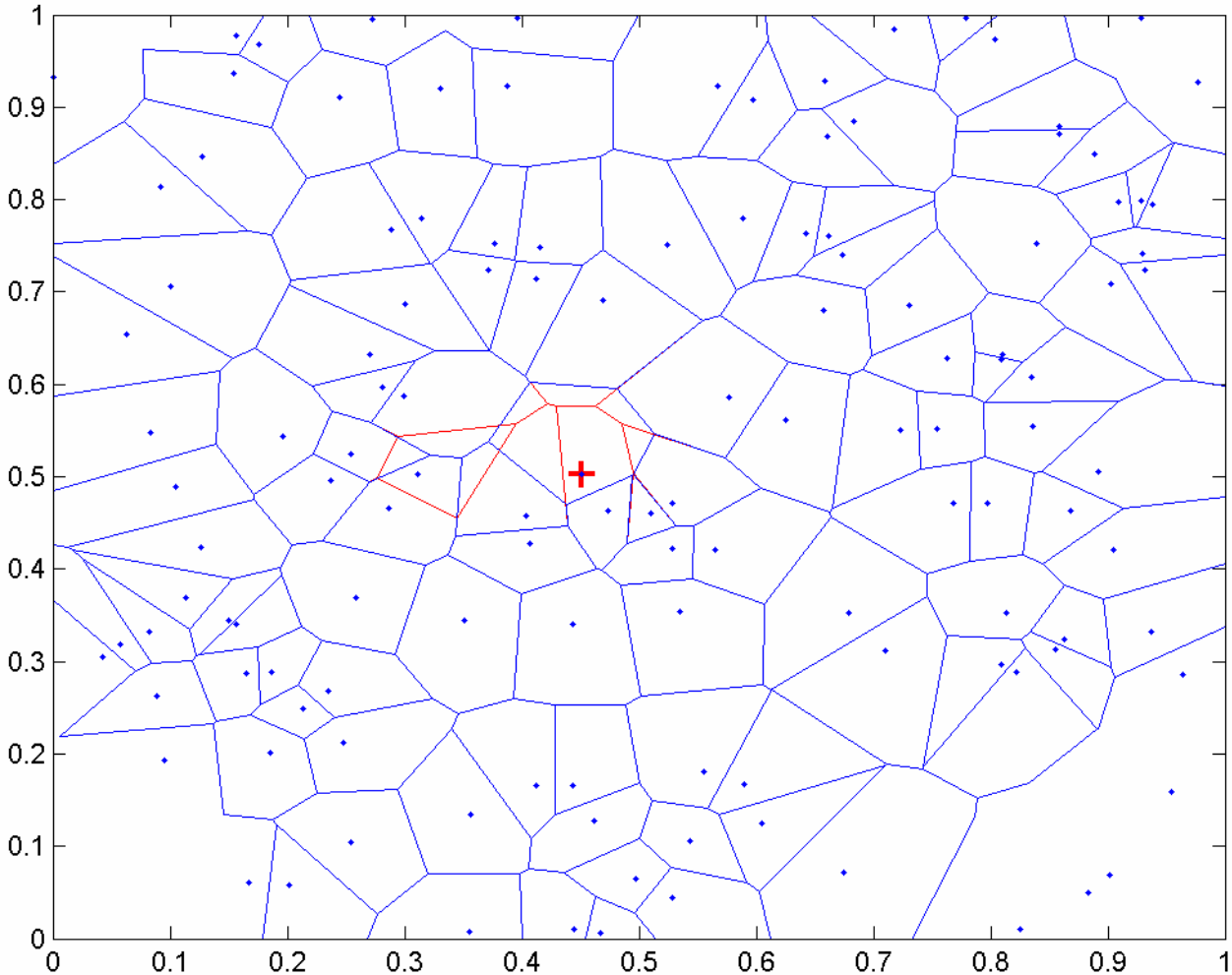
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


1
0.9
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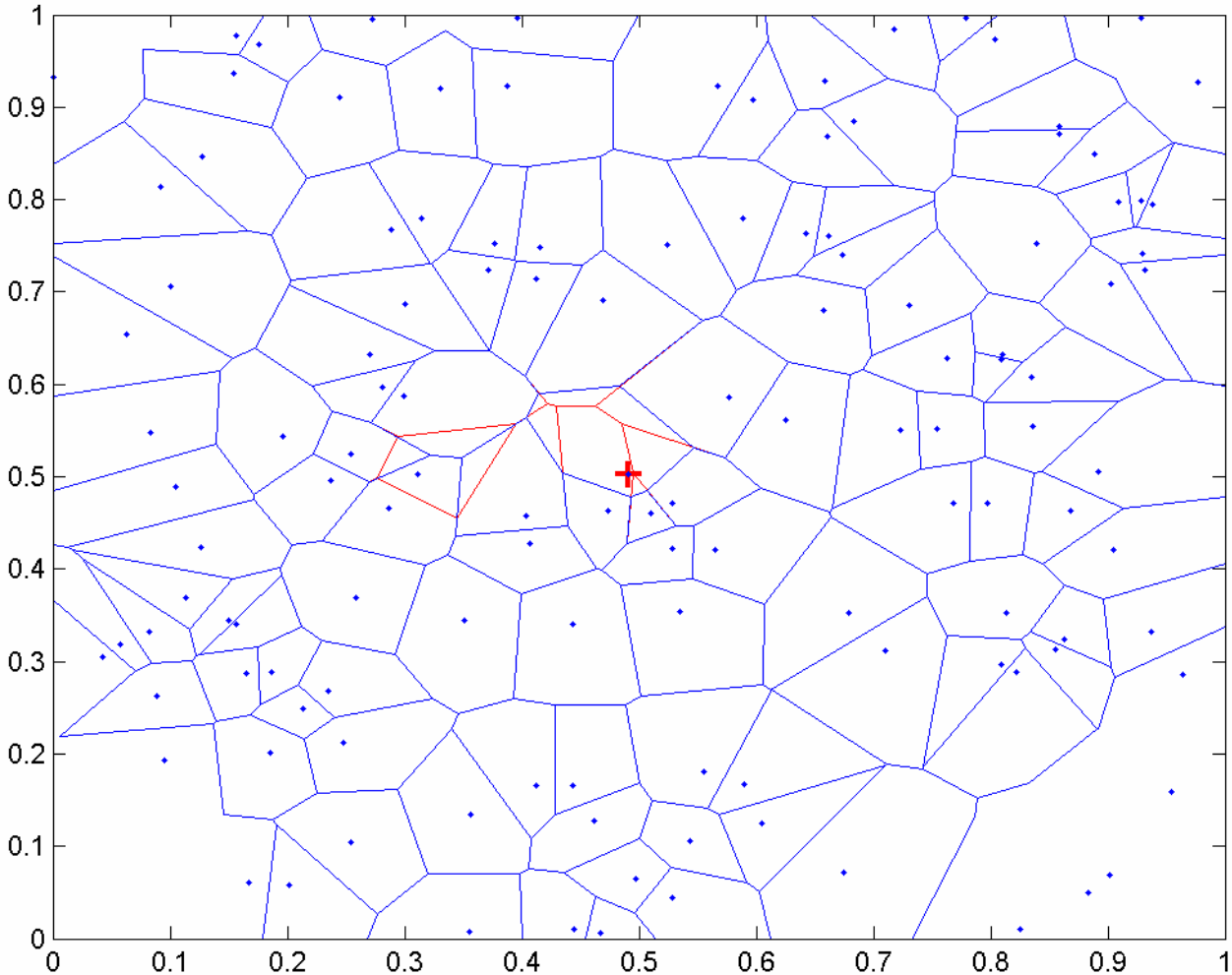
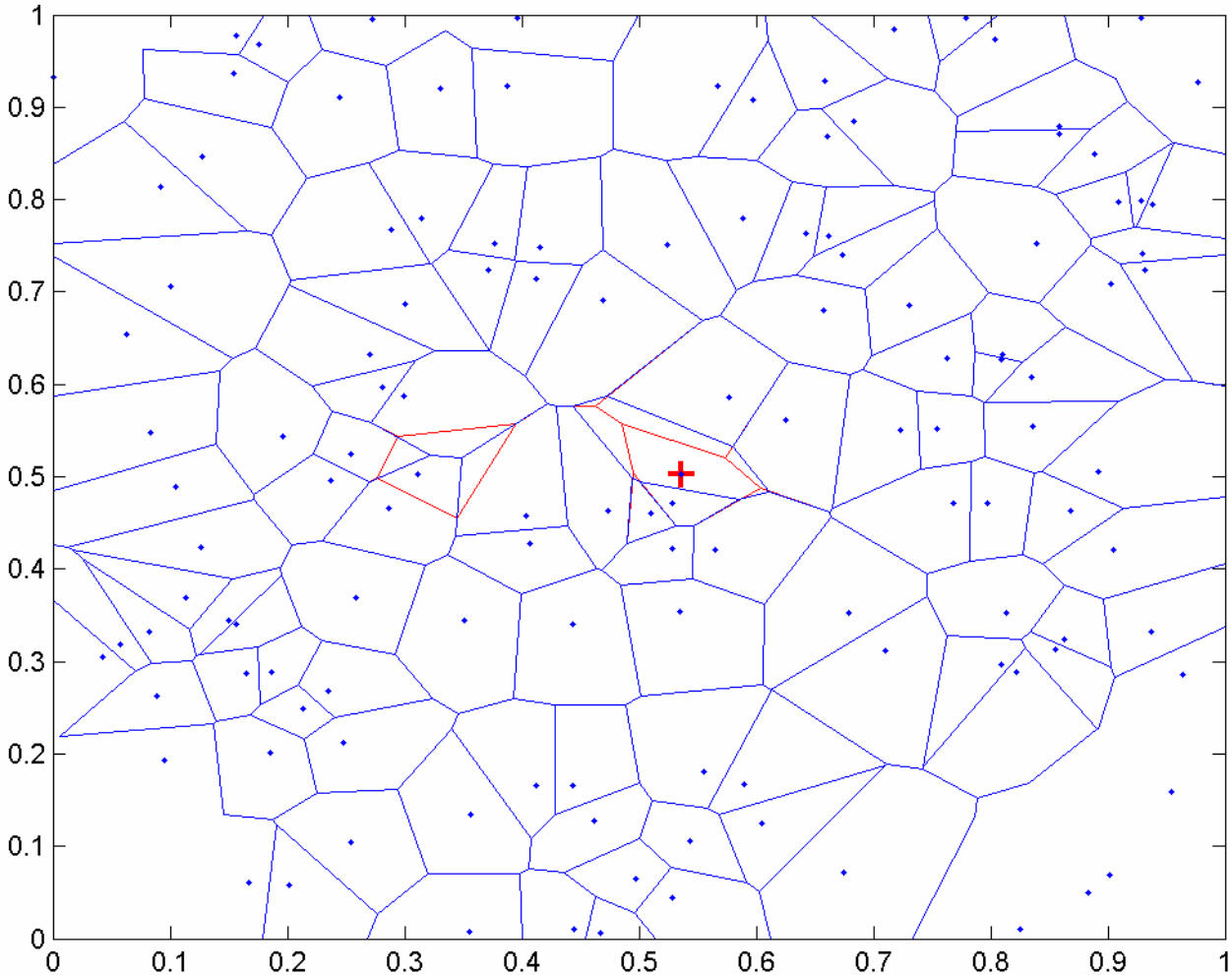
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


1
0.9
0.8
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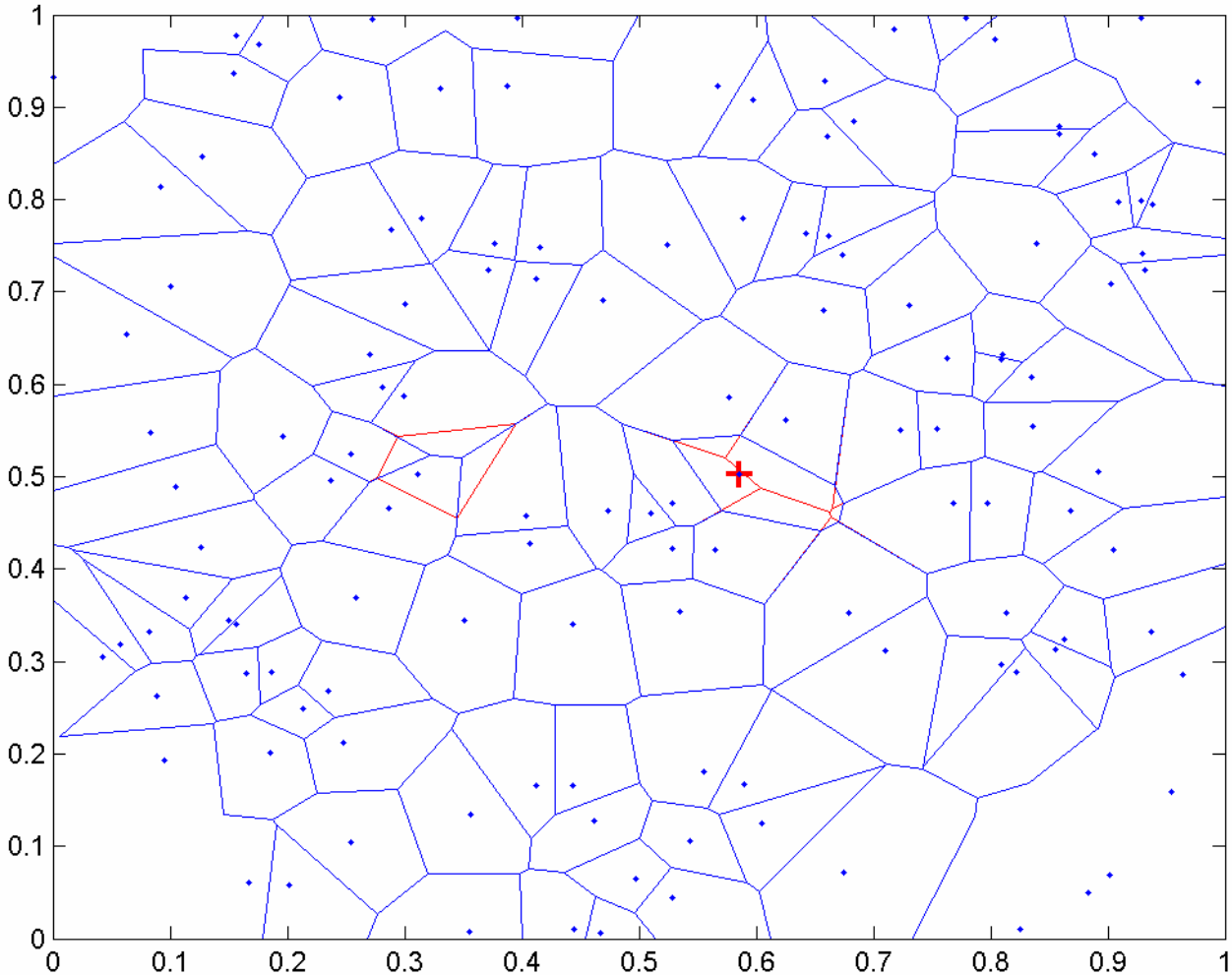
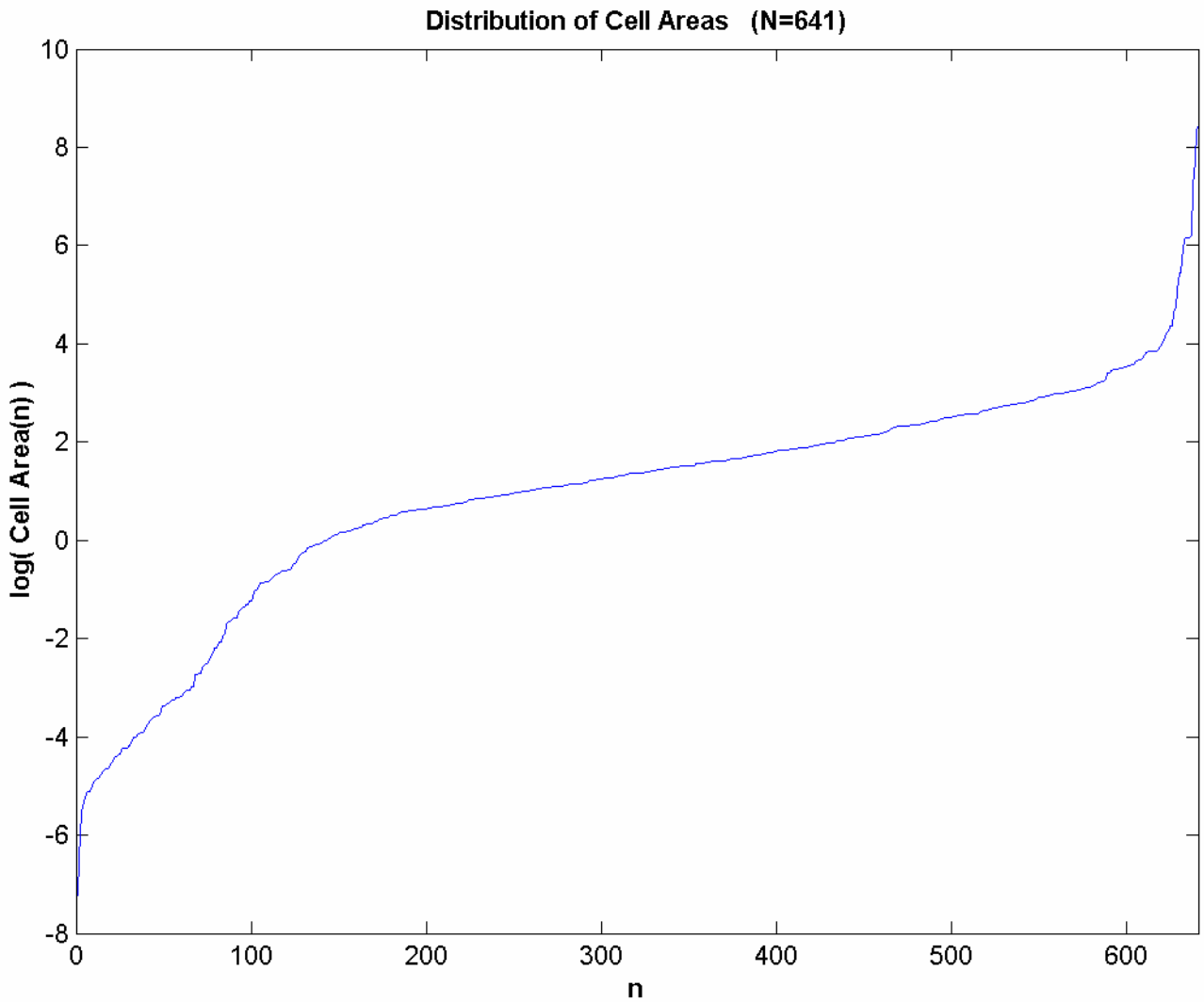
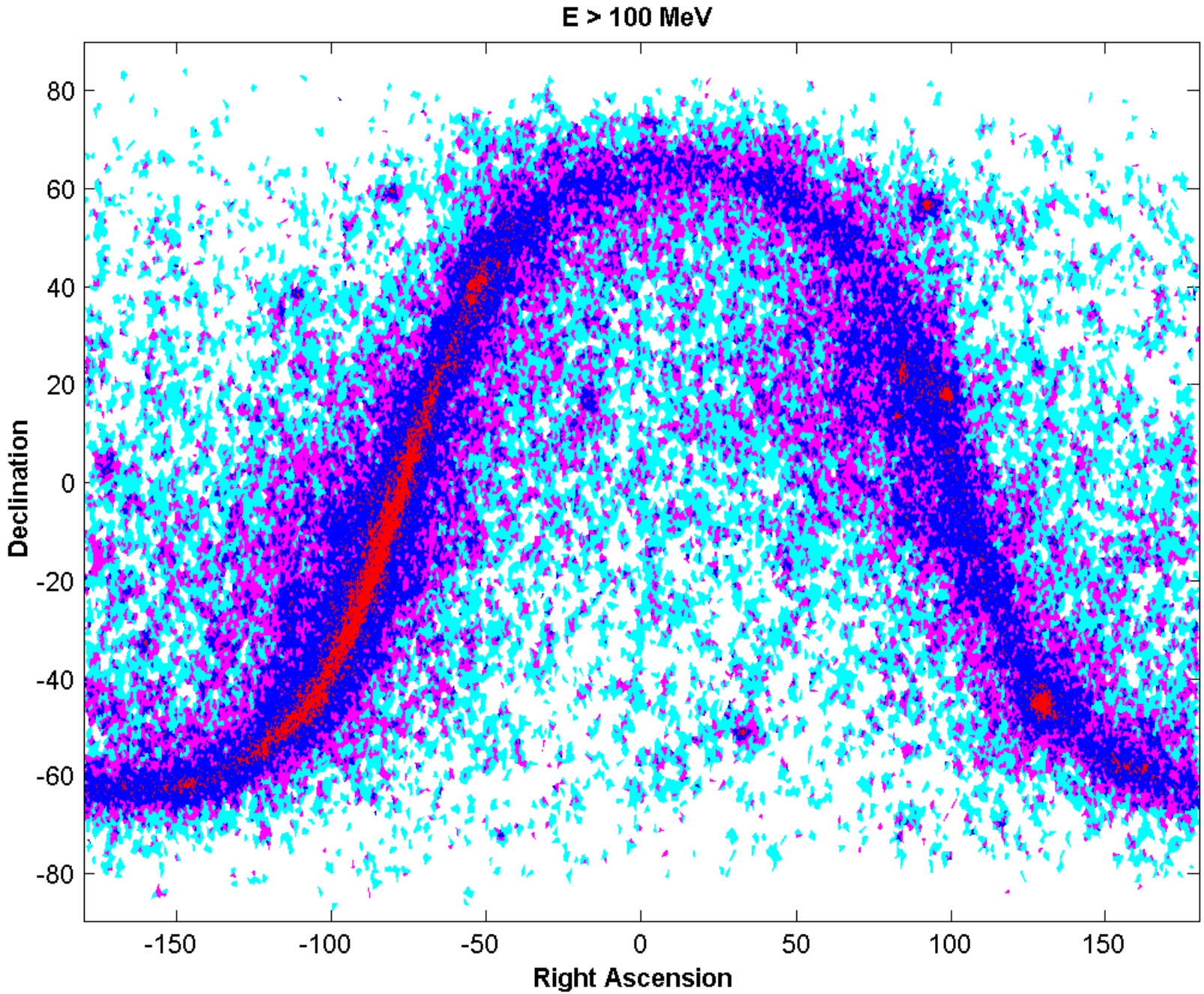
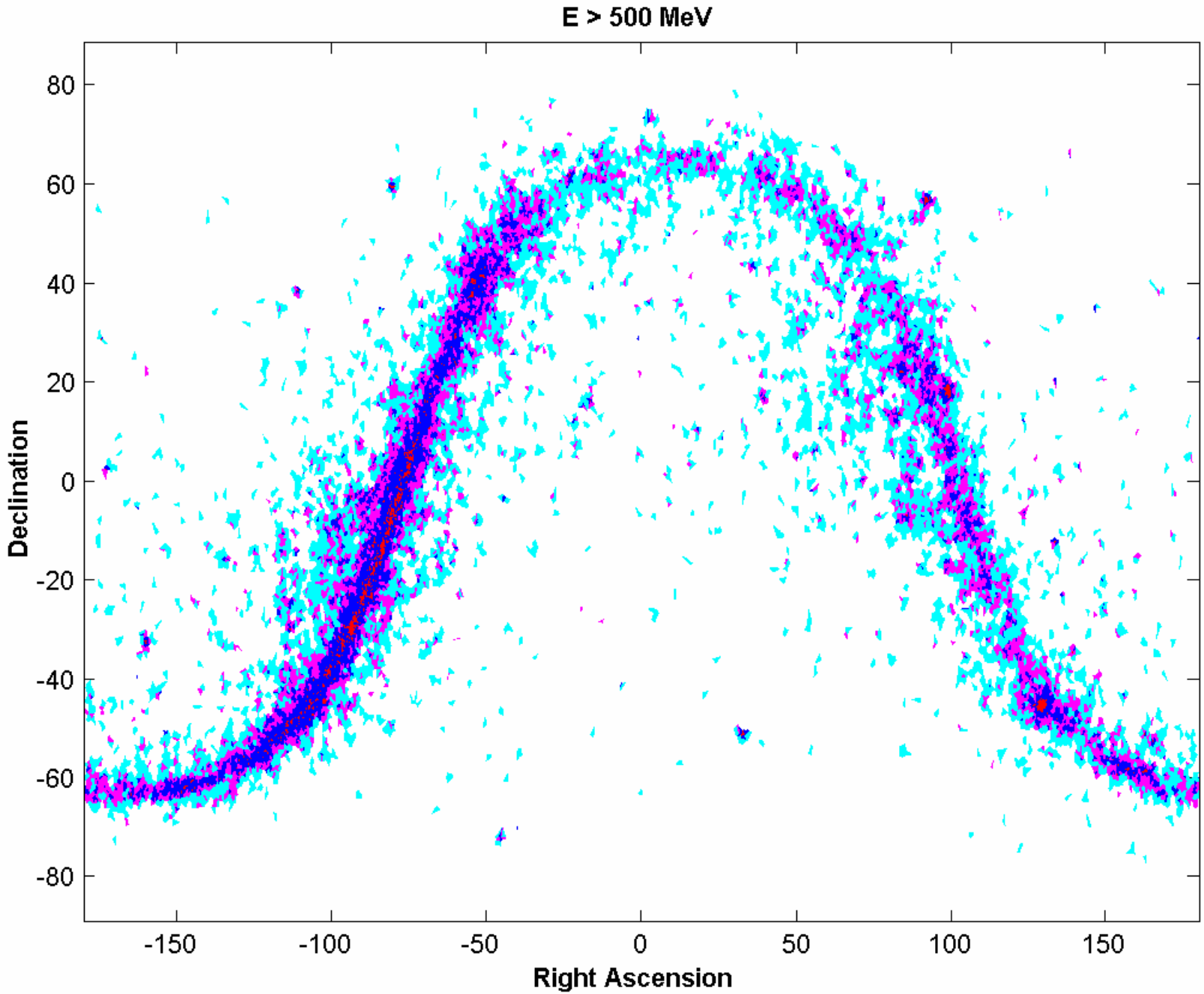
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

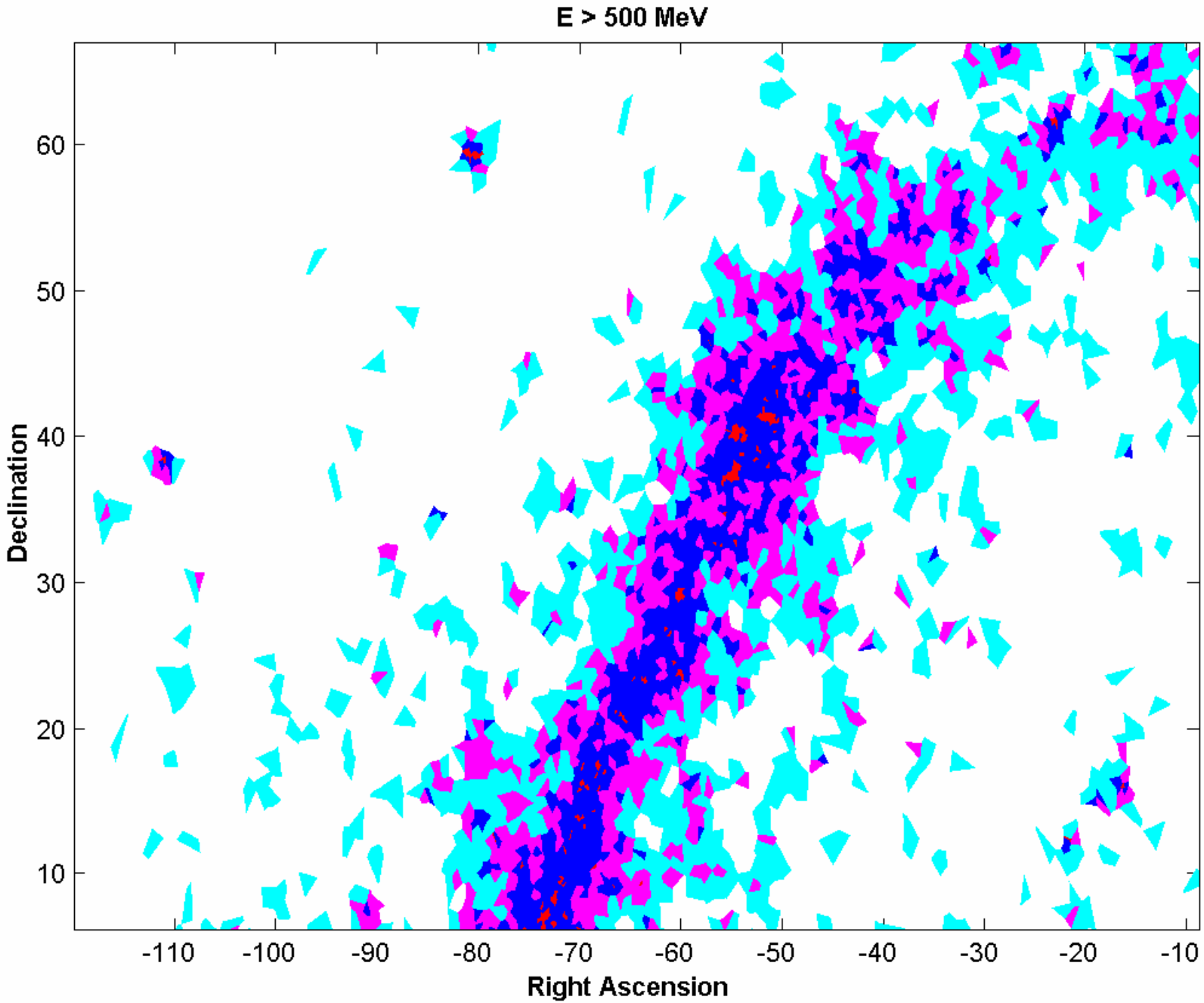

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

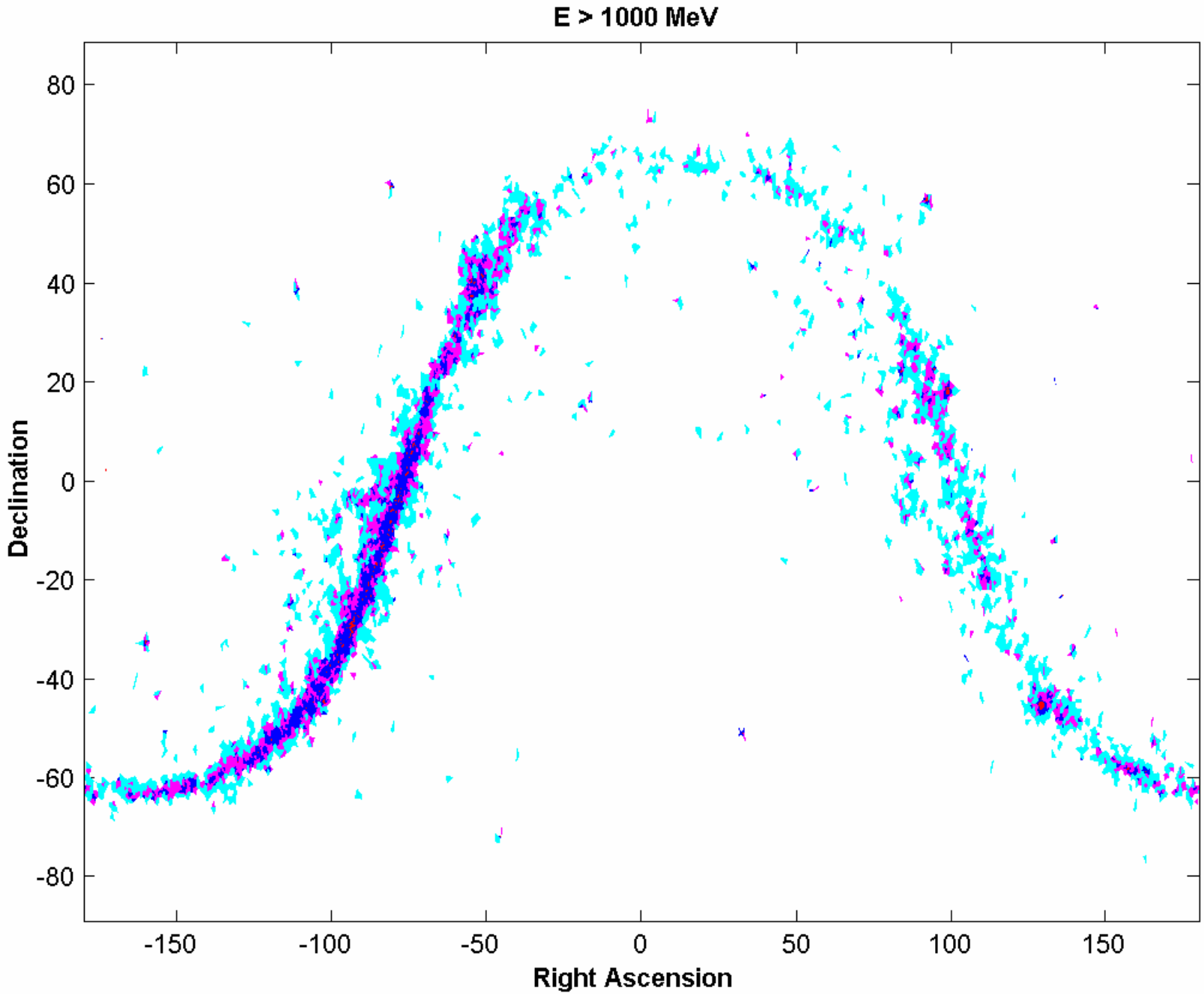
Selecting the smallest Voronoi cells yields the regions of highest photon density …

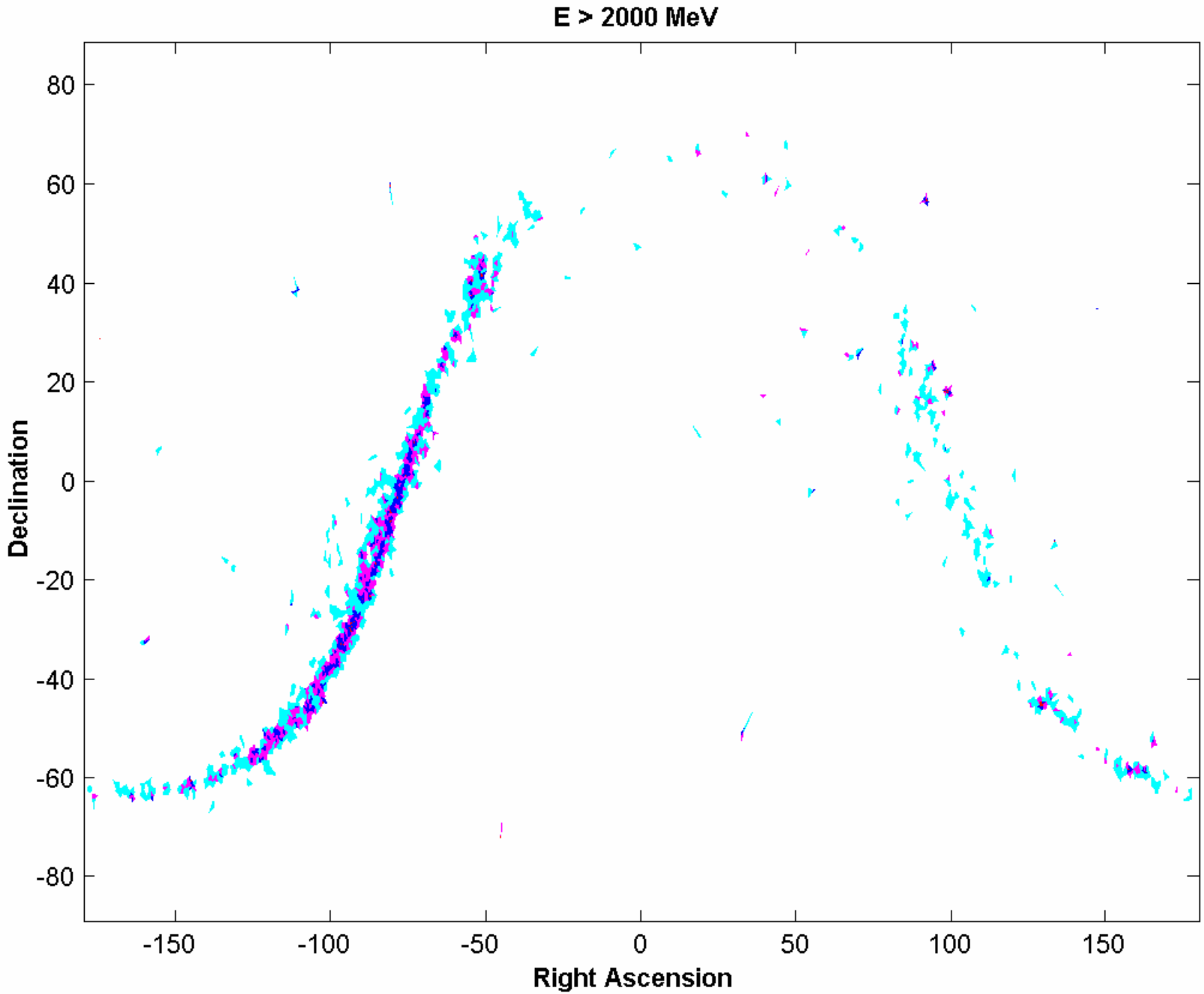

Distribution of Cell Areas (N=641)
log(Cell Area(n))
n
10
8
6
4
2
0
-2
-4
-6
-8
0
100
200
300
400
500
600

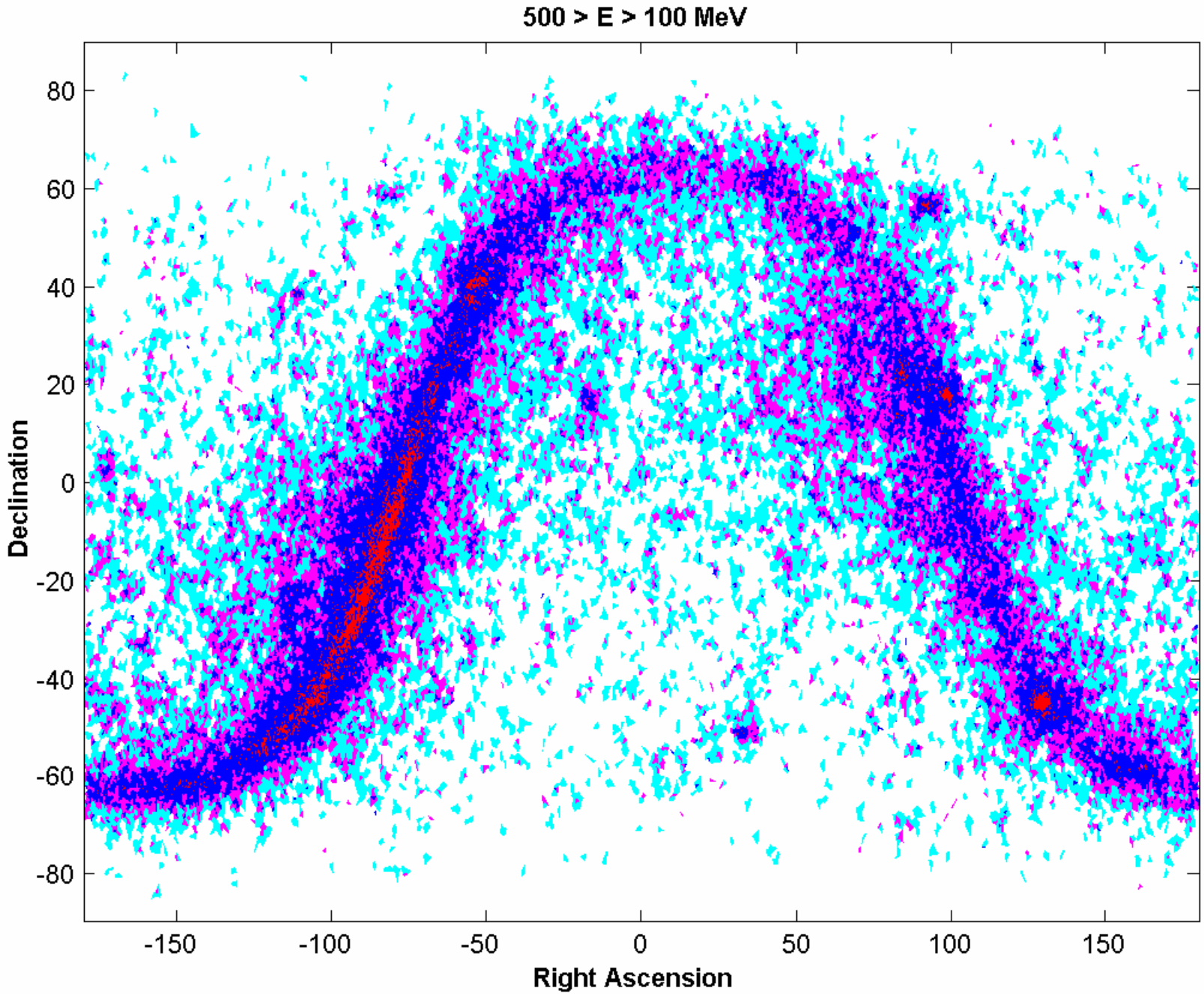

E > 100 MeV
Declination
Right Ascension
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150

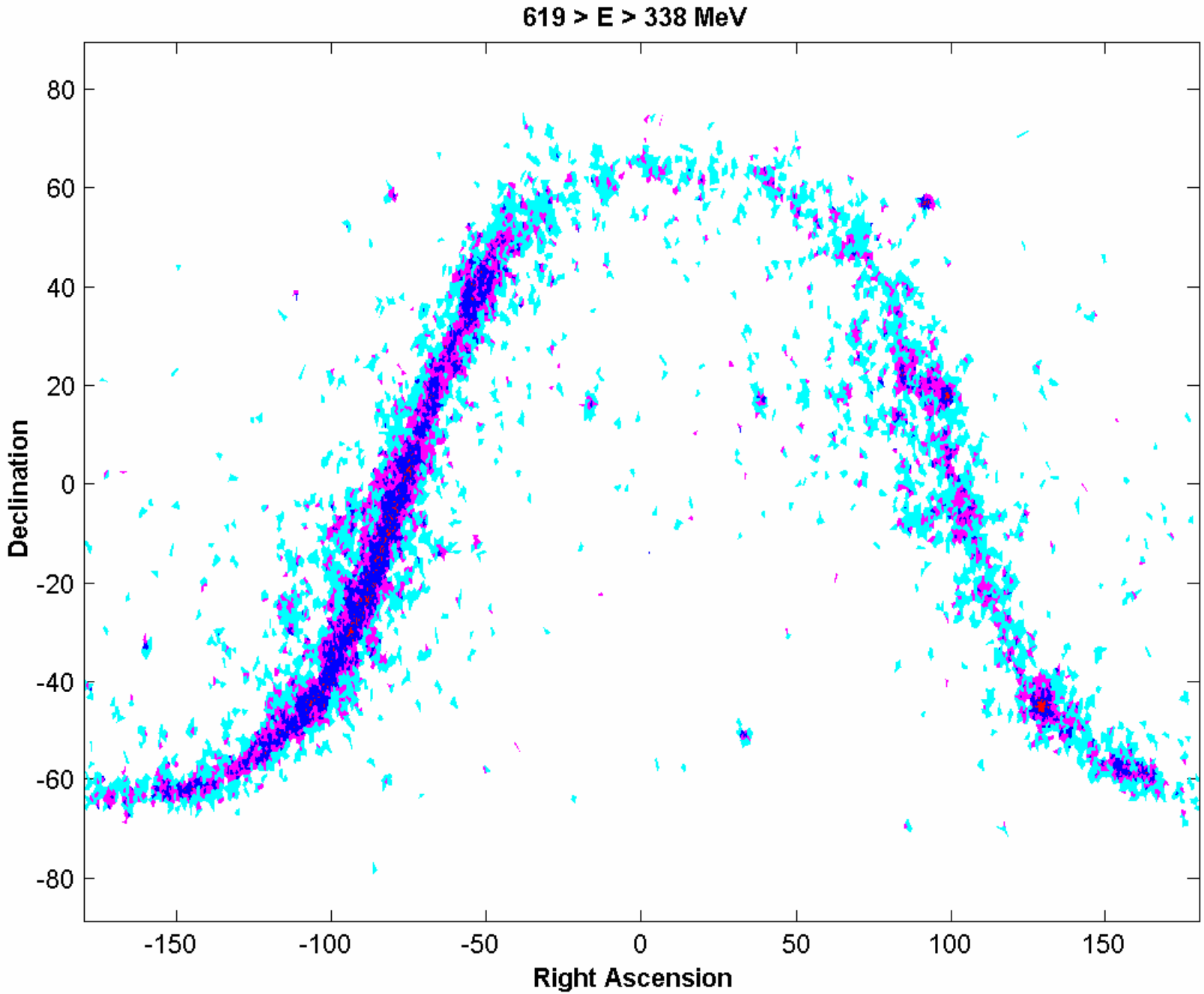

E > 500 MeV
Declination
Right Ascension
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150


E > 500 MeV
Declination
60
50
40
30
20
10
-110
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
Right Ascension

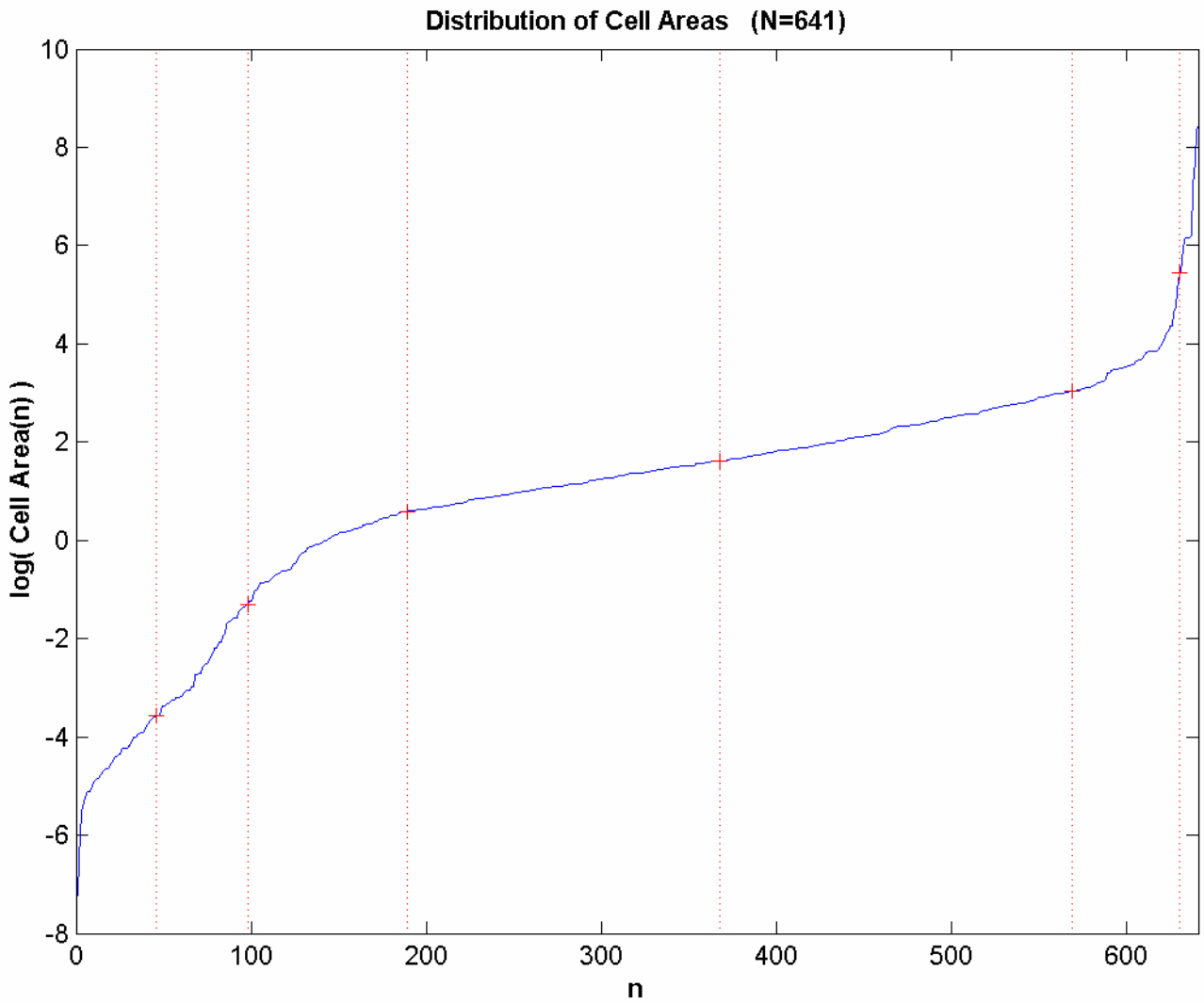

E > 1000 MeV
Declination
Right Ascension
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150

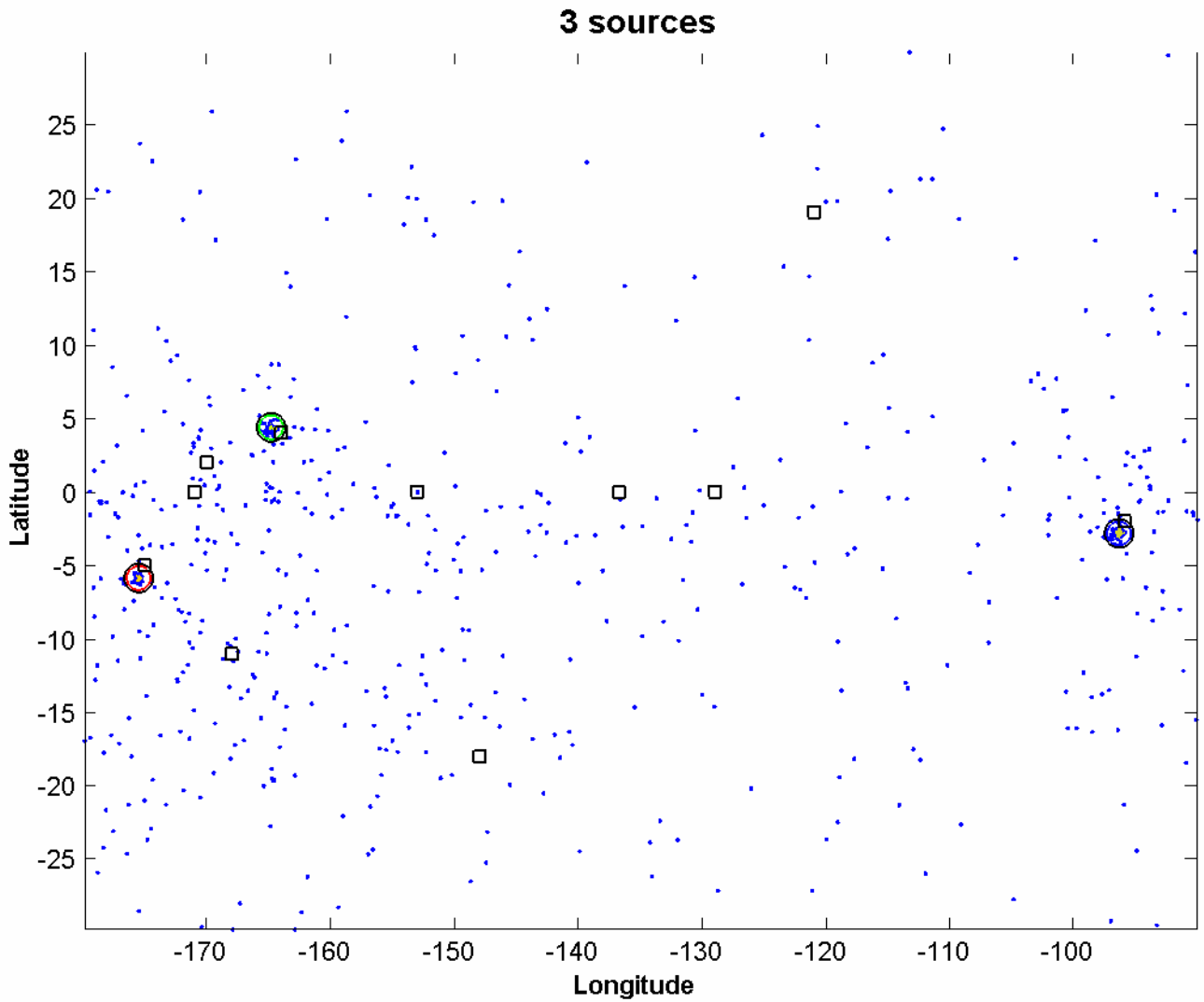

E > 2000 MeV
Declination
Right Ascension
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150

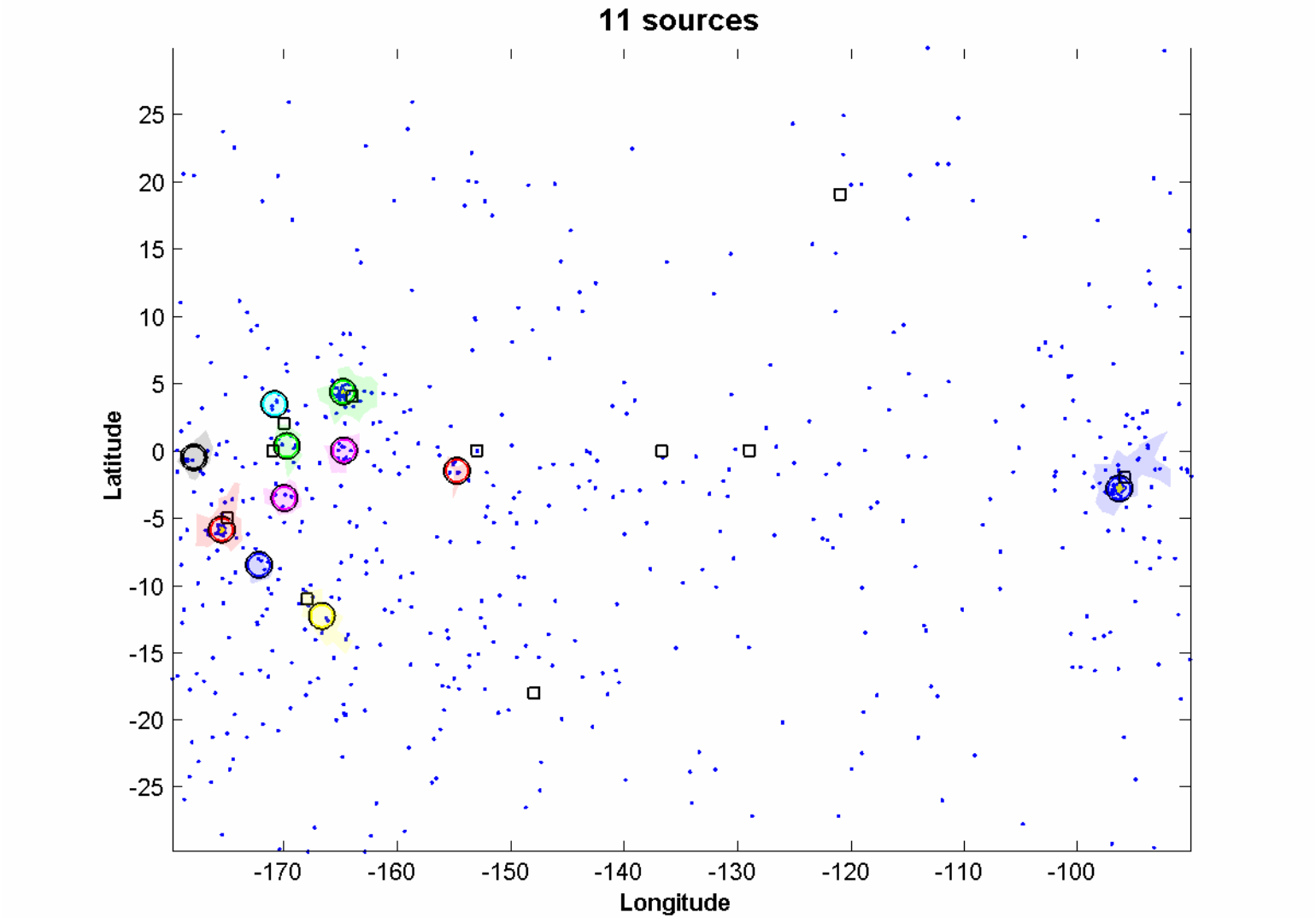

500 > E > 100 MeV
Declination
Right Ascension
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150

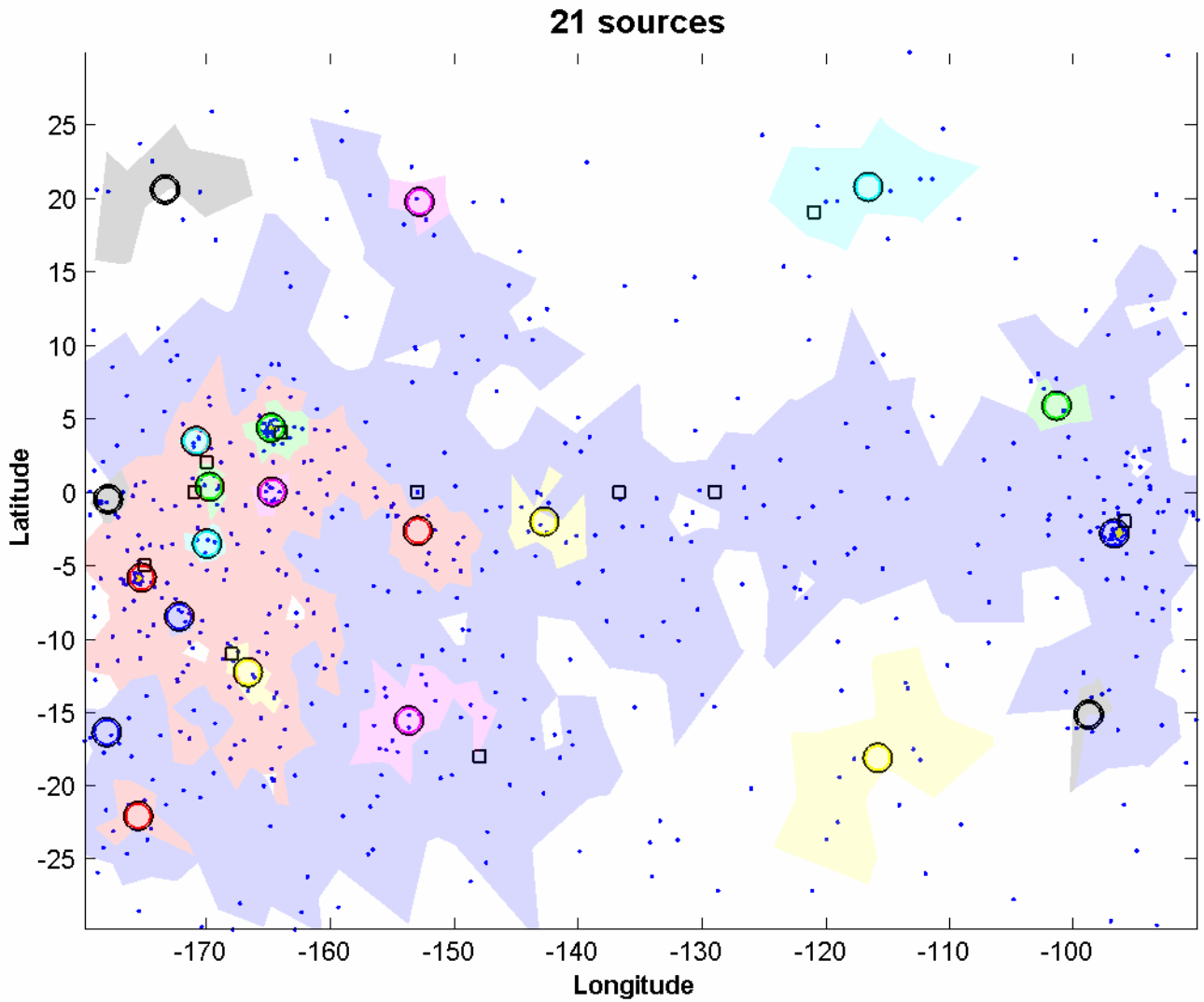

619 > E > 338 MeV
Declination
Right Ascension
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150

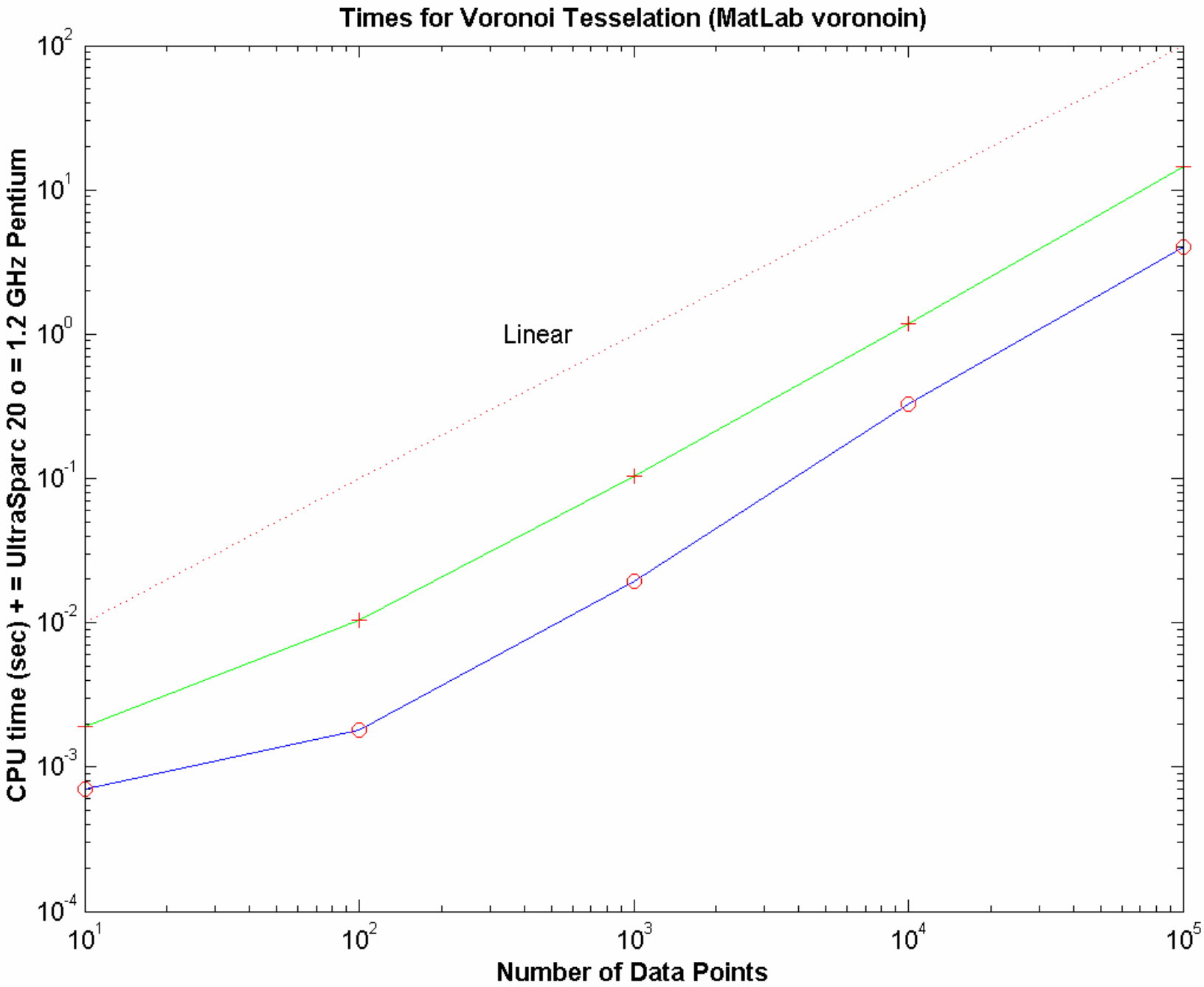
Bayesian Blocks is a procedure to find the optimal partition of the data …


Distribution of Cell Areas (N=641)
log(Cell Area(n))
n
10
8
6
4
2
0
-2
-4
-6
-8
0
100
200
300
400
500
600


3 sources
Latitude
Longitude
25
20
15
10
5
0
-5
-10
-15
-20
-25
-170
-160
-150
-140
-130
-120
-110
-100


11 sources
Latitude
Longitude
25
20
15
10
5
0
-5
-10
-15
-20
-25
-170
-160
-150
-140
-130
-120
-110
-100


21 sources
Latitude
Longitude
25
20
15
10
5
0
-5
-10
-15
-20
-25
-170
-160
-150
-140
-130
-120
-110
-100


Times for Voronoi Tesselation (MatLab voronoin)
CPU time (sec) + = UltraSparc 20 o = 1.2 GHz Pentium
Number of Data Points
Linear
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^1
10^2
10^3
10^4
10^5

#	Long	Lat	Num Phot	Source Energy
1	62.50	20.11	731	8765209.6
2	52.63	-0.003	1045	7030645.0
3	75.59	0.31	753	4379964.7
4	92.63	-10.45	482	3018021.7
5	97.21	17.20	516	7797753.1
6	78.06	1.93	454	1335709.1
7	80.45	0.68	332	530160.4
8	88.81	25.03	342	710672.4
9	55.93	-17.10	297	1229239.6
10	74.16	-2.61	224	654753.5
11	80.60	3.44	209	584043.3
12	44.44	13.37	324	1074323.7
13	65.96	-0.41	214	520481.0
14	44.39	2.68	267	1391815.8
15	88.86	22.91	132	143376.8
16	61.78	-3.79	174	401054.0
17	67.94	11.17	176	852013.4
18	56.97	17.82	188	341654.0
19	74.76	1.28	208	262288.3
20	81.75	-26.04	165	128282.8

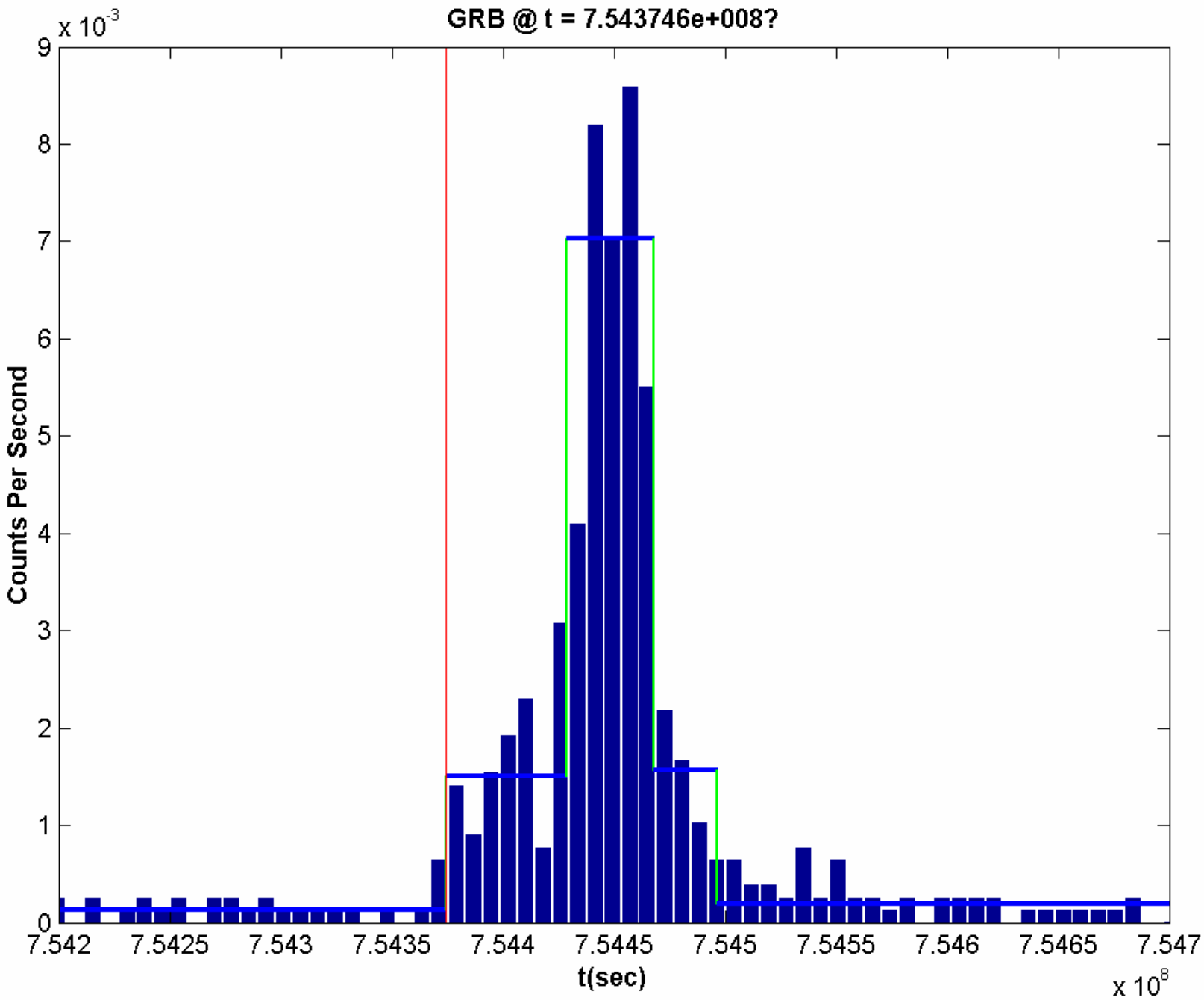
#	Long	Lati	Num Phot	Source Energy
21	52.29	-29.17	392	53034.6
22	46.53	7.63	143	162876.1
23	62.01	34.12	262	428850.9
24	48.95	-9.95	154	120926.9
25	98.98	30.17	383	34728.1
26	108.20	-9.59	253	171568.7
27	103.91	14.66	135	36411.2
28	98.42	24.16	205	118234.0
29	44.05	-5.08	134	35185.0
30	47.94	22.86	218	23638.0
31	72.45	32.72	140	23931.4
32	66.67	-32.08	152	24316.0
33	36.39	7.41	150	11782.7
34	40.72	-13.23	167	14916.5
35	73.34	-31.56	131	25798.9
36	92.38	-32.26	307	33192.3
37	96.36	-24.95	135	15657.4
38	110.82	3.55	153	53667.8
39	103.30	-20.01	155	14870.6

Action Items

- Post-processing step (identify sources from density estimate)
  - Better Ideas
  - Speed up (tree storage methods?)
- How to deal with PSF:
  - Constant*
  - Function of Energy
- Deal with variable exposure*

* Solved in 1D, but problematic in 2D+

And, just for fun …


GRB @ t = 7.543746e+008?
x 10^-3
9
8
7
6
5
4
3
2
1
0
Counts Per Second
7.542
7.5425
7.543
7.5435
7.544
7.5445
7.545
7.5455
7.546
7.5465
7.547
t(sec)
x 10^8