Updated AGASA event list above 4×10^{19}eV

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Abstract

After our Ap.J. publication of the Akeno Giant Air Shower Array (AGASA) results in 1999 (Takeda et al., 1999), we observed nine events with energies above 4×10^{19}eV until May 2000. This short report lists the coordinates of these events, and shows the updated energy spectrum and arrival direction map. The analysis was carried out with the same procedure employed in the Ap.J. publication.

1 Introduction

The Akeno Giant Air Shower Array (AGASA) has been operated in stable since 1990 and the exposure exceeds 4.0×10^{16} m^2 s sr until the end of May 2000. Since there are many requests to use new events after the publication of the event list in PRL [1] and Ap.J. [2], we show the updated list in this report. The analysis was carried out with the same parameters used in the previous papers [1, 2].

Although the zenith angle range is limited less than 45° in the present analysis, our dataset has now enough statistics to determine experimentally the lateral distribution of shower particles and the attenuation of S(600) with atmospheric depth to larger zenith angles in energy range of $\gtrsim 3 \times 10^{19}$eV. Our energy estimation procedure for larger zenith angles is now under careful investigation, and we may be able to apply a refined attenuation length beyond 45°. This may modify the parameters in the energy estimation procedure slightly; but we can extend our observable sky to larger zenith angles than 45° and increase the effective exposure of AGASA in our next full-paper publication.

In this report, we first show the updated energy spectrum above 3×10^{18}eV with events until May 2000. And then we show the cosmic-ray arrival direction distribution with the additional dataset of the Akeno 20 km^2 array (A20) before 1990. Important informations for the present analysis are listed below, and for details refer our publications [1, 2, 3, 4, 5, 6, 7, 8].

Exposure :	4.0×10^{16} m^2 s sr
Energy conversion formula :	$E = 2.03 \times 10^{17}\ S_0(600)$ eV
Attenuation of S(600) :	$S_\theta(600) = S_0(600) \exp\left[-\frac{920}{500}(\sec\theta - 1) - \frac{920}{594}(\sec\theta - 1)^2\right]$
Error in S(600) determination :	$\pm$ 30 % above 10^{19}eV
Error in arrival direction determination :	1.6° above 4×10^{19}eV

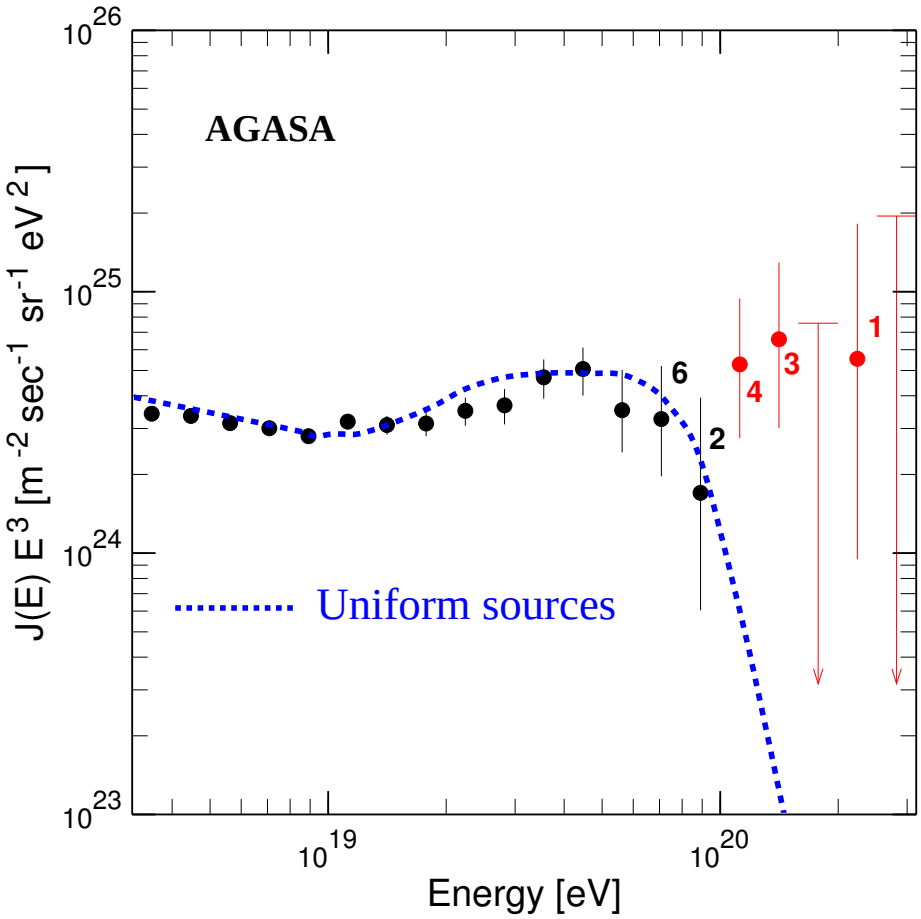

Figure 1: Energy spectrum observed with AGASA. The vertical axis is multiplied by E^3. Error bars represent the Poisson upper and lower limits at 68% and arrows are 90% C.L. upper limits. Numbers attached to points show the number of events in each energy bin. The dashed curve represents the spectrum expected for extragalactic sources distributed uniformly in the Universe, taking account of the energy determination error.

2 Updated Results

The updated energy spectrum observed with AGASA (without A20) is shown in Figure 1, multiplied by E^3 in order to emphasize details of the steeply falling spectrum. Error bars represent the Poisson upper and lower limits at 68% and arrows are 90% C.L. upper limits. Numbers attached to points show the number of events in each energy bin. The dashed curve represents the spectrum expected for extragalactic sources distributed uniformly in the Universe, taking account of the energy determination error [9]. Now we observed 8 events above 10^{20}eV.

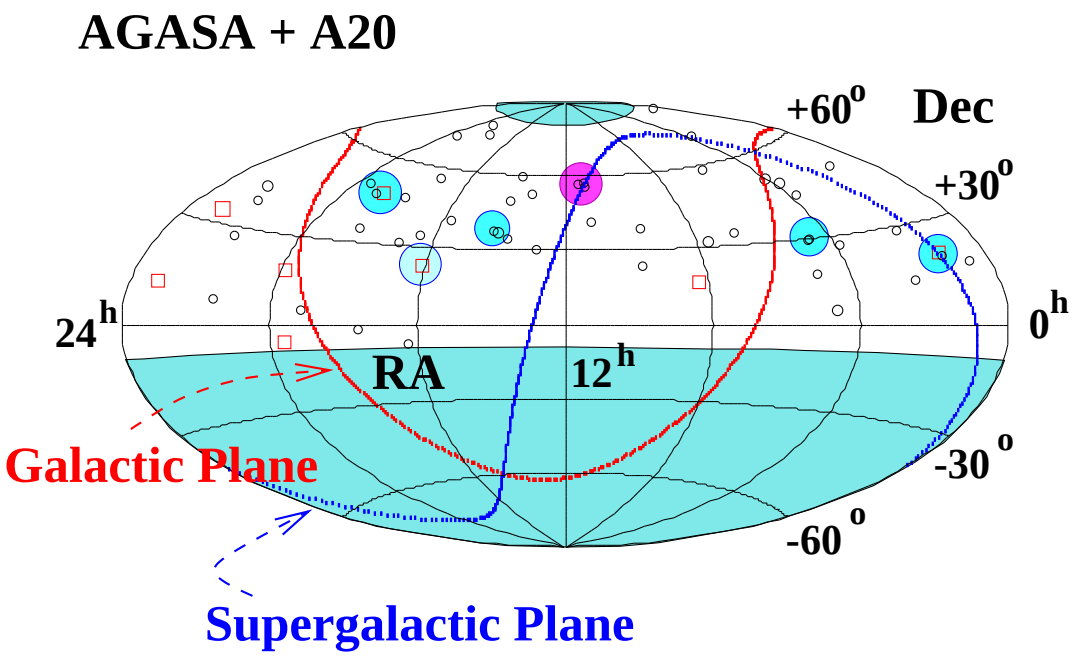

Figure 2: Arrival directions of cosmic rays with energies above $10^{19.0}$eV on the equatorial coordinates. Open circles, and open squares represent cosmic rays with energies of $(4-10)\times 10^{19}$eV, and $\geq 10^{20}$eV, respectively. The galactic and supergalactic planes are shown by the red and blue curves. Large circles indicate event clusters within 2.5° as noted in Table 1.

Figure 2 shows arrival directions of cosmic rays with energies above 4×10^{19}eV in the equatorial coordinates. Open circles, and Open squares represent cosmic rays with energies of $(4-10)\times 10^{19}$eV, and $\geq 10^{20}$eV, respectively. The shaded regions indicate the celestial regions excluded in this paper due to the zenith angle cut of $\leq 45°$. The galactic and supergalactic planes are drawn by the red and blue curves. The shaded circle near the center is the C2 triplet – three events are observed within 2.5° – and the chance probability of observing such triplet under an isotropic distribution is about 1 %. This value becomes somewhat larger than our Ap.J. publication [2], but this triplet is an interesting phenomenon. A new doublet is observed around (14^h 10^m, 37.5°), which is referred to as "C6" on the basis of our Ap.J. publication [2].

Table 1: AGASA + A20 events above 4×10^{19}eV

Date	Time	Energy	Coordinates				
			α	δ	l^G	b^G	
84/12/12	14:18:02	6.81×10^{19} eV	$22^h\ 21^m$	38.4°	93.3°	−15.7°	
84/12/17	10:28:16	9.79	$18^h\ 29^m$	35.3°	63.5°	19.4°	
86/01/05	19:31:03	5.47	$4^h\ 38^m$	30.1°	170.4°	−11.2°	C4
86/10/23	14:25:15	6.22	$14^h\ 02^m$	49.9°	96.8°	63.4°	
87/11/26	17:49:20	4.82	$21^h\ 57^m$	27.6°	82.1°	−21.1°	
89/03/14	02:45:39	5.27	$13^h\ 48^m$	34.7°	68.3°	75.6°	
89/08/16	08:32:01	4.07	$5^h\ 51^m$	58.5°	154.5°	15.6°	
90/11/25	11:05:39	4.51	$16^h\ 17^m$	−7.2°	6.1°	29.6°	
91/04/03	00:32:40	5.09	$15^h\ 47^m$	41.0°	65.7°	51.5°	
91/04/20	08:24:49	4.35	$18^h\ 59^m$	47.8°	77.9°	18.4°	C3
91/05/31	13:07:04	5.53	$3^h\ 37^m$	69.5°	136.6°	11.2°	
91/11/29	14:53:03	9.10	$19^h\ 06^m$	77.2°	108.8°	25.6°	
91/12/10	18:59:10	4.24	$0^h\ 12^m$	78.6°	121.0°	15.9°	
92/01/07	03:16:49	4.51	$9^h\ 36^m$	38.6°	184.3°	48.0°	
92/01/24	12:26:17	4.88	$17^h\ 52^m$	47.9°	74.8°	29.4°	
92/02/01	17:20:52	5.53	$0^h\ 34^m$	17.7°	117.2°	−45.0°	
92/03/30	03:05:30	4.47	$17^h\ 03^m$	31.4°	53.6°	35.6°	
92/08/01	13:00:47	5.50	$11^h\ 29^m$	57.1°	143.2°	56.6°	C2
92/09/13	08:59:44	9.25	$6^h\ 44^m$	34.9°	180.5°	13.9°	
93/01/12	02:41:13	**10.1**	$8^h\ 17^m$	16.8°	206.7°	26.4°	
93/01/21	07:58:06	4.46	$13^h\ 55^m$	59.8°	108.8°	55.5°	
93/04/22	09:39:56	4.42	$1^h\ 56^m$	29.0°	139.8°	−31.7°	
93/06/12	06:14:27	6.49	$1^h\ 16^m$	50.0°	127.0°	−12.7°	
93/12/03	21:32:47	**21.3**	$1^h\ 15^m$	21.1°	130.5°	−41.4°	C1
94/07/06	20:34:54	**13.4***	$18^h\ 45^m$	48.3°	77.6°	20.9°	C3
94/07/28	08:23:37	4.08	$4^h\ 56^m$	18.0°	182.8°	−15.5°	
95/01/26	03:27:16	7.76	$11^h\ 14^m$	57.6°	145.5°	55.1°	C2
95/03/29	06:12:27	4.27	$17^h\ 37^m$	−1.6°	22.8°	15.7°	
95/04/04	23:15:09	5.79	$12^h\ 52^m$	30.6°	117.5°	86.5°	
95/10/29	00:32:16	5.07	$1^h\ 14^m$	20.0°	130.2°	−42.5°	C1

$*$ The value on the Ap.J. publication is a typo.

Table 1: AGASA + A20 events above 4×10^{19}eV (contd.)

Date	Time	Energy	Coordinates				
			α	δ	l^G	b^G	
95/11/15	04:27:45	4.89×10^{19} eV	$4^h\ 41^m$	29.9°	171.1°	−10.8°	C4
96/01/11	09:01:21	**14.4**	$16^h\ 06^m$	23.0°	38.9°	45.8°	C5
96/01/19	21:46:12	4.80	$3^h\ 52^m$	27.1°	165.4°	−20.4°	
96/05/13	00:07:48	4.78	$17^h\ 56^m$	74.1°	105.1°	29.8°	
96/10/06	13:36:43	5.68	$13^h\ 18^m$	52.9°	113.8°	63.7°	
96/10/22	15:24:10	**10.5**	$19^h\ 54^m$	18.7°	56.8°	−4.8°	
96/11/12	16:58:42	7.46	$21^h\ 37^m$	8.1°	62.7°	−31.3°	
96/12/08	12:08:39	4.30	$16^h\ 31^m$	34.6°	56.2°	42.8°	
96/12/24	07:36:36	4.97	$14^h\ 17^m$	37.7°	68.5°	69.1°	C6
97/03/03	07:17:44	4.39	$19^h\ 37^m$	71.1°	103.0°	21.9°	
97/03/30	07:58:21	**15.0**	$19^h\ 38^m$	−5.8°	33.1°	−13.1°	
97/04/28	13:46:18	4.20	$2^h\ 18^m$	13.8°	152.9°	−43.9°	
97/11/20	07:23:25	7.21	$11^h\ 09^m$	41.8°	171.2°	64.6°	
98/02/06	00:12:26	4.11	$9^h\ 47^m$	23.7°	207.2°	48.6°	
98/03/30	08:17:26	6.93	$17^h\ 16^m$	56.3°	84.5°	35.3°	
98/04/04	20:07:03	5.35	$11^h\ 13^m$	56.0°	147.5°	56.2°	C2
98/06/12	06:43:49	**12.0**	$23^h\ 16^m$	12.3°	89.5°	−44.3°	
98/09/03	23:42:48	4.69	$19^h\ 36^m$	50.7°	83.1°	14.0°	
98/10/27	00:45:37	6.11	$3^h\ 45^m$	44.9°	152.4°	−7.8°	
99/01/22	08:43:54	7.53	$19^h\ 11^m$	5.3°	39.9°	−2.1°	
99/07/22	08:11:14	4.09	$7^h\ 39^m$	32.2°	187.5°	23.6°	
99/07/28	04:08:49	7.16	$3^h\ 46^m$	49.5°	149.8°	−4.0°	
99/09/22	01:43:30	**10.4**	$23^h\ 03^m$	33.9°	98.5°	−23.8°	
99/09/25	20:13:49	4.95	$22^h\ 40^m$	42.6°	98.8°	−14.0°	
99/10/20	03:46:21	6.19	$4^h\ 37^m$	5.1°	191.3°	−26.5°	
99/10/20	22:01:35	4.29	$4^h\ 02^m$	51.7°	150.3°	−0.7°	
00/05/26	18:38:16	4.98	$14^h\ 08^m$	37.1°	69.3°	71.0°	C6
97/04/10	02:48:48	3.89**	$15^h\ 58^m$	23.7°	39.1°	47.8°	C5

** This energy is just below the 4×10^{19}eV cut.

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