~~Check figure for systematic deviation.~~

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DETECTION OF ANISOTROPY IN THE COSMIC BLACKBODY RADIATION*

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$$T(\hat{r}) = T_0 + T_1 \cos(\hat{r}, \hat{r}_{MAX})$$

ABSTRACT

We have detected anisotropy in the cosmic blackbody radiation with a 33 GHz (0.9 cm) twin-antenna Dicke radiometer flown aboard a U-2 aircraft to an altitude of 20 km. In data spanning approximately two-thirds of the northern hemisphere, we observe an anisotropy which is well-fit by a first-order spherical harmonic with an amplitude of $(3.2 \pm 0.6) \times 10^{-3}$°K, and an axis of symmetry in the direction (10.8 ± 0.5 hr R.A., 5° ± 10° dec). When expected backgrounds are subtracted, the amplitude is $(3.5 \pm 0.6) \times 10^{-3}$°K. This observation is readily interpreted as due to motion of the earth relative to the radiation with a velocity of 390 ± 60 km/sec.

direction of maximum temp

[redacted]

The observed isotropy of the 3°K cosmic blackbody radiation to about one part in 10^3 is the strongest evidence in support of the cosmological principle, the basic assumption of cosmology that the universe is isotropic and homogeneous on a large scale. Anisotropy at the 10^{-3} to 10^{-4} level is expected to exist from the Doppler shift due to the motion of the earth with respect to the ancient matter which emitted the radiation.[1] Anisotropies would also exist if there were non-symmetric expansion of the universe or large scale irregularities in the distribution of matter or energy. Until recently, interference from galactic emissions had prevented anisotropy in the cosmic blackbody radiation from being unambiguously observed.[2] Preliminary claims of a positive effect have been reported now by Corey and Wilkinson[3] and by this group.[4] We present here the results of a survey spanning approximately two-thirds of the northern hemisphere, taken at 0.9 cm, a wavelength at which the galactic background is small.

The experiment was conducted in a series of flights aboard the NASA-Ames Earth Survey (U-2) Aircraft. Anisotropy in the cosmic radiation was detected with a twin antenna Dicke radiometer which measured the difference in sky temperature between two regions 60° apart and on opposite sides of the zenith. The central frequency of the system was 33 GHz with a bandwidth of 2 GHz. Its sensitivity was limited by thermal noise with an RMS fluctuation of 0.044°K for an integration time of one second, or about 1 millidegree Kelvin (m°K) for a half hour. The apparatus is shown schematically in Figure 1; details of its design and construction are published elsewhere.[5]

Effort was made in the design of the apparatus to reduce all expected systematic errors well below the millidegree-Kelvin level. The

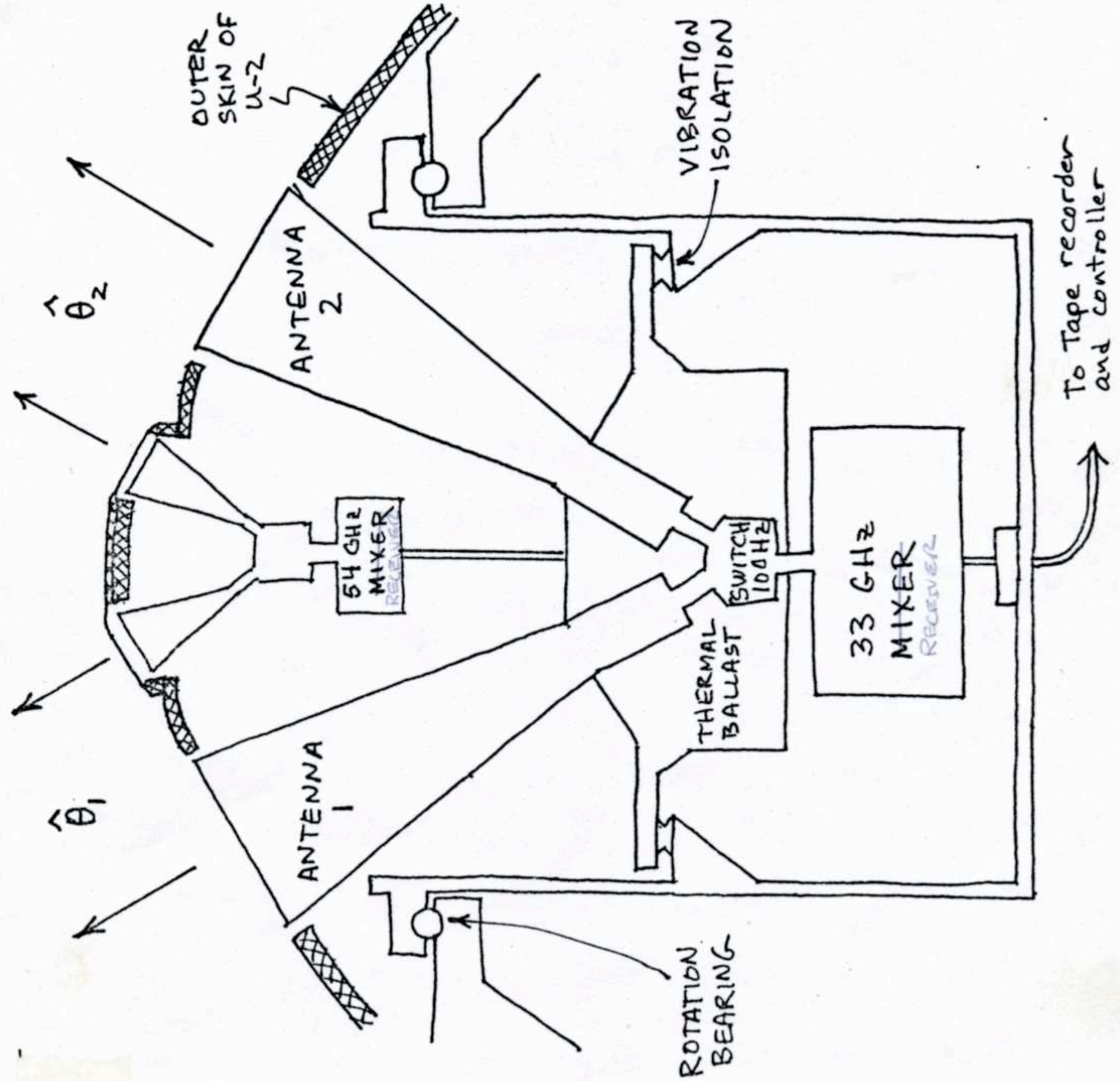


FIG. 1

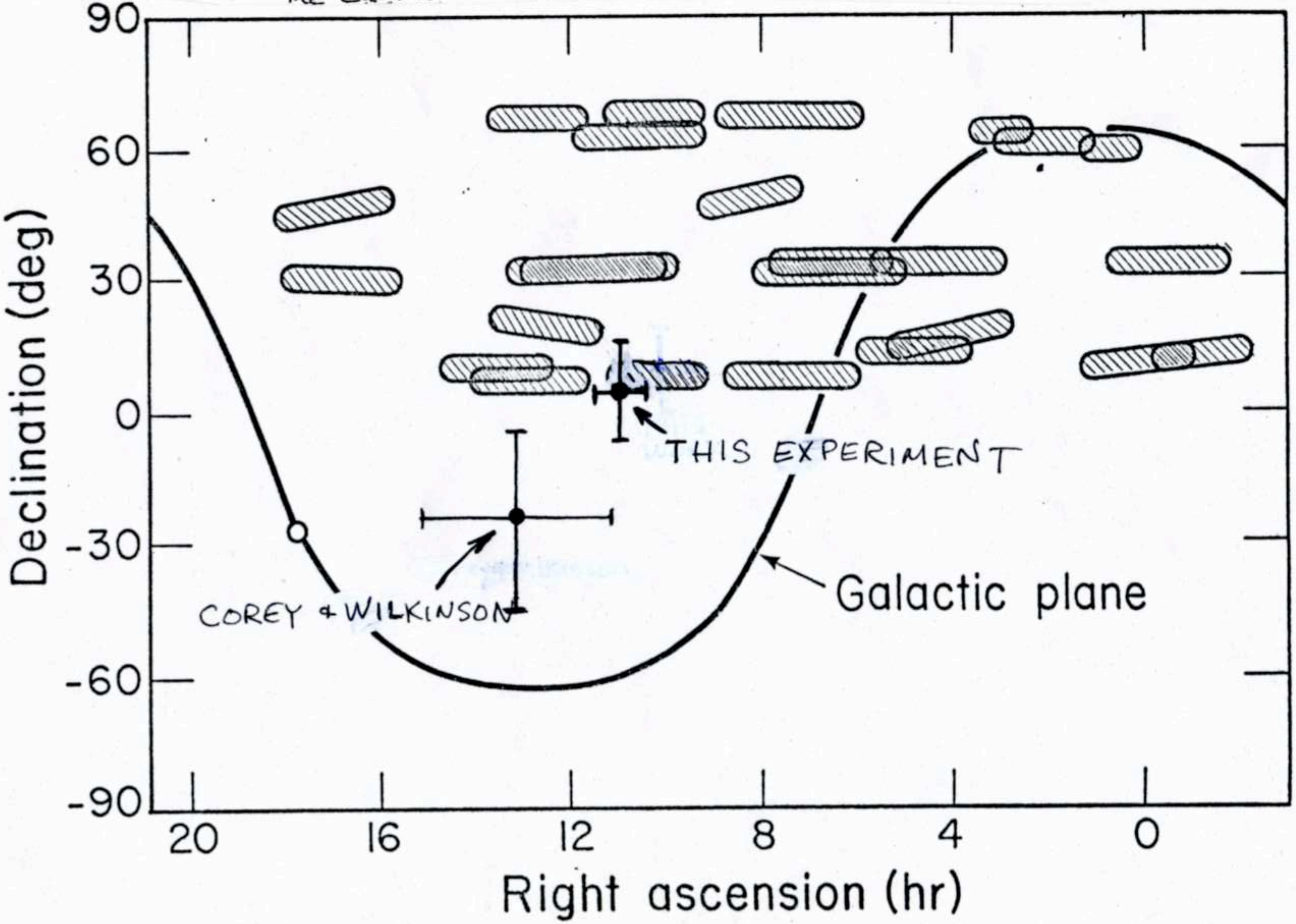
1. Schematic view of the apparatus mounted in the upper hatch of the U-2 aircraft. The anisotropy reported in this paper was detected with the 33 GHz radiometer; the 54 GHz radiometer monitored the oxygen anisotropy above the aircraft.

apparatus was r.f. and magnetically shielded, and was thermally stabilized. The antennas were of a special design (dual-mode corrugated cones) with a beam pattern 7° wide (FWHM) but whose sidelobes in the direction of the earth were below 70 dB, so that anisotropic emission from the earth and aircraft was less than 0.2 m°K. To measure potential anisotropic oxygen emission into the two antennas, we included in the apparatus a second twin-antenna radiometer operating at 54 GHz, sensitive to the strong oxygen emission region centered at 60 GHz. Atmospheric emission at 54 GHz is approximately 500 times as strong as at 33 GHz; the monitor was calibrated at altitude by banking the airplane at angles of 5° to 25°. The monitor showed during data-taking periods that the autopilot maintained level flight to better than 0.2° of bank; the resulting temperature difference at 33 GHz is less than 0.2 m°K.

Spurious anisotropies were detected and eliminated through a hierarchy of reversals. Rapid switching (100 Hz) between the two antennas reduced the effects of gain fluctuations (1/f noise). Spurious anisotropy generated by imbalance in the two arms of the radiometer (≈60 m°K) was canceled by interchange of the two antennas through a rotation of the apparatus by 180° about the vertical every 64 seconds. Spurious anisotropy associated with the rotation state of the antennas (≈2 m°K) was eliminated by reversing the flight path of the airplane every 20 minutes.

The data reported here were taken on eight flights between December 1976 and May 1977. Each flight yielded about 3.5 hours of data taken at altitude; Fig. 2 shows the total sky coverage. A typical flight plan consisted of six pairs of "legs" flown in opposite directions along the ground. In addition to the data legs, when possible the flights included

FIGURE 2. Sky coverage for the eight flights is indicated by the shaded regions. Each ~~region~~ oval region consists of several ~~flight~~ "legs" from the same flight. The width of ~~the~~ each region was determined from the antenna pattern (7° FWHM), and the length was set by the motion of the U-2 and the ~~rotation of~~ the earth.



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add data points ??

a "moon leg" in which one antenna pointed directly at the moon for a few minutes; this allowed us to determine our absolute calibration at altitude to about 2%.

The data were fit by a least-squares method to a sum of spherical harmonics. Only the first spherical harmonic is necessary to obtain a good fit (χ^2 = 91 for 80 data points). Thus the temperature in the direction $\hat{\theta}$ is given by:

$$T(\theta) = T_o + T_1 \cos(\hat{\theta},\hat{n}) \quad (1)$$

Here T_o is the average blackbody temperature (not measured in this experiment) and T_1 and $\hat{n}$ are the parameters of the fit and $(\hat{\theta},\hat{n})$ is the angle made by the unit vectors $\hat{\theta}$ and $\hat{n}$. The best fit is obtained for T_1 = 3.2 ± 0.6 m°K and $\hat{n}$ = (10.8 ± 0.5 hr R.A.; 5° ± 10° dec). In galactic coordinates $\hat{n}$ = (54° ± 10° lat.; 245° ± 15° long.).

Inclusion of second-order spherical harmonics in the fit changes the values of T_1 and $\hat{n}$ by much less than one standard deviation. An additional fit was made in which background contributions (Table I) were calculated and subtracted for each leg prior to the least-squares minimization; the resulting best-fit values were T_1 = 3.5 ± 0.6 m°K and $\hat{n}$ = (11.0 ± 0.5 hr R.A.; 6° ± 10° dec).

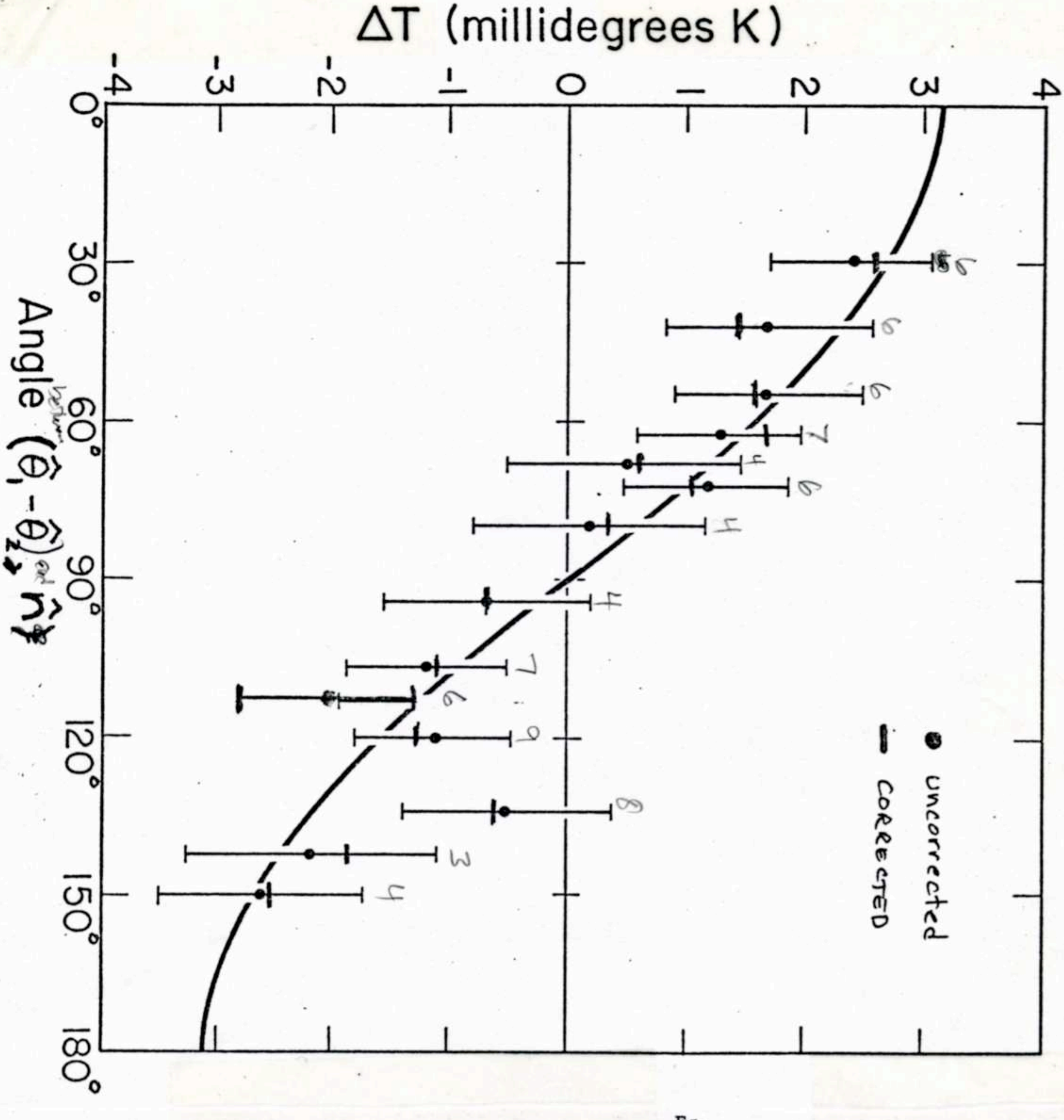
The data, with and without corrections, are plotted in Fig. 3, along with the best fit curve to the uncorrected data. The residuals are small; to a 90% confidence level they are $\lesssim 10^{-3}$°K. Thus, *except for a component that varies as cosine $(\hat{\theta},\hat{n})$*, the cosmic blackbody radiation is isotropic to one part in 3000.

The cosine anisotropy is most readily interpreted as due to the motion of the earth relative to the rest frame of the cosmic blackbody radiation, what Peebles calls the "new Aether Drift". Using 2.7°K for T_o and the fit to the corrected data, we calculate that the earth is

TABLE I

RESIDUAL SYSTEMATIC EFFECTS

EFFECT	MAXIMUM CORRECTION (m°K)	RESULTING CHANGE IN FIT (m°K)
Galactic Backgrounds		
Synchrotron Radiation	0.5	0.1
Ionized Hydrogen (HII Regions)	0.1	0.0
Radio Sources	0.1	0.0
Dust	0.0	0.0
Atmospheric Anisotropy	0.15	0.1
Antenna Side Lobes	0.2	0.0
Antenna Temperature Difference	0.1	0.1
Motion of Earth Around Sun	0.24	0.1
Jupiter	0.0	0.0
Combined	0.5	0.3 m°K



3. Comparison of the data with the fit to Eq. 1. The temperature difference $\Delta T = T(\hat{\theta}_1) - T(\hat{\theta}_2)$ is plotted versus A, the angle between the vectors $(\hat{\theta}_1 - \hat{\theta}_2)$ and $\hat{n}$, the direction of maximum temperature, $\hat{n}$ = (10.8 hr R.A.; 5° dec.). Data from legs with nearly equal values of A were combined; each data point plotted represents ~2hrs of data. The large dots represent the uncorrected data; the horizontal bars show the data with expected systematic effects subtracted out. The errors shown are statistical only.

moving at a velocity of $v = (T_1/T_o)\cdot c = 390 \pm 60$ km/sec in the direction $\hat{n}$, towards the constellation Leo. This result differs from the preliminary result reported by Corey and Wilkinson by about twice their reported errors.[6] In addition it differs substantially from the values of the peculiar velocity for the motion of the sun measured with respect to nearby galaxies by Ford and Rubin[7] and by Visvanathan and Sandage.[8] If we subtract from our measured velocity the component due to the rotation of the Milky-Way galaxy[9] ≈300 km/sec, we calculate the net motion of the Milky-Way with respect to the conocial reference frame of cosmology to be 607 ± 70 km/sec in the direction (R.A. = 10.5 ± 0.5 hr, dec. = −19° ± 15°). These various velocities are summarized in Table II. The large peculiar velocity of the Milky Way galaxy is unexpected, and presents a challenge to cosmological theory.

The limits on the second and higher order spherical harmonics place new constraints on several phenomena of cosmological important. Hawking and Collins have shown[10] that vorticity, equivalent to a net rotation of the universe, can contribute a second order spherical harmonic due to the transverse Doppler shift. The limit one can place on this rotation depends strongly on the model of the Universe that is assumed. Using a semi-classical model, and assuming the blackbody radiation has not scattered since it was emitted at a redshift z, the rotation of the universe contributes a second order harmonic of amplitude:[11]

$$T_2 = \frac{T_o\, \omega^2 (1+z)^4}{8\, H_o^2\, (1+2q_o z)} \qquad (2)$$

where ω is the present value for the angular velocity of the universe, present value of Hubble's constant $H_o \approx 10^{-10}$ yr^{-1}, and we take the acceleration parameter $q_o \approx 0.03$. Using our limit $T_2 \leq 10^{-3}$°K, and z = 1500, omit or galactic?

TABLE II

Peculiar Velocities (km/sec)

Reference	V(km/sec)	R.A.(hrs)	dec	V_x(km/sec)	l	V_y(km/sec)	b	V_z(km/sec)
MOTION OF SUN RELATIVE TO COSMIC BLACKBODY RADIATION								
a. Corey & Wilkinson[2]	270 ± 70	13 ± 2	-25° ± 20°	-236		63		-114
b. This work	390 ± 60	~~10.8~~ 11.0 ± 0.5	6° ± 10°	-369		-120		41
MOTION OF SUN RELATIVE TO NEARBY GALAXIES								
c. deVaucouleurs & Peters[9]	400 ± 200	14 ± 2	-20° ± 20°	-326		188		-137
d. Rubin et al.[7]	600 ± 125	2 ± 1	53° ± 11°	313	135°	-181	-8°	479
e. Visvanathen & Sandage[8]	300 ± 125	22.5 ± 0.5	52° ± 11°	182	90°	75	0°	252
f. Kahil, Tamman & Sandage[9]	308				107° ± 4°		-8° ± 5°	
g. Schecter[10]	346 + 76	18	45°		72°		28°	
MOTION OF SUN IN ORBIT AROUND MILKY-WAY GALAXY								
h. -	300 ± 50	21.1	48°	146		138		223
MOTION OF MILKY-WAY GALAXY RELATIVE TO COSMIC BLACKBODY								
i. This work and ref. h.	604 ± 70	10.2 ± 0.5	-18° ± 10°	-515		-258		-182

we calculate that the rotation of the Universe is less than 10^{-11} seconds of arc per century.

Our limit on T_2 also puts a constraint on the existence of large wavelength gravitational radiation. Using the calculation of Burke[13], we conclude that the mass-density of such radiation in the Universe is $\lesssim \rho_c$, where ρ_c is the critical mass density necessary to close the universe.

In summary, we have observed anisotropy that varies as cosine$(\hat{\theta},\hat{n})$. Except for this component, the cosmic blackbody radiation is isotropic to one part in 3000. The cosine component is most readily interpreted as due to the motion of the earth with respect to the radiation with a velocity of 390 ± 60 km/sec (the "new Aether drift"), but we cannot eliminate the possibility that some of the anisotropy is due to an intrinsic variation in the temperature of the cosmic blackbody radiation itself.

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References and Footnotes

1. Peebles, P. J. E., 1971, "Physical Cosmology" (Princeton: Princeton University Press; Weinberg, S., 1972, "Gravitation and Cosmology: Principles and Application of the General Theory of Relativity (John Wiley and Sons Inc, N.Y.)

2 Both Conklin (ref) and Henry (ref) claimed to observe a first-order harmonic. However in both experiments backgrounds were much larger than the observed effect, and the resulting fits were very poor. In both experiments the one-standard-deviation errors in the direction of the earth's velocity cover a large part of the sky. (Conklin quotes probable errors, not standard-deviations.)

3 Corey, B. E and Wilkinson, D.T. 1976, Bulletin of the AAS 8, 351
~~Cory and Wilkinson, Bulletin of the AAS.~~

4 G. Smoot, invited talk, APS Conference, 28 April 1977., Washington, DC

5 G.F. Smoot, M.V. Gorenstein, R.A. Muller, J.A. Tyson, submitted to the Reviews of ~~Modern~~ Scientific Instruments.

6 The reported errors in the preliminary results of Corey and Wilkinson (ref 3) were statistical only. Newer results from their group (D. Wilkinson, private communication) are in closer agreement with our results.

7. Rubin, V.C., Ford, W.K., Thonnard, N., Roberts, M.S. and Graham, J.A. 1976, A.J. 81, 687

8. Visvanathan, N. and Sandage, A., 1977, ApJ, Aug 15. No 37

9. Yahil, A., Tammann, G.A., and Sandage 1977 ApJ Nov 15

10. Schecter, P. L., Steward Observatory, University of Arizona in press

11. Collins, C.B. and Hawking, S.W., 1973, Monthly Not R AstrSoc 162, 307-320.

12. Pollaine, S. and Smoot, G, unpublished memo No. 343

13. Burke, W.L. 1975, ApJ 196: 329-334 March 1.

14. de Vaucouleurs, G and Peters, W.L. 1968, Nature 220, 868

FIGURE CAPTIONS

1. Schematic view of the apparatus mounted in the upper hatch of the U-2 aircraft. The anisotropy reported in this paper was detected with the 33 GHz radiometer; the 54 GHz radiometer monitored the oxygen anisotropy above the aircraft.

2. Sky coverage for the eight flights is indicated by the shaded regions. Each ~~region~~ oval region consists of several ~~flight~~ "legs" from the same flight. The width of ~~the~~ each region was determined from the antenna pattern (7^{o} FWHM), and the length was set by the motion of the U-2 and the rotation of the earth. ~~celestial sphere above the airplane.~~

3. Comparison of the data with the fit to ~~equation~~ Eq. 1. The temperature difference $\Delta T = T(\hat{\theta}_1) - T(\hat{\theta}_2)$ is plotted versus A, ~~where A is~~ the angle between the vectors $(\hat{\theta}_1 - \hat{\theta}_2)$ and $\hat{n}$, ~~where n is~~ the direction of maximum temperature. $\hat{n}$ = (10.8 hr R.A.; 5^{o} dec.). Data from legs with nearly equal values of A were combined; each data point plotted represents ~2hrs of data. The large dots represent the uncorrected data; the horizontal bars show the data with expected systematic effects subtracted out. The errors shown are statistical only.

(corrected) ΔT	leg	θ	ΔT	σ
5.1	55	23	4.9	1.6
5.2	80	25	5.0	1.6
-1.6	20	29	-1.7	3.5
1.2	53	31	1.1	1.6
2.2	78	32	-.4	1.6
2.9	76	36	2.9	1.6
2.0	12	40	1.6	2.6
2.9	51	41	2.9	1.6
3.8	8	41	3.7	3.6
2.0	4	43	1.8	2.7
-.4	10	45	-.3	3.6
0.7	58	46	.5	1.6
11.4	2	49	10.9	2.8
-8.2	23	51	-8.4	3.9
2.8	38	53	2.6	1.6
+3.3	60	54	3.2	1.6
.64	5	56	.2	2.4
-1.1	66	58	-1.3	1.6
1.5	64	60	1.3	1.6
3.5	30	60	3.2	2.7
2.2	44	60	2.1	1.6
3.0	18	62	2.4	3.6
-.7	40	62	-.9	1.6
.35	46	63	.3	1.6
3.2	62	63	2.9	1.6
-1.2	48	66	-1.2	1.6
3.0	28	67	3.2	3.1
.8	36	69	1.1	1.6
3.2	16	69	3	3.7

$\bar{x}$ σ

4.3 ± 1.1

1.2 ± 0.9

2.4 ± 0.7 (6)

3.1 ± 0.7 (1)

1.7 ± 0.9 (6)

1.8 ± 0.9 (2)

1.7 ± 0.6

1.7 ± 0.8 (6)

1.9 ± 0.6 (3)

1.3 ± 0.7

1.5 ± 0.7 (4)

1.0 ± 0.6

0.5 ± 1.0

0.4 ± 1.0 (5)

ΔTcorr	lag	θ	ΔT	σ
−0.95	56	71	−.8	1.6
3.8	42	71	3.6	1.6
2.5	32	72	2.2	2.9
−.3	69	72	−.2	1.6
−1.2	26	73	−1.0	2.8
2.5	34	74	2.6	1.6
1.0	14	77	.8	5.0
1.1	71	78	1.1	1.6
−.6	24	79	−.3	2.9
−.7	73	83	−.6	1.6
1.4	74	92	1.4	1.6
−2.3	68	92	0.0	1.6
−9.6	11	94	−9.3	5.5
−2.8	72	99	−2.8	1.6
−2.9	43	104	−2.4	1.6
−.3	25	105	−.5	2.8
−2.5	33	105	−2.2	2.6
0.8	70	105	.94	1.6
−2.1	15	107	−1.9	4.1
−1.7	49	109	−1.8	1.6
−1.1	35	109	−1.1	1.6
1.3	27	110	1.1	2.9
−3.0	41	113	−2.5	1.6
−5.9	57	113	−1.19	−5.9
0	37	113	−.15	1.6
−2.8	63	113	−2.3	1.6
−0.06	47	113	−.14	1.6

1.2 ± 0.7
1.2 ± 0.7 (6)

0.2 ± 1.0
0.1 ± 1.0 (7)

0.9 ± 0.6

−0.7 ± 0.9
−1.1 ± 0.9 (8)

−1.2 ± 0.7
−1.3 ± 0.7 (9)

−1.0 ± 0.6

−5.89 +1.6

~~−1.1 ± 0.8~~
−2.0 ± 0.7
−2.1 ± 0.7 (10)

	leg	θ	ΔT	σ		
-5.4	17	115	-5.3	3.7		
-4.9	29	115	-5.1	2.9		
-3.6	31	116	-3.2	2.9		-1.1 ± 0.5
-3.1	45	118	-3.1	1.6	-2.9	
-3.8	61	121	-3.6	1.6	~~[illegible]~~ ± 0.7 (11)	
1.2	19	122	1.3	3.9	-3.2 ± 0.7	
-2.5	67	122	-2.1	1.6		
-3.0	65	122	-2.6	1.6		
-3.3	39	122	-2.8	1.6		
-1.4	1	128	-.8	2.7		
-.5	6	132	-.15	2.9		
.7	59	131	.93	1.6		
8.2	22	134	8.4	3.6	-0.5 ± 0.9	
-2.1	50	134	-1.9	1.6	(12)	
-2.5	3	135	-1.8	2.8	-.84 ± 0.9	
-5.5	7	137	-5.2	3.1		
-2.45	9	137	-2.5	4.9		
1.6	21	140	1.7	3.9		-1.7 ± 0.6
-3.7	75	141	-3.5	1.6	-2.2 ± 1.1	
-1.9	52	144	-1.6	1.6	-2.5 ± 1.1 (13)	
-2.2	77	147	-1.9	1.6		
-1.8	13	148	-1.6	2.6	-2.6 ± 0.9	
-3.25	79	151	-2.9	1.6	-2.94 ± 0.9 (14)	
-3.8	54	153	-3.4	1.6		

COMPARISON OF DATA WITH FIT

NUMBER	NFLT	LEG		THETA	FIT	DELT	SIGMA	DIFFERENCE	CHI	
1	4	1		128.32	-1.91	-.79	2.69	1.12	.17348	.17
2	4	2	12	48.55	2.04	10.87	2.77	8.83	10.16177	10.3
3	4	3		134.54	-2.16	-1.76	2.83	.40	.02009	10.35
4	4	4	10	42.91	2.26	1.76	2.73	-.50	.03320	10.38
5	4	6		56.46	1.70	.20	2.40	-1.50	.39221	10.78
6	4	7		131.55	-2.04	-.15	2.86	1.89	.43870	11.21
7	5	1		136.56	-2.24	-5.25	3.12	-3.01	.93234	12.15
8	5	2	9	41.49	2.31	3.70	3.59	1.39	.15022	12.30
9	5	3		137.18	-2.26	-2.48	4.90	-.22	.00201	12.30
10	5	4	—	44.64	2.19	-.32	3.58	-2.51	.49284	12.79
11	5	5		94.22	-.23	-9.29	5.52	-9.06	2.69612	15.49
12	5	6	7	40.62	2.34	1.64	2.65	-.70	.06983	15.56
13	5	7		147.86	-2.61	-1.64	2.65	.97	.13421	15.69
14	6	1		77.07	.69	.76	4.97	.07	.00020	15.69
15	6	2		107.40	-.92	-1.88	4.13	-.96	.05379	15.75
16	6	3		69.48	1.08	3.00	3.72	1.92	.26598	16.01
17	6	4		114.74	-1.29	-5.29	3.73	-4.00	1.14951	17.16
18	6	5		62.15	1.44	2.86	3.56	1.42	.15874	17.32
19	6	6		121.63	-1.62	1.30	3.93	2.92	.55134	17.87
20	6	7	3	28.84	2.70	-1.71	3.50	-4.41	1.59014	19.46
21	6	8		140.50	-2.38	1.71	3.93	4.09	1.08387	20.55
22	6	12		133.61	-2.13	8.40	3.65	10.53	8.32187	28.87
23	6	13	13	51.45	1.93	-8.40	3.88	-10.33	7.08221	35.95
24	7	1		78.22	.58	-.27	2.92	-.85	.08435	36.03
25	7	2		104.50	-.77	-.45	2.80	.32	.01329	36.05
26	7	3		72.61	.92	-1.04	2.76	-1.96	.50616	36.55
27	7	4		110.40	-1.08	1.07	2.86	2.15	.56319	37.12
28	7	5		67.16	1.20	3.25	3.05	2.05	.45196	37.57
29	7	6		115.30	-1.32	-5.08	2.92	-3.76	1.65797	39.23
30	7	7		59.82	1.55	3.18	2.72	1.63	.35749	39.58
31	7	8		116.10	-1.36	-3.25	2.93	-1.89	.41639	40.00
32	7	9		71.57	.98	2.18	2.93	1.20	.16846	40.17
33	7	10		104.62	-.78	-2.18	2.65	-1.40	.27915	40.45
34	8	1		74.88	.85	2.64	1.60	1.79	1.25508	41.70
35	8	2		109.34	-1.02	-1.13	1.60	-.11	.00448	41.71
36	8	3		68.71	1.12	1.06	1.60	-.06	.00151	41.71
37	8	4		113.42	-1.23	-.15	1.60	1.08	.45356	42.16
38	8	5		53.05	1.86	2.56	1.60	.70	.19270	42.36
39	8	6		122.14	-1.64	-2.78	1.60	-1.14	.50455	42.86
40	8	7		61.79	1.46	-.94	1.60	-2.40	2.25215	45.11
41	8	8		113.15	-1.21	-2.49	1.60	-1.28	.63557	45.75
42	8	9		71.28	.99	3.61	1.60	2.62	2.67711	48.42
43	8	10		104.15	-.76	-2.39	1.60	-1.63	1.04399	49.47
44	9	1		60.11	1.54	2.10	1.60	.56	.12229	49.59
45	9	2		118.79	-1.49	-3.14	1.60	-1.65	1.06612	50.66
46	9	3		62.63	1.42	.32	1.60	-1.10	.47344	51.13
47	9	4		113.35	-1.22	-.14	1.60	1.08	.45947	51.59
48	9	5		65.85	1.26	-1.24	1.60	-2.50	2.45028	54.04
49	9	6		109.39	-1.03	-1.82	1.60	-.79	.24658	54.29
50	9	7		134.37	-2.16	-1.94	1.60	.22	.01894	54.31
51	9	8	8	40.70	2.34	2.89	1.60	.55	.11718	54.42
52	9	9		143.85	-2.49	-1.57	1.60	.92	.33345	54.76
53	9	10	4	31.47	2.63	1.13	1.60	-1.50	.88434	55.64
54	9	11		153.27	-2.76	-3.37	1.60	-.61	.14627	55.79
55	9	12	1	22.57	2.85	4.89	1.60	2.04	1.62314	57.41
56	10	1		70.99	1.01	-.85	1.60	-1.86	1.34609	58.76
57	10	2		112.64	-1.19	-5.89	1.60	-4.70	8.63389	67.39
58	10	3	11	45.60	2.16	.54	1.60	-1.62	1.02294	68.41
59	10	4		131.24	-2.04	.93	1.60	2.97	3.43794	71.85
60	10	5		54.40	1.80	3.16	1.60	1.36	.72359	72.57

61	10	6		121.24	-1.60	-3.59	1.60	-1.99	1.54301	74
62	10	7		63.40	1.38	2.93	1.60	1.55	.93352	75
63	10	8		113.06	-1.21	-2.27	1.60	-1.06	.43882	75
64	10	9		59.68	1.56	1.35	1.60	-.21	.01731	75
65	10	10		121.65	-1.62	-2.64	1.60	-1.02	.40530	75
66	10	11		58.09	1.63	-1.27	1.60	-2.90	3.29426	79
67	10	12		122.32	-1.65	-2.09	1.60	-.44	.07493	79
68	11	0		92.23	-.12	0.00	1.60	.12	.00564	79
69	11	1		72.02	.95	-.21	1.60	-1.16	.52966	79
70	11	2		108.47	-.82	.94	1.60	1.76	1.21520	81
71	11	3		78.14	.64	1.07	1.60	.43	.07376	81
72	11	4		99.49	-.51	-2.77	1.60	-2.26	1.99621	83
73	11	5		82.98	.38	-.59	1.60	-.97	.36606	83
74	11	6		91.81	-.10	1.43	1.60	1.53	.91094	84
75	11	7		140.93	-2.40	-3.52	1.60	-1.12	.49141	84
76	11	8	6	36.07	2.50	2.90	1.60	.40	.06336	84
77	11	9		146.79	-2.58	-1.91	1.60	.67	.17768	85
78	11	10	5	32.37	2.61 ?	-.36	1.60	-2.97	3.44322	88
79	11	11		150.90	-2.70	-2.92	1.60	-.22	.01915	88
80	11	12	2	25.37	2.79	5.02	1.60	2.23	1.94143	90